When you think about our solar system, what comes to mind? The Sun? Planets? What about moons?

Often overlooked, moons are the bit players, the extras, the chorus. As natural satellites, they're the things that go around the things that go around the Sun.

But as it turns out, they're pretty important.

Without moons, our solar system would be very different. In fact, without them, we might not be here at all.

(MUSIC CHANGE)

For most of human history, we knew of only one moon - ours. Even today, we still call it the Moon.

It's our constant companion. In orbit around Earth, the Moon’s phases have followed the same regular, predictable pattern for far longer than we’ve been around.

But the Moon wasn't always with us, and it's anything but mundane. The mere fact of its existence suggests that it has beaten some astonishingly tough odds.

(MUSIC CHANGE)

This is Earth, about four-and-a-half billion years ago. Back then, our young planet had no moon. That is, until a rock about the size of Mars crossed its path.

The immense cloud of debris thrown into space from this impact gradually coalesced into a giant, molten ball. Our Moon, born from Earth itself.

As it cooled, the molten rock crystallized. The heaviest materials sank. Lighter ones floated to the surface, creating the gray highlands we see today.

Gigantic collisions began to shape the Moon’s appearance. These huge, stray rocks from a turbulent young solar system smashed into the Moon in cataclysmic explosions, creating enormous craters, some as big as entire countries.

Oceans of lava seeped out through cracks, rolling over the surface and spreading into the crater basins, cooling and hardening to form dark plains called "maria."
The rain of debris continued for hundreds of millions of years, littering the surface with craters the size of softballs, houses, and cities. Eventually, the bombardment slowed.

With no atmosphere, no weather, no lakes or rivers, the Moon has hardly changed in three billion years.

Just as it did for those before us, it lingers in the sky, inspiring our curiosity, compelling us into space. But unlike our ancestors, we've actually been there…

(MUSIC CHANGE)

This is Mare Serenitatis, the Sea of Serenity. It’s about the size of Texas. Although we call them seas and oceans, these vast plains are all rock.

At the edge of this crater basin, mountains surround the Taurus-Littrow valley, the last place touched by humans, in 1972.

We have, literally, left our imprint on the Moon.

History has left its marks here, too. Scars of ancient events, the Moon’s features can be read like an unconventional history book.

Craters - and craters within craters - reveal a chronological record that we use to piece together the Moon's past.

(MUSIC CHANGE)

We're now at the Moon's south pole. The rocks deep inside these craters have been in shadow for billions of years. Evidence of hydrogen within them made us wonder:

What other secrets do they hide?

To find out, in 2009, the LCROSS mission deliberately crashed a spacecraft here. The impact lifted a 6-mile high plume of ice and vapor, the first definitive proof of water ice on the Moon.

It seems there’s still plenty to discover about our nearest neighbor. So we keep sending spacecraft.

The twin GRAIL orbiters, flying in tandem, measured the Moon's gravity to help us understand what’s beneath its surface.

Cameras aboard the Lunar Reconnaissance Orbiter are mapping the Moon in unprecedented detail to find potential landing sites and resources, paving the way for sending humans back.

Meanwhile, more missions, planned by countries all over the world, represent international efforts to learn as much as we can about our Moon.

(MUSIC CHANGE)

Together, the Earth and Moon are a finely tuned system, the result of billions of years of gravity at work.
Earth's gravity holds the Moon in orbit, locking one face toward us at all times.

The Moon, in turn, pulls on Earth, stabilizing and slowing Earth’s rotation over time. Without the Moon, an Earth day would last only 9 hours, resulting in faster winds and more frequent, far more devastating storms.

The Moon’s pull also creates the rise and fall of tides and helps transfer minerals from the land to the oceans, where life first started. Without tides, essential nutrients might have spread more slowly, possibly hindering the development of early life.

Without the Moon, life on Earth might not exist at all.

(MUSIC CHANGE)

Our Moon is important, at least to us, but today we know it’s just one of many.

Four hundred years ago, Galileo spotted the very first moons beyond our own. Each night, while observing Jupiter, he saw four points of light that changed position around the planet.

He realized that these were actually moons - the first compelling evidence that not everything orbited the Earth. This revelation set the stage for modern astronomy.

Today, centuries later, we use unmanned spacecraft to scout the realm of the gas giant planets.

Galileo's four moons were just the beginning. By 1980, spacecraft had encountered twelve more, bringing Jupiter’s moon count to sixteen.

Then, the digital age changed everything, bringing a whole new wave of discoveries.

We now know of more than sixty-five moons orbiting Jupiter. And we keep finding more.

No two moons are exactly alike. Each tells a unique story, shaped by its origin and its relationship with everything around it. And together, they offer us a glimpse of just how diverse - and extreme – moons can be.

(MUSIC CHANGE)

Jupiter’s Ganymede, the largest moon in the solar system, dwarfs the planet Mercury.

Its scarred surface echoes the history of our own Moon, battered but then mostly unchanged through the ages.

But not all moons have such ancient terrain. Some are altered by the very same processes we see on Earth, exaggerated to wild extremes.

Take Io -- a moon so close to Jupiter, that Jupiter’s immense gravity wreaks havoc on it.

Just as our Moon pulls on Earth to cause the tides, Jupiter and its other moons pull even harder on Io, hard enough to stretch and contort the rock, causing slow waves in the solid surface.
The friction from the twisting rock generates huge amounts of heat within the moon. Sulfuric gas spews outward, billowing hundreds of miles high, then freezes and falls back to the surface in crystals, like toxic snow.

With lakes of sulfur and lava to renew it, much of Io's surface is never more than a few days old.

*(MUSIC CHANGE)*

Europa looks peaceful by comparison, but Jupiter's gravity is also at work here.

This icy surface is always changing, so we don't see many craters. Instead, Europa’s chaotic terrain and crisscrossing patterns suggest movement similar to ice shelves in Antarctica.

What’s driving this motion? We'll need to peer beneath Europa's frozen shell to find out…

Liquid water. Europa's enormous, underground ocean might contain more water than all of Earth's oceans, lakes, and rivers combined.

Beneath Europa’s icy crust, tidal friction warms the inside of the moon and prevents this water from freezing.

Embedded in the ice above are smaller pockets of liquid water, which might connect to this deeper ocean. As heated water seeps up through these hidden lakes, icebergs could break and move around, then refreeze to create the chaotic surface we see.

If that's the case, nutrients on the surface might be mixing with ocean water and heat energy deep inside the moon, combining the three most crucial ingredients for life.

Is life possible in these buried lakes and oceans? We don’t know...yet, but Europa expands the way we think about moons.

*(MUSIC CHANGE)*

Moons that are close to Jupiter, such as Io and Europa, orbit quickly in neat, circular paths, always moving in the same direction as the planet spins.

These moons, as old as Jupiter itself, formed from leftover debris that didn't become part of the planet.

But moons form in different ways, and often much later than the planets they orbit.

When a chance collision destroys a moon, the bits left behind can become a group of smaller, second-generation moons.

The moons farther out have unruly, tilted orbits. Some even orbit backward.

This odd motion suggests that these moons formed somewhere else and then drifted close enough to be captured by Jupiter's powerful gravity.

So… where did they come from?

*(MUSIC CHANGE)*
Scientists aren’t sure, but these moons have a lot in common with objects in today’s asteroid belt. Here, between the orbits of Jupiter and Mars, hundreds of thousands of rocky objects orbit the Sun.

Compared with planets, most asteroids are tiny, oddly-shaped chunks of rock and metal. Even so, some have moons of their own.

Mars has captured moons, too.

Each barely the size of a small city, tiny Deimos and Phobos zip around Mars in a matter of hours.

The same tidal forces that slow Earth's rotation also play out in the Martian system. As Deimos orbits, it imperceptibly slows the rotation of Mars. This exchange of energy gives the moon a slight boost that gradually drives it farther and farther away from the planet.

The opposite is true for Phobos. It’s spiraling inward, and someday could crash into Mars, while Deimos may be hurled back out into space.

Sometimes, moons have an even more dramatic end.

(MUSIC CHANGE)

Do you recognize this planet?

Without its iconic rings, it's far less spectacular. But scientists believe that Saturn didn’t originally form with rings.

Exactly how it happened is still a mystery. But, in almost all theories, Saturn's rings begin ... with a moon.

An ancient moon, and possibly bigger than our own, that swings just a little too close…

Saturn's gravity pulls and stresses the moon until it breaks, its outermost icy layers stripping away, ripping apart into trillions of pieces.

After many orbits, the moon's rocky core spirals inward, is swallowed into the planet, and disappears.

Leftover particles collide, sometimes clumping together to form the seeds that will later become icy interior moons.

Over time, the rest settle into an incredibly thin rotating disk - the magnificent rings of Saturn.

(MUSIC CHANGE)

Trillions of tiny particles, each orbiting Saturn like a miniature, barely perceptible moon. All part of a complex, perpetually evolving system, like an ever-changing dance, guided by gravity.
Shepherd moons, orbiting within the rings, sweep out great swaths of debris from their orbits. These moons can be tiny, barely a few miles across. But their gravity still creates gaps in the rings dozens of miles wide.

Other shepherds, like these, tug smaller particles into mysterious shapes and patterns.

The relentless pull of Mimas, the largest shepherd, clears the biggest gap in Saturn's rings. A near-victim of gravity, it bears the scar of a tremendous collision that almost destroyed it.

Farther out, the moon Enceladus shapes the rings by making one of its own. Near its south pole, water vapor, ice, and dust shoot hundreds of miles into space.

These geysers may be this moon’s way of releasing pressure built up from tidal forces within. They supply fresh particles to this hazy outer ring.

The more we learn, the more moons surprise us. And Saturn’s giant moon, Titan, might be the most surprising of all.

(MUSIC CHANGE)

Most moons can’t retain an atmosphere. Titan does.

In many ways, this alien world may seem like a very orange Earth. Its atmosphere is mostly nitrogen, and Titan is as big as a planet.

Beneath the moon's clouds, we find continents and mountain ranges of rock-hard ice, and between them…

…lakes, and flowing rivers. It’s the only other world beyond Earth known to support liquid on its surface. But that’s not water.

At nearly 300 degrees below zero, all water here is frozen. *These* are vast oceans of liquid methane and ethane.

The Sun’s heat, present but weak at this distance, slowly evaporates the liquid and drives methane gas into the atmosphere, where it rises, cools, and condenses. Methane clouds.

Methane raindrops eventually become heavy enough to fall back to the surface, flowing through rivers, carving out networks of channels, and finding their way back to the oceans, where the cycle begins again.

Earth’s water cycle, which keeps water in all its forms moving through the oceans, clouds, and land, is crucial for life.

Could some kind of life survive, even thrive, on liquid methane? We’re not sure, but Titan offers a tantalizing glimpse of what might be possible on another world.

(MUSIC CHANGE)

We're now almost 2 billion miles away from the Sun. From here, it's just a tiny, brilliant dot. Because it’s so remote, we know less about the planets and moons out here.
We do know that Uranus has at least 27 moons, and that some are likely to collide very soon…in only a few million years.

We also know that Neptune’s largest moon, Triton, orbits “backward”, suggesting it was captured.

Triton is a giant compared to other captured moons. Too cold and too far away to have come from the asteroid belt, Triton once belonged to the Kuiper Belt, a swarm of ancient, icy chunks that orbit the Sun beyond Neptune.

This might be the most famous Kuiper Belt Object of all: Pluto. Like Triton, Pluto is a world plunged in deep-freeze.

Even Pluto, a world smaller than our Moon, has at least five moons of its own. Its biggest, Charon, is half the size of Pluto, an unusually large moon for such a small object.

Strictly speaking, Charon doesn’t orbit Pluto! The two orbit a point in space between them.

With Nix, Hydra, and two more moons discovered in 2011 and 2012, we wonder if Pluto hides even more surprises.

Many other objects beyond Neptune have moons, including Eris and Haumea, two of the largest worlds out here. And with hundreds of thousands, maybe even millions, of objects, who knows how many more moons we’ll find.

(MUSIC CHANGE)

We used to think of the solar system as the Sun, its planets, and our silvery, dusty Moon. Now it seems there’s much more here than we ever imagined.

Millions of objects, all sharing an ancient common origin, influencing one another, but each also on its own independent path as distinct and extraordinary, as unique and intriguing, as each of us. No two are the same, each a product of infinite circumstances, guided by the laws of physics, and chance.

The result? A system rich with countless worlds, and Earth is part of this complex system, dynamic and evolving.

(MUSIC CHANGE)

For humans, our exploration of the universe started with a single moon…our own.

When we stepped onto the Moon, it ushered in a new era of discovery, and transformed our perspective of Earth in ways we never anticipated.

We don’t know where we’ll go next, or when. Yet, one thing’s for sure: Our Moon – and all the other moons we’ve found – will continue to inspire us.

Our adventures have only begun.

(END OF SHOW – CREDITS AND MUSIC)