The Gravity of the Situation: Crash Course Astronomy #7

Crash Course: Astronomy
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We live â€" and stop me if Iâ€™m going too fast â€" on a planet. I mean, sure, duh. But this isnâ€™t the natural state of the Universe; or, at least, itâ€™s not the way things usually are. Most of the Universe is pretty empty â€" thatâ€™s why we call it â€œspaceâ€• â€" and if I were to magically transport you someplace randomly in the cosmos, the chances are youâ€™d be a million light years from the nearest substantial object. Evolving on a planet has warped our sense of physics. If I throw an object away from me, it comes back. Thatâ€™s bizarre! It should just keep going, moving away from me at a constant speed. Instead though it goes up, slows, stops, then falls back down toward me. The difference between living on a planet and being in deep space is gravity. Gravity from an object goes on forever, but it gets weaker rapidly with distance. A zillion light years away, the Earthâ€™s gravity is fantastically weak, but here on Earth itâ€™s literally a force to be reckoned with. And in some places it can be a lot stronger than what we experience right here. For most of history, gravity was just a fact of life, neither understood nor examined terribly closely. In the mid 1600s, scientists like Robert Hooke and Isaac Newton started investigating it using math â€" in fact, the two men got into a bitter feud over who thought of what first. But whoever it was who first got it right, now we have a much better understanding of how gravity works. One thing before we get to gravity. An important concept that comes up a lot is mass. Itâ€™s a bit tricky to define, but you can think of it as how much stuff makes up an object. I know, thatâ€™s not very scientific sounding, but itâ€™s not a bad way to think about it. Something with more mass has more stuff in it. Size doesnâ€™t really play into this; two objects can have the same mass but one can be much larger than the other. In that case, the bigger objectâ€™s mass is more spread out, so we say it has lower density, where density is how much mass is inside a given volume. In science terms, mass tells us how much an object resists having its motion changed. An object with more mass is harder to get moving than an object with less mass, which is pretty obvious if youâ€™ve ever tried pushing on a toy car versus a real truck. But mass is also defined using gravity. Everything that has mass also has gravity and can inflict this force on another object. The amount of force you feel from the gravity of an object like a planet depends on three things: How much mass it has, how much mass you have, and how far away you are from it. In fact, distance dominates here; the force of gravity weakens with the square of the distance. Double your distance from an object and the force of gravity drops by 2 x 2 = 4 times. Go 10 times farther away and the force drops by 10 x 10 = 100 times. Gravity is also attractive: It can only draw things in, not repel them. But how it attracts things is where it gets fun. If I hold up a rock and let go of it, it falls to the ground. What might be hard to see is that it gets faster the longer it drops. Forces accelerate objects, so the longer the force acts, the more the objectâ€™s velocity changes â€“ in this case getting faster. If I drop a rock from higher up, itâ€™ll move faster when it hits the ground. Other forces act on moving objects, as well, like friction and air resistance, counteracting gravity, making this acceleration hard to see. But in space, the force of gravity becomes very clear. Two objects that have mass will attract each other. If there are no other forces acting on them, theyâ€™ll accelerate toward each other until they meet. Remember, though, that the force of gravity depends on those masses. If one is really massive, and the other not so much, then in more practical terms the massive one will pull in the less massive one. The more massive one does move, but much less than the other one. When objects are free to move under the effects of gravity, we say they are in orbit. The simplest kind of orbit may not be what you think: Itâ€™s actually just a line! When you drop a rock, itâ€™s very briefly in orbit. Ignoring things like the Earthâ€™s rotation (which adds a bit of sideways motion) itâ€™s close enough to say the rock just falls straight down, and is stopped because the Earth itself gets in the way. Thatâ€™s not a terribly interesting orbit! So what if, instead of dropping the rock, we throw it? That gives it a little bit of sideways motion, so instead of hitting the ground at my feet, it hits a bit farther away. If I throw it harder, it moves horizontally even more before it hits. What if I throw it really hard? This is where Newtonâ€™s genius comes in. He realized that if you throw the ball hard enough sideways, it will fall at the exact same rate the Earth would curve away underneath it. As Douglas Adams said in â€œHitchhiker's Guide to the Galaxy,â€• flying is just falling and missing the ground. It turns out, thatâ€™s exactly what orbiting is, too. A rock thrown hard enough sideways will fall toward the Earth, but always miss it, going instead into a circular path around it, guided only by gravity. It will orbit the Earth in a circle, taking about 90 minutes to go around the planet once. Circles are simple orbits. The speed at which the orbiting satellite travels depends on the mass of the object itâ€™s orbiting, and its distance from it. The farther it is, the weaker gravity is, so it doesnâ€™t have to travel as quickly to maintain the orbit. Roughly 400 years ago, the astronomer Johannes Kepler realized that there can be other shapes of orbits as well. He discovered the planets orbit the Sun on ellipses, when previously it was thought they orbited in perfect circles. An elliptical orbit happens when you throw the rock sideways even harder than it takes for a circular orbit; it goes up higher on one end of the orbit than on the other. In fact, the harder you throw the rock, the more elongated the orbit gets. An orbit like this is still closed; that is, the orbit repeats itself and the rock is still bound to the Earth by gravity. At some point, though if you throw the rock hard enough, an amazing thing happens: It can escape. Remember, gravity gets weaker with distance. If you throw a rock hard enough, while gravity can slow it down, the gravity gets weaker the farther away the rock is. If the rock has enough velocity, gravity weakens too quickly to stop it. The rock can escape, moving away forever, so we call this the escape velocity. The escape velocity of an object like a planet or star depends on how much mass it has and how big it is. For the Earth, that turns out to be about 11 kilometers per second â€" for Jupiter, itâ€™s about 58 kilometers per second, and for the Sun itâ€™s a whopping 600 kilometers per second. Whatever the particular escape velocity for your cosmic location is, if you fling a rock away from it faster than that, I hope you kissed it goodbye first, â€˜cause it ainâ€™t coming back. One way to think of it is that the rock is always slowing, getting ever closer to stopping, but it never actually stops. If it could travel infinitely far away, it would stop, but thatâ€™s kind of a long trip. This works in reverse, too. If I go way far away from the Earth and drop a rock, itâ€™ll accelerate. When it hits the planet itâ€™ll be moving at escape velocity, that same 11 kilometers per second. And if I give it a little sideways kick, itâ€™ll miss the Earth but still pass us at escape velocity. An escape orbit is open â€" it doesnâ€™t come back â€" and is shaped like a parabola. What if you throw the rock even harder than that? The rock doesnâ€™t come back, and moves away even faster. The orbit is now a hyperbola, which is similar to a parabola, but is even more open. The rock never stops, even at infinity. It just keeps movinâ€™ on. Like all forces, gravity gets weaker with distance. But its force never quite drops to zero; it just gets smaller and smaller as you get farther and farther away. So why then are astronauts on the space station â€œweightlessâ€•? Gravity is still pulling on the astronauts! In fact, at the height of the station, Earthâ€™s gravity has only decreased by a little bit; itâ€™s still about 90% as strong as it is on the Earthâ€™s surface. If they were in a tower 320 kilometers high theyâ€™d weigh 90% of what they do on the Earthâ€™s surface. But the big difference is that the astronauts are in orbit, falling around the Earth. Weight is actually not just the force of gravity on a mass, but how hard a surface pushes back on that mass. For example, when you stand on the ground, the ground pushes back. Otherwise youâ€™d fall through! The force of the ground back on you is what causes you to have weight. In free fall, thereâ€™s nothing pushing back. Youâ€™re falling freely, and so you have no weight. NASA likes to call this condition â€œmicrogravityâ€•, since there are subtle forces acting on you. This actually highlights the difference between mass and weight. In space you have the same mass as you do on Earth, but no weight. If another astronaut pushed on you theyâ€™d have to exert a force, but if you stood on a scale in space it

wouldnâ€™t register anything. Space is weird. Well, compared to Earth. One more thing, and this is truly weird: Photons, particles of light, have no mass, yet they can be affected by gravity, too, bending their direction of flight as they pass a massive object! It turns out gravity can actually warp space! Light travels along the fabric of space like a truck on the road, and if the road curves, so does the truck. I know this is an odd concept, and weâ€™ll be dealing with it later in more detail when we push escape velocity to its limitsâ€¦ with black holes. Today you learned that gravity is a force, and everything with mass has gravity. Gravity accelerates object, changing their speed and/or direction. An object moving along a path controlled by gravity is said to be in orbit, and there are many different kinds: straight lines, circles, ellipses, parabolae, and hyperbolae. You canâ€™t ever escape gravity, but if you travel faster than escape velocity for an object youâ€™ll get away from it without falling back. And if youâ€™re in orbit, in free fall, you have no weight, but you still have mass. This episode is brought to you by Squarespace. The latest version of their platform, Squarespace Seven, has a completely redesigned interface, integrations with Getty Images and Google Apps, new templates, and a new feature called Cover Pages. Try Squarespace at Squarespace.com, and enter the code Crash Course at checkout for a special offer. Squarespace. Start Here. Go Anywhere. Crash Course Astronomy is produced in association with PBS Digital Studios, and you can head over to their channel and find more awesome videos. 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 Michael Aranda, edited by Nicole Sweeney, and the graphics team is Thought CafÃ©.