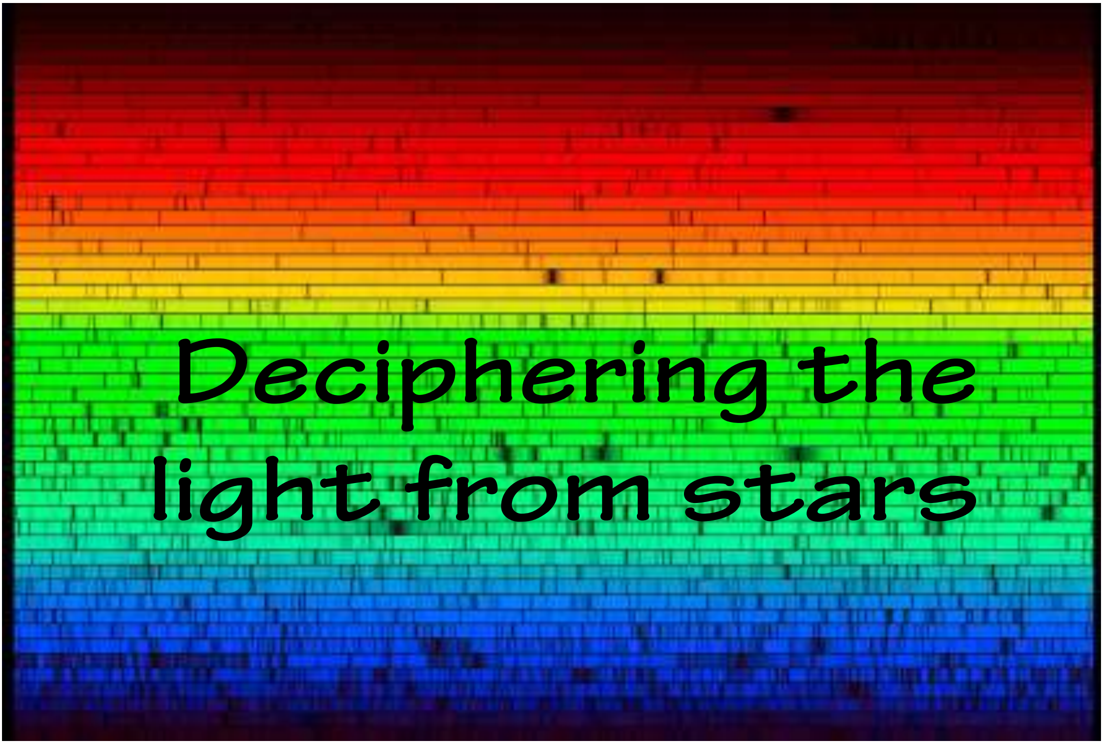
The Universe in my pocket



Deciphering the light from stars

No. 30

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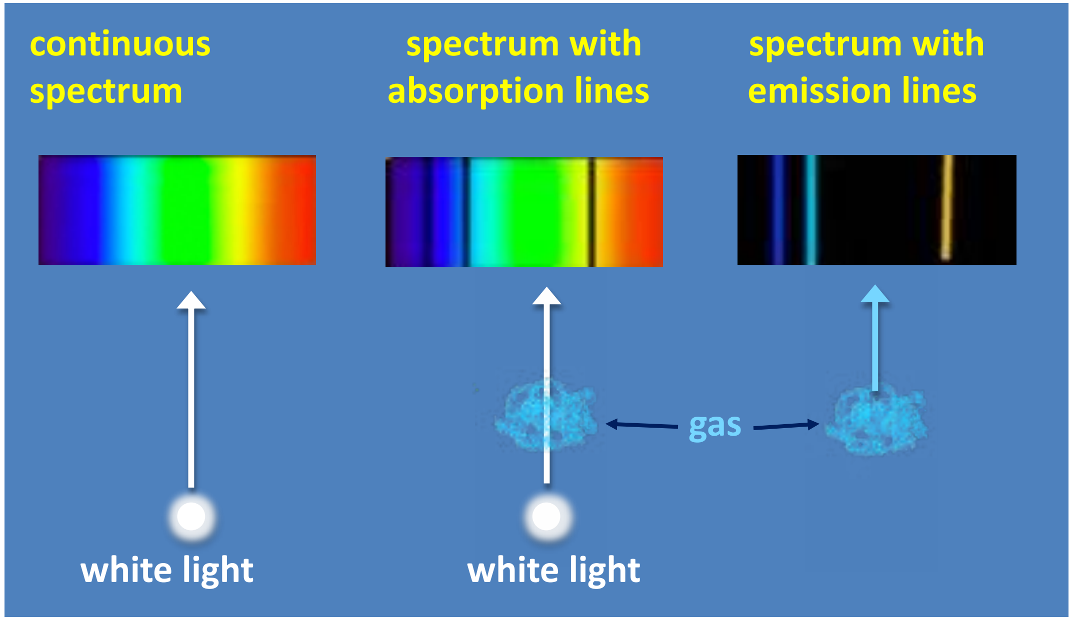
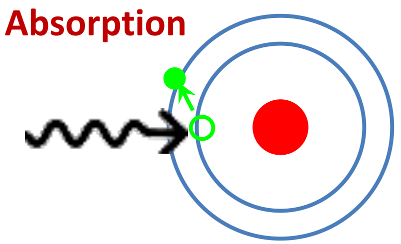
Paris Observatory

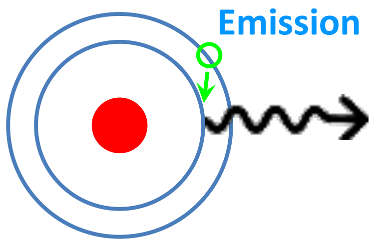
Types of spectra



A photon (a 'grain of light') can excite an atom by moving an electron to a higher energy level. If the photon has sufficient energy, it can ionise the atom, i.e. remove the electron from the atom. In both cases, the photon is absorbed.

In the reverse process, de-excitation or recombination, a photon is emitted.



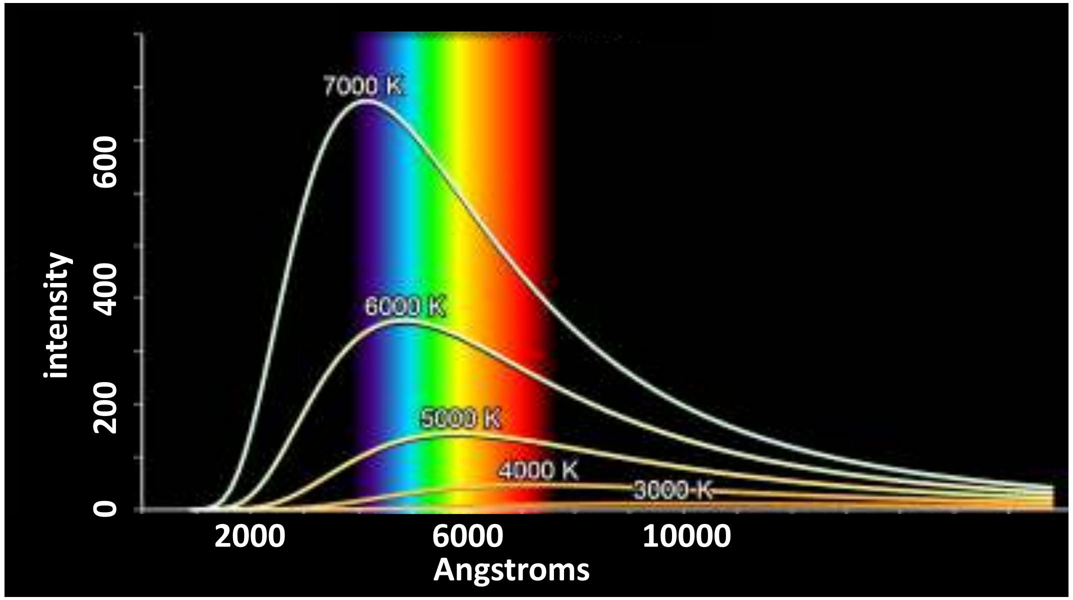


In 1835 the French philosopher Auguste Comte said that we would never know what the stars are made of.

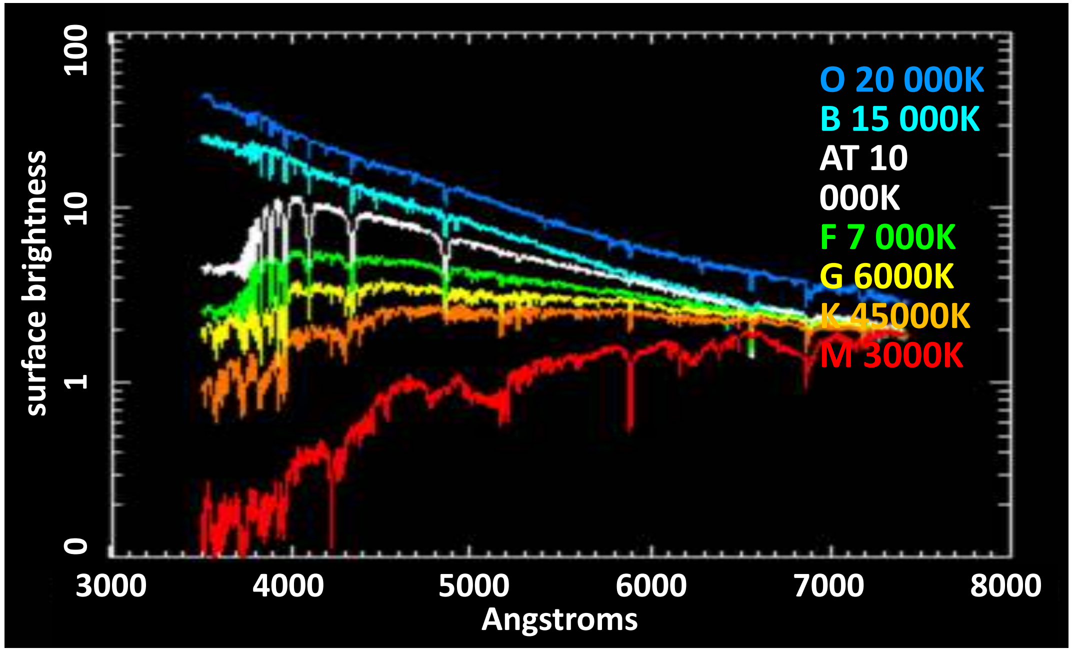
However, Isaac Newton had already shown that if a beam of light from the Sun is spread apart by a prism, a spot with the colours of the rainbow is obtained: a 'spectrum' (see TUIMP 2).

In 1814, Joseph von Fraunhoffer built a spectrograph that discovered more than 500 dark lines in the spectrum of the Sun. But it was not until 1860 that Gustav Kirchoff showed that these lines originate from chemical elements in the upper layers of the Sun. The identification of these lines began soon afterwards, contradicting Comte's pessimistic prediction.

This was the beginning of astrophysics, the branch of astronomy that studies the nature of stars by analysing the radiation they emit.



Radiation intensity of a hot body as a function of wavelength for various values of the temperature.



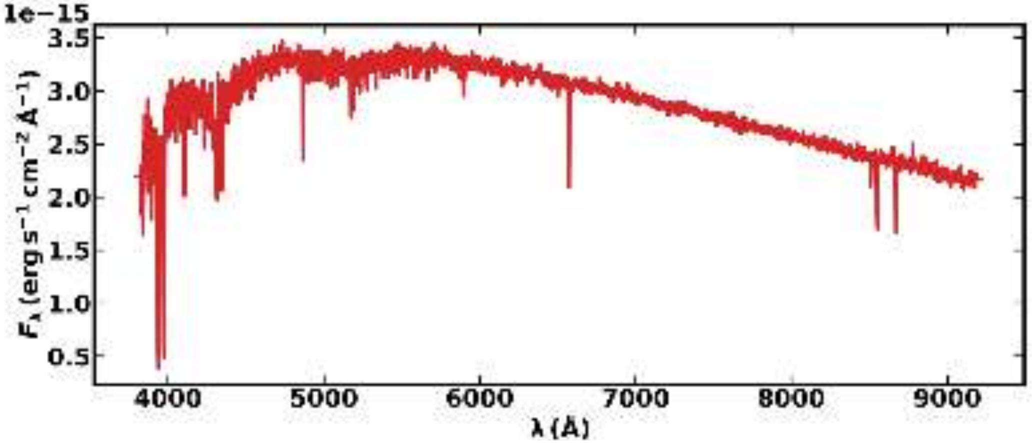
Spectra of stars of different types in the visible light range of the electromagnetic spectrum.

The temperatures of the stars

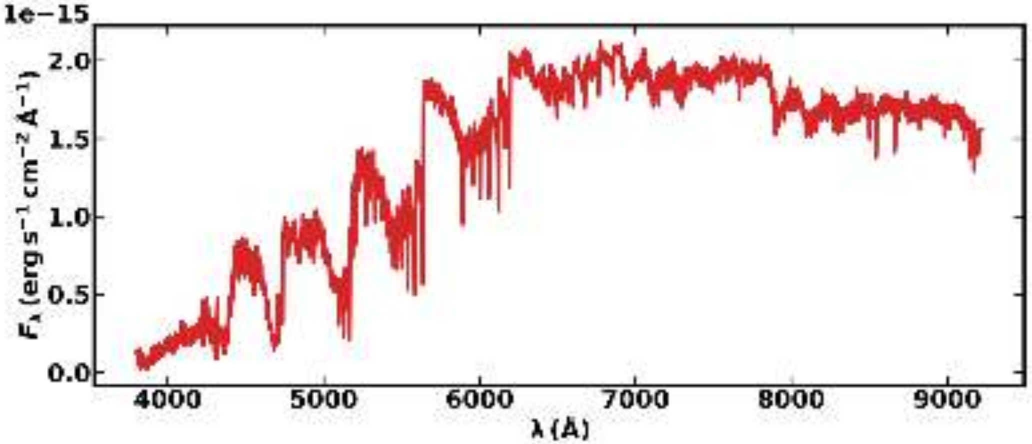
Not all stars have the same colour. The cooler ones are red. The hotter ones are blue. The Sun, with a surface temperature of 5500°C (5800 K), is yellow. These colour differences arise because of the way the shape of a star's radiation spectrum varies with temperature, as shown in the figure on the opposite page.

Below are visible spectra of real stars of different types (O, B, A, F, G, K, M). Each type has its own temperature. In addition to the overall distribution of radiation intensity, there are also absorption lines of varying depth due to elements present in the atmosphere of the stars in the form of atoms or ions.

Here are the spectra of two stars that differ only in their chemical composition.



Above: a G-type star of normal composition (similar to the Sun).



Above: a G-type star with a surface very rich in carbon (produced in the star's interior and brought to the surface by convection). The deep, broad lines and the depression at shorter wavelengths are due to carbonaceous molecules.

The composition of the stars

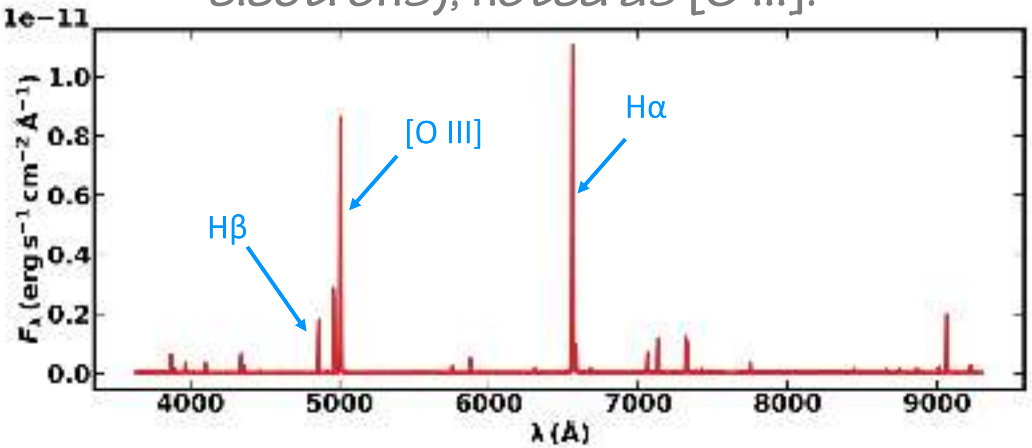
Today, thanks to the absorption lines observed in the spectra of stars, astronomers know which elements are present in their atmospheres and can measure their abundance.

The chemical composition of the atmosphere of a star is, in general, identical to that of the molecular cloud in which it formed. The interior of the star has a different chemical composition from the atmosphere because of the nucleosynthetic reactions that occur there (see TUIMP14) but this is not measured directly.

It can be seen that, broadly speaking, stars have a chemical composition similar to that of the Sun. However, stars in the outermost parts of the Galaxy tend to be less rich in elements heavier than helium, because they are less enriched by nucleosynthesis products.

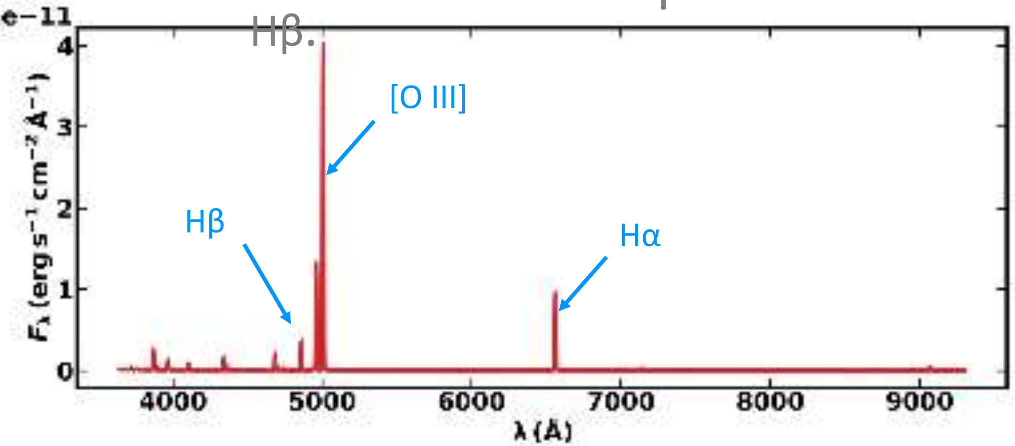

(ESA/Hubble)

The planetary nebula Hb12, ionised by a 48 000 K star. The strongest lines in its spectrum are the hydrogen **recombination** lines Hα and Hβ and the **forbidden** lines of the O^{++} ion (oxygen atom that has lost two electrons), noted as [O III].




(ESA/Hubble)

The planetary nebula NGC 7662 ionised by a 130 000 K star. Because this star is hotter, it produces a higher proportion of O^{++} ions, and the [O III] lines are more intense compared to Hα and Hβ.



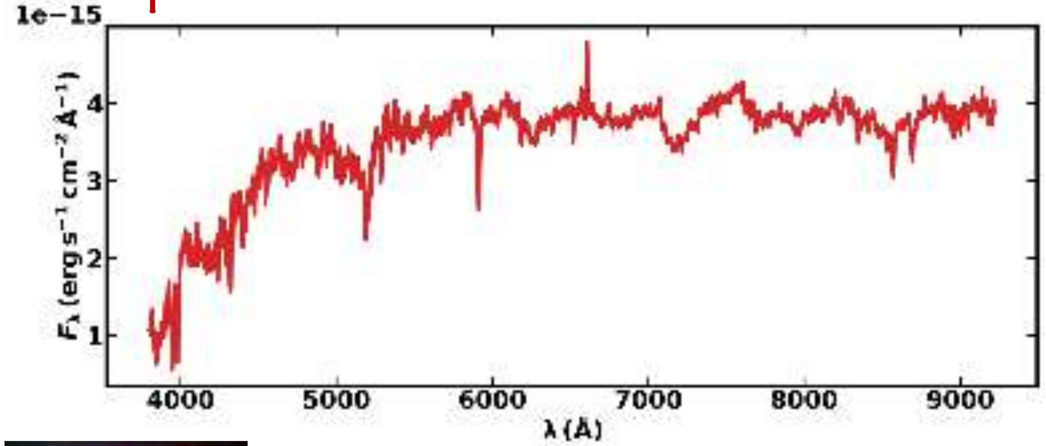
Spectra of ionised nebulae

Nebulae are clouds of diffuse gas. They can be ionised by young massive stars with temperatures around 40000K (these are the 'HII regions') or by less massive evolved stars that can exceed 100000K (these are the 'planetary nebulae').

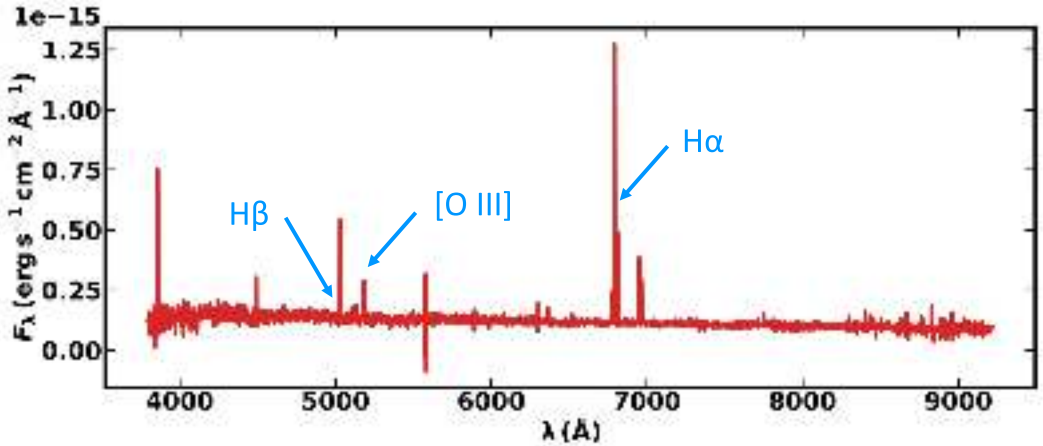
The spectra of ionised nebulae are very different from stellar spectra. While the latter show mostly absorption lines, the bulk of the light in nebulae is emitted in only a few lines, which originate either from recombinations of hydrogen and helium or from collisions with free electrons in the gas.

These collisional lines are not observed in stars and were first attributed to an unknown element, called 'nebulium'. It was not until 1928 that Ira Bowen showed that these lines originate from known elements but only occur at very low densities. They are called 'forbidden lines'

An elliptical galaxy. Its spectrum, obtained as part of the Sloan Digital Survey (SDSS), shows decreasing intensity towards shorter wavelengths because most of the stars of the galaxy are red . The characteristic absorption lines of these stars can be seen.



A spiral galaxy. Its spectrum, showing emission lines, is similar to that of an HII region.



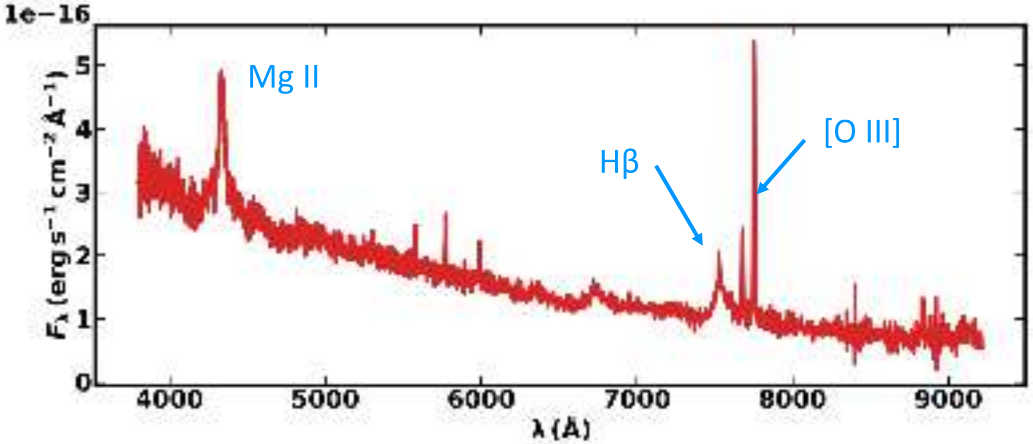
The spectra of galaxies

A galaxy contains millions or even billions of stars and sometimes gas. The spectrum of a galaxy is therefore expected to look like a combination of stellar spectra and possibly nebular spectra.

Elliptical galaxies (see TUIMP 3 and 23) contain no gas and no new stars have formed in them for a long time. They are populated only by old, red stars. All the massive stars they once contained have exploded as supernovas. Their spectra show only absorption lines.

Spiral galaxies contain gas and massive stars (O- and B-type) capable of ionising the gas. Thus their spectra show intense emission lines, superimposed on a spectrum dominated by hot stars.

A quasar located at a redshift z of 0.548, which corresponds to a distance of about 10 billion light years.



At this redshift, the lines are shifted in wavelength by more than 50%. For example, the Hβ line of hydrogen is observed at 7524Å while its rest wavelength is 4861 Å. We even see a line of ionised magnesium (Mg II) that never appears in the optical spectra of nearby galaxies.

Some lines (Hβ, Mg II) are very broad, because they form near the black hole in a zone where the rotation speed reaches 20 000 km/s.

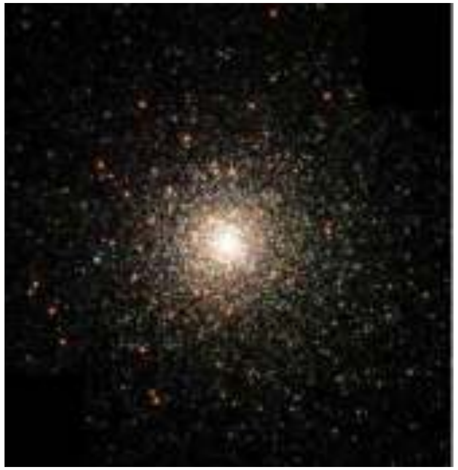
The spectrum rises towards the blue because of the emission from the accretion disc which is very hot.

Quasar spectra

Quasars are objects located at very large distances and contain a supermassive black hole at their centre, which attracts the surrounding matter (see TUIMP 6). Before falling into the black hole, the matter is coiled into an 'accretion disc' and heated to hundreds of thousands of degrees. This results in a very blue spectrum.

The emission lines are broadened and redshifted (this shift is called ‘redshift’).

The broadening and redshift are due to the Doppler effect (see TUIMP 15), which changes the frequency of the light wave as a function of the speed of the source relative to the observer. The lines are redshifted due to the recession of quasars due to the expansion of the Universe and broadened due to the rotation of matter around the black hole.



Quiz

Which of these objects has emission lines in its spectrum?

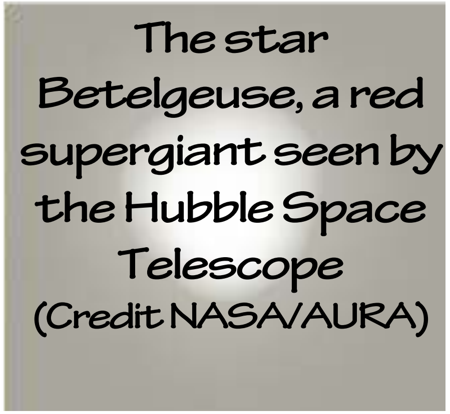
Answer on the back

An image of the Sun.
(Credit NASA).

The globular cluster M80
(credit AURA/STScI/NASA).

Only the planetary nebula has emission lines in its spectrum.

The planetary nebula Abell 39
(Credit NOAO).



The star Betelgeuse, a red supergiant seen by the Hubble Space Telescope
(Credit NASA/AURA)

Europa, a satellite of Jupiter. Photo taken by the Voyager space probe.
(Credit NASA).

All other objects have stellar-like spectra.

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This booklet was written in 2021 by Grażyna Stasińska, from Paris Observatory, with the help of Natalia Vale Asari (UFSC, Brazil).

Cover image: The spectrum of the Sun cut into bands and stacked on top of each other. It shows all the absorption lines formed in the Sun's atmosphere in the visible range. This is the 'barcode' of the Sun. This spectrum was obtained with the solar telescope at the National Solar Observatory at Kitt Peak, Arizona (USA).

To find out more about this collection and the topics presented in this booklet you can visit http://www.tuimp.org

Translation: Stan Kurtz