Controlling Galactic Spin: Unravelling the Causal Origin of their Angular Momentum in a Cosmological Context

LUNDS UNIVERSITET

With **A. Storck, Z. Kocjan, E. Pichon-Pharabod** &
Agertz, Pontzen, Peiris, Pichon, Dubois

Cadiou, Pontzen & Peiris 21 · Cadiou, Pontzen +21 · Kocjan, Cadiou, Agertz, Pontzen 24 · Cadiou, Pichon-Pharabod+24

Corentin Cadiou
BuGS
22/02/24

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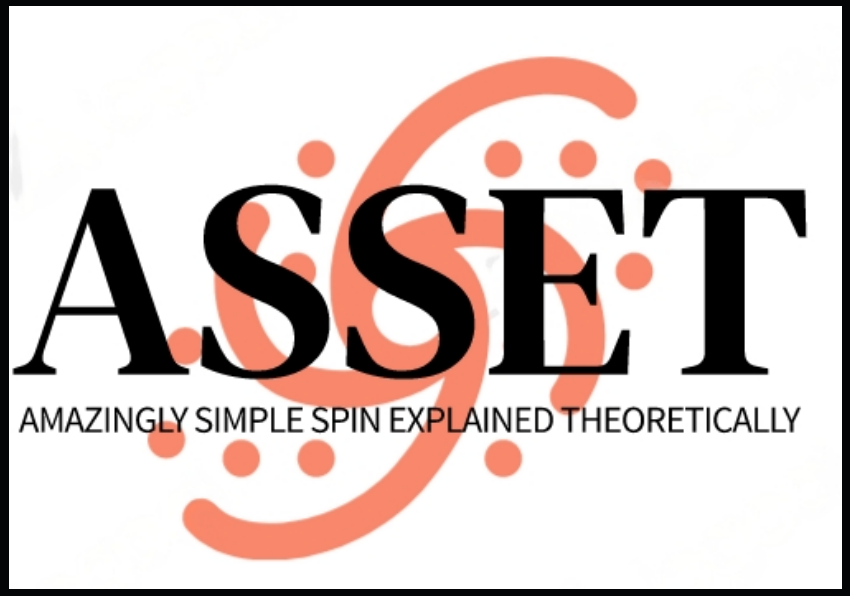

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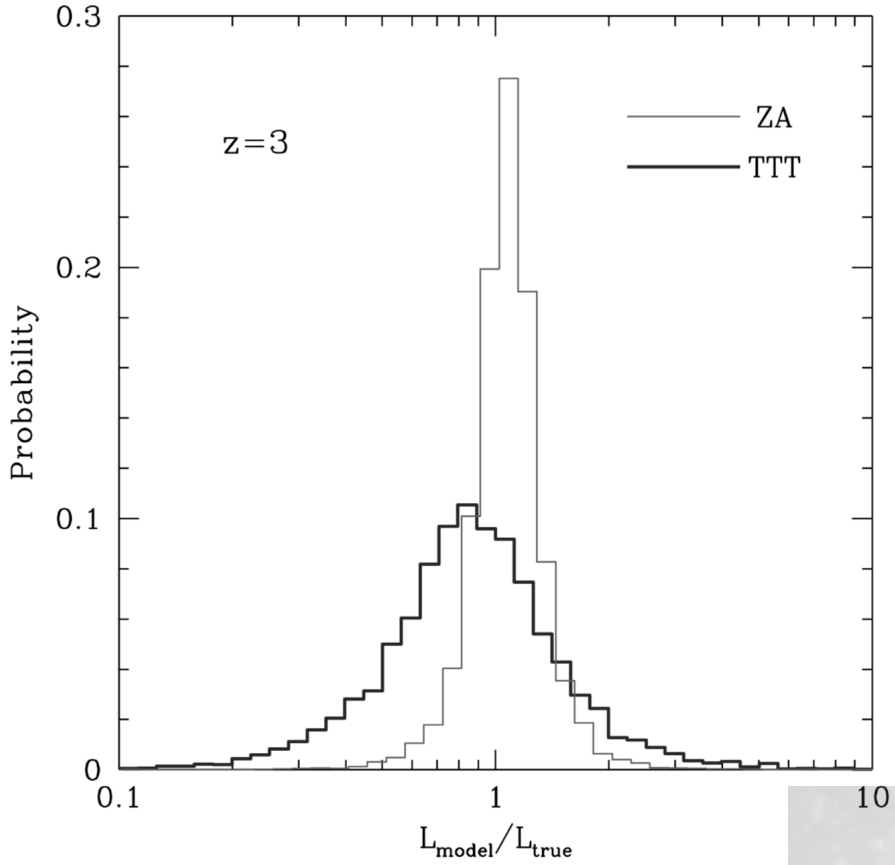
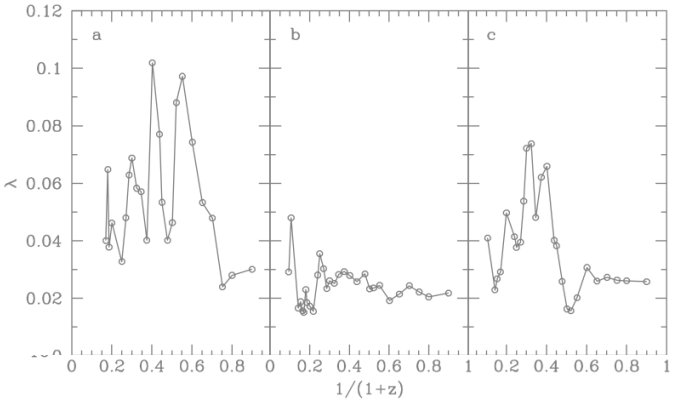


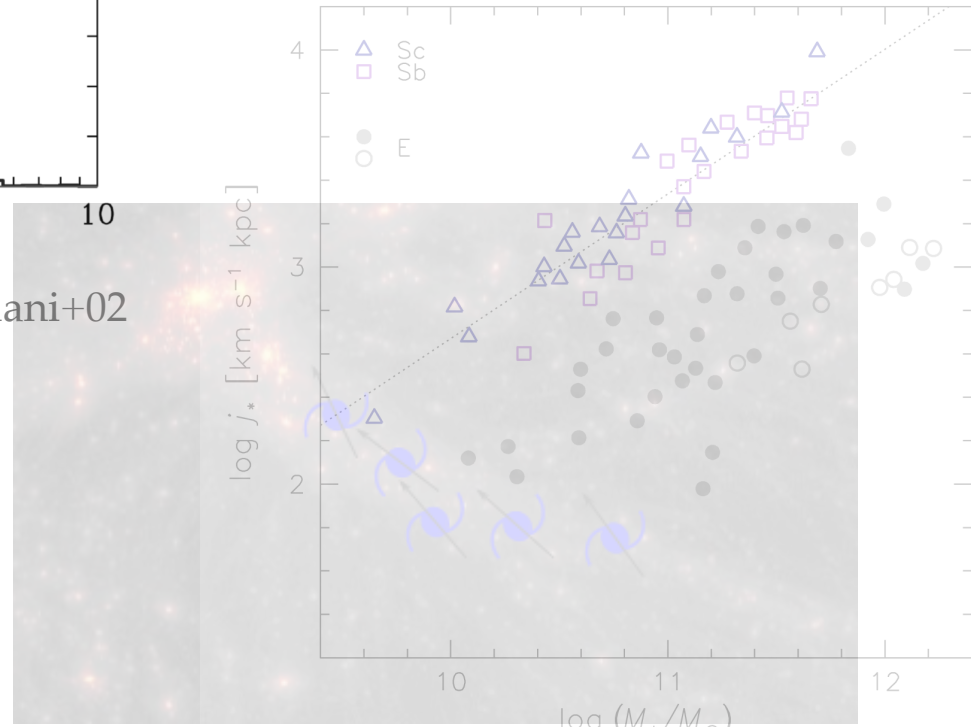


Vitviska+02, Benson+20

Angular momentum:

1. *Qualitatively* understood
2. Abrupt changes with mergers
3. Crucial for galaxy formation + weak lensing

Porciani+02



Fall+80

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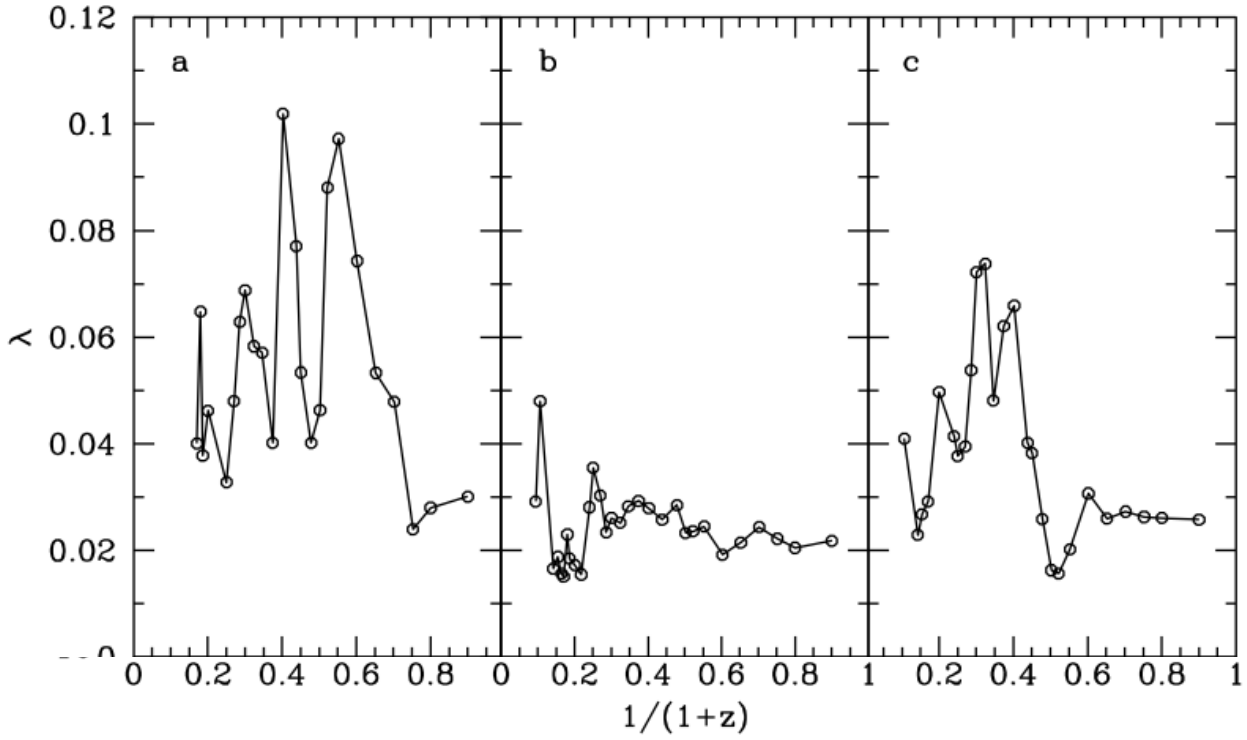

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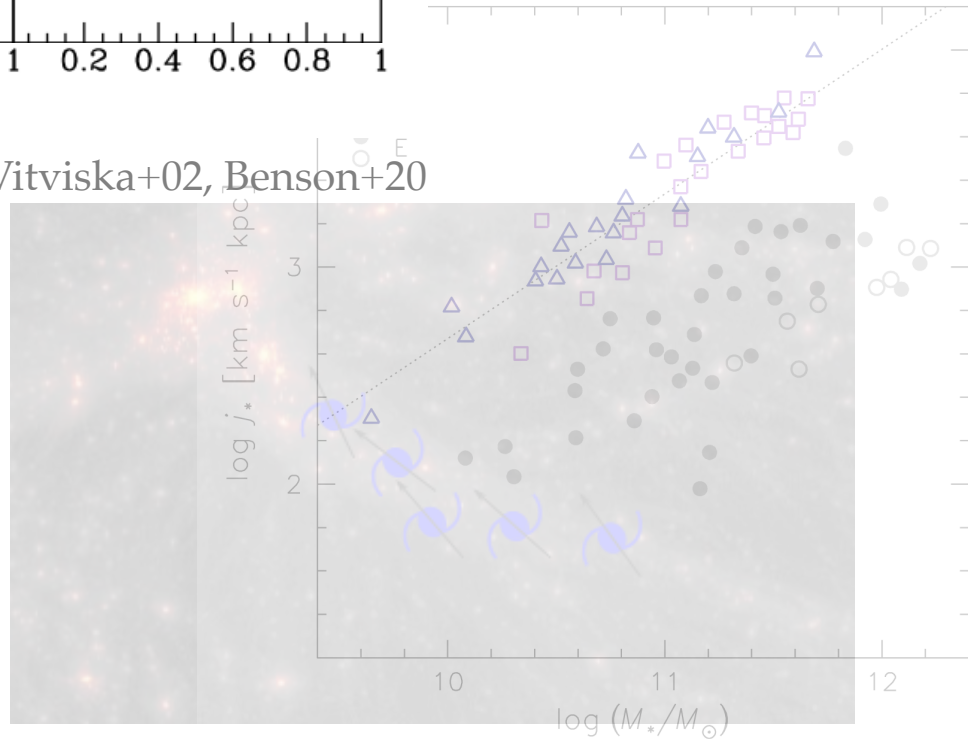

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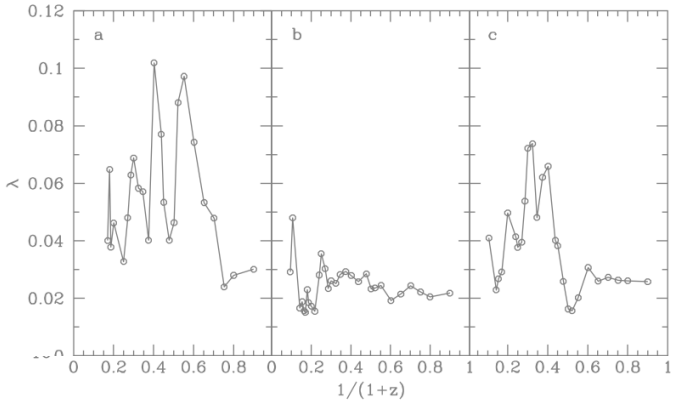

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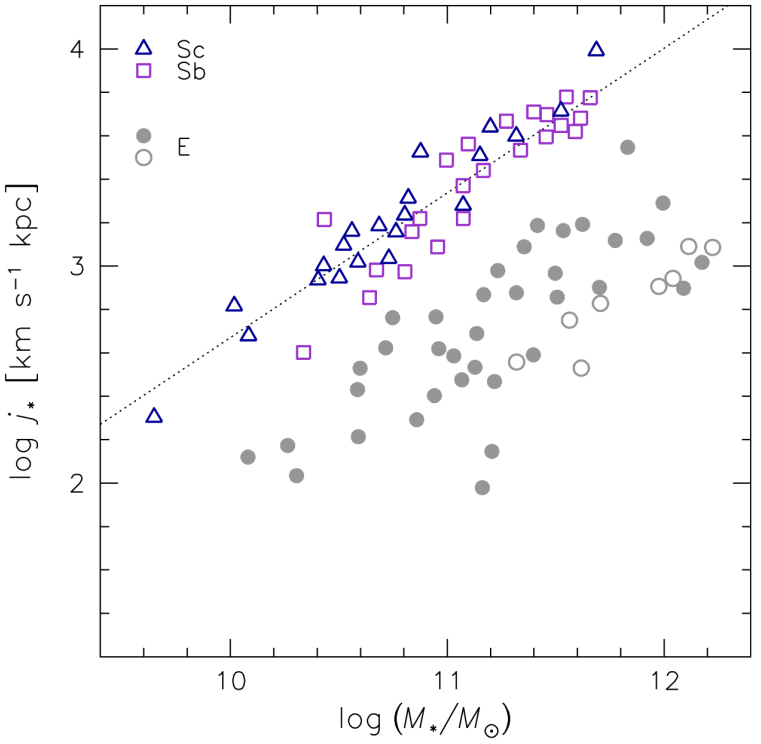

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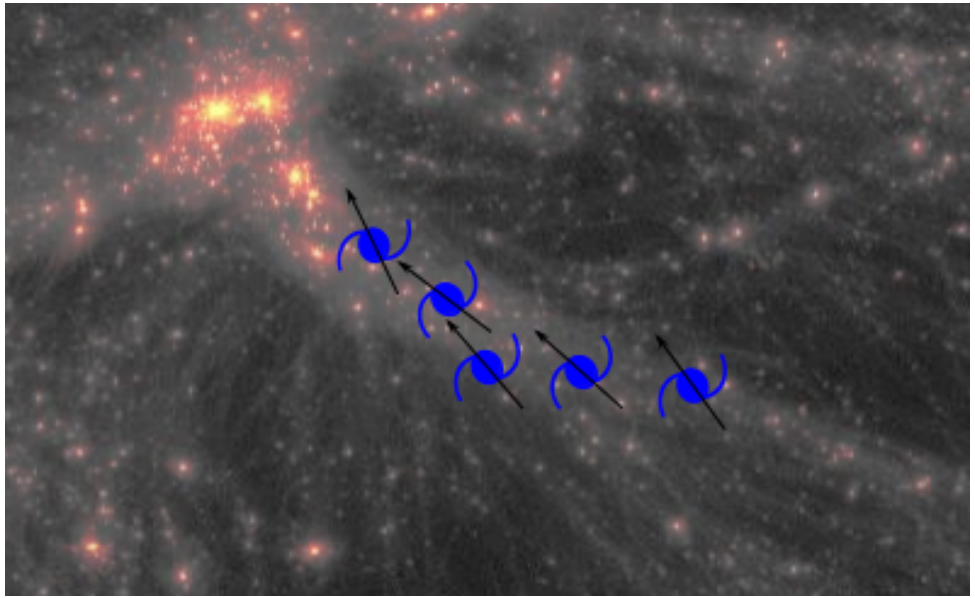

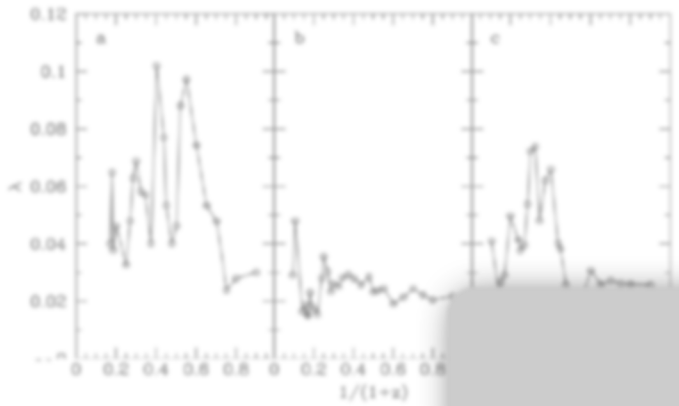

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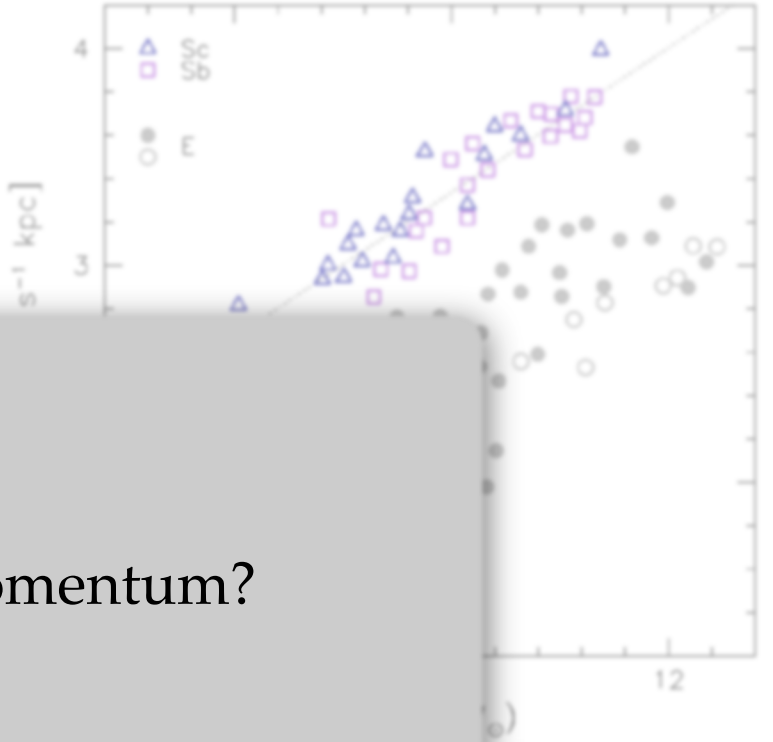

Fall+80

- What's the origin of angular momentum?
- Are mergers truly stochastic?
- How does it translate to galaxy properties?

Angular mor

1. Abrupt cl
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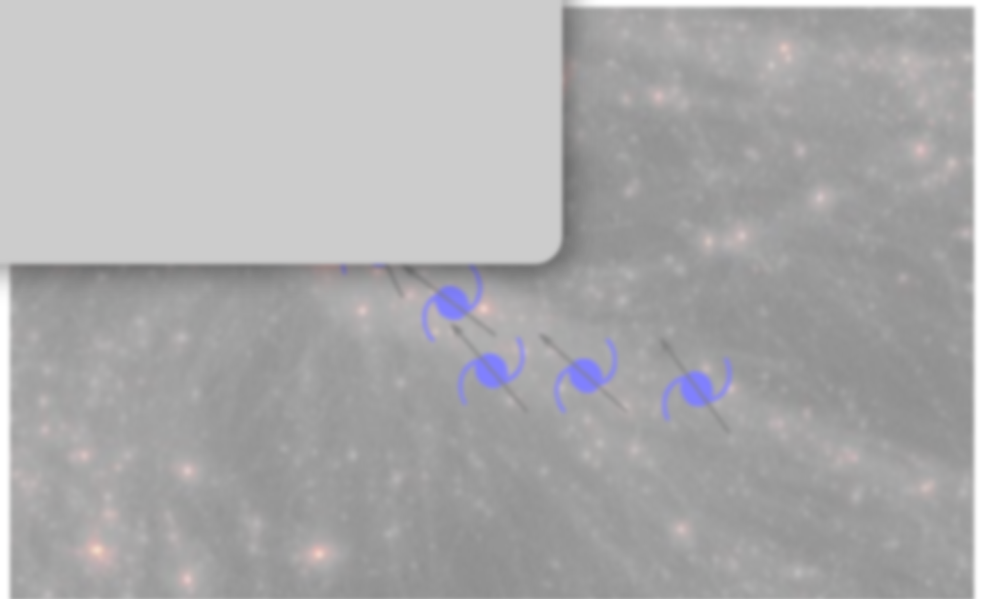
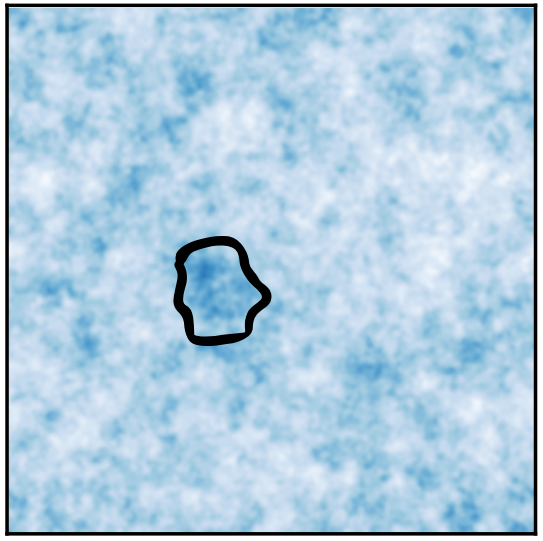
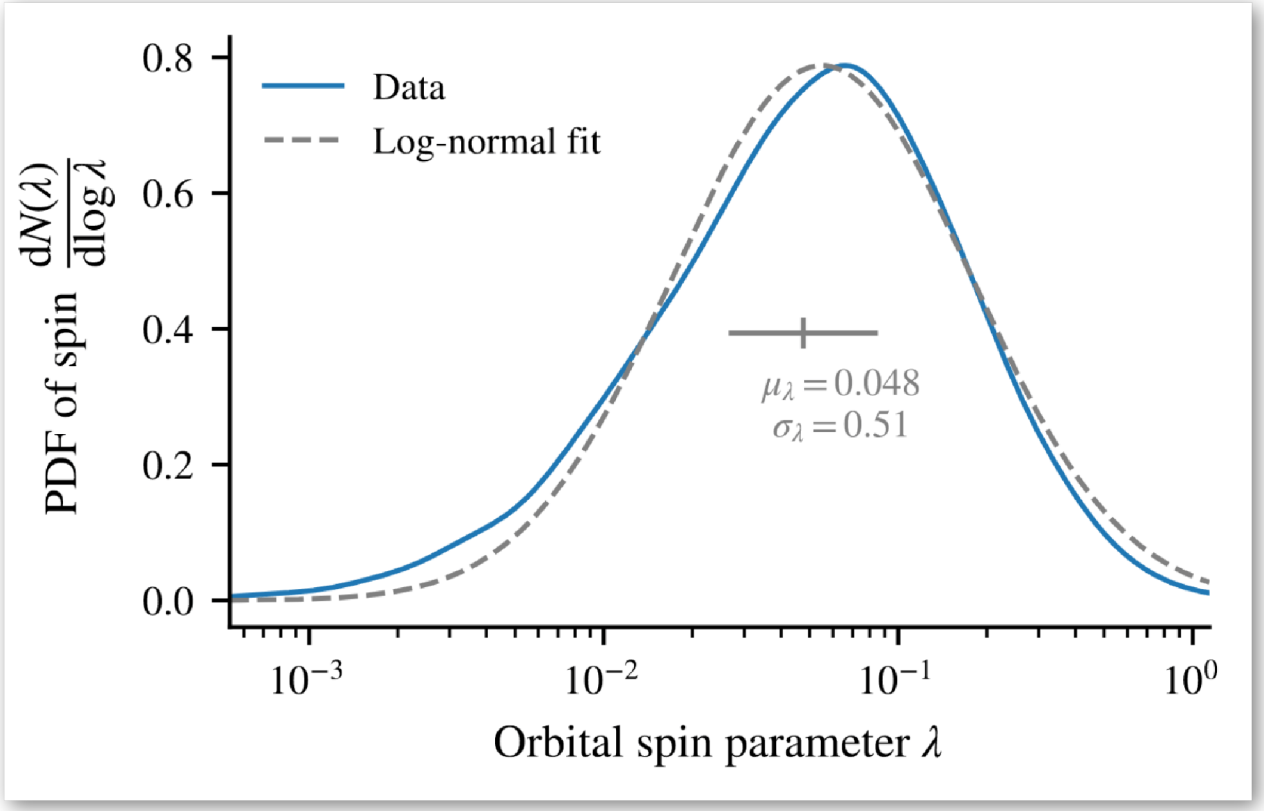


We can make some reasonable model of *orbital* spin from mergers





See Cadiou, Pichon-Pharabod+24

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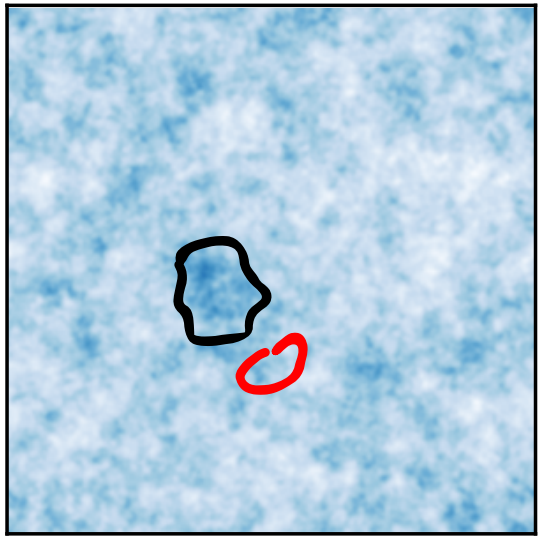

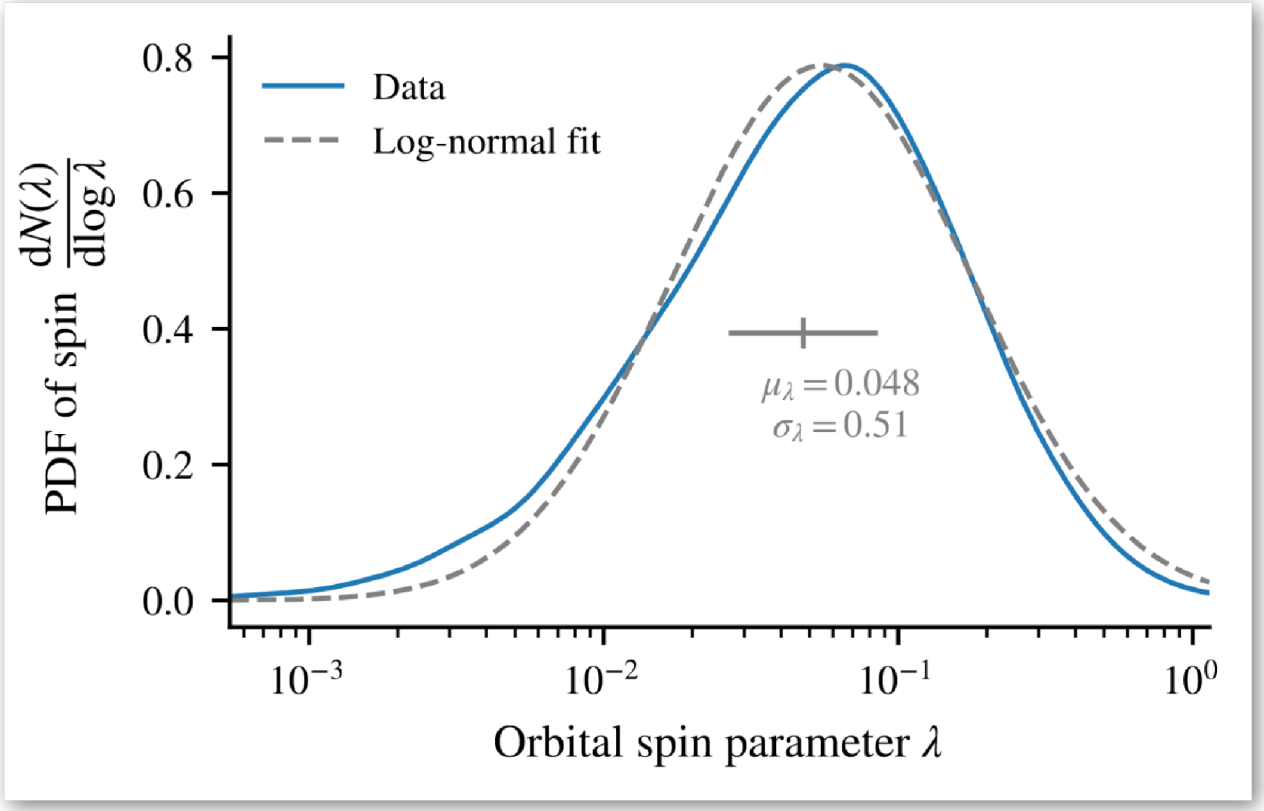

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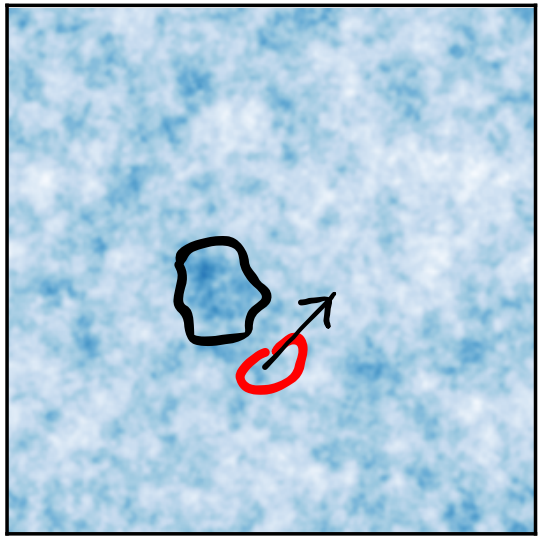
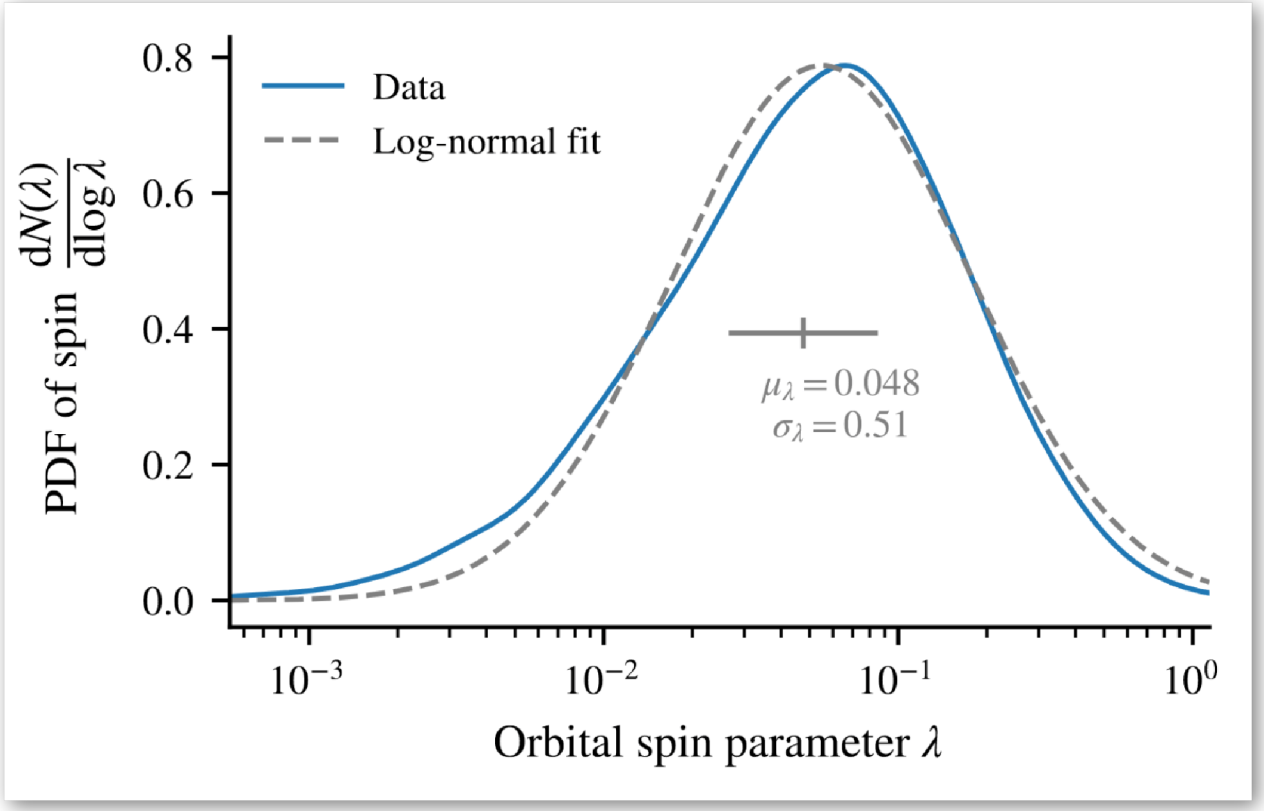
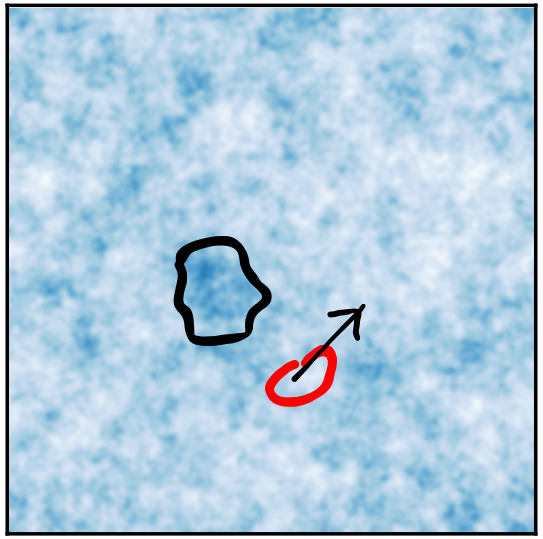




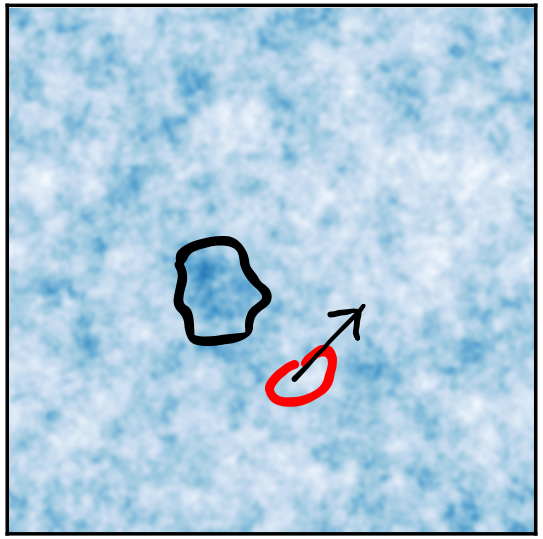
See Cadiou, Pichon-Pharabod+24

We're at a conference about simulations
why bother with theory?



This is actually done by minimizing $(\delta_{\rm new} - \delta_{\rm old})^\dagger \mathbf{C}^{-1} (\delta_{\rm new} - \delta_{\rm old})$
with the constrains $\tau^{(i)}_{\rm new} = f \tau^{(i)}_{\rm old}, \quad i = x, y, z$

See Cadiou+21a
based on genetic modifications: Roth+16, Rey&Pontzen 18, Stopyra+20



"Find the most likely ΛCDM realisation
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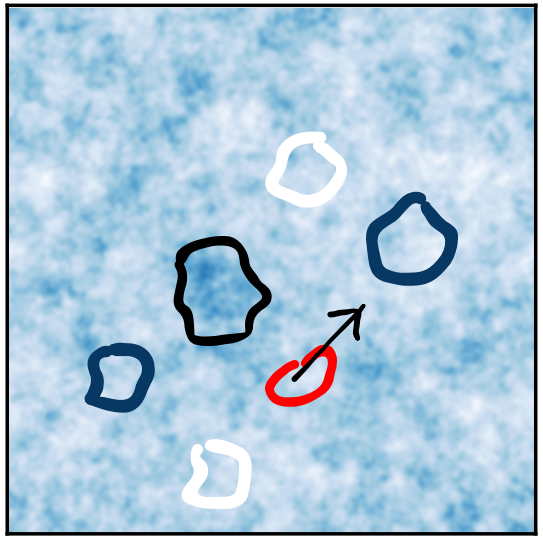

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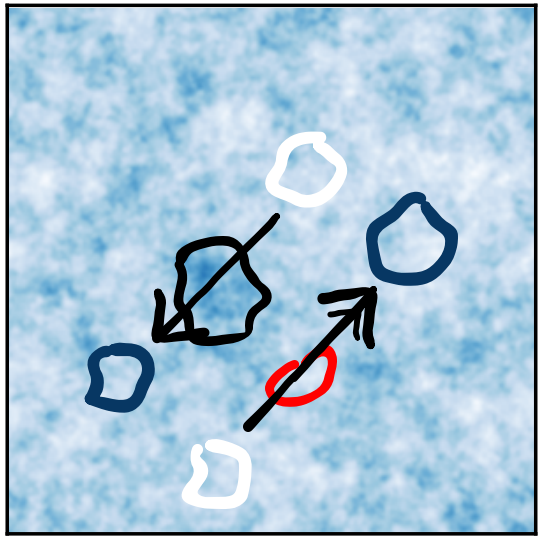

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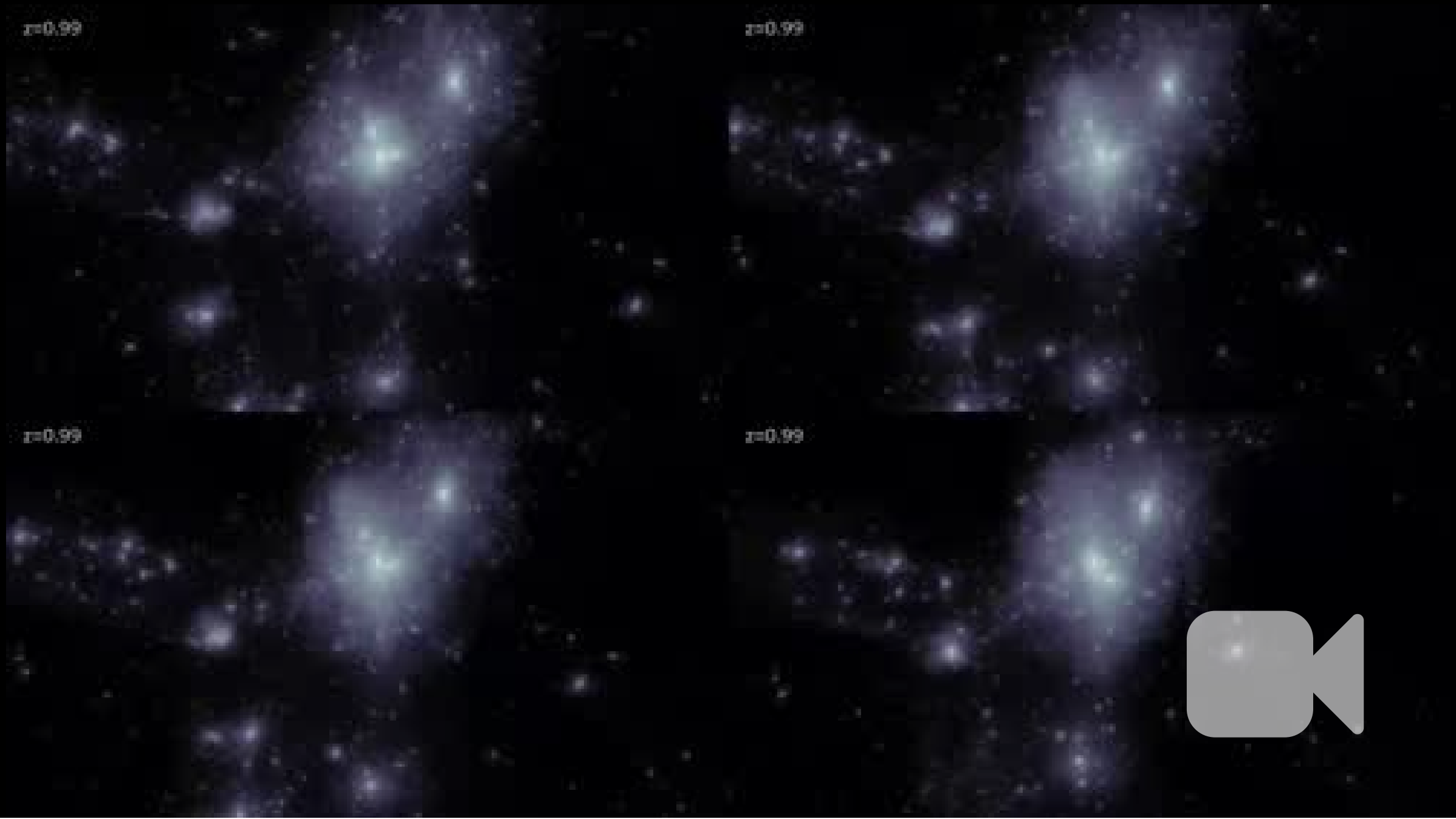
Changes to tides at $z = 100$, effect at $z < 1$



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tides $\times 0.5 \Rightarrow$ merger @ $z = 0.7$

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tides $\times 2 \Rightarrow$ merger @ $z = 0.2$

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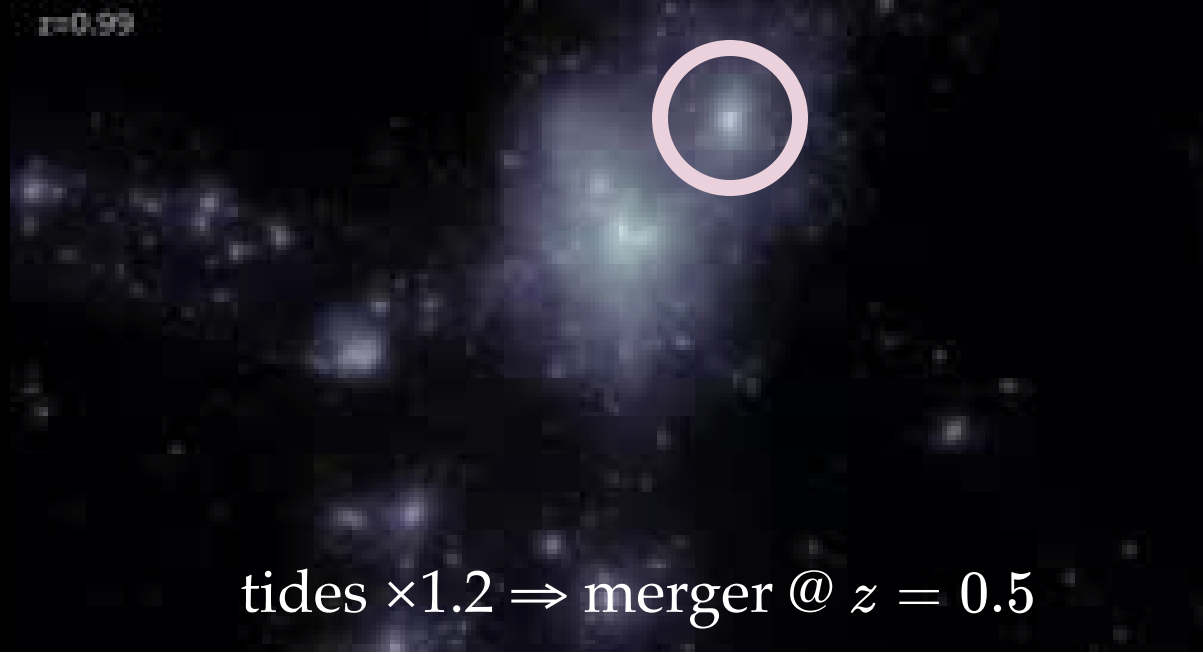
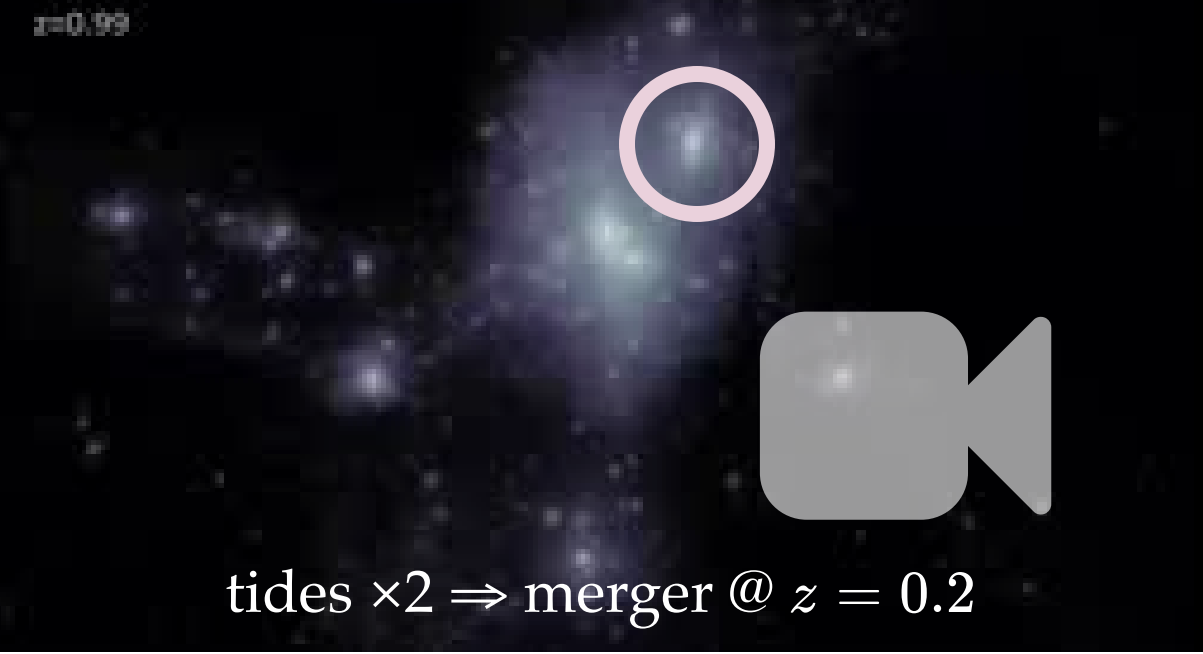


tides $\times 1.2 \Rightarrow$ merger @ $z = 0.5$



tides $\times 2 \Rightarrow$ merger @ $z = 0.2$


z=0.99


z=0.99

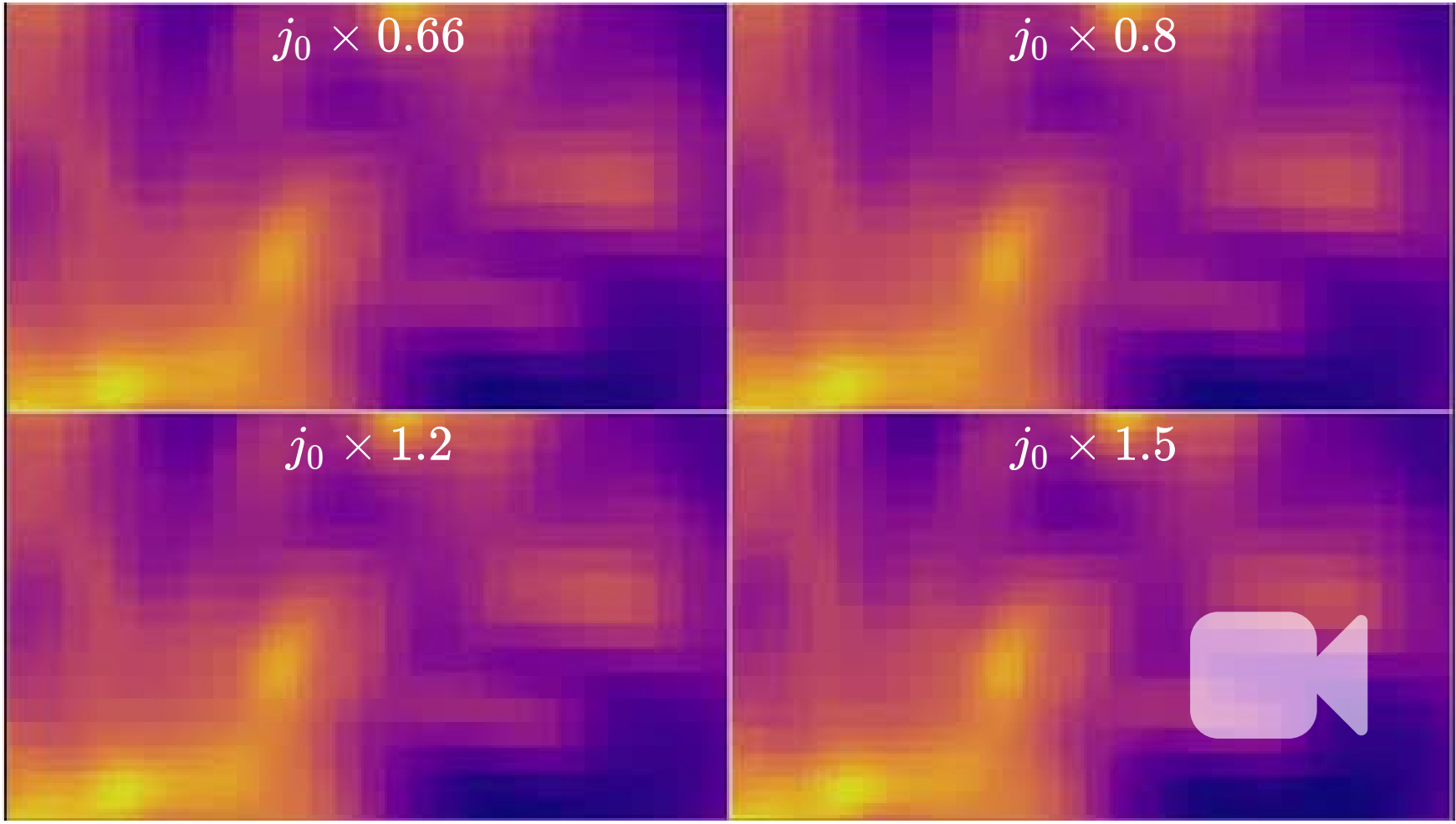

z=0.99

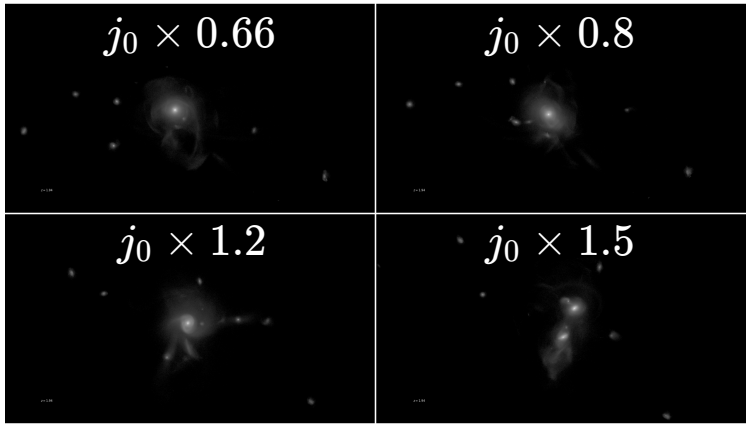

z=0.99

Unraveling the origin of baryonic angular momentum

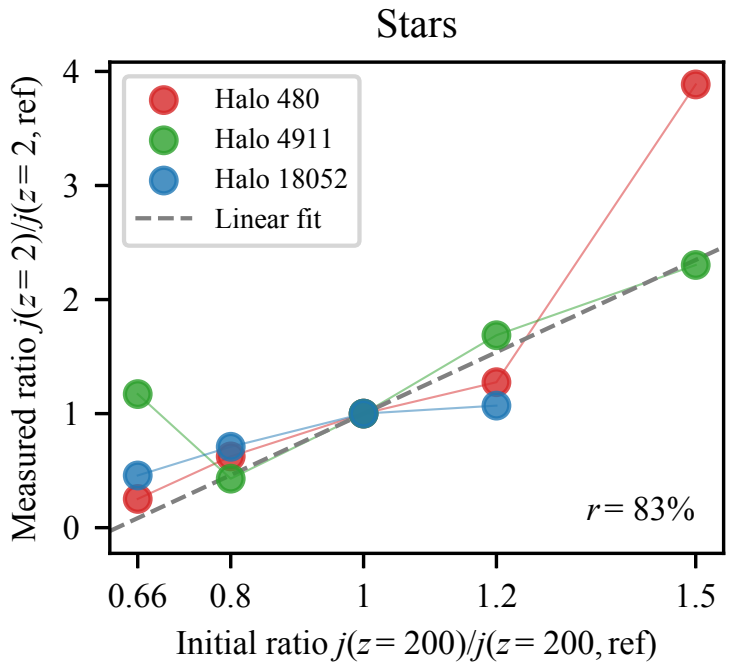
Full hydro simulations (RAMSES, New-Horizon model):

- Resolve disk height $\Delta x_{\rm min} = 35$ pc
- $M_{\rm 200c} = 10^{12}$ M$_\odot$ @ $z = 2$
- SF + AGN & SN feedback
- 3 galaxies, 5× scenario each



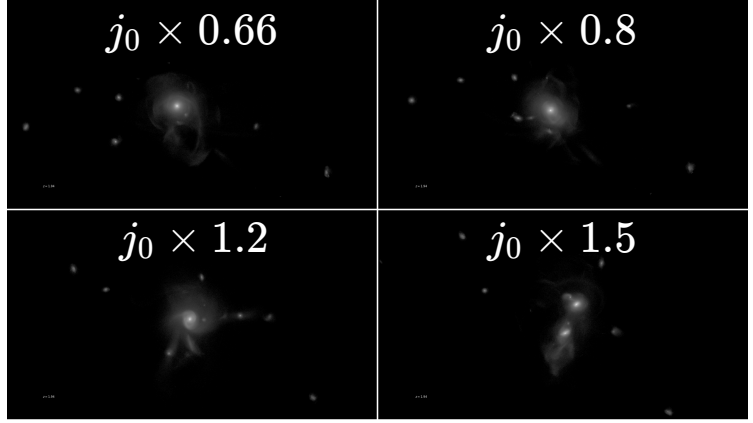


OUTPUT: Ang. mom $z = 2$



INPUT: Changes to tides $z = \infty$

See Cadiou+21a



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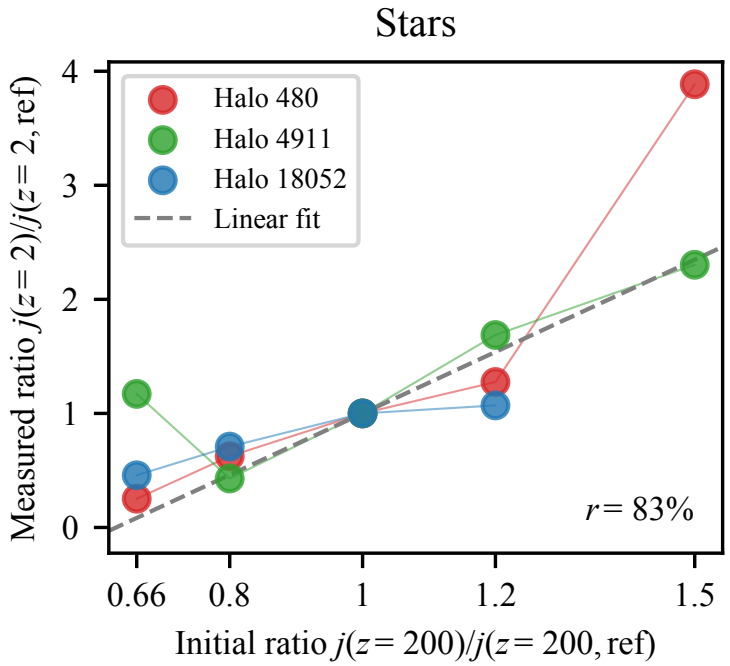

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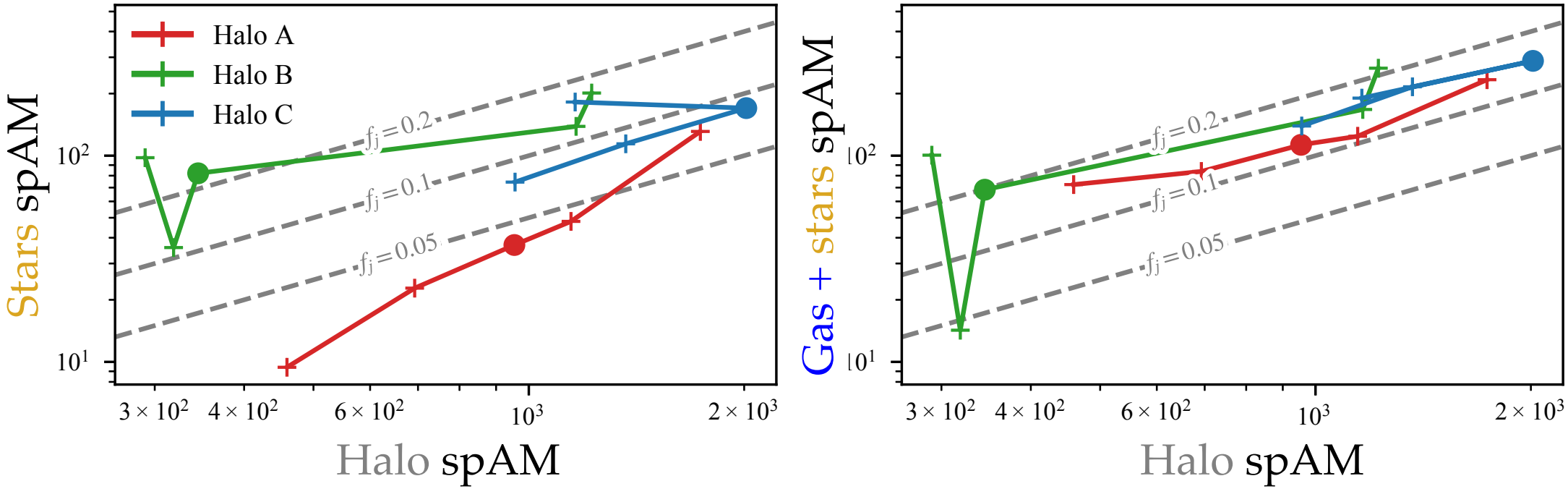
Stellar angular momentum responds ~linearly to large-scale tides

See Cadiou+21a



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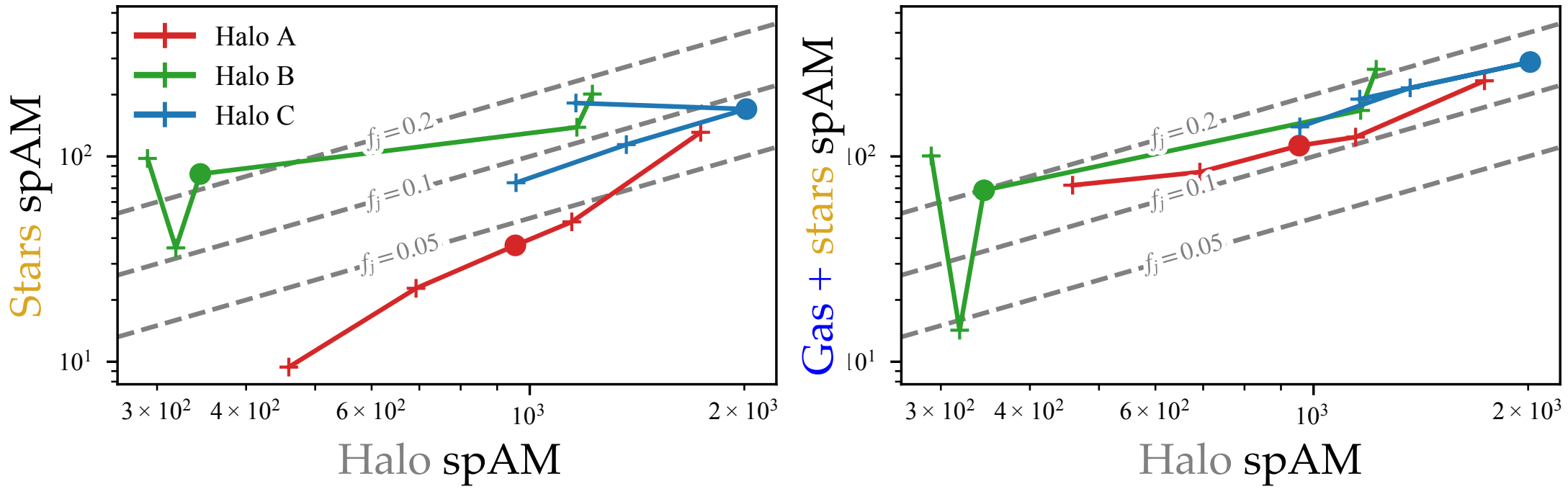


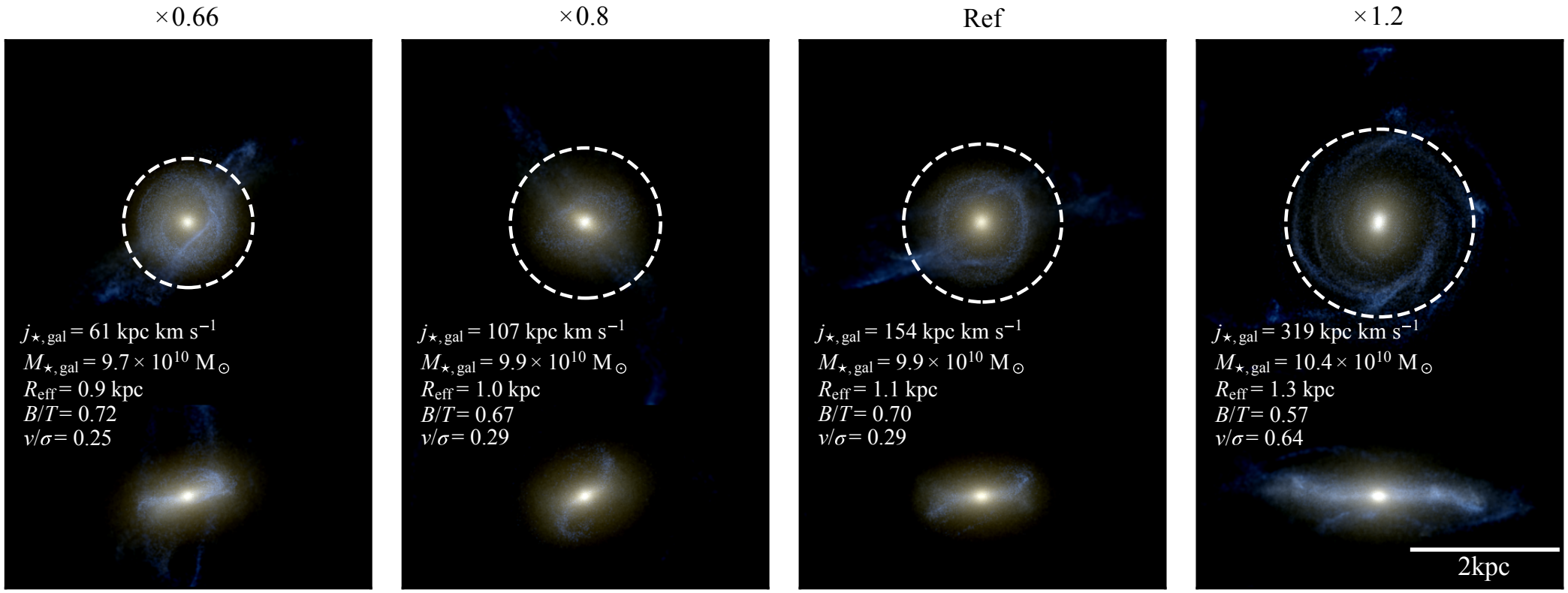
Halo and disk evolve separately,

but $\lambda_{\rm baryon} \propto \lambda_{\rm DM}$

See Cadiou+21a

Special case: no massive satellite

Low tides → High tides



$\mathcal{B}$ ↘

R_{eff} ↗ →

v/σ ↗

See Cadiou+21a

Large-scale torques control mergers **deterministically**
which controls secondary galaxy properties

… what happens to the gas?

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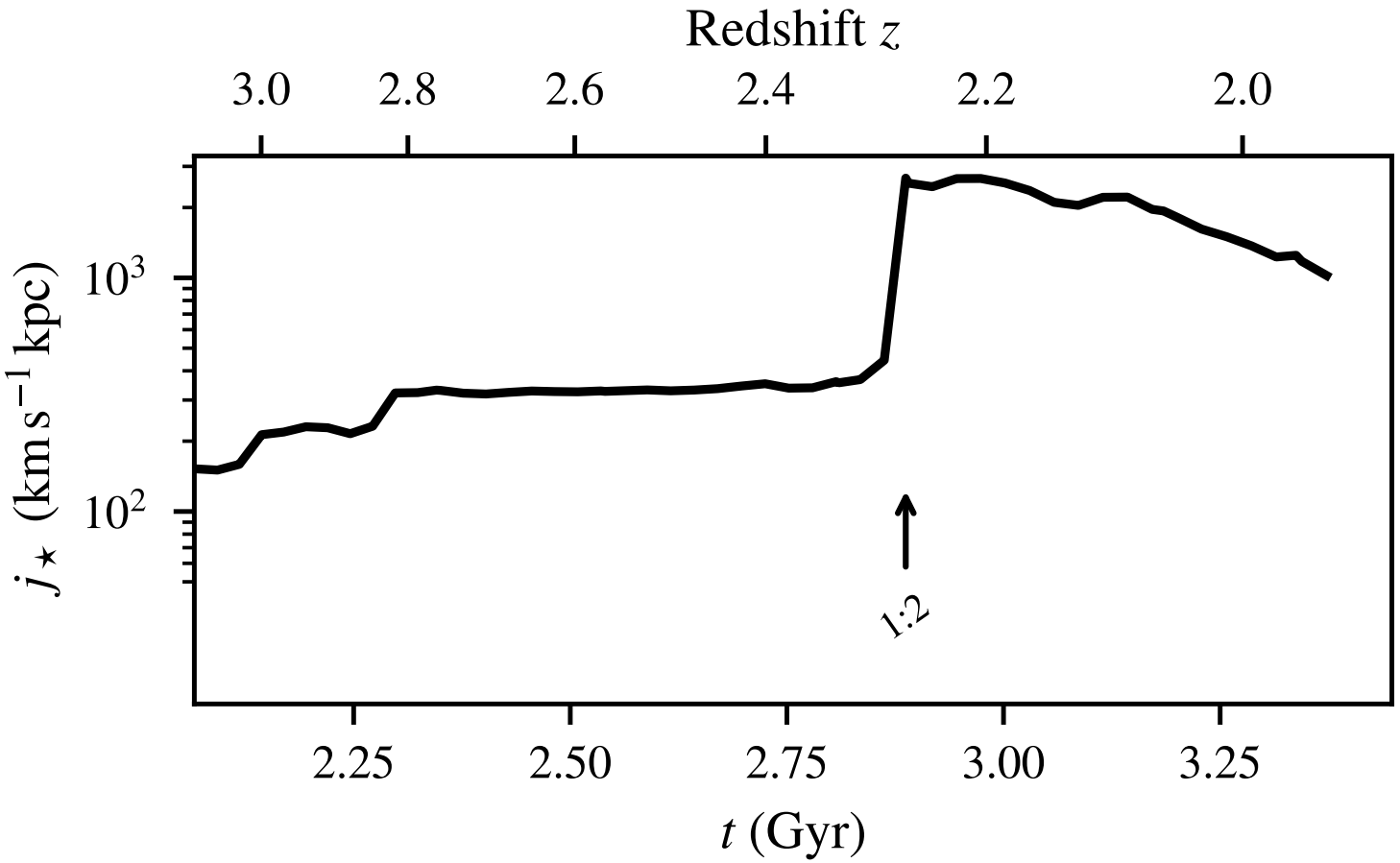

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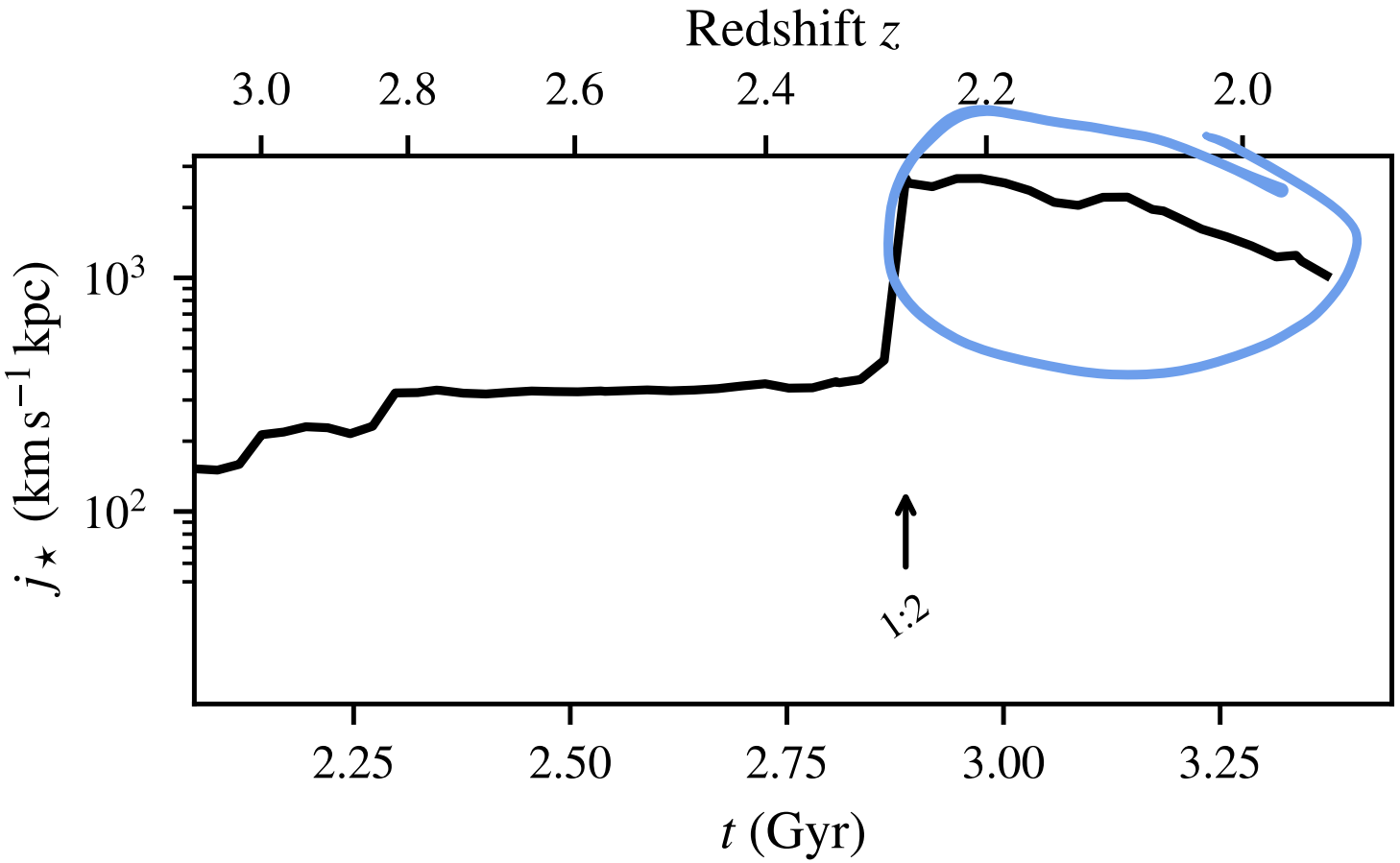
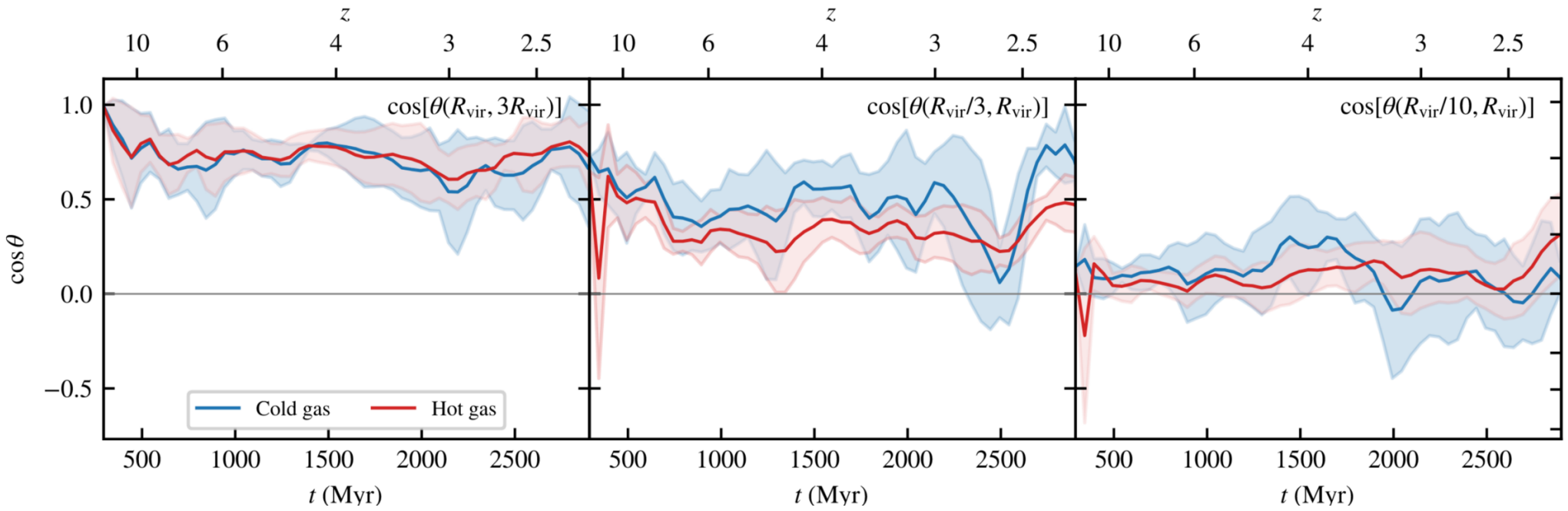


Tracking *Lagrangian* trajectories, comparing $\vec{j}$ to

$\parallel$ to direction @ $R_{\rm vir}$

$\perp$ to direction @ $R_{\rm vir}$



Tracers: Cadiou+19

Cadiou+21b, see also Danovich+15, Prieto+17

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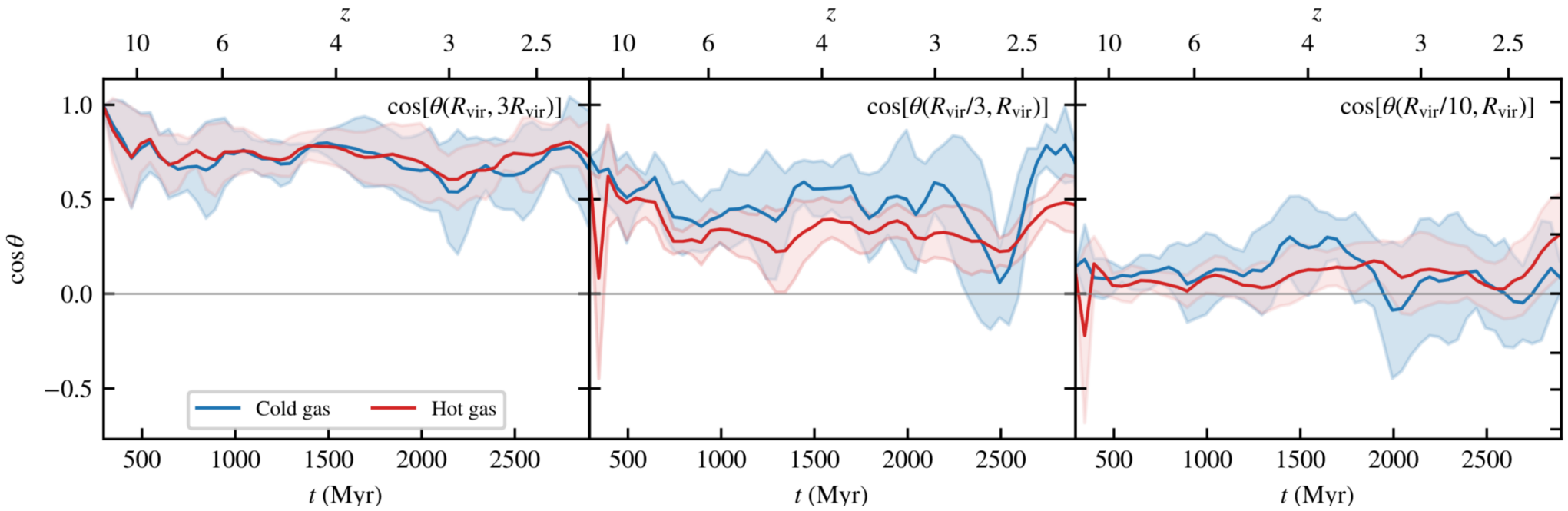


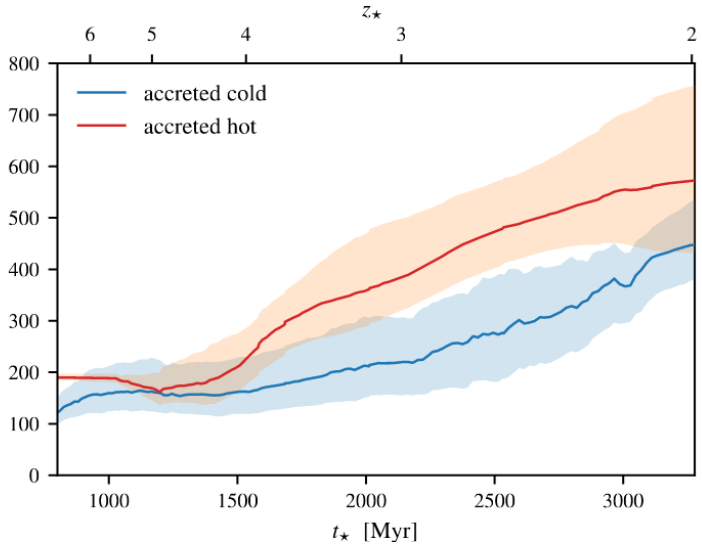
Most of re-alignment happens in the inner CGM $0.1 \leq \dfrac{r}{R_{\rm vir}} \leq 0.3$

The longer gas remains in inner CGM, the more it realigns (with disk)

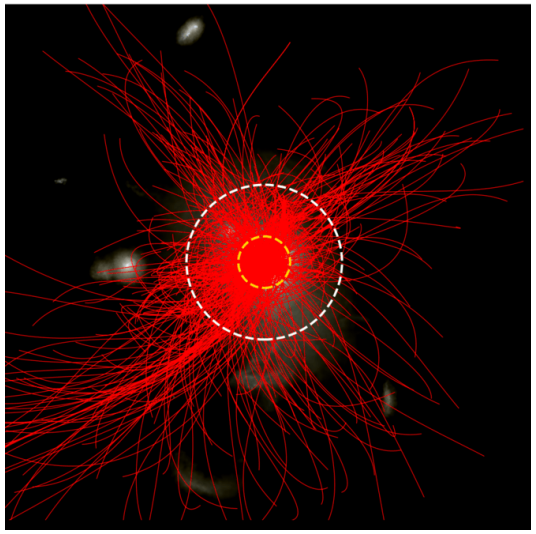
Tracers: Cadiou+19

Cadiou+21b, see also Danovich+15, Prieto+17

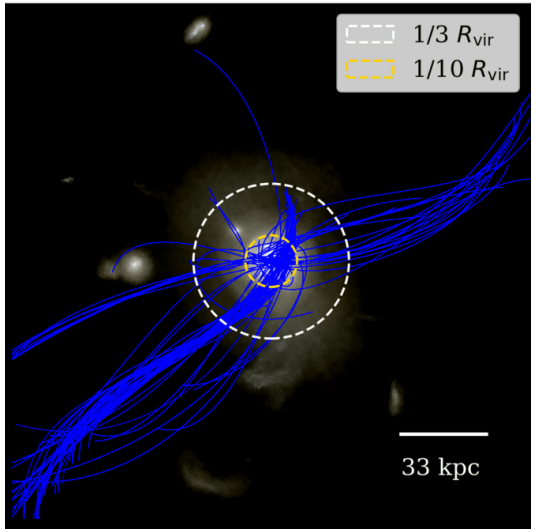
Time $2R_{\rm vir} \rightarrow R_{\rm vir}/3$



Hot gas



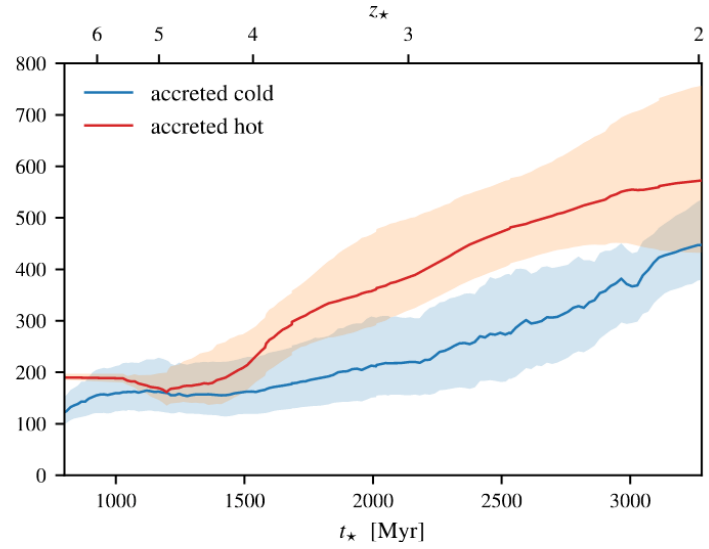
Fast cold gas



⚠ Only looking at gas that *will* form stars eventually

Kocjan, Cadiou+24

Time $2R_{\rm vir} \rightarrow R_{\rm vir}/3$



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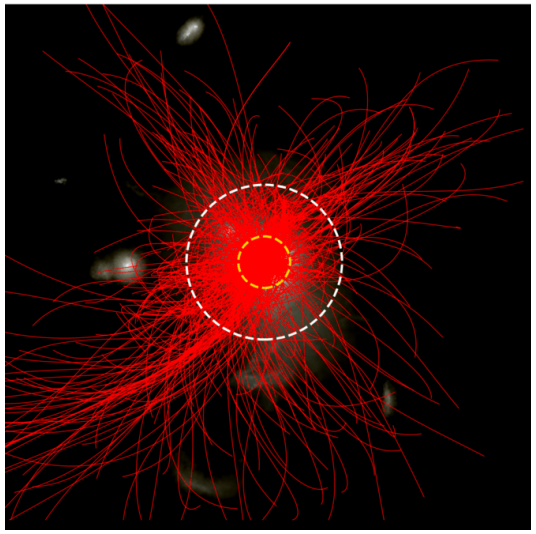
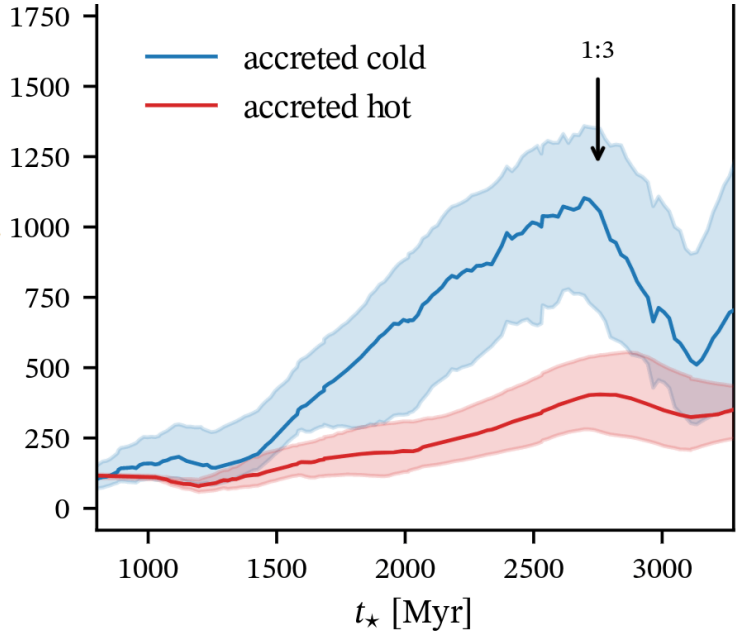


Time $R_{\rm vir}/3 \rightarrow$ ⭐



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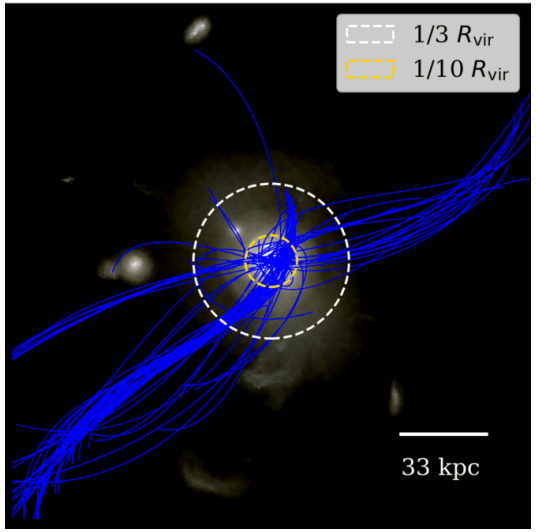

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Conclusions

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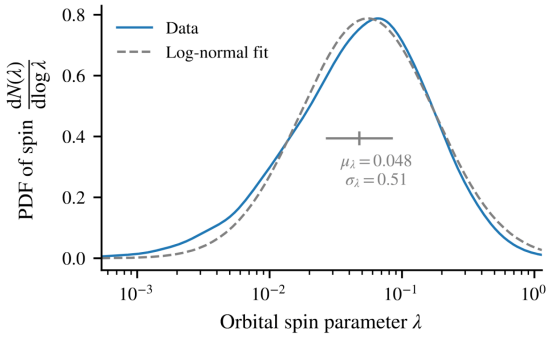
So how to build a *rotating* galaxy from scratch?



Conclusions

So how to build a *rotating* galaxy from scratch?

1. Tides determine merger orbital parameters & angular momentum accretion

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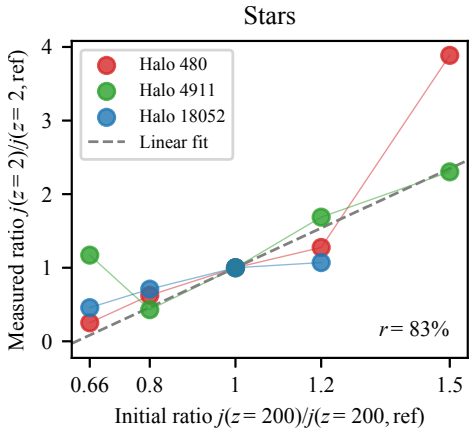

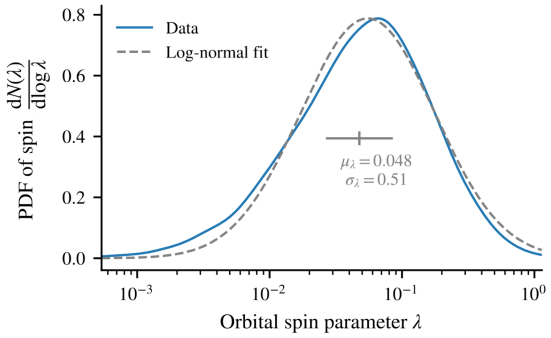

Conclusions

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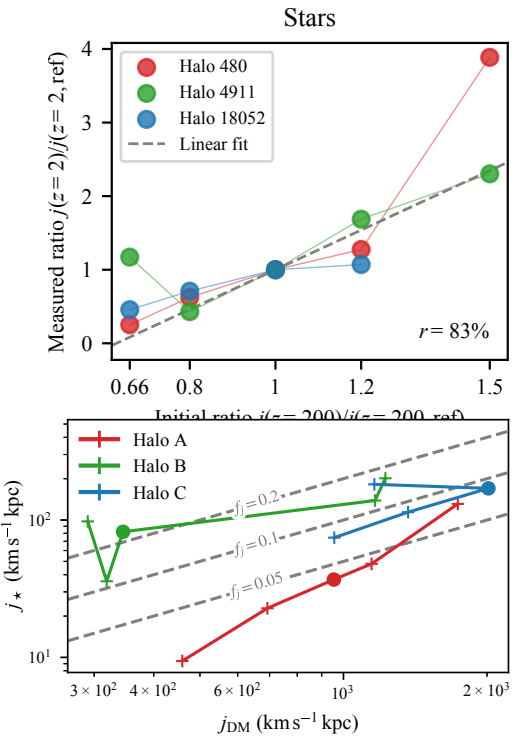
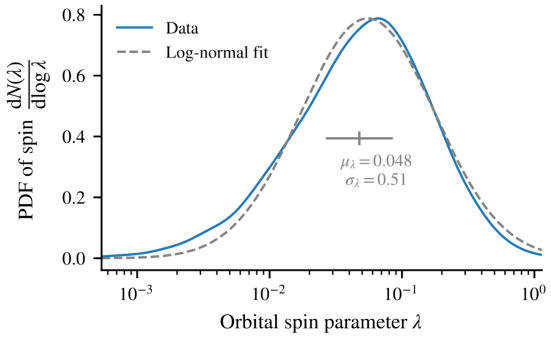
   Explains $j_\star - M_\star - \mathcal{B}$ relation (and Tully-Fisher?)





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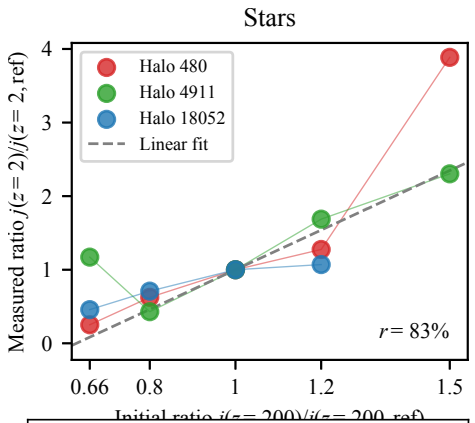
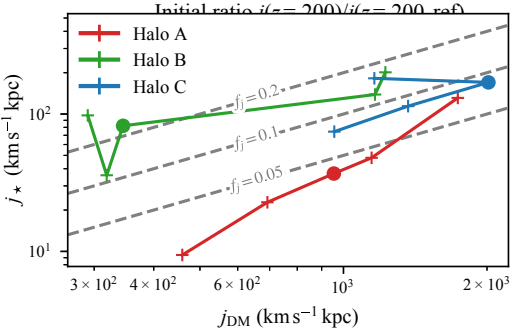
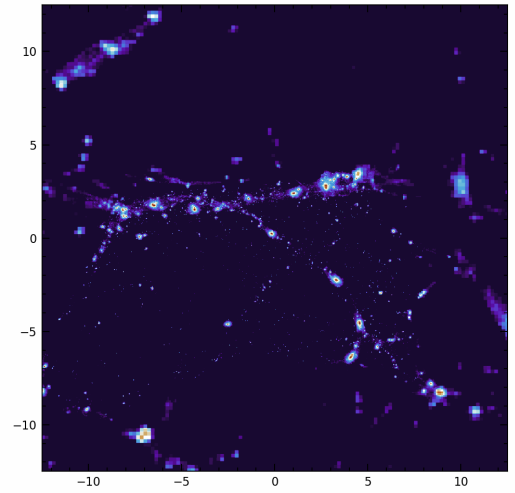
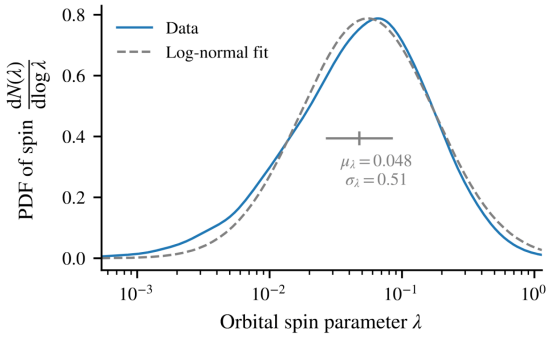
   Galaxies are <u>less stochastic</u> than expected
   Galactic spin & DM <u>spins</u> are partially <u>independent</u> at the level of <u>individual</u> galaxies









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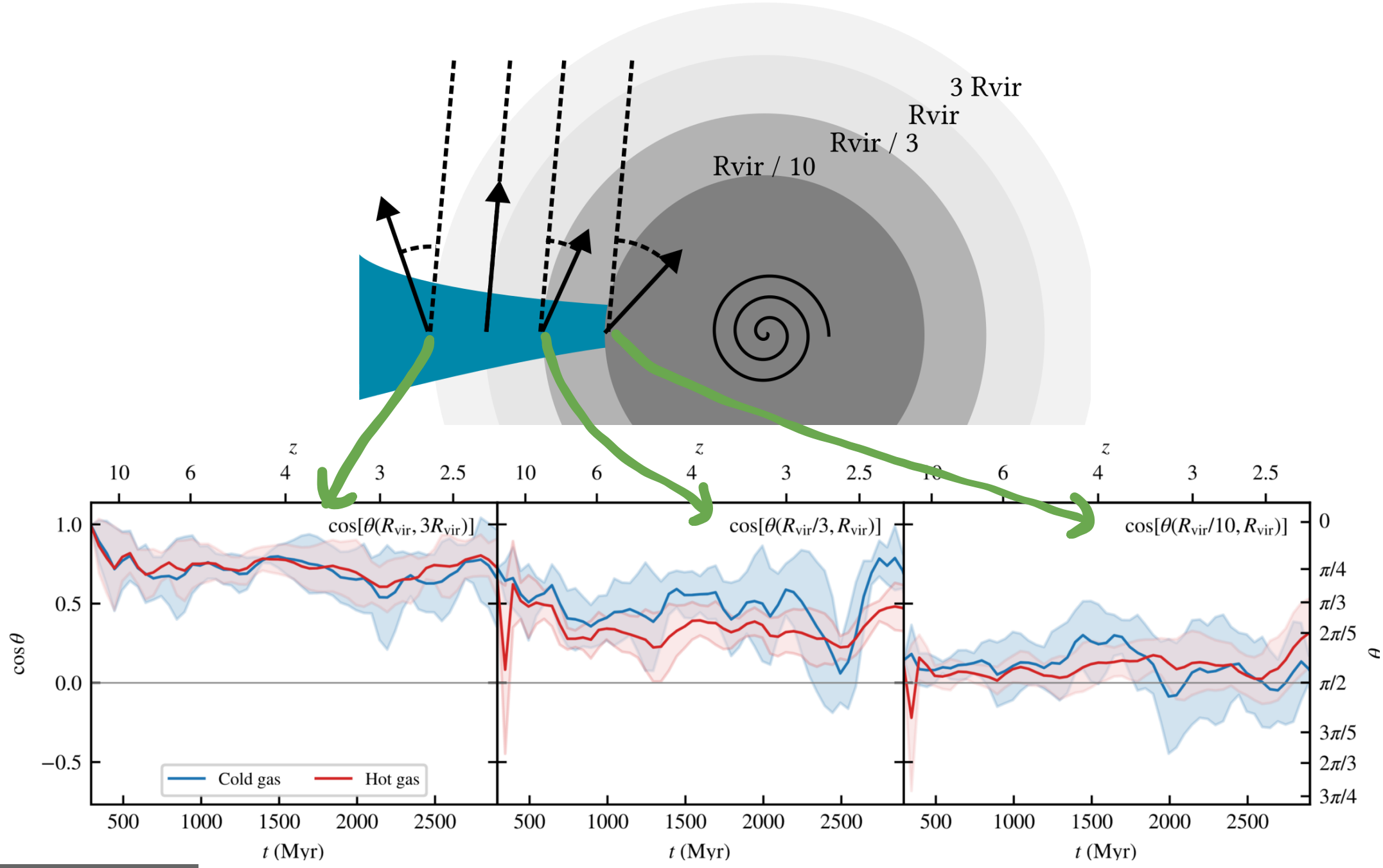
4. Moving forwards? Beyond-linear interactions with environment matter
   Spoiler: at MW mass, non-linear modulation ~ linear ones
   See next talk!


3 Rvir
Rvir
Rvir / 3
Rvir / 10
z
10
6
4
3
2.5
cos[θ(R_vir, 3R_vir)]
cos[θ(R_vir/3, R_vir)]
cos[θ(R_vir/10, R_vir)]
cos θ
1.0
0.5
0.0
−0.5
θ
0
π/4
π/3
2π/5
π/2
3π/5
2π/3
3π/4
Cold gas
Hot gas
500
1000
1500
2000
2500
t (Myr)

Cadiou+21b