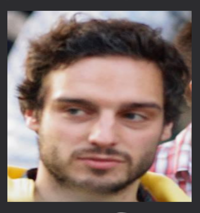
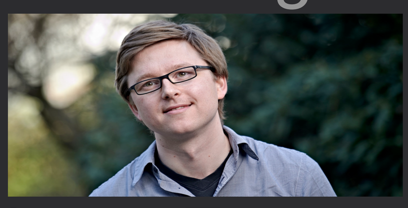
Zooming in on Protoplanetary Disks

Michael Küffmeier[1], Troels Haugbølle[1], Åke Nordlund[1], Paolo Padoan[2]

[1] Centre for Star and Planet Formation, University of Copenhagen, Denmark
[2] ICREA & ICC, University of Barcelona, Spain

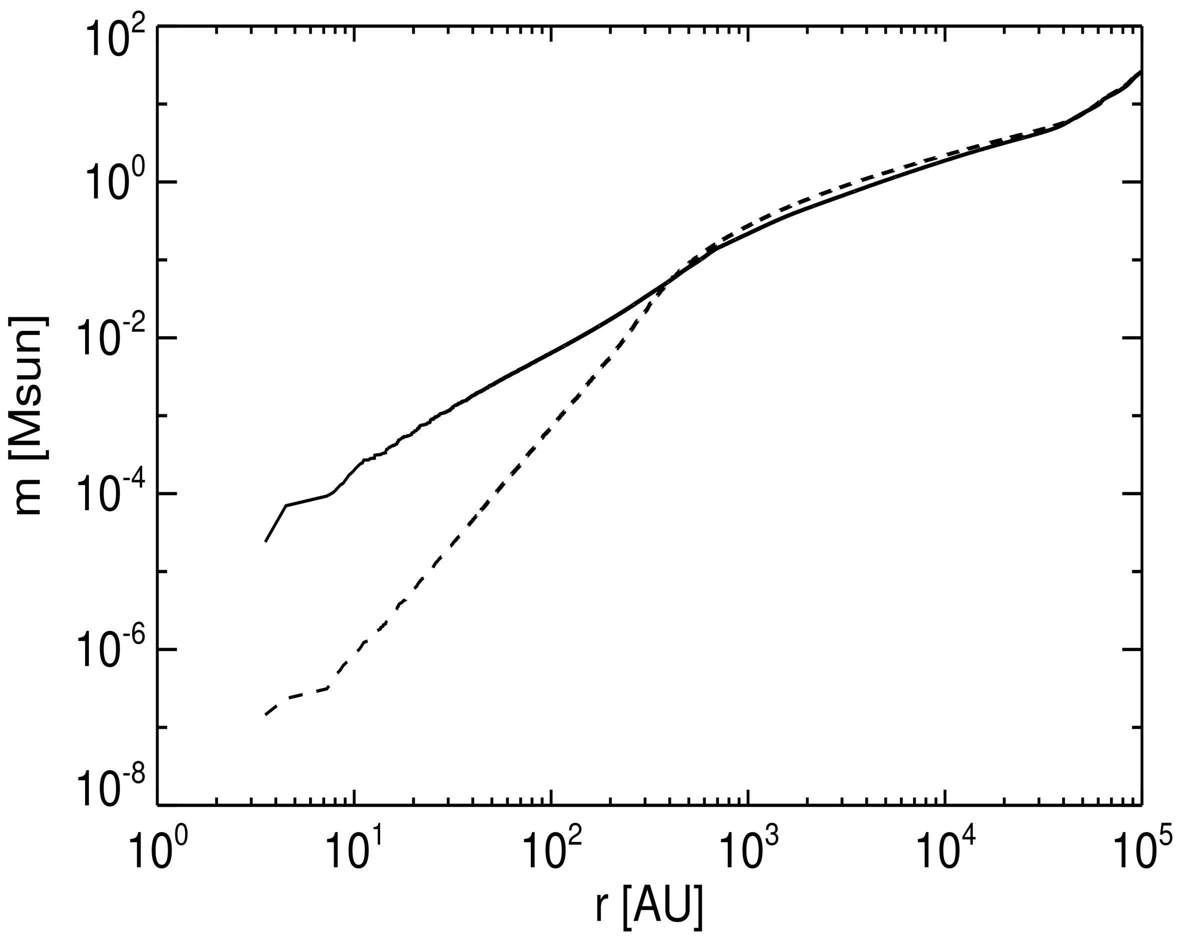
STARPLAN

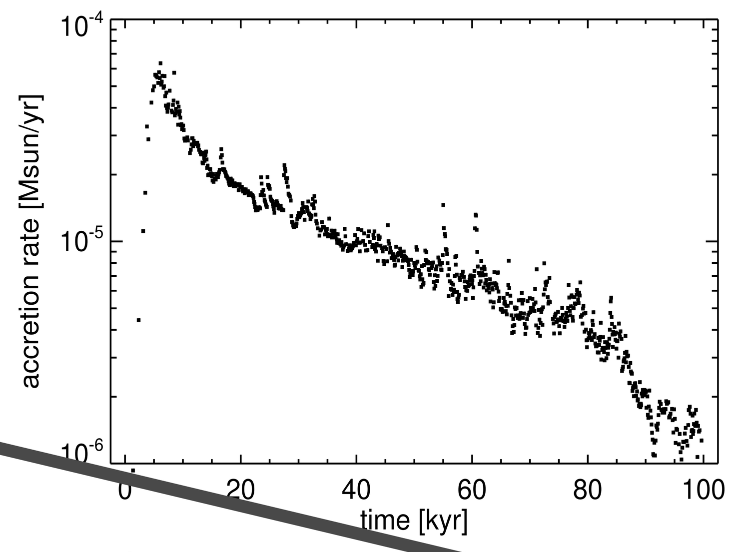
Introduction

We show visualizations of models of protoplanetary disks obtained by zooming in from models of ~100000 solar mass Giant Molecular Clouds to protoplanetary disk scales, selectively following the collapse of a few 1-2 solar mass protostellar systems. The models and visualizations demonstrate the extremely important roles played by magnetic fields in this process.

Mass distribution

The plot to the right hand side illustrates the distribution of integrated mass in relation to the distance from the central sink particle (star). The dashed line shows the initial mass-radius relation which is rather steep. As you can see, the mass quickly develops a dependency on radius of $m \propto r^{3/2}$, which is characteristic for a free-fall collapse. This feature is a direct consequence of magnetic field braking.

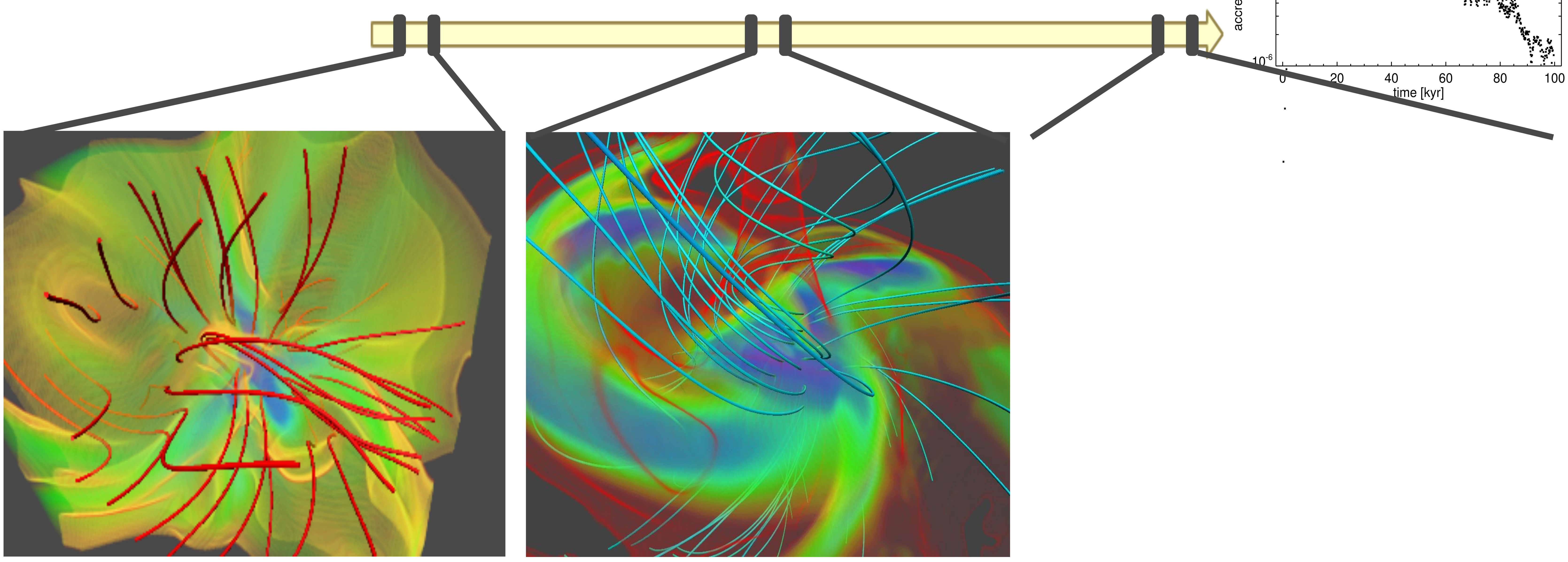




Stellar accretion time scale ~100 kyr

~10^4 AU

~10 AU



Importance of Magnetic Fields

1) They are responsible for fast and efficient accretion. The mass m(r) follows the free-fall scaling relation.

2) They produce bipolar outflows and therefore serve as a major sink for angular momentum as well as energy.

3) They suppress turbulence in the protoplanetary disk with crucial consequences for planetary formation since it may allow planetesimal formation via gravitational instability as proposed by Goldreich & Ward (1973).

Goldreich-Ward mechanism

Small solid particles settle vertically onto the disk. Together with radial drifting, material is collected in the midplane of the disk, thereby forming a solid disk with higher density compared to its environment. This enhancement causes gravitational instability in the disk. Consequently, clumps of solid particles form in the sub-disk due to fragmentation. Finally, physical collisions of these clumps induce dissipation of energy, which enables the formation of planetesimals by gravitational collapse of the clumps.[1), 2)]

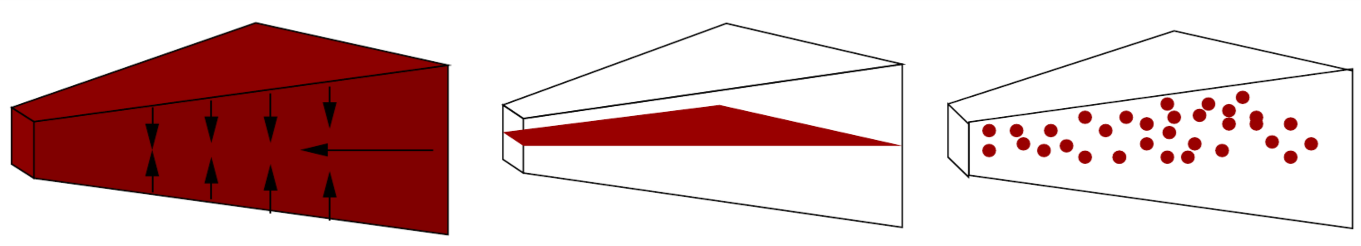


Figure from P. Armitage, astro-ph/0701485

Summary

- Ab initio simulation of formation of circum-stellar disks is first of this kind
- Scale range ~9 orders of magnitude
- Anchored to giant molecular cloud scales
- Illustrates large scale flows and interactions of magnetic fields

See also other posters with results from our RAMSES models of star formation:

1G021: Tracing Protostellar Evolution Using Gas Kinematics, Christian Brinch
1H009: Understanding Disk Formation: Bridging the Gap from Theory to High Resolution Observations, Søren Frimann
1H004: Accretion and Formation of Protostellar Systems, Troels Haugbølle
1H002: Zooming in on the Formation of Proto-Planetary Disks, Åke Nordlund

References:
1) P. Armitage 2007, astro-ph/0701485
2) P. Goldreich & W. R. Ward, 1973, ApJ, 183, 1051