Collapse of the Protosolar Molecular Cloud Core: The First Accretion Period and Constraints on CAI Formation

Johannes Schönke* and Mario Trieloff**

*Interdisciplinary Center for Scientific Computing, University of Heidelberg, INF 368, 69120 Heidelberg, Germany
**Institute of Earth Sciences, University of Heidelberg, INF 234-236, 69120 Heidelberg, Germany
email: johannes.schoenke@iwr.uni-heidelberg.de
mario.trieloff@geow.uni-heidelberg.de

Model of cloud core collapse

We present numerical studies of a collapsing molecular cloud core which cover the first and second collapse phase and the complete first accretion period of the protostellar core. Thereby we focus on the interactions between the newly formed protostar and the surrounding accretion disk.

There are two important processes which lead to a strong mixing and a highly non-stationary flow field in the system: 1. The dust evaporation in the first core (still consisting of molecular hydrogen) forces a thermal restructuring and heavy convection due to different optical properties in the dust-free regions (see Fig. 1[†]). 2. The high accretion luminosity of the second (protostellar) core heats up the surrounding accretion disk of the first core and initiates an almost complete blow-out of the disk (see Fig. 2). After some time, this process stops the accretion onto the second core and therefore the blow-out. When reaching a distance of about 500 AU from the center, the blown-out material starts to fall back to the protostar (see Fig. 3).

These findings (cf. [4]) illustrate that the picture of an accretion disk evolving quasi-stationary and uninfluenced by the protostar is definitely incorrect. This conclusion is also supported by other numerical investigations (cf. eg., [1]). The star formation process is rather non-stationary and cyclic. Short and rapid accretion phases (lasting on the order of 100 yr) alternate with long and quiet outflow periods (lasting several kyr). This could also explain why observed protostars are less luminous than expected for stationary accretion and possibly explain sudden increases in luminosity such as e.g., FU Orionis activities (cf. eg., [2]).

Implications for CAI formation

The described scenario furthermore offers an environment for CAI formation that better than previously fits cosmochemical constraints.

[†]All given ages in the text and figures are measured from the moment where the first core becomes optically thick.

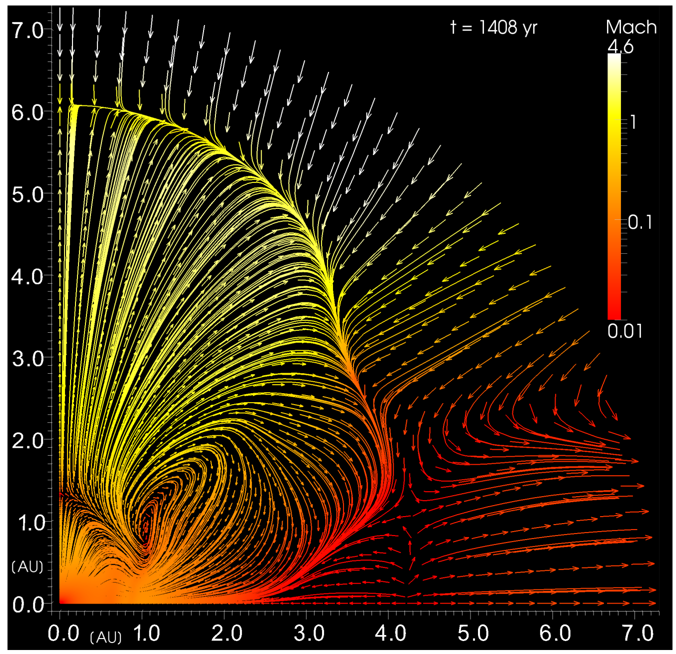

Figure 1: Meridional cross-section (left border: rotation axis; bottom line: equator) of the non-stationary flow field with additional streamlines at 1408 yr is plotted. The absolute magnitude of the velocities is given by the color scale in terms of the Mach number $|\mathbf{v}|/c_\mathrm{s}$. The vector length scales with the radius and has no physical meaning.

First, the necessary high formation temperatures (>1600 K) are already reached in the first core inside 1 AU after 1400 yr (see Fig. 4) during a relatively short time interval. Second, fast cooling rates of CAIs can be achieved by a rapid outward transport due to large scale convective flows described above (Fig. 1), and by the blow-out process driven by the protostar (Fig. 2 and 3). This process transports and dispenses the newly formed minerals out to distances of up to 500 AU within about 5 kyr, while subsequent fall-back lasts also about 5 kyr.

It is likely from our calcuations that several blow-out and fall-back cycles occur (though increasingly less extreme), so an open question to be answered is in which of these cycles CAI formation occurred, while taking into account present upper limits of formation time intervals of a few

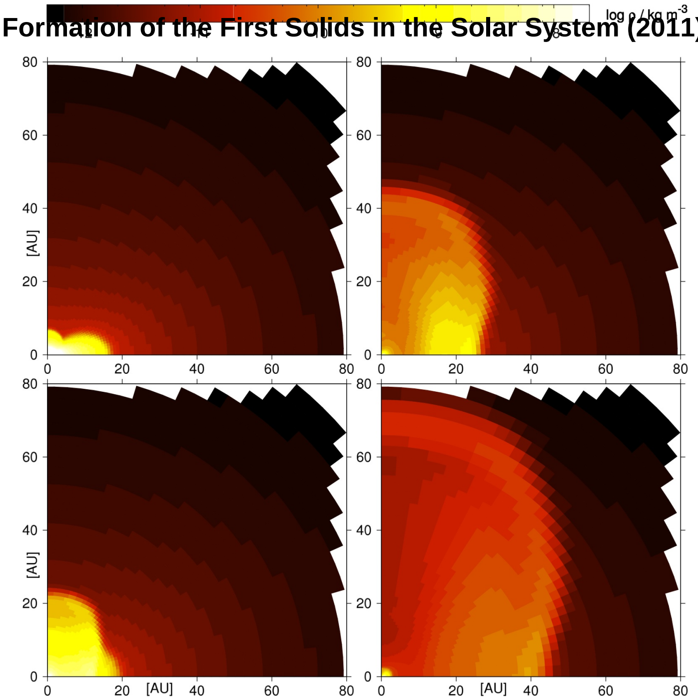

Figure 2: Meridional cross-sections of the density distribution. Plotted are several snapshots of the blow-out of matter previously forming the first core. Times are 1410 yr (upper left), 1430 yr (lower left), 1450 yr (upper right), and 1482 yr (lower right).

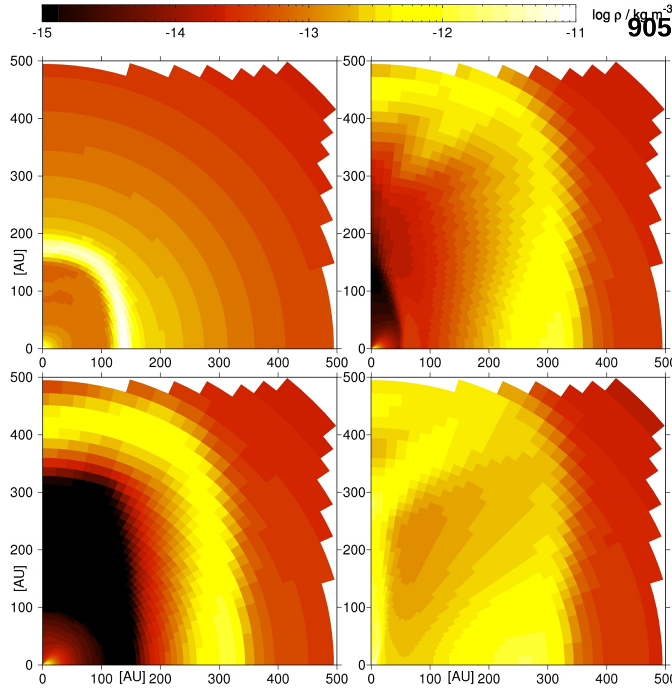

Figure 3: Meridional cross-sections of the density distribution (note the larger spatial scale and the shifted density scale compared to Fig. 2). Plotted is the long time evolution of the blown-out first core in form of density distributions at 2 kyr (upper left), 4 kyr (lower left), 5 kyr (upper right), and 6 kyr (lower right).

to a few 10 kyrs (cf. [3]). Our model also offers possibilities that CAI material was reprocessed within subsequent cycles at high temperatures and low temperatures (leading to the well-known formation of secondary minerals). Finally, storage in outer parts of the disk for several Myr before incorporation into chondrites also appears feasible for material transported far outward under specific conditions in the locally strongly varying flow fields (Fig. 1).

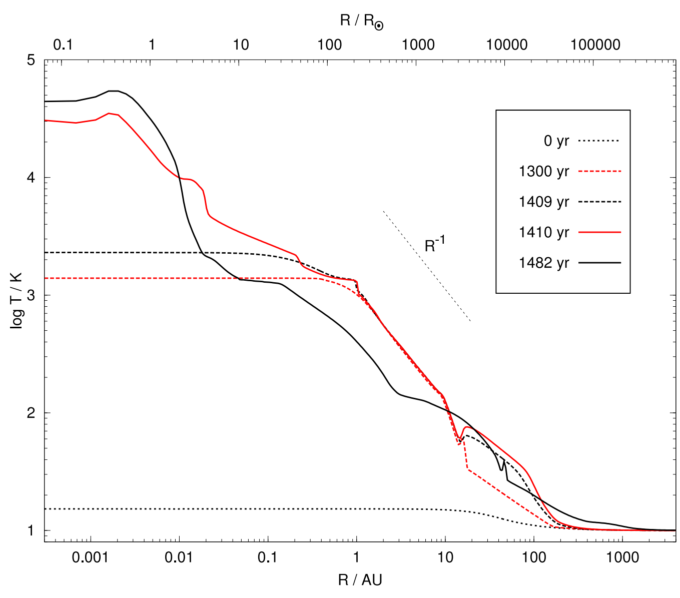

Figure 4: Midplane temperature distribution for various evolution times.

References

[1] M. R. Bate. Collapse of a molecular cloud core to stellar densities: the radiative impact of stellar core formation on the circumstellar disc. *MNRAS*, 404:L79–L83, May 2010.

[2] L. Hartmann and S. J. Kenyon. The FU Orionis Phenomenon. *ARA&A*, 34:207–240, 1996.

[3] B. Jacobsen, Q.-Z. Yin, F. Moynier, Y. Amelin, A. N. Krot, K. Nagashima, I. D. Hutcheon, and H. Palme. ^{26}Al ^{26}Mg and ^{207}Pb ^{206}Pb systematics of Allende CAIs: Canonical solar initial ^{26}Al/^{27}Al ratio reinstated. *Earth and Planetary Science Letters*, 272:353–364, July 2008.

[4] J. Schönke and W. M. Tscharnuter. Protostellar collapse of rotating cloud cores. Covering the complete first accretion period of the stellar core. *A&A*, 526:A139+, February 2011.