COLLAPSE OF LOW MASS CORES 2

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OUTLINE

SPHERICAL UNMAGNETIZED COLLAPSE

- 4 stages
- Limitations of the model

MAGNETIC EFFECTS

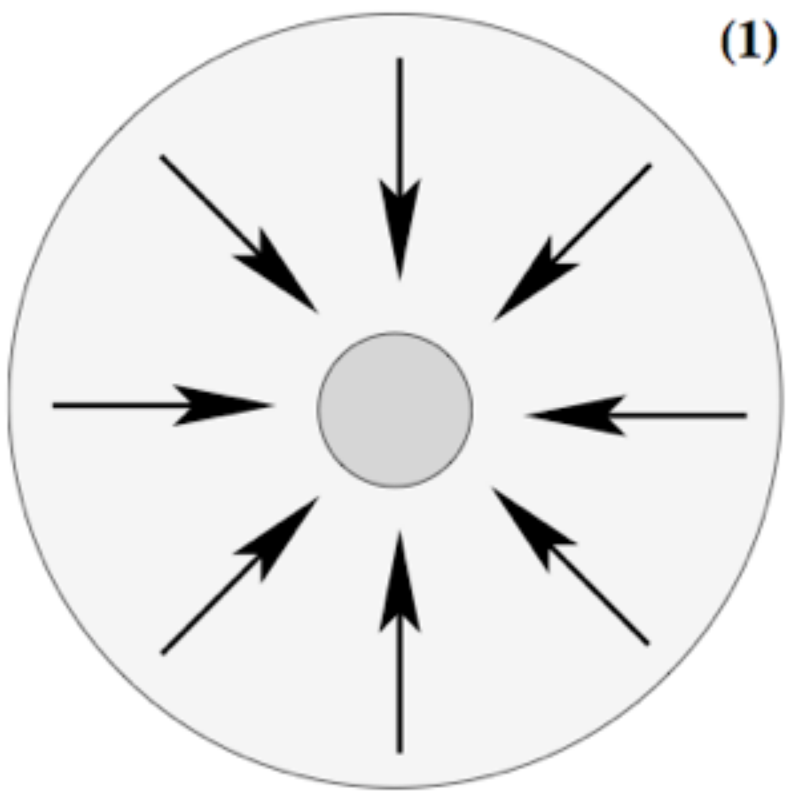
- Magnetic tension
- Ambipolar diffusion
- Ohmic Dissipation

ROTATIONAL EFFECTS

- Disk creation
- Disk destruction

SPHERICAL UNMAGNETIZED COLLAPSE

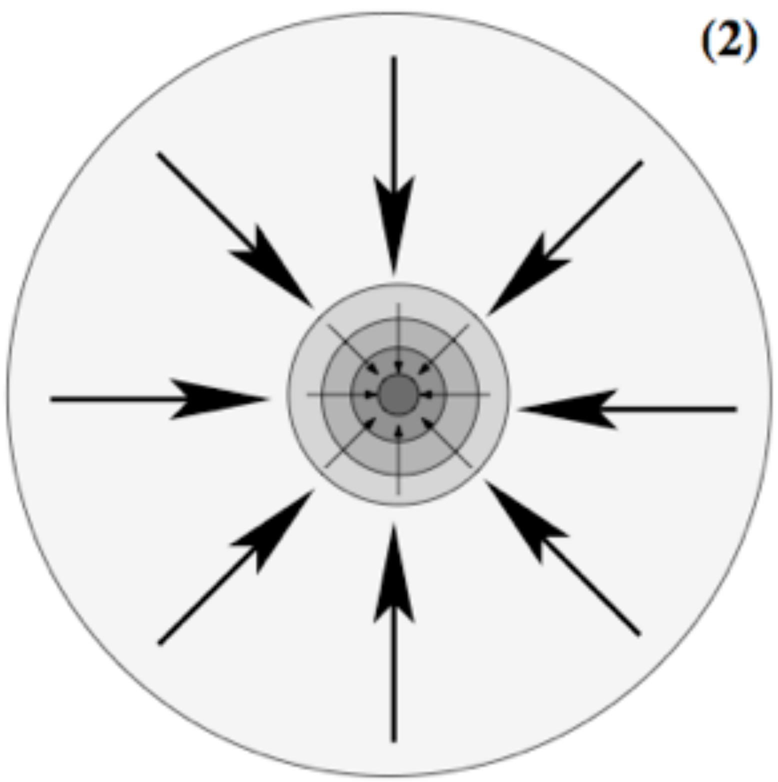
I- CORE BUILDING



from Gong & Prof. Ostriker 2009

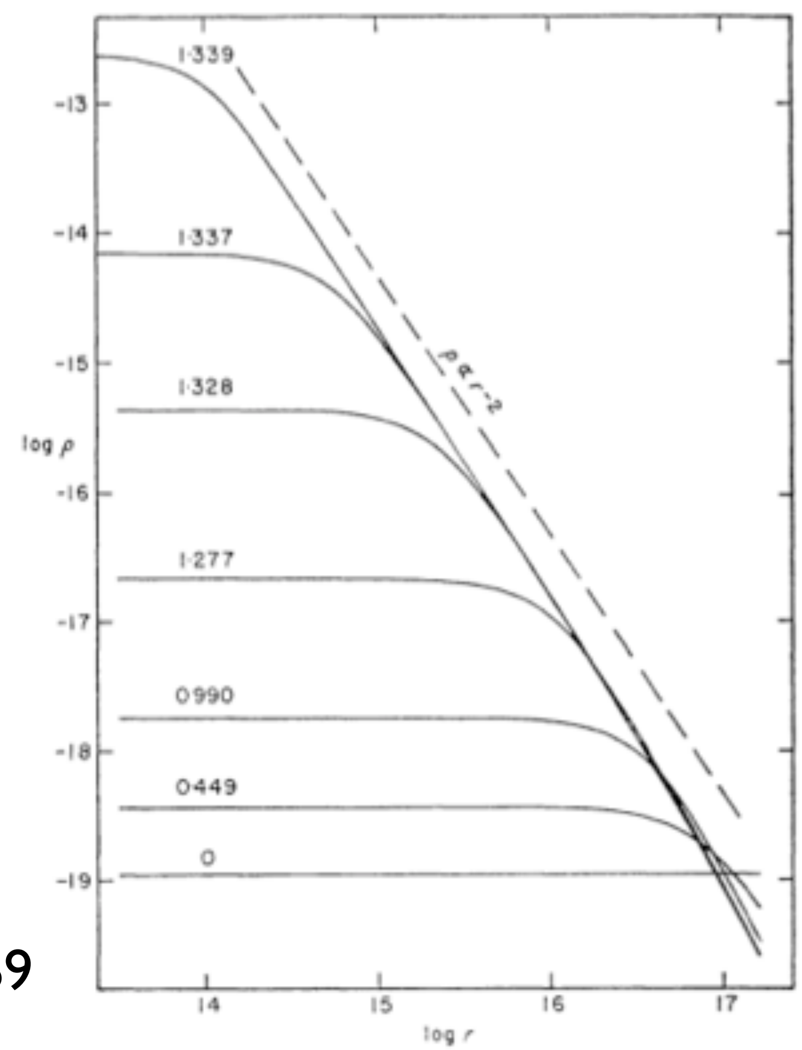
- supersonic turbulent converging flow
- isothermal flow everywhere
- shock propagating outwards in mass, inwards in radius

2- CORE COLLAPSE



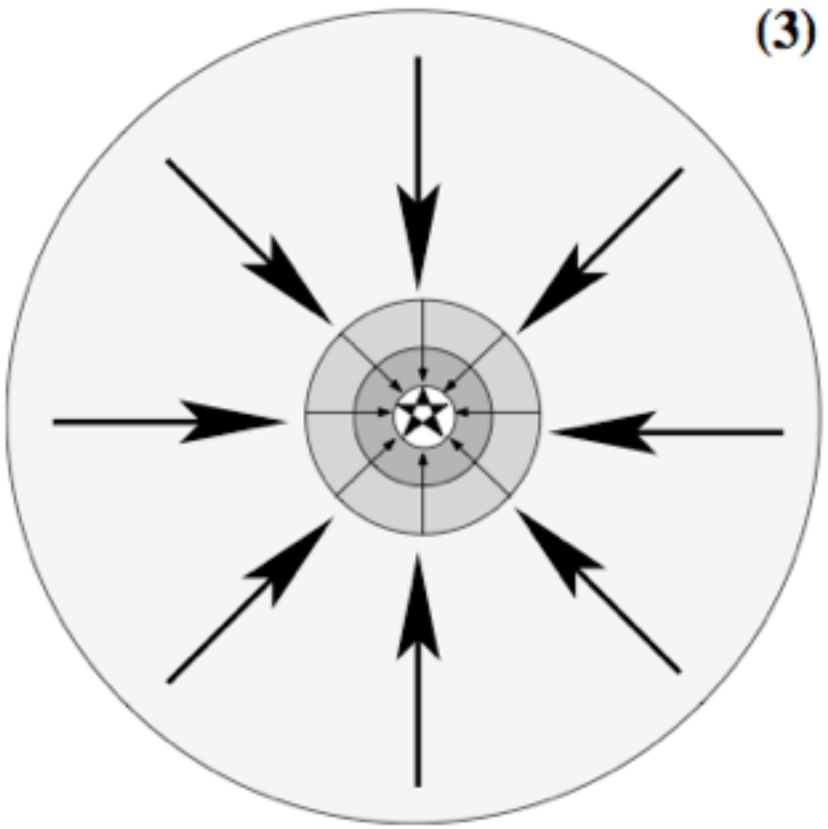
from Gong & Prof. Ostriker 2009

- outside-in collapse, forming adiabatic core, then protostar
- envelope: marginal Jeans stability, $\rho \propto r^{-2}$



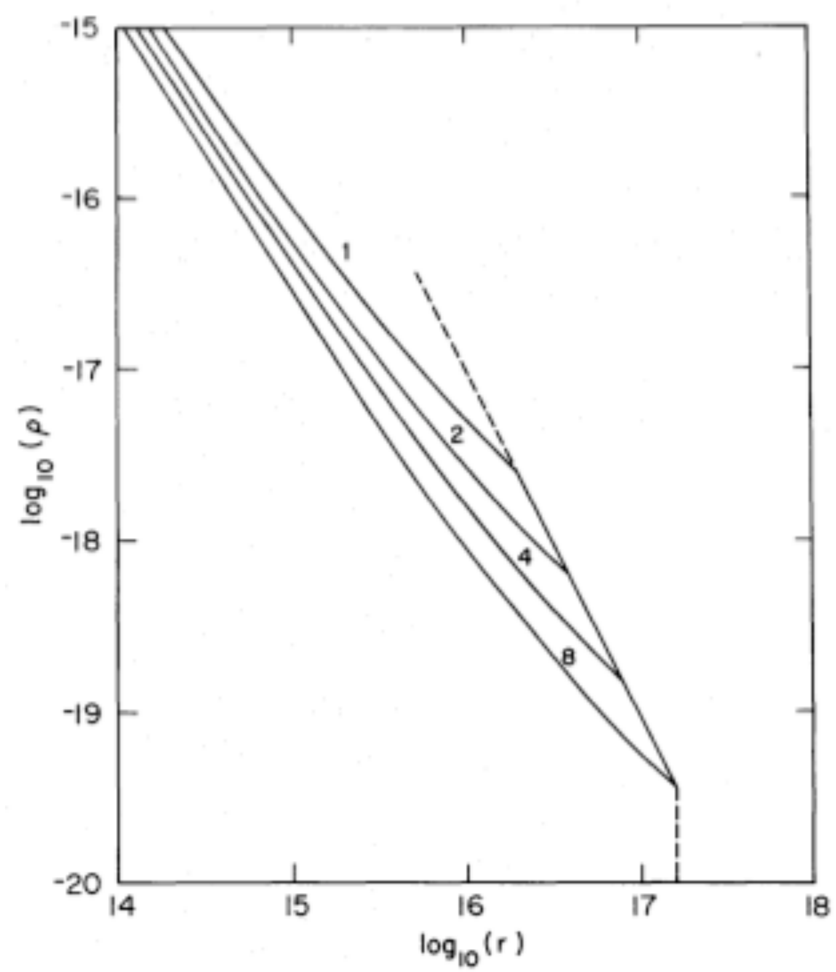
from Larson 1969

3- ENVELOPE INFALL



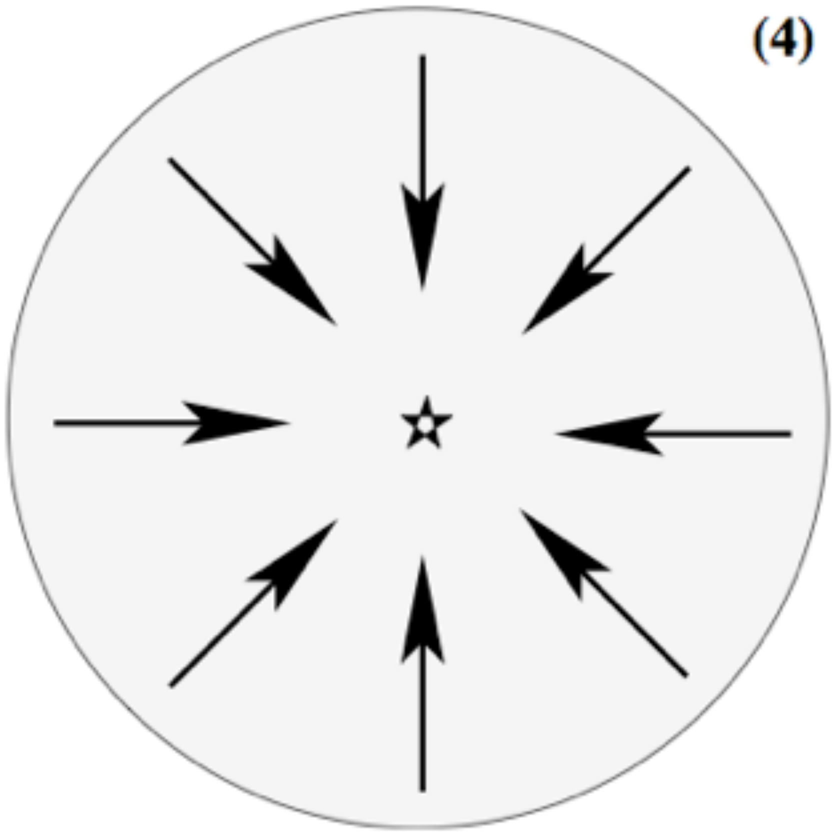
from Gong & Prof. Ostriker 2009

- inner envelope free-falls: inside-out collapse onto the protostar, until rarefaction and shock meet



from Shu 1977

4- LATE ACCRETION



from Gong & Prof. Ostriker 2009

- late accretion of ambient gas onto the protostar
- Bondi accretion:

$$\begin{cases} \rho \propto r^{-3/2} \\ v_r \propto r^{-1/2} \end{cases}$$

LIMITATIONS

- Accretion rate variations consistent with data, but too low: spasmodic accretion needed
- «Angular momentum problem»
- «Magnetic flux problem»
- What about disks?

MAGNETIC EFFECTS

ideal MHD: MAGNETIC TENSION

$$\begin{cases} \rho\left(\partial_t \vec{v} + \vec{v}\cdot\vec{\nabla}\vec{v}\right) = -\rho\vec{\nabla}\phi - \vec{\nabla}\left(P + \frac{B^2}{2\mu_0}\right) + \frac{1}{\mu}\left(\vec{B}\cdot\vec{\nabla}\right)\vec{B} \\ \partial_t \vec{B} = \vec{\nabla}\wedge\left(\vec{v}\wedge\vec{B}\right) \end{cases}$$

- radiation pressure << thermodynamical pressure

- magnetic field frozen in the fluid $\frac{D}{Dt}\int \vec{B}\cdot d\vec{A} = 0$
- magnetic tension ⟶ slows down collapse

ideal MHD: MAGNETIC TENSION

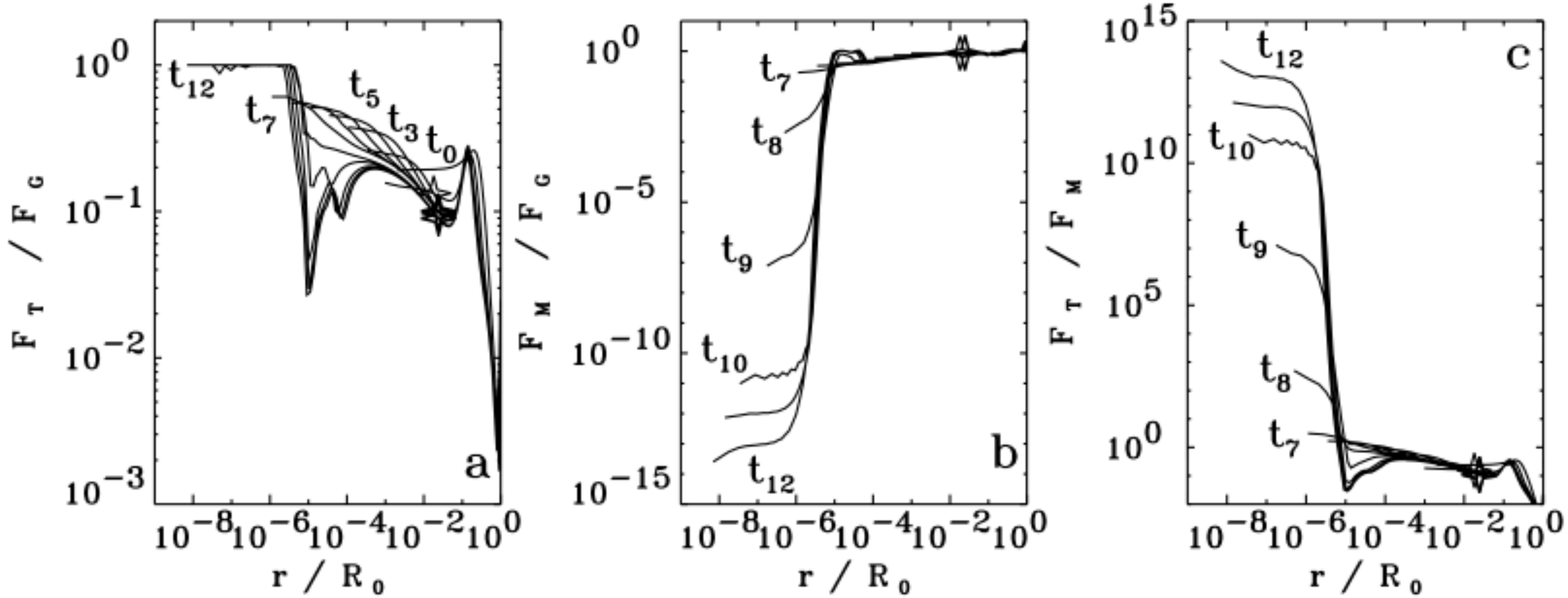


FIG. 4.—Radial profiles of physical quantities at different times, as in Fig. 2. (*a*) Ratio of thermal-pressure and gravitational forces. (*b*) Ratio of magnetic and gravitational forces. (*c*) Ratio of thermal-pressure and magnetic forces. The star symbol on a curve, present only after a supercritical core forms, marks the instantaneous radius of the supercritical core.

from Tassis & Mouschovias 2007

- Everywhere except hydrostatic core Fth < Fm
- at the border of the core, Fm/Fg is significant («magnetic wall»)

→ collapse solwer than free fall

non-ideal MHD: AMBIPOLAR DIFFUSION

$$\begin{cases} \rho\left(\partial_t \vec{v} + \vec{v}\cdot\vec{\nabla}\vec{v}\right) = -\rho\vec{\nabla}\phi - \vec{\nabla}P + \frac{1}{\mu}\left(\vec{\nabla}\wedge\vec{B}\right)\wedge\vec{B} \\ \partial_t \vec{B} = \vec{\nabla}\wedge\left\{\vec{v}\wedge\vec{B} - \frac{(\vec{\nabla}\wedge\vec{B})\wedge\vec{B}}{\mu e n_e} + \frac{[(\vec{\nabla}\wedge\vec{B})\wedge\vec{B}]\wedge\vec{B}}{\mu\gamma\rho\rho_{\mathrm{ions}}} - \frac{\vec{\nabla}\wedge\vec{B}}{\mu\sigma}\right\} \end{cases}$$

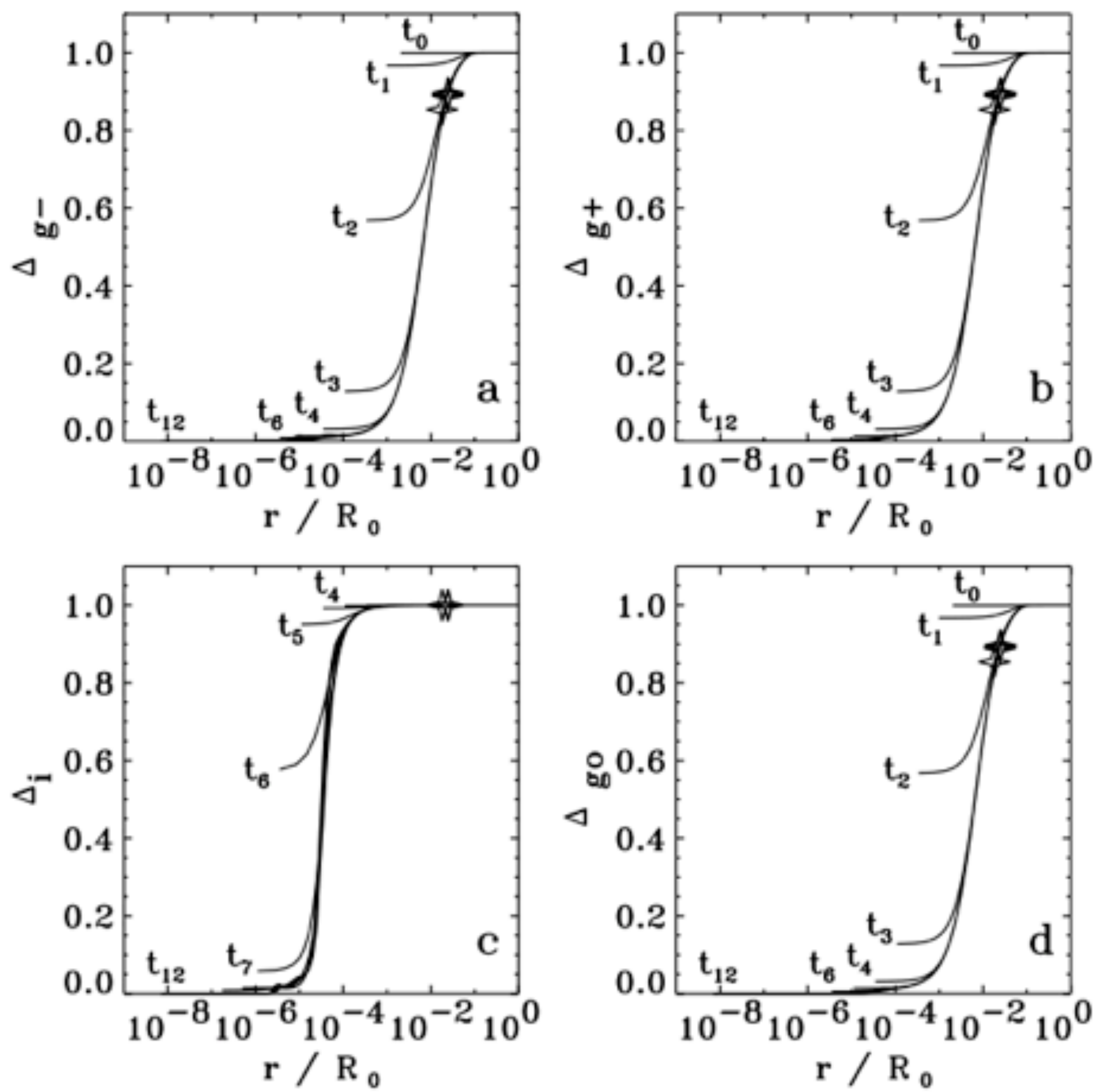
- Magnetic field not frozen in the fluid anymore
- Multi-fluids system: neutral, ions, electrons, grains

→
- Neutral particles experience free fall
- helps the magnetic flux problem

non-ideal MHD: AMBIPOLAR DIFFUSION

Attachment parameter:

$$\Delta_X = \frac{v_X - v_n}{v_B - v_n}$$



from Tassis & Mouschovias 2007

- at low density, everyone is attached
- grains species detach where the core forms
- ions detach inside the magnetic shock
- electrons never detach completely
- at late times, thermo ionization in the center reattaches everyone

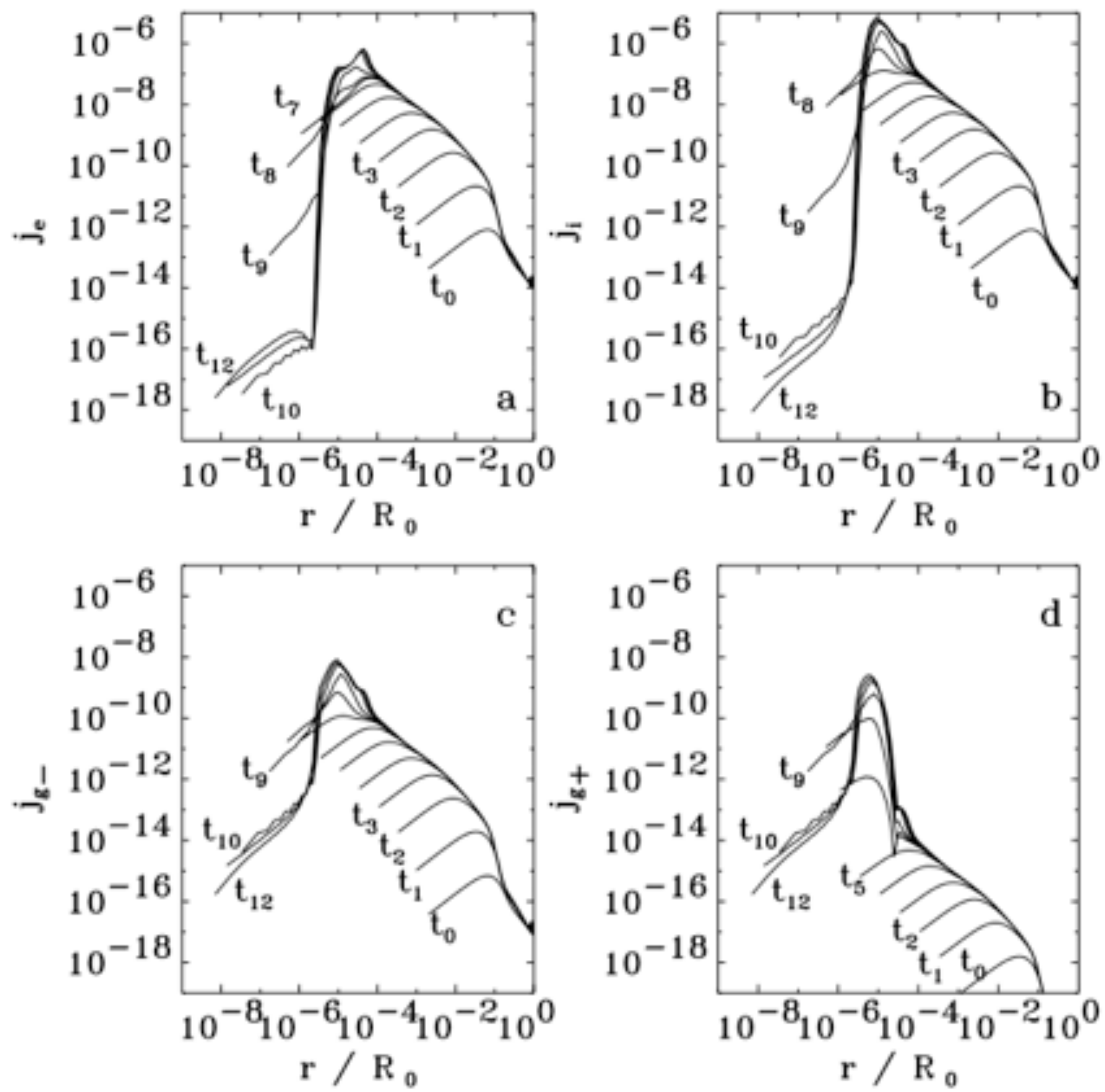
non-ideal MHD: OHMIC DISSIPATION

$$\left\{ \begin{array}{l} \rho \left(\partial_t \vec{v} + \vec{v} \cdot \vec{\nabla} \vec{v} \right) = -\rho \vec{\nabla} \phi - \vec{\nabla} P + \frac{1}{\mu} \left(\vec{\nabla} \wedge \vec{B} \right) \wedge \vec{B} \\ \partial_t \vec{B} = \vec{\nabla} \wedge \left\{ \vec{v} \wedge \vec{B} - \frac{(\vec{\nabla} \wedge \vec{B}) \wedge \vec{B}}{\mu e n_e} + \frac{[(\vec{\nabla} \wedge \vec{B}) \wedge \vec{B}] \wedge \vec{B}}{\mu \gamma \rho \rho_{\mathrm{ions}}} - \frac{\vec{\nabla} \wedge \vec{B}}{\mu \sigma} \right\} \end{array} \right.$$

- Finite conductivity effect
- leads to dissipation

→ helps the magnetic flux problem

non-ideal MHD: OHMIC DISSIPATION

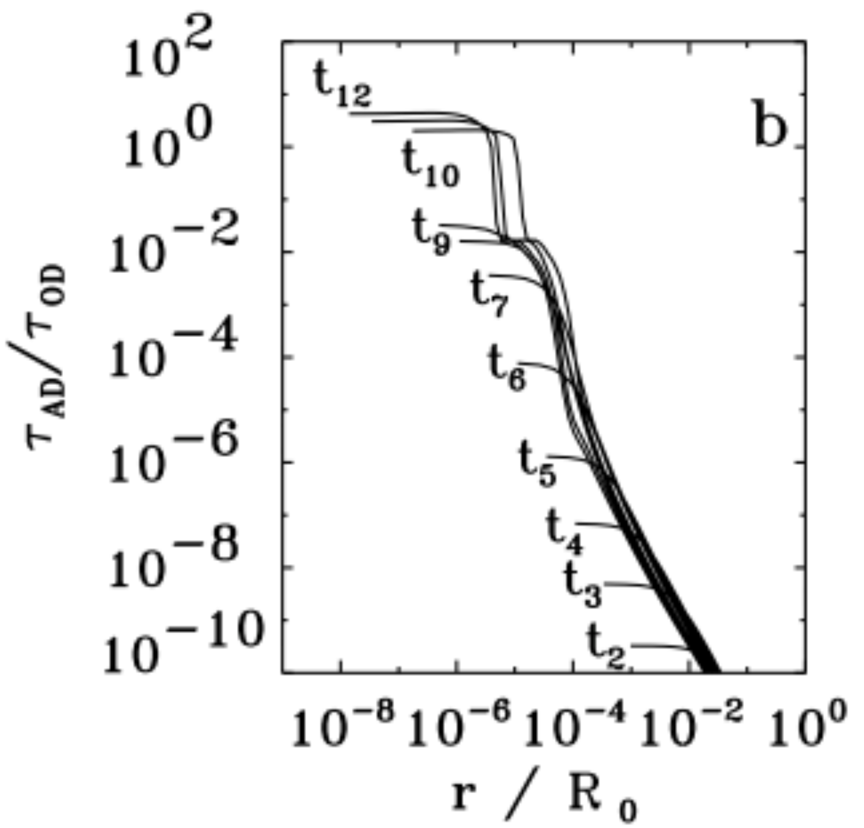


from Tassis & Mouschovias 2007

- low density: electrons & ions
- higher density: ions (electrons stuck on grains)
- innermost region: grains

Magnetic flux problem: Ambipolar diffusion VS Ohmic dissipation

$$1/\tau_{\rm flux} = 1/\tau_{\rm ambi.} + 1/\tau_{\rm ohmic}$$

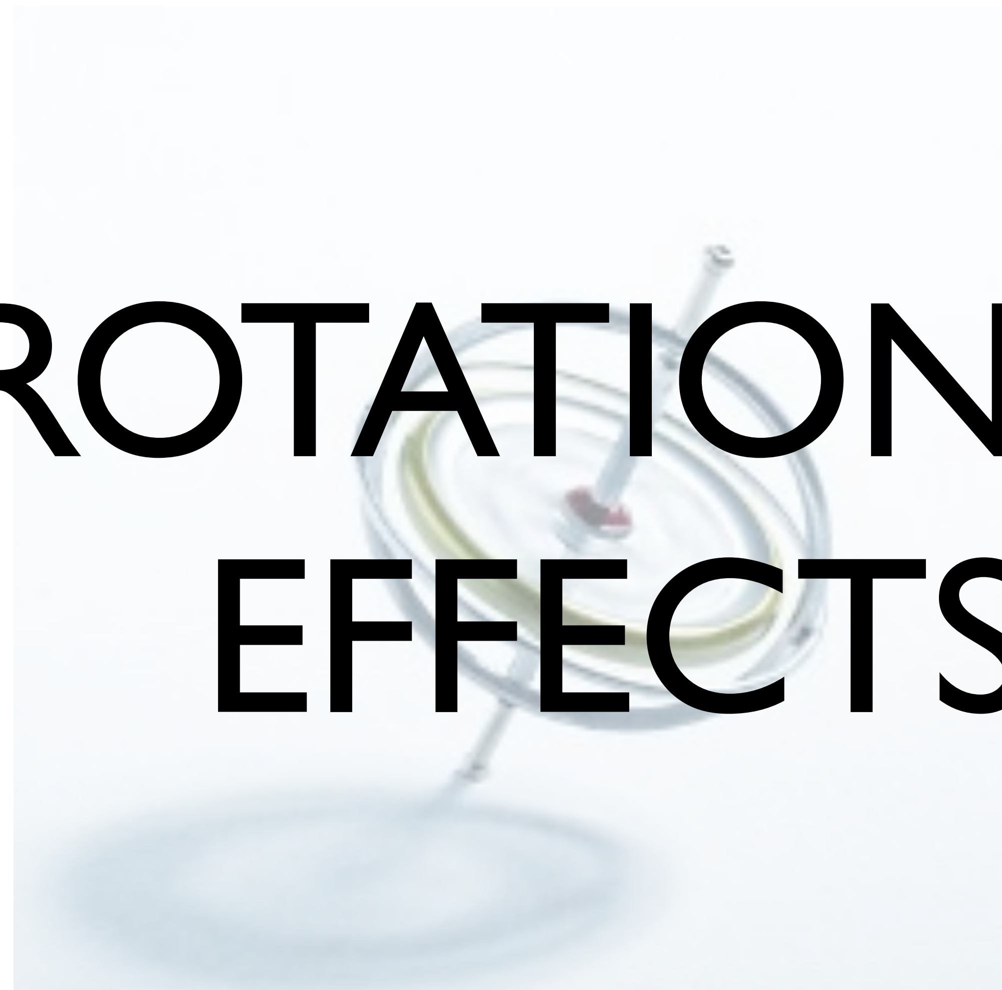


from Tassis & Mouschovias 2007

- Ambi. diff. reduces flux/mass by allowing to load the magnetic tubes with more mass - dominates outside the core;
- Ohmic diss. reduces flux/mass by damping the magnetic field - dominates inside, when the grains become the main current carrier

→ Not sufficient!

ROTATIONAL EFFECTS



ROTATIONAL EFFECTS

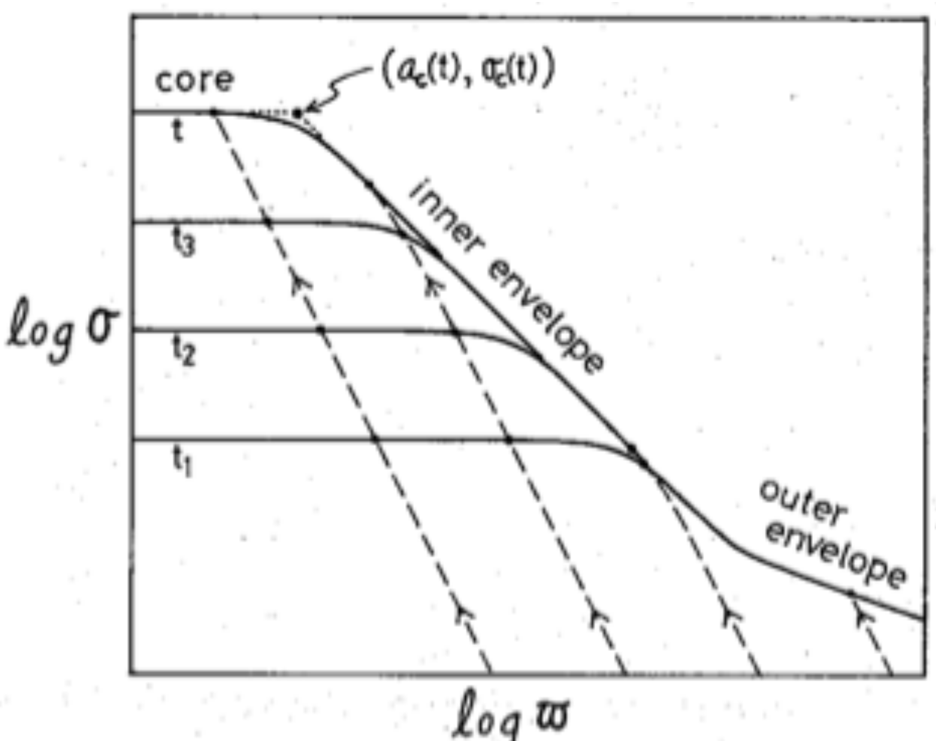


Fig. 4. Schematic diagram of evolution of column density profile of a collapsing axisymmetric cloud. The cloud has generally a nearly uniform core (with the column density σ_c and the radius a_c), an inner envelope and an outer envelope.

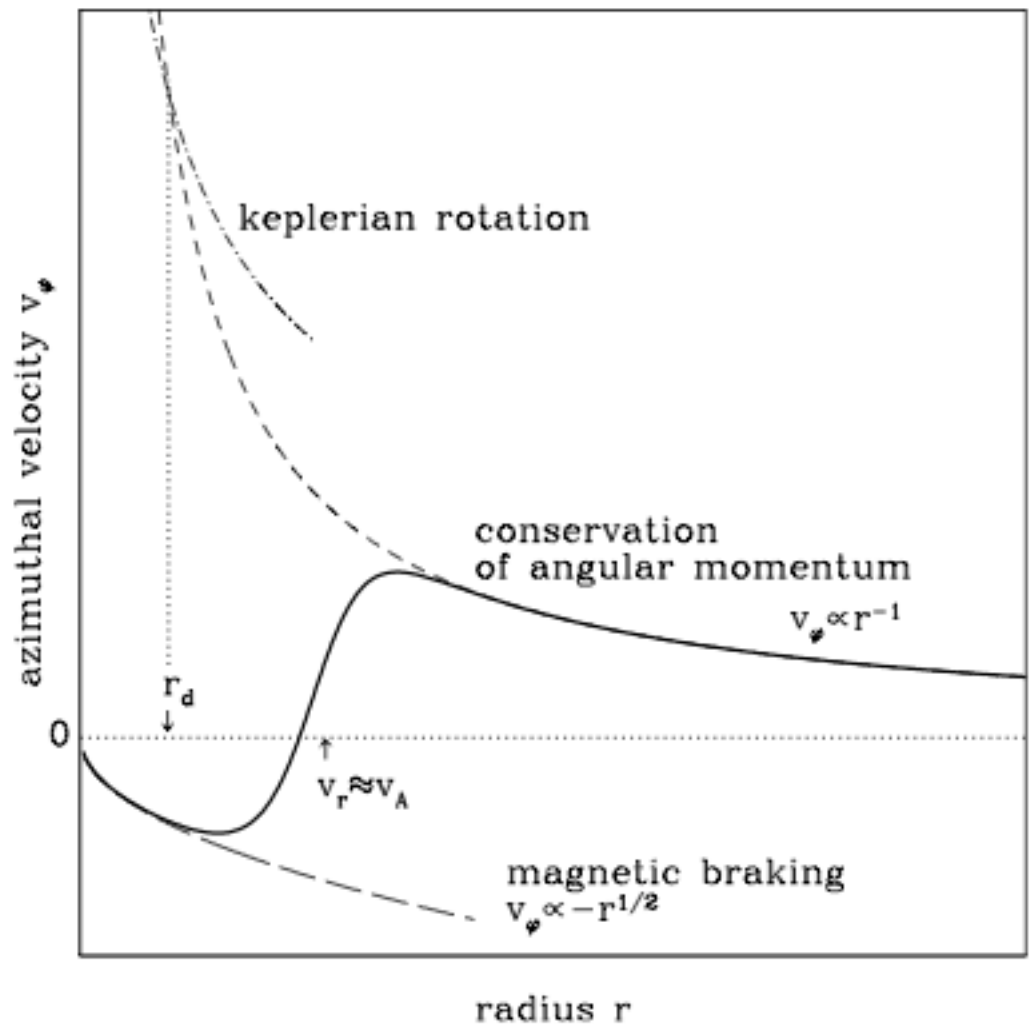
from Narita et al. 1984

- same profile for inner envelope: $$\begin{cases} \rho \propto r^{-2} \\ \omega \propto r^{-1} \end{cases}$$
- core and inner envelope don't get flattened
- outer envelope gets flattened into a disk, and may fragment into rings

Rotating VS Magnetized disks

- identical density and radial velocity profiles
- accretion is axial VS conical

ideal MHD disk braking



from Galli et al. 2006

- Angular momentum outward transport (analogous to MRI) efficient for $v_r \leqslant v_{\mathrm{Alfvén}}$

→ no rotation supported disk
helps the angular momentum problem...

non ideal MHD effects

- Ohmic dissipation damps magnetic field
- Hall effect can spin up disk
- Ambi. diff. can increase braking, by creating confined areas of increased magnetic field

→ disk problem

CONCLUSION

CONCLUSION

- Magnetic flux problem, Angular momentum problem, Disk problem are current research topics
- the physical processes are certainly the right ones
- the quantitative details are in progress

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