The Interstellar Medium

Section 1: Introduction

In our Galaxy, in common with other spiral galaxies, there is matter between the stars which forms the *interstellar medium.* This material is of relatively small mass compared to the total mass of the Galaxy, say 10^9 $M_\odot$ out of a total of about 10^{11} $M_\odot$, but the ISM has a significant effect upon the evolution of the Galaxy as a whole since it is the site of star formation. The ISM is, however, relatively inconspicuous at optical wavelengths so its nature and importance were only fully discovered within the last century as astronomy observations moved beyond the optical range.

Even with only optical observations it was possible to see that there was something between the stars. Figure 1 shows an optical all-sky image as derived from photographs at Lund Observatory in Sweden in the 1953–1955. This is plotted in galactic coordinates so the galactic plane runs from left to right across the center of the plot and the direction of the center of our Galaxy is right in the center of the plot. As is customary in such plots, an Aitoff projection is used to preserve areas, and galactic longitude runs from $-180°$ to $+180°$ across the image, from left to right.

What is dramaticly shown in Figure 1 is the existence of dark clouds across a large section of the Galaxy to the left of the centre of the image. This covers an area near the plane for galactic longitudes 310° to 350°, and we now know that this is due to the next inner-most spiral arm, the Sagittarius-Carina Arm, and its associated ISM gas and dust.

A modern version of this type of picture, for the region around the galactic plane, is shown in Figure 2, assembled from wide angle photographs by Axel Mellinger of the University of Posdam in Germany. A better view of this panorama can be found on the network at `http://moore4.cchem.berkeley.edu/~axel/images.html#mwpan` (this is a mirror of the original site in Germany). The image shows the dark clouds and some HII regions–the red bits, due to Hα emission–all along the galactic plane. The range of galactic latitude is about $\pm 20°$ and galactic longitude runs from $-180°$ at left to $+180°$ at right as in the previous Figure. That is the usual way things are presented, so the galactic centre is in the middle of the plot.

While such dark clouds have been known to astronomers since the 1770's, it was only in this century that it was realized that there is also a pervasive ISM over the entire plane of our Galaxy. It happens that the Sun is currently situated quite near the plane of the galactic disk, being located about 7 parsecs "south" of the plane, and so when we look out to distant reaches of our Galaxy, or beyond, the region near the galactic plane is heavily

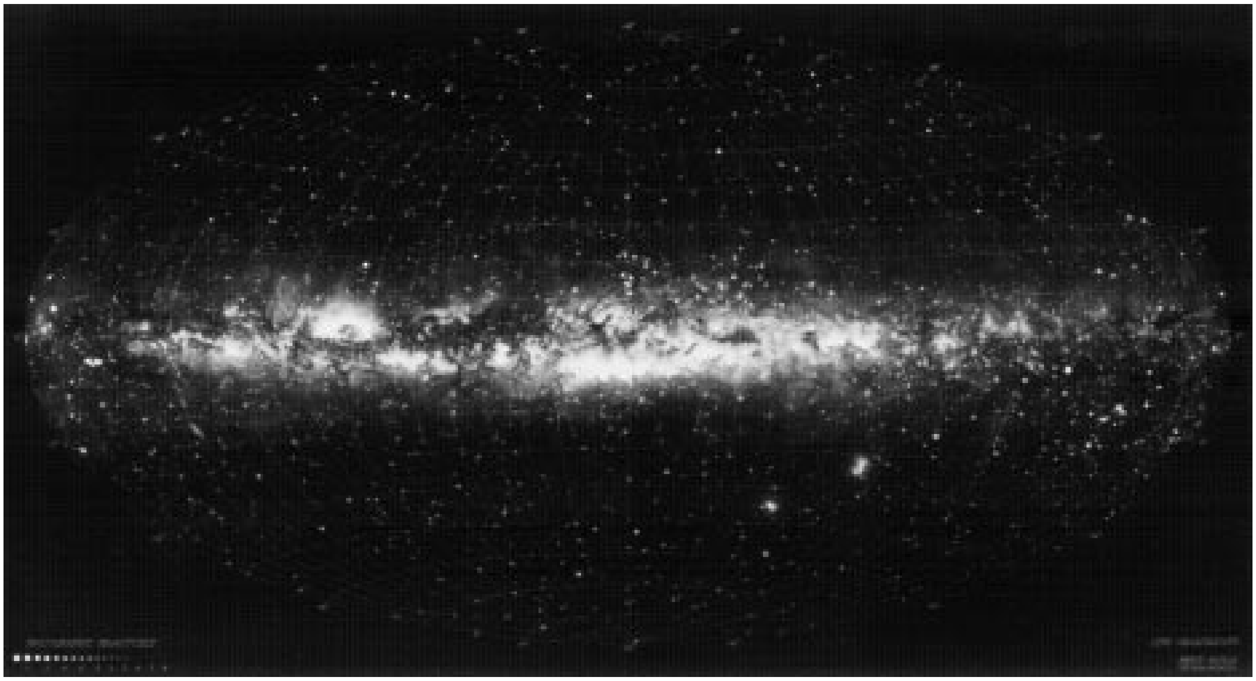

Figure 1—An optical all-sky picture in the photographic band (somewhere between V and B, roughly) as made at the Lund Observatory in Sweden. The original picture is actually a 1 by 2 metre painting of the Milky Way with the 7000 brightest stars superimposed. The original image used here comes from `http://www.astro.lu.se/~eva/milkyway.html` courtesy of Lund Observatory.

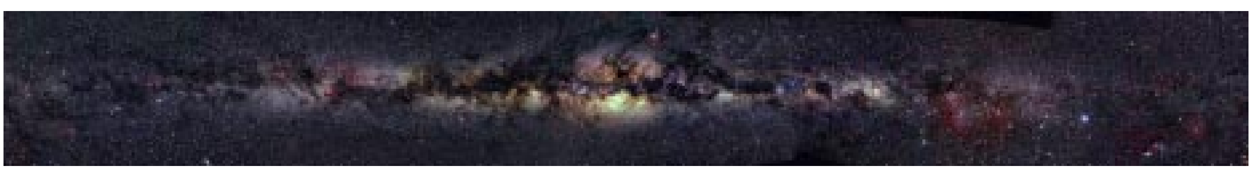

Figure 2—An optical panorama of the galactic plane created from a set of wide-angle photographs by Axel Mellinger. The image covers approximately $\pm 20^\circ$ galactic latitude. Galactic longitude runs from -180° at right to $+180^\circ$ at left.

obscured.

Section 1–1: The Galaxy at Infrared Wavelengths

A rather different picture of things can be seen in infrared images of the sky. The *Cosmic Background Explorer* (*COBE*) carried out all sky observations at a number of wavelengths between 1.25 μm and 240 μm with the FIRAS instrument and at wavelengths between 104.5 μm and 4.414 mm with the DIRBE instrument. These observations were made at a low angular resolution, about 7° at longer wavelengths, but they still give us a picture of the sky over a quite broad range of wavelengths. If one forms a colour image from the near infrared J, K, and L filters Figure 3 results; it shows mostly stars and the absorption by gas and dust in the ISM is at about the minimum possible outside of at very long wavelengths. One then clearly sees the spiral nature of our Galaxy and its bulge, plus there is still some dust absorption on the plane.

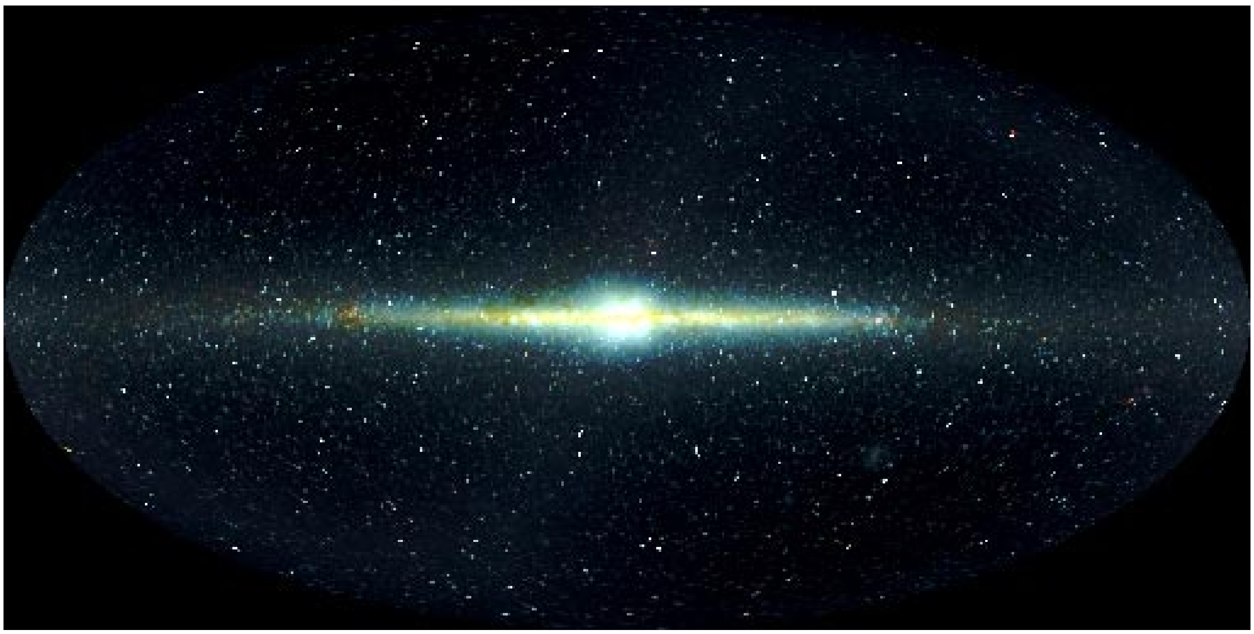

Figure 3—The Galaxy in the near infrared using the J (1.25 μm), K (2.2 μm), and L (3.4 μm) broad-band filter observations from the *COBE* satellite. These are coded as blue, green, and red respectively to form the image.

Going to very long wavelengths the situation is quite different. Carrying out the same process with the 100, 140, and 240 μm data for the colours gives Figure 4. There are NO ordinary stars detected at these wavelengths, in part due to the large field of view, and only a very few stars with circumstellar dust shells weakly detected. The vast majority of the emission is due to diffuse clouds of cool dust (cool meaning temperatures of the order of 20 K or less) in the ISM.

A few individual features can be seen in Figure 4. At far right below the plane is the Orion Nebula. In the mid-right further off the plane is the LMC. On the plane to the left of centre there is a bright spot which marks the tangent to the Sagittarius arm, at about 310° degrees longitude, and at 280° there is a larger, more diffuse patch in Cygnus which marks a major star-forming region of the Cygnus spiral arm. In the outer Galaxy on the plane at left there is a bright spot for the W3–5 cloud complex and at right a cloud

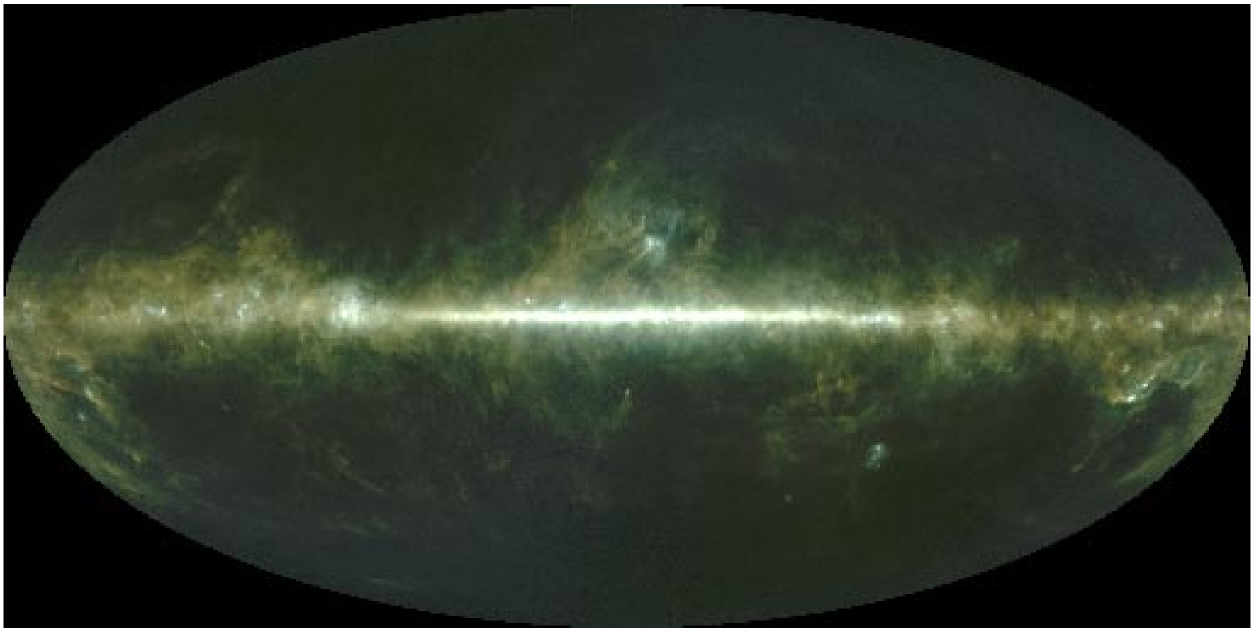

Figure 4—The Galaxy in the far infrared using the 100 μm, 140 μm, and 240 μm broad-band filter observations from the *COBE* satellite. These are coded as blue, green, and red respectively to form the image. In contrast to the previous image, this one is dominated by ISM emission.

associated with the Gem OB1 association. One also sees a higher latitude cloud almost directly "above" the galactic centre.

A spectrum from *COBE*, covering from 104 μm to 4.4 mm, is shown in Figure 5. This is the spectrum at position 17H 15M, -32° $24'$, so it is for a point near the galactic plane. A comparison spectrum from a point 7° off the plane is used for to subtract out the cosmic background emission, and the resulting net spectrum is shown. There is a cool dust component which peaks at a wavelength of about 140 μm, corresponding to a temperature of about 21 K if the dust grains radiate as blackbodies. Near the top of the ISM spectrum there is a strong line from the ISM, a C^+ line structure line due to the fine structure transition in the ground state, $^2P_{3/2} \rightarrow {}^2P_{1/2}$, at 157.7409 μm. This line comes from a diffuse partially ionized component of the ISM; carbon can be ionized by ultraviolet photons which have energies of more than 11.25 eV, so those photons with wavelengths between 1101.72 Å and the Lyman edge at 911.76 Å can ionize carbon but do not ionize hydrogen. Thus C^+ is common wherever there is a source of these ultraviolet photons, including a large fraction of the galactic disk since hot stars produce such emission.

Section 2: Outline

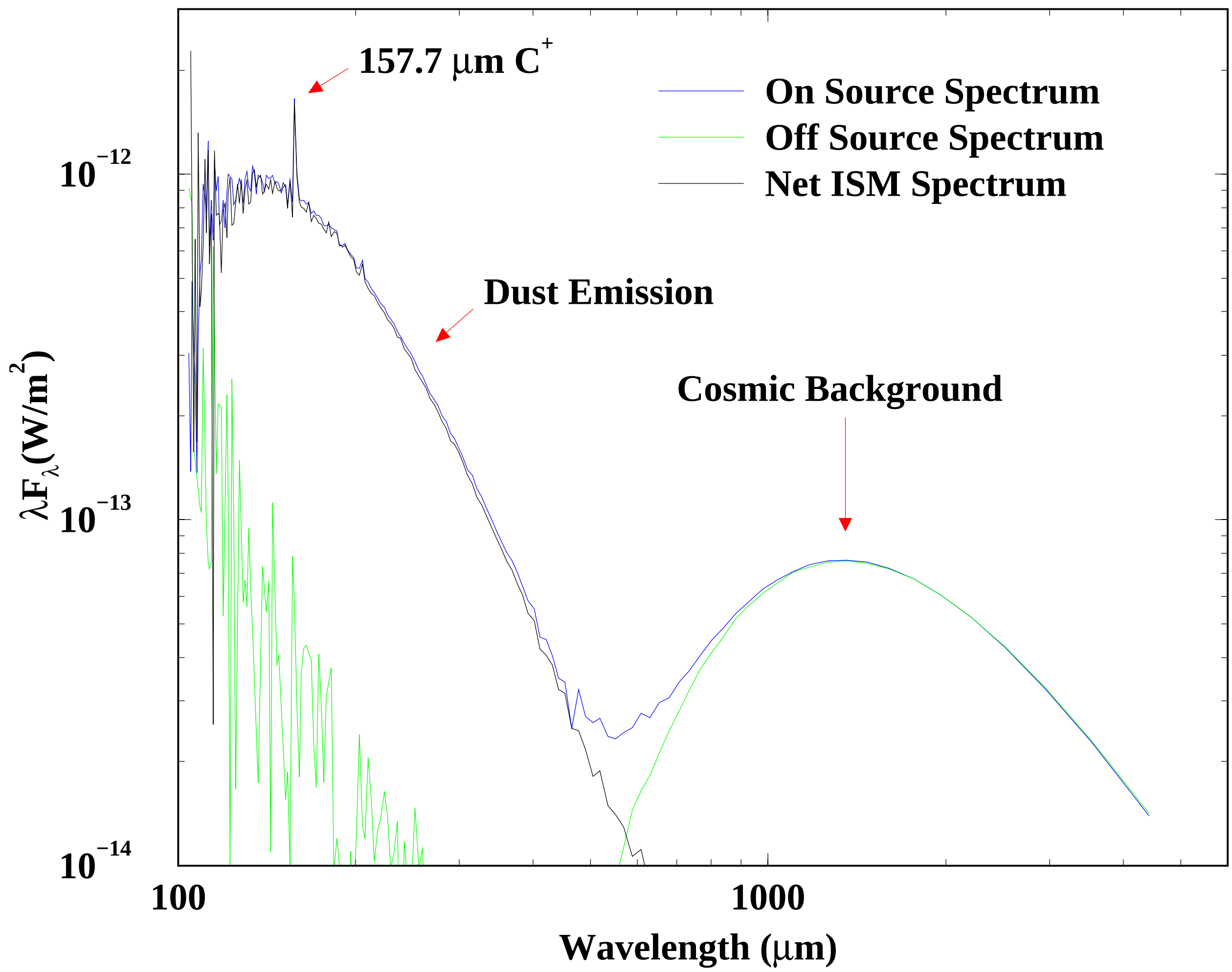

Figure 5—A *COBE* spectrum for a position on the galactic plane, showing the ISM and cosmic background emission components. The cosmic background emission is subtracted by taking an off-source spectrum, in this case 7° off the plane, and subtracting it off. The resulting spectrum has a black-body-like shape and peaks around 140 μm. There is also an emission line at 157.7 μm from C^+ from the ISM, which is seen all over the sky.

These notes are divided into chapters which cover the following topics:

(a) ionized regions in the ISM: H II regions and planetary nebulae;

(b) molecular line emission from the ISM;

(c) supernova remnants, and shock fronts in the ISM;

(d) dust in the ISM

(e) molecular clouds; and

(f) star formation.

Historically the study of ionized regions and supernova remnants formed the core of the study of the ISM, say in the first half of the 1900's, but at present the main thrusts of ISM research are concerned with molecular clouds, the global ISM, and particularly with star formation. My goal is to put more emphasis on those topics in these notes, and to not spend as much time on HII regions and supernova remnants as would be the case if I followed any of the classic textbooks, such as Spitzer's book *Physical Processes in the Interstellar Medium* or Kaler's book *The Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*.

There are various colour Figures in these notes, which do not come out properly from the monochrome printer. I have thus created a WWW page `http://www.iras.ucalgary.ca/~volk/figs.html` where all of these diagrams can be looked at on screen. The Figures are arranged in the same order as in the notes.