This presentation is about something familiar to us, tides, in unfamiliar settings like moons around other planets. Ocean tides on Earth may seem boring, but the same mechanism can cause volcanoes and geysers on other moons and even rip apart comets.

Please feel free to email me with comments or questions. I would like to point out NMSU’s Astronomy department webpage. If you click on “Public Events” there is a link to Request a Visit from one of the graduate students. Activities and talks in the past have included careers in astronomy, studying the Sun with solar telescopes, making comets from dry ice, a football field scale model of the solar system, and misconceptions about astronomy. We do this for free because we enjoy sharing astronomy … and we like to talk.
What causes ocean tides on Earth? The Moon! How does it work? Something to do with gravity, right? The model inside our heads of how this would work has something like a bulge of water that points toward the Moon. That makes intuitive sense because the Moon is attracting the water gravitationally.
However, a person standing on the Earth in this model would only experience ONE HIGH TIDE and ONE LOW TIDE. Anyone familiar with the ocean, bays, or harbors can tell you that there are two high and two low tides each day. Our intuitive model doesn’t explain observations!
Gravity depends on the mass of object and the distance they’re separated. The greater the separation, the weaker the force of gravity. Since moons and planets are not points (they’re big balls), this results in tides being raised. For example, the Moon raises tides on the Earth. One side of the Earth is closer to the Moon than the other side. The closer side feels a stronger gravitational force than the center of the Earth, and the further side feels a weaker gravitational force than the center of the Earth.

The yellow arrows represent the force of gravity at three places: facing the Moon, center of the Earth, and facing away from the Moon. The part of the Earth at that center point feels an attraction to the Moon that is stronger than the side that isn’t facing the moon but not as strong as the side facing the Moon. From the point of view of the center of the Earth, the side facing away from the Moon isn’t being pulled as much --- so it looks like it’s being pushed away by the Moon!

These forces want to stretch the Earth to look like the blue oval. The rocky part of the Earth isn’t very elastic, so it doesn’t stretch that much; but the water does! The water is raised by about three feet on both sides of the Earth because of the gravitational attraction to the Moon! The picture shows this effect greatly exaggerated. There are two “high tides” in this picture: one the side of the Earth closest to the Moon, and one on the side furthest from the Moon. As the Earth rotates, different parts of the Earth are pointed toward and away from the Moon, so different parts of the ocean are raised in “water bulges”. How much is the water raised? About 3 or 4 feet!
This animation shows the Earth being tidally distorted by the Moon (highly exaggerated). The undistorted shape of the Earth is show as a white circle. A red point on the Earth marks a place on the West Coast of America. The “high tide” regions are where the water bulge of the Earth points toward and away from the Moon. The Earth rotates, so different regions move in and out of high tide. The inset box shows the tide condition at the red point and also shows whether the Moon is up or not. First, watch the animation noting when the Moon is up. Then, watch the animation and note when high and low tide occur.

The exact time of high and low tide at any particular location, as well as how strong they’ll be, are determined by local geography (the shape of the bay or harbor, how steep the ground is). The other planets in the solar system are too far away to raise tides in Earth’s water, but the Sun is massive enough that it can raise tides even though it’s 93 million miles away from the Earth. The tides from the Sun are weaker than the Moon’s tides. Sometimes the Moon and Sun stretch the Earth’s water in the same direction, resulting in an unusually high tide called a Spring Tide. Sometimes the Moon and Sun cancel each other’s tides out, resulting in an unusually low tide called a Neap Tide.

The Earth also raises tides on the Moon, and the Apollo astronauts used seismographs to detect moonquakes that were caused by the change in stretching as the Moon orbits the Earth.
There are a lot of moons in our solar system. Here are a few of the larger ones shown to scale (with the size of the Earth as a reference). They all look different! Some have atmospheres like Titan; many have color differences like Iapetus, Rhea, and Ganymede; some have craters like our Moon and Callisto.
While each moon is interesting as a little world, we'll go through examples of unusual activity on four moons in particular: Jupiter's Io and Europa, Saturn's Enceladus, and Neptune's Triton. The odd things observed about these moons are like puzzle pieces or evidence of just how powerful tidal forces can be.
Io is Jupiter’s innermost moon. It doesn’t look like our Moon since there are very few craters on Io. This is odd because Io is old and should have lots of craters. An infrared picture gives us a clue about what is happening. Infrared light is like heat detection, so those spots that look like acne are very hot!
In fact, those spots are volcanoes! There aren’t any craters on Io because the surface is covered in lava flows and volcanic gases, just like a new layer of snow erases footprints! The Voyager and Galileo spacecraft saw plumes of sulfur from erupting volcanoes. A zoomed in view (false color but shown as yellow because most of Io’s surface is covered in sulfur) shows lava flowing from a volcano. Io is the most volcanic body in the solar system!

While the water bulge on Earth is about 3 feet high, the land bulge on Io is about 330 feet --- and Io is almost half the size of Earth! There are immense tidal forces being raised on Io!
Europa is the next moon out from Io and it also doesn’t have many craters. Instead, it’s smooth and covered in cracks and plates.
These cracks highly resemble ice flows on Earth. Astronomers have studied Europa and know that the surface is salty water ice. Since Jupiter is 5x as far from the Sun as the Earth is, it should be very, very, very cold ---- so water should be a solid. However, if Europa were a solid ice ball, it should have a surface with lots of craters!

Europa has a sub-surface ocean of liquid water! The ice plates flow on this ocean much like tectonic plates on the Earth: they collide, fold over or under each other, and get created anew from the liquid water beneath. Europa refreshes its surface and erases old craters. The mystery here is that Jupiter is too far from the Sun for water to be a liquid!
Saturn’s moon Enceladus resembles Europa because it is smooth (although there are a few craters) and also has large cracks. Enceladus is somehow refreshing its surface, but not quite as much as Europa. Saturn is 10x further from the Sun than the Earth, so it’s even colder than Jupiter and there is less of a reason to have liquid water!
The Cassini spacecraft orbits Saturn and studies it and its moons. It found that the large cracks have geysers of salty water and ammonia. Even if Enceladus doesn’t have a full subsurface ocean like Europa, what could be warming the water to a liquid?
Neptune is 19x further from the Sun than the Earth and its largest moon, Triton, also shows ice-like cracks (middle of image) and geysers (black plumes at the top of the image).
Tidal Heating Activity

Take about 25 minutes for the Tidal Heating Activity with elastic bands.

While we cannot recommend any name brand, this activity has been done well with Goody “bright and bold” hair elastics for girls, especially since they can be purchased for only a few dollars for a pack of three sizes (of which the largest size works best).
Tidal Heating Activity

• Stretching elastic bands!
• Changing stretching = friction = heat
• Gravity stretches Moons = tidal force
• Changing tidal forces also cause heat
• Certain arrangements result in lots of stretching

If you stretch a rubber band a lot (or bend a paper clip a lot), you can feel it get hot. The friction of stretching the material generates heat, and the more the stretch is varied the more heat is generated. Tidal forces can stretch moons. Changing tidal forces can vary how they’re stretched and, just like the elastic band, make them get hot. Certain combinations of being closer to a planet and having other moons raise tidal forces results in a lot of heat!
Tidal forces can be so strong that they rip objects apart. The activity had you calculate this Roche Limit for Saturn. Saturn’s rings are made of small icy particles. These particles should have clumped to form a moon, but they couldn’t because the tidal force would pull them apart again!
The Cassini spacecraft has given us some amazing shots of Saturn. In this one we see tiny lumpy Epimetheus in the foreground and massive atmosphere-shrouded Titan in the background. Wait, how can a moon exist inside Saturn’s Roche Limit? Shouldn’t it have been ripped apart?!

There is another factor to take into account: the size of the moon. Remember how tidal force was the difference between the force of gravity on the near and far side of a moon? The smaller an object is, the less that difference is, and the weaker the tidal force on it. This is how moons can exist in the rings, but notice that they are very small!
Notice how the moons are smaller the closer they are to Saturn.

Remember the geysers on Enceladus? The gas and ice spewed from the cracks doesn’t fall back to the surface --- it orbits Saturn. The geysers of Enceladus maintain Saturn’s fluffy E ring.
Objects can be heated by the Sun. Some moons are very far from the Sun but are heated somehow. Gravity depends on distance, and the closer something is the stronger the force of gravity. Tidal force is how the side of a moon that is closer to a planet feels a stronger gravitational force than the further side of the moon. Planets have tidal forces on moons, moons have tidal forces on planets, and moons can even have tidal forces on each other! The more the tidal force changes, the more the moon stretches, and the more it heats. This heat causes activity like volcanoes and geysers and can keep water liquid to form oceans. This is exciting because one of the requirements for life is water --- and tidal heating can allow liquid water to exist in more places in the solar system! NASA’s mantra for finding signs of life in the solar system is “follow the water”, so it would be exciting to study active icy-watery moons like Europa!