
Based on Cosmos: A Personal Voyage by Carl Sagan, Ann Druyan & Steven Soter

Directed by Brannon Braga, Bill Pope & Ann Druyan

Presented by Neil deGrasse Tyson

Composer(s) Alan Silvestri

Country of origin United States

Original language(s) English

No. of episodes 13 (List of episodes)

1 - Standing Up in the Milky Way
2 - Some of the Things That Molecules Do
3 - When Knowledge Conquered Fear
4 - A Sky Full of Ghosts
5 - Hiding In The Light
6 - Deeper, Deeper, Deeper Still
7 - The Clean Room
8 - Sisters of the Sun
9 - The Lost Worlds of Planet Earth
10 - The Electric Boy
11 - The Immortals
12 - The World Set Free
13 - Unafraid Of The Dark
1 - Standing Up in the Milky Way

The cosmos is all there is, or ever was, or ever will be.

Come with me.

A generation ago, the astronomer Carl Sagan stood here and launched hundreds of millions of us on a great adventure: the exploration of the universe revealed by science.

It's time to get going again.

We're about to begin a journey that will take us from the infinitesimal to the infinite, from the dawn of time to the distant future.

We'll explore galaxies and suns and worlds, surf the gravity waves of space-time, encounter beings that live in fire and ice, explore the planets of stars that never die, discover atoms as massive as suns and universes smaller than atoms.

Cosmos is also a story about us.

It's the saga of how wandering bands of hunters and gatherers found their way to the stars, one adventure with many heroes.

To make this journey, we'll need imagination.

But imagination alone is not enough because the reality of nature is far more wondrous than anything we can imagine.

This adventure is made possible by generations of searchers strictly adhering to a simple set of rules test ideas by experiment and observation, build on those ideas that pass the test, reject the ones that fail, follow the evidence wherever it leads and question everything.

Accept these terms, and the cosmos is yours.

Now come with me.

In this ship of the Imagination, free from the shackles of space and time, we can go anywhere.

If you want to see where we are in space, just look out the front window.

In the dimension of time, the past lies beneath us.

Here's what Earth looked like If you want to see the future, look up.

And this is how it could appear If we're going to be venturing out into the farthest reaches
of the cosmos, we need to know our cosmic address, and this is the first line of that address.

We're leaving the Earth, the only home we've ever known, for the farthest reaches of the cosmos.

Our nearest neighbor, the Moon, has no sky, no ocean, no life just the scars of cosmic impacts.

Our star powers the wind and the waves and all the life on the surface of our world.

The Sun holds all the worlds of the solar system in its gravitational embrace, starting with Mercury to cloud-covered Venus, where runaway greenhouse effect has turned it into a kind of hell.

Mars a world with as much land as Earth itself.

A belt of rocky asteroids circles the Sun between the orbits of Mars and Jupiter.

With its four giant moons and dozens of smaller ones, Jupiter is like its own little solar system.

It has more mass than all the other planets combined.

Jupiter's Great Red Spot a hurricane three times the size of our whole planet that's been raging for centuries.

The crown jewel of our solar system, Saturn, ringed by freeways of countless orbiting and slowly tumbling snowballs every snowball, a little moon.

Uranus and Neptune, the outermost planets, unknown to the ancients and only discovered after the invention of the telescope.

Beyond the outermost planet, there's a swarm of tens of thousands of frozen worlds.

And Pluto is one them.

Of all our spacecraft, this is the one that's traveled farthest from home Voyager 1.

She bears a message to a billion years from now, something of who we were, how we felt and the music we made.

The deeper waters of this vast cosmic ocean and their numberless worlds lie ahead.

From out here, the Sun may look like just another star.

But it still exerts its gravitational hold on a trillion frozen comets, leftovers from the
formation of the solar system nearly five billion years ago.

It's called the Oort Cloud.

No one has ever seen it before, nor could they, because each one of these little worlds is as far from its nearest neighbor as Earth is from Saturn.

This enormous cloud of comets encloses the solar system, which is the second line of our cosmic address.

We've only been able to detect the planets of other stars for a few decades, but we already know that planets are plentiful they outnumber the stars.

Almost all of them will be very different from Earth, and hostile to life as we know it.

But what do we know about life? We've met only one kind so far.

Earthlife.

See anything? Just empty space, right? Human eyes see only a sliver of the light that shines in the cosmos.

But science gives us the power to see what our senses cannot.

Infrared is the kind of light made visible by night-vision goggles.

Throw an infrared sensor across the darkness Rogue planet.

World without a sun.

Our galaxy has billions of them, adrift in perpetual night.

They're orphans, cast away from their mother stars during the chaotic birth of their native star systems.

Rogue planets are molten at the core but frozen at the surface.

There may be oceans of liquid water in the zone between those extremes.

Who knows what might be swimming there? This is what the Milky Way looks like in infrared.

Every single dot, not just the bright ones, is a star.

How many stars? How many worlds? How many ways of being alive? Where are we in this picture? See that trailing outer arm? That's where we live about 30,000 light-years from the center.
The Milky Way Galaxy is the next line of our cosmic address.

We're now a hundred thousand light-years from home.

It would take light, the fastest thing there is, a hundred thousand years to reach us from Earth.

This is the Great Spiral in Andromeda, the galaxy next door.

We call our two giant galaxies and a smattering of smaller ones the "local group." Can't even find our home galaxy from out here.

It's just one of thousands in the Virgo Supercluster.

On this scale, all the objects we see, including the tiniest dots, are galaxies.

Each galaxy contains billions of suns and countless worlds.

Yet, the entire Virgo Supercluster itself forms but a tiny part of our universe.

This is the cosmos on the grandest scale we know a network of a hundred billion galaxies.

It's the last line of our cosmic address for now.

Observable universe?! What does that mean? Even for us, in our Ship of the Imagination, there's a limit to how far we can see in space-time.

It's our cosmic horizon.

Beyond that horizon lie parts of the universe that are too far away.

There hasn't been enough time in the 13.8 billion year history of the universe for their light to have reached us.

Many of us suspect that all of this all the worlds, stars, galaxies and clusters in our observable universe is but one tiny bubble in an infinite ocean of other universes a multiverse.

Universe upon universe.

Worlds without end.

Feeling a little small? Well, in the context of the cosmos, we are small.

We may just be little guys living on a speck of dust, afloat in a staggering immensity, but we don't think small.
This cosmic perspective is relatively new.

A mere four centuries ago, our tiny world was oblivious to the rest of the cosmos.

There were no telescopes.

The universe was only what you could see with the naked eye.

Back in 1599, everyone knew that the Sun, planets and stars were just lights in the sky that revolved around the Earth, and that we were the center of a little universe, a universe made for us.

There was only one man on the whole planet who envisioned an infinitely grander cosmos.

And how was he spending New Year's Eve of the year 1600? Why, in prison, of course.

There comes a time in our lives when we first realize we're not the center of the universe, that we belong to something much greater than ourselves.

It's part of growing up.

And as it happens to each of us, so it began to happen to our civilization in the 16th century.

Imagine a world before telescopes, when the universe was only what you could see with the naked eye.

It was obvious that Earth was motionless, and that everything in the heavens the Sun, the Moon, the stars, the planets revolved around us and then a Polish astronomer and priest named Copernicus made a radical proposal.

The Earth was not the center.

It was just one of the planets, and, like them, it revolved around the Sun.

Many, like the Protestant reformer Martin Luther, took this idea as a scandalous affront to Scripture.

They were horrified.

But for one man, Copernicus didn't go far enough.

His name was Giordano Bruno, and he was a natural-born rebel.

He longed to bust out of that cramped little universe.

Even as a young Dominican monk in Naples, he was a misfit.
This was a time when there was no freedom of thought in Italy.

But Bruno hungered to know everything about God's creation.

He dared to read the books banned by the Church, and that was his undoing.

In one of them, an ancient Roman, a man dead for more than 1,500 years whispered to him of a universe far greater, one as boundless as his idea of God.

Lucretius asked the reader to imagine standing at the edge of the universe and shooting an arrow outward.

If the arrow keeps going, then clearly, the universe extends beyond what you thought was the edge.

But if the arrow doesn't keep going say it hits a wall then that wall must lie beyond what you thought was the edge of the universe.

Now if you stand on that wall and shoot another arrow, there are only the same two possible outcomes it either flies forever out into space, or it hits some boundary where you can stand and shoot yet another arrow.

Either way, the universe is unbounded.

The cosmos must be infinite.

This made perfect sense to Bruno.

The God he worshiped was infinite.

So how, he reasoned, could Creation be anything less? It was the last steady job he ever had.

And then, when he was 30, he had the vision that sealed his fate.

In this dream, he awakened to a world enclosed inside a confining bowl of stars.

This was the cosmos of Bruno's time.

He experienced a sickening moment of fear, as if the bottom of everything was falling away beneath his feet.

But he summoned up his courage.

I spread confident wings to space and soared toward the infinite, leaving far behind me what others strained to see from a distance.

Here, there was no up, no down, no edge, no center.
I saw that the Sun was just another star, and the stars were other Suns, each escorted by other Earths like our own.

The revelation of this immensity was like falling in love.

Bruno became an evangelist, spreading the gospel of infinity throughout Europe.

He assumed that other lovers of God would naturally embrace this grander and more glorious view of Creation.

What a fool I was.

He was excommunicated by the Roman Catholic Church in his homeland, expelled by the Calvinists in Switzerland, and by the Lutherans in Germany.

Bruno jumped at an invitation to lecture at Oxford, in England.

At last, he thought, a chance to share his vision with an audience of his peers.

I have come to present a new vision of the cosmos.

Copernicus was right to argue that our world is not the center of the universe.

The Earth goes around the Sun.

It's a planet, just like the others.

But Copernicus was only the dawn.

I bring you the sunrise.

The stars are other fiery suns, made of the same substance as the Earth, and they have their own watery earths, with plants and animals no less noble than our own.

Are you mad or merely ignorant? Everyone knows there is only one world.

What everyone knows is wrong.

Our infinite God has created a boundless universe with an infinite number of worlds.

Do they not read Aristotle where you come from? Or even the Bible? I beg you, reject antiquity, tradition, faith, and authority.

Let us begin anew, by doubting everything we assume - has been proven.

- Heretic! Infidel! Your God is too small.

A wiser man would have learned his lesson.
But Bruno was not such a man.

He couldn't keep his soaring vision of the cosmos to himself, despite the fact that the penalty for doing so in his world was the most vicious form of cruel and unusual punishment.

Giordano Bruno lived at a time when there was no such thing as the separation of church and state, or the notion that freedom of speech was a sacred right of every individual.

Expressing an idea that didn't conform to traditional belief could land you in deep trouble.

Recklessly, Bruno returned to Italy.

Maybe he was homesick.

But still, he must have known that his homeland was one of the most dangerous places in Europe he could possibly go.

The Roman Catholic Church maintained a system of courts known as the Inquisition, and its sole purpose was to investigate and torment anyone who dared voice views that differed from theirs.

It wasn't long before Bruno fell into the clutches of the thought police.

This wanderer, who worshiped an infinite universe, languished in confinement for eight years.

Through relentless interrogations, he stubbornly refused to renounce his views.

Why was the Church willing to go to such lengths to torment Bruno? What were they afraid of? If Bruno was right, then the sacred books and the authority of the Church would be open to question.

Finally, the cardinals of the Inquisition rendered their verdict.

You are found guilty of questioning the Holy Trinity and the divinity of Jesus Christ.

Of believing that God's wrath is not eternal, that everyone will be saved.

Of asserting the existence of other worlds.

All of the books you have written will be gathered up and burned in St. Peter's Square.

Reverend Father, these eight years of confinement have given me much time to reflect.

So you will recant? My love and reverence for the Creator inspires in me the vision of an
infinite Creation.

You shall be turned over to the Governor of Rome to administer the appropriate punishment for those who will not repent.

It may be that you are more afraid to deliver this judgment than I am to hear it.

Ten years after Bruno's martyrdom, Galileo first looked through a telescope, realizing that Bruno had been right all along.

The Milky Way was made of countless stars invisible to the naked eye, and some of those lights in the sky were actually other worlds.

Bruno was no scientist.

His vision of the cosmos was a lucky guess, because he had no evidence to support it.

Like most guesses, it could well have turned out wrong.

But once the idea was in the air, it gave others a target to aim at.

If only to disprove it.

Bruno glimpsed the vastness of space.

But he had no inkling of the staggering immensity of time.

How can we humans, who rarely live more than a century, hope to grasp the vast expanse of time that is the history of the cosmos? The universe is In order to imagine all of cosmic time, let's compress it into a single calendar year.

The cosmic calendar begins on January 1st with the birth of our universe.

It contains everything that's happened since then, up to now, which on this calendar is midnight December 31st.

On this scale, every month represents about a billion years.

Every day represents nearly Let's go back as far as we can, to the very first moment of the universe.

January 1st, the Big Bang.

It's as far back as we can see in time for now.

Our entire universe emerged from a point smaller than a single atom.

Space itself exploded in a cosmic fire, launching the expansion of the universe and giving
birth to all the energy and all the matter we know today.

I know that sounds crazy, but there's strong observational evidence to support the Big Bang theory.

And it includes the amount of helium in the cosmos and the glow of radio waves left over from the explosion.

As it expanded, the universe cooled, and there was darkness for about 200 million years.

Gravity was pulling together clumps of gas and heating them until the first stars burst into light on January 10th.

On January 13th, these stars coalesced into the first small galaxies.

These galaxies merged to form still larger ones, including our own Milky Way, which formed about 11 billion years ago, on March 15th of the cosmic year.

Hundreds of billions of suns.

Which one is ours? It's not yet born.

It will rise from the ashes of other stars.

See those lights flashing like paparazzi? Each one is a supernova, the blazing death of a giant star.

Stars die and are born in places like this one a stellar nursery.

They condense like raindrops from giant clouds of gas and dust.

They get so hot that the nuclei of the atoms fuse together deep within them to make the oxygen we breathe, the carbon in our muscles, the calcium in our bones, the iron in our blood, all of it was cooked in the fiery hearts of long-vanished stars.

You, me, everyone we are made of star stuff.

This star stuff is recycled and enriched, again and again, through succeeding generations of stars.

How much longer until the birth of our Sun? A long time.

It won't begin to shine for another six billion years.

Our Sun's birthday is August 31st on the Cosmic Calendar four and a half billion years ago.

As with the other worlds of our solar system, Earth was formed from a disk of gas and
dust orbiting the newborn Sun.

Repeated collisions produced a growing ball of debris.

See that asteroid? No, not that one. The one over there.

We exist because the gravity of that one next to it just nudged it an inch to the left.

What difference could an inch make on the scale the solar system? Just wait, you'll see.

The Earth took one hell of a beating in its first billion years.

Fragments of orbiting debris collided and coalesced, until they snowballed to form our Moon.

The Moon is a souvenir of that violent epoch.

If you stood on the surface of that long ago Earth, the Moon would have looked a hundred times brighter.

It was ten times closer back then, locked in a much more intimate gravitational embrace.

As the Earth cooled, seas began to form.

The tides were a thousand times higher then.

Over the eons, tidal friction within Earth pushed the Moon away.

Life began somewhere around here, September 21st, three and a half billion years ago on our little world.

We still don't know how life got started.

For all we know, it may have come from another part of the Milky Way.

The origin of life is one of the greatest unsolved mysteries of science.

That's life cooking, evolving all the biochemical recipes for its incredibly complex activities.

By November 9th, life was breathing, moving, eating, responding to its environment.

We owe a lot to those pioneering microbes.

Oh, yeah one other thing.

They also invented sex.
December 17th was quite a day.
Life in the sea really took off, it was exploding with a diversity of larger plants and animals.

Tiktaalik was one of the first animals to venture onto land.
It must have felt like visiting another planet.

Forests, dinosaurs, birds, insects, they all evolved in the final week of December.
The first flower bloomed on December 28th.

As these ancient forests grew and died and sank beneath the surface, their remains transformed into coal.

we humans are burning most of that coal to power and imperil our civilization.

Remember that asteroid back in the formation of the solar system the one that got nudged a little to the left? Well, here it comes.

It's 6:24 AM on December 30th on the Cosmic Calendar.

For more than a hundred million years, the dinosaurs were lords of the Earth, while our ancestors, small mammals, scurried fearfully underfoot.

The asteroid changed all that.

Suppose it hadn't been nudged at all.

It would have missed the Earth entirely, and for all we know, the dinosaurs might still be here but we wouldn't.

This is a good example of the extreme contingency, the chance nature, of existence.

The universe is already more than 13 and a half billion years old.

Still no sign of us.

In the vast ocean of time that this calendar represents, we humans only evolved within the last hour of the last day of the cosmic year.

11:59 and 46 seconds.

All of recorded history occupies only the last 14 seconds, and every person you've ever heard of lived somewhere in there.

All those kings and battles, migrations and inventions, wars and loves, everything in the
history books happened here, in the last seconds of the Cosmic Calendar.

But if we want to explore such a brief moment of cosmic time we'll have to change scale.

We are newcomers to the cosmos.

Our own story only begins on the last night of the cosmic year.

It's 9:45 on New Year's Eve.

Three and a half million years ago, our ancestors, yours and mine, left these traces.

We stood up, and parted ways from them.

Once we were standing on two feet, our eyes were no longer fixated on the ground.

Now we were free to look up in wonder.

For the longest part of human existence, say the last 40,000 generations, we were wanderers, living in small bands of hunters and gatherers, making tools, controlling fire, naming things, all within the last hour of the Cosmic Calendar.

To find out what happens next, we'll have to change scale to see the last minute of the last night of the cosmic year.

We're so very young on the time scale of the universe that we didn't start painting our first pictures until the last 60 seconds of the cosmic year, a mere 30,000 years ago.

This is when we invented astronomy.

In fact, we're all descended from astronomers.

Our survival depended on knowing how to read the stars in order to predict the coming of the winter and the migration of the wild herds.

And then, around 10,000 years ago, there began a revolution in the way we lived.

Our ancestors learned how to shape their environment, taming wild plants and animals, cultivating land and settling down.

This changed everything.

For the first time in our history, we had more stuff than we could carry.

We needed a way to keep track of it.

At 14 seconds to midnight, or about 6,000 years ago, we invented writing.
And it wasn't long before we started recording more than bushels of grain.

Writing allowed us to save our thoughts and send them much further in space and time.

Tiny markings on a clay tablet became a means for us to vanquish mortality.

It shook the world.

Moses was born seven seconds ago.

Buddha, six seconds ago.

Jesus, five seconds ago.

Mohammed, three seconds ago.

It was not even two seconds ago that, for better or worse, the two halves of the Earth discovered each other.

And it was only in the very last second of the Cosmic Calendar that we began to use science to reveal nature's secrets and her laws.

The scientific method is so powerful that in a mere four centuries, it has taken us from Galileo's first look through a telescope at another world to leaving our footprints on the Moon.

It allowed us to look out across space and time to discover where and when we are in the cosmos.

We are a way for the cosmos to know itself.

Carl Sagan guided the maiden voyage of Cosmos a generation ago.

He was the most successful science communicator of the 20th century, but he was first and foremost a scientist.

Carl contributed enormously to our knowledge of the planets.

He correctly predicted the existence of methane lakes on Saturn's giant moon Titan.

He showed that the atmosphere of the early Earth must have contained powerful greenhouse gases.

He was the first to understand that seasonal changes on Mars were due to windblown dust.

Carl was a pioneer in the search for extraterrestrial life and intelligence.
He played a leading role in every major spacecraft mission to explore the solar system during the first 40 years of the Space Age.

But that's not all he did.

This is Carl Sagan's own calendar from 1975.

Who was I back then? I was just a 17-year-old kid from the Bronx with dreams of becoming a scientist, and somehow the world's most famous astronomer found time to invite me to Ithaca, in upstate New York, and spend a Saturday with him.

I remember that snowy day like it was yesterday.

He met me at the bus stop and showed me his laboratory at Cornell University.

Carl reached behind his desk and inscribed this book for me.

"For Neil, a future astronomer. Carl." At the end of the day, he drove me back to the bus station.

The snow was falling harder.

He wrote his phone number his home phone number on a scrap of paper and he said, "If the bus can't get through, call me and spend the night at my home with my family." I already knew I wanted to become a scientist, but that afternoon, I learned from Carl the kind of person I wanted to become.

He reached out to me and to countless others, inspiring so many of us to study, teach and do science.

Science is a cooperative enterprise, spanning the generations.

It's the passing of a torch from teacher to student to teacher, a community of minds reaching back to antiquity and forward to the stars.

Now, come with me.

Our journey is just beginning.
2 - Some of the Things That Molecules Do

This is a story about you and me and your dog.

There was a time not long ago before dogs.

They didn't exist.

Now there are big ones, small ones, snugglers, guardians, hunters.

Every kind of dog you could possibly want.

How did that happen? It's not just dogs.

Where did all the different kinds of living creatures come from? The answer is a transforming power that sounds like something straight out of a fairy tale or myth, but it's no such thing.

Let's go back across 30,000 years to a time before dogs, when our ancestors lived in the endless winter of the last ice age.

Our ancestors were wanderers living in small bands.

They slept beneath the stars.

The sky was their storybook, calendar, an instruction manual for living.

It told them when the bitter colds would come, when the wild grains would ripen, when the herds of caribou and bison would be on the move.

Their idea of home was Earth itself.

But they lived in fear of other hungry creatures the mountain lions and the bears that competed with them for the same prey and the wolves that threatened to carry off and devour the most vulnerable among them.

All the wolves want to get at the bone, but most of them are too frightened to come close enough.

Their fear is due to high levels of stress hormones in their blood.

It's a matter of survival.

Because coming too close to humans can be fatal.

But a few wolves-- due to natural variations-- have lower levels of those hormones.

This makes them less afraid of humans.
This wolf has discovered what a branch of his ancestors figured out some 15,000 years ago an excellent survival strategy; the domestication of humans.

Let the humans do the hunting, don't threaten them, and they'll let you scavenge their garbage.

You'll eat more regularly, you'll leave more offspring, and those offspring will inherit your disposition.

This selection for tameness would be reinforced with each generation until that line of wild wolves evolves into dogs.

You might call this "survival of the friendliest." Then as now, this was a good deal for the humans, too.

The scavenging dogs weren't just a sanitation squad.

They worked security.

As this interspecies partnership continued over time, the dogs' appearance changed also.

Cuteness became a selective advantage.

The more adorable you were, the better chance you had to live and pass on your genes to another generation.

What began as an alliance of convenience became a friendship that deepened over time.

To see what happens next, let's leave our distant ancestors of some 20,000 years ago to visit the more recent past during an intermission in the Ice Age.

This break in the climate starts a revolution.

Instead of wandering, people are settling down.

There's something new in the world villages.

People still hunt and gather, but now they also produce food and clothing agriculture.

The wolves have traded their freedom in exchange for a steady meal.

They've given up their right to choose a mate.

Now the humans choose for them.

They consistently kill off the dogs that can't be trained; the ones that bite the feeding hand.
And they breed the dogs that please them.

They nurture those dogs that do their bidding hunting, herding, guarding, hauling, and keeping them company.

From every litter, the humans select the puppies they like best.

Over the generations, the dogs evolve.

This kind of evolution is called "artificial selection" or "breeding." Turning wolves into dogs was the first time we humans took evolution into our own hands.

And we've been doing it ever since to shape all the plants and animals that we depend on.

In a blink of cosmic time, just 15,000 or 20,000 years, we turned gray wolves into all the kinds of dogs we love today.

Think of it.

Every breed of dog you've ever seen was sculpted by human hands.

Many of our best friends-- the most popular breeds-- were created in only the last few centuries.

The awesome power of evolution transformed the ravenous wolf into the faithful shepherd who protects the herd and drives the wolf away.

Artificial selection turned the wolf into the shepherd and the wild grasses into wheat and corn.

In fact, almost every plant and animal that we eat today was bred from a wild, less-edible ancestor.

If artificial selection can work such profound changes in only 10,000 or 15,000 years, what can natural selection do operating over billions of years? The answer is all the beauty and diversity of life.

How does it work? Our Ship of the Imagination can take us anywhere in space and time, even to the hidden microcosmos, where one kind of life can be transformed into another.

Come with me.

May not seem like it, but we've been living in an ice age for the last two million years.

This just happens to be one of the long intermissions.

For most of those two million years, the climate has been cold and dry.
The North Polar ice cap extended much farther south than it does today.

In one of those long, cold glacial periods when the winter sea ice stretched from the North Pole all the way down to what is now Los Angeles, great bears roamed the frozen wastes of Ireland.

This might look like an ordinary bear, but something extraordinary is happening inside her.

Something that will give rise to a new species.

In order to see it, we'll need to descend down to a much smaller scale, to the cellular level, so that we can explore the bear's reproductive system.

We'll take the subclavian artery through the heart.

Almost there.

Those are some of her eggs.

To see what's going on in one of them, we'll have to get even smaller.

We'll have to shrink down to the molecular level.

Our Ship of the Imagination is now so small, you could fit a million of them into a grain of sand.

See those guys over there strutting along those girders? They are proteins called kinesin.

These kinesin are part of the transport crew that's busy moving cargo around the cell.

How alien they seem.

And yet these tiny creatures-- and beings like them-- are a part of every living cell, including the ones inside you.

If life has a sanctuary, it's here in the nucleus which contains our DNA the ancient scripture of our genetic code.

And it's written in a language that all life can read.

DNA is a molecule shaped like a long twisted ladder or double helix.

The rungs of the ladder are made of four different kinds of smaller molecules.

These are the letters of the genetic alphabet.

Particular arrangements of those letters spell out the instructions for all living things,
telling them how to grow, move, digest, sense the environment, heal, reproduce.

The DNA double helix is a molecular machine with about 100 billion parts called "atoms." There are as many atoms in a single molecule of your DNA as there are stars in a typical galaxy.

The same is true for dogs and bears and every living thing.

We are, each of us, a little universe.

The DNA message handed down from cell to cell and from generation to generation is copied with extreme care.

The birth of a new DNA molecule begins when an unwinding protein separates the two strands of the double helix, breaking the rungs apart.

Inside the liquid of the nucleus, the molecular letters of the genetic code float freely.

Each strand of the helix copies its lost partner, resulting in two identical DNA molecules.

That's how life reproduces genes and transmits them from one generation to the next.

When a living cell divides in two, each one takes away with it a complete copy of the DNA.

A specialized protein proofreads to make sure that only the right letters are accepted so that the DNA is accurately copied.

But nobody's perfect.

Occasionally, a proofreading error slips through, making a small, random change in the genetic instructions.

A mutation has occurred in the bear's egg cell.

A random event as tiny as this one can have consequences on a far grander scale.

That mutation altered the gene that controls fur color.

It will affect the production of dark pigment in the fur of the bear's offspring.

Most mutations are harmless.

Some are deadly.

But a few, purely by chance, can give an organism a critical advantage over the competition.
A year has passed.

Our bear is now a mother.

And as a result of that mutation, one of her two cubs was born with a white coat.

When the cubs get old enough to venture out on their own, which bear is more likely to be able to sneak up on unsuspecting prey? The brown bear can be seen against the snow a mile away.

The white bear prospers and passes on its own particular set of genes.

This happens repeatedly.

Over succeeding generations, the gene for white fur spreads through the entire population of Arctic bears.

The gene for dark fur loses out in the competition for survival.

Mutations are entirely random and happen all the time.

But the environment rewards those that increase the chance for survival.

It naturally selects the living things that are better suited to survive.

And that selection is the opposite of random.

The two populations of bears separated, and over thousands of years, evolved other characteristics that set them apart.

They became different species.

That's what Charles Darwin meant by "the origin of species." An individual bear doesn't evolve; the population of bears evolves over generations.

If the Arctic ice continues to dwindle due to global warming, the polar bears may go extinct.

They'll be replaced by brown bears, better adapted to the now defrosted environment.

This is a different story from the one about the dogs.

No breeder guided these changes.

Instead, the environment itself selects them.

This is evolution by natural selection, the most revolutionary concept in the history of science.
Darwin first presented the evidence for this idea in 1859.

The uproar it caused has never subsided.

Why? We all understand the twinge of discomfort at the thought that we share a common ancestor with the apes.

No one can embarrass you like a relative.

Our closest ones, the chimpanzees, they frequently behave inappropriately in public.

There's an understandable human need to distance ourselves from them.

A central premise of traditional belief is that we were created separately from all the other animals.

It's easy to see why this idea has taken hold.

It makes us feel special.

But what about our kinship with the trees? How does that make you feel? Okay, here's a segment of the oak tree's DNA.

Think of it like a bar code.

The instructions written in the code of life tell the tree how to metabolize sugar.

Now let's compare it with the same section of my own DNA.

The DNA doesn't lie.

This tree and me-- we're long-lost cousins.

And it's not just the trees.

If you go back far enough, you'll find that we share a common ancestor with the butterfly gray wolf mushroom shark bacterium sparrow.

What a family! Other parts of the bar code vary from species to species.

That's what makes the difference between an owl and an octopus.

Unless you have an identical twin, there's no one else in the universe with the exact same DNA as you.

Within other species, the genetic differences provide the raw material for natural selection.
The environment selects which genes survive and multiply.

When it comes to the genetic instructions for life's most basic functions--say, digesting sugars--we and other species are almost identical.

That's because those functions are so basic to life, they evolved before the various life-forms branched off from each other.

This is our Tree of Life.

Science has made it possible for us to construct this family tree for all the species of life on Earth.

Close genetic relatives occupy the same branch of the tree, while more distant cousins are farther away.

Each twig is a living species.

And the trunk of the tree represents the common ancestors of all life on Earth.

The stuff of life is so malleable that once it got started, the environment molded it into a staggering variety of forms--10,000 times more than we can possibly show here.

Biologists have catalogued a half a million different kinds of beetles alone.

Not to mention the numberless varieties of bacteria.

There are many millions of living species of animals and plants, most of them still unknown to science.

Think of that--we have yet to make contact with most of the forms of terrestrial life.

That's how many kinds of life there are on this tiny planet alone.

The Tree of Life extends its feelers in all directions, finding and exploiting what works, creating new environments and opportunities for new forms.

The Tree of Life is three and a half billion years old.

That's plenty of time to develop an impressive repertoire of tricks.

Evolution can disguise an animal as a plant taking thousands of generations to contrive an elaborate costume that fools predators into looking elsewhere for someone to eat.

Or it can disguise a plant as an animal, evolving blossoms that take on the appearance of a wasp--the orchid's way of fooling real wasps into pollinating it.

This is the awesome shape-shifting power of natural selection.
Among the dense, tangled limbs of the vast Tree of Life you are here.

One tiny branch among countless millions.

Science reveals that all life on Earth is one.

Darwin discovered the actual mechanism of evolution.

The prevailing belief was that the complexity and variety of life must be the work of an intelligent designer, who created each of these millions of different species separately.

Living things are just too intricate, it was said, to be the result of unguided evolution.

Consider the human eye, a masterpiece of complexity.

It requires a cornea, iris, lens, retina, optic nerves, muscles, let alone the brain's elaborate neural network to interpret images.

It's more complicated than any device ever crafted by human intelligence.

Therefore, it was argued, the human eye can't be the result of mindless evolution.

To know if that's true, we need to travel across time to a world before there were eyes to see.

In the beginning, life was blind.

This is what our world looked like four billion years ago, before there were any eyes to see.

Until a few hundred million years passed, and then, one day, there was a microscopic copying error in the DNA of a bacterium.

This random mutation gave that microbe a protein molecule that absorbed sunlight.

Want to know what the world looked like to a light-sensitive bacterium? Take a look at the right side of the screen.

Mutations continued to occur at random, as they always do in any population of living things.

Another mutation caused a dark bacterium to flee intense light.

What is going on here? Night and day.

Those bacteria that could tell light from dark had a decisive advantage over the ones that couldn't.
Why? Because the daytime brought harsh, ultraviolet light that damages DNA.
The sensitive bacteria fled the intense light to safely exchange their DNA in the dark.
They survived in greater numbers than the bacteria that stayed at the surface.
Over time, those light-sensitive proteins became concentrated in a pigment spot on the
more advanced, one-celled organism.
This made it possible to find the light, an overwhelming advantage for an organism that
harvests sunlight to make food.
Here's a flatworm's-eye view of the world.
This multi-celled organism evolved a dimple in the pigment spot.
The bowl-shaped depression allowed the animal to distinguish light from shadow to
crudely make out objects in its vicinity, including those to eat and those that might eat it a
tremendous advantage.
Later, things became a little clearer.
The dimple deepened and evolved into a socket with a small opening.
Over thousands of generations, natural selection was slowly sculpting the eye.
The opening contracted to a pinhole covered by a protective transparent membrane.
Only a little light could enter the tiny hole, but it was enough to paint a dim image on the
sensitive inner surface of the eye.
This sharpened the focus.
A larger opening would have let in more light to make a brighter image but one that was
out of focus.
This development launched the visual equivalent of an arms race.
The competition needed to keep up to survive.
But then a splendid new feature of the eye evolved, a lens that provided both brightness
and sharp focus.
In the eyes of primitive fish, the transparent gel near the pinhole formed into a lens.
At the same time, the pinhole enlarged to let in more and more light.
Fish could now see in high-def, both close up and far away.
And then something terrible happened.

Have you ever noticed that a straw in a glass of water looks bent at the surface of the water? That's because light bends when it goes from one medium to another, say from water to air.

Our eyes originally evolved to see in water.

The watery fluid in those eyes neatly eliminated the distortion of that bending effect.

But for land animals, the light carries images from dry air into their still-watery eyes.

That bends the light rays, causing all kinds of distortions.

When our amphibious ancestors left the water for the land, their eyes, exquisitely evolved to see in water, were lousy for seeing in the air.

Our vision has never been as good since.

We like to think of our eyes as state-of-the-art, but 375 million years later, we still can't see things right in front of our noses or discern fine details in near darkness the way fish can.

When we left the water, why didn't nature just start over again and evolve us a new set of eyes that were optimal for seeing in the air? Nature doesn't work that way.

Evolution reshapes existing structures over generations, adapting them with small changes.

It can't just go back to the drawing board and start from scratch.

At every stage of its development, the evolving eye functioned well enough to provide a selective advantage for survival.

And among animals alive today, we find eyes at all these stages of development.

And all of them function.

The complexity of the human eye poses no challenge to evolution by natural selection.

In fact, the eye and all of biology makes no sense without evolution.

Some claim that evolution is just a theory, as if it were merely an opinion.

The theory of evolution, like the theory of gravity, is a scientific fact.

Evolution really happened.
Accepting our kinship with all life on Earth is not only solid science.
In my view, it's also a soaring spiritual experience.
Because evolution is blind, it cannot anticipate or adapt to catastrophic events.
The Tree of Life has some broken branches.
Many of them were severed in the five greatest catastrophes that life has ever known.
Somewhere, there's a memorial to the multitude of lost species, the Halls of Extinction.
Come with me.
Welcome to the Halls of Extinction.
A monument to the broken branches of the Tree of Life.
For every single one of the millions of species alive today, perhaps a thousand others have perished.
Most of them died out in the everyday competition with other life-forms.
But many of them were swept away in vast cataclysms that overwhelmed the planet.
In the last 500 million years, this has happened five times.
Five mass extinctions that devastated life on Earth.
The worst one of all happened some 250 million years ago, at the end of an era known as the Permian.
Trilobites were armored animals that hunted in great herds across the seafloor.
They were among the first animals to evolve image-forming eyes.
Trilobites had a good long run, some 270 million years.
Earth was once the planet of the trilobites.
But now they're all gone, extinct.
The last of them were swept from life's stage along with countless other species in an unparalleled environmental disaster.
The apocalypse began in what is now Siberia, with volcanic eruptions on a scale unlike anything in human experience.
Earth was very different then, with one single supercontinent and one great ocean.
Relentless floods of fiery lava engulfed an area larger than Western Europe.

The pulsing eruptions went on for hundreds of thousands of years.

The molten rock ignited coal deposits and polluted the air with carbon dioxide and other greenhouse gases.

This heated the Earth and stopped the ocean currents from circulating.

Noxious bacteria bloomed, but nearly everything else in the seas died.

The stagnant waters belched deadly hydrogen sulfide gas into the air, which suffocated most of the land animals.

Nine in ten of all species on the planet went extinct.

We call it The Great Dying.

Life on Earth came so near to being wiped out that it took more than ten million years to recover.

But new life-forms slowly evolved to fill the openings left by the Permian holocaust.

Among the biggest winners were the dinosaurs.

Now the Earth was their planet.

Their reign continued for over 150 million years.

Until it, too, came crashing down in another mass extinction.

Life on Earth has taken quite a beating over the eons.

And yet it's still there.

The tenacity of life is mind-boggling.

We keep finding it where no one thought it could be.

That nameless corridor? That's for another day.

I know an animal that can live in boiling water or in solid ice.

It can go ten years without a drop of water.

It can travel naked in the cold vacuum and intense radiation of space and will return unscathed.

The tardigrade, or water bear.
It's equally at home atop the tallest mountains and in the deepest trenches of the sea.
And in our own backyards, where they live among the moss in countless numbers.
You've probably never noticed them because they're so small.
About the size of a pinpoint.
But they're tough.
The tardigrades have survived all five mass extinctions.
They've been in business for a half a billion years.
We used to think that life was finicky, that it would only take hold where it was not too hot, not too cold, not too dark or salty or acidic or radioactive.
And whatever you do, don't forget to add water.
We were wrong.
As the hardy tardigrade demonstrates, life can endure conditions that would mean certain death for us humans.
But differences between us and life found in even the most extreme environments on our planet are only variations on a single theme, dialects of a single language.
The genetic code of Earth life.

But what would life be like on other worlds? Worlds with a completely different history, chemistry and evolution from our planet? There's a distant world I want to take you to-- a world far different from our own, but one that may harbor life.

If it does, it promises to be unlike anything we've ever seen before.

Clouds and haze completely hide the surface of Titan, Saturn's giant moon.

Titan reminds me a little bit of home.
Like Earth, it has an atmosphere that's mostly nitrogen.
But it's four times denser.
Titan's air has no oxygen at all.
And it's far colder than anywhere on Earth.

But still I want to go there.
We have to descend through a couple hundred kilometers of smog before we can even see the surface.

But hidden beneath lies a weirdly familiar landscape.

Titan is the only other world in the solar system where it ever rains.

It has rivers and coastlines.

Titan has hundreds of lakes.

One of them larger than Lake Superior in North America.

Vapor rising from the lakes condenses and falls again as rain.

The rain feeds rivers, which carve valleys into the landscape, just like on Earth.

But with one big difference.

On Titan, the seas and the rain are made not of water but of methane and ethane.

On Earth, those molecules form natural gas.

On frigid Titan, they're liquid.

Titan has lots of water, but all of it is frozen hard as rock.

In fact, the landscape and mountains are made mainly of water ice.

At hundreds of degrees below zero, Titan is far too cold for water to ever be liquid.

Astrobiologists since Carl Sagan have wondered if life might swim in Titan's hydrocarbon lakes.

The chemical basis for such life would have to be entirely different from anything we know.

All life on Earth depends on liquid water.

And Titan's surface has none of that.

But we can imagine other kinds of life.

There might be creatures that inhale hydrogen instead of oxygen.

And exhale methane instead of carbon dioxide.

They might use acetylene instead of sugar as an energy source.
How could we find out if such creatures rule a hidden empire beneath the oil-dark waves? We're diving down deep into the Kraken Sea, named for the mythic Norse sea monster.

Even if there is one of those down there, we probably couldn't see it.

It's so dark.

If you took all the oil and natural gas on Earth, it would amount to but a tiny fraction of Titan's reserves.

Let's turn on some lights.

We're now 200 meters beneath the surface.

Did you see something? Over there, by that vent.

Maybe it was just my imagination.

I guess we'll have to come back if we want to find out for sure.

There's one last story I want to tell you.

And it's the greatest story science has ever told.

It's the story of life on our world.

Welcome to the Earth of four billion years ago.

This was our planet before life.

Nobody knows how life got started.

Most of the evidence from that time was destroyed by impact and erosion.

Science works on the frontier between knowledge and ignorance.

We're not afraid to admit what we don't know.

There's no shame in that.

The only shame is to pretend that we have all the answers.

Maybe someone watching this will be the first to solve the mystery of how life on Earth began.

The evidence from living microbes suggest that their earliest ancestors preferred high temperatures.

Life on Earth may have arisen in hot water around submerged volcanic vents.
In Carl Sagan’s original Cosmos series, he traced the unbroken thread that stretches directly from the one-celled organisms of nearly four billion years ago to you.

Four billion years in 40 seconds.

From creatures who had yet to discern day from night to beings who are exploring the cosmos.

Those are some of the things that molecules do given four billion years of evolution.
3 - When Knowledge Conquered Fear

We were born into a mystery, one that has haunted us since at least as long as we've been human.

We awakened on this tiny world beneath a blanket of stars, like an abandoned baby left on a doorstep without a note to explain where we came from, who we are, how our universe came to be.

And with no idea how to end our cosmic isolation.

We've had to figure it all out for ourselves.

Best thing we had going for us was our intelligence, especially our gift for pattern recognition, sharpened over eons of evolution.

The ones who were good at spotting prey and predator, telling poisonous plants from the nourishing ones, they had a better chance to live and reproduce.

They survived and passed on those genes for pattern recognition with its obvious advantages.

Cultures all over the planet looked up at the same stars and found different pictures there.

We used this gift for recognizing patterns in nature to read the calendar in the sky.

The messages written in the stars told our forefathers and mothers when to camp and when to move on.

When the migratory herds and when the rains and the cold would come.

And when they would cease for a time.

When they observed the direct connection between the motions of the stars and the seasonal cycles of life on Earth, they concluded, naturally, that what happens up there must be directed at us down here.

It makes sense, right? If the sky was a calendar and somebody stuck a Post-it note on top of it, what else could it be but a message? And so, when the heavenly order was suddenly violated by the apparition of a comet in the sky they took it personally.

Can we really blame them? Back then, they had no other logical explanation for what was happening.

This was long before anyone had yet to imagine Earth as a spinning planet with a tilted axis, revolving around the Sun.
Every ancient human culture made the same mistake, a comet must be a message, sent by
the gods or one particular god.

And almost invariably, our ancestors concluded the news was not good.

It didn't matter if you were an ancient Aztec, Anglo-Saxon, Babylonian, Hindu.

Comets were portents of doom.

The only difference among them was the precise nature of the coming disaster.

"Dis-aster," as in the Greek word for "bad star." To the Masai of East Africa, a comet
meant famine.

To the Zulu in the south, it meant war.

To the Eghap people of the west, it meant disease.

To the Djaga of Zaire, specifically "smallpox." To their neighbors, the Luba, a comet
foretold the death of a leader.

The ancient Chinese were remarkably systematic.

Starting in roughly 1400 BC, they began recording and cataloguing the apparitions of
comets.

A three-tailed comet meant calamity for the state.

A four-tailed comet signified an epidemic was coming.

The human talent for pattern recognition is a two-edged sword.

We're especially good at finding patterns, even when they aren't really there-- something
known as "false pattern recognition." We hunger for significance, for signs that our
personal existence is of special meaning to the universe.

To that end, we're all too eager to deceive ourselves and others, to discern a sacred image
in a grilled cheese sandwich or find a divine warning in a comet.

Today, we know exactly where comets come from and what they're made of.

Our Ship of the Imagination, fueled by equal parts of science and wonder, can take us
anywhere in space and time.

It can travel faster than light and render visible those things that cannot be seen.

It's carrying us to a mysterious realm that lies one light-year from the Sun.
What is this swarm of worlds? Was it organized by alien beings? No.

Just gravity.

These are the snows of yesteryear, drifting mountains of ice and rock, the preserved remnants of the birth of the solar system.

It's called the Oort Cloud, after Jan Oort, the Dutch astronomer who foretold its existence back in 1950.

He was trying to solve a paradox.

There's so many ways for comets to die.

Because they cross the orbits of planets, comets frequently collide with them.

Comets are largely made of ice, so every time they come near the Sun, they lose a part of themselves through evaporation.

And after several thousand trips, their ice is all gone, and what remains of the comet is now an asteroid.

Comets can be gravitationally ejected from the solar system and exiled into space.

And yet, somehow, the comets keep coming.

Oort and other astronomers wondered, "Where do all the comets come from?" Oort calculated the rate at which new comets appear and concluded that there must be a vast, spherical swarm of them, a few light-years across, surrounding the Sun.

Oort's logic still holds up, even after all the discoveries we've made about comets and the solar system in the many decades since.

And yet, the Oort Cloud is a sight that no one has ever seen.

Nor could we.

It's dark out here.

And each comet is about as far from its closest neighbor as the Earth is from Saturn.

But science gives us special powers of our own.

It gave Jan Oort the gift of prophecy.

Oort was also the first to correctly estimate the distance between the Sun and the center of our galaxy.
That's a big deal-- finding out where we are in the Milky Way.

Our star is about 30,000 light-years from the center.

Oort was also the first guy to use a radio telescope to map the galaxy's spiral structure.

And he discovered that the center of our galaxy was a place of titanic explosions, the first indication that there might have been a supermassive black hole lurking there.

Does the fact that most of us know the names of mass murderers, but never heard of Jan Oort, say anything about us? The Oort Cloud is so enormous that it takes one of its comets about a million years to complete a single trip around the Sun.

Out here, at the far edge of the solar system, even a little tug from the gravity of a passing star can liberate some of these comets from their gravitational bondage to the Sun.

Some comets are flung out of the solar system to wander interstellar space.

But for others, there's a different fate.

This one is plunging towards the Sun, gaining speed in an unbroken free fall that lasts hundreds of thousands of years.

When Neptune's gravity gives it another tug, there's a small change in course.

Mighty Jupiter, the most massive object in our solar system-- other than the Sun-- attracts the comet with its powerful gravitational pull, bending its path.

When our comet reaches the inner solar system heat from the Sun bakes it.

A beautiful transformation begins.

The barren, sooty iceberg now sports a glowing halo and a tail.

These layers tell the story of how the comet was made, some four billion years ago.

During the 40,000 generations of humanity, there must have been roughly 100,000 apparitions of a bright comet.

For all that time, the best we could do was look up in helpless wonder, prisoners of Earth with nowhere to turn for an explanation beyond our guilt and our fears.

But then a friendship began between two men that led to a permanent revolution in human thought.

Isaac Newton and Edmond Halley could not know it, but their collaboration would ultimately set us free from our long confinement on this tiny world.
The Comet of 1664 sent shivers of dread throughout Europe, and the terror seemed justified when the Plague and the Great Fire of London followed soon after.

There, with long bloody hair, a blazing star threatens the world with famine, plague and war.

To princes, it spells death to kingdoms, many crosses to all estates, inevitable losses to herdsmen, rot, to plowmen, hapless seasons, to sailors, it brings storms, to cities, civil treasons.

But for one child, the comet was not the least bit frightening.

For him, it was a thing of wonder.

Like all of us, Edmond Halley was born curious.

Hell's bells! He was lucky to have a father who encouraged and nurtured his curiosity, buying him the best scientific instruments and even funding his expedition to make the first accurate star map of the Southern Hemisphere.

Halley dropped out of Oxford when he was 20, and sailed to St. Helena, an island below the equator, off the west coast of Africa.

Hell's bells.

The problem was, nobody told Halley that the weather on St. Helena was generally lousy; it took him 12 frustrating months to observe enough southern stars to make a complete map.

The gods and heroes of ancient Greece were now joined by the mythic figures of a new world and age, a toucan, a compass, a bird of paradise.

When Halley came home with the other half of the sky, his map created a sensation.

Now merchants and explorers could navigate by the stars visible anywhere on Earth.

At the time, the World Society of London was the world's clearinghouse of scientific discovery.

Its motto, "Nullius in verba," sums up the heart of the scientific method.

It's Latin for "see for yourself." In other words, "question authority." Halley's star maps caught the attention of the Society's Curator of Experiments.

I'd show him to you if I could, but no portrait of Robert Hooke exists from his time, only
the verbal descriptions of his contemporaries.

They called him "lean, bent, ugly." He was possibly the most inventive person who ever lived.

And despite his appearance, he was the most sought-after party guest in all of London.

Why? Hooke's insatiable curiosity encompassed absolutely everything.

Hooke discovered a little cosmos, and we still call it by the name he gave it, the cell.

Hooke discovered the cell by looking at a piece of cork with one of his own inventions, the compound microscope.

He anticipated aspects of Darwin's theory of evolution by almost 200 years.

Hooke also improved the telescope.

The drawings he made of the astronomical bodies he observed attest to his uncanny precision.

After the Great Fire destroyed central London in 1666, Hooke partnered with the architect Christopher Wren to redesign and rebuild the city.

Hooke was the foremost experimentalist of his age.

Using coiled springs, he derived the "law of elasticity," known today as Hooke's Law.

He perfected the air pump, the height of technology in its time, and used it to experiment on respiration and sound.

And he experimented with cannabis.

He reported to a meeting of the Royal Society that a sea captain friend of his "had so often experimented with it, that there is no cause of fear, though possibly there may be of laughter." But coffee was the drug of choice for England in the 17th century.

Coffeehouses sprang up all over London.

This is where people came to get news, to launch new ventures, and to debate ideas.

The coffeehouse was an oasis of equality in a class-obsessed society.

Here, a poor man needn't give up his seat to a rich man, nor submit to his opinion.

It was a kind of laboratory of democracy.

In this highly caffeinated atmosphere, Halley and Hooke met Christopher Wren to discuss
a deep mystery.

Why do the planets move as they do? The astronomer Johannes Kepler had demonstrated, some 80 years before, that the orbits of the planets around the Sun were not perfect circles, but actually ellipses, and that the closer a planet was to the Sun, the faster it moved.

Why? Could some invisible force from the Sun be responsible for this change in motion? If so, how did it work? Could there be a simple mathematical law to describe it? Maybe something like Hooke's Law of Elasticity? Perhaps.

But try as he might, Christopher Wren couldn't figure it out.

Damned if I haven't tried.

It's beyond me.

I'll wager a book worth 40 shillings to the man who can solve it! That book is mine, Mr. Wren.

I've already done the calculation.

Halley was delighted.

Show us, Mr. Hooke.

But months passed, and Hooke failed to deliver.

He couldn't do the math.

None of them could.

Finally, Halley had enough of Hooke's excuses.

Halley knew there must be someone, somewhere, up to the challenge.

What about that mathematician at Cambridge? Clever fellow.

He had solved central questions about the nature of light years before, when he was still only 22.

And he invented the reflecting telescope.

Odd bird.

Dropped out of sight a while back; some squabble over Hooke and his discovery about light.
Went completely to pieces over it and has been hiding out in Cambridge ever since.

Halley wondered if this strange, and by all accounts, exceedingly difficult man, might succeed where Hooke and others had failed.

What he couldn't know, what no one could possibly imagine at the time, were the countless ways the world would be forever changed by this meeting on an August day in 1684.

Isaac Newton was born in England on Christmas Day in 1642.

Before he even opened his eyes, his father was already dead.

His mother left him when he was only three and did not return until he was 11.

When she did, it was with a new family and husband, a stepfather who Isaac Newton despised.

Newton's refuge from his miserable family life was his passion to understand how things worked, especially nature itself.

In 1661, the talented young Isaac entered Trinity College at Cambridge University where he was a consistently lousy student, one without friends or a loving family to provide any warmth or encouragement.

Newton mostly kept to himself, sequestered in his room, studying ancient Greek philosophers, geometry and languages, and pondering deep questions on the nature of matter, space, time, and motion.

This budding scientist was also a passionate mystic.

Newton believed that a secret knowledge called alchemy, known only to a small group of ancient philosophers, was waiting to be rediscovered.

He hoped to learn how to change ordinary metals into silver and gold, and maybe even cook up the elixir of life, the key to immortality.

He was also obsessed with finding hidden messages in the words of the Bible.

He combed through translations in several different languages, hoping to decipher coded instructions from God.

He made elaborate calculations in an effort to discover the date of the Second Coming.

His lifelong research in alchemy and biblical chronology never led anywhere.

When Halley found Newton that fateful day, he was living as a virtual recluse.
Newton had gone into hiding 13 years earlier, after Robert Hooke had publicly accused Newton of stealing his groundbreaking work on light and color.

In fact, it was Isaac Newton who solved the mystery of the spectrum of light, not Robert Hooke.

This wound was painful and deep, and Newton resolved to never expose himself to that kind of public humiliation ever again.

Sir, I don't suppose you recall our meeting a few years ago? Yes, Mr. Halley.

I'm sorry to bother you.

Never mind the formalities, get to your point.

I've been talking with our friends, Mr. Wren and Mr. Hooke.

That scoundrel Hooke's no friend of mine.

Yes, I understand, sir.

But the thing is we've been debating the puzzling question of planetary motion.

We all agree that some force of attraction from the Sun governs the motions of the planets.

We suspect there must be a mathematical law to describe how this force changes with distance.

And knowing of your skill Yes, yes, the attraction of gravity weakens with the square of the distance.

That's why the planets move in ellipses.

But, sir, how can you know this? Why, I have calculated it some five years ago.

I beg you, show it to me.

The calculation is here somewhere.

Well, no matter.

I shall redo it and be sure to send it on to you.

This is stupendous! Why have we not had word of it before? Newton remembered all too well what Hooke had done to him the last time he put forth an idea.

Just when Halley may have begun to wonder if Newton was bluffing as Hooke had done
earlier, a messenger arrived with an envelope from Newton.

Here are the opening pages of modern science with its all-embracing vision of nature universal laws of motion, gravity not just for the Earth, but for the cosmos.

Halley raced back to Cambridge.

Mr. Newton, I beseech you to work all of this into a book as soon as possible.

I can assure you the Royal Society will publish it.

But there was one little problem.

We are in agreement that Mr. Newton has produced a masterpiece.

However, I'm afraid the Royal Society has well, regrettably sales for the History of Fish have not lived up to our financial expectations.

It's an impressive book.

Extremely comprehensive.

Really.

It's filled with lavish illustrations of well, fish.

The disappointing sales led to a bigger problem.

The Royal Society pretty much blew its total annual budget on the History of Fish.

In fact, they were so strapped for cash, they had to pay poor Halley's salary with copies of their worst-selling book.

With no money to print Newton's Principia, the scientific revolution hung in the balance.

Without Halley's heroic efforts, the reclusive Newton's masterwork might never have seen the light of day.

But Halley was a man on a mission, absolutely determined to bring Newton's genius to the world.

That pre-scientific world, the world ruled by fear, was poised at the edge of a revolution.

Everything depended on whether or not Edmond Halley could get Newton's book out to the wider world.

Halley resolved not only to edit Newton's book, but to publish it at his own expense.
Newton completed the first two volumes, laying the mathematical framework for the physics of motion.

The third volume would settle once and for all who won the coffeehouse wager.

Newton applied his principles to explain all the known motions of the Earth, the Moon and the planets.

Unfortunately, there was this problem.

Now Halley also took on the role of Newton's psychotherapist.

Isaac, I'm afraid that Mr. Hooke requires an acknowledgment in the preface of your third volume.

But I have done so.

Thanking him, Mr. Wren and yourself for prodding me to think again on astronomical matters.

Mr. Hooke has been going about London saying that you got the Law of Gravity from him.

Why, that litigious little Never! I would sooner burn the third volume than deface it with such a lie.

To hell with Hooke.

He will be long forgotten when your ideas are still being celebrated.

More copies of that dreadful book? Wherever shall we put them all? We talked about this, Mary, dear.

This is my salary from the Society.

They have nothing else with which to pay me.

If only Mr. Hooke and Mr. Newton were more like you.

Halley and Wren decided to confront Hooke about his false claims.

That law is mine, I tell you! I proved it first.

Then fetch your proof here at once.

Let us see it.

Surely we have waited on it long enough.
You'll simply have to take my word for it.

Empty claims may persuade elsewhere, but not here.

Put up or shut up, Mr. Hooke.

Blasted Newton.

I'll make him pay.

If it wasn't for Edmond Halley, Newton's great book would've never been conceived, nor written, nor printed.

Okay.

So what? What difference does that make to us? What's the big deal? When Isaac Newton was born in this house in 1642, the world was very different.

Everyone looked at the perfection of the clockwork motions of the planets in the sky and could only understand it as the work of a master clock maker.

How else to explain it? There was only one way such a thing could come about in their imagination; only one answer for them-- God.

For reasons beyond our understanding, God just created the solar system that way.

But this explanation is the closing of a door.

It doesn't lead to other questions.

Along came Newton, a God-loving man who's also a genius.

He could write the laws of nature in perfect mathematical sentences-- formulas that applied universally to apples, moons, planets and so much more.

With one foot still in the Middle Ages, Isaac Newton imagined the whole solar system.

Newton's laws of gravity and motion revealed how the Sun held distant worlds captive.

His laws swept away the need for a master clock maker to explain the precision and beauty of the solar system.

Gravity is the clock maker.

Matter obeyed commandments we could discover, laws the Bible hadn't mentioned.

Newton's answer to why the solar system is the way it is opened the way to an infinite number of questions.
Principia also happened to include the invention of calculus, and the first sound theoretical basis for an end to our imprisonment on Earth-- space travel.

Newton envisioned the firing of a cannonball with increasingly greater explosive thrust. He reasoned that with enough velocity, the bounds of gravity could be broken, and the cannonball could escape to orbit the Earth.

This changed everything.

Newton's Principia Mathematica set us free in another way.

By finding the natural laws governing the comings and goings of comets, he decoupled the motions of the heavens from their ancient connections to our fears.

If Halley hadn't been standing next to Newton for all those years, perhaps the world would remember him for his own accomplishments and discoveries.

But the only thing that comes to mind for most people is the comet, the irony is that discovering a comet is actually one of the few things that Halley never did.

After the publication of the Principia Halley was commanded by his king to lead three ocean voyages, scientific expeditions to solve navigational problems for the British navy. Halley used this opportunity to make the first map of the Earth's magnetic field And he was also a businessman.

Halley perfected the diving bell and used his invention to start a flourishing commercial salvage operation.

Mmm, ah, Dr. Halley's gone and done it this time.

I reckon he's been down there at least three hours.

Not one to risk the lives of others, Halley personally tested his own invention.

I make it exactly four hours since our descent.

Not at all bad for ten fathoms.

He invented the weather map.

And the symbols he devised for indicating prevailing winds are still in use today.

Halley laid the groundwork for the science of population statistics.

How? He compared the birth, marriage, death, and population densities of London and Paris.
He actually had to pace off the entire perimeter of Paris, on foot, to learn its true dimensions.

He came to the conclusion that since roughly half of all adults fail to reproduce children, who themselves survive to reproduce, every married couple must have four children in order to maintain the population.

And it was Edmond Halley who gave us the actual scale of the solar system.

He figured out a clever way to find the distance from Earth to the Sun.

It involved precisely measuring the time it took for the planet Venus to cross the Sun's disc.

27 years after Halley's death, Captain James Cook made his first voyage to Tahiti for the express purpose of testing Halley's method during a transit of Venus across the Sun.

Using a special filter to protect his vision from being destroyed by looking directly at the Sun, Cook and his men made it possible for us to know that the Sun is 93 million miles from Earth.

And Halley was the first to realize that the so-called "fixed" stars were not fixed at all.

How'd he do it? He pored over the observations made by the ancient Greek astronomers of the brightest stars.

And he compared their observations with the ones he himself made of the same stars 1,800 years later.

Why hadn't anyone noticed this before? Halley figured out that it would only become apparent if you waited long enough between observations.

It's hard to perceive the motions of things that are far away.

And the stars are so very far away, that you would need to track them for many centuries before you could detect that they moved at all.

Halley discovered the first clue to a magnificent reality, all the stars are in motion, streaming past each other, rising and falling like merry-go-round horses in their Newtonian dance around the center of our galaxy.

And, oh, yes, there was that thing about the comet.

What were those strange and beautiful celestial visitors that appeared without warning from time to time? Halley set out to solve this mystery as a detective would, by gathering all credible eyewitness testimony.
The earliest precise observations of a comet that Halley could find were made in Constantinople by Nikephoros Gregoras, a Byzantine astronomer and monk in June 1337.

Halley hunted down every astronomical observation of a comet recorded in Europe between 1472 and 1698.

And remember, there was no such thing as a search engine or a computer.

All Halley had were his books and his mind.

Now here comes the hard part, Halley had to take the observations made for each comet and find the shape of its actual path through space.

No one else but Newton had yet attempted to apply his new set of laws to an astronomical question.

In an arduous tour de force of mathematical brilliance, Halley discovered that comets were bound to the Sun in long elliptical orbits.

And he was the first to know that the comets seen in 1531, were one and the same--a single comet that returned every 76 years.

In a stunning example of true pattern recognition, he predicted it would be seen again more than 50 years in the future.

For millennia, comets had been props for mystics, who considered them to be merely omens of human events.

Halley shattered their monopoly, beating them at their own game, a game that no scientist had ever played before prophecy.

And he did not hedge his bet.

Like Babe Ruth predicting where his next home run would land in the stands, Halley stated flatly that the comet would return at the end of 1758, from a particular part of the sky, following a specific path.

There is hardly a prophecy attempted by the mystics that ever even strives for comparable precision.

That's Halley's Comet.

Out here at the edge of the solar system, it doesn't look like much.

Just a big hunk of ice and rock in space.

That's because beyond the orbit of Neptune, nearly five billion kilometers from the Sun,
comets lead very quiet lives.

As it reaches the far end of its orbit, it'll slow down till the Sun allows it to go no farther.

Then it will begin its long fall back to the inner solar system.

Halley's comet is in free fall around the Sun.

Everything in our solar system-- the Earth, the Moon, the other planets, comets, asteroids, all of them are falling around the Sun.

Gravity pulls the planets towards the Sun, but because of their orbital momentum, they keep moving around the Sun, never falling into it.

Robert Hooke had died years before, having ruined his health with some bad habits daily doses of wormwood, opium, mercury.

A few months later, Newton was elected to replace him as president of the Royal Society.

It is said that a portrait of Hooke once hung on these walls.

Halley lived on to accomplish many more astonishing feats.

He worked right up to his death at age 85.

His final act was to call for a glass of wine.

He downed it with pleasure and breathed his last breath.

Some believe that it was on a night like this that Isaac Newton finally took his revenge against Robert Hooke.

But Halley's prophecy was not forgotten.

50 years later, as the time of the predicted return approached, the world's astronomers vied to be the first to catch sight of his comet.

They weren't disappointed.

It's been welcomed back every 76 years since.

When Halley's Comet returns to our skies, sunlight will warm up the ice on its surface, once again setting loose the dust and gases trapped within.

Halley's Comet most recently visited our neighborhood back in 1986.

And if you're seeing this in 2061, then you'll know it's back.
May you feel the wonder of all those who came before you and none of the fear.

Newton's laws made it possible for Edmond Halley to see some 50 years into the future and predict the behavior of a single comet.

Scientists have been using these laws ever since, opening the way to the Moon and even beyond our solar system.

The baby in the basket is learning to walk and to know the cosmos.

Which brings me to one last prophecy.

Using nothing more than Newton's laws of gravitation, we astronomers can confidently predict that several billion years from now, our home galaxy, the Milky Way, will merge with our neighboring galaxy Andromeda.

Because the distances between the stars are so great compared to their sizes, few if any stars in either galaxy will actually collide.

Any life on the worlds of that far-off future should be safe, but they would be treated to an amazing, billion-year-long light show a dance of a half a trillion stars to music first heard on one little world by a man who had but one true friend.
4 - A Sky Full of Ghosts

Seeing is not believing.

Our senses can deceive us.

Even the stars are not what they appear to be.

The cosmos, as revealed by science, is stranger than we ever could have imagined.

Light and time and space and gravity conspire to create realities which lie beyond human experience.

That's where we're headed.

Come with me.

Back in 1802, on a night like this, the astronomer William Herschel strolled the beach on the English coast, with his son John.

Herschel was the first person ever to see into the deeper waters of the cosmic ocean.

There he glimpsed the magic trick that light does with time.

Father do you believe in ghosts? Why, yes, my son! You, you do? I would not have thought so.

Oh, no, not in the human kind of ghost.

No not at all.

But look up, my boy, and see a sky full of them.

The stars, Father? I do not follow.

Every star is a sun as big, as bright as our own.

Just imagine how far away from us you'd have to move the Sun to make it appear as small and faint as a star.

The light from the stars travels very fast faster than anything but not infinitely fast.

It takes time for their light to reach us.

For the nearest ones, it takes years.

For others, centuries.

Some stars are so far away, it takes eons for their light to get to Earth.
By the time the light from some stars gets here, they are already dead.

For those stars, we see only their ghosts.

We see their light, but their bodies perished long, long ago.

John, I have seen further back in time than any man before me-- millions of years into the past.

William Herschel was the first person to understand that a telescope is a time machine.

We cannot look out into space without seeing back in time.

In one second, light travels 300,000 kilometers, or 186,000 miles.

That's nearly the distance from the Earth to the Moon.

So, the Moon is about one light-second away.

The next time you look at the Moon, you'll be seeing one second into the past.

That Sun it's not really there.

It won't actually be above the horizon for another two minutes.

The sunrise is an illusion.

Earth's atmosphere bends the incoming rays of sunlight like a lens or a glass of water.

So we see the image of the Sun projected above the horizon before the physical Sun is actually there.

That Sun behind me is a mirage.

No more real than the shimmering image that hovers in the distance over a desert road on a hot day.

Sunlight takes about eight minutes to reach Earth, so the Sun is eight light-minutes away.

From Earth, we can only ever see the Sun as it was eight minutes ago.

And another thing, the Sun doesn't really "rise" at all.

The Earth turns and we turn with it.

It may not look like it, but right at this moment, I'm moving faster than a jet plane and so are you and everyone on Earth.

While I'm at it, that horizon it's not really there at all.
There's no edge.

The horizon is just another illusion.

The distance between Earth and the outermost planet Neptune varies as the planets orbit the Sun.

On average, the light makes that trip in four hours.

So for us on Earth, the Neptune we see is always four hours in the past-- four light-hours away.

But the distances to the planets, even the farthest one are mere baby steps on a much grander scale of the stars and galaxies.

As soon as we leave the Sun's immediate neighborhood, we need to change the unitive distance from light-hours to light-years.

A light-year is the yardstick of the cosmos.

A single one is nearly ten trillion kilometers, or about six trillion miles.

It's a unitive distance, just like a meter or a mile.

It's the distance light travels in a year.

The nearest star to the Sun, Proxima Centauri, is a little more than four light-years away from Earth.

How far away is four light-years? NASA's Voyager spacecraft moves at more than 56,000 kilometers an hour.

Even at that astonishing speed, it would take Voyager more than 80,000 years to reach the nearest star.

And the stars of the Pleiades cluster, 400 light-years away.

The Ship of the Imagination is equipped with a highly unusual capability-- one-of-a-kind, actually.

It makes it possible for us to see what was happening when the light from a distant star or galaxy first set out on its long journey to Earth.

When that light left the Pleiades, about 400 years ago, Galileo was taking his first look through a telescope.

A few years later, he tried to measure the speed of light, but he couldn't do it.
He had a very clever plan, but the technology of that era just wasn't good enough to measure the motion of anything that moves as fast as light.

When we look at the Crab Nebula from Earth, we're seeing much farther back in time. The Crab Nebula was once a giant star, ten times the mass of the Sun, until it exploded in a supernova.

At its heart is a pulsar, a collapsed star the size of a city, spinning 30 times a second.

This pulsar's whirling magnetic field whips nearby electrons into a frenzy, accelerating them to almost the speed of light.

They shine with a blue glow that lights up the tendrils of gas still unraveling from the supernova.

The Crab Nebula is about 6,500 light-years from Earth.

According to some beliefs, that's the age of the whole universe.

But if the universe were only 6,500 years old, how could we see the light from anything more distant than the Crab Nebula? We couldn't.

There wouldn't have been enough time for the light to get to Earth from anywhere farther away than 6,500 light-years in any direction.

That's just enough time for light to travel through a tiny portion of our Milky Way galaxy.

To believe in a universe as young as is to extinguish the light from most of the galaxy, not to mention the light from all the 100 billion other galaxies in the observable universe.

The center of our own galaxy is about 30,000 light-years from Earth.

The light we see today coming from the core of the Milky Way left there when our ancestors were perfecting a way to vanquish death by making art with the power to inspire those who would come long after they were gone.

The light we see coming from the Sombrero Galaxy is 30 million years old.

Our ancestors were living in trees when that light started out.

They weighed about five kilos and had long tails.

But even 30 million light-years away is still in our own cosmic backyard.

That galaxy is part of the Coma Cluster, 320 million light-years away.

What was going on back home when the light you are seeing began its trip to Earth? No
familiar continents, oceans or rivers.

Our distant ancestors were just leaving the water for the land.

That's pretty old light, but not nearly the oldest light we can see.

The oldest light is very faint, a pale ghost in the night.

See that red blob inside the circle? That's one of the oldest galaxies we've ever seen.

You're looking at 13.4-billion year-old starlight as captured by the Hubble space telescope.

It's coming from the very first generation of stars.

What was happening on Earth back then? Absolutely nothing.

There was no Earth, no Sun, no Milky Way.

They would not come to be for billions of years.

When we try to look even farther into the universe, we come to what appears to be the end of space but actually it's the beginning of time.

Earth pulls on us.

Our lives are a relentless struggle with gravity.

That little girl is trying her best to climb out of a gravitational well.

From our first efforts to stand to our final surrender, we are struggling to overcome the Earth's pull.

We are born, live and die in a force field-- one that is almost as old as the universe itself.

And how old is that? To visualize the 13.

8 billion year age of the universe, we've compressed all of cosmic time into a single year-at-a-glance calendar.

Midnight on December 31 is this very moment right now.

And January 1 is the beginning of time.

See that glowing fog out there? It's radiation left over from the Big Bang, the explosion that made the universe Right now, we're at the very edge of known space and time.

So what happened before the Big Bang? Nobody knows.
No evidence survives from before that moment.

We've got some pretty crazy ideas about where the universe came from, which we'll get to, in time.

Where are we in the universe? At the very center.

In the observed universe, everyone gets to feel special.

No matter which galaxy you happen to live in, when you look out to the universe, you'll find yourself at the center of the cosmic horizon.

But this is just an illusion.

In reality, there is no center, and the cosmic horizon is no more real than the horizon at sea.

It's what you get when you have a finite speed of light in a universe that had a beginning in time.

A few hundred million years after the Big Bang, vast clouds of hydrogen and helium condensed into the first stars and galaxies.

With these new sources of light, the long dark ages of the universe ended.

As space continued to expand, cosmic evolution unfolded on grander scales.

As the first generation of stars died, they seeded space with heavier elements, making possible the formation of planets, and ultimately, life.

Matter and energy were formed in the Big Bang.

But that's not all.

Space and time were created, too, and all the forces that bind matter together, including gravity.

Isaac Newton discovered a mathematical law that describes how gravity works.

With that law, he could explain the motions of the planets.

More than 100 years later, William Herschel realized gravity could do much more.

John, can you keep a secret? Yes, Father.

I've made a discovery and have yet to tell another soul.

The gravity that holds us to the Earth-- the same gravity that Newton showed keeps the
planets in their orbits-- I've discovered that it also rules the distant stars.

Father but how can you know this? Can you find the constellation of the Lion? There.

Well done.

Can you now find the star that joins the Lion's head to his body? That one.

That star is really two stars so close together that they appear to be one.

I've been watching them through my telescope since long before you were born.

They dance around each other very slowly.

More slowly than any planet moves around the Sun.

Many of the stars we see tonight, perhaps most of them, dance with invisible partners.

Gravity's empire governs all the heavens.

A century earlier, Isaac Newton had been haunted by the same absence of a mechanism for gravity.

How could distant bodies affect each other across empty space without actually touching? This "action at a distance," as he called it, baffled him.

In the 19th century, Michael Faraday discovered that we were surrounded by invisible fields of force that explained how gravity works.

The apple and the Earth don't touch each other, but the fields between them do.

He imagined those lines of gravitational force radiating out into space from every massive body-- the Earth, the Moon, the Sun, everything.

Here was the answer to that question that had stumped Newton.

In 1865, James Clerk Maxwell translated Faraday's idea about fields of electricity and magnetism into mathematical laws.

He discovered that these fields move through space in waves.

When he calculated how fast they move, it turned out to be the speed of light.

We were beginning to discover the threads of the cosmic tapestry, but we were not yet able to discern the rich pattern that time, light, space and gravity weave.

As Albert Einstein worked in Berlin on his theory of gravity, he kept the portraits of these three men before him.
He knew he was standing on their shoulders.

Years before, as a teenager, he had an insight that was as Earth-shaking as any idea of theirs.

And it happened one summer while he was daydreaming in Italy.

In the summer of 1895, Einstein's father's business in Germany had failed, and the family had moved here to northern Italy.

Young Einstein loved wandering these roads and giving his mind free rein to explore.

There's something timeless about this place.

Nothing here has really changed since the time of Einstein's early daydreams.

One day, he began to think about light and how fast it travels.

In everyday life, we always measure the speed of a moving object with respect to something else.

Something that's presumably not moving.

Something in the cosmos that's not in motion.

For example, I'm moving about ten kilometers per hour relative to the ground.

But as I mentioned earlier, the ground is moving.

Earth is turning at more than 1,600 kilometers per hour while it orbits the Sun at more than 100,000 kilometers per hour.

And the Sun is moving through the galaxy at a half a million miles per hour.

And the Milky Way is moving through the universe at nearly one and a half million miles an hour.

There is no fixed place in the cosmos.

All of nature is in motion.

It was hard even for the young Einstein to imagine some absolute standard to measure all those relative motions against.

This is the very book that inspired Einstein as a young boy.

Give a kid a book and you change the world.
In a way, even the universe.

Look at this-- the very first page, it describes the astonishing speed of electricity through wires and light through space.

Einstein remembered what he'd learned as a child from this book, and perhaps, for the first time, right here, wondered what the world would look like if you could travel at the speed of light.

The more Einstein thought about it, the more troubled he became.

If you imagine traveling at the speed of light, paradoxes seem to pop up everywhere.

Einstein was shocked to realize that so much of what had been uncritically accepted as truth by even the greatest authorities on the subject was just plain wrong.

When traveling at high speeds, there are certain rules which must be obeyed.

Einstein called these rules "The Principles of Relativity." Imagine that young woman who just blew past us on the motorbike, imagine she was riding her bike through the cosmos.

Light from a moving object travels at the same speed, no matter whether the object is at rest or in motion.

Her speed is not added to the speed of light.

The light from her motorbike still travels at the speed of light.

Nature commands, "Thou shalt not add my speed to the speed of light." Also, no material object can travel at or faster than the speed of light.

There's nothing in physics that prevents you from traveling as close to the speed of light as you like.

is just fine, but no matter how hard you try, you never gain that last decimal point.

For reality to be logically consistent, there must be a cosmic speed limit.

The crack of that whip is due to its tip moving faster than the speed of sound.

It makes a shockwave, a mini sonic boom, in the Italian countryside.

A thunderclap works the same way, and so does the sound of a passing supersonic jet.

So why is the speed of light any more a barrier than the speed of sound? The answer is not just that light travels about a million times faster than sound.

And it's not merely an engineering problem, like building the first supersonic jet.
Instead, the light barrier is a fundamental law of nature, as basic as gravity.

Einstein found his absolute framework for the world, this sturdy pillar among all the relative motions within the motions of the cosmos.

Light travels just as fast, no matter how fast or slow its source is moving.

Speed of light is constant, relative to everything else.

Nothing can ever catch up with light.

The thing about the laws of nature is that they're unbreakable.

The job of physicists is to discover these commandments, the ones that do not vary from culture to culture or time to time and hold true throughout the cosmos.

That's why, as Einstein showed, funny things happen close to the speed of light.

Traveling close to the speed of light is kind of an elixir of life because your biological clock slows down relative to those you leave behind.

This phenomenon may provide us humans, who only live for a century or so, a practical means to travel to the stars, where the magic show of spacetime really gets crazy.

The 19th-century astronomer William Herschel loved to share the wonders of the universe with his son John.

I once had a friend, very clever fellow, an astronomer and a parson at Leeds, by the name of John Michell.

Poor man died when you were a babe, God rest his soul.

He held that some stars are invisible.

They really exist, but we shall never see them.

"Dark stars," Michell called them.

With all due respect, Father, surely your friend was mistaken.

If no one can see them, then how can we possibly know they exist? Did you see the man who left those footprints, John? Why, no, Father.

I did not.

But do you know that he exists? John Michell is one of the greatest scientists you've probably never heard of.
He lived and worked in England in the 18th century.

If he ever sat for a portrait, it no longer exists.

He was once described by an acquaintance as "a short little man, of black complexion, and fat." Michell imagined a star so big, so massive, that nothing, not even light, could escape its gravitational grip.

Can you find the dark star? You can't see it with your eyes, not directly, but it may leave a kind of footprint on the cosmic shore.

Michell realized that we might be able to detect some of these dark stars because of their extreme gravity.

If one happened to be near a smaller, luminous companion star, that star would appear to travel in a tight orbit around nothing.

Even though we can't see it, we know something with a lot of mass has to be right there.

A dark star, or what today we call a black hole.

What does a black hole look like and what would it be like inside? We'll get there, but first, let's make a pit stop in my hometown, New York City, where it's always seemed to me that everything is in constant motion.

I've lived here most of my life.

There's always something new to see.

But one thing never changes-- gravity.

Gravity on Earth has been the same for the past four and a half billion years.

But what if, today, we could alter it? Gravity is a distortion in the shape of spacetime as Einstein showed.

Space can expand and contract and warp without limit.

If the Earth's size or density were even a little different, its gravity would be, too.

There's an infinite range of possibilities.

New Yorkers feel right at home in the gravitational pull of the Earth, called "one g." Suppose we turn off the gravity on one of its streets.

People and objects that were already in motion are launched into flight.

Now what if I turn the gravity up to, say, eight or nine g's? Out of compassion, let's
evacuate the area.

This is about the same g-force that a fighter pilot in a high-speed turn would feel.

A few minutes of this wouldn't hurt you, but it wouldn't be comfortable.

At 100,000 g's, even fire hydrants become crushed by their own enormous weight.

But at millions of g's, even light bows to gravity.

The light still moves at its constant speed, but it cannot escape.

Michell's dark star our black hole.

And the nearest one may be closer than you think.

Not every star can become a black hole.

Only about one in a thousand is massive enough.

The nearest one could be within 100 light years of Earth.

Black holes aren't the mythic cosmic vacuum cleaners of science fiction.

They don't go around gobbling up unsuspecting worlds.

You've got to come to them.

But if you do, it might be the last thing you ever see.

That was us resisting a few million g's of gravity.

Don't forget, that thing swallows light.

We'll keep our distance.

When giant stars exhaust their nuclear fuel, they can no longer stay hot enough to fend off the inward pull of their own gravity.

The most massive stars collapse into darkness, leaving only their gravity behind.

This black hole enshrouds the shrunken corpse of a supergiant star.

The star itself has shriveled into something even smaller than this darkness, only 64 kilometers wide.

This is the first black hole ever discovered-- Cygnus X-1.

How did we on Earth ever find something so small and dark and far away? We looked at
it in another kind of light.

X-rays.

In X-ray light, we lost sight of the blue star because its surface is a tepid 30,000 degrees.

But the disk of gas around the black hole glowed brilliantly in X-rays at 100 million degrees.

As William Herschel discovered, many stars have close companions forming a binary star system.

But if one member of such a pair is enormous and the other is compact, the smaller star can drain and consume the atmosphere of its larger sibling.

This neurotic relationship can last for millions of years.

The atmosphere of the larger star was being siphoned onto a glowing hot accretion disk that revolves around and spirals into a black hole.

The overwhelming gravity was accelerating the blue star's gas into a death spiral, crossing the spacetime boundary, never to be seen again.

The fateful boundary that separates a black hole from the rest of the universe is called an event horizon.

From our point of view, the substance in the disk slows down as it approaches the event horizon, never quite reaching it.

But if you were riding on that spiraling gas-- and I don't advise it-- you would sail past the event horizon in a matter of seconds into the undiscovered country from which no traveler returns.

We have searched the hearts of dozens of galaxies, and in every case, we have found a super-massive black hole.

Our own galaxy is no exception.

The stars nearest the center of our galaxy whip around at more than 40 million kilometers an hour.

What could make them move so fast? The only logical explanation is that something with the mass of four million suns lies at the center.

So where's the blazing light of four million suns? Since we can't see it, it must be imprisoned inside a black hole.
Earth is far enough away to be perfectly safe.

Other worlds might not be so lucky.

If you somehow survived the perilous journey across the event horizon, you'd be able to look back out and see the entire future history of the universe unfold before your eyes.

How? Because when spacetime is warped by the extreme gravity of a black hole, time is stretched to the limit.

But what would be in front of you? Before we go there, I should warn you that we're entering uncharted scientific territory.

For all we know, there may be undiscovered laws of physics that govern events at the center of a black hole.

But until the next Einstein comes along, let's perform a thought experiment.

That's how John Michell first imagined dark stars in the 18th century, and how Einstein conceived of his theory of relativity. Do you believe in ghosts? Oh, no, not in the human kind of ghosts.

No, not at all.

But look up, my boy, and see a sky full of them.

If you could survive the trip into a black hole, you might emerge in another place and time in our own universe, circumventing the first commandment of relativity — thou shalt not travel faster than light.

Nothing can move through space faster than light.

But space is not mere emptiness.

Its properties can stretch and shrink and can be deformed.

And when that happens, time is deformed, too.

Einstein discovered that space and time are just two aspects of the same thing, spacetime.

Spacetime itself can deform enough to carry you anywhere at any speed.

Black holes may very well be tunnels through the universe.

On this intergalactic subway system, you could travel to the farthest reaches of spacetime, or you might arrive in someplace even more amazing.

We might find ourselves in an altogether different universe.
But how can a whole universe fit inside of a black hole, which is only a small part of our universe? It's another magic trick of spacetime.

The phenomenal gravity of a black hole can warp the space of an entire universe inside it. Our local gravity might be a drag to us, but it's really feeble compared with what goes on inside a collapsed star.

As far as we know, when a giant star collapses to make a black hole, the extreme density and pressure at the center mimic the Big Bang, which gave rise to our universe.

And a universe inside a black hole might give rise to its own black holes. And those could lead to other universes. Maybe that's how our cosmos came to be.

For all we know, if you want to see what it's like inside a black hole, just look around you.

William Herschel went on to discover that the sun and its planets are moving through the Milky Way.

And whatever became of his son John? He grew up to become a great scientist. His deep-space observations built on those of his father to become the basis for the standard catalog of galaxies we use today.

When William was in failing health, John stayed with him through the long nights at his telescope to help him sweep the stars.

And when his father died, John wrote his epitaph "He broke through the walls of heaven." John often reminisced about those summer nights with his father.

Maybe that's why he sought a way to preserve the past.

John Herschel was one of the founders of a new form of time travel, a means to capture light and memories.

He actually coined a word for it, photography.

When you think about it, photography is a form of time travel. This man is staring at us from across the centuries a ghost preserved by light.

It's not hard to imagine that in the near future, we'll be able to capture the past in all three dimensions.
We'll be able to step inside a memory.

It may not be possible to travel backward in time, but perhaps, one day, we can bring the past to us.

Here's a moment from my past.

Like John Herschel, I'm remembering a younger version of myself.

December 20, 1975.

A snowy day in Ithaca, New York.

A branchpoint on the road that brought me to this moment with you.

It was the day I met Carl Sagan.

Reminds me of those ghost stars in the sky you know, the ones that still shine their light upon us long after they're gone.
The age and size of the cosmos are written in light.

The nature of beauty and the substance of the stars, the laws of space and time they were there all along, but we never saw them until we devised a more powerful way of seeing.

The story of this awakening has many beginnings and no ending.

Its heroes come from many times and places-- an Ancient Chinese philosopher, a wizard who amazed the caliphs of 11th-century Iraq, a poor German orphan enslaved to a harsh master.

Each one brought us a little closer to unlocking the secrets hidden in light.

Most of their names are forever lost to us, but somewhere, long ago, someone glanced up to see light perform one of its magic tricks.

Who knows? Maybe that quirk of light inspired the very first artist.

Where did all this come from? How did we evolve from small wandering bands of hunters and gatherers living beneath the stars to become the builders of a global civilization? How did we get from there to here? There's no one answer.

Climate change, the domestication of fire, the invention of tools, language, agriculture all played a role.

Maybe there was something else, too.

In China, more than 2,000 years ago, a philosopher named Mo Tze is said to have observed that light could be made to paint a picture inside a locked treasure room.

This was the description of the first camera the camera obscura, the prototype of all image-forming cameras, including the one that's bringing you this picture.

Taking advantage of this funny thing that light does resulted in what could be called the first movie.

Mo Tze, master of light, worked against all forms of darkness.

A military genius who only used his talents to prevent violence, he was legendary for traveling among the kingdoms of the warring states, employing ingenious strategies to talk kings out of going to war.

He was one of the first to dream of universal love and an end to poverty and other forms of inequality; of government for the people and to argue against blind obedience to ritual
and authority.

In his writings, you can find early stirrings of the scientific approach.

By Mo Tze's time, the Chinese had already been recording their thoughts in books for at least a thousand years.

Still, our knowledge of him is only fragmentary.

It consists largely of the collection of essays attributed to him and his disciples.

In one of them, entitled "Against Fate," a three-pronged test for every doctrine is proposed.

Question its basis-- ask if it can be verified by the sights and senses of common people-- ask how it is to be applied and if it will benefit the greatest number.

Mo Tze was extremely popular, but a few hundred years after his death, Qin Shi Huang, the first emperor, and unifier of China, took power.

He took a continent and turned it into a nation that now bears his name China.

Most of us know Emperor Qin for the army of 7,000 terra cotta warriors that guard his tomb.

In Emperor Qin's drive to consolidate his far-flung empire, he took drastic measures to standardize everything within it.

This included mandating a single coinage, making uniform all weights and measures, the widths of carts and roads, as well as the precise way the Chinese language was to be written, including what you were allowed to write and think.

Emperor Qin's philosophy-- the only one permitted-- was called "legalism," which is just what it sounded like, do as the law says or else.

It's a philosophy that's not highly conducive to questioning authority.

that all the books of the hundred schools of thought shall be burned, that anyone who uses history to criticize the present shall have his family executed.

The works of Mo Tze and Confucius and other philosophers were destroyed in the world's first book burning.

Hundreds of scholars bravely resisted by trying to preserve the forbidden books.

They were buried alive in the capitol.
Science needs the light of free expression to flourish.

It depends on the fearless questioning of authority, the open exchange of ideas.

Sparks of curiosity in the writings of Mo Tze and his disciples were effectively stomped out.

It would be another thousand years before the next movie.

Luckily, our Ship of the Imagination can take us anywhere in space and time.

The ancient Chinese and Greeks observed that light could be made to do wonderful things-- but no one asked that question favored by small children and geniuses alike.

Why? Until a thousand years ago In the city of Basra, Iraq, there lived another master of light.

Ibn al-Hazen had a passionate desire to understand nature.

He questioned everything, especially those things that everyone else took for granted.

"How do we see?" he asked.

Some of the great authorities who came before him had taught that rays come out of our eyes and travel to the objects we see before returning to our eyes.

But al-Hazen reasoned that the stars were too far distant for something in our eyes to travel all the way to them and back in the blink of an eye.

Excellent reasoning, but al-Hazen didn't stop there.

He searched for ways to compel nature to divulge her secrets.

His culture was open to new ideas and questioning.

It was the golden age of science in the Islamic world.

One that stretched from Cordoba in Spain all the way to Samarkand in Central Asia.

Christian and Jewish scholars were honored guests at the research institutes of Baghdad, Cairo, and other Islamic capitols.

Instead of burning books, the caliphs sent emissaries around the world in search of books.

The caliphs lavishly funded projects to translate, study, and preserve them for future generations.

Much of the light of Ancient Greek science would have been permanently extinguished
without their efforts.

The reawakening to science that took place in Europe, hundreds of years later, was kindled by a flame that had been long tended by Islamic scholars and scientists.

The Arabs also imported ideas from India to the West, including the so-called Arabic numerals that we all use today, and the concept of zero which comes in handy when you want to write "billions and billions." Arabic astronomy was so influential, that we still call most of the bright stars by their Arabic names.

And the "al's" in algebra, algorithm, alchemy, and alcohol are just some of the traces left from the time when Arabic was the language of science.

In the 11th century, Ibn al-Hazen set about trying to test his ideas about light and how we see.

So we devised an experiment to determine how light moves.

We erected a tent in full daylight and sealed it tightly so that only a single ray of light could pierce its inner darkness.

With little more than his brains and a straight piece of wood-- a ruler-- al-Hazen had accomplished a great leap forward in the history of science.

He discovered that light moves in straight lines.

But he was just getting started.

Al-Hazen figured out that the key to forming any image-- whether you're talking about an eye or camera obscura-- is a small opening to restrict the light that can enter an otherwise darkened chamber.

That aperture excludes the chaos of extraneous light rays that surround us.

The smaller the aperture, the fewer directions that light can come from.

And that makes the image sharper.

So instead of being blinded by the light, we can see everything it has to show us.

Al-Hazen made his own camera obscura and dazzled the caliphs.

A camera obscura works best in bright light.

The stars of the night sky are way too dim for this.

We somehow need a bigger opening to collect light, but we also need to maintain focus.
A telescope collects light from any spot in its field of view across the entire lens or mirror, an opening much larger than the camera obscura hole.

This is one of the first telescopes the one that Galileo looked through in 1609.

With it, he pulled aside the heavy curtain of night and began to discover the cosmos.

The lens made it possible for a telescope to have a much larger light-collecting area than our eyes have.

Big buckets catch more rain than small ones.

Modern telescopes have larger collecting areas, highly sensitive detectors, and they track the same object for hours at a time to accumulate as much of its light as possible.

Space-based telescopes such as the Hubble, have captured light from the most distant and ancient galaxies, giving us vastly clearer pictures of the cosmos.

Al-Hazen discovered how images are formed by light, but that was far from his greatest achievement.

Ibn al-Hazen was the first person ever to set down the rules of science.

He created an error-correcting mechanism, a systematic and relentless way to sift out misconceptions in our thinking.

Finding truth is difficult and the road to it is rough.

As seekers after truth, you will be wise to withhold judgment and not simply put your trust in the writings of the ancients.

You must question and critically examine those writings from every side.

You must submit only to argument and experiment and not to the sayings of any person.

For every human being is vulnerable to all kinds of imperfection.

As seekers after truth, we must also suspect and question our own ideas as we perform our investigations, to avoid falling into prejudice or careless thinking.

Take this course, and truth will be revealed to you.

This is the method of science.

So powerful that it's carried our robotic emissaries to the edge of the solar system and beyond.

It has doubled our lifespan, made the lost worlds of the past come alive.
Science has enabled us to predict events in the distant future and to communicate with each other at the speed of light, as I am with you, right at this moment.

This way of thinking has given us powers that al-Hazen himself would have regarded as wizardry.

But it was he who put us on this rough, endless road.

And now it has taken us to a place where even light itself is enshrouded in darkness.

Light has properties unlike anything else in the realm of human existence.

Take the speed of light.

The basic particle of light, the photon, is born traveling at the speed of light as it emerges from an atom or a molecule.

A photon never knows any other speed, and we've not found another phenomenon that accelerates from zero to top speed instantaneously.

Nothing else could move as fast.

When we try to accelerate other particles closer and closer to the speed of light, they resist more and more, as though they're getting heavier and heavier.

No experiment yet devised has ever made a particle move as fast as light.

What was that? You hear something? Where was I? Oh, yeah.

I don't know anything else in life that behaves like light.

I cannot reconcile its strange properties with everything else my senses tell me.

Our urge to trust our senses overpowers what our measuring devices tell us about the actual nature of reality.

Our senses work fine for life-size objects moving at mammal speeds, but are ill-adapted for the wonderland laws of lightspeed.

We don't even know why there's a cosmic speed limit.

Time stands still when you're traveling at the speed of light.

What is light, anyway? Isaac Newton's enduring fascination with light began when he was a child in this very house.

By the time he was in his 20s, Newton became the first person to decipher the mystery of the rainbow.
Newton discovered that some light, or white light, is a mixture of all the colors of the rainbow.

Major discovery.

He named the displays of colors a "spectrum" from the Latin for "phantom" or "apparition." Begging your pardon, Master Newton, the cook frets that your dinner will spoil, sir.

No, Isaac, don't put the magnifying glass down! Something even more amazing is hidden in the light-- a code, a key to the cosmos.

Isaac Newton didn't miss much, but that one was a beaut.

He just walked right past the door to a hidden universe; a door that would not swing open again for another 150 years.

It would fall on another scientist, working in the year 1800, to stumble on a piece of evidence for the unseen worlds that surround us.

By night, William Herschel scanned the heavens with the largest telescope of his time.

By day, Herschel performed experiments.

From Newton's earlier work, it was known that sunlight is a blend of different colors.

And everyone knew, just from being outside, that sunlight carries heat.

William Herschel asked whether some colors of light carry more heat than others.

The nature of scientific genius is to question what the rest of us take for granted and then do the experiment.

The thermometer that Herschel placed outside the spectrum was his control.

The control in any experiment always lacks the factor being tested.

That way, you know if what you're testing is really the thing responsible for the observation.

In Herschel's experiment, the relationship between color and temperature was being tested, and so his control was a thermometer over the part of the white sheet that was not illuminated by sunlight at all.

There's that sound again.

What is that? Okay, red light is warmer than blue light.
Interesting discovery, but not exactly revolutionary.

No, there's nothing wrong with your thermometer.

You've just discovered a new kind of light.

Herschel was the first to detect this unseen presence lurking just below the red end of the spectrum.

That's why it came to be called "infrared." "Infra" is Latin for the word "below." It's invisible.

Our eyes are not sensitive to this kind of light, but our skin is-- we feel it as heat.

Now, that's a really big discovery.

But far greater secrets were still hiding deep inside the light.

At about the same time that William Herschel was discovering infrared light in his parlor in England, a young boy named Joseph Fraunhofer was trapped in hopeless drudgery.

He stood over a cauldron of toxic chemicals and endlessly stirred.

Joseph had been orphaned at the age of 11 and given to a harsh master named Weichselberger, the royal mirror-maker.

He prevented Joseph from going to school.

Instead, Joseph labored in the glass-making workshop by day, and tended to the master's household chores by night.

Hurry up, stupid! And remember, no reading.

Until Joseph got his big break.

Weichselberger's house collapsed.

Maximilian, the future king of Bavaria, hurried to the scene of the calamity to see if he could help.

Maximilian was known for taking an interest in his subjects, which was highly unusual for its time.

In attracting the concern of the future king of Bavaria, young Joseph Fraunhofer found an aperture into a different universe.

And not just for himself.
Prince Maximilian gave Joseph money and asked his privy councilor to provide further help to the boy, should it be needed.

Weichselberger continued to exploit him and prevent him from attending school.

But the prince's councilor intervened, offering Joseph a position at the Optical Institute.

This small gesture of kindness really paid off.

By the time he was 27, Joseph Fraunhofer was the world's leading designer of high-quality lenses, telescopes and other optical instruments.

His firm was housed here, in the old Benediktbeuren Abbey.

In the early 19th century, this was top-secret, ultra-high technology.

The Benedictine monks of earlier times had taken a vow of secrecy.

This local tradition, and the ability to restrict access to Fraunhofer's laboratory, allowed him to maintain control of trade and state secrets.

Fraunhofer was experimenting with prisms to find the best types of glass for precision lenses.

How, he wondered, could he get a better look at the spectrum that a prism produced? Friedrich, bring me the theodolite, please.

Okay, while Fraunhofer sets up his theodolite-- it's a kind of telescope-- I want to show you something in another part of the abbey.

Sound waves are so beautiful to hear.

Imagine how beautiful they'd be to see.

You ever wondered why organ pipes have different lengths? I press a key it sends compressed air into a particular pipe, producing sound waves.

If we could slow the sound waves down a few hundred times, they would look like this.

The length of the pipe determines the length of the sound wave that can fit inside it.

A short pipe gives you a short sound wave.

Short sounds waves have high pitch, or frequency.

Let's stop the waves for a better look.

The distance between adjacent waves is called the wavelength.
A long pipe gives you a long sound wave with a low pitch, or low frequency.

The medieval manuscript of this music, "Carmina Burana," was discovered in this very abbey.

Sound waves can't travel through a vacuum.

They need matter to ride on, like molecules of air, or water, or rock.

But light waves fly solo.

They can move through empty space.

And fast-- a million times faster than sound waves in air.

And the wavelengths of the light we see are so much shorter than sound waves.

About 50,000 light waves would fit right in here.

Oh, yeah.

Fraunhofer.

Just in time.

We didn't miss it.

Just as the wavelength of sound determines the pitch that we hear, the wavelength of light determines the color that we see.

But how does a prism spread out the colors concealed in a beam of sunlight? When light travels through air or space, all its colors move at the same speed.

But when it hits glass at an angle, the light slows down and changes direction.

Inside the prism, each color moves at a different speed.

In glass, violet light, which is carried by the shortest waves we see, slows down more than red light, which has the longest waves.

These changes in speed pry the colors apart, sending their waves off in slightly different directions.

That's how a prism works.

If I seem unduly emotional about this, it's because Joseph Fraunhofer is about to do what Isaac Newton could've done, but didn't.
And it'll have a powerful effect on the course of my own life.

You are witnessing the marriage of physics and astronomy, the birth of my own field of science, astrophysics.

Written in the light, in those vertical black lines is secret code.

Fraunhofer looked at them, and wondered Why? A code that comes to us from an alien universe.

What is the message written in these dark, vertical lines? It took a hundred years of thinking, questioning, searching to decipher it.

Lovely, isn't it? Why? There are many layers to the fine structure of beauty the chemistry of the Earth and its atmosphere the evolution of life Many distinct threads.

Let's just examine one, at the surface the colors of nature that dazzle us.

What's really happening? How does the red, the blue the astonishing palette of nature's colors how do they happen? Light waves of different lengths from the Sun strike the Earth.

The petals of these particular flowers absorb all the low-energy, long red wavelengths of light.

But the petals reflect the shorter, high-energy blue wavelengths.

That interaction between starlight and petal-- or water, or Van Gogh-- is what makes blue.

The longest waves, the ones we see as red, have the lowest energy.

Color is the way our eyes perceive how energetic light waves are.

A sunset a flag the eyes of your beloved that shiny new car.

The feelings they inspire happen when something inside you is triggered by a particular variation in the frequency and energy of light waves.

And the secret message? Those black vertical lines in Fraunhofer's spectrum? What makes them? They occur when the light waves of those particular colors are being absorbed.

It happens on another level of reality, far smaller than the world we're used to operating in.

To get there, we'll need to become ten billion times smaller than we are.
We could pick any one of these atoms.

But let's go for the hydrogen atom.

The hydrogen atom is the most plentiful kind of atom in the cosmos.

And the simplest.

It has only one electron.

And only one proton.

We've entered the quantum realm.

It doesn't correspond to ordinary human experience.

Common sense is no help here at all.

Take the hydrogen atom’s electron, for example.

In an atom, an electron doesn't exist between orbitals.

It disappears from one orbital and reappears in another.

It's as if you took an elevator from the second floor to the fourth floor, but ceased to exist in between.

And another thing.

Quantum elevators only stop at certain floors.

The sizes of the electron orbits are strictly limited, and different for the atoms of every element.

That's why the elements are different.

The chemistry of anything is determined by its electron orbits.

The force that holds an electron in orbit has nothing to do with gravity.

It's a force of electrical attraction.

The electron dances a wavy ring around the central nucleus of a hydrogen atom.

And makes quantum leaps from orbit to orbit.

Up or down.

The larger the orbit, the greater the energy of an electron.
An electron has to get energy to leap to a larger orbit.

And it has to lose energy to jump back down.

Every upward leap is caused by an atom absorbing a light wave.

But we have no idea what causes the downward leaps.

What we do know that such leaps always produce a light wave whose color matches the energy difference between the orbitals.

The Sun's surface radiates light waves of all colors.

If you look at sunlight through a prism, you'll see its spectrum.

When you magnify the spectrum with a telescope, as Joseph Fraunhofer did, you raise the curtain on the electron dance within the atom.

When the energy of the electron flags, and it drops to a lower orbital, the light wave it emits scatters.

Most of it doesn't reach us.

That leaves a dark gap or black vertical line in the spectrum.

These dark lines are the shadows cast by hydrogen atoms in the atmosphere of the Sun.

Sodium atoms cast different shadows.

Their electrons dance to a different tune.

A grain of table salt is composed of sodium and chlorine atoms.

Ten million billion of them doing their crazy dances in a single grain of salt.

And a single iron atom with 26 electrons is like a great big production number in a Broadway musical.

When you look at a star with a spectroscope, you see the dark lines from all the elements in its atmosphere.

Show me the spectrum of anything, whether here on Earth or from a distant star, and I'll tell you what it's made of.

Fraunhofer's lines are the atomic signatures of the elements writ large across the cosmos.

As with every other major revelation in the history of science, it opened the way to newer and deeper mysteries.
And to the revelation that there were many more secrets hiding in the light.

When Joseph Fraunhofer combined a prism with a telescope and turned it toward the skies, he brought the stars much closer to us.

When he was only 39, he contracted a fatal illness.

Perhaps as a result of his early and long-term exposure to the toxic chemicals of glassmaking.

You never know where the next genius will come from.

How many of them do we leave in the rubble? The prince and his kingdom were immeasurably enriched by that act of kindness to a poor orphan.

Fraunhofer's discoveries transformed Bavaria from a rural backwater to a technological powerhouse.

As he lay dying, the government was desperate to preserve every shred of his precious knowledge about the high technology of optical glass.

But it could only be divulged to a person with top security clearance-- the director of the mint.

The government kept Fraunhofer's technology for making perfect optical glass a State secret for another hundred years.

This would prove to be a major obstacle for someone we'll meet later in our journey.

But Fraunhofer would allow no such secrecy where his pure scientific research was concerned.

He knew that science requires openness to flourish; that our understanding of nature belongs to the world.

As soon as Fraunhofer discovered the spectral lines, he published everything he knew about them.

And the reverberations of his momentous discovery echo still.

His spectral lines revealed that the visible cosmos is all made of the same elements.

The planets The stars The galaxies We, ourselves, and all of life The same star stuff.

He made it possible for us to know what's in the atmosphere of other worlds.

And in galaxies millions of light-years away.
Spectral lines revealed not only the composition of far-off objects, but also their motion towards or away from us.

Using them, we discovered that our universe is expanding.

But perhaps the greatest revelation of spectroscopy is the discovery of the thing it cannot see.

A hidden universe of dark matter six times more massive than the familiar cosmos.

It's made of some mysterious substance that does not emit, reflect or absorb any kind of light.

We only know it's there because of its gravity, which pulls on all the galaxies and speeds up the visible stars within them.

There are many more kinds of light than our eyes can see.

Confining our perception of nature to visible light is like listening to music in only one octave.

There are so many more.

They differ only in wavelength, but over a huge range.

For instance, infrared light the kind that William Herschel discovered Or X-ray light.

Or radio light.

Or in gamma-ray light.

These are not just different ways of seeing the same thing.

These other kinds of light reveal different objects and phenomena in the cosmos.

In gamma-ray light, for example, we can see mysterious explosions in distant galaxies that we would otherwise miss.

And in microwave light, we can see all the way back to the birth of the universe.

We have only just opened our eyes.
6 - Deeper, Deeper, Deeper Still

We live on one level of existence, but there are others.
These hidden dimensions of reality are everywhere.
Far away, across the light years.
Beneath our feet.
And even inside you and me.

We are made of atoms.
There are more atoms in your eye, than there are stars and all the galaxies of the known universe.
The same is true of any solid object larger than the tip of your little finger.
I'm a collection of three billion, billion, billion intricately arranged atoms called Neil Degrasse Tyson.
You are a similar collection with a different name.

We don't usually think of ourselves this way because that level of reality lies beyond the realm of our senses.
But we're not gonna let that stop us.

We can go deeper into the wonder.

Atoms let matter do funny things.
To understand water, you need to know what its atoms are doing.
Every molecule of water is composed of two tiny hydrogen atoms attached to a larger oxygen atom.
That's why we call it H20.
If it's not too hot or too cold, the molecules can slide and tumble past each other.
There's still some stickiness between the molecules, but not enough to lock them into a rigid solid.
That's what makes something a liquid.
The sun warms the water.
And with more energy, the molecules move faster.
That's all that temperature is.
Those molecules are moving fast enough to break the weak bonds that hold them to their neighbors.
That's evaporation.
The air we breathe is made of nitrogen and oxygen molecules with a scattering of water vapor and carbon dioxide.
Incoming! That's condensation.
A dewdrop is the momentary triumph of condensation over evaporation.
And while it lasts, it's a little cosmos with its own worlds creatures, drama.
To explore the far-flung realms of this dewdrop, we're gonna need a ship.
One with twin engines science and imagination.
That's a single-celled paramecium, one of a multitude of skilled hunter-warriors that roam the dewdrop.
But they, too, are hunted.
The Dileptus.
The paramecium's mortal enemy.
The paramecium might get lucky and score a direct hit.
Even if it doesn't, the recoil from the barrage will put some distance between the paramecium and its attacker.
What can I say? That's life in the dewdrop.
That little guy is tardigrade, an animal smaller than the head of a pin.
Don't underestimate them.
Tardigrades have been living on this planet a lot longer than we have.
About 500 million years.
For every one of us, there's at least a billion of them.
They can make a living anywhere on earth.
In the frigid peaks of the tallest mountains, in the cauldrons of erupting volcanoes, and in the deep ocean vents at the bottom of the sea.

Tardigrades are so tough, they can survive naked in the vacuum of space.

They've survived all five of the most recent mass extinctions on this planet.

A visitor from another world could be forgiven for thinking of earth as the planet of the tardigrades.

If we're ever gonna get to the bottom of this dewdrop, better get a move on.

Every leaf and tiny clump of moss has hundreds of thousands of microscopic mouths called Stomata.

Plants breathe through them, taking in carbon dioxide and exhaling the oxygen that we need to live.

The plants can survive without us.

But we and all the other animals we'd be toast without them.

The plants make food out of sunlight.

We animals can't do that.

To see how they do it, we have to go deeper, make ourselves about a thousand times smaller to get into their treasure house, the place where they keep the good stuff the chlorophyll.

That's the molecule that converts sunlight into energy.

Every one of those rectangles is a plant cell.

And those tiny green vehicles are its energy factories.

If we could steal their trade secrets, it would trigger a new industrial revolution.

But to spy on them, we're gonna need to go deeper still.

What alien world has the ship of the imagination carried us to this time? It's the cosmos Contained within a dewdrop.

We're on an industrial espionage mission.

If we can penetrate the trade secrets of the manufacturing process in that chloroplast, let's just say our whole future hangs in the balance.
This chloroplast is using sunlight to break water molecules into atoms of hydrogen and oxygen.

It combines the hydrogen with carbon dioxide to make sugar, and releases the oxygen as a waste product.

To see how it happens, we have to go even deeper, get even smaller.

We're talking atomic scale.

Bingo.

This assembly line is the heart of the molecular industrial complex.

At the molecular level, things happen too fast for us to see.

So we'll have to slow them down about a billion times.

Those larger molecules are carbon dioxide.

Each one of them is made of one carbon and two oxygen atoms.

When sunlight strikes a green molecule of chlorophyll, it sets in motion a series of chemical reactions, breaking apart water molecules and freeing energetic electrons.

And that's just the day shift, when sunlight supplies the incoming stream of energy.

There's a second shift that works day and night using the solar energy kept in reserve.

The energy of the free electrons is put to work, combining carbon dioxide with hydrogen from the water.

The end product is sugar, which stores the solar energy.

The chloroplast is a three-billion-year-old solar energy collector.

This sub-microscopic solar battery is what drives all the forests and the fields and the plankton of the seas.

And the animals.

Including us.

The solar-powered biosphere collects and processes six times more power than our entire civilization.

We understand on a chemical level how photosynthesis works.
We can recreate the process in a laboratory.

But we're not as good at it as plants are.

And it's not surprising, considering nature has been at this for billions of years, and we've only just started.

But if we could figure out the trade secrets of photosynthesis, every other source of energy we depend on today—coal, oil, natural gas—would become obsolete.

Photosynthesis is the ultimate green power.

It doesn't pollute the air and is, in fact, carbon neutral.

Artificial photosynthesis on a big enough scale could reduce the greenhouse effect that's driving climate change in a dangerous direction.

Uh-oh, place is evaporating.

Time to get out of here.

How fleeting is the life of a dewdrop.

It condenses from thin air in the cool of the night, only to vanish with the heat of the day.

And what of its inhabitants, the tardigrades? They'll be fine.

They can go without water for years.

It's hard to imagine, but plants covered the surface of the earth for hundreds of millions of years before they put forth their first flower.

That was about a hundred million years ago, shortly before the dinosaurs were wiped out.

Our world must've been a relatively drab-looking place back then, dominated by shades of green and brown.

Yeah, there were giant trees and ferns and other plant life, but not the purple of an iris or the crimson of a red, red rose.

Orchids were among the first flowering species to appear on earth, and they're the most diverse.

Darwin was particularly fascinated by the comet orchid of Madagascar, a flower whose pollen is hidden at the bottom of a very long, thin spur.

There can be no stronger test of an idea than its predictive power.
On the basis of his theory of evolution through natural selection, Darwin speculated that somewhere on the island of Madagascar, there must live flying insects with extraordinarily lengthy tongues, ones long enough to reach the pollen.

No one had ever seen such a beast there, but Darwin insisted that an animal fitting this description must exist.

Few people at the time believed him.

It wasn't until more than 50 years later that Darwin was proven right.

In 1903, a huge hawk moth, called the Morgan's sphinx was discovered in Madagascar.

Attracted by the Comet Orchid's scent, the moth slurps its pollen with its foot-long tongue, exactly as Darwin expected it would.

It's even more amazing that the Morgan's sphinx was discovered when you consider that more than 90% of Madagascar's rain forest had been destroyed.

In the years since Darwin's famous prediction, this moth species could have easily become extinct with all the others every one of them a unique phrase of life's poetry, written in the atoms by eons of evolution.

Ah, the fragrance of lilacs.

It's one of those scents that triggers a whole constellation of associations, all those junes of long ago.

But how does that happen? How does a smell prompt a movie to start running in your head? It's not something we can see.

Could it be a wave of energy, like light? Or is it some kind of microscopic particle? It's actually a molecule.

Every odor we can sense, whether it comes from burnt toast, gasoline, or a field of lilacs, is a cloud of molecules.

These molecules have particular shapes.

When I inhale them, they stimulate a particular set of receptor cells in my nose.

An electrical signal then travels to my brain, which identifies the scent as lilac.

Other scents are carried by different molecules with different shapes.

But when I smell a flower or the smoke from a campfire or the grease from a motor gear, I'm often flooded with memories.
Why is it that a simple thing such as the scent of a flower can trigger powerful memories? It has to do with the way our brains have evolved.

Our sense of smell kicks in when the olfactory nerve in our brain is stimulated.

That nerve is located very close to the amygdala, a structure that is integral to our experience of emotion.

It's also very close to the Hippocampus, which helps us form memories.

The network of neurons that carry the scent signal from my nose to my brain has been fine-tuned over hundreds of millions of years of evolution.

It's a survival mechanism that can alert us to danger or guide us to safety.

If you can detect the predator before he's near enough to strike, or the fire before it traps you in the forest, you have a much better chance to survive and pass on your genes to the next generation.

That lovely scent from this field of flowers sets off a unique combination of nerve signals.

Only that exact combination can crack the safe where the memory of lilacs is stored inside my brain.

Wonder who they're for.

Maybe we'll find out later.

But first, there's another hidden cosmos waiting for us.

The plants are softly breathing, inhaling molecules of carbon dioxide and exhaling molecules of oxygen.

And I'm doing the opposite.

Unlike snowflakes and fingerprints, atoms or molecules of the same kind are utterly identical to one another.

With every breath we take, we inhale as many molecules as there are stars in all the galaxies in the visible universe.

And every breath we exhale is circulated through the air, and mixed gradually across the continents, it becomes available for others to breathe.

Breathe with me.
We all just inhaled about that once passed through the lungs of everyone who ever lived before us.

Think of it This kind of atomic reincarnation is another link to our distant ancestors, including those who first launched us on our explorations of the unseen universes.

These universes are as real as you or me, and they surround us.

There was a moment when we awakened to a new way of thinking and seeing.

It happened about 2,500 years ago on the Greek islands that lie between the empires of the east and west.

There, merchants, tourists and sailors freely mingled, exchanging tales of great kings and gods.

In Ionian cities and towns like Miletus, in what is now Turkey, the most fundamental elements of the way we live now first appeared.

Here, for the first time, reenactments of aspects of life created and executed by professionals with the expectation of touching something deep within the hearts of the audience, or just making them laugh The first plays, dramas and comedies, were performed.

Government by the people.

The first inklings, imperfect then as now, of a democracy, and the notion that the ordinary citizen might possess certain rights, come to us from this time and place.

But in my view, the most revolutionary innovation of all to come to us from this ancient world was the idea that natural events were neither punishment nor reward from capricious gods.

The workings of nature could be explained without invoking the supernatural.

The first person to express this thought was a man named Thales.

When the thunder clapped or the earth quaked, it was not because something you did had somehow displeased the very demanding gods.

No, it was the result of natural processes that we were capable of understanding.

Though none of the books he is said to have written survive, Thales kindled a flame that still burns to this day: The very idea of cosmos out of chaos, a universe governed by the order of natural laws that we can actually figure out.
This is the epic adventure that began in the mind of Thales.

Only a century following Thales' death, another genius came along.

And he, more than any other, was the first to discover the existence of the hidden universes that surround us.

Democritus of Abdera was a true scientist, a man with a passionate desire to know the cosmos and to have fun.

This is the man who once said, "a life without parties would be like an endless road without an end." You mean, that's it? That's all there is? Just a bunch of atoms in a void?
Yep.

Well, think about it.

The world has to be made of countless indivisible particles in a void.

Otherwise, nothing could move or grow, be divided or changed.

Without atoms and empty space for them to move in, so don't be sad, my friends.

Just think of the infinite possibilities that arise from different arrangements of those atoms.

Here's to the atoms in this cup and in this wine And to the laughter they make possible.

Dispersed through the Clay of the cup are microscopic mineral grains, different kinds of crystals, each with its own distinctive atomic architecture.

Mineral structures are exquisite, but they have a limited repertoire.

A grain of quartz is a lattice of the same three atoms repeated, without variation, over and over again.

Even a relatively complex mineral lattice like topaz, composed of ten or so atoms, can only repeat the identical atomic structure again and again.

Toenon, to free it from the lattice prison of endless repetition, you need an atom that can bond in all directions with other atoms like itself as well as with atoms of different kinds.

Behold the carbon atom the essential element for life on earth.

Why? Carbon is special because it can bond with up to four other atoms at a time.

It can connect with many different kinds of atoms, as well as other carbon atoms.

It can curl into rings and string together into chains, building molecules far more complex
than any crystal.

No other atom has the same flexibility.

Even atoms that have similar chemical properties, like silicon, can't form the amazing variety of molecules built on carbon.

The carbon-based molecules we call proteins, the molecules of life, contain literally hundreds of thousands of atoms.

Carbon atoms are the backbone of the molecules that make every living thing on earth, including us.

That's the difference between rocks and living things.

Life can make enormous molecules of stunning size and complexity, freeing matter to improvise, evolve, and even love.

Take it easy, dad.

He never actually touched her.

In everyday life on our world, on the scale of atoms, material objects never really touch.

Each atom has a tiny nucleus at its center, surrounded by an electron cloud of lines of force.

As the atoms approach each other, the boy's electron clouds push away the girl's.

More than 99.9% of the matter of any atom is concentrated in its nucleus.

The nucleus is surrounded by an electron cloud which produces an invisible field of force, and acts like a shock absorber.

The configuration of the electron cloud determines the nature of an element.

In the ordinary course of things here on earth, the nuclei never touch.

We have a sensation of touching, but that's really just our invisible force fields overlapping and repelling each other.

The nucleus is very small compared to the rest of the atom.

If an atom were the size of this cathedral, its nucleus would be the size of that mote of dust.

An atom is mostly empty space.
To understand the nature of matter, we have to go deeper still, to a place 100,000 times smaller than the atom: Its nucleus.

The simplest and most plentiful atom in the cosmos is hydrogen.

Its nucleus is a single proton, which makes hydrogen element number one.

The clouds that surround it are the realms where the atom's lone electron is permitted to roam.

What happens when you have a nucleus with two protons? Protons repel each other.
In order to hold them together in a nucleus, you need other particles called neutrons.
Their job is to keep the protons from getting out of line.
They overwhelm the protons with their strong attractive nuclear force.
A nucleus with two protons is element number two, otherwise known as helium.
A nucleus with six protons is element number six, which is carbon, the fundamental building block of life.
The nucleus of a gold atom has 79 protons.
They attract 79 electrons in clouds around it.
The way light interacts with those electrons is what makes gold glitter.
Every additional proton in the nucleus requires enough neutrons to bind them together Up to a point.
There's an upper limit to the number of neutrons you can stuff into a nucleus before it becomes unstable.
I know a place where the nuclei of different atoms actually do touch each other.
The sun looks like a solid object, but it's not.
It's so hot that all its atoms are always in their gaseous state.
The bonds that join atoms to make solids and liquids on earth are not strong enough to withstand the heat of the broiling sun.
Those arcing streams of incandescent gas that dwarf the earth are guided by magnetic lines of force that emanate from below the surface of the sun.
Why is the sun so hot? Because its own stupendous gravity is squeezing its atoms
The energy of gravity is being transformed into the energy of moving atoms.

That's what heat is.

The deeper we go into the sun, the greater the squeezing and the higher the temperature.

In the heart of the sun, the atoms are moving so fast that when they collide, they fuse.

Their nuclei touch.

The sun is a nuclear fusion reactor, held together by its own gravity.

It's balanced between the inward pull of gravity and the outward push of its hot gases.

That balance has lasted billions of years, providing stability that made possible the evolution of life on earth.

In the sun's core, the fusion of hydrogen into helium releases nuclear energy in the form of photons.

These particles of light slowly work their way to the surface, where they're seen as sunlight.

Helium is the ash of the sun's nuclear furnace.

The sun is a medium-sized star.

Its core is only a lukewarm ten million degrees hot enough to fuse hydrogen, but too cold to fuse helium.

There are many stars in the galaxy that get much hotter, because they're more massive and have more gravity.

Such stars fuse helium into heavier elements, like carbon and oxygen.

In their old age, they gently diffuse these elements into space.

Other stars, more massive yet, live fast and die young in cataclysmic supernova explosions.

In our galaxy, such stars go supernova about once a century.

These explosions are far hotter than the core of the sun hot enough to transform elements like iron into all the heavier ones and spew them into space.

The large magellanic cloud is a neighboring galaxy of our milky way.
It's visible in the skies of the Southern hemisphere.

When a supernova explodes, its brightness rivals that of its entire galaxy.

But all that light is only about one percent of the energy liberated in the explosion.

The rest of the energy is carried off by the most common and the most mysterious particles in the cosmos.

There are trillions of them passing through you right now, and yet tracking down even one of them will take us to one of the strangest places on earth.

Stalking the wild neutrino is the rarest of sport.

The lengths one must go to track them down is nothing short of astonishing.

Welcome to Super Kamiokande, the subterranean Japanese neutrino detection chamber.

We're more than a half mile beneath earth's surface.

You might ask, "well, who in their right mind would bury an astronomical observatory so far underground?" Those who hunt the most elusive prey in the cosmos: The neutrino.

This enormous array of light detectors surrounding 50,000 tons of distilled water is a trap designed to catch neutrinos only.

Other particles, such as cosmic rays mostly protons and electrons that rain down from space cannot get through all that rock above us.

But matter poses no obstacle to a neutrino.

A neutrino could pass through without even slowing down.

Neutrinos hardly interact with matter at all.

That's why you need so much of it to catch even one of them.

On those rare occasions when a neutrino actually does collide with a particle of ordinary matter, it produces a ghostly, ring-shaped flash of light.

We're lying in wait for a particle that weighs next to nothing.

Even the miniscule electron has more than a million times its mass. There! When the supernova in the large magellanic cloud blew its top in 1987, this is what it would have looked like in here.

Now remember, the large magellanic cloud is in our Southern hemisphere, so the neutrinos didn't come through that half-mile of rock above us, they had to pass through
the thousands of miles of rock and iron below us to reach this detector.

But the coolest thing was that those neutrinos hit earth three hours before the light from the supernova did.

If nothing can travel faster than light, how could that possibly be? This is a dead star walking.

It may look normal, but deep within it something cataclysmic is happening.

This blue super giant star has already begun to explode inside.

Like rats deserting a sinking ship, the neutrinos produced in the heart of the exploding star race outward at near the speed of light, through overlying mass in only a few seconds.

But the shock wave of the exploding gas plods along from the center of the star at 1/10,000 the speed of light until it finally reaches the star's surface, turning it into supernova 1987a.

It took hours for the explosion to reach the surface of the star and blow it wide open, exposing the super hot core.

The neutrinos had an insurmountable head start.

That's why the flash of light arrived on earth so much later than the shower of neutrinos.

Before anyone had ever snared the wild neutrino, it existed in the mind of a theoretical physicist.

Just as Charles Darwin knew there must be an extremely long-nosed creature flying around somewhere in Madagascar, a 20th-century physicist named Wolfgang Pauli was desperately seeking a particle to rescue one of the pillars of modern physics, the law of the conservation of energy.

So why didn't I flinch? Because the laws of science differ fundamentally from those of other human endeavors.

In order for an idea to become a scientific law, it has to unbreakable.

That's why I was willing to bet this face on the laws of conservation of energy.

Now, if you try this at home, take care not to give the cannonball a push.

That's adding energy, and the ball will surely come back and do some damage.

You just have to let it go, like this.
By lifting the ball, you give it gravitational energy, which is the potential to fall and accelerate.

The cannonball is going fastest when it's at the bottom of its arc, and at that moment, it's converted all of its gravitational energy to the energy of motion.

As it swings, the cannonball is constantly exchanging one of these two kinds of energy for the other, but the total amount of energy remains constant.

That's an example of the law of conservation of energy.

Once the cannonball is released, it can never gain more energy than it had to begin with.

It has no way to fly up and break my nose.

The energy accounting books are always strictly balanced.

There's no such thing as cheating.

So in the 20th century, when physicists first calculated the energy of atoms precisely, they were startled to discover an apparent violation of this law.

They found that in some radioactive atoms, the nucleus can spontaneously eject an electron.

This transforms the atom into a different element.

The physicists were mystified.

The energy of the escaped electron plus that of the new element adds up to less than the energy in the original nucleus.

But the law says, "thou shall not destroy or create energy." So where did the missing energy go? In 1930 Wolfgang Pauli predicted there must be an undiscovered particle, one that makes off with the missing energy.

At the time, Pauli lamented that such a phantom particle might be so minute, swift and evasive as to forever defy detection.

But that was a rare failure of his imagination because science is always searching for a way to go deeper still.

A generation later, Pauli's neutrinos were actually detected for the first time in radiation from a nuclear reactor.

And we've been finding them, with difficulty, ever since.
There are scientists today who are trying to find a way to ride those neutrinos all the way back to the beginning of time.

We'll go as far as they have gone to come up against the wall of forever.

The wall of forever is nothing new.

Our ancestors came up against it almost as soon as they first started imagining it.

A million dawns ago, in the 13th century bc, the Egyptian this temple at Abu Simbel to honor the Pharaoh Ramses II, depicted here in four colossal statues.

Reigning even above even this mighty king is the falcon-headed Ra-Harakhti, God of the sun.

The temple was designed so that the light from the rising sun could only enter the sanctuary on two days every year.

As the rays enter the temple, they burnish the statues of the gods with their golden light before penetrating the sanctuary.

Even then, one God remains in shadow.

Ptah, lord of creation, as if the origin of the universe must forever be concealed.

Feel the sun on your face.

The energy that warms you began its journey some ten million years ago in the heart of the sun.

Unlike neutrinos, the photons needed that long to work their way out from the core to the surface.

Why? Because they were colliding billions of times per second with the sun's atoms, every collision sending them off in a random direction.

But once they finally reached the surface, they were free to dash nonstop, at the speed of light, in a mere eight minutes and 20 seconds from the sun to you.

Ten-million-year-old light on your face.

What was happening when that light left the heart of the sun? The cosmic calendar compresses the entire 13.8 billion year history of the universe into a single year.

Every month represents about a billion years.
Every day, about 40 million years.

The universe is so old that, on the cosmic calendar, ten million years ago only takes us back as far as of the last day of the year.

And what about us? Humans had yet to evolve.

Ten million years ago, our ancestors were anthropoid apes, swinging through the trees of Africa.

To us, ten million years seems like a long time, but it's only the length of an afternoon on the timescale of the cosmos.

The sun began fusing hydrogen August 31 on the cosmic calendar.

Our milky way galaxy is about 10,000 million years old.

The first galaxies formed about a few billion years earlier.

Something keeps me from going any further back in time.

What is this? It's the nature of light and time.

Because light travels at a finite speed, to look across space is to look back in time.

So the farther we see, the older the light.

This is as far back in the history of the cosmos as we can see with light.

It's a baby picture of universe, when it was only 380,000 years old.

That's 15 minutes into January 1 on the cosmic calendar.

If we look as far as we can see in any direction using microwave telescopes, this is what we see, the glow left over from the Big Bang.

Imagine that all the matter and energy of the observable universe was concentrated into something no larger than this.

That's the size of the universe when it was a trillionth of a trillionth of a trillionth of a second old.

All the matter and energy of the hundred billion galaxies now splayed out across the billions of light-years were once pent up in something the size of a marble.

Can you imagine how tightly packed that marble must have been? Far too dense for any kind of light to move through it, but no obstacle for the likes of neutrinos.
The big bang must have produced stupendous numbers of neutrinos, which flew unhindered through that inconceivable crush of matter.

The very thing that makes them almost impossible to detect is what allows neutrinos to sail through the curtain that conceals the beginning of time.

Where are they now? They are here, they're there, everywhere throughout the universe.

Neutrinos from creation are within you.

From a marble To the cosmos.

This is the road that Thales and Democritus put us on some 2,500 years ago a road of endless searching, a relentless, systematic hunt for new worlds and an ever-deepening understanding of nature.

Who among you will pick up that torch and take us down that next stretch of road?
7 - The Clean Room

Once there was a man who went searching for the true age of the earth.
In his struggles to discover it, he stumbled on a grave threat.
Beautiful spring day, Pasadena, California.
Business is booming, life's good.
Except for one man, a geochemist named Clair Patterson, known as Pat.
He knows that everyone he sees is in danger from an invisible menace.
And he's determined to put a stop to it, no matter what the cost.
You can't really tell Pat Patterson's story without going all the way back to the time long before the earth, our home, was built, when the stars brought forth its substance.
Iron. For the planet's molten core.
Oxygen. For the rocks and the water and the air.
Carbon. For diamonds. And life.
A star is born, ours.
For the first few million years, things ran smoothly as dust grains snowballed into progressively larger objects.
But once these objects grew massive enough to have sufficient gravity, they began pulling each other into crossing orbits.
This is how our world looked when it was new.
No part of the earth's surface could survive intact from that time to the present.
So, with all its birth and early childhood records erased, how could we ever hope to know with any certainty the ge of our world? People have been wondering about this since antiquity.
In 1650 archbishop James Ussher of Ireland made a calculation that seemed to settle the question.
Like almost everyone else of his time and his world, he accepted the biblical account of creation as authoritative.
But the Bible does not give exact years, so Ussher searched for an event in the Old
Testament that corresponded to a known historical date.

He found it in the second book of kings, the death of the Babylonian ruler Nebuchadnezzar in 562 B.C.

Usher added up the generations of the prophets and the Patriarchs, the 139 "Begats" of the Old Testament, between Adam and the time of Nebuchadnezzar, and discovered that the world began on October 22 in the year 4004 B.C. At 6:00 P.M. It was a Saturday.

Archbishop Ussher's chronology was taken as gospel in the Western world.

Until we turned to another book to find the age of the earth, the one that was written in the rocks themselves.

Most of the rock layers in the walls of the Grand Canyon are made of sediments, deposited as fine grains in a time when this part of the world was a sea.

Over eons, the sediments were compressed into rock under the weight of succeeding layers, with the oldest ones at the bottom.

Pick a layer, any layer.

How about that one? Once upon a time, there must have been shallow water here.

Back in the Precambrian period, about a billion years ago, there was only one kind of life.

These blue-green bacteria were busy harvesting sunlight and making oxygen.

For them, it was just a waste product, but for the animals who evolved later, including us, it was the breath of life.

Okay.

Pick another layer.

How about that one? This layer is known as the bright angel shale.

It formed about 530 million years ago.

These tracks were left So you want to know the age of the earth? Just figure out how long it took to deposit each layer and then, instead of counting the "Begats," add up all the layers.

Easy, right? We know from observing this process, because it still happens today in oceans and lakes around the world.

That sediments can be laid down at widely different rates.
It usually happens very slowly, say a foot of sediment per 1,000 years.

But when the's a rare catastrophic flood, it can happen much faster, as much as a foot in just a few days.

Many geologists tried this method to calculate the age of the earth.

They used the Grand Canyon and other sedimentary sequences around the planet.

But their answers ranged too widely to be of much use, anywhere between three million years and 15 billion.

And there were other problems with this method: Even the deepest layers of rock are not the oldest things on earth.

Why? Because not even rocks could survive the earth's violent infancy.

In space it's another story.

Are there any mementos from when the earth was born, objects that could possibly tell us its true age? I know a place where the unused bricks and mortar left over from the creation of our solar system can be found.

It lies between the orbits of Jupiter and Mars.

Here is the stuff of the newborn earth, adrift in cold storage, unchanged ever since that time.

A million or so years ago, a large asteroid happened to jostle a much smaller one, sending it on a new trajectory, a collision course that ended one night some 50,000 years ago.

It must have shattered the peace of the Grand Canyon as it sailed overhead to blast out this crater in what would one day be known as Arizona.

Fragments of the iron asteroid that made this crater have survived intact.

If we just knew how long ago that iron was forged, we'd know the age of the solar system.

Including the earth.

But how could we know that? Pick a rock.

Any rock.

How about that one? Some atoms in this rock could be radioactive, which means they spontaneously disintegrate and become other elements.
A uranium atom first becomes a thorium atom.

On average, it takes a few billion years.

The thorium is much more unstable.

In less than a month it turns into protactinium.

A minute later, protactinium becomes something else.

The atom undergoes ten more nuclear transmutations Until it reaches the last stop on the decay chain: A stable atom of lead.

And lead it will remain For eternity.

In the 20th century there was a huge effort, lasting decades, to measure the time it takes for each radioactive element to transmute into another element.

Physicists discovered that the atoms of each unstable element decay at a constant rate.

The nucleus of an atom is a kind of sanctuary, immune to the shocks and upheavals of its environment.

Hit it with a hammer.

Boil it in oil.

Vaporize it.

The nuclear clock goes on ticking, keeping an absolute standard of time that does not look to the sun and the stars.

What better way to find the true age of the earth than with the uranium atom? If you knew what fraction of the uranium in a rock had turned into lead, you could calculate how much time had passed since the rock was formed.

But there's a problem.

The rocks in the earth that were present when it was formed are no more.

They've all been crushed, melted, remade.

There is a way to calculate the amount of lead that was present from the beginning.

It's a gift from the heavens: Meteorites.

This one A fragment of the one that made this giant crater Was ideal.
The amount of lead deep inside this meteorite is exactly the same as when earth formed.

Since you know the constant rate of uranium decay, that should give you the age of the meteorite, which was made at the same time as the earth.

All you had to do was measure the amount of lead in meteorites.

Easy, right? A scientist named Harrison Brown, at the University of Chicago, first understood this in 1947.

He chose a young graduate student, Clair Patterson, to do the work.

Patterson couldn't possibly know how this assignment would alter the course of his life
And ours.

What seemed like pure scientific research turned out to be so much more.

Clair Patterson, son of a letter carrier from Iowa, was rebellious by nature and not very good in school.

But he was a natural born scientist.

A geologist named Harrison Brown gave Patterson what seemed like a straightforward scientific assignment.

First off, Pat You mind if I call you Pat? Now, I know you're no geologist probably couldn't tell granite from feldspar but I hear you really know your way around a mass spectrometer, Pat.

Good.

You married, Pat? Yeah, Laurie.

Yeah, she-she's a chemist, too.

Uh, we worked on the Manhattan Project together, at Oak Ridge.

Good.

Okay, well, first thing you need to know: There are these tiny crystals called zircons.

Real small, size of a pinhead, tight as a drum and tough.

Nothing gets in or out of ’em.

And I'm talking for billions of years.

We know how old these grains are because we’ve already dated the rocks they came from.
Each little zircon has only a few parts per million of uranium inside, and that uranium is
decaying to even tinier amounts of lead.

Now, you figure out how to measure that lead, and you'll know how to do it for a
meteorite.

You think you can do that, Pat? Yeah.

Yeah, I I don't see why not.

Good, because when you do, you'll be the first man to know the age of the earth.

And you'll be famous.

It'll be easy.

Duck soup.

While Patterson tried to measure the trace amounts of lead in the zircon grains, another
grad student, George Tilton, was measuring the amount of uranium in the same grains.

All Patterson had to do was measure the amount of lead with equal accuracy.

She's all yours, Pat.

Measured it six times.

Same result: Yeah, nice going, George, thanks.

Tilton's results were always the same.

But Patterson's results on the lead content of the same grains were wildly inconsistent.

This made no sense.

Could the lab have been contaminated by previous experiments with lead? Maybe it was
the naturally high amounts of lead in the environment that were messing up his results.

Patterson did everything he could to cleanse the lab of any lead.

There was still 100 times too much lead.

He had been at it for more than two years.

Duck soup, my ass.

Patterson realized he would have to boil his containers and tools in acid and purify all his
chemicals to further reduce the lead in his lab.
Hey, you Oh, I No! I'm new here.

Uh, where's the men's room? Ugh, damn it.

All of Patterson's obsessive scouring and sterilizing had still not solved the problem.

He would need to design his own lab and build it from scratch.

The opportunity arose when Harrison Brown moved to the California Institute of Technology in Pasadena and invited Patterson to join him.

Okay, Tom, that's enough.

We can move through the interlock, now.

Patterson had now been at it for six years, doggedly tracking down and eliminating the many sources of lead that were compromising his instruments.

He had built the world's first ultra-clean room.

He was finally able to measure how much lead was actually in the rock.

One whose age had already been established.

Now, at last, Patterson was ready to tackle the iron meteorite, to find the true age of the earth.

He brought his meteorite specimen back to the Argonne National Laboratory Where the world's most accurate mass spectrometer had just become operational.

Doc, this can't wait till tomorrow? Okay, little buddy, we're gonna have to vaporize you.

A mass spectrometer uses magnets to separate the elements contained in a sample, so that the amounts of each element can be quantified.

This would provide the last missing piece in the puzzle of the earth's true age.

Now I'm gonna ionize you, yeah.

Sounds worse than it is.

What's an electron between friends? Having isolated the sample from any outside lead contamination, Patterson was, at last, ready to measure the amount of lead and uranium in the sample and calculate how many years before it had formed.

The true age of the earth.

Thank you to all the scientists who came before.
Thank you, geologists.

Thank you, Charles Lyell.

Thank you, Michael Faraday.

J. J. Thomson.

Ernest Rutherford.

Thank you, Harrison Brown.

The world is four and a half billion years old.

We did it.

Mom? Mom.

Patterson wanted his mother to be the first person to know what he had struggled The true age of the earth.

His reward for this discovery? A world of trouble.

He didn't know it, but he was on a collision course with some of the most powerful people on the planet.

To the ancient Romans, the majestic ringed planet Saturn was not a real place, not a world, but a God King, a son of the marriage of heaven and earth, the God of lead.

These columns are all that remain of this oldest temple in the Roman forum, first consecrated to Saturn 2,500 years ago.

It also served as Rome's treasury and its bureau of weights and measures.

Tonight is Saturnalia, the wild december holiday in Saturn's honor.

And everyday life will be turned upside down.

The masters will serve the slaves, no wars or executions will be allowed, and gifts will be exchanged.

A couple of hundred years from now, when the early church fathers look for a way to attract more pagans, they'll decide to turn Saturnalia into Christmas, making it the latest in a long line of winter solstice holidays to be re-purposed.

This towering wooden statue of Saturn was dressed in red woolen underwear on only one night of the year.
But in ancient Rome, this God had another, darker side.

That other Saturn is a cold and sullen, sluggish ghoul, given to irrational bouts of rage.

He committed an unspeakable act of violence against his father, and devoured his own children.

Of all the planets visible to the unaided eyes of the ancients, Saturn is the slowest, which could explain why it's named after the God of lead.

But there's no denying that the more negative aspects of Saturn's personality reflect the age-old knowledge of the symptoms of lead poisoning.

Funny thing about the Romans.

Even though they knew that contact with lead inevitably poisoned people, rendered them sterile and drove them mad, what metal did they use to make the pipes that carried the water through their legendary aqueducts? I'll give you a hint.

The word "plumbing" comes from the Latin word for lead, "plumbum." What metal did they use to line their famous baths? And how did they sweeten their wines when they were too sour? What did they use to line their vats and cooking pots? There are some historians who believe that the widespread use of lead was a major cause in the decline and fall of the Roman Empire.

Why did they continue to use lead long after they knew it was toxic? It was cheap, very malleable, easy to work with, and the ones who were exposed to it at its most lethal levels the miners and workers who processed the lead were considered expendable.

Their lives didn't matter.

They were slaves.

Most of the earth's lead started off at a safe distance from living things, down below the surface, but about 8,500 years ago, humans began figuring out how to dig into the earth and extract metals from rock.

By the time this villa was new, just a couple of thousand years ago, the romans were producing Why is lead so poisonous to us? Because when it gets into our bodies, lead mimics other metals, like zinc and iron, the ones our cells actually need to grow and flourish.

Enzymes in the cell are fooled by the lead's masquerade, and they begin to dance.

But it's a dance of death, because the lead is an imposter that can't fulfill the cell's vital needs.
Lead also blocks neurotransmitters, the communication network between the cells.

It interferes with the molecular receptors that are vital to memory and learning.

This is especially damaging to children, but lead poisoning spares no one.

Starting at the turn of the 20th century, the makers of leaded paint hired the fledgling advertising industry to persuade the consumer that lead was child-friendly.

A little toy lead soldier once to the Dutch boy said, "we have some fine relations who all contain some lead." "Why don't you give a party so folks can meet and see the other happy members of the great lead family?" The first one at the party was gay electric light.

"He said, " I'm very brilliant." "I always shine at night." "No little of my brilliance is due to my glass head," which gives a light much brighter "because it's made with lead." A pair or rubbers entered and took the Dutch boy's arm.

"They said, " we are protectors who keep you dry and warm.

"You knew when we were molded, the man who made us said," we're strong and tough and lively "because in us, there's lead." But lead production didn't really shift into high gear until the early 1920's when chemist Thomas Midgley and inventor.

Charles Kettering of General Motors found that tetraethyl lead could be marketed as an anti-knock additive to gasoline.

They formed a new company called the Ethyl Corporation.

It had once been considered for use as a poison gas by the U.S. war department.

Unlike the lead in paint, tetraethyl lead was fat soluble.

A half a cup of it on your skin could kill you.

The manufacturers calculated that they could sell Only problem was, some of the workers who processed the stuff in factories in Delaware and New Jersey were going insane, hallucinating, jumping out of windows.

They died screaming.

This was a selling job that would require a lot more than dancing light bulbs.

What was needed was a man of science to calm the public's fears and improve lead's image.

They found the right man for the job.
This was one of the first times that the authority of science was used to cloak a threat to public health and the environment.

Robert Kehoe, a young doctor from Cincinnati, was hired by GM.

He raised scientific doubts in the public mind about the dangers of lead.

Lead was naturally occurring in the environment, he said.

Yes, there might be occupational hazards for the people who worked with lead, but that could be best handled by industry self-regulation.

And there was no evidence to suggest that lead posed any threat to the consumer.

For decades no one challenged him Until Clair Patterson went searching for the age of the earth.

Claire Patterson's research on the age of the earth had made him the world's leading expert on measuring trace amounts of lead.

And like everyone else at the time, he assumed the prevalence of lead occurred naturally.

True scientist that he was, he set out to discover everything he could about how lead circulates through the environment.

On a grant from the American Petroleum Institute, he carefully measured the concentrations of lead in deep and shallow seawater.

Once again, Patterson found that his initial data made no sense.

There were only minuscule concentrations of lead in the deep ocean water.

But in shallow waters and at the surface, the concentrations of lead were hundreds of times greater.

In any ocean, it takes a few hundred years for the shallow waters to mix with the deep.

This told Patterson that the large amount of lead in the surface waters had arrived recently.

Otherwise it would have been more evenly distributed.

Knowing the quantity of lead in the shallow seas and the time needed to mix it into the deeper layers, he was able to estimate the rate of lead contamination at the surface.

Patterson asked himself what could possibly supply lead to the world's oceans at such a rate.
Where's all that lead coming from? I think I know, Harrison.

It's from leaded gasoline.

Well, then we've got a problem, Pat, because that's the same place the money comes from.

But Patterson would not give in.

He went right to work on publishing the scientific paper that would make the case against leaded gasoline.

When he sent the paper to the prestigious scientific journal Nature, Patterson put his own name second.

He often did that with his students to advance their reputations.

He made a lifelong point of shunning the limelight and the privileges that come with it.

Only three days after publication the push-back began.

- Hello, Dr. Patterson.

- Pleasure to meet you.

Very impressed by your work.

Your work is of great interest to us in the petroleum and chemical industries.

Well, it wouldn't have been possible without your funding.

Precisely.

And there's so much more we'd like to do for you.

Well, I've been thinking about measuring lead in polar ice to see if it shows the same kind of pattern as the oceans.

Lead? But you've already done that.

We're thinking it's time you move on to other trace elements.

In fact, Dr. Patterson, our ability to fund you in any other line of research is Virtually limitless.

Lead is a neurotoxin.

When you ship your tetraethyl lead from the factory before you add it to the gasoline it's
handled just like a chemical weapon.

There's a reason for that.

Where do you suppose all that lead goes after it leaves the tailpipe? Think about what it might be doing to us and our kids.

Dr. Kehoe has shown that the level of lead in the environment is as natural as snow in December.

Then why doesn't it show up in the deep water? Here, let me just show you.

Thanks for your time.

Wait, you're just gonna keep on putting millions of tons of poison into the air we breathe? If my research doesn't put you out of business, some future scientist will.

Patterson's funding from the oil industry vanished overnight.

In fact, they tried to get him fired.

But the U.S. government The Army, the Navy, the atomic energy commission, the public health service, and the National Science Foundation Stood by him, supporting his research on lead pollution.

His investigations took him from Greenland in the far north to Antarctica in the far south, and to rivers, mountains and valleys in between.

In even the most hostile conditions, Patterson and his team worked to replicate the immaculate environment of the clean room.

Their plastic suits were replaced daily.

Working ten-to 12-hour days in subzero weather, they dug a 200-foot-long shaft into the ice of Antarctica.

It was a form of time travel, to recover snow that had fallen three centuries ago, before the start of the Industrial Revolution.

Nose! Wipe your nose, damn it! There's a thousand times more lead in you than in this ice! You want to contaminate the whole damn sample?! After four grueling weeks of painstaking sample collection, Patterson was ready to go back to the lab.

As with the oceans, he found that the amount of lead was much lower in the snow of a few hundred years before.

No matter where he searched on earth, no matter how far he traveled back in time, the
results always told the same story: The naturally occurring levels in the air and water in
the past, were far lower.

For thousands of years, lead had been known to cause brain damage, developmental
impairment, violent behavior, and even death.

In searching for the age of the earth, Patterson had stumbled on the evidence for a mass
poisoning on an unprecedented scale.

But Kehoe and the other scientists employed by the lead industry persuaded the public
they had nothing to worry about.

Until one man started to pay attention.

Patterson went public with his discoveries about lead in a big way.

He published his findings in a major environmental health journal and sent copies to
various government leaders, including one highly influential senator.

Edmund Muskie of Maine was the chairman of the senate subcommittee on air and water
pollution.

In 1966 he held hearings on the lead question.

The first witness was Dr. Robert Kehoe, longtime scientific advocate for leaded gasoline.

Is it, uh, your conclusion that, in 1937 to the present time, there has been no increase in
the amount of lead taken in from the atmosphere by the average traffic policeman, service
station attendant, or Or motorist? There is not the slightest evidence that there has been a
change in this picture during this period of time.

Not the slightest.

The hearings were scheduled to take place, when the fiercest critic, Claire Patterson was
off in Antarctica.

But he unexpectedly appeared on the fifth day of testimony.

Uh, looks like there seems to be an increase in the concentration of lead in people as a
result of exposure to the environment.

Is that correct? That is correct.

In identifying typical lead levels, you use actual measurements you've taken in the field?
Yes.

Are these observations different from the ones we've been hearing about from other
witnesses? No, th They're the same observations.

You You've testified that there has been no change in natural lead levels, is that correct? That is correct.

You're sure about that? Absolutely.

The levels we see in people today may be typical.

But they are not by any means natural.

So you don't disagree with Dr. Kehoe's numbers? Uh, no, no.

You're saying that the same numbers are leading to different conclusions? Yes.

You know, this is the kind of thing we expect to hear from lawyers, not scientists.

I would agree with that, yes.

You seem to be very sure of your conclusions, Dr. Kehoe.

It so happens that I have more experience in this field than anyone else alive.

At these levels, lead is a severe chronic insult to the human body.

There is no medical evidence that lead has introduced a danger to public health.

It's irresponsible to mine millions of tons of toxic material and disperse it into the environment! If there was proof of harm, we would have found it.

Not if your purpose is to sell lead.

Patterson fought the industry for another 20 years before lead was finally banned in U.S. consumer products.

The man who figured out the age of the earth was also responsible for one of the greatest public health victories of the 20th century.

In just a few years, average lead levels in the blood of children plummeted by some 75%.

Today, the medical consensus is unanimous there's no such thing as a nontoxic level of lead in humans, however small.

Today, scientists sound the alarm on other environmental dangers.

Vested interests still hire their own scientists to confuse the issue.

But in the end, nature will not be fooled.
8 - Sisters of the Sun

We pulled the stars from the skies and brought them down to Earth.

But at what cost? When we turned on all these lights we lost something precious.

The stars.

A long time ago, in a world lit only by fire, our relationship with the stars was far more personal.

For thousands of generations, we watched the stars as if our lives depended on it.

Because they did.

We humans were not the biggest, the strongest, nor the fastest of all the animals we competed against.

But we did have one thing going for us our intelligence.

One aspect of that was a genius for pattern recognition.

Night after night, we watched the stars.

And over time, our ancestors noticed that the motions of the stars across the nights of the year foretold changes on Earth that threatened or enhanced our chances for survival.

In a time when our imaginations were the only stage where stories came to life, before there were movies or TVs or electronic devices of any kind, every human culture connected the dots to form their own pictures.

These images became the illustrations of a storybook that, on a deeper level, was also a survival manual.

The names and personalities of the gods, heroes, farm animals or familiar objects varied from culture to culture.

But there was one particularly gorgeous group of stars known to the Ancient Greeks and to us today as the Pleiades, a star cluster formed about 100 million years ago.

Each of them is some 40 times brighter than our Sun.

And Alcyone, the most luminous, outshines our Sun 1,000 times.

For ages, the Pleiades have been used as an eye test for people all over the world.

If you could see at least six of them, you were considered normal.
If you saw more than seven, you were an ideal candidate for a warrior or scout.

Among the Ancient Celts and Druids of the British Isles, the Pleiades were believed to have a haunting significance.

On the night of the year that they reach the highest point in the sky at midnight, the spirits of the dead were thought to wander the Earth.

This is believed to be the origin of the holiday once known as Samhain, now called Halloween.

All over the Earth, our ancestors told wonderful stories to explain how the Pleiades came to be in the sky.

For the Kiowa people of North America, it happened something like this.

Long, long ago, some young women snuck away from their campsite to dance freely beneath the stars.

Rock, save us! Rock, take pity on us! The rock heard their cries and grew taller.

Until it became what is today known as the Devil's Tower.

The maidens were transformed into the stars of the Pleiades, which may be seen hanging above the tower in midwinter.

The Ancient Greeks also saw those seven jewels as seven maidens, the seven daughters of Atlas, pursued not by bears, but by Orion the hunter, who spied them when he was out walking one day.

Orion became mad with desire.

For seven years, he chased them relentlessly.

- Exhausted - Zeus, help us. they prayed to Zeus for deliverance.

Zeus, the king of the gods, felt sorry for them, and transformed those seven maidens into the Pleiades.

But the gods are, if anything, capricious.

When Orion was killed by the sting of a scorpion, Zeus placed him in the sky where he could resume his pursuit of the seven gorgeous sisters.

Our ancestors, they wove brilliantly imaginative stories.

But they can bring us no closer to the stars than our dreams.
It took yet another few thousand years until three brilliant scientists unlocked the secrets of the true lives of the stars.

In 1901, Harvard was a man's world.

But an astronomer named Edward Charles Pickering broke that rule.

Oh, Pickering's office is just down the hallway.

And that door over there leads to the room where he keeps his computers.

We're supposed to call those women "computers," but, uh, I've heard more than one fellow refer to those gals as "Pickering's Harem." Pickering assembled a team of women to map and classify the types of stars.

One of them provided the key to our understanding of the substance of the stars.

And another devised a way for us to calculate the size of the universe.

For some reason, you probably never heard of either of them.

Wonder why.

That's Annie Jump Cannon, the leader of the team.

Before she was through, she catalogued a quarter of a million stars.

Number 11 is a B7.

That's Alcyone in the Pleiades.

Cannon lost her hearing during a bout of scarlet fever when she was a young woman.

Number 12 is a B6.

That's Henrietta Swan Leavitt.

She's also deaf.

And she's the other great scientist in the room.

Leavitt discovered the law that astronomers still use more than a century later to measure the distances to the stars and the size of the cosmos itself.

Annie Jump Cannon sent out a Christmas card explaining what she and her sisters were actually doing.

The light from a star is allowed to fall through a prism placed in the telescope, she wrote.
Thus magnified, the starlight is split up into a band showing its component colors, the red rays going to one end and the violet to the other.

This is the spectrum of the star.

It shows the presence of fine, dark lines.

By comparing them with lines given by glowing substances in the laboratory, we can determine that the same elements familiar to us on the Earth also exist in the outermost star.

This is plate number 12358B.

Number one at this plate is a B-type star.

Make that a B2.

It took Cannon decades to classify the spectral character of hundreds of thousands of stars according to the scheme that she devised.

Cannon discovered that the stars fell into a continuous sequence of seven broad categories according to their spectral line patterns.

Each was designated by a letter.

But the spectral lines of two stars in the same letter class could differ in subtle ways, minute variations that Cannon learned to recognize from memory.

To distinguish these spectra from one another, she assigned ten numerical subcategories for each class.

Annie Jump Cannon organized the stars, but it would fall to another scientist to decipher the hidden meaning in her work.

In the England of 1923, women were forbidden from pursuing advanced degrees in science.

But Cecelia Payne had attended a lecture in London by the astronomer Sir Arthur Eddington, the first scientist to provide evidence that Einstein's revolutionary General Theory of Relativity was correct.

From that moment on, she knew that nothing would deter her from pursuing her big dreams.

She resolved to emigrate to America, where women had already gained the freedom to study the stars.
Her application was accepted at Harvard.

What she would discover there would challenge one of the central beliefs of astronomy.

The resulting impact would be the dawn of modern astrophysics.

As the decades passed, Annie Jump Cannon and her team kept sifting the stars, checking each one's spectral signature with a fleeting glance and then dropping them into one of seven categories.

They became hundreds of thousands of dots in a larger picture which no one could yet understand.

Into this community of women came one more.

Well, hello there.

You must be Miss Payne.

We've been waiting for you.

Come on in.

Cecilia Payne had never experienced such kindness in a scientific setting before.

This sisterhood generously shared the fruits of their labors with her, and she turned their observations into a radical new understanding of the stars.

The two women became great friends.

Cannon taught Payne everything she had learned about stellar spectra.

And Payne began to analyze Cannon's data to see if she could determine the actual chemical composition and physical state of the stars.

She brought to this work her expertise in theoretical and atomic physics.

The most prominent features in the spectra of stars showed the presence of heavy elements such as calcium and iron, which are among the most abundant elements in the Earth.

So astronomers naturally concluded that the stars were made of the same elements as the Earth and in roughly the same proportions.

In 1924, Henry Norris Russell was the dean of American astronomers, having made major contributions to our understanding of the stars.

the chemical elements that we have here on Earth are also present in the spectrum of the
Sun.

So we can assume that the composition of the Sun resembles that of the Earth.

If one were to heat the crust of the Earth to incandescence, its spectrum would resemble that of the Sun.

Annie, I think I now understand what it all means.

All your years of work.

Tell me.

I've calculated what the spectra should look like across a wide range of temperatures, and they match your system of classification perfectly.

The spectrum of any star tells you exactly how hot it is.

Your "O-B-A-F-G-K-M" is really a temperature scale of the stars from the hottest to the coldest.

Here's the headline, Annie.

Thanks to your work, I've discovered that the stars are made almost entirely of hydrogen and helium.

There's a million times more hydrogen and helium than the metals in the stars.

I know, it sounds daft.

Are you certain? Has anyone else checked your calculations? Not yet, but it's all in my thesis, which is already on its way to Professor Russell.

Poor woman.

Russell felt sorry for Cecilia Payne.

Her thesis appeared to him to be fundamentally flawed.

It is clearly impossible that hydrogen should be a million times more abundant than the metals.

Her carefully gathered evidence flew in the face of conventional scientific wisdom.

"How could I be right," she asked, "if that must mean that such a distinguished scientist was wrong?" Despite her confidence in the quality of her research, she caved and added a sentence to her thesis that undermined its greatest insight.
It would be four years before Russell realized that Payne was right.

To his credit, as soon as he did, he acknowledged that it was her discovery.

Payne's "Stellar Atmospheres" is widely regarded as the most brilliant PhD thesis ever written in astronomy.

It became the standard text in its field.

I was to blame for not having pressed my point.

I had given in to authority when I believed I was right.

If you are sure of your facts, you should defend your position.

The words of the powerful may prevail in other spheres of human experience, but in science, the only thing that counts is the evidence and the logic of the argument itself.

Cecilia Payne's interpretation of Annie Jump Cannon's sequence of stellar spectra made it possible for us to read the life stories of the stars and to trace the story of life itself back to its beginnings in their fiery deaths.

There are many kinds of stars.

Some are bright like the Sun.

Some are dim.

The greatest stars are ten million times larger than the smallest ones.

Some stars are old beyond imagining, more than ten billion years of age.

Others are being born right now.

When atoms fuse in the hearts of stars, they make starlight.

Stars are born in litters, formed from the gas and dust of interstellar clouds.

The mass of the individual stars in a litter can range from the runts-- not much larger than the largest planets-- to the supergiant stars that dwarf the Sun.

The stars in the nebula below Orion's Belt are newborns, around five million years old, and still swaddled in the gas and dust that gave birth to them.

The stars in the Pleiades are already toddlers, about 100 million years old.

They've shed their blankets of gas and dust, but they're still bound together by their mutual gravity.
Another few hundred million years, and they'll drift apart and go their separate ways, never to meet again.

Most of the stars of the Big Dipper are adolescents, roughly half a billion years old. They've already drifted apart from their birth cluster, although we can still trace their common ancestry.

Eventually, they'll spread out around the Milky Way galaxy.

But most of the familiar constellations are a mix of entirely unrelated stars, some faint and nearby, others bright and far away.

Our own Sun? From the distance of even a few light-years, it's hard to find amidst the other stars.

It's that one.

Our Sun is middle-aged and a long way from where it was born.

Its sister stars, hatched from the same interstellar cloud, are dispersed throughout the galaxy.

Many of them have their own planets.

Perhaps some of them nurture the evolution of life and intelligence.

Most of the stars in our night sky actually orbit around one or more stellar companions.

With the naked eye, we usually can't see the fainter members in such double and multiple star systems.

On a world with three suns, the nights would be rare and the days might alternate between red and blue.

It is the destiny of stars to collapse.

Of the thousands of stars you see when you look up at the night sky, every one of them is living in an interval between two collapses an initial collapse of a dark, interstellar gas cloud to form the star, and a final collapse of the luminous star on its way to its ultimate fate.

Gravity makes stars contract, unless some other force intervenes.

The Sun is a great, big ball of incandescent gas.

The super hot gas in its core pushes the Sun to expand outward.
At the same time, the Sun's own gravity pulls it inward to contract.

And our Sun is poised between these two forces in a stable equilibrium between gravity and nuclear fire, a balance it will maintain for another four billion years.

But as the Sun consumes hydrogen, its core very slowly shrinks, and the Sun's surface gradually expands in response.

It happens very slowly, imperceptibly, over the course of millions of years.

But in about a billion years, the Sun will be ten percent brighter than it is today.

Ten percent may not sound like much, but that extra heat will have a big effect on Earth.

When the Sun finally exhausts its nuclear fuel four or five billion years from now, its gas will cool and the pressure will fall.

The Sun's interior can no longer support the weight of the outer layers, and the initial collapse will resume.

Nothing lasts forever.

Even the stars die.

Helium, the ash of ten billion years of hydrogen fusion, has built up in the core.

With no nuclear fire to sustain its weight, the core collapses until it becomes hot enough to start fusing helium into carbon and oxygen.

The core of the Sun is now much hotter than it was before.

Its atmosphere rapidly expands.

Over the next billion years, it'll become bloated to more than 100 times its original size--a red giant star.

It will envelop and devour the planets Mercury and Venus and possibly the Earth.

I like to think that tens of millions of years before that far distant future, if there still be life born of Earth, it will have found new homes among the stars.

Once the Sun burns through its helium, it will become highly unstable, casting off its outer layers into space.

The exposed, super hot core will flood its surroundings with high-energy ultraviolet light.

The atoms will perform a wild, fluorescent dance.
The Sun will collapse like a soufflé, shrinking a hundredfold to the size of the Earth.

And at that point, the Sun will be so dense that its overcrowded electrons will push back, stopping any further contraction.

The kernel of light at the center will be the only part of the Sun that endures, a white dwarf star that will go on shining dimly for another 100 billion years.

Will the beings of a distant future, sailing past this wreck of a star, have any idea of the life and worlds that it once warmed? The psychedelic death shrouds of ordinary stars are fleeting, lasting only tens of thousands of years before dissipating in the interstellar gas and dust from which the new stars will be born.

The stars in a binary star system can have a different fate.

Sirius, the brightest star in the night sky, has a very faint stellar companion-- a white dwarf.

It was once a Sun-like star.

Someday, when Sirius runs out of fuel and becomes a red giant, it will shed its substance onto the white dwarf.

The intense gravity of the companion will attract that gas, pulling it into a spiraling disk.

When the gas from the larger star falls onto the surface of the white dwarf, it will trigger nuclear explosions.

The greatest burst will release 100,000 times more energy than the Sun.

Each one of those star bursts is called a "nova," from the Latin for "new." A star about 15 times as massive as the Sun, one like Rigel, the blue supergiant that forms the right foot of Orion, has a different fate in store.

Its collapse will not be stopped by the pressure of electrons.

The star will keep falling in on itself, until its nuclei become so overcrowded that they push back.

Rigel will shrink down about 100,000 times, until there's no space left between the nuclei and it can shrink no more.

At that point, it ignites a more powerful nuclear reaction, a supernova.

Most stellar evolution takes millions or billions of years.

But the interior collapse that triggers a supernova explosion takes only seconds.
What remains will be an atomic nucleus the size of a small city-- a rapidly rotating neutron star called a pulsar.

But for a star more than 30 times as massive as the Sun-- a star like Alnilam, in Orion's Belt-- there will be no stopping its collapse.

In a few million years, when Alnilam runs out of fuel, it, too, will go supernova.

The imploding core of Alnilam will be so massive that not even nuclear forces will be strong enough to hold off its collapse.

Nothing can withstand such gravity.

And such a star has an astonishing destiny.

It will continue to collapse, crossing a boundary in space-time called the "event horizon," beyond which we cannot see.

When it traverses that frontier, the star will vanish completely from sight.

It will be inside a black hole, a place where gravity is so strong that nothing, not even light, can escape.

But there's an even more dramatic fate that awaits a rare kind of star.

There's one of them in our galaxy.

It's so unstable that when it goes, it won't become a mere nova or supernova.

It'll become something far more catastrophic a hypernova.

And it could happen in our lifetime.

There are few places on Earth to get a better view of the night sky than the Australian Outback.

No buildings, no cars, streetlights, nothing out here; just lots of starlight and the occasional kangaroo.

You can get a particularly good view of the Milky Way from down here.

The center of our galaxy rises high in the sky, and it arches across the heavens like the backbone of night.

We live in a spiral galaxy.

And when we look at the Milky Way, we're seeing light from billions of stars in its spiral disk.
And under this beautiful dark sky, you can see that the Milky Way isn't a uniform band of light.

There are dark patches, breaks in the starlight.

Those dark patches are caused by interstellar dust.

The dust blocks the starlight, and there's lots of it.

Most cultures looked up at the stars and connected the dots to form familiar images in the sky.

Constellations.

But the Aboriginal people of Australia saw a pattern in the darkness running through the Milky Way.

They saw an emu, a large bird native to this continent.

Not in the stars, but in the absence of stars.

There are so many ways to look at the night sky.

For a million years or more, we've watched the sky.

And a lot's happened in that time.

Supernova explode in our galaxy about once a century.

If we could compress all those nights of stargazing into a single minute, this is what we would see.

Now, if our eyes were telescopes, if they were light buckets as big as wagon wheels and our vision was not limited to just one kind of light, then this is the Milky Way we would see.

A galaxy in near-infrared light with streaming tendrils of dust hurled outward by those exploding supernovas, silhouetted against a backdrop of countless stars.

About 7,500 light-years away, in another part of our galaxy, there is a place of upheaval on an inconceivable scale.

This is the Carina Nebula.

A star-making machine.

It takes a ray of light The titanic stars born here sear the surrounding gas and dust with their fierce ultraviolet radiation.
When a massive star dies, it blows itself to smithereens.

Its substance is propelled across the vastness to be stirred by starlight and gathered up by gravity.

Stars to dust and dust to stars.

In the cosmos, nothing is wasted.

But there's an upper limit to how massive a star can be.

Back in the 17th century, when Edmond Halley crossed the equator to map the southern constellations, Eta Carinae seemed like just another faint star.

But in 1843, Eta Carinae suddenly became the second brightest star in the sky, outshined only by Sirius.

And it's been flipping out ever since.

That dumbbell-shaped cloud is the expanding remnant of that event.

At its center is one crazy star.

Talk about unstable-- Eta Carinae is at least 100 times more massive than the Sun, and pouring out five million times more light.

It's pushing the upper limit of what a star can be.

What's more, there's evidence that Eta Carinae is being gravitationally tormented by an evil twin-- another massive star in orbit around it as close as Saturn is to the Sun.

The core of a supermassive star pours out so much light that the outward pressure can overwhelm the star's gravity.

If a star is too massive, its radiation pressure overpowers its gravity and blows the star apart.

The fate of Eta Carinae was sealed when it was born millions of years ago.

When it finally does blow up-- and who knows, maybe it already has; after all, we're looking at it by light that left the star it will be a cataclysm unlike anything we've seen before.

A hypernova.

An explosion so powerful, it'll make a supernova seem like a firecracker by comparison.

If there are nearby solar systems with planets harboring life, their days are numbered.
A hypernova spews so much radiation into space-- not just light, but X-rays and gamma rays-- that planets that are dozens or perhaps hundreds of light-years away could be stripped of their atmospheres and bathed in deadly radiation.

It would wreak havoc in thousands of nearby star systems.

Right about now, you're probably asking yourself, "Are we safe?" If Eta Carinae blows up, what happens to Earth? Rest assured, Earth will be just fine.

Remember, we're 7,500 light-years away from Eta Carinae.

The intensity of radiation from a star, even an exploding star, falls off rapidly with distance.

But still, Eta Carinae in its death throes will put on quite a show.

It will light up the night of the southern hemisphere with the brightness of a second moon.

The most dramatic swan song a star can sing.

Our ancestors worshipped the Sun.

And they were far from foolish.

It makes good sense to revere the Sun and stars, because we are their children.

The silicon in the rocks, the oxygen in the air, the carbon in our DNA, the iron in our skyscrapers, the silver in our jewelry were all made in stars billions of years ago.

Our planet, our society and we ourselves are stardust.

Well, what is it that makes the atoms dance? How is the energy of a star transformed into everything that happens in the world? What is energy? We're awash in it.

When hydrogen atoms fuse inside the Sun, they make helium atoms.

And this fusion emits a burst of energy that can wander inside the Sun for ten million years before making its way to the surface.

And once there, it's free to fly straight from the Sun to the Earth as visible light.

If it should strike the surface of a leaf, it will be stored in the plant as chemical energy.

Sunshine into moonshine.

I can feel my brain turning the chemical energy of the wine into the electrical energy of my thoughts and directing my vocal chords to produce the acoustic energy of my voice.
Such transformations of energy are happening everywhere all the time.

Energy from our star drives the wind and the waves and the life around us.

How lucky we are to have this vast source of clean energy falling like manna from heaven on all of us.

To Annie Jump Cannon, Henrietta Swan Leavitt and Cecilia Payne for blazing the trail to modern astrophysics.

And to all the sisters of the Sun.

There's no refuge from change in the cosmos.

Some ten or 20 million years from now, it'll seem for a cosmic moment as if Orion is finally about to catch the seven sisters.

But before he has them in his clutches, the biggest stars of Orion will go supernova.

Orion's pursuit of the Pleiades will finally end, and the seven sisters will glide serenely into the waiting arms of the Milky Way.

We on Earth marvel-- and rightly so-- at the return of our solitary Sun.

But from a planet orbiting a star in a distant globular cluster, a still more glorious dawn awaits.

Not a sunrise but a galaxy rise.

A morning filled with 200 billion suns.

The rising of the Milky Way.

An enormous spiral form with collapsing gas clouds, condensing planetary systems, luminous supergiants, stable middle-aged suns, red giants, white dwarfs, planetary nebulas, supernovas, neutron stars, pulsars, black holes and, there is every reason to think, other exotic objects that we have yet to discover.

From such a world, high above the Milky Way, it would be clear, as it is beginning to be clear on our world, that we are made by the atoms and the stars, that our matter and our form are forged by the great and ancient cosmos, of which we are a part.
NEIL DEGRASSE TYSON: Yes, this is home.

This is Earth.

Having trouble finding a familiar continent? The past is another planet.

Actually, many.

I'm standing on the great expanse of time that has elapsed since the Big Bang.

In order to think about it, we've compressed it all into a single year.

It's the early morning of December 23 on this Cosmic Calendar of ours, or about 350 million years ago, when our world was a mere four billion years old.

Earth looks so different.

You might not even know the place.

The stars wouldn't help you.

Even the constellations would have been different back then.

The dinosaurs were still more than 100 million years in the future.

There were no birds, no flowers.

And the air was different, too.

The atmosphere had more oxygen than at any other time in Earth's history, before or since.

This allowed insects to grow much larger than they do today.

How? Insects don't have lungs.

Life-giving oxygen is taken in through openings in the outside of their bodies and transported through a network of tubes.

If an insect were too large, the outer reaches of these tubes would absorb all the oxygen before it could ever get to its internal organs.

But during the Carboniferous Period, the atmosphere had almost twice the oxygen as today.

Insects could then grow much bigger and still get enough oxygen in their bodies.
That's why the dragonflies here are as big as eagles and the millipedes the size of alligators.

So why was there so much oxygen back then? It was produced by a new kind of life.

DEGRASSE TYSON: What kind of life could've changed the Earth's atmosphere so dramatically? Plants that could reach for the sky--trees.

In their competition for sunlight, trees evolved a way to defy gravity.

Before trees, the tallest vegetation was only about waist-high.

And then something wonderful happened.

A plant molecule evolved that was both strong and flexible, a material that could support a lot of weight, yet bend in the wind without breaking.

Lignin made trees possible.

Now life could build upward.

And this opened a whole new territory, a three-dimensional matrix for communities far above the ground.

Earth became the Planet of the Trees.

But lignin had a downside: it was hard to swallow.

When nature's demolition crew, the fungi and bacteria, tried to eat anything with lignin in it, they got a really bad case of indigestion.

And termites wouldn't evolve for at least another 100 million years.

What to do with all those dead trees? It took the fungi and bacteria millions of years to evolve the biochemical means to consume them.

Meanwhile, the trees just kept springing up, dying, falling over and getting buried by the mud that built up over eons.

Eventually, there were hundreds of billions of trees entombed in the Earth, buried forests all over the Earth.

What possible harm could come from that? (waves crashing in distance) This cliff in Nova Scotia is another kind of calendar.

It tells the story of that other world that once flourished right here.

And this is the death mask of that 300 million-year-old tree.
It was cast by minerals that replaced the original wood cell by cell-- in other words, a fossil.

The tree surrendered its organic molecules to the environment long ago, its carbon and water.

Only its shape remains.

When this tree was alive, it took in carbon dioxide and water and used sunlight to turn them into energy-rich organic matter.

The tree gave off oxygen as a waste product.

That's what trees and other plants still do.

When plants die, they decay, and this reverses the transaction.

Their organic matter combines with oxygen and decomposes, putting carbon dioxide back into the air.

This balances the books for the chemistry of Earth's atmosphere.

But if the trees are buried before they can decay, two things happen they take the carbon and stored solar energy with them and leave the oxygen behind to build up in the atmosphere.

That's what happened around 300 million years ago.

There was an oxygen surplus.

That's how the bugs got so big.

And what became of all that buried carbon? It lay there for eons before dealing life on Earth its most devastating blow of all time.

There are places on this planet where you can walk through time and read the history written in the rocks.

This beach in Nova Scotia is one of them.

Every layer is a page.

Each one tells the story of a flood, one after another, over millions of years.

The layer cake of flood deposits was slowly buried and turned into rock by heat and pressure.

The same forces that built mountains then tilted and uplifted them, along with the
entombed fossil forest.

The newer layers were always deposited on top of the older ones.

All the pages are in the correct order, bearing witness to what happened here over millions of years.

Back that way lies the more distant past.

And with every step I take, I move about 1,000 years closer to the present and away from the world of 300 million years ago.

lies that way.

This was the beginning of the end of the Permian world, an event of unequalled carnage.

The Permian is the darkest corridor in this memorial to the broken branches on the Tree of Life-- the Halls of Extinction.

Death has never come so close to reigning supreme on this world in the quarter billion years since.

The eruptions, in what is now Siberia, lasted for hundreds of thousands of years.

The lava flooded and buried more than a million square miles.

This event dwarfs any volcanic eruption in historical times.

Huge quantities of carbon dioxide came pouring out of the volcanic fissures.

This greenhouse gas warmed the climate.

And this is where the long-buried forests of the earlier Carboniferous Period reenter the story.

During the intervening those trees had turned into immense deposits of coal, and as it happened, one of the world's largest accumulations of coal was buried right there in Siberia.

The heat from the lava baked the coal, driving methane and sulfur-rich gases out of the ground.

They were laden with toxic and radioactive ash particles-- coal smoke.

This witch's brew polluted the atmosphere and radically destabilized Earth's climate.

A sulfuric acid haze blocked incoming sunlight and darkened the planet.
Global temperatures plummeted to subfreezing.

During lulls in the eruptions, the acid haze fell back to the surface.

But the carbon dioxide remained and built up in the atmosphere to cause global warming.

Years of frigid cold alternating with millennia of stifling heat battered a dwindling population of plants and animals.

They had no chance to adapt to the drastic swings in climate.

As the global warming continued, the surface and the bottom waters slowly mixed, raising the temperature of the once-frigid depths of the sea floor.

Methane-rich ices that had been frozen in the sediments began to melt.

Newly liberated methane gas made its way to the surface and into the atmosphere.

Methane traps heat far more efficiently than carbon dioxide, so the climate got even hotter.

And the methane also destroyed the ozone layer in the stratosphere.

The natural sunscreen that protects life from deadly ultraviolet rays was eaten away.

The circulatory system of the world ocean shut down.

These stagnant waters became oxygen-starved, killing almost all the fish in the sea.

But one kind of life flourished in this brutal environment bacteria that produced deadly hydrogen sulfide gas as a waste product.

That was the last straw.

The poison gas killed almost all the remaining plants and animals on the land.

This was the Great Dying.

The closest life on Earth has ever come to annihilation.

Nine in ten of all species perished.

It took a long time for life to bounce back.

For a few million years, Earth could have been called the Planet of the Dead.

We are descended from one of the few species that managed to squeak by.

You are human and alive at this very moment because they managed to endure,
conveying their DNA through one of the most treacherous periods in the history of life.

DEGRASSE TYSON: This mountain was made entirely by life.

The life that flourished back in the glory days of the Permian, before all hell broke loose.

This is part of the 400 mile-long Guadalupe Mountain chain that runs through Texas and New Mexico.

It's the world's largest fossil reef.

All this was once a great inland sea.

The reef flourished and grew for millions of years, and was home to multitudes of sponges, green algae, and animals too small to see.

When these creatures died, they sank to the bottom and were buried in the silt.

Over millions of years, their remains were converted into oil and gas.

Eventually, the basin silted in and the reef died.

This marine ghost town was then buried a mile beneath the surface.

Later, tectonic forces lifted the skeletal reef high above sea level, where it was eroded and sculpted over eons by wind and rain.

Just imagine what this place looked like 275 million years ago, when it was a vibrant, tropical inland sea, dotted with islands and brimming with life.

Until about New England and North Africa were next-door neighbors.

There was no such thing as the Atlantic Ocean.

Those thin blue fingers at the center-- they were lakes.

They were the first outward signs that the supercontinent was splitting apart and that life on Earth was due for another big shake-up.

A million years later, the lakes became a long bay, which would grow into the Atlantic Ocean.

These profound changes at the surface were merely symptoms of a drama that was unfolding far beneath, in the depths of the Earth.

By the time we got here, the telltale traces of global upheaval were buried at the bottom of the deep blue sea.
We were completely cut off from the great story of Earth's violent past-- a species of amnesiacs trying to find out who we were and what happened before we awakened.

In 1570, Abraham Ortelius created the first modern world atlas, reflecting on the discoveries of the previous 80 years-- the Golden Age of Exploration.

Before the ink was dry, Ortelius stepped back from his masterpiece and became the first of many to notice the striking puzzle-piece fit between the continents on either side of the Atlantic.

He later wrote that the Americas were torn away from Europe and Africa by earthquakes and floods.

But Ortelius's observation remained nothing more than a hunch for the next couple of centuries until an early 20th century German astronomer and meteorologist amassed the evidence to build the scientific case for it.

Alfred Wegener had been drafted during the First World War, but was wounded soon after.

As he recovered in a field hospital, he scoured scientific literature for clues to the Earth's past.

Years before, Wegener had happened upon an intriguing paper in the stacks of his university library.

It puzzled Wegener that fossils of the same species of a now-extinct fern were reported to be found on both sides of the Atlantic.

Even more curious were the discoveries of fossils of the same dinosaurs on both continents.

In the early 20th century, geologists explained how life crossed the oceans by imagining that land bridges had once existed between them.

It was thought that these land bridges gradually disintegrated and vanished beneath the waves long ago.

But there was one piece of evidence that convinced Wegener that the prevailing scientific view must be wrong the Earth itself.

Why would a mountain range cross the oceanic divide to continue on another continent? And why would you find the same unique pattern in the layers of rocks in both Brazil and South Africa? And another thing under what circumstances could tropical plants have flourished in the frozen wastes of the Arctic? Wegener concluded that there was only one
logical solution to this puzzle There had once been a single supercontinent on Earth.

He named it Pangaea.

So Wegener becomes the toast of the scientific world, right? Not exactly.

Most geologists ridiculed Wegener's hypothesis of continental drift.

They preferred their imaginary natural land bridges to explain away Wegener's evidence.

How, they asked, could a continent plow through the solid rock of the ocean floor?

Wegener had no convincing answer.

He became the laughingstock of the field; a pariah at scientific conferences.

(dogs barking) Despite this, Wegener continued to fight for his ideas, conducting daring research expeditions to gather evidence.

On one of these, he learned that colleagues were trapped on an ice cap without food.

On his way back from the mission, he became lost in a blizzard.

A day or two after his 50th birthday, he disappeared, never knowing that, in time, he would be vindicated and come to be viewed as one of the greatest geologists in history.

Scientists are human.

We have our blind spots and prejudices.

Science is a mechanism designed to ferret them out.

Problem is, we aren't always faithful to the core values of science.

Few people knew this better than Marie Tharp.

It's 1952, and Marie is patiently enduring the slights of her fellow members of the geology department.

Her degrees in geology and mathematics count for little with them.

Bruce Heezen, a graduate student from Iowa, has just returned from a lengthy expedition to map the ocean floor using sonar.

(Heezen grunts) Will you do something with these? Bruce, look.

It's-- it's all come together.

There's this giant rift valley that runs through the bottom of the Atlantic.
Aw, geez, Marie, come on.

This is just more girl talk.

You're not in enough trouble with everyone here already? This sounds too much like continental drift.

You want to end up like Wegener? DEGRASSE TYSON: But Marie would not be dissuaded.

Years later, when Marie and Bruce placed a map of oceanic earthquake epicenters on a light table over her seafloor map, the earthquakes fell right along the rift valley.

This was the smoking gun for Wegener's moving continents.

Heezen now knew that Marie had been right all along.

Together, they created the first true map of the Earth, including the ocean floor.

We were at last ready to read the autobiography of the Earth.

DEGRASSE TYSON: Let's take the Ship of the Imagination to a part of the world that has been off-limits to all but a few of us.

Two-thirds of the Earth lies beneath more than It's a vast and largely unexplored frontier.

Everybody knows the Alps and the Rockies, but some of the world's most amazing mountain ranges are hidden from view.

Below 1,000 meters, we enter a world where there is no sunlight.

Hidden in the darkness, a world of wonders.

This is the longest submarine mountain range in the world, the Atlantic Mid-Ocean Ridge.

It wraps around our globe like the seam on a baseball.

The past is another planet, but most of us don't really know this one.

We don't see the mountains for the water.

This is the world that Marie Tharp was the first to imagine.

The highest peaks of the ridge rise over four kilometers above the ocean floor.

There are sprawling mountain ranges and canyons, too.
We've now entered the Marianas Trench, the deepest canyon on Earth, more than ten kilometers deep.

It formed when tectonic forces pushed the seabed under the adjoining continental plate.

More people have walked on the Moon than have ever been down here.

The pressure here is a crushing eight tons per square inch.

Being this deep in the ocean is like having 50 jumbo jets stacked on top of you.

Yet even here, life has taken hold.

The fact that sunlight can't penetrate the deep ocean doesn't mean there isn't light down here.

Many underwater species glow in the dark, through a process called bioluminescence.

Our long history as land mammals, denizens of the sunlit world, hasn't prepared us for the amazing variety of life that evolution has crafted in the deep oceans.

Since there's no sunlight down here, there's no photosynthesis.

That means there are no plants to feed on, and yet, even here, in a world of permanent midnight, there's a thriving food chain.

It begins with a process called chemosynthesis.

These microscopic creatures have learned to eat what's pouring out of that vent a noxious compound called hydrogen sulfide.

That thick black smoke provides the chemical energy that makes life possible here.

Tiny crustaceans eat the bacteria, and the larger animals eat the crustaceans.

One day, on some future Earth, these mountains could very well end up above the water.

Tectonic forces continue to shape our planet.

The future is also another planet.

It was a volcano like this one that created the Hawaiian islands millions of years ago.

We live on the crust of a seething cauldron.

At the center of our planet, there's an iron core.

It's nested inside of a larger, liquid iron shell.
Wrapped over this is the part called the mantle.

It's rocky but hot and viscous.

Like a pot of soup cooking on a stove, the mantle is churning.

What keeps it moving? Two things the heat left over from Earth's formation, and the decay of radioactive elements in the core.

And this outer layer-- the crust, where you and me and everyone we know lives-- is only as thick as the skin on an apple.

The mantle drags the solid overlying crust along with it.

The crust resists because it's cool and rigid.

From time to time, it reaches the breaking point.

When that happens, the Earth quakes.

It's not because somebody misbehaved and is being punished.

It's due to random forces that are governed by the laws of nature.

Our sense of the stability of the Earth is an illusion due to the shortness of our lives.

If we could watch our planet on its own timescale, in which big changes take millions of years to play out, we would see it as the dynamic organism it really is.

(rumbling, crackling) This is the world of the late Triassic period about 200 million years ago.

That little guy? It's one of our distant ancestors.

He lived in Newark, New Jersey.

Wherever you walk on Earth lost worlds lie buried beneath your feet. 50 or 100 million years ago, even the most seemingly ordinary places have been the scene of epic change.

These Palisades are a monument to the breakup of the supercontinent Pangaea.

The sequence of volcanic eruptions that made these cliffs also led to the next mass extinction-- the one that ended the Triassic world.

But a catastrophic extinction event for one species is a golden opportunity for another.

The Triassic extinctions offered one group that had been around for a while the chance to take center stage.
The dinosaurs had a good, long run for 170 million years.

Back then, India was an island.

It crept northward at the pace of a few inches per year on its slow but inexorable rendezvous with Asia.

Then, once again, the molten rock beneath Earth's surface burst forth and flooded a huge area of western India.

The knockout punch literally came out of the blue.

(rumbling, whooshing) Few animals larger than a hundred pounds survived the catastrophes of the late Cretaceous.

The dust cloud brought night and cold to the surface for months.

The dinosaurs froze and starved to death.

But there were small creatures who took shelter in the Earth.

And when they emerged they found that the monsters who had hunted and terrorized them were gone.

The Earth was becoming the Planet of the Mammals.

And the Earth continued its ceaseless changing.

This was once a desert where nothing could grow.

It was a million square miles of sand and salt, far more hostile than any environment on Earth today.

Daytime temperatures were hot enough to bake bread.

And it was more than a mile below sea level, so the atmospheric pressure was about 50% higher than what we're used to.

It would be hard to think of a more unpromising environment on this planet.

Yet this was the basin of the Mediterranean five and a half million years ago, before it became a sea.

The Earth never stops moving for long.

The natural dam at the western end of the deep basin gave way, probably due to earthquakes.
And the deluge began.

The torrential waters rushed in at a rate 40,000 times greater than Niagara Falls, turning a vast desert into the Mediterranean Sea in less than a year.

There were as yet no humans to witness this enormous flood, nor to admire the beauty it created.

Meanwhile, half a world away, a broad channel separated North and South America allowing ocean currents to flow from the Atlantic into the Pacific Ocean.

Tectonic forces gradually brought these two continents together, closing the channel and creating the Isthmus of Panama.

This reorganized the worldwide pattern of ocean currents, which, in turn, affected the global climate.

In Africa, the lush green forest canopy gave way to a sparser landscape.

Some species that were highly specialized for life in the trees became extinct.

But the generalists, the ones that could find a way to make a living no matter what life threw at them, endured and evolved.

Our ancestors had once burrowed deep in the ground to avoid predators who stalked the surface.

But when the dinosaurs perished, they emerged into the daylight, and over the eons, made new lives in the branches of the trees.

They developed opposable thumbs and toes for swinging from branch to branch, across the broad canopy of treetops, where all their needs were fulfilled.

They could also walk upright, but only for short distances.

With so many trees around, they didn’t have to go very far.

But then it got colder, and the trees thinned out, broad grasslands sprang up, and our ancestors were forced to traverse them in search of food.

You needed a totally different skill set to make it on the savanna.

In the old days, you could sit perched on your tree branch and watch the big cats from a safe distance.

Now you were playing on the same dangerous field.
The survivors were those who evolved the ability to walk great distances on their hind legs and to run when necessary.

This changed the way they looked at the world. Hands and arms were no longer tied up with walking. They were free to gather food and pick up sticks and bones. These could be used as weapons and tools.

Think of it A change in the topography of a small piece of land half a world away reroutes ocean currents. Africa grows colder and drier. Most of the trees can't withstand the new climate.

The primates who lived in them have to seek other homes, and before you know it, they're using tools to remake the planet.

The Earth has shaped the course of human destiny, but so has the invisible pull of distant worlds.

DEGRASSE TYSON: The planets have influenced our lives, but not in the way you think.

The gravitational pull of Venus-- small but close-- and that of Jupiter-- distant but massive-- tilted the Earth's axis this way and that and ever so slightly tweaked the shape of its orbit.

This periodically altered the amount of sunlight falling on the edge of the northern ice cap. Sometimes it made the summers there colder, and the glaciers advanced southward from one year to the next, grinding and scraping, and crushing everything in their path. That's what we call an ice age.

At other times, changes in Earth's axis and orbit made the Arctic summers warmer. And the melting glaciers began to retreat.

Imagine how resourceful our ancestors had to be in order to survive these radical changes in climate.

With each glacial period, the ice sheets grow at the expense of the oceans; the world sea
level falls by more than 400 feet, uncovering wide areas of land along the edges of the continents. 15 to 25,000 years ago, there was a period when the ice receded, exposing a temporary land bridge.

The gateway to the other half of the planet swings open.

Bands of wanderers crossed the land bridge to North America and parts south.

About 10,000 years ago, the manic swings of the climate and sea levels came to a stop.

A new and gentler climate age began.

It's the one we live in now.

When the great ice sheets melted, the sea rose to its present height and the rivers carried silt from the highlands to build great delta plains where they met the sea.

On those fertile plains, we learned a new way of life how to grow things, to feed ourselves and more.

For most of us, this meant an end to a million years of wandering.

The way the planets tug at each other, the way the skin of the Earth moves, the way those motions affect climate and the evolution of life and intelligence-- they all combined to give us the means to turn the mud of those river deltas into the first civilizations.

There's nothing like an interglacial period, one of those balmy intermissions in an ice age.

And the great news is that this one is due to last for another 50,000 years.

What a break for our kind.

Just one problem.

We can't seem to stop burning up all those buried trees from way back in the Carboniferous Age, in the form of coal; and the remains of ancient plankton, in the form of oil and gas.

If we could, we'd be home free, climate-wise.

Instead, we're dumping carbon dioxide into the atmosphere at a rate the Earth hasn't seen since the great climate catastrophes of the past, the ones that led to mass extinctions.

We just can't seem to break our addiction to the kinds of fuel that'll bring back a climate last seen by the dinosaurs; a climate that will drown our coastal cities and wreak havoc on the environment and our ability to feed ourselves.
All the while, the glorious sun pours immaculate, free energy down upon us; more than we will ever need.

Why can't we summon the ingenuity and courage of the generations that came before us? The dinosaurs never saw that asteroid coming.

What's our excuse? There's a corridor in the Halls of Extinction that is, right now, empty and unmarked.

The autobiography of the Earth is still being written.

There's a chance that the end of our story lies in there.

DEGRASSE TYSON: Congratulations.

You're alive.

There's an unbroken thread that stretches across more than three billion years that connects us to the first life that ever touched this world.

Think of how tough, resourceful and lucky all of our countless ancestors must have been to survive long enough to pass on the message of life to the next and the next and the next generation, hundreds of millions of times before it came to us.

There were so many rivers to cross, so many hazards along the way.

Predators, starvation, disease, miscalculation, long winters, drought, flood and violence.

Not to mention the occasional upheavals that erupted from within our planet and the apocalyptic bolts that come from the blue.

No matter where we hail from or who our parents were, we are descended from the hearty survivors of unimaginable catastrophes.

Each of us is a runner in the longest and most dangerous relay race there ever was, and at this moment, we hold the baton in our hands.

The past is another planet.

And so is the future.

Some 250 million years from now, many geologists think that the lands of the Earth will be united once again.

All this beauty will have vanished and the Earth of our moment in time will take its place among the lost worlds.
The great internal engine of plate tectonics is indifferent to life, as are the small changes in the Earth's orbit and tilt and the occasional collisions with little worlds on rogue orbits.

These processes have no notion of what has been going on over billions of years on our planet's surface.

They do not care.

Each of us is a tiny being riding on the outermost skin of one of the smaller planets for a few dozen trips around the local star.

The things that live the longest on Earth endure for only about a millionth of the age of our planet.

So, of course, the individual organisms see nothing of the overall pattern.

Of changing continents climate evolution.

That we understand even a little of our origins is one of the great triumphs of human insight and courage.

Who we are and why we are here can only be glimpsed by piecing together something of the full picture, which must encompass eons of time millions of species and a multitude of worlds.

In this perspective, it's not surprising that we're a mystery to ourselves and that, despite our manifest pretension, we are far from being masters of our own little house.

This new corridor has no name above the entrance to designate its epoch, and we don't yet know which failed species will be memorialized within its walls.

What happens here, in countless ways, both large and small, is being written by us.

Right now.
10 - The Electric Boy

Can you see me? Can you hear me? How? I could be thousands of miles away, and yet, when you turn on whatever device is bringing my image and voice to you, I'm there. Instantaneously.

How is that possible? To our ancestors, it would've seemed like sorcery.

For them, speed of communication was only as fast as the swiftest horse or sailing ships.

Our messages travel invisibly at the speed of light.

How did we attain such mythic powers? It all began in the mind of one person.

A child of poverty of whom nothing was expected.

In fact, if this man had not lived the world we know might not exist today.

Sooner or later, someone would've likely figured out some of his discoveries.

But if Michael Faraday had never lived, we might still be living as our ancestors did in the 17th century.

Unaware of armies of invisible servants awaiting our commands.

This is the story of how we learned to make electrons do our bidding.

In a way, it begins with the greatest genius who ever lived-- Isaac Newton.

This is Woolsthorpe, Newton's ancestral home.

He walked these fields, tormented by mystery.

Newton, the man who figured out the formula for the motions of the planets around the Sun, wanted to know how does the Sun make the planets act that way without touching them? How do all the apples know how to fall? Another genius was puzzled by another aspect of the same mystery.

You see, son? No matter how I turn the compass, the needle always points the same way.

Except But how? They do not touch.

I didn't hear a "Thank you," Albert.

I can still remember this.

The experience made a deep and lasting impression on me.
Something deeply hidden had to be behind things.

Between the lifetimes of Einstein and Newton, there lived another genius, one of equal stature.

The man who solved the mystery that stumped Newton, also laid the foundation for Einstein's revolutionary insights.

And for the way we live now.

In 1791, in a squalid slum in the suburbs of London, Michael Faraday was born.

He showed little promise at school.

Pray tell us a word that begins with the letter R.

Well? Wabbit? The word is "Rabbit." Once again, and correctly this time.

Wabbit? Do you mock me? Have I not told you how to pronounce the letter R? Surely you can at least tell us your name? Michael "Fawaday," ma'am.

Take this ha'penny, and buy me a cane, so that I may give your insolent brother a proper flogging.

History does not record that Michael Faraday ever attended school again.

Faraday took his family's fundamentalist Christian faith to heart.

It would always remain a source of strength, comfort and humility for him.

He was sent to work at a bookbindery at the age of 13.

By day, he bound the books, and by night, he read them.

It was the beginning of a lifelong fascination with electricity.

After years of working in the bookbindery, Faraday, now 21, yearned to escape to a larger world.

His big break came when a customer gave him a ticket to a sensational new kind of entertainment-- science for the public.

And it started right here at London's Royal Institution.

Humphry Davy was not only one of the leading scientists of his day, he discovered several the chemical elements, including calcium and sodium.

He was also a consummate showman.
And primitive demonstrations of electricity never failed as a crowd pleaser.

May we have the lights lowered, please? I am about to unleash the might of the 2,000 massive chemical batteries stored in the cellar beneath our feet.

And now, behold the power of the mysterious force of electrical fluid to illuminate our future.

Faraday was too busy taking notes to applaud.

Faraday created a transcript of Davy's lecture.

Using the skills he had learned as an apprentice, he bound them into this book.

Perhaps such a gift would bring him to the attention of the great man.

Maybe this gesture could be his means of escape to a much larger universe.

Good day, sir.

I wish you to deliver this parcel to Sir Humphry.

It was a long shot, anyway.

But Faraday hoped something would come of it.

And it did.

Uh, the experiment is ready for you now, sir.

Ampere tells me that poor Dulong lost an eye and three fingers working with this.

My eyes! My eyes! When a chemical experiment blew up in the face of the world-renowned scientist Humphry Davy, he remembered Michael Faraday, the lad who had gone through such lengths to copy down and bind the transcript of his lecture.

You have a first-rate memory, young man.

And I shall have temporary need of a secretary.

Sir, I dream of a life in service to science.

I would advise you to stick to the bookbinding.

Science is a harsh mistress.

Surely, a person of your station and modest means must have a trade.

Trade is vicious and selfish.
Men of science are amiable and morally superior.

I take it I'm the first man of science you've ever met.

Faraday made himself indispensable to Davy.

The temporary job became a permanent one, and the Royal Institution became his lifelong home.

By day, he assisted Davy in the lab, at day's end, he climbed the stairs to the little apartment where his beloved bride Sarah was waiting.

Humphry Davy and the chemist William Wollaston were experimenting with a mysterious phenomenon, one with potentially far-reaching implications.

This is the identical setup to Orsted's.

Now close the circuit, Davy, and watch closely.

What could be driving the needle away from the wire? Damned if I know.

But it's as if the electric current makes the wire behave like some kind of magnet.

Electricity must have something to do with magnetism.

Now if we could only get it to turn continuously, imagine what might be accomplished if we could put these forces to work.

After you've tidied up, Faraday, you might see what you can make of it.

Davy may have been having a bit of fun at the expense of his young assistant, but Faraday was on fire.

Up to now, electricity had been nothing more than an entertaining novelty toy.

It could make a light flash for an instant or turn a compass needle briefly, but it had no practical application.

Faraday immediately set about designing the experiment, devoting every moment of his spare time to the problem.

If Faraday succeeded, he would be putting an infinitely large, invisible, and as-yet- undiscovered army of electrons at the command of human whim.

How does a revolution begin? Sometimes it doesn't take much.

A piece of metal, a bowl of mercury, a bit of cork.
Sarah dear, send your little brother down.

I'm about to try something knew, and I want him to see it.

Why don't you do the honors, Georgie.

There she goes.

There she goes! This was the first motor converting electric current into continuous mechanical motion.

Looks pretty feeble, right? But that turning spindle is the beginning of a revolution, one that dwarfs all the shots fired and bombs ever detonated in the sheer magnitude of its effect on our civilization.

Try to imagine all the businesses, industries, technologies, transformations of the way we live that have their beginnings in that ecstatic moment in Michael Faraday's laboratory.

News of Faraday's invention spread quickly, and suddenly, Davy's assistant was the toast of London.

Davy didn't take it well.

He had, after all, discovered all those elements.

Now people were saying that his greatest discovery was Michael Faraday.

Davy made sure that Faraday wouldn't be making any more headlines anytime soon.

You sent for me, sir? I have a new challenge for you.

I want you to take over our efforts to improve the quality of British optical glass.

Those damned Bavarians are running circles around us.

Glass? With all due respect, sir, I know nothing at all of glass-making.

Then you will learn, Faraday.

We all know what a quick study you are.

Just analyze the chemical composition of their glass and work backwards to see how they made it.

It shouldn't take you long.

But Faraday struggled for four years without any success.
This is even worse than the last batch.

No matter how hard he tried, Faraday could not figure out what Joseph Fraunhofer had discovered years before.

What Faraday failed to grasp was that casting perfect optical glass for telescopes was a craft as well as a science, and the masters in Bavaria kept their secrets under lock and key.

Faraday never did learn their secret.

He kept a single glass brick as a souvenir of this failure.

Years later, it would change the course of his life and ours.

Davy's death finally brought an end to this fruitless project, and Faraday, the boy from the slums, succeeded him as Director of the Laboratory.

Faraday used his new authority to do something unprecedented-- a series of annual Christmas lectures on science for the young beginning in 1825 and continuing to this day.

At one of the first Christmas lectures, Faraday enchanted his audience with displays of the new powers that were at his disposal.

Suppose I want to fire a portion of gunpowder.

I can readily do it with the power of electricity.

If I receive electricity through this conducting wire, I can then give it to anything I touch.

But I must stand on these insulating glass legs to prevent the electricity from going away into the floor.

Now I am electrified! Whoa! Do you think I could light this gas jet just by touching it with my finger? No, don't do it! No! No! Don't! Now, mind you, don't try this at home.

And now, my children, you have seen for yourselves how this invisible force of electricity can be made to serve new purposes utterly unattainable by the powers we have now.

The invention of a motor that could work continuously, eliminating countless human hours of drudgery, would be more than enough to make you a fortune and land you in the history books.

But that's not how Michael Faraday saw it.

He had absolutely no interest in patenting his ideas or personally profiting from them.
And as for the history books, he had only written the first sentence of an entry that would be many pages long.

Mr. Anderson, may I ask you to dim the lights, please? Gentlemen, I am about to induce a current of electricity merely by moving a magnet.

Please observe what happens in the gap between the wires when I do so.

Do you see how the current only flows when the magnet is moving? This is the conversion of motion into electricity.

This was the first generator.

From here, electricity would become available on demand.

Faraday was continuing to change the world and the way people lived, and then, suddenly, an illness attacked his incomparable mind.

My dear Schoenbein, I would be very grateful to have your opinion regarding Regarding Dear Schoenbein Regarding My dear husband, whatever is the matter? I began a letter to Schoenbein and could not remember what I meant to say.

This is no cause for alarm.

You work too hard.

- You're exhausted.

- No.

Sarah, this is different.

Horribly different.

It's the third time my memory has failed me in as many days.

I fear I'm losing my mind.

And what would I be without that? Why, my darling husband, of course.

When Faraday was 49, he began to battle severe memory loss and depression.

His work came to a standstill.

And although he never fully recovered, his greatest achievements still lay ahead.

Faraday had immersed himself so deeply in electrical and magnetic experiments that he came to visualize the space around a magnet as filled with invisible lines of force.
A magnet was not simply the magnetized bar of iron that you could see.
It was also the unseen something in the space around the bar.
And that something he called a field.
A magnetic field.
Faraday believed in the unity of nature.
Having demonstrated the connections between electricity and magnetism, he wondered, were these two forces also connected to a third-- light? If he could only show a connection among these three invisible phenomena, one of nature's most intimate secrets would at last be revealed.
So, what did he do? He designed an experiment.
Faraday knew that light can travel as a wave.
Waves of light vibrate randomly in all directions.
But there's a way to isolate a single wave of light.
It's called polarization.
When light bounces off a reflective surface, like a mirror, it becomes polarized.
Faraday wanted to see if that single ray of light could be manipulated by the invisible magnetic field.
The eyepiece contained a crystal that acted as a kind of picket fence for light.
Light could only pass through it if it was somehow moved by the magnet.
He placed a lantern before a mirror, one that he would only see through the eyepiece if its reflection could pass through the picket fence.
If this is hard to understand, don't feel bad.
Scientists could not explain this phenomenon for another 100 years.
Faraday knew that magnetism had no effect on light that was moving through air.
But what about when it was moving through other materials? So what kind of material could he use to help the magnet move the light? He tried hundreds of different transparent chemicals and objects but saw nothing through the eyepiece.
The light was not twisted by the magnet.
He tried crystals of calcite, sodium carbonate, calcium sulfate, and still, he saw nothing.

He tried acids.

Sulfuric acid, muriatic acid, carbonic acid.

He tried gases, oxygen, nitrogen, hydrogen with no success.

The magnetic field induced in these substances could not twist the light from his lamp back into view.

Damn! In desperation, he decided to try the glass brick, the souvenir of his years of bondage to Davy.

It did the trick.

The force of the magnet twisted the light so that it could pass through the crystal.

So, what's the big deal? Faraday had demonstrated the existence of the physical reality that surrounds us, but which no one had ever been able to detect.

It was as dramatic a breakthrough as seeing the cosmos for the very first time through a telescope.

By showing that an electromagnetic force could manipulate light, Faraday had discovered a deeper unity of nature.

He had opened a door for Einstein and all the physicists who came after him to glimpse the interplay of hidden, primal forces in the universe.

Even as he approached the summit of his genius, he was plagued by depression and doubts about his ability to retain even the simplest thoughts.

My dear friend, I find a difficulty in answering or even acknowledging properly a scientific letter, for I cannot now hold it at once in my mind.

The memory of the parts fail me.

P.S. You will be sorry to see the tone of this short note, but my dearest husband is not quite so well as usual, but I hope he will improve.

Yours very truly, S. Faraday.

As a young man, Faraday had risen from poverty, in one of the most class-conscious societies the world has ever known, to become the most celebrated scientist of his time.

By age 40, he had invented the electric motor, the transformer, the generator, machines
that would change everything about the home, the farm, the factory.

Now, at 60, decades after the fertile periods of the greatest physicists, plagued by memory loss and melancholy, he fearlessly probed deeper into the mysterious invisible forces.

The world thought that Michael Faraday was a has-been.

Despite his depression, he remained as passionately curious as ever.

Having discovered the unity of electricity, magnetism and light, Faraday needed to know how this trinity of natural forces work together.

this is the way the ladies walk This was nothing new.

Children had been playing with magnets and iron filings for centuries.

Everyone had always assumed that this lovely pattern was just something that iron did.

Faraday knew that electric current turns a wire into a magnet, so he expected to find related patterns in iron filings around a wire carrying electricity.

But where others saw merely lovely shapes, Faraday saw something profound.

The patterns were not simply a quirk of iron filings; they existed in the space around a magnet or an electric current, even in the absence of iron filings.

The patterns were the traces, the footprints of invisible fields of force, that reached out into the space around anything magnetic.

The compass needle that people wondered at for a thousand years was not reacting to some far away magnetic North Pole.

It was detecting a continuous force field that stretched all the way there.

Earth itself is a giant magnet.

And like any other magnet, its lines of force extend far out into the space surrounding it.

They're everywhere, all around us.

They've always been.

But nobody had ever noticed them before.

Nobody human, that is.

Birds are the last living descendants of the dinosaurs.
Pigeons and other birds are remarkably good at finding their way around. They can migrate thousands of miles without getting lost. How? Partly by recognizing familiar landmarks-- rivers, mountains, stars. Even certain smells can serve as signposts for migrating birds. But birds also have an inner compass. They can actually sense the Earth's magnetic field. Their brains process magnetic data in much the same way ours process visual data. By sensing the direction of the field, birds can tell north from south. That's one way North American birds know which way to go when they head south for the winter.

The field is stronger near the poles than it is at the equator, a fact that birds use to figure out their latitude.

There are also small irregularities in the field, locations where the field is a little weaker or stronger. Just like a distinctive mountain or river, these magnetic anomalies can serve as landmarks.

For thousands of years, humans have used carrier pigeons to send messages to distant locations. It was a crucial method of communication as recently as World War II. When you think about it, we've been using magnetic fields to communicate for a long time.

We just didn't know it.

So why does our planet have a magnetic field at all? What causes it? The answer lies deep inside the Earth.

Liquid iron, circulating around the solid part of the core as Earth rotates, acts like a wire carrying an electric current.

And as Faraday showed us, electric currents produce magnetic fields. And that's a good thing.
Our magnetic field protects us from the onslaught of cosmic rays, which would be very damaging to our biosphere.

Cosmic rays can rip through DNA.

Without our magnetic field, the rate of mutation in living organisms would be much higher.

Fortunately, most of this cosmic shrapnel gets trapped in the Van Allen belts, donut-shaped zones of charged particles corralled by our magnetic shield.

Knowing that the Earth itself is like a giant bar magnet explains one of the most beautiful sights in the sky, the aurora.

Charged particles from the Sun, the solar wind, are constantly bombarding the Earth.

You can think of the solar wind as a kind of electric current.

Our planet's magnetic field channels that current towards the North and South Poles.

When it hits our atmosphere, the oxygen and nitrogen molecules in the air glow like giant fluorescent lightbulbs.

When Faraday pursued his last and most profound discovery, the poverty of his childhood stymied him as it never had before.

He needed help and found it in one who had come from another world.

Michael Faraday had solved the mystery that baffled Isaac Newton.

This was how the Sun told the planets how to move without touching them.

The Sun does touch the planets with its gravitational field, and Earth's gravitational field tells the apples how to fall.

All this is a dream.

Unfortunately, that was the prevailing view among his fellow scientists.

Faraday was dreaming.

They admired his inventiveness and his genius for experimentation, but they regarded his invisible "lines of force" and his ideas about light and gravity as hand-waving, meaning there was nothing solid to back it up.

Some openly ridiculed his theories.

They needed to see his ideas expressed in the language of modern physics, precise
equations.

This was the one area where Faraday's childhood poverty and lack of formal education actually held him back.

He couldn't do the math.

Faraday had finally hit a wall that he could not overcome.

And then, the greatest theoretical physicist of the 19th century came along.

James Clerk Maxwell was born into a world of wealth and privilege, an only child of doting middle-aged parents.

By his early 20s, he had made a name for himself as a mathematician.

While other scientists had come to think of Faraday as old-fashioned; a great figure of the past but no part of the future of physics, James Clerk Maxwell knew better.

He began by reading everything Faraday had written on electricity.

He became convinced that Faraday's fields of force were real, and he set out to give them a precise mathematical formulation.

An equation in physics is just a shorthand description of something that can be represented in space and time.

For instance, the equation that describes the arc of a pendulum shows that it can never swing higher than its initial height.

When Maxwell translated Faraday's experimental observation on electromagnetic fields into equations, he discovered an asymmetry.

See that bottom one? It cries out for something else.

Great mathematician that he was, Maxwell added a single term to balance it.

This tweaking of the equation changed Faraday's static field into waves that spread outward at the speed of light.

It wasn't long before we found a way to turn those waves into couriers for our messages.

Can you see me? Can you hear me? This is how.

This technology has transformed human civilization from a patchwork of cities, towns and villages into an intercommunicating organism linking us at light speed to each other and to the cosmos.
Nothing is too wonderful to be true, if it be consistent with the laws of nature.
11 - The Immortals

NEIL DEGRASSE TYSON: Must we die? Are there beings in the cosmos who live forever afloat on an endless journey down the river of time? DEGRASSE TYSON: Our ancestors marked the passage of time by the Moon and stars.

But it was the people who once lived here, around 5,000 years ago, who first started chopping up time into smaller bite-sized portions of hours and minutes.

They call this place Uruk.

We call it Iraq.

It's a part of Mesopotamia, the land between the Tigris and the Euphrates rivers.

The city was invented here.

And one of humanity's greatest victories was won in the ceaseless battle against time.

It was here that we learned how to write.

Death could no longer silence us.

And writing gave us the power to reach across the millennia and speak inside the heads of the living.

No one has ever spoken across a longer stretch of time's river than this Akkadian princess, daughter of the first emperor in history, and priestess of the Moon Enheduanna.

For not only did she write poetry, but Enheduanna did something no one before her had ever done she signed her name to her work.

She's the first person for whom we can say we know who she was, and what she dreamed.

She dreamt of stepping through the Gate of Wonder.

Here's a thought Enheduanna sent across more than 4,000 years to you.

It's from her work entitled Lady of the Largest Heart.

(Enheduanna speaking Sumerian) ENHEDUANNA (translated): Innana, the planet Venus, goddess of love, will have a great destiny throughout the entire universe.

(echoing): throughout the entire universe.

And Uruk is also the place where the epic tale of "The Hero's Journey" was first written down.
Before Batman, Luke Skywalker, Odysseus before them all there was a man named Gilgamesh who left home on a quest to vanquish time.

Gilgamesh was searching for immortality.

He looked everywhere, gained complete wisdom, uncovered what was hidden.

He brought back a tale of times before the Great Flood.

(creature growling) He built the Wall of Uruk, which no future king will ever match.

Read the story of that man Gilgamesh, a hero born of Uruk, who went through all kinds of sufferings.

Who crossed the ocean, the broad seas, as far as the sunrise; who inspected the edges of the world, searching for eternal life.

On his travels, Gilgamesh encountered a wise man named Utnapishtim, who told him the story of a flood that destroyed the world, and how one of the gods instructed Utnapishtim to build an ark to rescue his family and the animals.

(thunder crashing) (dove cooing) The earliest surviving account of the flood legend was written down in Mesopotamia, a thousand years before it was retold as the story of Noah in the Old Testament.

So, you could say Gilgamesh fulfilled his quest for immortality.

We still read the Epic of Gilgamesh, and with every reader, he lives again.

And all those heroes and superheroes who have come since follow in the footsteps of the first hero's journey another kind of immortality; a story sent from one civilization to another across thousands of years.

But life itself sends its own stories across billions of years.

It's a message that every one of us carries inside, inscribed in all the cells of our bodies, in a language that all life on Earth can read.

The genetic code is written in an alphabet consisting of only four letters.

Each letter is a molecule made of atoms; each word is three letters long.

Every living thing is a masterpiece, written by nature and edited by evolution; the instructions for running and reproducing the intricate machinery of life.

The essential message of life has been copied and recopied for more than 3 billion years.
But where did that message come from? Nobody knows.

Perhaps it began in a shallow, sunlit pool, just like this.

Somehow, carbon-rich molecules began using energy to make crude copies of themselves.

Some varieties were better at making copies, and left more offspring.

The competing molecules became more elaborate.

Evolution and life itself was underway.

Or life could’ve started in the searing heat of a volcanic vent on the deep sea floor.

Or is it possible that life came to Earth as a hitchhiker? Let me tell you a story about a traveler from another world.

The peace of the Egyptian village of Nakhla, near Alexandria, was abruptly shattered on a June morning in 1911.

Written in this meteorite was a message from another planet.

But 70 years would pass before anyone could read it.

In 1976, NASA landed two Viking spacecraft on Mars.

Carl Sagan took us there on our original journey through the cosmos.

CARL SAGAN: We found that the Martian air was less than one percent as dense as ours, and made mostly of carbon dioxide.

There were smaller amounts of nitrogen, argon, water vapor and oxygen.

DEGRASSE TYSON: A few years later, when scientists thought to analyze the gasses trapped inside the Nakhla meteorite, and other members of its class, they found a striking similarity the vast majority of meteorites are fragments of asteroids.

But the kind that hit Nakhla, on Earth, could only have come from one place Mars.

TYSON: Welcome to Mars.

Over a billion years ago, a volcano erupted here and its lava cooled into solid rock.

Hundreds of millions of years later, this area was flooded with water.

And long after that flood, an asteroid the size of the Rock of Gibraltar crashed into the Martian surface, blasting out a huge crater.
Much of the debris was ejected back out into space, where it orbited the Sun until a gravitational tug from its home planet, Mars, diverted one of the boulders into a collision course with Earth.

Its arrival shook up the little village of Nakhla.

Meteorites of the type that hit Nakhla are the vehicles of a natural interplanetary transit system that sends rocks between the planets.

Such a meteorite can safely shelter microscopic cargo the seeds of life an interplanetary ark.

Most rocks are porous, full of tiny nooks and crannies, where life can stow away.

We know that some microbes can survive the hostile environment of space.

Take these guys, for instance.

These microbes spent a year and a half riding on the outside of the International Space Station, exposed to the extreme temperatures, vacuum, and radiation of space.

And some of them were still alive and kicking when they were brought back to Earth.

Even more astonishing are these creatures, awakened from a deathlike sleep of eight million years.

They were frozen in the Antarctic ice millions of years before our species even existed.

And they're still alive.

If life can withstand the hardships of space and endure for millennia, then it could ride the natural interplanetary transit system from world to world.

It's a good bet that our microbial ancestors spent some time in space.

Why do we think so? The Earth is four-and-a-half- billion-years old.

For the first half of its lifetime, large asteroids were bombarding the planet every few million years.

The most violent impacts vaporized the oceans and even melted the surface rock.

Each such collision would have completely sterilized the planet for thousands of years.

But we know from fossils in the rocks that bacteria were evolving on Earth during this formative period.

So how could life have survived such a lethal series of blows? Whenever one of those big
asteroids hit the Earth, the explosion would blast out a crater, launching millions of boulders into space.

Many of those rocks carried living bacteria inside.

Some of the bugs would have survived in space, while all those left behind on Earth would have been fried.

A few thousand years after each impact, the Earth would have cooled down enough for water to condense into oceans.

The planet would again be habitable.

Meanwhile, most of the rocks launched into space would have been orbiting the Sun.

Some of them would encounter the Earth again, reenter the atmosphere as meteorites, and deliver their precious cargo of life to re-seed the planet like Noah's ark.

What this means is that life doesn't have to start over again from scratch after each catastrophe.

It can pick up where it left off.

When the solar system was young, Venus was probably more like Earth, with oceans and maybe even life.

Venus, Earth, and Mars were all exchanging rocks with each other, due to asteroid impacts.

Does life on Earth carry any traces of interplanetary voyages made in the distant past? Why is it that some microbes can survive the intense radiation and vacuum of space? These conditions don't naturally exist on Earth.

Maybe those bugs are telling us that their ancestors survived those same conditions in space, a few billion years ago.

So we know that microbes can stow away in rocks and survive the voyage from planet to planet.

But what about trip from star to star an interstellar odyssey? The dandelion.

Around 30 million years ago, it evolved another way to send its own message of life through space and time.

Each seedling is a little paratrooper, floating on the wind, risking everything for a safe place to land.
Updrafts can carry them higher into the air.

A dandelion can travel dozens, possibly hundreds of kilometers, even crossing over mountain ranges.

Evolution has shaped it into an exquisite flying machine.

The seed is another kind or ark, ensuring the survival of its species by riding the currents of the atmosphere to safe harbors.

Each seed in its DNA carries a story, the character and destiny of the next dandelion life propagates by retelling its story.

Is it possible that life could survive the journey from star to star? The stars are about a million times farther apart from each other than are the planets.

Space is so vast that it would take billions of years for a rock ejected from the Earth to collide with a planet circling another star.

Any stowaway microbes would never survive the cosmic radiation for that long.

But there's a plausible scenario for how life could spread from one solar system to another.

The stars of the Milky Way are drawn by gravity in their own enormous orbits around its center.

Our Sun, for example, takes some 225 million years to complete a single orbit.

During each revolution around the galaxy, our solar system will pass through two or three gigantic interstellar clouds, each of them many light years across.

Galaxies are world-making machines.

Our Milky Way has more than 100 of these vast clouds, a place where gas and dust condense to form new stars and planets.

In its travels through the Milky Way, our Sun is accompanied not only by its planets, but also by a trillion distant comets.

When our solar system passes through an interstellar cloud, the gravity of the massive cloud stirs up the outermost comets.

Some comets will be hurled out into the space between the stars.

Others will plunge inward falling towards the Sun.
And some of them may collide with the planets.

The high-speed impact of a comet with a rocky planet will launch boulders like rockets into space.

If that planet should happen to be inhabited, many of those rocks will carry passengers living microbes.

After thousands of years, fragments of the rocks ejected from Earth can fall as meteors into the atmospheres of newborn planets in the interstellar cloud.

If the stowaway microbes should happen to come in contact with liquid water, they can revive and reproduce.

This may be how life comes barreling into the barren places.

The sun emerges from the cloud, having scattered the seeds of life among the newborn worlds of other stars.

Those new worlds, now touched by life, will then leave their birth cloud and go their separate ways.

Eventually, their stars will carry them through other interstellar clouds, where they may seed still more new worlds.

Imagine this process repeated from world to world, each one bringing life to others.

Life would then propagate, like a slow chain reaction, through the entire galaxy.

This could be how life came to Earth.

We do not know for sure.

Are there any beings out there like us? Do they ask the same questions? Do they share our fears? Do they have heroes and adventures? If they do exist, where are they? How might they make their presence known? How did we first announce our presence to the galaxy? It was 1946, the year after the Second World War ended.

NEWSREEL ANNOUNCER: The vivid imaginations of HG Wells and Buck Rogers never cooked up a more fantastic experience than the Army engineers at their laboratory in Belmar, New Jersey.

It opens up unlimited possibilities for interstellar experiment.

DEGRASSE TYSON: American engineers bounced a beam of radio waves off the Moon, and were able to detect its echo.
They called this experiment Project Diana.

It was the first interstellar message ever sent by our species (bell tolling) an eerie, tolling bell.

If one allows the imagination free reign, many future possibilities appear.

Spaceships, carrying passengers at thousands of miles per hour, can be controlled and communication established with their passengers, for we now know that the Earth’s atmosphere can be penetrated.

DEGRASSE TYSON: Traveling at the speed of light, it takes just over one second for a radio wave to reach the lunar surface.

But the expanding wavefront is much bigger than the Moon.

Most of the wave passes right by it, but the central part gets bounced back.

After a round-trip travel time of two and a half seconds, it hits our planet.

Project Diana transmitted a series of powerful radio waves one every four seconds to "ping" the Moon.

(bell tolling) The parts that missed the Moon are traveling still.

(garbled voices, static) It was just the beginning.

After World War II, television stations cropped up all over the United States, and other parts of the world.

(various overlapping voices and static) The Project Diana message and the FM radio, television and radar signals of the 20th century all move outward at the speed of light.

These transmissions make up a vast sphere of radio waves, expanding away from the Earth in all directions.

You could say that our world is radiating stories.

Our ancestors etched the story of Gilgamesh into clay tablets, sending that epic tale into the future.

We've encoded our stories in radio waves and beamed them into space.

They cover one light-year of distance that's six trillion miles for every year of time since they were sent.
We've been sending our stories into space for over 70 years.

The leading edge of these signals has already washed over thousands of planets of other stars.

If any of these worlds are home to a civilization with radio telescopes, they could already know that we're here.

What if other worlds are sending their stories into space? Since 1960, we've been listening for extraterrestrial radio signals without hearing so much as a tolling bell.

But our search has been sporadic and limited to certain parts of the sky.

For all we know, we may have just missed an alien signal, looking in the wrong place at the wrong time.

We've only listened to a miniscule fraction of the stars in our galaxy.

And there may be another problem we are, to some extent, prisoners of our own moment in time and the limits of our technology.

Radio and television broadcasting may be only a brief passing phase in our technological development.

When we imagine alien civilizations broadcasting signals with radio telescopes, are we any different from earlier generations who imagined riding cannon shells to the Moon? Civilizations even slightly more advanced than ours may have already moved on to some other mode of communication, one that we have yet to discover or even imagine.

Their messages could be swirling around us, at this very moment, but we lack the means to perceive them, just as all of our ancestors, up to a little more than a century ago, would have been oblivious to the most urgent radio signal from another world.

But there's another, more troubling possibility civilizations, like other living things, may only live so long before perishing due to natural causes, or violence, or self-inflicted wounds.

Whether or not we ever make contact with intelligent alien life may depend on a critical question.

What is the life expectancy of a civilization? DEGRASSE TYSON: By the time of Enheduanna, the first person to ever get a writing credit, civilization was already more than 1,000 years old.

But today, her glorious city is a barren wasteland.
What went wrong? One problem was the almost ceaseless warfare between the cities of Mesopotamia, which continually destroyed their achievements.

They glorified military conquest and ultimately became its victims.

Another cause of decline was that their technical know-how overran their understanding of nature.

The ingenious irrigation system that was the basis for the great civilizations of Mesopotamia had an unintended consequence the water channeled into their farmlands every year evaporated and left its salt behind.

Over generations, the salt accumulated and began to kill the crops.

And then, about 2,200 BC, not long after the time of Enheduanna, disaster struck a drought of truly epic proportions, lasting for many decades.

The rains stopped, crops withered, and there was famine and anarchy.

Barbarians invaded.

The streets of many cities were littered with dead.

There could be only one explanation.

Enlil, the supreme god, was angry because one of his temples had been destroyed.

The people of Mesopotamia could not know that the same drought was crushing the dawning civilizations of Egypt, Greece, India, Pakistan and China.

All the gods of the Earth must have been really angry about something.

For all their brilliance, the people of those civilizations had no inkling they were experiencing (bird screeches) abrupt climate change.

3,000 years later, the climate would change abruptly for another glorious civilization, this one in Central America.

At its peak, the Mayan civilization perished, wiped out by a series of severe droughts over the course of a century.

We still carry within us the echoes of these extinct civilizations in our languages and our myths.

Today, we have a single global civilization.

How long will it live? There are so many ways for a civilization to die.
Let's start with the ones that we probably wouldn't be able to do much about.

That supernova is 1,000 light-years away.

If it were much closer, say less than 30 light-years from Earth, its cosmic radiation would shred the atmosphere's protective ozone layer and destroy our civilization.

Lucky for us, none of the stars close enough to harm us are likely to go supernova any time in the next few hundred million years.

Every million years or so, a supervolcano erupts somewhere on Earth.

The last time it happened was 74,000 years ago, on the island of Sumatra, in what is now Indonesia.

It spewed hundreds of times more rock, ash and toxic gas than any single volcano in recorded history.

The molten rock that erupted from Earth's crust left this caldera, 100 kilometers long, now filled with a lake.

The Toba volcano sent more than 600 cubic miles of pulverized rock soaring skyward.

The westward wind carried the volcanic ash over India, where it fell out in a smothering blanket over the subcontinent.

The eruption loaded the upper atmosphere with sulfur gases.

The result was a global haze that blocked most of the sunlight from reaching the surface for at least five years.

It was like one five-year-long cloudy day.

This so-called "volcanic winter" resembled a "nuclear winter," but without the radiation.

Temperatures fell everywhere.

Plants and animals froze even in the tropics, dying in enormous numbers.

But life is hardy.

Only a few species were driven to extinction.

One of our ancestors in central India sharpened this stone blade in the years before the Toba eruption.

And this blade was one of dozens that were found in the soil layer above the volcanic fallout.
This tells us that some toolmakers, even in the area directly affected by the volcano, managed to survive the cataclysm.

But the global human population must have plummeted before rebounding.

If an eruption like this were to happen tomorrow, our civilization would be brought to its knees, although the human species would survive.

I can imagine that our technology of a few hundred years from now would allow us to siphon off the energy of a threatening supervolcano before it explodes.

We could then use that energy for our own purposes.

About once every million years, a small asteroid collides with the Earth, causing a similar amount of devastation.

With our current science and technology, we already know how to prevent an asteroid impact.

We would see it coming years in advance and could send a spacecraft there to deflect it into a harmless orbit.

With the technology of a thousand years from now, we might even be able to mitigate the deadly effects of a nearby supernova on Earth's atmosphere.

But what happens when the danger to a civilization is invisible? When no one can see it coming? DEGRASSE TYSON: Beginning with Columbus, the European invaders of the Americas had a secret weapon that even they knew nothing about.

They were carrying bacteria and viruses for deadly diseases, such as smallpox, that the original Americans had never been exposed to.

The Europeans like to believe that it was their valor and superior weapons and culture that won them the New World.

The real conquistadors were the armies of the pathogens that raced on ahead to infect and kill nine out of ten of all the Indians of North, Central and South America.

The great civilizations of the New World crumbled under the onslaught of invading microbes.

Without his invisible army, Cortez and those who followed might never have stood a chance.

But what about civilizations that self-destruct? Our economic systems were formed when the planet and its air, rivers, oceans, lands, all seemed infinite.
They evolved long before we first saw the Earth as the tiny organism that it actually is.

They're all alike in one respect they're profit-driven, and therefore, focused on short-term gain.

The prevailing economic systems, no matter what their ideologies, have no built-in mechanisms for protecting our descendants of even 100 years from now, let alone, 100,000.

In one respect, we're ahead of the people of Ancient Mesopotamia.

Unlike them, we understand what's happening to our world.

For example, we're pumping greenhouse gasses into our atmosphere at a rate not seen on Earth for a million years.

And the scientific consensus that we're destabilizing our climate.

Yet our civilization seems to be in the grip of denial; a kind of paralysis.

There's a disconnect between what we know and what we do.

Being able to adapt our behavior to challenges is as good a definition of intelligence as any I know.

If our greater intelligence is the hallmark of our species, then we should use it, as all other beings use their distinctive advantages to help ensure that their offspring prosper, and their heredity is passed on, and that the fabric of nature that sustains us is protected.

Human intelligence is imperfect, surely, and newly arisen.

The ease with which it can be sweet-talked, overwhelmed, or subverted by other hard-wired tendencies, sometimes themselves disguised as the light of reason, is worrisome.

But if our intelligence is the only edge, we must learn to use it better.

To sharpen it.

To understand its limitations and deficiencies.

To use it as cats use stealth before pouncing.

As walking sticks use camouflage.

To make it the tool of our survival.

If we do this, we can solve almost any problem we are likely to confront in the next 100,000 years.
And now we’ve arrived at the place where our ancient dreams of immortality and modern astrophysics converge.

Giant elliptical galaxies are something like Florida, where the oldest stars in the universe may be found.

This is a red dwarf star, smaller and fainter than our Sun.

Red dwarfs are by far the most plentiful stars in the cosmos.

Unlike the Sun, which is halfway through its 10-billion-year lifetime, red dwarfs will continue to provide light and warmth to their planets for trillions of years.

That's hundreds of times longer than the present age of the universe.

What would intelligent beings do if they had an eternity to develop their understanding of the universe? Perhaps they would learn how to open shortcuts in the fabric of spacetime, to travel between galaxies faster than the speed of light.

Maybe they would create whole new universes as artistic or scientific experiments.

Of course no one, or at least nobody on Earth, knows what the immortals might do.

(film projector whirring) If one allows the imagination free reign.

But what about us? What is our own future? What would the Cosmic Calendar of the next 14 billion years look like? If the original Cosmic Calendar includes all of time from the birth of the universe until this very moment what would the Cosmic Calendar look like for the next 14 billion years? Just as with the Cosmic Calendar of the past, every month the future calendar equals about a billion years; every day, some 40 million.

Science makes it possible for us to foretell certain astronomical events in the unimaginably distant future the death of the Sun, for example.

In some five billion years, our star will have exhausted its hydrogen the nuclear fuel that powers it becoming a red giant.

I know that sounds depressing, but if we apply our intelligence, our descendants of that distant future will have long departed from the lost worlds of the Sun.

Who knows? Human events entail too many variables, too many uncertainties, to make scientific statements about our future.

But we can still dream.

The next golden age of human achievement begins here and now New Year's Day of the
next cosmic year.

In the first tenth of a second, we take the vision of the pale blue dot to heart, and learn how to share this tiny world with each other.

The last internal combustion engine is placed in a museum, as the effects of climate change reverse and diminish.

A fifth of a second into this future people will stop dying from the effects of poverty.

The planet is now a completely self-sustaining, intercommunicating organism.

A half-second from now, the polar ice caps are restored to the way they were in the 19th century, and the forecast is mild and pleasant for the next cosmic minute and a half 40,000 years.

By the time we are ready to settle even the nearest other planetary systems, we will have changed.

The simple passage of so many generations will have changed us.

Necessity will have changed us.

We are an adaptable species.

It will not be we who reach Alpha Centauri and the other nearby star systems on our interstellar arks.

It will be a species very like us, but with more of our strengths and fewer of our weaknesses; more confident, far-seeing, capable and wise.

For all our failings, despite our flaws and limitations, we humans are capable of greatness.

What new wonders, undreamt of in our time, will we have accomplished in another generation and another? How far will our nomadic species have wandered by the end of the next century, and the next millennium? Our remote descendants, safely arrayed on many worlds throughout the solar system and beyond, will be unified by their common heritage, by their regard for their home planet, and by their knowledge that, whatever other life may be, the only humans in all the universe came from Earth.

They will gaze up and strain to find the blue dot in their skies.

They will marvel at how vulnerable the repository of all our potential once was, how perilous our infancy, how humble our beginnings, how many rivers we had to cross before we found our way.
12 - The World Set Free

NEIL DEGRASSE TYSON: Once there was a world not so very different from our own.

There were occasional natural catastrophes, massive volcanic eruptions and, every once in a while, an asteroid would come barreling out of the blue to do some damage.

But for the first billion years or so, it would've seemed like a paradise.

This is what we think the planet Venus might have looked like when our solar system was young.

Then things started to go horribly wrong.

DEGRASSE TYSON: The planet Venus, which once may have seemed like a heaven, turned into a kind of hell.

The difference between the two can be a delicate balance, far more delicate than you might imagine.

Once things began to unravel, there was no way back.

This is what Venus, our nearest planetary neighbor, looks like today.

Venus's oceans are long gone.

The surface is hotter than a broiling oven, hot enough to melt lead.

Why? You might think it's because Venus is 30% closer to the Sun than the Earth is, but that's not the reason.

Venus is completely covered by clouds of sulfuric acid that keep almost all the sunlight from reaching the surface.

That ought to make Venus much colder than the Earth.

So why is Venus scorching hot? It's because the small amount of sunlight that trickles in through the clouds to reach the surface can't get back out again.

The flow of energy is blocked by a dense atmosphere of carbon dioxide.

That carbon dioxide gas-- or CO2 for short-- acts like a smothering blanket to keep the heat in.

No one is burning coal or driving big gas-guzzlers on Venus.

Nature can destroy an environment without any help from intelligent life.
Venus is in the grip of a runaway greenhouse effect.

Why does it look like we're inside a bowl? It's due to the intense atmospheric pressure.

That's the wreck of Venera 13.

In 1982, the scientists and engineers of what was then the Soviet Union successfully landed this spacecraft on Venus.

They managed to keep it refrigerated for over two hours, so it could photograph its surroundings and transmit the images back to Earth before the onboard electronics were fried.

Venus and Earth started out with about the same amount of carbon, but the two worlds were propelled along radically different paths, and carbon was the decisive element in both stories.

On Venus, it's almost all in the form of gas-- carbon dioxide-- in the atmosphere.

Most of the carbon on Earth has been stored for eons in solid vaults of carbonate rock, like this one, part of a chain that forms the celebrated White Cliffs of Dover, right on the English Channel.

What titan built this wonder of the world? A creature a thousand times smaller than a pinhead.

Trillions of them.

One-celled algae.

Volcanoes supply carbon dioxide to the atmosphere, and the oceans slowly absorb it.

Working over the course of millions of years, the microscopic algae harvested the carbon dioxide and turned it into these tiny shells.

They accumulated in thick deposits of chalk, or limestone, on the ocean floor.

Later, the restless Earth pushed up the seafloor and carved out these massive cliffs.

Other marine creatures took in carbon dioxide to build enormous coral reefs.

And the oceans converted dissolved CO2 into limestone even without any help from life.

As a result, only a trace amount was left as a gas in Earth's atmosphere.

Not even three-hundredths of one percent.

Think of it-- fewer than three molecules out of every ten thousand.
And yet, it makes the critical difference between a barren wasteland and a garden of life on Earth.

With no CO2 at all, the Earth would be frozen.

And with twice as many, we're still talking about only six molecules out of ten thousand.

Things would get uncomfortably hot and cause us some serious problems but never as hot as Venus; not even close.

That planet lost its ocean to space billions of years ago.

Without an ocean, it had no way to capture CO2 from the atmosphere and store it as a mineral.

The CO2 from erupting volcanoes just continued to build up.

Today, that atmosphere is 90 times heavier than ours.

Almost all of it is heat-trapping carbon dioxide.

That's why Venus is such a ferocious inferno so hostile to life.

The Earth, in stunning contrast, is alive.

It breathes but very slowly.

A single breath takes a whole year.

The forests contain most of Earth's life, and most forests are in the Northern Hemisphere.

When spring comes to the north, the forests inhale carbon dioxide from the air and grow, turning the land green.

The amount of CO2 in the atmosphere goes down.

When fall comes and the plants drop their leaves, they decay, exhaling the carbon dioxide back into the atmosphere.

The same thing happens in the Southern Hemisphere at the opposite time of the year.

But the Southern Hemisphere is mostly ocean.

So it's the forests of the north that control the annual changes in the global CO2.

The Earth has been breathing like this for tens of millions of years.

But nobody noticed until 1958, when an oceanographer named Charles David Keeling
devised a way to accurately measure the amount of carbon dioxide in the atmosphere.

Keeling discovered the Earth's exquisite respiration.

But he also discovered something shocking-- a rapid rise, unprecedented in human history, in the overall level of CO2, one that has continued ever since.

It's a striking departure from the CO2 levels that prevailed during the rise of agriculture and civilization.

In fact, the Earth has seen nothing like it for three million years.

How can we be so sure? The evidence is written in water.

DEGRASSE TYSON: The Earth keeps a detailed diary written in the snows of yesteryear.

Climate scientists have drilled ice cores from the depths of glaciers in Greenland and Antarctica.

The ice layers have ancient air trapped inside them.

We can read the unbroken record of Earth's atmosphere that extends back over the last 800,000 years.

In all that time, the amount of carbon dioxide in the air never rose above three-hundredths of one percent.

That is, until the turn of the 20th century.

And it's been going up steadily and rapidly ever since.

It's now more than 40% higher than before the Industrial Revolution.

By burning coal, oil and gas, our civilization is exhaling carbon dioxide much faster than Earth can absorb it.

So CO2 is building up in the atmosphere.

The planet is heating up.

Every warm object radiates a kind of light we can't see with the naked eye-- thermal infrared light.

We all glow with invisible heat radiation, even in the dark.

This is what the Earth looks like in the infrared.
You're seeing the planet's own body heat.

Incoming light from the Sun hits the surface.

The Earth absorbs much of that energy, which heats the planet up and makes the surface glow in infrared light.

But the carbon dioxide in the atmosphere absorbs most of that outgoing heat radiation, sending much of it right back to the surface.

This makes the planet even warmer.

That's all there is to the greenhouse effect.

It's basic physics, just bookkeeping of the energy flow.

There's nothing controversial about it.

If we didn't have any carbon dioxide in our atmosphere, the Earth would just be a great big snowball, and we wouldn't be here.

So, a little greenhouse effect is a good thing.

But a big one can destabilize the climate and wreck our way of life.

All right but how do we know that we're the problem? Maybe the Earth itself is causing the rise in CO2.

Maybe it has nothing to do with the coal and oil we burn.

Maybe it's those damn volcanoes.

(deep rumbling) Every few years, Mount Etna, in Sicily, blows its stack.

Each big eruption sends millions of tons of CO2 into the atmosphere.

Now, combine that with the output of all the other volcanic activity on the planet.

Let's take the largest scientific estimate-- about 500 million tons of volcanic CO2 entering the atmosphere every year.

Sounds like a lot, right? But that's not even two percent of the 30 billion tons of CO2 that our civilization is cranking out every year.

And, funny thing, the measured increase in CO2 in the atmosphere tallies with the known amount we're dumping there by burning coal, oil and gas.

Volcanic CO2 has a distinct signature-- it's slightly heavier than the kind produced by
burning fossil fuels.

We can tell the difference between the two when we examine them at the atomic level.

It's clear that the increased CO2 in the air is not from volcanoes.

What's more, the observed warming is as much as predicted from the measured increase in carbon dioxide.

It's a pretty tight case.

Our fingerprints are all over this one.

How much is 30 billion tons of CO2 per year? If you compressed it into solid form, it would occupy about the same volume as the White Cliffs of Dover.

And we're adding that much CO2 to the air every year, relentlessly, year after year.

Unlucky for us, the main waste product of our civilization is not just any substance.

It happens to be the chief climate-regulating gas of our global thermostat, year in, year out.

Too bad CO2 is an invisible gas.

Maybe if we could see it (car engine starts) If our eyes were sensitive to CO2-- and perhaps there are such beings in the cosmos-- if we could see all that carbon dioxide, then we would overcome the denial and grasp the magnitude of our impact on the atmosphere.

But the evidence that the world is getting warmer is all around us.

For starters, let's just check the thermometers.

Weather stations around the world have been keeping reliable temperature records since the 1880s, and NASA has used the data to compile a map tracking the average temperatures around the world through time.

Yellow means warmer temperatures than the average, for any region in the 1880s.

Orange means hot.

And red means hotter.

The world is warmer than it was in the 19th century.

Back then, at the greatest fair the world has ever seen, a forgotten genius demonstrated the solution to this problem.
Come with me.

DEGRASSE TYSON: Once there was a world that was not too hot and not too cold.

It was just right.

Then there came a time when the life it sustained began to notice our lovely planet was changing.

And it's not as if we didn't see it coming.

As far back as 1896, the Swedish scientist Svante Arrhenius calculated that doubling the amount of CO2 in the atmosphere would melt the Arctic ice.

In the 1930s, the American physicist EO Hulburt, at the Naval Research Laboratory, confirmed that result.

So far, it was still just theoretical.

But then, the English engineer Guy Callendar assembled the evidence to show that both the CO2 and the average global temperature were actually increasing.

Even now, man may be unwittingly changing the world's climate through the waste products of his civilization.

Due to our release, through factories and automobiles every year, of more than six billion tons of carbon dioxide, which helps air absorb heat from the Sun, our atmosphere seems to be getting warmer.

This is bad? Well, it's been calculated, a few degrees rise in the Earth's temperature would melt the polar ice caps.

DEGRASSE TYSON: In 1960, Carl Sagan's PhD thesis included the first calculation of the runaway greenhouse effect on Venus.

This was part of a career-long interest in the atmospheres of the planets, including our own.

In the original Cosmos series, in 1980, Carl Sagan warned SAGAN: We are releasing vast quantities of carbon dioxide, increasing the greenhouse effect.

It may not take much to destabilize the Earth's climate, to convert this heaven, our only home in the cosmos, into a kind of hell.

Since Carl spoke those words, we've burdened the atmosphere of our world with an additional of carbon dioxide.
If we don't change our ways, what will the planet be like in our children's future? Based on scientific projections, if we just keep on doing business as usual, our kids are in for a rough ride.

Killer heat waves, record droughts, rising sea levels, mass extinction of species.

We inherited a bountiful world made possible by a relatively stable climate.

Agriculture and civilization flourished for thousands of years.

And now, our carelessness and greed put all of that at risk.

Okay, so if we scientists are so good at making these dire, long-term predictions about the climate, how come we're so lousy about predicting the weather? Besides, this year, we had a colder winter in my town.

For all us scientists know, we could be in for global cooling.

Here's the difference between weather and climate Weather is what the atmosphere does in the short term-- hour to hour, day to day.

Weather is chaotic, which means that even a microscopic disturbance can lead to large-scale changes.

That's why those ten-day weather forecasts are useless.

A butterfly flaps its wings in Bali, and six weeks later, your outdoor wedding in Maine is ruined.

Climate is the long-term average of the weather, over a number of years.

It's shaped by global forces that alter the energy balance in the atmosphere, such as changes in the Sun, the tilt of the Earth's axis, the amount of sunlight the Earth reflects back to space and the concentration of greenhouse gases in the air.

A change in any of them affects the climate in ways that are broadly predictable.

My friend's meandering represents the short-term fluctuations-- that's weather.

It's almost impossible to predict what'll attract his interest next, but not hard to know what the range of his meandering will be, because I'm holding him on a leash.

We can't observe climate directly-- all we see is the weather-- but the average weather, over the course of years, reveals a pattern.

I represent that long-term trend, which is climate.
Keep your eye on the man, not the dog.

Weather is hard to predict, like my friend here, but climate is predictable.

Climate has changed many times in the long history of the Earth but always in response to a global force.

The strongest force driving climate change right now is the increasing CO2 from the burning of fossil fuels, which is trapping more heat from the Sun.

All that additional energy has to go somewhere.

Some of it warms the air.

Most of it ends up in the oceans.

All over the world, the oceans are getting warmer.

It's most obvious in the Arctic Ocean and the lands that surround it.

Okay, so we're losing the summer sea ice in a place where hardly anyone ever goes.

What do I care if there's no ice around the North Pole? Ice is the brightest natural surface on the Earth, and open ocean water is the darkest.

Ice reflects incoming sunlight back to space.

Water absorbs sunlight and gets warmer, which melts even more ice, which exposes still more ocean surface to absorb even more sunlight.

This is what we call a positive feedback loop.

It's one of many natural mechanisms that magnify any warming caused by CO2 alone.

We're at Drew Point, Alaska, on the edge of the Arctic Ocean.

DEGRASSE TYSON: When I was born, the shoreline was a mile farther out, and it was breaking off at a rate of about 20 feet per year.

Now it's being eaten away at about 50 feet per year.

The Arctic Ocean is warming and at an increasing rate.

So it's ice-free during more of the year.

That leaves the shore here more exposed to erosion from storms, which are also getting more powerful, another effect of climate change.
The northern reaches of Alaska, Siberia and Canada are mostly permafrost, ground that has been frozen year-round for millennia.

It contains lots of organic matter, old leaves and roots from plants that grew thousands of years ago.

Because the Arctic regions are warming faster than anywhere else on Earth, the permafrost is thawing and its contents are rotting, just like when you unplug the freezer.

The thawing permafrost is releasing carbon dioxide and methane, an even more potent greenhouse gas, into the atmosphere.

This is making things even warmer, another example of a positive feedback mechanism.

The world's permafrost stores enough carbon to more than double the CO2 in the atmosphere.

At the rate we're going, global warming could release most of it by the end of the century. We might be tipping the climate past a point of no return into an unpredictable slide.

Okay, the air, the water and the land are all getting warmer, so global warming is really happening.

But maybe it's not our fault.

Maybe it's just nature.

Maybe it's the Sun.

No, it's not the Sun.

We've been monitoring the Sun very closely for decades, and the solar energy output hasn't changed.

What's more, the Earth is warming more at night than in daytime, and more in winter than in summer.

That's exactly what we expect from greenhouse warming, but the opposite of what increased solar output would cause.

It's now clear beyond any reasonable doubt that we are changing the climate.

The Sun isn't the problem.

But it is the solution, and we've known this for a long time, much longer than you might think.
Paris, September 1878.

The Eiffel Tower won't be built for years to come.

Witness one of the most glorious spectacles the world has ever seen.

The magnificent head of the Statue of Liberty has just been completed.

Thousands of exhibitors from around the planet covered 66 acres of Paris with their inventions and goods.

Edison's first public demonstration of the lightbulb will not take place for another year.

There's no such thing as electrical appliances.

People don't flick switches and press buttons.

It's a hand-cranked, horse-drawn world.

That's the guy we came to see, the one with the crazy moustache.

He's a math teacher named Augustin Mouchot.

Remember, it's 1878.

This is a world lit mostly by gaslight.

The automobile is still years away.

But Mouchot, here, is dazzling the crowd with his solar power concentrator.

The Sun belongs to all of us! Even though it is 150 million kilometers away from us, feel its awesome power! My invention concentrates the free energy of the Sun and converts it into mechanical motion.

It can power any kind of machine.

It can produce electricity or run a printing press or make ice on a hot day.

Et voilà ! (spectators gasp, chatter) (chuckles) Think of it, sunlight converted into ice.

You see, my friends, what wonders we can work if we harness the bounteous energy of the Sun.

The world will someday run out of coal, but the magnificent Sun will always be there for us.

Mouchot took home the gold medal from the fair.
But the price of coal tumbled, becoming so cheap that there was no interest in solar energy.

Besides, no one understood, back then, what the true cost was of burning fossil fuel.

Mouchot's research funding was cut off.

years of the 20th century, another door opened to an alternative future.

It happened in Egypt, on the banks of the Nile.

DEGRASSE TYSON: Memo to future time travelers this would be an excellent entry point for averting climate change.

Egypt, 1913.

That's Frank Shuman of Philadelphia.

He's only had three years of schooling, but his genius for innovation more than makes up for that.

Before he was 30, Shuman had invented safety glass.

Its use in automobiles and skylights saved countless lives and made him a very rich man, rich enough to pursue his real passion, solar energy.

Shuman led the team that designed and built an array of solar energy concentrators.

It could power a steam engine.

Shuman is hoping to use the Sun's power to irrigate the desert and turn it green.

The official inauguration of Shuman's solar power plant, in 1913, was a dazzling success.

He had invented a practical way to tap the Sun's energy on an industrial scale, making solar energy even cheaper than coal.

The British and German governments both offered Shuman generous funding to develop his invention.

It was the ideal source of abundant power in tropical regions, where imported coal was prohibitively expensive.

But Shuman was dreaming even bigger.

In a letter to Scientific American, he calculated that his solar power plants, if deployed in an area of the Sahara Desert only 150 miles on a side, could supply as much power as consumed by all the industries of the world.
But it was not to be.

The market for a liquid fossil fuel, petroleum, was exploding for shipping, home heating, and cars and trucks.

Oil was abundant, cheaper even than coal, and much easier to get out of the ground and process.

It took 100 men a week to fuel a ship with coal, but with oil, one man could do the job in a single day.

A year after Shuman's triumph in the desert, World War I broke out.

His solar collectors were recycled into weapons.

Frank Shuman's dream of a solar-powered civilization would have to wait another century before it was reborn.

There's another inexhaustible source of clean energy for the world.

The winds themselves are solar powered, because our star drives the winds and the waves.

Unlike solar collectors, wind farms take up very little land, and none at all, if offshore, where the winds are strongest.

If we could tap even one percent of their power, we'd have enough energy to run our civilization.

And more solar energy falls on Earth in one hour than all the energy our civilization consumes in an entire year.

If we could harness a tiny fraction of the available solar and wind power, we could supply all our energy needs forever, and without adding any carbon to the atmosphere.

It's not too late.

There's a future worth fighting for.

How do I know? Every one of us comes from a long line of survivors.

Our species is nothing if not adaptive.

It was only because our ancestors learned to think long-term, and act accordingly, that we're here at all.

We've had our backs to the wall before, and we came through to scale new heights.
In fact, the most mythic human accomplishments of all came out of our darkest hour.

DEGRASSE TYSON: Once there was a world rigged with 60,000 hair-triggered nuclear weapons.

The combatants were the two most powerful countries on Earth, and they were locked in a deadly embrace, each vowing that they would rather see everything we love destroyed than submit to the will of the other.

When I was three years old, the largest man-made explosion of all time was detonated by the Soviet Union.

That terror has subsided, to be replaced by new fears.

The danger that the 2,000 largest cities on Earth would be reduced to rubble in the space of an afternoon is no longer one of them.

The nuclear rivalry between the United States and the Soviet Union had another by-product.

The Apollo missions to the Moon were an extension of the arms race that raged between them.

Sending people to orbit the Earth or go to the Moon requires big, reliable, powerful rockets-- precisely the same technology you need to carry a nuclear warhead halfway around the planet to destroy your enemy's largest cities.

PRESIDENT KENNEDY: I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.

DEGRASSE TYSON: President Kennedy's 1961 speech electrified the nation, and it contained much that was remarkably prophetic-- but not a word about a scientific objective for going to the Moon.

No questions about the Moon's origin or the hope of bringing back samples to analyze.

No, the Apollo missions were conceived as a demonstration of the superior power and precision of our strategic missiles.

But a funny thing happened to us on our way to the Moon.

We looked homeward and discovered another world-- our own.

For the first time, we inhabitants of Earth could step back and see it as it really is-- one world, indivisible, and kind of small in the cosmic context.
Whatever the reason we first mustered the enormous resources required for the Apollo program, however mired it was in Cold War nationalism and the instruments of death, the inescapable recognition of the unity and fragility of the Earth is its clear and luminous dividend, the unexpected gift of Apollo.

A project conceived in deadly competition made us recognize our community.

What titan built this wonder of the world? It was the Ifugao people of the Philippines, working with not much more than their hands.

About 10,000 years ago, our ancestors all over the world took advantage of another form of climate change, the gentler climate of the intermission in the ice age-- they invented agriculture.

They gave up the ceaseless wandering, hunting and gathering that had been their way of life for a million years or so, to settle down and produce food.

They found a way to harvest ten to a hundred times more solar energy than the environment naturally provided for their ancestors.

People all over the world made the difficult transition from nomadic cultures to agricultural ones that used solar energy more efficiently.

It gave rise to civilization.

We stand on the shoulders of those who did the hard work that such a fundamental transformation required.

Now it's our turn.

Once there was a world If life ever existed on Venus, it would have had no chance to avert the hellish destiny of this world.

This runaway greenhouse effect was unstoppable.

(thunder crashing) Once there was a world ours.

And that world is now.

There are no scientific or technological obstacles to protecting our world and the precious life that it supports.

It all depends on what we truly value and if we can summon the will to act.

PRESIDENT KENNEDY: But why, some say, the Moon? Why choose this as our goal? And they may well ask, why climb the highest mountain? We choose to go to the Moon
we choose to go to the Moon (applause, cheering) we choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard.
13 - Unafraid Of The Dark

1 (sail rustling) NEIL DEGRASSE TYSON: The dream of becoming a citizen of the cosmos was born here, more than two millennia ago, in the city of Alexandria, named after and conceived by its dead conqueror, Alexander the Great.

The Ptolemys, the Greek kings who inherited the Egyptian portion of Alexander's empire, built this library and its associated research institution.

Rarely, if ever, before or since, has there been a government that was willing to spend so much of its gross national product on the acquisition of knowledge.

And it paid off.

Big time.

Every ship entering Alexandria's harbor was searched-- not for contraband, but for books that might be copied and stored here, in what was then the greatest library on Earth.

Here, Eratosthenes, one of the chief librarians, accurately calculated the size of the Earth and invented geography.

Pythagoras.

Hypatia.

Euclid.

Euclid set forth the precepts of geometry in a textbook that remained in use for 2,300 years.

The Old Testament Bible comes down to us mainly from the Greek translations made here.

The original manuscripts of the masterpieces of Greek comedy and drama, poetry, science, engineering, medicine and history-- the total work product of the awakening of ancient civilization-- were kept here.

Estimates vary on the total number of scrolls.

They range from 500,000 to nearly a million.

And all of it all of this is but a tiny fraction of the information that you have at your fingertips at this very moment.

The collective knowledge of our species, our own electronic Library of Alexandria, may be accessed by anyone who has a device and the interest and the freedom to do so.
This was not true in Alexandria, where knowledge belonged to the elite.

So in the fourth century AD, when the mob came to destroy the library and the genius of classical civilization, there were not enough people to defend it.

What will happen the next time the mob comes? DEGRASSE TYSON: We've come a long way together, traveling from deep inside the heart of an atom clear out to the cosmic horizon, and from the beginning of time to the distant future.

I think we're ready to perform an experiment.

It's not the kind of experiment that requires a laboratory.

You can do it in your head.

It's called a "thought experiment." Pick a star-- any one of the hundreds of billions of stars in our Milky Way Galaxy, which is just one galaxy out of the hundred billion in the known universe.

How about that star? Or that one? Okay, this one.

It's orbited by dozens of planets and moons.

Suppose, on one of them, there lives an intelligent species, one the ten million life-forms on that planet, and there's a subgroup of that species who believe they have it all figured out-- their world is the center of the universe, a universe made for them, and that they know everything they need to know about it-- their knowledge is complete.

How seriously would you take their claim? Our ancestors believed the universe was made for them.

It was natural to assume that we were at the center.

After all, it looks like the Sun and stars all revolve around us.

We still speak of the Sun "rising." The architecture of our language, myths and dreams comes from that prescientific age.

This is our planet as it was known then, just before Columbus set sail.

This first globe of the Earth was cutting-edge when Martin Behaim made it in 1492.

Like everyone else, he believed that the jigsaw puzzle of geography was complete.

There were three continents Europe, Africa and Asia, and only the great world ocean in between.
Behaim had no clue that North and South America even existed.

It's easy to feel smug, right? Well, the fact is Martin Behaim knew infinitely more about his world, the Earth, than we know about ours, the universe.

A recent lesson in humility will serve to illustrate.

In 1912, Victor Hess made a series of voyages into the sky above Austria, and found the thing that scientists love best a mystery that defied understanding in terms of conventional scientific wisdom.

And even today, a century later, we are still searching for a complete explanation of what Hess found.

A new kind of energy had recently been discovered, radioactivity.

It was given off by certain elements, like radium.

But it was also found in the air, even far away from radioactive rocks.

It was everywhere.

Where did this strange energy come from? No one knew.

Hess suspected that it might come from above the Earth.

To test his hypothesis, he carried radiation detectors high into the sky.

During a risky ascent in a hydrogen balloon, he attained an altitude of more than three miles.

When he reached the thin, cold, upper half of the atmosphere (wind whistles) he found that the radiation was more than twice as strong as on the ground.

The radiation must be coming from above.

That's why its intensity was weaker on the ground-- the Earth's atmosphere was absorbing most of it.

Some thought that the radiation might come from the Sun.

To test that idea, Hess timed one of his ascents to coincide with a solar eclipse.

But the eclipse had no effect on the radiation.

Hess also found that the radiation was just as strong at night as in daylight.

It was coming from above, but not from the Sun.
What Hess did not know was that the solar wind doesn't move that quickly.

And so, for the wrong reason, he came to the right conclusion.

Hess had discovered cosmic rays-- showers of subatomic particles that crisscross the universe at literally the speed of light.

Without the shielding effect of the Earth's atmosphere, they would be lethal.

Some cosmic rays can carry as much energy as a bullet fired from a rifle.

It would take decades to trace those cosmic rays back to a death of unimaginable violence.

DEGRASSE TYSON: The cosmic rays that Victor Hess detected in the skies above Austria posed a mystery to scientists.

Radioactivity in minerals on Earth-- like uranium ore-- comes from the disintegration of atoms.

But cosmic rays were of a different nature.

They were far more powerful than anything known in Hess's world.

Scientists wondered for two decades what could possibly produce cosmic rays.

Enter Fritz Zwicky, the most brilliant man you've never heard of.

In 1933, he and a colleague discovered that some stars flare up to become as bright as their entire galaxy for a few weeks, before fading out again.

Fritz Zwicky was the first person to understand what just happened.

He correctly surmised that this is the way a massive star dies-- it blows its guts out into space.

He called this kind of stellar death a "supernova" and predicted that the dying star would shrink from about a million miles across to only ten.

This corpse would be so dense that a single grain of it would weigh as much as the Great Pyramid in Egypt.

It would consist almost entirely of subatomic particles called neutrons, so he named these bizarre objects "neutron stars." And 35 years after Zwicky predicted their existence, astronomers began to find them.

We call them "pulsars" when they spin rapidly and emit regular pulses of radio energy.
Supernovas and neutron stars could account for a wide range of cosmic rays, but not the most energetic ones.

Nothing yet known to science can explain them, and we're fine with that.

It's one of the things I love about science, we don't have to pretend we have all the answers.

Zwicky also came up with the idea that the gravity of a galaxy warps the fabric of space around it, to act like a lens.

This distorts and magnifies light from any other galaxy lying directly behind it.

So, astronomers on Earth would see multiple images of that same distant galaxy, deformed, as in a funhouse mirror.

40 years after this prediction, we started finding them, too.

And Zwicky made yet another discovery back in the 1930s.

While studying the Coma Cluster of galaxies, he noticed something funny about the way they moved.

The galaxies were going way too fast, so fast that they should've been flying apart from each other, because all the stars in all those galaxies had far too little gravity to hold the cluster together.

Zwicky thought that something else must be binding them to each other.

That mysterious missing component would have to weigh something like 50 times as much as the stars themselves.

But no one paid much attention to this wild notion.

Just another one of Zwicky's crazy ideas.

In our solar system, the innermost planet, Mercury, moves much faster than the outermost one, Neptune.

And that makes sense, right? The harder you push or pull on something, the faster it goes.

The Sun's gravity weakens with increasing distance, so, the planets that are farther from the Sun move more slowly.

Everyone expected that the outermost stars in a galaxy would act the same way.

Most of the stars are concentrated towards the center, so, their collective gravity pulls on
the other stars the same way the Sun pulls on the planets.

But in the 1970s, when astronomer Vera Rubin studied the Andromeda Galaxy, she discovered that the outer stars obeyed no such rule.

Unlike the outer planets of the solar system, the outer stars in the galaxy were all going at the same speed as the stars that were closer in, and they were moving way faster than expected.

"That's funny," Vera thought.

"There must be something weird about the Andromeda Galaxy." So she looked at another galaxy.

Same story.

And another.

Vera studied 60 galaxies and found that all of them seemed to be violating the Law of Gravity, a core principle of physics.

After some initial healthy skepticism, her colleagues looked for themselves, and found that Vera was right.

It's not that Isaac Newton had gotten the Law of Gravity wrong; Vera Rubin had discovered that the gravity of something massive and invisible was forcing the stars to go fast.

And then, someone remembered crazy old Fritz Zwicky, and the unknown source of gravity in the galaxy clusters that he called "dark matter," back in 1933.

Vera Rubin had verified the existence of a new, much larger cosmos.

And just like the one we thought we knew, it was filled with mystery.

Dark matter is completely unobservable, except for its gravitational effect, which makes visible stars and galaxies move faster.

Its nature is another deep mystery.

Rubin had provided the evidence for an invisible universe nearly ten times more massive than the one we thought we knew.

It was as if we had been standing on the seashore at night, mistakenly believing that the froth on the waves was all there was to the ocean.

Vera Rubin looked at the stars and realized they were merely the foam on the waves, and
that the greatest part of the ocean remained unknown.

But wait.

It gets crazier.

Our Milky Way Galaxy, a few hundred billion stars, plus the clouds of gas and dust, the stuff of once and future stars-- and about a hundred billion other galaxies-- all of that, including those uncounted billions of trillions of planets, moons, and comets-- amounts to only five percent of what is actually there.

Because there's a bigger unsolved mystery than dark matter-- dark energy, which makes up even more of the cosmos and drives its expansion.

And it was Fritz Zwicky's supernovas that lit the way to the revelation of its existence.

In one scenario, a star consumes all of its nuclear fuel then cools, and suddenly collapses under its own gravity.

The star rebounds in a massive explosion, leaving behind a neutron star or a black hole.

Since the mass of the original star can fall within a wide range, its peak brightness as a supernova can also vary widely.

So, you can't tell how far away it is just from how bright it looks.

A relatively nearby supernova might appear just as bright as one that was more powerful, but farther away.

But there's another kind of supernova that comes in only one strength.

It marks the violent grand finale of a tango danced by a giant star and a dwarf.

As the two stars orbit closely around each other, the giant sheds its outer layers of gas onto the dwarf.

When the added weight becomes too much for it to bear, the dwarf detonates like a stupendous thermonuclear bomb.

For a few weeks, the brilliance of such a supernova rivals the combined light of all the stars in its galaxy.

This kind of supernova always has the same maximum power output, about five billion times brighter than our Sun.

With big telescopes, we can see them in galaxies very far away, out toward the edge of the observable universe.
Because all such supernovas have the same wattage, they're ideal tools for measuring
distances to the farthest reaches of the universe.

We call them "standard candles." In 1929, Edwin Hubble discovered that the universe is
expanding.

The distant galaxies are drifting away from one another.

Later, we learned that the expansion began some 14 billion years ago with the explosive
birth of the universe-- the big bang.

Everybody assumed that the rate of expansion would be slowing down, due to the mutual
pull of gravity between all the parts of the universe.

If there is enough dark matter, its gravity would eventually bring the expansion to a stop,
and the universe would then fall back on itself.

In that case, everything would eventually collapse in a big crunch.

On the other hand, if the universe had less dark matter, the expansion would continue
forever, just getting slower and slower.

Two competing teams of astronomers were observing those supernovas in distant
galaxies.

It turned out to be another one of those "that's funny" moments.

In 1998, both teams independently came to the same conclusion.

The expansion isn't slowing down at all it's speeding up.

This means the universe will continue to expand forever.

There seems to be a mysterious force in the universe, one that overwhelms gravity on the
grandest scale to push the cosmos apart.

Most of the energy of the universe is bound up in this unknown force.

We call it "dark energy," but that name, like "dark matter," is merely a code word for our
ignorance.

It's okay not to know all the answers.

It's better to admit our ignorance than to believe answers that might be wrong.

Pretending to know everything closes the door to finding out what's really there.

Tonight, our ships sail into even more exotic waters.
Come with me.

DEGRASSE TYSON: Only two of our ships have ventured into the great dark ocean of interstellar space.

The longest odyssey in all of history was launched back in 1977-- NASA's Voyager 1 and 2.

The Voyagers move about 40,000 miles an hour.

They gave us our first close-up look at Jupiter's Great Red Spot, a hurricane three times the size of Earth and one that's been raging since at least 1644, when it was first observed.

For all we know, it could be thousands of years old.

The Voyagers discovered the first active volcano on another world, on Jupiter's moon Io and an ocean beneath the icy surface of the moon Europa with at least twice as much water as we have here on Earth.

The Voyagers dared to fly across Saturn's rings and revealed that they were made of hundreds of thin bands of orbiting snowballs.

On Saturn's giant moon Titan, Voyager detected an atmosphere four times denser than Earth's.

That hinted at the existence of hydrocarbon seas on Titan, which we later confirmed.

Voyager 2 gave us our first portrait of the outermost planet, Neptune where the winds roar at 1,000 miles per hour and its moon Triton, where geysers of boiling nitrogen shoot five miles high.

Voyager successfully completed its mission of discovery to the outer planets, but its odyssey into the darkness was just beginning.

Voyager 1 became the first of our spacecraft to enter an uncharted realm.

The Sun is constantly shooting out streams of charged particles in all directions, moving at a million miles an hour.

This solar wind blows a vast magnetic bubble, our heliosphere, that extends beyond the outer planets.

It pushes out against the thin gas of interstellar space.

There's a border where one ends and the other begins.
Voyager 1 reported back to Earth that its detectors were being pummeled by more and more cosmic rays.

Until then, we didn't know where the interstellar ocean began.

Voyager 1 pressed on past a boundary we had never crossed before.

The heliosphere shields us from most of the deadly cosmic rays.

When stormy solar winds blow, this zone of protection grows; in calm solar weather, it shrinks.

When a star goes supernova in our galactic neighborhood the debris from the exploded star pushes the heliosphere back towards the Sun.

If it's strong enough to push it all the way back to Earth's orbit, our planet gets a radioactive bath of supernova debris.

Luckily, this doesn't happen very often.

The last one was perhaps two million years ago.

A neighboring star explodes a million years before there's even such a thing as the human species.

How can we possibly know this? Because the dying star left its traces miles below the surface of the ocean.

Manganese nodules, small rocks like this one, are scattered over much of the deep sea floor.

They grow very slowly.

I'm talking a millimeter in a million years, layer upon layer.

These nodules grow in partnership with bacteria by taking up minerals dissolved in the seawater.

A supernova produces a radioactive form of iron, unlike anything made by natural processes on Earth.

Researchers found telltale traces of this iron in a thin layer below the surface of the manganese nodules.

They used the known rate of growth of the nodules to date that layer and to connect it to the fate of a star that perished eons ago.
The difference between seeing nothing but a pebble and reading the history of the cosmos inscribed inside it is science.

The interstellar ocean is dark and deep.

Out here, the Sun is just the brightest star in the sky.

Yet the Voyagers maintain their regular communications with NASA's Jet Propulsion Laboratory, talking back and forth across the light-hours that separate these ships from their home port.

No other objects touched by human hands have ever ventured this far from home.

Even after they lose their ability to respond to our command, the last and, by far, the longest phase of the Voyager mission will begin.

Back in 1979, when both Voyagers rounded Jupiter, its massive gravity acted as a slingshot, flinging them out of the solar system to travel among the stars of our galaxy for a billion years.

Carl Sagan recognized that the Voyager mission offered two free tickets to something approaching eternity.

He assembled a small team to create a message to any civilization that might, one day, encounter the derelict spacecraft.

26 centuries ago, the Assyrian king Esarhaddon wrote "I had monuments made of bronze and inscriptions of baked clay.

I left them in the foundations for future times." These hieroglyphics continue that ancient tradition.

They are inscribed on the cover of a message designed to be read by the beings of other worlds and times.

What could we possibly have in common with an alien civilization with its own separate evolutionary history and one so far advanced beyond us that they can patrol interstellar space? One thing at least, a universal language science.

It's hard to break the bonds of gravity.

You can only sail the cosmic seas if you speak mathematics and physics.

Hydrogen is the most common element in the universe.

The electron in a hydrogen atom flips the direction of its spin at a constant rate, or
frequency.

Hydrogen atoms are like tiny natural clocks-- tick tock.

Now we have a unit of time in common with the extraterrestrials.

This will come in handy when we get to the next level of the message.

Here's our return address in space.

Pulsars are rapidly-spinning neutron stars that give off regular bursts of radio waves.

You can set your clock by them.

The Sun is at the center of this diagram, and the lines point to the 14 nearest pulsars.

A simple code labels each pulsar with its unique frequency, using the ticktock of the hydrogen atom as the unit of time.

So alien astronomers could use this diagram to locate the home star of the Voyager spacecraft in our galaxy.

They could also tell how long ago the spacecraft was launched.

And that's important because the Voyager record has a projected shelf life of 1,000 million years.

Become an extraterrestrial archaeologist for a few moments.

An artifact has been fished out of the interstellar ocean.

(classical music playing) It was made by beings that lived about a billion years ago.

What would you make of them and their world? (guitar playing blues) They've sent us their music and greetings in 59 human languages.

(various languages overlap, speaking greetings) NICK SAGAN: Hello from the children of planet Earth.

DEGRASSE TYSON: And one whale language.

(whales singing) And a sound essay that includes a Saturn V rocket launch.

(jet engine whooshes) A mother's first words to her newborn baby.

(baby crying) WOMAN: Oh, come on now.

Be a good boy be a good boy.
The brain waves of a young woman newly fallen in love.

(staticky crackling) And the sound of a pulsar.

(steady, rhythmic crackling) (Blind Willie Johnson's "Dark Was the Night" playing) All of that will live for a billion years.

("Dark Was the Night" continues, then fades) How long is a billion years? If you can press all the time since the Big Bang, the explosive birth of the universe, into a single Earth year, a billion years is about one month of that year.

What was happening on Earth a billion years ago? Most of Earth's land was amassed into a supercontinent called Rodinia.

It was a barren desert-- no animals, no plants.

A billion years ago, there wasn't enough oxygen in our atmosphere to form an ozone layer, and without it, ultraviolet radiation prevented life from colonizing the land.

Rodinia probably looked more like Mars than present-day Earth.

The giant world ocean produced huge rainstorms causing flooding and erosion.

Glaciers formed, and their slow but relentless movements carved the land into new shapes.

Single-celled organisms dominated the oceans, but some existed in colonies called "microbial mats," and the first multicellular organisms would soon evolve.

And a billion years from now, what will Earth be like long after our cities, the Egyptian pyramids, the Rocky Mountains have all been eroded to dust? There are few things we can say with confidence about such a far distant time.

The only thing we can say for sure is that Earth as we know it will be so changed that we would scarcely recognize it as home.

But even a thousand million years from now, something of who we were and the music that we made in that long-ago spring will live on.

In that distant future, our Sun will have completed another four orbits around the center of the galaxy and the Voyagers will have ventured far from the Sun.

Carl Sagan was a member of Voyager's imaging team, and it was his idea that Voyager take one last picture.

A generation before, an astronaut on the last Apollo flight to the Moon had taken a
picture of the whole Earth-- the planet as a world without borders.

It became an icon of a new consciousness.

Carl realized the next step in this process.

He convinced NASA to turn the Voyager 1 camera back towards Earth when the spacecraft went beyond Neptune for one last look homeward at what he called the pale blue dot.

CARL SAGAN: That's here.

That's home.

That's us.

On it, everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives.

The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every superstar, every supreme leader, every saint and sinner in the history of our species, lived there on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast, cosmic arena.

Think of the rivers of blood spilled by all those generals and emperors so that in glory and triumph they could become the momentary masters of a fraction of a dot.

Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner.

How frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the universe, are challenged by this point of pale light.

Our planet is a lonely speck in the great, enveloping cosmic dark.

In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.

The Earth is the only world known so far to harbor life.
There is nowhere else, at least in the near future, to which our species could migrate.

Visit, yes.

Settle, not yet.

Like it or not, for the moment, the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience.

There is perhaps no better demonstration of the folly of human conceits than this distant image.

To me, it underscores our responsibility to deal more kindly with one another and to preserve and cherish the pale blue dot, the only home we've ever known.

DEGRASSE TYSON: How did we, tiny creatures living on that speck of dust, ever manage to figure out how to send spacecraft out among the stars of the Milky Way? Only a few centuries ago, a mere second of cosmic time, we knew nothing of where or when we were.

Oblivious to the rest of the cosmos, we inhabited a kind of prison-- a tiny universe bounded by a nutshell.

How did we escape from the prison? It was the work of generations of searchers who took five simple rules to heart.

Question authority.

No idea is true just because someone says so, including me.

Think for yourself.

Question yourself.

Don't believe anything just because you want to.

Believing something doesn't make it so.

Test ideas by the evidence gained from observation and experiment.

If a favorite idea fails a well-designed test, it's wrong! Get over it.

Follow the evidence, wherever it leads.

If you have no evidence, reserve judgment.

And perhaps the most important rule of all Remember, you could be wrong.
Even the best scientists have been wrong about some things.

Newton, Einstein, and every other great scientist in history, they all made mistakes.

Of course they did-- they were human.

Science is a way to keep from fooling ourselves and each other.

Have scientists known sin? Of course.

We have misused science, just as we have every other tool at our disposal, and that's why we can't afford to leave it in the hands of a powerful few.

The more science belongs to all of us, the less likely it is to be misused.

These values undermine the appeals of fanaticism and ignorance and, after all, the universe is mostly dark, dotted by islands of light.

Learning the age of the Earth or the distance to the stars or how life evolves-- what difference does that make? Well, part of it depends on how big a universe you're willing to live in.

Some of us like it small.

That's fine.

Understandable.

But I like it big.

And when I take all of this into my heart and my mind, I'm uplifted by it.

And when I have that feeling, I want to know that it's real, that it's not just something happening inside my own head, because it matters what's true, and our imagination is nothing compared with Nature's awesome reality.

I want to know what's in those dark places, and what happened before the Big Bang.

I want to know what lies beyond the cosmic horizon, and how life began.

Are there other places in the cosmos where matter and energy have become alive and aware? I want to know my ancestors-- all of them.

I want to be a good, strong link in the chain of generations.

I want to protect my children and the children of ages to come.

We, who embody the local eyes and ears and thoughts and feelings of the cosmos, we've
begun to learn the story of our origins-- star stuff contemplating the evolution of matter, tracing that long path by which it arrived at consciousness.

We and the other living things on this planet carry a legacy of cosmic evolution spanning billions of years.

If we take that knowledge to heart, if we come to know and love nature as it really is, then we will surely be remembered by our descendants as good, strong links in the chain of life.

And our children will continue this sacred searching, seeing for us as we have seen for those who came before, discovering wonders yet undreamt of in the cosmos.