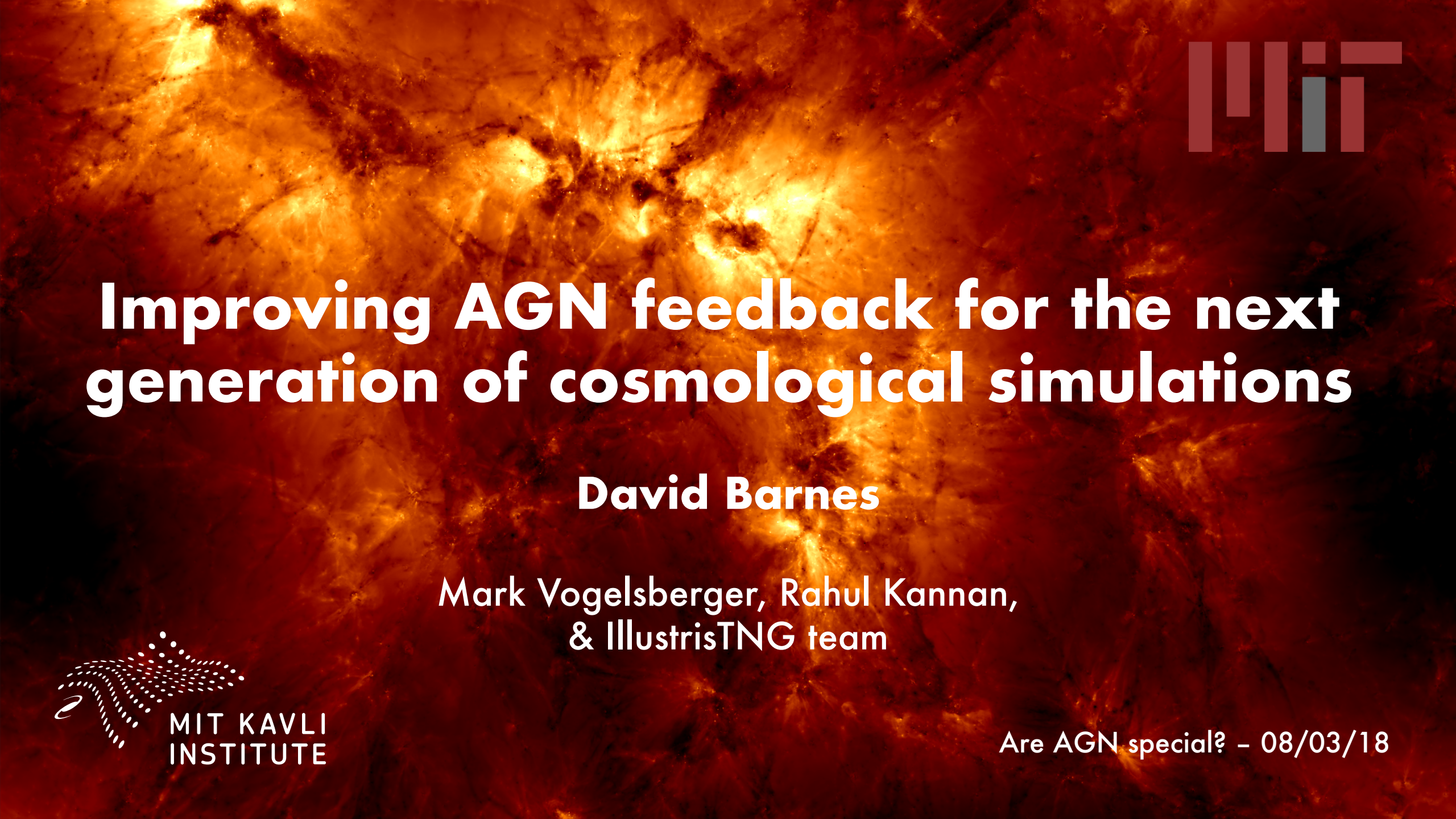

Improving AGN feedback for the next generation of cosmological simulations

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Mark Vogelsberger, Rahul Kannan,
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MIT KAVLI INSTITUTE

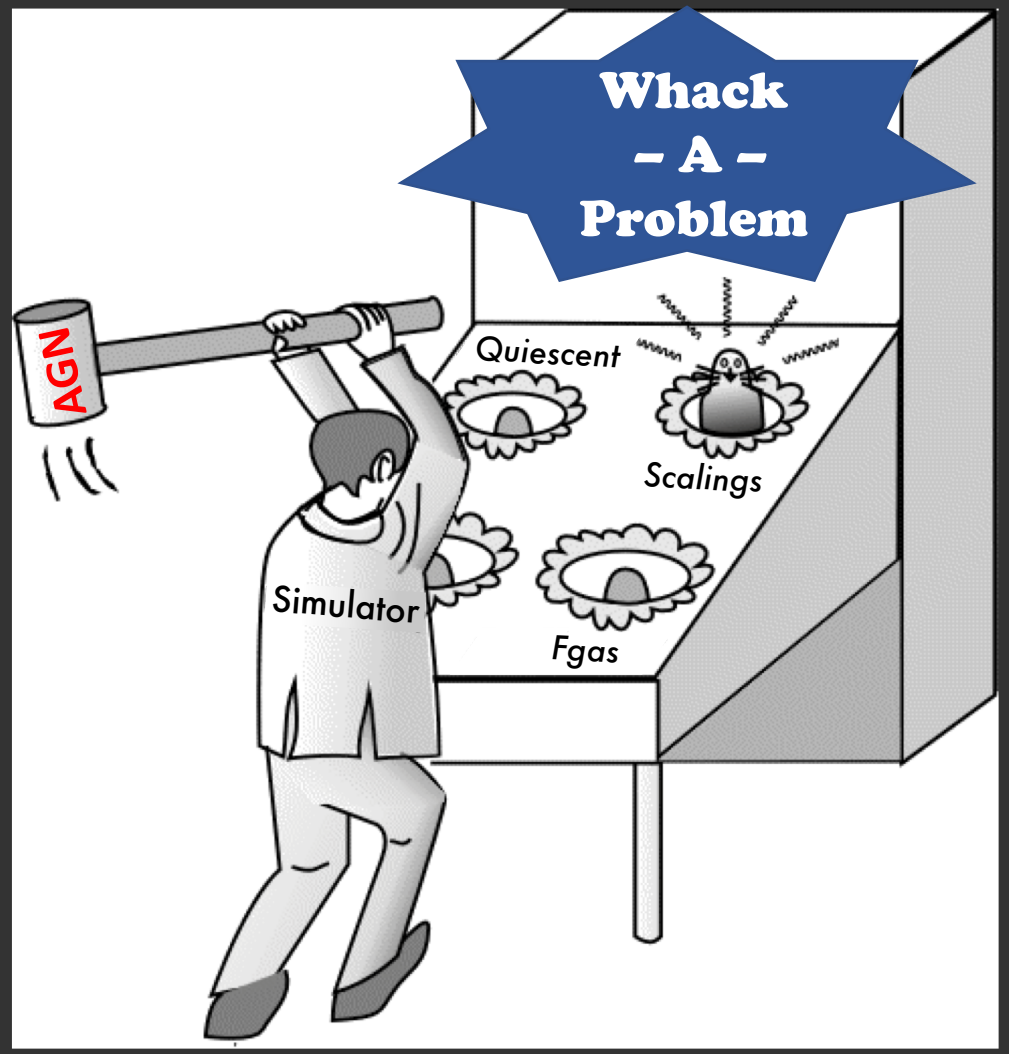
Are AGN special? – 08/03/18

Outline

- Are AGN special?
- Convergence
- Are we missing physics?
- Quasar feedback preview

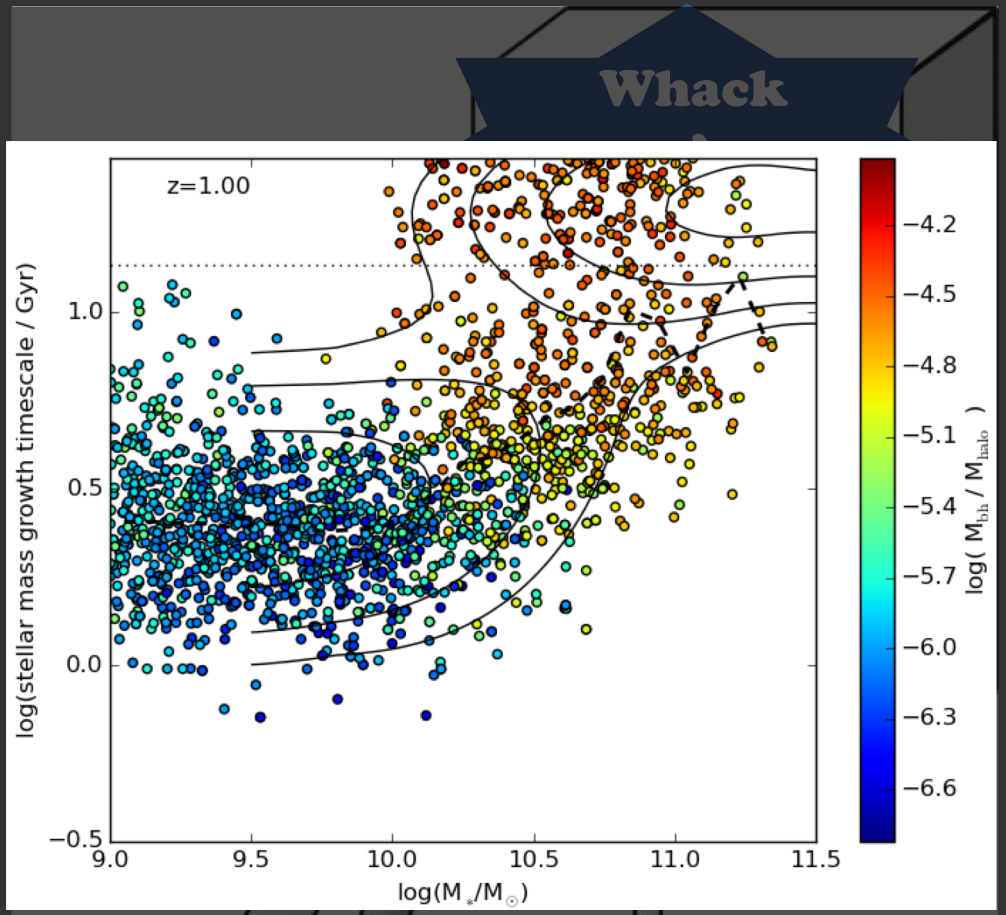
Are AGN special?

. . . in simulations their feeback is



- Recent advances in numerical simulations are driven by **calibrated** AGN feedback

. . . their feedback is in simulations



Bower+ 2017

- Recent advances in numerical simulations are driven by **calibrated** AGN feedback
- Feedback leads to the formation of the quiescent galaxy population

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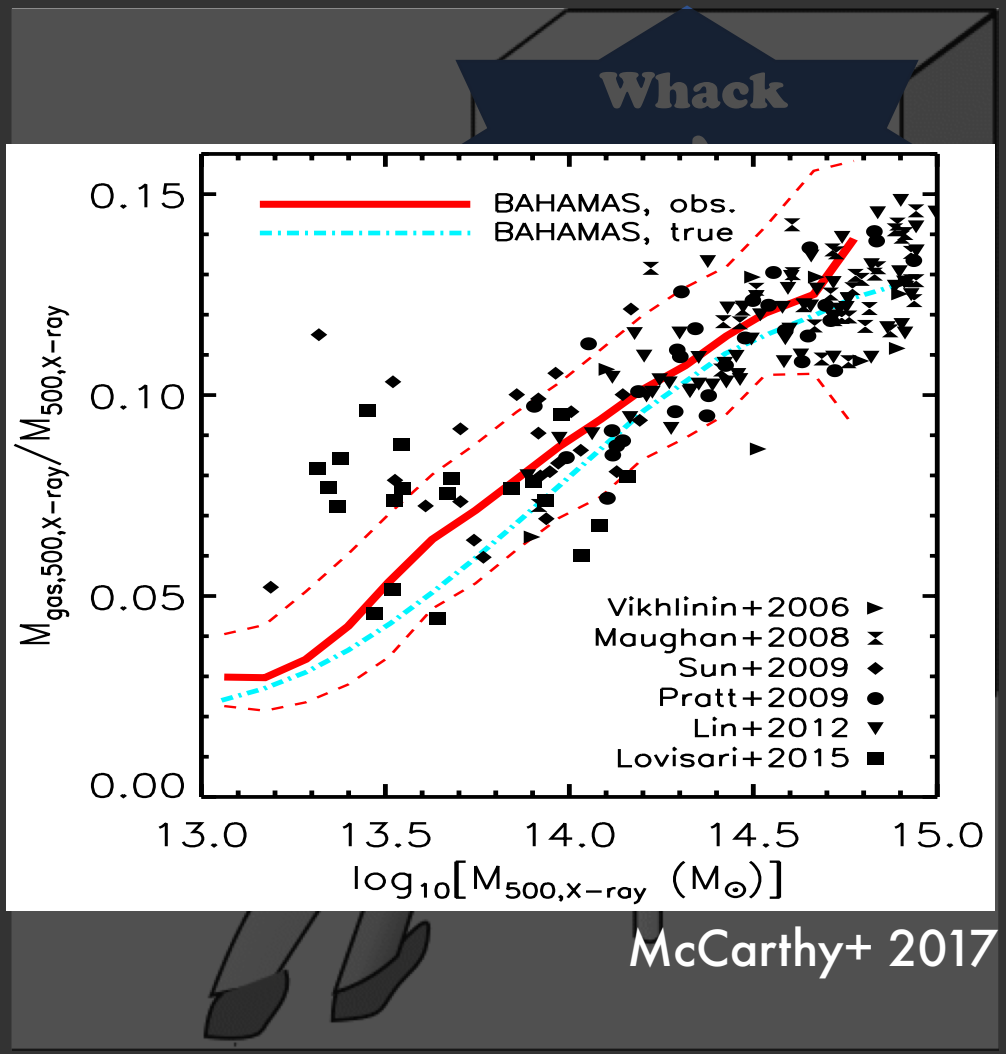
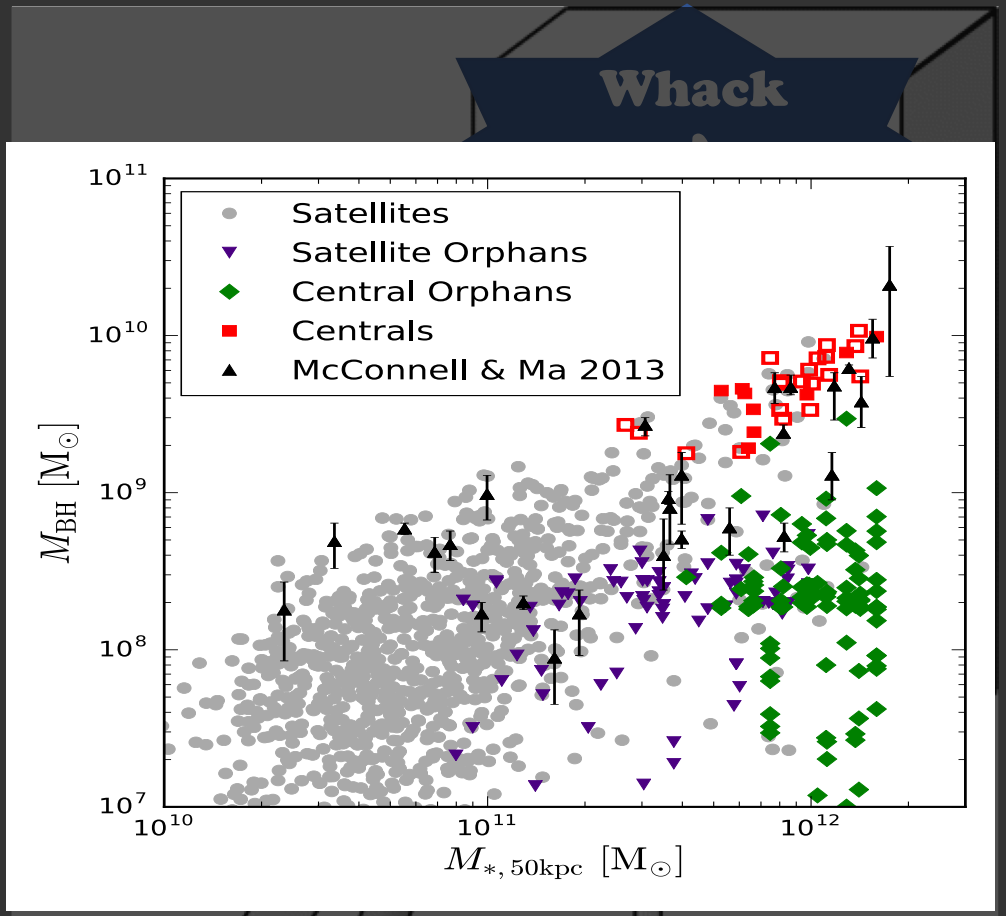


McCarthy+ 2017

- Recent advances in numerical simulations are driven by **calibrated** AGN feedback
- Feedback leads to the formation of the quiescent galaxy population
- Feedback ejects gas from shallower potentials producing the observed gas fraction

. . . their feedback is in simulations



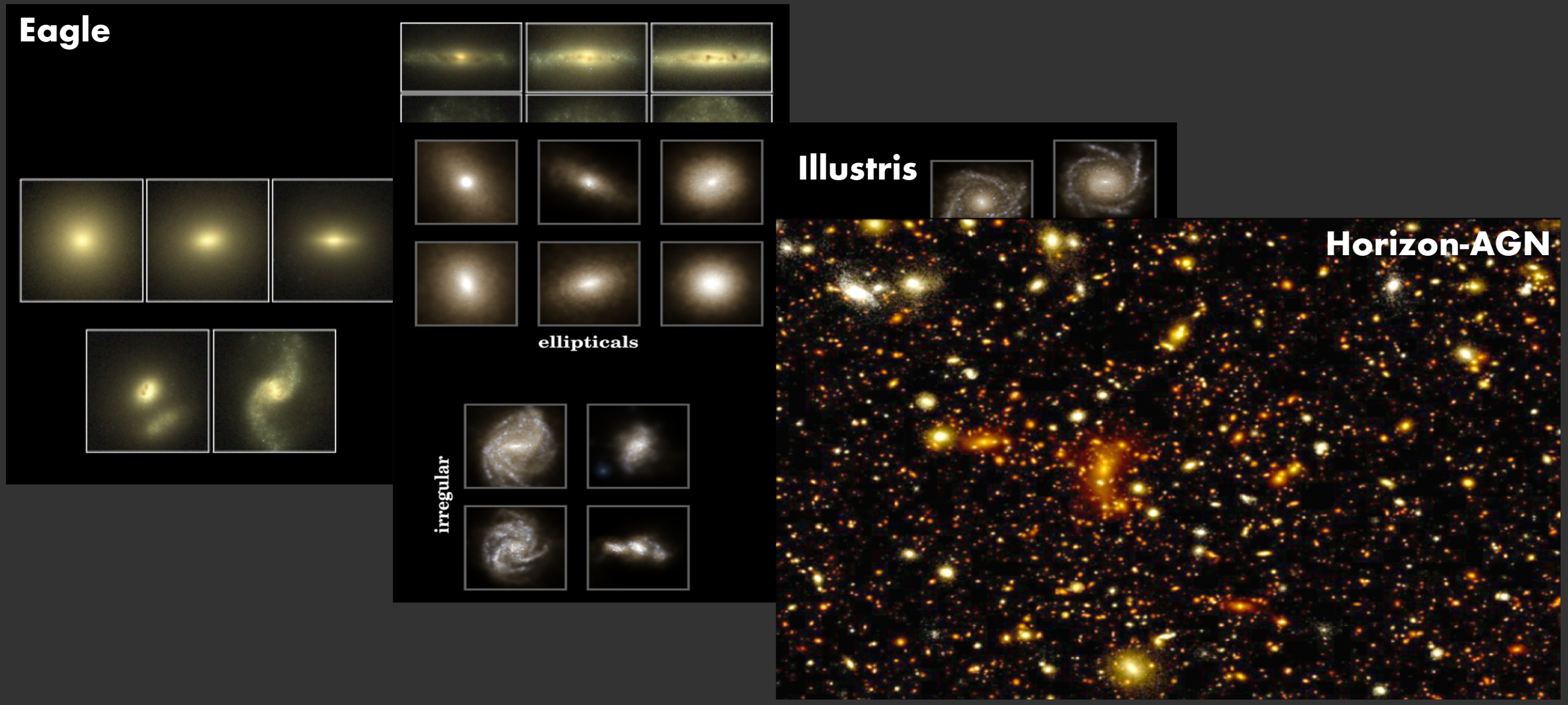
Barnes+ 2017b

- Recent advances in numerical simulations are driven by **calibrated** AGN feedback
- Feedback leads to the formation of the quiescent galaxy population
- Feedback ejects gas from shallower potentials producing the observed gas fraction
- Feedback establishes the BH-galaxy scaling relations

AGN receipe

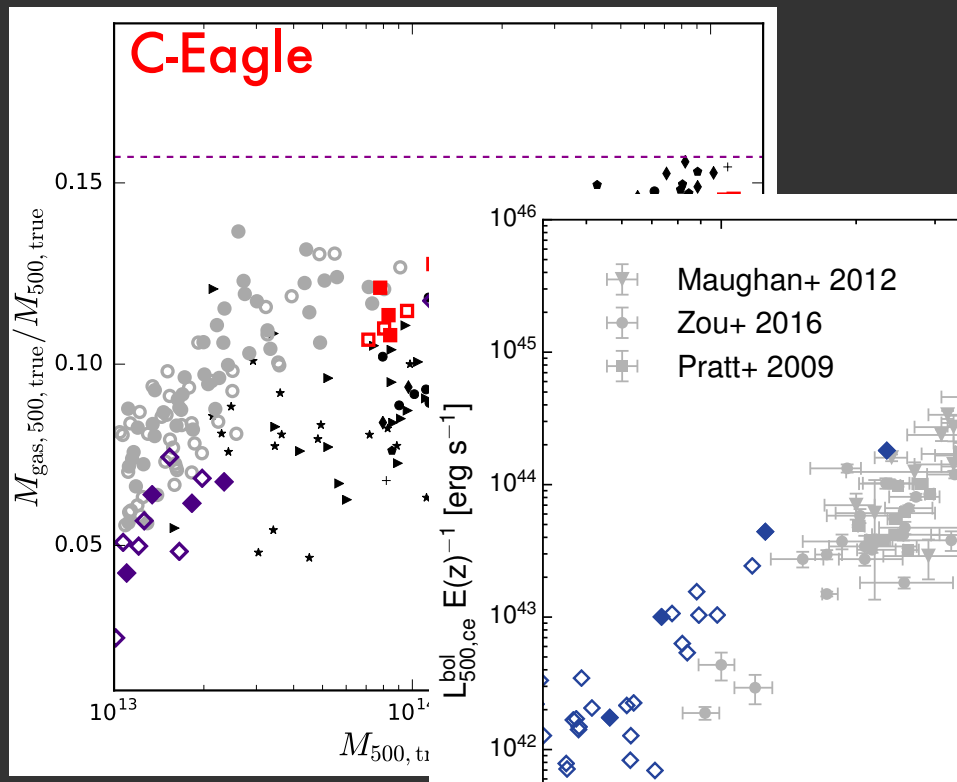
- Numerical treatment of BHs is relatively crude
- Most cosmological simulations follow a similar recipe:
    - Seed mass BHs placed in haloes of a certain mass
    - BHs grow through Bondi-Hoyle-*like* accretion and mergers
    - BHs deposit energy and/or momentum into their surroundings
    - Some models split feedback into "quasar" and "radio" modes
- **Calibration**
- Warning: Energy injected & duty cycle typically numerically driven

Convergence . . . of simulations



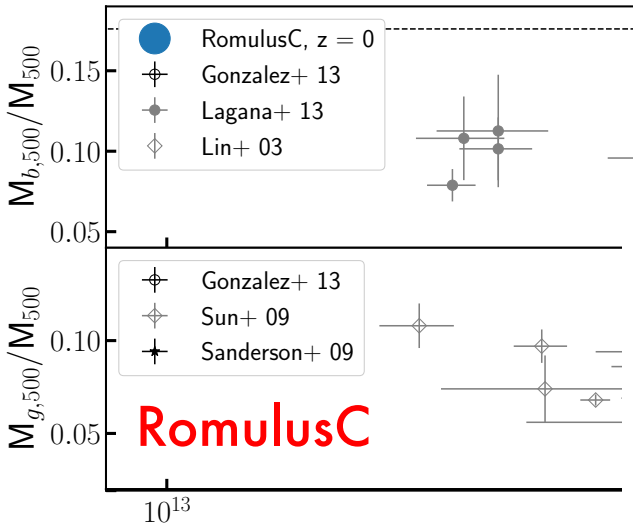
However . . .

- Extending these models to dense environments highlights shortcomings

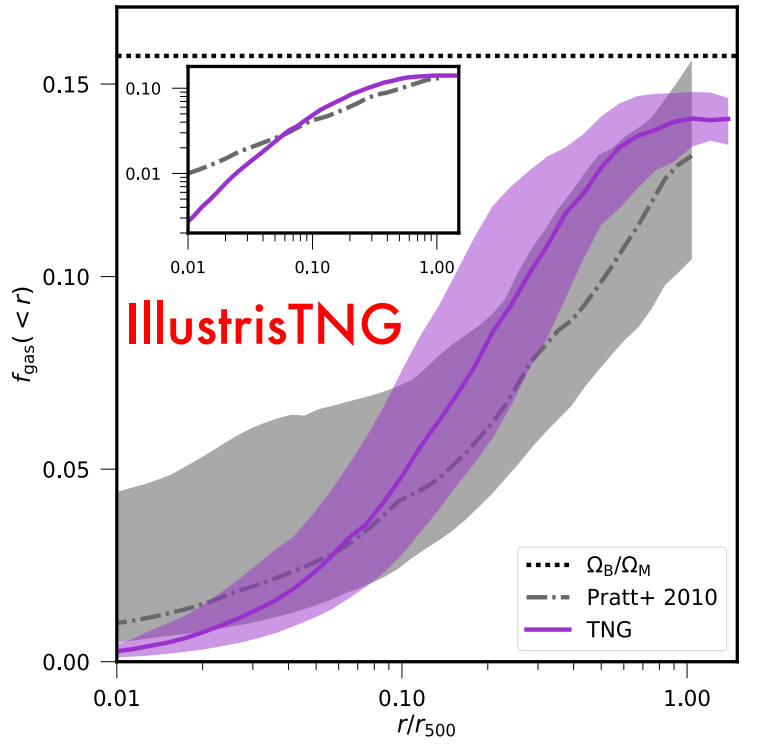


Barnes+ 2017b

Henden+ 2018



Tremmel+ 2018



Barnes+ 2017c

Modelling or missing processes?

- Current cosmological simulations still lack many physical processes

- Simulations are missing:
  - Cosmic rays → an exciting area
  - Heat transport → only impacts clusters
  - Improved AGN models → model radiation

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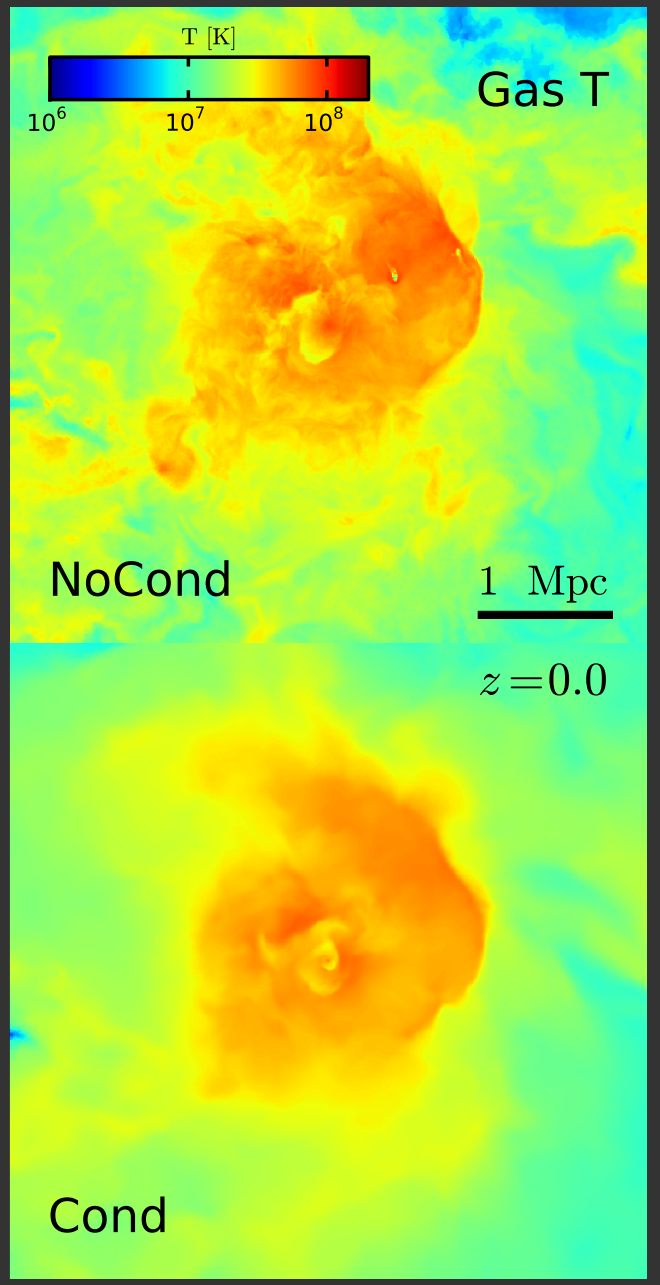
NASA/CXC/SAO LOFAR/ASTRON NAOJ/Subaru

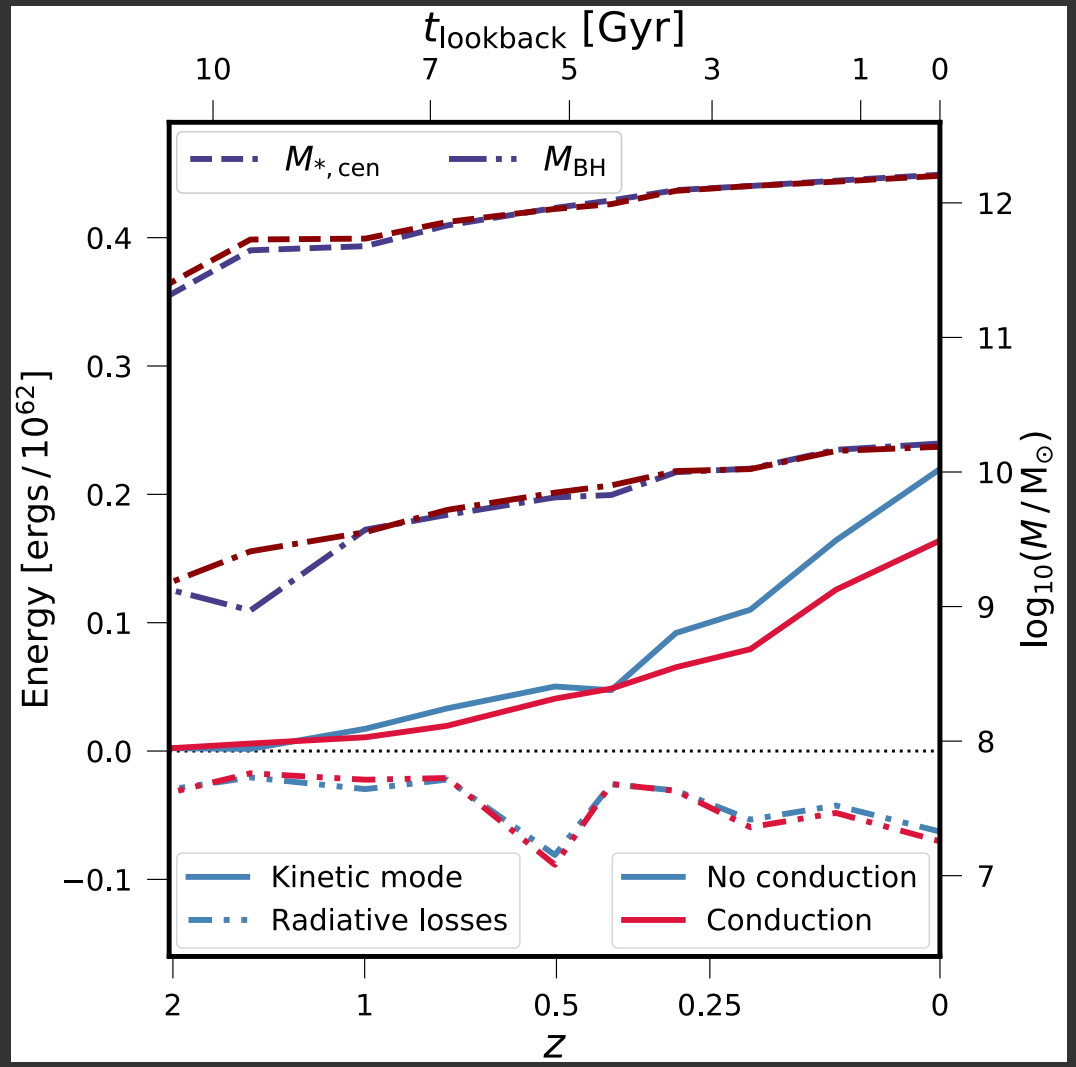
Modelling or missing processes?

- Current cosmological simulations still lack many physical processes
- Simulations are missing:
  - Cosmic rays → an exciting area
  - Heat transport → **anisotropic case?**
  - Improved AGN models → model radiation
- 12 clusters simulated using IllustrisTNG model with and without anisotropic thermal conduction
- Use full Spitzer parallel to magnetic field to explore maximum effect



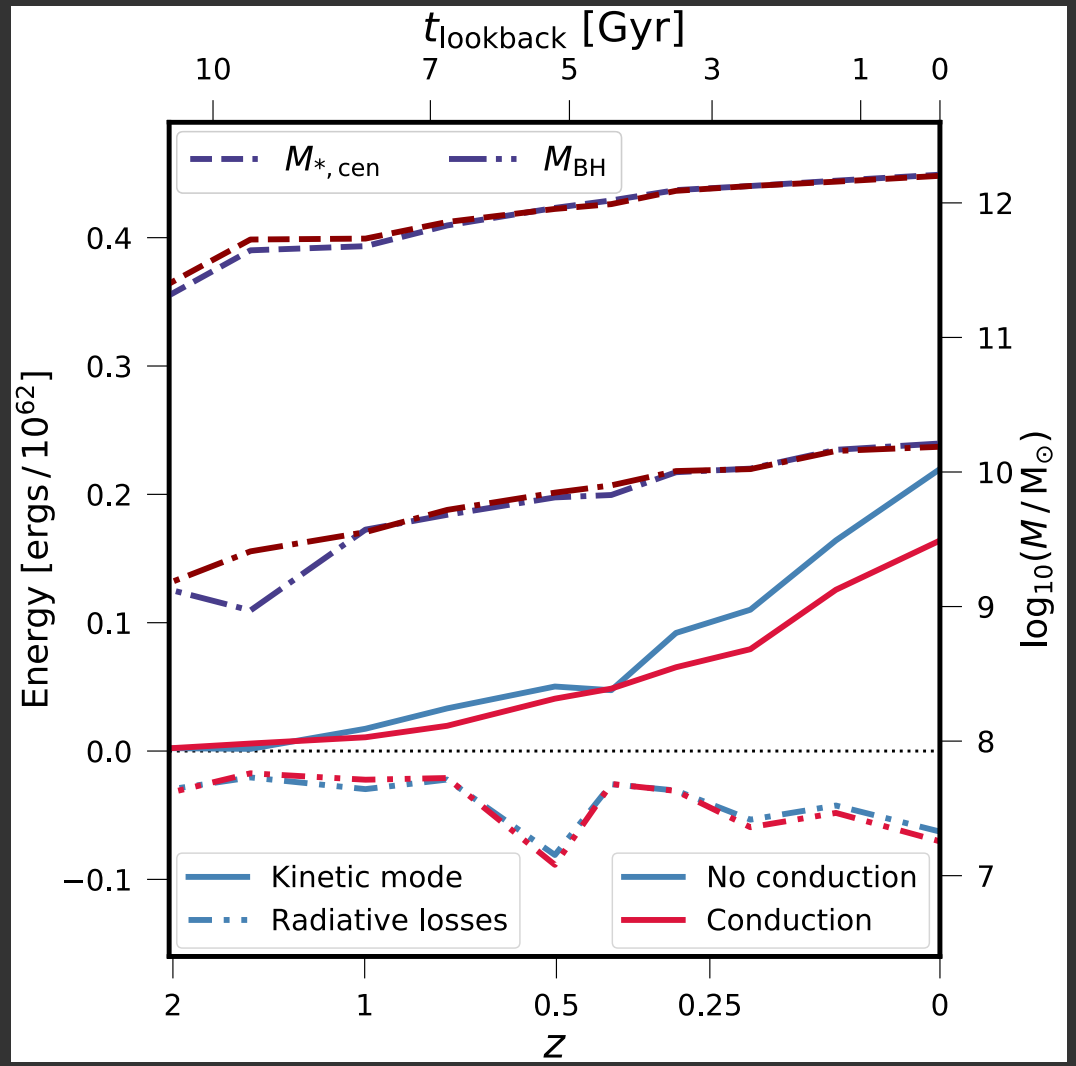
Kannan+ 17

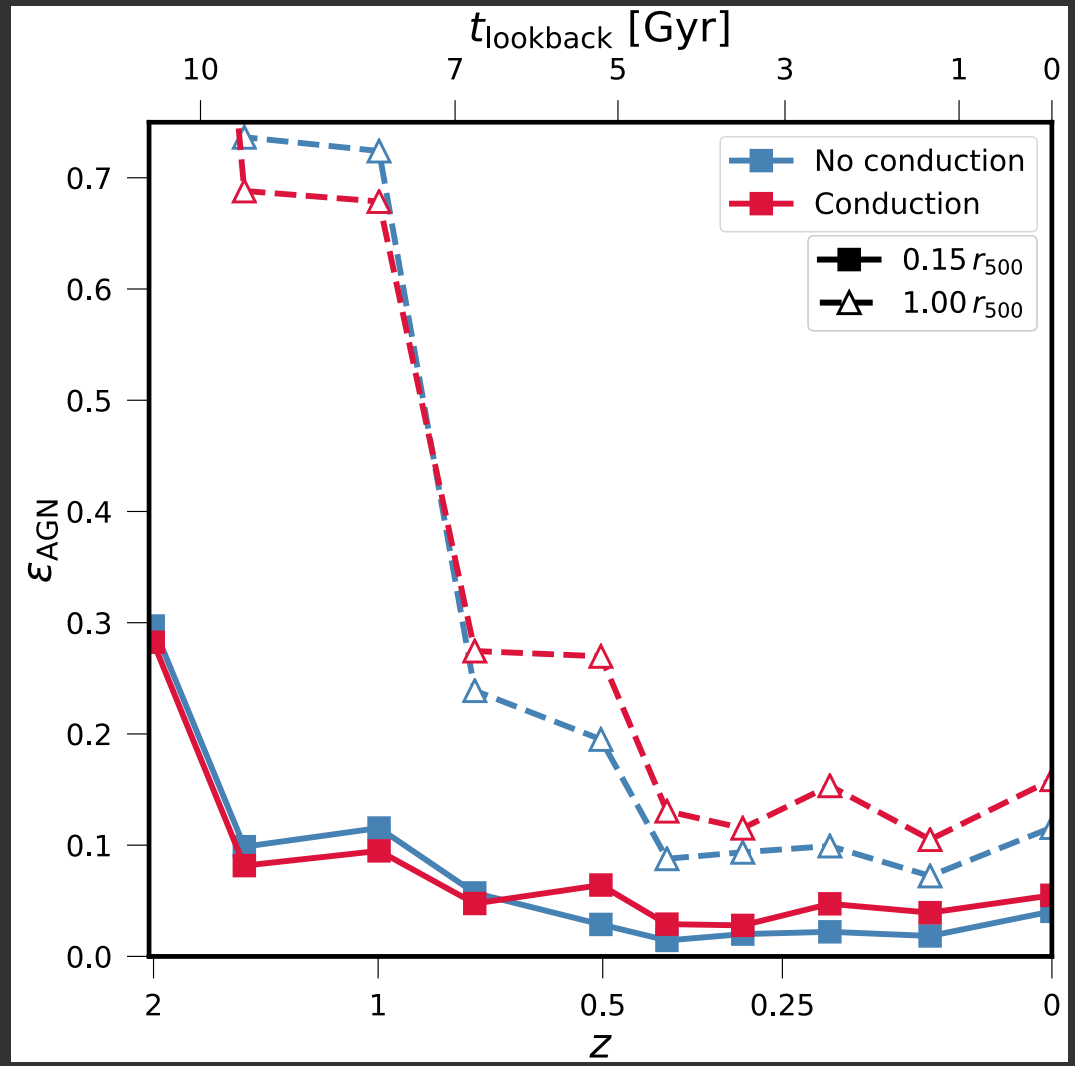
Less energy injected...



Barnes+ 2018

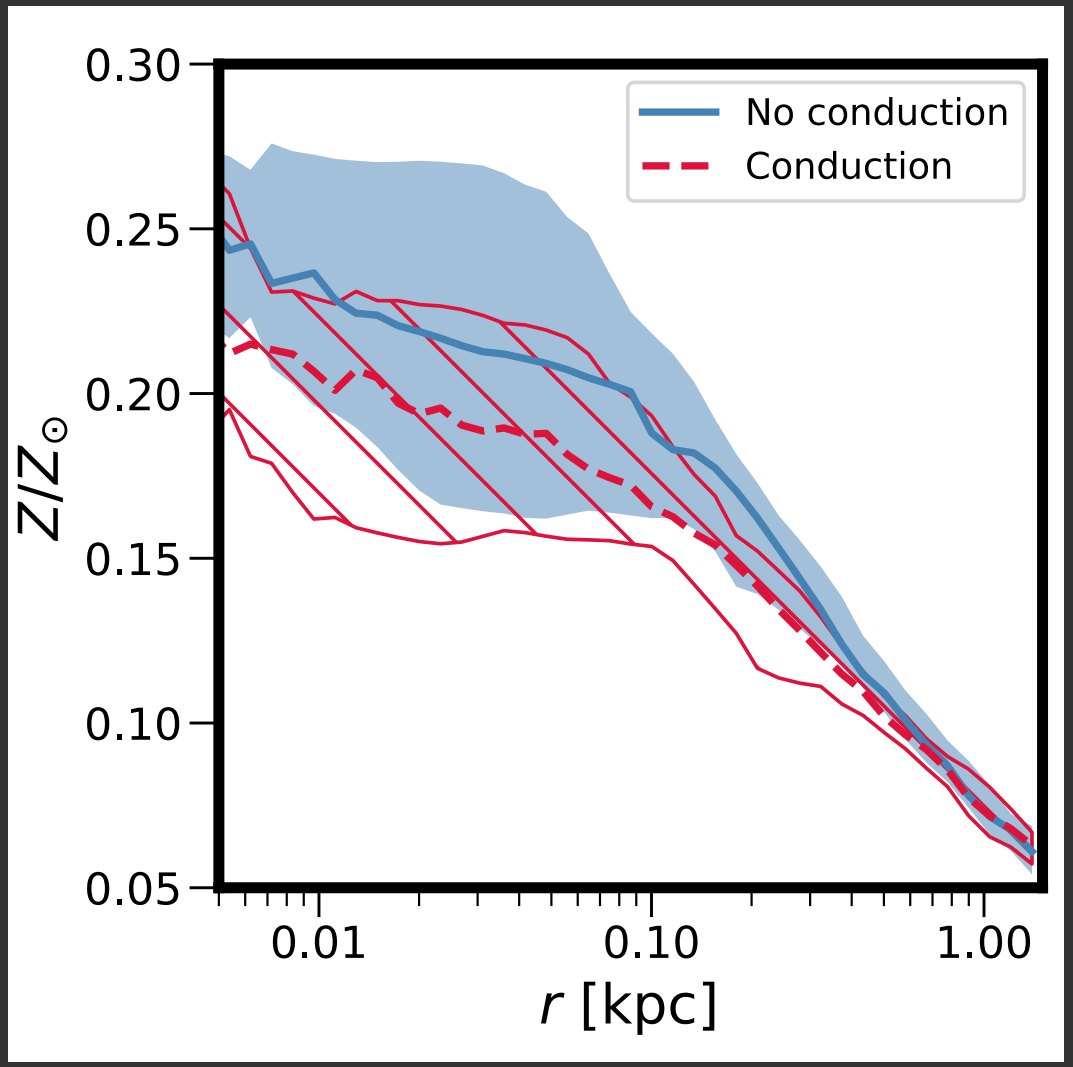
...but more efficiently coupled



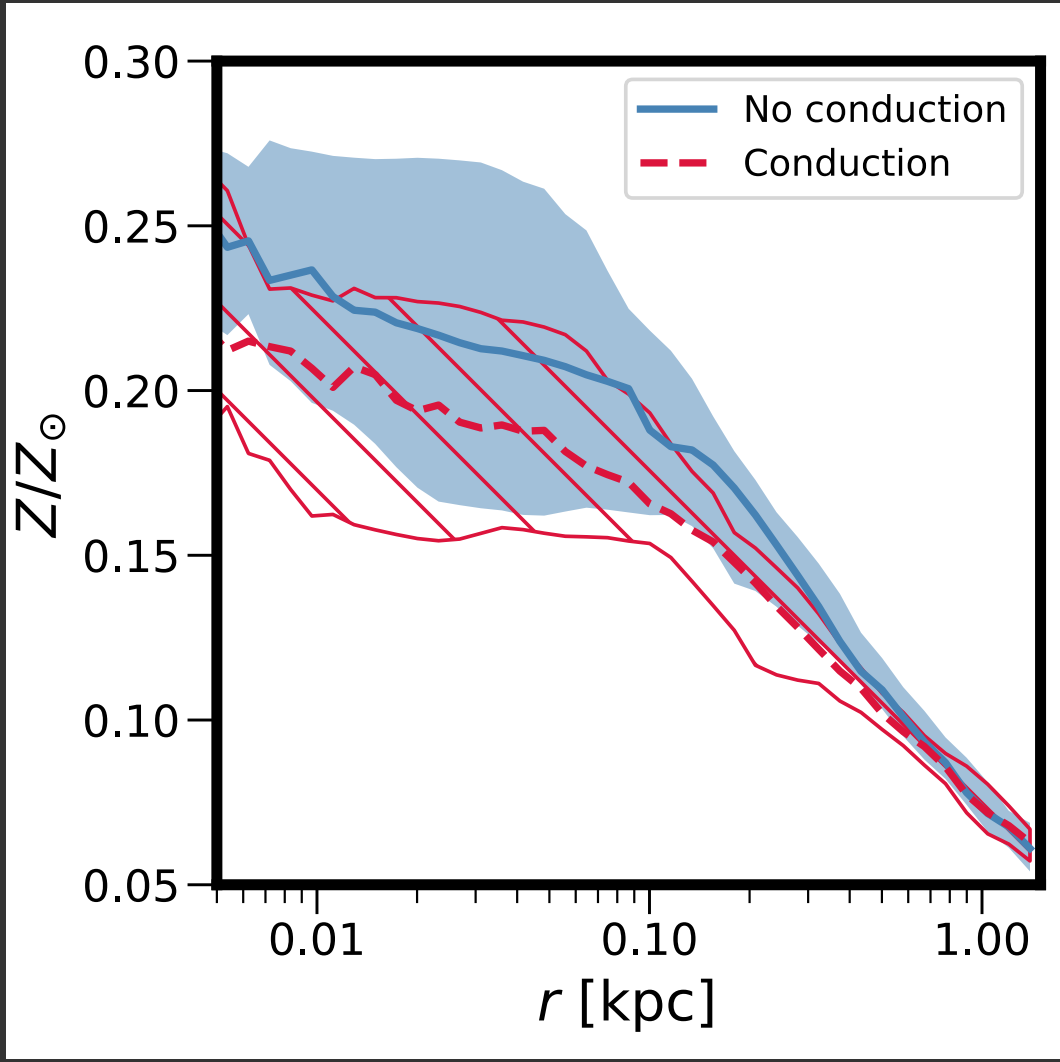


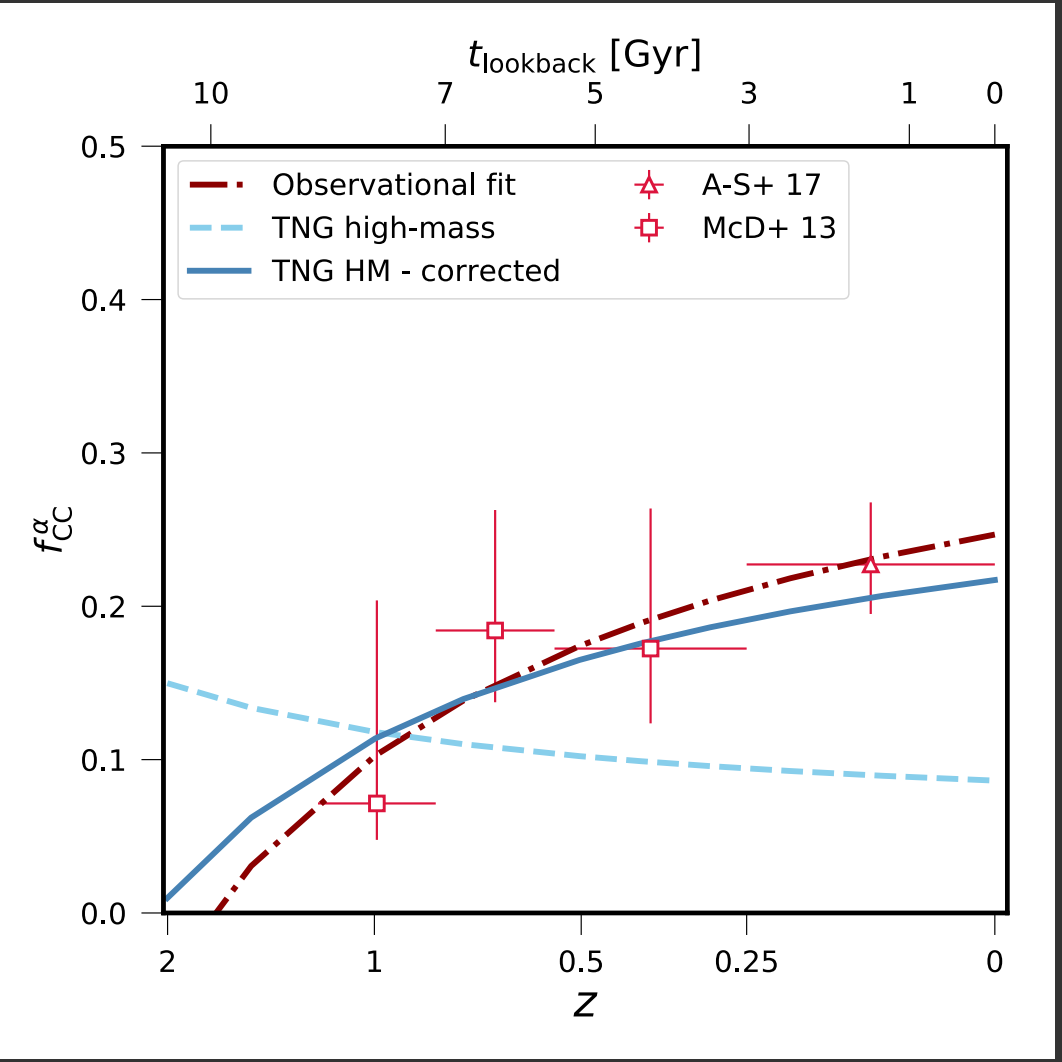
Barnes+ 2018

Increased mixing . . .



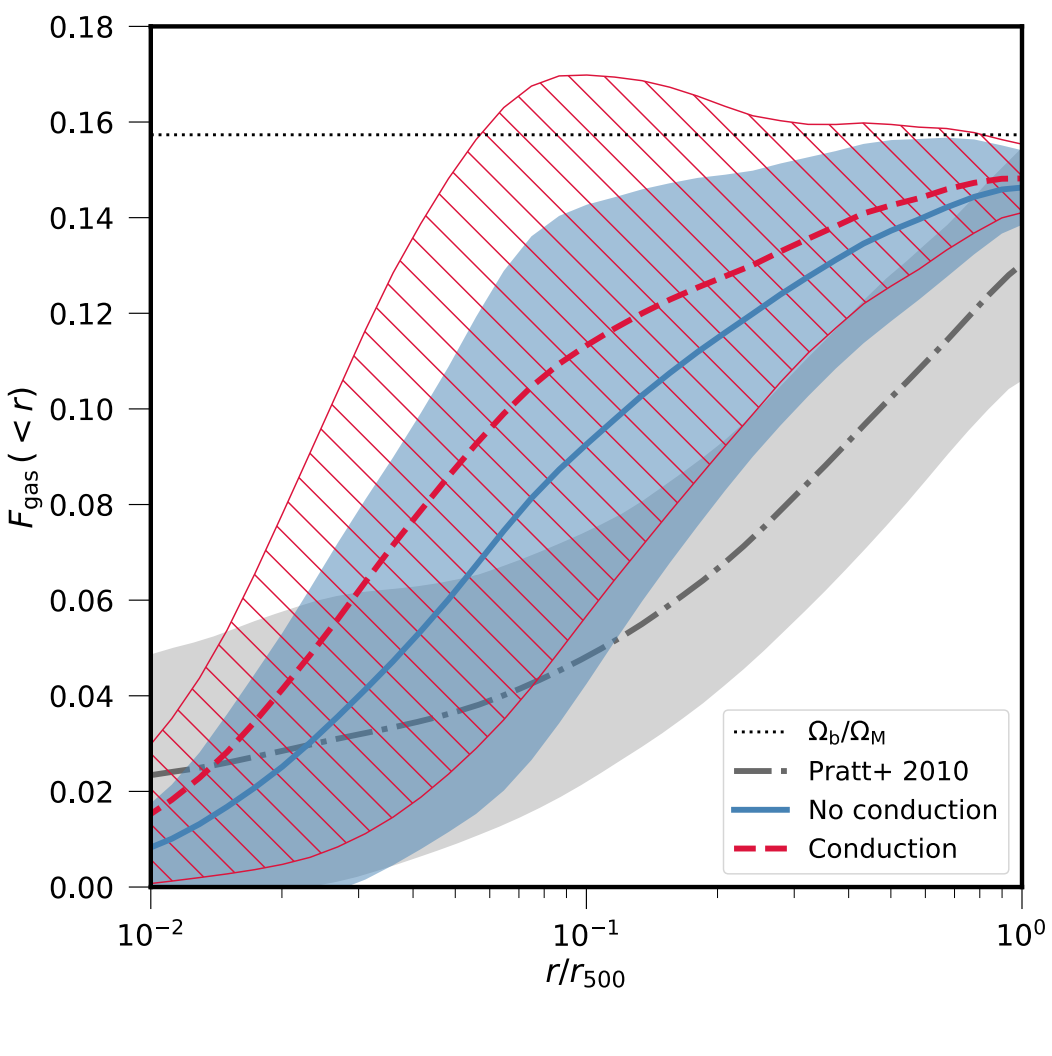
Improved thermal structure evolution . . .

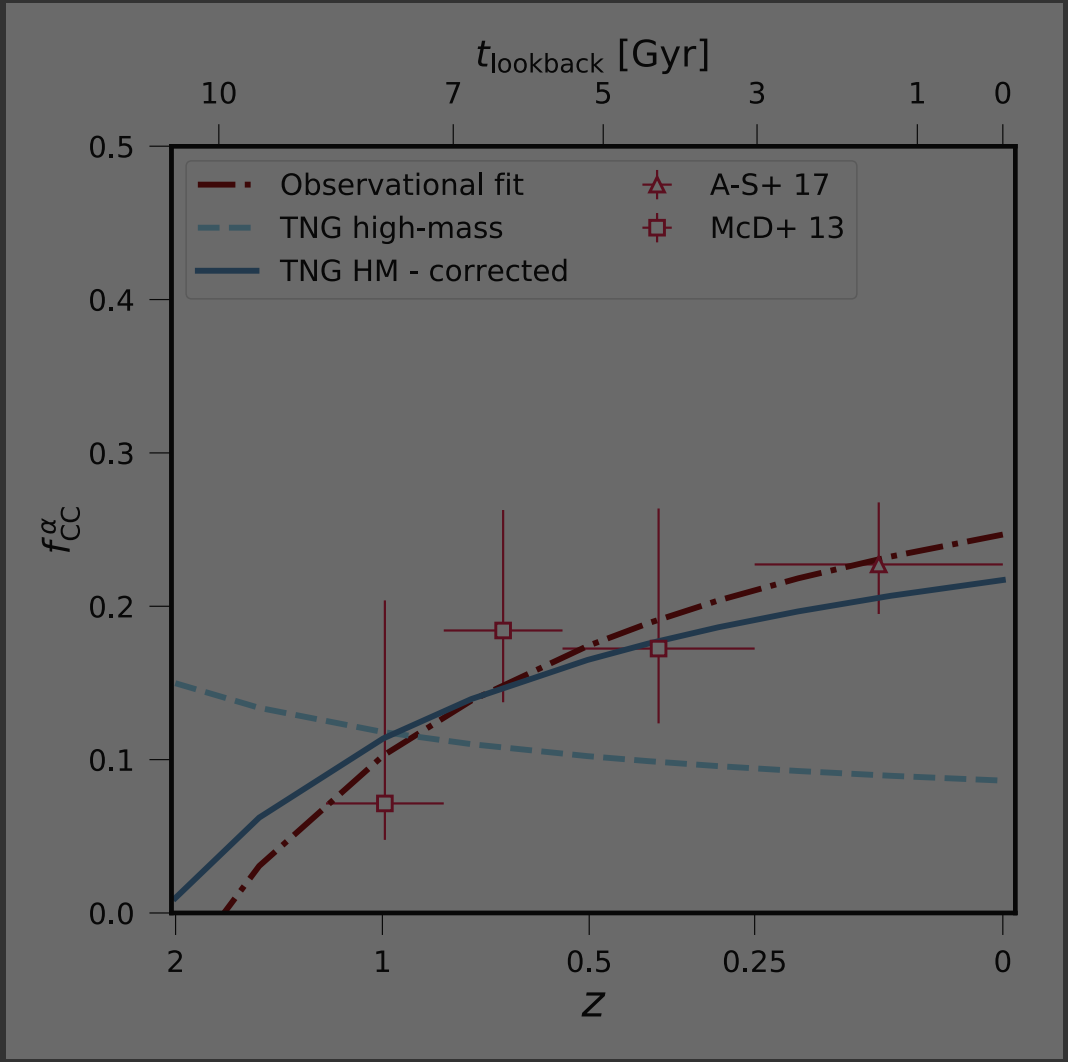




Barnes+ 2018

. . . but still too gas rich



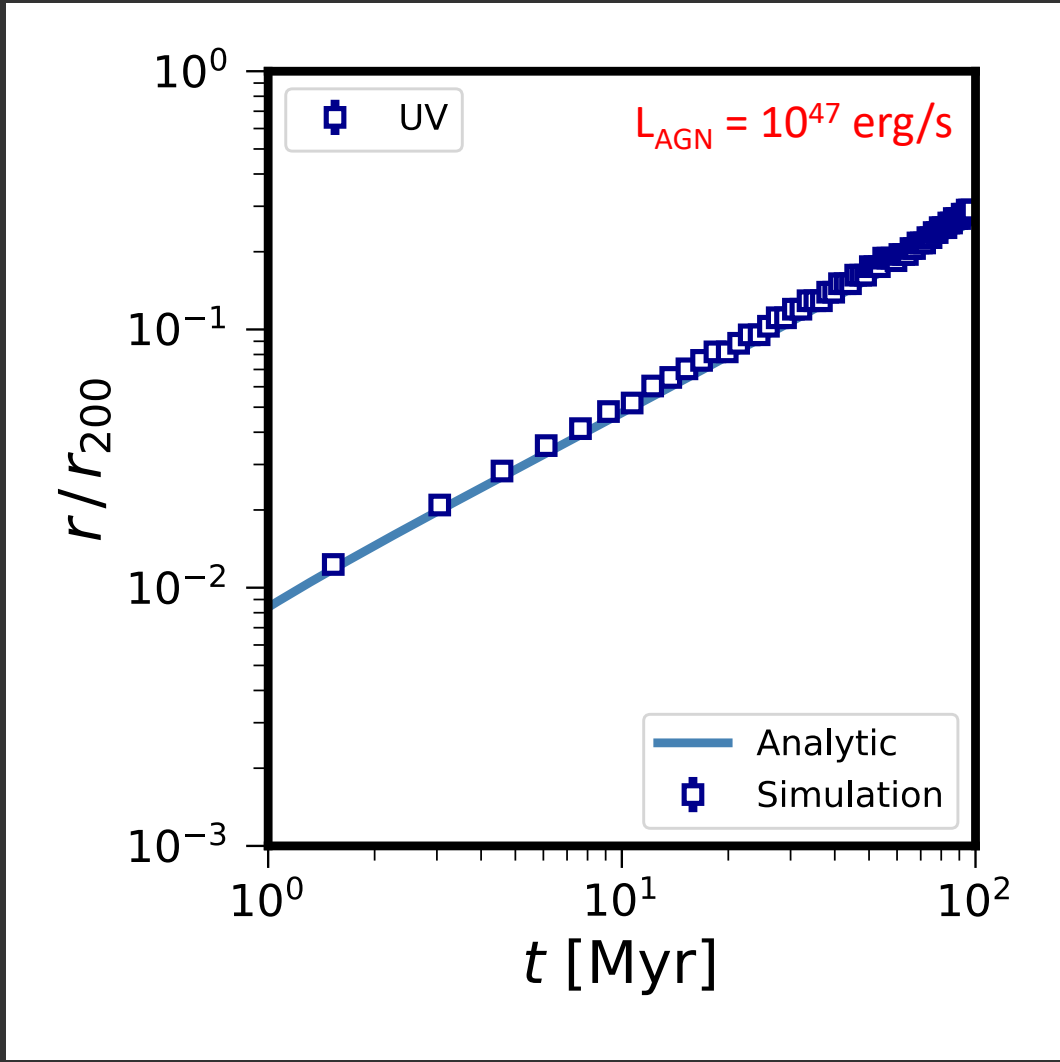


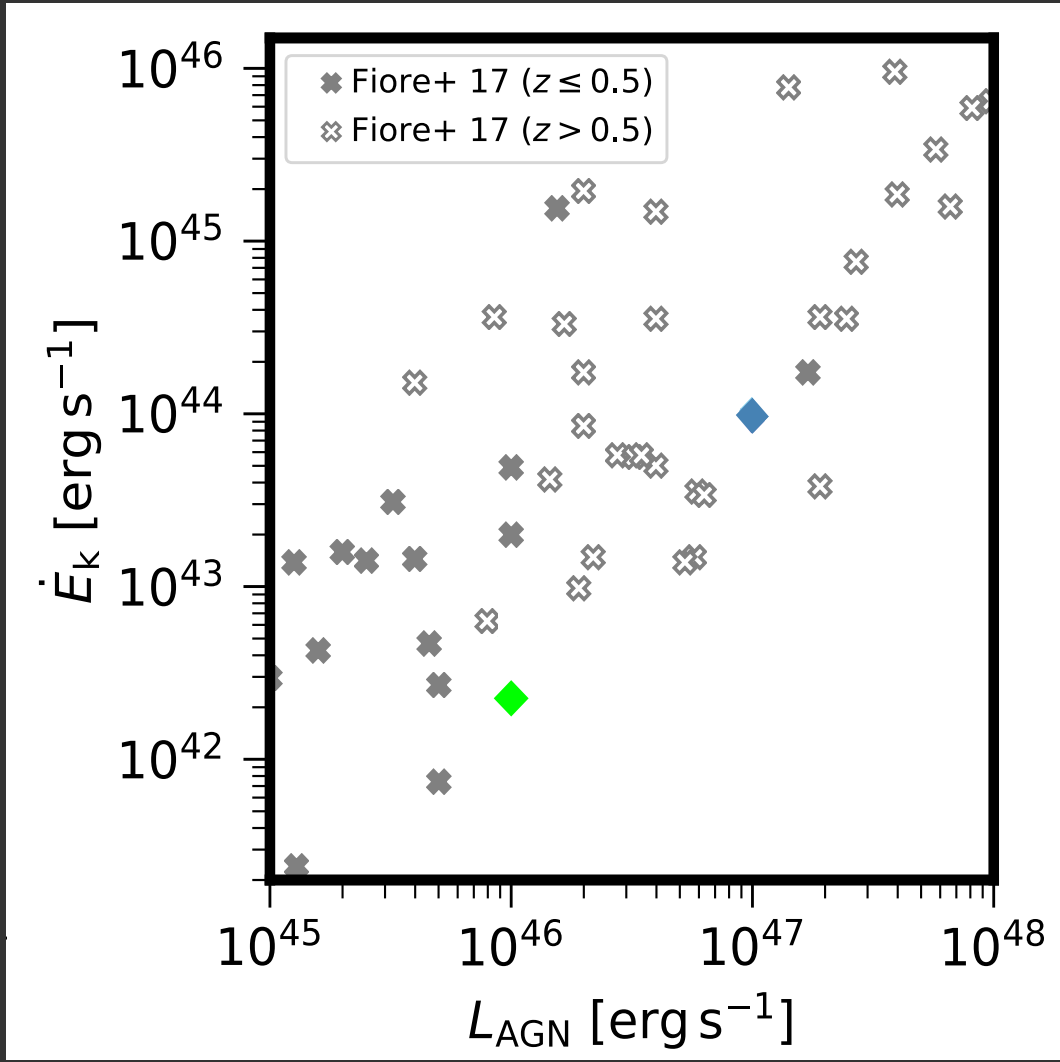
Barnes+ 2018

Quasar feedback preview

- Dense environments in simulations contain too much gas
- Can we better model high accretion rate feedback to remedy the problem?
- Large body of idealized theoretical work has shown that directly coupled radiative AGN feedback can drive outflows from haloes (Fabian+ 99, Novak+ 12, Thompson+ 15, Ishibashi+ 15,17,18, Costa+ 18a,b, etc.)
- Assumes: dust and gas hydrodynamically coupled, constant dust to gas ratio
- Using ArepoRT (Kannan+ 18), place a BH in the center of an NFW halo and inject radiation in the UV band at a constant luminosity

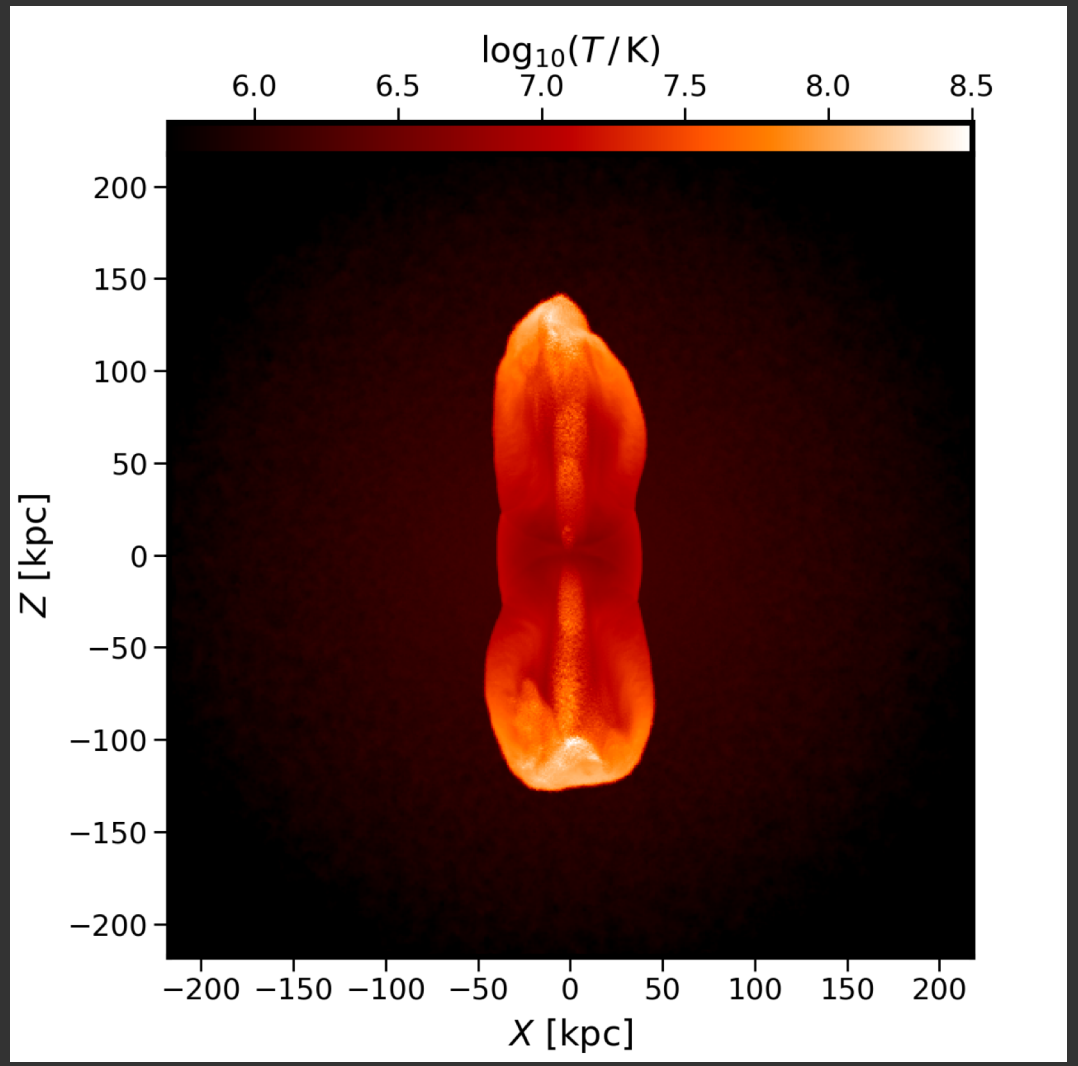
Reproduces the analytic expectation

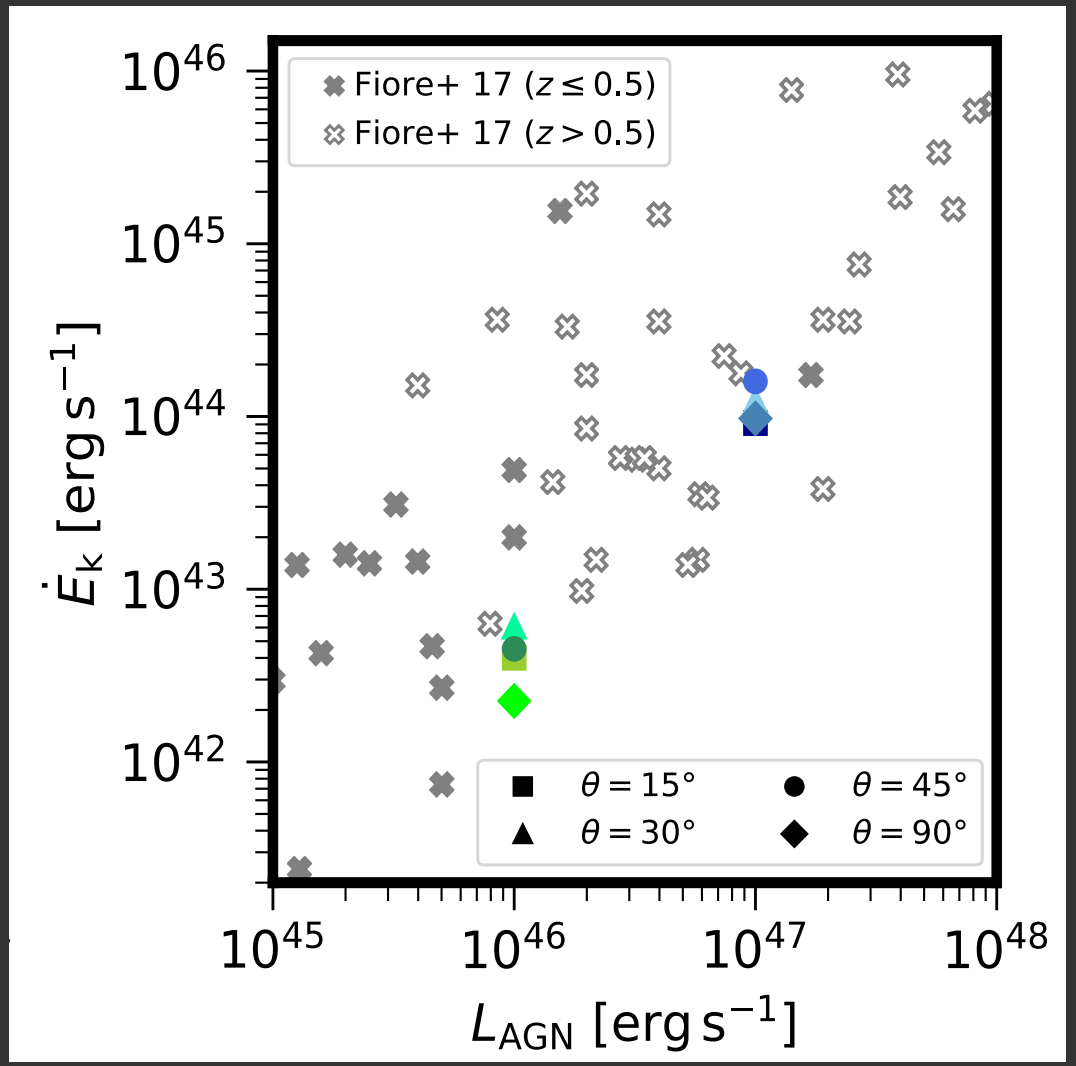




Barnes+ in prep.

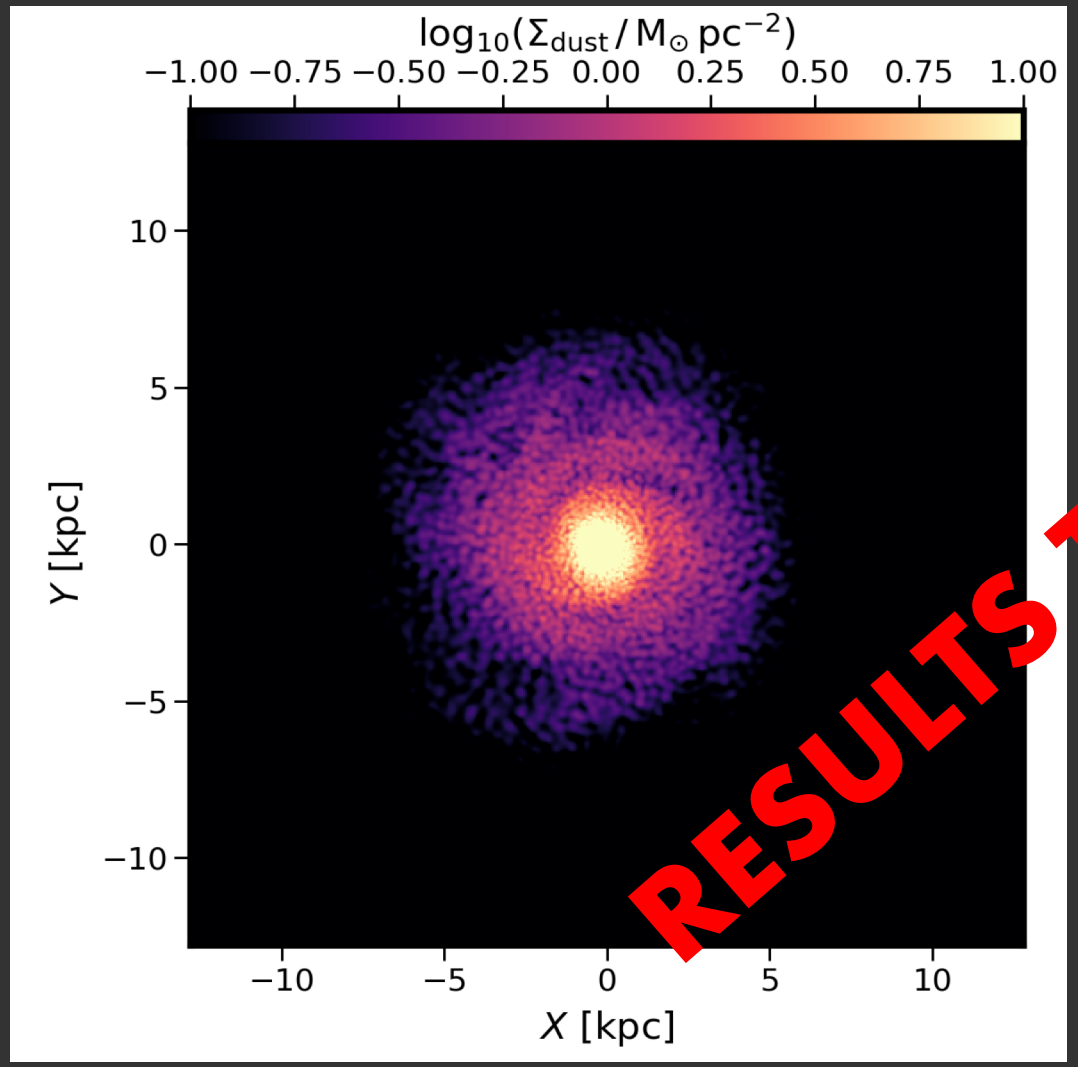
Collimated?

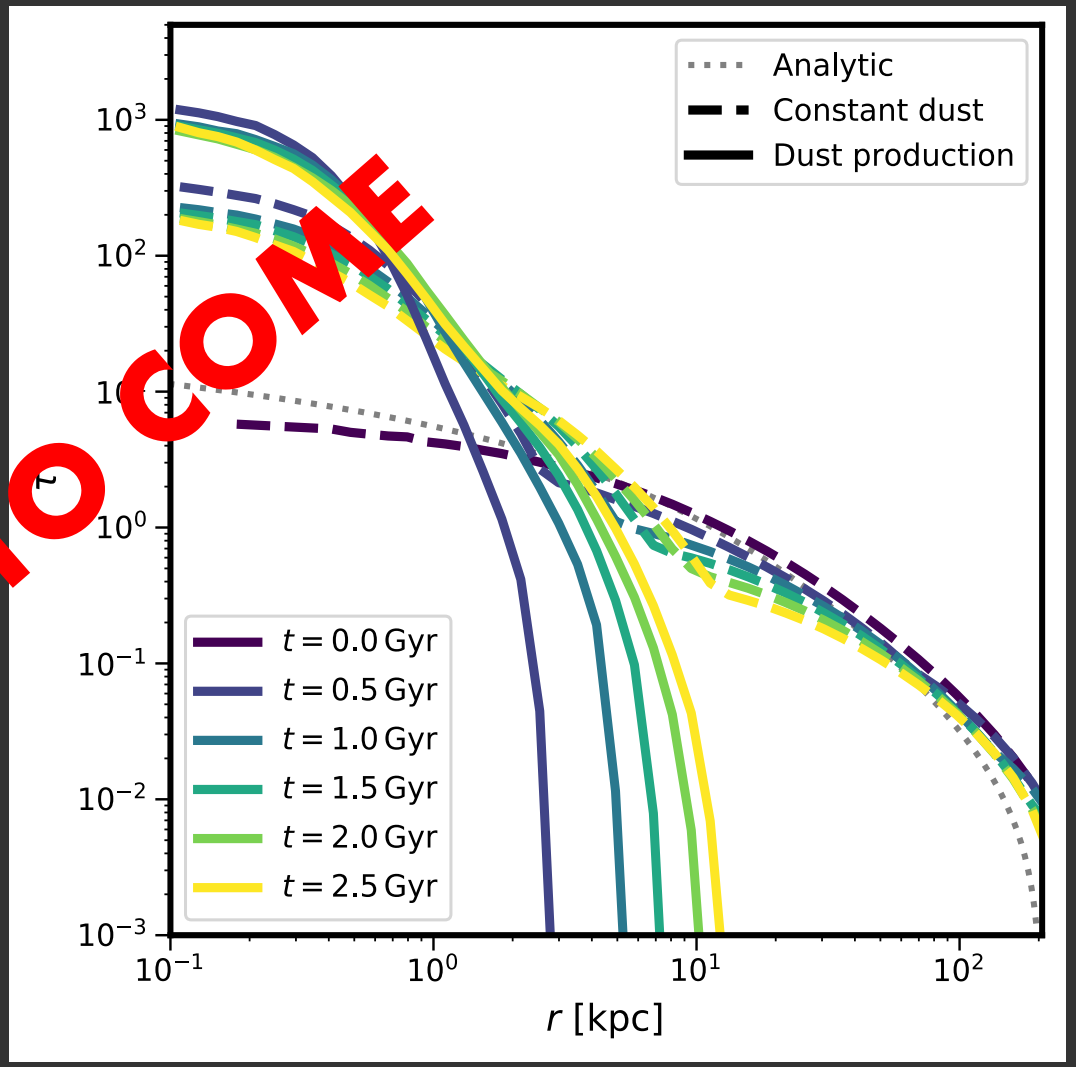




Barnes+ in prep.

More realistic dust distributions





RESULTS TO COME

Barnes+ in prep.

Conclusions

- AGN feedback is special in simulations, solving a host of issues
- However, in dense environments such as clusters the current models are too crude
- Incorporating additional physical processes such as anisotropic thermal conduction reduces the impact of AGN at low redshift
- Models of AGN feedback must continue to improve