Chapter 18 The Interstellar Medium

Interstellar Matter

When you see pictures of a galaxy such as the Milky Way, you see areas where there doesn't appear to be anything. Fig. 18.1 these areas are not holes in the galaxy, but rather areas where large amounts of interstellar matter is found. This material blocks out the light from these objects and it appears that there is nothing there. You can see that the material is not evenly spread out in space, but rather clumps together. Some areas have a little matter, some have a moderate amount, and some areas have a large amount and blocks things from us that are nearby.

Gas and Dust

The material found between the stars is collectively called the *interstellar medium*. It is made up of 2 components: *dust* and *gas*. The gas is made up of individual atoms and very simple molecules while the dust is more complex than that. The dust is made up of clumps of atoms and molecules not unlike chalk dust, smoke, soot, or fog. The gas itself doesn't block out any light. It is the dust that really blocks out the light. The dust grain is has a size of 10^{-7} m which is very similar to the wavelength of a photon of light. Thus the dust clouds are transparent to long wavelengths such as radio waves but opaque to the shorter wavelengths. The dimming of the starlight by the dust is called *extinction*. Since the longer wavelengths get through and the shorter ones are blocked, that causes the objects to show up redder than normal. That is called *reddening*. Once in a while you will find a small, compact interstellar cloud. These are called *globules*. Fig. 18.2 You can see from looking at Barnard 68 that the stars near the edge all appear red in color. This is a good example of reddening. When looking at the center of Barnard 68 you see a good example of extinction also.

Overall Density

You will find that no part of the galaxy is devoid of dust and gas. However the density is extremely low throughout most of the galaxy. The average is about 1 molecule per cubic centimeter. Some areas have a density of about 10^4 to 10^9 molecules per cubic centimeter. This is much better than the best vacuum ever pulled on Earth which is about 10^{10} molecules per cubic centimeter. Interstellar dust is even rarer. There are only about 1000 dust particles per cubic kilometer. So how can gas and dust affect light? The answer is that space is so vast. Light travels millions or billions of ly to reach us so it travels through vast amounts of dust and gas. Even though there is very little dust out there, it makes space a very dirty place. The Earth's atmosphere is about a million times cleaner than space.

Composition

We have studied the interstellar gas as light from distant stars passes through it. We can take the spectrum and determine the composition. We find that it is very much like the stars themselves. About 90% of it is atomic or molecular hydrogen, 9 % is helium, and the other 1 % is heavy elements. Some of the heaviest elements, such as iron, magnesium, and carbon, aren't present. It is thought that these heavy elements formed the dust particles. We really don't know much about the interstellar dust. Infrared evidence shows silicates, graphite and iron in the dust. The dust probably contains dirty ices also (methane and ethane).

Dust Shape

Dust particles are apparently elongated in shape. We know this because light from the stars is partially *polarized*. This means that light, which has waves in all directions, is filtered by the dust and light that is going in one direction passes through. The alignment of the dust grains is a big topic. It is thought that there is a weak magnetic field and the dust grains are all aligned, thus causing the light to be polarized.

Emission Nebulae

When you look at the Milky Way, you see bright areas that contain untold myriads of stars while the dark areas are places that you see vast amounts of dust and gas blocking the light. If you look more closely, you will see large fuzzy patches. These are known as *emission nebulae*.

Observations of Emission Nebulae

The term nebula has been applied to any fuzzy patch in space. We now know that many of these nebulae are clouds of dust and gas. If you have stars lying behind the nebula, you get a *dark nebula*. If the stars lie inside the cloud, you have a bright emission nebula. If you look at a close up of an emission nebula you can see the hot stars found inside the nebula. Most are relatively small. You find hot O and B class stars inside the nebulae. This causes the gas to be ionized due to the huge amounts of energy being put out. This causes the gas to glow. The red glow is caused by the hydrogen atoms emitting light in the red part of the visible spectrum. Other elements do the same thing, but since hydrogen is so plentiful it hides the other elements. You find in the Trifid Nebula dark lanes running through the nebula. It has been found that these dark lanes are actually part of the nebula, not just a line of sight object. The interaction between stars and dust is seen in the Eagle Nebula. You can see the 3 pillars of gas that have helped form the stars that are there. The cloud in the vicinity of the stars has been dispersed. This is known as *photoevaporation*. The bright fuzzy areas in the clouds are where hot stars are causing that evaporation. The bluish areas in the nebulae are called *reflection nebulae*. This is caused by starlight being scattered by the dust particles. Ionization levels are marked by roman numerals. If it is normal, it is given an I, if the atom has lost 1 electron it is marked as II, and so on. Since emission nebulae are composed mainly ionized hydrogen gas, they are called *HII regions*. Atomic hydrogen is called HI regions.

Nebular Spectra

Most of the photons emitted in an emission nebula escape the nebula. Some of these reach the Earth ands can be studied. You might think that the spectra of the star inside and the nebula would be hard to separate, but they aren't. Each is very distinct. The emission nebula is hot and thin so you see emission lines while the star shows absorption lines. You will find that the spectra show 90 % hydrogen, 9 % helium and 1 % heavy elements. From all of this information, we calculated that the nebula is 10^{22} times less dense than a typical planet. Spectral line widths show that the gas has a temperature of around 8000 K.

“Forbidden” Lines

When studying the spectra, not only did they see red, but they also saw a greenish tint. They had no idea what it was. Some scientists invented nebulium to account for it. Much later we determined that it was due to electron transitions that couldn’t be replicated on Earth. The greenish tint comes from OIII (doubly ionized oxygen). The structure of the oxygen allows an ion to remain in the higher energy state for hours. If the atom is left undisturbed will it emit a photon. These lines are referred to as being forbidden since we can’t reproduce them. Within the nebula there are very few collisions between atoms, so the ionized atom remains undisturbed.

Dark Dust Clouds

When you look at space, 99 % of it is devoid of stars. It is just dark. The typical temperature of interstellar matter is about 100 K. These cold regions are actually interspersed with low density, hot “bubbles” of gas which are associated with the formation and deaths of stars. One of the things found in these cold dark voids in space are the *dark dust clouds*. These clouds are colder than the surrounding space. The temperature may be only in the tens of K and they may be millions of times denser. As dense as these clouds are they are still a better vacuum than we can do on Earth.

Obscuration of Visible Light

Most of these clouds are bigger than our solar system and may be as large as many parsecs across. They are almost completely made up of gas, yet it is the dust that absorbs the starlight. As you can see there are areas that seem not to have any stars. Some 18th century astronomers thought that these were simply empty areas in space. In the 19th century astronomers began to realize this was not true. Before radio astronomy nothing could be proved. But as you can see from the radio image there is gas and dust between those stars and us.

Here is an area called Rho Ophiuchi and you can see the dark gas and dust that is blocking the light. It is several parsecs across. It is too cold to emit in the visible light, but it does emit in the infrared.

Absorption Spectra

In the 1930’s astronomers started to realize the true extent of these clouds as they studied the optical spectra of distant stars. These clouds absorb some of the energy and depending upon the density, composition, and temperature of the cloud, they showed up in the spectra. This is where they really came to understand the clouds. Since the clouds are cold and low density their spectra was easily distinguished from the star’s spectra. They found that the composition of the clouds is similar to other astronomical objects, which shouldn’t be a surprise.

21-Centimeter Radiation

When we take the spectra of these cold, dark clouds, we only see the information that comes from near-by stars that energize the cloud. So we are probably missing some information. To truly probe these clouds we must use a *radio telescope*. IN the hydrogen atom, we have the electron spinning around the proton. But you will also find that the proton and electron spin on their axis, which leads to 2 configurations: one where they both spin in the same direction which is called the parallel state. The other is called the antiparallel state where the proton and electron spin in opposite direction. Antiparallel states have slightly less energy than the parallel states. Parallel state atoms will eventually slow down and reverse the electron spin and become an antiparallel atom. When this happens it releases a photon of light. The wavelength of this light is found at 21 cm range. This hydrogen flip radiation is called the *21 cm radiation*. By studying the 21 cm radiation we can better understand the clouds of atomic hydrogen. By using radio telescopes we can observe any cloud day or night. If it is true that the hydrogen atoms are slowing down, then why do we see any 21 cm radiation at all? Well some of the atoms are energized in the clouds due to collisions between the atoms. This means that some of the hydrogen atoms that slowed down have been revitalized and now are parallel state atoms again. Since this radiation is much larger than the size of the dust grains, it comes to us unaltered by anything.

Interstellar Molecules
It was found that in some of the cold clouds (20 K) that there is no atomic hydrogen, but rather molecules. These are now called *molecular clouds*.

Molecular Spectral Lines
Molecules, like atoms, provide us with a spectral fingerprint. But unlike an atom, the molecule can not only spin, but they can vibrate and rotate. Like the atom, it will go from a fast rotation to a slower rotation. At this point it emits a photon of light. The energy emitted is low, so it is found in the radio range. It is fortunate that it emits in the radio because things like the optical, UV, and infrared can't be used due to low wavelengths. Why are molecules found only in the densest clouds? One idea is that the outer clouds protect the molecules from being torn apart.

Molecular Tracers
Well you would expect astronomers to jump on the molecular hydrogen (H_2) to study the clouds. Unfortunately the H_2 doesn't absorb or emit in the radio. The 21 cm wavelength doesn't help because it only measures the atomic hydrogen. Astronomers now use the measurement of over 120 other molecules in the clouds to gather information. Examples of these molecules are CO, HCN, NH_3, and H_2O. The quantities of these molecules are such that they are a million times less than the H_2. These molecules are called *tracers*. Theses molecules were produced by chemical reactions within the cloud. You may find that different molecules are found in different quantities depending where they are in the cloud due to temperature and densities. Radio and infrared maps made of these clouds reveal that they may by 50 pc across and contain enough material to make 1 million Suns. They are called *molecular cloud complexes*. In the Milky Way there are about a thousand of these clouds.