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DEEP15 CONFERENCE @ SINTRA

The Growth of Star Forming galaxies and their Supermassive Black Holes over cosmic time

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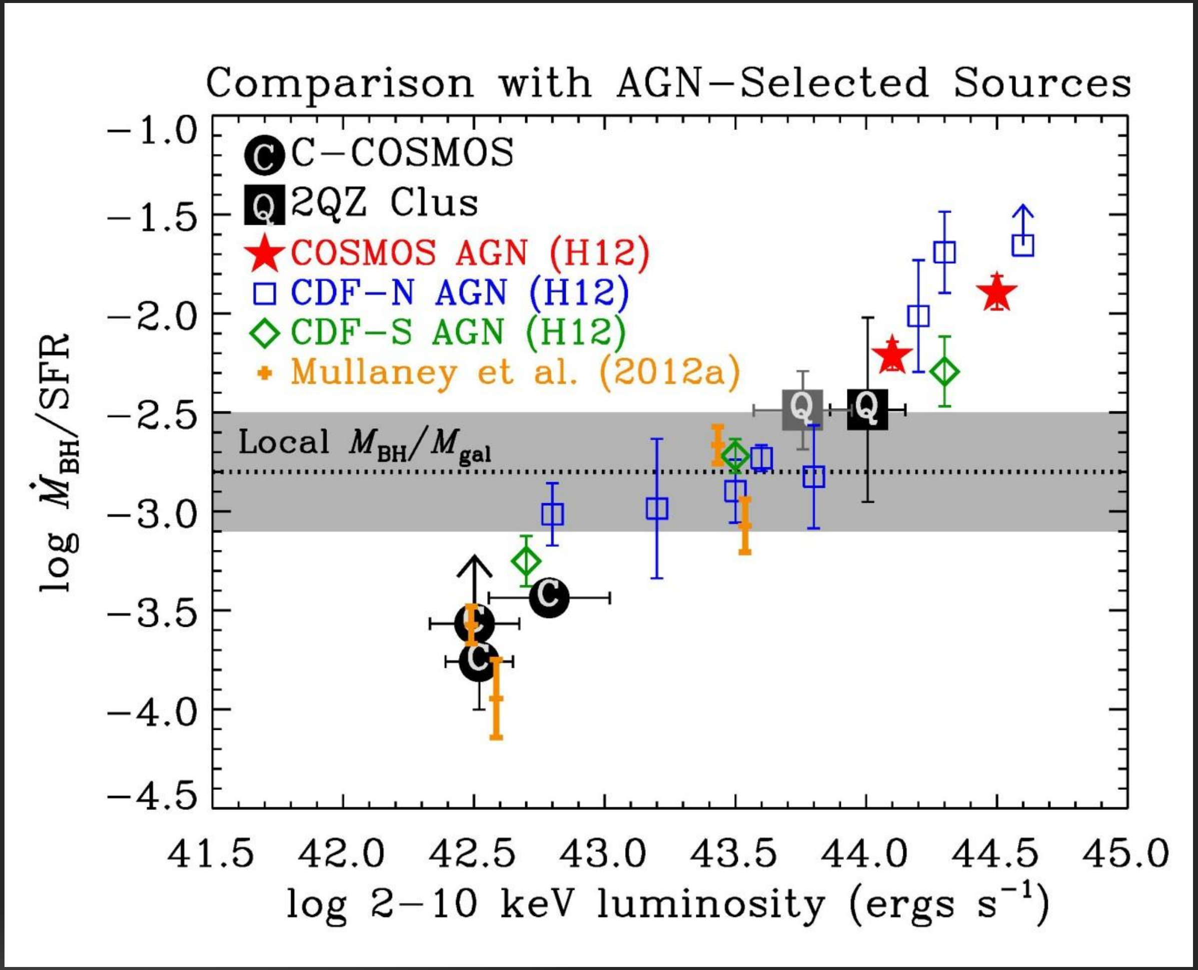
INTRODUCTION

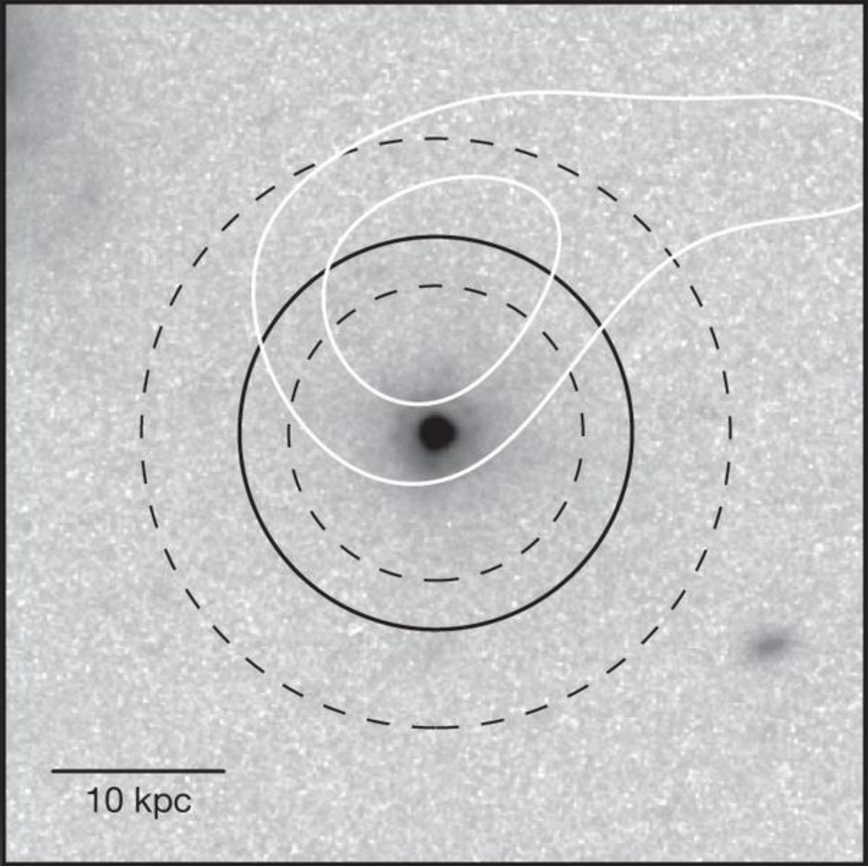
- Understanding galaxy formation and evolution → understanding Star Formation and Supermassive Black Hole Accretion histories.
- Star formation → Growth of the galaxy
- Black Hole Accretion → Growth of the Black Hole



Lehmer et al, 2013

REGULATION: SF OR AGN?

- AGN thought responsible for galaxy evolution at the highest masses (Silk & Rees, 1998; Bower et al, 2006).
- Star Formation is also important and shown to work (Bolatto et al, 2013; Geach et al. 2014).



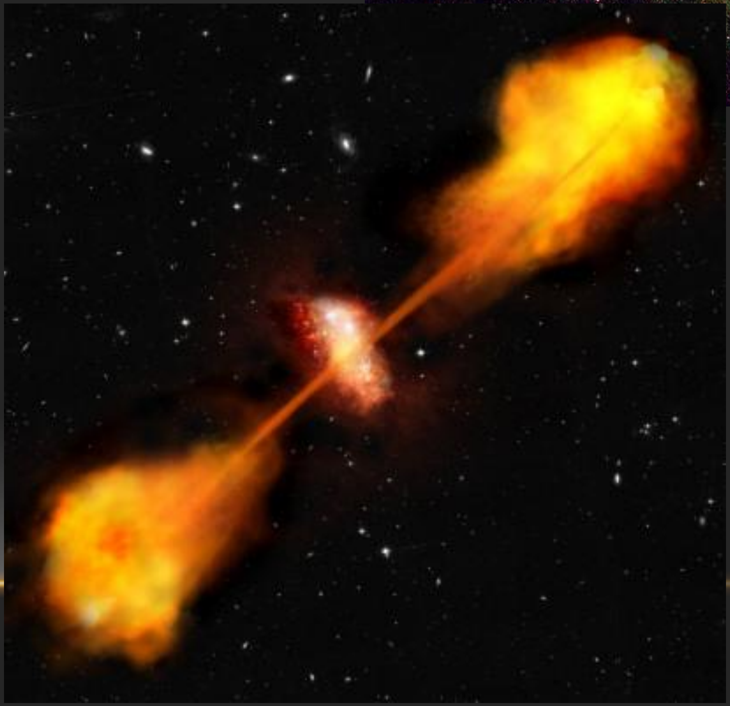
Geach et al, 2014, Nature

TRACING SFR AND BHAR

- Star Formation → Young, Massive Stars → H-alpha and Far Infrared emission.
  - Massive stars → small lifetime ~ duration of star formation period.

- Black Hole activity → Relativistic Jets and emission from accretion disk → X-rays, Radio, color-color selections.

NASA, Hui Yang University of Illinois



ESA/C. Carreau/ATG medialab

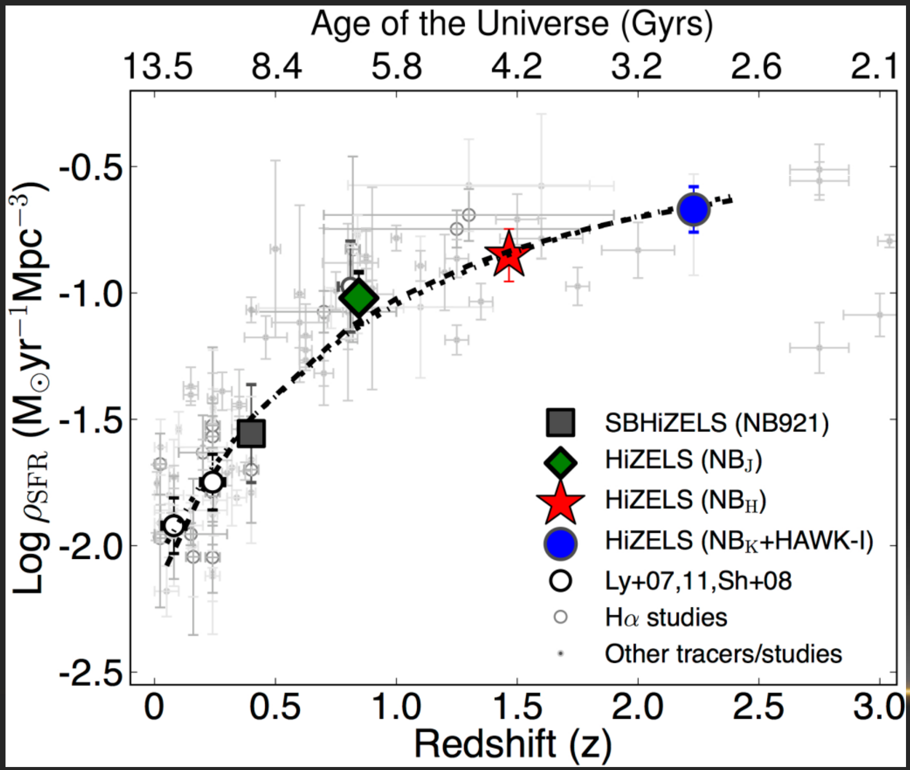
OBJECTIVES/GOALS

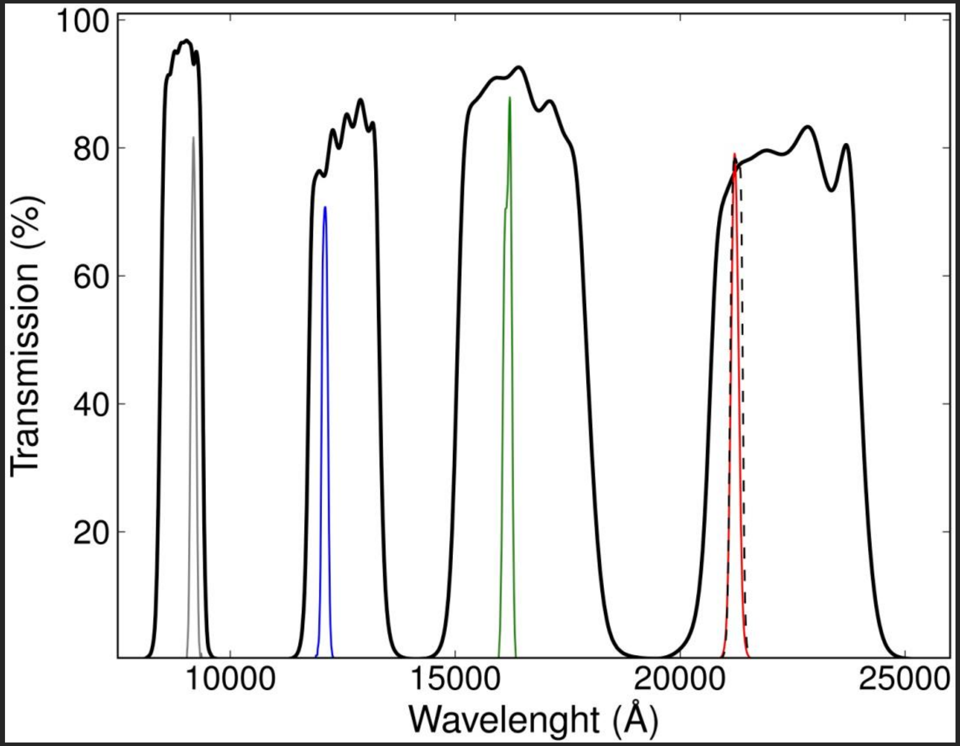
- Most works focus on AGN-selected samples when studying SFR and/or BHAR (e.g. Stanley et al, 2015).

- We are interested in understanding how AGN and SF processes influence each other and in particular,
  - We are interested in knowing how the typical star-forming galaxy and its central supermassive black hole grow (but see also, e.g. Delvecchio et al, 2015).

SAMPLE

- The High Redshift Emission Line Survey (HiZELS; Geach et al. 2008; Best et al. 2010; Sobral et al. 2009a,b, 2012, 2013).
- Hundreds of star-forming galaxies per redshift with four different redshift bins.



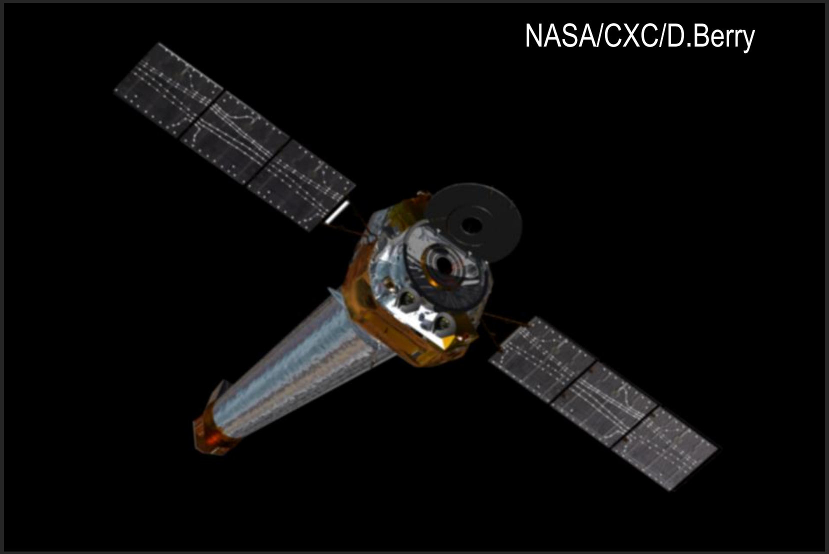


Sobral et al, 2013

- The COSMOS field (Scoville et al. 2007).
  - C-Chandra, VLA-COSMOS, HerMES.

METHODOLOGY

- X-rays → Black Hole Accretion Rates (Lehmer, et al, 2013, Ranalli et al. 2003)
  - Direct detection – source matching between HiZELS and Chandra-COSMOS catalogs.
  - Stacking of the entire galaxy sample.
- Infrared – Star Formation Rates & AGN color-color selection
- Radio → Star Formation Rates



$$L_X = 4\pi d_L{}^2 f_X (1+z)^{\Gamma-2}\ \mathrm{erg\,s^{-1}}$$

Afonso et al. 2006

Source ID (Sobral et al. 2013 catalogue)	Redshift	Log Luminosity (X-Rays) $\mathrm{erg\,s^{-1}}$	Log LX-LX$_{(SFR)}$ $\mathrm{erg\,s^{-1}}$	SFR (Hα) $M_\odot\,yr^{-1}$	SFR (FIR) $M_\odot\,yr^{-1}$	$\dot{M}_{BH}$ (obs) $M_\odot\,yr^{-1}$	$\dot{M}_{BH}$ (SFR corrected) $M_\odot\,yr^{-1}$
HiZELS-COSMOS-NB921 DTC S12-9334	0.4	42.21	42.18	0.22	9.58	0.006	0.005
HiZELS-COSMOS-NB921 DTC S12-93079	0.4	41.97	41.96	0.13	3.16	0.003	0.003
HiZELS-COSMOS-NBJ DTC S12-22675	0.84	43.32	43.32	3.97	17.67	0.074	0.074
HiZELS-COSMOS-NBJ DTC S12-32820	0.84	43.82	43.82	5.73	23.93	0.235	0.235
HiZELS-COSMOS-NBJ DTC S12-33061	0.84	43.77	43.77	9.23	25.07	0.209	0.207
HiZELS-COSMOS-NBJ DTC S12-26956	0.84	43.89	43.89	13.23	31.02	0.276	0.273
HiZELS-COSMOS-NBJ DTC S12-11275	0.84	42.76	42.74	4.78	22.26	0.02	0.019
HiZELS-COSMOS-NBJ DTC S12-6454	0.84	42.85	42.84	4.12	21.25	0.025	0.024
HiZELS-COSMOS-NBJ DTC S12-4541	0.84	42.96	42.95	7.68	24.18	0.032	0.032
HiZELS-COSMOS-NBJ DTC S12-2436	0.84	42.69	42.68	3.51	13.1	0.017	0.017
HiZELS-COSMOS-NBH DTC S12-23041	1.47	43.93	43.92	25.69	99.97	0.302	0.297
HiZELS-COSMOS-NBH DTC S12-19279	1.47	44.88	44.88	581.3	322.94	2.69	2.69
HiZELS-COSMOS-NBH DTC S12-20593	1.47	43.40	43.38	89.47	133.21	0.089	0.085
HiZELS-COSMOS-NBH DTC S12-44372	1.47	42.96	42.91	20.48	92.11	0.032	0.029
HiZELS-COSMOS-NBK DTC S12B-1528	2.23	43.66	43.62	104.03	460.16	0.162	0.147
HiZELS-COSMOS-NBK DTC S12B-1073	2.23	43.68	43.61	365.78	639.86	0.17	0.147
HiZELS-COSMOS-NBK DTC S12B-9274	2.23	43.45	43.41	21.91	272.64	0.1	0.091
HiZELS-COSMOS-NBK DTC S12B-1139	2.23	43.48	43.40	114.28	463.35	0.107	0.09
HiZELS-COSMOS-NBK DTC S12B-2306	2.23	43.38	43.32	48.80	324.34	0.085	0.074

$$\dot{M}_{BH} = \frac{(1-\epsilon)L_{bol}^{AGN}}{(\epsilon c^2)}$$

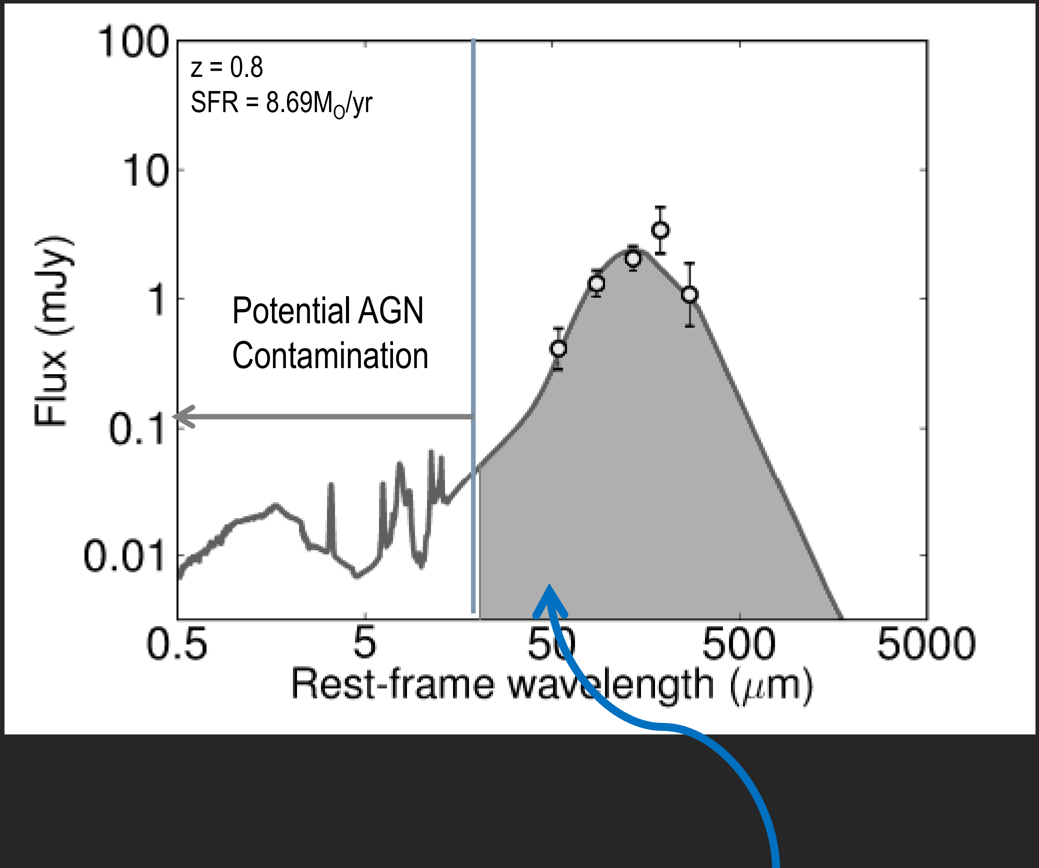
Lehmer et al. 2013

Calhau et al, in prep.

METHODOLOGY

- X-rays → Black Hole Accretion Rates
- Far-Infrared – Star Formation Rates (Kennicutt, 1998)
  - Direct Detection – source matching between HiZELS, HerMES (Oliver et al, 2012) and PEP (Lutz et al, 2011) Catalogs.
  - Stacking of the entire sample.
  - SED fitting (Polletta et al. 2007).
- Mid-Infrared – AGN color-color selection
- Radio → Star Formation Rates

Calhau et al, in prep.



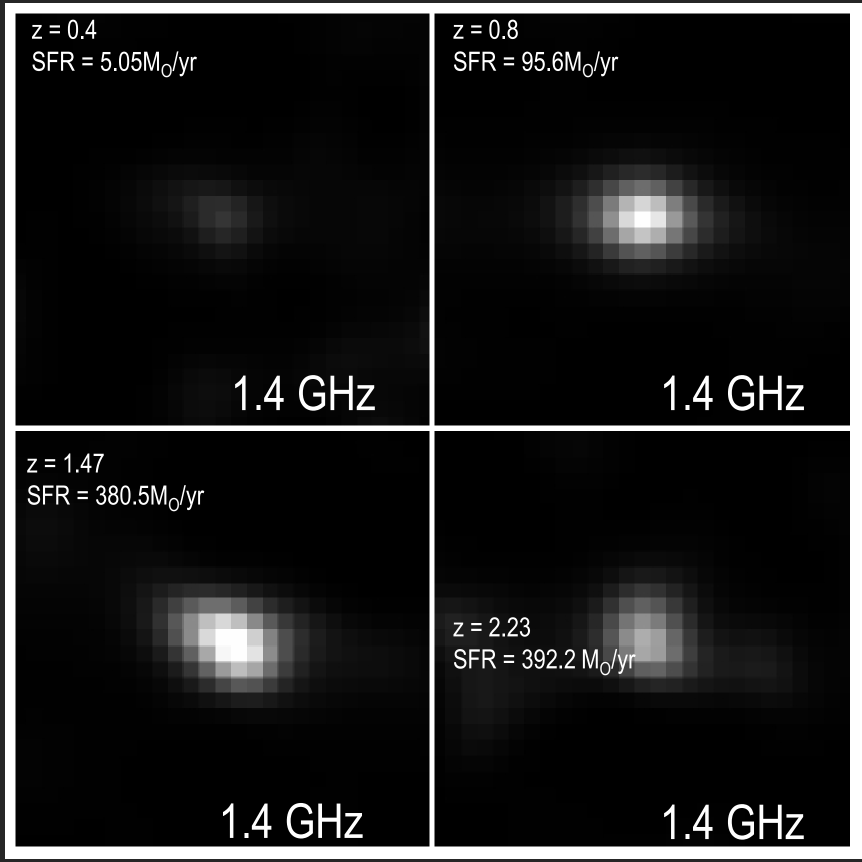
Integrate and convert luminosity density to SFR

METHODOLOGY

- X-rays → Black Hole Accretion Rates
- Infrared – Star Formation Rates & AGN color-color selection
- Radio → Star Formation Rates (Yun et al. 2001)
  - Direct detection – source matching between HiZELS and VLA-COSMOS catalogs.
  - Stacking without the matched sources (see algo e.g. karim et al. 2011).

$$L_{1.4GHz} = 4\pi d_L{}^2 S_{1.4GHz} 10^{-33} (1+z)^{\alpha-1}\ WHz^{-1}$$

Afonso et al. 2006



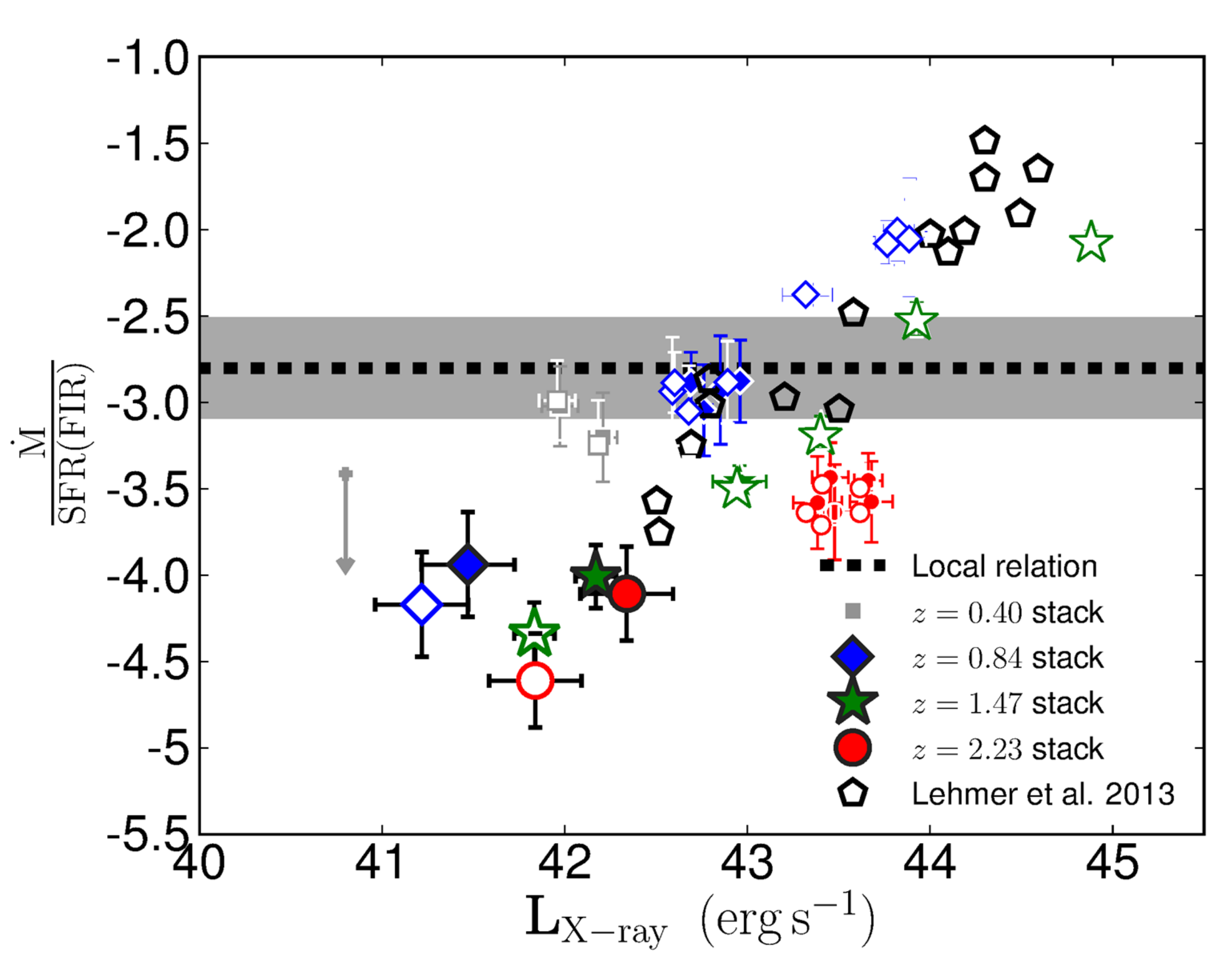
Calhau et al, in prep.

$$SFR_{1.4GHz} = 5.9 \times 10^{-22} L_{1.4GHz}\ (M_\odot\ yr^{-1})$$

Yun et al. 2001

RESULTS

- Typical Star Forming galaxies grow their stellar mass much quicker than their black holes (logarithmic BHAR/SFR ratio of -4).
  - SFR's of the order of 10 to 100 M_{sun}/yr.
  - AGN accretion rate of the order of 0.001 M_{sun}/yr.



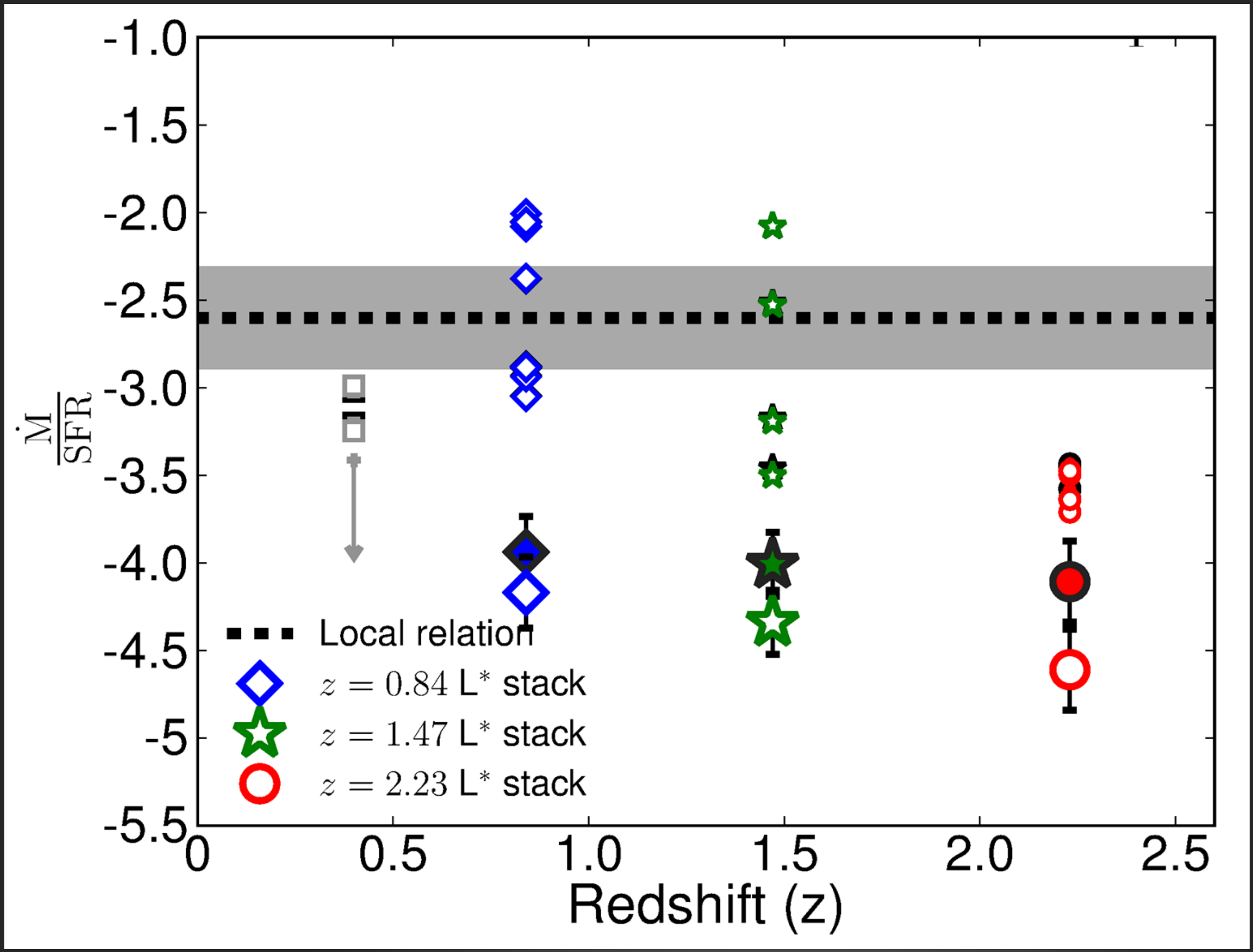
Color-filled markers: Observed,

Empty markers: BHAR corrected for X-ray SF emission contamination.

Calhau et al, in prep.

RESULTS

- Little evolution of the BHAR/SFR ratio for star-forming galaxies with redshift.



Color-filled markers: Observed.

Empty markers: BHAR corrected for X-ray SF emission contamination.

Likely need short periods of rapid black hole growth.

Calhau et al, in prep.

RESULTS

- The relative black hole mass to stellar mass growth is relatively constant for star forming galaxies since z=2.23
- Black hole accretion and Star Formation of our typical star-forming galaxies may evolve at equivalent rates across cosmic time, but,
- In order for the galaxies to reach the Local Relation, the AGN need to have periods of high activity over small periods of time.
- The central supermassive black holes and star formation mechanism likely form a single way of regulating galaxy growth.

THANK YOU FOR YOUR TIME