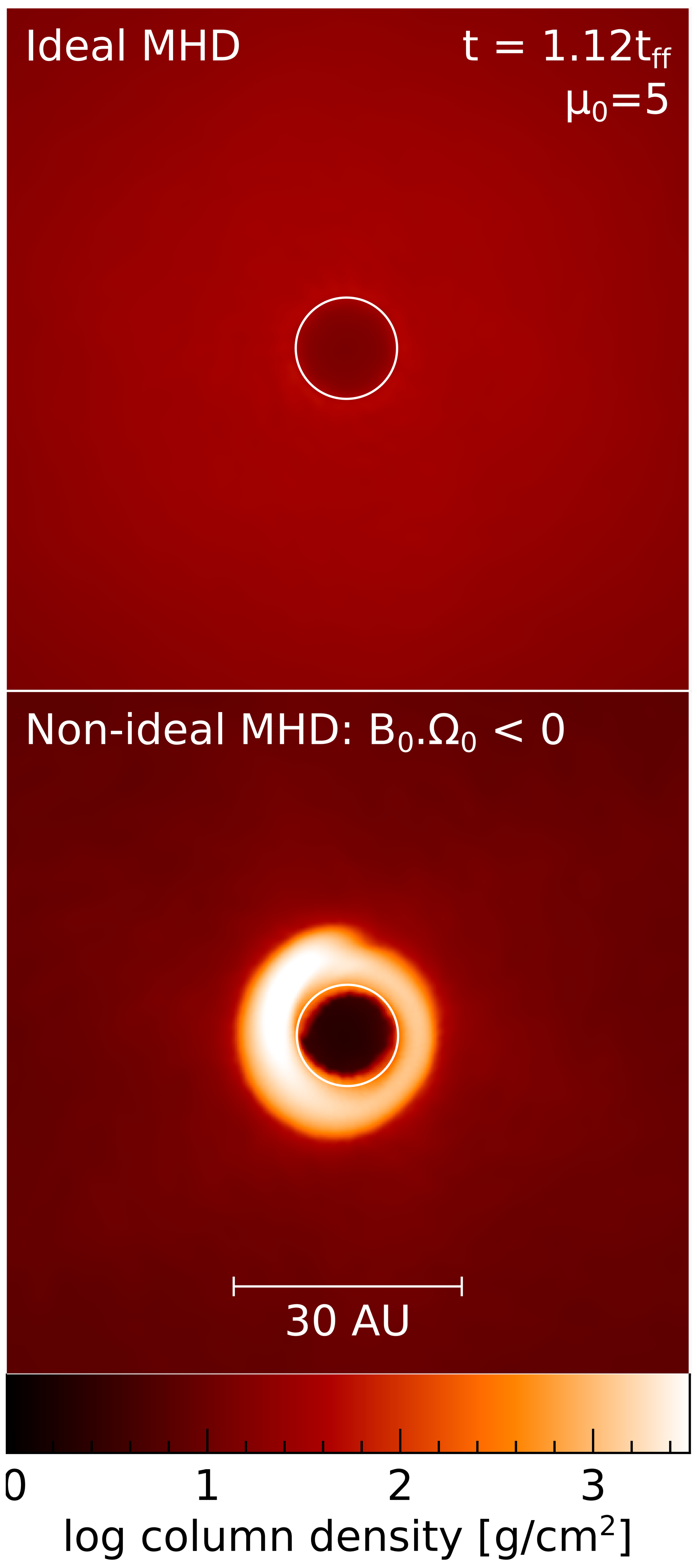
Isolated vs Binary Protostars: The importance of non-ideal MHD

James Wurster[1,2,*], Daniel Price[2] & Matthew Bate[1]
[1]School of Physics, University of Exeter, Stocker Rd, Exeter EX4 4QL, UK
[2]Monash Centre for Astrophysics, School of Physics & Astronomy, Monash University
*email: j.wurster@exeter.ac.uk; web: www.astro.ex.ac.uk/people/wurster/



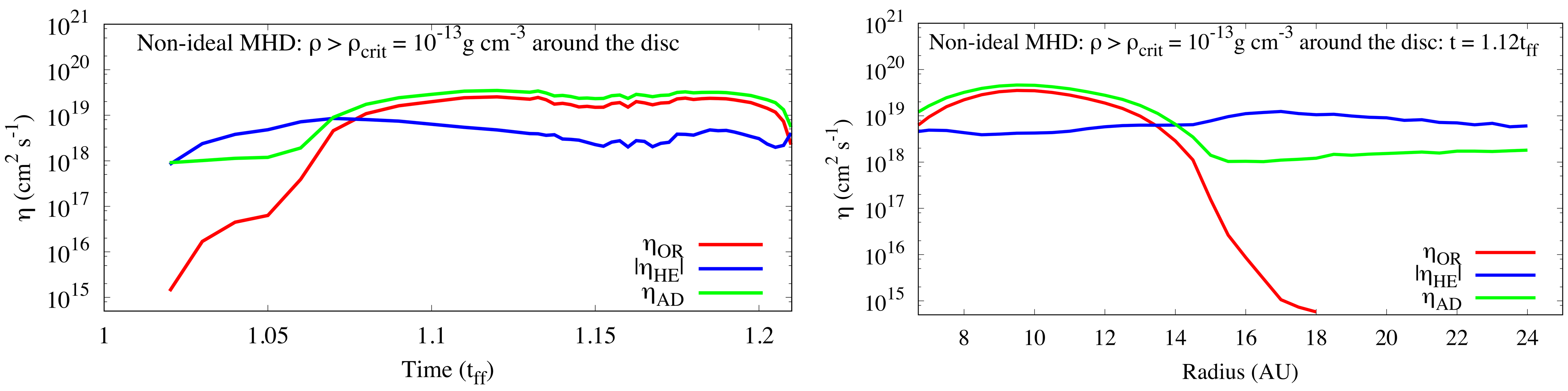
Isolated protostar formation:

Numerical simulations cannot form discs in the presence of strong, ideal magnetic fields, given idealised initial conditions. This is the magnetic braking catastrophe.

We model the collapse of a rotating $1M_{sun}$ gas cloud of radius 4×10^{16} cm, which is threaded with a magnetic field that is anti-aligned to the rotation axis. The initial rotation, sound speed and mass-to-flux ratio (i.e. magnetic field strength) are $\Omega_0 = 1.77\times10^{-13}$ rad s^{-1}, $c_{s,0} = 2.19\times10^{4}$ cm s^{-1}, and 5 times critical.

No disc forms when using ideal MHD. When non-ideal MHD is included, a ~15 AU disc forms. The Hall effect is dependent on the direction of the magnetic field with respect to the rotation vector, and its coefficient, η_{HE}, is ~1.5 orders of magnitude lower than the ambipolar diffusion coefficient, η_{AD}, in the middle of the disc at $t = 1.12t_{ff}$. Although weaker, it is strong enough that no disc forms if the initial magnetic field is aligned with the rotation axis.

In summary, non-ideal MHD is important during the formation of isolated protostars.



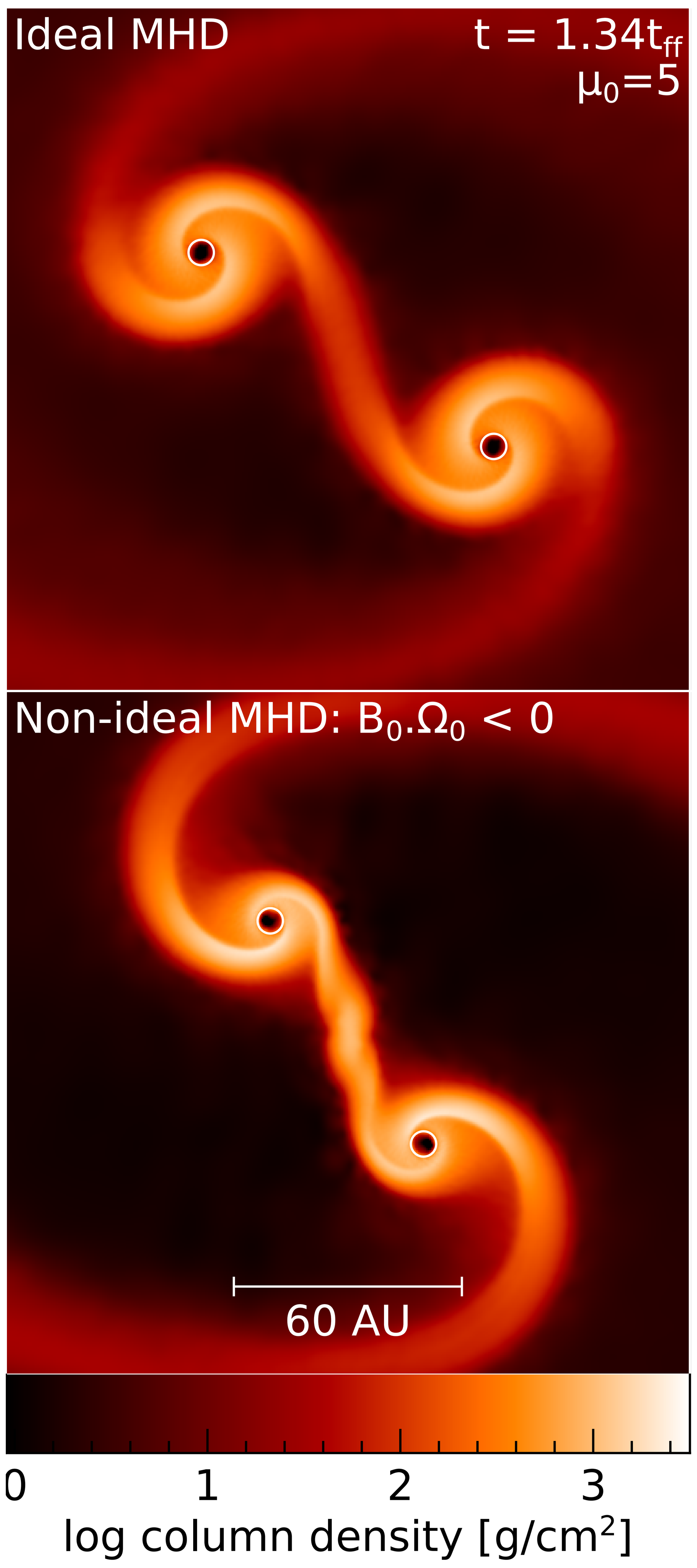
Binary protostar formation:

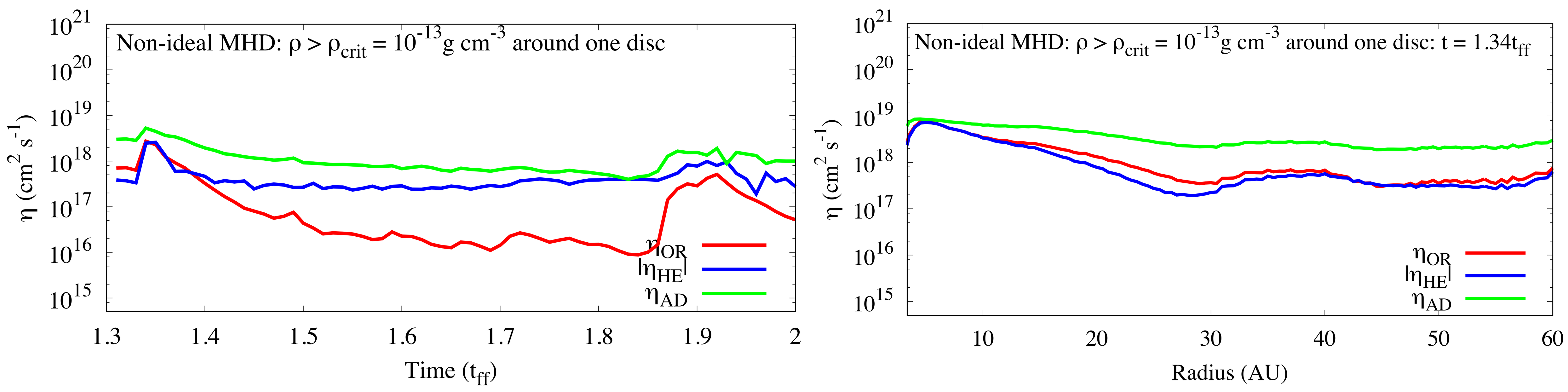
Discs form ubiquitously in our numerical simulations of wide binary formation, even in the presence of strong, ideal magnetic fields and idealised initial conditions.

We model the collapse of a magnetised, perturbed rotating $1M_{sun}$ gas cloud of radius 4×10^{16} cm. The initial rotation, sound speed, mass-to-flux ratio, and perturbation are $\Omega_0 = 1.006\times10^{-12}$ rad s^{-1} (5.7x larger than the isolated models), $c_{s,0} = 1.87\times10^{4}$ cm s^{-1}, 5 times critical, and an $m = 2$ perturbation with an amplitude of $A_0 = 0.1$.

First periastron is smaller and first apoastron is larger in the non-ideal model compared to the ideal model. Compared to the isolated protostars, these non-ideal discs have magnetic fields ~10 times weaker, a value of plasma β that is ~10 times higher, and non-ideal coefficients that are 1-2 orders of magnitude lower. Thus, the non-ideal effects are weaker in these binary models than in isolated protostar models.

In summary, non-ideal effects cause small differences in the evolution, which may then be amplified by the binary interactions. Thus, non-ideal MHD has only a small effect on binary formation, with the initial conditions playing the dominant role.





References:
Braiding & Wardle (2012): The Hall effect in accretion flows
Wurster, Price & Bate (2016): Can non-ideal magnetohydrodynamics prevent the magnetic braking catastrophe?
Wurster, Price & Bate (in prep): The impact of non-ideal magnetohydrodynamics on binary star formation