Leibniz-Institut für
Astrophysik Potsdam

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How magnetic fields alter feedback and angular momentum transfer in MW-like galaxies

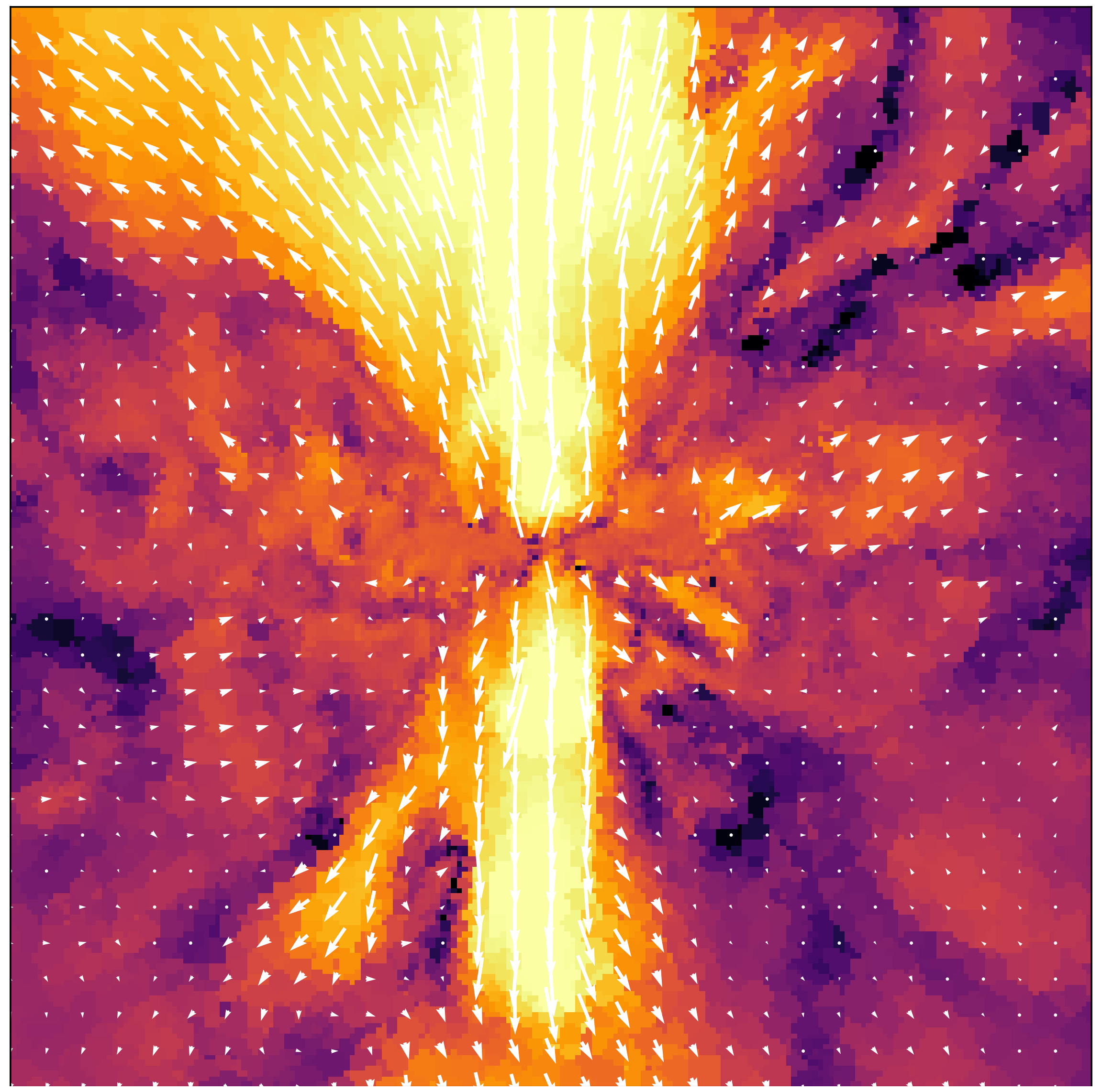
Joseph Whittingham

Martin Sparre (UoP)

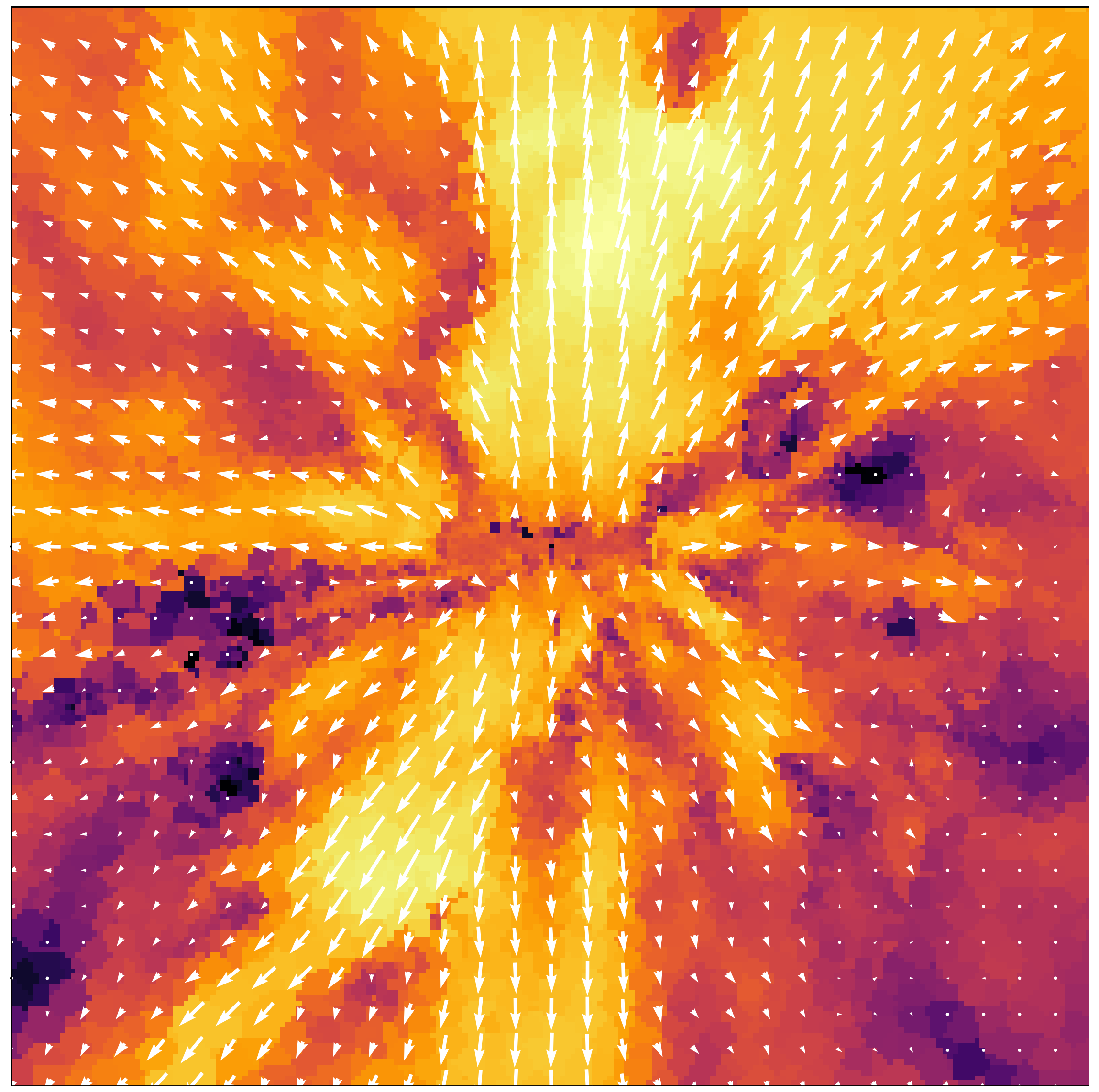
Christoph Pfrommer (AIP)

Rüdiger Pakmor (MPA)

MHD



Hydro



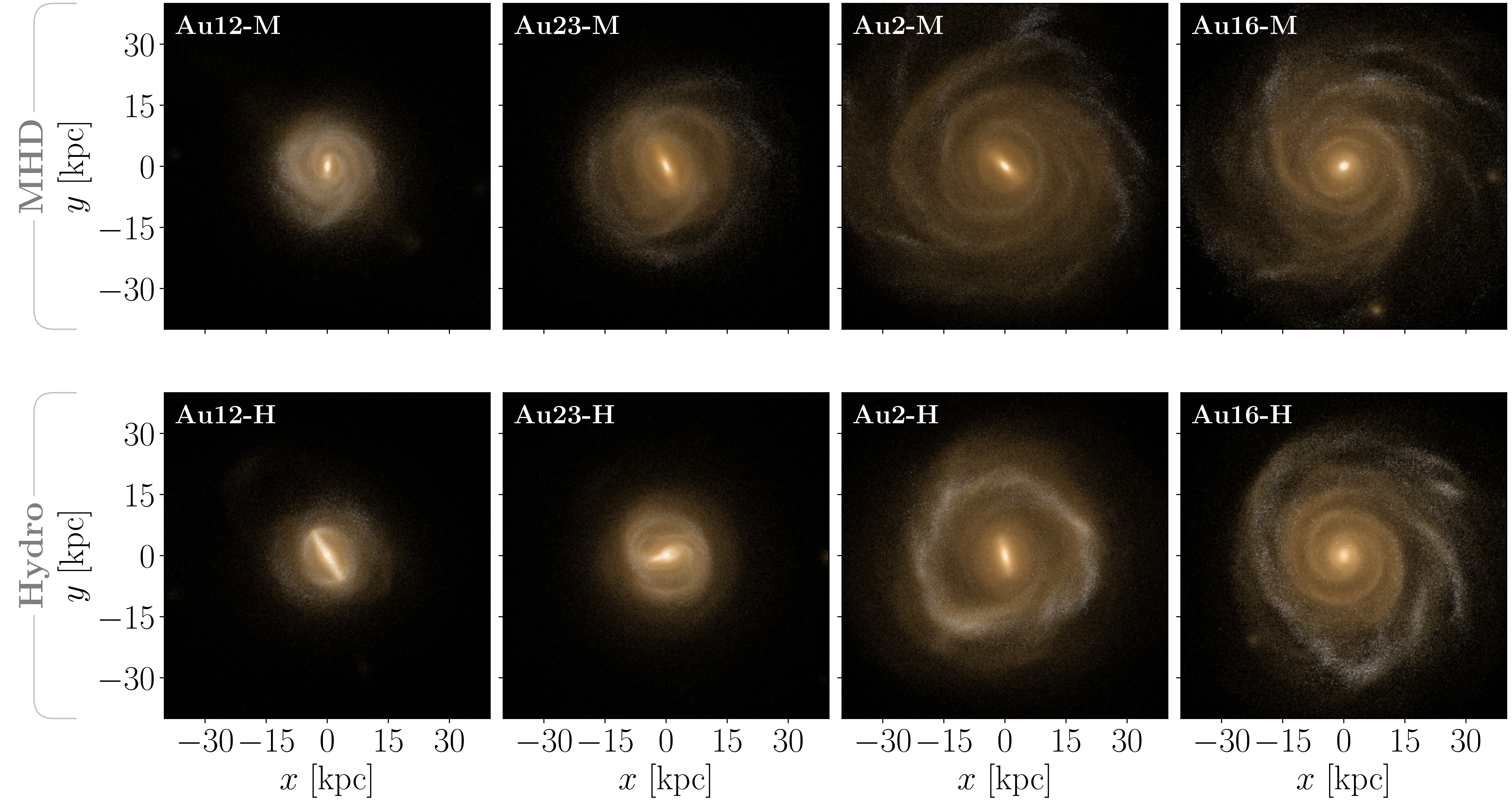
Magnetic fields change disc galaxies

MHD galaxies:

- Larger radius
- Flocculent spirals

Hydro galaxies:

- Larger bars
- Ring structures



Mock stellar light images from Auriga (re-)sims at z=0

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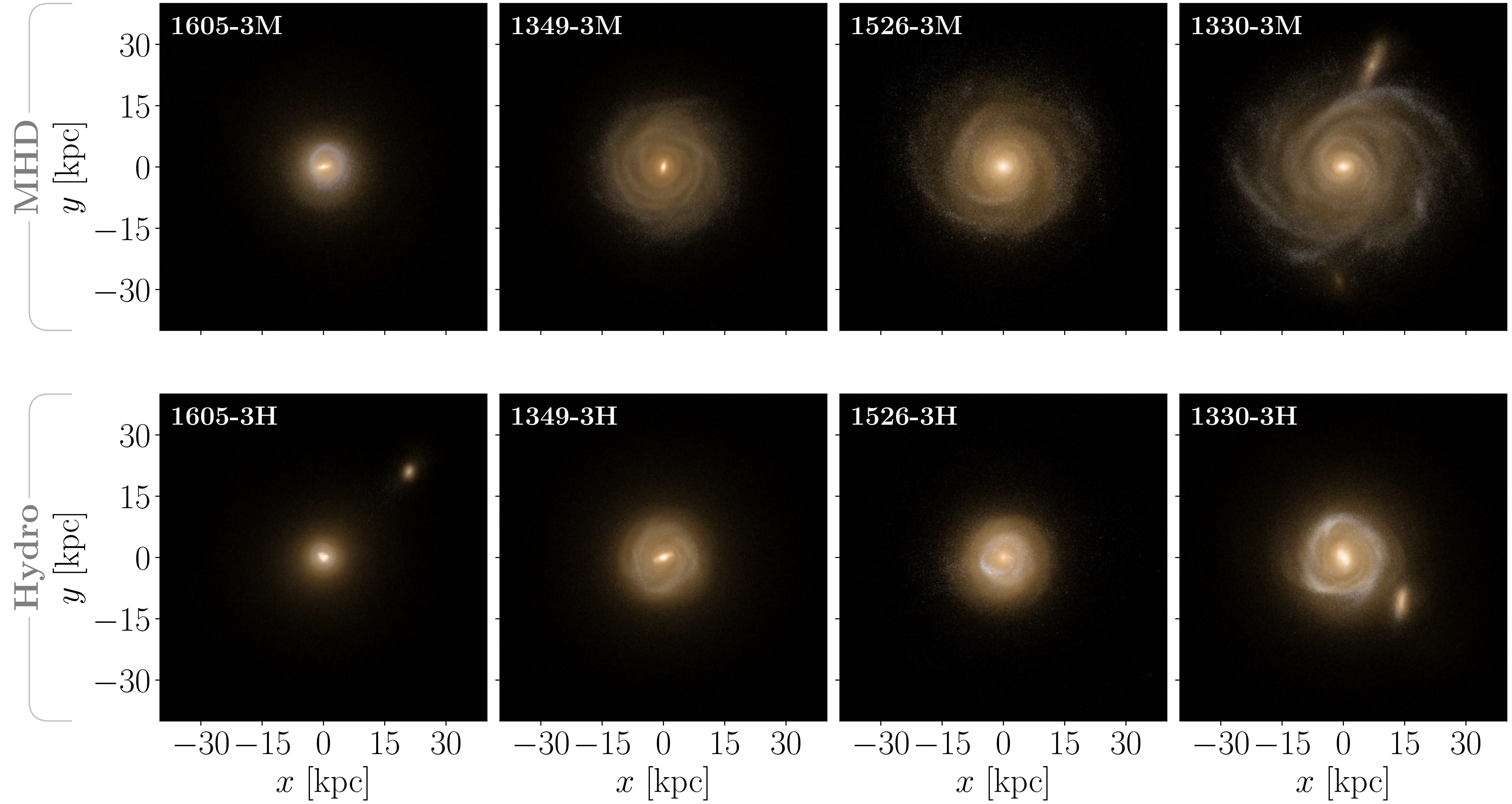
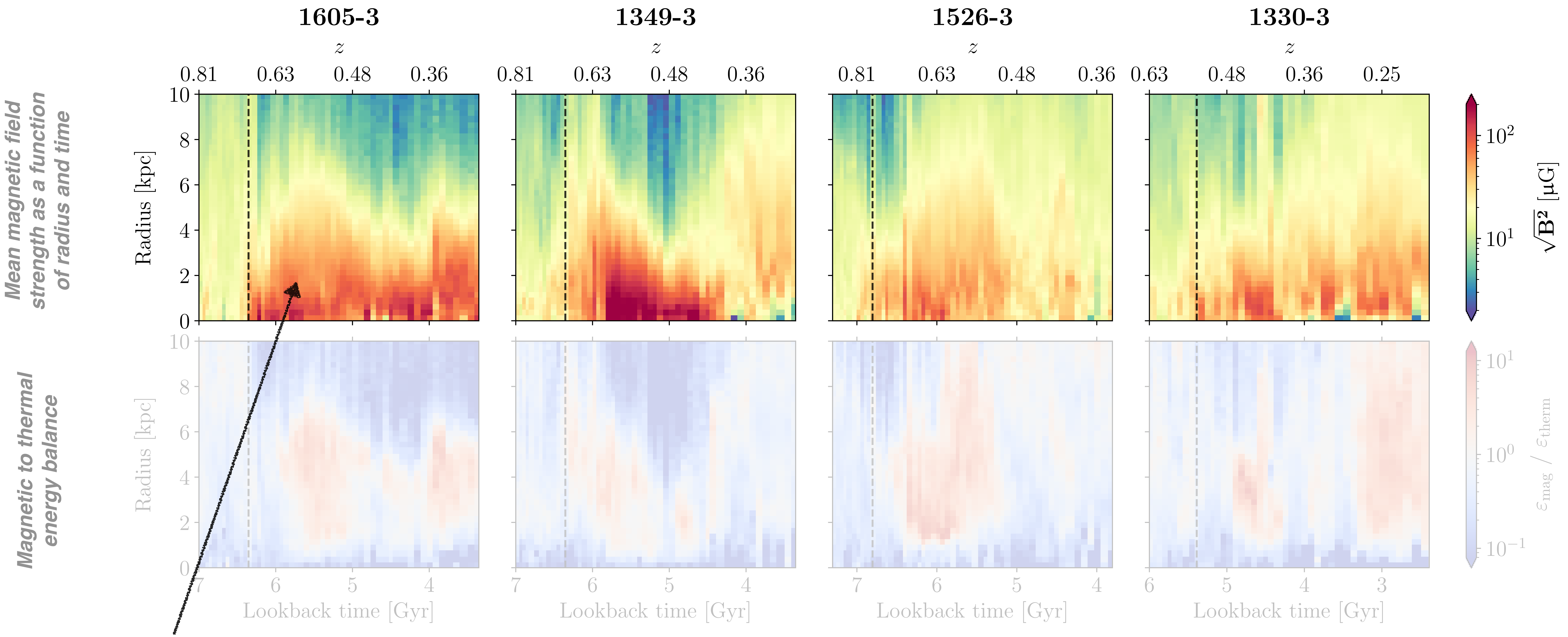
Effect excited by gas-rich *mergers*!



Mock stellar light images from Auriga* galaxy merger *sims at z=0

Why mergers?

Dashed black lines: start of merger



Sustained amplification by up to an order of magnitude for a few Gyr

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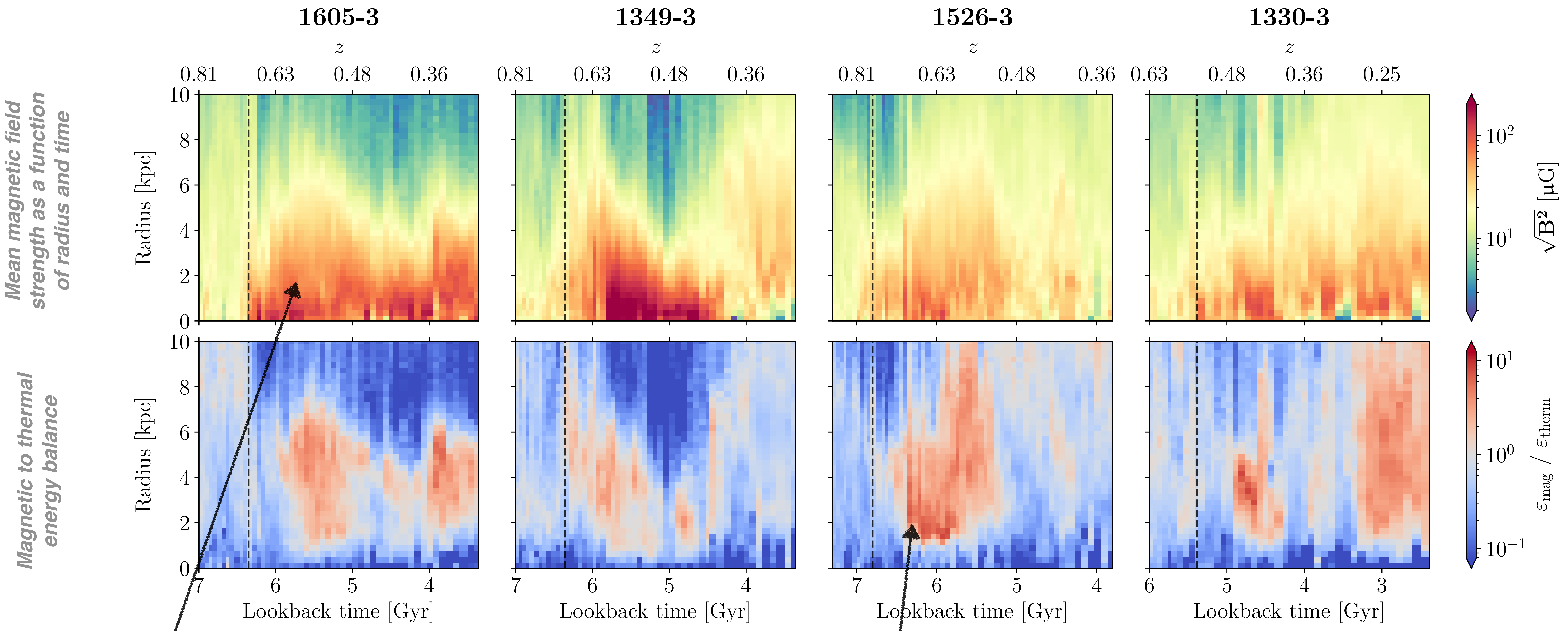

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Magnetic energy can dominate over thermal energy

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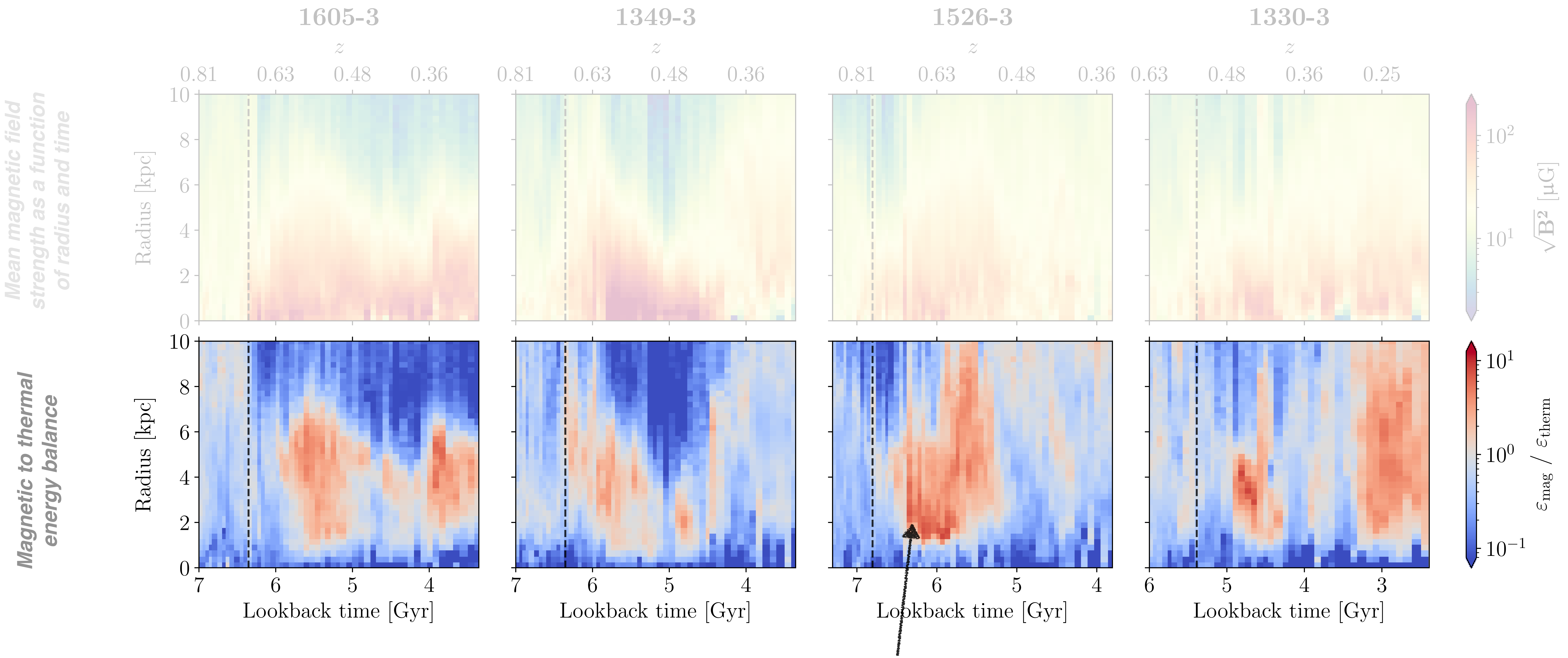
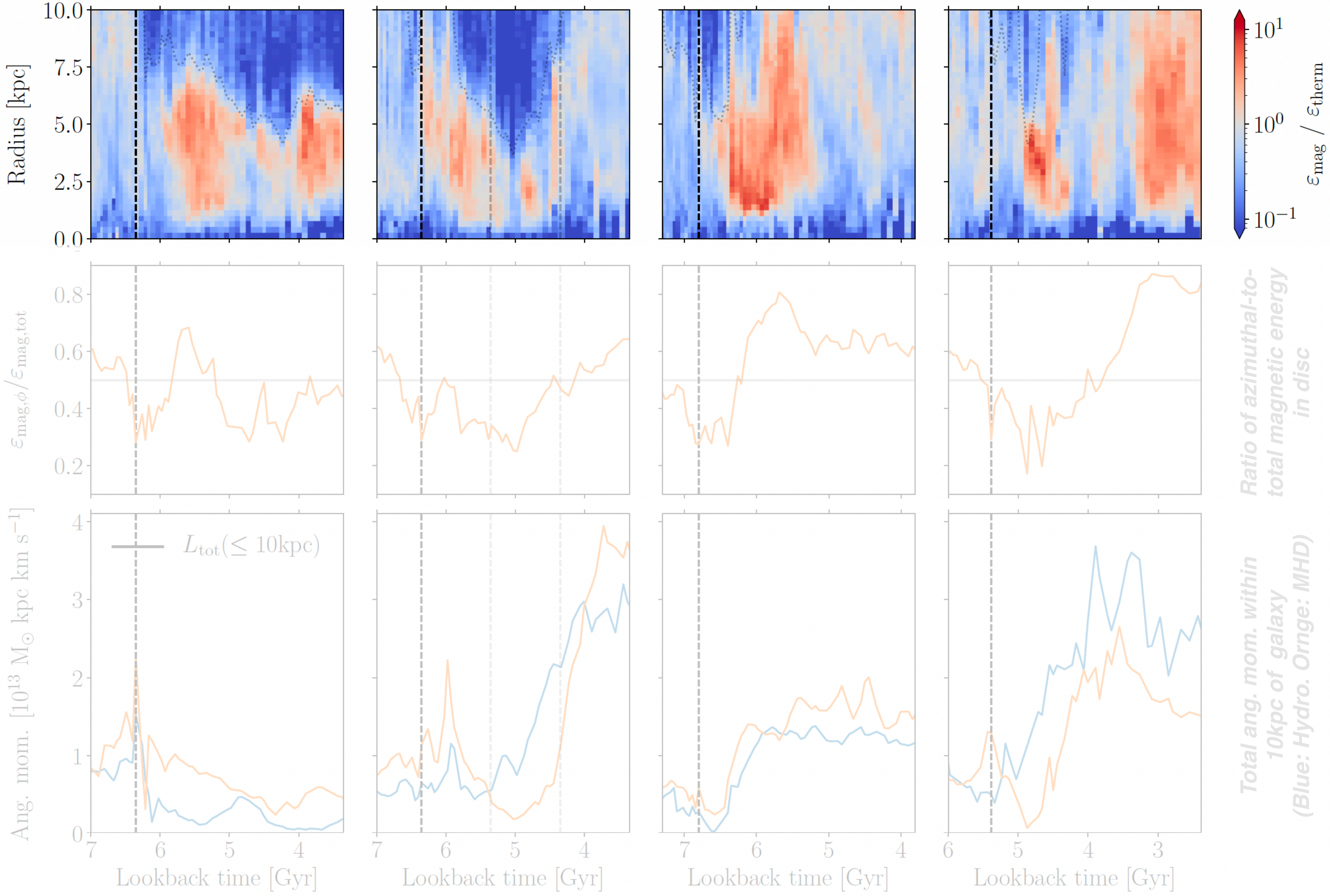


Magnetic energy can dominate over thermal energy

What does the magnetic field do?

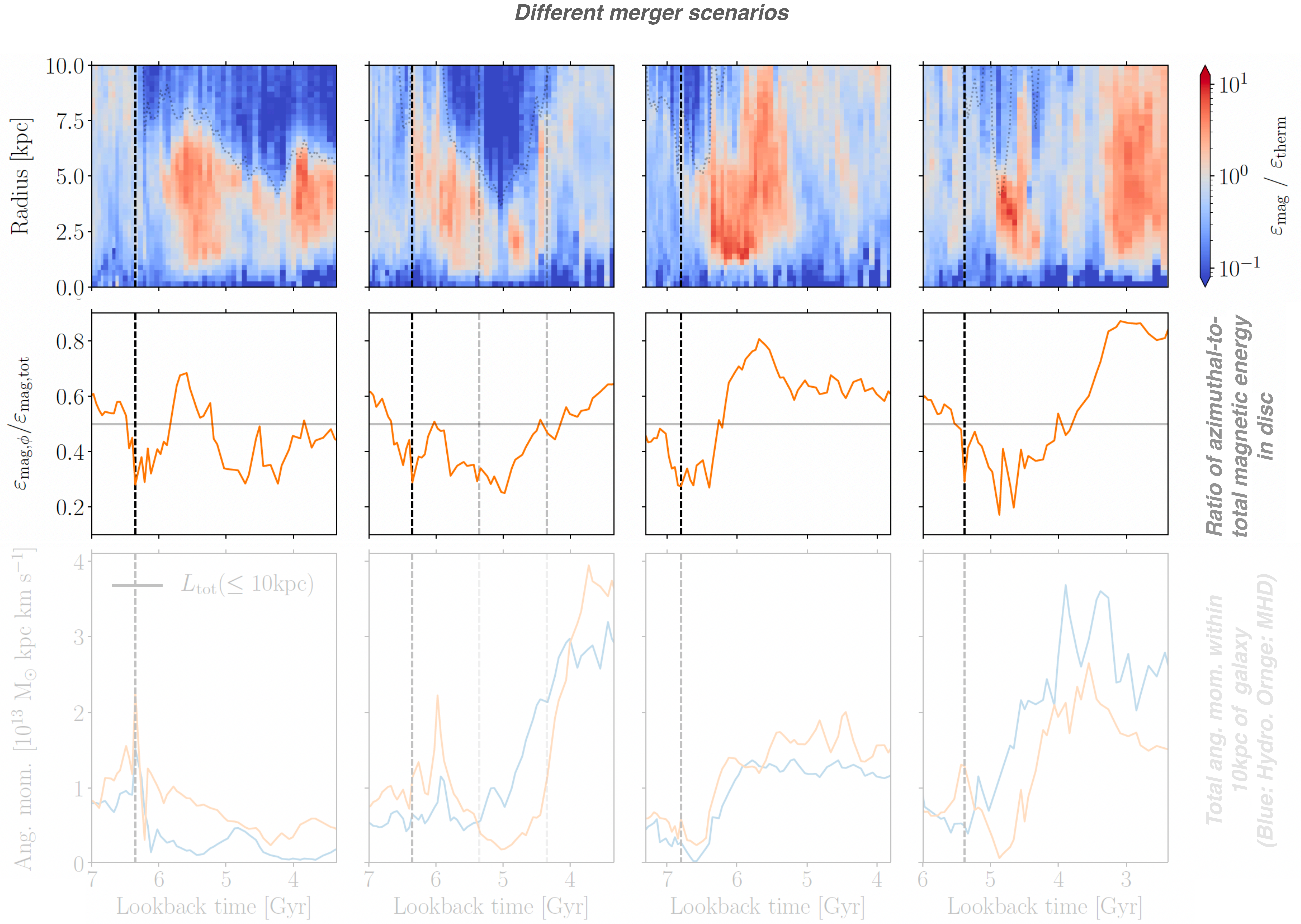
Different merger scenarios



Orange: MHD
Blue: Hydro

What does the magnetic field do?

Magnetic field typically non-azimuthal when amplified



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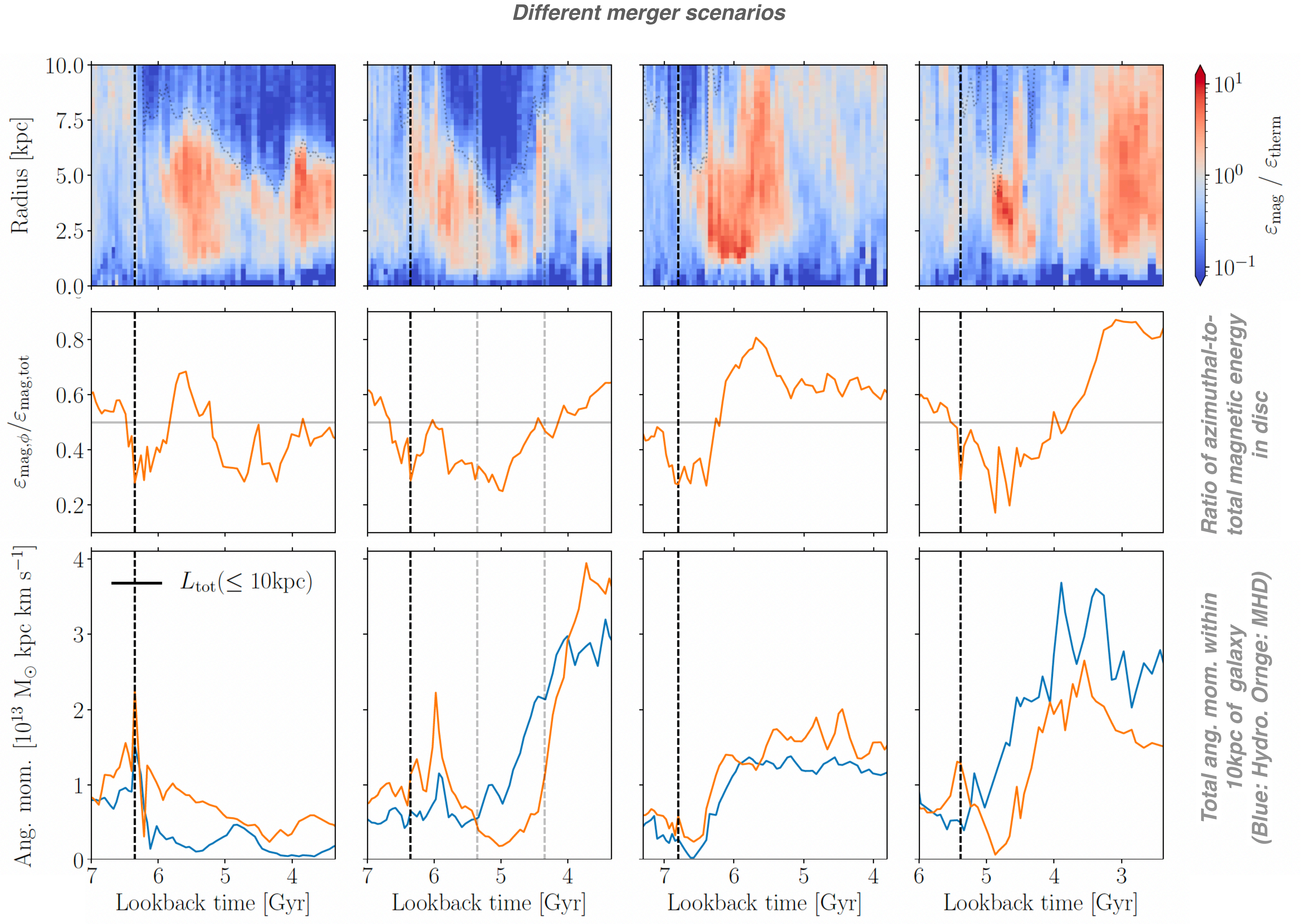
→ efficient ang. mom. transport!



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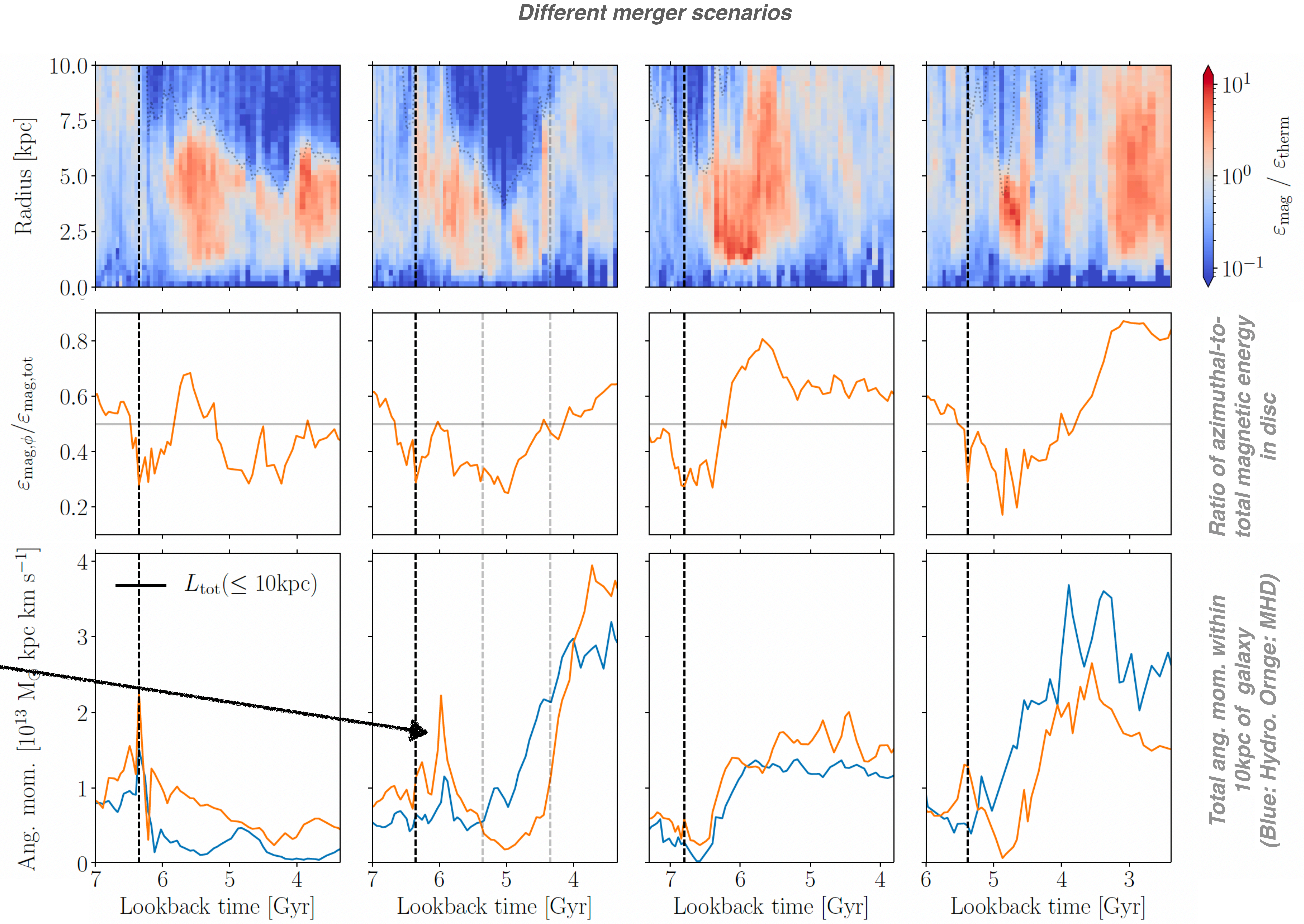
First shrinks disc…

… before growing it quickly!



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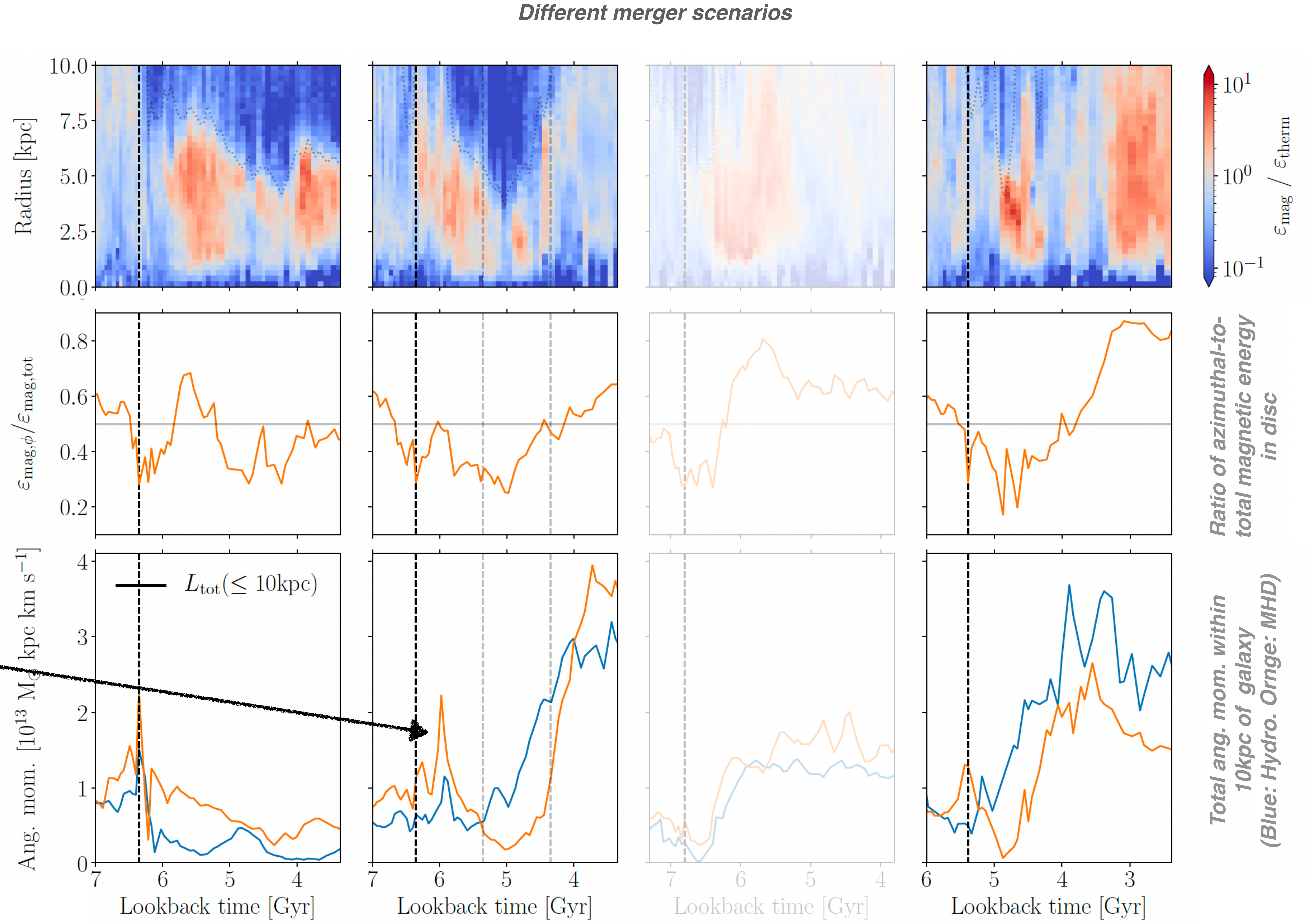
(not seen in 3rd scenario, where the ang. mom. of progenitors align)



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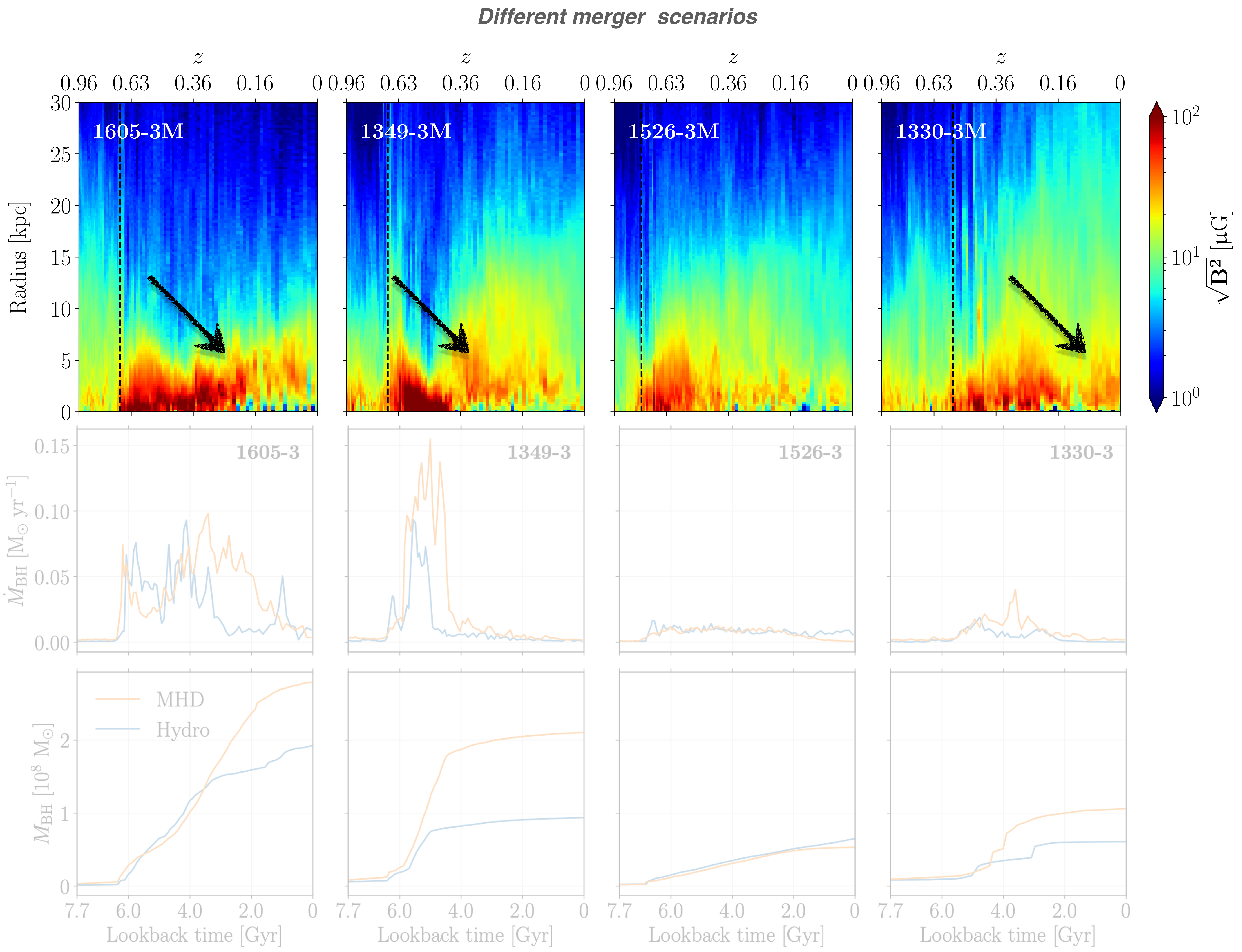
What does the magnetic field do?

Magnetic fields act to increase:

- Central gas densities



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What does the magnetic field do?

Magnetic fields act to increase:

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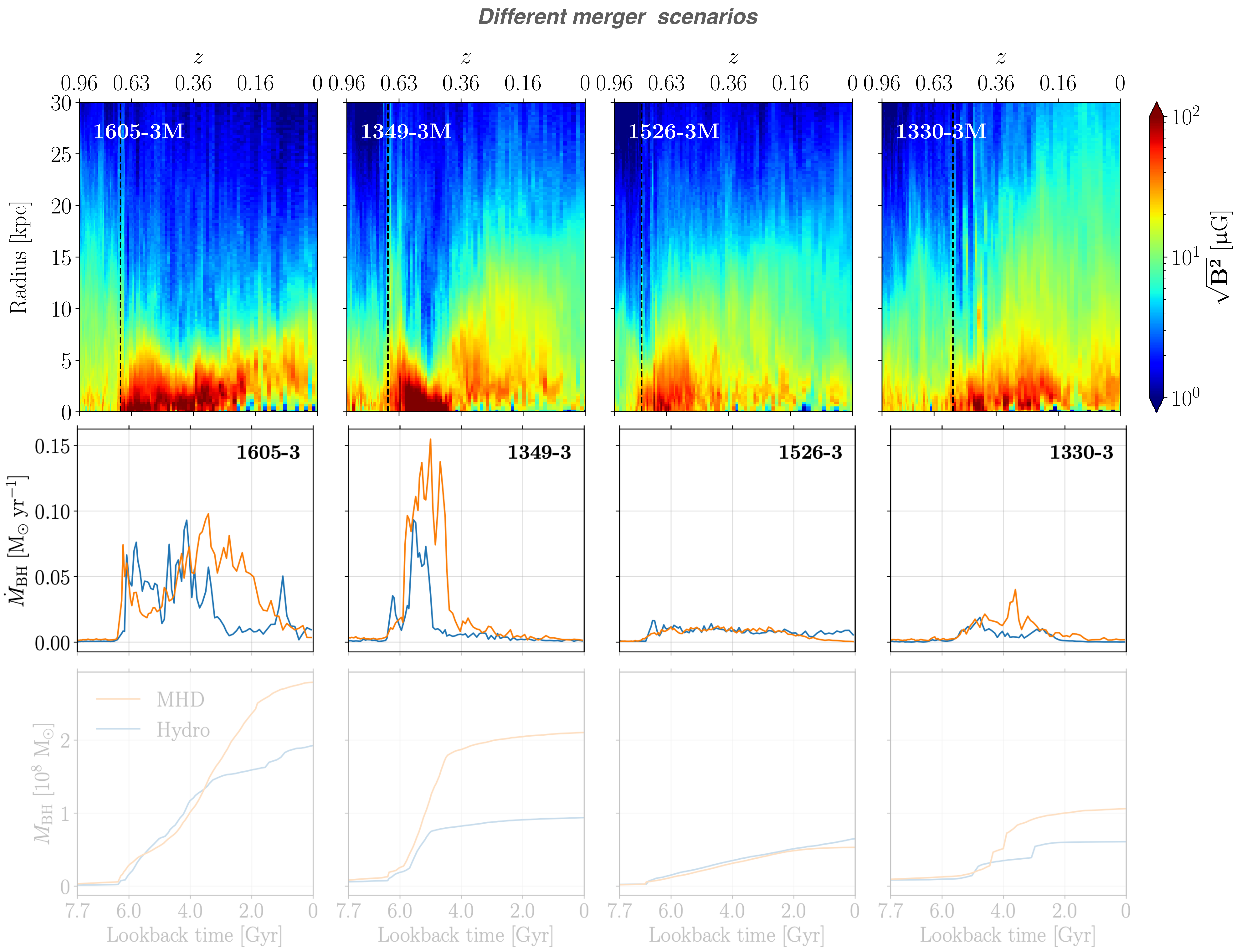
- Black hole accretion



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What does the magnetic field do?

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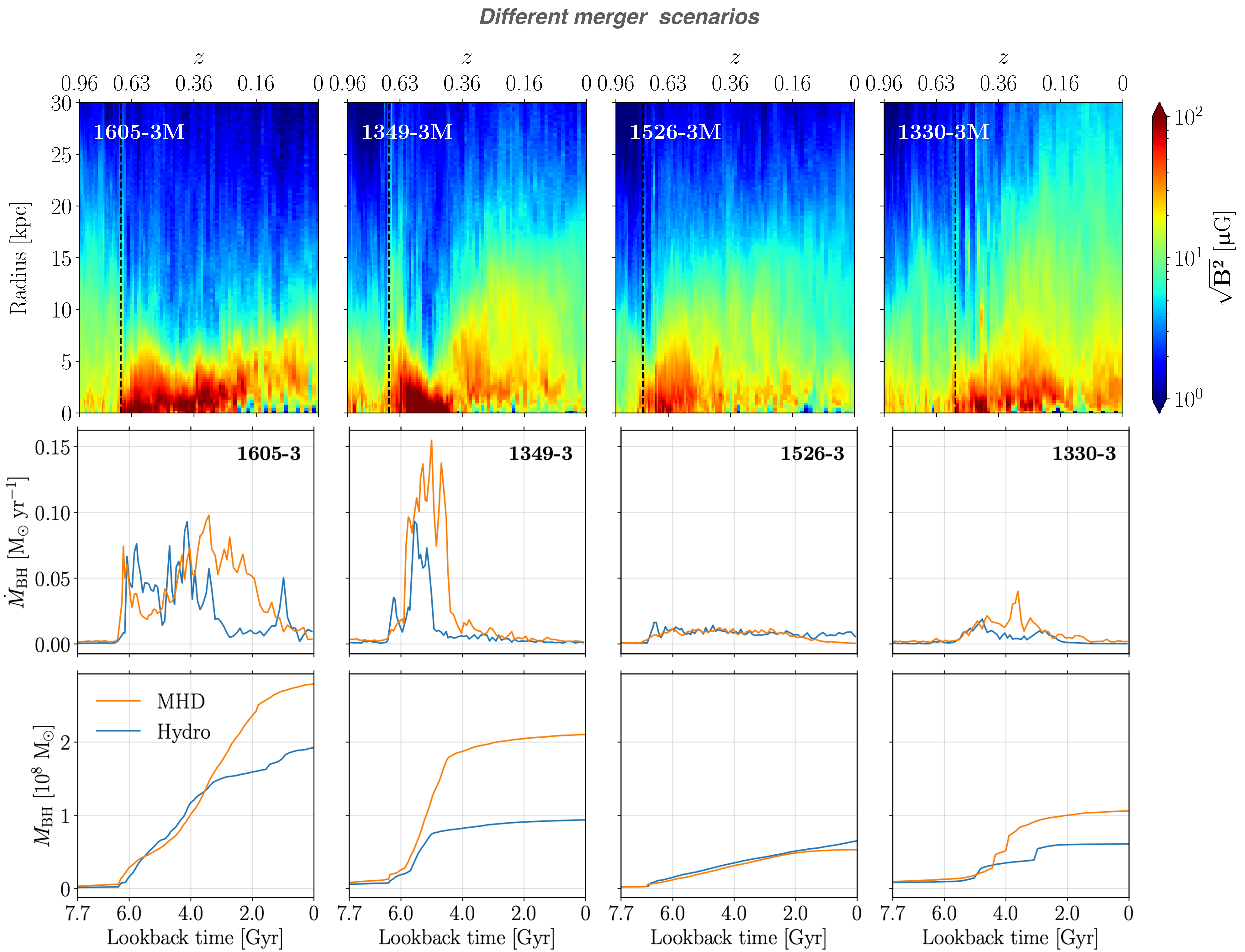
- Black hole masses!



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- Black hole masses!

$$\dot{E} = \epsilon_f \epsilon_r \dot{M}_{BH} c^2$$

Increased AGN feedback!

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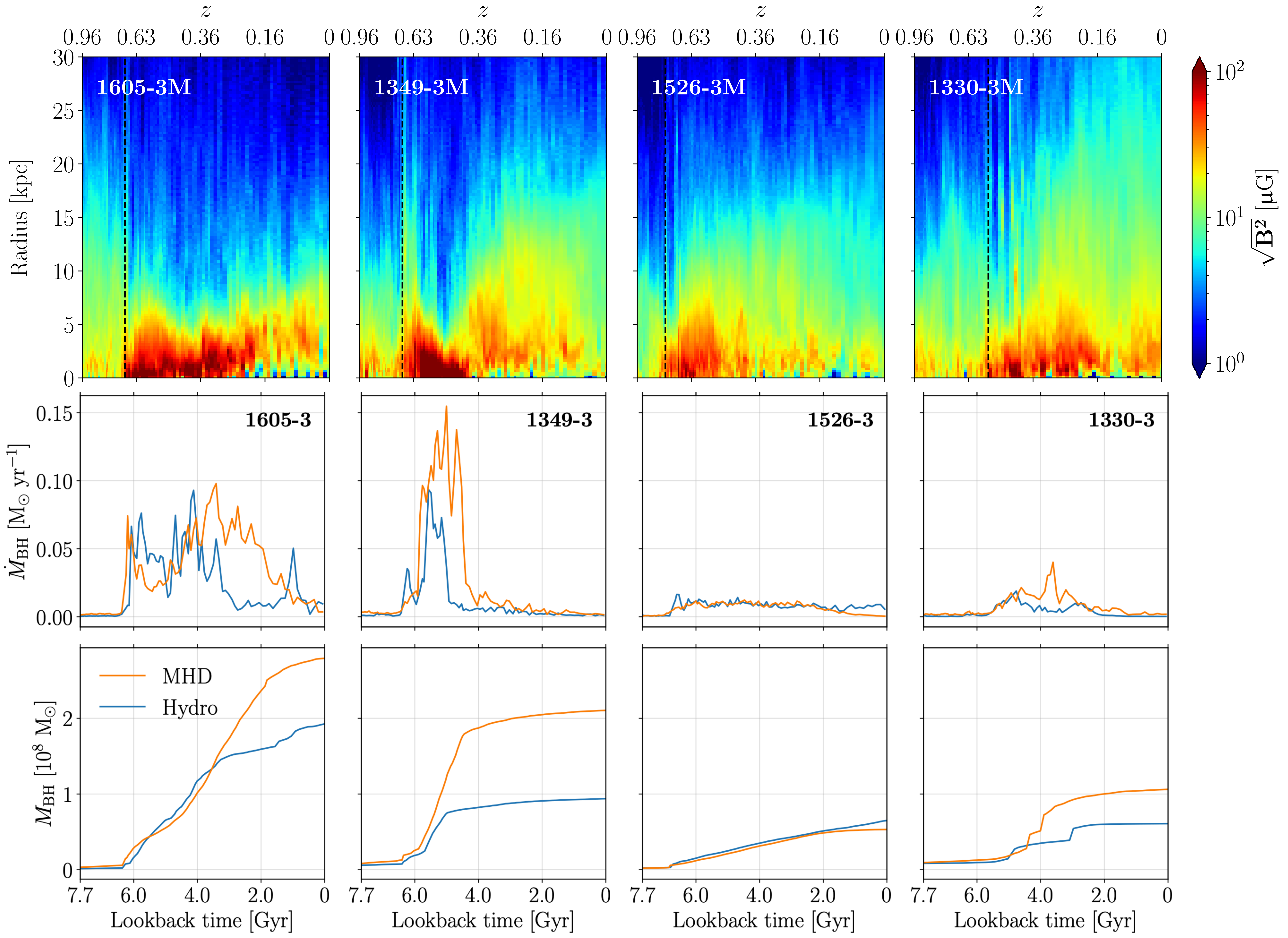
Different merger scenarios

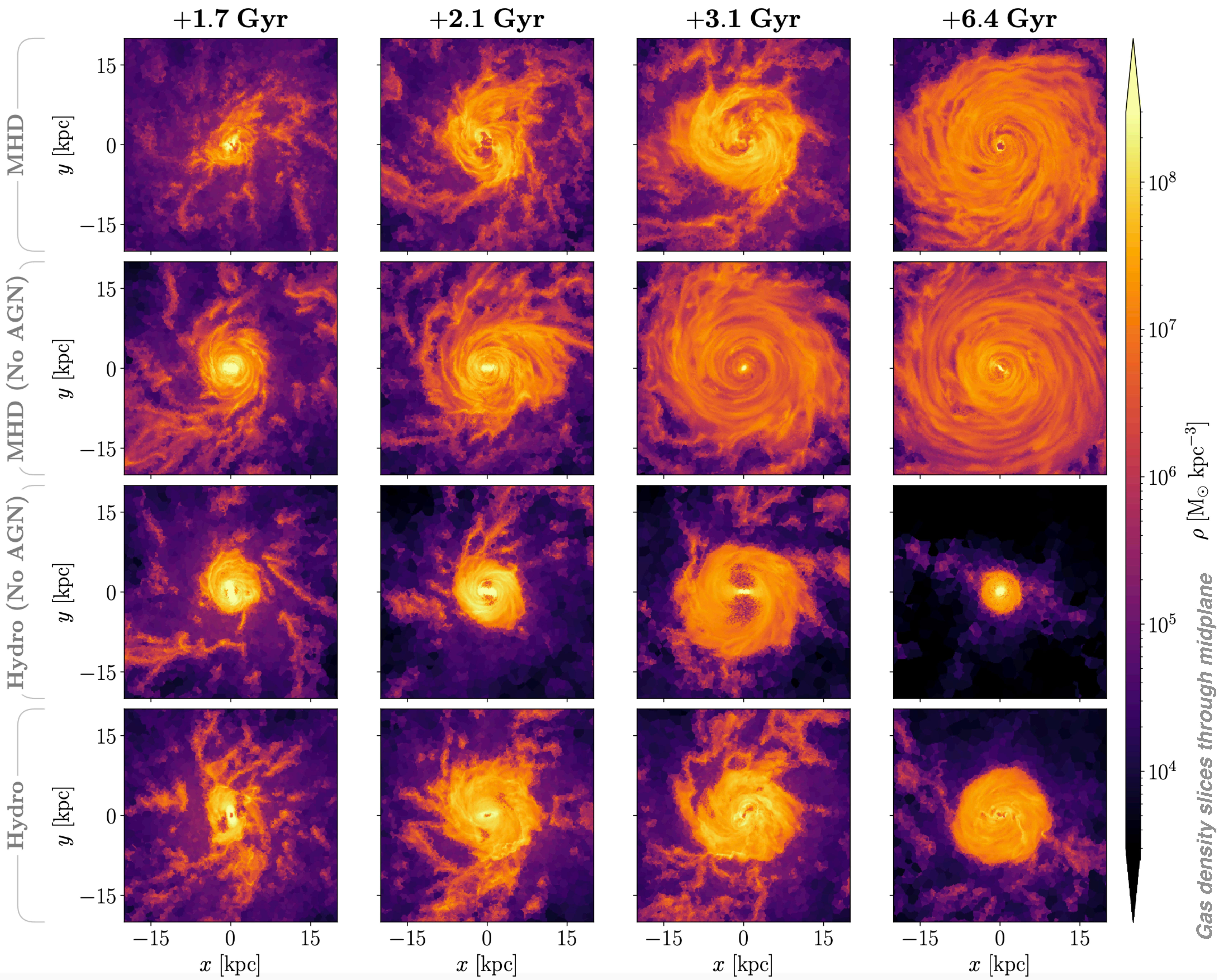


The impact of the SMBH
(is surprisingly weak!)

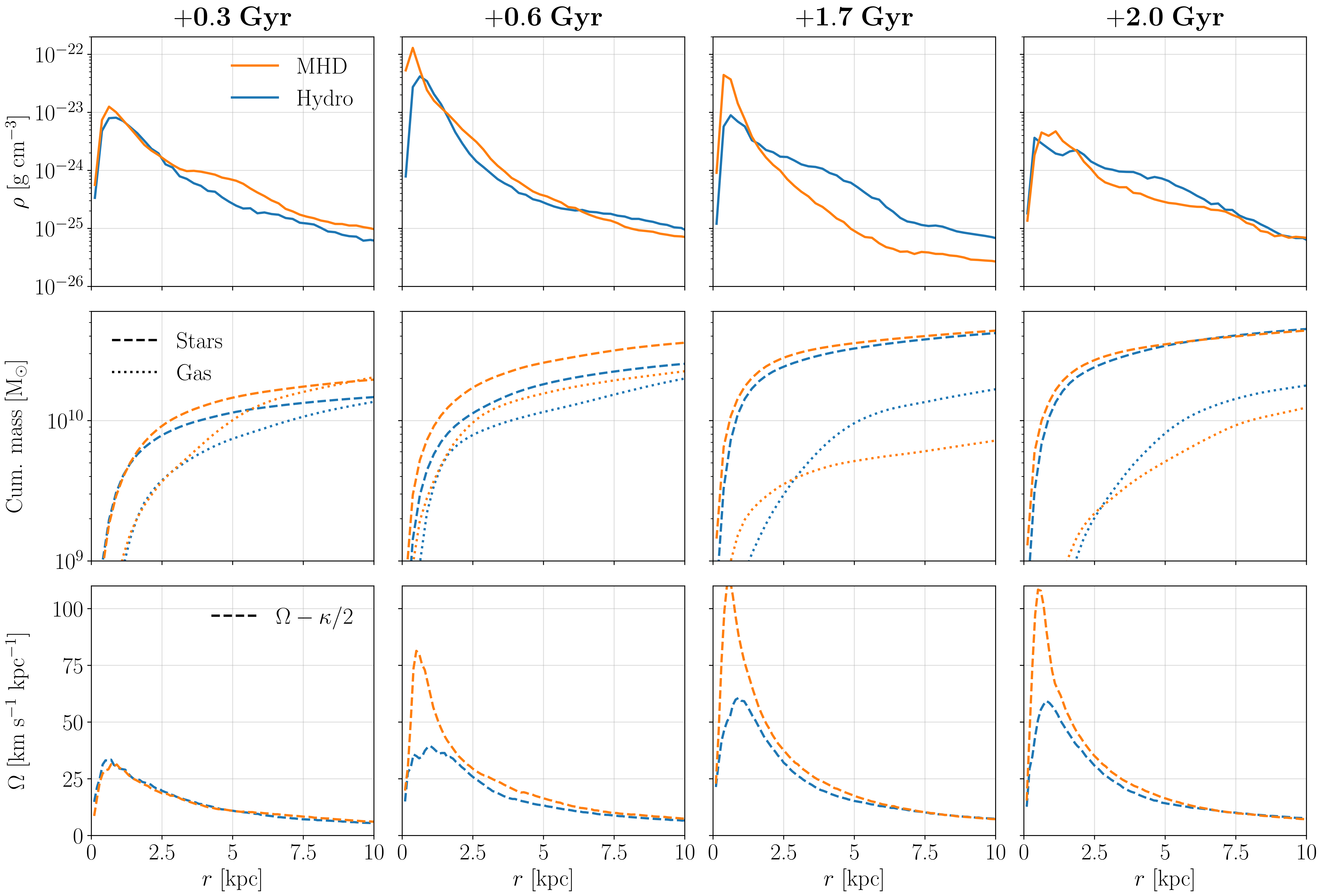
Ran two extra simulations with quasar feedback turned off at start of merger

See same morphological changes anyway; in fact, differences are bigger without AGN feedback!

AGN appears to suppress effect rather than cause it.



The effect of increased concentration *pt. 2*



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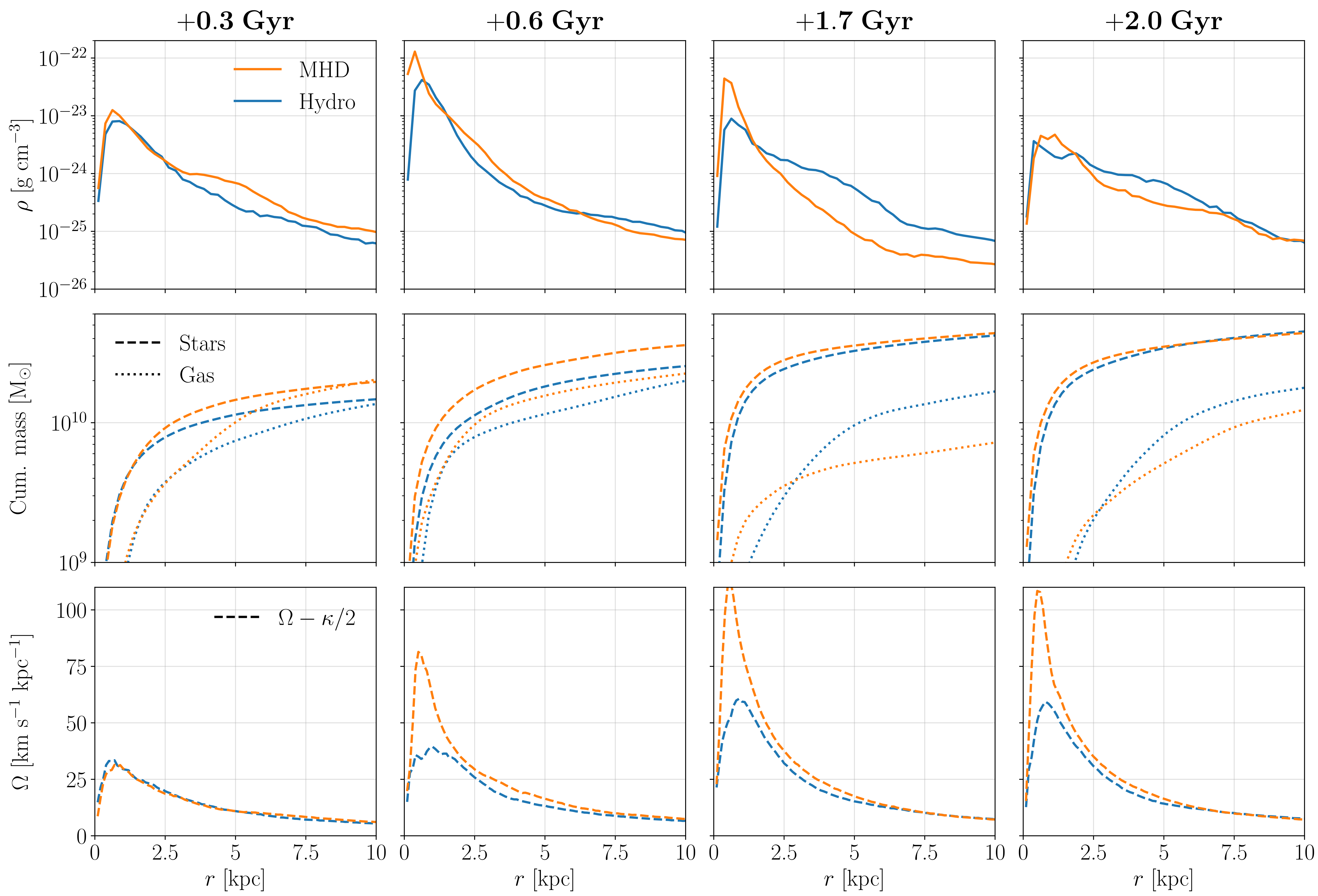
The effect of increased concentration *pt. 2*

...increases the subsequent stellar concentration



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The effect of increased concentration *pt. 2*

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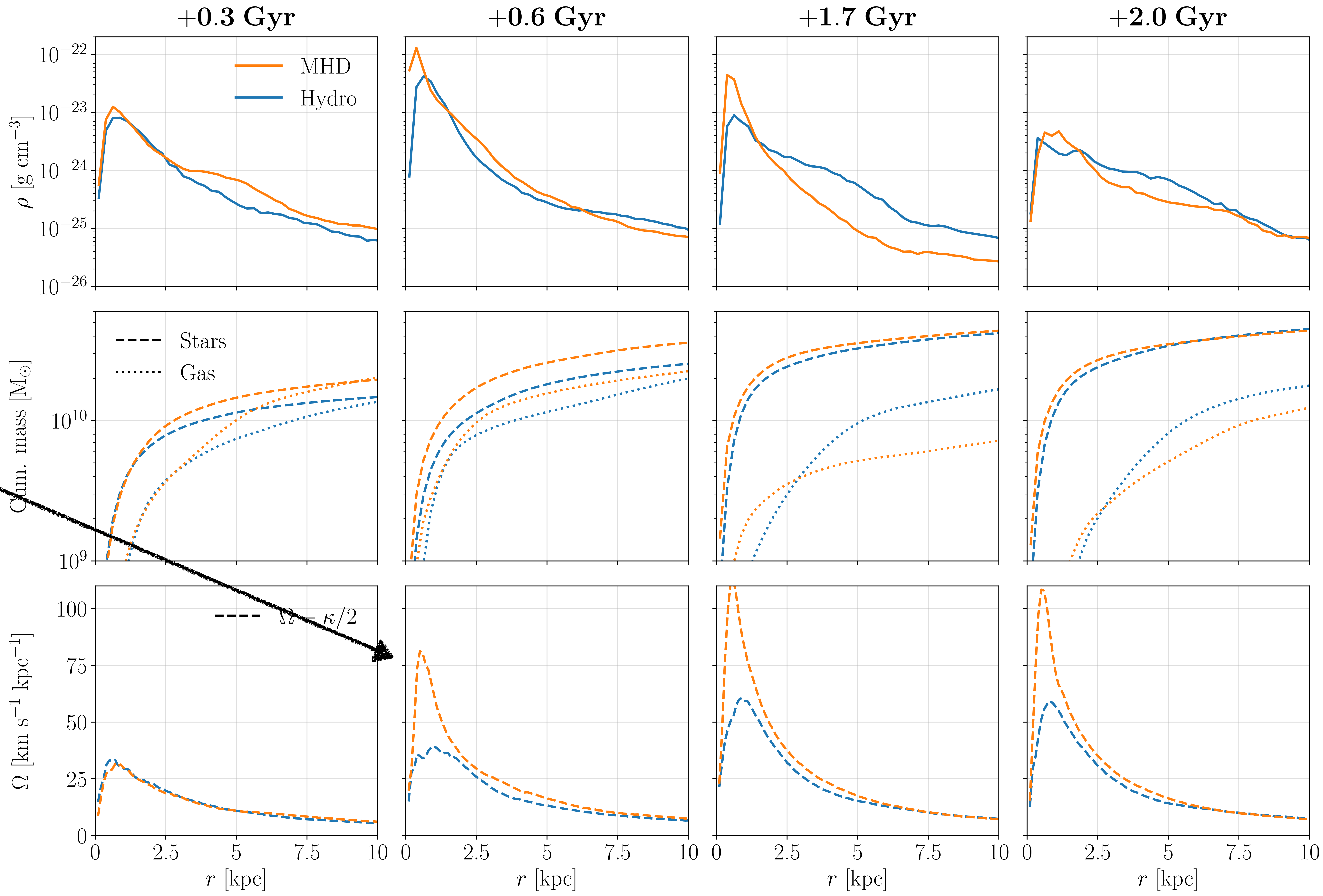
Larger barrier to avoid inner Lindblad resonance (ILR)



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The effect of increased concentration *pt. 2*

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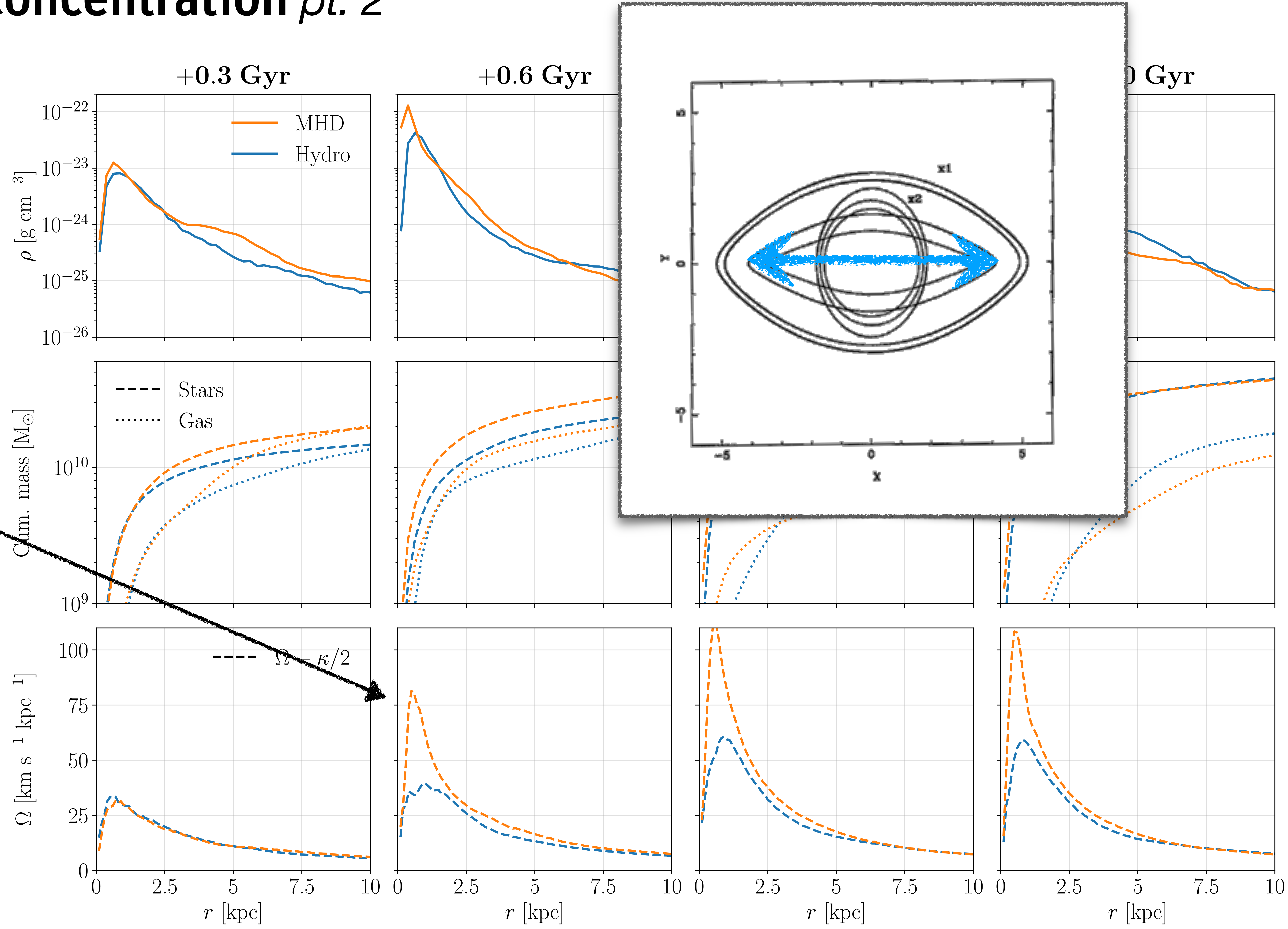
Larger barrier to avoid inner Lindblad resonance (ILR)

A large ILR suppresses bar formation

- "x_2" orbits exist within ILR and are aligned orthogonally to bar, acting against it



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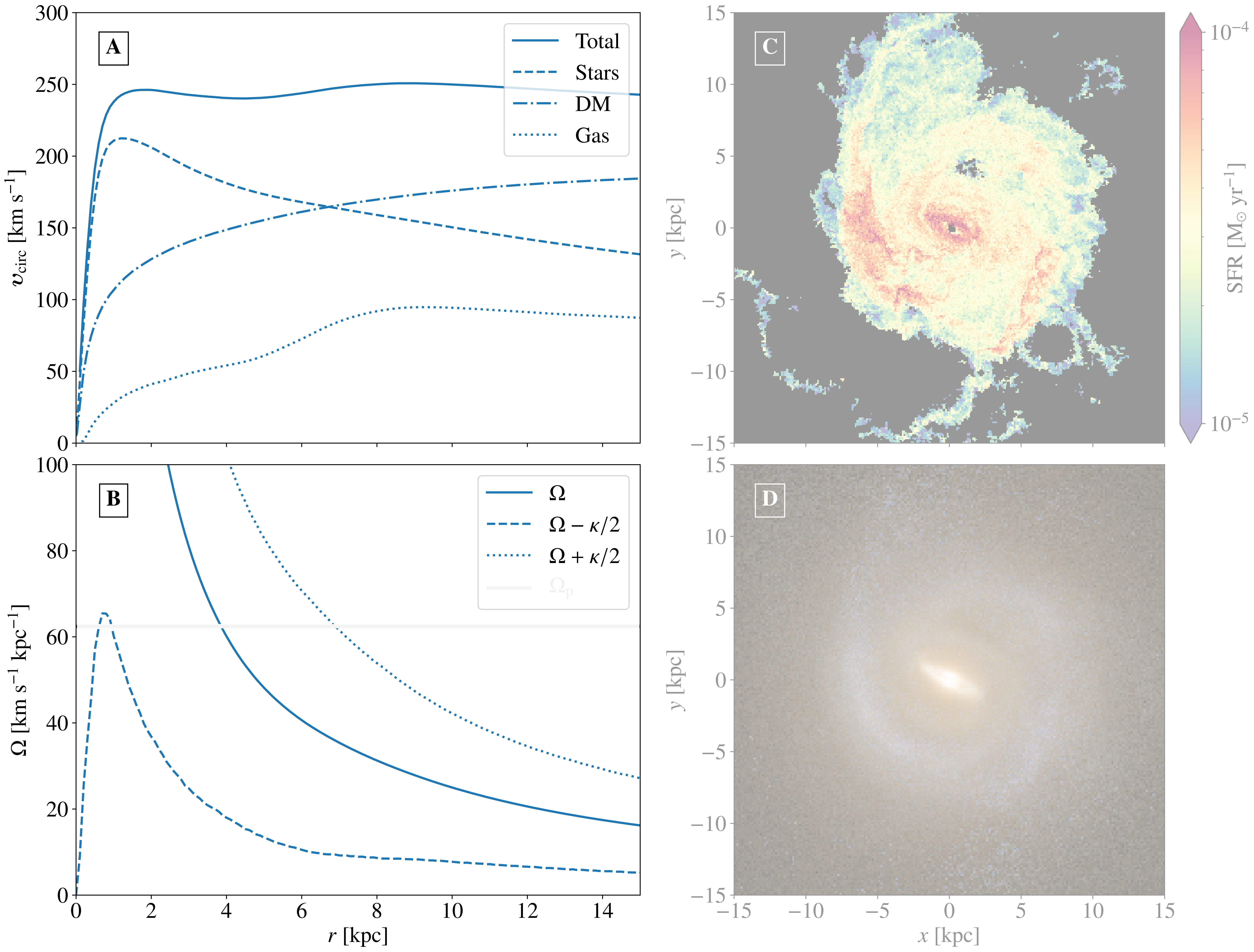
The effect of *not* having increased concentration

Two other important resonances: co-rotation, and outer Lindblad (OLR)

Key formula:

$$\Omega = v_{\mathrm{circ}}/r$$

$$\kappa^2 = 2\Omega\left(\Omega + \frac{\mathrm{d}v_{\mathrm{circ}}}{\mathrm{d}r}\right)$$



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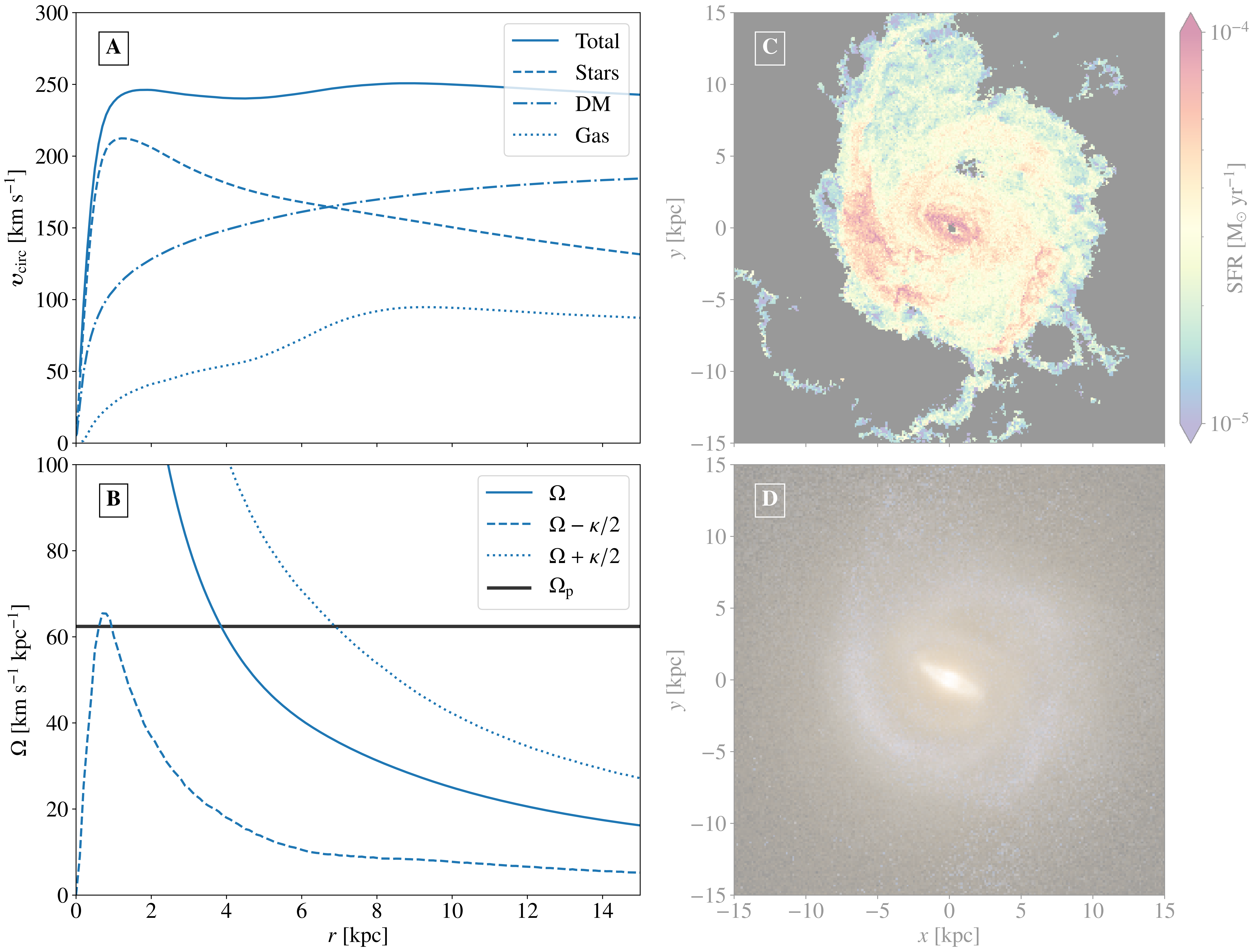
Intersection of bar pattern frequency and resonant profiles gives (radial) position of resonances



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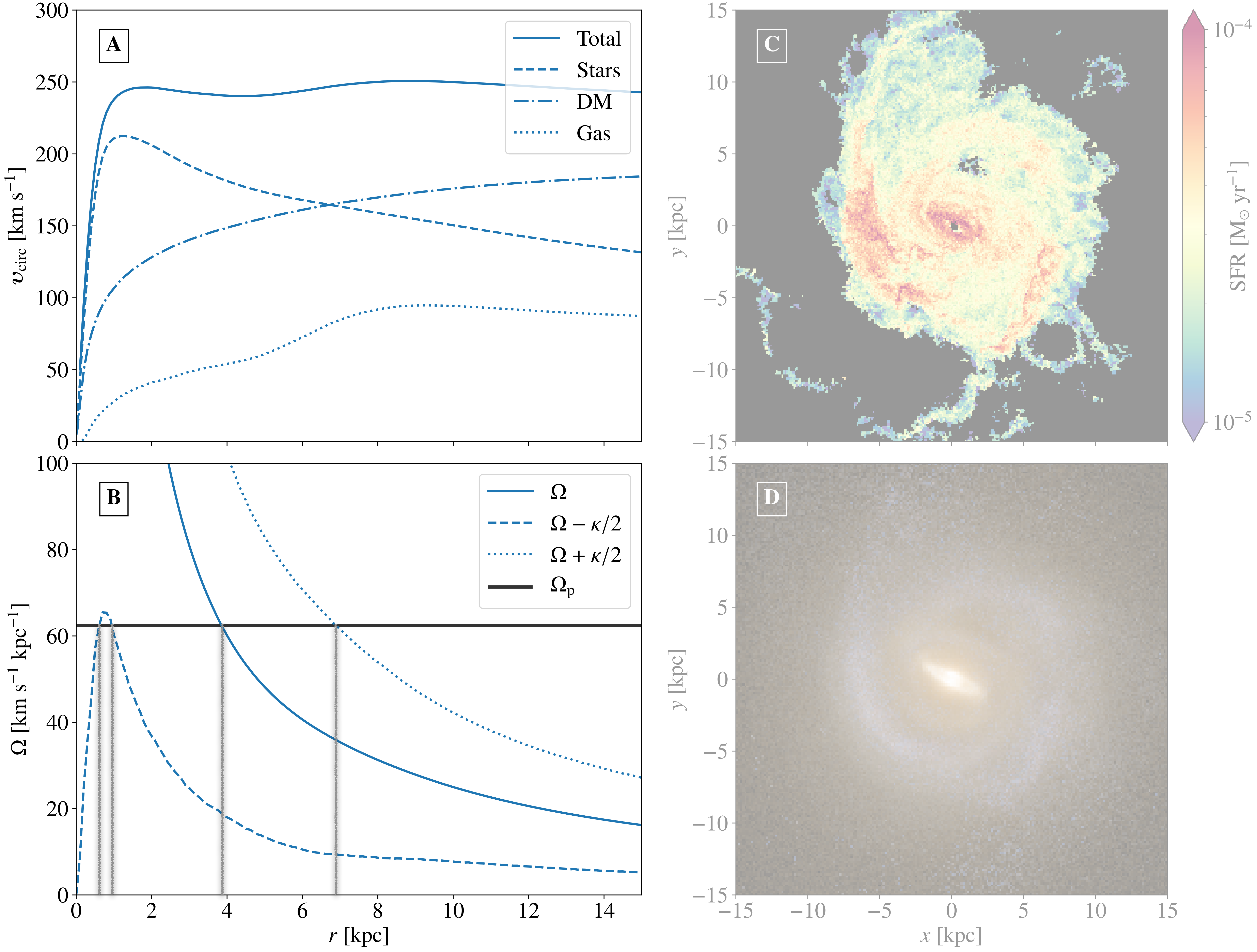

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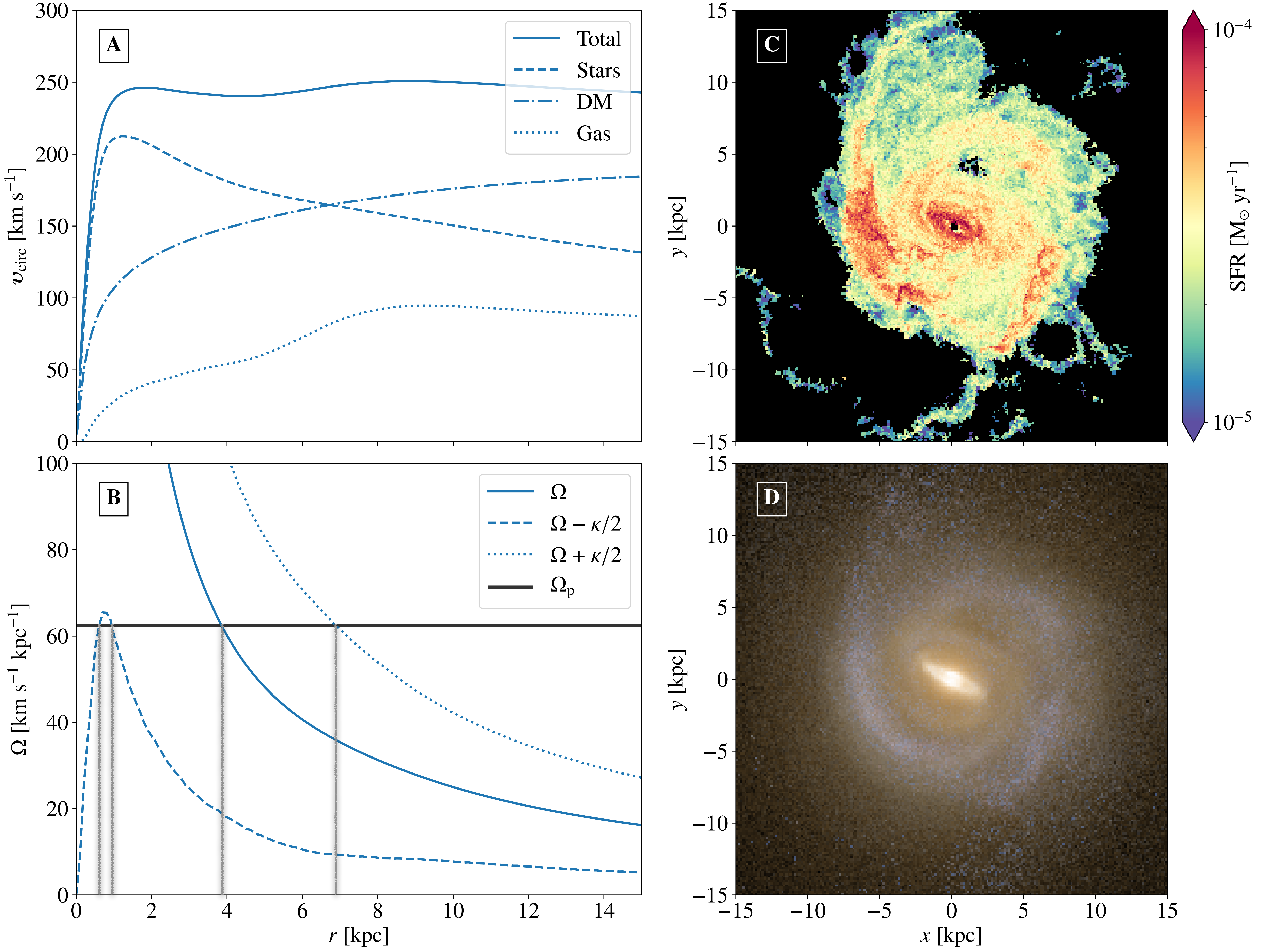

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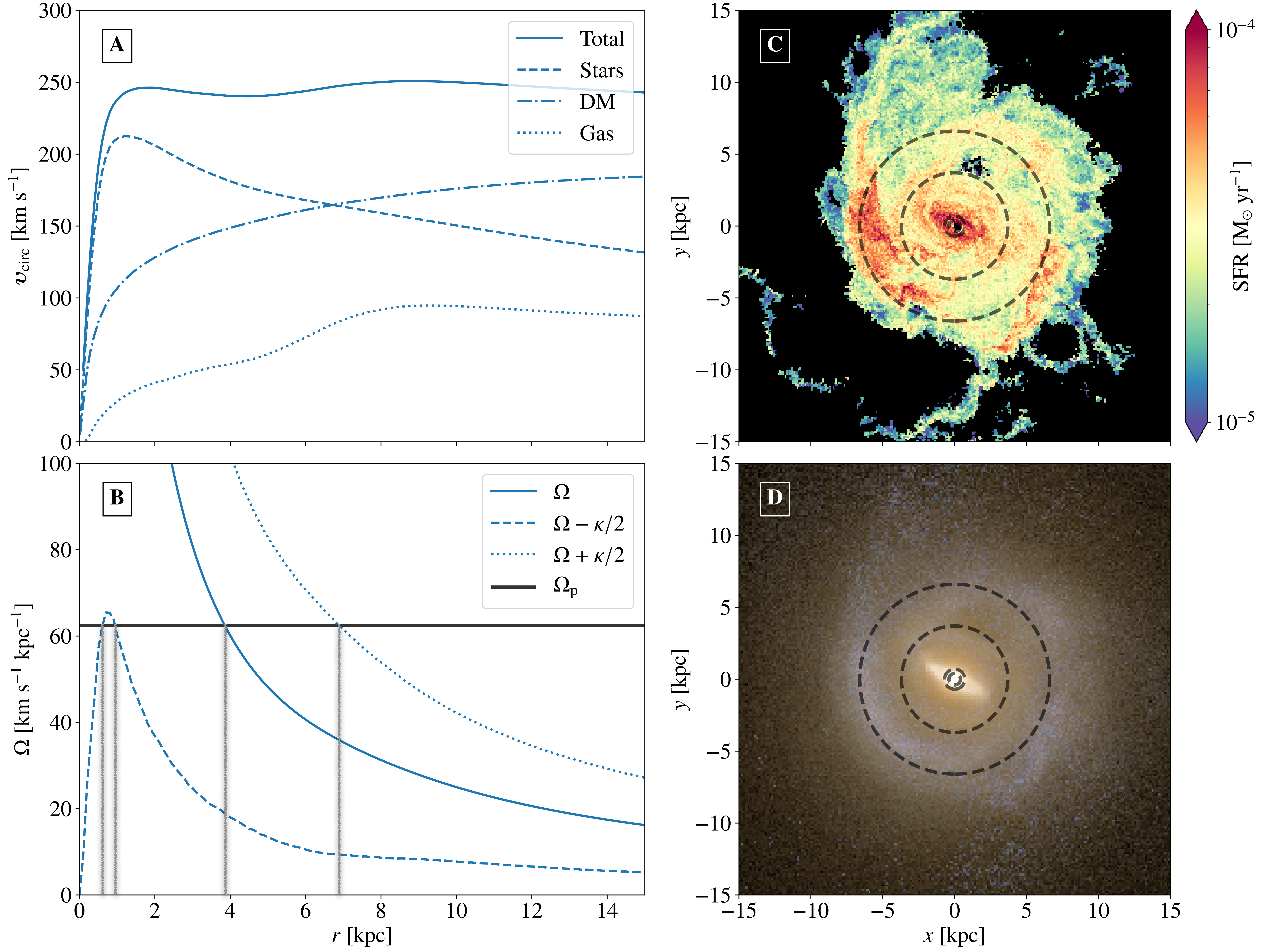
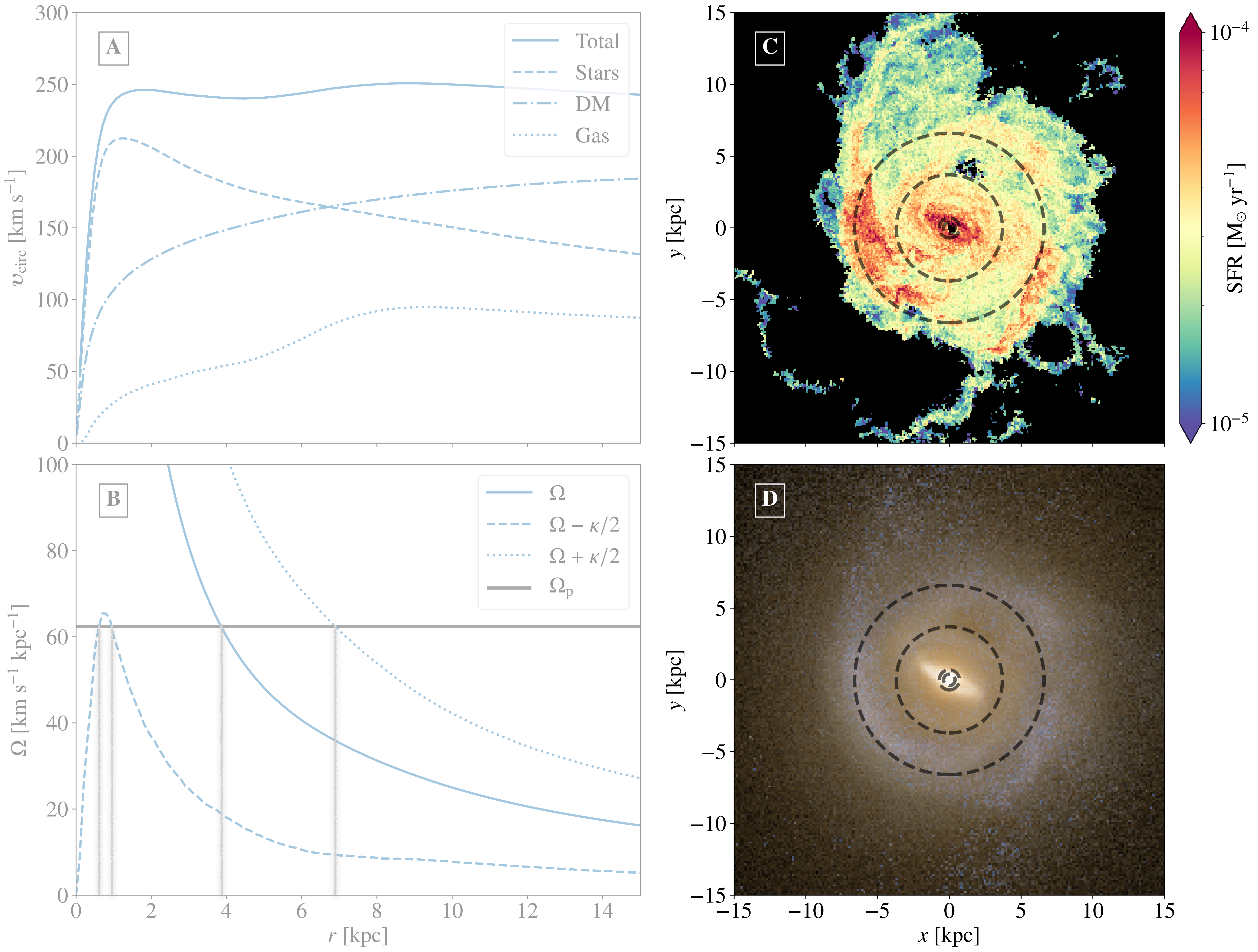


The effect of *not* having increased concentration

Bar acts to drive gas away from co-rotation resonance and towards ILR and OLR (as expected from theory!)

Results in high gas density

→ high SFR density!



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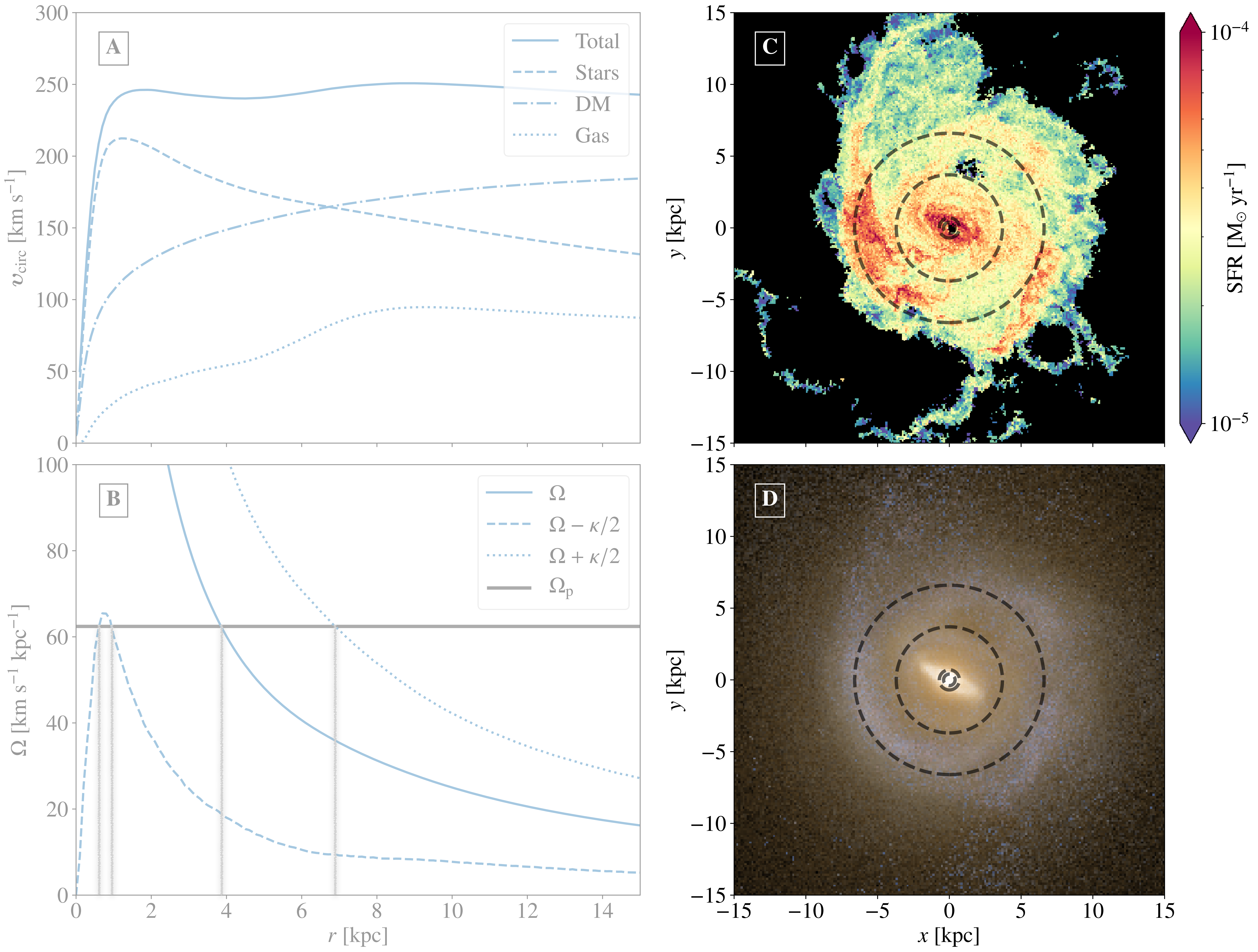
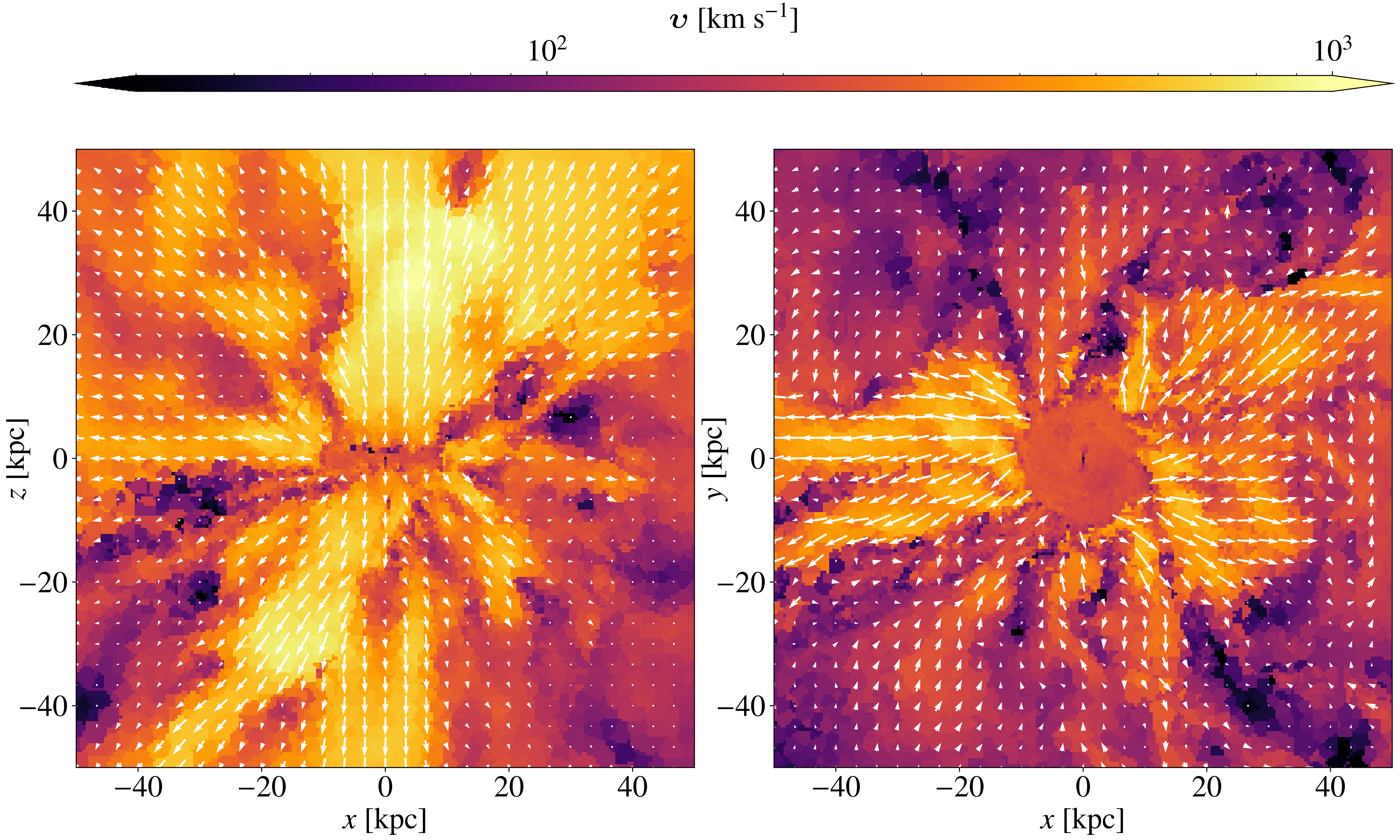
Increased stellar feedback!



Impact of …increased *stellar* feedback in *hydro*

Winds in hydro run severely disrupts the local CGM

- Accreting gas must have a strong radial component
- Galaxy stays compact



Edge-on slice showing gas velocity ***Face-on slice showing gas velocity***

Impact of ...increased *AGN* feedback in *MHD*

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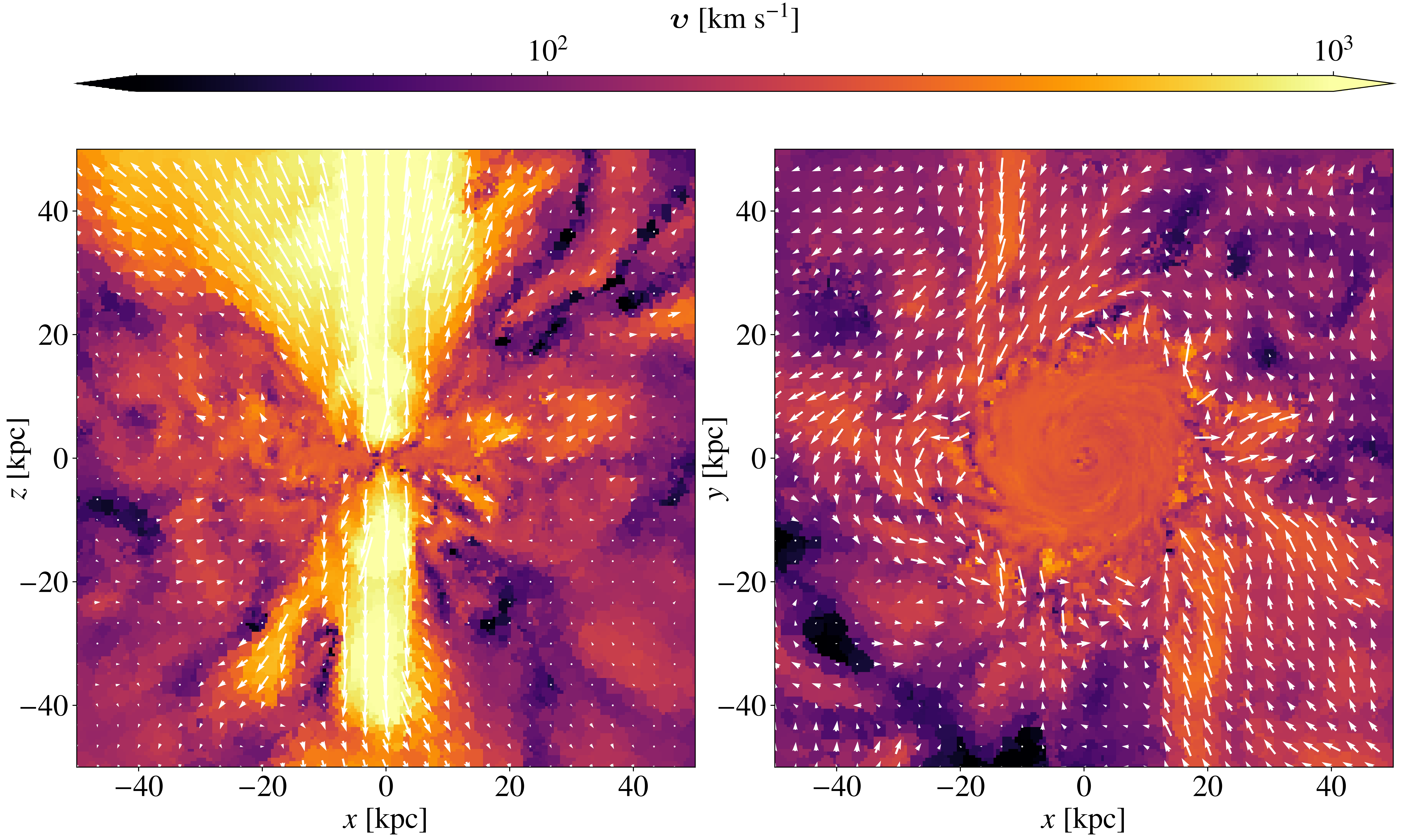
Star formation is more distributed in MHD sims

- Stellar wind is weaker
- AGN is less disruptive
- Gas at the outskirts retains its ang. mom.



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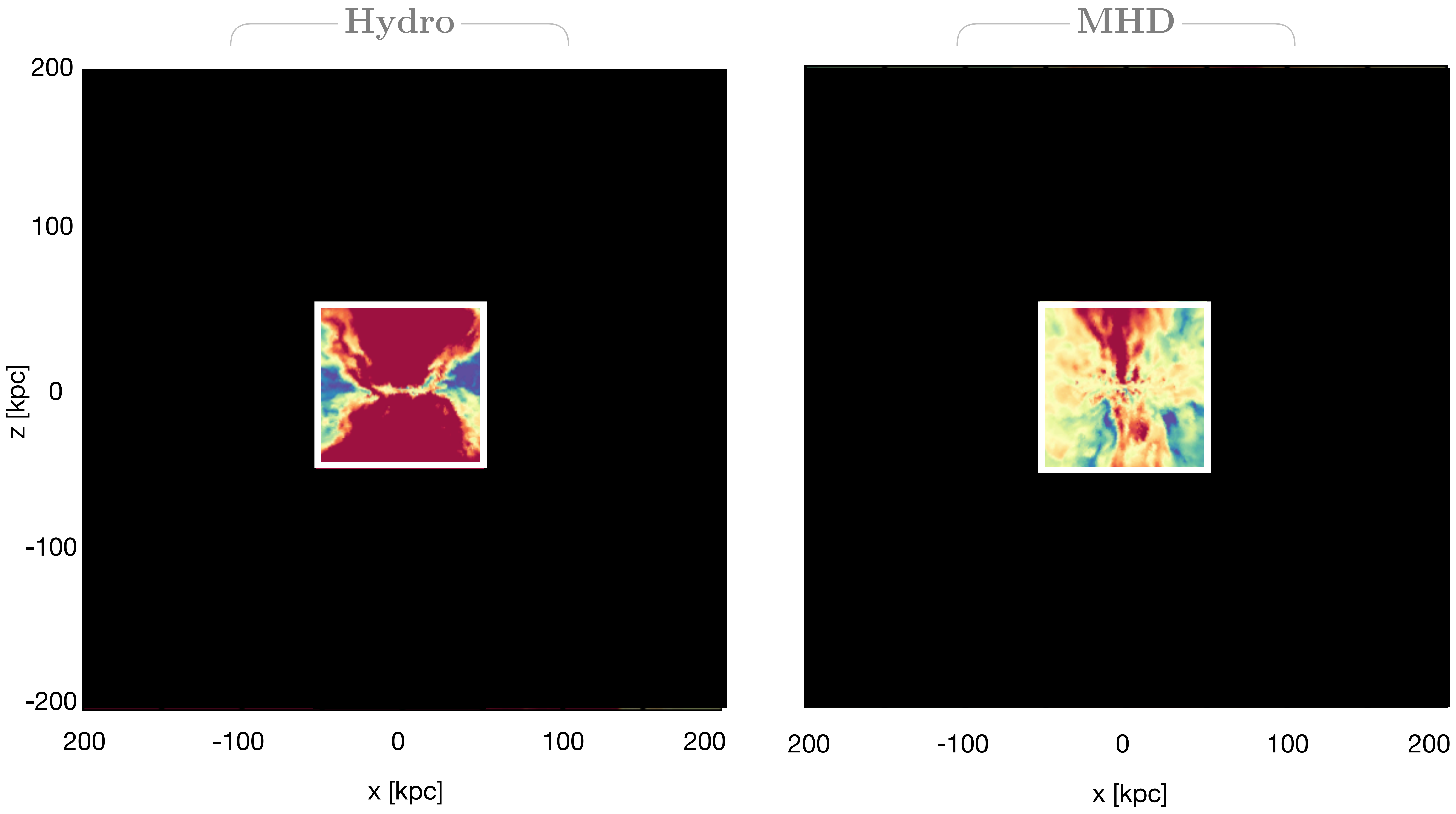

Wider impact on the CGM!

Credit: van de Voort, et al. (2021)

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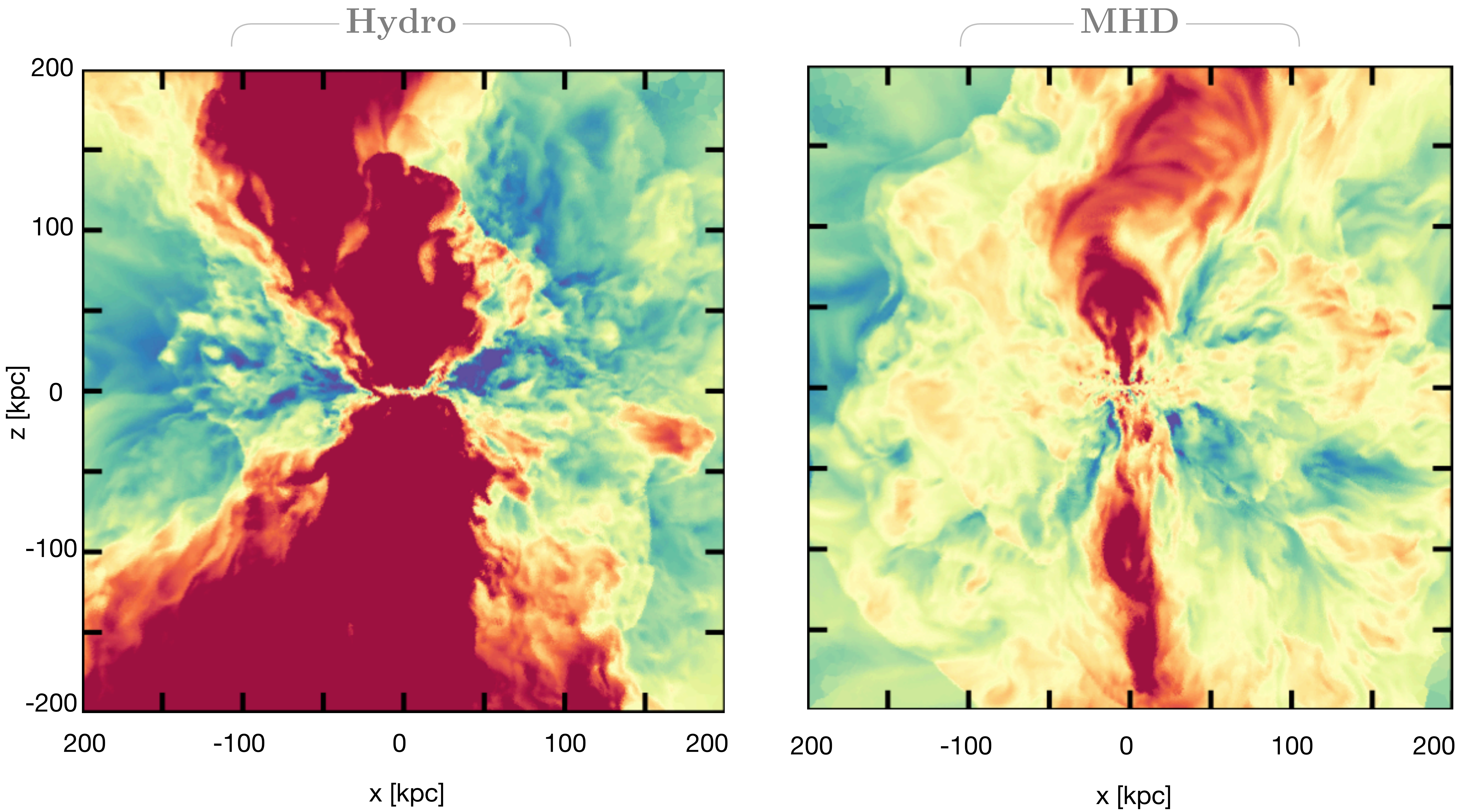

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Application to other physics models?

Tuning feedback parameters in Auriga ruled out

→ Different SFR/ AGN impacts checked

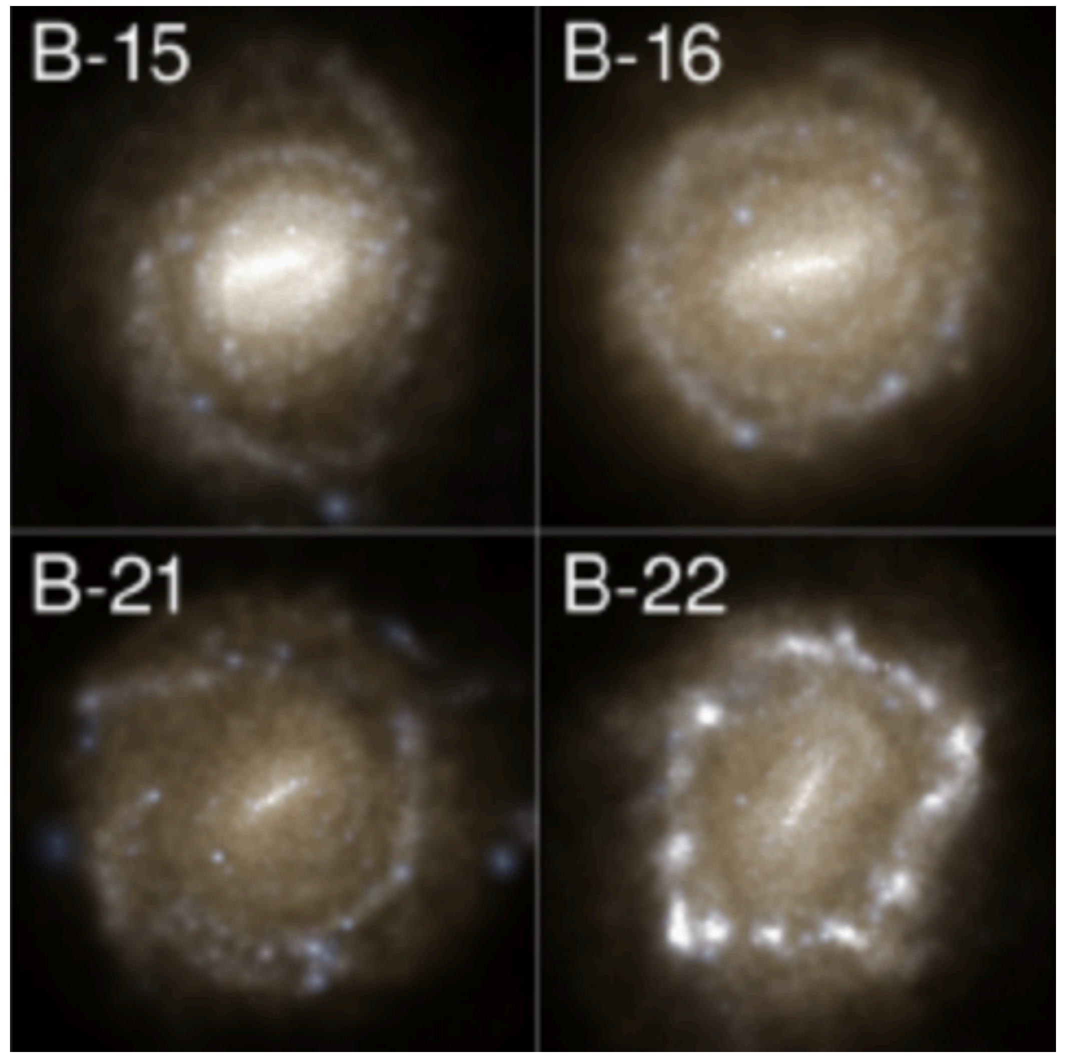
Feedback tends to suppress accretion of high ang. mom. gas

...but magnetic fields can bring it into the galaxy

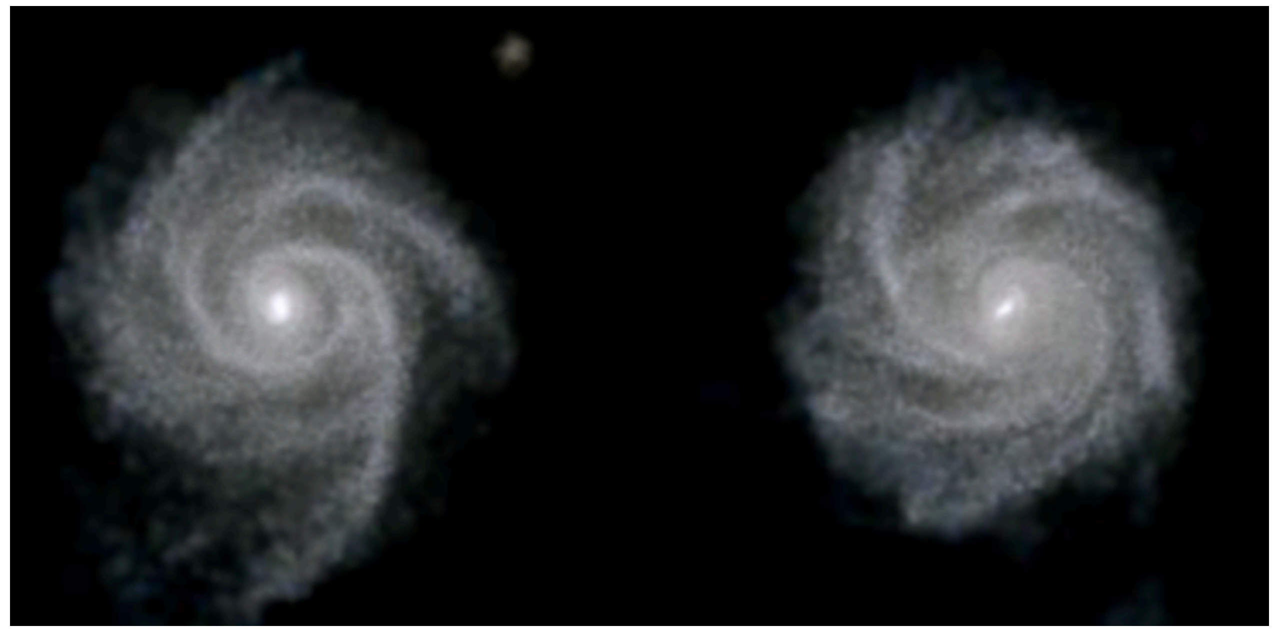
→ Shrink disc before growing it substantially

Depends on strong enough magnetic fields!

Bar and ring galaxies produced in original Illustris →



Nice spirals in Illustris TNG



Credits: *https://www.illustris-project.org/media/*
https://ras.ac.uk/media/361

Conclusions

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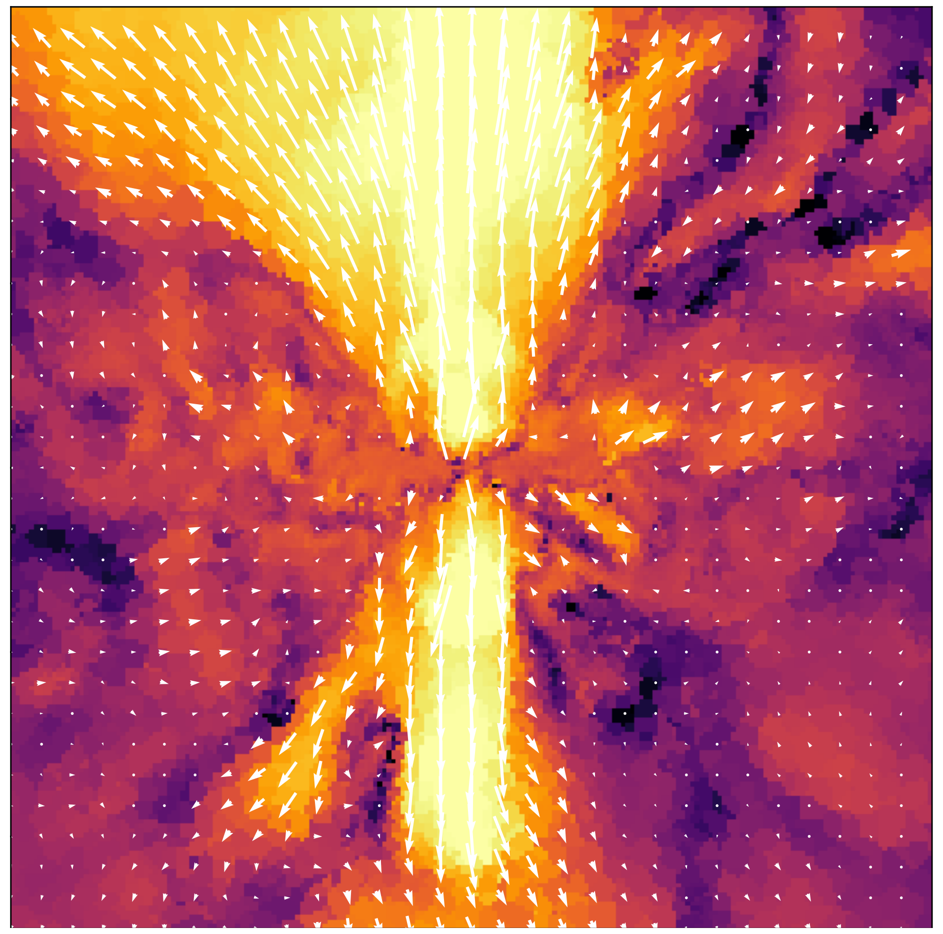
Magnetic fields

- *change the morphology* of disc galaxies in Auriga

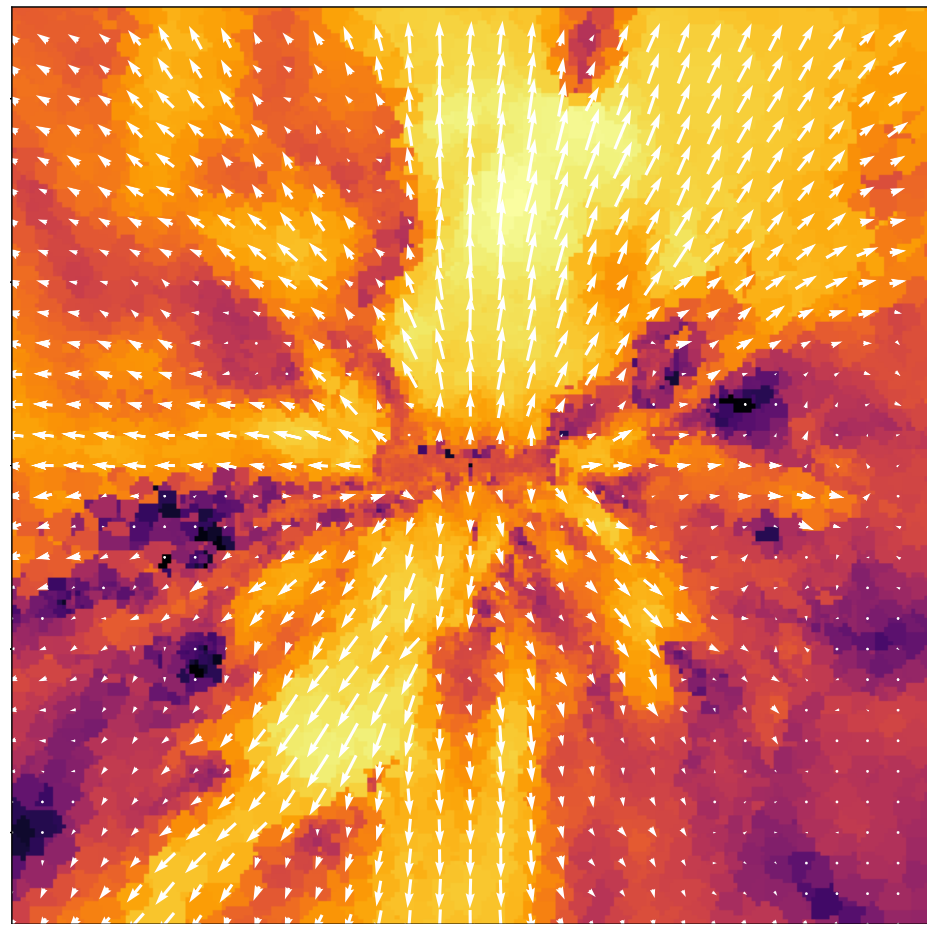
...by

- typically *increasing central gas density*
- fuelling *black hole growth*
- suppressing *bar formation*
- changing *feedback channel* from stellar to AGN!

MHD



Hydro



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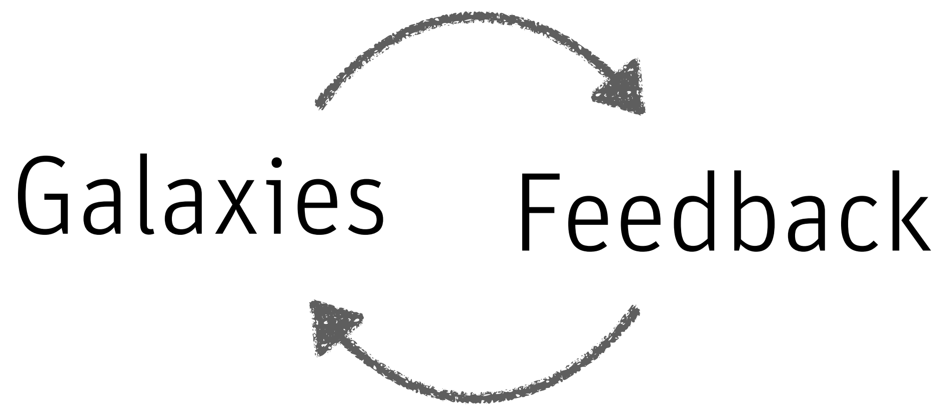
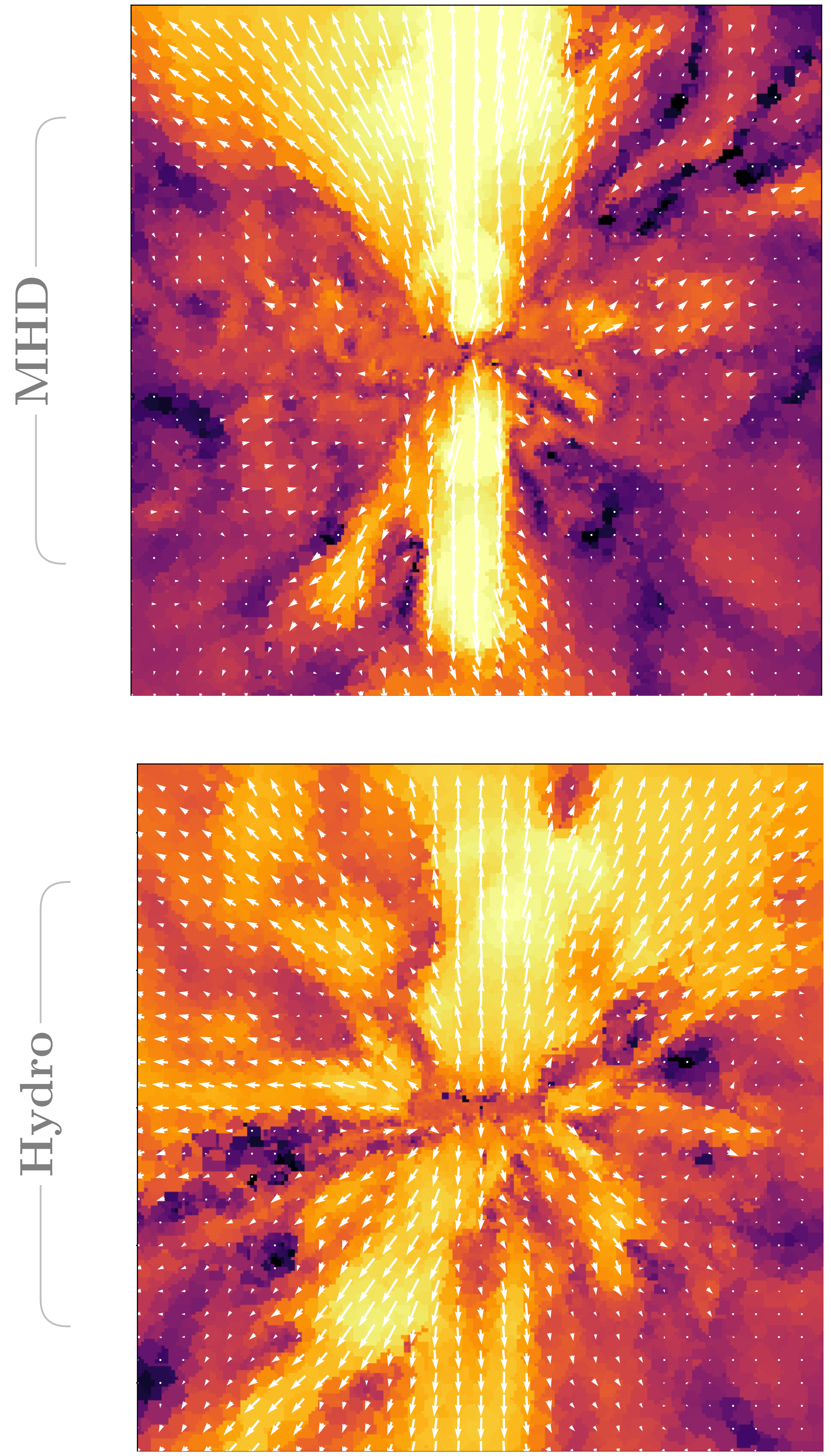
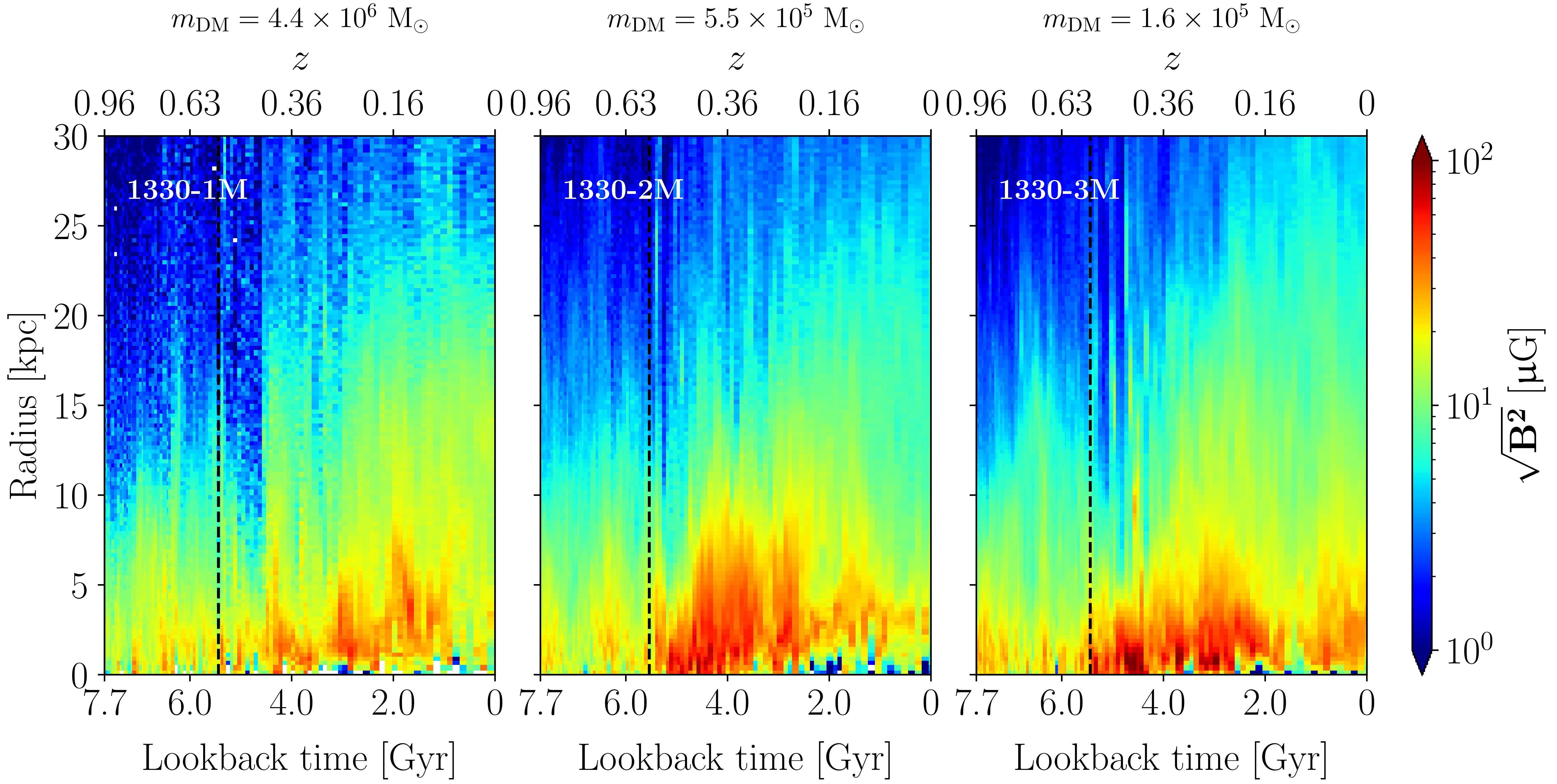




Mergers amplify magnetic fields, *but…*

Sufficient resolution is required to realise the effect



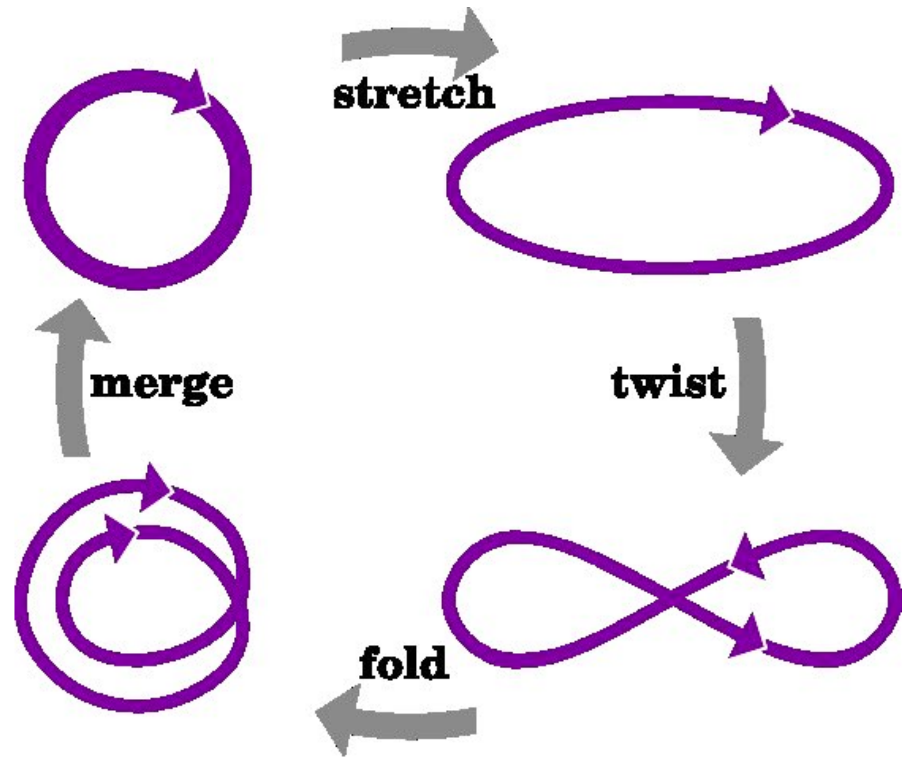
Mean radial magnetic field strength in the disc as a function of time
(Resolution becomes finer left to right)

Mergers amplify magnetic fields, *but...*

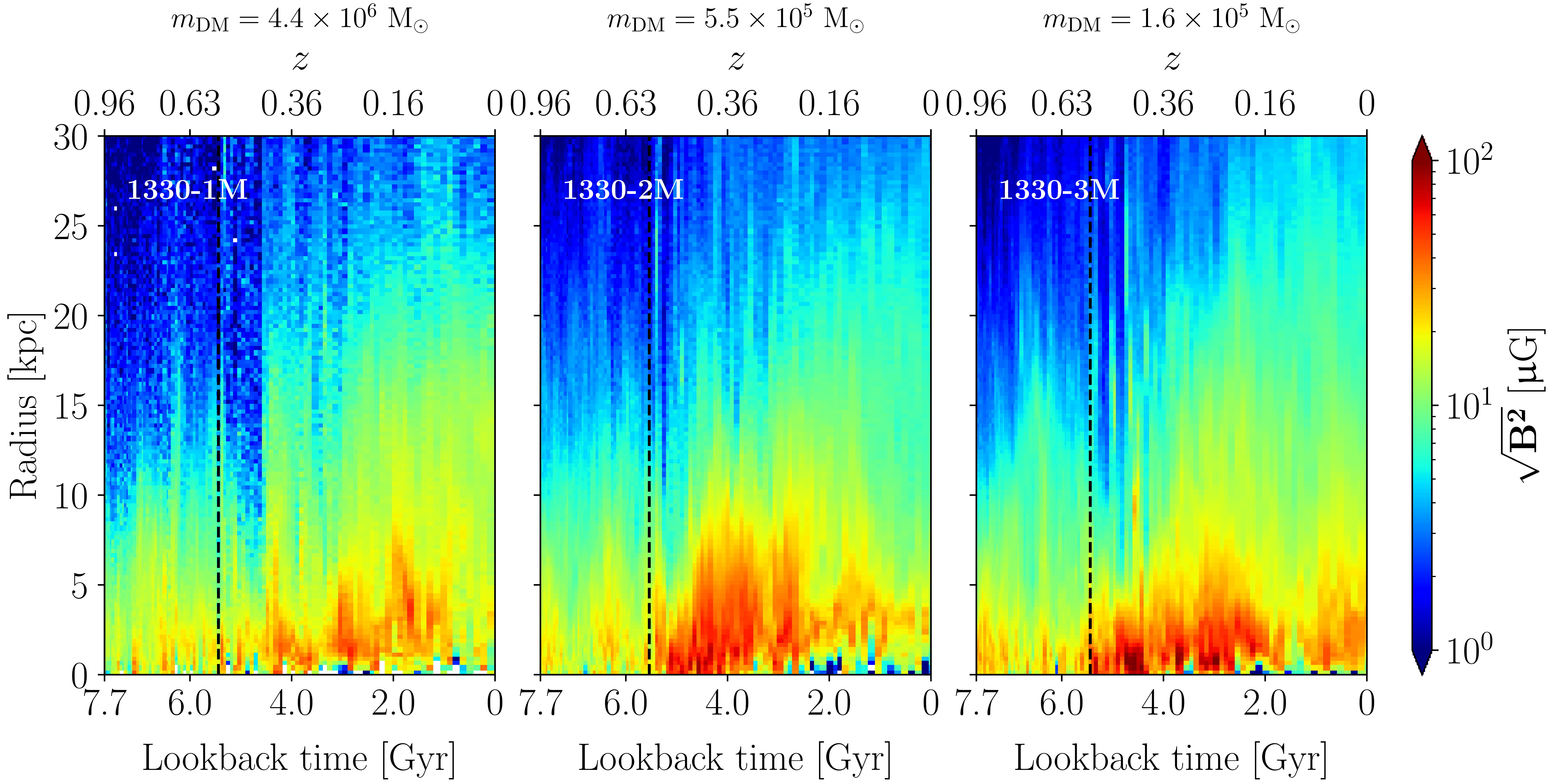
Sufficient resolution is required to realise the effect

Originates from the need to resolve sufficiently small-scale eddies

(i.e. to realise a small-scale dynamo!)



Credit: J. Schober



Mean radial magnetic field strength in the disc as a function of time
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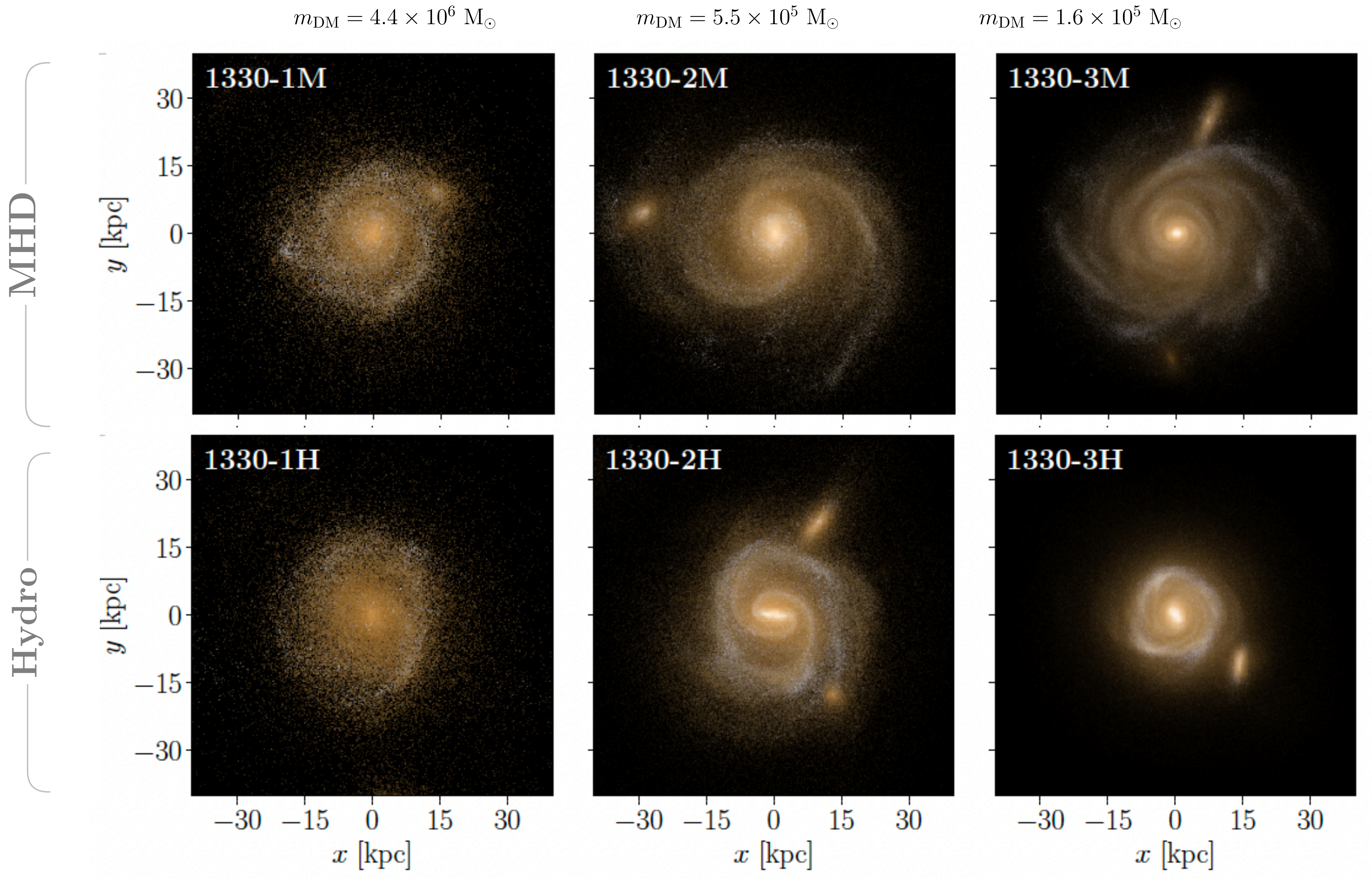
Impact of resolution?

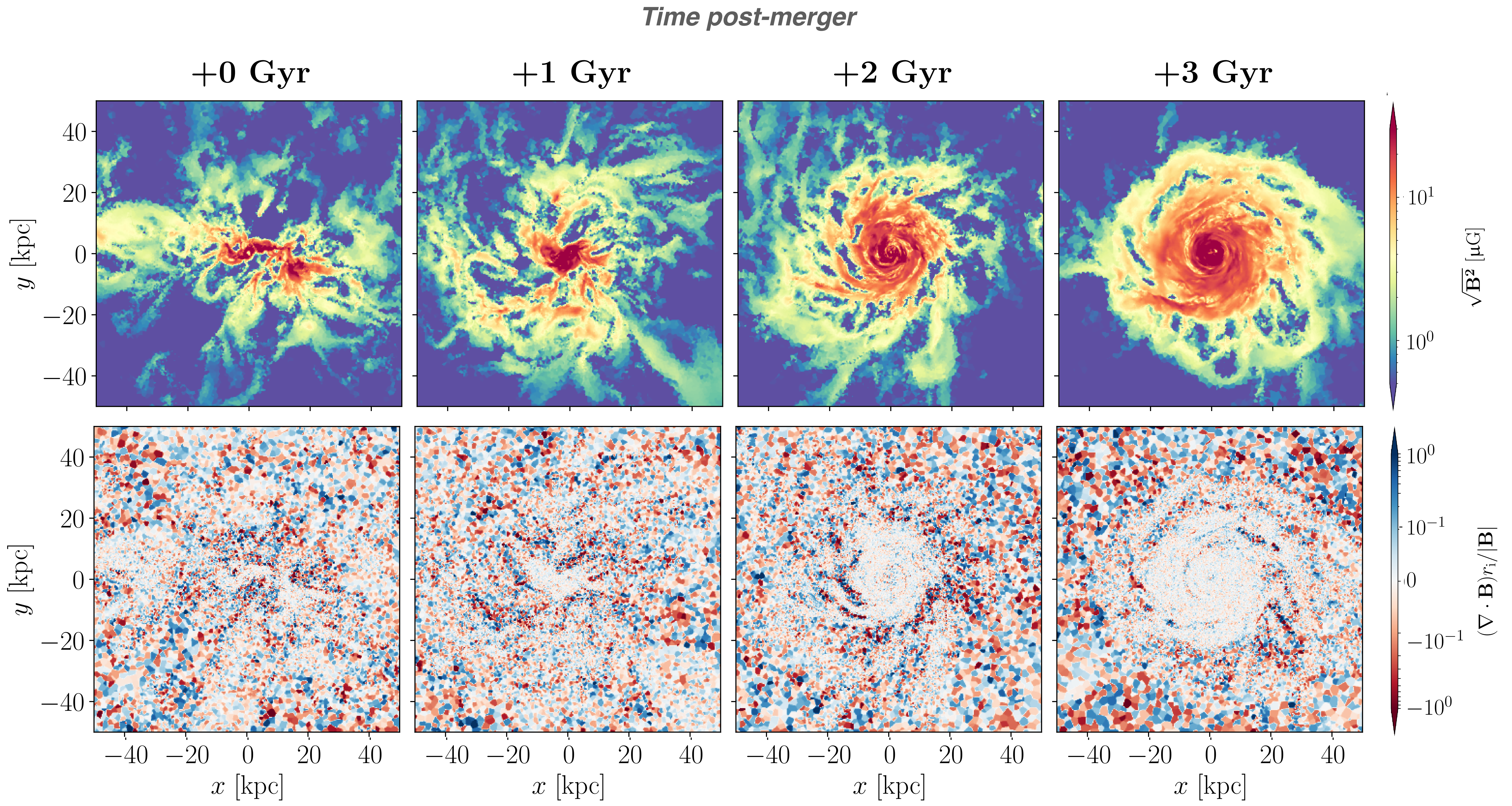
Increasing resolution ---->



What about our MHD solver?

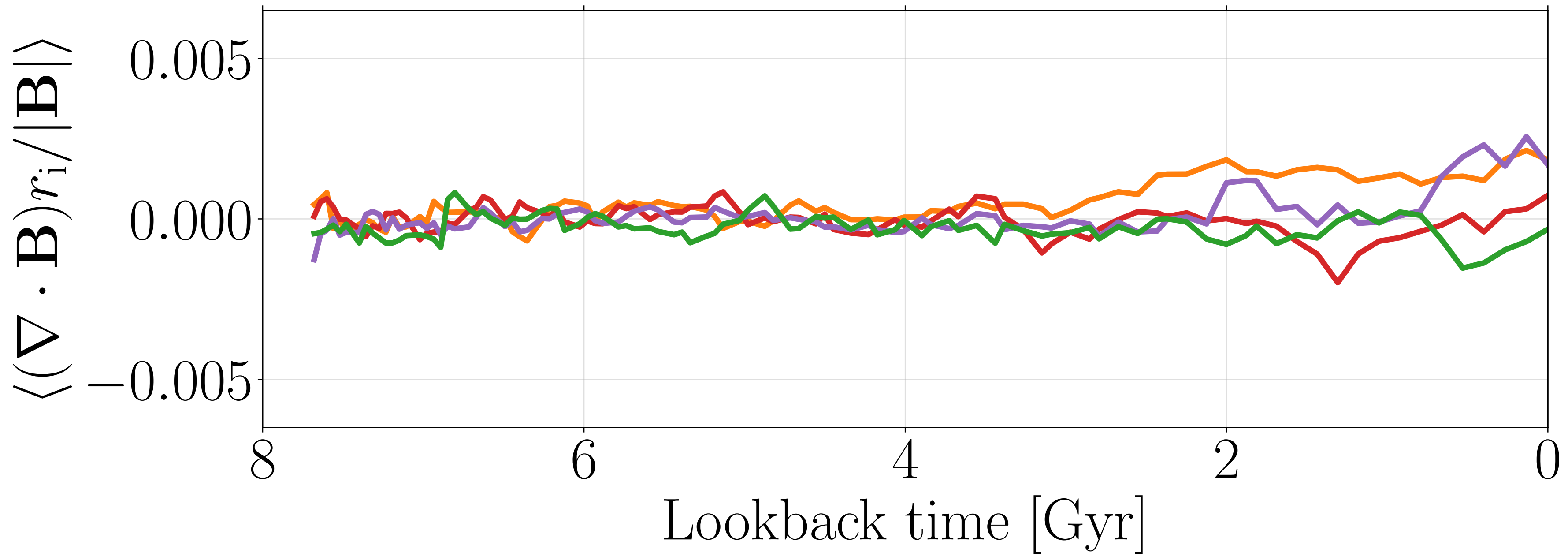
Divergence is:

- Low in disc
- Uncorrelated spatially and temporally



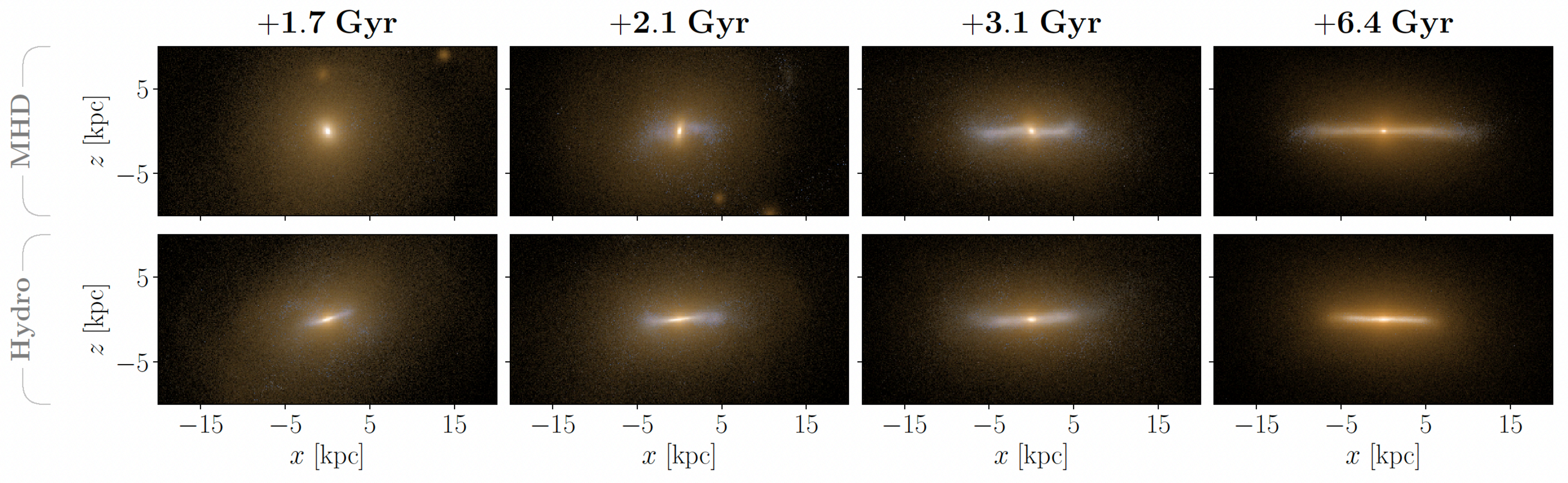
Relative divergence globally low

(<0.5%)



Using all cells within 100kpc of the main progenitor!

Further evidence of angular momentum transfer

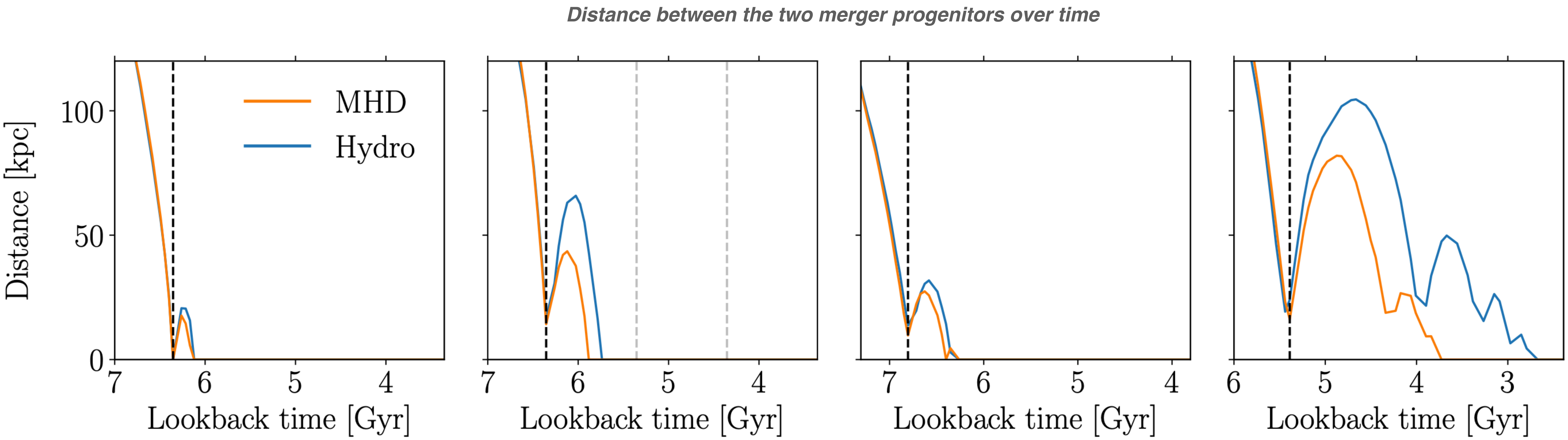


Edge-on m*ock gri visual image from stellar light for 1349-3M and 1349-3H*

Gas accretes with (initially) different alignment in MHD case

→ new stellar disc forms misaligned to old population

Further evidence of angular momentum transfer



Angular momentum transfer speeds up merger

(most effective when merger is "in-spiralling")