High-redshift sub-L* AGN in the Chandra Deep Fields: paving the way for *Lynx*

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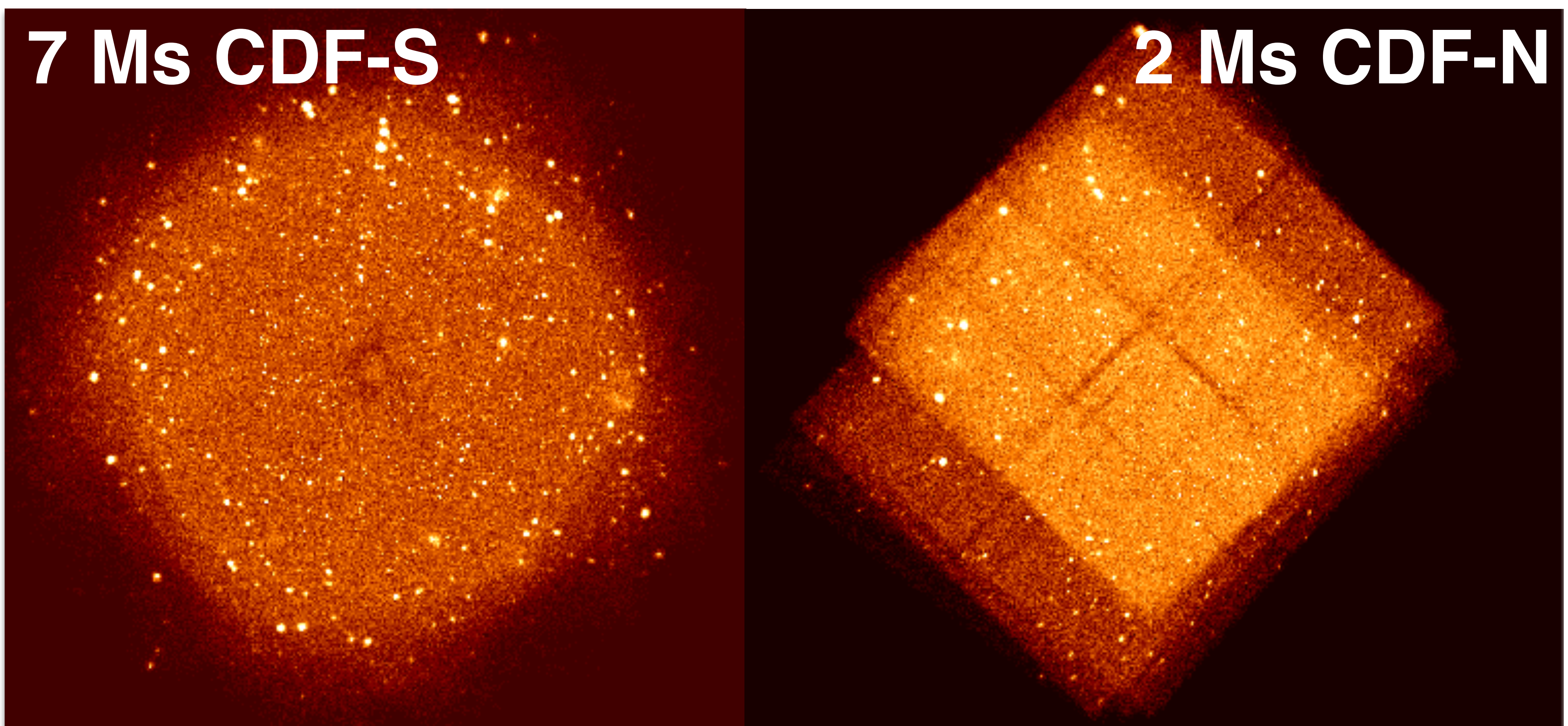
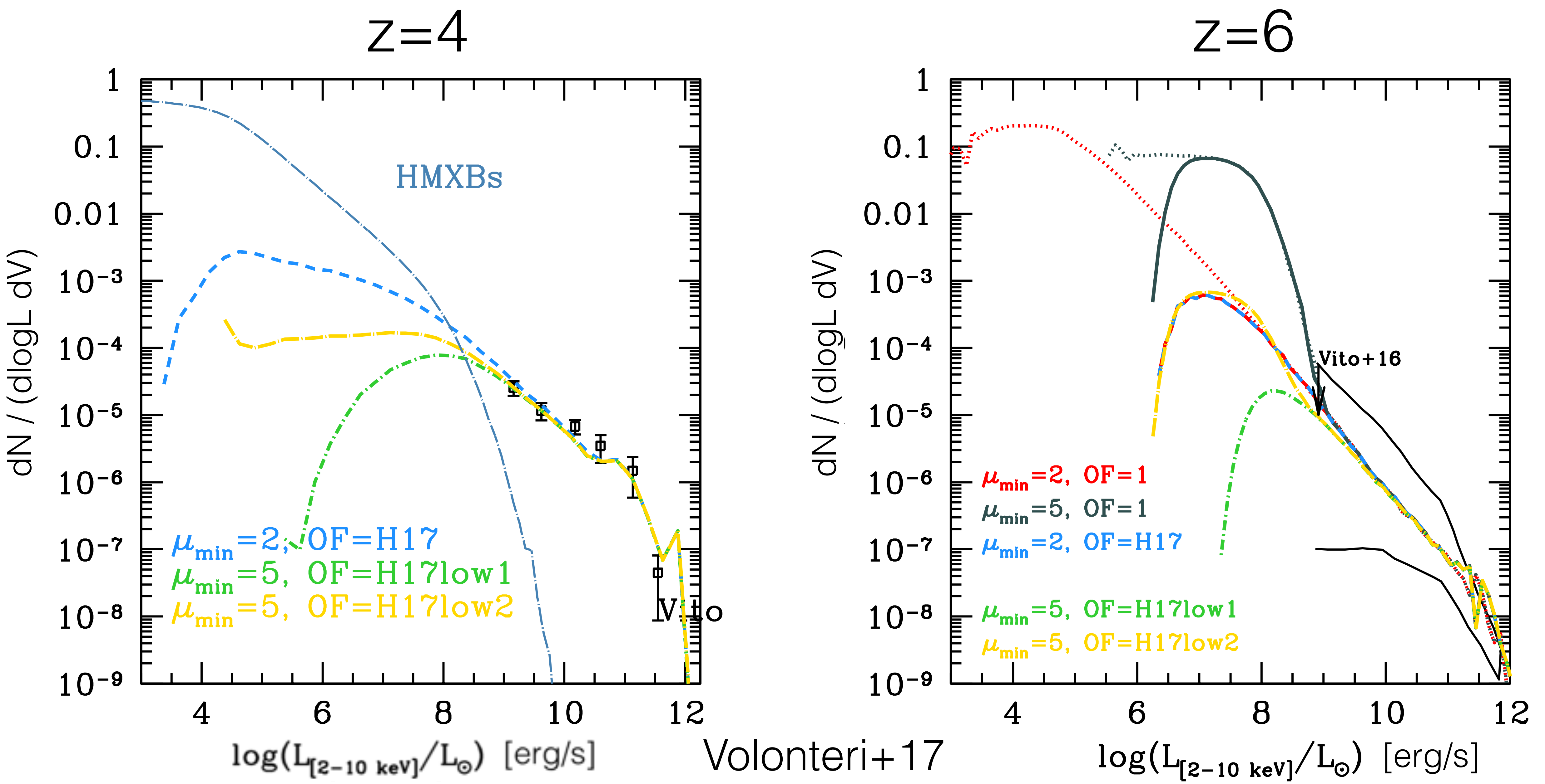
in collaboration with **W.N. Brandt**, G. Yang, R. Gilli, B. Luo, C. Vignali, the CDF-S Team and the *Lynx* "First accretion light" WG

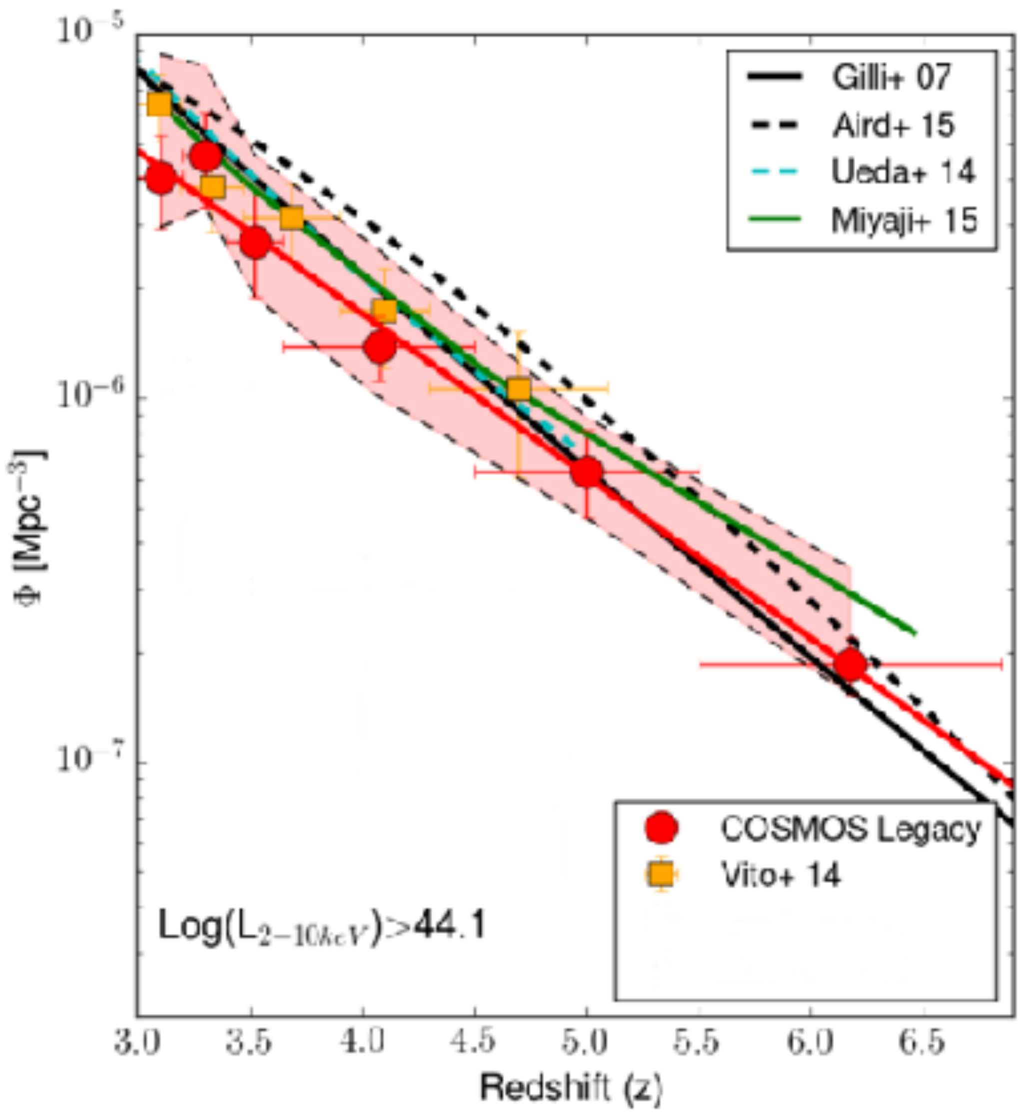


Low-L AGN at high redshift: why do we care?

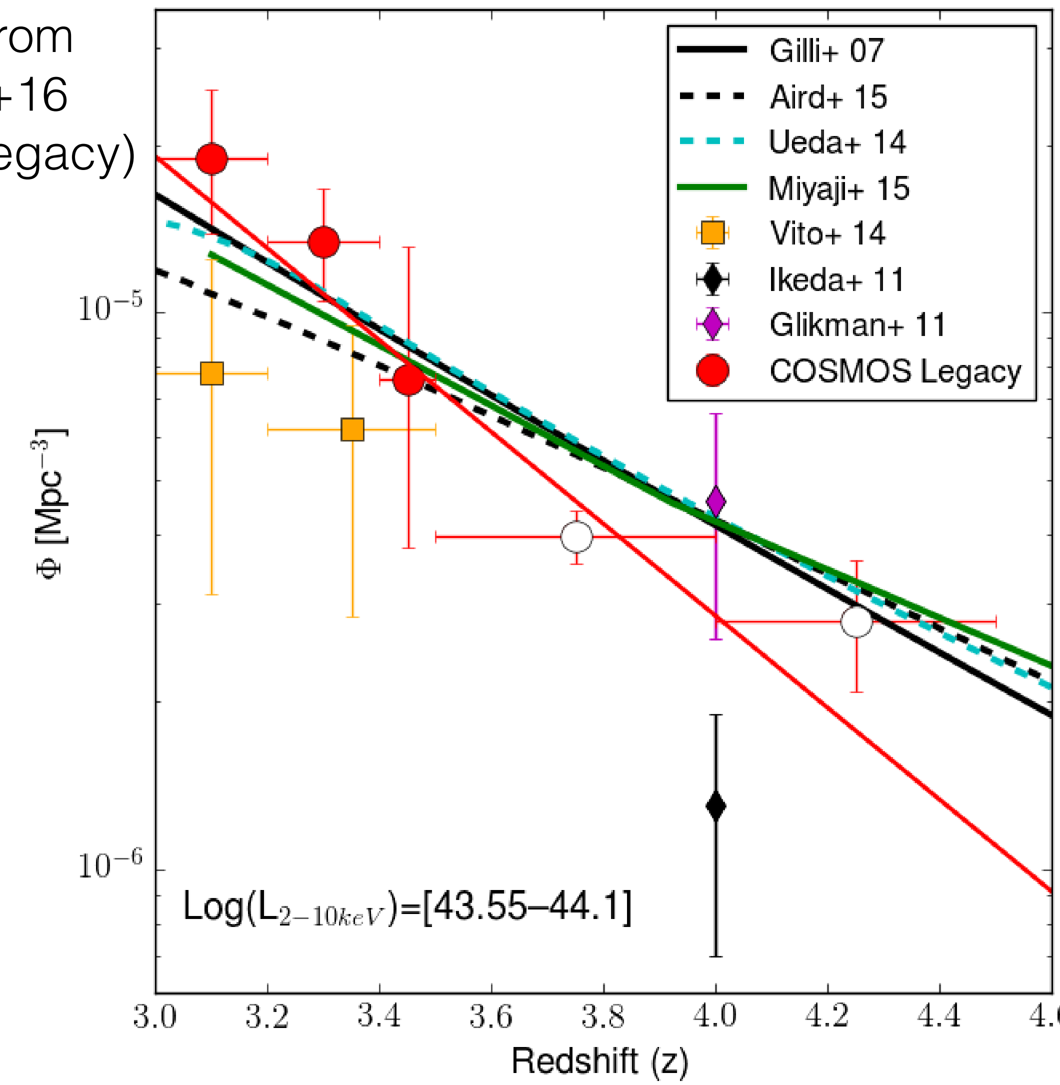


Different combinations of the physical parameters driving the formation and growth of BH seeds (e.g. seed mass, occupation fraction, Eddington ratio distribution, etc.) produce different shapes of the AGN XLF faint end!

High-z (3<z<5) AGN in X-ray surveys: space density evolution



adapted from Marchesi+16 (COSMOS-Legacy)



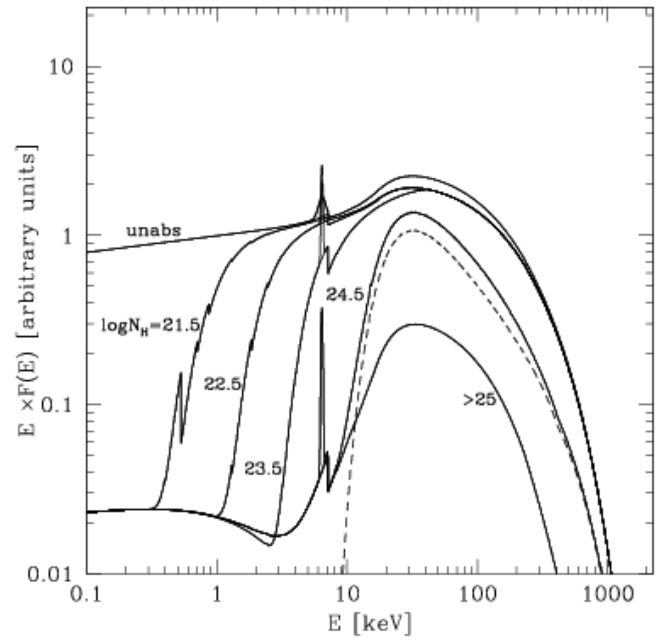
For L≳L$_*$, logΦ declines as $(1+z)^{-6}$, similarly to optical QSOs (e.g. McGreer+13). At lower luminosities, uncertain evolution.

(e.g. Brusa+09, Civano+11, Hiroi+12, Vito+13, Kalfountzou+14, Vito+14, Georgakakis+15, Giallongo+15, Cappelluti+16, Marchesi+16, Vito+16)

Why X-rays?

1) Ubiquitous in AGN

2) Obscuration



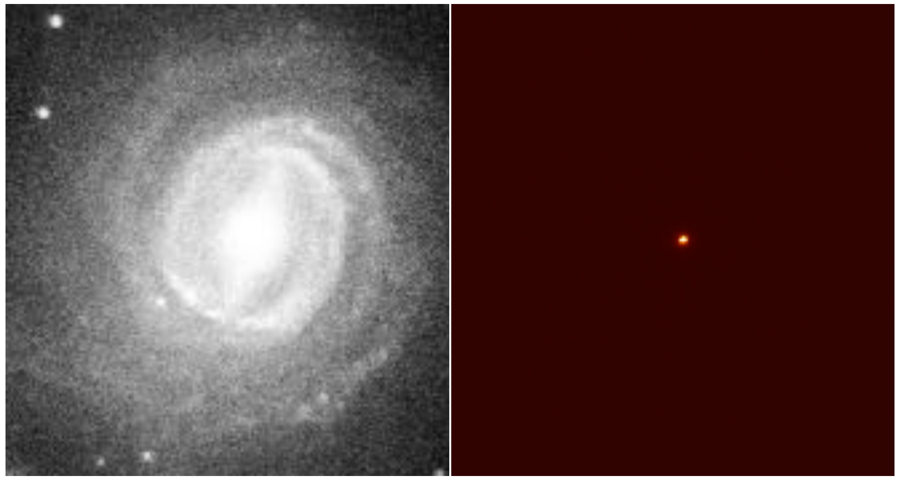
Gilli+07

3) Galaxy dilution

Brandt & Alexander 2015

NGC 3783

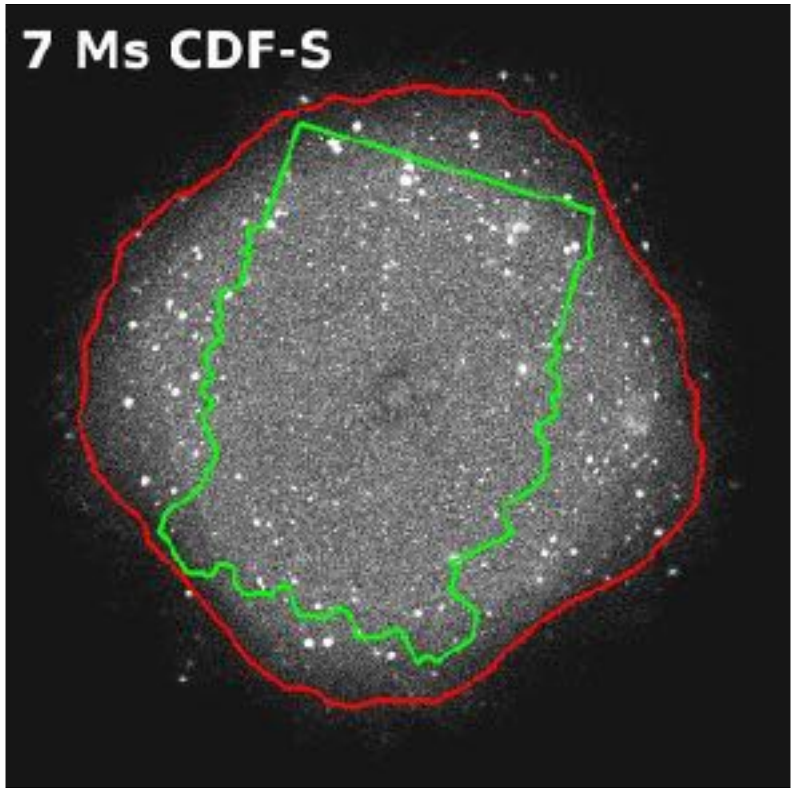
optical X-ray



Clean and less biased selection (especially at high-z)!

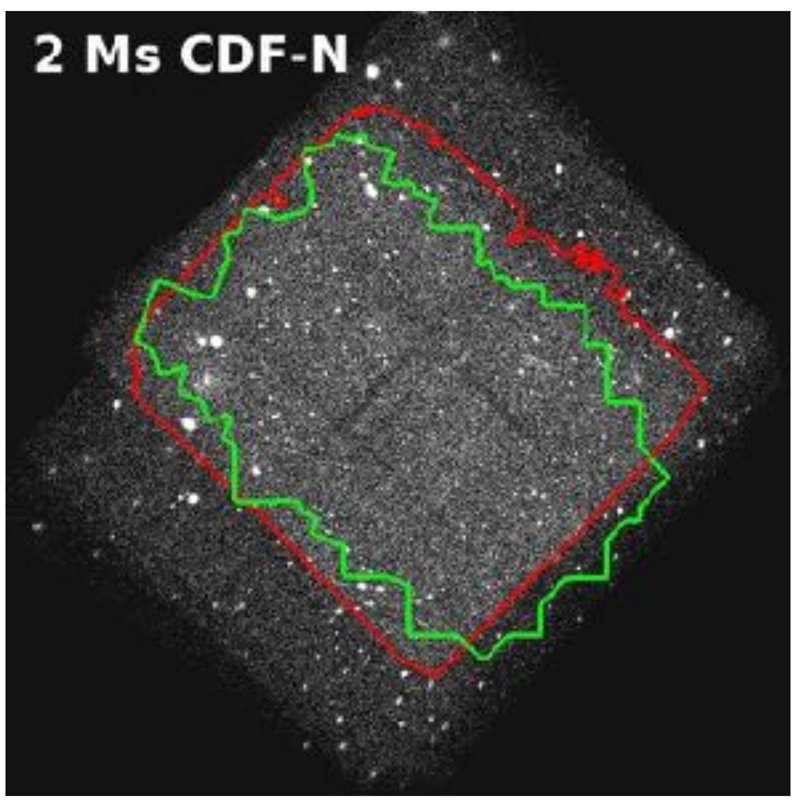
But optical/IR data needed for identification

The data-set



7 Ms CDF-S (Luo+17)

- **Deepest X-ray survey to date!** F_{lim}~6.4 x 10^{-18} erg cm^{-2} s^{-1}
- A~484 $arcmin^2$
- **Deep radio-UV coverage** (e.g. CANDELS/GOODS-S)
- 1008 X-ray sources
- **~98.5% multi-wavelength identification,**
- **~98% redshift** (~65% spec-z, phot-z from Straatman+16, Santini+15, Hsu+14, Skelton+14, etc.)



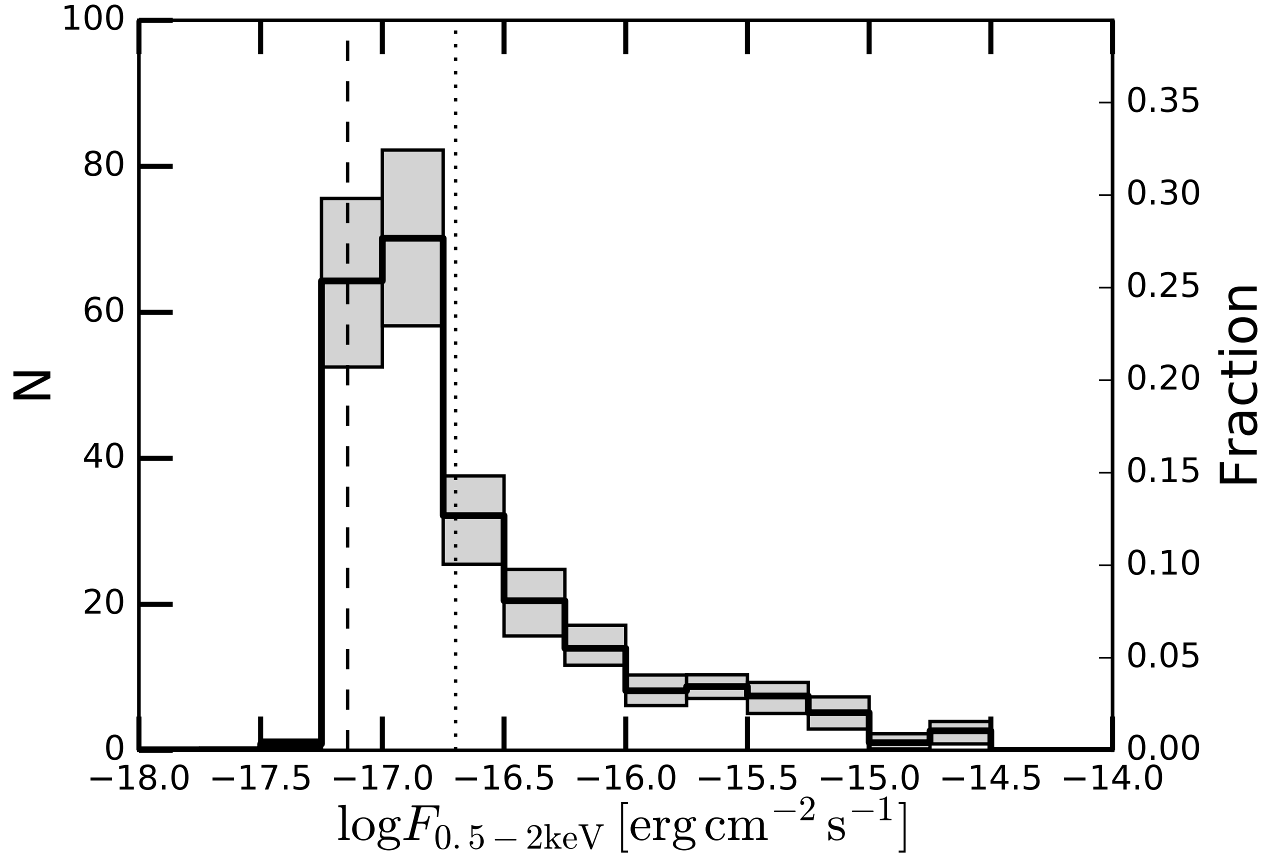
2 Ms CDF-N (Xue+16)

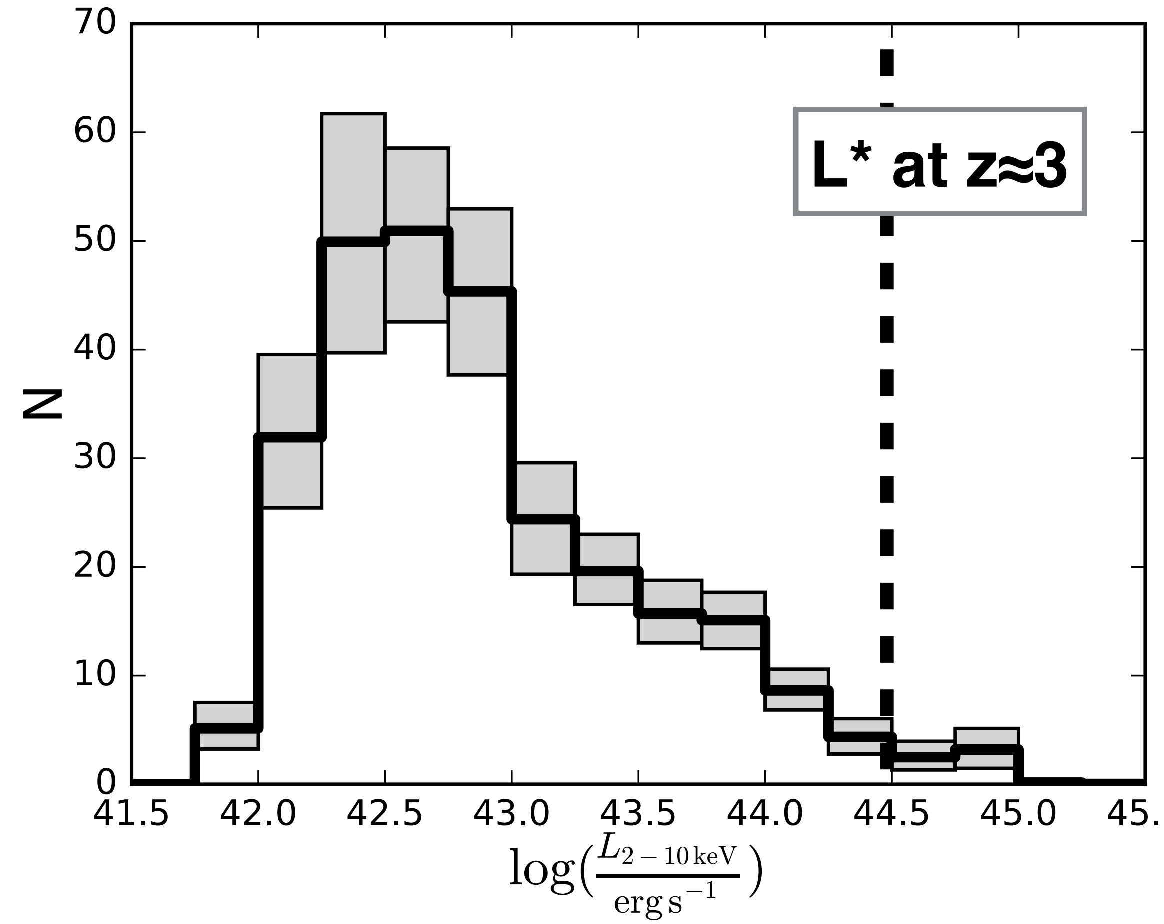
- **Second deepest X-ray survey to date!** F_{lim}~1.2 x 10^{-17} erg cm^{-2} s^{-1}
- A~447 $arcmin^2$
- **Deep radio-UV coverage** (e.g. CANDELS/GOODS-N)
- 683 X-ray sources
- **~98% multi-wavelength identification,**
- **>93% redshift** (>50% spec-z, phot-z from Yang+14, Skelton+14, Kodra+ in prep.)

Final sample of ~101 AGN at $3<z<6$

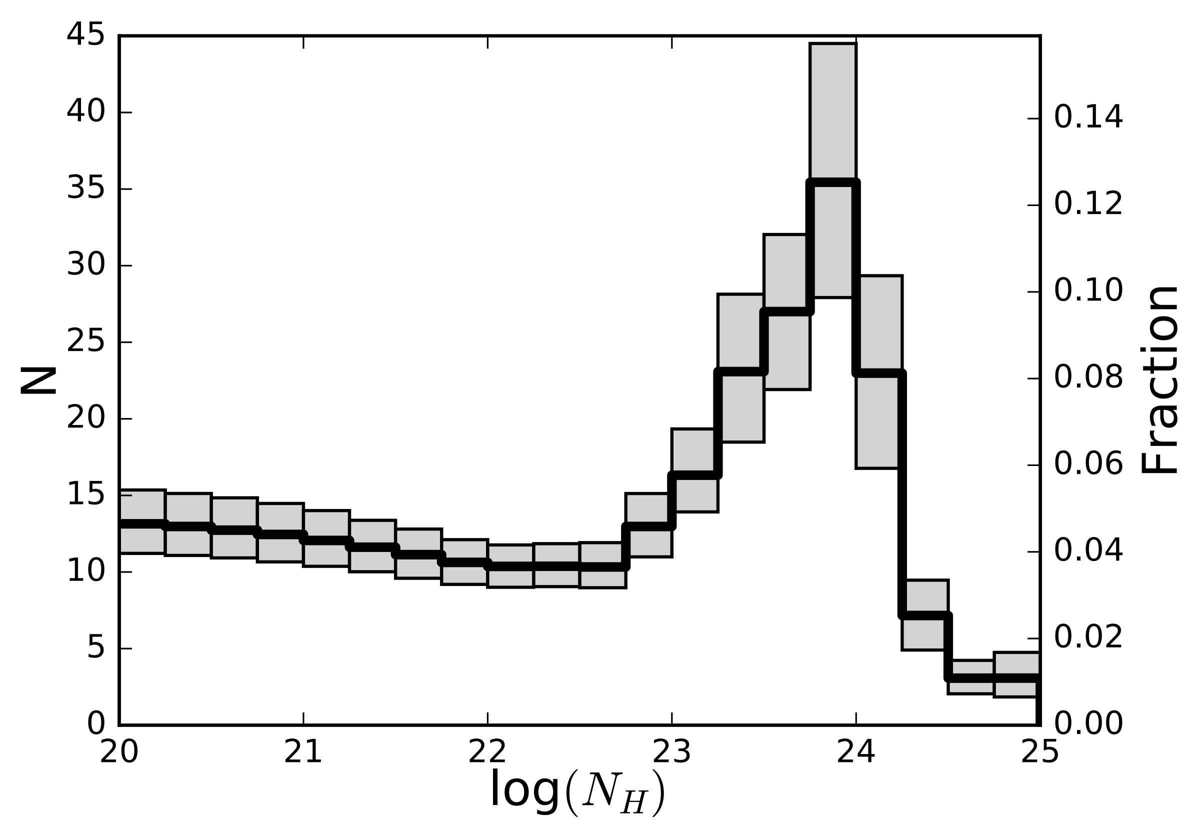
Parameter distributions

Vito et al. (submitted)

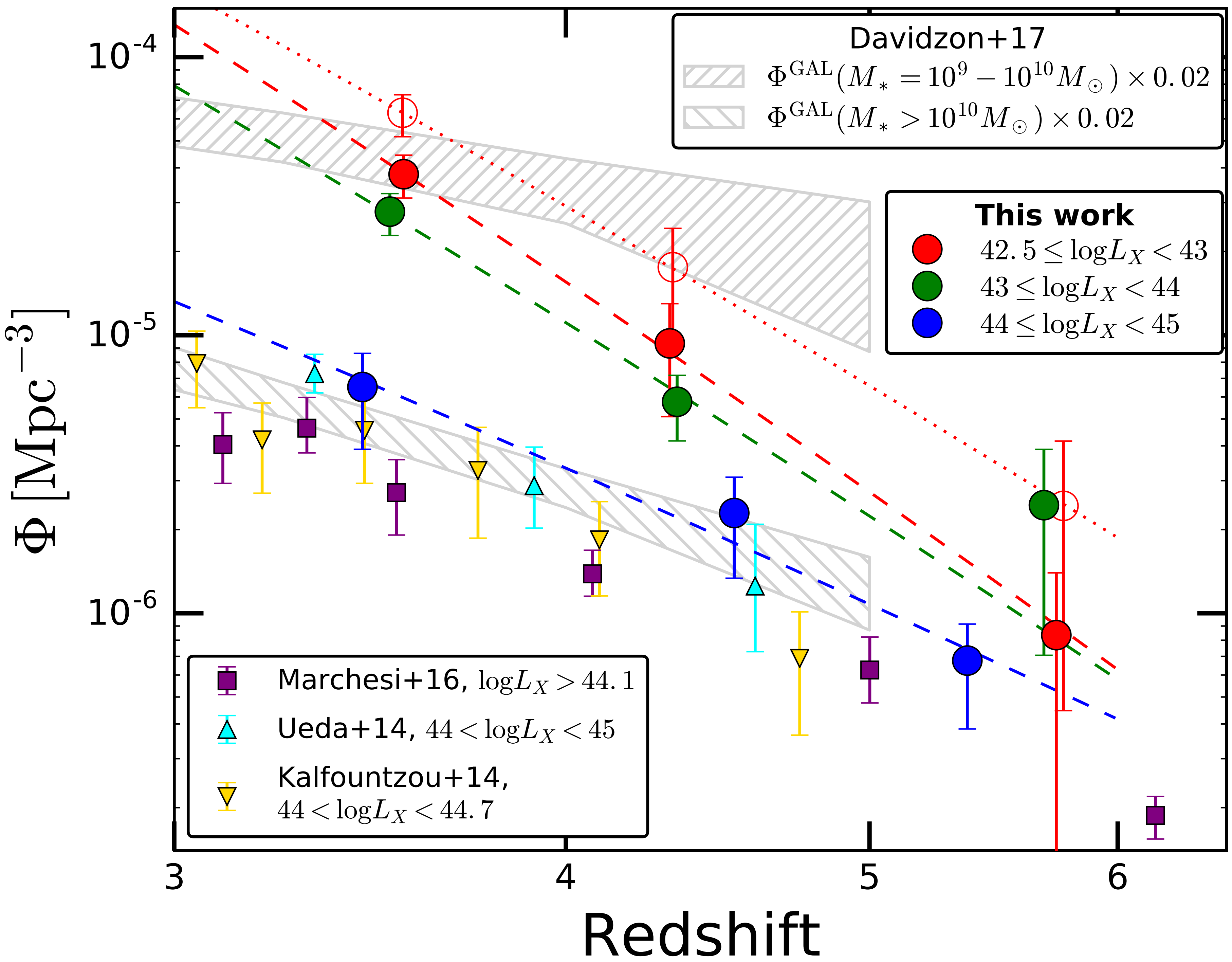




observed
0.5-7 keV
↓
Rest-frame
2-40 keV
at z=3-6



AGN space density



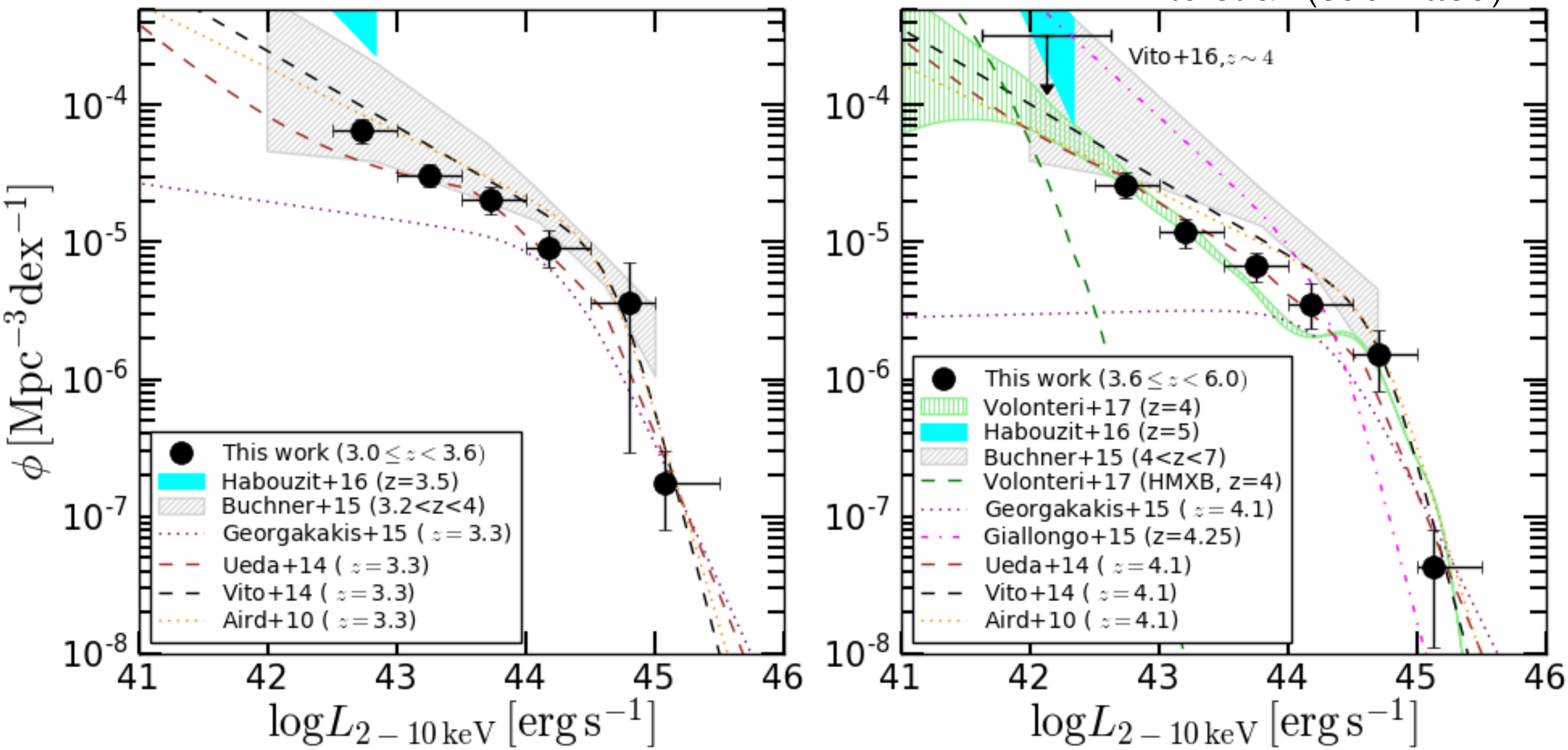
Decline at high-L driven by evolution of number of massive galaxies?

Hints for steepening at low-L (not matched by low-mass galaxies): change of the accretion parameters (Eddington ratio, occupation fraction, etc.)?

Vito et al. (submitted)

AGN X-ray luminosity function

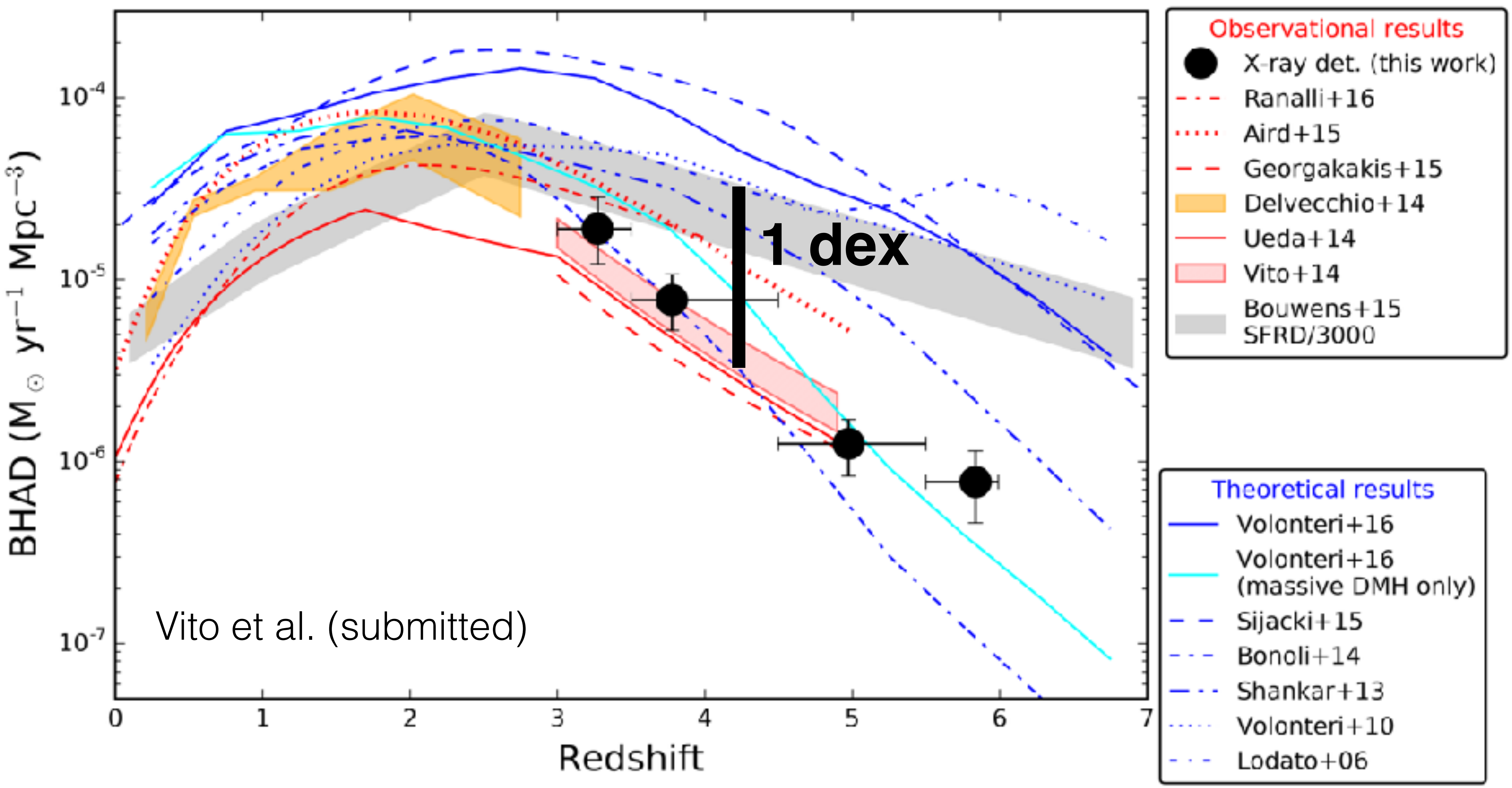
Vito et al. (submitted)



Most accurate observational derivation of the faint-end at z>3!

No evidence for very steep slopes, i.e. AGN unlikely to drive cosmic Reionization

BHAD in AGN vs galaxy



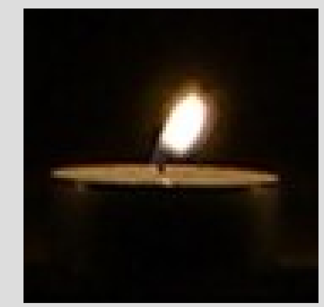
~1 dex of difference in the BHAD from models and observations!
significant contribution from low-rate accretion (i.e. not detected even by the deepest X-ray surveys) in galaxies?

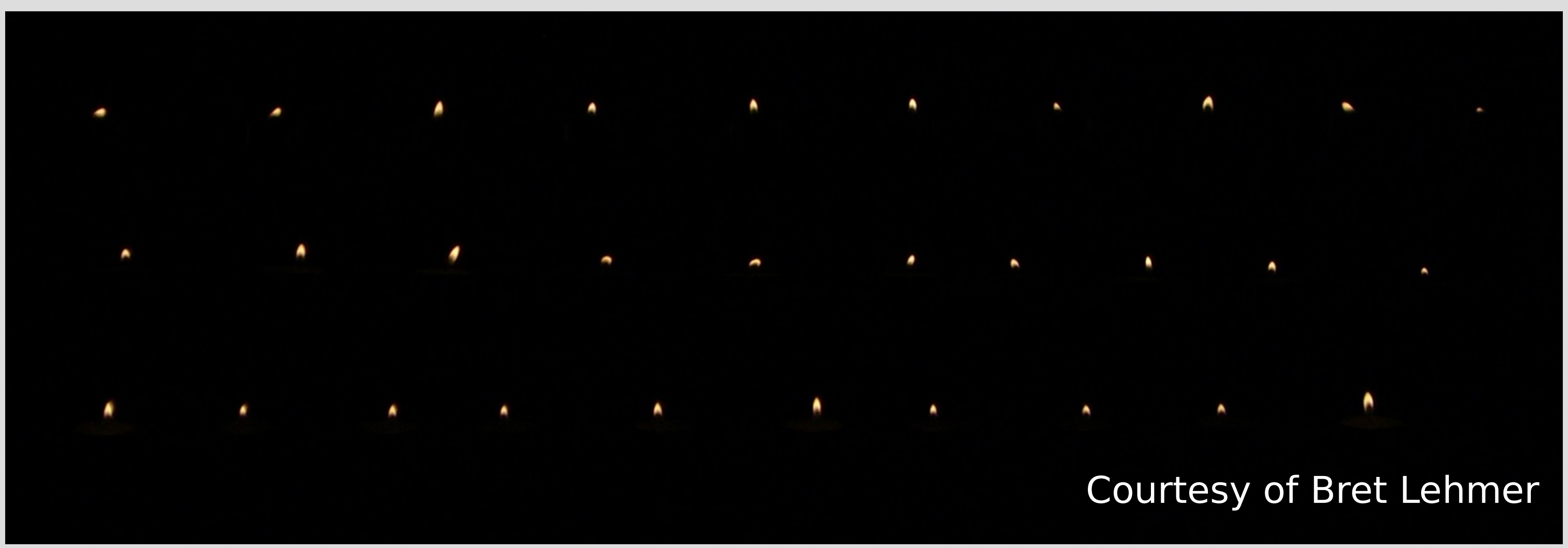
Enhancing *Chandra* sensitivity: stacking analysis

Credits: B. Lehmer

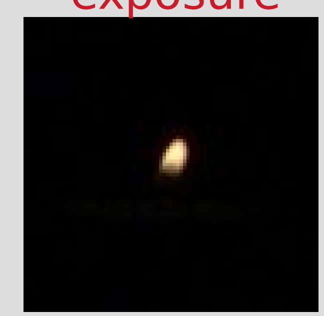
Stacking: A Romantic Example

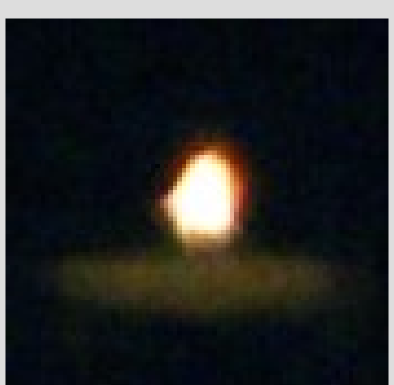
3 / 100 second exposure





1 / 1000 second exposure



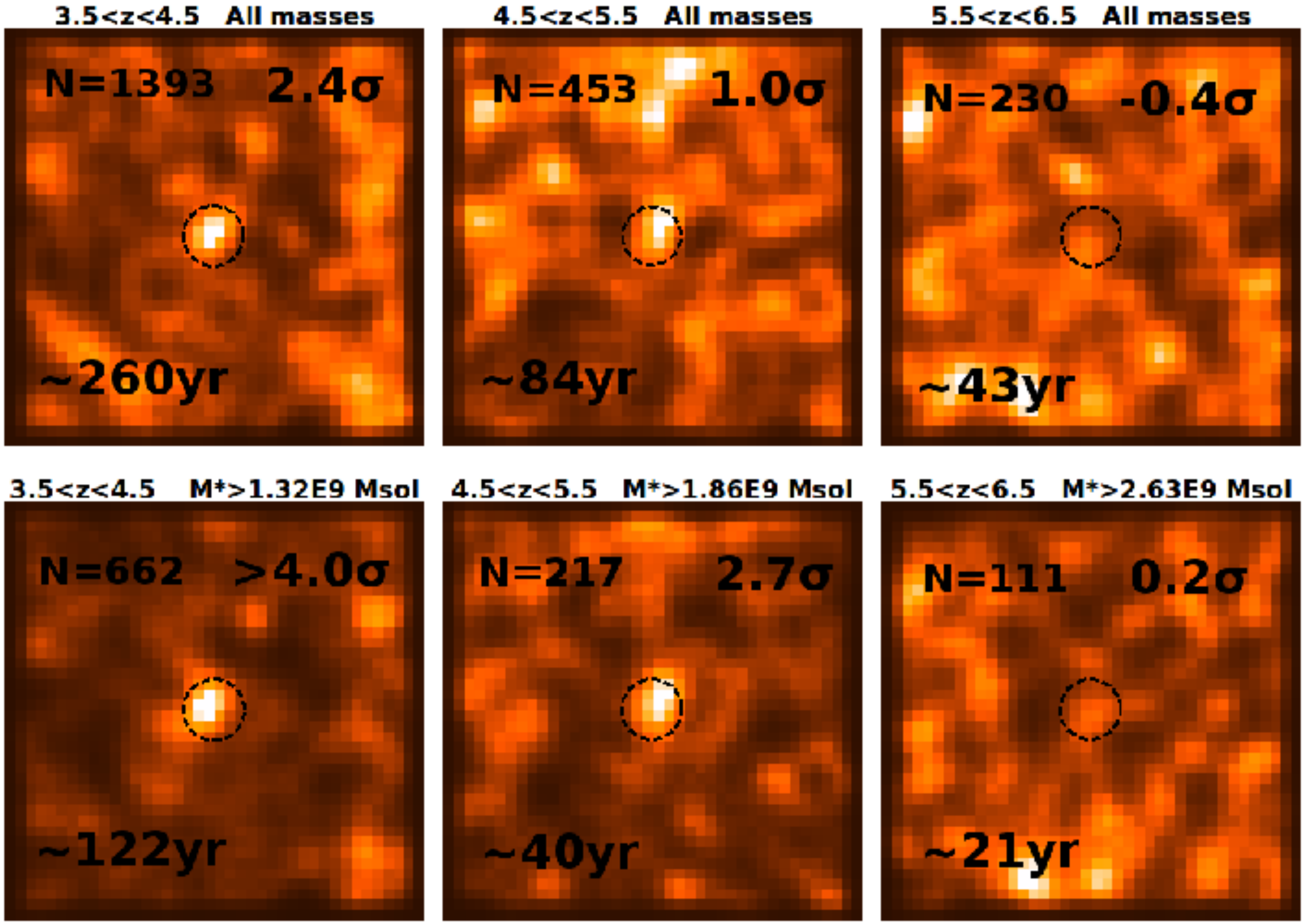


Stacked image of 30 candles with 1 / 1000 sec exposure.

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

Results from stacking analysis of z=3.5-6.5 galaxies

Vito+16

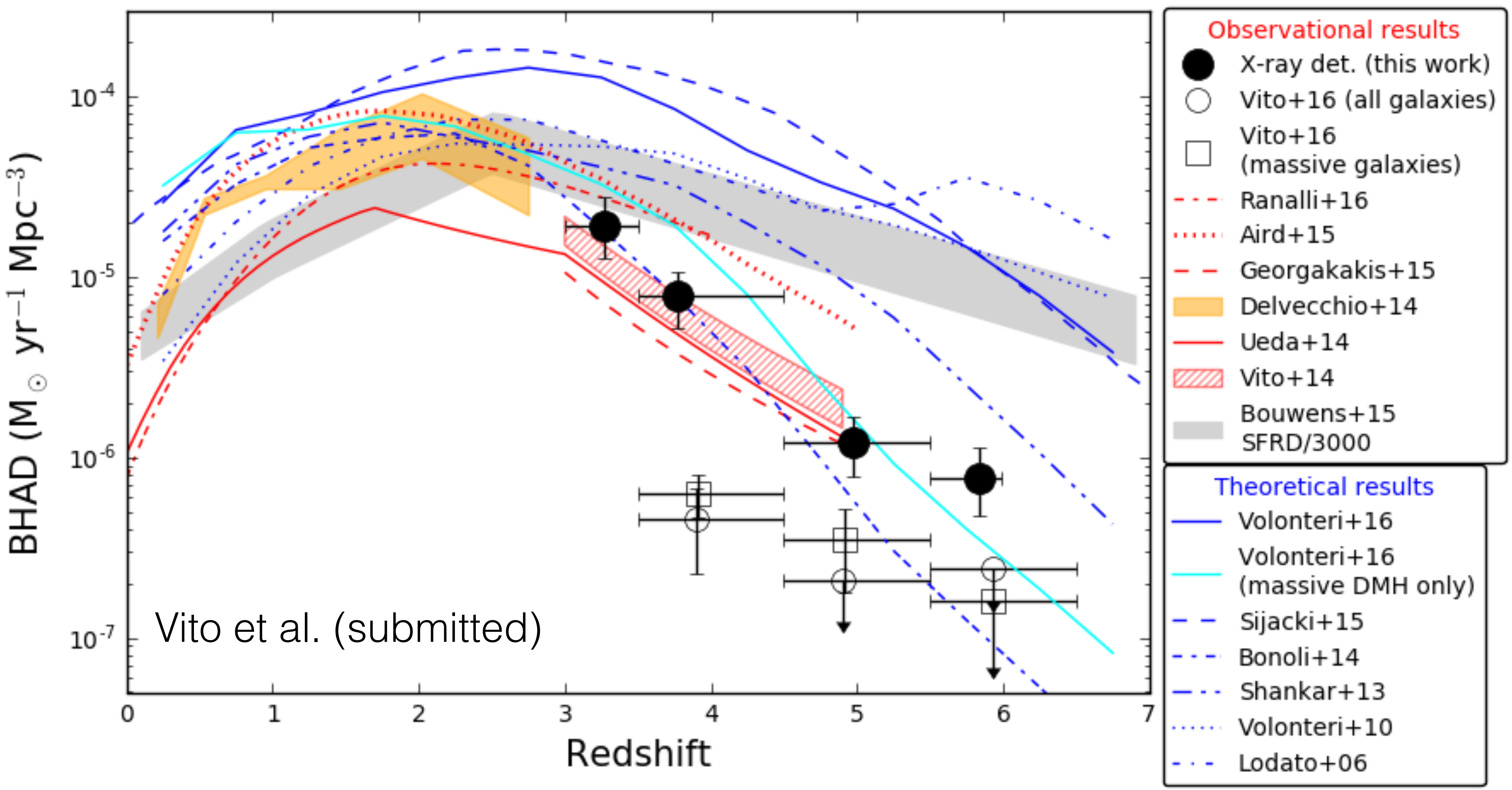


Tens to hundreds years of effective Chandra exposure!

Signal mostly due to XRBs, but useful constraints and upper limits on SMBH accretion!

JWST will provide samples of galaxies up to z~10!
We will derive the average X-ray emission in galaxies during the Reionization epoch!

BHAD in AGN vs galaxy



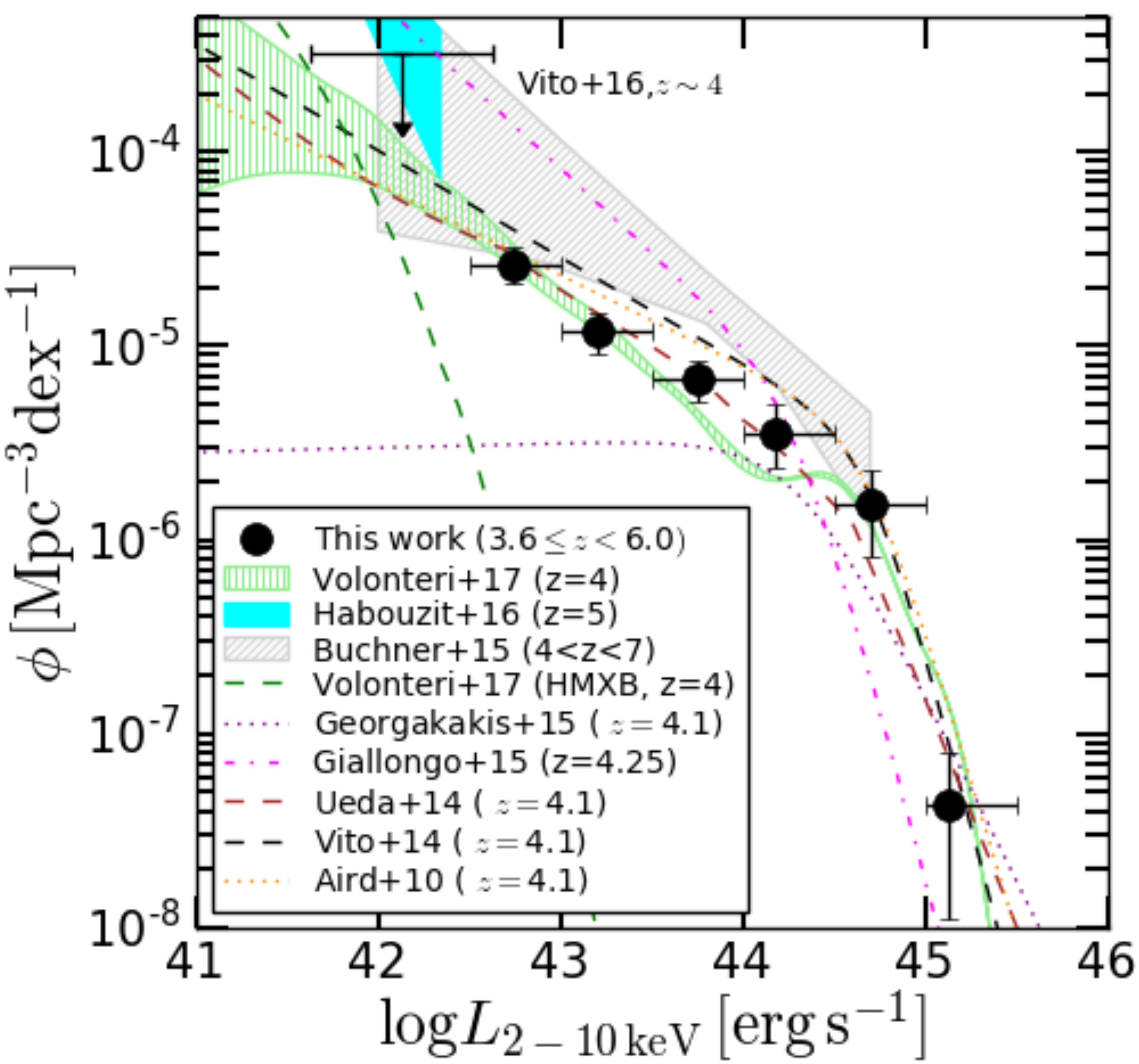
Most of the BH growth happens during the short AGN phase

Low-rate accretion not enough for observations to match simulations

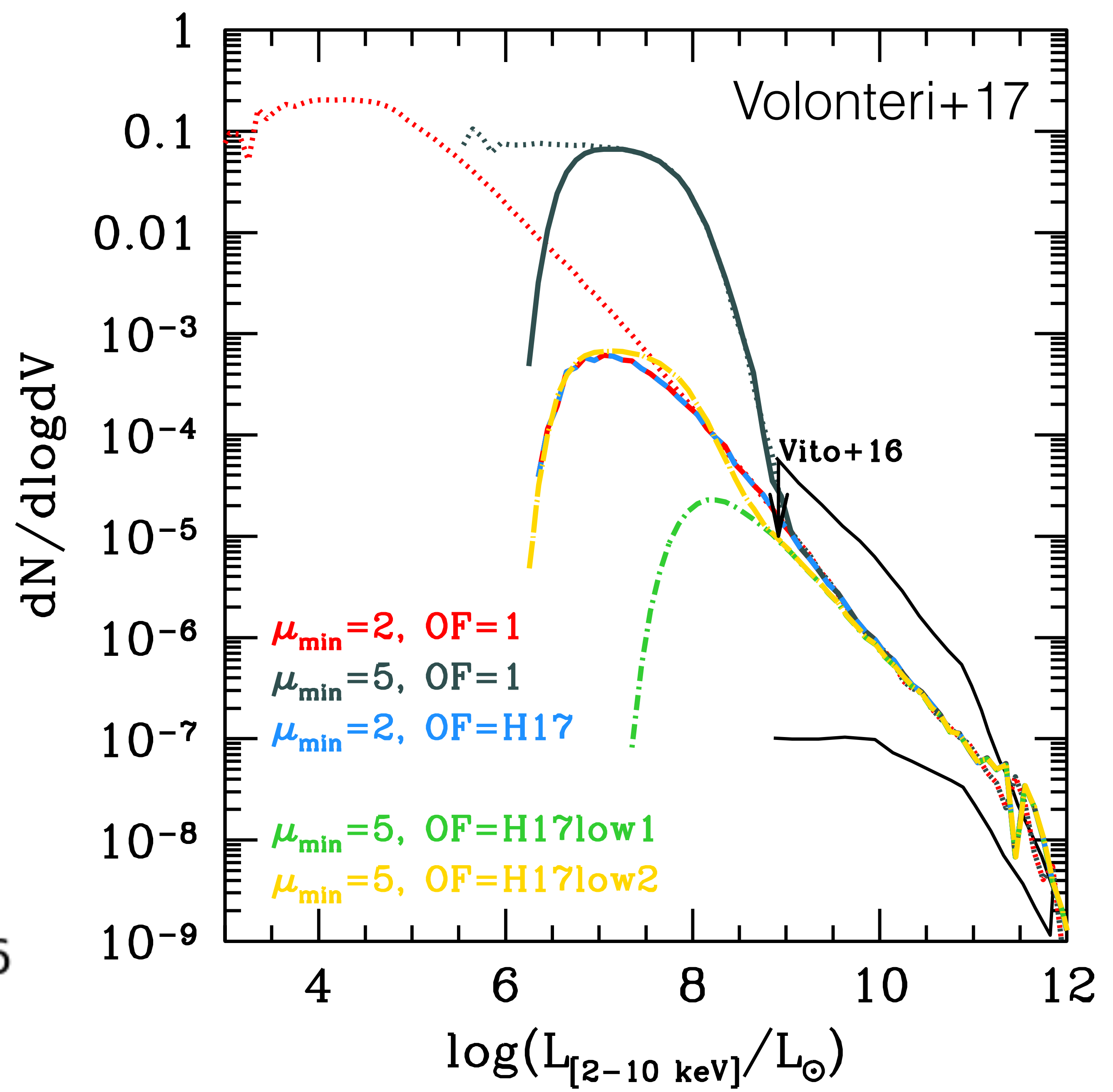
What causes the different slopes of BHAD and SFRD?

(see also Aird+15; complex combination of parameters, e.g., occupation fraction, duty cycle, Eddington ratio distribution, etc…)

XLF faint end at high-z as a tool to study BH seed formation and growth

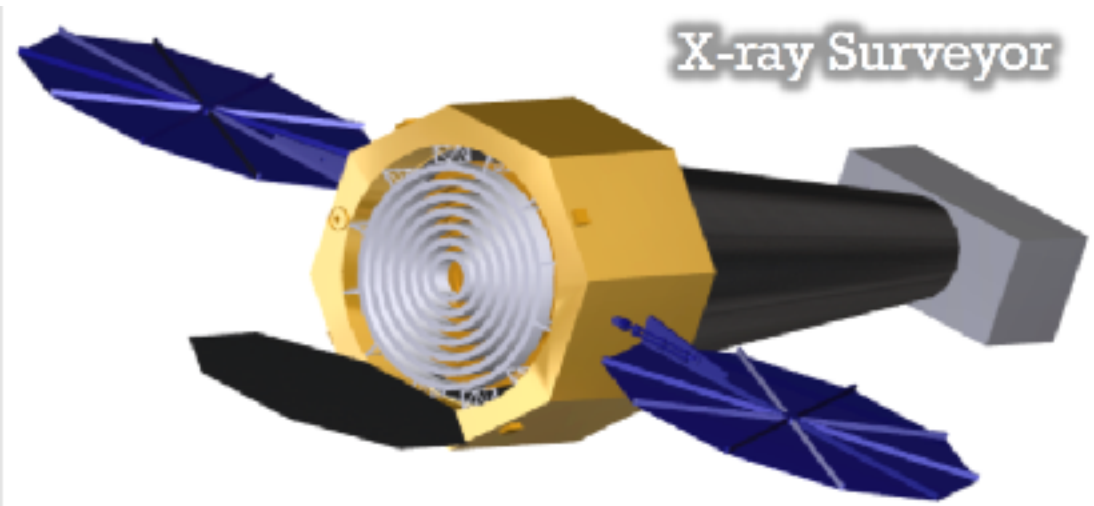


Vito et al. (submitted)



Need to push at lower-L and higher-z! E.g. *Lynx*

Lynx (Weisskopf et al. 2015)



- *Chandra*-like angular resolution
- f.o.v.=0.12 deg^2=15x *Chandra* (for sub-arcsec resolution)
- 30-50x effective area of *Chandra*
- 20x *Chandra* sensitivity

Credits: Alexey Vikhlinin

Detection threshold @ 4Msec (0.5-2 keV) (for known locations)	3.0×10^{-19} erg/s/cm^2 (1.1×10^{-19})
2–10 keV luminosity at z=10 assuming Γ=1.7	3.7×10^{41} erg/s (1.35×10^{41})
Bolometric luminosity at z=10, assuming 10% correction	3.7×10^{42} erg/s (1.35×10^{42})
Black Hole Mass assuming Eddington rate	29,000 Msun (11,000 Msun)

These numbers eventually may be a factor of 2 better! (work in progress on the detection procedure)

Lynx sensitivity

Credits: Alexey Vikhlinin

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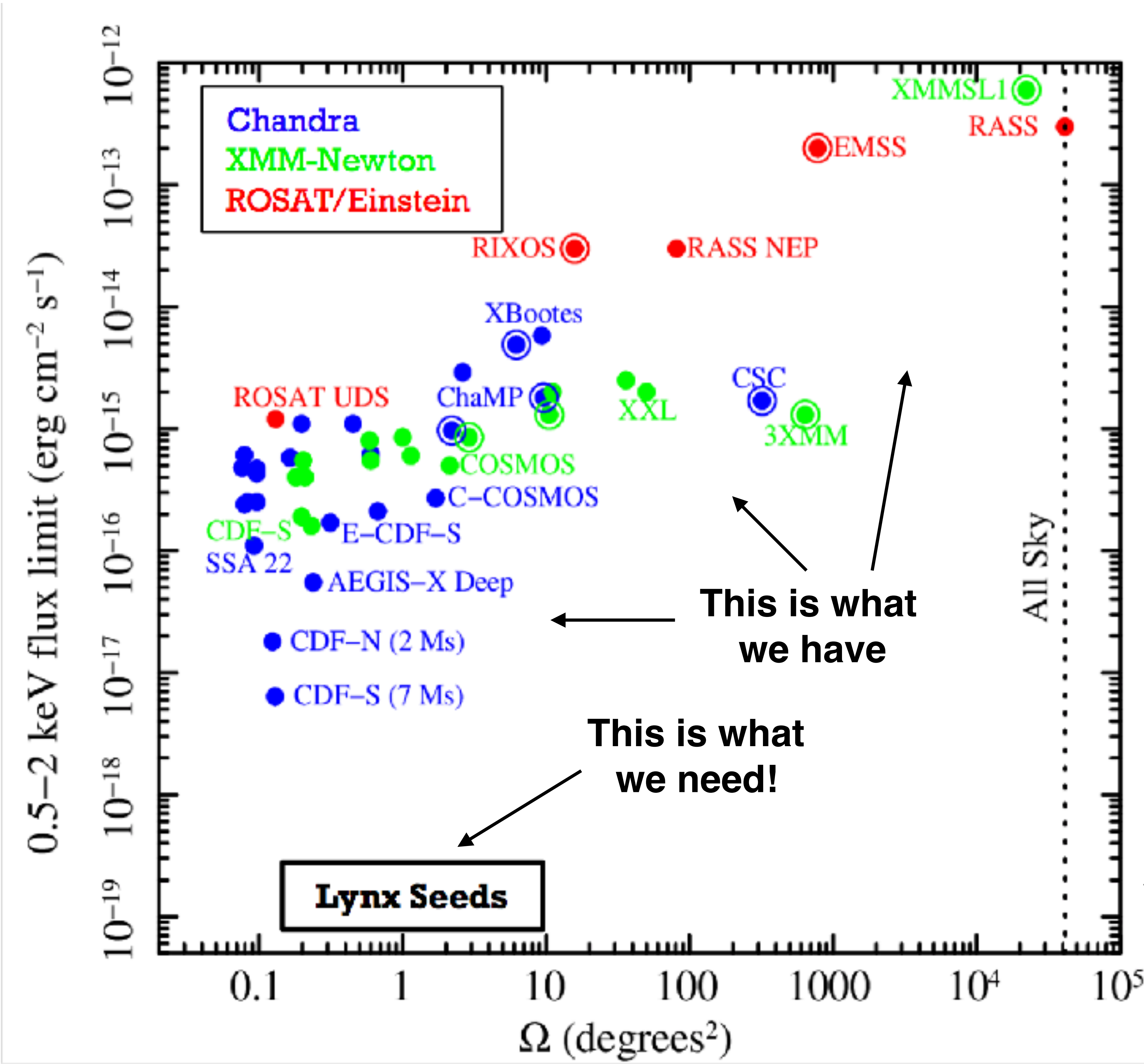
on behalf of the Lynx "first accretion light" working group:

Under reasonable assumptions about space density

(from Habouzit+16 and Volonteri+17 or from DM halo arguments)

and physical parameters (λ_{Edd}=1, K_{bol}=10%), we expect to detect **~1000 accreting BH at z=8-9 with $\log L_X \gtrsim 41$ and $\log(M_{BH}/M_\odot) \gtrsim 4$ in ~ 1 deg^2**

Hunting BH seeds in the early universe

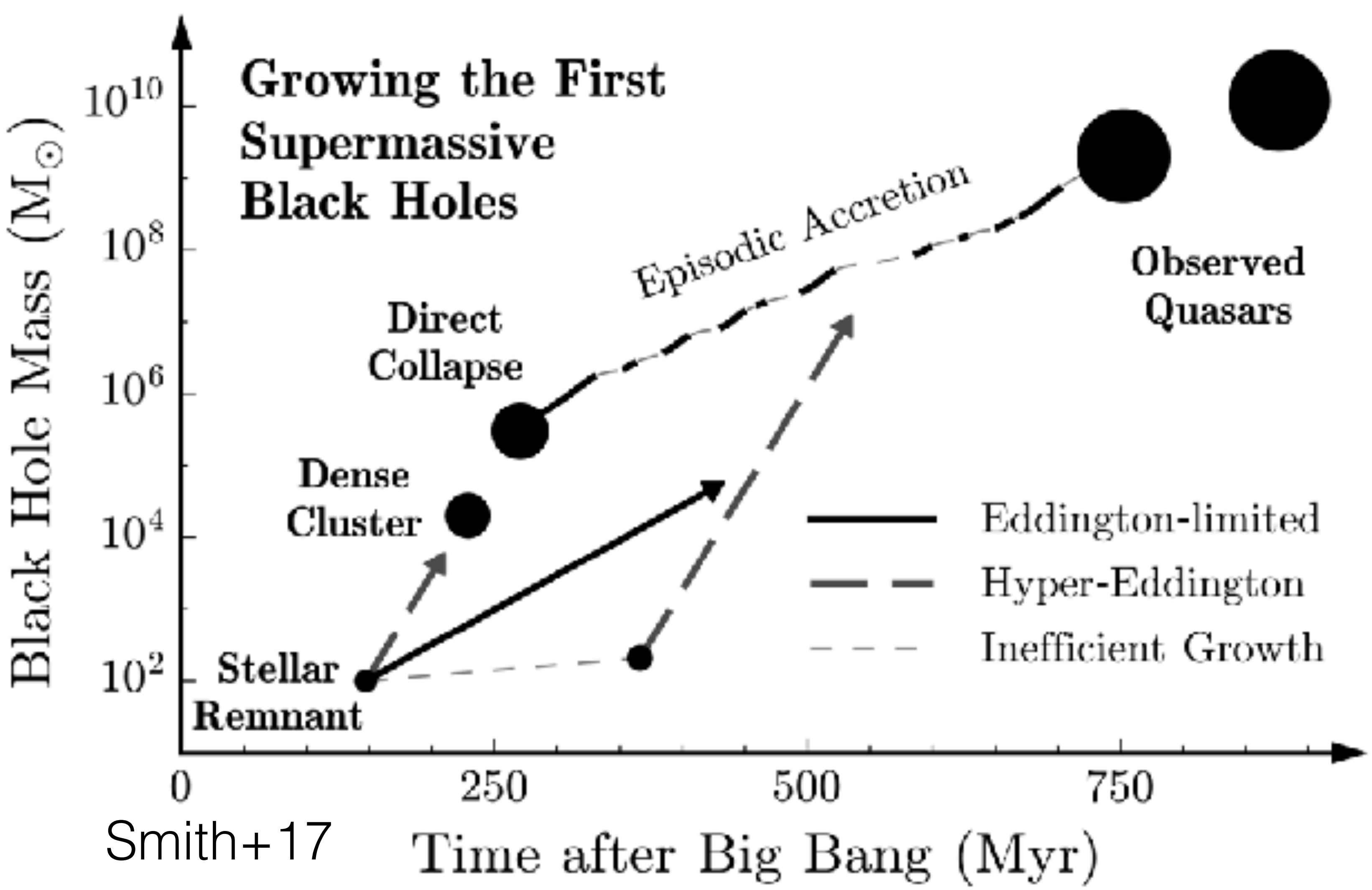


Adapted from W.N. Brandt talk at Lynx meeting

~1000 accreting BH at z=8-9
with $\log L_X \gtrsim 41$ and $\log(M_{BH}/M_\odot) \gtrsim 4$ in ~ 1 deg^2

Enough to sample accurately the XLF and place tight constraints to physical parameters regulating BH seed formation and growth

(e.g. Volonteri+12,+16, Haiman+13, Johnson&Haardt+16, and references therein)



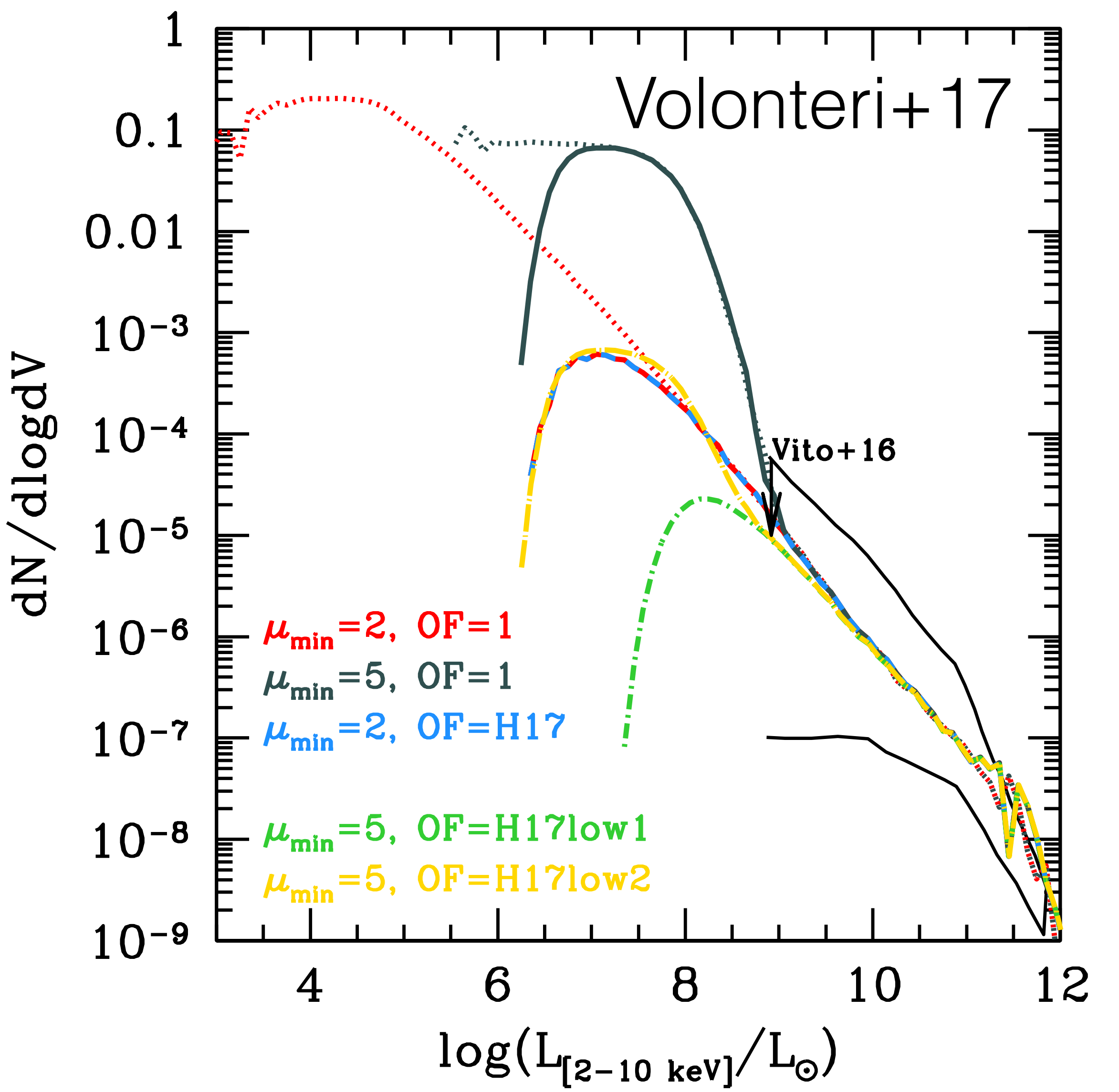
Smith+17

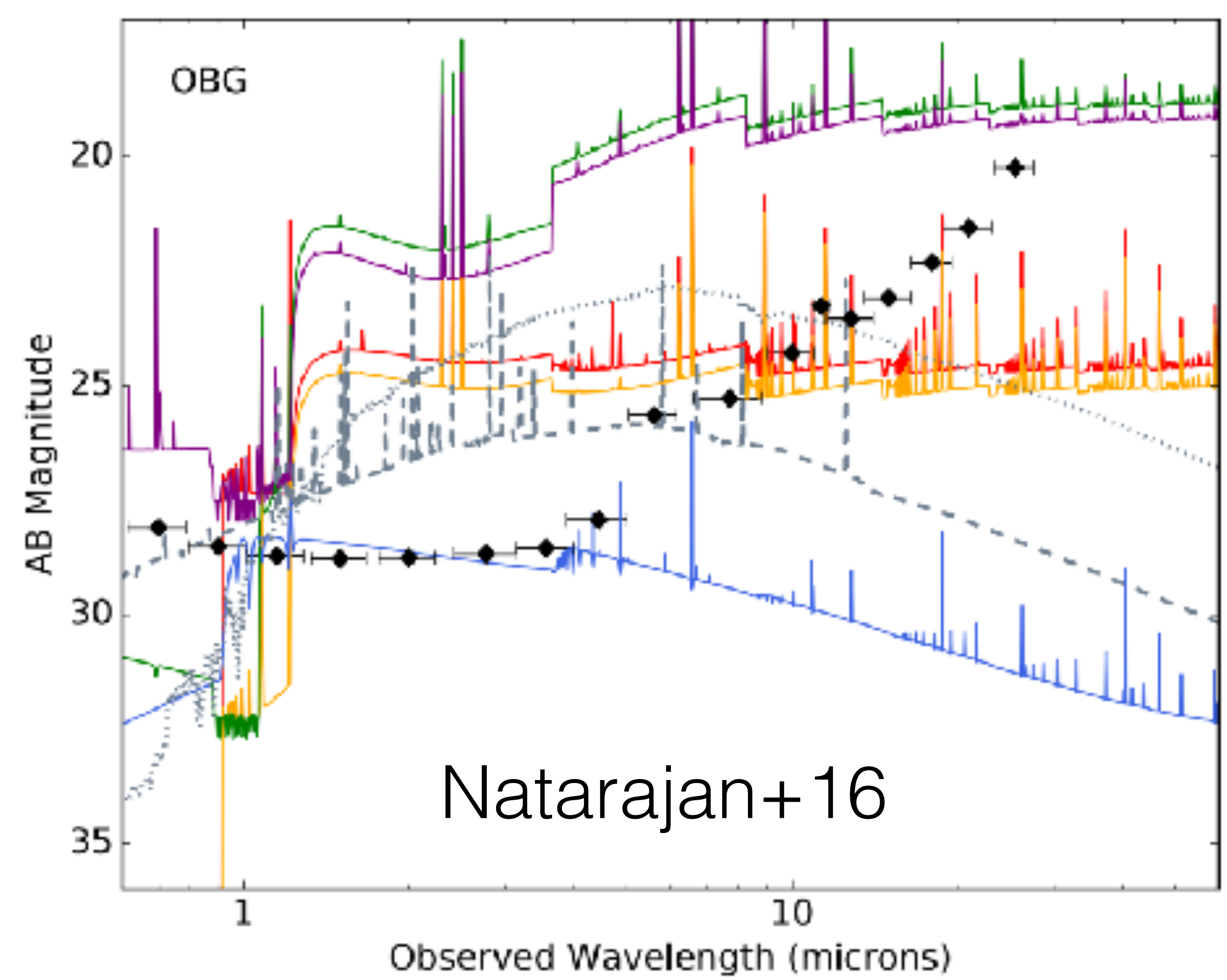
1. seed mass distribution (light or heavy seeds?)
2. occupation fraction
3. λ_{Edd} distribution
4. feedback
5. etc.

~1000 accreting BH at z=8-9 with $\log L_X \gtrsim 41$ and $\log(M_{BH}/M_\odot) \gtrsim 4$ in ~ 1 deg^2

*N*eed deep (m~29.5) IR observations to identify them as high-z sources! JWST and WFIRST can do it! (e.g., Mason+15)

XLF faint-end shape, IR colors (e.g., Natarajan+16, Pacucci+15) and IR/X-ray flux ratio will constrain typical seed mass





~1000 accreting BH at z=8-9
with $\log L_X \gtrsim 41$ and $\log(M_{BH}/M_\odot) \gtrsim 4$ in ~ 1 deg^2

Enough to sample accurately the XLF and place tight constraints to physical parameters regulating BH seed formation and growth

But significant uncertainties due to…

1. modelling
   (e.g. factors of several in space density)
2. XRB contribution/confusion
3. ancillary data
   (i.e. NIR/MIR with JWST/WFIRST, we need rest-frame UV m~29.5)

Work in progress here!

https://wwwastro.msfc.nasa.gov/lynx/