IDIA Inter-University Institute for Data Intensive Astronomy

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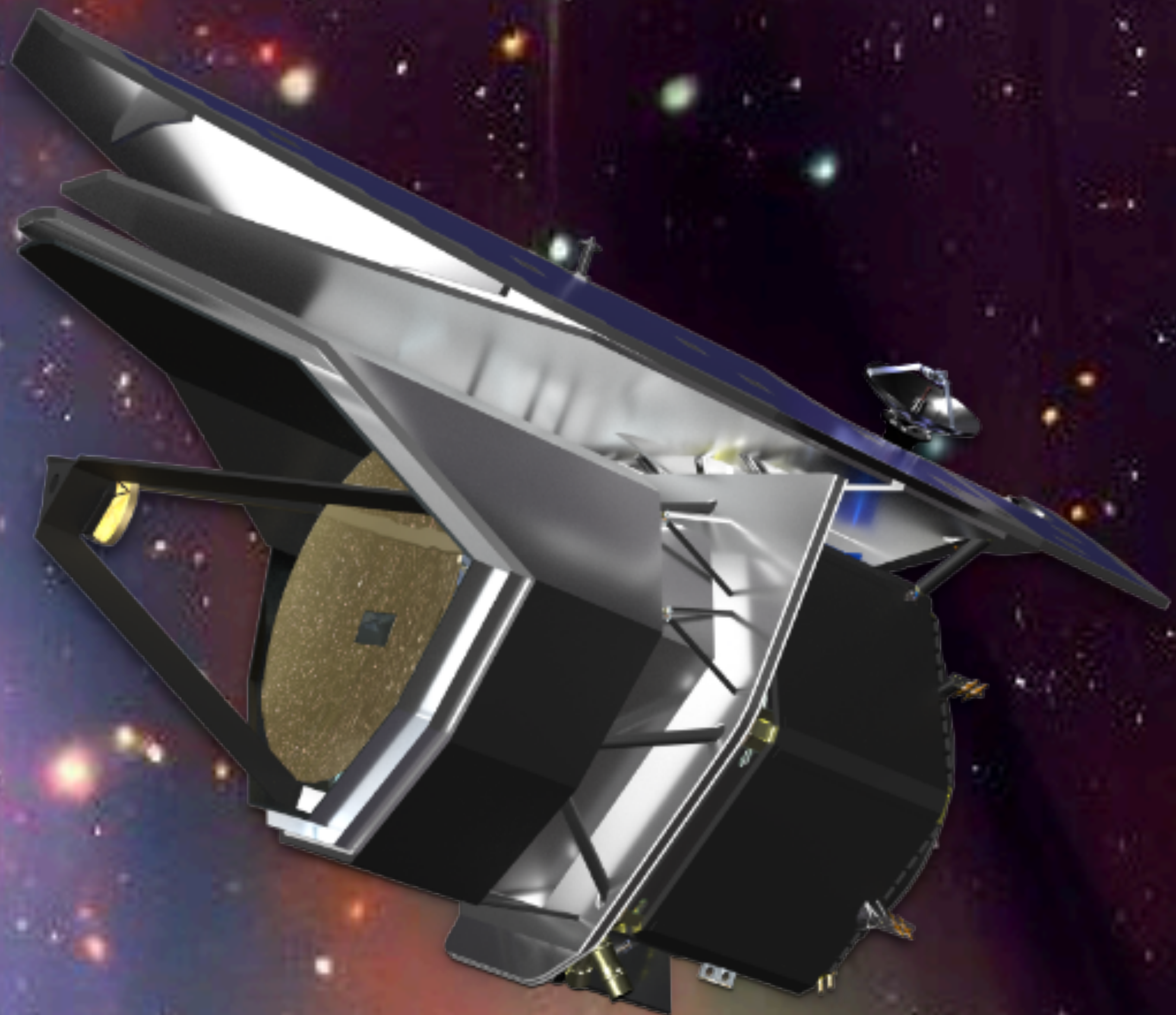
A New Hope for Obscured AGN: The Prima-NewAthena Alliance



Luigi Barchiesi

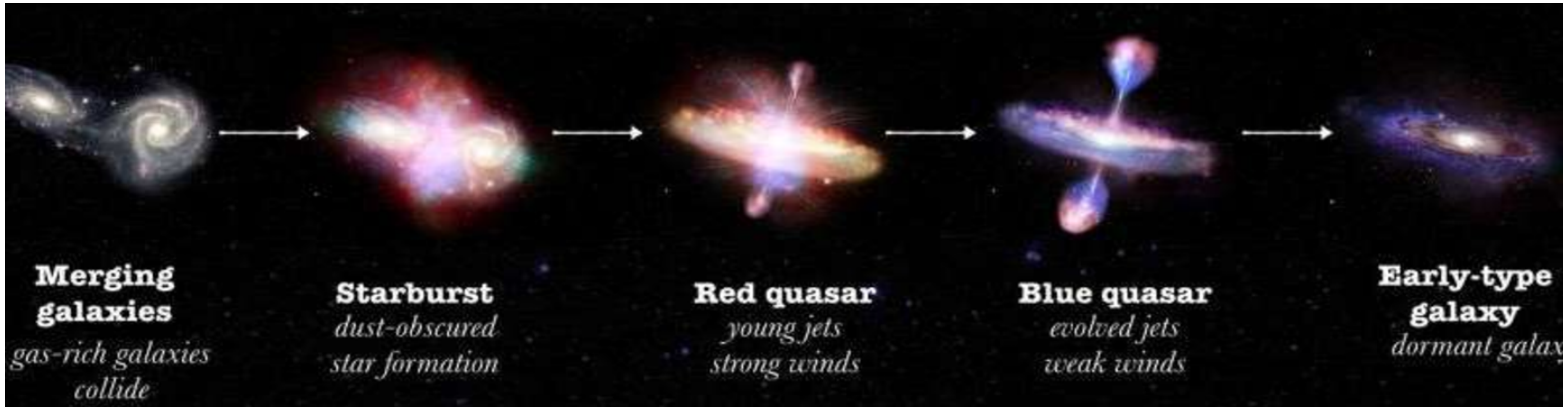
UCT

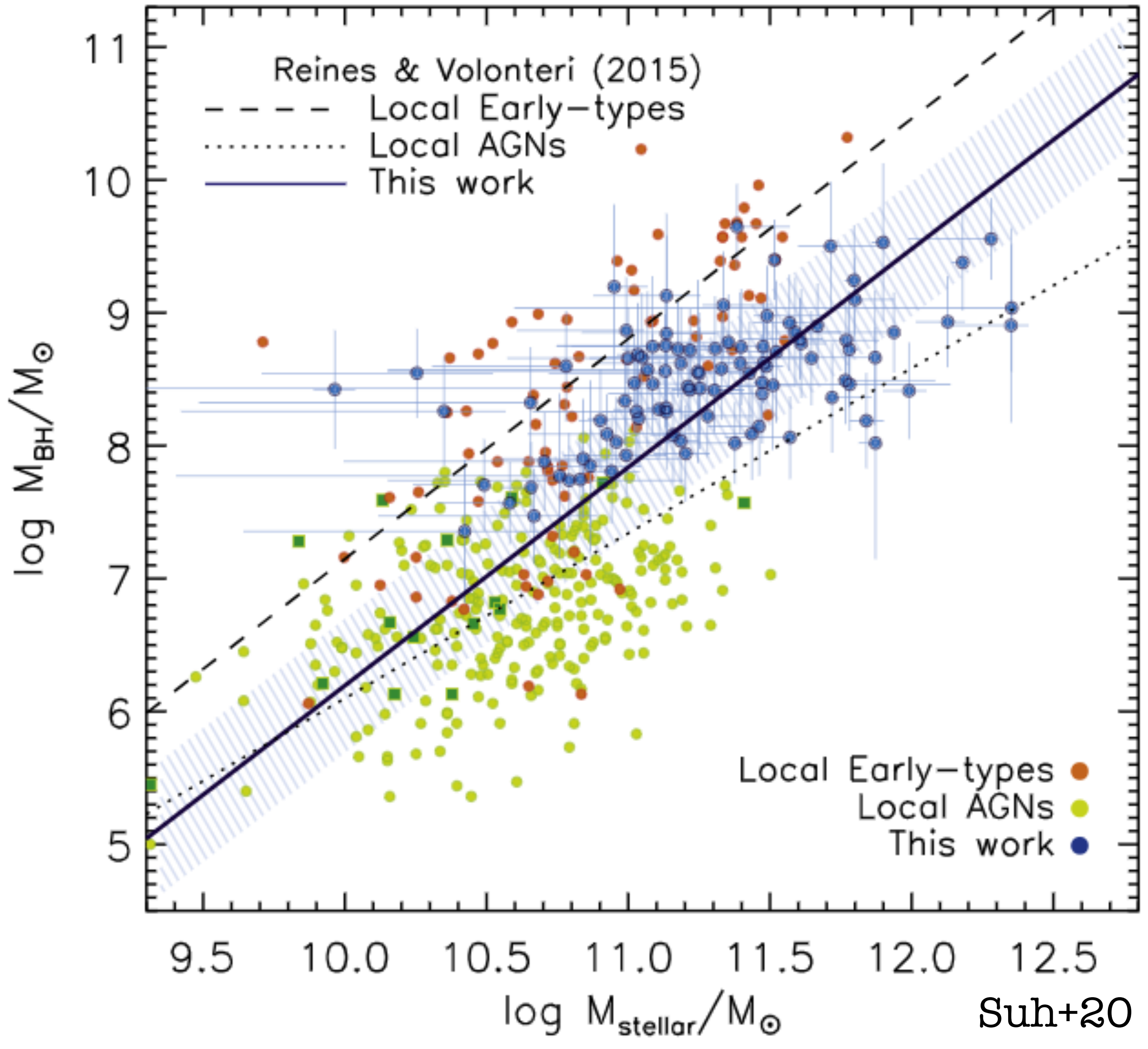
L. Bisigello, F. Calura, F.J. Carrera, I. Delvecchio, C. Gruppioni, L. Marchetti, F. Pozzi, M. Vaccari, C. Vignali

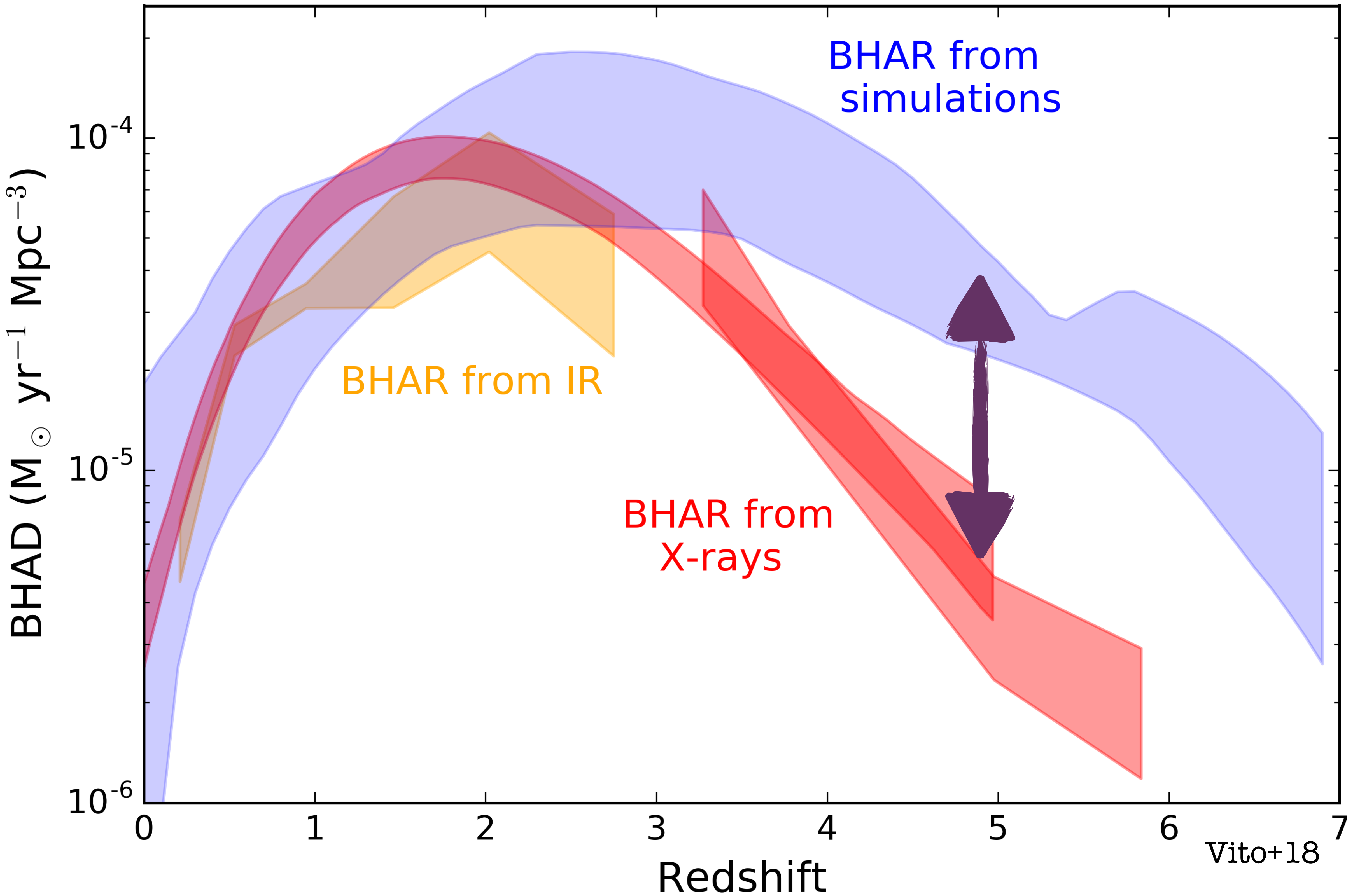
Why are we interested in obscured AGN?

Obscured AGN

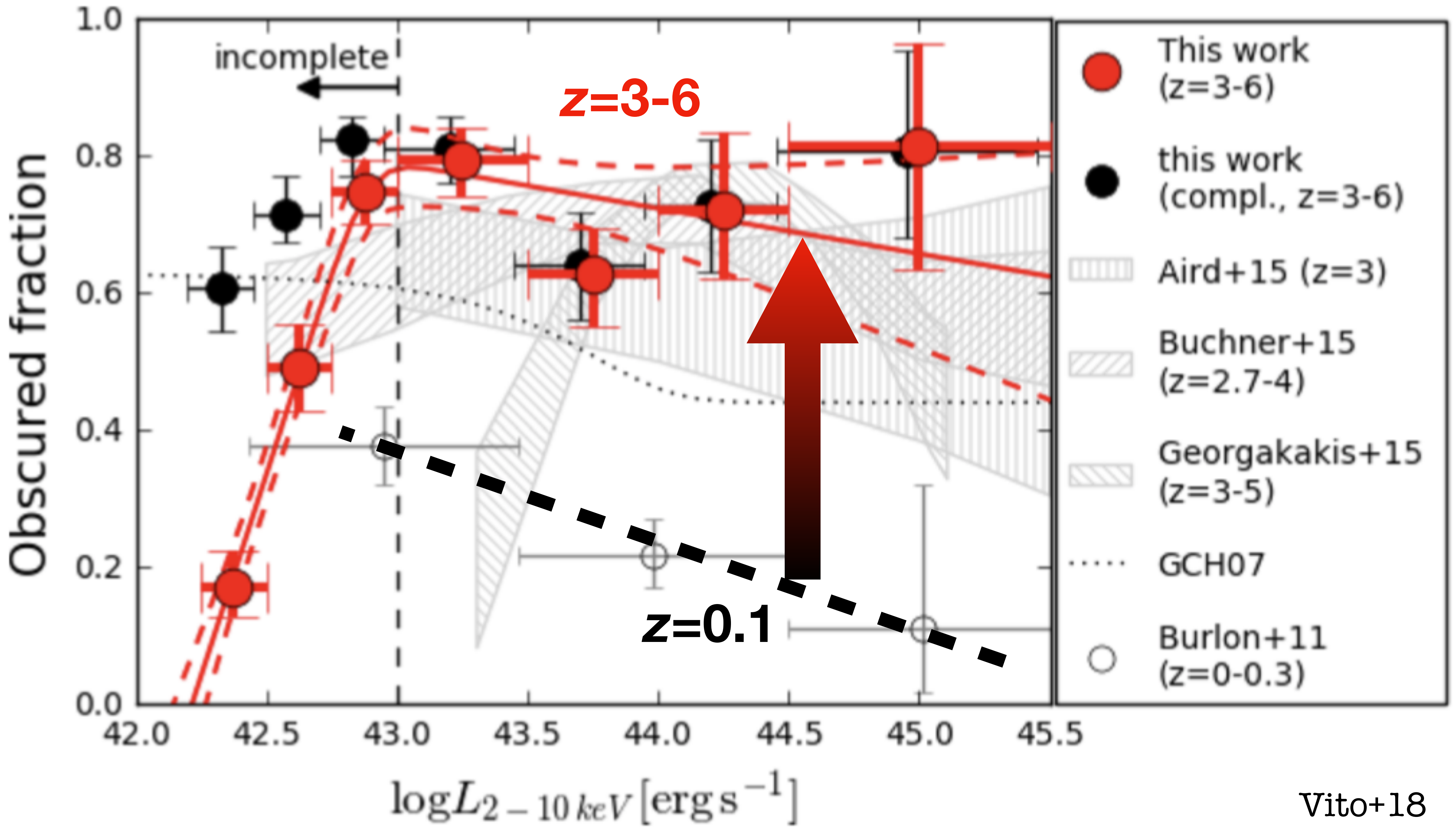
- Scaling relations between the MBH and properties of the host galaxy reveal that SF and BH growth influence each other
- **Obscured Accretion** is a key phase in the BH-galaxy co-evolution, where **most of the BH growth and SF** is expected
- **Gap** between measured **BHAD** and values expected from simulations may indicates that we are **missing a large fraction of the obscured accretion**



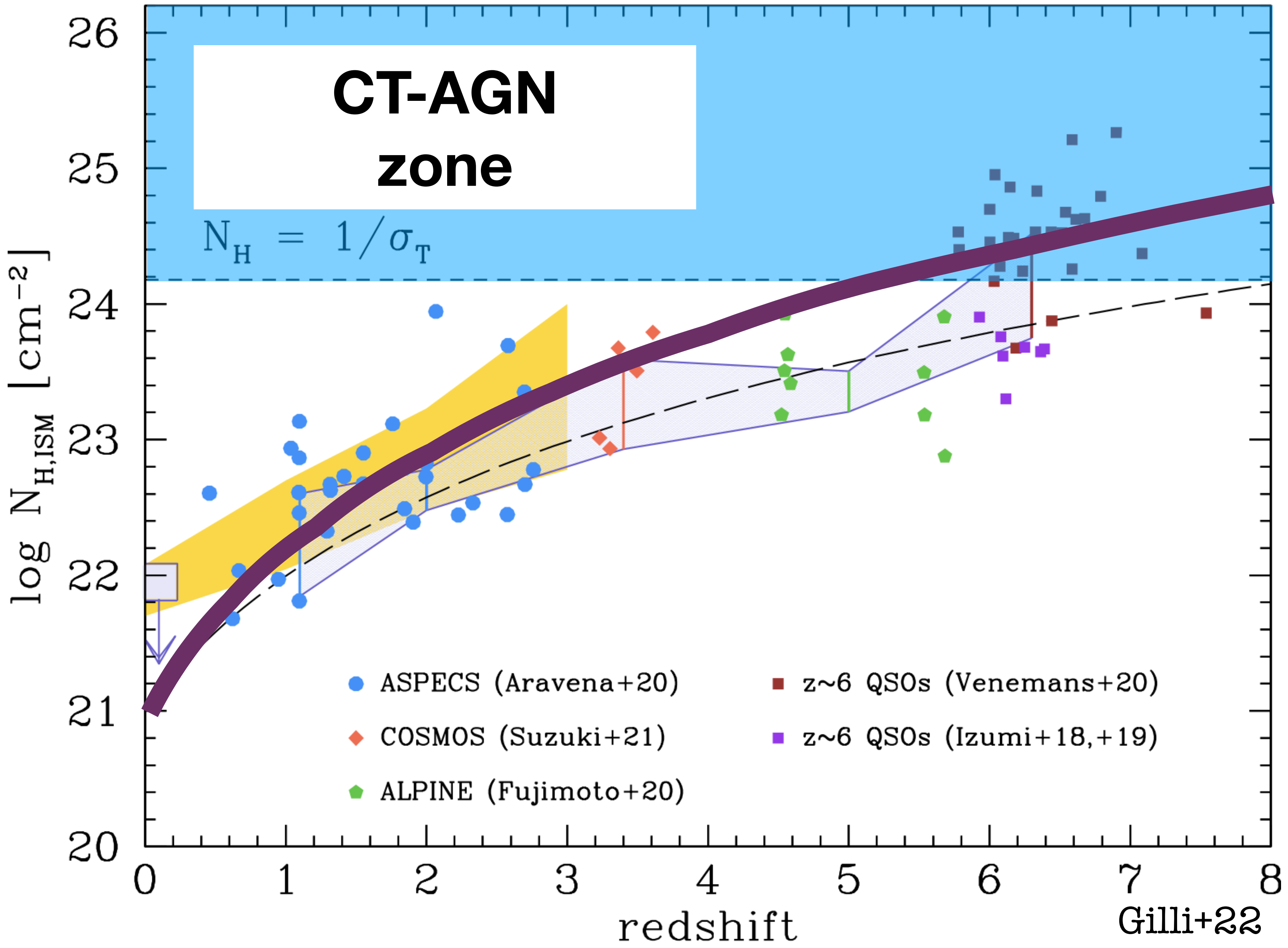




Why are we interested in obscured AGN?



Vito+18



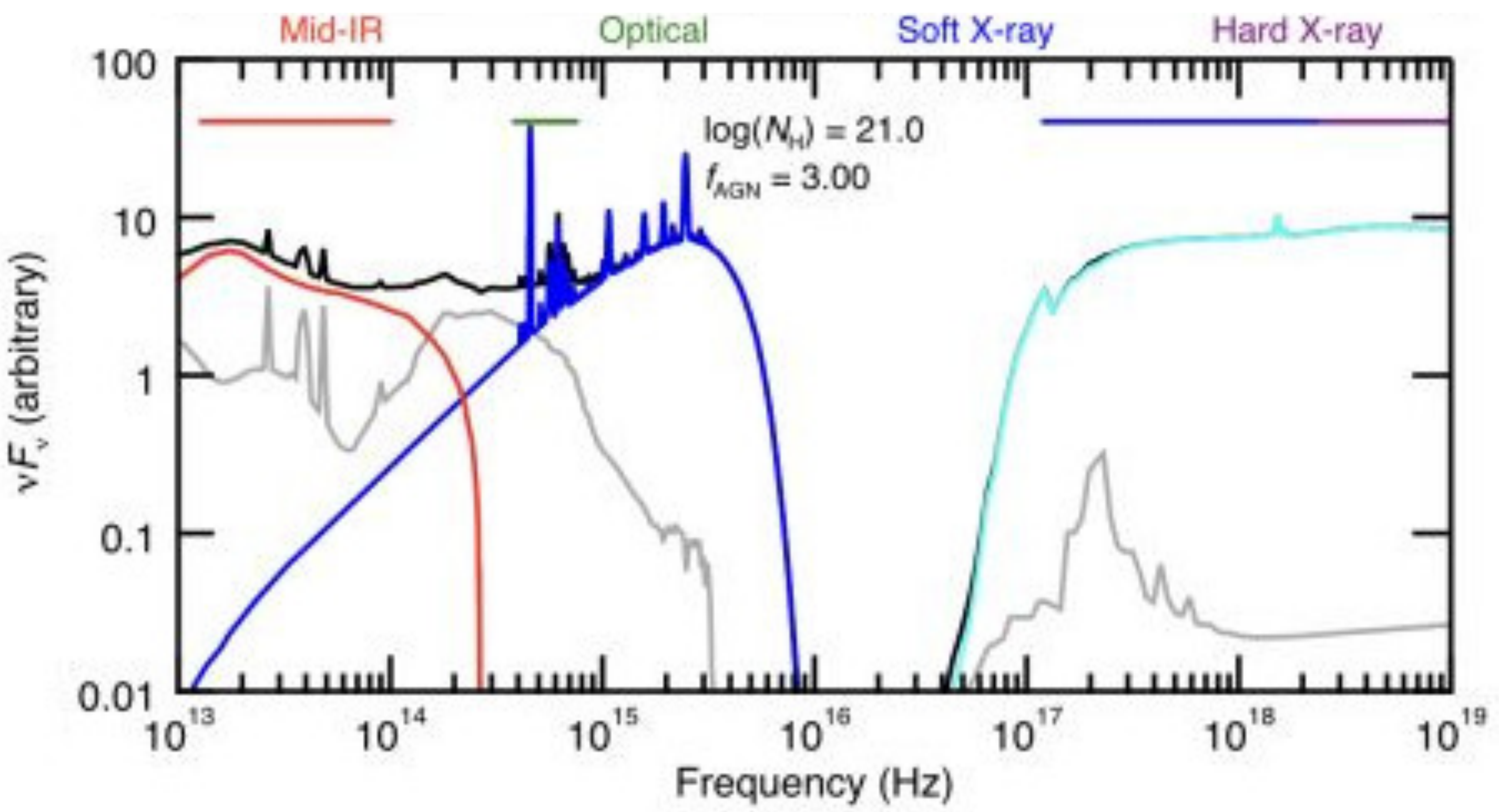
Gilli+22

Obscured AGN at high-z

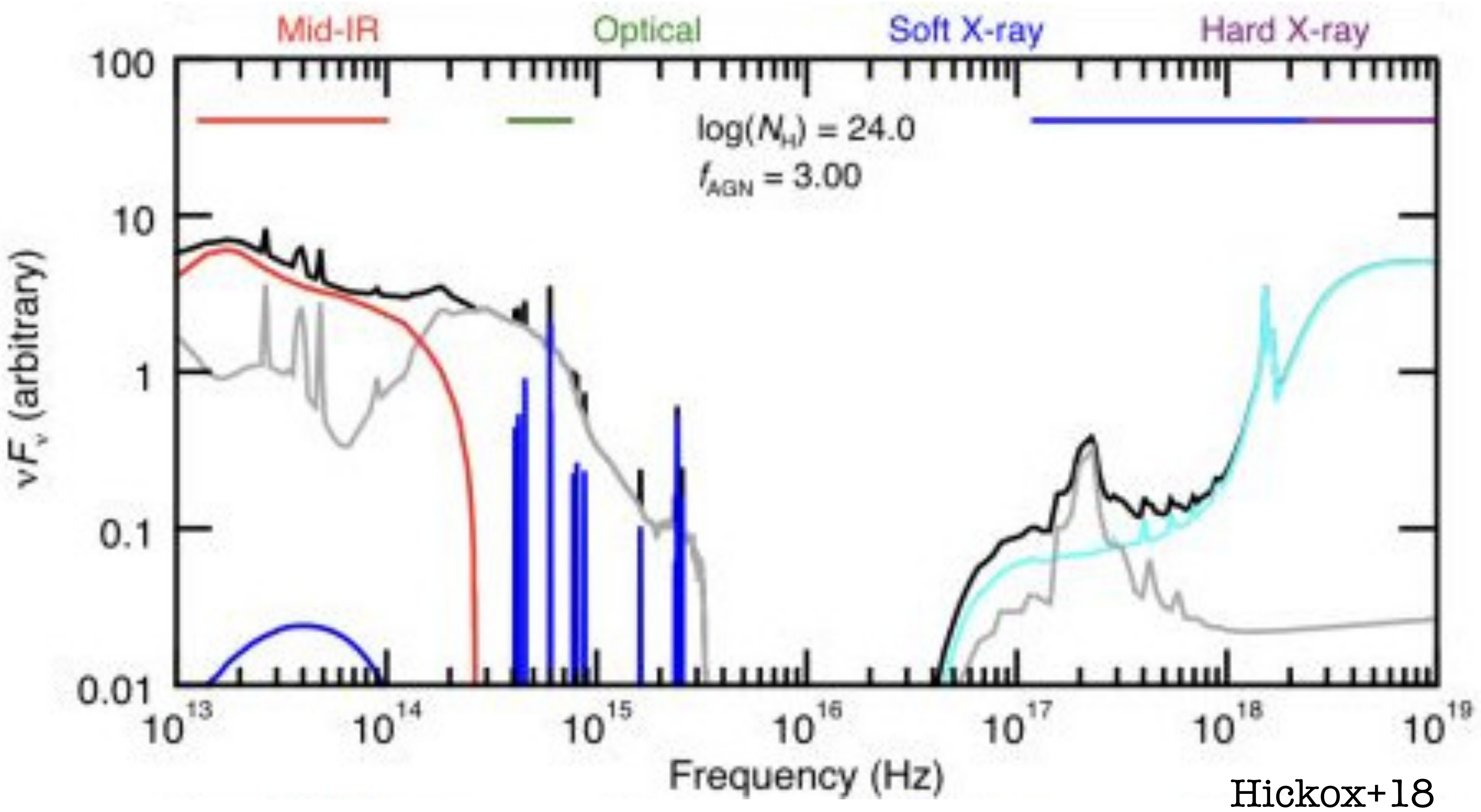
- Fraction of **obscured AGN increases with redshifted** (e.g. Vito+18)
- **High-z galaxies** tend to be more compact (Bouwens+14, Oesch+10) and more gas rich (Dessauges-Zavadsky+20) -> denser **ISM** responsible for **increasing obscured AGN fraction**
- ~80-90% of SMBH at z>6-8 are likely hidden from our view, primarily by the ISM in their host

How to select obscured AGN?

Unobscured AGN



Obscured AGN



Hickox+18

Selecting Obscured AGN

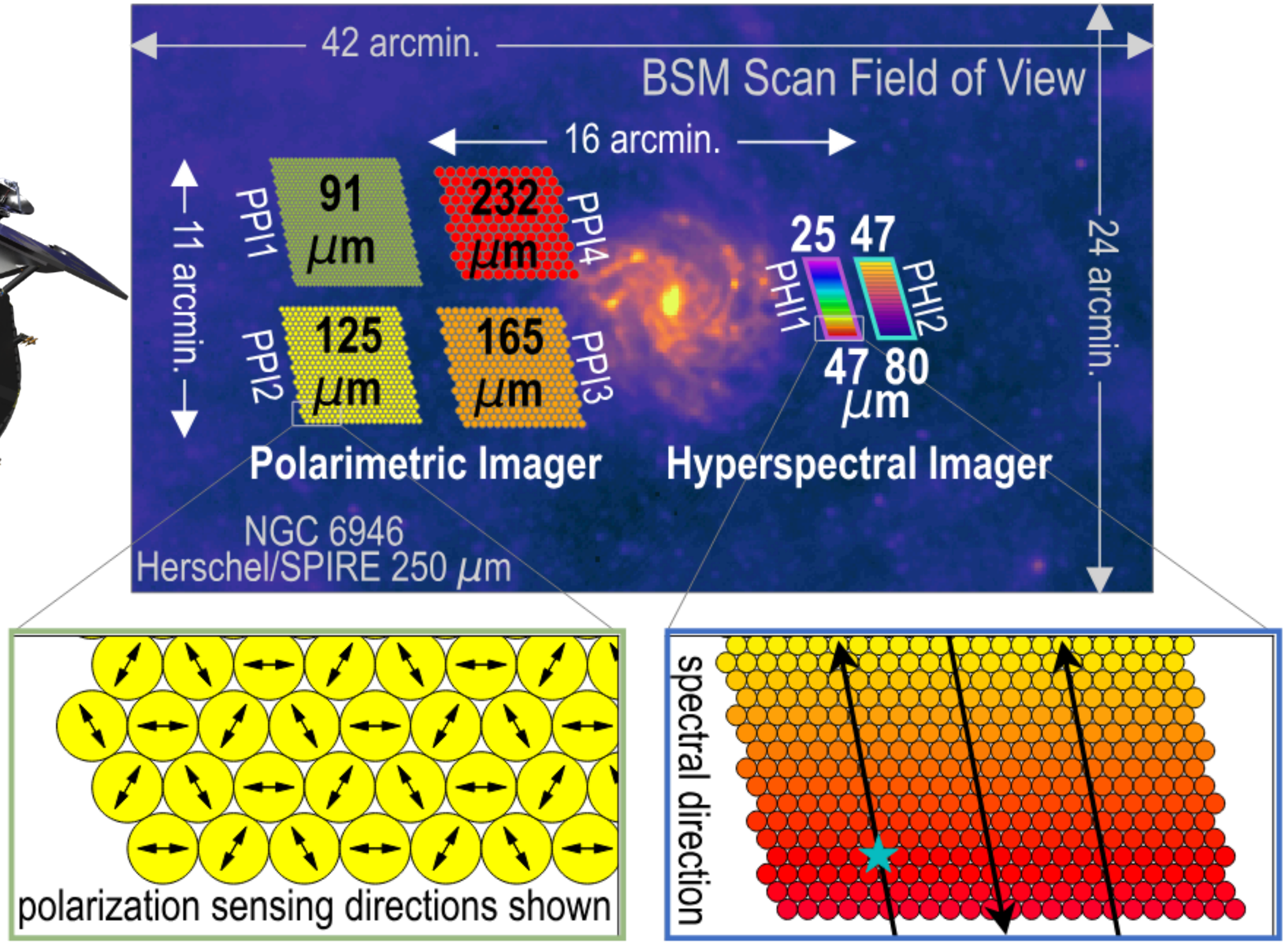
- Soft **X-rays** are a secure way to select AGN, but **absorbed for high NH**
- Hard X-rays are not significantly absorbed, allow us to characterise the obscuration. But current instruments are not so sensitive
- High ionisation lines ([OIII], [NeV]), but time expensive
- **IR** does not suffer from obscuration, it **traces the intrinsic AGN emission** reprocessed by the torus -> however, difficult to disentangle the AGN and host-galaxy emission

PRobe far-Infrared Mission for Astrophysics

- NASA mission concept with international collaboration
- Cryogenically cooled FIR observatory with 1.8m diameter
- Launch 2032
- **24-260um** wavelength range

PRIMAger

- **PHI** - PRIMA Hyperspectral Imager
  - Linearly Variable Filters - LVF
  - R=10 in the 24-80um wavelength range
  - FWHM = 4-7 arcsec
- **PPI** - PRIMA Polarimetric Imager
  - 4 filters in the 80-260um range



PRIMA collaboration

FIRESS

- 24-235um
- Low (R~100) and High (R~4400-12000) resolution spectrometer

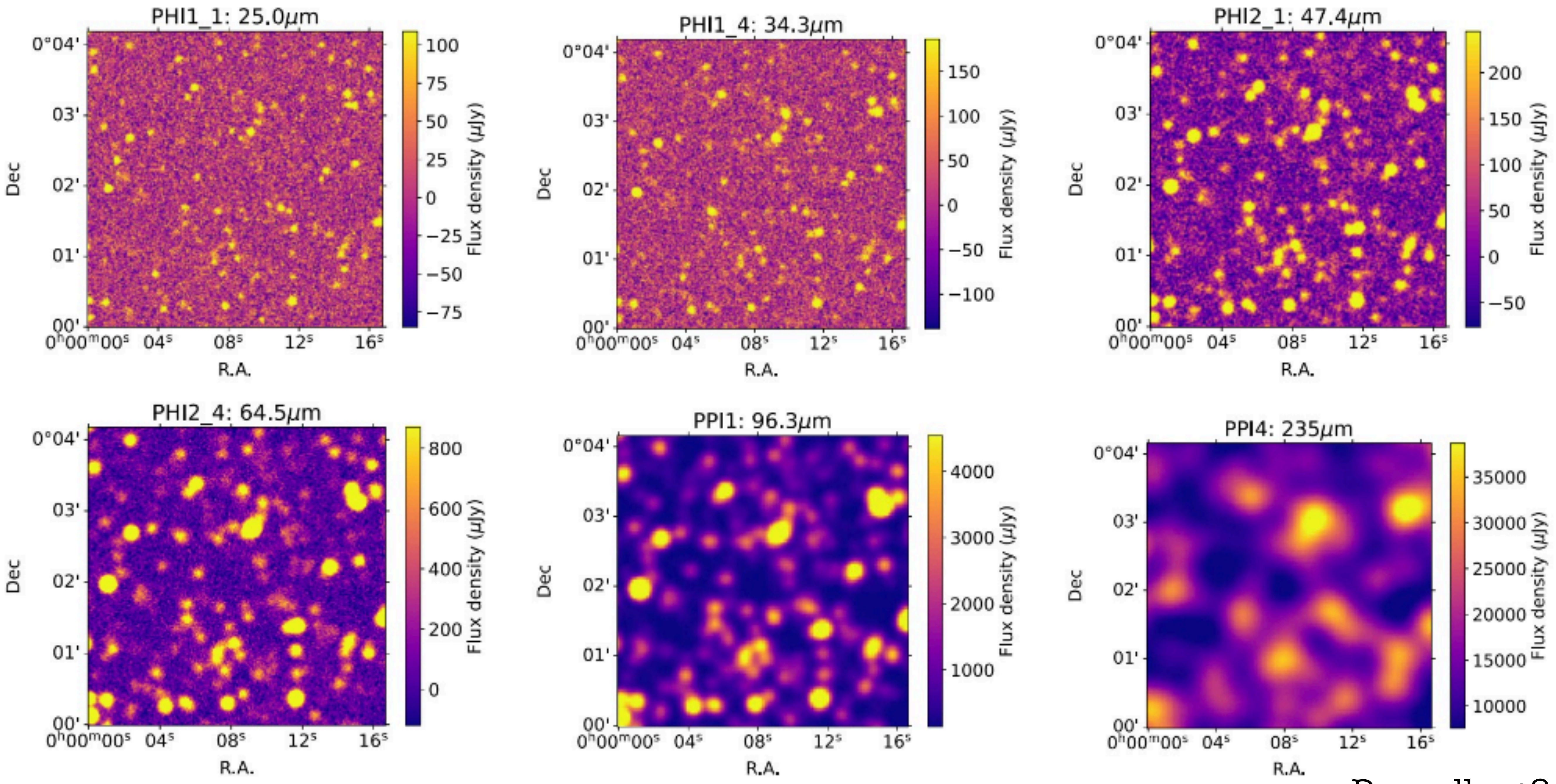
Surveys with PRIMA & Athena

PRIMA mapping speed

- up to 4 magnitude higher than Herschel at 100um
- ~2 dex better than Spitzer at 24um

PRIMA confusion

- Continuous coverage in the 24-260um range
- Deblending
- Possible priors at shorter wavelengths
- Recover the source fluxes more than 1 dex below the classical confusion limit (Donnellan+24)



Donnallan+24

Survey	Area	Instrument	t_{field}(ks)	t_{tot} (hr)	Sensitivity
Deep	1 deg^2	*PRIMAger*		1000	$92 - 229\ \mu$Jy
		NewAthena WFI	300	> 200	$1 - 2 \times 10^{-16}$ erg s^{-1}
Wide	28 deg^2	*PRIMAger*		1000	$486 - 1211\ \mu$Jy
		NewAthena WFI	200	~ 4000	$1.5 - 3 \times 10^{-16}$ erg s^{-1}

New Athena

New Advanced Telescope for High-EN Astrophysics

- ESA L class mission
- 12m focal length
- Planned launch 2037

WFI

- Wide Field Image and spectroscopy
- FWMH <170 eV at 7 keV
- **0.2 - 15 keV**
- 40x40 arcmin FOV
- Wedding cake survey strategy:
    - 12 deg2 30x300ks pointings
    - **28 deg2 70x200ks pointings**
    - 344 deg2 860x10ks pointings

X-IFU

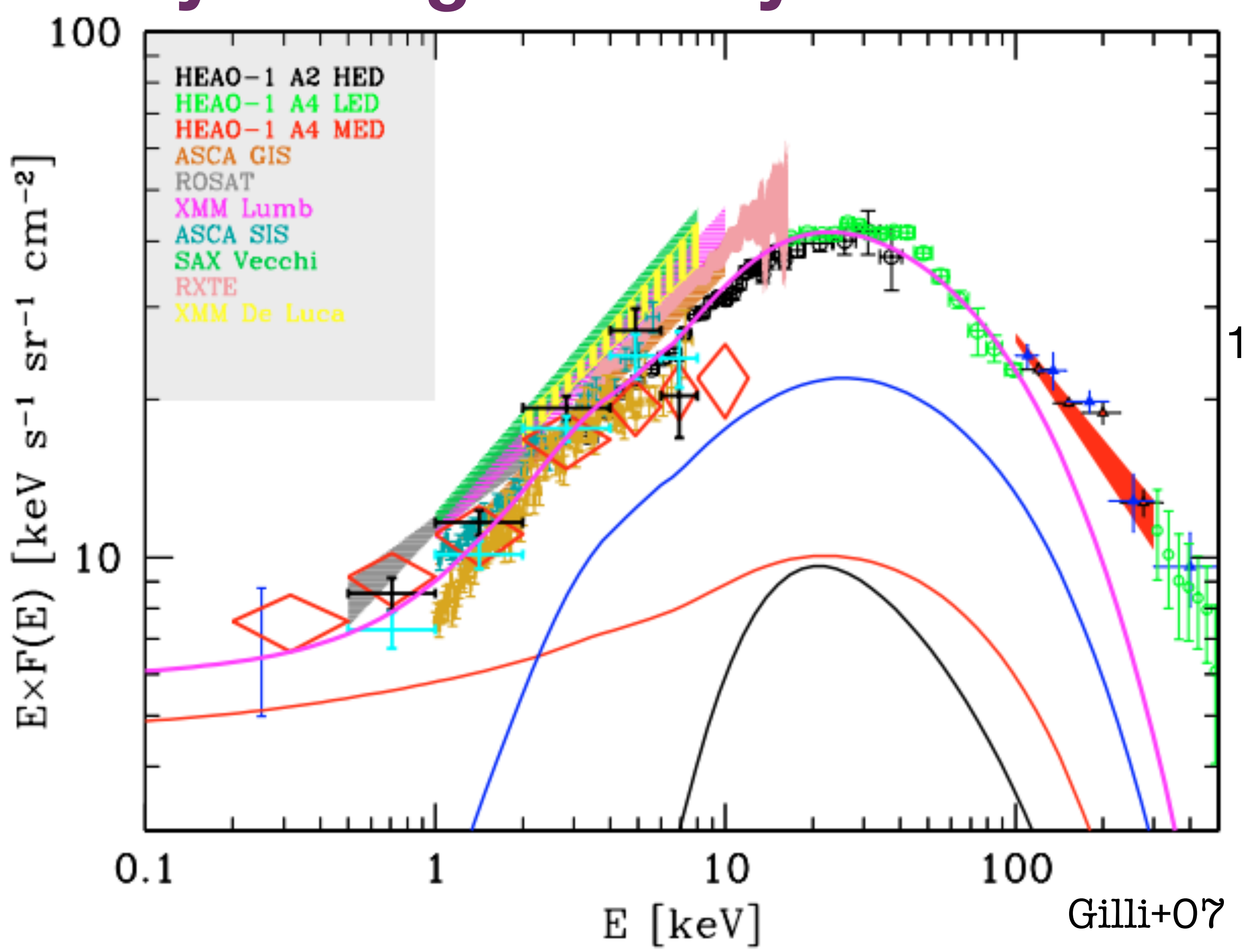
- X-ray Integral Field Unit
- Spatially resolved high-resolution spectroscopy
- 5 arcsec pixel-size with FWMH <4 eV
- 4arcmin FOV

Simulating AGN detection - X-ray

Intrinsic AGN number as function of z, N_H, and L_X

1. N_H, z, L_X bins:
   - 21 z bins $z \in [0,10]$
   - 10 $L_X \in [10^{42}, 10^{48}]$ erg/s
   - 6 N_H bins with $\log(N_H/cm^{-2}) \in [20,26]$
2. Gilli+07 **XRB synthesis model to obtain the *log N(>S)*** source density in each bin and the total intensity. S is the 2-10keV flux
3. X-ray spectral model: Brightman&Nandra11 torus + Γ=1.9 power-law + reflection

X-ray Background Synthesis Model



Unobscured

Compton-Thin
$10^{22}cm^{-2} < N_H < 10^{24}cm^{-2}$

Compton-Tick
$N_H > 10^{24}cm^{-2}$

All AGN

Simulating AGN detection - X-ray

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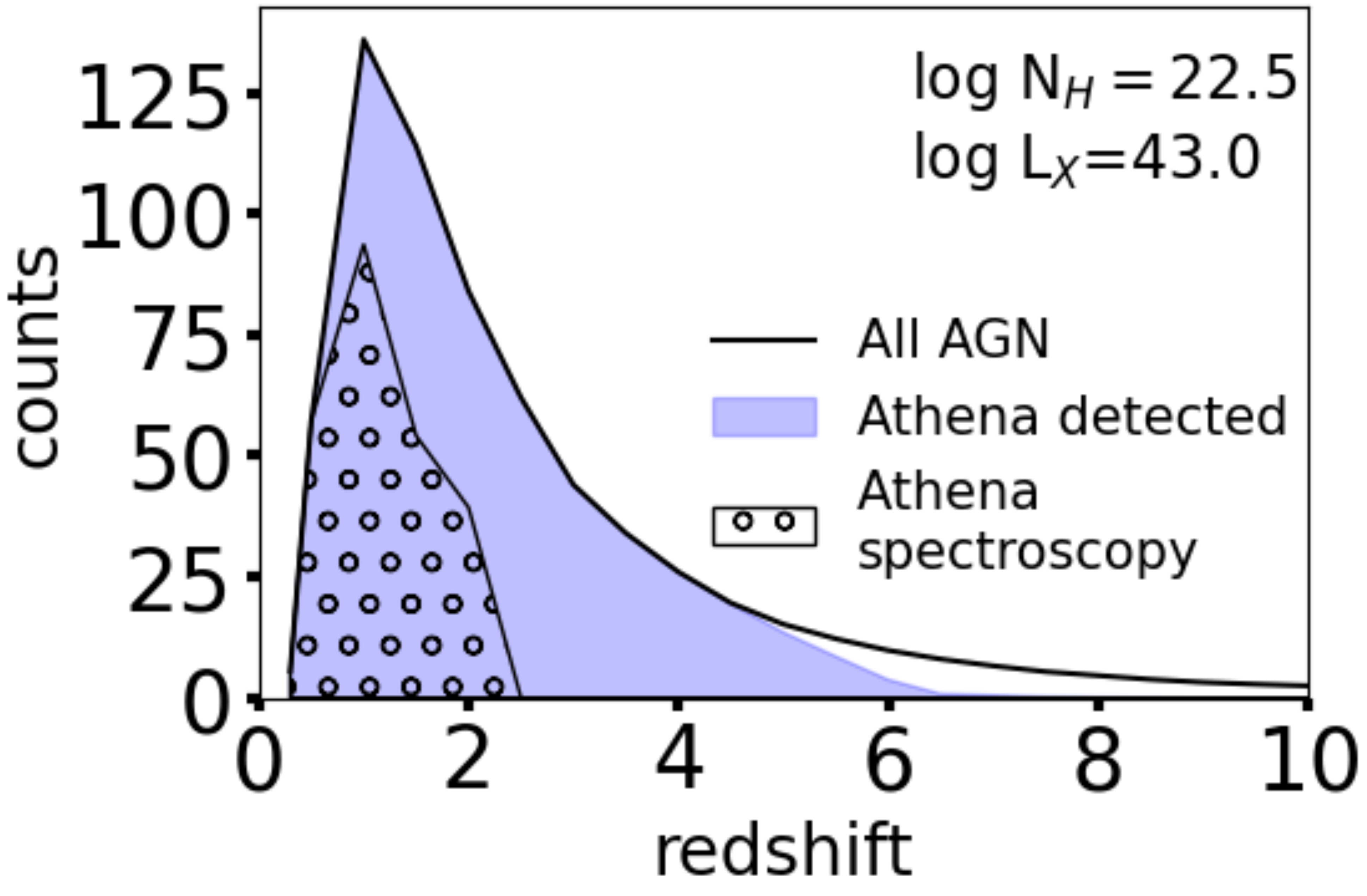
Number of X-ray detected AGN

4. Athena WFI response matrix to convert fluxes to counts
5. Inclusion of particle background, diffuse galactic background, XRB, stray light, and galactic absorption
6. Depending on the (z, L_X, N_H, t_{exp}) a fraction f_{det} will be detected. (1-f_{det}) will contribute to the background
7. 5σ detection + spectra simulation to recover L_X and N_H

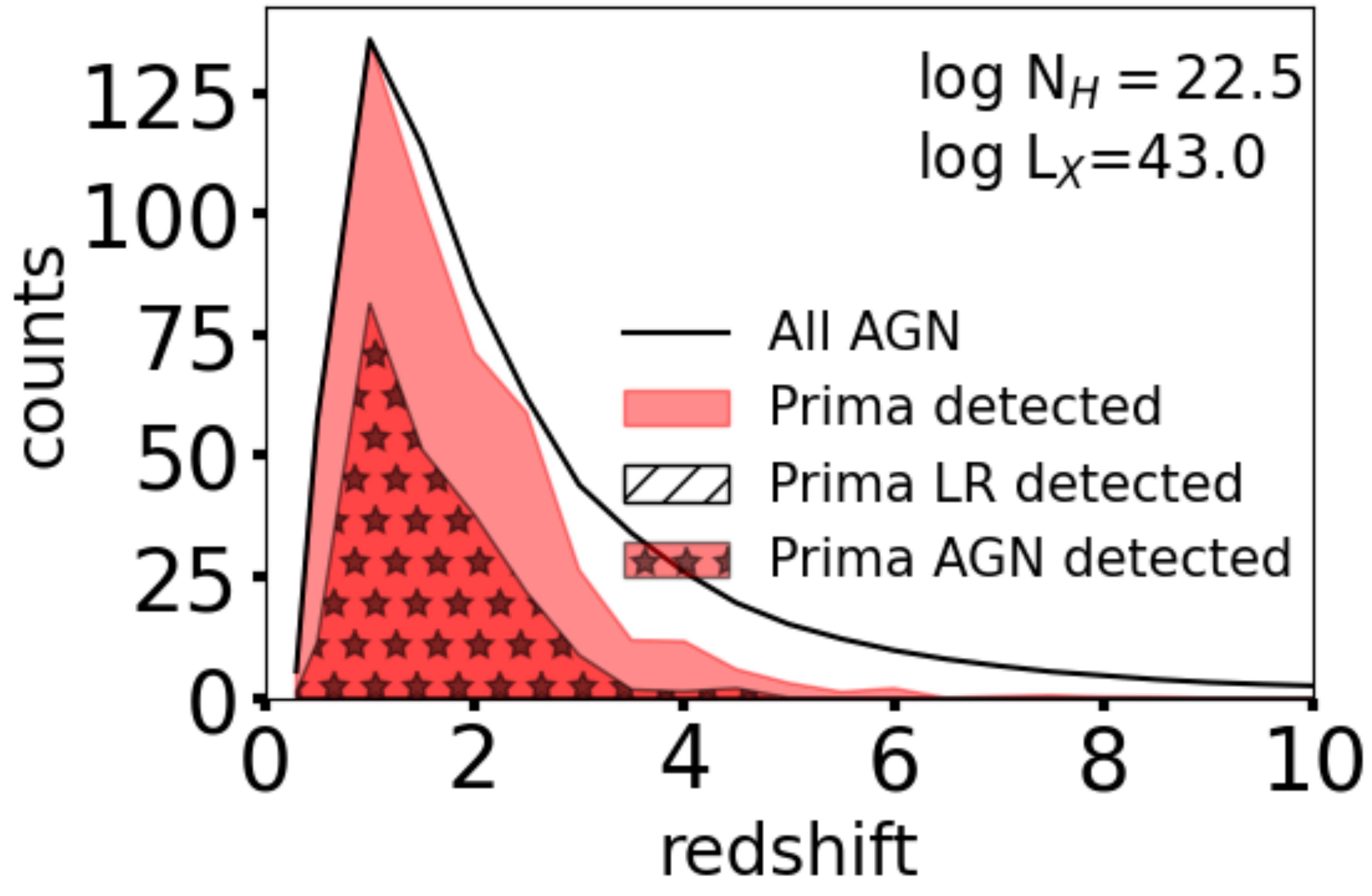
New Athena X-ray detection



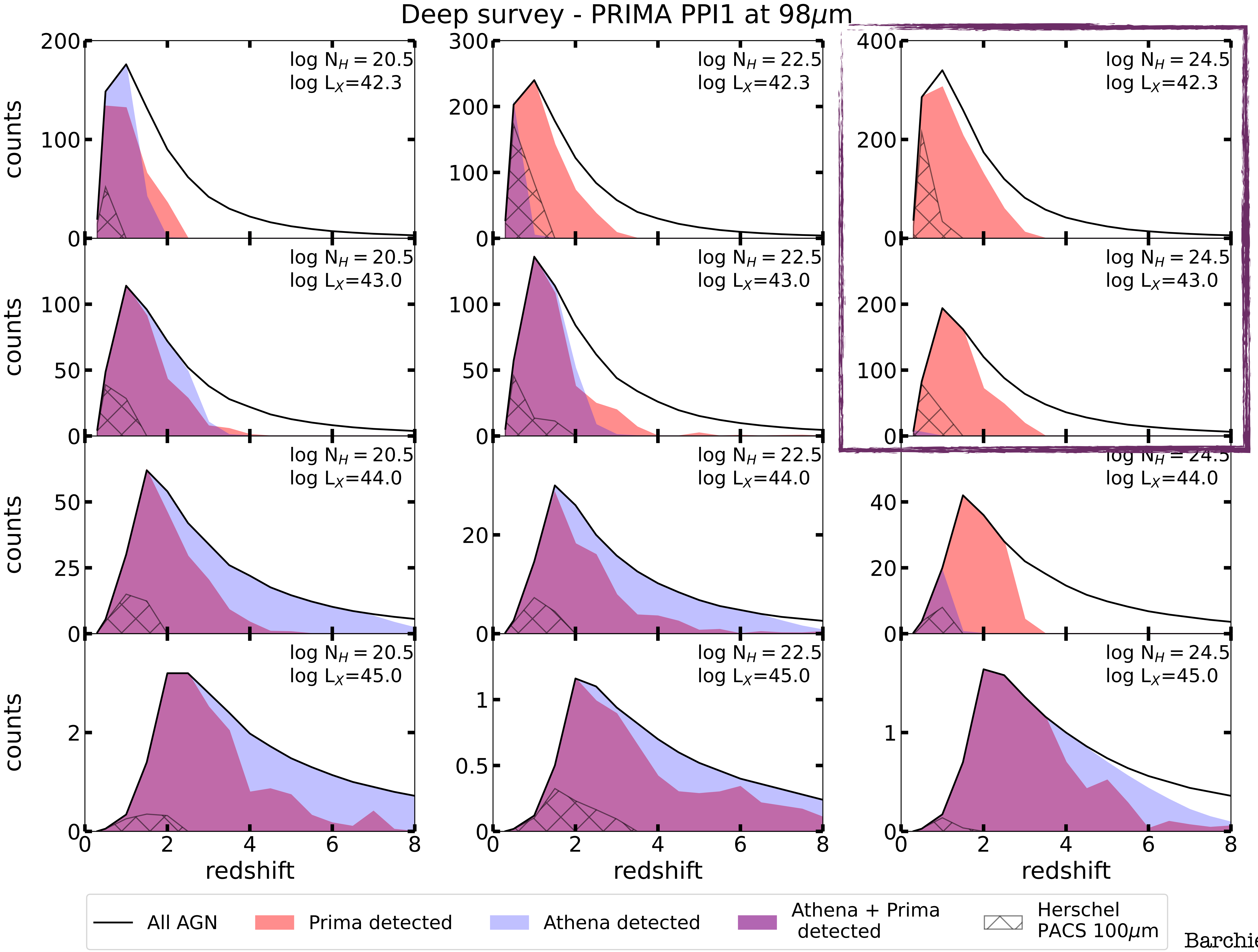
Number of IR-detected AGN

1. Sample of **422 X-ray and IR detected AGN** in the COSMOS field
2. All AGN with X-ray spectra (Lanzuisi+17) and SED-fitting (Delvecchio+14,+15)
3. For each bin we randomly extracted 20 template SED with corresponding L_X and N_H
4. Measure the **total flux in each band**
5. If **flux > 5σ detection limit** -> **the AGN is detected**
6. Check if the host or the AGN is the dominant source of emission in the filter

PRIMA IR detection

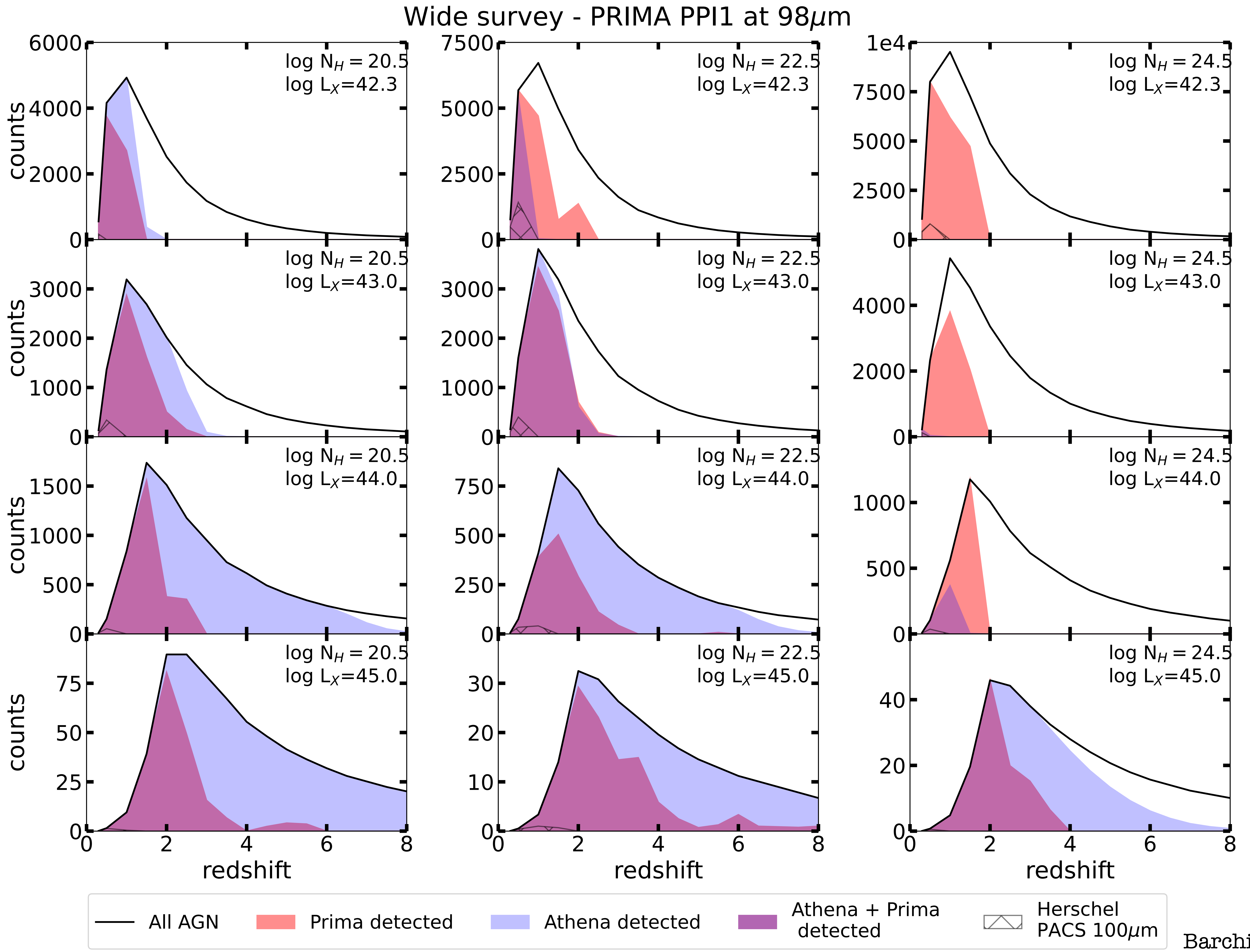


AGN detection @~100um - Deep survey



Barchiesi+25

AGN detection @~100um - Wide survey

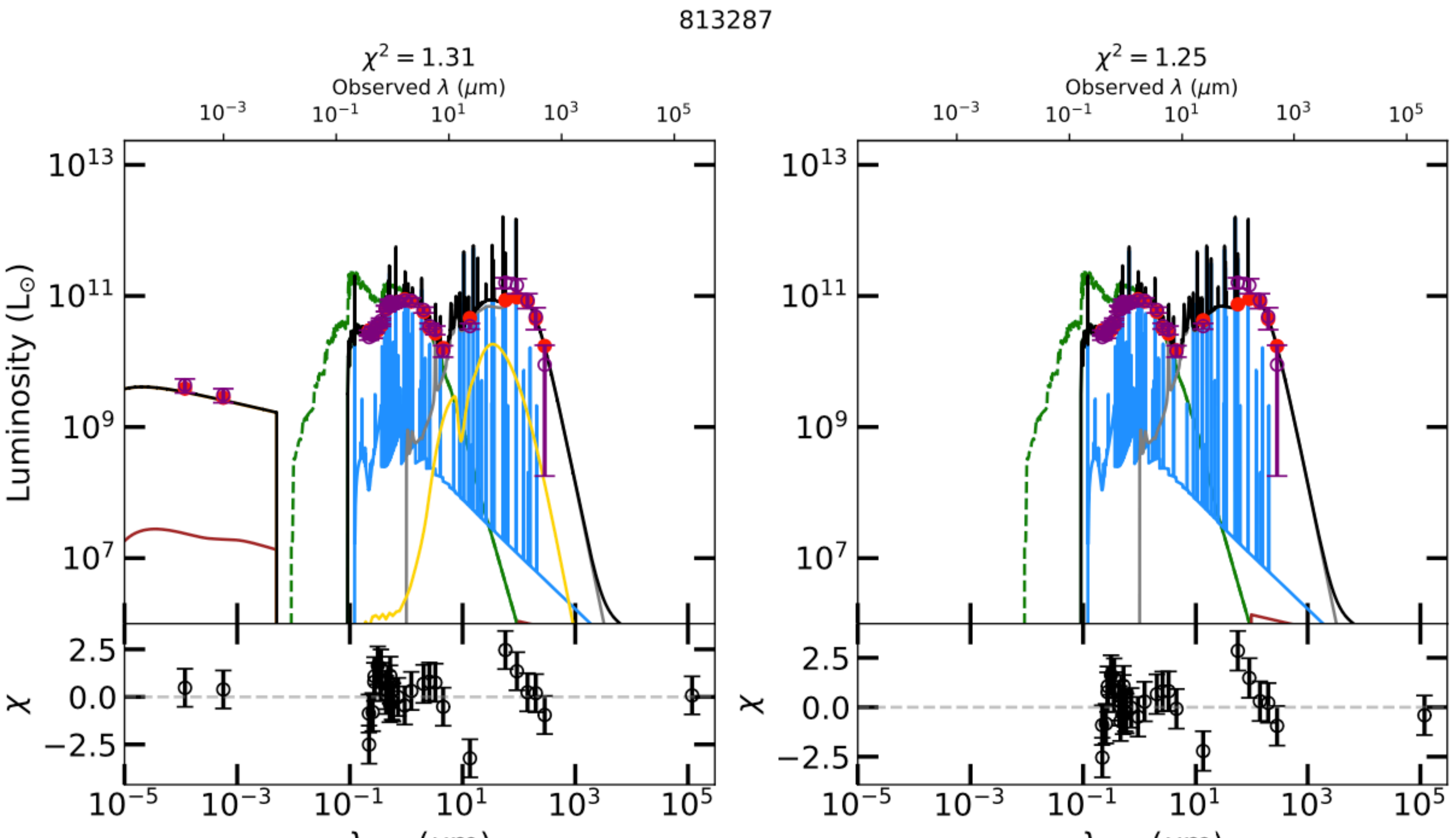


Barchiesi+25

28 deg² Wide Survey

- > 200,000 AGN detected
- > 90,000 CT-AGN

PRIMA - NewAthena synergies

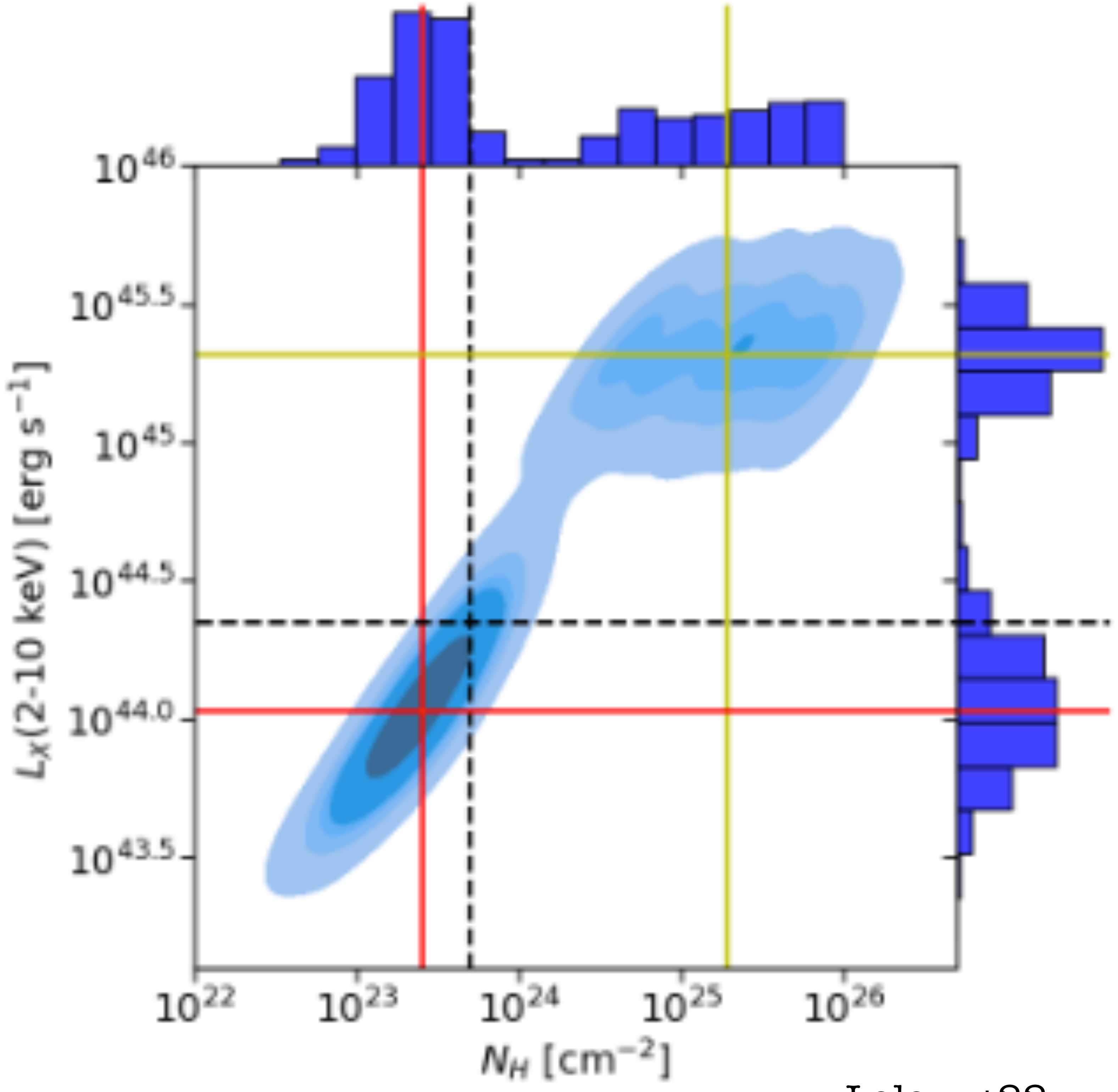


Barchiesi+ in prep

X-rays -> IR

- X-ray detection helps in revealing and constraining the AGN emission, especially when the SED is host-galaxy dominated

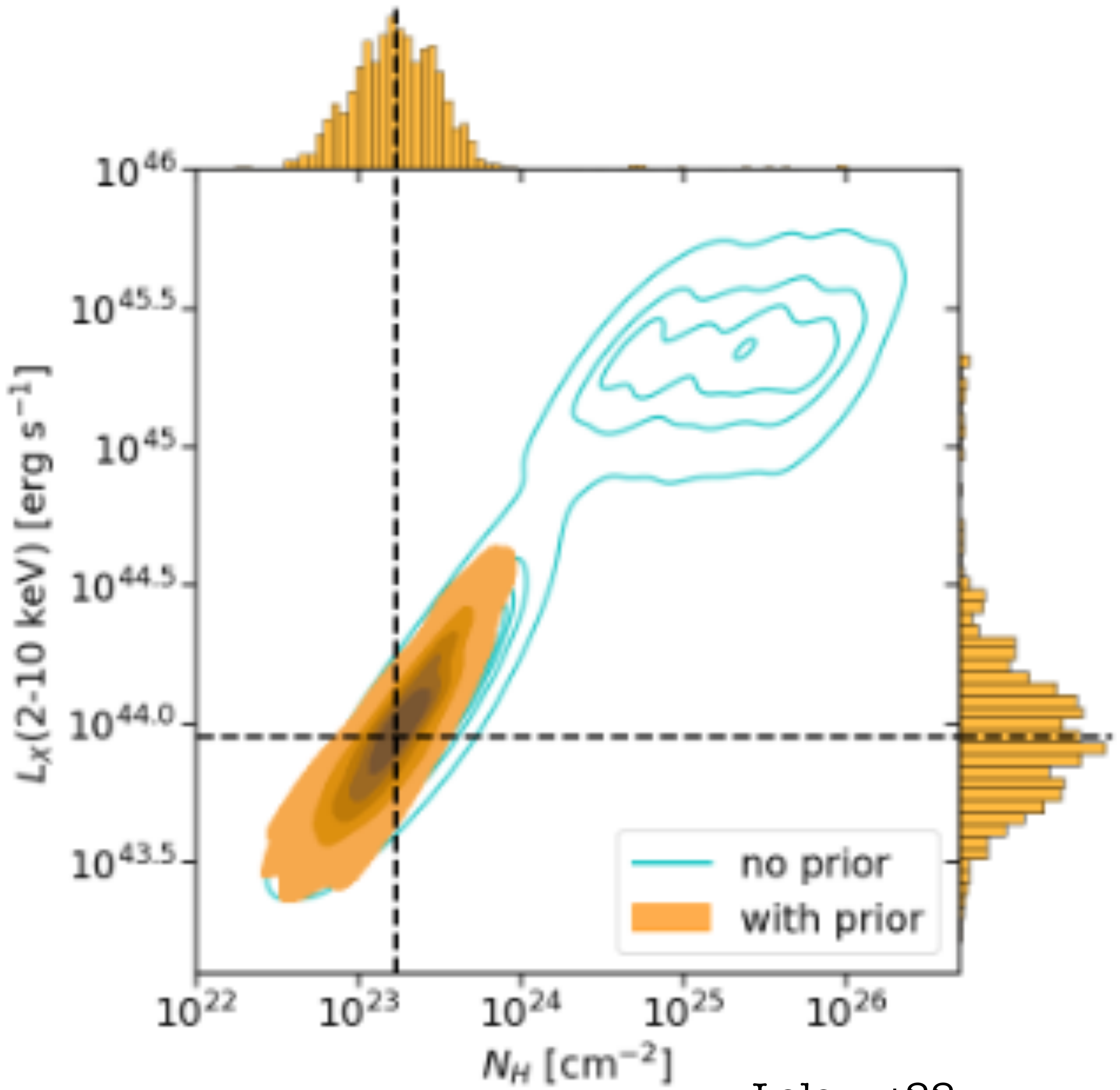
Only X-rays



Laloux+22

Density plot of the posterior distribution

IR priors + X-rays



Laloux+22

X-rays -> IR

- X-ray detection helps in revealing and constraining the AGN emission, especially when the SED is host-galaxy dominated

IR -> X-rays

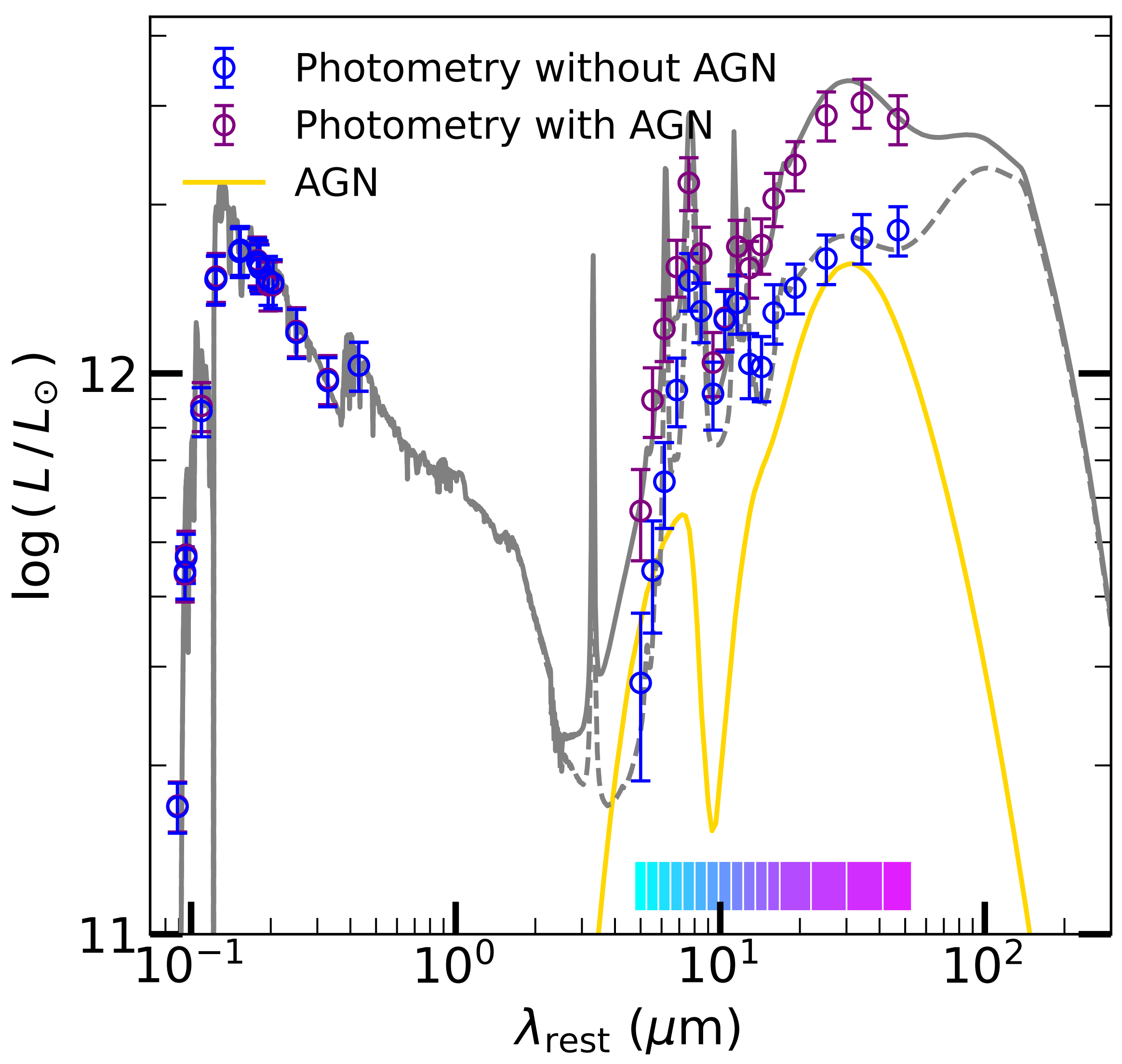
- IR SED-fitting to place constraints on the AGN intrinsic luminosity
  -> it helps in solving the degeneracies between X-ray luminosity and obscuration, especially for CT-AGN

AGN detection - PRIMA photometric coverage

Can we recognise them as obscured AGN?

CIGALE to simulate high-z AGN observations

- **Simulate** ~12000 **AGN and galaxies SED**
- 6 redshift bins in the 1 < z < 6 range
- 1280 different sources per bin
  - $M_* = 5\times10^{10}\ M_\odot$, $5\times10^{11}\ M_\odot$
  - $\log(\mathrm{SFR} / M_\odot\ \mathrm{yr}^{-1}) \in [-5, 4]$
  - $\log(L_{bolo} / \mathrm{erg\ s}^{-1}) \in [43, 48]$
- Optical NIR photometry similar to COSMOS2020
- **Add gaussian noise** for PRIMA Deep survey
- **Performed SED-fitting** and **compared measured values with the intrinsic ones** used to generate the SED



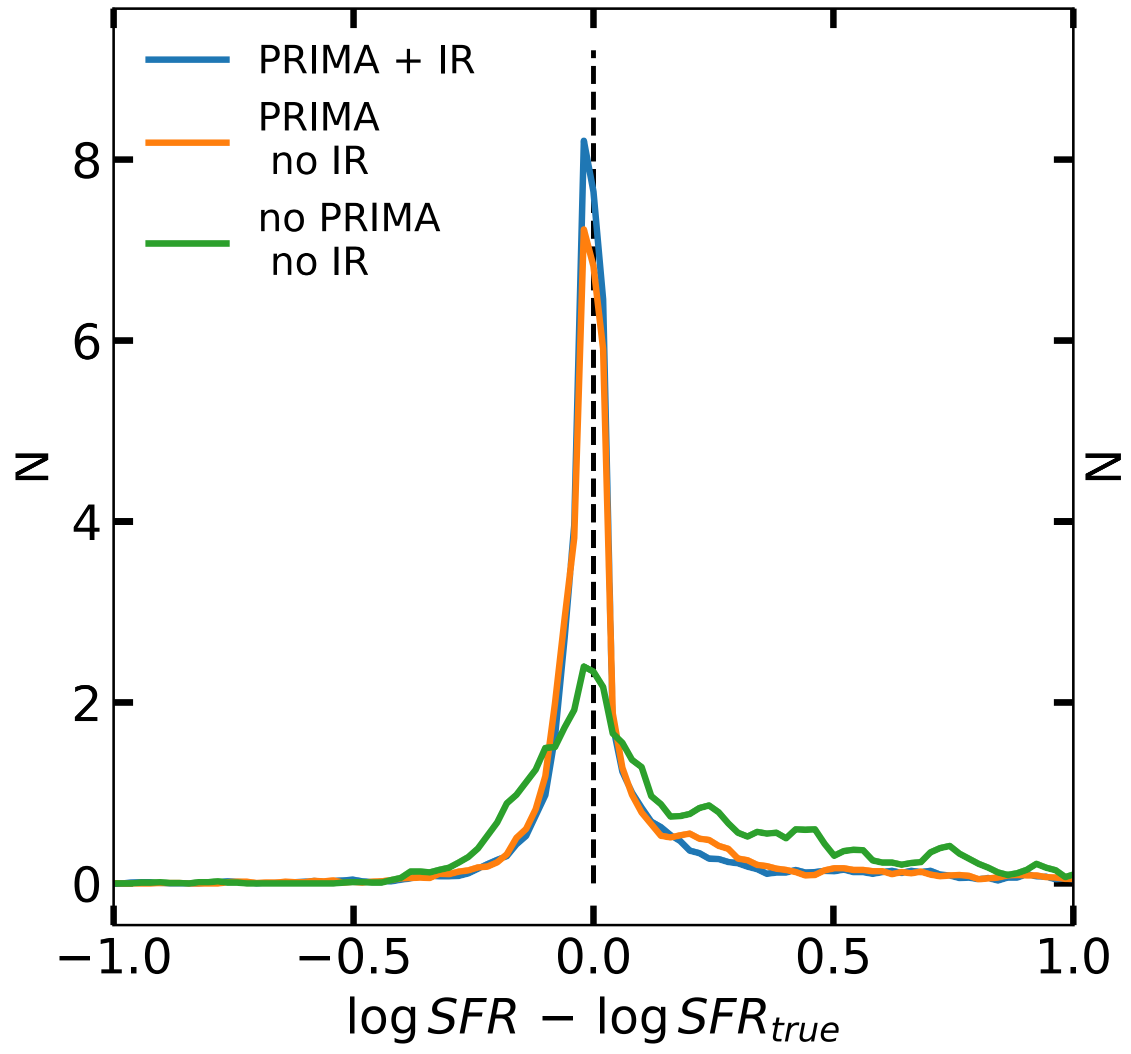
z=4

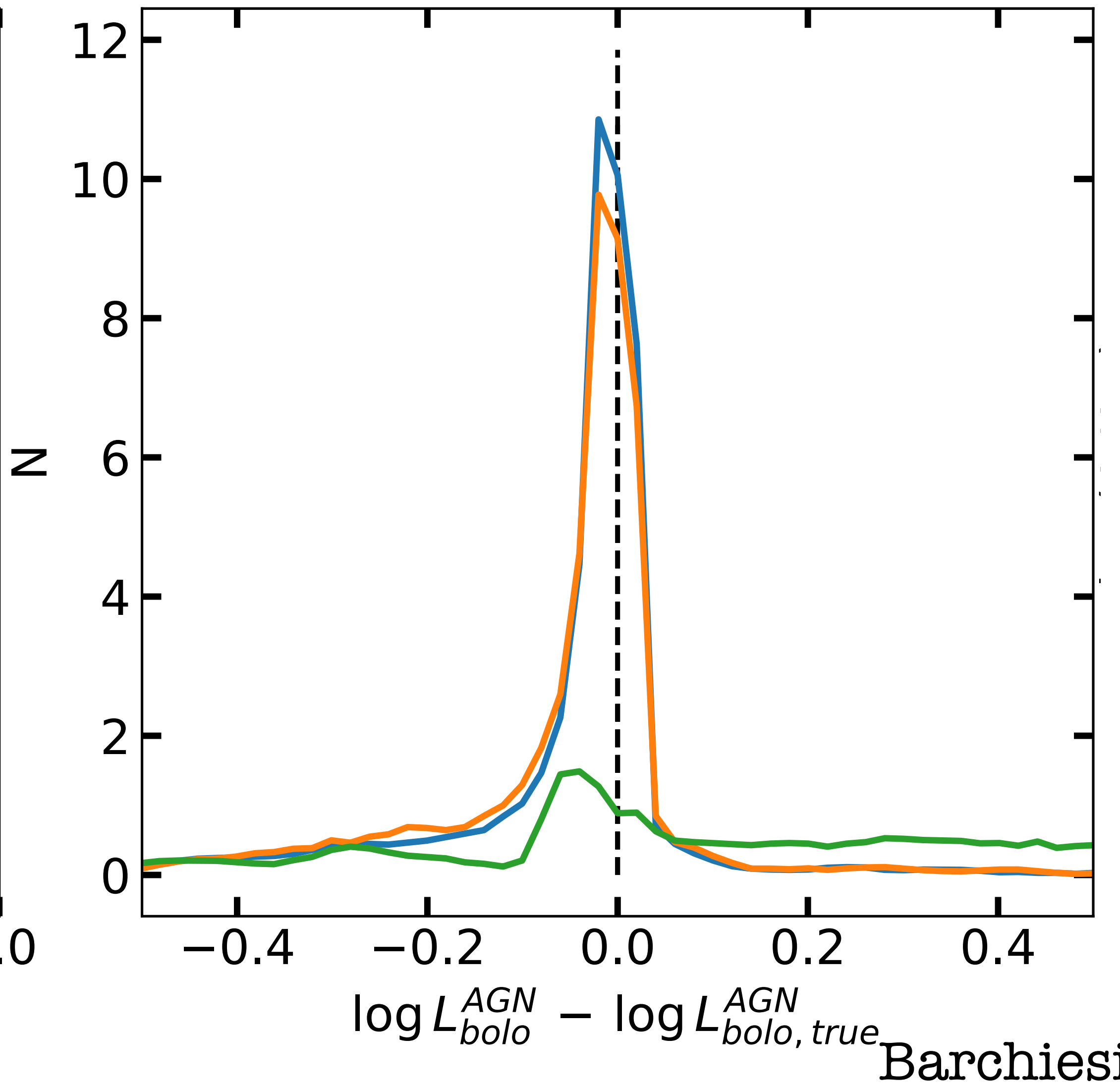
$\log(M_*/M_\odot) = 10.1$

SFR = 150 $M_\odot$/yr

$\log(L_{bolo} / \mathrm{erg\ s}^{-1}) = 45.6$

Normalised distribution of the difference between estimated and true value

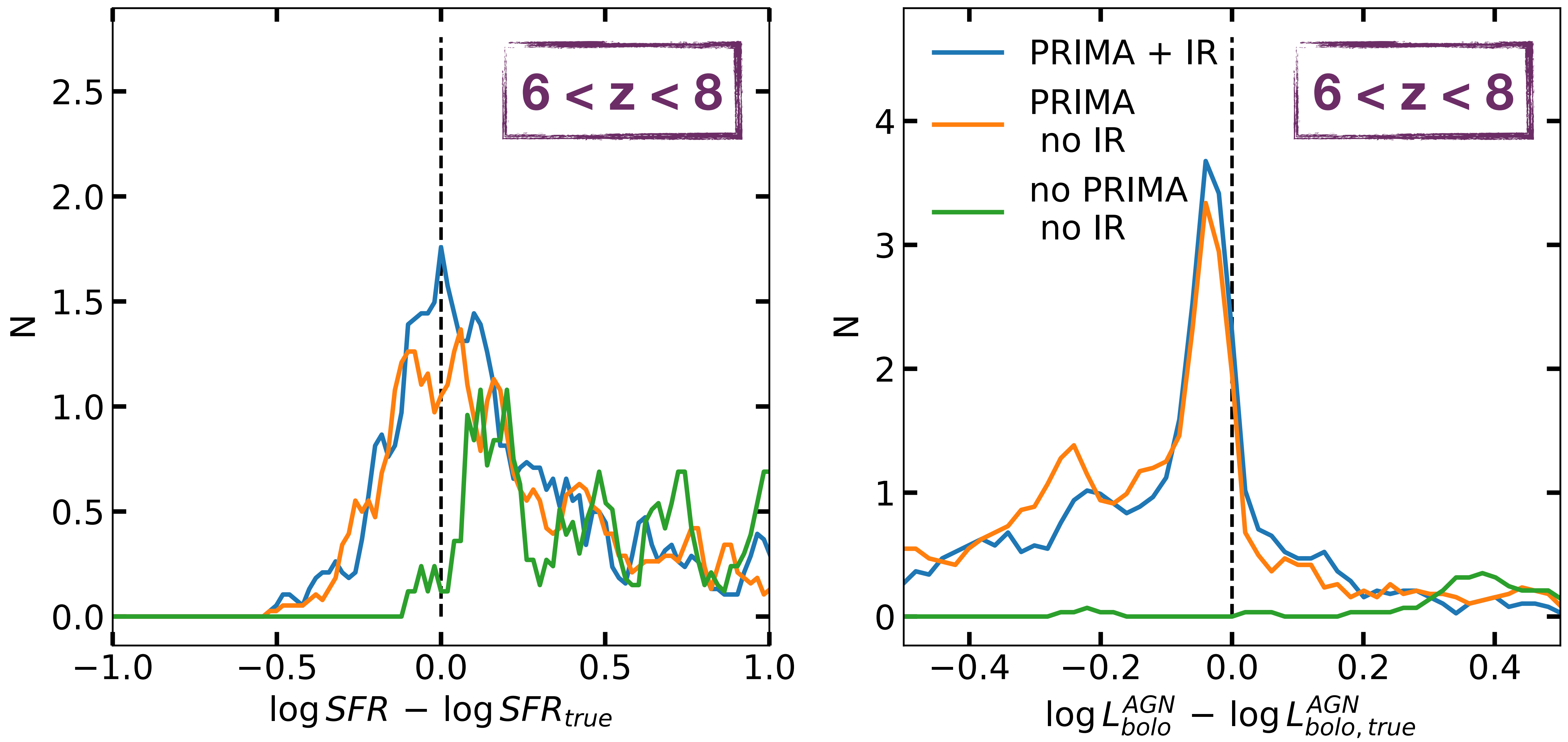


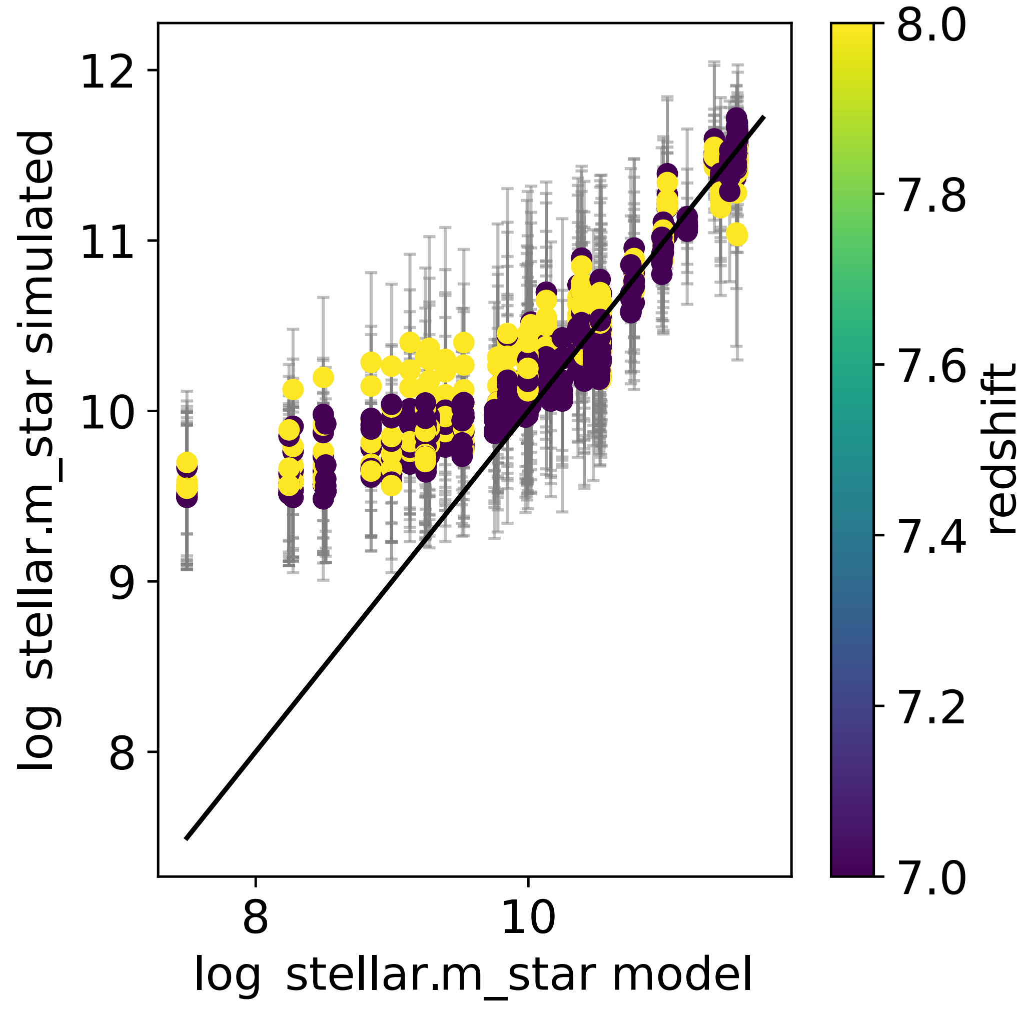


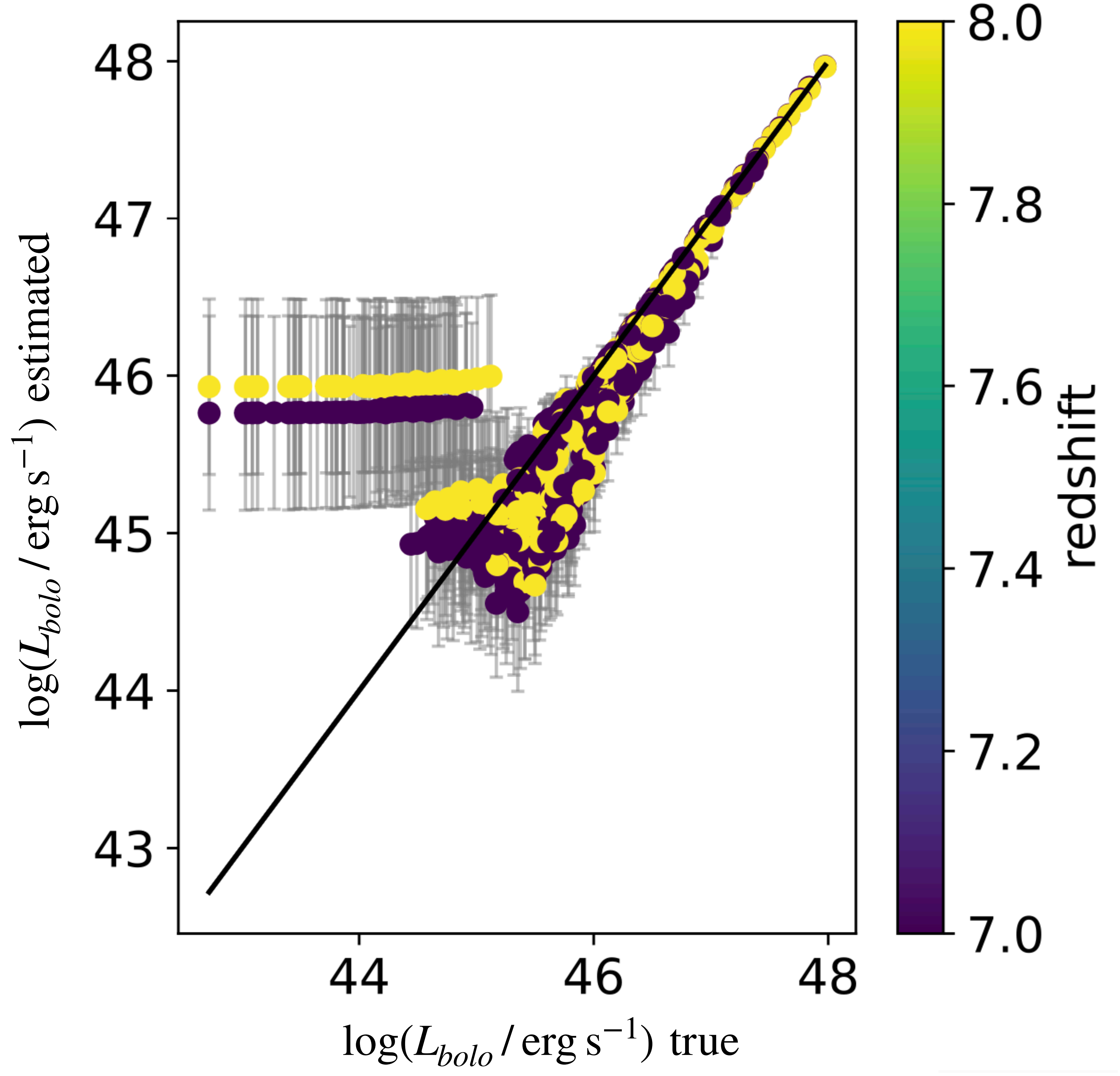
Barchiesi+25

Can we recognise them as obscured AGN? Even at z>6 ?

Normalised distribution of the difference between estimated and true value







AGN Bolometric LF and BHAD with PRIMA

Estimating the BHAD with PRIMA

- 11 redshift bins (Delvecchio+14 up to z~3 + extension up to z=10)
- L_{bolo} bins from L_X bins with Lusso+14 k_{bol}
- **Extracted N SED for each bin**, N is the expected number of object
- Removed those that would be undetected
- Used the remaining to compute the $\mathbf{V_{max}}$ and the **LF**

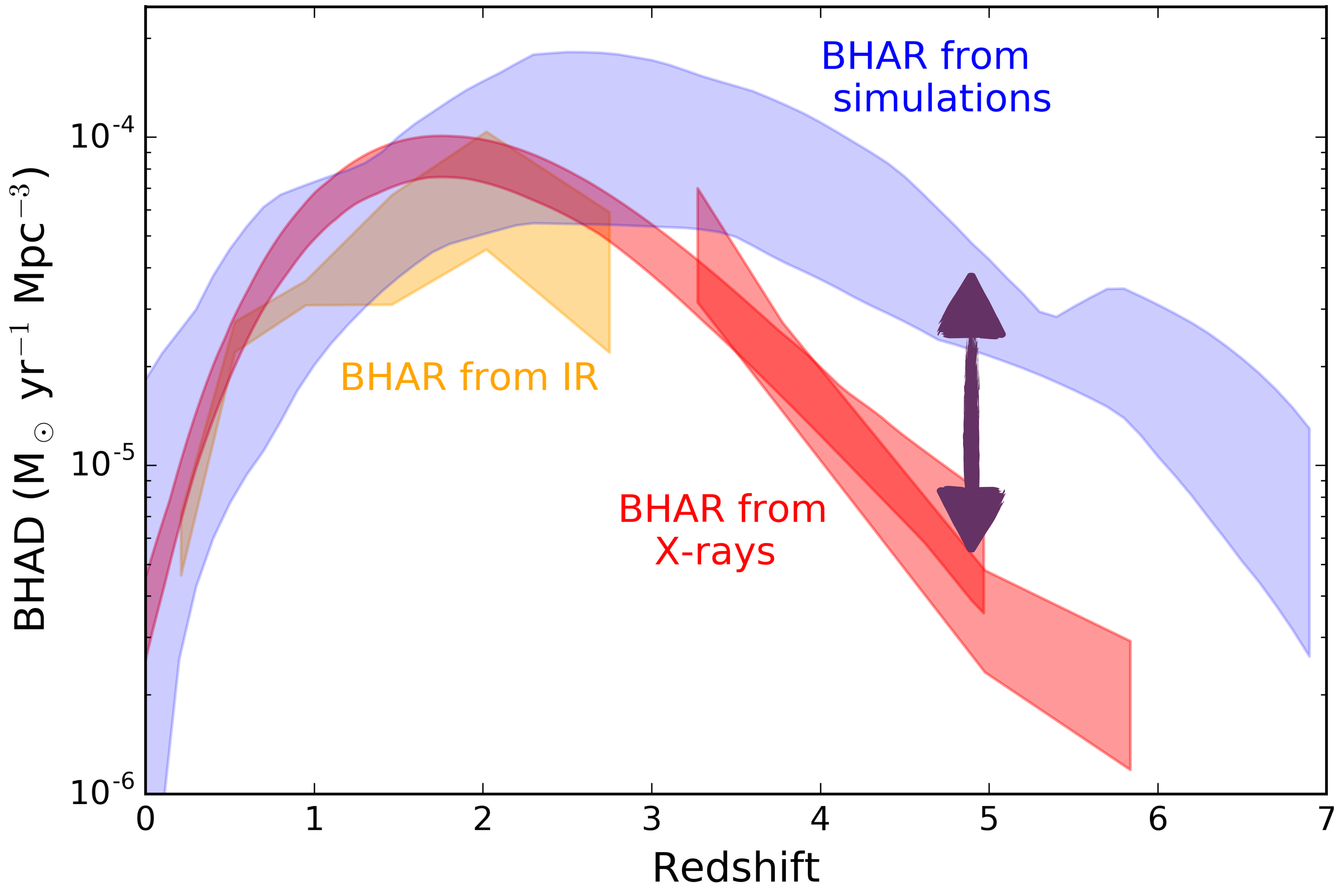
$$V_{\max} = \int_{z_{\min}}^{z_{\max}} \frac{dV}{dz}\,\Omega(z)\,dz \qquad \Phi(L_{bolo,z}) = \frac{1}{\Delta \log L_{bolo}} \sum_{i=1}^{n} \frac{1}{V_{\max,i}}$$

- **Fitted the LFs** with Modified Schecter functions with fixed slopes

$$\Phi(L)\mathrm{d}\log\mathrm{L} = \Phi^* \left(\frac{\mathrm{L}}{\mathrm{L}^*}\right)^{(1-\alpha)} \exp\left[-\frac{1}{2\sigma^2}\log^2_{10}\left(1+\frac{\mathrm{L}}{\mathrm{L}^*}\right)\right]\mathrm{d}\log\mathrm{L}$$

- **Integrating the LFs** in L_{bolo} provides us with the **BHAD**

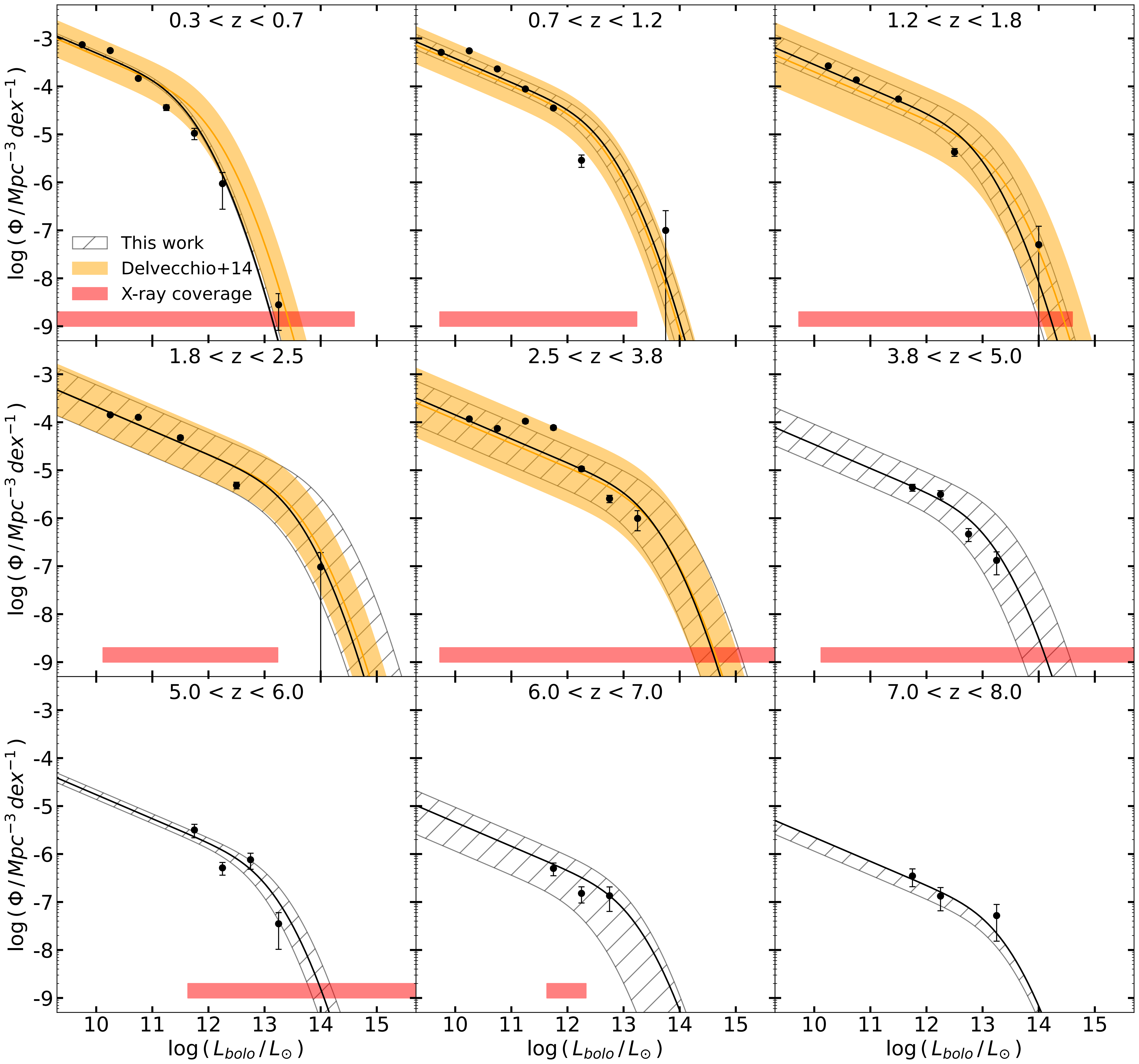
$$\Psi_{\mathrm{BHAD}}(z) = \int_0^{\infty} \frac{1-\epsilon}{\epsilon\, c^2} L_{bolo}\,\Phi(L_{bolo})\,d\log L_{bolo}$$



Recovering AGN Bolometric LF with PRIMA

LF with PRIMA

- LFs at ~100um
- Consistent with Delvecchio+14 at all redshifts
- We are able to **reliably fit the LF up to z=8**
- In the first bin we need more SED templates
- In the last bin, we fixed the luminosity of the knee, due to the low number of sources



Barchiesi+25

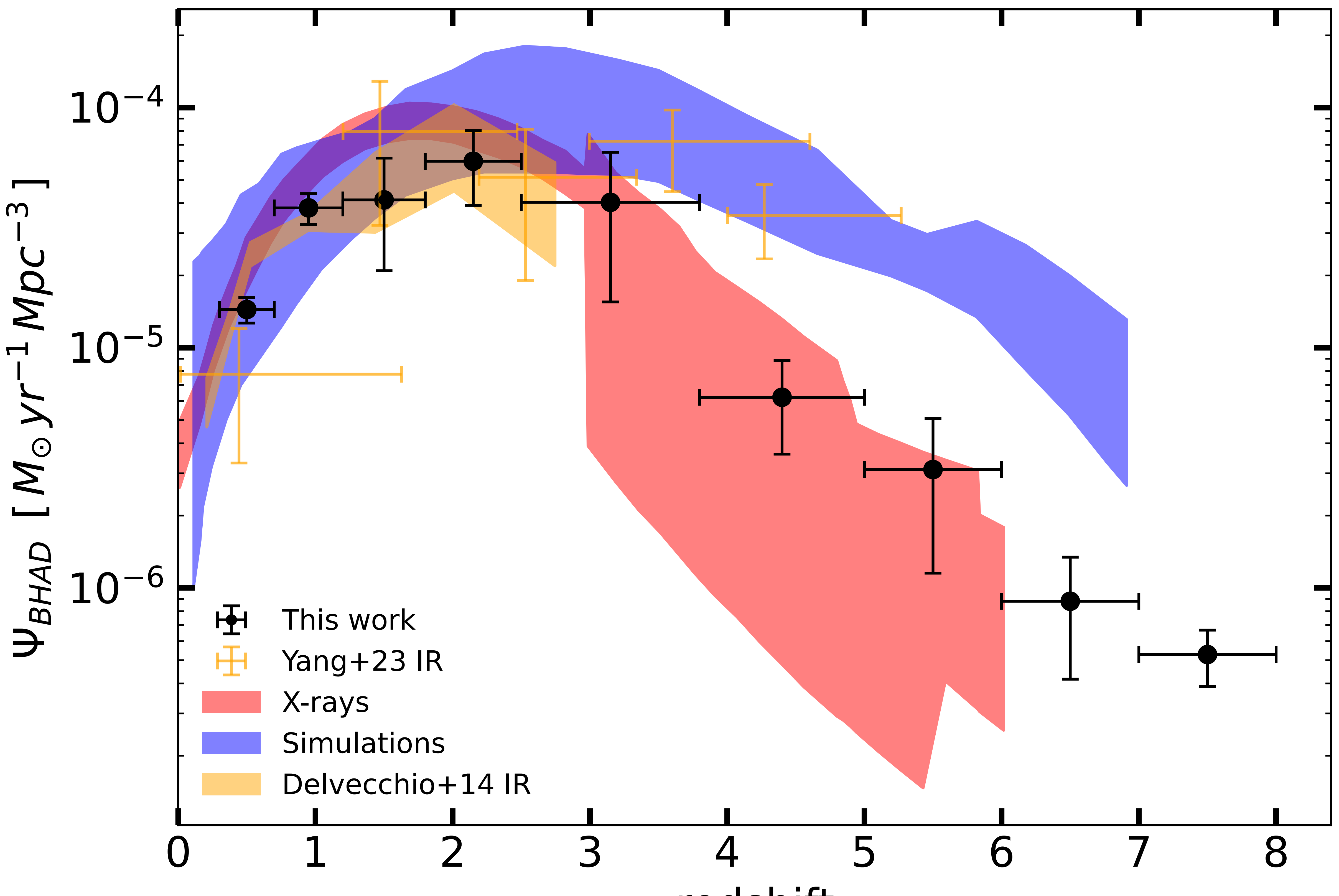
Measuring BHAD with PRIMA

Estimating the BHAD with PRIMA

- Up to z~3 consistent with Delvecchio+14 (IR), Yang+23 (IR), and X-ray-derived measurements
- At z>3, our estimates follow the measurements obtained from X-ray surveys
- We are **able to measure the BHAD up to z~8, with reasonable accuracy**

Sanity Check

- Applied the same method, starting from the SPRITZ simulations of Bisigello+24
- In SPRITZ, the number density is computed from IR-derived LFs and with different template SEDs
- The **intrinsic BHAD has a shallower evolution** (similar to Yang+23)
- Again, we are able to **measure the BHAD up to z~8-9**
- We **recover more than 90% of the BHAD at all redshifts**



Barchiesi+25

Conclusions

- **PRIMA** will allow us to measure the **BHAD at higher redshift** and **with better accuracy** than any current survey
- It will allow us to determine whether the BHAD gap at high-z is due to a population of every obscured AGN
- **Deep survey** will allow us to detect **~30% of all the AGN** (up to z~10) **in all the 16 bands**
- From the **Wide survey**, we expect **~30,000 AGN detected in all the 16 bands**
- NewAthena will detect and characterise AGN up to z~10
- **NewAthena for the most luminous** and the **un-obscured** + **PRIMA for the heavily obscured** missed by NewAthena
- Synergies for source characterisation: large number of PRIMA filter + X-ray detection to overcome the AGN-SF degeneracies
- Detections at 100um:
  - Deep survey: ~60% of all AGN with PRIMA (~10% with Herschel)
  - Wide survey: 30 times more AGN than Herschel

Thank you for the attention!

Bonus Slides

Sanity Check

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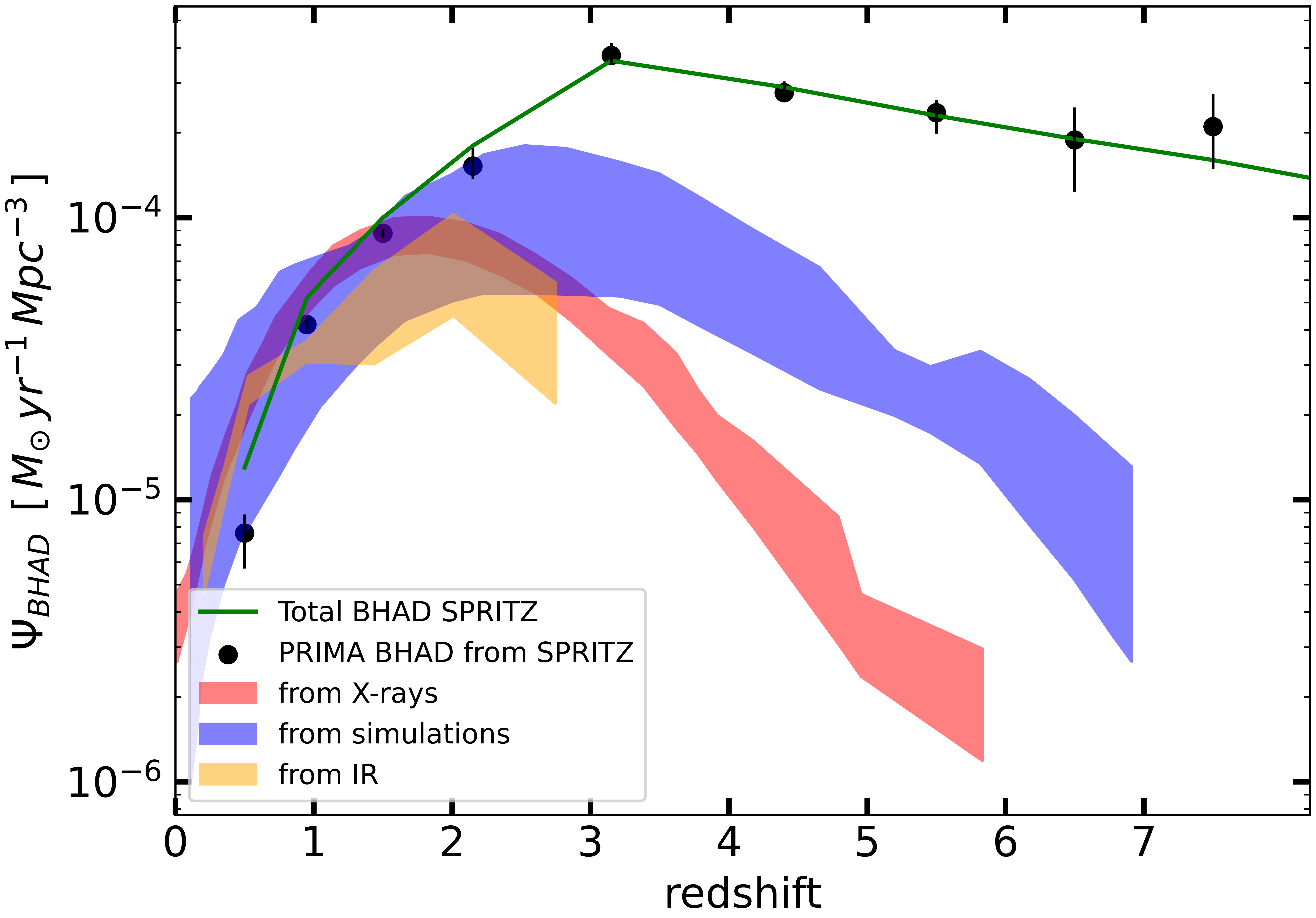
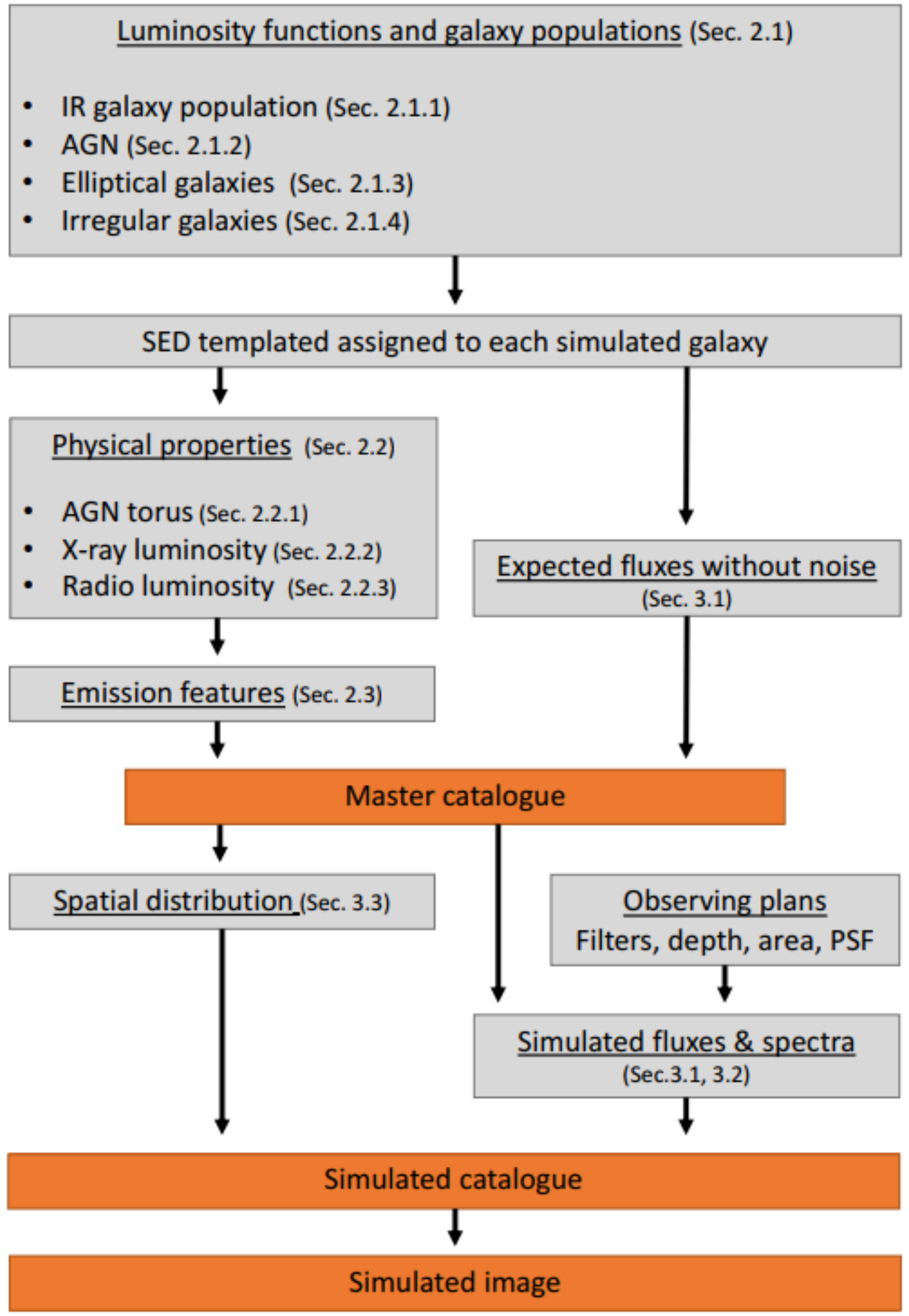
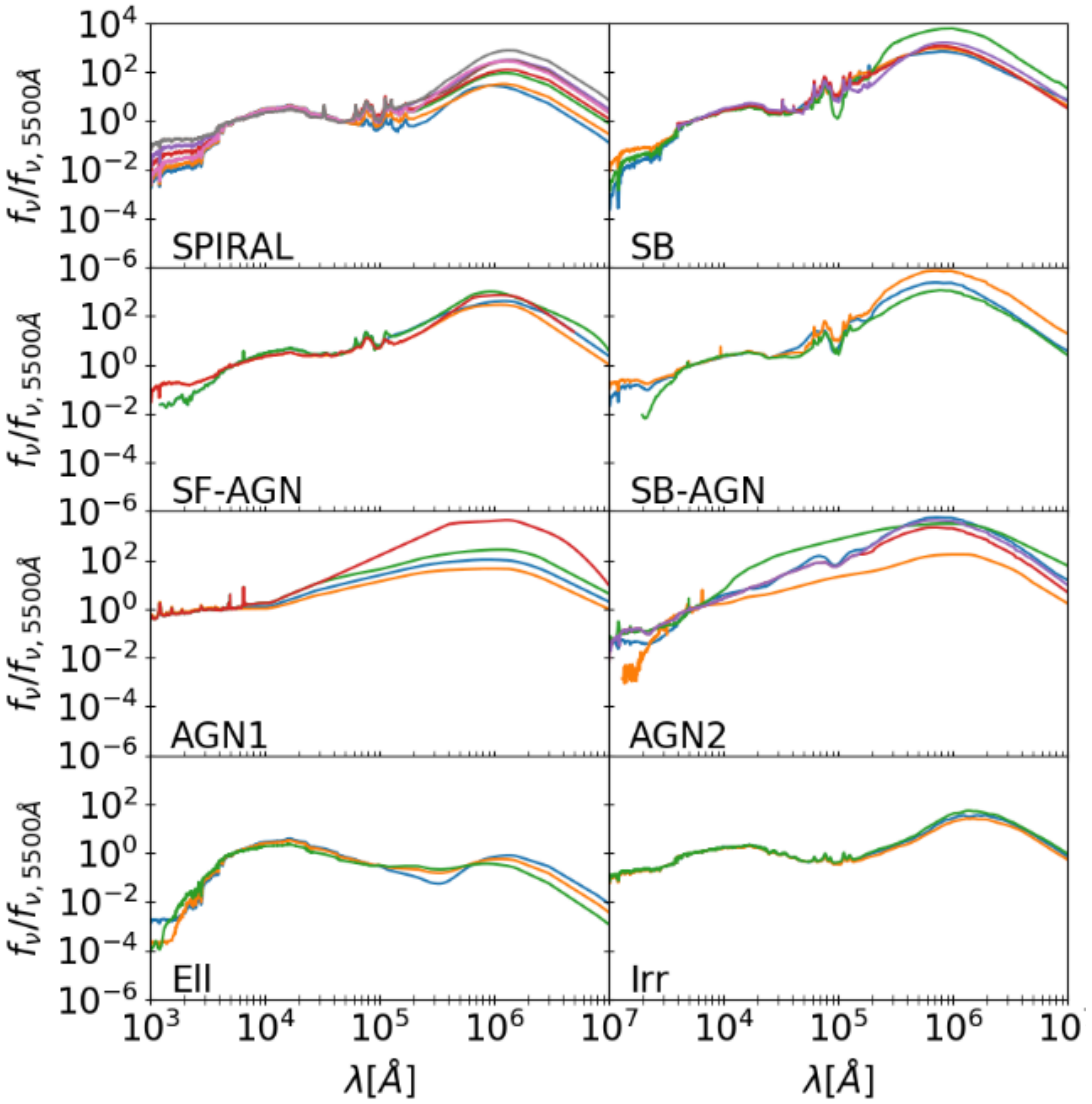


SPRITZ structure



SPRITZ SEDs



SPRITZ validation