Introduction to the interstellar medium (ISM)

- While the title of this course is “modern astrophysics,” it’s a bit of a misnomer. At least half of the course is spent discussing the physics of things other than stars: galaxies, the universe as a whole, and the stuff between the stars.

- When you look at the Milky Way on a dark summer night, you see a dark band running through its center. There is a terrific picture of the Milky Way in Shu’s book, Figure 12.1. I’m going to draw the Milky Way, not as seen from inside it, but as seen from our near neighbor, the Andromeda galaxy.

Objects in mirror are larger than they appear:

- Scale height for:
  - dust, H$_2$ and CO: 75 pc
  - young stars: 75 pc
  - HI (neutral hydrogen): 150 pc
  - H II (corona): 3 kpc
  - for older stars, $Z \approx Z_{\odot}$
  - for the oldest stars, $Z \approx 0.01Z_{\odot}$

- Not uniform:

Somewhere between 3 and 10 percent of the mass of the Milky Way is in gas.
• Where does it come from?
  1. Some primordial material – we observe deuterium that can only be primordial
  2. Mostly recycled material from stars – debris

• One very important feature for the ISM is that it’s chaotic – it looks like a fractal, with structure on many different scales. There is no natural size scale for the ISM.
  1. The thing that makes the study of stars relatively easy is that they’re round – spherical symmetry makes modeling much easier.
  2. But most of what we see in the ISM is not symmetric.
  3. What we do is we discuss those problems which are symmetric and wait for bigger computers to treat those which aren’t.

• Three moderately tractable problems:

![Diagram of a hot star with neutral and ionized regions](image)

(a) Photoionized nebula.

![Diagram of a supernova](image)

(b) Supernova.

![Diagram of spiral arms](image)

(c) Spiral arms.

These, at least, have some symmetry.

• Mostly, the interstellar medium is clouds embedded in diffuse gas:

<table>
<thead>
<tr>
<th>Type</th>
<th>Composition</th>
<th>n (cm$^{-3}$)</th>
<th>T(K)</th>
<th>size (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular clouds</td>
<td>H$_2$, CO, and dust</td>
<td>$10^3$–$10^6$</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Cool neutral</td>
<td>HI</td>
<td>$10^1$–$10^2$</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Warm neutral</td>
<td>HI</td>
<td>0.3</td>
<td>7000</td>
<td>20</td>
</tr>
<tr>
<td>Coronal gas</td>
<td>HII</td>
<td>$3 \times 10^{-3}$</td>
<td>$10^6$</td>
<td>pervasive</td>
</tr>
</tbody>
</table>
• These are all in pressure (but obviously not in thermal) equilibrium. The products $nkT$ had better be equal.

• How do we detect these?

1. molecular clouds are observed at millimeter wavelengths – they radiate emission lines from molecules – especially CO, but also HCOOH, NH$_3$, and even ethanol.
2. neutral HI is seen in emission from neutral hydrogen line at 21 cm: spin flip.
3. coronal gas is mostly in absorption against distant stars and quasars.

• Why do we see these different phases? What we see depends on how hot it is.
So why the coronal gas? It’s cooling, just very slowly; although it’s not in the disk.