17 Astro notes 2018/10/3 - Wed - Star formation, protostars

Mention SPS meeting tonight 5-6pm room 227.

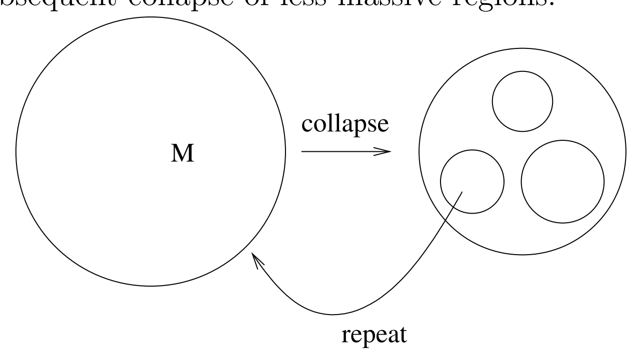
17.1 Star formation and fragmentation

we found the Jeans mass:

$$M_J = 500M_\odot \left(\frac{T}{10^4\ \mathrm{K}}\right)^{3/2} \left(\frac{1\ \mathrm{cm}^{-3}}{n}\right)^{1/2}$$

where $n = \rho/m_p$. In a region with T, ρ a mass in excess of this can collapse.

The problem is this is big. How do we get from this to the distribution of stellar masses from this? How does a collapsing mass fragment into $M_\odot$ chunks? We will simply try to answer why would it fragment at all? The Jean's mass scales as $M_J \propto T^{3/2}\rho^{-1/2}$. Imagine that the region keeps it's same temperuture as it collopses. Then M_J decreases during the collapse. Then as the jeans mass decreases this can allow for "fragmentation" or the subsequent collapse of less massive regions.



So what halts the fragmentation. As density is rising in the fragments, they eventually become optically thick and so can't necessarily radiate on the collapse time. After it becomes adiabatic. Then $T \propto \rho^{2/3}$. Then the Jeans mass, $M_J \propto \sqrt{\rho}$, which is increasing as collapse continues. This shuts off fragmentation.

Halting of fragmentation is then due to the isothermal-adiabatic transition. Hard because you have to do both the dynamics and radiative transfer.

What's a characteristic timescale? The dynamical time. This can be obtained by considering a simplified version of free-fall. Consider the acceleration of a particle at the surface of the star if pressure support is removed:

$$\frac{d^2R}{dt^2} = a = -\frac{GM}{R^2}$$

If we use this acceleration as if it were constant we can estimate the time it takes for the particle to cross a distance R:

$$\frac{1}{2}at_{\mathrm{dyn}}^2 \approx -R \implies t_{\mathrm{dyn}}^2 \simeq \frac{R^3}{GM}$$

One conventional way to write this, which is similar up to factors of order unity, is

$$t_{dyn} = \frac{1}{\sqrt{G\rho}} \simeq \frac{10^7 yrs}{(n/100)^{1/2}}$$

17.2 Halting Fragmentation

Want to estimate when fragmentation of the protostellar cloud into smaller and smaller chunks halts. This should determine the approximate mass scale at which individual stars would form, since the cloud could not fragment into any smaller pieces. In reality a wide range of masses are formed, but there is a characteristic scale. Estimate by finding when the freefall luminosity is similar to what can be emitted by radiative transfer. That is

$$L_{ff} \sim L_{rad}$$

Can make a simple estimate assume energy GM^2/R is released on collapse (free fall) time. This gives
(student)

$$L_{ff} \sim \frac{E_{grav}}{t_{dyn}} \sim \frac{GM^2/R}{1/\sqrt{G\rho}} \sim G^{3/2}\frac{M^{5/2}}{R^{5/2}}$$

The time when the medium becomes optically thick corresponds to when some modest fraction of the flux is carried by radiative diffusion

$$L_{rad} = e4\pi R^2 \sigma T^4$$

where e is some fudge efficiency factor. Then if we equate these two

$$L_{ff} \sim L_{rad}$$

get

$$M^{5/2} \sim R^{9/2} G^{-3/2} e\sigma T^4$$

The last ingredient is that for the collapsing mass

$$\frac{GM^2}{R} \sim \frac{M}{\mu m_p} kT$$

which was used to get the Jeans mass. Here μ is the mean weight of each particle in units of m_p, close to 1 since material is mostly hydrogen. This allows us to relate R to M with a factor of T, $R \propto M/T$. So that

$$M^{5/2} \propto M^{9/2}/T^{1/2}$$

or, with numbers,

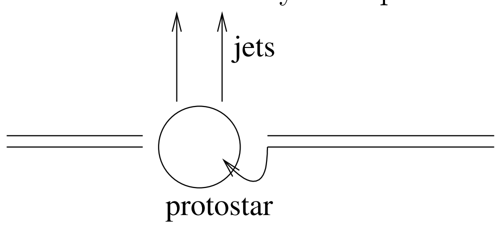
$$M_{iso-adiab} \sim 0.03 M_{\odot} \left(\frac{1}{e^{1/2}\mu^{9/4}}\right)\left(\frac{T}{10^4 \text{ K}}\right)^{1/4}$$

17.3 Protostars

But on this same timescale there is evidence that the "protostar" accretes more material from the surrounding cloud. The luminosity that such an object has is

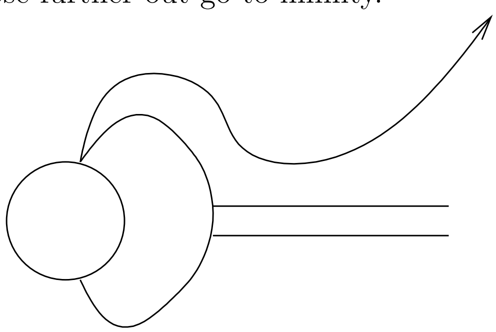
$$L = \dot{M}\frac{GM}{R}$$

just accretion luminosity. The picture is a disk with a jet.



For $M \simeq M_\odot$ the first $\sim (1-5)$ Myrs is this accretion stage.

Why the jets? Two questions: what launches them, and what collimates them. The resulting stars are NOT spinning very fast. The field lines truncate the disk, and then those further out go to infinity.



The problem is figuring out how incoming material chooses between the closed field line and the open one.

See figures in Feigelson & Montmerle 1999, ARA&A, 37, 363

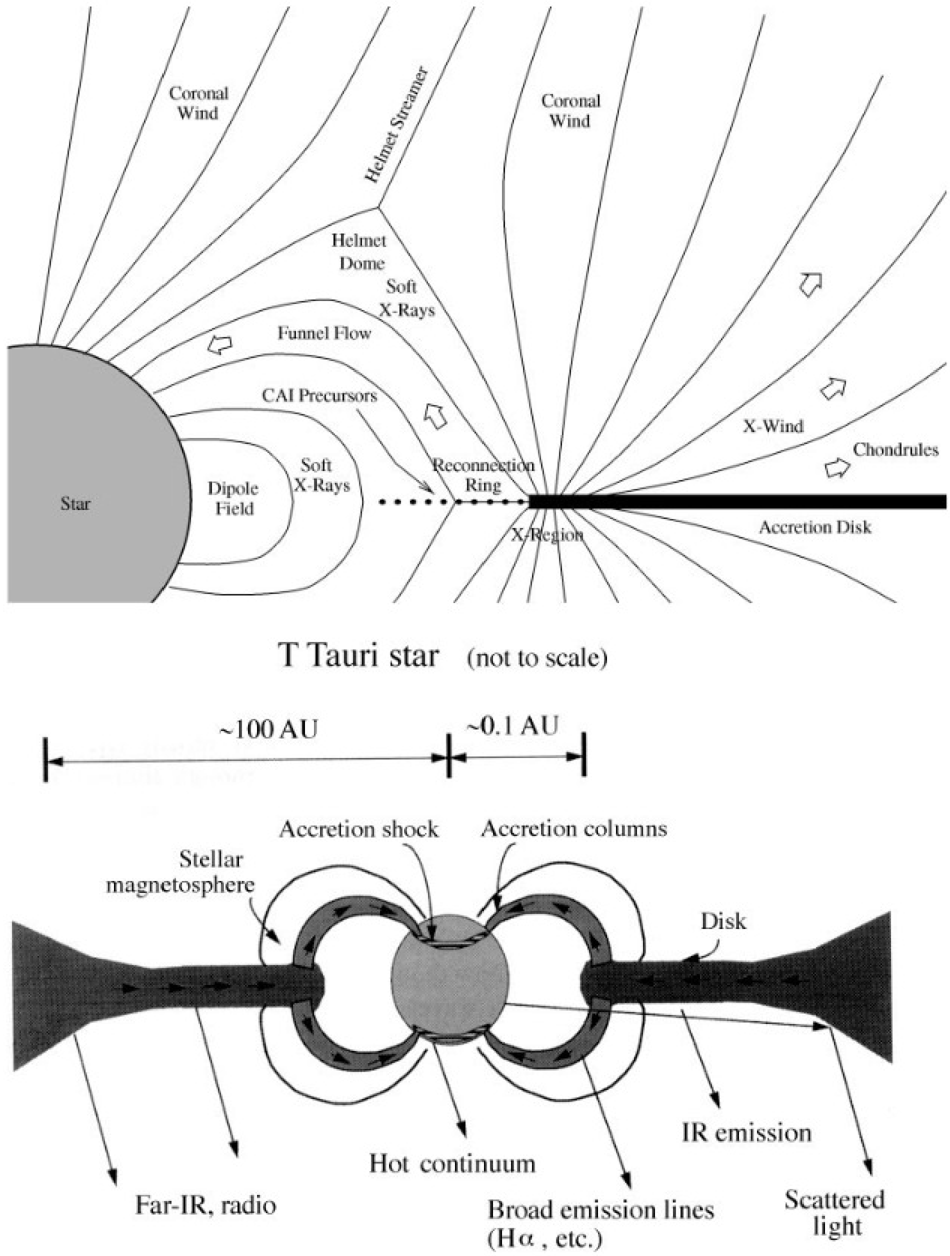


Figure 3 Two contemporary models for Class I–II YSOs, in which magnetic fields play crucial roles: (*top*) the x-wind model of YSOs showing magnetically collimated accretion and outflows with irradiated meteoritic solids (Shu et al 1997); (*bottom*) magnetically funneled accretion streams producing broadened emission lines (Hartmann 1998).

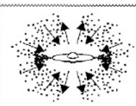
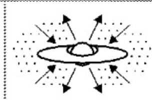
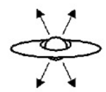
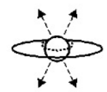
PROPERTIES	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)
DISK	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-RAY	?	Yes	Strong	Strong	Weak
THERMAL RADIO	Yes	Yes	Yes	No	No
NON-THERMAL RADIO	No	Yes	No ?	Yes	Yes

Figure 1 The stages of low-mass young stellar evolution. This review chiefly addresses the bottom three rows of the chart. (Adapted from Carkner 1998.)