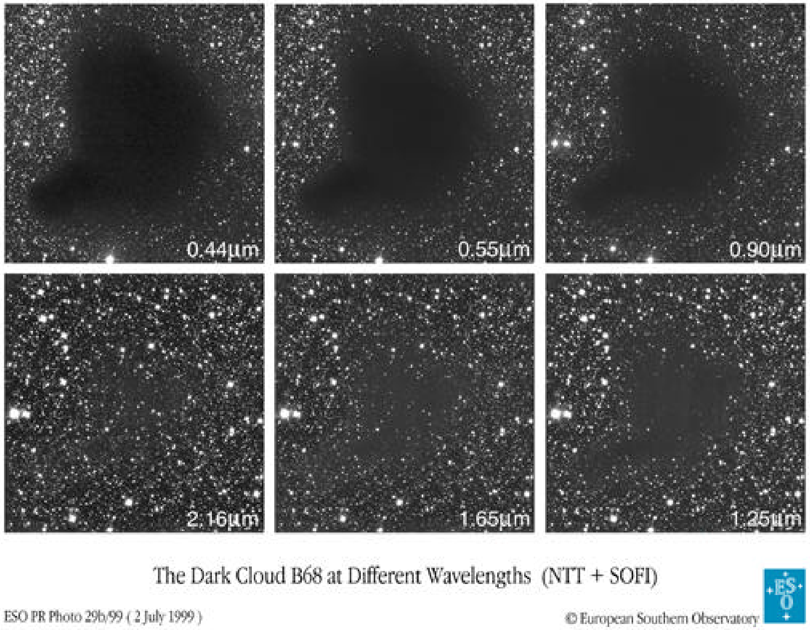
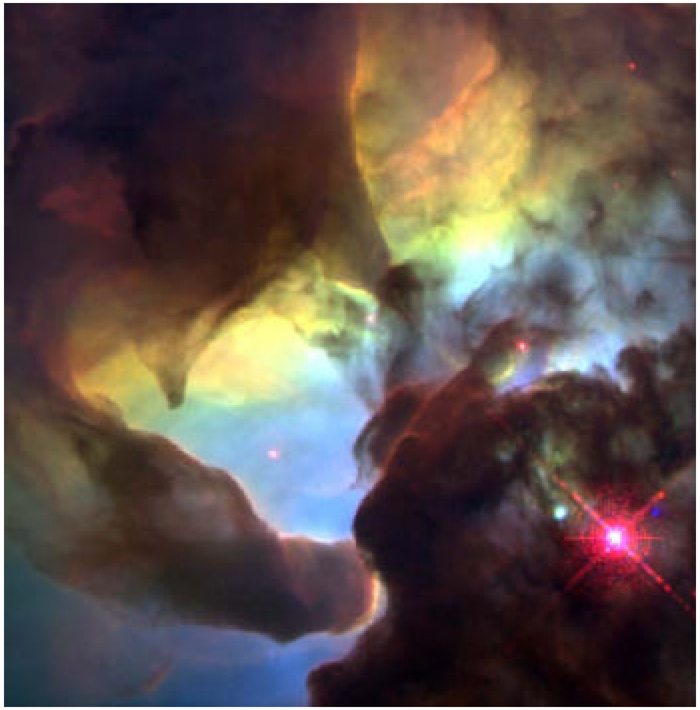
Interstellar Medium and Star Birth





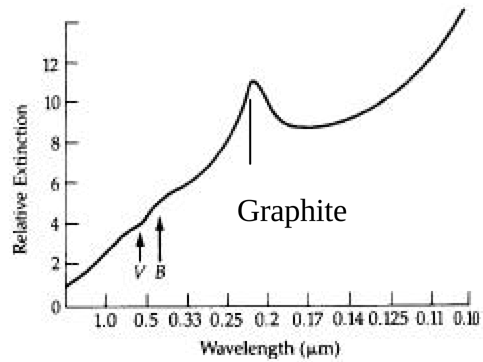
Interstellar dust

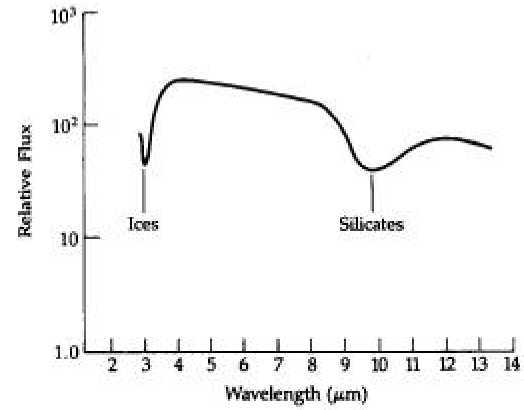
Lagoon nebula: dust + gas

Interstellar Dust

Extinction and scattering responsible for localized patches of darkness (dark clouds) , as well as widespread obscuration of light from distant stars.

Composition:





Graphite and silicates, with icy mantles. Sizes ~ 0.005 - 0.2 µm. Also, polycyclic aromatic hydrocarbons (PAH's).

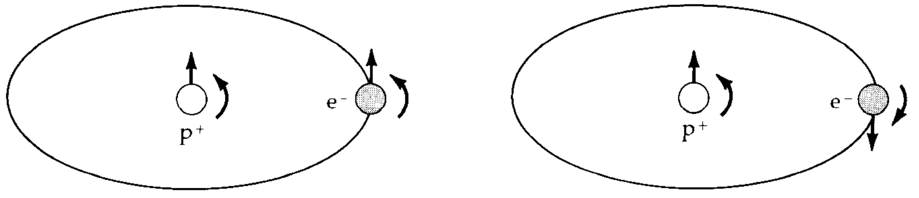
Dust amounts to only 1% of total mass of ISM (rest is gas), but inferred first due to strong extinction.

Origin: condensation within winds from cool supergiant stars.

Interstellar Gas

Hartmann (1904) - stationary (and narrow) *absorption* lines in the spectrum of spectroscopic binaries.

Van de Hulst (1945) - prediction of 21 cm *emission* line of H. Detected by Ewen and Purcell (1951), and others.



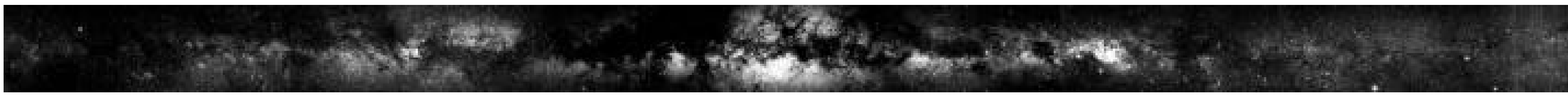
Hyperfine transition => antiparallel spins have lower energy.

It turns out dense regions allow the formation of molecules, H_2 and trace molecules like CO, CN, OH,… Detected by their spectral lines since mid 1960's.

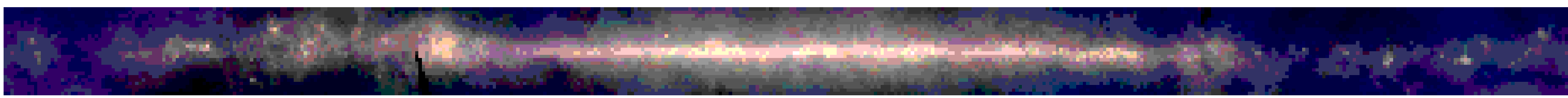
Interstellar Gas

Multiwavelength approach allows a panoramic view of galactic gas or dust, while only dark patches were visible in optical image.

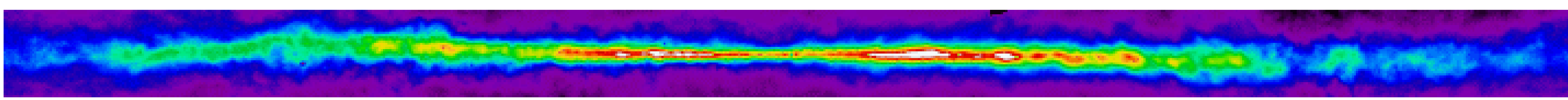
Optical



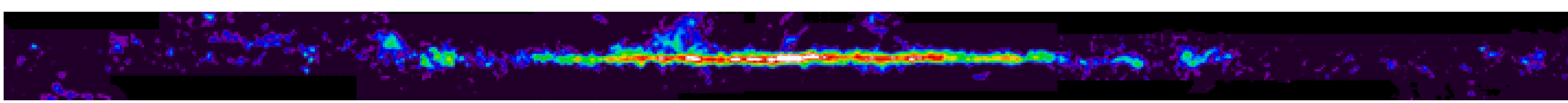
Infrared, 100 μm



Neutral Hydrogen H, in 21 cm line

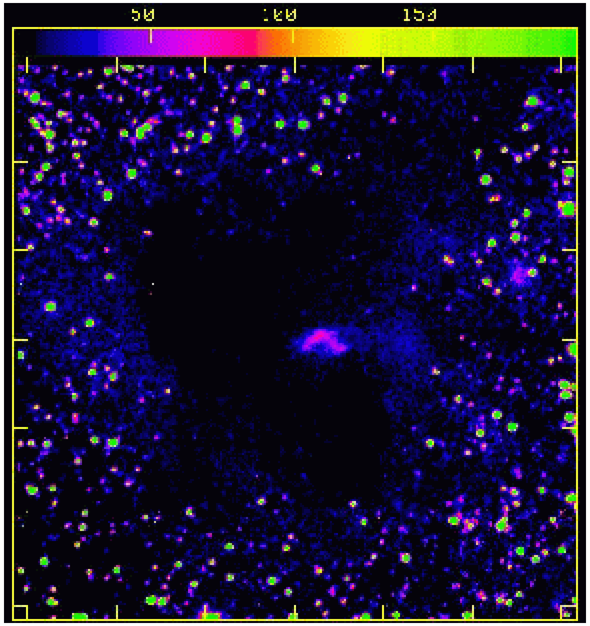


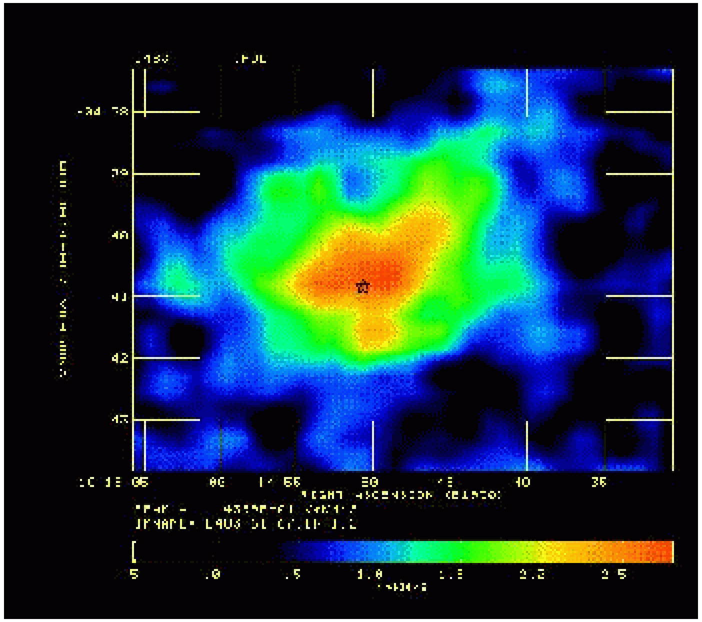
CO emission at 2.7 mm, a tracer of H_2



Gaseous Nebulae

<u>Dark nebulae</u> (<u>dark cloud</u>) - Dark patches in optical observations which hide more distant objects. Contain gas and dust. Dust blocks visual. Cool gas emits in wavelengths longer than visible.





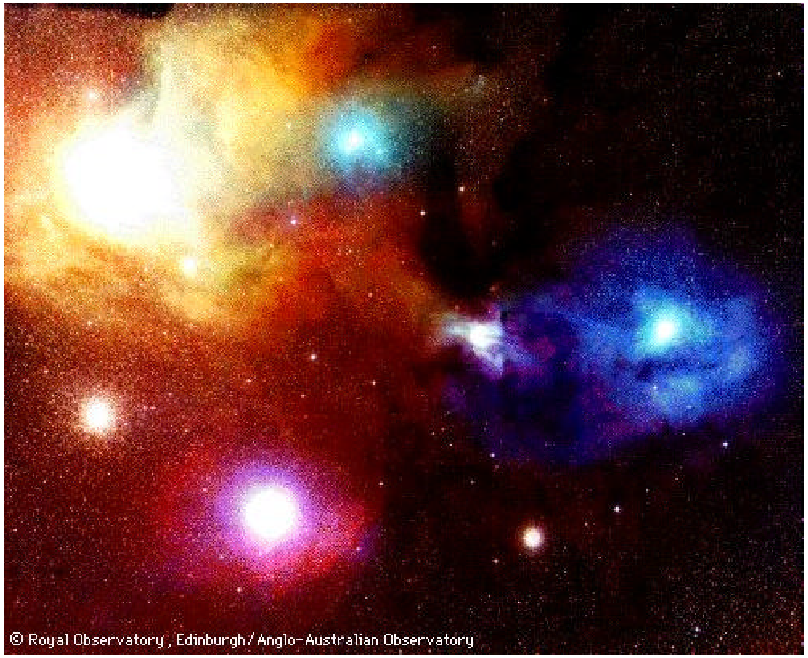
Optical

Same region in radio

Gaseous Nebulae

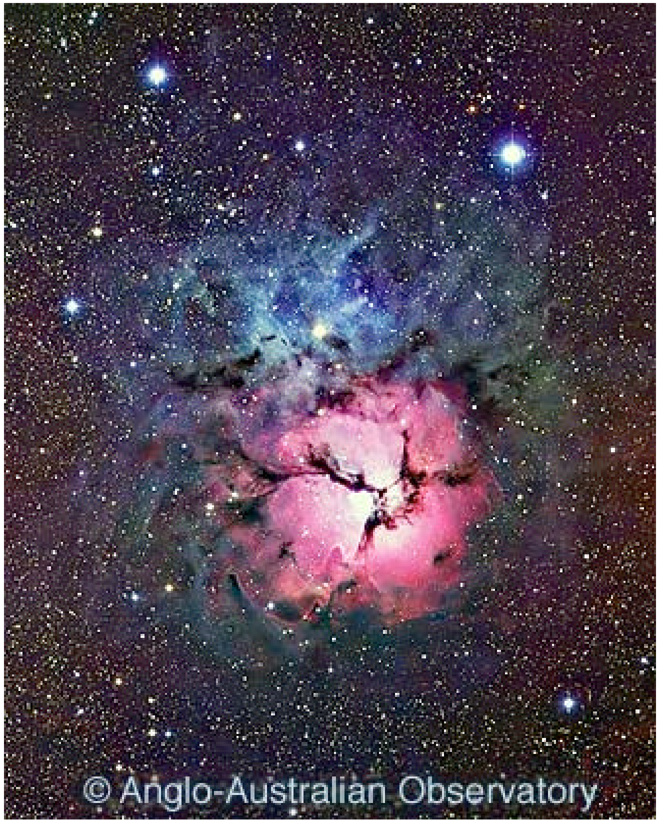
<u>Reflection nebulae</u> - scattered light (mainly by dust) from embedded star. Blue light scattered preferentially.

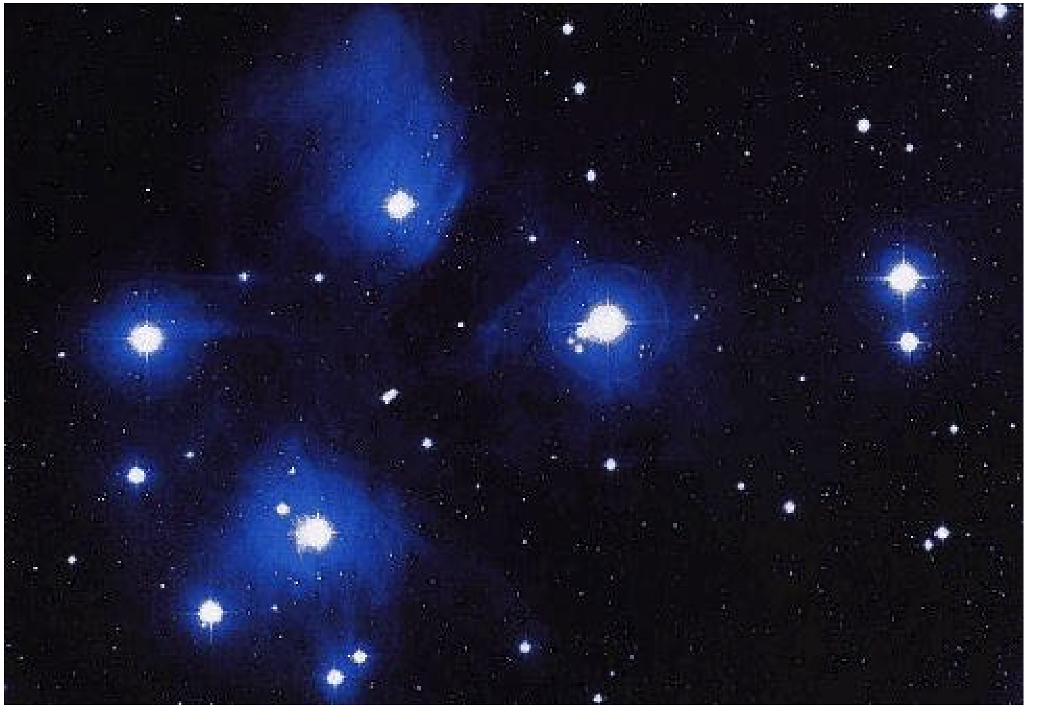
<u>Emission nebulae</u> - emission from recombining atoms (usually H) within zones of ionized material (H II regions) created by hot (type O or B) stars. Often see red Hα line emitted during recombination cascade.



Emission, reflection, and dark nebulae in rho Ophiuchus.

Gaseous Nebulae



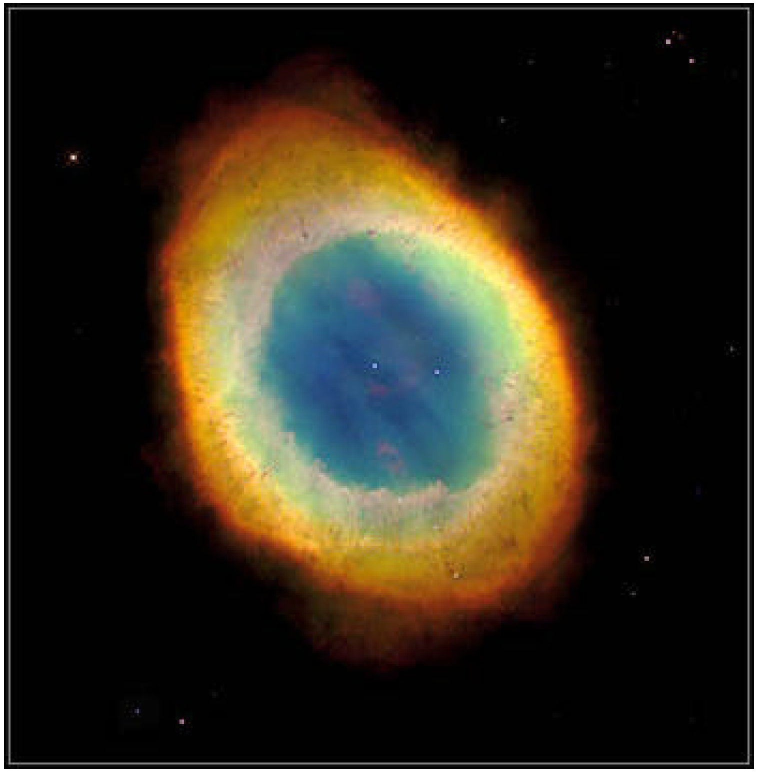


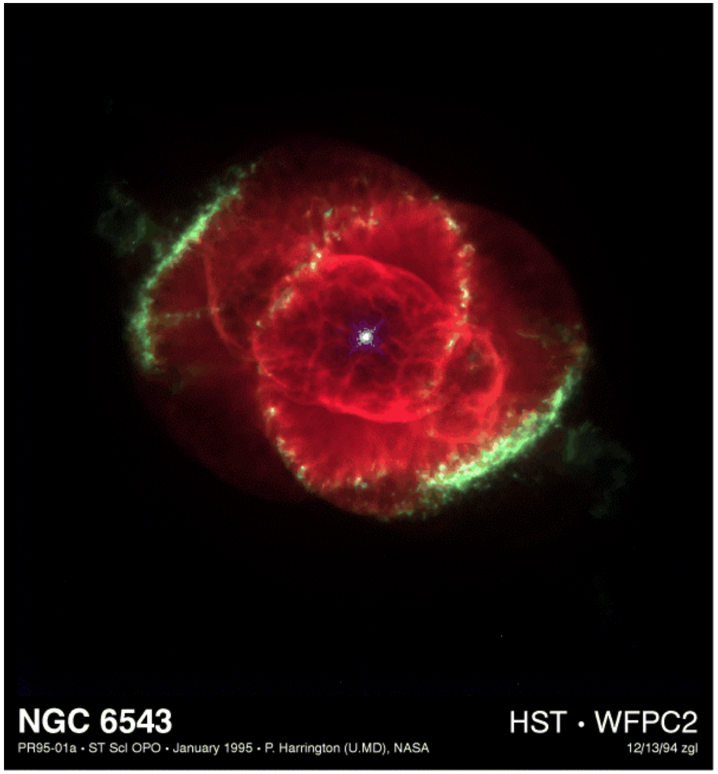
Trifid Nebula - emission, reflection and dark nebulae

The Pleiades star cluster - reflection nebulae

Gaseous Nebulae

Planetary nebulae - similar to emission nebulae, but exciting object is a hot evolved star. Material expelled from star in post-main sequence phase. Among most spectacular objects in the sky!



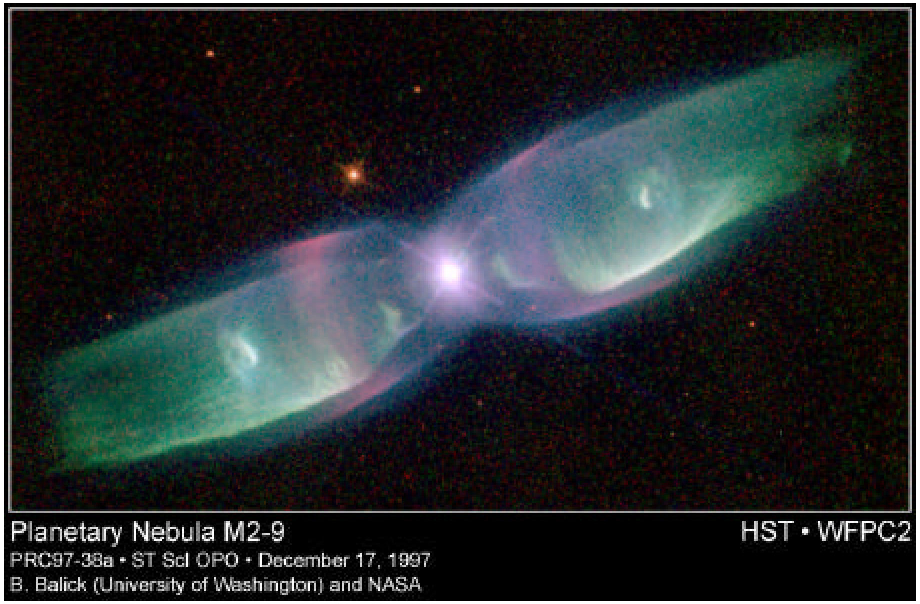


Ring nebula

Gaseous Nebulae

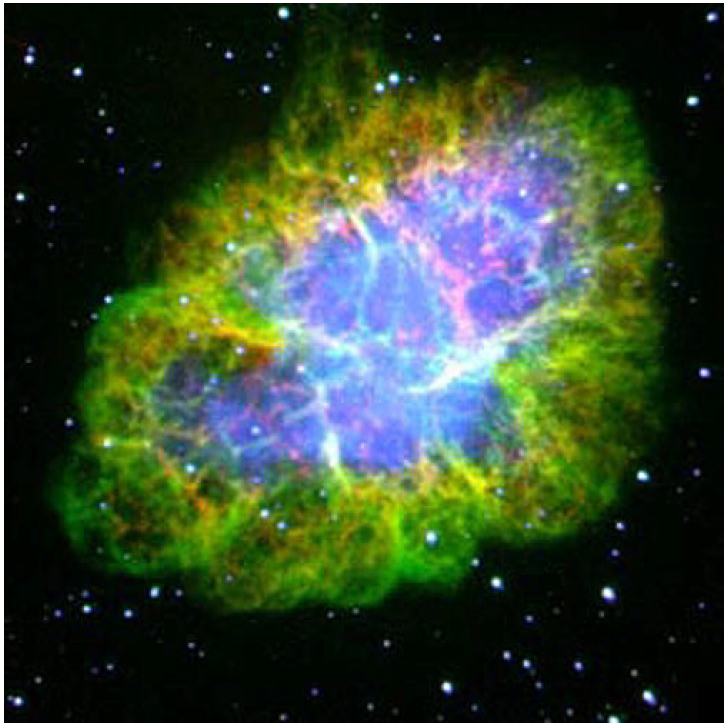
Diversity of planetary nebulae

IC 418 - Spirograph nebula

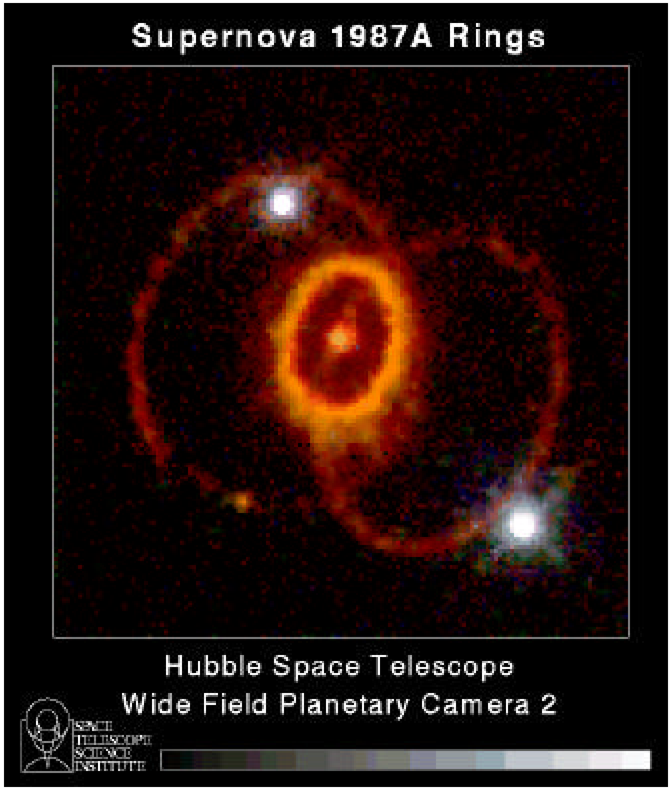


Gaseous Nebulae

Supernova remnants - optical emission from ionized material. Radio emission from relativistic electrons spiraling around magnetic fields.



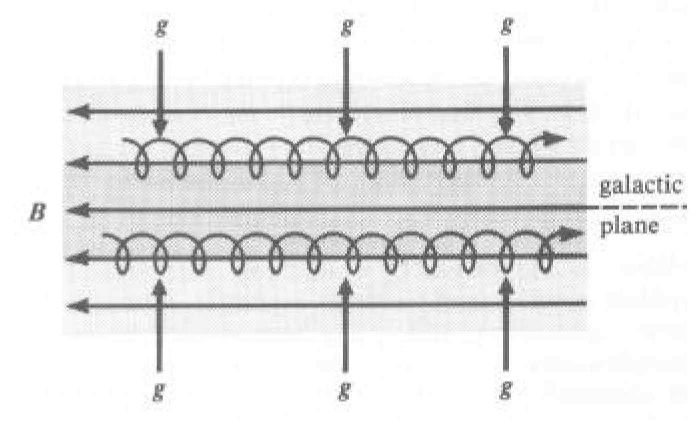
Crab nebula



Cosmic Rays and Magnetic Field

Cosmic rays - very high energy charged particles; p, e, He^{++}, Li^{+++}, … Ultrarelativistic energies, up to 10^{20} eV => $v \sim c$.

Origin: supernovae?
Are not gravitationally confined to the Galaxy. So why do we see them?



Interstellar $B \sim$ few x 10^{-10} T.

CR's spiral around ***B*** field => emit synchrotron radiation in radio band. A nonthermal form of radiation.

Note: Gas is confined by gravity and maintains currents that generate ***B***. CR's confined by ***B***, not gravity.

Size of Emission Nebulae (H II regions)

Apply steady-state condition: ionization rate = recombination rate.

Let N_* = # of Lyman continuum ($\lambda < 91.2$ nm) photons which leave the central star(s) per unit time.

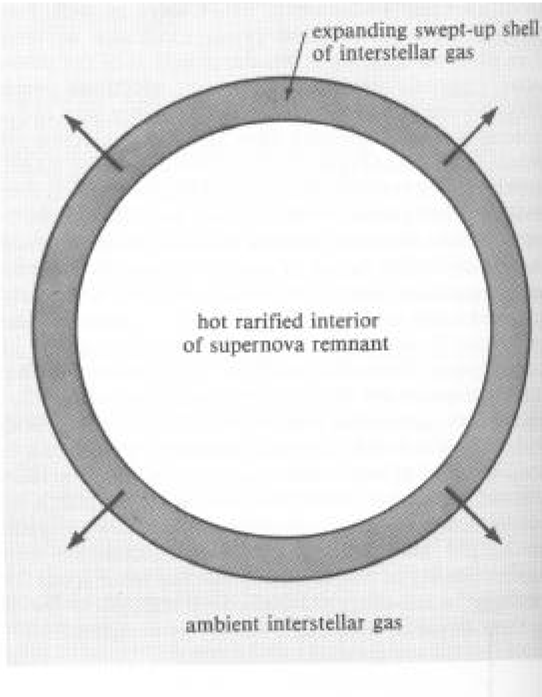
Let R = # of recombinations of protons and electrons into H atoms per unit volume per unit time = $\alpha\, n_e n_p = \alpha\, n^2$, where α is the recombination coefficient, and n is a number density.

$$N_* = \frac{4}{3}\pi r_s^3 R \quad \Rightarrow \quad r_s = \left(\frac{3N_*}{4\pi \alpha n^2} \right)^{1/3}.$$

↑ Stromgren radius

However, note that H II regions are rarely spherical.

Supernova Interaction with Interstellar Medium



Supernovae and stellar winds => mass, momentum, and energy transfer to ISM.

Make quick estimate using snowplow model (momentum conservation) for a supernova remnant.

Ejected mass $M_0 \approx 4 M_{Sun}, v_0 \approx 5{,}000\ \mathrm{km\,s^{-1}}$

Swept-up mass $M = \frac{4}{3} p\, r^3 r$

Momentum conservation => $\left(M + M_0\right) v = M_0 v_0.$

Shell dissipates when v ~ 10 km s^{-1}, the random speed of ISM gas.

So can sweep up $M = \frac{M_0 (v_0 - v)}{v} \approx 4 M_{Sun} \frac{5{,}000 - 10}{10} \approx 2{,}000\, M_{Sun}.$

Energy? $\frac{E}{E_0} = \frac{M v^2}{M_0 v_0^2} = \frac{2{,}000 M_{Sun} (10\ \mathrm{km\,s^{-1}})^2}{4 M_{Sun} (5{,}000\ \mathrm{km\,s^{-1}})^2} = 2 \times 10^{-3}.$ Where did it go?

Star Formation

Need gravity to dominate in a local region. What is a typical size scale for collapse?

Need $\left|U_{grav}\right| \approx \dfrac{GM^2}{L}$ to exceed $E_{th} = \dfrac{3}{2} NkT.$

Actual relation is $2E_{th} \leq -U_{grav}.$

Using $N = M / 2m_H$ for dense regions of molecular hydrogen

and $M \approx r L^3$ we get

$$L \geq L_J \approx \left(\frac{kT}{m_H G r} \right)^{1/2} \approx 10^7 \left(\frac{T}{r} \right)^{1/2} \text{ m.}$$

The “Jeans length”.

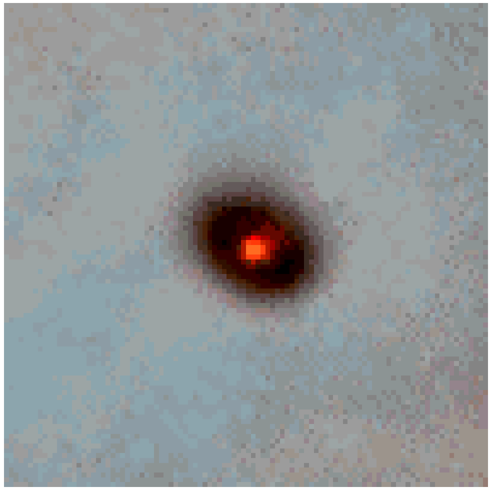
Star Formation

Some consequences of collapse:

Conservation of angular momentum => rapidly rotating disks.

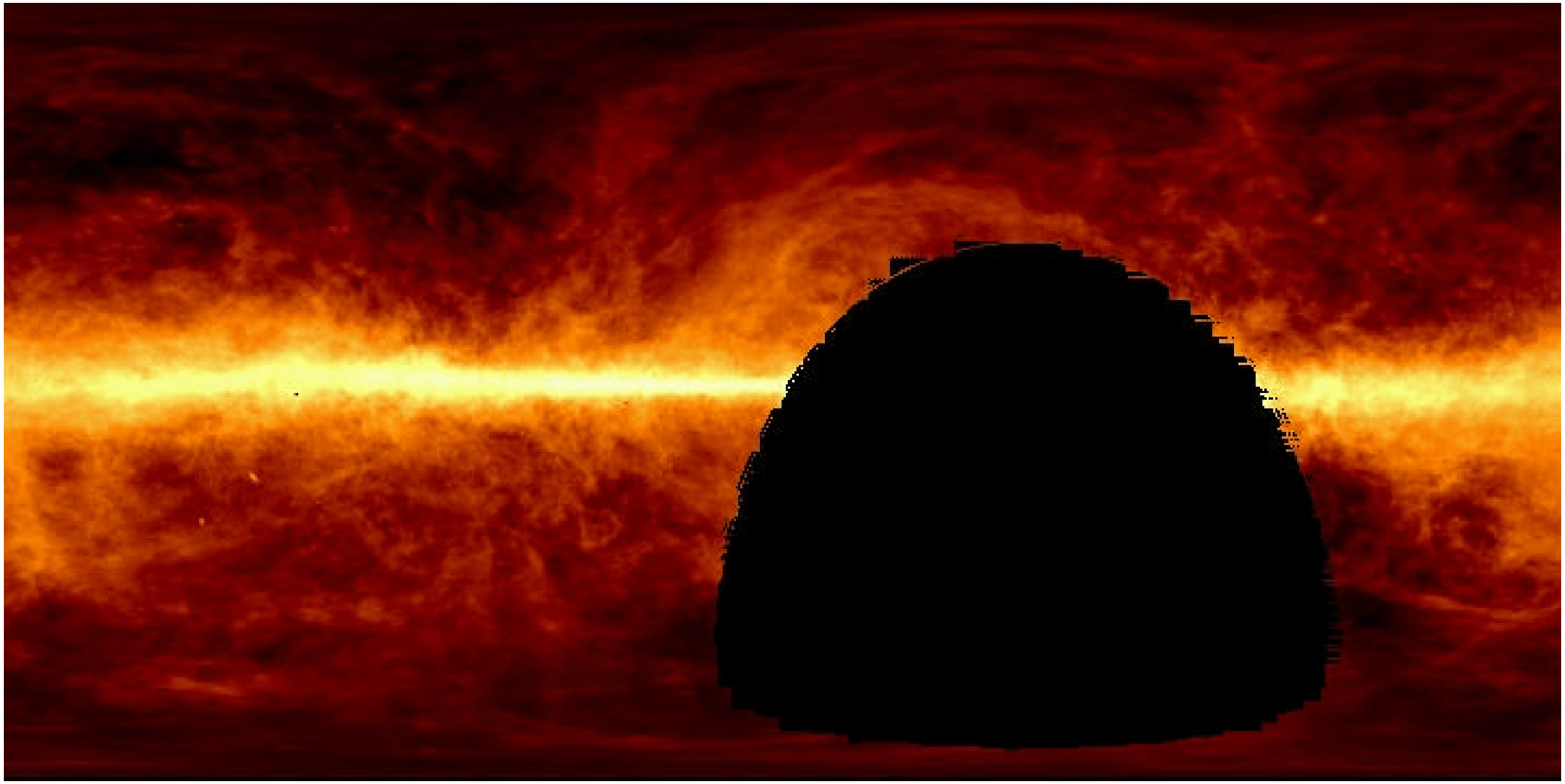
Conservation of magnetic flux => strong magnetic fields.

Magnetic field acts as the agent to eject high angular momentum material and allow collapse to form a star => infall + outflows.



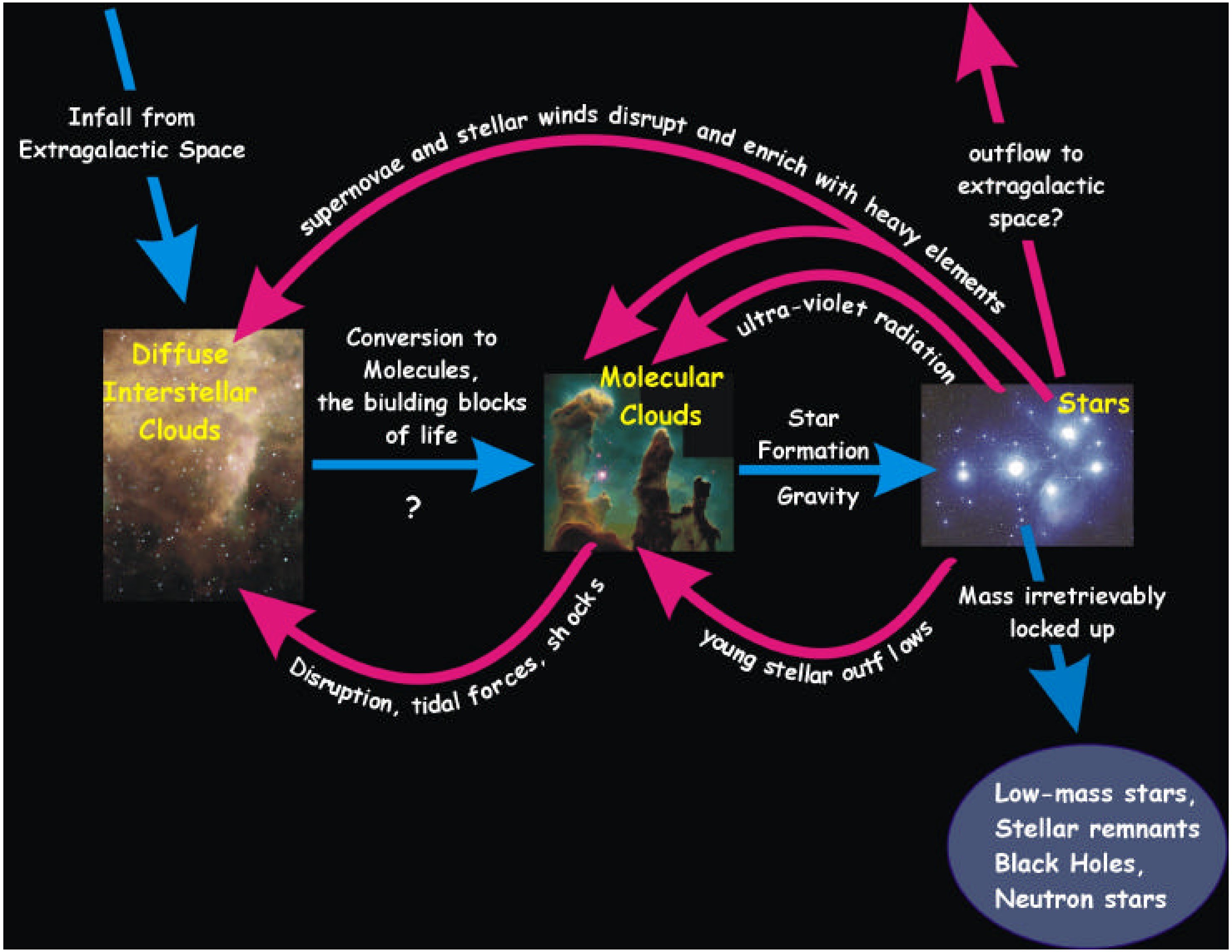
YSO with disk

Milky Way in Radio (21 cm)



See rich structure due to rotation, magnetic fields, and feedback from stars via supernovae and stellar winds.

The Evolution of Matter



The “ecosystem” of galaxies