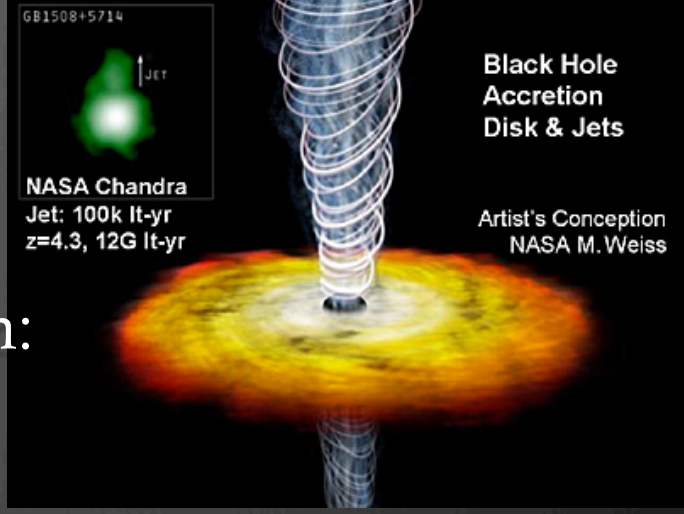
Simba:
Cosmological Galaxy Formation Simulations Including Black Hole Growth and Feedback

Romeel Davé (Edinburgh)
Daniel Anglés-Alcázar (CCA)
Mika Rafieferantsoa, Nicole Thomas (UWC)
Desika Narayanan, Qi Li (Florida)
Katarina Kraljic, Sarah Appleby, Dylan Robson, Jacob Christiansen (Edinburgh)

ROYAL OBSERVATORY EDINBURGH

Black Hole Growth: Bondi Accretion



Gravitational capture from a hot medium:

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

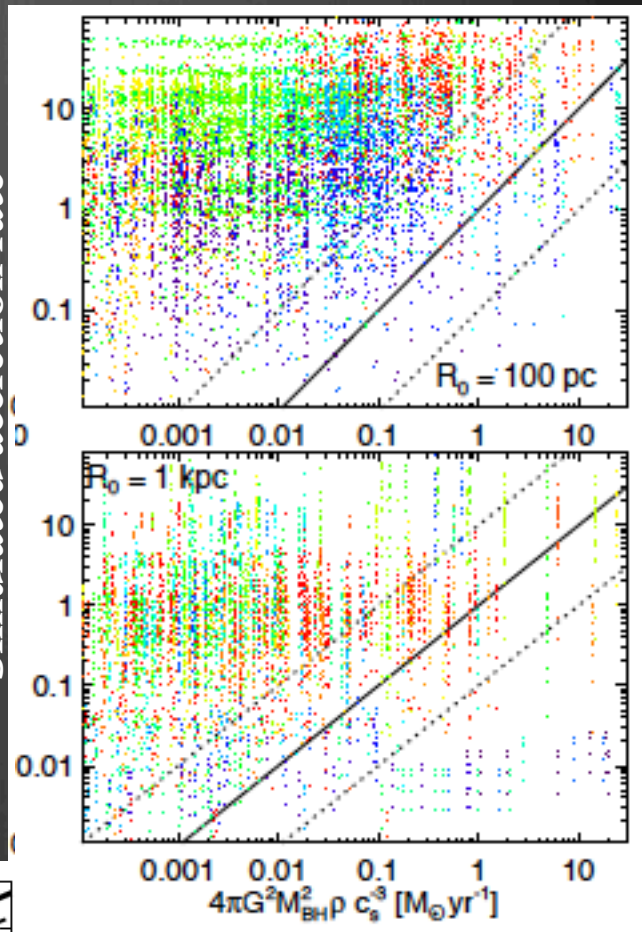
- Physics issue: Steep scaling w/BH mass: $dM_{BH}/dt \sim M_{BH}^2$ requires *self-regulated growth* to evolve along M_{BH}-σ. Feedback needs to be *quasi-spherical* to self-regulate, but observed BH feedback is not necessarily spherical.
- Numerical issue: Computing Bondi accretion requires knowing ρ, c_s at BH, which is poorly resolved in cosmological sims. boost factor α is sometimes required.
- BH accretion models find that *angular momentum loss* limits BH accretion, not local dispersion.

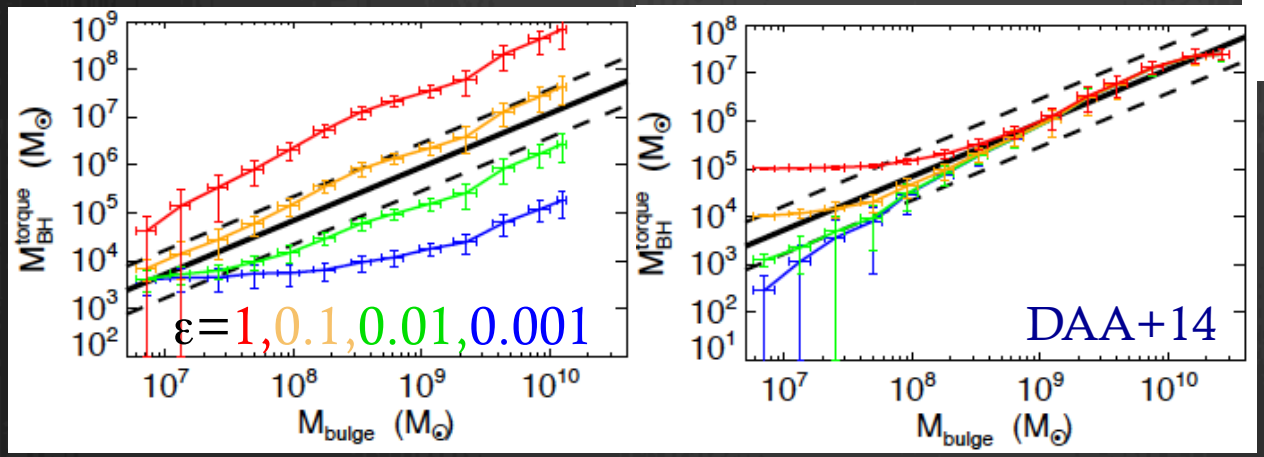
Torque-Limited Accretion

- BH accretion limited by angular momentum loss via disk instabilities – analytic model tested with iso disk sims (Hopkins&Quataert 2011):

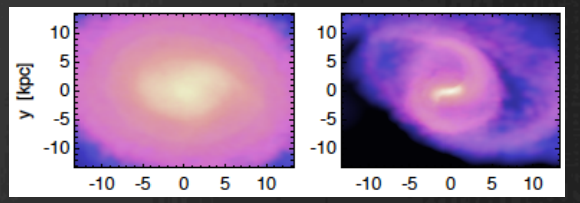
$$\dot{M}_{\rm Torque} \approx \alpha_{\rm T}\, f_{\rm disk}^{5/2} \times \left(\frac{M_{\rm BH}}{10^8\,{\rm M}_\odot}\right)^{1/6} \left(\frac{M_{\rm disk}(R_0)}{10^9\,{\rm M}_\odot}\right)^{1} \times \left(\frac{R_0}{100\,{\rm pc}}\right)^{-3/2} \left(1+\frac{f_0}{f_{\rm gas}}\right)^{-1} {\rm M}_\odot\,{\rm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

R_0~kpc encloses 256 neighbors





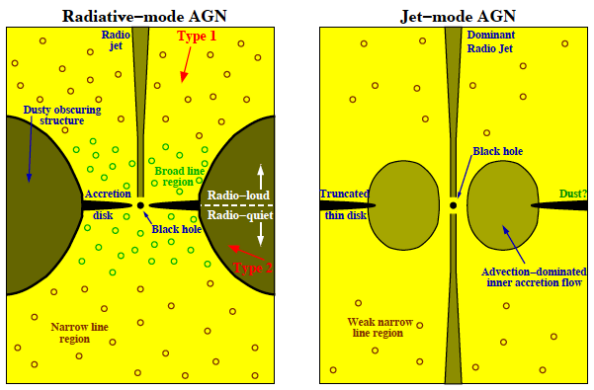
Hopkins & Quataert 11



1 free parameter ε~0.05-0.1 Converges to M-σ w/o feedback!

Two-mode BH Feedback

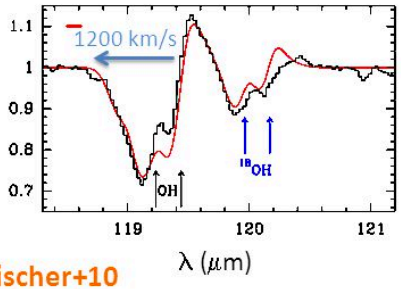
- Heckman & Best 2014: HERGs ('cold') at f_{Edd}<~0.02, LERG ('hot') f_{Edd}>~0.02
- *Jet mode:* Red & dead, v~10^4 km/s, p>~few L/c
- *Radiative mode:* ULIRGs, v~10^3 km/s, p~20L/c



HB14

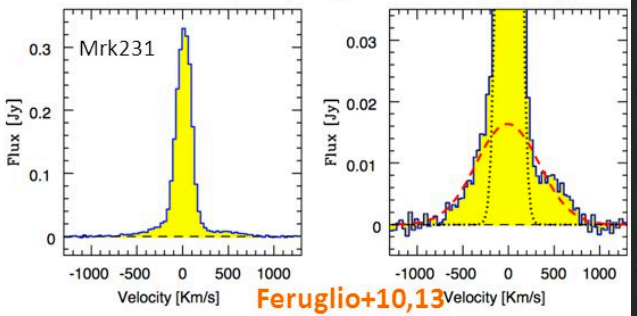
Evidence for massive quasar-driven molecular outflows

OH P-Cygni profiles



Fischer+10
Sturm+11

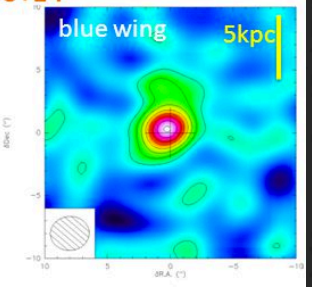
CO(1-0) high velocity wings



Feruglio+10,13
Cicone+14

Massive molecular outflows (~1000 $M_\odot$/yr)
Extended on kpc scales
P_K ~ 0.05 L_{AGN}
Momentum rate ~ 20 L_{AGN}/c

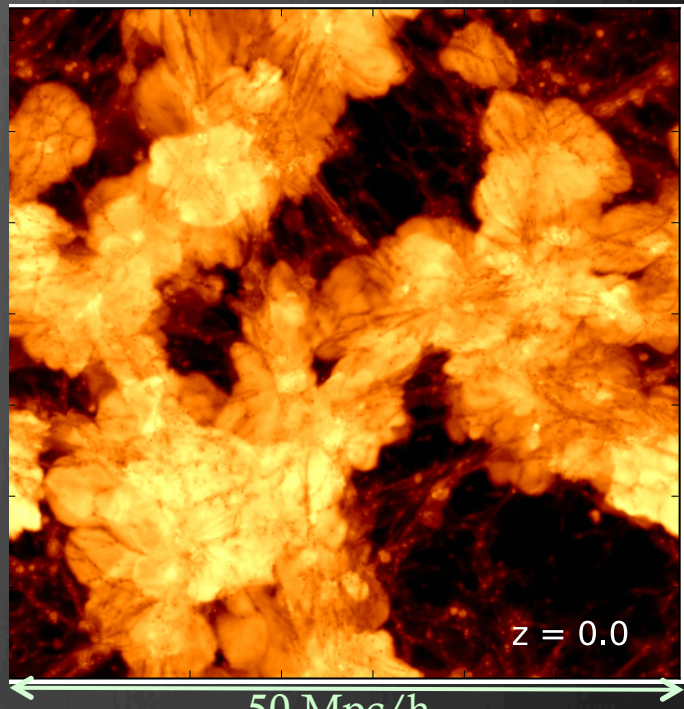
...as expected (and required) by models

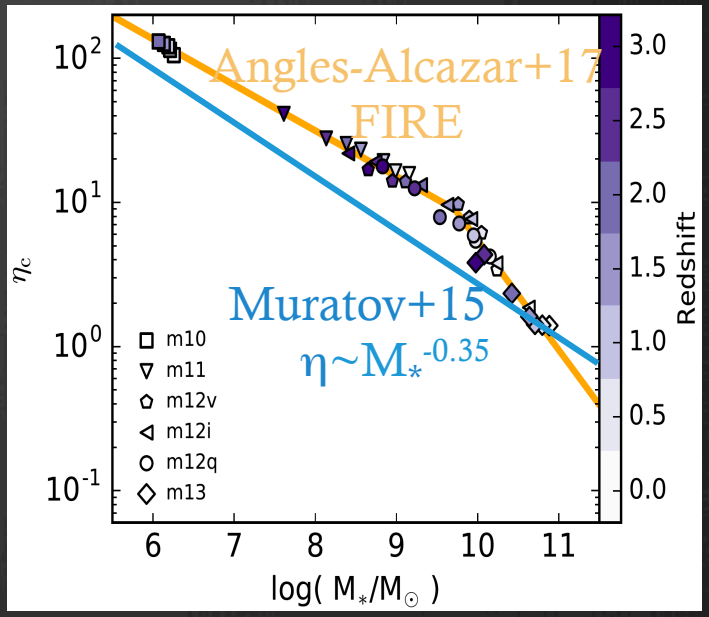


from R. Maiolino

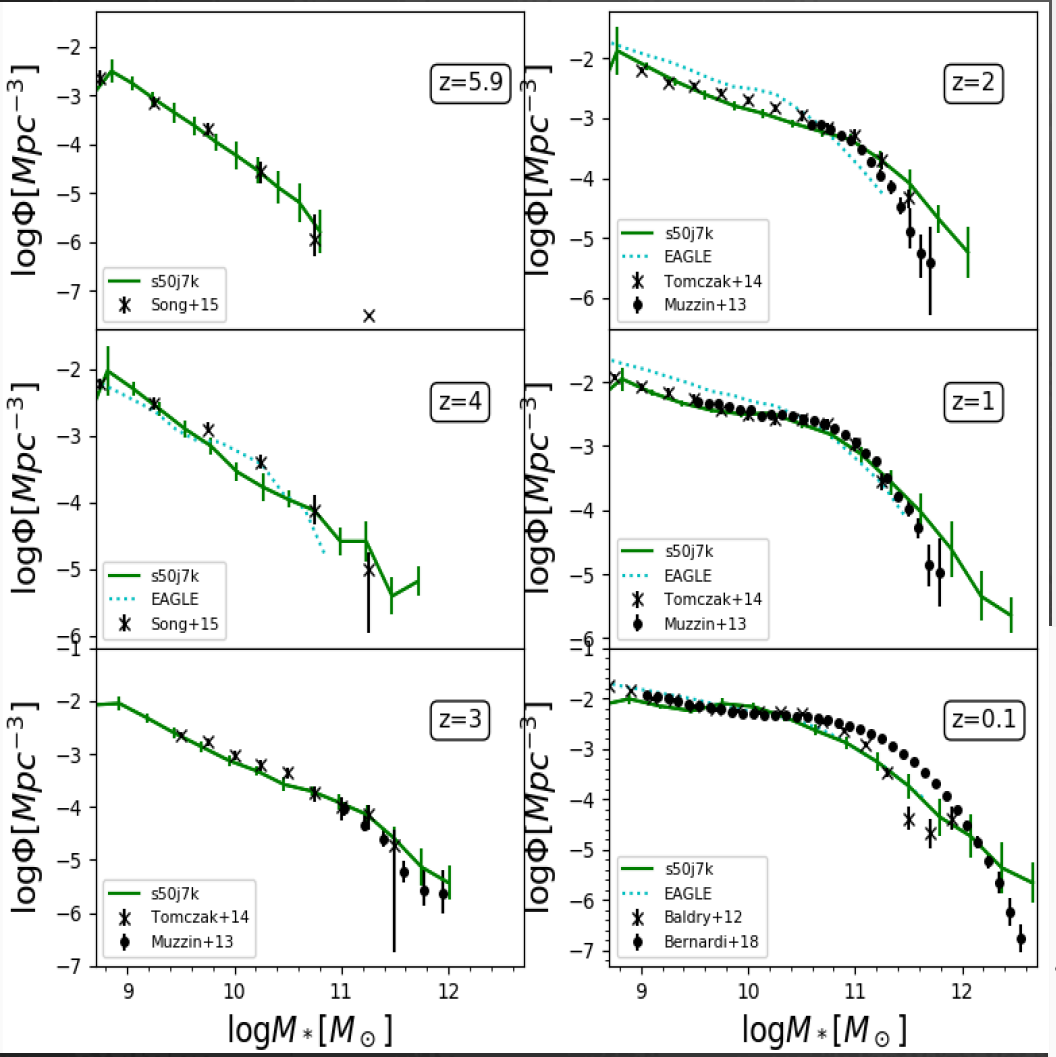
Simba

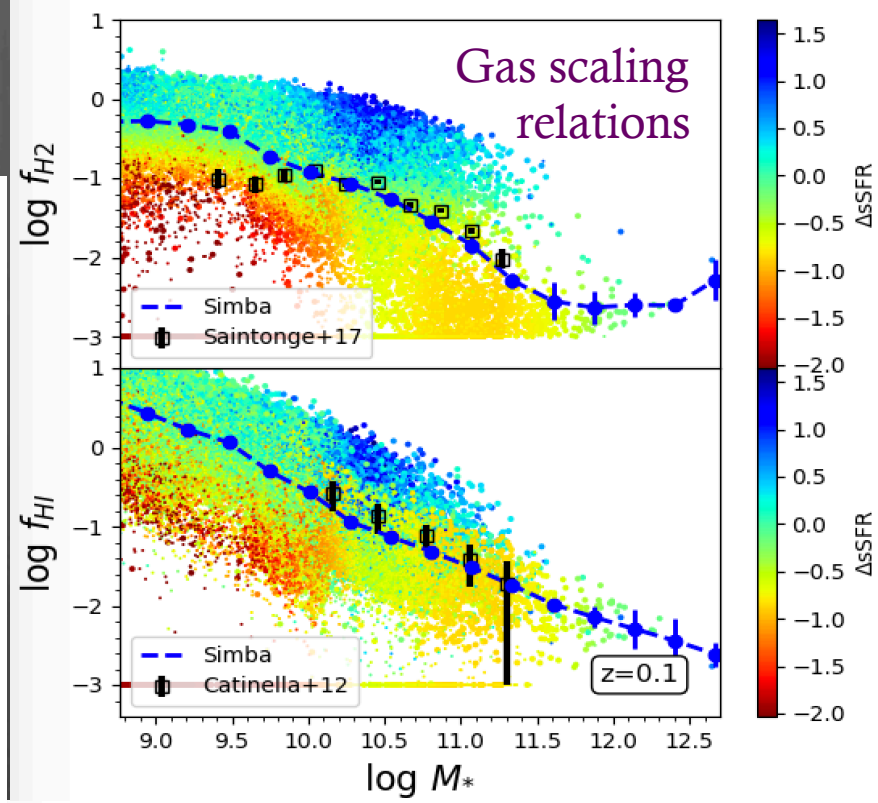
- Gizmo, Grackle-3.1 cooling+heating, H_2-based SF, pressurized ISM, enrichment from Type II/Ia + AGB, on-the-fly self-shielding for HI.
- **SF Feedback:** Kinetic decoupled winds based on FIRE particle tracking results.
- **BH Growth:** Torque-limited accretion (ε=0.1) for T<10^5K, Bondi for T>10^5K.
- $M_{seed}=10^4$ @ $M_*=3x10^9$, <3x Eddington.
- **Radiative+Jet BH Feedback:**
  - *Always:* kinetic & bipolar, p=20 L_{bol}/c , θ =0°
  - *Radiative mode:* (f_{Edd}>0.1) v_{out}~500-1500km/s
  - *Jet mode:* f_{Edd}<~0.02, v_{out} up to 7000 km/s
  - *X-ray feedback* based on Choi+13 in jet mode
- **Dust** formation&destruction on the fly

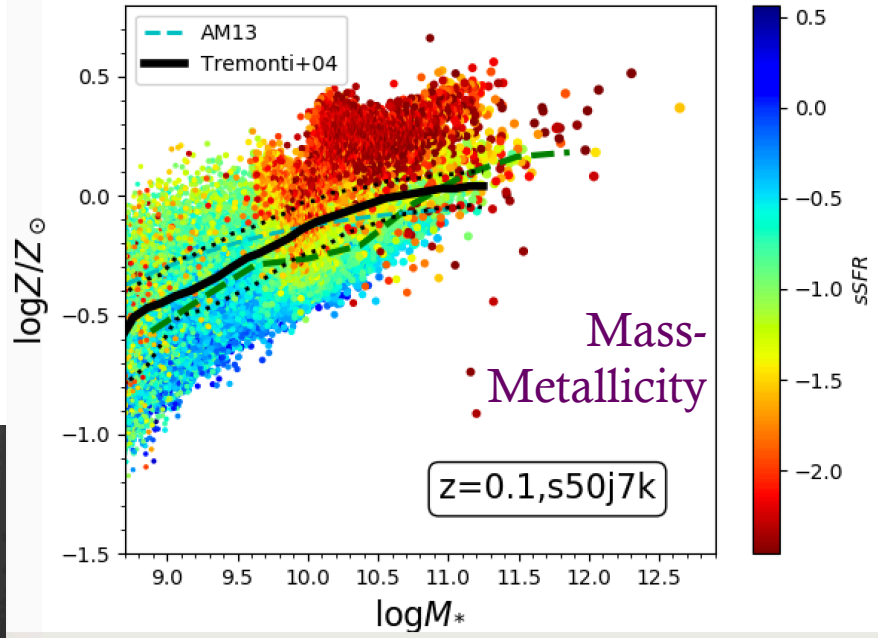




Stellar Mass Function

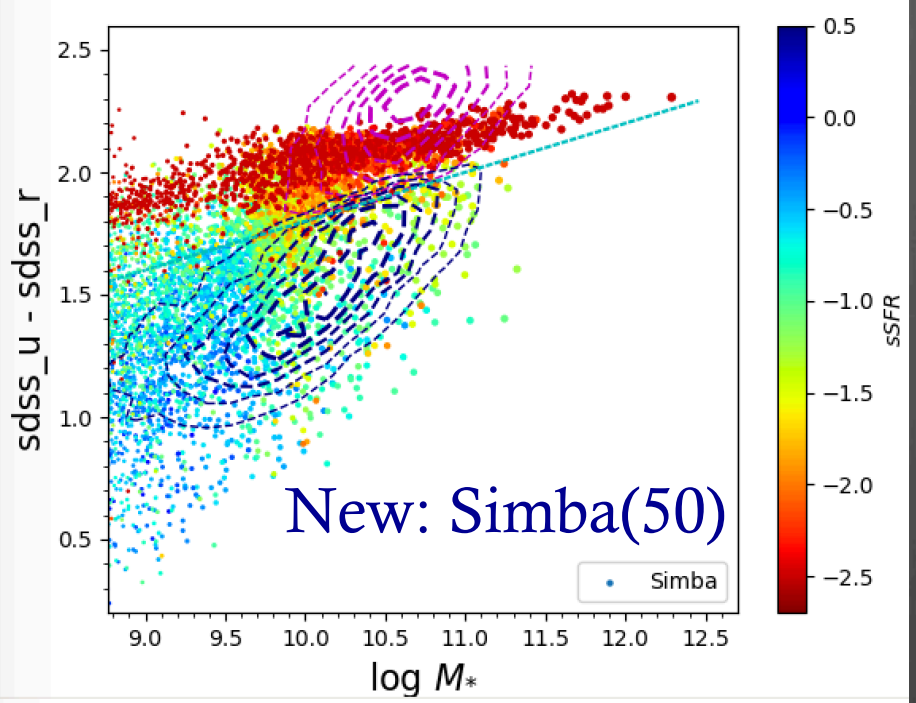


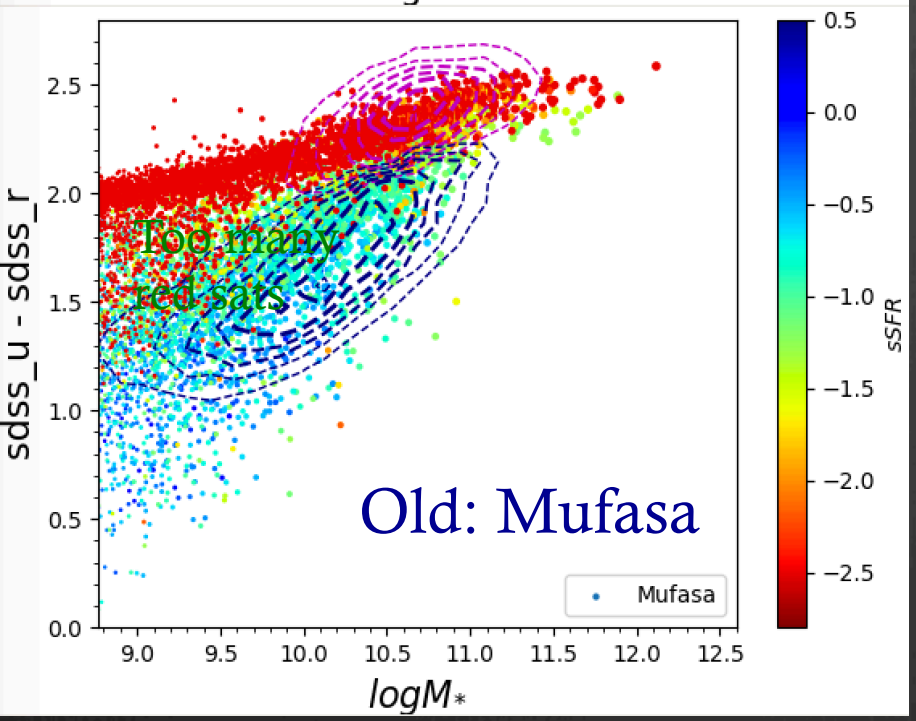


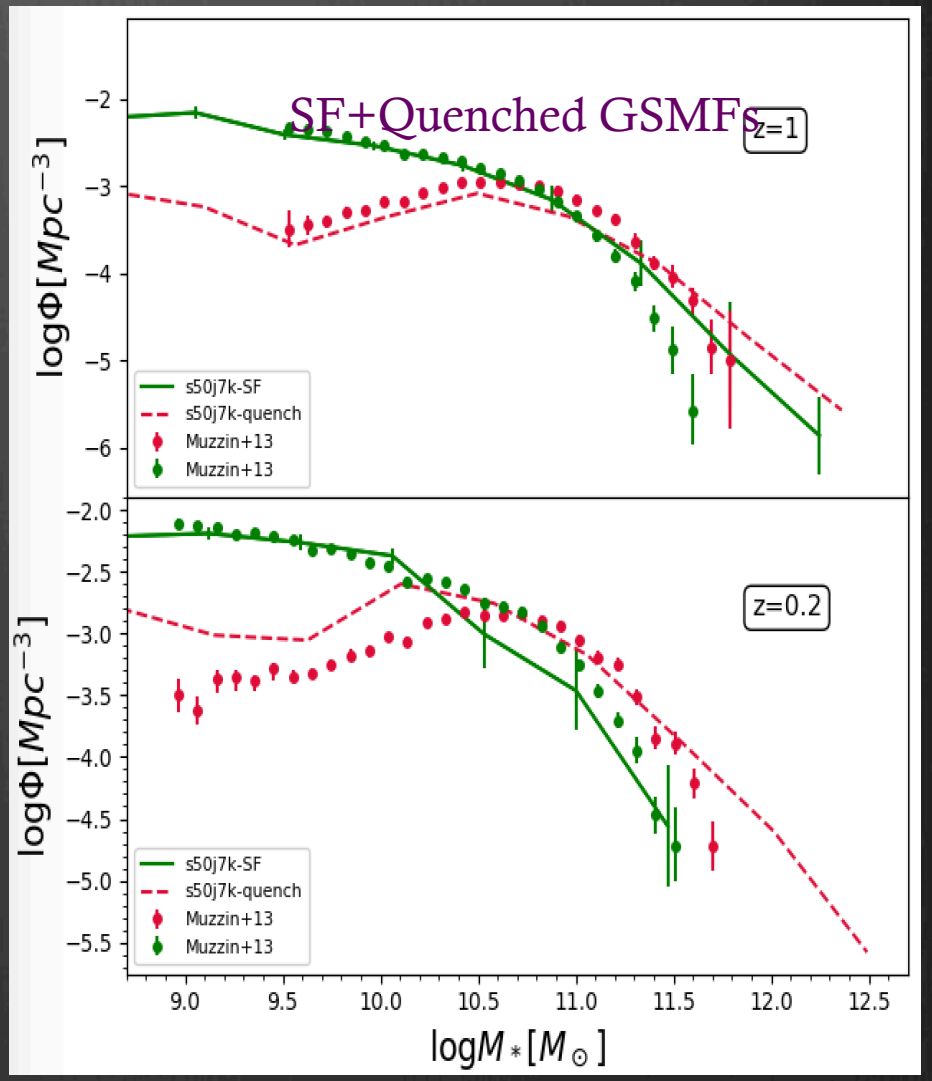


Galaxy colors

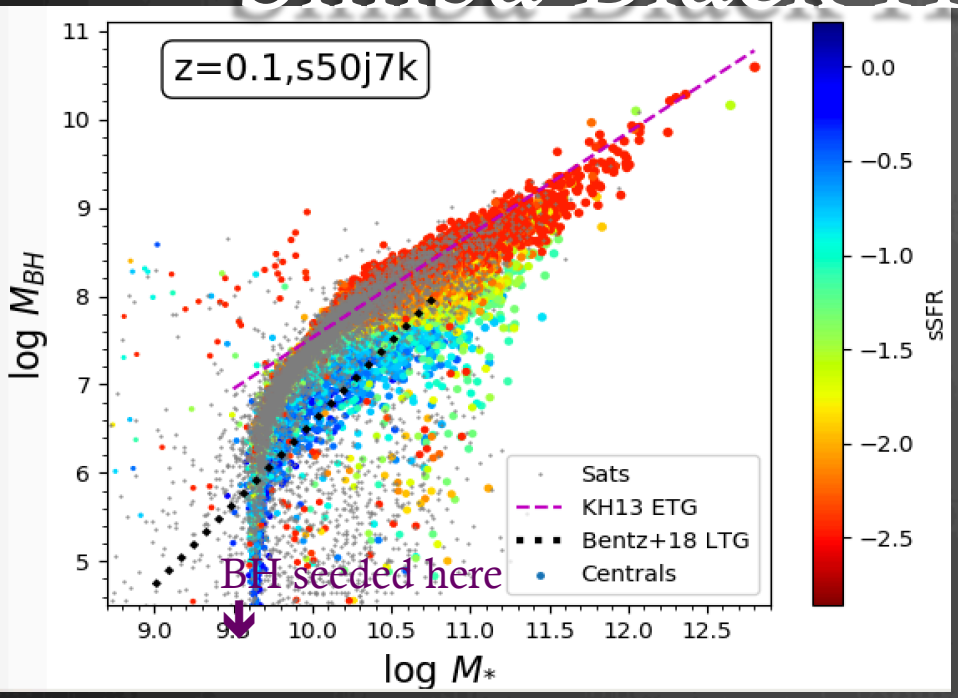
Colors using PyLOSER: pyloser.readthedocs.io

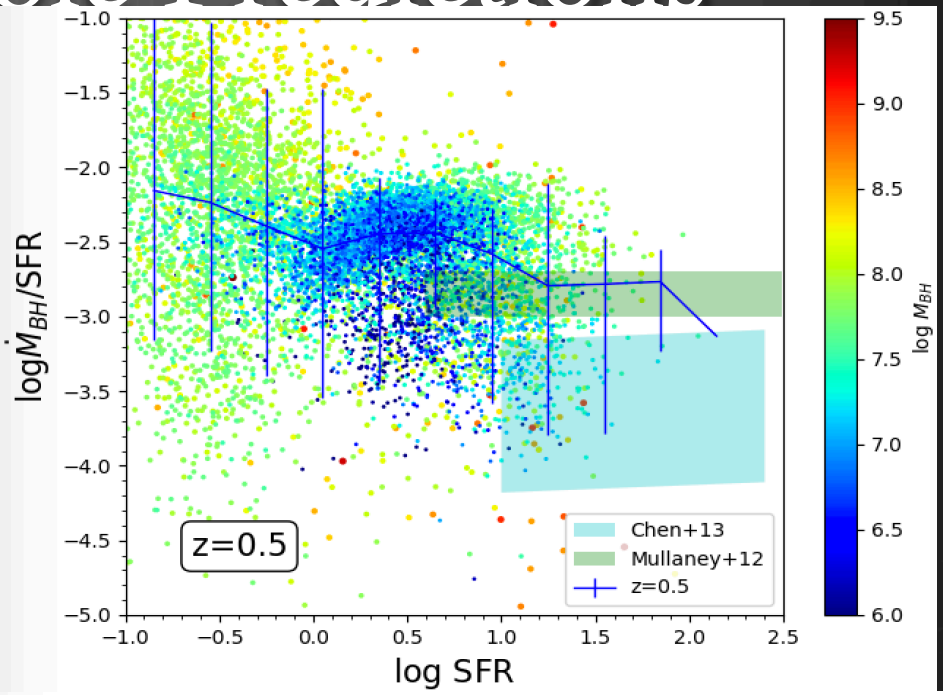


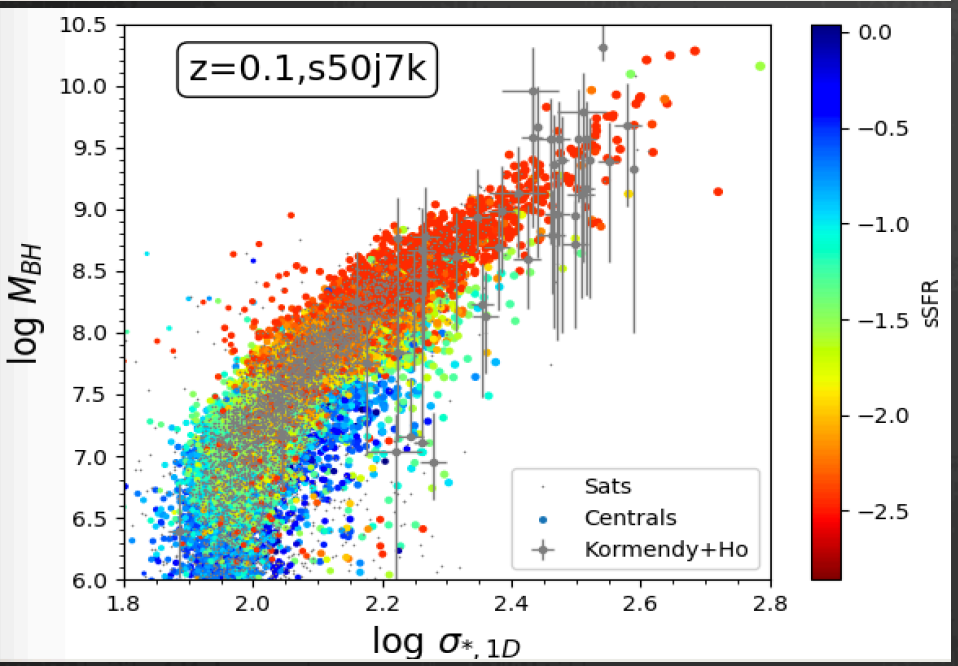


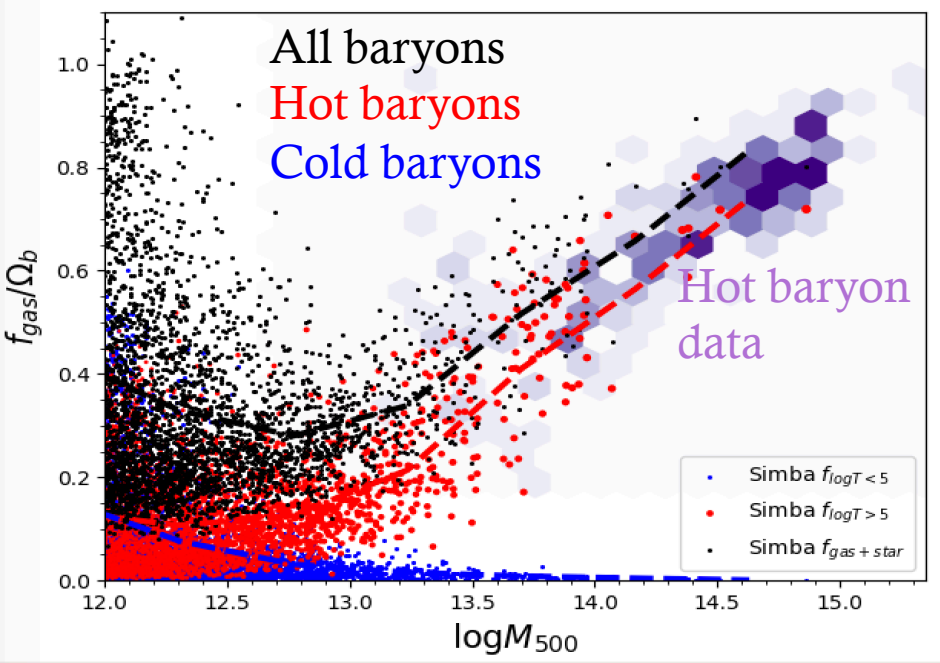


Simba Black Hole Predictions



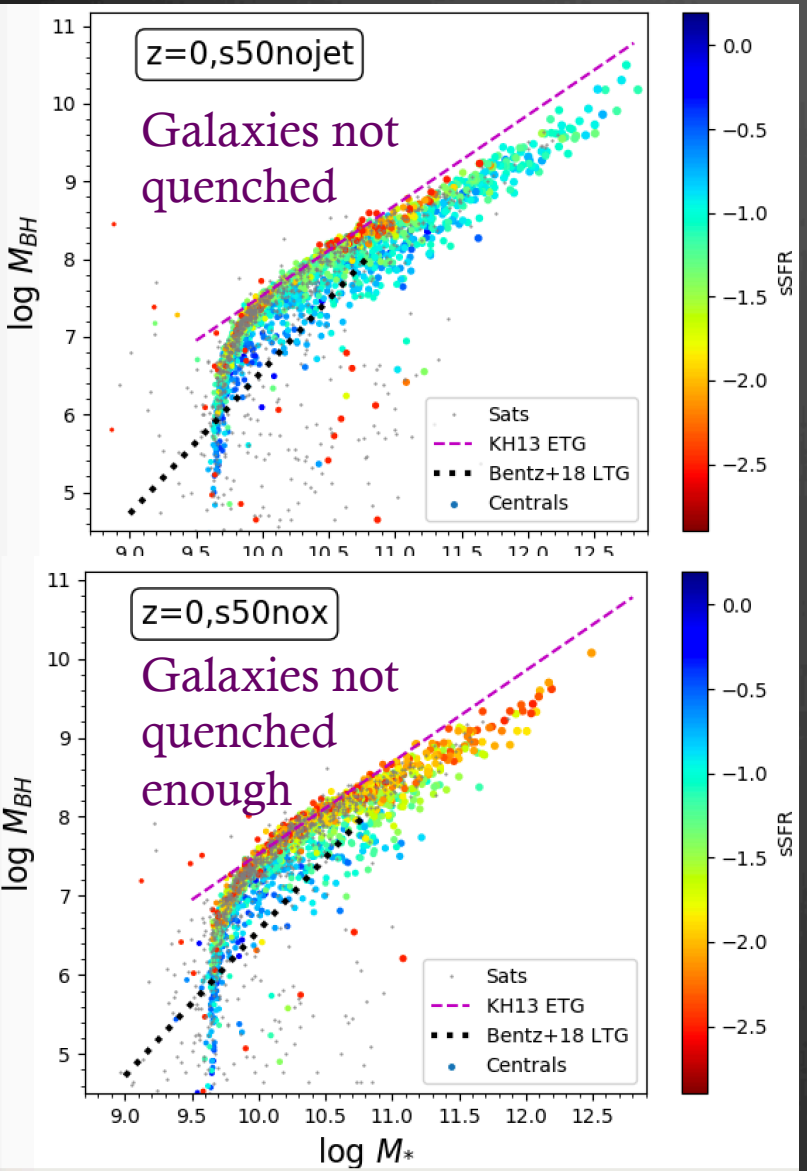


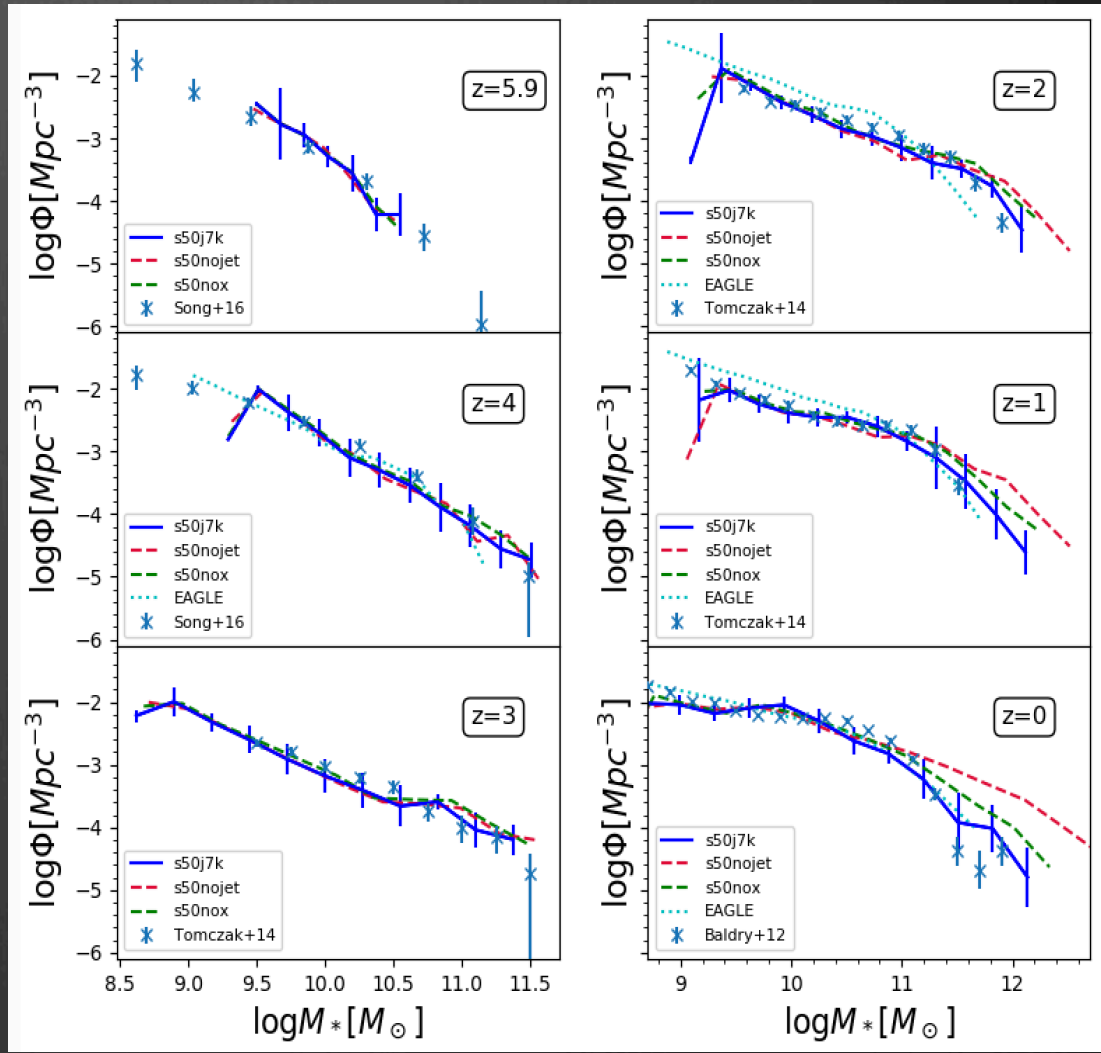




Which AGN feedback quenches?

- Jets responsible for quenching, truncating GSMF; X-ray feedback non-trivial.

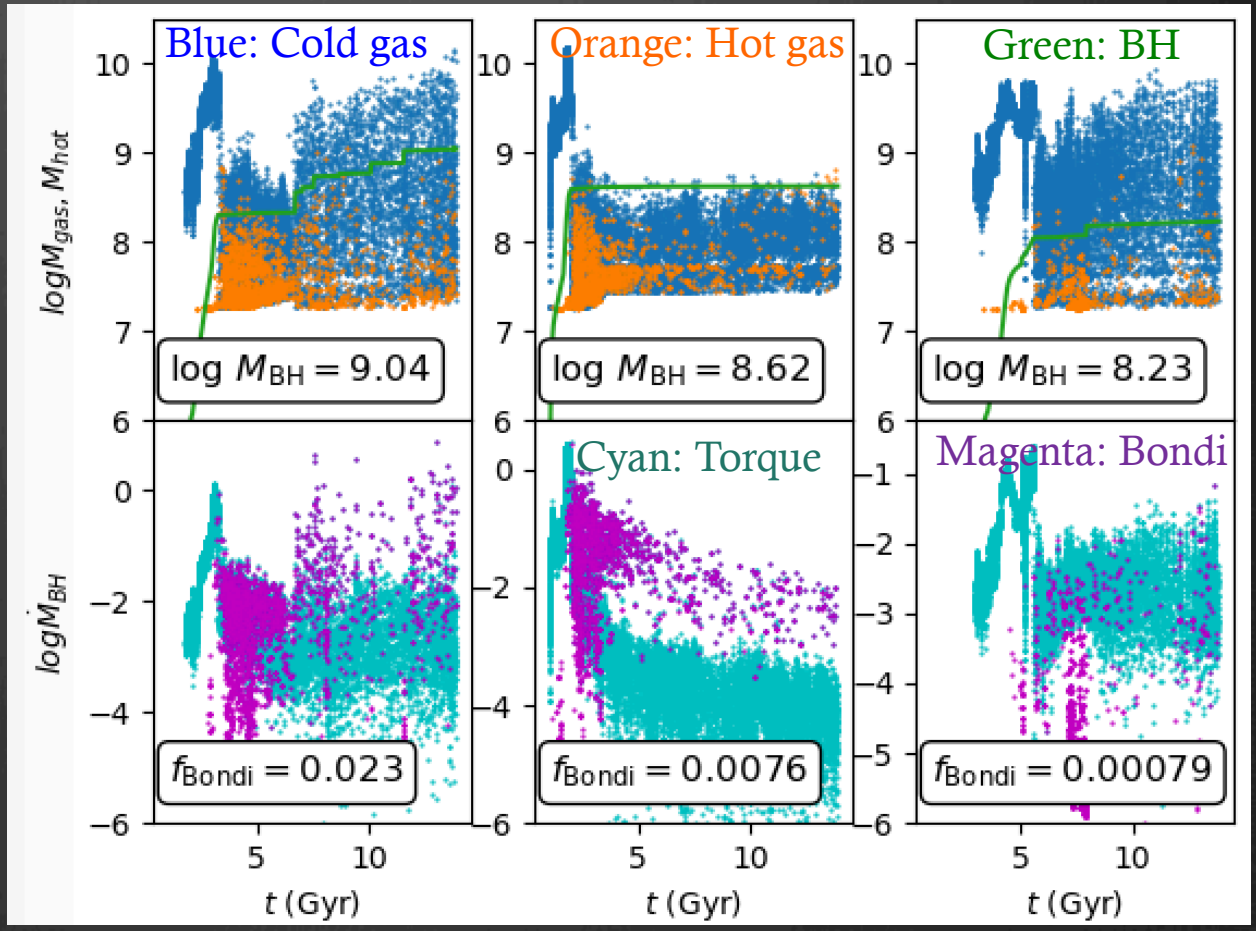




50 Mpc/h, 512^3 sims, all incl. radiative feedback

Torque-limited vs. Bondi Accretion: Which Dominates?

- Torque-limited accretion dominates globally., increasingly so to low M_{BH}.
- Bondi dominates at late times when hot gas is present, but intermittently.



- Simba = Mufasa+torque-limited BH feeding + bipolar jet feedback: matches star, gas, metal properties similarly to or better than Mufasa.
- Torque-limited model is an interesting alternative to Bondi. Works together with BH feedback to produce galaxy-BH co-evolution as observed.
- Suite: 100, 50, 25, 12.5 Mpc/h w/1024^3, plus cluster+galaxy zooms. Outputs and galaxy catalogs available upon request as completed.