

# AY 5: Galaxy Inquiry

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## 1 Schedule

- June 23: 1st lecture
  - Introductory survey (whole class)
  - Starter: observations of color-composite galaxy (5 min.)
- June 25: Day 1
  - 10:00: Introduction to inquiry (Ryan; 10 min.)
  - 10:10: Group discussion of galaxy observations (David talk; Liz records; 20 min.)
  - 10:30: Classify *ugriz* galaxy images (20 min.) (Liz introduces.)
  - 10:50: Draw representative galaxy diagrams (10 min.)
  - 11:00: Random-walk share-out (15 min.)
  - 11:15: Summary transition discussion (15 min.)
  - 11:30: Break/station setup (15 min.)
  - 11:45: Transition and early investigation (60 min.)
- June 27: Day 2
  - 10:00: Review plan (5 min.)
  - 10:05: Middle and late investigation; presentation prep. (40 min.)
  - 10:45: Share out (20 min.)
  - 11:05: Break/synthesis evaluation (15 min.)

- 11:20: Synthesis (David and Liz; 15 min.)  
11:35: Post-inquiry assessment: observations of merger (Ryan; 5 min.)  
11:40: Strongly suggested playtime (20 min.; *may be skipped*)  
12:00: Random-walk discussion of astronomy (Ryan; 45 min.)

## 2 Goals

### 1. Course goals:

- (a) Students will understand that electromagnetic radiation is all astronomers have to study.
- (b) Students will understand that a galaxy has components: stars, gas, and dust.
- (c) Students will understand how to interpret astronomical images. This can be evidenced by students viewing a slew of astronomical images of new objects and being able to make general statements based on the project effects and color-temperature content they learned.

### 2. Tier 1 (goals all students should meet):

- (a) Students will gain familiarity with the object of an astronomical image, learning to see past errant objects such as foreground stars, background galaxies, and detector blemishes. The students will demonstrate this understanding by drawing the salient points of a class of galaxy images.
- (b) By assigning multi-color galaxy images into their own classification scheme, students will observe general similarities and differences between galaxies.
- (c) Students will draw a representative diagram of a galaxy from each classification group in color and with labels in order to identify the most fundamental characteristics of each classification group.
- (d) The details in the representative diagram will indicate the components of a galaxy the students identify.
- (e) The color-image classification stater will engage the students in the study of galaxies so that during the discussion of the classifications, the students will begin seeing the broad trends to be investigated at the stations.
- (f) Students will recall and apply ideas briefly introduced in first lecture and internalize the use of e.g., filters, blackbody radiation in astronomy.

3. **Tier 2** (goals some students will meet):

(a) **Color-temperature station:**

- i. Students will utilize “white light is composed of all colors” to assess the peak color of the bulb as seen through the filters.
- ii. Students will learn “hotter, brighter, bluer” and “cooler, dimmer, redder.” They will point this out when looking at any (new) astronomical image.
- iii. Students will discover that a radiating object’s color is related to the amount of heat it is producing by observing the color and measuring the temperature of various heat sources (e.g., incandescent bulb, hot plate, cigarette lighter).
- iv. Students will link galaxy components by color and model the entire galaxy as a collection of light sources of different temperature, thereby coming to understand that certain galaxy regions consist of hotter light sources (stars) than other regions. These students will demonstrate this by viewing a movie of a galaxy merger and discussing the images in terms of temperature of stars.
- v. Challenge: Students will realize that heat is not the only physical property that affects color, and that things like chemical composition, scattering effects, etc. also affect color. Students will use prior knowledge of campfires to understand that certain substances burn blue/green (copper), red/ orange (salt).

(b) **Project effects station:**

- i. Students will understand that the information from astronomical images is a projection from 3-D into 2-D.
- ii. Students will understand that even though more than one object can create the same shape, that the “simplest” one is the most likely.
- iii. Students will also learn to distinguish between possible 3-D models that produce the same 2-D projection from “statistical” arguments, whereby they see that more often one model looks like a real galaxy than the other model.
- iv. Some students will learn to consider the three-dimensional aspects of the astronomical galaxies shown in the two-dimensional images. They will demonstrate a higher level understanding of this by determining the likelihood of certain two-dimensional objects being the true structure of three-dimensional objects. Or the students will figure out which images from different perspectives of a simulated galaxy are the same.

- v. Advanced goal: Students will understand that most materials are not completely opaque, *i.e.*, various degrees of extinction.
- vi. Advanced goal: In the same way you can make a shape out of components, students will understand that galaxies can be comprised of multiple components.

## 3 Succinct, Detailed Outline

### 3.1 First Lecture

- Present class with a single galaxy observation. Students write down at least two observations individually and submit.

### 3.2 Inquiry Day 1

- Attendance **10:00**
- Introduction to facilitators and to inquiry; set expectations, “rules of engagement,” goals, grading, and schedule. **10:00–10:10** (Ryan)
- Display the same galaxy image from 1st lecture and ask the students to share some of their observations. Record these on the board in columns of color, shape, and QWWNDWATT. Make note of observations that are particularly interesting/important (planted or from 1st lecture and make sure that they get recorded. **10:10–10:30** (David talks; Liz records)
- Form groups of 2–3 (by random assignment). Each group will be given 17 (prime!) galaxy images. Ask students to classify them into 4 distinct types with at least 3 galaxies each. Tell them will present their results. *Write task on poster.* **10:30–10:50** (Liz)
- For each classification, a representative image should be drawn (with color options). A written description should also be included (can be just a list). Tape galaxy images to diagram. **10:50–11:00**
- Groups present their classification schemes—piggy-backing on differences—and tape them around room. **11:00–11:15**
- Using the students classifications and observations, elicit students to seeing the broad trends used to classify: color, shape, misc. Inform them that after a break they will investigate either color or shape in detail (since those investigable in-class); have them think about what they find the most interesting **11:15–11:30**

- Break and station setup **11:30–11:45**
- Ask students to split to stations by interest. If strongly uneven, ask for volunteers to swap, letting them know they will have chance to experiment at other station on Friday. **wiki, wiki**
- Students will engage in “early investigation” by learning to use the equipment and sorting out exactly what their question is. Facilitators will guide their students to be interested and engaged in their station and feel *ownership* of the investigation. **11:45–12:40**
- Facilitators will wrap up their individual stations before dismissing their students. Facilitators may ask students to record their thoughts so they can readily resume again later. Facilitators may “assign” their students to *e.g.*, bring something back to class or observe some phenomenon at home. **12:40–12:45**

### 3.3 Inquiry Day 2

- Attendance **10:00**
- Address group: review state of schedule and goals for the day. **10:00–10:05**
- Middle and late investigation at stations: students should be focused on their question/task. They should be conquering the Tier 1 goals and beginning to tackle Tier 2, as accessible by their station. Students should develop a working mental model that allows them to make predictions. **10:05–10:35**
- Students begin working on presentations. State expectations and requirements for share out (3–5 minute/person; everyone should speak; state clearly their question and their conclusion/mental model.) **10:35–10:45**
- Groups share out. Facilitators should take notes on their synthesis outlines in order to pinpoint groups and names when re-iterating the goals. **10:45–11:05**
- Break and last-minute pre-synthesis pow-wow **11:05–11:20**
- Synthesis (pre-planned, mostly): David and Liz congratulates group, reiterates goals (as discovered by groups), dispels any very troubling (residual) misconceptions, and gives the “So what?” for the whole inquiry. **11:20–11:35** (David, then Liz)
- Post-inquiry assessment: display image of merger and have students *submit* in writing observations but also discuss. **11:35–11:40**

- Strongly encouraged playtime with alternate station. Perhaps cross-pollinate groups and have them pair-share. May skip to next activity. **11:40–12:00**
- Lead students to applying their recently-acquired knowledge to images other (unfamiliar) astronomical objects. **12:00–12:45** (Ryan)

## 4 Student Observations

NGC1672 (<http://antwrp.gsfc.nasa.gov/apod/ap070418.html>): “Many spiral galaxies have bars across their centers. Even our own Milky Way Galaxy is thought to have a modest central bar. Prominently barred spiral galaxy NGC 1672, pictured above, was captured in spectacular detail in this recently released image taken by the orbiting Hubble Space Telescope. Visible are dark filamentary dust lanes, young clusters of bright blue stars, red emission nebulae of glowing hydrogen gas, a long bright bar of stars across the center, and a bright active nucleus that likely houses a supermassive black hole. Light takes about 60 million years to reach us from NGC 1672, which spans about 75,000 light years across. NGC 1672, which appears toward the constellation of the Swordfish (Dorado), is being studied to find out how a spiral bar contributes to star formation in a galaxy’s central regions.”

- Color (may be compare-contrast sort of observations)
  - There are several colors.
  - Most of it is blue/gray.
  - The center is white.
  - The center is red.
  - Most of the dots/stars are red.
  - It is fainter at the edges.
  - There are dark red streaks.
  - Some of the spiky dots/stars are blue-white. (Could be QWWNDWATT.)
  - Some of the fuzzy dots are orange == background galaxies. (Could be QWWNDWATT.)
  - The pink parts are near white parts. (May be QWWNDWATT because HII regions.)
  - The denser gaseous material/less transparent stuff is whiter/bluer.
  - White is where there is all colors.
  - The stars are dimmed by the dust and gas.
  - Misconceptions about Color
    - \* Blue parts are cooler == blue is “cool color.”
    - \* Red parts are hotter == red is a “warm color.”
    - \* The center should be white == prior experience with images.

- Shape
  - There is a center.
  - The center is small compared to the full galaxy.
  - There is no definite edge.
  - There are streaks of red == dust lanes.
  - It is a spiral./It is swirly./It looks like it's spinning.
  - There are three/N arms.
  - It is not round.
  - It is oval.
  - It is flat.
  - It is tilted.
  - It is clumpy.
  - It is messy.
  - The center oval is not aligned with the outside oval.
  - There is a stream swooping up and to the left.
  - It is not symmetric.
  - It looks like there's something blocking the light.
  - There are holes in the galaxy.
  - It looks transparent.
  - Except for the center.
  - Misconceptions about Shape
    - \* The stars are behind the fuzzy foreground material.
    - \* The center should be big.
    - \* This galaxy is merging because the left arm is a tidal tail.
- Color-shape connection (may be QWWNDWATT)
  - The dots/stars are in the spirals/swirls.
  - The reddish dark lanes trace the spirals/swirls.
- QWWNDWATT
  - It is pretty.



- There are spikes coming of of the stars == diffraction spikes.
- It's black/dark blue at the edges == background.
- There's a fuzzy red point in the upper center == background galaxy.
- There's a fuzzy red point in the galaxy toward the upper right == background galaxy.
- Some galaxies are smaller than other or visa versa == due to size on image and not physical.
- There is star formation. (And any other such facts based on external knowledge.)

## 5 Introduction, Observations Discussion, Transition

### 5.1 Intro

1. Introduction to inquiry (also see PDP “Contexting Scripts” document):
  - (a) Explain purpose of inquiry, in general: “Inquiry may be unfamiliar but can be lots of fun and very rewarding if you stay engaged in the activity.”
  - (b) Explain purpose with respect to the course: “During the first lecture, Kathy planted many ideas about astronomical images, and today we’re going to apply the various facts briefly covered, so that you will learn them and remember them better, because they’re important for the rest of the class.”
2. Explain the process of inquiry:
  - (a) You (students) presented with puzzling problem.
  - (b) Guide you to see the big trends and get you to wonder why things are as they are.
  - (c) Investigate one or two parts of the puzzle in a focused manner.
  - (d) Share what you have learned and listen to what others have learned (and how!)
  - (e) “Liz and David are *facilitators* of your learning. They are not here to ‘give the answer.’ Don’t ask.”
  - (f) “Ryan is backing up Liz and David. He is helping organize behind the scenes, and he’ll often defer discussing topics with you to your facilitator, whether it be Liz or David.”
3. Explain why inquiry: “Inquiry is much closer to the way scientists actually investigate—they are never given a lab handout that says ‘step A do this, step B do that, etc’—inquiry is much closer to ‘real science.’ ”
4. Ground rules (similar to class):
  - (a) From the syllabus:
    - i. Each student should take responsibility for his/her own learning (*e.g.*, ask questions, seek additional help).

- ii. All students should be respectful and supportive of their peers' learning (*e.g.*, help each other with difficult concepts but do not just "give the answer").
  - iii. Everyone should actively participate in class (*e.g.*, discussions, activities, demonstrations).
- (b) Everyone expected to contribute, and the facilitators will call on you to share. Please don't think we're picking on you; just speak up.
  - (c) "Inquiry can be frustrating (just like doing real science) but it's also an indication that you are pushing the boundaries of what you understand/know."
  - (d) "It's okay if the inquiry process doesn't come easily. This is also about getting better at engaging in the scientific process."
  - (e) "If you get stuck, it's okay—take a break, get a drink, see what other groups are doing. Your facilitator will also help. There are two types of stuck: done stuck and stuck stuck." (Explain and say what will happen in those cases.)

#### 5. Expectations:

- (a) Be on time.
- (b) This will be graded (from the syllabus):
  - i. *Grade*: 5% of your total course grade is participating in the two days of the inquiry. (5% of your total grade is the written summary of your participation in the inquiry, described below.) You will be graded on:
    - Attending both days of the inquiry (and being on time.) You will be working in teams, and it would be very unfortunate to miss a team member during any portion of the inquiry.
    - Participating in the tasks and challenges that the facilitators lay out.
    - Sharing your questions, comments, and ideas throughout the inquiry.
    - This is a non-traditional grade, since inquiry is more about the process of learning than about right or wrong. Ryan, David, and Liz will score your participation on how engaged you are throughout, how much you push your understanding, how you interact with your peers, how you improve in your scientific process skills, etc.
  - ii. Assignment: **email** written summary *in the body of the email* (no word processing or formatting necessary; due: **5 PM**, Saturday, June 28)

- Address the following in whatever order and in however many words necessary:
  - What did you learn? How did you learn this?
  - What were the key points that the facilitators wanted you to learn? Did you learn these key points? Why or why not?
  - What more would you have liked to investigate and why? If nothing, why?
  - Did the “The Secret to Raising Smart Kids” reading influence your inquiry experience? Why or why not?
  - Any questions, comments, concerns?
- The summary is worth 5% of your grade. It will be graded on how clearly you recount your experience with—and your thoughts on—the inquiry.
- This is not an English grammar class; the summary does not have to be fancy, just informative. *But* it is expected that you will *e.g.*, clearly distinguish between fact and opinion, use complete sentences and proper capitalization, check spelling, etc.

6. Schedule:

- (a) Use flip chart and keep schedule displayed.
- (b) Not too detailed (*e.g.*, exclude “Transition (5 min.)”)

## 5.2 Observation Discussion

1. Display starter image again.
2. Ask for volunteers to share observations and record on board under different *unlabeled* columns: color, shape, QWWNDWATT.
3. Bring up key observations from “Introductory Survey” (pre-assessment). Even use planted ones.
  - (a) *e.g.*, say, “Someone mentioned that the outer regions appear bluer than the inner regions.”
4. Normalize the jargon to be used. If someone says, ‘spiky dots’ ask if anyone knows what they are and if not, introduce as “stars.” *Make them clarify what they are talking about by pointing* (laser pointer or something).

5. Dissuade interest in artifacts of observations (foreground stars, background galaxies, detector effects).
6. Forestall discussion on what people know (prior knowledge), what they suspect (leave for investigation), and keep notes on what should be covered *sometime* (investigation, small-group discussion, synthesis, future lectures).

### **5.3 Transition to classification activity**

1. Guide towards interest in how this one galaxy compares to others:
  - (a) Do you think other galaxies look like this?
  - (b) What might be the same between galaxies? Different?
2. Present task of methodically organizing set of galaxy images:
  - (a) Count off to form groups of 3–4.
  - (b) The categories must have at least three galaxies, and there must be at least four groups.
  - (c) Really keep a mind to why you think some galaxies are more alike than others, and why they belong in the same groups.
  - (d) State that the students will have to share their classification scheme later (so don't worry about it now).
3. **Write task on poster.**

## **6 Classify Galaxies, Draw Diagrams, Share out**

### **6.1 Classify**

1. Allow about 5–10 minutes for the students to just orient themselves.
2. Wander around and take notes. Then introduce yourself as the facilitator.
3. If interpersonal conflicts arise, if early enough, suggest changing groups.
4. If students struggle between groups (trying to fit the required number of galaxies per groups and number of groups), suggest they consider how they would change if they prioritized one aspect over another. (Kind of like poker.)

5. Emphasize early that they should be articulating why they make the decisions they do..
6. Facilitators should formulate challenges to why some galaxies more similar than others. Bring up similarities with other galaxies not in the current category. *Do not necessarily have the same discussion with every group but sow diversity.* Some useful back-pocket questions:
  - (a) How would your classification scheme change if the images were in black and white?
  - (b) What other attribute could you have used to classify with?
  - (c) What if we could view this galaxy from another location, would your classification change?
  - (d) What is similar across your groups?
  - (e) If this (spiral) galaxy was all red, would you group it with this all-red (elliptical) galaxy?
  - (f) Why do you think this (spiral) galaxy is red when these other ones are mostly blue?
  - (g) If you were to build a model of you galaxy group instead of drawing a diagram, what would it look like? (Save “Why?” for later.)
7. Make sure room has evenly divided interest between structure (projection) and colors.
  - (a) Plant seeds about projections:
    - i. Why do you draw that line as a thick donuts?
    - ii. Why do you draw that just as a circle? Do you think it has another dimension?
    - iii. What does your diagram look like from another angle?
  - (b) Plant seeds about colors:
    - i. What are the predominate colors? Is that curious?
    - ii. Is there any blue in this red galaxy? Is there any red in this blue galaxy?
    - iii. Do you notice any texture difference between locations of blue light versus red?

## 6.2 Diagrams

1. Late in the time, request (to whole room) that people consolidate their galaxy group/category by drawing one diagram of each group/category. Let them know, historically, before CCDs and photographic plates, astronomers had to do this.
  - (a) Then ask for written description and title.
  - (b) State that everyone will share out; each member should say something (but this will be on-the-fly informal).

## 6.3 Discuss

1. David and Liz asks for a volunteer to describe one of their classifications. If no one volunteers, ask one group that seems comfortable to come forward and present.
2. Ask if any group had some of the first groups galaxies in another category. Would they share? (Focusing on why they chose differently.)
3. Ask if there's a third way of classifying the contentious galaxy. If not, ask if a group feels inspired to share now; is there a complementary galaxy type? Or, possibly one group has a similar classification, but they called it something different.
4. Facilitators should refer back to the original types of observations (made about the demo galaxy/starter) and how these aspects have come to be applied to the rest of the galaxies.
5. Continue random-walking through the sharing. Keep emphasizing the importance of colors and of shapes.
6. If students feel they have nothing new to contribute, elicit discussion of how that group converged on that classification scheme.
7. After everyone has shared, ask what are the most important characteristics that people used to classify. Also, what were common observations from the starter galaxy observations? (If everything has been planned well, there should be agreement on colors and shapes.)
8. If other characteristics are mentioned, acknowledge their importance, say they will be addressed later (write them down on the "Address Later" post-it), but let the students know that it is not investigable at this time.

9. Announce that color and shape can be, in part, investigated in class, and that's what we're going to do next and everyone should think about what they want to focus on.
10. Break (clear everyone out of the room and set up the stations.)

## 7 Investigation at Stations

1. Present stations as "Color" and "Shape" and ask students to divide by interest. If there's imbalance, ask for volunteers to balance out; let them know there will be play time later with the other station.
2. **Early investigation:** students are learning about the equipment, they are sorting out their question, they are playing.
3. **Middle investigation:** students have focused on a question, they have designed an experiment or procedure that will rigorously tackle the question, they are gathering data, drawing results, etc.
4. **Late investigation:** students are articulating their results, have developed their mental model of the phenomenon, are preparing to present.

### 7.1 Color-Temperature Station

1. General setup:
  - (a) Bulb safety.
  - (b) Experiments should be done in the dark so we know the heat of the object is producing the color (and not reflection of light).
  - (c) Limit equipment to focus early. Do not put out all gel filters immediately and only a select set of bulbs with different wattages.
2. Students choosing color-related questions will be guided to this station. The type of questions addressed at the C-T station are, "Why are the outer regions blue and inner regions orange?" and "Why are some galaxies blue and others yellow/ orange?" Etc.
3. Facilitation ideas to start them on the inquiry activity (tie in with galaxy pictures/ diagrams discussed in first half of class).
  - Do you think you can observe galaxies during the daytime? What about at night?



- What other objects can you see clearly (are bright/ have color) at night?
  - stars
  - moon, planets (may have to explain that these are special cases—being illuminated by another light source. Or leave this to Kathy for a later lecture.)
  - aurora (special case, but unlikely to be suggested)
  - airplanes, satellites, etc.
- What about on the ground, here on Earth, or in your house? (Possibly think about looking down at the Earth from afar. What would stand out?)
  - porch lights, flashlights, street lamps, headlights, etc.
  - fluorescent signs, cell phones/ LCD/ LED lights (another special case—has to do with composition as opposed to thermal light. Street lamps and headlights also technically fall into this category.)
  - lightning, fireworks, lasers (yet more special cases...)
  - fire, glow from volcanos (example works better for Hawaii students...)
  - candles
  - Glow from gas oven or heater. Fireplace.
  - what else?
- Think about your galaxy diagram (or galaxy pictures) as a collection of light bulbs of different colors (like Light Brite). Other than using different types of glass or painting the glass, can a light bulb give off different colors (most people will probably say no)? What is actually producing the light (A: the glow from the filament, but people may say the electrical current, or something else which is part of the answer and can be guided to the answer we want)?
- What about thinking of your galaxy as a collection of little fires/ flames? Can flames be different colors? Observe this.

4. Students will be given a demonstration of the RGB box.

- Help get at the concept that brighter stars (*i.e.*, easier to see) are bluer, which is why when we look into the sky, we don't see lots of red stars (they're too dim).
- Link to galaxies—easier to observe blue galaxies (caveat: elliptical galaxies tend to be bigger and therefore brighter).
- Possibly try to link with inverse-square law for advanced groups—easier to see blue galaxies at greater distances than red galaxies.

- Students can experiment with changing the “filters” or light bulbs (or adding multiple light bulbs—then it’s not a point source any more, but this may be OK).
5. End of day 1. Students asked to go home and think about things that produce light/ color.
    - Ask them to observe things that give off light at night, paying special attention to the night sky to see if all stars looks the same (like yellow light bulbs), or whether there are different colors. Potential problem—summer in Santa Cruz is foggy.
    - But also, think about things in their own household that produce light/ color when the lights are off.
  6. Synthesis could use fire or to go beyond color-T (e.g., salt thrown in the fire).

## 7.2 Projection effects

1. General setup:
  - (a) Limit equipment. Do not put out play-doh.
2. The initial task is simply to explore 3-D shapes that can represent on of the galaxy classifications thought of in the previous exercises. **Initial prompt:**
  - Here are some materials, start by making galaxies that represent the various classifications that you made during the previous exercise. You can walk around the room and use whichever classification schemes that people came up with.
    - (a) Let students ‘make’ their own galaxies to get a spatial feel for them.
    - (b) Question to ask/point out: In how many directions is it truly representative?
3. If only one model is made, encourage them to make at least one more model.
  - (a) Leads to the question of likelihood, *i.e.*, which is more likely to be realistic and why.
4. **Prompts**
  - Can you make a different model that represents the same classification?
    - Which is more likely and why?

- If you turn/rotate the model, does it look the same?
  - Why did you use different components (e.g. plate + ball)? What do you think this says about real galaxies?
  - I noticed you only used completely light blocking materials, what does that mean? Is it realistic (i.e. where do you think galaxy light actually comes from)?
    - Refer to the color-temperature group.
  - Can you make a model that looks like a particular classification from only one angle?
  - How much can you hide? Is this likely in a real galaxy?
  - You have a bulk shape that works, can you make a more complicated model that shows more of the components/details?
    - How easy are the details to see/make?
5. First class session over: Ask students to bring in an object that they don't currently have available that could also represent a galaxy shape.
  6. Depending on where they are at, begin introducing the idea of components in a more systematic way.

### 7.3 Black and White Galaxy Images

Not completely designed and not used in 2008.

1. Give students three galaxies (elliptical, face-on spiral, edge-on spiral) in four filters (*ugri*). These will be exactly the images used to make color images for the first part. Don't say "filters."
2. Say: "the challenge at this station is to figure out what these images mean and how what you learn applies to the images we were using earlier and to the galaxies themselves."
3. Let them flounder.
4. If needed, prompt them to sort by object.
5. More floundering.
6. Next suggest they sort by what method of imaging (namely, filters) go together. This should be harder.

7. Encourage groups participating at this station to consult with other groups. Get a station consensus.
8. Ask them if they know what the different “method of imaging” is. Recall from first lecture.
9. Once everyone has agreed on the sets of filters (find some other word). Suggest that they number them to keep them straight. *What happens if they don't get it right on their own?*
10. Ask them how they would sort out the common effect of the different “methods of imaging.” Encourage systematic compare/contrast table.
11. Suggest they go look at the original classification images, hung up around the room. Hopefully someone should notice that the same galaxies are in their B&W sets as in the color sets.
12. Have the color-mapped B&W filter images on hand if they ask for them. Else, hand over at the appropriate time.
13. As they struggle for understanding, if no one has recalled the first day of class, remind them that there was a hint (color filters and photoshop, as well as the electromagnetic spectrum.)
14. Looking for a statement that diffuse material shows up more prominently in one time of material ( $g$  or  $r$ ) and point sources in another ( $u$ ).
15. Then by comparing with the original color images or with the colored print outs (transparencies), the students will start considering the point-source-dominated images to be blue and the diffuse-dominated images to be red.
16. Ask them what do the different colors mean; either guide them to the E&M spectrum poster on the wall or to visit with the color-temperature station.
17. To assess how well the students understand, ask them to re-justify or re-do their original classification based on their new knowledge of filters and structure.
18. Start students working on their presentations (poster optional). Suggest upon what they should present (based on consultation with other facilitators and upon the content goals).
19. *Where is the good stopping point in this station? Is there anything for the students to do over the long break? Read a web site? Play with some images online?*

## 8 Share out and synthesis

1. Facilitators should meet to assign order based on best content order. Probably projection effects then color-temperature. Also makes share out go faster.
2. Set expectations that all people will talk in roughly equal portions. **Posters required.** Demonstrations welcome. Each student only has 3–5 min. (so a group has X times that).
  - (a) Require posters to force students to think about what they will say. Prevent rambling.
  - (b) Posters (mostly figures) force students to commit to a mental model. They cannot just stand up in front of class and hand wave around a demo.
  - (c) Projection effects station groups will have to have worked on making 2-D images into 3-D models and now will have to make 3-D models into 2-D figures.
3. Example presentation posters from 2008:
  - The Luminality of Color
    - Hypothesis: Red is the most visible; blue is least visible; green... somewhere in between
    - Experimentation: RGB glass filters were set against “light box”; measurements were taken from 10 in. away from light source, with a “light meter” at 3 different wattages (intensity).
    - Results:
      - \* Red<sub>25</sub> 64; Red<sub>50</sub> 586; Red<sub>75</sub> 1790
      - \* Green<sub>25</sub> 58; Green<sub>50</sub> 675; Green<sub>75</sub> overflow (2000++)
      - \* Blue<sub>25</sub> 32; Blue<sub>50</sub> 210; Blue<sub>75</sub> 658
    - Conclusions ?
  - The Color Correlation Investigation
    - Step 1: Observations
      - \* difference in color by bulb type
      - \* color bolder in frosted bulb, but brighter in clear bulb
      - \* when dimmer, light came from coils; when brighter, light came from everywhere
    - Step 2: Light bulb hypothesis

- \* we took two 60 W bulbs, clear and frosted, to determine temp. differences.
- \* controlled variables by maintaining constant starting temp of 26°C
- \* clear bulb: 60 W bulb measured for 1 minute reached 135°F
- \* frosted bulb: under same conditions at 100% max output, reached 126°F.
- Step 3: testing heat
  - \* measured temp's at 20, 40, 60, 80, 100 percent max output
  - \* Clear bulb
  - \* 20% → 76°F, ended at 90°F
  - \* 40% → 80°F, ended at 102°F
  - \* 60% → 80°F, ended at 112°F
  - \* 80% → 80°F, ended at 128°F
  - \* 100% → 80°F, ended at 144°F
  - \* 100% standing → 180°F
- Conclusion: color, temperature and brightness are directly linked
- Fire diagram → electromagnetic
- Models
  - Spiral shape (figure) front and side
  - Irregular substances (figure) front and side—looks like flaming frisbee
  - Improbable shapes (figure) front and side of hourglass or triangular bulge with disk
  - Circle with haze (figure) front and side—ball with little clay balls on ends of toothpicks set all over in a thick disk
- What did we learn
  - Spiral galaxies
    - \* The paper plate shadow puppet showed that a spiral galaxy would mostly likely be in the shape of a spiral disc.
    - \* A tornado shape is unlikely but possible
  - Ring galaxies
    - \* Likely the result of a translucent sphere
    - \* Cylinder shape is also a possibility but unlikely.
  - Conclusion: galaxies likely take forms that when viewed from other angles look like other pictures of galaxies we have (and play-doh smells really good)

4. Facilitators keep notes on who shares what, to make specific references to share out.
5. Facilitators will ask clarifying question, specifically addressing questions to those students who may not have presented much content.
6. Synthesis will be simple re-iteration of main points. Emphasize that students figured out all that facilitators wanted them to learn. **Actually share the content goals on the documents you've been carrying.**
  - (a) Galaxy is composed of parts: stars, gas, and dust.
  - (b) The most likely 3-D model is the simplest and one that produces the most galaxy-like 2-D projections.
  - (c) "Hotter, brighter, bluer" and "Cooler, dimmer, redder."
7. Show one of Patrik's movie to demonstrate another form of modeling and a moving display of projection effects. C-T groups could also point out when there's a stark change in temperature by the changes in color.
8. Synthesis could use fire to demonstrate some of C-T concepts or to go beyond (*e.g.*, salt thrown in the fire).
9. Address any necessary misconceptions that arose during the course of the investigation that should be dispelled.
  - (a) Galaxies are not blocking light. They are sources of light.
  - (b) Color images are an art. The exact color-to-wavelength mapping is subjective. For example, the *u*-images are not wavelengths visible to the human eye.
  - (c) Reflected light does not indicate temperature. (School buses are not 6000 K.)
  - (d) Stars are hot/cool, not galaxies.
10. Show examples of using this knowledge in real astronomy research. (Always need to give "So what?" spiel.)
11. Articulate some of the broader course goals addressed by this activity (content, looking at images, set the tone for the course).
12. Let everyone know that there's a 15 min. break and when they come back, everyone should play with another station (required.)

## 9 Follow-up Activities

1. **Post-assessment:** display image of merging galaxies or galaxy group and ask students what they see.
2. Let students play with stations they didn't use during the inquiry; maybe match projection-effects group with C-T group and have them pair-share. Have students try out a few things they learned from watching. Even some new ideas they have.
3. For remainder of class time, Ryan will be in charge, and hopefully David and Liz will help foster discussion.

## 10 Materials and Room Preparation

1. Room should have lots of wall space, ability to be made dark, and big enough for (most) everyone.
2. **Tape down cords.**
3. Record on poster "Topics for Kathy to cover later."
4. Consider hanging poster of electromagnetic spectrum on wall (subtle hint).
5. **General** (mostly from CfAO):
  - 16 color images set (17 images)
  - Name tags
  - 6 power strips
  - Lots of blank computer paper (representative diagrams, misc.)
  - Graph paper
  - Post-it note posters with and without lines
  - Markers
  - Tape
  - Scissors
  - Colored pencils
  - Question strips (just in case)
  - Laptops with internet connection



## 6. Color-temperature station:

- Incandescent bulbs
  - 3 200W bulbs (CfAO & Liz provided)
  - Several lower wattages (25W, 75W, 100W) for experimentation (CfAO)
  - Consider having grid of bulbs with different watts but before students see that they rank the bulbs by temperature (start to see relationship between brightness and temperature).
- Thermometers (Thimann Labs)
  - Pasco radiation sensor and millivolt meter
  - Multi-meter thermometers with temperature converter
  - Basic thermometers (meat thermometers are good).
- Photometer (CfAO)
- 3 RGB boxes (use gel filters; CfAO)
  - Tried dichroics these out, but am skeptical about their use now. Added complication that the filters reflect light of a different color, so students may get stuck trying to understand this concept rather than the color-temp relation.
  - Also, the dichroic filters do not appear to show the relationship any clearer than the simple gel films. The bulb temperatures peak near yellow/ green light, and there's not a lot we can do about that.
- Extra gel filters (CfAO)
  - In case students want to redesign the RGB box? Or if we just want to have a couple extra setups. Easy for students to replace films with other colors, or to change their order.
- Dichroic filters (just in case; CfAO)
- 3 variacs (ISB 356 and Thimann labs)
- CMY transparency overlays (Liz)
- Something that shows color-temperature difference
  - Camp lantern: Patrik has one and it shows orange to white dichotomy.
  - Pocket lighters (just for demo; CfAO)
  - Candles (CfAO)
- Diffraction gratings
- Oven mitt

## 7. Project effects station:

- Various shapes (Frisbees, football, balls; David, Kathy)
- Scarves & tissue paper (Kathy)
- Styrofoam and paper plates with rims (to cut) (Kathy)
- Clay (David)
- Balloons (David)
  - Oblong shapes may have the effect of being opaque in one direction and mostly transparent from another
- 1 Overhead projector (Nat. Sci. Anx 102, ISB 356, ISB 129)
- Flashlights (CfAO)
- Bike light (David)
- Desk light (Kathy)
- Patrik movies to demonstrate projection effects  
(<http://www.ucolick.org/~patrik/sunrise/>)

## 11 Galaxies to Classify

Name	Classification	RA	Dec
Arp335	SA(s)bc pec	11:04:23.5	+04:49:43.0
M101-Pinwheel	SAB(rs)cd	14:03:12.5	+54:20:53.1
M108	SB(s)cd	11:11:30.43	+55:40:23.9
M109	SB(rs)bc, LINER	11:57:35.84	+53:22:35.3
M87-Virgo A	E+0-1 pec; NLRG Sy	12:30:49.4	+12:23:28.0
NGC1032	S0/a	02:39:23.6	+01:05:38.0
NGC2549	SA(r)	08:18:58.3	+57:48:11.0
NGC2681	(R')SAB(rs))/a Sy3	08:53:32.75	+51:18:50.0
NGC2967	SA(s)c	09:42:03.36	+00:20:09.5
NGC3440	SBb?	10:53:49.47	+57:07:07.1
NGC3521	SAB(rs)bc, LINER	11:05:48.95	-00:02:09.5
NGC4478	E2	12:30:17.4	+12:19:43.0
NGC4753	I0	12:52:22.07	-01:11:56.4
NGC5750	SB(r)0/a; HII? NLAGN	14:46:11.04	-00:13:22.8
NGC60	SA(r)cd pec	00:15:58.08	-00:18:10.8
NGC7108	E non-NED	21:41:53.74	-06:42:31.8
NGC936	SB(rs)0+	02:27:37.68	-01:09:17.9

## 12 Notes from 2008

- Consider what to do if people add or drop course during inquiry.
- Need more time to draw representative galaxy diagram (try 20 min)
- Need less time for random-walk share out
- Goals need to be better “operationalized” to include information about process skills.
- Process skills: consider what they should be learning/improving
  - team work so long as groups stay coherent
  - communication: lots of formal and informal chances (including questions)
  - Writing/recording/documenting/not-destroying-models
  - Differing between models
  - Conceptual (non-math) science
- Consider designing “lab notebooks” so students are forced/encouraged to record; can judge process skill later too
- In the prompt for classifying galaxies, explicitly say that the colors shown in the image are the colors one would see just looking at the galaxy. (My “CCDs are blind” and “photoshop” points were remembered, and some students didn’t want to classify considering color.)
- During the classification “random-walk,” let the students mull over the differences and similarities between every group’s classification scheme and their own; facilitators maybe should not be heavy-handed in pointing items out.
- 3rd station would be nice, also accommodate more students. This station would maybe include color filters on color images or overlays of various bands
- Consider randomizing at the stations in order to change groups; there was a tendency to just stay with group from classification activity.
- If groups break on content (*e.g.*, one temperature station and one color station), then don’t let one group usurp the other during share out. Some students presented what they did not do but had heard during first lecture.
- Projection effects comments:

- Need to keep groups as distinct groups; consider how the layout and the materials affect group dynamics.
  - Groups should have their own light source and own box of select materials (don't need to give both groups the same materials).
  - Need more to balance time needed at color-temperature station; also, students did not internalize usefulness of considering projection effects in images.
  - To drive home the statistical aspect, have students assign which of the classification galaxies match which model (projected somehow).
  - Add challenge to justify a structure-only classification scheme (same galaxies or new ones).
  - Work on students thinking conditionally, so that conclusions are like, “The bulge and disk model matches most spiral galaxies if the galaxy looks clumpy. Otherwise, the smoothness may suggest another shape and an elliptical galaxy.”
  - Or need to give students more information about the images; whether there is anything “hidden” like young, blue stars.
- Students seemed to keep the shape and color-temperature stations as separate facts. Need some way to get them integrated.
  - Perhaps the shape facilitator should give the color-temperature synthesis or visa versa; would have to pass off names that match groups to synthesis points
  - During the post-inquiry talk, Ryan pointed out that “scientists study different things but they talk” to draw stations/content together.
  - As for room set-up, need tables, not silly individual desks.
  - Prior knowledge seeds (reconsidered):
    - CCDs are blind but color images *can* be mapped to reality.
    - More about taxonomy; shape station needs to talk about stars, gas, and dust to talk about shapes “hiding” things.
    - Maybe inquiry came too early in course.