Magnetic fields
&
Star formation

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Collaborators: Matthew Bate & Daniel Price

Monash University (remote contribution)
February 25, 2020

University of St Andrews
University of Exeter
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DiRAC
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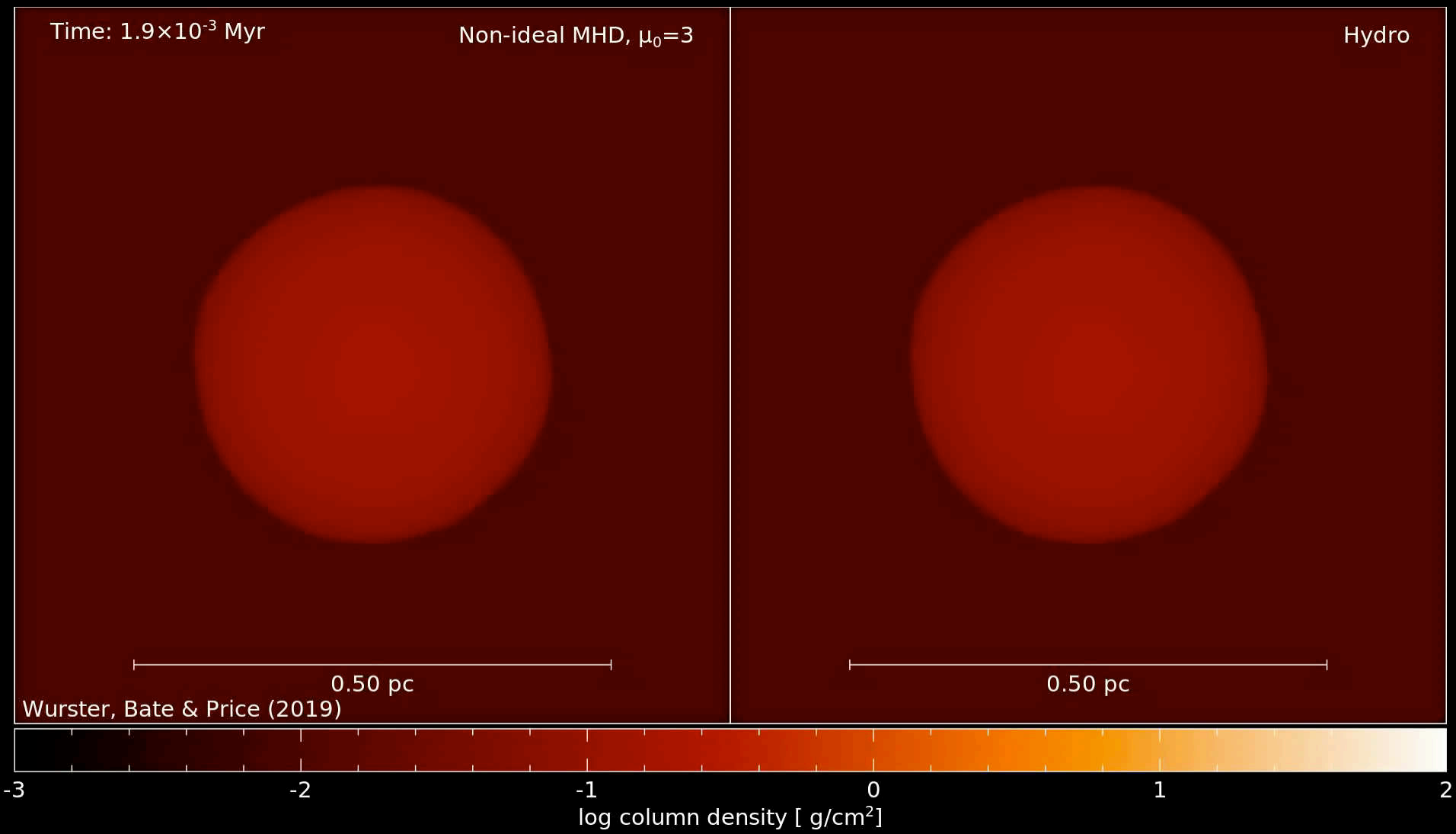
Star formation: From the beginning

Orion Molecular Cloud. (image credit: Drudis & Goldman via APOD)

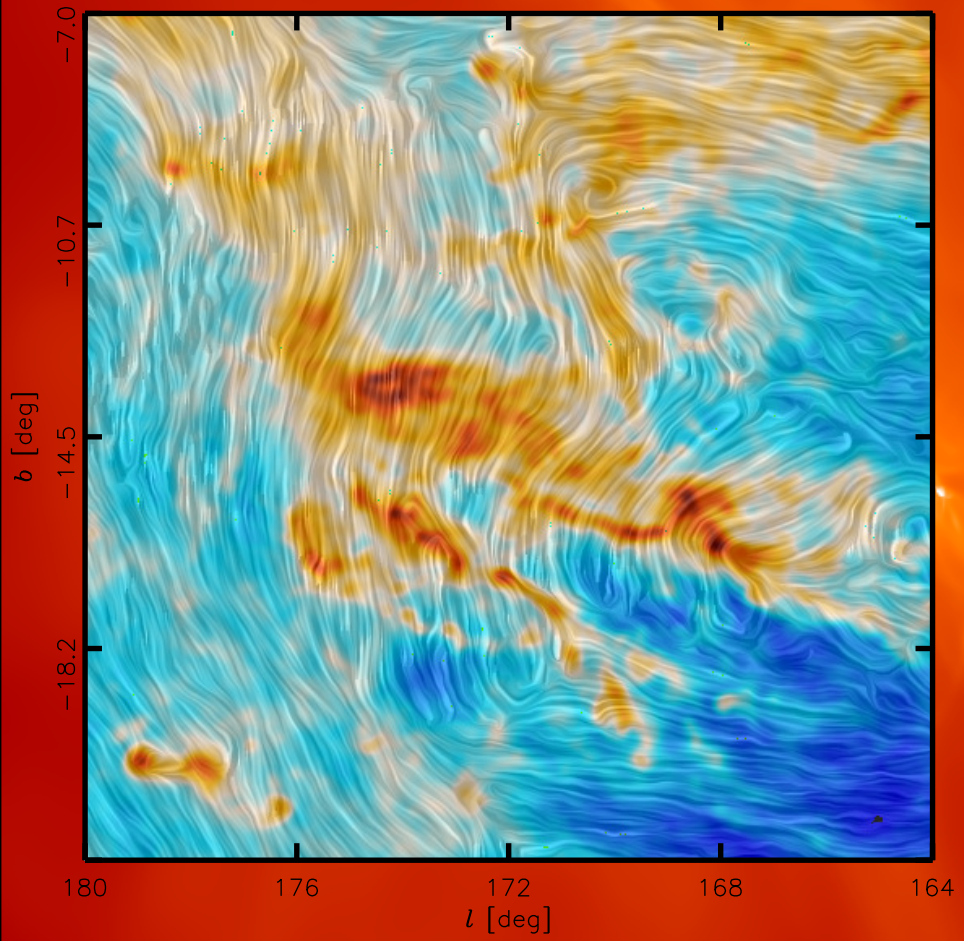
Star Cluster Formation: Non-ideal MHD vs Hydrodynamics

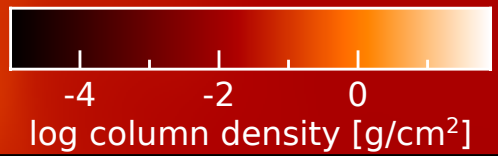


Wurster, Bate & Price (2019): https://www.youtube.com/watch?v=CLhmaOhj5RU

Magnetic fields in star forming regions

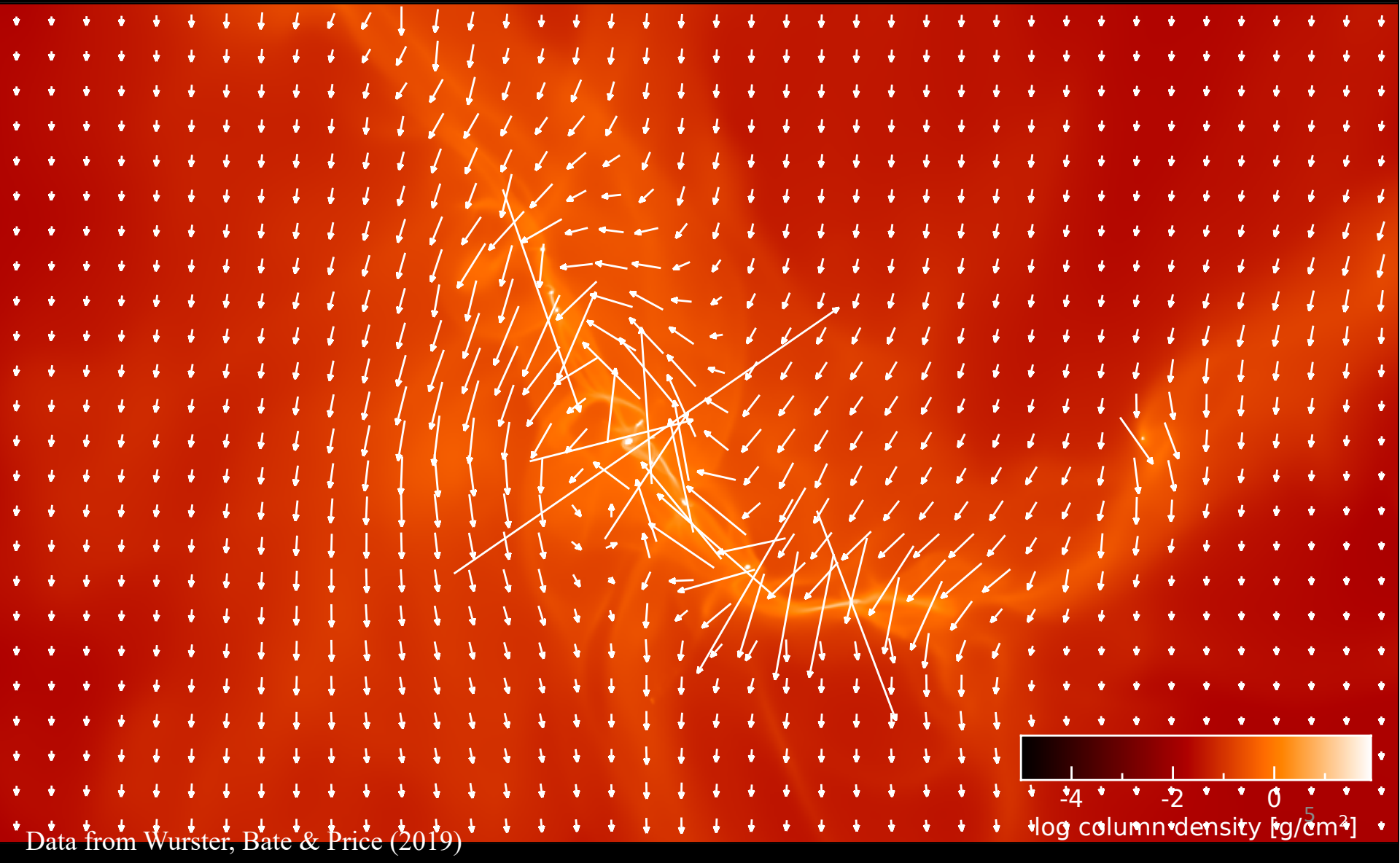
- Large-scale magnetic fields are perpendicular to dense structures
- Large-scale magnetic fields are parallel to low-density structures



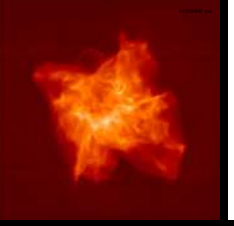


Planck Collaboration (2016)

Magnetic fields in star forming regions

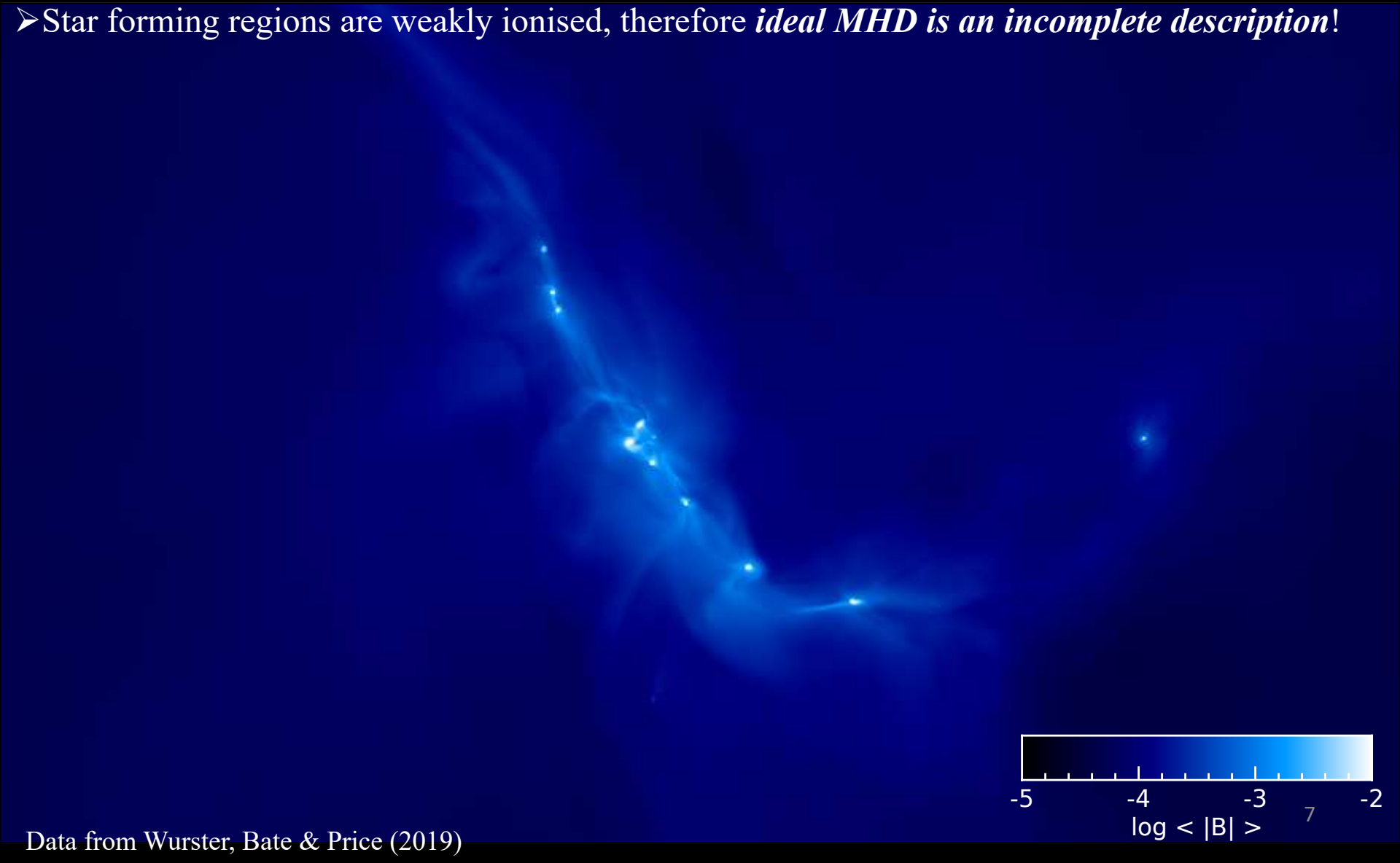


Data from Wurster, Bate & Price (2019)

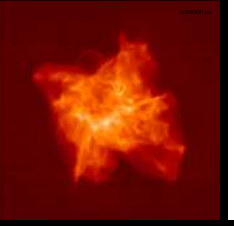


Magnetic fields in star forming regions

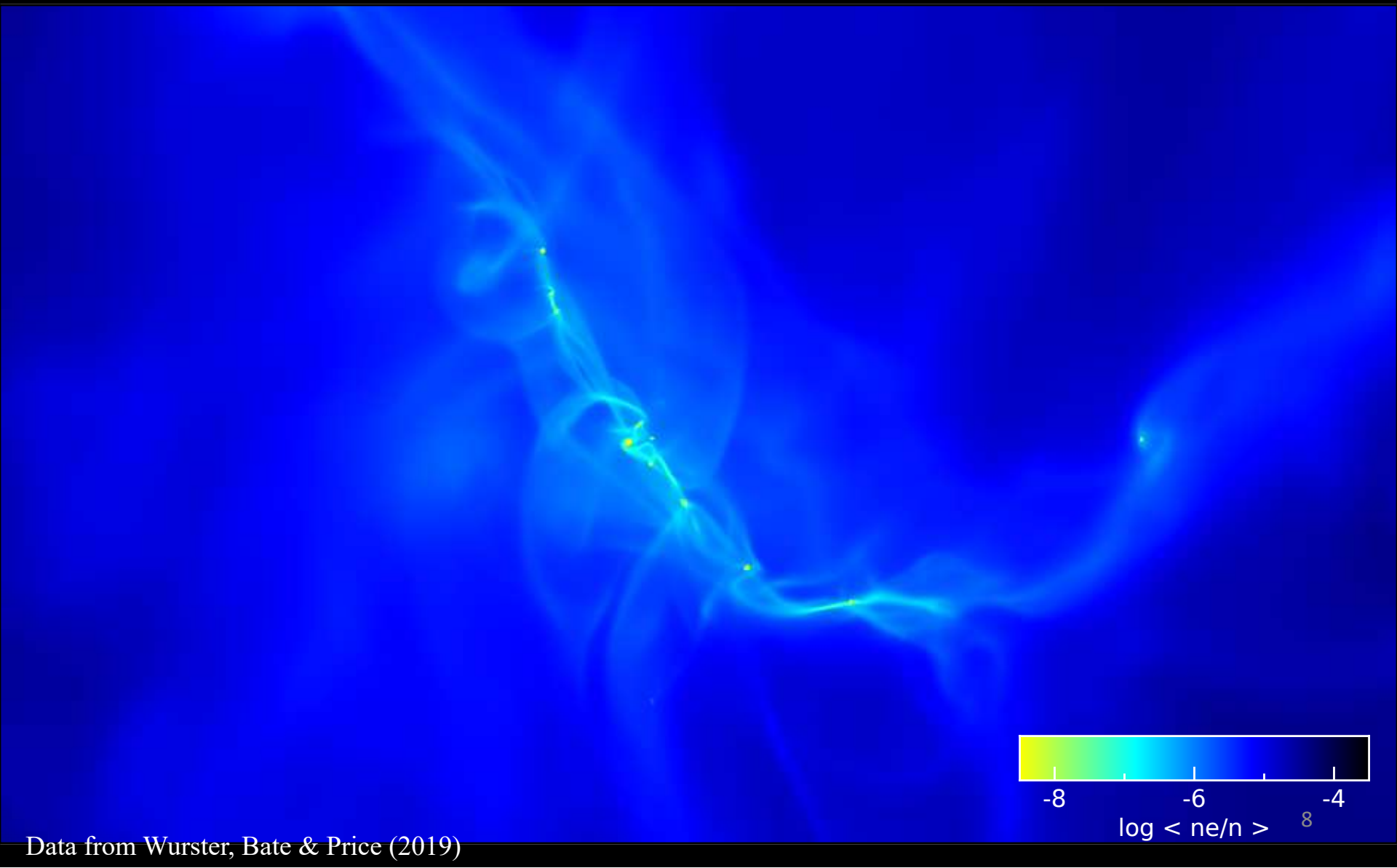
- Star forming regions are weakly ionised, therefore ***ideal MHD is an incomplete description***!



Data from Wurster, Bate & Price (2019)

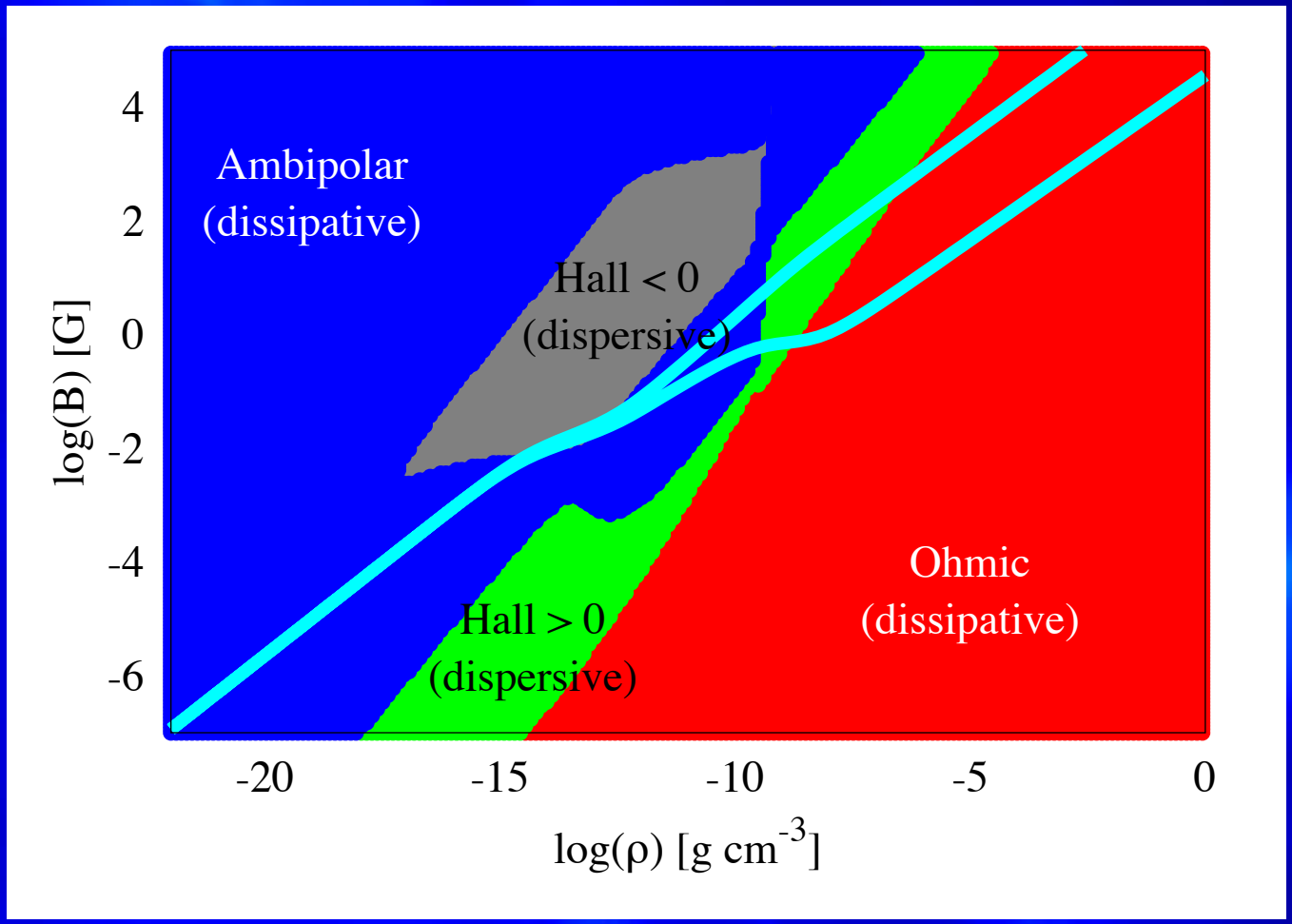


Magnetic fields in star forming regions: Ionisation fraction

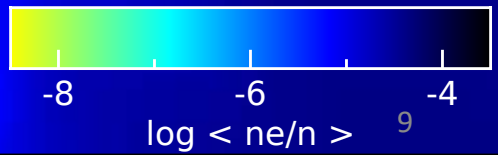


Data from Wurster, Bate & Price (2019)

Magnetic fields in star forming regions: Non-ideal Effects

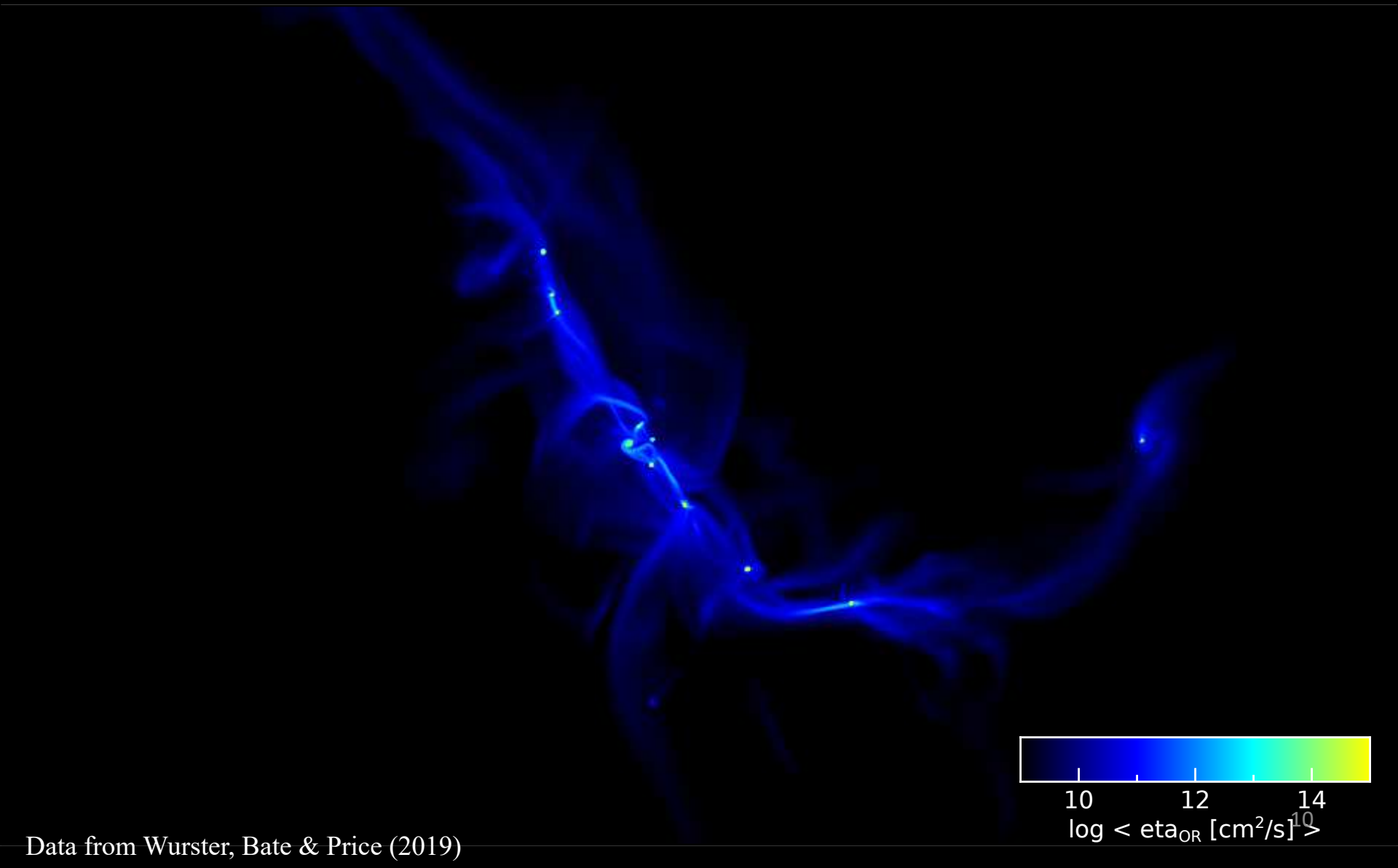


- Cyan lines is typical star forming tracks
- Values dependent on microphysics: Grain size, ionised species, cosmic ray ionisation rate



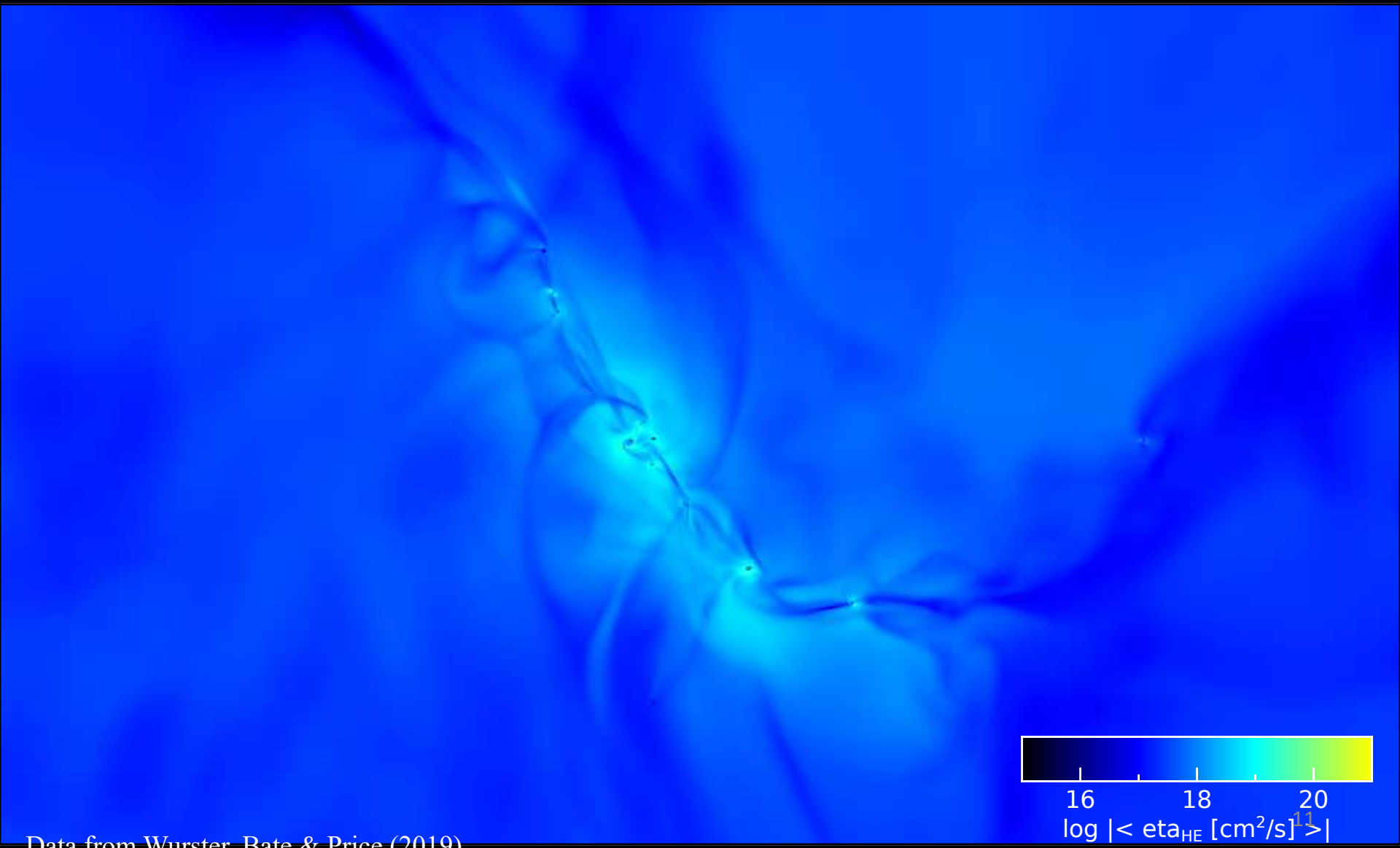
Adapted from Wardle (2007); constructed using NICIL v2.0 (Wurster, 2016)

Magnetic fields in star forming regions: Ohmic resistivity



Data from Wurster, Bate & Price (2019)

Magnetic fields in star forming regions: Hall effect

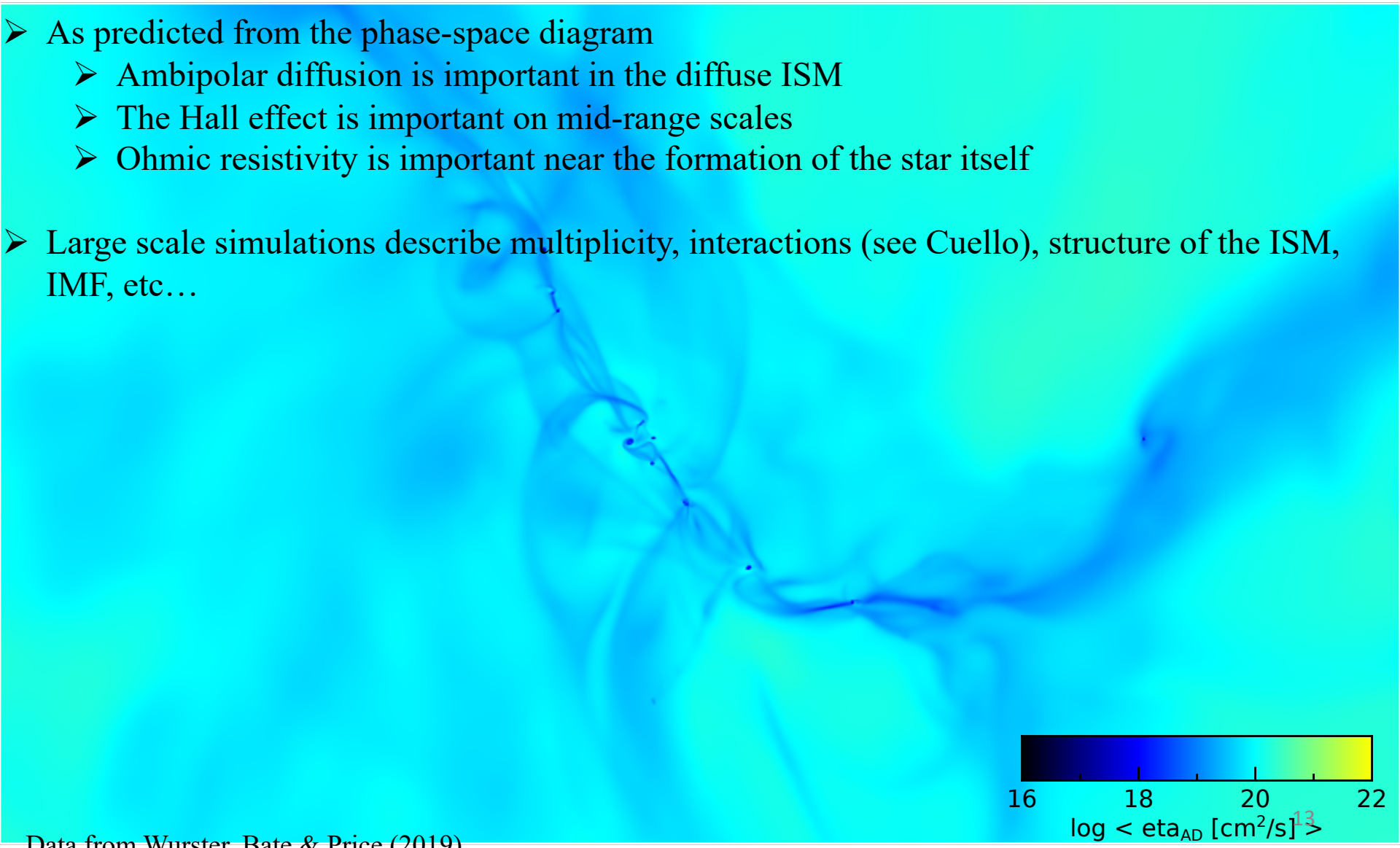


Data from Wurster, Bate & Price (2019)

Magnetic fields in star forming regions: Ambipolar diffusion

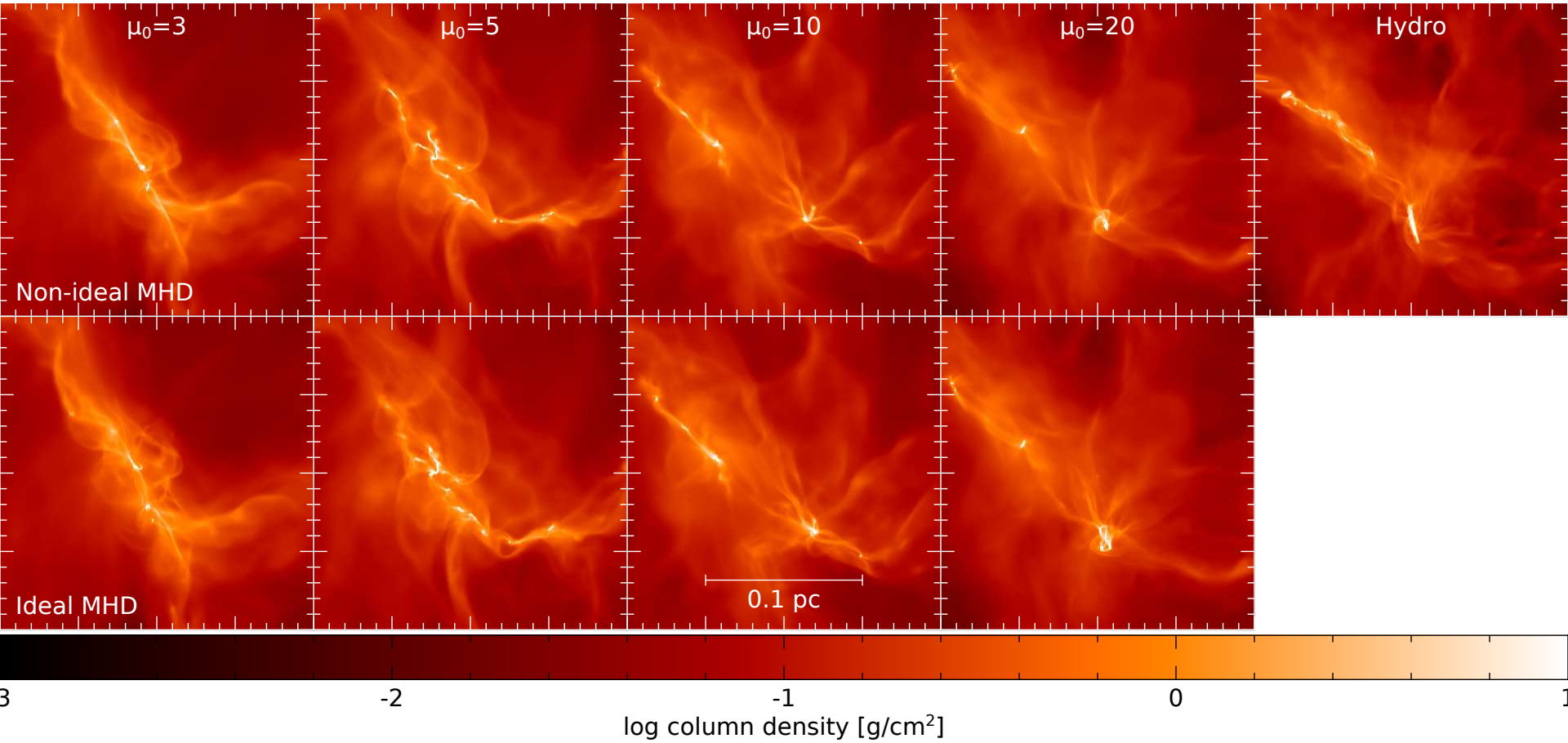
- As predicted from the phase-space diagram
  - Ambipolar diffusion is important in the diffuse ISM
  - The Hall effect is important on mid-range scales
  - Ohmic resistivity is important near the formation of the star itself

- Large scale simulations describe multiplicity, interactions (see Cuello), structure of the ISM, IMF, etc…



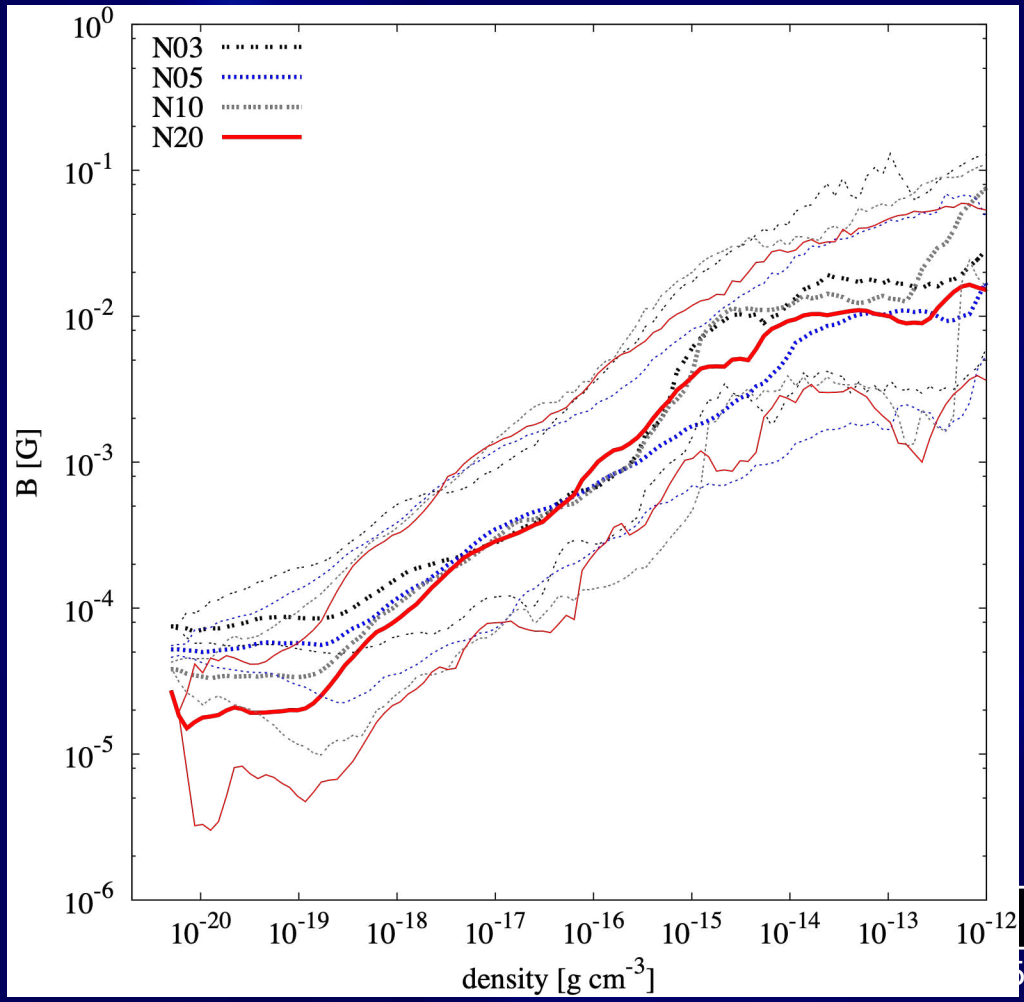
Data from Wurster, Bate & Price (2019)

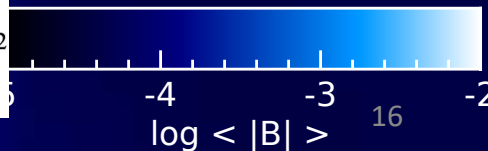
Magnetic fields in star forming regions



Magnetic fields in star forming regions

- Star forming regions have a wide range of initial magnetic field strengths, that are approximately independent of the global environment

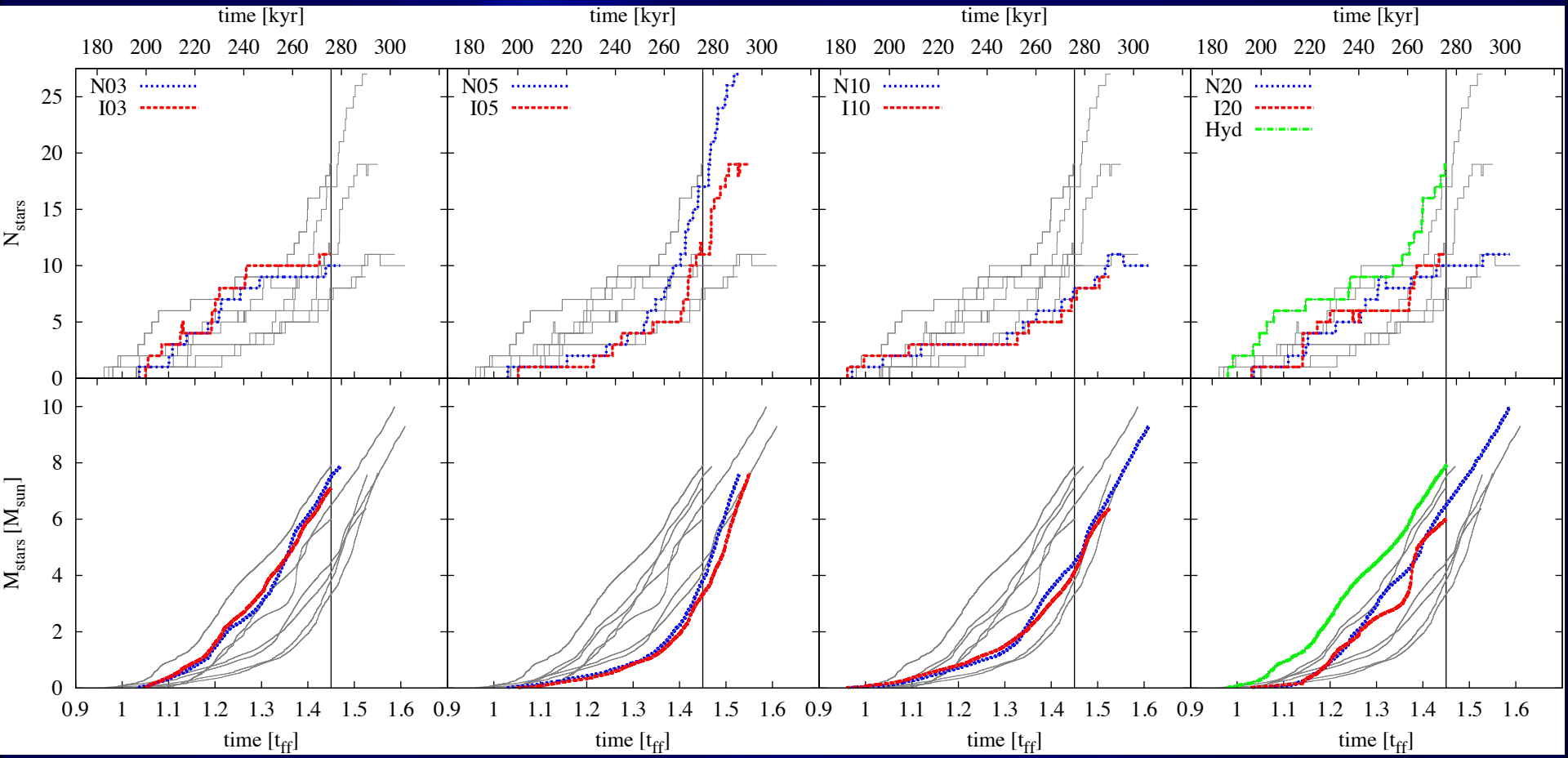




Wurster, Bate & Price (2019)

Star formation in magnetised SF regions

- No trend when stars form
- Excluding N03 & I03, there is more mass in stars with weaker initial magnetic field strengths



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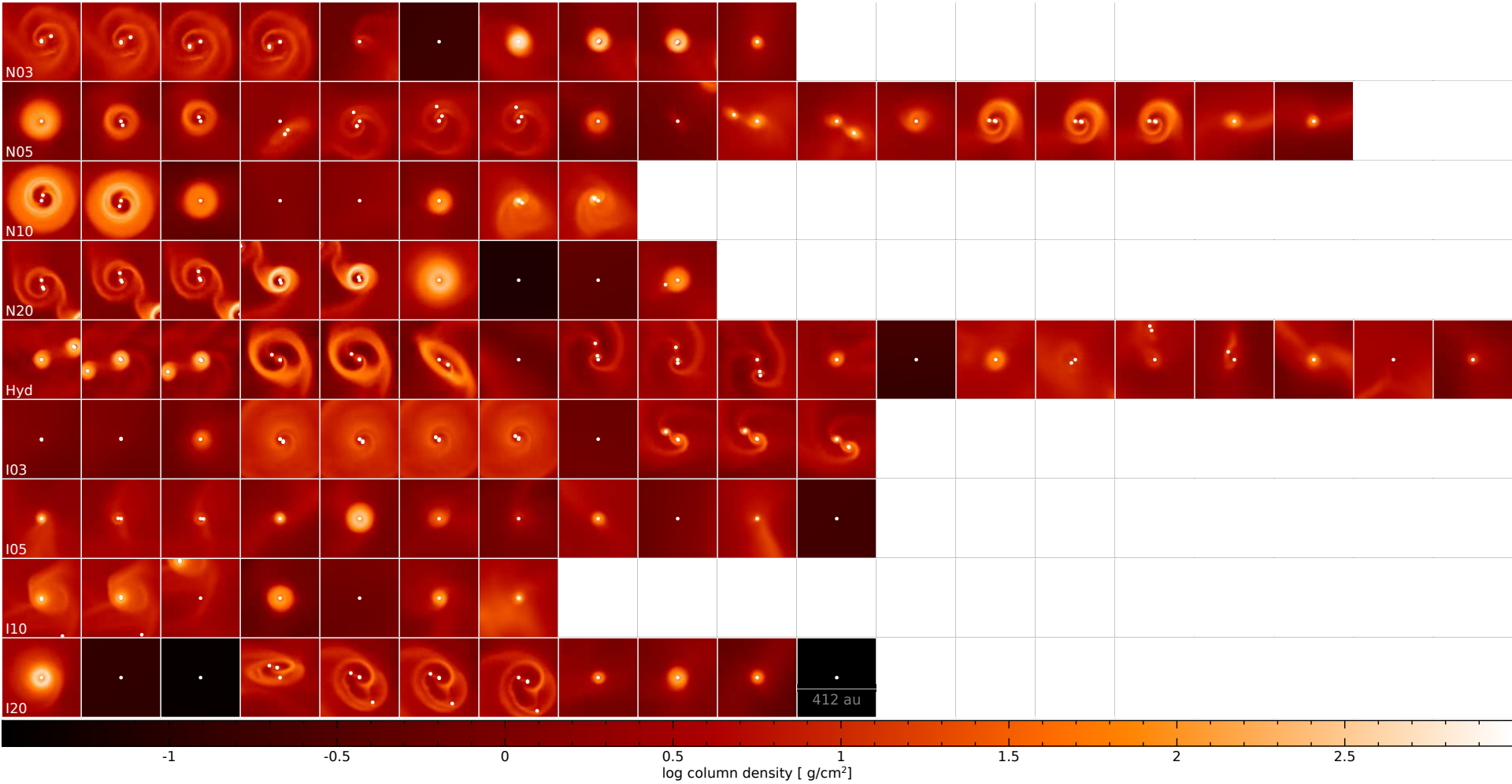
Wurster, Bate & Price (2019)

Disc formation in magnetised SF regions

➢Large protostellar discs form in *all* our models



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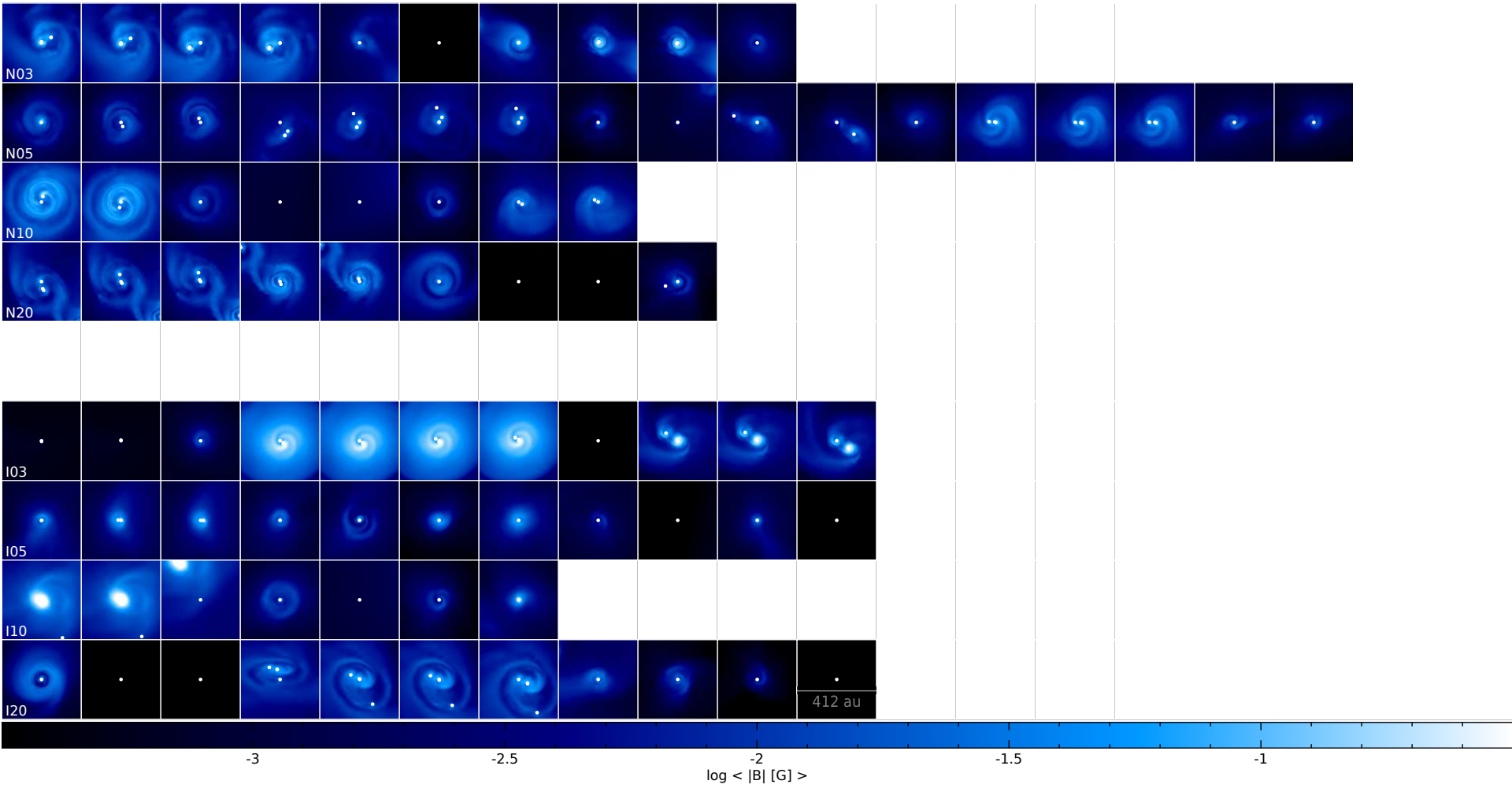
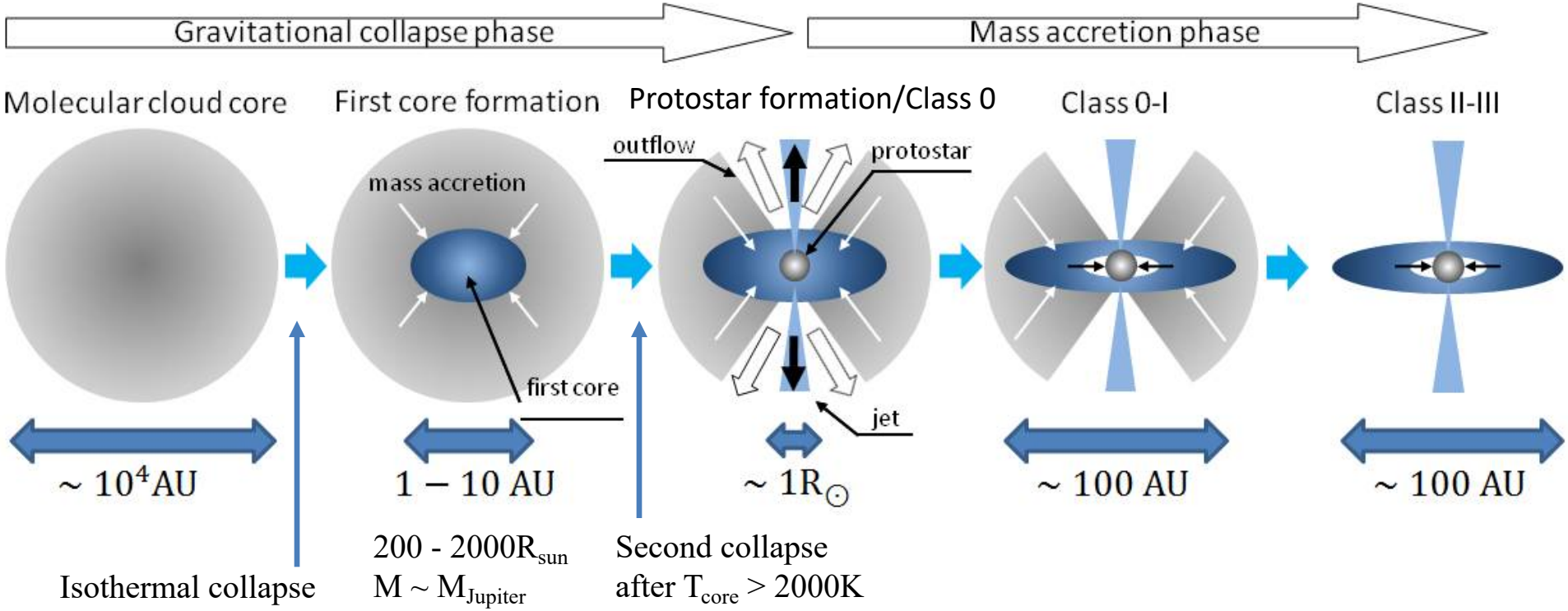


Wurster, Bate & Price (2019)

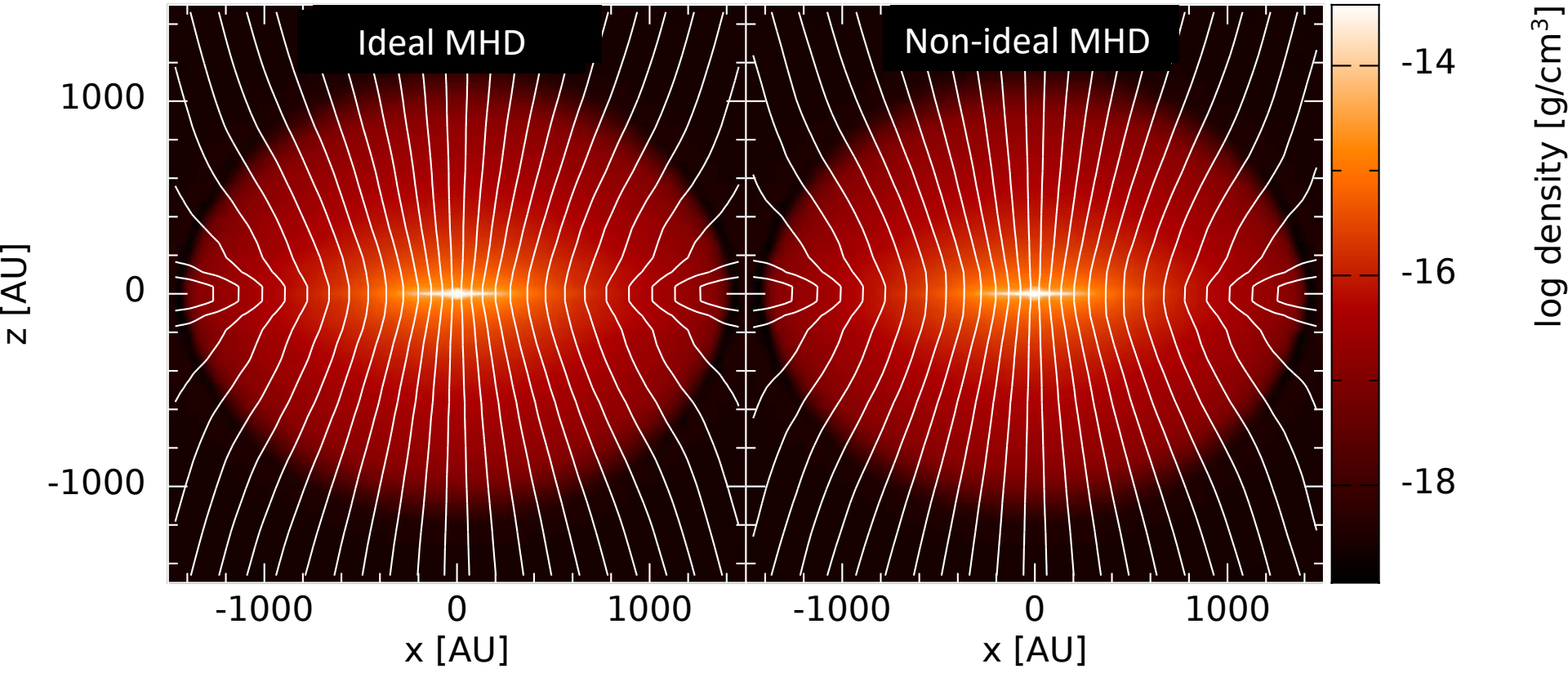
Star formation: An isolated star



Larson (1969); Illustration by Y. Tsukamoto
Background: Orion Molecular Cloud. (image credit: Drudis & Goldman via APOD)

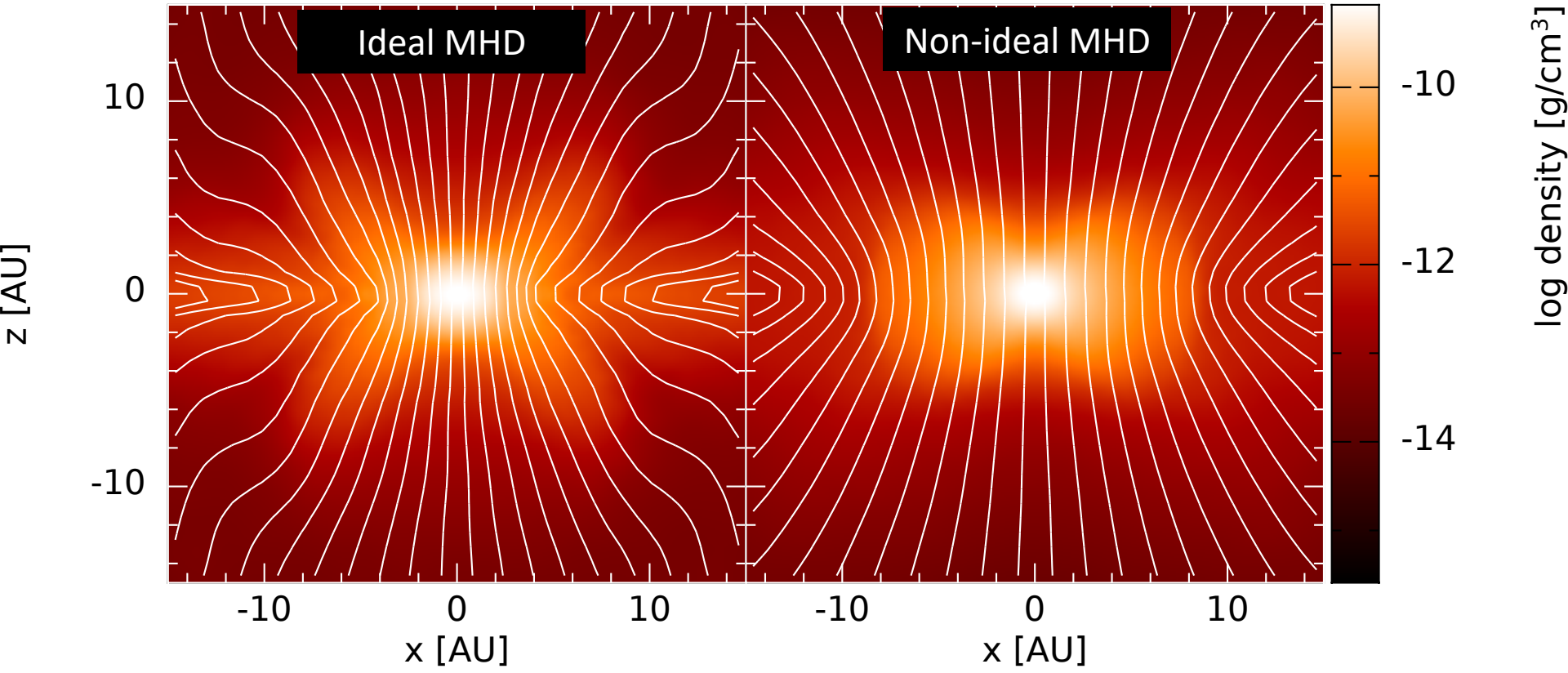
Star formation: Magnetic fields vs Gravity

- Strong field; large scale structure



Star formation: Magnetic fields vs Gravity

- Strong field
- small-scale magnetic fields get pinched into dense regions, creating an hour-glass shape



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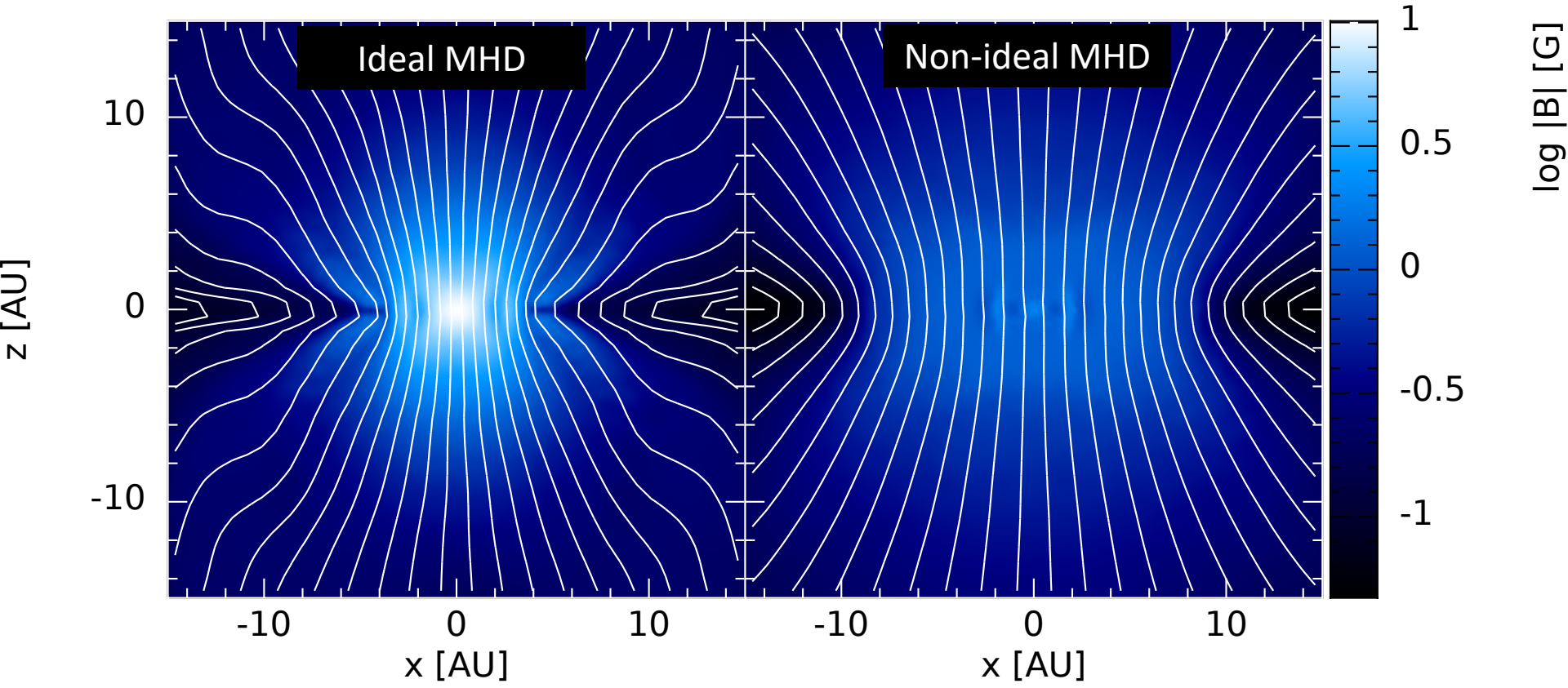

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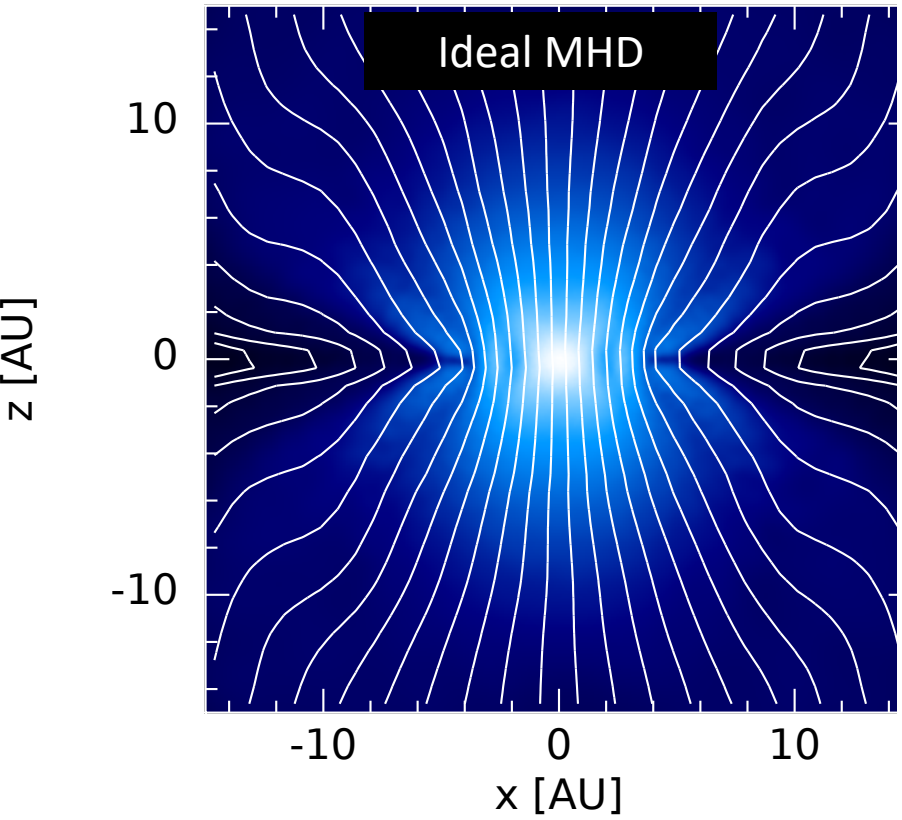
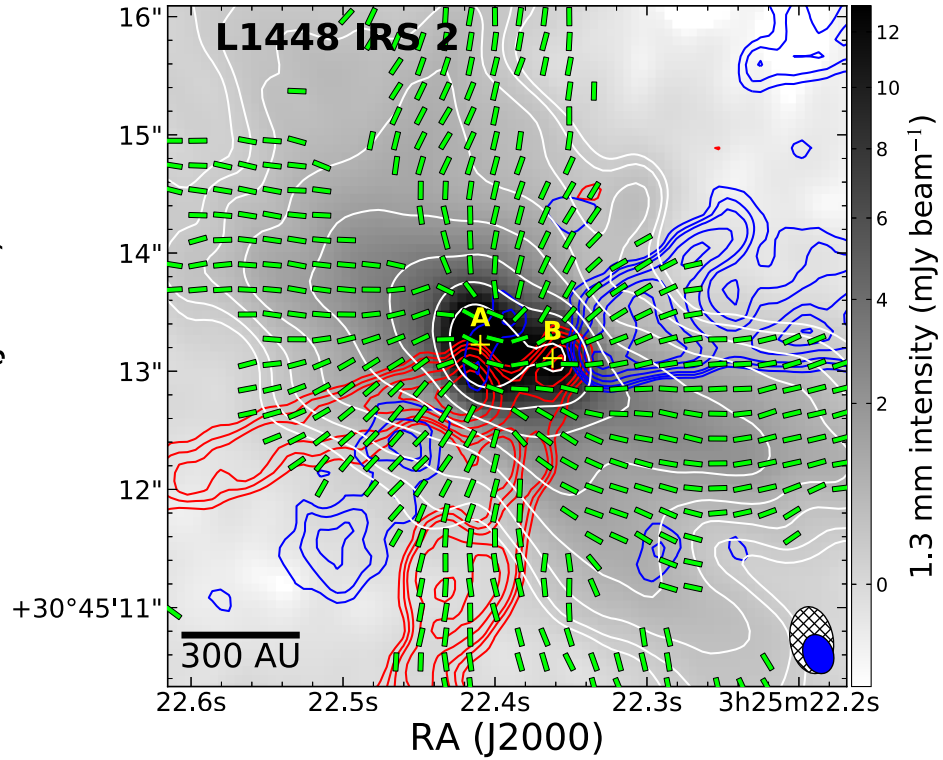
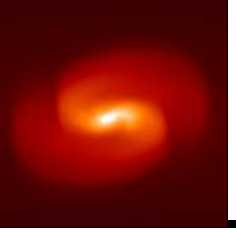




Right: Kwon+ (2019)

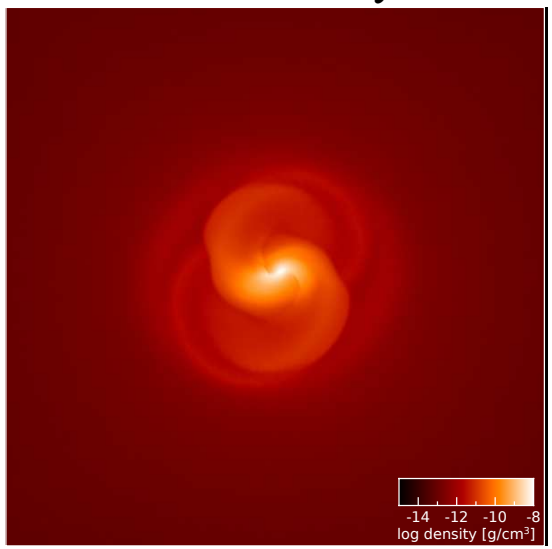


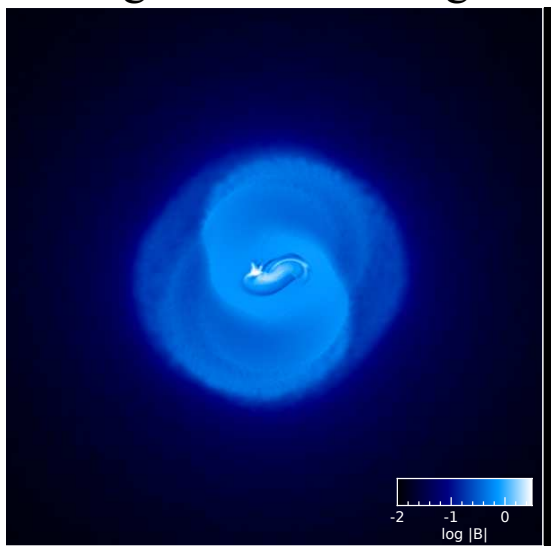
Star formation & Protoplanetary disc formation

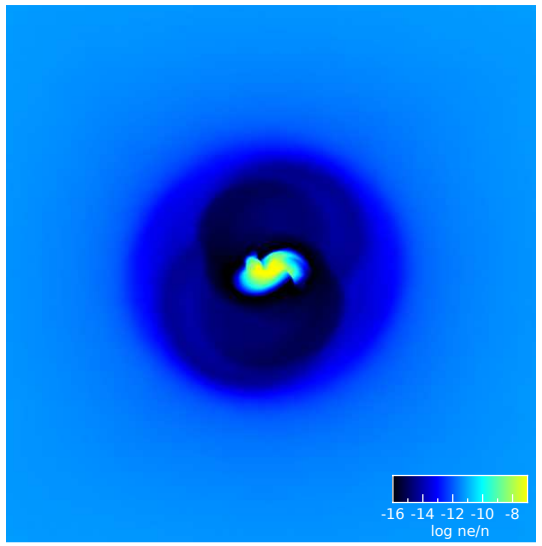
Gas density

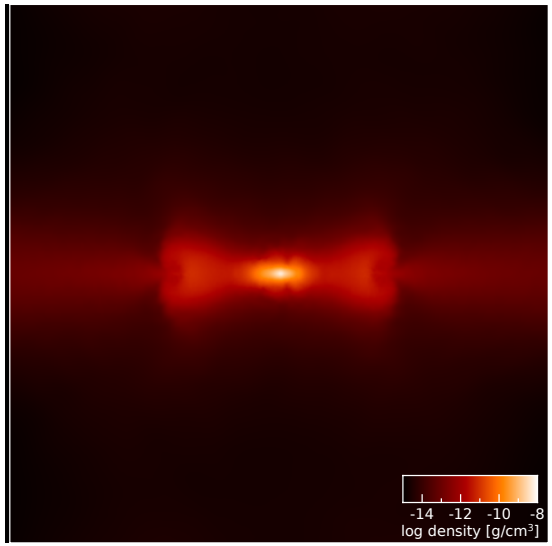
Magnetic field strength

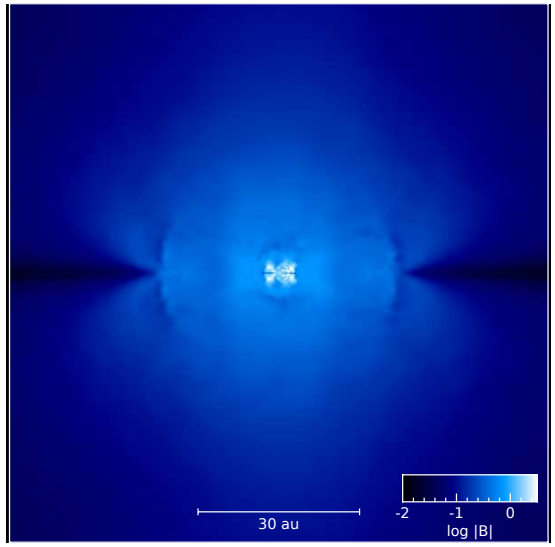
Ionisation fraction

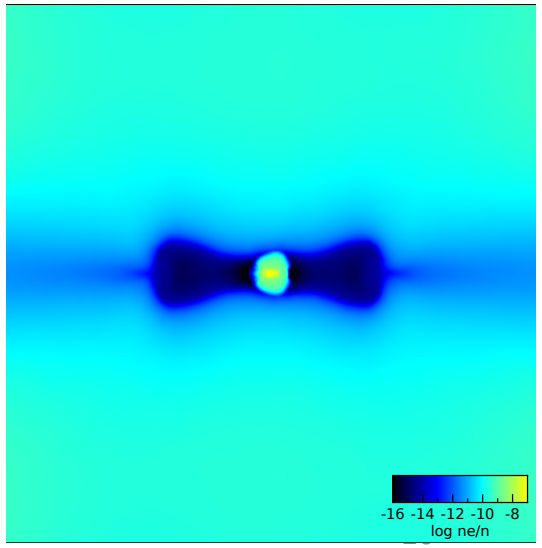




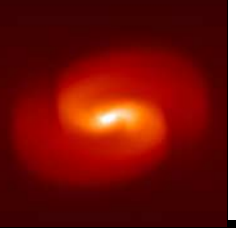








Data from Wurster, Bate & Price (2018c)

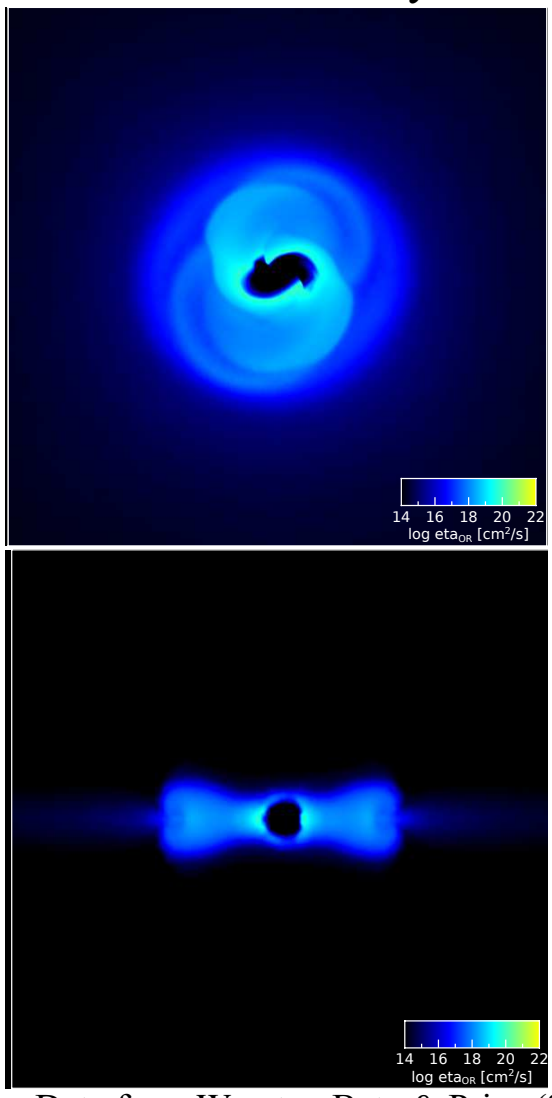


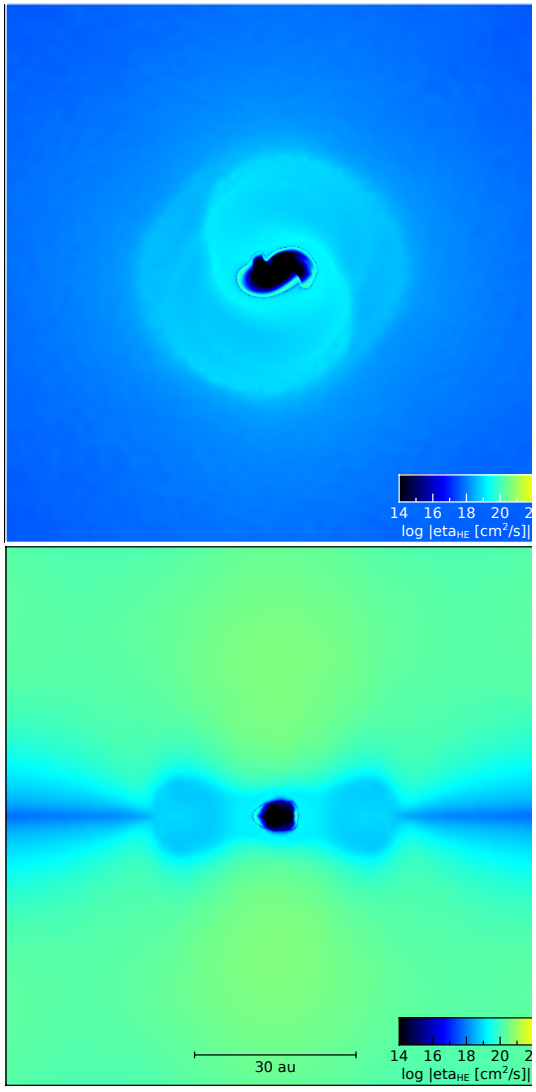
Star formation & Protoplanetary disc formation

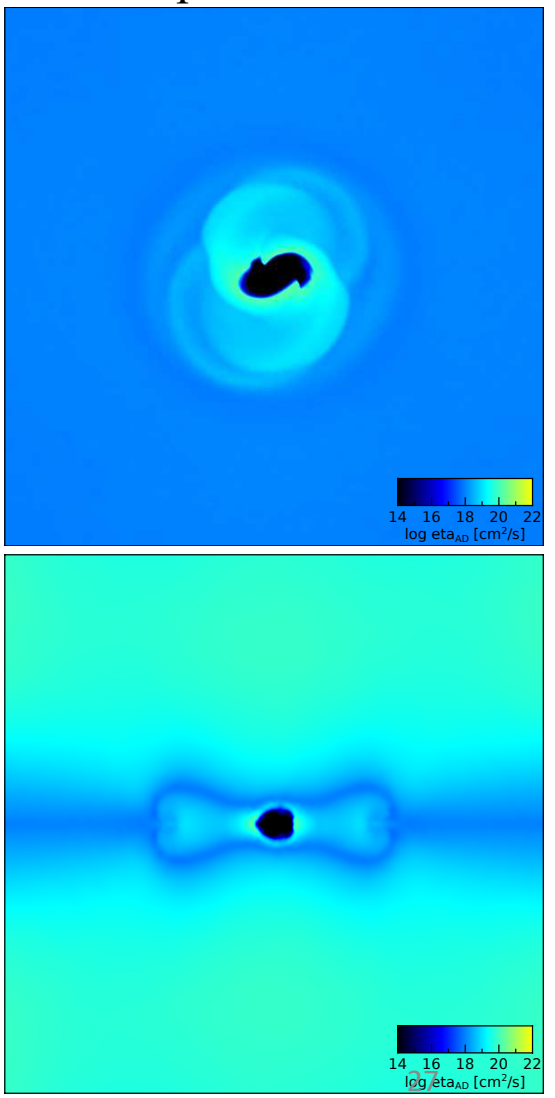
Ohmic resistivity

Hall Effect

Ambipolar diffusion



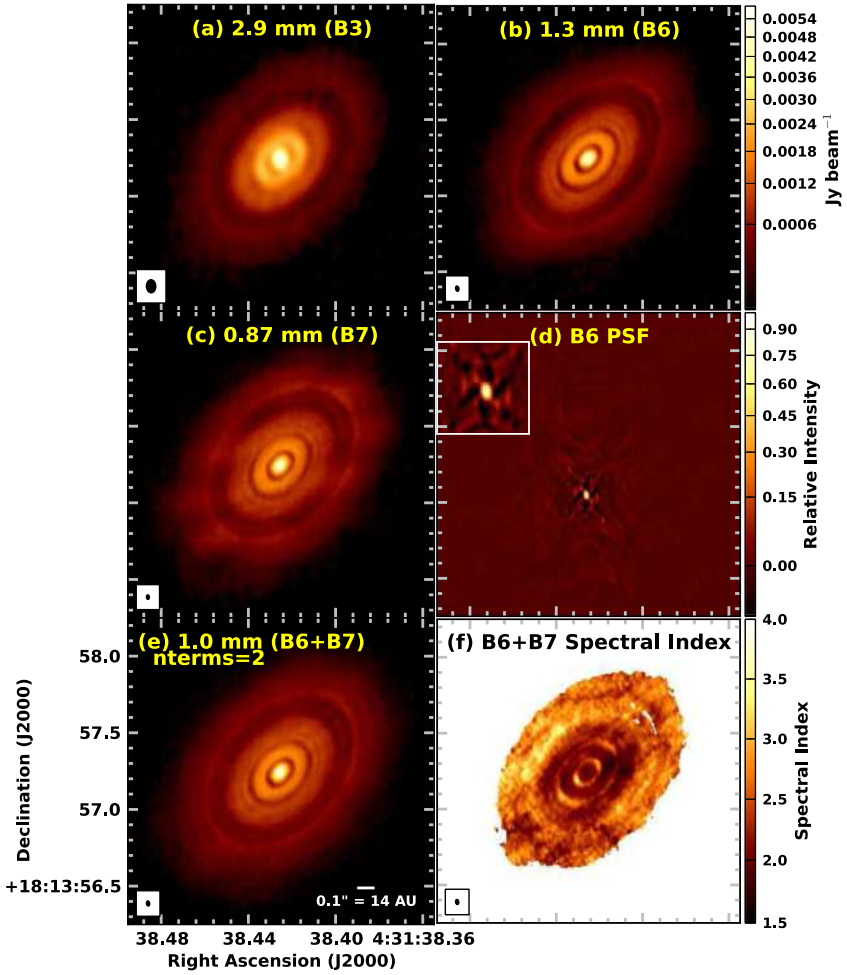




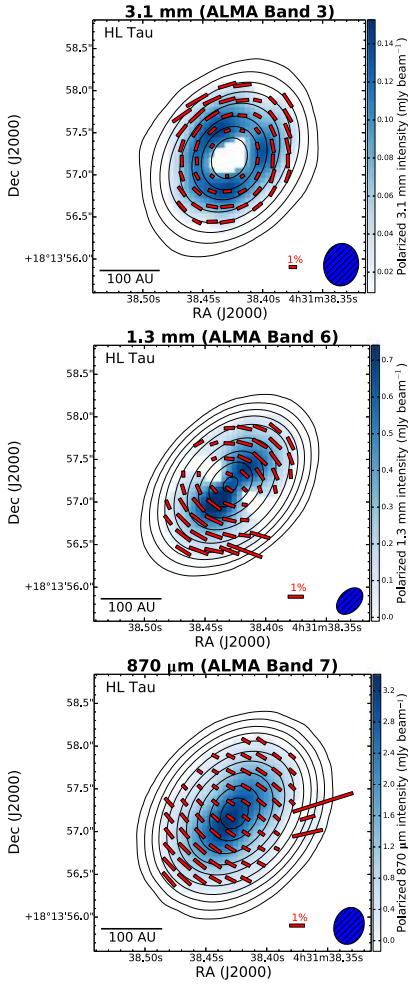
Data from Wurster, Bate & Price (2018c)

Star formation: What's next?

- Continue investigating star cluster formation & isolated star formation
- Need to incorporate dust:



ALMA Partnership (2015)



Stephens+ (2017)

Star formation: What's next?

- Continue investigating star cluster formation & isolated star formation

	PHANTOM	sphNG
HPC ……..	✓	✓
User-friendly ……	✓	~
Magnetohydrodynamics ……	✓	✓
Non-ideal MHD ……	✓	✓
Dust ……..	✓	~
Radiation ……	?	✓
MPI ……..	?	✓

Conclusions

- Star cluster formation:
  - Magnetic fields affect the large scale structure of the filaments
  - The star forming regions are only weakly ionised
  - Non-ideal MHD affects does not play a large role on the large scale

- Isolated, low-mass star formation:
  - Discs only form in purely hydro simulations, and those with non-ideal MHD
  - Discs are mostly neutral, and non-ideal MHD plays a fundamental role

- The way forward requires radiation non-ideal magnetohydrodynamics + dust in an HPC code

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