

Characterizing black hole growth across the galaxy population using deep X-ray data

James Aird
(University of Cambridge)

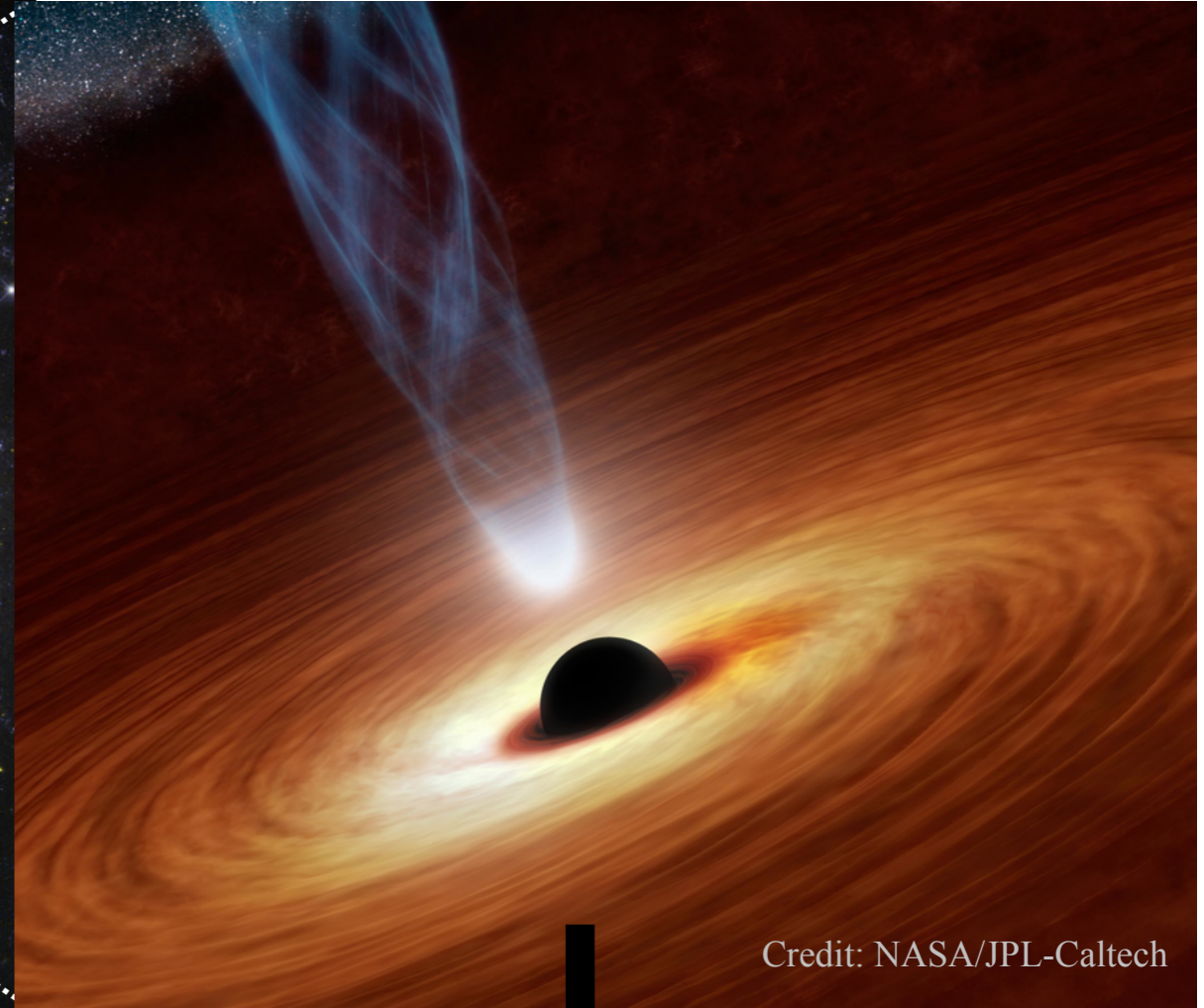
**Aird+2017, MNRAS, submitted
arXiv: 1705.01132**

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

Galaxies



Supermassive black holes



Credit: NASA/JPL-Caltech

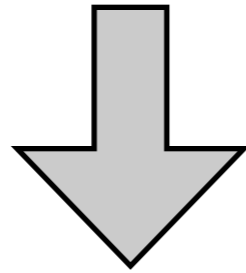


AGN

ESA/Hubble & NASA
Acknowledgement: Judy Schmidt

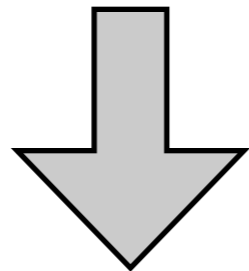
Elusive

Active **Galactic** Nuclei



Elusive

Active **Galactic** Nuclei

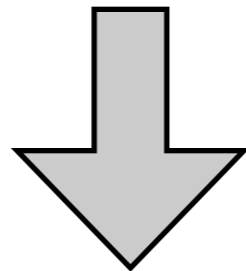


Select **galaxies**

in a particular range of
redshift, stellar mass etc.

Elusive

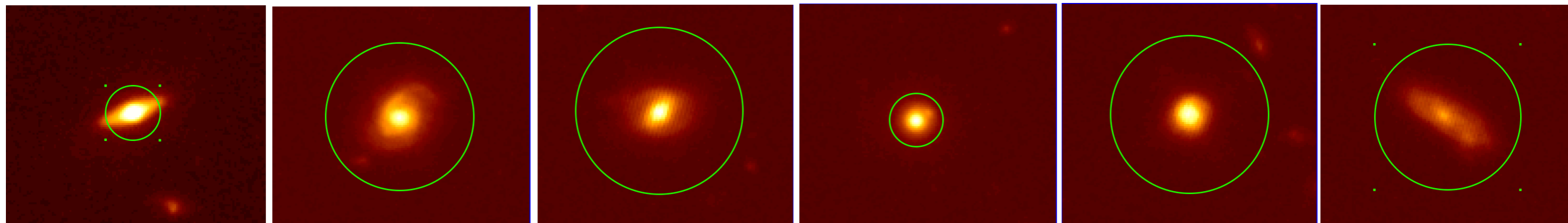
Active **Galactic** Nuclei



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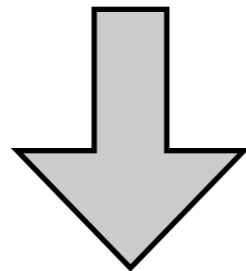
in a particular range of
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e.g. Near-IR selected galaxies from
the CANDELS/3DHST survey



Elusive

Active **Galactic** Nuclei



Select **galaxies**

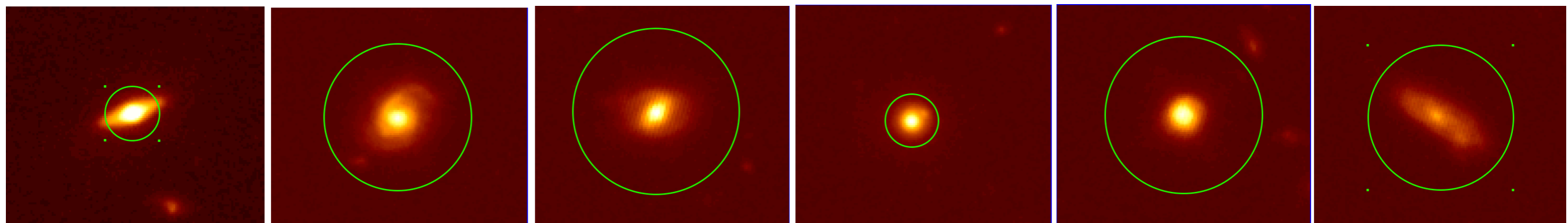
in a particular range of redshift, stellar mass etc.

e.g. Near-IR selected galaxies from the CANDELS/3DHST survey

- Highly complete!
- Allows for long-term AGN variability

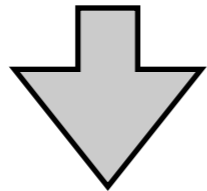
Assumptions/caveats:

- All **AGN** are in galaxies...
- AGN can only **add** light
- Restricted to AGN in a particular sample of galaxies



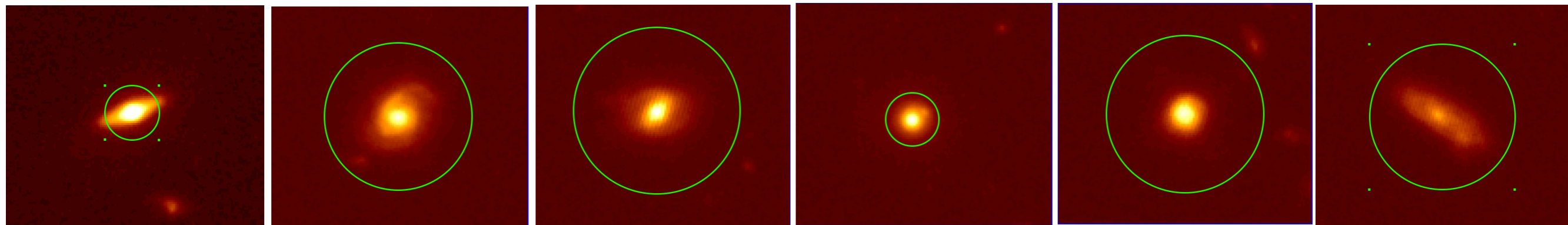
Elusive

Active **Galactic** Nuclei

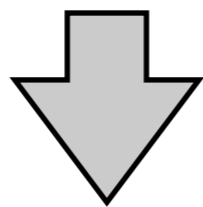


Select **galaxies**

in a particular range of
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e.g. Near-IR selected galaxies from the CANDELS/3DHST survey

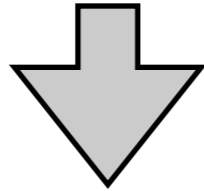


Characterize the AGN

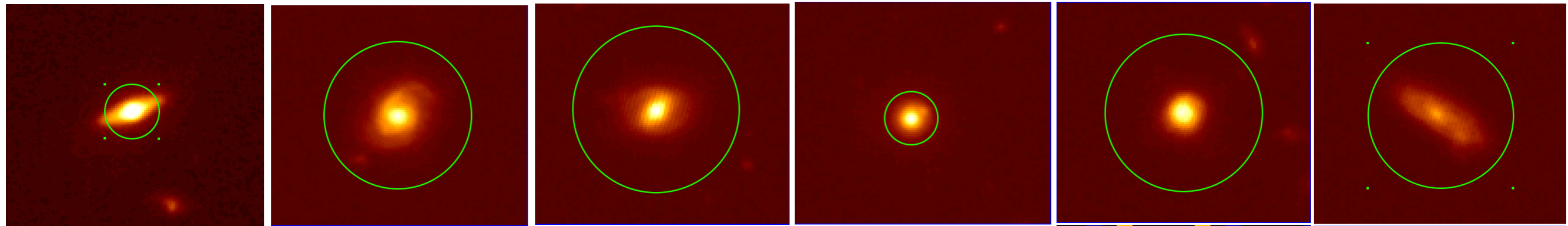
- luminosities/accretion rates
- fraction of galaxies where the central black hole is growing *at given accretion rate*

Elusive

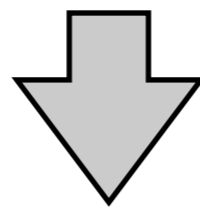
Active **Galactic** Nuclei



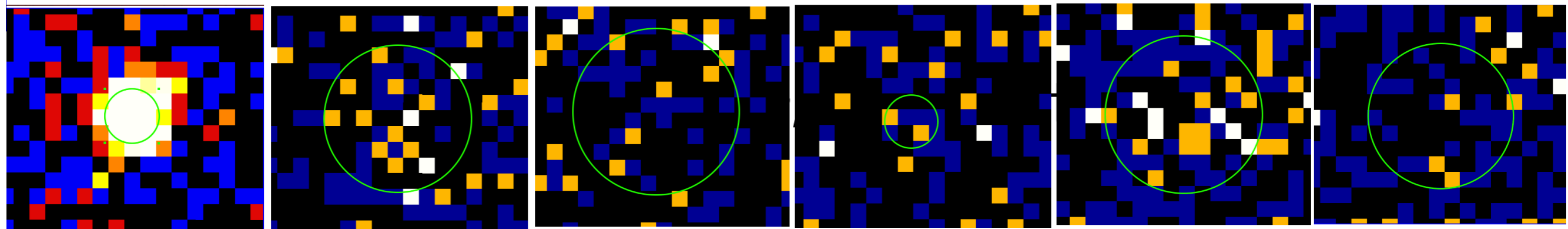
Select **galaxies**
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e.g. Near-IR selected galaxies from the CANDELS/3DHST survey



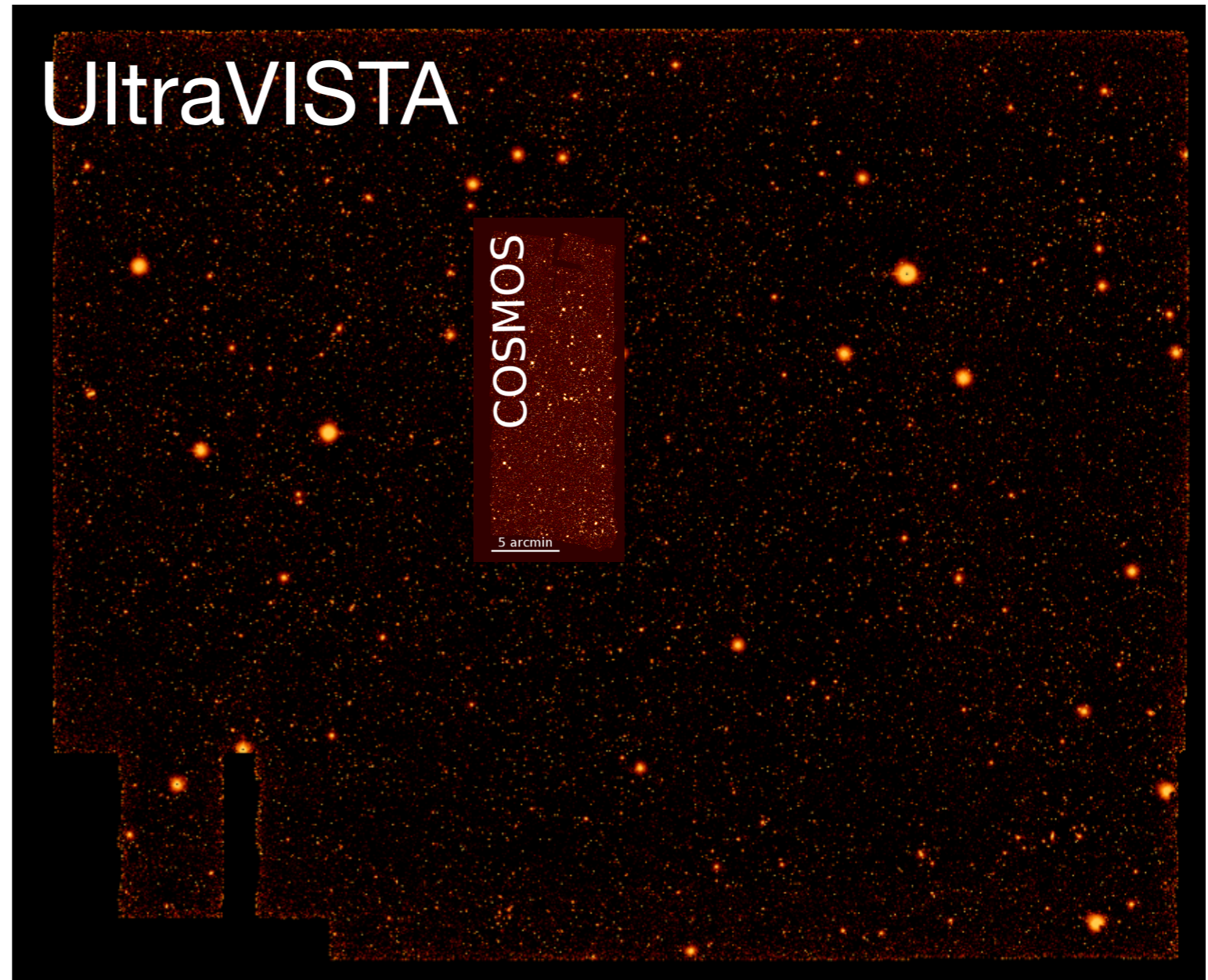
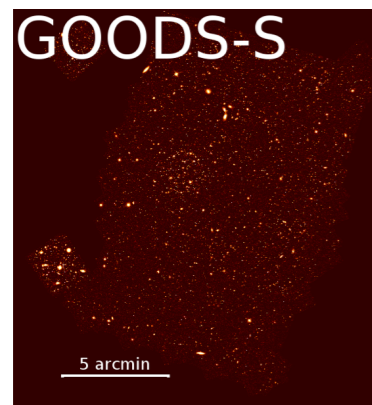
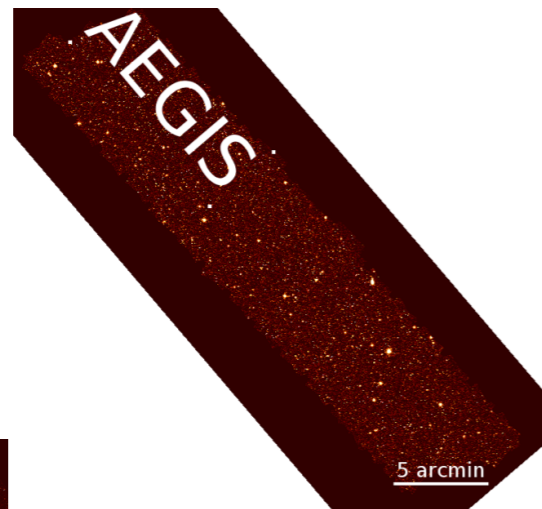
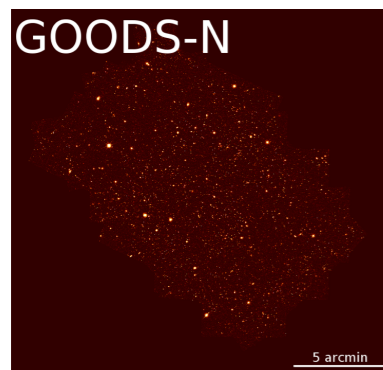
Characterize the AGN



e.g. deep Chandra X-ray imaging (2-7keV)

Starting point:
Select galaxies from deep **near-infrared** imaging

Aird+2017b, arXiv:1705.01132



CANDELS/3DHST
fields

(ultradeep WFC3 *H*-band
imaging)

+ UltraVISTA (deep K_S -band imaging over $\sim 1.6 \text{ deg}^2$)

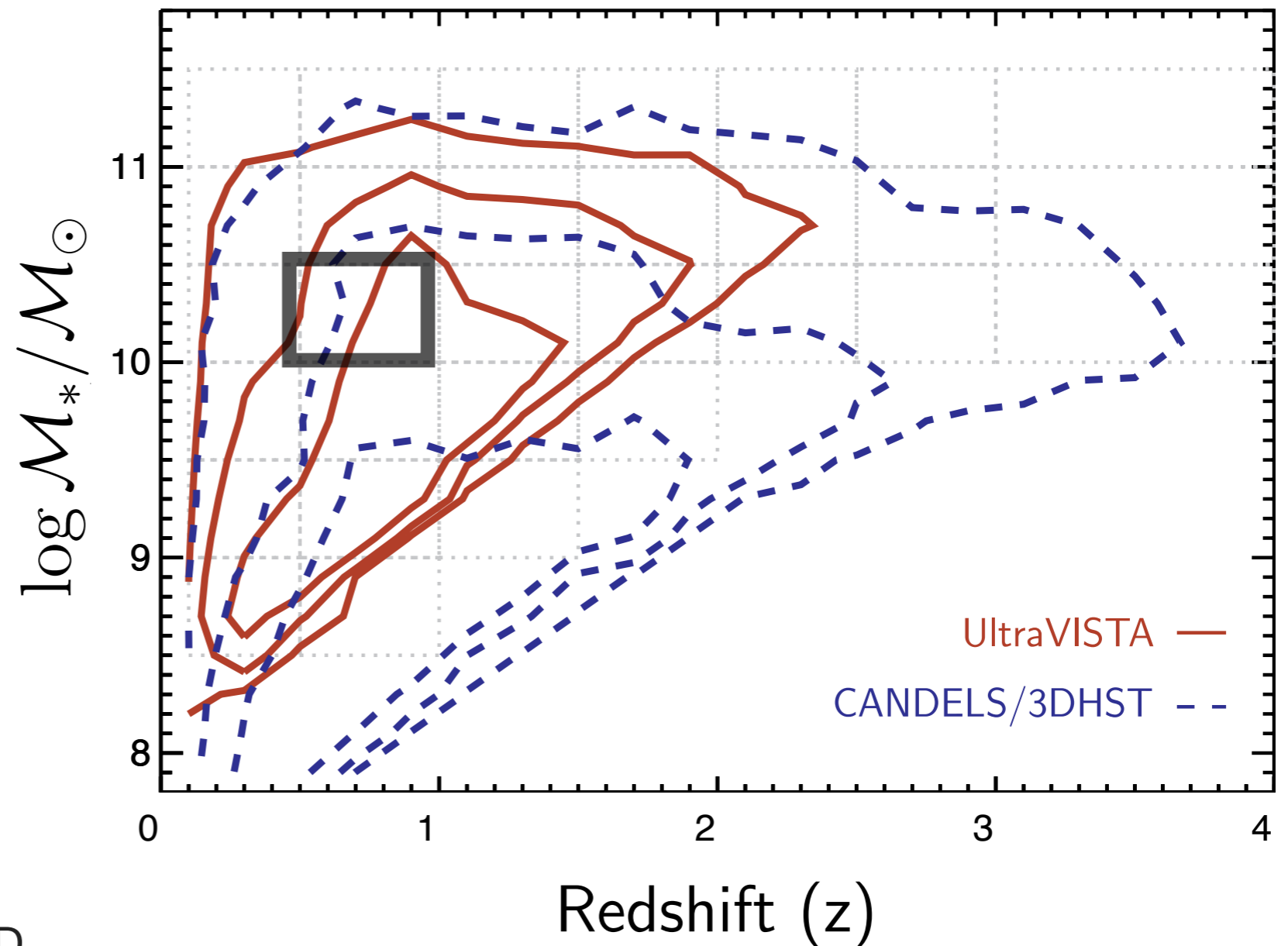
Starting point: Select galaxies from deep **near-infrared** imaging

Aird+2017b, arXiv:1705.01132

Identify $\sim 120,000$
galaxies out to $z \sim 4$

Select complete
samples of galaxies
for a given range in
stellar mass and
redshift

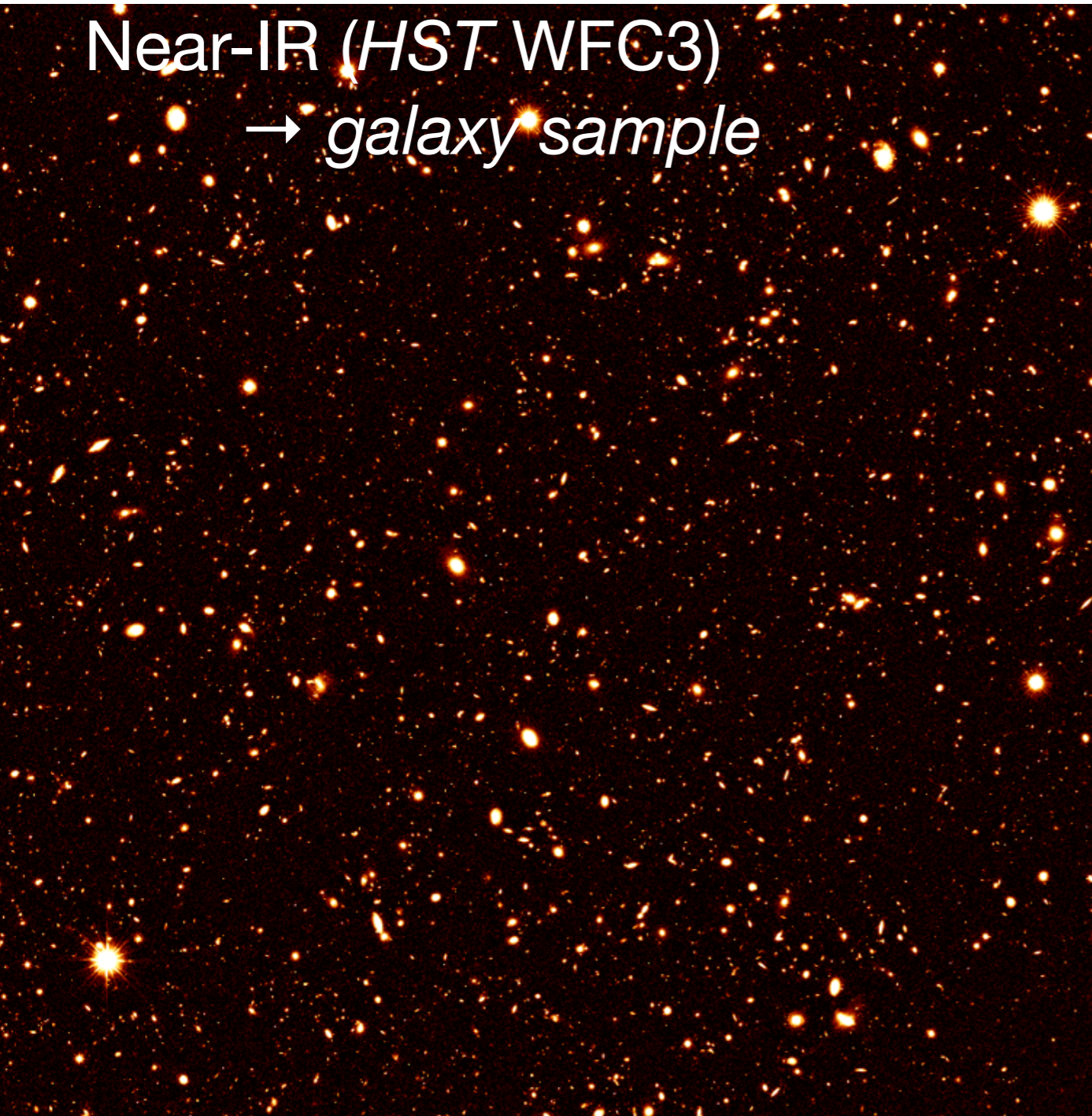
- Stellar masses from SED fitting of UV-optical-NIR SED (FAST: Kriek et al. 2009)



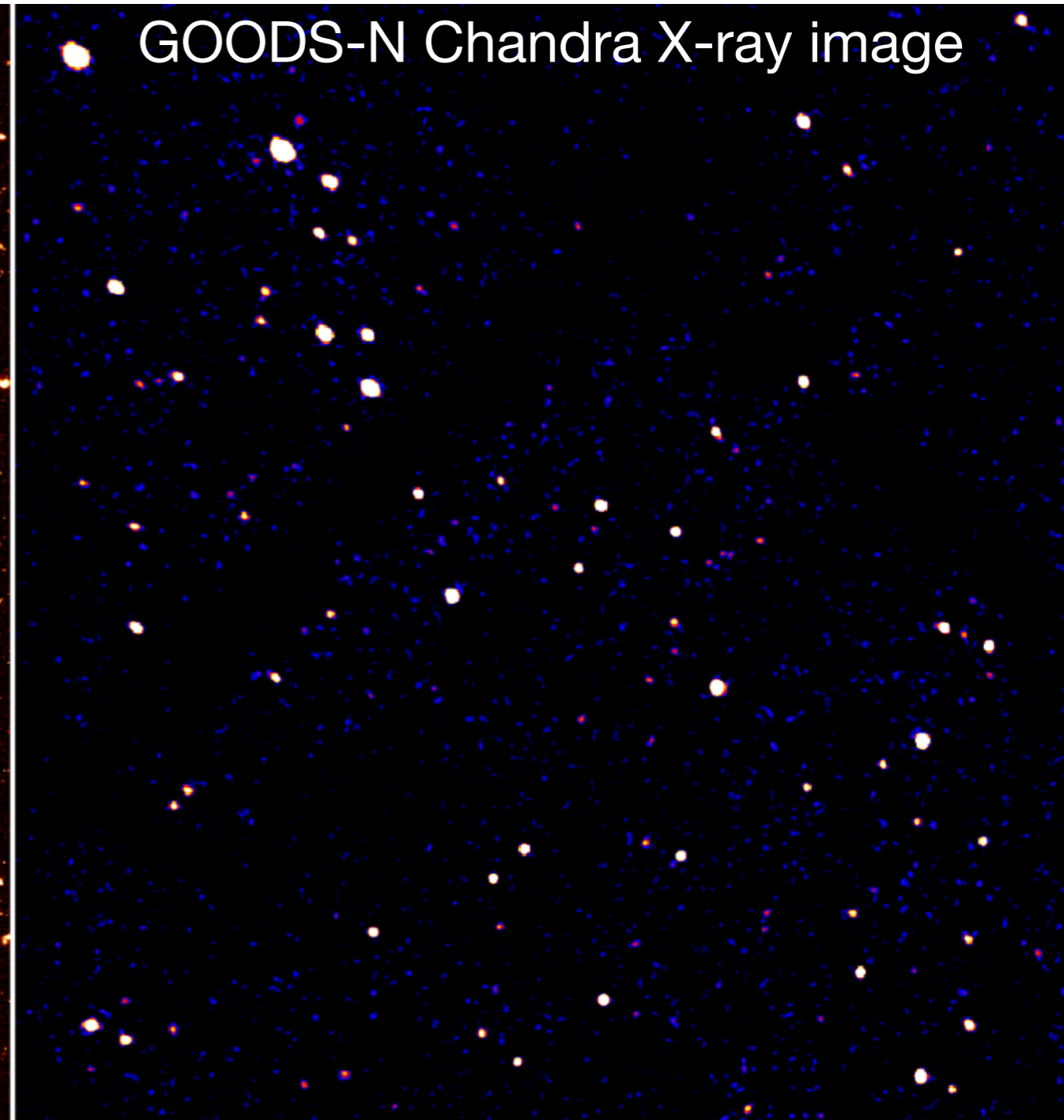
Extract Chandra X-ray data at the position
of *every* galaxy (CDFFS-4Ms, CDFN-2Ms, AEGIS 800ks, COSMOS 160ks)

Aird+2017b, arXiv:1705.01132

Near-IR (*HST* WFC3)
→ *galaxy sample*

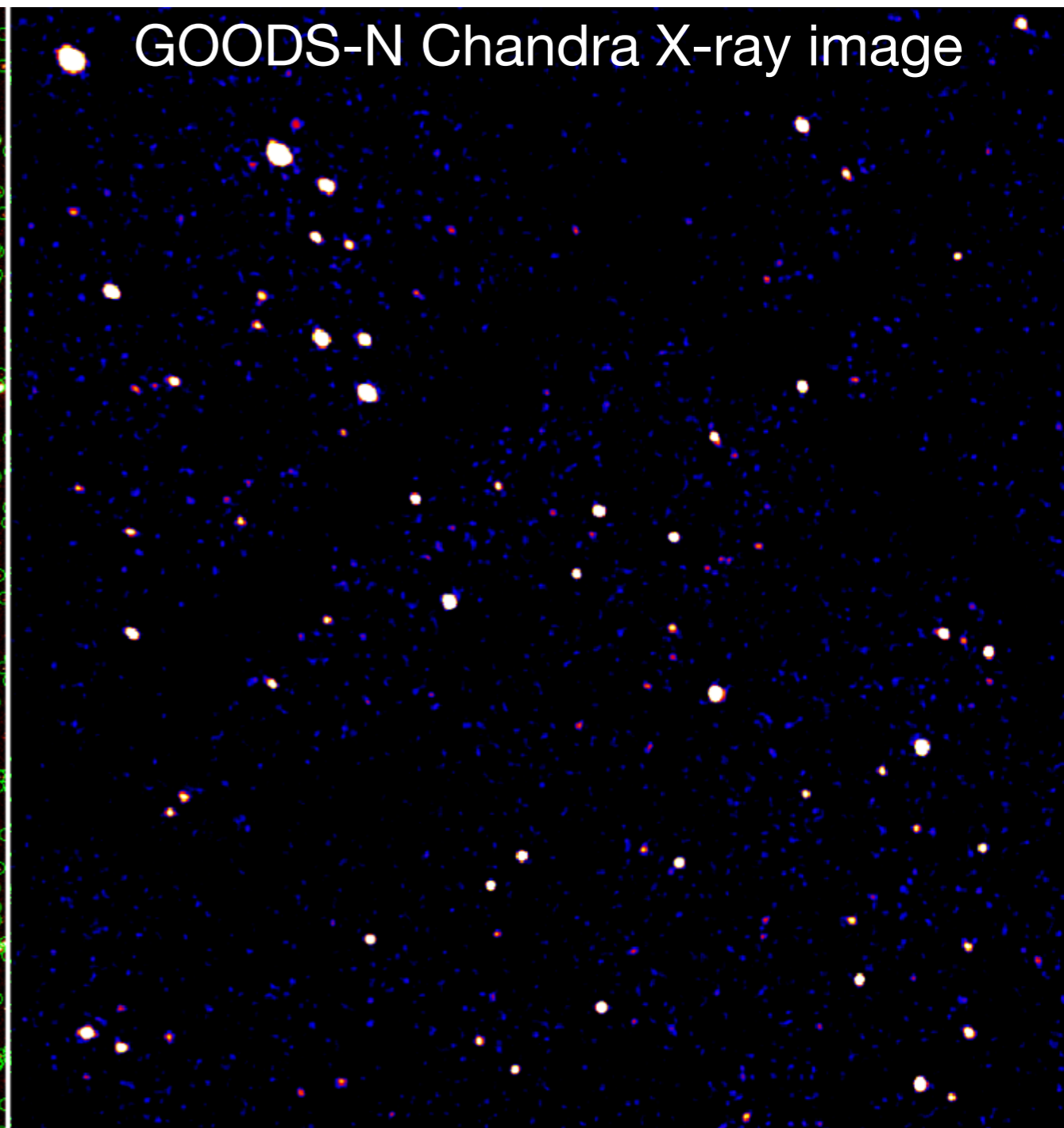
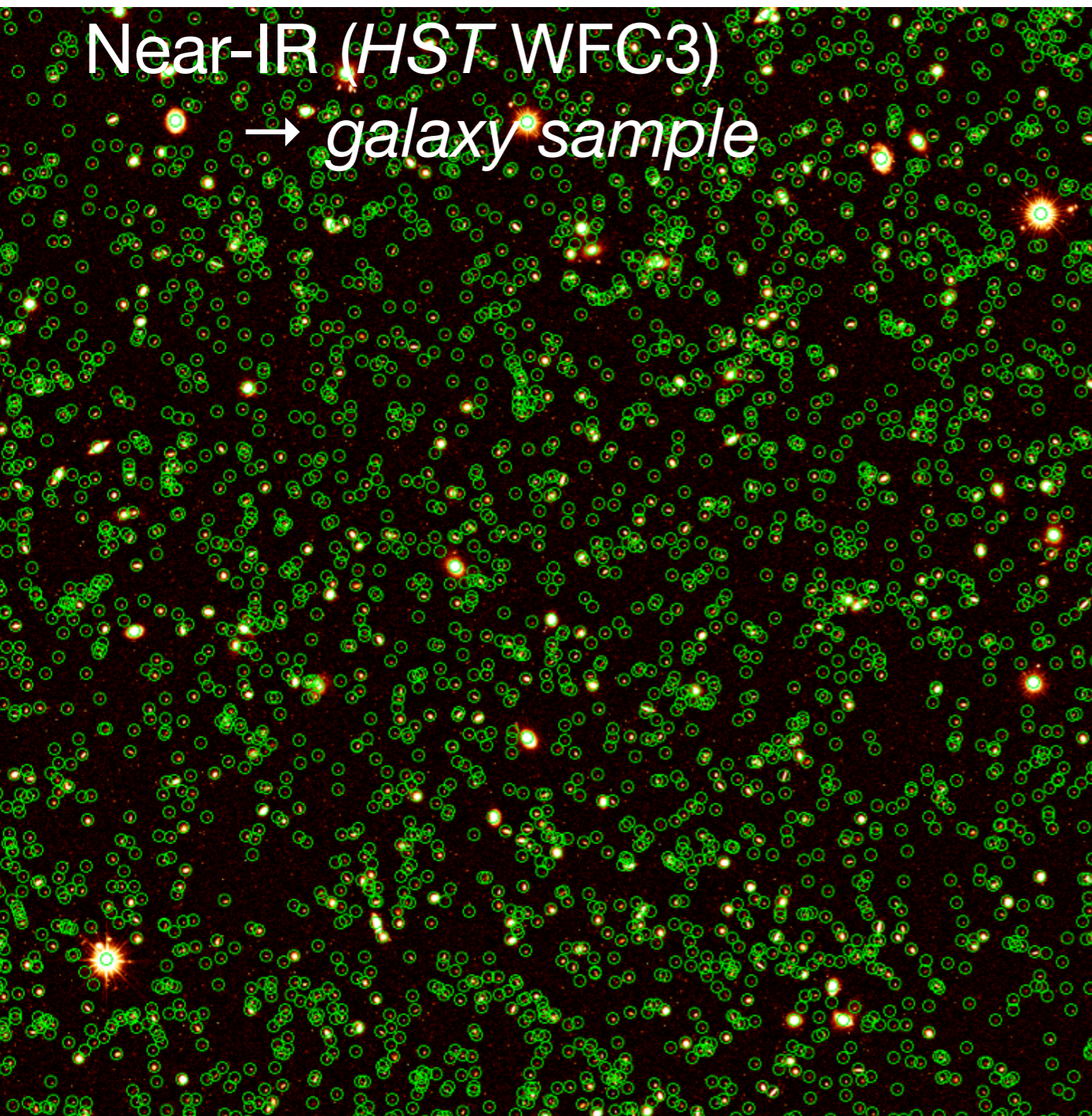


GOODS-N Chandra X-ray image



Extract Chandra X-ray data at the position
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Aird+2017b, arXiv:1705.01132

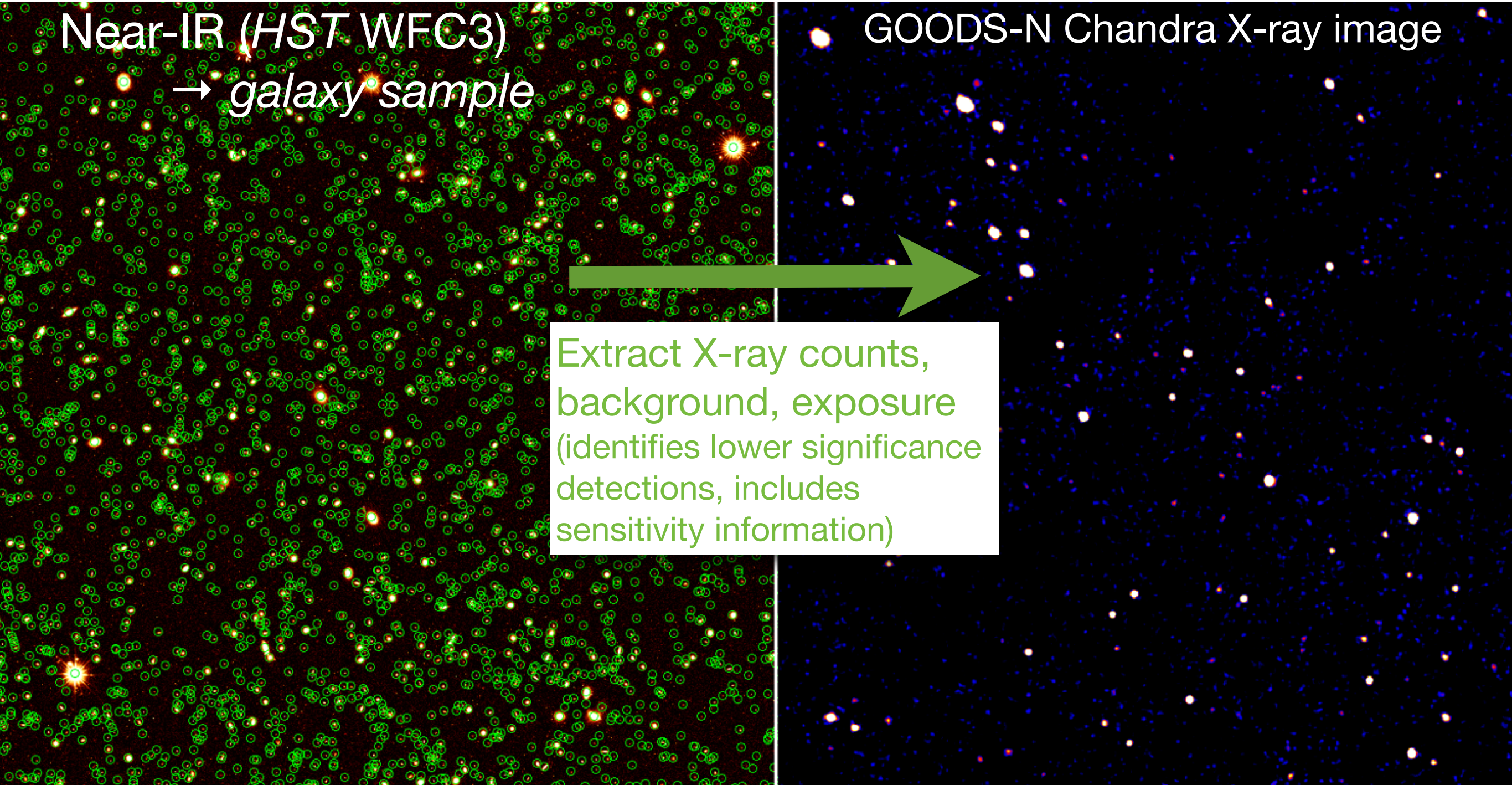


Extract Chandra X-ray data at the position of *every* galaxy (CDFFS-4Ms, CDFN-2Ms, AEGIS 800ks, COSMOS 160ks)

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Near-IR (HST WFC3)
→ galaxy sample

GOODS-N Chandra X-ray image



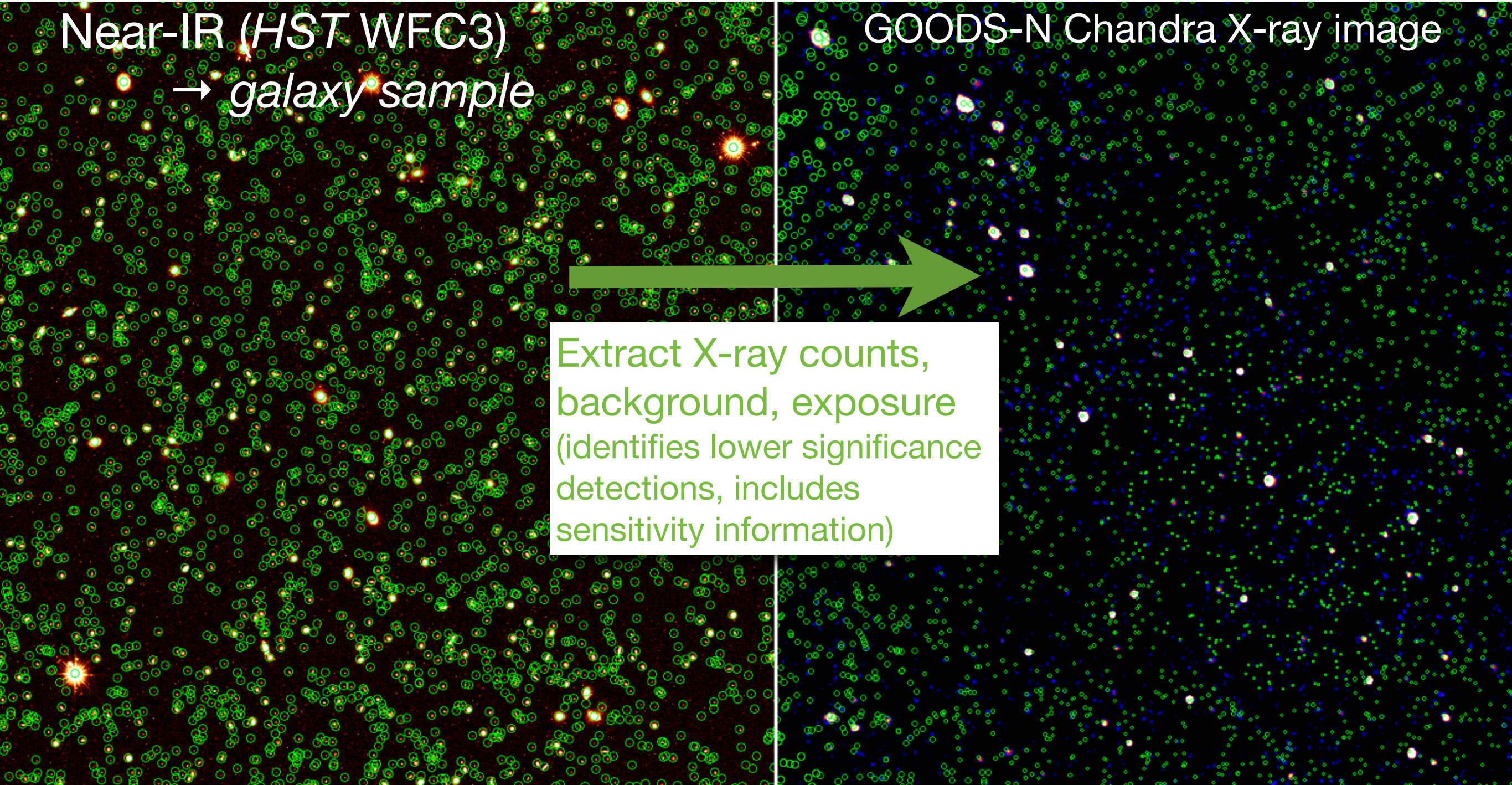
Extract X-ray counts,
background, exposure
(identifies lower significance
detections, includes
sensitivity information)

Extract Chandra X-ray data at the position of *every* galaxy (CDFFS-4Ms, CDFN-2Ms, AEGIS 800ks, COSMOS 160ks)

Aird+2017b, arXiv:1705.01132

Near-IR (HST WFC3)
→ *galaxy sample*

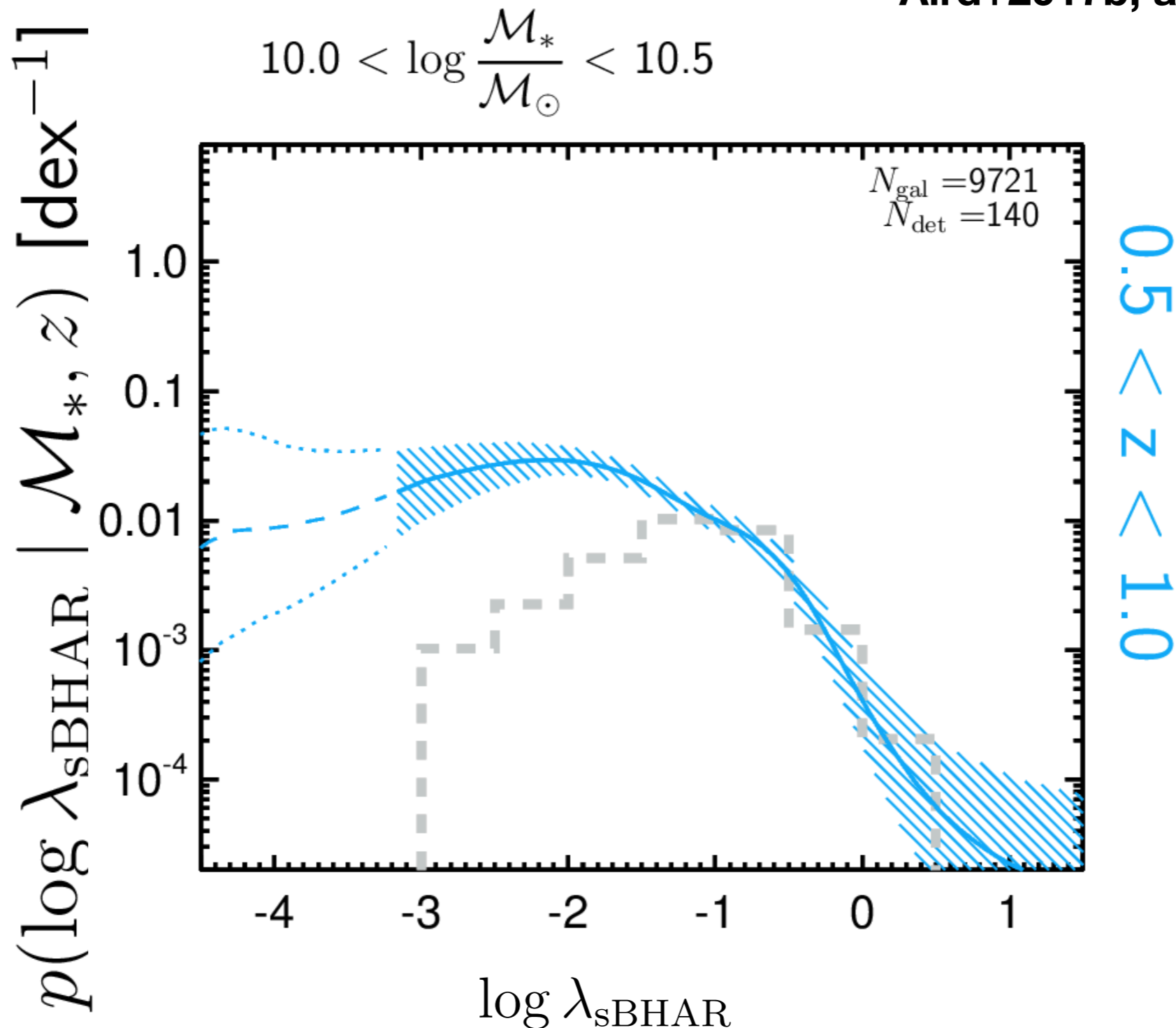
GOODS-N Chandra X-ray image



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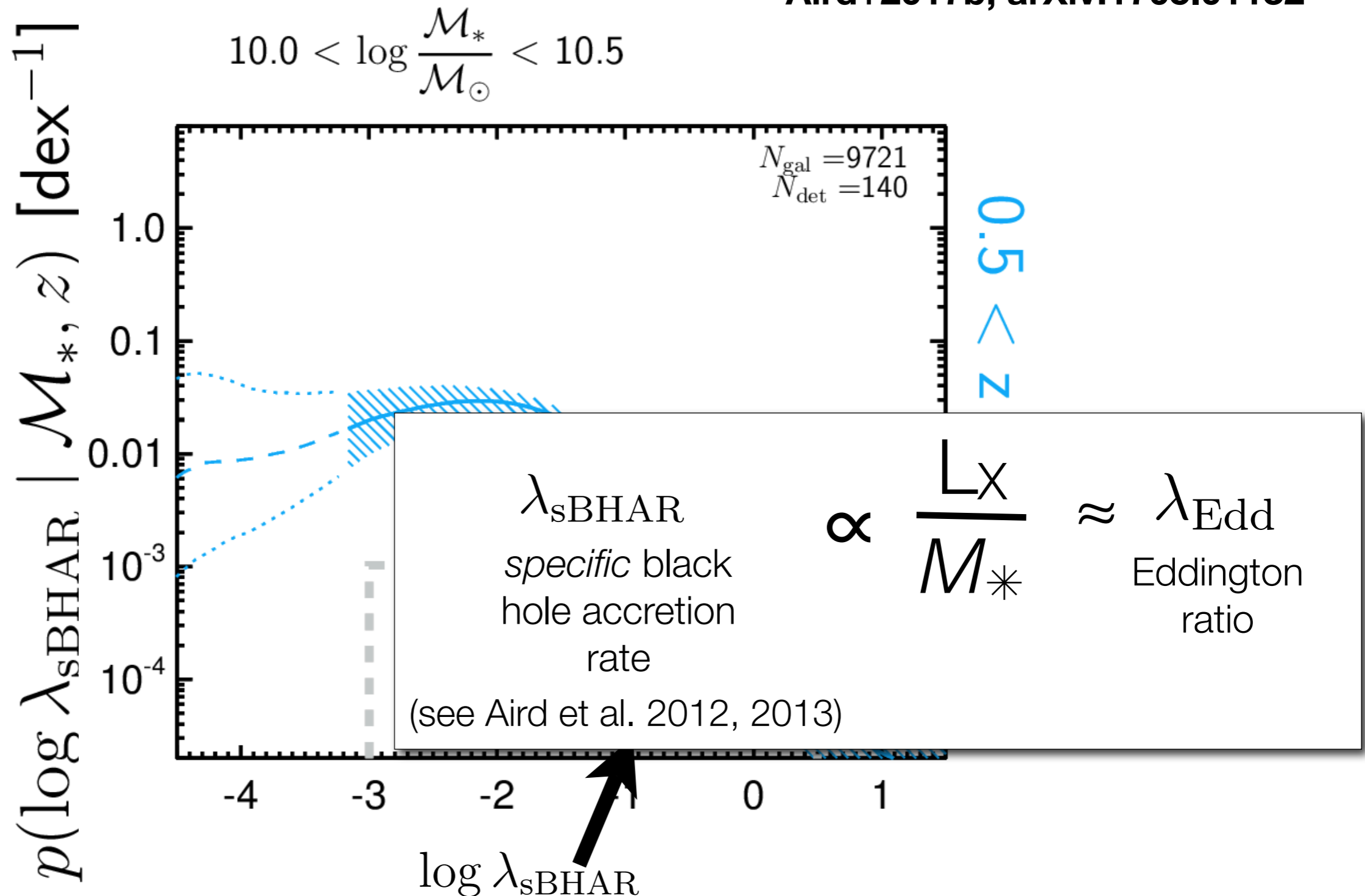
The probability distribution of **specific Black Hole Accretion Rates**

Aird+2017b, arXiv:1705.01132



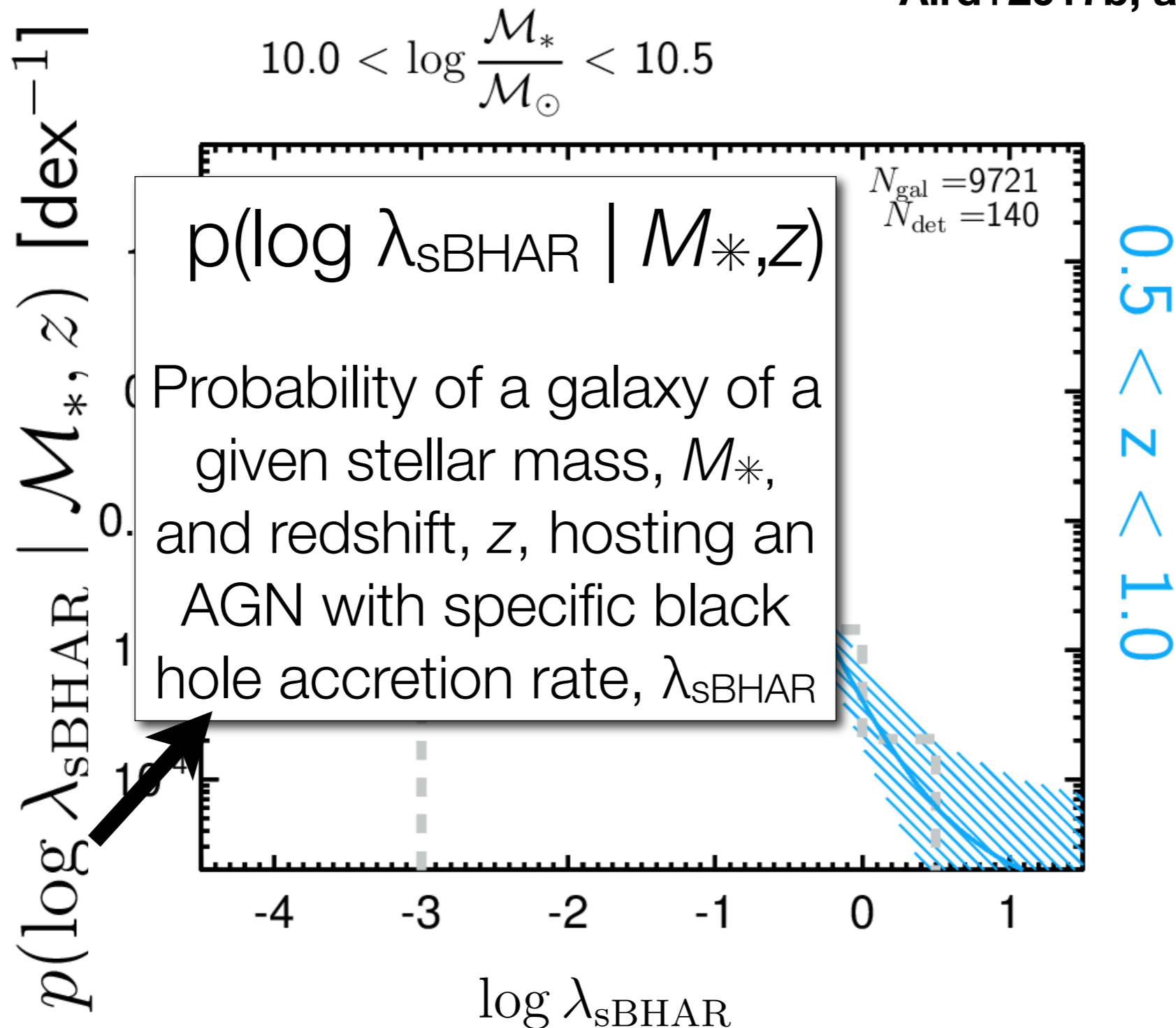
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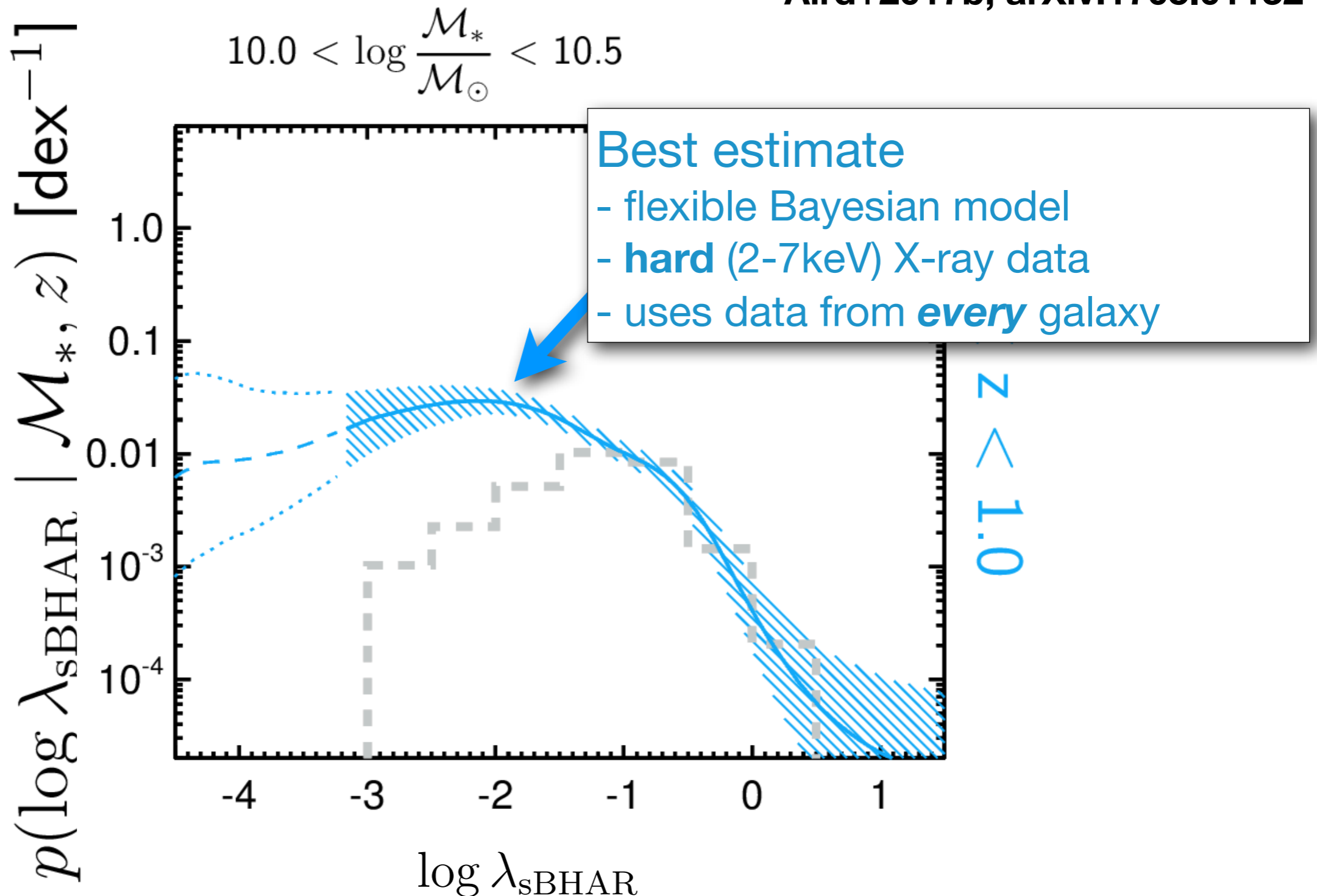
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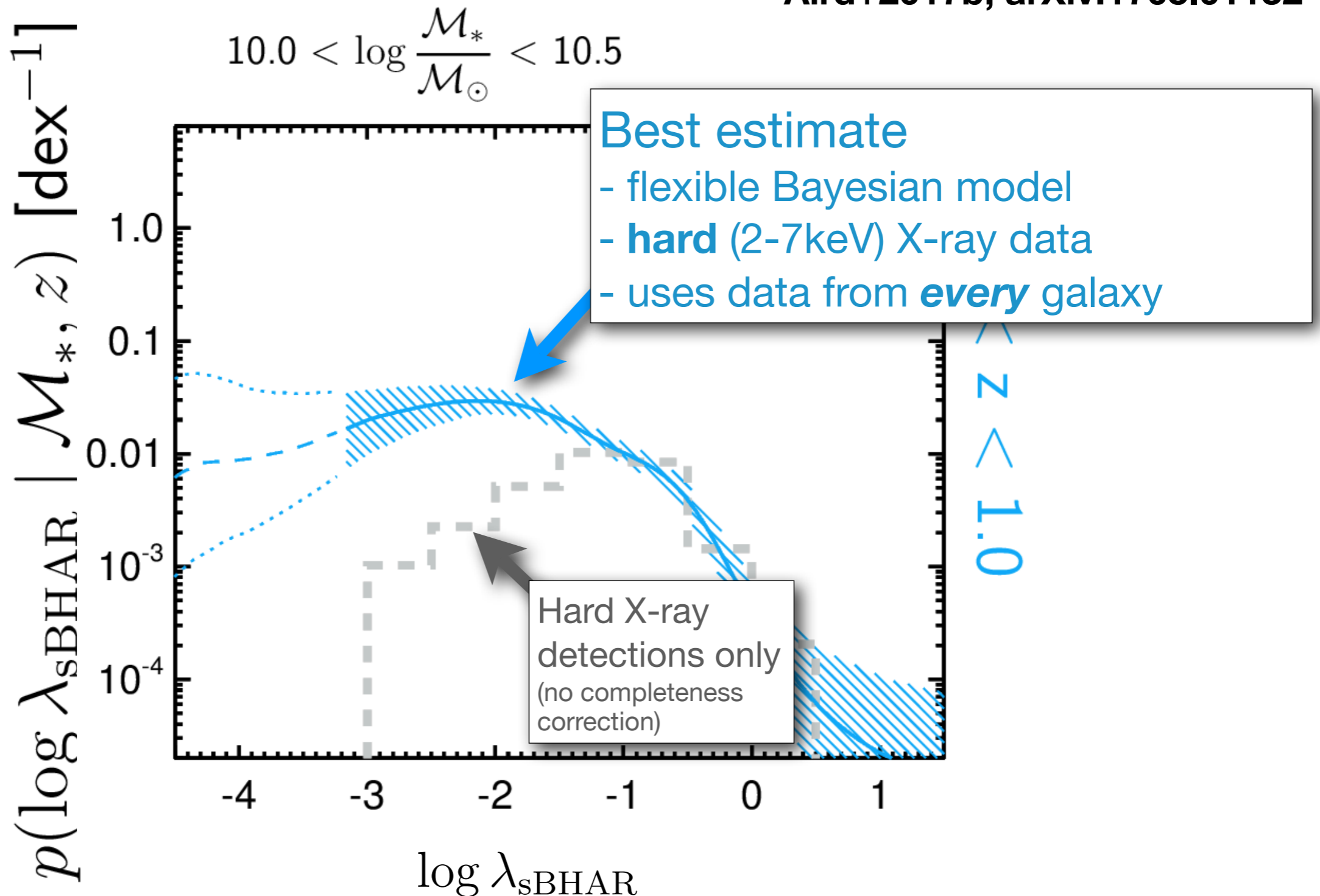
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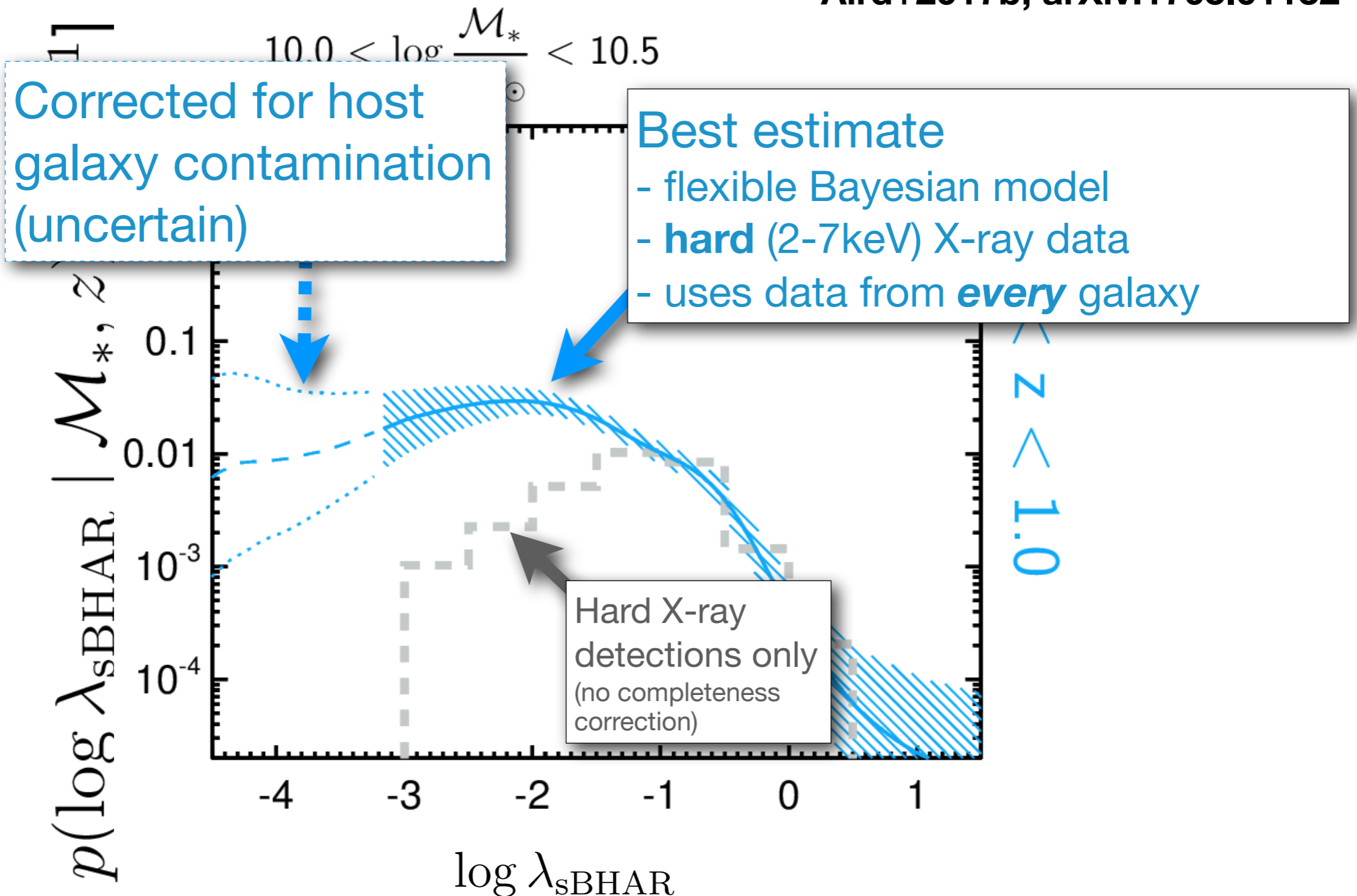
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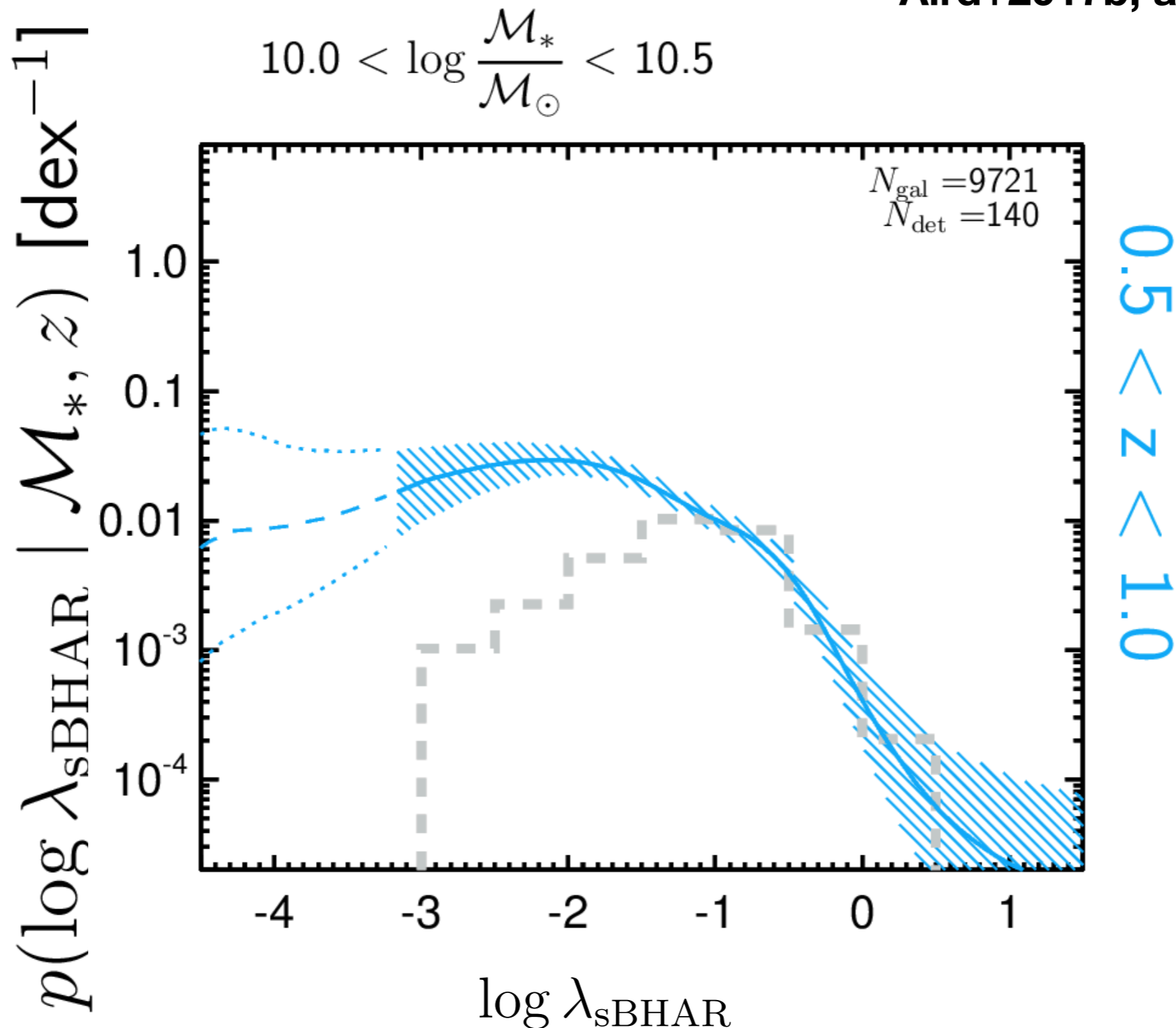
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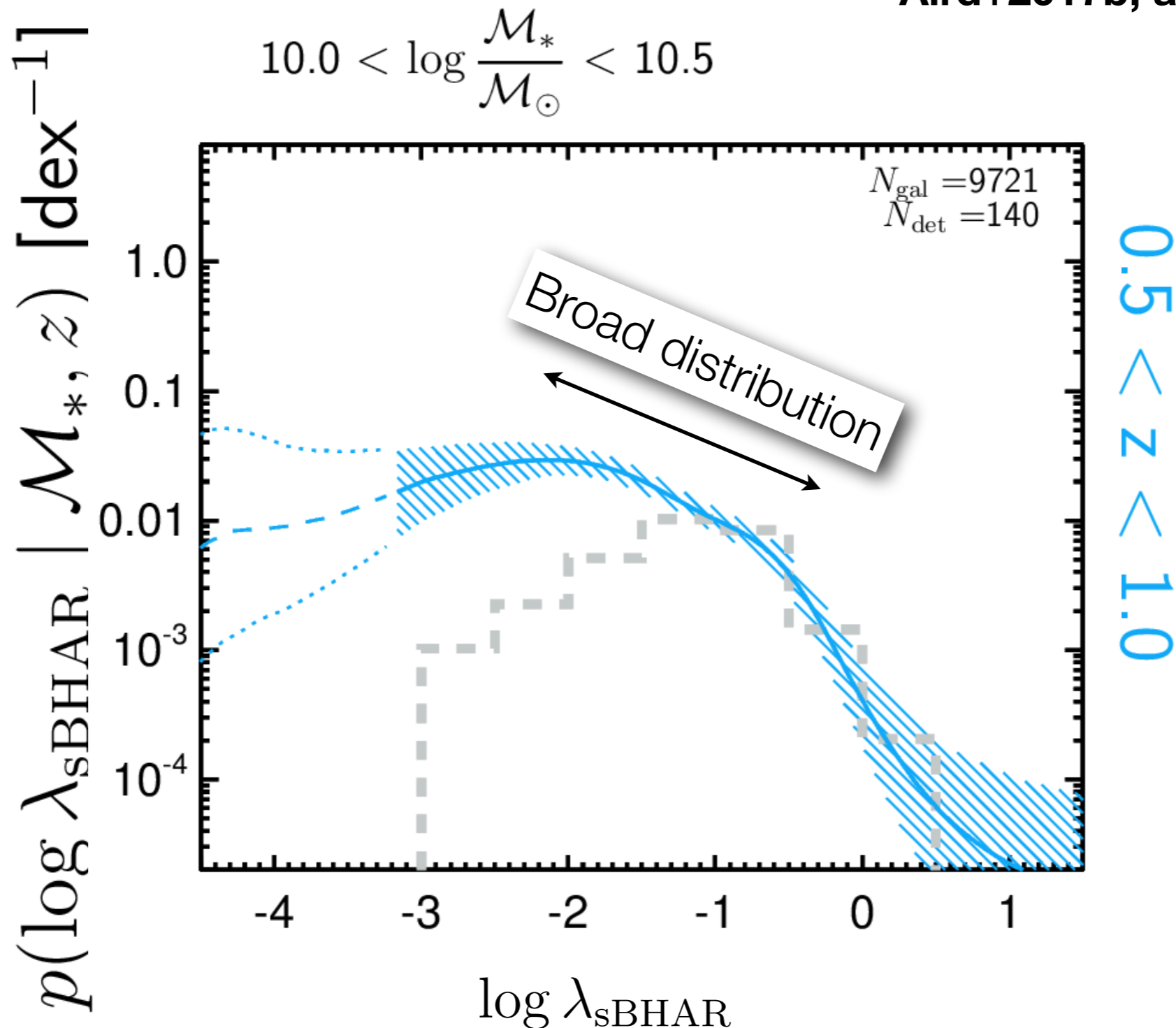
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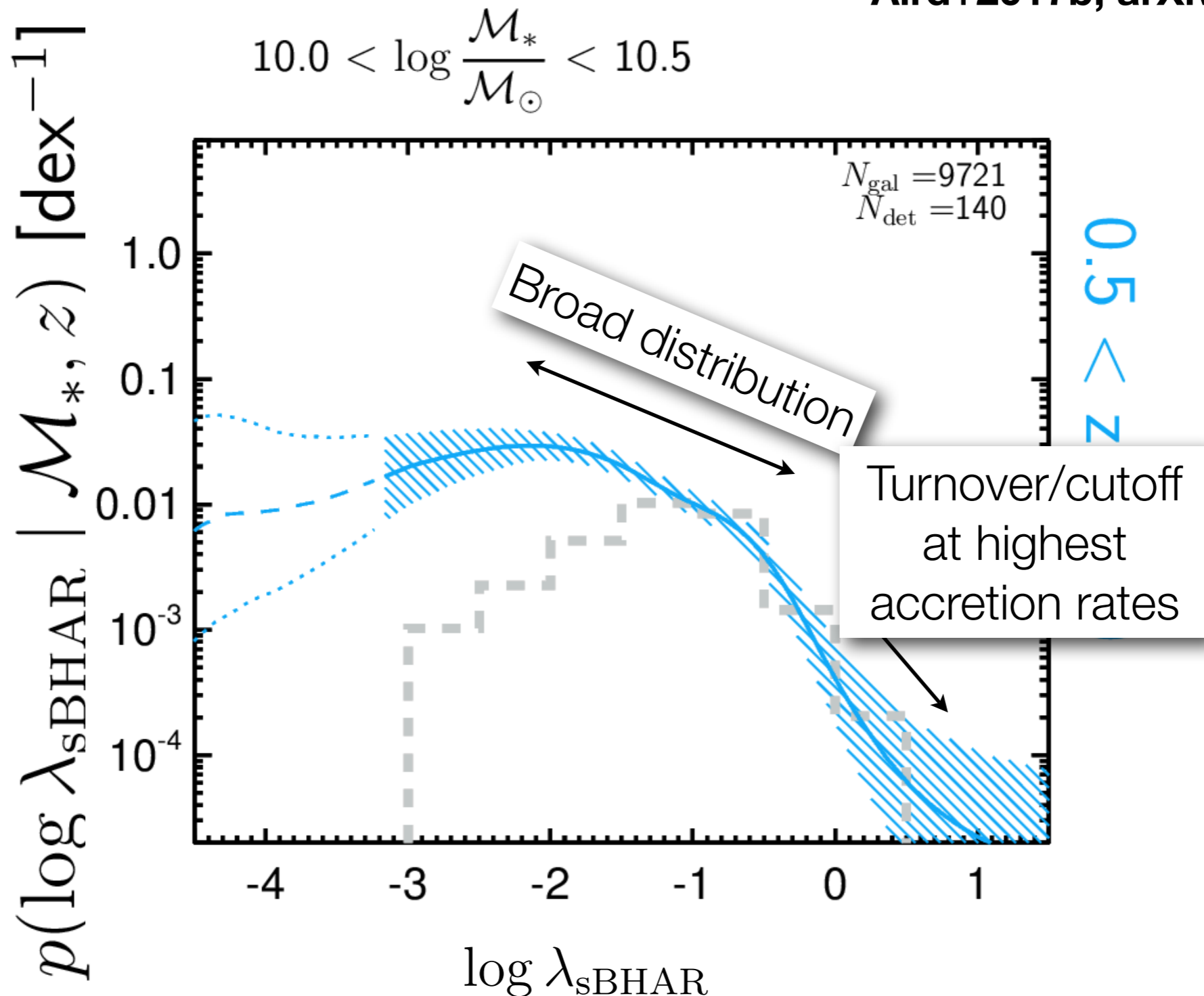
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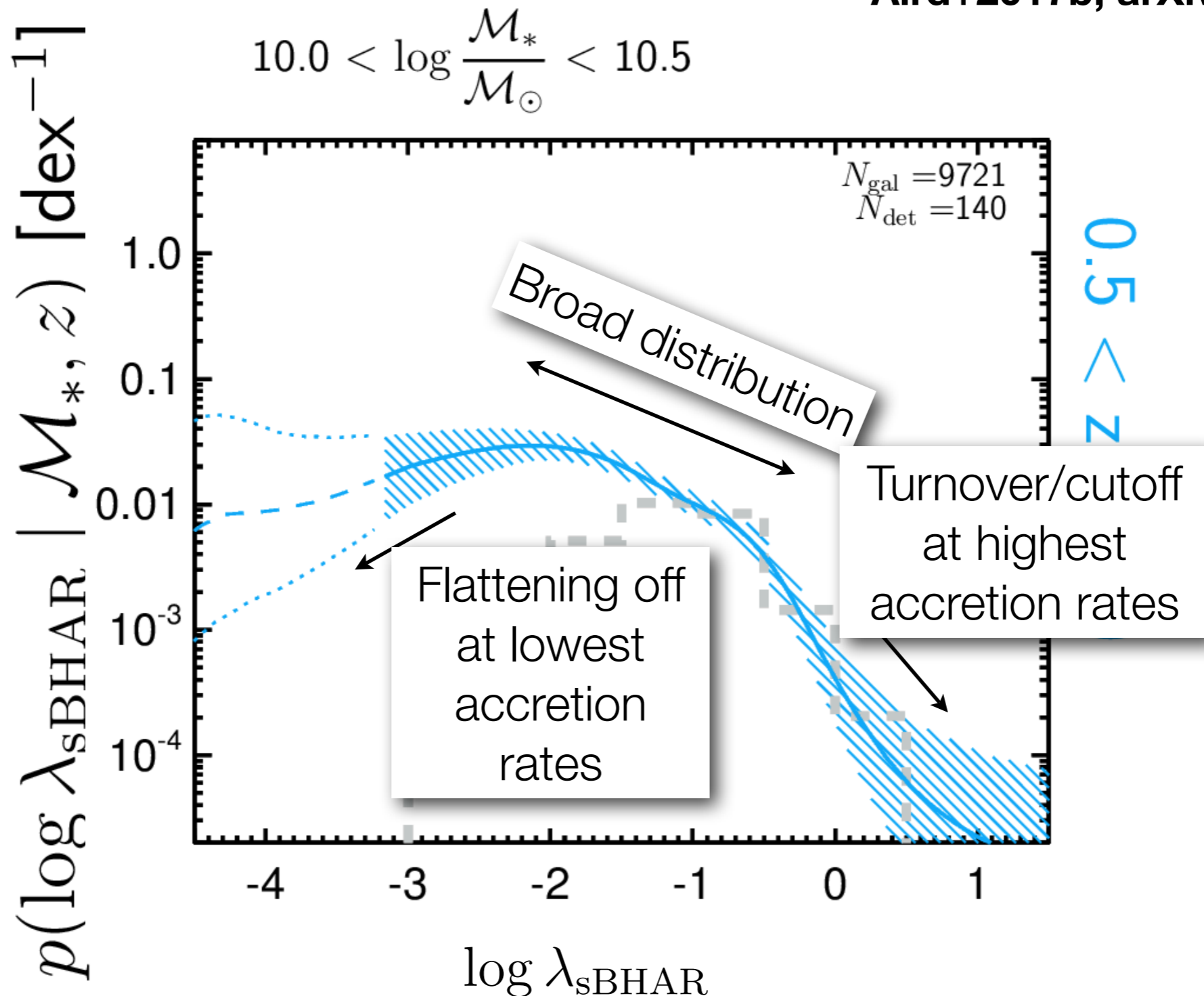
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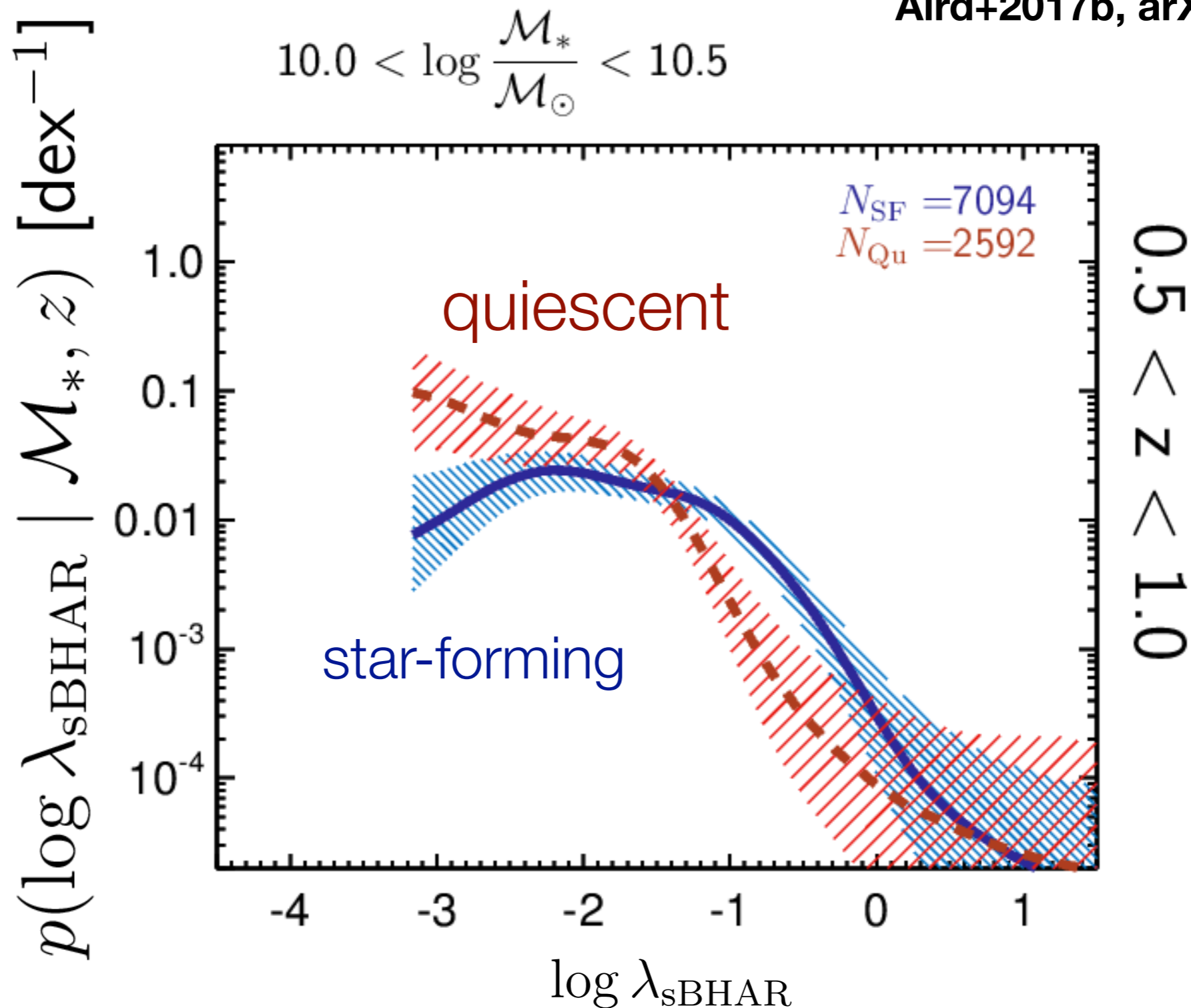
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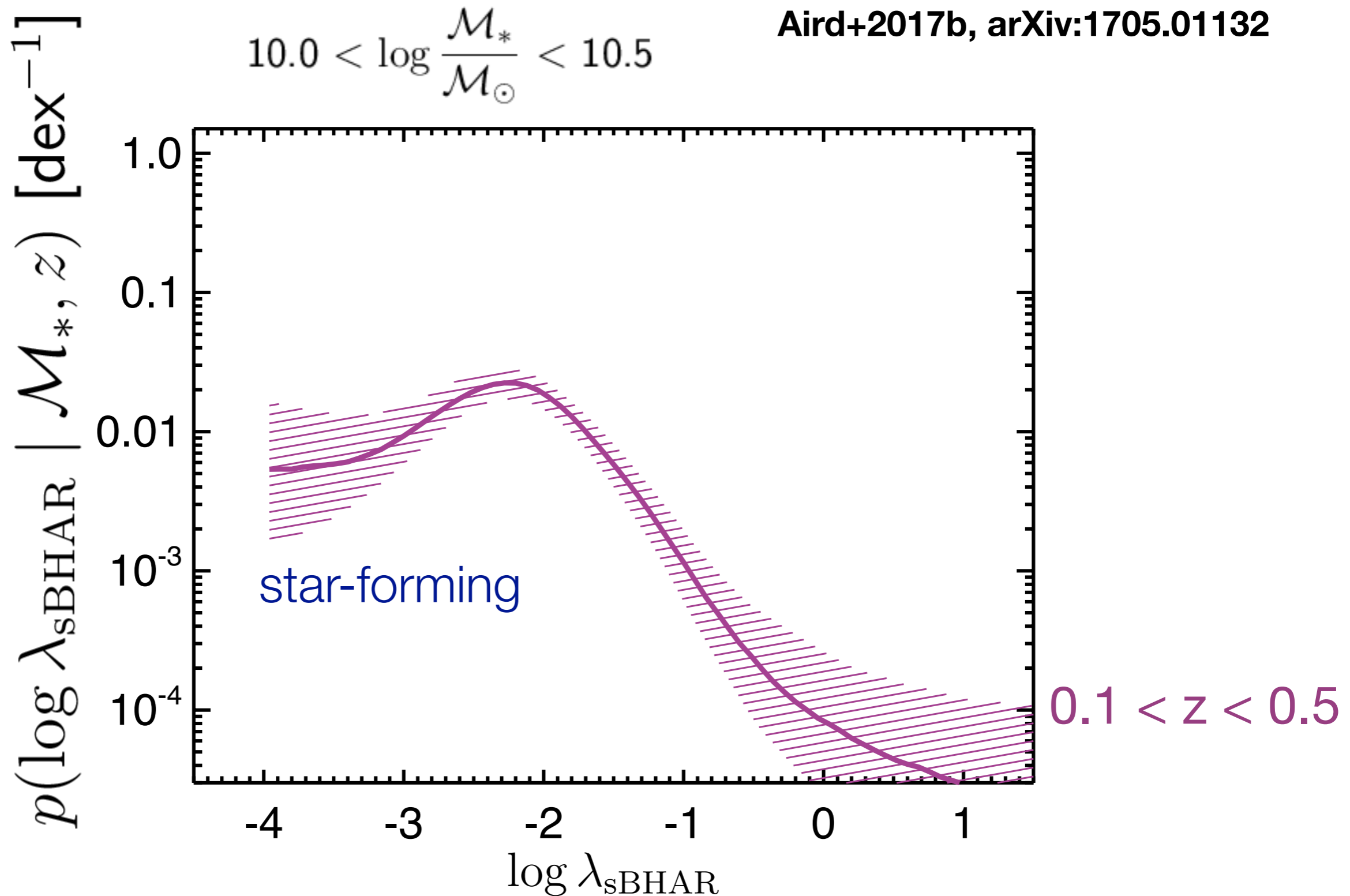


Distributions of sBHAR in **star-forming** vs. **quiescent** galaxies

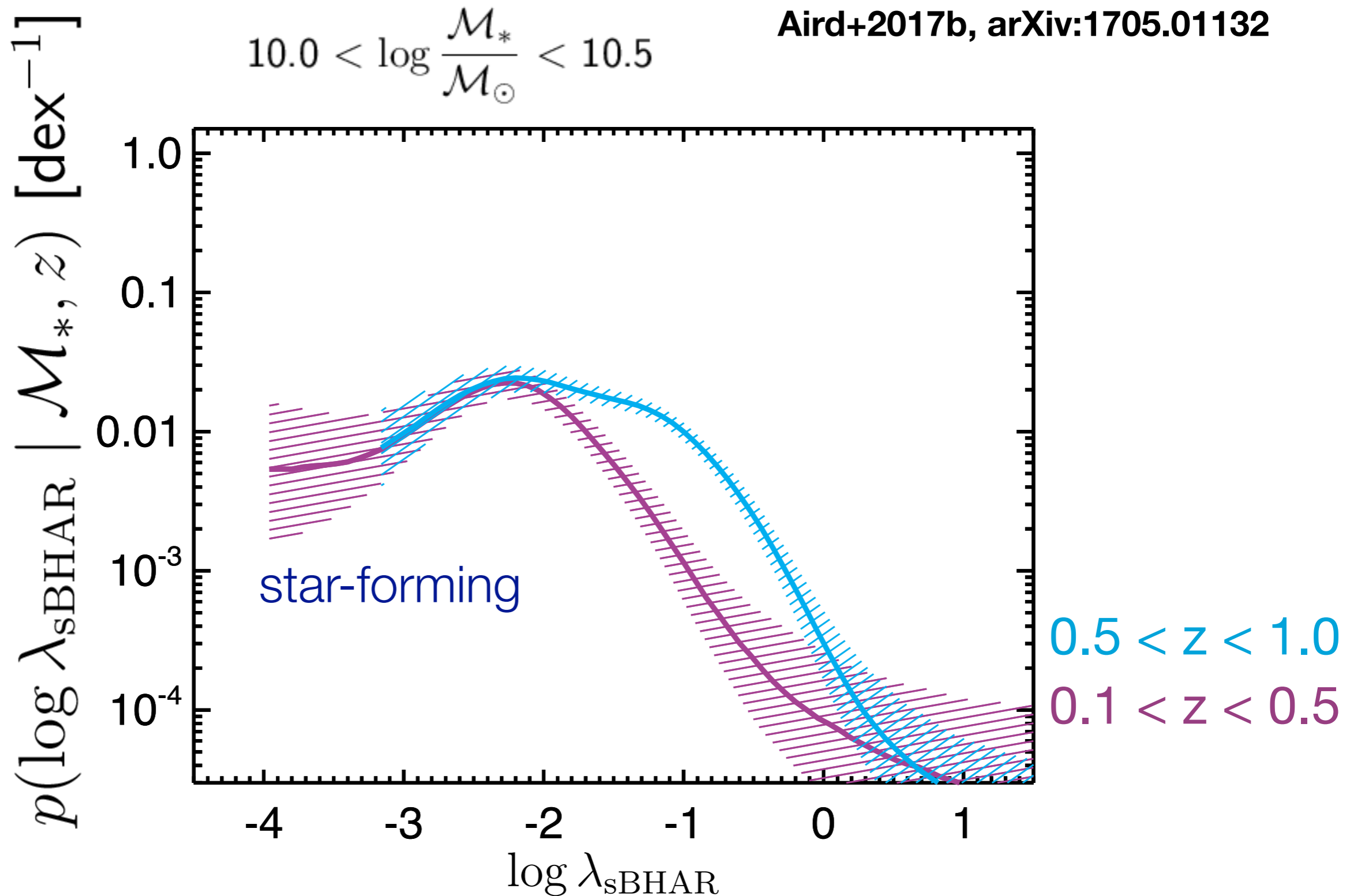
Aird+2017b, arXiv:1705.01132



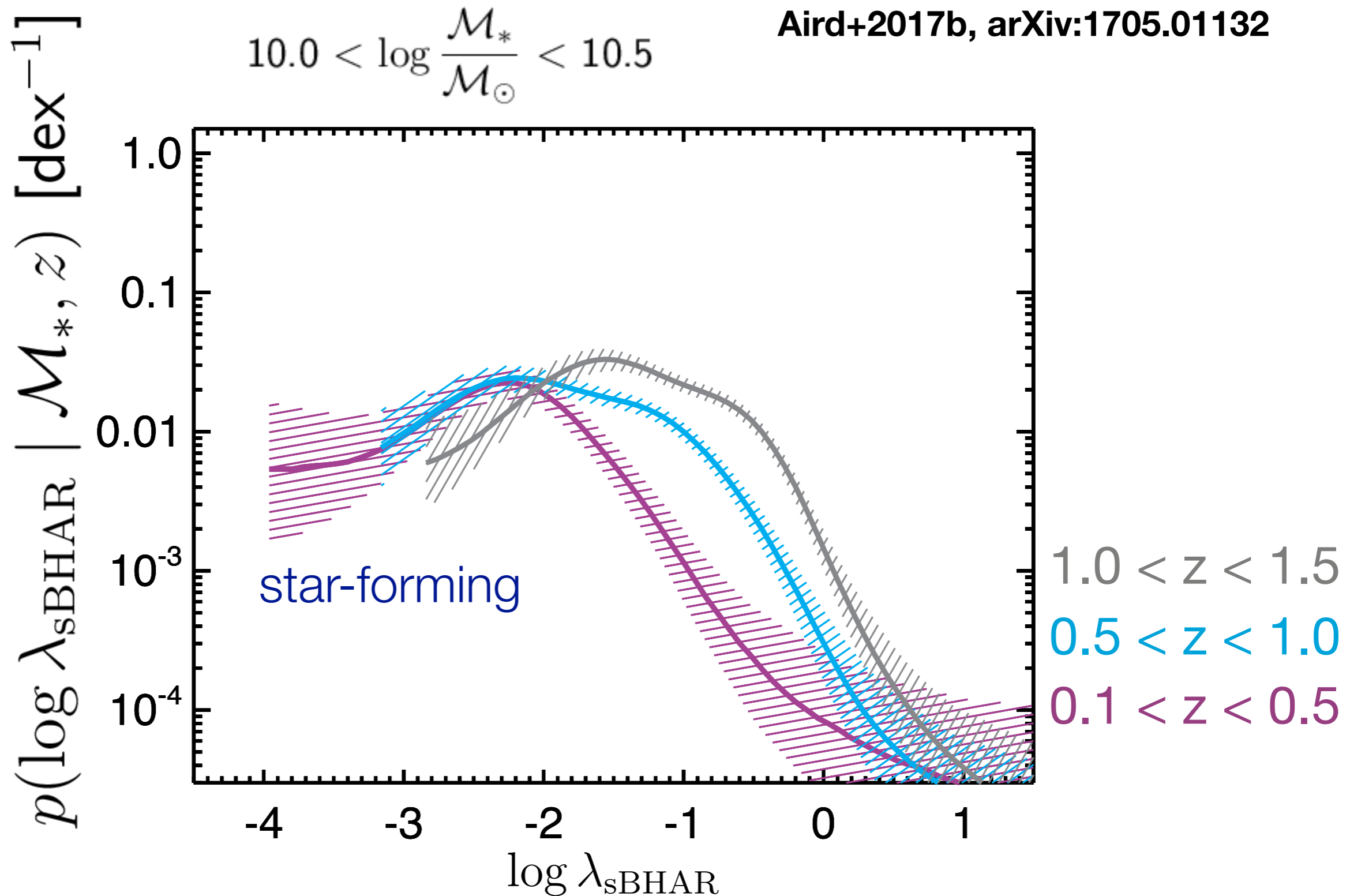
Distributions of sBHAR in **star-forming** galaxies as a function of **redshift**



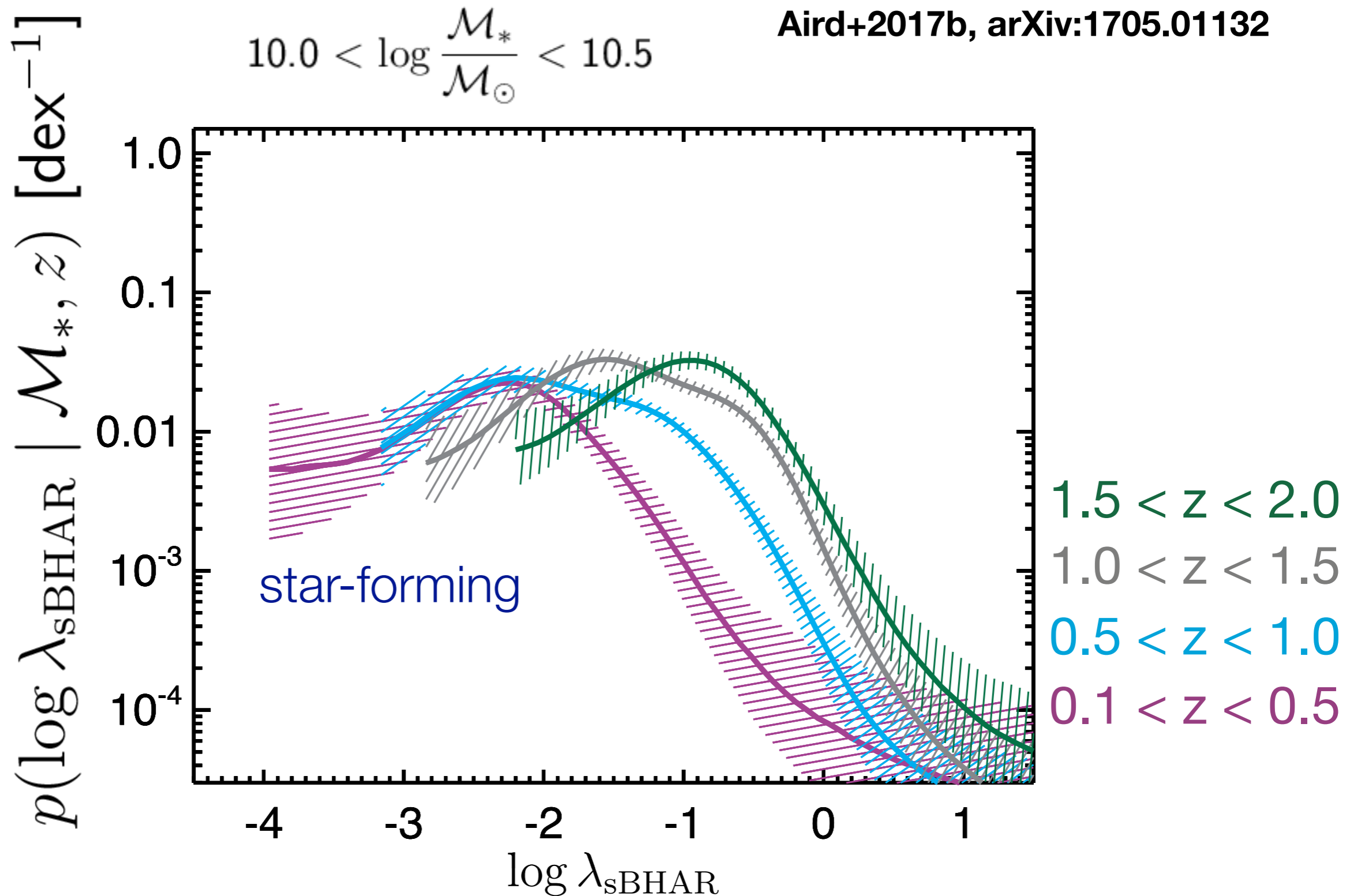
Distributions of sBHAR in **star-forming** galaxies as a function of **redshift**



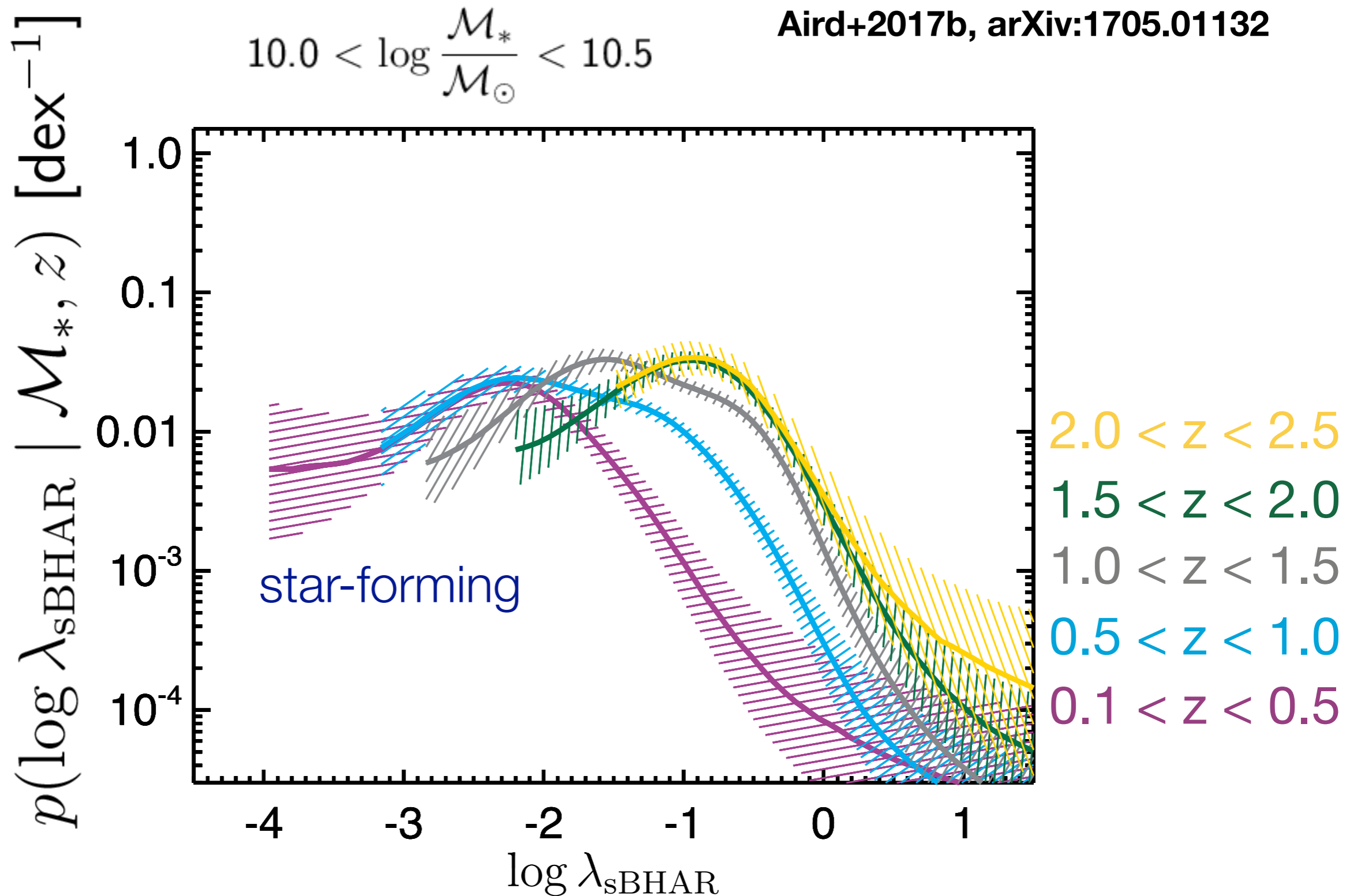
Distributions of sBHAR in **star-forming** galaxies as a function of **redshift**



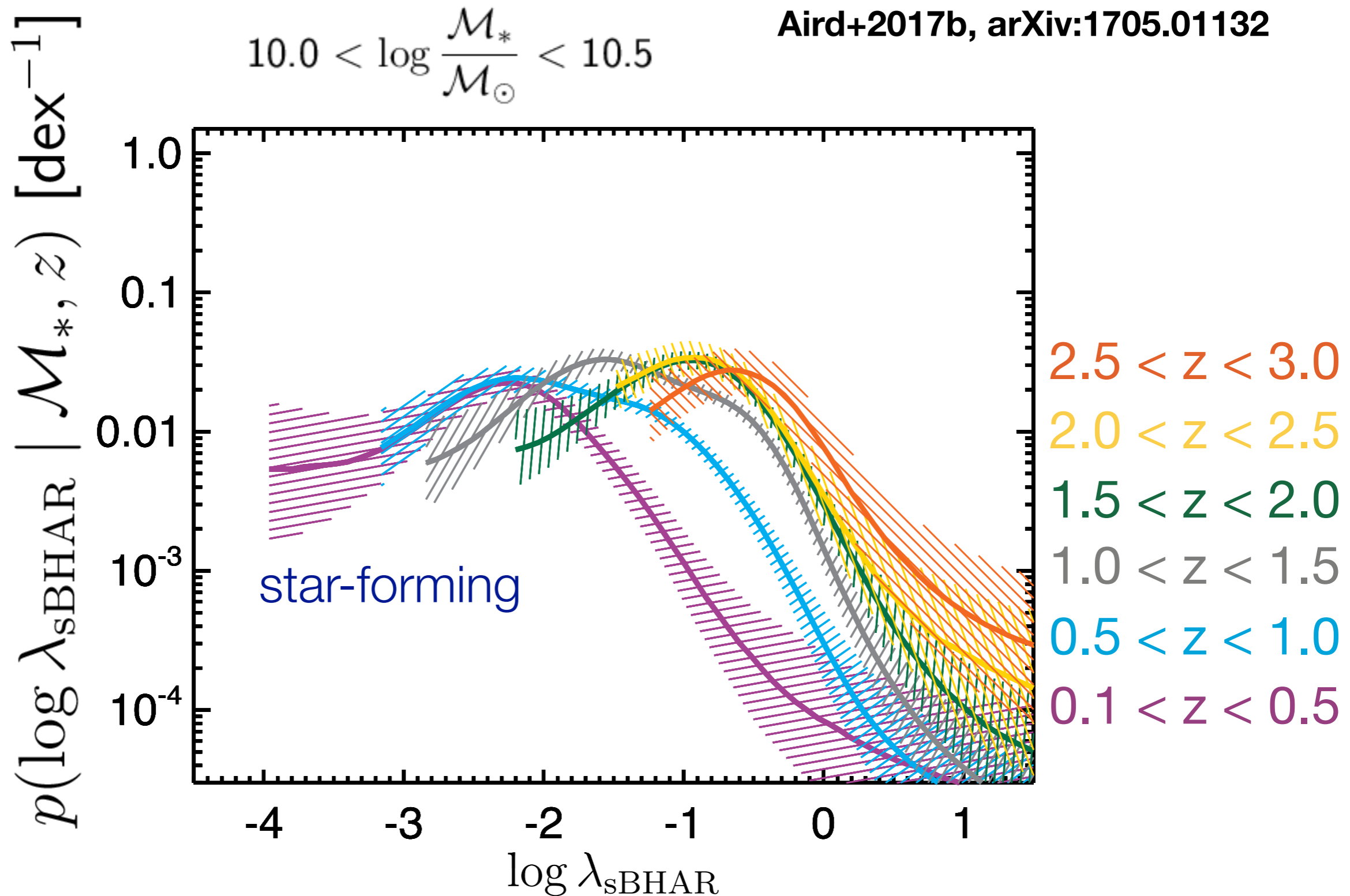
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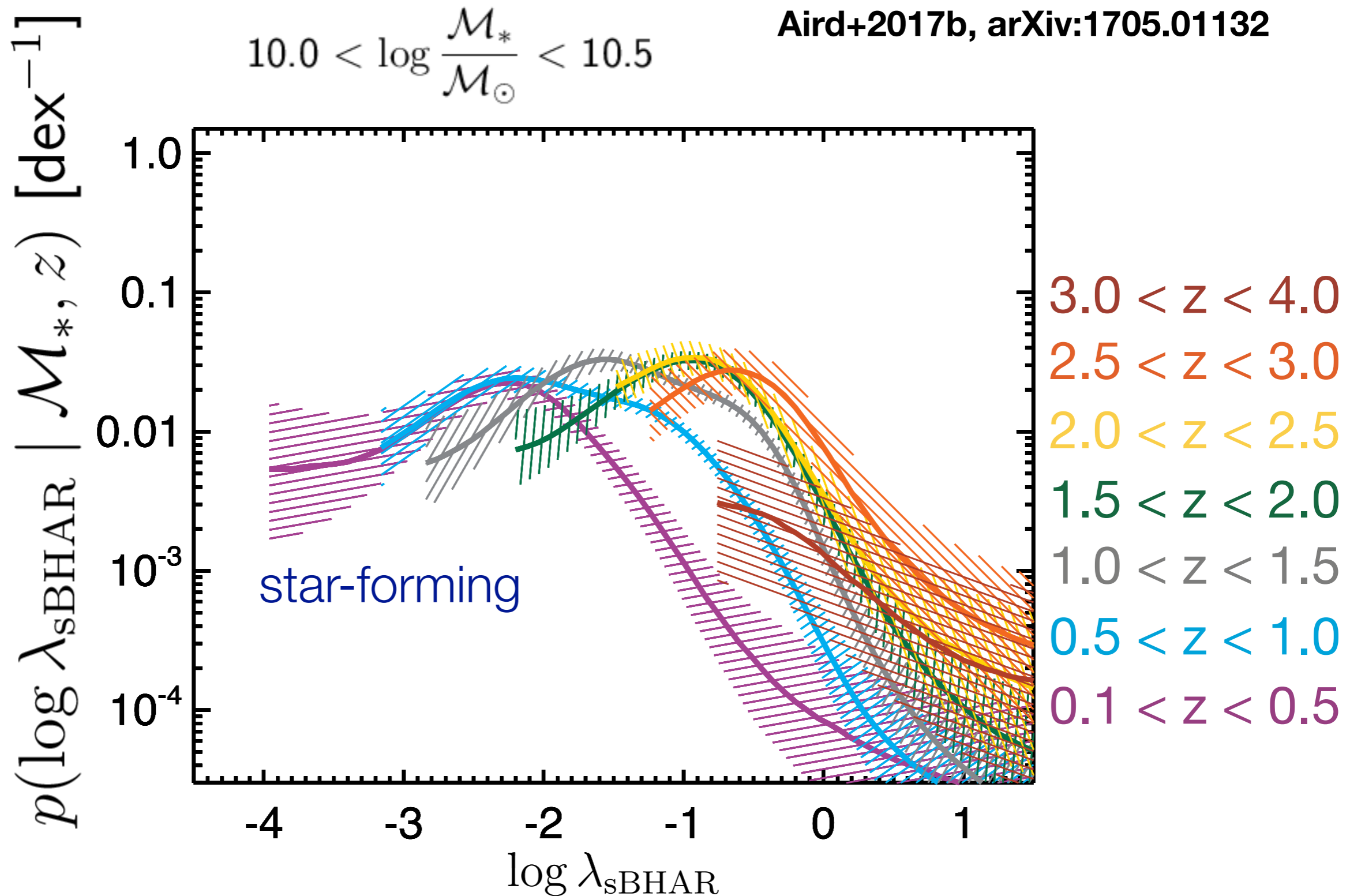
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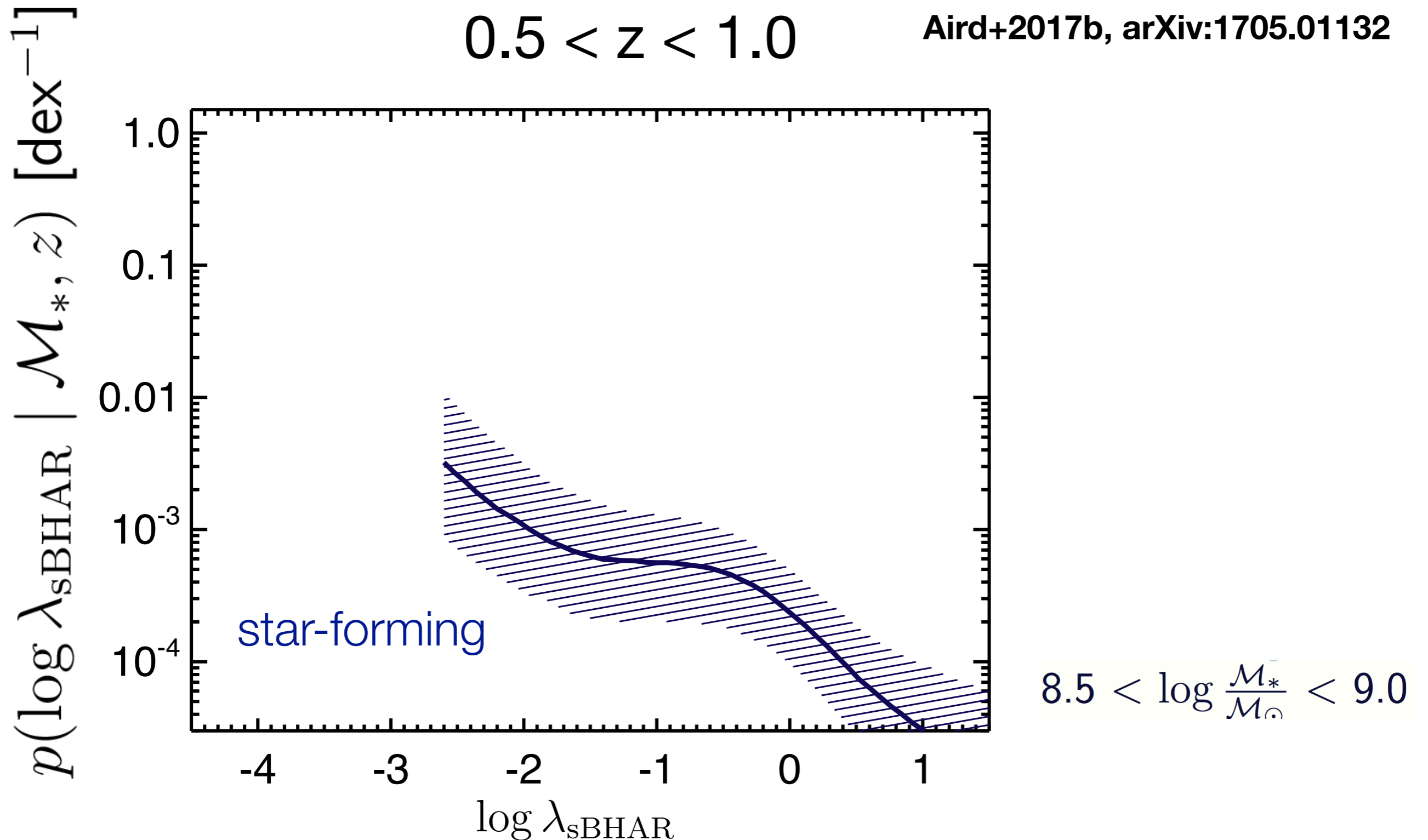
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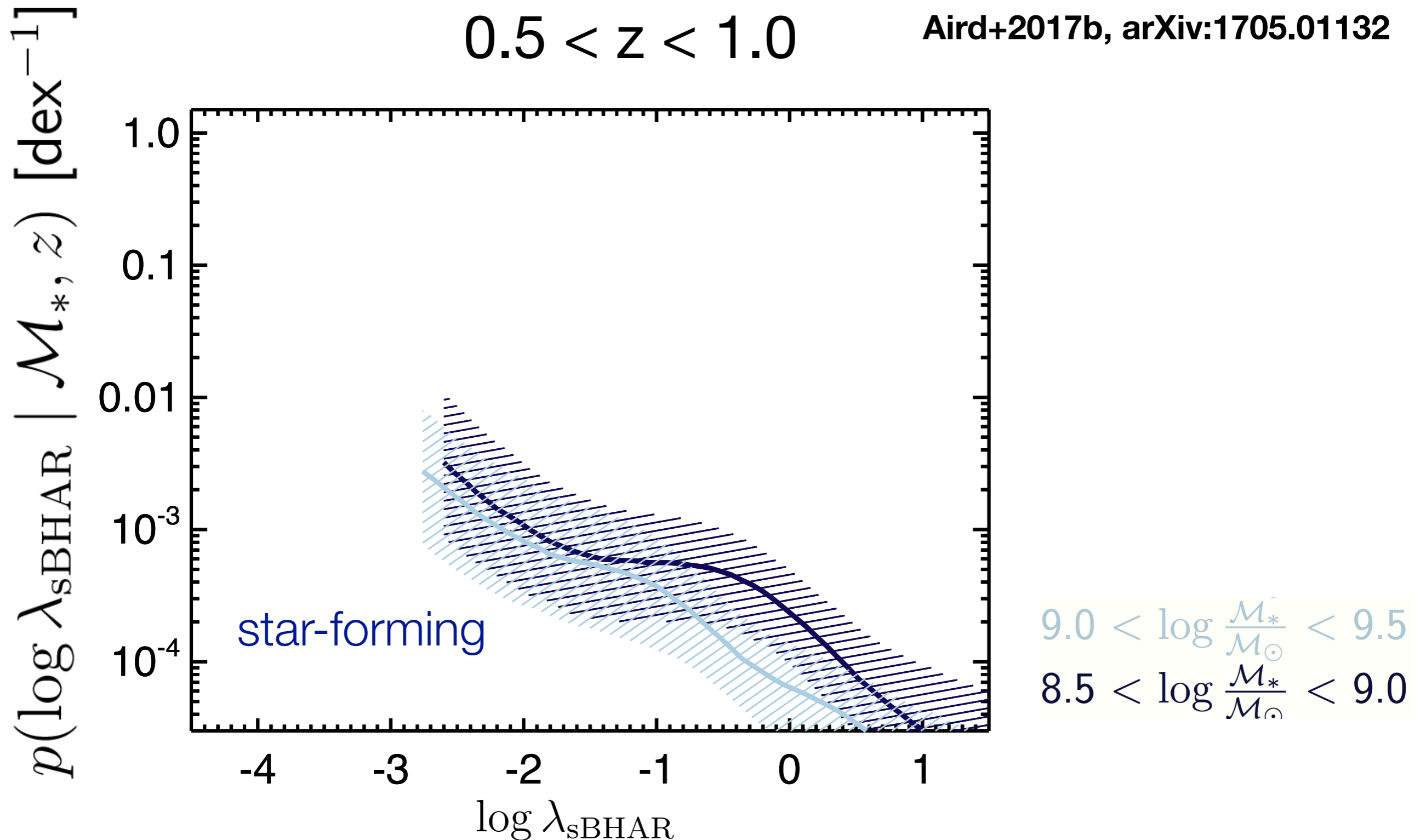
Distributions of sBHAR in **star-forming** galaxies as a function of **redshift**



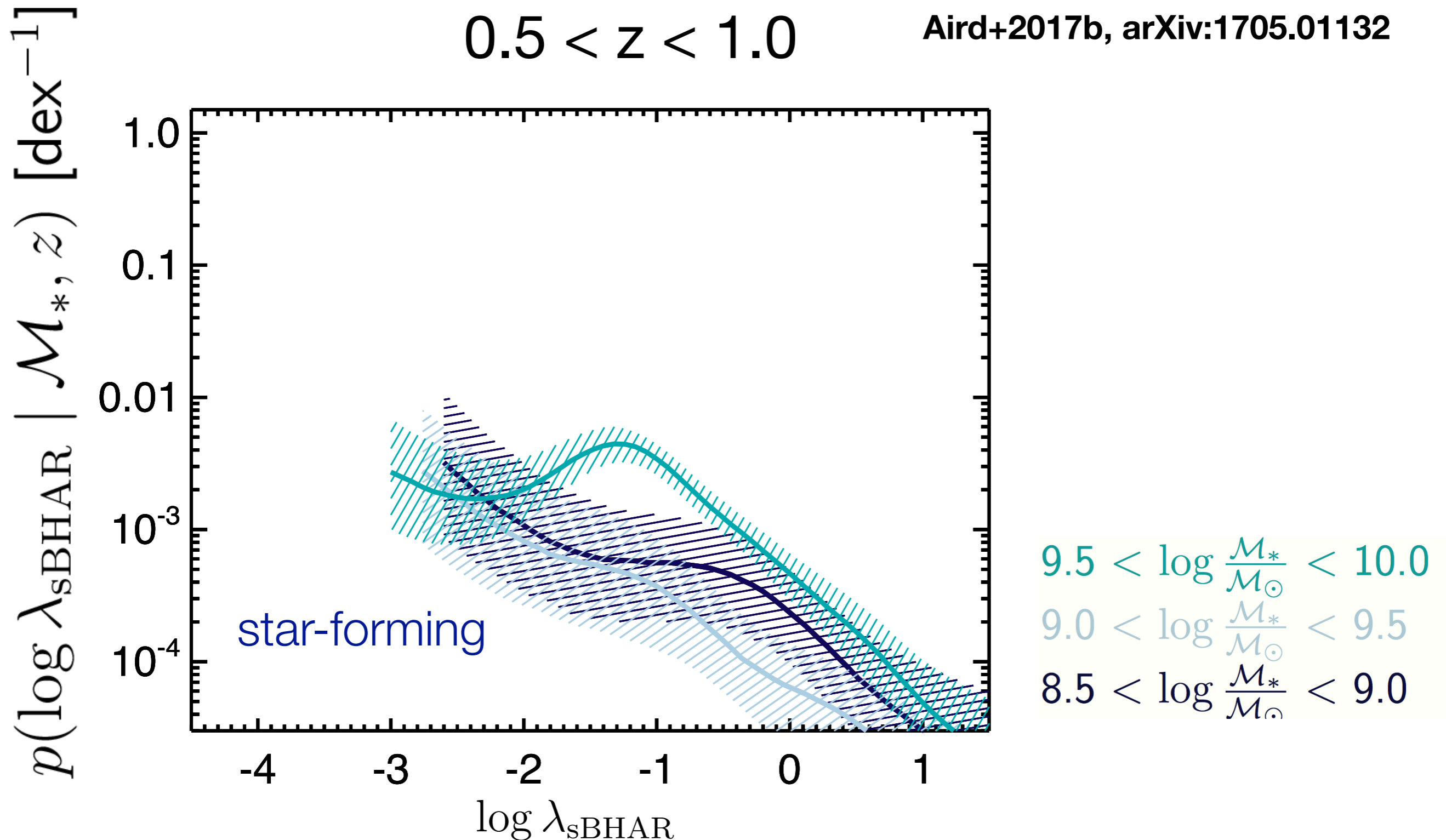
Distributions of sBHAR in **star-forming** galaxies as a function of **stellar mass**



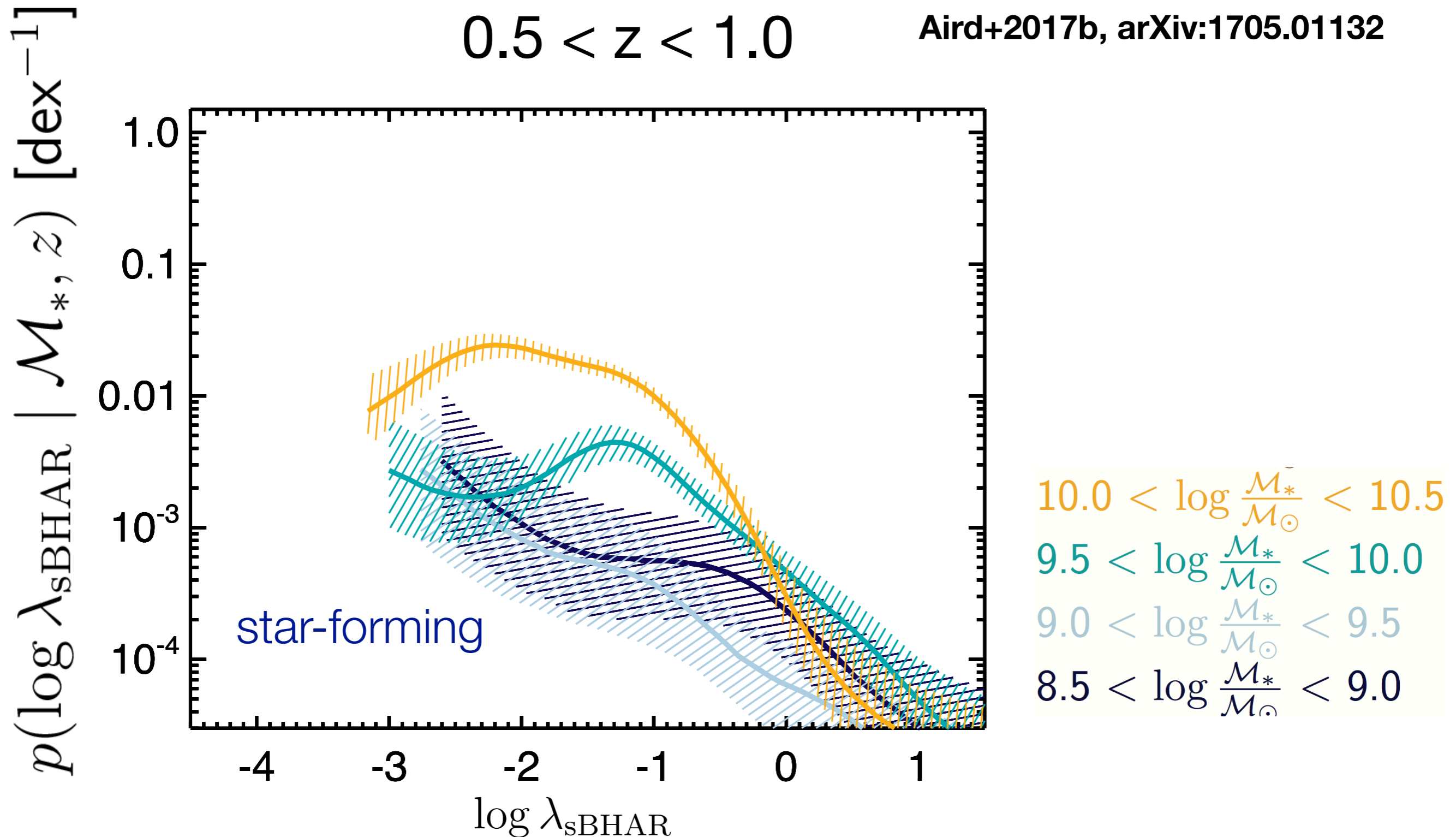
Distributions of sBHAR in **star-forming** galaxies as a function of **stellar mass**



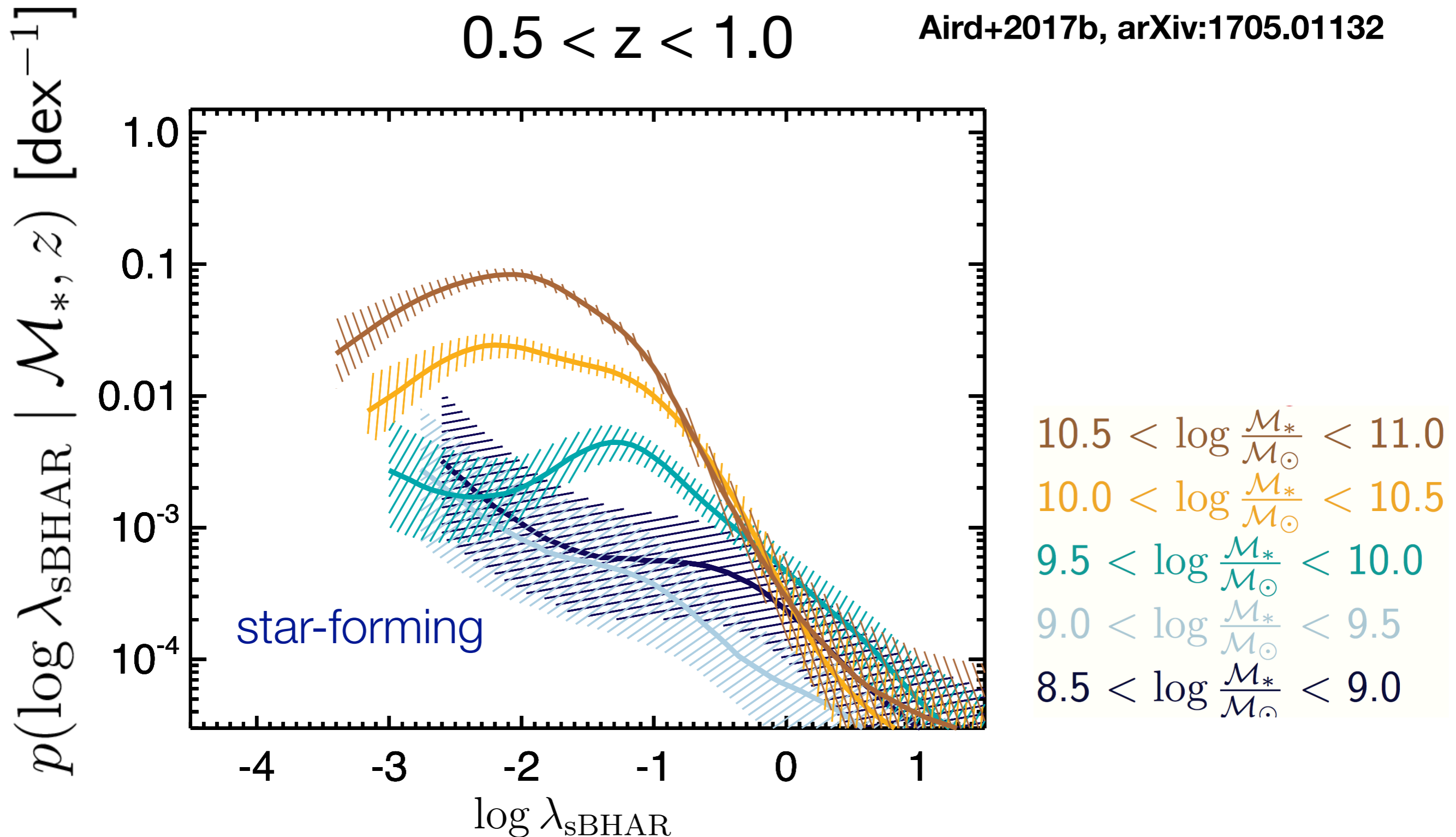
Distributions of sBHAR in **star-forming** galaxies as a function of **stellar mass**



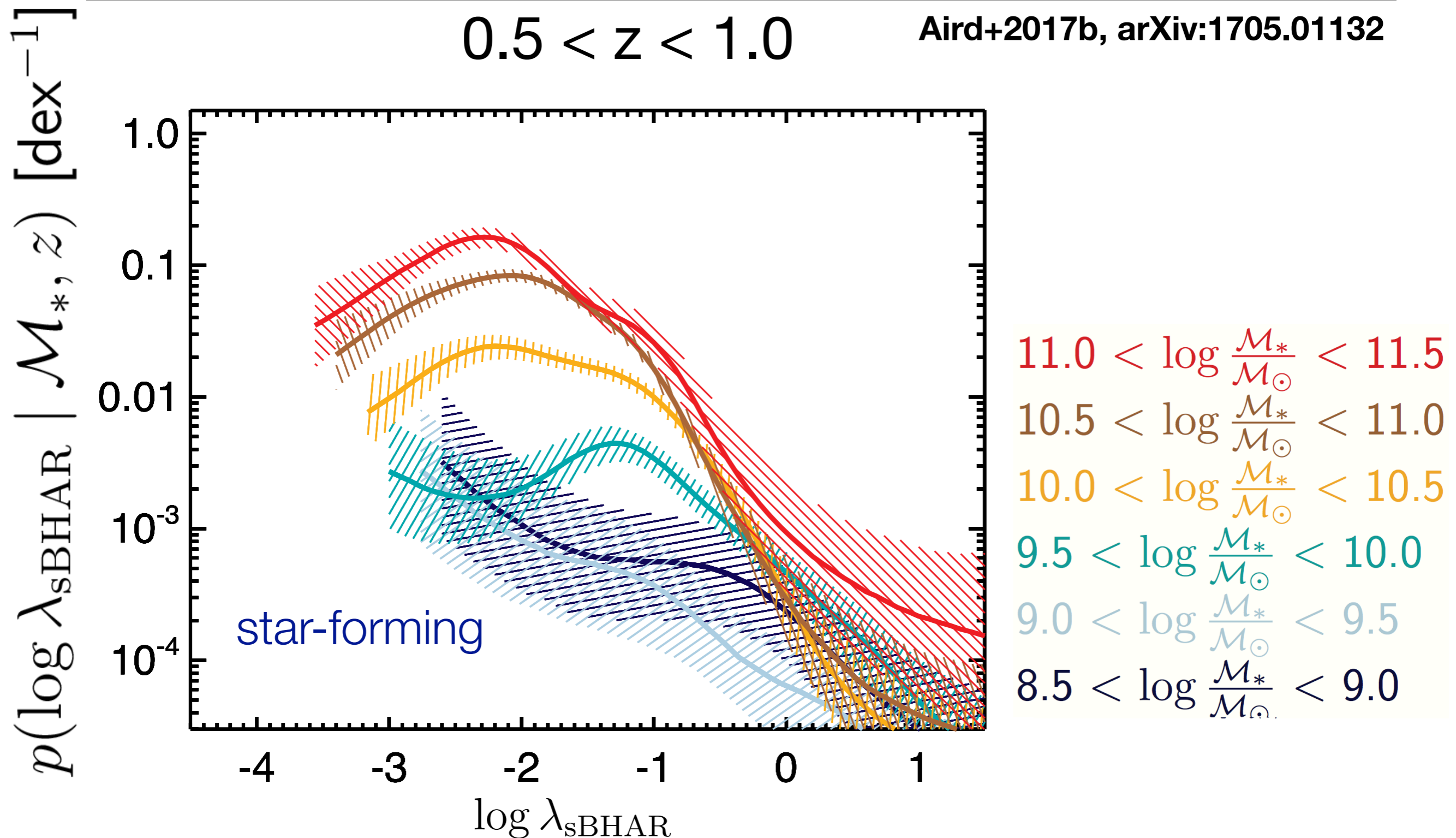
Distributions of sBHAR in **star-forming** galaxies as a function of **stellar mass**



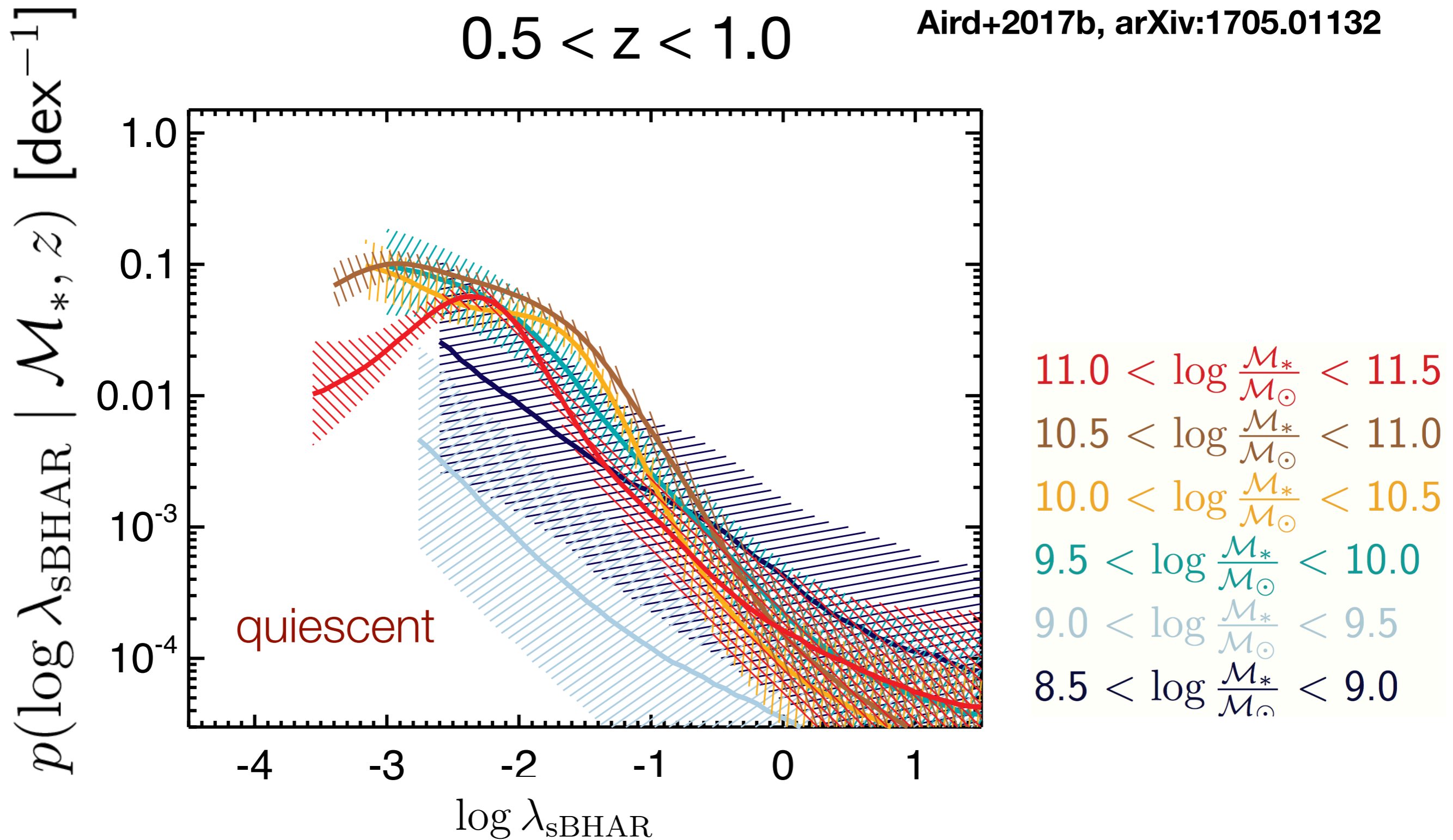
Distributions of sBHAR in **star-forming** galaxies as a function of **stellar mass**



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

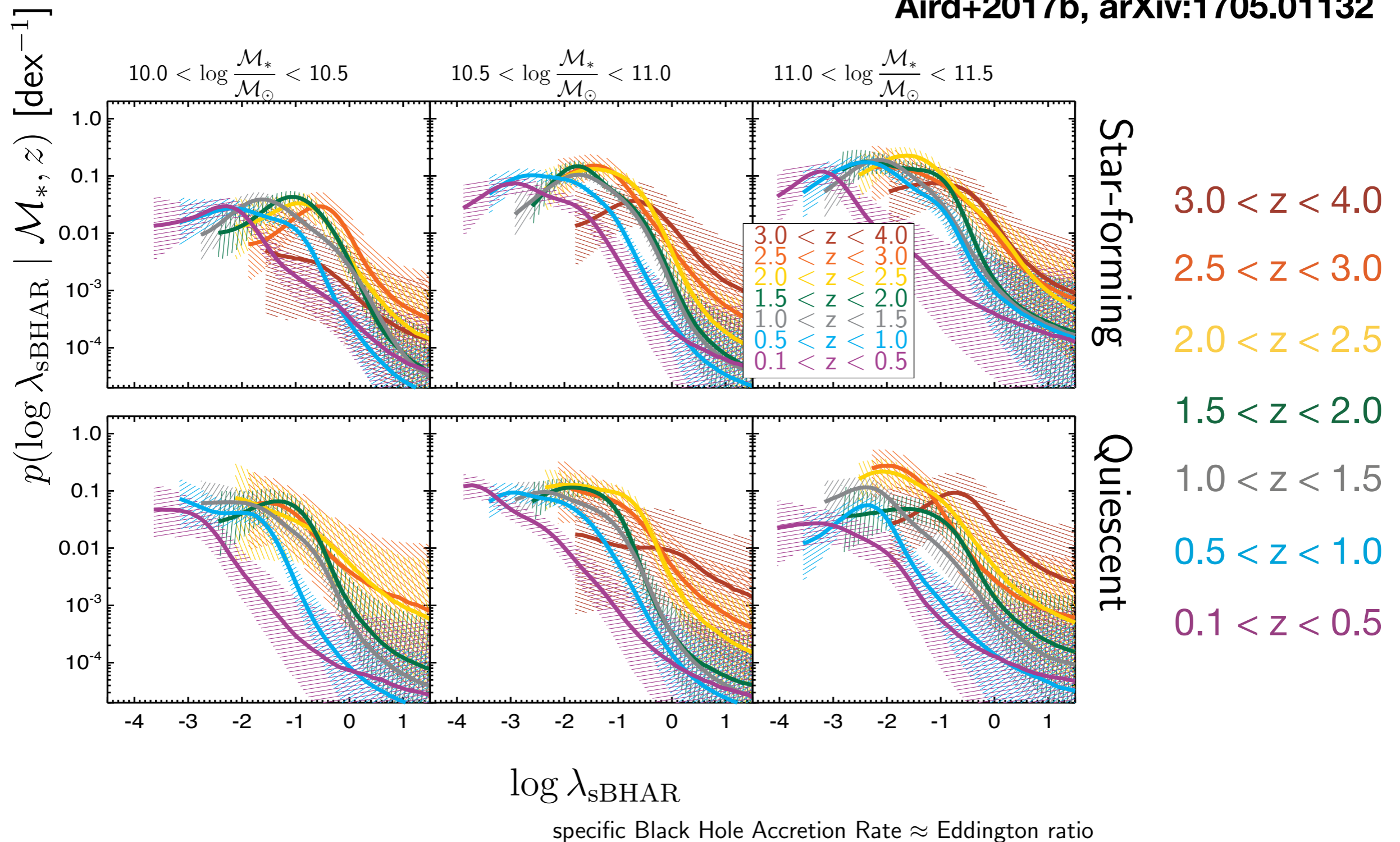


Distributions of sBHAR in **quiescent** galaxies as a function of **stellar mass**



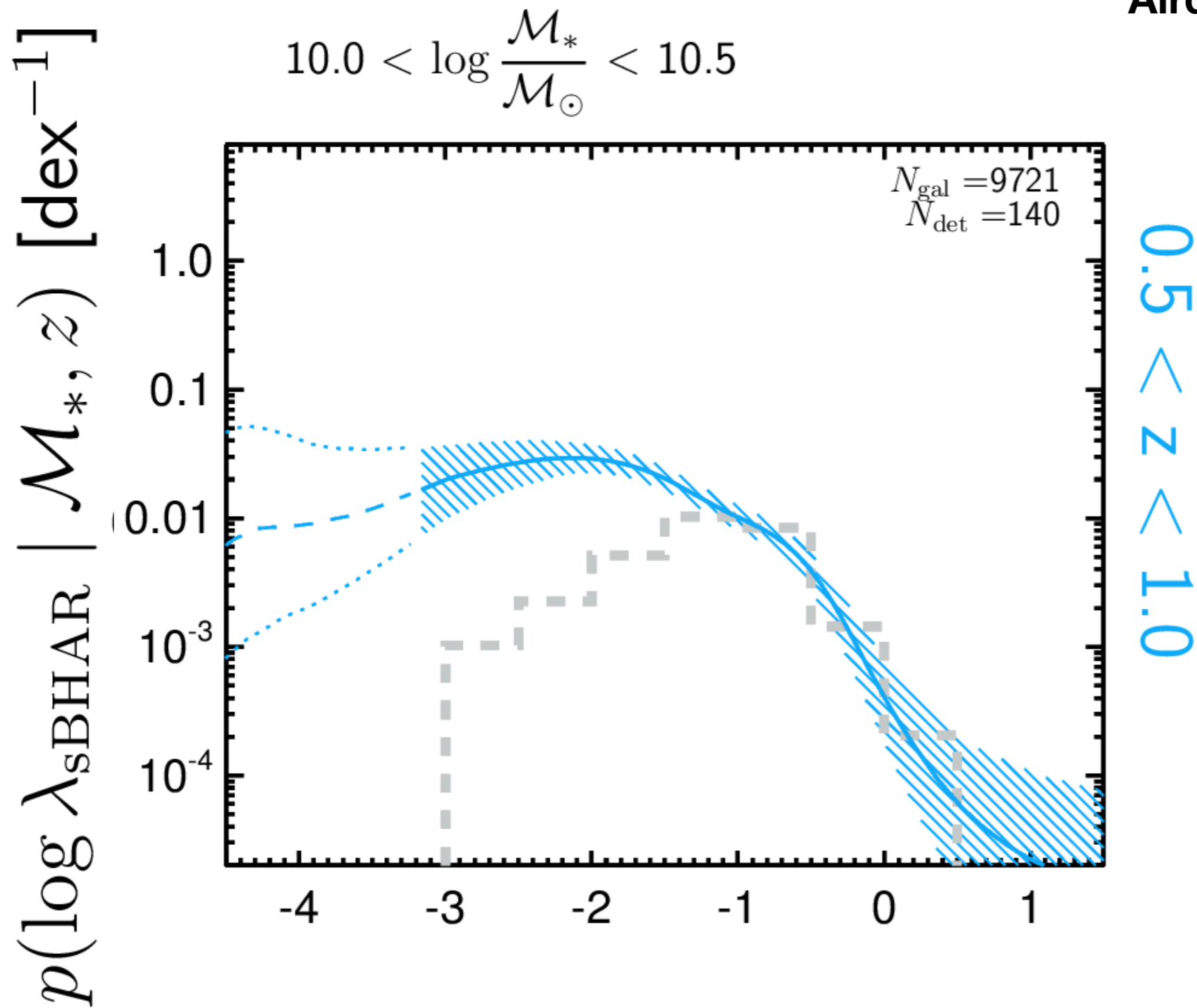
Distributions of sBHAR in star-forming and quiescent galaxies as a function of stellar mass, redshift....

Aird+2017b, arXiv:1705.01132



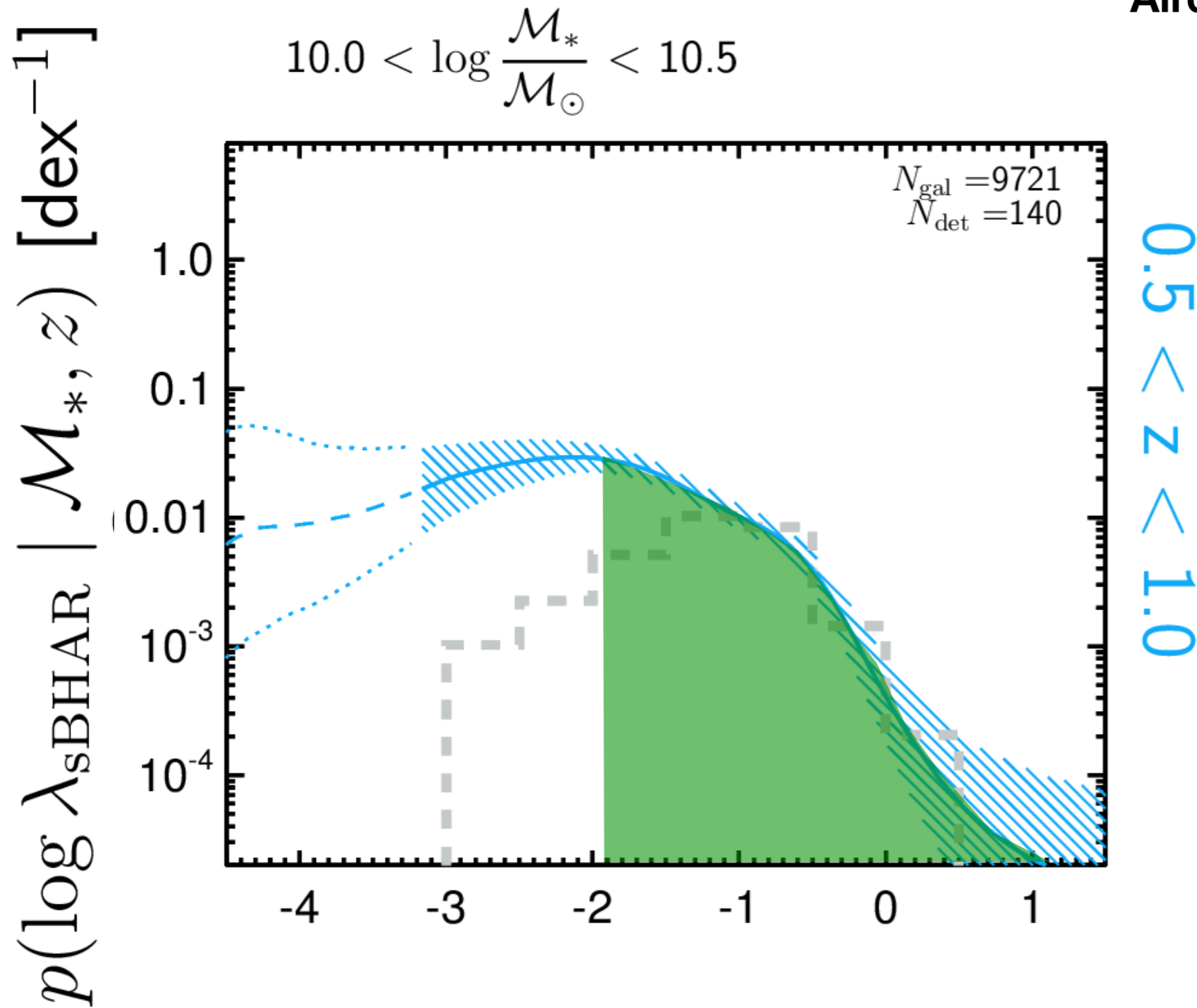
Summarizing the distributions: the duty cycle of AGN

Aird+2017b, arXiv:1705.01132



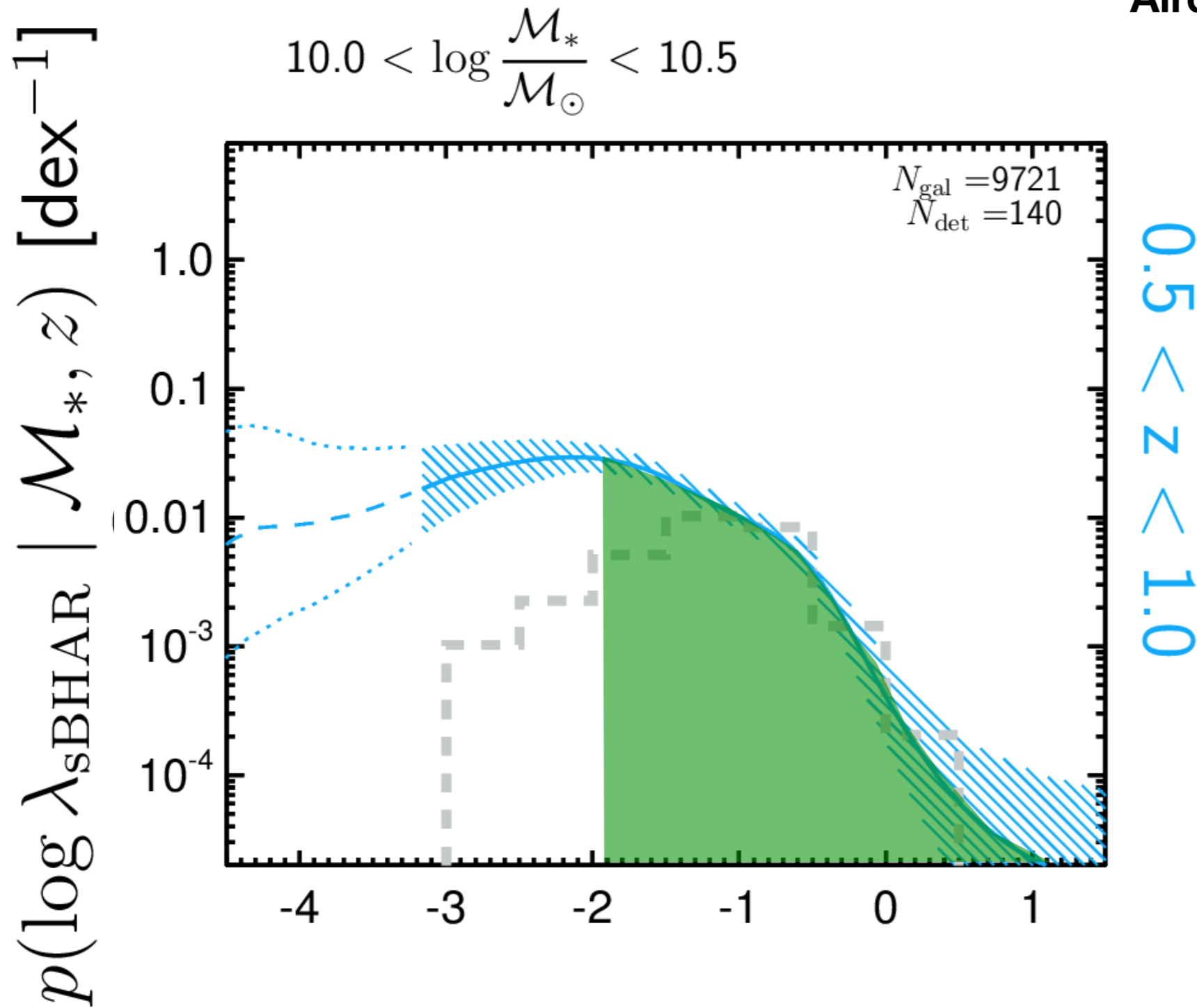
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Summarizing the distributions: the duty cycle of AGN

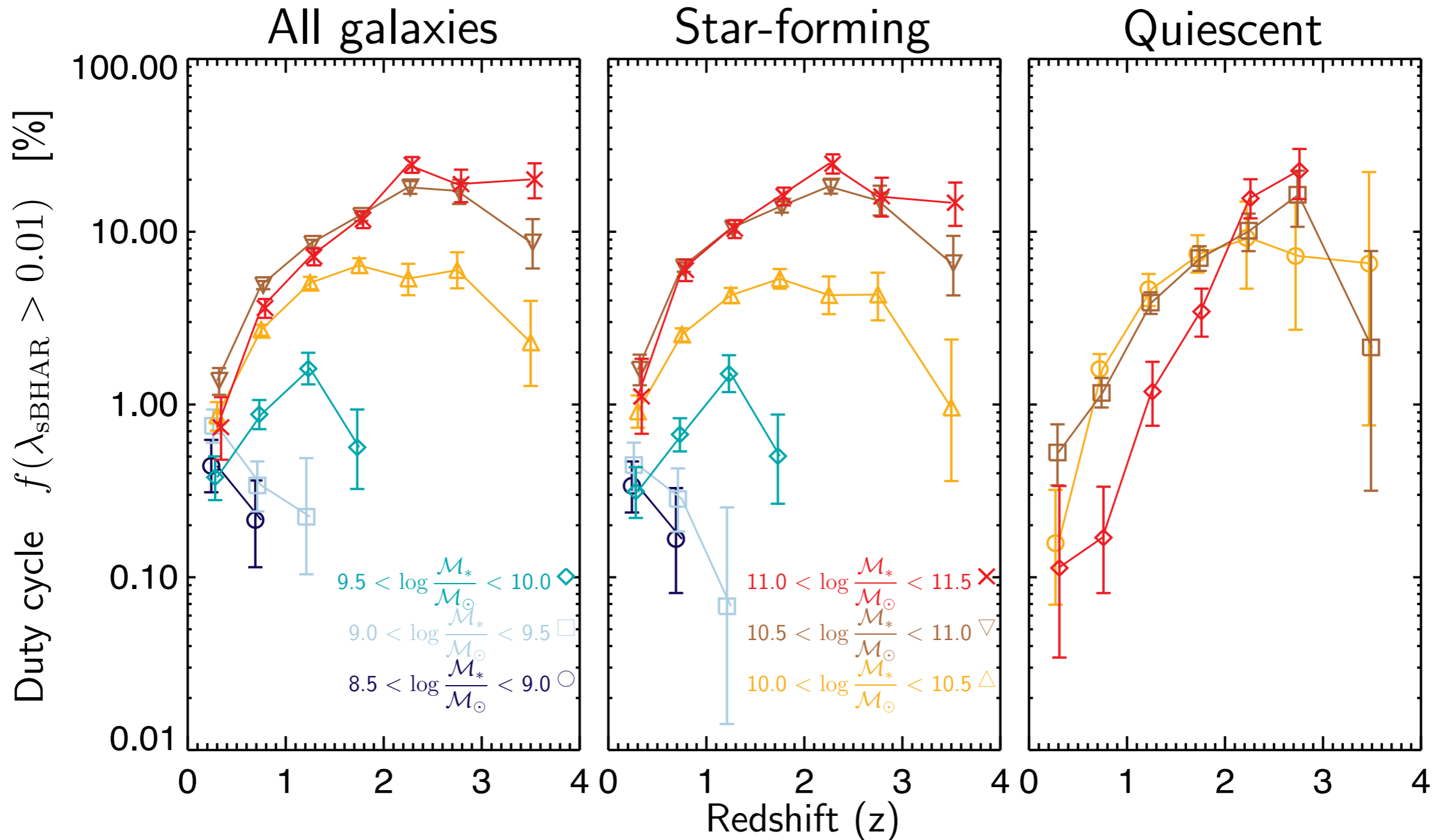
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The fraction of
galaxies
(of given M_* and z)
with an “AGN”

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

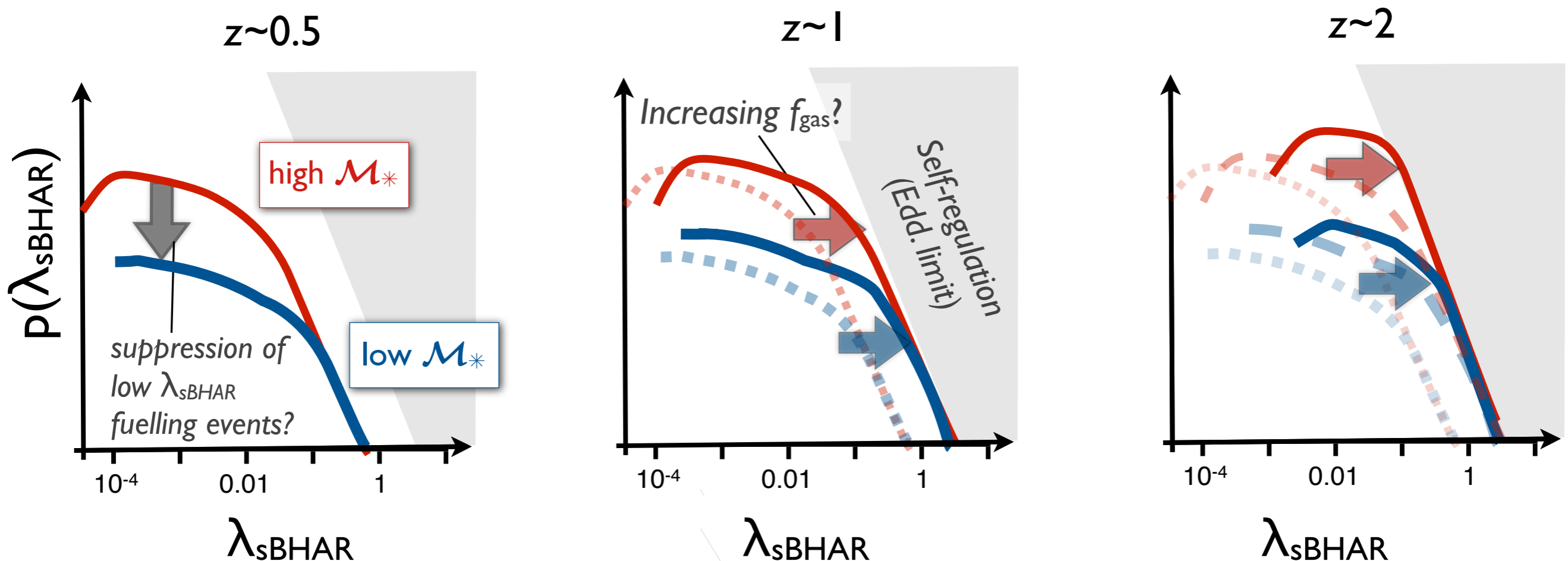
Aird+2017b, arXiv:1705.01132



Interpretation/conclusions

Star-forming galaxies

- Broad distribution of accretion rates reflects variability, indicating *stochastic accretion of cold gas*
- Suppression of low λ_{SBHAR} fuelling events at lower M_*
harder to release angular momentum in lower M_* galaxies? increased stellar feedback?
- Shift to higher accretion rates at higher z
related to *increased availability of cold gas?*
- Reaches a maximum at \sim Eddington limit?
BHs *self-regulate* growth at high z ?

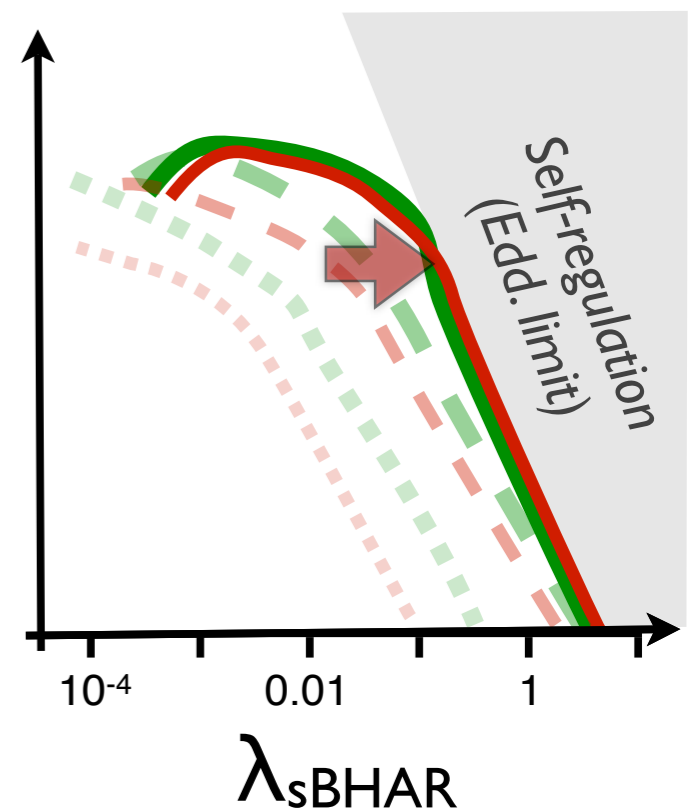
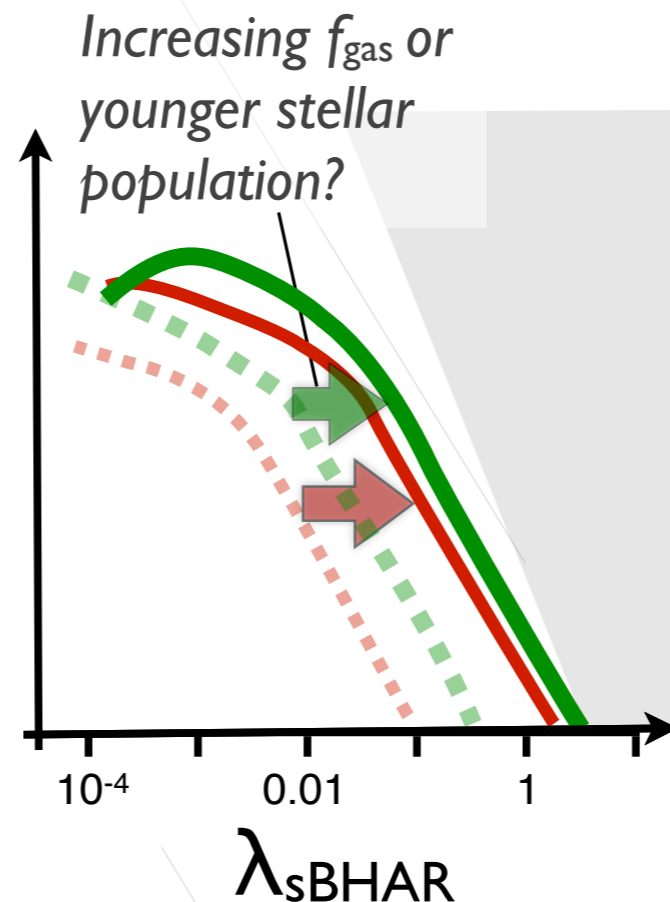
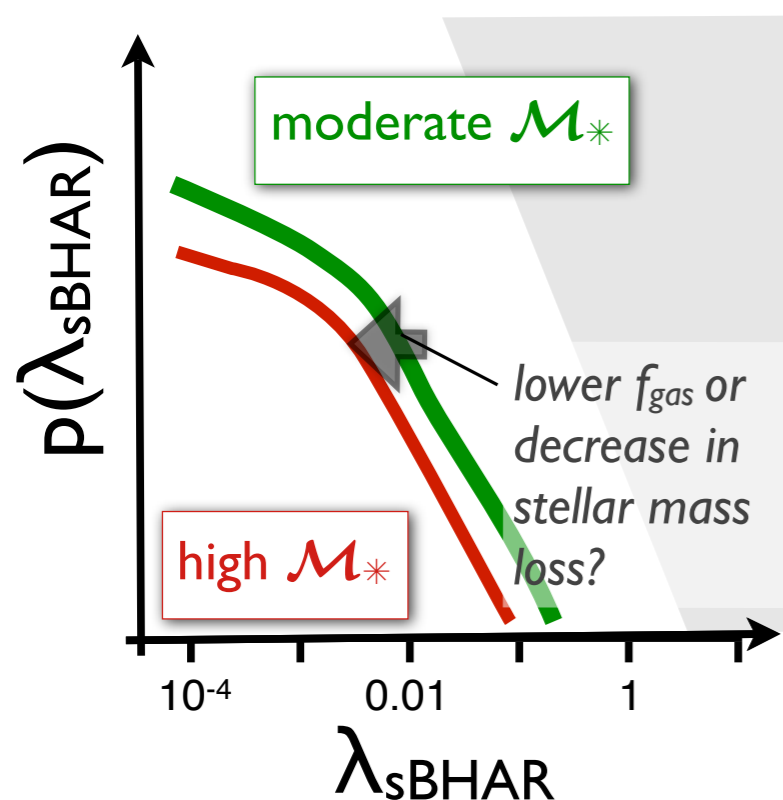


Interpretation/conclusions

Quiescent galaxies

- Generally contain weaker (lower λ_{sBHAR}) AGN than in SF galaxies (of equivalent M_* and z)
- *Decrease* in duty cycle (shift to lower λ_{sBHAR}) at *highest* M_*
- Evolves *more rapidly* with redshift (toward higher λ_{sBHAR} at higher z)
- Ultimately limited by self-regulation, but at higher redshift ($z > 2$)

Suggests a *different physical mechanism* (e.g. **stellar mass loss**) fuels AGN activity in quiescent galaxies compared to SF galaxies



Summary

- Use near-infrared (\sim stellar-mass) selected samples of galaxies combined with deep *Chandra* X-ray data to measure the probability distribution function of AGN accretion rates (and duty cycle) as a function of stellar mass and redshift
 - Broad distribution of accretion rates for a fixed galaxy property (redshift, stellar mass, star-forming vs. quiescent) reflecting **variability**

Star-forming galaxies

- Stellar-mass dependent $p(\lambda_{\text{SBHAR}})$ (suppression of low λ_{SBHAR} for lower M_* galaxies)
- Strong evolution with z , truncated at \sim Eddington limit
=> self-regulation of BH growth at high z

AGN fueled by stochastic accretion of cold gas?

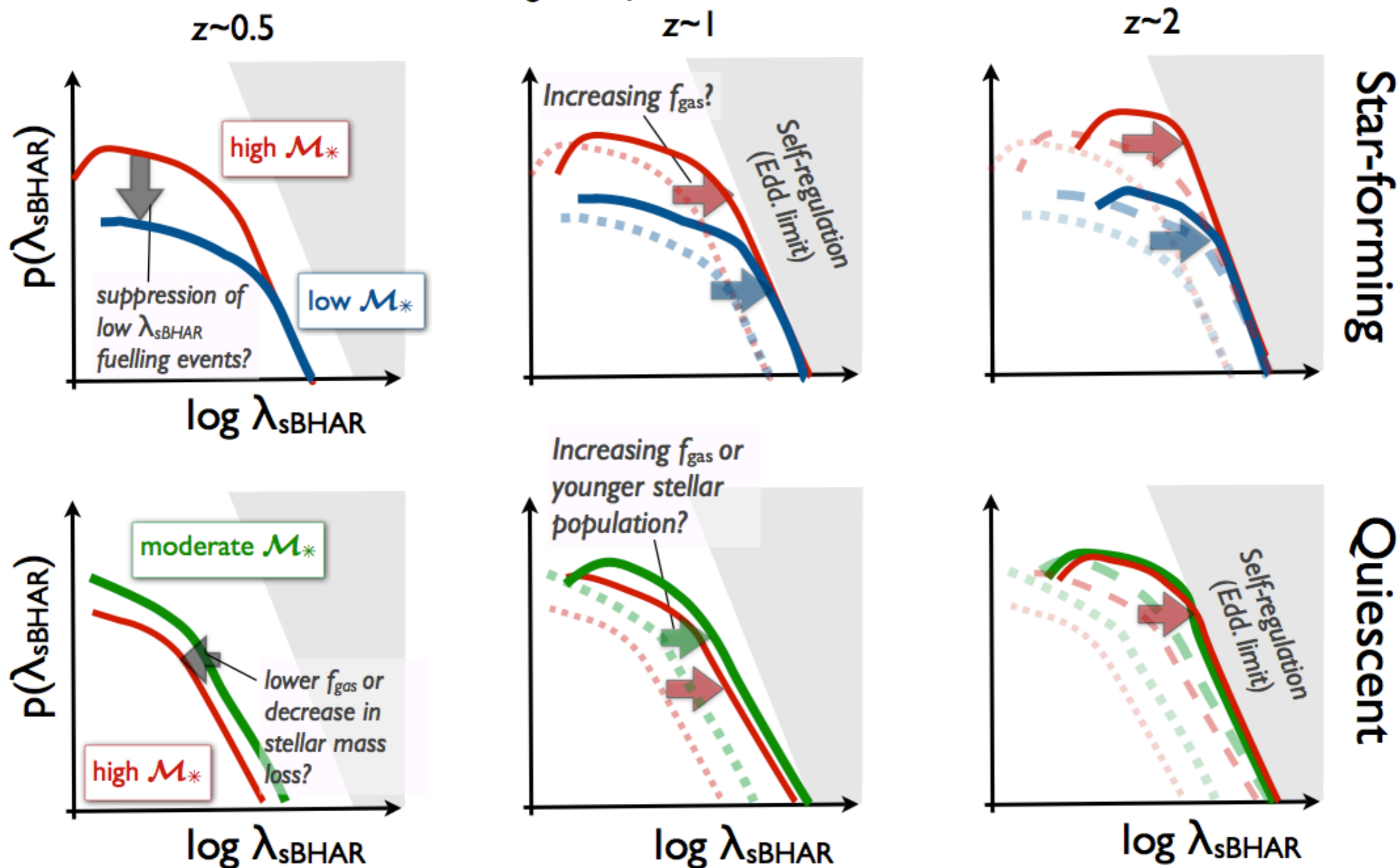
Quiescent galaxies

- generally have lower accretion rates/lower duty cycle.
- Different stellar mass dependence, also evolve to higher λ_{SBHAR} at higher z

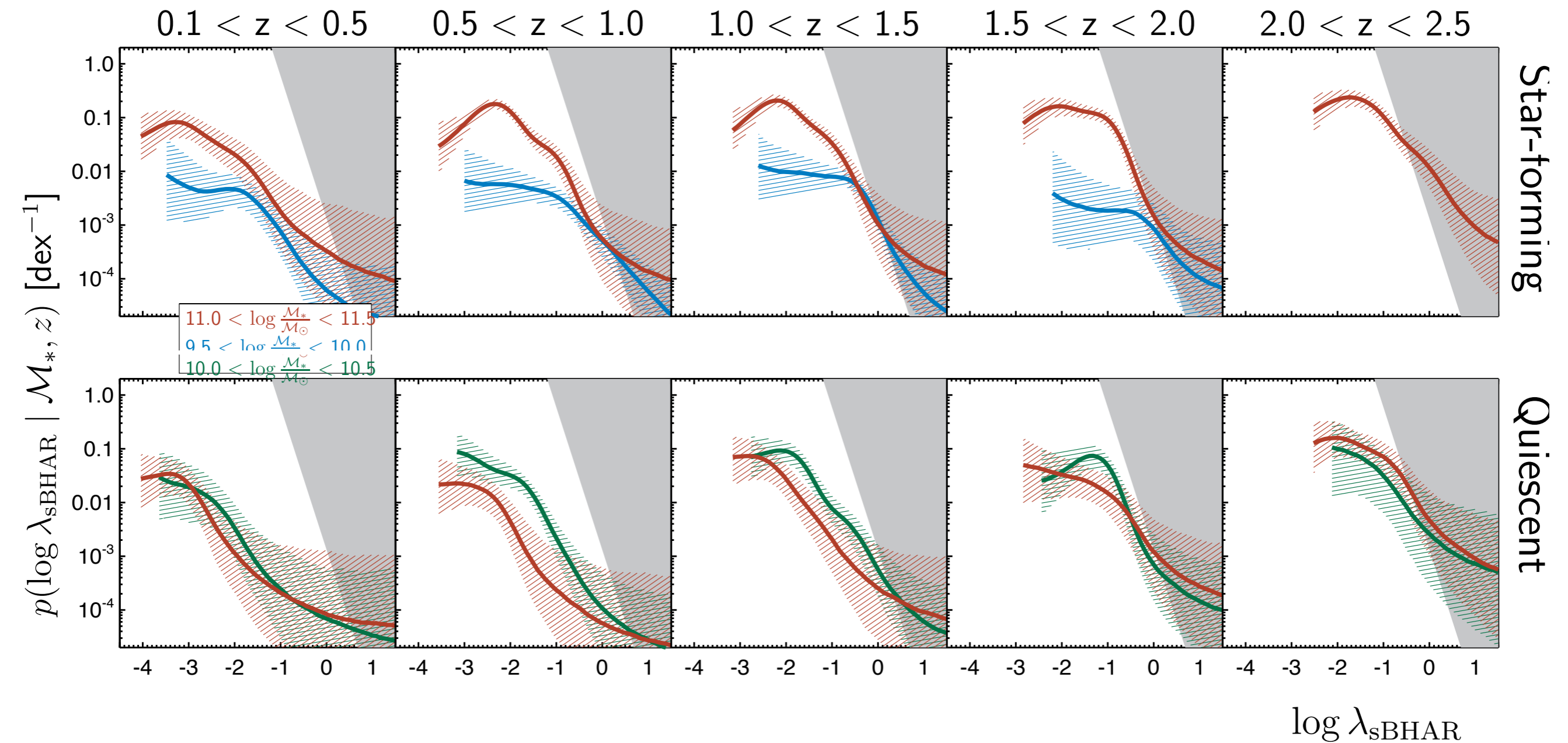
AGN fueled by stellar mass loss?

Sketch summarizing results of Aird et al. 2017 (arXiv:1705.01132)

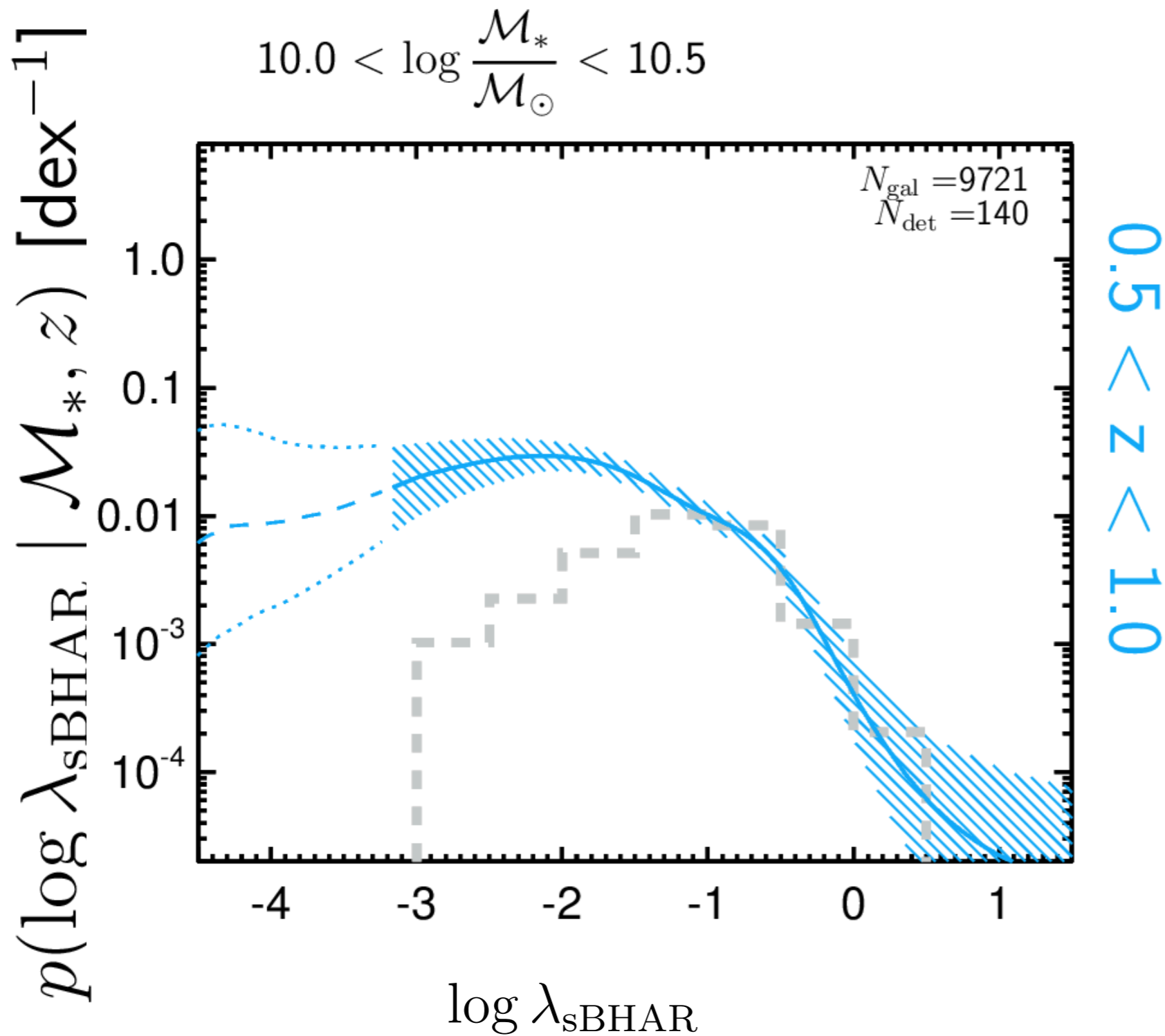
Increasing redshift \longrightarrow



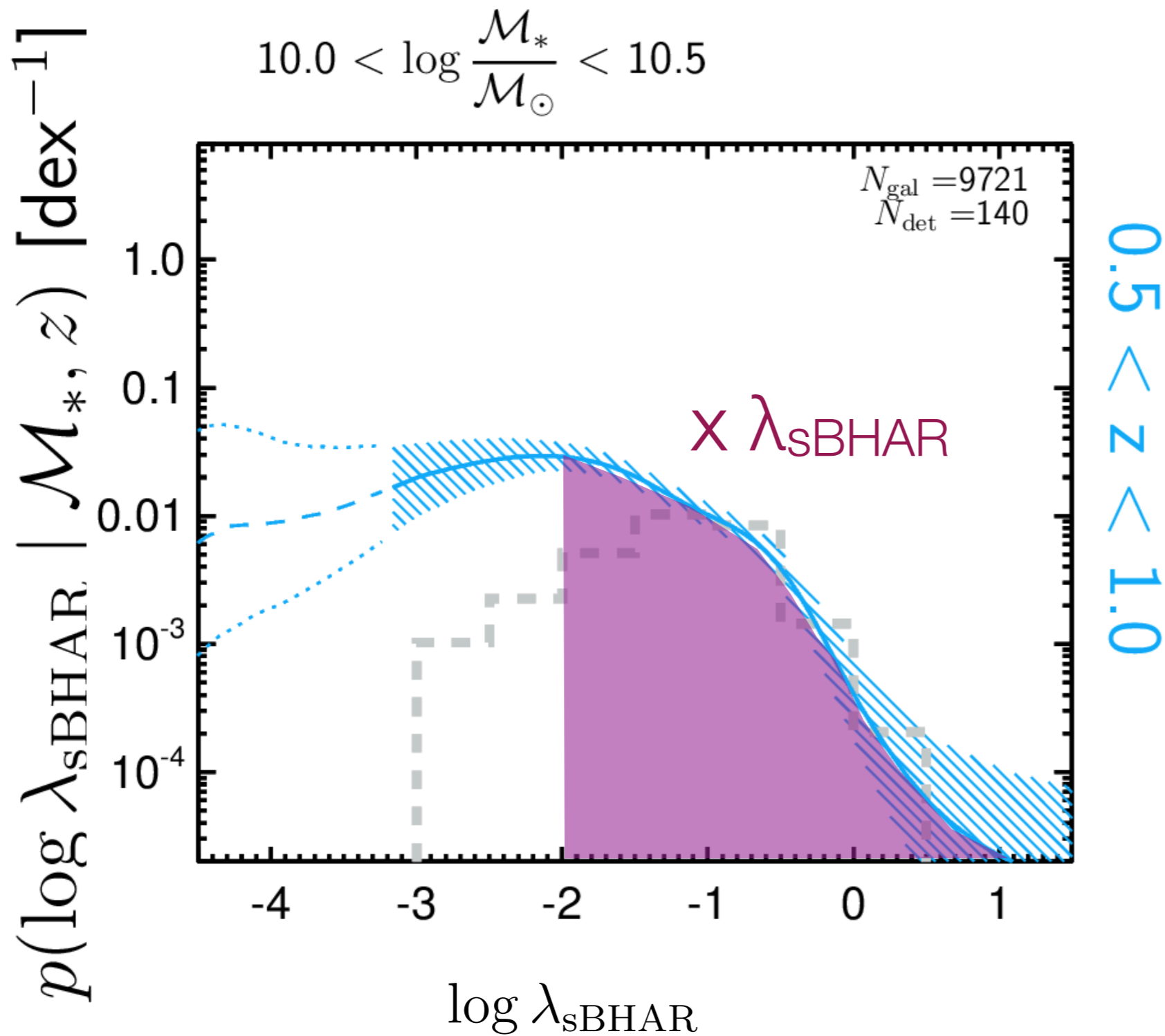
SHOW ME THE DATA



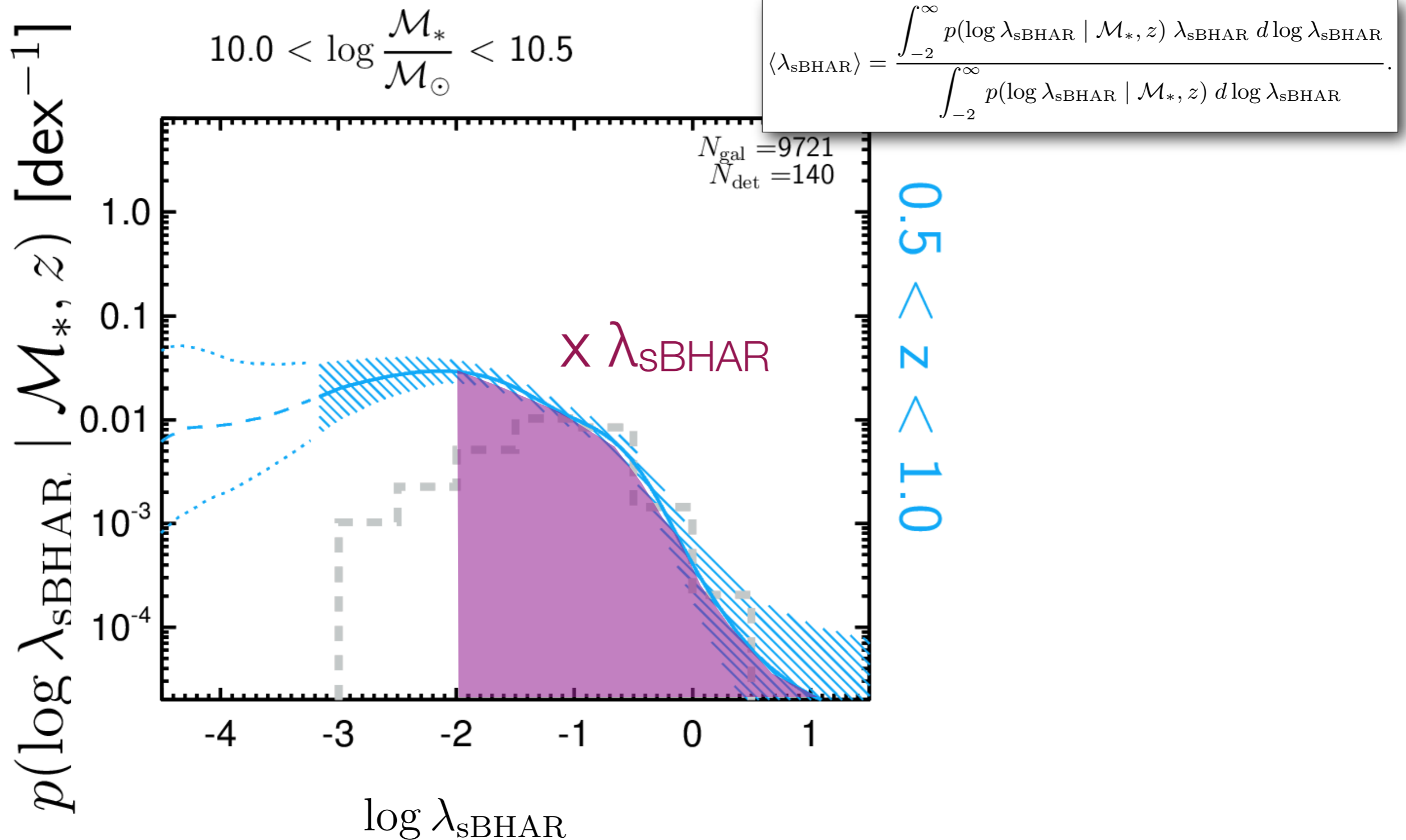
Summarizing the distributions: the *average* accretion rate



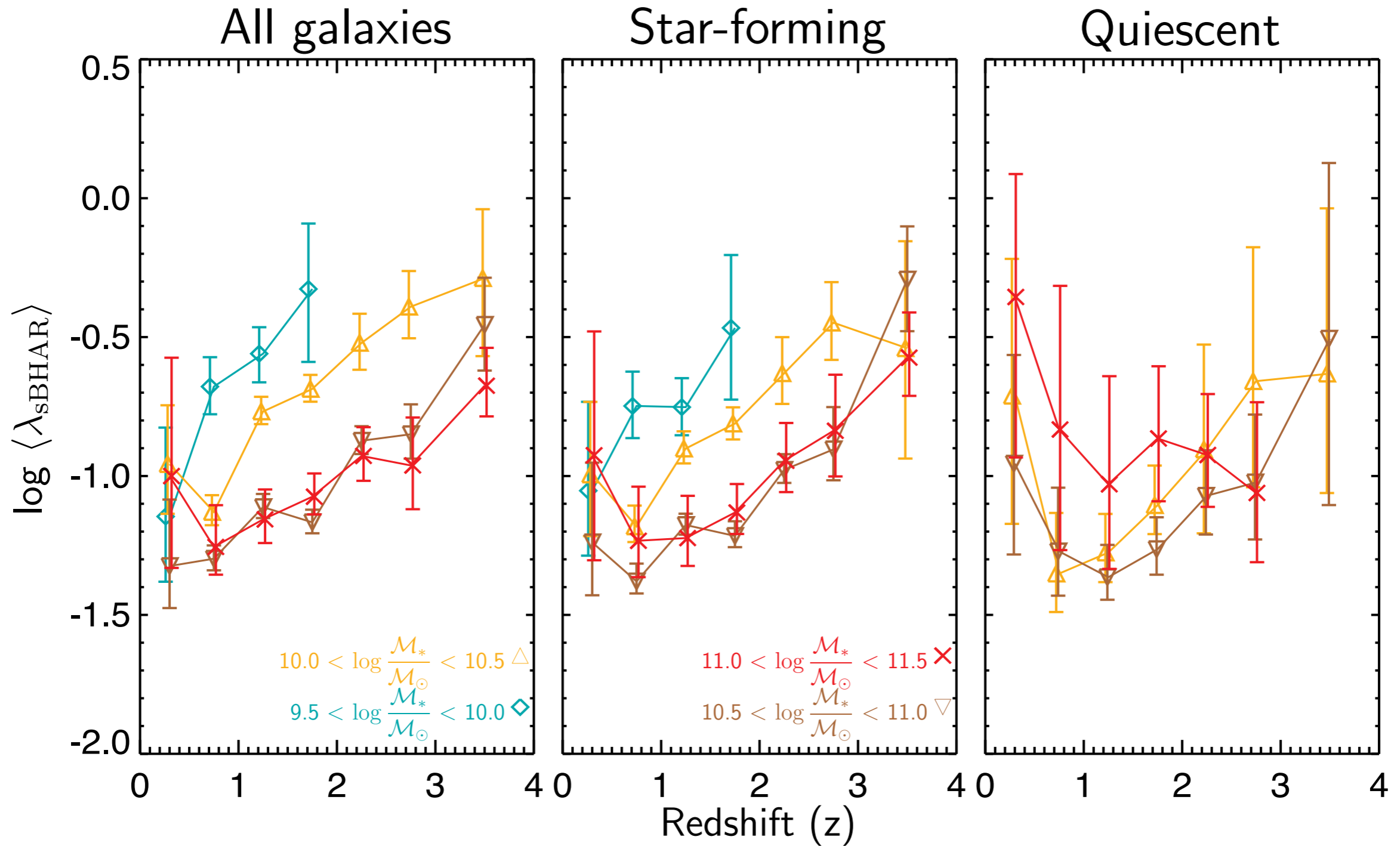
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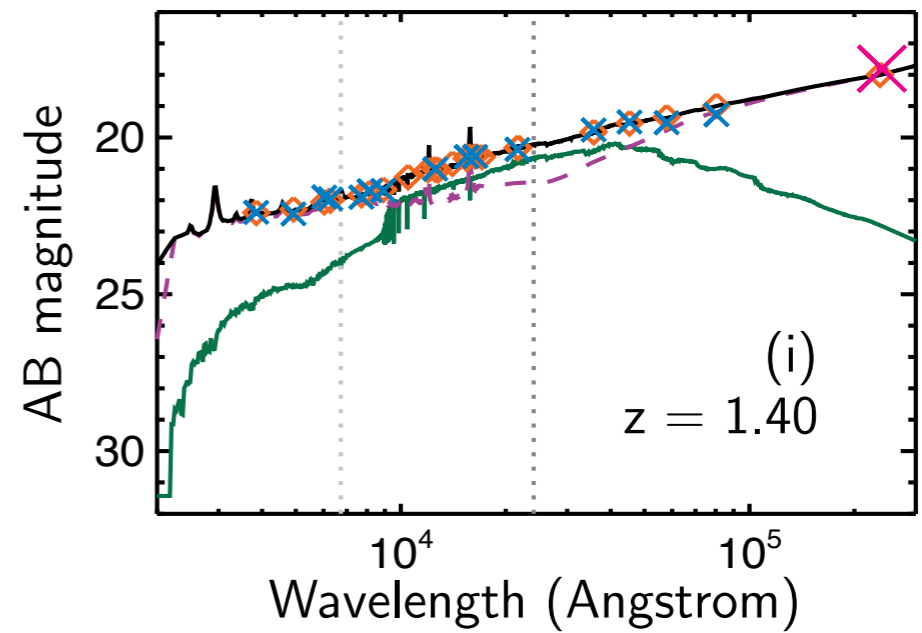
Summarizing the distributions: the *average* accretion rate



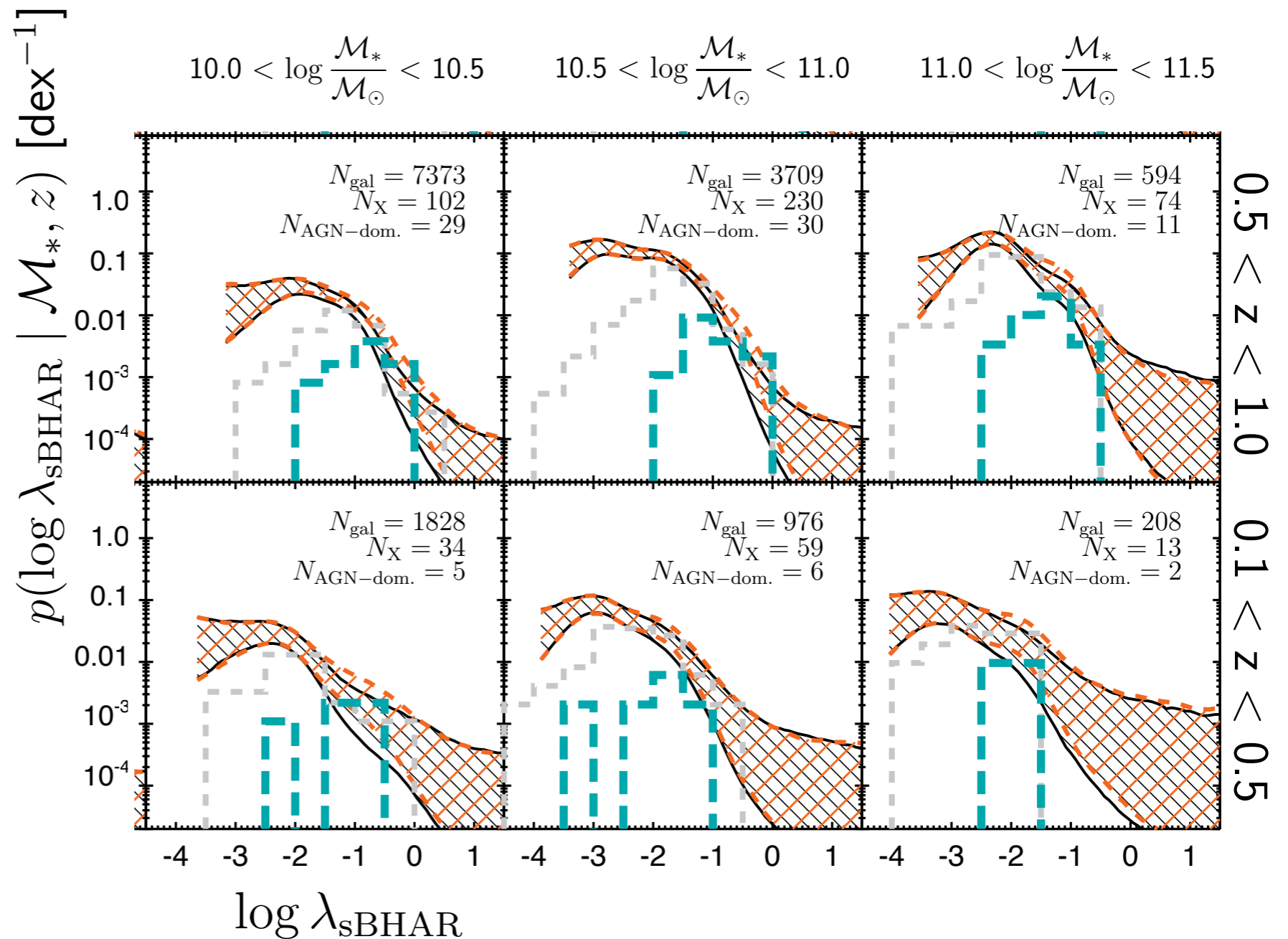
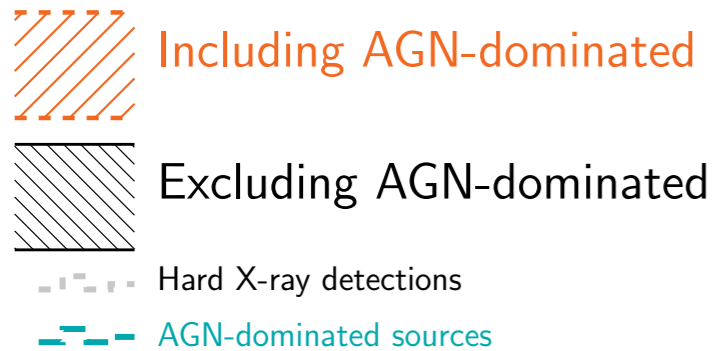
The average accretion rate as a function of stellar mass and redshift



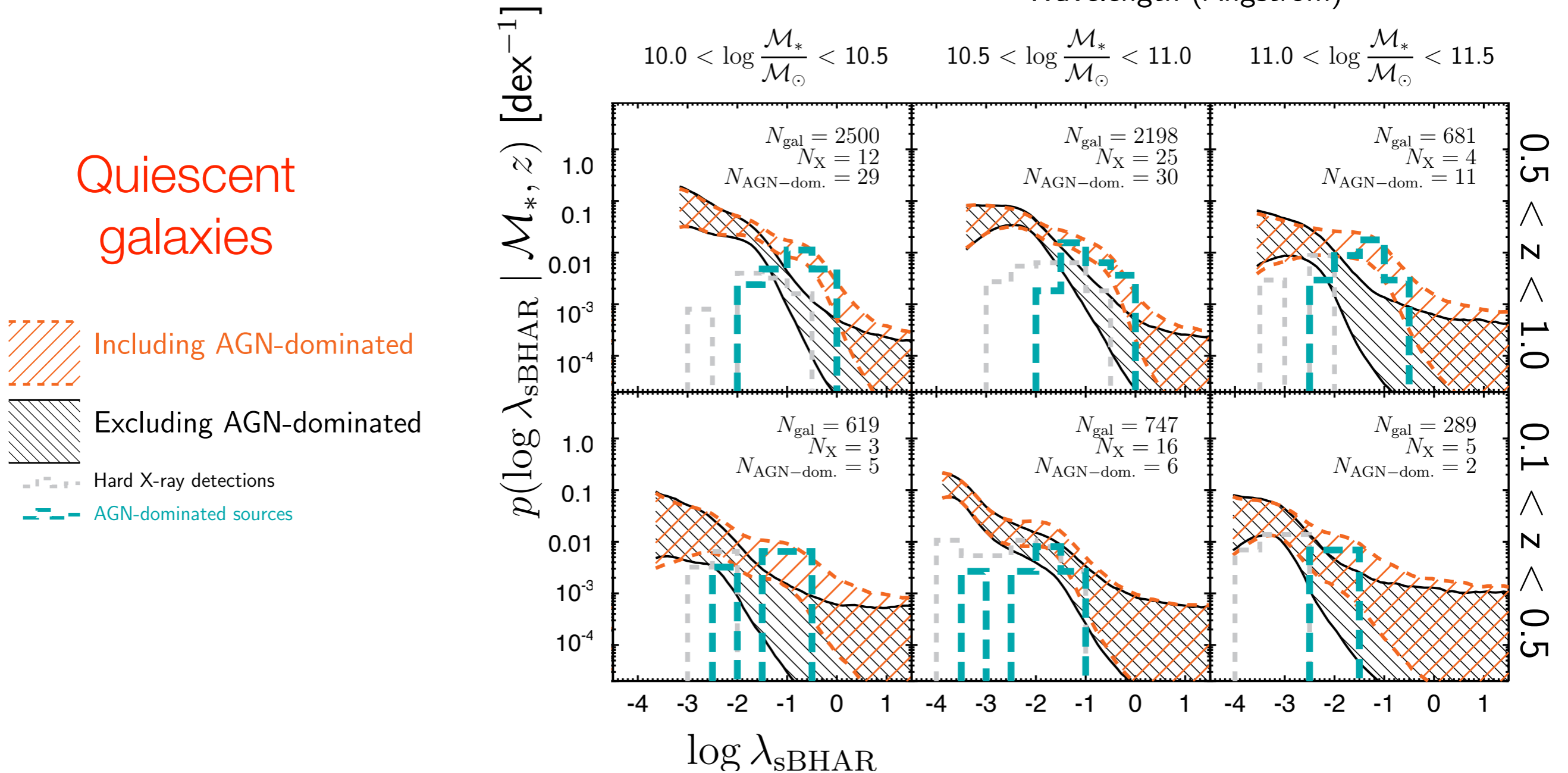
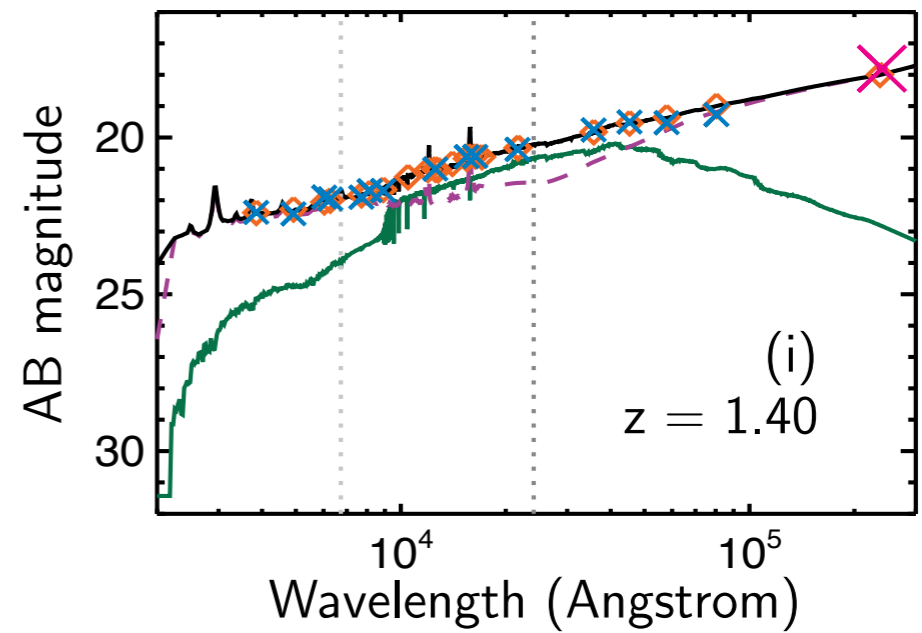
Effect of AGN-dominated sources (QSOs)



Star-forming galaxies

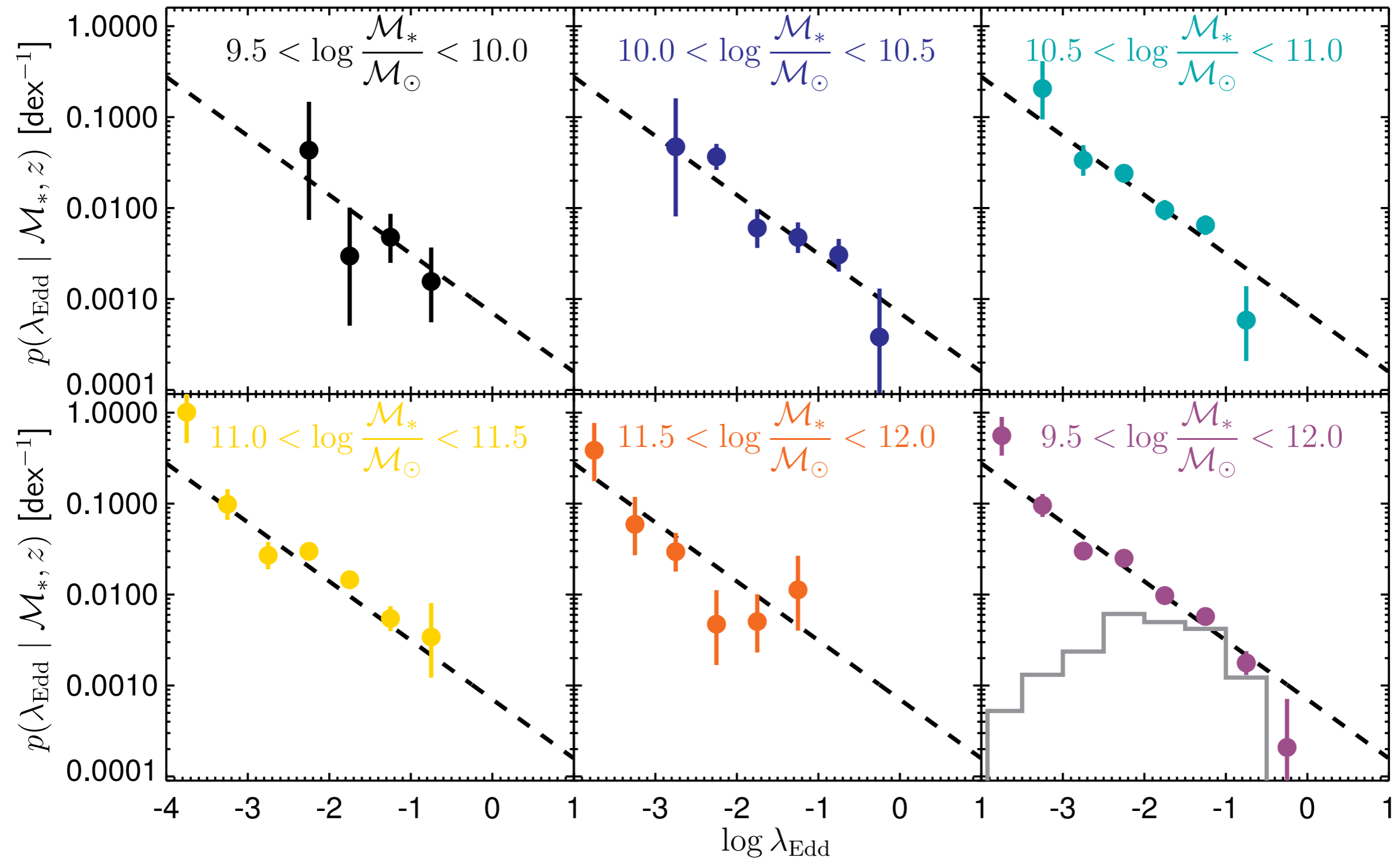


Effect of AGN-dominated sources (QSOs)



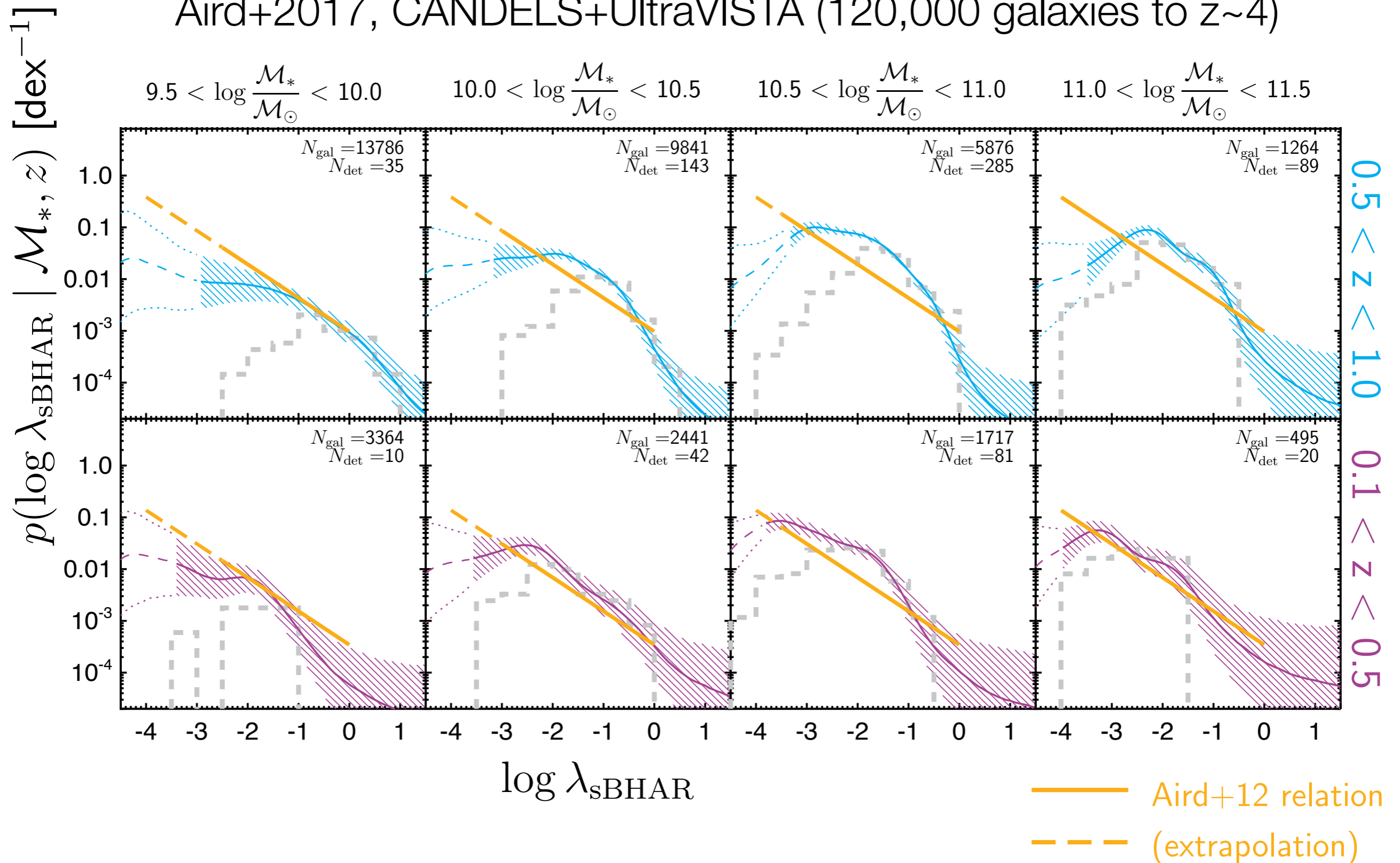
Mass-independent $p(\lambda)$?

Aird+2012, PRIMUS survey (20,000 galaxies), $0.1 < z < 1.0$

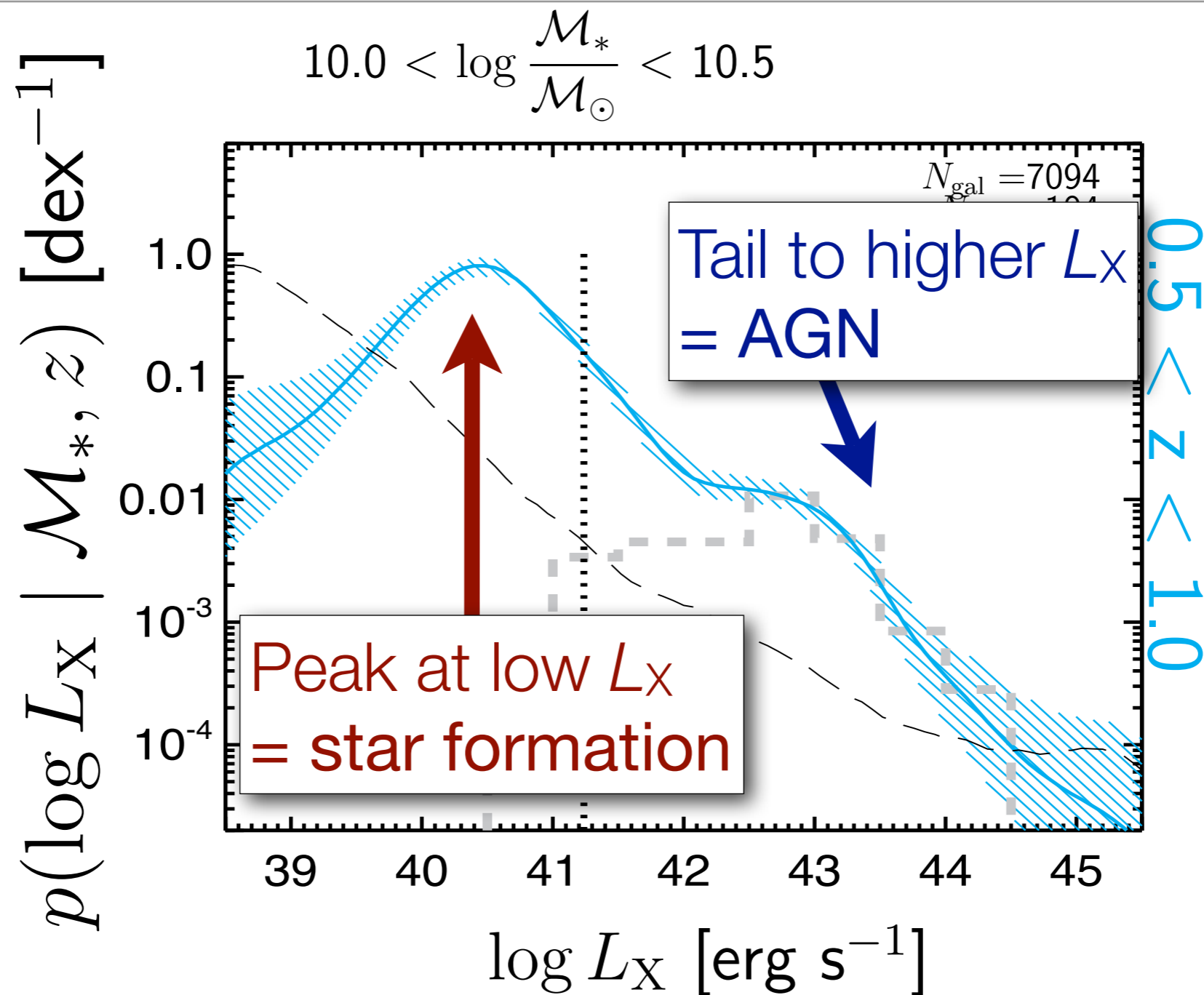


Mass-independent $p(\lambda)$?

Aird+2017, CANDELS+UltraVISTA (120,000 galaxies to $z \sim 4$)



Star formation emission at low X-ray luminosities



see Aird et al. 2017a, MNRAS, 465, 3390 (Paper I)