The effect of partial ionisation in star formation

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1st Phantom Users Workshop
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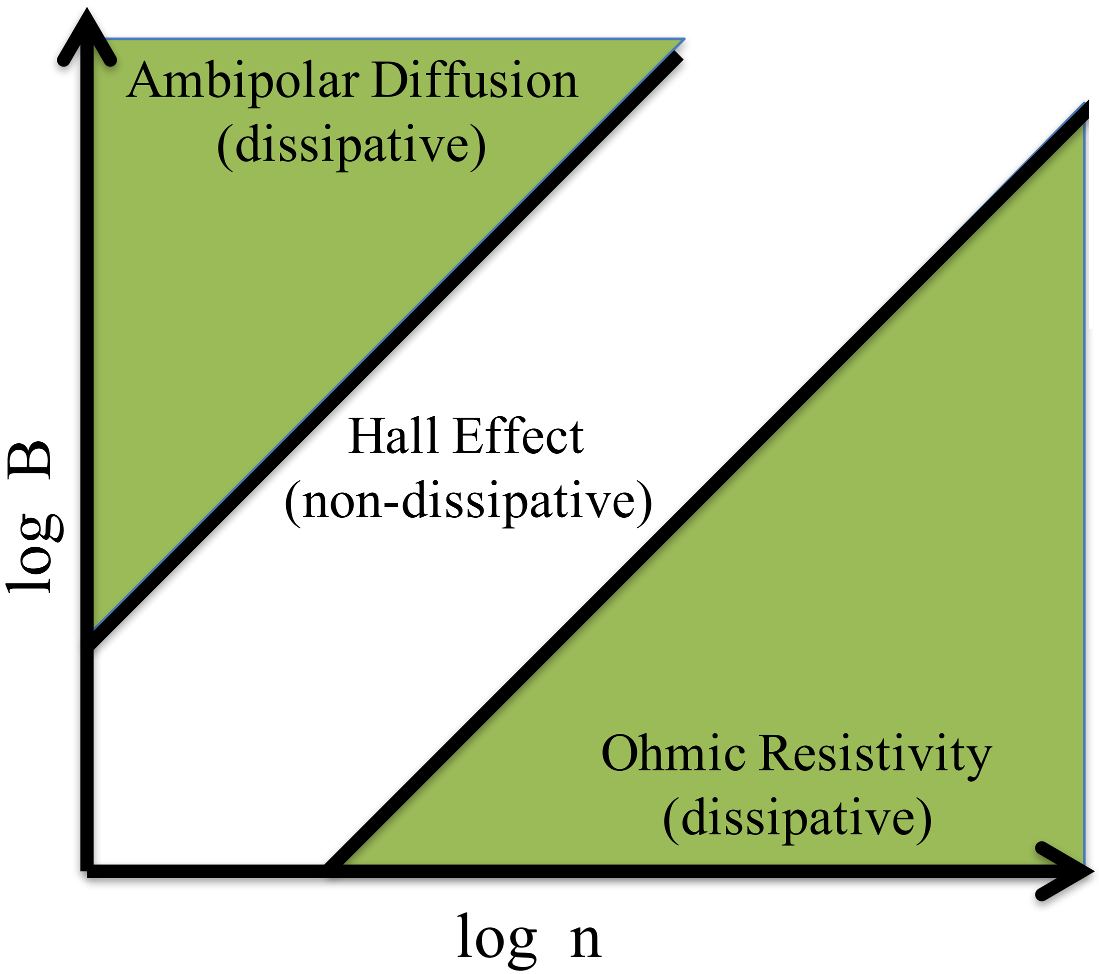
Non-ideal magnetohydrodynamics



Adapted from Wardle (2007)

$$\left.\frac{\mathrm{d}\boldsymbol{B}}{\mathrm{d}t}\right|_{\mathrm{OR}} = -\boldsymbol{\nabla} \times \eta_{\mathrm{OR}} \left(\boldsymbol{\nabla} \times \boldsymbol{B} \right),$$

$$\left.\frac{\mathrm{d}\boldsymbol{B}}{\mathrm{d}t}\right|_{\mathrm{HE}} = -\boldsymbol{\nabla} \times \eta_{\mathrm{HE}} \left[\left(\boldsymbol{\nabla} \times \boldsymbol{B} \right) \times \hat{\boldsymbol{B}} \right],$$

$$\left.\frac{\mathrm{d}\boldsymbol{B}}{\mathrm{d}t}\right|_{\mathrm{AD}} = \boldsymbol{\nabla} \times \eta_{\mathrm{AD}} \left\{ \left[\left(\boldsymbol{\nabla} \times \boldsymbol{B} \right) \times \hat{\boldsymbol{B}} \right] \times \hat{\boldsymbol{B}} \right\}.$$

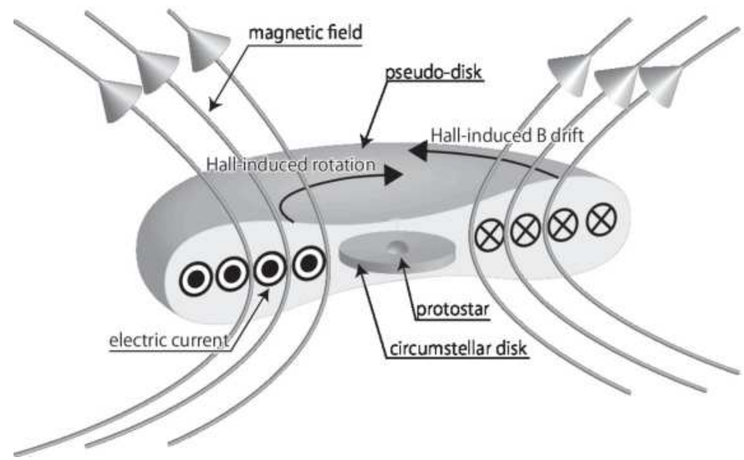
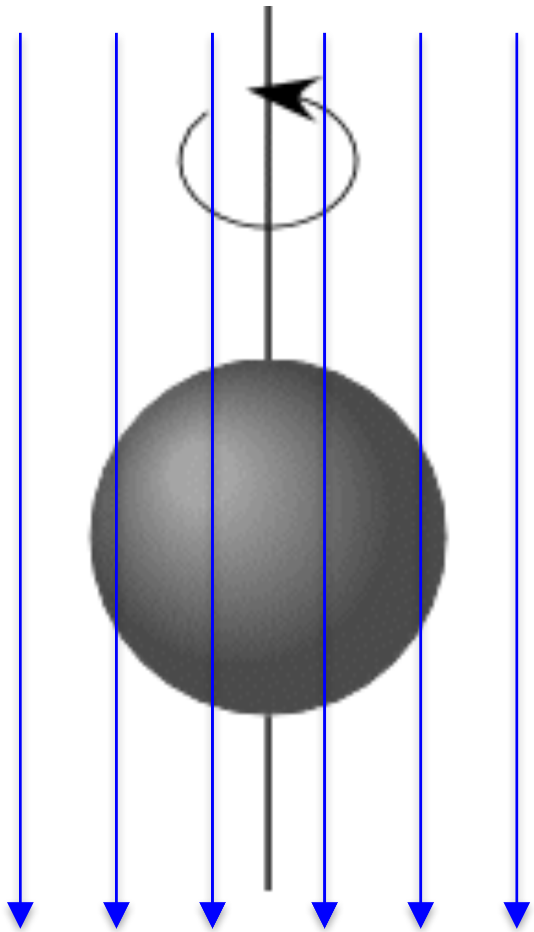


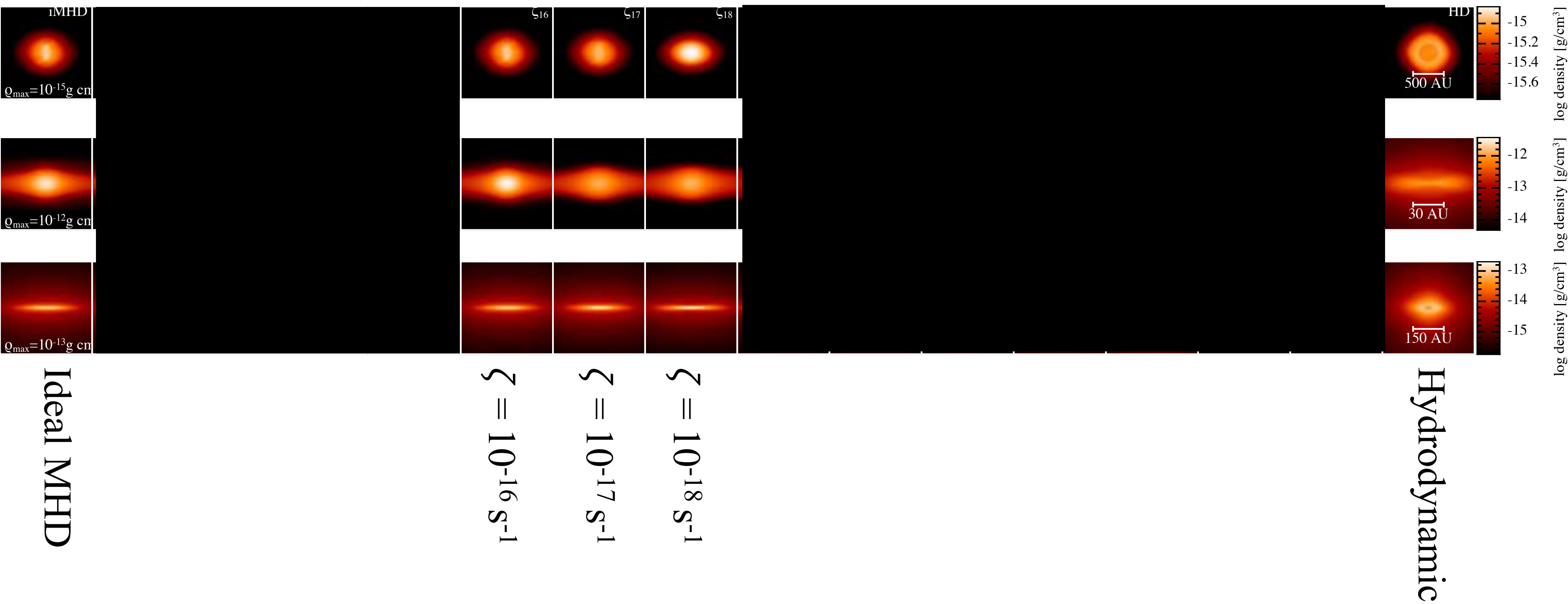
Image credit: Tsukamoto et al (2017);
see also: Braiding & Wardle (2012a,b)

Initial Conditions

- Initial conditions:
  - 1 M_{sun} of gas
  - Uniform density
  - Strong magnetic fields ($\mu_0 = 5$)
  - $\boldsymbol{\Omega}.\boldsymbol{B} < 0$ (primary suite)
  - $\boldsymbol{\Omega}.\boldsymbol{B} > 0$ (secondary suite)
- Processes included:
  - Non-ideal MHD
    - Ohmic resistivity
    - Hall Effect
    - Ambipolar diffusion

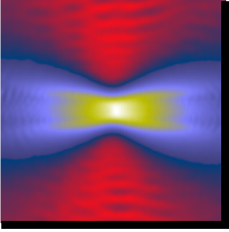


Extreme Regimes: Ionisation Algorithms

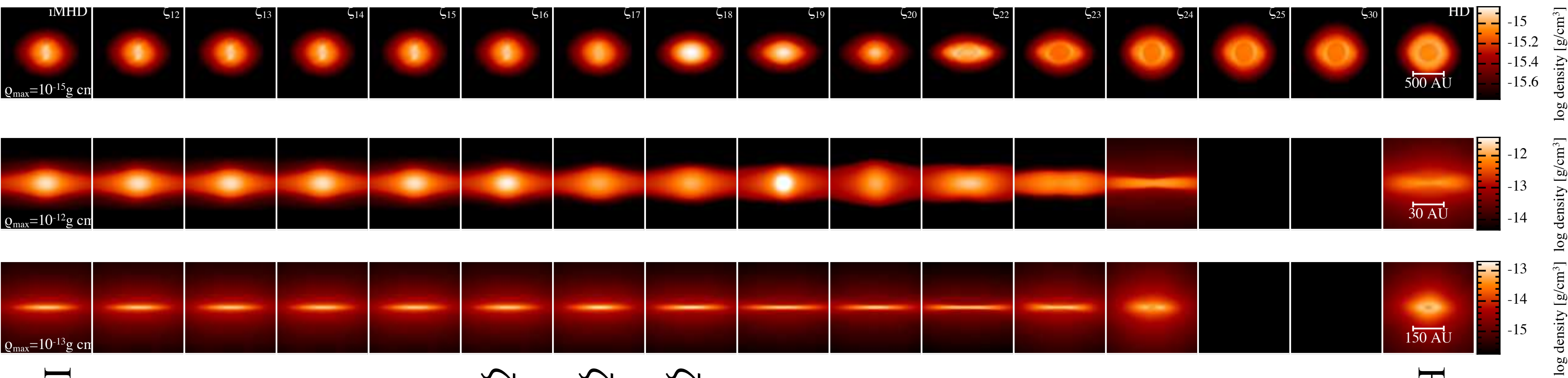


- Images are log(density).
- Rows are $\rho = 10^{-15}$ g cm^{-3}, $\rho = 10^{-13}$ g cm^{-3}, $\rho = 10^{-12}$ g cm^{-3}

Wurster, Bate & Price (2018b)



Extreme Regimes: Ionisation Algorithms



Ideal MHD

$\zeta = 10^{-16}$ s^{-1}

$\zeta = 10^{-17}$ s^{-1}

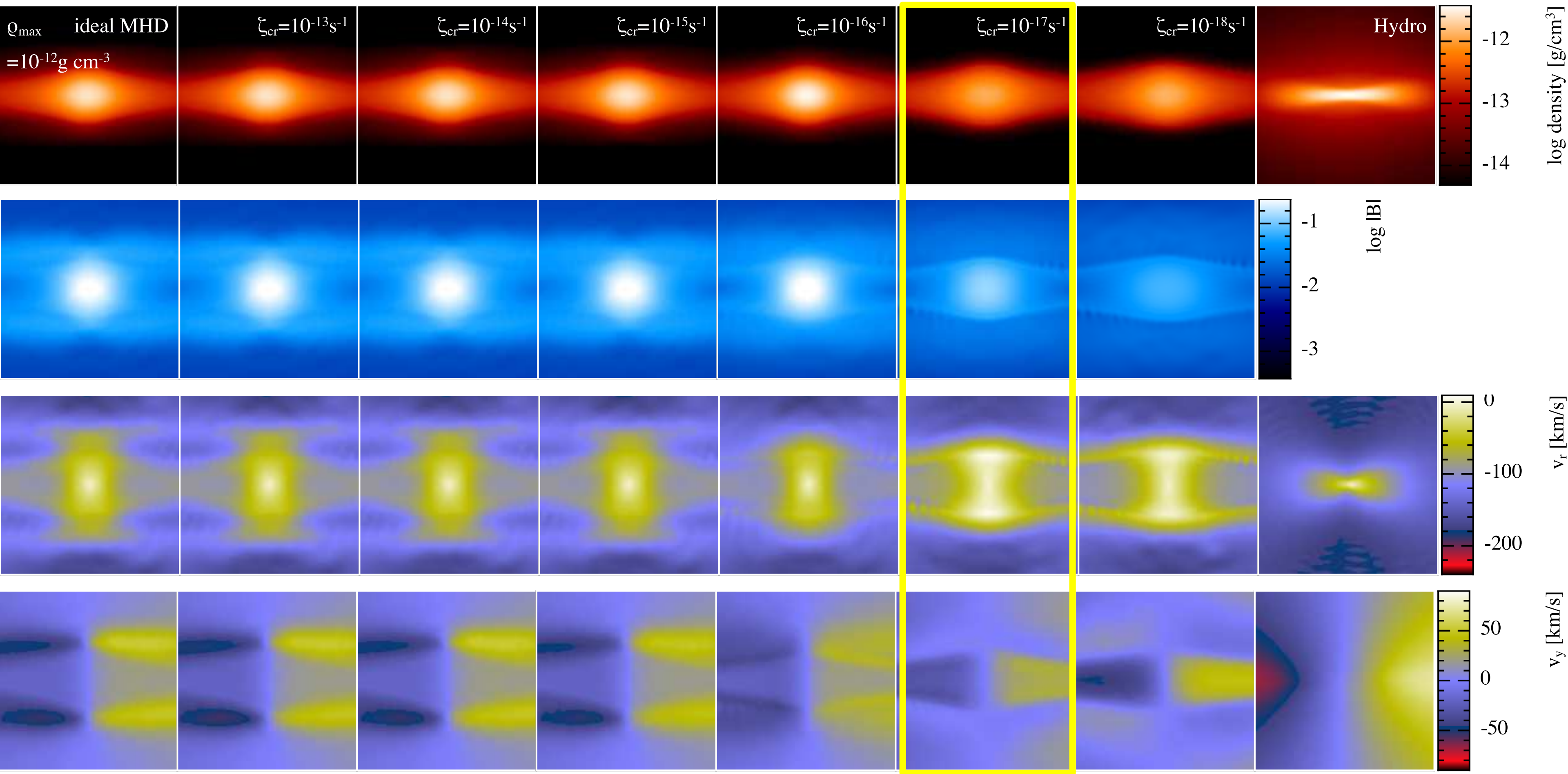
$\zeta = 10^{-18}$ s^{-1}

Hydrodynamic

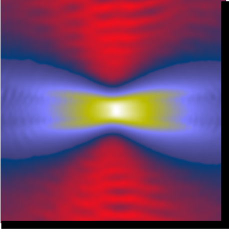
- Images are log(density).
- Rows are $\rho = 10^{-15}$ g cm^{-3}, $\rho = 10^{-13}$ g cm^{-3}, $\rho = 10^{-12}$ g cm^{-3}

Wurster, Bate & Price (2018b)

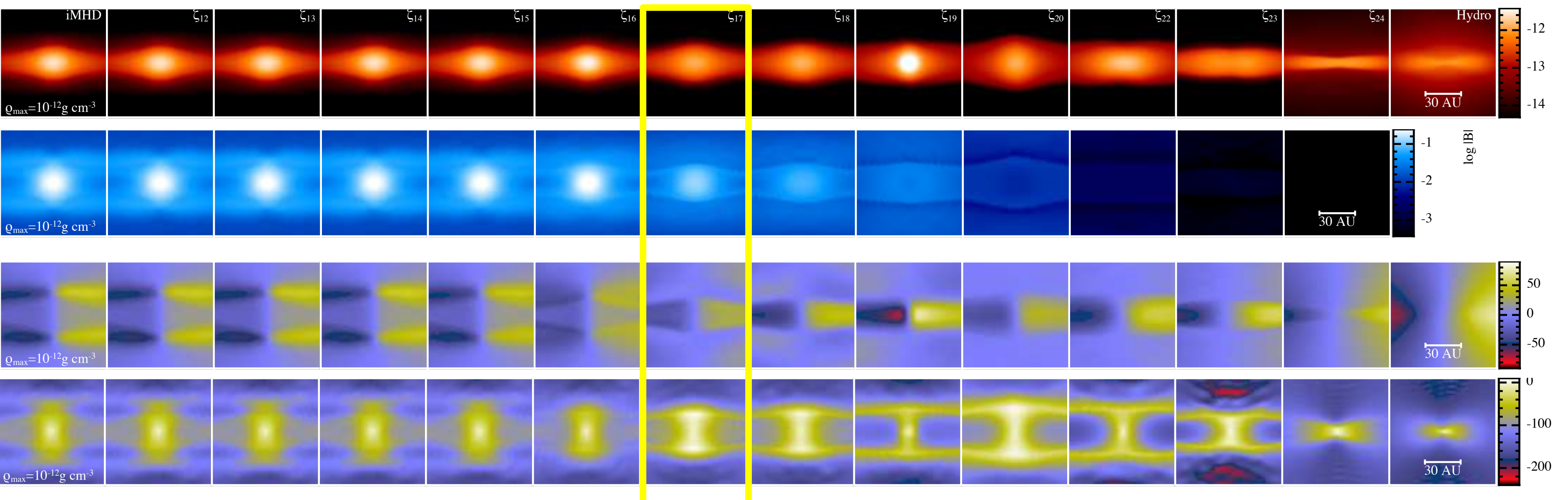
Extreme Regimes: Ionisation Algorithms



Wurster, Bate & Price (2018b)

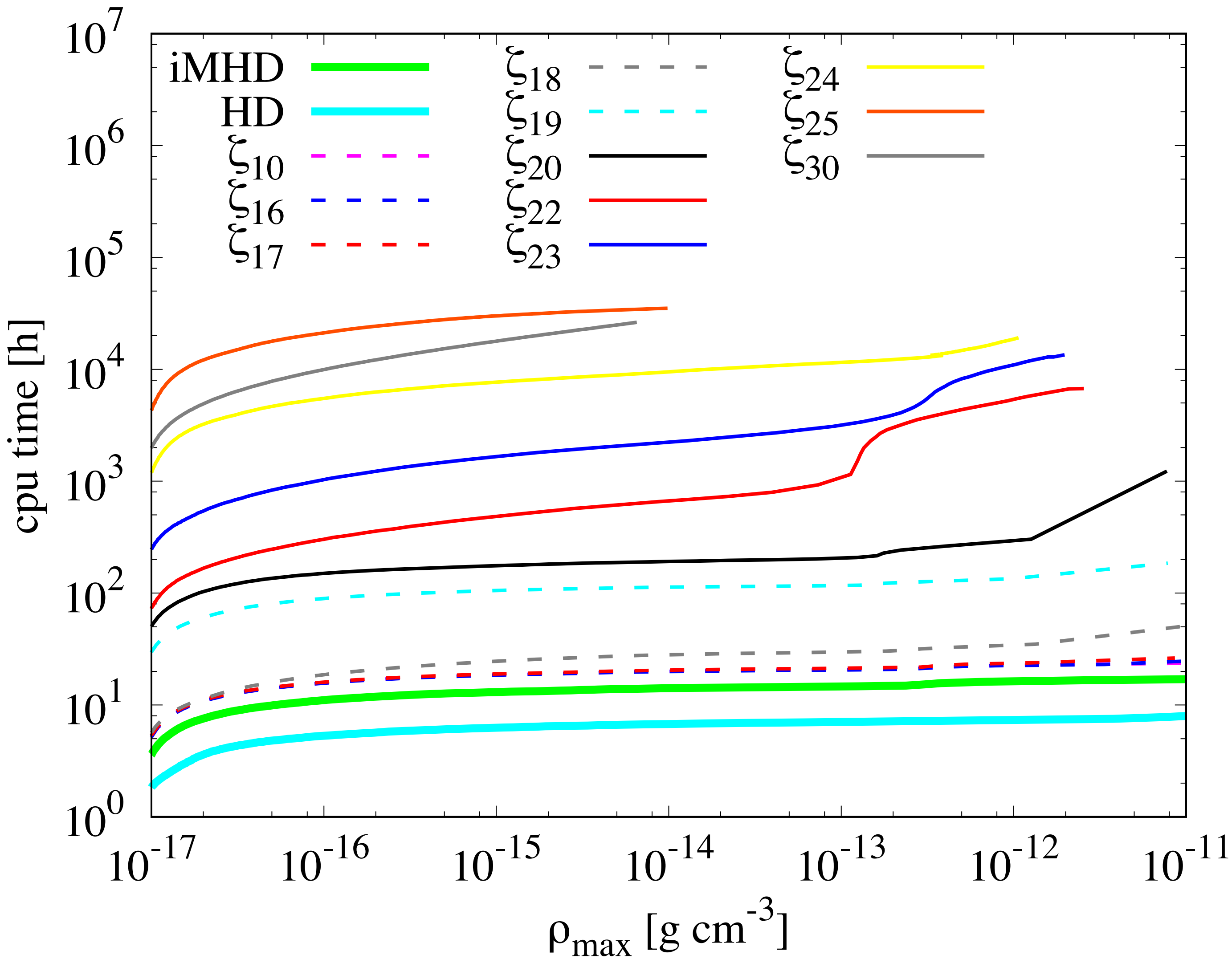


Extreme Regimes: Ionisation Algorithms

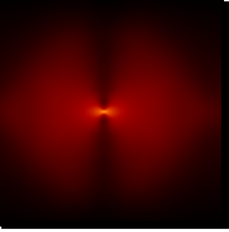


Wurster, Bate & Price (2018b)

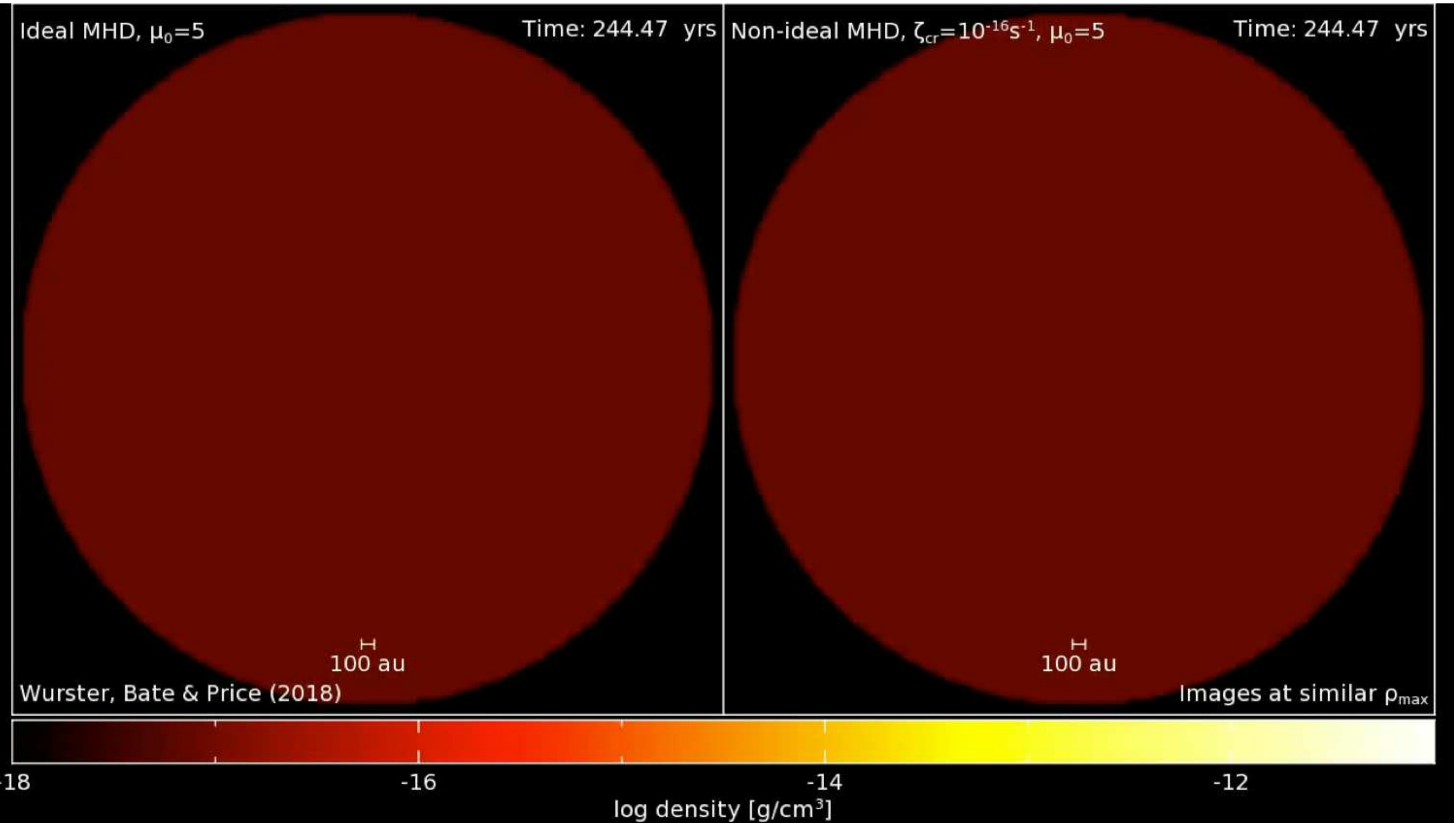
Extreme Regimes: Ionisation Algorithms



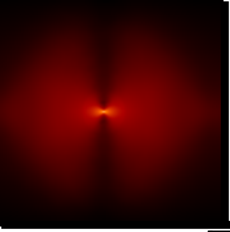
Wurster, Bate & Price (2018b)



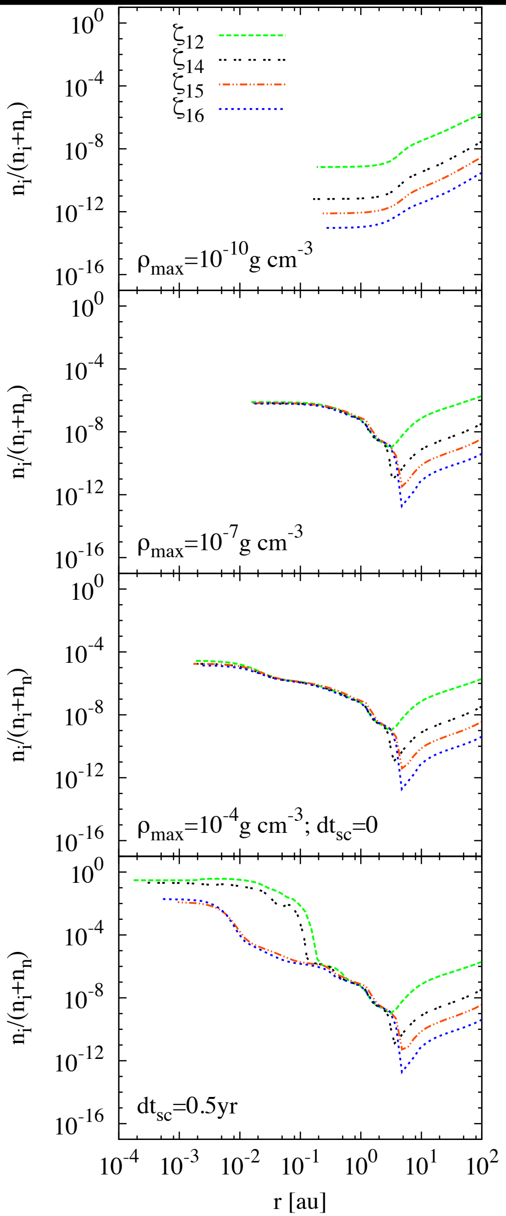
Collapse to stellar densities: Evolution of the density

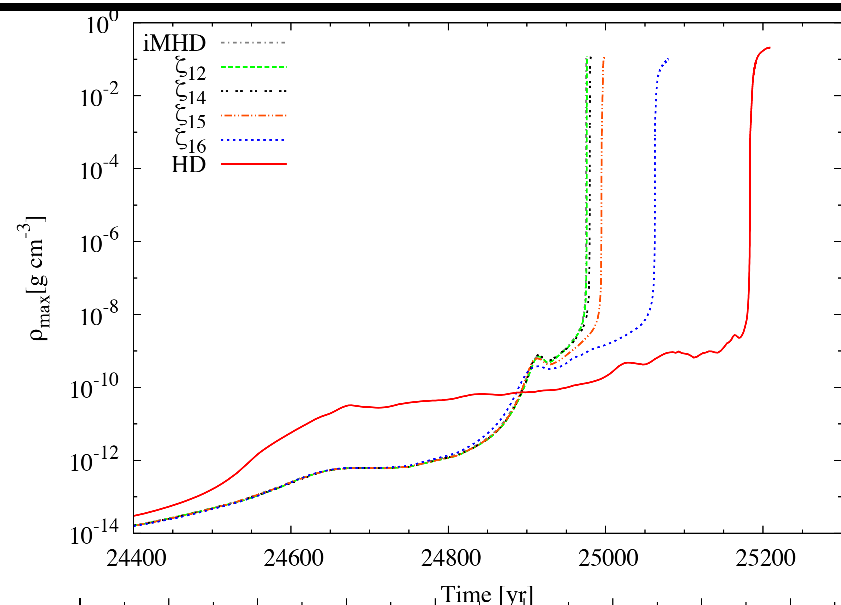


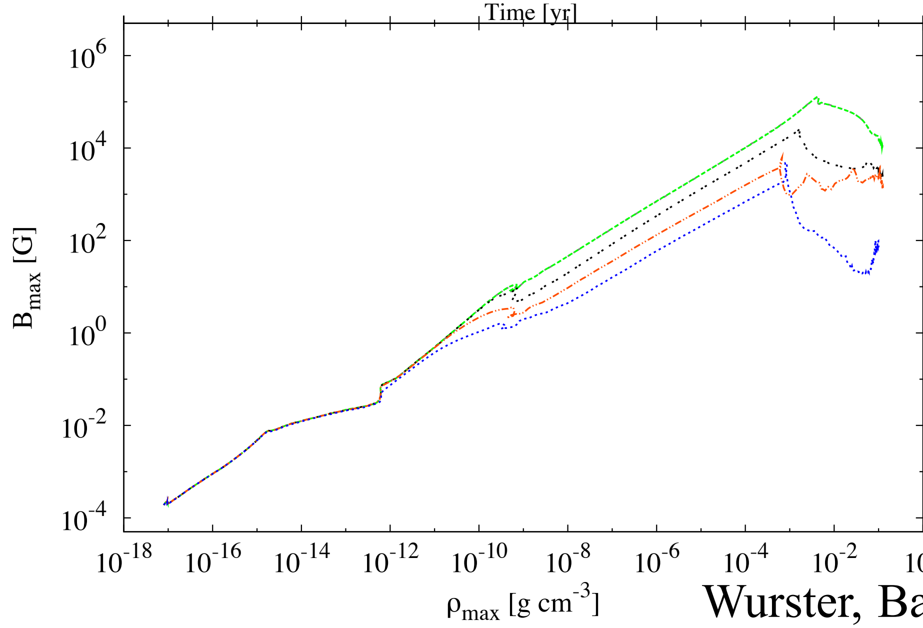
Video available at https://www.youtube.com/watch?v=CgErHuWdcPw&t=3s



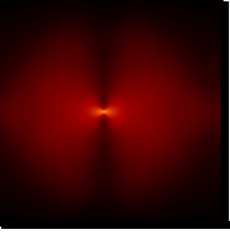
Collapse to stellar densities



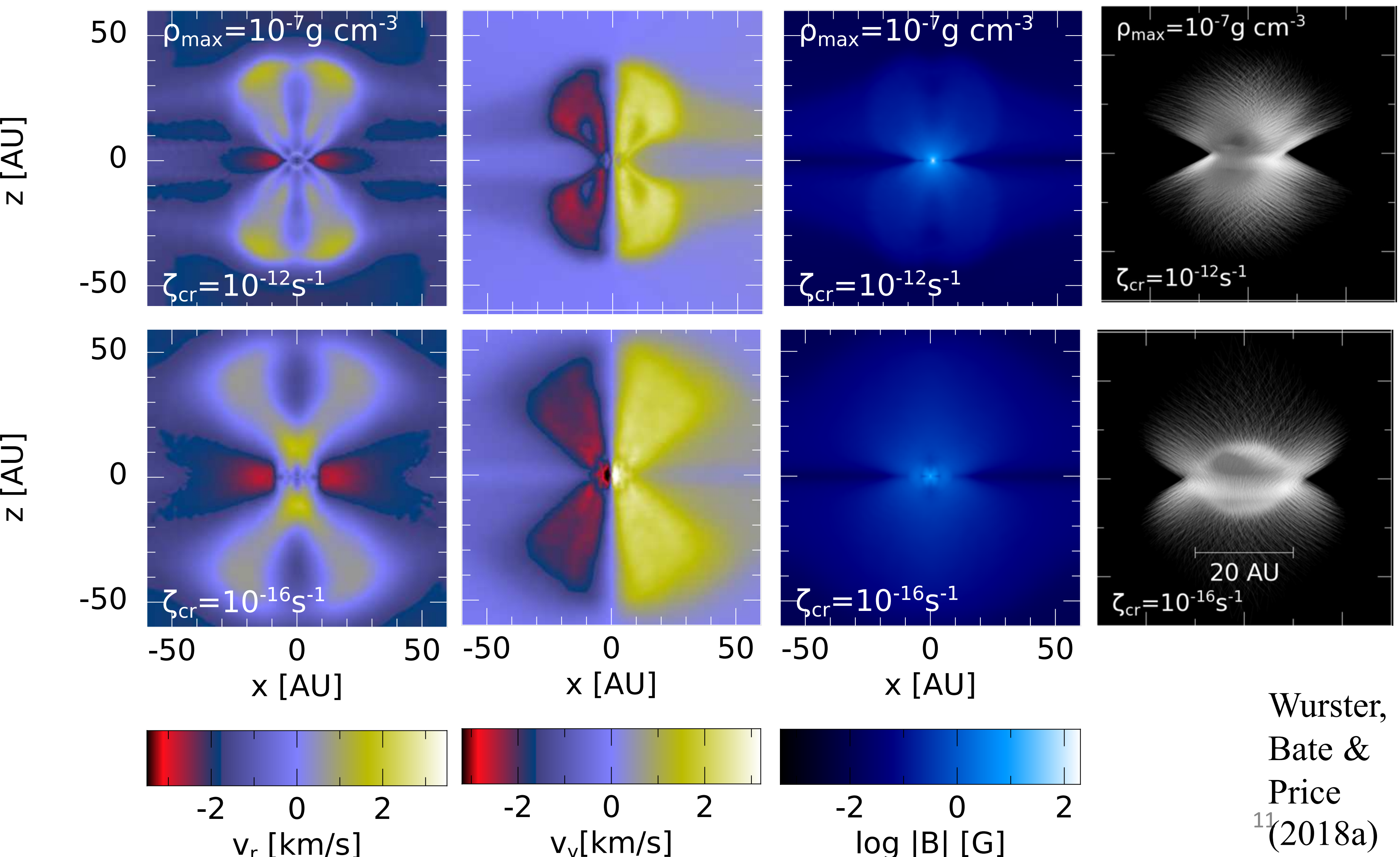




Wurster, Bate & Price (2018a)

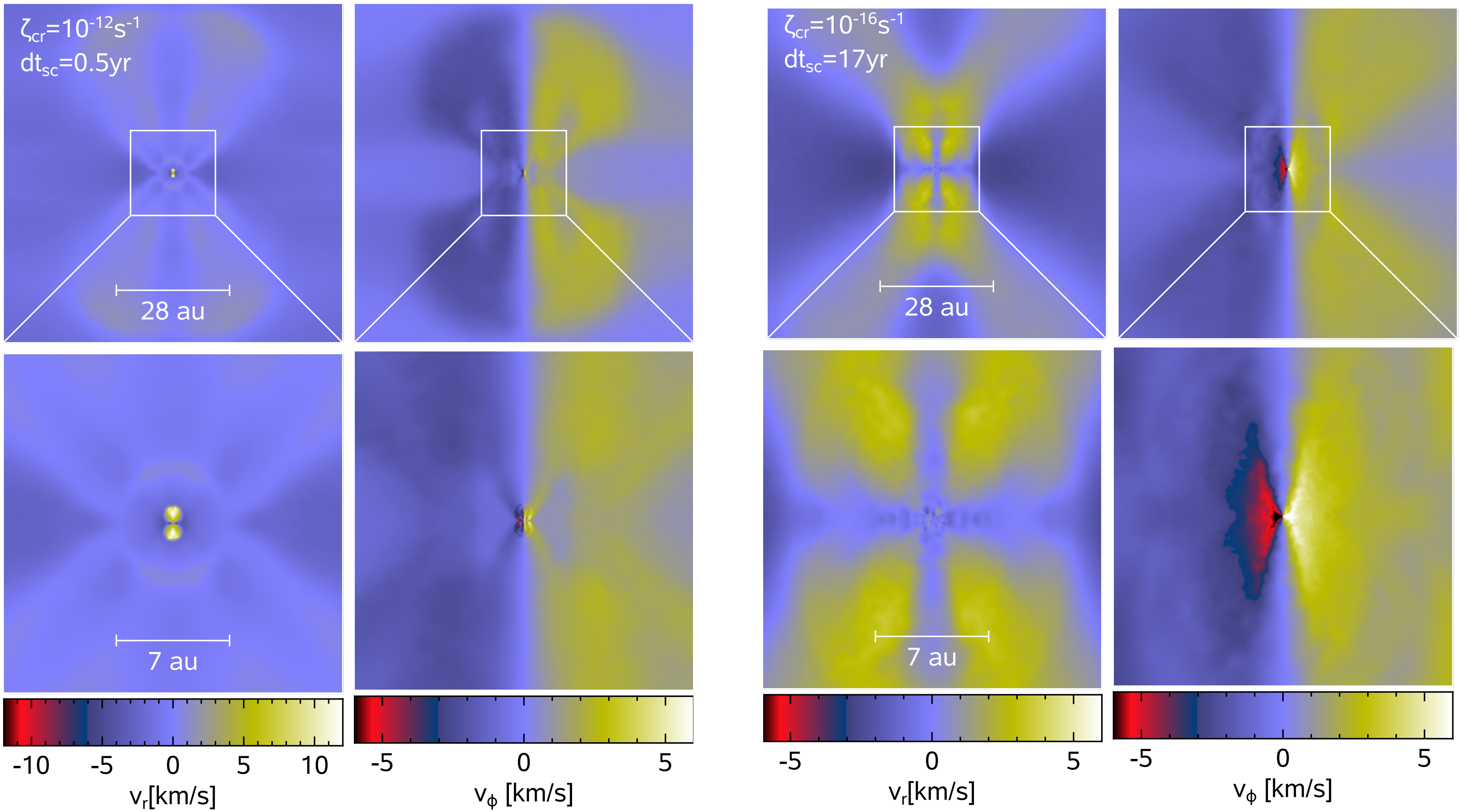


Collapse to stellar densities: First hydrostatic core



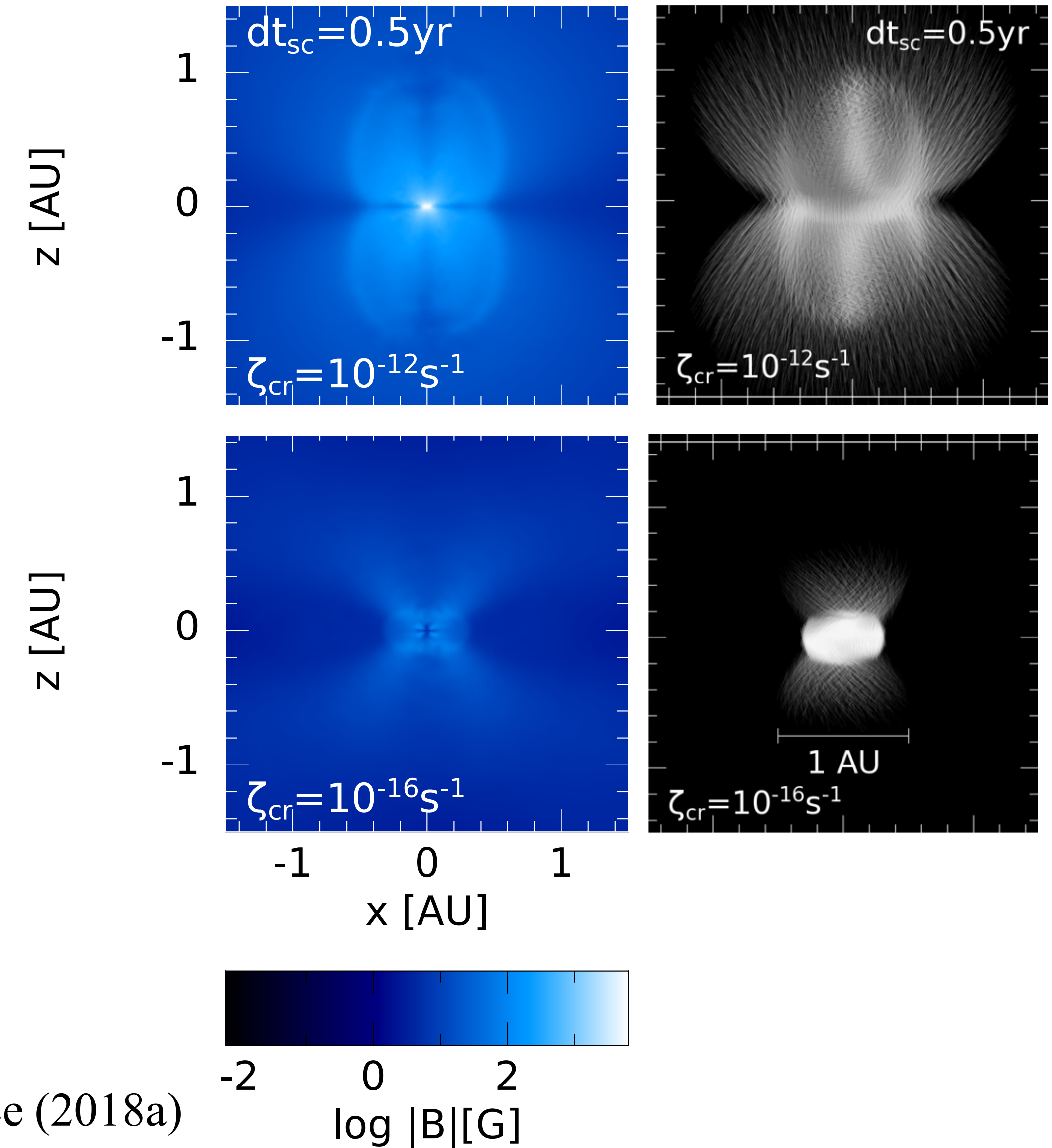
Wurster, Bate & Price (2018a)

Collapse to stellar densities: Stellar core



Wurster, Bate & Price (2018a)

Collapse to stellar densities: Stellar core



Wurster, Bate & Price (2018a)

Conclusions

- Modelled the collapse of a molecular cloud core through the first core to stellar densities; included Ohmic resistivity, ambipolar diffusion, the Hall effect
- The coefficient of the Hall effect is similar to the ambipolar diffusion in the medium surrounding the core

- High cosmic ray ionisation rates can reproduce ideal MHD collapses
- Low cosmic ray ionisation rates can approximate hydrodynamicals collapses, but cannot reproduce them

- Decreasing the cosmic ionisation rate increases the lifetime of the first hydrostatic core
- The first and second hydrostatic cores become thermally ionised, but the accreting material is still only ionised by cosmic rays
- The second core outflow is suppressed at low cosmic ray ionisation rates

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