Interstellar Medium (ISM)

- 1930s: open clusters contained fewer faint stars and redder stars the farther away the cluster is from us.
- ISM: Gas (very cold; individual atoms and small molecules) and dust (clumps of atoms and molecules)
- ISM causes
  - Extinction
  - Reddening
  - Polarization
- Composition and shape of ISM
  - Nebula (Emission, Reflection)
  - Dark dust clouds
  - Large scale H structures (21-cm radiation)
  - Molecular clouds

Density of interstellar matter

- Interstellar matter (gas and dust) is found everywhere in interstellar space but not distributed uniformly
- Overall density of the interstellar medium is very low
  - The gas averages roughly $10^6$ atoms per cubic meter—just one atom per cubic centimeter
  - Interstellar dust is even rarer—about one dust particle for every trillion or so gas atoms.

Composition of ISM

- Gas:—composition is more or less like stars or jovian planets
  - about 90%--is atomic or molecular hydrogen,
  - 9% is helium,
  - 1% heavier elements
  - Spectrum shows that generally the gas is deficient in some heavy elements, such as carbon, oxygen, silicon, magnesium, and iron, most likely because these elements have gone to form the interstellar dust
- Dust:—infrared observations indicate for silicates, carbon, and iron, supporting the theory that interstellar dust forms out of interstellar gas
  - there is also a indication for some “dirty ice,” a frozen mixture of water ice contaminated with trace amounts of ammonia, methane, and other compounds
Interstellar Gas

- 90% hydrogen
- Molecular hydrogen
- Atomic hydrogen
  - neutral form (HI) – most abundant
  - ionized form (HII)

Interstellar H

- Ionization state of an atom is represented by attaching roman numeral to its chemical symbol. e.g.
  - I – neutral atom
  - II – singly ionized atom (missing one electron)
  - III – doubly ionized atom (missing two electrons)

- Because emission nebulae are composed mainly of singly ionized hydrogen, they are often referred to as HII regions.
Spectroscopy in Astronomy

The emission and absorption spectra are characteristic of the chemical composition of the gas cloud.

Bohr’s Model of the Atom (1913)

1. \( e^- \) can only have specific (quantized) energy values

2. light is emitted as \( e^- \) moves from one energy level to a lower energy level

\[
E_n = -R_H \left( \frac{1}{n^2} \right)
\]

\( n \) (principal quantum number) = 1, 2, 3, ...

\( R_H \) (Rydberg constant) = 2.18 x 10^{-18} J

\[
E = h\nu
\]

\[
E = h\nu
\]

\[
E_{\text{photon}} = \Delta E = E_f - E_i
\]

\[
E_f = -R_H \left( \frac{1}{n_f^2} \right)
\]

\[
E_i = -R_H \left( \frac{1}{n_i^2} \right)
\]

\[
\Delta E = R_H \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)
\]
Calculate the wavelength (in nm) of a photon emitted by a hydrogen atom when its electron drops from the \( n = 5 \) state to the \( n = 3 \) state.

\[
E_{\text{photon}} = \Delta E = R_H \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)
\]

\[
E_{\text{photon}} = 2.18 \times 10^{-18} \text{ J} \times (1/25 - 1/9)
\]

\[
E_{\text{photon}} = -1.55 \times 10^{-19} \text{ J}
\]

\[
E_{\text{photon}} = \frac{h \times c}{\lambda}
\]

\[
\lambda = \frac{h \times c}{E_{\text{photon}}}
\]

\[
\lambda = 6.63 \times 10^{-34} \text{ (Js)} \times 3.00 \times 10^8 \text{ (m/s)}/1.55 \times 10^{-19} \text{ J}
\]

\[
\lambda = 1280 \text{ nm}
\]

Detecting ISM

Absorption lines they produce in starlight that passes through them.

- The wide, intense lines are formed in the star’s hot atmosphere.
- Narrower, weaker lines arise from the cold interstellar clouds.
- The smaller the cloud, the weaker the lines.
- The redshifts or blueshifts provide information on cloud velocities.

The Illumination of Nebulae

- Emission Nebulae – in the vicinity of a very hot stars – UV radiation \( \lambda < 912 \text{ A} \) – remove an electron from H atom – when a substitute e is captures – series of lines – light of the nebula is different from the light of the stars – Stroemgren Sphere – bright line spectra.
Emission Nebulae

- Forbidden Lines (oxygen)
- The relative strength does not show at one the relative abundance of the chemical elements in the gases of the nebula

ISM Types
Emission Nebulae (HII regions)

- Extended clouds of hot, glowing gas. Nebulae large enough to measure them
- The illumination -- UV radiation from a O- or B-type star ionizes surrounding nebular gases
- As hydrogen electrons recombine with nuclei, they emit red colored visible radiation (Halpha line)
- Nebular gas spectrum indicates composition similar to our sun, stars, and other ISM
- Spectral line widths imply that gas atoms and ions have temperature around 8000K.
- Size information coupled with estimates of matter in our line of sight (as revealed by nebulae’s total light emission) ascertain nebular density - 108 particles per cubic meter
- Emission spectrum produced by them allow us to measure their properties

The Illumination of Nebulae

- Dark Nebulae – no star to illuminate them – they dim the light of whatever lies behind
- Reflection Nebulae – around stars cooler than B1, B2 – starlight is scattered by the dust particles, same spectrum as the stars
Orion Nebula

Interaction between Nebulae
Through examination of interaction between dust and nebular gas, we see that dust lanes are part of the nebulae and not just dust in our line-of-sight.

Gas and Dust on Space

Effects of a star’s radiation on nearby gas and dust - reflected starlight

NGC 1999

Very dense cold cloud of gas
**The Trifid Nebula**

reddish H II region -- the hydrogen is ionized by nearby hot stars and glows through fluorescence

The surrounding blue region is a reflection nebula

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**Red glow – Hα line**

hot young stars associated with these clouds of gas ionize them

The blue color - small particles of dust, which scatter the light from the hot stars

Dark clouds

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**An Expanding Bubble located in the Large Magelanic cloud - bubble-like expanding shell of gas - 4000km/s**

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**The Vela Supernova Remnant**

About 12,000 years ago, a dying star in the constellation Vela exploded - shell of gas expanding outward from the site of the explosion
Gum Nebula is the closest supernova remnant

Vela-Puppis-Canis Major

Spanning 40 degrees across the sky
Front edge at 450 lyrs
Back edge at 1500 lyrs
Spatial distribution of the OB stars within the Nebula??
Distribution of interstellar extinction??

The 21-CM Line

- A new means of exploring the interstellar medium and its structure became available to astronomers in 1951, when a spectral line at 21 cm (1420 Mhz) produced by neutral hydrogen was discovered
- An electron revolves about a proton, it and the proton also spin like tiny rotating tops
- Once in 11 million years (on average) an electron, if spinning in the same sense as the proton to which it is bound and not disturbed by collisions with other atomic particles, will spontaneously change its spin to the opposite sense.
- This change drops the atom into a lower-energy state

21-Centimeter Radiation

When no background star is available, how astronomers get information about dark dust cloud or interstellar medium?

Then, astronomers observe them by using the process known as the 21-centimeter line.

- 21-cm line observation does not require light, only enough hydrogen to produce a detectable signal.
- Much gas in interstellar space consists of atomic hydrogen (H I form).
- Wavelength of 21-centimeter radiation is much larger than the typical size of interstellar dust particles, so they are not absorbed on their way to Earth and can be detected by radio telescopes.

21-cm radiation is produced whenever the electron in hydrogen atom reverse its spin, changing its energy very slightly in the process.
Molecular gas

- Mainly $\text{H}_2$.
- Dense clouds, only radio waves can be detected.
- Use radio observations of other "tracer" molecules: CO, HCN and other.
- Molecular clouds do not exist as distinct – found close to one another.

Dark Dust Clouds

- More than 90% of space is free from emission nebulae and stars. Within these dark voids - dark dust cloud.
- They are typically bigger than our solar system and irregular in shape.
- They are much colder (only few 10s of Kelvin) and much denser than their surroundings.
- Made primarily of gas, but the dust they contain either diminish or completely obscure the light from background stars.

Blocking of light by dusty grains

- **Extinction**: the general dimming of starlight by interstellar matter is called extinction.
- **Reddening**: dust preferentially absorbs short wavelength radiation. Because of this, blue part of light from distant stars is obscured more than red. So in addition to being generally diminished in overall brightness, stars also appear redder than they really are. This effect is know as reddening.
Blocking of Light

- Obscuration (blocking) is caused mainly by dust *dust grains*
- Light can be obscured (absorbed or scattered) only by particles having diameters comparable to or larger than the wavelength of radiation involved
- The size of typical dust grain is ~ 10^-7 m (0.1 µm), comparable in size to the wavelength of visible light. So dust grains try to block the visible light
- Obscuration produced by particles of a given size increases with decreasing wavelength (increasing frequency). So, Ultra violet, X-rays and Gamma rays etc. are blocked even more by Dust grains
- *But infrared and radio waves can pass through*

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**Great Rift in the Milky Way**

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**dark Dust Clouds**

Obscuration of visible light

A dark dust cloud in the foreground obscures the stars of the Milky Way. The background stars on the periphery of the dust cloud are only partially obscured because the dust layer is thinner there. They appear red because the dust grains absorb blue light more effectively than red light.

Credit: Two Micron All Sky Survey Project

APOGEE (February 25, 1996)
Horsehead Nebula
Located in the constellation Orion

Emission Nebula

Dark dust cloud

Visible and Infrared Images of the Horsehead Nebula in Orion

Shape of the ISM

- Gas:— particles are basically spherical.
- Dust:— individual particles are elongated but large scale structure is more complex.
Polarization of Light

Light is an electromagnetic radiation (combination of electric and magnetic field) and travels in a random orientation. But due to the shape of dust particles, sometimes light rays become aligned with all the electric field vibrating in the same plane. This is called polarization of light.

Model of an Interstellar Dust Grain

Typical grain sizes are $10^{-8}$ to $10^{-7}$ m
Core - rocky material (silicates or graphite)
mantle of ices
Interstellar dust grains may be the means of forming interstellar molecules

Maxwell (1873), proposed that visible light consists of electromagnetic waves.

Electromagnetic radiation is the emission and transmission of energy in the form of electromagnetic waves.

Speed of light ($c$) in vacuum = $3.00 \times 10^8$ m/s

Infrared Cirrus: 12.5 x 12.5-degree field near the south celestial pole.
Microscopic dust grains, which are heated by radiation from stars and re-radiate their energy in the infrared.
### Star-forming fields

**Carina – Crux – Centaurus**
- CarOB1, CarOB2, Tr16, Cr 228, Crux 1, 2 …

**Ara – Norma Field**

**Vela- Puppis-Canis Major**
- Cr 121, NGC 2439

**Monoceros OB2**