TA Guide for

ASTR 311 Tutorial: Black Holes

ver. 100311

Notes

Description

In this activity, students are introduced to tidal forces by estimating the tidal forces on Earth due to the Moon. Then they explore the extreme tidal forces around an Earth-mass black hole by tracking the motion of a poor astronaut who falls in and gets spaghettified. They use Play-doh to model the spaghettification.

Learning Goals

After this tutorial students should be able to

- describe what you would see and feel if you fell into a black hole; describe what an observer outside the black hole would see.

Set-up — 20 minutes

Materials:

- worksheets:
  - Pages 1, 2 (1 sheet, double-sided) – one per group
  - Page 3 – one per group
  - overhead of height *vs.* distance-fallen graph
  - 11×17 black hole graphic – one per group (enlarge the 8.5×11 graphic by 150%)
  - Page 4 (Questions) – 1 per student. Copy the black hole end of the 11×17 graphic onto the back so the students can trace on one of the body outlines.
- 1 container of Play-doh per group

Set out the Play-doh, 11×17 graphic and Pages 1,2 before the tutorial. You'll hand out the other pages as needed. As usual, invite the students to form groups of 2–3 as they arrive.

Part 0: Introduction and Motivation — 5–10 minutes

It's never a bad idea to let the students know why they are doing this, or any other, tutorial. Why should they care? Why should they invest the time and energy? The answer should be more than the marks they'll receive. Here's the big idea:

> The "corpses" left behind at the ends of stars' lives are some of the most extreme and bizarre environments in the Universe. Small stars turn into white dwarfs; medium-sized stars become neutron stars or pulsars; really massive stars turn into black holes.
>
> Black holes are the most bizarre, and interesting, because the curve space so much (or, as Newton would say, their gravity is so strong) that not even light can escape. And they're not science fiction: they exist! What's like near them?

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Part 1: Tidal Forces	10 minutes

This Part recalls what they did in Tutorial 1 when they computed they discovered how the force of gravity depends on the masses of the objects and the distance between them. Here we're only exploring the distance. The students shouldn't have too much trouble just working their way through the calculations.

The students repeat a couple of calculations (Questions 1. and 2.) they made back in Tutorial 1, just to get remember how it works. Then they're introduced to tidal forces, the difference-in-forces an object experiences if parts of it are it are closer or farther away, by calculating the tidal forces between the Earth and Moon.

Next, they calculate the tidal forces between their head and feet as they stand on Earth. The difference is very small: For a 2-metre tall person standing on Earth (radius $6\,378,000$ m)

$$\left(\frac{d_{\text{old}}}{d_{\text{new}}}\right)^2 = \left(\frac{6\,378\,000}{6\,378\,002}\right)^2 = 0.99999937$$

In other words, the force on your head is *very slightly* smaller than the force on your feet, by less than 1 part in a million. When the Earth is reduced in size to a grape (the Schwarzchild radius is about 9 mm), and you're floating 10 metres above it, the tidal forces are much bigger, with a 30% difference between your head and feet.

The rest of the activity won't mean much if a student doesn't have a feeling for where the force that rips the astronaut apart comes from. So it might be useful to briefly discuss this with the entire group before moving on to Part 2. We'd like someone in the class to explain that the size of the tidal force depends on how big the object being stretch is, compared to the distance to the other mass. Perhaps you can ask,

> Both Questions 4 and 5 asked about the difference in forces between your head and feet when you're standing above something with the mass of the Earth. How come one case had tiny tidal forces and one had quite large tidal forces?

We'd like someone to say, "2 metres is nothing compared to the radius of the Earth, but 2 metres is a lot when you're only 10 metres from the black hole."

TA-B hand-out Part 2

Part 2: The Black Hole of Death!	20 minutes

To introduce this Part, you might try something like,

> Strong tidal forces mean your feet are being pulled a lot more than your head. What does that feel like? What happens to you? In this Part, you'll figure out what happens to an astronaut who falls into a black hole...

Even though it's written down, it would probably be good to quickly go over how to use the graph. Referring to the overhead, first describe what the graph shows

Put up height-distance overhead

- "this is the height above the black hole"
- "the curve shows how far something falls in 1 millionth of a second because it's being pulled by the gravity of the black hole"

Notes

- Run through the feet example, from 10 m to 8 m to 4.8 m, tracing your finger across the graph (or writing on it)

Stress that you want them to use the Play-doh at each instant to make a model of the astronaut. Invite them to get creative – borrow some neighbour's colours to add a helmet and boots and also take some pictures with the cellphones. Yes, it seems kind of childish, playing with Play-doh, but by stretching the Play-doh from one position to the next, they're "filling in the blanks" between the snapshots at 1 millionth, 2 millionths, and so on. Stretching Play-doh (and simultaneously squishing it inside the "wedge") is what the astronaut is experiencing.

As they proceed, wander around reminding them that the astronaut has to stay inside the wedge (because he always falls directly towards the black hole) and that once the "distance fallen" is greater than the "height above", that part of the astronaut is lost inside the blackhole (and they don't have to continue calculating and tracking that piece.)

Part 3: Questions	Remainder of tutorial

As students finish killing the astronaut, hand out the Question sheet. When they're finished, ask them to put the Play-doh back in the container. They don't have to turn in the big 11×17 sheet, so someone can take it home, if they want.

Hand out Questions as needed

The first two Questions are pretty straightforward: trace one of the police outlines, describe "spaghettification". You could (should) have some interesting discussion about Question 3, what the astronaut should text his mom. Some students will make up some goofy txt message, then answer the next part about why the mom doesn't get the message ("because nothing, not even light, can escape from the black hole.") Some students immediately realize the message won't get out, anyway, so what's the point? Why should they make up a txt when it doesn't matter? Obviously, don't force them to write something down but encourage them to write down why it's meaningless to make up a txt message.

If they're keen, you might take the opportunity to ask them about whether or not studying the inside of black holes (as some astronomer's do) is "science"? By definition, nothing inside can communicate with outside: no information, no forces, no influence whatsoever. If the theory can make no measurable predictions (because you can't tell someone on the outside what to look for) than is it science? Hmm, good question...

Clean up

Pack up the containers of Play-doh and recycle the extra papers.