The systematic search for z ≳ 5 active galactic nuclei in the *Chandra* Deep Field South

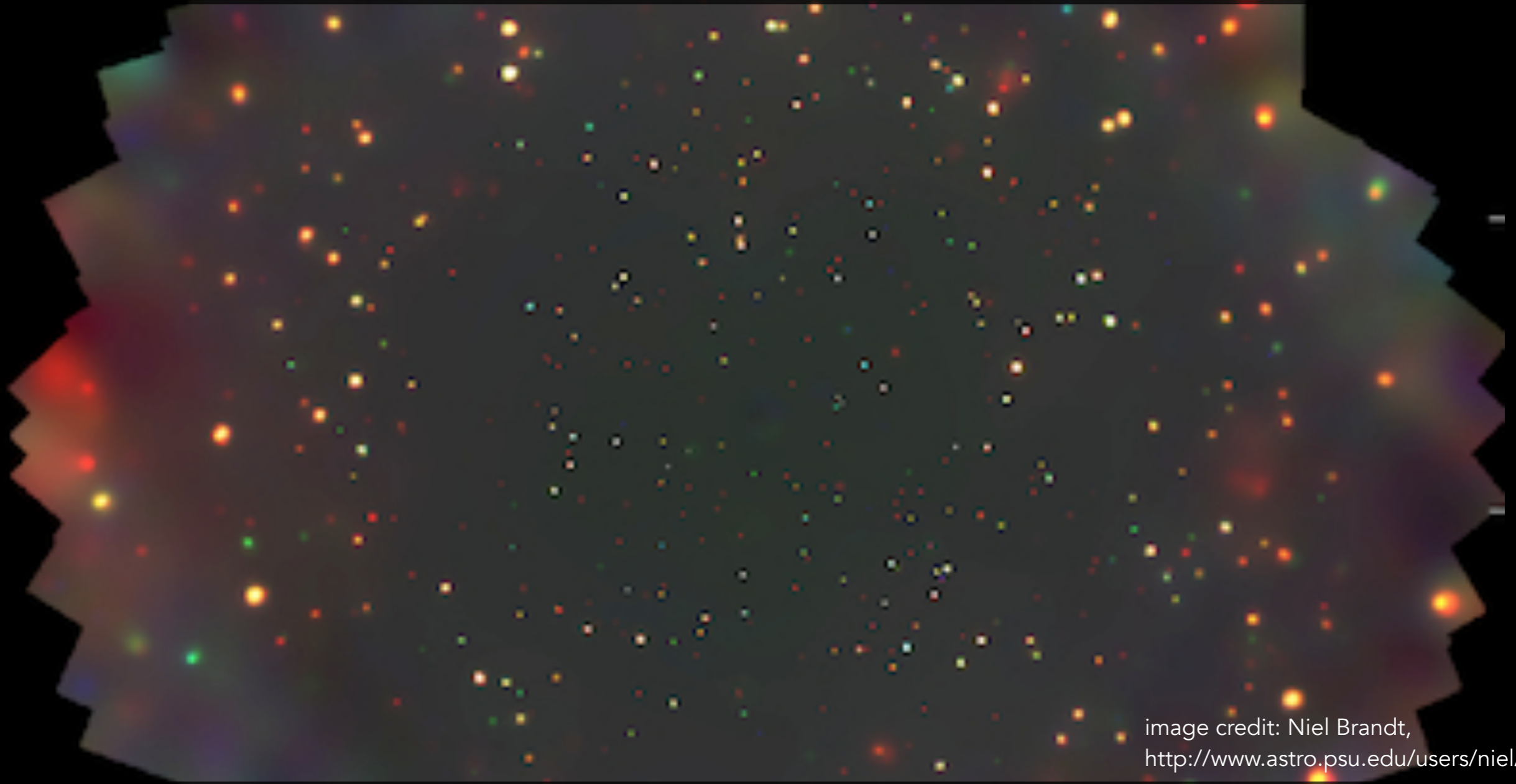image credit: Niel Brandt,
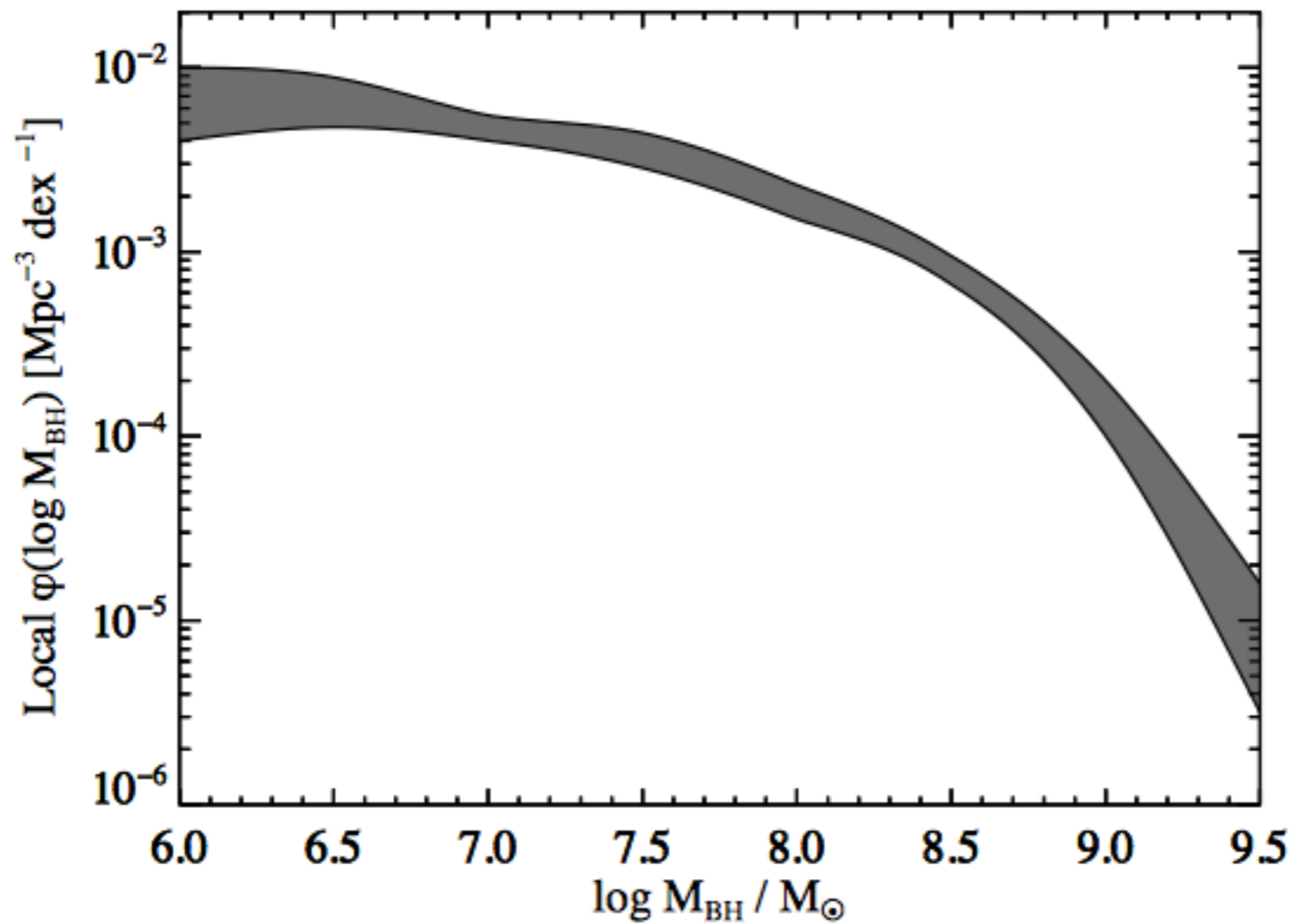http://www.astro.psu.edu/users/niel/cdfs/

Anna Weigel, ETH Zurich

Kevin Schawinski, Ezequiel Treister, Meg Urry, Michael Koss, Benny Trakhtenbrot

Motivation

Local BH mass function:

Kelly & Merloni, 2011

Motivation

Local BH mass function:
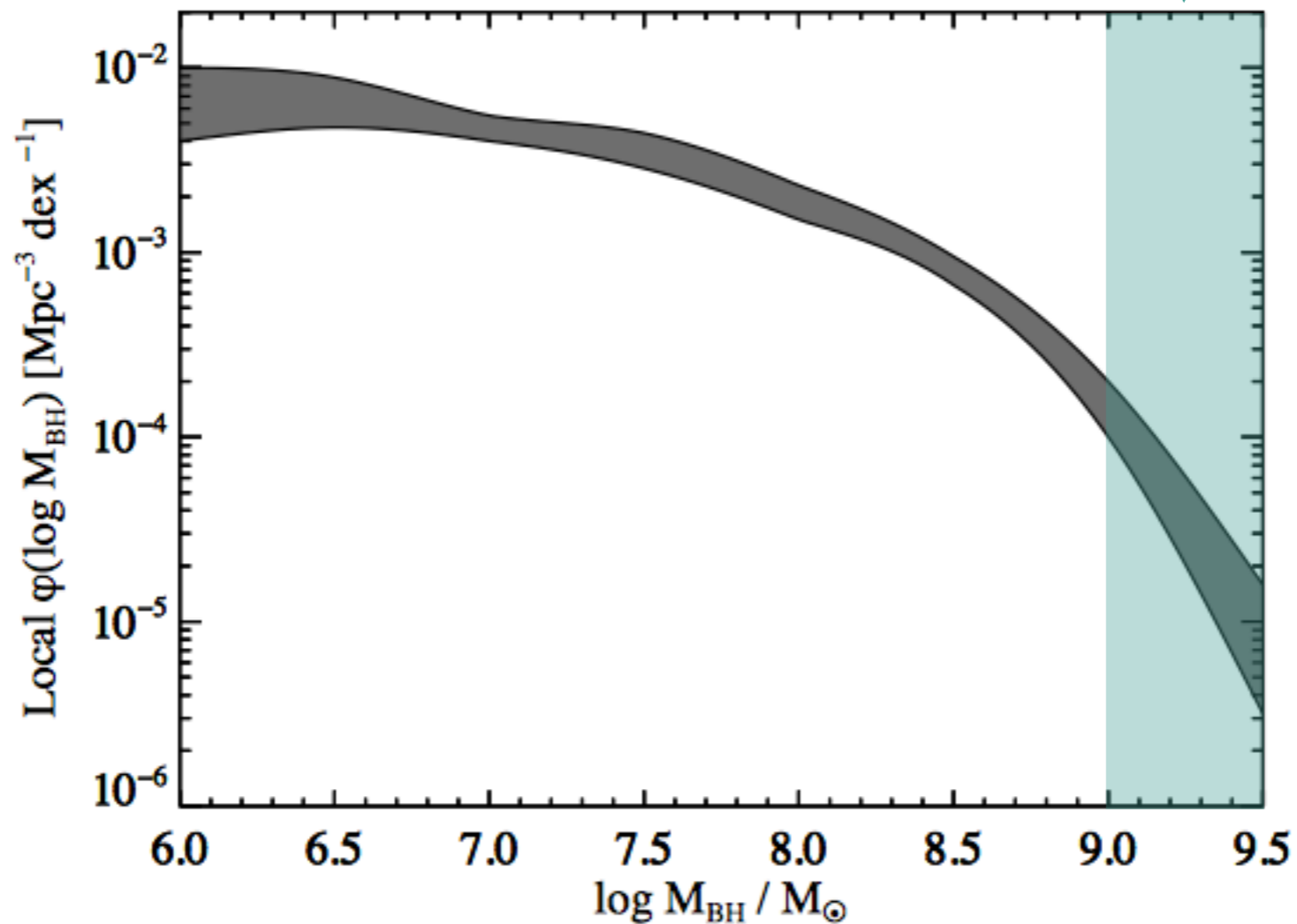
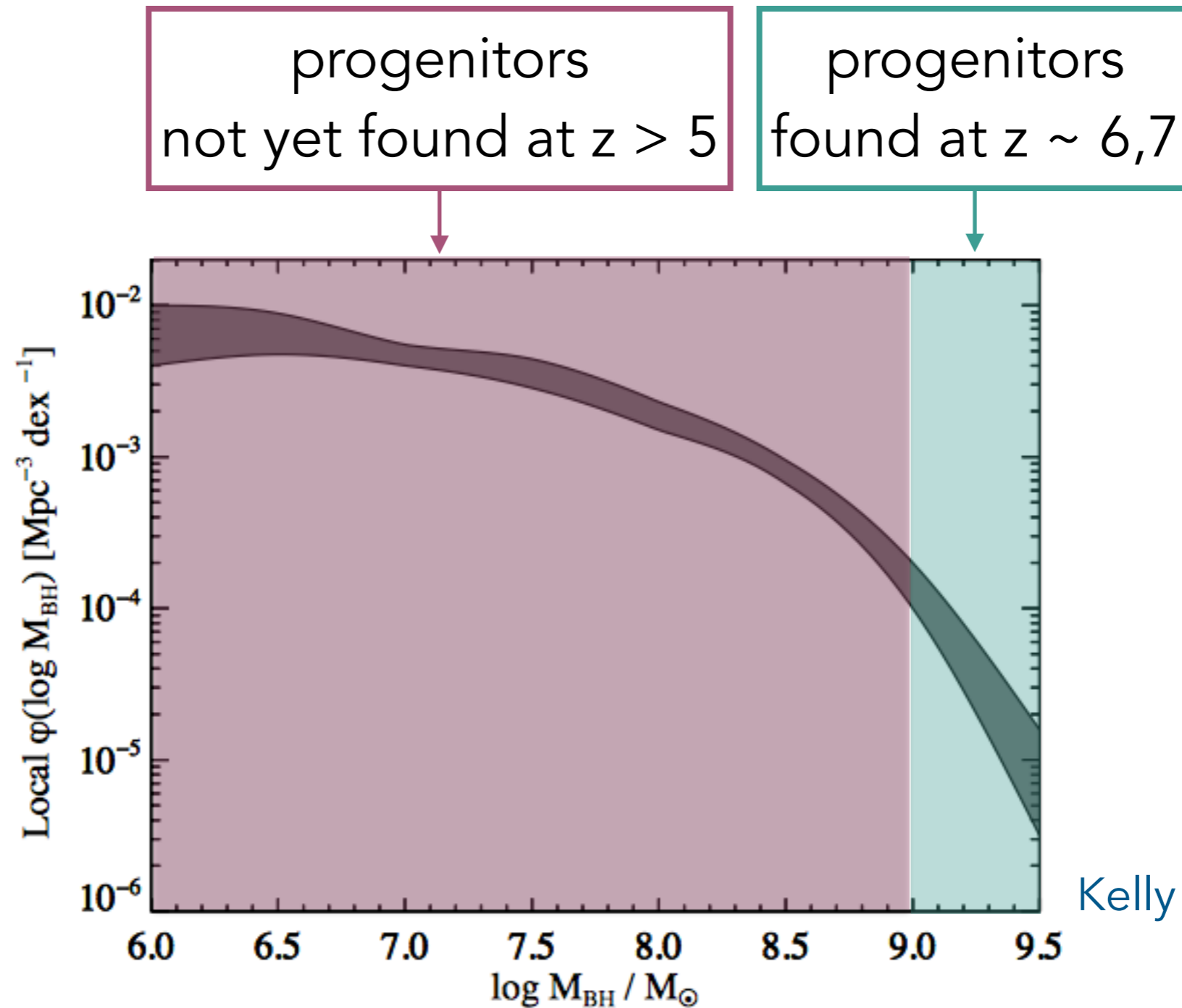Fan+ 2000, 2001
Willott, McLure & Jarvis 2003
Mortlock+ 2011
Wu+ 2015

progenitors
found at z ~ 6,7

Kelly & Merloni, 2011

Motivation

Local BH mass function:

progenitors
not yet found at z > 5

progenitors
found at z ~ 6,7

Kelly & Merloni, 2011

Expectations

▸ ~ 700 z ~ 5

  Lyman Break Galaxies

Stark+ 2009, Vanzella+ 2009, Wilkins+ 2010,
Bouwens+ 2014, Duncan+ 2014

▸ at z~3: AGN fraction ~ 3%

Nandra+ 2002

▸ expect to find ~ 20 z ~ 5
  AGN

Expectations

▸ ~ 700 z ~ 5 Lyman Break Galaxies

▸ at z~3: AGN fraction ~ 3%

▸ expect to find ~ 20 z ~ 5 AGN

Eddington ratio = 0.1
$N_H = 10^{22}$ cm^{-2}

$M_{BH} = 10^9 M_\odot$

hard band

$M_{BH} = 10^8 M_\odot$

soft band

$M_{BH} = 10^7 M_\odot$

$M_{BH} = 10^6 M_\odot$

log (X−ray Flux) in erg s^{-1} cm^{-2}

Redshift z

Data
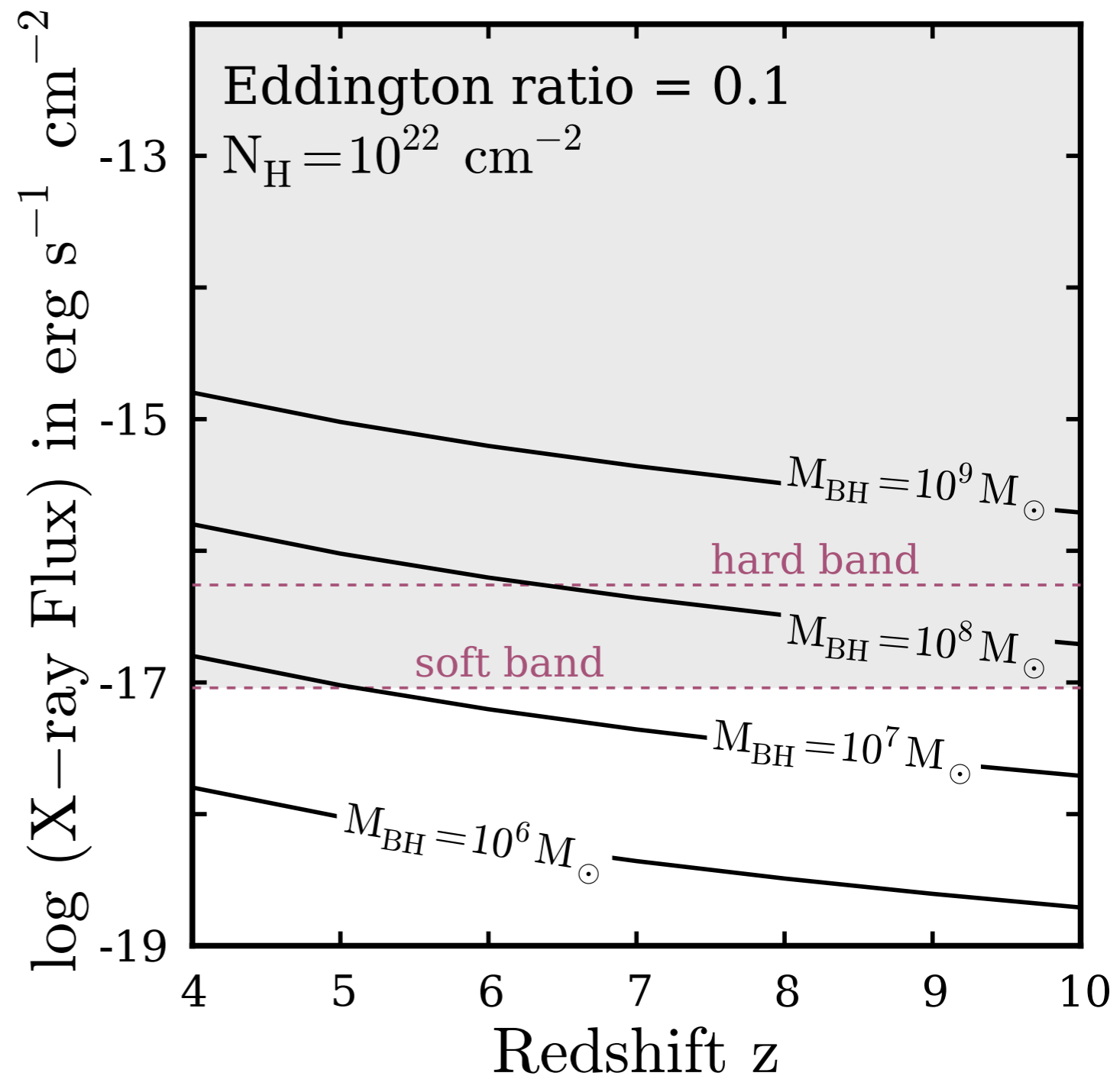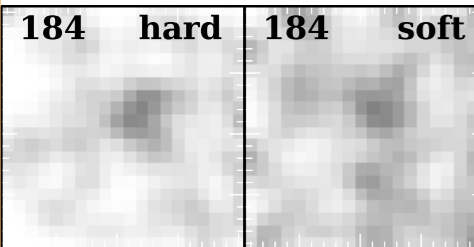
X-rays	optical	NIR	IR
184 hard 184 soft	184 *B* 184 *V* 184 *i* 184 *z*	184 *Y* 184 *J* 184 *H*	184 3.6 184 4.5
Chandra/ACIS, 4Ms-catalog	HST/ACS, GOODS	HST/WFC3, CANDELS	*Spitzer*/IRAC, SIMPLE

Xue+ 2011
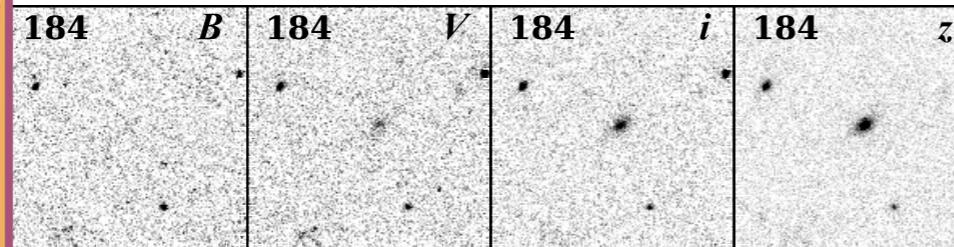
Giavalisco+ 2004
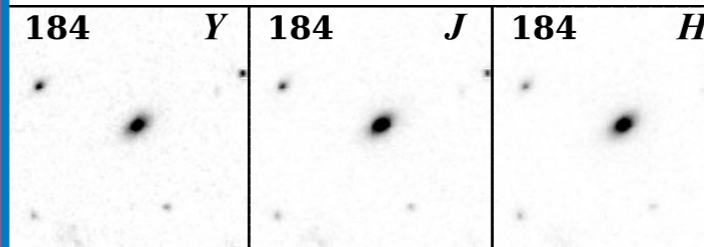
Grogin+ 2011,
Koekemoer+ 2011
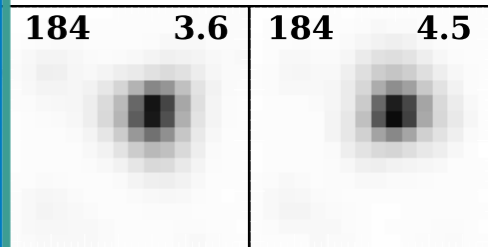
van Dokkum+ 2005,
Damen+ 2011

Redshift tests

visual class.

stacking

colour criteria

photo-z

Hardness Ratio

Redshift tests

visual class. | stacking | colour criteria | photo-z | Hardness Ratio

354 hard | 354 soft | 354 B | 354 V | 354 i | 354 z | 354 Y | 354 J | 354 H
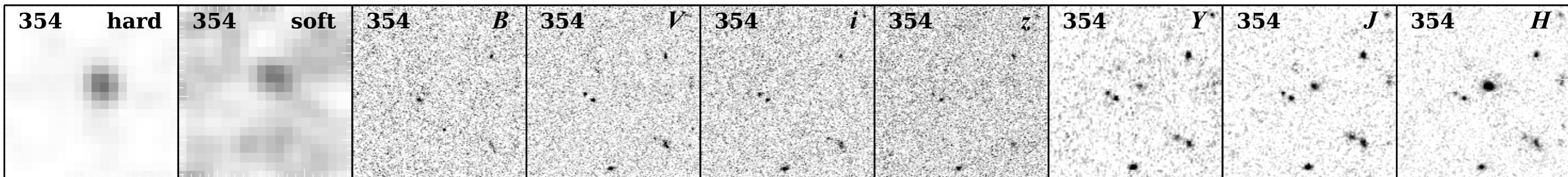
Steidel+ 1999
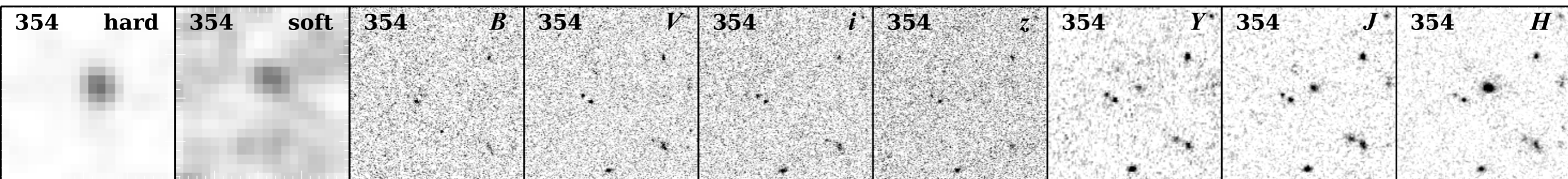Giavalisco 2002
Dunlop 2013

Redshift tests

visual class. stacking colour criteria photo-z Hardness Ratio

Redshift tests

visual class. | stacking | colour criteria | photo-z | Hardness Ratio

Vanzella+ 2009

Steidel+ 1999
Daddi+ 2004
van Dokkum+ 2003
Taniguchi+ 2005

$z \sim 5$

★ 303 (-0.31, 2.37)
★ 321 (0.86, 2.1)

$(V - i)_{AB}$

$(i - z)_{AB}$

Redshift tests

visual class. | stacking | colour criteria | **photo-z** | Hardness Ratio

EAZY:

Brammer, van Dokkum & Coppi 2008

244, excluding Spitzer bands

$z_{\rm phot} = 6.54$

244, including Spitzer bands

$z_{\rm phot} = 1.9$

$\log(\mathrm{Flux}\ \nu F_\nu)$ in erg s^{-1} cm^{-2}

Wavelength λ in μm

Redshift tests

visual class. | stacking | colour criteria | photo-z | Hardness Ratio

$$HR = \frac{H - S}{H + S}$$

Legend:
- $N_H = 10^{22.0}\ \mathrm{cm}^{-2}$
- $N_H = 10^{22.5}\ \mathrm{cm}^{-2}$
- $N_H = 10^{23.0}\ \mathrm{cm}^{-2}$
- $N_H = 10^{23.5}\ \mathrm{cm}^{-2}$

z = 4.34
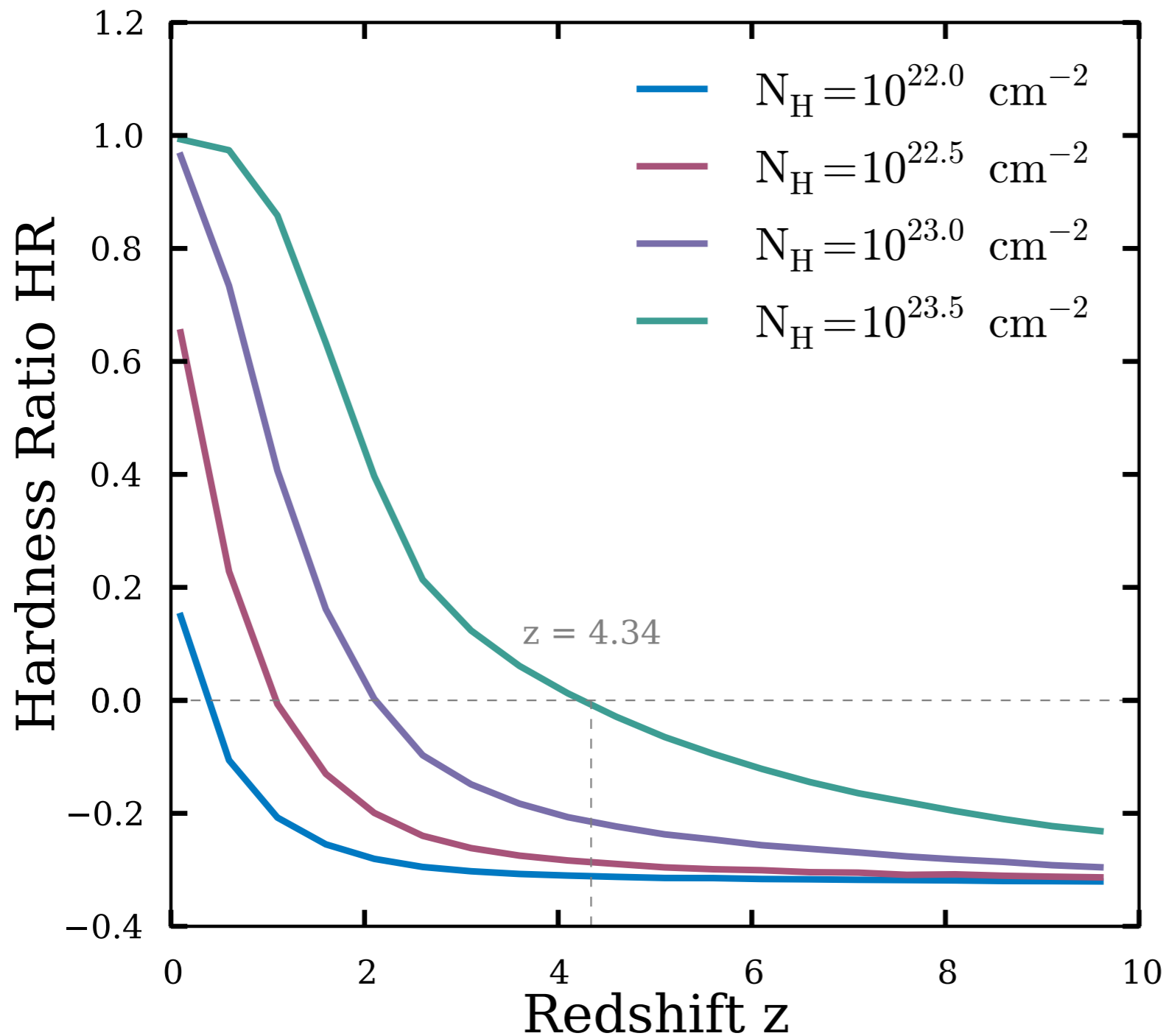
Wang+ 2004
Arnaud+ 1996

Redshift tests

visual class.

stacking

colour criteria

photo-z

Hardness Ratio

Redshift tests

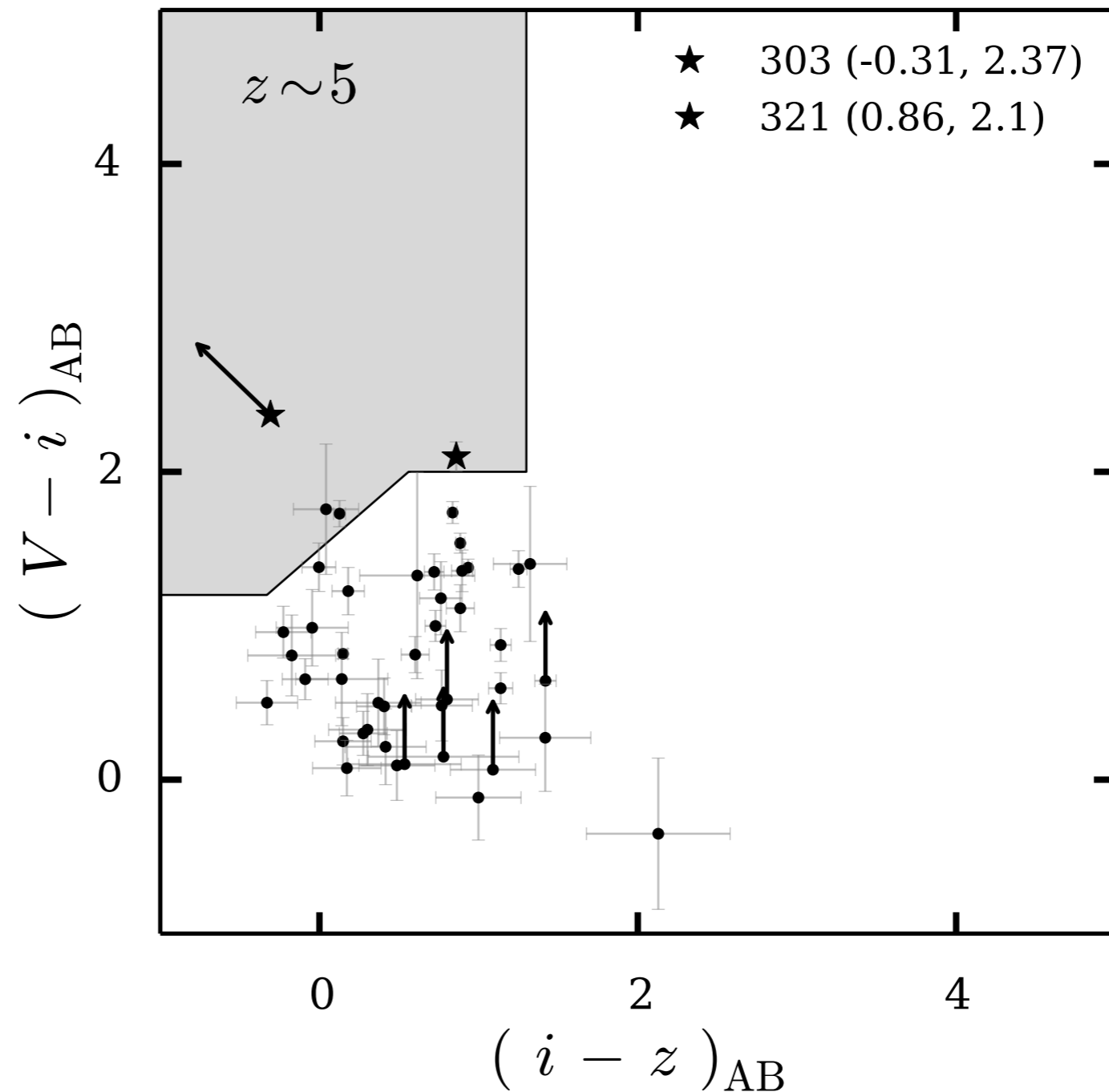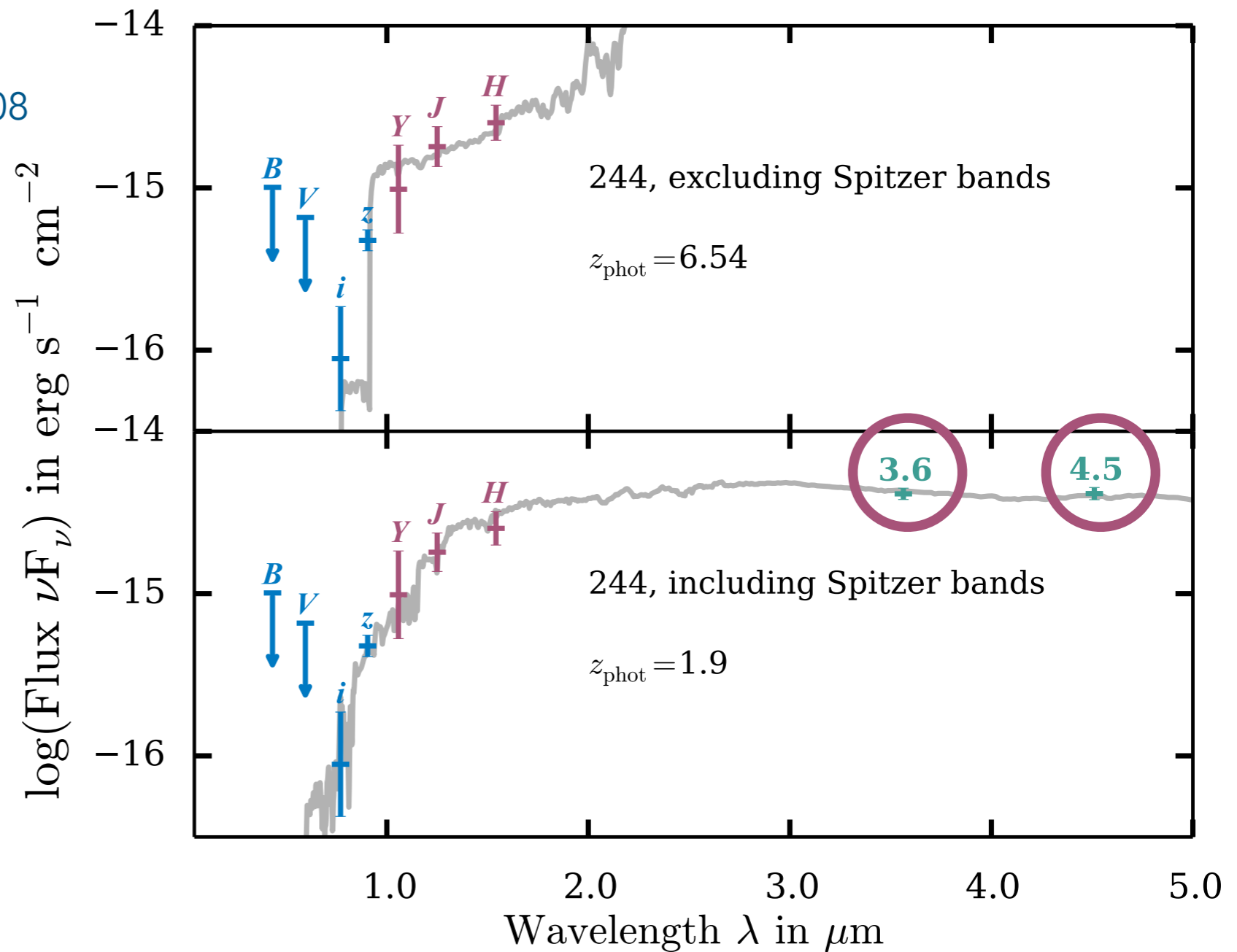visual class.　　stacking　　colour criteria　　photo-z　　Hardness Ratio

3 z ≳ 5 candidates

additional data
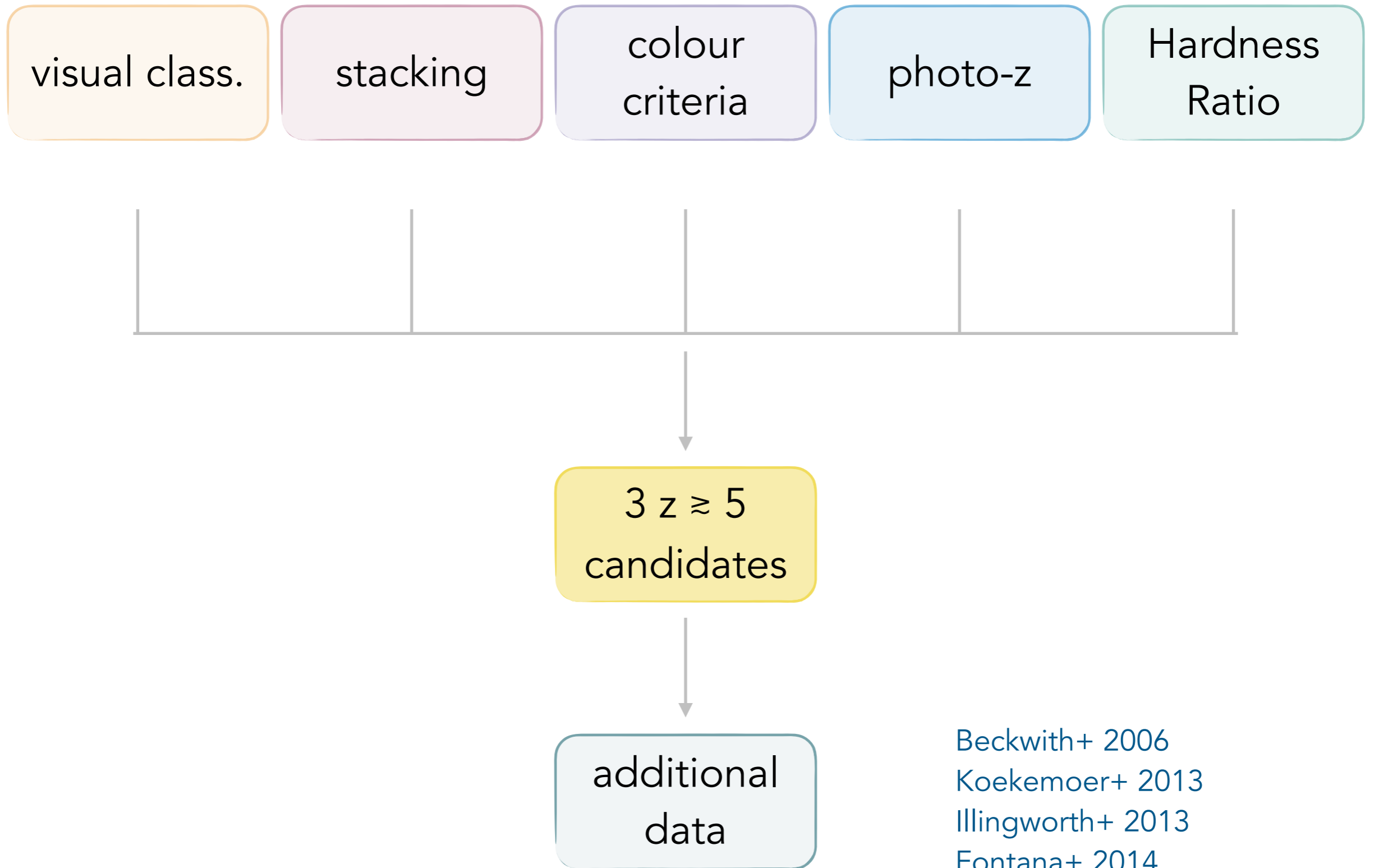
Beckwith+ 2006
Koekemoer+ 2013
Illingworth+ 2013
Fontana+ 2014

No convincing z ≳ 5 AGN candidates in the *Chandra* Deep Field South

Possible explanations

physical reasons

▸ BH occupation fraction

▸ AGN fraction

$$N_{AGN} = f_{active} \times f_{occ} \times N_{galaxies}$$

▸ super-Eddington

Volonteri & Silk 2014, Madau, Haardt & Dotti 2014, Alexander & Natarajan 2014

Possible explanations

physical reasons

‣ BH occupation fraction

‣ AGN fraction

‣ super-Eddington

observational reasons

‣ optically faint galaxies

Possible explanations

physical reasons

‣ BH occupation fraction

‣ AGN fraction

‣ super-Eddington

observational reasons

‣ optically faint galaxies

‣ X-ray obscuration

Possible explanations

physical reasons

- ▸ BH occupation fraction
- ▸ AGN fraction
- ▸ super-Eddington

observational reasons

- ▸ optically faint galaxies
- ▸ X-ray obscuration
- ▸ BH - BH coalescence

Possible explanations

physical reasons

- ‣ BH occupation fraction
- ‣ AGN fraction
- ‣ super-Eddington

2.8 Ms *Chandra* COSMOS Legacy Survey, Francesca Civano

observational reasons

- ‣ optically faint galaxies
- ‣ X-ray obscuration
- ‣ BH - BH coalescence

7 Ms *Chandra* survey, Niel Brandt

Summary

‣ searched for z ≳ 5 AGN in the *Chandra* Deep Field South

‣ *Chandra* 4-Ms + GOODS, CANDELS, *Spitzer*

‣ 5 redshift tests

‣ no convincing z ≳ 5 AGN candidates

‣ explanations: low BH occupation/AGN fraction, super Eddington growth, optically faint/obscured galaxies, BH - BH coalescence