Eclipses: Crash Course Astronomy #5

Crash Course: Astronomy
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We humans of planet Earth benefit from a great coincidence. It's a coincidence of time, and of space. And of math.

The coincidence is this: the Sun is about 400 times wider than the Moon, and it's also on average about 400 times farther away than the Moon.

The apparent size of an object in the sky depends on how big it is and how far away it is... so these numbers being equal means the Sun and the Moon appear to be about the same size in the sky.

And that's where another interesting thing comes in: Sometimes, the Moon passes directly between the Earth and the Sun. It doesn't happen all that often, but when it does, you get magic.

Or even better: You get SCIENCE.

You get an eclipse.

An eclipse is a generic term in astronomy for when one object passes into the shadow of another object, darkening or blocking it.

A solar eclipse is when the Moon blocks the Sun, casting a shadow on the Earth, and a lunar eclipse is when the Earth blocks the Sun, casting a shadow on the Moon.

But how do they work?

Well, the Moon orbits the Earth once per month, and the Earth orbits the Sun once per year. If the Moon's orbit were perfectly aligned with the Earth's, essentially sharing the same plane, we'd get a solar eclipse every new Moon and a lunar eclipse every full Moon!

But we don't. That's because the Moon's orbit is tilted with respect to Earth's, by about 5°.

What that means is that, at new Moon, the Moon can be as much as 5° away from the Sun, passing "above" or "below" the Sun in the sky, thereby missing it, from our perspective.

But sometimes the Moon is in the right place at the right time, and at new Moon, it lies perfectly in line between the Sun and the Earth. And when that happens, we get a solar eclipse. This geometry happens at least twice per year, and sometimes as much as five times per year.

What's happening physically in space is that the Moon is casting a long shadow. Usually that shadow misses the Earth, but during an eclipse the Moon's shadow falls on the Earth's surface.

In fact, there are two shadows from the Moon, one inside the other. One is a narrow cone, tapering to a point away from the Moon. If you're anywhere physically inside this cone, the Moon appears big enough to completely block the Sun. That means this shadow is very dark, and we call it the umbra (which is Latin for – you guessed it – "shadow").

Outside of this deep umbral shadow is a wider conical region where, if you're in it, the Sun is only partially blocked; you can still see some of the Sun past the Moon. You're getting less light, and so you're technically shadowed, but it's not quite as dark as the umbra. This region is called the "penumbra"; "pen" in this case for Latin meaning "almost," or "nearly."

When the umbra touches the Earth, we get a total solar eclipse. But what does that look like from the ground?

You don't get a total eclipse right away. First, the edge of the Moon slips in front of the Sun, and we see a little dip in the Sun's limb, its edge as seen from Earth (that's the start of the penumbra sweeping over you).

As the Moon slowly moves, that dip grows, becoming a bite. The Sun becomes a thick crescent, then a thin one.

As the Sun becomes an ever-thinner crescent, the sky begins to darken. Then, finally, the Moon's black disk completely covers the Sun — the umbra sweeps over your location. And at that moment, totality begins.

You might think that this just means the sky gets dark, and it's like night outside for a while. But a total eclipse is far more than that. And that's because of the Sun's corona.

As I'll cover in more detail in a future episode, the corona is the sun's atmosphere, an ethereally thin envelope of gas that stretches from the Sun's surface into space for millions of kilometers.

It's really faint, and therefore usually completely overwhelmed by the intensely bright light from the Sun.

But when the Moon blocks the Sun's face, the corona becomes visible. It surrounds the Sun, filaments and tendrils extending into the sky, an incredibly beautiful sight. I know many people who have said it's the most spectacular thing they have ever seen.

And there's more. The Moon's edge isn't smooth — there are craters and other depressions. Craters right at the Moon's edge allow sunlight to stream past. We see these as bright patches around the eclipsed Sun, which are called Baily's Beads - because they were first described by English astronomer Francis Baily in 1836!

Because the Moon and Sun are very nearly the same apparent size, totality is brief.

The longest it can last is only about seven or eight minutes. That's how long it takes the umbra to move over one spot on the Earth. When totality ends, and the Moon starts to move off of the Sun's face, for a moment just a single spot of the Sun is unblocked, glowing fiercely on one side of the Moon. Sometimes you can get a circle of light around the Moon's surface, and together with the bright spot it looks like a celestial wedding ring. In fact, this is called the Diamond Ring effect.

Then, inexorably, the Moon pulls away from the Sun, and the order of events is reversed. The umbra is gone, but you're still in the penumbral shadow. The Sun shows a thin crescent, then a thick one, then a dip in its side… and then it's all over.

The umbral shadow of the Moon is pretty small where it hits the Earth, so a total eclipse is a local event. If you're too far north and south, you don't get a total eclipse, you only get a partial one. Which is still cool, but lacks the mystique of a total eclipse.

Remember too that the Moon's orbit around the Earth is an ellipse. That means sometimes it's closer to the Earth, and sometimes farther.

If a solar eclipse happens when the Moon is at the far end of its orbit, it can actually be smaller than the Sun in the sky. It doesn't block the entire face of the Sun, and it leaves a ring of light around the black circle of the Moon.

This technical name for this shape is annulus, so this event is called an annular eclipse.

A lot of people think if you look at a total solar eclipse you can go permanently and completely blind. That's really not true. But, some parts of eclipse-watching are more dangerous than others.

I mean, obviously it's not a good idea to stand there and stare at the sun. Looking at even the uneclipsed Sun for more than a moment is painful, and that pain is the result of the damage that solar radiation is doing to your retinas. So I don't recommend it — Duh.

But when viewing an eclipse, the real concern is right after totality ends. During totality it's dark, so your pupils have dilated to let more light in. But then there's the flash of sunlight when the Moon moves off, and that's intense enough to damage your retinas.

That's why astronomers recommend extreme caution when viewing an eclipse; because that flash can catch you by surprise.

When viewing the Sun, don't just stand there and stare at it; you should always have eye protection. And make sure you have safety-approved filters; don't try the the home-made tricks you might have heard of -- like looking through an old CD or DVD, or using old-style camera film as a filter.

These can let through too much infrared and ultraviolet light, and again can dilate your pupils, actually making things worse.

Lots of companies make inexpensive filters that are great for Sun-spotting; we have links in dooblydoo for more information on eye safety.

Now, you don't have to worry about hurting your eyes at all when viewing a lunar eclipse. Because, in that case, it's the Earth that blocks the Sun, and the Earth's shadow falls on the Moon. So go nuts.

But one big difference between the two kinds of eclipses is who can see them.

A solar eclipse is localized to one spot on the Earth, or really a swath along the ground as the Moon's umbral shadow sweeps across the Earth's surface.

But a lunar eclipse is when the Moon moves into Earth's shadow, so anyone on Earth facing the Moon can see a lunar eclipse. This is why I've seen dozens of lunar eclipses but never a total solar one. I've never been at the right place at the right time. Not that I'm bitter.

The Earth has umbral and penumbral shadows, too. When the Moon first enters the Earth's penumbra, the dimming is so slight you hardly notice it. But as the Moon moves deeper into the penumbra, it starts to darken. Sometimes it changes color, turning a deep orange or blood red.

That's because the Earth is starting to block the sunlight heading toward the moon, and the only light that gets through is coming through the thickest part of our atmosphere. This blocks blue and green light, leaving only red to come through.

That's why the Moon and Sun look red to us when they're on the horizon, rising and setting, too. When you look upon the red eclipsed Moon, you're seeing the light from all the sunrises and sunsets in the world hitting the Moon and reflecting back to us.

Finally, the Moon starts to enter the Earth's umbra, and the real eclipse begins. At first it looks like a bite is taken out of it — that curving arc is the shadow of the edge of the Earth! The Moon moves deeper and deeper into the shadow until it's completely darkened. The Earth is bigger than the Moon, so the Earth's umbra is much wider; while a solar eclipse is over in minutes, a total lunar eclipse can last nearly two hours. I once saw a lunar eclipse so deep that it took me a minute to find the Moon in the sky!

There's not a lot of new science you can do with a lunar eclipse. But if you know a little geometry, you can use the size and shape of the Earth's shadow on the Moon to get the relative sizes of the Earth and Moon.

Ancient Greeks did just this, and got a number that wasn't too far off. They also knew how big the Earth was using other methods, and so they had a decent estimate for the size of the Moon…nearly 2000 years before the invention of the telescope!

They also knew the shape of the Earth's shadow was always a circle, which only makes sense if the Earth were a sphere. If the Earth were flat, it would sometimes cast a thin shadow, but it never does. Pretty clever, those ancient Greeks.

One final note. Because of tides from the Earth — which we'll learn more about in detail in a later episode — the Moon is slowly moving away from the Earth, by about 4 centimeters a year.

As it recedes, it's slowly getting smaller in the sky. This means that, eventually, it will be too far away to completely cover the Sun, and we won't get any more total eclipses.

Doing the rough math, that will be in about a billion years. Better watch eclipses while you can.

Today you learned that a solar eclipse is when the Moon blocks the Sun so its shadow falls on the Earth, and a lunar eclipse is when the Earth's shadow falls on the Moon. We don't get them every two weeks because the Moon's orbit is tilted. And if you're clever, you can use lunar eclipses to figure out how big the Earth and Moon are.

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