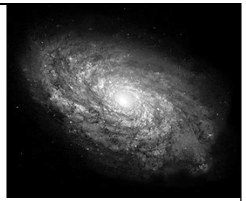
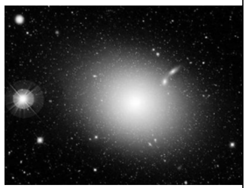
FORMATION AND EVOLUTION OF GALAXIES



Lecture 17

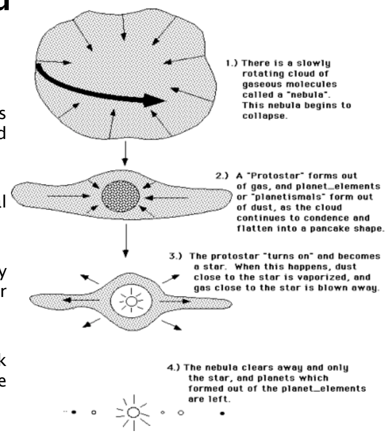
- Star formation
- Starbursts
- Galaxy interactions and mergers



Somak Raychaudhury

Cloud Collapse and Star/Planet Formation

- Jeans cloud collapse equations describe the conditions required for an ISM cloud to collapse.
- As a cloud collapses, central temperature increases.
- This is accompanied by spinning-up of the central star (to conserve AM).
- If the cloud is rotating, the disk also flattens into an oblate spheroid.

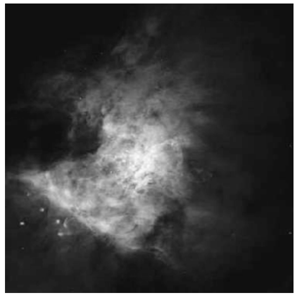


Time-scale for collapse

- The collapse time-scale t_{ff} when $M > M_J$ is given by the time a mass element at the cloud surface needs to reach the centre.
- In free-fall, an mass element is subject to acceleration $g = \frac{GM}{R^2}$
- By approximating R using $R^3 \sim M/\rho \Rightarrow t_{ff} \approx (G\rho)^{-1/2}$
- Higher density at cloud centre = > $\boxed{\text{faster collapse.}}$
- For typical molecular cloud, $t_{ff} \sim 10^3$ years (ie very short).

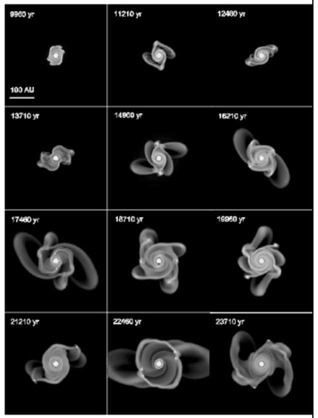
Nebular Collapse

- The Solar system was formed from a giant molecular cloud, known as a *primordial nebula*.
  - Similar to the Orion Nebula (right).
- This nebula may have only contained only 10-20% more mass than the present solar system.
- Due to some disturbance, perhaps a nearby supernova, the gas was perturbed, causing ripples of increased density
- The denser material began to collapse under its own gravity…



Proto-star and Disk Formation

- The original nebula must have possessed some angular momentum. Due to the spin, the cloud collapsed faster along the 'poles' than the equator.
- The result is that the cloud collapsed into a spinning disk.
- Disk material cannot easily fall all the remaining way into the centre because of its rotational motion, unless it can somehow lose some energy, e.g. by friction in the disk (collisions).
- The initial collapse takes just a few 100,000 years.



Problem of star formation efficiency

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

$$\boxed{t_{\mathrm{ff}} = \sqrt{\frac{3\pi}{32G\rho}} = \frac{3.4\times10^{10}}{\sqrt{n}}\ \mathrm{yr}}$$

For interstellar medium (ISM) in our galaxy: $\boxed{n \approx 2\times10^{5}\ \mathrm{m}^{-3}}$

$$\boxed{t_{\mathrm{ff}} = 8\times10^{6}\ \mathrm{yr}}$$

Total amount of molecular gas in the Galaxy: $\boxed{\sim 2\times10^{9} M_{\mathrm{sun}}}$

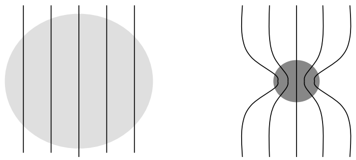
Expected star formation rate: $\boxed{\sim 250\ M_{\mathrm{sun}}/\mathrm{year}}$

Observed star formation rate: $\boxed{\sim 3\ M_{\mathrm{sun}}/\mathrm{year}}$

Something slows star formation down...

Magnetic field support

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



Replace Jeans mass with critical mass, defined as:

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

nT is nano-Tesla!

Magnetic field support

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

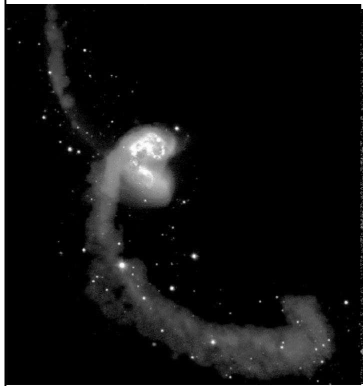
Jeans mass *decreases:* $\boxed{M_J \propto \frac{1}{\sqrt{\rho}}}$

If no magnetic fields: there will come a time when $M>M_J$ and the cloud will collapse.

But M_{cr} stays constant (the magnetic flux will be frozen in the cloud)

So if B-field is strong enough to support a cloud, no compression will cause it to collapse.

Interacting galaxies



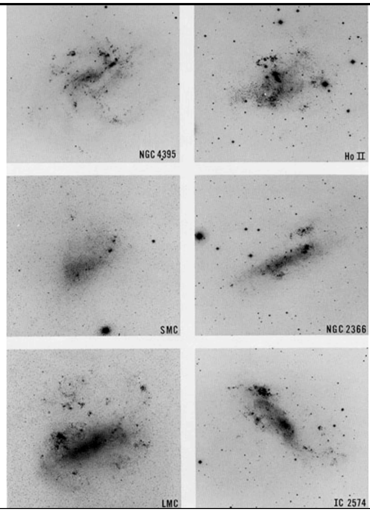

The Antennae Arp 273

Star formation in Galaxies

Observables

- Broadband colours
- $H\alpha$ fluxes or other hydrogen recombination lines, but *not* $Ly\alpha$ (resonant scattering eventually followed by dust absorption)
- Far IR
- Radio continuum
- Molecular gas CO- seen in mm waves

Star formation regions are obvious in these Sm-Irr galaxies



What regulates the star formation?

- Negative and positive feedback processes
  - \+ Gravitational collapse of gas clouds
  - \+ Cooling – atomic, molecular, dust
  - \+ Gas compression from stellar winds
  - \- Sputtering on dust particles
  - \- Ionization
  - \- Heating and expansion of gas clouds
- The normal state is *self regulated* – i.e starbursts are shortlived, effects of galaxy interactions are mostly controlled

Star formation in Galaxies

A simple prescription that seems to work also for starbursts:

- Schmidt law (Schmidt 1959; Kennicutt, 1998)

$$\Sigma_{SFR} \propto \Sigma_{gas}{}^{N}$$

Based on densities of young stars and gas in the galactic disk. Justified globally, not locally.

- Alternatively (Silk 1977): $\Sigma_{SFR} \propto \dfrac{\Sigma_{gas}}{\tau_{dyn}} \propto \Sigma_{gas}\Omega_{gas}$

Where Ω is the angular rotation speed.

Both laws are semiempirical and give similar results.

The difficulty of deriving information about the lower mass limit:

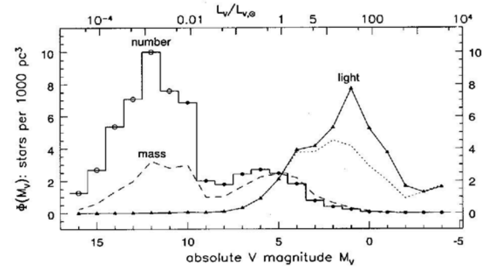
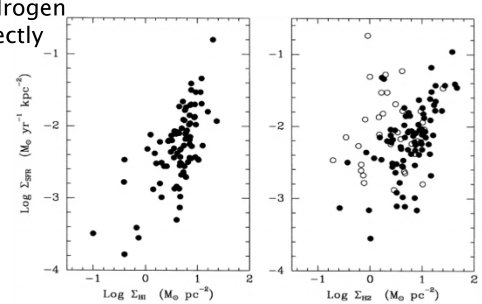


Figure 2.3 Luminosity function $\Phi(M_V)$ for nearby stars: solid dots are from the stars of Figure 2.2; open circles are from *photometric parallax*. The solid line and triangles show $L_V\Phi(M_V)$, light from stars in each magnitude bin; the dotted curve shows the light of main-sequence stars alone. The dashed curve gives $\mathcal{M}\Phi_{MS}(M_V)$, the mass in main-sequence stars: units are $L_\odot$ or $\mathcal{M}_\odot$ per 10 pc cube.

We can't detect molecular hydrogen directly

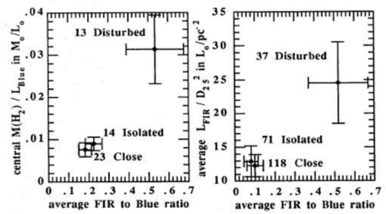
SFR based on Hα. H_2 densities based on constant CO/H_2 conversion factor.



○ : $L<10^{10}\ L_o$

● : $L>10^{10}\ L_o$

Kennicutt 1998, ApJ 498, 541



More $M(H_2)$ in proportion for disturbed=interacting

More star-formation, too

Would it be the conversion X? Problems, since high density

$X \sim n^{1/2}/T_r$

Star formation efficiency

$SFE=L_{FIR}/M(H_2)$

SFE too large?