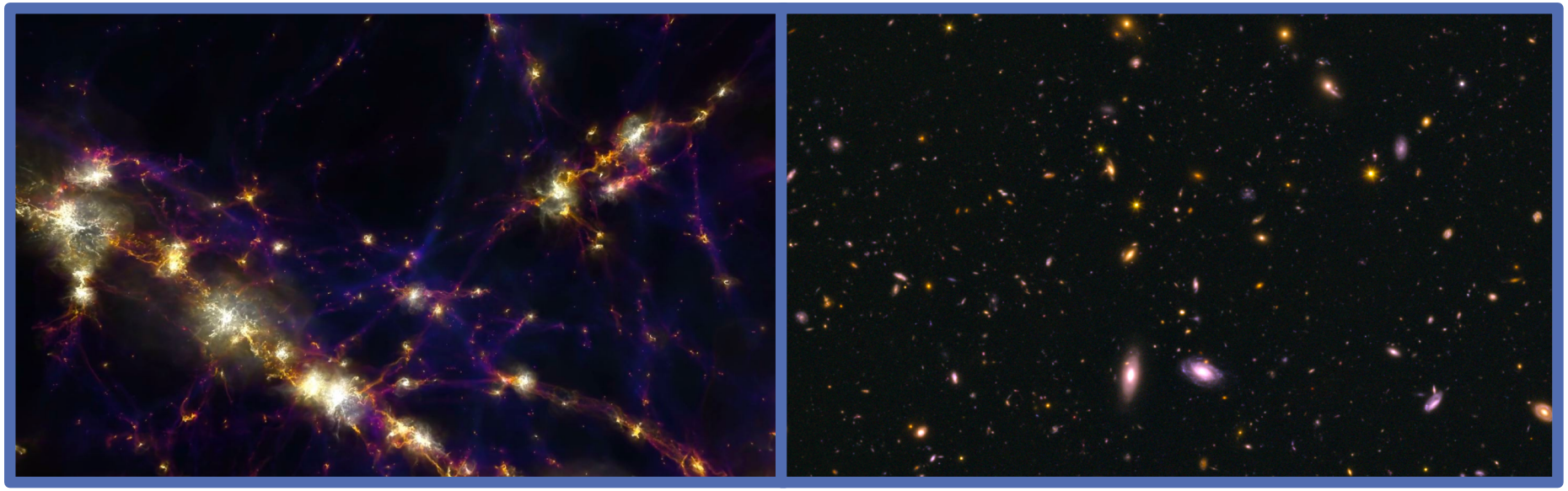
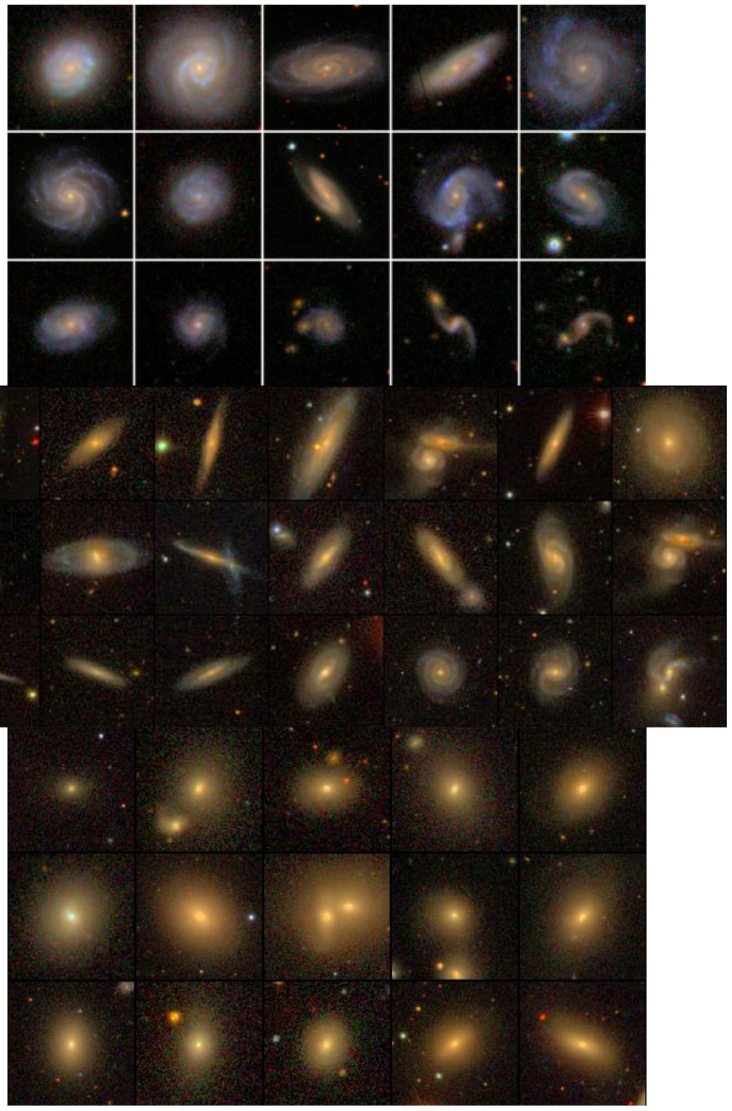
Black hole-galaxy scaling relations: clues to the physics behind quiescence



Bryan A. Terrazas

Eric Bell, Joanna Woo, Bruno Henriques, Simon White, Andrea Cattaneo, Annalisa Pillepich, Melanie Habouzit*, Yuan Li, Rachel Somerville, and the IllustrisTNG team

Star-forming



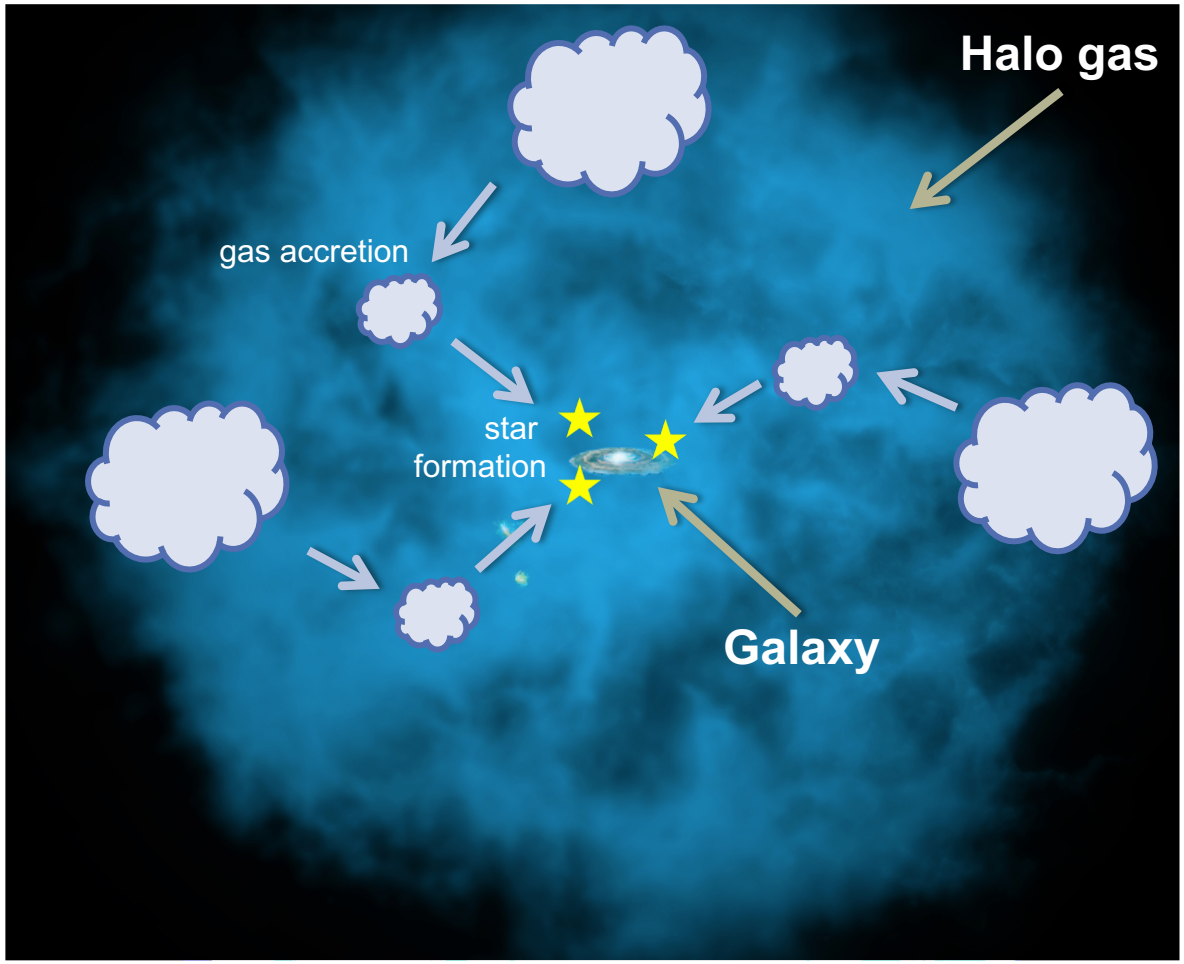
Quiescent

SDSS

disky
blue, young stars
lots of cold gas

bulge-y
redder, older stars
less/no cold gas

How do *central* galaxies become quiescent?



Accretion of cold gas from gas halo provides fuel for SF

Binney 1977, Silk 1977, White & Rees 1978, Fall & Efstathiou 1980, Katz & Gunn 1991, Kereš et al. 2005

SF is regulated by via stellar feedback

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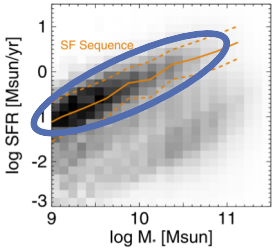
→ Star forming main sequence



Chang+15

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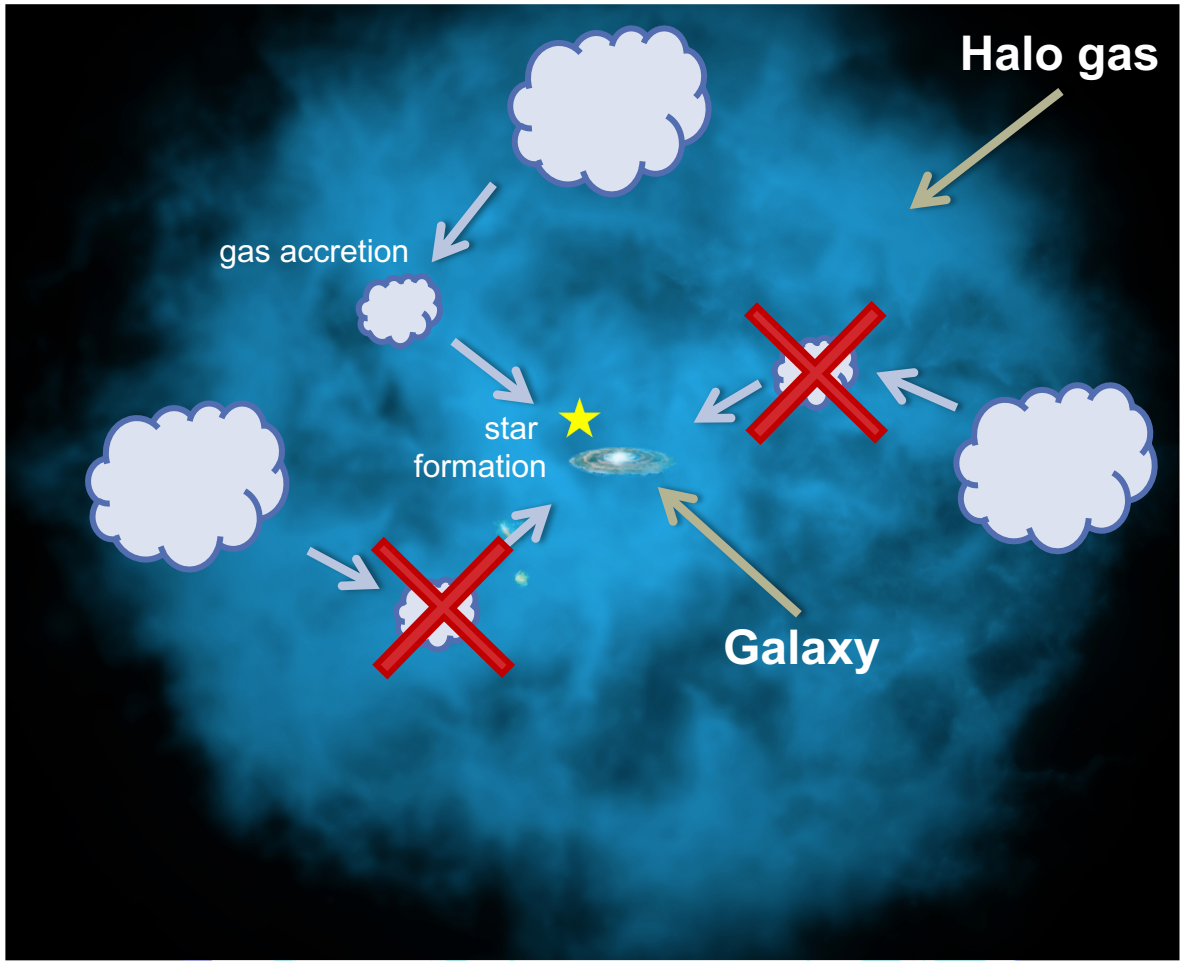

** For long term quiescence,
re-accretion must be prevented

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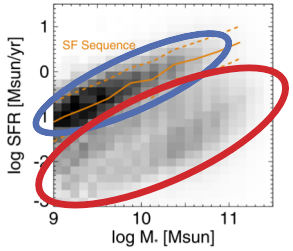
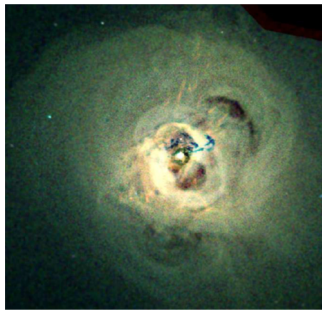
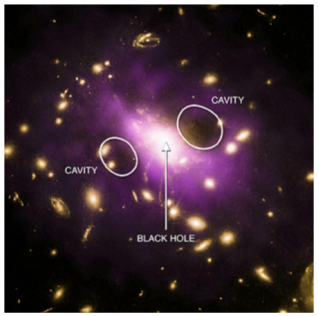


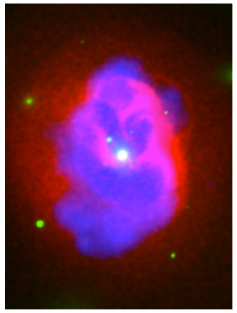
Chang+15

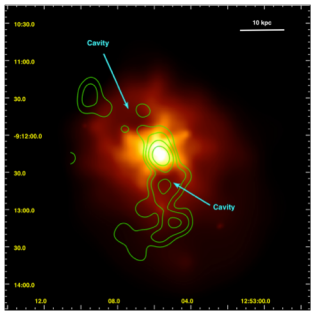
Quiescence* – the disruption of this cycle of regulation between gas cooling and SF

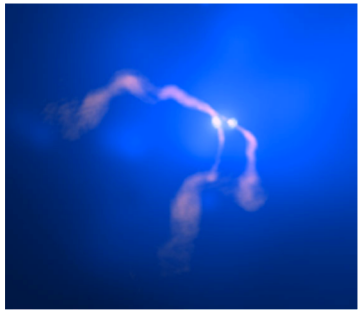
Observational
evidence of disruption?





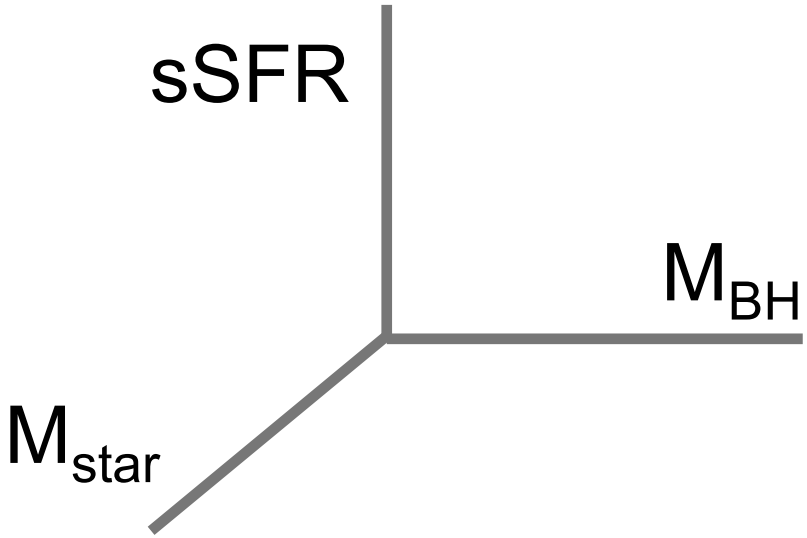






M_{star}	M_{BH}	sSFR
↓	↓	↓
$M_{halo} \propto M_{gas}$	$E_{BH\ feedback} \sim \eta M_{BH} c^2$	~ distance from SFMS ~ degree of quiescence

Total Cooling VS Heating → Net cooling



- $M_{star} \rightarrow L_K$ (2MASS)
- $M_{BH} \rightarrow$ Dynamically detected
  (van den Bosch 16, Saglia+16)
- SFR $\rightarrow L_{FIR}$ (IRAS)

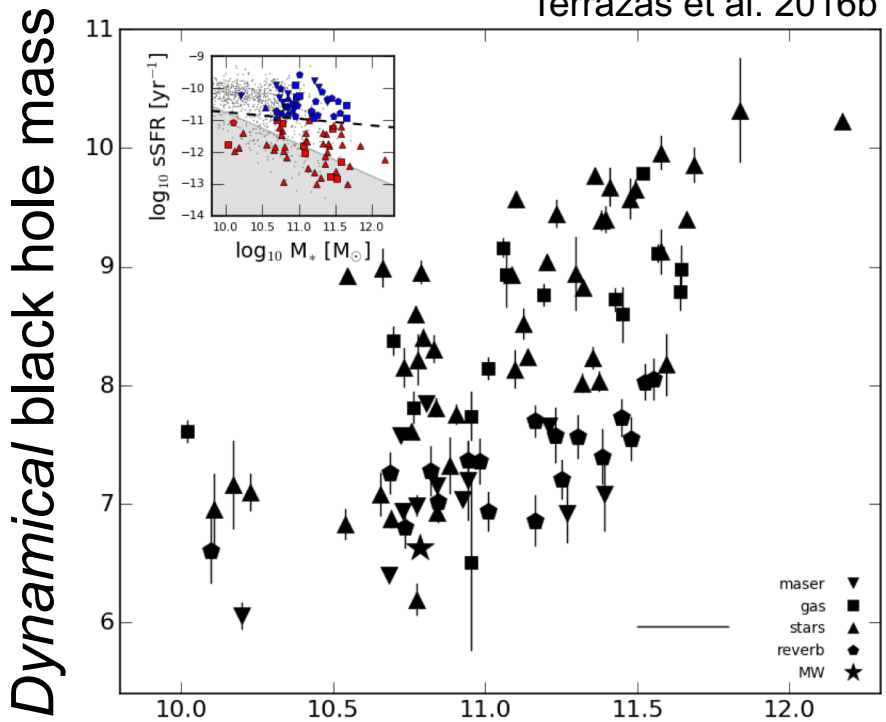
- maser
- gas
- stars
- reverb. Mapped
- MW

Central galaxies only

91 galaxies

Terrazas et al. 2016b

(heating)



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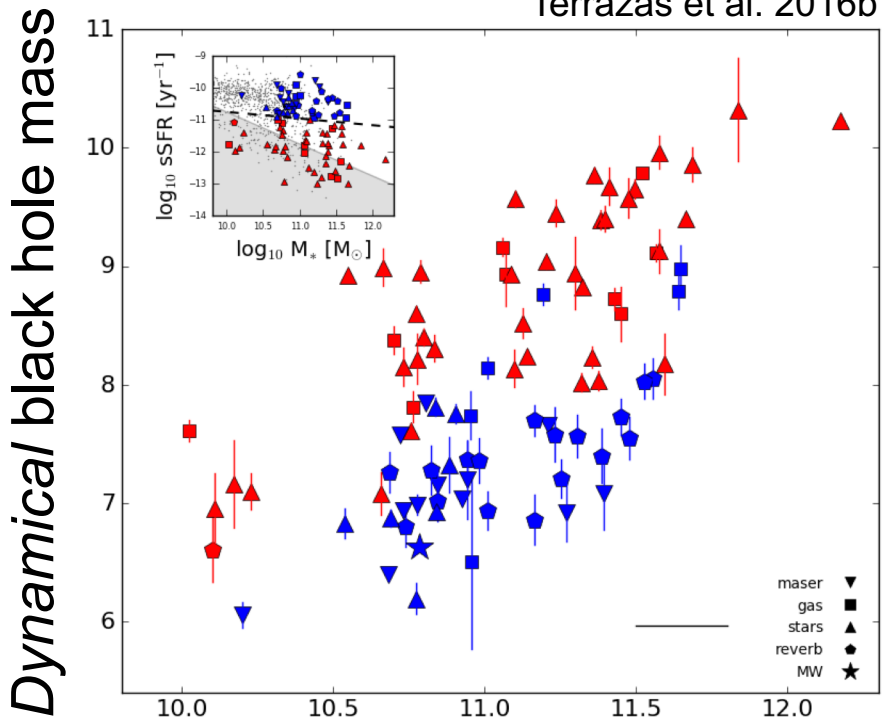

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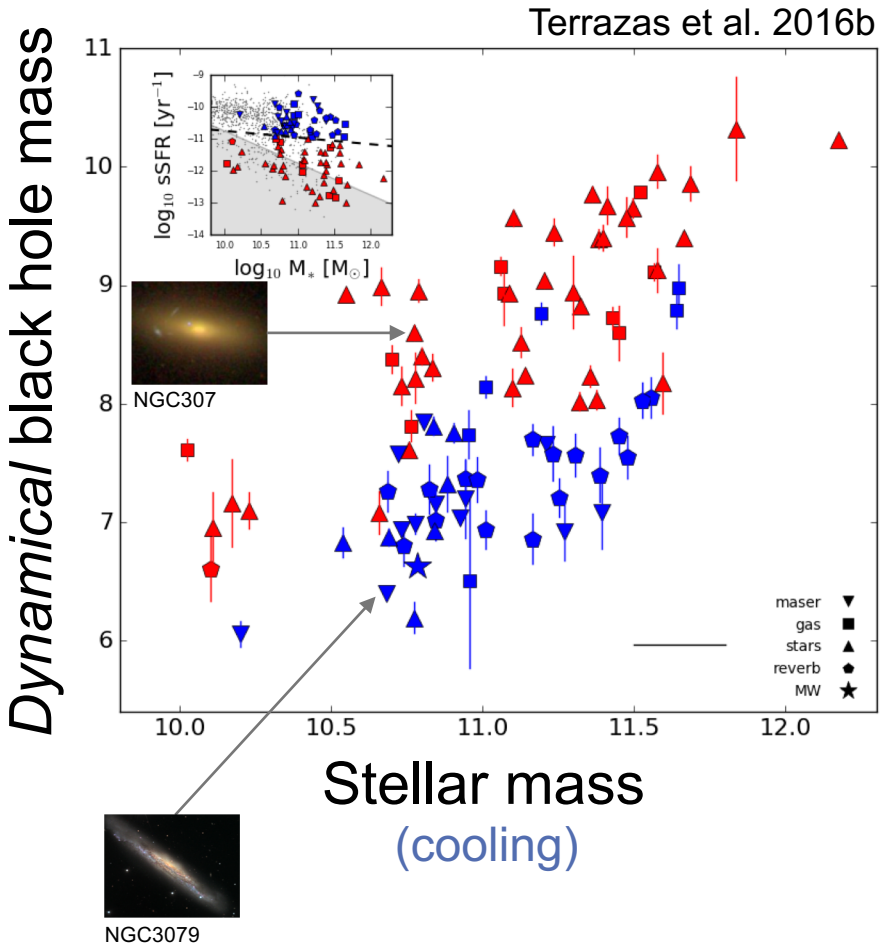

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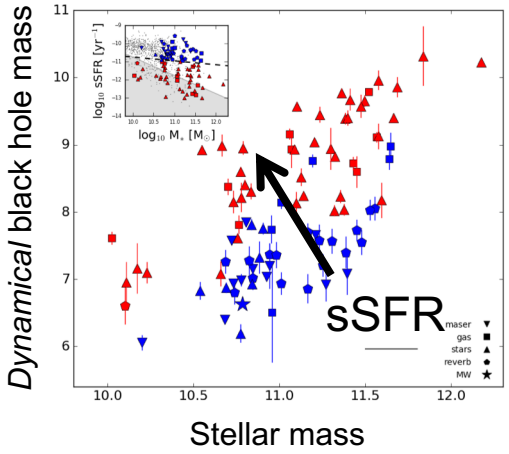
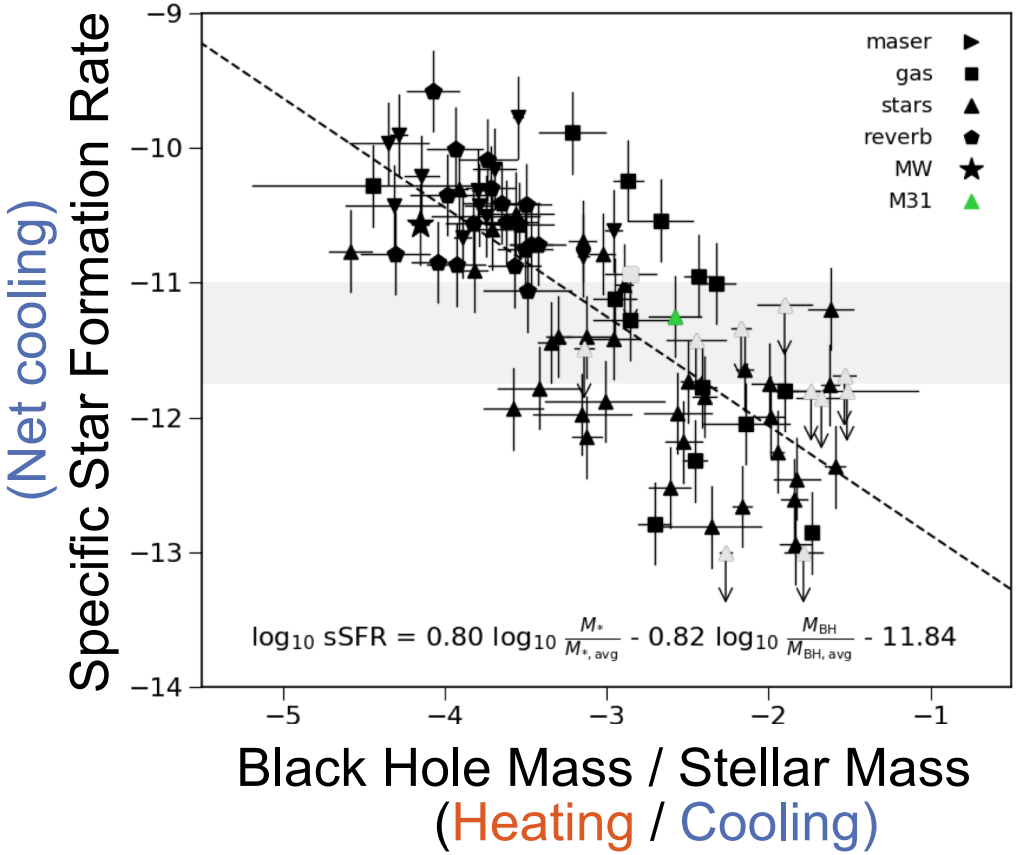


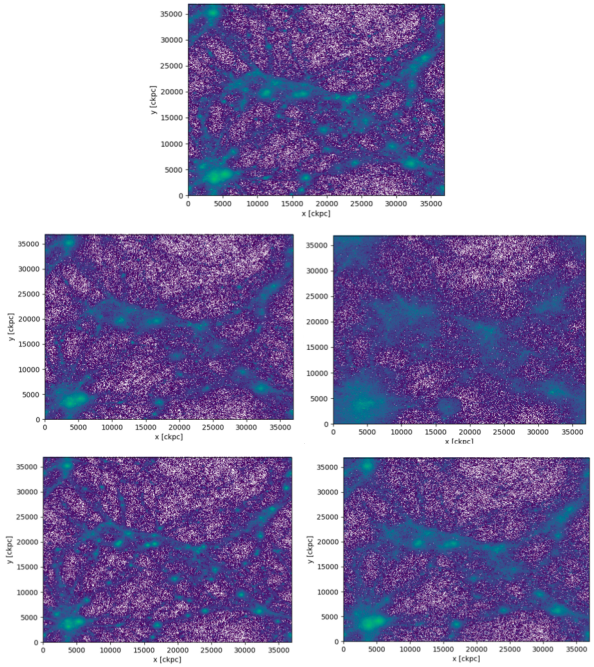
Terrazas et al. 2017

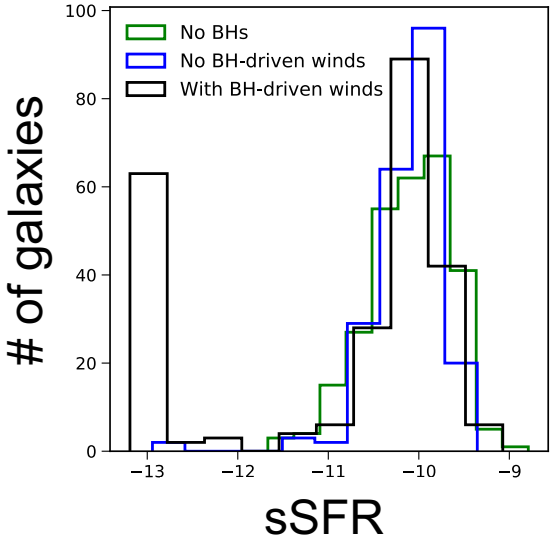


sSFR is a smoothly decreasing function of M_{BH}/M_{star}

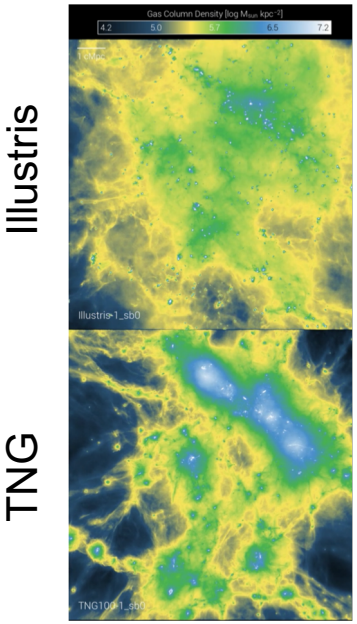
What does this look like in models? → IllustrisTNG

25 Mpc/h box length





Gas column density



↓

Dozens of model variations that alter the subgrid physics.

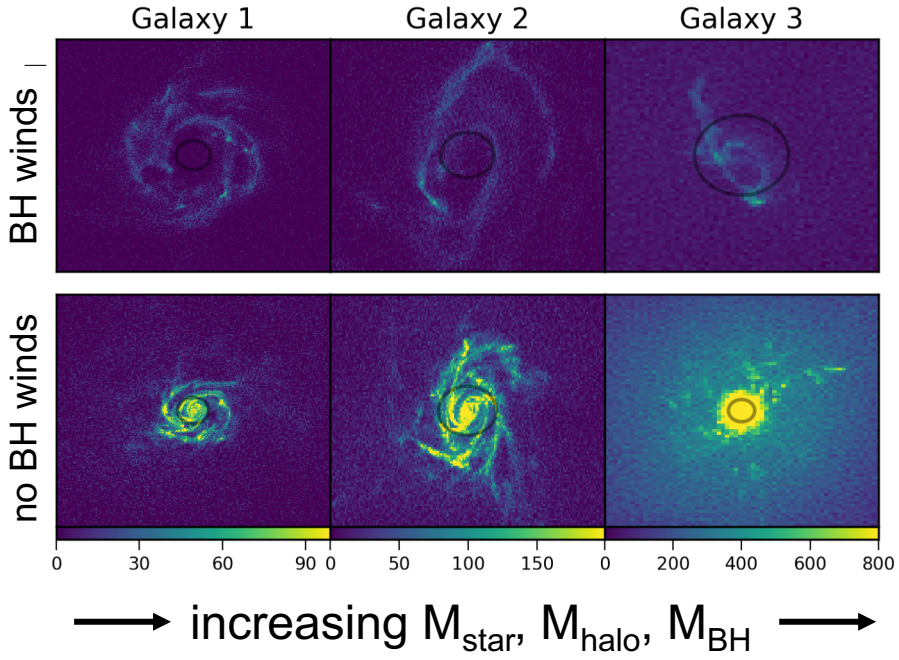
↓

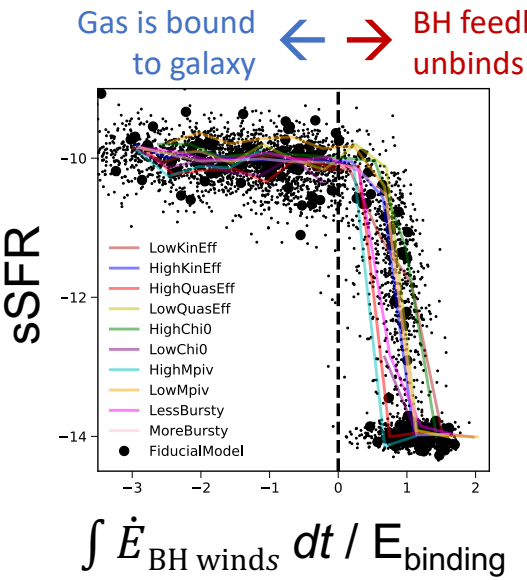
TNG requires *low-accretion rate* BH feedback produce quiescence.

↓

Halo gas is retained, unlike in original Illustris.

What causes quiescence in TNG?





Quiescence occurs when:

BH wind energy → $\int \dot{E}_{\mathrm{BH\ winds}}\, dt > \frac{3GM(<2re)}{5(2re)}$ ← Gravitational binding energy

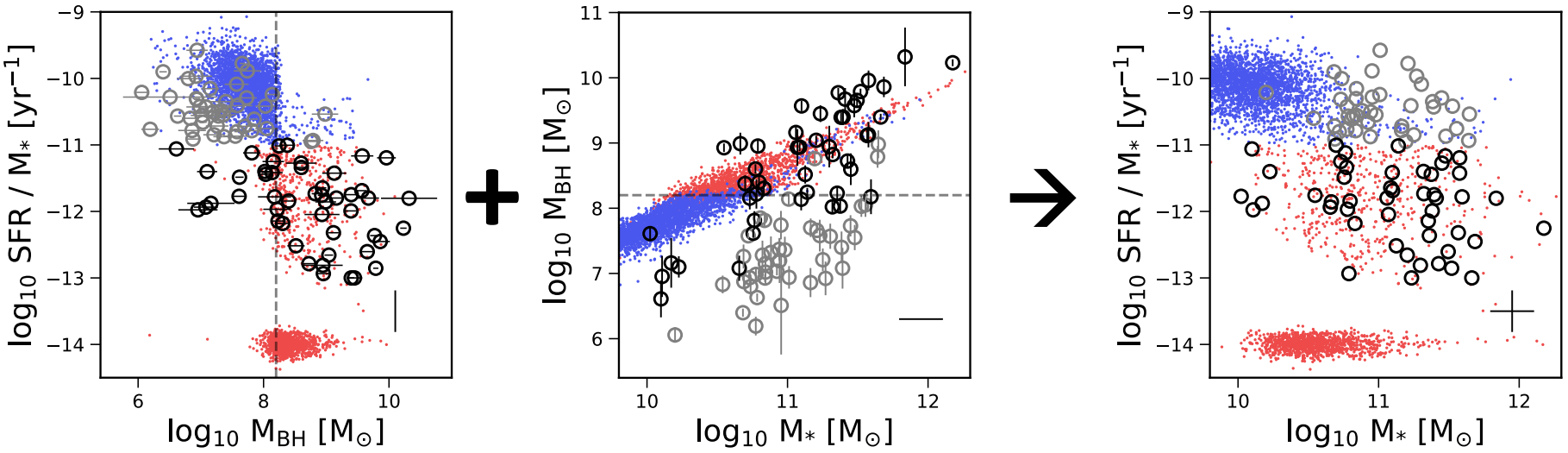
(Note: high-accretion rate quasar mode does very little to the galaxy's SF in TNG)

Terrazas+18, in prep

$M_{star} - M_{BH} - sSFR$

• SF • Q TNG

o SF o Q Observations



Onset of quiescence is too abrupt, winds are too effective

Quiescence correlates with BH mass

M_{BH} - M_{star} relation is too tight – substantial scatter in observations

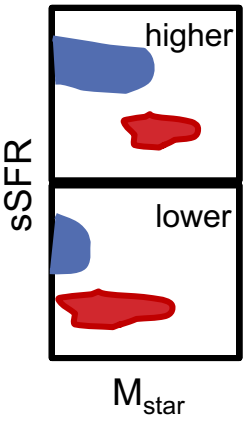
BH mass is the property which determines quiescence.

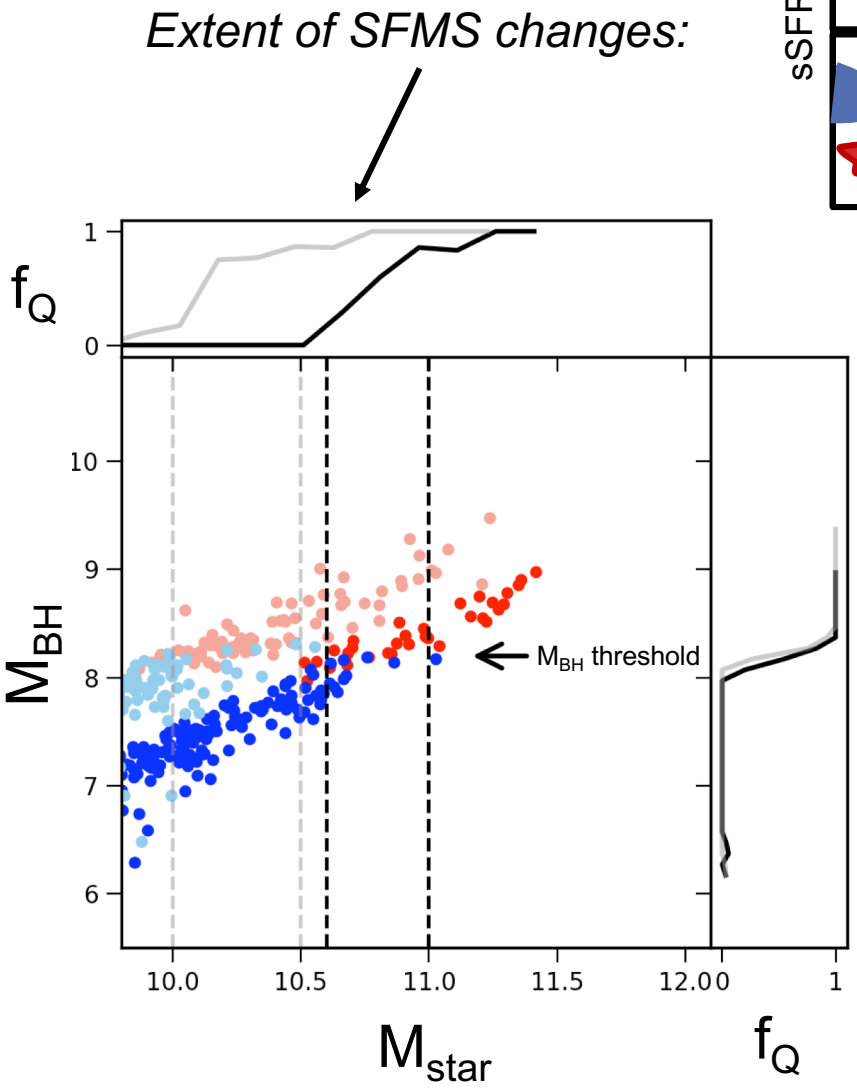
→ *the way BHs populate galaxies will determine the stellar mass distribution of SF + Q galaxies.*

Lower + higher quasar efficiency

Quasar feedback regulates M_{BH} growth in TNG

Normalization changes → lower M_{star} galaxies can host more massive BHs



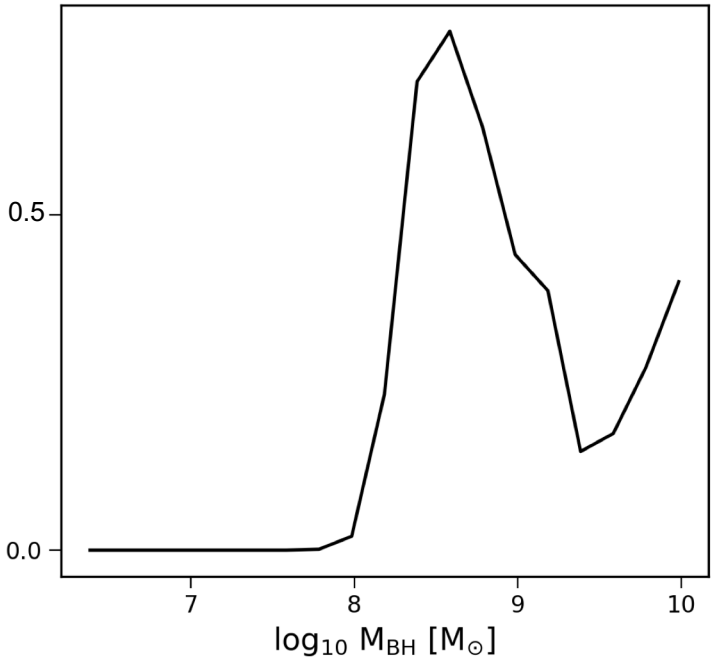


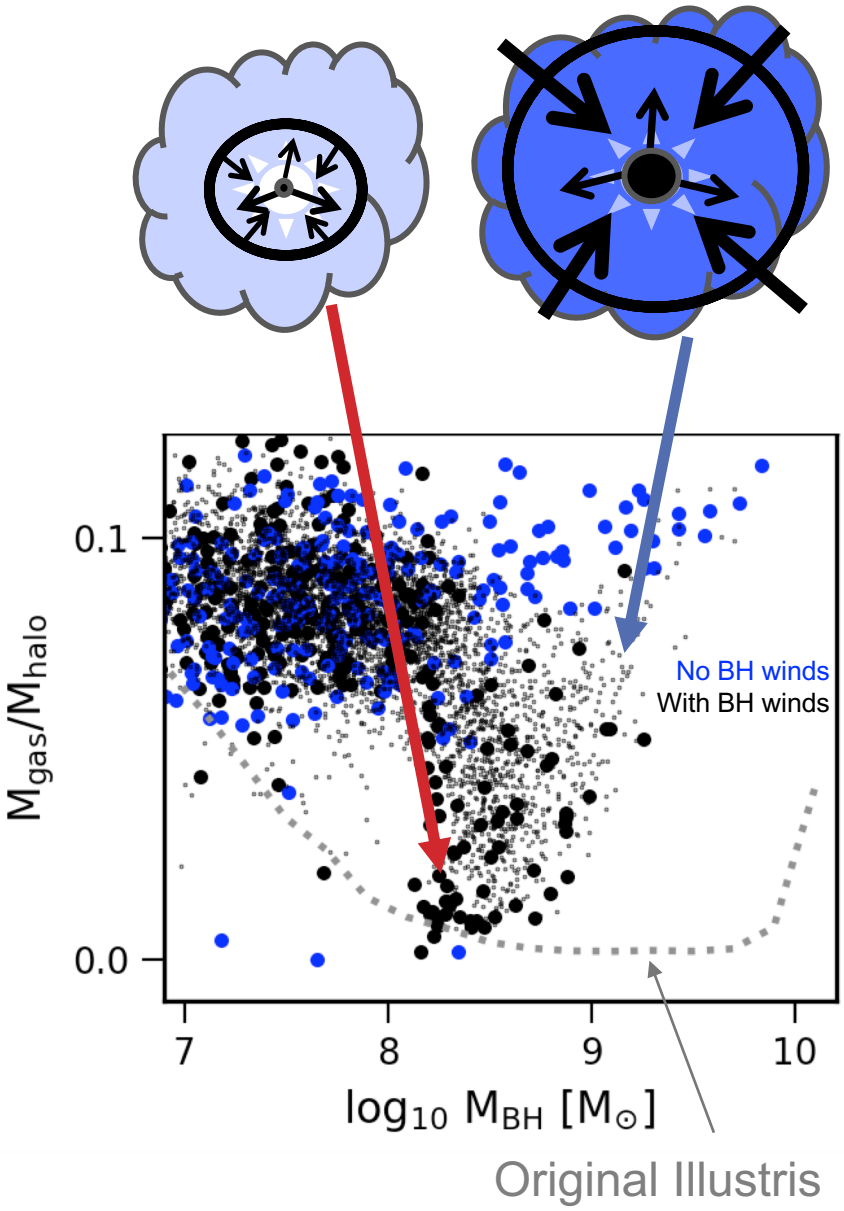
Halo gas retention

Better than Illustris, but kinetic winds still throw gas out of the halo

Kinetic winds more effective at low masses above the BH threshold mass
→ can't compete with halo's gravity at higher masses

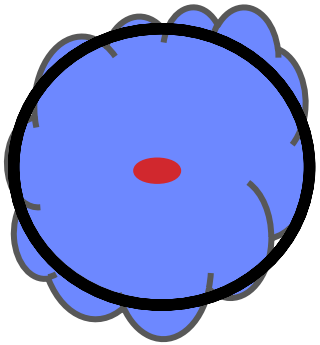
Fraction of *completely* quiescent galaxies





Some concluding thoughts:

- How do you suppress gas cooling while retaining the gas halo?



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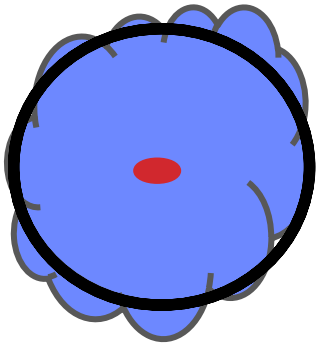

- How do you suppress gas cooling while retaining the gas halo?
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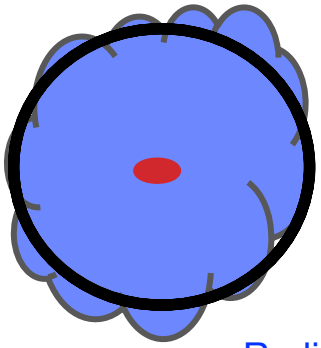

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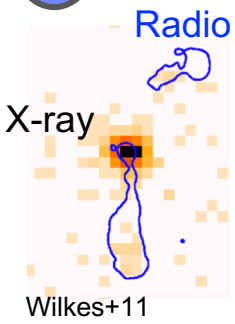

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  - Observational evidence for co-existence in the same galaxy
  - Quasars observed to fuel outflows – yet are short lived – impact?

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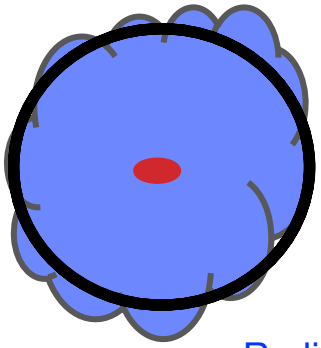

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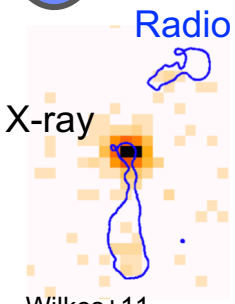

Wilkes+11

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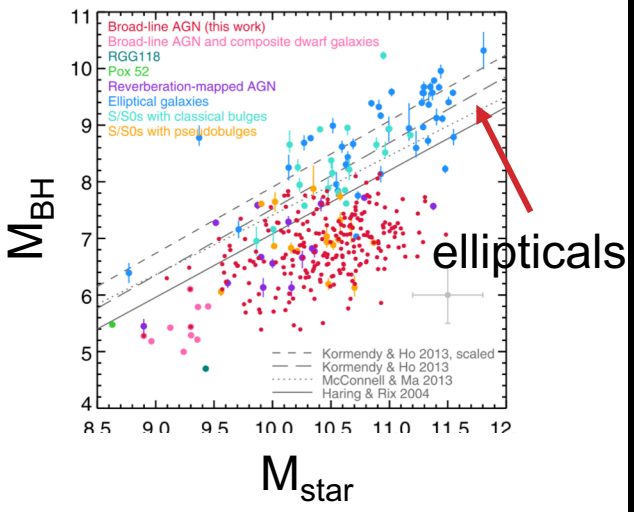
  - BH growth prescriptions tightly coupling to the growth of the galaxy.
  - Models attempt to reproduce relation for entire galaxy population based on measurements for only ellipticals/early-types

    See: Reines & Volunteri 15, Savorgnan+16, van den Bosch+16, Saglia+16, Terrazas+16,17



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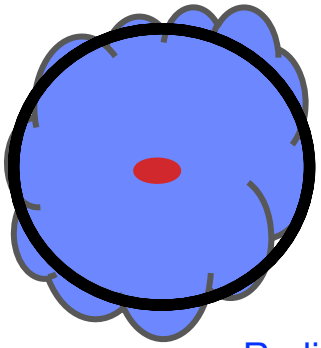

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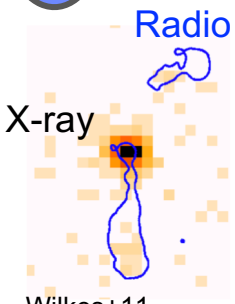

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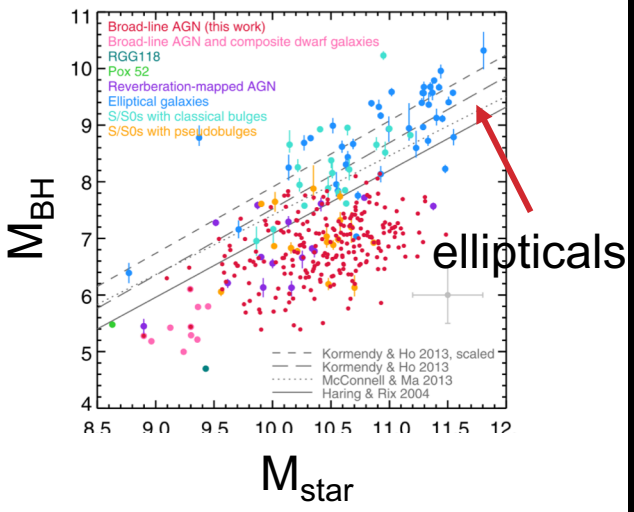
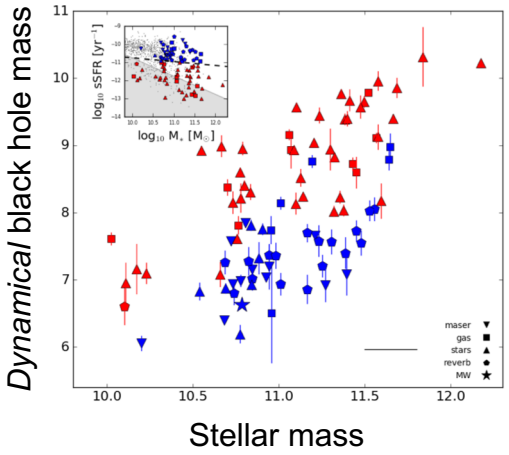


→ Models are most interesting when they go wrong

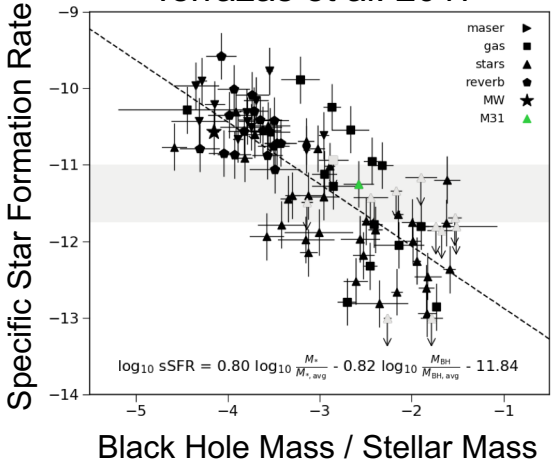
Terrazas et al. 2016b



Quiescence correlates with M_{BH}

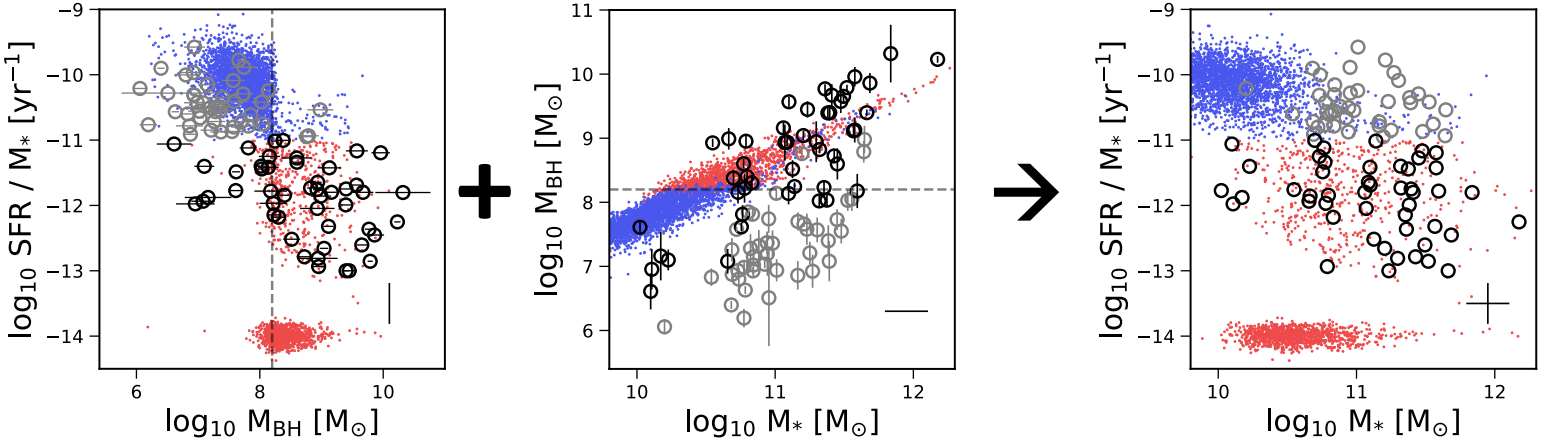
Scatter in M_{BH}-M_{star} relation matters

Terrazas et al. 2017

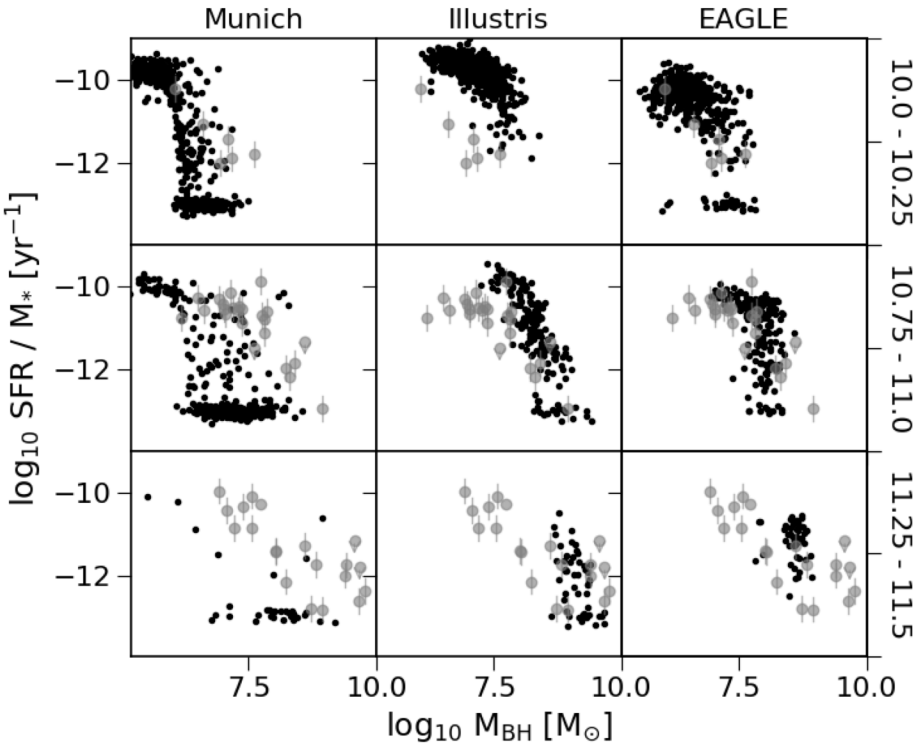


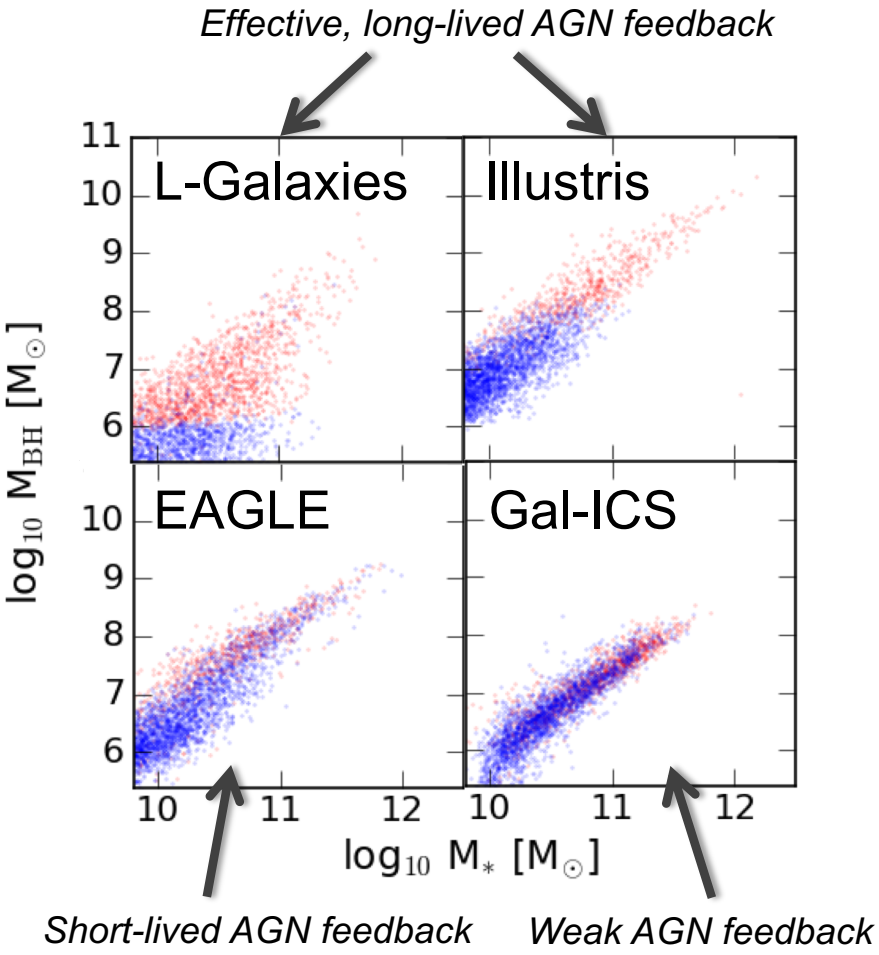
M_{BH}-M_{star}-sSFR space is a powerful tool to investigate quiescence due to BH feedback

Terrazas+18, in prep



Additional slides

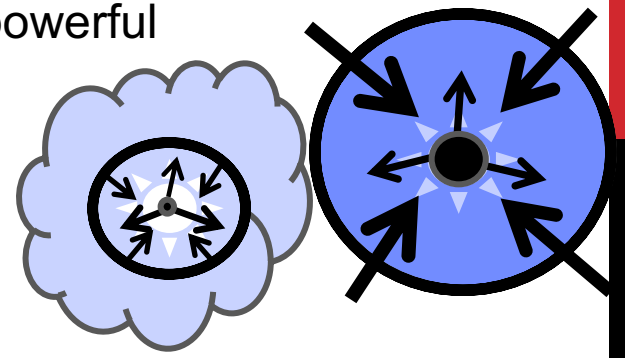




Terrazas+16b

Changing the burstiness of kinetic winds

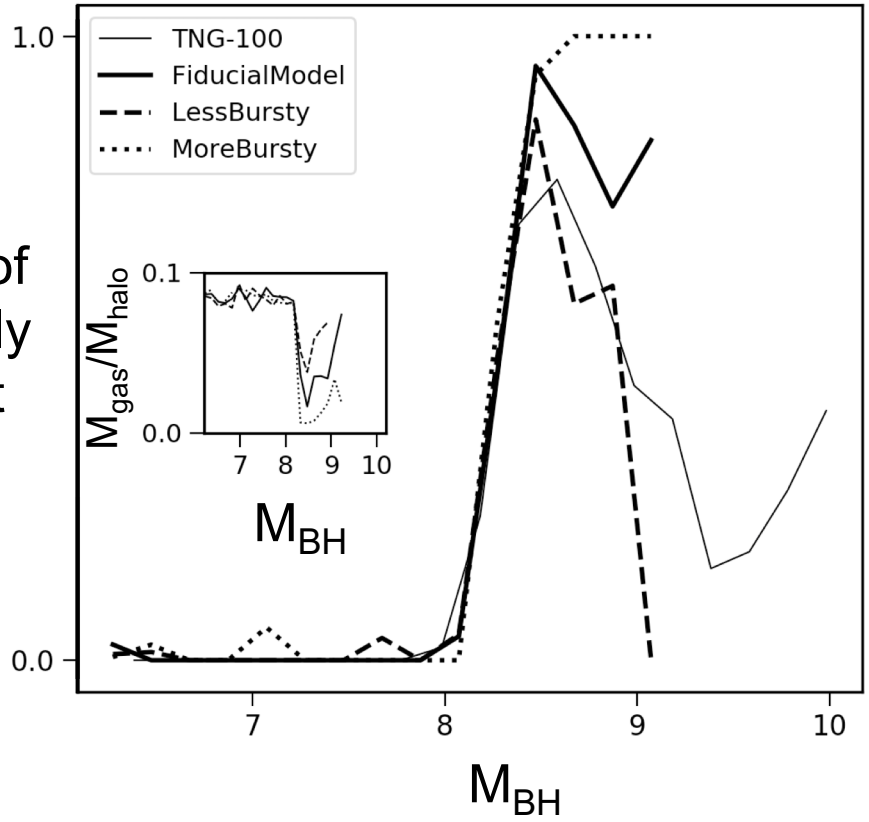
More bursty = less frequent, more powerful



Quiescence depends on TNG's ability to throw gas out of not only the galaxy but also the entire halo

Kinetic winds most efficient in low mass galaxies above the M_{BH} threshold – less efficient at higher masses

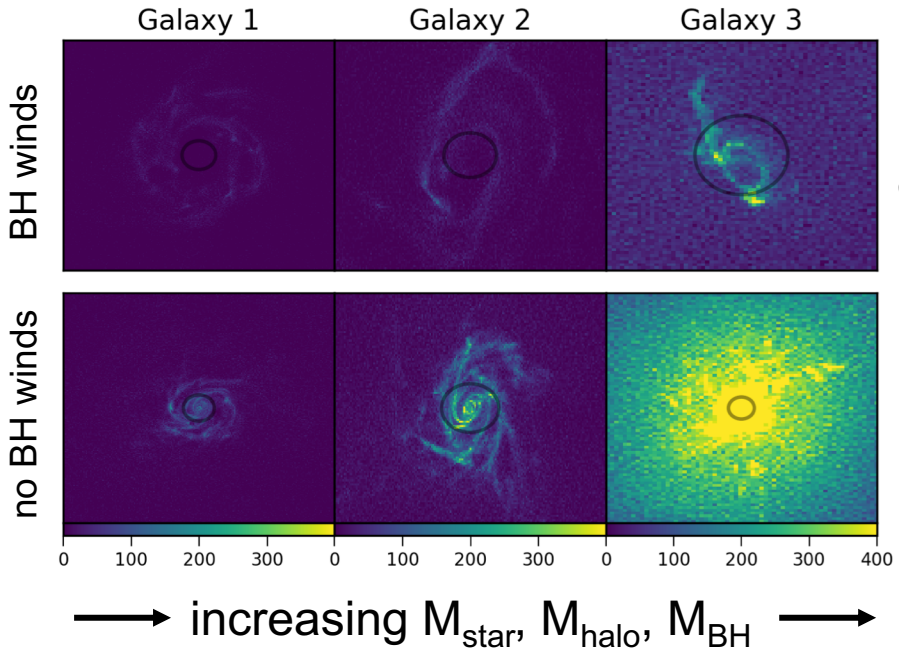
Fraction of completely quiescent galaxies

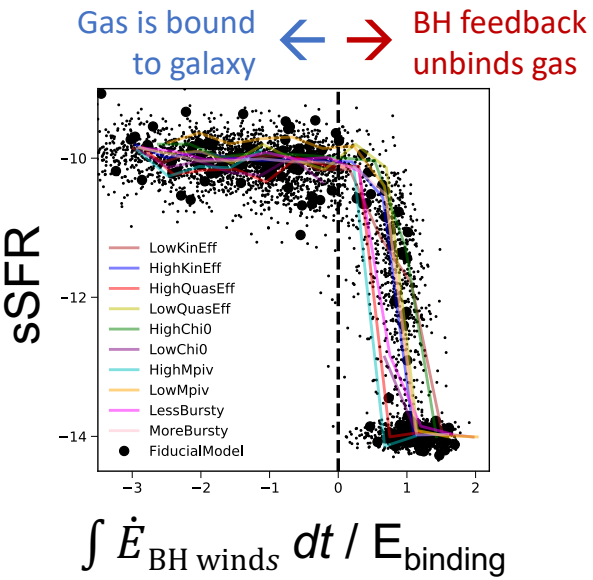


Terrazas+18, in prep

Terrazas+18, in prep

What causes quiescence in TNG?





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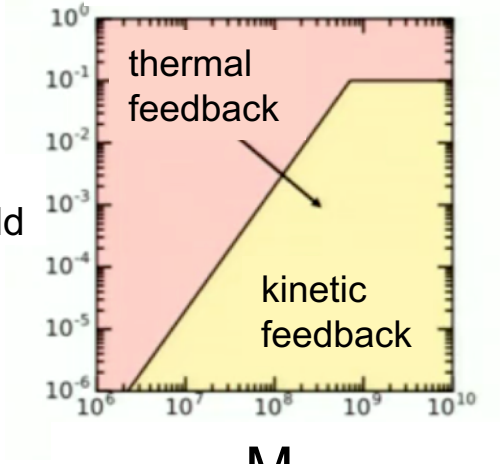
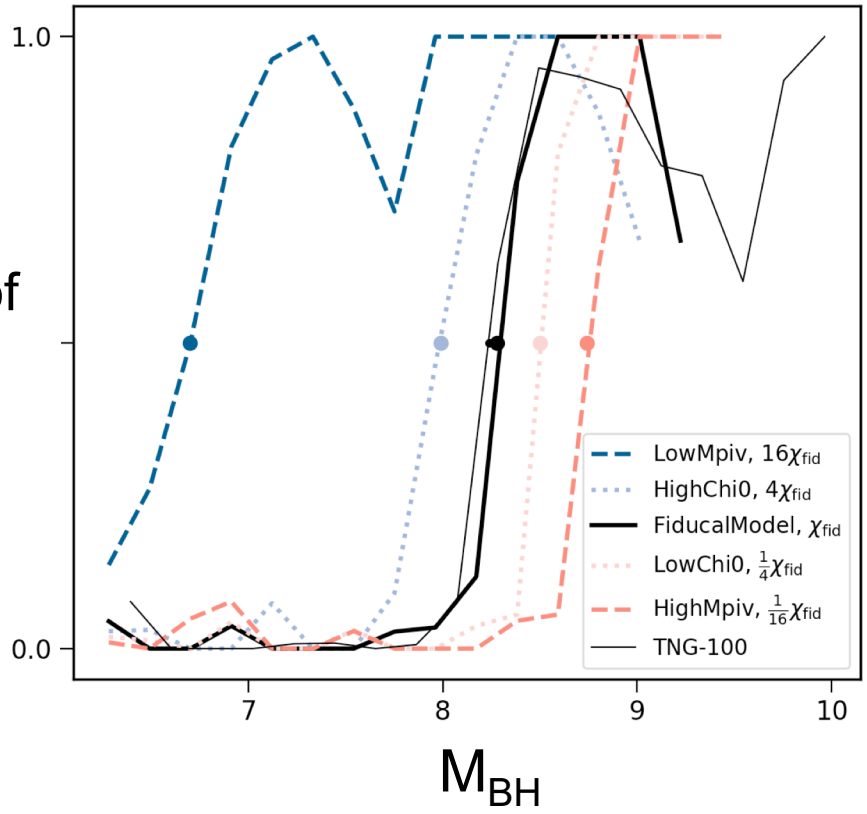
Changing the thermal-kinetic mode threshold

from Melanie Habouzit's talk



Fraction of quiescent galaxies



Location of M_{BH} threshold can change if you change the mass at which BHs begin accumulating kinetic wind energy

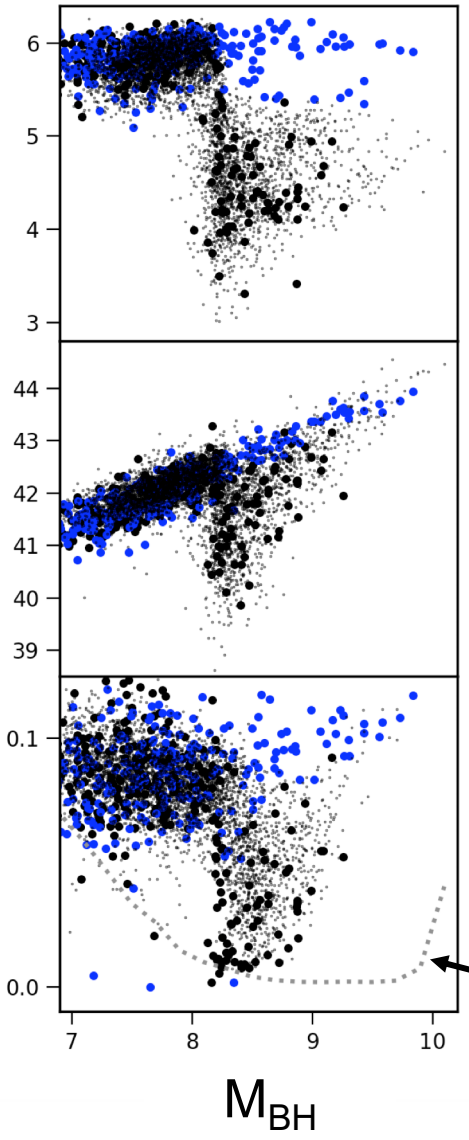
Terrazas+18, in prep

Cumulative BH wind energy → $\int \dot{E}_{\mathrm{BH\ winds}}\, dt \sim M_{BH}$

Average gas density within $2r_e$

Cooling Rate

M_{gas} / M_{halo}



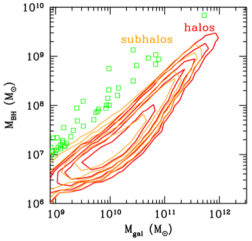
- with BH winds
- without BH winds

Drastic decrease in gas density, cooling rate, and halo gas mass at threshold M_{BH}

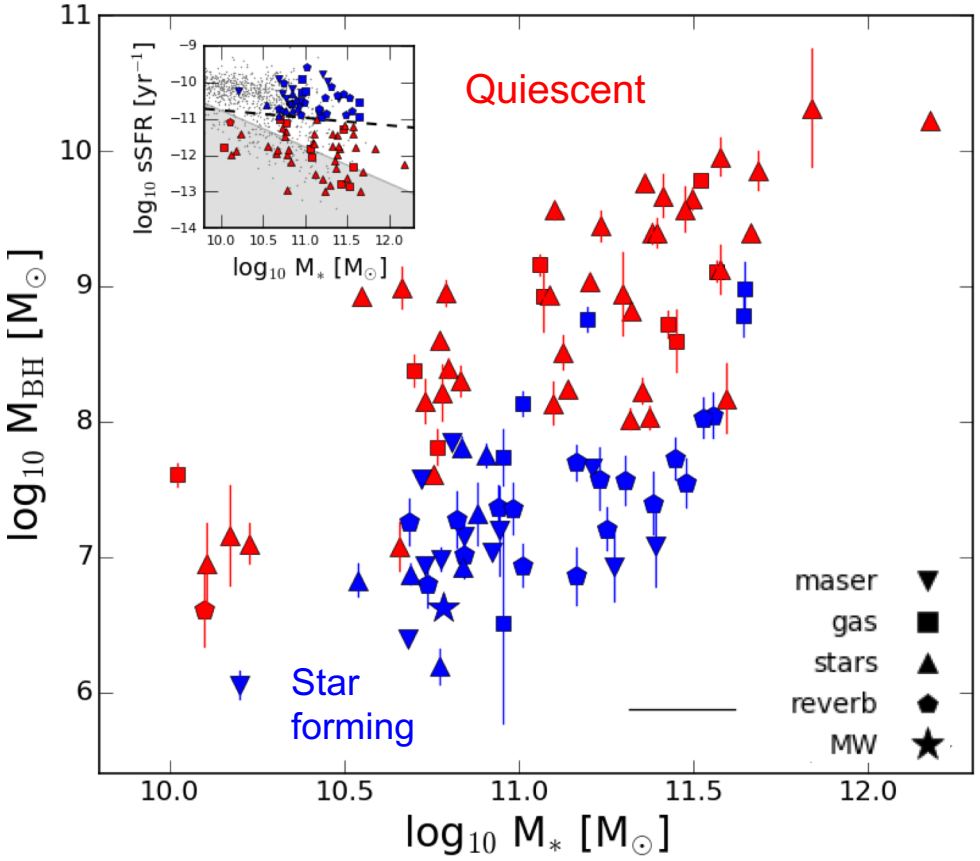
Original Illustris

Terrazas+18, in prep

Volonteri+15: Horizon-AGN

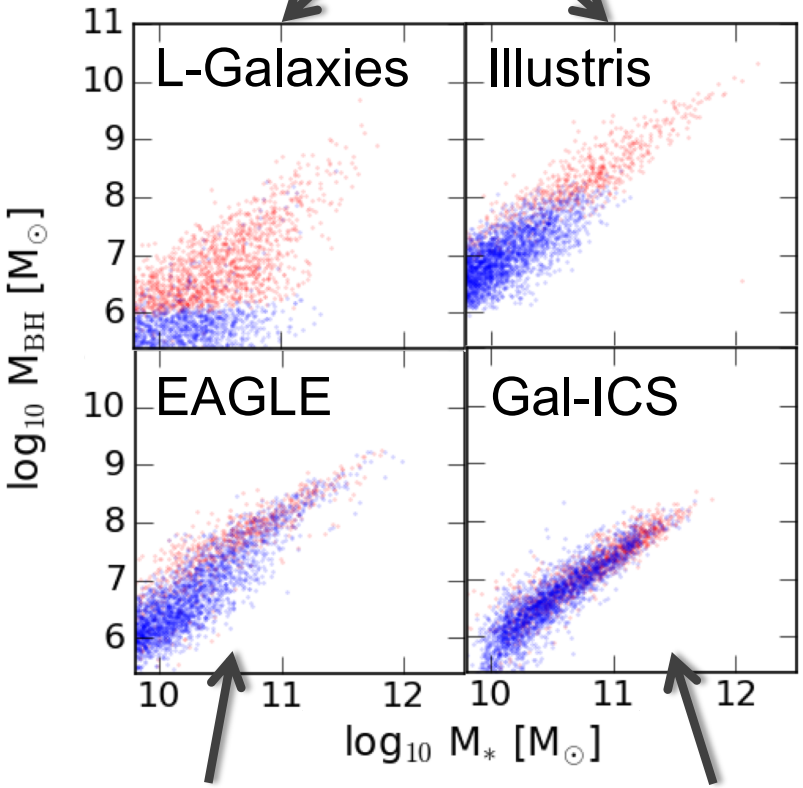


Observations



Comparing with Models

Effective, long-lived AGN feedback



Short-lived AGN feedback *Weak AGN feedback*

Terrazas+16b

Terrazas+16b