On the formation of disks during the collapse of magnetized prestellar cores

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Thermal Support
Consider a cloud of initial radius $R$ and a constant temperature $T$

When $R$ decreases, $\frac{E_{\text{therm}}}{E_{\text{grav}}} \text{ decreases:}$

$$\frac{E_{\text{therm}}}{E_{\text{grav}}} = \frac{3}{2} \frac{M}{m_p} \frac{kT}{GM^2/R} \propto R$$

Centrifugal Support and Angular Momentum Conservation

When $R$ decreases, $\frac{E_{\text{rot}}}{E_{\text{grav}}} \text{ increases:}$

$$\frac{E_{\text{rot}}}{E_{\text{grav}}} = \frac{MR^2 \omega^2}{GM^2/R} \propto \frac{1}{R}$$

Magnetic Support and Flux Conservation

When $R$ decreases, $\frac{E_{\text{mag}}}{E_{\text{grav}}} \text{ is constant:}$

Typically one infers $\mu = (M/\phi)/(M/\phi)_c = 1-4$

(Crutcher et al. 1999, 2004)
Consequences:

- Centrifugal forces: non-isotropic and become dominant
  \[\Rightarrow\text{flattening of the envelope, formation of a centrifugally supported disk}\]

- Magnetic forces: non-isotropic and stay comparable to gravity
  \[\Rightarrow\text{flattening of the envelope BUT NOT the formation of a supported structure}\]

This flattening which \textit{looks like a disk} is sometimes called a pseudo disk (Galli & Shu 1993, Li & Shu 1996). \textit{A pseudo-disk is simply a flattened envelope.}

\textbf{Magnetic field brakes the cloud} (twisting of the field lines)
\[\Rightarrow\text{transfer angular momentum from the inner part towards the outer parts}\]
\[\Rightarrow\text{Angular momentum not conserved (locally)}\]
\[\Rightarrow\text{rotation does not necessarily imply disk formation}\]
Zoom into the central part of a collapse calculation (1 solar mass slowly rotating core)

XY hydro

XY MHD $\mu=2$

B, $\omega$

XZ hydro

XZ MHD $\mu=2$

B, $\omega$

300 AU
Density, rotation and infall velocity profiles

Thermally supported core
Centrifugally supported disk

Density
Infall velocity
Rotation velocity

No disk!
Allen et al. 2003
Fromang et al. 2006
Price & Bate 2007
Mellon & Li 2008

Hennebelle & Fromang 2008
- Low magnetic fields allow disk formation but the disk is stabilized and does not fragment.
- Stronger fields prevent disk formation.

Hennebelle & Teyssier 2008 (see also Machida et al. 2005)
Can non ideal MHD modify this? (Mellon & Li 2009, Duffin & Pudritz 2009)

Mulet-Marquis et al. in prep

\[ \tau_{\text{amb}} / \tau_{\text{ff}} = 8 \] for critical cores
\[ \tau_{\text{amb}} \propto B^2 \Rightarrow \text{too slow!} \]

Non ideal MHD processes ambipolar diffusion and Ohmic dissipation (Shu et al. 06, Machida et al. 2008) can induce the formation of small 10 AU objects
Can different magnetic configurations modify this?

Magnetic braking less efficient when $\alpha$ increases

$\mu=5, \alpha=0^\circ$  
$\mu=5, \alpha=20^\circ$  
$\mu=5, \alpha=90^\circ$

Hennebelle & Ciardi (2009)
\( \mu = 5, \alpha = 20^\circ \)

\( \mu = 5, \alpha = 90^\circ \)
Impact of stronger fields

\( \mu = 5, \alpha = 90^\circ \)

\( t = 0.0229 \) (Myrs), \( \mu = 5, \alpha = 90^\circ \)

\( v = 2.6199 \) (km/s)

\( \mu = 2, \alpha = 90^\circ \)

\( t = 0.0263 \) (Myrs), \( \mu = 2, \alpha = 90^\circ \)

\( v = 2.7153 \) (km/s)
Radiative transfer + MHD calculation

density

Commercon et al. in prep
Conclusions

-A complicated problem => a complex answer
….and the field is fastly developing.

-In the aligned case, centrifugally supported disks do not form even for small values of the magnetic field ($\mu=5-10$)

-The aligned case is a little special…
Disks form for larger values of $B$ if the angle between the rotation and the magnetic field is large enough (but $\mu=2-3$ seems to be the limit)

-Difficulty to bridge the gap between class-0/class-I phase yet Magnetic field transfer momentum, if no envelope left, then nothing to brake. Class-I disks should form!