Electromagnetic Radiation

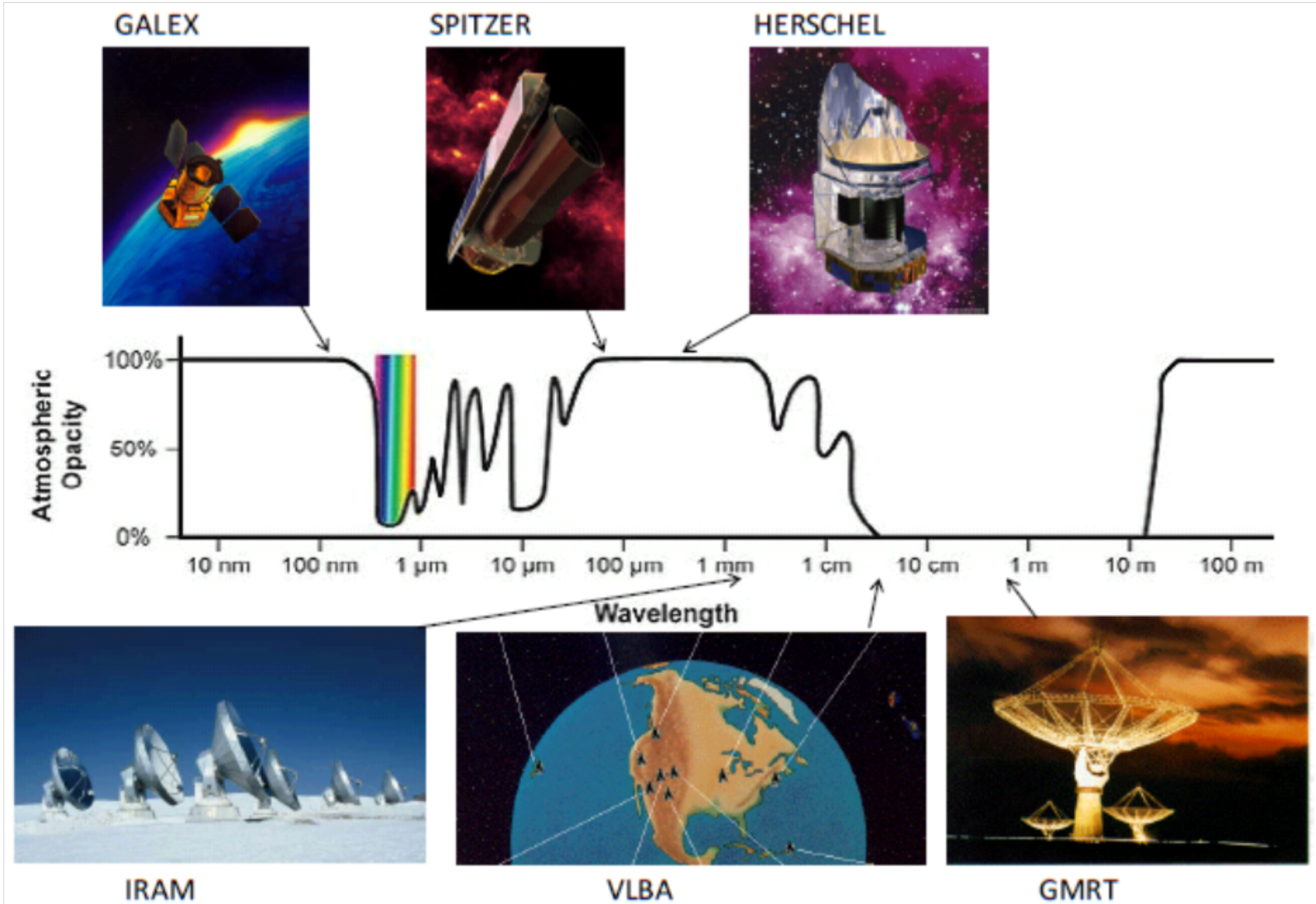
Waves & their properties

Electromagnetic waves?

The electromagnetic spectrum

Radio spectra

Electromagnetic windows



Why is light important to astronomy?

Most astronomical objects are so distant that the only way we have to study them is by the “light” that they emit or absorb.

Understanding the physics of light is an important part of astronomy or astrophysics. We need to understand what physical processes we are observing.

Light is also known as *electromagnetic radiation* or as *electromagnetic waves*.

First, a few wave basics…

Basic facts about waves

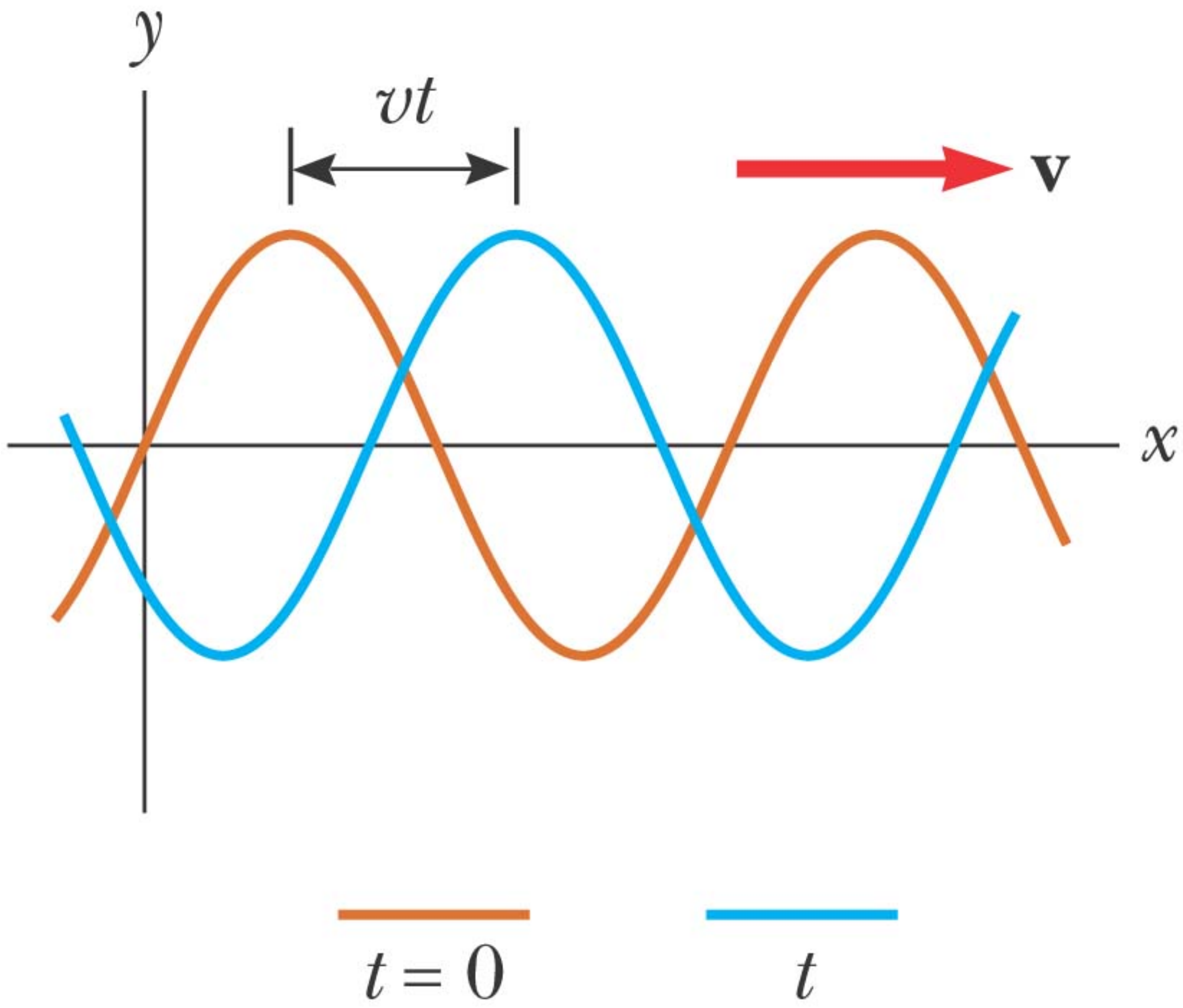
All waves are periodic disturbances or oscillations which propagate (i.e. move) from one place to another.

You are probably familiar with sound waves, water waves, waves on a string, etc.

Most waves occur in a medium, a substance that provides support for the waves. The medium itself does not travel, but the wave travels and carries energy on/in the medium.

Waves are usually *transverse* (oscillation is perpendicular to direction of travel) or *longitudinal* (oscillation parallel to direction of travel) … some complicated waves are mixed.

Light is a transverse wave

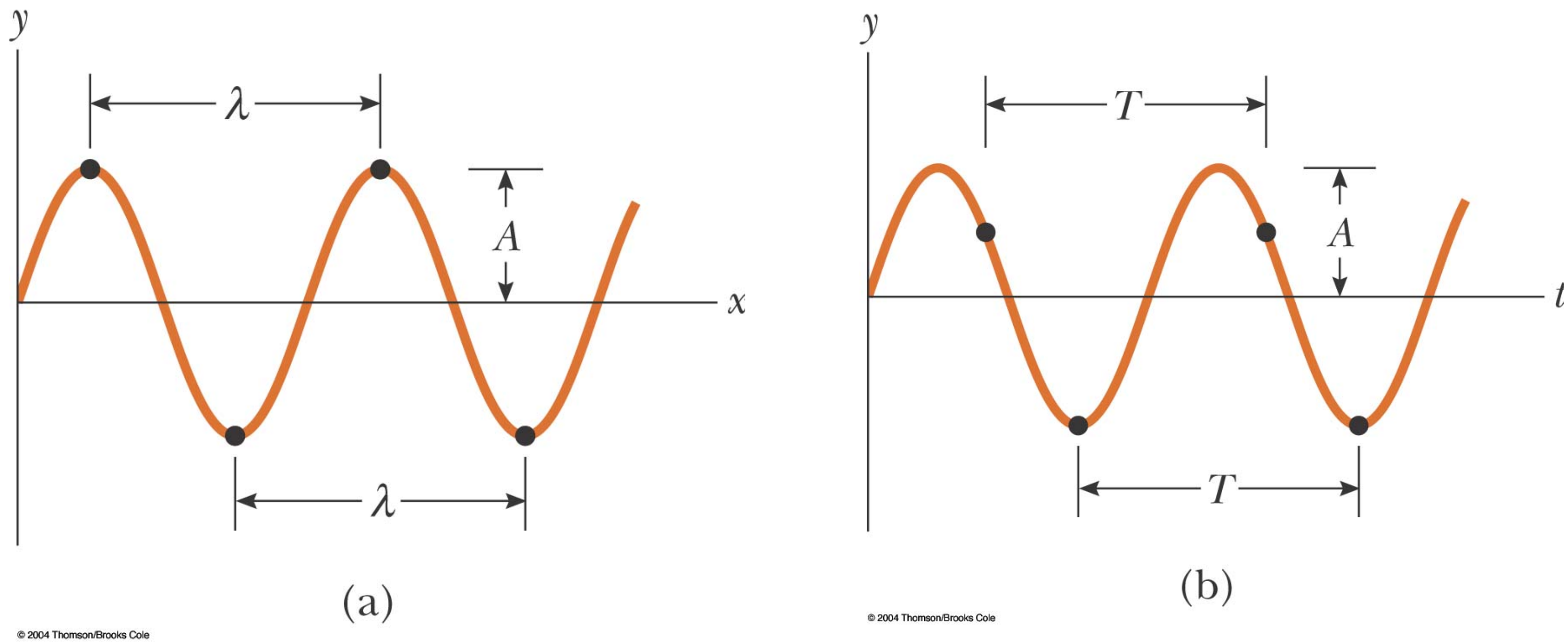


This is a sketch of a transverse wave. Red represents the wave at t=0 and blue a time *t* later.

The medium in a transverse wave oscillates perpendicular to the direction of travel.

The medium itself does not propagate.

Wave characteristics



- Wavelength (λ) in m – the length of a single oscillation
- Period (T) in s – the time taken for a single oscillation
- Amplitude (A) – the height of the wave peak or depth of the wave trough
- Frequency (ν) in Hz – the number of oscillations that occur in 1 second
- Velocity (c) in m/s – the speed of the wave's propagation

Simple wave relations

- Fairly obviously, $\nu = 1/T$
- If the velocity of the wave is c then in 1 second, c/λ wave crests will have passed a given point
- But the frequency ν is the number of waves (oscillations) that occur in 1 second so we get $\nu = c/\lambda$ or:

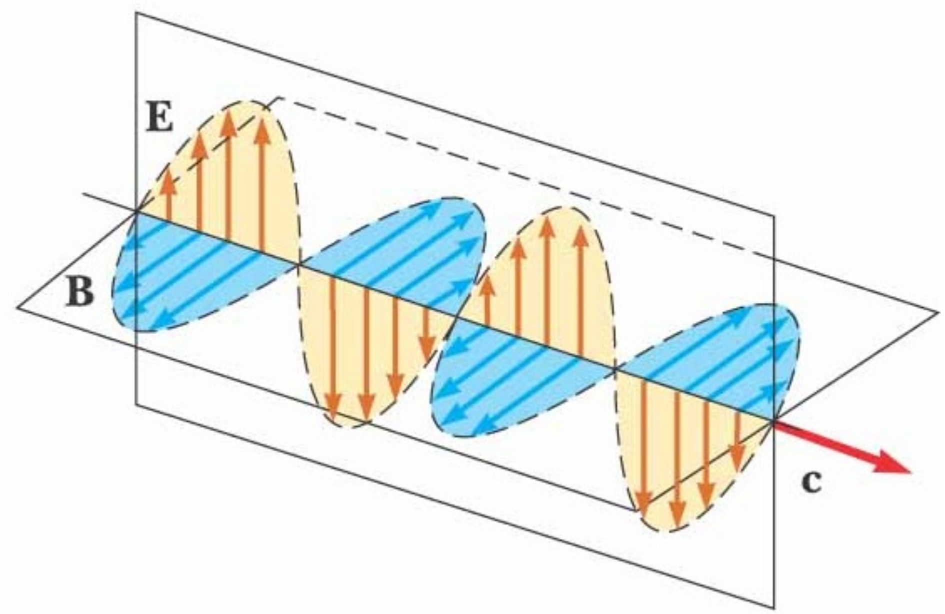
$$c = \lambda\nu$$

Electromagnetic waves

Electromagnetic waves do not require a medium to propagate through – they can travel through a vacuum.

So what oscillates?

An electromagnetic wave is a self-propagating oscillation of two *fields* – one electric and the other magnetic.



The two fields are perpendicular to one another and also to the direction of travel of the electromagnetic wave.

Electromagnetic waves 2

Electromagnetic waves travel through space at a constant velocity. In a vacuum this velocity is

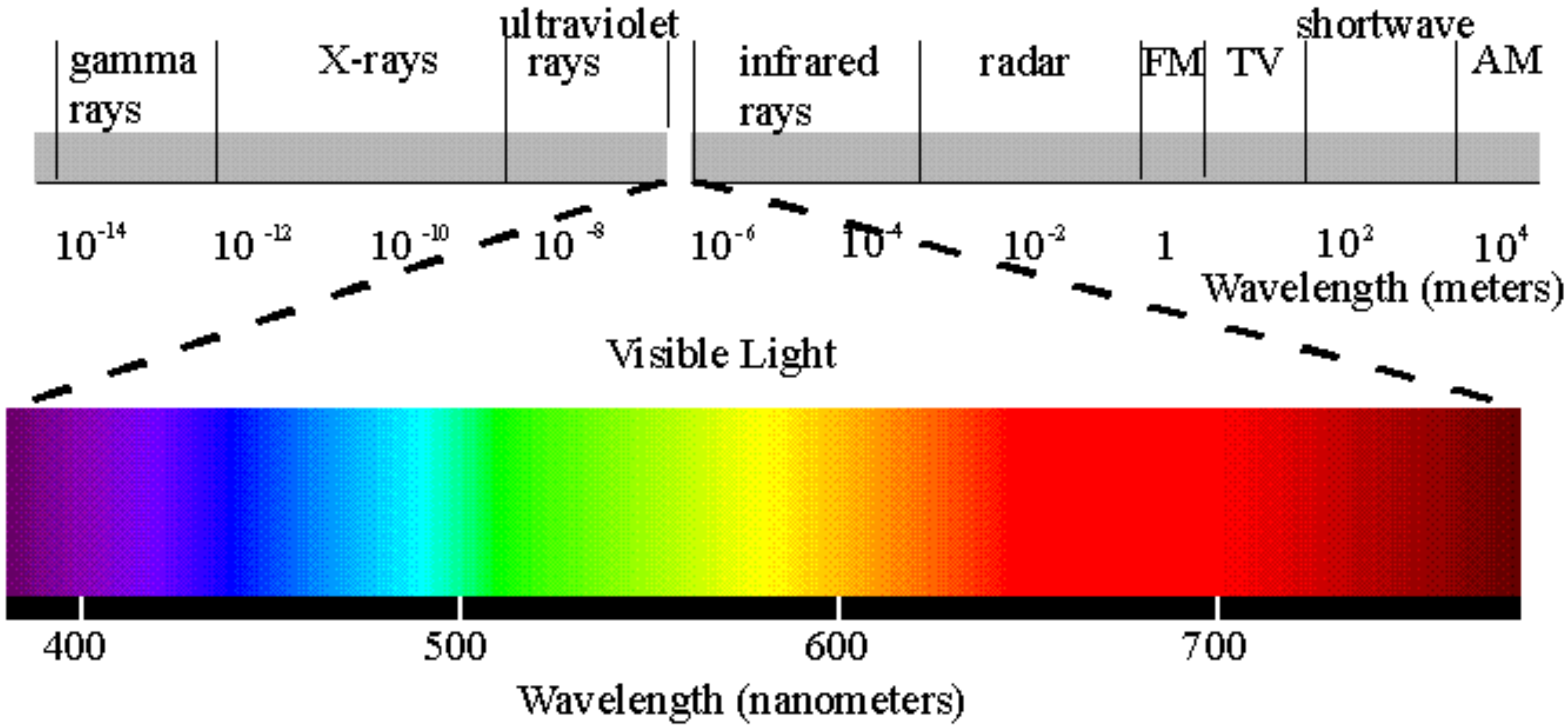
$$c_0 = 299792458 \text{ m s}^{-1} \text{ exactly}$$

(this velocity is the maximum, in another medium like glass the velocity of the waves is lower)

We can also define the *polarisation* of EM waves by the direction of the E-field – if the E-field only oscillates in a single plane then the waves are *plane polarised.*

Most light sources are unpolarised, i.e. the E-field oscillates in a random direction, but some astrophysical sources emit polarised light.

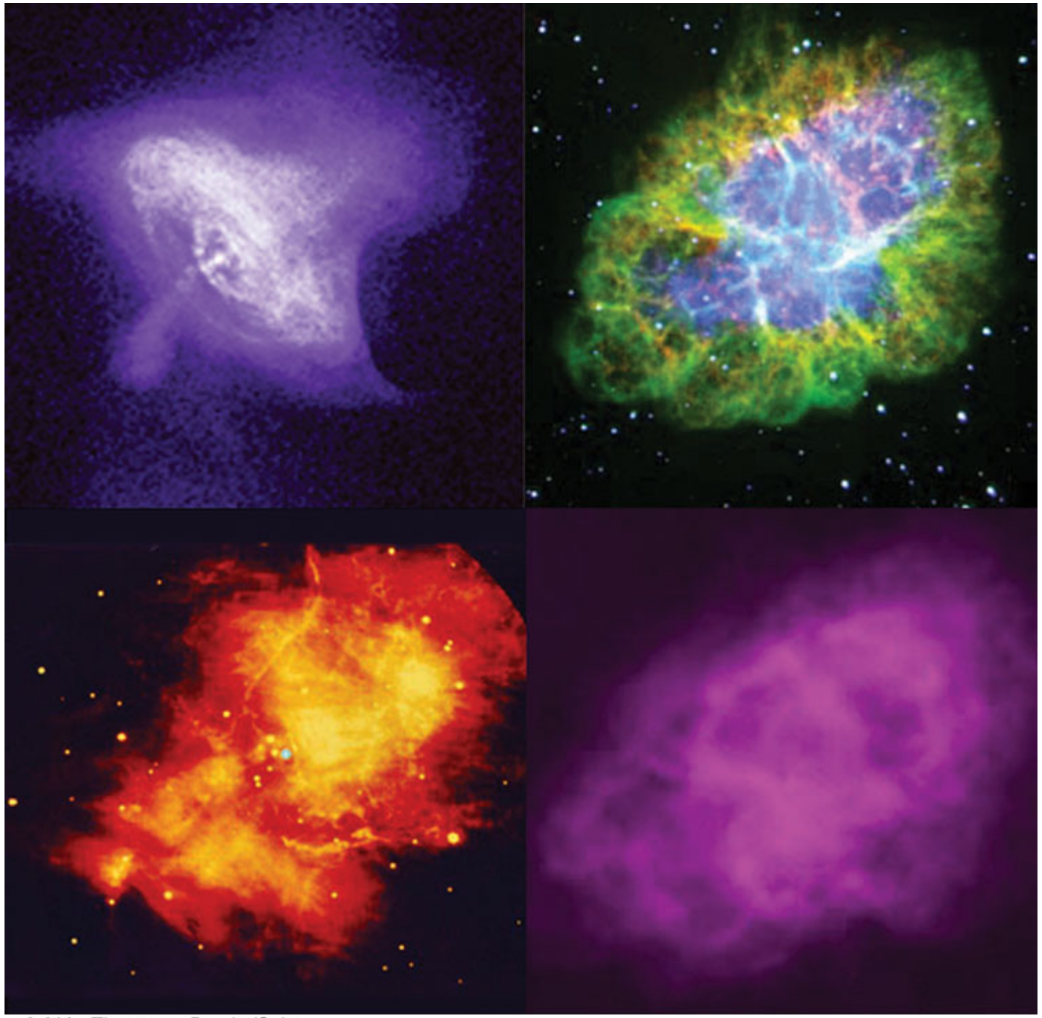
The electromagnetic spectrum



Our vision is only sensitive to a small part of the EM spectrum from λ=390 nm (violet) to λ= 720 nm (far red). N.B. 1 nm = 10^{-9} m

But as astronomers we use as much of the spectrum as possible from gamma rays (λ=10^{-6} nm) to radio waves (λ= a few m). Why?

The electromagnetic spectrum



The Crab Nebula at different wavelengths

Top left: X-rays

Top right: Visible light

Bottom left: Infrared

Bottom right: Radio waves

Generating electromagnetic waves

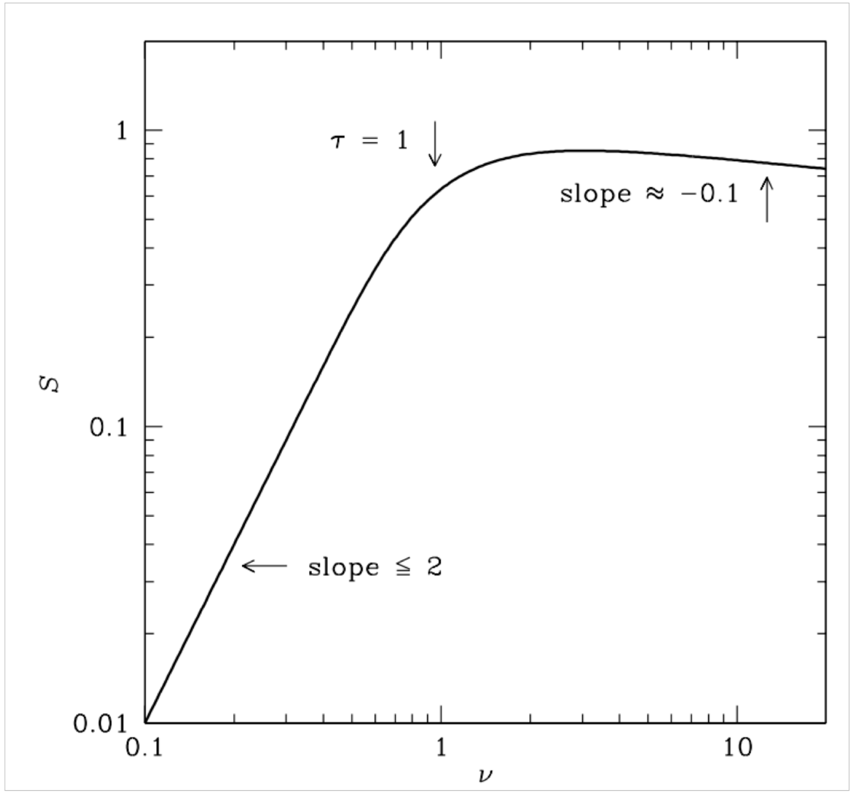
Electromagnetic waves are generated when a charged particle is accelerated (or decelerated). An oscillating electric field (E) is induced by the motion of the particle, which in turn induces a perpendicular magnetic field (B).

The two fields combine to form an electromagnetic wave. This process can happen in a number of ways including

- Cooling of atoms/molecules (electrons slow down)
  Thermal radiation
- Magnetic fields accelerate particles
  Synchrotron radiation
- Electrons change their energy state in atoms/molecules
  Spectral line radiation

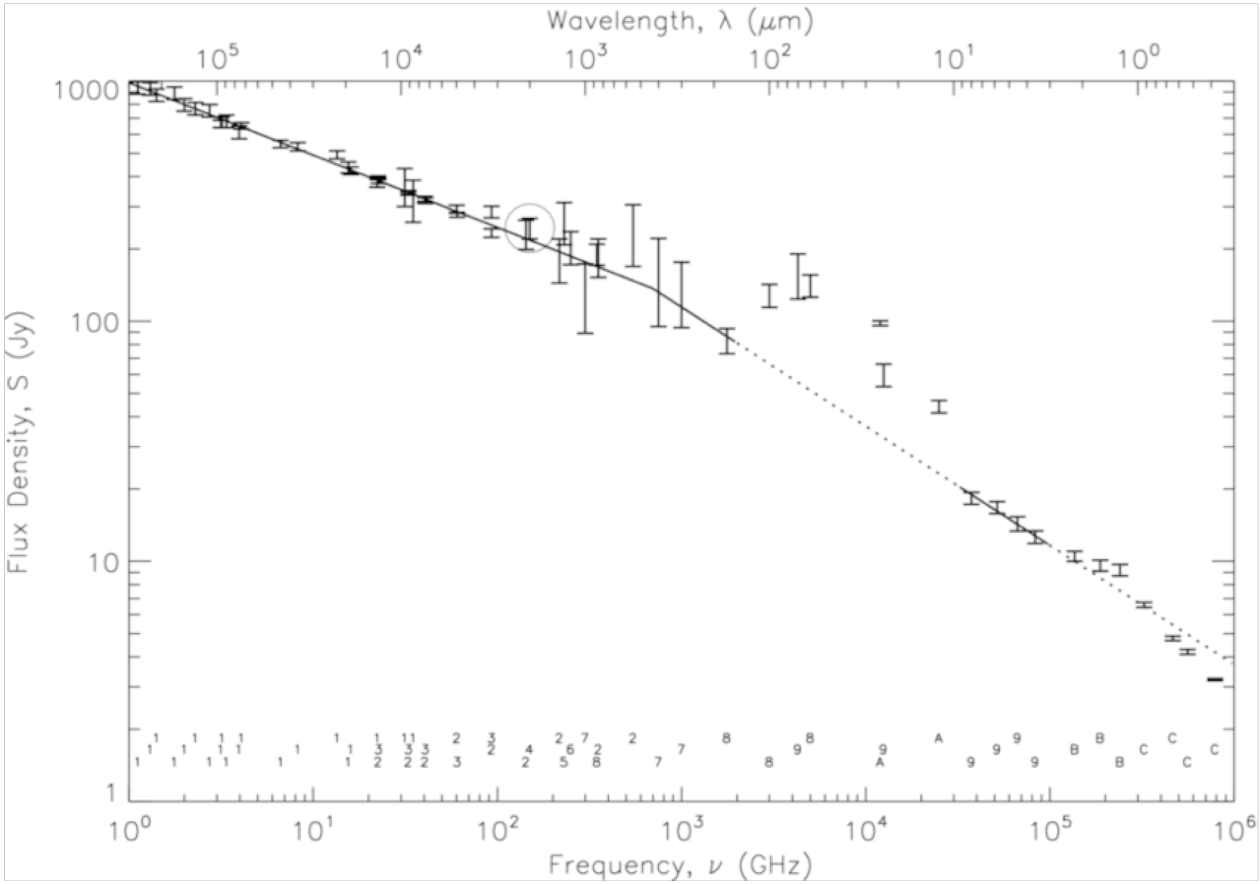
Thermal radiation

Bremsstrahlung – the slowing of electrons as they encounter ions. This tends to give a rather flat radio spectrum in the optically thin regime. Typical for HII regions.



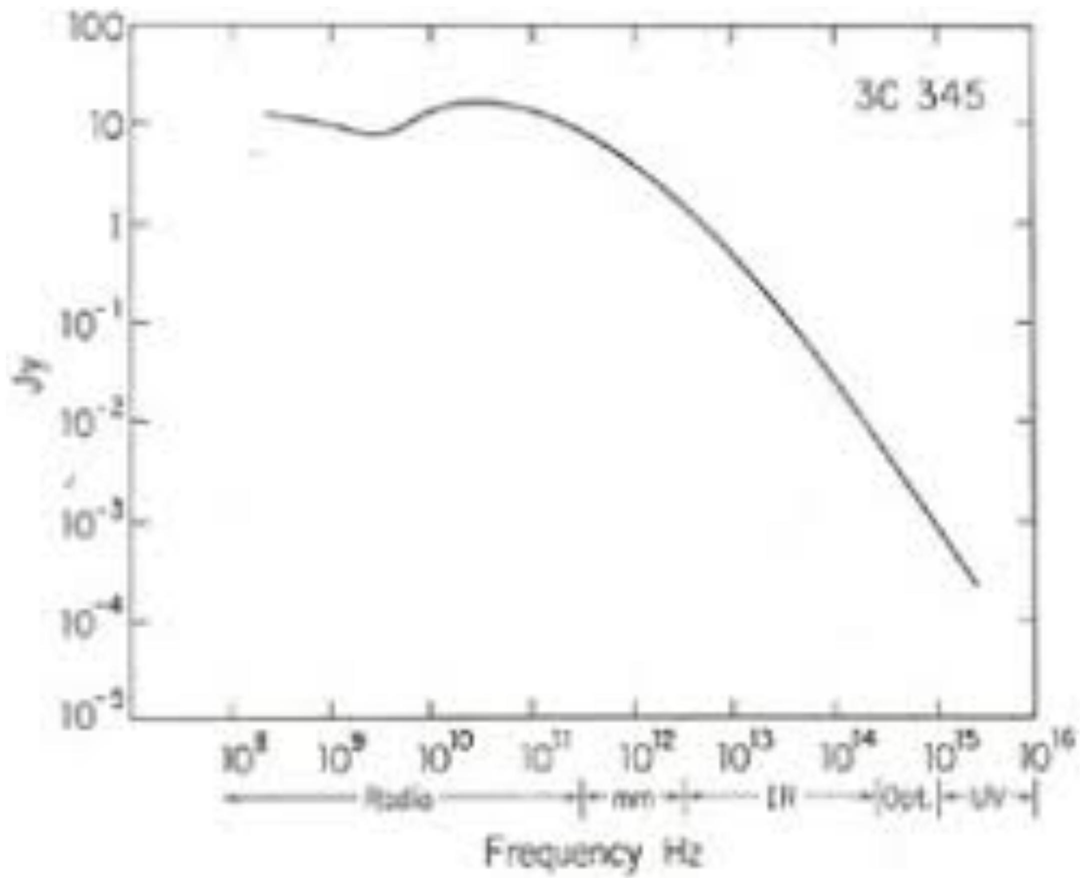
Non-thermal radiation

In the radio this usually means synchrotron emission. The spectrum is often steep, as in the Crab Nebula.



Non-thermal radiation

In the radio this usually means synchrotron emission. If the source is compact, then there may be a self-absorption turnover at low frequencies, similar to thermal radiation.



Line radiation

This is a major subject for astronomers, since the line frequency gives speed of motion (Doppler effect). In the radio we usually work with simple molecules or the 21-cm line of hydrogen.

IRC 60169

Water masers