Electromagnetic Waves

Astronomy, the science of the gaze, is primarily based on collecting electromagnetic waves emitted by celestial objects.

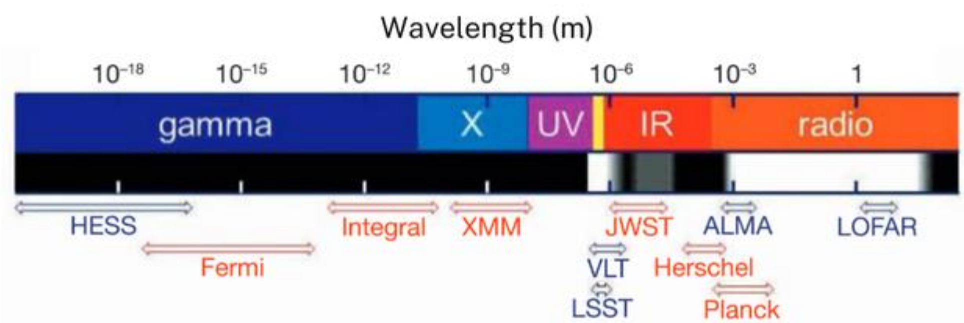
The electromagnetic spectrum

The distribution of the different spectral domain as a function of wavelength is depicted below, with the narrow yellow band representing the visible range. Below the spectrum, atmospheric absorption is illustrated with shades of grey, from black (high opacity) to white (transparency). The figure also highlights the spectral bands used by some of the observation tools described in the text. Terrestrial instruments are marked in blue, spatial-based instruments in orange.

For centuries, the nature of light rays was the most contentious issue in physics, with two seemingly fundamentally different theories vying for acceptance: the particle theory, which considered light as a stream of discrete particles, and the wave theory, which likened light to ripples spreading across a water surface. The wave theory seemed to triumph in 1864 when Maxwell's equations predicted the existence of electromagnetic waves travelling at the speed of light. However, in 1905, Einstein reintroduced the particle theory to explain the photoelectric effect. Light, which behaves sometimes as a wave and other times as a particle – two facets of a more complex reality –, can be described in two ways:

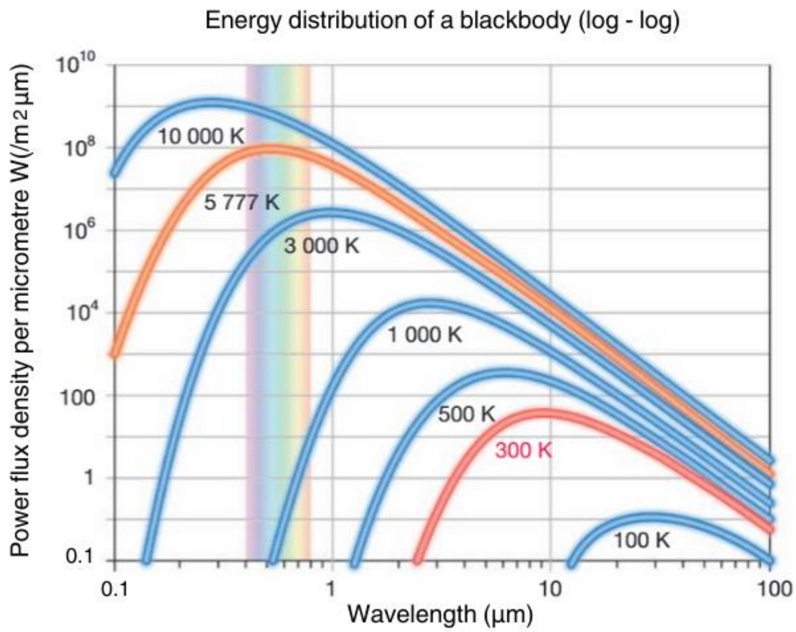
• In 'classical' physics, light is a variation of the electromagnetic field propagating in the absence of a physical medium. This electromagnetic wave of period T is characterised by its frequency ν ($T = 1/\nu$) and its wavelength ($\lambda = cT$), where c is the speed of light in a vacuum (c = 299,792,458 m/s).

• In quantum mechanics, an electromagnetic wave of frequency ν is associated with a zero-mass particle, the photon, carrying energy $E = h\nu$, where h is Planck's constant ($h = 6.626\ 10^{-34}$ J·s). This energy is usually expressed in electron-volts (eV), with 1 Ev = 1.602×10^{-19} J.



Credit: J. Paul

For both historical and physical reasons, the electromagnetic spectrum – all the electromagnetic waves organised by wavelengths – is divided into several spectral domains with very arbitrary limits, except for the visible range, which is determined by human physiology. Earth's atmosphere blocks electromagnetic waves in most wavelength ranges, apart from those within the visible range and specific infrared and radio bands. Therefore, it was not until the advent of space exploration that means of observation on Earth and in space enabled humanity to probe the cosmos across the full electromagnetic spectrum.



Credit: J. Lequeux

Blackbody spectra

Distribution of the power flux density radiated per wavelength unit by blackbodies at different temperatures is illustrated above. The logarithmic scale used on both axes effectively gives access to a wide range of values, though it tends to squash the curves. The red curve represents the emission of a blackbody at 300 K, which approximates the surface temperature. The orange curve represents the emission of a blackbody at 5,777 K, corresponding to the surface temperature of the Sun; the peak is in the visible range.

Most celestial objects emit electromagnetic waves, with wavelengths determined by their temperature. The simplest case is that of a perfectly absorbing body, known as a 'blackbody', wose radiation law is shown above. The Sun, stars, planets and their moons behave in much the same way as blackbodies. Other emission mechanisms are at work in the Universe, such as gamma radiation resulting from the interaction of relativistic charged particles with atomic nuclei, or synchrotron radiation, produced by the interaction of relativistic electrons with a magnetic field, which dominates radio wave emissions from most stars.

Domain	Wavelength (m)	Frequency (Hz)	Energy (eV)
Radio	$> 3 \times 10^{-4}$	$< 10^{12}$	$< 4.1 \times 10^{-3}$
Infrared	7.5×10^{-7} to 3×10^{-4}	10^{12} to 4×10^{14}	4.1×10^{-3} to 1.77
Visible	4×10^{-7} to 7.5×10^{-7}	4×10^{14} to 7.5×10^{14}	1.77 to 3.1
Ultraviolet	10^{-8} to 4×10^{-7}	7.5×10^{14} to 3×10^{16}	3.1 to 120
X	2×10^{-11} to 10^{-8}	3×10^{16} to 1.5×10^{19}	120 to 6×10^{4}
Gamma	$< 2 \times 10^{-11}$	$> 1.5 \times 10^{19}$	$> 6 \times 10^{4}$

Translated from 'Les ondes électromagnétiques', Passeport pour les deux infinis, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG