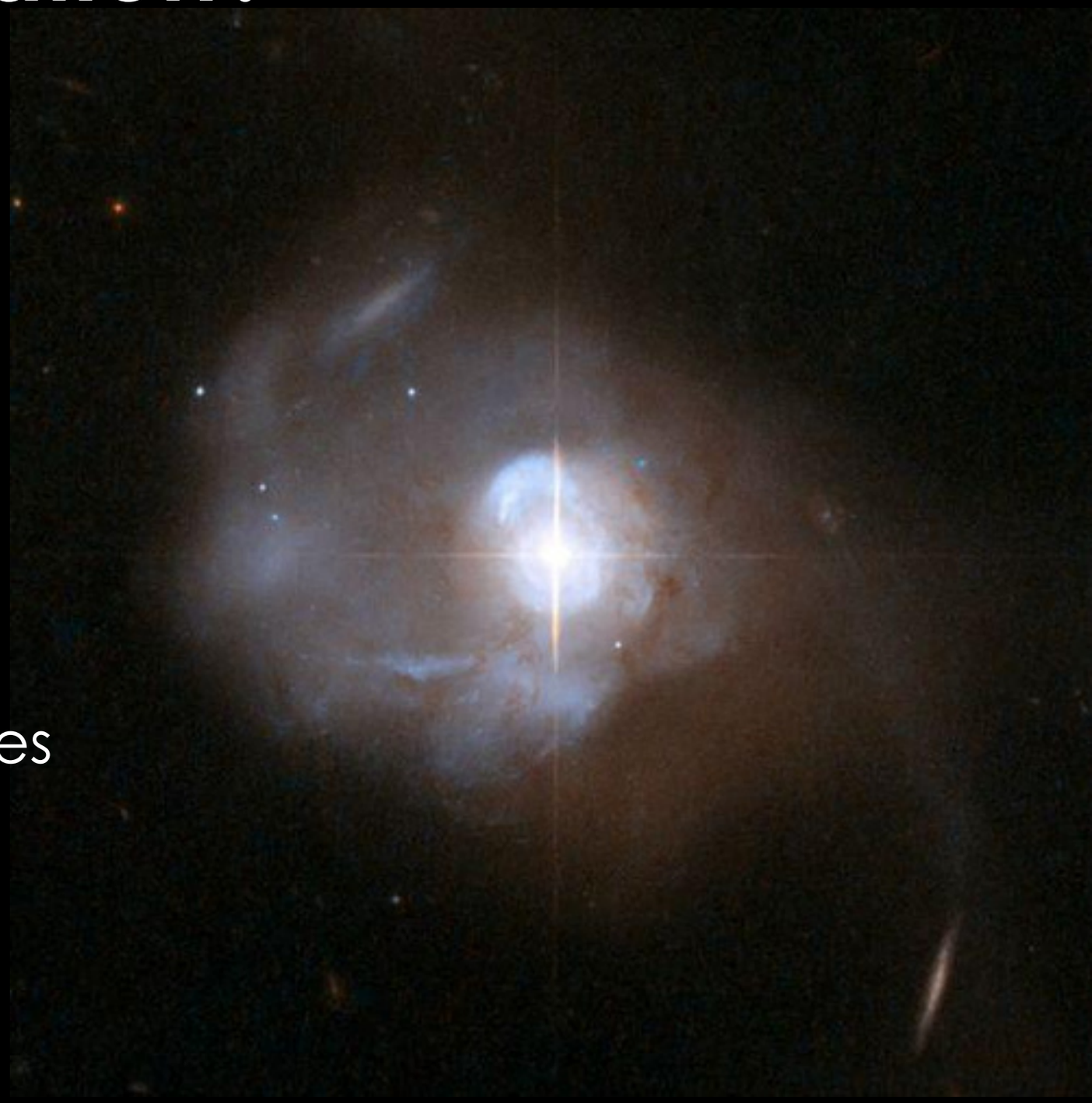
The SF-AGN connection: Does AGN activity follow or prevent star formation?

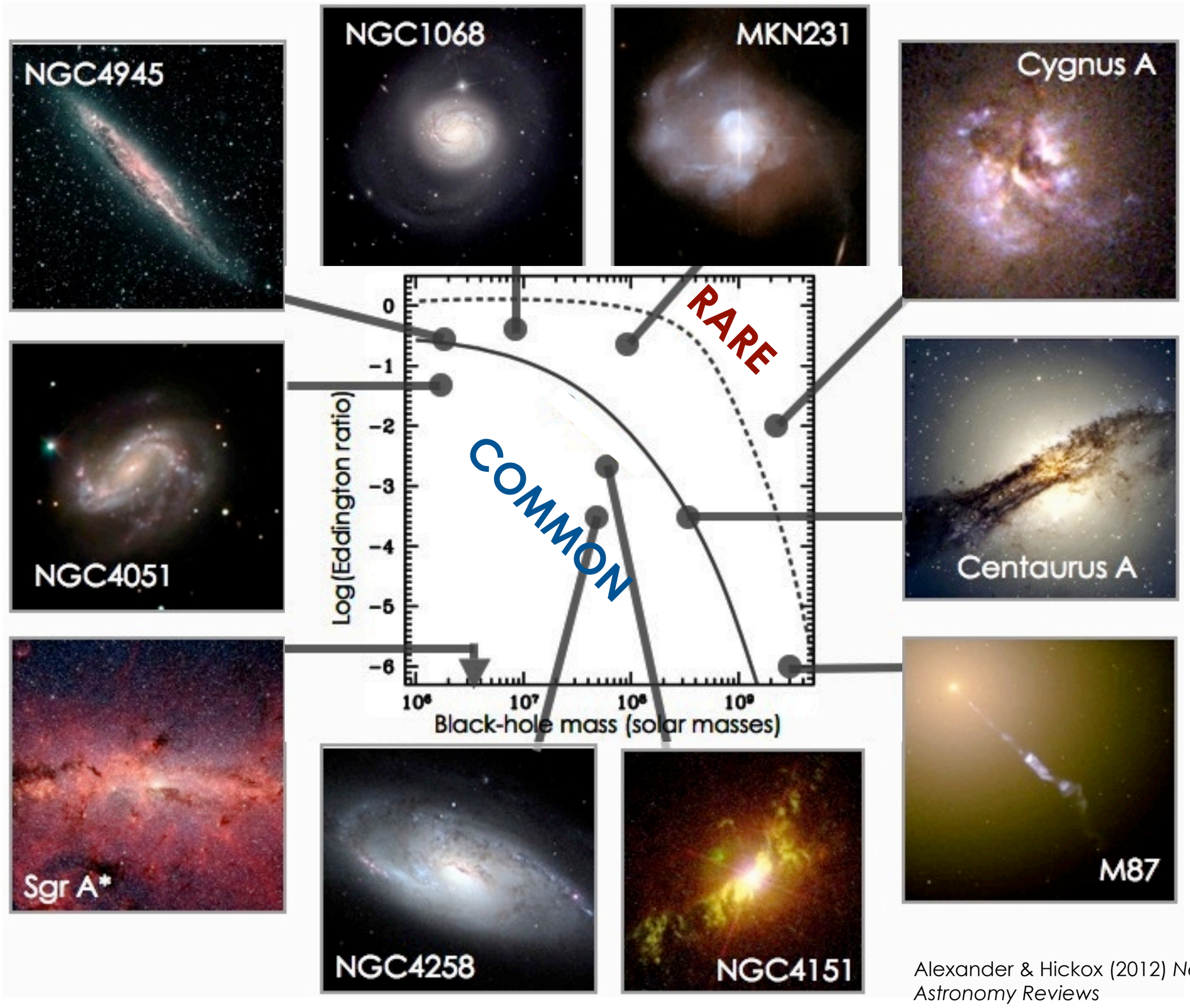
Ryan C. Hickox

Dartmouth

AGN vs. Star Formation:
The Fate of the Gas in Galaxies
Durham, UK
28 July 2014



A wide variety of active galactic nuclei



Alexander & Hickox (2012) *New Astronomy Reviews*
Model curves courtesy A. Merloni

Accretion state **changes with Eddington ratio**

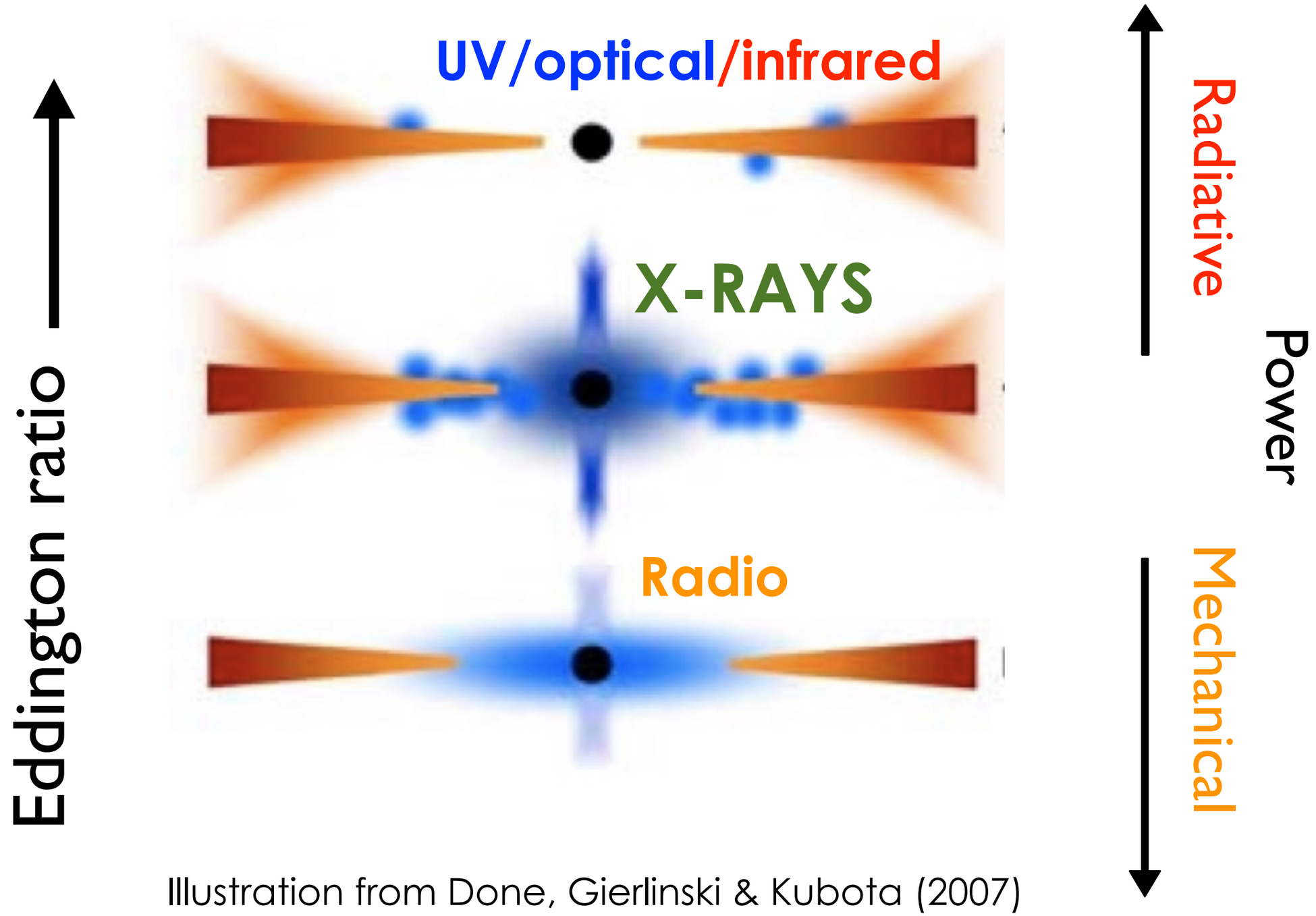
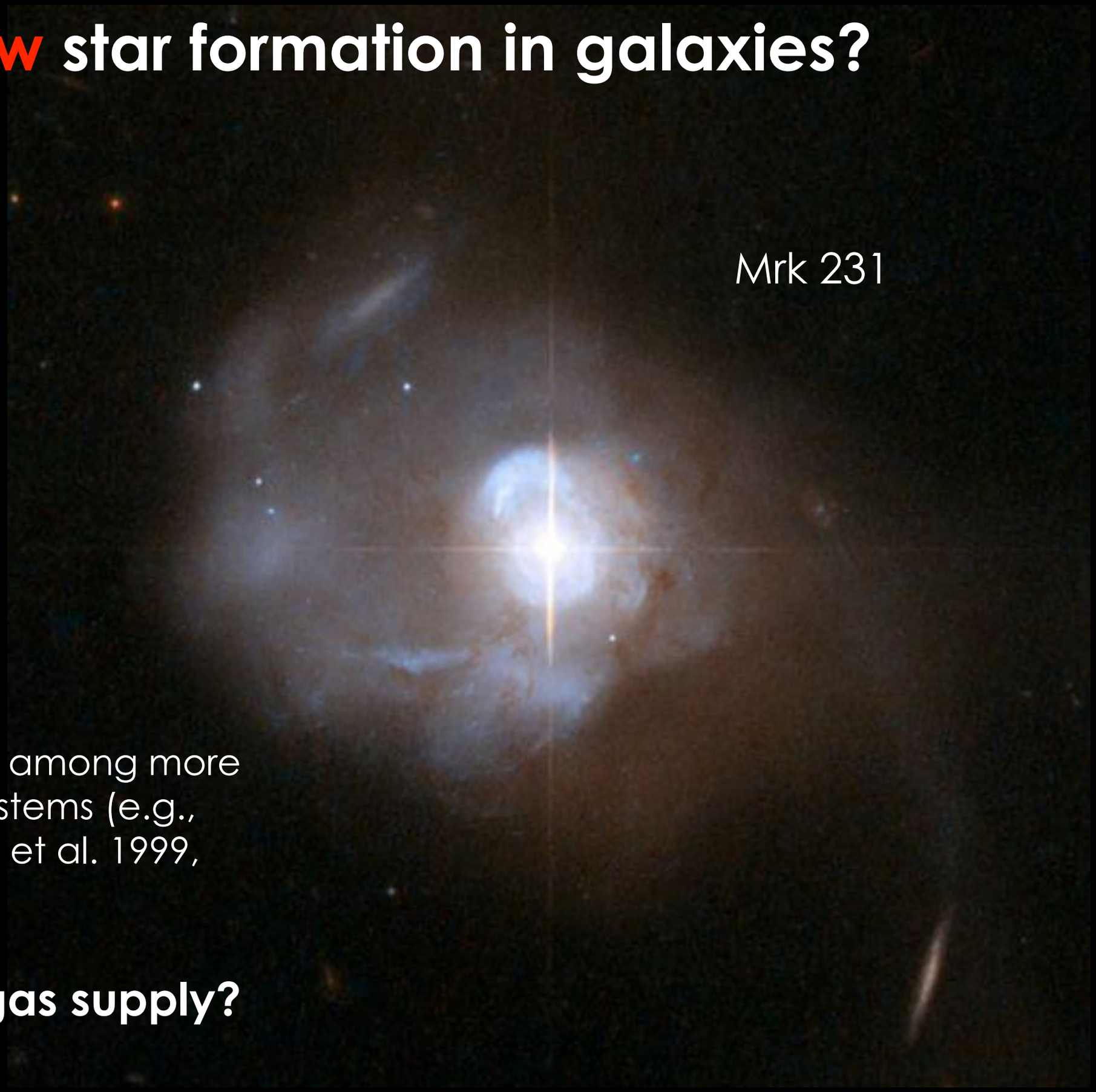


Illustration from Done, Gierlinski & Kubota (2007)

Also strongly affected by **host galaxy contamination and other selection effects:** Hopkins et al. (2009)

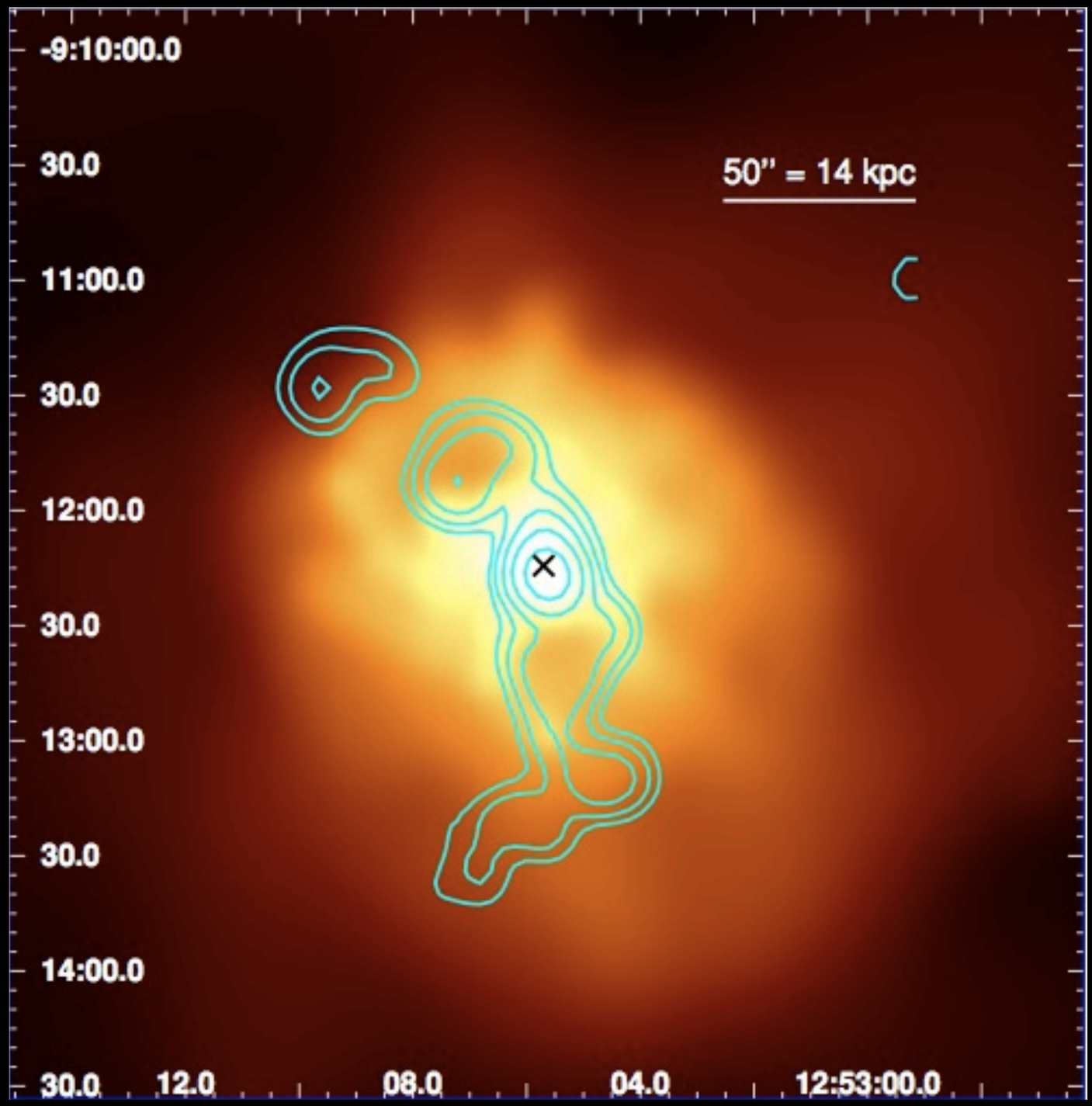
Do AGN follow star formation in galaxies?



Higher fraction of AGN among more strongly star-forming systems (e.g., Kim et al. 1998, Veilleux et al. 1999, Tran et al. 2001)

A common cold gas supply?

Do AGN prevent star formation in galaxies?



HCG 62 (Gitti et al. 2010), see many others for similar examples

AGN can be energetically dominant?

Do AGN follow star formation?

OR

Do AGN prevent star formation?

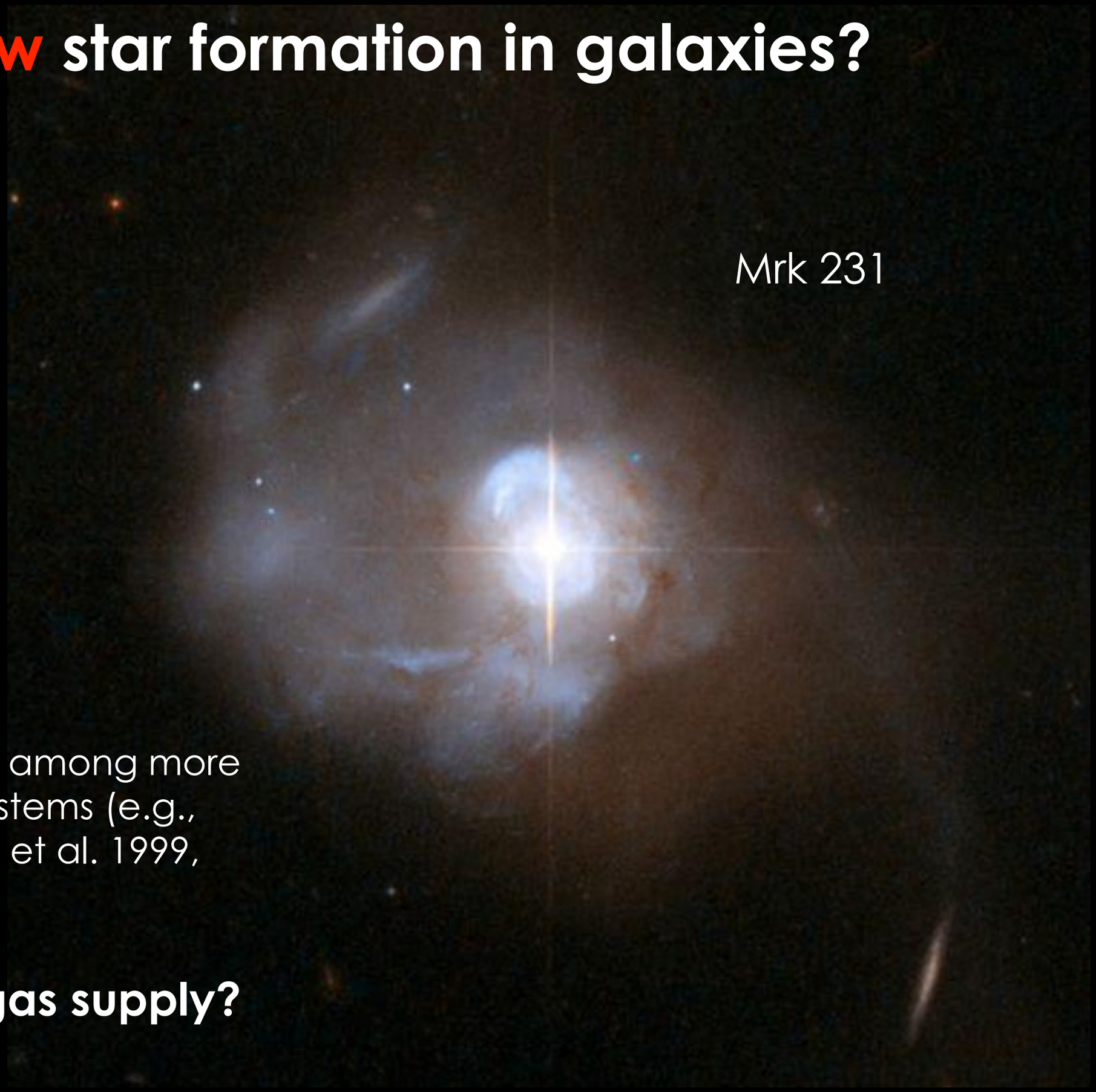
Do AGN follow star formation?

OR

Do AGN prevent star formation?

YES

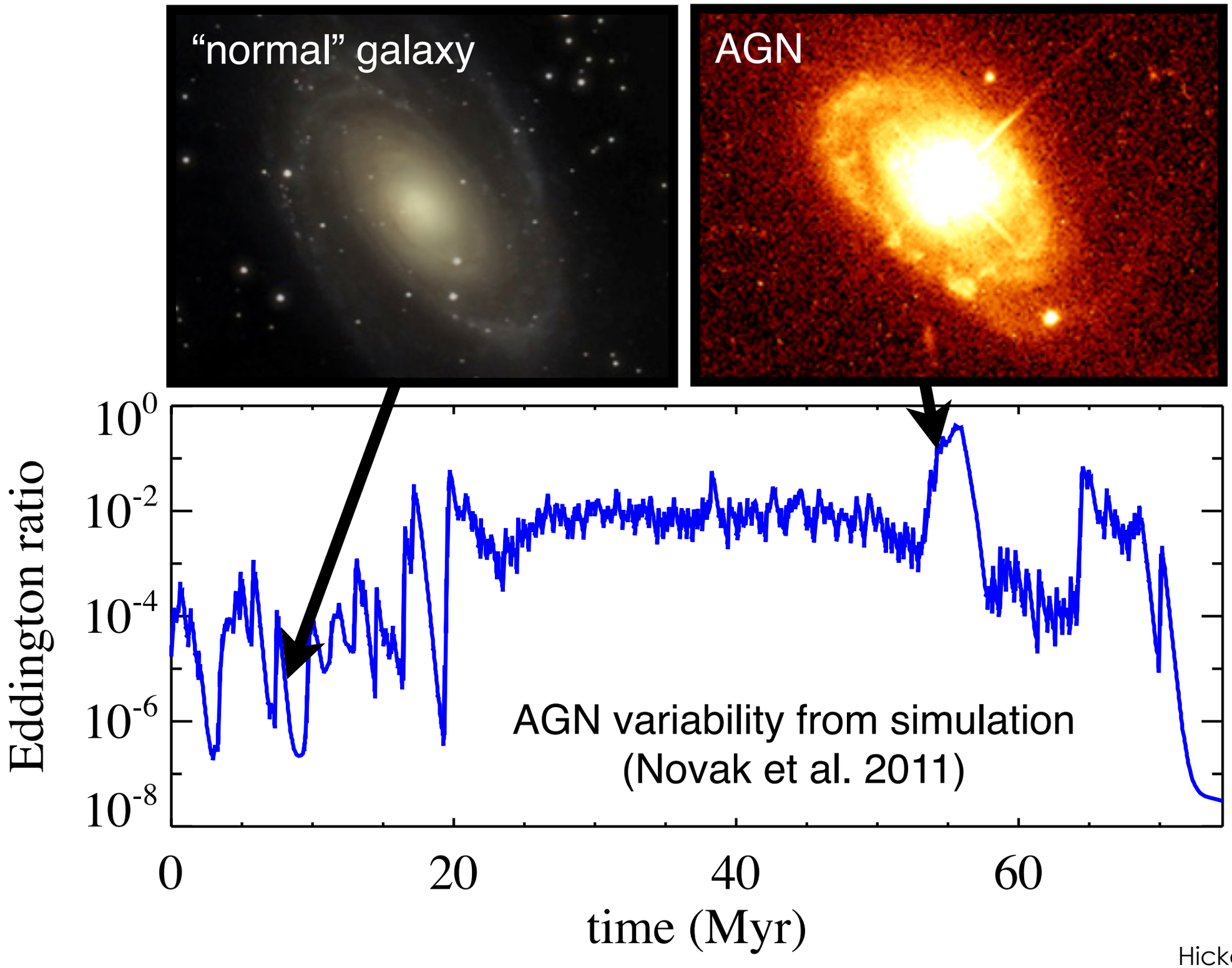
Do AGN follow star formation in galaxies?



Higher fraction of AGN among more strongly star-forming systems (e.g., Kim et al. 1998, Veilleux et al. 1999, Tran et al. 2001)

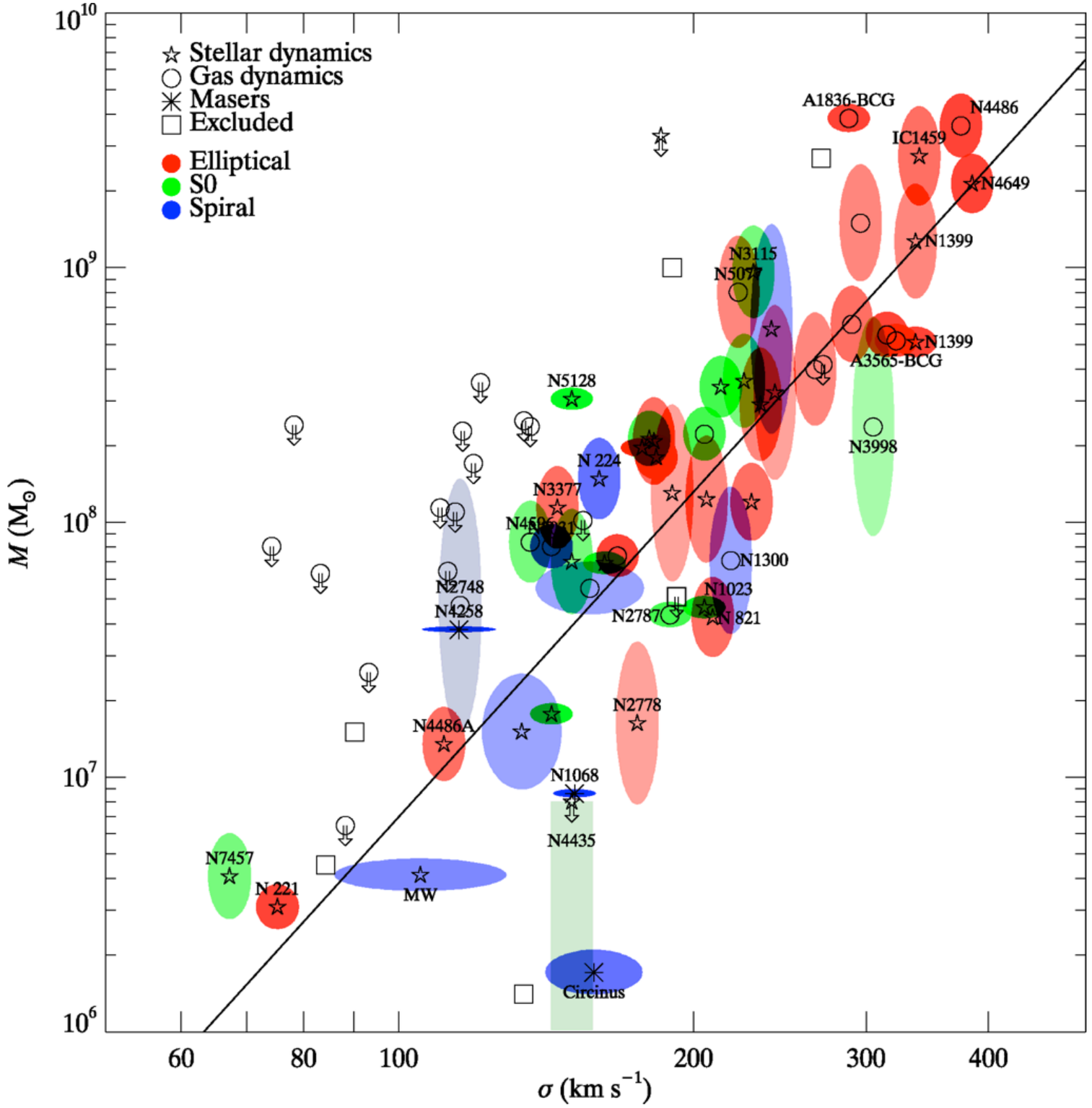
A common cold gas supply?

AGN variability means this is largely a **statistical** problem!



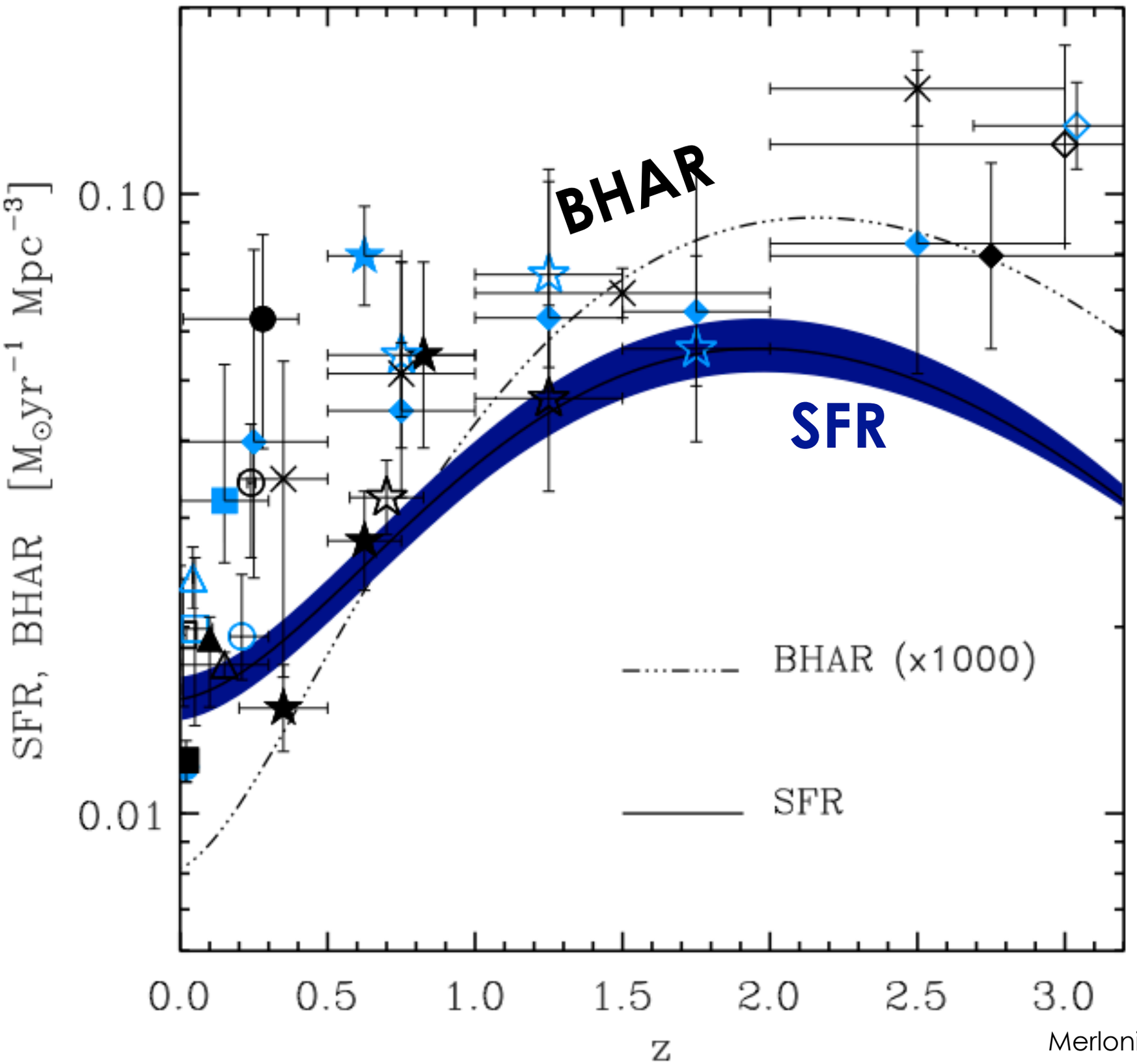
Hickox et al. (2014)

BH-galaxy correlations



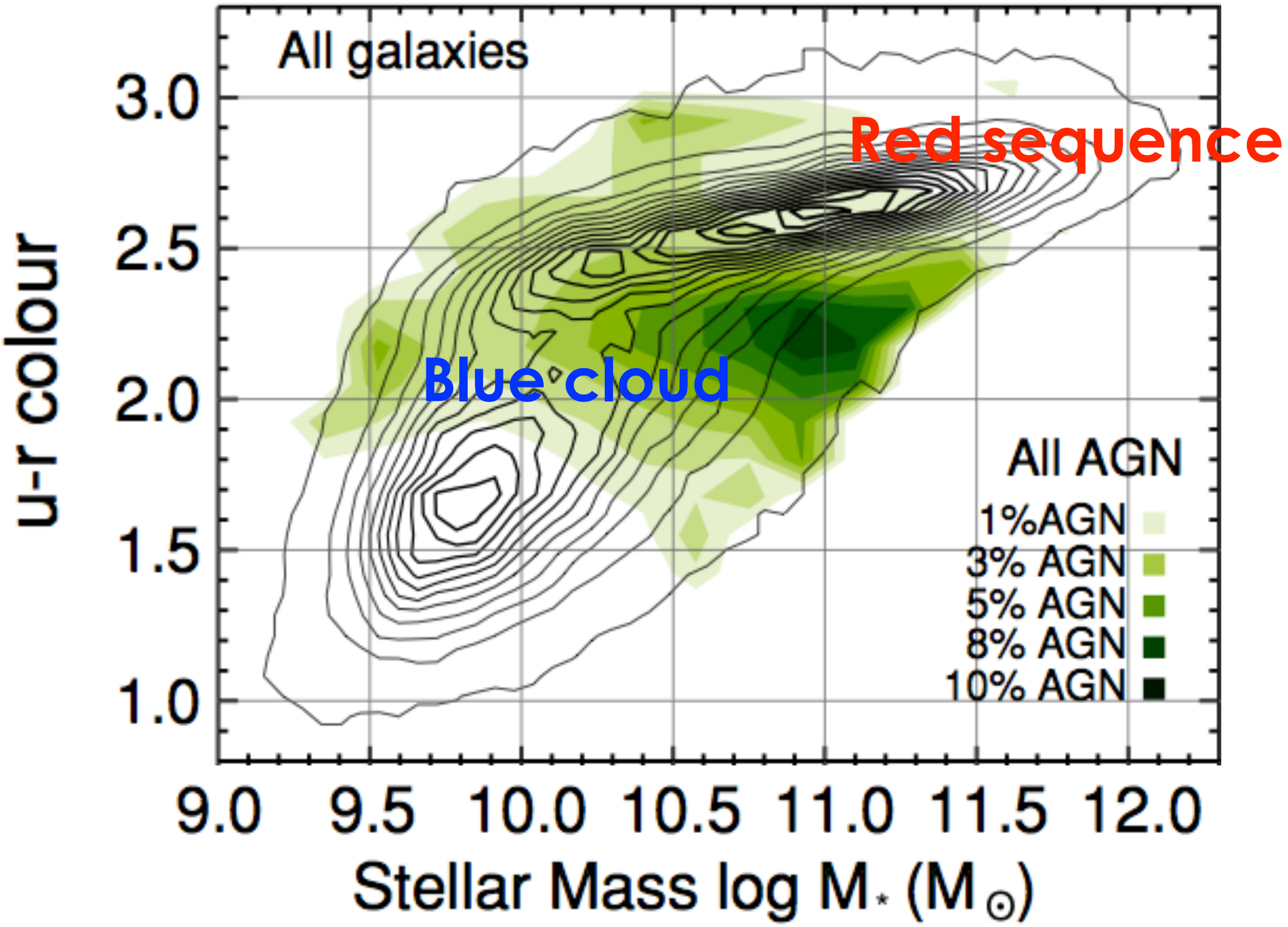
Gultekin et al. (2009); see Kormendy & Ho (2013)

Cosmic evolution of star formation and BH growth



Merloni & Heinz (2012)

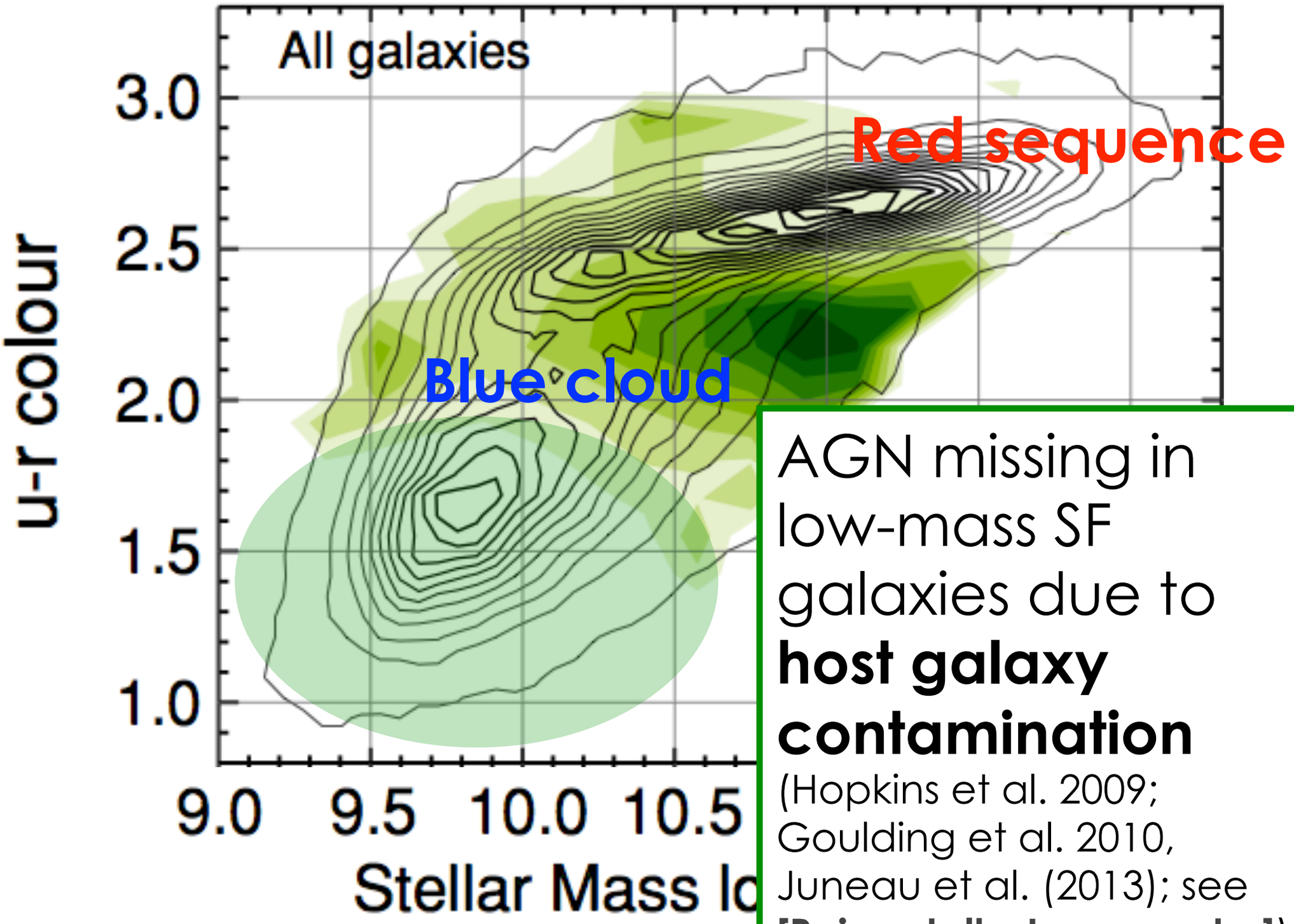
What galaxies host AGN?



SDSS narrow-line AGN

Schawinski et al. (2010)

What galaxies host AGN?

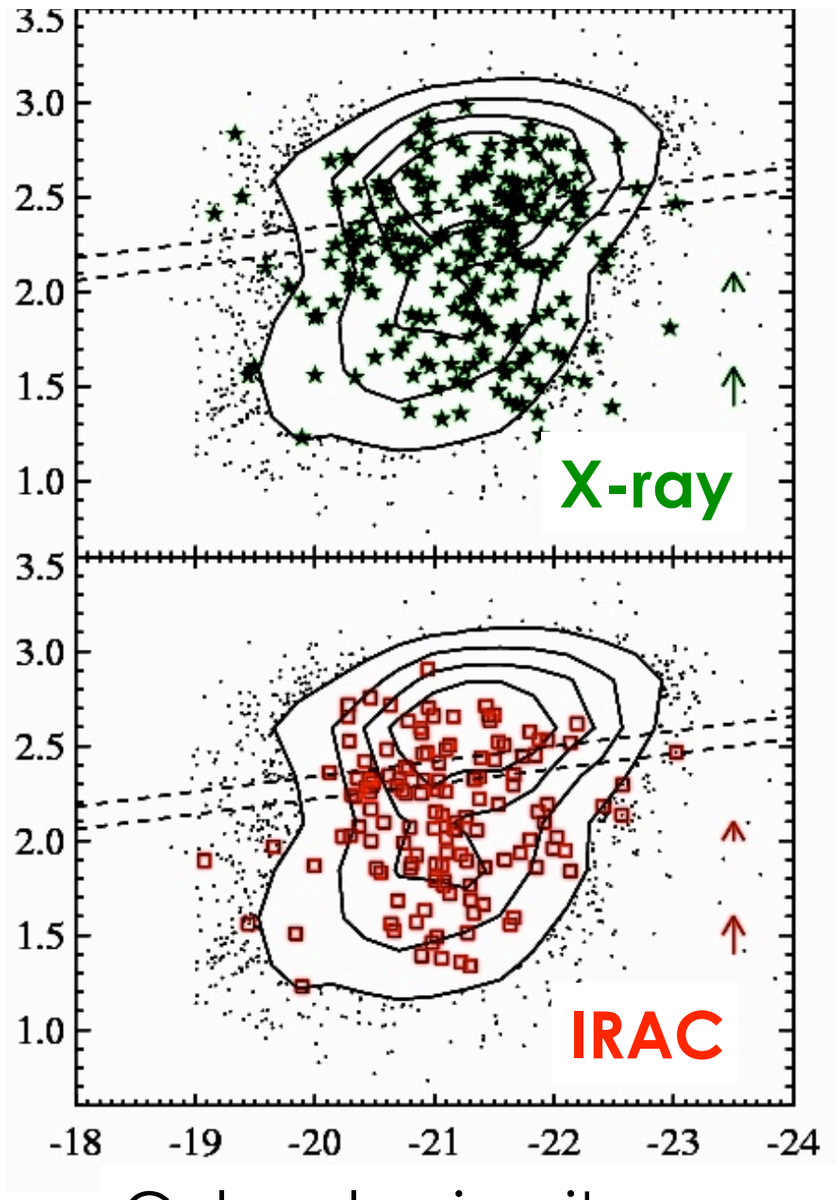


AGN missing in low-mass SF galaxies due to **host galaxy contamination**
(Hopkins et al. 2009; Goulding et al. 2010, Juneau et al. (2013); see **[Reines talk, Jones poster]**)

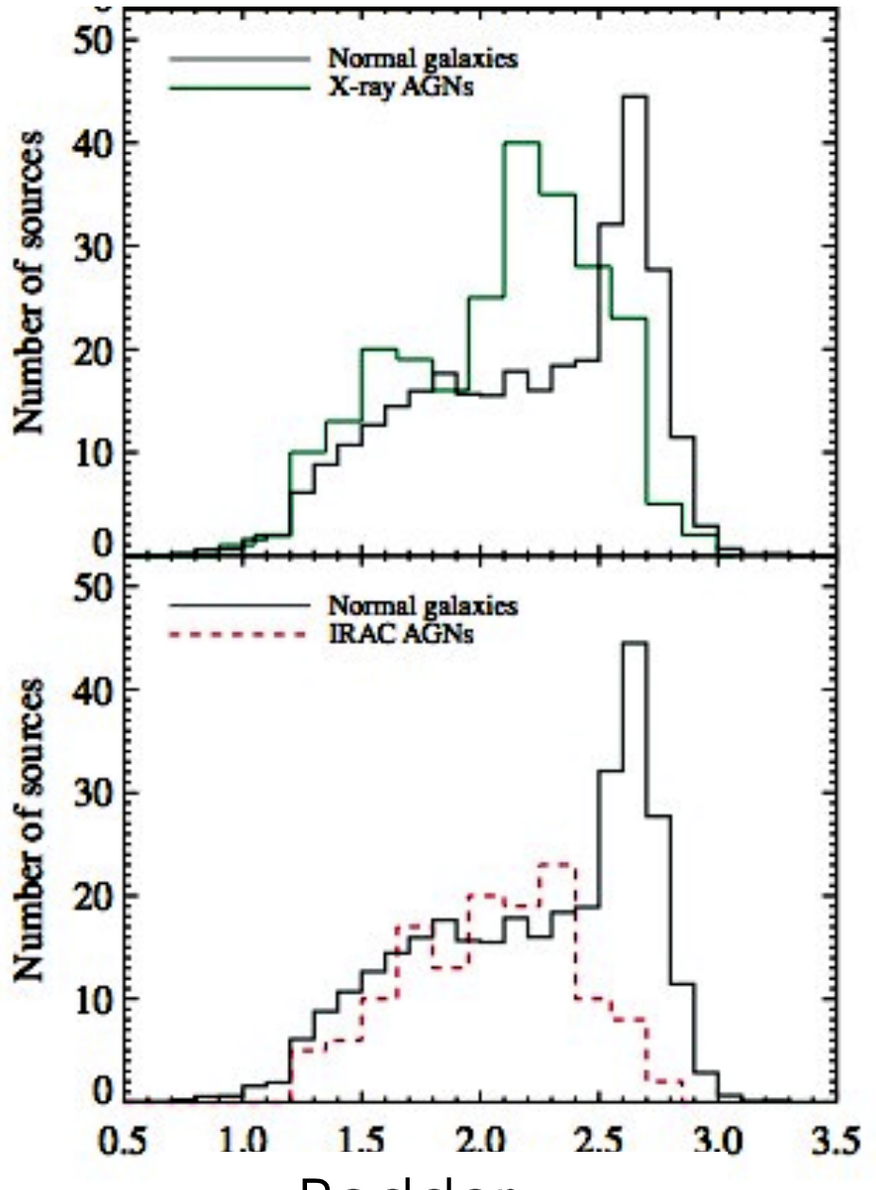
SDSS narrow-line AGN

Schawinski et al. (2010)

Redder →



Galaxy luminosity →



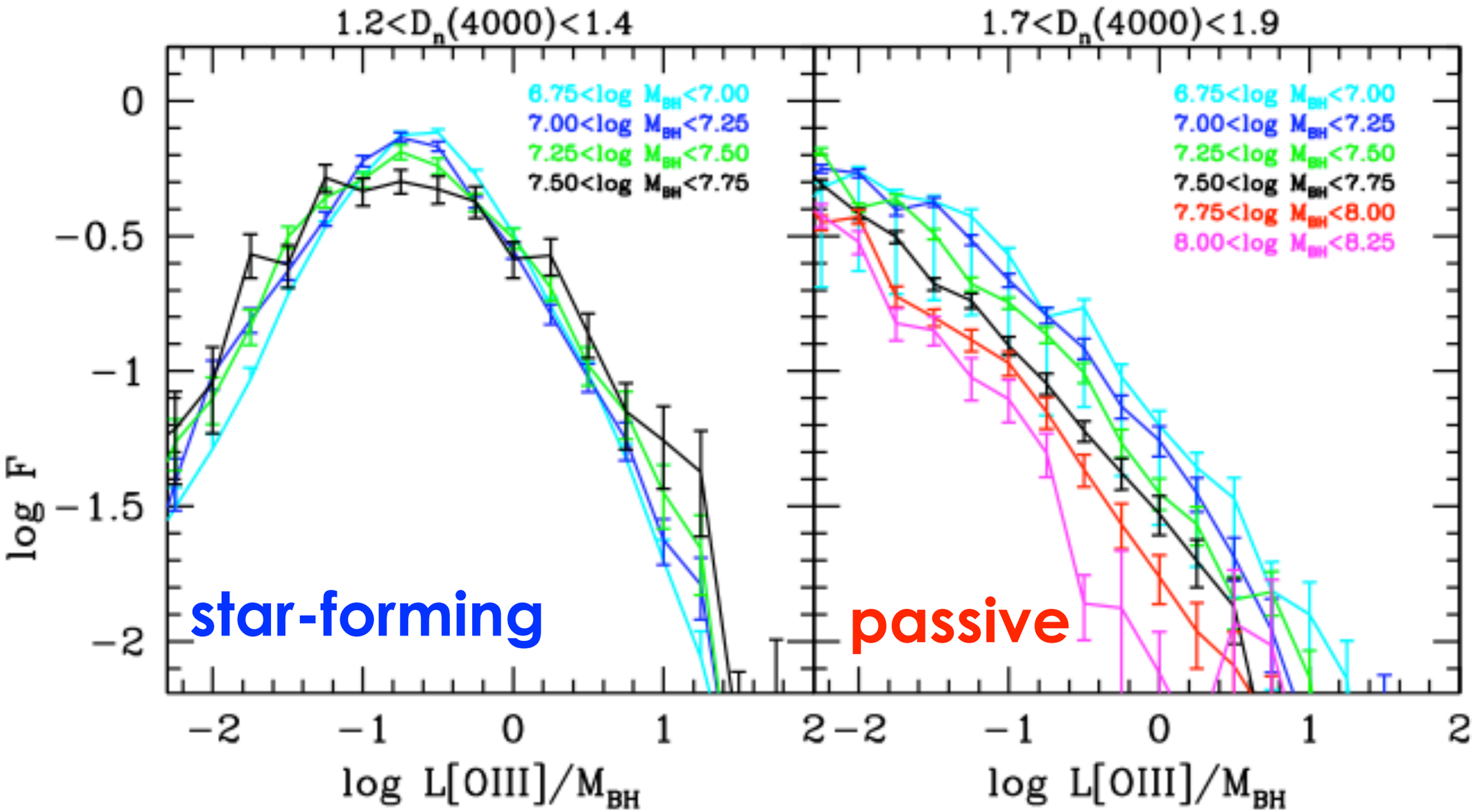
Redder →

Hickox et al. (2009)

See also:

X-ray (e.g., Nandra et al. 2007, Silverman et al. 2007, Alonso-Hererro et al. 2008, Georgakakis et al. 2008, Schawinski et al. 2009, Cardamone et al. 2010, Xue et al. 2010) optical (Kauffmann & Heckman 2009, Schawinski et al. 2010) and infrared (Goulding et al. 2009)

SF galaxies have systematically **higher Eddington ratios**



Kaufmann & Heckman (2009)

SDSS narrow-line AGN

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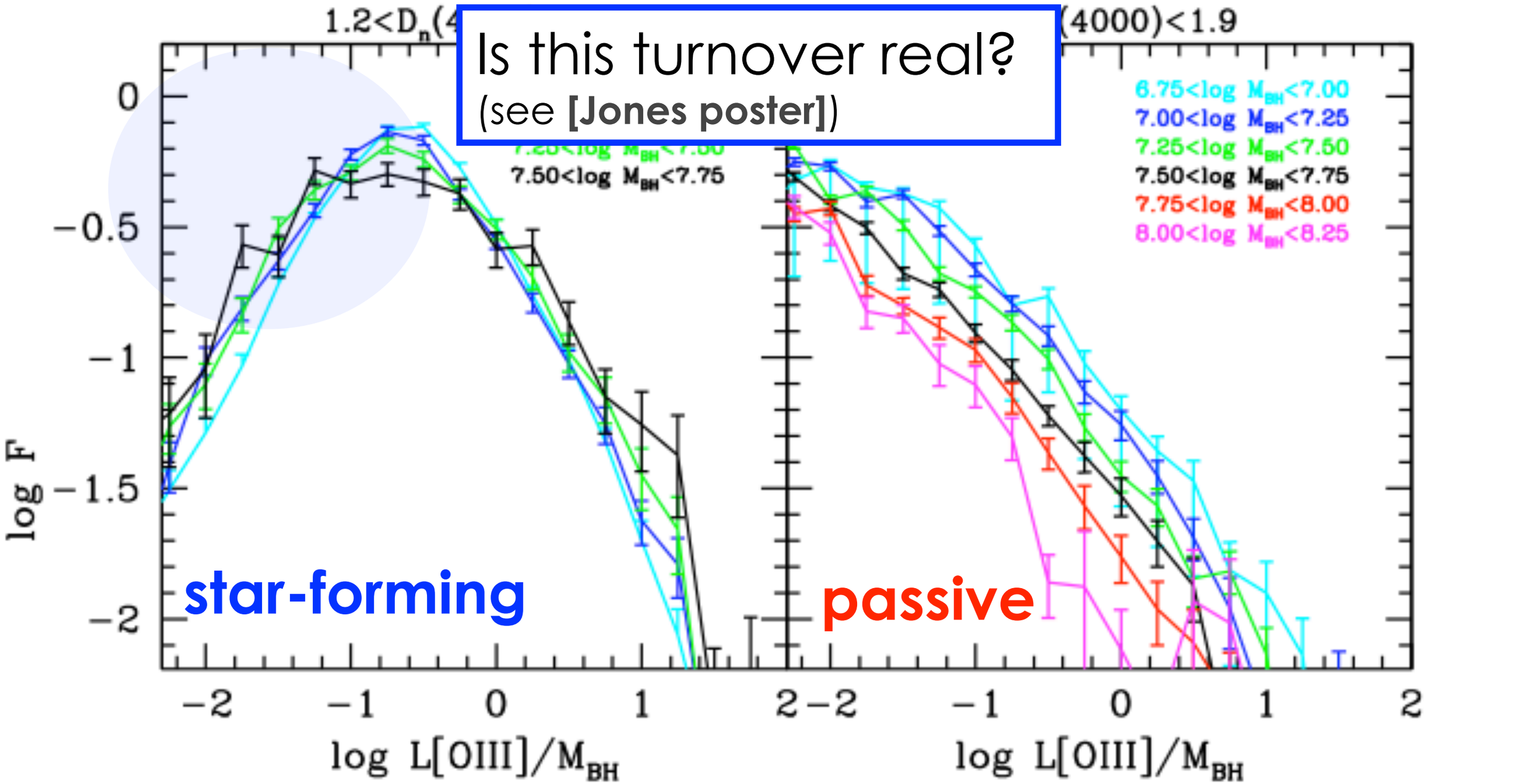

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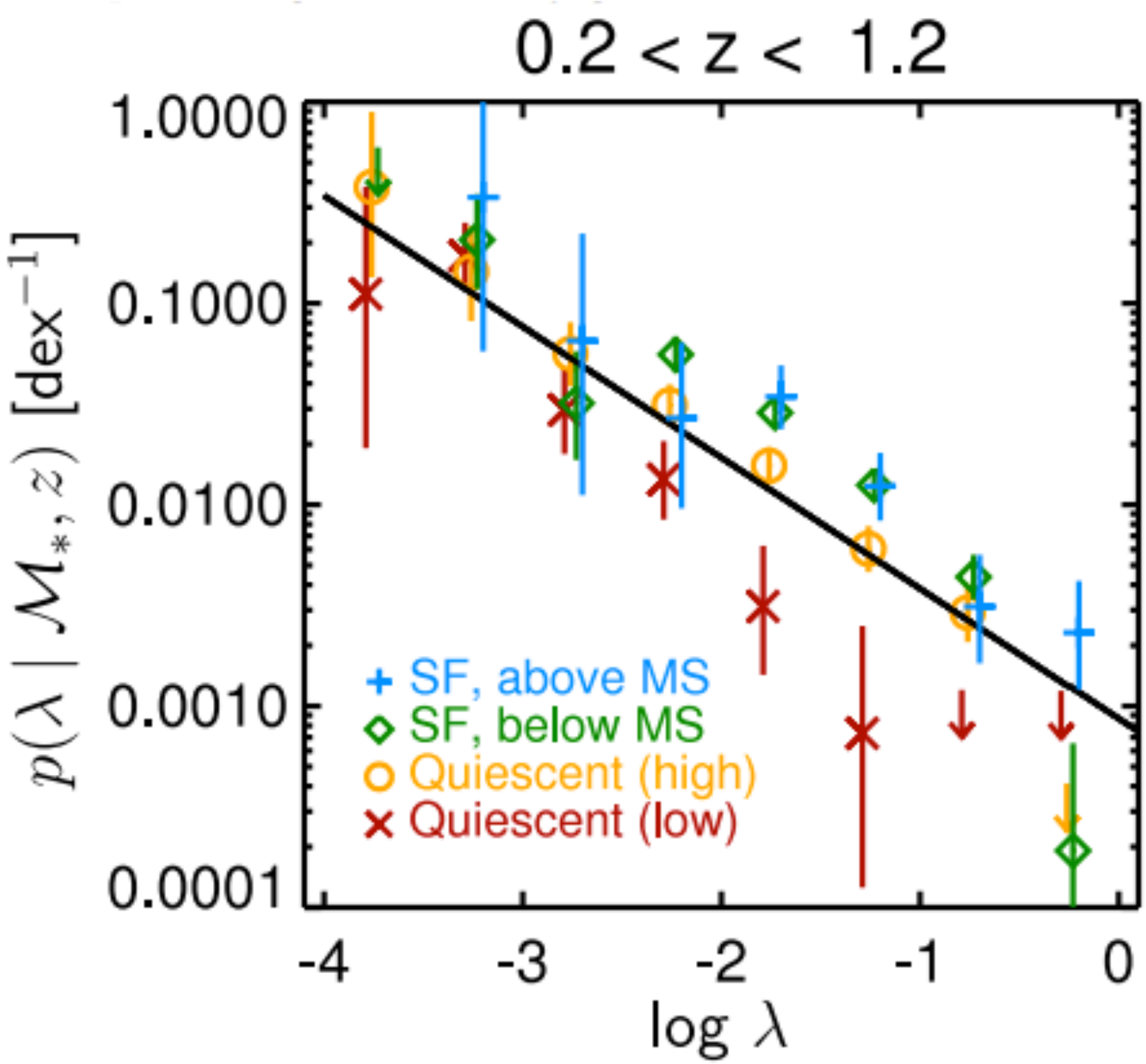
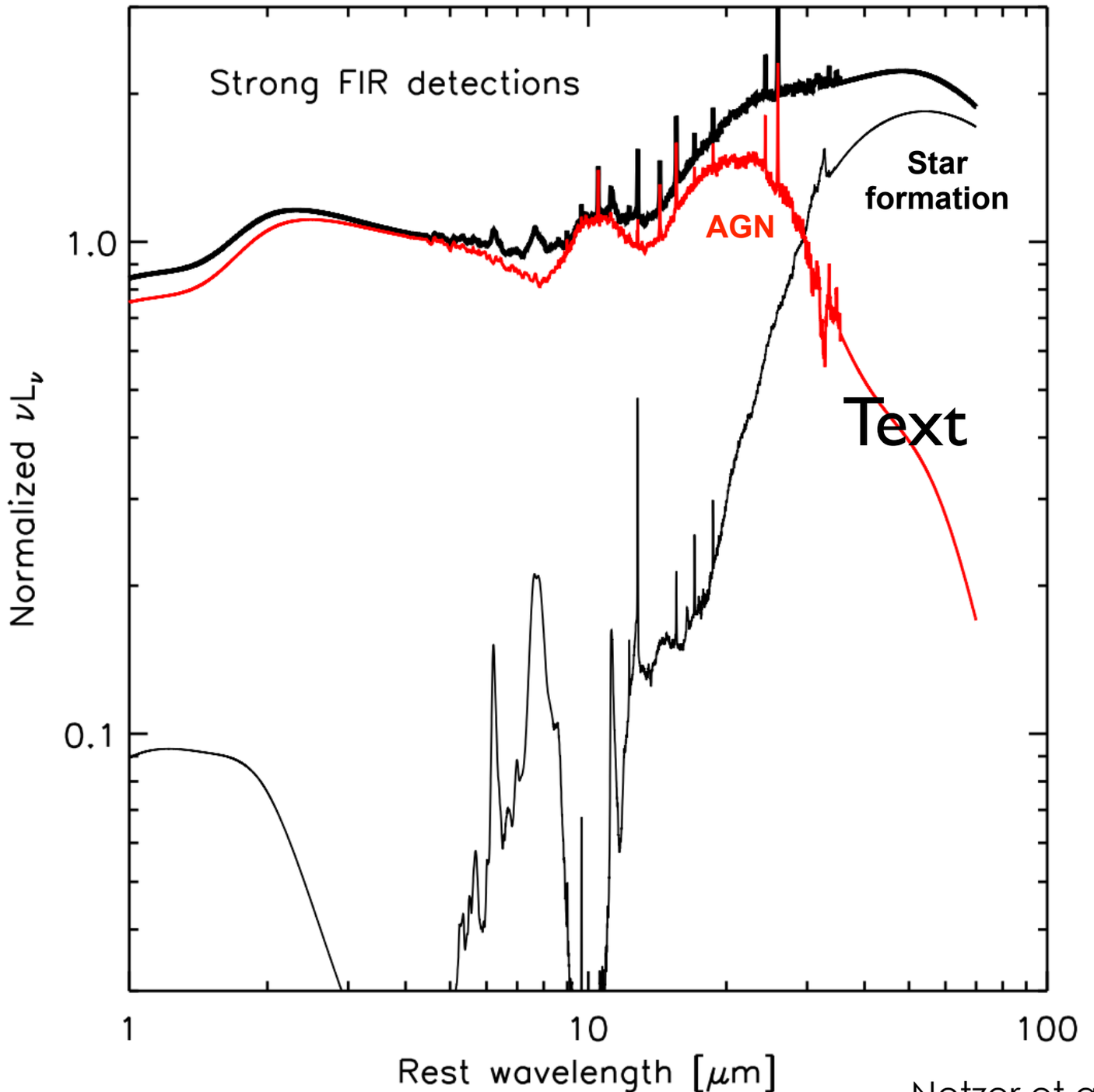


Azadi et al. (2014)

[Azadi talk]

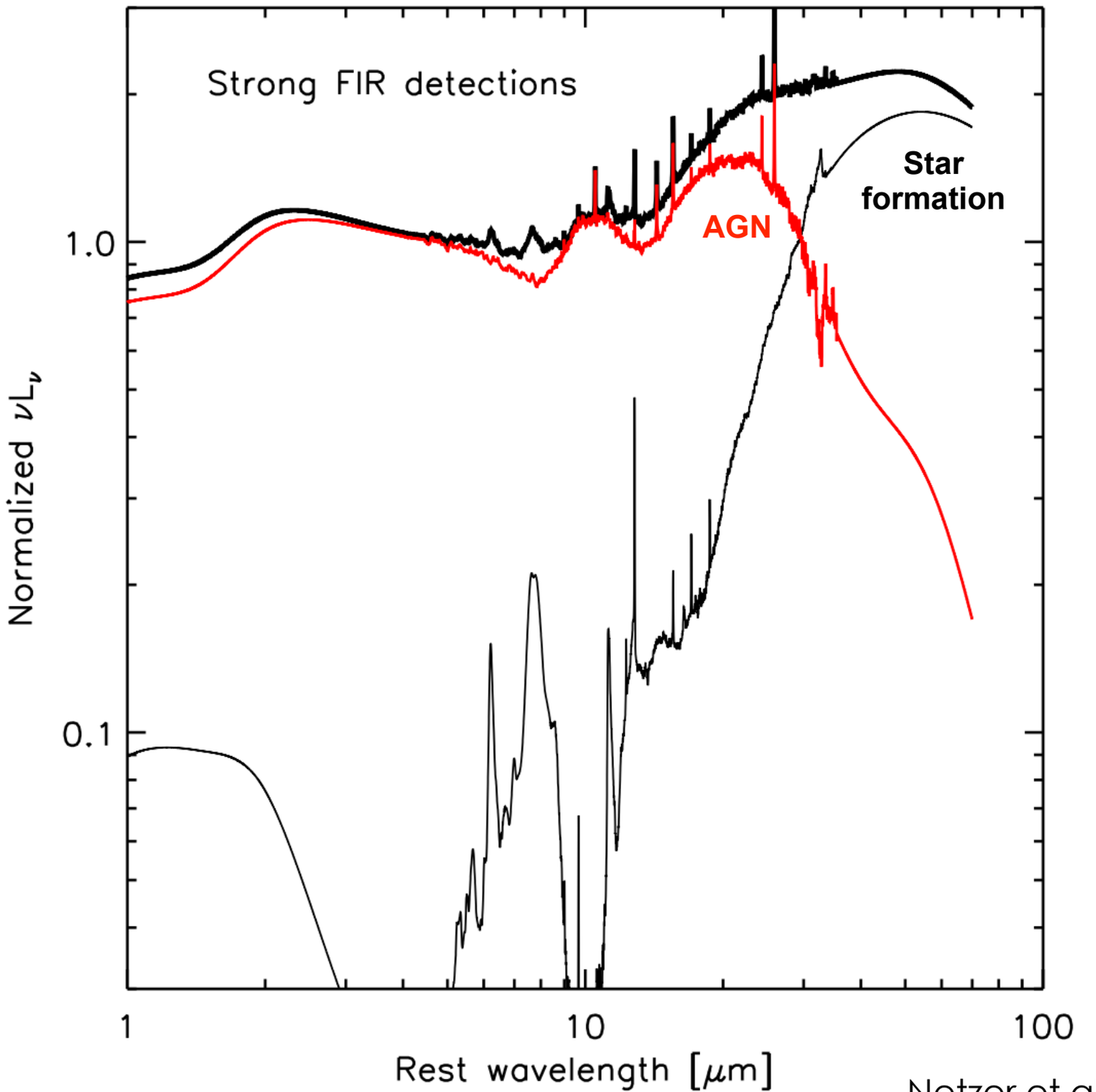
Disentangling AGN and star formation signatures is a **challenge!**



Netzer et al. (2007)
see also Mullaney, et al. (2011)

[Talks by Hatziminaoglou; posters by: Jones, Matsuoka, Mingo, Ori-Floranes, Podigachoski, Rocca-Volmerange, White]

More direct measures of galaxy star formation rates with ***Herschel***



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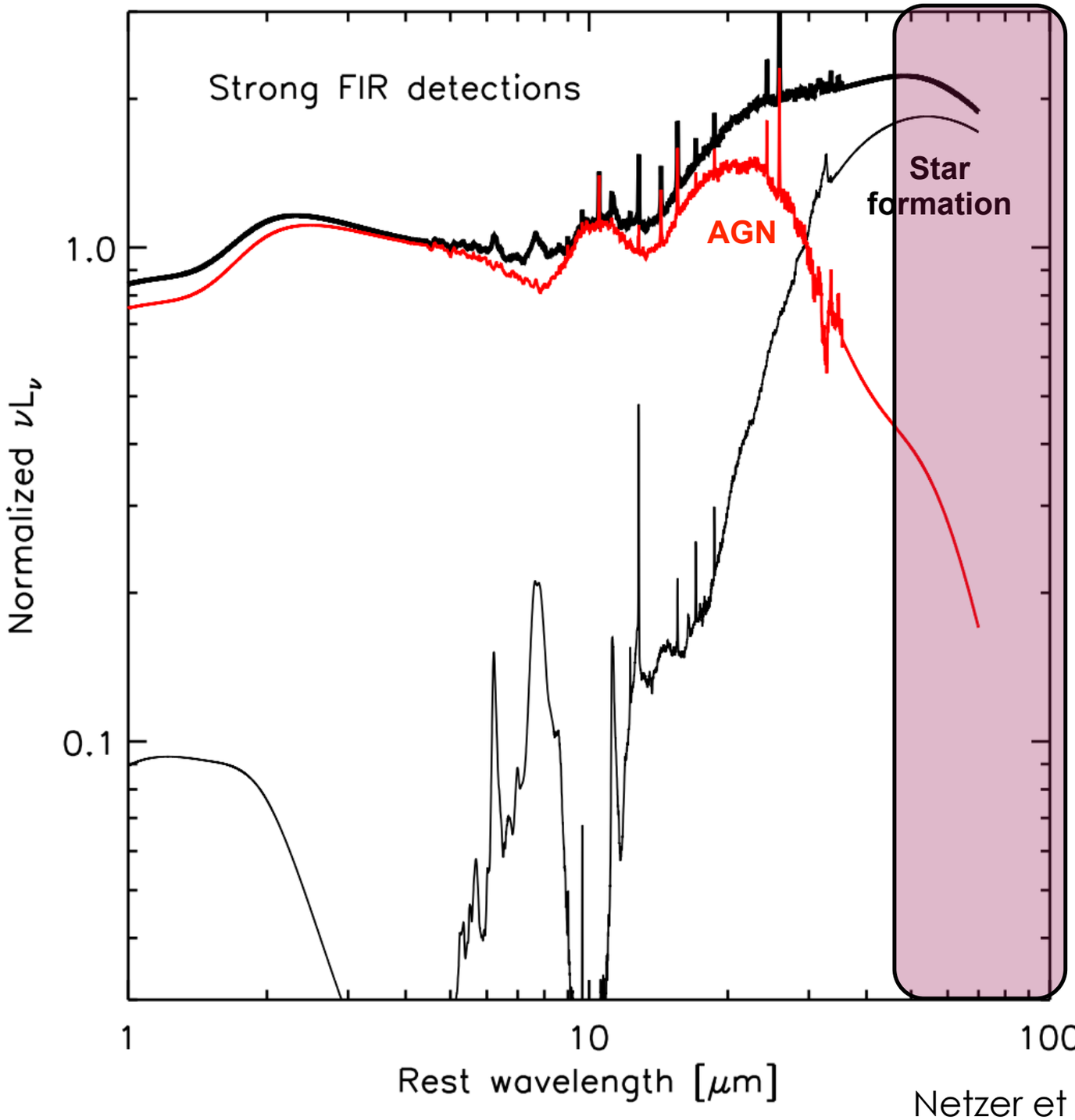
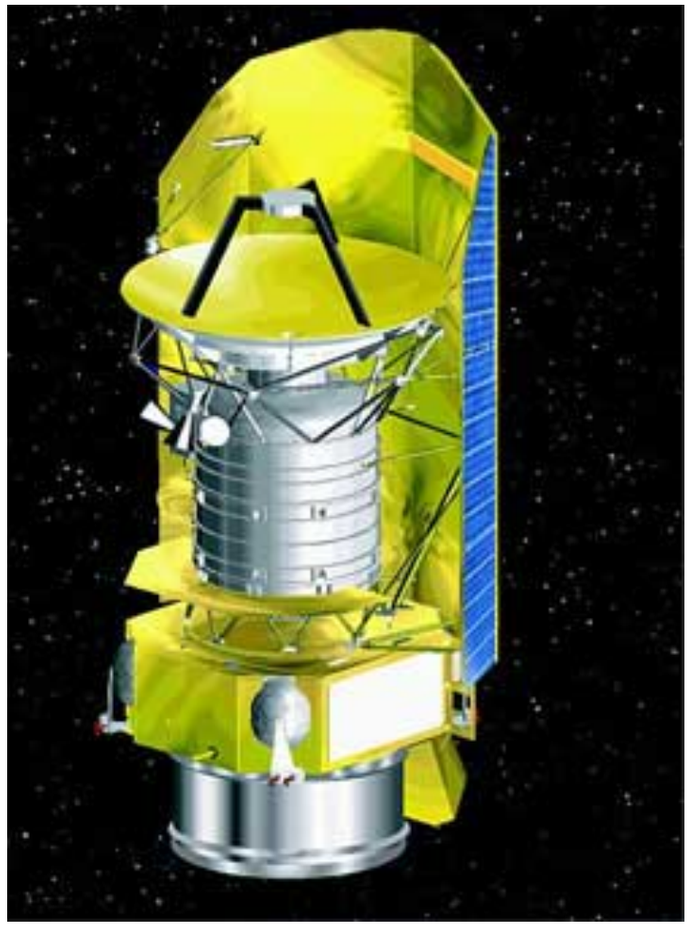
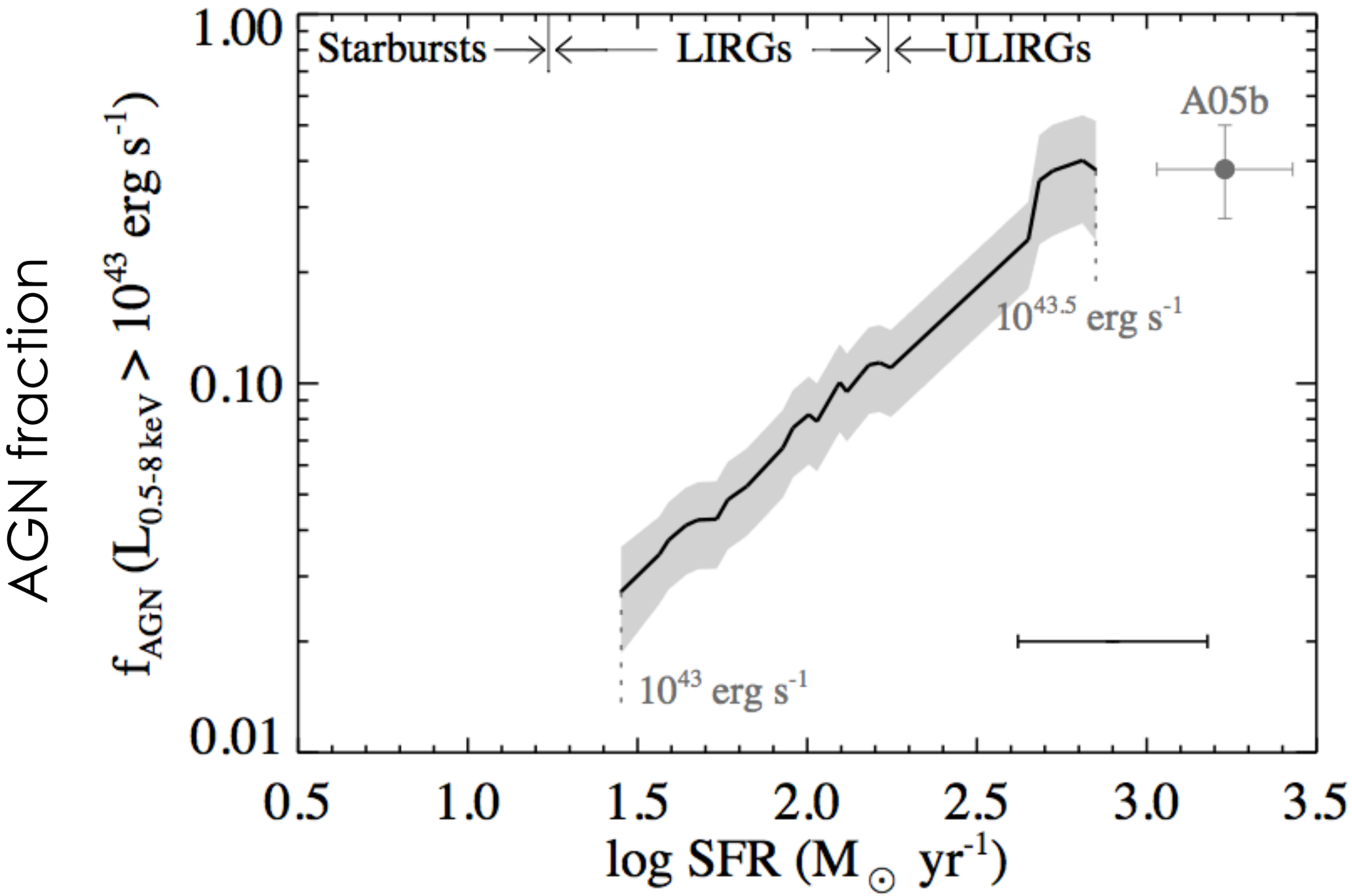




Netzer et al. (2007)
see also Mullaney, et al. (2011)

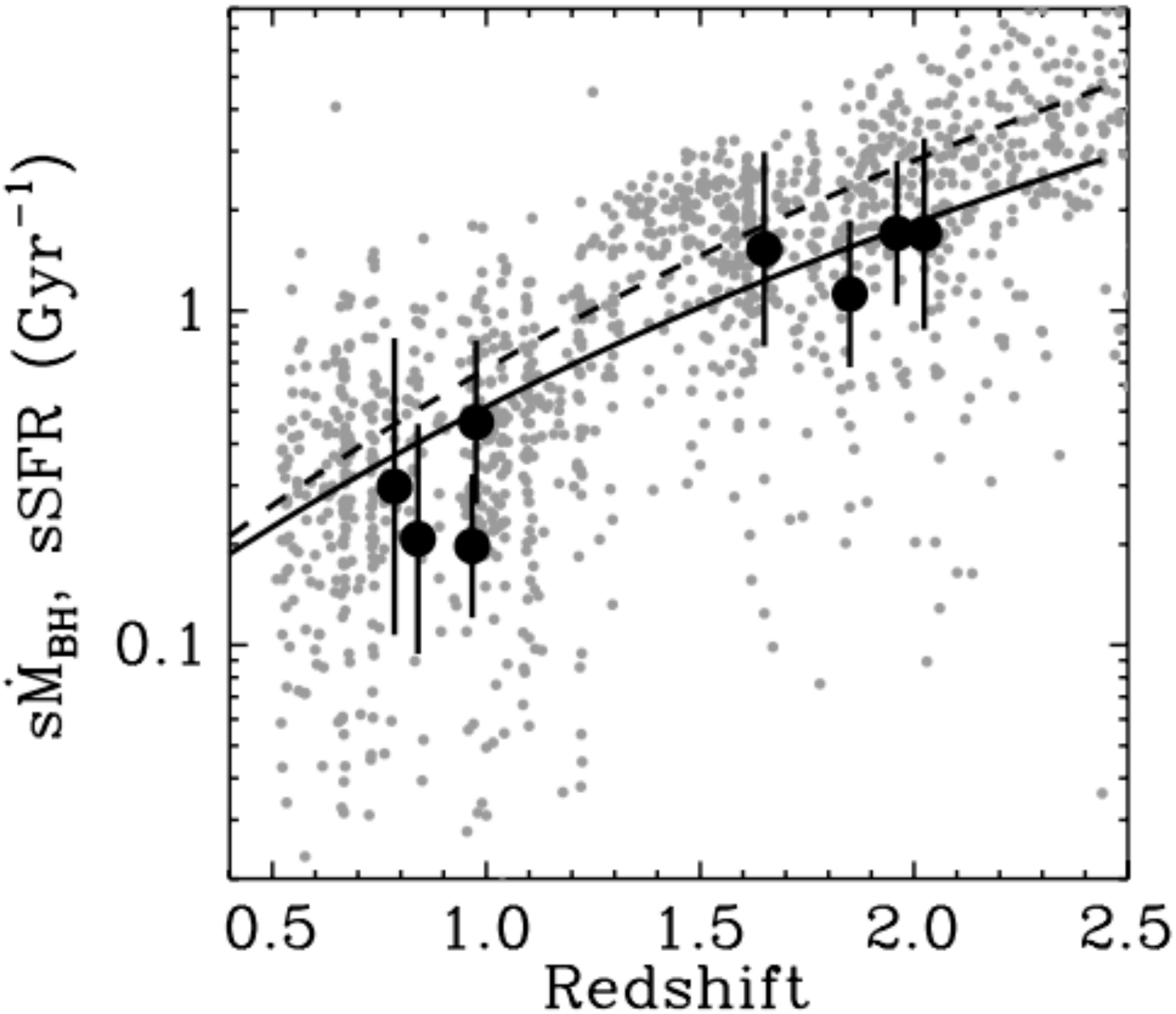
More rapidly SF galaxies are **more likely** to host an AGN



Rafferty et al. (2011), Rosario et al. (2013), and many others

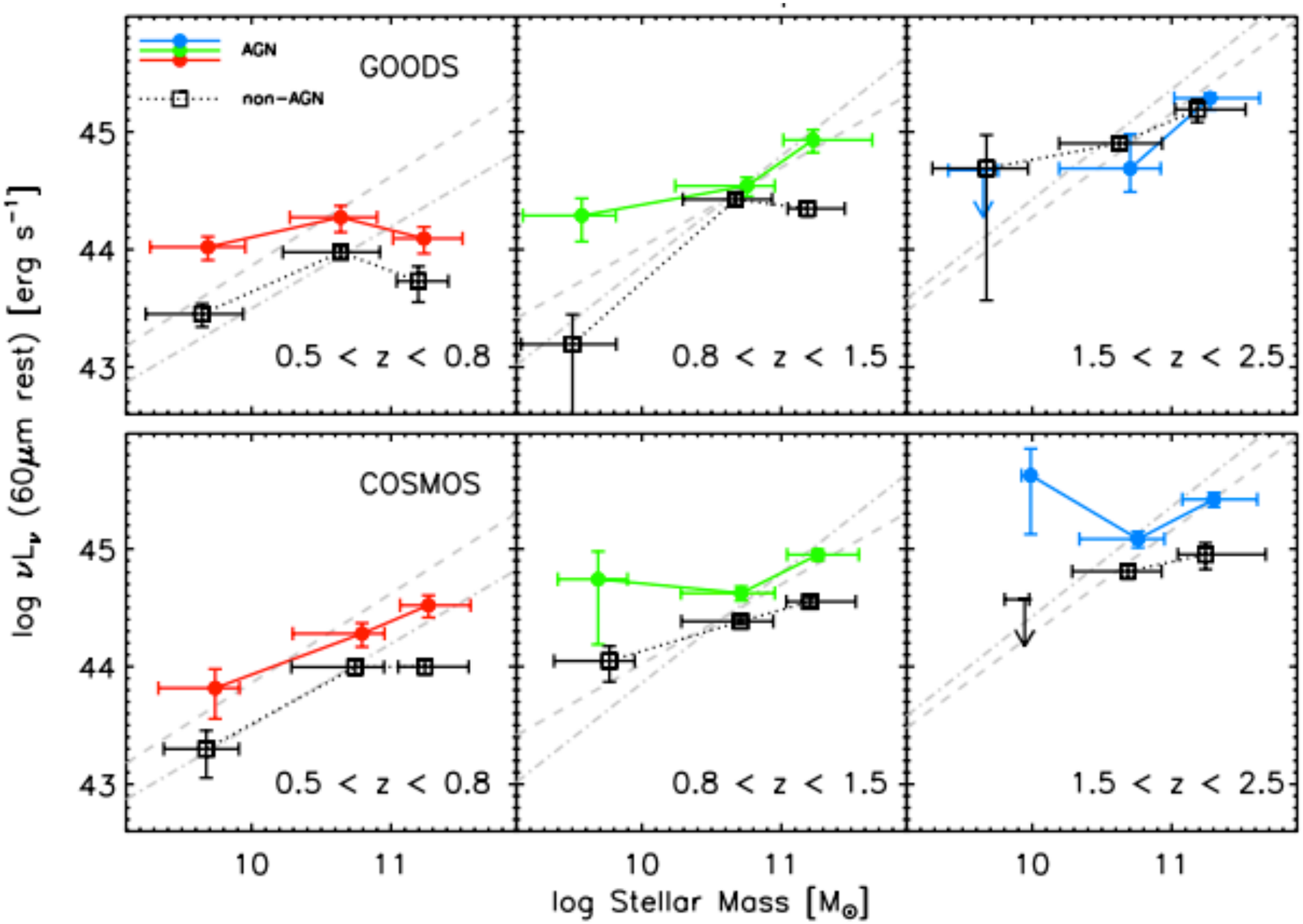
[Juneau talk]

BH growth (sBHAR) evolves like galaxy growth (sSFR)



Mullaney, et al. (2012b) see also Aird et al. (2012; 2013), Bongiorno et al. (2012); Rosario et al. (2013b). Stanely et al (2014)

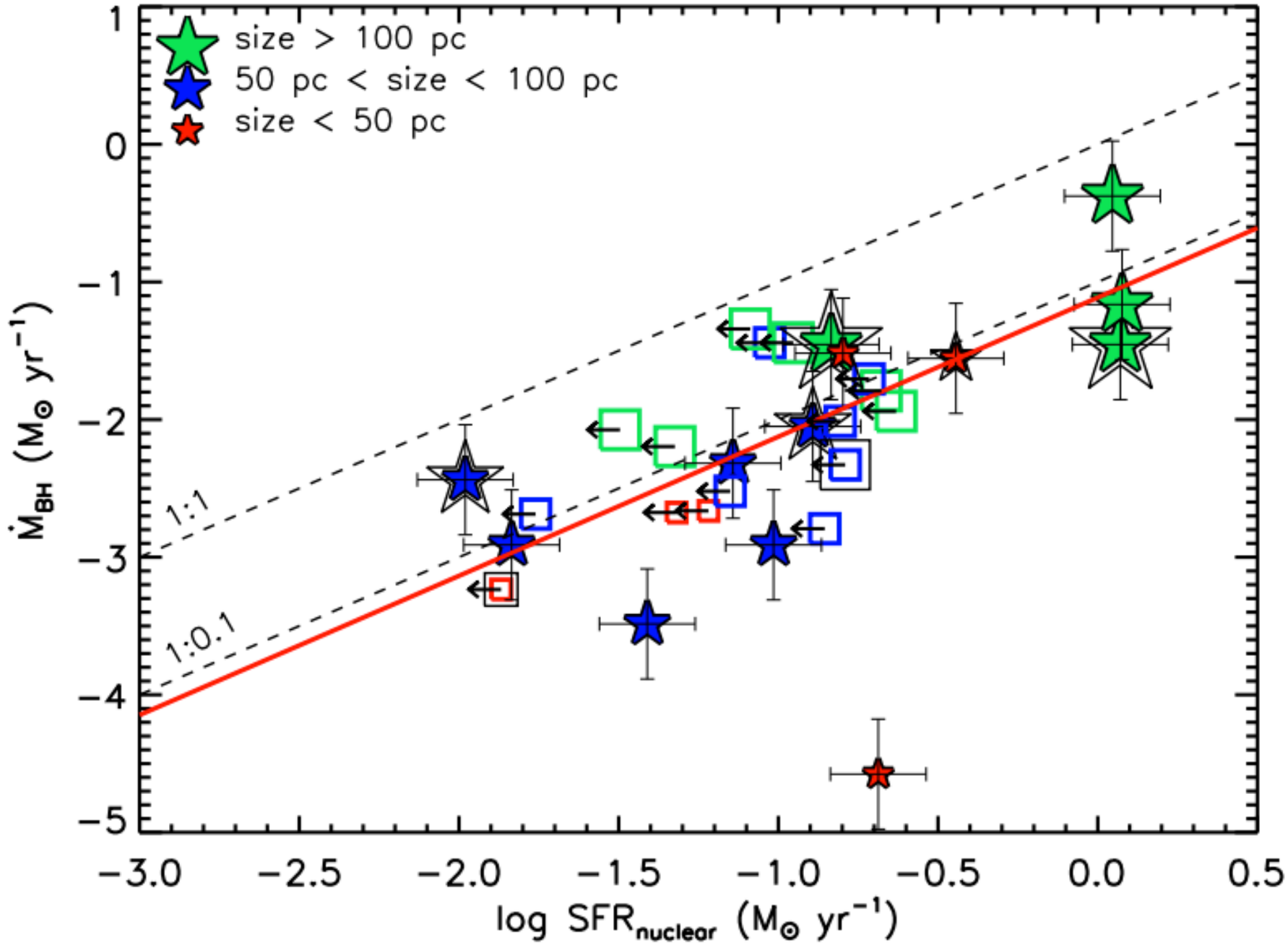
Higher star formation rates and gas masses for AGN than in mass-color matched galaxies



[Vito talk]

Santini et al. (2012), Vito et al. (2014)

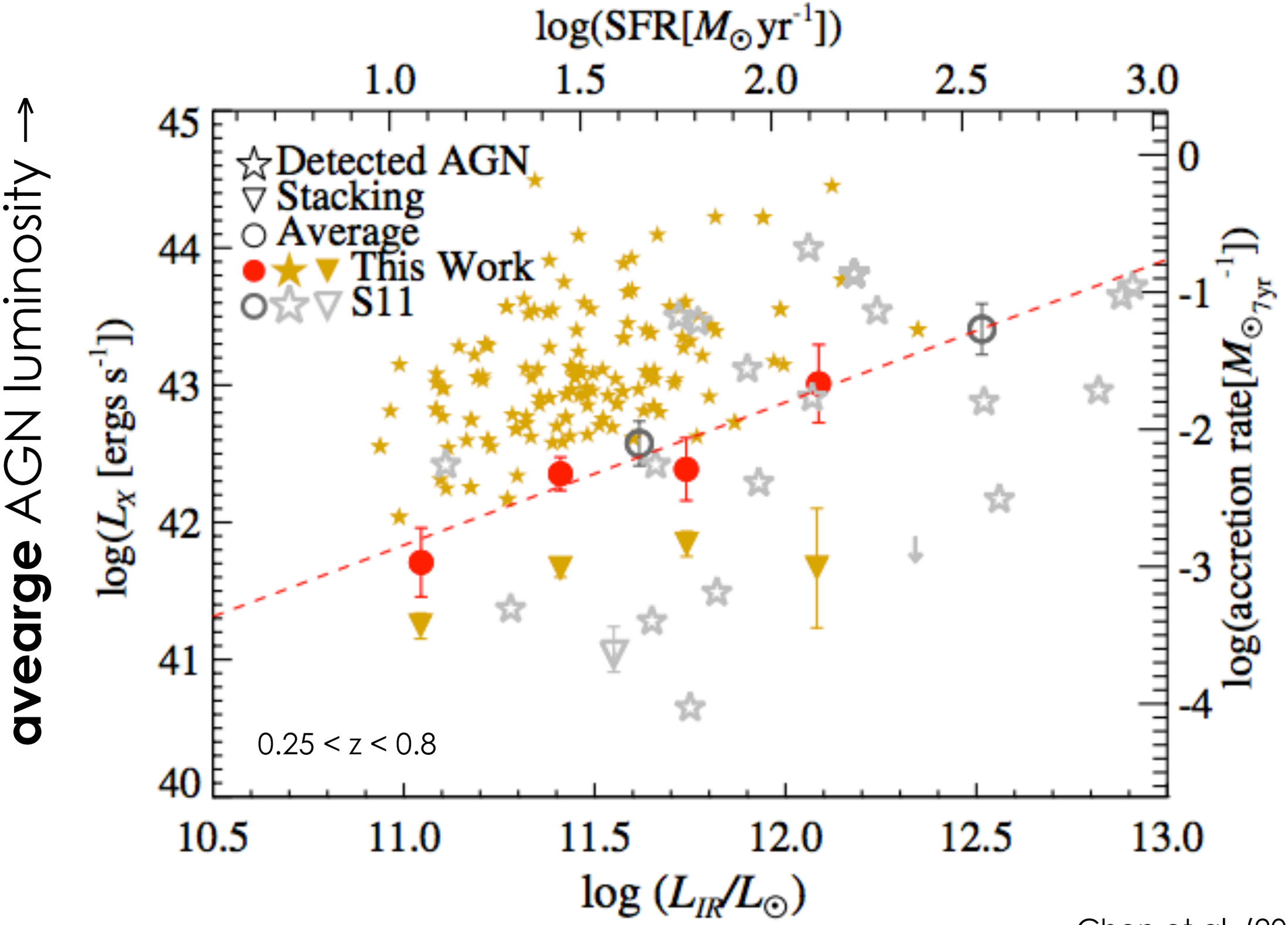
BH accretion strongly correlated with **nuclear star formation** for individual AGN



[Shimizu talk]

Esquej et al. (2014); see also Diamond-Stanic et al. (2012); LaMassa et al. (2013)

Global SFR is correlated with ***average* BHAR**



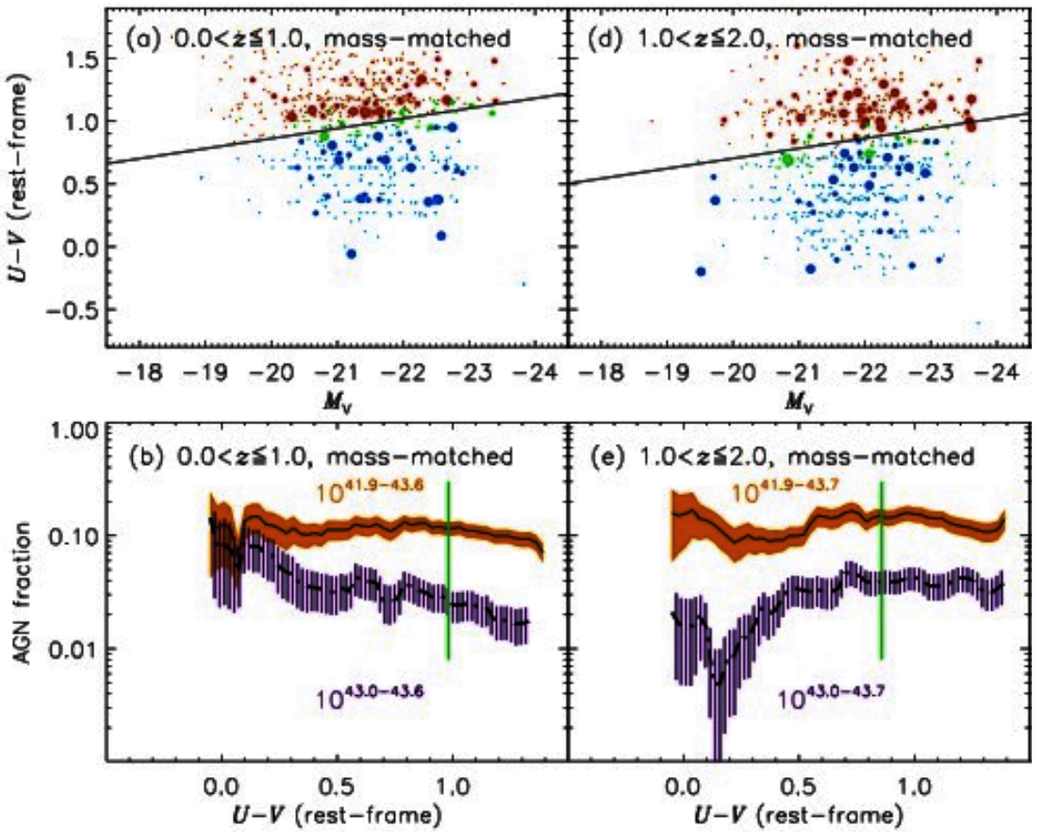
avearge AGN luminosity →

observed IR luminosity →

Chen et al. (2013)

BUT for typical AGN: small or zero difference between AGN hosts and "normal" galaxies?

- **Optical colors**



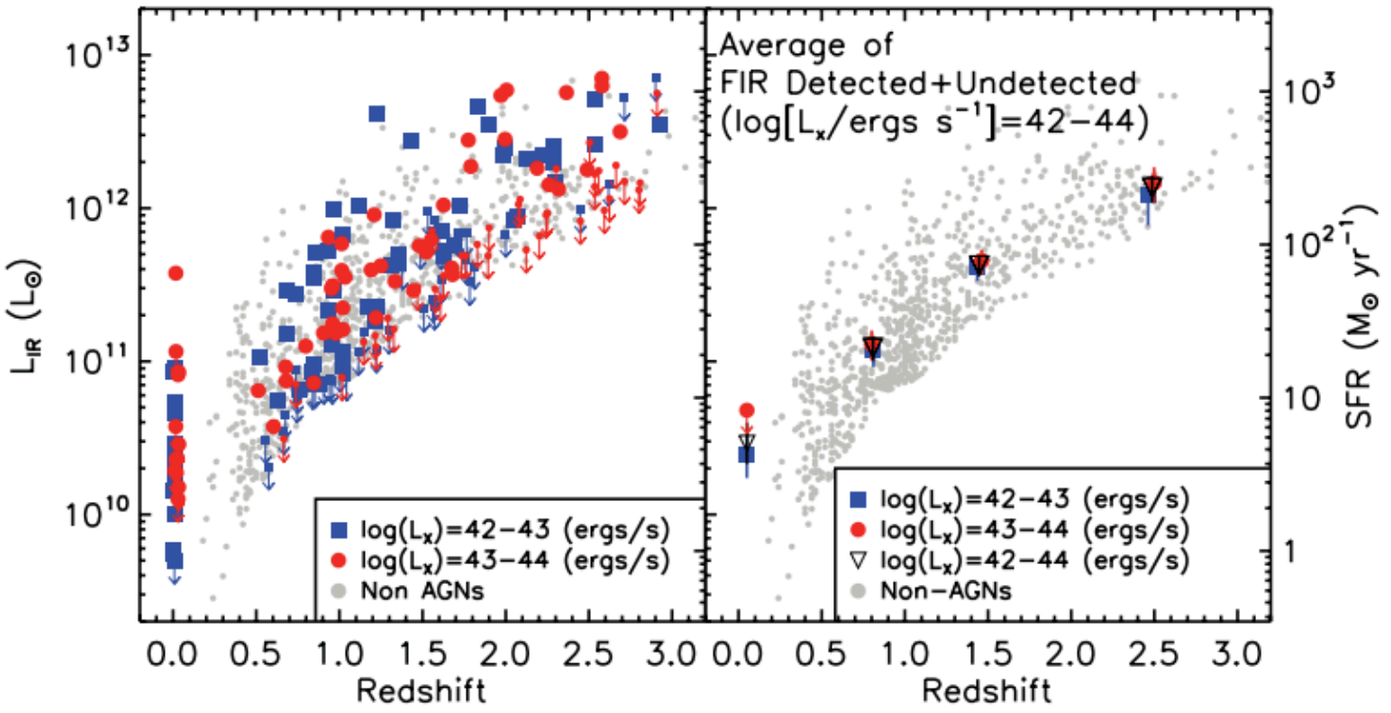
Xue et al. (2010)

see also Cardamone et al. (2010), others...

- **Clustering**

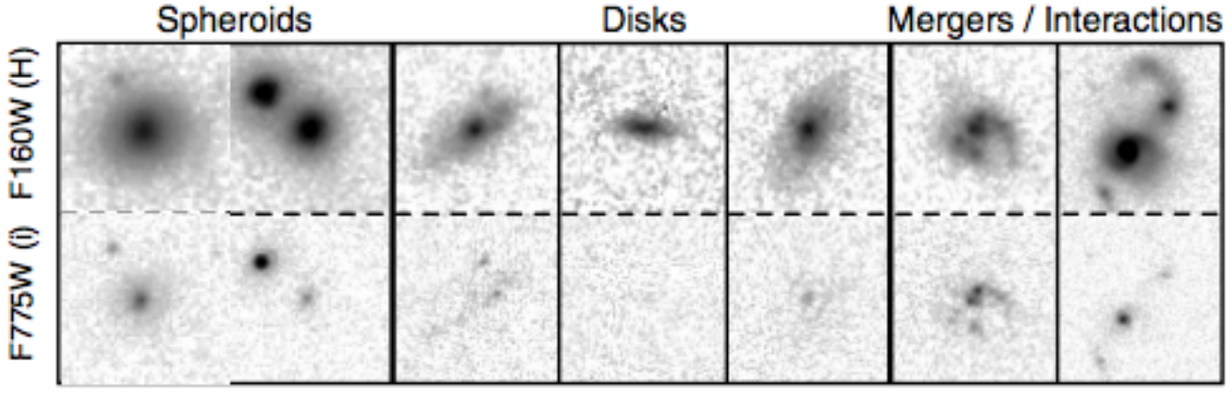
Hickox et al. (2009); Coil et al. (2009); many others

- **SFRs**



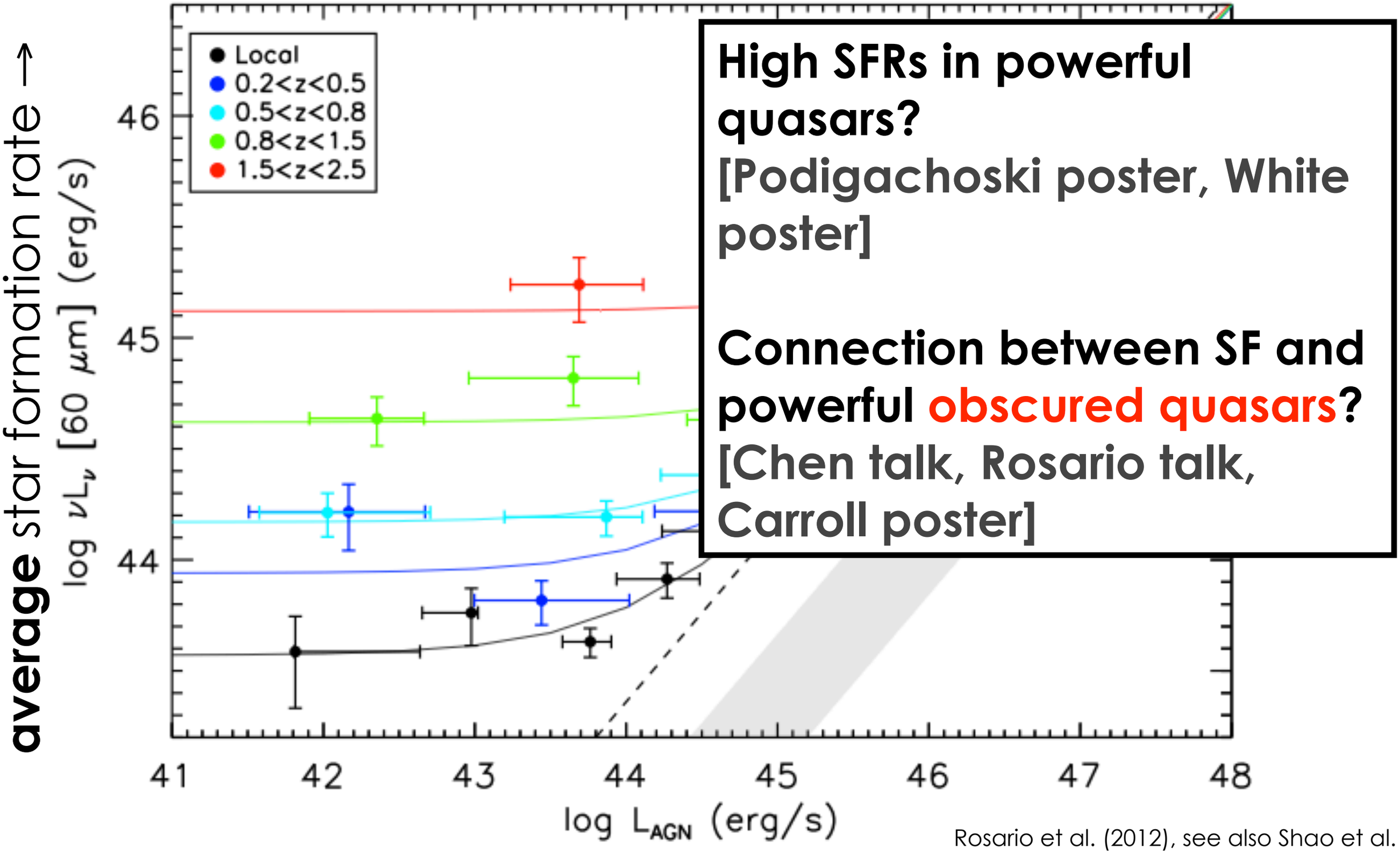
Mullaney et al. (2012a), see also Rosario et al. (2013a,b)

- **Morphologies**



Kocevski et al. (2012); see also Georgakakis et al. (2009); Cisternas et al. (2010); Schawinski et al. (2011); and others

BUT: Weak correlation between AGN luminosity and SF?



average star formation rate →

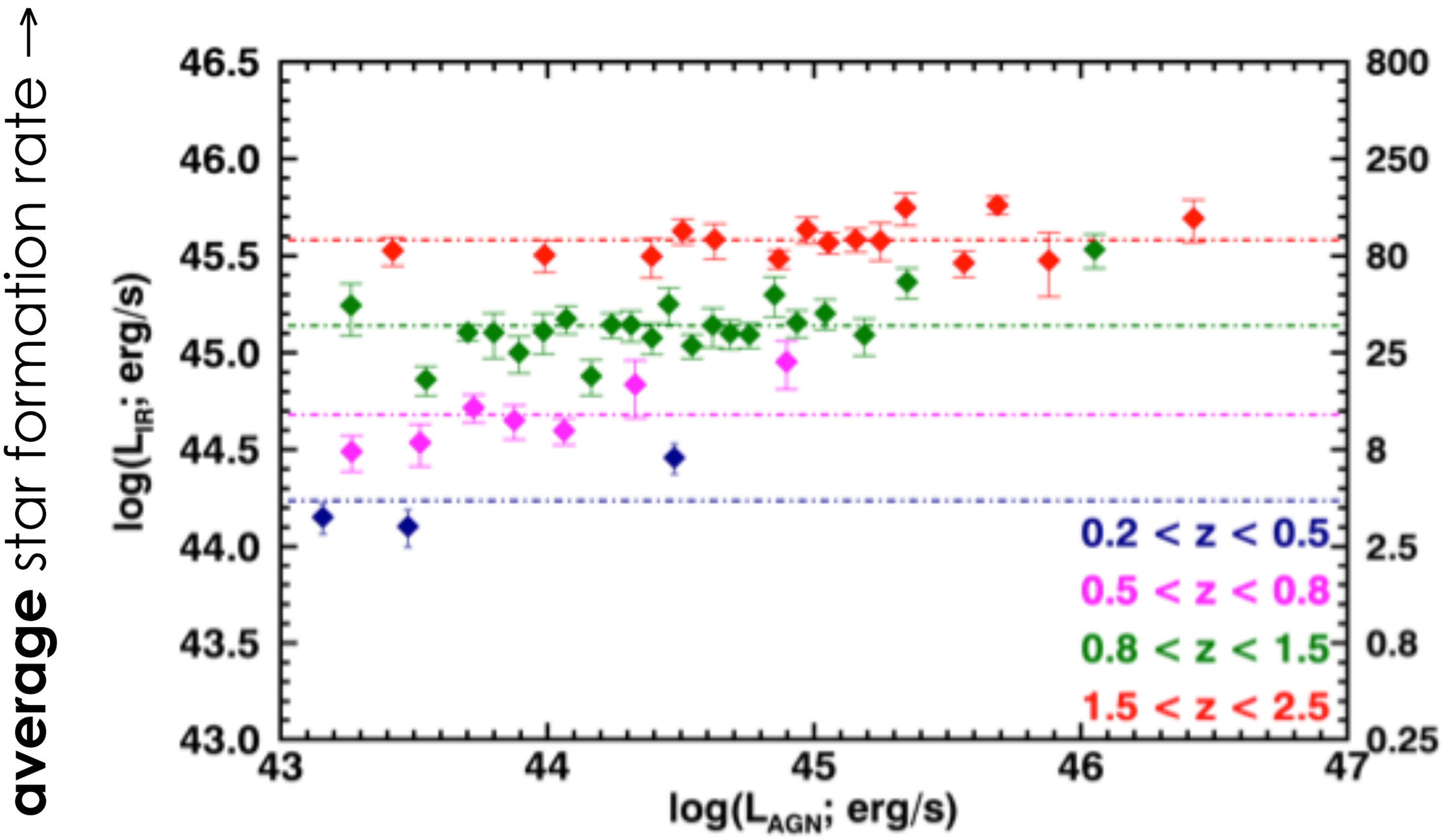
observed AGN luminosity →

High SFRs in powerful quasars?
[Podigachoski poster, White poster]

Connection between SF and powerful obscured quasars?
[Chen talk, Rosario talk, Carroll poster]

Rosario et al. (2012), see also Shao et al. (2010), Mullaney et al. (2010, 2012), Rovilos et al. (2012), Harrison et al. (2012)

Host AGN SFRs rise with redshift like the **SF main sequence?**

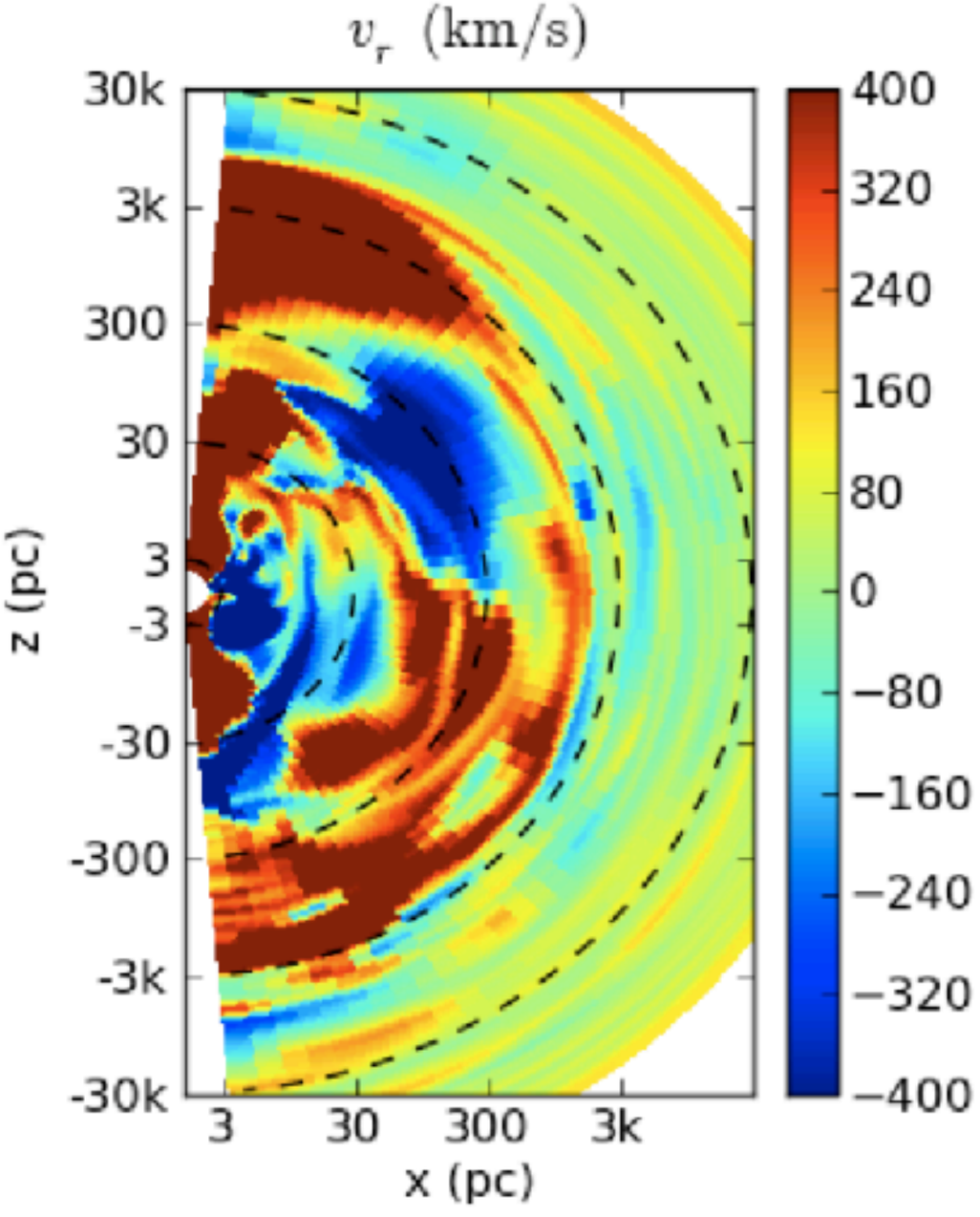


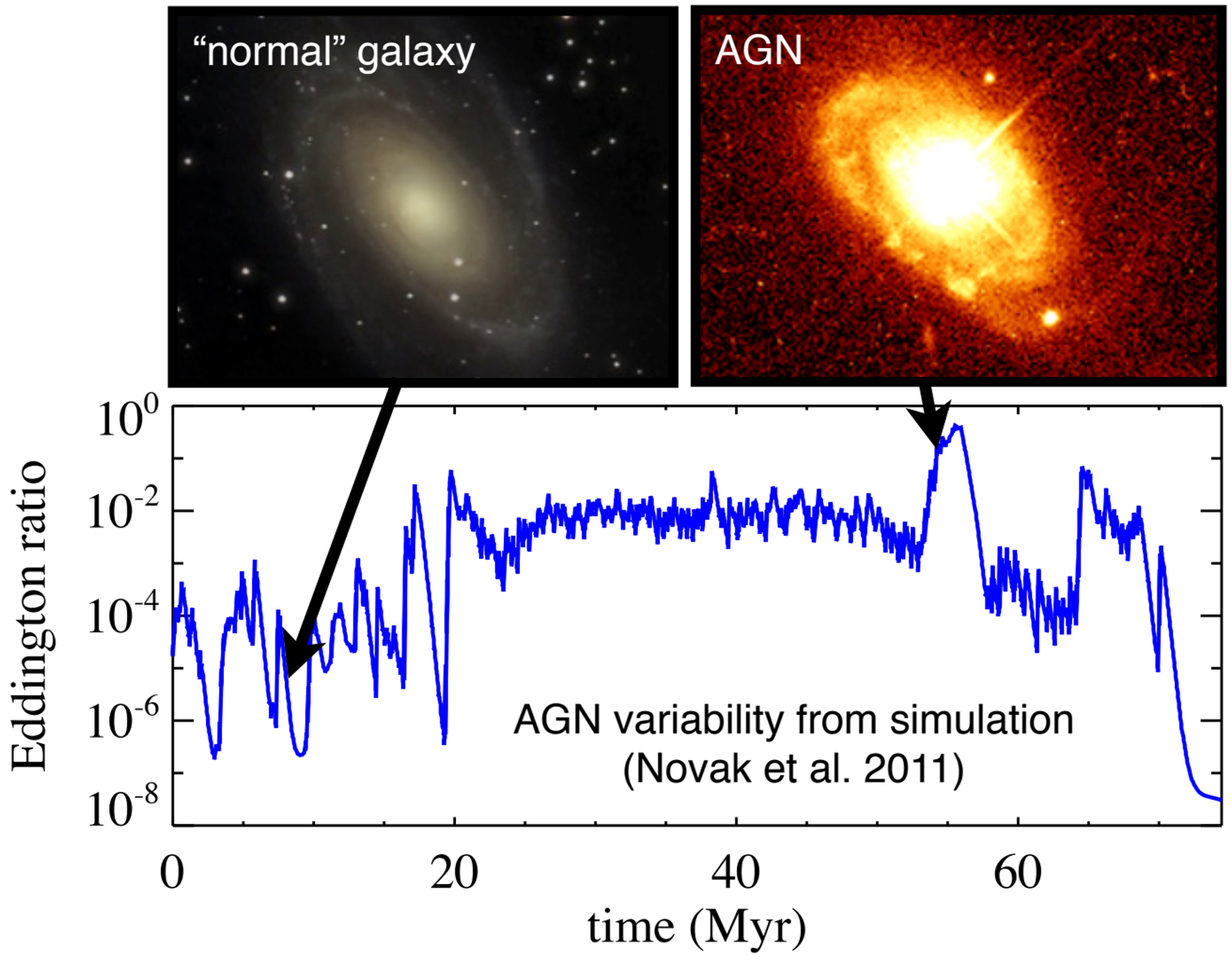
observed AGN luminosity →

[Rosario talk, Stanley poster, Matsuoka poster, Woo poster]

Stanley et al. (in prep)

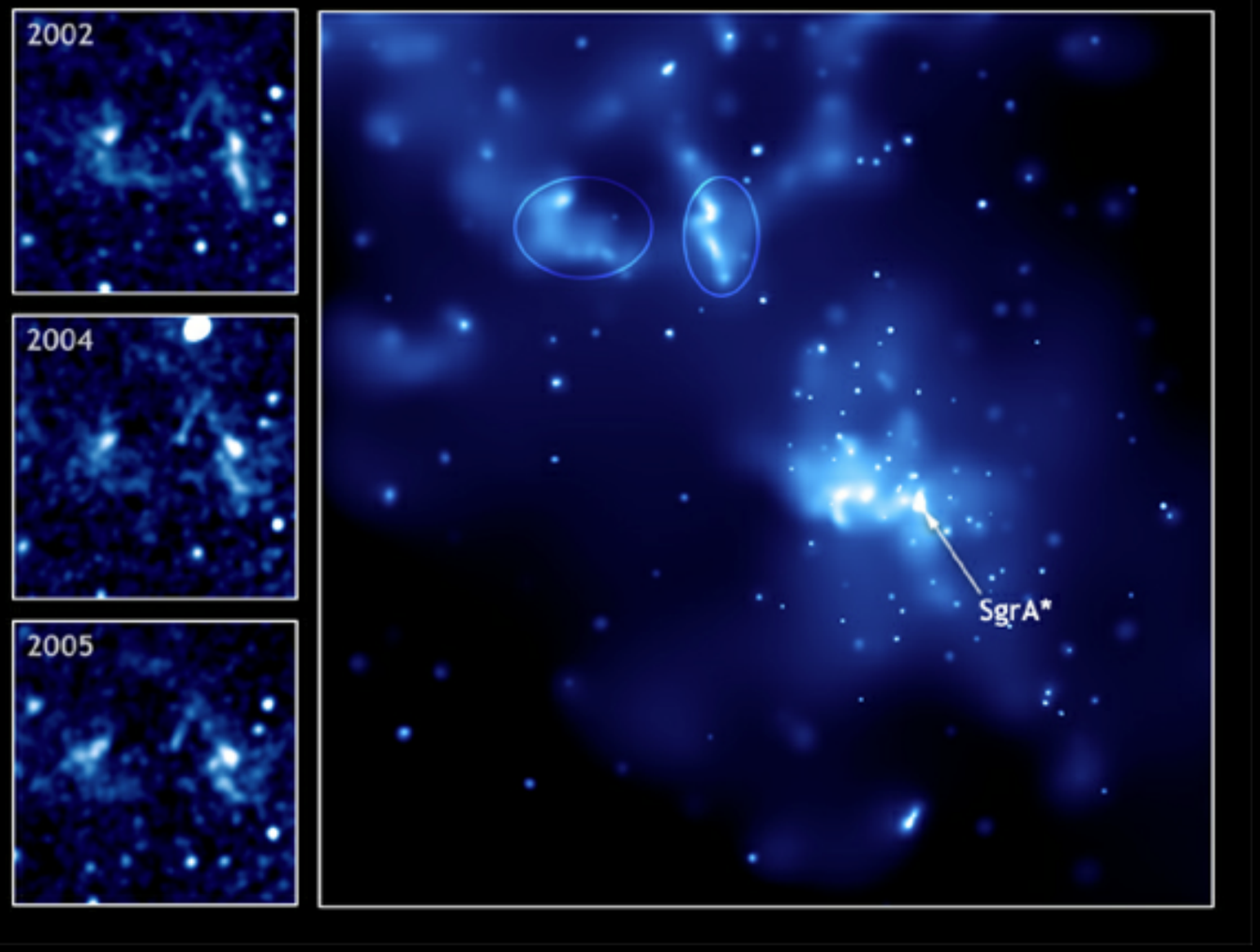
Importance of AGN **variability**





Hickox et al. (2014)

Galactic Center

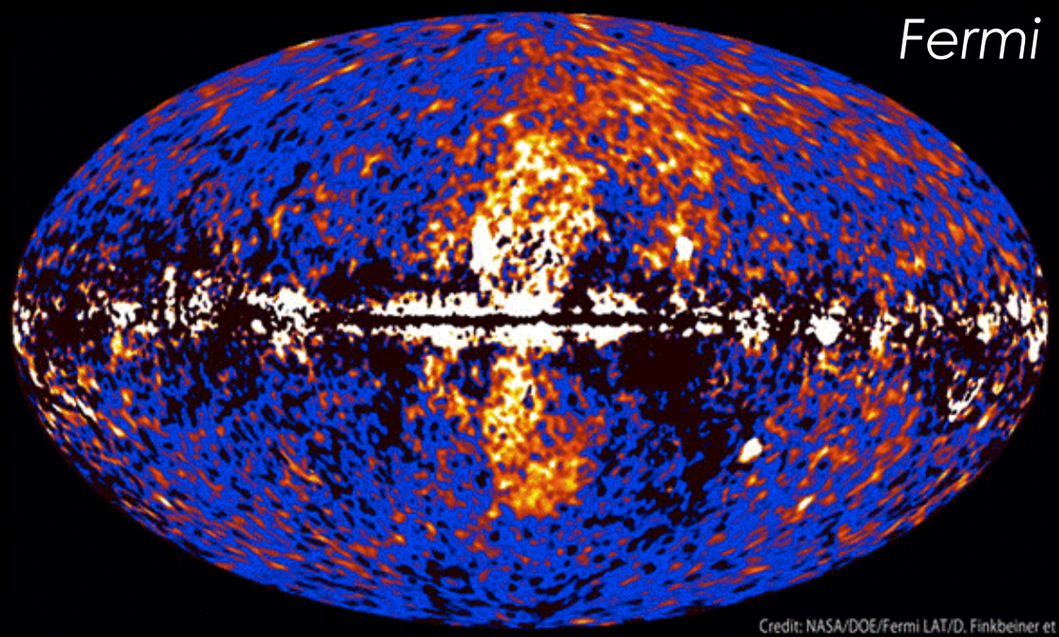


Muno et al. (2007), Ponti et al. (2010)

Hanny's Voorwerp

Schawinski et al. (2011), Keel et al. (2011)

Fermi Bubbles



Fermi Bubbles

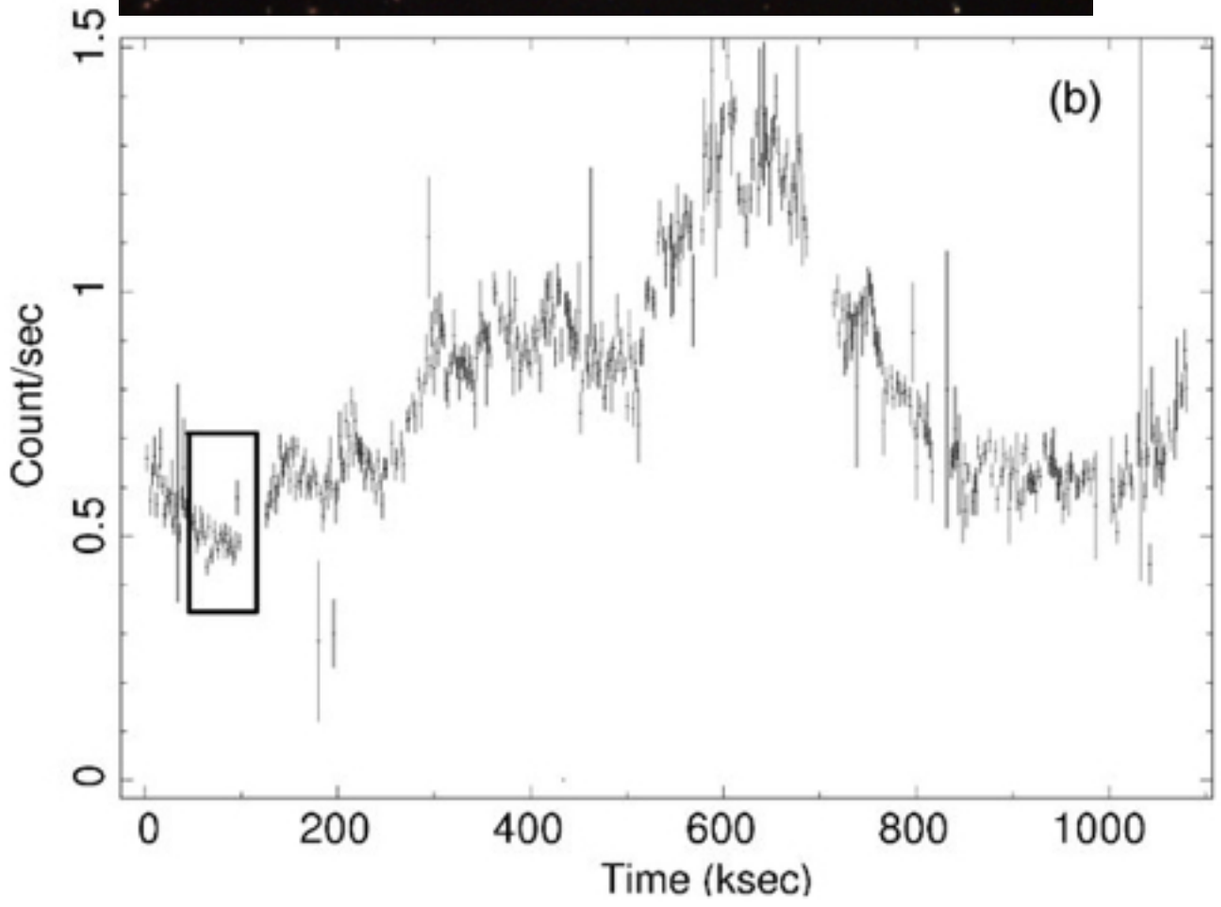
What does it mean for an AGN to be **“on”**?

A fluorescent bulb at 1000 frames per second (http://www.youtube.com/watch?v=5pNtjOYkAbA)

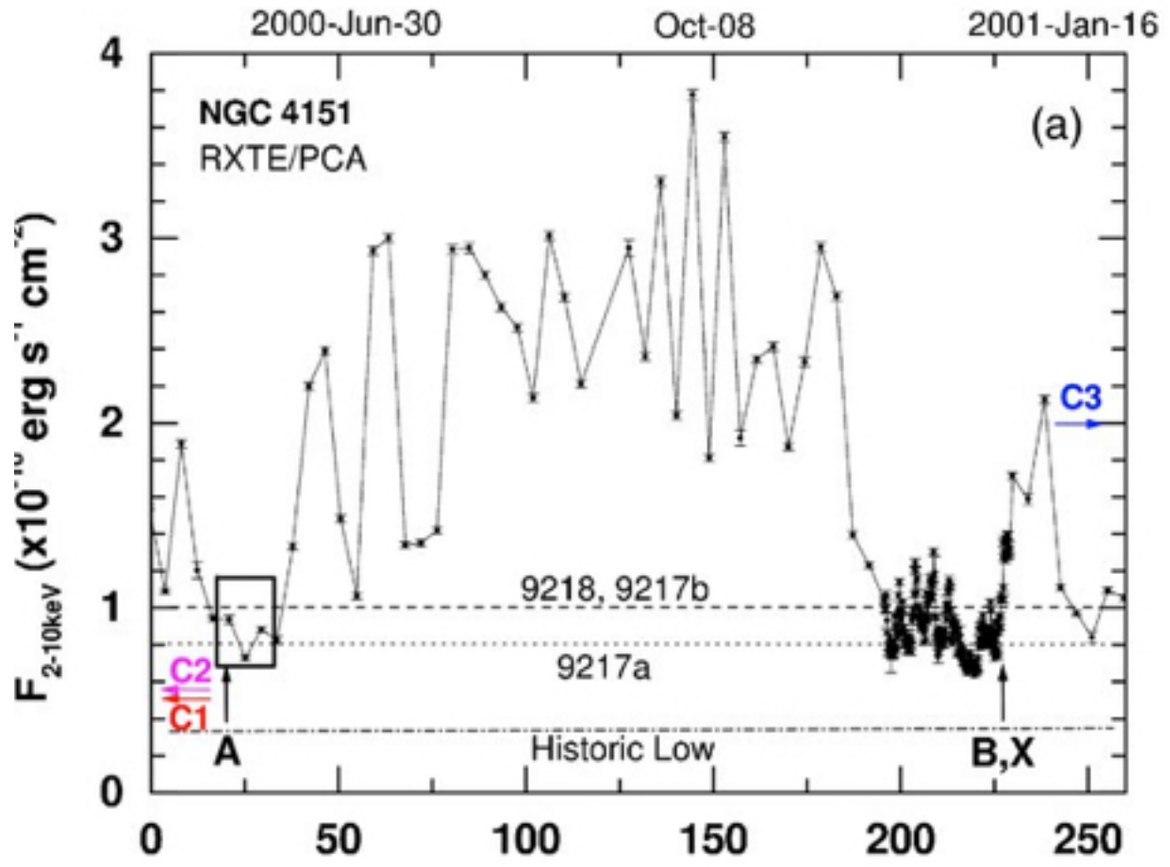
BUT…

NOT observable as "variability"

Wang et al. (2010)

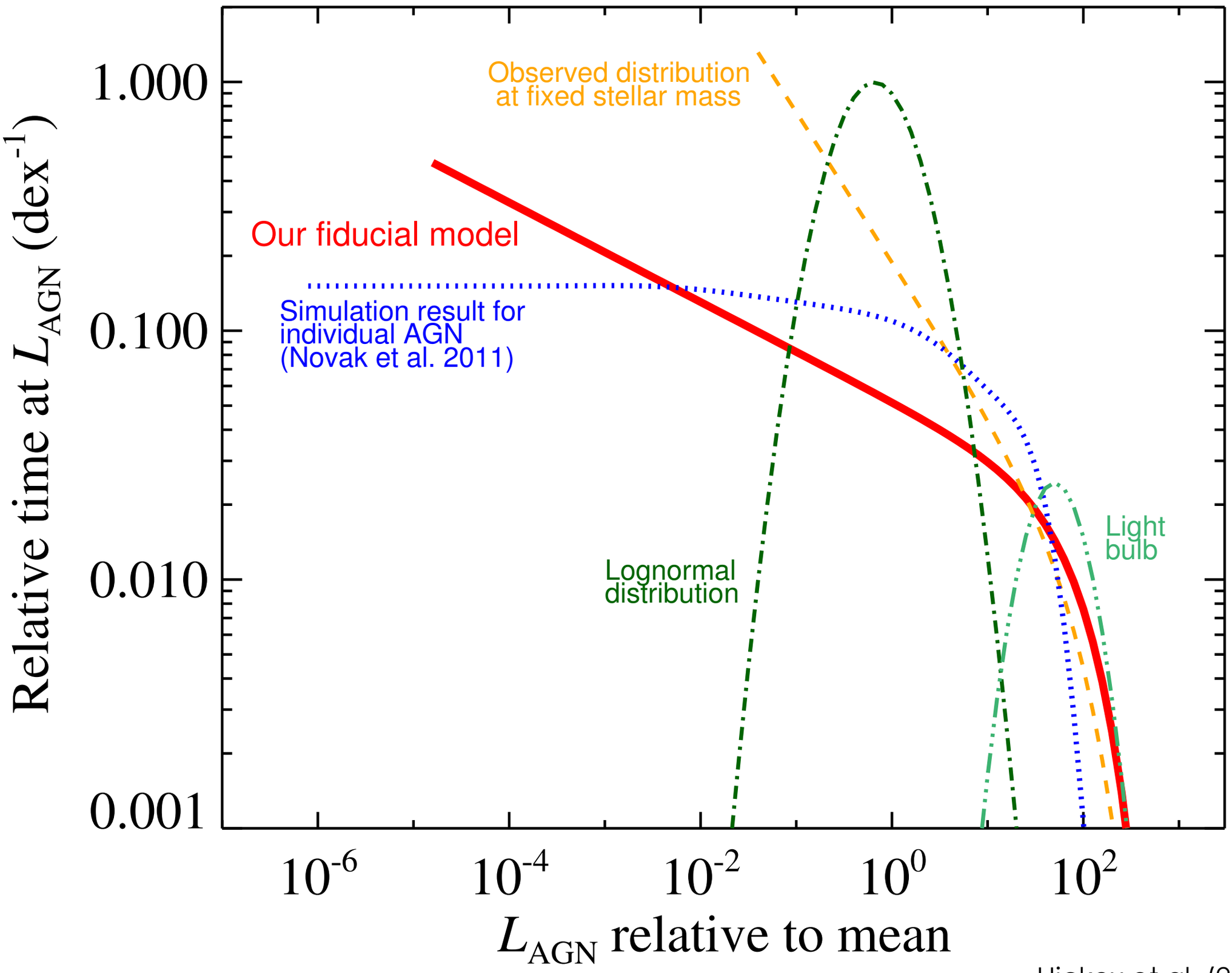


~days



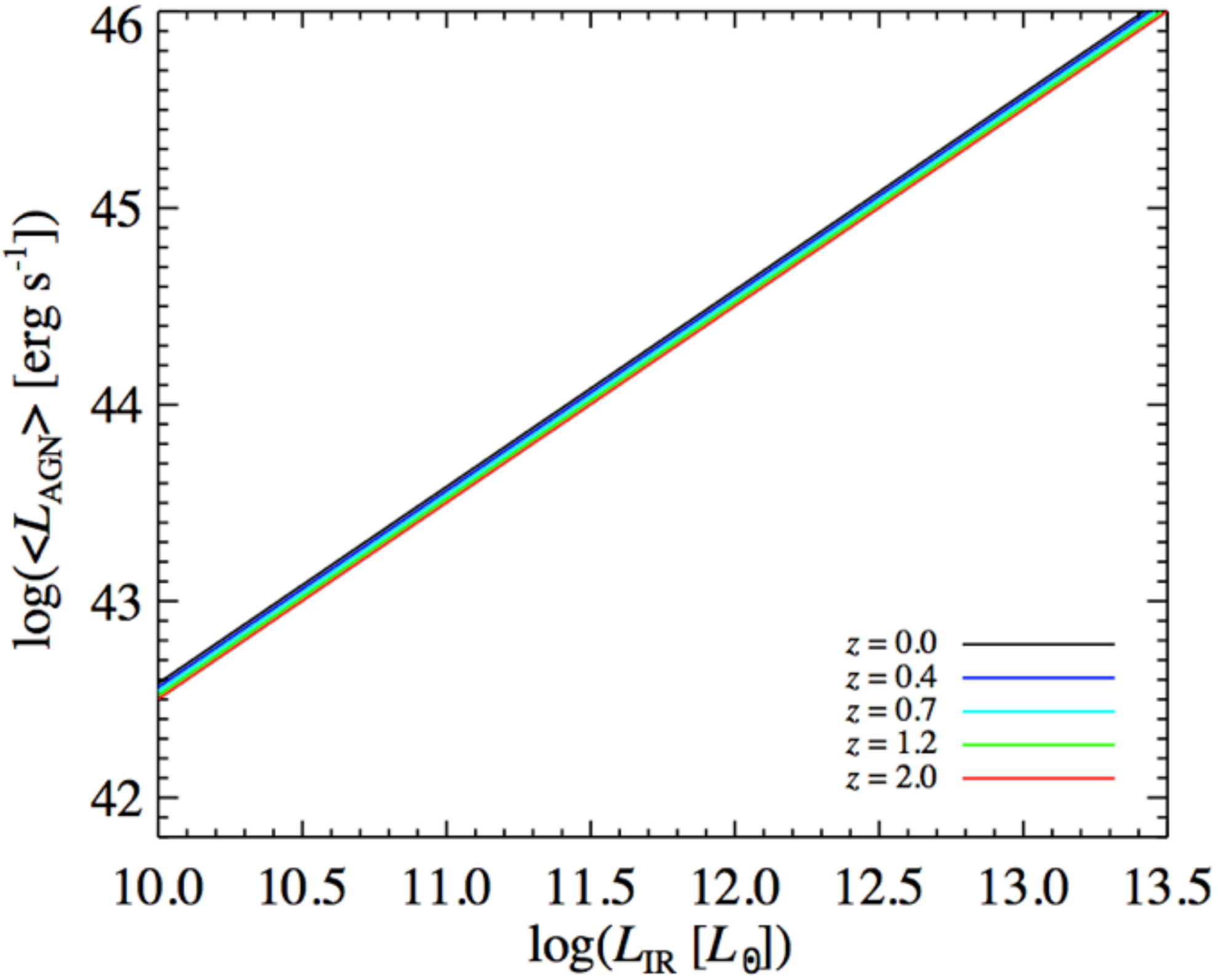
~months

Variation over many orders of magnitude

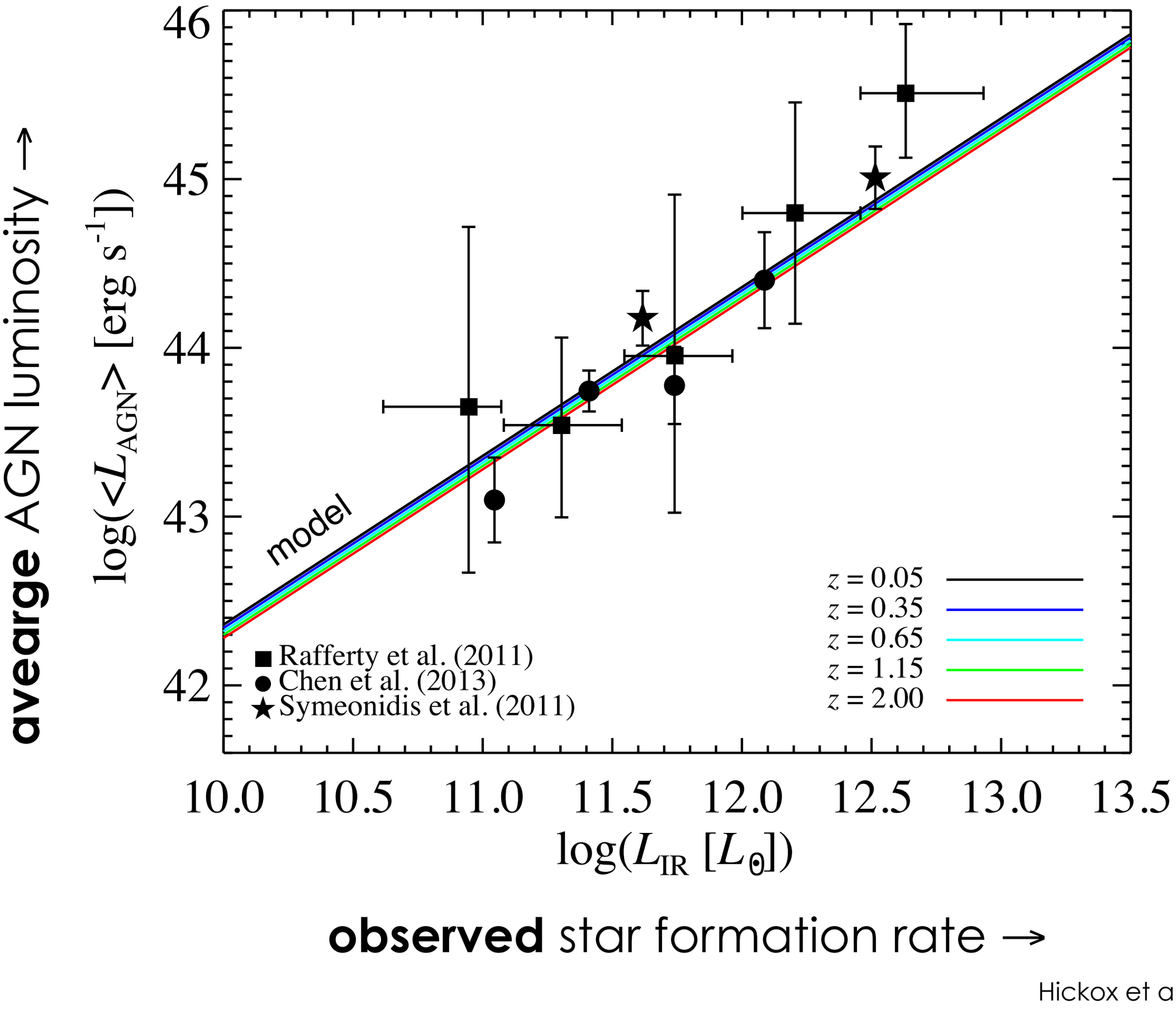


Hickox et al. (2014)

avearge AGN luminosity →

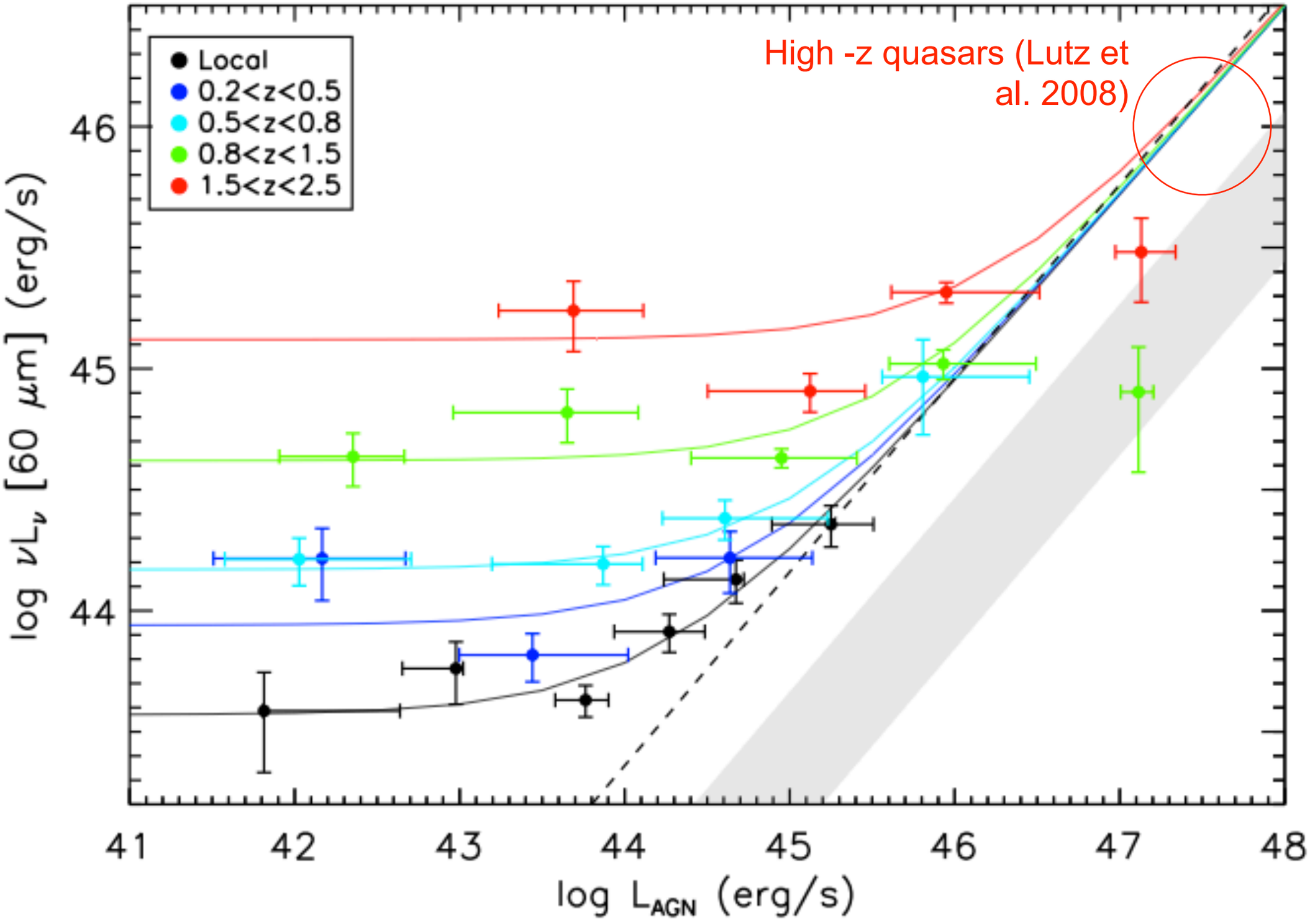


observed star formation rate →



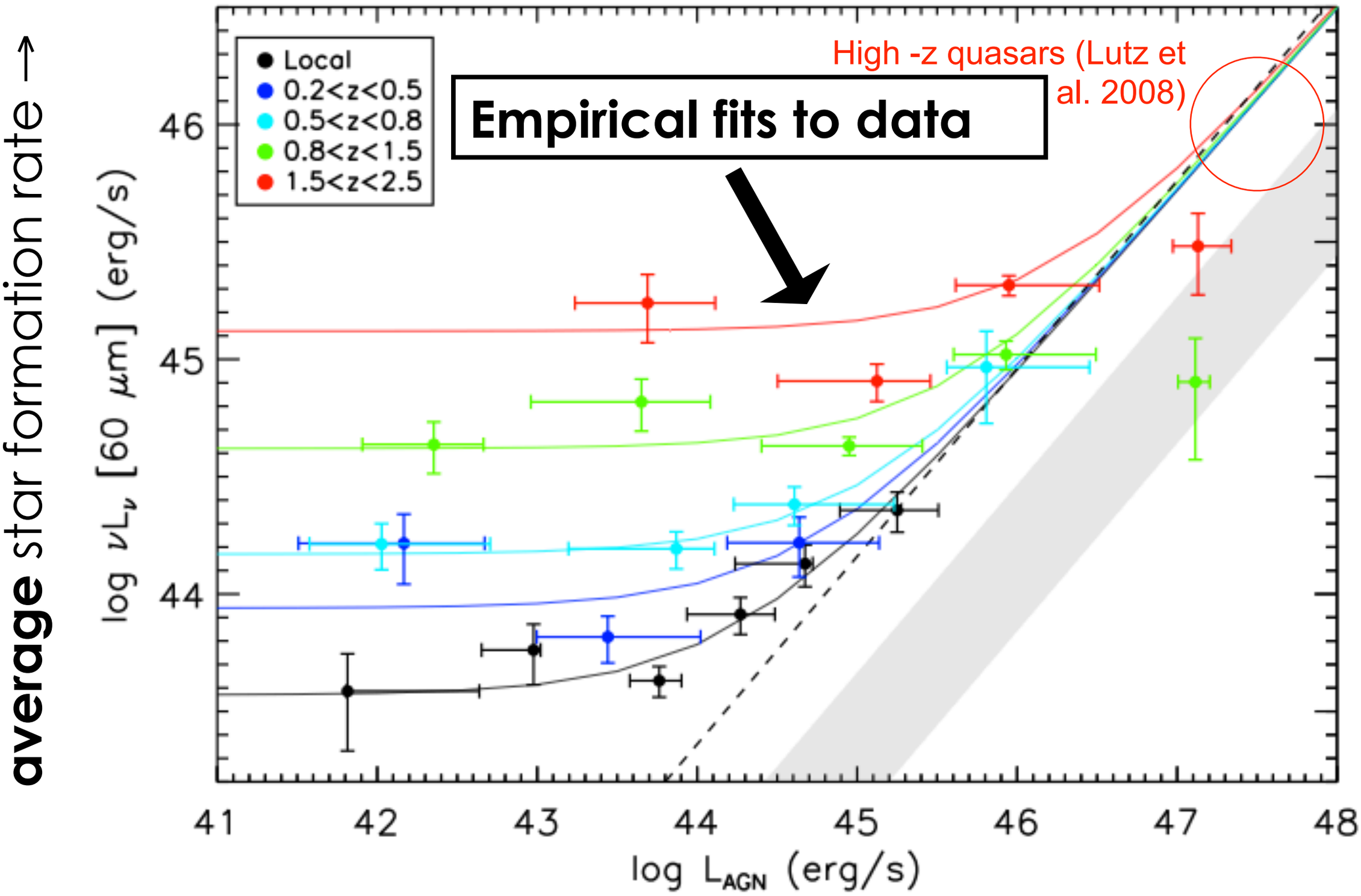
Hickox et al. (2014)

average star formation rate →

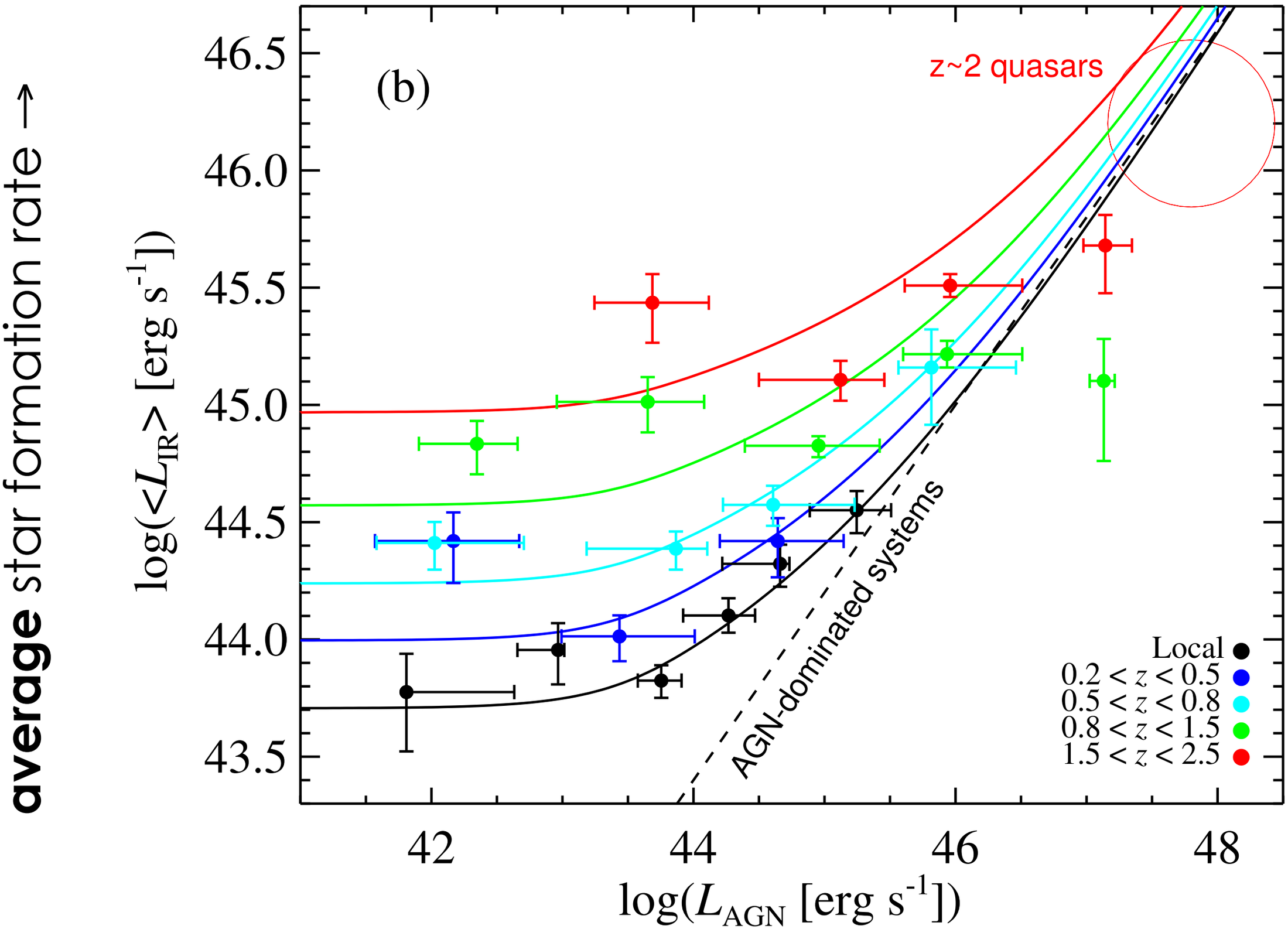


observed AGN luminosity →

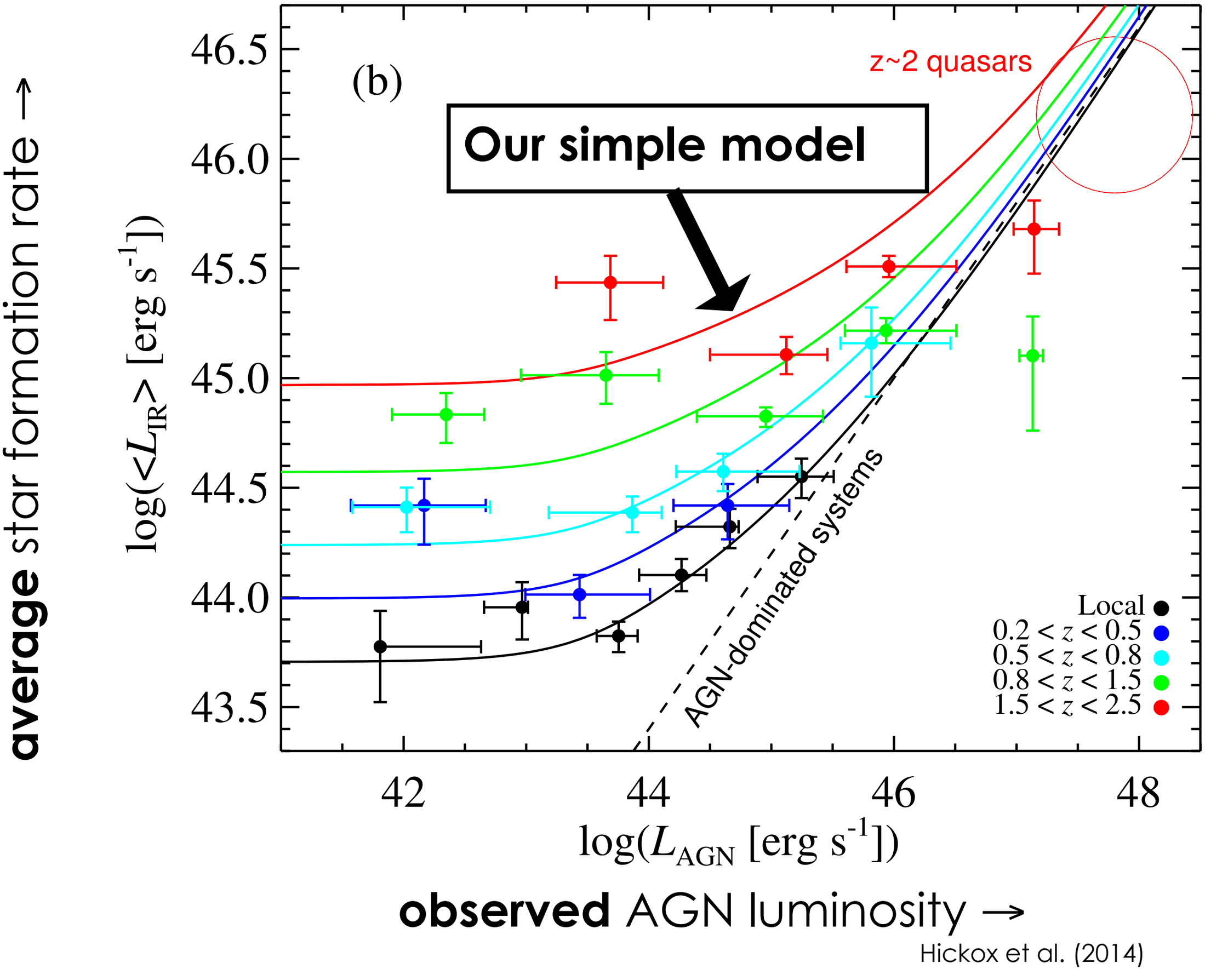
Rosario et al. (2012)



Rosario et al. (2012)

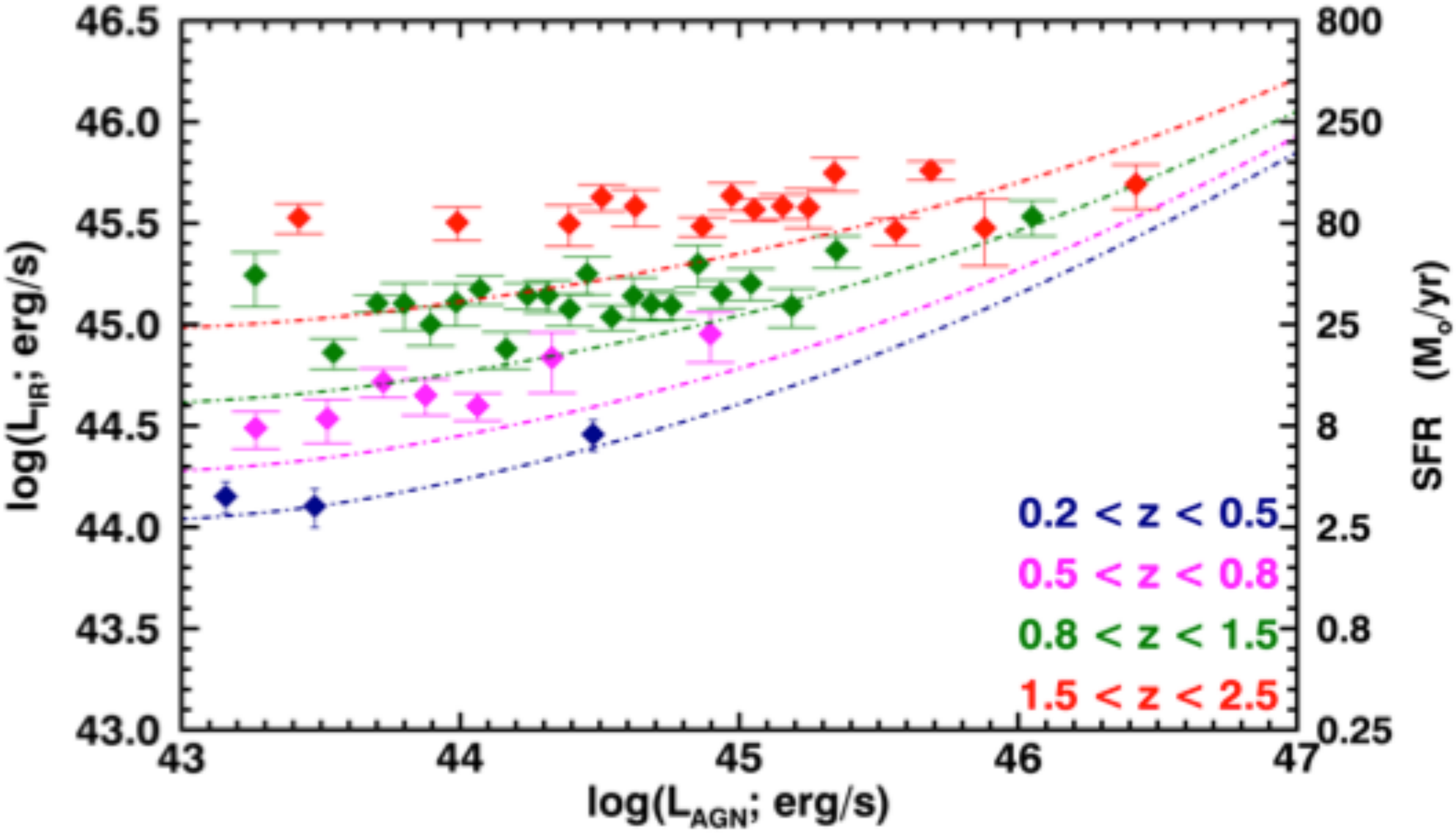


Hickox et al. (2014)



Hickox et al. (2014)

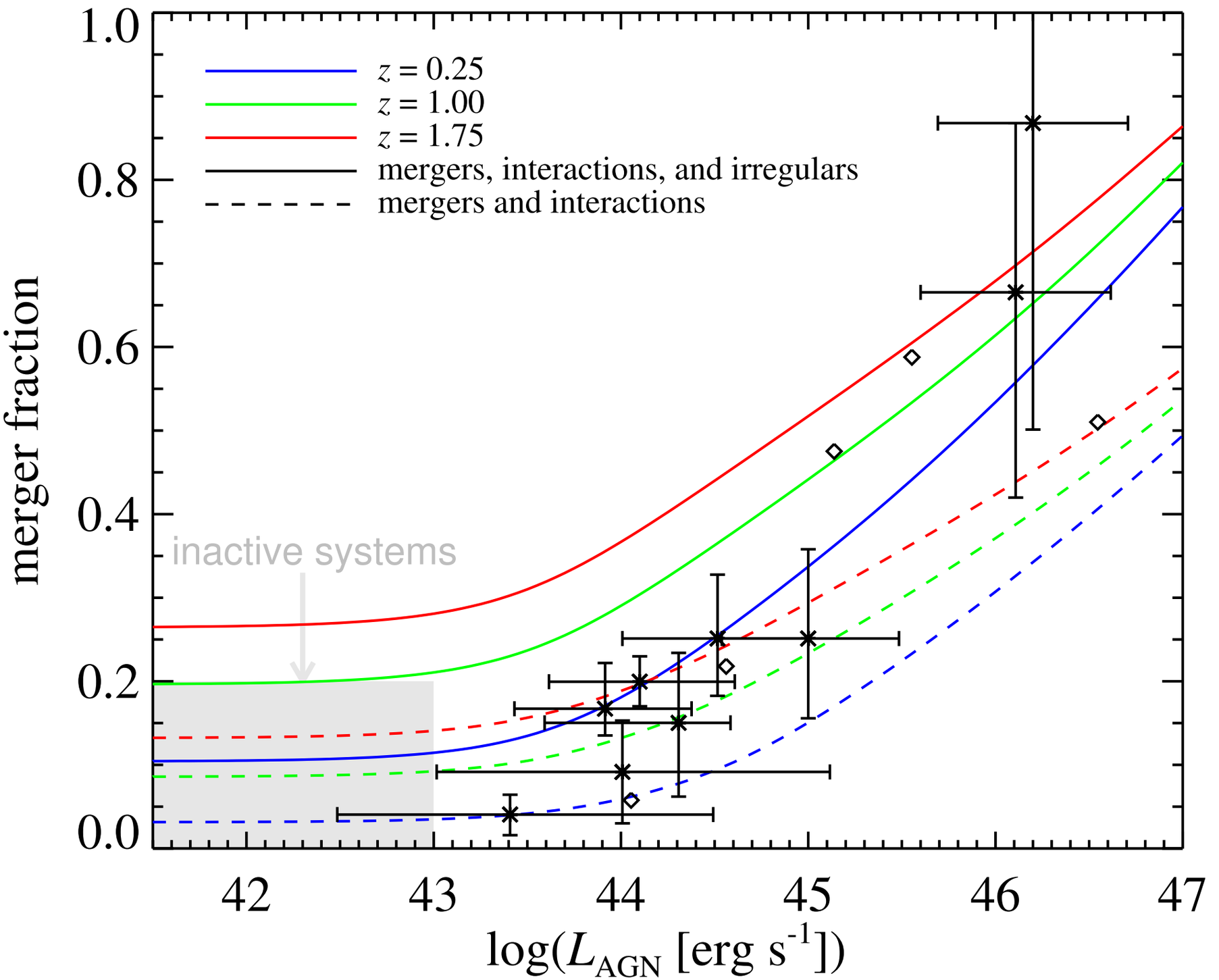
average star formation rate →



observed AGN luminosity →

See **poster by Stanley**

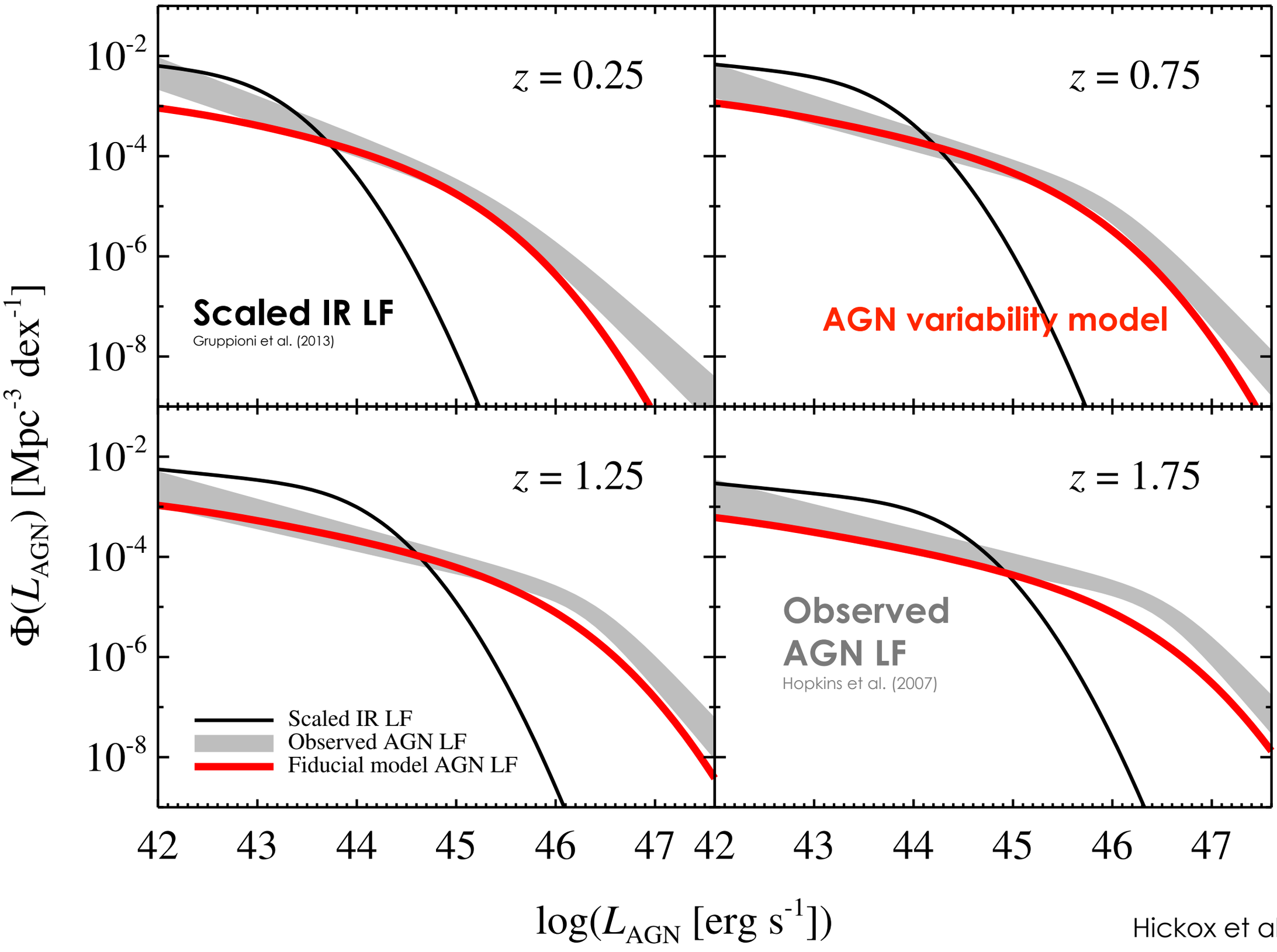
Connection to **mergers**



SF merger fractions from Kartaltepe et al. (2012)
AGN data from Treister et al. (2012)

Hickox et al. (2014)

Modeling the AGN **luminosity function**

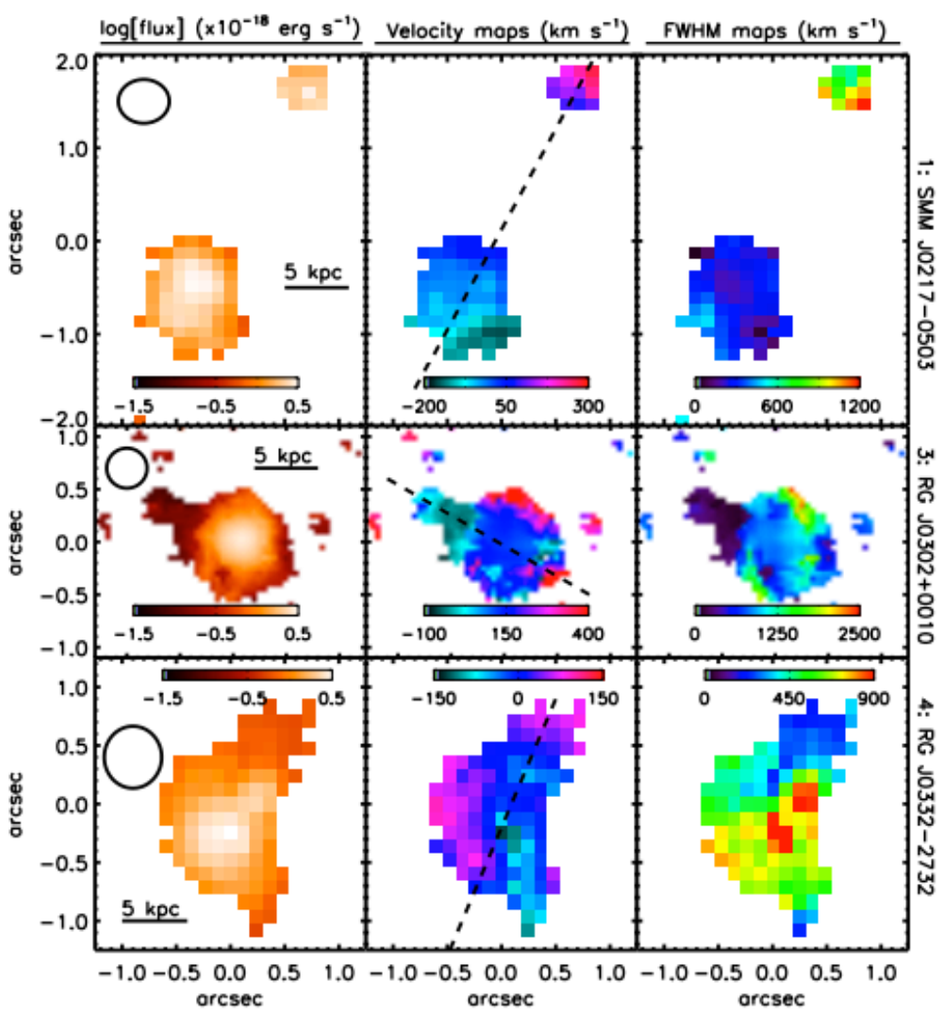


Hickox et al. (2014)

How about **radiatively-driven feedback?**

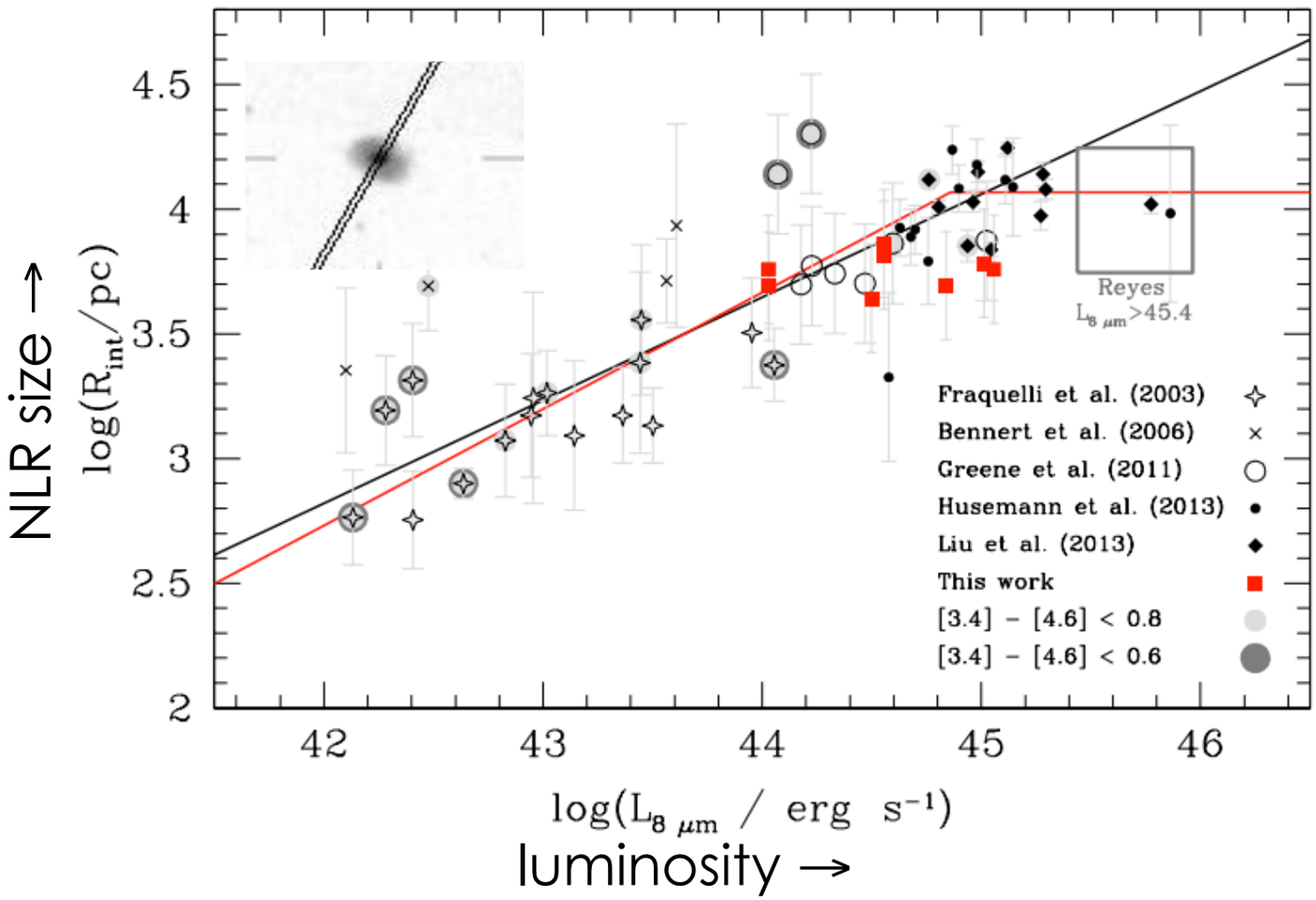
Credit: ESO

Powerful radiatively-driven feedback



Broad (> 1000 km/s) high-velocity (200-500 km/s) [OIII] gas

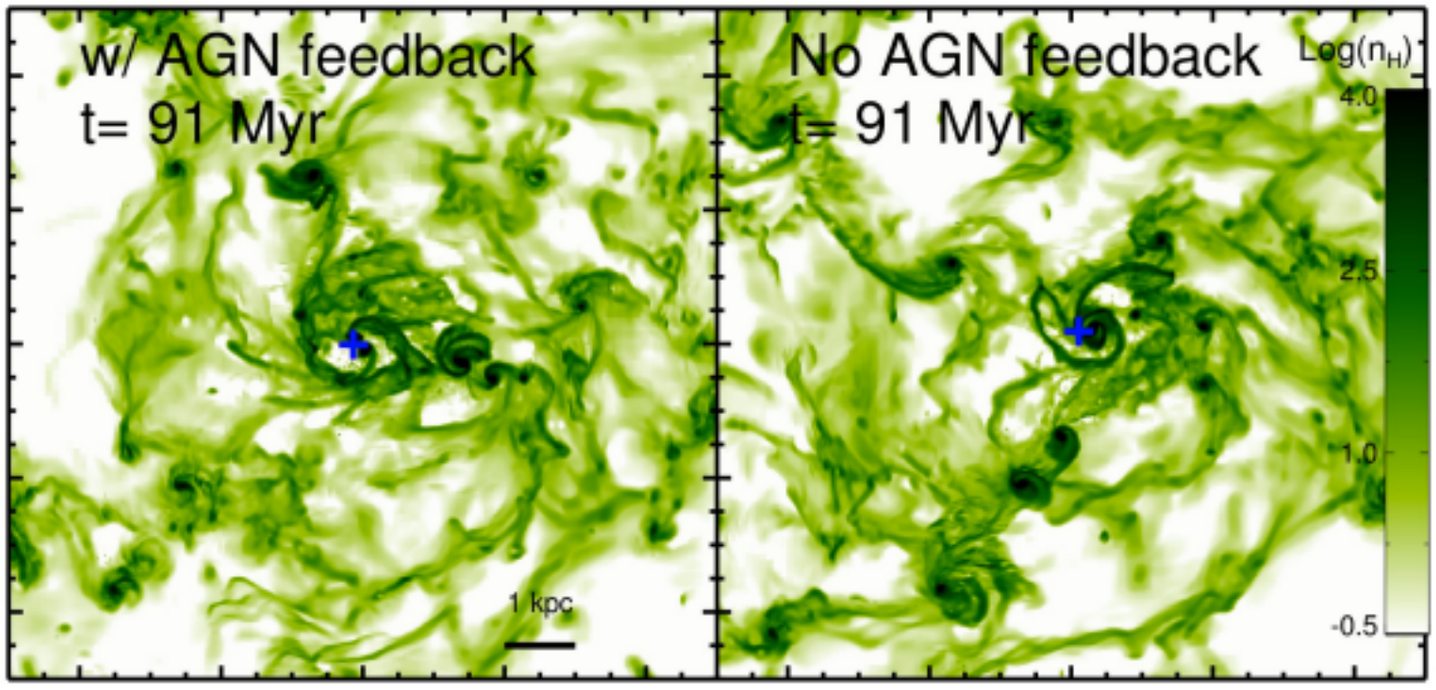
Harrison et al. (2012)

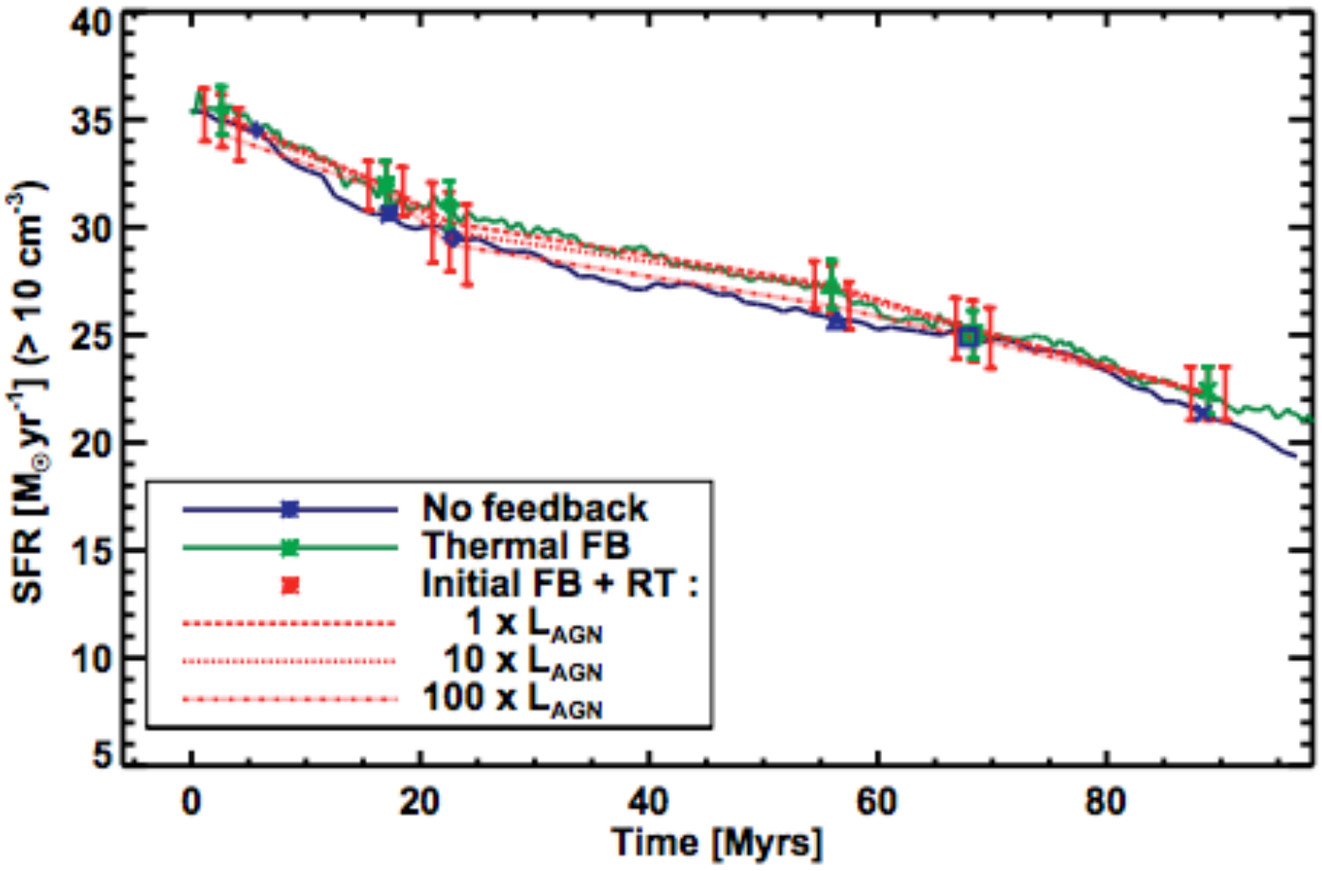


Galaxy-wide photoionization from powerful quasars

Hainline et al. (2013, 2014) **see poster**

No significant effect on high-z star-forming galaxies?

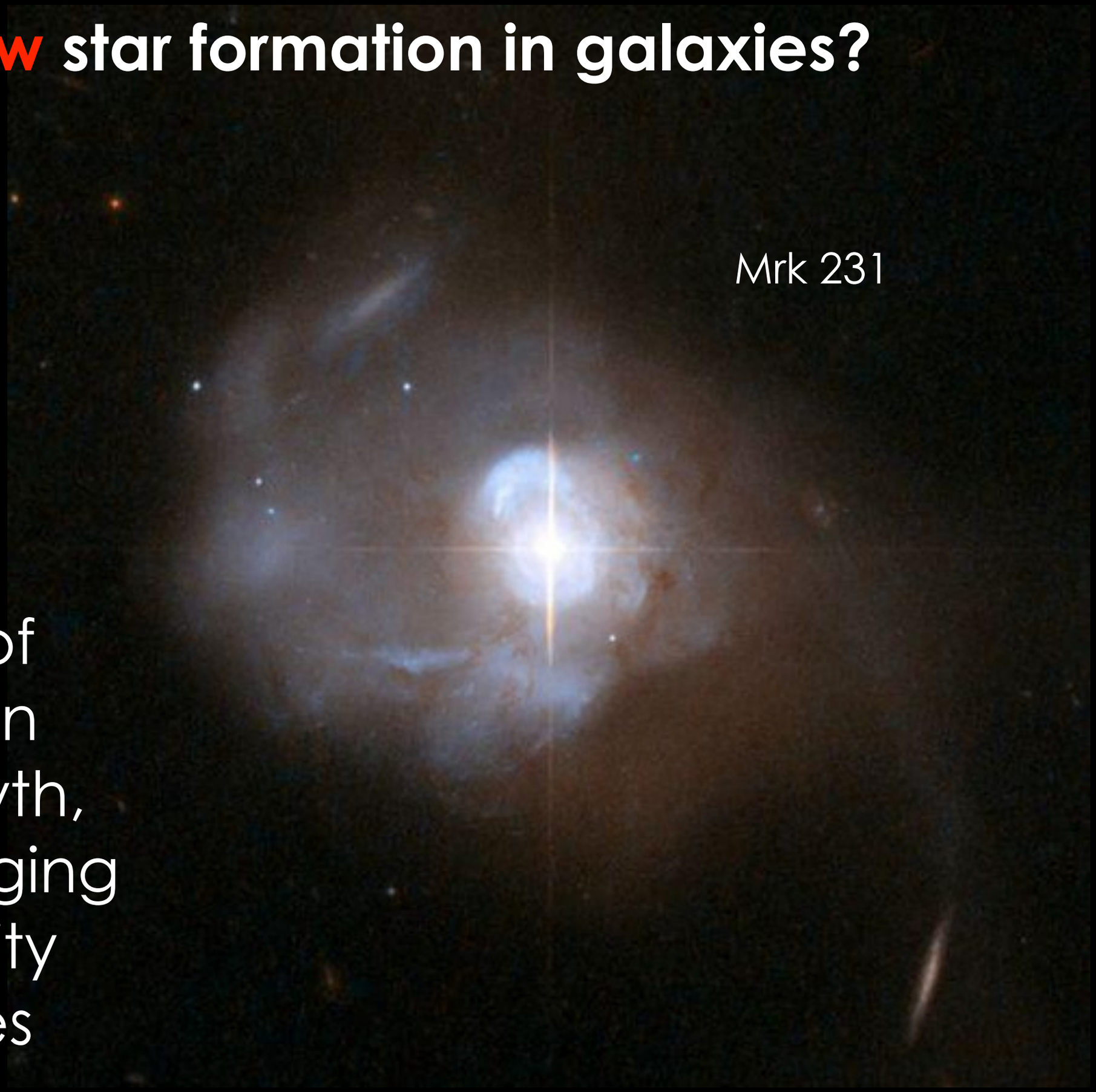




Gabor & Bournaud (2014),
Roos et al. (2014)

But **positive feedback from AGN may trigger SF?**
(e.g., Zubovas et al. 2013,
Nayakshin et al. 2013)

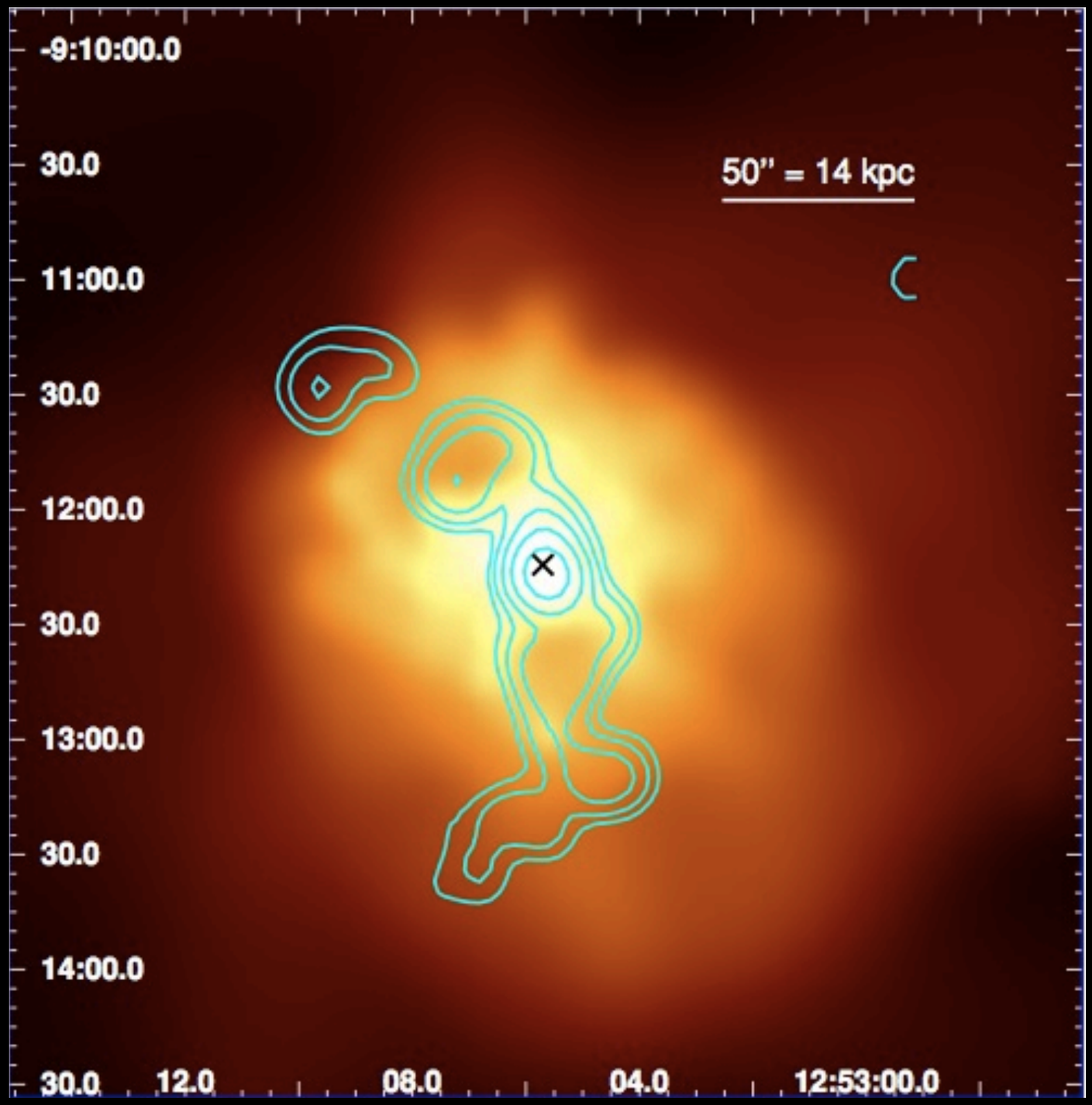
Do AGN follow star formation in galaxies?



YES

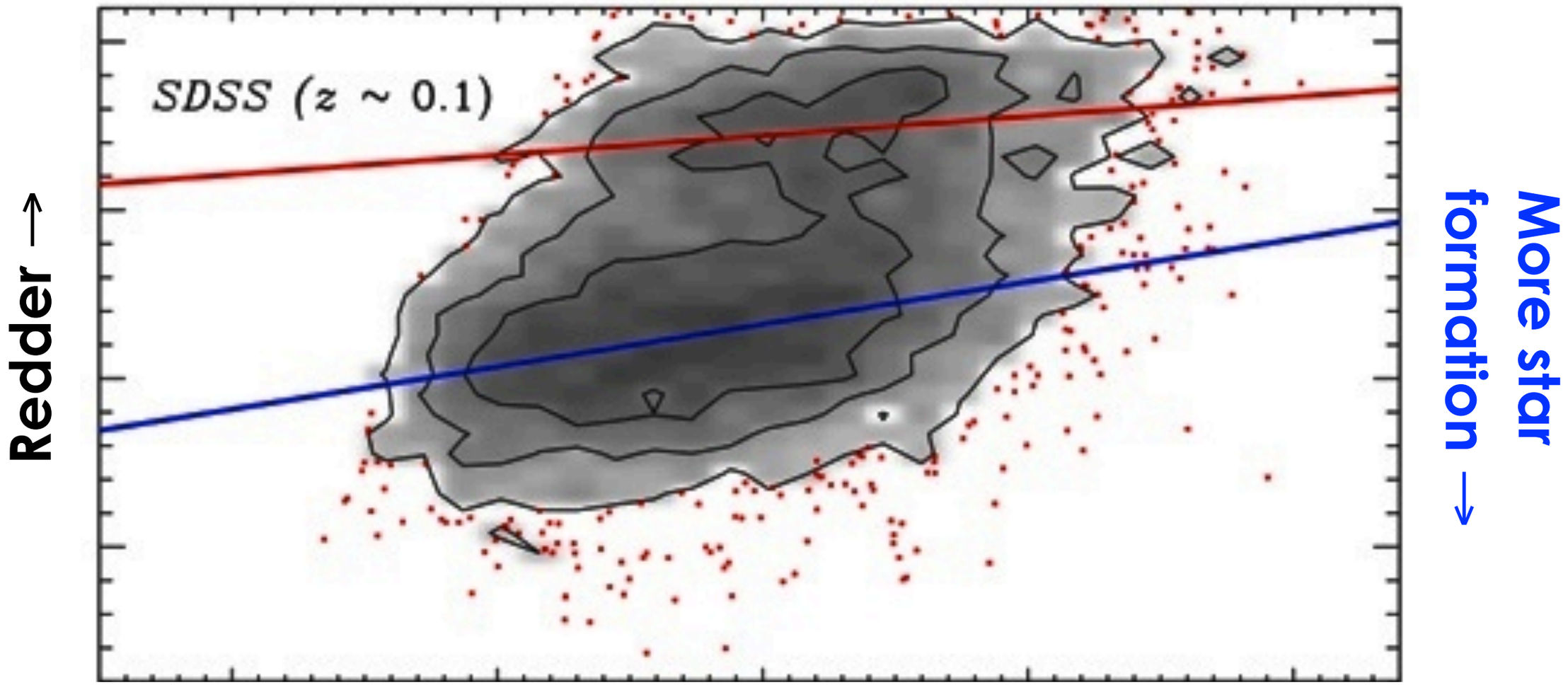
for the bulk of star formation and BH growth, when averaging over variability on timescales

Do AGN prevent star formation in galaxies?



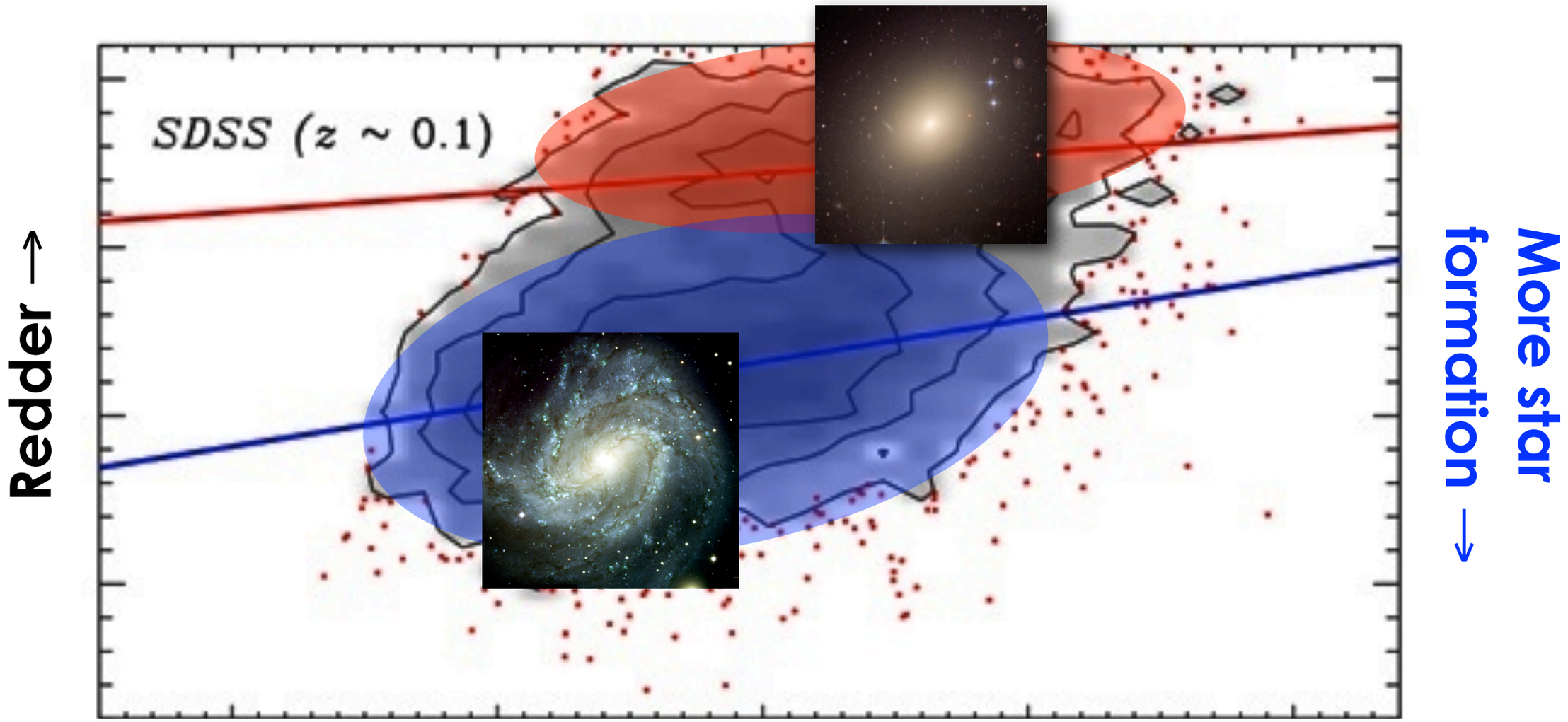
HCG 62 (Gitti et al. 2010), see many others for similar examples

AGN and galaxy colors



Blanton (2006)

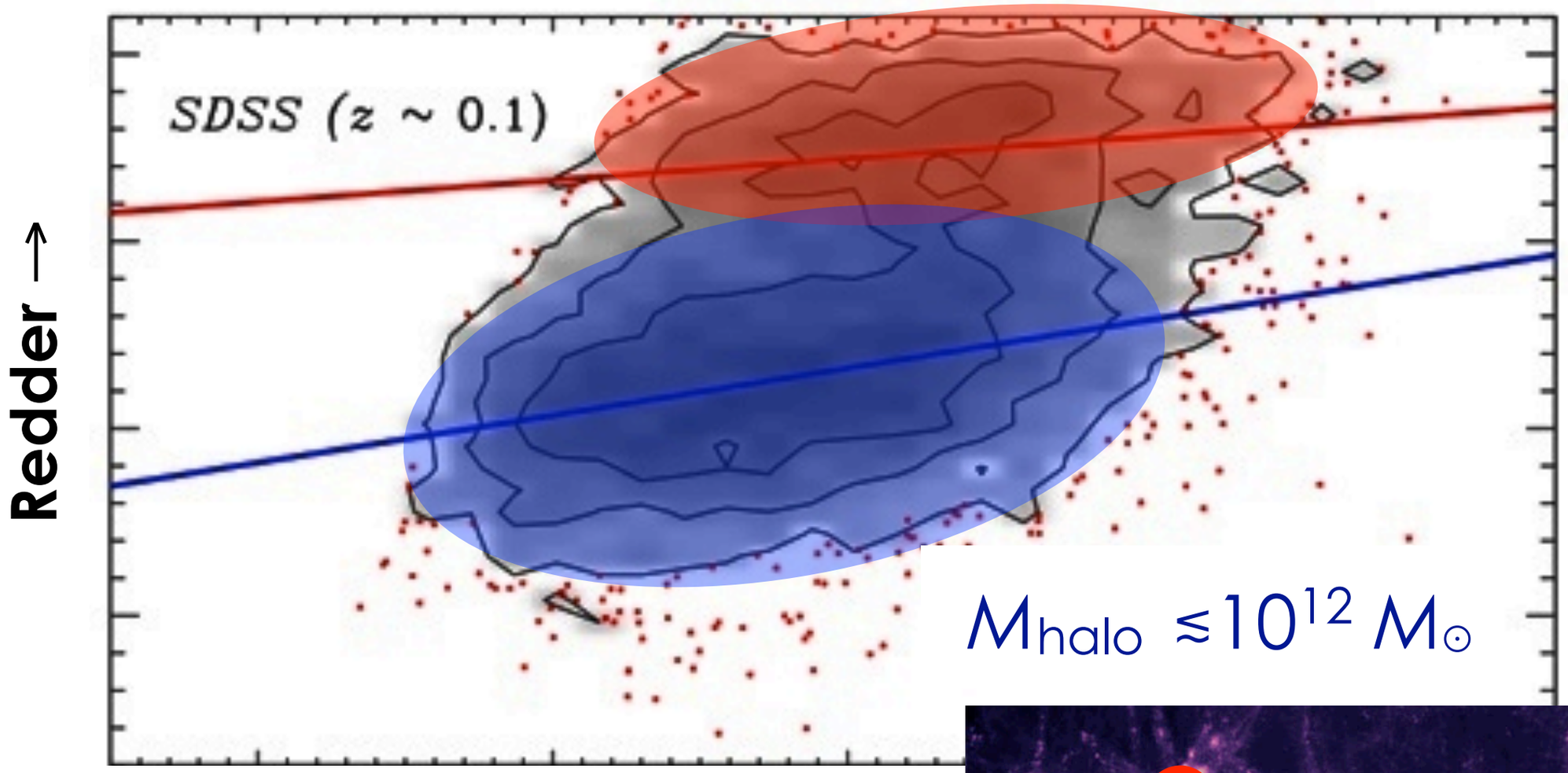
AGN and galaxy colors

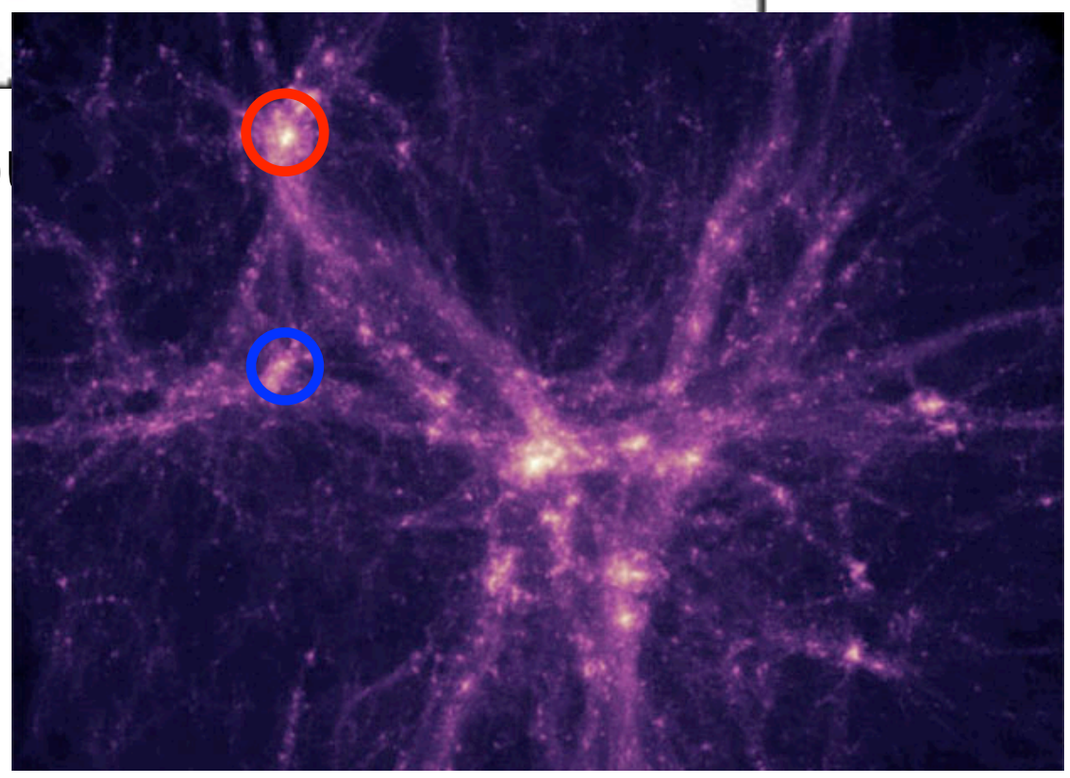


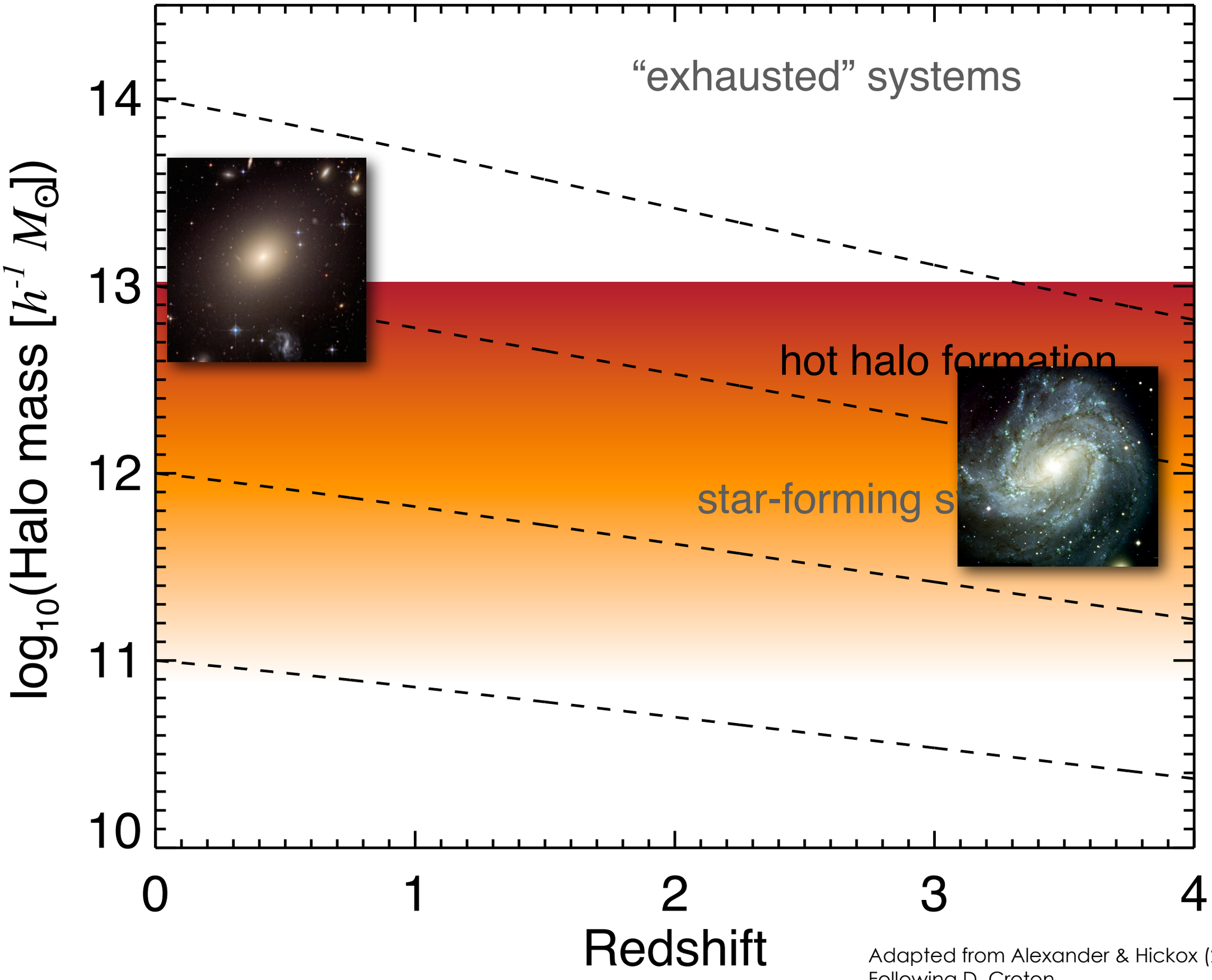
Blanton (2006)

AGN and galaxy colors

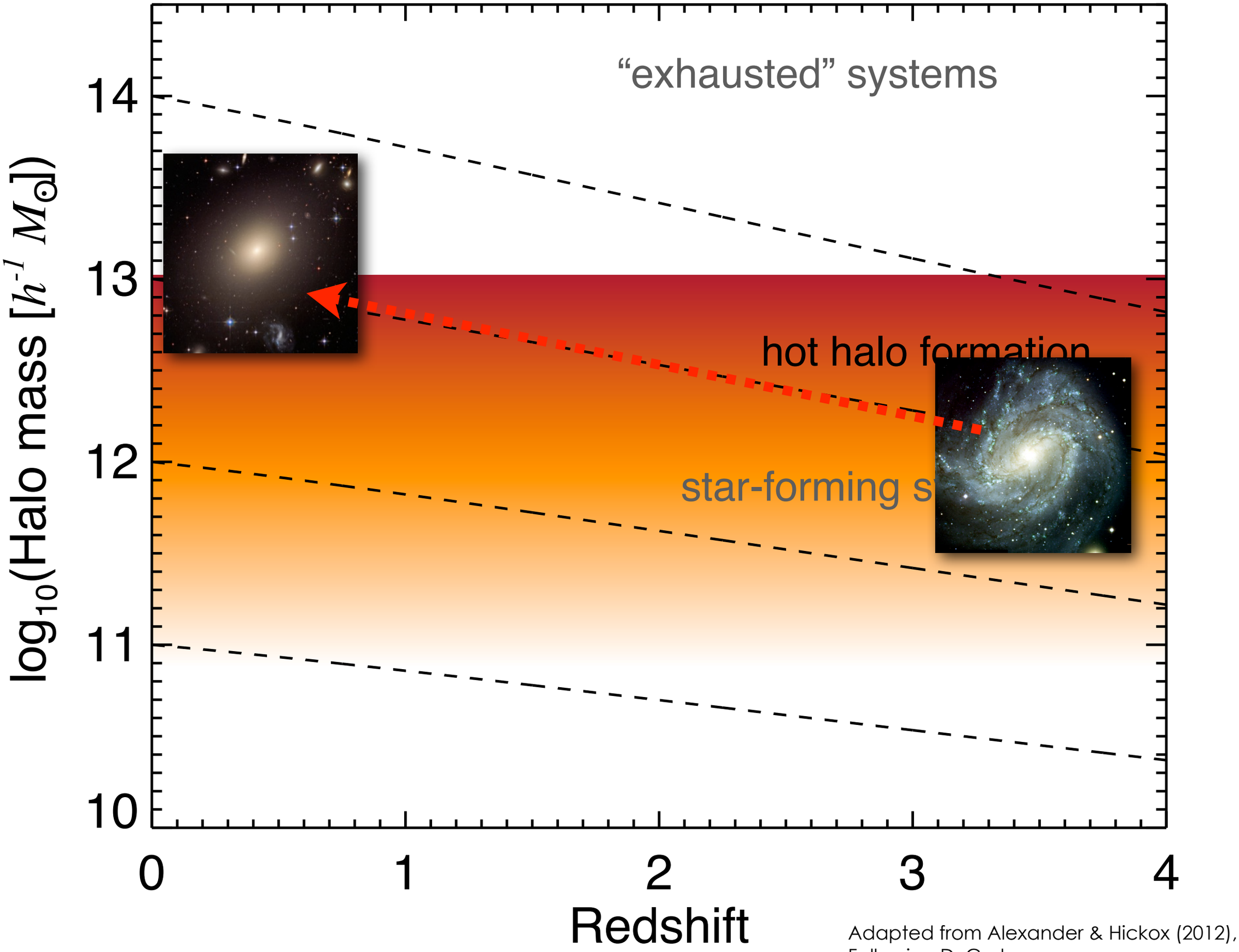
$M_{halo} \sim 10^{13}\ M_\odot$





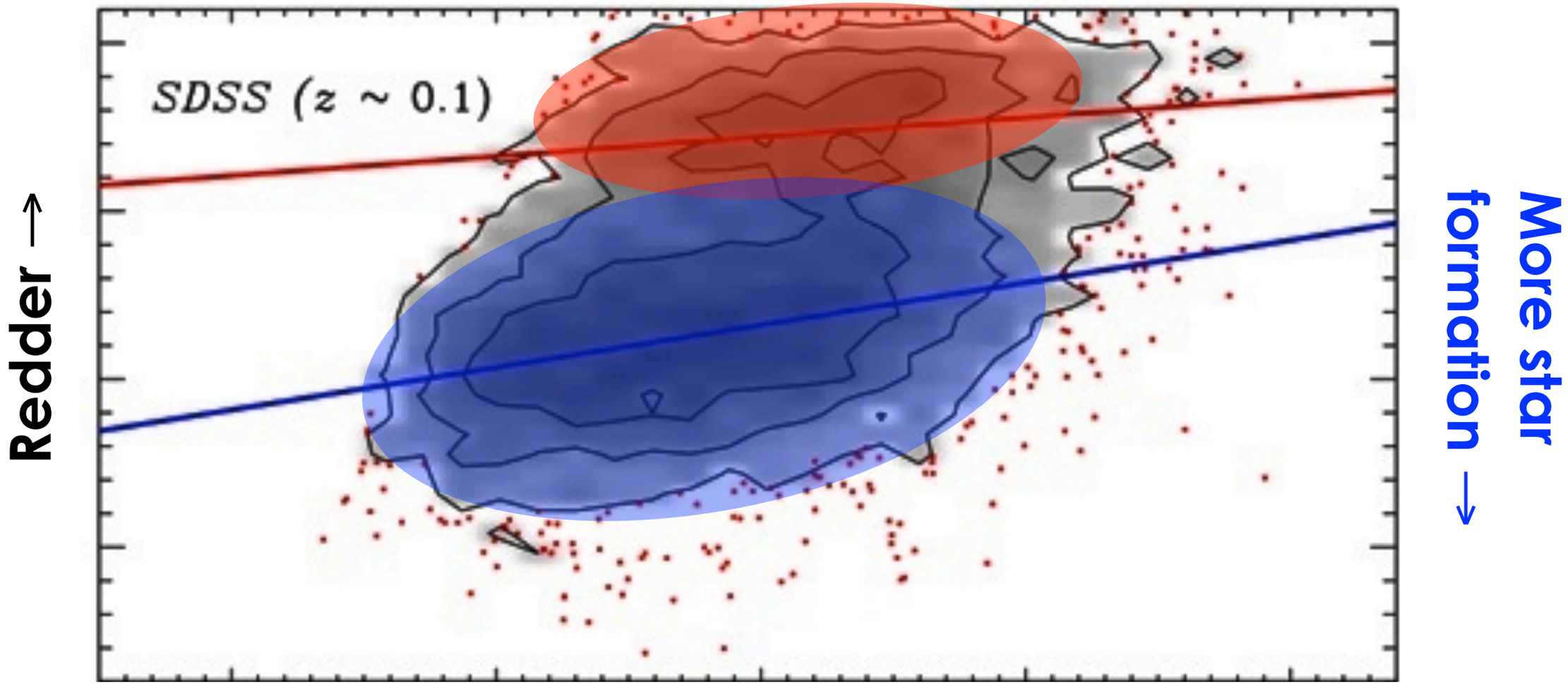


Adapted from Alexander & Hickox (2012),
Following D. Croton



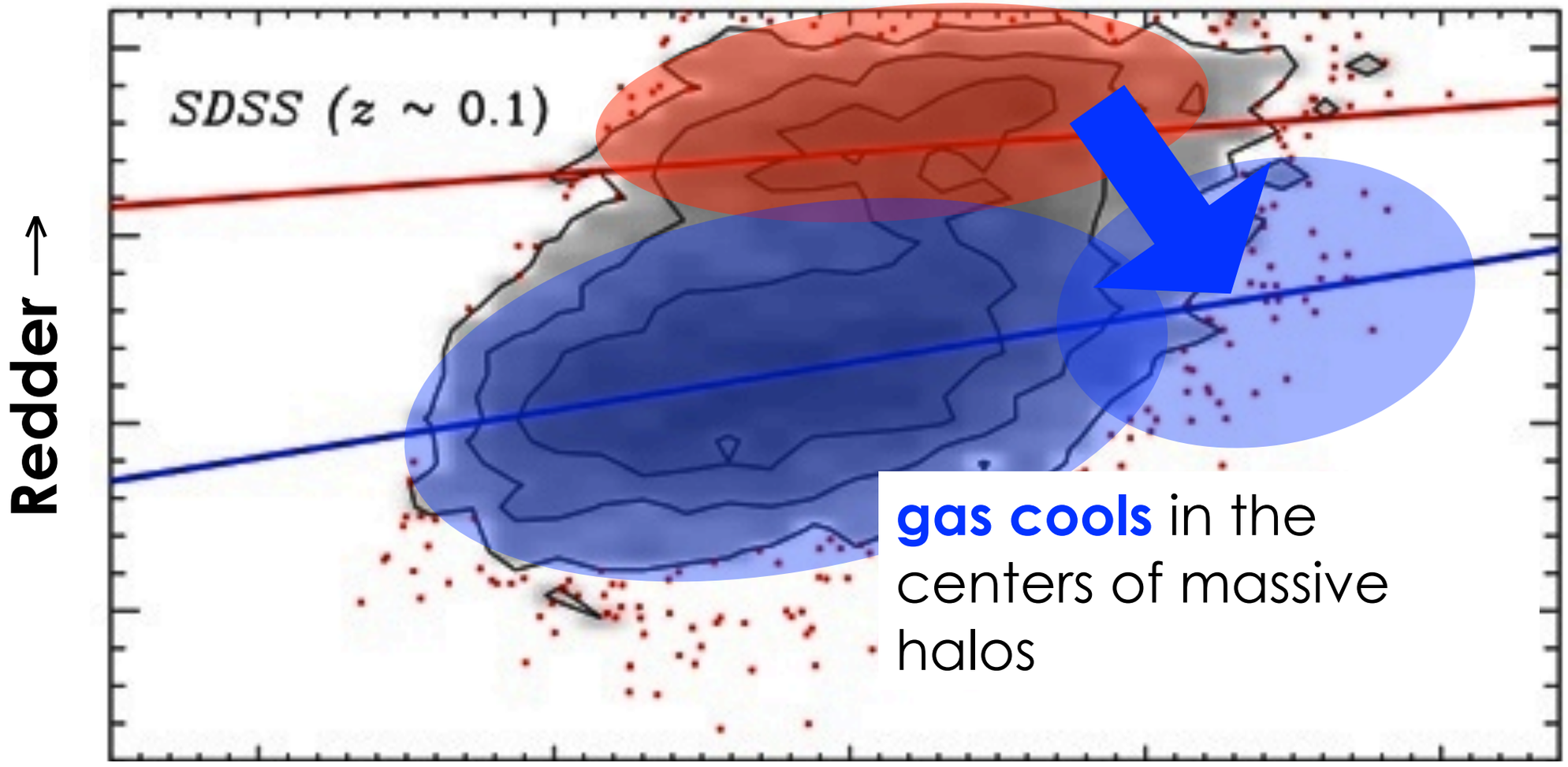
Adapted from Alexander & Hickox (2012),
Following D. Croton

The need for black hole feedback



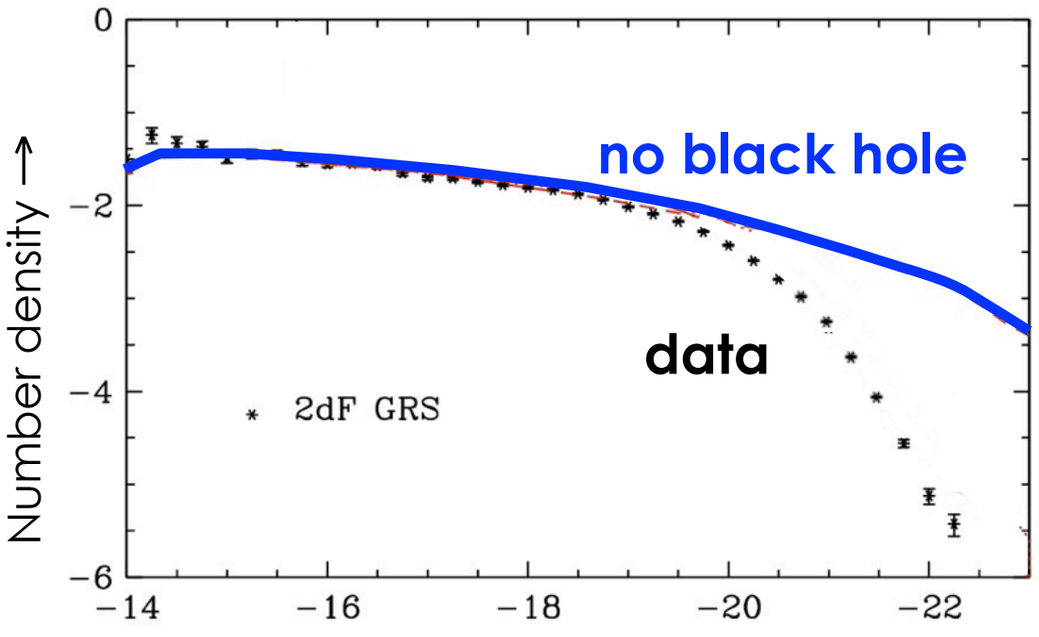
Blanton (2006)

The need for black hole feedback



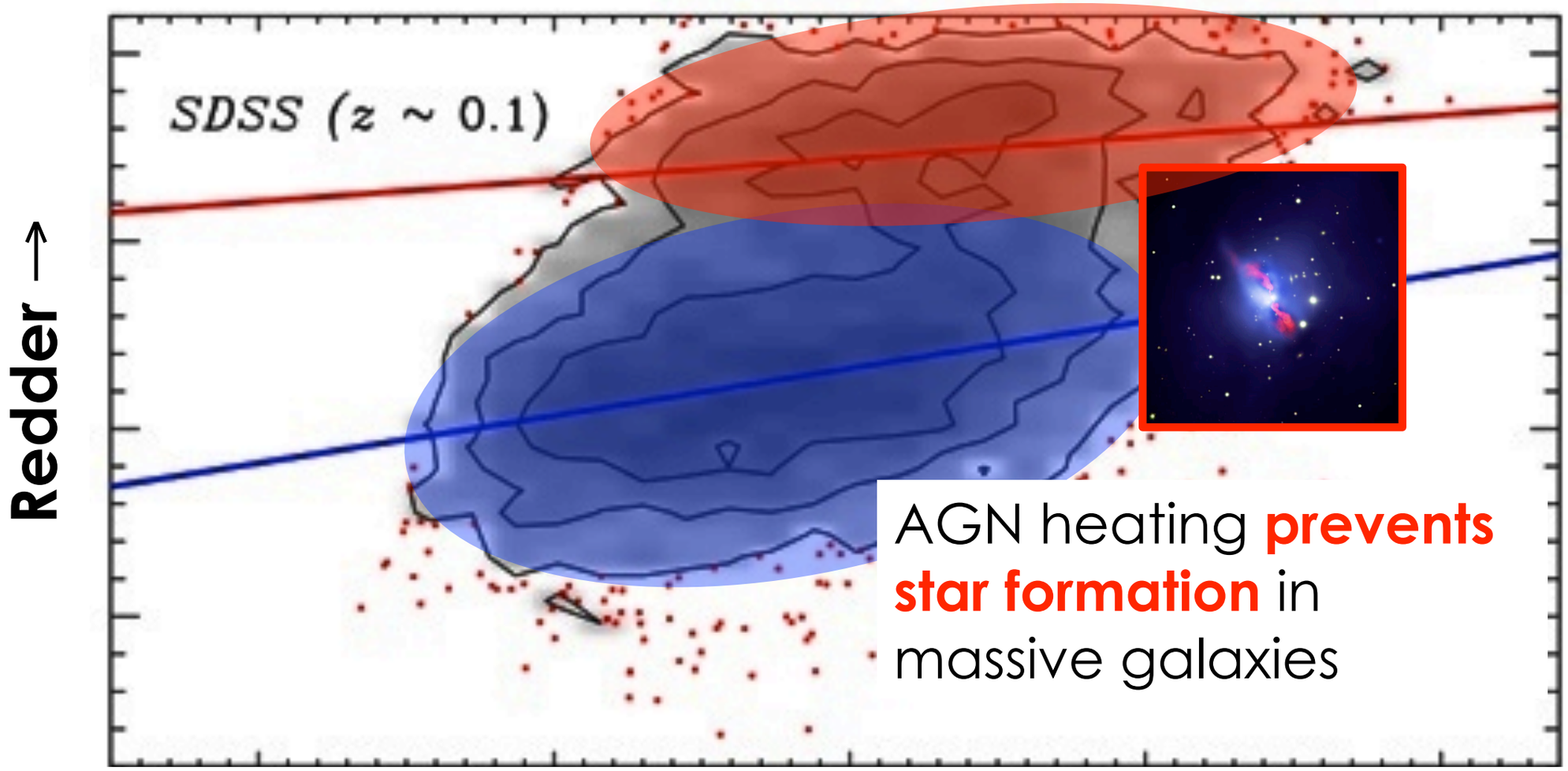
More luminous →

Blanton (2006)

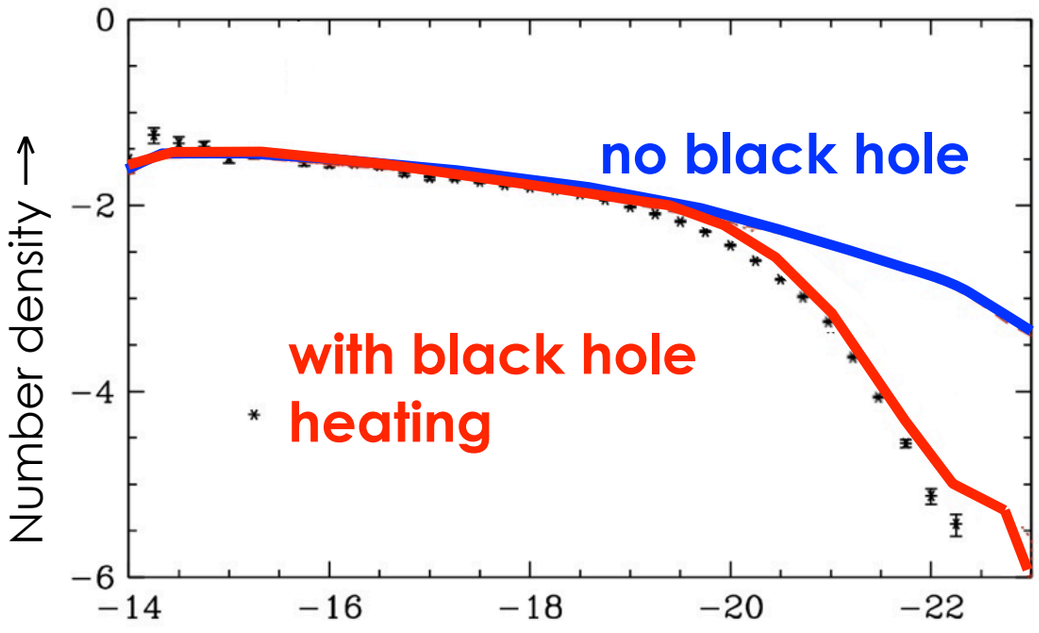


Bower et al. (2006), see also Croton et al. (2006), etc.

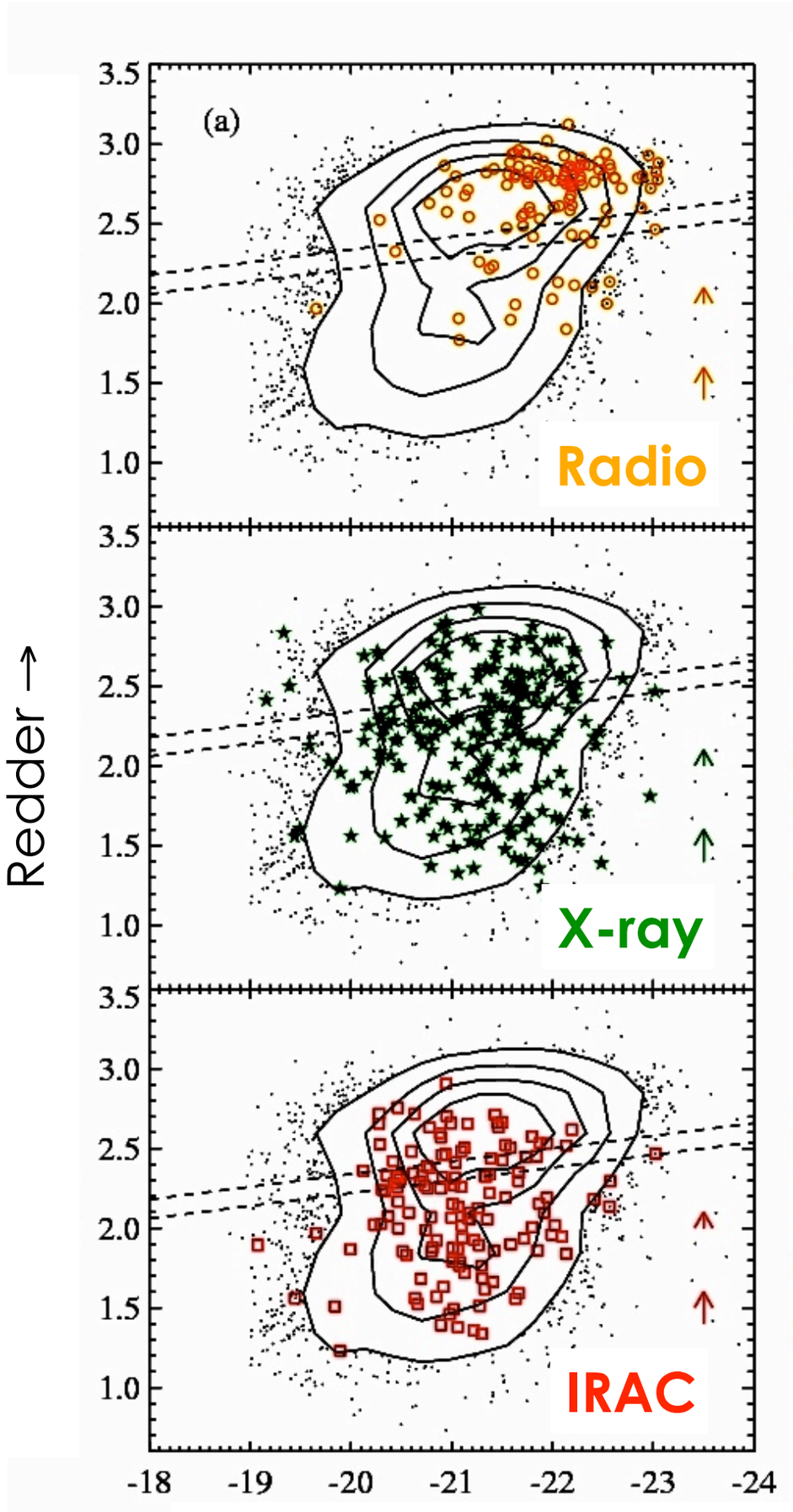
The need for black hole feedback

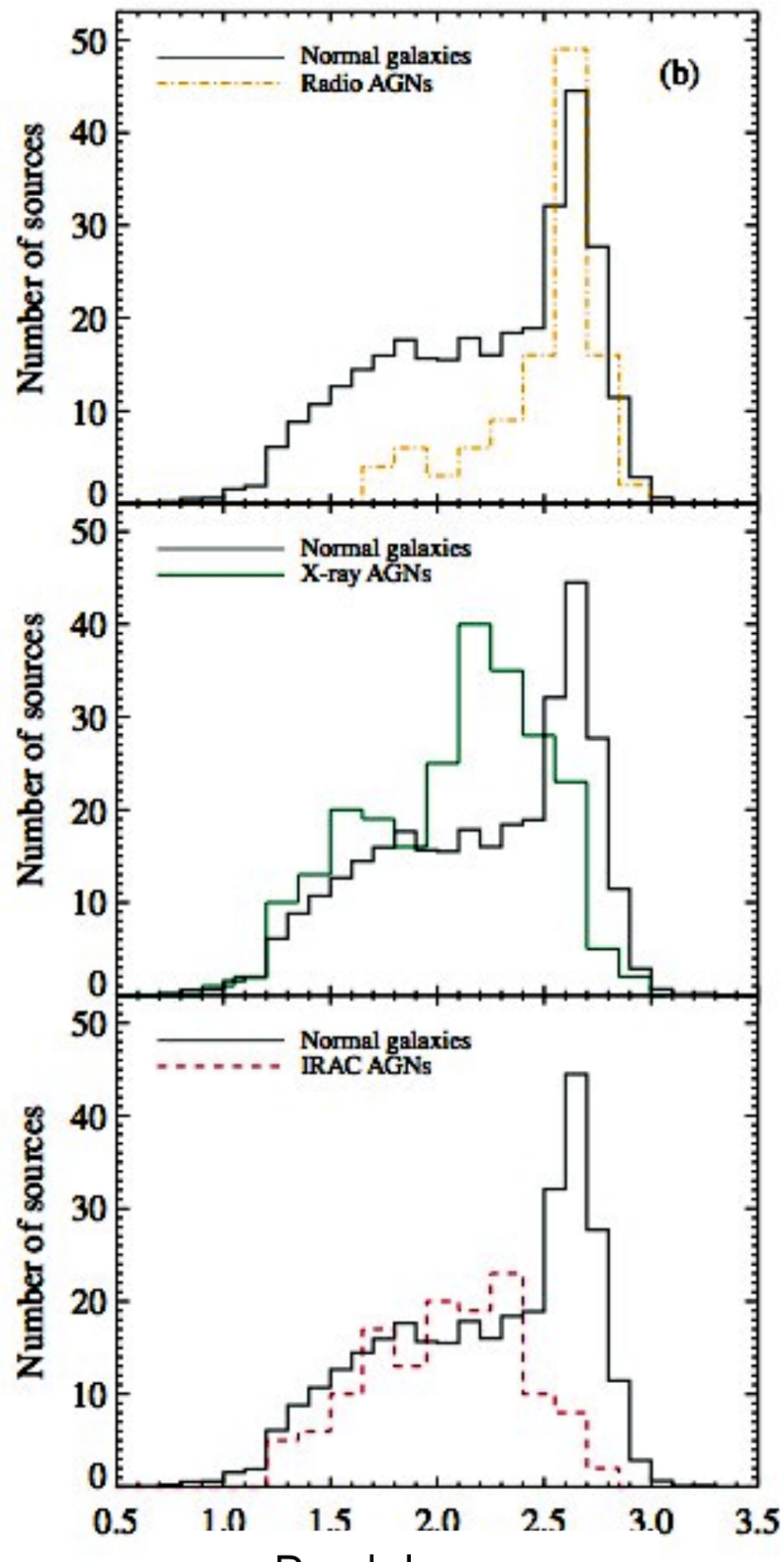


Blanton (2006)



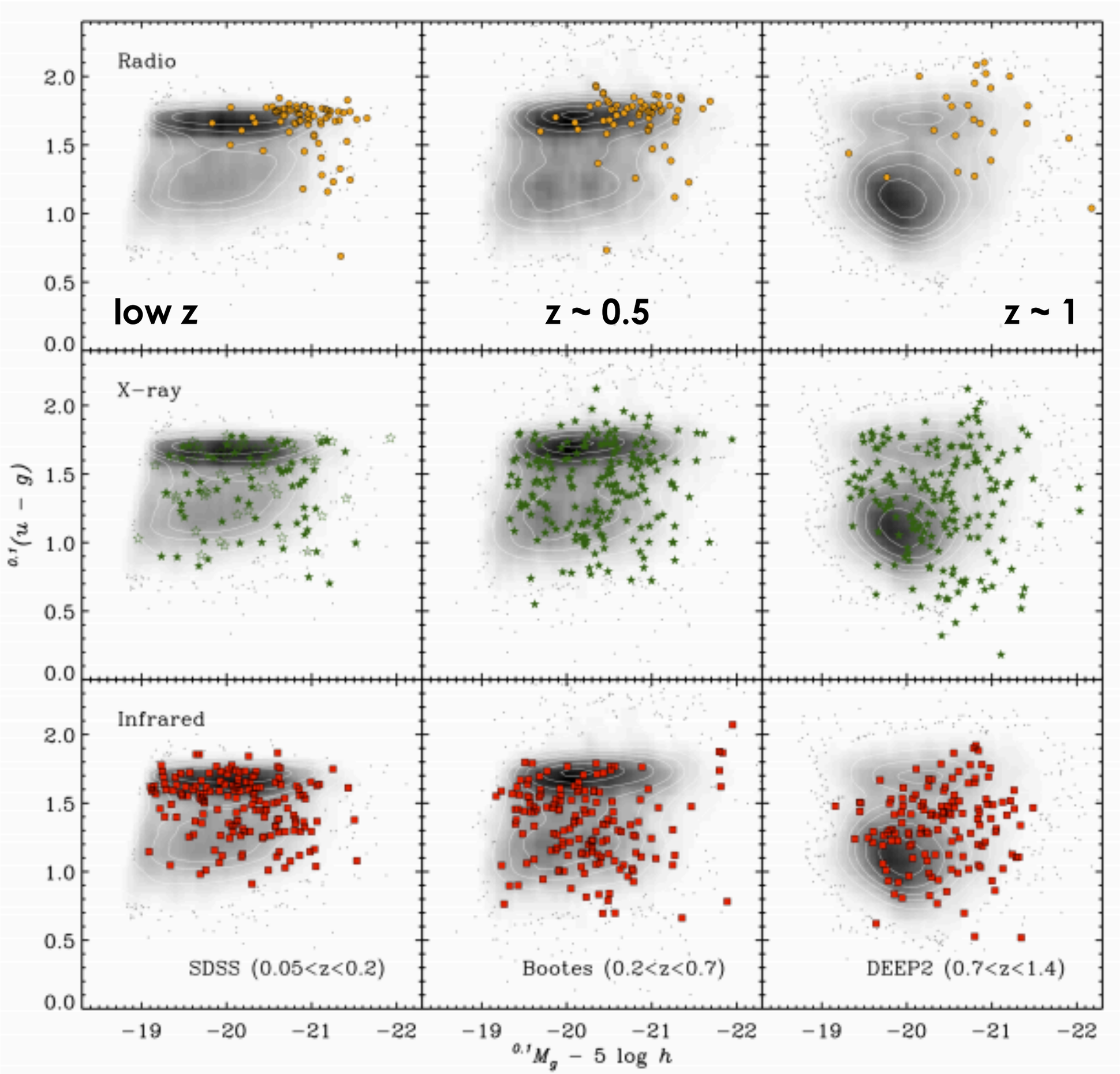
Bower et al. (2006), see also Croton et al. (2006), etc.





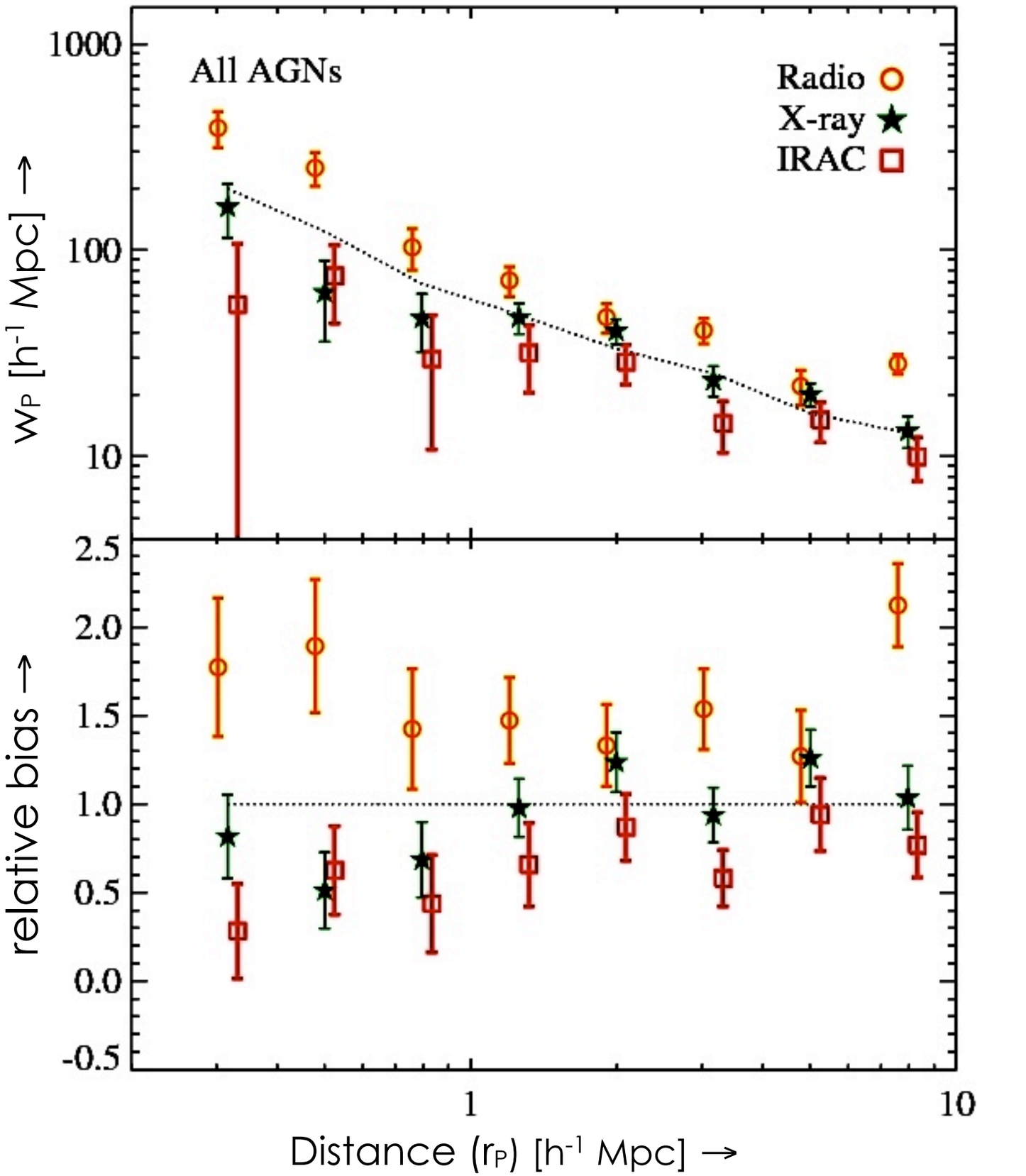
Hickox et al. (2009)

[Gurkan Uygun poster]

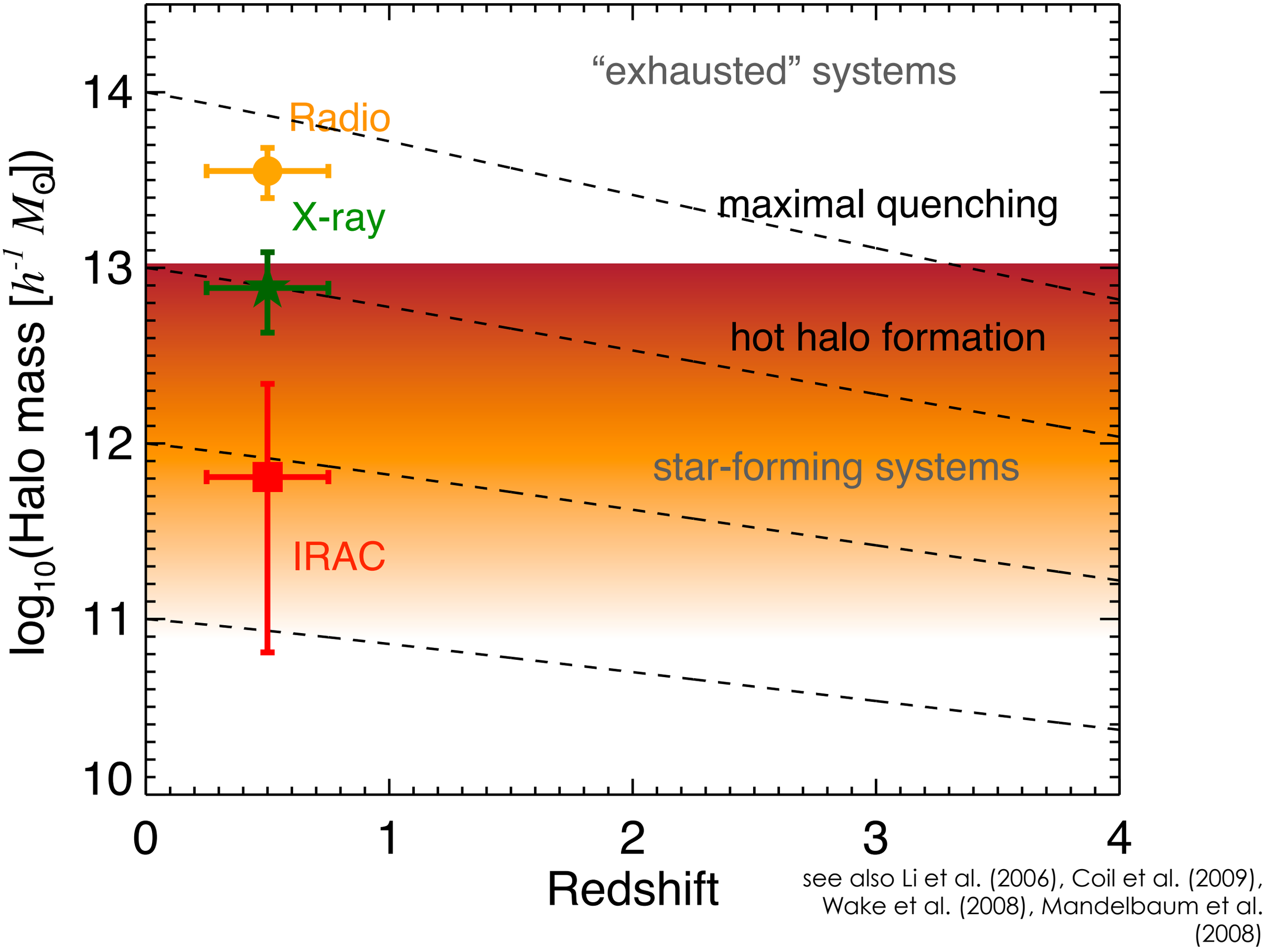


Goulding, RCH et al. (2014)

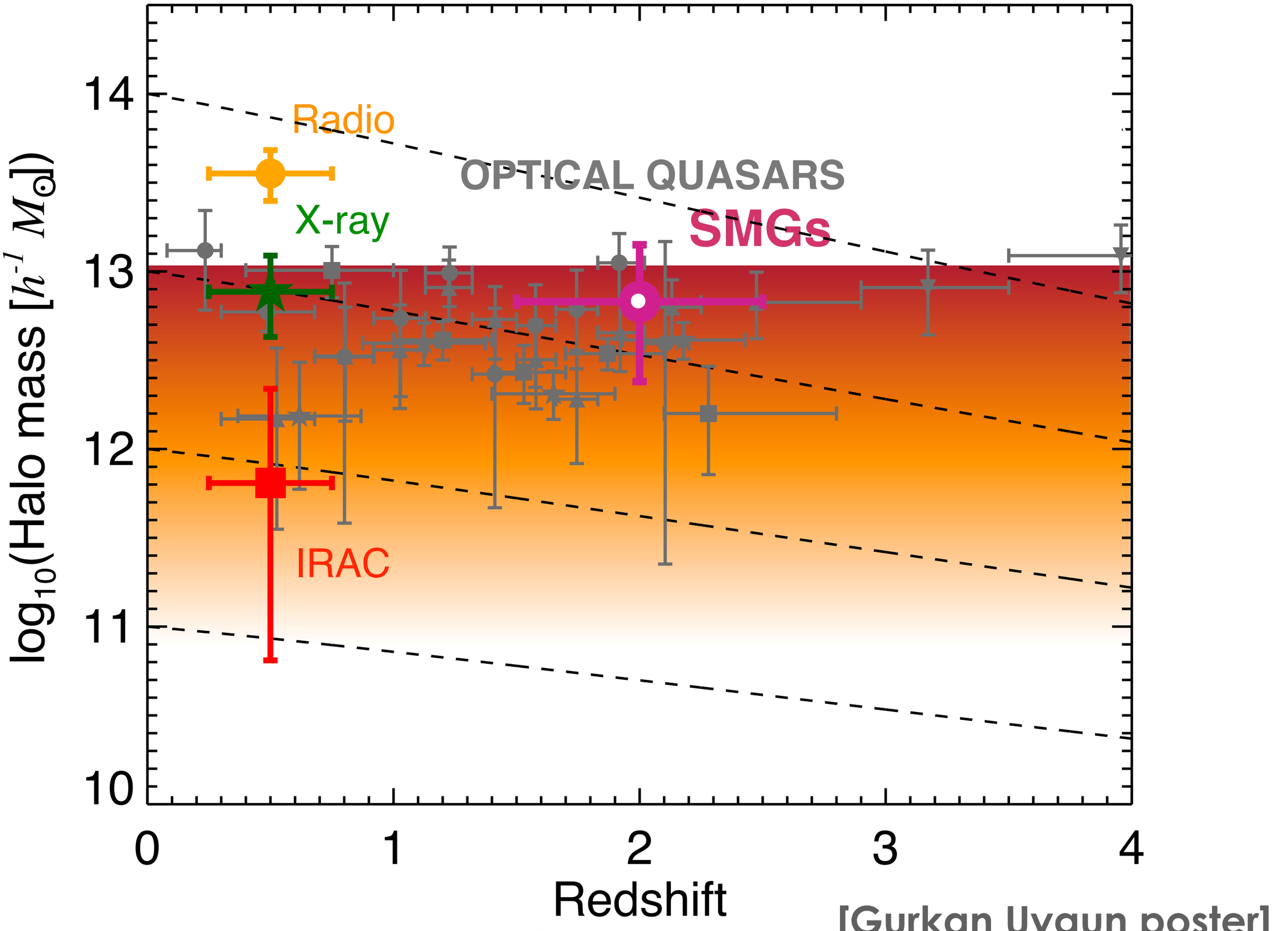
Spatial clustering tell us ***dark matter halo mass***



Hickox et al. (2009)



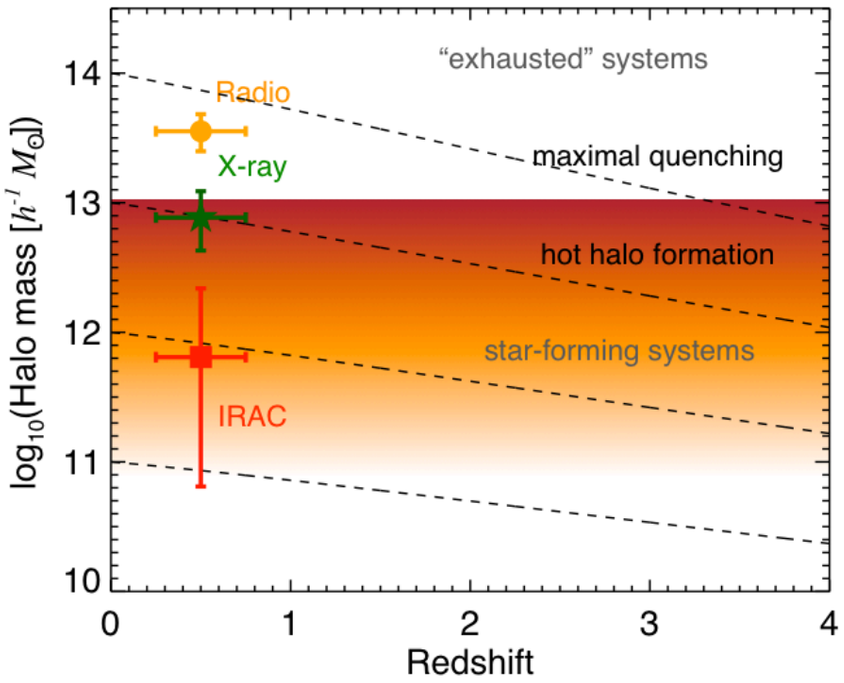
see also Li et al. (2006), Coil et al. (2009), Wake et al. (2008), Mandelbaum et al. (2008)



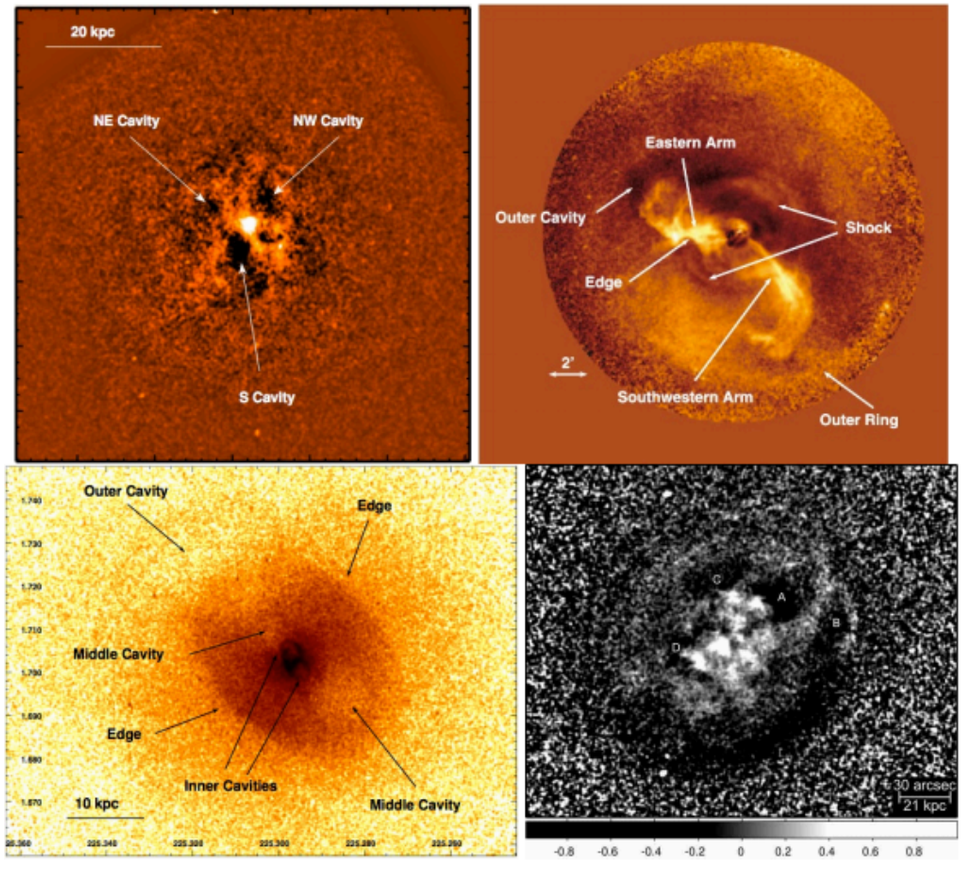
[Gurkan Uygun poster]

See refs in Hickox et al. (2011, 2012), although see Magliocchetti et al. (2014)

Does this actually work?

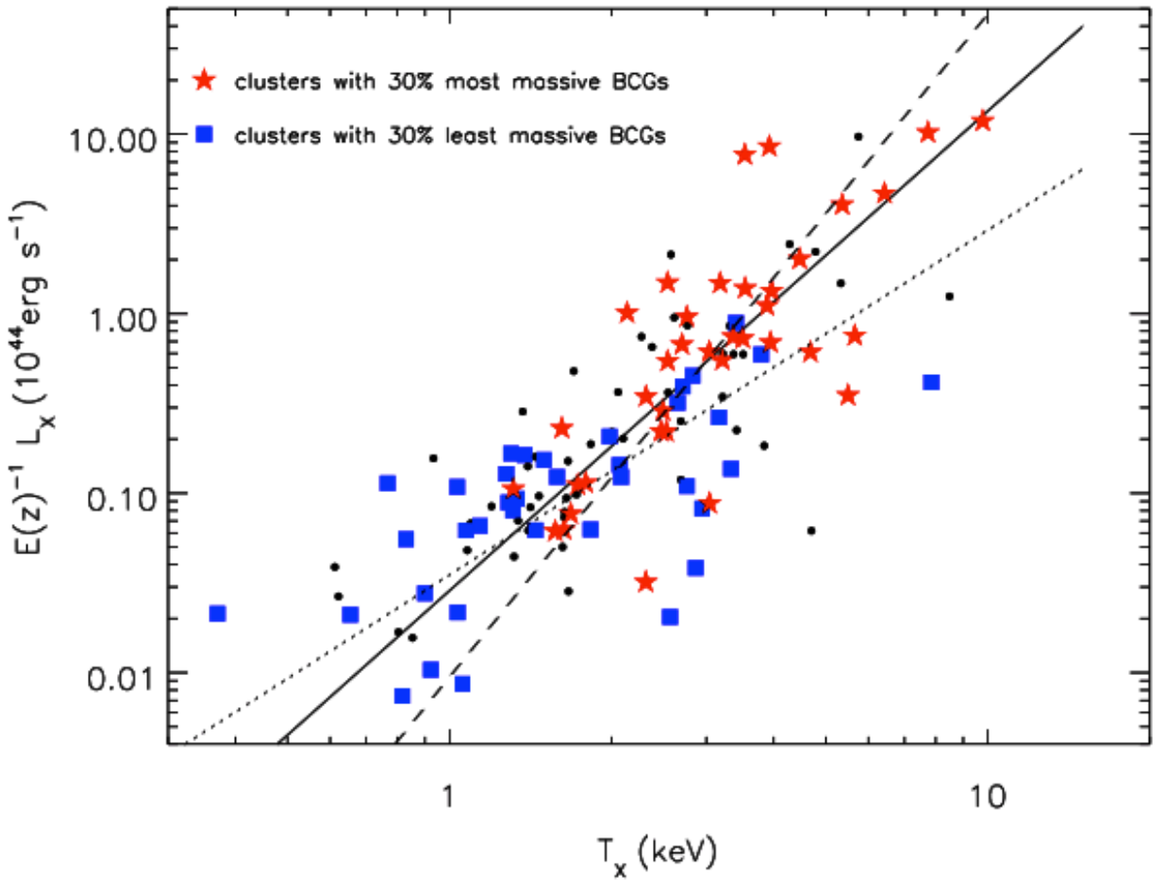


Cooling of hot atmospheres appears balanced by PdV work on cavities



McNamara & Nulsen (2012) for review

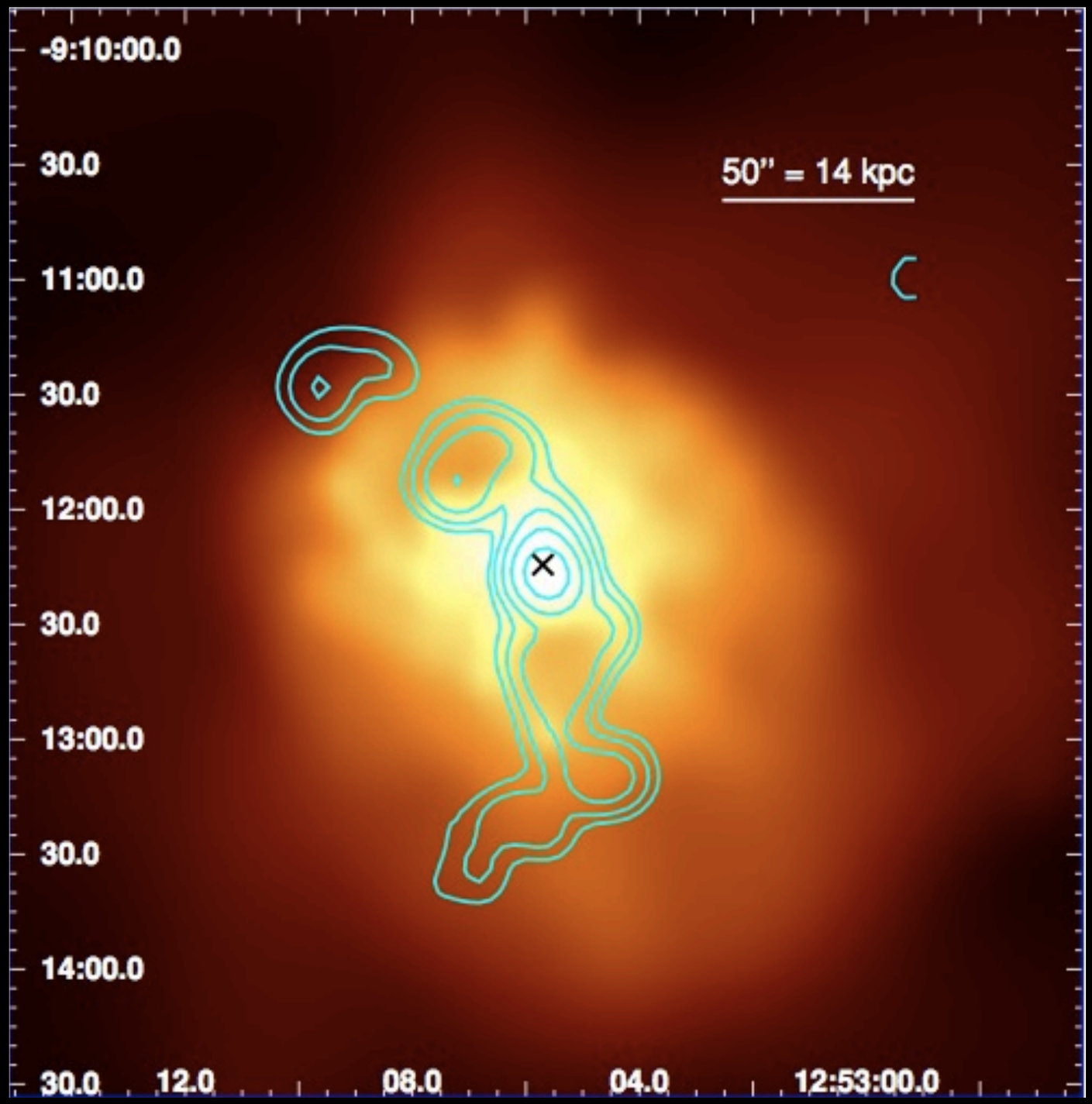
State of cluster/group gas is correlated with BCG properties



Stott et al. (2012)

Do AGN prevent star formation in galaxies?

YES
for mechanical outflows in massive galaxies and halos



HCG 62 (Gitti et al. 2010), see many others for similar examples

Do AGN follow star formation?

OR

Do AGN prevent star formation?

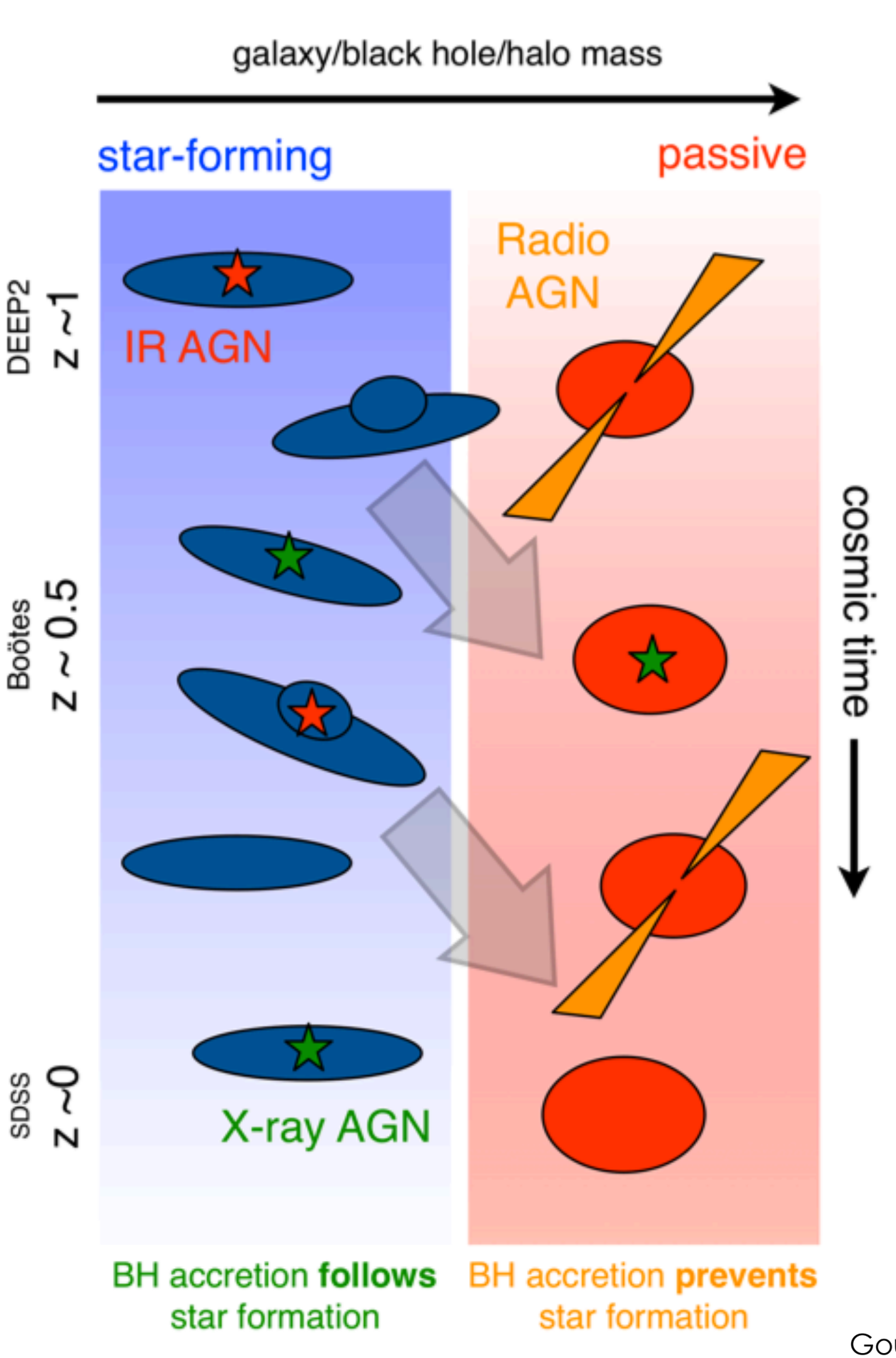
Do AGN follow star formation?

OR

Do AGN prevent star formation?

YES

depending on evolutionary stage (and thus halo mass) and mode of accretion



AGN **follow** star formation in low-mass, cold gas-rich halos

AGN **prevent** cooling flows and star formation in massive halos

Understanding of the population must take into account stochastic **variability**

Goulding et al. (2014)