Tides: Crash Course Astronomy #8

Crash Course: Astronomy
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Yâ€™know, if Shakespeare had been an astronomer, heâ€™d have said that â€œthere is a tide in the affairs of the Universe, and on such a full sea are we now afloat.â€• He wouldâ€™ve been right. You might just think of tides as the ocean going in and out every day, but in fact what astronomers call tides are a subtle but inexorable force that have literally shaped most objects in the Universe. And to understand tides, we start with gravity. Gravity is a force, and it weakens with distance. An important thing to note is that we measure gravity from the center of mass of an object, not its surface. One way to think of the center of mass of an object is the average position in an object of all its mass. For an evenly distributed sphere, thatâ€™s itâ€™s center. Right now, unless youâ€™re an astronaut, youâ€™re about 6400 kilometers from the center of the Earth. If you stand up, your head is a couple of meters farther away from the Earthâ€™s center than your feet. Since gravity weakens with distance, the force of Earthâ€™s gravity on your head is an eensy weensy bit less than it is on your feet. How much less? A mere 0.00005%. And thatâ€™s way too small for you to ever notice. But what if you were taller? Well, the taller you are, the farther your head is from the Earthâ€™s center, and the weaker force it will feel. If you were, say, about 300 kilometers tall, the force of gravity would drop by about 10% at your head. That probably would be enough to notice, if you werenâ€™t dying from asphyxiation and, yâ€™know, being 300 kilometers tall. This change in the force of gravity over distance is what astronomers call the tidal force. When you have a massive object affecting another object with its gravity, its tidal force depends on several factors. For one thing, it depends on how strong the gravity is from the first object; the stronger the force of gravity, the stronger the tidal force will be on the affected object. It also depends on how wide the affected object is. The wider it is, the more the force of gravity from the first object changes across it, and the bigger the tidal force. Finally, it depends on how far the affected object is from the first object. The farther away the affected object is, the lower the tidal force will be. Tides depend on gravity, and if gravity is weaker, so is the tidal force. The overall effect of the tidal force is to stretch an object. Youâ€™re applying a stronger force on one end than you are on the other, so youâ€™re pulling harder on one end. Thatâ€™ll stretch it! And this is where tidal forces become very important. Look at the Moon. It has gravity, but much less than the Earth because itâ€™s less massive. Itâ€™s 380,000 kilometers away, so the gravitational force it has on you is pretty small. And youâ€™re pretty small compared to that distance, just a couple of meters long from head to feet. But the Earth is big! Itâ€™s nearly 13,000 kilometers across. That means the side of the Earth facing the Moon is about 13,000 kilometers closer to the Moon than the other side of the Earth. This is a pretty big distance, enough for tides to become important. The side of the Earth facing the Moon is pulled harder by the Moon than the other side of the Earth, so the Earth stretches. It becomes ever so slightly football-shaped, like a sphere with two bulges, one pointing toward the Moon, and one pointing away. This is probably the weirdest thing about tidal forces. You might expect only one bulge, on the side of the Earth facing the Moon. But remember, we measure gravity from the centers of objects. The side of the Earth facing the Moon feels a stronger pull toward the Moon than the Earthâ€™s center, so itâ€™s pulled away from the center. But the side facing away from the Moon feels a weaker force toward the Moon than the Earthâ€™s center. This means the center of the Earth is being pulled away from the far side. This is exactly the same as if the far side is being pulled away from the center, and thatâ€™s why you get two bulges on opposite sides of the Earth. The tidal force is therefore strongest on the sides of the Earth facing toward and away from the Moon, and weakest halfway in between them on each side. A lot of the Earth is covered in water, and water responds to this changing force, this stretching. The water bulges up where the tidal force is strongest, on opposite sides of the Earth. If thereâ€™s a beach on one of those spots, the water will cover it, and we say itâ€™s high tide. If a beach is where the tidal force is low, the waterâ€™s been pulled away from it, and itâ€™s low tide. But wait a second: The Earth is spinning! If youâ€™re on the part of the Earth facing the Moon, youâ€™re at high tide. Six hours later, a quarter of a day, the Earthâ€™s rotation has swept you around to the spot where itâ€™s low tide. Six hours after that youâ€™re at high tide again, and then another six hours later youâ€™re at low tide for the second time that day. Finally, a day after you started, youâ€™re back at high tide once more. And thatâ€™s why we have two high tides and two low tides every day. Very generally speaking, the ocean tide causes the sea level to rise and fall by a meter or two, every day. Incidentally, the solid Earth can bulge as well. Itâ€™s not as fluid as water, but it can move. The tidal force stretches the solid Earth by about 30 centimeters. If you just sit in your house all day, you move up and down by about that much...twice! Like the saying goes, a rising tide lifts allâ€¦ surfaces. The Earthâ€™s spin has another effect. Lag in the water flow means the water canâ€™t respond instantly to the tidal force from the Moon. The Earthâ€™s spin actually sweeps the bulges forward a bit along the Earth. So picture this: the bulge nearest the Moon is actually a bit ahead of the Earth-Moon line. That bulge has mass; not a lot, but some. Since it has mass, it has gravity, and that pulls on the Moon. It pulls the Moon forward in its orbit a bit, like pulling on a dogâ€™s leash, accelerating it. The Moon responds to this tug by going into a higher orbit: The Moon is actually moving away from the Earth! The rate of recession of the moon has been measured and itâ€™s something like a few centimeters per year, roughly the same speed your fingernails grow. Now get this: the Moon has gravity. Just as the bulge is pulling the Moon ahead, the Moon is pulling the bulge back, slowing it down. Because of friction with the rest of the Earth, this slowing of the bulge is actually slowing the rotation of the Earth itself, making the day longer. The effect is small, but again itâ€™s measurable. OK, letâ€™s get a little change of perspective. Everything Iâ€™ve said about the Moonâ€™s tidal effect on the Earth works the other way, too. The Moon feels tides from the Earth, and theyâ€™re pretty strong because the Earth is more massive and has more gravity than the Moon. Just like Earth, there are two tidal bulges on the Moon; one facing the Earth and one facing away. Long ago, the Moon was closer to the Earth, and spinning rapidly. The Moonâ€™s tidal bulges didnâ€™t align with the Earth, and the Earthâ€™s gravity tugged on them, slowing the Moonâ€™s spin and moving it farther away. As it moved farther away, the time it took to orbit once around the Earth increased: Its orbital period got longer. Eventually, the lengthening rotation of the Moon matched how long it took to go around the Earth. When that happened, the axis of the bulges pointed right at the Earth. Thatâ€™s why the Moon only shows one face to us! It spins once per month, and goes around us once per month. If it didnâ€™t spin at all, over that month weâ€™d see the entire lunar surface. But since it does spin once per orbit, we only ever see one face. This is called tidal locking, and itâ€™s worked on nearly every big moon in the solar system; tides from their home planet have matched their spin and orbital period. These moons all show the same face toward their planet! Now wait a second. If the Moon has gravity, which causes tides, and is the root cause behind all these shenanigans, what about the Sun? Itâ€™s even bigger than the Moon! Tides depends on the gravity from an object, and your distance from it. The Sun is far more massive than the Moon, but much farther away. These two effects largely cancel each other out, and when you do the math, you find the Sunâ€™s tidal force on the Earth is just about half that of the Moonâ€™s. The way the Sunâ€™s tidal force and the Moonâ€™s tidal force interact on Earth depends on their geometry, which changes as the Moon orbits us. At new Moon, the Earth, Moon, and Sun are in a line. The Moonâ€™s tidal force aligns with the Sunâ€™s, reinforcing it. This means we get an extra high high tide and an extra low low tide on Earth. We call this the spring tide. When the Moon is at first quarter, the tidal bulge from the Moon is 90Â° around from the Sunâ€™s; high tide from the Moon overlaps low tide from the Sun. We get a slightly lower high tide, and a slightly higher low tide. We call those neap tides. The pattern repeats when the Moon is full; the Moon, Earth, and Sun fall

along a line again, and we get spring tides. A week later the Moon has moved around, and we get neap tides again. Not only that, the Moon orbits the Earth on an ellipse. When itâ€™s closest to us we feel a stronger effect. If that also happens at New or Full Moon, we get an added kick to the spring tides. This is called the proxigean tide, and can lead to flooding in low-lying areas. Unless you live on the coast, I bet you had no idea tides were so complex! Tides are universal; they work wherever thereâ€™s gravity. If two stars orbit each other, each raises a tide in the other. Just like the Earth and Moon, that can slow their spin and increase their separation. Many planets orbiting other stars may be tidally locked to those stars. Near a black hole, where the gravity is incredibly intense, the tides are so strong they would pull you like taffy into a long, thin string. Astronomers call this effectâ€¦ spaghettification. No, seriously, thatâ€™s what we call it! Today you learned that tides are due to the changing force of gravity over distance. The strength of the tidal force from an object depends on the gravity of the object, and the size of and distance to the second object. Tides raise two bulges in an object, creating two high tides and two low tides per day on Earth. Tides have slowed the Earthâ€™s rotation, moved the Moon away from the Earth, and locked the Moonâ€™s rotation and orbit so that the Moon always has one side facing us. So. Tide goes in. Tide goes out. It turns out, I can explain that. Now you can too. Crash Course is produced in association with PBS Digital Studios. This episode was written by me, Phil Plait. The script was edited by Blake de Pastino, and our consultant is Dr. Michelle Thaller. It was co-directed by Nicholas Jenkins and Nicole Sweeney, and the graphics team is Thought CafÃ©.