Multiwavelength Astronomy: Galaxies in a Different Light

Teacher Edition grades 9-12

Introduction:

Throughout this activity students should begin to realize that there is a wealth of information that we can learn about many objects in nature even if we can't see it with our own eyes. Students will review basic concepts about the electromagnetic spectrum, and then learn about false-color imaging, Wien's law, and galactic astronomy. They will combine all of this knowledge to see how observing galaxies at different wavelengths enables astronomers to gather huge amounts of fascinating information about galactic structure and composition. Visually inspecting the multiwavelength images should enable students to recognize the variety of "hidden" information that can be gathered from looking at more than just the visible part of the spectrum. For instance, while some galaxies have features that are obscured by dust in visible light, the infrared images show the light the dust emits and what may be concealed inside of it. Or they may see that X-ray and radio observations give astronomers a means of seeing large-scale structure that may not be visible in ultraviolet, visible, or infrared.

Prerequisites:

Prior to this activity, students should have a basic understanding of the electromagnetic spectrum, i.e. that radio, ultraviolet, x-rays, etc. are all forms of light with different wavelengths/energies, and because they are light, they all travel equally fast at the speed of light. This subject matter is not addressed in the previous scaffolding activity (see below), but is a necessary prerequisite knowledge base that should be taught prior to conducting the activity.

Recommendation: Before doing this activity, do prior scaffolding activity: *The NASA Ceres Project Galaxy Classification Activity* found at http://btc.montana.edu/ceres/html/Galaxy/gal1.html. The activity covers different types of galaxies and how they are classified. If you are doing this (*Multiwavelength Astronomy*) activity alone without proceeding to the next activities in the Building Bridges Galaxy Evolution scaffolding, then the *Galaxy Classification* activity is not necessary, but still recommended.

Estimated time for activity: 90 minutes --- (Optional: to save classroom time [~15-20 minutes] the coloring activity "False Color Galaxies" may be assigned as homework to be completed the night before.)

Student Product:

In pairs, students will answer questions in the student guide and complete a short coloring activity. Students will also match galaxy images taken in different wavelength regions and fill out the corresponding tables, which include providing justification behind their reasoning. After the activity, students should understand there is important information gained by observing galaxies (or anything) in different wavelengths and some of the galaxy features emit in those wavelengths.

Materials:

- multiwavelength.zip file
- computer for classroom with internet browser (no connection necessary once file is downloaded)
- projector connected to computer
- Standard Image Set, one for each pair of students
- Student worksheets "Multiwavelength Astronomy: Your World in a Different Light", one 9 page worksheet for each pair of students

- Student coloring activity sheet "Multiwavelength Astronomy: False Color Galaxies", one 2 page worksheet for each pair of students
- Markers: (blue, green, yellow, pink/orange/red) 1 set for each pair of students

Standards:

NSES:

- Physical Science- Interaction of energy and matter.
- Science and Technology- Understanding about science and technology.

TEKS:

- 112.42 - 2C, 2D, 5C
- 112.47 – 2C, 2D, 8B, 8C
- 112.48 - 2C, 2D, 4B, 5C

Teacher Preparation:

Teacher must print and cut out the galaxy images from the Standard Image Sets. Recommended: print on card stock; print with low toner to enable students to see details – printing with normal toner levels makes contrast on the cards too extreme.

- Standard Image Set: Print enough copies for each pair of students to have one entire set. Cut the image cards apart. The images will be sorted as per the following instructions. All images have a label below them indicating the wavelength of the image. Sort the cards by wavelength so there are three subsets of images – visible, radio, and ultraviolet.
- Teacher must also download the Answer Guide zip file and unzip it. In the classroom, have a computer available and provide a projection system* for the class to check answers simultaneously. The Answer Guide is also used while the students fill out the Student Worksheet.
- Optional: Download and print the coloring portion of the activity ("False Color Galaxies") and give to students to complete as homework the night before. This will save about 15 minutes of classroom time.
- PLEASE READ THROUGH THE ENTIRE ACTIVITY AND TEST THE POWERPOINT SLIDE SHOW BEFORE PRESENTING TO THE CLASS

Appendix:

For teachers without computer projection capabilities, please download and print the three pages that have the color images needed for filling out the Student Worksheet. Teachers can print these pages as a transparency for the students to view while filling out the Student Worksheet.

However, students should be given a chance to view all the color images in the Answer Guide to enhance comprehension, even if the teacher cannot project them. Doing this gives the students a chance to extend their knowledge by viewing infrared and X-ray wavelengths of many of these galaxies as well. The powerpoint slideshow for this activity can be found at http://outreach.as.utexas.edu/marykay/galaxy/galaxy.html

DO NOT give this web address to students! But you can download the powerpoint file and pass that on to them if they'd like to see more on their own computer later.

TO BEGIN:
Group students into pairs, then pass out one Student Worksheet "*Multiwavelength Astronomy: Your World in a Different Light*" to each pair.

Engage:

***Project the first slide of the Answer Guide.**

Begin by asking students what different wavelengths can tell us about things in the real world. Students may answer that infrared is heat so you can tell how hot something is, or that people use x-rays to see inside the body/luggage. Give the example of a doctor trying to learn more about you because you're sick. What wavelengths do doctors use? Visible light - they look you over on the outside; infrared - they take your temperature; X-rays - used to see through your skin/deeper inside you. If you are very ill, they may use an MRI (radio wave), or treat a cancer with gamma rays.

* Teachers without computer projection systems see Appendix.

Explore:

Instruct the pairs of students to read page 1.

When everyone is finished reading, continue to the next page…

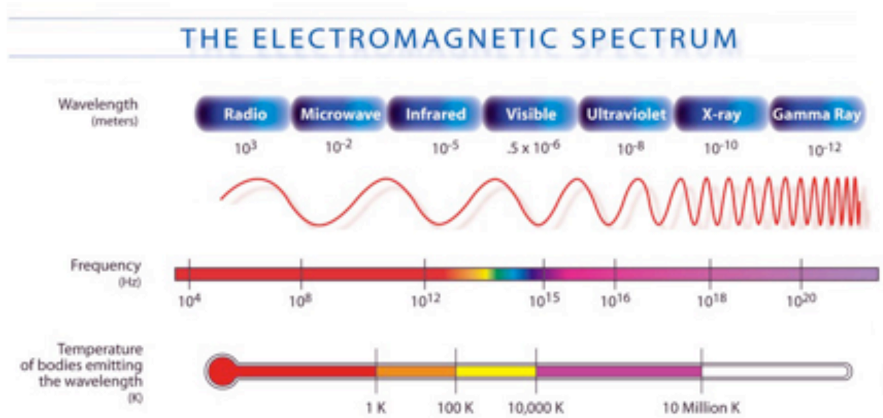
Multiwavelength Astronomy: Your World in a Different Light

Introduction

What would it be like if you were colorblind? How much information would you fail to receive from the world around you? You would probably have difficulties identifying types of apples, for instance. If you could not tell the difference between yellows, reds, and greens, how could you begin to sort a pile of apples by variety?

In a way, all humans are colorblind. We're colorblind to colors like ultraviolet and infrared and for everyone except Superman, we're colorblind to X-rays. People just cannot see those wavelengths of light, and since that is what defines colors, we can think of these ranges of the electromagnetic spectrum as extreme colors. These colors include gamma-rays, X-rays, ultraviolet, infrared, microwave, and radio, while our eyes can only see the usual ROY G BIV variety.

Take a look at the following image. Note what a tiny portion of the spectrum is actually made up of colors we can see (visible). How much more could we learn about the world and the universe if only we could see in those other wavelengths?



So how can we see in these other wavelengths? Well, with our naked eyes, we can't. However, we can build instruments and sensors that are sensitive to these colors and represent them in a way that we can still interpret. This is where false-color imaging comes in...

Explain:

***Project the second slide: "Infrared Dog"**

Instruct the students to read along and answer the questions on the top of page 2 of the worksheet while projecting the second slide of the Answer Guide, "Infrared Dog". Point out that the dog is actually emitting the infrared radiation, as opposed to reflecting it (it would be reflecting in a visible light image).

Answers: The hot areas of the dog are the *<u>ears, eyes, and mouth</u>*. *The cold areas are the areas insulated by* *<u>fur and the nose</u>*. After students have answered on their sheets, ask the class what they thought the answers were and discuss why this makes sense. *Infrared senses hotter areas, so the bright areas are the areas that open to the interior of the dog's body, while the cold areas are insulated and far from the center of the dog, except the nose, which is kept wet and cold.*

***…after students have answered the Infrared Dog questions, project slide three: "X-ray Challenge"**

Have the students read through the bottom of page 2 and answer the questions.

The mystery object is a pocket *<u>solar calculator</u>*. *The bright areas are the* *<u>circuitry (the denser materials)</u>*.

This image is made by emitting X-rays through the calculator, and then catching the remaining radiation on the on the other side (usually with film). The bright areas are those that reflect the X-rays, hence the rays don't make it to the film. The dark areas are where the X-rays made it all the way through without being reflected by any dense material. (*Note: astronomers usually utilize X-rays in a different way…they are interested in the object that is emitting the radiation, not so much in what is in between. This picture is only used to emphasize the idea that scientist can detect "hidden" objects by looking at different wavelengths.)*

False Color?

Look at the two images on the slide show of a dog that were taken in the infrared. These are two versions of the same image, with the same scale of temperature, but the right picture has a larger range of colors to show the same range in temperature. When there are more colors in the same temperature range, you can easily detect more detail about small temperature differences.

Of course, the dog isn't actually purple. The people who make images using invisible wavelengths, such as infrared, choose the visible colors to represent those wavelengths. They try to make the information useful at a glance, like in these pictures.

Which areas on the dog are hottest? ______________________________

Which are coolest? ______________________________

When you look at a dog in visible light, can you tell which areas are hottest and coolest just by looking?

____

X-Ray Challenge

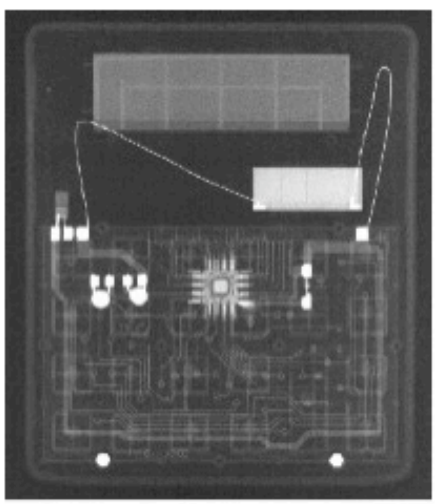


Figure 0 - Image from University Hospitals of Cleveland, Department of Radiology

Maybe you're not Superman, but using the right equipment, anyone can see in X-rays. The X-ray wavelength is so small that it only interacts with dense matter on Earth, like metal or bone.

If you put an object in between an X-ray emitter and an X-ray detector, you can see where the dense materials are located (shown as white in this picture).

This picture was taken with the object still sealed, so the X-rays are penetrating through the outer part we would normally see. What do you think this object is?

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What are the bright areas highlighting?

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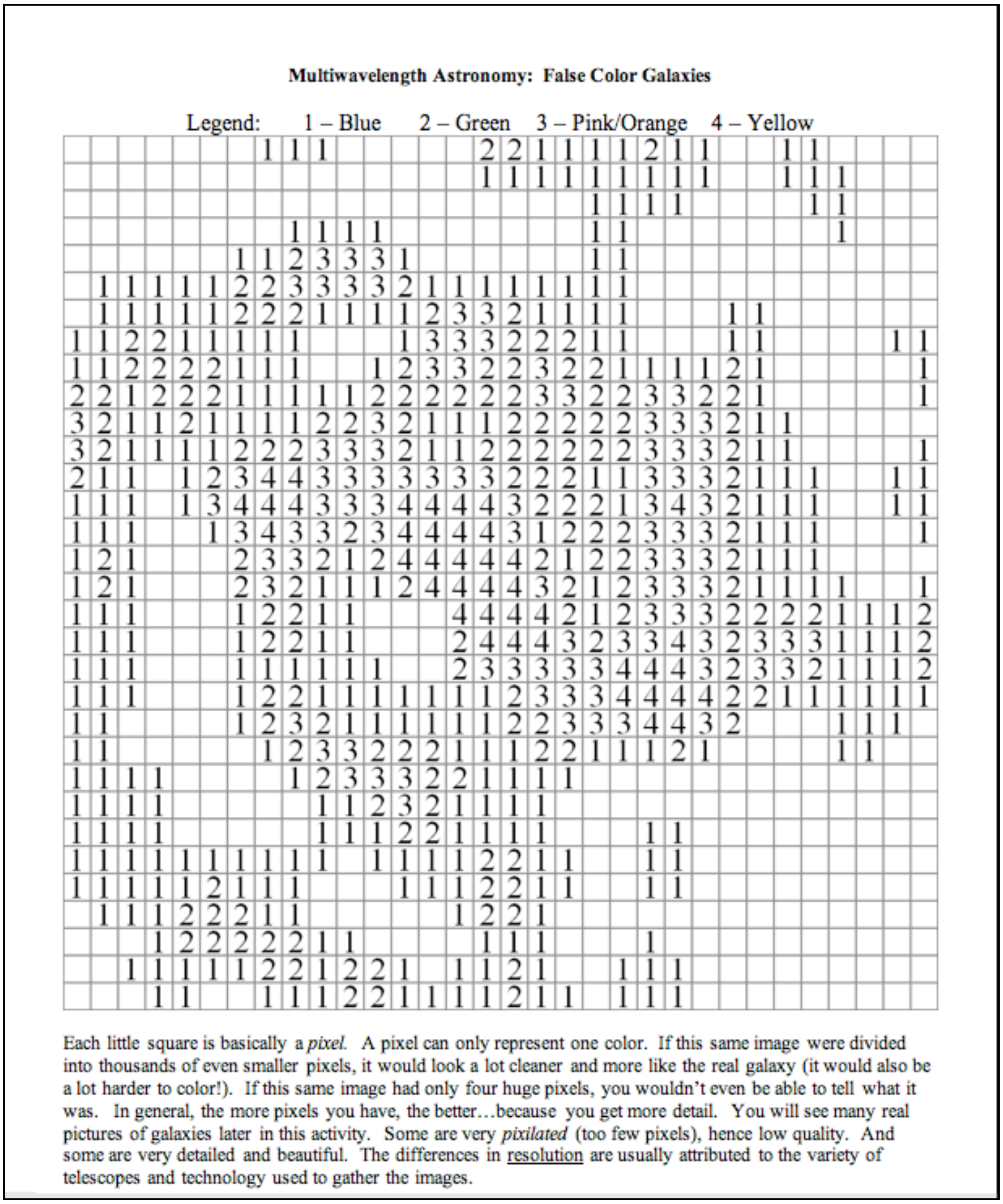


Pass out the "Multiwavelength Astronomy: False Color Galaxies" sheets.

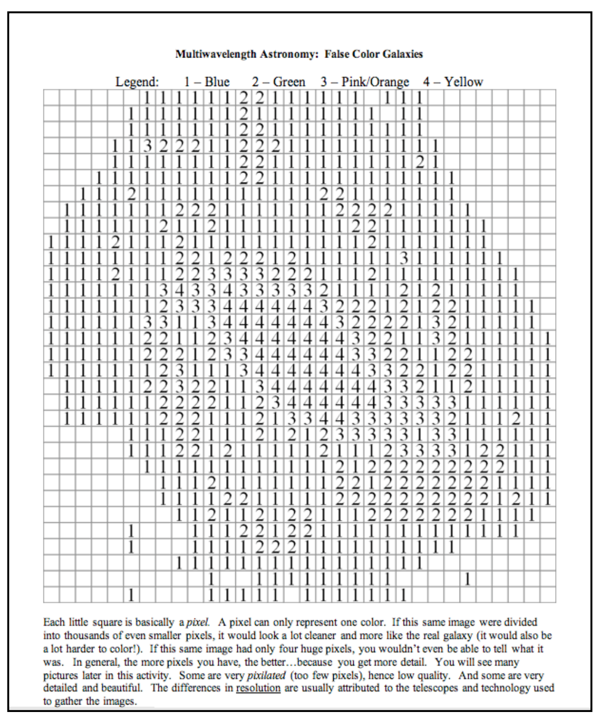
******Note: This coloring activity can be assigned as homework to be done the night before the activity******

Each group should get both pages 1 and 2. Pass out markers so each pair has the 4 colors.

Have each student take a sheet and color according to the legend. Students may realize while coloring that their picture does not match their partner's. This is intentional.

After students have filled in the sheets using markers, explain that both members of each pair have an image of the same galaxy. The image on page 1 is from the radio band, and page 2 is in the visible. <u>Stress that the differences are due to different details seen in different wavelengths.</u> This is how astronomers get more information by looking in different wavelengths. Sometimes they see structures that were not observable in other wavelengths. Have students note details visible in one wavelength and not the other.

The students should also read the short paragraph about pixilation and resolution at the bottom of their sheet. (The exact same paragraph is on both pages).



***Project slide four: "Wien's Law"**

Have the students read through pages 3 and 4 of the Student Guide and answer the questions.

Wien's Law

Where Do All Of These Different Wavelengths Come From?

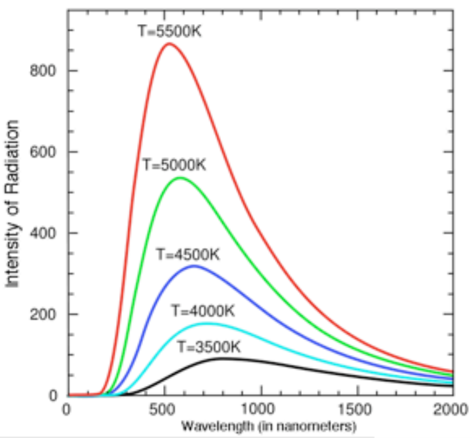
Right now, every object in the room around you is emitting electromagnetic waves…your shoes, your chair, the wall, even you…Everything is radiating! Anything with any heat energy whatsoever radiates electromagnetic waves. The only way an object could not emit radiation is if its temperature were *absolute zero* (0° Kelvin, or about -460° Fahrenheit). But the laws of thermodynamics tell us that it impossible for something to get that cold, so you can correctly say that every single object in the entire universe is emitting electromagnetic waves!

Some objects are better emitters than others. For example, a light bulb filament will emit radiation much more efficiently than a pencil eraser. Stars happen to be some of the best emitters around; they are very close to being perfect emitters (which physicists call *black bodies*).

Most objects, especially stars, will emit electromagnetic waves in almost every possible wavelength, from gamma rays all the way to radio waves. But each object will emit significantly more radiation in some wavelengths compared to others. The wavelength where an object emits the most radiation is called its *wavelength of maximum intensity*. The wavelength of maximum intensity doesn't really depend on what the object is made of…So, what does it depend on? TEMPERATURE!

In fact there is a nice, simple law of physics that describes the relationship between the wavelength of maximum intensity and temperature.

It's called **Wien's Law:** $\lambda_{max}\ (\text{nm}) = \dfrac{3{,}000{,}000\ (\text{K}\cdot\text{nm})}{\text{Temperature (K)}}$ nm - nanometers, K - Kelvin



Look closely at where the peak of each curve is.

Do hotter objects give off their maximum radiation at shorter or longer wavelengths?

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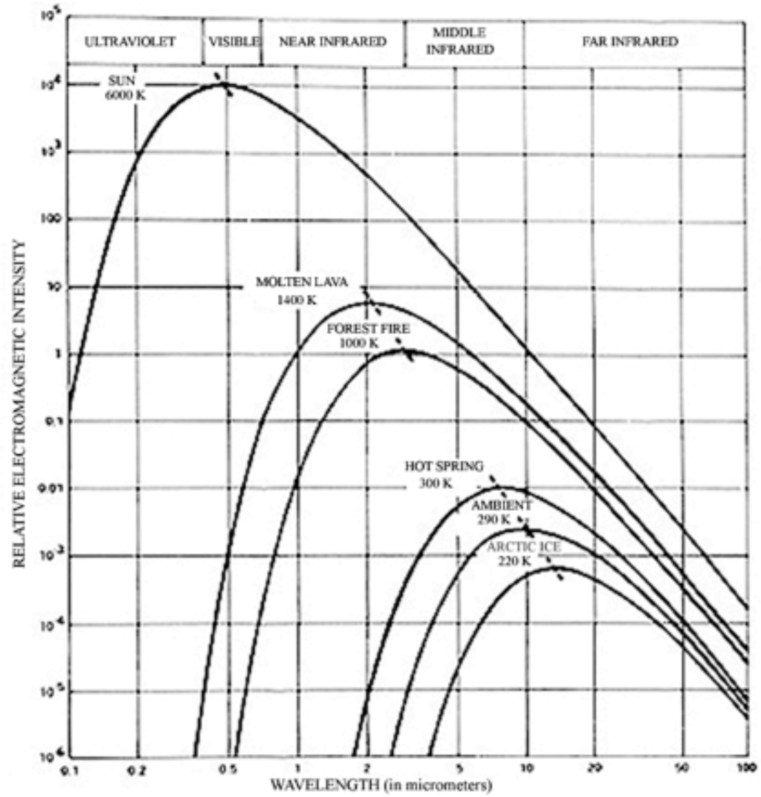
This graph shows the radiation curves for some temperatures that you can relate to:



Where do you think extremely hot young stars (100,000°K) emit most of their radiation? (circle one)

Ultraviolet   Visible   Infrared   Microwave   Radio

Have you ever noticed your doctor taking your temperature by pointing an instrument in your ear for a split second? Well, that instrument is an infrared detector that finds your wavelength of maximum intensity and then converts it into your body's temperature. It is a perfect example of utilizing Wien's Law.

Answer to question on page 3:
Hotter objects give off their maximum radiation at ***shorter*** *wavelengths.*

Answer to question on page 4:
Hot young stars (100,000 K) emit most of their radiation in the ***Ultraviolet*** *part of the electromagnetic spectrum.*

***Project slide five: “Galaxy Features”**

Have the students turn to page 5.

Talk through the slide and the chart with the students.

Explain that specific parts of a galaxy emit light in different wavelengths. When astronomers take images that are in different wavelengths, they see the features that emit light there. In order to view the differences, astronomers use "false colors" (similar to the dog images) to denote different wavelength regions.

For instance, ultraviolet images highlight areas of the galaxy where there are hot, young stars. For spiral galaxies, this is often in the spiral arms. In visible wavelengths, these stars appear blue. Most stars in general are seen when viewed in visible light, this includes stars like our sun. The nucleus (core) of a spiral galaxy has more evolved (cooler and older) red stars. In some visible images, astronomers see dark areas caused by dust that block the light coming from behind; since the dust emits light in the infrared, astronomers can detect structures, using infrared observations, that are sometimes obscured in the visible. X-rays indicate very hot gas in and around the galaxy (false colored as yellow/orange in the slide), along with very energetic stars (green). Cool gas in the galaxy emits radio radiation. Knowing these features match certain wavelengths, astronomers can better determine the structure of the galaxies in the images.

How Does All of This Relate to Galactic Astronomy?

When astronomers first started looking at galaxies, they could only see them in the visible wavelengths. From what they saw, they were only able to describe galaxies in the most basic way: large collections of stars, sometimes with a spiral structure. They couldn’t understand much more than that.

Now that we have the technology to detect other wavelengths of light, we are finding out all sorts of fascinating information about what galaxies are made of, how they evolve, which parts are the most active, and much more. As we just learned, each wavelength can show us objects that represent specific temperatures. The table below puts it all together:

Type Of Radiation	Characteristic Temperature	Objects Emitting This Type of Radiation
Gamma rays	more than 10^8 Kelvin (K)	* Pulsars or Neutron Stars * Accretion disks around black holes * Interstellar clouds
X-rays	10^6-10^8 K	* Regions of hot, shocked gas * Gas in clusters of galaxies * Neutron stars * Supernova remnants * Stellar corona
Ultraviolet	10^4-10^6 K	* Supernova remnants * Very hot stars * Quasars
Visible	10^3-10^4 K	* Stars * Galaxies * Reflection nebulae * Emission nebulae
Infrared	10-10^3 K	* Cool stars * Star Forming Regions * Interstellar dust warmed by starlight * Planets * Comets * Asteroids
Radio	less than 10 K	* Cosmic Background Radiation * Scattering of free electrons in interstellar plasmas * Cold interstellar medium * Regions near white dwarfs * Regions near neutron stars * Supernova remnants * Dense regions of interstellar space (e.g. near the galactic center) * Cold, dense parts of the interstellar medium - concentrated in the spiral arms of galaxies in molecular clouds (often the site of star formation). * Cold molecular clouds

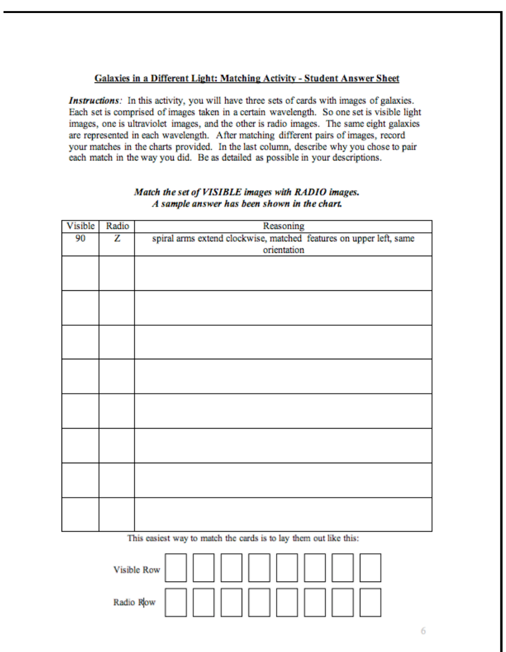
Table courtesy of NASA/JPL-Caltech

Elaborate:

***Project slide six: "Multiwavelength Astronomy"**

Matching sets of image cards activity (pages 6,7, & 8 of the Student Guide)
(An important thing to note is that the images of each galaxy are all of the same orientation and scale, as you may see in these examples that can be inspected via the Power Point Answer Guide:
-Orientation: the x-ray image of M82 (slide 12) really is showing matter at right angles to the plane of the galaxy seen in the other images.
-Scale: M100 (slide 8) -In the ultraviolet images looks as though it could be a zoom-in of the center of the galaxy, but it is not. The crescent shape doesn't seem to strictly match the spiral arms, and yet the size and orientation of this image is the same as the others.)
The images on the cards are negatives of the real pictures (black and white are reversed). This saves ink and results in crisper, longer lasting images.

- Pass out, to each pair of students, the RADIO and VISIBLE card sets from the Standard Image Set. DO NOT pass out the Ultraviolet cards yet.
- Have each pair designate one of themselves as a data recorder. This student will write their data on the answer sheet.
- Ask the pairs of students to match the image cards so each visible card has a radio mate. There should be eight image card pairs. This works best when students line up the eight images from one set across the top of their desks, then match the corresponding image cards below. Then have the data recorder write down their answers on page 6 of their worksheet and justify their decisions in the "Reasoning" column. **Give students a time limit for each matching set. 5-6 minutes is suggested, no more.** ***DON'T GIVE THE ANSWERS YET***
- Have students put aside the radio image set. Pass out the ULTRAVIOLET card set. Ask students to match the image cards in ultraviolet and visible, so there are eight pairs, each with a visible and ultraviolet image card. The data recorder should record answers and reasoning on page 7 of the student worksheet. Give students the 5-6 minute time limit for matching and recording.
- Leaving the visible-ultraviolet matches out on the desk, have students then get out their radio image card set and match them so that for each galaxy, there are three images – one in visible, one in radio, and one in ultraviolet. Have the data recorder record their answers on page 8. Give students a 5-6 minute time limit.



Galaxies in a Different Light: Matching Activity - Student Answer Sheet

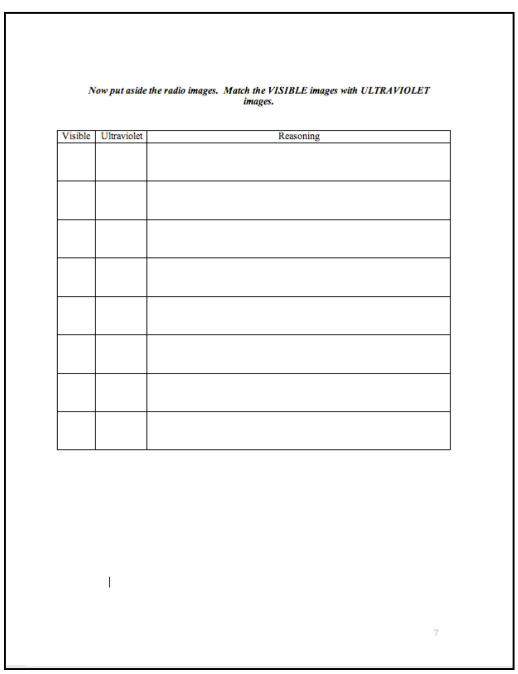
***Instructions**:* In this activity, you will have three sets of cards with images of galaxies. Each set is comprised of images taken in a certain wavelength. So one set is visible light images, one is ultraviolet images, and the other is radio images. The same eight galaxies are represented in each wavelength. After matching different pairs of images, record your matches in the charts provided. In the last column, describe why you chose to pair each match in the way you did. Be as detailed as possible in your descriptions.

Match the set of VISIBLE images with RADIO images.
A sample answer has been shown in the chart.

Visible	Radio	Reasoning
90	Z	spiral arms extend clockwise, matched features on upper left, same orientation

This easiest way to match the cards is to lay them out like this:

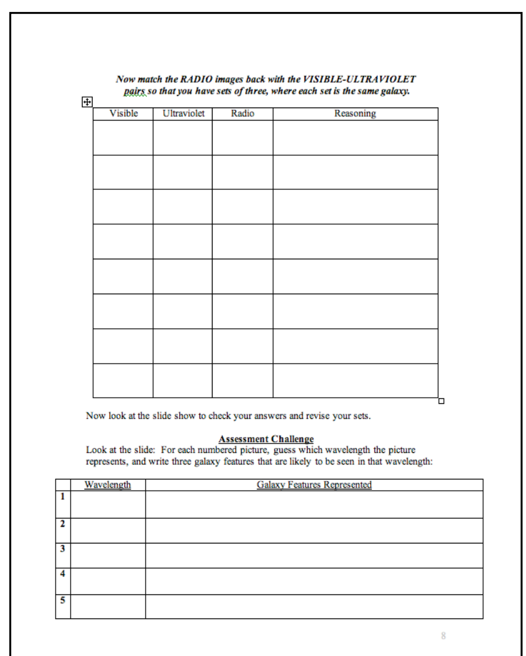
6



Now put aside the radio images. Match the VISIBLE images with ULTRAVIOLET images.

Visible	Ultraviolet	Reasoning

7



Now match the RADIO images back with the VISIBLE-ULTRAVIOLET pairs so that you have sets of three, where each set is the same galaxy.

Visible	Ultraviolet	Radio	Reasoning

Now look at the slide show to check your answers and revise your sets.

Assessment Challenge
Look at the slide: For each numbered picture, guess which wavelength the picture represents, and write three galaxy features that are likely to be seen in that wavelength:

	Wavelength	Galaxy Features Represented
1		
2		
3		
4		
5		

8

Discuss which wavelengths were the least similar (hardest to match) and why. Students may respond radio and ultraviolet. These two wavelengths are the farthest apart in the electromagnetic spectrum (out of the three they were asked to match). Also, many pictures have poor resolution and are highly pixilated (especially in the radio band). This is usually due to differences in telescopes used to gather the images. Ask students if different parts of a galaxy are seen more easily in some wavelengths than others (e.g. spiral arms, core, dust, gas, stars).

ANSWERS to matching activity:
***Project slide seven and onward. Stop at "Assessment Challenge."**
Show the Answer Guide slides one at a time so that students can check their results and rearrange, if necessary. This should be a chance for students to assess themselves in their logic for matching, but also revise and rethink their answers. Seeing the color images should also solidify why certain image cards matched, especially when details are lost in the printing.

Below is a table of the correct results:

Visible	Ultraviolet	Radio	Galaxy Name
1	VII	C	M94
2	IV	A	M100
3	III	G	M31
4	II	H	M101
5	VI	D	M33
6	I	F	M82
7	V	E	M81
8	VIII	B	SMC

If you wish to review galaxy types, here is a resource list.:

TYPE	**Examples**
Irregular	Centaurus A, Small Magellanic Cloud, Large Magellanic Cloud, M82
Elliptical	M84, M87
Spiral	M31, M33, M65, M74, M77, M81, M94, M100, M101, M104, M106
Barred Spiral	M83, NGC 1313

Evaluate:

***Project slide fourteen "Assessment Challenge."**
Have students examine the slide and discuss with their partner which galaxy features are emitting in each image. This will have the students consider which wavelengths the images are taken in based on the features they can notice. Students should be remembering the discussion of the "Galaxy Features" slide and applying their understanding of different wavelengths based on the matching they did. They can also refer back to the chart on page 5. There is a table to record answers at the bottom of page 8 of the student guide.

Students will guess the wavelength, and write three galaxy features that are related to that wavelength.

Answers:

1) *Infrared*
2) *X-Ray*
3) *Visible*
4) *Ultraviolet*
5) *Radio*

For each wavelength, they should write at least three corresponding features that are listed in the chart on page 5 of the student guide (page 7 of the teacher guide). Guessing the correct wavelength is not important, but listing the correct features for their chosen wavelength is important.

At this point, mention to students that professional astronomers will look at these pictures and notice very different features than the students: ***When looking at pictures such as these, experts will instantly notice what is relevant and important scientific information, while novices (e.g. the students) will tend to focus on somewhat irrelevant features.***

For example, in the ultraviolet picture (#4 on the current slide), novices might notice that there are three bright dots and a hazy blob shape. A professional astronomer at the University of Texas recently looked at the exact same picture, and he instantly knew which galaxy it was (M82). He quickly dismissed the bright dots as irrelevant foreground stars. He then began discussing how the UV image highlights the newest star-forming regions of the galaxy, which would likely be distributed along the spiral arms if we could see this galaxy face-on. He also mentioned that it is obvious that there is a huge amount of extinction (dust blocking out the light) that contributes to the apparent irregular shape of the galaxy.

Extend:

The last two pages (pgs. 9 & 10) of the student guide refer the students to three different websites that they can visit to follow-up on any interests or questions they have about the galaxy images and the telescopes used to gather them. There is also a list of some of the telescopes used to gather the images, with short descriptions of each. *The students can tear this last page off and take it home.*

(Tear this page off if you'd like to hold on to it)

-To see more awesome pictures like the ones in the slide show, and to find out even more about the telescopes involved in capturing them, please visit NASA's CoolCosmos website:

http://coolcosmos.ipac.caltech.edu//

-To learn about the history of telescopes and the evolution of astronomical technology, please visit the Space Telescope Science Institute's website called *Telescopes from the Ground Up:*

http://amazing-space.stsci.edu/resources/explorations/groundup/

-To find a local astronomy club in your area, please visit:

http://nightsky.jpl.nasa.gov/club-map.cfm

Telescope Source Information for Images on Galaxy Cards

ASTRO-1: these images were gathered from telescopes mounted on board a Space Shuttle. Three different ultraviolet telescopes were mounted in the payload of the Space Shuttle Columbia and made 231 observations over a 9-day period (Dec. 2nd-11th, 1990)

ASTRO-2: a follow-up project to ASTRO-1, these images were also gathered from telescopes that were carried on board a Space Shuttle. This time, the same three UV telescopes were mounted on the Space Shuttle Endeavour. They made several hundred observations over a 16-day period (March 2nd-18th, 1995), which set the record for the longest shuttle mission at the time.

GALEX: The Galaxy Evolution Explorer (GALEX) is an orbiting space telescope that observes galaxies in ultraviolet light across 10 billion years of cosmic history. With sensitive ultraviolet detectors, a large field of view, and its location above the ultraviolet-absorbing atmosphere of the Earth, GALEX is able to do one-of-a-kind observations, including an extra-galactic all-sky survey.

NRAO: The National Radio Astronomy Observatory is an organization that designs, builds and operates the world's most sophisticated and advanced radio telescopes. They gather info from hundreds of radio telescopes from all around the world working in unison. Radio telescopes are typically very large dishes (like in the movie *Contact*, which has scenes filmed at a the VLA [see below] and at the 1,000 ft. Arecibo telescope in Puerto Rico – the largest in the world).

VLA: The Very Large Array, one of the world's premier astronomical radio observatories, consists of 27 radio antennas in a Y-shaped configuration on the Plains of San Agustin fifty miles west of Socorro, New Mexico. Each antenna is 25 meters (82 feet) in diameter. The data from the antennas is combined electronically to give the resolution of an antenna 36km (22 miles) across, with the sensitivity of a dish 130 meters (422 feet) in diameter. Most people will recognize from the movie *Contact*. It is operated by the NRAO.

NVSS: The NRAO VLA Sky Survey (see above) is a huge survey of the sky done in radio wavelengths. Completed by the NRAO using the VLA, the information gathered is provided free to the entire astronomical community to help advance science.

RAIUB/MPIFR: The Radio Astronomical Institute of the University of Bonn and the Max-Planck-Institute for Radio Astronomy are German institutions that use a 100-meter radio telescope located in a protected valley in western Germany (near Effelsburg). The combination of the high surface accuracy of the dish and the construction principle of 'homologous distortion' enables observations at unprecedented high frequencies for such a large telescope. The telescope can be used to observe radio emission from celestial objects in a wavelength range from 73cm (408MHz) down to 3.5mm.

Effelsburg: see above (RAIUB/MPIFR)

AAO: The Anglo-Australian Observatory, located in Australia, houses a 4-meter equatorially mounted telescope. Its excellent optics, exceptional mechanical stability and precision computer control make it one of the finest telescopes in the world. Like most telescopes, the AAT can be used in many configurations, each requiring a different instrument or detector to collect and analyze the light. Most astronomers use charge coupled devices (CCDs) to collect data. These highly sensitive solid-state devices convert feeble light into digital signals which are then collected and stored on computers for further analysis, rather like an electronic photograph.

Grasslands Observatory: this is a small, privately owned, observatory located in Southeastern Arizona. It houses a 24-inch reflecting telescope that is well suited for optical astronomy.

IAC/RGO/Malin: This image was actually taken using the Isaac Newton Telescope, located in La Palma, Spain. It has a 100-inch primary mirror.

KPNO: The Kitt Peak National Observatory is located near Tuscon, Arizona. KPNO has 19 optical/infrared telescopes and two radio telescopes onsite. It supports the most diverse collection of astronomical observatories on Earth for nighttime optical and infrared astronomy and daytime study of the Sun. The visual image from KPNO used in this activity was taken on a 0.9 meter telescope.

The other images were taken by amateur astronomers whose info is not available – Amateurs help out a lot!