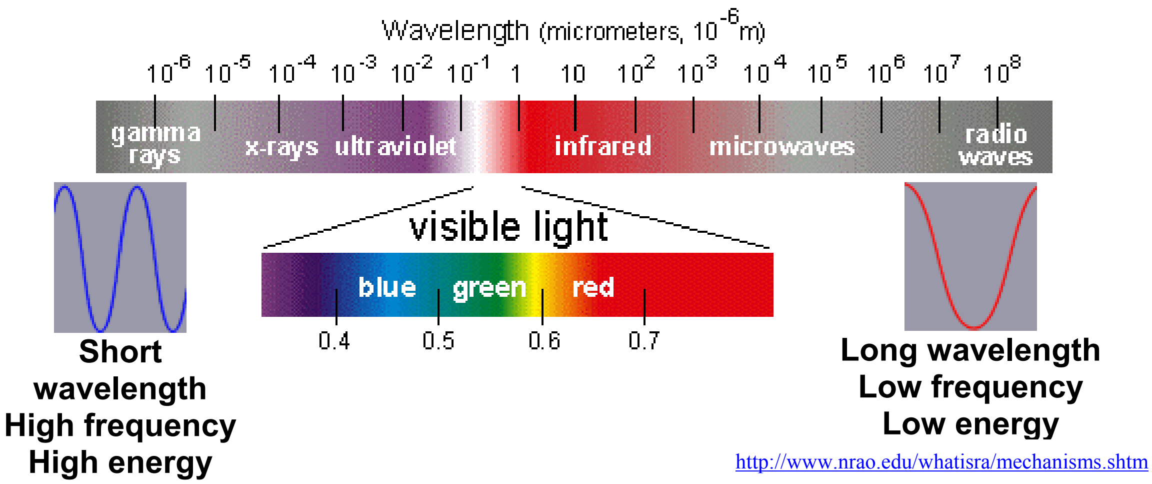
RESEARCH BACKGROUND ON RADIO ASTRONOMY

Electromagnetic Radiation

Energy from the sun and other radio stars or areas of the universe studied in radio astronomy is referred to electromagnetic radiation and is caused from the emission and acceleration of charged particles from a source through electrical and magnetic fields. These particles are characterized by different wavelengths (λ) and classified in ranges in an electromagnetic spectrum (EMS). From these different wavelengths we can also determine the frequency (v) of radiation emitted. The wavelength is the shortest distance between two corresponding points of a wave where the wave pattern repeats itself, while frequency is determined by the number of waves that pass a given point in a specific time. The unit for frequency (Hz) is named for Heinrich Hertz, an early pioneer in the study of EMS. Frequency and wavelengths are related mathematically; as the wavelength decreases the frequency and energy of the wave increase. All forms of electromagnetic waves travel at the speed of light (c) and this relationship is illustrated in the following equation

$$\mathbf{c=\lambda} \boldsymbol{v}$$

Waves from the sun that have very long wavelengths and lower frequencies studied in radio astronomy are called radio waves. As the wavelength decreases, the type of radiation defined in the EMS changes from radio waves, a type of radiation including higher frequency microwaves, to infrared, visible light, ultraviolet light, x-rays and high frequency gamma rays. While mechanical waves such as sound waves require a medium in which to travel, electromagnetic radiation travels through a vacuum in space. The following is an image of the EMS showing the range of wavelengths and how they relate to frequency and energy increases.



http://www.nrao.edu/whatisra/mechanisms.shtm

The electromagnetic waves in the EMS have special characteristics and properties. A wave is formed when photons, little packets of energy that are always moving, travel with a velocity of 3×10^{8} meters/second or the speed of light (c), and move in a perpendicular direction to the oscillation of the electrical and magnetic fields of a radiating source of energy. The atoms that comprise the energy source have electrons that spin about the nucleus in various energy levels or states. When these electrons become excited and absorb or emit energy, they move higher or lower within these energy levels that surround the nucleus of the atom. These moves are accompanied by the absorption or emission of photons. In 1905, Einstein introduced the theory of photons having dual wave-particle characteristics. A few years previously, Maxwell Planck had suggested the idea of a quantum or minimum quantity of energy that can be lost or gained by an atom. He proposed that the energy of these photons is related to the frequency and the wavelength in the following equation:

$$\mathbf{E}=h\nu \quad \textbf{or} \quad \lambda=\mathbf{c}/\nu$$

$h=6.63 \times 10^{-27}$ ergs/sec is known as Planck's constant where erg is a unit of energy

The waves in EMS can also be characterized by amplitude, which is the height or displacement of each wave from the rest or equilibrium position. As seen in the following picture, the high points of each wave motion are called crests and the troughs are the low points. Each crest or each trough is spaced one wavelength distance from the next. The shortest time interval during which a wave motion repeats itself is called the period of the wave. Wave velocity is the product of the frequency and the wavelength.

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In addition, the characteristics of waves allow two or more waves to exist in the same area at the same time. Although each wave has an individual affect in radio emissions they can be superimposed or combined in a way algebraically with different results. This is called wave interference. When the wave displacements are in the same direction, this is called constructive interference. At this point, the waves are in phase with the resulting wave exhibiting a larger amplitude than either individual wave. When two waves overlap, where the displacements are opposite but equal, the result is destructive interference and the waves are now out of phase.

Optical vs. Radio Telescopes

In years past we were only able to use optical telescopes to see objects in the EMS range of visible light, that range of wavelengths which our eye could detect, but that is only a very small portion of the entire range of electromagnetic radiation that we receive. As mentioned, radio waves have longer wavelengths that are not detected by the human eye, but can be detected by special telescopes that gather information about the phase and amplitude of the radio waves. These radio telescopes have allowed us to broaden our studies of the universe and gather additional information from various astronomical sources.

Similar to how the EMS is defined by regions of increasing wavelength, the radio region of the EMS has its own range of wavelength and frequencies that astronomers use to observe emissions from the sun and other celestial sources of radiation. In the 1930's, radio astronomers and research physicists used various letters of the alphabet to identify the different bands of radio frequency in order to maintain secrecy from the enemy about the radio frequencies they were using in developing radar technology for the military. Common radio band names with their wavelength and frequency counterparts are shown in the illustration below.

Band	**Wavelength**	**Frequency**
P-band	90 cm	327 MHz
L-band	20 cm	1.4 GHz
C-band	6.0 cm	5.0 GHz
X-band	3.6 cm	8.5 GHz
U-band	2.0 cm	15 GHz
K-band	1.3 cm	23 GHz
Q-band	7 mm	45 GHz

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Radio telescopes operate in a band of frequency that correlates to the wavelength of incoming radio waves. Since the radio waves have a much greater wavelength than visible light, radio telescopes are designed to collect as much energy as possible and therefore are much larger. Radio telescopes do not have a lens to focus the shorter wavelengths of light, but instead use a parabolic shaped dish or *reflector* to collect and reflect the longer radio waves or power toward a *subreflector* situated close to the prime focus which directs the radiation to a *feed* at the center of the reflector. A receiver behind the feed amplifies the signal and detects the appropriate range of frequency. Next, a computer processes the signal in such a way that it remains in direct proportion to the strength of the radio waves detected. The image produced is a true representation then of the incoming radio waves detected by the reflector.

Another reason radio telescopes are much larger than optical telescopes is related to angular resolution, the angular area of the sky where the radio waves from sources can be detected which is proportional to the wavelength divided by the antenna's diameter.   The larger telescopes allow for greater sensitivity and resolution, making them able to detect fainter objects in the sky or distinguish between two objects close together.

In optical telescopes, the wavelengths, which can be detected from the ground are limited to a size of about 4 cm, while radio telescopes allow detection of much larger wavelengths, however the resolving power of radio telescopes becomes less. We compensate in radio astronomy by using telescopes or a combination of telescopes with larger diameters like the Very Large Array near Magdelena, New Mexico, or even larger interferometers like the Very Large Baseline Array, (VLBA) that includes other telescopes with the VLA to make an even larger interferometer.

Thermal and Non-Thermal Emission

The mechanism for the way that sources emit electromagnetic radiation can be generally classified as either thermal or non-thermal forms of emission. As expected, thermal emission is dependent on the temperature of the emitting source and includes blackbody radiation, free-free emission and spectral line emission. Blackbodies are objects that have a temperature above absolute zero[1] and emit wavelengths in the EMS dependent on their temperature. Cooler objects around 1000 Kelvin emit wavelengths more in the infrared region of the EMS, while hotter objects, like stars, emit mostly visible light. Extremely hot objects like white dwarfs emit high frequency ultraviolet radiation. Free-free emission and spectral line emission are also a result of the transition or movement of electrons from higher energy levels to lower levels, but in a somewhat different fashion than blackbodies. The source of energy in the sun stems from nuclear fusion with hydrogen being converted in a multi-step reaction to helium resulting in temperatures that range from more than 5000 K to over 10,000 K.

Non-thermal emissions are a result of charged particles moving in a magnetic field, which also causes the electron to accelerate and change direction as they spiral around the field. The frequency of the emission is related to the velocity of the electrons traveling near the speed of light. Non-thermal forms of emission include synchrotron emission from supernova remnants, quasars, or active galactic nuclei (AGN), and gyrosynchrotron emission emitted by pulsars, which are a result of the death of massive stars as they run out of fuel and their cores begin to collapse. Masers (microwave amplification by stimulated emission of radiation) are a third form of non-thermal emission and are intriguing objects that amplify faint emission from distant sources at specific frequencies. Masers are molecules, acting as a group like energized electrons, that become energized and move to lower energy levels emitting a photon, which in turn produces a domino effect on nearby molecules causing them to also change energy levels. In order for these masers to return to their original energy state, they rely on outside energy sources like a star to provide the energy to enable their move. Groups of molecules identified to act like masers include the hydroxyl radical (OH), water, methanol, formaldehyde, silicon oxide and ammonia.

Sensitivity and Resolution

As mentioned earlier, in order to observe objects that are often very small and/or that are very faint, astronomers need to maximize the light gathering power and resolving power of the telescope. If one increases the collecting area of a dish, one can increase the amount of radiation that is focused onto the receiver, thus enhancing the sensitivity of the telescope. To make accurate measurements one must be able to distinguish objects. The ability to distinguish objects is called the telescope's resolution and this also depends on the linear size of the collector. This relationship is given by

$$\Theta = \frac{\lambda}{D}\text{, where }\theta\text{=angle between sources and D=diameter of the dish}$$

To achieve an increase in the sensitivity and resolution of a telescope one can build bigger dishes – up to a limit. Due to structural limits, telescopes can only be built up to a few hundred meters or so. The larger the size of a telescope presents many challenges, especially if one wants to move or redirect a telescope to observe different parts of the sky. The largest radio telescope is the Arecibo telescope in Puerto Rico, which is 308 m in diameter.