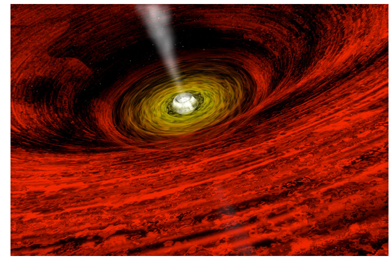
ASTR 311 Tutorial 4: Black Holes

White dwarfs and neutron stars are two bizarre forms of stellar corpses left behind after the star collapses. For a very massive star, though, nothing can stop its end-of-life collapse. The star becomes a black hole, one of the strangest and most extreme objects in the Universe.



Falling into a black hole

How extreme? Spacetime is so curved (or as Newton would say, “gravity is so strong”) not even light can escape once it falls into a black hole. What would happen to a star or a planet that gets too close to the black hole? In this tutorial, you’ll figure that out by watching a poor astronaut fall into *the black hole of death!*

Part 1: Tidal Forces

In Tutorial 1, we saw that the force of gravity between two objects is an “inverse square” law. For example, if the distance d between two objects increases by a factor of 3, the force F between them decreases by a factor of 9. Refresh your memory with these two examples:

1. Suppose the force of gravity between two objects is F_{old}. If the distance between the objects increases by a factor of 2 how does the new force F_{new} compare to the old force?

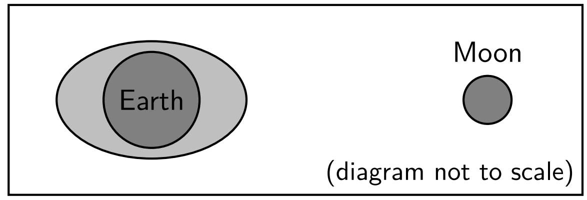
2. Suppose the force of gravity between two objects is F_{old}. If the distance between the objects decreases by a factor of 200 how does the new force F_{new} compare to the old force?

In both cases, you’ve been doing the calculation $F_{\text{new}} = \left(\frac{d_{\text{old}}}{d_{\text{new}}}\right)^2 F_{\text{old}}$.

This formula makes sense because if the new distance is bigger than the old distance, the force decreases but when the new distance is smaller than the old distance, the force increases. The formula makes it easier to look at more interesting cases. Try it on these:

3. The Moon is 384 400 km away. Earth is 6378 km in radius, so the water on the surface of Earth nearest the Moon is closer to the Moon (only $d_{\text{old}} = 384\,400 - 6378 = 378\,002$ km) than the water on the far side of Earth (at distance $d_{\text{new}} = 384\,400 + 6378 = 390\,778$ km). Compare the gravitational force F_{new} between the Moon and the far-side water to the force F_{old} between the Moon and the near-side water. (If you need a calculator, you can log onto the lab computers with username `user`, password `mars-310`)

You should find the far-side force is only about 0.94 of the near-side force. This difference means the Moon pulls more on the near-side water which causes it to pile up. At the same time, the Moon pulls the Earth away from the far-side water, leaving behind a pile of water. These matching near-side and far-side bulges are what causes **the tides** on Earth.



For this reason, this difference-in-forces that causes one object (the Moon) to distort or stretch another (the layer of water on the surface of Earth) is called a **tidal force**.

Where else are tidal forces important?

4. When you're standing up, your head is farther from the center of the Earth than your feet so the force of gravity between Earth and your head is *slightly* smaller than the force between Earth and your feet. How much smaller? Take $d_{\text{old}} = 6\,378\,000$ m (the radius of the Earth, in metres) and $d_{\text{new}} = 6\,378\,000 + 2$ m, pretending you are 2 m tall. Compute how much the force changes:

If your calculator has enough decimal places, you might have found a *tiny* change in the forces. That's because the *change in distance* 2 m, is so small compared to the *actual distance* 6 378 000 m, that the tidal forces are incredibly small.

5. What if the Earth was very small, though? If we shrink the Earth (keeping the mass the same) until it is only 9 mm in radius – about the size of a grape – it will become a **black hole**. Suppose an astronaut is floating above the blackhole-Earth, so his feet are $d_{\text{old}} = 10$ m from the center and his head is $d_{\text{new}} = 12$ m from the center. Compare the forces between the black hole and the astronaut's head (F_{new}) and feet (F_{old}).

You should find the force on his head is about 30% less than the force on his feet. What would the extra force on his feet do to him? And what happens as he get closer to the black hole and the tidal forces grow?

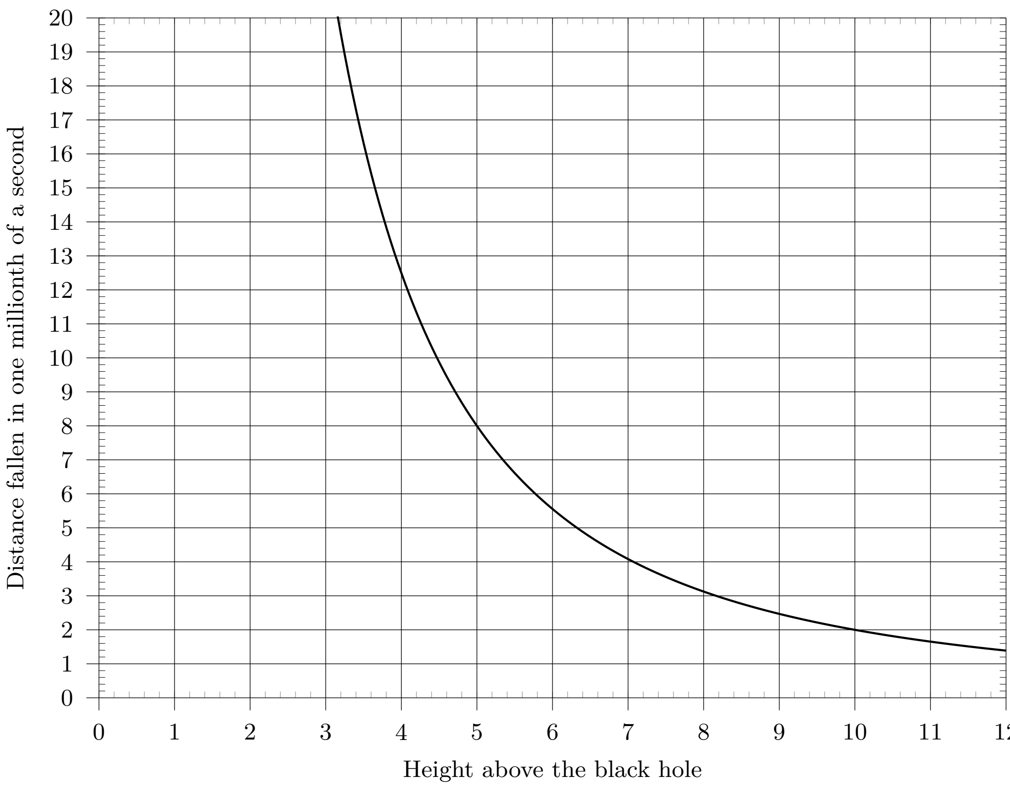
Turn to Part 2 and enter *the black hole of death!*

Part 2: The Black Hole of Death!

Suppose a 2-metre tall astronaut is floating above an Earth-mass black hole: his feet are 10 m up, his hands are 11 m up and his head is 12 m up. **Use your Play-Doh** to make a little astronaut and place him on the large sheet of paper, with his feet, hands and head at the right distances from the black hole. Draw a "police outline" around the astronaut body to record his position.

This graph shows show how far an object at a certain height above the black hole will fall in *1 millionth of a second*. We'll use it to track the motion of the astronaut.

For example, in the first millionth of a second, the astronaut's feet at height 10 will fall 2, down to height 8. Now the graph shows an object at height 8 will fall about 3.2, so after 2 millionths of a second, the feet will be at height $8 - 3.2 = 4.8$, and so on. Once an objects reaches the black hole (at height 0) it's gone forever...



Record the heights of the astronaut's feet, hands and head in this Table as he falls into the black hole. After each millionth of second, move the Play-Doh astronaut and draw a new police outline around him. Since the astronaut always falls directly towards the black hole, he'll stay inside the "wedge" coming out of the black hole.

time	feet		hands		head		Move	draw
	height	falls	height	falls	height	fall	Play-Doh	outline
0 (start)	**10**	2	**11**		**12**			
1 millionth	8	3.2						
2 millionths	4.8							
3 millionths								
4 millionths								
5 millionths								

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Part 3: Questions

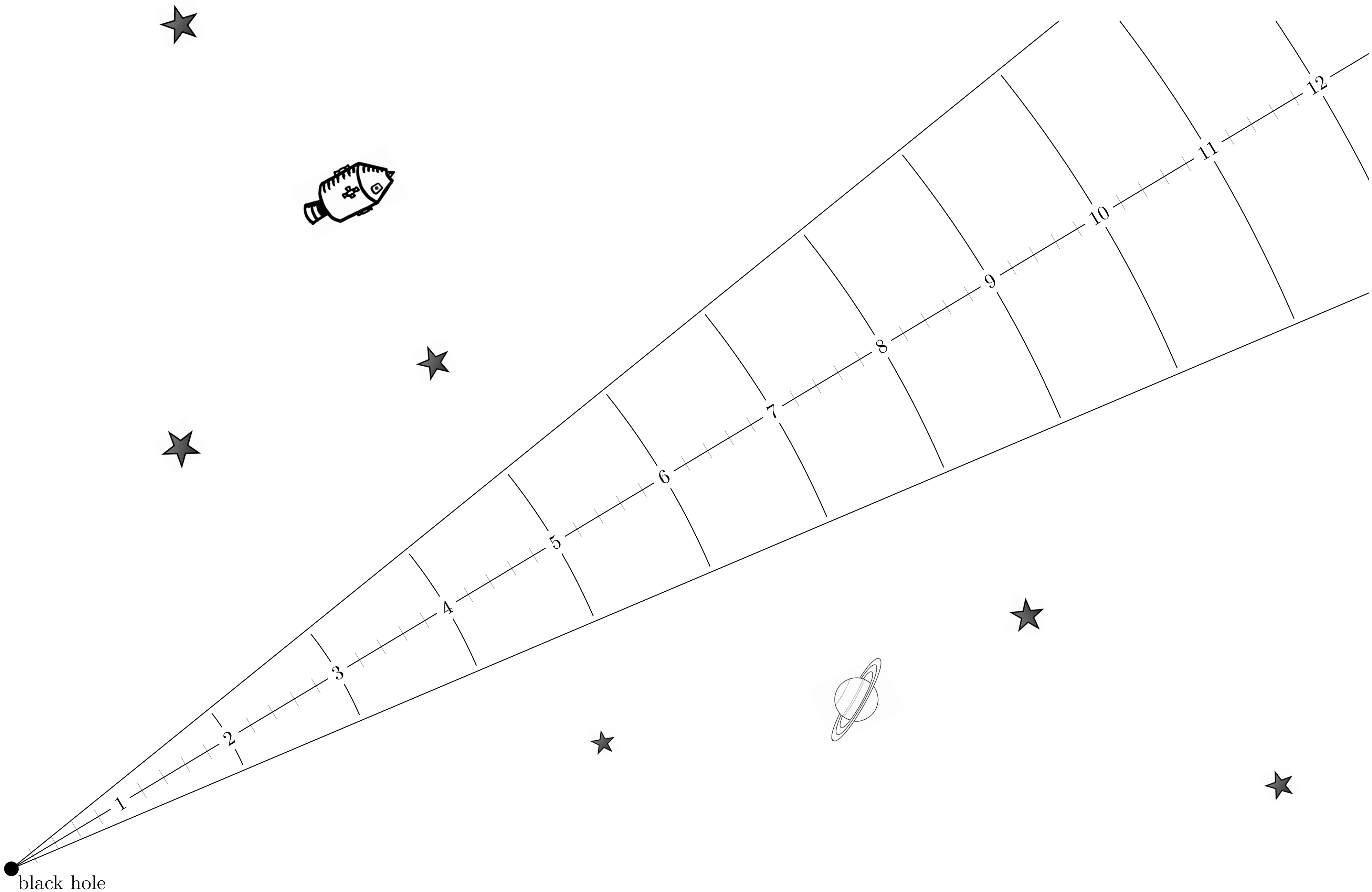
Please hand in this worksheet when you are finished.

1. On the back of this page, trace/copy/redraw the "police outline" of the 3 millionths astronaut. This will help you remember what happened to the astronaut when you're studying later, and it will help us know how the activity went for you.

2. In your own words, describe what happens to the astronaut. Why do you think it's called "spaghettification"?

3. At a safe distance, the astronaut's mom is watching his trip into the black hole. Suppose he's wearing a super strong spacesuit and he survives the trip. What message should the astronaut text her after he enters the black hole?

   Explain why his mom will never receive the message.



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black hole