Electromagnetic Spectrum Name: ______________________________ Period: ______

Question	Answer
Electromagnetic Spectrum 1. What is the electromagnetic spectrum?	
2. What is radiation?	
3. What is the source of radio waves in space?	
4. How do astronomers use microwaves?	
5. What does infrared light help us map in space?	
6. What objects in space emit ultraviolet light?	
7. What in the universe emits x-rays?	
8. What is the biggest gamma-ray generator?	
9. What do we call the massless particles of electromagnetic radiation?	
10. How do these particles travel?	
11. What three terms can be used to express electromagnetic radiation?	
12. What are the units for these terms?	

Observatories Across the Electromagnetic Spectrum

1. Why do we have to use some telescopes aboard satellites?
2. What is interferometry?
3. By putting a radio telescope in orbit around Earth, radio astronomers can make images as if they had what size telescope?
4. Why do astronomers use satellite-based telescopes to observe cosmic microwaves?
5. What are the microwaves of the Cosmic Background Radiation a remnant of?
6. What is the biggest challenge to using an infrared telescope?
7. What part of the spectrum is used by optical astronomy?
8. What do visible-light observatories in space avoid?
9. An ultraviolet telescope is much like a regular visible light telescope. What is the primary difference?
10. Why do X-ray telescopes pose a particular challenge?

11. Why have there been no no focusing gamma-ray telescopes?	
12. What do astronomers rely on instead?	
13. How can astronomers use ground-based astronomy to detect the highest energy gamma-rays?	

The following terms are in your reading. Find them and write definitions:

1. Electromagnetic radiation
2. Electromagnetic spectrum
3. Frequency
4. Interferometry
5. Photon
6. Radiation
7. Wavelength

Electromagnetic Spectrum

Source: High Energy Astrophysics Science Archive Research Center

The electromagnetic (EM) spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation. The other types of EM radiation that make up the electromagnetic spectrum are microwaves, infrared light, ultraviolet light, X-rays and gamma-rays.

You know more about the electromagnetic spectrum than you may think. The image here shows where you might encounter each portion of the EM spectrum in your day-to-day life.

Radio: Your radio captures radio waves emitted by radio stations, bringing your favorite tunes. Radio waves are also emitted by stars and gases in space.

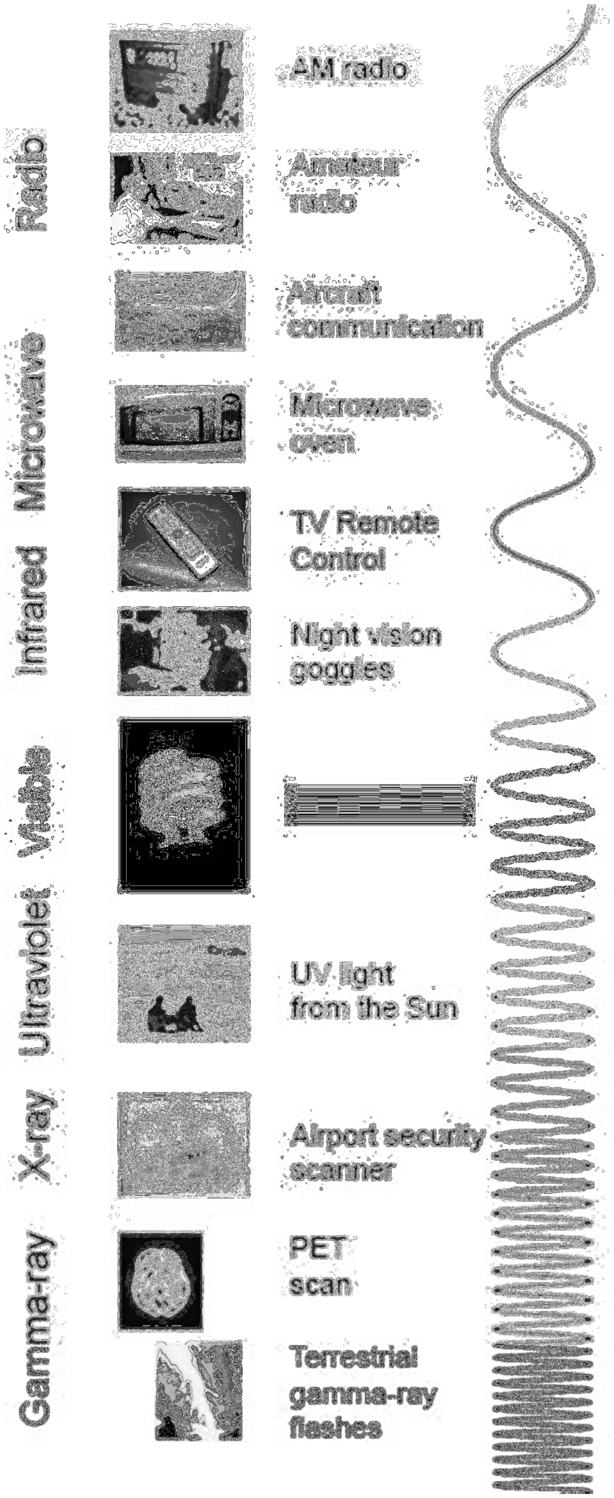
Microwave: Microwave radiation will cook your popcorn in just a few minutes, but is also used by astronomers to learn about the structure of nearby galaxies.

Infrared: Night vision goggles pick up the infrared light emitted by our skin and objects with heat. In space, infrared light helps us map the dust between stars.

Visible: Our eyes detect visible light. Fireflies, light bulbs, and stars all emit visible light.

Ultraviolet: Ultraviolet radiation is emitted by the Sun is the reason skin tans and burns. "Hot" objects in space emit UV radiation as well.

X-ray: A dentist uses X-rays to image your teeth, and airport security uses them to see through your bag. Hot gases in the Universe also emit X-rays.



Gamma ray: Doctors use gamma-ray imaging to see inside your body. The biggest gamma-ray generator of all is the Universe.

Is a radio wave the same as a gamma ray?

Are radio waves completely different physical objects than gamma-rays? They are produced in different processes and are detected in different ways, but they are not fundamentally different. Radio waves, gamma-rays, visible light, and all the other parts of the electromagnetic spectrum are electromagnetic radiation.

Electromagnetic radiation can be described in terms of a stream of mass-less particles, called photons, each traveling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy. The different types of radiation are defined by the amount of energy found in the photons. Radio waves have photons with low energies, microwave photons have a little more energy than radio waves, infrared photons have still more, then visible, ultraviolet, X-rays, and, the most energetic of all, gamma-rays.

Measuring electromagnetic radiation

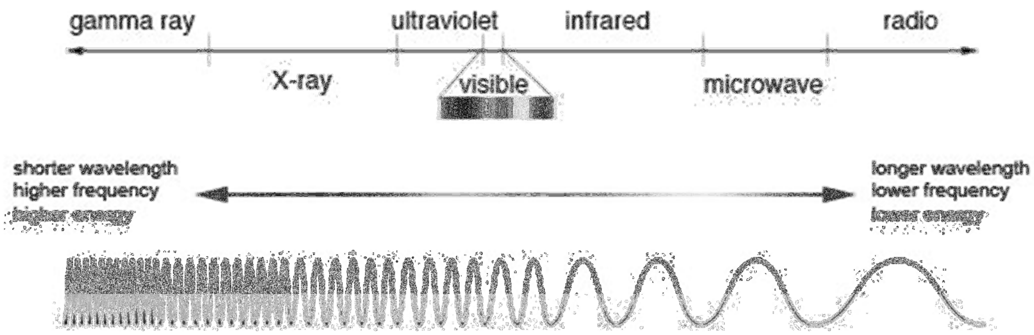
Electromagnetic radiation can be expressed in terms of energy, wavelength, or frequency. Frequency is measured in cycles per second, or Hertz. Wavelength is measured in meters. Energy is measured in electron volts. Each of these three quantities for describing EM radiation are related to each other in a precise mathematical way. But why have three ways of describing things, each with a different set of physical units?

The short answer is that scientists don't like to use numbers any bigger or smaller than they have to. It is much easier to say or write "two kilometers" than "two thousand meters." Generally, scientists use whatever units are easiest for the type of EM radiation they work with.

Astronomers who study radio waves tend to use wavelengths or frequencies. Most of the radio part of the EM spectrum falls in the range from about 1 cm to 1 km, which is 30 gigahertz (GHz) to 300 kilohertz (kHz) in frequencies. The radio is a very broad part of the EM spectrum.

Infrared and optical astronomers generally use wavelength. Infrared astronomers use microns (millionths of a meter) for wavelengths, so their part of the EM spectrum falls in the range of 1 to 100 microns. Optical astronomers use both angstroms (0.00000001 cm, or 10^{-8} cm) and nanometers (0.0000001 cm, or 10^{-7} cm). Using nanometers, violet, blue, green, yellow, orange, and red light have wavelengths between 400 and 700 nanometers. (This range is just a tiny part of the entire EM spectrum, so the light our eyes can see is just a little fraction of all the EM radiation around us.)

The wavelengths of ultraviolet, X-ray, and gamma-ray regions of the EM spectrum are very small. Instead of using wavelengths, astronomers that study these portions of the EM spectrum usually refer to these photons by their energies, measured in electron volts (eV). Ultraviolet radiation falls in the range from a few electron volts to about 100 eV. X-ray photons have energies in the range 100 eV to 100,000 eV (or 100 keV). Gamma-rays then are all the photons with energies greater than 100 keV.

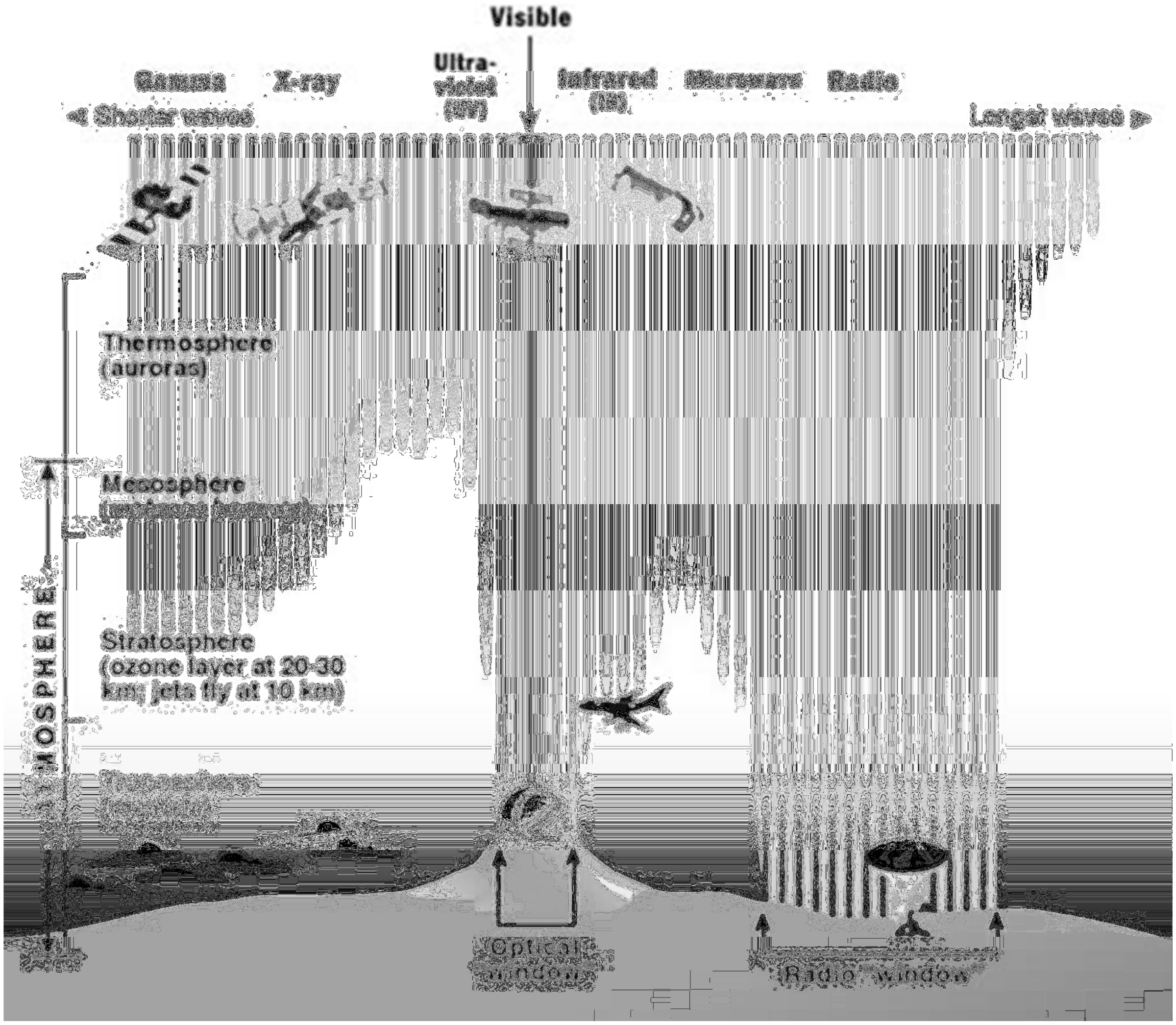


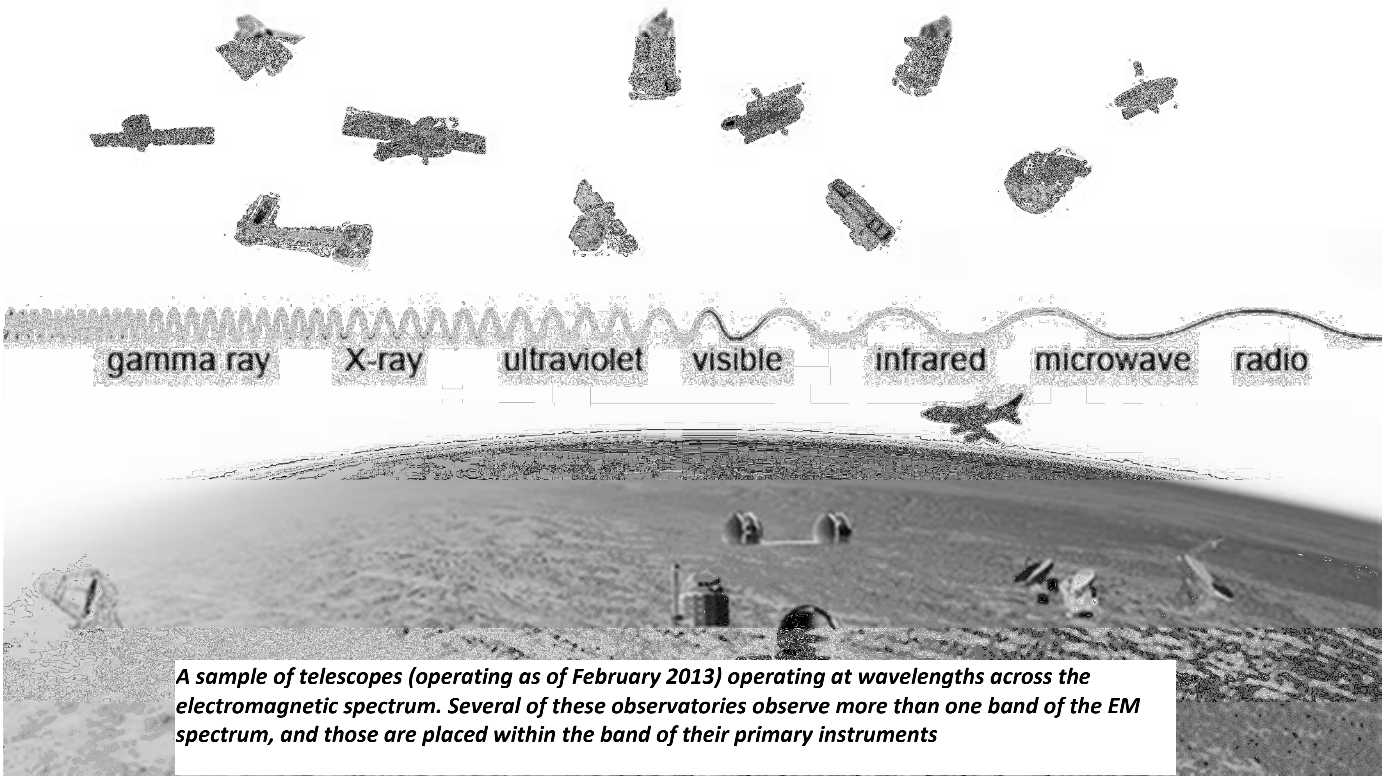
Why do we put telescopes in orbit?

The Earth's atmosphere stops most types of electromagnetic radiation from space from reaching Earth's surface. This illustration shows how far into the atmosphere different parts of the EM spectrum can go before being absorbed. Only portions of radio and visible light reach the surface.

Most electromagnetic radiation from space is unable to reach the surface of the Earth. Radio frequencies, visible light and some ultraviolet light makes it to sea level. Astronomers can observe some infrared wavelengths by putting telescopes on mountain tops. Balloon experiments can reach 35 km above the surface and can operate for months. Rocket flights can take instruments all the way above the Earth's atmosphere, but only for a few minutes before they fall back to Earth.

For long-term observations, however, it is best to have your detector on an orbiting satellite and get above it all!





A sample of telescopes (operating as of February 2013) operating at wavelengths across the electromagnetic spectrum. Several of these observatories observe more than one band of the EM spectrum, and those are placed within the band of their primary instruments

Observatories Across the Electromagnetic Spectrum

Astronomers use a number of telescopes sensitive to different parts of the electromagnetic spectrum to study objects in space. Even though all light is fundamentally the same thing, the way that astronomers observe light depends on the portion of the spectrum they wish to study.

For example, different detectors are sensitive to different wavelengths of light. In addition, not all light can get through the Earth's atmosphere, so for some wavelengths we *have* to use telescopes aboard satellites. Even the way we collect the light can change depending on the wavelength. Here we briefly introduce observatories used for each band of the EM spectrum.

Radio observatories

Radio waves can make it through the Earth's atmosphere without significant obstacles. In fact, radio telescopes can observe even on cloudy days. In principle, then, we don't need to put radio telescopes in space. However, space-based radio observatories complement Earth-bound radio telescopes in some important ways.

A special technique used in radio astronomy is called "interferometry." Radio astronomers can combine data from two telescopes that are very far apart and create images that have the same resolution as if they had a single telescope as big as the distance between the two telescopes. This means radio telescope arrays can see incredibly small details. One example is the Very Large Baseline Array (VLBA), which consists of 10 radio observatories that reach from Hawaii to Puerto Rico, nearly a third of the way around the world.

By putting a radio telescope in orbit around Earth, radio astronomers can make images as if they had a radio telescope the size of the entire planet. The first mission dedicated to space interferometry was the Japanese HALCA mission which ran from 1997 to 2005. The second dedicated mission is the Russian Spektr-R satellite, which launched in 2011.

Microwave observatories

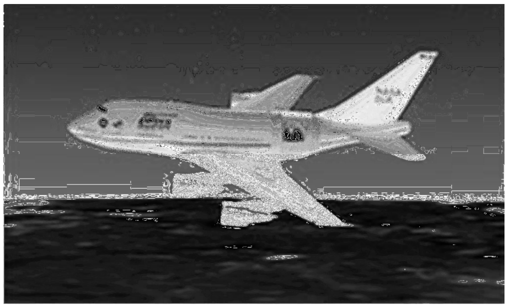
Artist's conception of the European Space Agency's (ESA's) Planck observatory cruising to its orbit. (Credit: ESA/D. Ducros)

The Earth's atmosphere blocks much of the light in the microwave band, so astronomers use satellite-based telescopes to observe cosmic microwaves. The entire sky is a source of microwaves in every direction, most often referred to as the cosmic microwave background (or CMB for short). These microwaves are the remnant of the Big Bang, a term used to describe the early universe.

A very long time ago, all the matter in existence was scrunched together in a very small, hot ball. The ball expanded outward and became our universe as it cooled. Since the Big Bang, which is estimated to have taken place 13.7 billion years ago, it has cooled all the way to just three degrees above absolute zero. It is this "three degrees" that we measure as the microwave background.

The first precise measurements of the temperature of the microwave background across the entire sky was done by the Cosmic Background Explorer (COBE) satellite from 1989 to 1993. Since then, the Wilkinson Microwave Anisotropy Probe (WMAP) refined the COBE measurements, operating from 2001 to 2010. More recently, the Planck mission was launched in 2009 and will further improve astronomer's understanding of the CMB.

Infrared observatories



Artist's conception of SOFIA flying at sunset (Credit: NASA)

Infrared astronomy has to overcome a number of challenges. While some infrared radiation can make it through Earth's atmosphere, the longer wavelengths are blocked. But that's not the biggest challenge – everything that has heat emits infrared light. That means that the atmosphere, the telescope, and even the infrared detectors themselves all emit infrared light.

Ground-based infrared telescopes reside at high altitudes in dry climates in an effort to get above much of the water vapor in the atmosphere that absorbs infrared. However, ground-based infrared observatories must still account for the atmosphere in their measurements. To do this, the infrared emission from the atmosphere is measured at the same time as the measurement of the cosmic object being observed. Then, the emission from the atmosphere can be subtracted to get an accurate measurement of the cosmic object. The telescopes, for both ground-based and space/airborne observatories, are also designed to limit the spurious infrared radiation from reaching the detector, and the detectors are cooled to limit their infrared emissions.

In 2003, NASA launched the Spitzer Space Telescope into an earth-trailing, heliocentric orbit, where it does not have to contend with the comparatively warm environment in near-Earth space. Spitzer ran out of coolant in 2009, but one of it's instruments continues to operate in a reduced capacity. Another major infrared facility is the

Stratospheric Observatory for Infrared Astronomy (SOFIA). SOFIA carries a large telescope inside a 747 aircraft flying at an altitude sufficient to get it well above most of the Earth's infrared absorbing atmosphere.

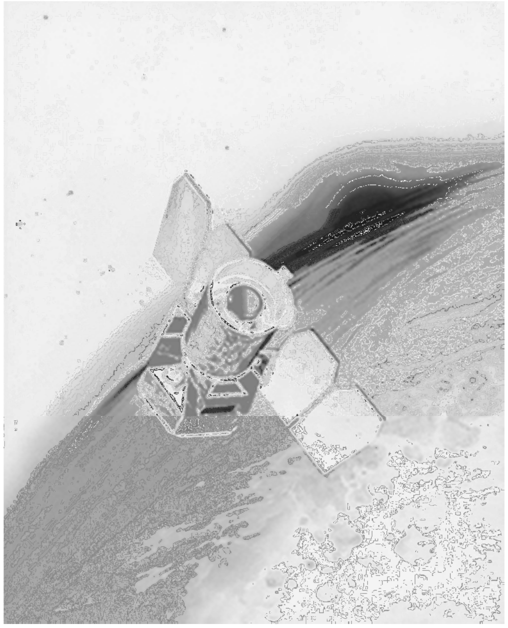
Visible spectrum observatories

The Hubble Space Telescope just after it was captured by the Space Shuttle Atlantis to be serviced in 2009. (Credit: NASA)

Visible light can pass right through our atmosphere, which is why astronomy is as old as humanity. Ancient humans could look up at the night sky and see the stars above them. Today, there is an army of ground-based telescope facilities for visible astronomy (also called "optical astronomy"). However, there are limits to ground-based optical astronomy. As light passes through the atmosphere, it is distorted by the turbulence within the atmosphere. Astronomers can improve their chances of a good image by putting observatories on mountain-tops (above some of the atmosphere), but there will still be limits to how crisp their images will be, especially for faint sources.

Visible-light observatories in space avoid the turbulence of the Earth's atmosphere. In addition, they can observe a somewhat wider portion of the electromagnetic spectrum, in particular ultraviolet light that is absorbed by the Earth's atmosphere. The Hubble Space Telescope is perhaps the most famous optical telescope in orbit. Also in orbit is the Kepler observatory. Kepler is using visible light to survey a portion of the Milky Way galaxy to discover planetary systems. The Swift satellite also carries an Ultraviolet and Optical Telescope (the UVOT) to perform observations of gamma-ray bursts.

Ultraviolet observatories



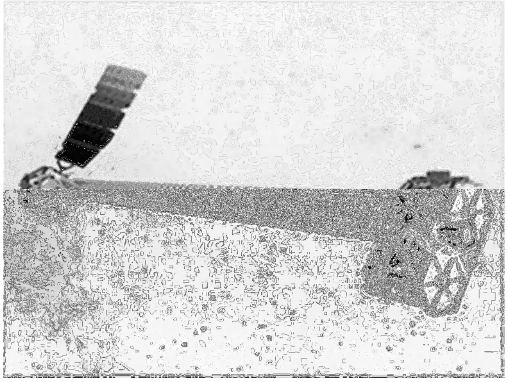
Artist's concept of the GALEX satellite in orbit. (Credit: NASA/JPL-Caltech)

The Earth's atmosphere absorbs ultraviolet light, so ultraviolet astronomy must be done using telescopes in space. Other than carefully-select materials for filters, a ultraviolet telescope is much like a regular visible light telescope. The primary difference being that the ultraviolet telescope must be above Earth's atmosphere to observe cosmic sources.

The GALEX observatory is the most recent dedicated ultraviolet observatory. It was launched in 2003, and is still operating as of February 2013. Its goal was to observe the history of star formation in our Universe in ultraviolet wavelengths, and it has observed over a half-billion galaxies going back to when our Universe was just about 3 billion years old.

In addition to GALEX, the Hubble Space Telescope and the UltraViolet and Optical Telescope on Swift can both perform a great deal of observing at ultraviolet wavelengths, but they only cover a portion of the spectrum that GALEX observes.

X-ray observatories



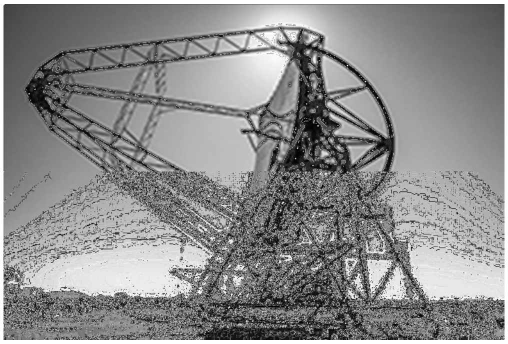
Artist's concept of the NuSTAR satellite. (Credit: NASA/JPL-Caltech)

X-ray wavelengths are another portion of the electromagnetic spectrum that are blocked by Earth's atmosphere. X-rays also pose a particular challenge because they are so small and energetic that they don't bounce off mirrors like lower-energy forms of light. Instead, they pass right through. Unless they just barely graze the surface of the mirror.

Focusing X-ray telescope require long focal lengths. In other words, the mirrors where light enters the telescope must be separated from the X-ray detectors by several meters. However, launching such a large observatory is costly and limits the launch vehicles to only the most powerful rockets (the Space Shuttle in the case of the Chandra X-ray Observatory).

In 2012, the Nuclear Spectroscopic Telescope Array (or NuSTAR for short), solved this problem by designing an observatory with a deployable mast. In other words, NuSTAR was designed with its mirror module and detector module on a mast, or boom, that could be extended once it was in orbit. By doing that, NuSTAR could be launched on a low-cost rocket.

Gamma-ray observatories



One of the HESS telescopes. (Credit: HESS Collaboration)

Not only are gamma-rays blocked by Earth's atmosphere, but they are even harder than X-rays to focus. In fact, so far, there have been no focusing gamma-ray telescopes. Instead, astronomers rely on alternate ways to determine where in the sky gamma-rays are produced. This can be properties of the detector or using special "masks" that cast gamma-ray shadows on the detector.

The Swift satellite was launched in 2004 to help solve the mystery of gamma-ray bursts. Swift has a gamma-ray detector that can observe half the sky at a time, and if it detects a gamma-ray burst, the satellite can quickly point its X-ray and optical telescopes in the direction of the burst. The Fermi Space Telescope was launched in 2008 and is designed to study energetic phenomena from a variety of cosmic sources, including pulsars, black holes, active galaxies, diffuse gamma-ray emission and gamma-ray bursts.

It might be surprising to know that astronomers can use ground-based astronomy to detect the highest energy gamma-rays. For these gamma-rays, the telescopes don't detect the gamma-rays directly. Instead, they use the atmosphere itself as a detector. The HESS array has been in operation for over 10 years. The array began with four telescopes arranged in a square, and recently added the HESS II telescope to its ranks.