Weak Baryonic Suppression in Astrid: A Challenge for Roman Weak Lensing Cosmology

Shifting Landscapes in Astrophysics: New Frontiers to Explore with Roman (Caltech/IPAC)

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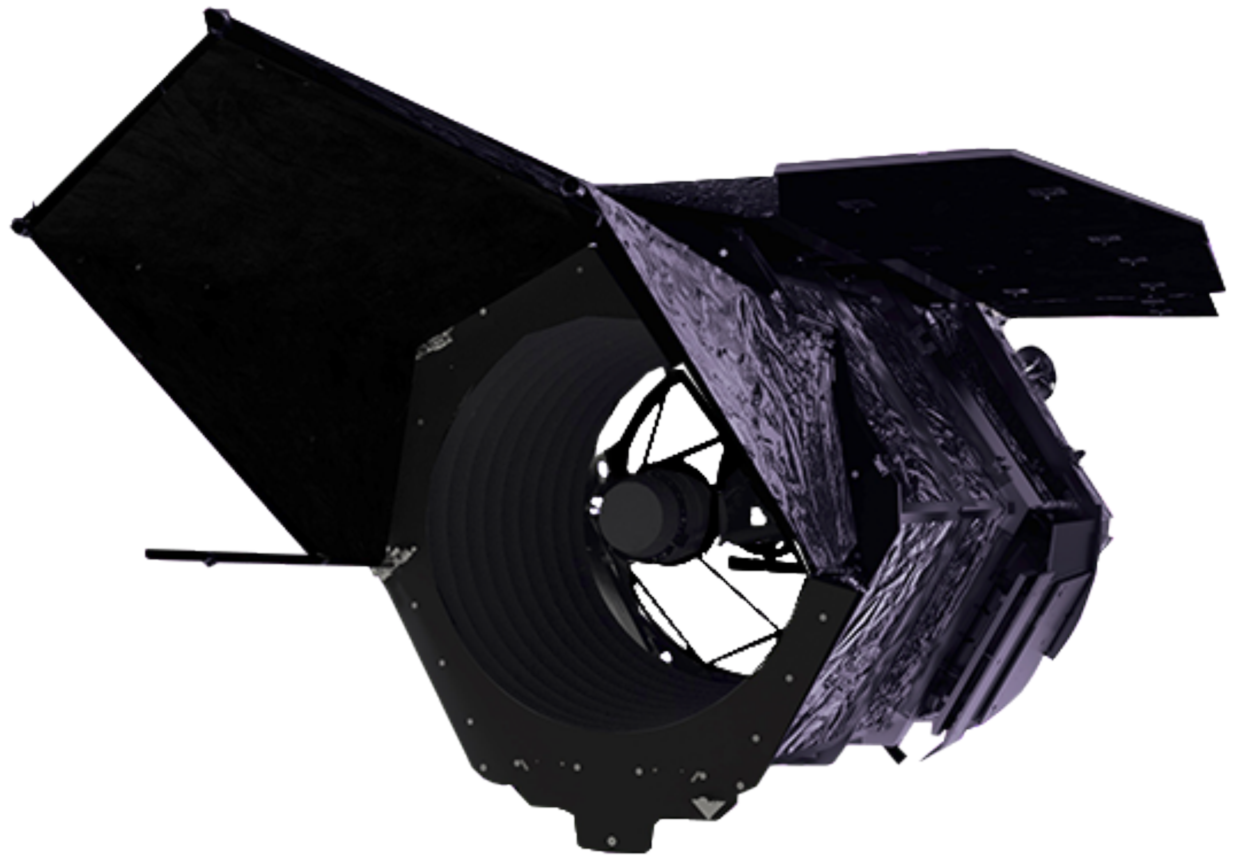
- Motivation
- Astrid
- Controlled Experiments
- Discussion
- Conclusions

Motivation

- Ongoing and upcoming surveys (LSST, Euclid, Roman, etc.) will provide unprecedented weak gravitational lensing data with high precision



Roman Space Telescope

→ cosmic shear

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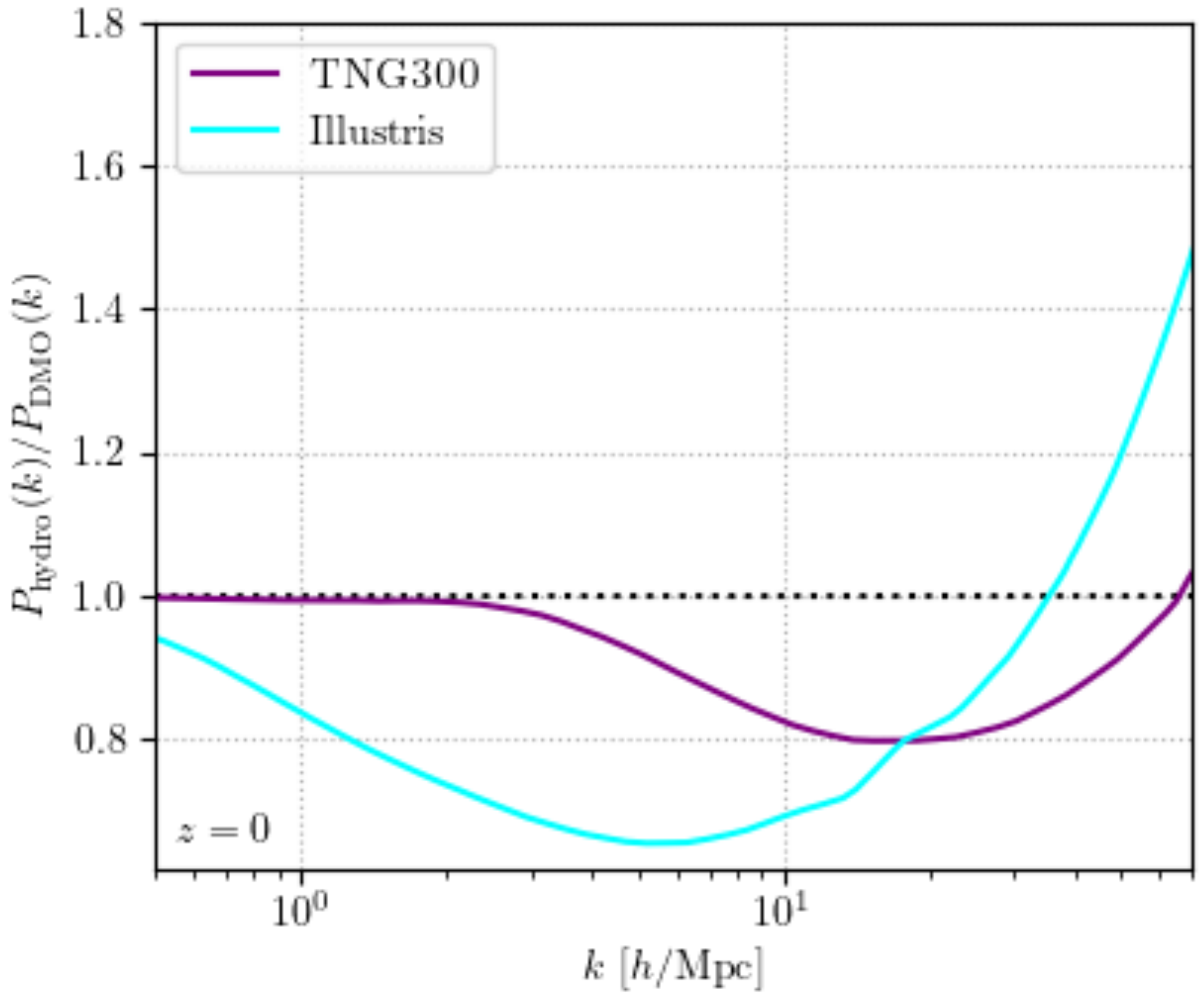
cosmology
(Ω_{m}, σ_8, etc.)

Motivation

- Interpreting observational data down to nonlinear scales requires accurate theoretical predictions
- Baryonic effects on large-scale structure must be considered
  - AGN feedback can expel gas from galaxies/galaxy groups
  - e.g., Illustris (Vogelsberger+2014), IllustrisTNG (Springel+2018) simulations: the matter power spectrum is suppressed by >20% at z=0 (relative to dark matter only)



Motivation

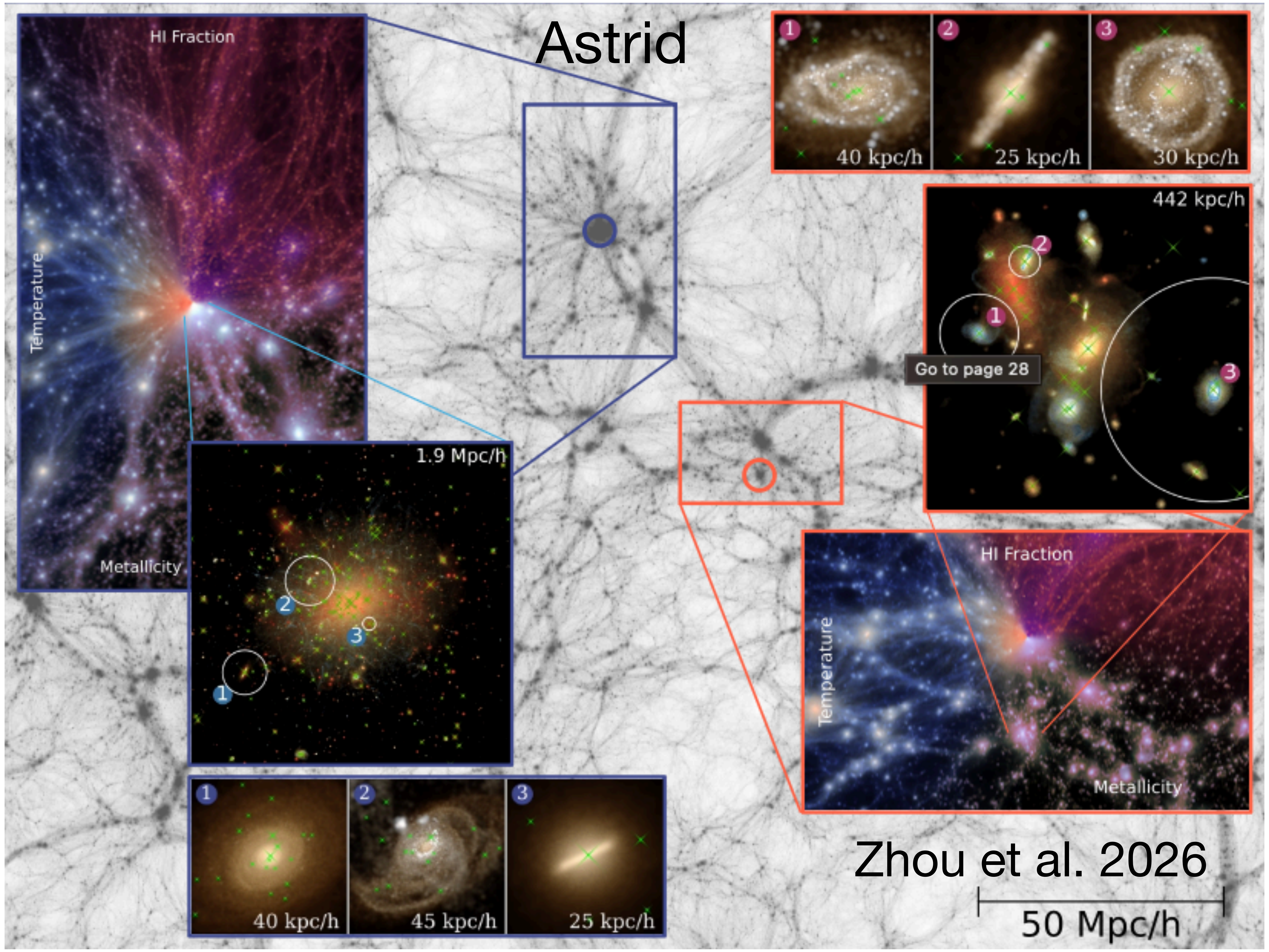
- Potential solution to the S_8 tension within ΛCDM (CMB vs. Weak lensing)
  - $S_8 \equiv \sigma_8\sqrt{\Omega_{\rm m}/0.3}$
  - strong baryonic suppression of $P(k)$ is required

Problem:

We still do not know how to produce such strong suppression physically!

Astrid: Introduction

- One of the largest cosmological hydrodynamical simulations ever evolved to z=0
- 2×5500^3 particles
- Volume: $(250\,\mathrm{Mpc}/h)^3$
- AGN feedback: two modes
  (following TNG, Weinberger+2017)
  - thermal
  - kinetic (high mass, low accretion rates/Eddington ratios)

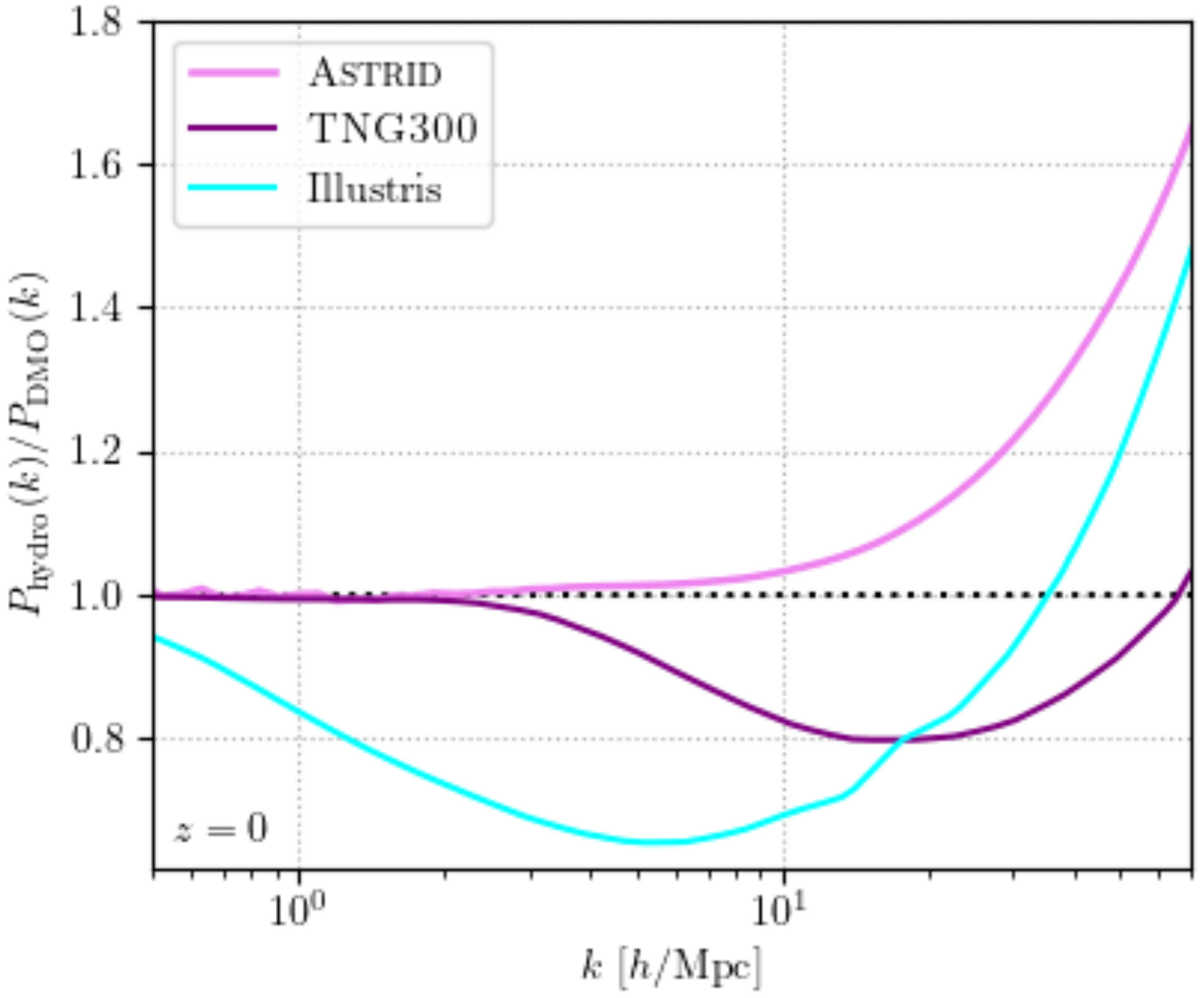


Astrid: Introduction

- Astrid-DMO (newly performed): the dark matter-only counterpart
  - 5500^3 dark matter particles
  - Volume: $(250\,\mathrm{Mpc}/h)^3$
- We measure $P_{\mathrm{hydro}}(k)/P_{\mathrm{DMO}}(k)$ to quantify the impact of baryons on matter clustering

Astrid: Results

- No suppression at z=0!
- Mild suppression at z=0.2 (not shown here)



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  - A more important reason: black hole (BH) dynamics treatment

Astrid: BH Dynamics Model

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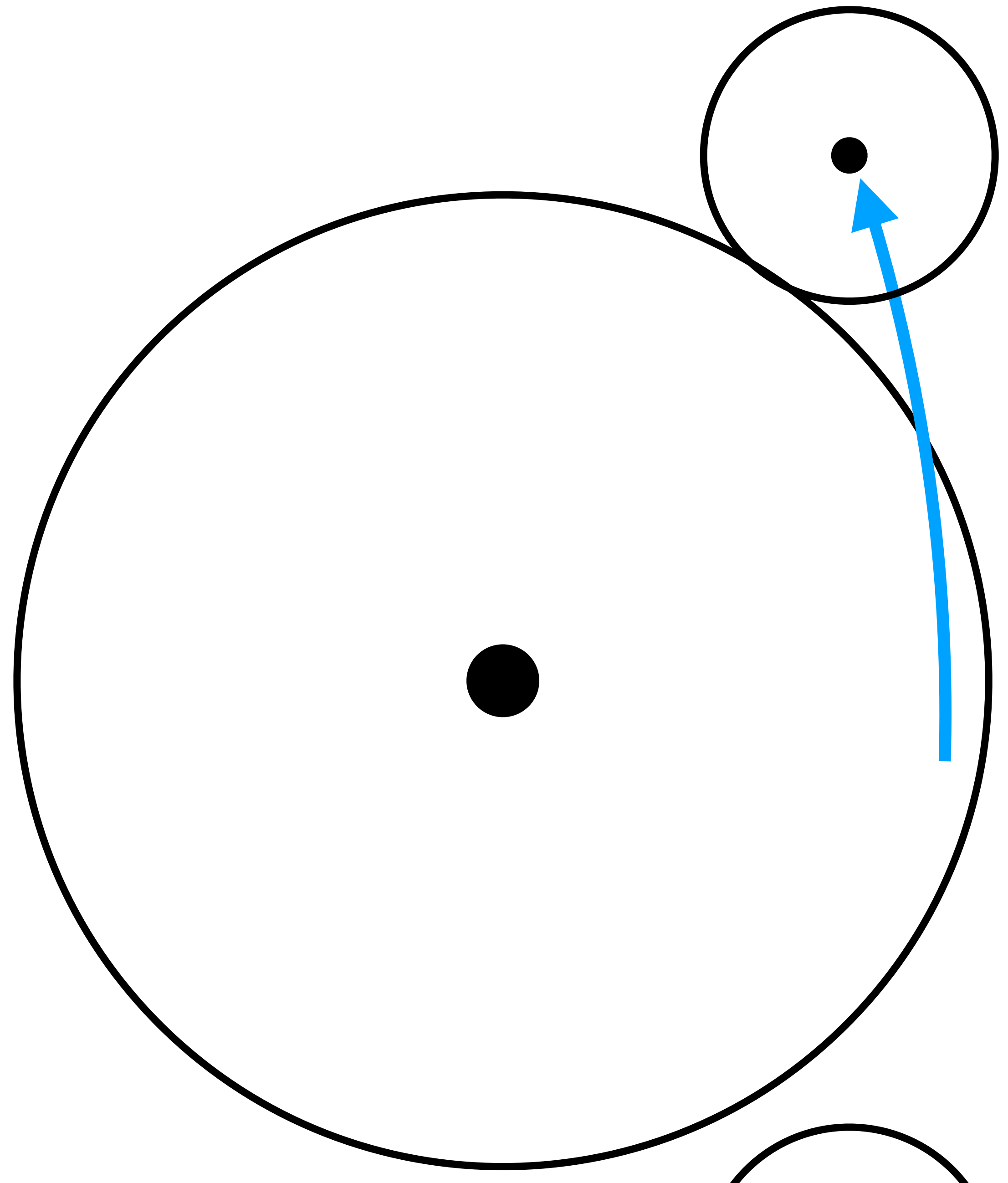
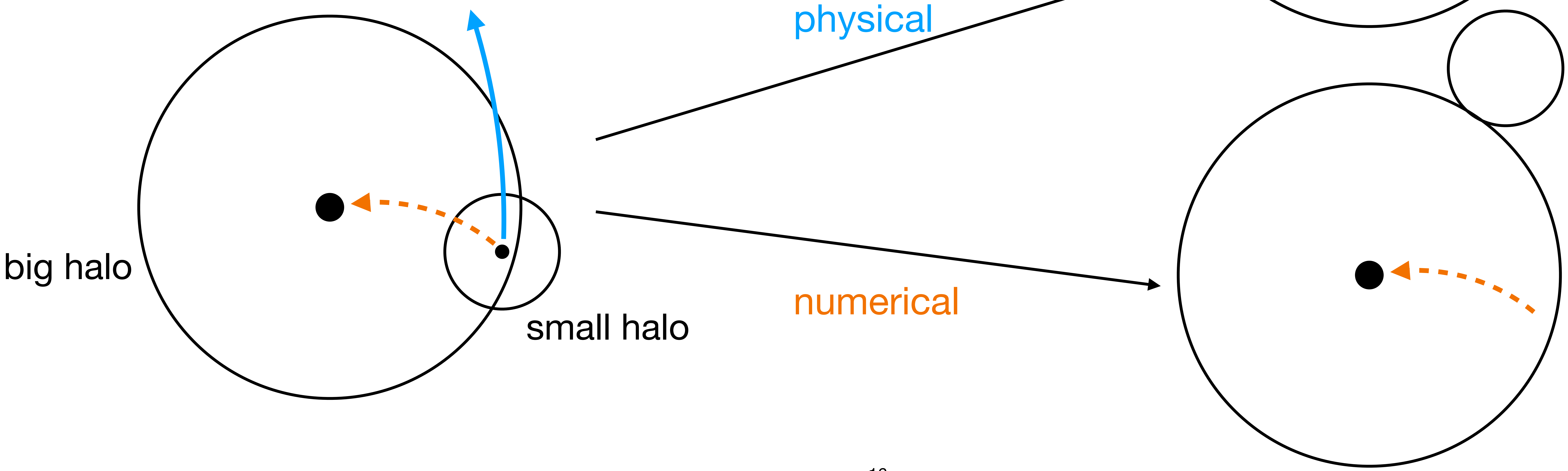
- Most state-of-the-art simulations:
    - BH repositioning: pins/repositions the BH to the potential minimum
    - side effect: artificially boosts BH merger rates!

Astrid: BH Dynamics Model

- BH repositioning:
  - small (or sub-) halos can lose their BHs when passing by/through massive halos with deeper potential wells
  - small BHs are swallowed too efficiently (Chen+2022)





Astrid: BH Dynamics Model

- Astrid: subgrid dynamical friction (DF) model
  - Orbital evolution of BHs
  - BHs merge more physically: sufficiently close and gravitationally bound (gravity and velocities); avoids spurious mergers (though not totally at low resolution)

Controlled Experiments: Design

- Numerical experiments: small-volume simulations (run using MP-Gadget, Feng+2018)
  - 640^3 particles, $(50\,\mathrm{Mpc}/h)^3$ box (resolution ~2x lower than Astrid's)
  - Repositioning vs. Dynamical friction (DF), also tested with a stronger (TNG-like) feedback model

Simulation	BH dynamics	Feedback model
SV-DF	Dynamical friction	Fiducial
SV-REPOS	Repositioning	Fiducial
SV-DF-S	Dynamical friction	Stronger feedback
SV-REPOS-S	Repositioning	Stronger feedback

Controlled Experiments: Results

- Kinetic feedback energy released by BHs, E_{kf}
  - Repositioning:

    more mergers

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    high-mass BHs overgrow

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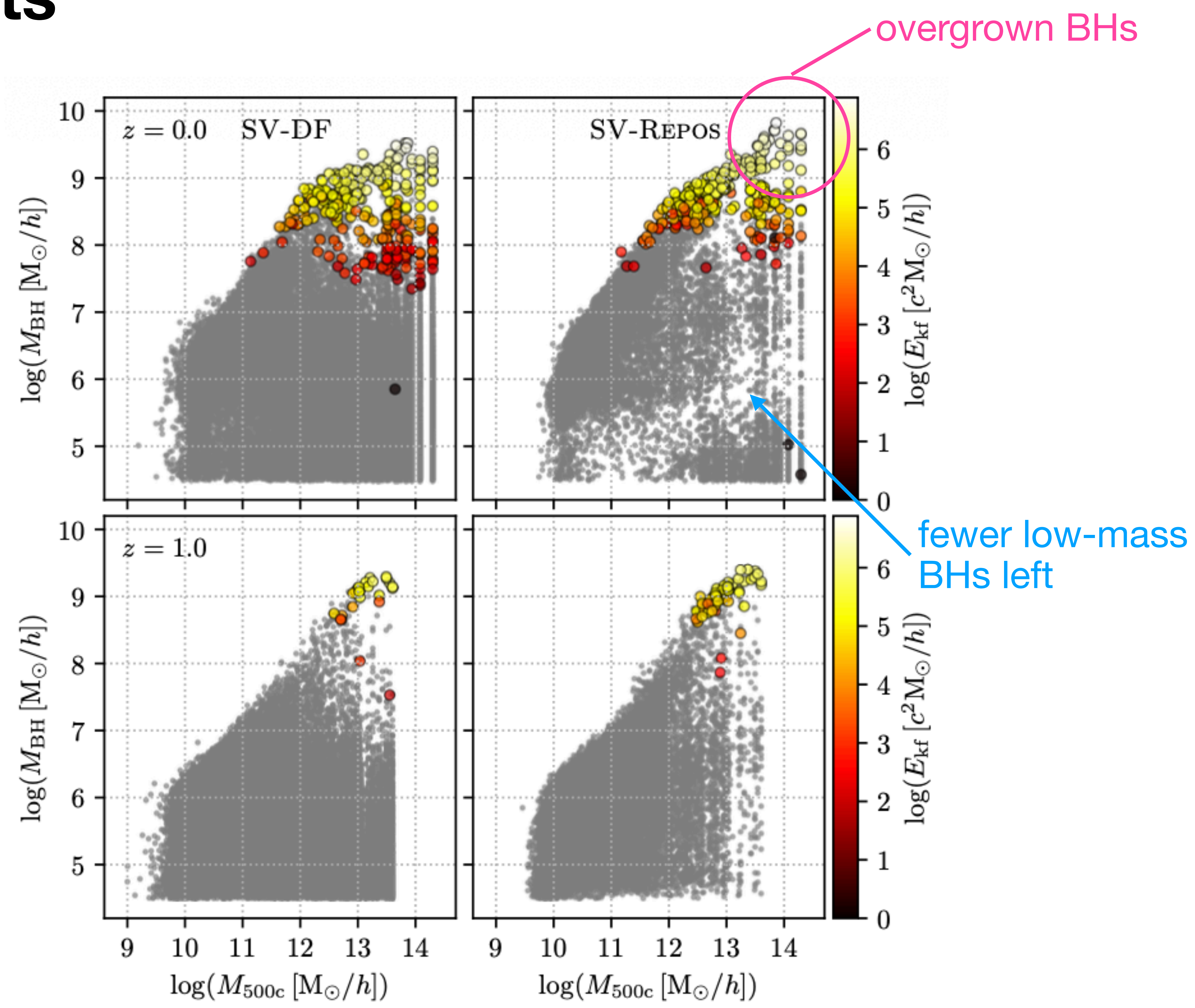
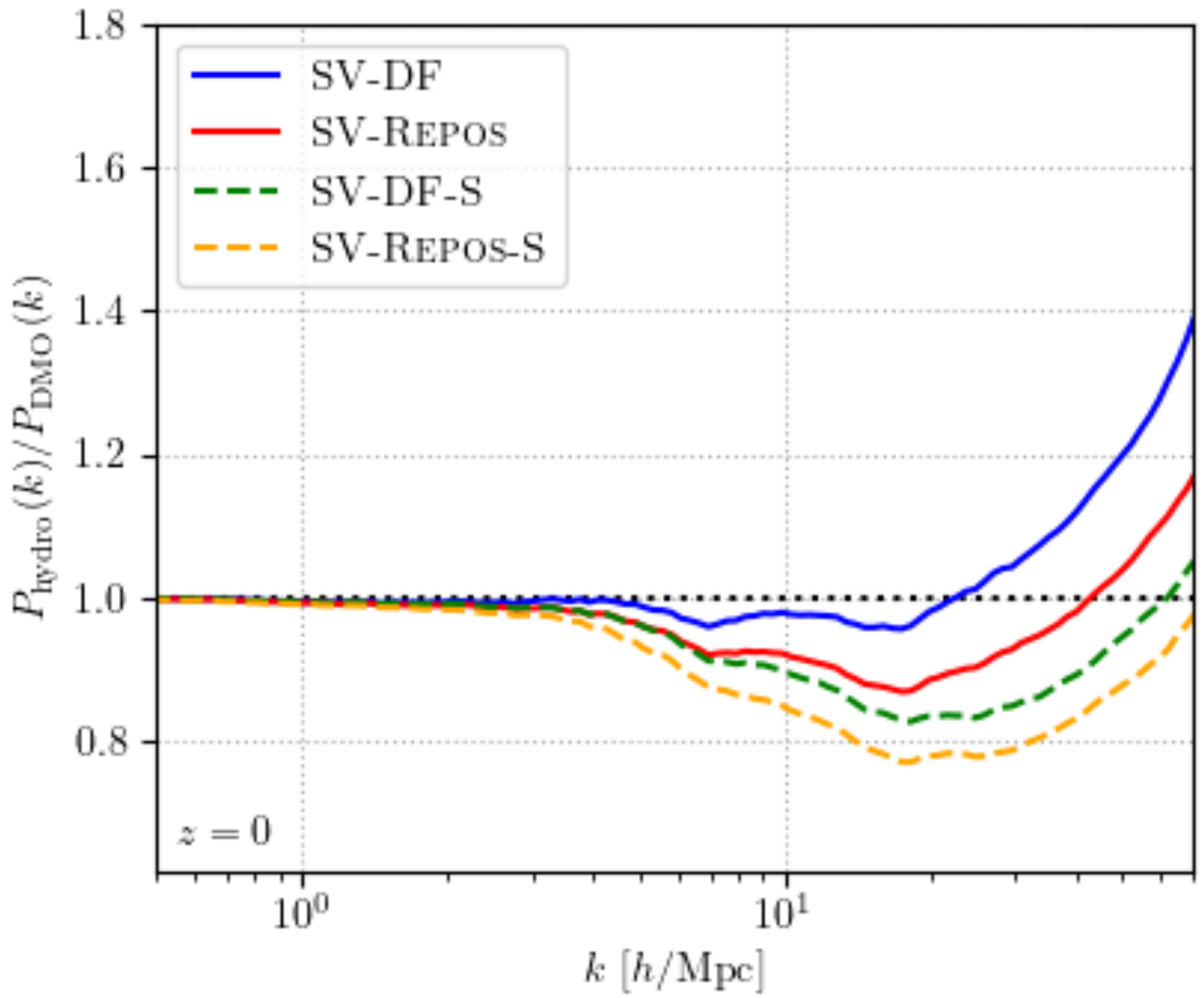
    more kinetic feedback energy

    - z=1, E ~ 1.8x
    - z=0, E ~ 1.2x



Controlled Experiments: Results

- Baryonic suppression of $P(k)$



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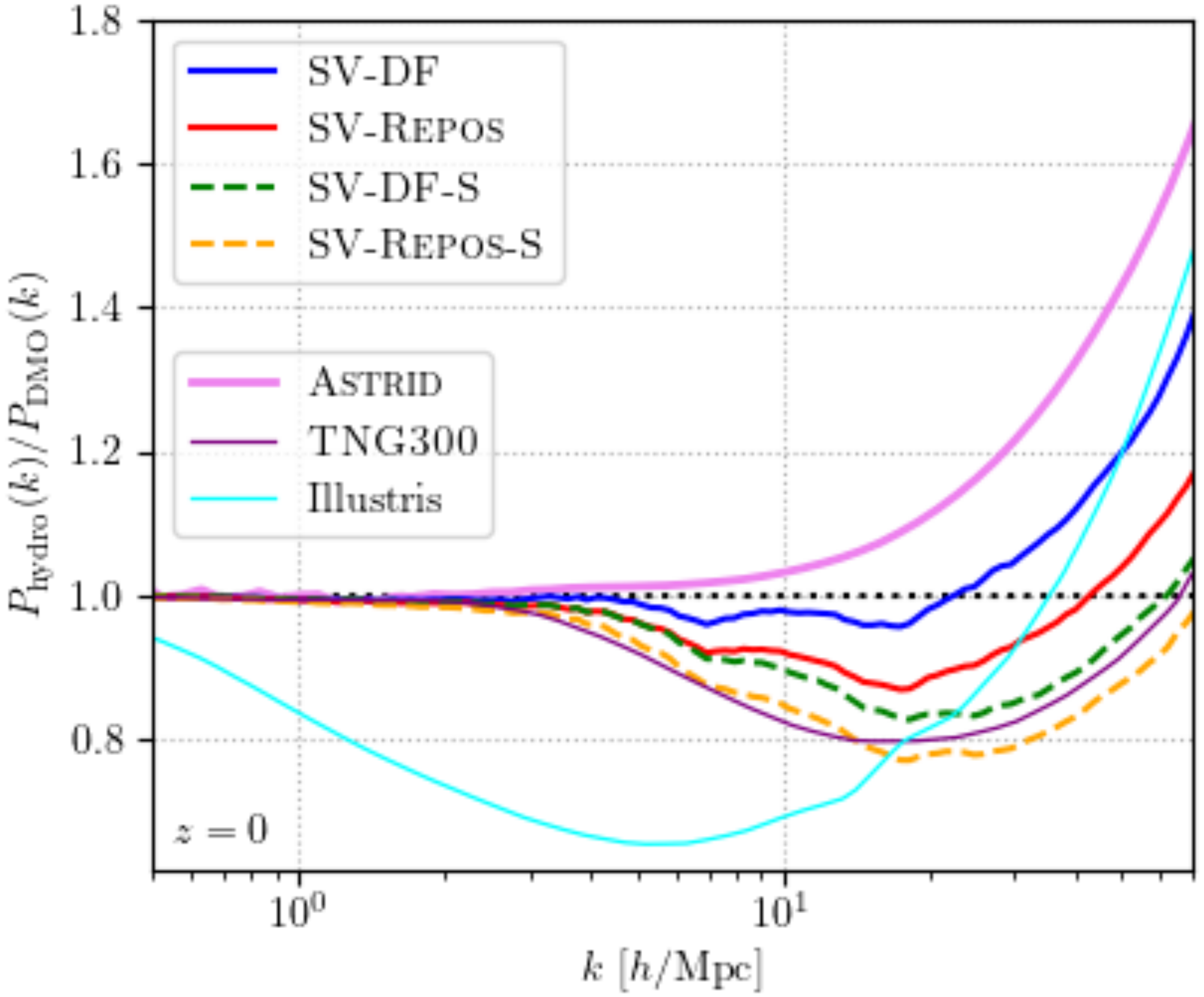

- Note: SV-DF shows lower power than Astrid because of its lower resolution

Controlled Experiments: Results

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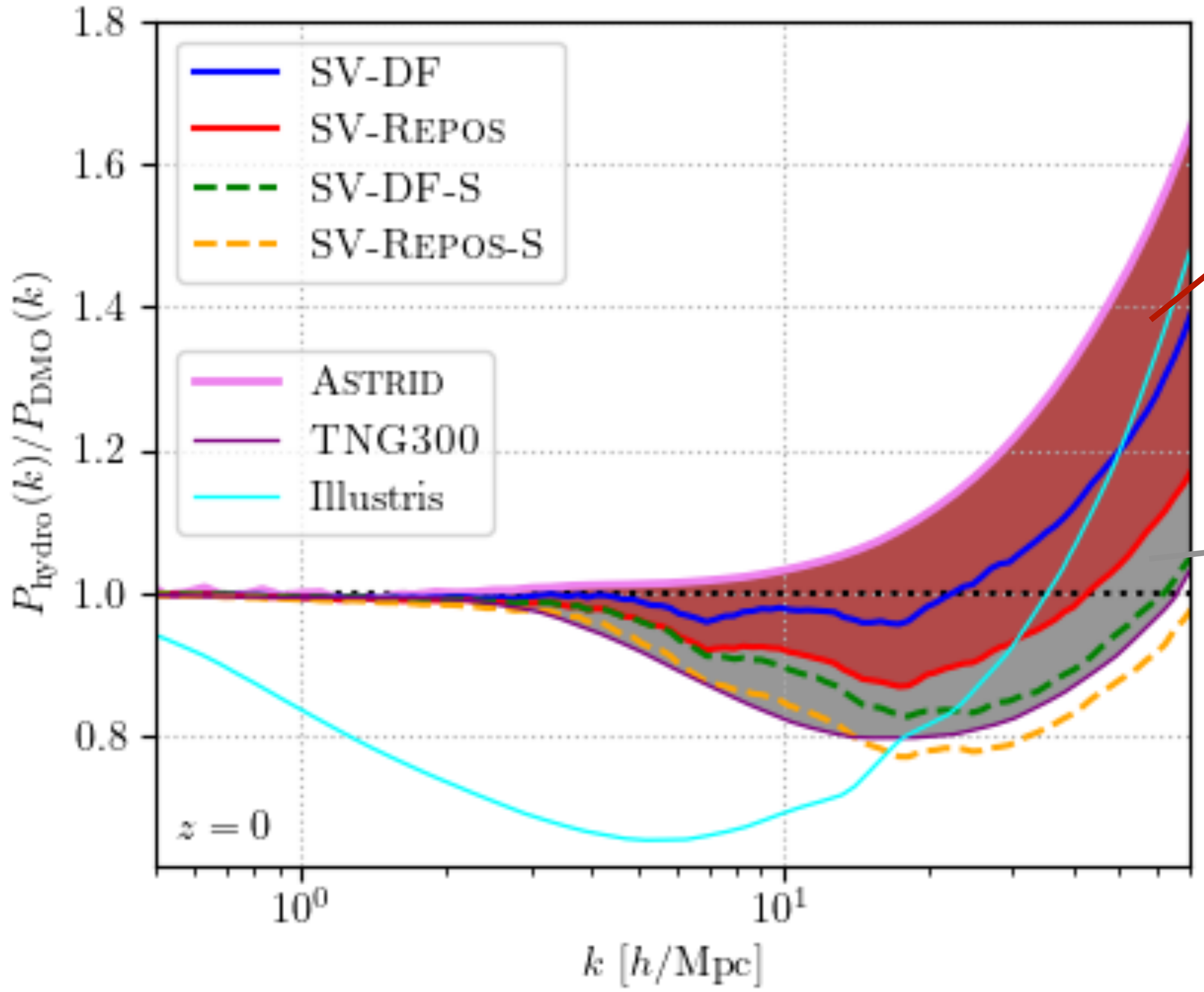
Astrid vs. TNG

BH dynamics



feedback model

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Discussion

- Astrid is not perfect: the baryonic suppression is too weak
  - too much gas remains in halos compared with observations (will be shown in the paper)
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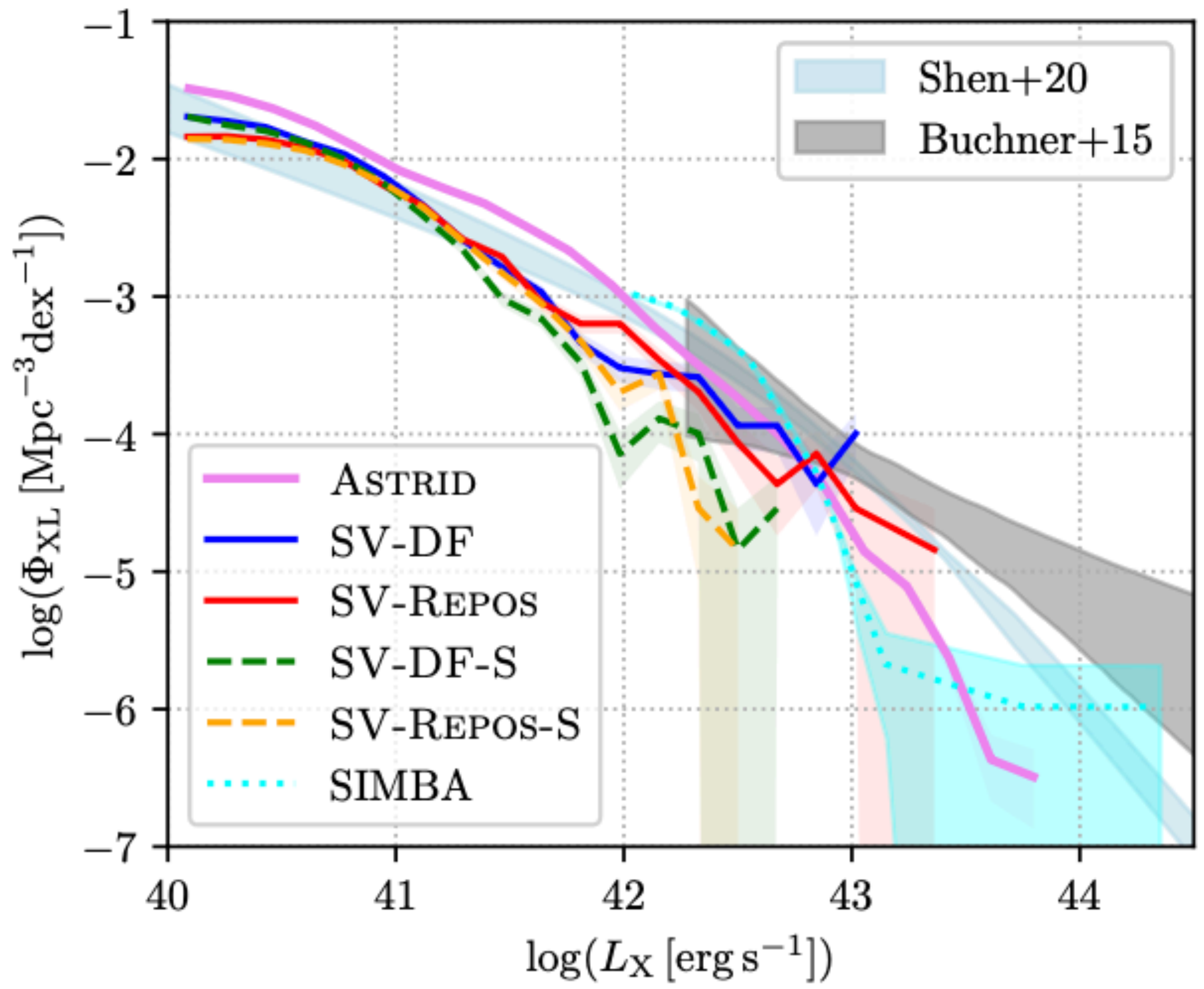
  - ~~simply increase the feedback strength?~~

    Other galaxy properties can be worse, e.g. AGN hard X-ray luminosity function (z=0)



Discussion

- Solutions?
  - jet feedback (e.g., SIMBA)?
  - new BH seeding prescription?
  - or, non-baryon physics (novel dark-sector models)?
  - other possibilities?

Conclusions

Yang+2026 (arXiv:2605.04176)

- BH repositioning artificially enhances AGN feedback and baryonic suppression of matter clustering

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Much of the strong P(k) suppression shown in most simulations may arise from numerical artifacts

- Current theoretical models are still behind observations (No perfect simulations yet!)

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We advocate developing new models (with dynamical friction) that can evacuate gas efficiently without compromising other galaxy properties

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fully exploit Roman data