Helium in the Universe

The presence of large amounts of the element helium in the universe is a clue to the early universe being very dense and hot – similar to the conditions that are currently found inside stars.

In order to understand this, we have to start by seeing how astronomers can estimate the proportion of any element in the universe. This, as one might imagine, can be quite a technical and fiddly exercise in detail, but in essence astronomers exploit the ability of elements to interact with light.

If you take any object and warm it sufficiently, it will start to glow (give off light). The colours (wavelengths) of the light that it gives off can be a clue to the elements present in the object. A sodium street lamp glows yellow, as the gas in the lamp is (mostly) sodium. Equally, if you have a gas of an element and pass light from another source through the gas, then the atoms will absorb some of that light. The colours that are absorbed will tell you what elements are in the gas.

Astronomers can use both of these techniques.

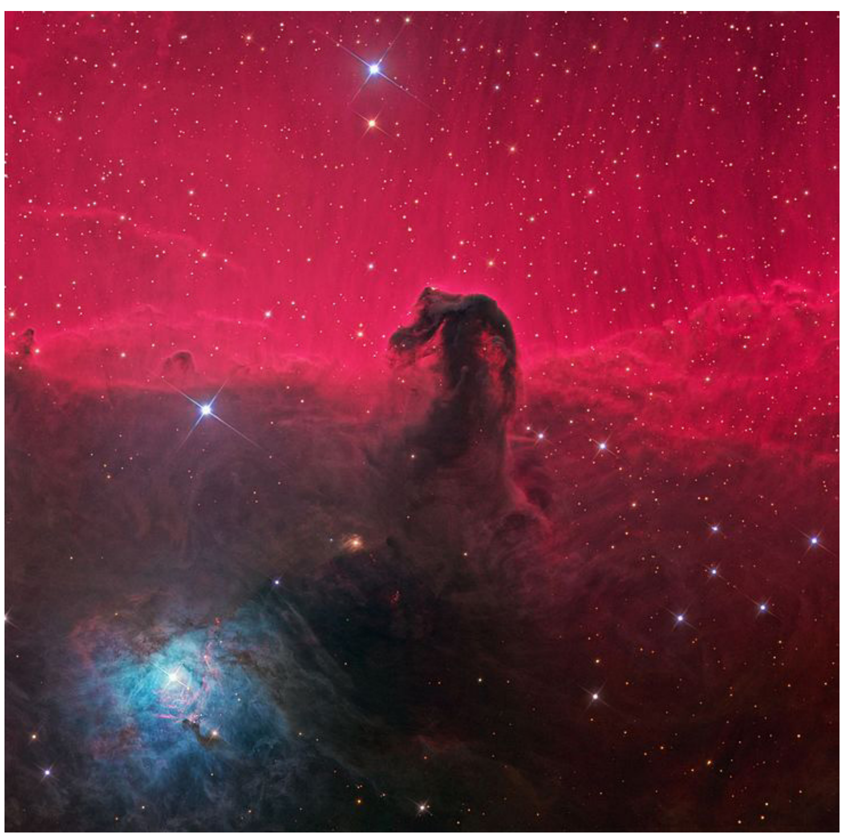

Figure 1: The Horsehead Nebula (image credit: Ken Crawford).

The pink glow in the background of Figure 1 is due to a cloud of hydrogen in space. The dark cloud in the shape of a horse's head is in front of the hydrogen cloud and so blocks out some of the light (it also casts a shadow as can be seen below the 'muzzle'). Giant clouds of gas in space are called *nebulae*. This particular one is called the *Horse Head Nebula*.

The curtain of pink glow above the horse's head is due to the giant cloud of hydrogen gas emitting light. It is being warmed by the light of the bright star towards the top of the picture (although warmed is a relative term!). The pinky glow tells us the specific wavelengths being emitted, which are characteristic of hydrogen.

The bright structure towards the bottom left is also a cloud of gas giving off light. The 'cloud-like' structure along the same level as the horse's head and to the right is seen as it is reflecting some light towards us, not giving off its own.

By studying pictures such as these and by analysing the light from stars and galaxies, astronomers have discovered that the ordinary matter in the universe[1] is composed of:

Hydrogen 75% by mass

Helium 25% by mass

Heavier elements <0.01% by mass.

Hydrogen is the simplest element as it is just one proton and an electron. Helium contains two protons and two neutrons as well as two electrons (in its most common form).

We know that inside the core of a star, the temperature is hot enough for certain nuclear reactions to take place. Typically, these reactions combine four nuclei of hydrogen together to make one nucleus of helium. This process, nuclear fusion, produces the energy that powers a star.

The problem is the amount of helium that can be seen in the visible universe. The oldest stars that we observe seem to be about 12 billion years old[2] and they have roughly the same proportion of hydrogen and helium in them. This indicates that the helium was produced *before* the first stars were born.

About three minutes after the Big Bang, the whole universe was about as hot and as dense as the core of a typical star now. This means that the sort of nuclear reactions that are currently turning some hydrogen into helium inside stars were happening everywhere in the young universe. A detailed calculation taking lots of factors into account predicts exactly 25% helium produced at this stage of the Big Bang. The match to the experimental value is remarkable.

The reactions come to an end as the universe becomes too cold and as the expansion has dropped the density that can support the reactions[3]. This period of the universe's history has been called the *nucleosynthesis era*.

The Big Bang also created trace amounts of slightly heavier elements such as lithium. Delicate study of old stars and nebulae has found these elements in precisely the predicted amounts, adding to a strong body of evidence that the basic idea of Big Bang nucleosynthesis is correct.

[1] There is also the deeply mysterious **dark matter**, which is most of the matter content and is currently unidentified.

[2] This figure is always changing as we find new 'oldest' stars. One way to estimate the age of a star is to look for radioactive elements in it. As radioactive elements decay with time, we can use the amount found to date the star. The technique is similar to carbon 14 dating used on Earth.

[3] The density of the universe, the rate at which it is expanding and the rate at which free neutrons decay are crucial factors that have to be taken into account. The balance of these factors is critical and has been cited as an example of 'fine tuning' in the universe.