Astronomy Cast Episode 160
Eclipses

Fraser: Astronomy Cast Episode 160 for Monday October 19, 2009, Eclipses. Welcome to Astronomy Cast, our weekly facts-based journey through the cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hello, Pamela.
Pamela: Hey Fraser, how's it going?
Fraser: It's going very well. Alright... so, every now and then the moon destroys the sun. Ok, not destroys but covers... ok, not really covers but from here on Earth, sitting inside the shadow of the moon, that's what it sure looks like. These events are called eclipses or more precisely transits and occultations. They occur whenever one object passes in front of another from a third perspective. They're beautiful and exciting and deliver a tremendous amount of science as well. Now I think you, once again, let's sort of delve into Pamela's personal life history, you had a pretty exciting little adventure this summer.
Pamela: I did... I did. This summer, 2009, I traveled to the China Sea and off the coast of Japan and China was on a boat called the Costa Allegra with the Eclipse of the Century tour group attempting very hard to view what was supposed to be the longest eclipse of the century that we're currently living in. It was supposed to last about 6 minutes 30 seconds, depending on exactly where you were along the line of the eclipse you'd get a little longer or a little shorter. It was a valiant attempt because that particular time of year is typhoon season and the weather is chronically awful, but we tried. And we did experience utter darkness for 6-ish minutes while getting rained on.
Fraser: Oh.. oh no... so you flew half-way across the world...
Pamela: Literally, yes...
Fraser: ... got a great big cruise ship, went out into the south China Sea, right to the eclipse point and it was raining and.... Did you see anything? Did you see any parts of the sun being chopped away?
Pamela: There were three different moments during the lead-up to the eclipse where a crescent sun peaked through the clouds. In one case it was kind of funny because if you rotated the picture 90 degrees, it ended up looking like a smiley face because of two darker points in the clouds and then the sun beneath. So we saw these small fragments leading up to the eclipse, and then at the eclipse and after the eclipse it just rained... hard... a lot. There's pictures on starstryder.com. You can go share in my rainy-day experience.
Fraser: See, I was seething with jealousy the whole time, and really that made me feel better.
Pamela: We got rained on and I got motion sickness. For the first time in my life I had to leave my own public presentation to go become very ill.
Fraser: So have you ever seen a total eclipse, then... work out?
Pamela: No. I saw a partial eclipse under gorgeous northern Michigan skies back in undergraduate, but it was a partial eclipse.
Fraser: We had a pretty big eclipse in Vancouver... I can't even remember... it was back in the early '80s... like '81... '82... Things got a little dim, but that was it.

Pamela: Yeah. So it did get amazingly dark.
Fraser: Alright, so then what is an eclipse... just to sort of fill up the textbook.
Pamela: Well, an eclipse can take many different forms, and like you said, it's always when one object passes in front of another and blocks out its light. So, for instance, I can drive a semi-truck in front of floodlights and cause a truck-eclipse... or , I guess, a floodlight eclipse. I can put the moon in front of the sun and cause a solar eclipse.
Fraser: So if you have a truck sitting on a pier and a boat goes past the truck behind....
Pamela: Then that would be a truck eclipse.
Fraser: Would that be an occultation, though? A boat occultation?
Pamela: This is where the language gets tricky because historically, we've used the word eclipse when it was the moon or the sun disappearing. We've used transit for little tiny things passing in front of larger things. If Venus or Mercury passes in front of the sun, if an extrasolar planet passes in front of an alien star, those are transits. We tend to use the word occultation for when an asteroid nearby passes between us and a far off distant star. So, in all cases we have this eclipsing behavior... we have one object blocking out the light from another. With eclipses, we're typically referring to the complete destruction of light from an object in our own solar system by another object in our own solar system. Moon blocking Sun... Earth blocking light from Sun from hitting moon. When we talk about transit, it's small thing not completely blocking light of a star and when we talk about occultations it's typically objects in two completely different solar systems... one in our solar system blocking the light from an object in another solar system.
Fraser: Ok, so let's focus on the traditional solar eclipse first. So, what is going on to make a solar eclipse happen?
Pamela: Well we live during a wonderful time when our Moon is periodically just the right distance from the planet Earth that its disk can pass exactly between us and the sun. This doesn't happen every single month because the orbit of the moon is inclined just enough that most months, if you were to draw a line from your eyeballs to the sun through the new moon, the moon would actually not be on that line. It would be above the sun or below the sun, so you'd be making this crazy triangle as you went from eyes to moon to sun. It's that crazy triangle... the fact that the moon appears in the sky above or below the sun that prevents eclipses from happening. That inclined orbit has two points... two nodes... where the orbit of the moon crosses the ecliptic... it crosses that line that the sun is on in the sky. When the moon does that, if it happens to be during a new moon, then the moon does block all the light from the sun. The ancient Chinese refer to this as the dragon eating the sun and would bang pots to scare away the dragon. Throughout all of history there have been stories of, in one case, a king dying of fright of a solar eclipse and battles ending due to a solar eclipse. It's a very dramatic and creepy experience. It's strictly because the moon is just the right distance. Now the thing is, the moon is getting further and further away over time. And its orbit... it's not a perfect circle. So even now there's some times when the moon just happens to be at the right point at its orbit, when it's on that point where it's crossing the ecliptic, it's too far from the earth to be large enough in the sky to completely block the sun. In those cases we end up with what's called an annular eclipse where you see this annulus of light around the moon... a donut of sun essentially hanging in the sky.
Fraser: Right, because the distance between the earth and the moon changes over the course of the moon's orbit, and the distance between the earth and the sun changes over

the course of the earth's orbit, and so when you have both at their furthest point, then... or actually when you get the moon at its furthest point from the earth it's actually smaller in the sky and doesn't completely cover up the sun. And other times when it's at its closest point in its orbit, then it nicely covers up the sun.

Pamela: And with the sun's changing distance as well, all of this affects how long eclipses can potentially last. This year it just happened to be that the sun was about as far as it gets from the earth during the eclipse... not entirely as far as it gets but about as far as it gets from the earth... which made it small.

Fraser: So, that's the smallest sun, right...

Pamela: And the moon was about as close as it gets... not as close, but about as close... which made a big moon.

Fraser: Biggest moon...

Pamela: And so that bigger moon was able to block out the smaller sun for a longer period of time. Now other eclipses might only last a minute or less because you don't have just the right combinations. In some cases, you actually end up with hybrid eclipses where the changes in distance for the moon actually lead the eclipse in some parts of the world to be annular and in other parts of the world it's a total eclipse. Those are the weirdest eclipses of all.

Fraser: So, then why do only certain parts of the earth get to see the eclipse? Why doesn't everybody get to see the eclipse?

Pamela: The problem is that you have to be in the shadow to see the eclipse. Just traveling a few miles in some cases can take you out of the area where the shadow of the moon touches the earth. You can sort of imagine this if you go out on a sunny day and hold a golf ball up. The shadow of that golf ball only touches one area on the ground. Now the closer you bring the golf ball to the planet, basically because human beings are short, you don't really within your height see that big a difference in the size of the shadow. But if you took that golf ball up to the top of the building and used the golf ball and a really long stick to cast a shadow onto the street below, you'd see that the shadow was much smaller. The further you move that golf ball from the surface of the planet, the smaller the shadow appears. You have to be exactly in the shadow to get the sun blocked out to your eyes. It's like holding up your hand to block the sun except you're holding up the moon, which is way cooler than holding up your hand to block the sun.

Fraser: Right, so you can kind of imagine as the moon passes... is orbiting around the earth... and things are working out perfectly, that the moon's shadow kind of shows up on one side of the earth and then zips across the planet and then is off into space again. Because the moon is always casting a shadow from the sun, right? It's just when that shadow happens to cross the earth that some lucky people on Earth will happen to see the eclipse.

Pamela: Exactly. One of the really weird things is the combination of the earth's rotation and the moon orbiting around the planet and the earth and moon together orbiting around the sun cause all sorts of motions of that shadow. So if you pull up maps of eclipse paths, you'll see that there are series of different identical-looking paths... they may cross slightly different parts of the planet, repeating as they go... but there are many, many different types of shadow paths across the planet. It's one amazing way to get a real sense of all the motions that are going on. We've all moved flashlights around to cause shadows to dance on the wall, well all the different motions of the planet, the moon, and the sun and the earth and moon around it cause the moon's shadow to dance around on the planet Earth.

Fraser: Right. So then let's reverse the scenario, and let's talk about a lunar eclipse because that... everybody gets to see. So this, I guess, is obviously the opposite. The moon has traveled completely around the earth, and now it's going through the earth's shadow.

Pamela: And we consistently get two lunar eclipses about every six months. Sometimes we can get lucky and we'll actually have two eclipses one lunar month apart, which is kinda cool, where you can get three... and if everything lines up absolutely perfectly... and I don't remember the frequency of this... even four eclipses of some sort or another in one year.

Fraser: But they are bunched up, I know, in one month increments. So you get two eclipses, and then six months of waiting, and then two eclipses.

Pamela: And these are again occurring when the moon crosses that ecliptic line, but now it's happening during full moon. The reason we get a full moon every month is because the moon's orbit keeps it out of the earth's shadow most of the time and it's able to reflect back at us an entire face-worth of sunlight. Now, if the moon happens to get in the way of the earth's shadow, we see it glow only from light that's refracted around by our atmosphere. It glows this bloody-red color, in some cases, of refracted light.

Fraser: And the lunar eclipse is like in all of astronomy... it's one of the things that everybody can do. About half the lunar eclipses will be visible from any place on earth. So you have a 50-50 shot of being able to see the lunar eclipse... mostly. And it's gorgeous... it's amazing. If you have a clear sky, you get chomps taken out of the moon and then at the moment of total eclipse, it turns this blood-red color. It can turn different colors of red or brown, depending on what's in the atmosphere. It's just amazing. So if you... once again... lifeless, right? See Saturn... see a meteor shower... see a lunar eclipse. If you don't make a holiday out of getting outside and gathering your friends together and watching the eclipse... and in many cases you don't have to do anything... you just look out your window and you can see a lunar eclipse.

Pamela: Some of them are more noticeable than others. The earth's shadow has two different parts to it... the umbra and the penumbra. This is the effect of... does the edge of the sunlight from the sun pass on one side or the other of the planet Earth. Each point on the sun is giving off light in all different directions, so if you draw complex ray diagrams... we'll put these on our website... you end up with the shadow that has the darkest part of the shadow and then it has a lighter part of the shadow. There's the occasional unfortunate eclipse where you see absolutely nothing because the sun and the moon and the earth line up so that the moon only goes through the lesser part of these two shadows. But when you get lucky, it lingers for a long time in the darkest part of the shadow. You never know what color the moon's going to be. What color you see depends on when was the last time a volcano went off... what is the current level of pollution in the atmosphere... which is a bit depressing but it does affect what you see with lunar eclipses. They are truly fabulous and I have to admit I'm still bitter because the very first baseball game I was ever taken to see was during a lunar eclipse. And where we were sitting in the stands.... the eclipse was directly behind us and I couldn't see it. Then, the Red Sox had the audacity to lose the game. So I saw a losing game and missed my lunar eclipse. It was very sad.

Fraser: Ohhhh... yeah... so thanks to pollution for making pretty eclipses... that's something that pollution's good for. So, as we said, those are happening with the moon passing into the earth's shadow... opposite of the solar eclipse. Now are there any other kinds of eclipses that we get just even here in our solar system? We can sometimes see shadows passing on the face of Jupiter, right?
Pamela: Right, so here what we're seeing is transits of the moons of Jupiter cross the face. You can see the shadows touching the face of Jupiter, and what's neat is often the alignments allow you to see the well-lit-up planet off a little bit lagging or above the shadow itself so you can see both worlds and then the little dark dot on the surface of Jupiter.
Fraser: So, if you were on the surface of Jupiter, what would you see?
Pamela: If you were on the surface of Jupiter you'd be seeing a solar eclipse at that moment if you were under that little dot floating in the gaseous atmosphere of Jupiter.
Fraser: But I guess it wouldn't really be an eclipse because it would just be the tiny moon passing in front of the sun, but it wouldn't be blocking the same way that our moon does.
Pamela: Well, as long as you're within the shadow... it is. That's the amazing thing. Even for worlds like Jupiter, what matters is how close is that little moon...
Fraser: And how small is the sun... right....
Pamela: If that little moon is close enough to you and the sun is so far away once you get to Jupiter that it's much smaller in the sky, you can still get that full solar eclipse.
Fraser: So when we see that little shadow, that means that from that point on Jupiter's surface... obviously it doesn't have a surface, just cloud tops... the light of the sun is being blocked by that moon, and so they would appear similar in the sky. That's amazing. But from here on Earth, watching that happen, we're seeing a transit.
Pamela: Yes. Yes. And then we also get to see transits of Mercury and Venus in front of the sun, and this is actually one of the first ways that we were able to start mapping our solar system rather accurately.
Fraser: Here comes the science!
Pamela: Yeah. So people were able to predict... so, we suspect that Venus will pass in front of the sun on these given days... and Venus passing in front of the sun doesn't happen very often because you have to get the earth, which is on a tilted orbit, and Venus, which is on a tilted orbit, to have their tilts... have their points in their orbits such that where they are exactly puts them on a line with the sun at the same time. And this tends to happen in groups of two, where you'll get a pair roughly every 21 ½ or 105 ½ years. We're in fact in the middle of a pair right now where there's a transit of Venus in 2004 and will be another one in 2012.
Fraser: 2012! Isn't that the end of the universe?
Pamela: We'll still be around to report on it. Back in the 1700s, the pair in 1761 and 1769, they realized that we could use these transits to figure out how far away the sun is because if you have people on north-south lines on the planet Earth go measure where on the disk of the sun they see Venus crossing... depending on where you are on that north-south line you'll have an angle that puts Venus a little higher up on the disk, a little lower down on the disk, and we know the size of the earth... so we can get one side of the triangle. We can then by looking at that change at where it appears on the sun, that's an angle. We know the ratio of the distance from here to Venus and from Venus to the sun

from Kepler's equations. Putting all these pieces together, we can finally calculate what is one astronomical unit. So they were finally able to start to make that measurement in 1761 and 1769. And then they were able to get good solid measurements in the 1870s and 1880s with the next pair of Venus transits.
Fraser: Right, and there are some amazing stories... the quest for the earlier explorers to get to the places they had to be to view the transits... the trials and tribulations... attacks by pirates... a horrible nightmare just to get that really precise astronomical data. They're some of the most important measurements that have ever been made in astronomy and in science. The stories are amazing, so I highly recommend.... look them up... there's some great books on the history of trying to get those measurements.
Pamela: Then join us somewhere on the planet in 2012 to replicate the measurements. If you happen to be in the Boston area, Harvard University has in their Science Center, on display, at least last I looked, some of the telescopes that were used in those early measurements to try to track Venus crossing the sun.
Fraser: So, before we move away from eclipses in the solar system, because we're going to talk about some other ones, let's talk a bit about safety and observation and how to do that. So, let's say that you want to see a solar eclipse. What are the ways to see one safely?
Pamela: So my favorite way is you can actually take a kitchen colander, a strainer like you use for spaghetti, hold it up and cast the sun's light through the little holes. This acts like a pinhole projector and you can get hundreds of little images cast on the ground of the eclipsing sun.
Fraser: Yeah, don't look up through it, just let the shadows fall on the ground.
Pamela: And watch the shadows. Now there's of course all sorts of different filters you can get... Thousand Oaks is just one of the many companies that makes filters. They're one of the ones here in the United States. Call up the people at Oceanside Photo and Telescope... tell them, "I'm going to go see a solar eclipse—what should I get?" That's what I do. They'll help you pick out the right equipment for your binoculars, for your eyes, for your telescope. Any old solar filter that you can use on any old normal day will allow you to watch up until the moment of totality safely. Then during totality, they're a little bit too overzealous in blocking the sun's light, and so you'll need something slightly different.
Fraser: You can actually see it with your unaided eye during totality, can't you?
Pamela: Yeah... it's during the really long eclipses that you have to start worrying about the ultra-violet. But, kitchen colander is always the best way to go. For transits of Venus and Mercury, where Mercury transits are a lot more common, my favorite thing to do is to get one of the little Astroscans, they look like little cherry tomato telescopes, and use them to project the image up on a wall. Then you can get a nice magnified view.
Fraser: Yeah... what I did was I had a little spotting scope, and also I've done this with binoculars, and you just hold the binoculars and you point them up towards the sun... not looking through them, so you're letting the light of the sun come out the other end of the binoculars and land on a piece of paper or on the ground, and you'll see the sun. Now the problem is that if you do it too long, you'll wreck your binoculars.
Pamela: Right.

Fraser: And that's what I did. You'll heat up the interior of the binoculars and you'll ruin the optics. It's good to just catch a glimpse of it but not to study it for any length of time.

Pamela: Right. And the Astroscan... the one that I used... did survive the ordeal, but I will admit that the light was going through a very dirty office window, into my Astroscan, and then getting projected onto my office wall because I was really lazy in graduate school during the last transit.

Fraser: But the great thing about using binoculars or a really... this is what you could use a department store telescope for... something you don't mind destroying... is that because then you could kind of blow up the image. Then you can have a really big image, and you can really see the eclipse or you can see the sunspots... you can see all that kind of stuff on it. So that's really great. And with a lunar eclipse... completely safe. If your eyes don't hurt looking at the regular full moon, you're fine to look at a lunar eclipse. Now I want to talk a bit about science because we're now finding eclipses, transits, on other solar systems. It's a way that astronomers are looking for planets.

Pamela: And it's also a way that we're better understanding the planetary bodies in our own system. So, with extrasolar planets, we go out... and this is actually one of the things the Herschel Space Telescope is dedicated to doing... is you watch a star, a nearby star, any old star, but with high, high precision. So, this is generally only done with the nearest and brightest stars that you can get the best... we call it signal to noise... the highest accuracy measurements. You can do this with a four-inch telescope if you have the right CCD, the right digital camera attached to your telescope. You look for slight, slight variations in the amount of light from the star, and you see if these slight variations repeat themselves. You should be able to make a plot where you see a nice large flat period of time where the star is very, very bright, and then depending on the size of the planet it will either drop straight down to a little bit fainter or gradually drop down to a little bit fainter... stay there for a little while while the planet goes in front of the star... and then reverse itself and come back out and go back up to being nice and bright again. That very slight variation allows you to start to understand what's the period of the planet's orbit? How long does it take for this cycle to repeat over and over? It allows us to understand how big is this star... how long did it take it to get from being completely not in front of the star to being completely in front of the star? A big planet will gradually cause the light to get fainter whereas a little tiny planet will cause the star's light to very quickly get a little bit fainter. By looking at all these different things we can understand the size of the planet, the orbital inclination... does the planet cut across the top edge of the star or cut across the middle of the front of the star? It's a great way to learn all the little details that we can't measure directly about those stars and planets.

Fraser: Yeah, but it's just like a fluke thing... it's like there maybe tens of thousands of stars in our nearby neighborhood, but only a fraction of those are the ones that have the star and the planet in the perfect angle so that we can see it here on earth.

Pamela: And the other side to that is there's only a fraction of the stars out in the universe that are lined up so that when they look at us, they see us and Jupiter and the other planets cutting in front of the sun. Now what's amazing about this technique is as the planet passes in front of the star, that star's light goes through the planet's atmosphere. We can measure what are the chemicals in that planet's atmosphere. We've already found water on planets around other stars. Now this means that aliens out along

that line that allows the earth to pass directly in front of the sun, if they can see us and they can see our atmosphere, they can see all the pollution that we've put into the atmosphere, and they'll know we're here.
Fraser: And the oxygen, right?
Pamela: Well, and the oxygen... but oxygen just means plants.
Fraser: And so this is how we're just right on the edge of being able to discover life on other planets because we now have the technology to detect, with Kepler, just about Earth-size worlds going around other stars. With the Terrestrial Planet Finder, after we nag NASA to bring the mission back, it will be able to sense the atmospheres of Earth-size planets going around other stars using this method. It will watch how the atmosphere of the planet changes the starlight coming from the star and be able to detect whether or not there's pollution in the atmosphere and make a pretty good guess about whether there's life on that planet. That's about the most important question we could possibly ask.... which is why the Terrestrial Planet Finder should be resurrected.
Pamela: And my personal bet... and I'm willing to take this up with Seth Shostak at an "I'll pay for his dinner if I'm right" type of level... or actually he should pay for my dinner if I'm right and I'll pay for his if he finds aliens his way first... I think we're going to find intelligent life on other worlds first by finding how they've destroyed their atmosphere, and only later via radio communications. I think this is a much more straightforward way to say ah, there's industrial something going on over there.
Fraser: Yeah, I totally agree. If we get more and more powerful telescopes, we'll be able to study more and more stars and their planets, and be able to turn up larger and larger area... or volume of space... more and more of these planets and be able to detect their atmospheres and eventually we'll be turning up civilizations one after the other.... I hope.
Pamela: I hope, too. But for now, if you want to get involved, look up when a solar eclipse is... look up when a lunar eclipse is... find a transit... watch a moon pass in front of Jupiter. And if you want to do science, the one science that's still open for anyone is watching an asteroid passing in front of a star.
Fraser: Yeah, this is one thing... maybe we should just take a second because we really didn't talk about occultations too much... which is the method that we just talked about for finding life... this is how astronomers found the atmosphere on Pluto, right?
Pamela: Right. So, any time that a planet passes in front of a star, any time an asteroid passes in front of a distant star, that star's light gets blocked out and before it gets blocked out if there's an atmosphere, it passes through the atmosphere. And one neat way to map the shape of all those potato-shaped asteroids out there, is to get a bunch of people on the planet earth lined up perpendicular to the passage of that object across the sky and say ok, I see the star blocked out for this long... I see the star blocked out for this long.... and because each of them will have a different angle between the asteroid and the star, they'll see the star cut across a different part of the asteroid, and whoever sees the star's light blocked out the longest, just looked across the fat part of the asteroid. The person who sees it not blocked out for very long at all has looked at the skinny part of the asteroid. So we can build three-dimensional maps of asteroids over time as they rotate and pass in front of multiple stars, and that's just really cool.
Fraser: There's always a need for amateur astronomers to get involved in doing those timings.

Pamela: And if you're into Ham radio you can get involved with people all over the world doing the same thing, watching the star's light blink out and blink back on.
Fraser: Perfect. Alright, well thanks a lot, Pamela. We'll talk to you on another show.
Pamela: Sounds great, Fraser. I'll talk to you later.
Fraser: Bye.