Is Black Hole Growth in Galaxies Self-Regulated?

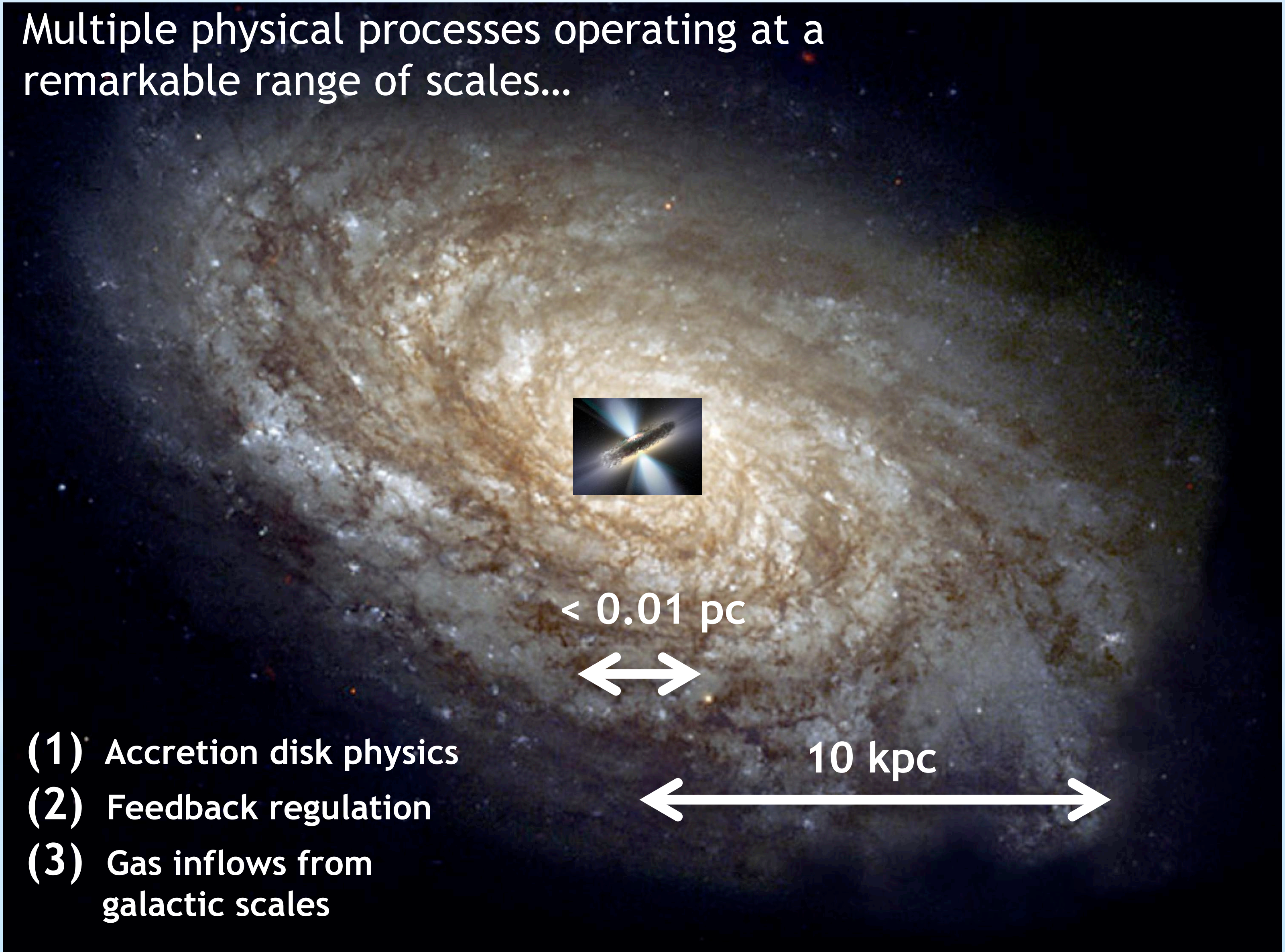
Daniel Anglés-Alcázar
PhD Graduate Student
University of Arizona

with

Feryal Özel and Romeel Davé

Black Hole growth in Galaxies

Multiple physical processes operating at a remarkable range of scales…



(1) Accretion disk physics
(2) Feedback regulation
(3) Gas inflows from galactic scales

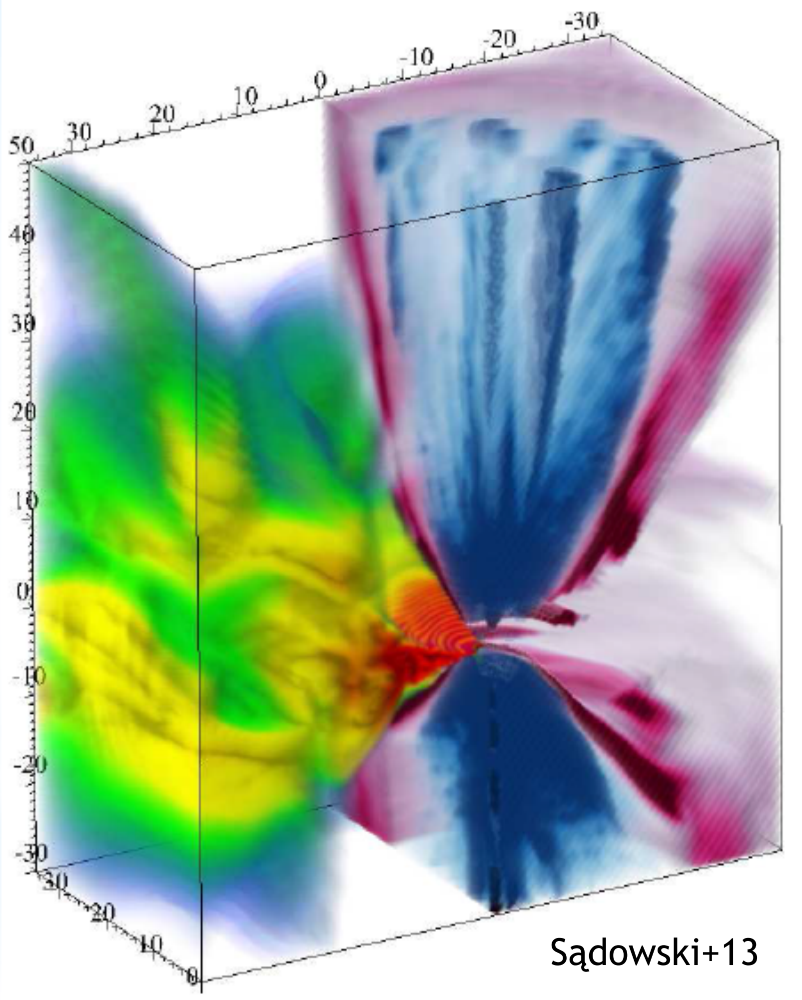
Black Hole growth in Galaxies

(1) Accretion disk physics:

→Black hole feeding by viscous transport of angular momentum

→Significant mass loss to winds and outflows

Proga+00, Proga+08, Sądowski+13,…
Reynolds97, King+13, Tombesi+13,…



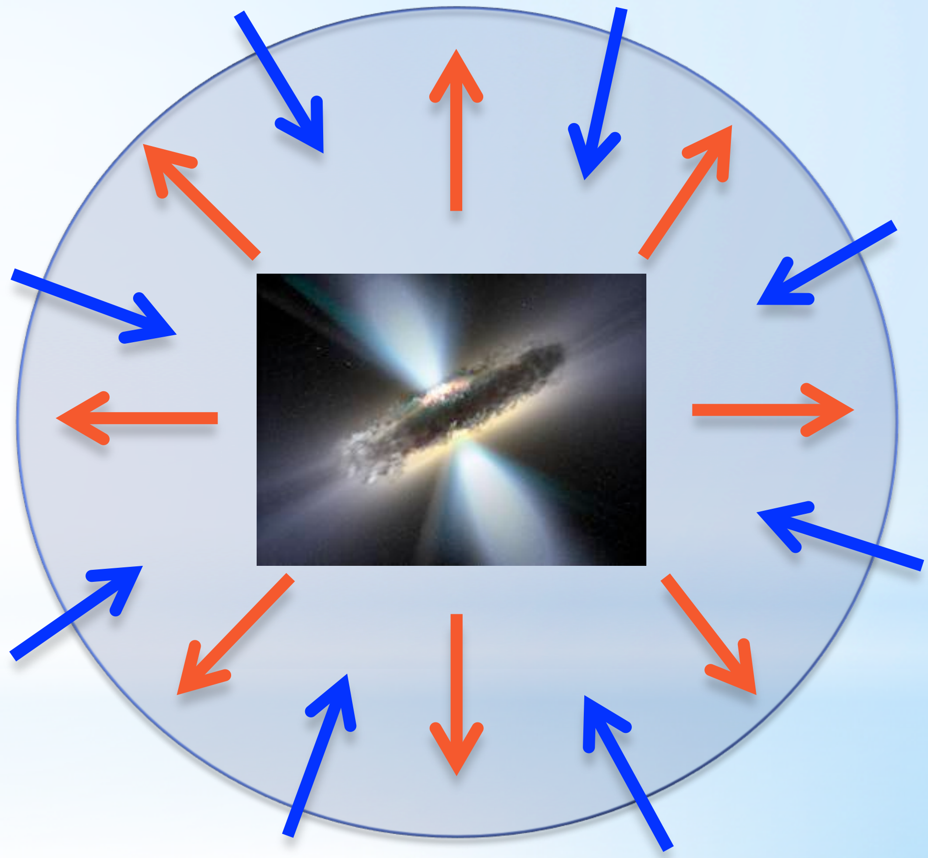
Black Hole growth in Galaxies

(2) Feedback regulation:

→Impact of energy and/or momentum output on the inflowing gas from larger scales

→AGN feedback invoked to regulate BH growth and fix galaxy formation problems

Silk&Rees98, King03, Murray+05, DiMatteo+05,08, Dubois**+13,…**



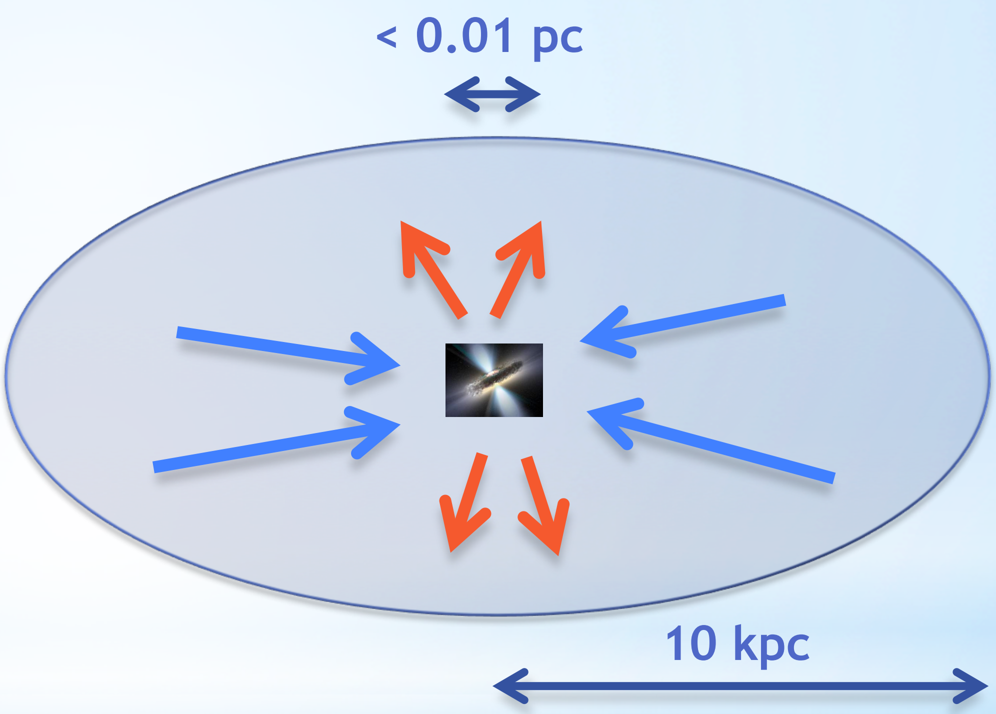
Black Hole growth in Galaxies

(3) Transport of gas from galactic scales down to the accretion disk

→Angular momentum neglected in cosmo sims by using Bondi prescription

→How much feedback do we need if we account for angular momentum?

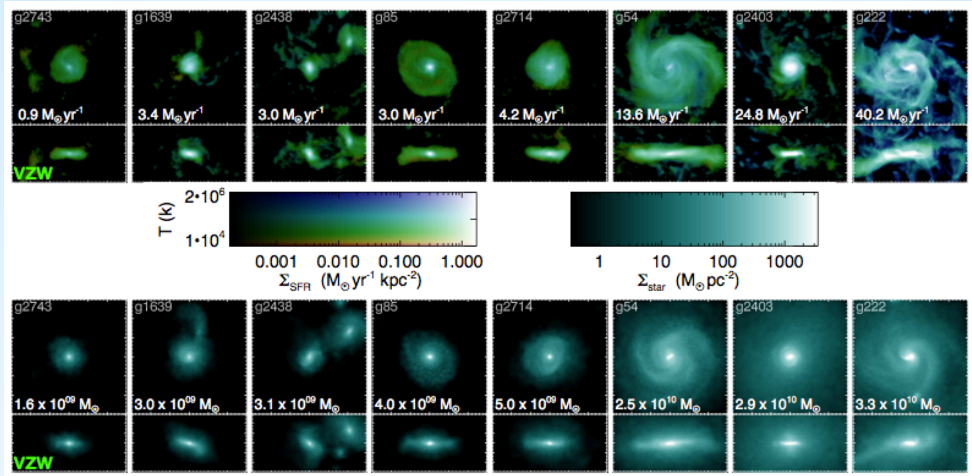
→Gravitational torques dominate transport of angular momentum



Jogee06, Escala06,07

What is the role of gravitational torques on the evolution of massive BHs over cosmic time?

Cosmological zoom simulations



Central BH accretion rate in post-processing:

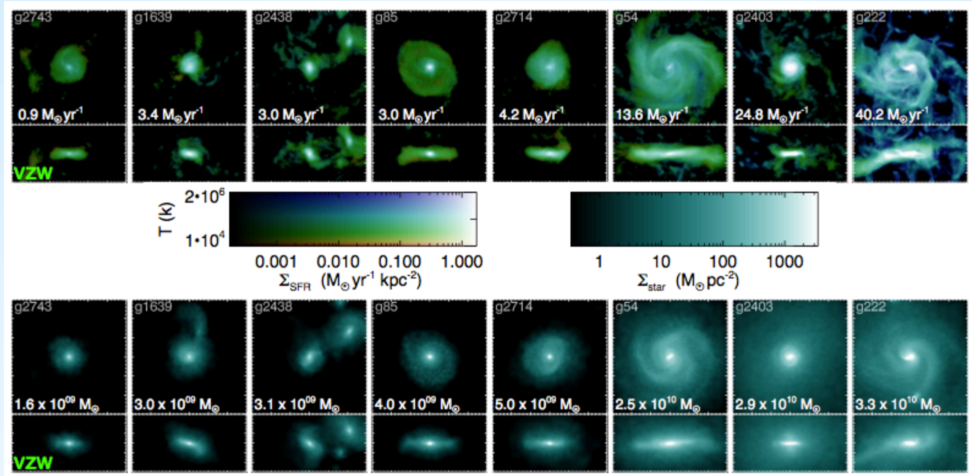
Gravitational torque model

(Hopkins & Quataert 2010,2011)

$$\dot{M}_{\rm Torque} \approx \alpha_{\rm T}\, f_{\rm disk}^{5/2} \times \left(\frac{M_{\rm BH}}{10^8\,{\rm M}_\odot}\right)^{1/6} \left(\frac{M_{\rm disk}(R_0)}{10^9\,{\rm M}_\odot}\right) \times \left(\frac{R_0}{100\,{\rm pc}}\right)^{-3/2} \left(1+\frac{f_0}{f_{\rm gas}}\right)^{-1} {\rm M}_\odot\,{\rm yr}^{-1}$$

- Parameterize angular momentum transport below the resolution
- Gas inflows down to 0.01 pc scales as a function of galaxy properties

Cosmological zoom simulations



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Bondi

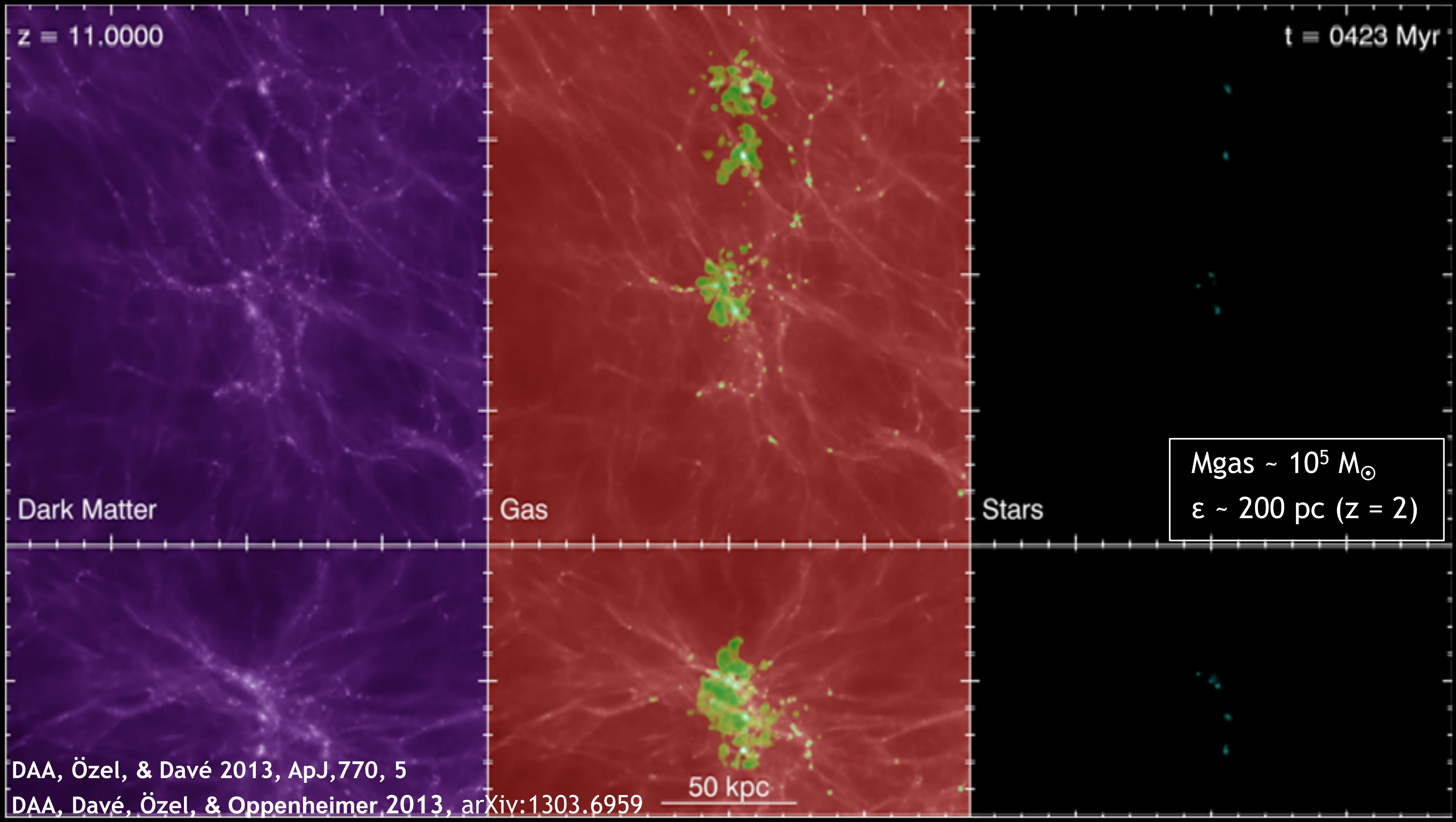
(Bondi52,…)

$$\dot{M}_{\rm Bondi} = \alpha\, \frac{4\pi\, G^2\, M_{\rm BH}^2\, \rho}{(c_{\rm s}^2 + v^2)^{3/2}}$$

Cosmological Zoom Simulations

→Gadget2 (Springel05) extended (Oppenheimer & Davé):

Multi-phase ISM, metal cooling, UV background, feedback (energy, mass, metals) from type Ia-II SNe, AGB stars, momentum-driven winds,…



Mgas ~ 10^5 $M_\odot$

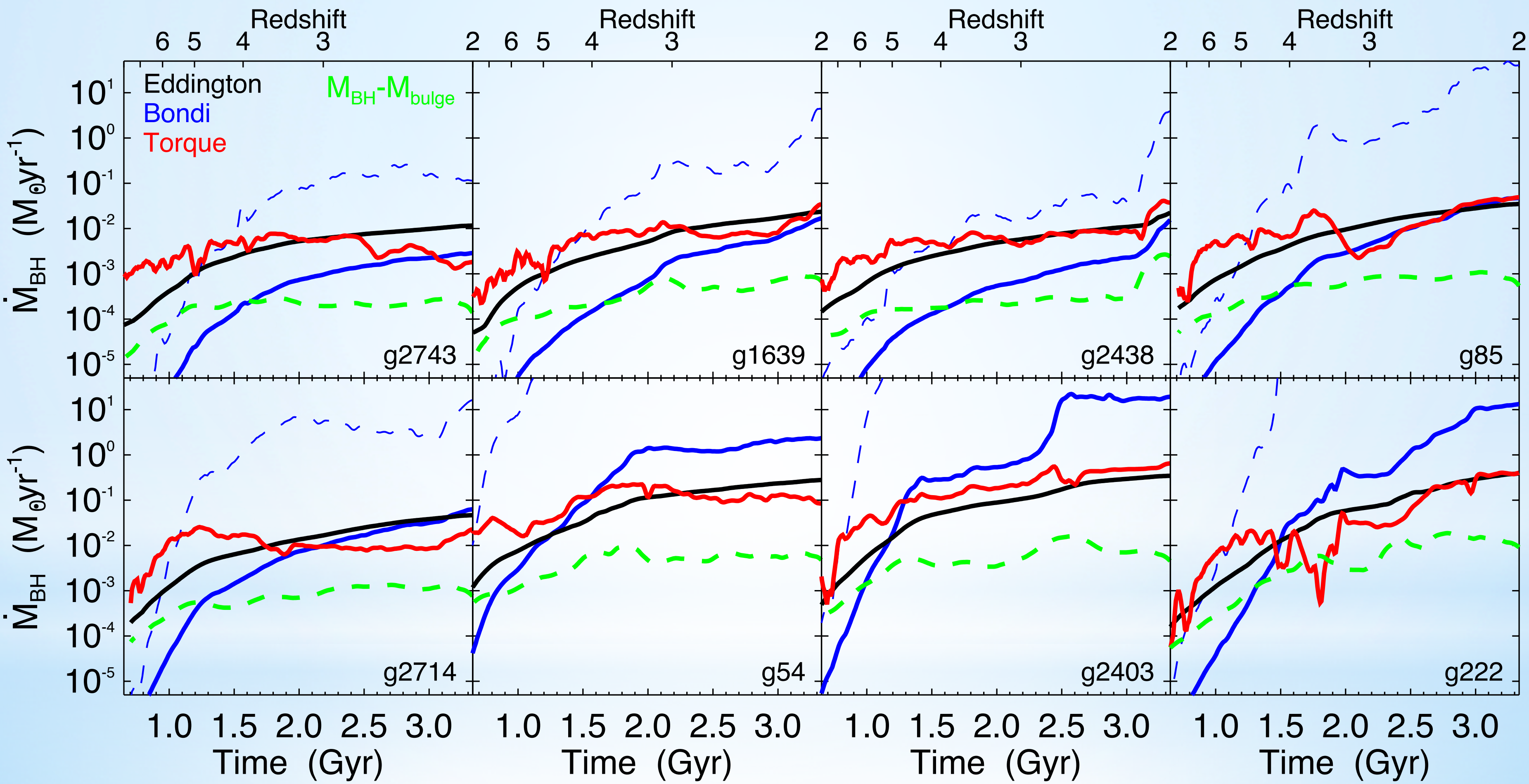
ε ~ 200 pc (z = 2)

DAA, Özel, & Davé 2013, ApJ,770, 5

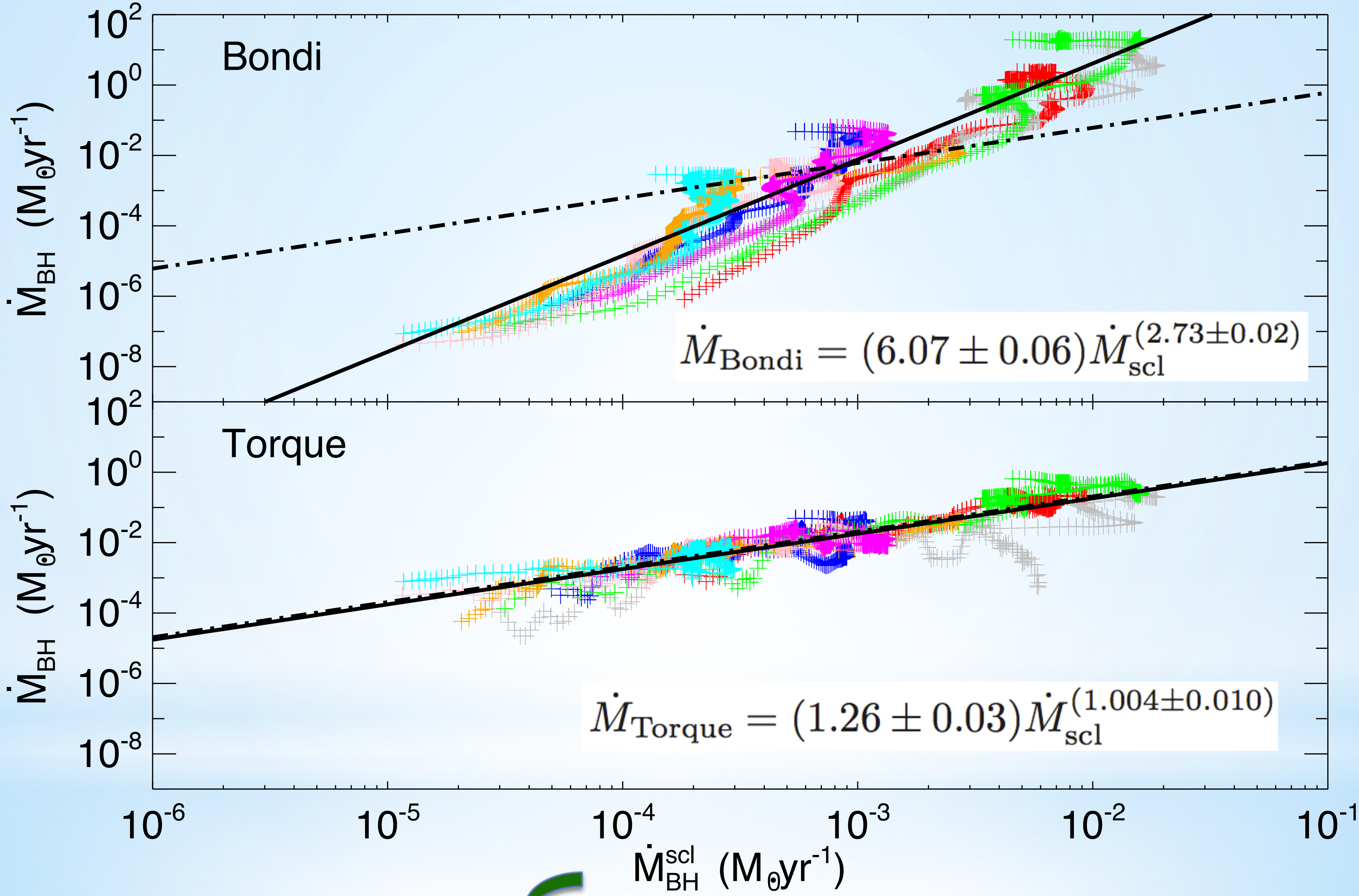
DAA, Davé, Özel, & Oppenheimer 2013, arXiv:1303.6959

Accretion rates

→ **Bondi** → **Gravitational torque** → **Eddington**

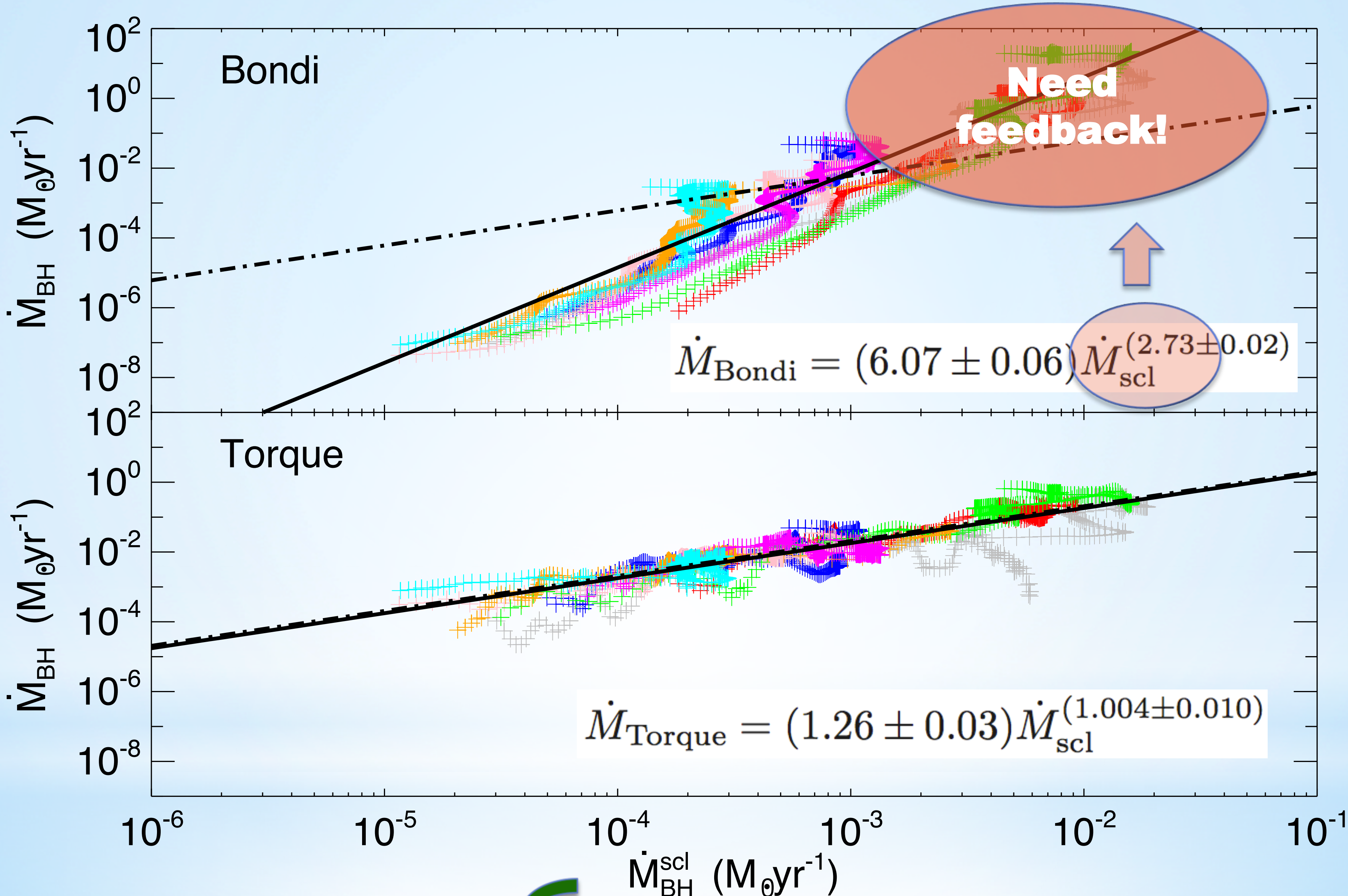


→ **Accretion rate to grow along M_{BH}-M_{bulge} relation**



DAA, Özel, & Davé 2013, ApJ,770, 5

BH growing according to scaling relation



DAA, Özel, & Davé 2013, ApJ,770, 5

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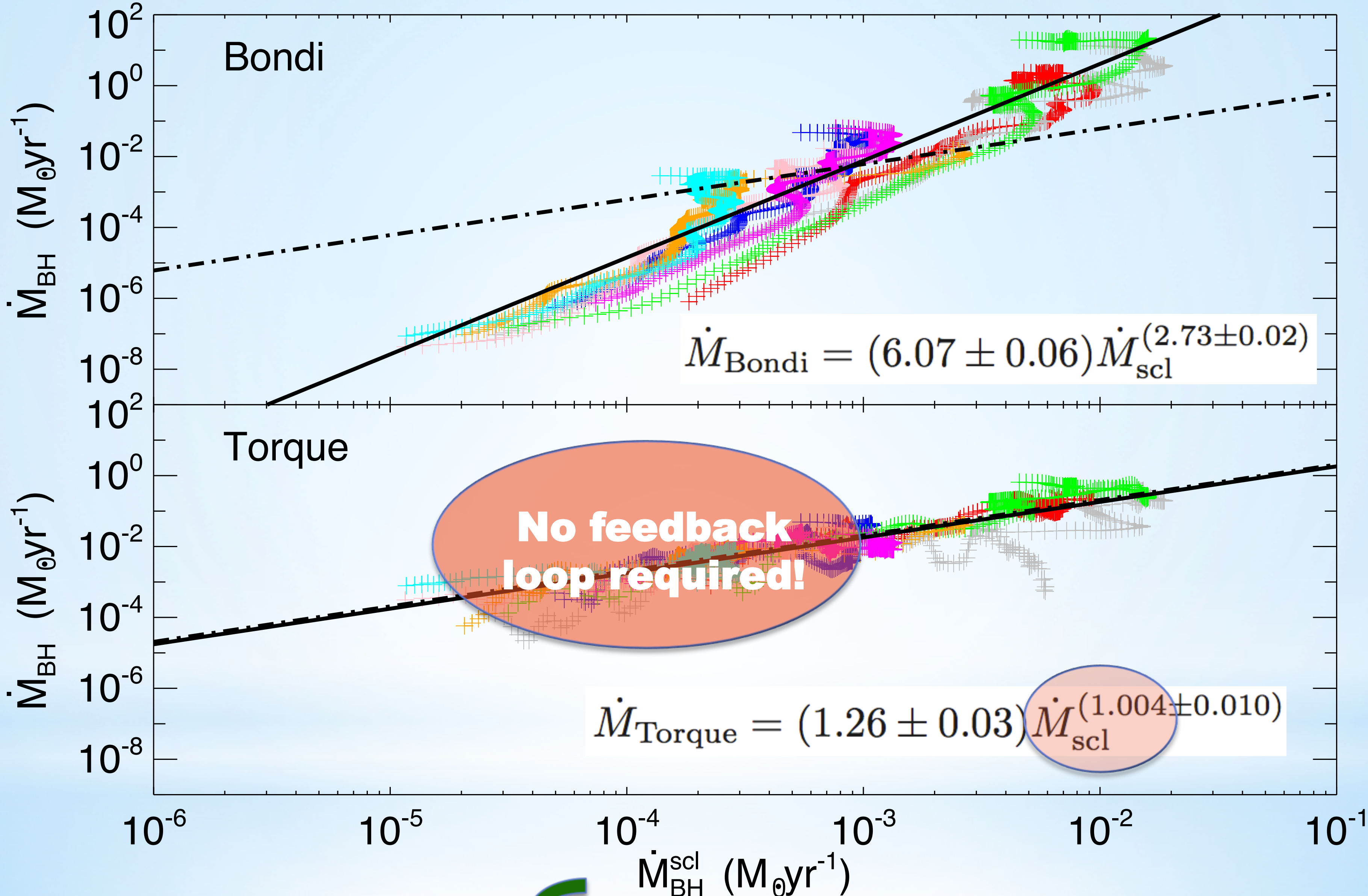
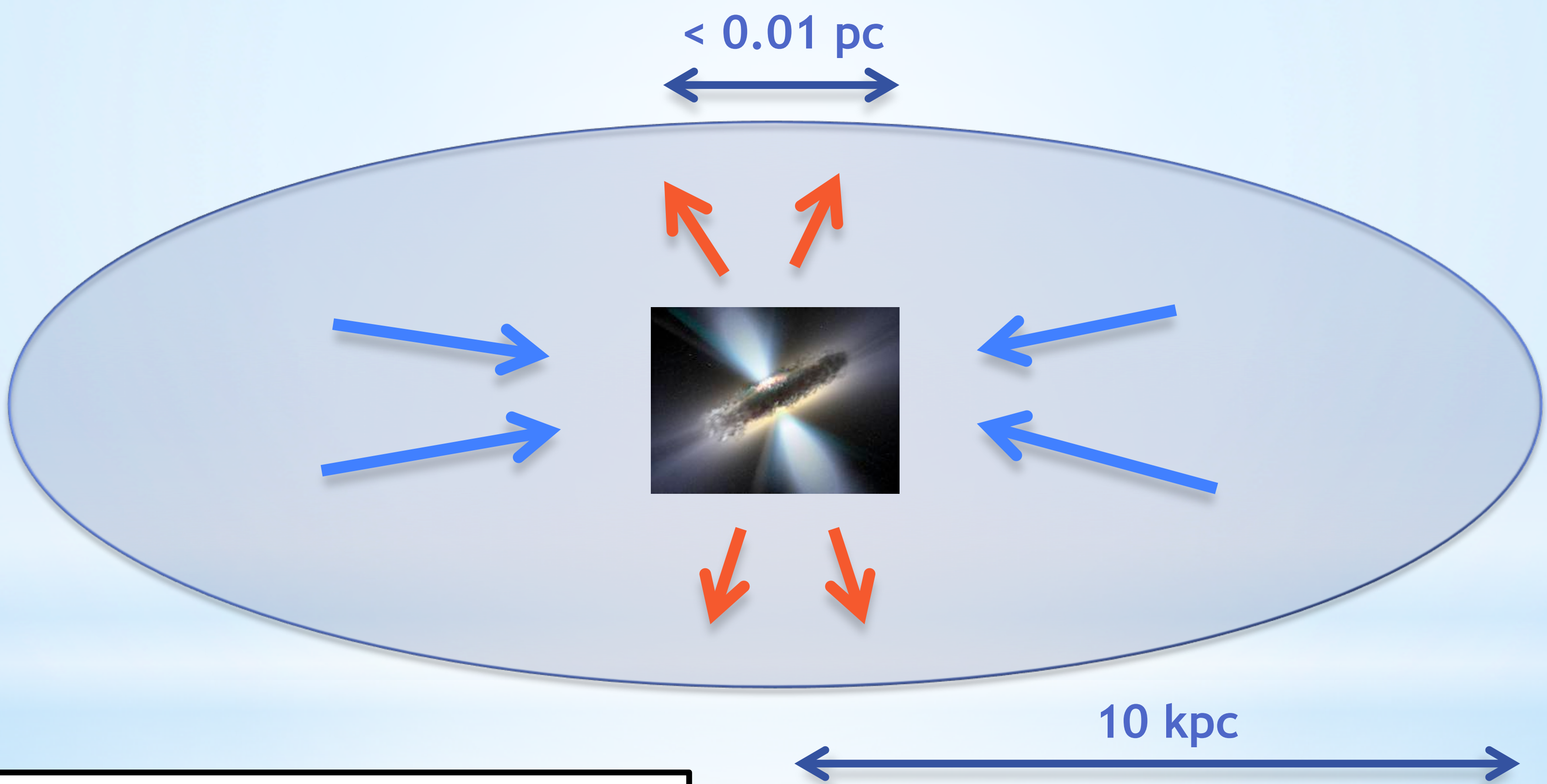


BH Growth according to scaling relations

DAA, Özel, & Davé 2013, ApJ,770, 5

Torque-limited growth

$$dM_{\rm BH}/dt = \epsilon_{\rm m}\, \dot{M}_{\rm Torque}(t)$$



INFLOWS = TORQUE

OUTFLOWS = (1 - ε) TORQUE

Torque-limited growth

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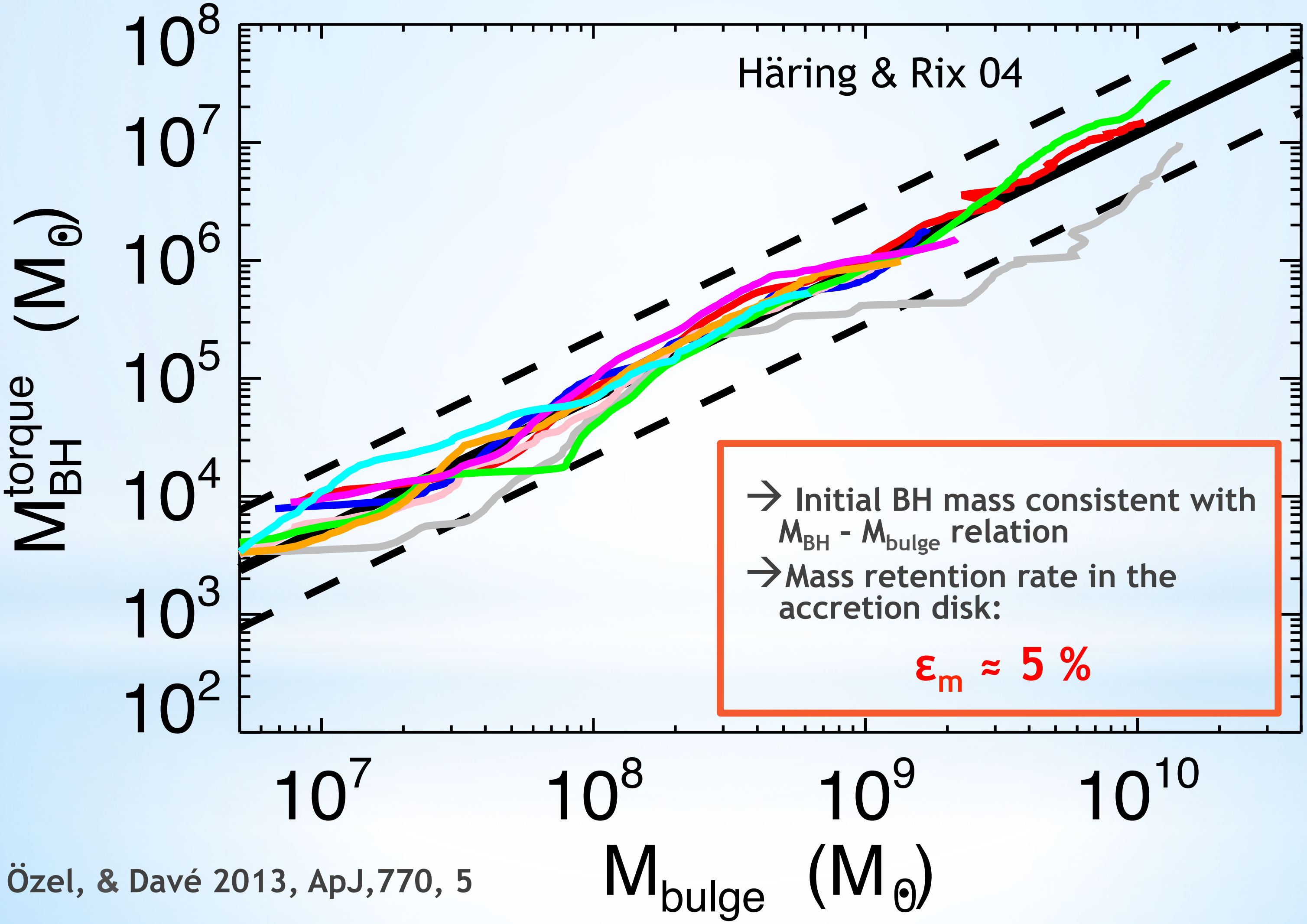

→ Initial BH mass consistent with M_{BH} - M_{bulge} relation

→ Mass retention rate in the accretion disk:

$\varepsilon_m \approx 5$ %

DAA, Özel, & Davé 2013, ApJ,770, 5

Torque-limited growth

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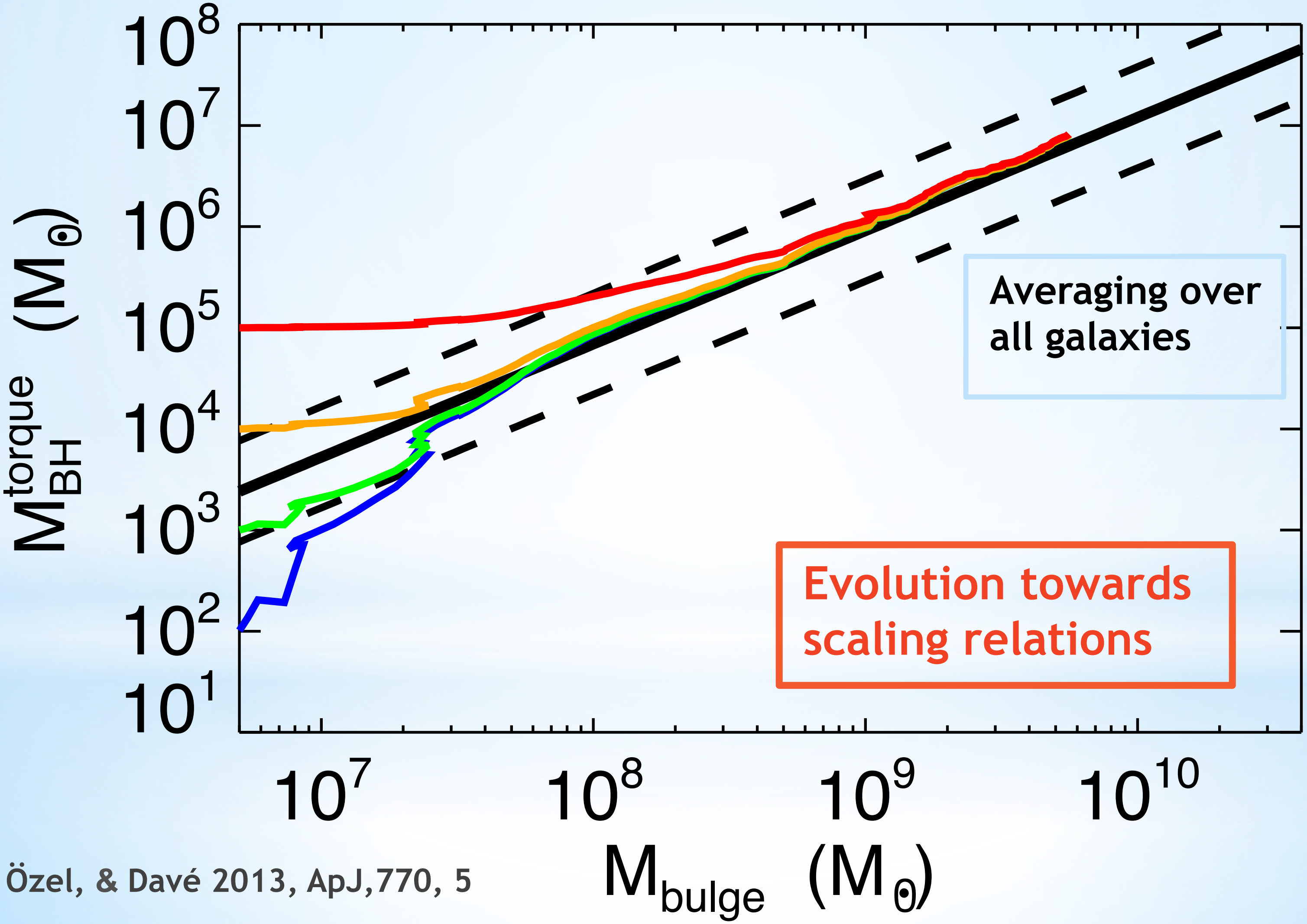

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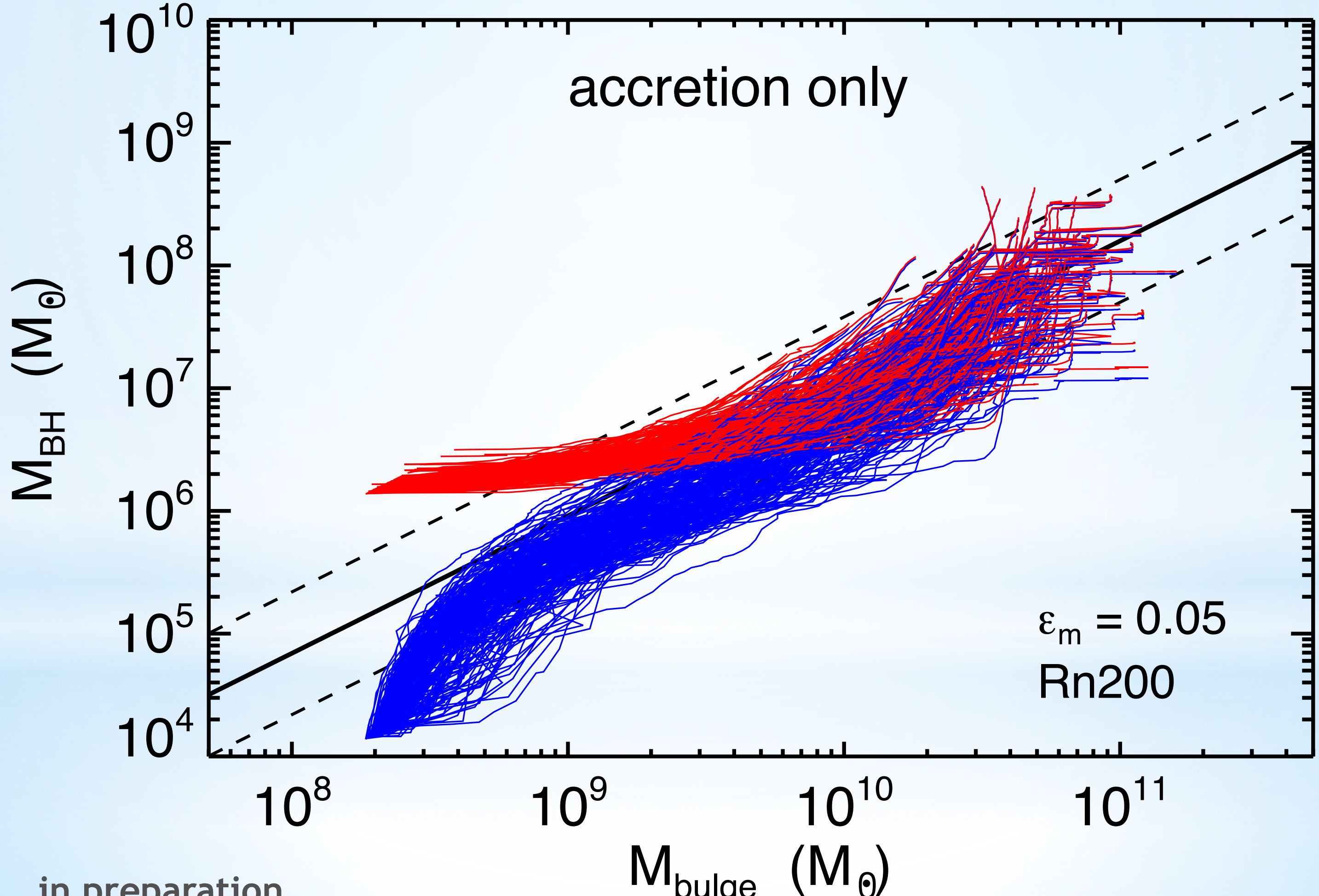
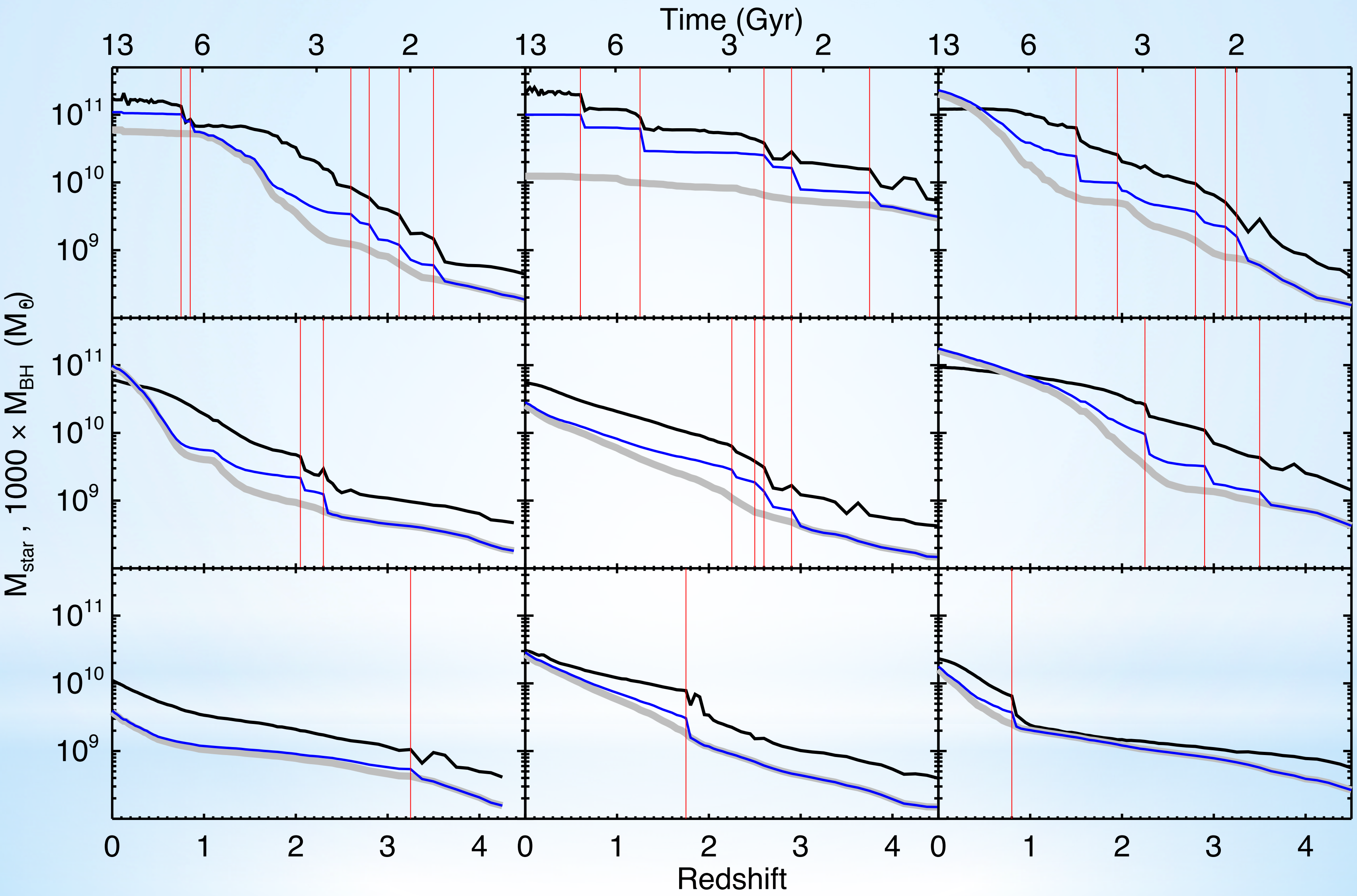
Torque-limited growth

Extended galaxy sample down to z = 0 from full cosmological simulation



DAA et al., in preparation

Smooth accretion vs BH mergers



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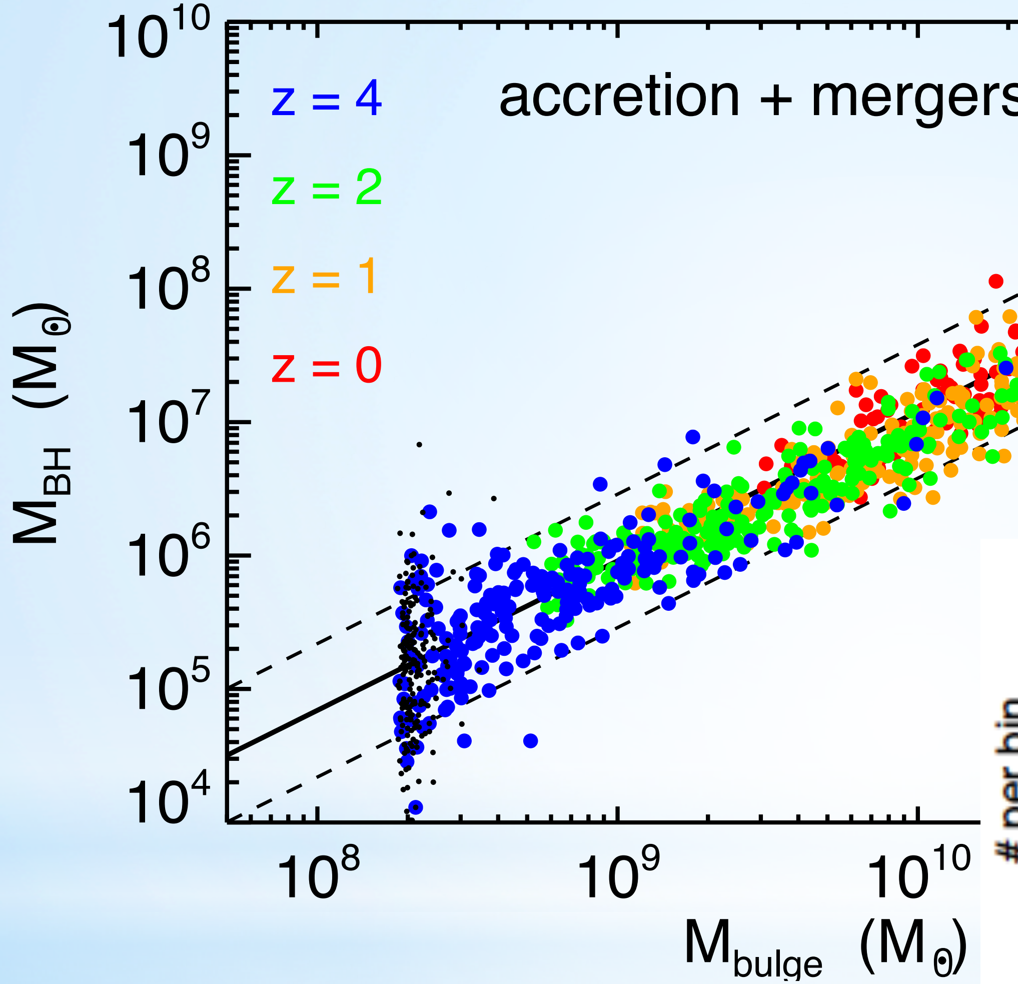
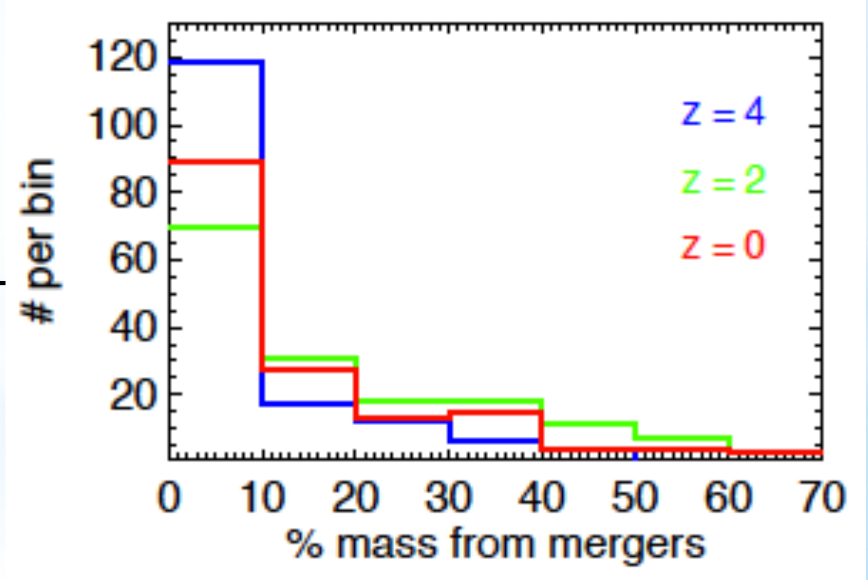
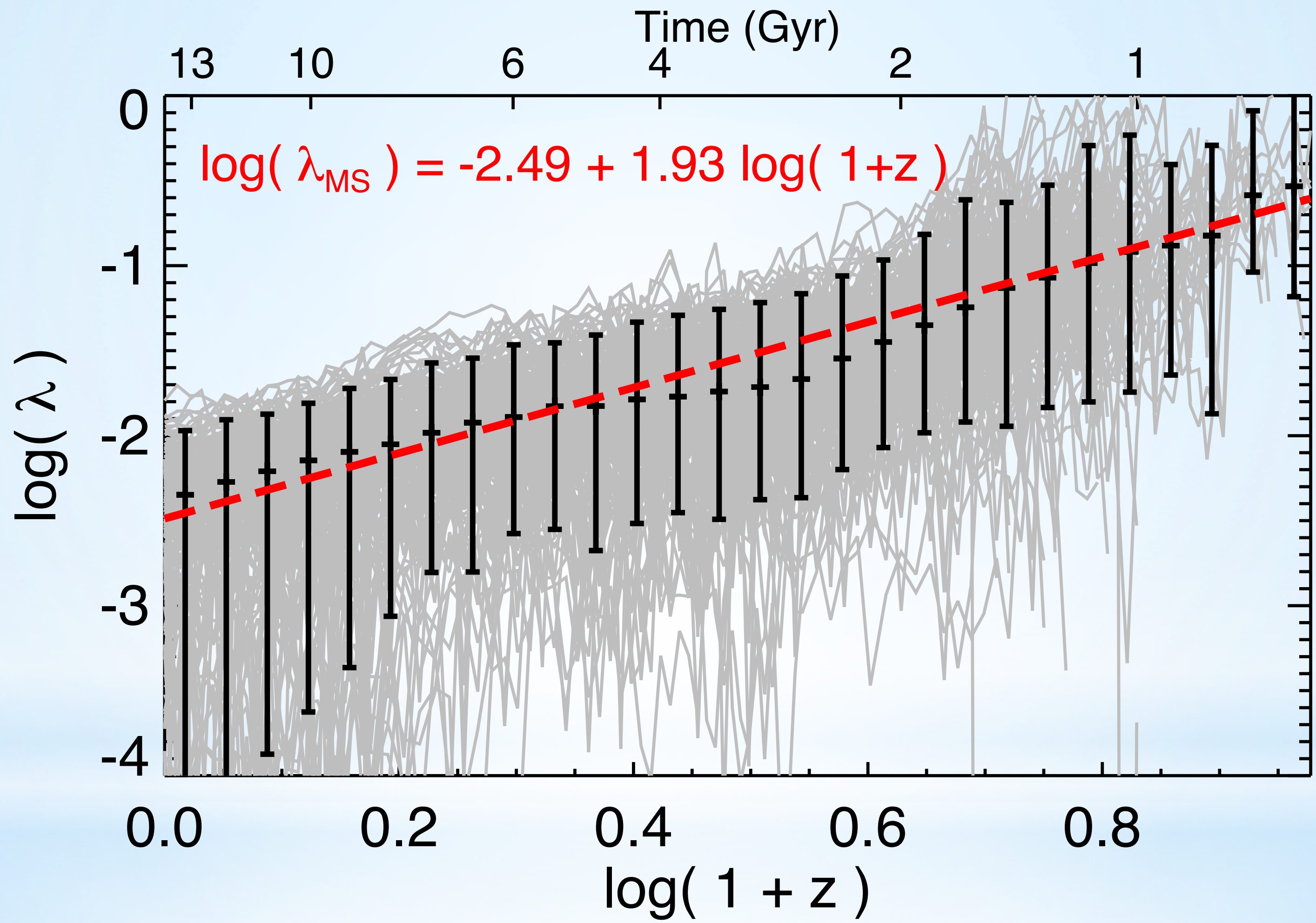




DAA et al., in preparation

Evolution of Eddington ratios



DAA et al., in preparation

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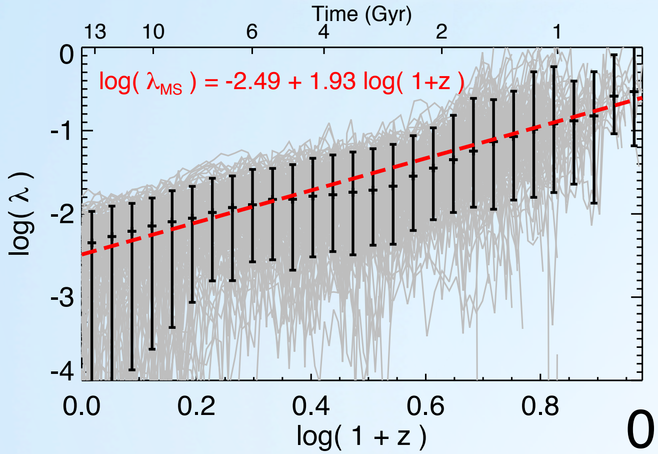
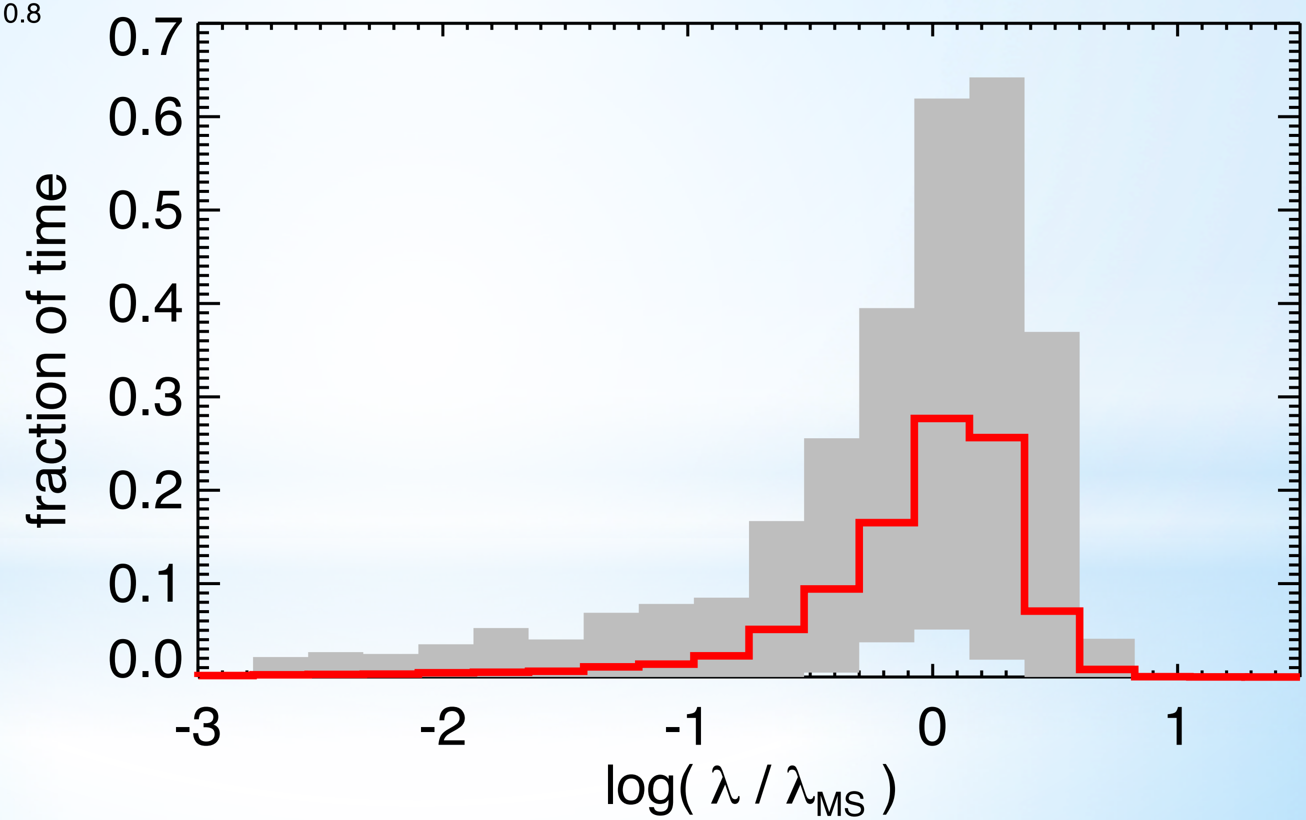


Main sequence for black hole growth?



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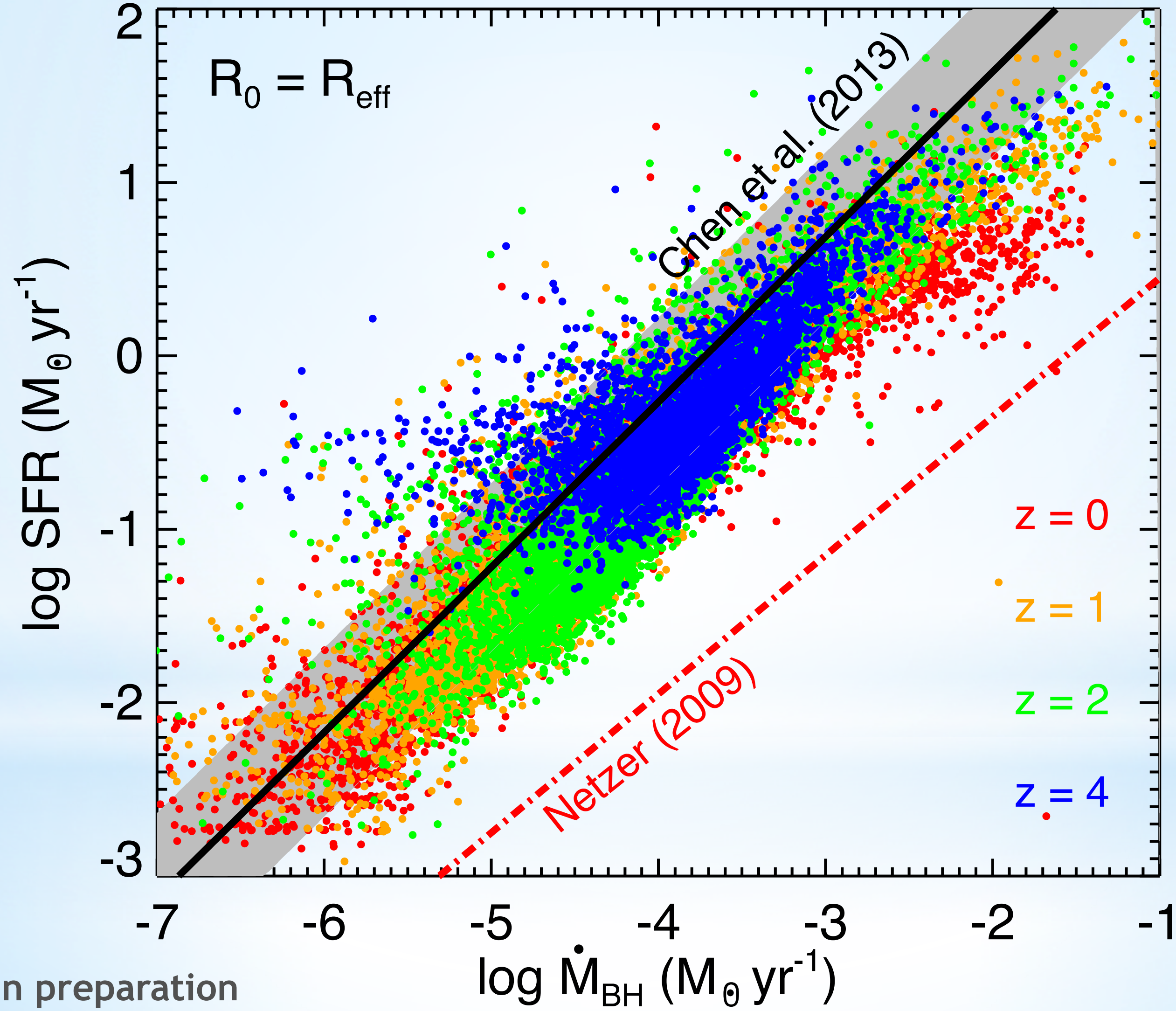
SFR – AGN connection

Averaging over galaxy evolution time-scales!



DAA et al., in preparation

Conclusions

DAA, Özel, & Davé 2013, ApJ,770, 5

DAA et al., in preparation

– Torque-limited growth yields black holes and host galaxies evolving towards the M_{BH}-M_{bulge} relation with no need for mass averaging through mergers or additional self-regulation processes.

– Strong outflows are required to suppress black hole growth by ejecting a significant amount of mass but there is no need for coupling to galaxy-scale gas in order to regulate black holes in a non-linear feedback loop.

– Eddington ratios can be described by a broad lognormal distribution with median value evolving roughly as $\lambda_{MS} \propto (1 + z)^{1.9}$, suggesting a main sequence for black hole growth similar to the cosmic evolution of specific SFRs.

– Cosmological gas infall and transport of angular momentum in the galaxy by gravitational instabilities regulate the long-term co-evolution of black holes and star-forming galaxies.