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This guide has been provided as a companion to *Expanded View*.  
It is our hope that you will use the included information to learn more about NASA's Great Observatories and Expand your View of the Universe.
Show Synopsis

We can see a multitude of color, spanning the rainbow from red to blue; but what if you could see the colors beyond these limits? What color is redder than red, or bluer than blue? *Expanded View* introduces the electromagnetic spectrum and multi-wavelength observation with examples from Hubble, Spitzer, and Chandra. Audiences learn how images are captured and what the colors tell us about the composition of deep sky objects. *Expanded View* is intended to illustrate the importance of multi-wavelength observation by describing how NASAs Great Observatories work together.

The Electromagnetic Spectrum

Light comes in all different wavelengths; with radio waves having the longest wavelength and gamma rays having the shortest. To illustrate this concept, let’s look at the electromagnetic spectrum.

If you look at the area with the rainbow labeled "visible," you will notice that it is a very small portion of the chart. The wavelengths to the left of visible light are too long for our eyes to detect, while those on the right are too short. As the wavelength decreases, the energy level of the wave increases, so X-Rays are higher energy than Infrared waves. The Hubble Space Telescope operates in the visible range of the spectrum, as well as near infrared and the longer wavelength end of ultraviolet. Just because we can’t see these wavelengths, doesn’t mean we aren’t effected by them. Let’s explore the spectrum.
Radio Waves - on the far left end of the spectrum you will notice the section labeled Radio. These wavelengths are very important to our everyday lives. The bands that carry cell phone signals, television signals and radio signals are all found within the "Radio" region of the electromagnetic spectrum. Many objects in space also emit radio waves, these are detected here on Earth with radio telescopes.

Microwaves are the next longest waves on the spectrum. If you take a closer look at the scale where microwaves are found, you will notice that the lengths of these waves are familiar to you, ranging from 1 meter into the range of millimeters. We use microwaves for all sorts of things here on earth, from heating up your lunch to detecting weather patterns. One of the greatest moments of astronomy was the discovery of Cosmic Microwave Background radiation which comes to us from every direction in space - letting us "see" the edge of the detectable universe.

Infrared light is measured in micrometers. This symbol "µ", pronounced like m-you, means micro. When placed in front of the symbol m for meter, this means micron, or 1 millionth of a meter. Infrared wavelengths are still too long for our eyes to detect, but you interact with it every moment. Cup your hands near your face - but don't actually touch your face. If you wait for just a moment, you will feel heat from your face on your hands (or vice-versa). This heat is infrared radiation – what does this mean? It means that you glow in the infrared wavelengths. This is why night vision goggles and infrared cameras work - they detect infrared wavelengths allowing you to "see" in the dark. The Spitzer Space Telescope detects the infrared radiation in space.
We already touched on the Visible portion of the spectrum, but if you look at the scale you will see that it spans between 0.7 μm and 0.4 μm. Not everyone's eyes are the same, so the endpoints are approximate, but this is a really small range compared to the whole spectrum. This is why it is so important to have instruments able to detect other wavelengths – enabling us to "see" the rest of the universe.

Ultraviolet wavelengths are measured in nanometers, meaning 1 billionth of a meter. Some insects are capable of seeing ultraviolet: this allows them to find the nectar-rich flowers which have markings that fluoresce under ultraviolet light. Many of the ultraviolet waves from our sun are blocked by our atmosphere; which is good for us because ultraviolet can be harmful to our cells and cause painful sunburns. Telescopes in space are necessary for studying ultraviolet emissions. The Hubble Space Telescope’s ultraviolet capabilities have allowed scientists to compare the shapes of nearby and distant galaxies and study the cloud bands on the planet Venus.

Next on our illustration we find x-rays. X-Rays are found at wavelengths of 3 nanometers (nm) to 0.03 nm. Wavelengths in this range are medically useful when properly administered: they allow medical professionals to diagnose damage to bones or teeth, but can be extremely harmful to our cells if over used. X-Rays from space are mostly filtered out by our atmosphere, so we need to put x-ray observatories in space to study objects in the x-ray range. The Chandra X-Ray Observatory enables us to view objects in stunning detail. These new details give us a better understanding of the universe.
The final stop on our spectrum is Gamma Rays, which have wavelengths so small that they are measured in angstroms which are symbolized by Å. One angstrom is equal to 0.1 nanometers. These wavelengths are extremely high energy and will kill living cells. Doctors sometimes use gamma rays in the treatment of cancerous tumors. Gamma Rays are produced in space by the hottest objects, like supernova explosions, black holes, and neutron stars. Like ultraviolet and x-rays, the atmosphere prevents gamma rays from reaching the surface of the earth so these wavelengths also need to be studied from space. During its mission, the Compton Gamma Ray Observatory made several important discoveries, such as the production of gamma rays from pulsars, and was critical in the study of gamma ray bursts.

Spectroscopy

Spectroscopy is the study of how electromagnetic radiation, which we’ve just introduced, interacts with atoms. Atoms absorb and emit radiation across the entire spectrum; with each atom having a unique pattern. By analyzing the data that is collected by the space telescopes, scientist use these patterns of absorption or emission to tell what type of atoms and molecules the object is made up of. This information helps us to learn about the many mysteries our our Universe, including the processes of star formation and death, formation of solar systems, and the formation and evolution of galaxies. Because scientists know the unique signature pattern of each element, astronomers can search for specific wavelengths thus determining what the object is composed of.

For example: this image of the Cat’s eye Nebula from the Hubble space telescope shows Hydrogen in red, neutral Oxygen in blue, and ionized Nitrogen in Green. This information is helping the astronomers studying this object to understand the complicated structure of the dying star.

Image Credit: J.P. Harrington and K.J. Borkowski (University of Maryland), and NASA
Purpose

Spectroscopy is a way for astronomers and chemists to figure out component elements of some cloud, star, or other object, using observable light. Students will learn that different elements produce different spectral “signatures” when excited.

Materials

• Various Gas Discharge Tubes (Recommended Minimum: H, He, Ne, & Hg)
• Gas Discharge Tube Power Supply
• Diffraction Grating Glasses or Slides (one per student or pair of students)

Optional Materials

• Incandescent Light Bulb (Type T10 or similar, with a long, vertical filament)
• Unshaded Lamp Base or Suitable Power supply for Incandescent Bulb
• Didymium Glass Slide or One set of Didymium Safety Glasses
• Image of the Solar Spectrum (Internet Search for “Sun Spectrum” or similar)

Lab Preparation

• Set Up the light source(s), with Hydrogen to be illuminated first, if available.
• Hand out the diffraction grating glasses or slides.

Safety Notes

• The gas discharge tube power supply will operate at high voltage (usually 5000 V) take care not to touch electrodes while the unit is in operation.

• Follow the manufacturer’s recommended duty cycle for each gas discharge tube (usually 30 sec on, 30-60 sec off).

• Gas discharge tubes can become very hot during use. Use caution when handling.

• The gas discharge tubes are made of glass and the Hg tube contains mercury. Take care not to drop the tubes.

• These safety notes are not an exhaustive list. Read and follow all warning labels.
Activity

- Display or share some HST photos of deep space objects with composition data.
- Discuss the composition of these objects (H, He, O, C, etc).
- Ask students to think about ways to figure out the composition of deep space objects.
- Point out that the objects in question are too far away for direct chemical sampling.
- Turn off room lights, activate Hydrogen tube.
- Ask the students to identify the colors that they see.
- Explain that they are observing the “discrete emission spectrum of Hydrogen.”

Additional Activity (Using Optional Equipment)

- Activate the incandescent bulb and ask students to observe its spectrum.
- Explain that they are observing a “continuous emission spectrum,” this is similar to the emission spectrum of a star.
- Ask the students to think of ways to determine the composition of stars.
- Point out that there are no discrete emission lines.
- Hold the didymium glass in front of the illuminated incandescent bulb, so the students can observe its absorption spectrum.
- Indicate that the students are observing the absorption spectrum of didymium.
- Explain that while elements emit specific colors of light when excited, they absorb those specific colors of light from other light sources when not excited.
- Display or share an image of the Sun’s spectrum. Discuss how the absorption spectrum of a star provides evidence of the star’s composition.
NASA’s Great Observatories

While the Hubble Space Telescope is very well known, it is one of four orbiting space telescopes in the Great Observatories family. Hubble is joined by the Spitzer Space Telescope, the Chandra X-Ray Observatory, and the now de-orbited Compton Gamma Ray Observatory. Expanded View focuses on the three remaining Great Observatories; Hubble, Spitzer, and Chandra.

Earth’s atmosphere is not just for breathing, it’s a shield against x-rays, gamma rays, and high energy ultraviolet radiation. The atmosphere also blocks much of the infrared spectrum. That’s great for living things, but it also means there’s a lot to “see” beyond what our atmosphere allows. If we want to observe in these wavelengths, we need to position our instruments above the atmosphere.

The atmosphere presents another problem for visible spectrum observers: atmospheric distortion. Our atmosphere is an unevenly heated, constantly churning fluid. Turbulence in our atmosphere is what makes the stars seem to twinkle at night. While this might not seem like a big deal, it’s a real problem for astronomers. Atmospheric distortion reduces the clarity of telescopic images and limits the resolving power of our equipment.

Placing a telescope in space is the obvious solution, but adaptive optics technology has made a lot of progress since the launch of Hubble. With technology, ground based observatories are beginning to match and sometimes surpass the resolving power of the Hubble Space Telescope.

Three important things to consider when designing a telescope are resolution, sensitivity, and wavelength coverage. The resolution of an instrument tells us the smallest measure at which two neighboring objects can be discerned as separate objects. For instance, the image of the cat’s eye nebula discussed above probably has two orbiting stars in the center, but Hubble doesn’t have high enough resolution to discern them as separate objects, however, the shape of the nebula implies the existence of two stars.

The sensitivity of an instrument indicates to the minimum brightness that a telescope can detect. If an object is too far away, or too dim for a telescope to detect, it is outside of the telescope’s sensitivity range. Wavelength coverage is just what it sounds like; the wavelengths of light is the observatory capable of viewing. Increasing the coverage means adding additional instruments, thus increasing the weight of the telescope; but also increasing our ability to understand the nature of observed objects.
The Hubble Space Telescope: 110-1100 nm

The Hubble Space Telescope was launched in 1990 aboard the Space Shuttle Discovery. After overcoming some technical difficulties, the instrument began returning some of the sharpest astrophotographs ever recorded.

Hubble has gathered the evidence for many discoveries. One of its most important photographs is shown here.

This is the “Hubble Ultra Deep Field,” a picture of a tiny area of the sky. Except for a handful of foreground stars, everything you can see in this picture – every little speck – is a galaxy.

Image Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

The Hubble Space Telescope is a Cassegrain reflector, this means it has a primary mirror which collects the light and directs it to a secondary mirror which focuses the light which is then sent to the observatories instruments. The Hubble servicing mission in 2009 added improved instruments and extended the longevity of the telescope with new batteries, six new gyroscopes, replaced the fine guidance sensor and added a new thermal blanket to protect the instrument.
One of the new instruments installed was the Wide Field Camera 3 (WFC3); which can observe in near ultraviolet, visible, and infrared wavelengths but not at the same time. This camera will be used to study dark matter and dark energy, two of the greatest mysteries of the Universe.

The Cosmic Origins Spectograph (COS), also new, uses the ultraviolet range, and will be used to determine the composition of the universe.

Hubble also has an Advanced Camera for Surveys (ACS) which operates in the visible range and studies the evolution of galactic clusters, distant objects in the Universe, and dark matter distribution.

The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) observes in the infrared range while the Space Telescope Imaging Spectrograph collects wavelengths much like the Cosmic Origins Spectograph, but on the scale of galaxies rather than smaller things like stars.

Finally, Hubble has Fine Guidance Sensors (FGS) which allow it to lock onto objects using guide stars. In this way the telescope stays pointed at the object it’s observing, allowing extended periods of data collection.

Hubble has enlightened us to many of the Universe’s mysteries. With the new upgrades, it will continue to do so for many years to come.
The Spitzer Space Telescope was launched in 2003 aboard a Delta II rocket. Spitzer observes in the infrared wavelengths. Among other things, infrared is useful for “seeing through” clouds of dust and gas.

The photograph below is Spitzer’s view of the center of our galaxy in infrared. Photographing the galactic center in visible light is problematic because thick clouds of dust and gas obscure our view. As an infrared instrument, Spitzer can see right through those clouds, revealing the swarm of stars orbiting the center of our galaxy.

Spitzer has three main instruments: the Infrared Array Camera (IRAC), which operates in the near and mid infrared ranges, the Infrared Spectrograph (IRS) which operates in the mid infrared range providing low and high resolution spectroscopy, and the Multi-band Imaging Photometer for Spitzer (MIPS) which operates in the far infrared range for imaging and some spectroscopic collection.

Spitzer has to be cooled in order to observe infrared without interference from its own heat. A special Earth-trailing orbit carries Spitzer slowly away from the infrared glow of our planet, it also has a special solar shield to help keep it cool. In addition, the telescope was kept cool cryogenically with liquid helium until May of 2009 when the last of the Helium boiled away. Spitzer has now entered its “warm phase.” It can still observe in wavelengths of 3.6 and 4.5 microns, but it is now too warm to observe in other infrared wavelengths.
The Chandra X-Ray Observatory was carried into orbit aboard the Space Shuttle Columbia in 1999. Chandra follows a highly elliptical orbit, taking the spacecraft up to 0.33 lunar distances from Earth at its farthest point. This reduces Chandra’s exposure to interference from the radiation belts that surround the Earth.

In this photograph, the black hole at the center of one galaxy sprays a neighboring galaxy with a jet of super heated particles. (Chandra’s observation is shown in purple.)


The Chandra X-Ray Observatory consists of an X-Ray telescope which uses mirrors to focus the X-Rays on its four scientific instruments. Each of these elements are housed inside the Observatory which is powered by solar arrays.

Chandra has a High Resolution Camera (HRC) which images hot matter in the centers of exploded stars and distant galaxies. The Chandra Advanced CCD Imaging Spectrometer (ACIS) allows us to study temperature changes across X-Ray sources and chemical variations across supernova remnants. Finally, the High Energy Transmission Grating Spectrometer (HETGS) and the Low Energy Transmission Grating Spectrometer (LETGS) allow scientists to analyze the composition and physical properties of objects in space.
False Coloration

It is important to understand that many of the images from these observatories are not displayed in their true colors. Obviously, we are unable to see wavelengths outside of the visible range, so these must be assigned colors that we can see. Hubble also uses false coloration, even within the visible range of the spectrum. Some of the reasons for false coloration have already been touched upon when we talked about spectroscopy: we can assign colors to specific wavelengths allowing us to study important aspects of an object such as composition.

Recall the image from our discussion on spectroscopy – if we look up the wavelengths used in this image, we see that the hydrogen alpha line (depicted by red) is at 656.3 nm, the neutral oxygen (shown in blue) is at 630 nm, and ionized nitrogen (shown here in green) is found at 658.4 nm. Now, if we look at our electromagnetic spectrum we see that all of these fall within the red light region of the spectrum. If this image were shown in true color from these wavelengths, we would not be able to see the nitrogen at the edge of the shockwave or the oxygen surrounding the dying star. This method of false coloration is called “Enhanced Color” because it is used to bring out details which would otherwise be difficult to discern.

Image Credit: J.P. Harrington and K.J. Borkowski (University of Maryland), and NASA

There are other reasons to use false coloration; colors are assigned to wavelengths outside of the visible spectrum so that we can observe them. This is know as representative coloration and is used by all of the great observatories.

These coloration methods are critical to the study of the objects; however, it is important to remember that the image may not be shown in natural coloration. Don’t forget to read the accompanying information on the images that you view. Natural-colored images from the Hubble Space Telescope allow us to view the object as it would look if our eyes were as powerful as the telescope, these colors occur in the visible spectrum.

For more information on False Coloration, visit: http://hubblesite.org/gallery/behind_the_pictures/meaning_of_color/
Spectral Coverage

NASA’s Great Observatories were designed to cover a wide range of the spectrum. (The range of the Compton Gamma Ray Observatory is nearly off the right side of our scale.)

This wide range of coverage has allowed us to learn much about our Universe. Radio and microwaves travel through our atmosphere without difficulty, so it isn’t necessary to put radio and microwave telescopes into space.

For example: lets look at this image of the crab nebula. This image is composited from Hubble, Spitzer, and Chandra data (Image Credit: NASA, ESA, CXC, JPL-Caltech, J. Hester and A. Loll (Arizona State Univ.), R. Gehrz (Univ. Minn.), and STScI.)

If we break this down into it's individual components, we will see the contribution of each observatory.

Here is Hubble’s view of the remnant. This is a false color image showing what the nebula is composed of. It also shows us the intricate detail of the remnant’s shape.

Image Credit: NASA, ESA, J. Hester and A. Loll (Arizona State University)
Spitzer’s view shows the warm dust and gas of the remnant. Note the interesting structure, which contains hot gasses.

Image Credit: NASA/JPL-Caltech/Univ. Minn./R.Gehrz

The image from Chandra gives us a lot of important information (Credit: NASA/CXC/ASU/J. Hester et al.) Stars more than eight times the mass of our sun die in a supernova explosion, the end result of this explosion depends again on the mass of the star. If the star is between 8 - 25 times the mass of our sun, the star will become what is called a neutron star, if it is more massive than 25 times our sun, it will become a black hole. The crab nebula, contains a special type of neutron star called a pulsar. Neutron stars are the remnants of the massive star that have collapsed and are spinning extremely fast. These stars have magnetic fields, and sometimes the axis of the star and magnetic field are not in perfect alignment, when this happens, charged particles emitted by the neutron star, spiral up the magnetic field lines and are discharged as a pulse of light that we can detect. Chandra's image shows the structure of the surrounding shockwave as a ring around the central pulsar, along with the jets from particles leaving the core.

Bringing these images together, lets us see the overall shape of the remnant, helping us to understand it's properties. Over the years of their operation, the observatories have also made multiple observations of this remnant, giving us information about how it is evolving and changing over time. Observations have shown that the remnant is expanding away from the initial explosion at over three million miles per hour.

Image Credit: NASA, ESA, CXC, JPL-Caltech, J. Hester and A. Loll (Arizona State Univ.), R. Gehrz (Univ. Minn.), and STScI.
Vocabulary

**Accretion Disk**
A relatively flat, disk-like cloud of dust and gas orbiting a massive object.

**Angstrom**
Also spelled "Ångström" and abbreviated as Å, the angstrom is a unit of length.

\[ 1 \, \text{Å} = 1.0 \times 10^{-10} \, \text{m} = 1/10,000,000,000 \, \text{m} \]

**Atmospheric Distortion**
Earth's constantly moving, turbulent, unevenly heated atmosphere causes slight refraction of the light from stars, planets, and deep space objects. Atmospheric distortion limits the resolving power of astronomical sensing equipment within the atmosphere.

**Black Hole**
The collapsed remains of a "dead," supermassive star. Black holes are so gravitationally attractive, that the escape speed exceeds the speed of light within a certain radius. A star greater than 25 solar masses will collapse into a black hole following its supernova explosion.

**Chandra X-Ray Observatory**
An Earth-orbiting observatory that is sensitive in the x-ray band.

**Earth Trailing Solar Orbit**
An orbit about the Sun, with a radius of about 1 AU, and a position "behind" Earth. The Spitzer Space Telescope is in an Earth Trailing Solar Orbit.

**Electromagnetic Spectrum**
The range of all wavelengths of electromagnetic radiation. The Electromagnetic Spectrum (also known as the EM Spectrum) includes all possible electromagnetic frequencies, from the longest radio waves to the shortest gamma waves.

**Elliptical Orbit**
An orbit that traces an elliptical- or oval-shaped path. The Chandra X-Ray Observatory follows a highly elliptical orbit.

**Galactic Center**
The rotational and gravitational center of a galaxy. Galactic centers are typically densely populated with high mass stars and one or more supermassive black holes.

**Galaxy**
A gravitationally bound system of stars, nebulae, planets, gas, dust, and dark matter. Our Solar System is part of the Milky Way Galaxy.

**Gamma Ray**
The high-energy, short wavelength end of the electromagnetic spectrum, with wavelengths shorter than 0.1 Å.
**Hubble Space Telescope**
An Earth-orbiting observatory that is sensitive in the visible, near infrared, and low-frequency ultraviolet bands.

**Infrared**
A band of the electromagnetic spectrum between the red end of the visible spectrum and microwaves, with wavelengths between 0.75 µm and 1,000 µm.

**Micron**
Also known as a "micrometer" and abbreviated as µm, the micron is a unit of length.  
1 µm = 1x10^{-6} m = 1/1,000,000 m

**Microwave**
A band of the electromagnetic spectrum between infrared and radio, with wavelengths generally defined between 3 mm and 30 cm.

**Near Infrared**
A narrowly defined segment of the infrared band, just beyond the red end of the visible spectrum, with wavelengths between 0.75 µm and 1.4 µm.

**Nebula**
A cloud of dust and gas. There are several types of nebulae: star forming regions, supernova remnants, planetary nebulae, among others.

**Neutron Star**
The super compact remains of a "dead," high mass star. A star that is 8-25 solar masses will collapse into a neutron star after its supernova explosion.

**Planetary Nebula**
The remains of a sun-like star following its "death." Stars as large as 8 solar masses slowly eject their outer atmospheres after running out of fusible material.

**Protostar**
In the early stages of star formation, a condensed mass of dust and gas that is gravitationally bound, but has not achieved sufficient temperature or pressure to begin fusion.

**Radio**
The low-energy, long wavelength end of the electromagnetic spectrum, with wavelengths of 30 cm and longer.

**Resolution**
In astronomy, a measurement of the resolving power of a telescopic instrument. Resolution typically refers to the angular size of the smallest discernible feature in an image.

**Sensitivity**
A measurement of the detection range of an instrument. Sensitivity can refer to the range of observable frequencies and/or the lowest detectable input for a given device.
**Shock Wave**
In astrophysics, the term shock wave refers to: the expanding front of a supernova explosion, the bow shock of a star or planet, or some other disturbance traveling through a medium.

**Spectroscopy**
The study of the interactions between radiation and matter. In astronomy, spectroscopy is used to determine the composition and Doppler shift of distant objects.

**Spitzer Space Telescope**
An Earth-trailing, solar-orbiting Observatory that is sensitive in the infrared band.

**Supernova**
The rebounding explosion marking the "death" of a high mass star. Stars larger then 8 solar masses explode violently after running out of fusible material. Elements heavier than iron are created in supernova explosions.

**Supernova Remnant**
The expanding remains of a dead star, following its supernova explosion. The debris is eventually incorporated into nebulae, stars, planets, and the interstellar medium.

**Ultraviolet**
A band of the electromagnetic spectrum between x-rays and the blue-violet end of the visible spectrum, with wavelengths between 10 nm and 390 nm.

**Visible Light**
The range of the electromagnetic spectrum that humans can detect optically. The visible spectrum is often represented as a rainbow, with wavelength limits at approximately 390 nm (blue-violet) and 750 nm (red).

**Wavelength**
The distance between repeated features in a wave. Wavelength is inversely related to the energy level of electromagnetic waves: long wavelengths (eg: radio waves or microwaves) have less energy than short wavelengths, (eg: x-rays or gamma rays).

**X-Ray**
A band of the electromagnetic spectrum between gamma rays and the ultraviolet band, with wavelengths between 0.01 nm and 10 nm.

**X-Ray flare**
A sudden burst of x-ray radiation, produced by stars and exotic sources.
Now that you know how these observatories work individually and together, it is time to Expand your View of the Universe.

Choose an image from one of the space telescopes’ image galleries:

**Hubble:**
http://hubblesite.org/gallery/album/entire

**Spitzer:**

**Chandra:**
http://chandra.harvard.edu/photo/

After you have chosen your image, learn everything you can about that object using the data on the space telescope websites. See if it has been observed by more than one observatory and compare the findings if it has.

Now that you are an expert on your celestial object you are going to share your knowledge with the class. Prepare a short presentation for your classmates about the significance of your object and the observatories findings. Be CREATIVE, you can use posters, drawings, printouts of the image, powerpoint presentations etc. The Universe is your playground on this project, so have fun.

Some suggested study questions:

What do the colors in the image mean?
Which wavelengths were used to photograph the image?
Where is the object in the sky and can it be seen with a telescope?
Project Evaluation

Student Name__________________________________  Date__________________

Object Name__________________________________________________________

Observatory(s) Used____________________________________________________

Wavelengths in Image__________________________________________________

What Type of Coloration is Used?_________________________________________

Student’s knowledge about the object   _____ / 50

Student’s Creativity in Presentation of object   _____ / 30

Student’s Ability to Answer Questions about object   _____ / 10

Quality of Visual Aids used in Presentation   _____ / 10

Notes:
Assessment

NAME_____________________________         DATE_____________________

Label the following on the Electromagnetic Spectrum:

Infrared  Ultraviolet  Hubble  Radio
Gamma Ray  Visible  Chandra  X-Ray
Microwave  Spitzer

What waveband does Chandra operate in? What kinds of objects can Chandra observe?

How do the multiple telescopes help “Expand the View?”

If you could get time on all these telescopes at once, what would you observe, and why?
For next generation space telescopes, do you think resolution, sensitivity, or wavelength coverage is most important? Give your reasons for your decision.

Now, pick one of the options you did not choose and argue for it in the same way. Such decisions are never cut-and-dried, and it’s important to be able to understand the arguments on all sides.
References and Resources

**Electromagnetic Spectrum**
http://science.hq.nasa.gov/kids/imagers/ems/radio.html

**NASA’s Great Observatories**

**Hubble Space Telescope**

About the Telescope:
http://hubblesite.org/the_telescope/

Images:
http://hubblesite.org/gallery/album/

False Coloration:
http://hubblesite.org/gallery/behind_the_pictures/

**Spitzer Space Telescope**

About the Telescope:
http://www.spitzer.caltech.edu/about/index.shtml

Images:

Fun Classroom Activities:
http://coolcosmos.ipac.caltech.edu/

**Chandra X-Ray Observatory**

About the Telescope:
http://chandra.harvard.edu/about/

Images:
http://chandra.harvard.edu/photo/