Formation of Protostellar Discs

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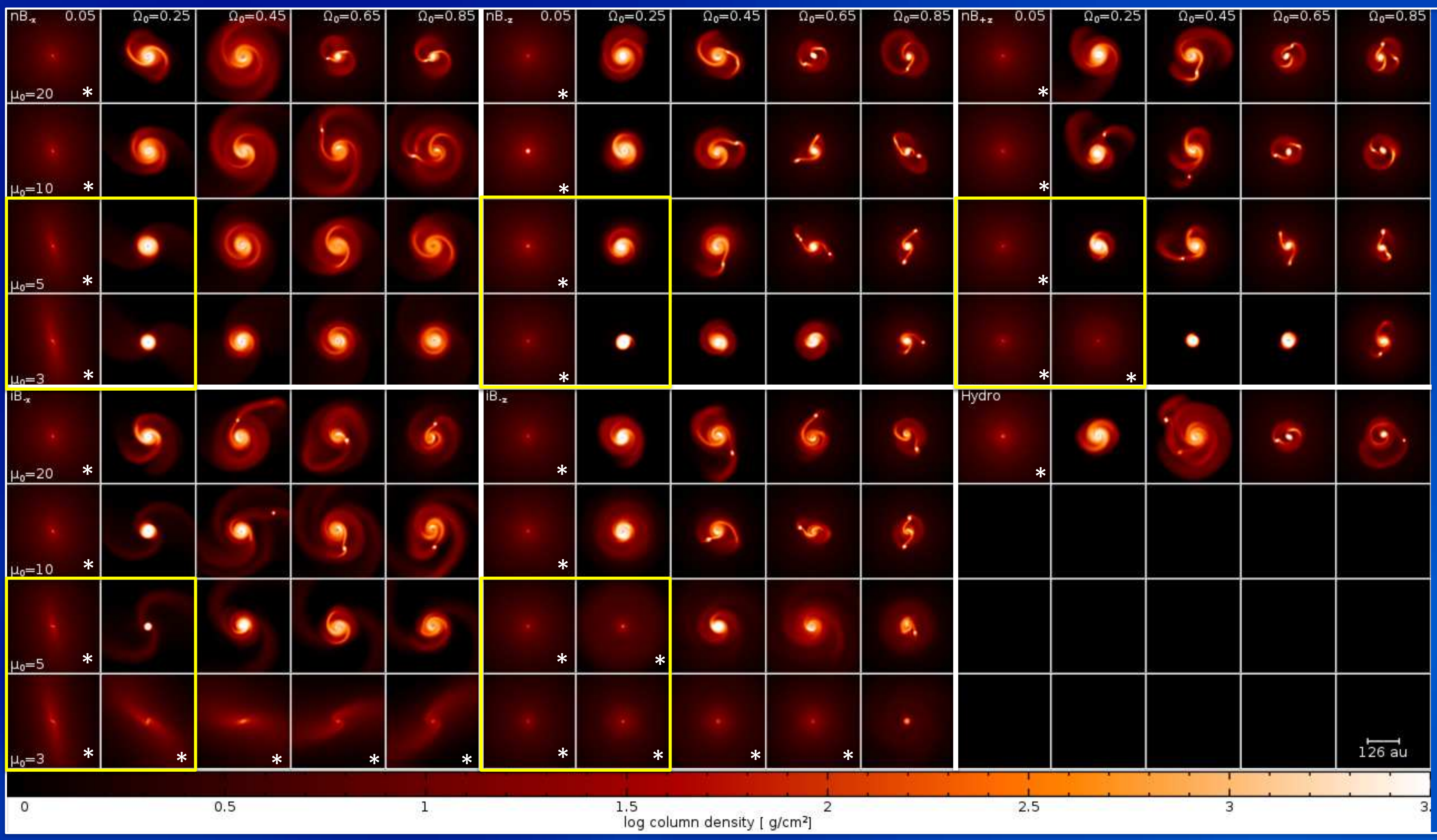
Disc formation: A parameter study

We perform smoothed particle radiative non-ideal magnetohydrodynamics simulations of low-mass star and protostellar disc formation in a magnetised medium. We initialise our simulations as $1M_{sun}$ rotating Bonnor-Ebert spheres, threaded with a magnetic field. Our non-ideal MHD models include Ohmic resistivity, ambipolar diffusion and the Hall effect. Sink particles are used to model the long-term evolution. We investigate the effect of the initial rotation rate, the magnetic field strength, and magnetic field orientation.



Gas column density at the end of each simulation. The figure is subdivided into 6 panels, where the top panels use non-ideal MHD, and the bottom panels use ideal MHD (left and centre) or pure hydrodynamics (right). In each panel, the initial rotation rate increases from left to right, and the initial magnetic field strength increases from top to bottom. The frames marked with asterisks do not form discs. The frames outlined in yellow represent the more probable initial conditions. The initial rotation rates correspond to ratios of rotational energy to gravitational potential energy of $\boldsymbol{\beta}_r = 4.4 \times 10^{-4}$ 0.011, 0.035, 0.074, and 0.13.

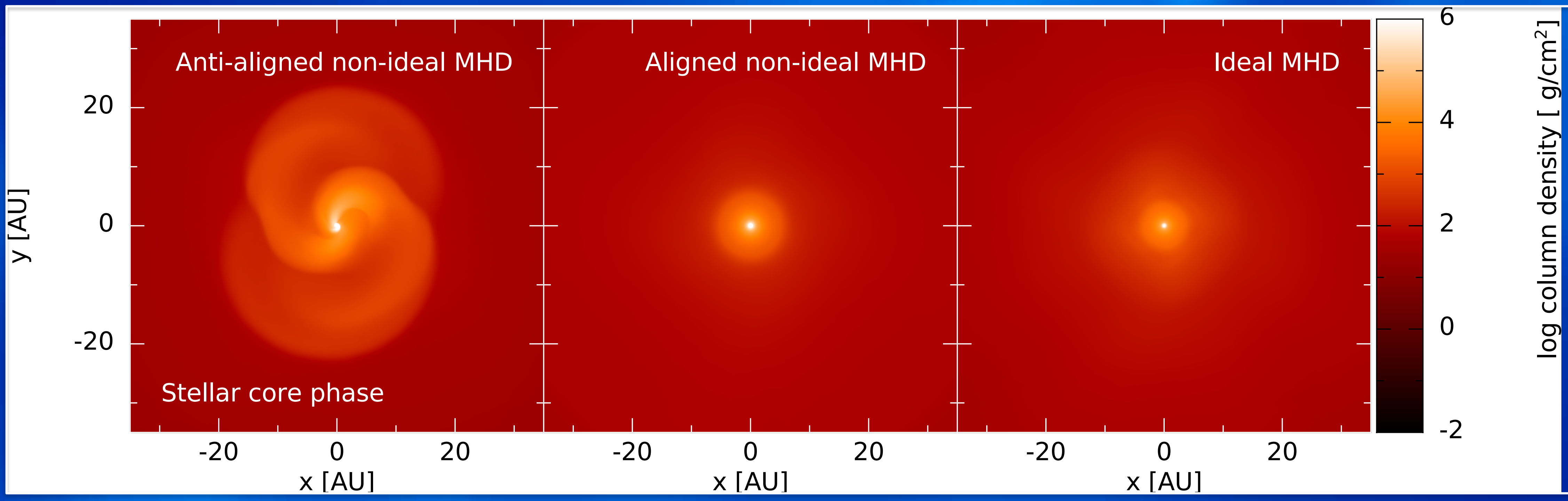
(Wurster & Bate 2019)

Discs form and survive in 74 of the 105 models, suggesting that disc formation should be common. 41 discs fragment, where the fragment represents a second star rather than a planet. As expected, discs form in models with faster initial rotations and/or weaker initial magnetic field strengths.

Disc formation is typically hindered in the models with the more probable initial rotation rates and magnetic field strengths. In this parameter space, disc formation is promoted when the initial magnetic field is perpendicular to the rotation axis (B_{-x}) or when non-ideal MHD is included for the B_{-z} orientation (i.e. when the magnetic field vector is anti-aligned with the rotation vector). For initially strong magnetic field strengths, the $B_{\pm z}$ initial orientation is more probable (Wurster, Bate & Price in prep), thus non-ideal MHD processes are required for disc formation in the observationally motivated parameter space.

Disc formation during protostar formation

We perform three high resolution simulations in the observationally motivated parameter space. We initialise our simulations as $1M_{sun}$ rotating spheres of uniform density, threaded with a magnetic field parallel to the rotation axis. The initial magnetic field strength has a normalised mass-to-flux ratio of $\boldsymbol{\mu}_0 = 5$ and $\boldsymbol{\beta}_r = 0.005$. Sink particles are not used.



Gas column density during the stellar core phase. See QR-code for video of the evolution.

(Wurster, Bate & Price 2018)

Protostellar discs of similar size to those observed (~25au) form during the first hydrostatic core phase in the anti-aligned non-ideal MHD model; in this alignment, the Hall effect contributes to the angular momentum near the protostar. A ~1au disc forms during the stellar core phase in the aligned non-ideal MHD model; in this alignment, the Hall effect extracts angular momentum from near the protostar, but Ohmic resistivity and ambipolar diffusion decrease the magnetic field strength. No disc forms in the ideal MHD model. Thus, in an observationally motivated parameter space, a large protostellar disc will only form if the non-ideal MHD processes are included and the magnetic field vector is anti-aligned with the rotation vector.

References:

J. Wurster & M.R. Bate. MNRAS, 486:2587-2603, June 2019.
J. Wurster, M.R. Bate & D.J. Price. MNRAS, 480:4434-4442, Nov 2018.
J. Wurster, M.R. Bate & D.J. Price. In prep.

Background image: Gas column density of a star cluster (Wurster, Bate & Price. In prep.)

Personal website QR-code: