SF2A 2019
P. Di Matteo, O. Creevey, A. Crida, G. Kordopatis, J. Malzac, J.-B. Marquette, M. N'Diaye, O. Venot (eds)

FORMATION OF PROTOPLANETARY DISK BY GRAVITATIONAL COLLAPSE OF A NON-ROTATING, NON-AXISYMMETRICAL CLOUD.

A. Verliat[1], P. Hennebelle[1 2], A. J. Maury[1 3] and M. Gaudel[1]

Abstract.
Protoplanetary disks are thought to be inherited from large scale rotation, through the conservation of angular momentum during the collapse of a prestellar dense core. We investigate the possibility for a protostellar disk to be formed from a motionless dense core containing non-axisymmetric density fluctuations. The rotation is thus generated locally by the asymmetry of the collapse. Our hydrodynamic simulations lead to the formation of disks of a hundred astronomical units in radius. The kinematics of our model are consistent with typically observed values of velocity gradients and specific angular momentum in protostellar cores.

Keywords: Methods: numerical , Protoplanetary disks , ISM: clouds , ISM: kinematics and dynamics , Turbulence , Stars: formation

1 Theory

Let's name $\mathcal{R}$ and O the frame and center of the simulation box, $\mathcal{R}'$ and C the frame and center of the disk, G the center of mass, m_i and M_i the mass and position of each cell i. We consider motionless initial conditions to ensure that the angular momentum computed in the simulation box frame, in relation to the center of the box — $\sigma_{\mathbf{0}}|_{\mathcal{R}}$ — is null and conserved. The angular momentum computed in the frame of the disk, in relation to the center of the disk can be expressed as:

$$\sigma_{\mathbf{C}}|_{\mathcal{R}'} = \sum_i m_i \mathbf{CM_i} \times \frac{\mathrm{d}\mathbf{CM_i}}{\mathrm{d}t} = M\mathbf{GC} \times \frac{\mathrm{d}\mathbf{GC}}{\mathrm{d}t} \qquad (1.1)$$

If G and C do not coincide, and the disk have a proper motion, $\sigma_{\mathbf{C}}|_{\mathcal{R}'}$ is not null and not conserved. A rotationally supported structure naturally forms around C.

2 Numerical setup

We ran purely hydrodynamics simulations with $\mathcal{R}$AMSES. This numerical Eulerian code uses Adaptative Mesh Refinement (AMR) technique to enhance resolution locally, where it is needed, on a Cartesian mesh (Teyssier 2002).

We set a 3D cubic box with sides of 70000 AU (about 0.33 pc), in which we put a prestellar dense core of 17500 AU in diameter and 2.5 $M_\odot$. We use 10 levels of AMR, leading to a 0.26 AU equivalent maximum resolution. Initially we set all velocities to zero, ensuring $\sigma_{\mathbf{0}}|_{\mathcal{R}} = \mathbf{0}$. We use a barotropic equation of state. To break the axisymmetry we add random density perturbations over the flat profile of the core. These initial conditions are illustrated in Fig. 1.

We define the *perturbation level* as the ratio between the root mean square value and the mean value of the density.

[1] Laboratoire AIM, Paris-Saclay, CEA Saclay/IRFU/DAp – CNRS – Université Paris Diderot, 91191 Gif-sur-Yvette Cedex, France
[2] LERMA (UMR CNRS 8112), Ecole Normale Supérieure, 75231 Paris Cedex, France
[3] Harvard-Smithsonian Center for Astrophysics, 60 Garden street, Cambridge, MA 02138, USA

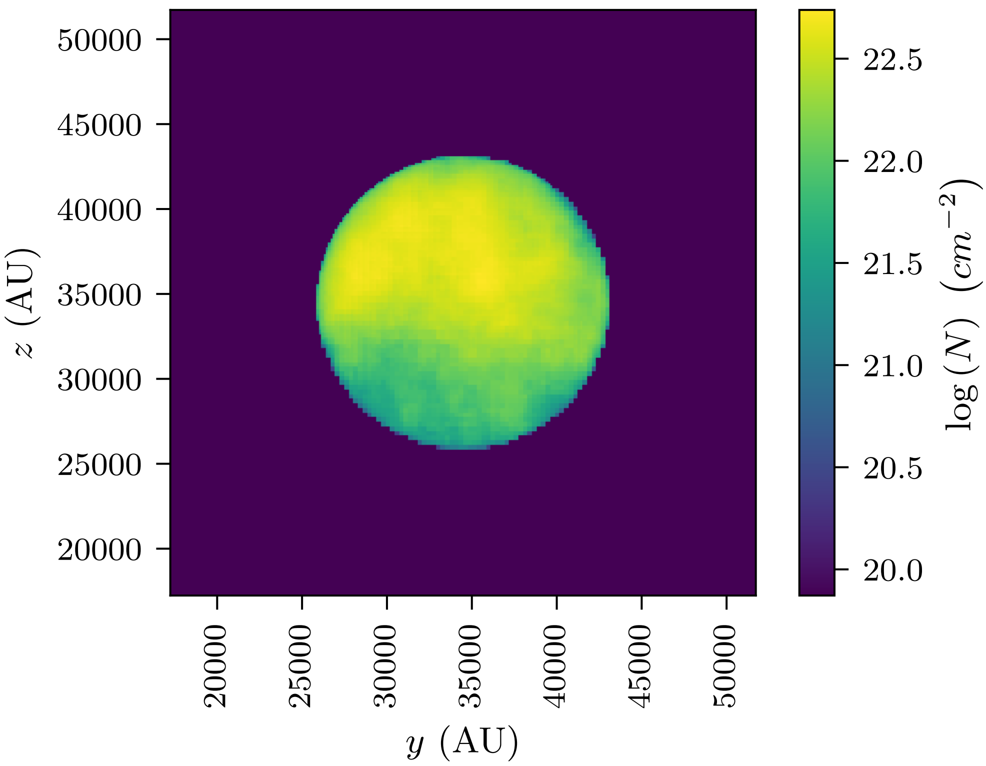

Fig. 1. Column density illustrating initial conditions for the simulation with 50% of perturbations.

3 Results

As expected from our theoretical development, we observe the formation of a disk, as illustrated in Fig. 2

4 Comparison with observations

To compare our model with observations, we analyse our simulations by computing velocity gradients as it is done observationally. To do so, we fit velocities along the line of sight with a solid-body rotation profile. The results are plotted in Fig. 3.

We observe a large dispersion of velocity gradient directions over the different scales with even reversals for the x and y projections. The specific angular momentum is roughly constant over the scales, with a mean value of $\sim 3\ 10^{-4}\ km.s^{-1}.pc$, which is consistent with the step in the observational values, showed in Fig. 4.

5 Conclusions

We showed that protostellar disks can emerge from a non-axisymmetrical gravitational collapse. The formation of these large disks in our model does no longer depend on specificities of large scales, but is due to a more generic process resulting from density perturbations of the gas. We showed that the different features of the model based on the analysis of velocity gradients are consistent with observations.

This work is the subject of a publication — Verliat et al. (submitted) — where you will find more details.

References

Belloche, A. 2013, 62, 25

Teyssier, R. 2002, A&A, 385, 337

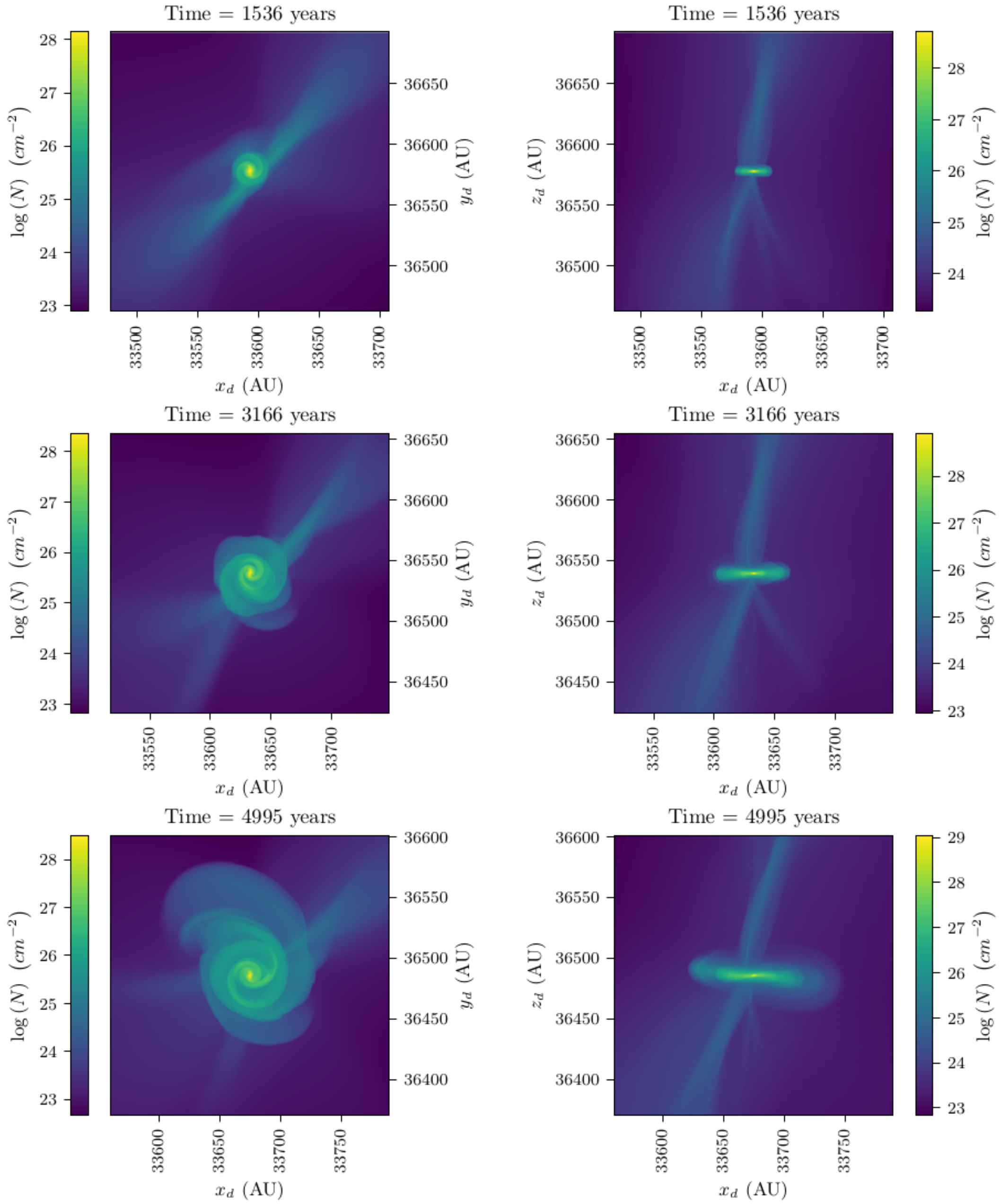

Fig. 2. Simulation with 50% of perturbations at three different times. **Left:** Face-on projection. **Right:** Edge-on projection.

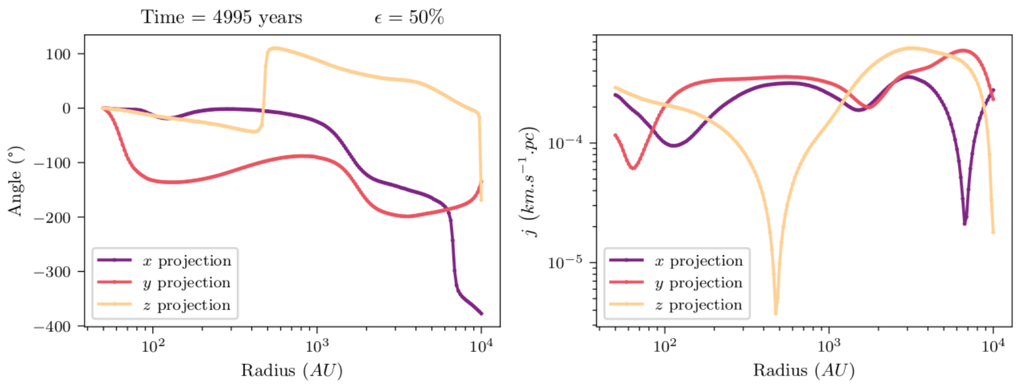

Fig. 3. Velocity gradients analysis at different scales in the simulation with 50% of perturbations. **Left**: angular direction of velocity gradients in comparison to the one of the disk scale gradient. **Right**: specific angular momentum as computed from observations.

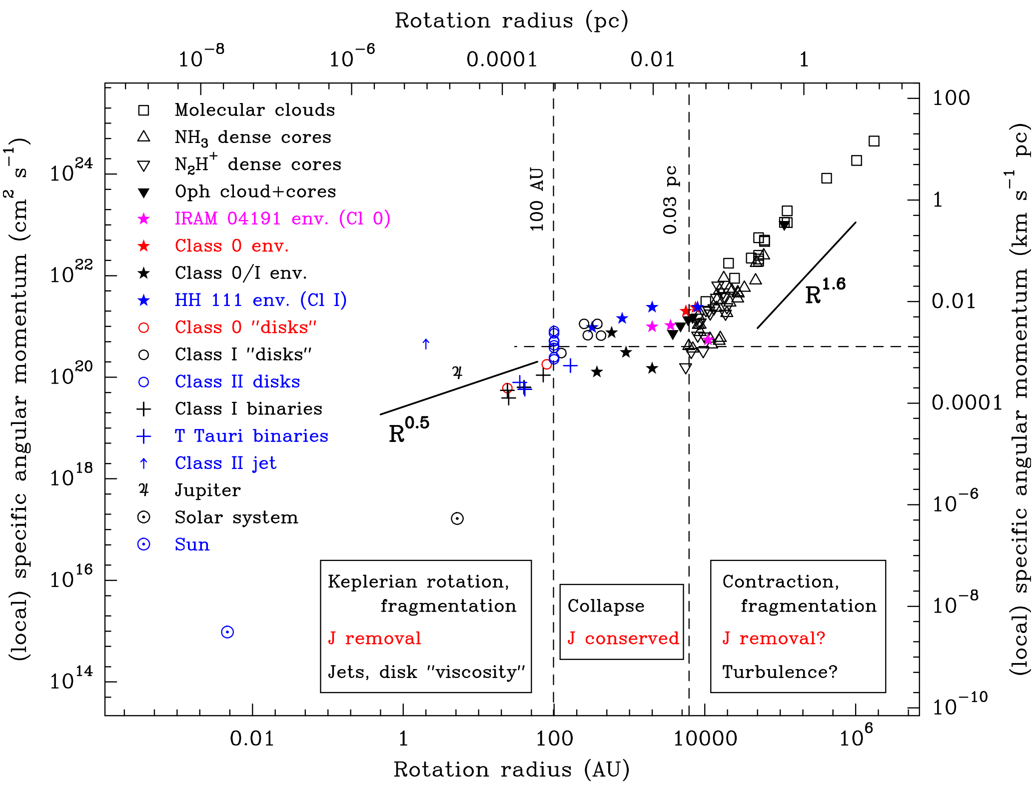

Fig. 4. Specific angular momentum in several objects, deducted from observations (Belloche 2013).