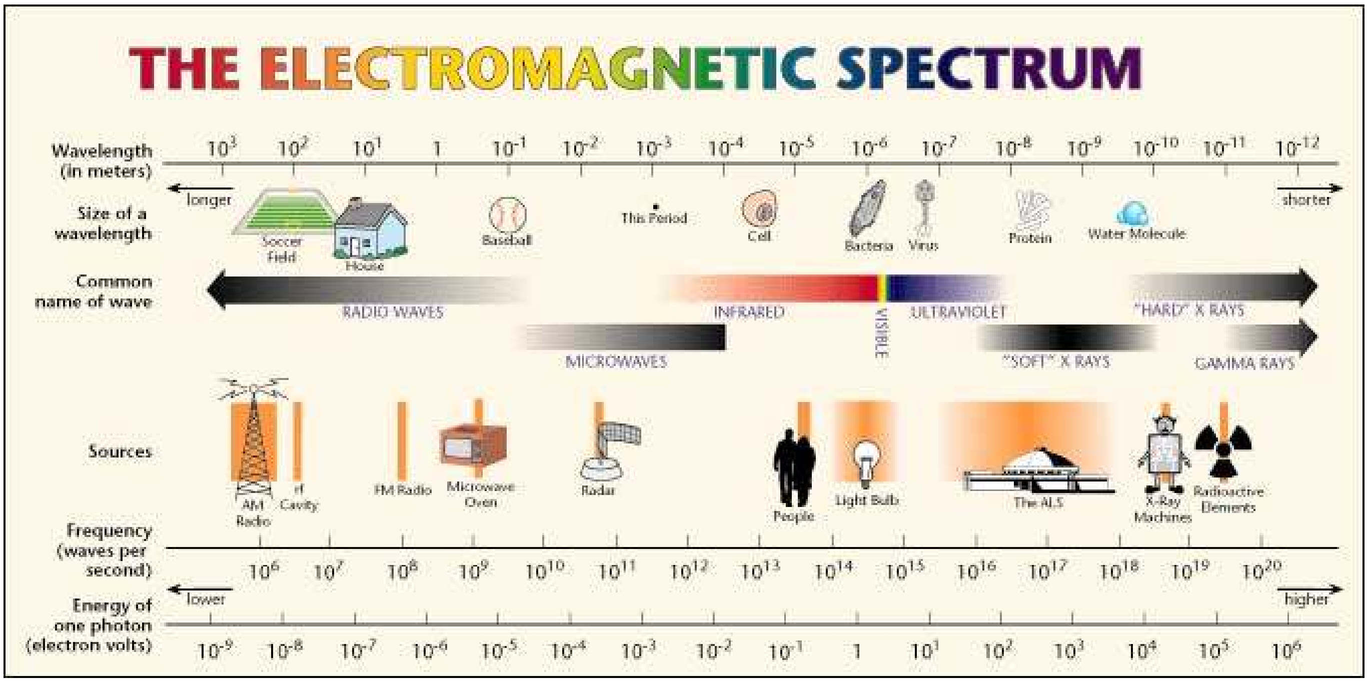
Introduction to Radio Astronomy

What is Radio?
Radio is part of the Electromagnetic Spectrum (EM) along with Light.

The Electromagnetic Spectrum
Whenever an electric charge changes speed or direction it gives off an electromagnetic (EM) wave. How fast the wave 'wiggles' determines what kind of EM radiation is created. EM can be placed in order from lowest energy to highest energy as follows: Radio, Infrared, Visible Light, Ultraviolet, X-Rays, and Gamma Rays. The chart below also shows Frequency and Wavelength as well as Energy. These three are related through two equations: $f=c/\lambda$ and $E=hf$ (f=Frequency; c=speed of light (~300,000km/sec); λ=wavelength; E=energy; h= Planck's constant (~6.626×10^{-34} Joules·sec)). The equations show that as the energy increases, the wavelength decreases and the frequency increases.



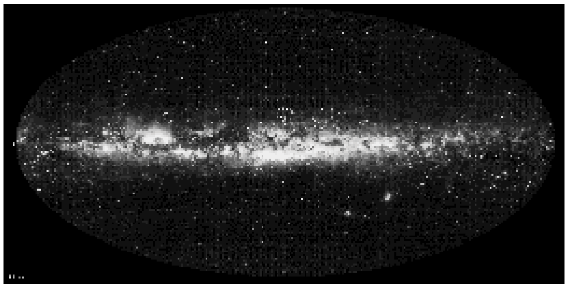
http://son.nasa.gov/tass/images/cont_emspec2.jpg

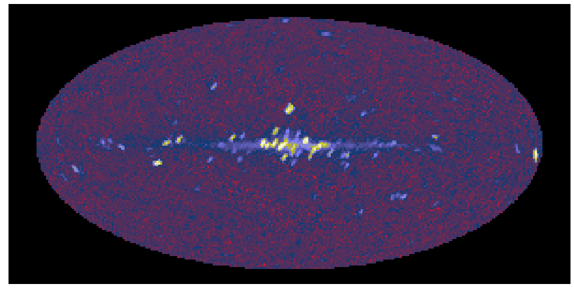
EM vs. Sound
What are the differences between these two?

- Sound is longitudinal (travels with the wave direction) while light is transverse (travels perpendicular to the wave direction).
- Sound travels at about 1,100 ft/sec while light travels at about 186,000 miles/sec.
- Sound travels only in matter while light can travel through a vacuum.
- Sound is vibrating matter while light is vibrating electrons.

The EM Spectrum and Objects You Can See With It
As the picture below shows, many objects are viewed better in different types of electromagnetic (EM) radiation. Remember that the higher up in the picture you go, the more energetic the object has to be. Therefore, cooler objects will be near the bottom while really 'hot' objects will be near the top. Remember that all pictures that are not visible light are representations in false color (i.e.: made so we can see them as if we could see that frequency of the electromagnetic spectrum).

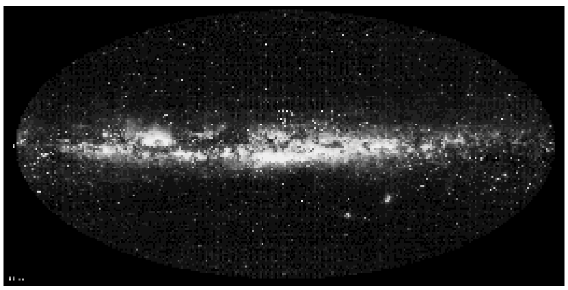
The EM Spectrum - X-Rays

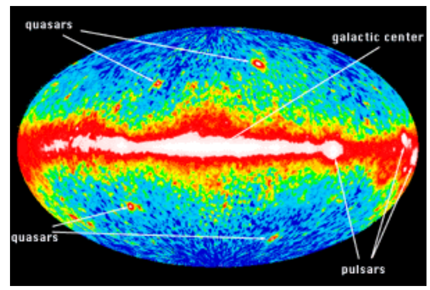




These two pictures show the Milky Way galaxy in visible light (left) and X-Rays (right). X-Ray radiation is used to view very hot objects. You can see the galaxy clearly in both pictures but using the X-Ray image we can now see very energetic objects that are invisible to our eyes and optical telescopes. Note that not all of these objects are within the plane of the galaxy (majority of mass is oriented horizontally in this view).

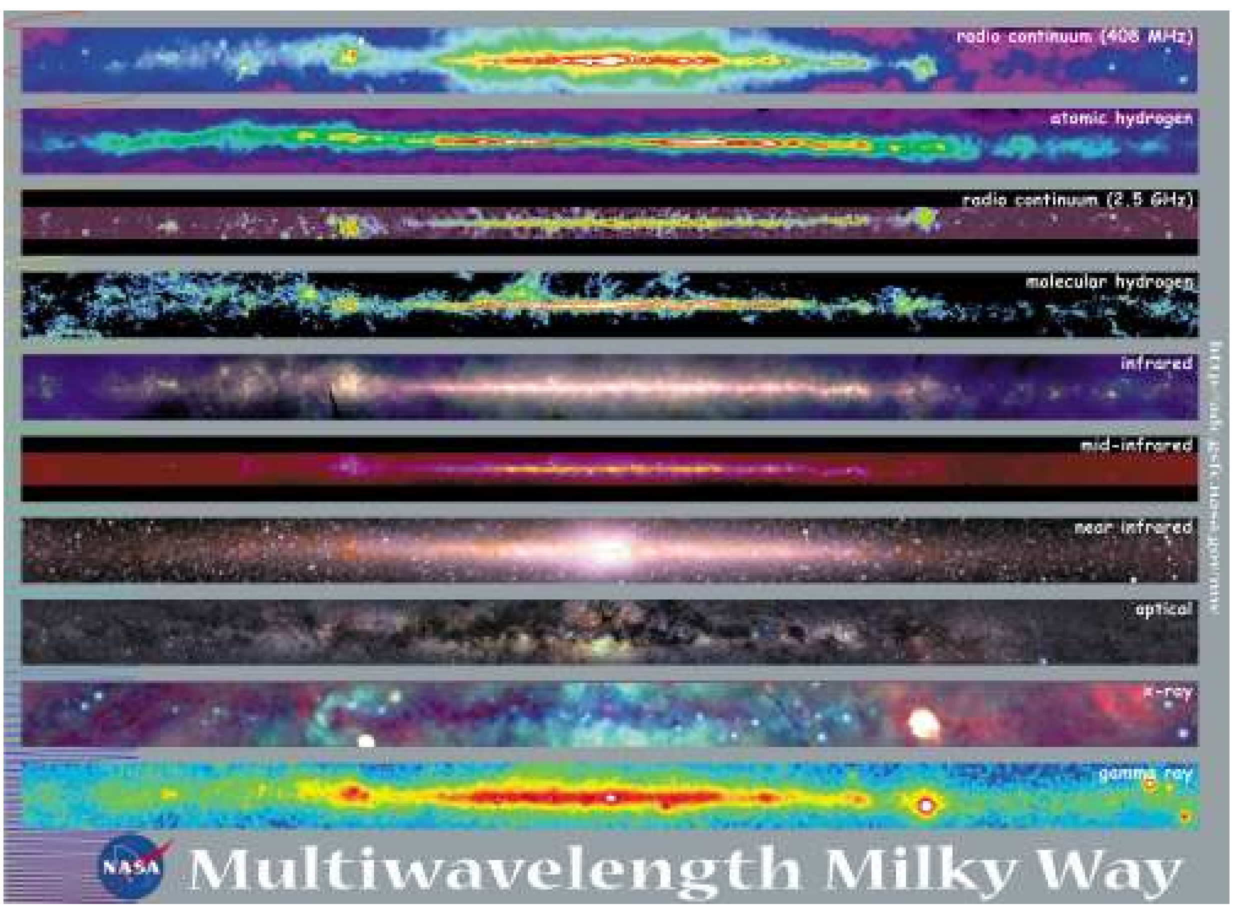
The EM Spectrum-Gamma Rays





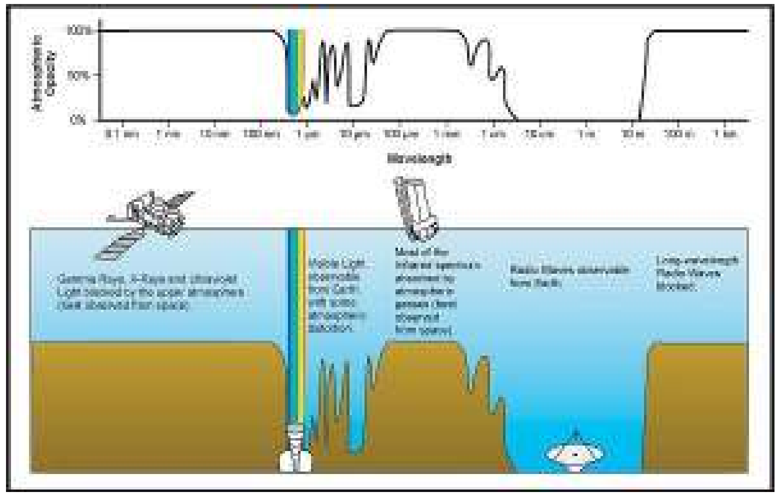
These two pictures show the Milky Way galaxy in visible light (left) and Gamma Rays (right). Gamma Ray radiation is used to image the most energetic objects. You can see the galaxy clearly in both pictures but using the Gamma Ray image we can now see the most energetic objects in our part of the universe that are invisible to our eyes and optical telescopes. Note that not all of these objects are within the plane of the galaxy.

Milky Way Galaxy at Different Wavelengths



Why Radio?
Wavelengths Available From Earth

As you can see from the picture to the right, only light and radio are readily available from Earth's surface (a few wavelengths of IR are as well). If you want to observe from Earth's surface, you need optical or radio telescopes. Also note that radio offers at least 100 times more observable wavelengths than optical.



Picture from: ipac.jpl.nasa.gov/media_images/large_jpg/background/transgraph_colorized.jpg

What Causes Radio Emissions?

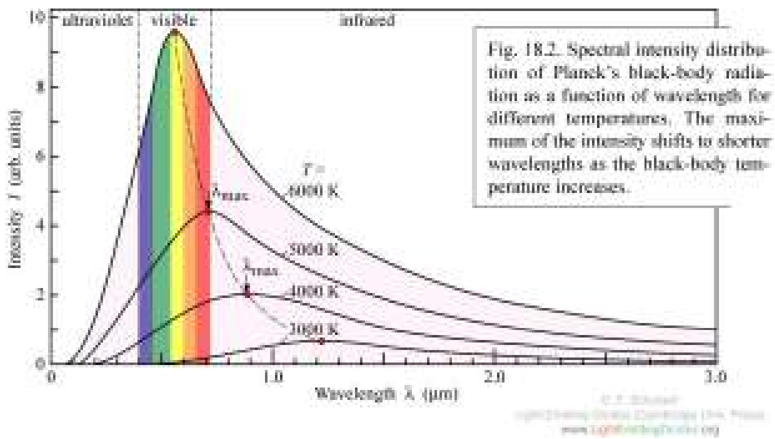
I. Thermal Radiation

All objects with a temperature emit radiation in proportion to their absolute temperature (more accurately - proportional to T^4). Thermal Radiation is the most basic form of EM radiation. There are three types of thermal radiation observed:

- Blackbody
- Free-Free
- Spectral Line

Blackbody Radiation and Temperature

The radiation given off by any object is related to its temperature. The lower the temperature, the lower the energy or frequency of radiation given off and vice versa. A blackbody is a theoretical object that completely absorbs all of the radiation that hits it, and reflects nothing. The object reaches a stable temperature and re-radiates energy in a characteristic pattern (spectrum). The spectrum peaks at a wavelength that depends only on the object's temperature.

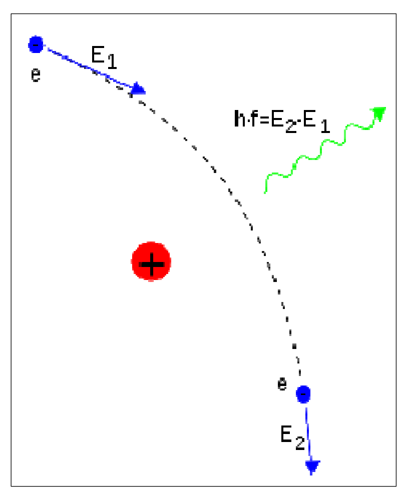


Picture from: www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap18/F18-02%20Planck%20black%20body.jpg

Free-Free Thermal Radiation

Another form of thermal emission comes from gas which has been ionized. Atoms in the gas become ionized when their electrons become stripped from the atom. This results in charged particles moving around in the ionized gas. As this happens, the electrons are accelerated by the charged particles, and the plasma emits radiation continuously. This type of radiation is called "free-free" emission or "bremsstrahlung".

Some sources of free-free emission in the radio region of the EM spectrum include ionized gas near star-forming regions or Active Galactic Nuclei (AGN).

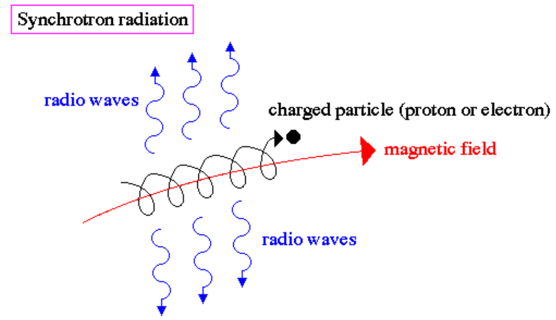


Picture from: en.wikipedia.org/wiki/File:Bremsstrahlung.svg

Spectral Line Thermal Radiation
Spectral line emission involves the transition of electrons in atoms from a higher energy state to lower energy state. When this happens, a photon is emitted with the same energy as the energy difference between the two levels. The emission of this photon at a certain discrete energy shows up as a distinct "line" or wavelength in the EM spectrum.

Non-Thermal Radiation
Non-thermal emission does not have the characteristic curve of blackbody radiation. It turns out to be the opposite, with radiation increasing at longer wavelengths.
There are 2 basic types:

- Synchrotron (see picture at right for explanation)
- Maser



synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field

Picture from: http://abyss.uoregon.edu/~js/images/synchrotron.gif

Synchrotron radiation is caused by a charged particle spiraling around a strong magnetic field line and emitting radio signals. (A similar radiation is cyclotron radiation which occurs when the field and particle values remain constant – rare in astronomy). This occurs at Jupiter and many other objects in the sky such as galaxies and black holes.
Masers are naturally occurring stimulated radiation at a single frequency associated with a particular chemical such as water, hydroxide (OH) and many others. They are generated in much the same way that lasers are. Atoms are forced into excited energy states and can amplify radiation at a specific frequency. These atoms are placed in a chamber that creates feedback and produces coherent radiation (all one frequency of radiation – like a laser). Objects that may have masers in them range from comets, planetary atmospheres, stars, nebulae, supernova remnants and galaxies.

Noise and its Nature
There are several sources of noise in radio astronomy. First, there is the noise associated with objects in space. Any object will emit EM radiation at varying intensities and frequencies therefore generating a random noise background level. Second, there are man-made signals which bleed into our frequencies of interest. Anyone who has attended the SARA Conference and met Wes Sizemore knows about NRAO's efforts to rid themselves of interference from electric blankets, cell phones, laptops, digital cameras and the like. Third are the electronic noise sources brought about by quantum fluctuations within chips and other electronics.
In many radio astronomy observation programs, the signal is many times smaller than the background noise and the signal must be detected using a variety of techniques (see chart on right). These include using a larger antenna to gather more signal, longer integration times (averaging of data), extensive filtering and data processing strategies, cooling of electronics, etc.

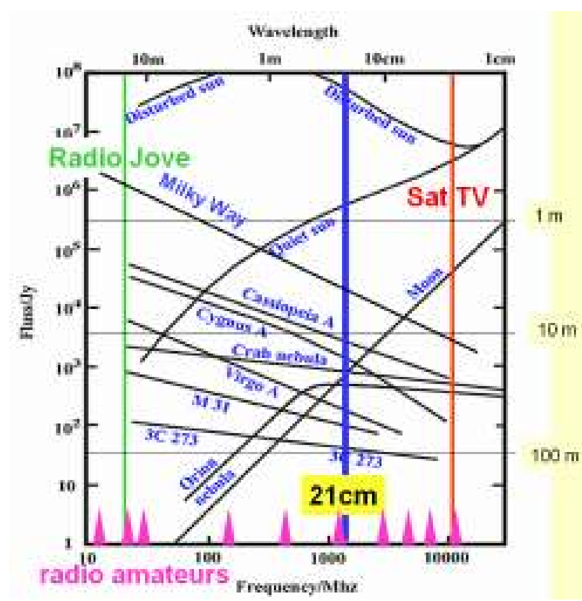


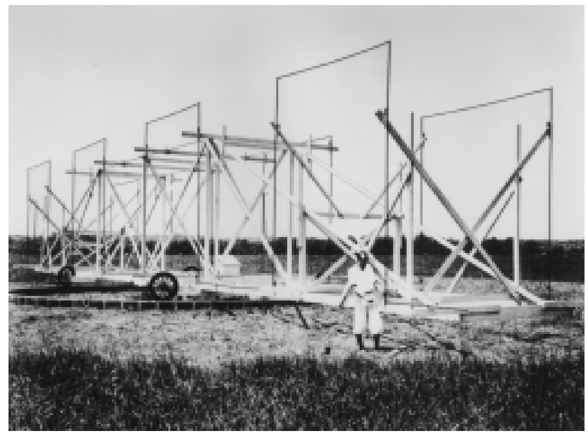
Chart from: astro.u-strasbg.fr/~koppen/Haystack/basics.html

How Was Radio Astronomy Discovered? (Pictures in this section from the NRAO website)

Karl Jansky – 1905-1950

Karl Jansky joined the staff of the Bell Telephone Laboratories in Holmdel, NJ, in 1928. Jansky had the job of investigating the sources of static that might interfere with radio voice transmissions at "short wavelengths" (wavelengths of about 10-20 meters). These wavelengths were being considered for transatlantic radio telephones. After recording signals from all directions for several months, Jansky identified three types of static:

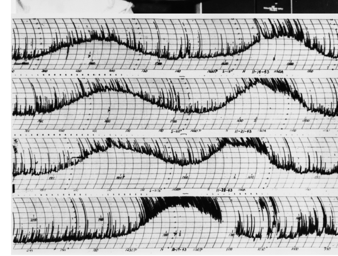
- nearby thunderstorms
- distant thunderstorms, and
- a faint steady hiss of unknown origin.



Jansky spent over a year investigating the third type of static. It rose and fell once a day, leading Jansky to think at first that he was seeing radiation from the Sun. The signal repeated not every 24 hours, but every 23 hours and 56 minutes (sidereal time – the motion of the stars). This is characteristic of the fixed stars, and other objects far from our solar system. He eventually figured out that the radiation was coming from the Milky Way and was strongest in the direction of the center of our Milky Way galaxy, in the constellation of Sagittarius. The discovery was widely publicized, appearing in the New York Times of May 5, 1933. Jansky wanted to follow-up on this discovery but Bell Labs did not. Although fascinated by the discovery – no one investigated it for several years.

Grote Reber – 1911-2002

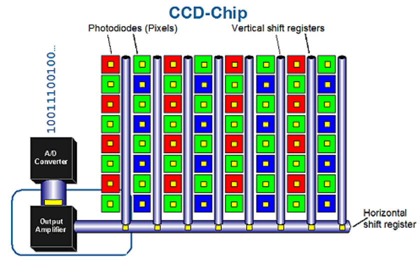
Grote Reber learned about Karl Jansky's discovery (1932) of radio waves from the Milky Way Galaxy and wanted to follow up this discovery and learn more about cosmic radio waves. Reber built a parabolic dish reflector in his backyard in Wheaton, IL in 1937 because this shape focuses waves to the same focus for all wavelengths. Reber spent long hours every night scanning the skies with his radio telescope. He had to do the work at night because there was too much interference from the sparks in automobile engines during the daytime. After two failed attempts he finally succeeded with a receiver at 160 MHz (1.9 meters wavelength) to detect radio emissions from the Milky Way. In the years from 1938 to 1943, Reber made the first surveys of radio waves from the sky and published his results both in engineering and astronomy journals, ensuring radio astronomy's future.



For more on the history of radio astronomy check out the history section of the NRAO's website: www.nrao.edu/index.php/learn/radioastronomy/radioastronomyhistory

Imaging: Radio vs. Optical

Optical Imaging



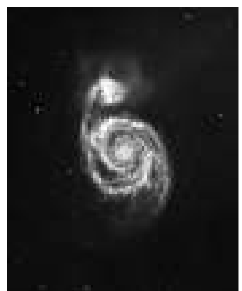
Picture from: www.axis.com/edu/axis/images/ccd.gif

Images taken on modern optical telescopes use CCD cameras (digital cameras) which use millions of dots (pixels) to represent the data. Photodiodes collect light energy and convert these to voltages which are downloaded by row and column to maintain their position information and allow the re-construction of the image. Pixels are obvious in the image below. One optical image contains millions of pixels – all captured at the same time! They become more noticeable at higher magnifications and lower resolutions. (See picture to left)

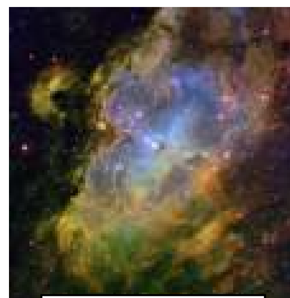
Below are some examples of digital astronomy images taken with a CCD camera (note: all recent astrophotography have been done with CCD cameras).

Picture from: photo.net/equipment/digital/basics/pixels.jpg

Solar Flare



M 51 Galaxy



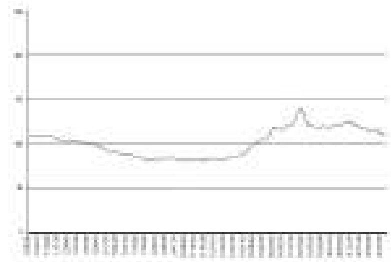
Eagle Nebula

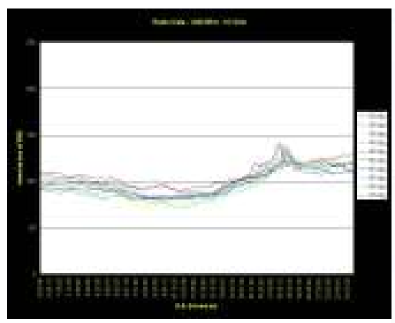
M 13 Globular Cluster

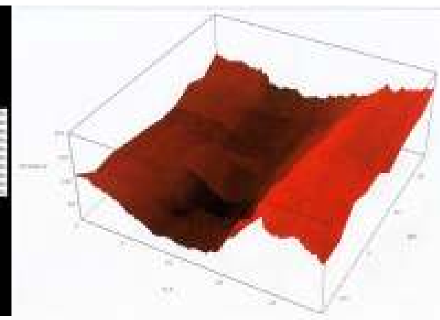
Pictures from www.noao.edu/image_gallery

Radio Imaging

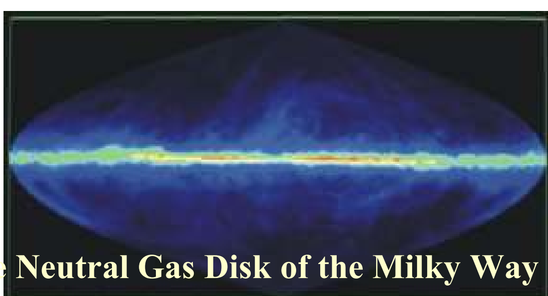
In contrast, radio telescopes can only collect one pixel at a time! Each radio image is a composite of many data collections. Each image take hours, days, or even years! (One full sky image of an amateur's back yard sky could take years!). A big advantage of professional radio astronomy imaging is angular resolution (the ability to separate two different objects). Professional radio telescopes (the VLBI – Very Long Baseline Interferometry) can observe much smaller than a milliarcsecond (This is the angle a hair makes at 10 miles!) whereas, optical telescopes can resolve only to 5 milliarcseconds with the Keck Telescope. Radio telescopes can resolve better because you can simulate much larger radio telescopes by linking many radio telescopes together. Their effective size is based on the diameter of the farthest linked telescopes! On the other hand, an amateur can only achieve expect to achieve at best a few degrees of resolution due to our small antenna size. For example, a 10' dish observing at 1.42 GHz would have a resolution of about 4-5 degrees. Below left is an example from an amateur radio telescope's data showing a 24 hour drift scan of detected voltages made up of thousands of pixels. (One pixel every 10 seconds – this time is called integration time). To make this chart, the radio telescope is locked in position and the sky rotates by. As objects enter the antenna's view (beam), their energy (detected voltage) increases compared with the background sky and peaks are recorded (See the twin peaks of the Milky Way galaxy's core ¾ of the way through the chart). When enough single charts have been collected they can be combined to get a multiple chart. When all charts are put together, they can be assembled into an image (middle picture below). The far right picture shows the same data in image form using black (low intensity) and red (high intensity).





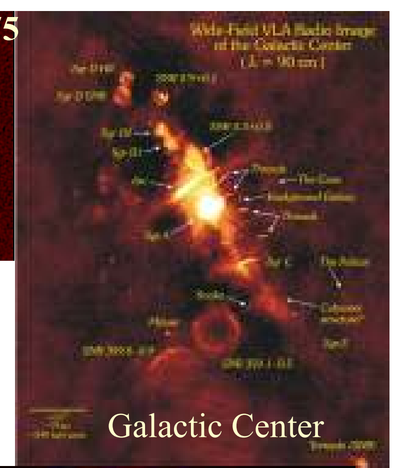


Professional Radio Images

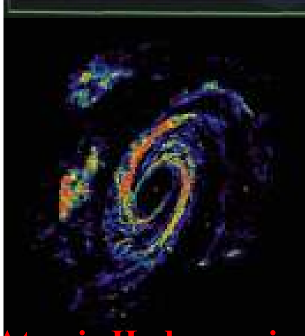


The Neutral Gas Disk of the Milky Way

Radio Quasar 3C175



Galactic Center



Atomic Hydrogen in M81

Radio Galaxy 3C288

Saturn

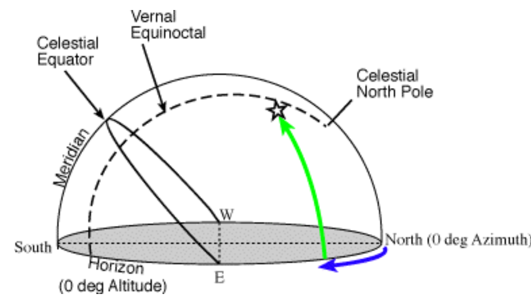
Images from: www.nrao.edu/imagegallery/php/level1.php

Locating radio objects in the sky (RA and DEC)

To share information with others, a reference system must be adopted. The system used by astronomers is the celestial coordinate system. After years of teaching that the night sky is not a sphere that rotates around the earth, it is ironic that this is what we are going to envision for our coordinate system. Since both the surface of the earth and the celestial sphere are surfaces of spheres (or nearly so) we can define any point on those surfaces with two coordinates. In nearly the same way that we use Longitude and Latitude to find a point on the surface of the earth, we use Right Ascension (RA) and Declination (DEC) to find objects on the celestial sphere.

Azimuth and Altitude

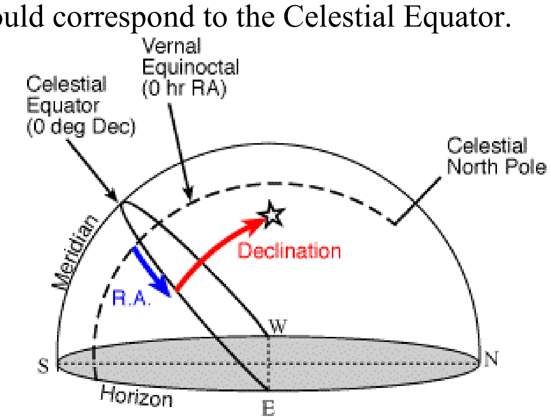
If you were to go out tonight and try to show someone the 'Big Dipper' you'd probably point to the object and use Azimuth and Altitude. Azimuth is the angle around the horizontal from due north and running clockwise. It corresponds to the compass directions with 0 degrees representing due North, 90 degrees due East, 180 degrees due South, and 270 due West. Altitude is the height of the object, in degrees above the horizon. Altitude can range from 0 degrees (on the horizon) to 90 degrees (directly overhead). A good approximation of these to use at night is your hand at arm's length. Your whole hand (thumb through pinky) is about 10 degrees and each finger is about 2 degrees. Although Altitude and Azimuth are useful for observing at night and showing others constellations and other objects, it is not helpful for us. This is because none of us are at the exact same latitude and longitude and so my altitude and azimuth information for the 'Big Dipper' would be different for you. Also, as the object rises and sets, it changes position in the sky. (See picture above)



Graphic used by permission from Dr. Jim McDonald

Right Ascension and Declination

As I mentioned above, Right Ascension (RA) and Declination (DEC) are similar to longitude and latitude. If you picture the earth's North Pole projected into the sky this would correspond to the Celestial North Pole. And if you project the earth's equator into the sky this would correspond to the Celestial Equator. The longitude lines on a celestial sphere are called Right Ascension. Right Ascension is measured on the celestial equator in an easterly direction. Instead of measuring in degrees though, it is measured in hours, minutes, and seconds. A full rotation corresponds to 24 hours, roughly the time it takes for the sphere to rotate once around. Each hour of right ascension is about 15 degrees on the celestial sphere. The Right Ascension of 0 hours occurs on the Vernal Equinox (first day of spring – equal day and night – 12 hours each). Declination corresponds to latitude and is measured in degrees above or below the celestial equator. An object above the celestial equator has a positive declination; an object below the celestial equator has a negative declination. Since this coordinate system is relative to fixed objects in the celestial sphere, the Right Ascension and Declination do not change and can be shared with anyone on the earth. (See picture above)



Graphic used by permission from Dr. Jim McDonald

Practical Applications/Examples

Optical:

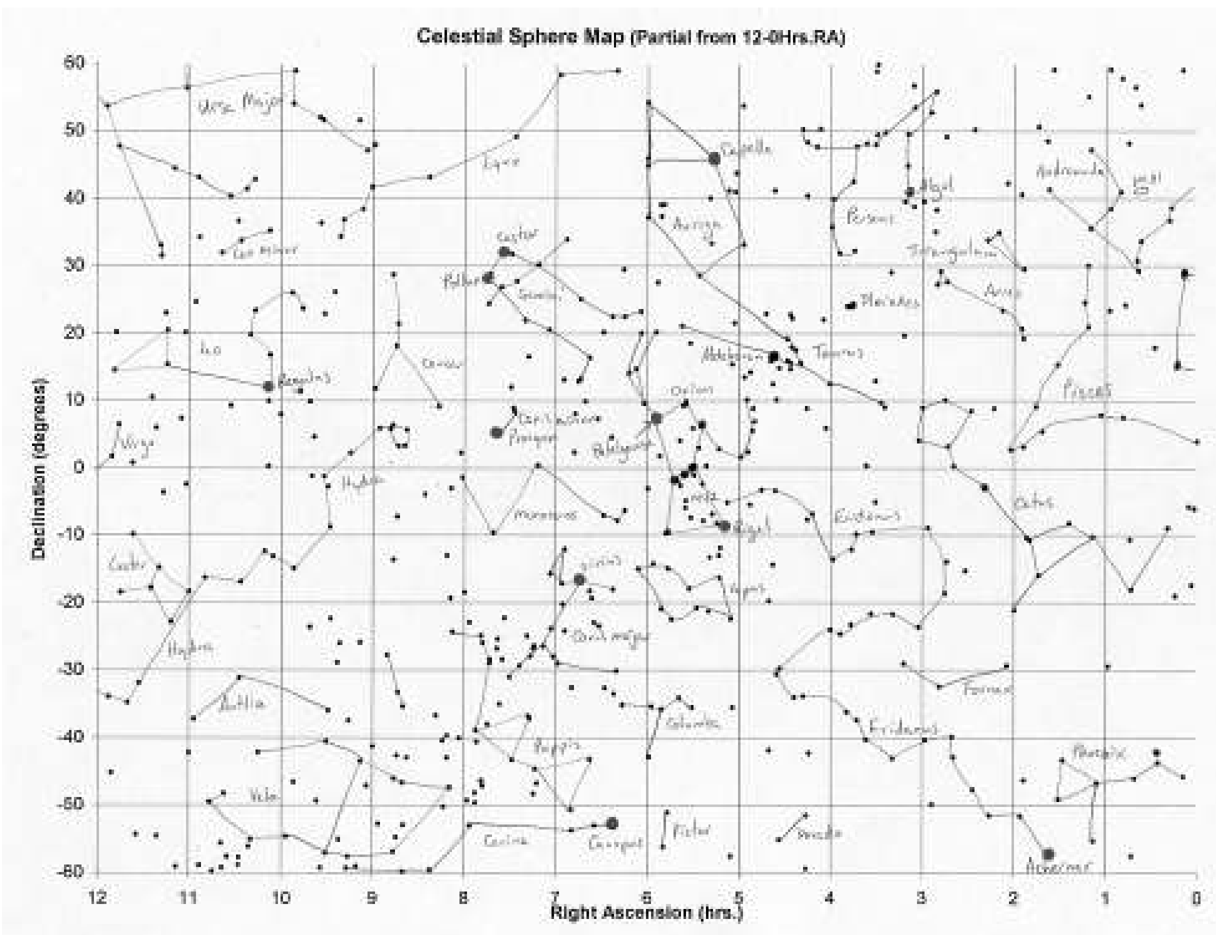
Now that we have a working knowledge of celestial coordinates, let's take a look at how to use them by looking at a portion of an optical sky map and do a few examples. Use the chart below to answer the following questions.

Find the star name and the constellation for the following:

Star #	RA	Dec	Star Name	Constellation
1	6:43	-17		
2	7:43	+28		
3	5:53	+07		

Find the RA and Dec for the following stars:

Star #	RA	Dec	Star Name	Constellation
4			Castor	Gemini
5			Capella	Auriga
6			Rigel	Orion



The answers are as follows:
Star #1 = Sirius, Canis Major
Star #2 = Pollux, Gemini
Star #3 = Betelgeuse, Orion
Star #4 = 7:30, +32
Star #5 = 5:14, +46
Star #6 = 5:13, -08

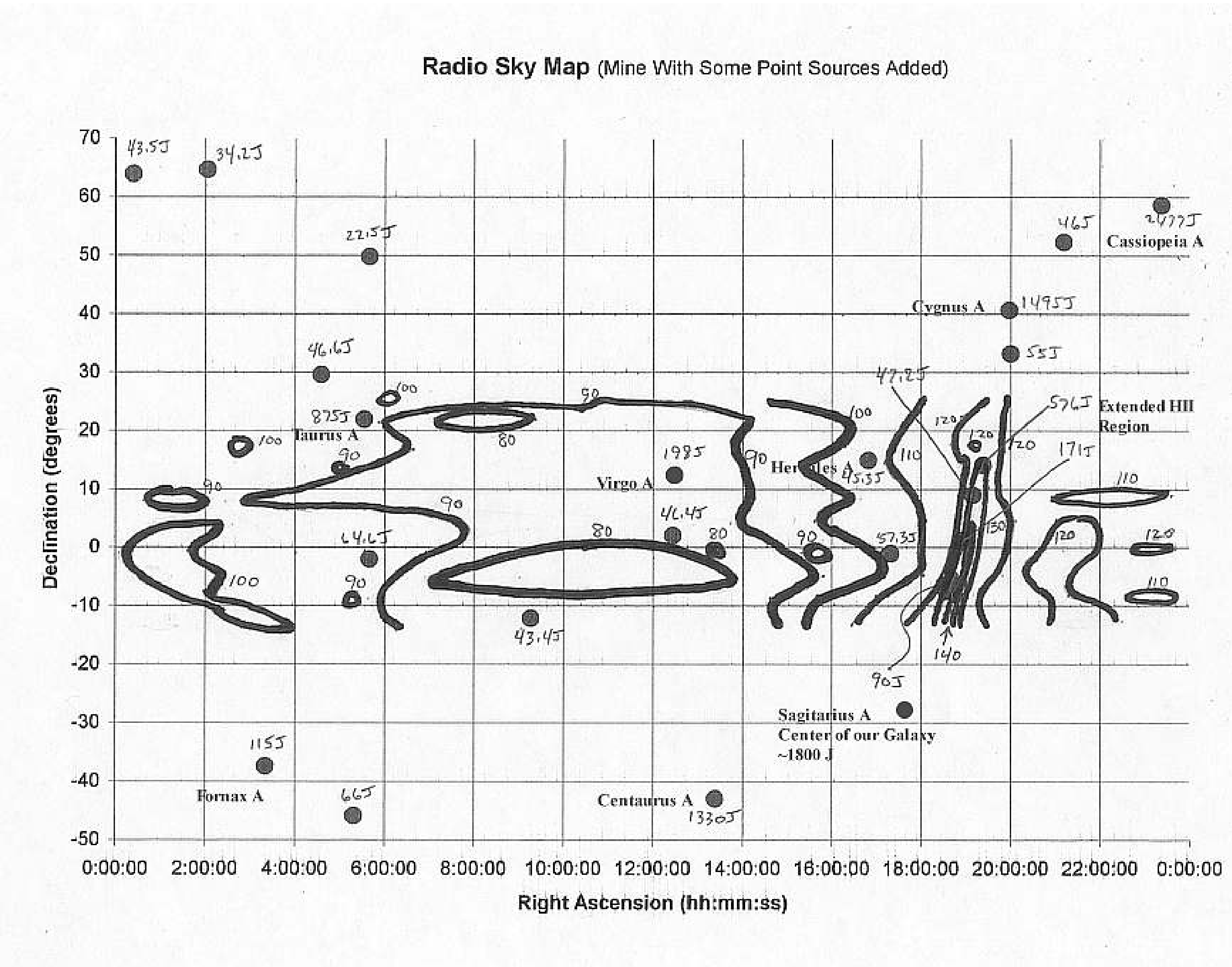
***Radio**:*

Below is a map I made of my observations with some point sources from charts with their flux in Janskys. Try the following examples:

#1) You find a large peak at 05:33:00 RA, +21:59:00 Dec - What object is it?

#2) You find a small peak at 16:49:00 RA, +15:02:00 Dec - What object is it?

#3) You find a large peak at 12:29:00 RA, +12:31:00 Dec - What object is it?



Answers to Radio Examples:
#1 Taurus A
#2 Hercules A
#3 Virgo A