Cosmic Castaways

A lesson on galaxy collisions & stellar orphans

appropriate for grades 9-12
keywords: galaxies, stars, gravity

A product of
Science on the Halfsphere
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CosmicCastaways

from galaxy collisions to orphan stars

This lesson was produced by
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and builds on the *Cosmic Castaways* planetarium show,
produced by Curtis Spivey, and Annie Wilson, and
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This is a joint production of
Southern Illinois University Edwardsville and
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Instructor's Guide

Overview for Educators

Objective:
This activity is designed to allow students to understand the structure of galaxies and nature of galaxy collisions. They will: watch a planetarium show, build their own galaxy, and engage with an interactive simulation illustrating how galaxies collide and merge gravitationally.

Grade Level:
Targeted: grades 9-12, but may be used with middle level and astronomy 101 students as well.

Time Required:
Plans for both two and three class period usage (~50 min./class) are

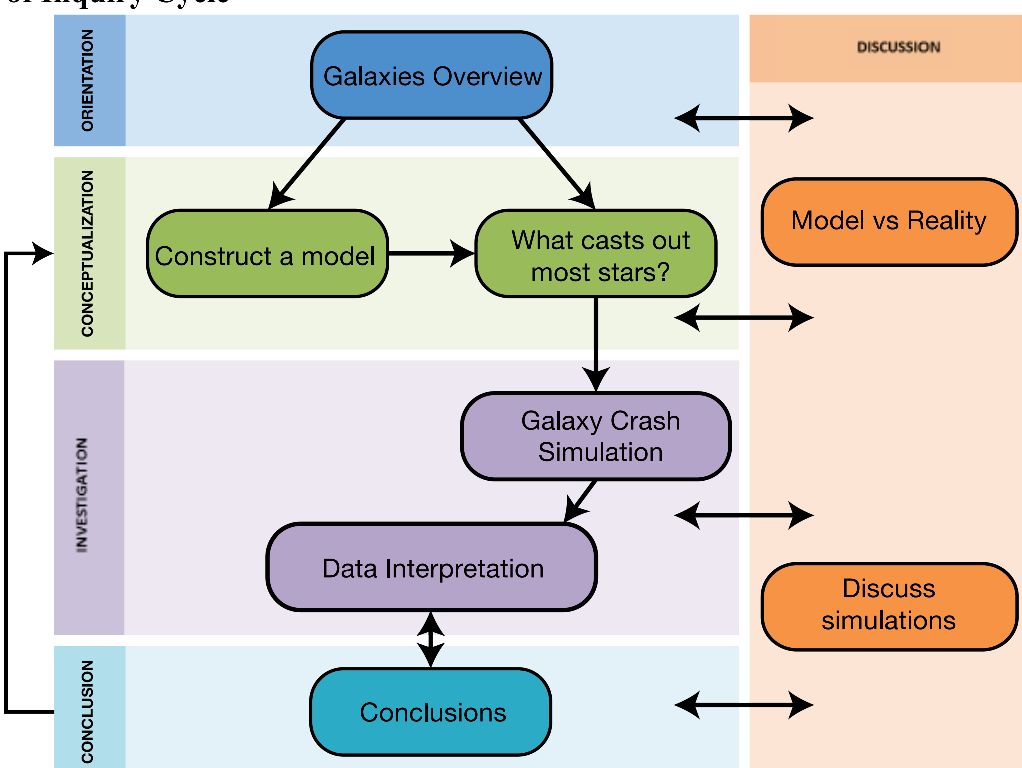
Next Generation Science Standards:

- ESS1.A: The Universe & Its Stars
- SEP 2: Developing & Using Models
- CCC 2: Cause & Effect
- CCC 7: Stability & Change

Common Core Standards:

- ELA/Literacy WHST.6-8.1: Write arguments focused on discipline content.
- CCSS.ELA-Literacy.WHST.6-8.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- CCSS.ELA-Literacy.W.11-12.3 Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details, and well-structured event sequences.

Aspects of Inquiry Cycle



Sequence of activities (3 class periods)

Hour 1:

Engage:	Discuss what students already know about galaxies (15 min)
Explore:	Construct a galaxy (20 min)
Explain:	How do their Galaxies compare to real galaxies (10 min)
	List Vocabulary & Concepts (5min)

Homework:

Elaborate:	Worksheets; write definitions for Vocabulary and Concepts

Hour 2:

Elaborate:	Watch the Cosmic Castaways show (25 min)
	Review Vocabulary & Concepts (20 min)

Hour 3:

Explore:	Galaxy Crash simulator OR Collision Sequence (35 min)
Evaluate:	Discuss findings from collisions (15 min)

Alternative A: Shortened Sequence of activities (2 class periods)

Hour 1:

Engage:	Discuss what students already know about galaxies (15min)
Explore:	Galaxy Construction (15 min – 25 min)
Explain:	How do their Galaxies compare to real galaxies
	List Vocabulary & Concepts (5min)

Homework:

Elaborate:	Worksheets; write definitions for Vocabulary and Concepts

Hour 2:

Elaborate:	Watch the Cosmic Castaways show (22 min)
	Review Vocabulary & Concepts (20min)

Alternative B: Shortened Sequence of activities (2 class periods)

Hour 1:

Engage:	Discuss what students already know about galaxies (15min)
Elaborate:	Watch the Cosmic Castaways show (22 min)
	Review Vocabulary & Concepts (20min)

Homework:

Elaborate:	Worksheets; write definitions for Vocabulary and Concepts

Hour 2:

Explore:	Galaxy Crash simulator OR Collision Sequence (25 min – 35 min)
Evaluate:	Discuss findings from collisions (15 min)

Instructor's Guide

Engagement: What are Galaxies?

Time required: minimum 5 minutes

Context:
Begin class with a discussion that allows you to judge the amount of knowledge and misn-information the students have about galaxies and their evolution through collisions and mergers.

Discussion Activities / Questions:
Begin class with a discussion that allows you to judge the amount of knowledge and min-information the students have about galaxies and their evolution through collisions and mergers.

- What are the types of Galaxies? Spiral, elliptical, and irregular
- Is possible for galaxies to collide? yes
- Ask students to make a list of all of the facts they know about galaxies. For instance, what are each of the following?
    - galaxy
    - star
    - central bulge
    - disk
    - halo
    - tidal tail
    - gravity
    - Milky Way
    - dark matter

Learn more about galaxies and galaxy types:
http://science.howstuffworks.com/dictionary/astronomy-terms/galaxy1.htm


Spiral galaxy M101 (left, credit NASA/ESA, CFHT, NOAO) is shaped like a pinwheel, with multiple arms in a disk. Spiral galaxies like this one have significant star formation, and many blue stars. Elliptical galaxy NGC 1132 is more cotton ball shaped, and has very little dust or star formation. Most of its stars are shades of orange and red. (Credit ESO)

Instructor's Guide

Explore: Galaxy Construction

Time required: 20 minutes

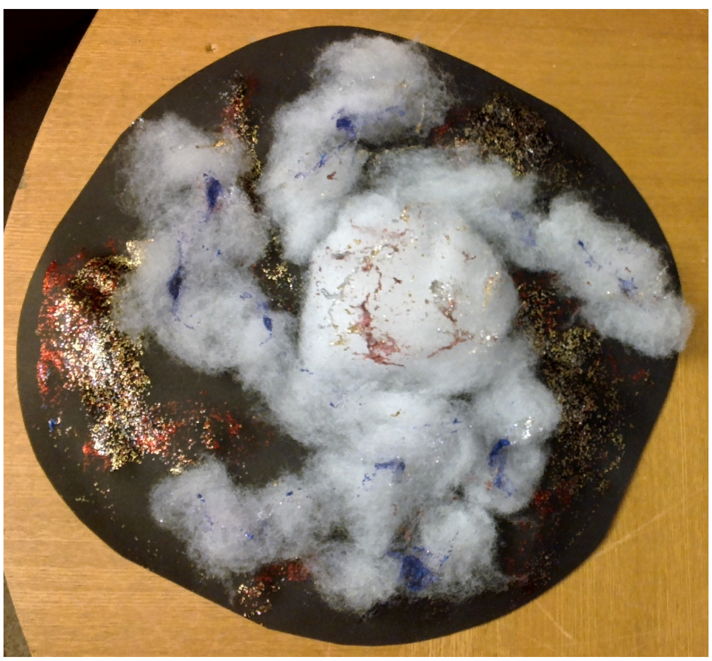
Context:
Students will make a model of the Milky Way.

Printed Materials for Students: (available in Appendix A)

- Guide to Galaxies, by StarDate.
  http://stardate.org/astro-guide/btss/galaxies
- Build your own Galaxy, by StarDate.
  http://mcdonaldobservatory.org/sites/default/files/pdfs/teachers/build_your_own_galaxy.pdf

Notes on Preparation:
As written, this exercise requires students to glue together two circles of poster board. The glue can take up to an hour to dry, making this exercise impossible to fit in the first class period. It is recommended that you either use one piece of foam board as a replacement for the poster board, or have students glue their boards together in a different class period.

Instructions:
Have students either work alone or in pairs. They should read the sheet on galaxies prior to beginning their galaxy construction.



Instructor's Guide

Explain: Model vs. Reality

Time required: 10 minutes

Context:
Models can never precisely imitate reality. At the close of class, have students discuss how their galaxy models fall short of actual galaxies. Use this discussion as an opportunity to review related vocabulary and concepts.

Explain:

Vocabulary:

- galaxy – a grouping of stars, gas, dust, and dark matter bound by gravity. Galaxies can come in spiral, elliptical, and various irregular shapes
- Star – a sphere of gas that is held together by its own gravity and undergoes nuclear fusion in its core
- central bulge – the roughly spherical grouping of, usually older, stars near the center of a galaxy, typically used in describing a disk or spiral galaxy
- disk – the flat, rotating structure of, usually younger, stars and gas in a galaxy which may or may not have spiral arms
- halo – a large spherical distribution of older stars and dark matter that extends many times beyond the visual borders of a disk or elliptical galaxy
- gravity – one of the fundamental forces of nature that creates attraction between any two objects with mass
- Milky Way – the name of the galaxy in which we reside. Also, the name given to the cloudy trail of stars seen in a dark sky from Earth, indicating the position of the disk of our galaxy.
- dark matter – invisible matter that has been theorized to exist primarily in the haloes of galaxies. Dark matter makes up much of the mass of galaxies and galaxy clusters, but it does not interact with light. It can, however, be detected by its gravitational effects.

Concepts:

- Galaxies come in various shapes and sizes.
- Galaxies are held together by gravitational force.

Instructor's Guide

Elaborate: Cosmic Castaways Video

Time required: 25 minutes

Context:
Students will watch the Cosmic Castaways video and learn about galaxy collisions.

Printed Materials for Students - OPTIONAL: (available in Appendix B)

- Transcript: http://cosmoquest.org/blog/scienceonthehalfsphere/files/2013/10/FinalCCastScript.pdf

Notes on Preparation:
The Cosmic Castaways video is easiest to watch using YouTube.com. If you don't have access to YouTube from your classroom, you can also download the movie files from the Science on the Halfsphere website: http://cosmoquest.org/blog/scienceonthehalfsphere/planetarium-shows/cosmic-castaways-show/

Instructions:

- Prepare the students to watch the show by asking them to write down any science vocabulary they hear and any concepts they think are interesting.
- Play the video.

Instructor's Guide

Elaborate: Understanding collisions

Time required: 10 minutes

Context:
Students will have picked up on new terms and concepts from watching the video. These should be discussed.

Explain:

Vocabulary:

- tidal tail – a trail of stars that has been pulled away from a galaxy through an interaction or merger with another galaxy.
- red giant – a star, larger and cooler than the Sun, that is near the end of its lifetime.
- orphan star – a star in between galaxies or outside the gravitational influence of any one particular galaxy.

Concept:

- Galaxies can collide and stars can enter into new orbits or be thrown clear of their parent galaxy into intergalactic space.

Instructor's Guide

Explore & Evaluate: Galaxy Crash

Time Required: 35 minutes

Context:
Students will explore the different processes that can occur when galaxies collide in different ways.

Printed Materials for Students: (available in Appendix C)

- Galaxy Crash instruction manual
- Worksheet

Notes on Preparation:
This activity requires computers that have java installed in the web browser. If your unsure if your computer has a current copy of Java go to this link:
http://www.java.com/en/download/testjava.jsp
As of this writing (October 8, 2013) Chrome does not support Java.

Instructions:

- Have students either work alone or in pairs at a computer.
- Prior to having the students begin, overview the following:
  - Go to the site: http://burro.cwru.edu/JavaLab/GalCrashWeb/
  - Click on "Applet" to open the simulation
  - Start a simulation and
    - Rotate the image by: Clicking and dragging in the viewer
    - Zoom the image: Hold the shift key and drag in the viewer
- Have the students work through the worksheet in Appendix C (answer key follows below)

Instructor's Guide

Crashing, Colliding Galaxies, & Orphan Stars – ANSWER KEY

Notes:

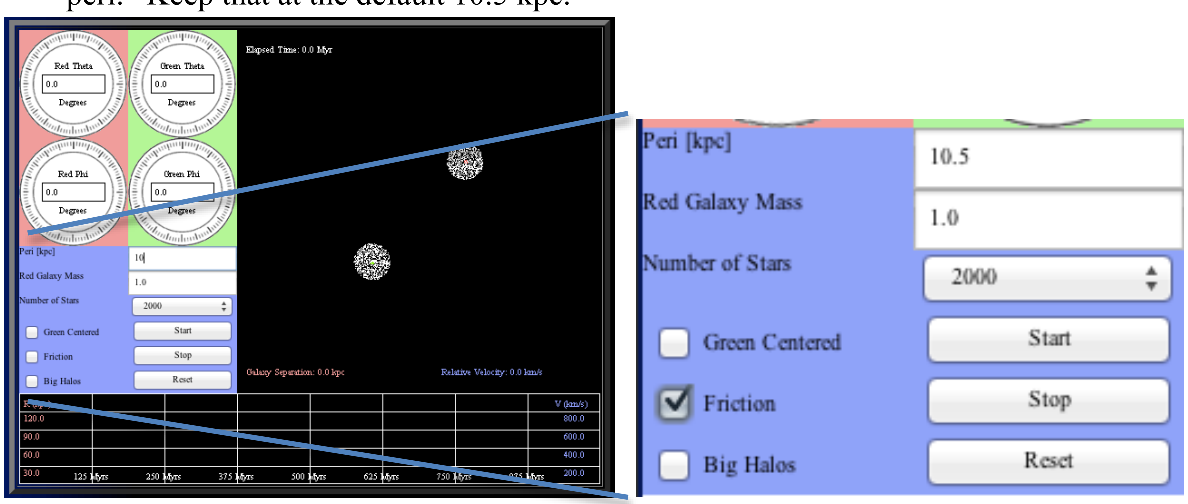
- Use Safari or Firefox with Java installed to use GalCrash - http://burro.cwru.edu/JavaLab/GalCrashWeb/
- Instructions on how to use the app are at the back of this packet
- Remember to click and drag on the simulation while it is running to see it from different angles!

Goal:

Can you discover what factors affect tidal tail formation in galaxy collisions and interactions?

1. **Orphaning Stars:** Before you get started, hypothesize what parameters will cause the most stars to be cast out of their galaxies to become cosmic castaways. Explain why you propose this.

2. **Set everything up:** We will select "friction" for these exercises. Dynamical friction is the loss of energy and momentum due to gravitational interactions, so this is more realistic. Set number of stars to the highest setting (2000). In the initial conditions: "red" galaxy mass is equal to the green galaxy mass (1.0). The angles are set to zero, so the initial disks are at the same orientation. The closest distance between the galaxy centers is "peri." Keep that at the default 10.5 kpc.



3. **Different galaxy masses**: Start by running the default simulation. What do you see happen? Describe the tidal tails produced. What is the end product? Are there any "cosmic castaways" or stars that are completely ejected from the system? (Note that the time is ticking in the upper left corner. You want to wait at least 2000 Myr, or two billion years.) Now, repeat for different red galaxy masses: 0.1, 5, 10. (Remember to click "Reset" after change parameters.) How are the tidal tails different in each case?

Red Galaxy Mass	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
0.1	*The little red galaxy has a thin tail but the green one hardly makes a tail at all. The galaxies don't end up merging, and the red galaxy has lost some stars.*	red	Y
1.0 (Default)	*This simulation makes long thick symmetric tidal tails, but the stars stay in large orbits and don't really escape. Systems merge.*	both	N
5	*The green galaxy is the smaller galaxy and it loses a lot of stars in a thick tail or fan. Not sure if they can ever come back or if they are lost "castaways. Systems merge.*	*green*	*y*
10	*Again the green (smaller) galaxy loses a lot of stars in a thick tail or fan, and the red (larger) galaxy hardly makes a tail at all. Systems merge.*	*green*	*y*

Do you see any trends in what happens as mass changes? Describe:

As the masses get more and more different, the smaller system gets a more and more disturbed: larger tail/fan, more lost stars.

Which of these made the most "cosmic castaways" or escaped stars? Why do you think this is the case?

When red mass = 10 times the mass of green. Both galaxies have to be big enough to produce the right kind of interaction, and the more uneven the masses, the better for losing stars. The smaller of the two galaxies is the one that loses the most stars.

4. **Different galaxy center distances**: Go back to initial conditions (red galaxy mass = 1). and again observe the tidal tails. Now, change the pericenter distance for each trial: 5, 1, 20 kpc. Describe the tidal tails in each trial. How do they change as the galaxy centers are closer at the collision? Farther away? Which scenarios produce cosmic castaways?

Galaxy separation: Peri	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
1 kpc	*Tails are straighter but shorter, and have less stars. They all seem to be orbiting and not lost. Galaxies merge.*	*Both*	*N*
5 kpc	*Looks very similar to previous case, but galaxies merge together faster.*	*both*	*N*
10.5 kpc (default)	*Same as before*	*both*	*N*
20 kpc	*Very short, skinny tails that don't live long before going back into their galaxies. The galaxies keep going and don't merge!*	*Both*	*N*

Do you see any trends in what happens as the smallest separation changes? Describe:

Mergers are similar until they galaxies are too far apart to merge.

Which of these made the most "cosmic castaways" or escaped stars? Why do you think this is the case?

Distance = 5 or 10 kpc are fairly similar, but probably lose more with 5 because the galaxies merge together faster and thus can't spring back out and "pick up" the stragglers. Too far away and the galaxies keep their stars, too close and the galaxies make smaller tails, and thus the end galaxy keeps the stars. There is a middle "sweet spot."

5. **Different galaxy angles**: Now, reset to initial conditions (peri = 10 kpc) and we are going to change the angle of the disks with respect to each other (theta). Run the simulation at zero degrees and again observe the tidal tails. Then, change red theta to 40 degrees. How are the tails different? (Remember to click and drag on the simulation to change your viewing angle!) Now increase red theta to 90 and run. How does this change the tidal tails? Turn red theta all the way up to 180, so that the disks are once again in the same plane but rotating in opposite directions. How does this affect tidal tails?

Galaxy theta (angle)	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
0° (default)	Same as before	both	N
40°	Tails are thinner and more stretched out and now have 3-dimensional shape. Castaways are few or none, since stars just seem to be in bigger orbits.	both	N
90°	Tails more "wrapped" around each other in 3-dimensions. One big tail of stars may be escaping, rather than two from before.	both	Y
180°	Only the green galaxy makes a tail! The red does not. Those stars are likely to become castaways as they keep moving outwards.	green	Y

How does rotation effect the formation of tidal tails? Describe:

Stars are more likely to escape if the angle between galaxies increases.

Which of these made the most "cosmic castaways" or escaped stars? Why do you think this is the case?

When theta = 180 degrees. For some reason, it disturbs the green galaxy a lot more, whereas the red stars stay near the center

6. **Orphan Stars:** Design a simulation that you think gives the maximum chance of having cosmic castaways, using your answers from the previous three sections. (You may need to refresh the application to set theta back to zero.)

What are its initial starting conditions?

- **Red Galaxy Mass**
  10

- **Peri (kpc)**
  5 or 10

- **Red Theta**
  180

Did you successfully form cosmic castaways? Describe your results (include sketch)

The smaller galaxy (green) loses a big fan of stars as cosmic castaways from the one big tidal tail. The galaxies do eventually merge to make one big disk galaxy.

Instructor's Guide

Explore & Evaluate: Galaxy Collision Sequence

Time Required: 25 - 35 minutes

Context:
Students will identify different stages in the process of galaxy collisions and mergers.

Printed Materials:

- Worksheet
- Picture packet

Instructions:

- Print out image packets, one for each group of students in your class. The color pictures should be printed in color for best results, and we suggest laminating the all of the images for multiple uses.
- Go back over the sequence in the *Cosmic Castaways* video that shows different stages of galaxy collisions through models and images (Time stamp 4:36 – 6:44).
- Divide the class into groups and hand out the picture packets, one to each group. Hand out worksheets (either one per group of one per student; see Appendix D). Have the students work through the worksheet (answer key follows).
- For more information on the Toomre Sequence, see Appendix E

Instructor's Guide

Galaxy Collision Sequence – ANSWER KEY

Goal: To put together a "movie" of how galaxies collide and merge together.

Since galaxy collisions take hundreds of millions of year to complete, astronomers can't watch a single collision sequence from the start to the finish. Instead, astronomers have to look at different galaxy pairs at the same time, who are at different times in the sequence. We call the entire process a "collision sequence" and the steps of the process are called "stages."

From watching the movie, you should have an idea of what the sequence should look like, as if they were frames from a movie. Use a pencil to roughly sketch out the collision sequence in four stages. Pay attention to how close the centers of each galaxy are from each other, and whether the tails are getting longer or shorter. For each drawing label the main features of that particular stage. Consult with the rest of the students in your group about your drawings.

a. Pre-merger

Galaxies are separated with no tidal tails

b. Early stage: First visible galaxy contact

Galaxies are close together and may already have long tidal tails

c. Middle stage: Galaxies have passed through each other

Galaxies are more disturbed, look less like spirals

d. Late stage: Final merger state

Galaxy is mostly elliptical with a few tidal tails

2. For astronomers to discover galaxy collisions, they first had to discover galaxies that had unusual shapes. This was done with black and white photographs of the sky. Once a list of interesting objects was found, astronomers then observed the objects in greater detail with more modern telescopes, including color images.

   Take a look at the 12 images in the picture packet. For each galaxy pair, there is a black and white discovery image and a detailed color image. Each image is labeled with a letter. The color images are usually zoomed in on the centers of the galaxy pair, and the images are usually rotated compared to the black and white images.

   Match each black and white image (A through F) to the corresponding color image (G through L). One way to do this is to lie out all of the 12 images on a desk or table, and move them around until each black and white and color images match up. Fill in the matches below.

   A corresponds to L
   B corresponds to H
   C corresponds to K
   D corresponds to G
   E corresponds to I
   F corresponds to J

3. Consider images G though L. Divide the galaxy pairs into "Early," "Middle," and "Late" stages. There should be two galaxy pairs for each stage. (Ignore the pre-merger stage from question 1.)

   Early: G and K
   Middle: L and I
   Late: J and H

   For each pair of images, what features in the images did you use to determine the collision stage? What feature is most likely to produce orphan stars or "cosmic castaways"?

   For the early stage images, the main bodies of the galaxies are very close together and there are long tidal tails. In the middle stage images, the galaxies are more chaotic and no longer look like two spirals, and the tidal tails are still present. In the late stages, the galaxies have mostly formed one big galaxy, and the tidal tails are less prominent.

Appendix A

Handouts for Galaxy Construction Activity

Student Guide: Galaxies - Cities of Stars

Stars beyond counting populate the universe. Most reside in dense groups known as galaxies. These 'island universes' come in many shapes and sizes, and contain anywhere from a few million stars to a trillion or more. Some are still churning out lots of new stars, while others are quietly living out their lives. And some galaxies are merging to form even bigger cities of stars.

Great Dates
1755
Immanuel Kant proposes that spiral 'nebulae' are really vast agglomerations of stars outside the Milky Way
1845
William Parsons, Lord Rosse, is the first to note that some 'nebulae' show a spiral structure
1864
William Huggins notes that the spectra of many 'nebulae' are different from those of stars
1923
Edwin Hubble discovers that M31 (and therefore, all galaxies) lies far outside the Milky Way
1951
Astronomers first measure the spiral structure of the Milky Way
1963
Maartin Schmidt finds that quasars are very far away, which means they are extremely powerful

Astronomer Edwin Hubble was studying an object in the autumn constellation Andromeda known as the Andromeda Nebula. Viewed through a telescope, it looks like a pinwheel, with bright streamers wrapping around a big bulge in the middle. At the time, most astronomers thought the Andromeda Nebula and similar objects were bright pockets of matter inside the Milky Way.

But on October 6, 1923, Hubble noticed a particular type of star inside the Andromeda Nebula (M31). Hubble realized that the star was a Cepheid variable, a type of star that astronomers use to measure distances in the universe.

Hubble found that this Cepheid -- as well as others that he saw on other photographs -- was far outside the Milky Way. When Hubble reported his findings the following year, astronomers realized that they had misnamed the Andromeda Nebula. It's not a nebula at all. Instead, it's a galaxy -- the first confirmed "city of stars" beyond the Milky Way.

In the decades since Hubble's discovery, astronomers have found that galaxies come in many shapes, sizes, and colors. Like the Andromeda galaxy and our own Milky Way, many are spiral shaped. Others look more like footballs, and still others have no regular form at all. The universe may contain 100 billion galaxies or more.

The smallest galaxies contain only a million stars or so. The Milky Way is home to several hundred billion stars. And the largest galaxies contain more than one trillion stars. Galaxies also contain vast clouds of gas and dust, which are the raw materials for new stars.

Galaxies also contain vast quantities of "dark matter" -- matter that produces no detectable light or other form of energy, but that reveals its presence through its gravitational pull on the visible stars and gas. In the Milky Way, dark matter appears to account for more than 90 percent of the galaxy's total mass. Most of the dark matter resides in a "halo" that surrounds the galaxy's bright disk and extends hundreds of thousands of light-years into space.

Galaxies are sprinkled throughout the universe. Only three galaxies outside the Milky Way are easily visible to the unaided eye -- the great galaxy in Andromeda (the Andromeda Nebula) and the Large and Small Magellanic Clouds. These are some of our nearest galactic neighbors. The farthest galaxies ever observed are more than 10 billion light-years away. These galaxies formed soon after the universe itself was born.

In theory, if the universe lasts long enough, the galaxies will die. Their stars will burn out. Some of the stars will drift away, but some will fall into giant "black holes" that lurk in the hearts of most galaxies. Eventually, all galaxies will disappear from sight.

You can find this Astro Guide at http://stardate.org/astro-guide/btss/galaxies
Explore the full Astro Guide library (http://stardate.org/astro-guide), including articles on:

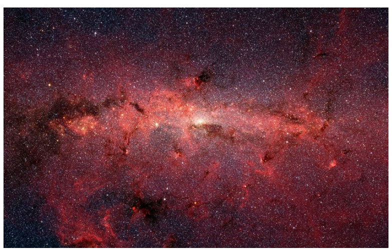
- Galaxy Formation
- The Milky Way
- Getting Together (Galaxy Mergers)

The exercise was created by StarDate (stardate.org) as part of the Astro Guides series. The Astro Guides for the Solar System and Beyond the Solar System are supported by the National Aeronautics and Space Administration under Grant Nos. NNG04G131G and NAG5-13147, respectively.

Student Activity: Build your own Galaxy

Introduction

Galaxies come in many shapes and sizes. Our Milky Way is a spiral galaxy, which looks like a pinwheel with arms of stars, gas, and dust. You can make your own Milky Way galaxy with materials you can find at a craft store. Before you begin this activity, review the section Galaxies: Cities of Stars and look for key information about our galaxy.



The Milky Way is a huge galaxy. For the 30-centimeter model, each centimeter represents about 3,300 light-years. The Sun is about 27,000 light-years from the center of the Milky Way. In your model, that's about halfway out from the center (8 cm or 3.2 in). Most of the stars you can see in the night sky are within one cm (0.4 in) of the Sun in your model. Our solar system is too small to see on the scale model of our galaxy. If our solar system were the size of a quarter, our galaxy would be almost the size of the United States.

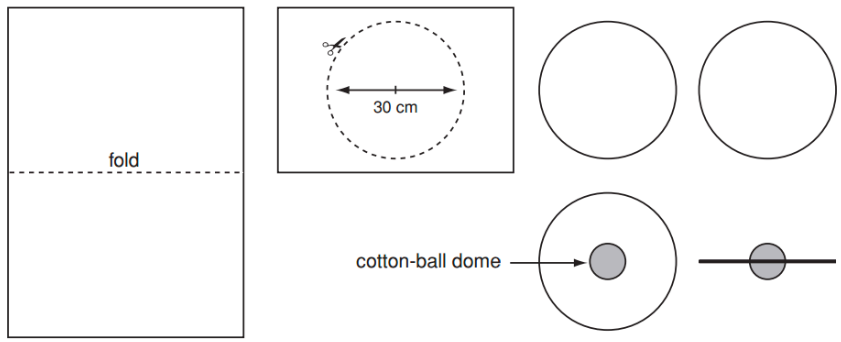
image credit: NASA/JPL

Materials

Bag of cotton balls	String or yarn
Half bag of polyester fabric batting	Pencil
Glue (white Elmer's glue)	Glitter (Red, Blue, Gold, Silver)

How to build your model

Your model can be as big (or small) as you like, but for convenience let's build a model 30 centimeters (12 inches) in diameter. You can scale it up or down to whatever size you wish. Gather materials at your favorite craft store.



Instructions

- Fold the black poster board in half, and trace a circle 30 centimeters (12 inches) wide.
- Cut out the circle. You should end up with two circles.
- Glue the two circles together, flat sides touching like a stack of pancakes.
- Let the glue set for about an hour.
- Build a dome of cotton balls in the center of the poster board circle. Apply dots of glue to the cotton balls to hold them together, and secure them to the poster board. The dome should be about 8 cm (3.2 in) across and 4 cm (1.6 in) high. Repeat on the other side of the poster board circle.
- Pull out the cotton into streams and spiral them around the cotton-ball dome.
- Dribble glue on the arms and sprinkle glitter (blue and silver) on the glue to represent newly forming stars.
- Dribble glue all over the poster board and foam ball, and sprinkle just this glue with gold and red glitter to represent older stars.
- You can add to your model by marking the position of our Sun with a "You Are Here" or "Home Sweet Home" sign. Mark the Sun 8 cm (3.2 in) from the center inside one of the spiral arms.
- You can decorate both sides of your galaxy model. Wait until all the glue has dried on the first side before decorating the second side.
- Punch a hole in your model, and thread it with string. Hang your model from the ceiling.

Some of the materials represent major characteristics of our galaxy:

Central bulge: the cotton-ball dome. The rounded structure in the central 6,400 light-years of the galaxy's center is what astronomers call the bulge of our galaxy.

Disk: foam batting on the poster board. The disk of stars in our galaxy contains gas, dust, and stars. Generally, it is flat like the brim of a wide hat. Astronomers estimate that the galaxy's disk is about 100,000 light-years in diameter.

Stars: glitter. The hottest and brightest stars are blue and white. But these stars live short lives — only ten million to a few hundred million years — and spend their whole lives close to where they were born in the spiral arms. Older stars found in the bulge and disk may be yellow, like the Sun, or red.

Extending your knowledge about galaxies

Stars are easy to see with your eyes, but lots of hydrogen clumped into cool gas clouds also orbits the galaxy. Astronomers can see these clouds because they emit radio waves at a specific wavelength. Using radio telescopes, astronomers map out these hydrogen clouds. Huge clumps of hydrogen emit radio waves at a wavelength of 21 centimeters (your microwave oven cooks food by emitting strong radio waves, called microwaves, at a 12-centimeter wave length). Astronomers have detected hydrogen far beyond the luminous stars of our galaxy. In your model, the hydrogen clouds would extend an additional nine centimeters from the edge of the disk. In real space, that's an extra 28,000 light-years!

Small (top) and Large Magellanic Clouds (Credit: NOAO)

Surrounding our galaxy is a halo of scattered stars and globular star clusters. These stars are much older than the stars in the disk. Some travel up or down through the disk. Their largest concentration is near the bulge. Your model can help you learn more about galaxies and how they are distributed in inter galactic space. Folks in the southern hemisphere can see two satellite galaxies close to the Milky Way. These are called the Large Magellanic Cloud and the Small Magellanic Cloud. On an intergalactic scale they are very close. The Large Magllanic Cloud is 165,000 light-years away, while the Small Magellanic Cloud is farther at 200,000 light-years. On the scale of a 30-cm size Milky Way, these two smaller satellite galaxies would be about 50 cm and 60 cm away. You can make model satellite galaxies using individual cotton balls. Tease the cotton balls out to make a messy blob, then add glue and glitter.

The Andromeda galaxy, M31 (Credit: NOAO)

On a grander scale is the Andromeda galaxy, a mere 2.5 million light-years from our galaxy. That sounds like a long distance, but compared to the size of the Milky Way, Andromeda is a close neighbor. If you made a second galaxy model representing Andromeda, and placed it about 25 Milky Way diameters away (7.5 meters or 25 feet), that would be the scale separation between these two giant spirals. So intergalactic space is big, but for galaxies it's rather crowded. For this reason, galaxies can collide and merge to form bigger galaxies.

Use your model while you stargaze

You can use your model to help you understand our place in the galaxy. When you look toward the stars in the constellation Sagittarius, you are looking toward the center of our galaxy. Line up your model so that its center lines up with Sagittarius. Then align the disk of your model with the Milky Way in the sky. Now you can imagine where we are inside our galaxy.

The original exercise is located at http://mcdonaldobservatory.org/sites/default/files/pdfs/teachers/build_your_own_galaxy.pdf

The exercise was created by StarDate (stardate.org) as part of the Beyond the Solar System series

Appendix B

Cosmic Castaways Transcript and Scene Notes

Cosmic Castaways Scene

Narration	**Visuals**	**Scene**
There are places where the night sky has no constellations. No Orion, no Big Dipper, nothing but a few lonely, far away stars and a few faint, ghostly patches of light. Most stars lie within the crowded boundaries of galaxies, traveling with their brothers and sisters in a vast galactic family. But some find themselves on their own, deep within the voids between the galaxies. These are the cosmic castaways...	Sunset on planet – nearly empty sky. Pull back off of planet to show star, zoom out to show isolation.	1
Title Sequence	Title enters from behind, whole scene fades out.	2
The Universe is full of stars. Some are huge, hundreds of times the size of the Sun. Others are tiny, barely larger than the familiar planet Jupiter. They come in a wide variety of colors – from the deepest red to dazzling blue. Most of these stars lie within galaxies; huge collections of stars, gas, dust, and dark matter that include our own Milky Way in their number.	Crowded star field; superimpose red star, yellow star, orange star, white star, blue star. Crossfade to cool Hubble Galaxy pic.	3
Just as our Solar System is one of many in our Milky Way galaxy, our Milky Way is just one of a myriad of galaxies. Galaxies do not exist alone. They are found in groups, held together by the same gravity that keeps their stars in orbit. Our Milky Way lies in a small galaxy group known as the Local Group, which contains a handful of large galaxies, and dozens of small galaxies.	Pull back to Local Group	4
As galaxies move within galaxy groups, sometimes wandering too close to one another, they can tug at each other through the force of gravity. These gravitational forces cause colossal changes to the shapes	Galaxy Merger with HST crossfade; more galactic collision photos.	

of the galaxies. Since this process takes place over hundreds of millions of years, astronomers cannot watch it from beginning to end. Their telescopes only catch snapshots in time, of different galaxies seen at different stages of this interaction sequence. With tools like the Hubble Space Telescope, dozens of these interacting galaxies have been imaged in amazing detail.		
This sort of collision is rare in small groups like our own Local Group. But, as we look beyond our home group, we encounter much larger collections of galaxies, called galaxy clusters. These immense systems are some of the largest structures in the Universe and contain thousands of galaxies. If the Local Group is like a small village of galaxies, galaxy clusters are like a big city – crowded and busy.	3D Map of Virgo Cluster flythrough? Wide view of Virgo Cluster?	
In galaxy clusters, the interactions between galaxies are much more common because the galaxies are crammed so close together. Computer simulations show us that in these dense environments many more stars will be gravitationally torn from their homes and left in the cosmic void. As we study these giant clusters, we witness numerous galaxies interacting with one another at the same time. Sometimes, long tails of stars are wrenched from galaxies during their too-close passages. Other times, the interactions produce fan-shaped plumes of castaways. One by one, gravity continually pries stars away from their galactic homes until 10 to 20 percent of the galaxies' stars are castaways - lost in the voids between the galaxies.	Mihos big galaxy cluster collision sequence.	
The intruder galaxy distorts the spiral galaxy and our star is hurled from its home along with many other stars as they are stretched out to form an enormous tidal tail. But the	Zoom into tidal tail, show stars moving away from collision. Fade out.	

tail is fragile – eventually, these stars will be scattered from gravitational pokes and prods of the other galaxies within the cluster, like a leaf torn from its tree in a windstorm. While evicted from its home, the star itself was not damaged, and its planets continued to orbit around it as they always had, oblivious to the large-scale chaos around them.		
Looking at the cluster as a whole, the light of our lost star and all its fellow castaways seems to be absent from our image. Like smoke from a fire disappearing in the wind, the light of the ghostly tidal tails has faded into the cosmic background as it spreads over tremendous distances. The starlight from these cosmic castaways is now so diffuse that it is much, much fainter – a hundred times fainter – than the dark, moonless night sky, making their light almost invisible. Too many other lights shine brighter than these castaways, and so they are all but lost in the glare of our busy universe. But they are not lost. It wasn't until the late 20^{th} century that astronomers had the tools they needed to search	Show moonless light sky on Earth w/ prominent Milky Way.	
The intruder galaxy distorts the spiral galaxy and our star is hurled from its home along with many other stars as they are stretched out to form an enormous tidal tail. But the tail is fragile – eventually, these stars will be scattered from gravitational pokes and prods of the other galaxies within the cluster, like a leaf torn from its tree in a windstorm. While evicted from its home, the star itself was not damaged, and its planets continued to orbit around it as they always had, oblivious to the large-scale chaos around them.	Zoom into tidal tail, show stars moving away from collision. Fade out.	
The most promising place to seek the light of these castaways is the nearby Virgo Cluster of Galaxies; the nearest galaxy cluster to Earth. It is about 55 million light years away,	Visible VC. Slowly crossfade to IC light image starting at "as it looked longer"	

and contains several thousand galaxies. Using a special telescope designed to search for this very faint light, astronomers spent months observing the center of the Virgo Cluster to search for its cosmic castaways. At first, the telescope saw only the bright galaxies in Virgo, as well as some stars from our own Milky Way in the foreground. But as it looked longer, probing deeper, an intricate web of tails and fans came into view in the space between the galaxies.		
This stunning image is a snapshot of the history of the Virgo Cluster. In this long exposure, the light of the cosmic castaways is able to shine visibly in the spaces between galaxies.	Crossfade complete. Fade out.	
Here is an image of one piece of the Virgo Cluster. Zooming in, we find a faint sprinkling of red objects. These are individual Red Giant castaways, peers to the star that we have followed, each of them lost forever between the galaxies.	Orange star swells and turns red. Fast zoom back to Earth orbit – Hubble pointed in star's direction.	
Credits	Slow roll from bottom to top superimposed over final scene.	

Appendix C

Galaxy Crash Simulation Handouts

Student Worksheet:
Crashing, Colliding Galaxies, & Orphan Stars

Notes:

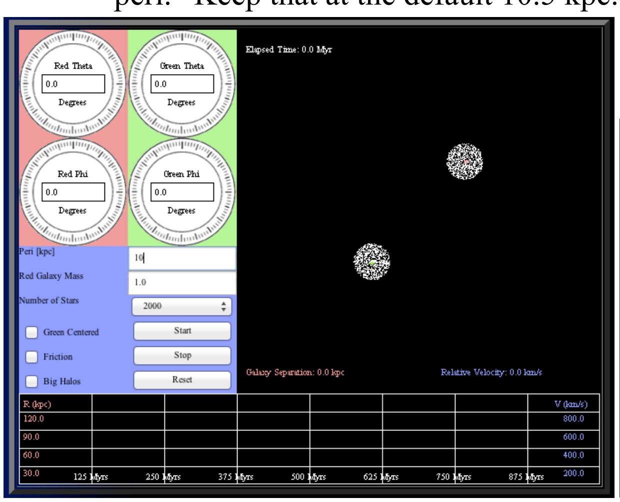
- Use Safari or Firefox with Java installed to use GalCrash - http://burro.cwru.edu/JavaLab/GalCrashWeb/
- Instructions on how to use the app are at the back of this packet
- Remember to click and drag on the simulation while it is running to see it from different angles!

Goal:

Can you discover what factors affect tidal tail formation in galaxy collisions and interactions?

1. **Orphaning Stars:** Before you get started, hypothesize what parameters will cause the most stars to be cast out of their galaxies to become cosmic castaways. Explain why you propose this.

2. **Set everything up:** We will select "friction" for these exercises. Dynamical friction is the loss of energy and momentum due to gravitational interactions, so this is more realistic. Set number of stars to the highest setting (2000). In the initial conditions: "red" galaxy mass is equal to the green galaxy mass (1.0). The angles are set to zero, so the initial disks are at the same orientation. The closest distance between the galaxy centers is "peri." Keep that at the default 10.5 kpc.



3. **Different galaxy masses**: Start by running the default simulation. What do you see happen? Describe the tidal tails produced. What is the end product? Are there any “cosmic castaways” or stars that are completely ejected from the system? (Note that the time is ticking in the upper left corner. You want to wait at least 2000 Myr, or two billion years.) Now, repeat for different red galaxy masses: 0.1, 5, 10. (Remember to click “Reset” after change parameters.) How are the tidal tails different in each case?

Red Galaxy Mass	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
0.1			
1.0 (Default)			
5			
10			

Do you see any trends in what happens as mass changes? Describe:

Which of these made the most “cosmic castaways” or escaped stars? Why do you think this is the case?

4. **Different galaxy center distances**: Go back to initial conditions (red galaxy mass = 1). and again observe the tidal tails. Now, change the pericenter distance for each trial: 5, 1, 20 kpc. Describe the tidal tails in each trial. How do they change as the galaxy centers are closer at the collision? Farther away? Which scenarios produce cosmic castaways?

Galaxy separation: Peri	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
1 kpc			
5 kpc			
10.5 kpc (default)			
20 kpc			

Do you see any trends in what happens as the smallest separation changes? Describe:

Which of these made the most “cosmic castaways” or escaped stars? Why do you think this is the case?

5. **Different galaxy angles**: Now, reset to initial conditions (peri = 10 kpc) and we are going to change the angle of the disks with respect to each other (theta). Run the simulation at zero degrees and again observe the tidal tails. Then, change red theta to 40 degrees. How are the tails different? (Remember to click and drag on the simulation to change your viewing angle!) Now increase red theta to 90 and run. How does this change the tidal tails? Turn red theta all the way up to 180, so that the disks are once again in the same plane but rotating in opposite directions. How does this affect tidal tails?

Galaxy theta (angle)	How do the galaxies interact?	Which galaxies form tidal tails? (Red/Green/Booth)	Orphan stars? (Y/N)
0° (default)			
40°			
90°			
180°			

How does rotation effect the formation of tidal tails? Describe:

Which of these made the most "cosmic castaways" or escaped stars? Why do you think this is the case?

6. **Orphan Stars:** Design a simulation that you think gives the maximum chance of having cosmic castaways, using your answers from the previous three sections. (You may need to refresh the application to set theta back to zero.)

   What are its initial starting conditions?

   - **Red Galaxy Mass**

   - **Peri (kpc)**

   - **Red Theta**

   Did you successfully form cosmic castaways? Describe your results (include sketch)

Student Guide:
Galaxy Crash

Simulation controls

Dials

Theta [ ]	the inclination of the galaxy in the orbital plane [in degrees].
Phi [ ]	the slew of the galaxy in the orbital plane [in degrees].

Note re theta and phi: The controls only let you adjust up. Refresh the window to return to 0

Other controls

Peri: ________	the distance of closest approach [in kiloparsecs].
Red Galaxy mass: ________	the mass of the Red (companion) galaxy [in terms of the Green (main) galaxy's mass, ie 1=equal mass].
Number of Stars: [-----------]	the total number of stars in the simulation, divided evenly between galaxies. The smaller the number, the faster this applet will run; the bigger the number, the cooler the simulation.
[ ] Green Centered	centers the view in on the green (main) galaxy, allowing the viewport to move with it.
[ ] Friction	turns on dynamical friction, calculated using a Chandrasekhar-like analytic implementation. This option will allow galaxies to merge.
[ ] Big Halos	makes the (unseen) dark matter halos four times bigger and more massive

To run the simulation

[START] starts or continues the simulation.
[STOP] pauses the simulation.
[RESET] initializes the simulation.

To control view

- To rotate the simulation, click and drag inside the viewport.
- To zoom in on simulation (or Rotate about the z-axis), hold the Shift key and drag inside the viewport.

Appendix D

Handouts for Galaxy Collision Sequence Activity

Student Worksheet:
Galaxy Collision Sequence

Goal: To put together a "movie" of how galaxies collide and merge together.

1. Since galaxy collisions take hundreds of millions of year to complete, astronomers can't watch a single collision sequence from the start to the finish. Instead, astronomers have to look at different galaxy pairs at the same time, each pair at a different time in the sequence. We call the entire process a "collision sequence" and the steps of the process are called "stages."

   From watching the movie, you should have an idea of what the sequence should look like, as if they were frames from a movie. Use a pencil to roughly sketch out the collision sequence in four stages. Pay attention to how close the centers of each galaxy are from each other, and whether the tails are getting longer or shorter. For each drawing label the main features of that particular stage. Consult with the rest of the students in your group about your drawings.

   a. Pre-merger

   b. Early stage: First visible galaxy contact

   c. Middle stage: Galaxies have passed through each other

d. Late stage: Final merger state

2. For astronomers to discover galaxy collisions, they first had to discover galaxies that had unusual shapes. This was done with black and white photographs of the sky. Once a list of interesting objects was found, astronomers then observed the objects in greater detail with more modern telescopes, including color images.

   Take a look at the 12 images in the picture packet. For each galaxy pair, there is a black and white discovery image and a detailed color image. Each image is labeled with a letter. The color images are usually zoomed in on the centers of the galaxy pair, and the images are usually rotated compared to the black and white images.

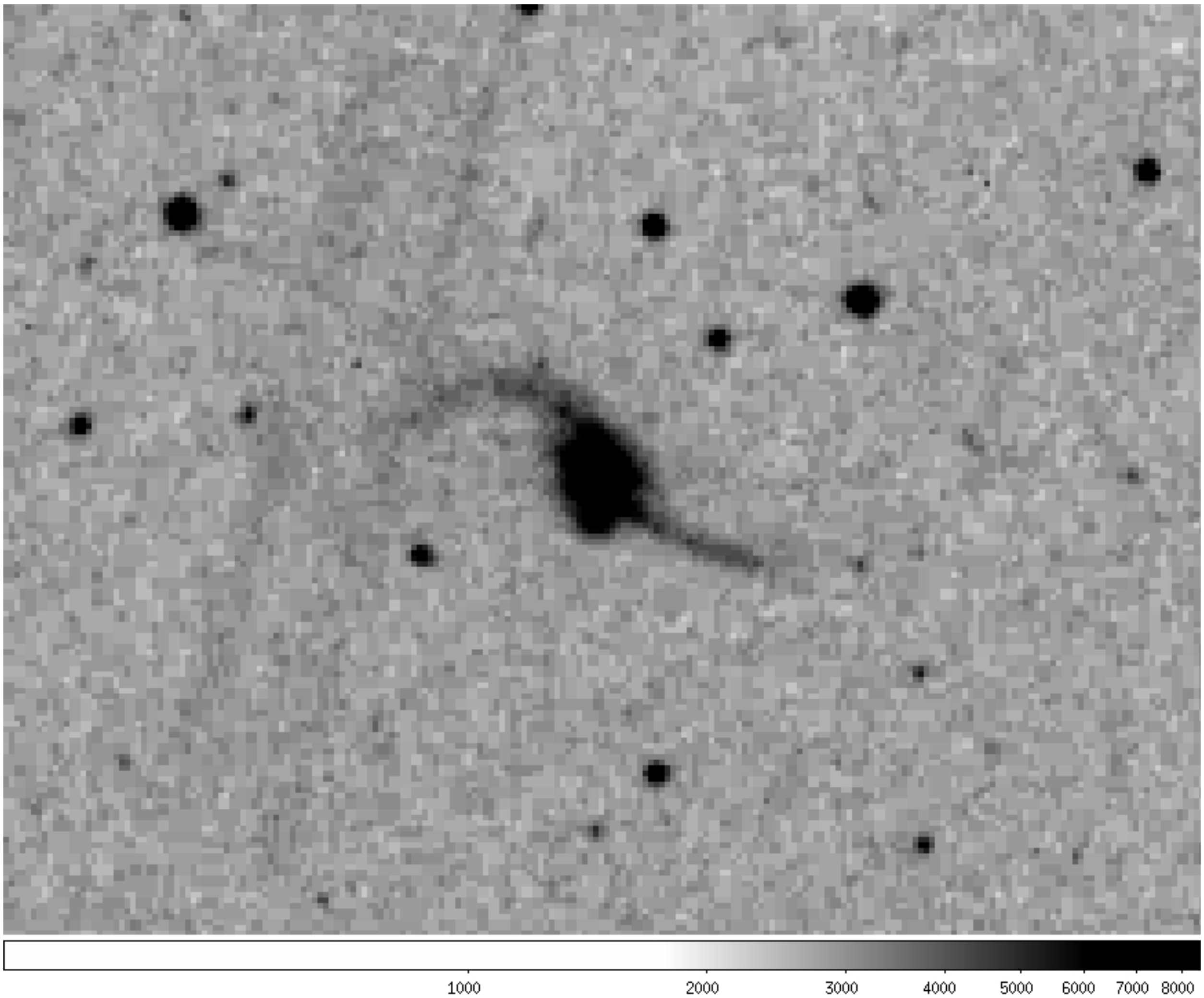
   Match each black and white image (A through F) to the corresponding color image (G through L). One way to do this is to lie out all of the 12 images on a desk or table, and move them around until each black and white and color images match up. Fill in the matches below.

   A corresponds to
   B corresponds to
   C corresponds to
   D corresponds to
   E corresponds to
   F corresponds to

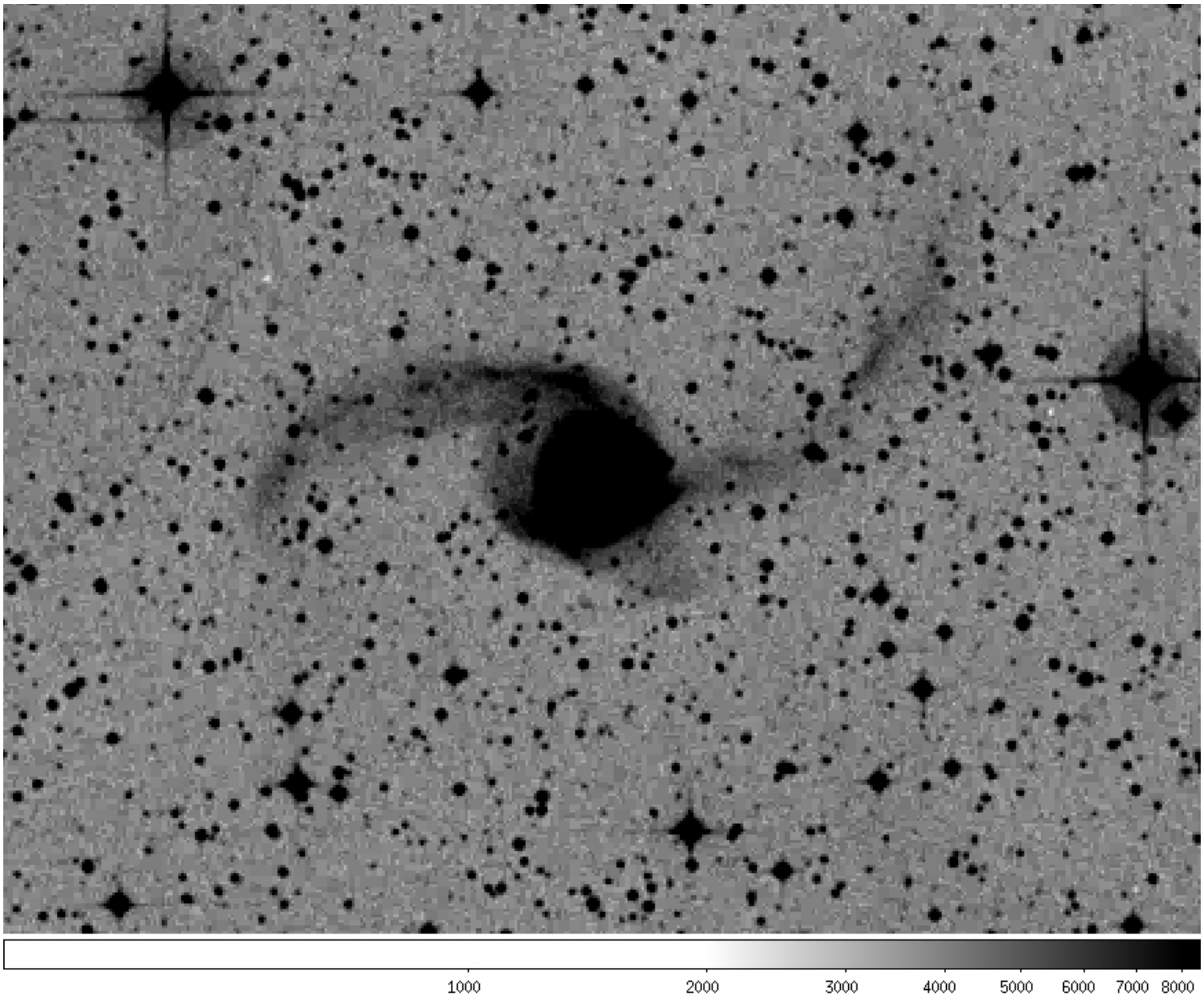
3. Consider images G though L. Divide the galaxy pairs into “Early,” “Middle,” and “Late” stages. There should be two galaxy pairs for each stage. (Ignore the pre-merger stage from question 1.)

   Early:
   Middle:
   Late:

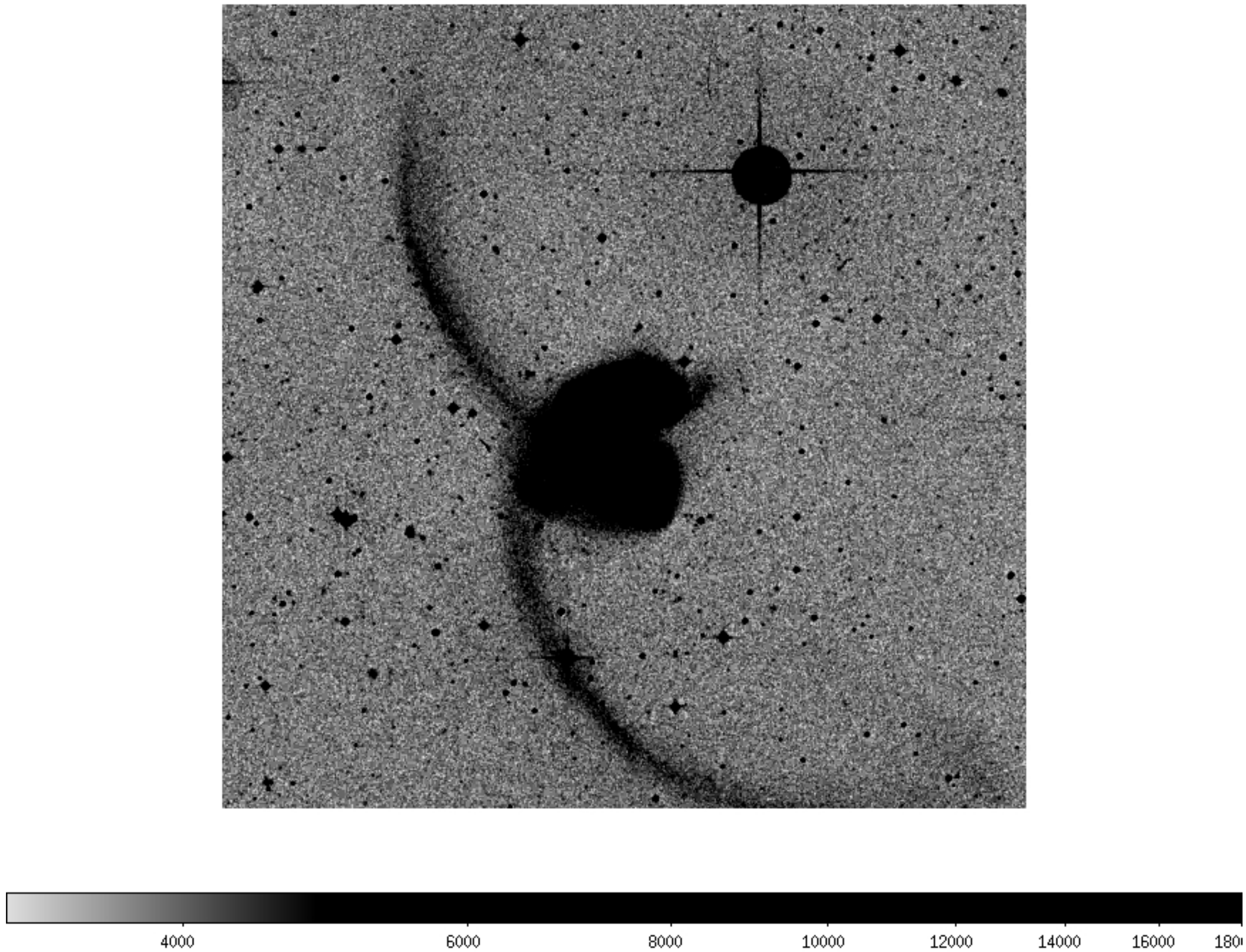
   For each pair of images, what features in the images did you use to determine the collision stage? What feature is most likely to produce orphan stars or “cosmic castaways”?



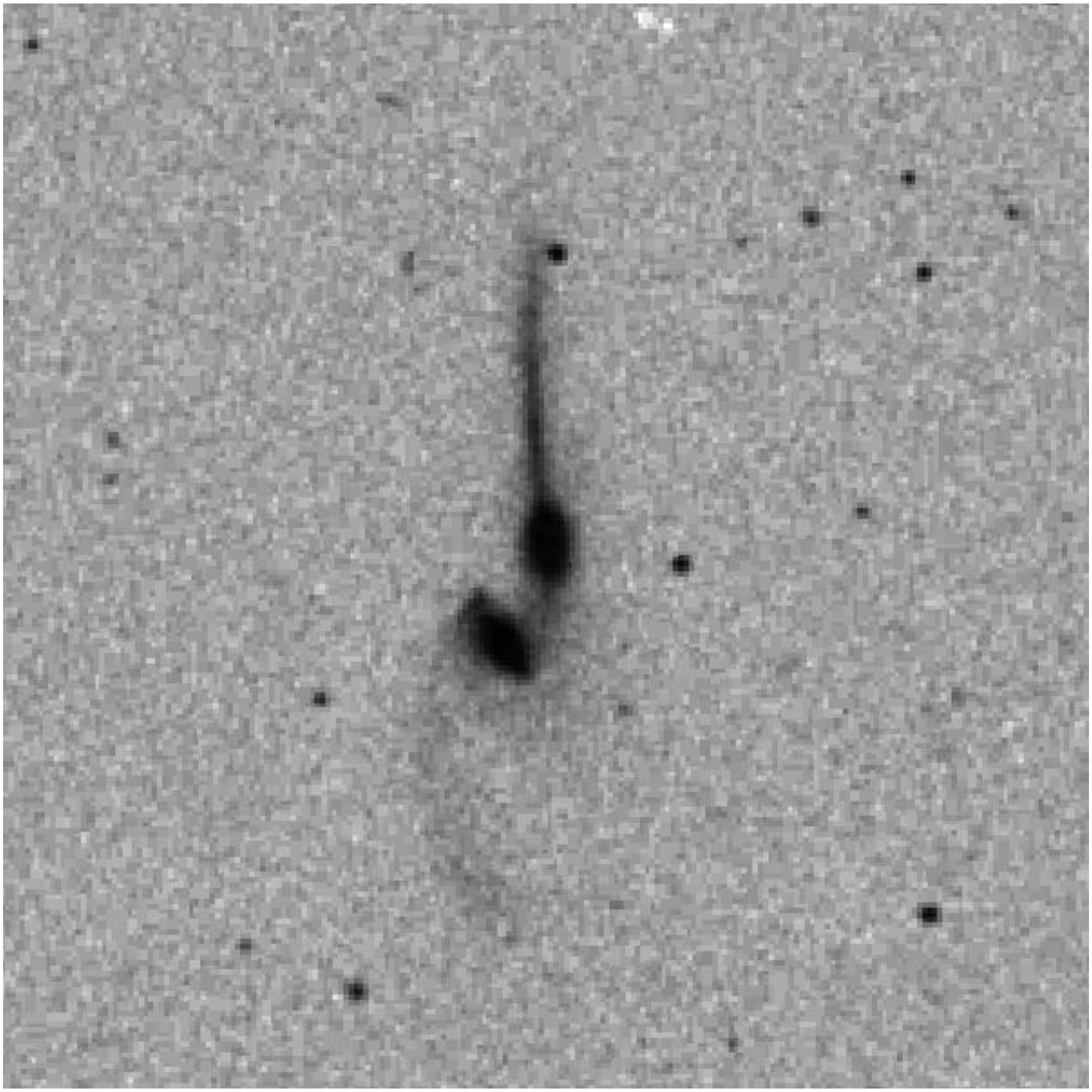
A



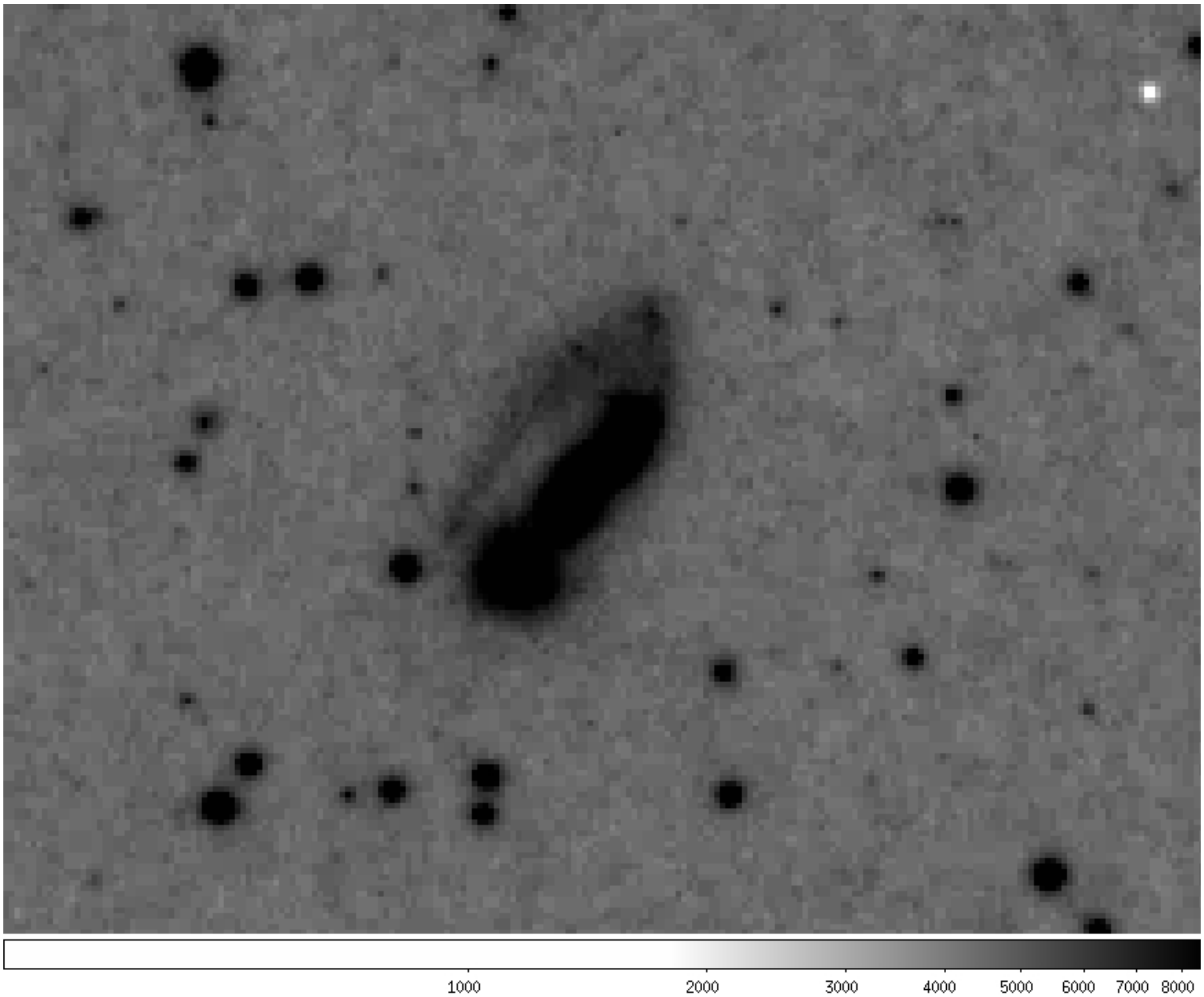
B



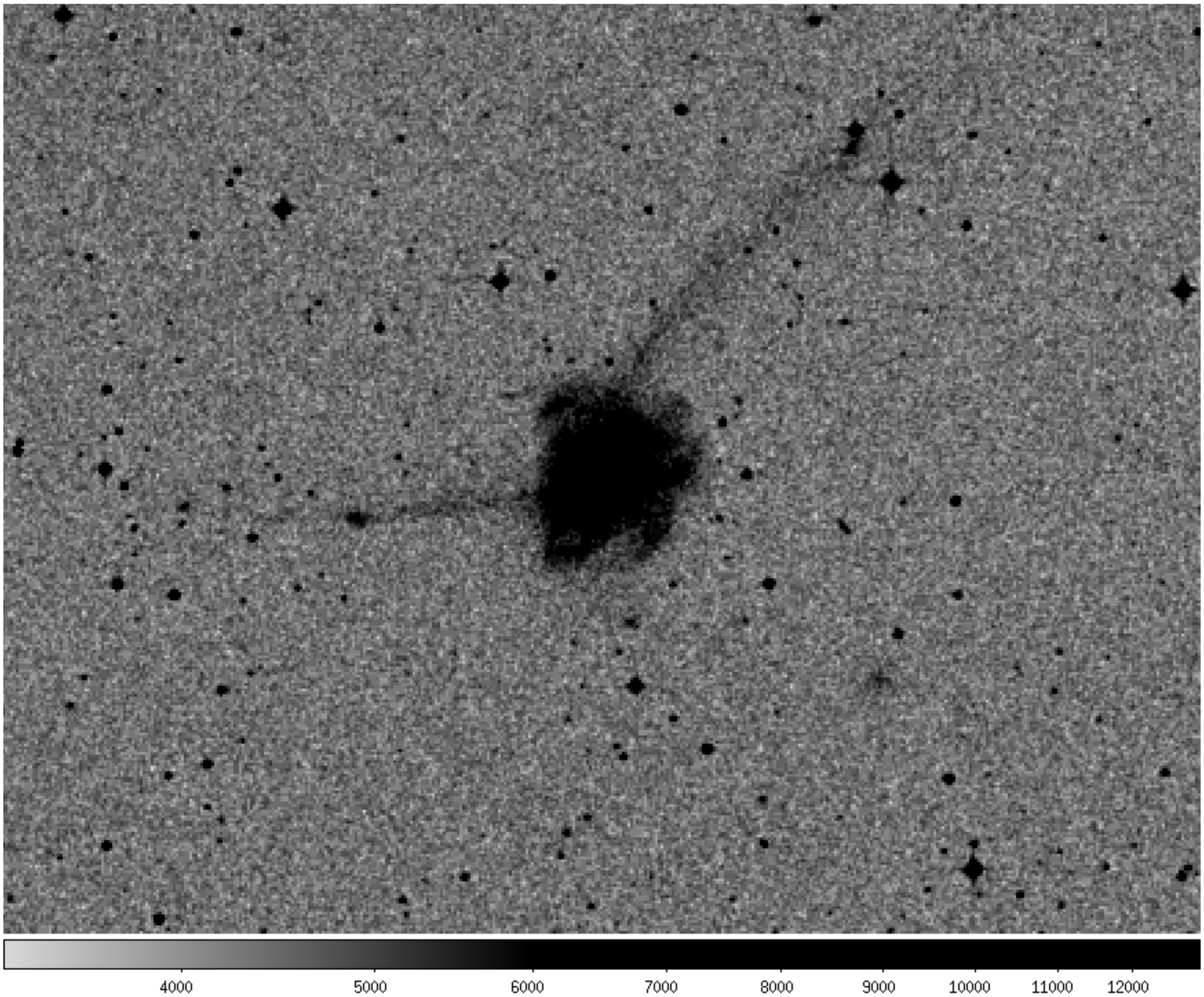
C



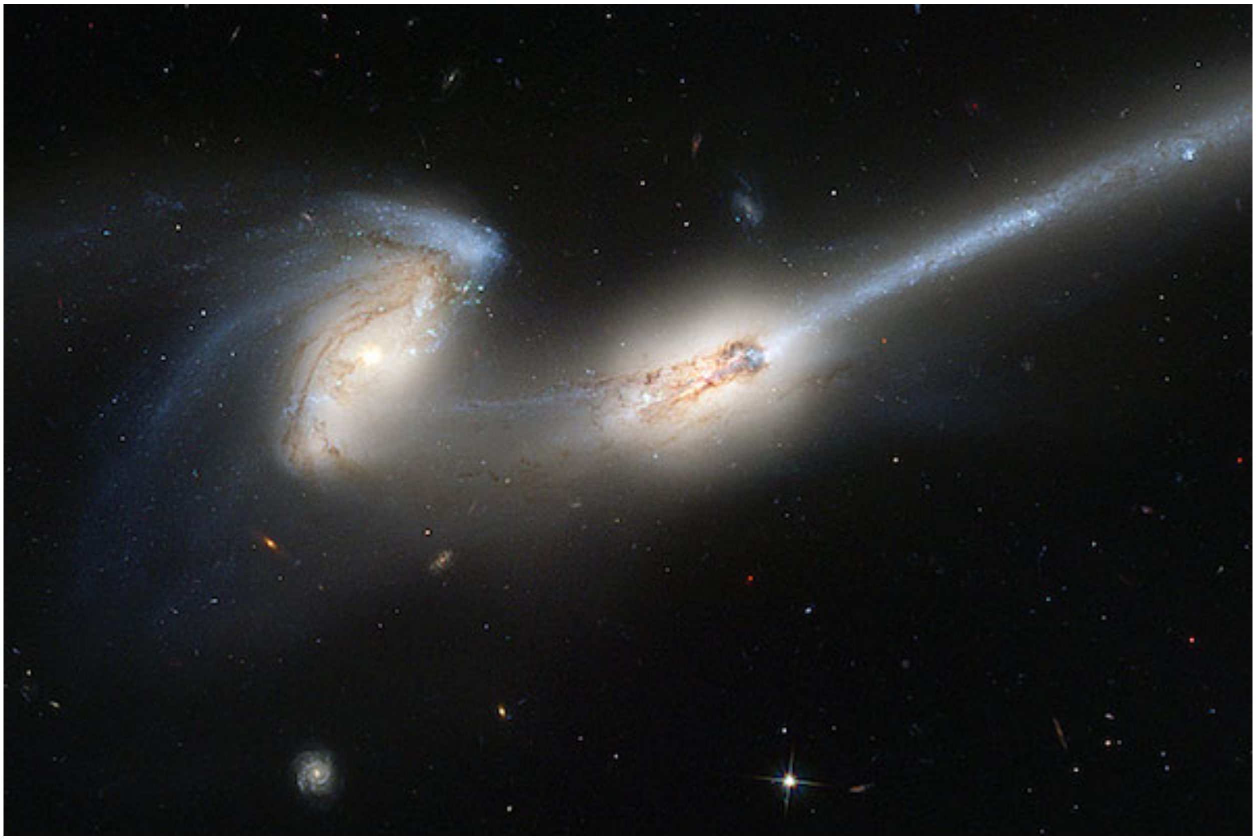
D



E



F



G

H

I

J

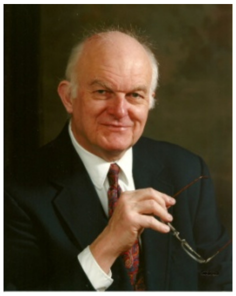
K

L

Appendix E

Toomre Sequence

What is the Toomre Sequence of galaxies?



Alar Toomre is a theoretical astronomer and mathematician. He was born in Estonia on February 5th, 1937, and emigrated to the United States with his family in 1949. He is known for many astronomical discoveries, including being one of the first persons to simulate galaxy interactions and collisions using a computer in the 1970s. Dr. Toomre's brother, Juri Toomre, is also a famous solar astronomer, and has worked with Alar on his galaxy interactions work. More information about Dr. Toomre can be found at: http://en.wikipedia.org/wiki/Alar_Toomre.

The Toomre Sequence: In a scientific paper published in 1977 (which can be seen at: http://ned.ipac.caltech.edu/level5/Toomre/Toomre_contents.html), Dr. Toomre presented a list of 11 pairs of galaxies that had unusual shapes. He argued that these galaxy pairs were interacting with each other through the force of gravity, and they would eventually merge into a single larger galaxy. Some of Dr. Toomre's sketches of the galaxy pairs are given below:

The 11 pairs were arranged roughly in order of time, according to Alar Toomre's judgments. So the sequence is not a precise one in time – it's better to think of the sequence as categories of "early, middle and late", as the galaxies come together, pass through each other, come back together, and then finally merge as a single galaxy.

The galaxy pairs were first discovered using the **Palomar Sky Survey**, which was a black and white photographic image survey of the entire sky taken in the 1950s. These are shown as the black and white images in the lab (Images A through F).

Once these objects were discovered, many follow-up observations of the galaxies in the Toomre Sequence have been made, including radio images of the galaxy pairs (for example, see http://www.cv.nrao.edu/~jhibbard/TSeq/), and *Hubble Space Telescope* images of the galaxy pairs (for example, see http://hubblesite.org/newscenter/archive/releases/2008/16/). It is some of these follow-up images, taken with more modern telescopes and imaging equipment, which are given in the lab as color images (Image G through L).

Why Study the Toomre Sequence? Galaxy collisions and mergers are important for the build up of large galaxies like our Milky Way. Collisions and mergers also encourage large bursts of star formation. Though a few stars are lost as "cosmic castaways" many more are formed that will continue to shine for billions of years. Though these irregularly shaped galaxies were initially difficult to classify, the Toomre brothers helped to solidify their importance to galaxy evolution in the Universe, a topic that is still under intense research in modern astronomy.