CRLS Astrophysics Lecture Series

Galaxy collisions

Ana Bonaca

Week 1: Introduction to galaxies and their interactions

Goals
Next week we will explore how galaxies interact using numerical simulations. To get ready, this week we will first learn about galaxies and their basic properties. Then we will look into the gravitational force, which determines the motions of galaxies and stars, and finally, we will watch what happens when two galaxies collide.

Outline
Similar to previous workshops, the following sections outline some questions to guide your exploration of the listed resources. Take note of any additional questions that come up, and we'll discuss them next week. If you are particularly interested in any of the topics, additional reading materials and activities are also suggested.

1. **Galaxies**
   Guiding questions: What is a galaxy? What are the two basic types of galaxies? Find a picture of a galaxy for each type, and describe it in a few sentences. What kind of a galaxy is the Milky Way? What about the Magellanic Clouds?

   Resources:
   "An Introduction to Galaxies" (http://planetary-science.org/astronomy/galaxies-4/an-introduction-to-galaxies/)
   "Categories in a Hubble Gallery" (http://hubblesite.org/categories/images)
   "Wikipedia | Magellanic Clouds" (https://en.wikipedia.org/wiki/Magellanic_Clouds)

   Want to learn more? Check out the Galaxy Zoo (https://www.galaxyzoo.org/)! Galaxy Zoo is a citizen-scientist program where you can classify galaxies by their appearance. Some of these galaxies are nearby, observed during large surveys of the local Universe, while some of them are among the most distant galaxies observed with the Hubble Space Telescope. Classifying these galaxies helps astronomers learn how galaxies form and evolve.

2. **Gravitational force**
   Guiding questions: What is the expression for the gravitational force between two point-mass objects? We'll now use this equation in two situations that will help us understand how galaxies interact. (1) Apply this formula to calculate the force that the Milky Way exerts on an average star in the Large Magellanic Cloud (LMC). You can assume that both the Milky Way and the star are point particles, and that the mass of the star equals the mass of the Sun. Look up all the relevant quantities and make sure to keep track of the units in your calculation (Google comes in handy here). (2) Now let's look up the size of the LMC. Calculate the force that the Milky Way exerts on a star at the closest side of the LMC, and a star on the far side of the LMC. What is the ratio of these forces compared to the force felt at the center of the LMC (calculated in the first part)? How do you think this effects the LMC?

Resources:
"Wikipedia | Newton's law of universal gravitation | Modern form" (https://en.wikipedia.org/wiki/Newton%27s_law_of_universal_gravitation#Modern_form)
"Wikipedia | Large Magellanic Cloud" (https://en.wikipedia.org/wiki/Large_Magellanic_Cloud)

Want to learn more? The difference between the gravitational forces felt at two sides of an object is called a tidal force. You've heard about the tides changing the shape of the Earth's oceans, but the same principle applies to many systems in astronomy, including in interacting galaxies! You can learn more about the tides from Neil DeGrasse Tyson's article "Tides and Time" that appeared in the Natural History Magazine (http://www.haydenplanetarium.org/tyson/read/1995/11/01/the-tidal-force).

3. **Galaxy interactions**
Guiding questions: Before reading or watching the resources in this section, take a guess about what will happen when two galaxies collide. Discuss the ideas you came up with in a group. Watch the video "Galaxy Collisions: Simulation vs Observations" next. Were you surprised with what happened? How do you think the masses of the two galaxies affect their interaction? (Hint: Think about this in terms of the gravitational force equation we examined earlier.) Finally, our goal next week will be to match one of the observed interacting systems with the galaxies you simulate (similar to what was done in the video), so pick one interacting pair from the Hubble's Gallery!

Resources:
"Galaxy Collisions: Simulation vs Observations" (https://apod.nasa.gov/apod/ap130514.html)
"What happens when galaxies collide?" (http://curious.astro.cornell.edu/about-us/96-the-universe/galaxies/formation-and-evolution/530-what-happens-when-galaxies-collide-beginner)
"Hubble Gallery of Interacting Galaxies" (http://hubblesite.org/images/news/19-interacting-galaxies/)

Want to learn more? Check out the attached article from the latest issue of Sky & Telescope. It talks about how we found evidence that many small galaxies have collided with the Milky Way.

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Week 2: Exploring interactions of galaxies

Goals
Last week we learned what galaxies are, and physical basics of their interactions. This week we will study in detail how the initial properties of galaxies affect the final outcome of their interaction.

Outline
The activity this week will be very hands-on, and open ended, so below is just a suggested outline with some references in case you want to try colliding galaxies again. As always, ask any questions that come up!

1. **Recap from last week**
   What are galaxies? Why are some galaxies interacting, and some not? What do you think are relevant properties of galaxies that decide how they will interact? What kind of galaxies did you like best? Are there any questions you had during the meeting last week?

2. **Galaxy Crash JavaLab**
   We will explore galaxy interactions using the Galaxy Crash JavaLab, developed by Chris Mihos: http://burro.cwru.edu/JavaLab/GalCrashWeb/main.html . Try colliding galaxies, and get familiar with the interface. What is the final result of the interaction? Do intermediate stages look anything like the images you selected last week?

3. **Experimenting with galaxy interactions**
   Of the galactic properties we came up in the first part, which ones can you control in the applet? Let's split up in groups and pick one of these parameters per group. The group goal is to study how changing your parameter affects the interaction of the two galaxies. Discuss within the group how to set up this experiment. Once you're done with modeling collisions, summarize your findings. After ~20 minutes, you will share your findings with the other groups.

4. **Reproducing observed galaxy pairs**
   Pull up the picture of a galaxy pair you chose from the Hubble gallery last week. Based on what you've learned as a class, vary the parameters of a galaxy collision and try to match the observed pair. Take a snapshot of the modeled galaxy pair, and show it next to the observed one.

Galaxy interactions in perspective

In this activity, we explored how a galaxy can change if another galaxy passes close by. However, this is only one way that a galaxy changes in response to its environment. Below is an illustration by Aeree Chung that summarizes all the different processes that can affect a galaxy. Find the ones we've been studying!