Chapter 18

The Interstellar Medium

Gas & Dust Among the Stars

Dr. Tariq Al-Abdullah

LEARNING GOALS:

18.1 INTERSTELLAR MATTER

18.2 EMISSION NEBULA

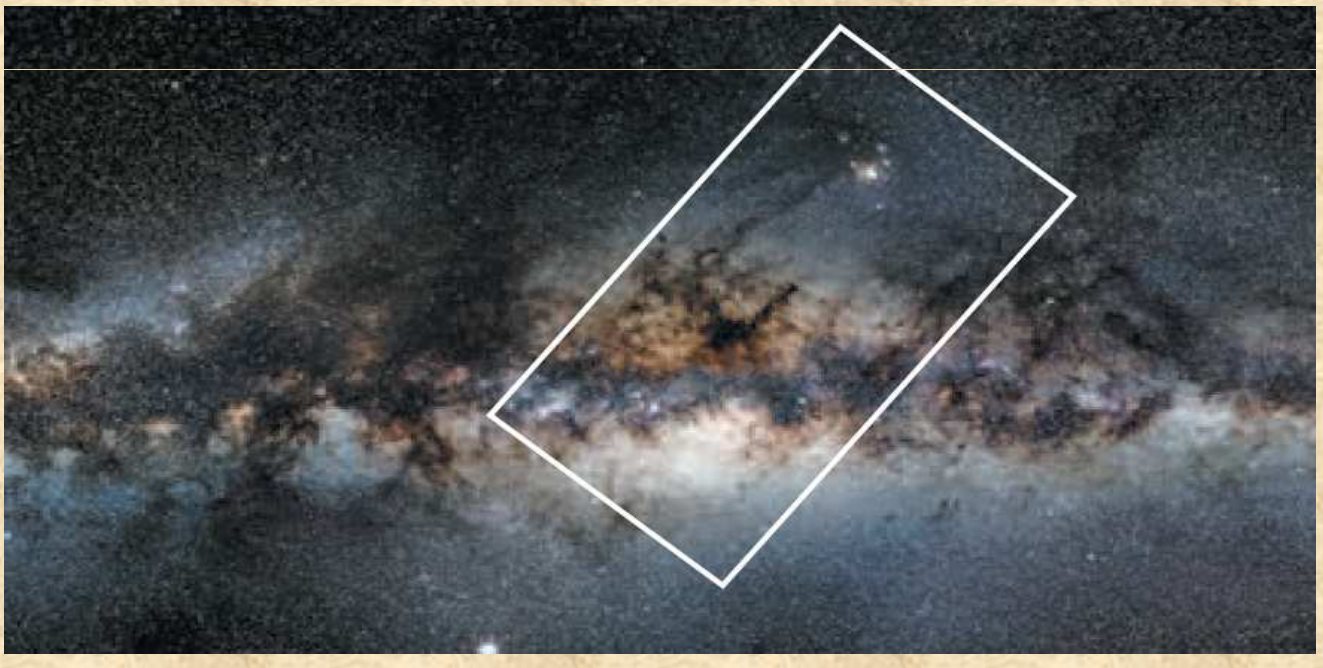
18.3 DARK DUST CLOUDS

18.4 21-CENTIMETER RADIATION

18.5 INTERSTELLAR MOLECULES

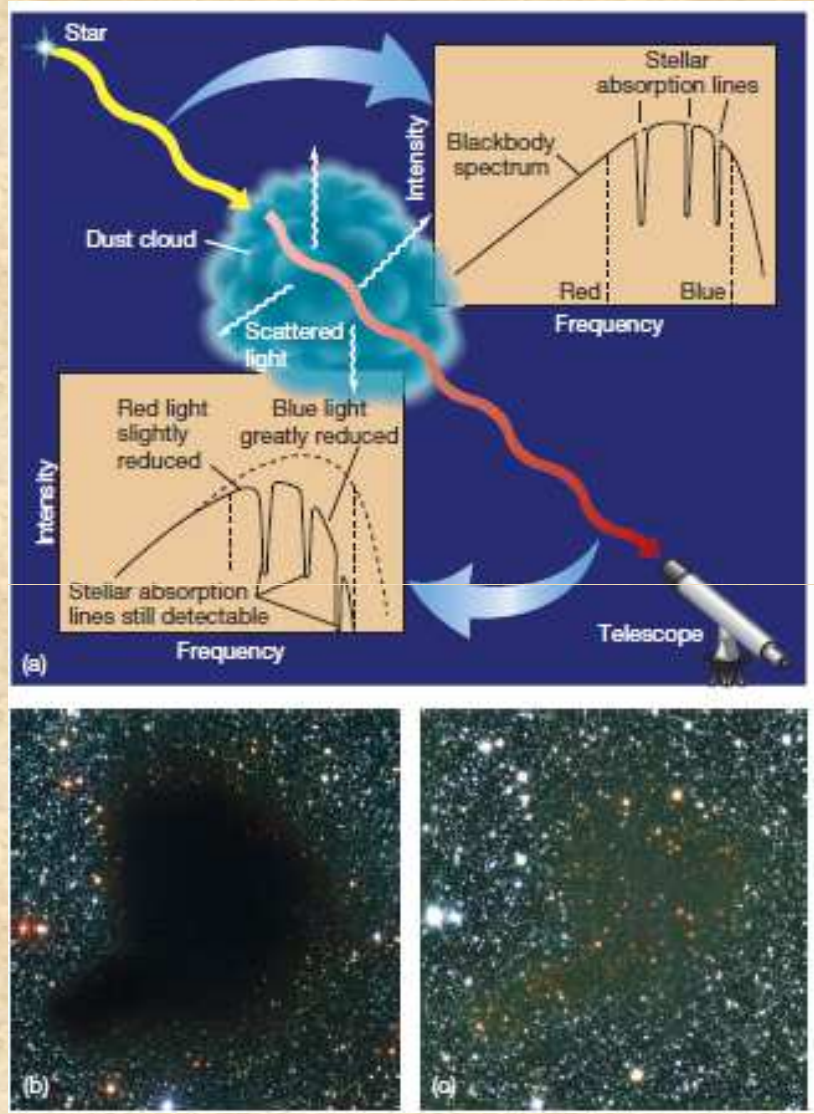
18.1 Interstellar Matter

- The dark areas are not simply holes in the stellar distribution.
- There are regions of space where interstellar matter blocks the light from stars beyond.
- Interstellar matter is distributed unevenly throughout space.
- the matter among the stars is called the Interstellar medium.



18.1 Interstellar Matter

- It is made up of two components: Gas and Dust (intermixed).
- Gas: individual atoms (10^{-10} m size) or small molecules (10^{-9} m across).
- Dust: more complex; clumps of atoms and molecules, grain 10^{-7} m.
- Gas is transparent but the dust is opaque.
- Dimming of starlight due to interstellar medium: Extinction.
- Interstellar Reddening: Why is the sky blue? Why is the sunset red?
- Spectral lines are still recognizable in the light reaching the Earth.



Interstellar Density

- The density of the stellar medium is extremely low, gas: 10^6 atom/m^3.
- Gas density ranging from 10^4 to 10^9 atom/m^3.
- Vacuum in the Lab is 10^{10} molecules/m^3, Atmosphere = 2.7 x 10^{19}/cm^3.
- Interstellar dust is rare: one dust particle for every 10^{12} atoms.
- on average 10^{-6} dust-particles are found per m^3; 10^3 particle/km^3.

- ***How sparse matter diminish light?***

•Interstellar space is vast, 1 pc among stars, 10^{-7} pc➔ matter can accumulate slowly but surely to affect the beam.

- **Between the Earth and α-Centauri (1.3 pc) ➔ 10 billion billion dust particles.**
- **Dust particles make space a relatively dirty place. (Earth million times cleaner)**

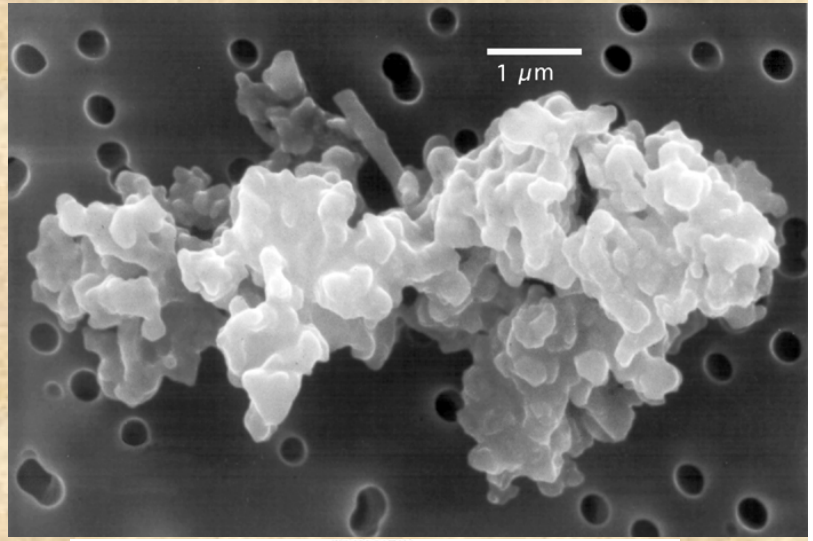
Interstellar Composition & Temperature

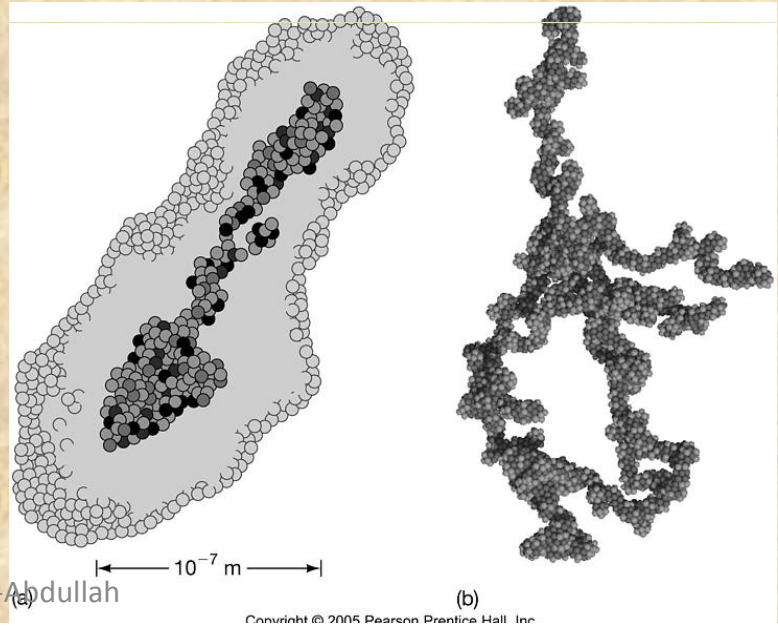
- **Gas**
  - about 90% hydrogen (by numbers of atoms); atomic or molecular
  - about 9% helium
  - remaining 1% heavier elements, such as C, O, Si, Mg, and Fe.
- **Dust**
  - like cigarette smoke
  - Not very well-known, silicates, graphite, iron, and dirty ice
- **Temperature**
  - few Kelvins to few hundred kelvins ➔ 100K is typical temperature (cold)
  - depends on nearness of stars to heat medium
- **Total Mass**

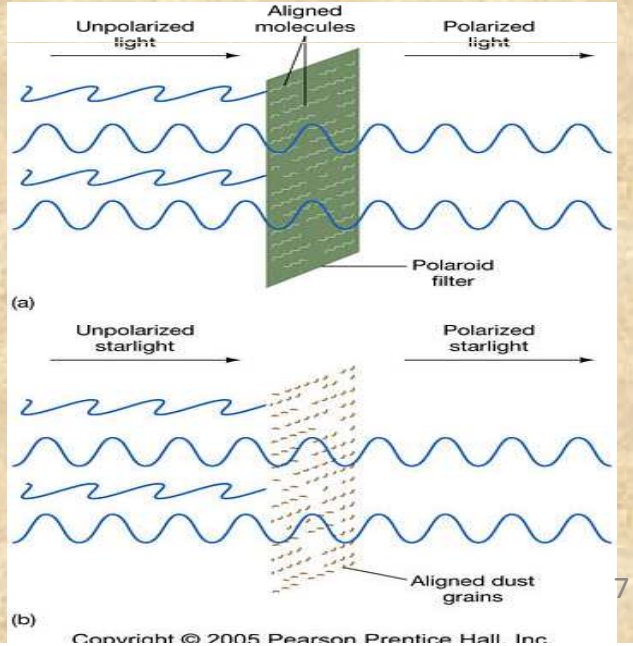
The density is low, but the total amount of mass in the interstellar region is nearly as much as the mass contained in the stars.

Dust Shape

- The shape of the dust is known better than their compositions.
- Typically elongated; few micrometers.
- Elongated shape, size, and orientations inferred from its polarizing effect on light
- They tend to be aligned over large regions of space ➔ a weak interstellar magnetic field

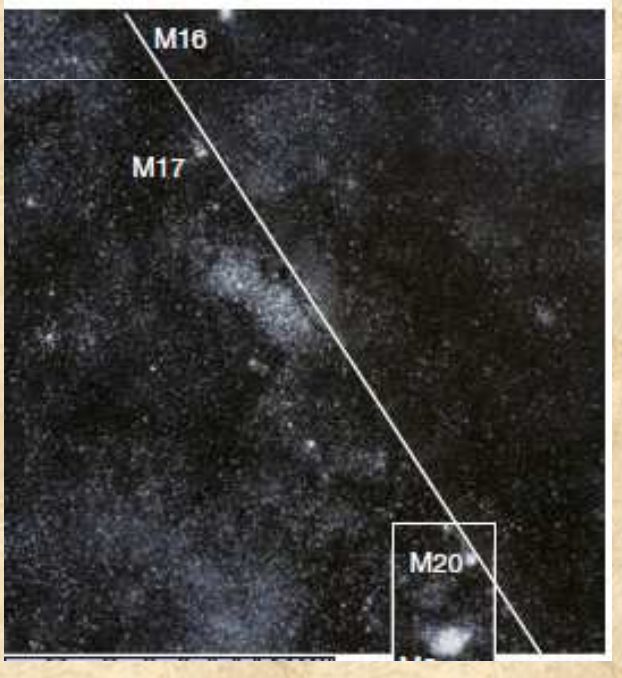






18.2 Emission Nebula

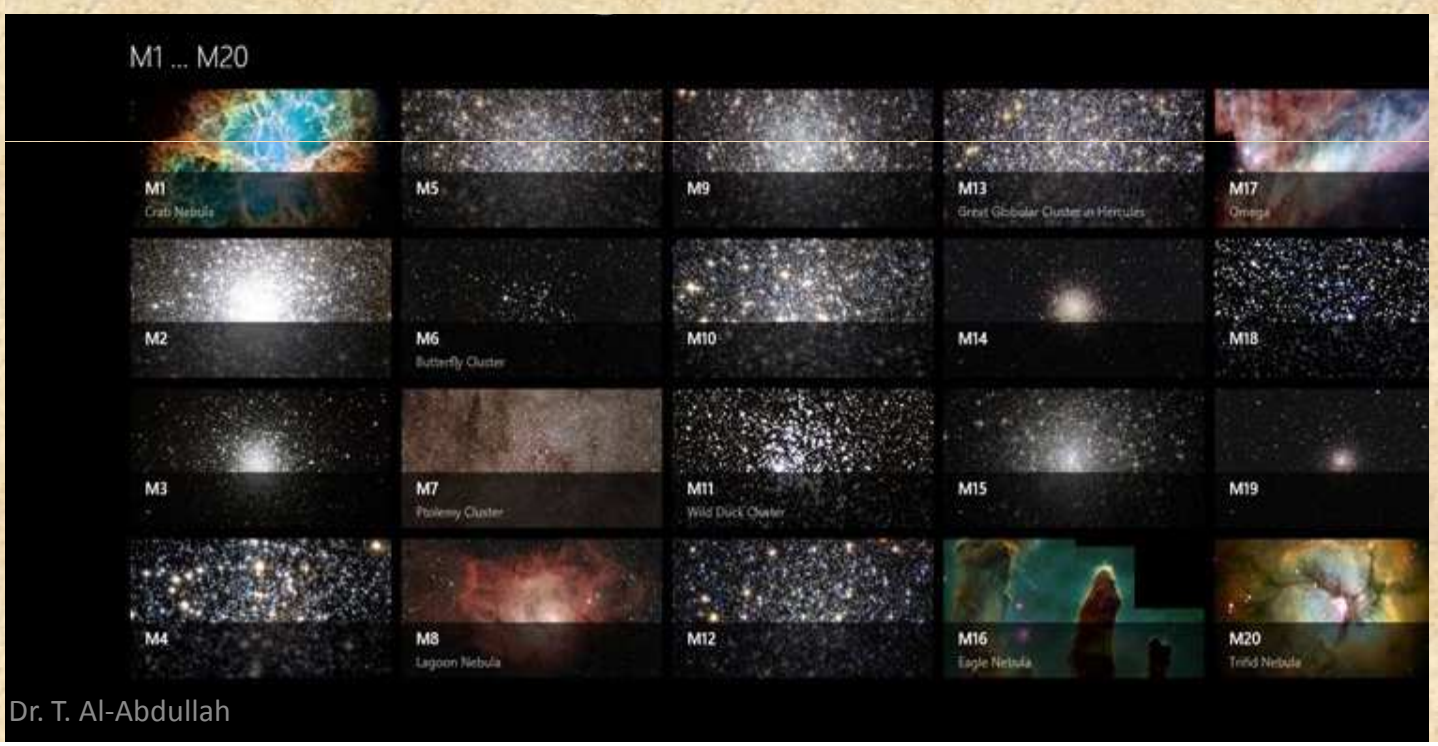
- Any bright or dark fuzzy patches of light; not sharply defined ➔ ***nebula***
- Nebula: clouds of interstellar dust and gas.
- Emission nebula: glowing clouds of hot interstellar matter, (hot young stars).
- Dark nebulae obscure stars lying behind.
- M20=1200pc to M16=1800pc; 1000pc apart, near the limit of visibility.



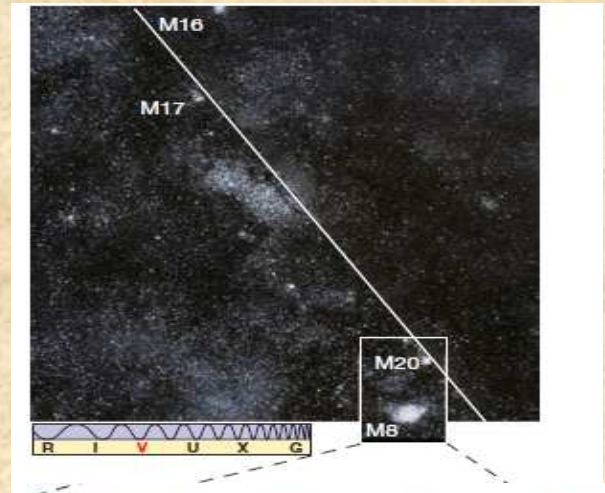
18.2 Emission Nebula

- Charles Messier (1730–1817): A French astronomer most notable for publishing an astronomical catalogue consisting of nebulae and star clusters that came to be known as the 110 "Messier objects".

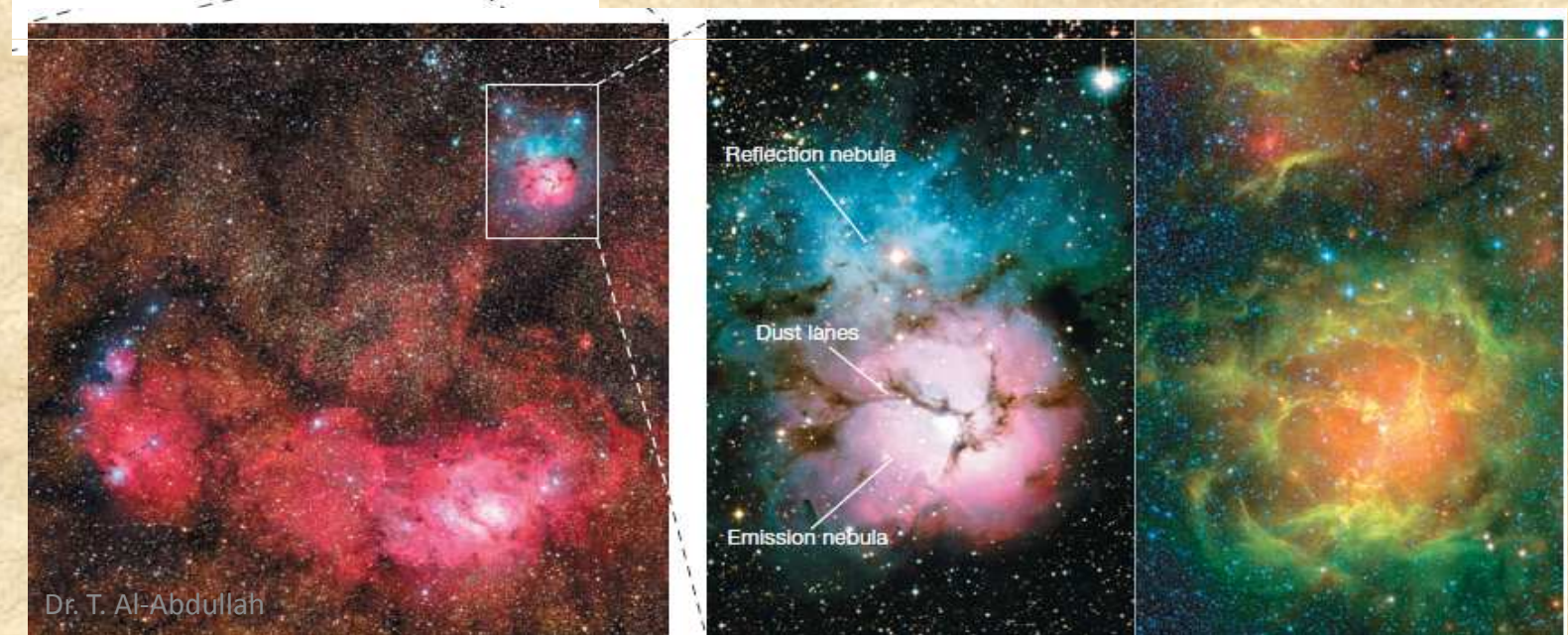
- The purpose of the catalogue was to help astronomical observers, in particular comet hunters such as himself, distinguish between permanent and transient visually diffuse objects in the sky.



18.2 Emission Nebula



- Further enlargement of M20 and its immediate environment .
- the total area of the close-up view is 10 pc across.
- Emission nebula are among the most spectacular objects in the universe.
- They appear as small undistinguished patches of light when viewed in the Milky Way.

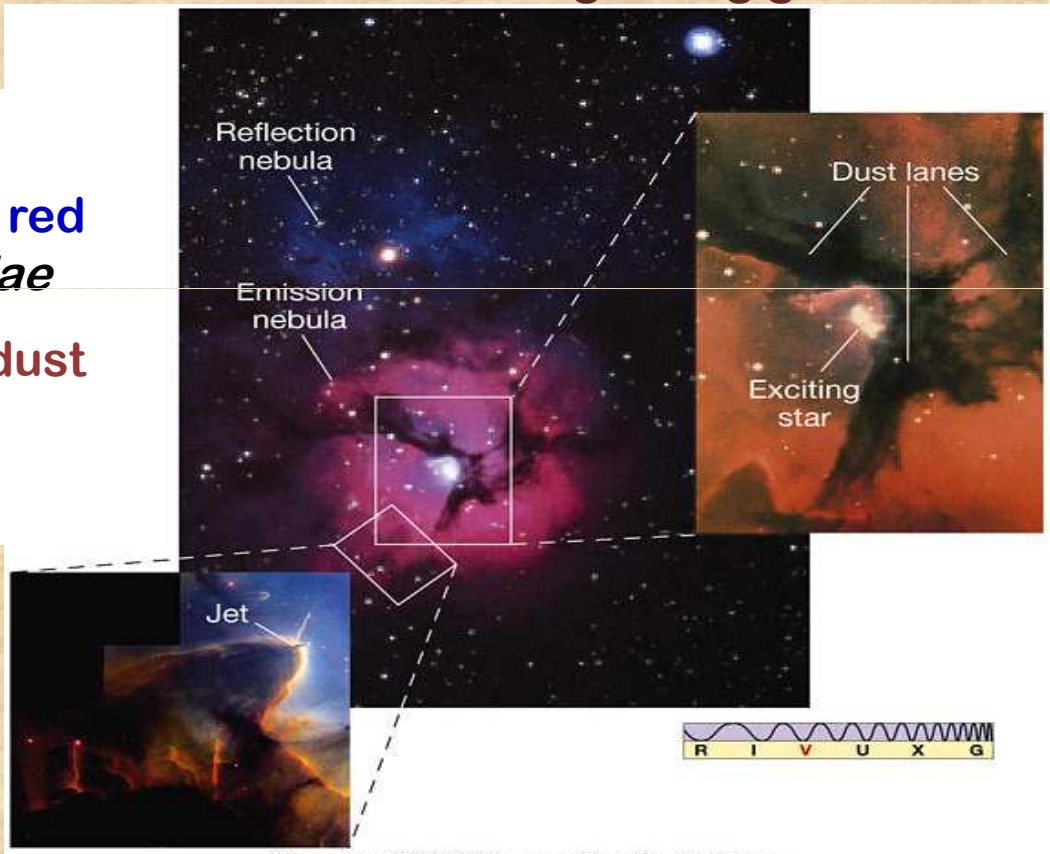


Star forming activity in those lanes of dust

18.2 Emission Nebula

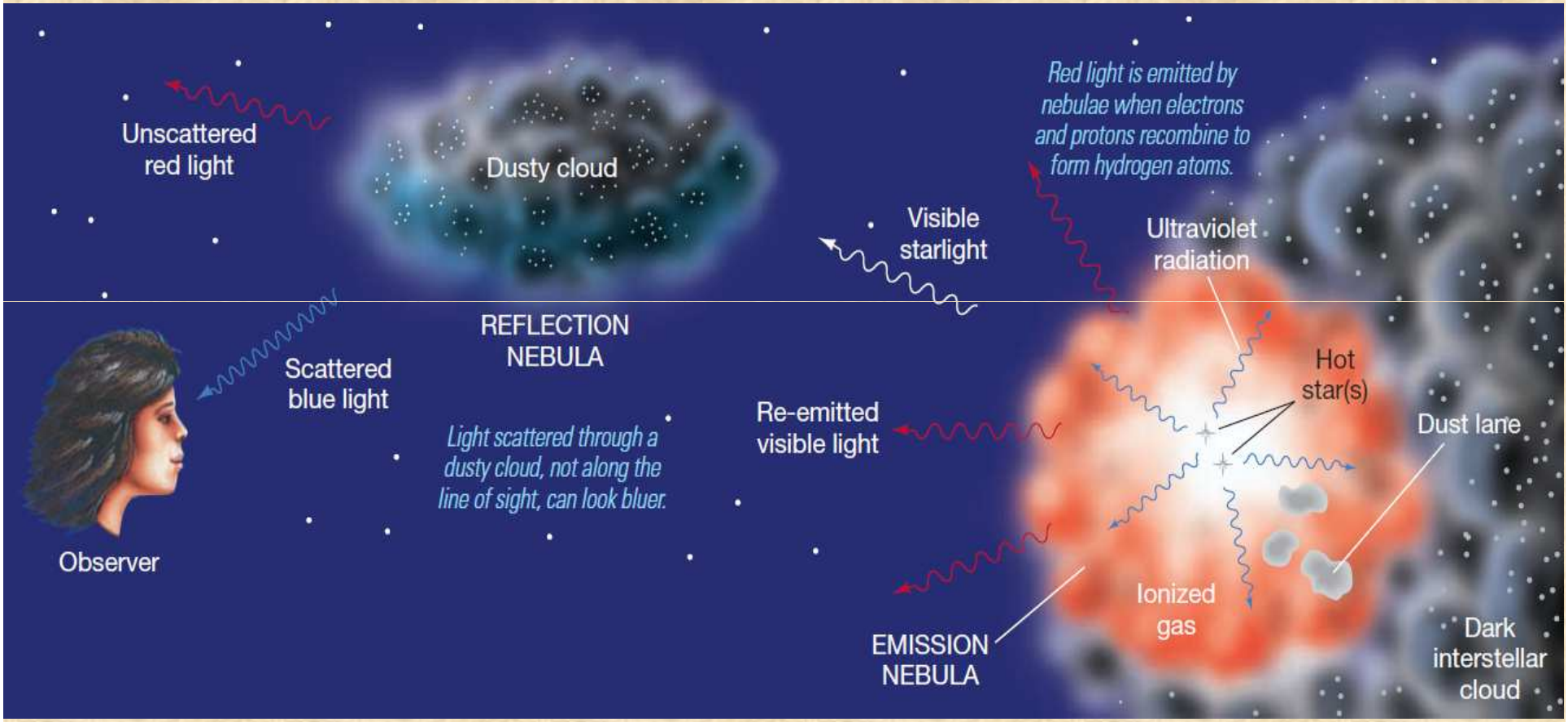
- Nebulae are regions of glowing ionized H (Hα); T=8000K, λ = 656.3 nm.
- At the center of nebula is a newly formed hot O- or B- star → UV light.
- UV light from star → ionized gas → recombination → visible glowing gas.

- Dust lanes are part of the nebula
- Bluish region is unrelated to the red emission nebula ➔ *Reflection nebulae*
- Star light scattered from the dust particles.



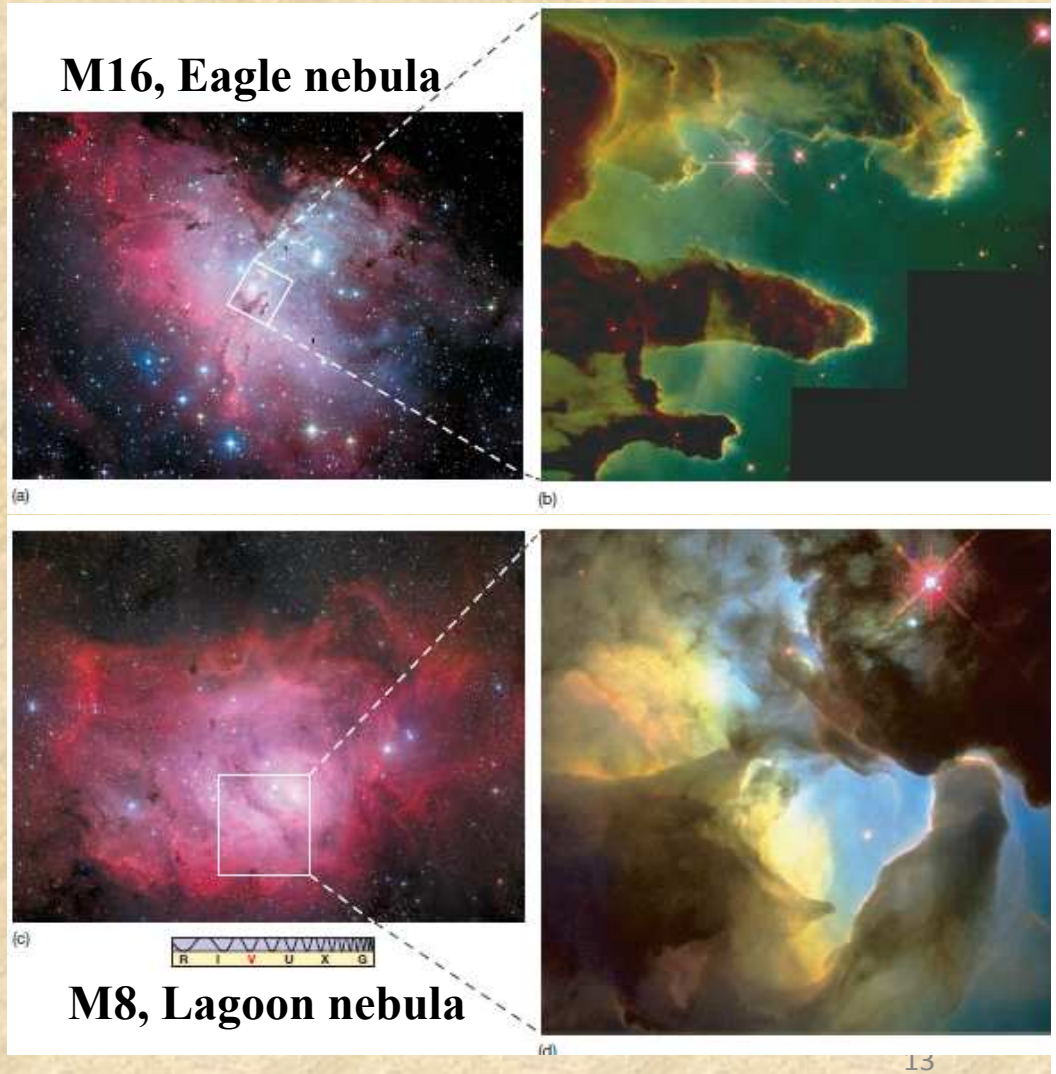
18.2 Emission Nebula

How nebula works?



18.2 Emission Nebula

- Interaction between stars and gas is shown in the figures.
- Part of the interstellar cloud from which the stars formed ➔ *Three dark pillars*
- The other part is heated and dispersed by their radiation ➔ *Photoevaporation*
- Because emission nebulae are composed of ionized hydrogen (HII region).
- Regions of space containing neutral hydrogen ➔ HI regions



Nebular Spectra

- Photons are emitted by recombination of electrons with nuclei, don't ionize more gas ➔ pass freely through the nebula.
- Nebular spectra are distinguishable from hot star-spectra: conditions are different
- Emission nebula are made of hot thin gas → detectable emission lines.
- Stars have a blackbody-like continuous spectrum and absorption lines.

NGC 2346 nebula:

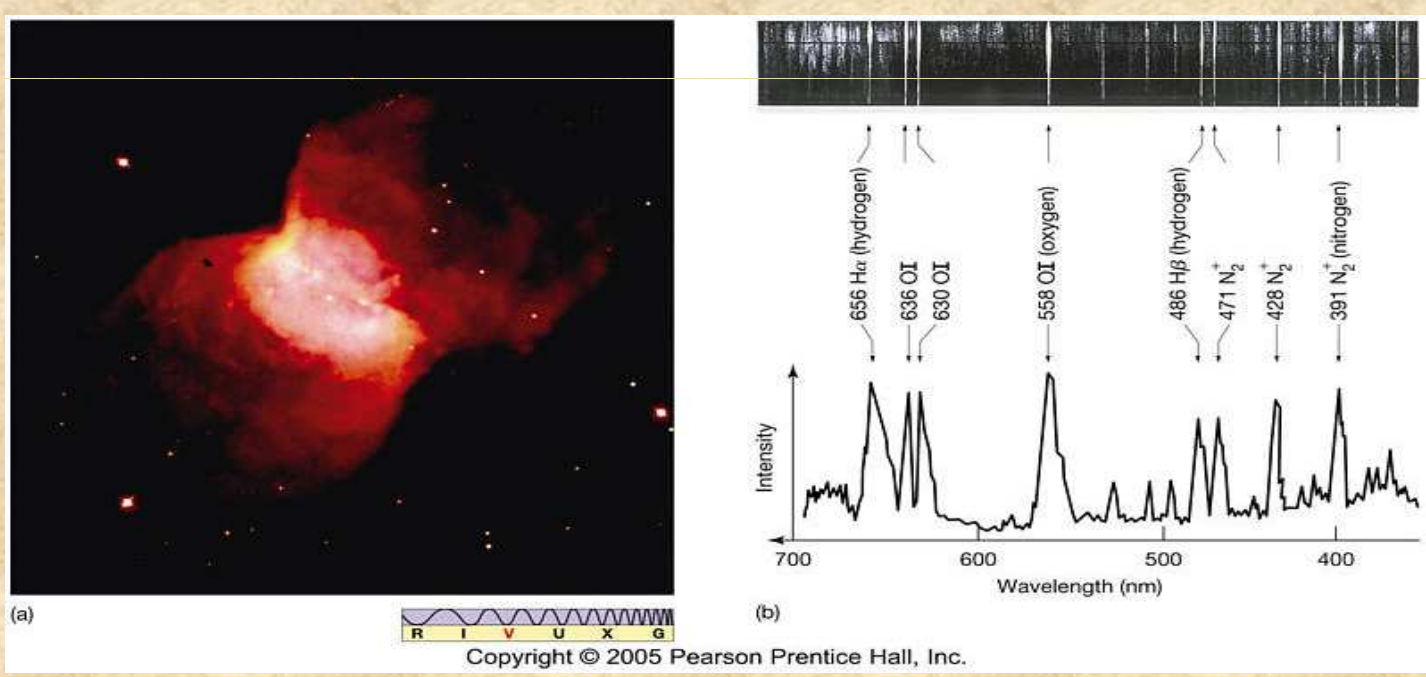
0.2 pc across

700 pc away

V & UV light

90% H, 9% He

1% others



Nebular Spectra

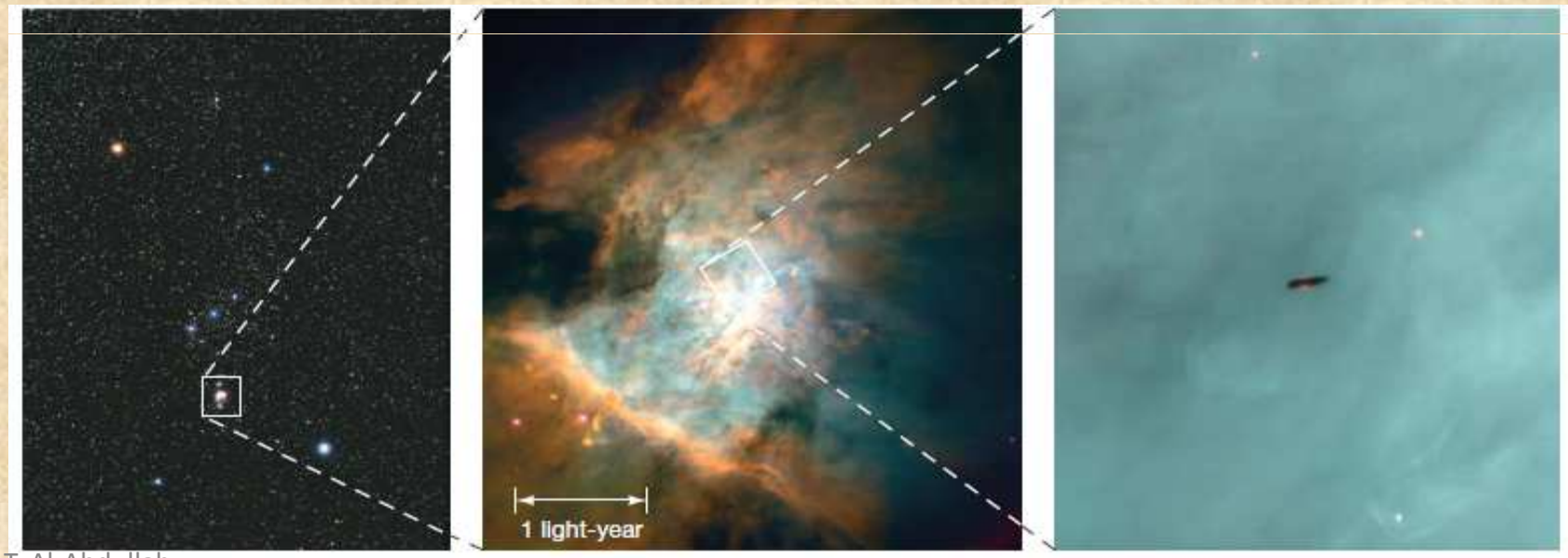
- Nebula are large ➔ measurable by simple geometry
- Information on size & estimate amount of matter ➔ ***Density***
- the density 10^{22} lower than that of a typical planet

TABLE 18.1 Some Nebular Properties

Object	Approximate Distance (pc)	Average Diameter (pc)	Density (10^6 particles/m^3)	Mass (solar masses)	Temperature (K)
M8	1200	14	80	2600	7500
M16	1800	8	90	600	8000
M17	1500	7	120	500	8700
M20	1600	6	100	250	8200

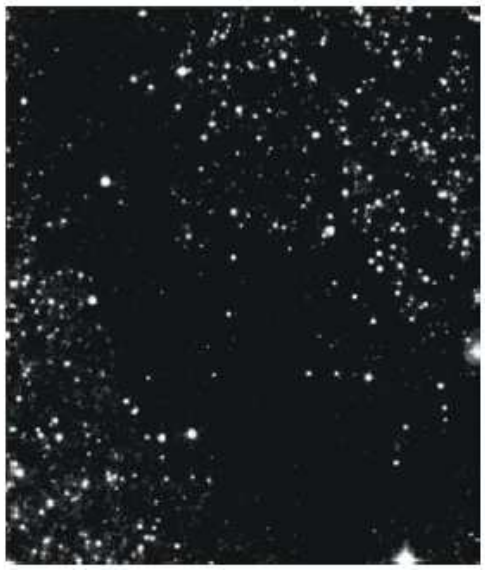
Forbidden Lines

- Few lines did not correspond to anything observed in terrestrial Lab.
- Green light in addition to the red light → nebula contains element unknown on Earth, old explanations.
- Doubly ionized Oxygen. emitted very slowly (few hours), only in very "low-density" situation, not realized on Earth, even in laboratory.
- These rare lines are referred to as "forbidden lines".



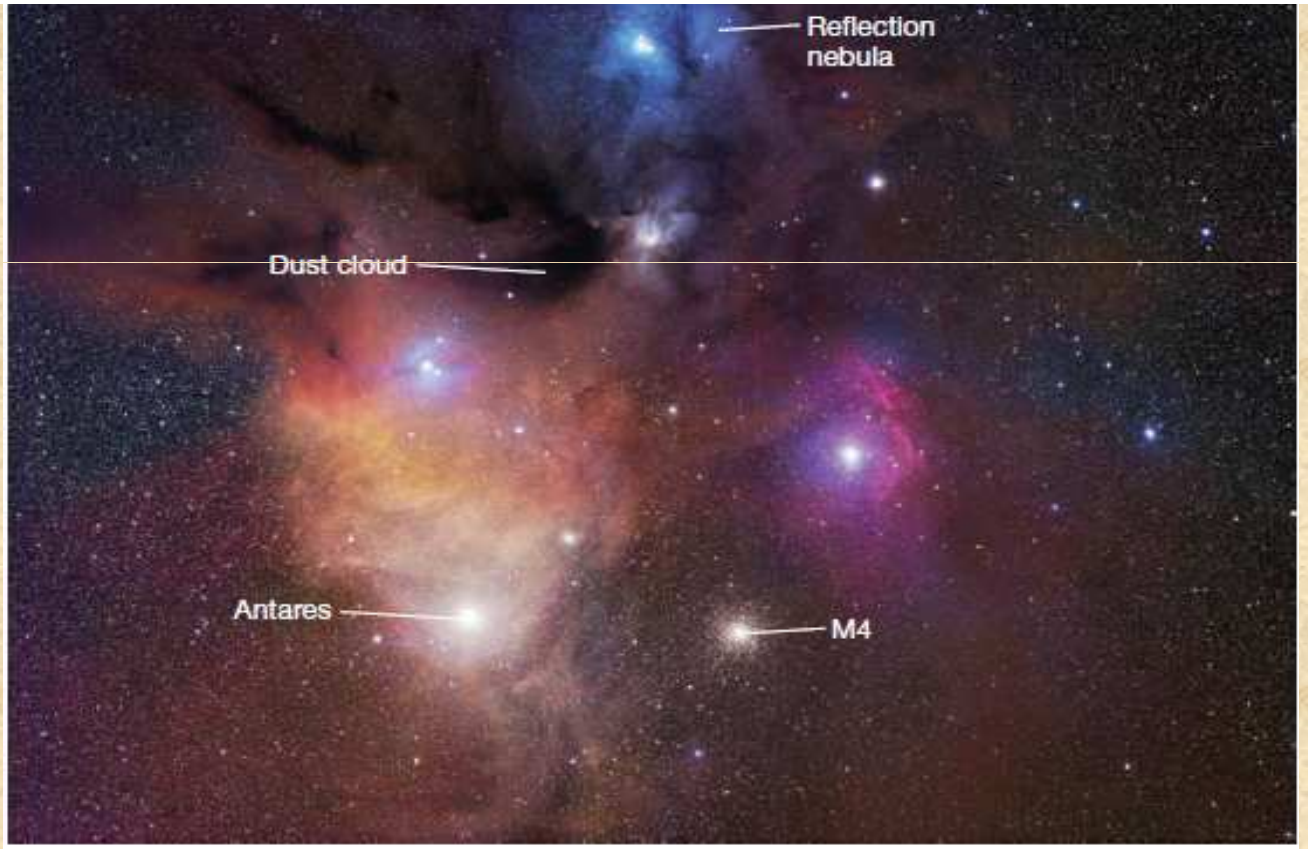
18.3 Dark Dust Clouds

- Emission nebulae are small component of interstellar space.
- 99% of space is devoid of nebular regions, No stars ➔ cold & dark.
- Average T of dark region is 100 K ➔ interstellar space is very cold.
- Within these dark voids among the nebulae ➔ Dark dust clouds.
- Colder (10 K) than its surroundings and million of times denser; 10^7-10^{12} atom/m^3. They are dense interstellar clouds compose of mainly gas.
- Absorption of star light is due to the dust.
- Emit radio wavelengths (CO molecule)



18.3 Dark Dust Clouds

The Ophiuchus dark dust cloud resides only (170 pc) 550 light-years away, surrounded by colorful stars and nebulae that are actually small illuminated parts of a much bigger, and invisible, molecular cloud

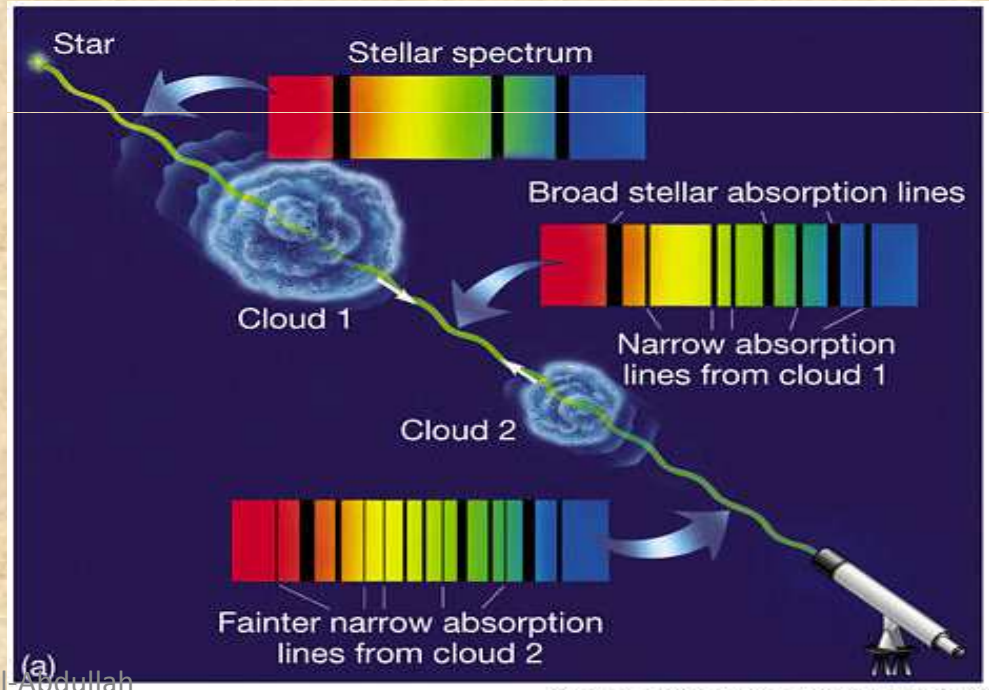


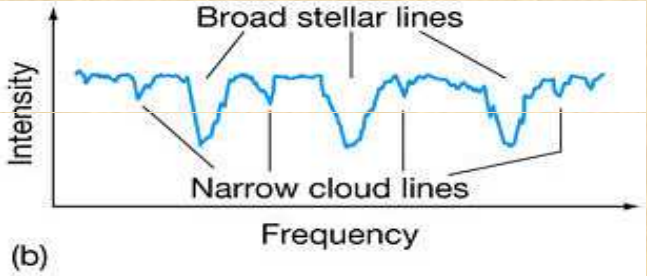
18.3 Dark Dust Clouds

This is the Horsehead Nebula, one of the most famous of dark dust clouds.

18.3 Dark Dust Clouds

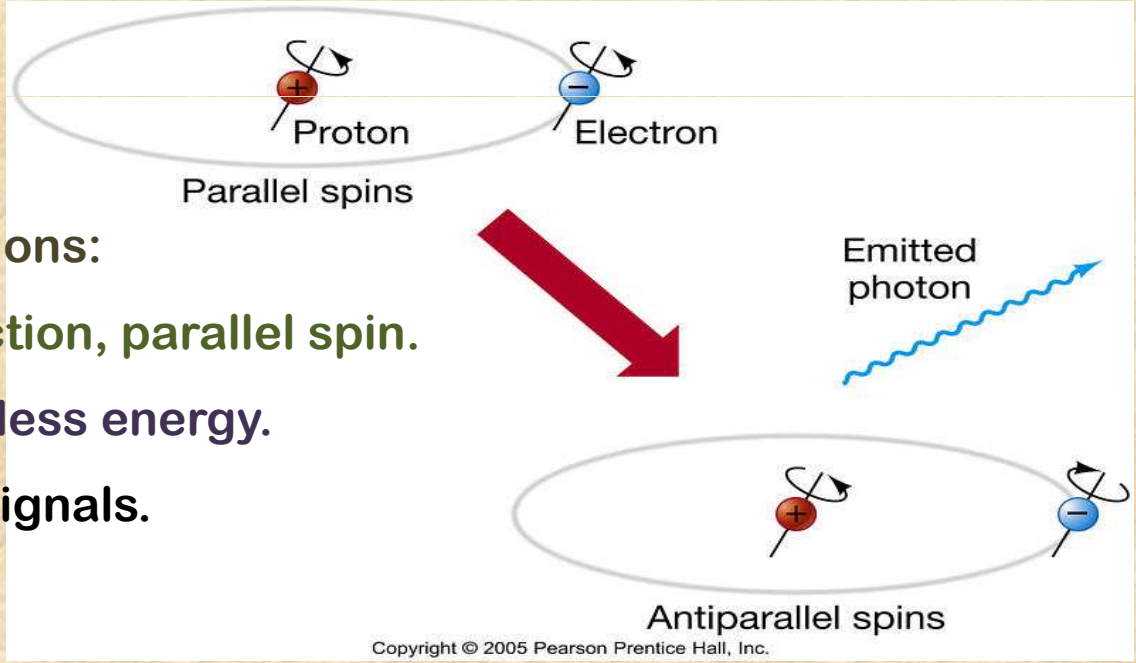
- Creates Absorption Spectra.
- The gas absorbs some of the stellar radiation → depends on the clouds' temperature, density, and composition.
- Broad stellar lines; hot high density gas
- Narrow cloud lines; cold low density gas.





18.4 21-Centimeter Radiation

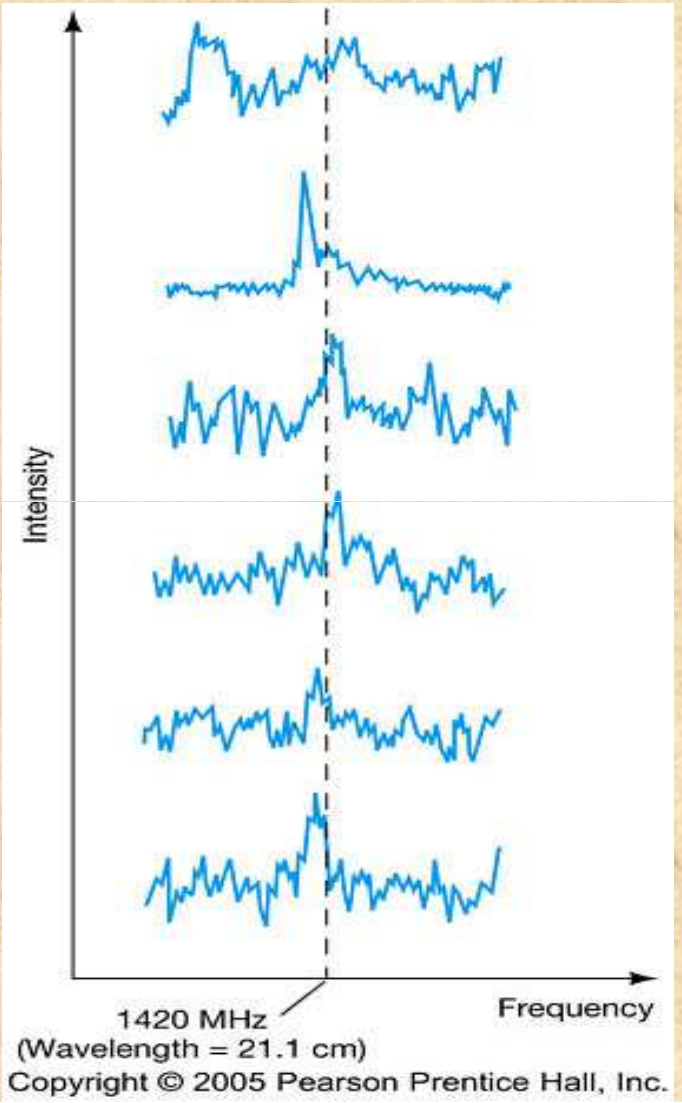
- To probe interstellar space more thoroughly, No obscurations.
- Find a way to detect cold, neutral interstellar matter anywhere in space through its own radiation.
- Low-energy *radio* emission produced by the interstellar gas.
- "radio emission" from hydrogen when the electron flips its spin. Q.M.



- Two possible spin configurations:
- e & p rotate in the same direction, parallel spin.
- e & p have anti-parallel spin, less energy.
- E-difference → 21-cm radio signals.

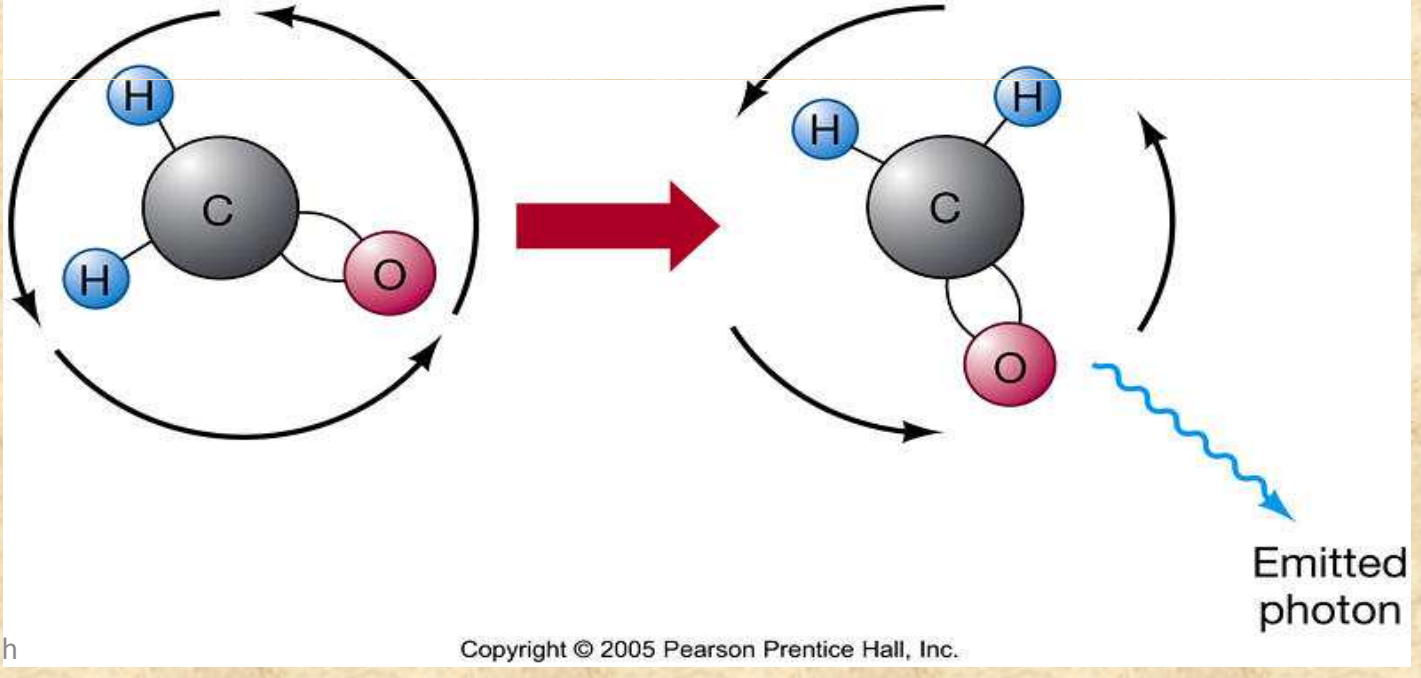
18.4 21-Centimeter Radiation

- 21-cm are characteristic signatures of cold H-atoms.
- Irregular 21-cm lines → several clumps of interstellar gas: each with its own T, ρ, velocity, and internal motion
- The intensity, width, Doppler shift of the resulted 21-cm radiation vary from place to place ➔ interferences & sophisticated → computer.
- 21-cm radiation yield densities (10^6 atom/m^3) and temp. (100K) in good agreement with optical spectroscopy.
- The peaks do not all occur at a 21-cm wavelength because the gas in the galaxy is moving relative to Earth.



18.5 Interstellar Molecules

- When the interstellar medium is cold (20 K) molecules can form, and the density often grows (10^{12} particle/m^3)
- Molecular clouds, different from dust clouds, emits only radio waves.
- Rapid to slow rotational state; molecules in space emit radio signals.
- Found in the densest and darkest of the interstellar clouds.

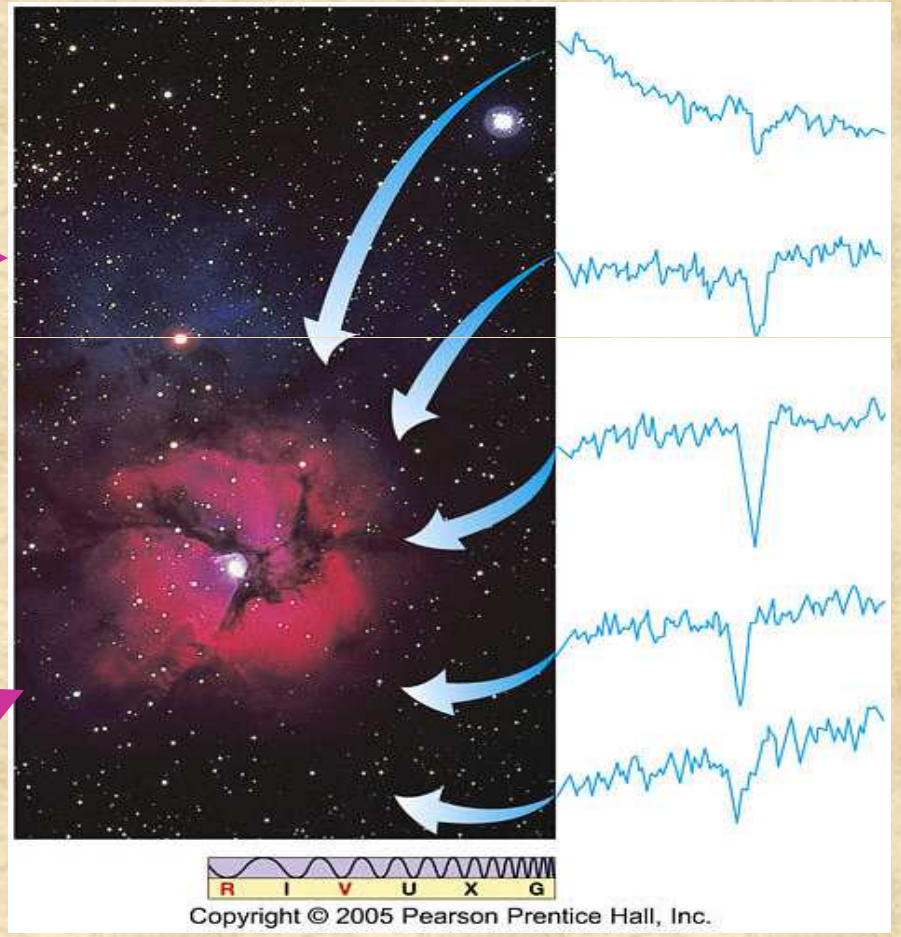


18.5 Interstellar Molecules

- H_2 is dominant, but emit only in UV region.

- The wavelength of the signals indicate from which molecule it comes by absorption in background radiations.:
  - Hydroxyl OH
  - Water H_2O
  - Ammonia NH_3
  - Formaldehyde H_2CO
  - Carbon monoxide CO
  - Molecular hydrogen H_2
  - About 120 others

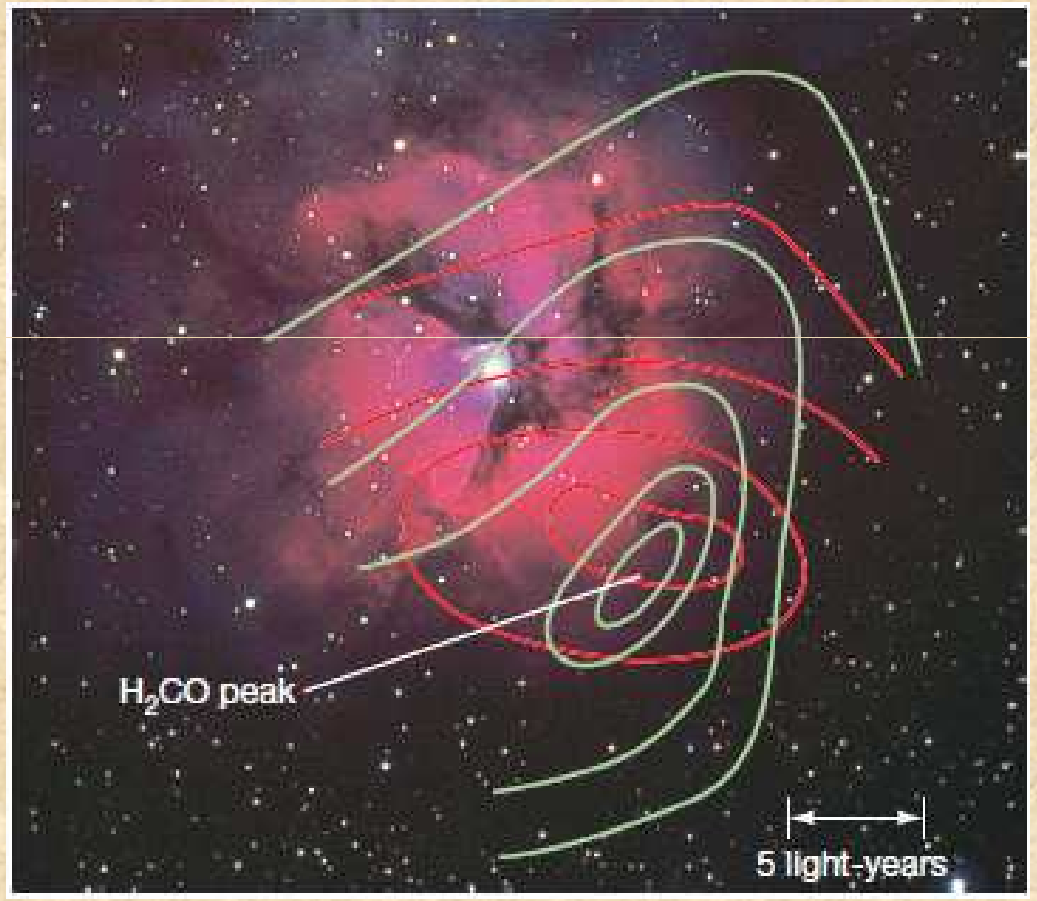
- Molecular traces 1 million : 1 billion H_2

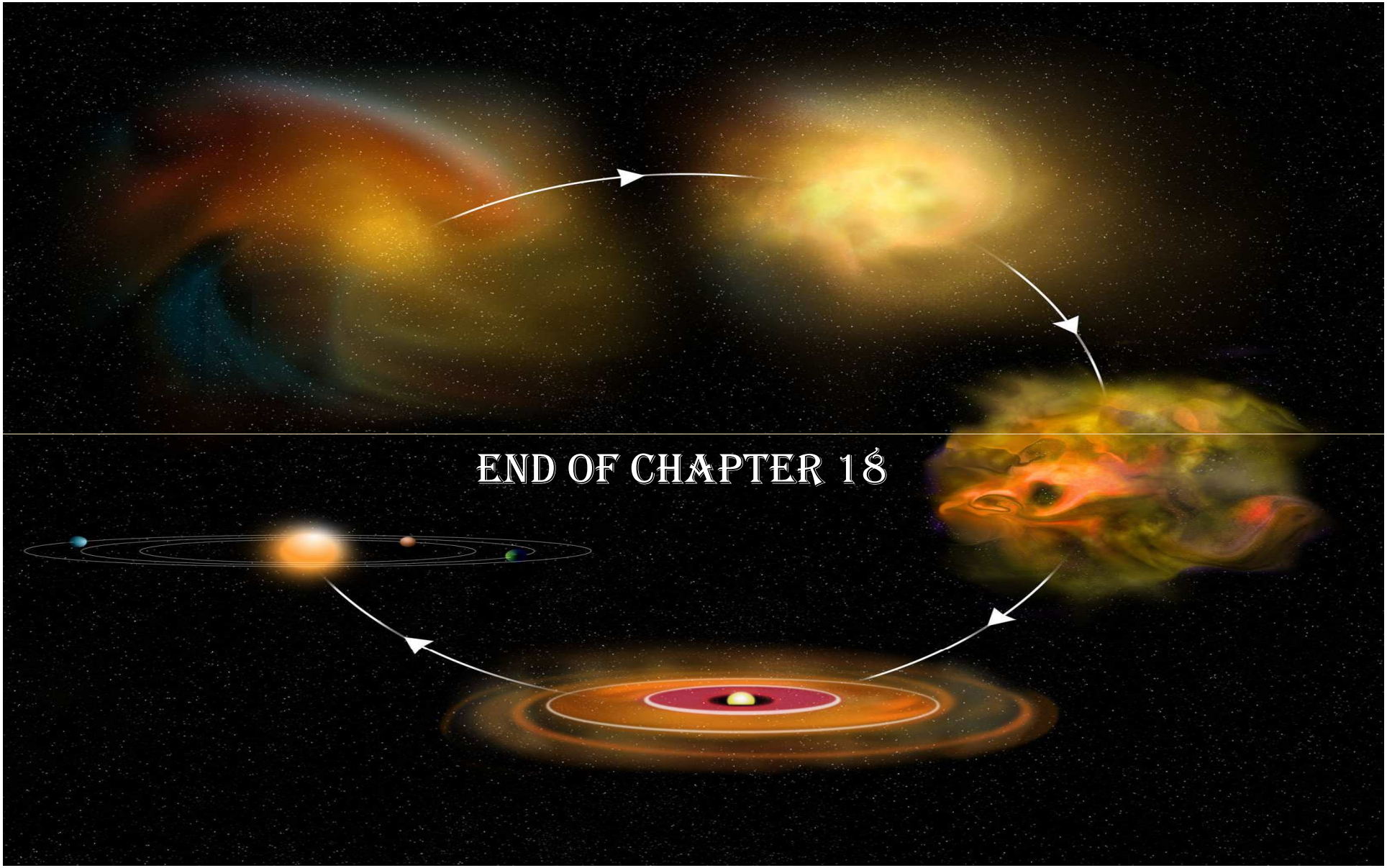


Molecular absorption near M20

18.5 Interstellar Molecules

- A contour map of the distribution of formaldehyde molecules near M20.
- The concentration peaks in a dark region well away from the visible nebula.

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