Where do Monsters Grow?

arXiv: 1704.06658

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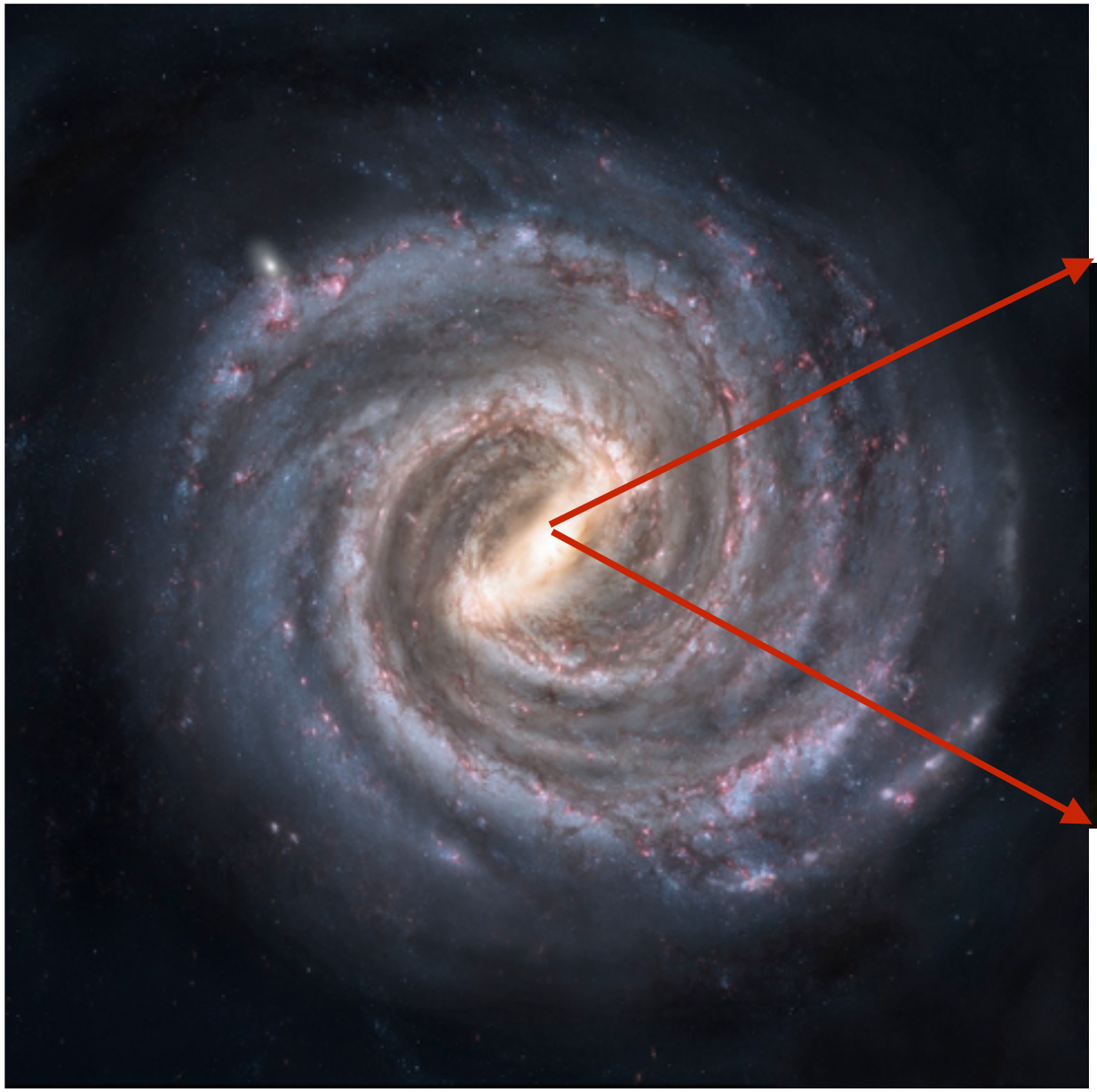
Black holes (monsters) are common in galactic centers

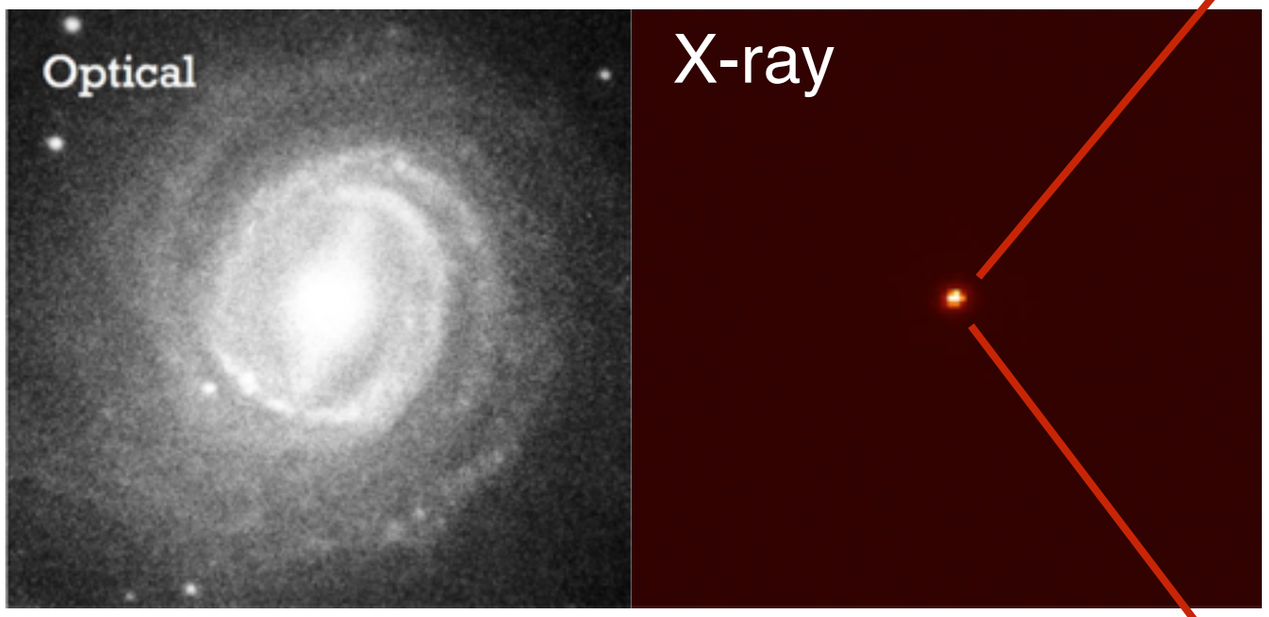


Credit: Wikipedia

Credit: Interstellar movie

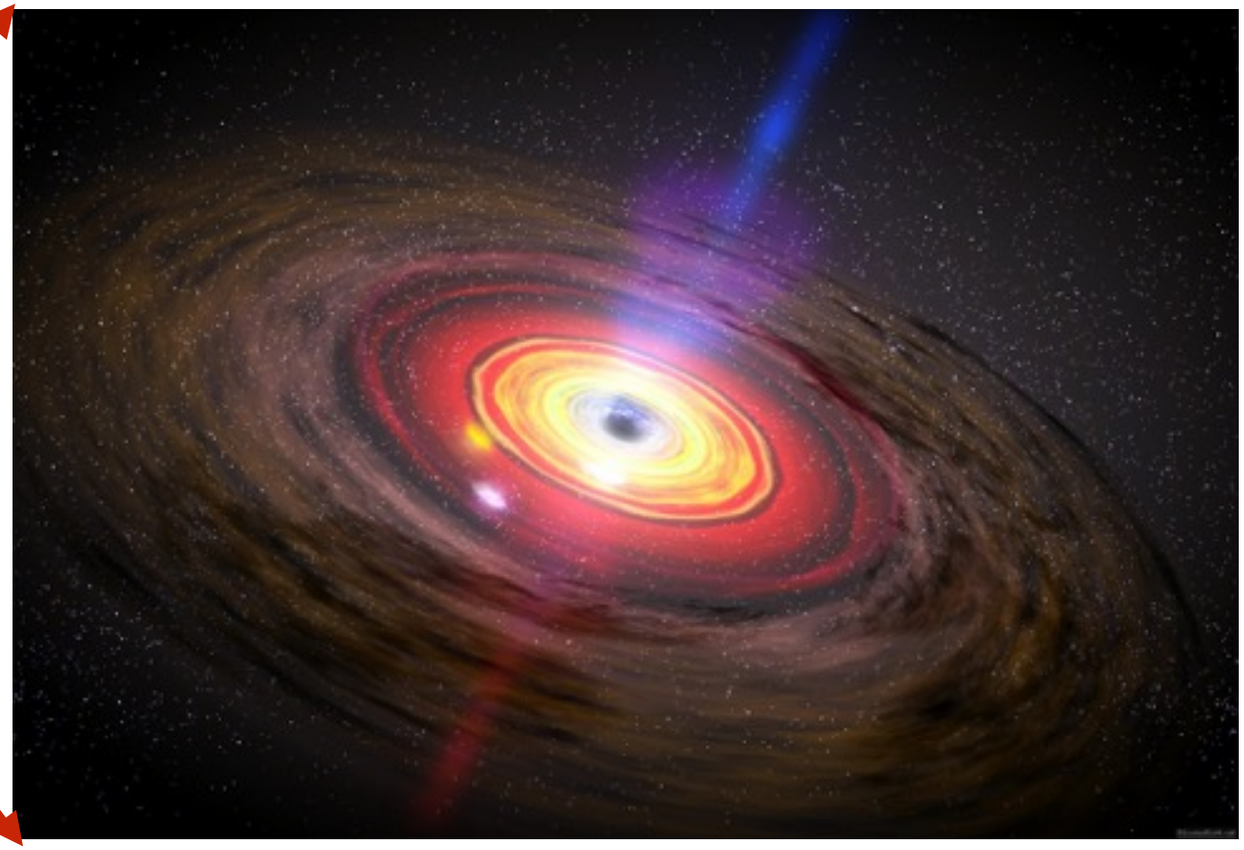
Growing black holes—active galactic nuclei (AGNs)

Observation



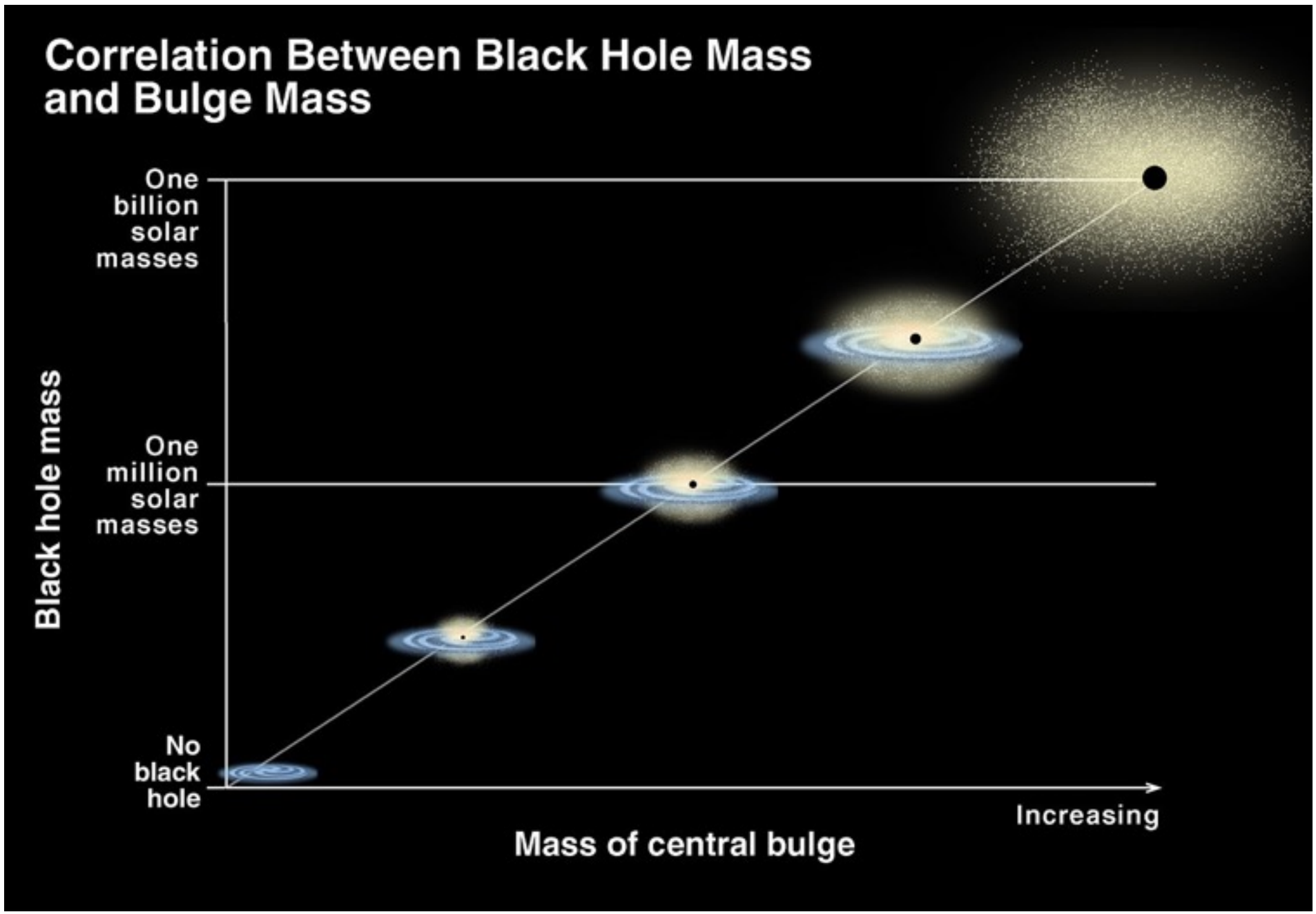
Brandt & Alexander (2015)

Artists' view



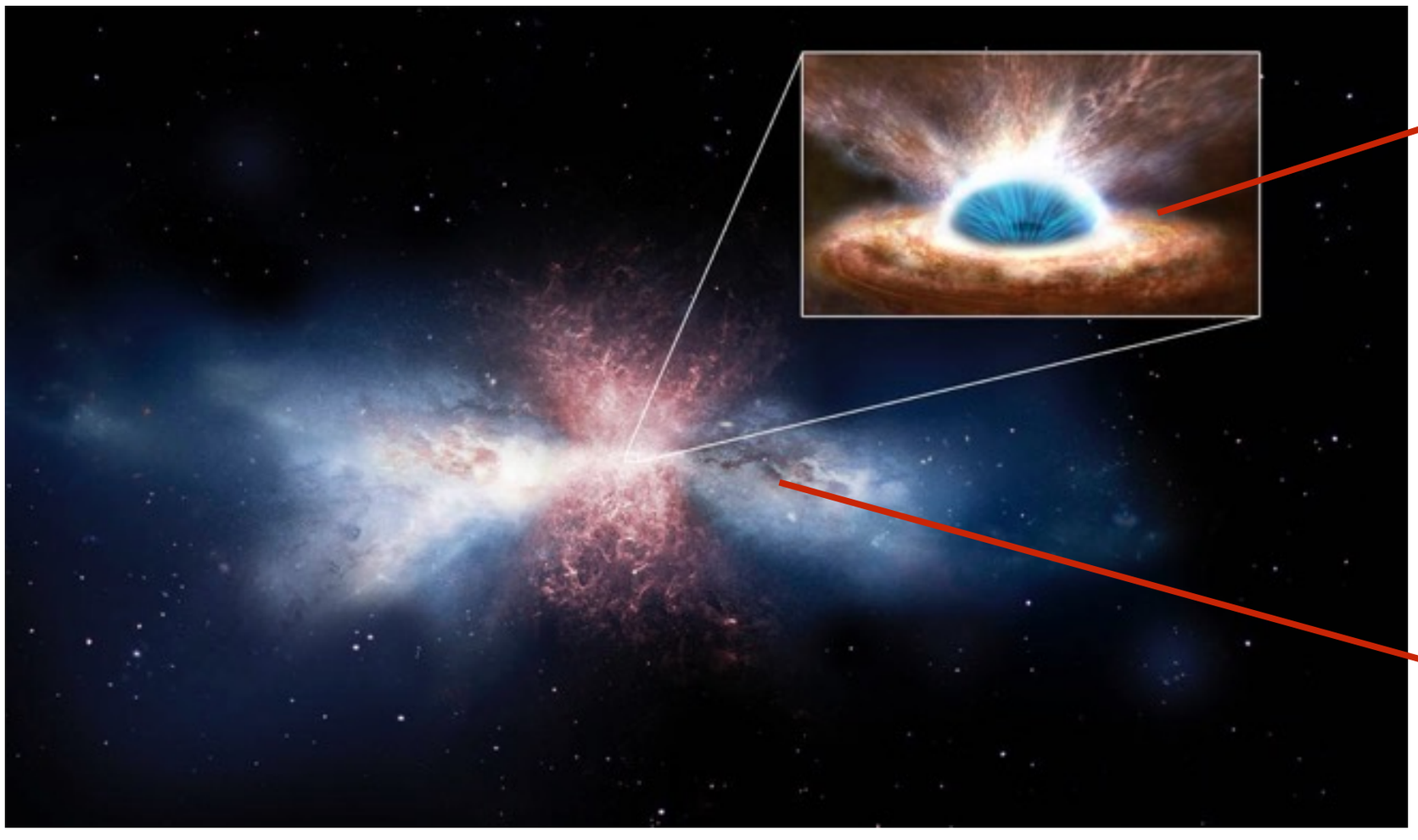
Credit: EducatedEarth.net

Black-hole mass is related to host galaxy properties in local universe



Credit: K. Cordes, S. Brown (STScI)

Black hole-galaxy coevolution?



Center:
black-hole
accretion

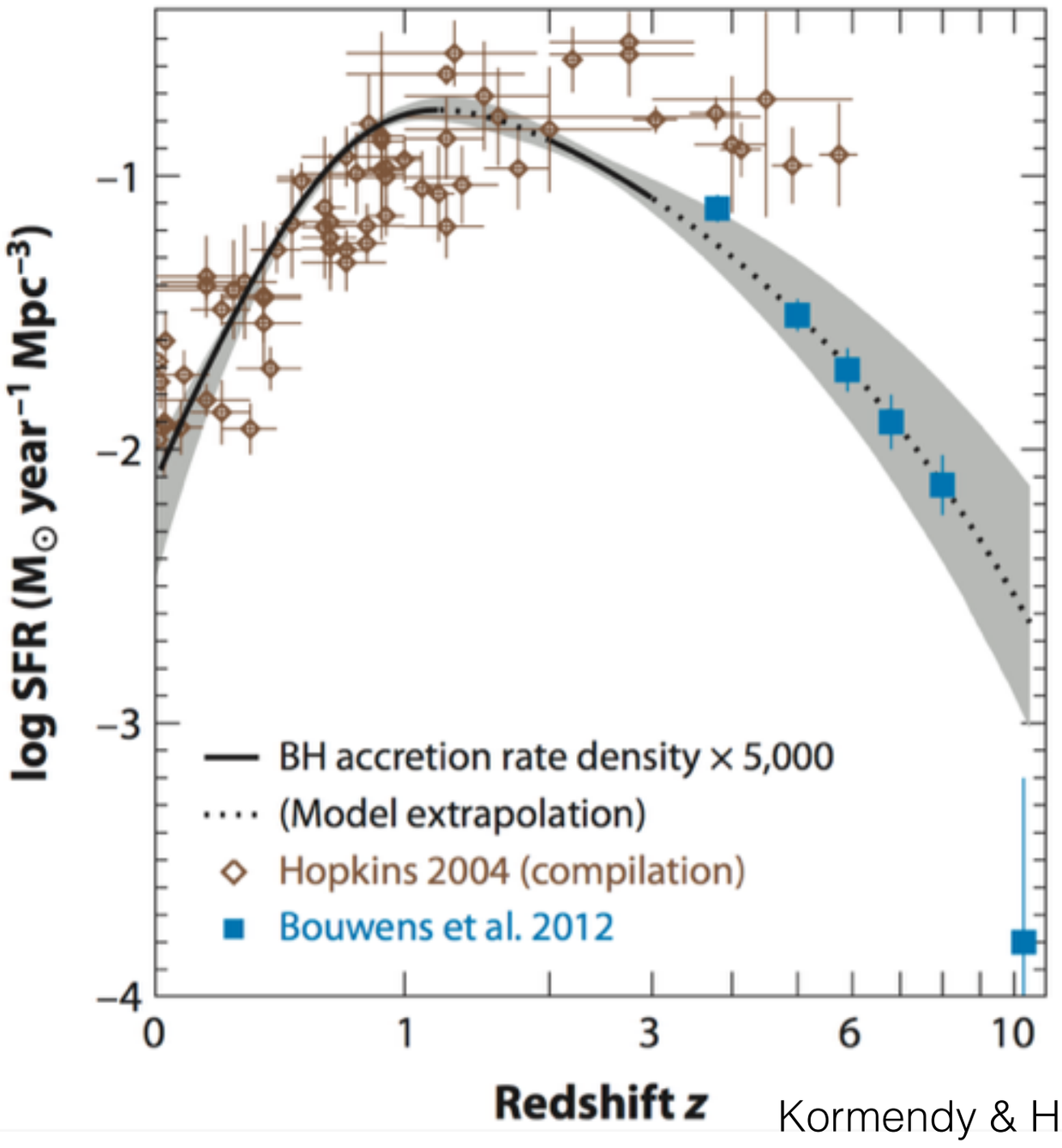
Outer parts:
star formation

Credits: ESA/ATG Medialab

Black-hole vs galaxy growth

- Total black-hole accretion rate (BHAR) and star-formation rate (SFR) are proportional

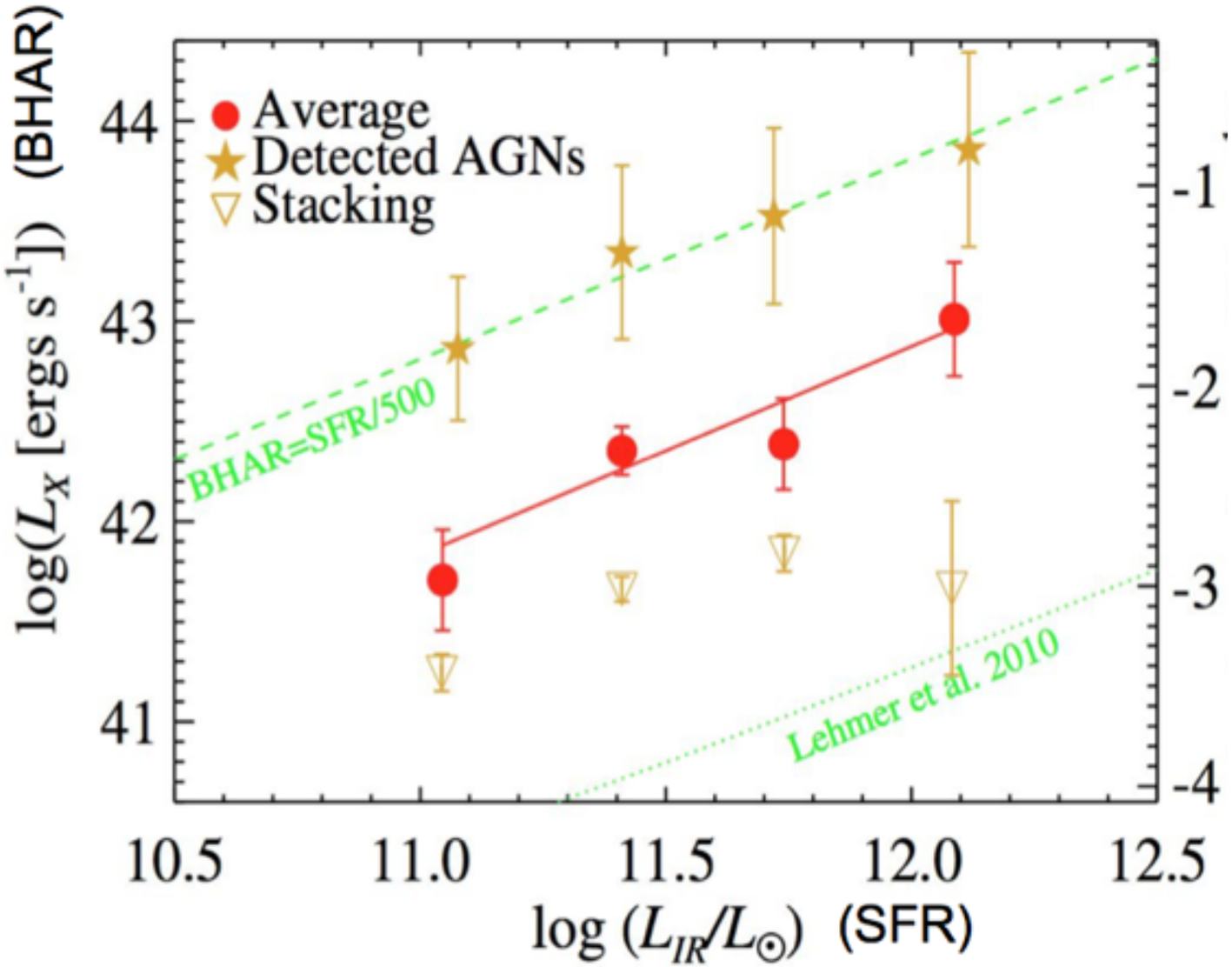
- SFR (total) ~ 5000 × BHAR (total)



Kormendy & Ho (2013)

BHAR-SFR relation: puzzling

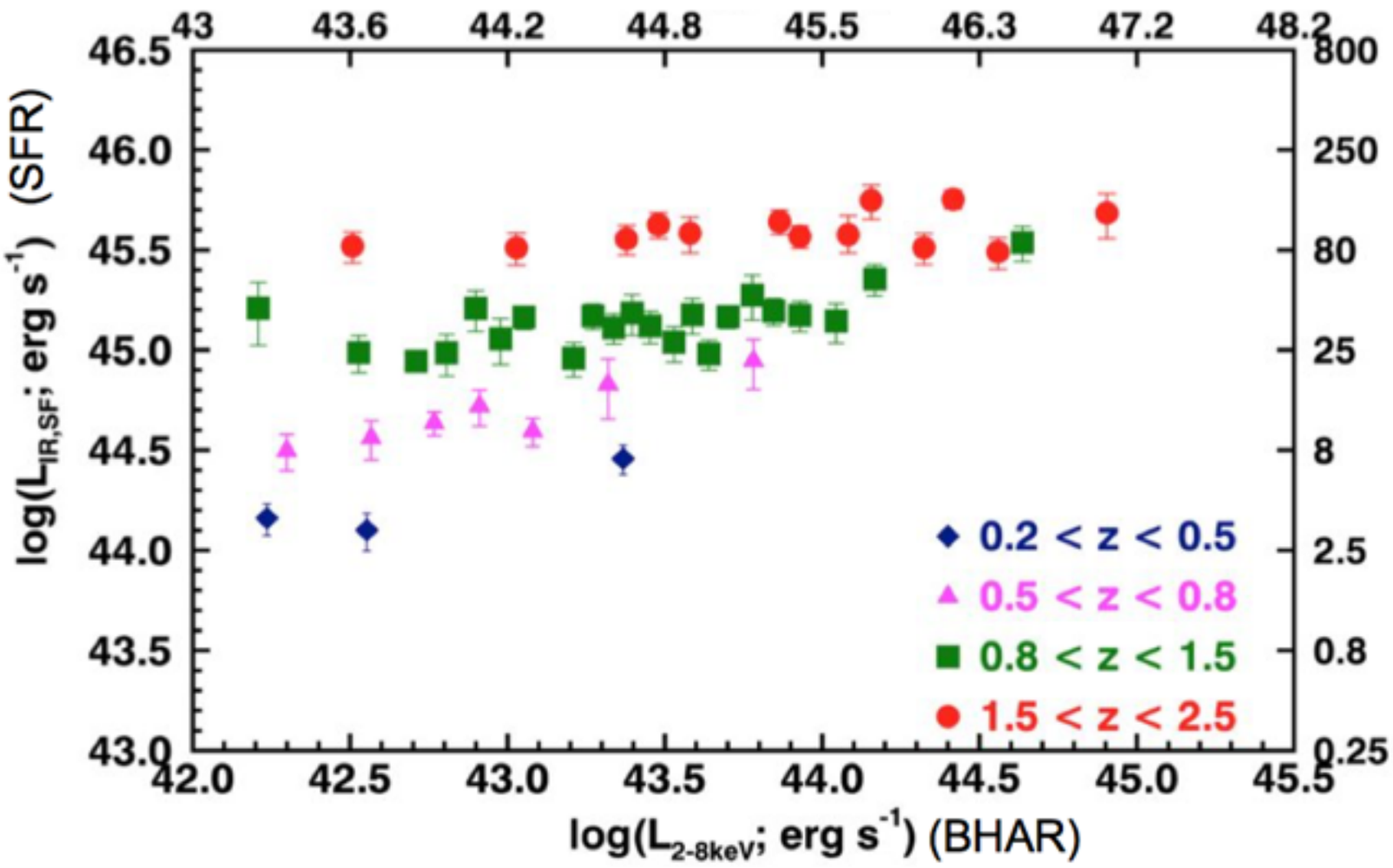
<BHAR>-SFR:
good linear relation



Chen et al. (2013)

BHAR-SFR relation: puzzling

<SFR>-BHAR:
flat, no correlation



Stanley et al. 2015

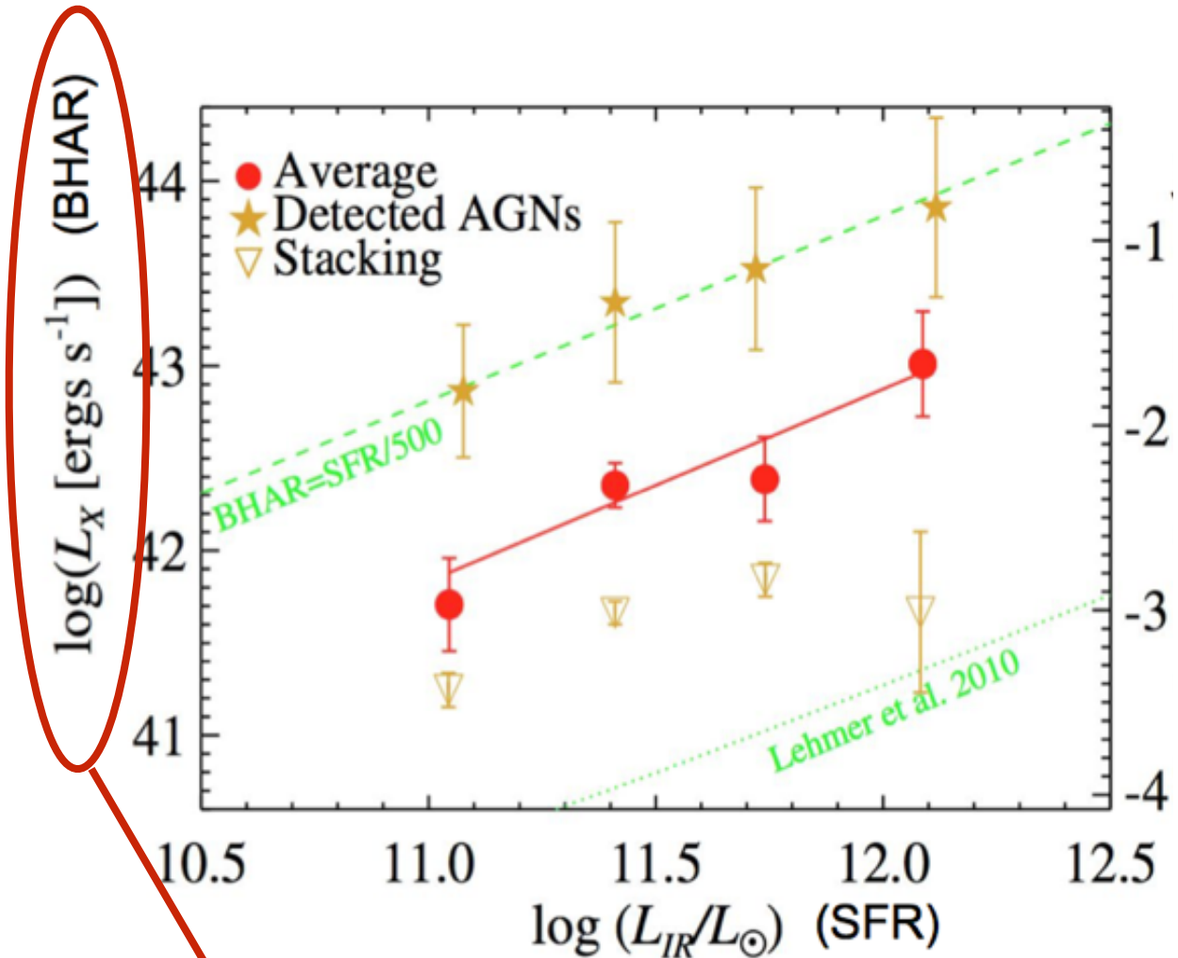
A model to solve the puzzle

Advanced by Hickox et al. (2014), assumes:

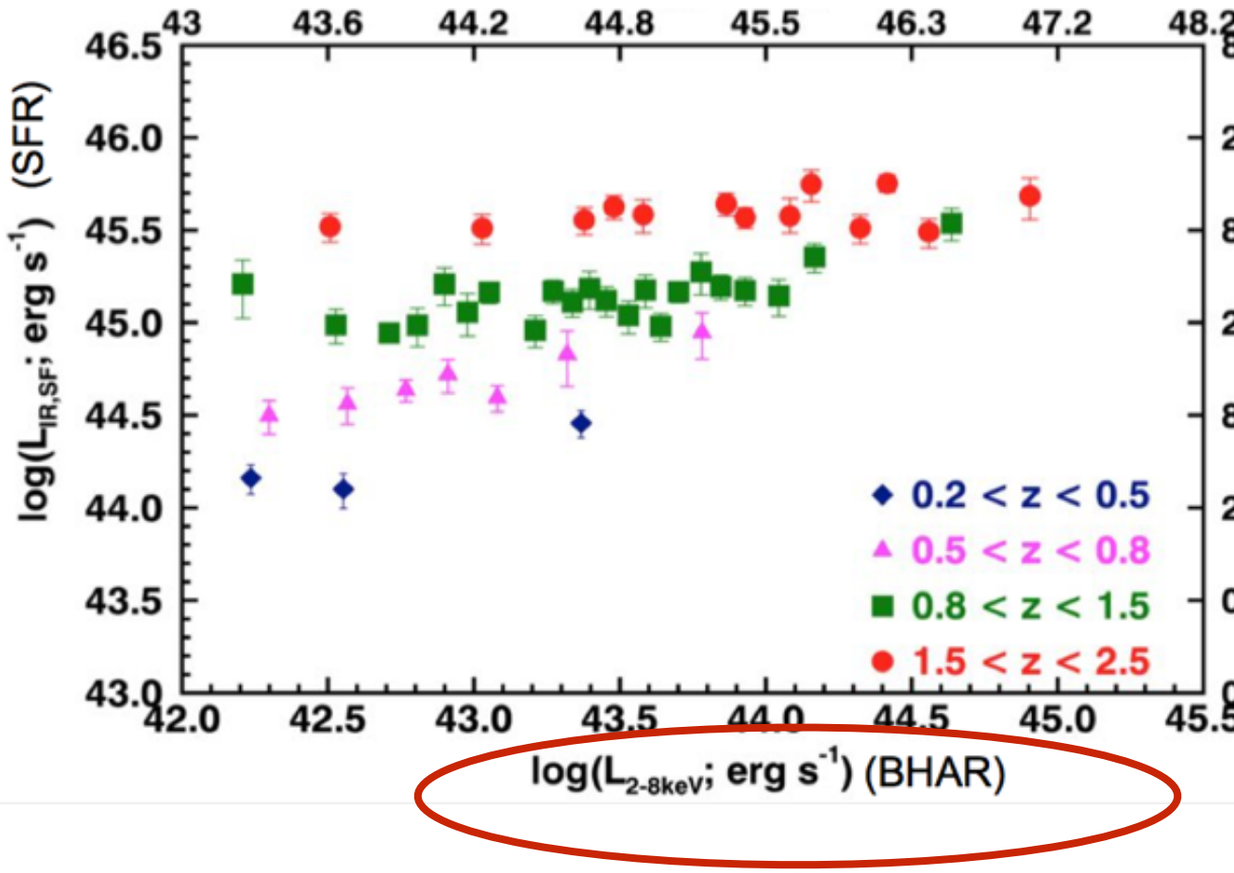
1. Long-term average BHAR ∝SFR

2. Observed (instantaneous) BHAR variable on<10 Myr; SFR~constant on ≳100 Myr.

View from the model



Long-term average BHAR;
reveal intrinsic BHAR-SFR relation



Instantaneous BHAR;
not very useful

Model assumptions?

1. Long-term average BHAR ∝SFR
2. Observed (instantaneous) BHAR variable on < 10 Myr; SFR ~ constant on ≳ 100 Myr.

Assumption 2: OK

Yang et al. (2016)

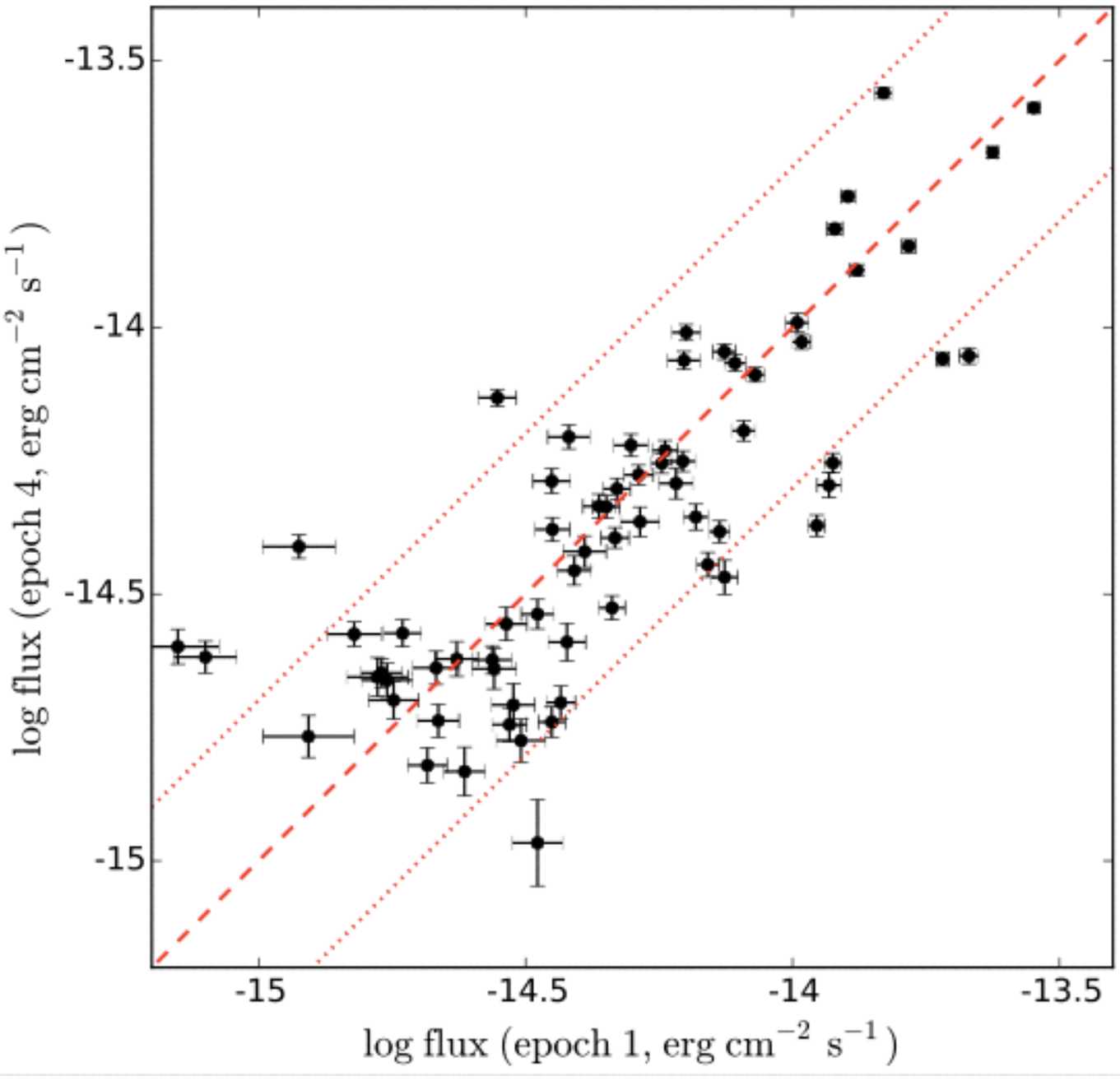
~15 year AGN
X-ray variability

Assumption 2: OK

Yang et al. (2016)

~15 year AGN
X-ray variability

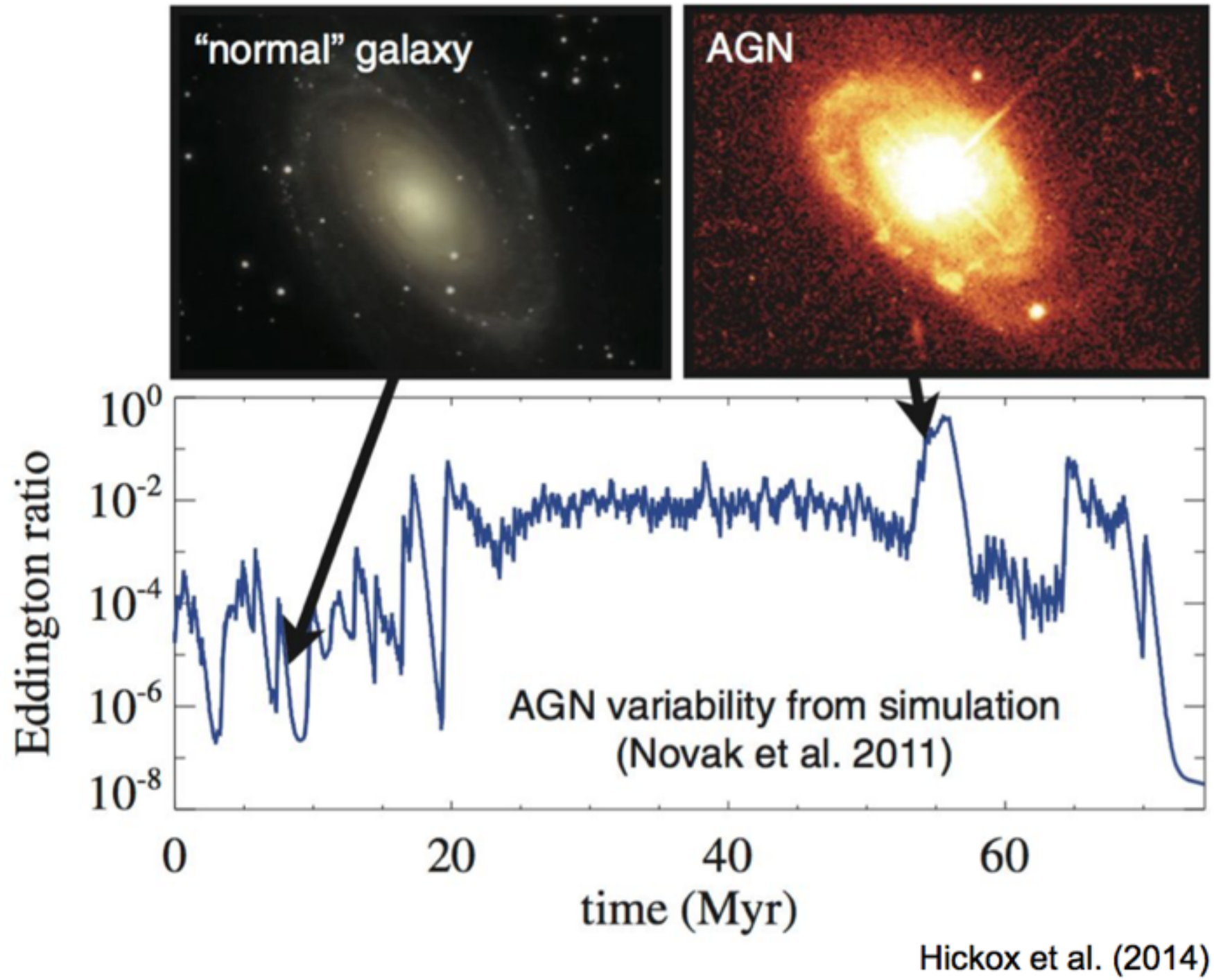
Assumption 2: OK



Yang et al. (2016)

- Observed amplitude ~ factor of 2 (Δt=15 yr)
- Longer timescale → larger amplitude

Assumption 2: OK



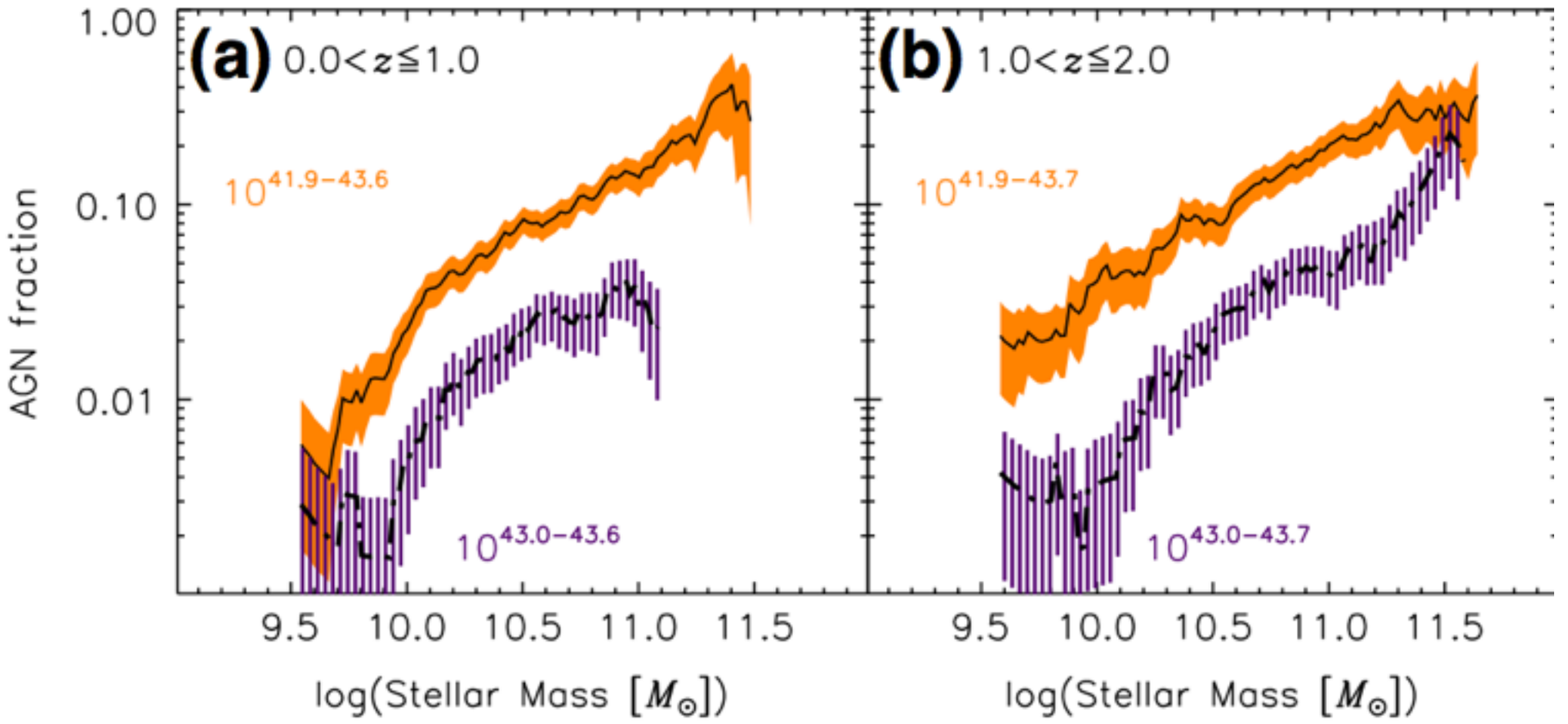
Hickox et al. (2014)

Model assumptions?

1. Long-term average BHAR ∝SFR
2. Observed (instantaneous) BHAR variable on < 10 Myr; SFR ~ constant on ≳ 100 Myr.

Assumption 1: ??

AGN fraction rises toward high M_{star}

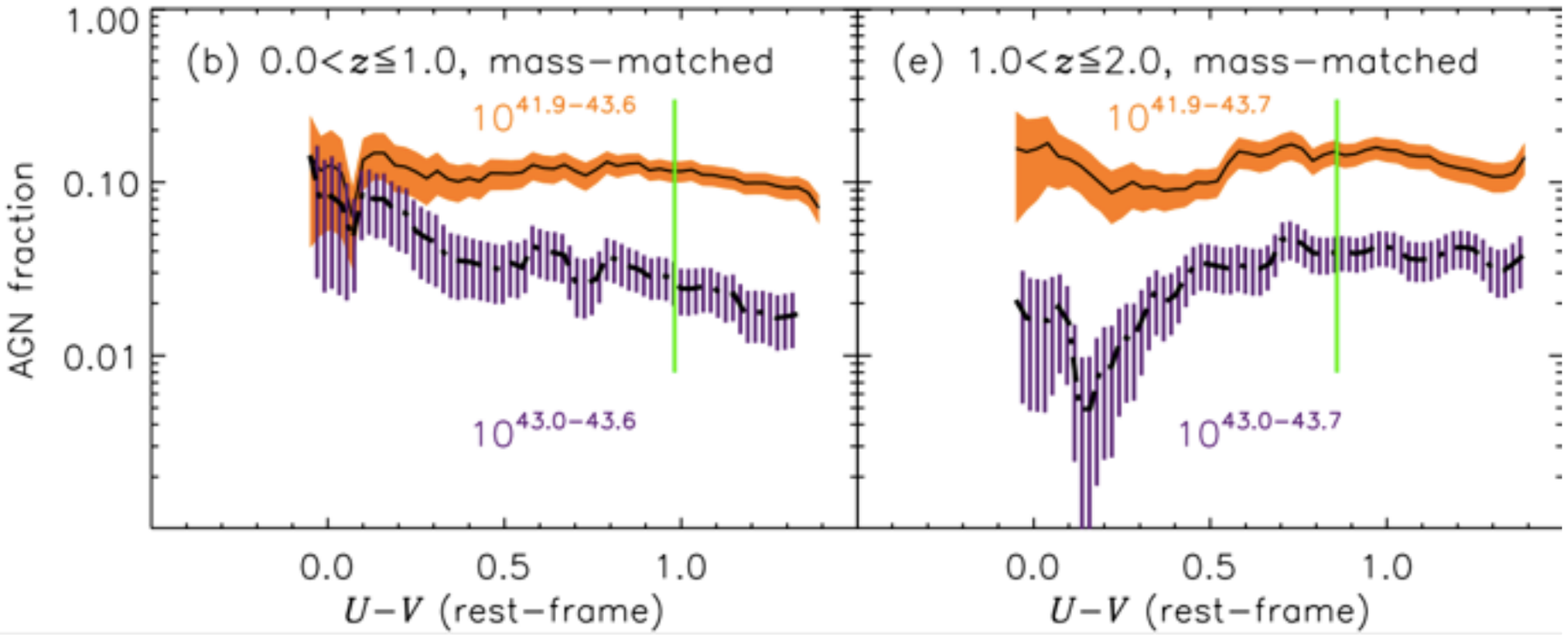


Xue et al. (2010)

Assumption 1: ??

- For mass-matched sample, AGNs do not favor red or blue hosts

- But color might not indicate SFR due to dust reddening

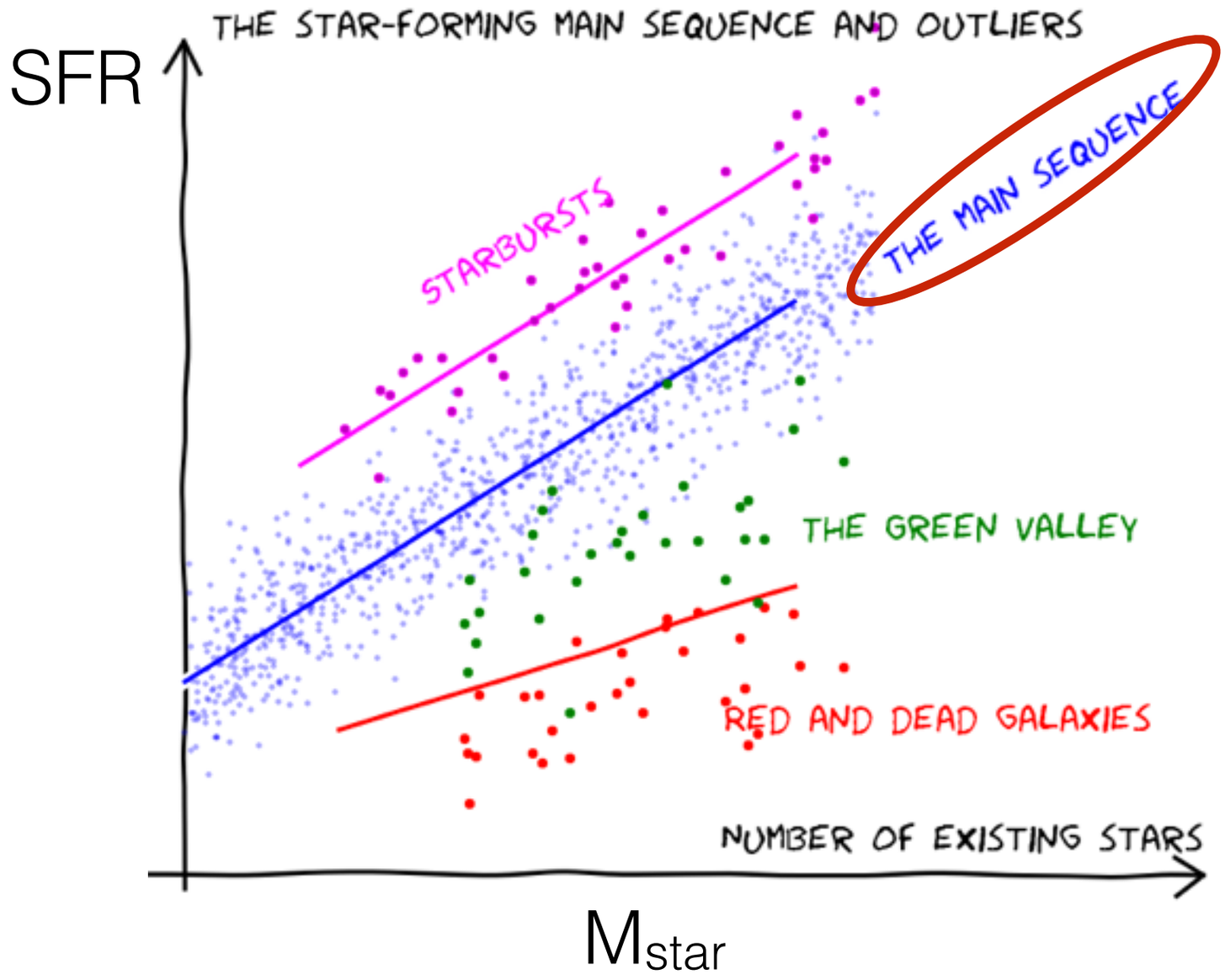


Xue et al. (2010)

SFR or M_{star}?

- Complicated due to star-formation main sequence ($SFR \propto M_{star}$)

- Need to control one variable while studying the other



Our data: CANDELS/GOODS-S

- Multiwavelength coverage (UV to mid-IR) by HST+VLT +...

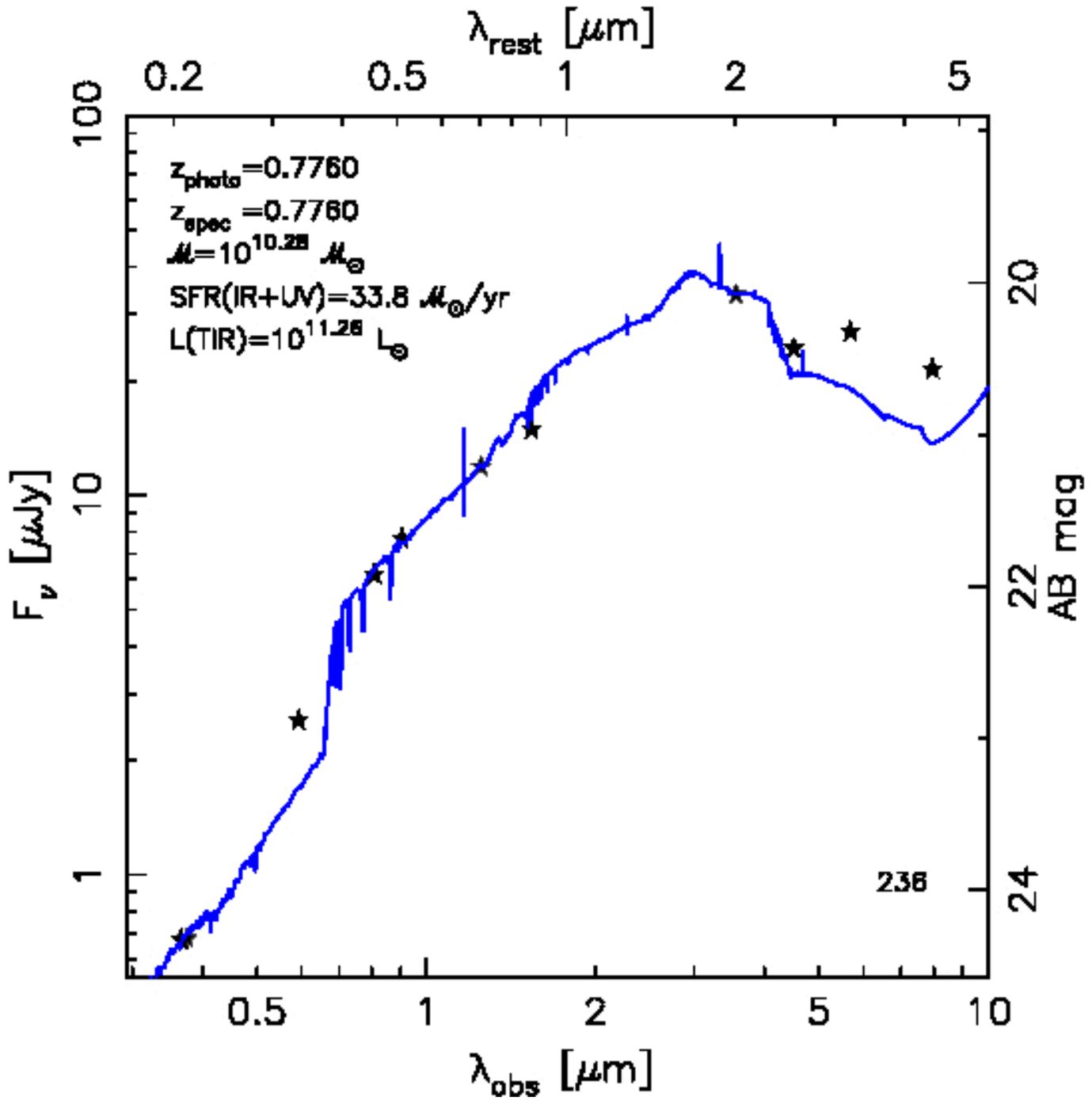
- 5σ limit: H=28 mag

- ~35,000 galaxies in 170 arcmin^2

SFR & M_{star} from SED fitting

- Performed by independent groups (Santini et al. 2015)

- We use their median SFR and M_{star}

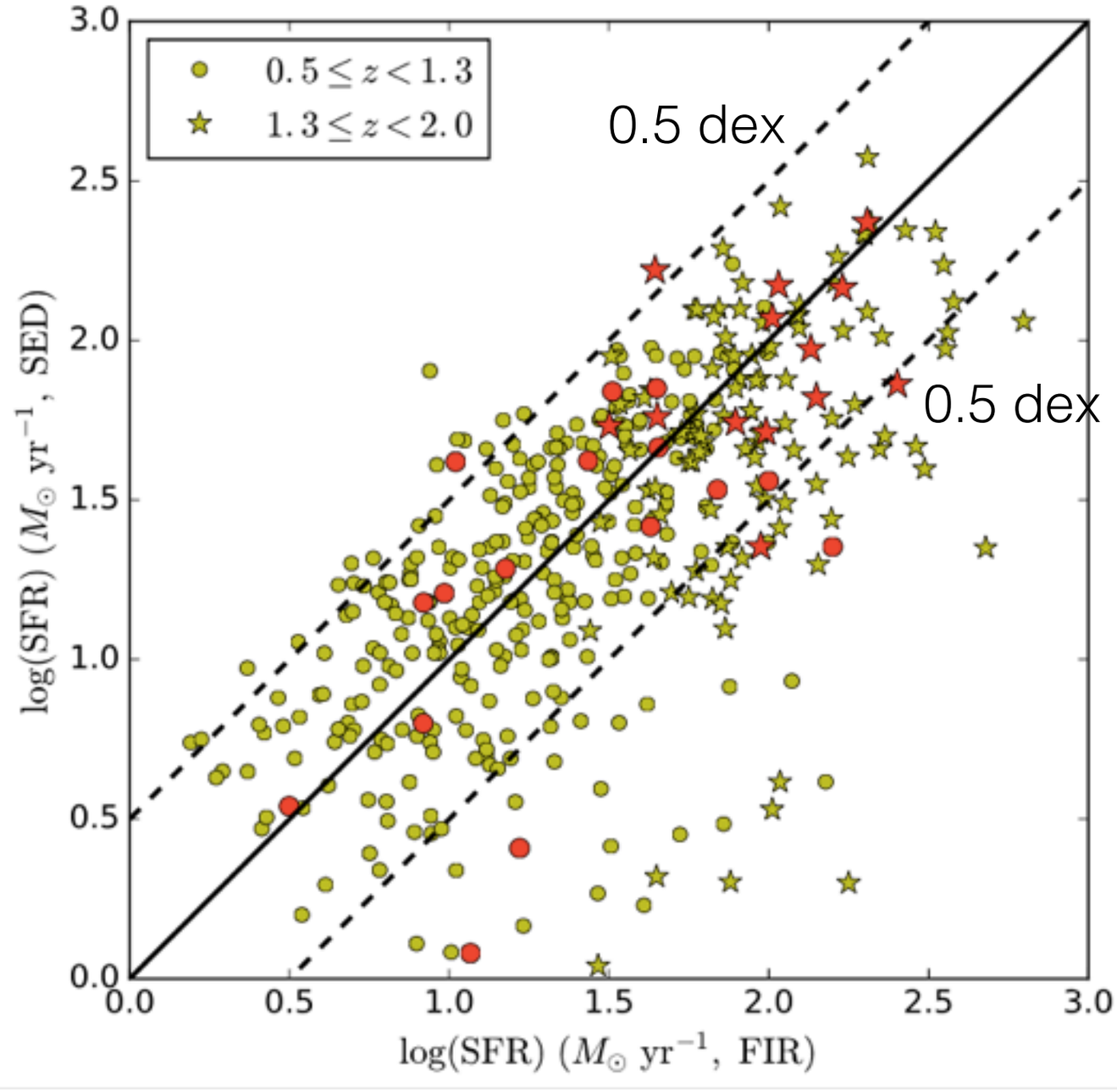


Credit: Rainbow database

Compared to FIR-based SFR

- Roughly agree with SFR from Far-IR (*Herschel*)

- AGNs do not have biased SFR

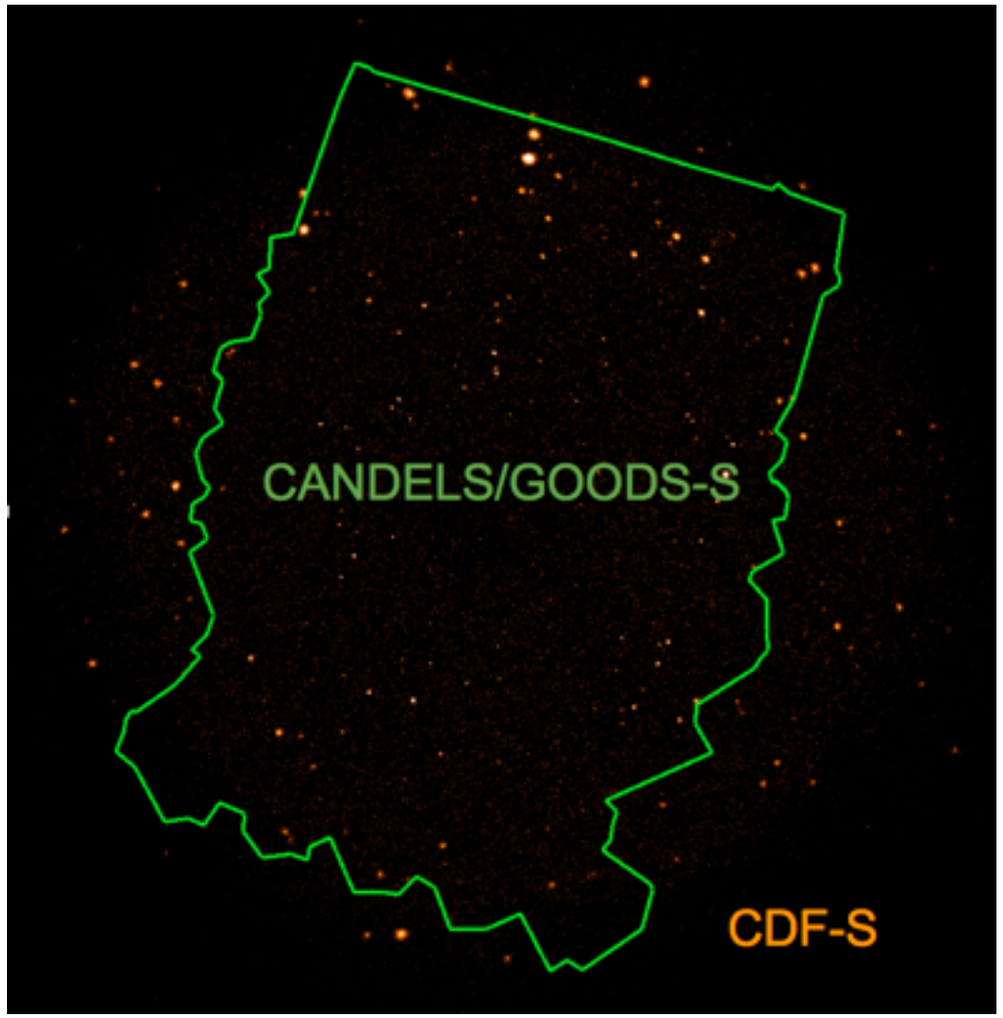


Our data: 7 Ms CDF-S

- 7 Ms (80 days!) observations of *Chandra*

- ~1000 X-ray sources (mostly AGNs)

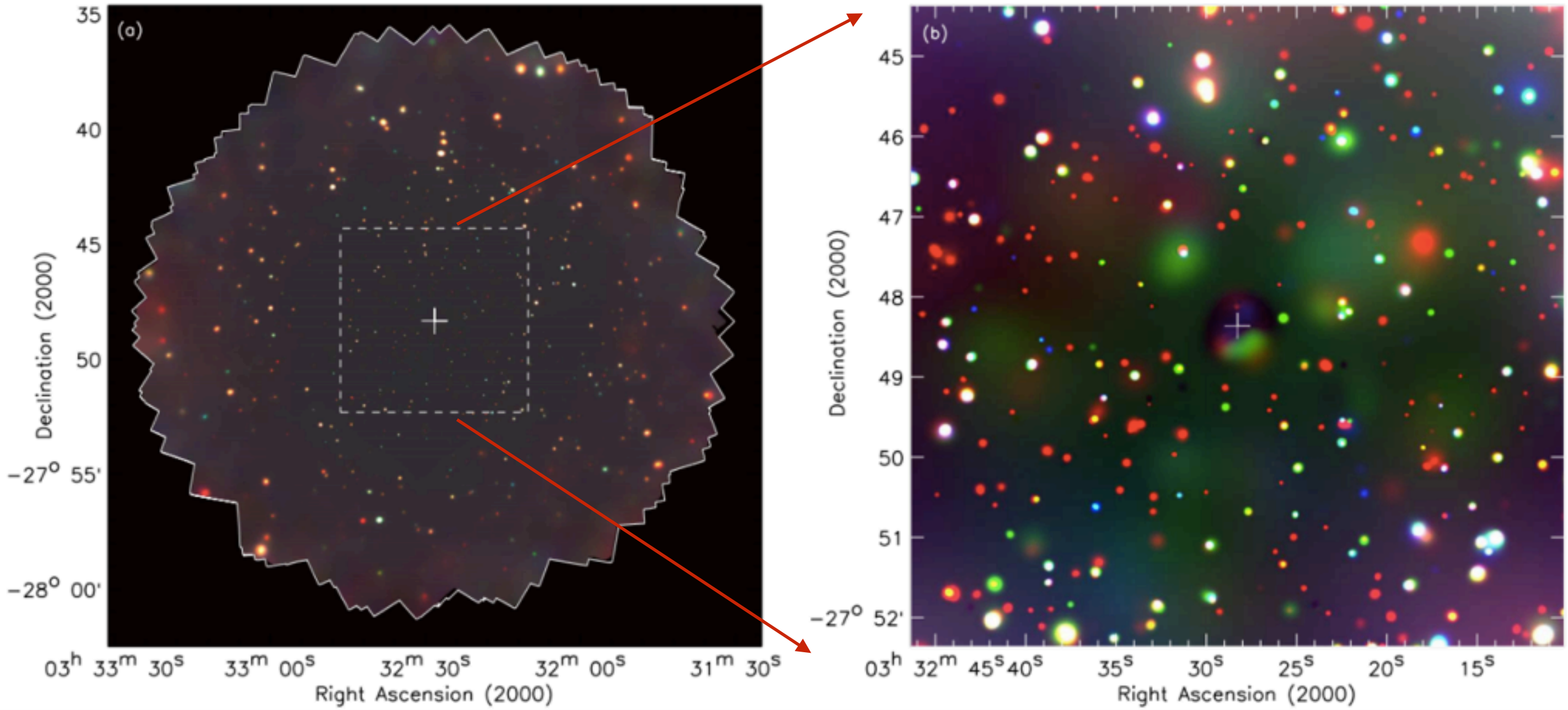
- measure BHAR



Luo et al. 2016

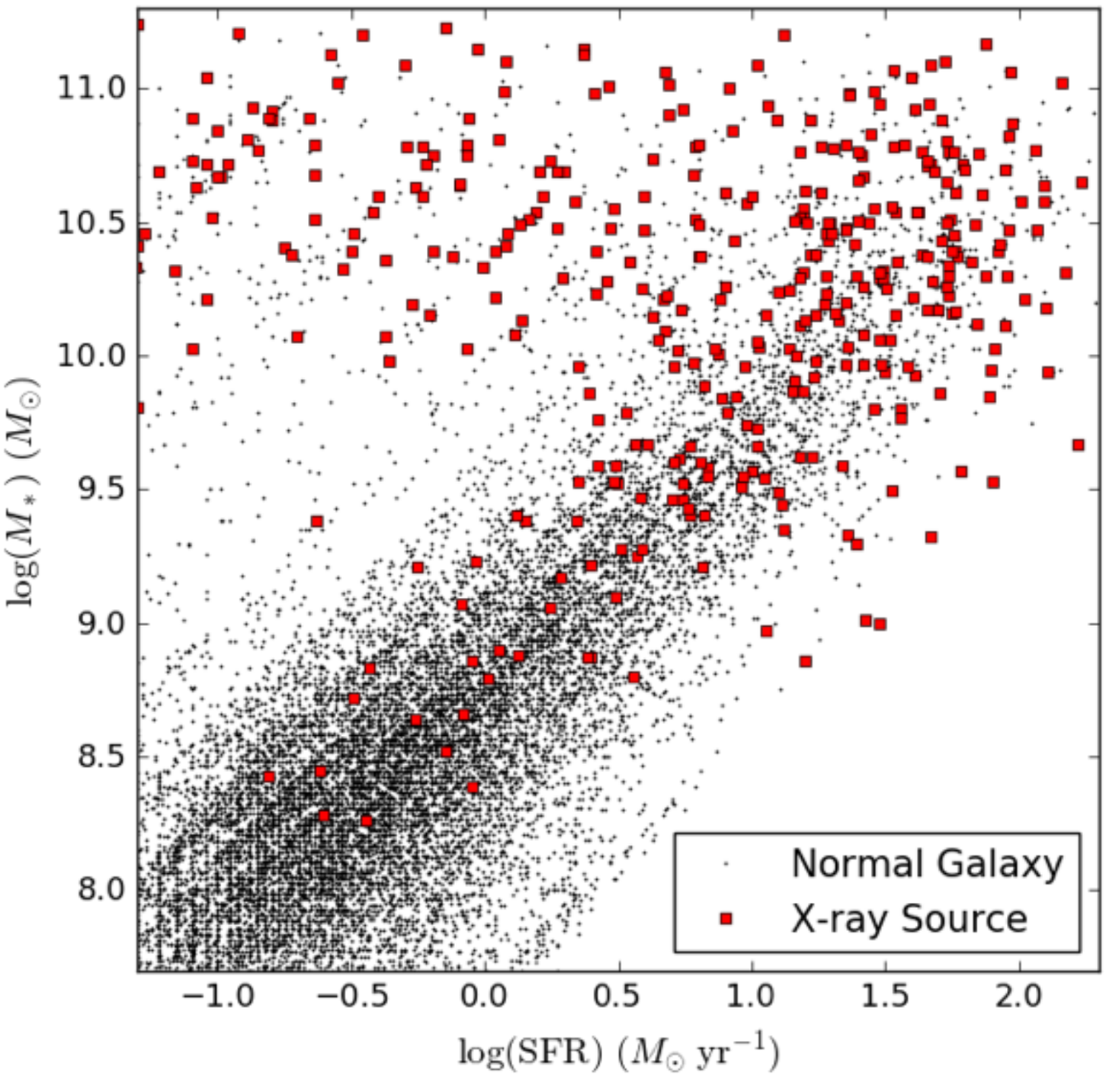
CDF-S: the deepest X-ray survey

X-ray source density ~ 50,000 deg^{-2}



Luo et al. 2016

The M_{star}-SFR Plane



Most X-ray sources have high M_{star}!

Measure BHAR

Detected (spectral fitting) Non-detected (stacking) X-ray binaries

$$\langle L_{\rm X}\rangle = \frac{(\sum_{\rm detect} L_{\rm X}) + \frac{N_{\rm non}}{N_{\rm stack}} L_{\rm X,stack} - \sum_{\rm all} L_{\rm X,XRB}}{N_{\rm detect} + N_{\rm non}}$$

$$\langle {\rm BHAR}\rangle = \frac{(1-\epsilon) k_{\rm bol} \langle L_{\rm X}\rangle}{\epsilon c^2}$$

$$= \frac{3.53 \langle L_{\rm X}\rangle}{10^{45}\ {\rm erg\ s^{-1}}} M_\odot\ {\rm yr}^{-1}$$

Sample-mean <BHAR> to approximate long-term average BHAR

Stacking

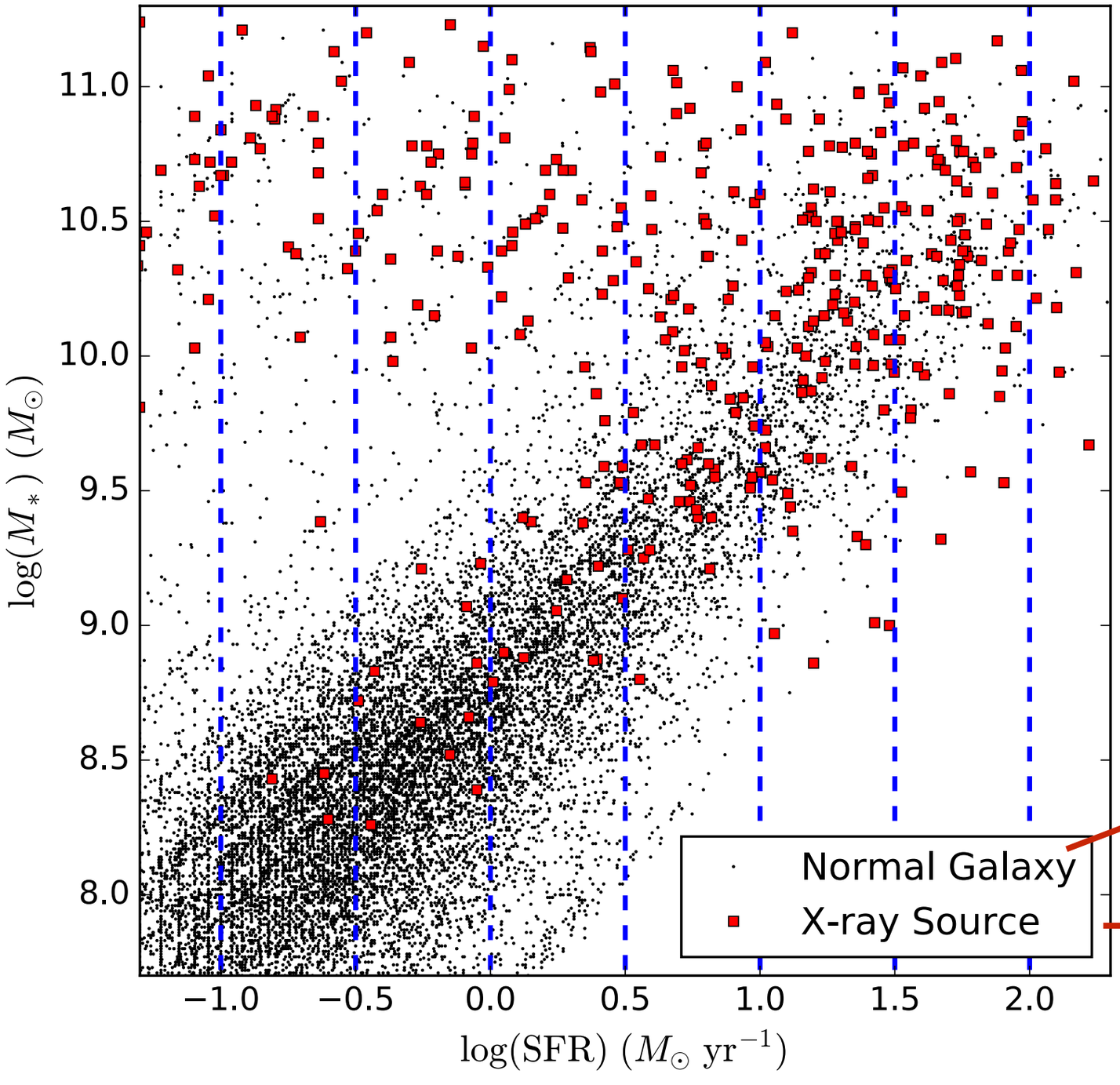
3/100 sec exposure

1/1000 sec exposure

Stacked image of 30 candles with 1 / 1000 sec exposure.

Effective stacked exposure of (30 × 1 / 1000 sec) = 3 / 100 sec.

BHAR vs SFR

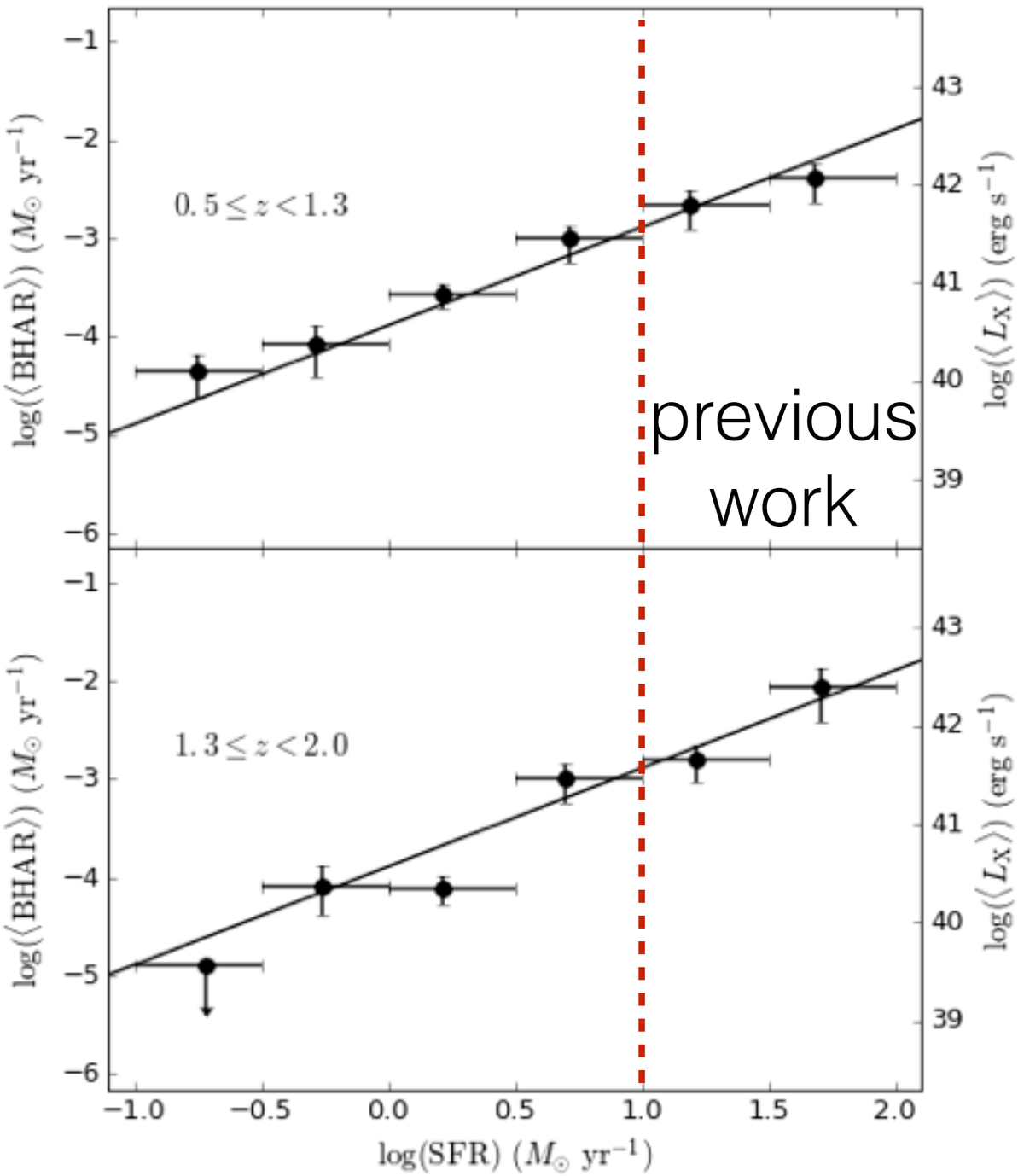


For each bin we calculate <BHAR>

Stacking

Spectral fitting

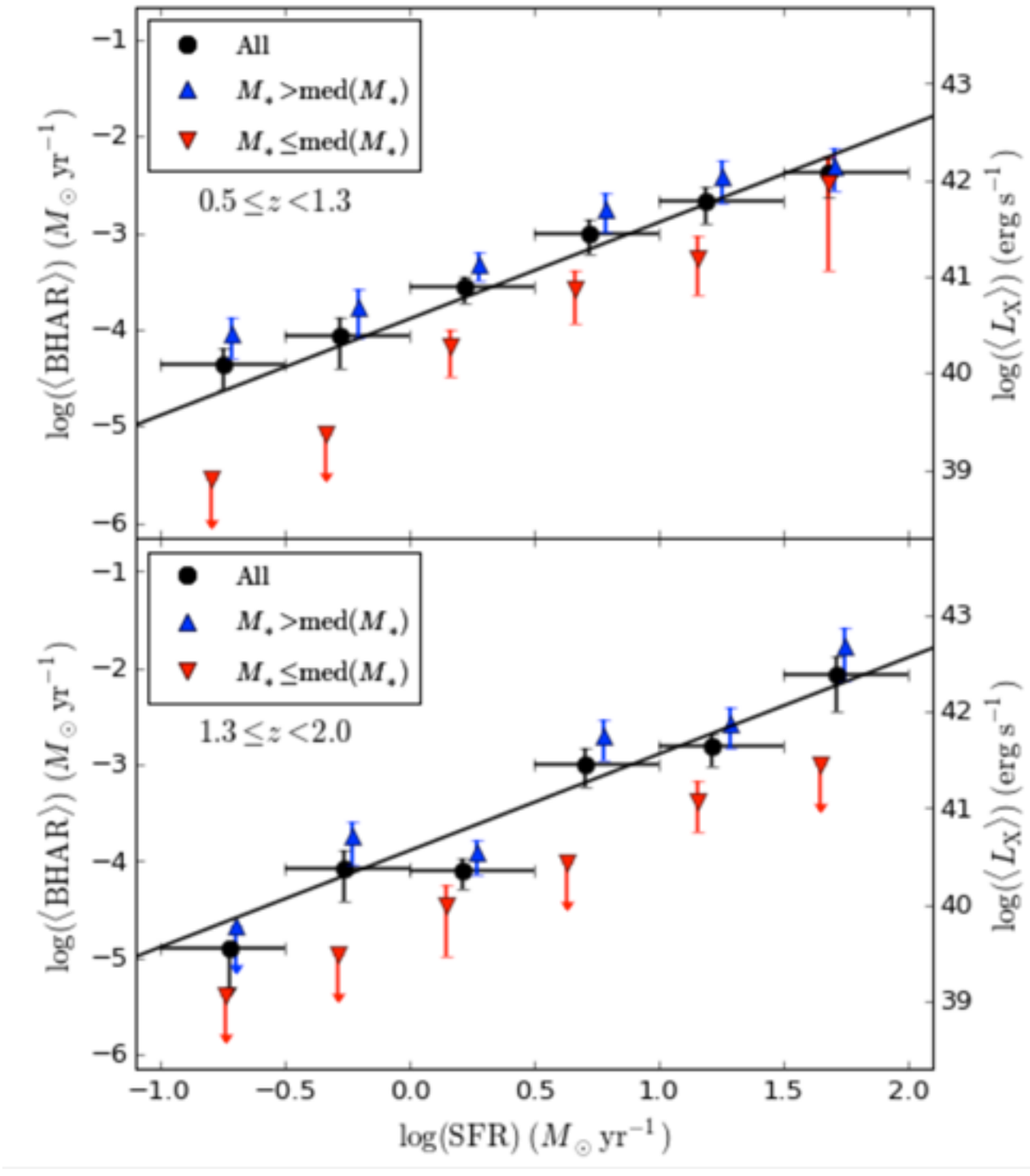
BHAR vs SFR



- <BHAR>-SFR relation fitted well by linear model (slope=1) down to SFR~0.1 M_{sun}/yr

- Hickox's model is correct?

BHAR vs SFR



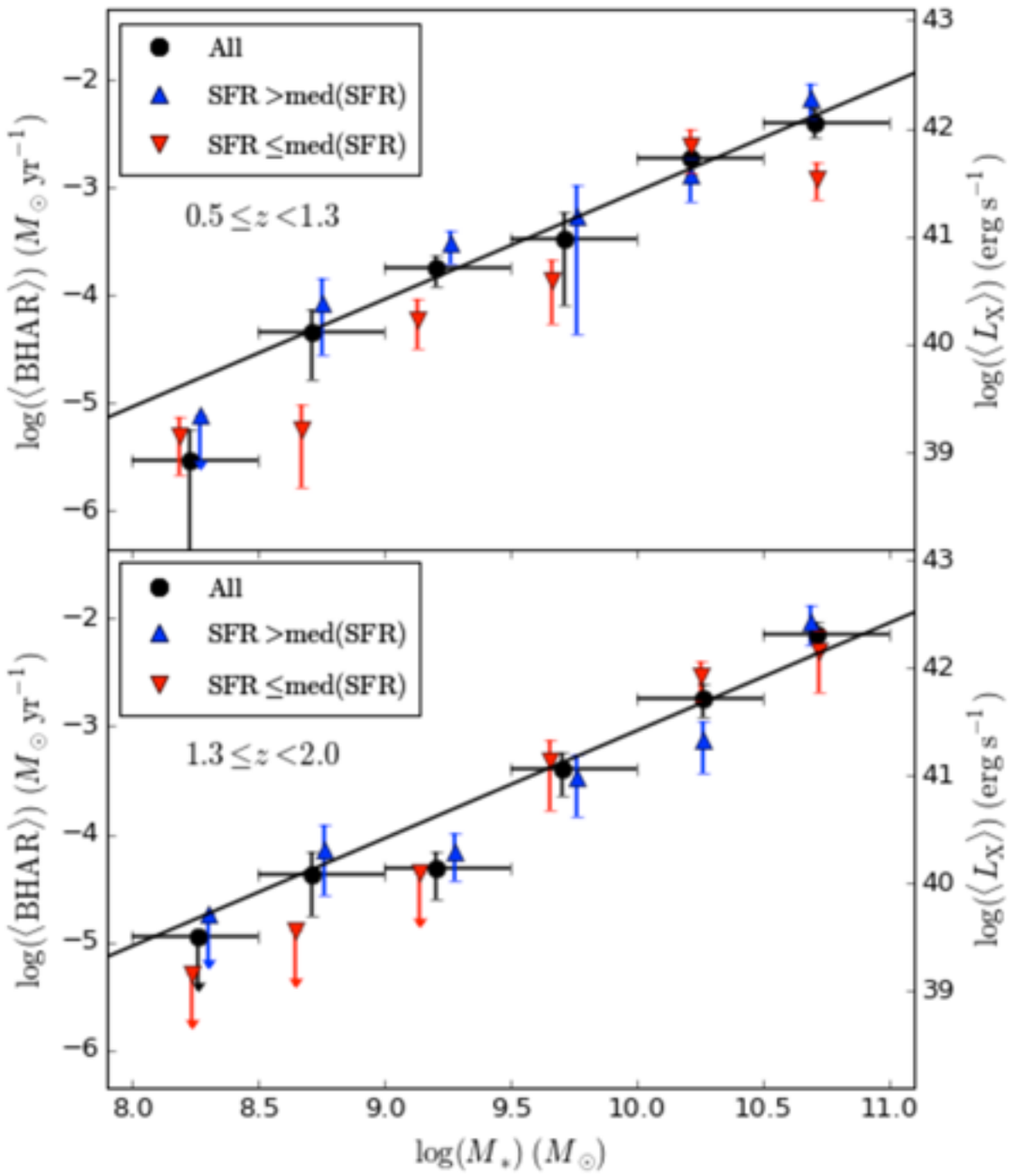
- But for SFR-controlled samples, massive galaxies have higher <BHAR>

- Hickox's model is unlikely correct!

BHAR vs. M_{star}

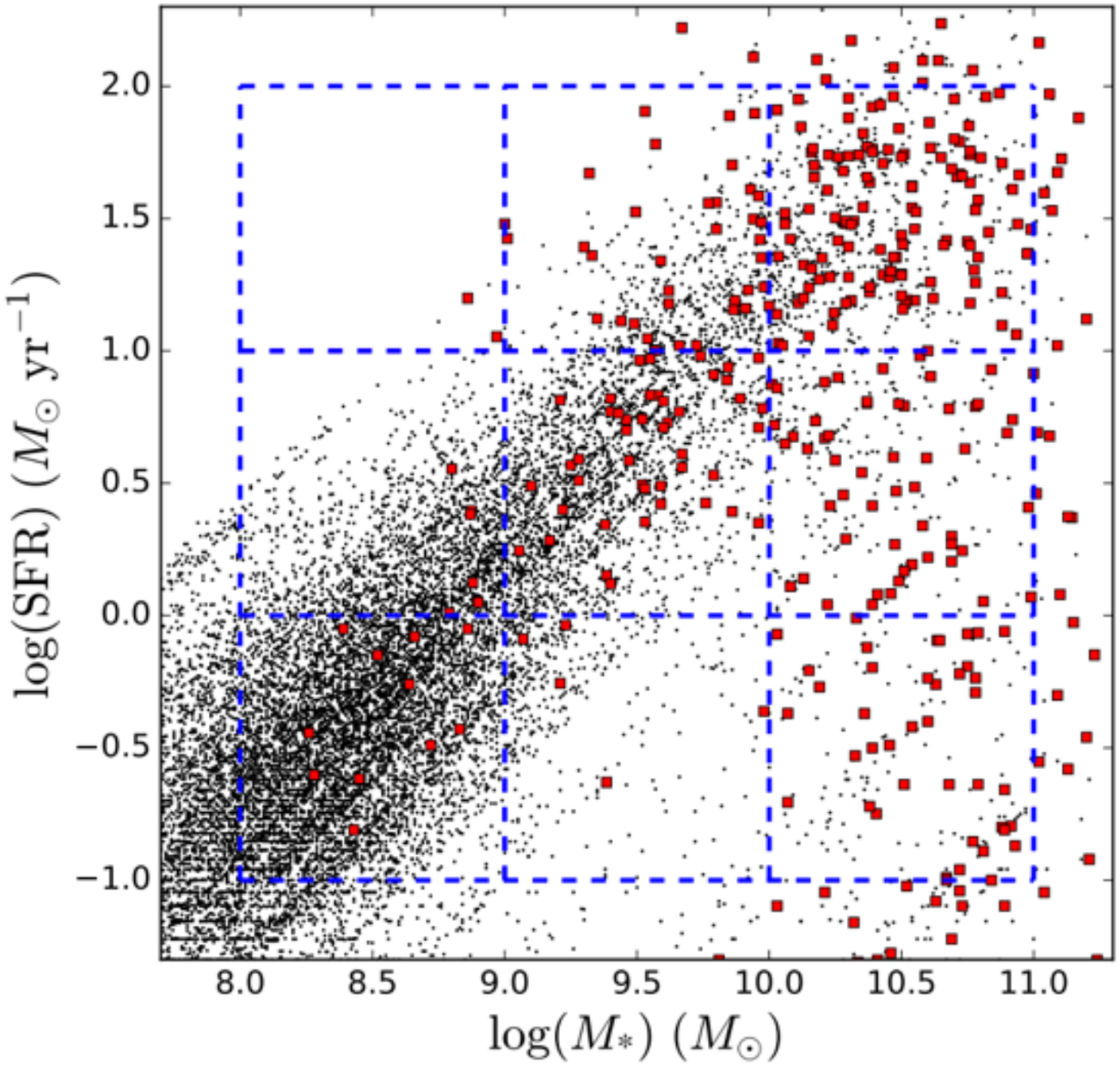
- <BHAR>-M_{star} relation can also be fitted well by a linear model

- For M_{star}-controlled samples, high-SFR sources have similar <BHAR> compared to low-SFR ones



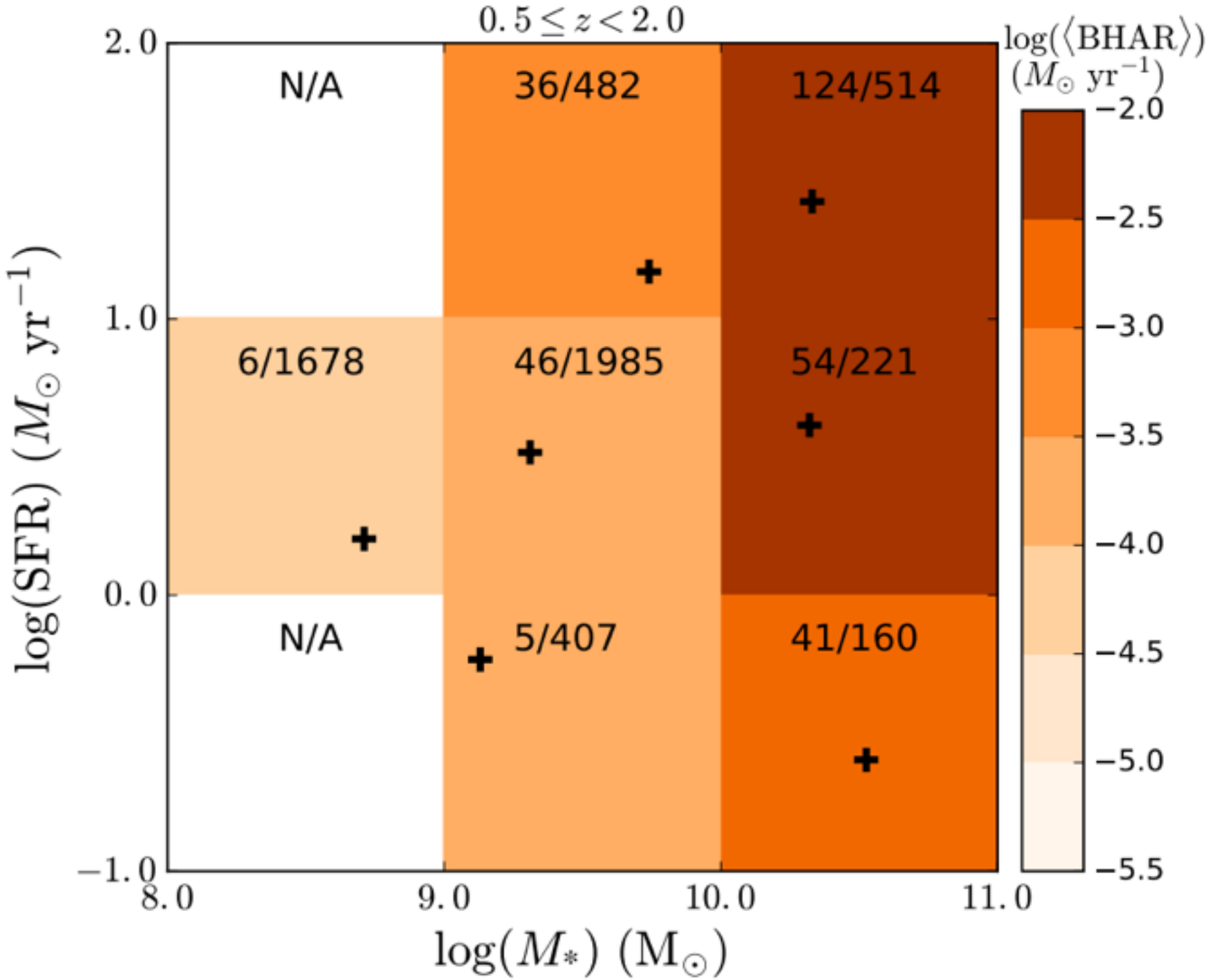
Quantitative Analyses

- M_{star} -SFR grids
- Calculate <BHAR> for each bin



Quantitative Analyses

Massive galaxies have higher <BHAR> regardless of SFR

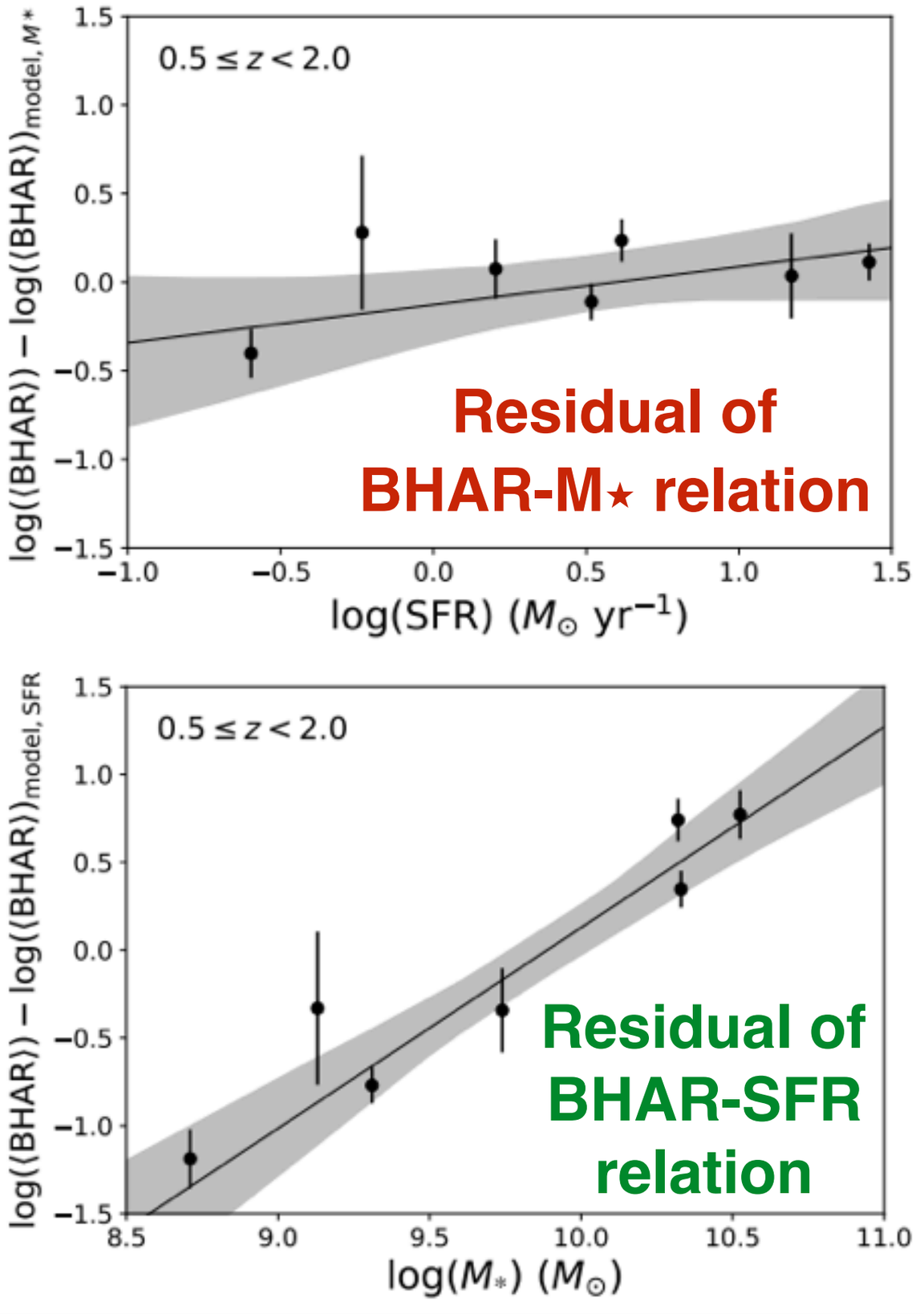


Partial correlation analyses:

<BHAR>-SFR: 1σ

<BHAR>-M⋆: 8σ

M⋆ is the driving factor for black-hole growth



Monsters mostly grow in massive hosts!

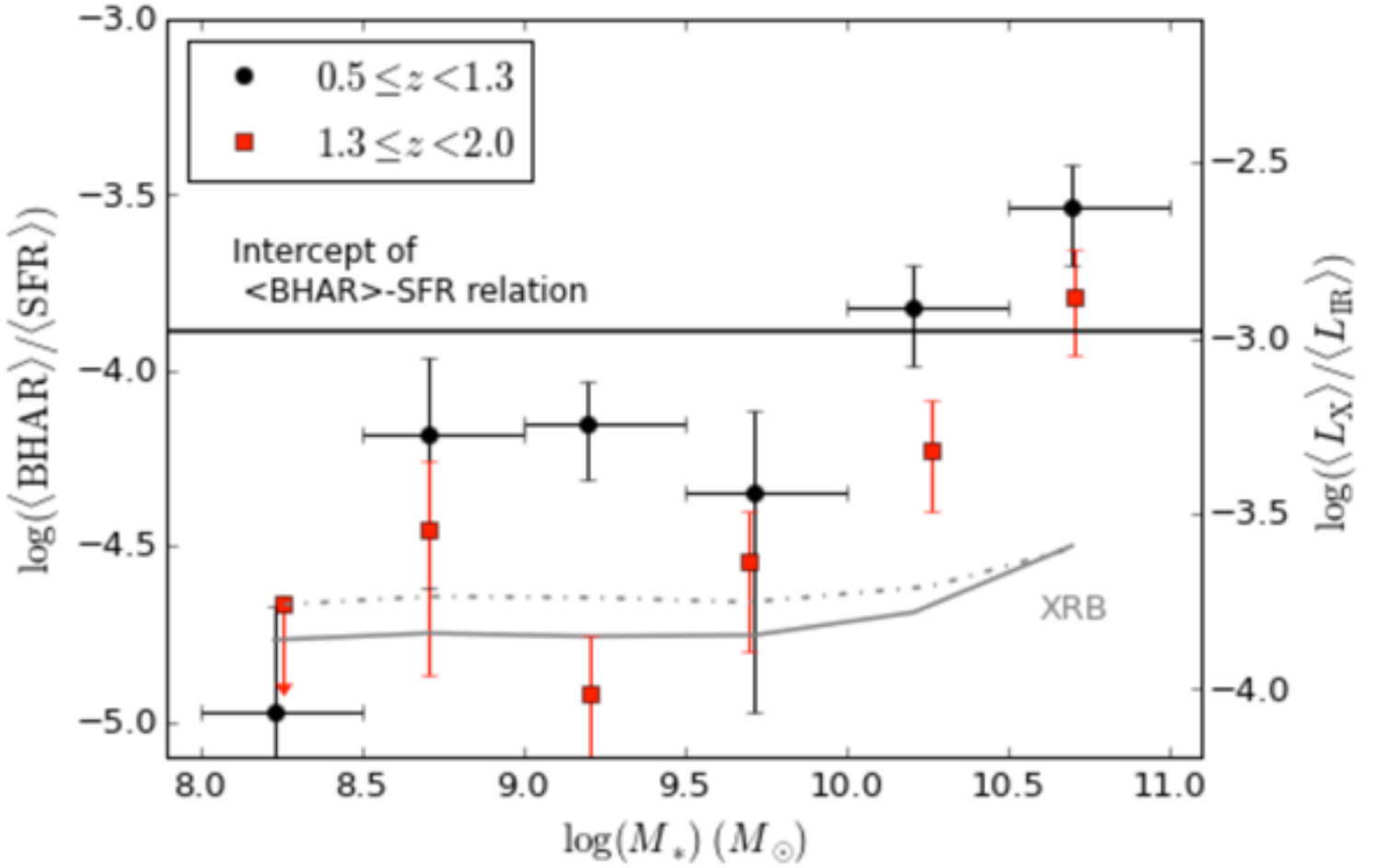
- Black-hole growth is mainly linked to M_{star} rather than SFR

- $\langle BHAR \rangle / M_{star} \sim 10^{-13}\ yr^{-1}$

- The observed <BHAR>-SFR relation is likely a secondary effect

BHAR/SFR

- <BHAR>/<SFR> depends on M_{star}
- In massive galaxies, black holes accrete gas more effectively

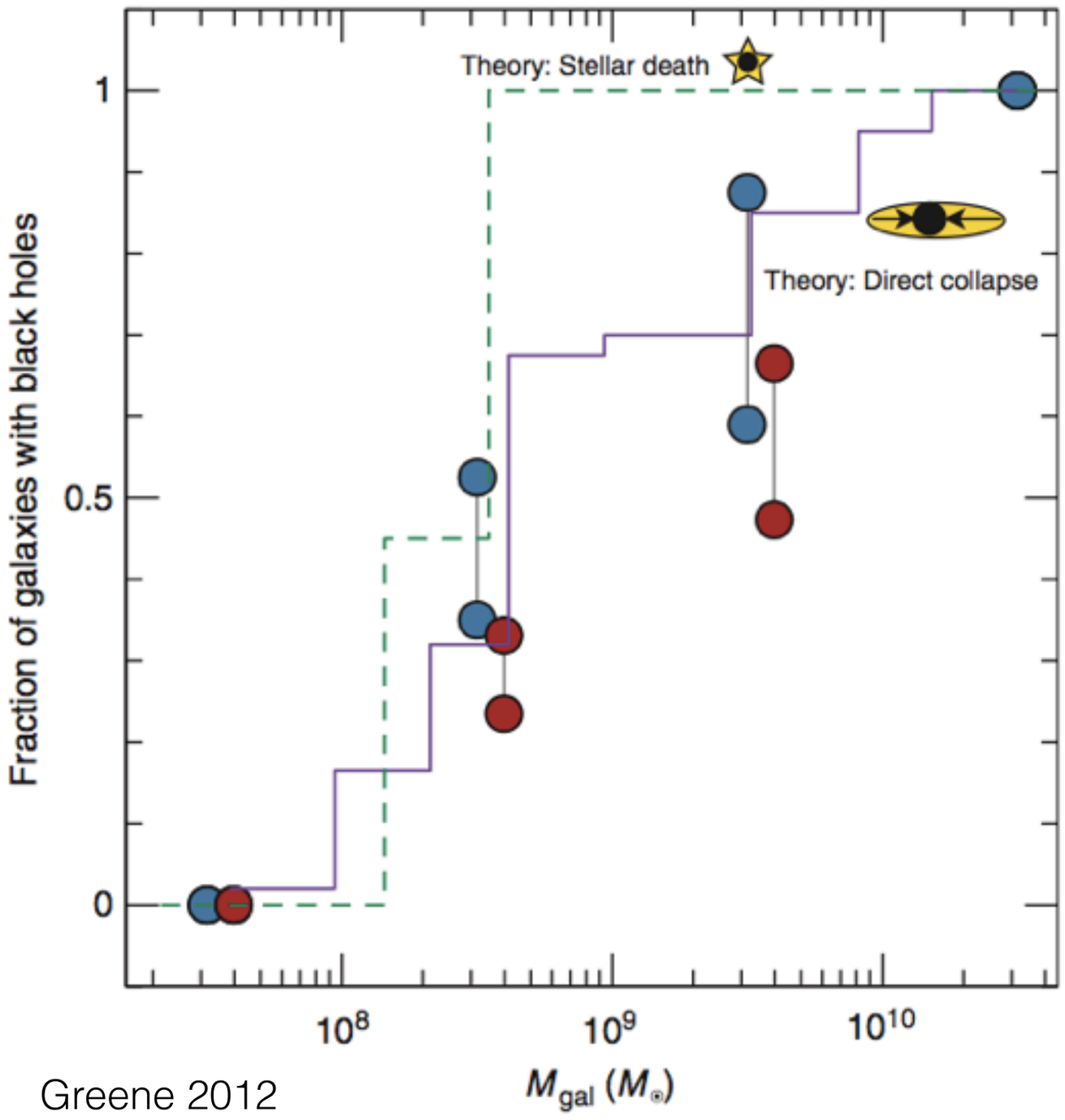


Possible Causes

- Massive galaxies have deeper gravitational potential well (Bellovary et al. 2013; Dubois et al. 2015)

- Some low-mass galaxies might not have SMBHs at all (Volonteri 2010; Miller et al. 2015)

BH occupation fraction



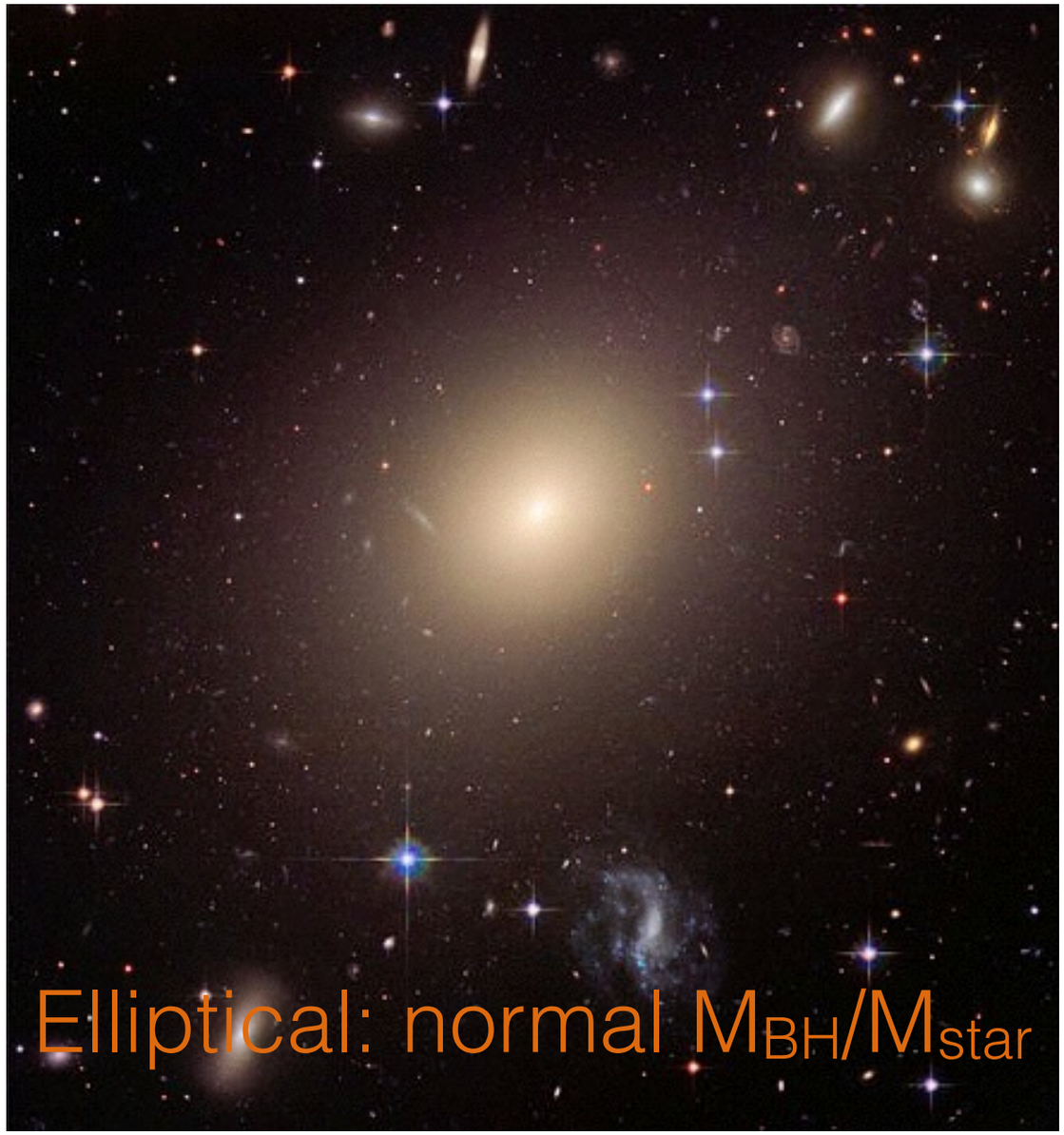
Greene 2012

Theories predict occupation fraction drops toward low M_{star}

SMG to Giant Elliptical

Credit: X-ray: NASA/CXC/IoA/D.Alexander et al.; Illustration: NASA/CXC/M.Weiss

$$\frac{M_{\rm BH}(t_0)}{M_*} \approx \frac{(t_2 - t_0){\rm BHAR}}{M_*} \ ({\rm elliptical})$$
$$\approx 10\ {\rm Gyr} \times 10^{-13}\ {\rm yr}^{-1}$$
$$\approx 10^{-3}.$$



Credit: Wikipedia

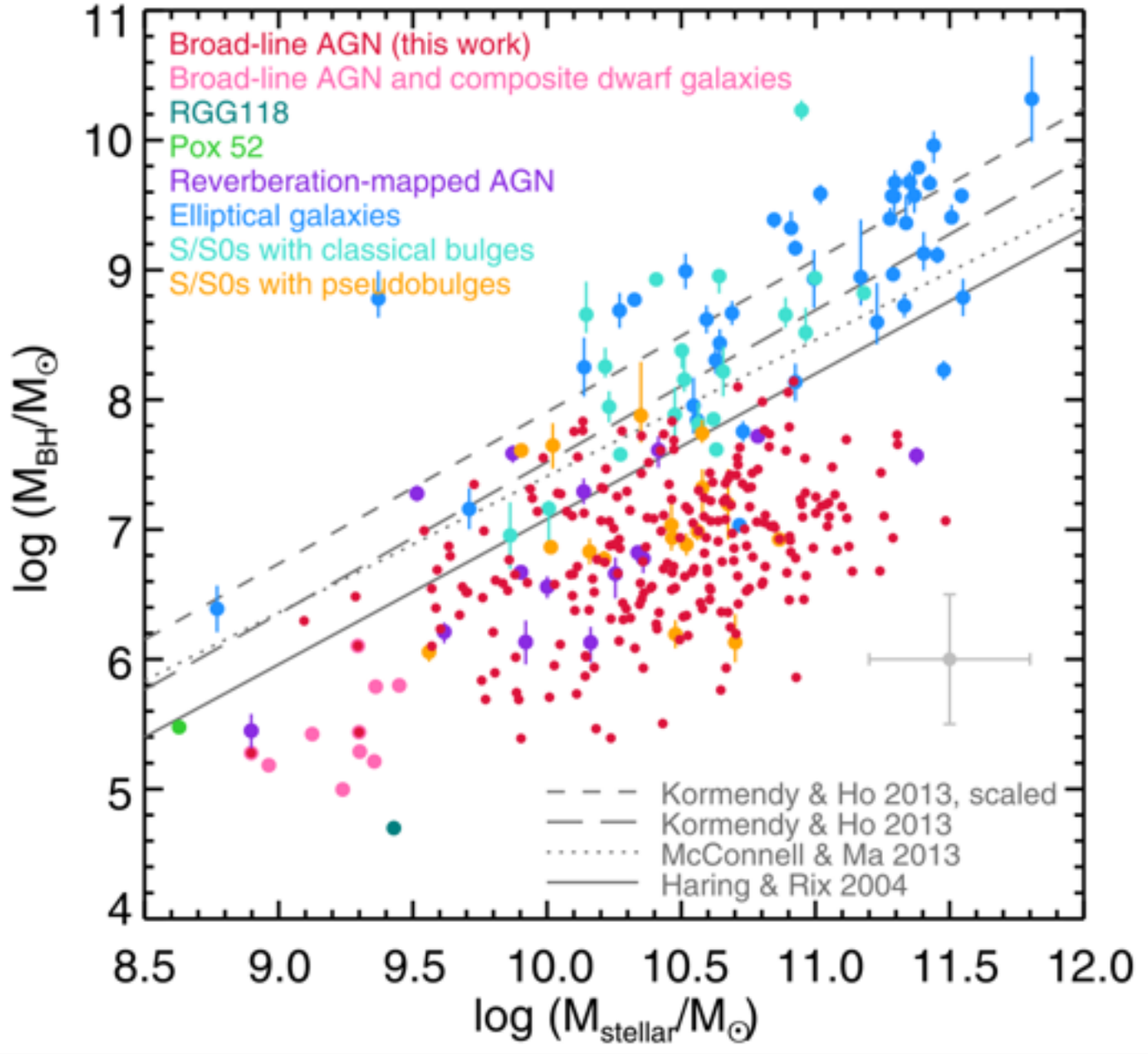
Star Forming Galaxies

$$\frac{M_{\rm BH}(t_0)}{M_*(t_0)} \approx \frac{\int_{t_2}^{t_0} {\rm BHAR}(t)dt}{\int_{t_2}^{t_0} {\rm SFR}(t)dt} \quad \text{(star-forming)}$$

$$\sim \frac{\rm BHAR}{\rm SFR}$$

$$\sim 10^{-4.5} - 10^{-3.5}, \quad (M_{star}\text{-dependent})$$

Lower than M_{BH}/M_{star} in giant ellipticals



Reines et al. 2015

Summary

- Observationally <BHAR> is proportional to both SFR and M_{star}

- Intrinsically, <BHAR> is mainly linked to M_{star} rather than SFR.

- Massive galaxies have higher <BHAR>/<SFR>, they grow their black hole more efficiently.