Accidental accretion and enhanced coagulation - clues to the origin of the Solar System

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1. Introduction

Observational facts seem to contradict well-established models of planet formation. These models assume planetary systems to form in isolation once the star has formed out of a protostellar cloud fragment. This model predicts strictly coplanar planetary systems. Observations of transiting extrasolar planets in recent years have revealed a wide range of inclinations between the orbital plane and the stellar equator (Triaud et al. 2010). *Even the Solar equatorial plane is inclined by about 7° against the planetary plane.*

Isolated planet formation cannot explain the observed misalignments. However, since the vast majority of stars are born in clusters dynamical interactions between cluster members and gas clumps or filaments may significantly affect the evolution of circumstellar discs. Close encounters between forming circumstellar discs and dense gas clouds or filaments are expected to be a viable mechanism for spin-orbit misalignments of planetary systems relative to their host star (Thies et al. 2011). There is further evidence that the young Solar System has been enriched with extrasolar material at least once (Young et al. 2011).

2. Accidental accretion

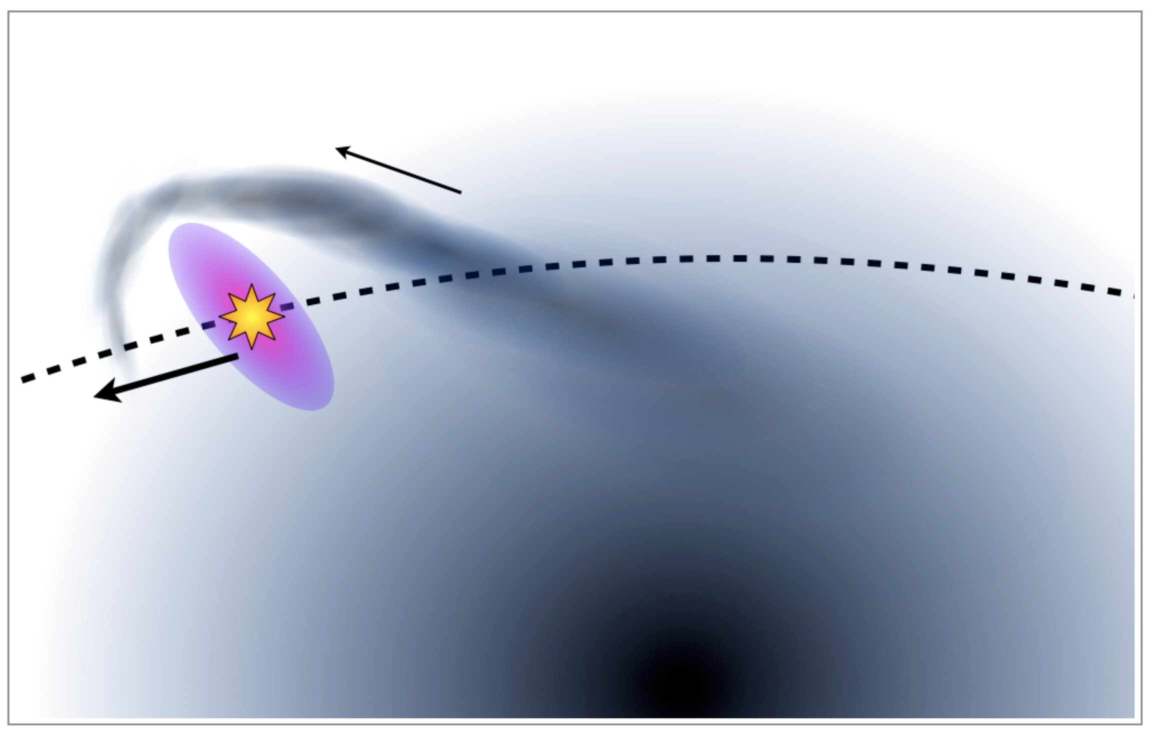

Fig. 1: Illustration of the gas capture mechanism: A star with a protoplanetary disc (PPD) passing through a gas cloud or filament, drawing gas from it.

A solar-type star with a protoplanetary disc (PPD; radius 50 AU, mass 0.096 M_{sun}) passes through a dense gaseous cloud, given here as a large, extended protostellar accretion disc of about 0.5 M_{sun} (Fig. 1). During the encounter, a few per cent of the cloud mass is captured and accreted into an annulus around the star (Fig. 2, top frames). The PPD is partially truncated, while the remaining inner region is compressed by up to an order of magnitude. While being initially completely uncorrelated the orientations of both structures (remaining PPD and captured annulus) steadily align to each other, eventually resulting in a combined new disc (bottom frames).

3. How to misalign planets

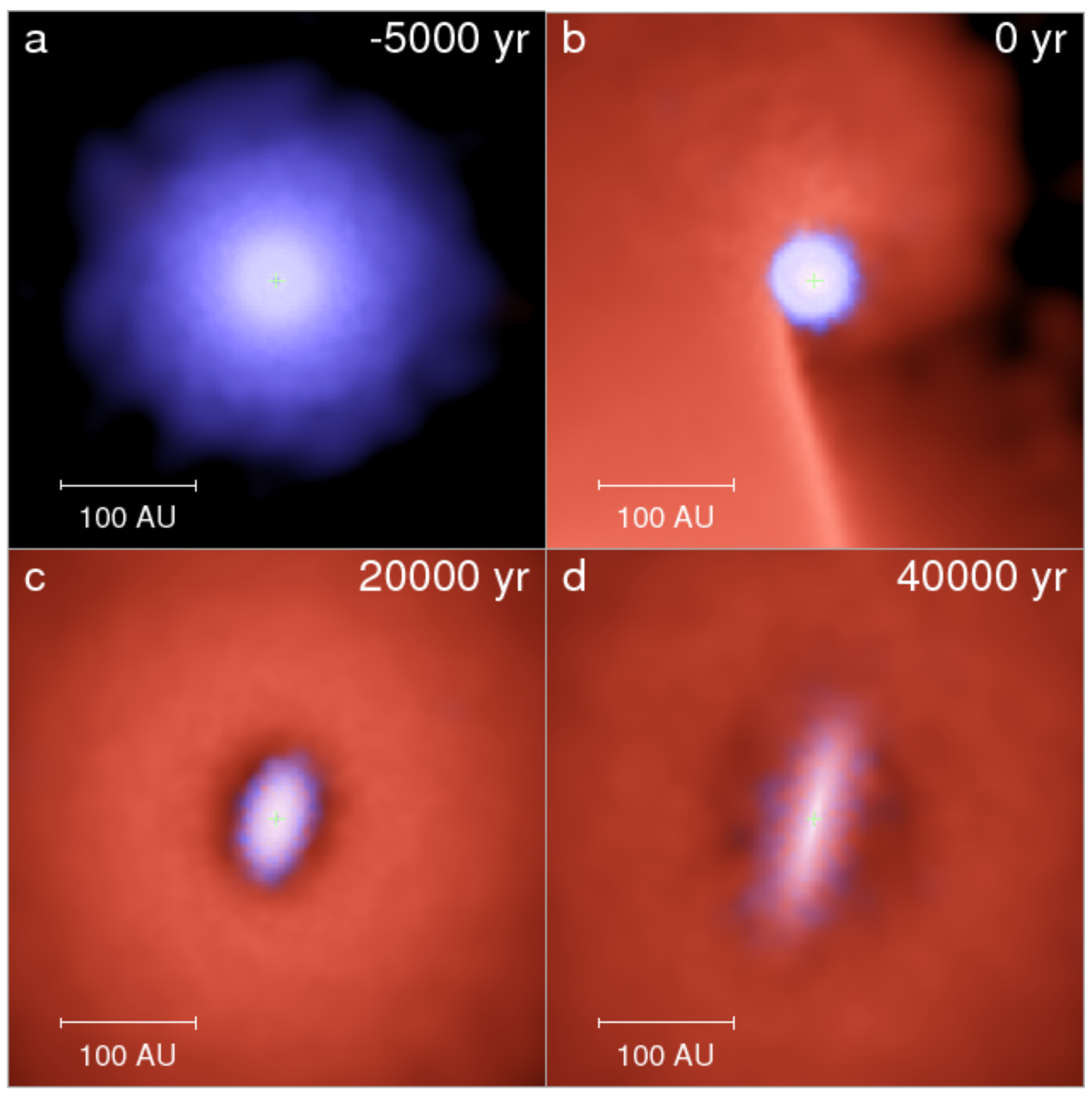

Fig. 2: Snapshots of a circumstellar disc around a Sun-type star capturing material from a passed-by gas cloud. The pre-existing PPD material is shown in blue, while the red colour refers to the captured gas. Bright regions are those of high density. The time stamp in each frame refers to the time of the encounter. The PPD is turned into edge-on orientation within 40,000 years.

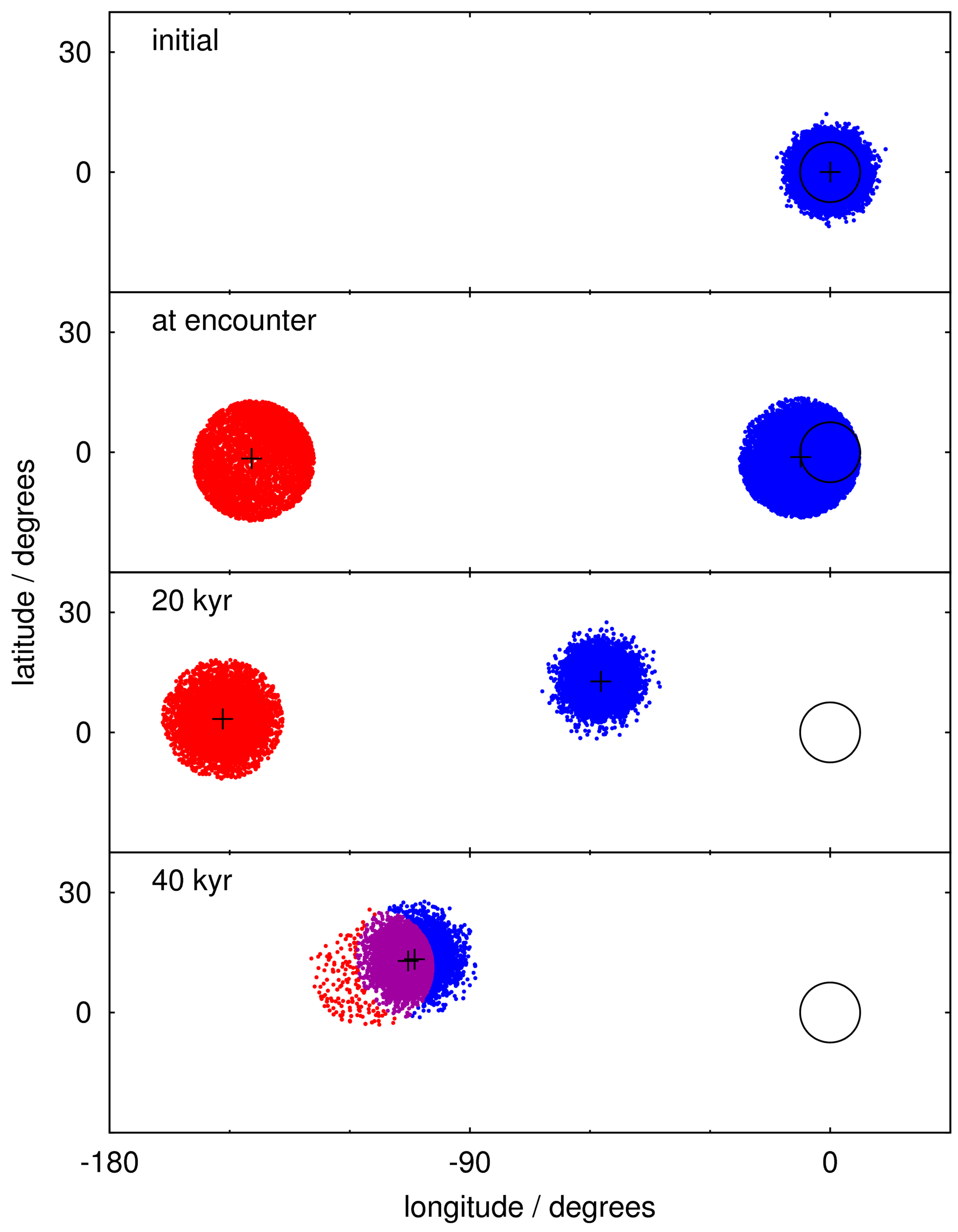

Fig. 3: The angular orientation of the PPD (blue) and the captured annulus (red) shown by the angular momentum vectors of the gas particles. After being completely uncorrelated both structures align to each other via drag forces within 40 kyr. The star, as a relatively compact object nearly unaffected by the disc, keeps its initial spin axis.

About 0.03 M_{sun} are accreted onto the star (less than the disc mass). The accreted annulus and the PPD align to each other by drag forces, eventually merging into a common disc, while the stellar rotation remains essentially unaffacted (Fig. 3). Any planets forming in such a disc will have strongly misaligned orbits. Pre-existing planets are similarly affected by inflowing gas.

4. Vortices as planet boosters

Vortices are a promising mechanism for rapid planetesimal formation (Barge & Sommeria 1995). While classical isolated disc models rely on self-inducing convective vortices, external perturbations may open another channel of inducing dust-trapping spins. We have computed the local spin evolution upon a tidal perturbation of a circumstellar disc by a passing low-mass star. Current SPH methods, however, are insufficient to resolve self-sustaining vorticity (Murante et al. 2011). Thus, only the initial stages of vortex development are shown here.

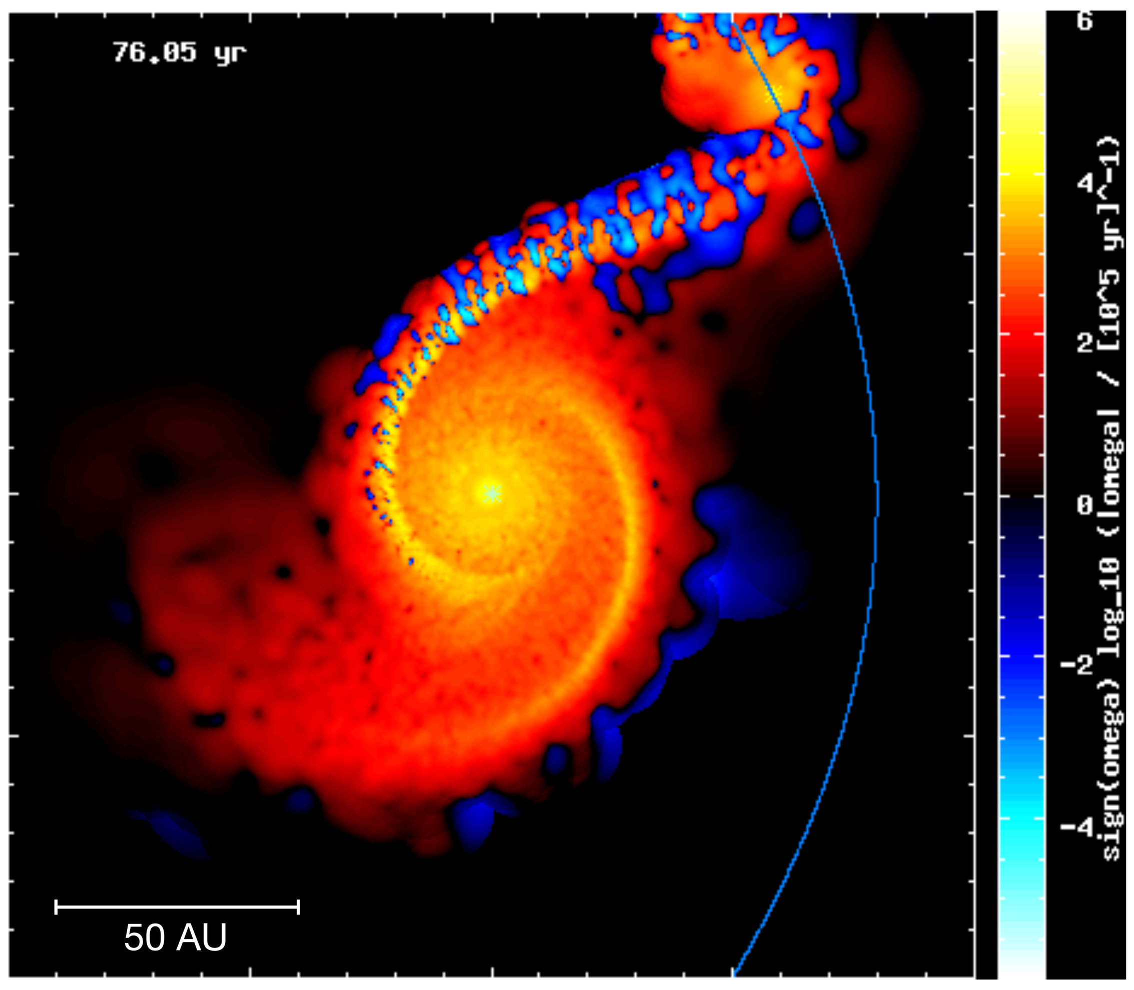

Fig. 4: Local vorticity in a tidally perturbed circumstellar disc. The flyby of a 0.5 M_{sun} star causes local inversions of the ambient rotation, providing possible seeds for persistent anticyclonic vortices which may act as dust traps.

5. Dust treatment and other issues

In the next two years our studies will include

- Enhanced dust coagulation in tidally induced vortices. While proposed from theory, dust trapping by small-scale, short-lived vortices remains to be shown.
- Implications to the Solar planets and the Kuiper Belt; planet formation in previously perturbed discs.

Recent work by Wilkins & Clarke (2011) suggests radiative cooling being strongly underestimated by Stamatellos *et al.*, i.e. disc fragmentation may be far more likely than previously known. In addition, code improvements to resolve subsonic turbulence are to be implemented and compared. In particular:

- Grid-based hydrodynamics (e.g. AMR),
- Godunov-type SPH (Murante et al. 2011)
- Moving Voronoi mesh (Springel 2011)

References

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Movies available on http://www.astro.uni-bonn.de/~ithies/SPH/