Observational ISM and Star Formation

Embarrassing moments in asteroid tracking.

<u>This Class (Lecture 8):</u>

Core Collapse &
Duncan Christie/Tyler Natoli

<u>Next Class:</u>

Collapse &
Kristopher Czaja/William Kormos

Music: *Black Hole Sun* – Soundgarden

Astro-ph

1. Star clusters in the solar neighborhood: a solution to Oort's problem
   (H. J. G. L. M. Lamers and M. Gieles)
   - Oort's problem: lack of old clusters in the solar neighborhood implies that clusters are destroyed on a timescale of less than a Gyr
     - much shorter than the predicted dissolution time of clusters due to stellar evolution and two-body relaxation in the tidal field of the Galaxy
   - Included (1) stellar evolution, (2) tidal stripping, (3) perturbations by spiral arms and (4) encounters with giant molecular clouds
   - Estimates match up with ~1 GYr (infant mortality rate of 50-95%)

http://arxiv.org/abs/astro-ph/0702183

Astro-ph

2. Magnetic Fields and Rotations of Protostars
   (Masahiro N. Machida, Shu-ichiro Inutsuka, Tomoaki Matsumoto)
   - Three-dimensional resistive MHD nested grid simulations. Starting with a Bonnor-Ebert isothermal cloud rotating in a uniform magnetic field, we calculate the cloud evolution from the molecular cloud core ($n=10^4$ cm^{-3}) to the stellar core ($n < 10^{22}$ cm^{-3}).

http://arxiv.org/abs/astro-ph/0702183

Talks

1. Graduate Student from Australia, Annie Hughes, will give a talk on her research interest of molecular cloud structure and evolution and the far-infrared/radio correlation, with particular emphasis on the LMC.
   - Star Formation Lunch, Thursday, Noon, in classroom
2. Connecting Local and Global Star Formation
   (Erik Rosolowsky)
   - Journal Club, Friday, Noon, in classroom ($1.50/slice of pizza)

Outline

- The support of cloud cores
- Isothermal spheres

Collapsing

- We have molecular cloud cores, now what happens?
- Keep in mind star formation is NOT just the results of clouds breaking into tiny dense structures
- The onset of collapse is a localized occurrence within the large complex
- But most cloud cores are not collapsing, supported by
  - Thermal motions
  - Interstellar magnetic fields
  - Maybe not turbulence if it diminishes with small scale

Danger Zone: Jean's Mass

In homogenous medium (density ρ_0) there is a maximum length scale before it collapses due to gravity/thermal pressures only

For λ larger than:

$$\lambda_J = \left(\frac{\pi a^2_{Thermal}}{G\rho_0} \right)^{1/2}$$

Derived by perturbation analysis of the continuity equation and Newton's law

$$\lambda_J = 0.19\,pc \left(\frac{T}{10\,K} \right)^{1/2} \left(\frac{n_{H2}}{10^4\ \mathrm{cm}} \right)^{-1/2}$$

Danger Zone: Jean's Mass

This is true for all waves (in all directions) with $\lambda > \lambda_J$. This defines maximum stable mass: a sphere with diameter λ_J.

$$M_J = \frac{m}{6} \rho_0 \left(\frac{\pi\, a^2_{Thermal}}{G\rho_0} \right)^{3/2}$$

Jean's mass

$$M_J = 1 M_{\mathrm{Sun}} \left(\frac{T}{10K} \right)^{3/2} \left(\frac{m_{H2}}{10^4\ \mathrm{cm}^{-3}} \right)^{-1/2}$$

The Star Formation Problem

Gas in the galaxy should be wildly gravitationally unstable. It should convert all its mass into stars on a free-fall time scale:

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32 G\rho}} = \frac{3.4\times 10^7}{\sqrt{n}} \text{ year}$$

For interstellar medium (ISM):

$$n \approx 1 \text{ to } 10 \text{ cm}^{-3}$$

$$t_{\rm ff} = 3.4\times 10^7 \text{ to } 3.4\times 10^6 \text{years}$$

The Star Formation Problem

Total amount of molecular gas in the Galaxy: $\sim 2\times 10^9 M_{\rm sun}$

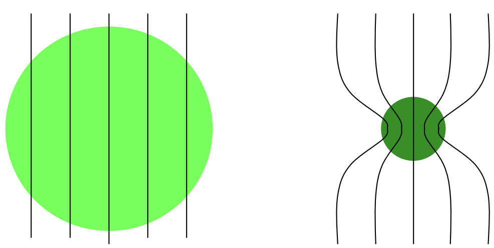
Expected star formation rate: $\sim 250\ M_{\rm sun}/\text{year}$

Observed star formation rate: $\sim 3\ M_{\rm sun}/\text{year}$

Something slows star formation down...

Magnetic Field Support

In presence of B-fields, the stability analysis changes. Magnetic fields can provide support against gravity.



Replace Jeans mass with critical mass, defined as:

$$M_{\rm cr} = 0.12 \frac{\Phi_{\rm M}}{{\rm G}^{1/2}} \approx 10^3 M_{\rm sun} \left(\frac{|\mathbf{B}|}{30\,\mu{\rm G}}\right)\left(\frac{R}{2\,{\rm pc}}\right)^2$$

Magnetic field support

Consider an initially stable cloud. We now compress it. The density increases, but the mass of the cloud stays constant.

So the Jean's mass *decreases:* $M_J \propto \frac{1}{\rho^{3/2}}$

- If no magnetic fields: there will come a time when $M>M_J$ and the cloud will collapse.
- But M_{cr} stays constant (magnetic flux freezing)
- So if B-field is strong enough to support a cloud, no compression will cause it to collapse (sub-critical).

Ambipolar diffusion

- But magnetic flux freezing is not perfect.
- Only the (few) electrons and ions are stuck to the field lines.
  - Would expect the plasma to be coupled to the neutrals
  - But interiors of cloud cores have low fractional ionization
  - The neutral molecules do not feel the B-field.

Mouschovias 1976 and others

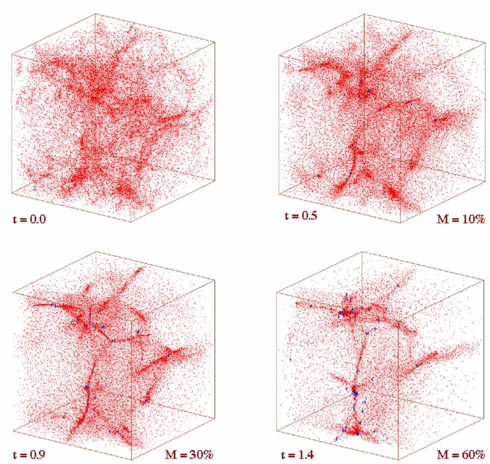
Ambipolar diffusion

- Neutrals may slowly diffuse through the ‘fixed’ background of ions and electrons.
- Depends on the friction between ions and neutrals
- The drift velocity if inversely proportional to this friction
- Slowly a cloud (supported by B-field) will expel the field, and contract, until it can no longer support itself, and then collapses

Mouschovias 1976 and others

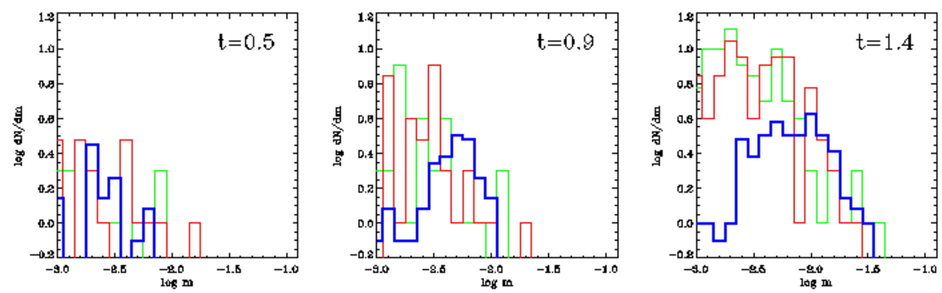
Supersonic turbulence

- Supersonic turbulence is alternative way to prevent GMCs to collapse
- Problem: very quickly decays (each shock converts almost all energy in heat)
- Possible solutions:
  - Energy input from young stars
  - Ionization from massive stars



Klessen & Burkert 1997

Star formation in turbulent GMCs



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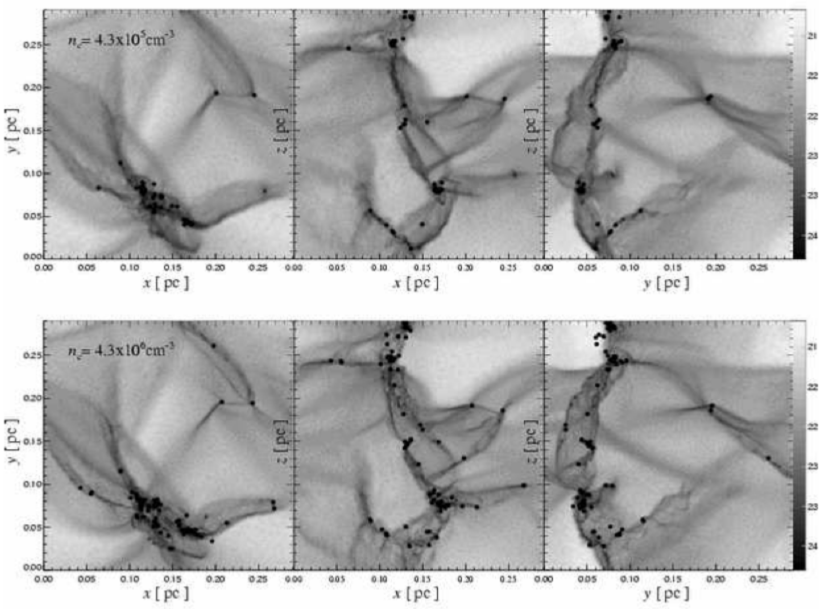

Jappsen, Klessen