Observational ISM and Star Formation

This Class (Lecture 10):

More Collapse &
Hsin-Lun Kuo/Kristen Samuels

Next Class:

More Collapse &
Brad Rockwell /Brett Hayes

Music: *Major Tom* – Peter Schilling

Astro-ph

1. The impact of magnetic fields on single and binary star formation
   (Daniel J. Price and Matthew R. Bate)
   - Magnetohydrodynamic (MHD) simulations of the collapse and fragmentation of molecular cloud cores using a new algorithm for MHD within the smoothed particle hydrodynamics (SPH) method
   - Magnetic pressure plays the dominant role in inhibiting fragmentation
   - Despite this, and contrary to several past studies, we find that strongly-perturbed molecular cloud cores are able to fragment to form wide binary systems even in the presence of quite strong magnetic fields.

http://arxiv.org/abs/astro-ph/0702410

Talks

Astro Colloquium: Dust evolution in young disks and the first stages of planet formation

Nuria Calvet, *University of Michigan*

Tuesday: 1600 in Astro Classroom

Outline

- Isothermal spheres
- Bonner-Ebert Spheres
- Collapse!

Isothermal Spheres

- Most of the early work is done assuming
  - Spherical clouds
  - Isothermal clouds
    - Not a bad assumption for dense, starless cores
- Use hydrostatic equilibrium and EOS of ideal isothermal gas, one gets the dimensionless isothermal Lane-Emden equation

$$\frac{1}{\zeta^2}\frac{d}{d\zeta}\left(\zeta^2\frac{d\psi}{d\zeta}\right)=\exp(-\psi)$$

Isothermal Spheres

$$\frac{1}{\zeta^2}\frac{d}{d\zeta}\left(\zeta^2\frac{d\psi}{d\zeta}\right)=\exp(-\psi)$$

Dimensionless radius

Dimensionless density

$$\zeta \equiv \left(\frac{4\pi G\rho_c}{c_s^2}\right)^{1/2} r$$

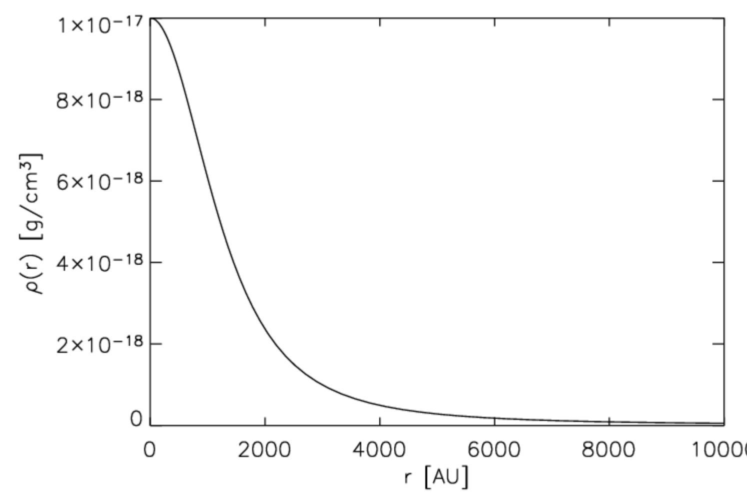
$$\rho(r)=\rho_c\exp(-\psi)$$

Lane-Emden: Boundaries

Use Boundary Conditions:

$$\psi(0)=0 \qquad \left.\frac{d\psi(\xi)}{d\xi}\right|_{\xi=0}=0$$

One Solution: Bonner-Ebert Sphere



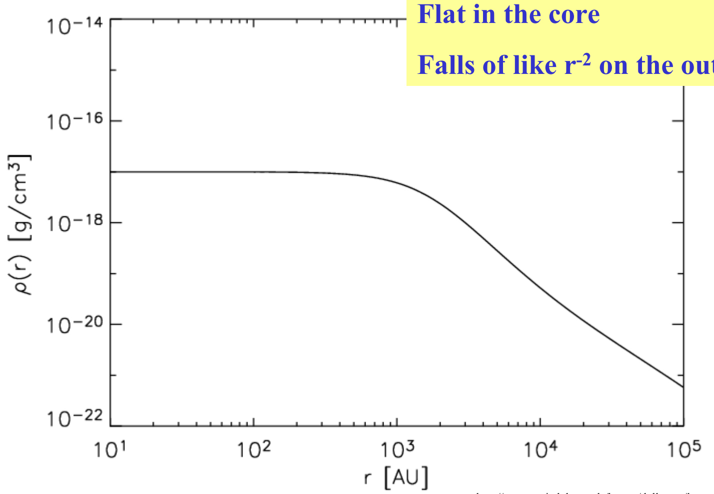
http://www.mpia-hd.mpg.de/homes/dullemon/lectures/starplanet/index.html

One Solution: Bonner-Ebert Sphere

Plotted logarithmically (which we will usually do from now on)

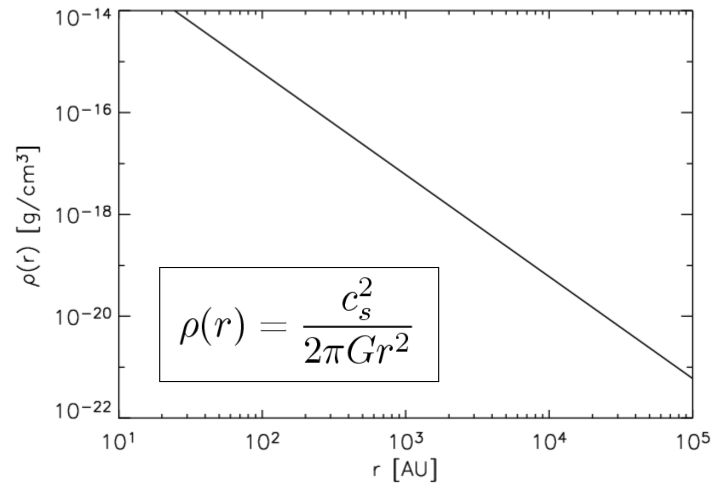
Flat in the core

Falls of like r^{-2} on the outside



Another Solution: Singular Isothermal Sphere

Limiting solution

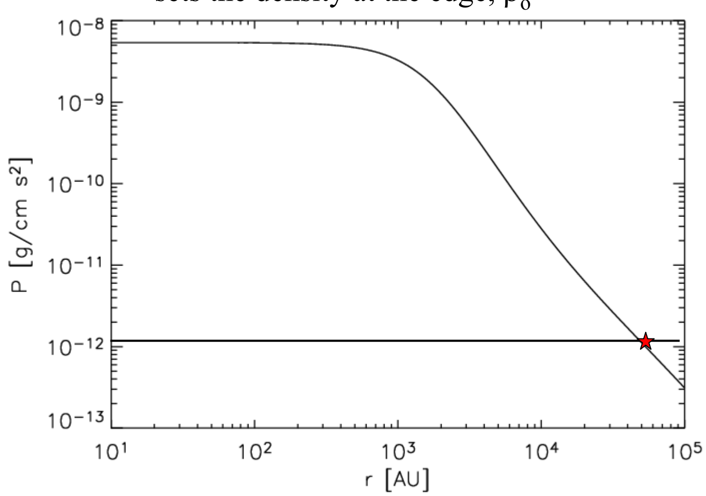


Hydrostatic self-gravitating spheres

Boundary condition:

Pressure at outer edge = pressure of GMC

sets the density at the edge, ρ_o

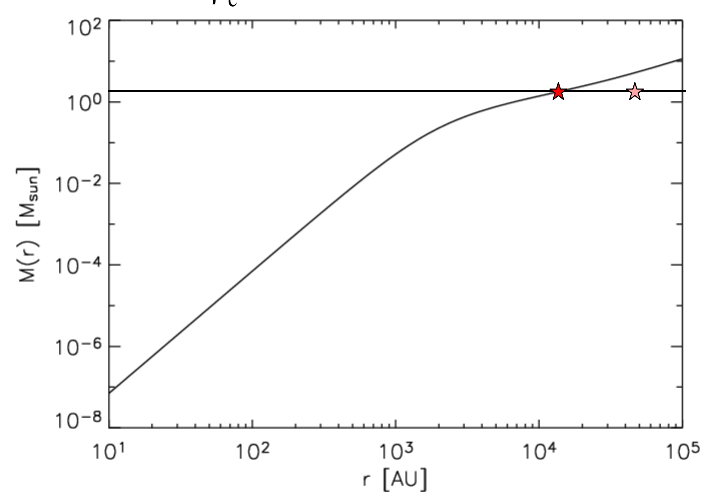


Hydrostatic self-gravitating spheres

Another boundary condition:

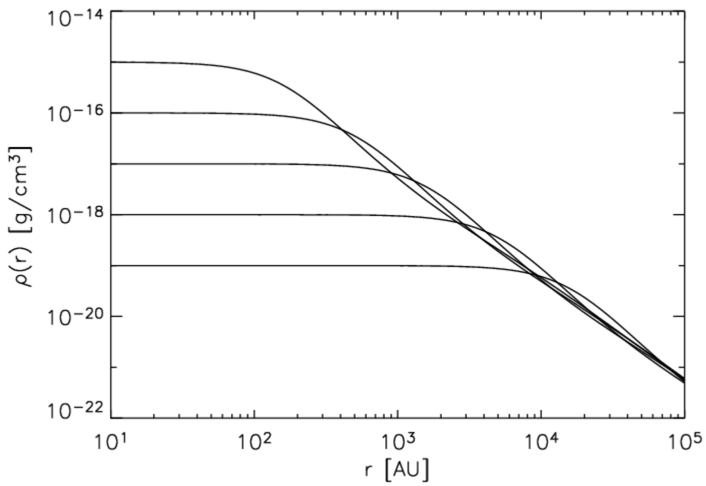
Mass of clump: one too many BC

That means ρ_c is determined



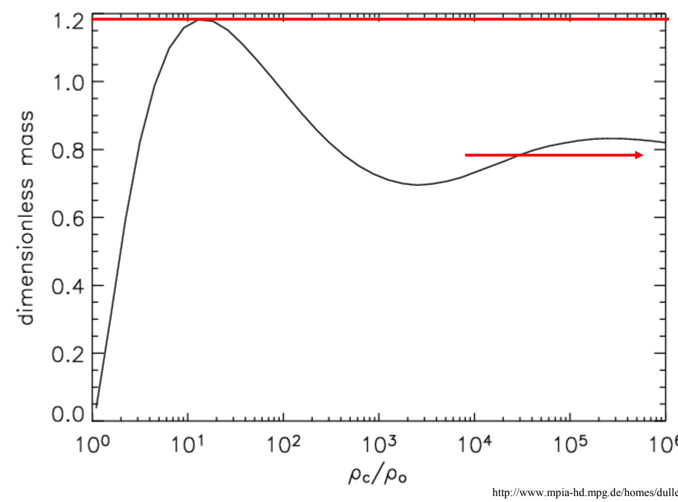
One Solution: Bonner-Ebert Sphere

Different starting ρ_c : a family of solutions

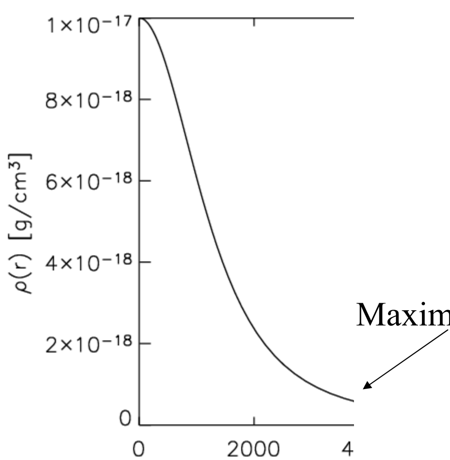


One Solution: Bonner-Ebert Sphere

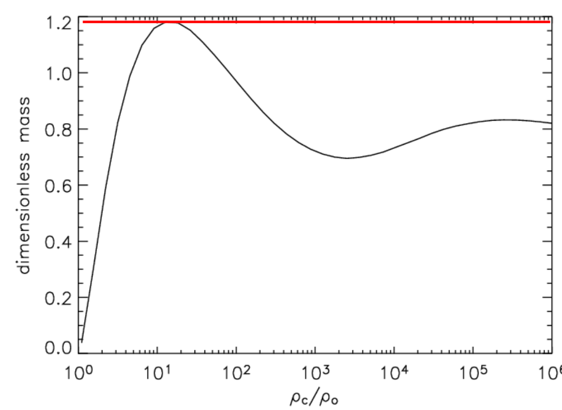
Can make a dimensionless mass to the solution.
Many modes of instability.



Stability of BE spheres



Bonnor-Ebert mass



$m_1 = 1.18$

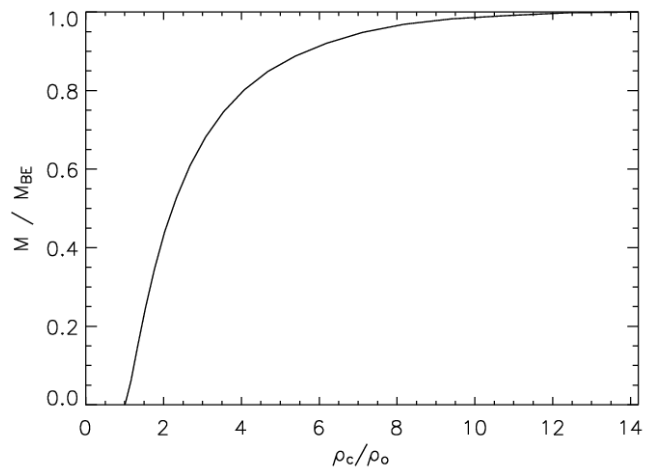
$$M_{BE} = \frac{m_1 c_s^4}{P_0^{1/2} G^{3/2}}$$

Ways to cause BE sphere to collapse:

- Increase external pressure until $M_{BE} < M$
- Load matter onto BE sphere until $M > M_{BE}$

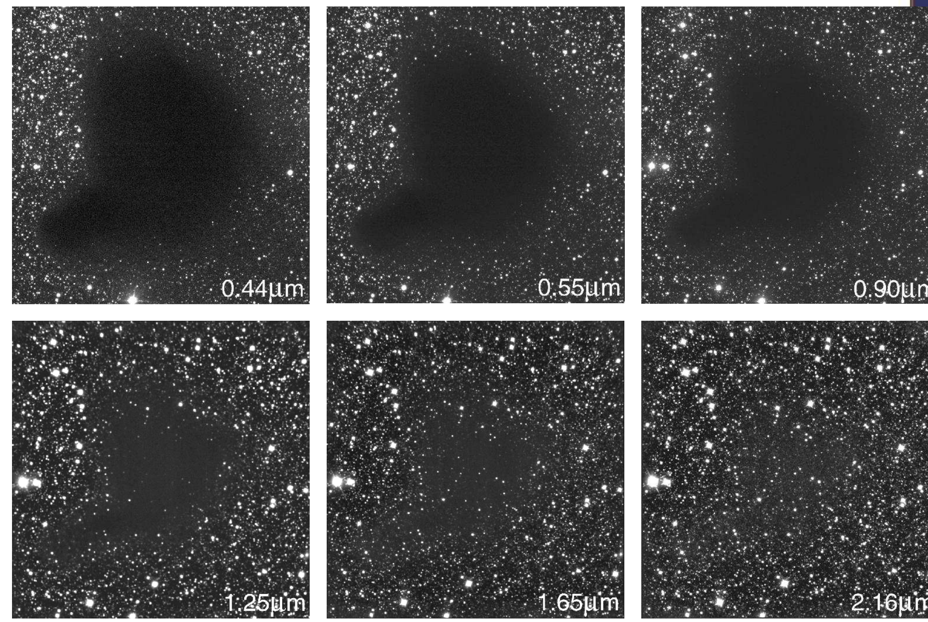
Bonnor-Ebert Mass

Now plotting the x-axis linear (only up to ρ_c/ρ_o =14.1) and divide y-axis through BE mass:



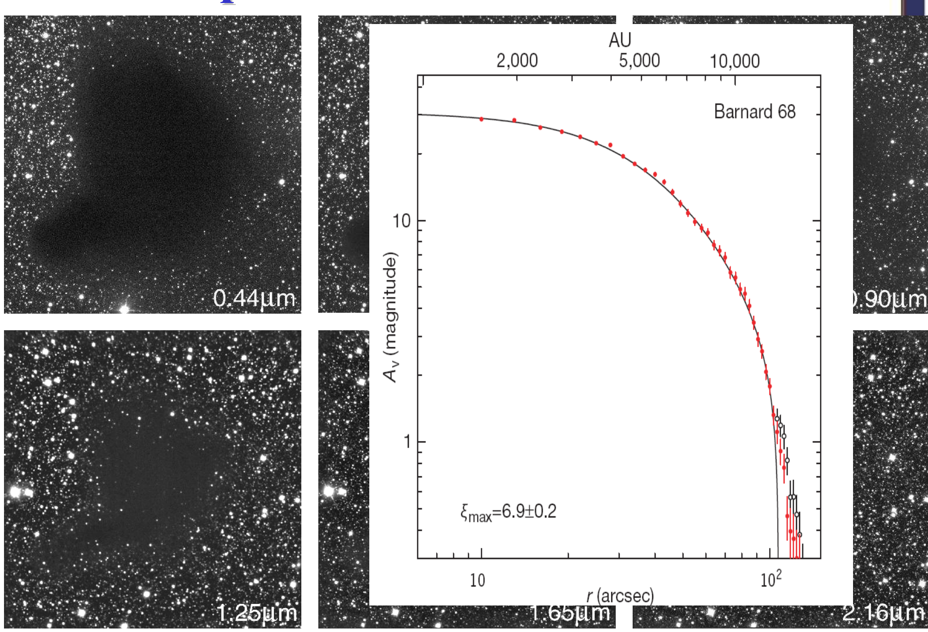
Hydrostatic clouds with large ρ_c/ρ_o must be very rare...

BE 'Sphere': Observations of B68



Alves, Lada, Lada 2001

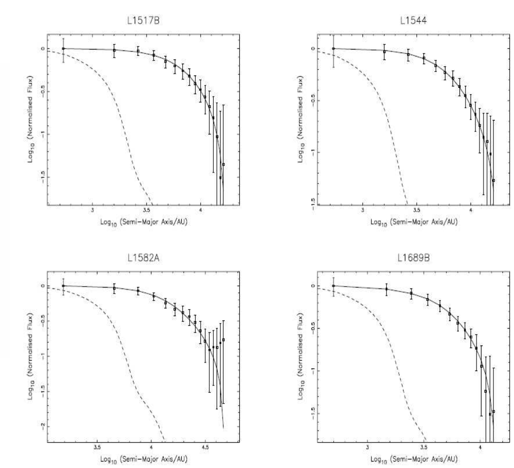
BE 'Sphere': Observations of B68



Alves, Lada, Lada 2001

Or Starless Cores

Source	R_{flat} (au)	ξ_{max}	R_{edge} (au)	T_{eff} (K)
L1521F	3400	$\geqslant$7.5	$\geqslant$13000	52
L1517B	5800	$\geqslant$10	$\geqslant$29000	35
L1544	4800	10	24000	71
L1582A	11000	9	50000	33
L1689B	3800	$\geqslant$14	$\geqslant$27000	28
L63	3600	$\geqslant$15	$\geqslant$27000	26
B133	6800	4	13000	24



Kirk et al. 2005

Spherically symmetric free falling cloud

Free fall velocity:

$$v_{\rm ff} = \sqrt{\frac{2GM(r)}{r}}$$

If stellar mass dominates:

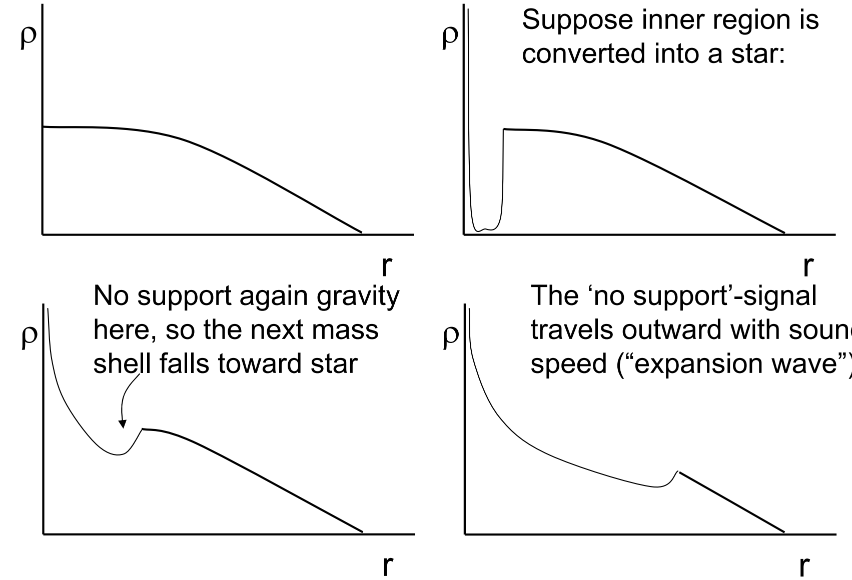
$$v_{\rm ff} = \sqrt{\frac{2GM_*}{r}}$$

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial (r^2 \rho v)}{\partial r} = 0 \quad \xrightarrow{\text{Stationary free-fall collapse}} \quad \frac{\partial (r^2 \rho v_{\rm ff})}{\partial r} = 0$$

$$\boxed{\rho(r) \propto r^{-3/2}}$$

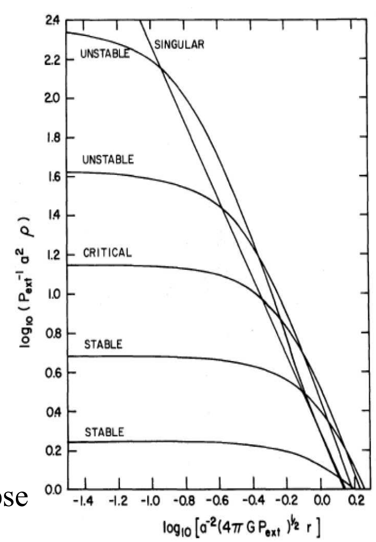
Inside-out collapse of metastable sphere



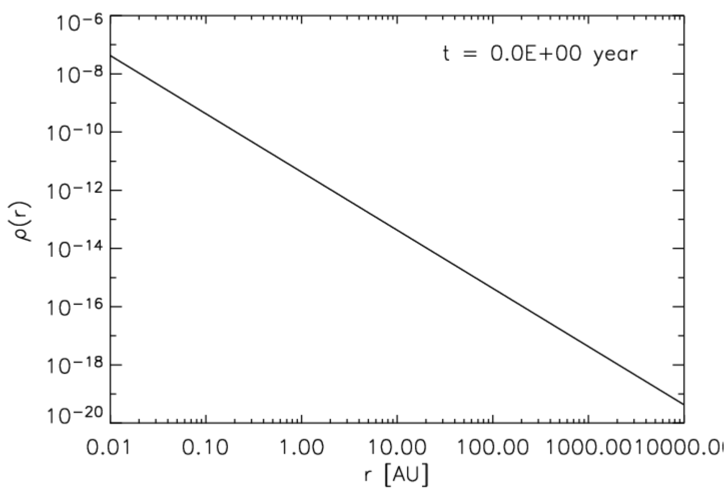
(warning: strongly exaggerated features)

Inside-Out Collapse Model of Shu (1977)

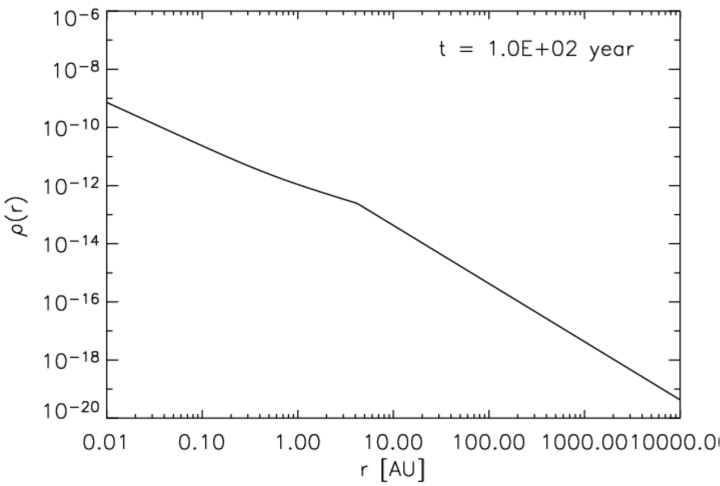
- The analytic model:
  - Starts from singular isothermal sphere
  - Models collapse from inside-out
  - Applies the `trick' of self-similarity
- Major drawback:
  - Singular isothermal sphere is unstable and therefore unphysical as an initial condition
- Nevertheless very popular because:
  - Only existing analytic model for collapse
  - Demonstrates much of the physics



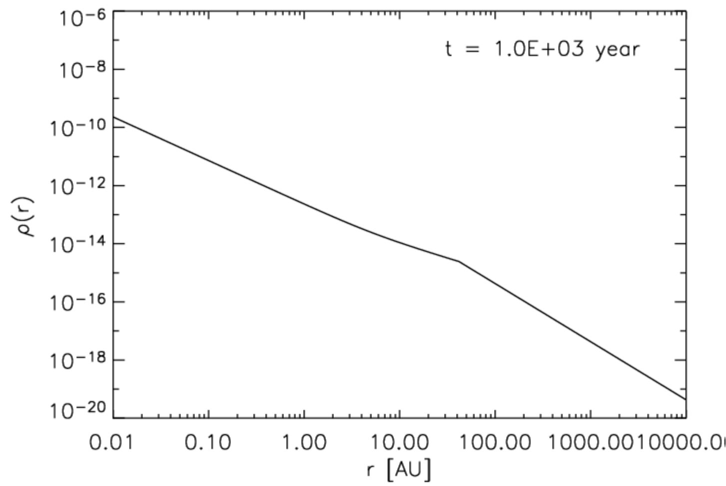
Inside-out Collapse



Inside-out Collapse



Inside-out Collapse



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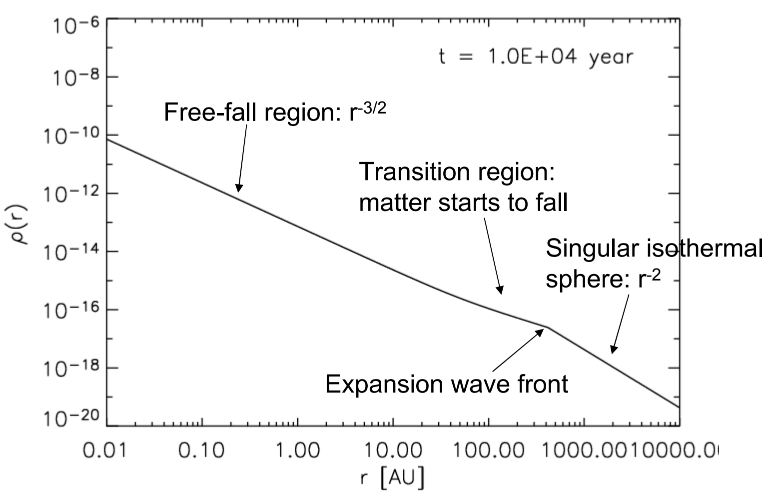

Inside-out Collapse

Deep down in free-fall region ($r << c_s t$):

$$\rho(r,t) = \frac{c_s^{3/2}}{17.96\,G} \frac{1}{\sqrt{t}} \frac{1}{r^{3/2}} \qquad v(r,t) = \sqrt{\frac{2GM_*(t)}{r}}$$

Accretion rate is constant: $\dot{M} = \frac{c_s^3 m_0}{G} = 0.975 \frac{c_s^3}{G}$

Stellar mass grows linear in time

Inside-Out Collapse

- In the envelope, the gas is at rest and does not know that the center is collapsing
- In the core, the velocities are supersonic and approach the free-fall velocity
- The accretion rate is time-independent at the transition region between free-falling core and static envelope, so it is moving outward with the speed of sound

Hydrostatic

- As the core collapses and becomes optically thick, the core heats up and supports itself thermally
  - a hydrostatic core
- When the temperature reaches 2000 K, H_2 dissociates, then collapse would continue

Missing

- Rotation
- Non-isothermality
- Magnetic fields