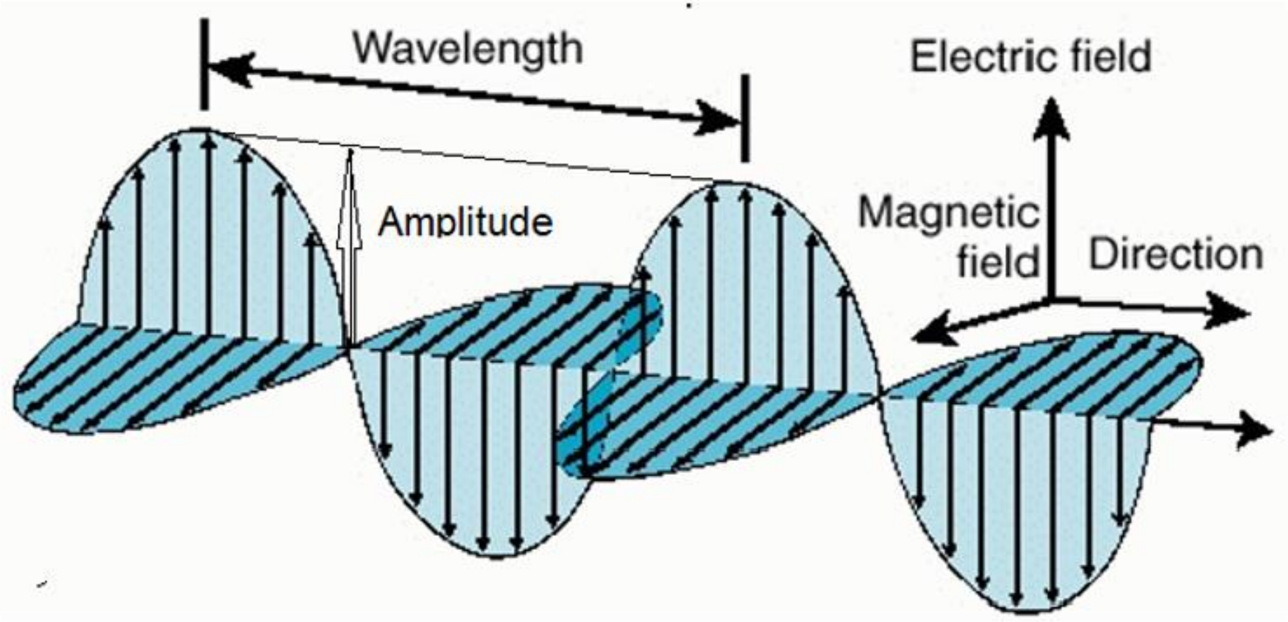
Astronomers study celestial sources such as stars, planets, galaxies and nebula by studying their electromagnetic (EM) energy emissions

Infrared image of Carina nebula taken using ESO’s VLT

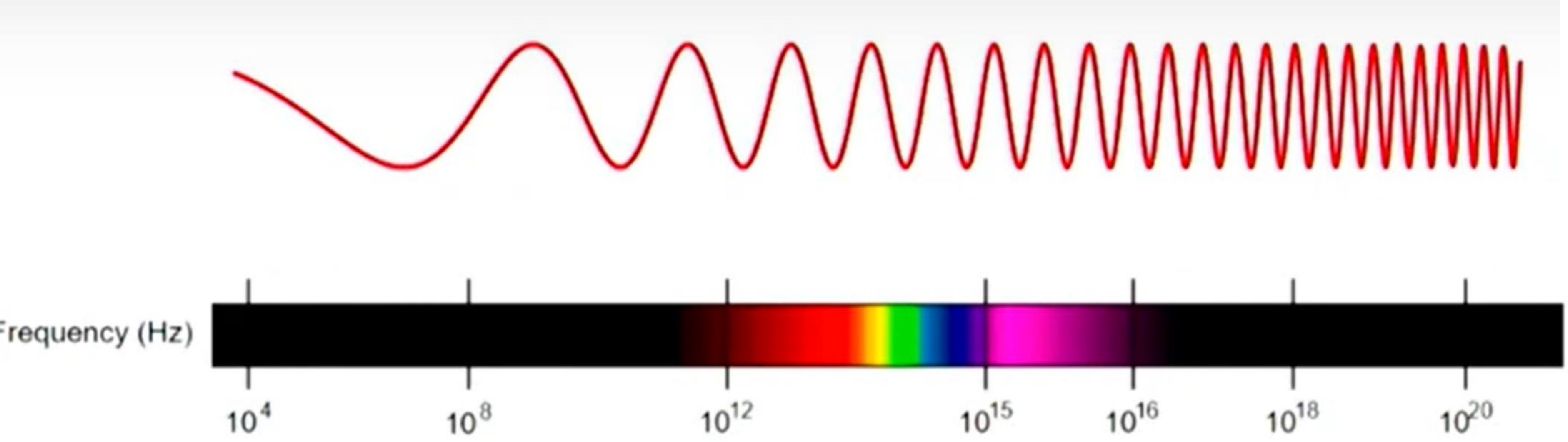
An electromagnetic wave



These emissions occur in the form of electromagnetic waves:
Electric and magnetic fields perpendicular to the direction of propagation

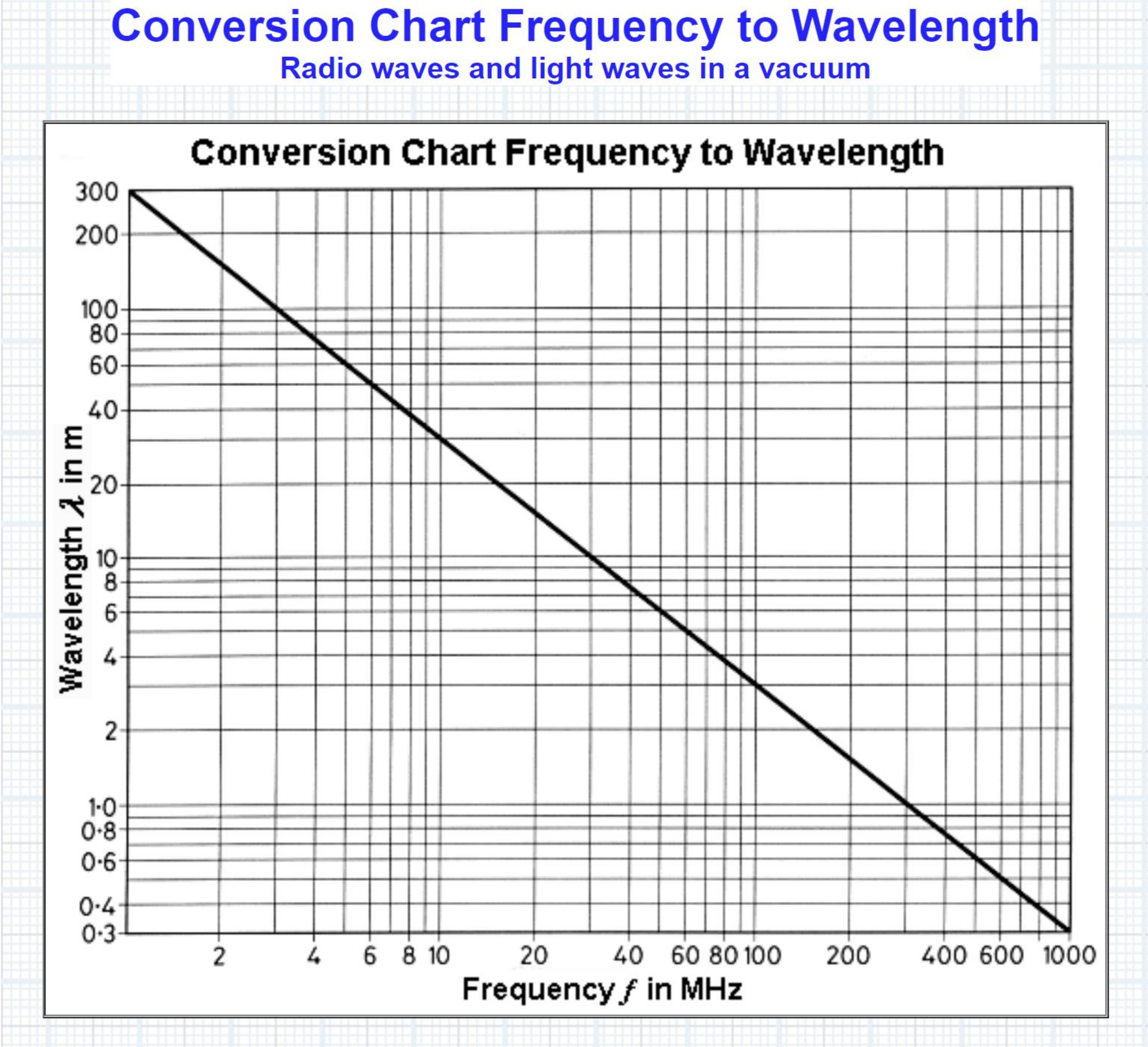
https://www.wonderwhizkids.com/conceptmaps/EM-Radiation.html

These EM waves form a continuous EM radiation spectrum

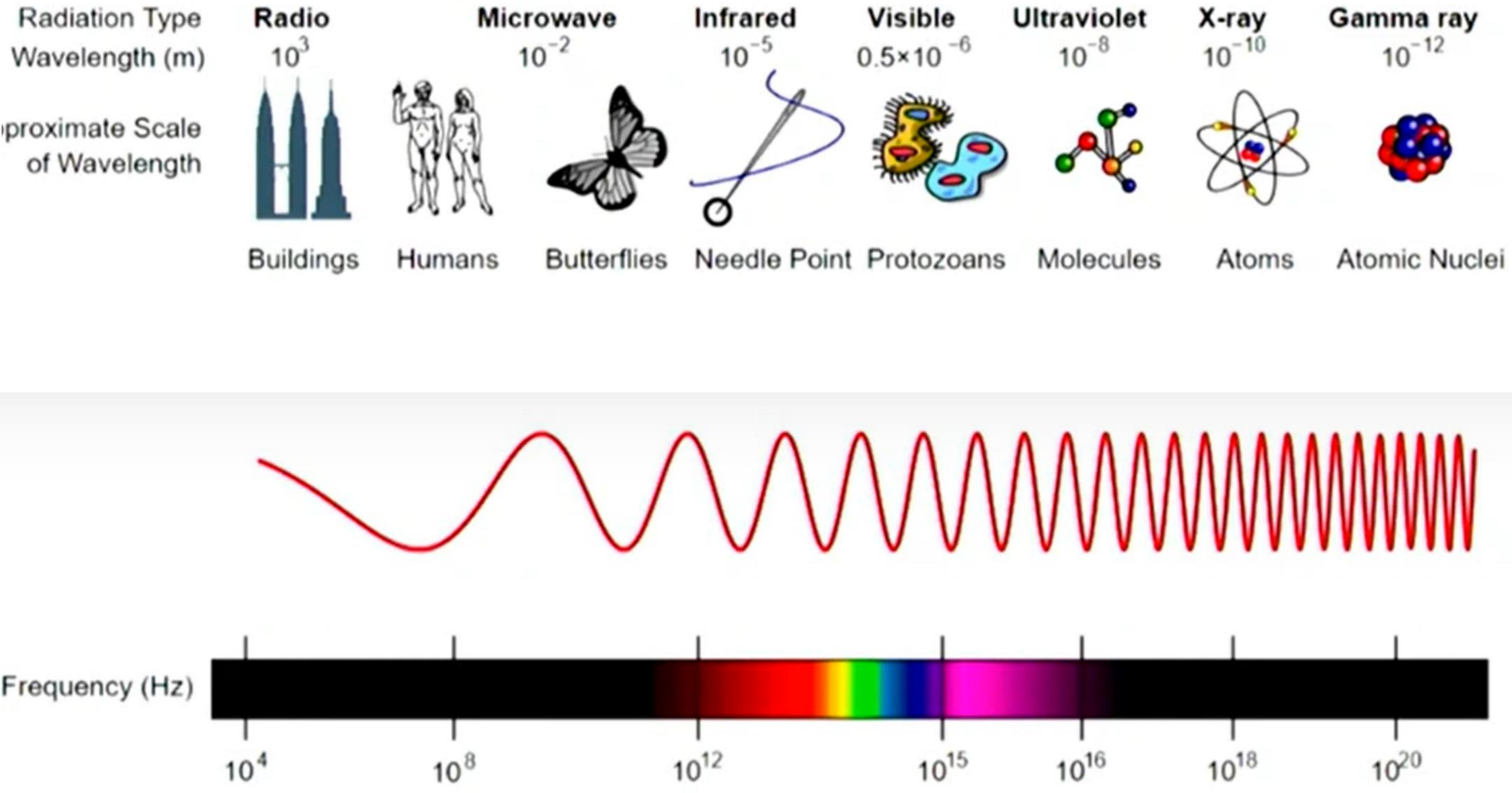


EM waves are described by either wavelength and amplitude, or frequency and amplitude. Frequency and amplitude are inversely proportional to each other; As one increases, the other decreases.

Metric Chart



We typically break this spectrum into a number of functional ranges



Radio waves

Radio waves have the longest wavelengths in the EM spectrum, according to NASA, ranging from about 1 millimeter (0.04 inches) to more than 100 kilometers (62 miles).

They also have the lowest frequencies, from about 3,000 cycles per second (Hz) or 3 kilohertz (kHz) up to about 300 billion hertz, or 300 gigahertz (GHz).

Visible Light

The visible light spectrum is in the middle of the EM spectrum frequencies in the range of visible light:

688 to 484 THz (6.88E+14 - 4.84E+14 Hz)

1 THz = 1,000,000,000,000 Hz)

wave length:

380-750 nm (0.00000038 - 0.00000075 m)

Gamma and X-rays

Gamma and X-rays are considered nuclear energy photons, in which a combination of high temperature and or pressure allows them to overcome their natural electromagnetic repulsion.

X-rays have wavelengths ranging from 0.01 to 10 nanometers, frequency ranging from 30 petahertz to 30 exahertz (31016 Hz to 31019 Hz), and energy ranging from 100 eV to 100 keV.

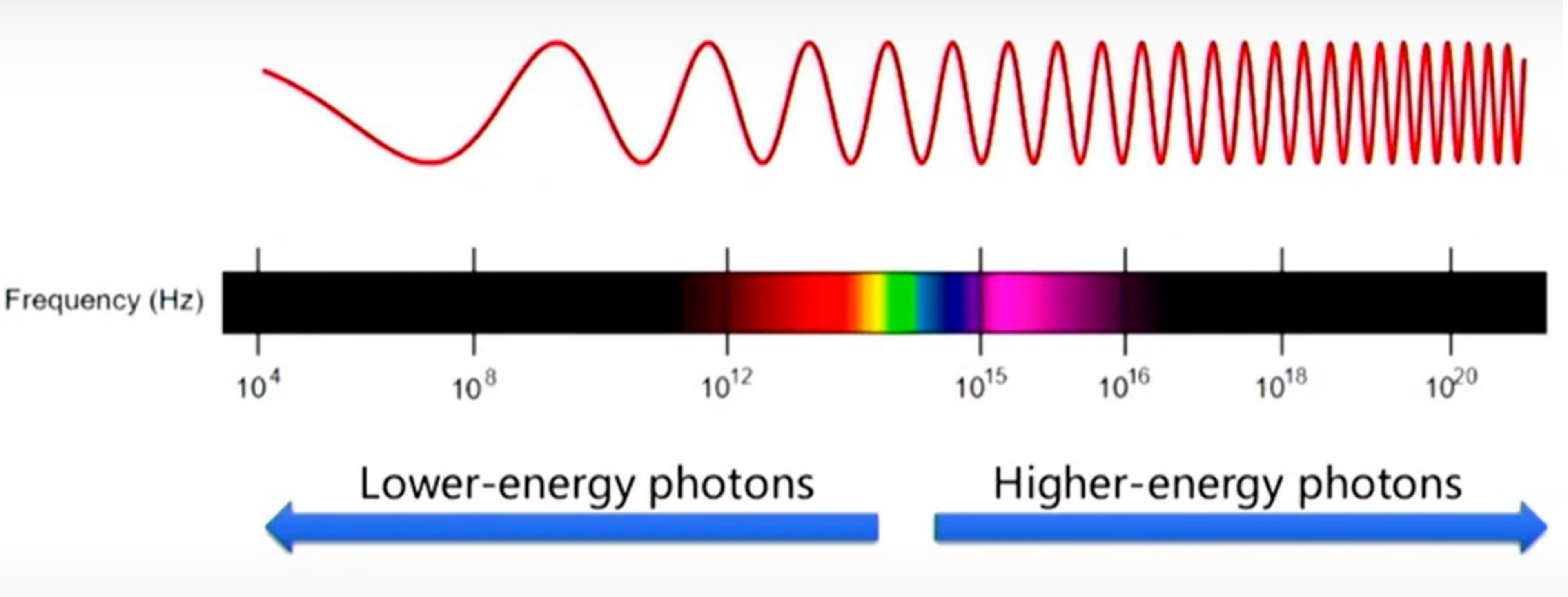
Gamma rays have wavelengths **shorter than 10^-11 meters** and frequencies above 30 x 10^18 hertz. The European Space Agency describes how gamma-ray photons have energies in excess of 100,000 electronvolts (eV).

While all EM waves are considered to consist of photons, photons are characterized by the quantum feature of wave-particle duality.

The Longer the wavelength, the more wave like the photon it is.

The shorter the wavelength, the more “particle” (photon) like it is, while

Visible light is in the middle of the spectrum, so it has both wave and particle characteristics.



Cosmic rays are not pure EM radiation; that is, they are not just photons. They are high energy particles emitted by celestial objects; the sun, stars, galaxies.

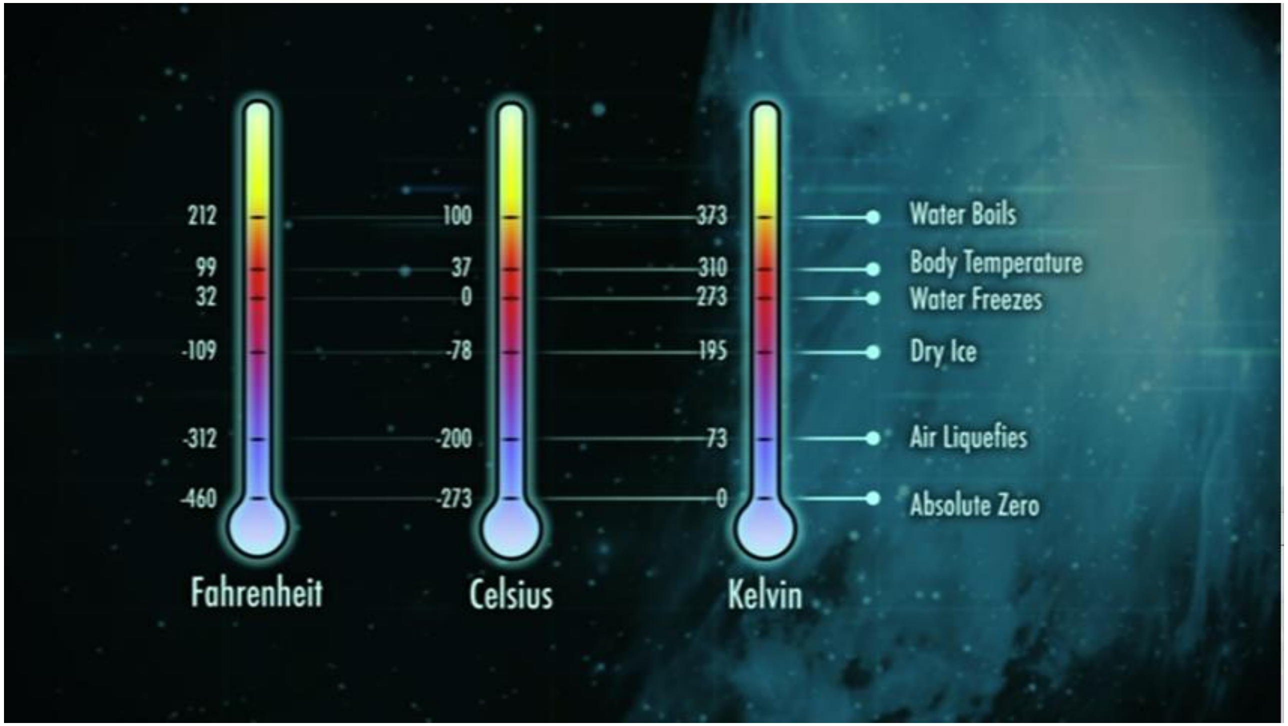
Cosmic rays consist mostly of protons, with sequentially decreasing amounts of alpha particles, carbon, nitrogen, oxygen nuclei, electrons, and gamma rays (photons)

Thermal Radiation

Three scales are typically used to measure temperature:

Fahrenheit, Celsius, and Kelvin

Very cold objects, near absolute zero, give off natural radio waves, even if they are not hot enough to be visible. Hotter objects emit thermal or nuclear radiation.

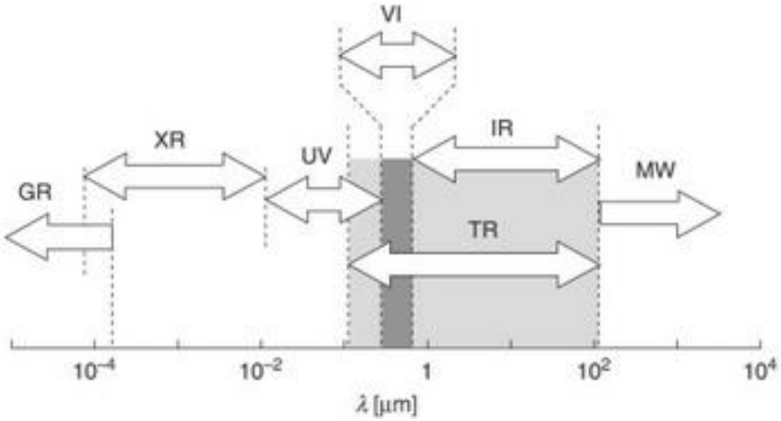


Thermal radiation in the EM spectrum

Most of the everyday objects we see, we see because of reflected light

Most of the celestial objects we see in the night sky we see because they emit thermal radiation

Thermal radiation is electromagnetic radiation emitted from all matter that is at a non-zero temperature in the wavelength range from 0.1 μm to 100 μm. It includes part of the ultraviolet (UV), and all of the visible and infrared (IR). It is called thermal radiation because it is caused by and affects the thermal state of matter.



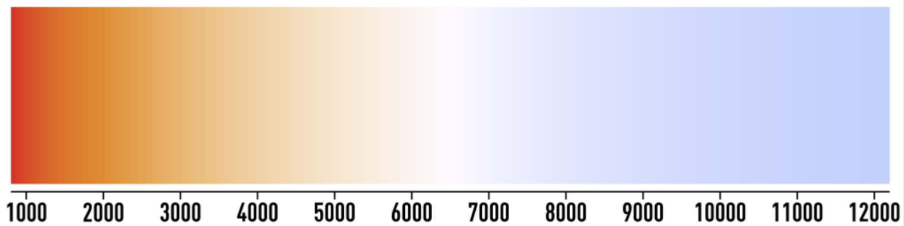
https://www.sciencedirect.com/topics/engineering/thermal-radiation

If you get something hot enough,
it will emit red light, the lowest visible thermal energy

As the object gets hotter, its thermal radiation will increase in intensity; the light turns orange, yellow, then blue then violet or low ultraviolet:

The Thermal Spectrum

As the energy of a star passes beyond the thermal range
It is considered to be in the high UV, X ray, or gamma ray range

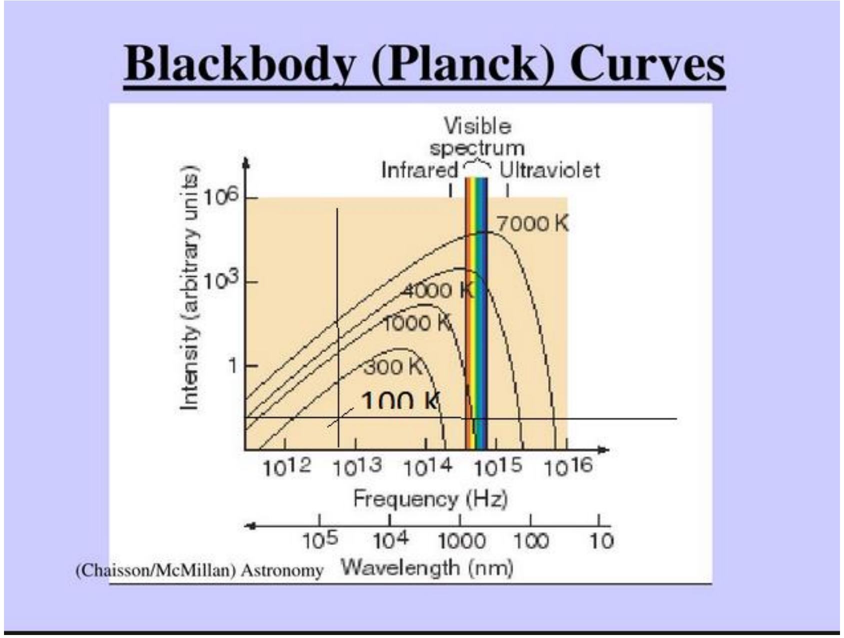


Color of a black body from 800 K to 12200 K. This range of colors approximates the range of colors of stars of different temperatures, as seen or photographed in the night sky.

There are no green stars because the ‘black-body spectrum’ of stars, which describes the amount of light at each wavelength and depends on temperature, doesn’t produce the same spectrum of colors as, for example, a rainbow. A star whose peak light emission is at a wavelength we might call ‘green’ actually produces almost as much red light, and our eyes interpret this combination as white, not green. For our eyes to see it as green, a star would have to emit only green light, which is not possible.

With the assumption that a black body is a perfect radiator, the intensity of EM radiation produced by heating such a black body may be plotted either as a function of frequency or wavelength on the horizontal scale

Such plots are called **Planck Curves, named after Max Planck**.

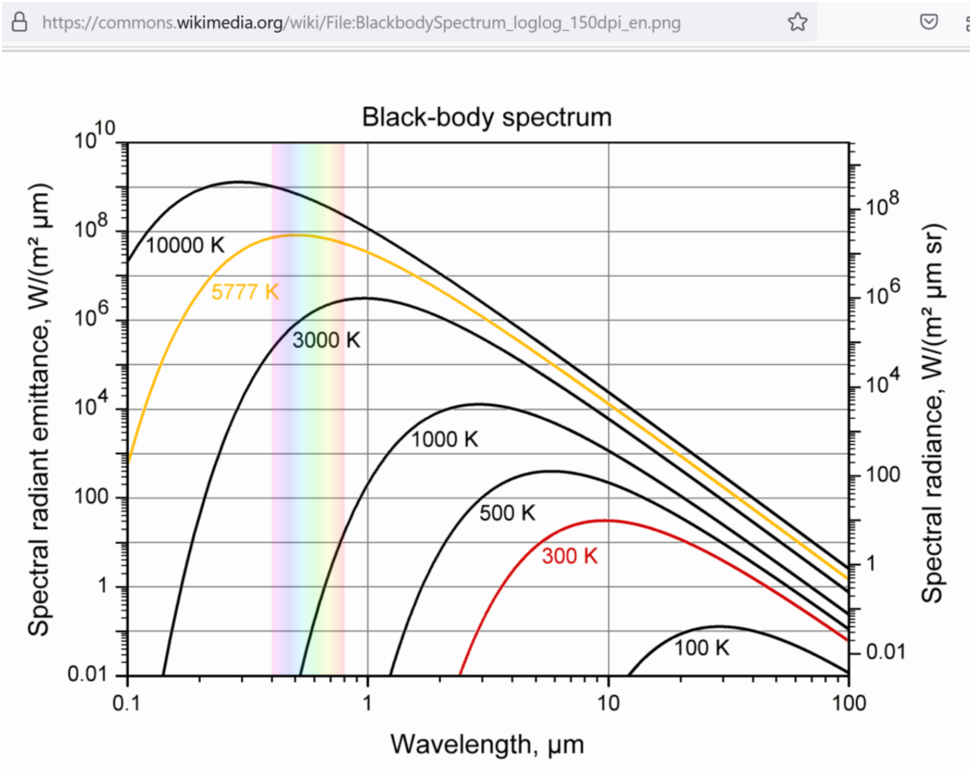


(Chaisson/McMillan) Astronomy

Note that intensity, a measure of brightness measured on the vertical axis, is independent of the EM frequency/wave length, measured on the horizontal axis

http://lifeng.lamost.org/courses/astrotoday/CHAISSON/AT303/HTML/AT30304.HTM

Kraus Planck curves



Planck curves for all heat based EM radiation have a similar shape, and usually appear as intensity on the vertical scale as a function of wavelength on the horizontal scale.

There is a steep drop-off at the higher frequencies, and a gradual drop off at lower frequencies, the frequencies of radio waves.

Intensity as a function of frequency for thermal and non-thermal radiation

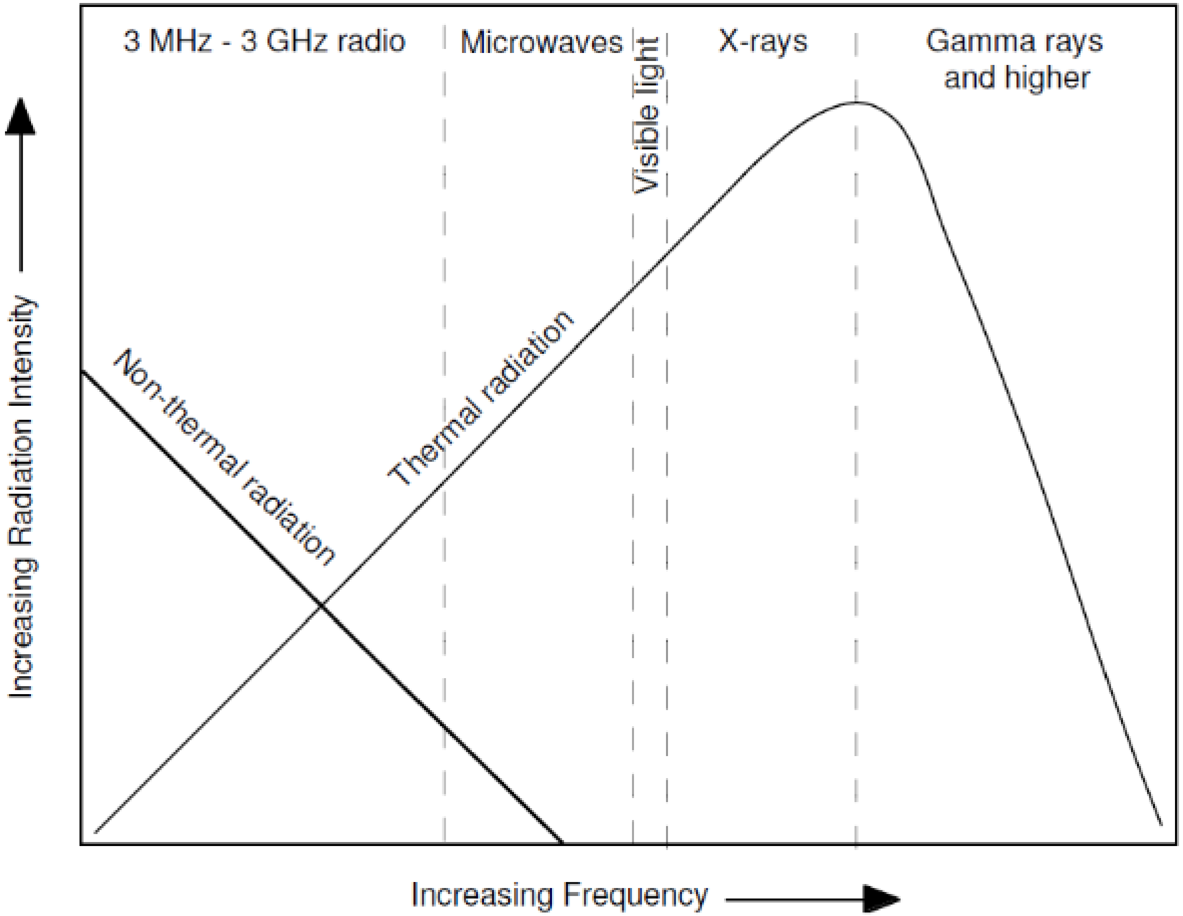


Figure 2.3: Thermal and non-thermal radiation vs frequency [12]

Stella Schleich; Stellenbosch University 2022
Design and implementation of a two-element interferometer
https://scholar.sun.ac.za/server/api/core/bitstreams/090e3f83-860e-4781-bf89-33623a517935/content

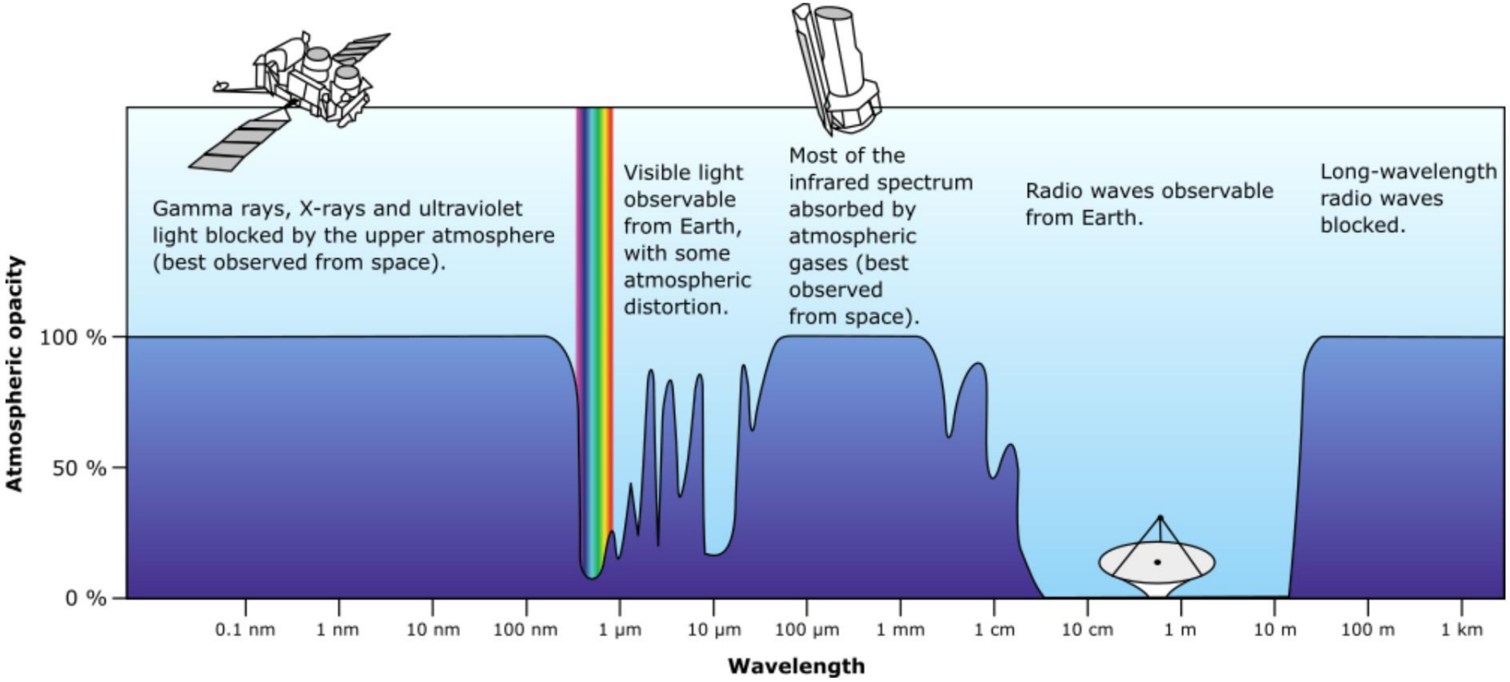
Microwaves, excessive ultraviolet, x-rays, gamma rays and cosmic rays are generally harmful to organisms.

Fortunately, microwaves are absorbed by **moisture** in the atmosphere;
the most energetic UV is absorbed by ozone in the atmosphere;

Oxygen and nitrogen atoms in the thermosphere
absorb nearly all x-rays and gamma rays;

and the Earth's atmosphere and **magnetic field**
absorb nearly all cosmic rays.

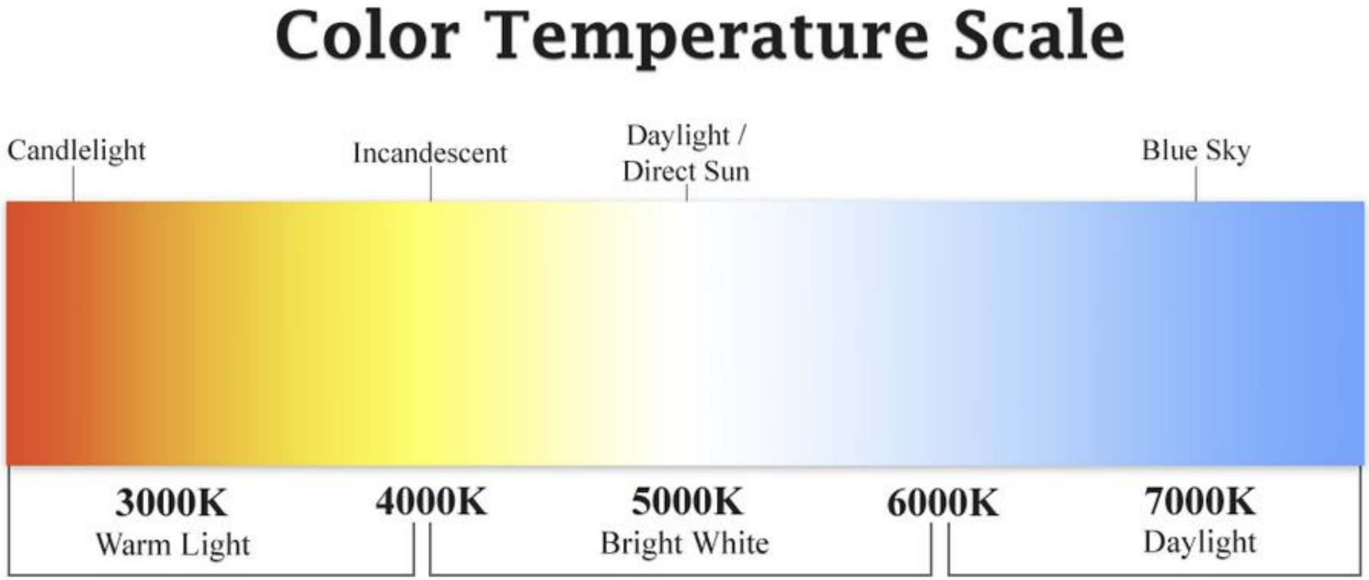
The positions of optical and radio astronomy in the electromagnetic spectrum coincide with the two principal transparent bands of the Earth’s atmosphere and ionosphere. Commonly referred to as the optical and radio Windows. Low frequency radio waves are reflected; Higher frequency radio waves travel further before being reflected, and radio waves within the radio window can penetrate the atmosphere from both directions. Visible light in the optical window is partially attenuated.



https://charleslabs.fr/en/project-Radio+Astronomy+Basics

"Brightness Temperature" of the sky is a measure of the amount of energy being given off by the sky at a fixed temperature.

The variation of brightness with frequency is called the brightness Spectrum. B, also K temperature



https://commercialledlights.com/blog/lighting-articles/color-temperature/

Sky brightness distribution of celestial sphere

Sky brightness B is a function of both position in the sky (azimuth and altitude) and frequency of the source radiation. In the case below, the brightest location is at the top of the vertical line, also called the local zenith.

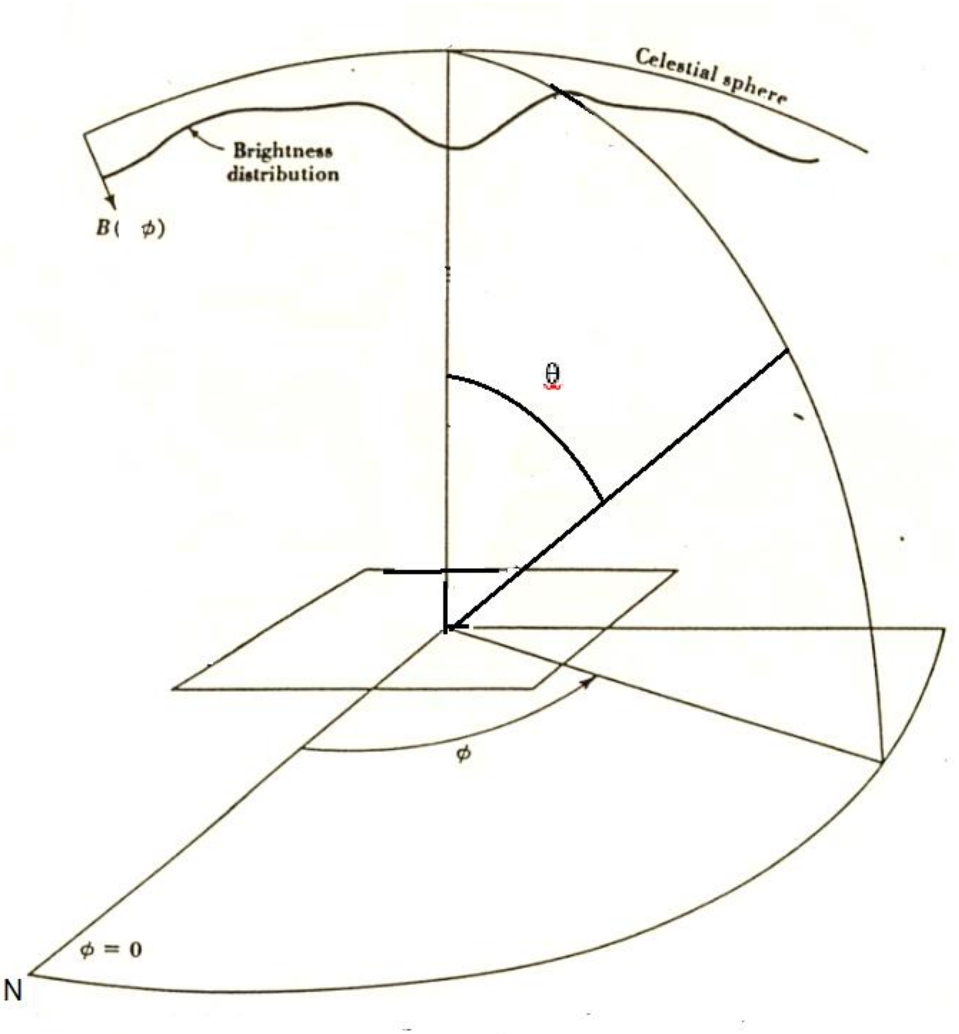


Image derived from *Radio Astronomy* 2nd edition John D Kraus