Mapping the incidence and distribution of AGN accretion across the galaxy population

James Aird
(Institute of Astronomy, University of Cambridge)

Alison Coil (UC San Diego)
Antonis Georgakakis (MPE)

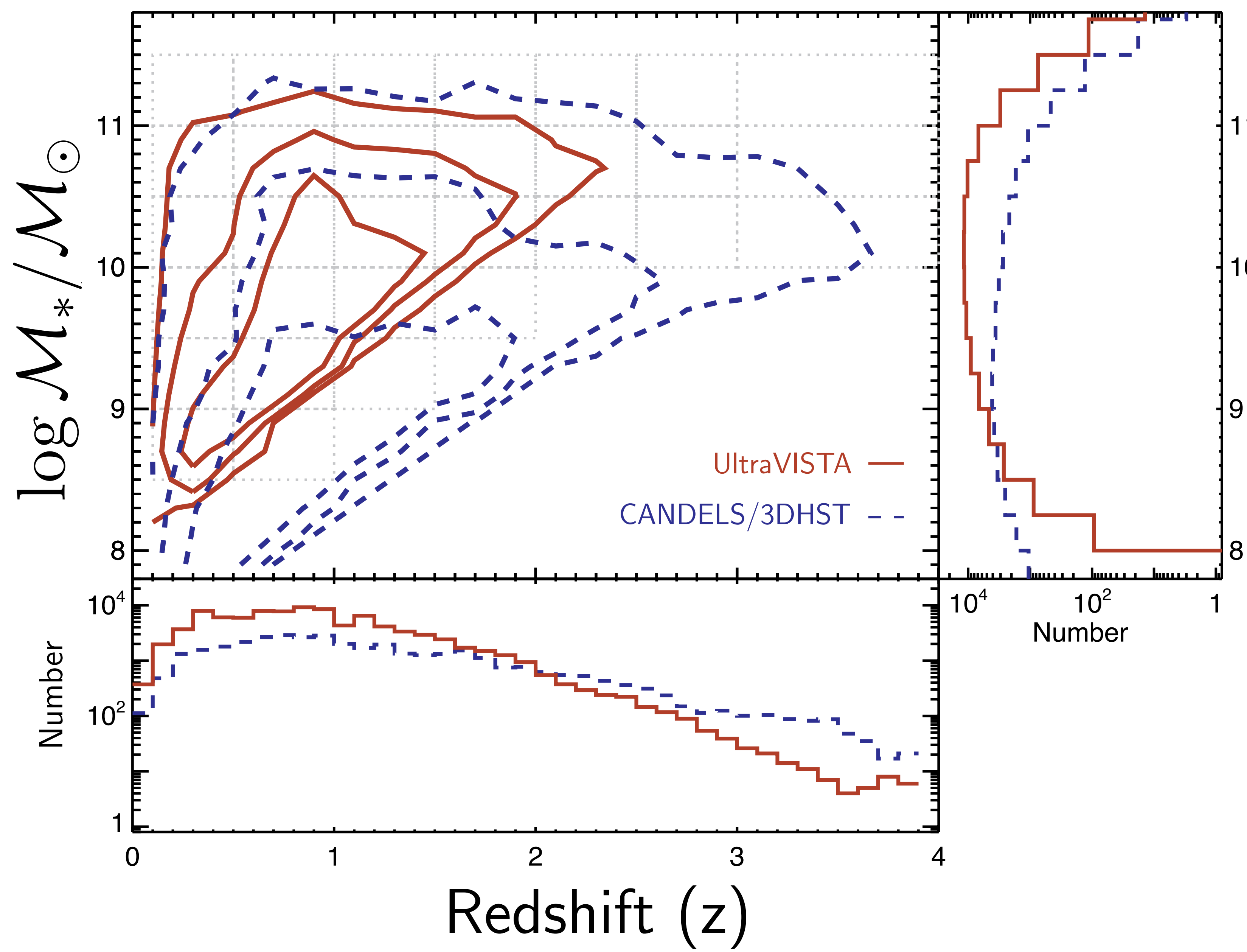
- Take near-IR selected galaxy samples in CANDELS and UltraVISTA fields
- Use deep Chandra X-ray data to track the *distribution* of BH accretion rates within these galaxies as a function of stellar mass, redshift, and galaxy type (star-forming vs. quiescent)

- Are more AGN found in certain types of galaxies?
- How rapidly are black holes growing in different types of galaxies and at different cosmic times?
- Is there a connection between the incidence of AGN and the transformation of the galaxy population?

CANDELS/3D-HST and UltraVISTA galaxy samples

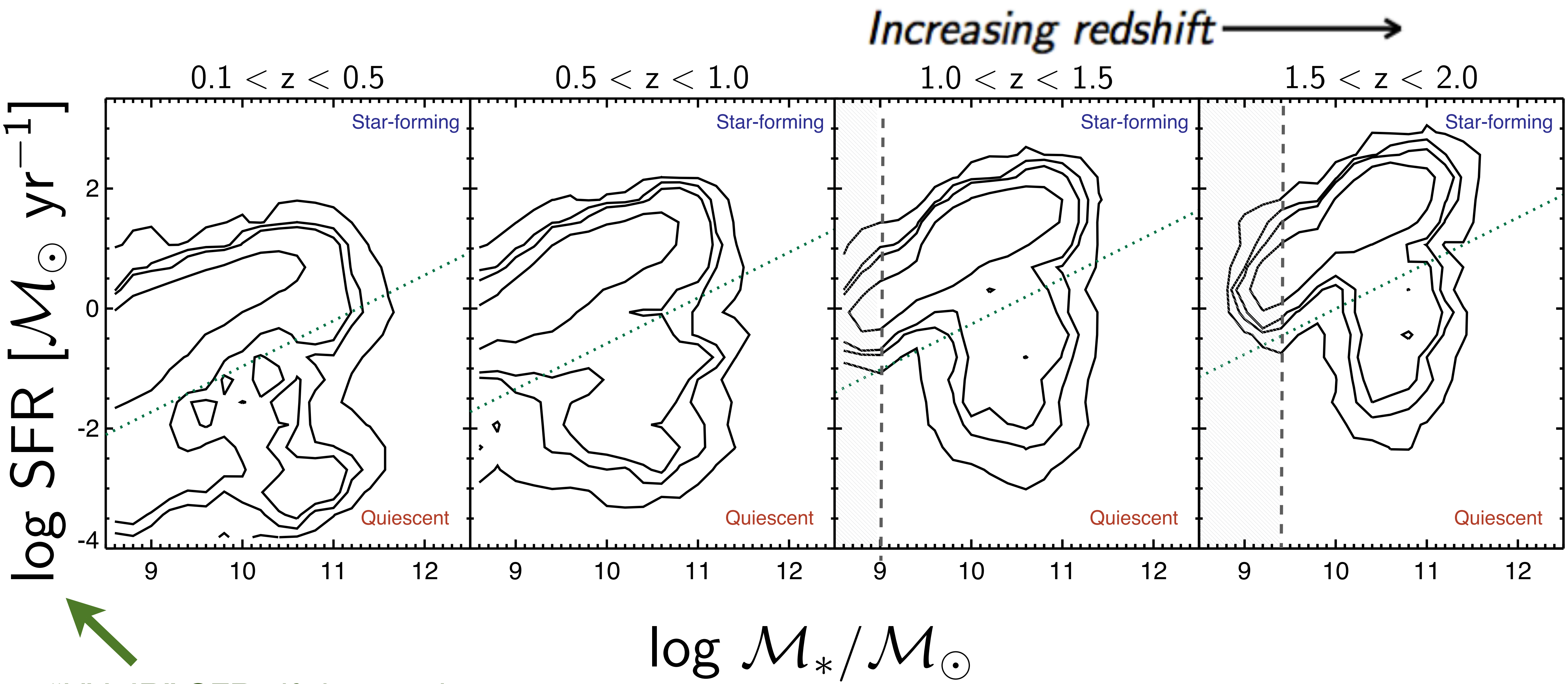
Aird et al. 2016 (in prep.)

- Near-IR selected sample of ~120,000 galaxies from:
  - CANDELS/3DHST fields
    (GOODS-S, GOODS-N, AEGIS, COSMOS)
    → low M_* high z
  - UltraVISTA imaging of COSMOS field
    (larger area → higher M_*, lower z)



- Redshifts from: spec-z, 3DHST grism redshifts, + high quality galaxy and AGN photo-z
  (Hsu et al. 2014; Nandra et al. 2015; Marchesi et al. 2016)
- Stellar masses from SED fitting of UV-optical-NIR SED
  (FAST: Kriek et al. 2009)

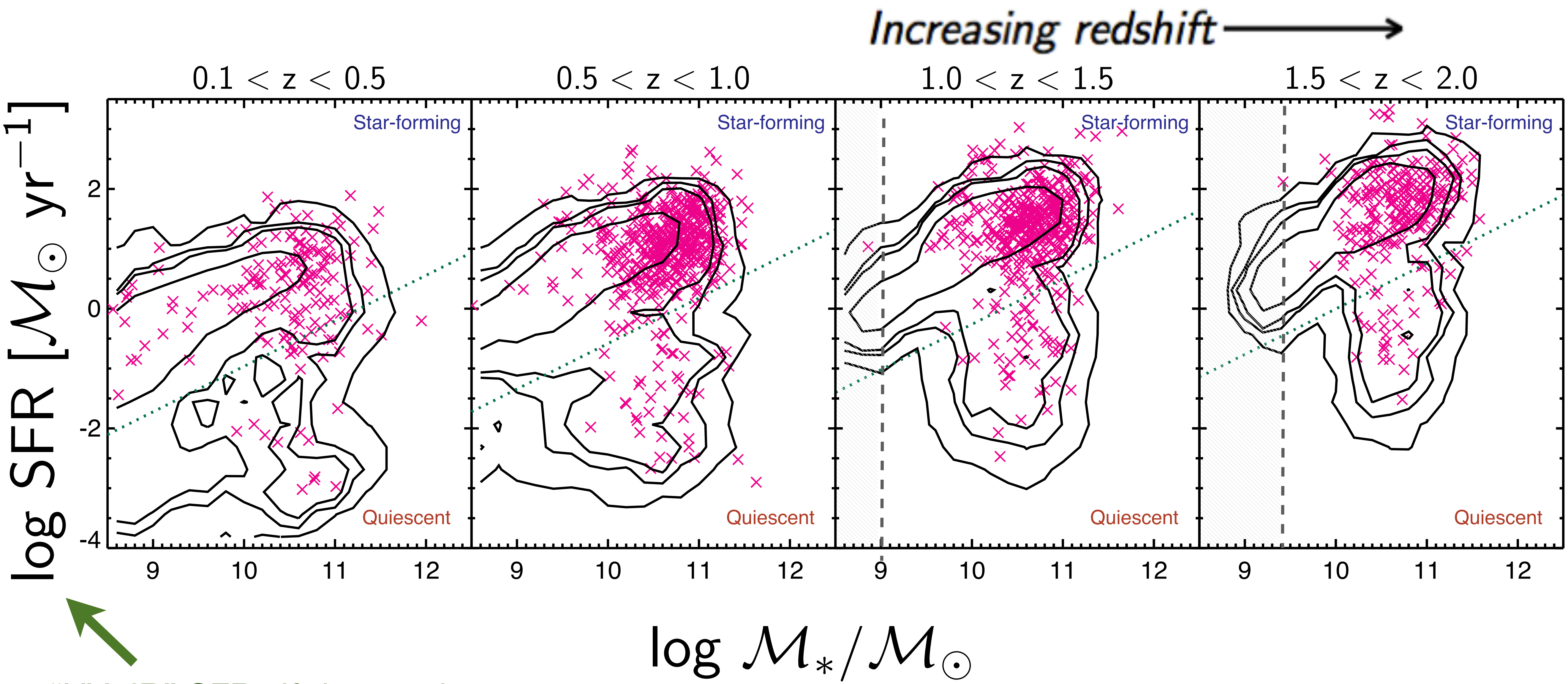
The "transforming" galaxy population



"UV+IR" SFRs if detected at MIPS 24μm, otherwise based on UV-to-NIR SED fitting

The “transforming” galaxy population

+ X-ray detected AGN



“UV+IR” SFRs if detected at MIPS 24μm, otherwise based on UV-to-NIR SED fitting

- two component (AGN+gal) to account for/remove AGN contribution for X-ray sources

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

3. Depth/sensitivity of the data used to select AGN

4. Ratio of AGN light to host galaxy (star-formation) light

5. AGN obscuration

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

“ AGN don’t “know” about their host galaxies - remember the range of scales ”

Phil Hopkins

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

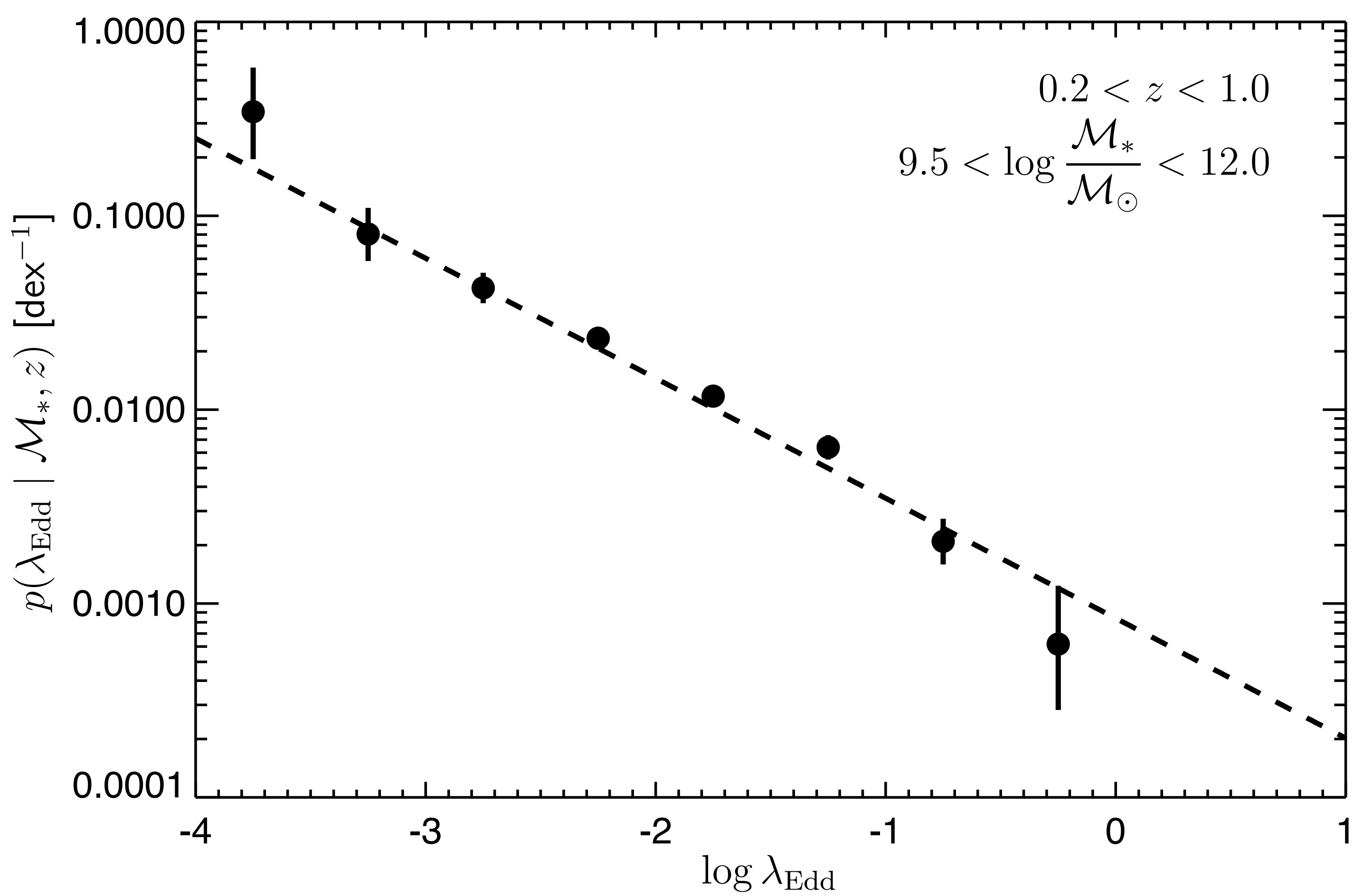
" AGN don't 'know' about their host galaxies - remember the range of scales "
Phil Hopkins

AGN fueling is a *stochastic* process

Need to measure the *distribution* of AGN activity over *large samples* of galaxies with a fixed range of properties

e.g. Aird et al. 2012

see also: Hickox et al. 2014, Chen et al. 2013, Bongiorno et al. 2012, Azadi et al. 2015, Stanley et al. 2015



Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

It is generally ***harder*** to identify an AGN in a ***lower*** mass galaxy as the same (specific) ***black hole accretion rate*** produces a ***lower*** observed luminosity than in a higher mass galaxy

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

It is generally ***harder*** to identify an AGN in a ***lower*** mass galaxy as the same (specific) ***black hole accretion rate*** produces a ***lower*** observed luminosity than in a higher mass galaxy

$$\lambda_{\mathrm{sBHAR}} \propto \frac{L_X}{M_*} \approx \lambda_{\mathrm{Edd}}$$

specific black hole accretion rate

Eddington ratio

(see Aird et al. 2012, 2013)

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

3. Depth/sensitivity of the data used to select AGN

Issues when relating AGN to galaxy properties

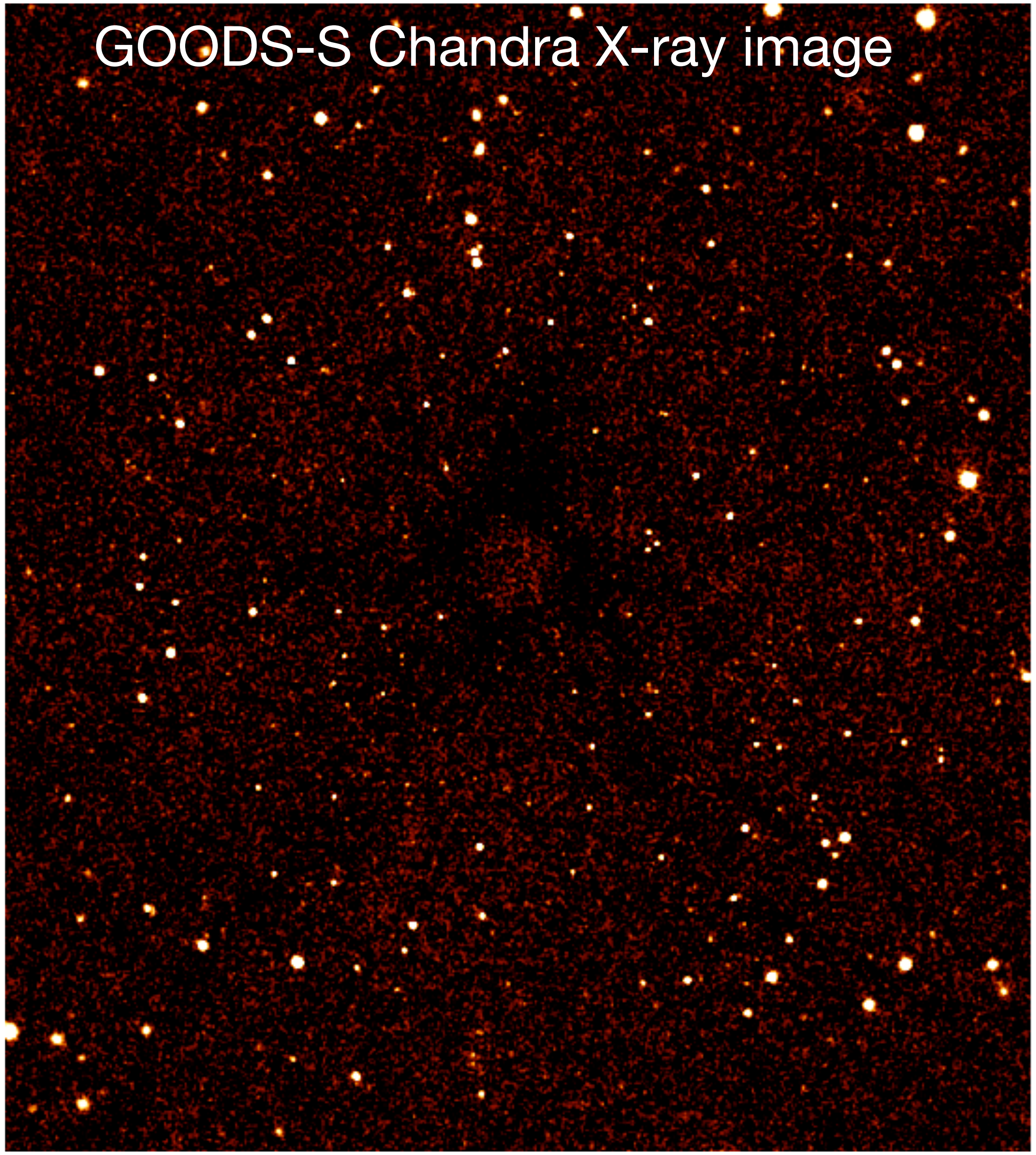
3. Depth/sensitivity of the data used to select **(X-ray)** AGN

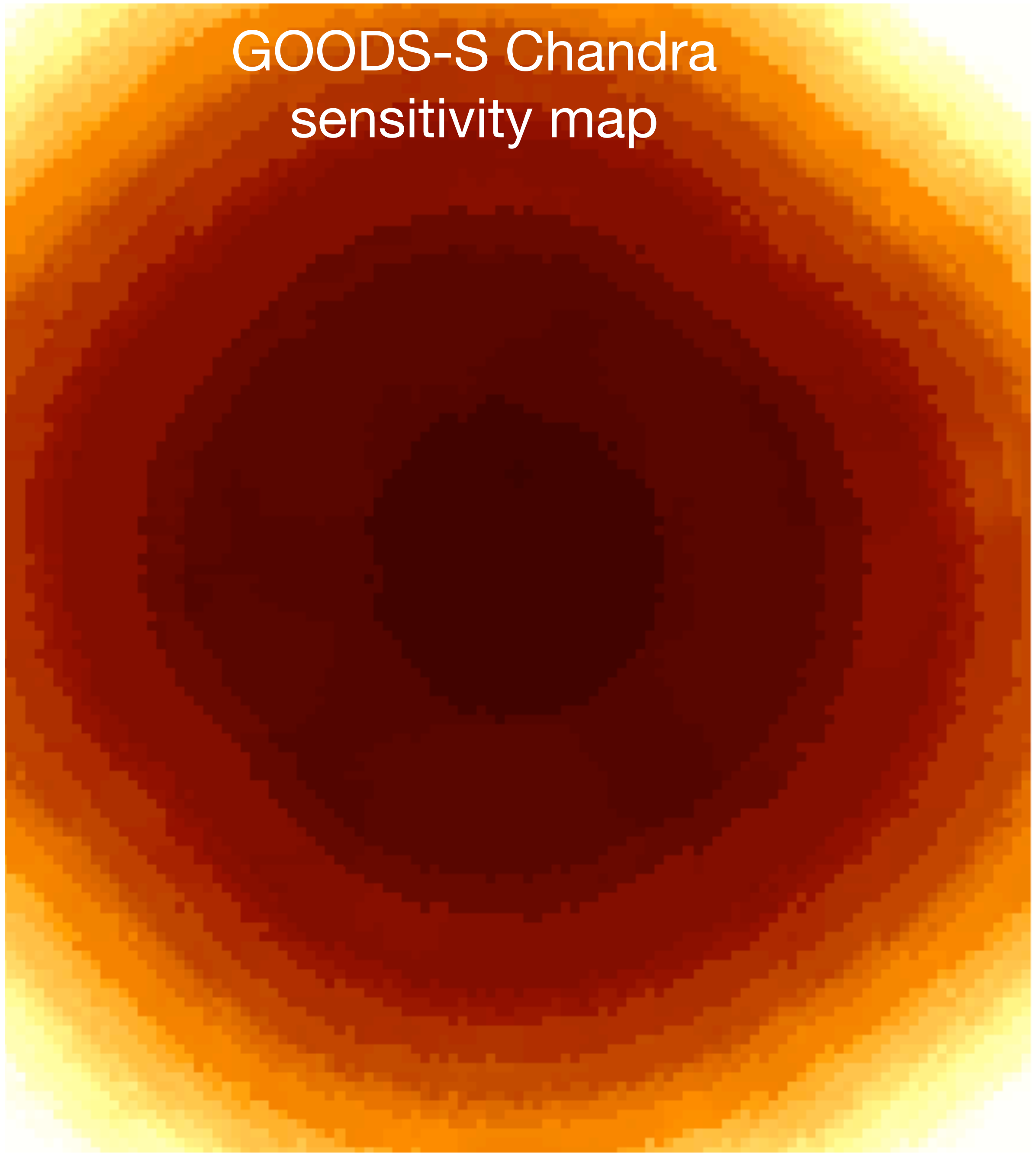
X-ray sensitivity varies substantially between fields *and within an individual deep Chandra field*

.... but this is well-understood and can be characterized

Issues when relating AGN to galaxy properties

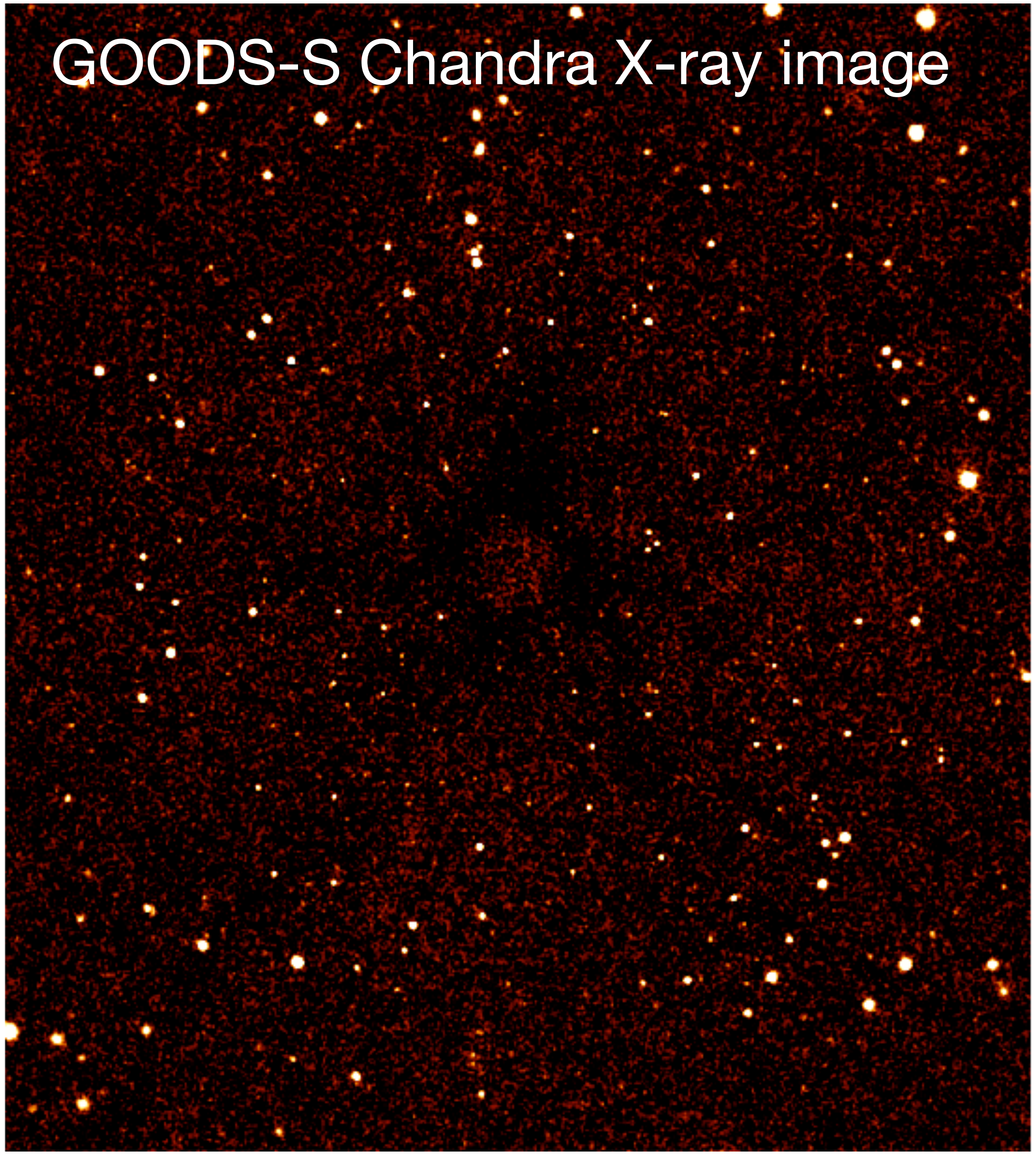
3. Depth/sensitivity of the data used to select **(X-ray)** AGN

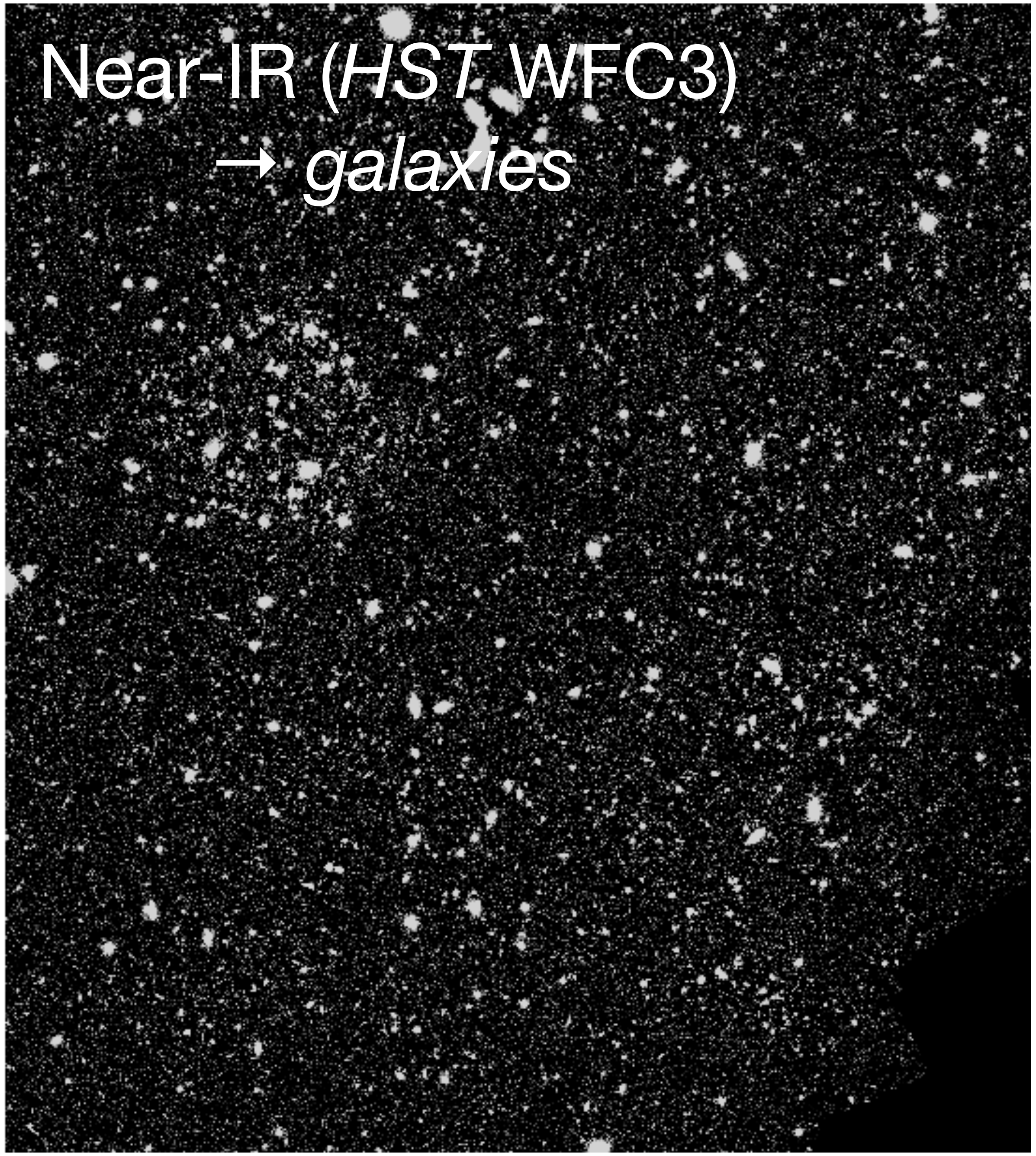




Issues when relating AGN to galaxy properties

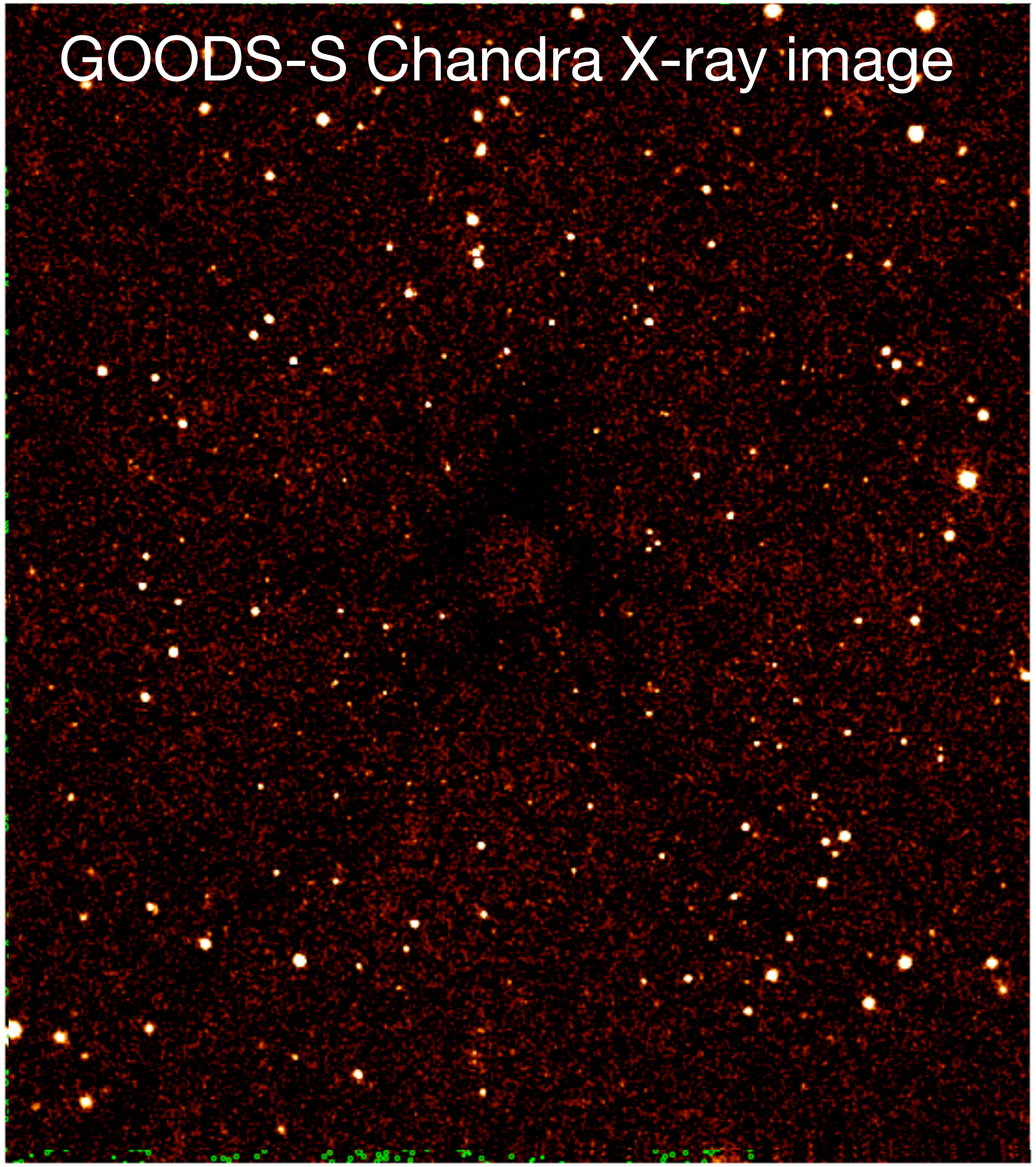
3. Depth/sensitivity of the data used to select **(X-ray)** AGN

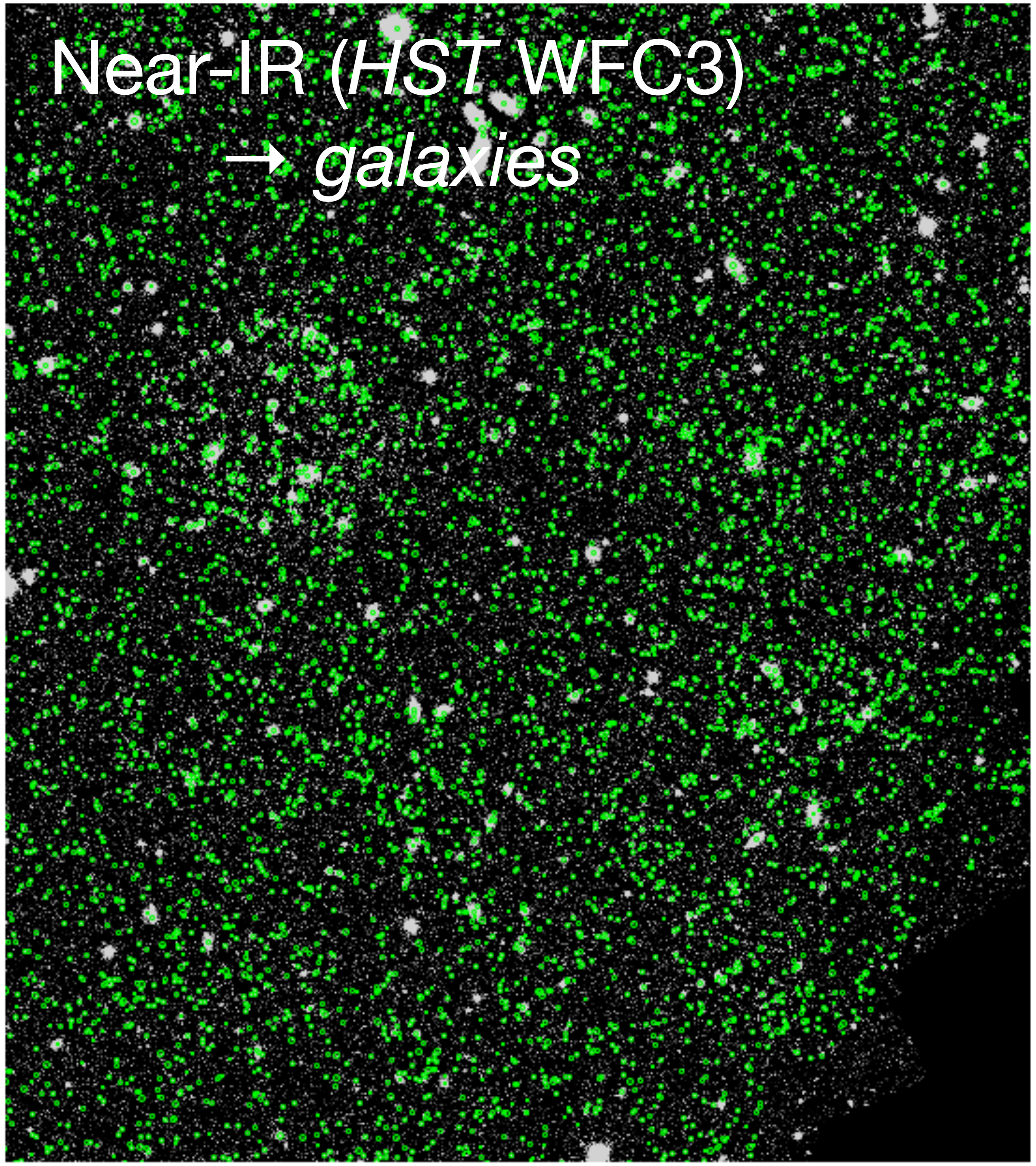




Issues when relating AGN to galaxy properties

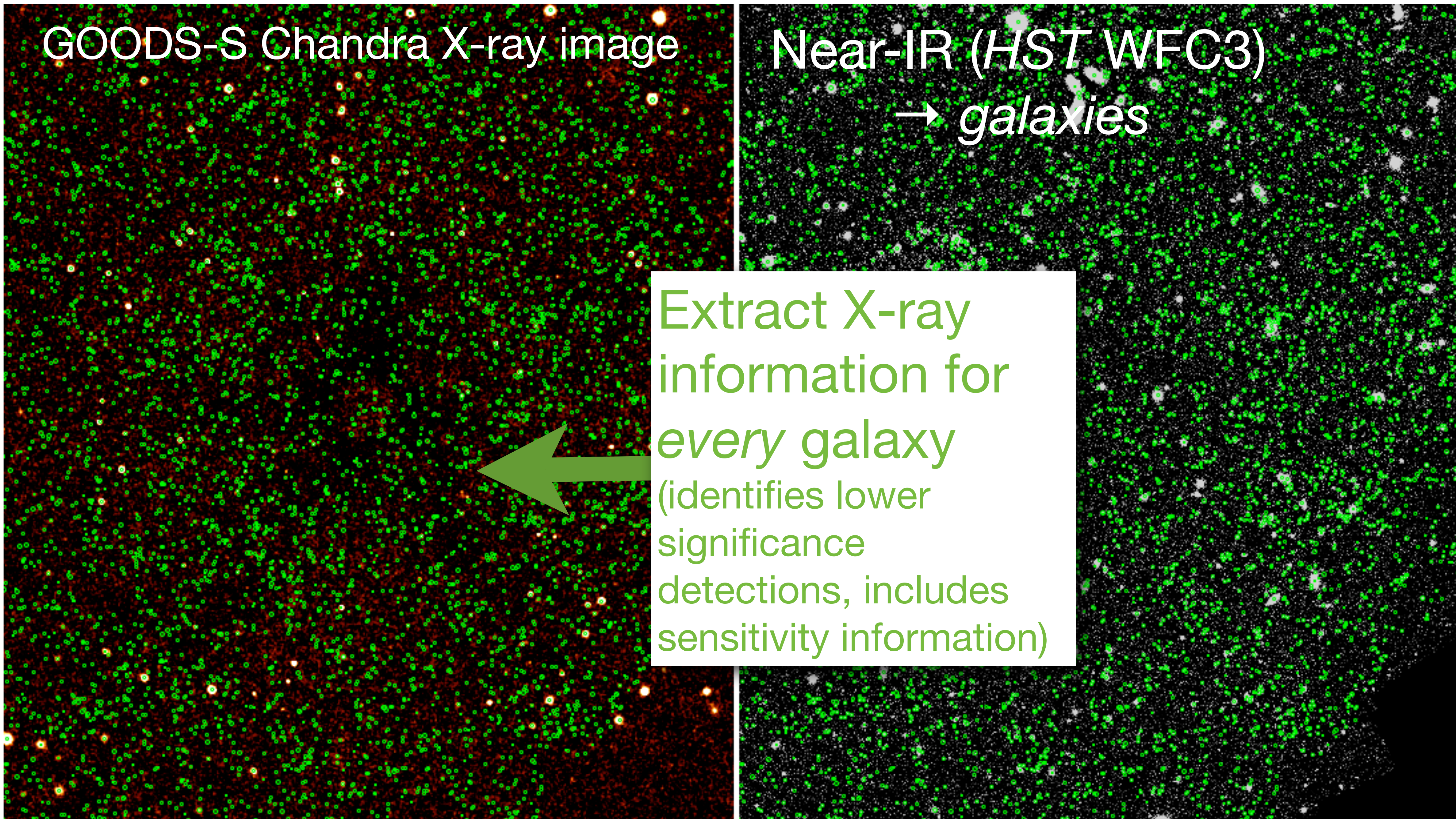
3. Depth/sensitivity of the data used to select **(X-ray)** AGN





Issues when relating AGN to galaxy properties

3. Depth/sensitivity of the data used to select **(X-ray)** AGN



Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

3. Depth/sensitivity of the data used to select AGN

4. Ratio of AGN light to host galaxy (star-formation) light

   X-ray emission from an AGN generally outshines galactic X-ray emission....
   but does set a limit on how low we can probe in accretion rate

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

3. Depth/sensitivity of the data used to select AGN

4. Ratio of AGN light to host galaxy (star-formation) light

5. AGN obscuration

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

3. Depth/sensitivity of the data used to select AGN

4. Ratio of AGN light to host galaxy (star-formation) light

5. AGN obscuration

Hard X-ray selection (2-7 keV, observed frame) robust for unobscured to moderately obscured AGN (up to $N_H \sim 10^{23-24}$ cm^{-2}), but will miss/underestimate L_X for Compton-thick sources

Issues when relating AGN to galaxy properties

1. AGN variability (short timescale relative to the host galaxy properties)

2. Mass-dependent selection biases

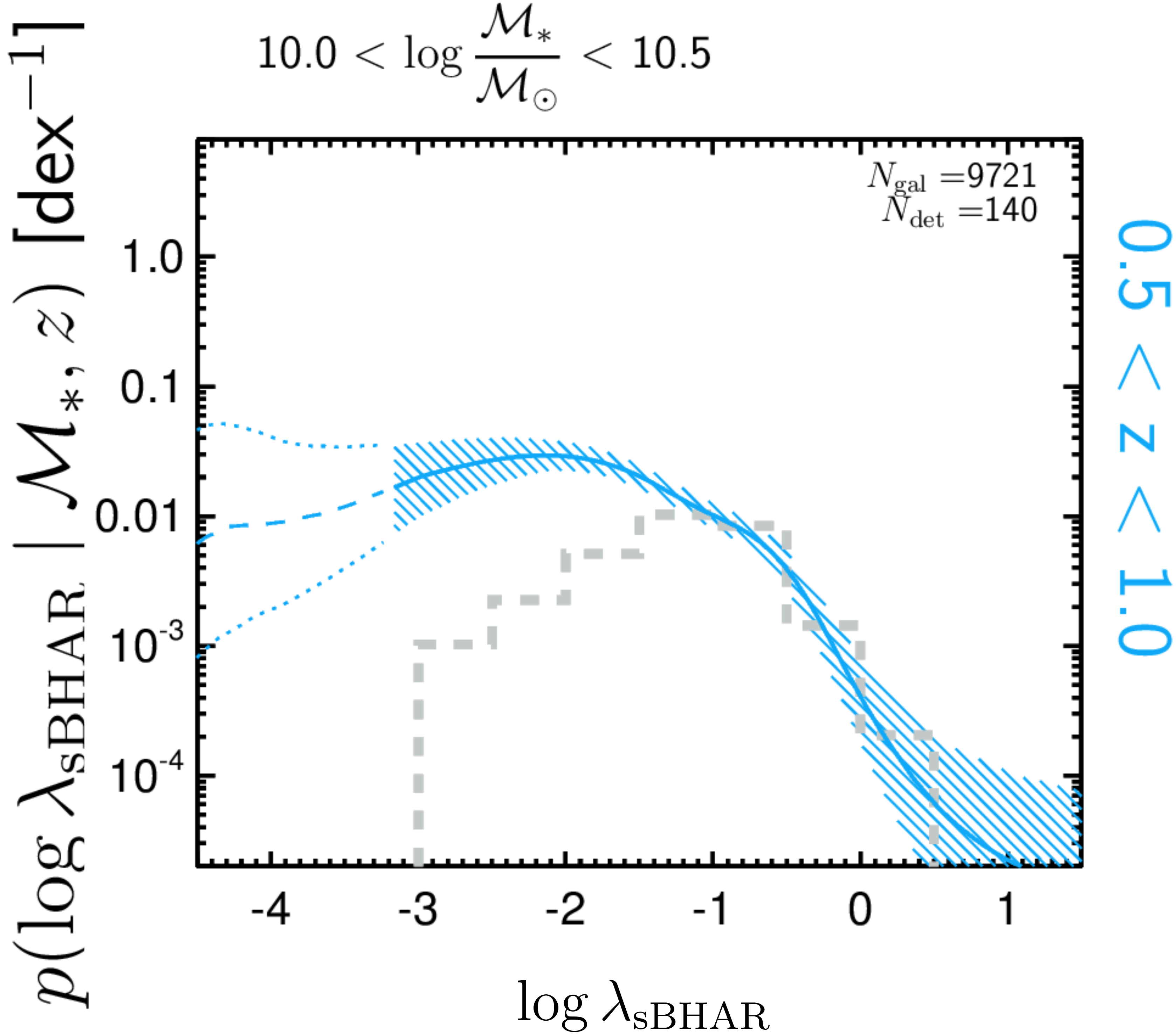
3. Depth/sensitivity of t… select AGN

4. Ratio of … st galaxy (star-formation) light

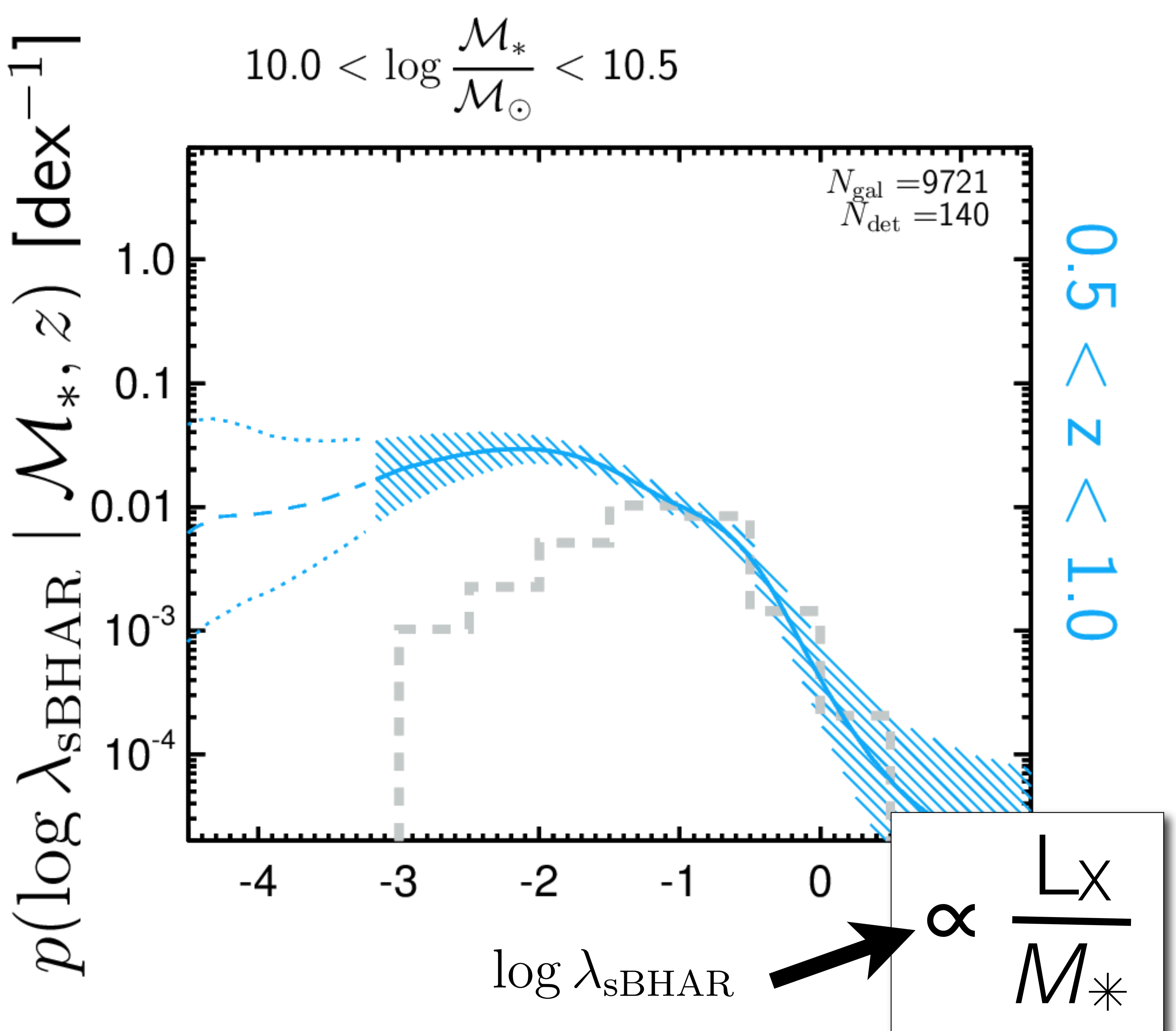
5. AGN obscuration

These issues will affect AGN selection at any wavelength

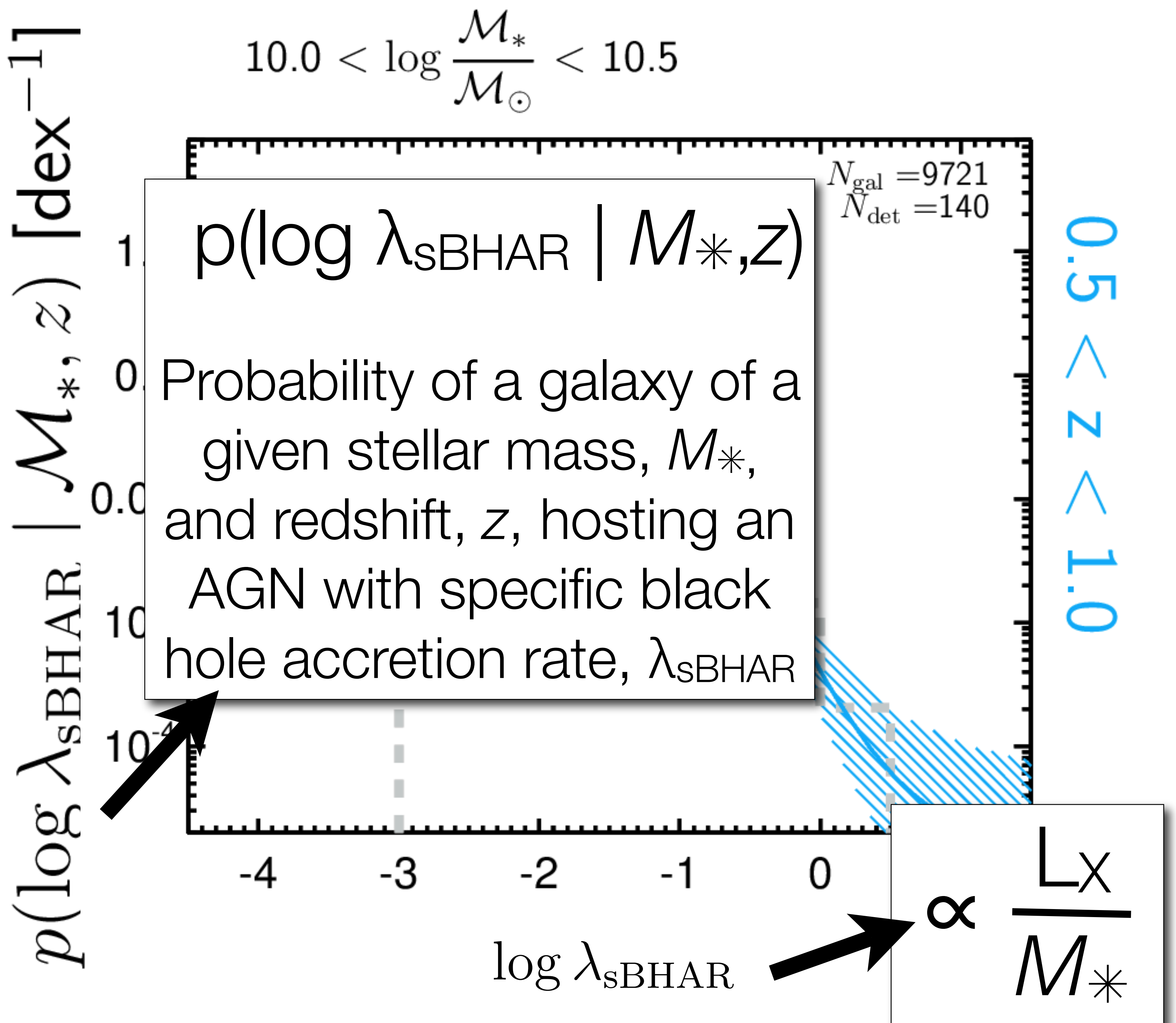
Distributions of specific black hole accretion rates as a function of stellar mass and redshift



Distributions of specific black hole accretion rates as a function of stellar mass and redshift



Distributions of specific black hole accretion rates as a function of stellar mass and redshift

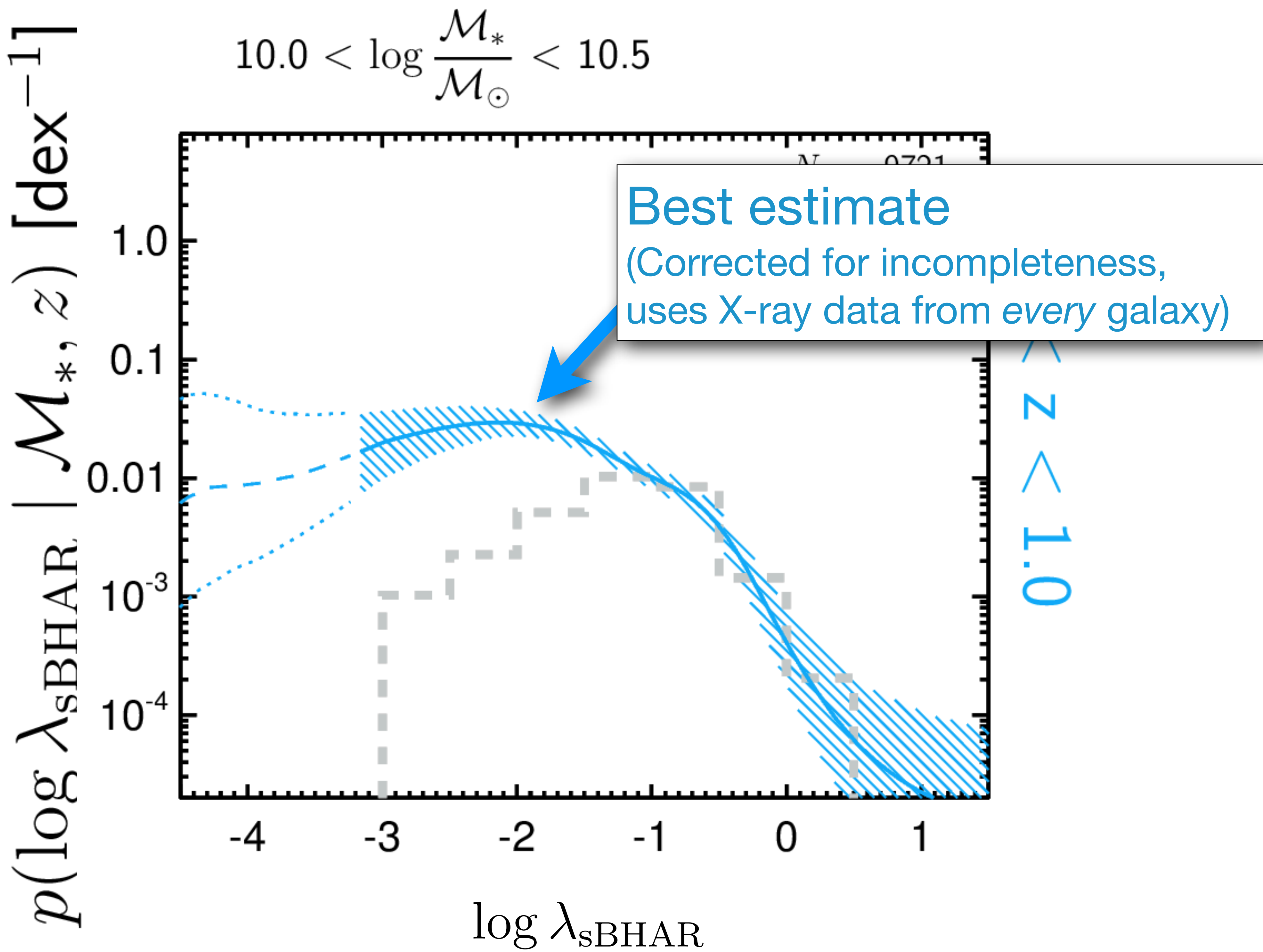


$p(\log \lambda_{sBHAR} \mid M_*, z)$

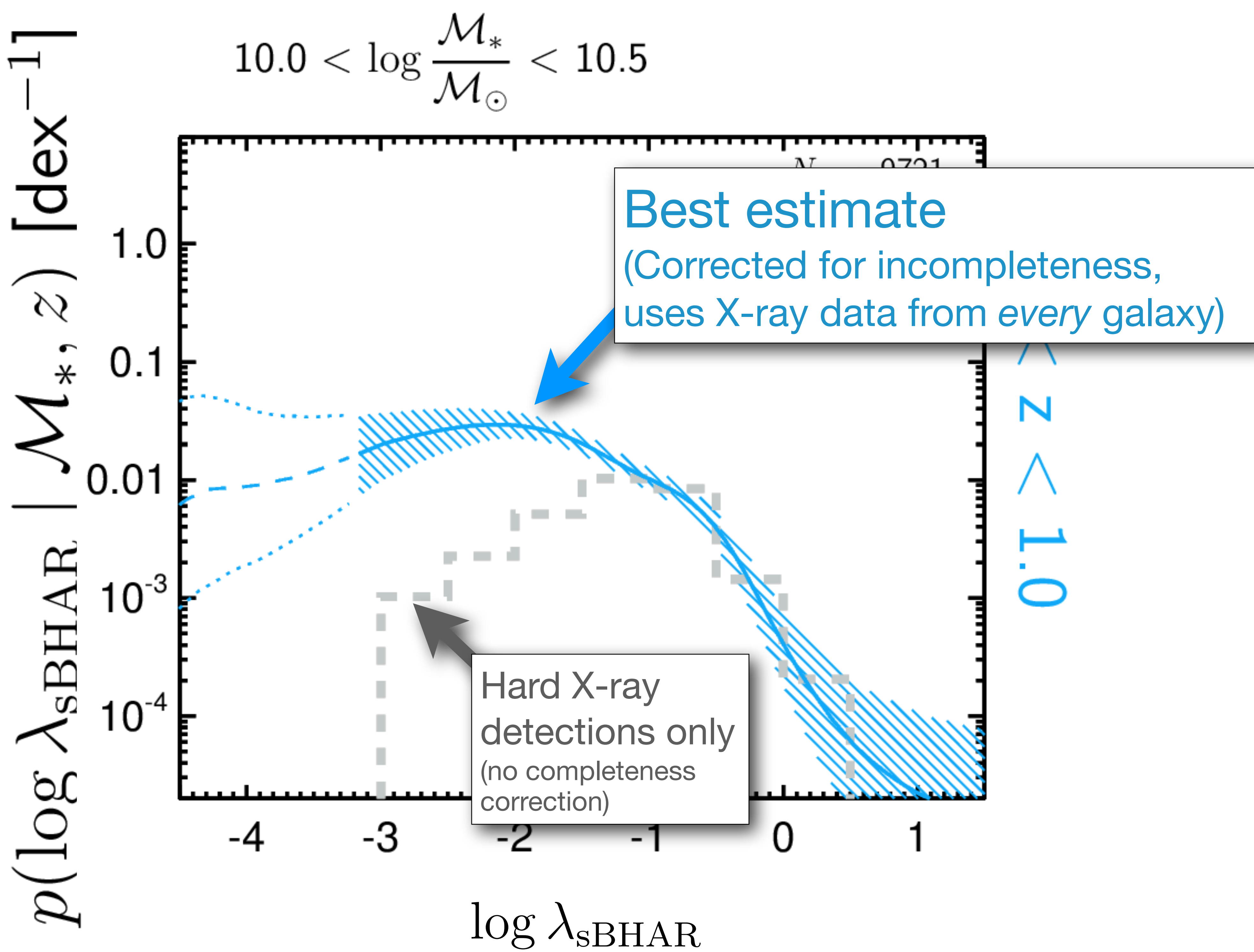
Probability of a galaxy of a given stellar mass, M_*, and redshift, z, hosting an AGN with specific black hole accretion rate, λ_{sBHAR}

$\propto \frac{L_X}{M_*}$

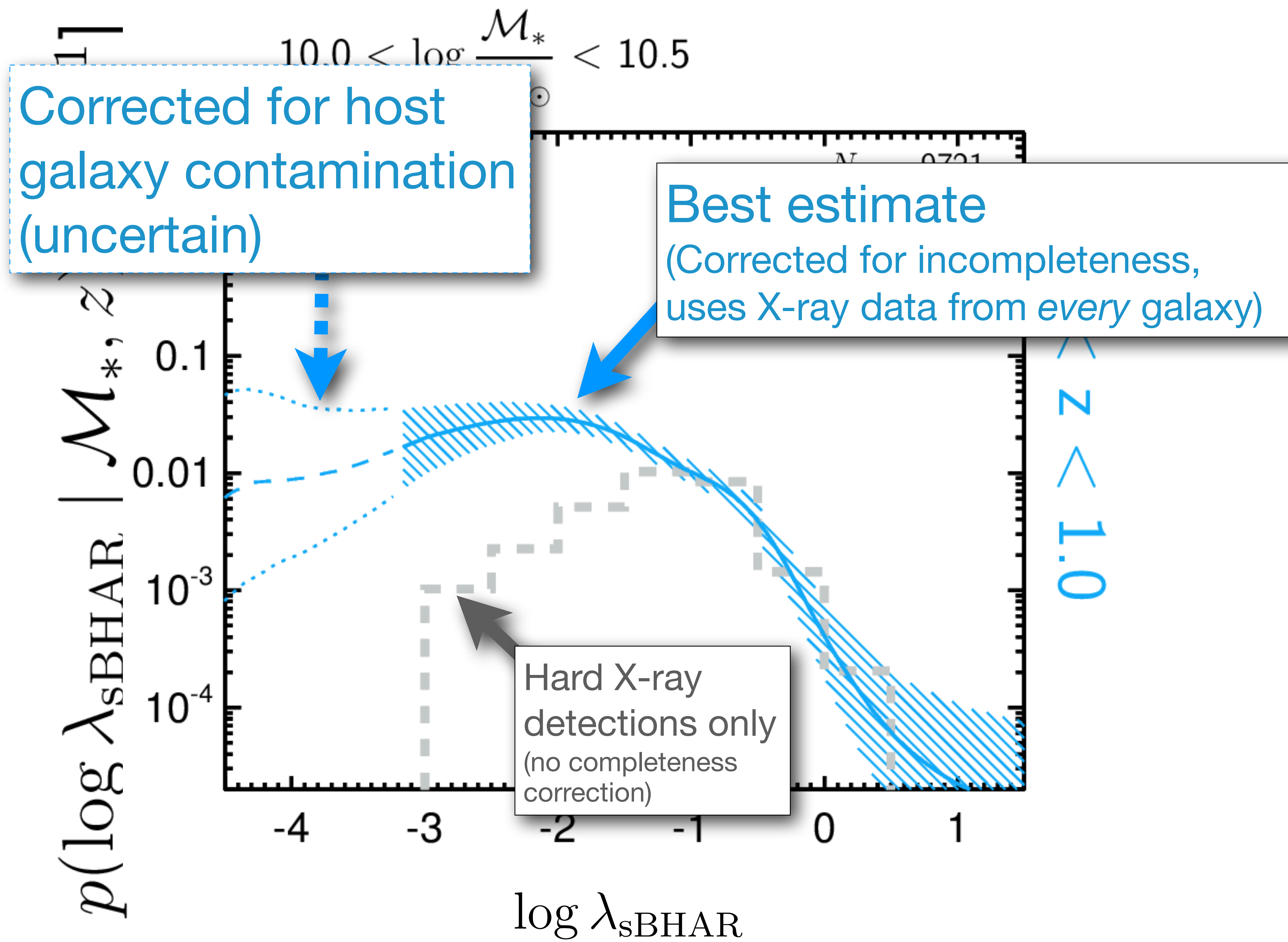
Distributions of specific black hole accretion rates as a function of stellar mass and redshift



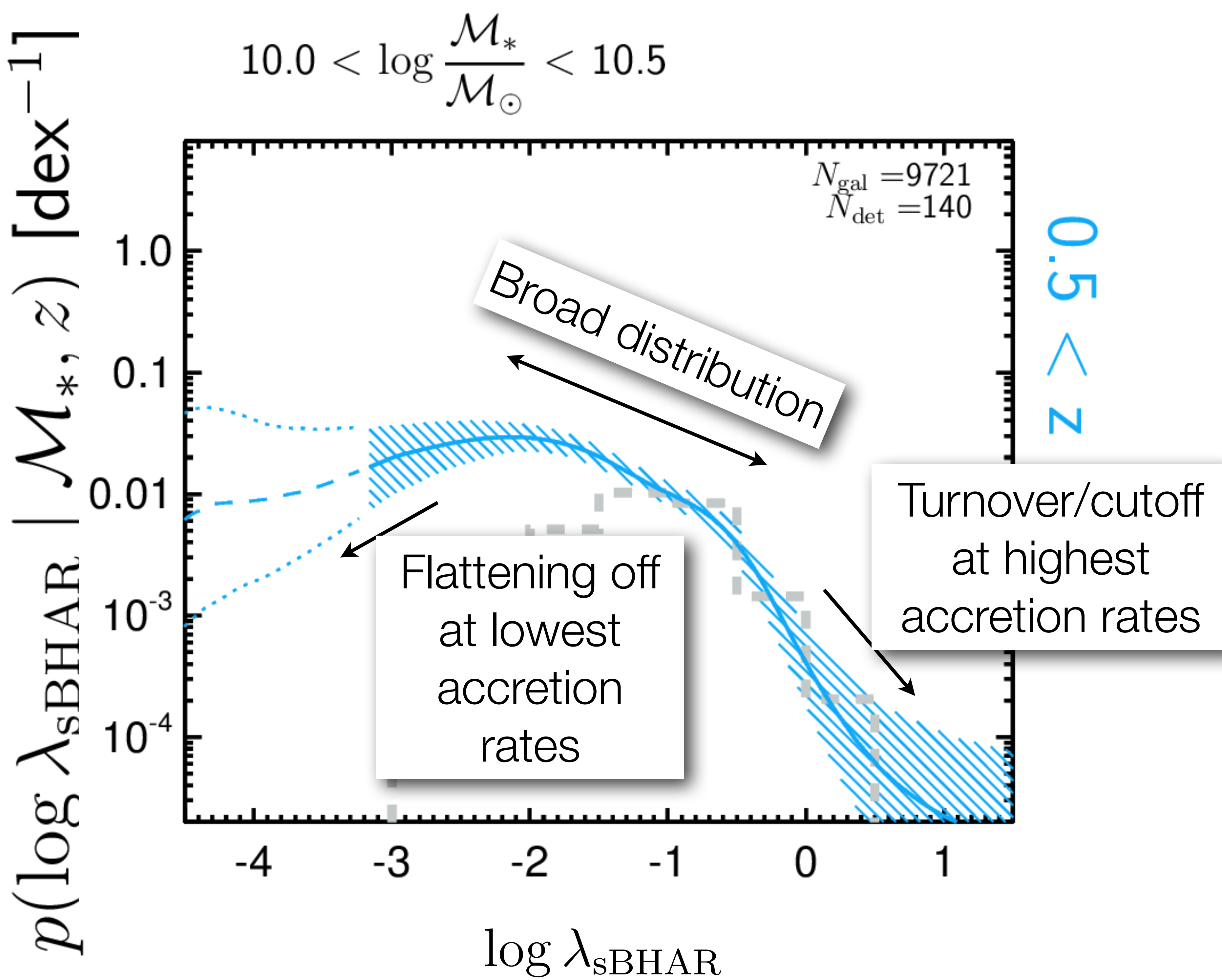
Distributions of specific black hole accretion rates as a function of stellar mass and redshift



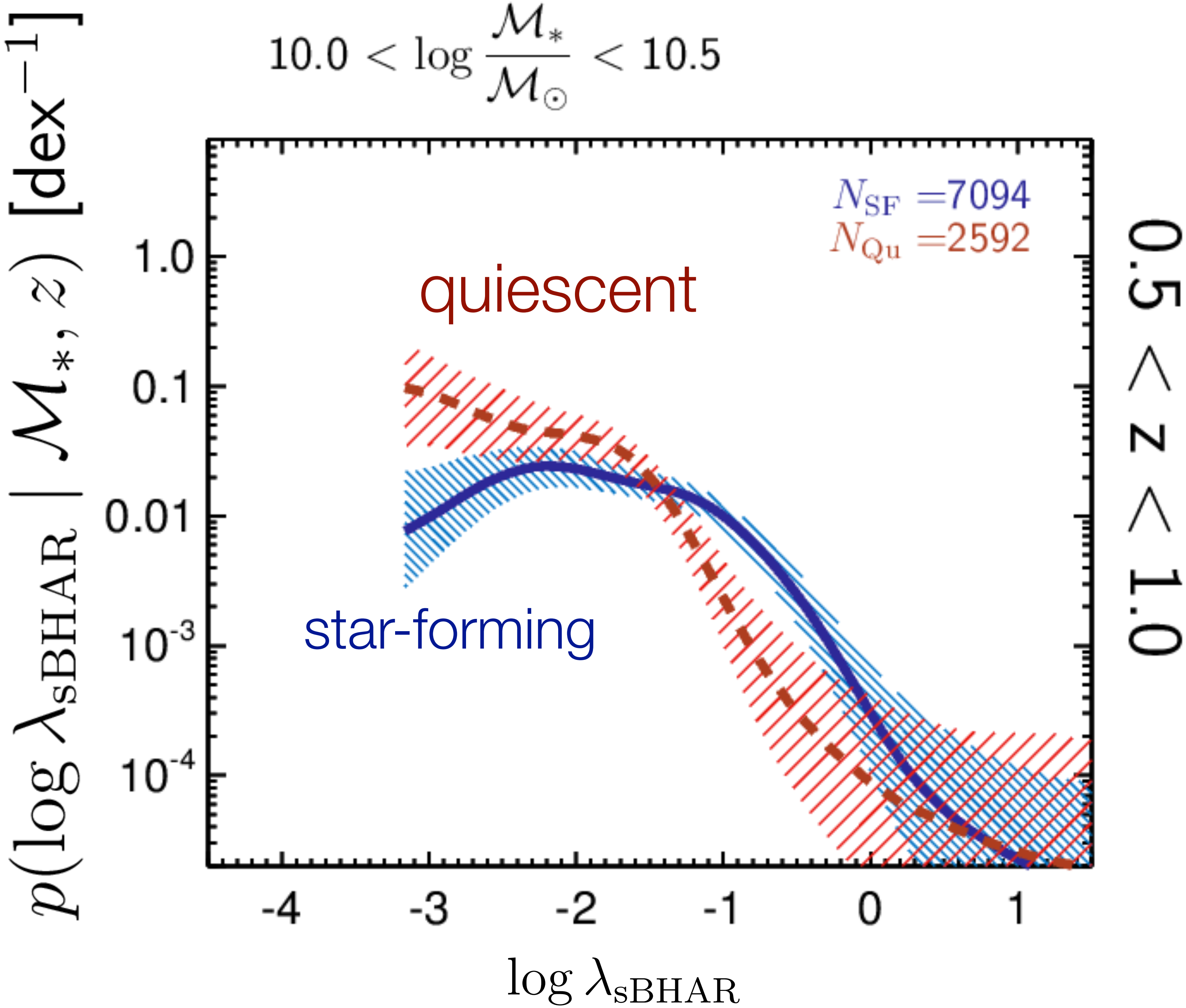
Distributions of specific black hole accretion rates as a function of stellar mass and redshift



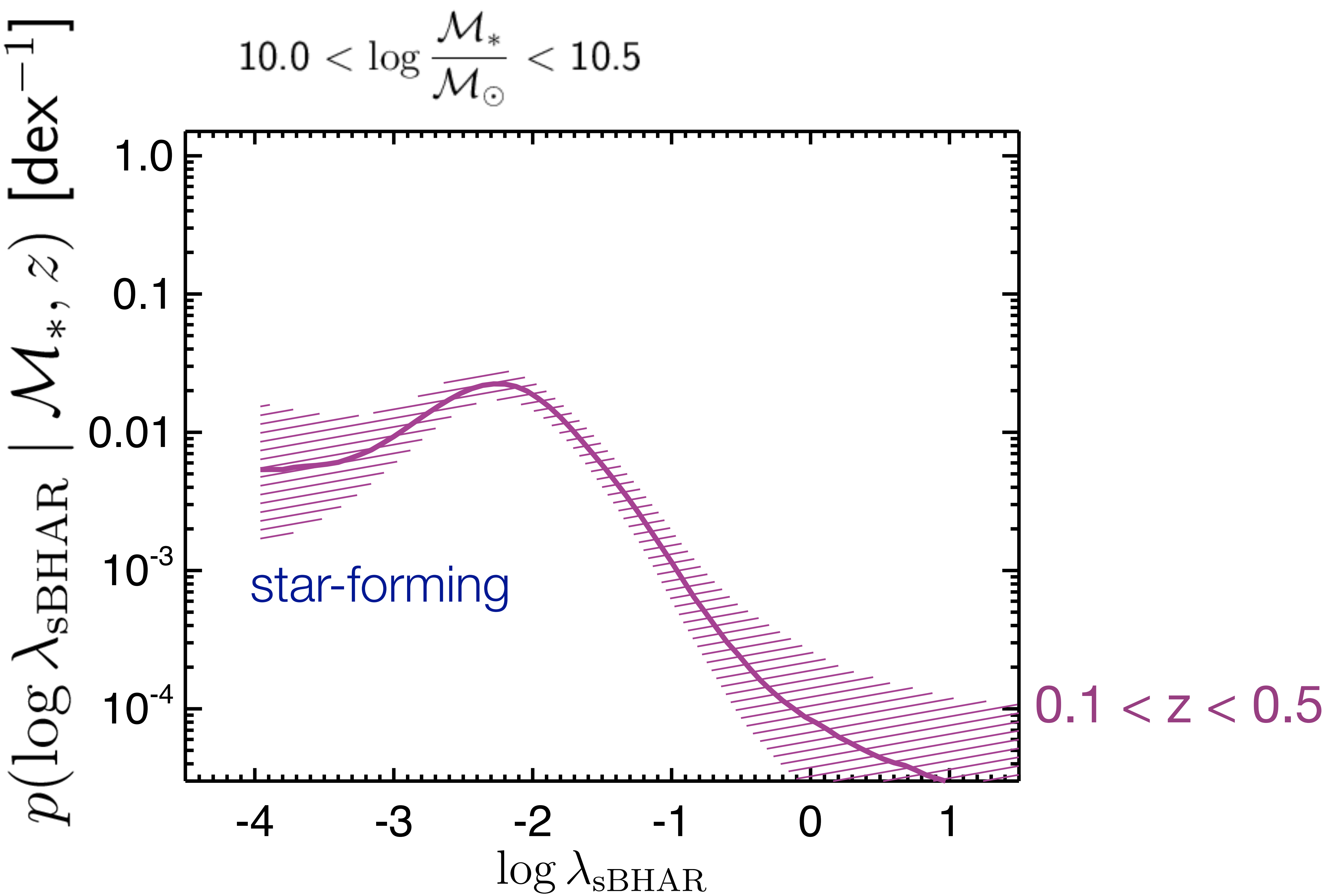
Distributions of specific black hole accretion rates as a function of stellar mass and redshift



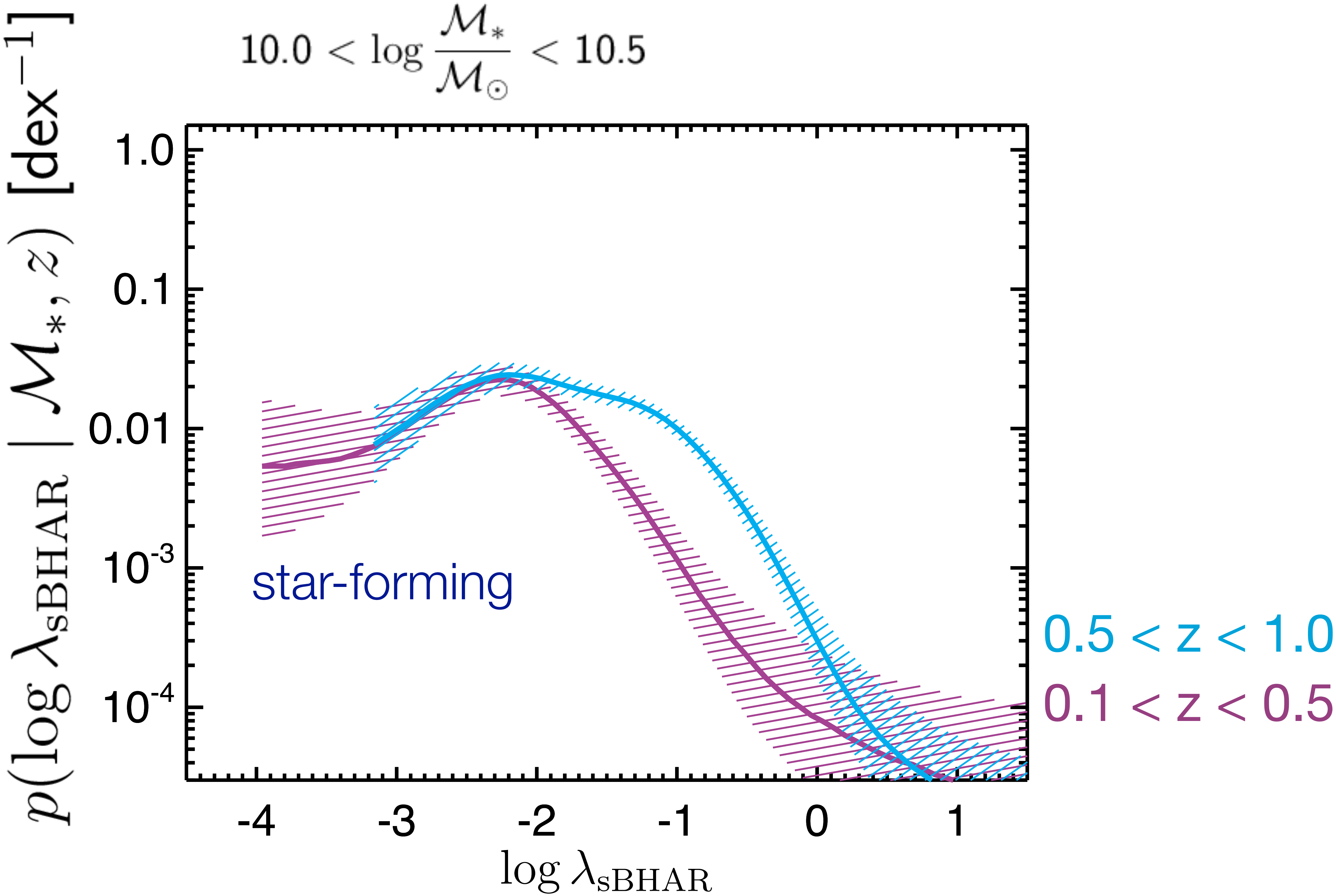
Distributions of sBHAR in star-forming vs. quiescent galaxies



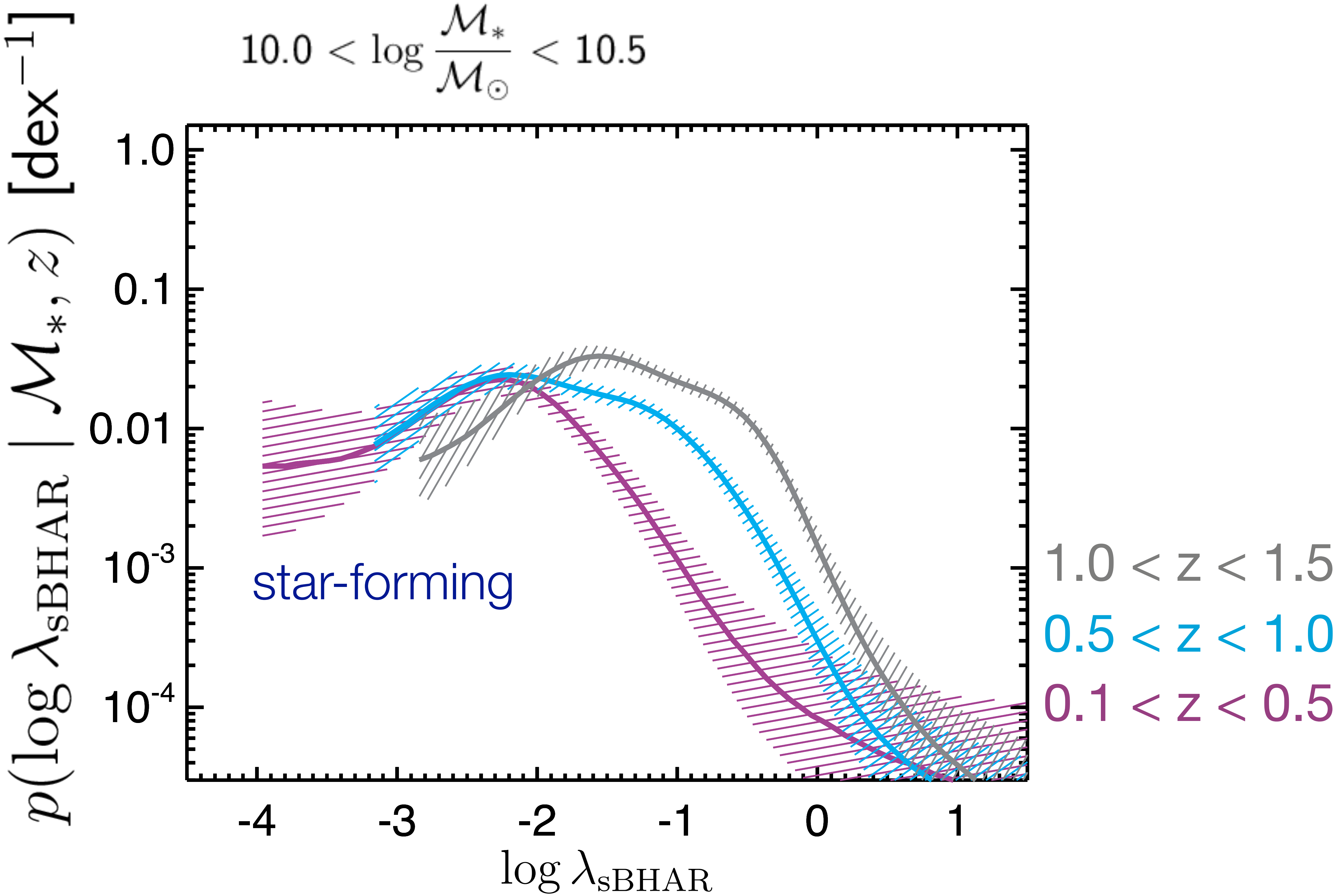
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



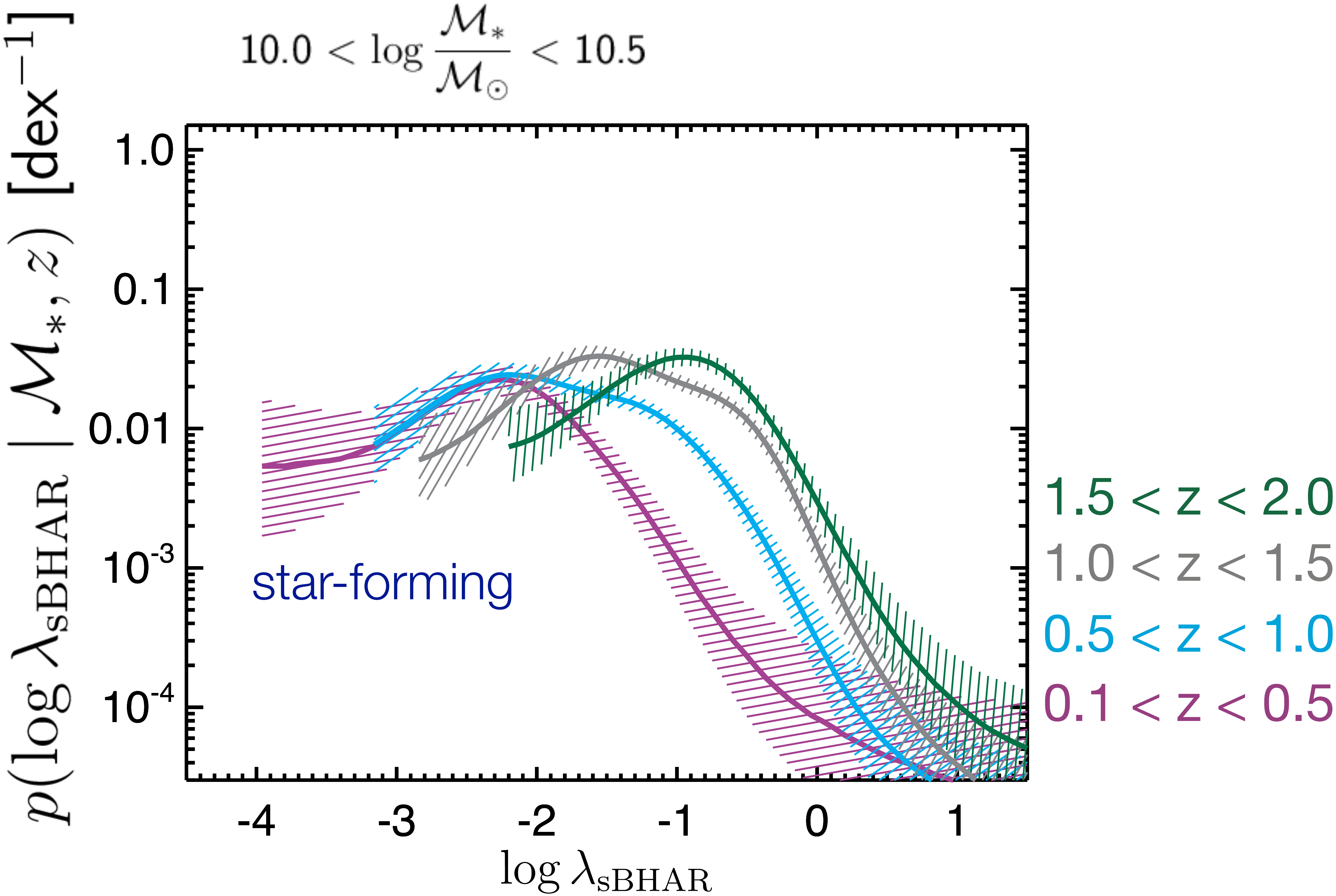
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



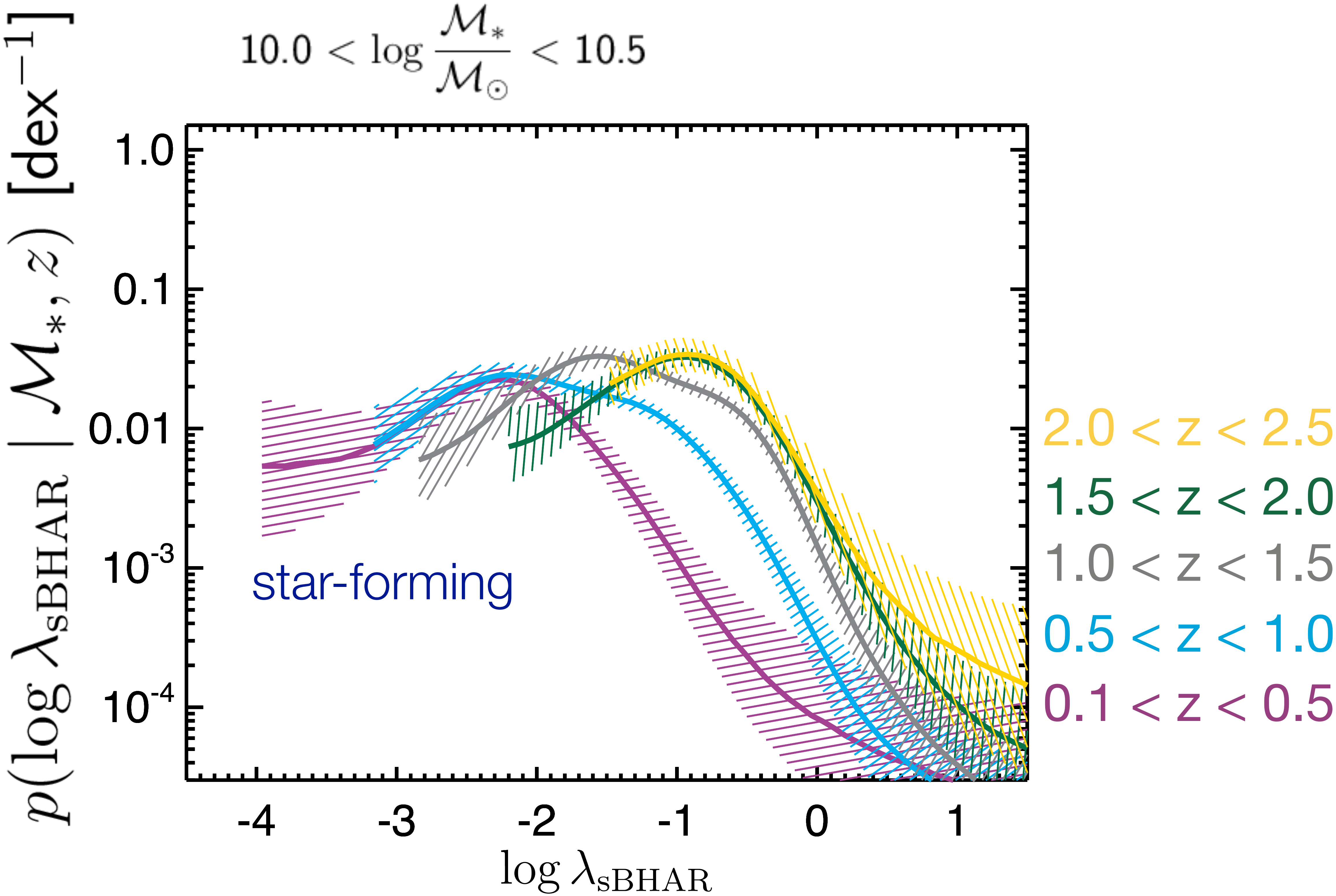
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



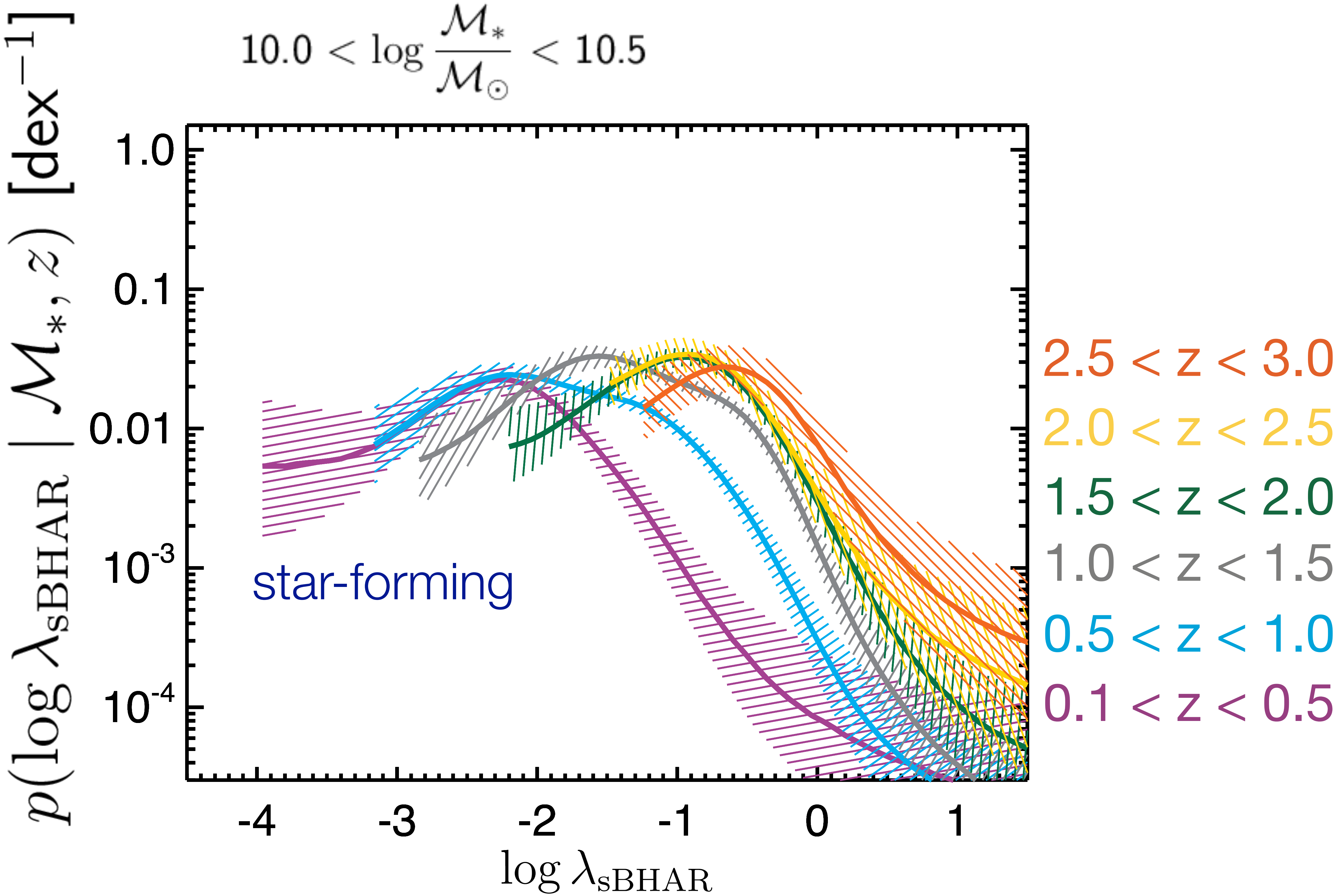
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



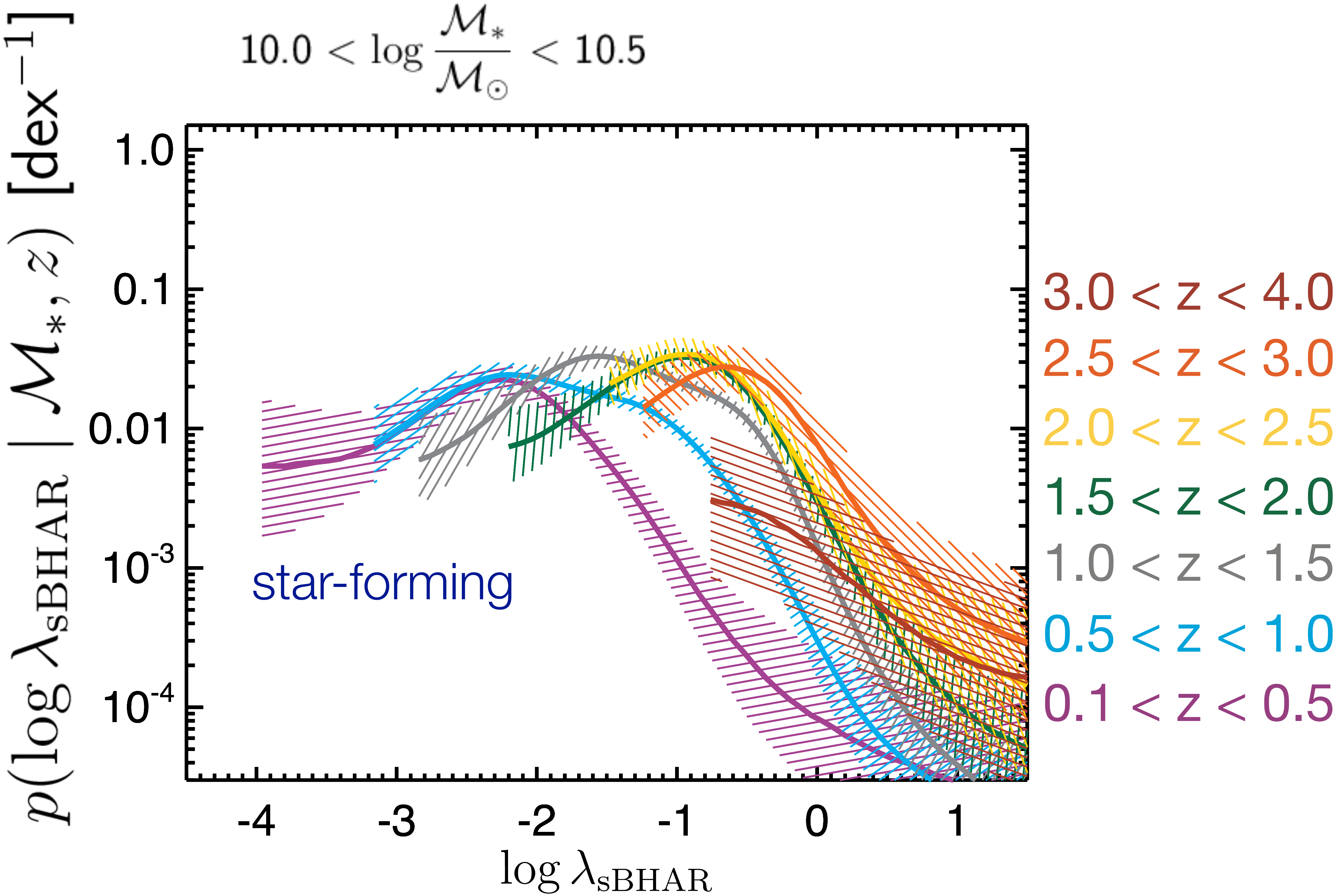
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



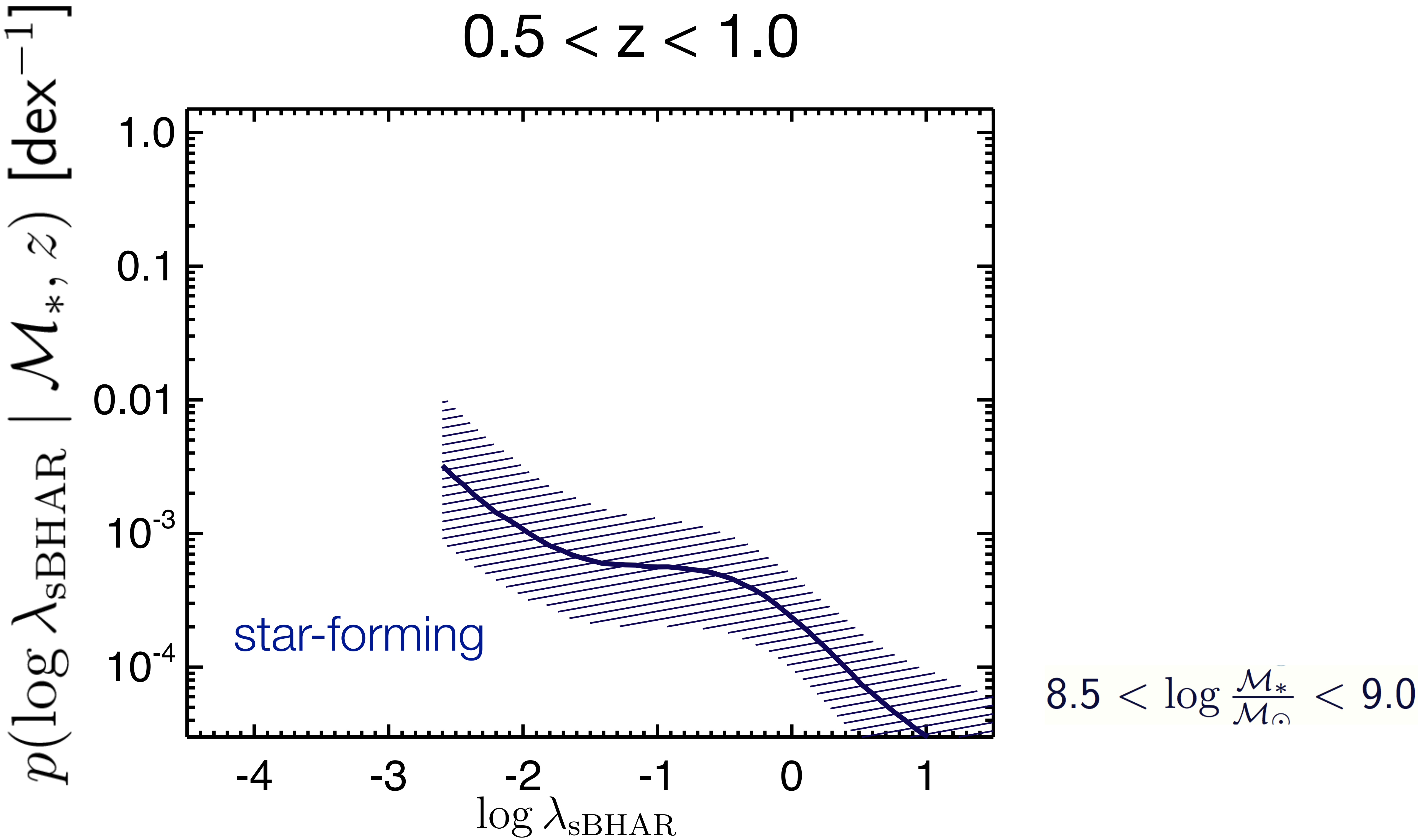
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



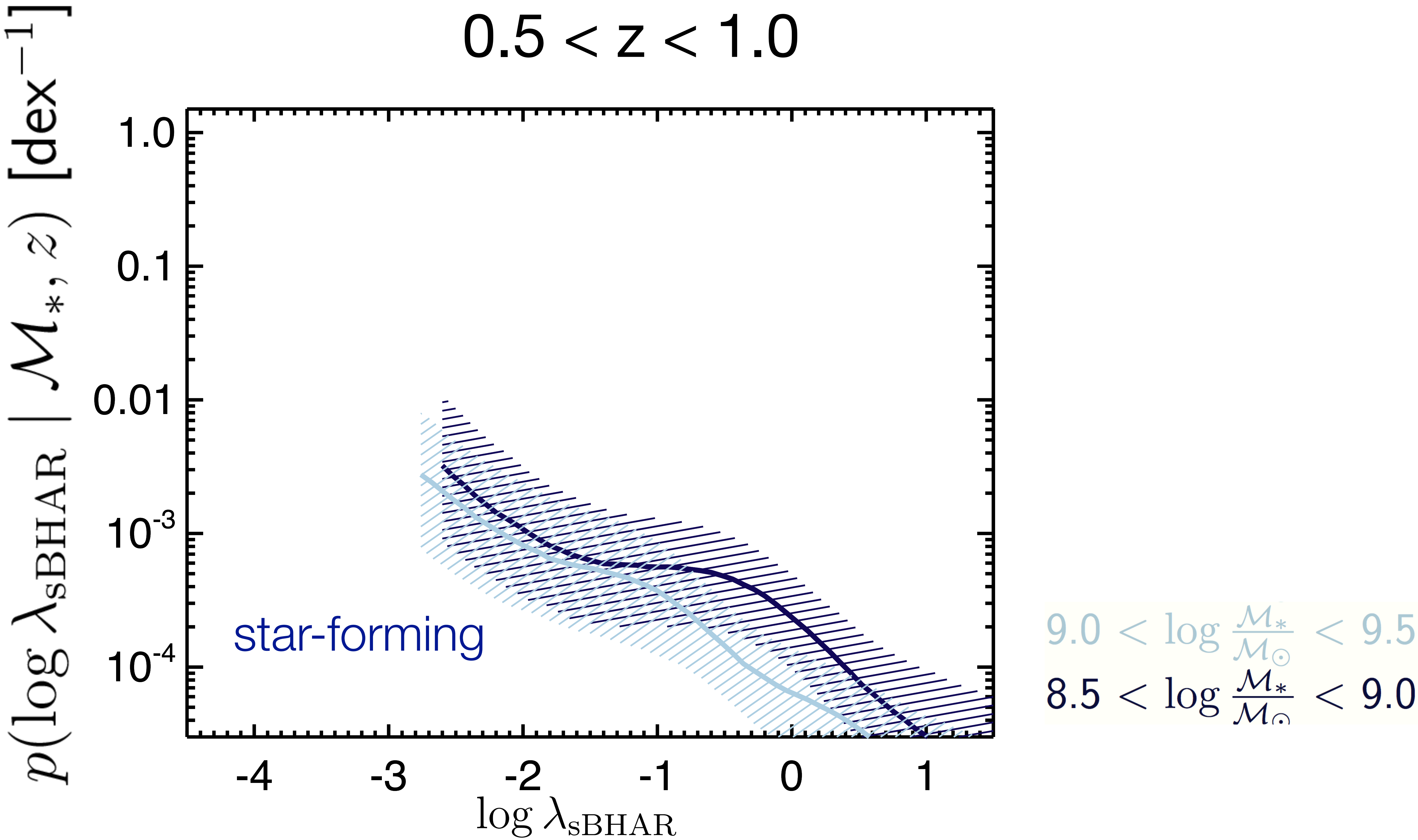
Distributions of sBHAR in star-forming galaxies as a function of **redshift**



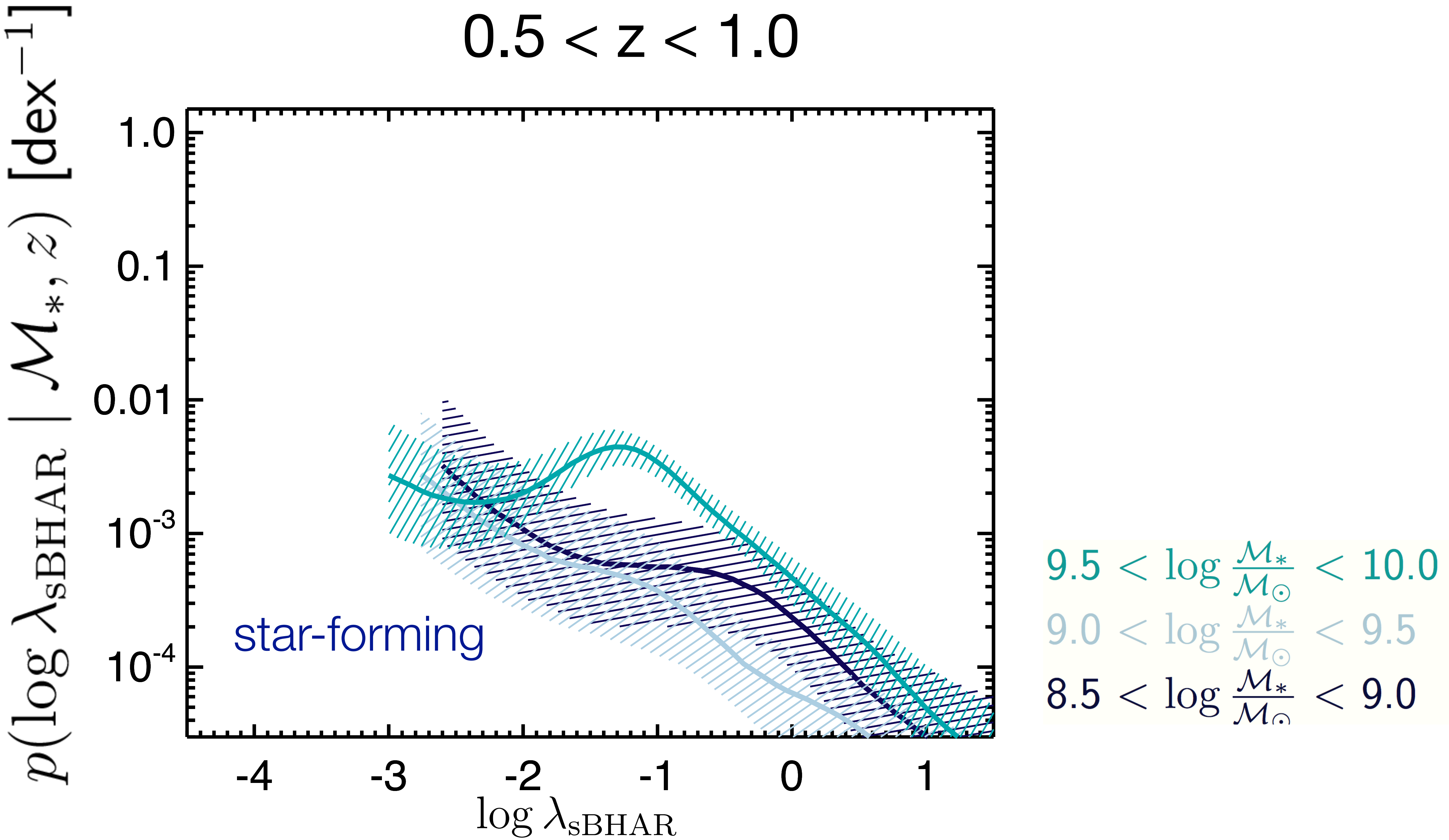
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



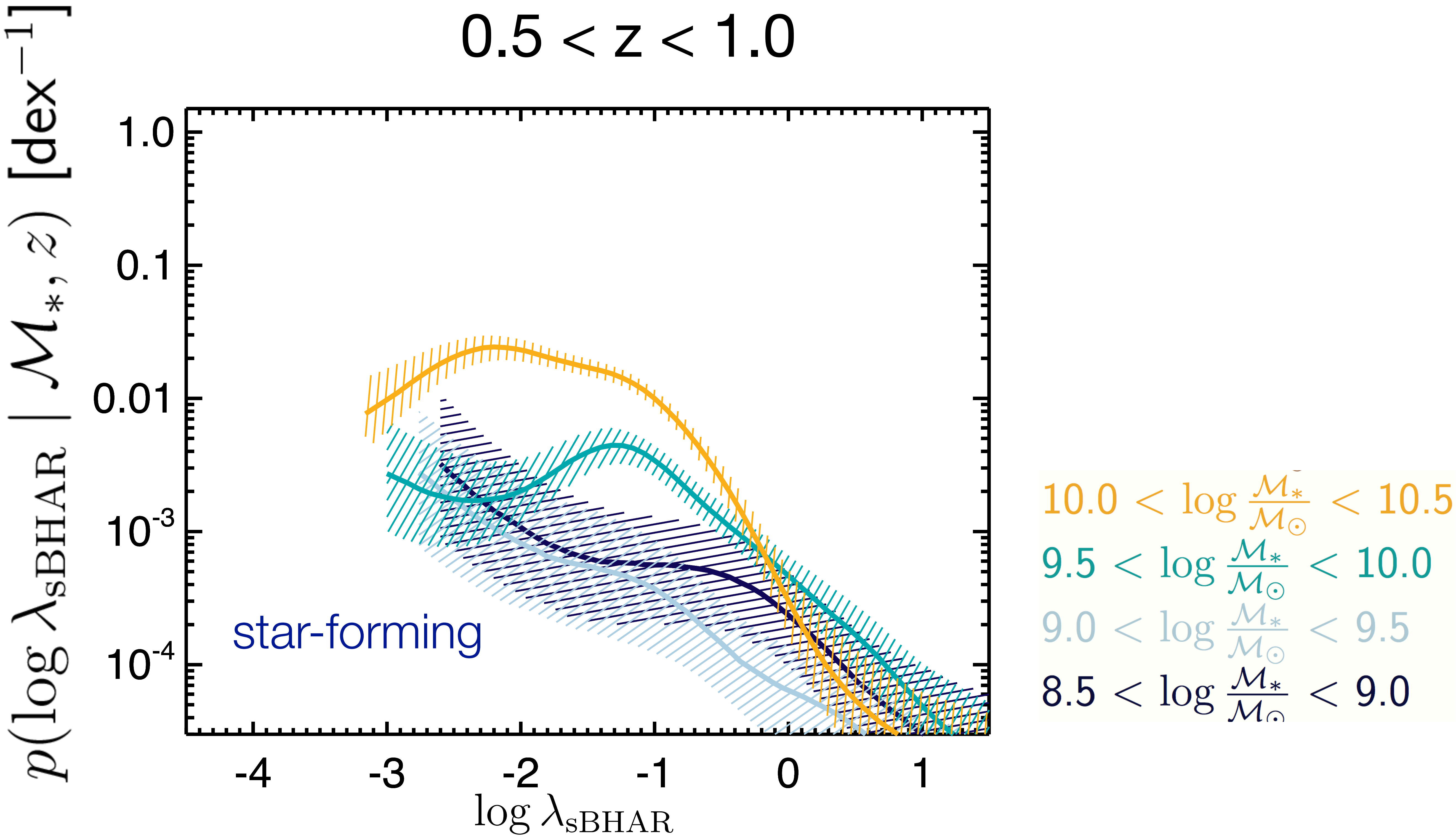
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



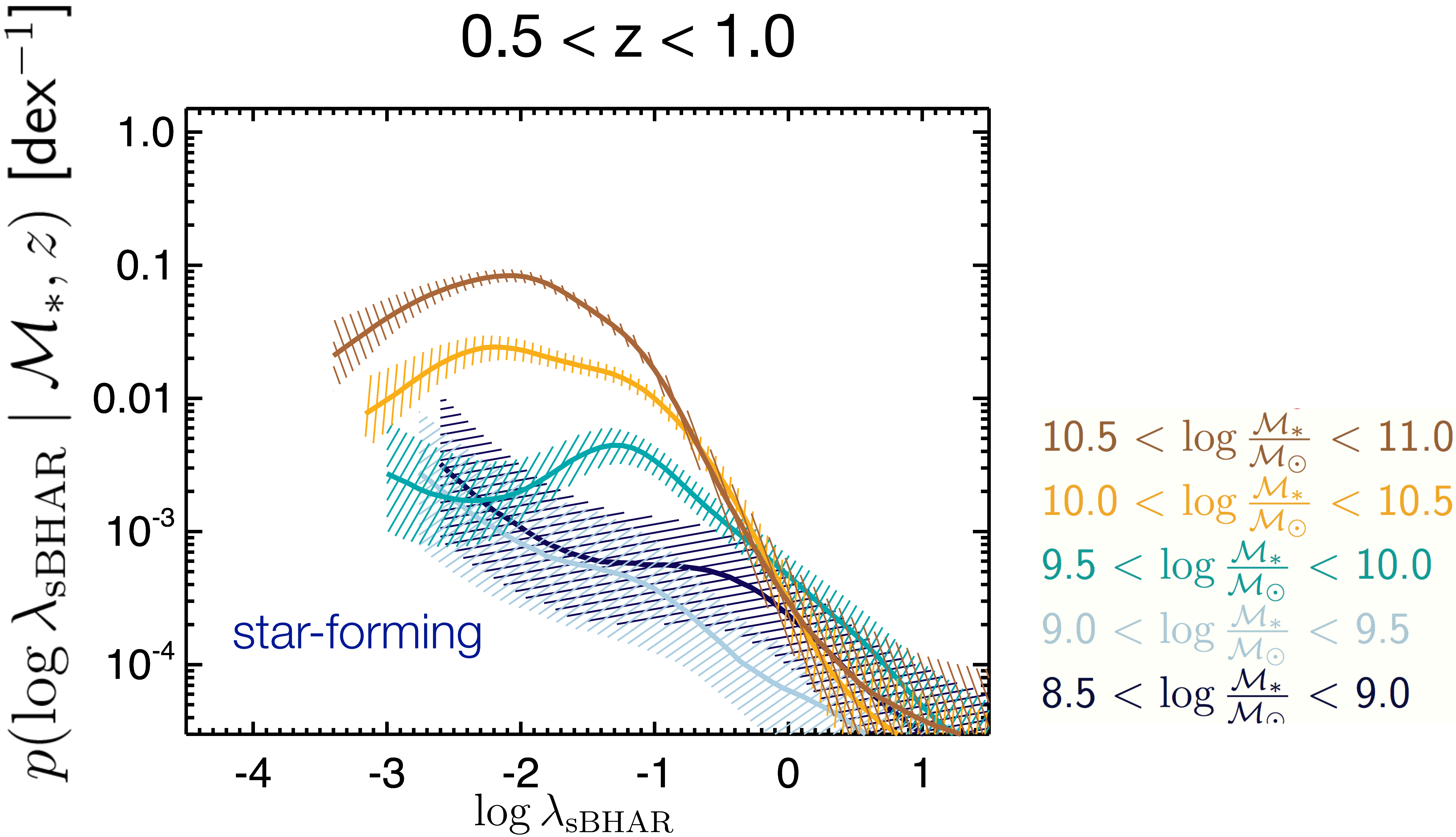
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



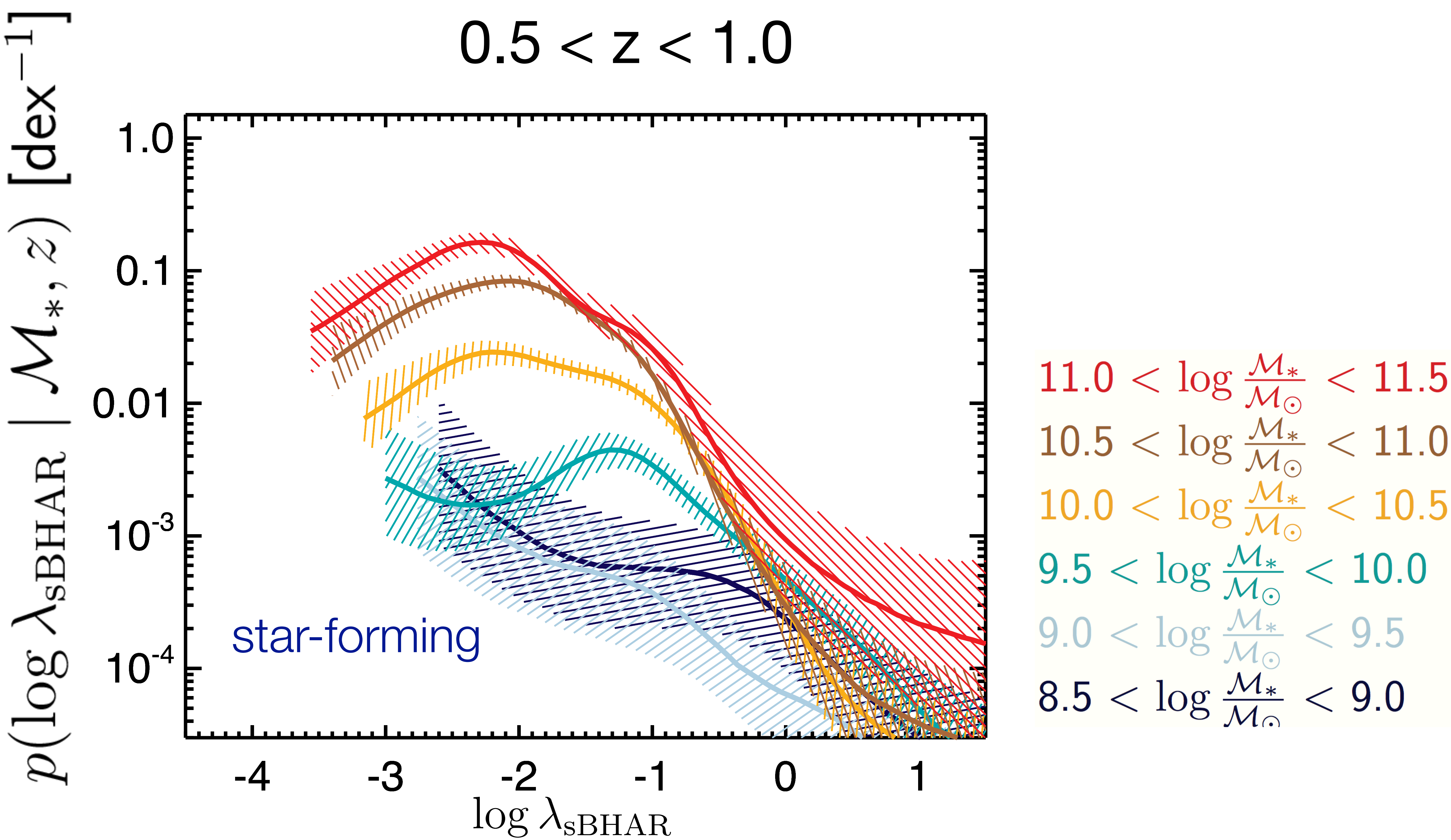
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



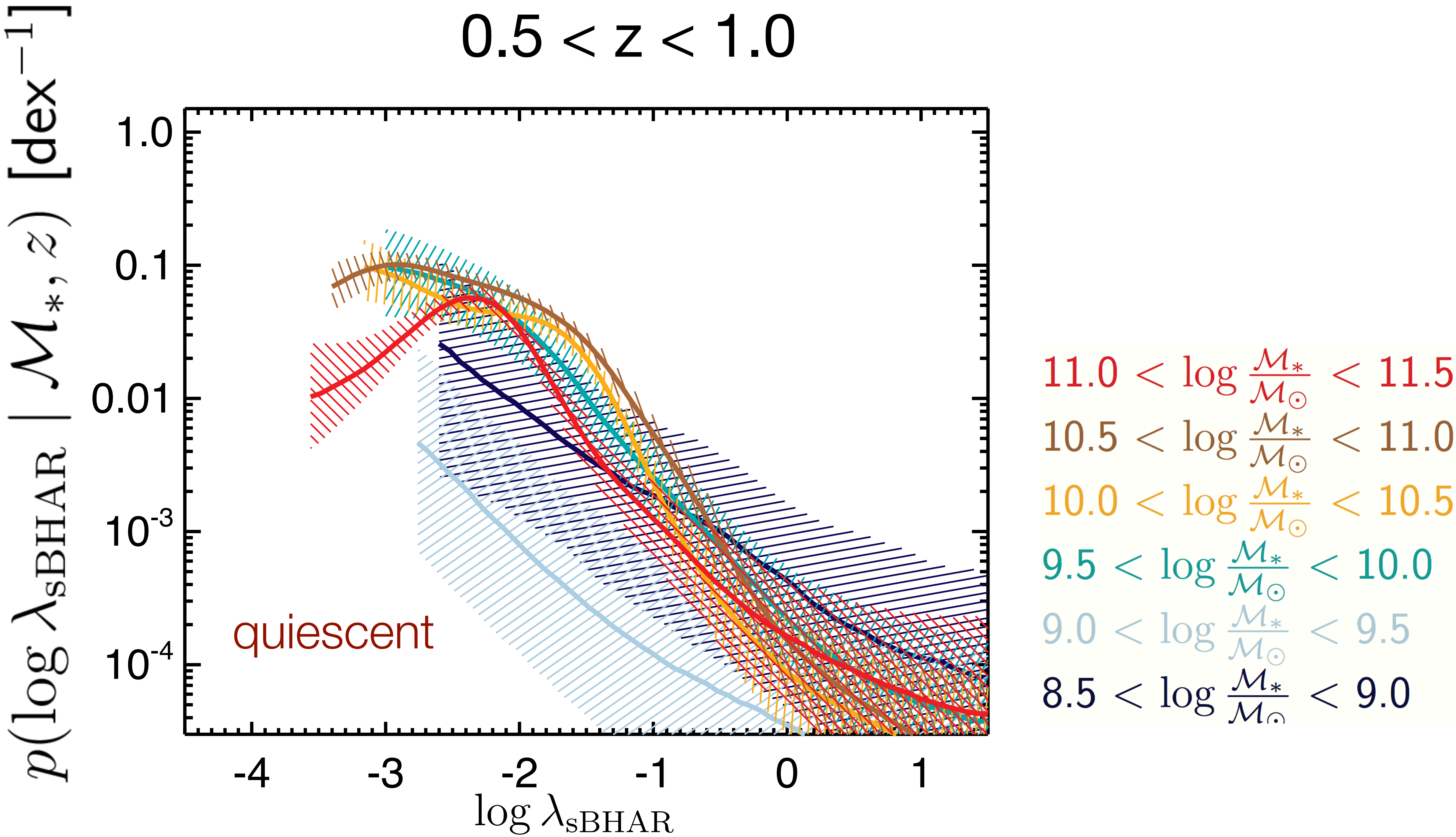
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



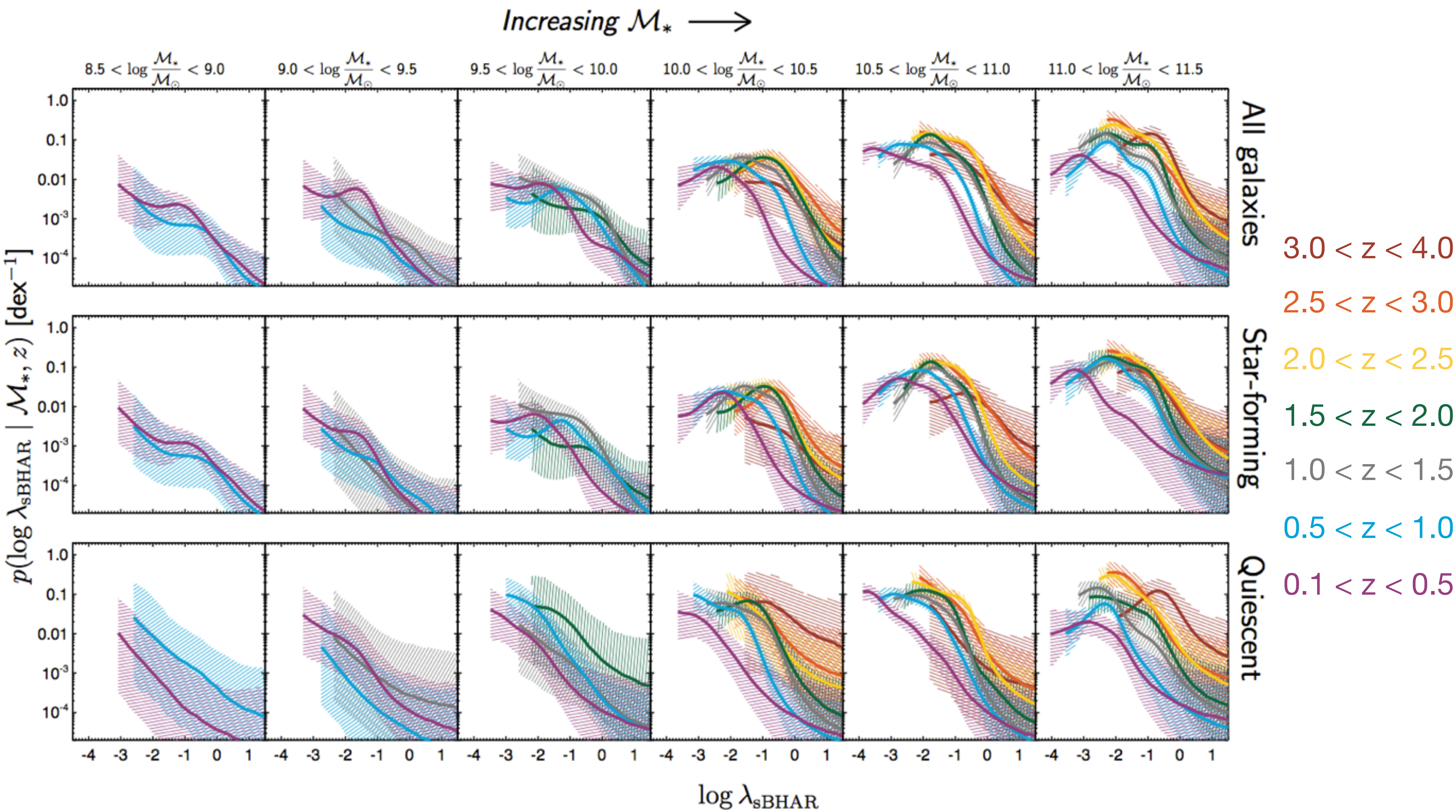
Distributions of sBHAR in star-forming galaxies as a function of **stellar mass**



Distributions of sBHAR in quiescent galaxies as a function of **stellar mass**

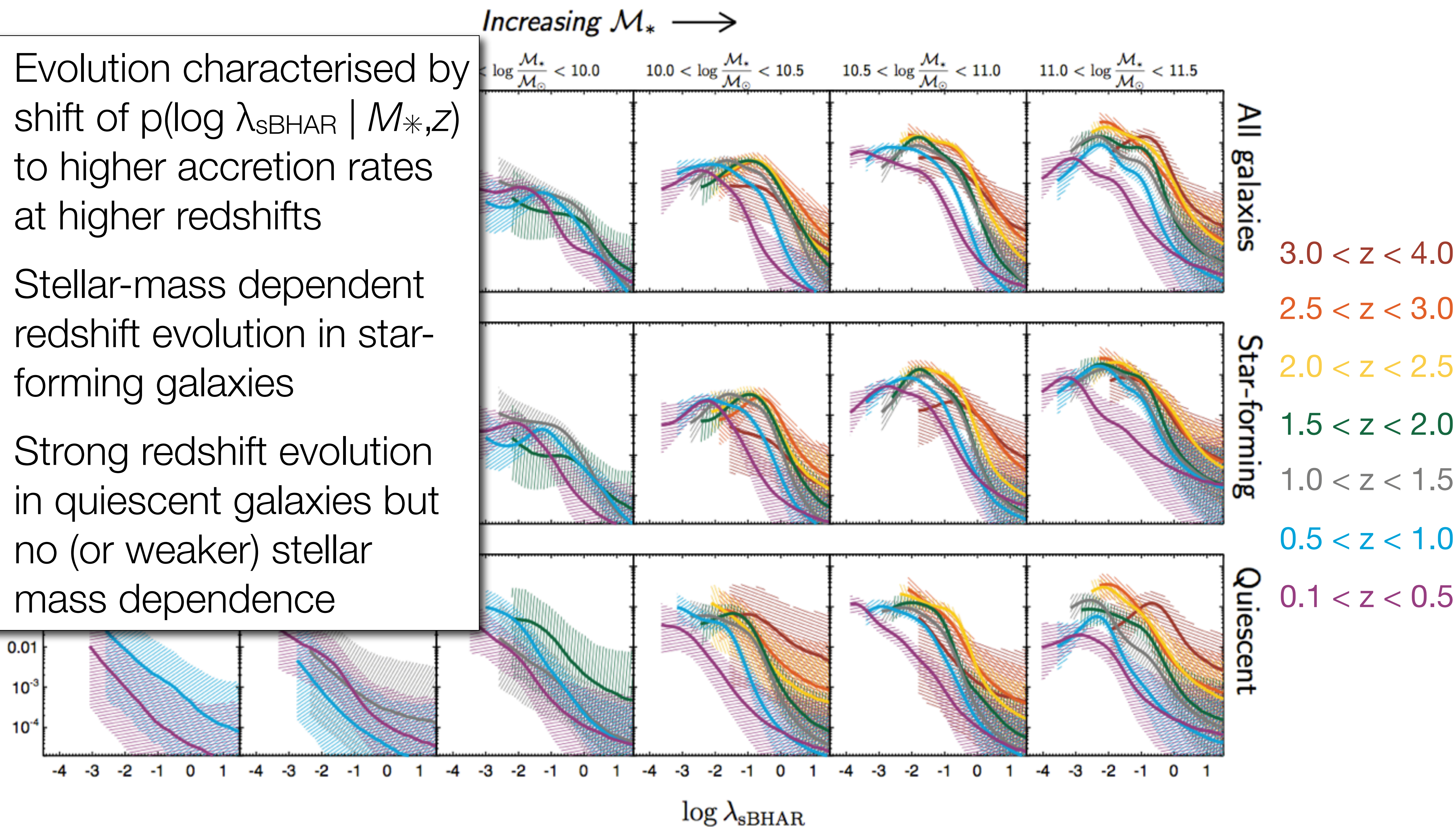


Distributions of sBHAR in all/star-forming/quiescent galaxies as a function of stellar mass, redshift....

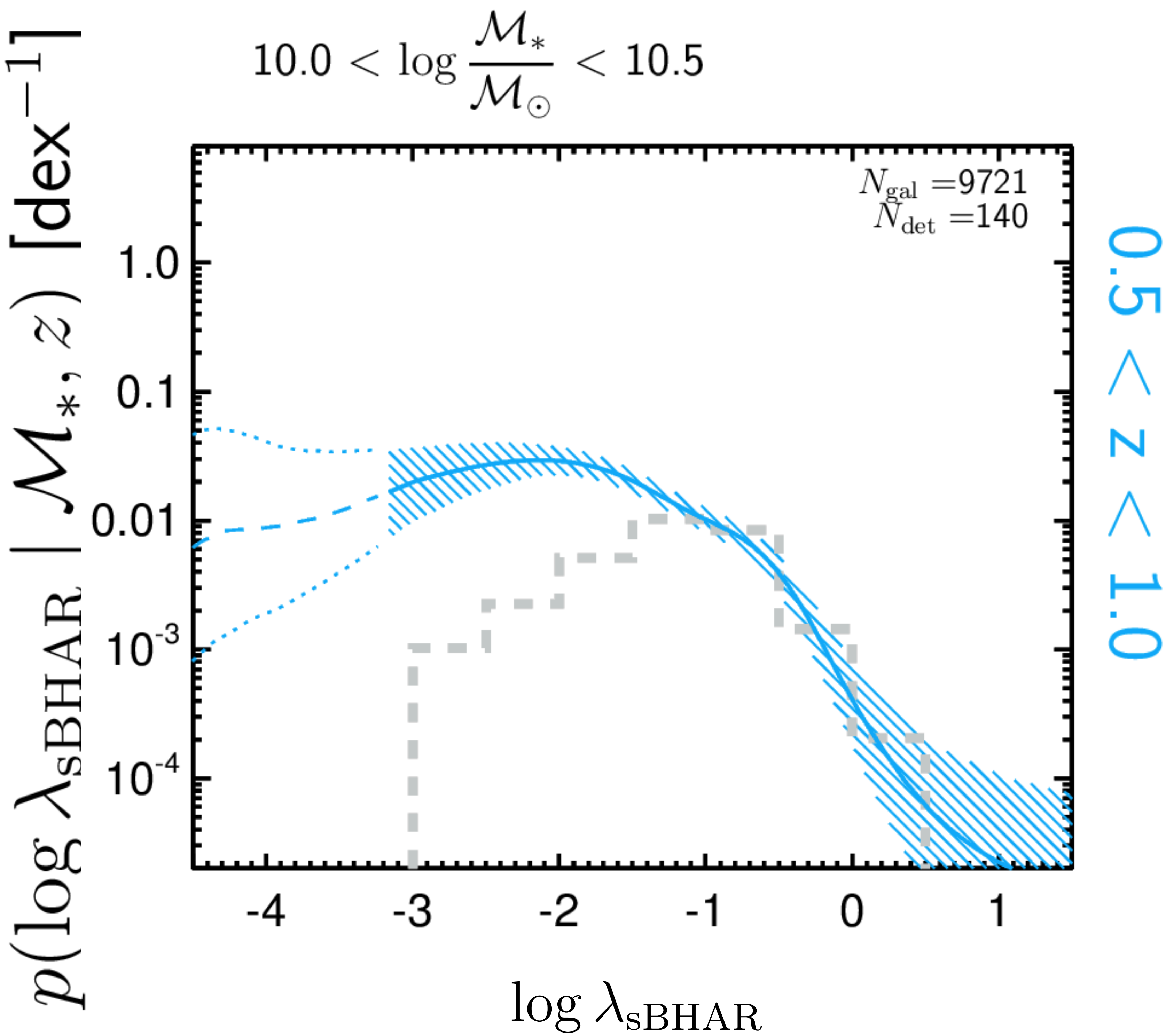


Distributions of sBHAR in all/star-forming/quiescent galaxies as a function of stellar mass, redshift....

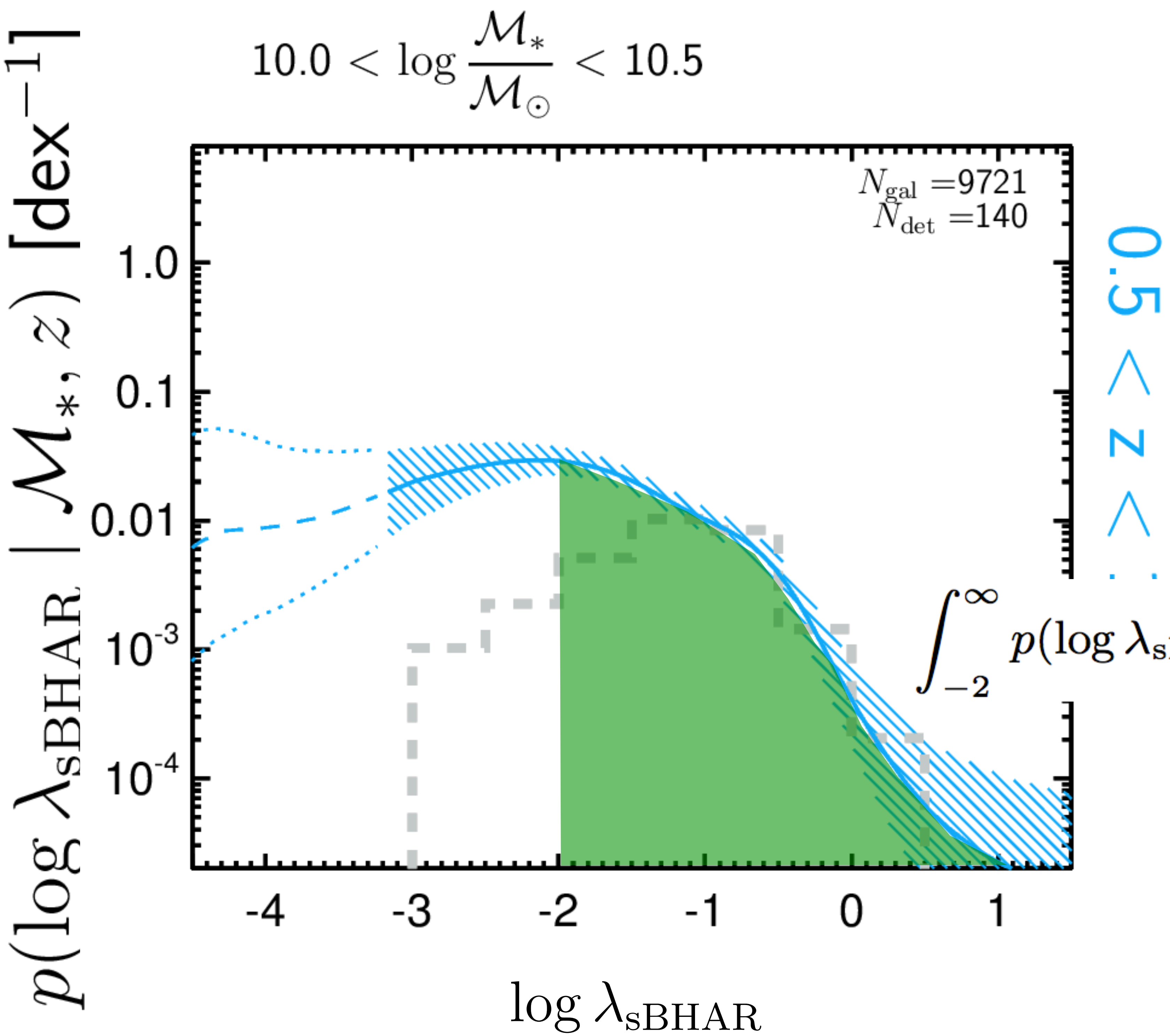
- Evolution characterised by shift of p(log λ_{sBHAR} | M_*,z) to higher accretion rates at higher redshifts
- Stellar-mass dependent redshift evolution in star-forming galaxies
- Strong redshift evolution in quiescent galaxies but no (or weaker) stellar mass dependence



Summarizing the distributions: the duty cycle of AGN

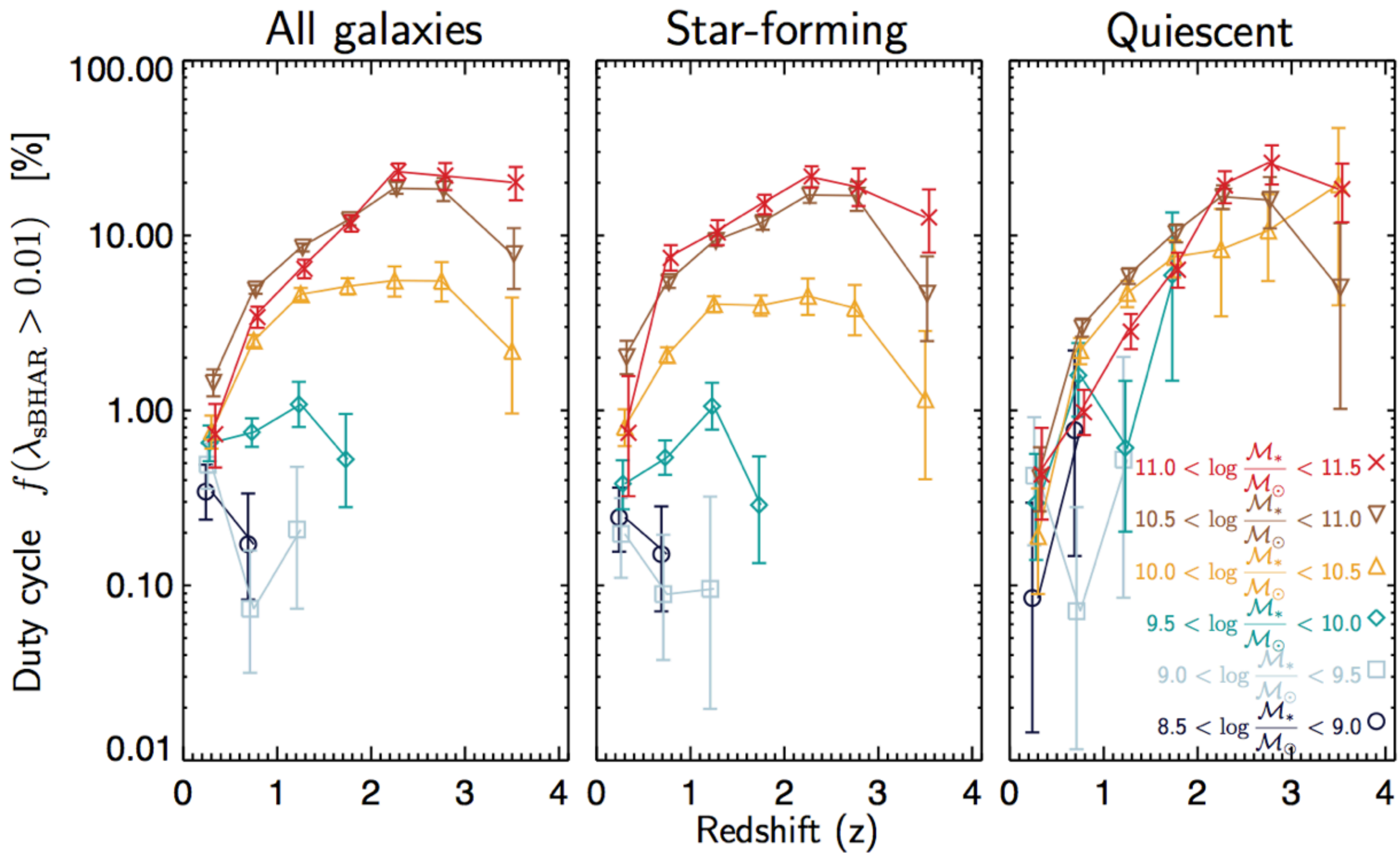


Summarizing the distributions: the duty cycle of AGN

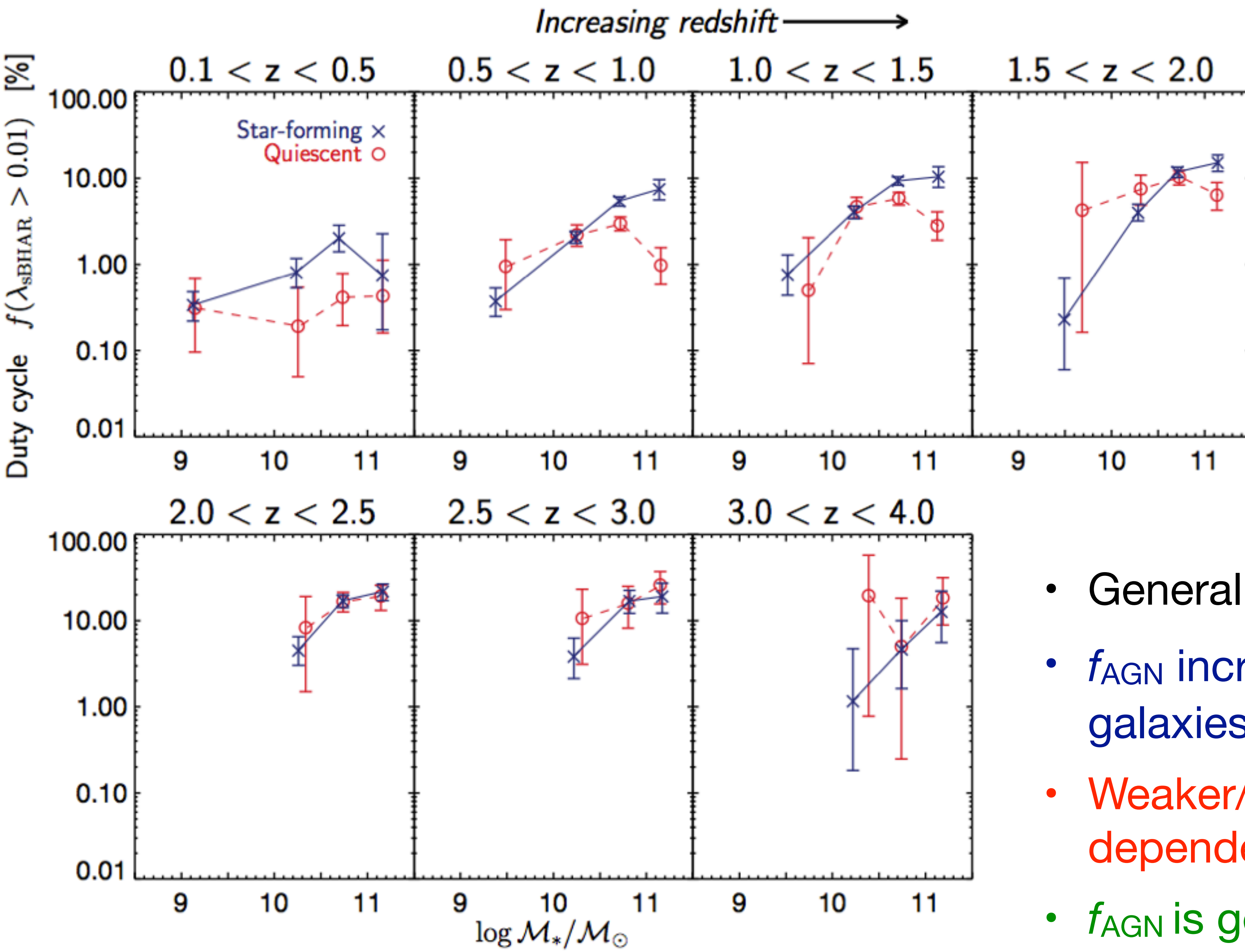


$$f(\lambda_{\rm sBHAR} > 0.01) = \int_{-2}^{\infty} p(\log \lambda_{\rm sBHAR} \mid \mathcal{M}_*, z)\, d\log \lambda_{\rm sBHAR}$$

The AGN duty cycle as a function of stellar mass and redshift



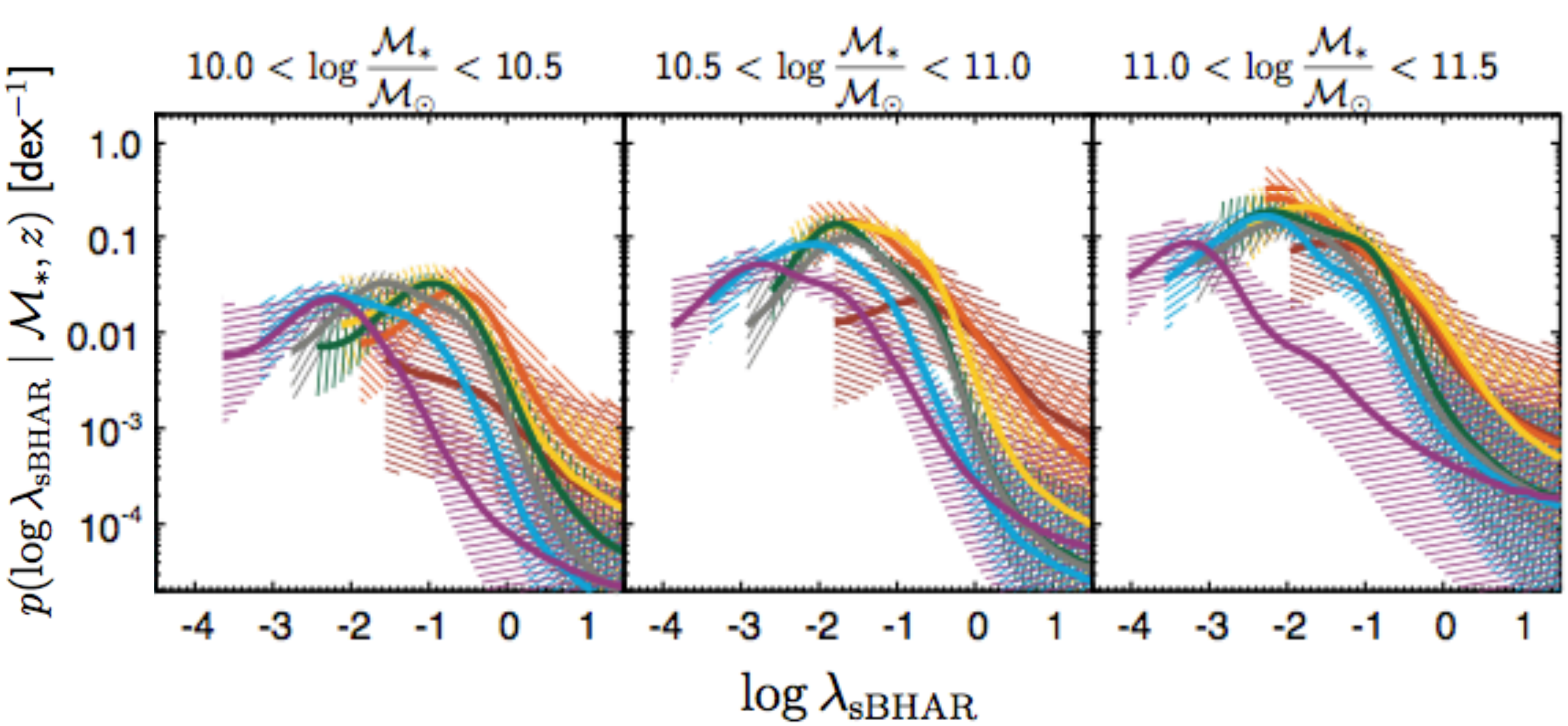
The AGN duty cycle in star-forming and quiescent galaxies as a function of stellar mass and redshift

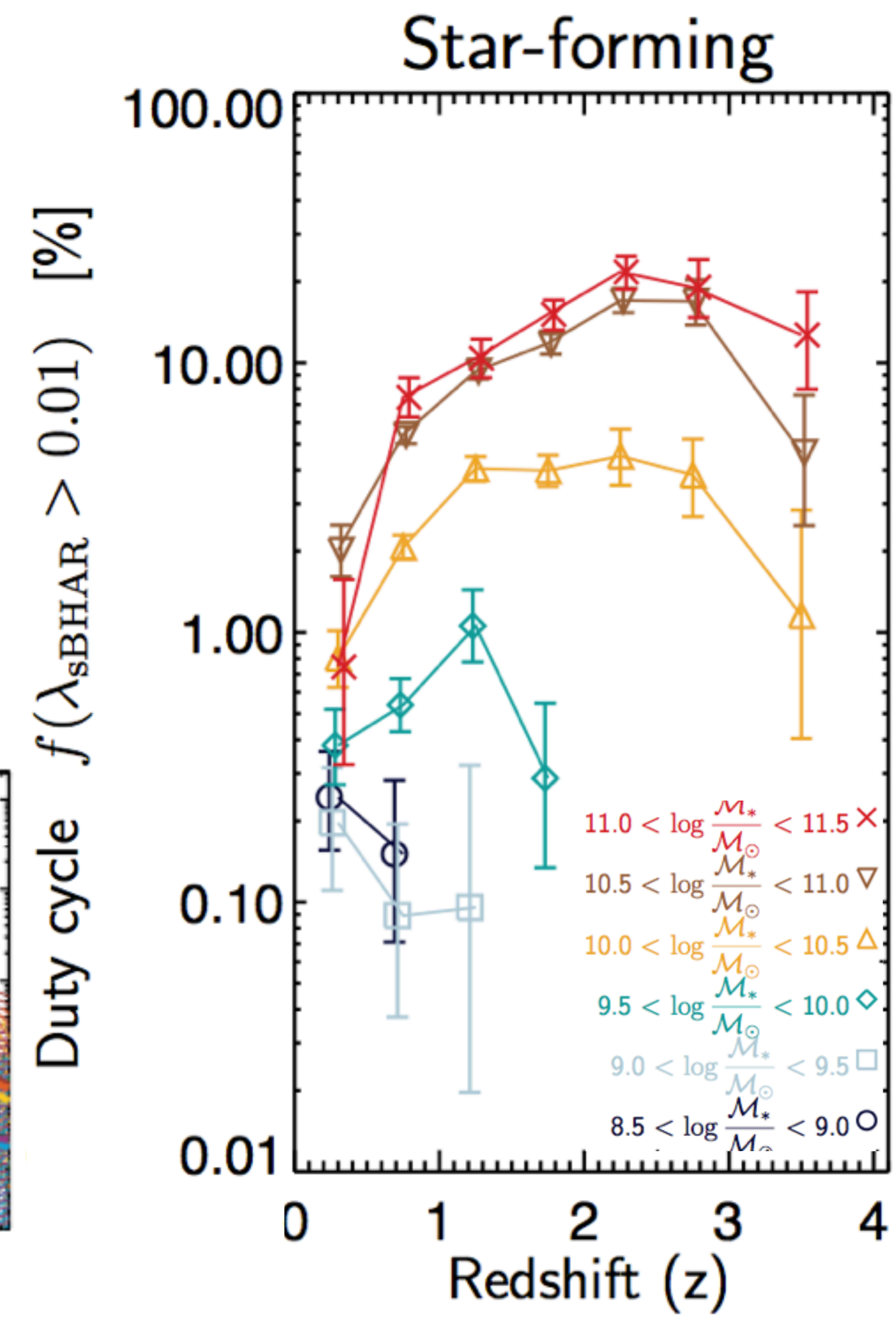


- Generally higher f_{AGN} at higher z
- f_{AGN} increases with M_* in SF galaxies
- Weaker/negative M_* dependence in Qu galaxies?
- f_{AGN} is generally higher in SF galaxies (at higher M_*, out to z~2)

Interpretation/conclusions

Star-forming galaxies

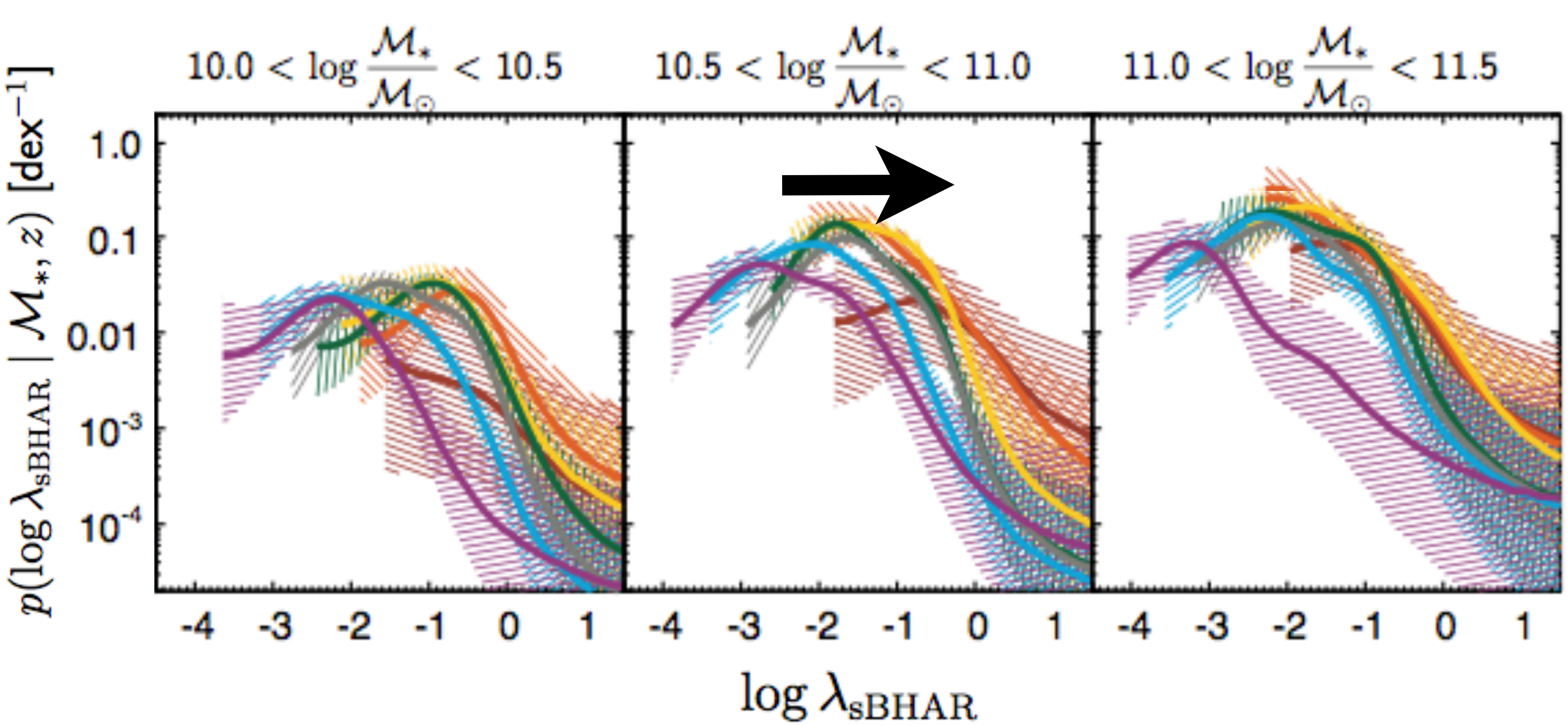


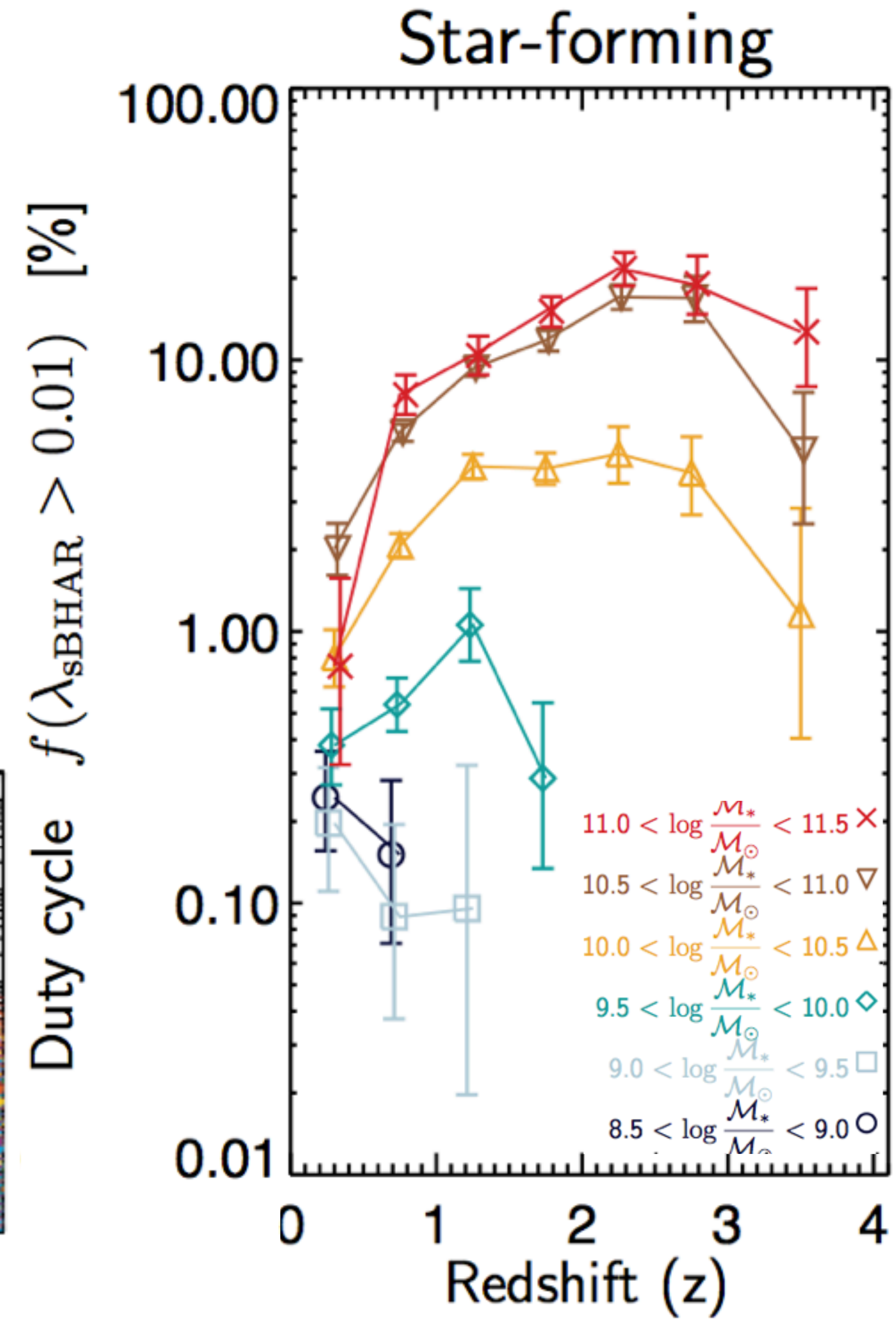


Interpretation/conclusions

Star-forming galaxies

- Shift to higher accretion rates at higher z
  related to increased availability of cold gas?

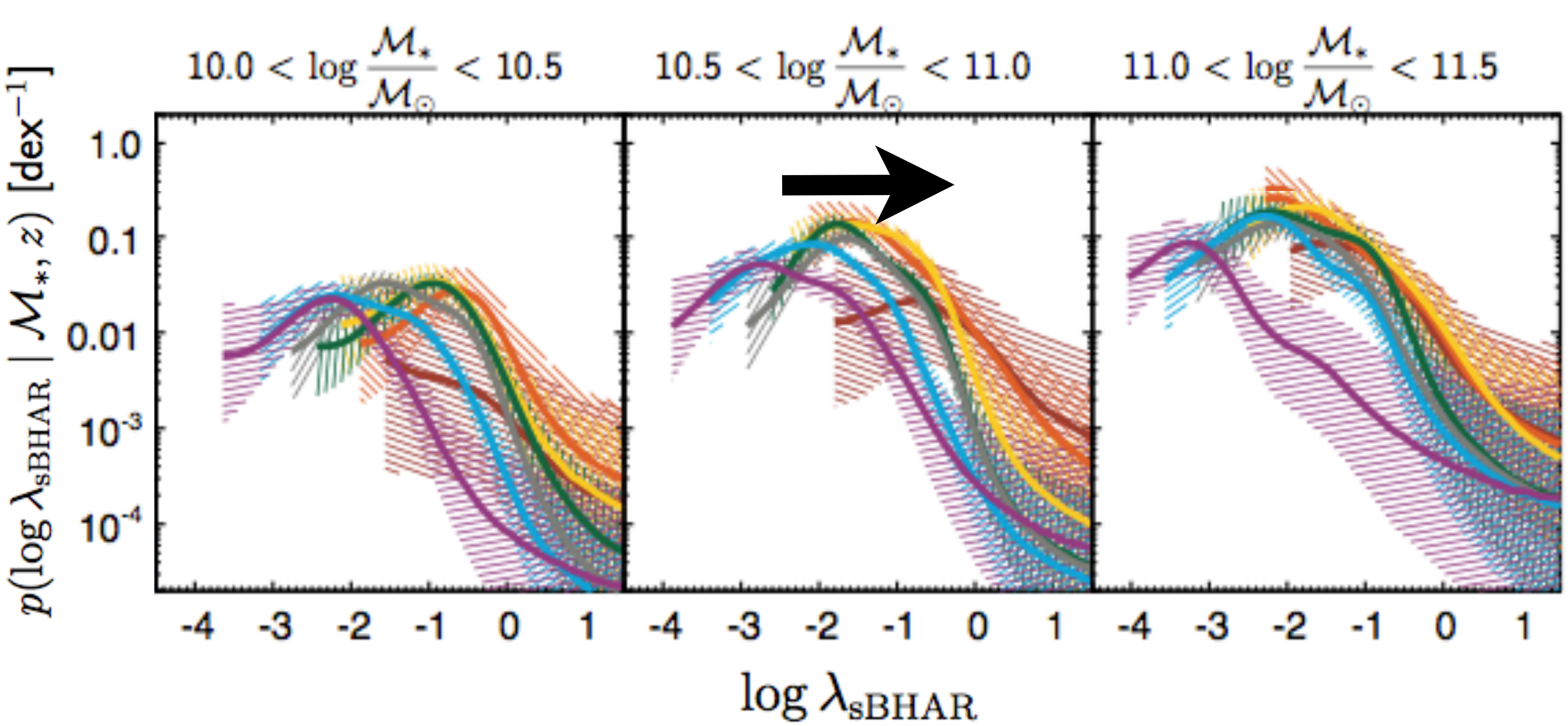


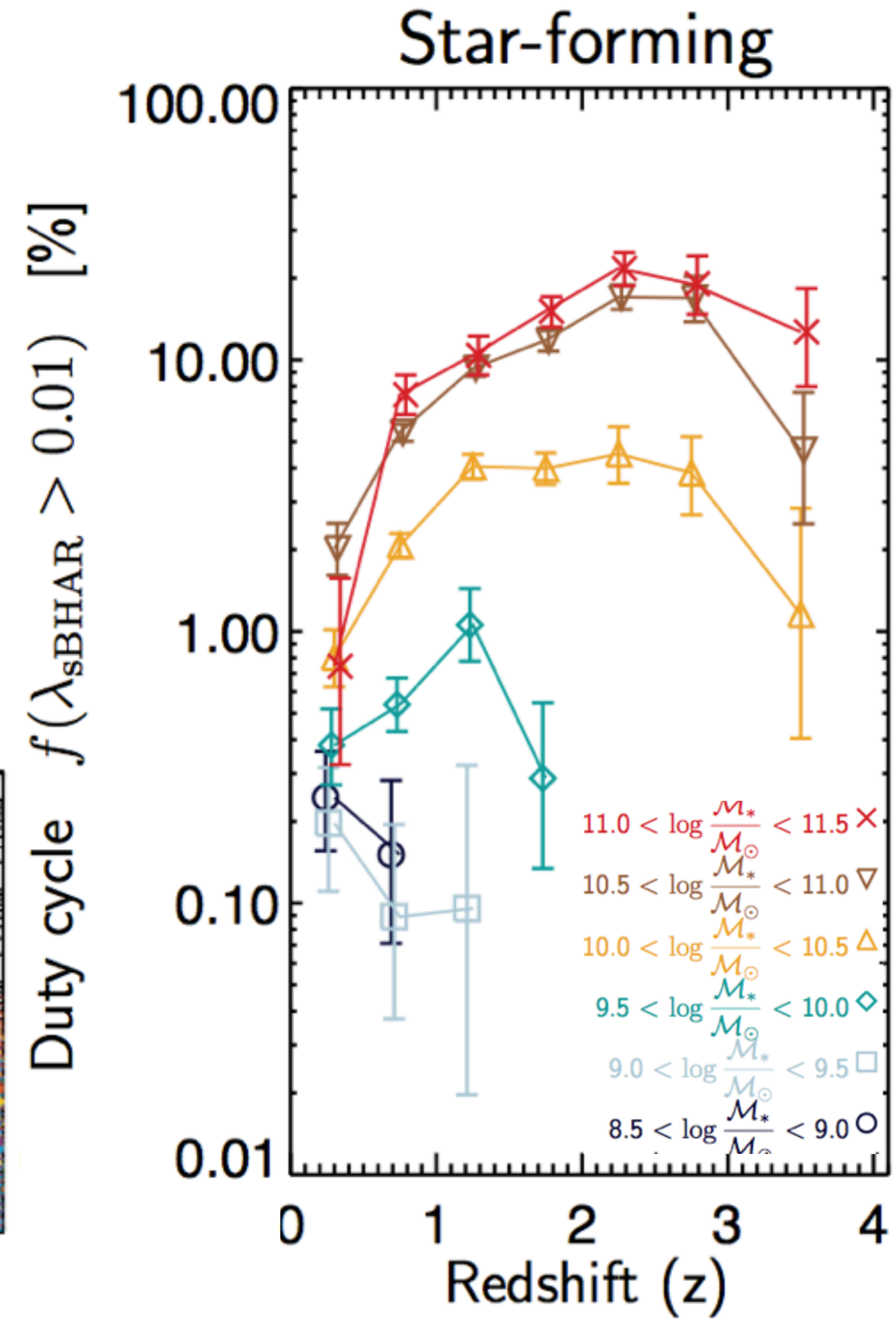


Interpretation/conclusions

Star-forming galaxies

- Shift to higher accretion rates at higher z
  related to increased availability of cold gas?
- Reaches a maximum at ~Eddington limit?
  BHs self-regulate own growth?

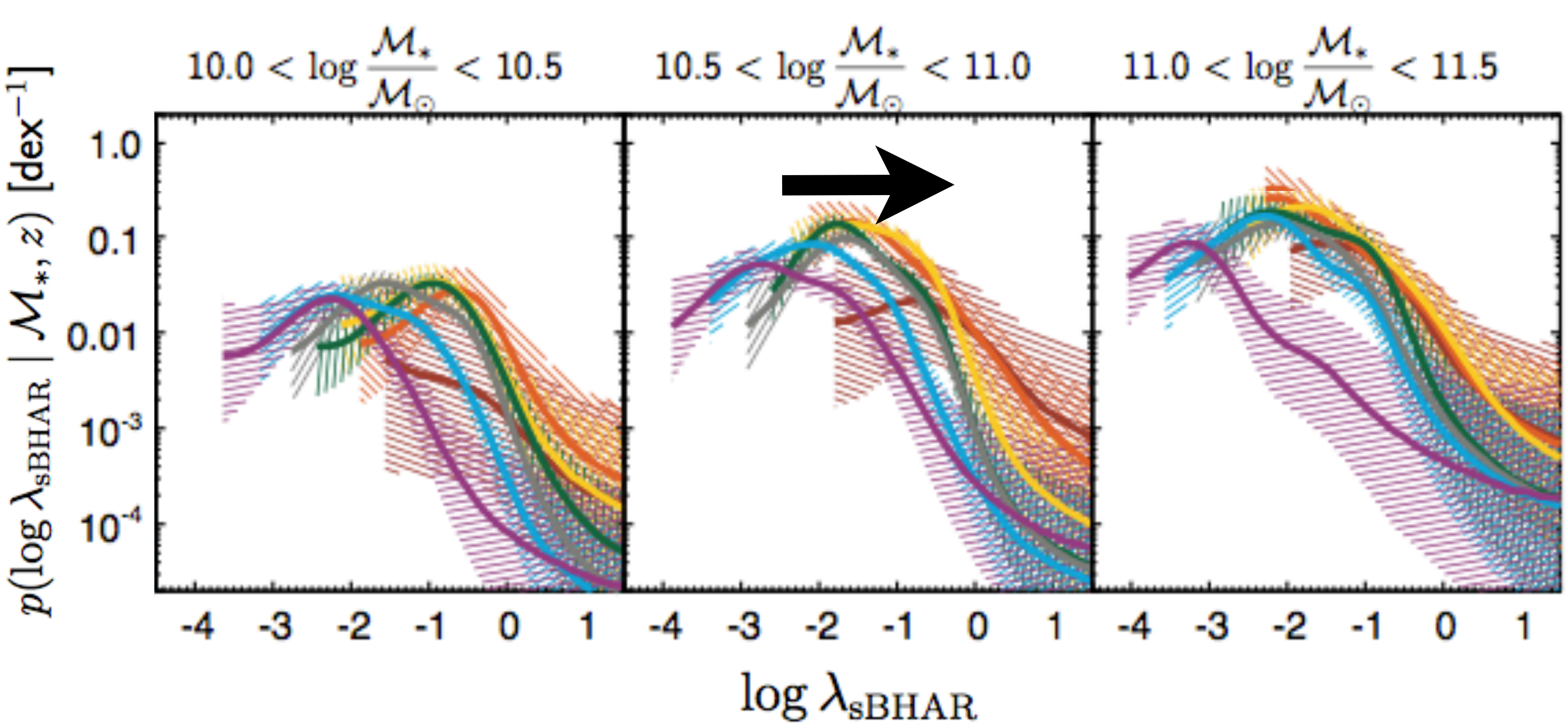


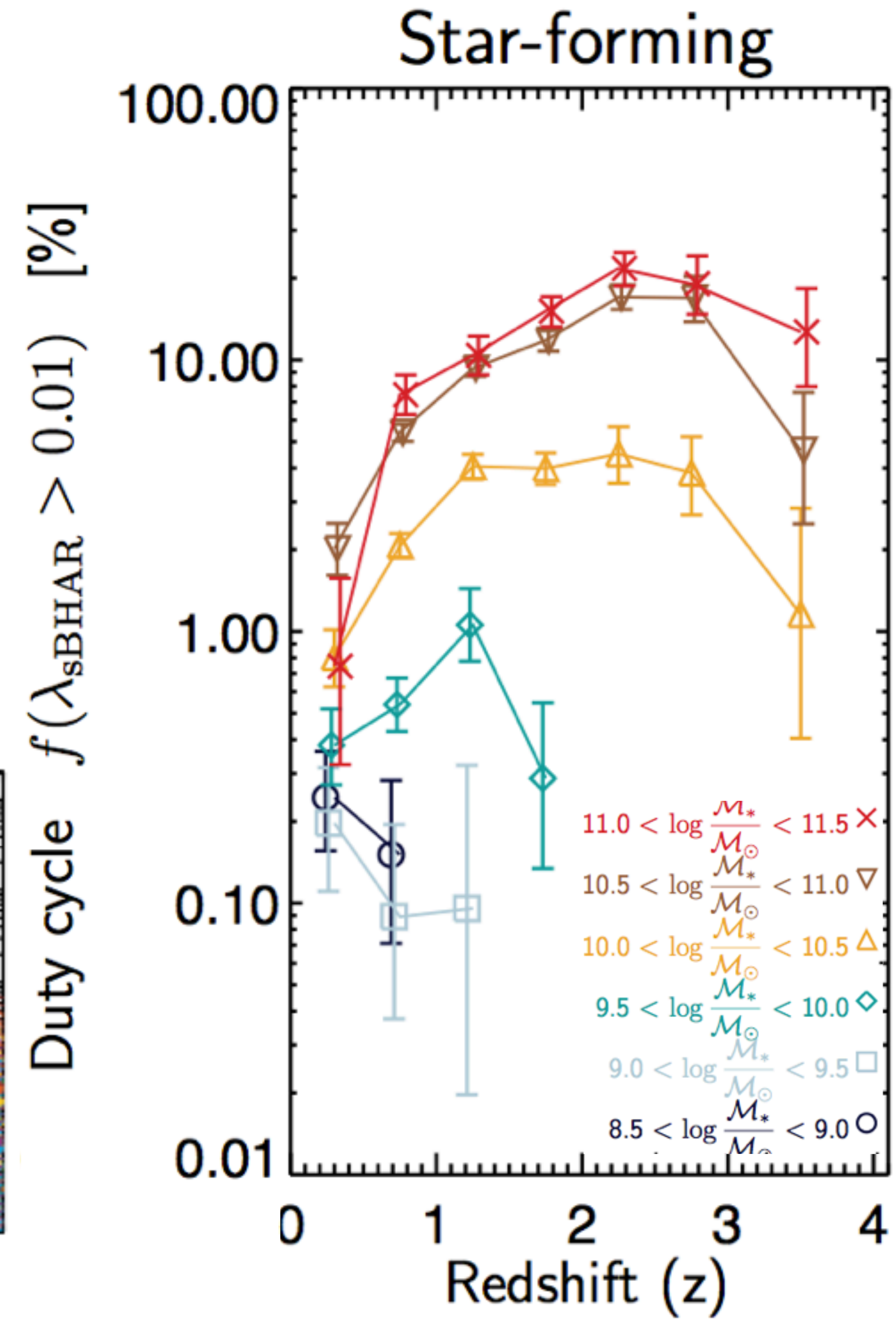


Interpretation/conclusions

Star-forming galaxies

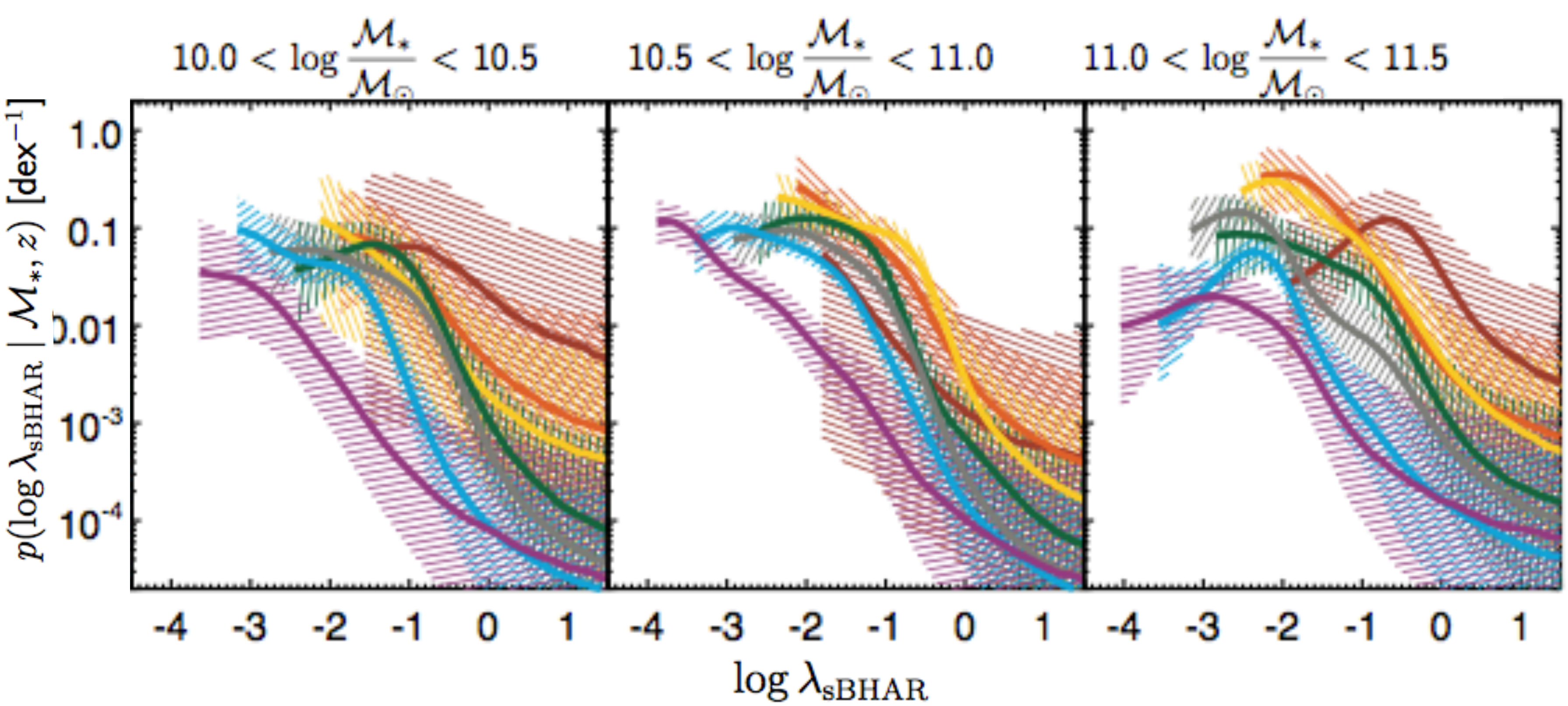
- Shift to higher accretion rates at higher z
  related to increased availability of cold gas?
- Reaches a maximum at ~Eddington limit?
  BHs self-regulate own growth?
- Stronger evolution in higher mass galaxies
  => “downsizing”? BHs in more massive galaxies are growing more rapidly at earlier cosmic times

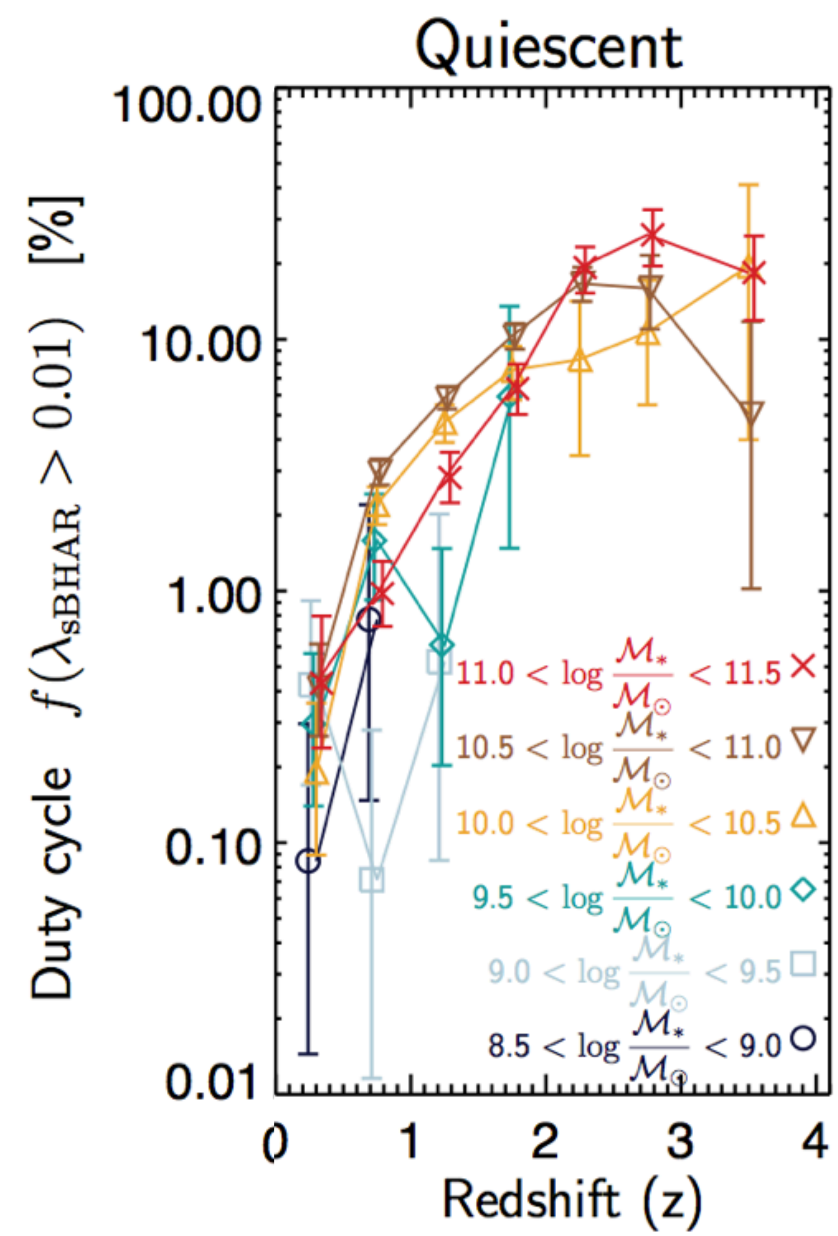




Interpretation/conclusions

Quiescent galaxies

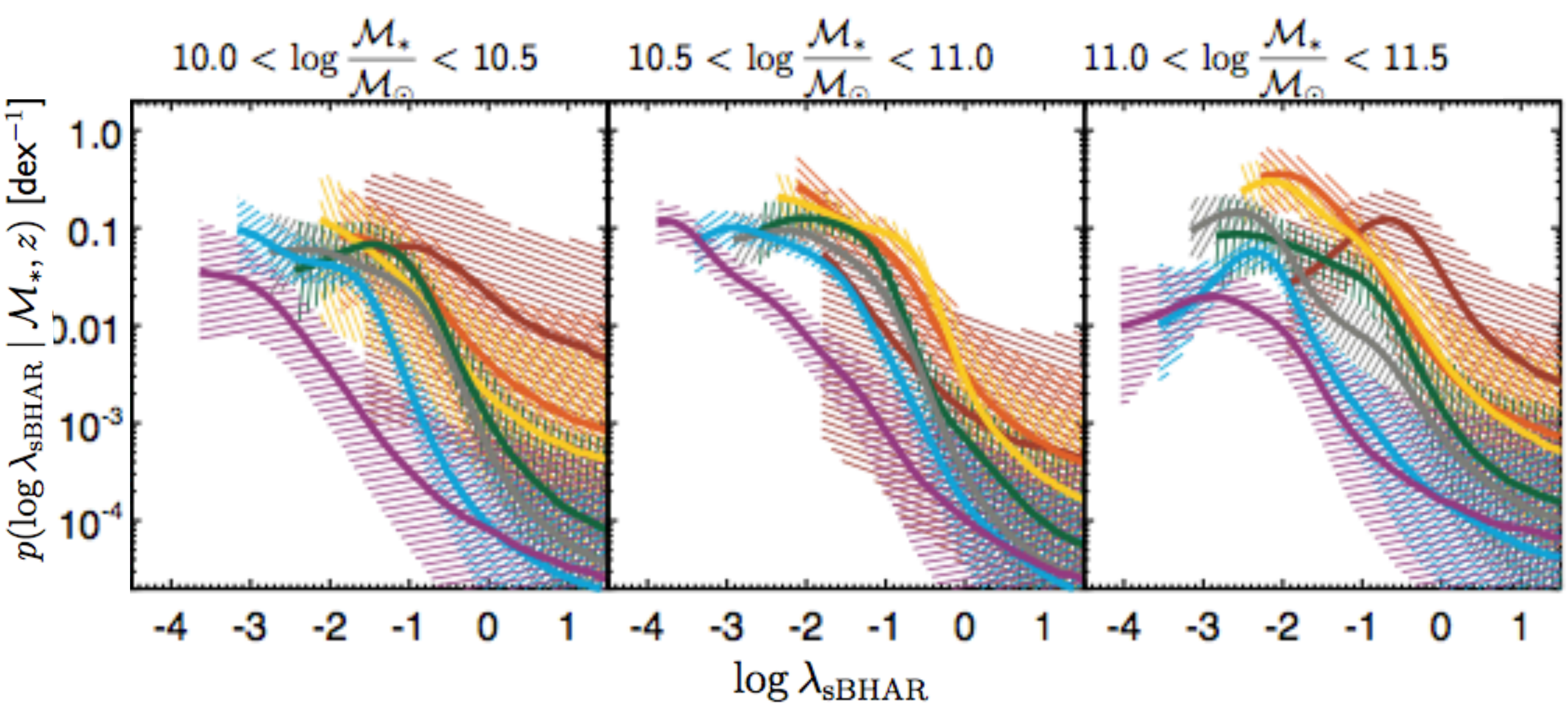


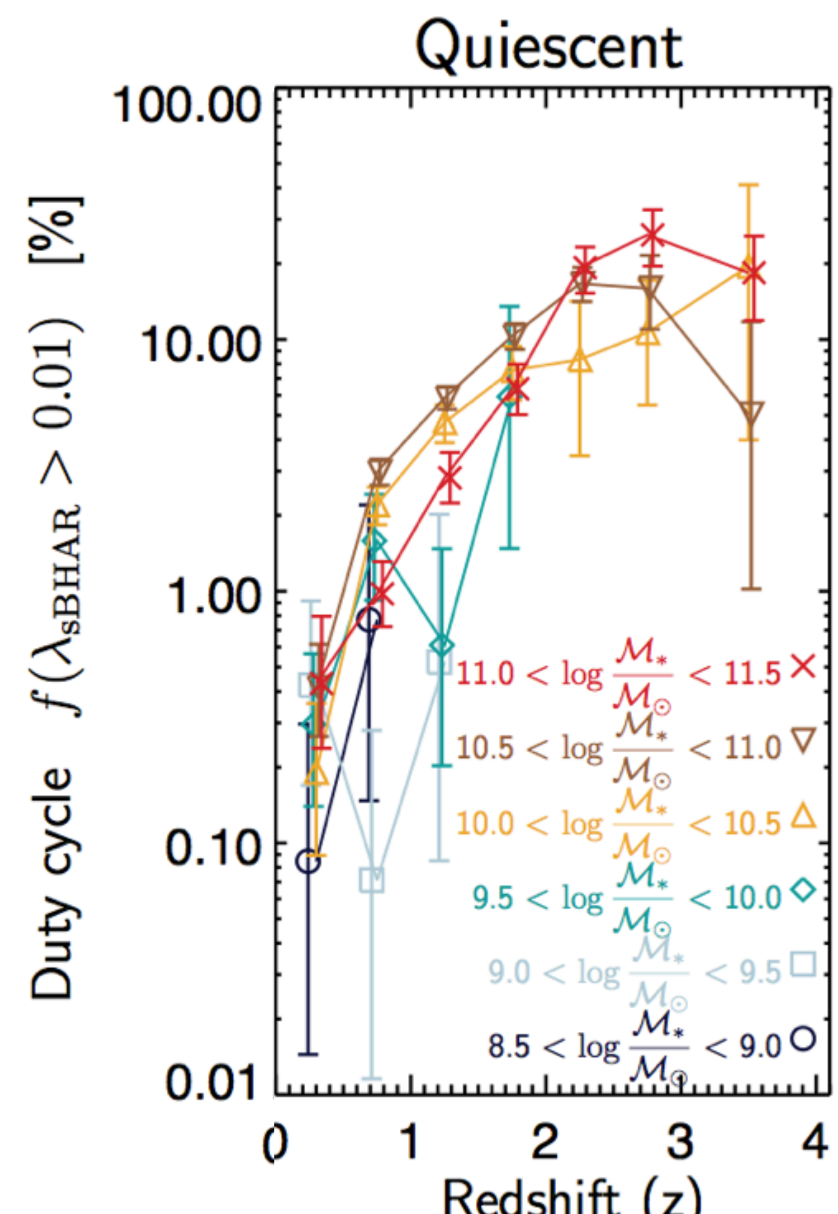


Interpretation/conclusions

Quiescent galaxies

- Generally contain weaker (lower sBHAR) AGN (at moderate to high M_{*} and z<2)

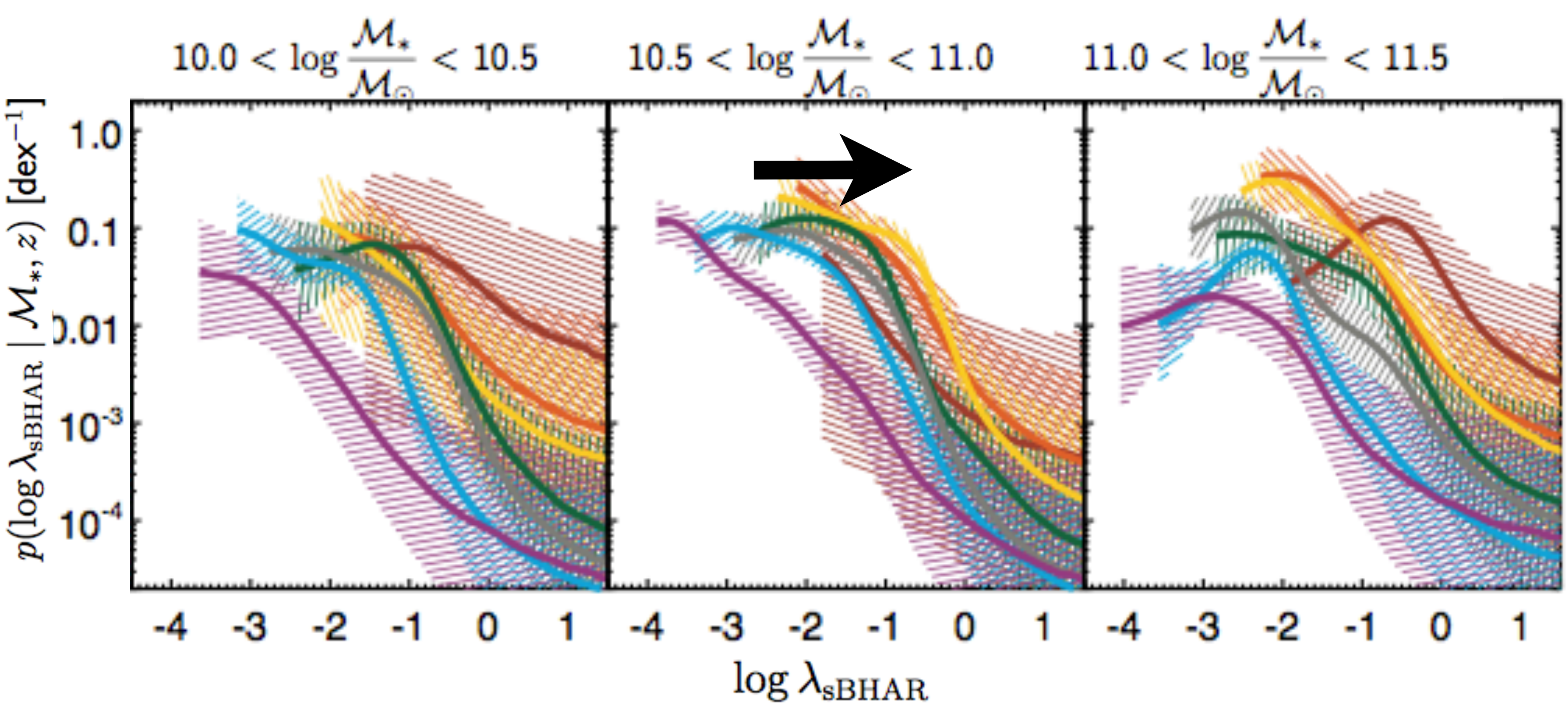


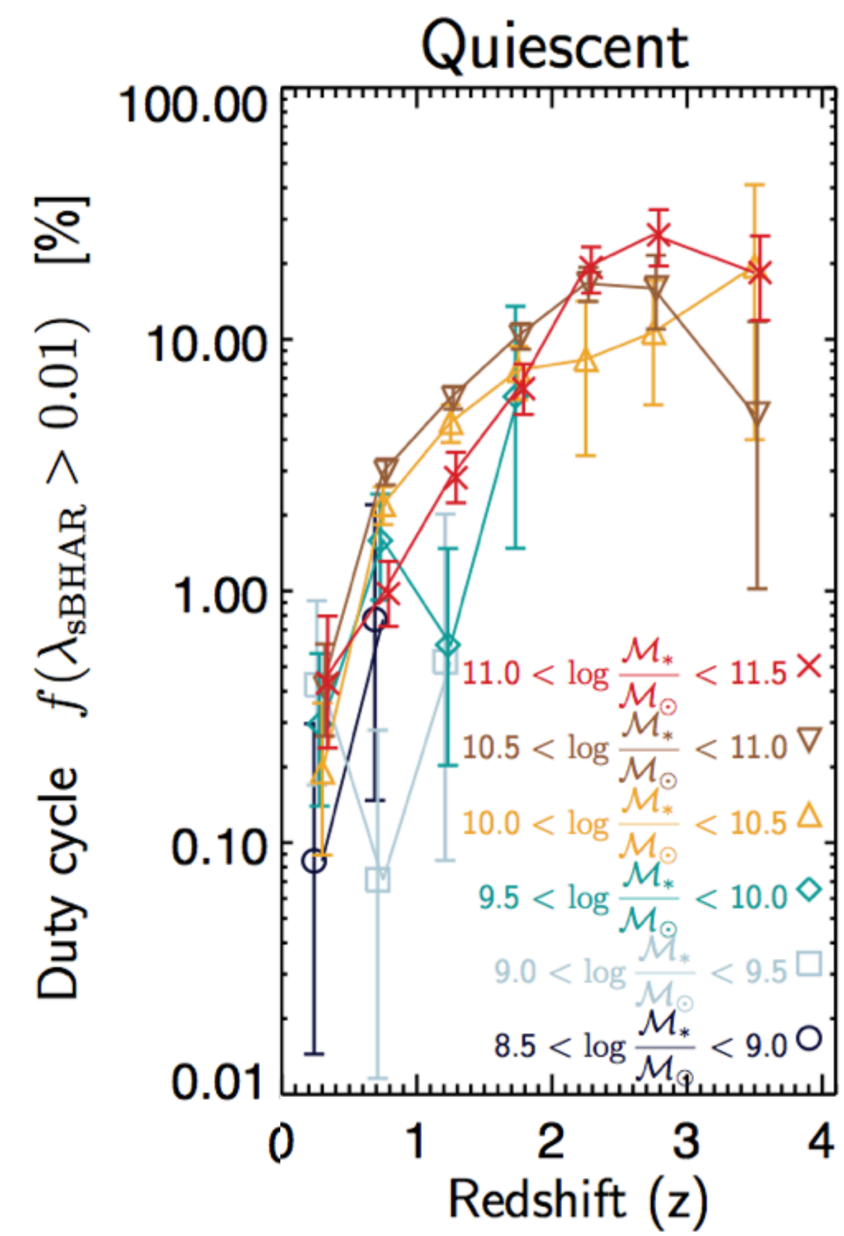


Interpretation/conclusions

Quiescent galaxies

- Generally contain weaker (lower sBHAR) AGN (at moderate to high M_* and z<2)
- As in SF galaxies, see a strong evolution to higher sBHAR at higher z
  Also related to increased gas availability? Or are we seeing relic AGN activity in 'recently' quenched galaxies?





Summary

- Using large galaxy samples combined with deep X-ray surveys, we can trace the **distribution** of black hole growth and unveil connections between the incidence AGN and the properties of galaxies

- Broad distribution of specific black hole accretion rates for a fixed galaxy property (redshift, stellar mass, star-forming vs. quiescent), likely reflecting the in variability of AGN fueling.

- Distributions shift to higher accretion rates at higher z (but ~Eddington limited)
  - *related to increased availability of cold gas?*

- Complex, stellar-mass dependent evolution in star-forming galaxies.
  -> Black holes in more massive star-forming galaxies are growing more rapidly at higher redshifts - *downsizing?*

- AGN in quiescent galaxies, generally have lower accretion rates/lower duty cycle. Also evolve strongly with redshift.
  - *also related to increased gas availability at higher z? or relic population?*