Resolving numerical star formation: A cautionary tale

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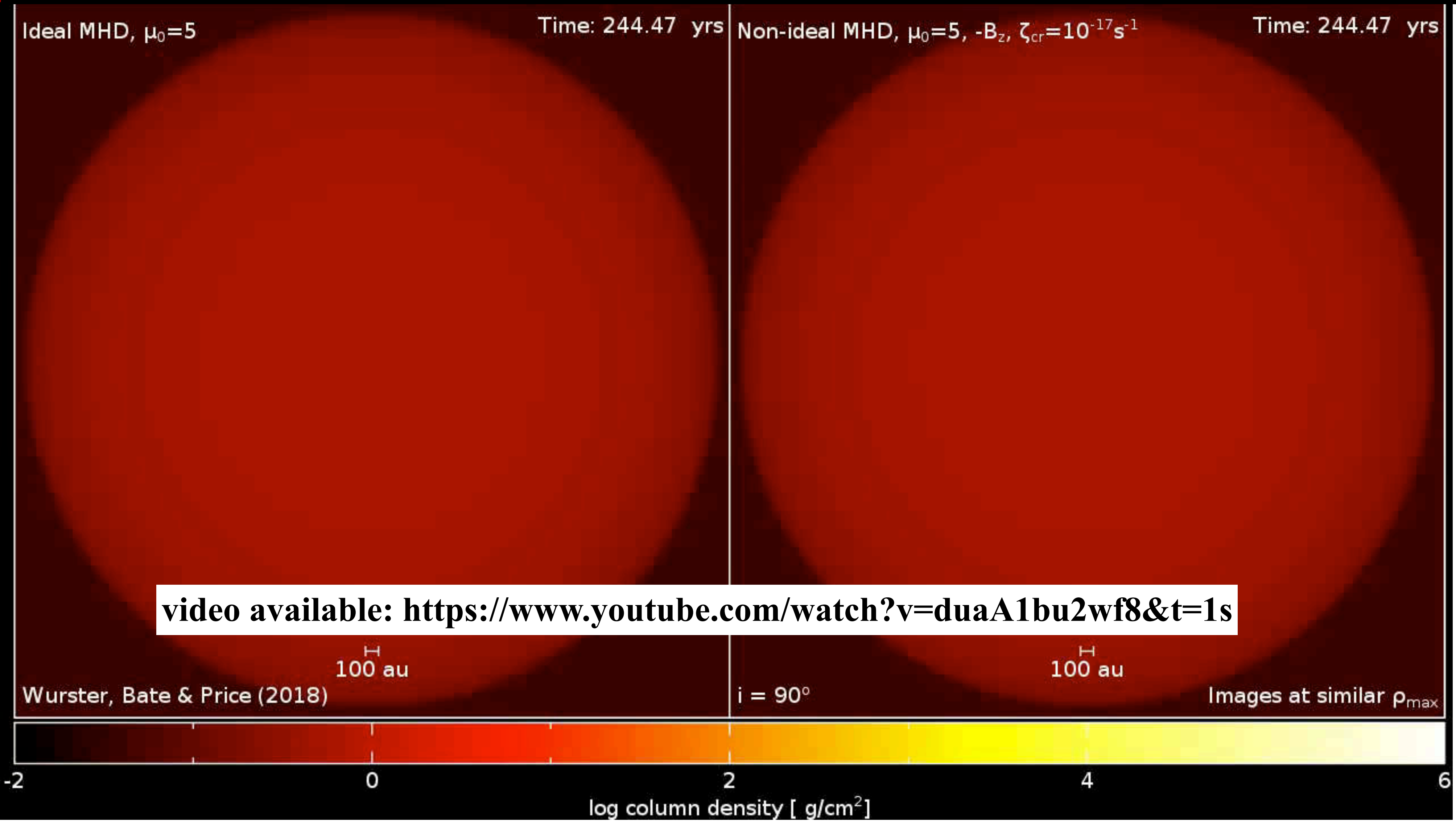
Numerical star formation

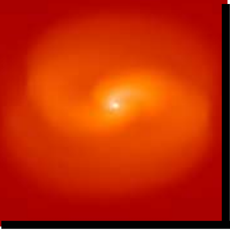


video available: https://www.youtube.com/watch?v=duaA1bu2wf8&t=1s

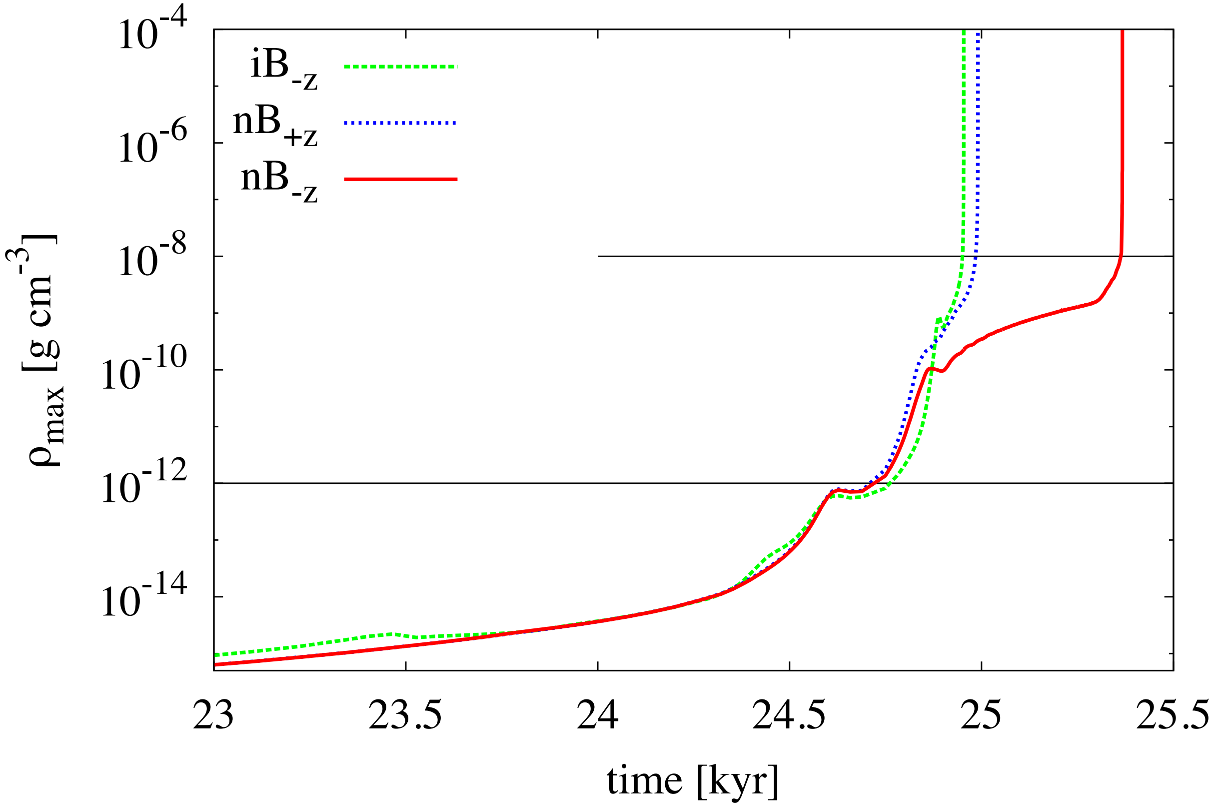
- Code sphNG
- M_4 Cubic spline kernel
- Fully compressible SPH
- Sphere-in-box setup with periodic boundary conditions
- Evolved density over 17 orders of magnitude
- Includes:
- adaptive *h*
- individual timesteps
- radiation non-ideal magnetohydrodynamics

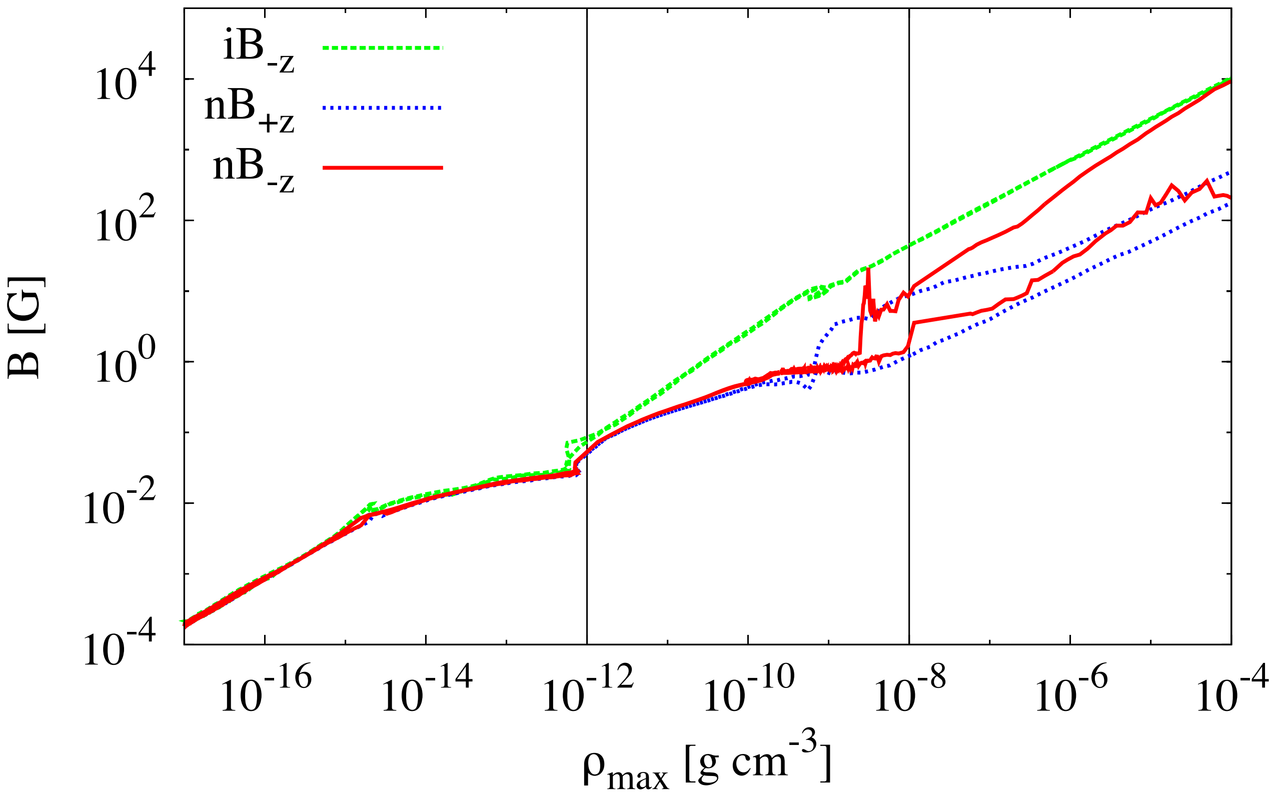
Wurster, Bate & Price (2018,ac)

Music: Jo-Anne Wurster

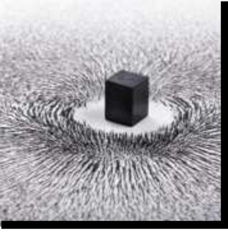


Global Evolution





- $\rho \sim 10^{-12}$ g cm^{-3}: Beginning of first core phase
- $\rho \sim 10^{-8}$ g cm^{-3}: End of first core phase
- $\rho \sim 10^{-4}$ g cm^{-3}: Birth of protostar
- Evolution diverges around $\rho \sim 10^{-12}$ g cm^{-3} due to the different physical processes



Magnetohydrodynamics

- Induction equation (continuum):

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\boldsymbol{B}}{\rho}\right) = \left(\frac{\boldsymbol{B}}{\rho}\cdot\boldsymbol{\nabla}\right)\boldsymbol{v}$$

- Induction equation (discretised):

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{B_a^i}{\rho_a}\right) = -\frac{1}{\Omega_a \rho_a^2}\sum_b m_b v_{ab}^i B_a^j \nabla_a^j W_{ab}\left(h_a\right)$$

- Artificial resistivity (from Price, Wurster + 2018):

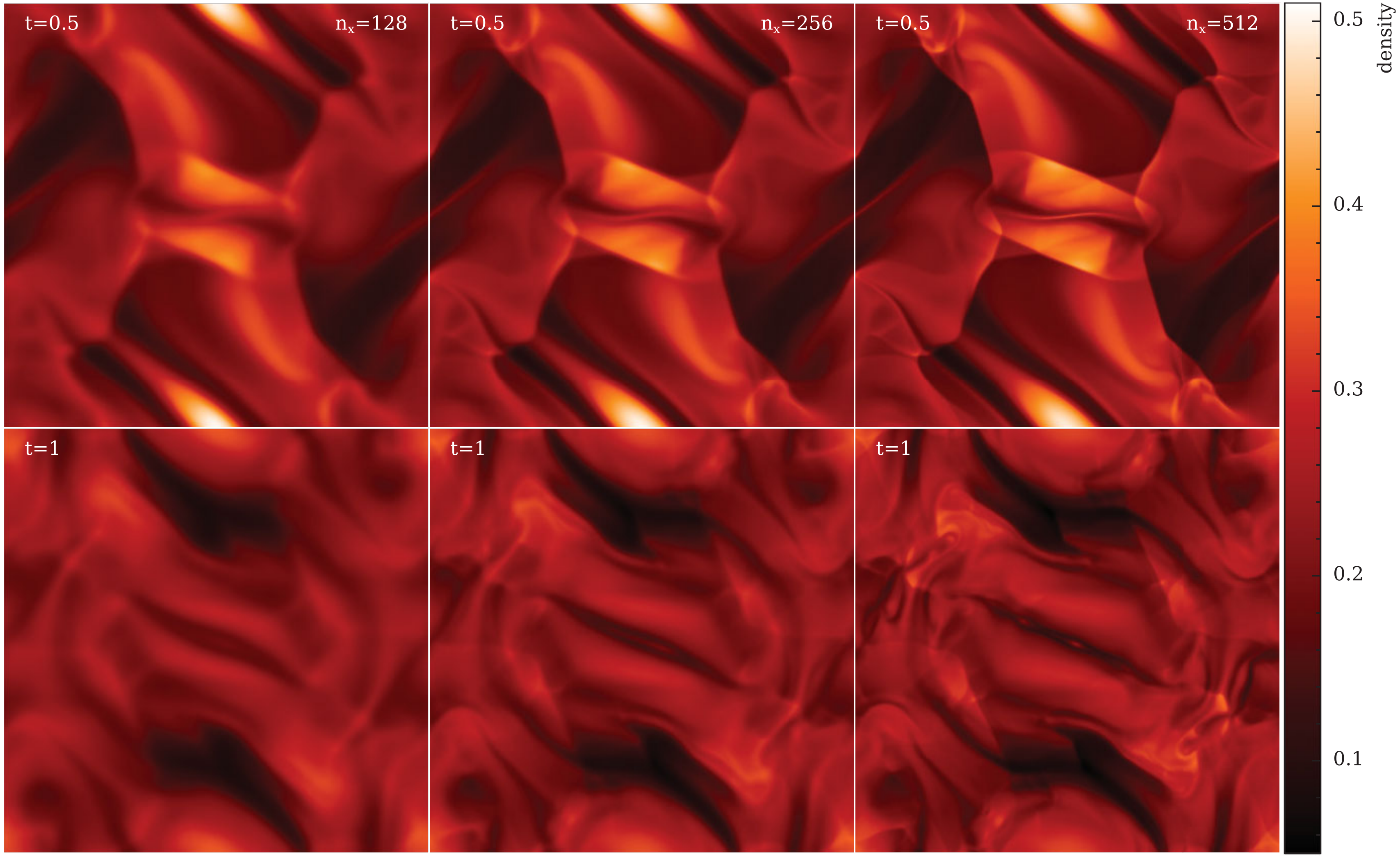
$$\left.\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{B_a^i}{\rho_a}\right)\right|_{\mathrm{art}} = \frac{1}{\Omega_a \rho_a^2}\sum_b m_b v_{\mathrm{sig},ab} B_{ab}^i \hat{r}_{ab}^j \nabla_a^j W_{ab}\left(h_a\right)$$

- Density (discretised):

$$\rho_a = \sum m_b W_b; \qquad h_a = 1.2\left(\frac{m_a}{\rho_a}\right)^{\frac{1}{3}}$$

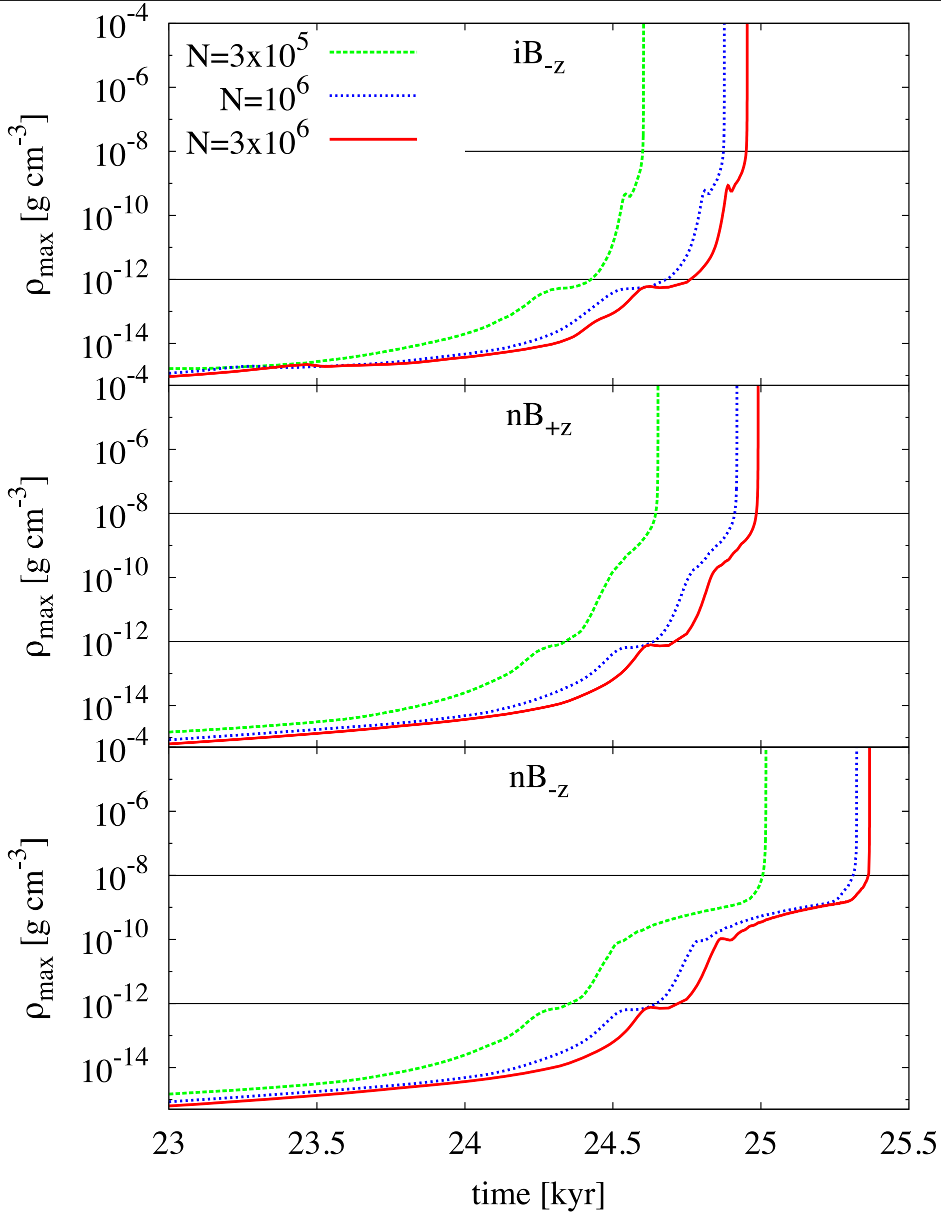
Orszag-Tang vortex: Resolution

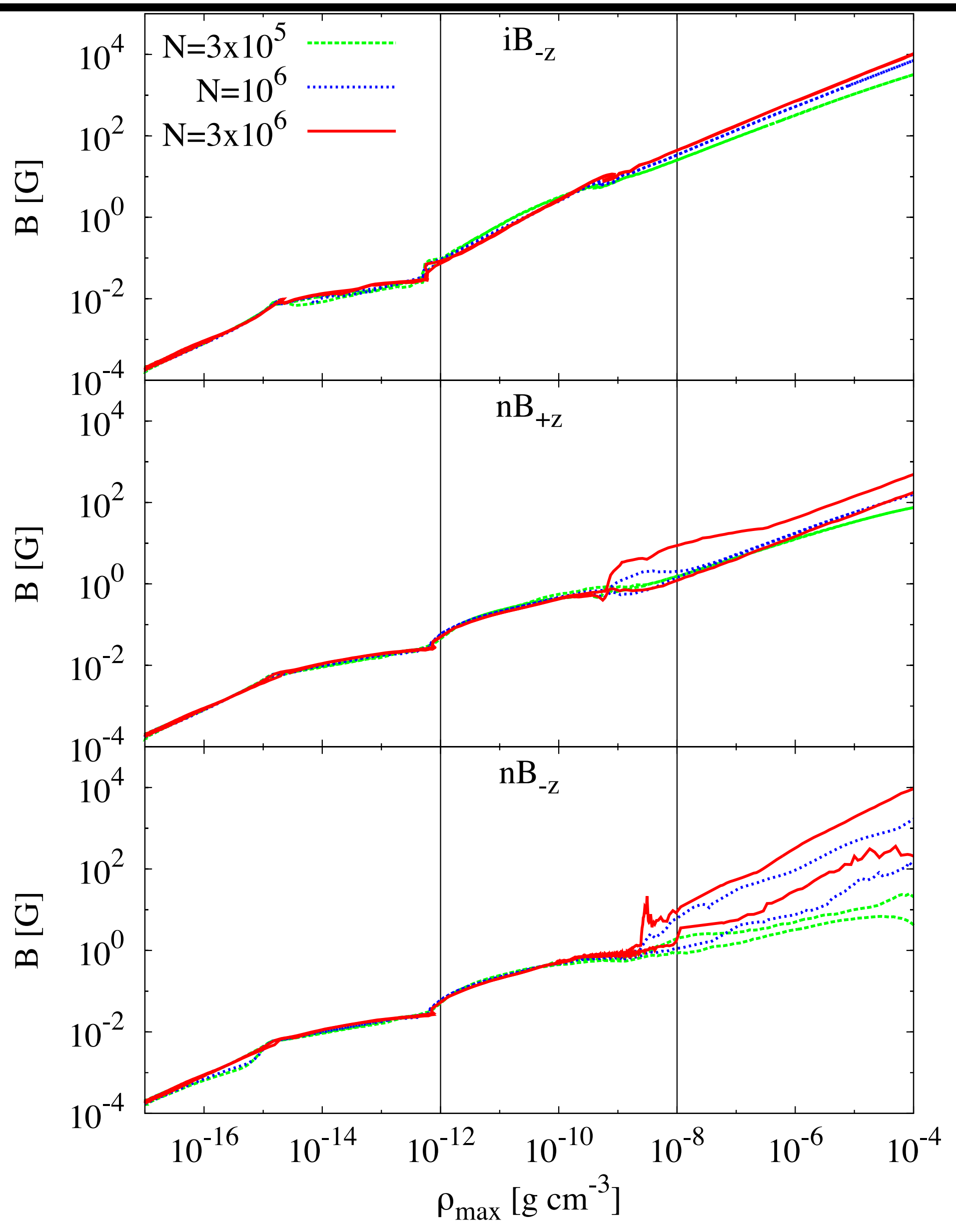
- Main features are visible at all resolutions, but better defined for higher resolution

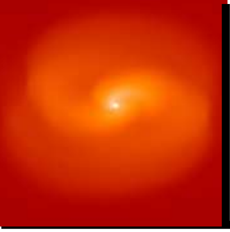


Price, Wurster + (2018)

Global Evolution: Resolution

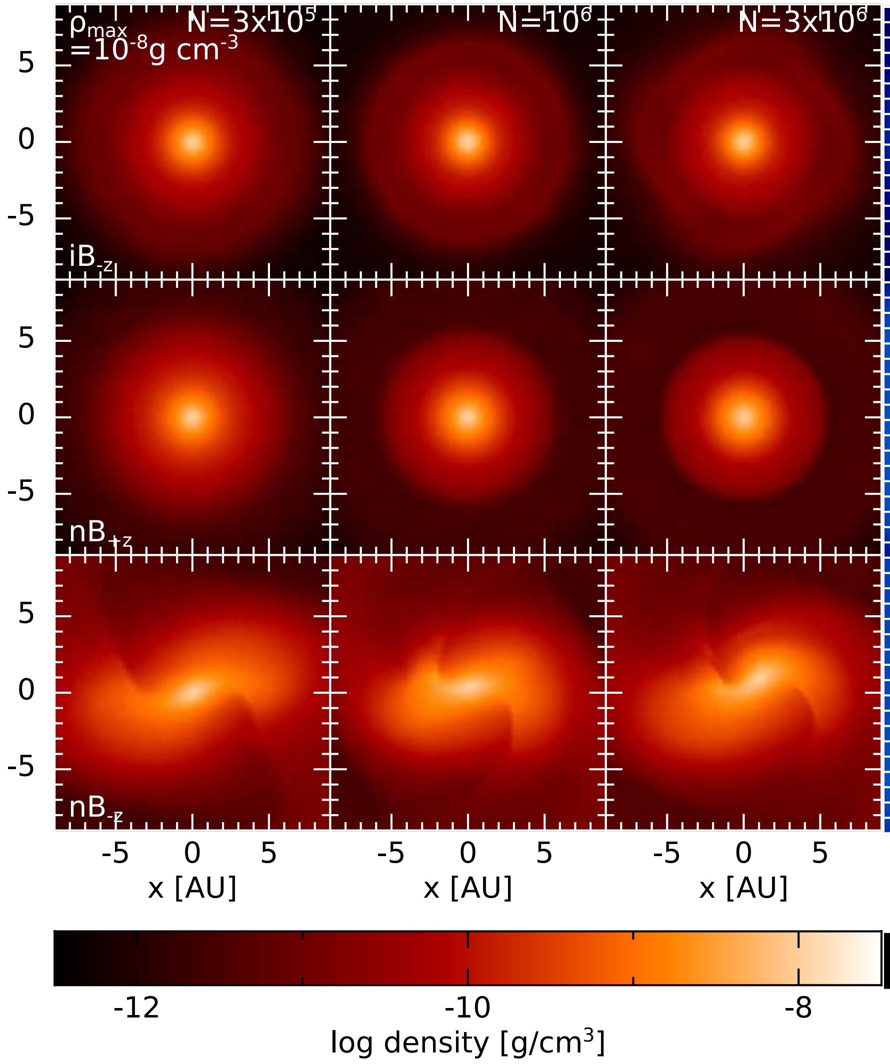




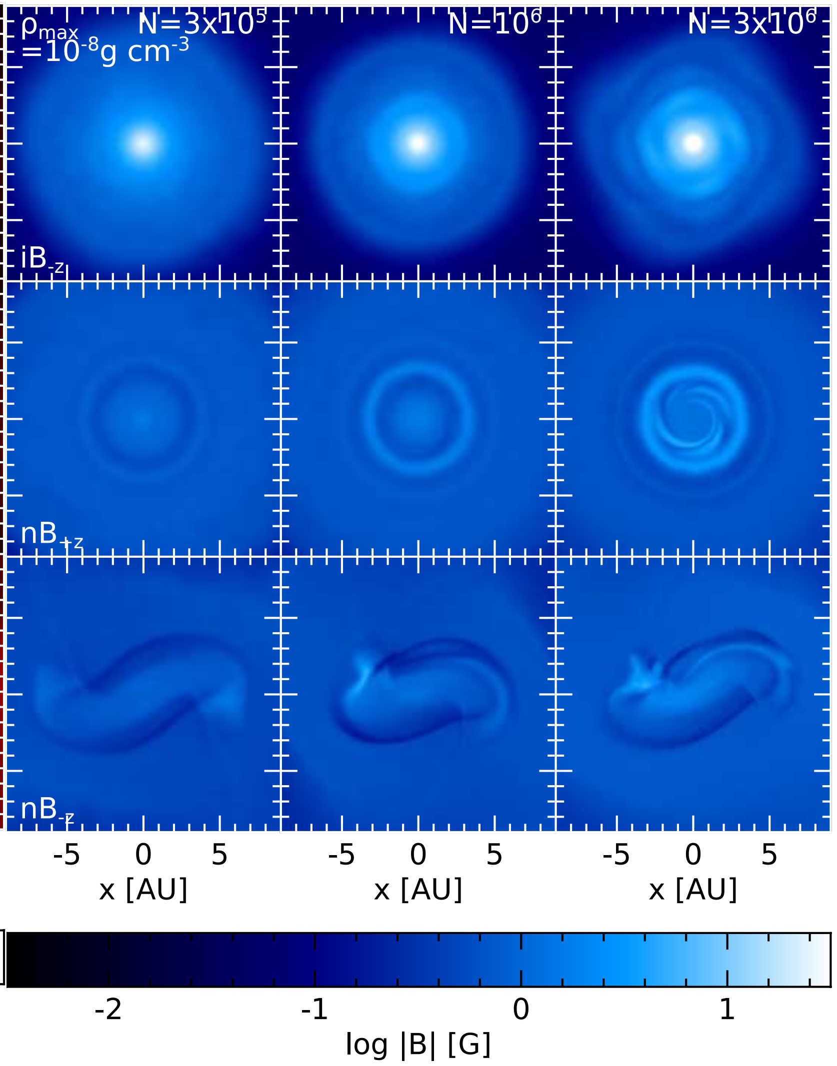


First hydrostatic core: end stage

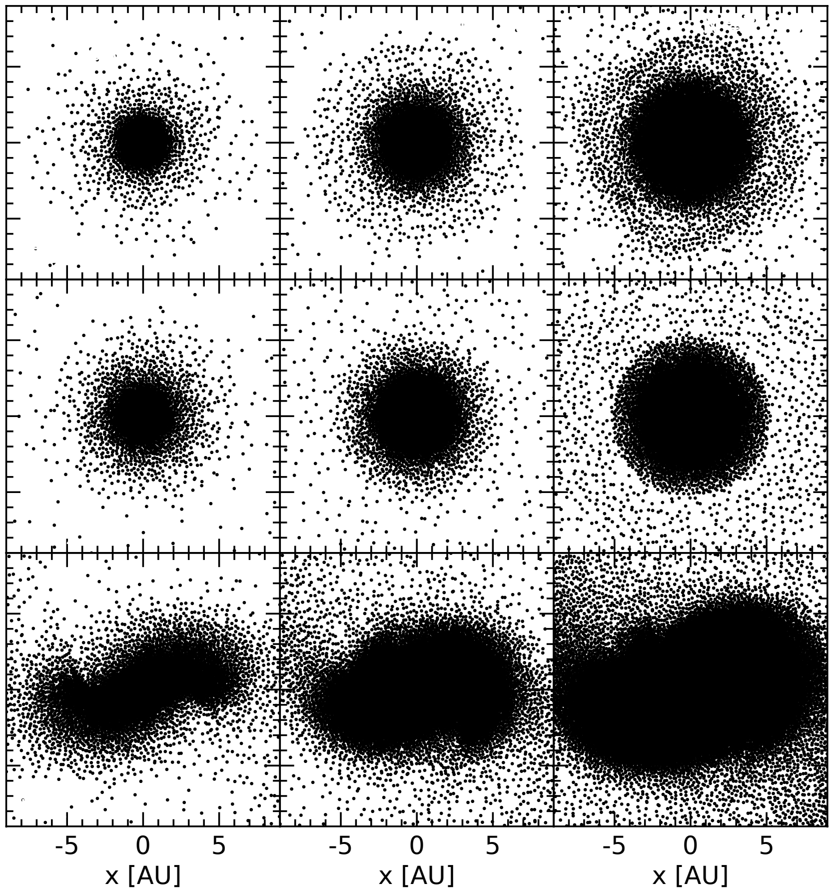
- Gas Density

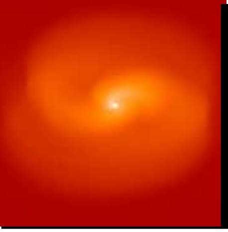


- Magnetic field strength



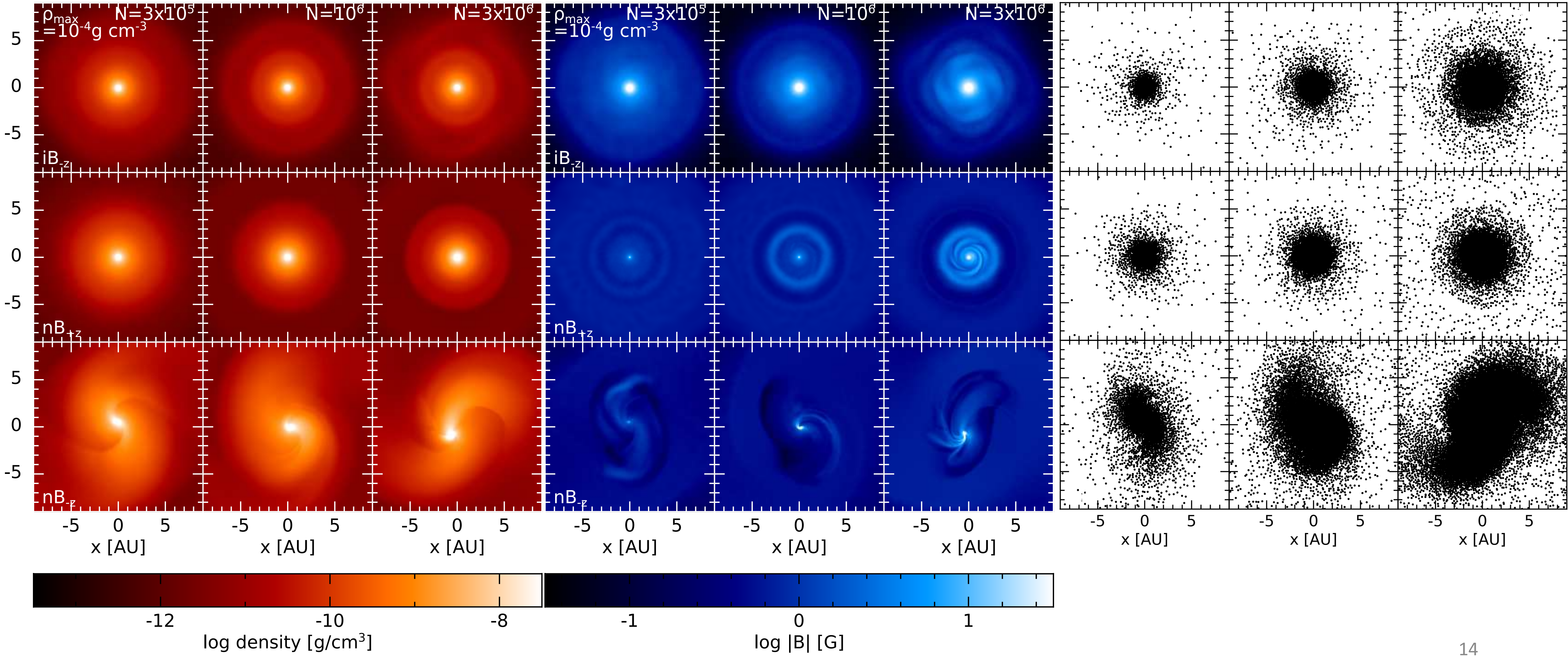
- Particles



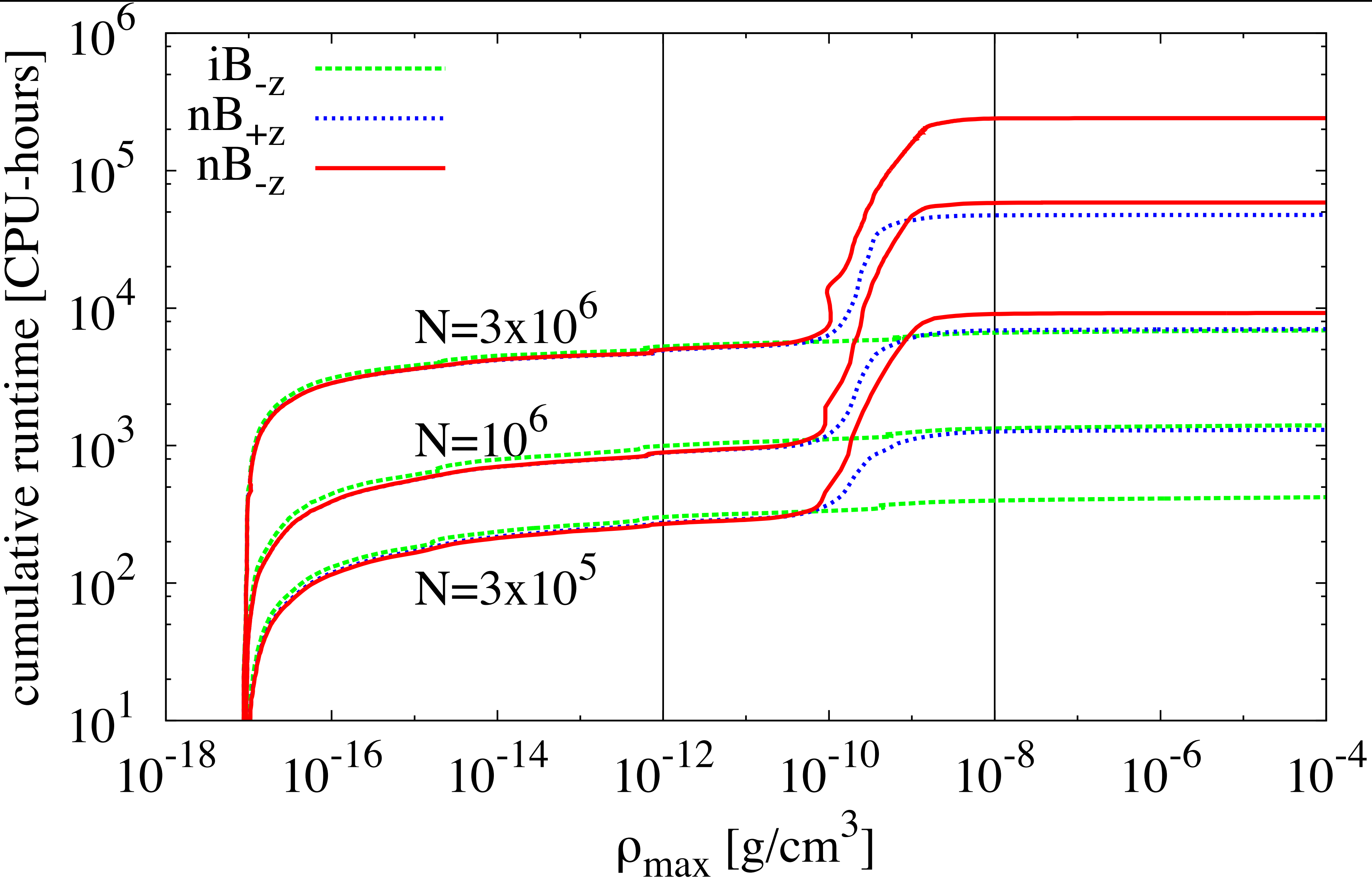


Stellar core: Resolution

- Gas Density
- Magnetic field strength
- Particles



Computational expense



Conclusions

- Collapse time and magnetic field strengths are governed by physical processes
  - Evolutions diverge during first hydrostatic core phase
- Decreasing resolution permits faster collapses; relative collapse time is is preserved
- During first hydrostatic core:
  - Density structures are qualitatively similar
  - Magnetic field structure resolution-dependent, especially nB_{+z}
- At stellar birth:
  - Density and magnetic field structure are resolution-dependent
- Performing very high resolution simulations can quickly become prohibitively expensive

Conference proceedings: https://arxiv.org/abs/1906.12276