The Interstellar Medium

CESAR’s Booklet

What is the Interstellar Medium?

The Interstellar Medium (ISM) is the material filling the space between the stars. It consists mainly of gas (99%) and dust (1%), mostly found in the form of clouds, or *nebulae* (plural of *nebula*).

About 75% of the interstellar gas is in the form of hydrogen, and nearly all the remaining 25% as helium. This gas is extremely cold (around 10 K) and diluted, about 1 atom per cubic centimetre (for comparison, the air we breathe has a density of about 30,000,000,000,000,000,000 molecules per cubic centimetre). However, despite this very low density, the amount of matter adds up over the vast distances between two stars.

Interstellar dust is not like the dust you might find under your bed. It consists mainly of silicates, iron, carbon and dirty ice. Dust particles are irregularly shaped and very small, just a fraction of a micron across (similar to the wavelength of blue light), and have typical temperatures of around 100 K.

How do astronomers study the ISM?

Observing the ISM

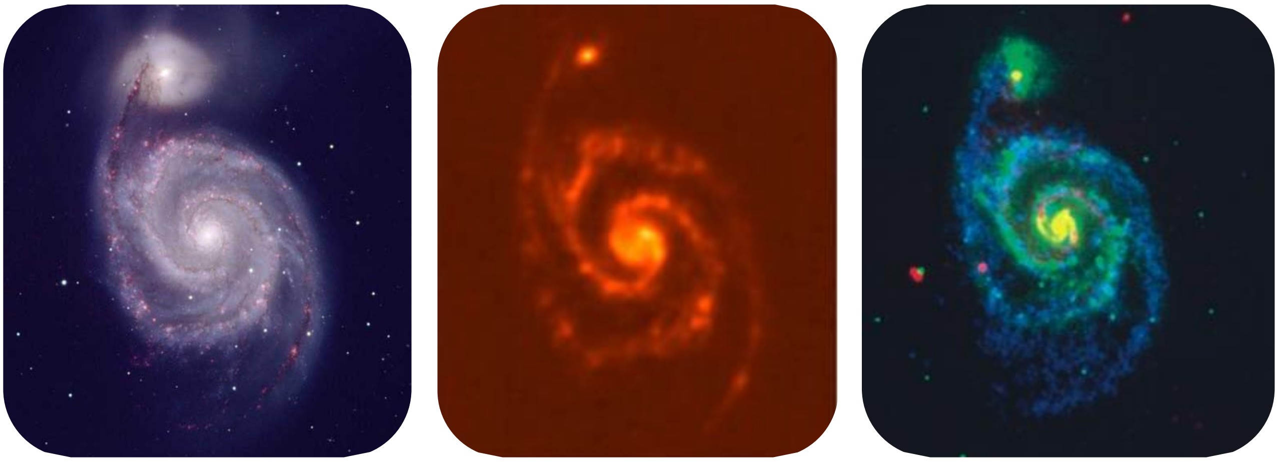

Figure 1: *M51, the Whirlpool Galaxy, observed in visible light (Hubble Space Telescope, left), far-infrared (Herschel, centre) and radio (NRAO, right). (Credits: ESA/NASA/NRAO)*

Figure 1 shows an example of how astronomers study the ISM using invisible light. Because of its really low temperature, interstellar gas emits light in the radio band of the electromagnetic spectrum. Thus, we can tell that the spiral arms of the Whirlpool Galaxy contain lots of gas because they are nicely seen in the radio image.

Dust is hotter than gas. Bodies of this temperature (about 100 K) mainly emit far-infrared light (light with very long wavelengths), and therefore, dust is a favourite target for infrared observatories. The infrared image of the Whirlpool Galaxy shown in the central panel of Figure 5 tells us that the spiral arms contain large amounts of dust as well.

21-cm radiation

Interstellar hydrogen gas is so cold that its thermal emission (the emission from a body because of its temperature) is very low even at radio wavelengths. Neutral atomic gas is more easily detected thanks to a feature at the 21-cm wavelength (corresponding to a frequency of 1420.4 MHz, in the radio domain) produced by the spins of the proton and electron in the hydrogen atom.

Spin is a purely quantum mechanical concept, but there is some analogy with a bar magnet. So in a hydrogen atom, the spins of proton and electron can either be *parallel* or *anti-parallel*. In the bar-magnet analogy: either the north-poles of both magnets point in the same direction (parallel) or in the opposite direction (anti-parallel). And just as in the bar-magnet case, there is a small energy difference between the two states, with the aligned state having higher energy.

When a hydrogen atom with aligned spins is left on its own, it has some small probability for a spontaneous spin reversal to the lower energy state. When it does so, it emits a photon with a wavelength of 21 cm.

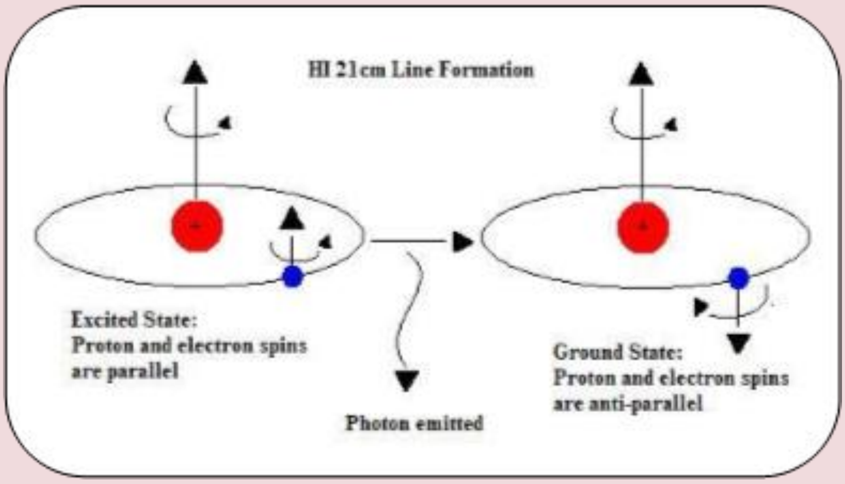

Figure 2: *Spin reversal generates 21cm radiation. (Credit: L. Home)*

The mean time it takes a hydrogen atom to perform such a spin reversal is several million years. But even though this is a rare transition, the large amount of hydrogen gas in the ISM means that enough hydrogen atoms are emitting the 21-cm line radiation at any one given time to be easily detected with radio telescopes.

And once the line is produced, its low probability becomes an advantage, since the 21-cm radiation can pass through a lot of hydrogen gas without it being absorbed again. Moreover, given the long wavelength, 21-cm radiation is not absorbed by dust.

21-cm radiation was used for example to map the structure of the Milky Way, proving that our Galaxy has several spiral arms.

Nebulae

However, if they become gravitationally unstable, ISM clouds can collapse and form stars that, in turn, heat up and ionise the surrounding gas, which glows with pinkish or reddish colour, and is thus observable in visible light. This type of glowing cloud is called an *emission nebula*; an example of this type of nebula is shown in the left panel of Figure 6.

Why do emission nebulae look reddish?

Young massive stars are very hot and emit lots of ultraviolet radiation. This radiation is able to heat up and ionise the hydrogen gas in the interstellar cloud: The electrons in the hydrogen atoms absorb the ultraviolet photons and move to higher energy states; and as they get back to the ground state, they release the extra energy in the form of new photons. Since the way back to the ground state may imply going through several intermediate energy states, the emitted photons will have a variety of energies, and thus frequencies (or wavelengths), that we can separate by observing a spectrum of the gas.

In the visible range, the most prominent line observed in the spectrum of atomic hydrogen, called Hα, corresponds to a wavelength of 656.28 nm. Our eyes perceive light of this wavelength as red colour.

Dust can also be noticed at visible wavelengths because of the effects it has on the light from the stars located within or behind it. For example, we may see the light that is being reflected and scattered by the dust; this is what we call a *reflection nebula*; because blue light (being more similar in size to dust grains) gets more scattered than red light, reflection nebulae glow blue. An example of this type of nebula is shown in the right panel of Figure 6.

Figure 6: *Types of nebulae: emission (Orion Nebula, left) and reflection (Pleiades, right). (Credits: AAO/ROE)*

If the dust is thick enough, the light will be completely blocked, leading to dark areas: we will see a dark cloud, as the one shown in the left panel of Figure 7. The reason is that, as explained above, the dust grains have sizes approximately matching the wavelengths of visible (blue) light; longer wavelengths, in the red and near-infrared range of the spectrum, do make it through the cloud. Therefore, astronomers use near-infrared telescopes to see through these dark clouds, as shown in the right panel of Figure 7.

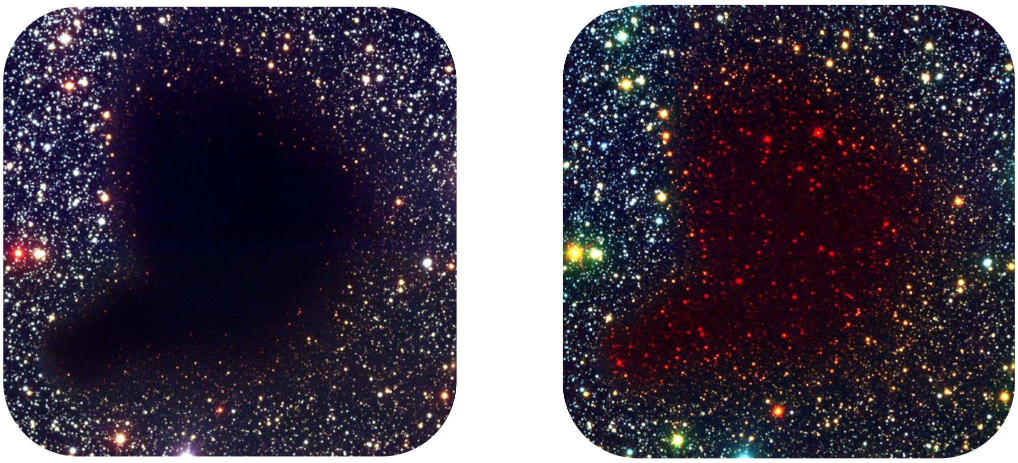

Figure 7: *The left panel shows Barnard 68, a dark cloud, as it is observed in visible light. The right panel shows the image in the left combined with a near-infrared image of the same cloud, where the stars hidden in the dust are unveiled. (Credit: ESO)*

Extinction and reddening

Because all or part of the blue light does not make it through an interstellar cloud, even if we can see the stars, they will look redder than they really are. This effect is called *reddening*. In addition, as part of the light is lost, they will also look dimmer than expected from their distance alone, an effect called *extinction*.

The effects of extinction and reddening are illustrated in Figure 8. It is important for astronomers to keep them in mind when studying astronomical objects; otherwise, they may think that these objects are farther away and cooler than they really are, and get wrong conclusions about them.

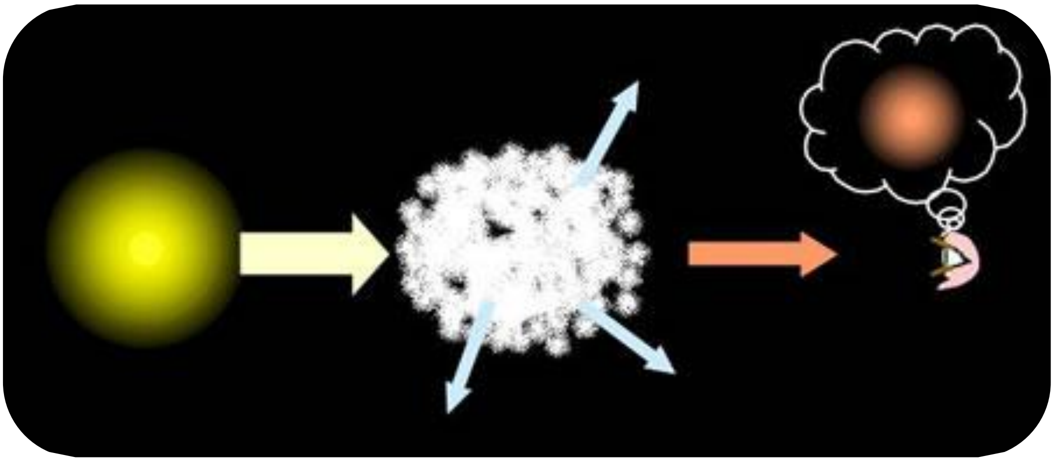

Figure 8: *Dust grains along the line of sight scatter and absorb blue light and let red light get through. The object behind the dust will look redder and fainter than it really is. (Credit: COSMOS, the SAO Encyclopedia of Astronomy)*

The stellar cradle

Stars form from interstellar matter. We know this, not only because the chemical components of the ISM are the same stars are made of, but also because forming stars and young star clusters are always found in association with interstellar clouds.

The birthplaces of stars are called *molecular clouds*. They are clouds whose size and density permits the formation of molecular hydrogen and other molecules (in contrast with other clouds containing mostly ionized gas). Molecular clouds are very cold (10 K); they have typical sizes of about 10,000 Solar Systems (10^{14} to 10^{15} km in diameter) and densities of about 1 billion particles per cubic meter –this is very low, but much higher than the average ISM.

An interstellar cloud is maintained in balance between two basic opposing influences: gravity (inward) and heat (outward). When this balance is perturbed, star formation may begin.

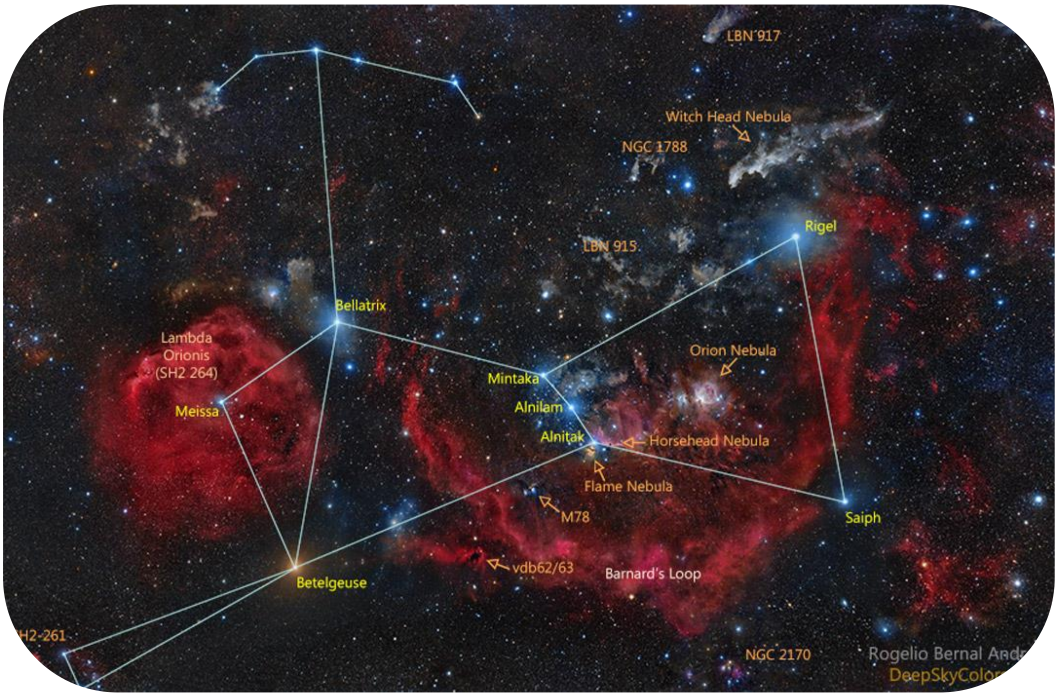

Figure 9: *Giant molecular cloud in Orion. (Credit: Rogelio Bernal Andreo/DeepSkyColors.com)*

References

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