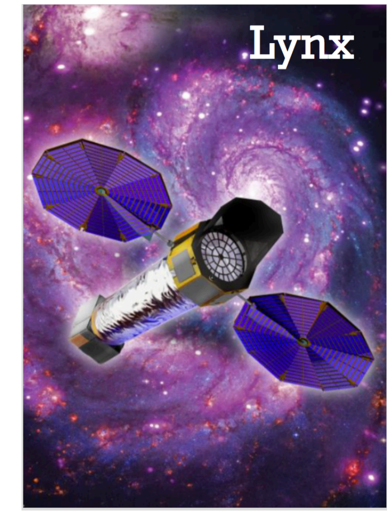
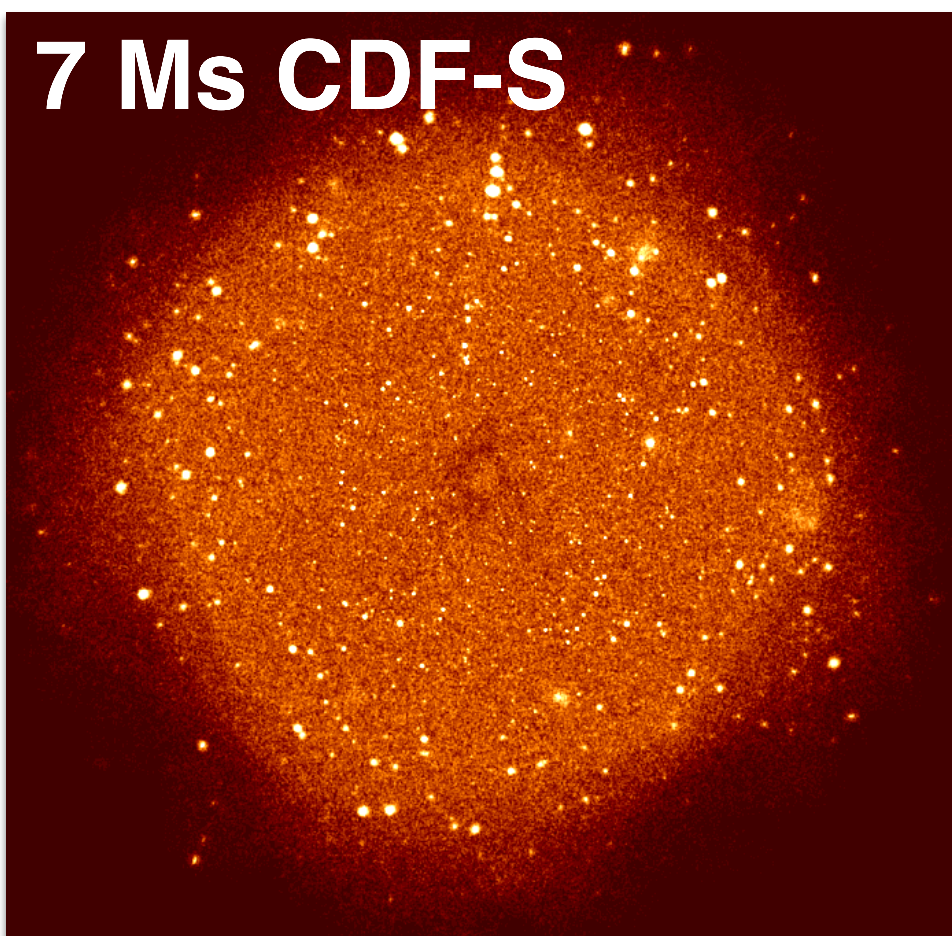
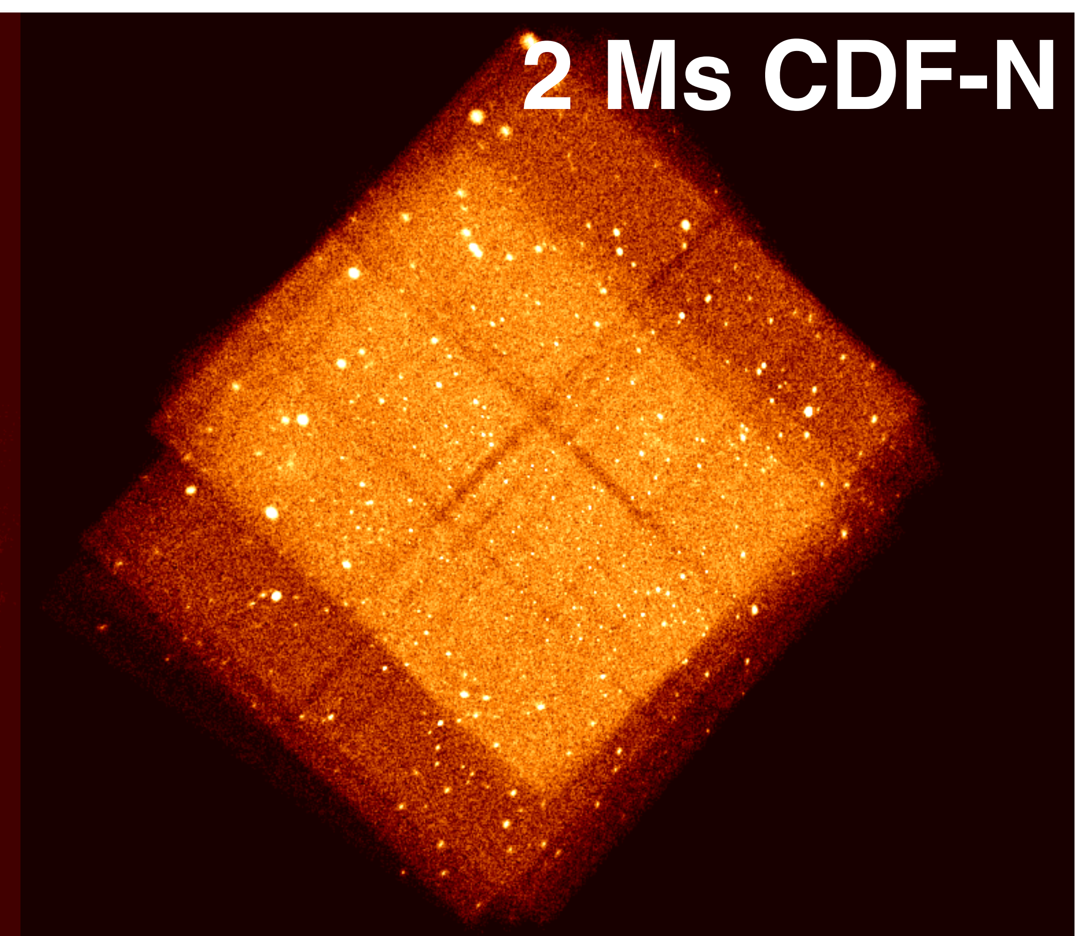
The early growth of (sub-L*) super-massive black holes as seen by Chandra (and *Lynx*)



Fabio Vito
PUC (Chile)
Penn State University (USA)

(mainly) *in collaboration with* W.N. Brandt, R. Gilli, C. Vignali, A. Comastri, F. Bauer, G. Yang

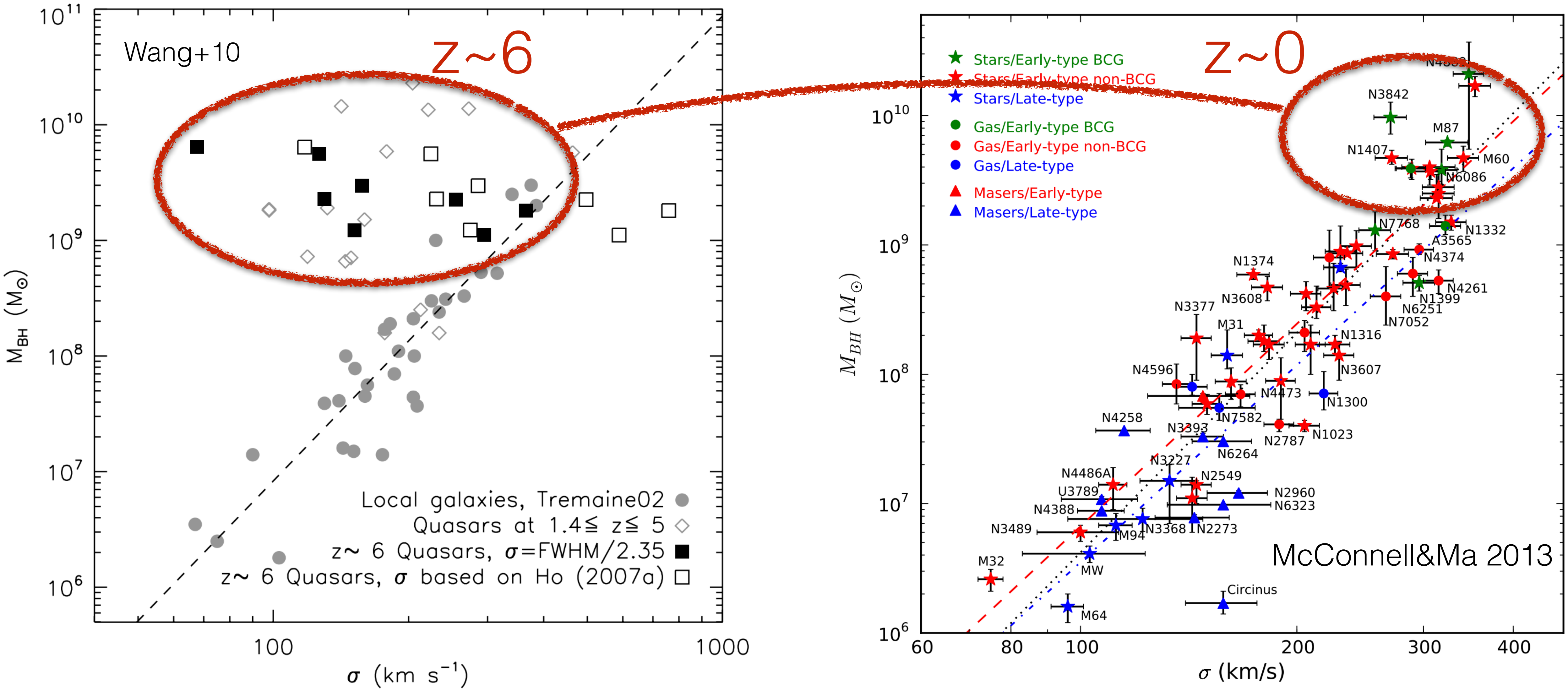




Optically selected z≳6 QSOs are extremely massive!

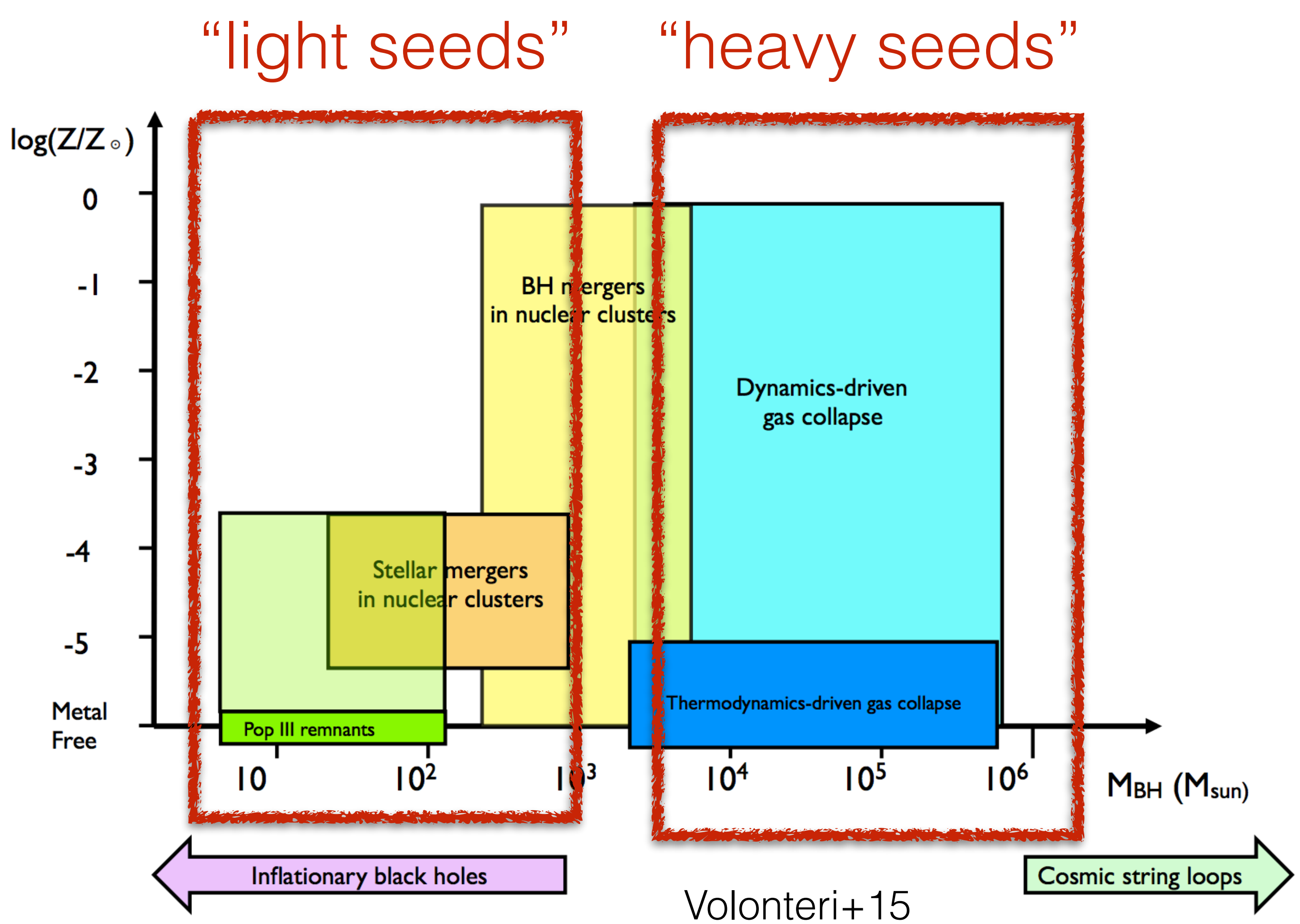
log(M_BH/Msun)~9-10

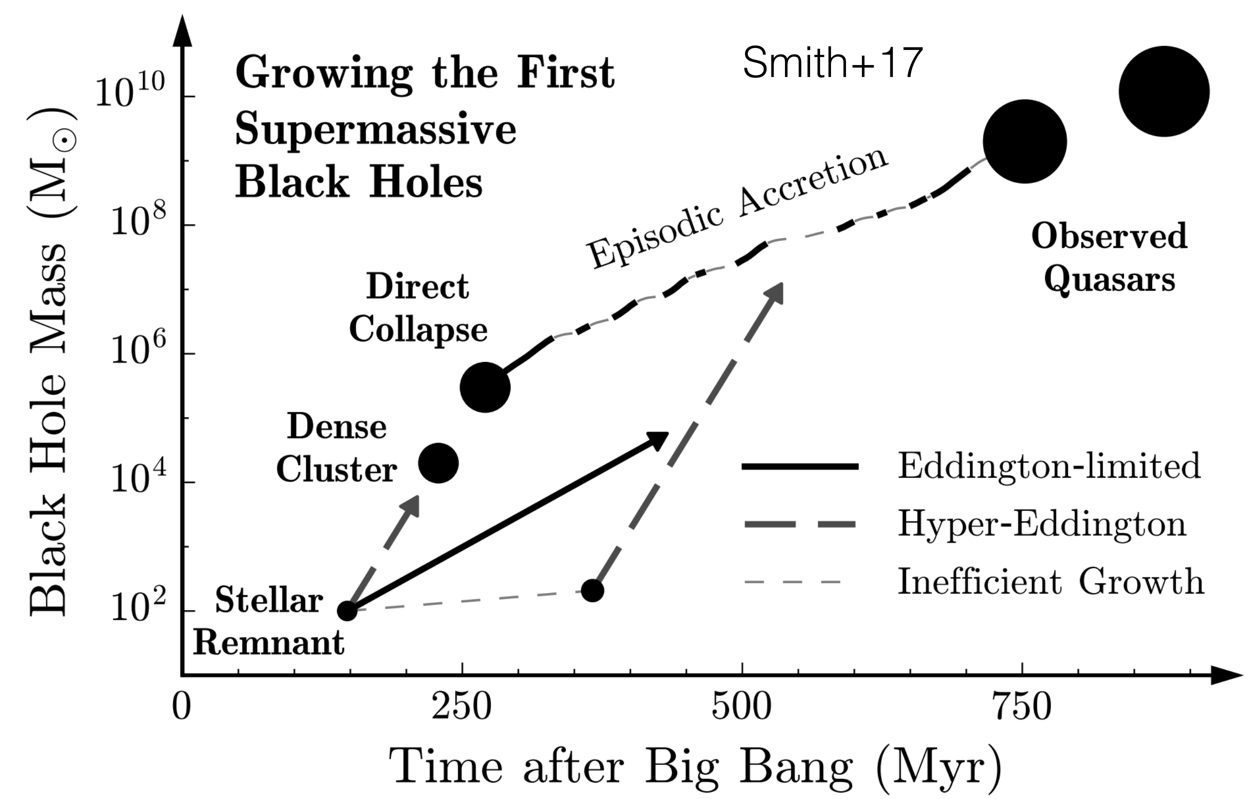
(e.g., Mortlock+11, Wu+15, Banados+18a)



How can you form such massive BH in <1Gyr??

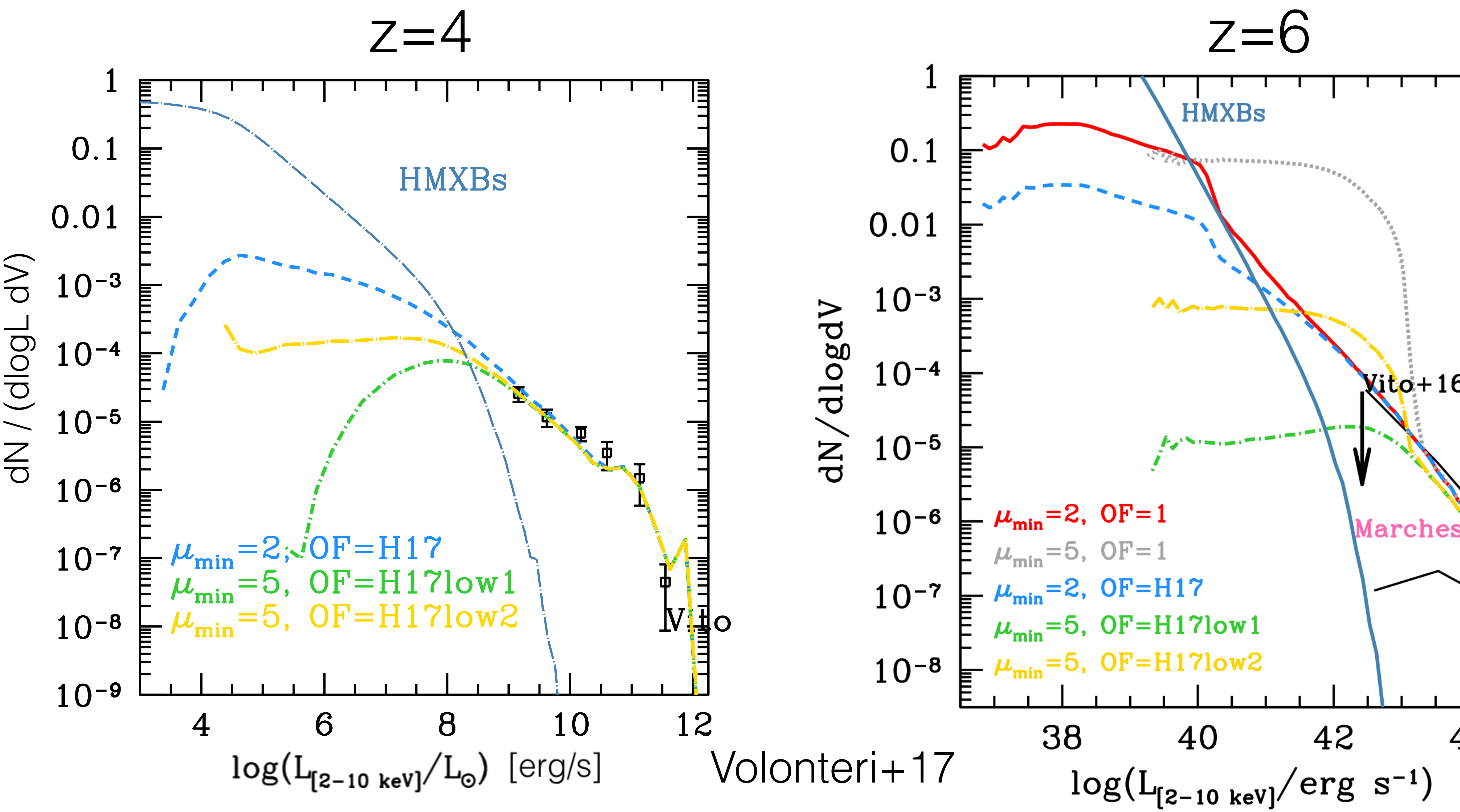
SMBH formation





Seed mass distribution, Eddington ratio distribution, occupation fraction, radiation efficiency, feedback, etc….

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



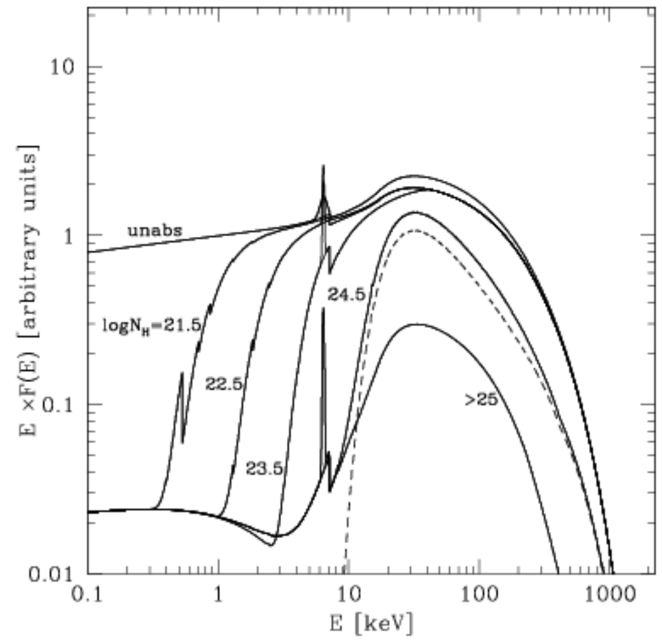
Volonteri+17

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!

Why X-rays?

1) Ubiquitous in AGN

2) Obscuration



Gilli+07

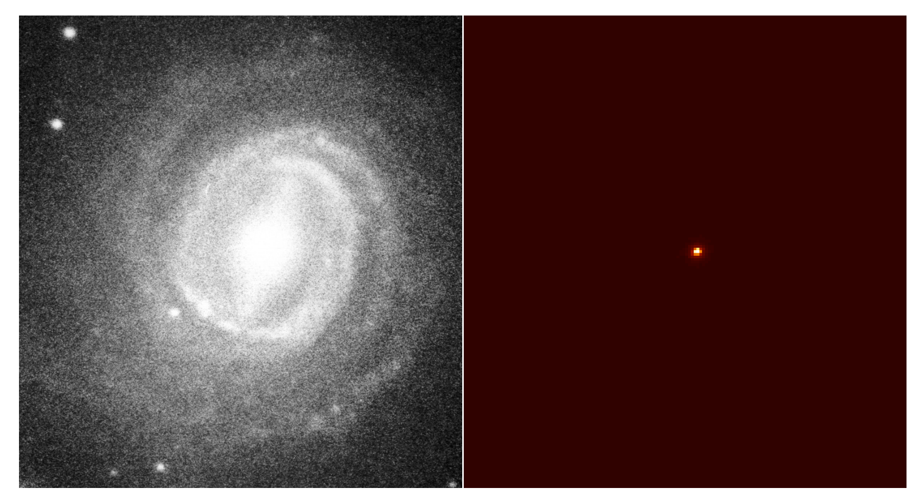
3) Galaxy dilution

Brandt & Alexander 2015

NGC 3783

optical

X-ray

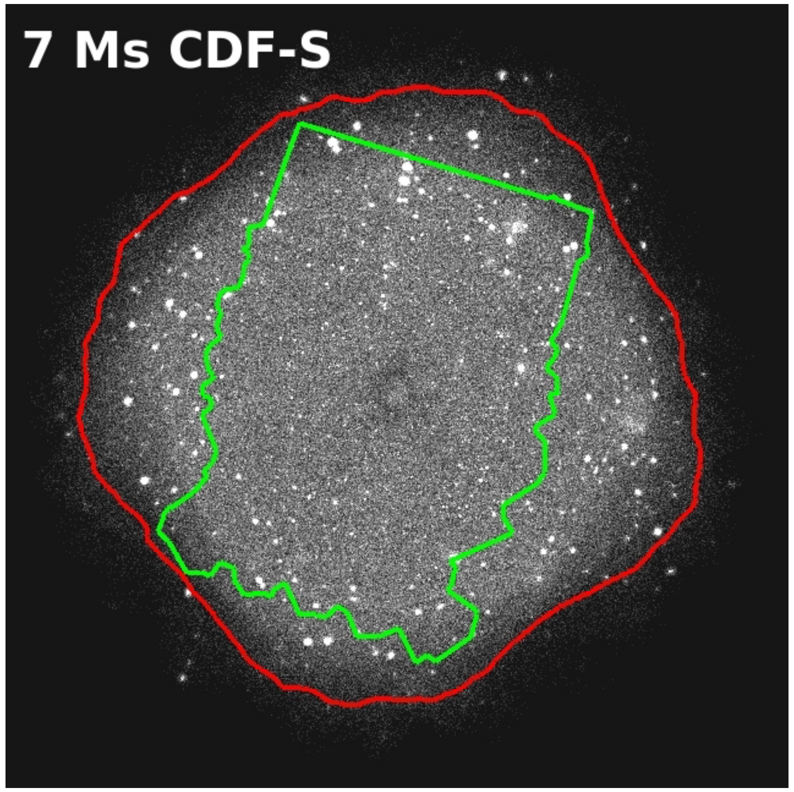


Clean and less biased selection (especially at high-z)!

But optical/IR data needed for identification

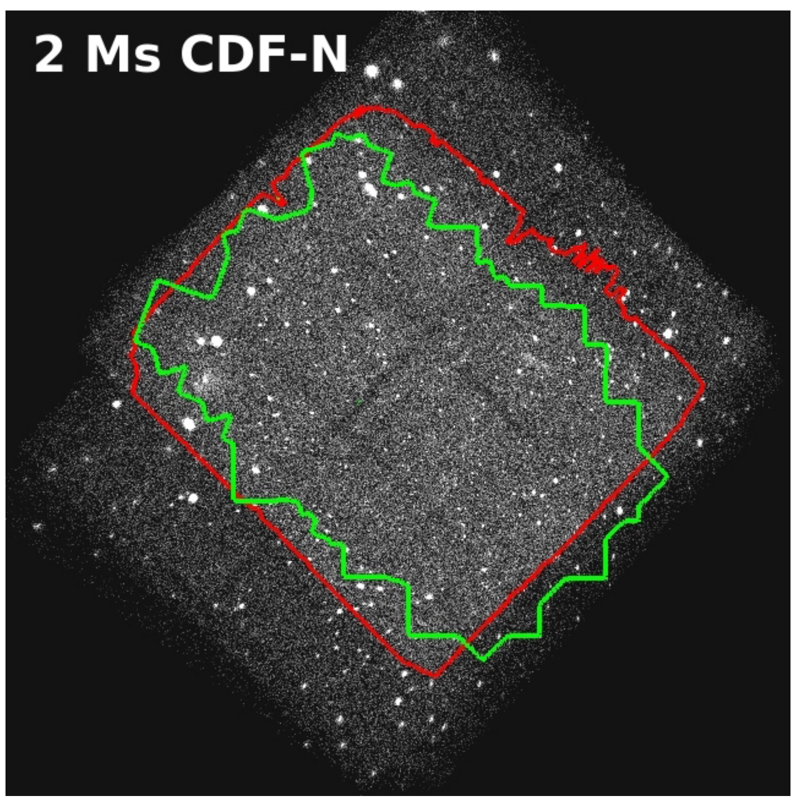
The data-set

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)



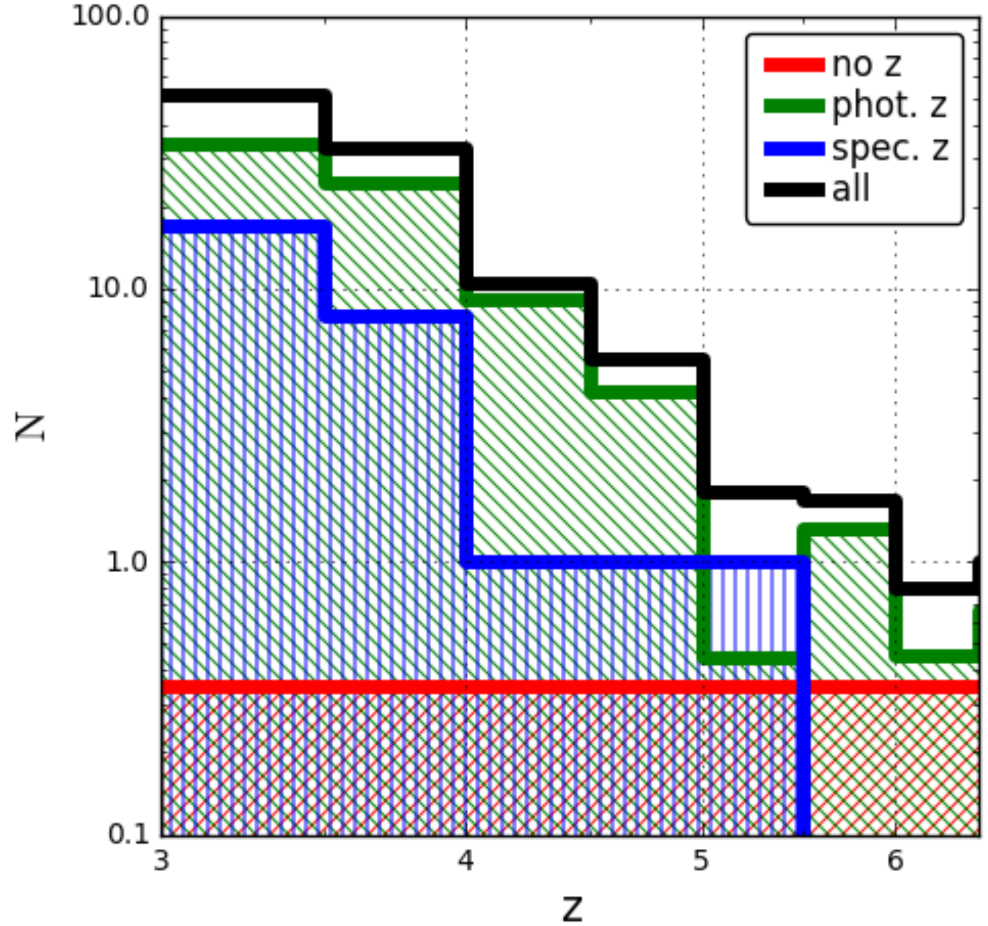
- **Second deepest X-ray survey to date!** F_{lim}~1.2 x 10^{-17} erg cm^{-2} s^{-1}
- A~447 $arcmin^2$
- **Deep radio-UV coverage** (e.g. CANDELS/GOODS-N)
- 683 X-ray sources
- **~98% multi-wavelength identification,**
- **>93% redshift** (>50% spec-z, phot-z from Yang+14, Skelton+14, Kodra+ in prep.)

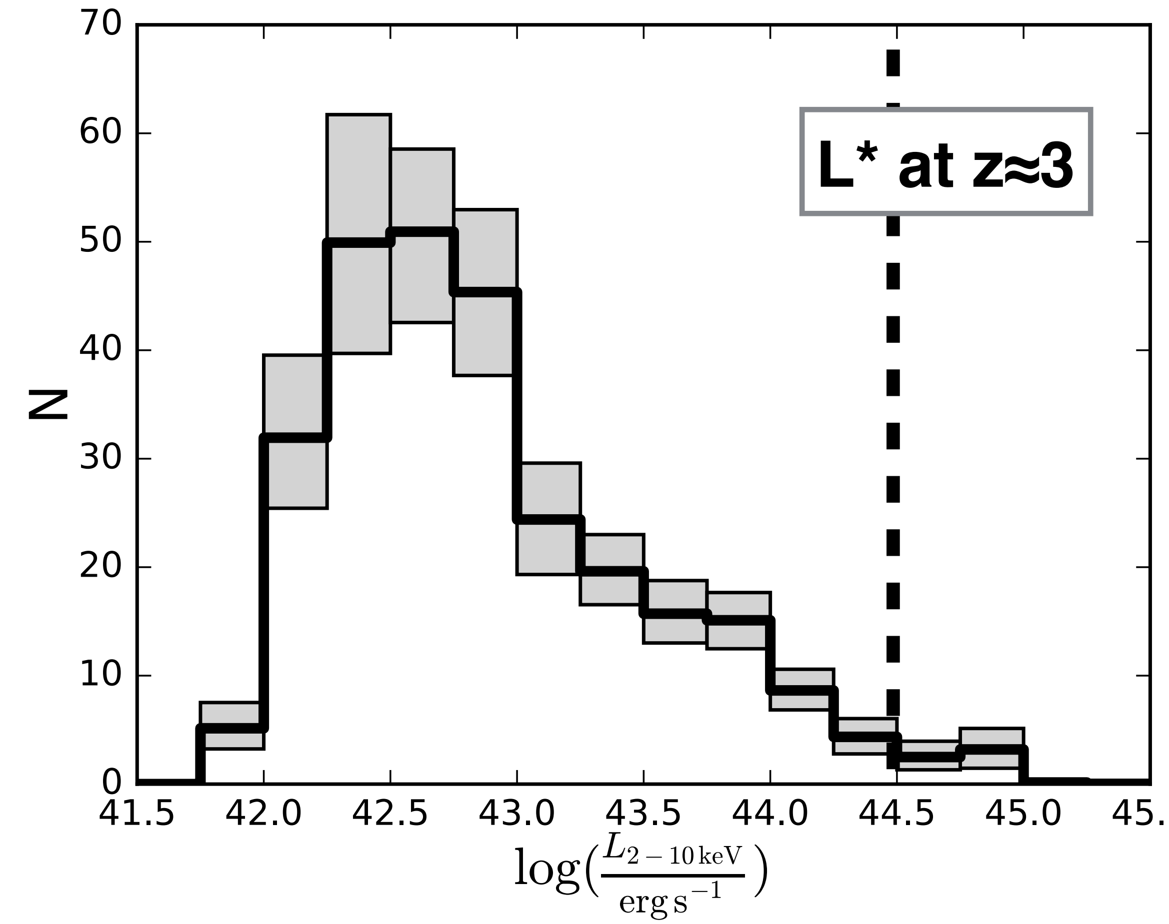
Final sample of ~101 AGN at 3<z<6

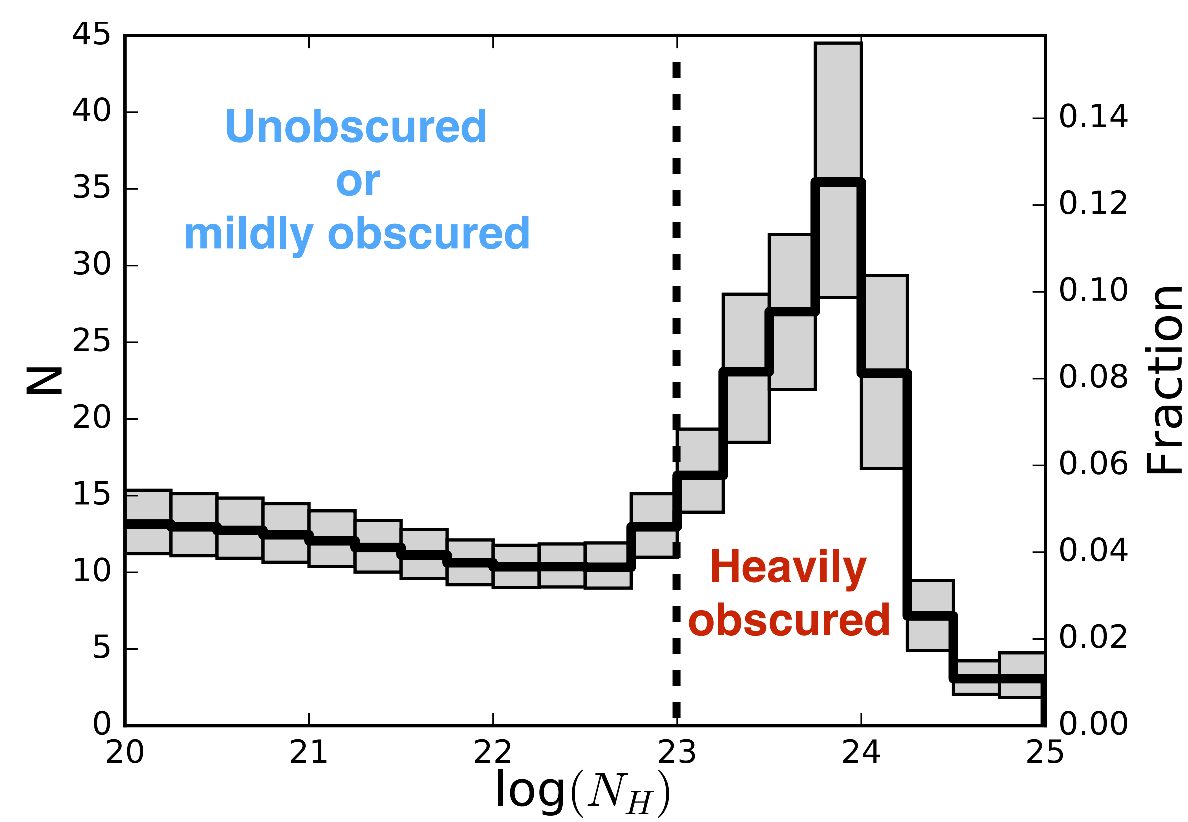
Parameter distributions

~100 z>3 candidates

Vito+18







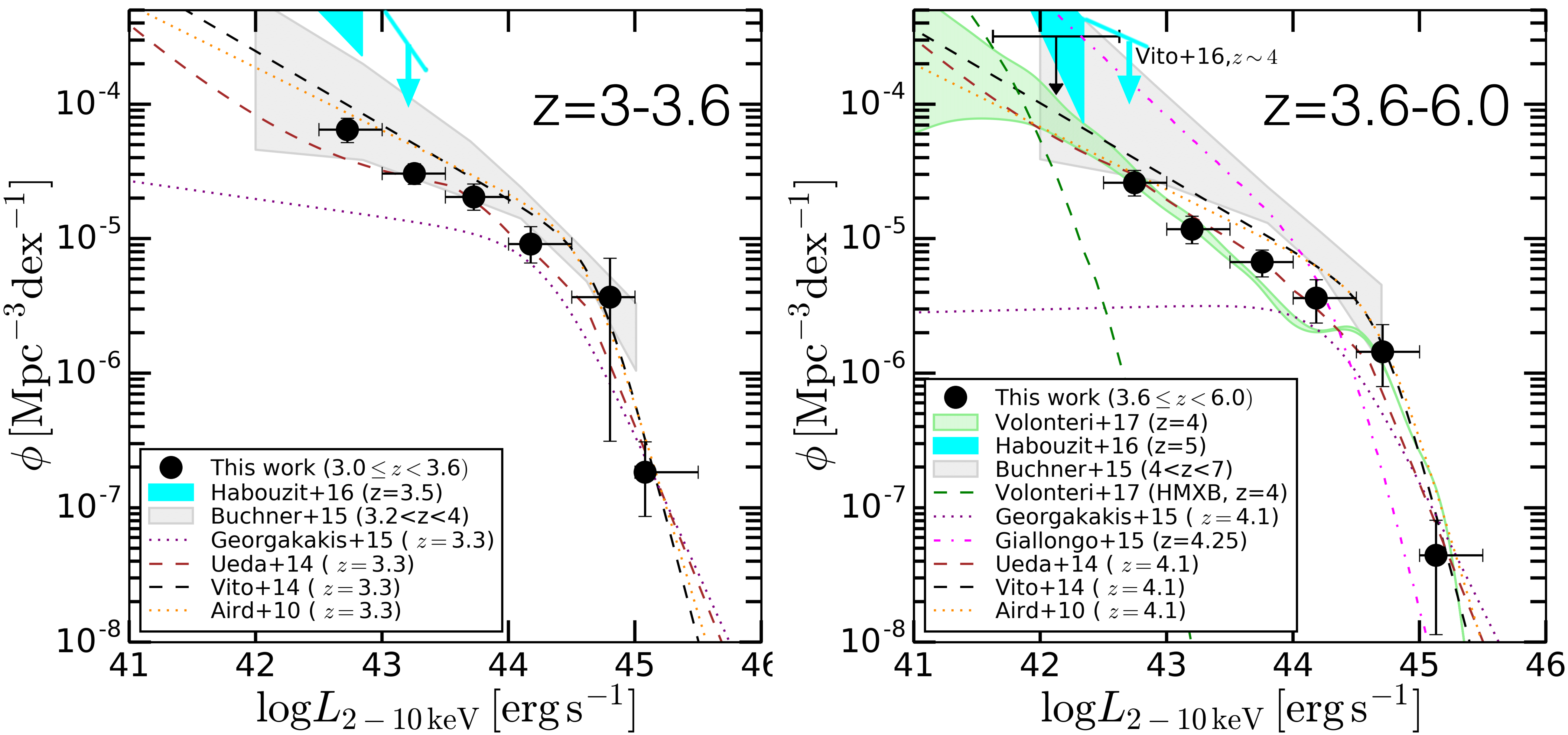
observed
0.5-7 keV

↓

Rest-frame
2-40 keV
at z=3-6

AGN X-ray luminosity function

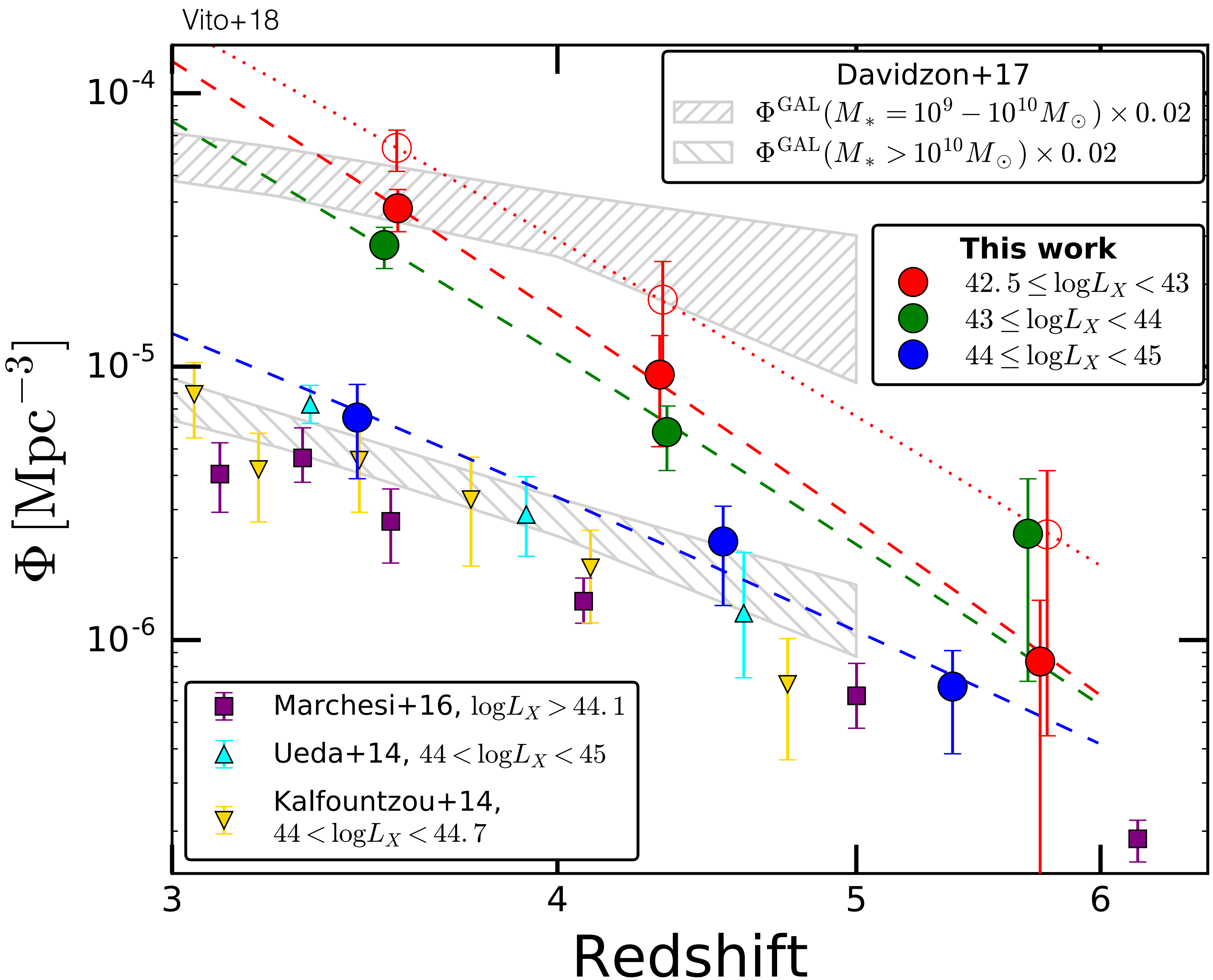
Vito+18



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

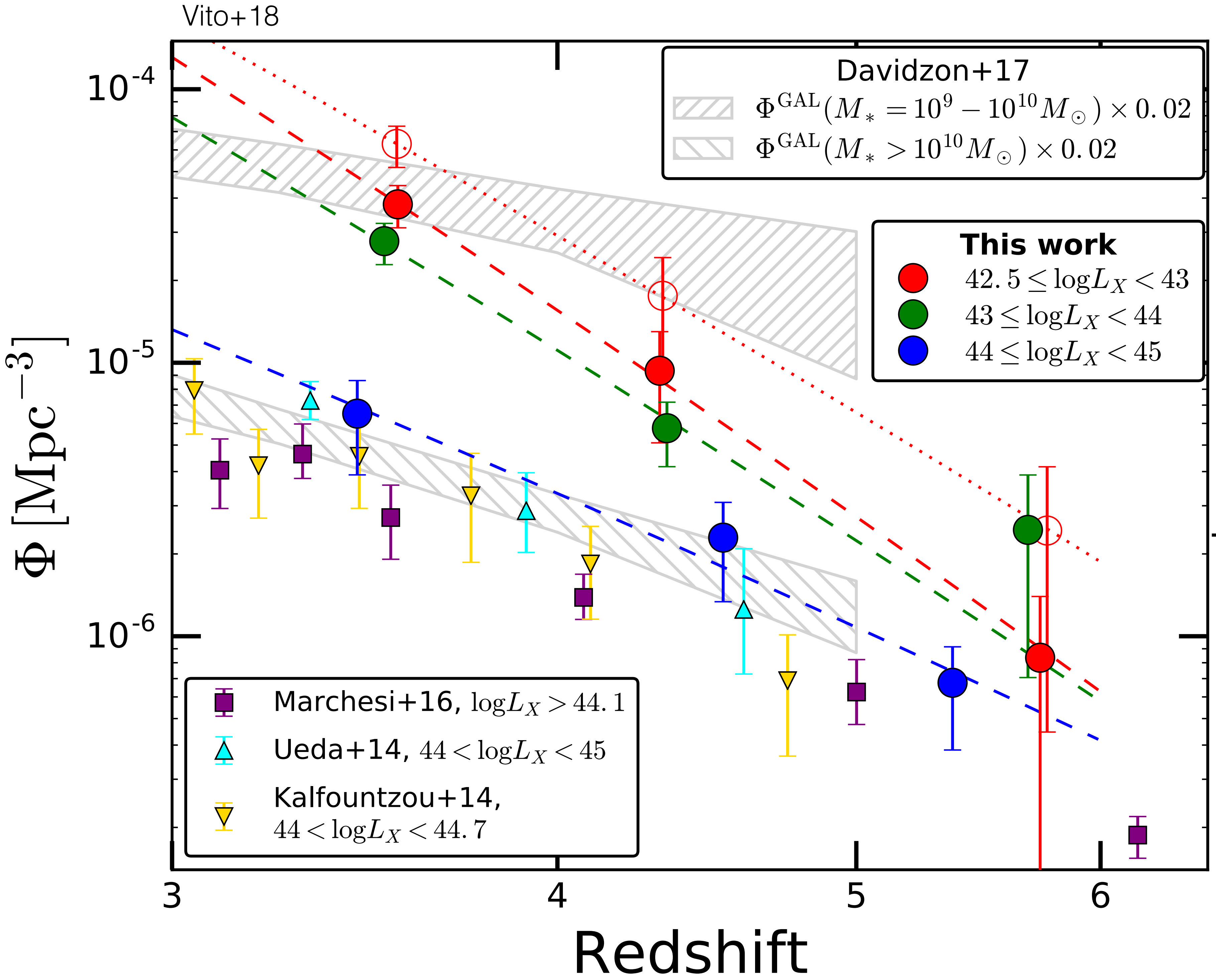
AGN space density



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.)?

AGN space density

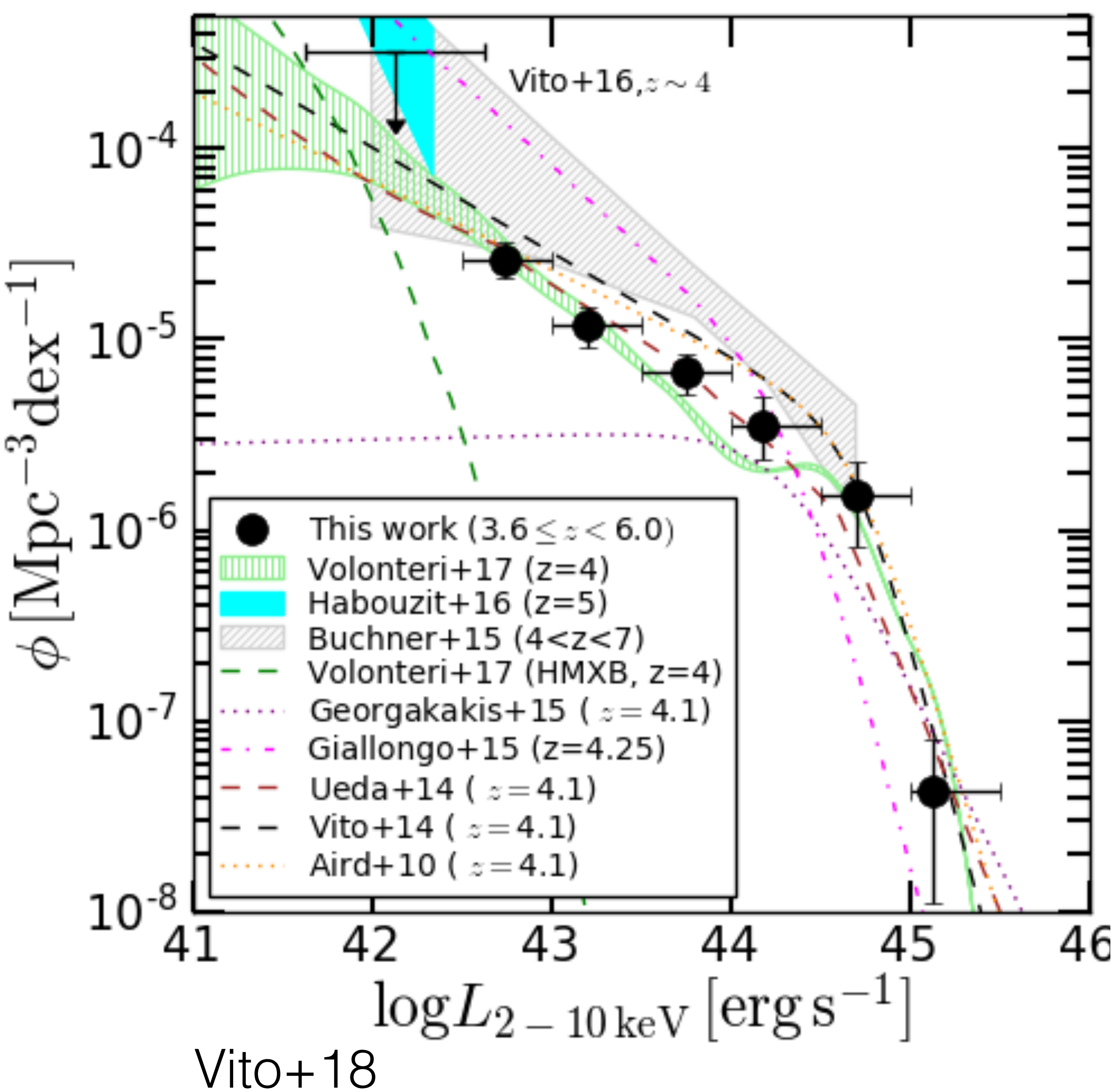


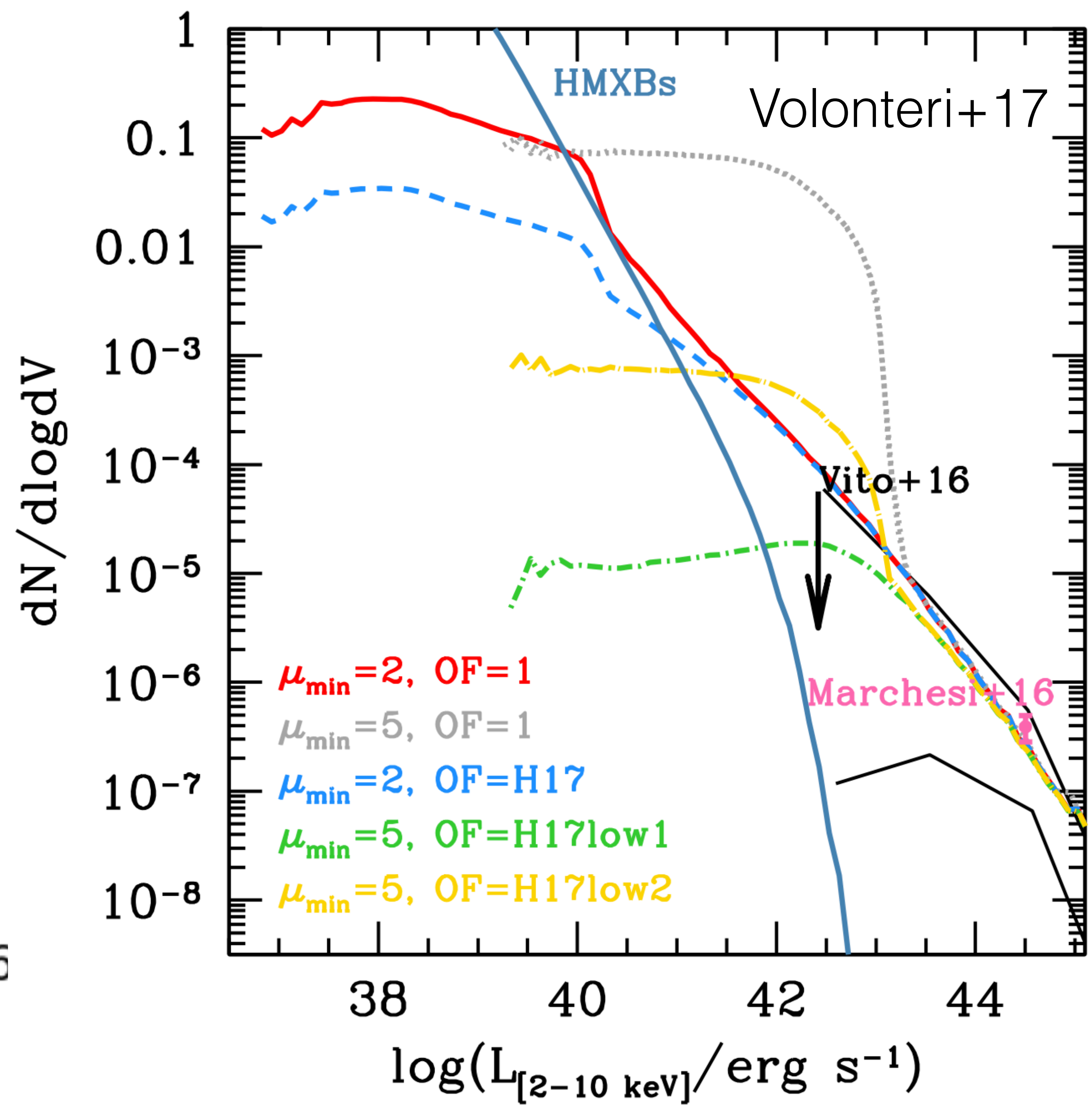
Main problem: spectroscopic identification

Need for follow-up campaigns to confirm the high-z candidates e.g. VLT (FORS2, MUSE, XSHOOTER) and ALMA

In the near future, VLT/MOONS and JWST

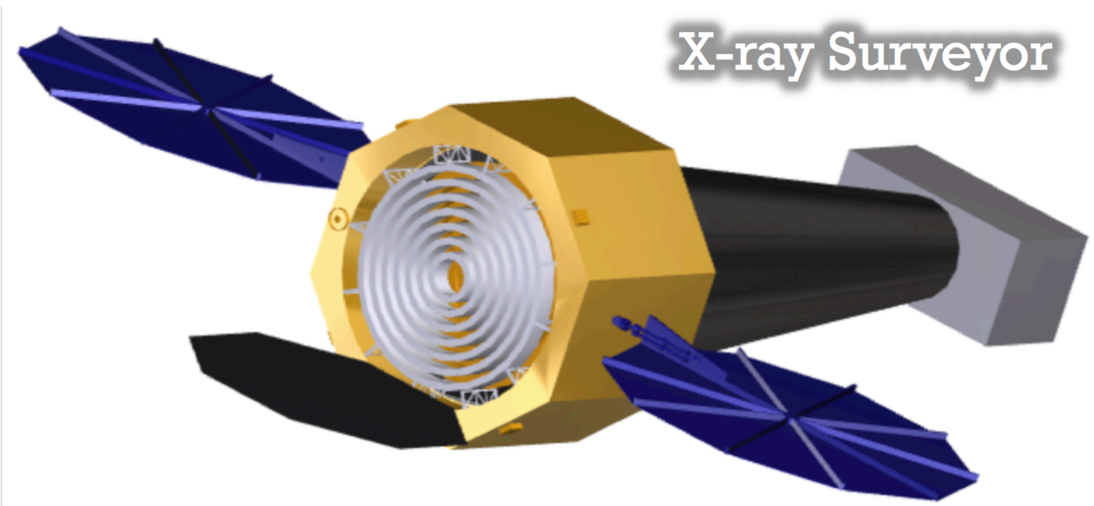
XLF faint end at high-z as a tool to study BH seed formation and growth





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

Lynx (Weisskopf et al. 2015)



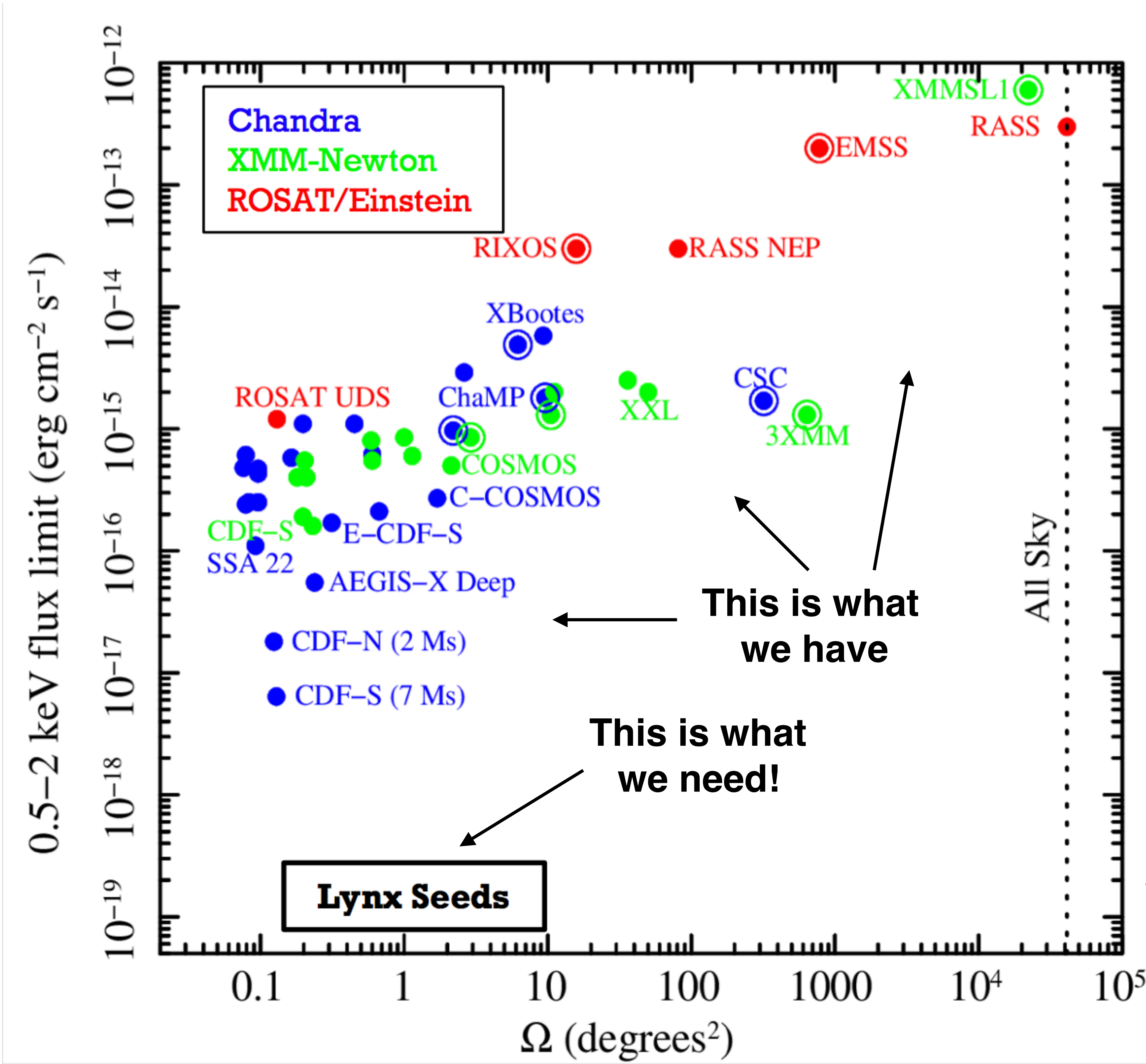
- *Chandra*-like angular resolution
- f.o.v.=0.12 deg^2=15x *Chandra*
  (for sub-arcsec resolution)
- 30-50x effective area of *Chandra*
- 20x *Chandra* sensitivity

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)

Hunting BH seeds in the early universe



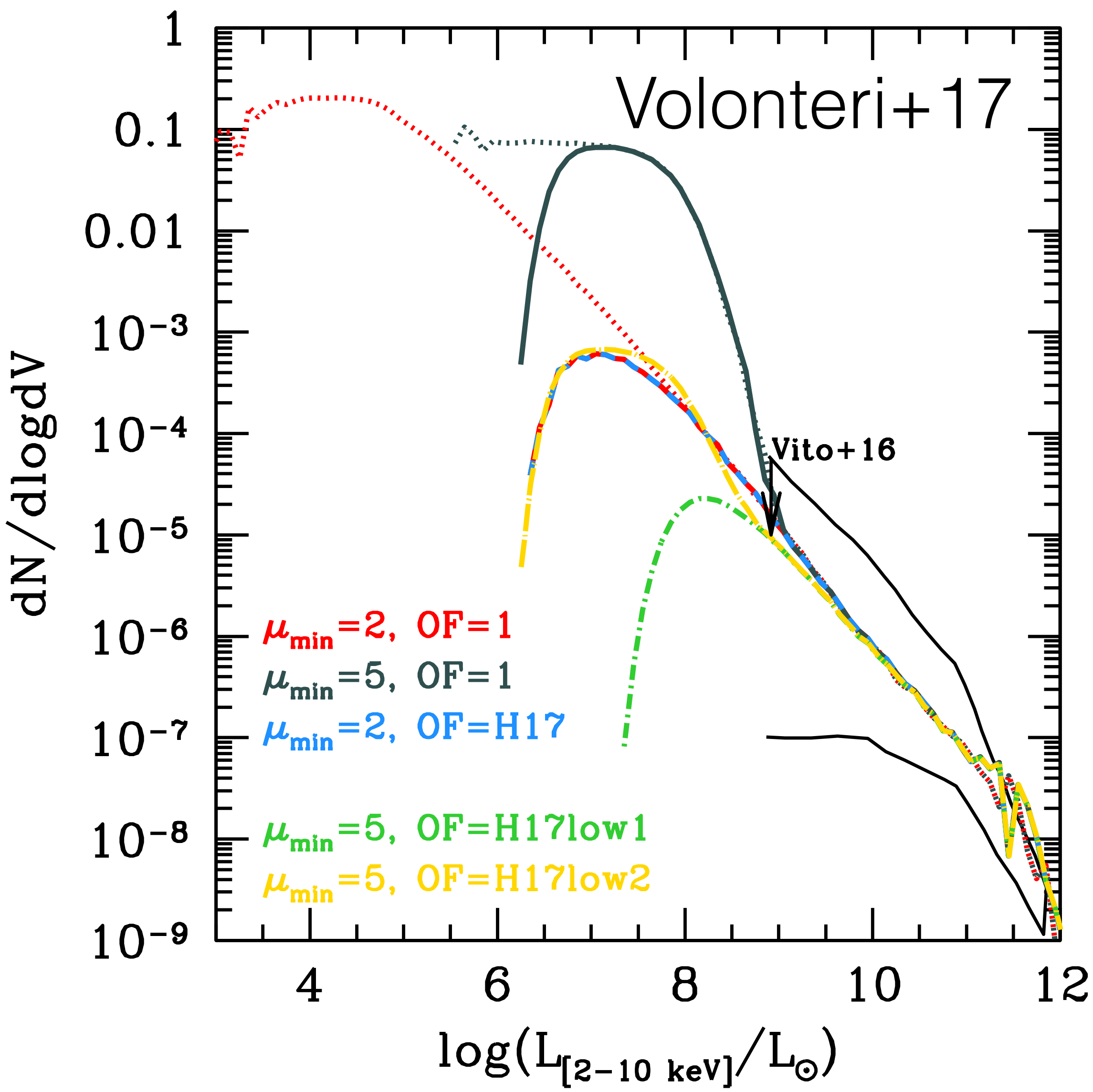
Adapted from W.N. Brandt talk at Lynx meeting

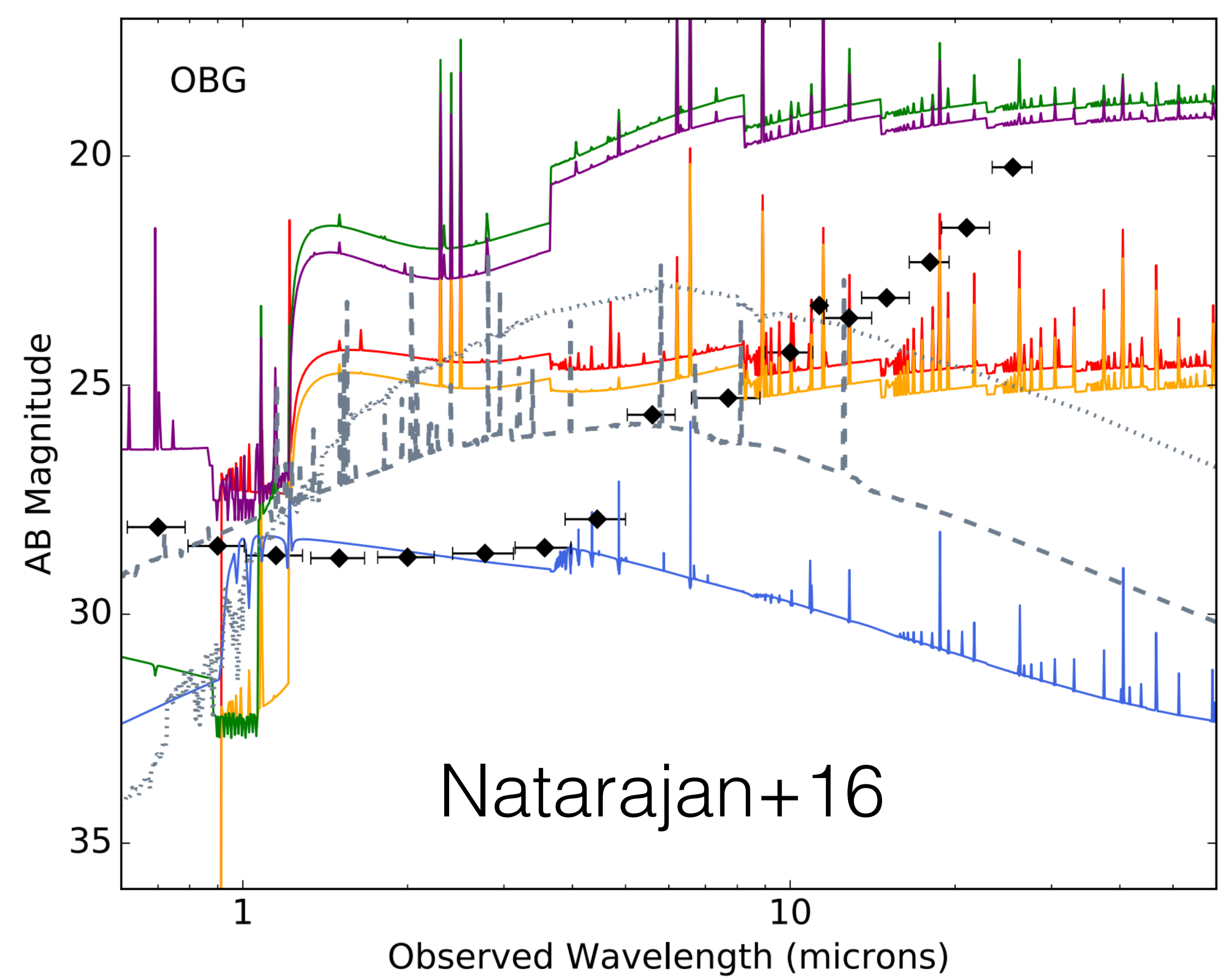
~1000 accreting BH at z=8-9 with $\log L_X \gtrsim 41$ and $\log(M_{BH}/M_\odot) \gtrsim 4$ in ~ 1 deg^2

*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, Valiante+18a,b) 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

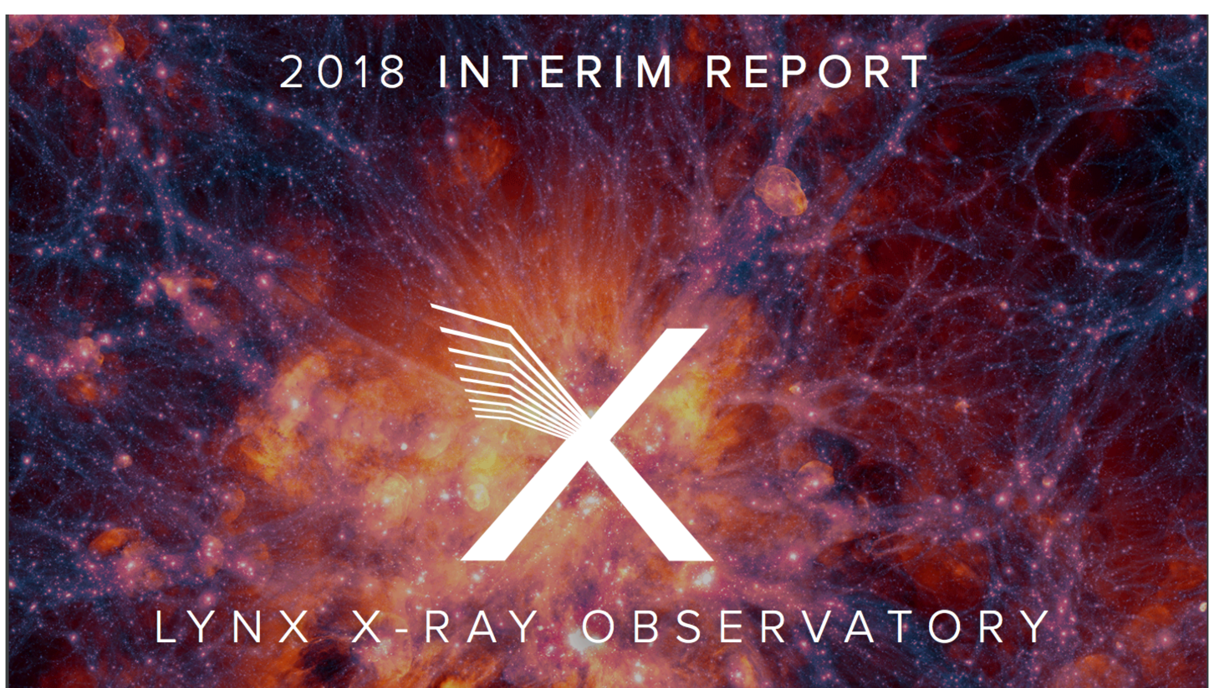
Enough to sample accurately the XLF and place tight constraints to physical parameters regulating BH seed formation and growth

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/



arXiv:1809.09642