The Interplay between Stellar and AGN feedback in Galaxy Groups

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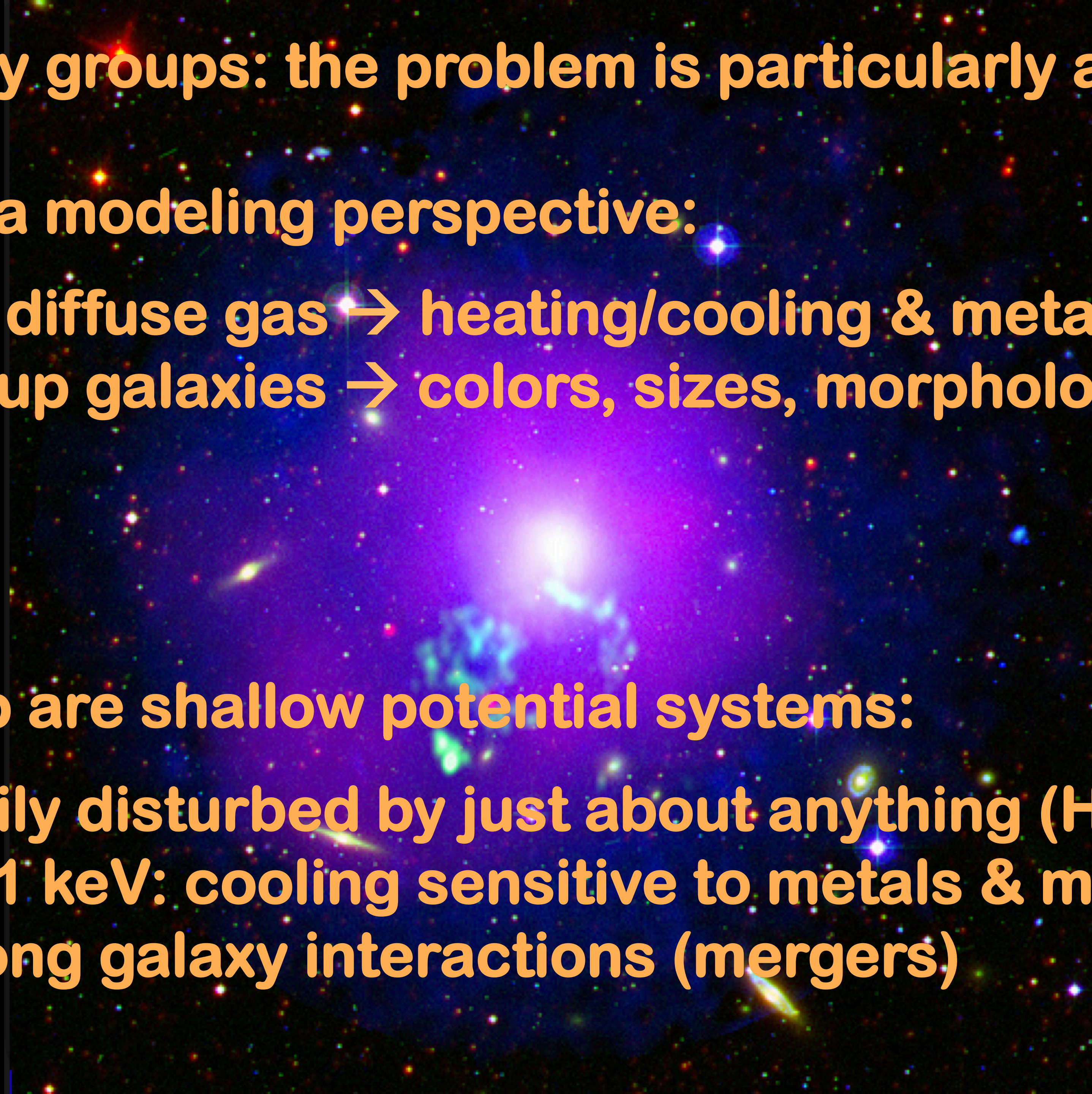
Trevor/Paris 2016

Oaxaca Workshop Summary – June 2016

<u>The obvious</u>: Stellar and AGN feedback are key for understanding galaxies, groups and…

<u>Problem #1</u>: We have a reasonable grasp of stellar physics but don't quite know how to capture this in cosmo-sims: Sub-grid implementation vary and seem ad hoc.

<u>Problem #2</u>: We only have a tenuous grasp of AGN physics and implementation (subgrid model) in cosmo-sims is often tuned to "fix" deficiencies in stellar feedback (in sims)



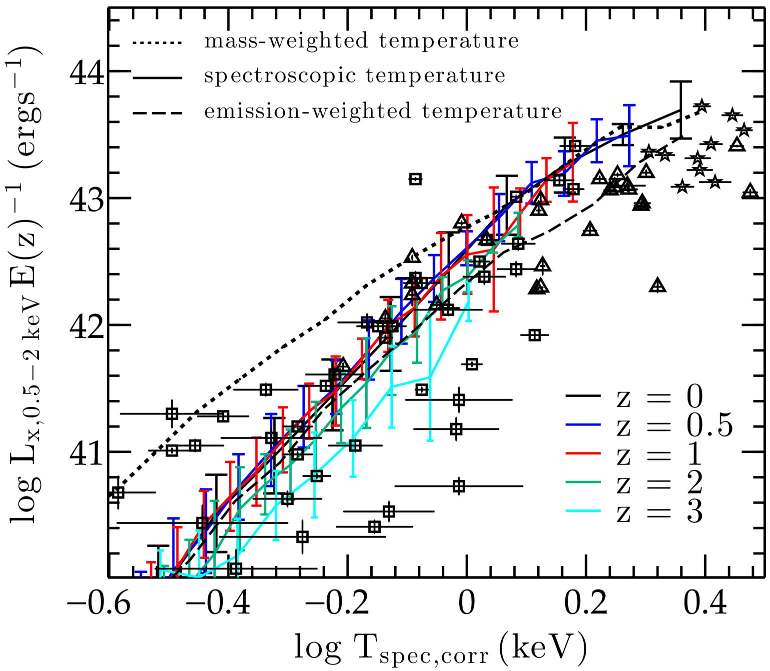
Galaxy groups: the problem is particularly acute.

From a modeling perspective:

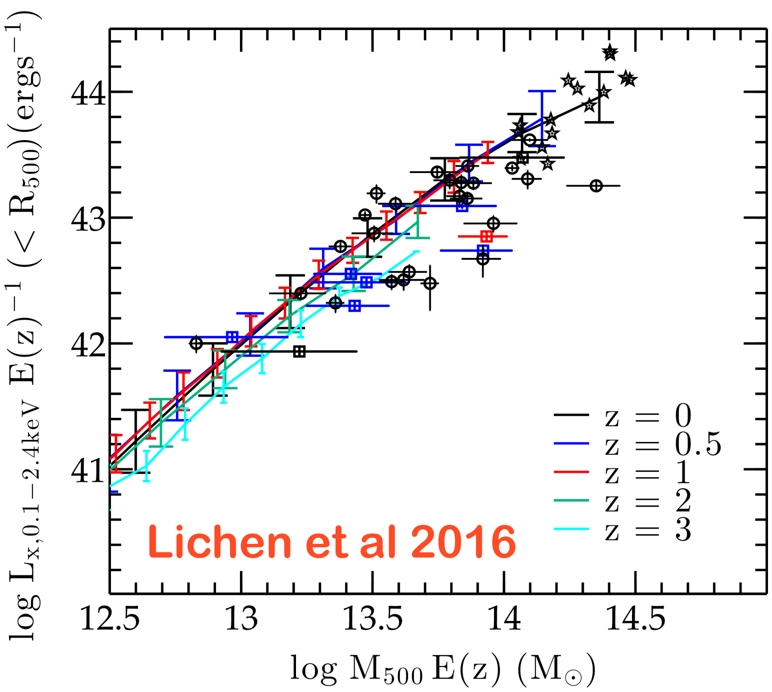
- Hot diffuse gas → heating/cooling & metallicity
- Group galaxies → colors, sizes, morphologies

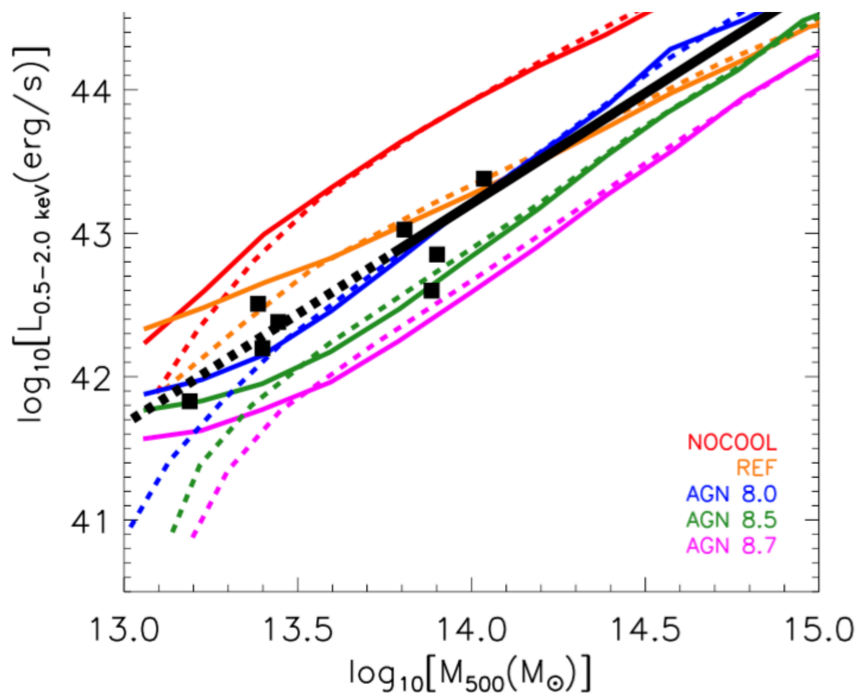
Group are shallow potential systems:

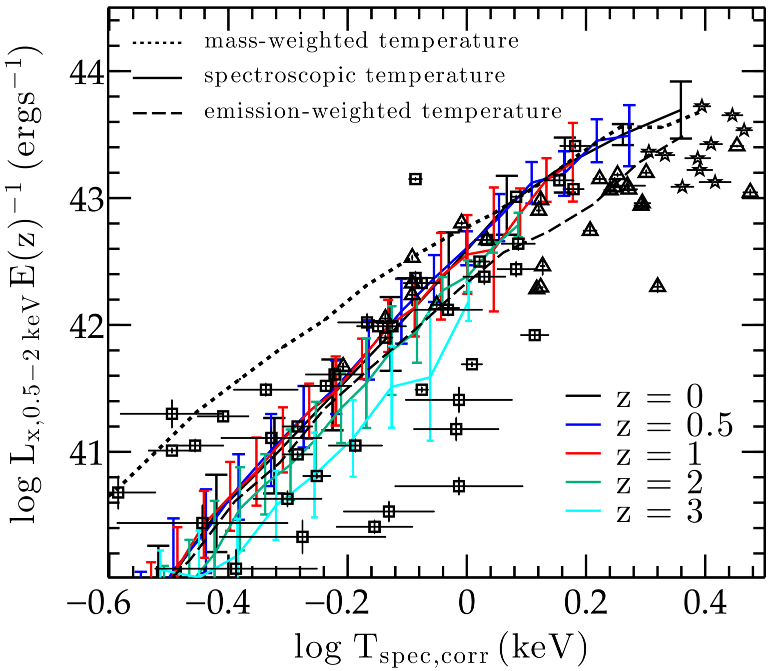
- Easily disturbed by just about anything (HSE)
- T < 1 keV: cooling sensitive to metals & mixing
- Strong galaxy interactions (mergers)

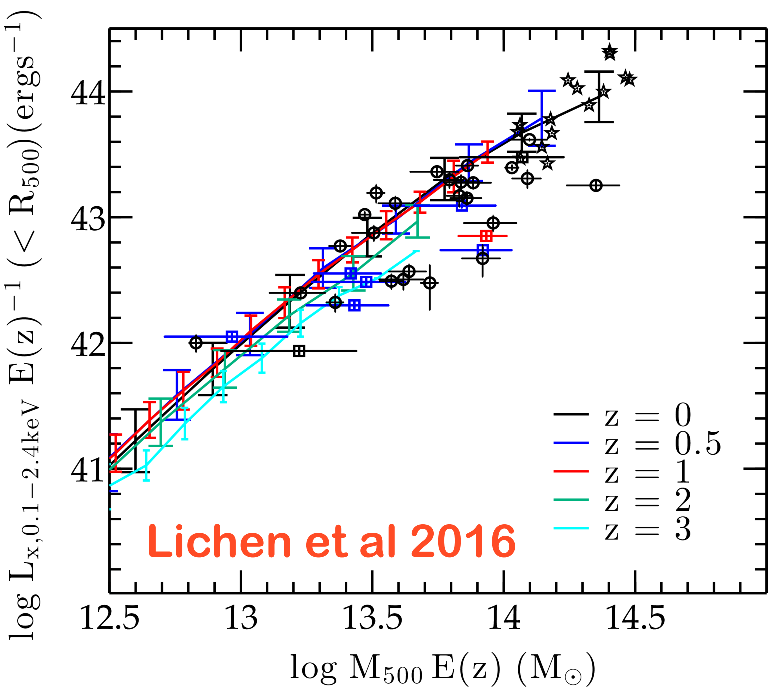


Cosmo-OWLS: Le Brun et al 2013









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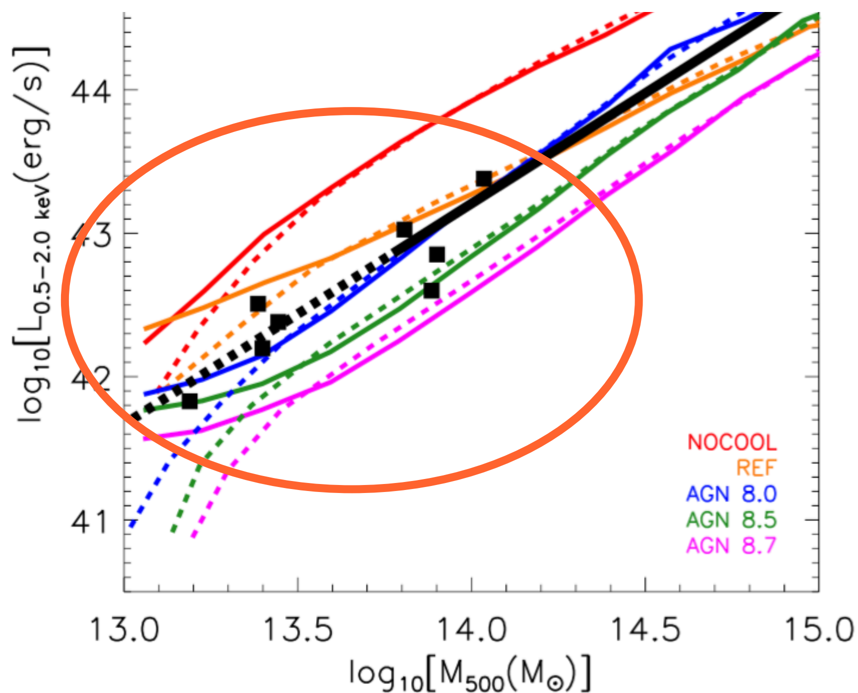

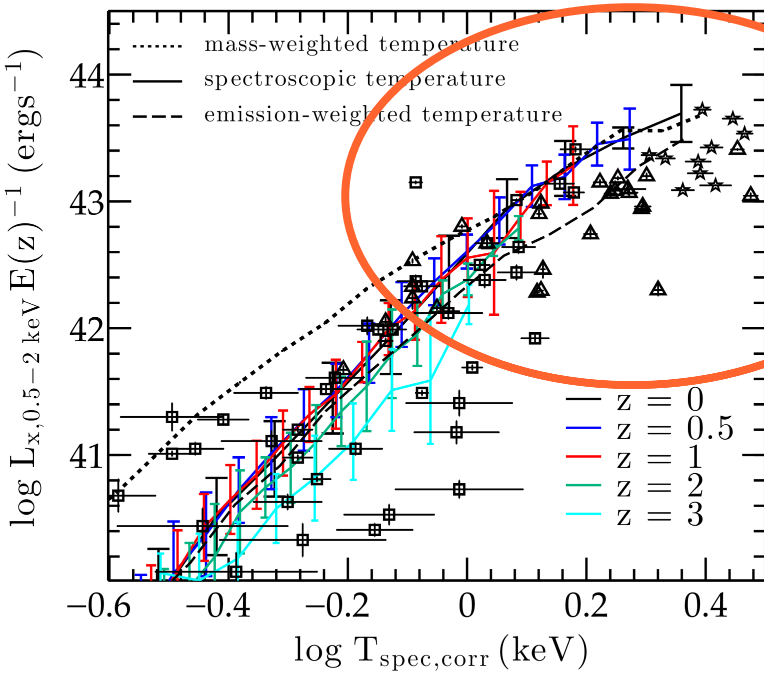

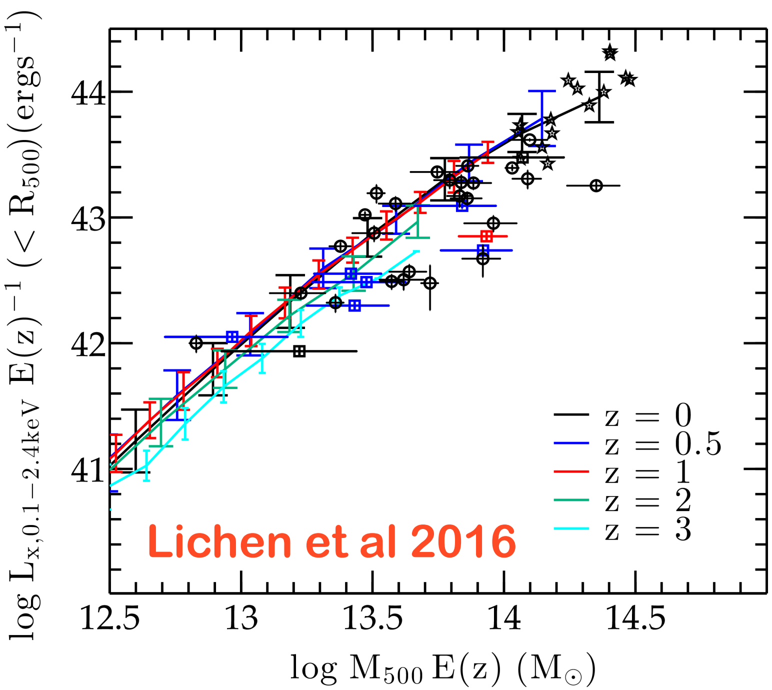

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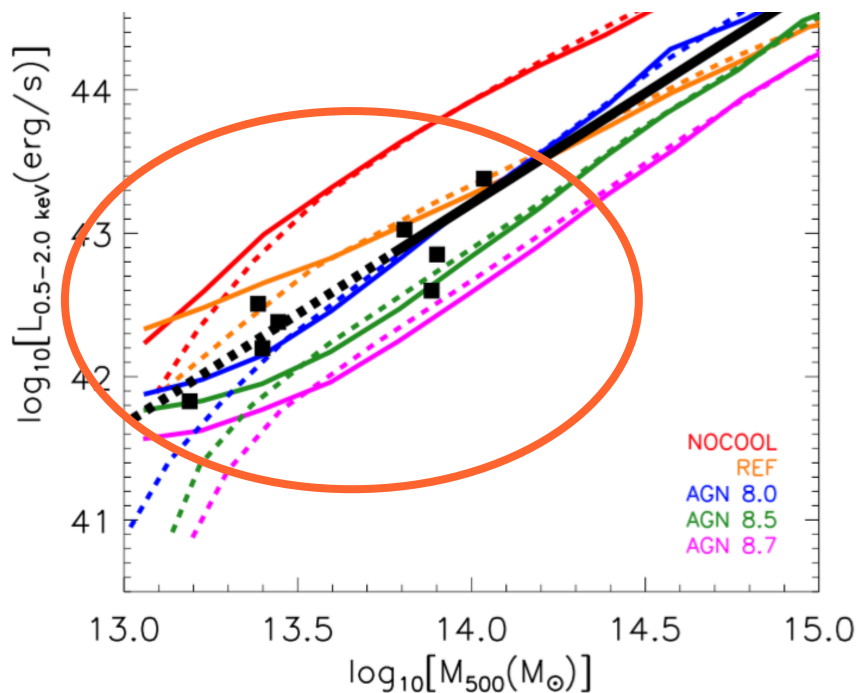

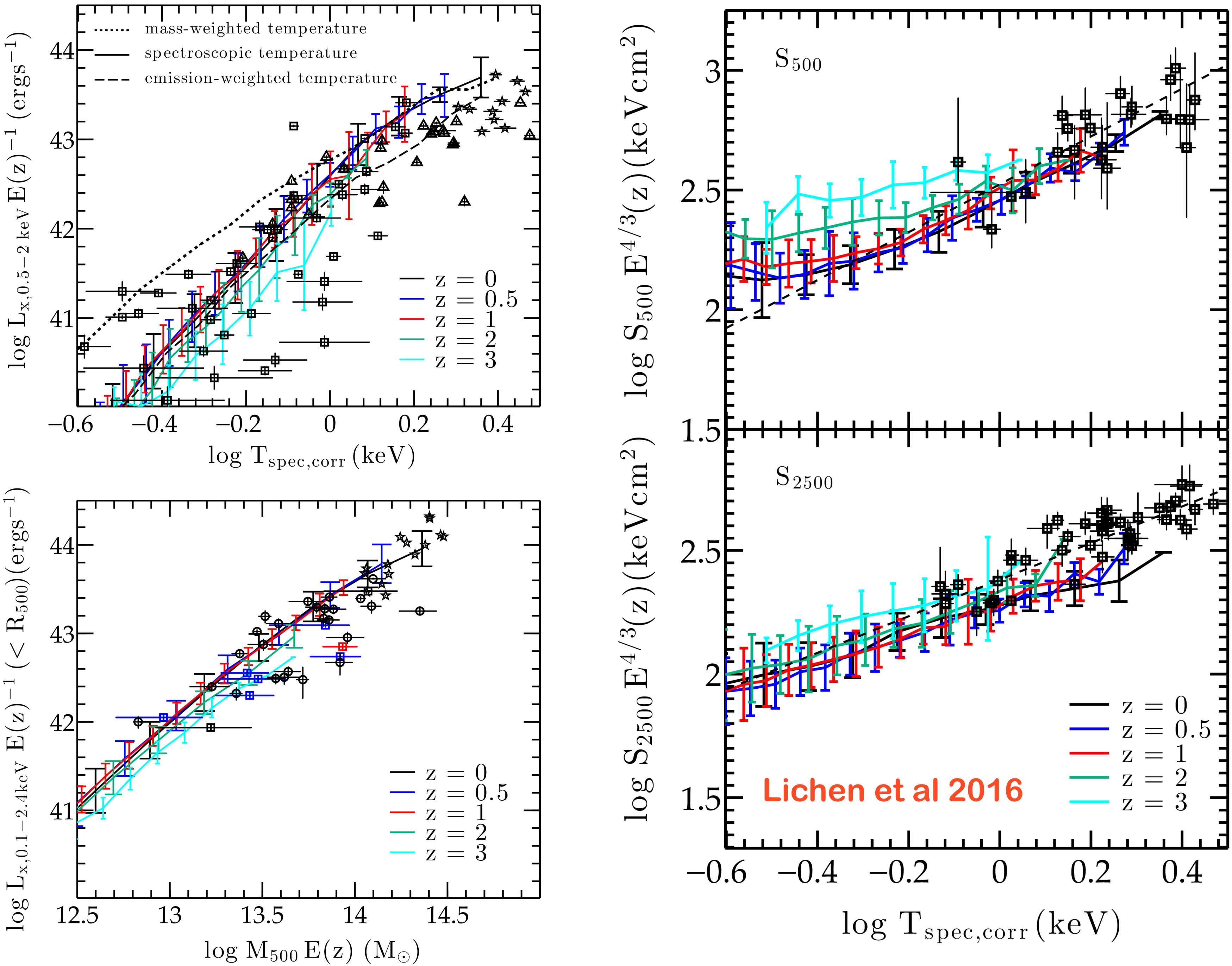

mass-weighted temperature
spectroscopic temperature
emission-weighted temperature
$\log L_{x,0.5-2\,keV}\,E(z)^{-1}\,(erg s^{-1})$
$\log T_{spec,corr}\,(keV)$
z = 0
z = 0.5
z = 1
z = 2
z = 3
$\log L_{x,0.1-2.4keV}\,E(z)^{-1}\,(< R_{500})\,(erg s^{-1})$
$\log M_{500}\,E(z)\,(M_\odot)$
z = 0
z = 0.5
z = 1
z = 2
z = 3
S_{500}
$\log S_{500}\,E^{4/3}(z)\,(keV cm^2)$
S_{2500}
$\log S_{2500}\,E^{4/3}(z)\,(keV cm^2)$
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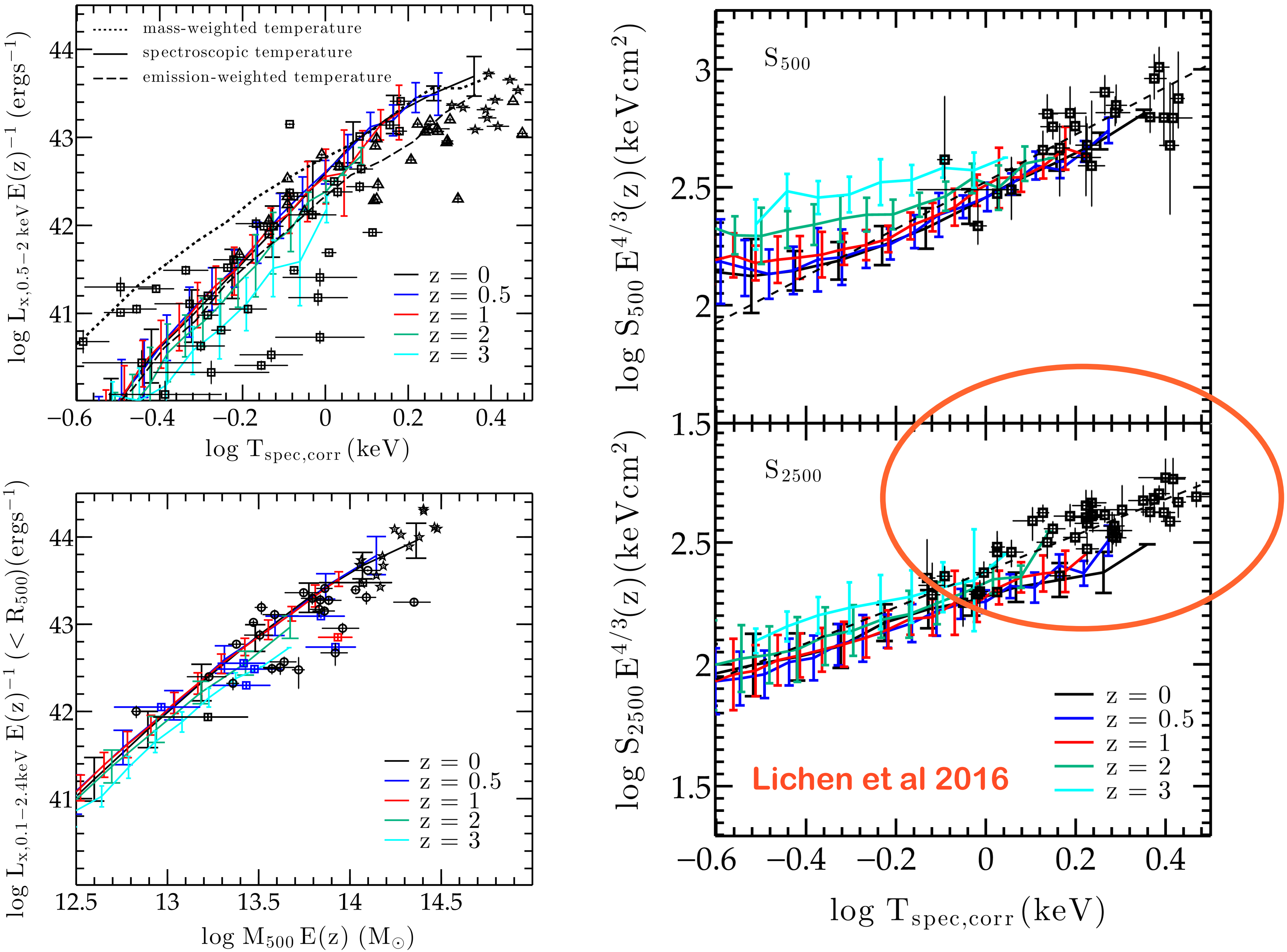
Lichen et al 2016
$\log T_{spec,corr}\,(keV)$



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S_{500}
log $S_{500}\,E^{4/3}(z)$ (keV cm^2)
S_{2500}
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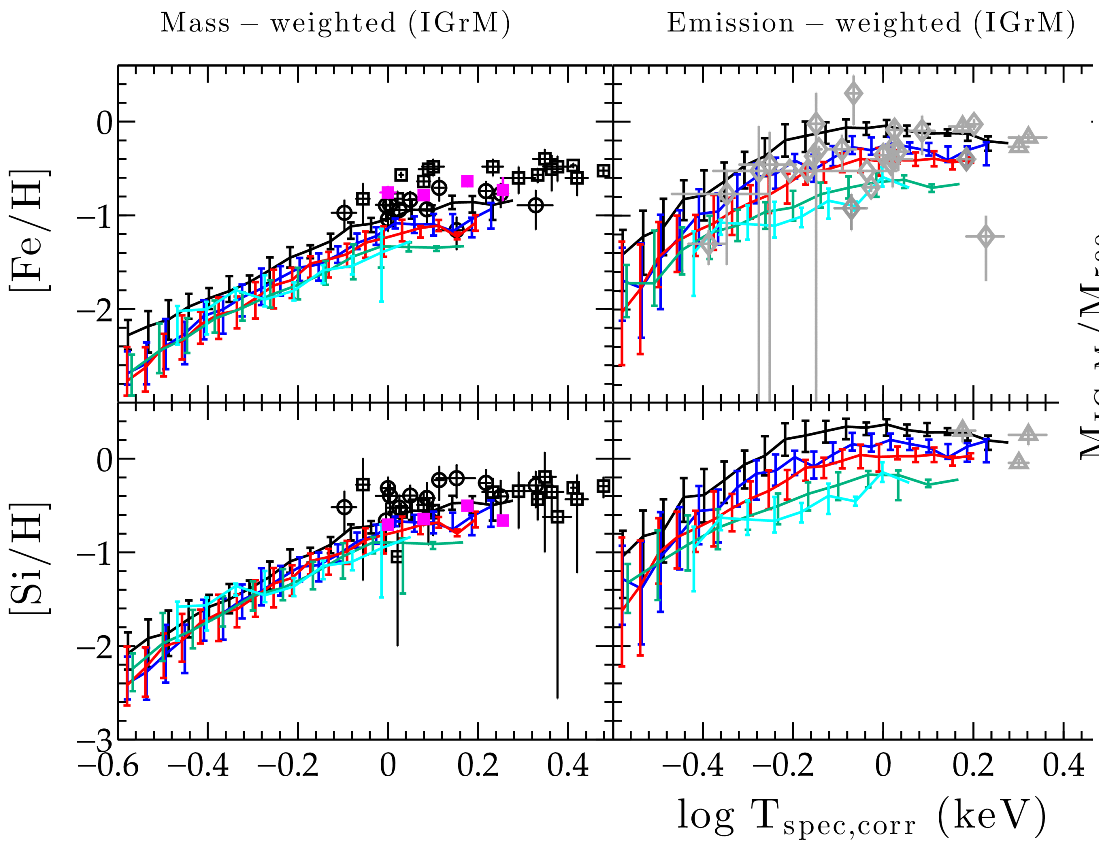
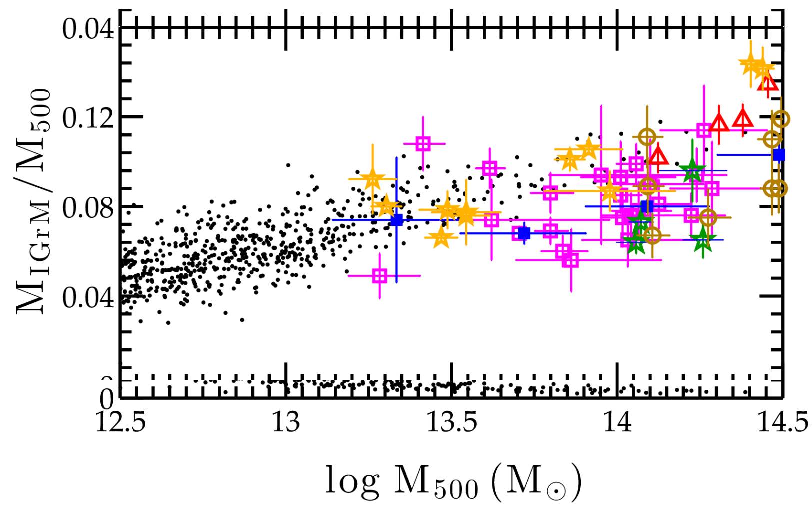
Lichen et al 2016

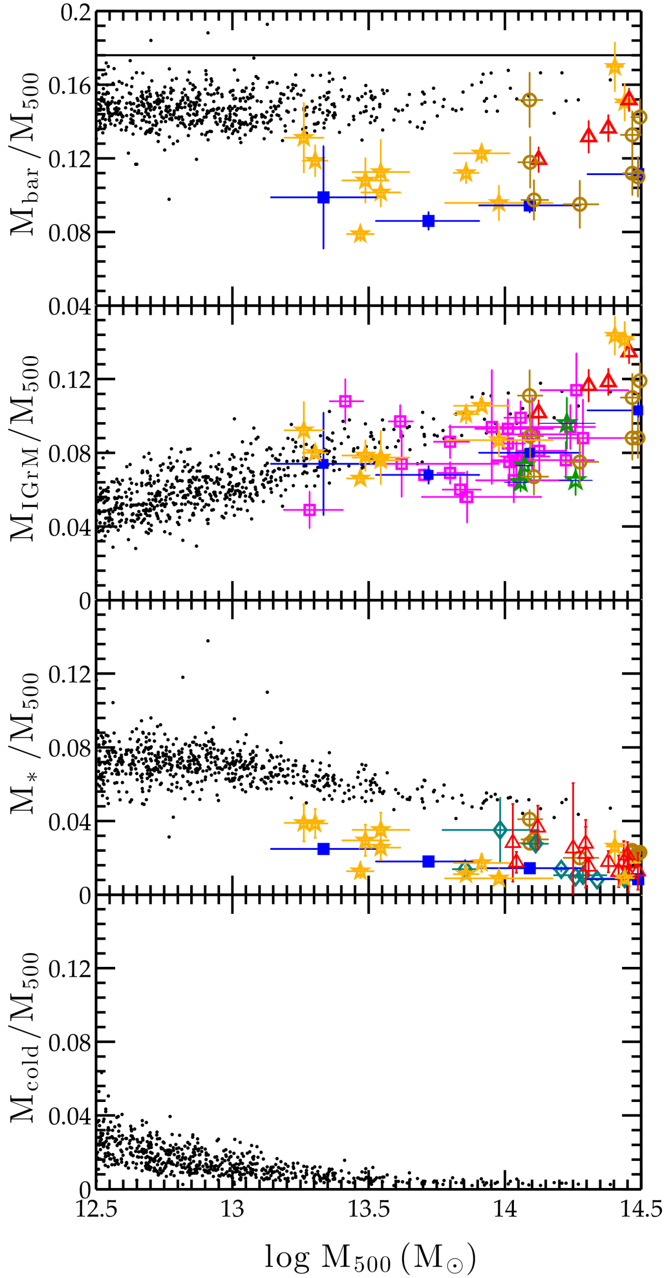
Global Metallicity and Hot Gas Fraction with R_{500}

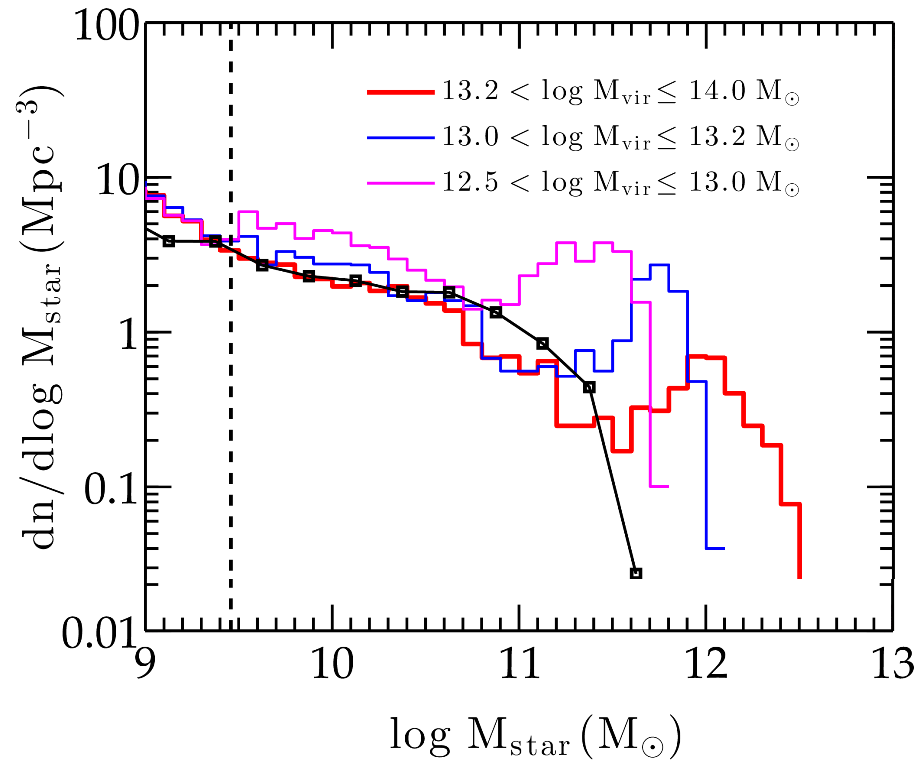




Lichen et al 2016

SO WHERE'S THE DOWN SIDE?





SO, CLEARLY A CASE FOR AGN FEEDBACK…

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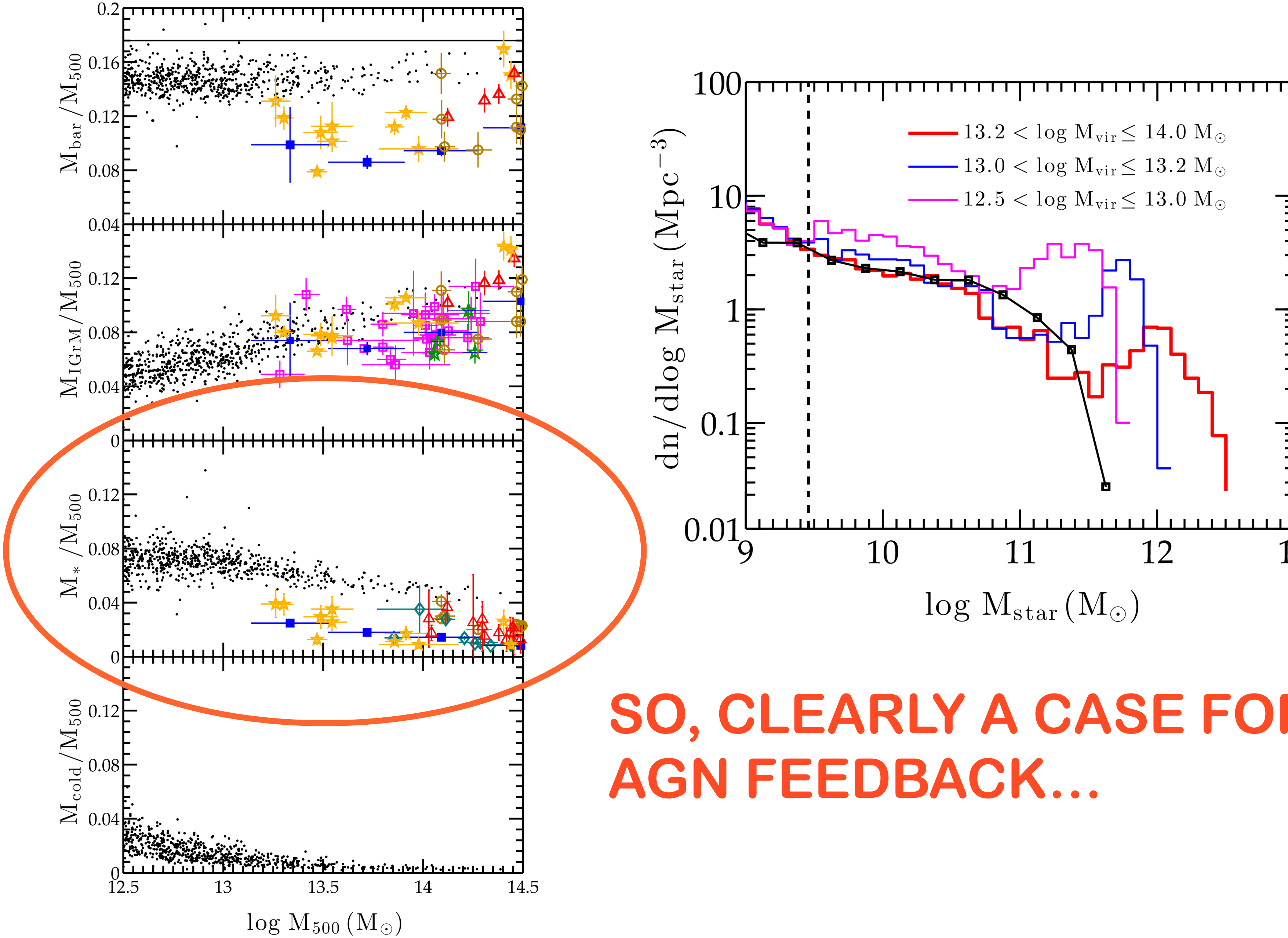

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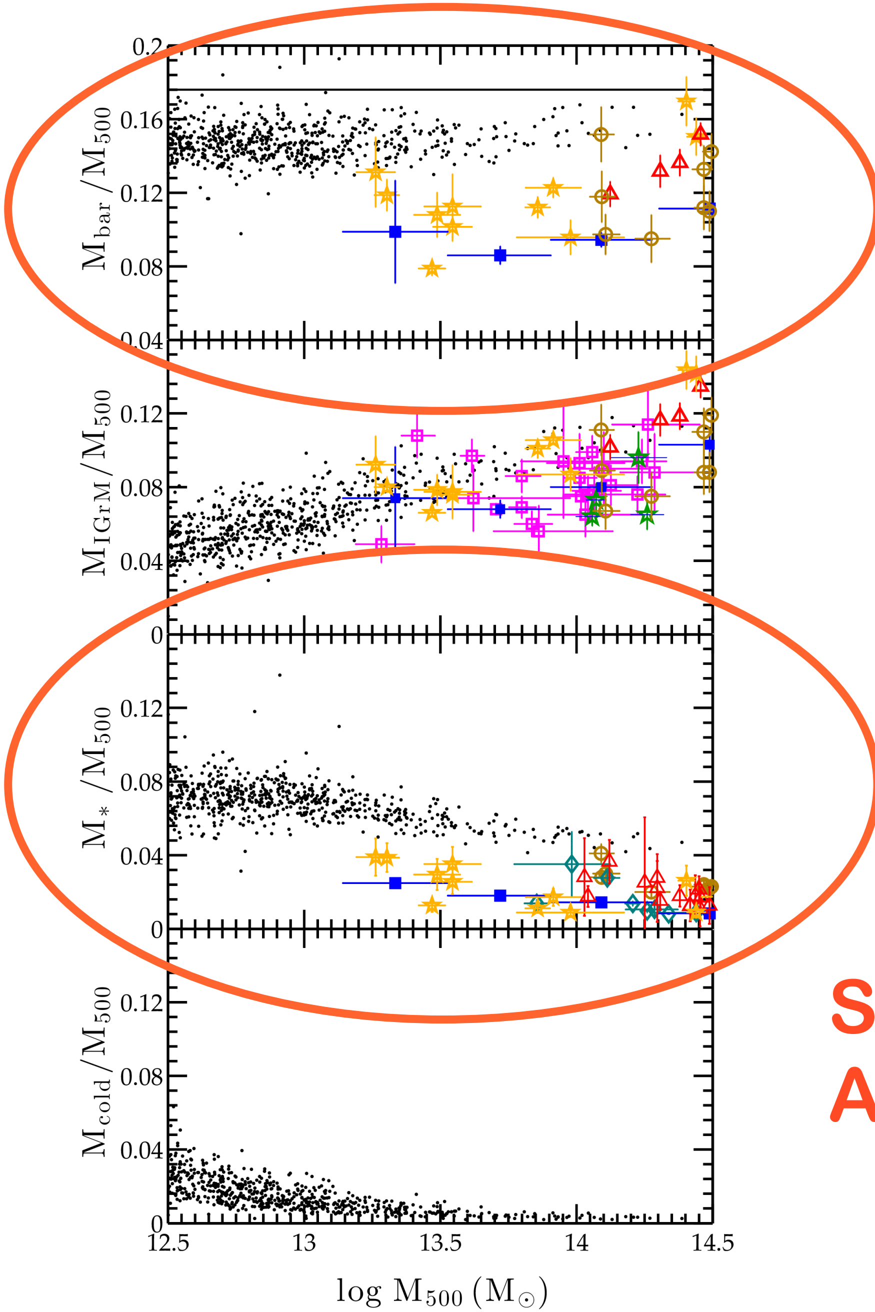

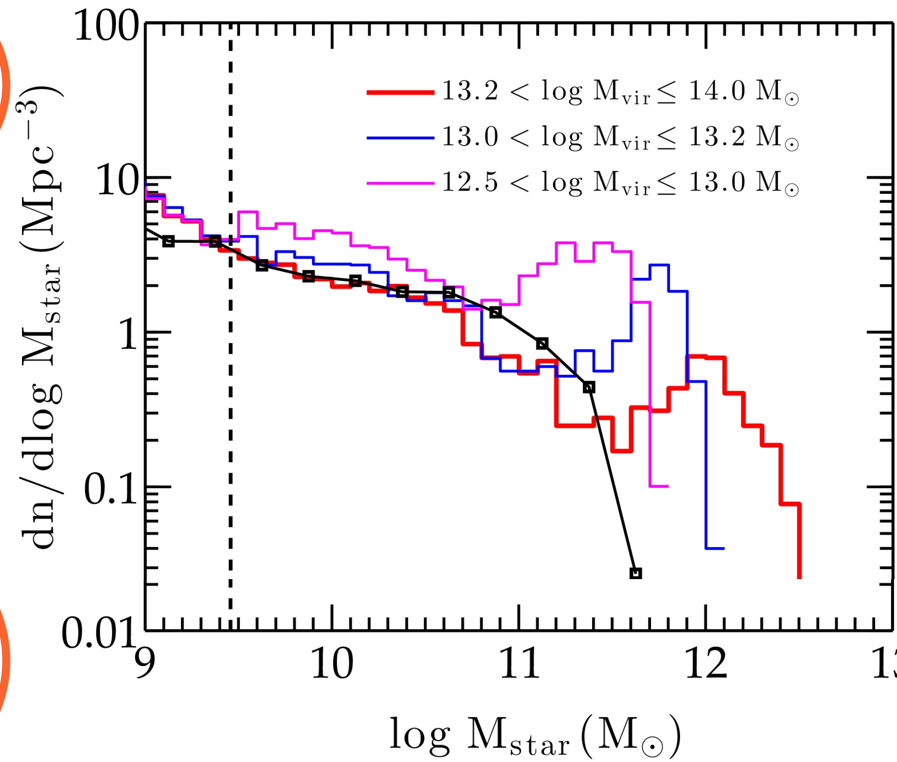

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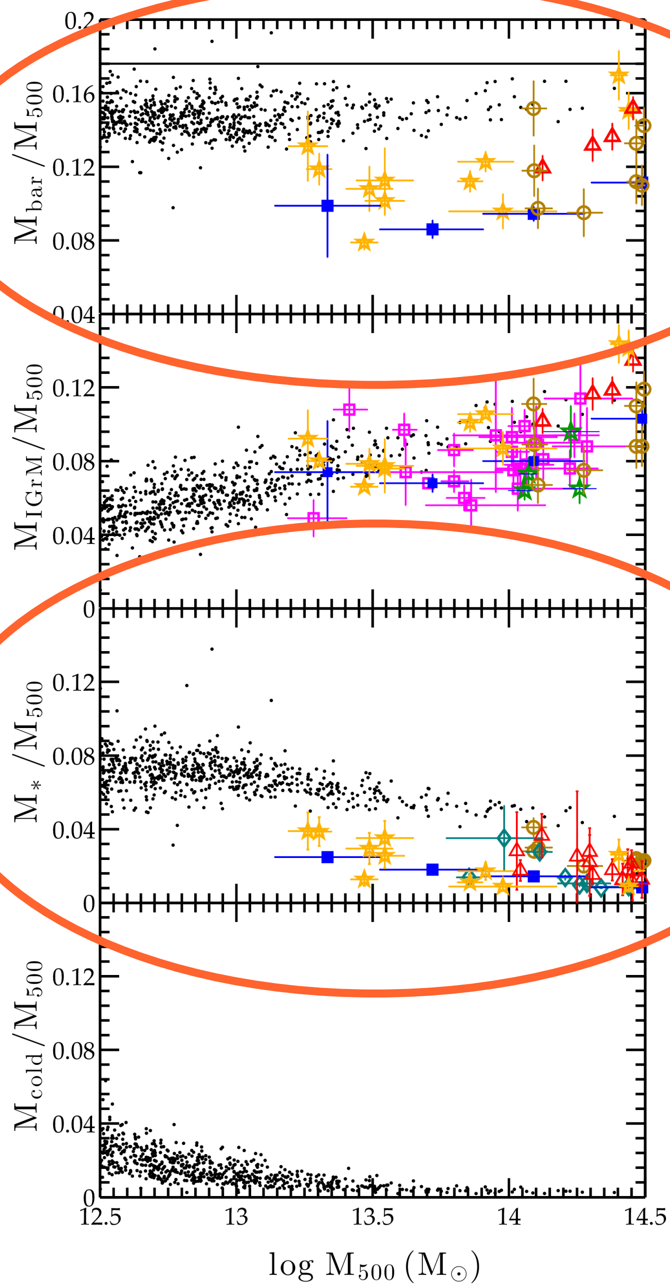
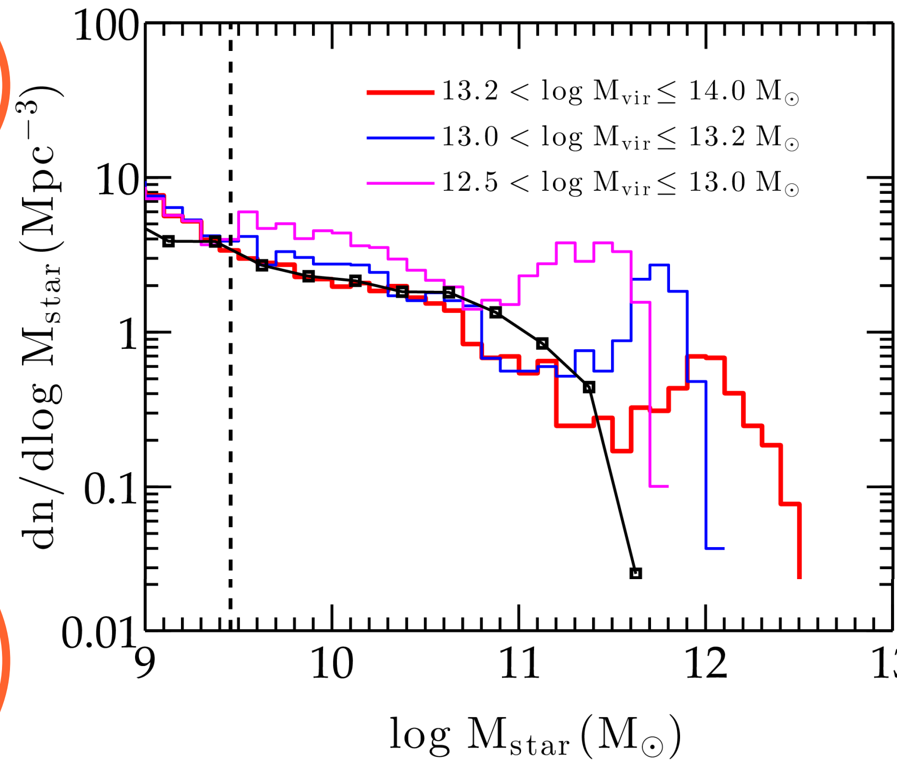
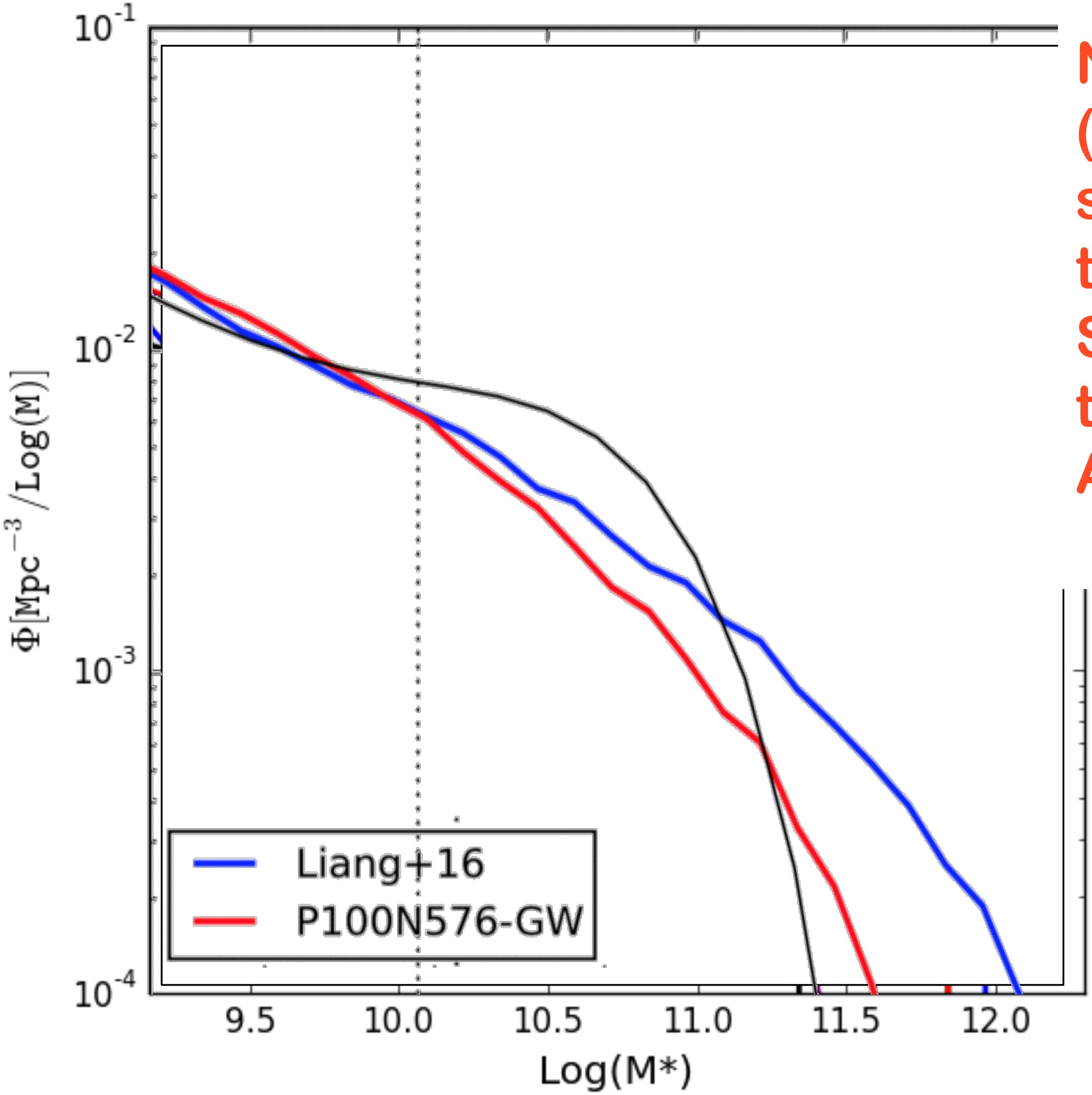




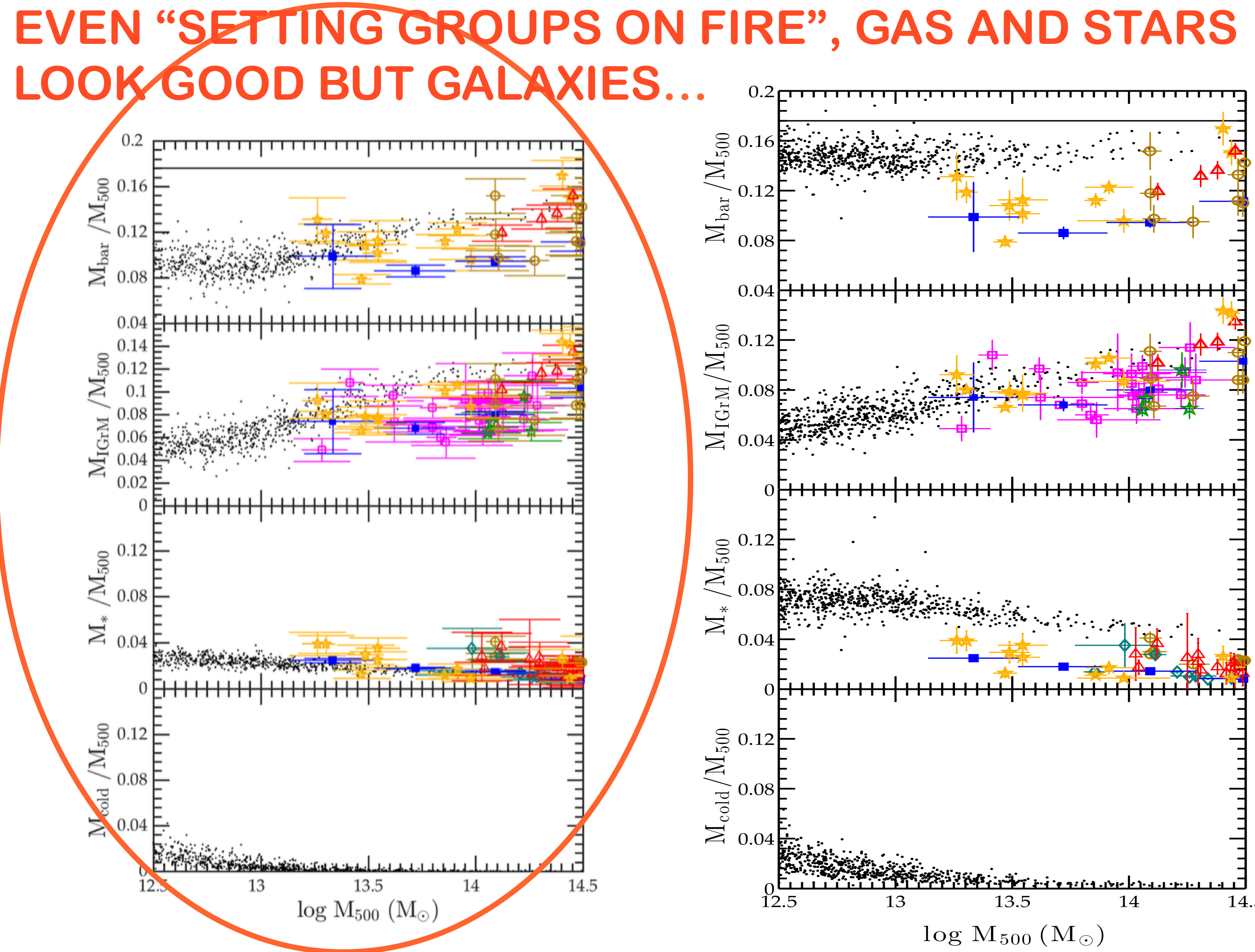
SO, CLEARLY A CASE FOR AGN FEEDBACK…OR IS IT?

SOME PRELIMINARY RESULTS: HUANG & KATZ



New wind model (FIRE+PHeW) strongly alters the bright end. So, if we are tuning stellar vs. AGN feedback…

EVEN "SETTING GROUPS ON FIRE", GAS AND STARS LOOK GOOD BUT GALAXIES…



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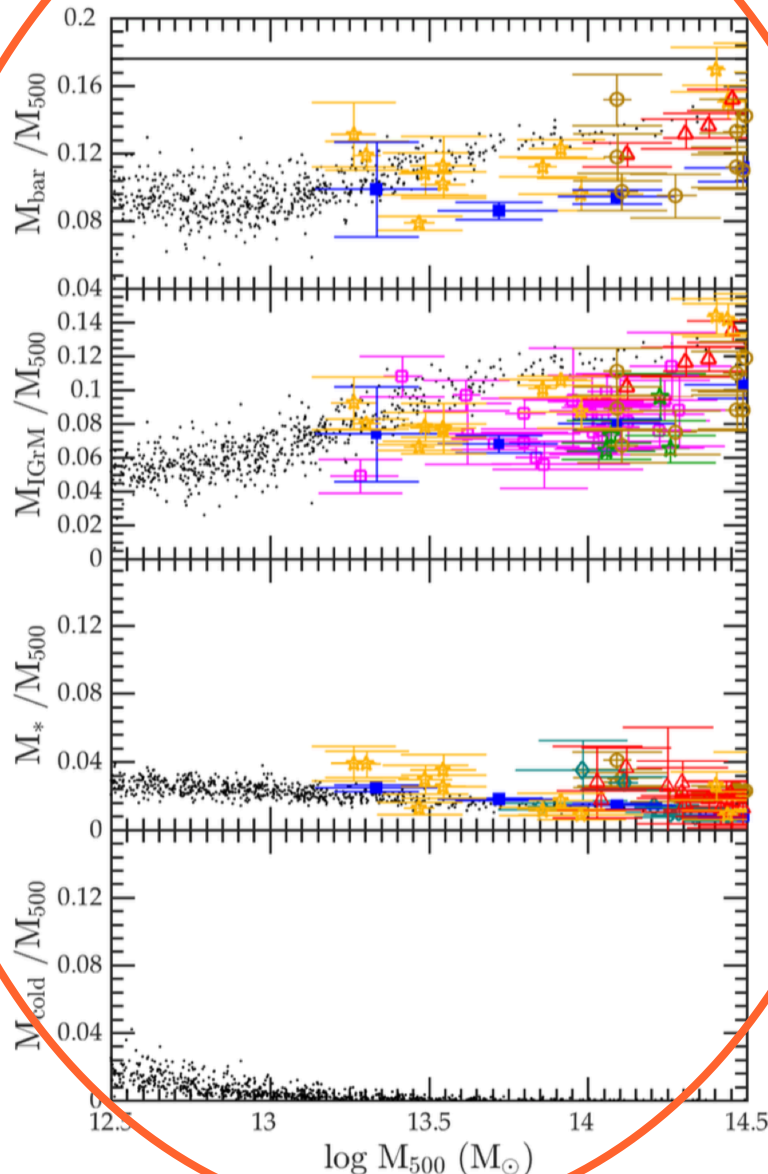
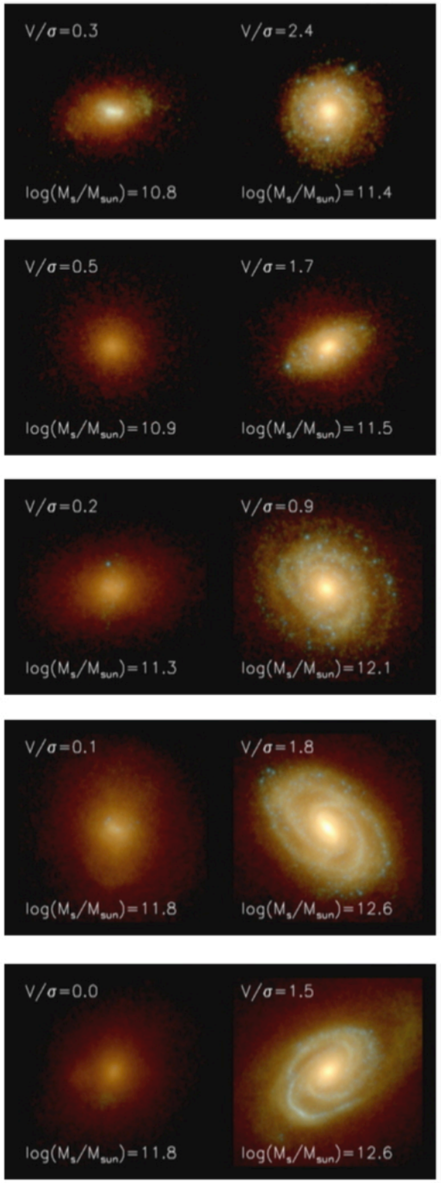
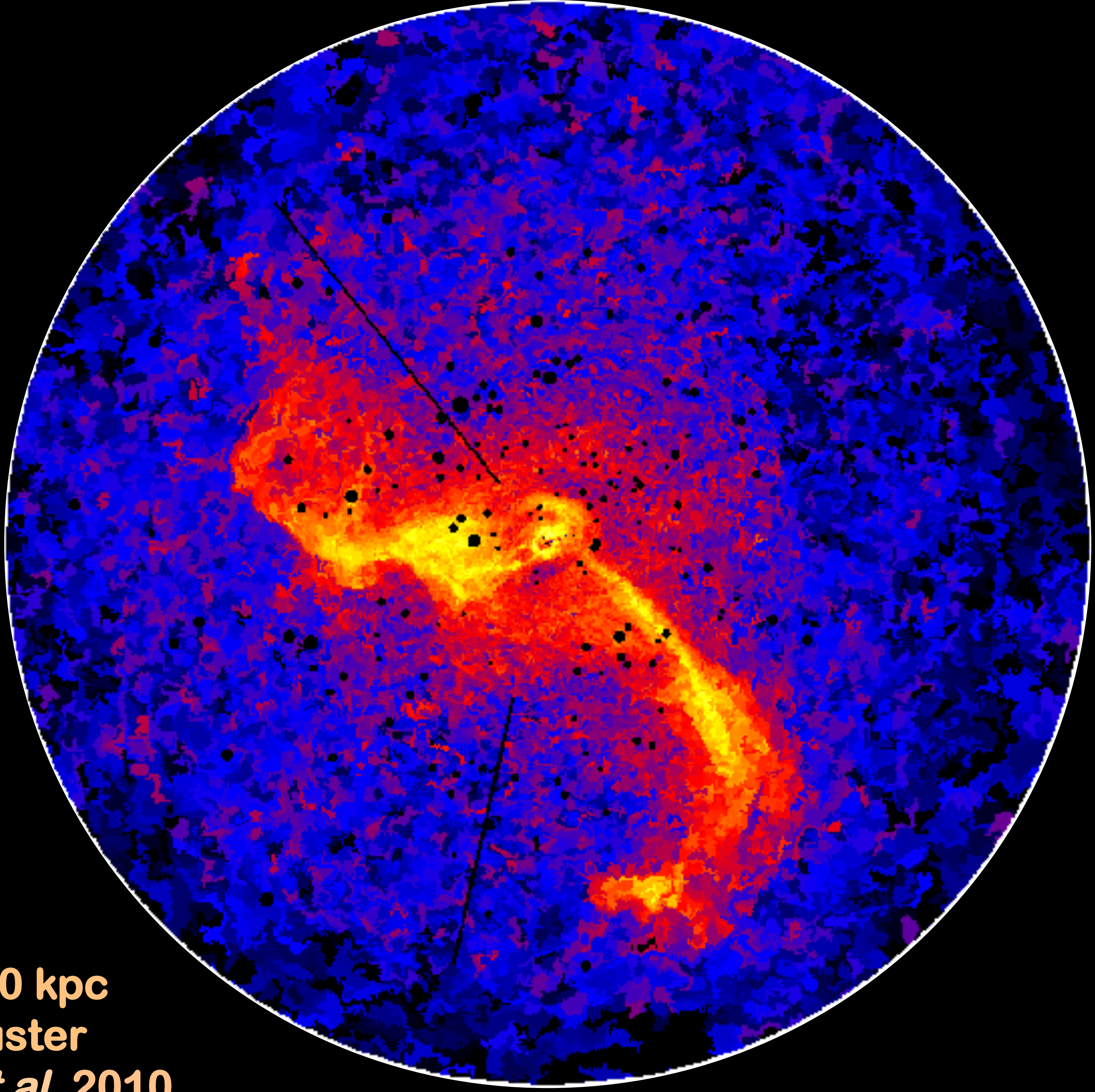


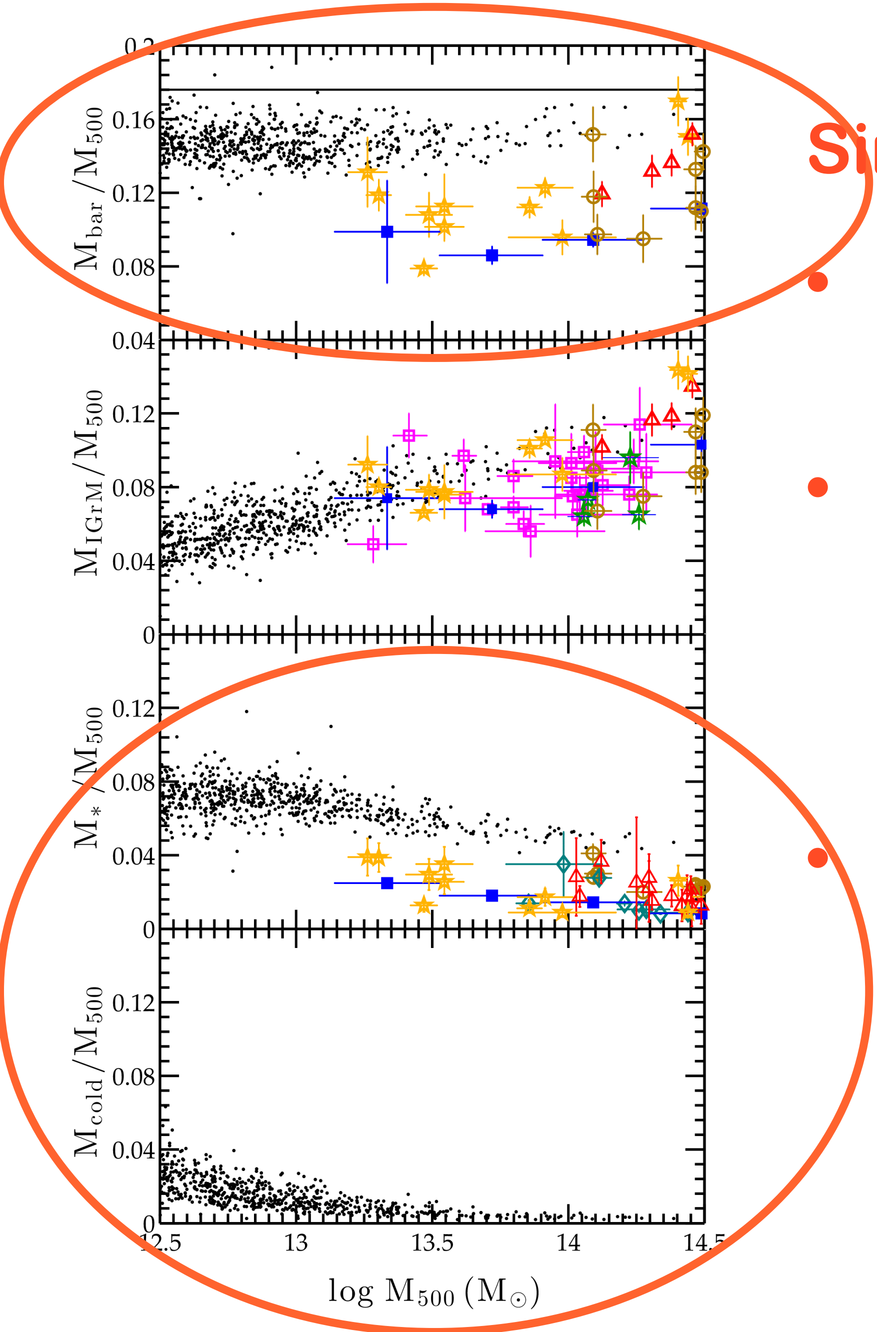


Dubois et al. 2016: With and Without Merger-drive QSO outburst



central 40 kpc
Virgo Cluster
Million *et al.* 2010

WHAT MUST AGN FEEDBACK DO?



Simple quenching won't work!

- Cold gas in central galaxies is responsible for SF
- Gas builds up during "massive galaxy" stage and is already present when groups form
- "AGNs" must prevent this build-up <u>and</u> must also suppress the baryon fraction in ellipticals and low mass groups.

OUT

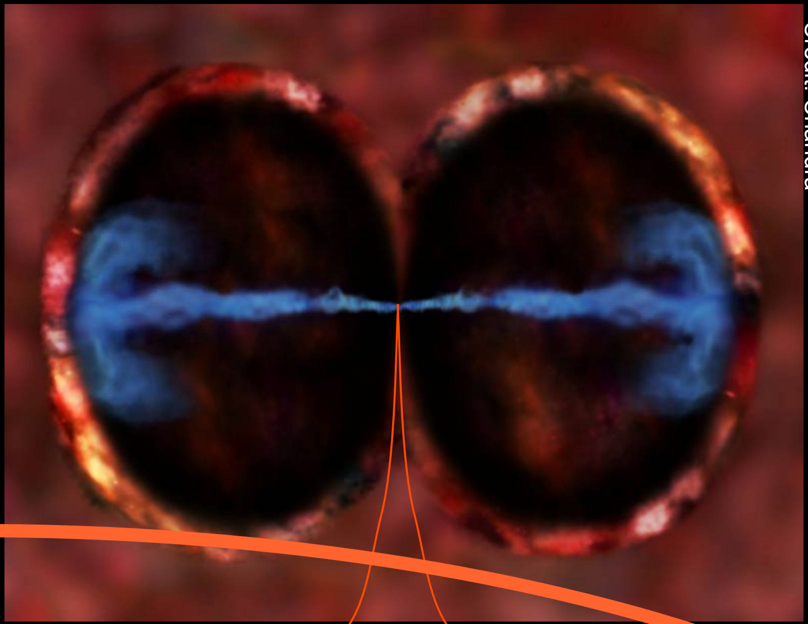
Jet Power:

energies and timescales required to "inflate" the bubbles

$$E_{\rm bubble} = 4PV$$

$$t_{\rm age} = R / c_s$$

$$P_{\rm jet} = E_{\rm bubble} / t_{\rm age}$$



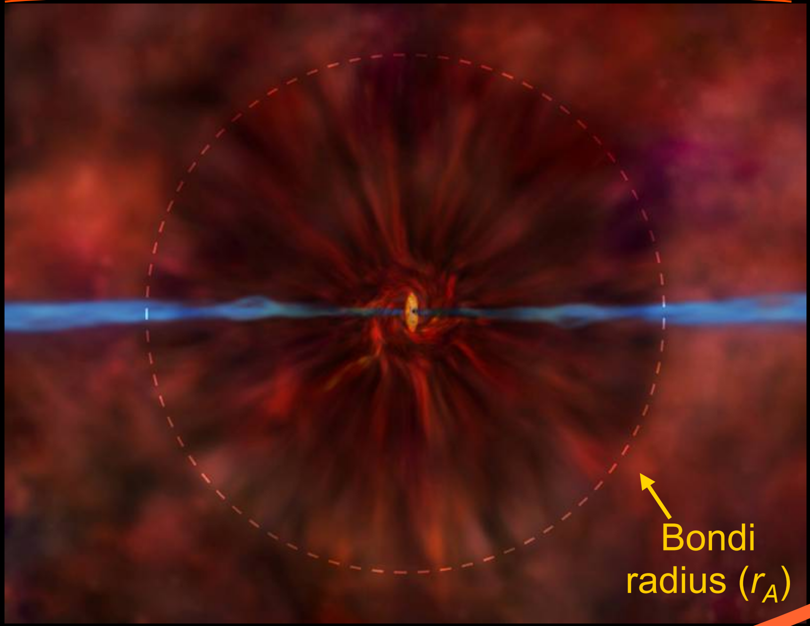
Credit: Chandra

IN

Accretion Rate:

X-ray density and temperature profiles + black hole masses, assuming Bondi-Hoyle accretion

$$\dot{M}_{\rm Bondi} = 4\pi r_{\rm A}^2 \rho_{\rm A} c_s(r_{\rm A})$$

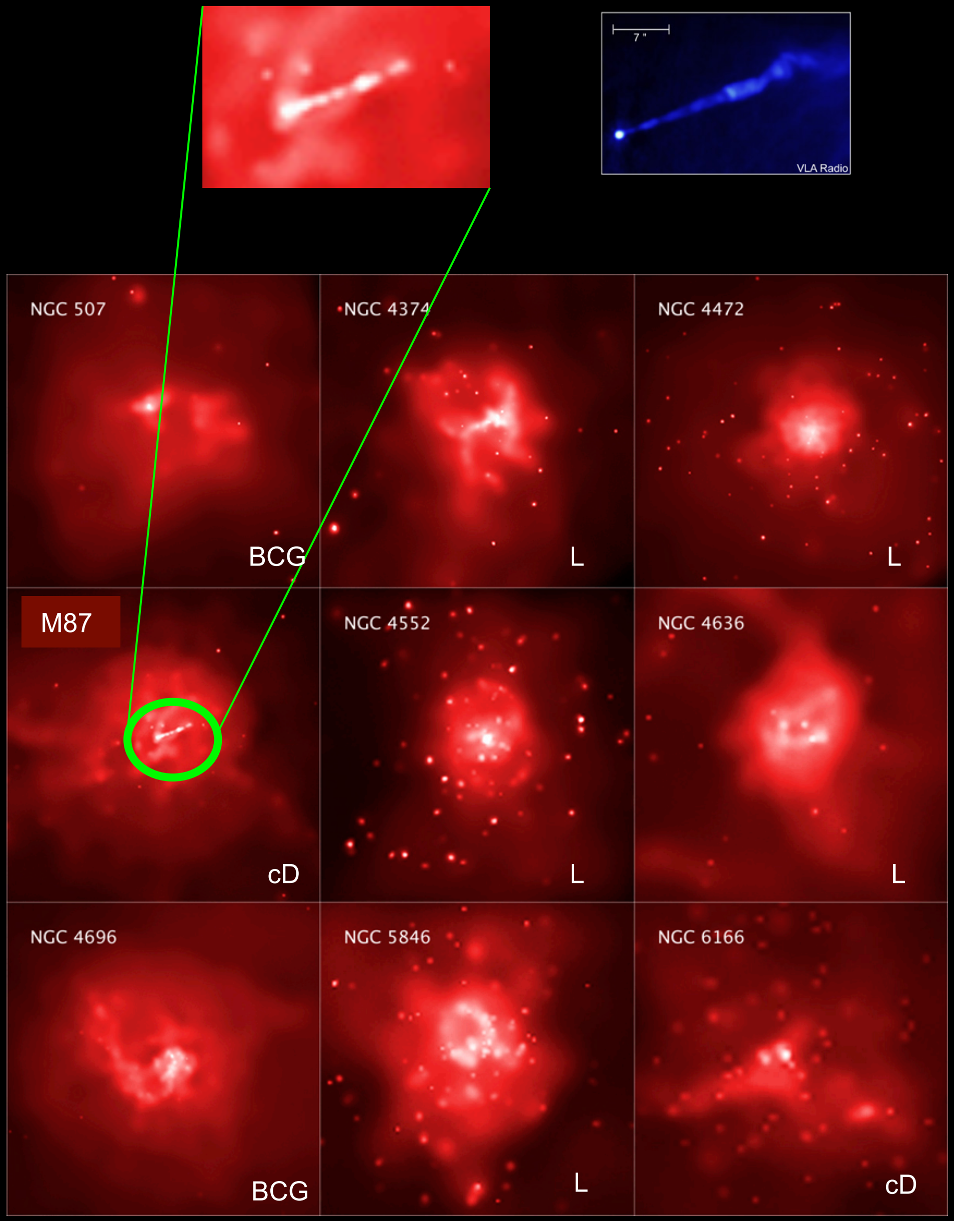


Allen et al considered nearby systems with $< 10\ R_{Bondi}$ resolved

Estimated P_{jet} from cavities or core radio luminosity

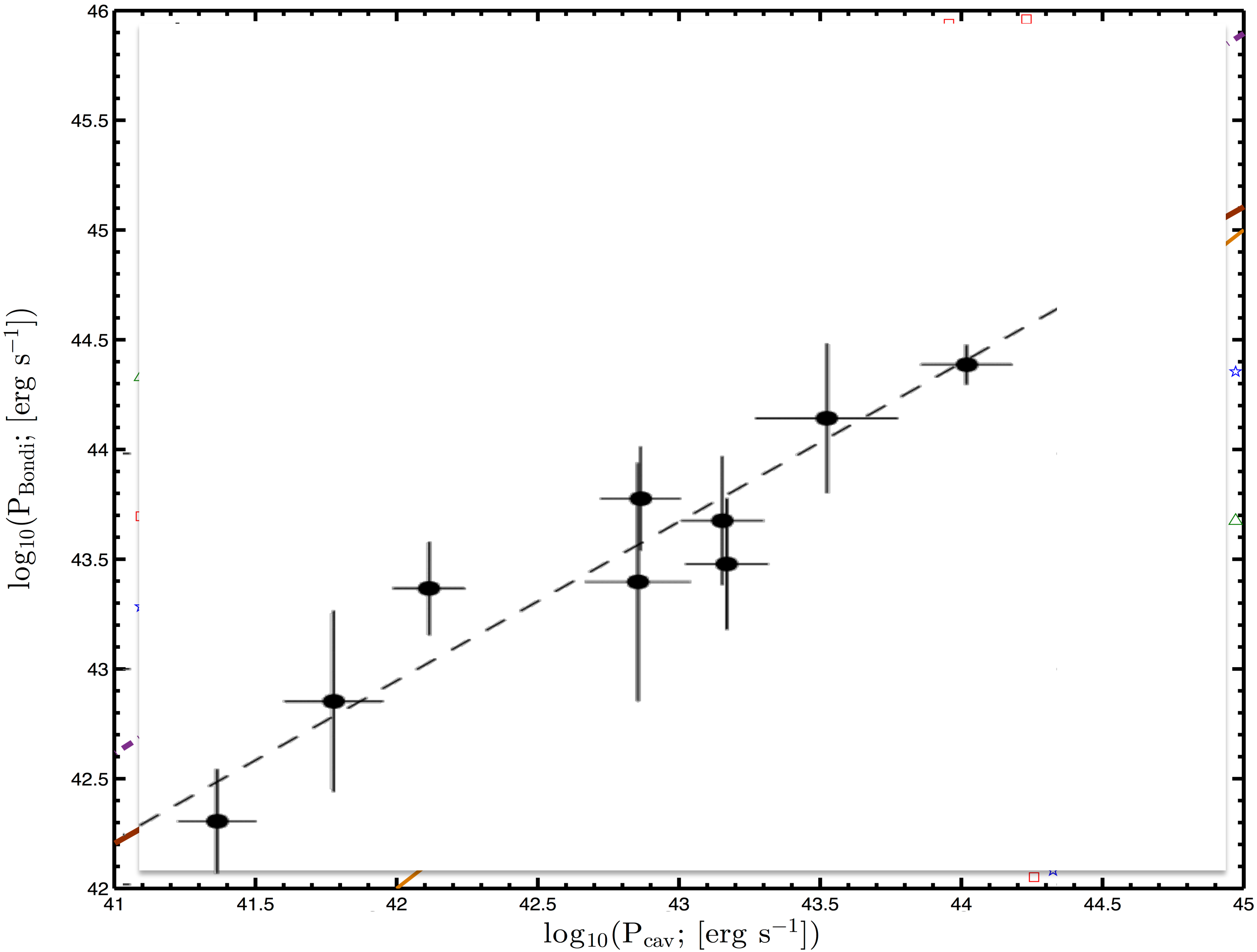
And computed:

$$\eta_{jet} = \left(\frac{P_{jet}}{\dot{M}_{BH} c^2} \right)$$

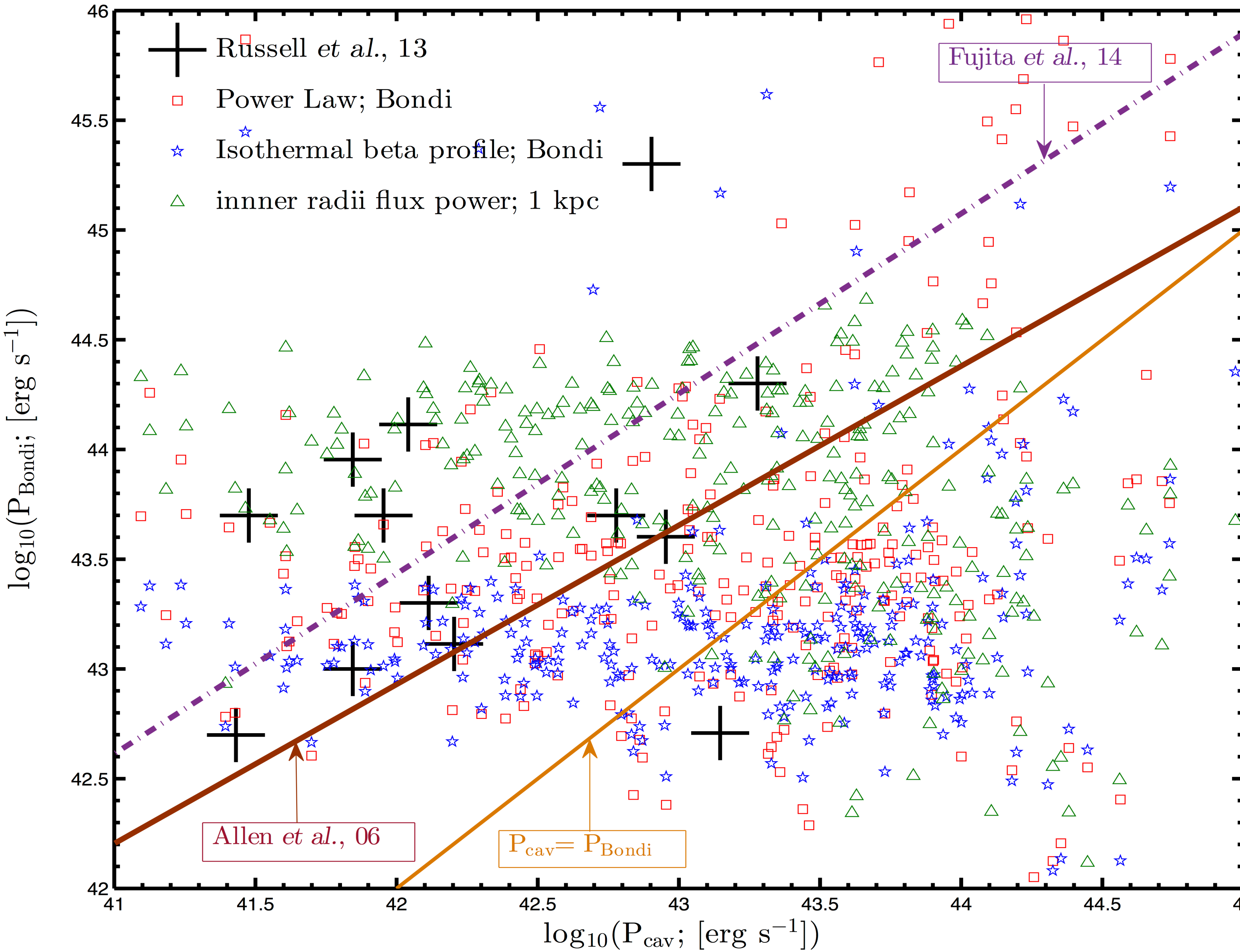


Interval: 0.5 – 8 keV

Allen et al. 2007; Russel et al 2013

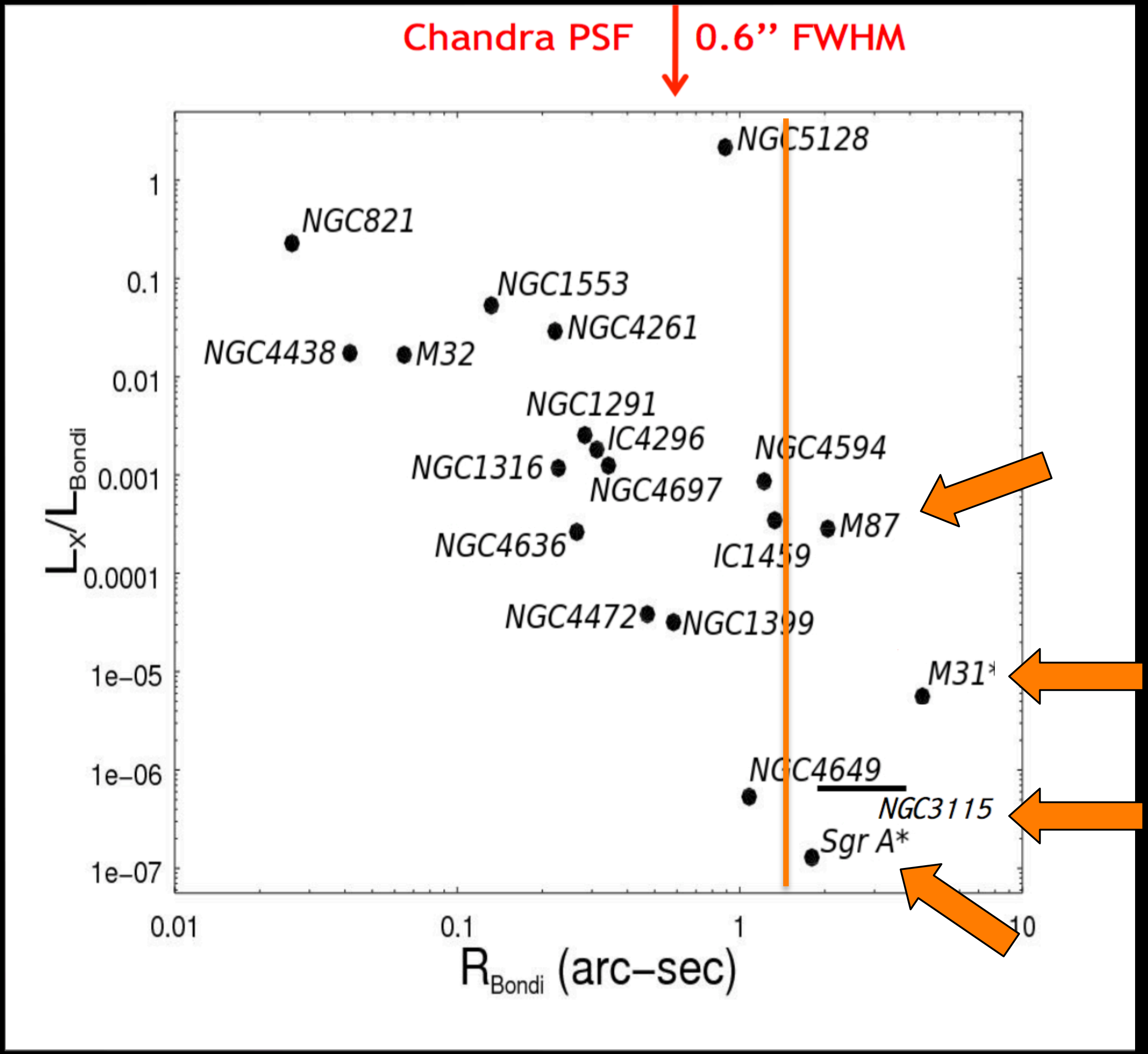


46
45.5
45
44.5
44
43.5
43
42.5
42
41
41.5
42
42.5
43
43.5
44
44.5
45
log10(P_Bondi; [erg s^-1])
log10(P_cav; [erg s^-1])



Russell et al., 13
Power Law; Bondi
Isothermal beta profile; Bondi
innner radii flux power; 1 kpc
Fujita et al., 14
Allen et al., 06
$P_{cav} = P_{Bondi}$
$\log_{10}(P_{Bondi}; [erg\ s^{-1}])$
$\log_{10}(P_{cav}; [erg\ s^{-1}])$
46
45.5
45
44.5
44
43.5
43
42.5
42
41
41.5
42
42.5
43
43.5
44
44.5
45

TESTING BONDI ACCRETION:



PROBING THE ACCRETION FLOW

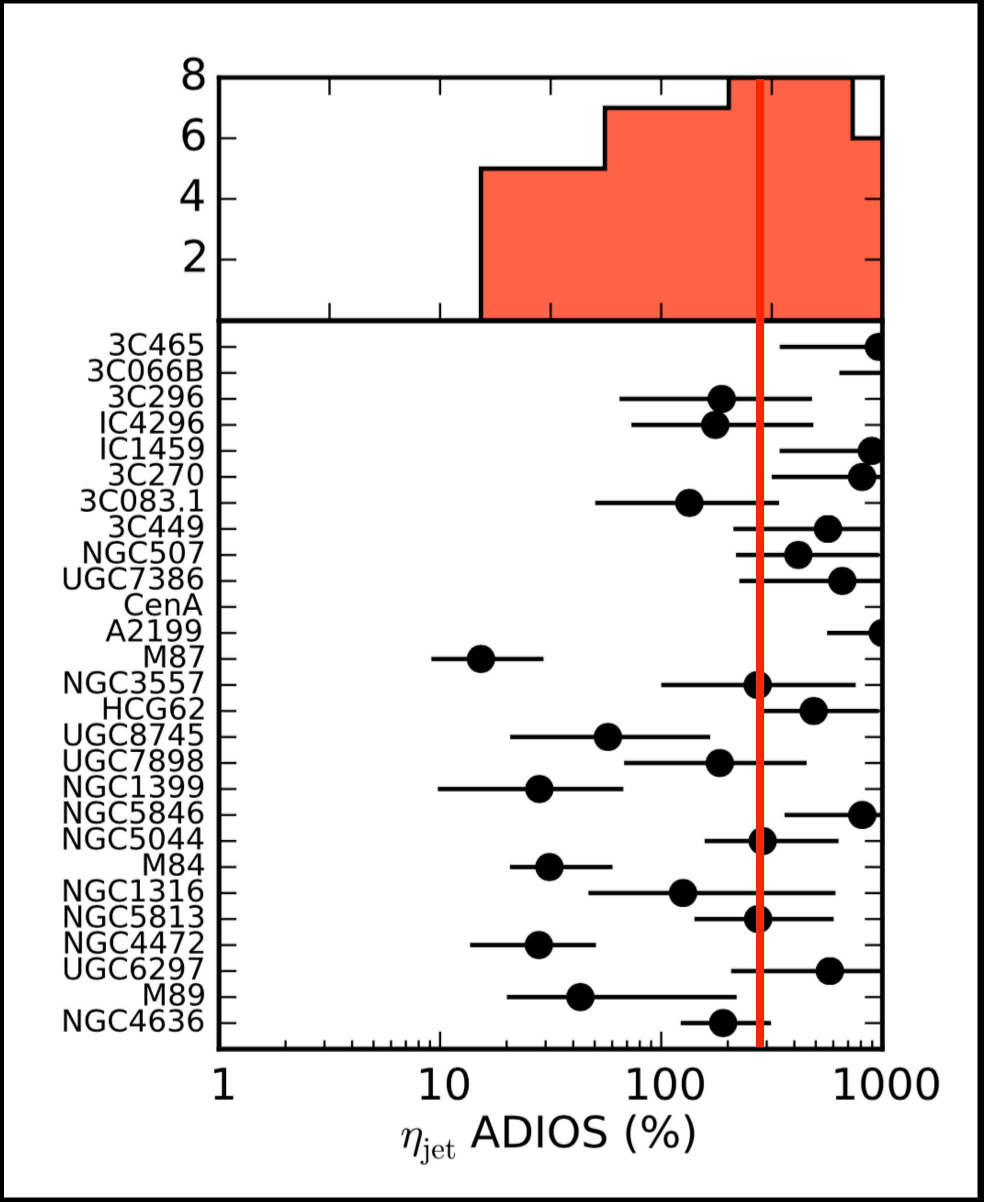
	M_{BH}	$M_{dot,Bondi}$	$L_{rad,nuclear}$	$M_{dot}(10R_s)$	
Sgr A*	$4x10^6$ $M_\odot$	$1x10^{-5}$ $M_\odot$/yr	$\sim10^{36}$ erg/s	$0.02\text{-}2x10^{-7}$ $M_\odot$/yr	Faraday Rotation
M31*	$1.4x10^8$	$5.5x10^{-5}$	$\sim10^{37}$		
NGC 3115	$1\text{-}2x10^9$	$2.2x10^{-2}$	few $x10^{37}$	$\sim2x10^{-4}$	Density Profile
M87 (Virgo)	$6.4x10^9$	0.1-0.2	$\sim2x10^{41}$	$0.7\text{-}1.4x10^{-3}$	Faraday Rotation and Density Profile

$$\left(\frac{r}{R_B}\right)^s \approx \left(\frac{10R_S}{10^5R_S}\right)^{0.5} = 0.01$$

JET EFFICIENCY…

2/3 of η_{jet} > 100%
The median is ~300%

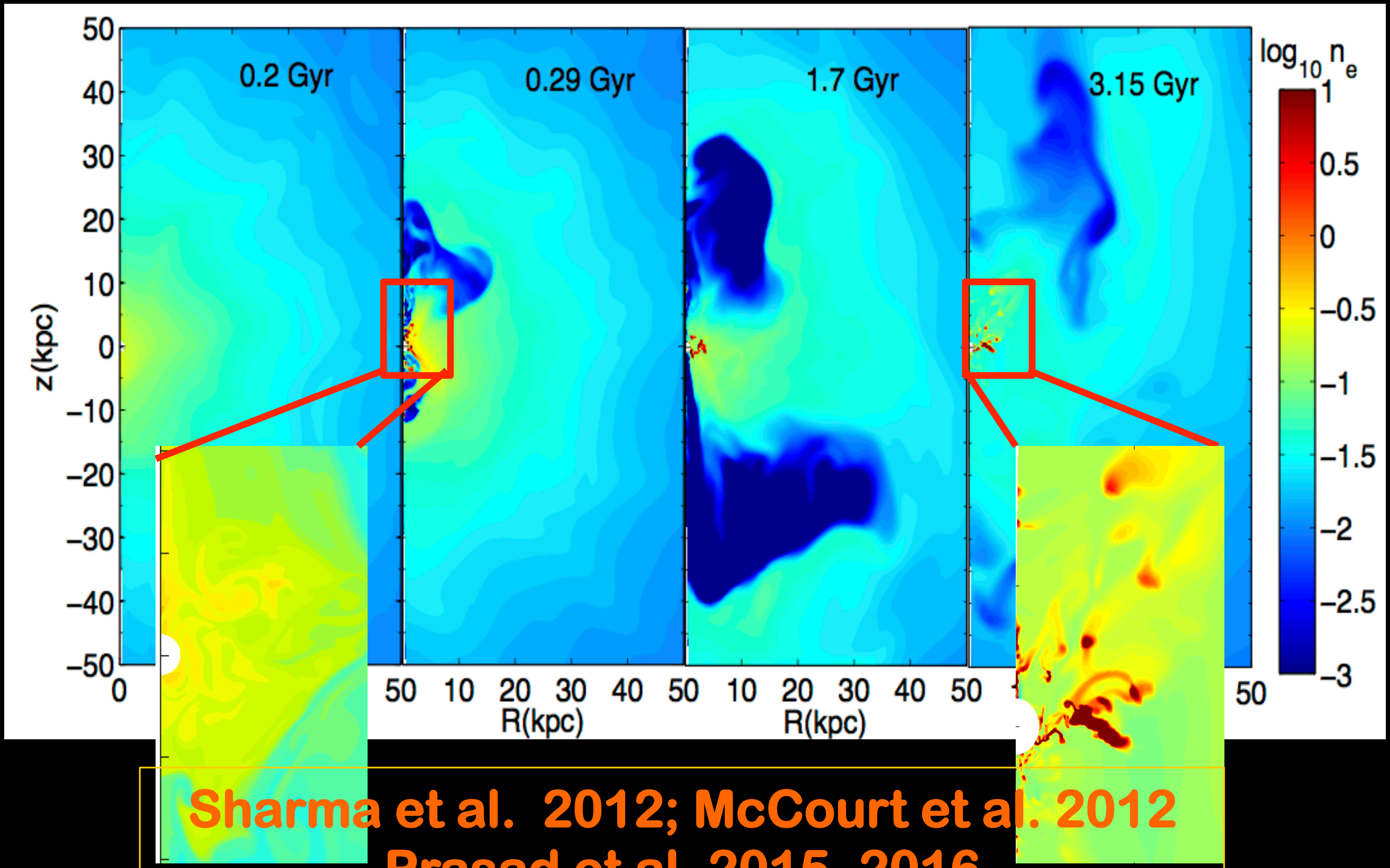
Unless the accretion flow elsewhere in the Universe behaves very differently than around nearby SMBHs, Bondi accretion of the hot ISM is NOT the main feeding mechanism.



Nemmen and Tchekhovskoy 2015

IF NOT HOT GAS, THEN WHAT?
COLD ACCRETION (first suggested by Pizzolato & Soker 2005)

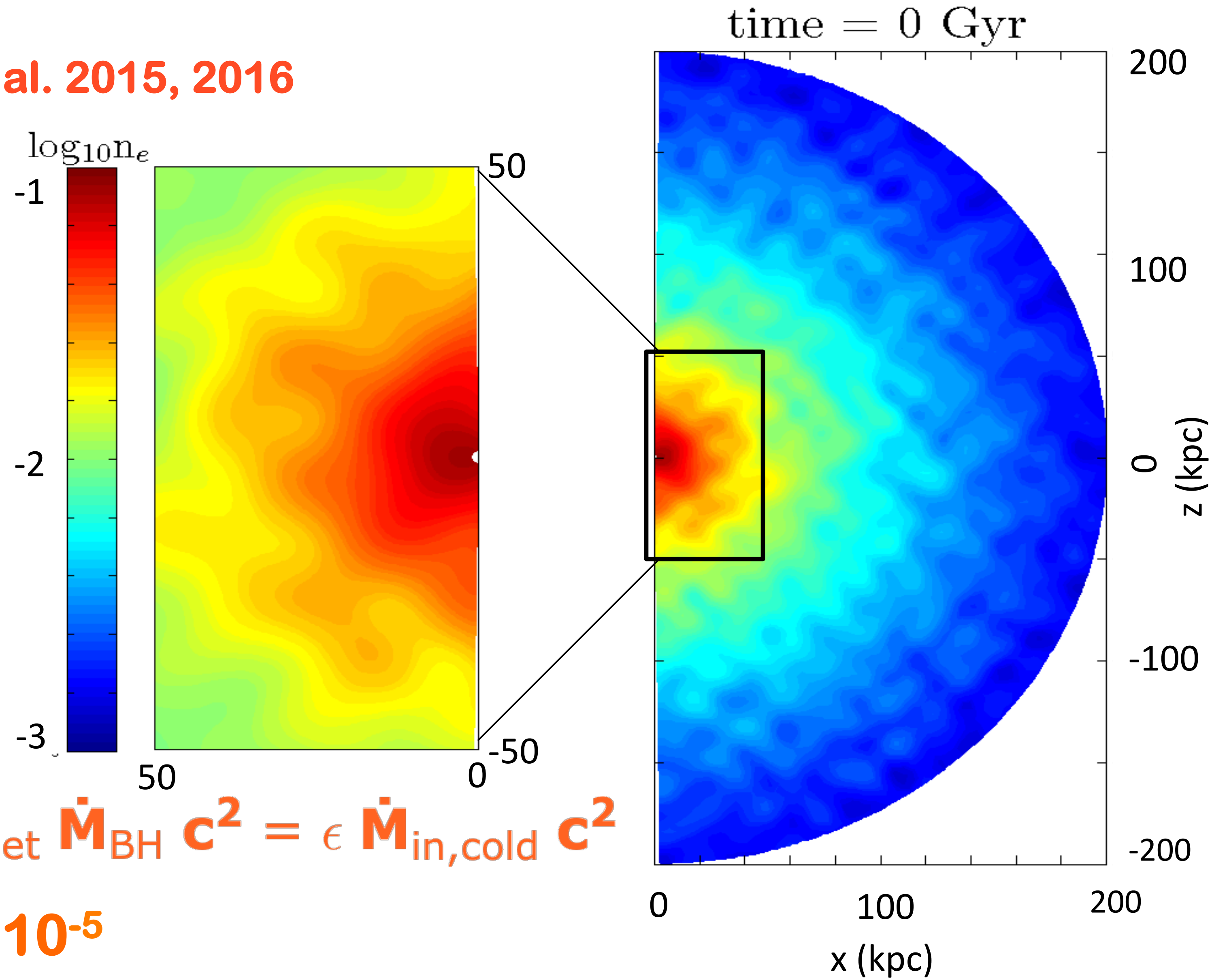
if $t_{cool}/t_{ff} > 10$, only hot phase; if $t_{cool}/t_{ff} < 10$, multiphase



Sharma et al. 2012; McCourt et al. 2012
Prasad et al. 2015, 2016

A SMALL FRACTION OF THE COOL GAS ACCRETES ONTO THE BH…

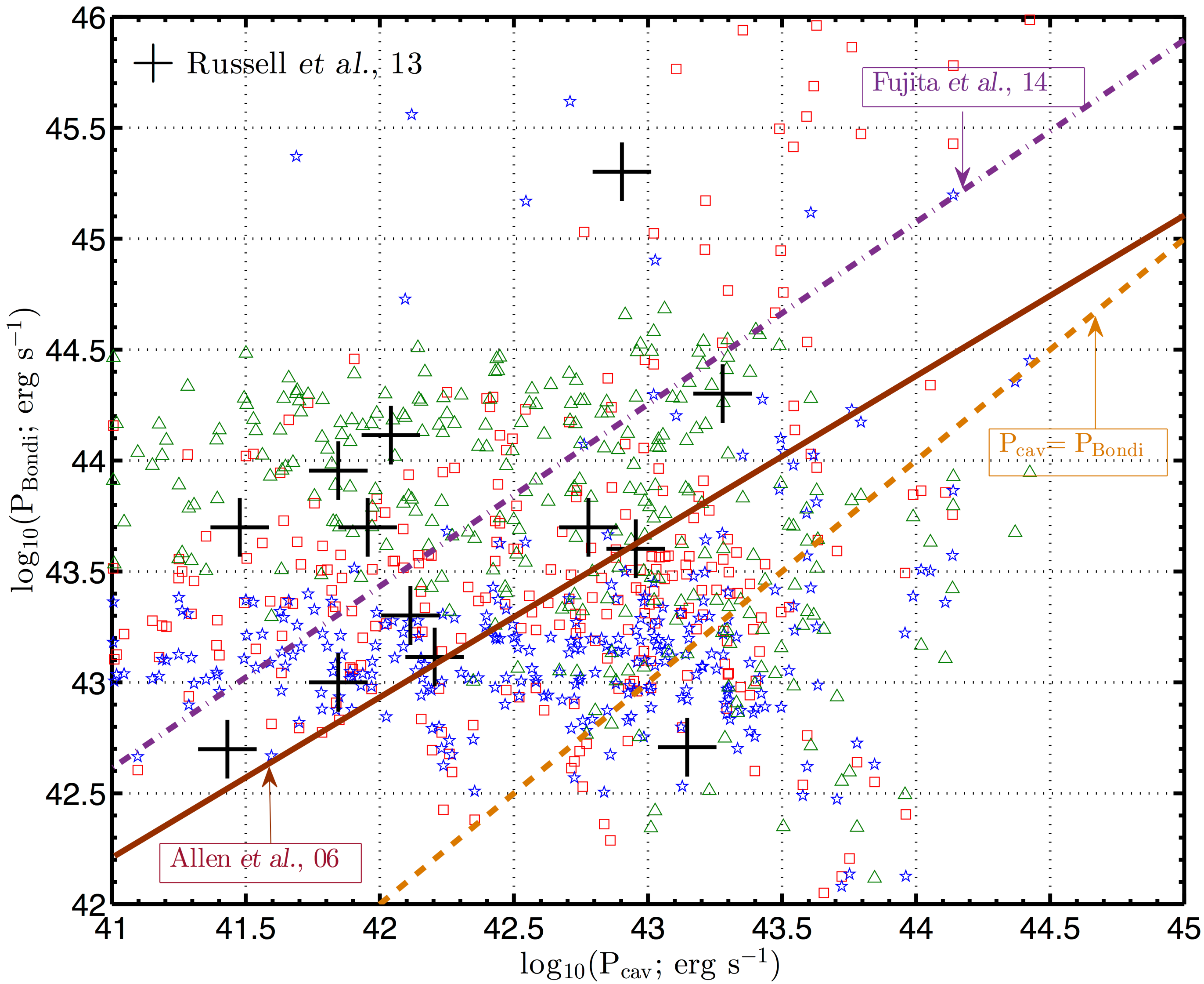
Prasad et al. 2015, 2016



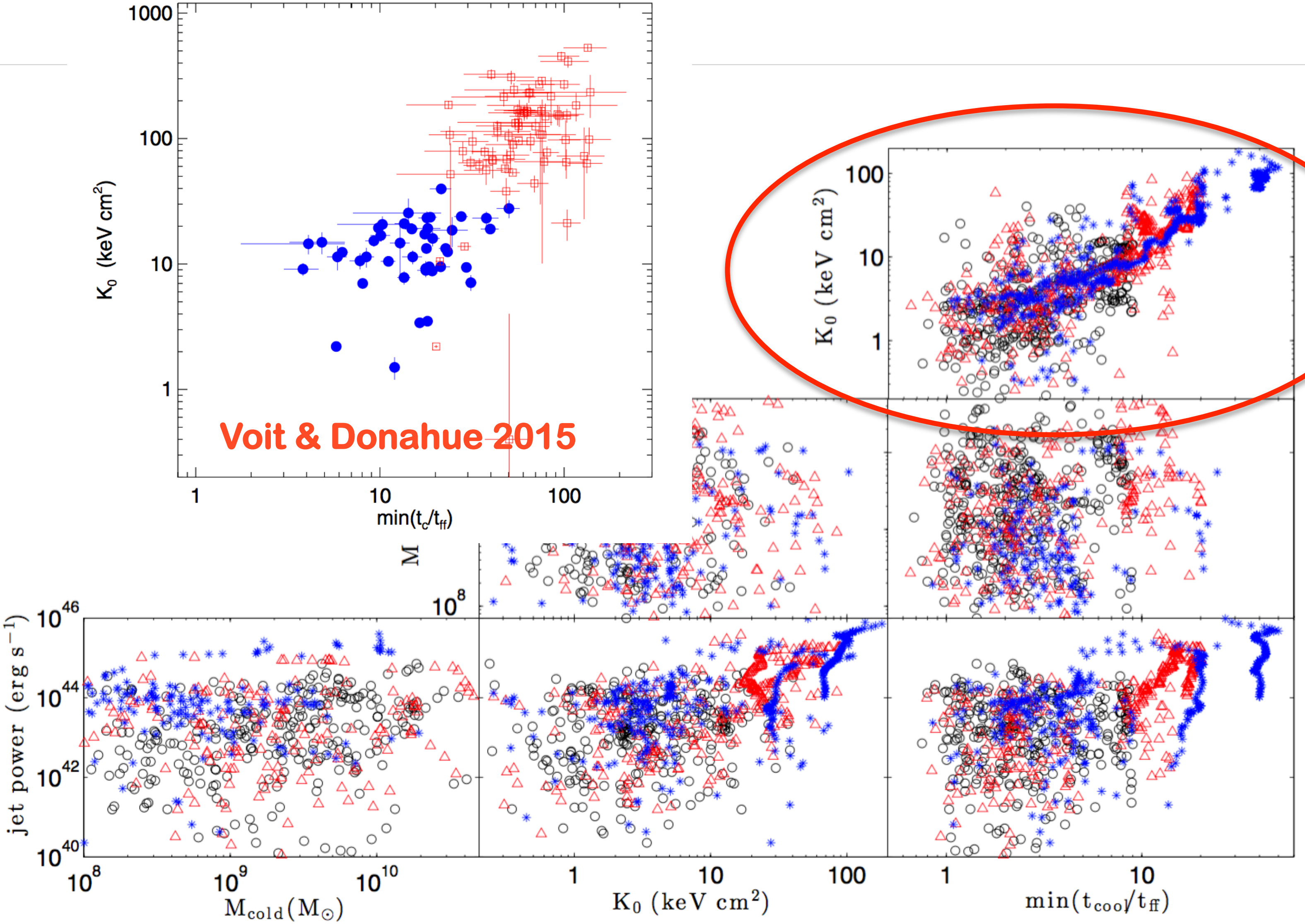
$$P_{jet} = \eta_{jet}\,\dot{M}_{BH}\,c^2 = \epsilon\,\dot{M}_{in,cold}\,c^2$$

$$\epsilon = 6 \times 10^{-5}$$

ONE OUTCOME OF THIS MODEL…

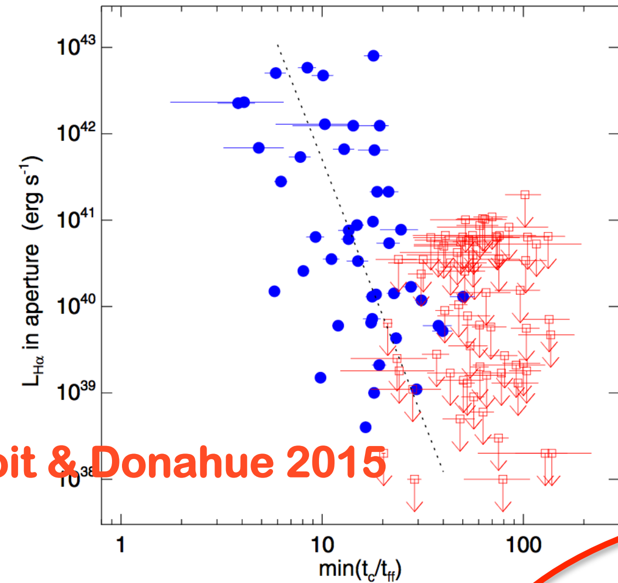


Prasad, Sharma & Babul 2016

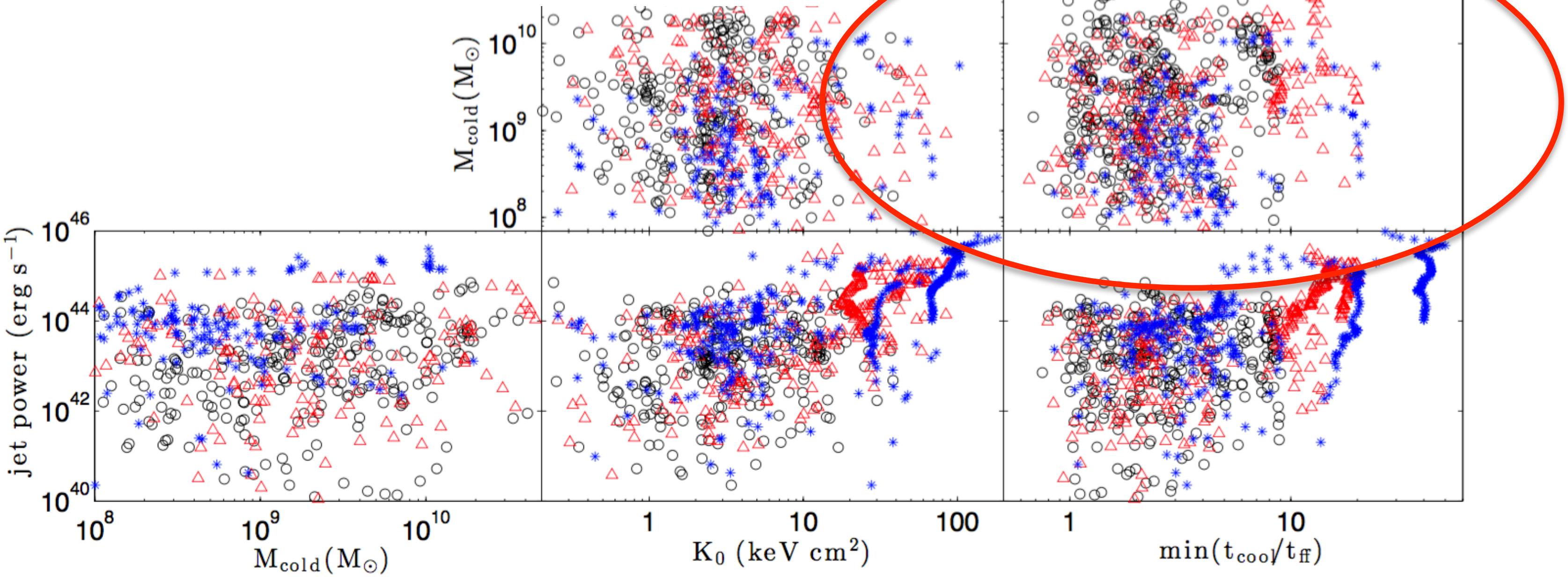


Prasad, Sharma & Babul 2015

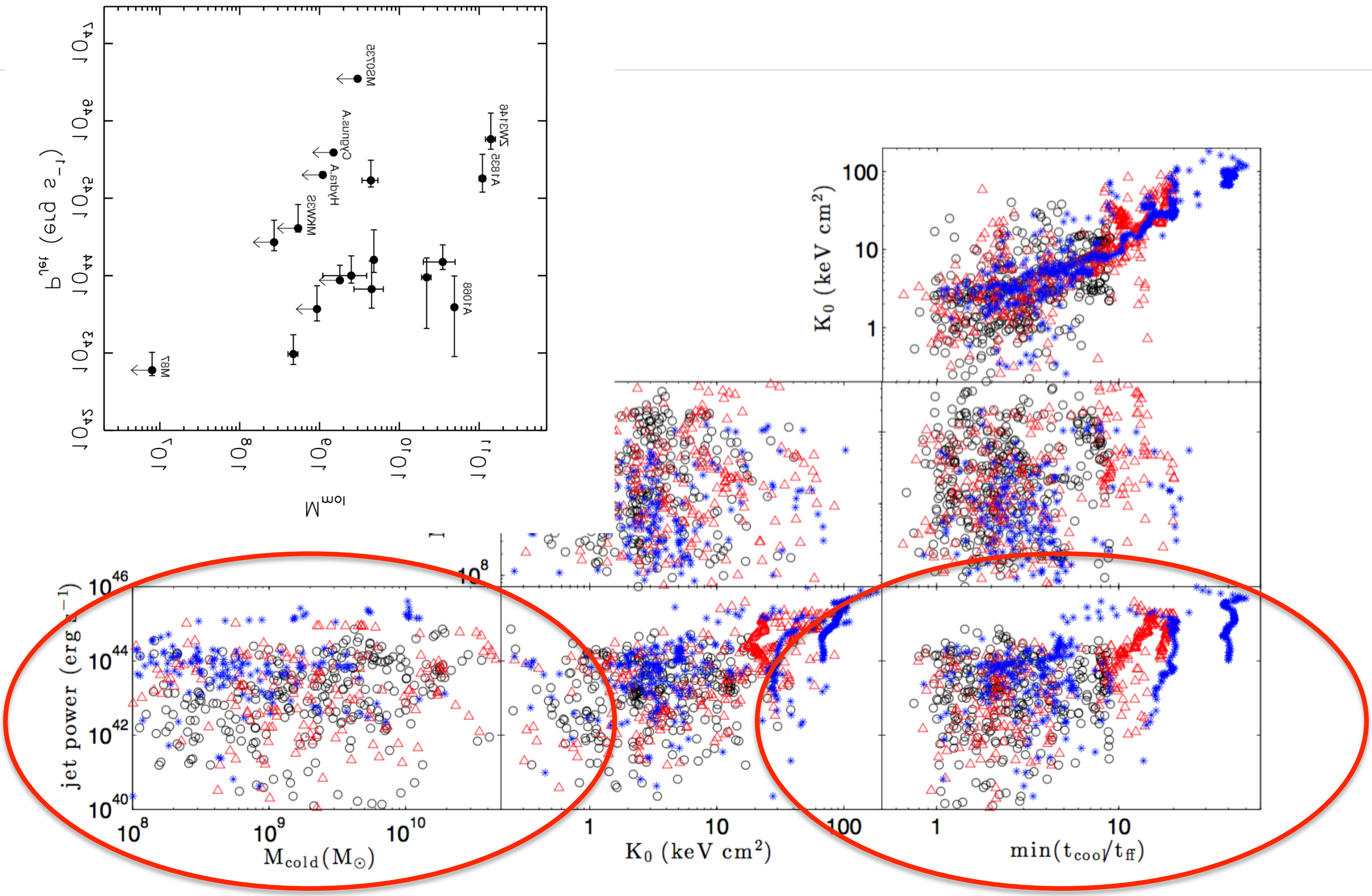
ld gas if t_{cool}/t_{ff} > 30



Voit & Donahue 2015



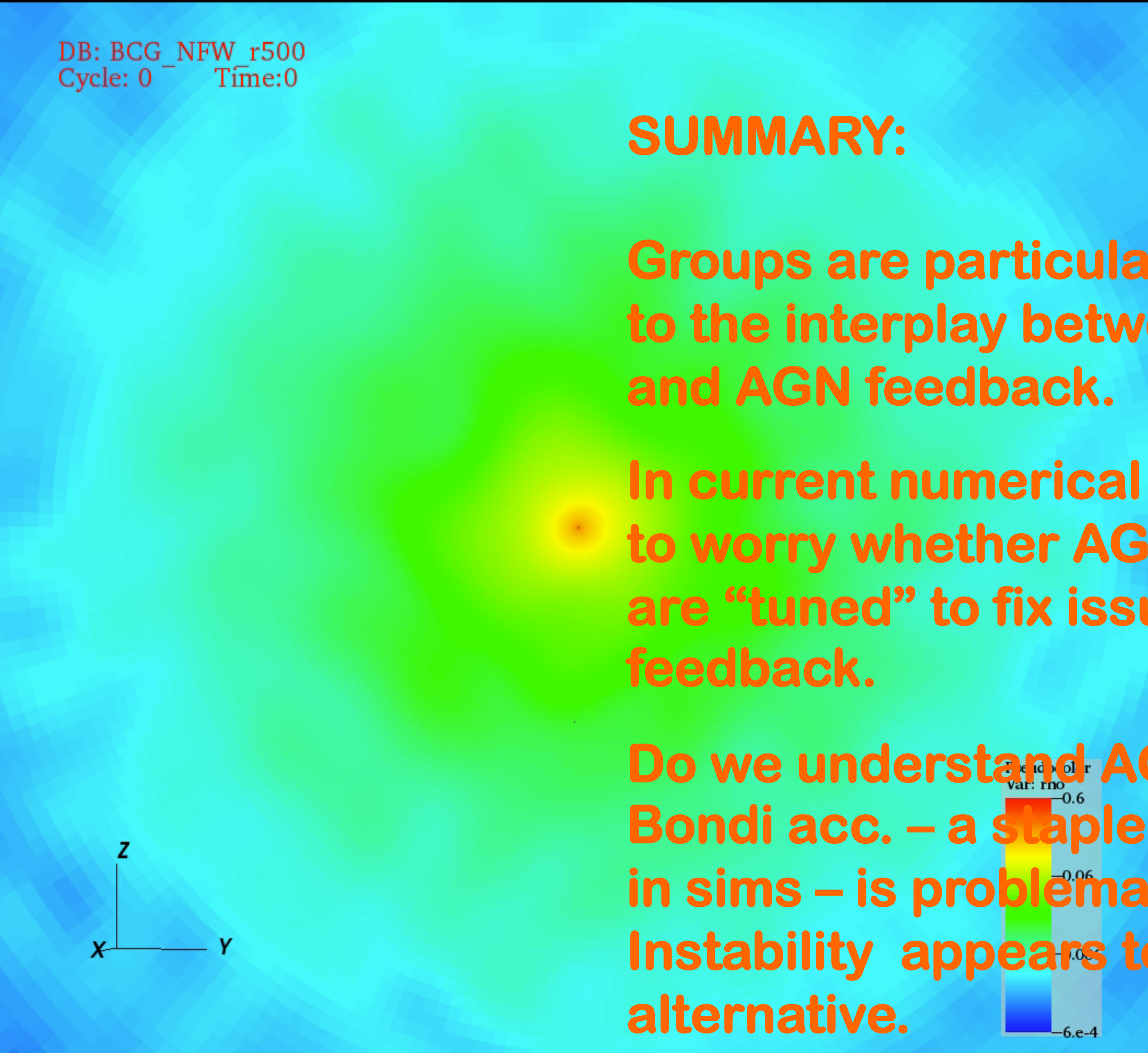
Prasad, Sharma & Babul 2015



Prasad, Sharma & Babul 2015

256x128x32 in (logr,θ,ϕ)
r_{min}=0.5 kpc,
r_{max}=0.5 Mpc
T ~1.2 Gyr

by Deovrat Prasad



SUMMARY:

Groups are particularly sensitive to the interplay between stellar and AGN feedback.

In current numerical models, need to worry whether AGN feedback are "tuned" to fix issues with stellar feedback.

Do we understand AGN physics? Bondi acc. – a staple of AGN models in sims – is problematic. Thermal Instability appears to be a better alternative.