CHAPTER 11: THE INTERSTELLAR MEDIUM

NOTES AND SKETCHES

11.1: THE INTERSTELLAR MEDIUM

Gas and Dust

- The empty vacuum of space is not actually entirely empty
- Interstellar medium permeates
- Gas: Individual atoms or free molecules
- Dust: Clumps of atoms or molecules
- Clumps: Still pretty tiny (10^{-7}m)

Scattering

- Dust grains are about the same size as the wavelength of blue visible light
- Shorter wavelength blue light is scattered
- Longer wavelengths are unaffected
- Regions with lots of dust are transparent to long wavelengths, but opaque to short wavelengths

Interstellar Reddening

- Light passing through dusty region (or cloud) will be "reddened"
- Blue light scatters, red light passes through: Object appears redder (therefore cooler) than it actually is
- Effect is cumulative: Longer path or thicker cloud
- More distant object along same line of sight: Longer path, more reddening
- Objects at same distance in different directions: Thicker medium, more reddening

Spectrum Correction

- Blue light scattered more than red, but some blue light still transmitted
- Same spectral lines appear for star: Additional absorption lines possible as gas/dust absorbs certain frequencies
- Same lines for star means correct identification and classification are not a problem

Density and Composition of the Interstellar Medium

- Not really empty is still pretty darn empty
- About 1 atom or molecule per cubic centimeter
- By comparison, the Earth's atmosphere has about 10^{19} molecules per cubic cm

Surprise! More Hydrogen!

- Easy to determine the composition of the gas: Spectroscopy
- It's hydrogen (90%)
- What not hydrogen is helium (9%)
- That last 1%: Everything else
- Dust is more complicated, because you have atoms and molecules stuck together

11.2: STAR-FORMING REGIONS

Nebulae

- Anything fuzzy that isn't a star (or planet) is a nebula
- Technically, a cloud of interstellar gas and/or dust
- Dark nebulae: Dark. Nebulous. Hence the name.

Emission Nebulae

- Glow because they are hot
- You will typically find a very hot, very new, O or B star (or maybe a few of them) in the center
- Cloud usually looks red because H-alpha absorption/emission dominates
- Dark dust lanes are part of nebula
- Typical density about 10^2 atoms per cm^3

Reflection Nebula

- Cooler: Not glowing
- Light is reflected/scattered instead of absorbed/emitted
- Bluish color

Ultraviolet Astronomy and the "Local Bubble"

NOTES AND SKETCHES

- Interstellar medium is not uniform, does not have uniform temperature
- Denser regions are cooler: Opaque to UV
- Very low density regions are hotter: Transparent to UV
- Sun is near the center of a low-density bubble
- Density about 5000 atoms per m^3, or 1 atom per every $200cm^3$
- Bubble is probably the result of a supernova explosion about 300,000 years ago

11.3: DARK DUST CLOUDS

- Very dark: Do not emit or reflect visible light
- Very cold: Less than 100K
- Very dense: 1000 atoms per cm^3 (very dense is obviously relative to interstellar media in general)

Obscuration of Visible Light

- How do you know it's there, if it's dark?
- Opaque to visible does not mean opaque to all frequencies: Low temperature, look for long wavelength, low frequency emissions
- No visible glow, but infrared glow
- Dark dust can have a radio signature
- Dark dust is cool enough to contain molecules

Another Hydrogen Emission Line

- Not the orbit-jumping type we looked at before
- Particles spin: Analogous to sun and planets spinning
- If electron and proton have matching spin, the electron can spontaneously "spin-flip"
- By flipping itself upside down, the electron's opposite spin results in a lower-energy state for the atom
- Energy has to be emitted in the process: Just a little bit, corresponding to a low-energy photon

21-Centimeter Radiation

- A hydrogen spin-flip transition emits a photon with wavelength = 21 cm (low frequency radio wave)
- So what? Well, the process is going to happen everywhere there's atomic hydrogen...which would be...everywhere
- Stronger line means more hydrogen
- Line is not attenuated: Long wavelength is not absorbed or affected by any other interstellar debris
- Does not tell you anything about actual stars, but tells you a lot about the "emptiness" between them

Molecular Gas

- The darkest, densest clouds are the most complex
- High density: About 10^6 molecules per cm^3 (again, dense is a very relative comparison)
- Low temperature: 20K-ish
- Molecular Clouds
- Molecules can form: Complex, multi-atom structures: HCN, NH_3, H_2O, H_2CO
- 21-cm line disappears: Atomic hydrogen actually forms molecular hydrogen (H_2)
- Lines from everything else start to show up across the radio frequencies

Molecular Cloud Complexes

- Bright emission nebulae emerge from these dark, dense clouds
- To quote the textbook: An emission nebula "bursts out" when star formation heats up a region and ionizes the cold cloud
- The cold clouds are not actually separate, discrete clouds: They trail across huge swaths of space

11.4 THE FORMATION OF STARS LIKE THE SUN

NOTES AND SKETCHES

Gravity and Heat

- Molecular cloud in equilibrium: Gravity pulls inward, balanced by outward heat pressure
- Disturb the equilibrium, gently (slowly): Cloud cools, molecules move more slowly, gravity is greater than pressure, clumps start to form
- Disturb the equilibrium, violently (rapidly): Shockwave from nearby supernova or an emission nebula "bursts out" with O and B star formation
- To generate star formation, the rapid method is the way to go (neither you nor I have the billions of years it would take to let a molecular cloud just cool and collapse "naturally")
- Lower limit: Less than about 10^{57} atoms, and you don't have enough mass to ultimately ignite the fusion reaction

Stage 1: An Interstellar Cloud

- Huge cloud: Tens of pc across
- Cold cloud: About 10K
- Dense cloud: At least 1000 particles per cm^3 (hopefully more)

Fragmentation

- Whatever starts the cloud collapse, as it collapses it fragments
- Local regions collapse together independently of other regions
- Cloud becomes many, multiple, smaller clouds (which helps explain multi-star systems)
- Fragmentation stops when the density of the pieces increases enough to increase the temperature and pressure
- This process takes several million years

Stage 2 : A Contracting Cloud Fragment

- Fragment mass: 1-2 solar masses
- Fragment size: 100 times the diameter of the solar system
- Fragment density: 10^6 particles per cm^3
- Fragment temperature: Gradient from about 100K at the center to about 10K at the edges
- Tens of thousands of years pass as this cloud keeps gradually collapsing

Stage 3: Almost a Protostar

- Size: Reduced to about the diameter of the solar system
- Density: Up to 10^{12} particles per cm^3
- Temperature: Gradient from about 10,000K at the center to about 10K at the edges
- What makes it "proto?" Starts to have a discernible shape, photospheric surface

Stage 4: A Protostar

- Still collapsing, getting hotter, getting denser
- All those beautiful complex molecules? Mostly shredded. Literally ripped into constituent particles by the high heat at the core
- Star is getting hot enough to radiate in the infrared/red (at the photosphere/surface), but no fusion yet (much hotter at core, still not hot enough)
- Properties can be plotted on H-R diagram: Start to map out lifecycle of star

Stage 5: Protostellar Evolution

- And so it goes: More collapsing, more heating up
- Rate starts to decrease: Collapsing more slowly

The T-Tauri Phase

- Remember that all this evolution is happening to a cloud that is spinning
- Spin generates protostellar winds
- Bipolar flow: Jets of matter shoot out perpendicular to the plane of rotation

Stages 6 and 7: A Newborn Star

- After the dramatic display of mass ejection during the T-Tauri phase, we are left (in this example) with a bit more than 1 solar mass
- It takes about 10 million years from when we first started, but we are finally going to light the fuse
- For that amount of mass, if you shrink it to 10^6 km across, heat it up to 10 million K at the core, you have enough pressure to ignite fusion
- Star is still a bit bigger and a bit cooler than the sun

And Still More Time Passes...

- Another 30-odd million years or so, while the star still slowly shrinks
- By the time it reaches the size of our sun, its temperature has increased to about 6000K
- Core always much, much hotter and much, much denser
- Call it Stage 7 when the star hits the main sequence and achieves hydrostatic equilibrium

NOTES AND SKETCHES

11.5: STARS AND OTHER MASSES

The Pre-Main Sequence

- Where a star lands on the main sequence depends on where it started: How much mass the original fragment contained
- How long it takes depends on the mass as well: More massive stars reach the main sequence more quickly

The Zero-Age Main Sequence

- What we call the main sequence on the H-R diagram is not an evolutionary path
- A star will not travel up or down the main sequence over the course of its lifetime
- The main sequence represents the properties a star possesses (temperature, color, luminosity) when it reaches a stable state
- A Stage 7 star will stay in the same place on the main sequence

"Failed" Stars

- Not every cloud fragment is massive enough to collapse into a fusion-powered star
- Low-mass fragments still collapse, but never ignite
- A fragment needs roughly 1/10 a solar mass for fusion

Brown Dwarfs

- Just spinning out there in space, tiny and getting colder (and therefore harder to detect)
- Same techniques for locating extrasolar planets can be used to find brown dwarfs
- How many are there? Nobody knows, but it's not unreasonable to guess that there may be as many of them as there are stars that lit up

11.6: STAR CLUSTERS

Astrophysics Learning Lab

- All the stars in a cluster formed from the same original cloud that fragmented
- Means they are made up from the same set of original molecules: Uniform composition
- Means they began their evolution at the same time: Uniform age
- Convenient for making comparisons between star types

Open Clusters

- Stars appear close together in the sky because they really are close together
- Can have up to several thousand stars
- Typically pretty small: A few pc across (small being a relative comparison)

Our Pals the Pleiades

- At least 1000 stars identified
- Most appear to be hot, but there is a huge search for brown dwarfs in the cluster
- Book states age as "less than 20 million years," based on presence of O-type stars
- Cluster has to be older than that, based on presence of dimmer, lower-mass stars
- Geoff Marcy (***Exo! Planet! Rock! Star! Astrophysicist!***) thinks it's closer to 115 million years

Globular Clusters

- Spherical distribution of low mass stars: About 50 pc diameter
- Located out of the galactic plane
- Huge number of stars (into the millions), all of them quite old
- Stars are all low-mass objects (less than solar mass)
- Makes them enormously old: Probably 10 billion years

Clusters and Nebulae

- Emission nebulae may contain star clusters
- Stars forming in close proximity to each other affect each other
- Giant stars can grow faster
- Collisions/mergers can occur
- Fewer large stars, more smaller stars

NOTES AND SKETCHES