Tracing Protostellar Evolution using Gas Kinematics

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From infall... 

...to rotation

Questions:

- How do protostars accrete over time?
- What is the chemical history of the material in PP-disks?
- What role does the environment play?

(Figure by M. Hogerheijde)

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Parameterizing the gas flow

\[
p + (1-p) = \vec{v} ; \quad p = [0,1]
\]

\[
\vec{v} = \begin{pmatrix} v_r \\ v_\phi \end{pmatrix} = \sqrt{\frac{GM_*}{r}} \begin{pmatrix} -\sqrt{2} \sin \alpha \\ \cos \alpha \end{pmatrix}
\]

(Brinch et al., 2008)
Spectra & P-V diagrams

Infall

Intensity

Velocity

Rotation

Intensity

Velocity

IRAS 2A

Offset along midplane (arcsec)

Velocity (km s^{-1})

L1489 IRS

Offset along midplane (arcsec)

Velocity (km s^{-1})

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Numerical star formation

- Copenhagen simulation
  (Haugbølle, Padoan, and Nordlund, in prep.)

- Ramses MHD with $256^3$
  base grid + 9 AMR levels
  $\sim 10^9$ grid cells
  ($512^3$ is currently running)

- 2000 cores for a month
  $\sim 1.5$ million cpu hours

- Tens of thousands stars

50 pc
3000 AU
30 AU resolution
Getting ISM qualities right

- The simulation reproduces...
  - the star formation rate
  - the initial mass function
  - the stellar mass accretion rate

(Haugbølle et al., in prep.)
Tracing chemistry in Ramses

- Tracer particles follow desorption and freeze-out
- Chemical reactions can be included as well

Method based on (van Weeren 2009)
Early snapshot

Late snapshot

A simulated low-mass protostar seen in HCO$^+$ J=3-2

Pipeline

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Stage 0

Stage I

\( \alpha = \arctan(\frac{v_r}{v_\phi}) \)

Fractional accreted mass

Infall

Rotation

1 kyr

20 kyr

70 kyr

125 kyr

180 kyr

230 kyr

500 kyr

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Conclusions...

- The gas velocity field can be used to determine the evolutionary stage of YSOs when calibrated with simulated sources.
- With a set most likely matches to data of sources from the hydro-simulation, it is possible to predict the physical and chemical future of an observed YSO.
- Environment seems to play an important role for the accretion history of YSOs.
Line modeling engine

- Using a Voronoi grid to speed up transport => 3D
- Large dynamic range in scales
- Similar resolution as AMR
- Available for download!

(Brinch & Hogerheijde 2010)