TA Guide for

ASTR 311 Tutorial: The Expanding Universe

ver. 101104

Notes

Description

In this activity, students tackle the problem of why it looks like we're at the center of the Universe (because galaxies are receding in all directions) and yet we're not. In fact, *everyone* feels they're at the center even though there is *no center*. They uncover, through the Hubble Law and Hubble contant, how the Universe expands between 14 billion years and 21 billion years using galaxies printed on an overhead transparency.

How the Universe expands without having a center is a tricky concept. We might not completely clear it up for the students, but we'll get them thinking about more than "the Big Bang was an explosion with matter flying through pre-existing (but empty) space."

Learning Goals

After this tutorial and lectures, students should be able to demonstrate and resolve the "optical illusion" where it appears we are at the center of the expanding Universe.

Materials and Set-up — 10 minutes

The students will work together *in pairs*, so the following materials are required:

- Hand-outs:
  - (per pair) Pages 1–3. Page 3 is a graph using data collected on Page 2, so don't bother stapling the pages to encourage the partners to work together: one reads data, one plots it.
  - (per pair) Map14 (Universe at 14 billion years) on paper. Since the students don't circle their home galaxy on Map14 (anymore), these should be re-usable.
  - (per pair) Map21 (Universe at 21 billion years) on overhead transparency. We're trying to use these maps over and over, to save on plastic, so the students will use dry erase markers. After the tutorial, do your best to wipe off the marker, but only keep the overhead if lines are sufficiently erased that they won't get confused with the new lines. If you have to make new overheads, use the stack bypass and be sure to select transparency as the paper type.
  - (per student) Page 4: Questions
- (per pair) 2 Post-it Notes for "gluing" the maps together
- (per pair) dry erase marker
- (per pair) ruler (made from an overhead transparency). The rulers we hand out are to-scale, so they can use they're own ruler, too, if they have one.

You can distribute everything but the Question sheet before the tutorial begins.

There are many recognized benefits to working collaboratively with a peer. When it works, the students in the group are not just brought up to the level of the highest student, they all surpass it. This tutorial activity is set up for 2 partners, so as students arrive, put the singles into pairs and split up the larger groups.

Part 0: Introduction and Motivation	5 minutes

We can't be sure how familiar the students are with the Big Bang, the expanding Universe, the Hubble Law and so on. The important concepts will be developed in the tutorial. At this stage, we just need to get everyone to the same starting point. So, put up the Hubble Ultra Deep Field picture and report these 4 observations:

1. We see galaxies in all directions and at all distances.
2. As Edwin Hubble first observed in the early 20th Century, the galaxies are moving away from us in all directions.
3. It looks like we're at the center of an expanding Universe.
4. There's one strange pattern: the farther away the galaxy, the faster it's moving away from us. [Don't continue into the explanation for this phenomenon, though – that's the goal of the tutorial]

Part 1: Observe the Expanding Universe	10 minutes

This activity is pretty straightforward. Just introduce them to the tools they'll use and let'em go...

Set up the scenario: it's 7 billion years in the future and the Universe is 21 billion years old. Students have a map ("Map21") of some galaxies printed on the overhead. They also have a paper map ("Map14") from when the Universe was only 14 billion years old (which is the current Universe, by the way.)

Tell them they're going to pick a "home galaxy" and that they need to align that galaxy on the two maps and then lock it in place with the Post-it Notes. The two maps need to be "squarely" aligned which means the sides of the pages are parallel. You can probably do all this just by holding up and demonstrating it at the front.

As they start drawing lines on the overhead, encourage them to add arrowhead to give the expansion a sense of direction. They'll find a nice, radial expansion of the galaxies away from their home. Students who live on the edge of the map might not quite see that, but the activity still works fine.

Part 2: Measure the Expanding Universe	15 min

There's no need to stop the entire group when moving onto Part 2. Each pair can proceed at their own pace. Part 1 was qualititative – find the pattern – and Part 2 is quantititative – measure the pattern.

They have to make two measurements for each of the chosen galaxies: the distance from the home galaxy on the "current" Map21 and the length of the arrow they drew in Part 1. They should use millimetres, but if they use centimetres, just get them to multiple both the Map21 distance and the recession velocity by 10.

After making all the measurements, they calculate each galaxy's recession velocity using the time span of 7 billion years, the time between the two maps. Finally, be sure they add their home galaxy (at distance 0 and with recession velocity 0).

Part 3: Analyzing the Expanding Universe	5 min

Based on their abilities in previous tutorials, the students shouldn't have much trouble making the graph. The last step is to calculate the Hubble constant which is the slope of the line. The answer is around 0.05 but it'll vary depending on how carefully they make their measurements.

In fact, though we don't go into it here, $1/H$ is the Hubble time, the age of the Universe. We've set that to 21 Gyrs so the Hubble constant should be $H = 1/21 = 0.048$.

Part 4: Questions	15 minutes

As they complete the graph, hand out the Question sheet. Here are some comments about the questions:

Hand out Part 3: Questions

1. A great answer would have two key observations:
   - the lines all point away from the home galaxy
   - the farther away the galaxy, the longer the line
2. This question gets the students to use the Hubble constant they calculated in Part 2. They must have done for something, right?

   With $H = 0.05$ we expect a 1 Mpc volume of space to expand at 0.05 Mpc/Myr and a 100 Mpc volume to expand at 5 Mpc/Myr. To test this, the students find a galaxy about 100 mm (i.e., 100 Mpc) from their home and calculate recession velocity, (length of arrow)/7. The two velocities seems to match pretty well.
3. The students should find they all have different home galaxies and use different galaxies to track the expansion, but they should all observe the 100-Mpc galaxy moving at about 5 Mpc/Myr and §\0 9h0 [«@@eO Hnj §9j§. Why? Because the expansion is uniform throughout the Universe. (Jim Zibin's analogy, if they've seen the raisin bread analogy in class: imagine the raisin bread analogy where there is extra yeast on one side of the loaf. That part would expand faster. That's *not* like the Universe where the expansion is the same everywhere.)
4. When the galaxies are traced back to the beginning, they're in a tight little bunch. Each group will think that bunch sits somewhere else on the page (clustered around their own home galaxy.)

   If they still seem to be thinking each of us has our own "center", you might try this sequence of questions to "open their eyes":

   (a) Where do you think all the galaxies will be at time 0? ("Here, at my home galaxy.")

   (b) And where does that other group think the galaxies will be? ("There, at their home galaxy.")

Notes

(c) Where do you think §\0´ will be at time 0? (“Here, right next to me.”)

(d) And where do §\0´ think ´n« will be at time 0? (“There, right next to them? Hey, that means we’re both actually in the same place!”)

The goal is get them thinking that there is no center (or maybe that everywhere is the center.)