Protostellar Collapse and Outflows using Smoothed Particle Magnetohydrodynamics

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Methods

We performed 3D *MHD protostellar collapse simulations* using the smoothed particle hydrodynamics (SPH) capabilities of the the GADGET code (Springel, 2005), which was recently extended by Dolag & Stasyszyn (2009) to allow for the treatment of ideal MHD. We use the traditional approach for ideal MHD employing the induction equation, but subtract the non-vanishing divergence term from the force equation to ensure numerical stability (Børve et al., 2001). Furthermore, we employ time-dependent artificial resistivity, introduced by Price & Monaghan 2005, as a regularization scheme.

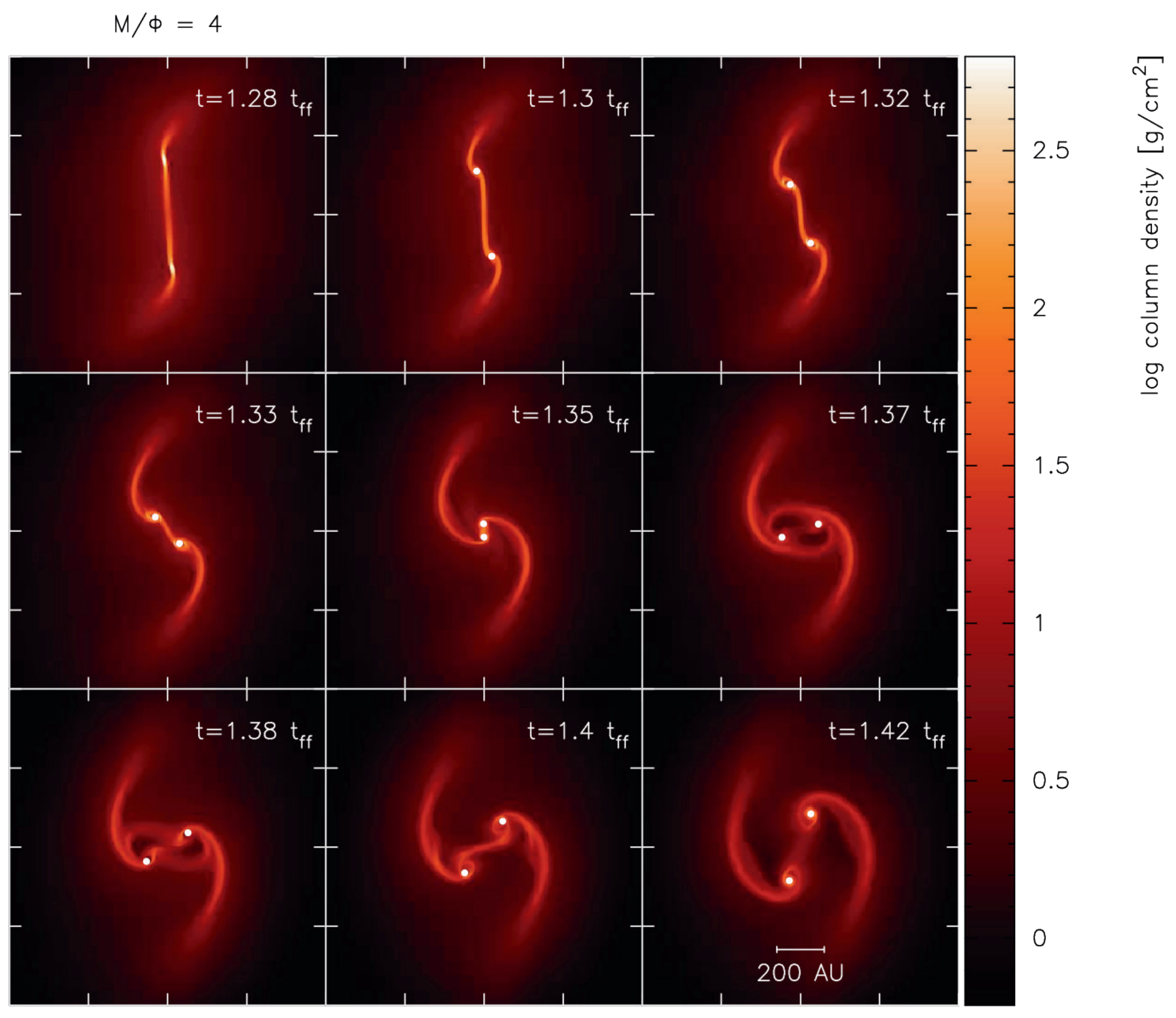
Collapse & Fragmentation

(Bürzle et al., 2011a)

Initial Conditions

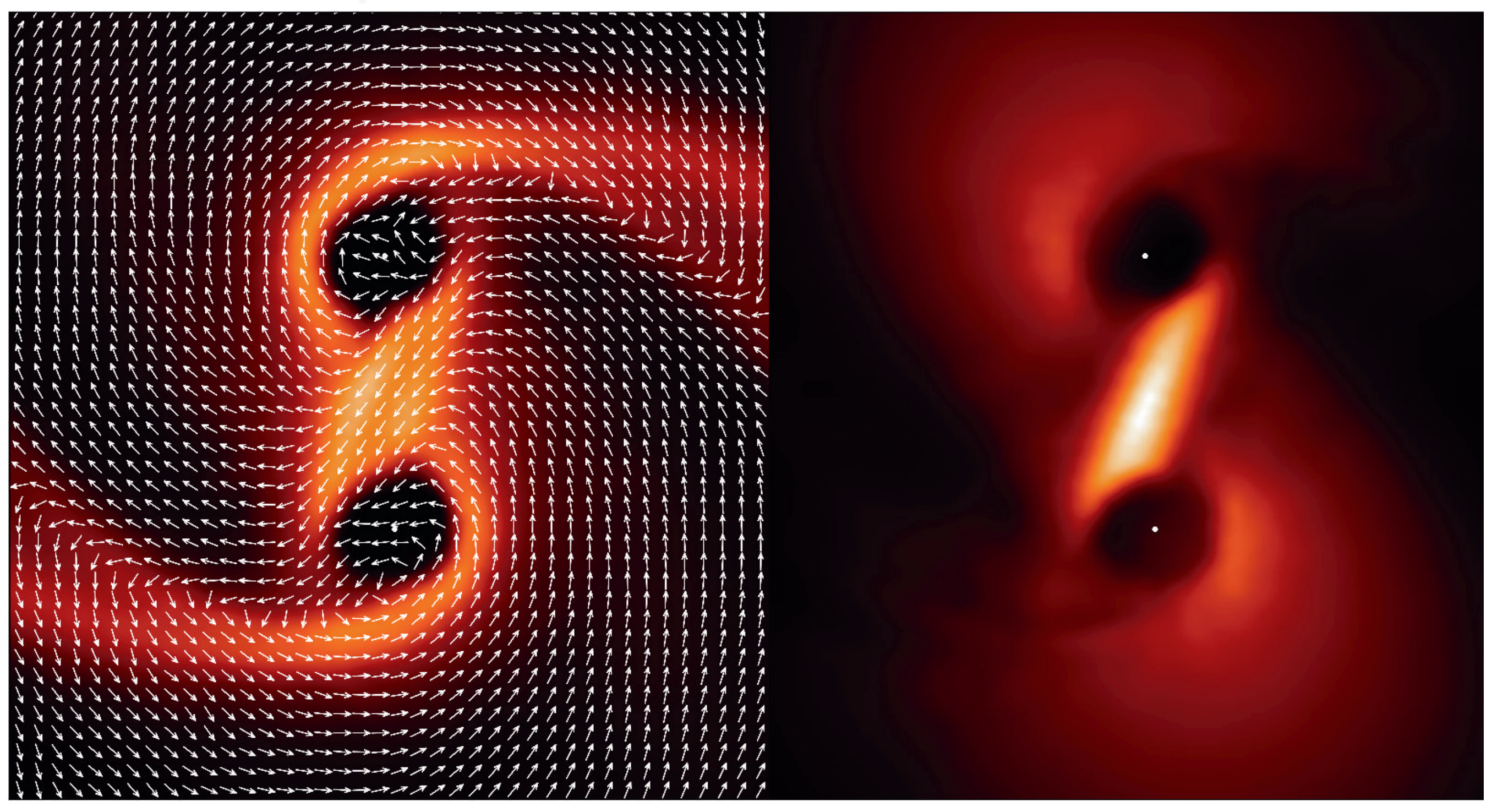
We used IC from Price & Bate (2007): Uniform sphere with M=1 $M_\odot$, R=0.013 pc, $\Omega=10^{-12}$ s^{-1} (β_{rot}=0.16), T=8.4 K (α_{therm}=0.26). B=0 - 814 µG, field initially aligned with rotation axis. m=2 density perturbation. Thermal evolution controlled by barotropic EOS. Free-fall time (t_{ff}): 24 000 yr.

Column density (x-y plane)



Simulation results with an initial field strength of B_0 = 203 µG. Contrary to Price & Bate (2007), who found only a single protostar in this case, we find formation of a binary system. We attribute this to the magnetic cushioning effect.

'Magnetic cushioning effect'



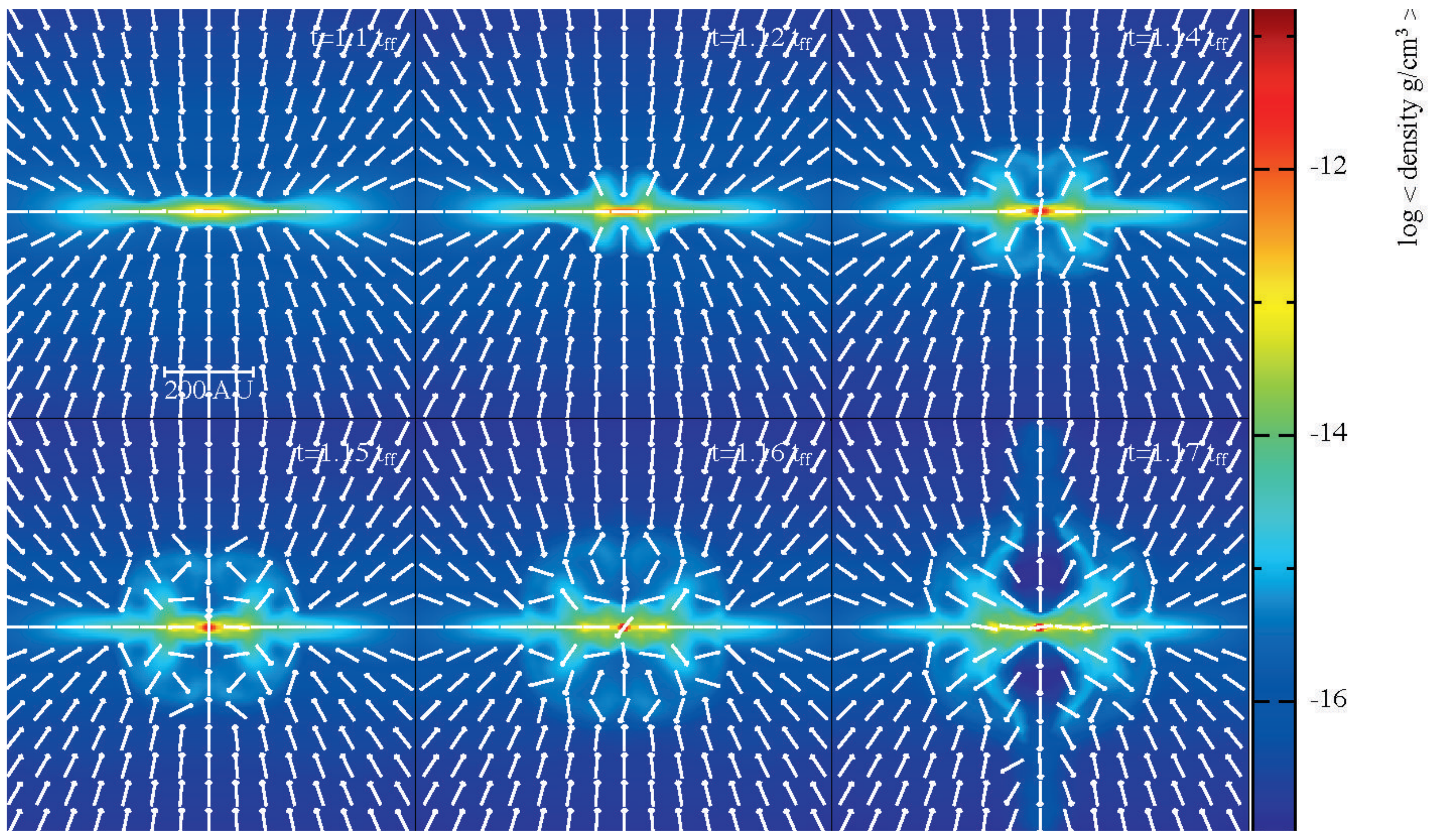
The system is shown at t=1.35 t_{ff}, thus corresponding to panel 5 above. The panel on the left hand side shows column density and integrated magnetic field vectors (normalized). The right-hand side shows the integrated magnetic pressure. The magnetic field forms a cushion, eventually preventing the objects from merging.

Protostellar Outflows

(Bürzle et al., 2011b)

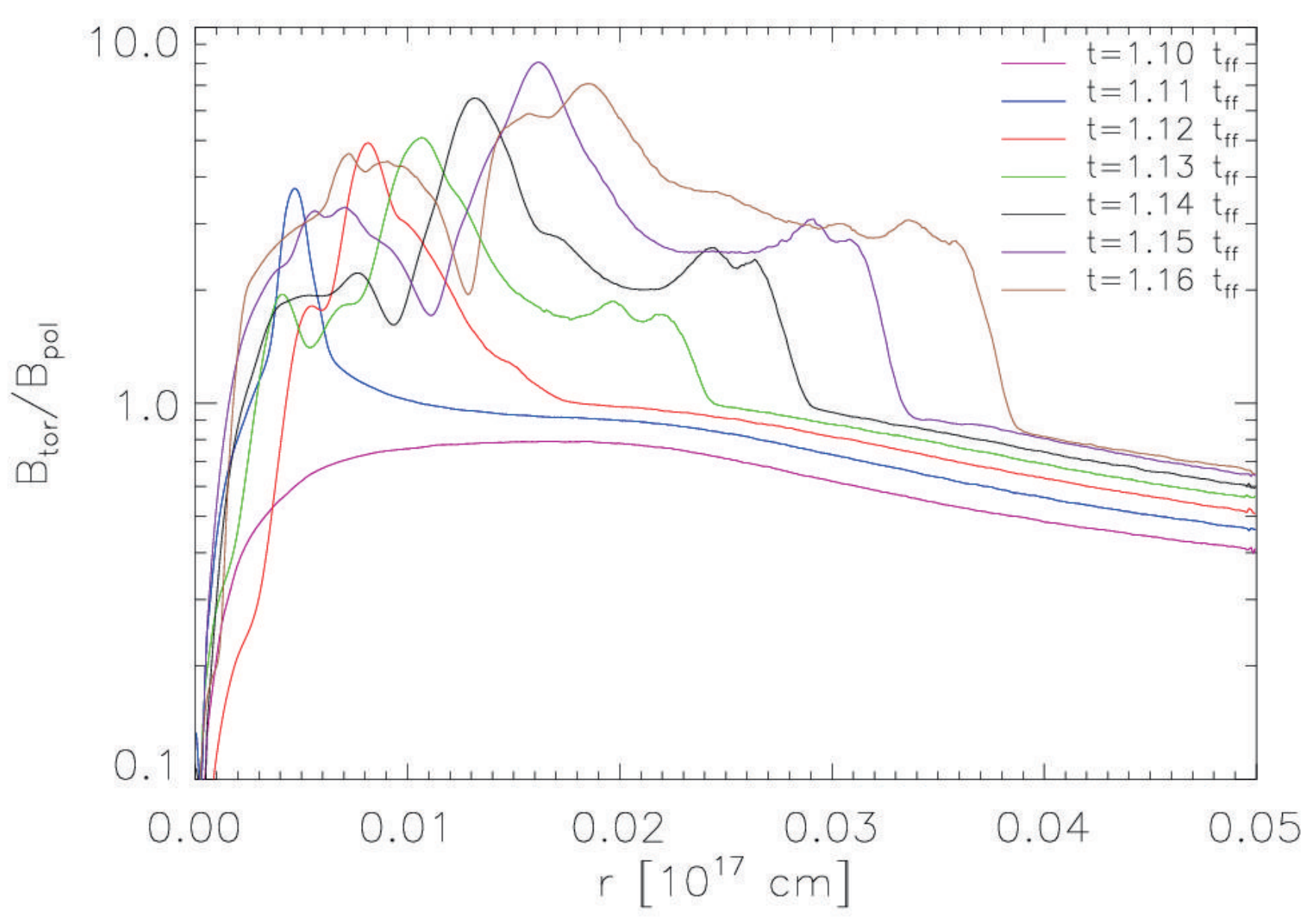
Following Hennebelle & Fromang (2008), we used: Uniform sphere with M=1 $M_\odot$, R=0.015 pc, Ω=4.3 10^{-13} s^{-1} (β_{rot}=0.045), T=11 K (α_{therm}=0.37), B=30 µG, field initially aligned with rotation axis. Thermal evolution controlled by barotropic EOS. Free-fall time (t_{ff}): 30 000 yr.

Density (near x-z plane)



A time-sequence of panels, starting at first core formation (1.10 t_{ff}). At 1.11 t_{ff}, a bipolar outflow with peak velocities of 1.9 km s^{-1} is ejected from the disc (vectors indicate velocities).

$B_{toroidal}/B_{poloidal}$ ratio



Sequence of spatial averages of B_{tor}/B_{pol} from 1.10 t_{ff} to 1.16 t_{ff} in central parts of the core, showing the generation of the toroidal part of the magnetic field, as well as its outward propagation with time. This suggests driving of the outflow by toroidal magnetic field components.

References

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