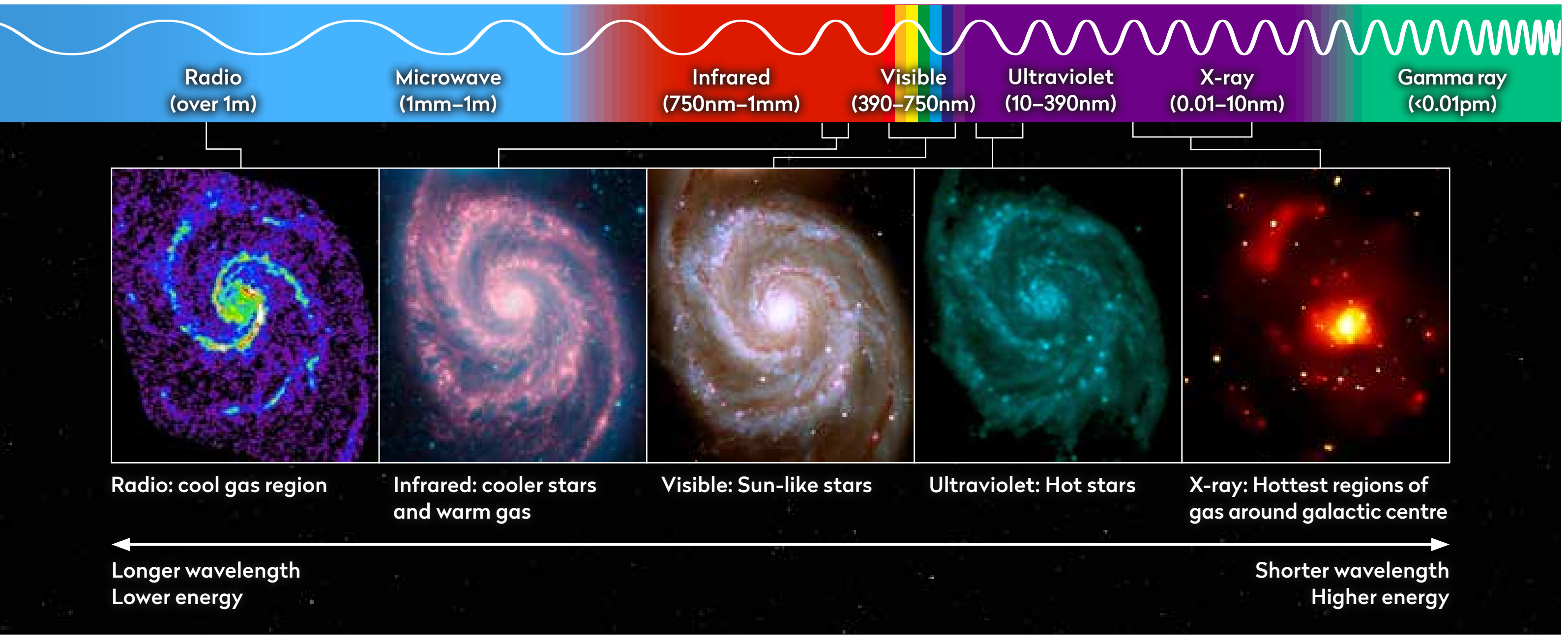
EXPLAINER

The electromagnetic spectrum

Jane Green explains what different kinds of light can reveal about our Universe



▲ Five views of the Whirlpool Galaxy, M51 in wavelengths from radio (left) to X-ray (right), unlocking a trove of information beyond what's visible to the human eye

When we think about light, most people only think in terms of what our eyes can see. But this 'visible' light is just a fraction of the light, or electromagnetic radiation, suffusing the cosmos. The entire range of this radiation is called the electromagnetic, or EM, spectrum.

Electromagnetic radiation is described as a stream of massless particles, called photons, travelling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy, and different types of radiation are defined by the amount of energy found in those photons. Radio waves have low energies, microwave photons have a little more energy, infrared photons have still more. Then comes visible, ultraviolet, X-rays, and finally the most energetic of all, gamma rays.

Just as ocean waves create vibrations or oscillations, light waves create 'disturbances' in space. Distinctly, they are the synchronised oscillations of magnetic and electric fields – hence the name electromagnetic.

The number of waves passing a point in one second is called the 'frequency' and is measured in hertz (Hz). The distance from the peak of one wave to the next is the 'wavelength'. These two attributes are inversely related; the larger the frequency, the smaller the wavelength, and vice versa. Electromagnetic waves all move at the speed of light no matter their wavelength, but our eyes are only able to detect visible light, which oscillates between 400 and 790 terahertz (THz). That's several hundred trillion times a second, with a wavelength the size of a large virus: 390 to 750 nanometres (1 nanometre = 1 billionth of a metre).

Seeing the full picture

The human brain interprets different wavelengths of visible light as colour, the longest wavelengths being red and the shortest violet. Most stars emit some of their electromagnetic energy as visible light. But just as there are sounds beyond the range of human hearing, there is light in the Universe which is invisible to our human eyes.

The more energetic a photon is, the faster it oscillates, and so the shorter its wavelength. Longer-wavelength radiation emanates from the cooler regions of space, while highly energetic phenomena create shorter wavelengths of radiation. This means that a star's colour can inform us how hot it is: red stars are coolest and blue the hottest (the opposite of what you're used to on hot and cold taps).

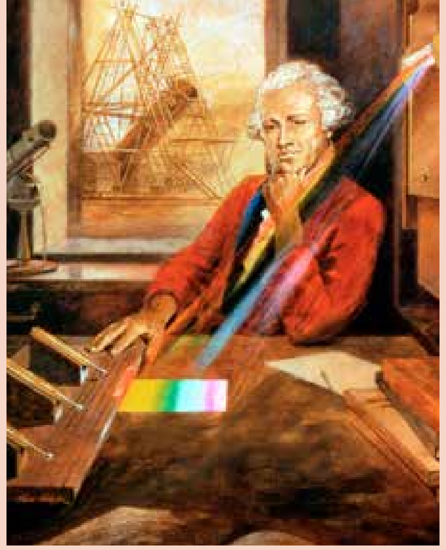
Astronomers observe the cosmos across the entire electromagnetic spectrum. By detecting low-energy, long-wavelength radio and microwaves we can study dense, cold interstellar clouds and map the structure of our Milky Way Galaxy. Exquisitely sensitive microwave telescopes are used to map the remnant glow of the Big Bang. Studying infrared waves, which transfer heat, enables astronomers to sift through drifting dust lanes that would otherwise block our view, allowing us to see our Galaxy's core, locate predominantly cool, dim stars and measure the temperature of exoplanets.

Radiation with wavelengths shorter than violet is called ultraviolet light, or UV. Astronomers use this to search for highly energetic hot blue stars and explore areas of star birth in distant galaxies. Beyond the ultraviolet are the highest energies of radiation: X-rays and gamma rays. Earth's atmosphere blocks this light, so astronomers employ orbiting telescopes to view the X-ray and gamma-ray Universe. Exotic X-ray sources such as neutron stars, superheated gas swirling around black holes and million-degree diffuse clouds lurking in galactic clusters are all visible with X-ray vision.

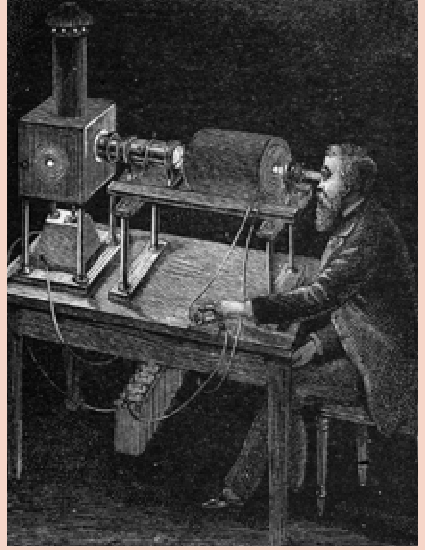
Gamma rays are the shortest wavelength of light and deadly to humans, but they expose extremely violent events, including supernovae, colliding neutron stars and cosmic radioactive decay. Indeed, the most energetic events in distant galaxies – gamma-ray bursts – are detectable with gamma-ray telescopes, providing evidence of stellar explosions and black hole births.

All these wavelengths of light, whether seen or unseen, form the electromagnetic spectrum – the toolbox used by astronomers in their exploration of space.

▲ Newton laid the foundations for modern optics with his discovery of a spectrum of colours within white light



▲ Making the connection of light with heat, Herschel discovered light beyond red (infrared) warmed thermometers the most



▲ James Clerk Maxwell made the huge conceptual leap that light in all its forms was waves of electromagnetic radiation

The history of decoding the EM spectrum

Over the centuries, the electromagnetic spectrum has been revealed piece by piece

1672 Isaac Newton used a glass prism to split white light into its constituent rainbow colours of red, orange, yellow, green, blue and violet.

1800 British astronomer William Herschel measured the temperature of each colour. A thermometer placed beyond the red light of the spectrum, where there appeared to be no visible light, was the warmest, revealing the existence of infrared light.

1801 German physicist Johann Wilhelm Ritter noticed paper soaked in silver chloride – which would later be used for photography – was darkened more by the 'invisible light' beyond violet than the colour itself, revealing the existence of ultraviolet light.

1867 Scottish scientist James Clerk Maxwell predicted the existence of light with longer wavelengths than infrared.

1887 German physicist Heinrich Rudolf Hertz demonstrated Maxwell's waves by producing radio waves in the laboratory.

1895 While experimenting with vacuum tubes, German scientist Wilhelm Conrad Rontgen detected invisible rays passing through the cardboard shields that blocked visible light. He called this radiation 'X-rays' to indicate it was unknown.

1900 French chemist and physicist Paul Villard observed radiation from radium (discovered two years earlier by the Curies). It was clear the waves were akin to X-rays but with much shorter wavelengths. The British physicist Ernest Rutherford proposed the name 'gamma rays' for this radiation.

▲ This glimpse of our Milky Way's core, fizzing with swirling gas and dust, was only made possible in infrared gathered by three orbiting space telescopes

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