GMCs & Star Formation

Formation
SF efficiency
The formation of individual stars

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H_2 in the ISM

Formation is dominated by recombination on dust grain surfaces.

$$t_{\rm form} = 1.5 \times 10^7 \text{ yr} \left(\frac{n}{100 \text{ cm}^{-3}} \right)^{-1}$$

for a mass ratio of ∼100 hydrogen atoms to dust.

Destruction is dominated by photodissociation.

- In an unattenduated interstellar radiation field, $t_{\rm life} \sim 600$ yr.
- Inside interstellar clouds, H_2 is protected by radiation attenuation by dust grains and itself (self-shielding).

Cloud formation mechanisms

Two main classes:

- Gas cools → molecules form → gas collapses
    - Thermal instability
- Gas is compressed, or loses additional non-thermal support → cooling…
    - Disk gravitational instability
    - Turbulence
    - Parker instability
    - Spiral arms
    - Galaxy interactions and mergers

Star formation efficiency in GMCs

The star formation (or gas consumption) time scale is defined as

$$\tau_{\rm SF} \equiv \frac{M_{\rm gas}}{\dot{M}_{\rm gas}}$$

For spiral galaxies, $\tau_{\rm SF} \simeq (1-5) \times 10^9$ yr, while for starburst galaxies, $\tau_{\rm SF} \sim 10^7 - 10^8$ yr.

Magnetic fields prevent GMC collapse

Unless the magnetic flux dissipates, a cloud with subcritical magnetic mass M_Φ will remain subcritical.

Ambipolar diffusion is a possible means of the magnetic flux dissipating in a molecular cloud. Its time scale is

$$\tau_{\rm ad} \simeq 1.1 \times 10^8 \text{ yr} \left(\frac{n}{100 \text{ cm}^{-3}}\right)^{1/2} \left(\frac{R}{10 \text{ pc}}\right)^{3/2} \left(\frac{B}{30\mu\text{G}}\right)^{-1}$$

We can define the star formation efficiency of a region as the ratio of its free-fall time, $\tau_{\rm ff,GMC}$ to the limiting mechanism of the star formation, τ_i,

$$\varepsilon_{\rm SF,GMC} \equiv \frac{\tau_{\rm ff,GMC}}{\tau_i}$$

Supersonic turbulence and SFE in GMCs

Turbulence can both suppress and promote gravitational collapse in GMCs.

Combining both turbulent motion and shock compression (which increases the density $\rho' = \mathcal{M}^2\rho$) changes the effective Jeans mass:

$$M_J \propto \frac{(\sigma_{\text{th}}^2 + \sigma_{\text{nt}}^2)^{3/2}}{\mathcal{M}\rho^{1/2}}$$

- On large scales, $\sigma_{\text{nt}} \gg \sigma_{\text{th}}$, so M_J increases, suppressing gravitational collapse.
- On small scales, $\sigma_{\text{nt}} \ll$ shock velocity, promoting gravitational collapse.

GMC clump size range

Volume-weighted probability distribution function (PDF)

$$\rho(\ln x)\, d\ln x = \frac{1}{\sqrt{2\pi\sigma^2_{\ln x}}} \exp\left[-\frac{(\ln x - \langle \ln x \rangle)^2}{2\sigma^2_{\ln x}}\right] d\ln x$$

where

$$\begin{aligned} x &\equiv \tfrac{n}{n_0} \\ n_0 &= \text{average density} \\ \langle \ln x \rangle &= -\tfrac{1}{2}\sigma^2_{\ln x} \end{aligned}$$

Source of the turbulence in GMCs

Initial formation of the galaxy is the most likely source of the supersonic turbulence in the GMCs. However, it will likely damp out on less than $t_{\mathrm{ff,GMC}}$, so a driving mechanism is needed.

External	Turbulence from the surrounding ISM
Internal	Protostellar outflows, stellar winds, ionizing radiation from new stars

Self-regulation of SF in GMCs

Various feedback processes from the star formation itself could regulate the rate of star formation in GMCs.

- Protostellar winds
- Stellar feedback

At the extreme, GMCs are likely destroyed by their own massive (OB) stars.

- HII regions
- Stellar winds
- SN explosions

Stellar feedback might also promote star formation ("induced" star formation) via supernova shocks, stellar winds, or ionization fronts.

Individual star formation in GMC cores

Formation process:

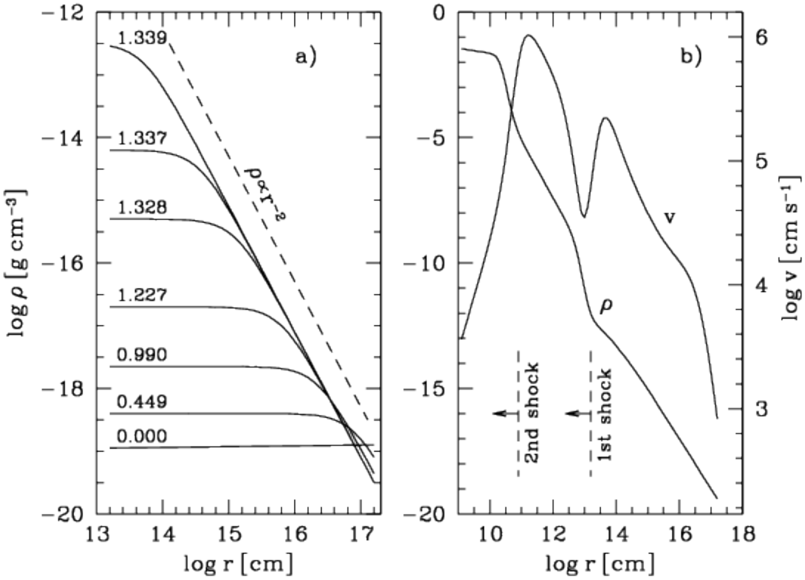
1. Dense core collapses
2. Accretion of infalling material onto protostar
3. Protostar feedback disperses gas around protostar, slowing or halting additional accretion
4. Protostar contracts to form pre-MS star

Time it takes to radiate away all of the gravitational potential energy is known as the Kelvin-Helmholtz time:

$$t_{\mathrm{KH}} = \frac{GM_*^2}{LR}$$

- Protostar luminosity dominated by accretion when the formation time is shorter than t_{KH}
- Protostar luminosity dominated by nuclear fusion when the formation time is longer than t_{KH}

Molecular core collapse to form low-mass stars



Effect of rotation and magnetic fields on low-mass star formation

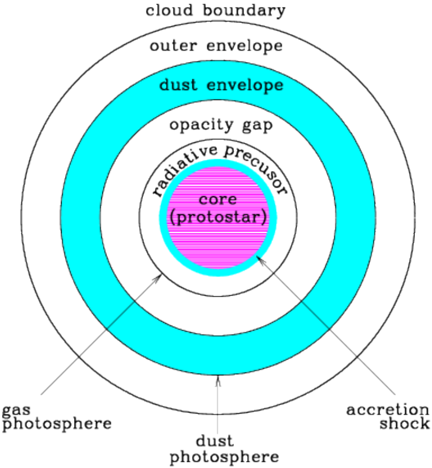
Protostellar disks are a result of the angular momentum of the gas particles.

Magnetic fields will hinder collapse of material in the perpendicular direction, also producing disks (though not rotationally supported).

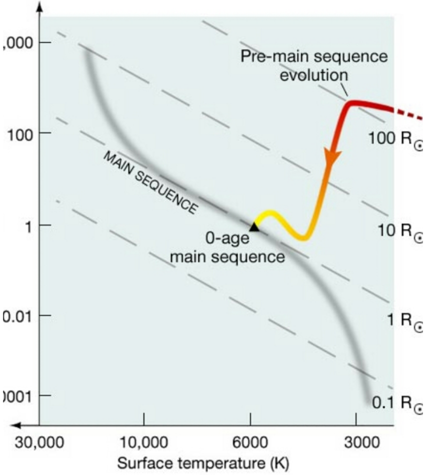
Protostars

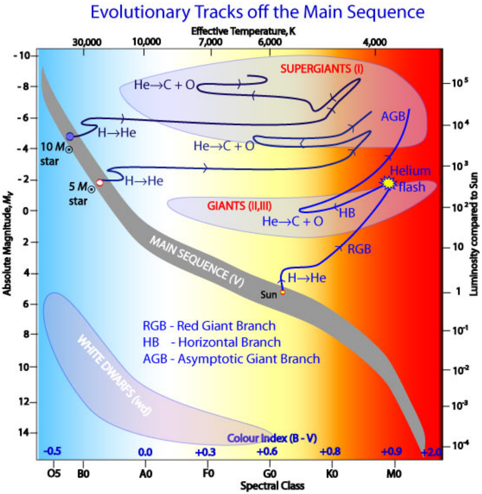
Initial protostar luminosity is due to accretion:

$$L = \frac{GM_c}{R_c}\dot{M}$$



Evolution of pre-MS stars




Evolutionary Tracks off the Main Sequence