Obscured Quasars

Daniel Stern (JPL/Caltech)

Particular kudos to:
R. Assef (Univ. Diego Portales)
E. Donoso (ICATE)
Peter Eisenhardt (JPL)
Jingwen Wu (UCLA)
Chao-Wei Tsai (JPL)
Lin Yan (IPAC)
Carrie Bridge (Caltech)
+ the rest of the WISE Extragalactic Team
+ NuSTAR Extragalactic Team

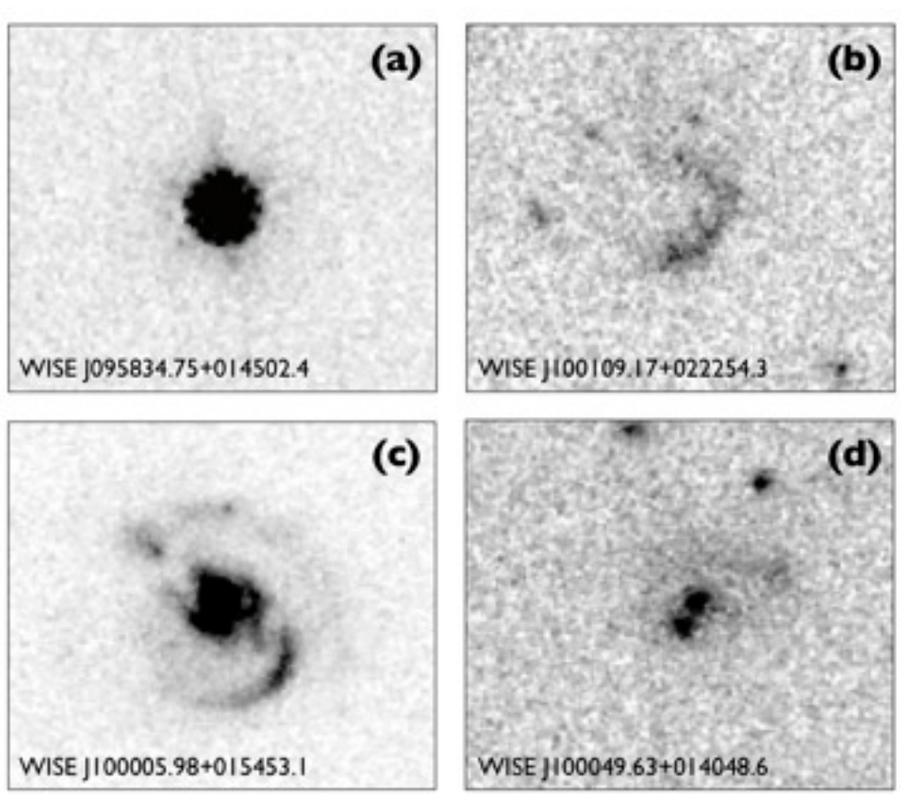
Q50 Meeting (Pasadena)
2013 September 10

quasar = "quasi-stellar radio source"

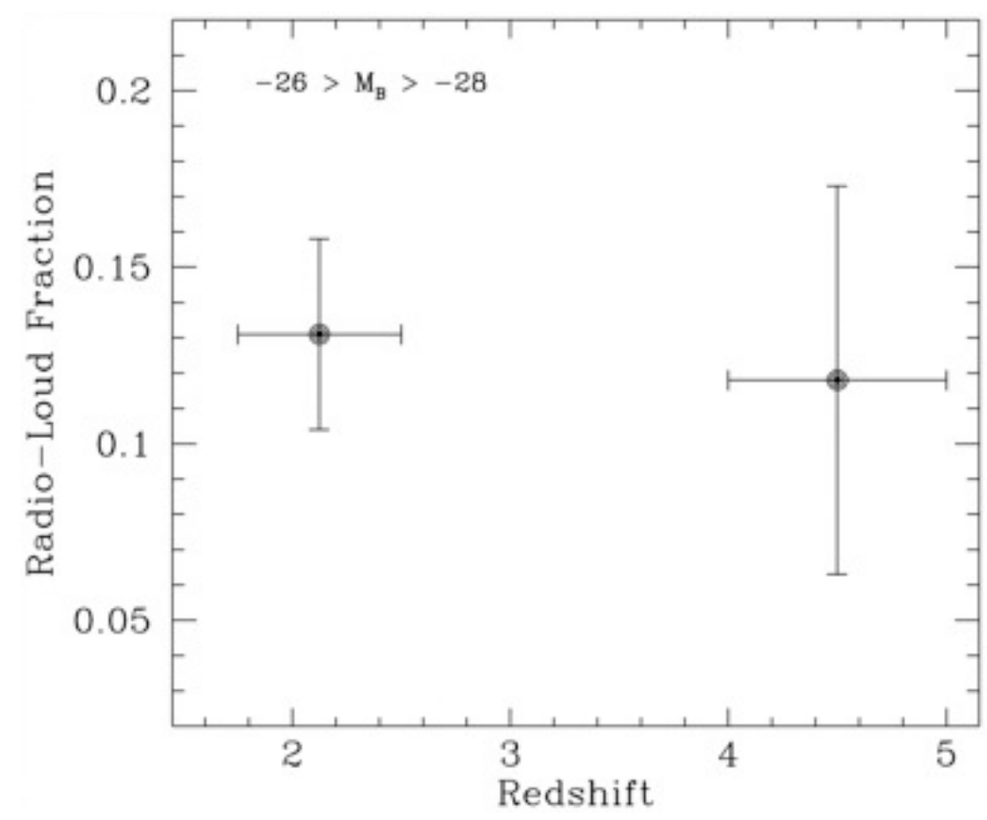
Not!

only ~50% of QSOs are quasi-stellar

only ~13% of QSOs are radio-loud



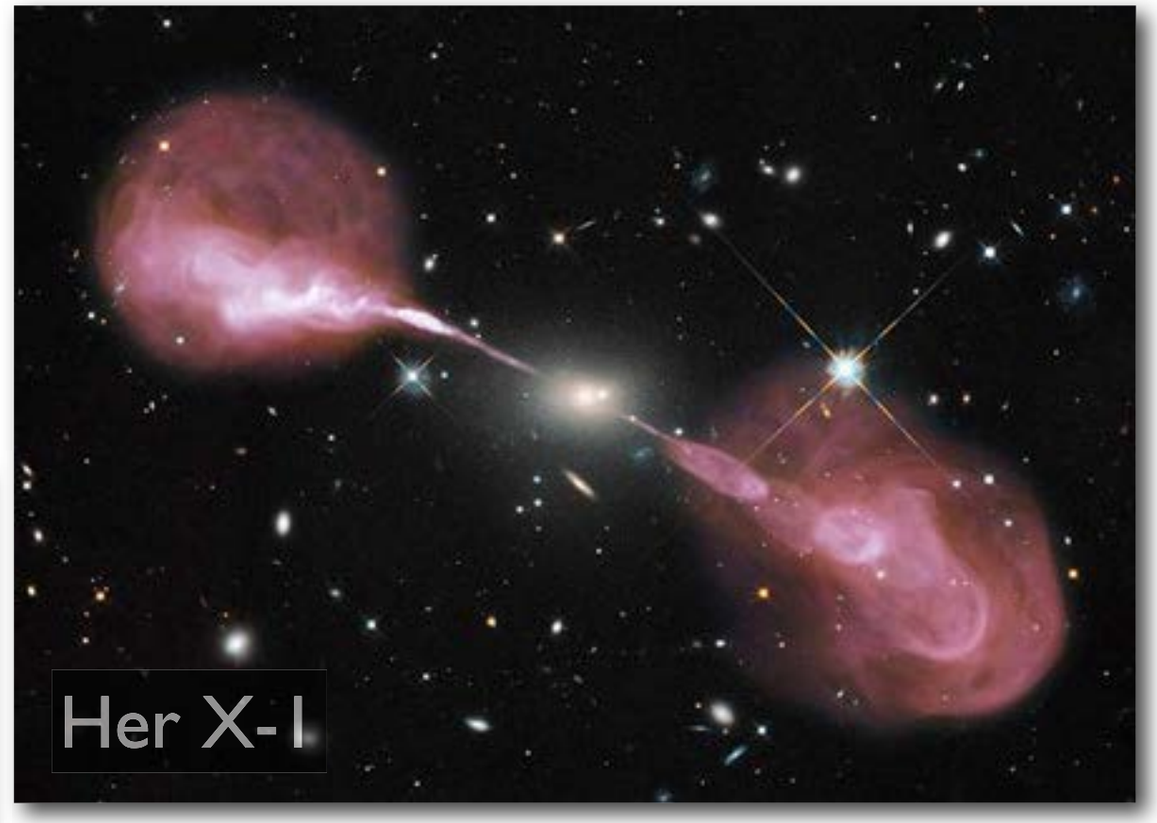
Stern, Assef et al. 2012, ApJ, 753, 30

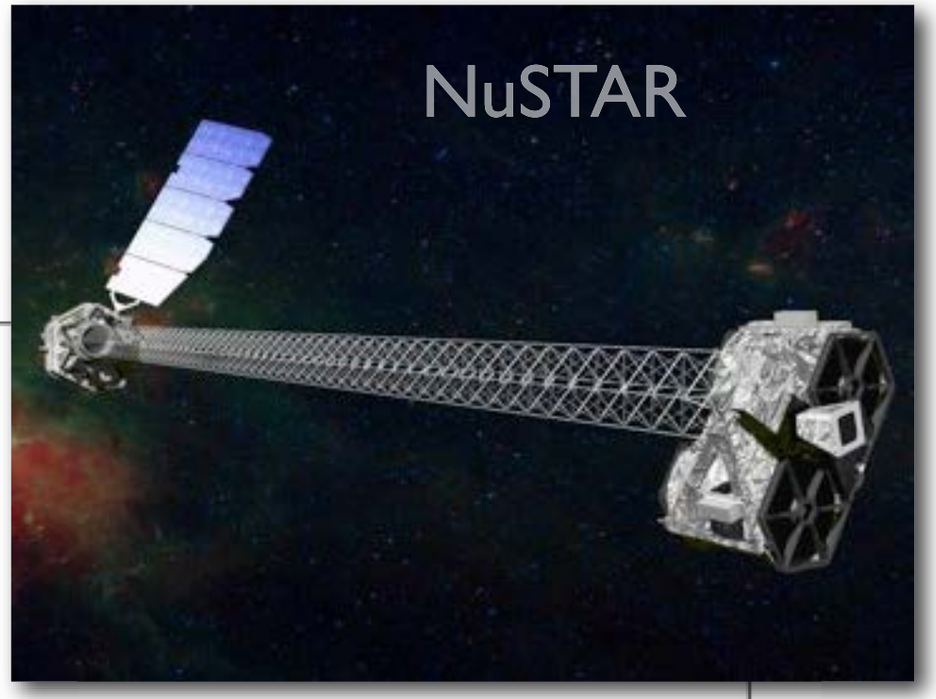


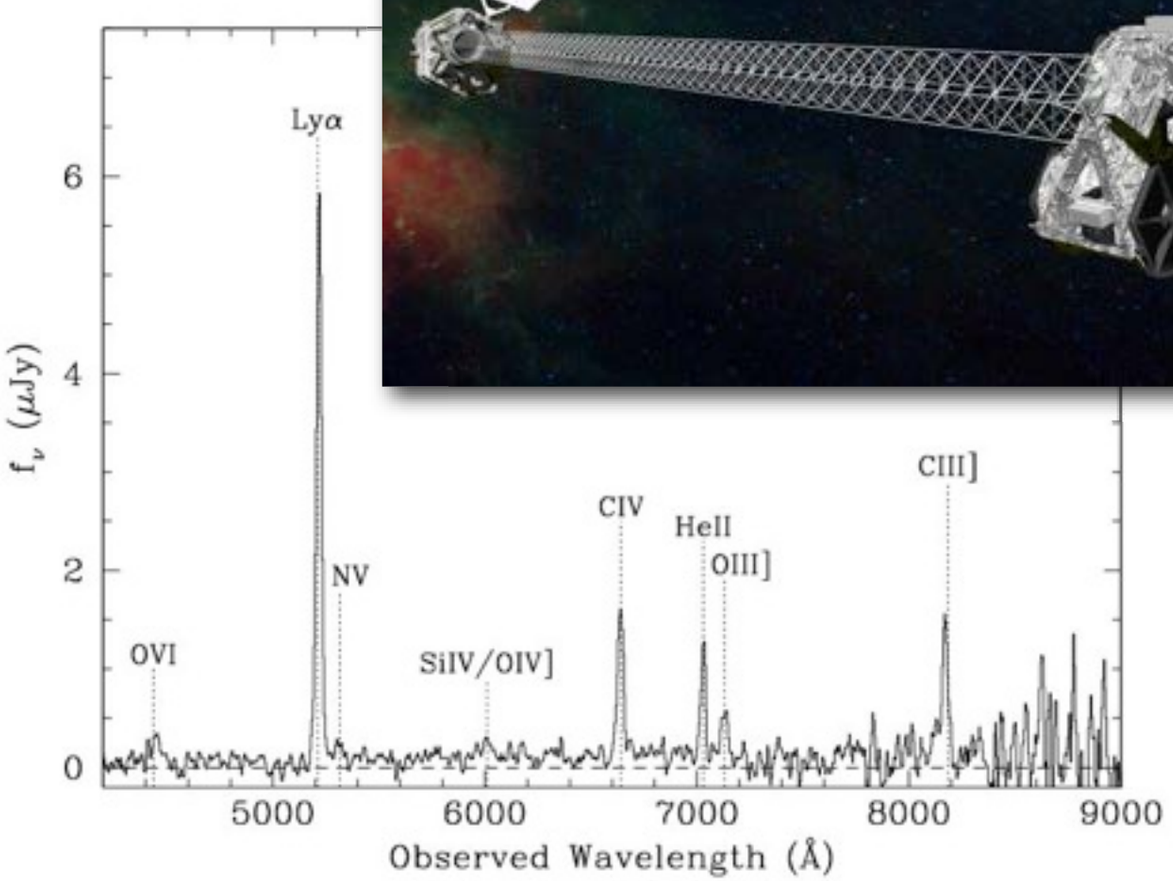
Stern, Djorgovski et al. 2000, AJ, 119, 1526

How to find obscured (or type-2) quasars?

- radio selection
- (hard) X-ray selection
- optical selection
- (mid-)infrared selection







How to find obscured (or type-2) quasars?

TABLE 1 The Highest Redshift Galaxy

View table image

Date	Galaxy	z	Search Technique	Reference
1999…	SSA 22-HCM1	5.74	Narrowband imaging	1
1998 Oct…	HDF 4-473.0	5.60	Photometric selection	2
1998 May…	0140+326 RD1	5.34	Serendipity	3
1997…	Cl 1358+62, G1/G2 arcs	4.92	Serendipity/gravitational lensing	4
1996…	BR 1202−0725	4.695	Narrowband imaging	5
1994…	8C 1435+63	4.26	Radio selection	6
1990…	4C 41.17	3.80	Radio selection	7
1988…	B2 0902+34	3.39	Radio selection	8
1985…	PHS 1614+051 companion	3.215	Narrowband imaging	9
1984…	3C 256	1.82	Radio selection	10
1983…	3C 324	1.206	Radio selection	11
1982…	3C 368	1.131	Radio selection	12
1979…	3C 6.1	0.840	Radio selection	13
1976…	3C 318	0.752	Radio selection	14
1975…	3C 411	0.469	Radio selection	15
1960…	3C 295	0.461	Radio selection	16
1956…	Cl 0855+0321	0.20	Cluster selection	17

Notes.—Status as of 1999 August. Tabulation restricted to confirmed spectroscopic sources. In particular, Hu et al. 1998 recently reported a likely (serendipitously discovered) candidate at $z = 5.63$ while Chen et al. 1999 report a candidate at $z = 6.68$ selected from deep *HST*/STIS grism spectroscopy. The authors deem both redshift determinations tentative given the current data (see Stern et al. 1999b). Note that Petitjean et al. 1996 refers to the spectroscopic confirmation of the $z = 4.7$ quasar companion initially identified by Djorgovski 1995 and Hu et al. 1996. Many sources with potentially higher photometric redshifts have been identified, but await spectroscopic confirmation.

References.—(1) Hu et al. 1999; (2) Weymann et al. 1998; (3) Dey et al. 1998; (4) Franx et al. 1997; (5) Petitjean et al. 1996; (6) Lacy et al. 1994; (7) Chambers et al. 1990; (8) Lilly 1988; (9) Djorgovski et al. 1985; McCarthy et al. 1987; (10) Spinrad & Djorgovski 1984; (11) Spinrad & Djorgovski 1983; (12) Spinrad 1982; (13) Smith et al. 1979; (14) Spinrad & Smith 1976; (15) Spinrad et al. 1975; (16) Minkowski 1960; (17) Humason, Mayall, & Sandage 1956.

Stern & Spinrad 1999, PASP, 111, 1475

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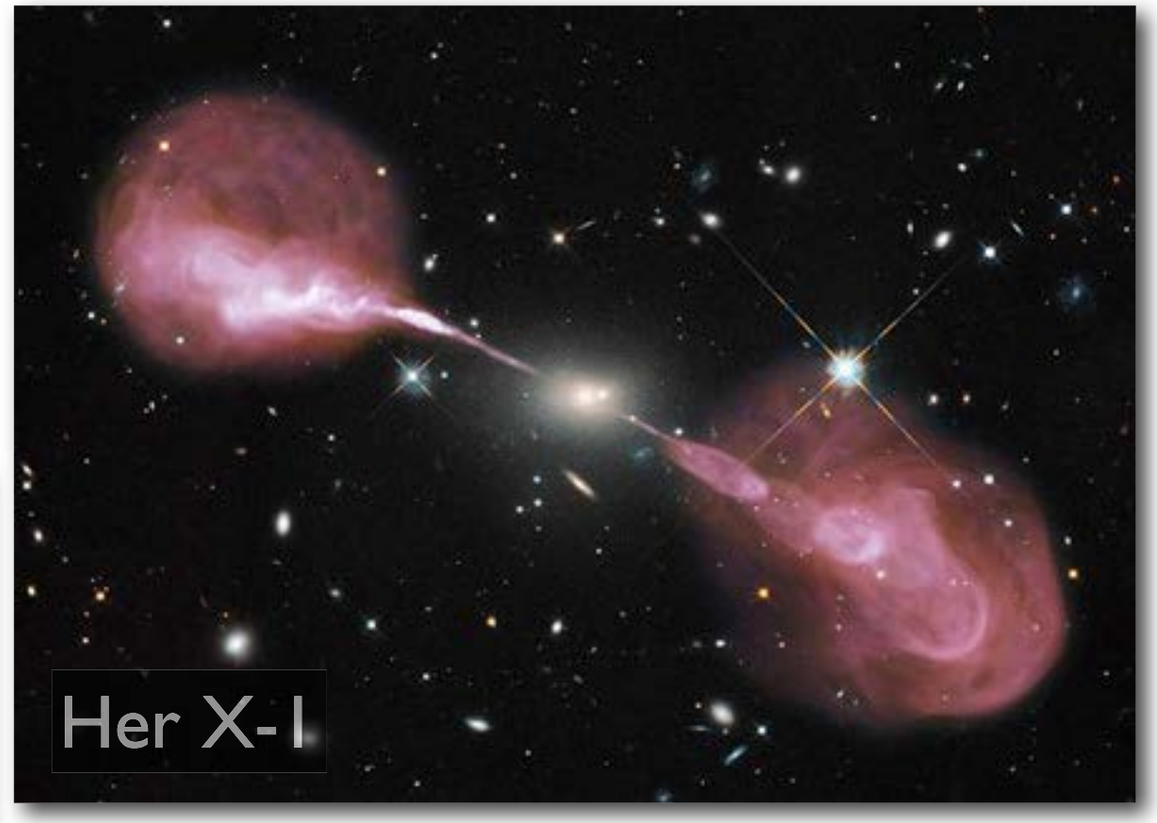
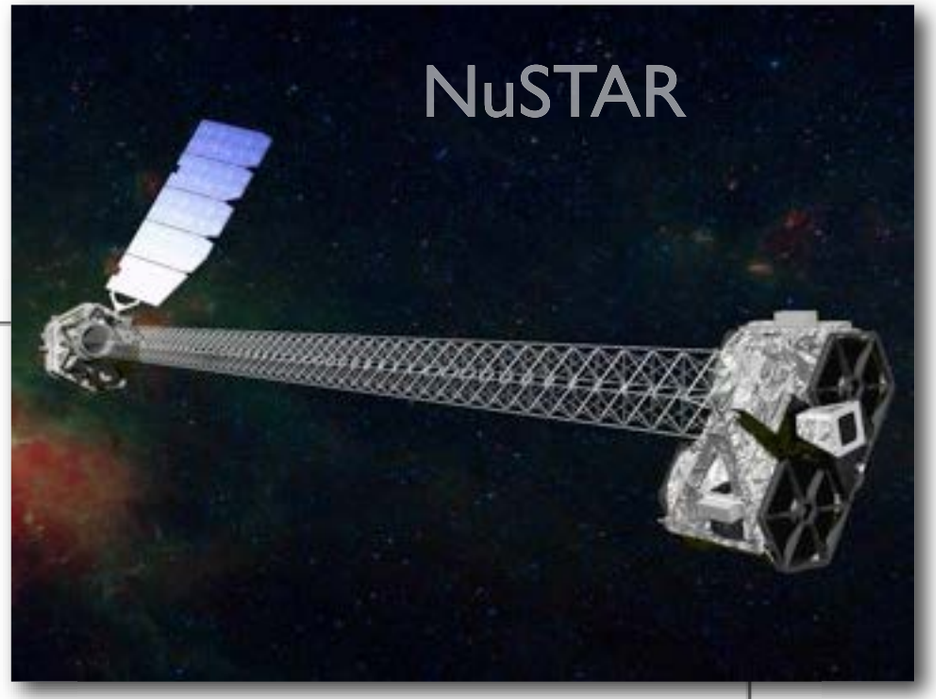
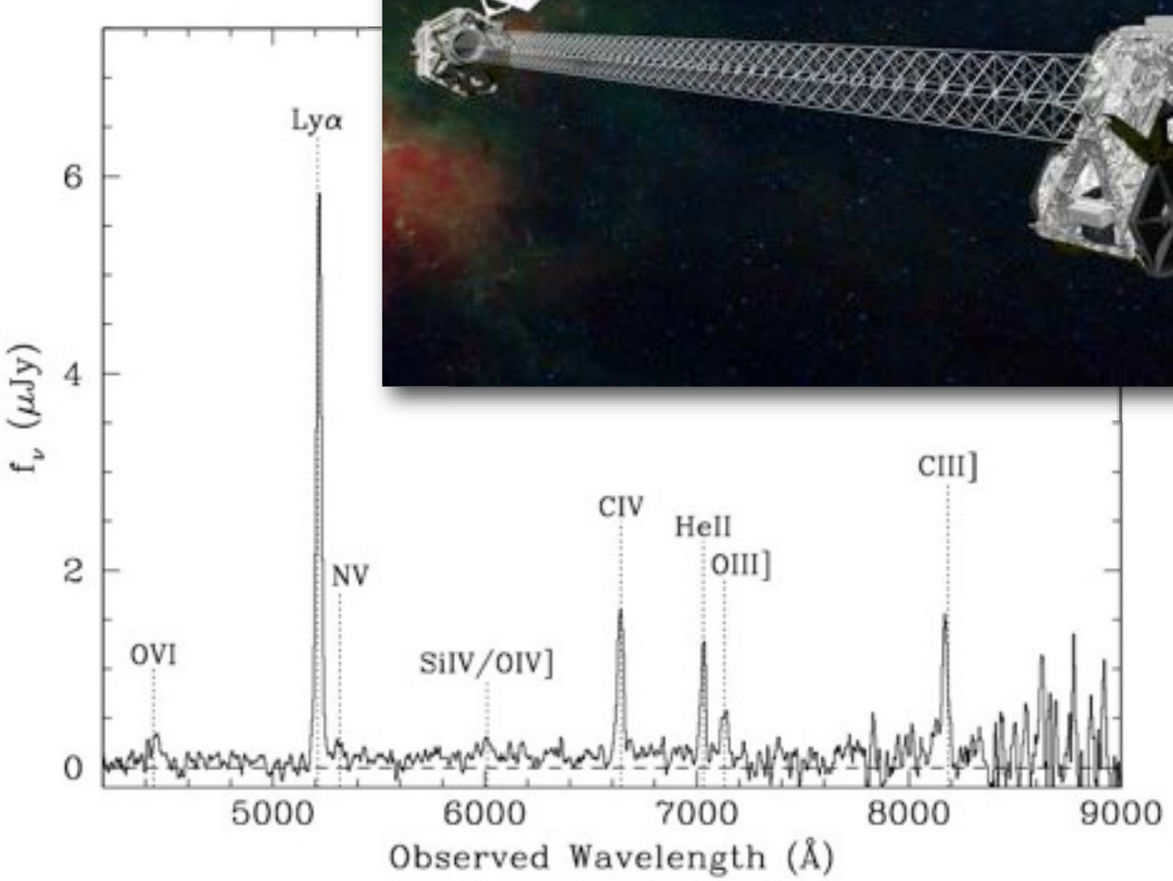
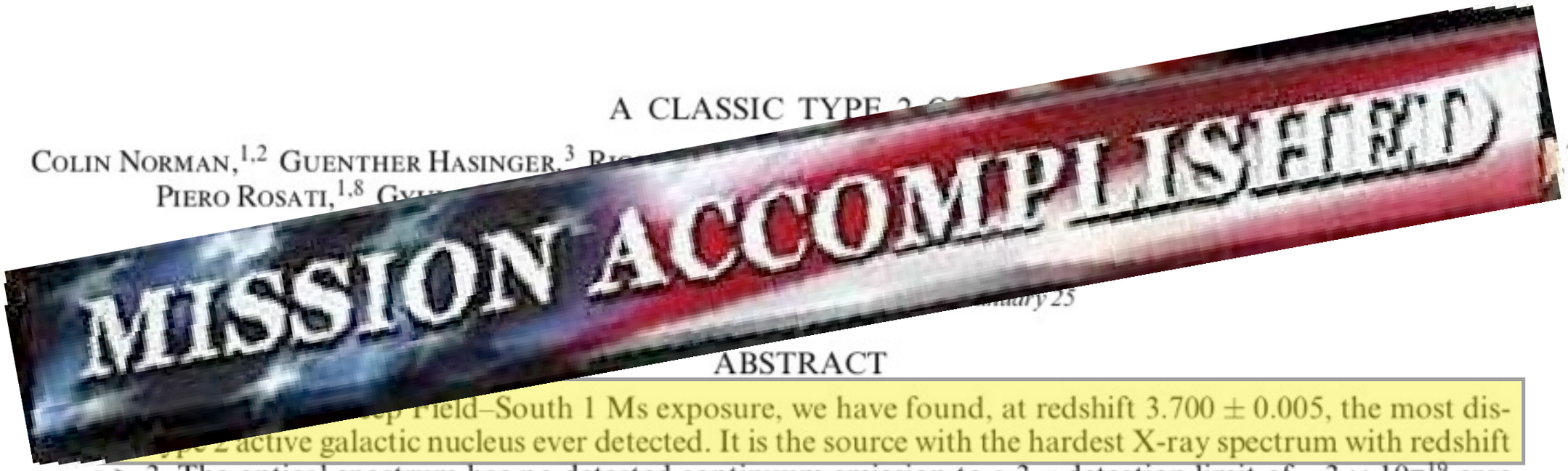






The Most Distant Obscured Quasar



A CLASSIC TYPE 2 Q

COLIN NORMAN,[1,2] GUENTHER HASINGER,[3] R
PIERO ROSATI,[1,8] G

ary 25

ABSTRACT

Field–South 1 Ms exposure, we have found, at redshift 3.700 ± 0.005, the most dis-
active galactic nucleus ever detected. It is the source with the hardest X-ray spectrum with redshift $z > 3$. The optical spectrum has no detected continuum emission to a 3 σ detection limit of $\sim 3 \times 10^{-19}$ ergs s^{-1} cm^{-2} $Å^{-1}$ and shows narrow lines of Lyα, C IV, N V, He II, O VI, [O III], and C III]. Their FWHM line widths have a range of ~700–2300 km s^{-1} with an average of approximately ~1500 km s^{-1}. The emitting gas is metal-rich ($Z \simeq 2.5$–$3\ Z_\odot$). In the X-ray spectrum of 130 counts in the 0.5–7 keV band, there is evidence for intrinsic absorption with $N_H \gtrsim 10^{24}$ cm^{-2}. An iron Kα line with rest-frame energy and equivalent width of ~6.4 keV and ~1 keV, respectively, in agreement with the obscuration scenario, is detected at a 2 σ level. If confirmed by our forthcoming *XMM-Newton* observations, this would be the highest redshift detection of Fe Kα. Depending on the assumed cosmology and the X-ray transfer model, the 2–10 keV rest frame luminosity corrected for absorption is $\sim 10^{45 \pm 0.5}$ ergs cm^{-2} s^{-1}, which makes our source a classic example of the long-sought type 2 QSO. From standard population synthesis models, these sources are expected to account for a relevant fraction of the black hole–powered QSO distribution at high redshift.

Subject headings: quasars: emission lines — quasars: individual (CXOCDFS J033229.9−275106) — X-rays: galaxies

On-line material: color figures

The Most Distant Obscured Quasar

A RADIO GALAXY AT $z = 5.19$[1]

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HUUB RÖTTGERING,[3] AND GEORGE MILEY[3]

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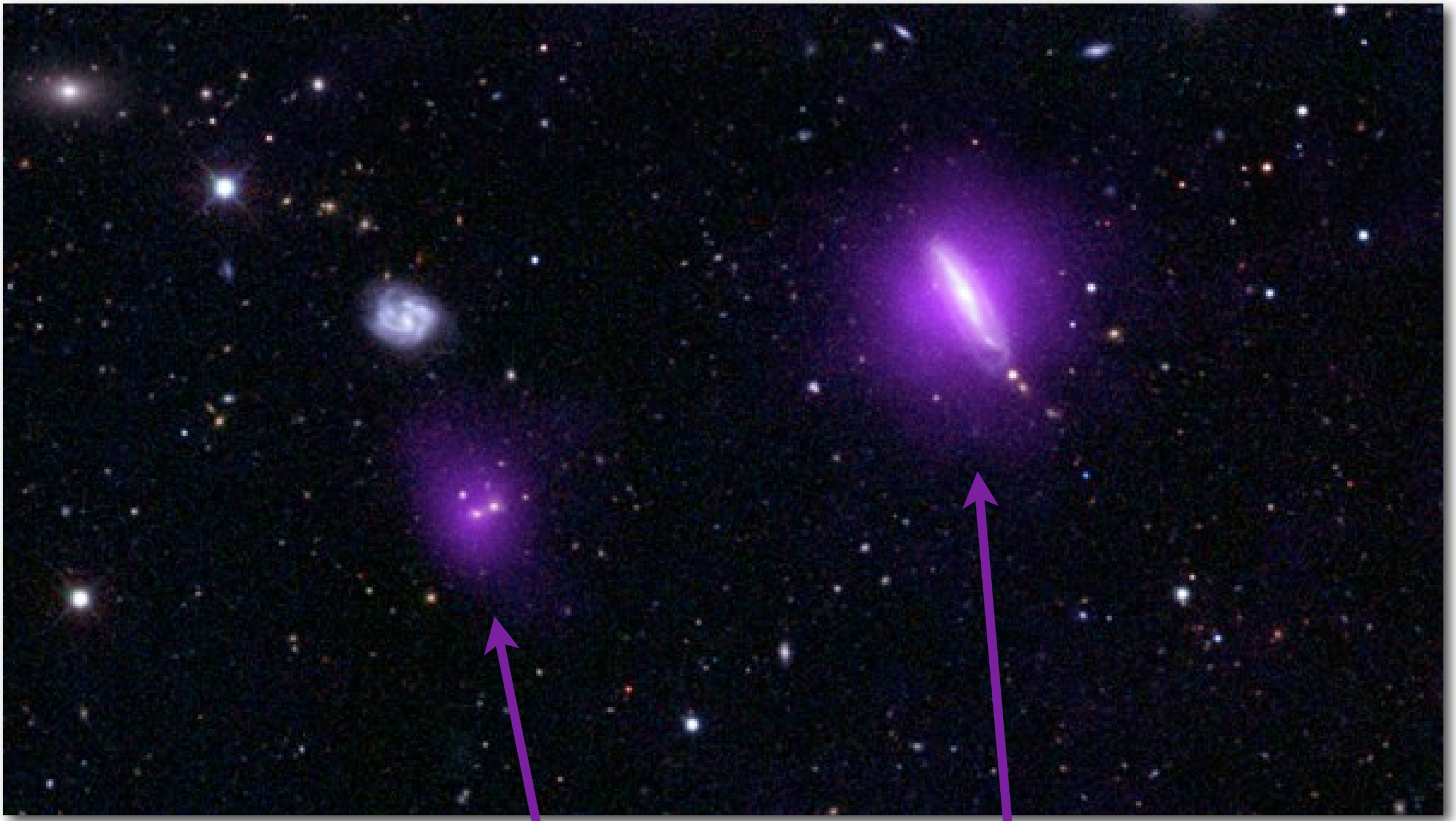
ABSTRACT

We report the discovery of the most distant known active galactic nucleus, the radio galaxy TN J0924−2201 at $z = 5.19$. The radio source was selected from a new sample of ultrasteep spectrum sources, has an extreme radio spectral index $\alpha_{365\,\mathrm{MHz}}^{1.4\,\mathrm{GHz}} = -1.63$, and is identified at near-IR wavelengths with a very faint, $K = 21.3 \pm 0.3$ object. Spectroscopic observations show a single emission line at $\lambda \sim 7530$ Å, which we identify as Lyα. The K-band image, sampling rest-frame U band, shows a multicomponent, radio-aligned morphology, which is typical of lower-redshift radio galaxies. TN J0924−2201 extends the near-IR Hubble, or K-z, relation for powerful radio galaxies to $z > 5$ and is consistent with models of massive galaxies forming at even higher redshifts.

Subject headings: early universe — galaxies: active — galaxies: distances and redshifts — galaxies: formation — galaxies: individual (TN J0924−2201)



NuSTAR's "first born"

- NuSTAR (in purple) serendipitous source in field of IC751

Alexander, Stern et al. 2013 ApJ, 773, 125

How to find obscured (or type-2) quasars?

- radio selection
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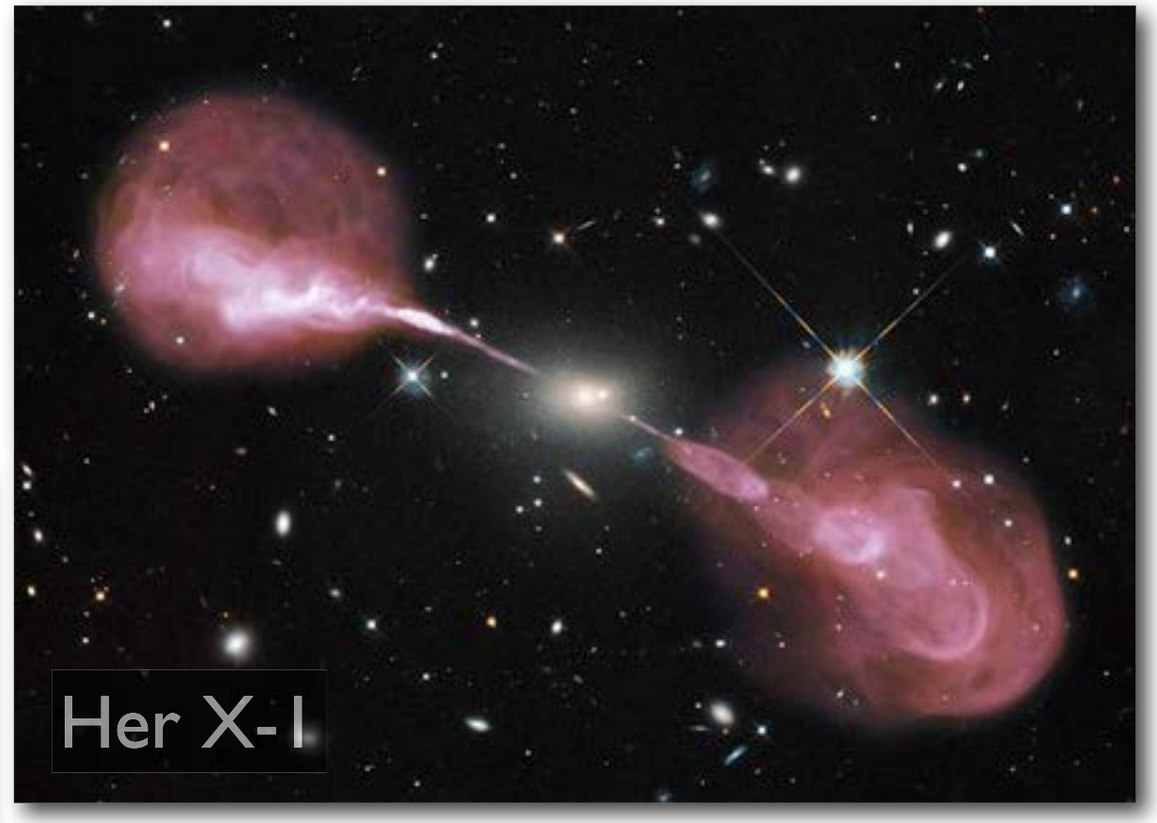
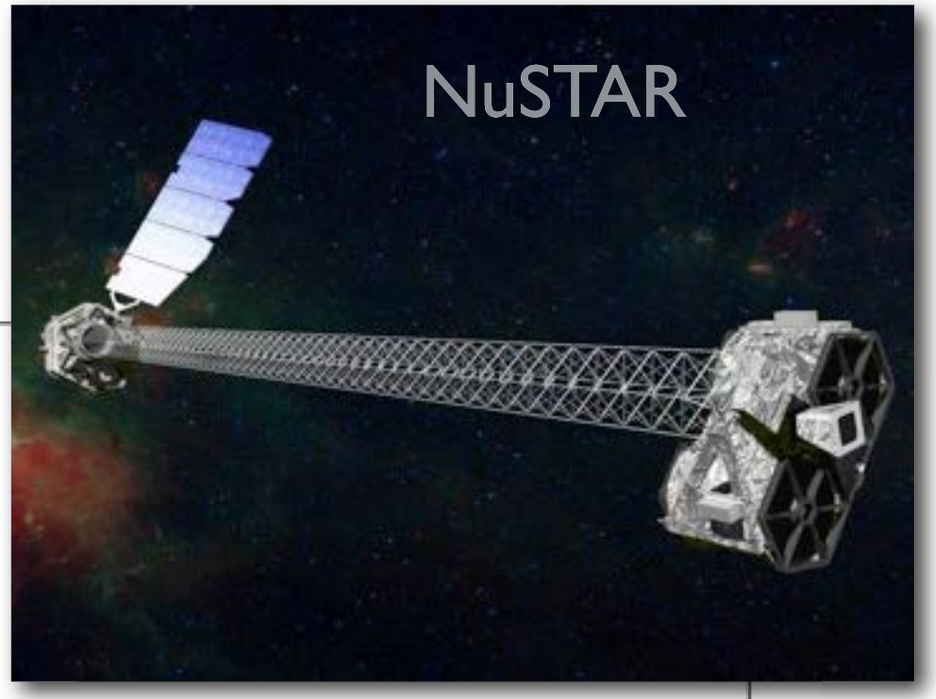
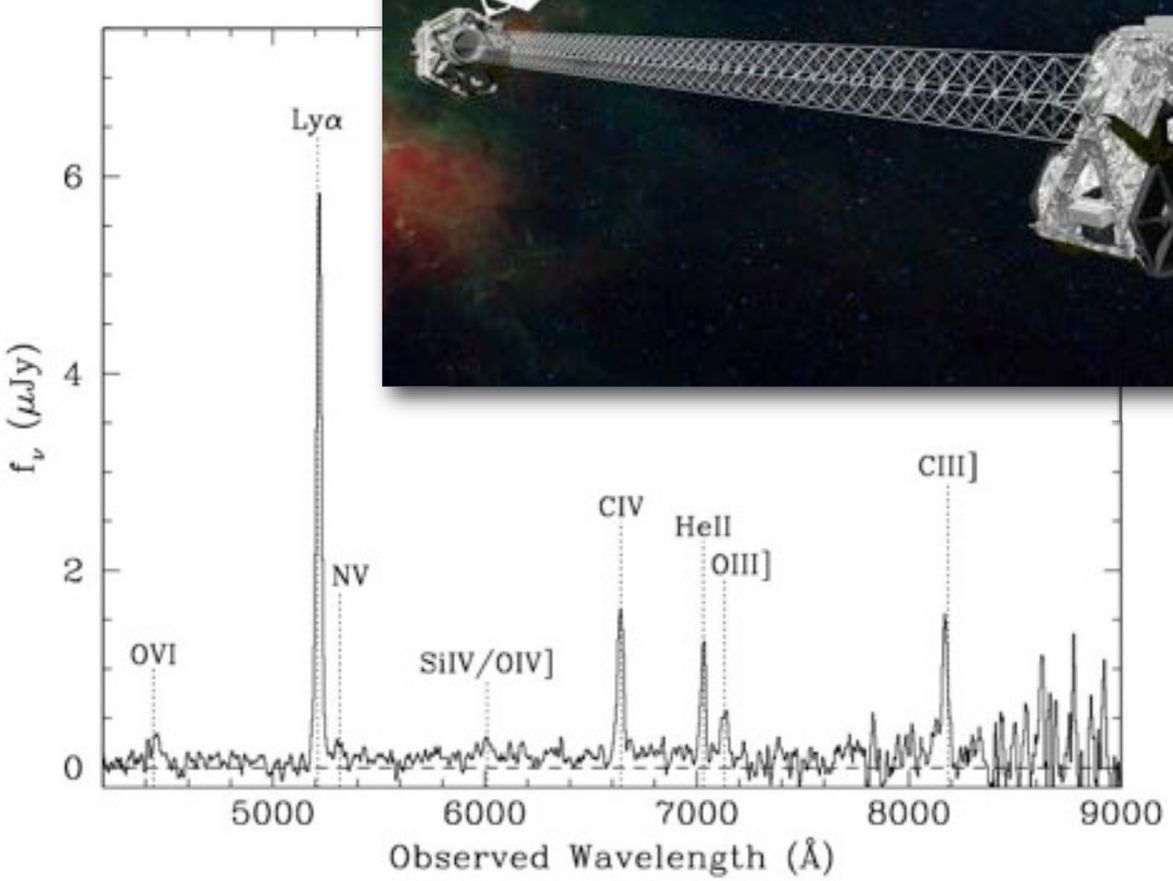
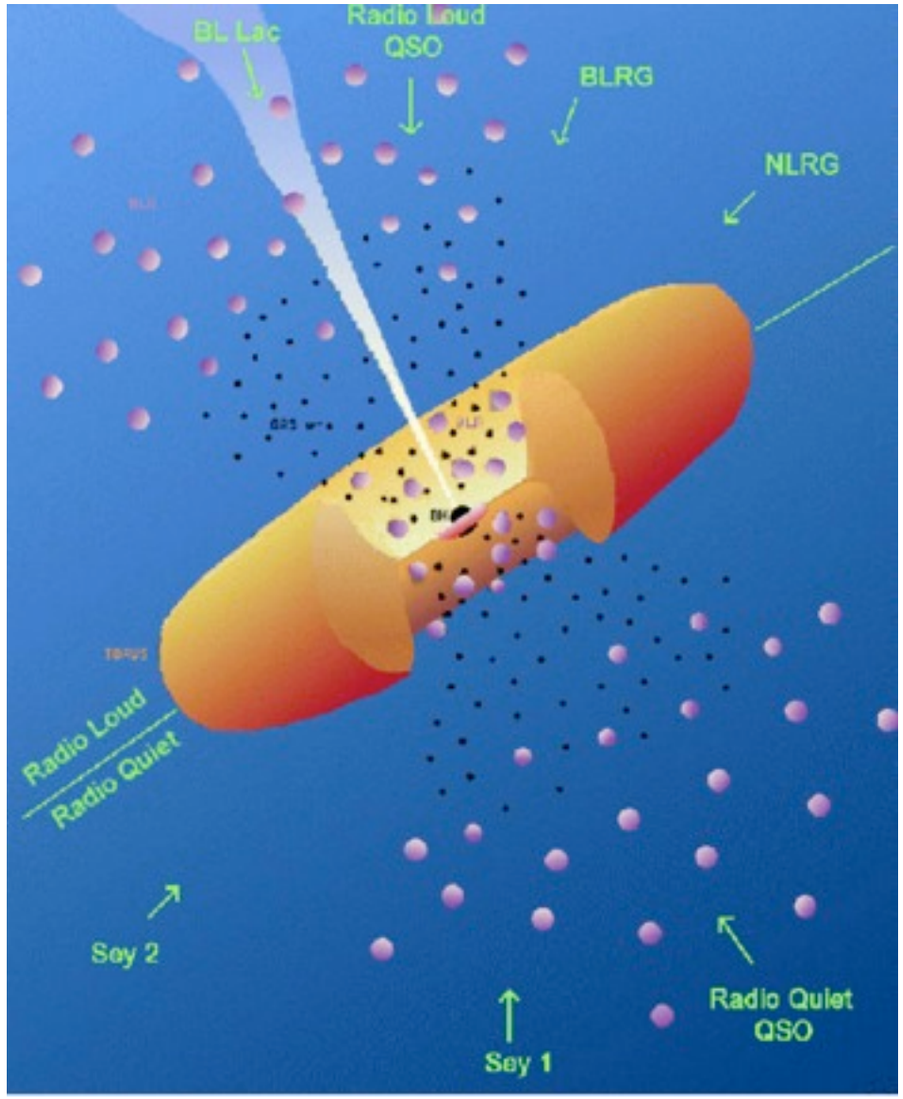
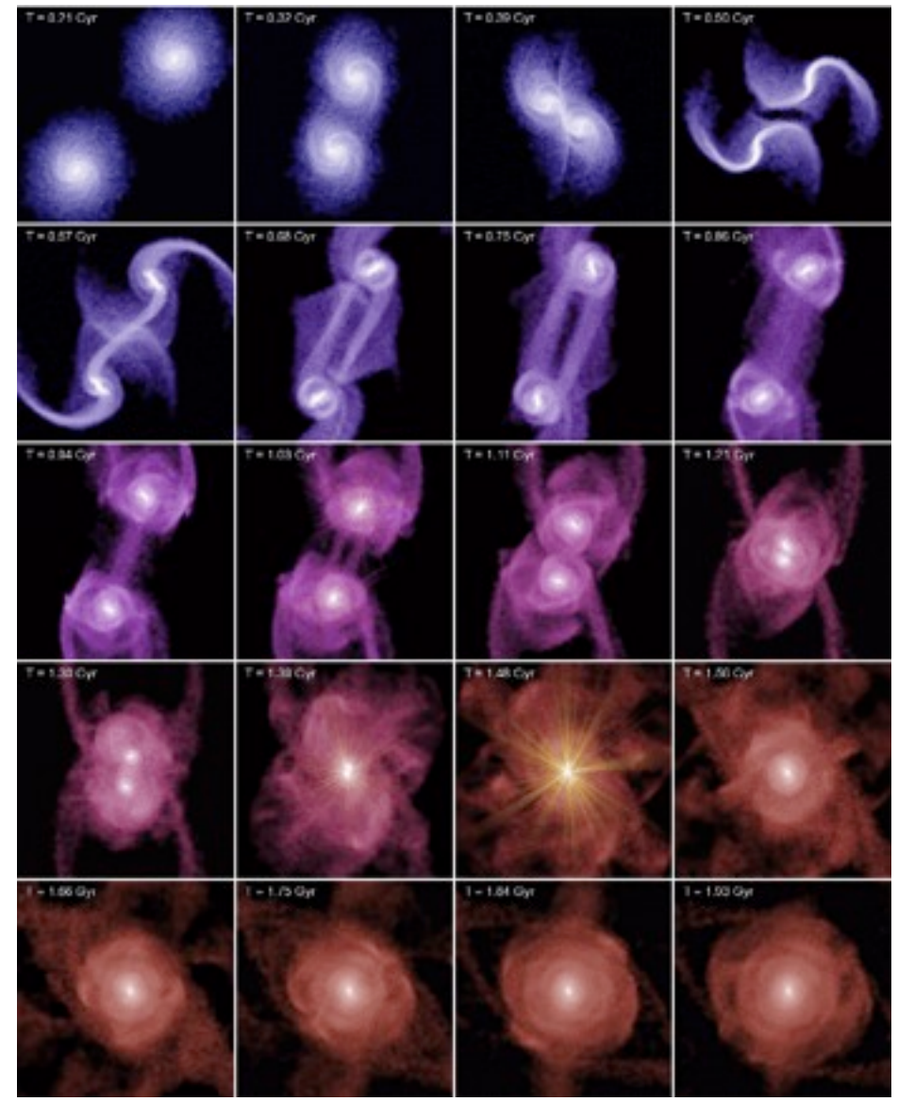






What causes the obscuration?



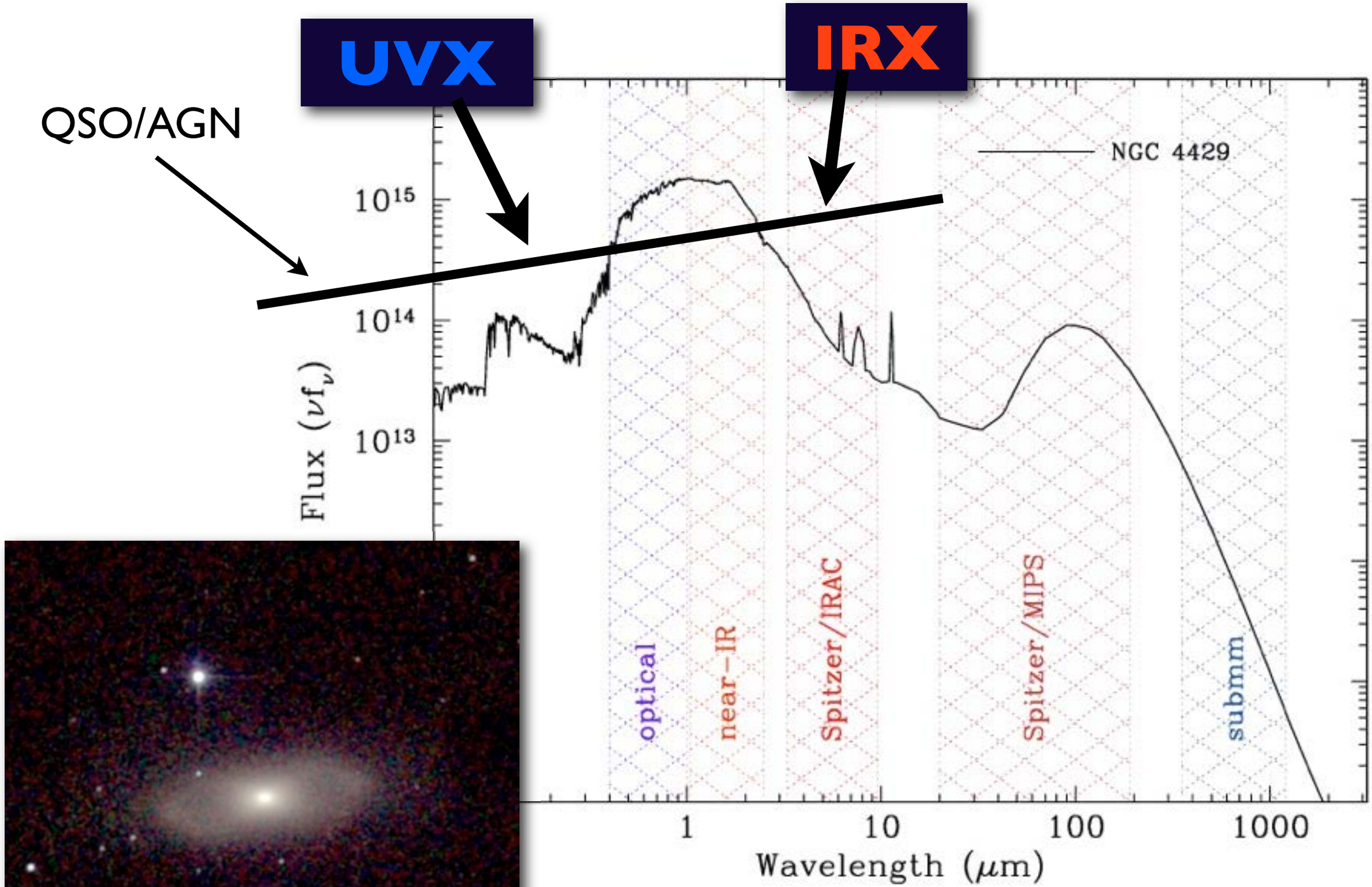


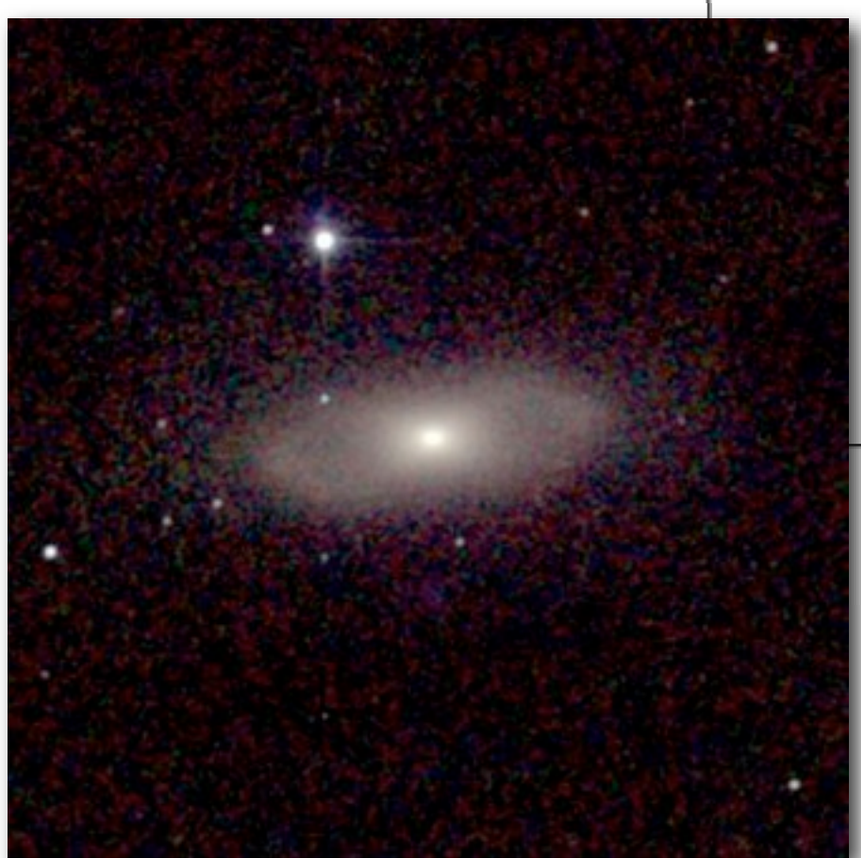
Orientation Models
obscuring torus

Urry & Padovani 1995, PASP, 107, 803

Dynamical Models
merger-induced obscuration

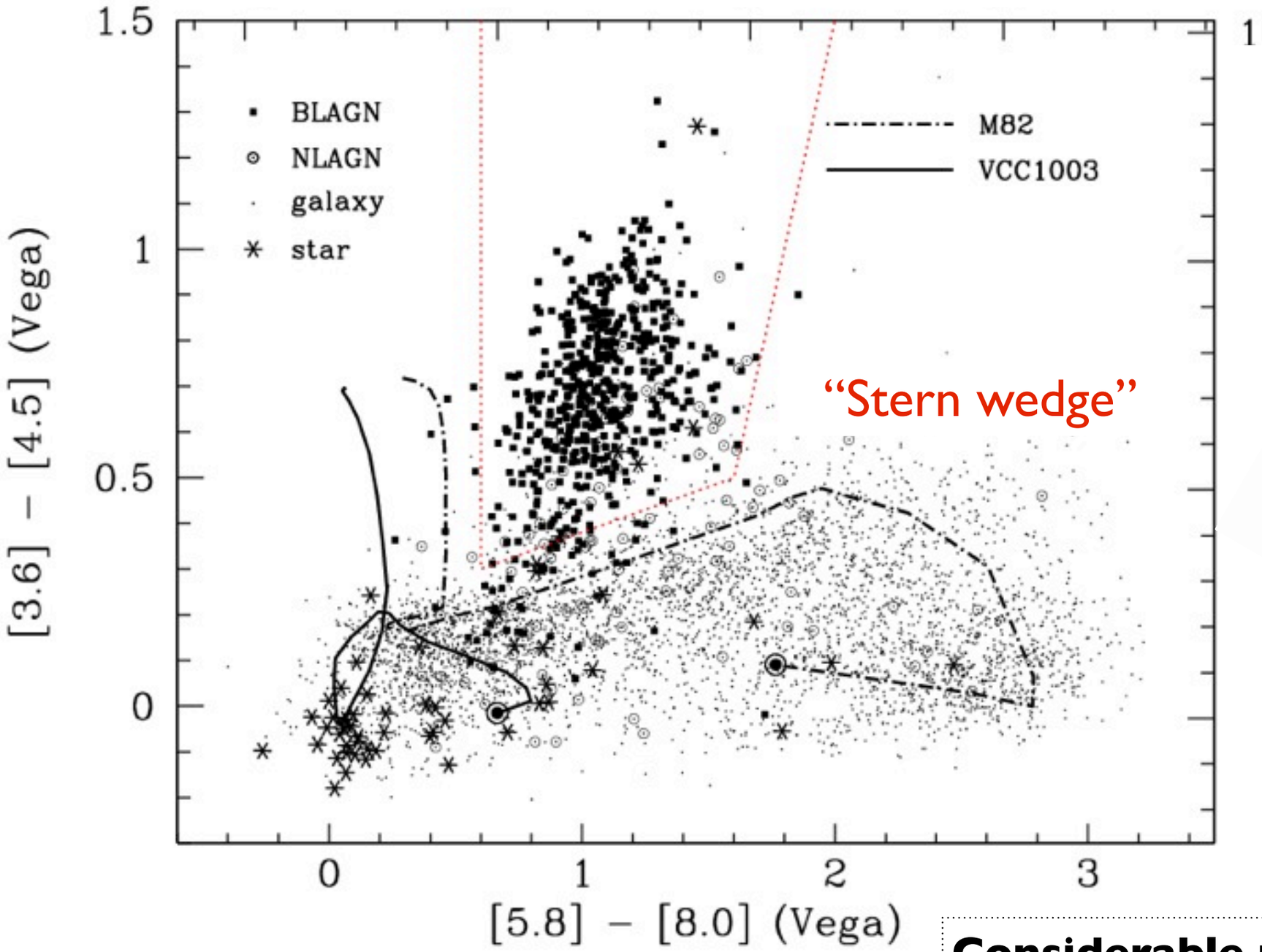
Hopkins et al. 2006, ApJS, 163, 1





NGC 4429 (SA in Virgo)

quasar/AGN emission:
dominated by a power-law

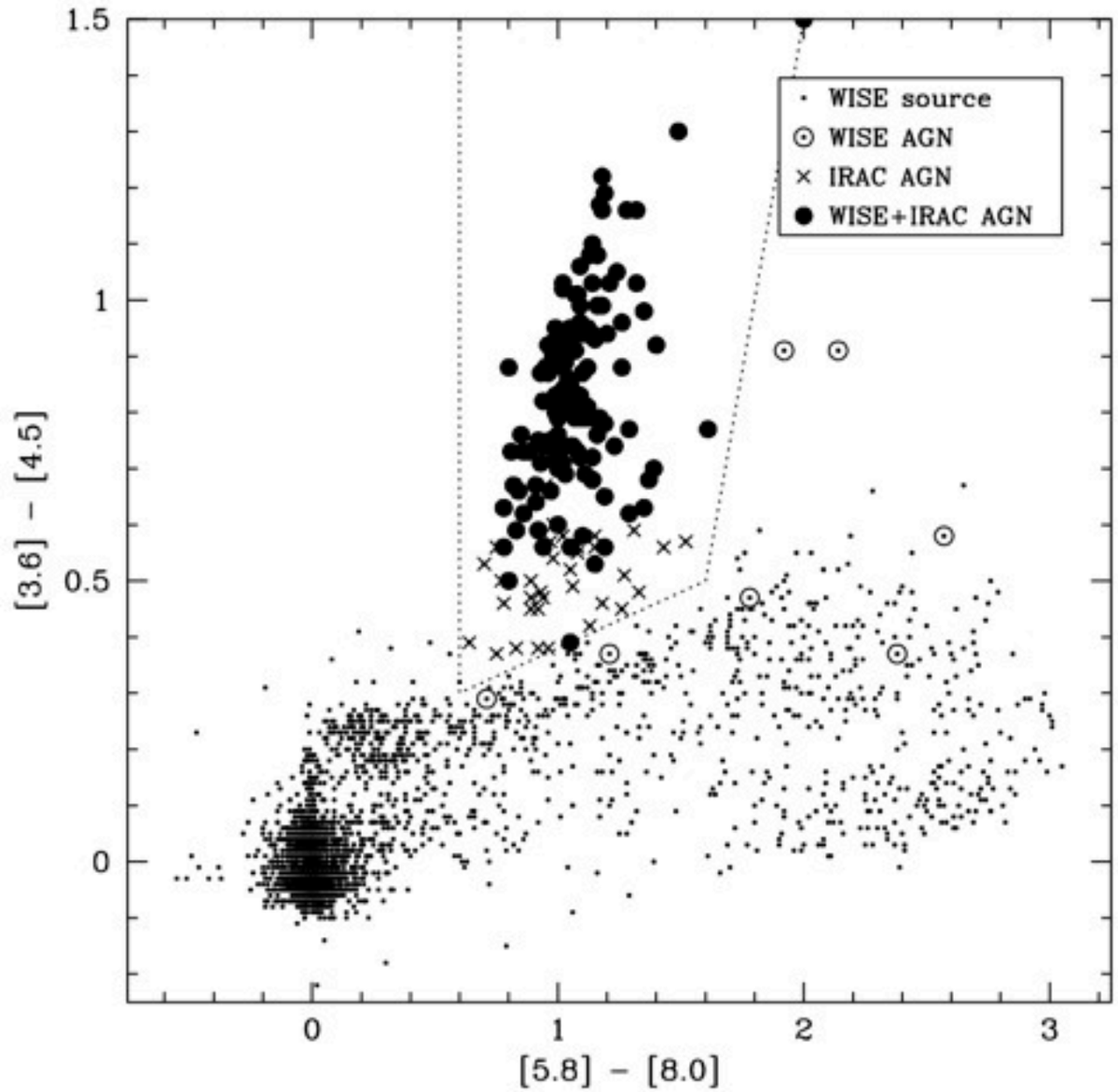


Spitzer

Considerable related literature:

Lacy et al. (2004) - "Lacy wedge"
Donley et al. (2007) - power-law selection
Donley et al. (2012) - color selection
Glikman et al. (2012) - FIRST-2MASS red QSOs
Edeleson & Malkan (2012) - S_{IX} parameter
etc....

Stern et al. 2005, ApJ, 631, 163



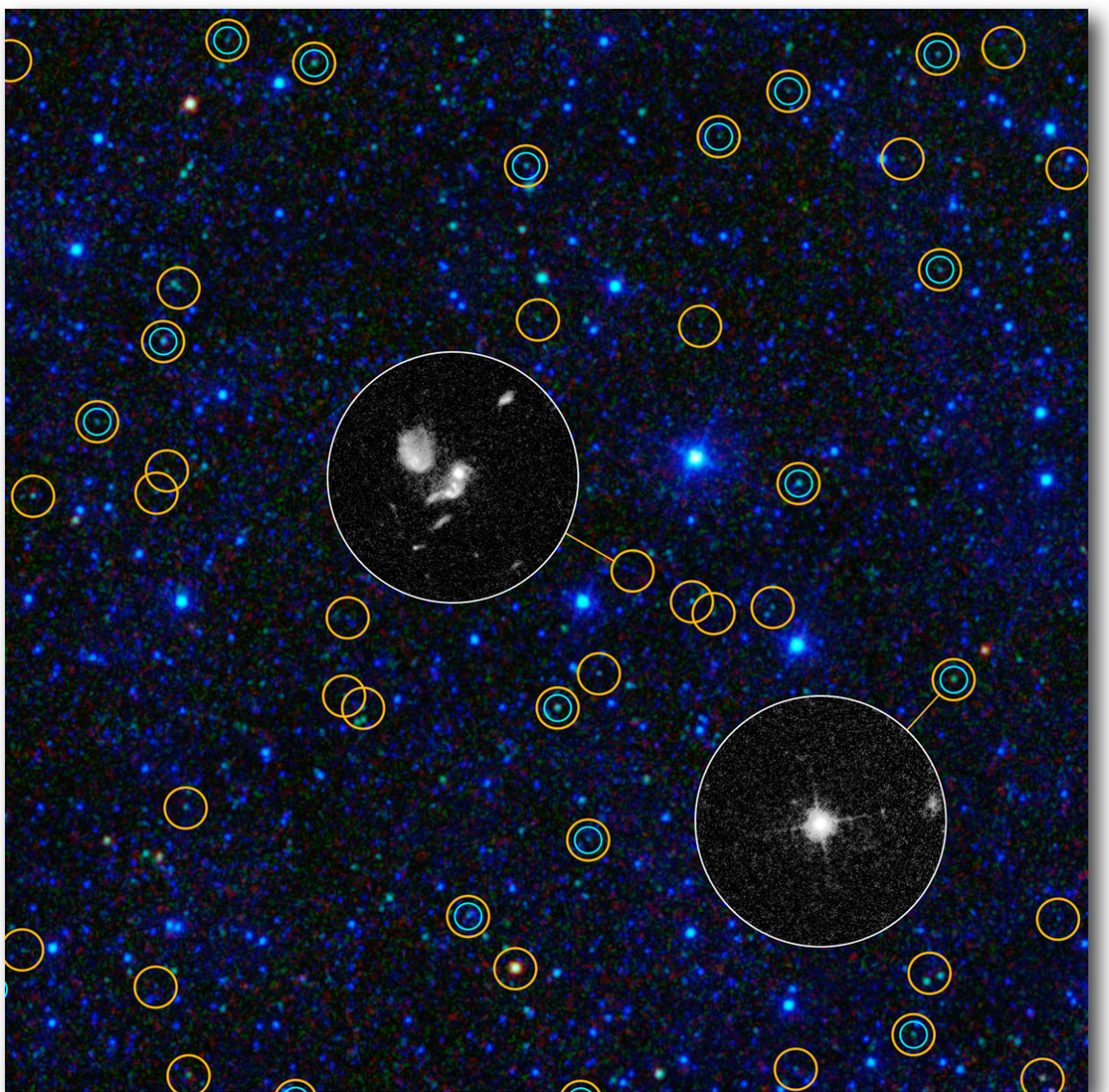
Mid-IR Sources in COSMOS at WISE Depth

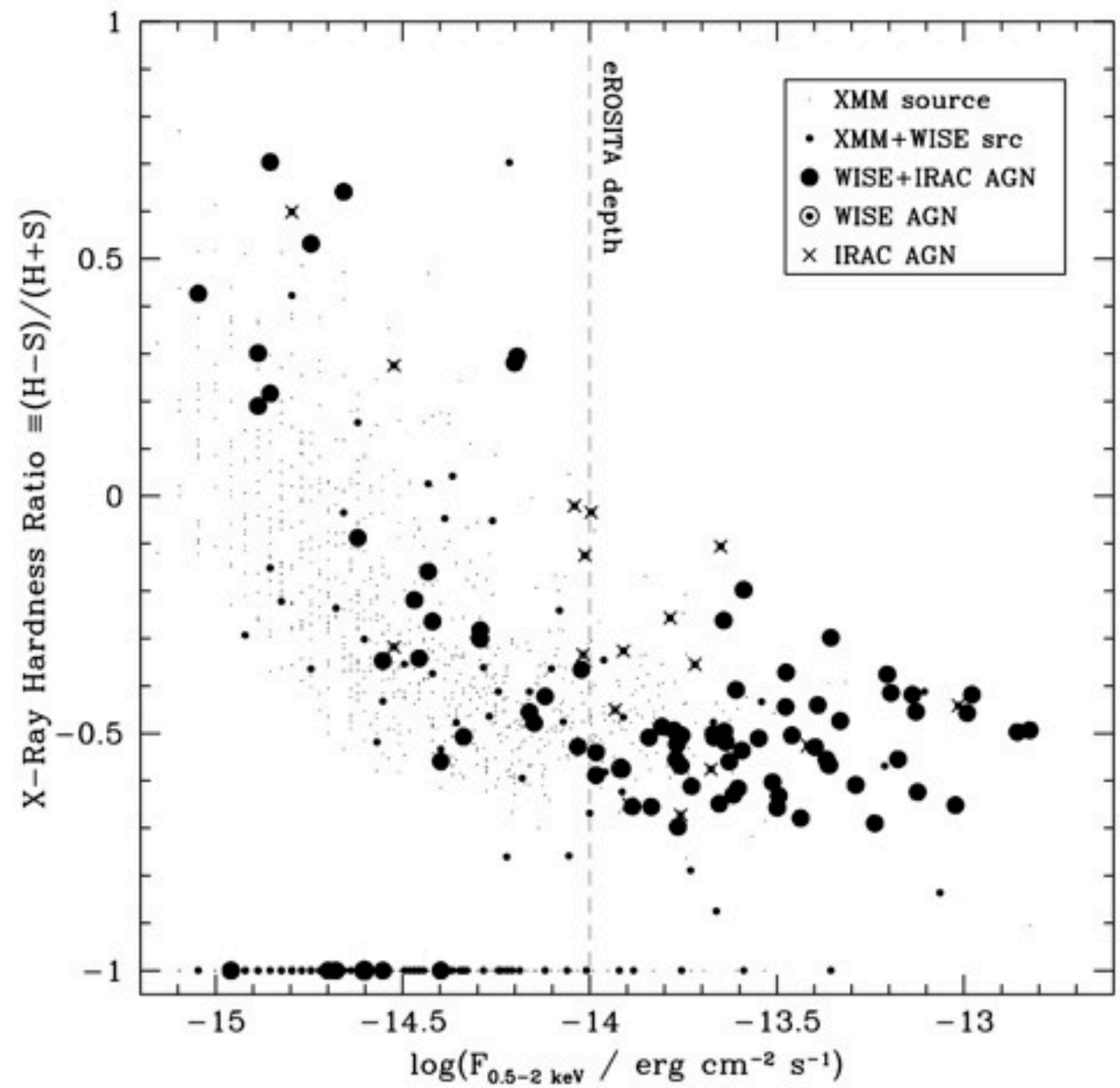
- Stern+12 replaces Stern+05 "wedge" with simple W1-W2 color cut + W2 depth cut (or Assef+13 presents W2-dep't W1-W2 color cut)
- identifies 62 luminous AGN per deg^2
- highly reliable (95%!) and complete (78%) AGN selection (relative to wedge selection)
- for comparison, initial SDSS selection gets 18 deg^{-2} w/ 66% reliability and 90% completeness (for type-1, unobscured QSOs); comparable AGN luminosities

Stern, Assef et al. 2012, ApJ, 753, 30
Assef, Stern et al. 2013, ApJ, 772, 26

Highlights WISE-Selected AGN (in COSMOS):

- 45% unresolved, 55% resolved
- can use r-W2 color to separate resolved & unresolved sources (e.g., type-1/2 AGN)
- 22% undetected by XMM (~60 ks)
- 13% undetected by Chandra (~100 ks)
- eROSITA predictions
- <z> = 1.11

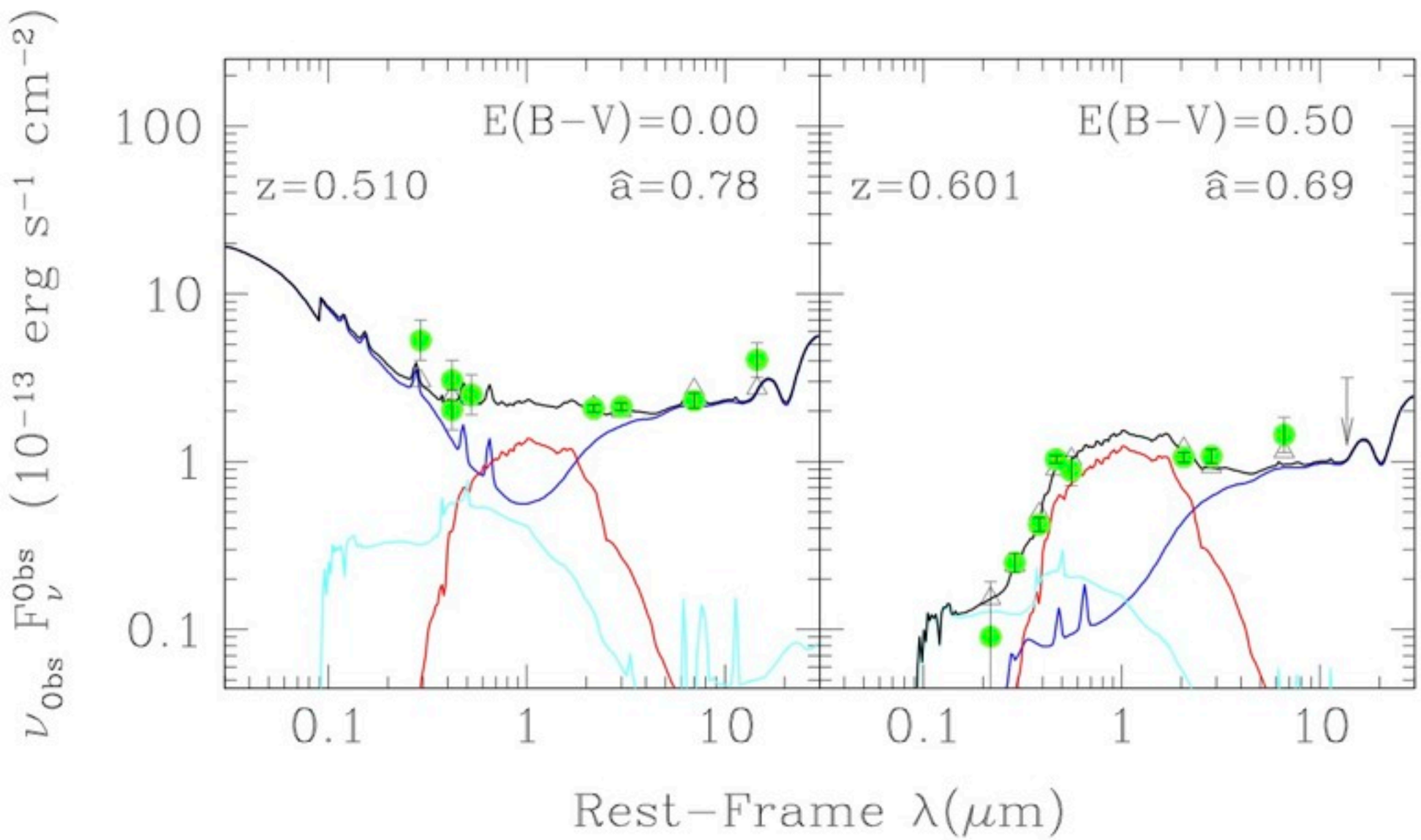




Stern, Assef et al. 2012, ApJ, 753, 30

Dust Reddening of WISE AGN (in Boötes)

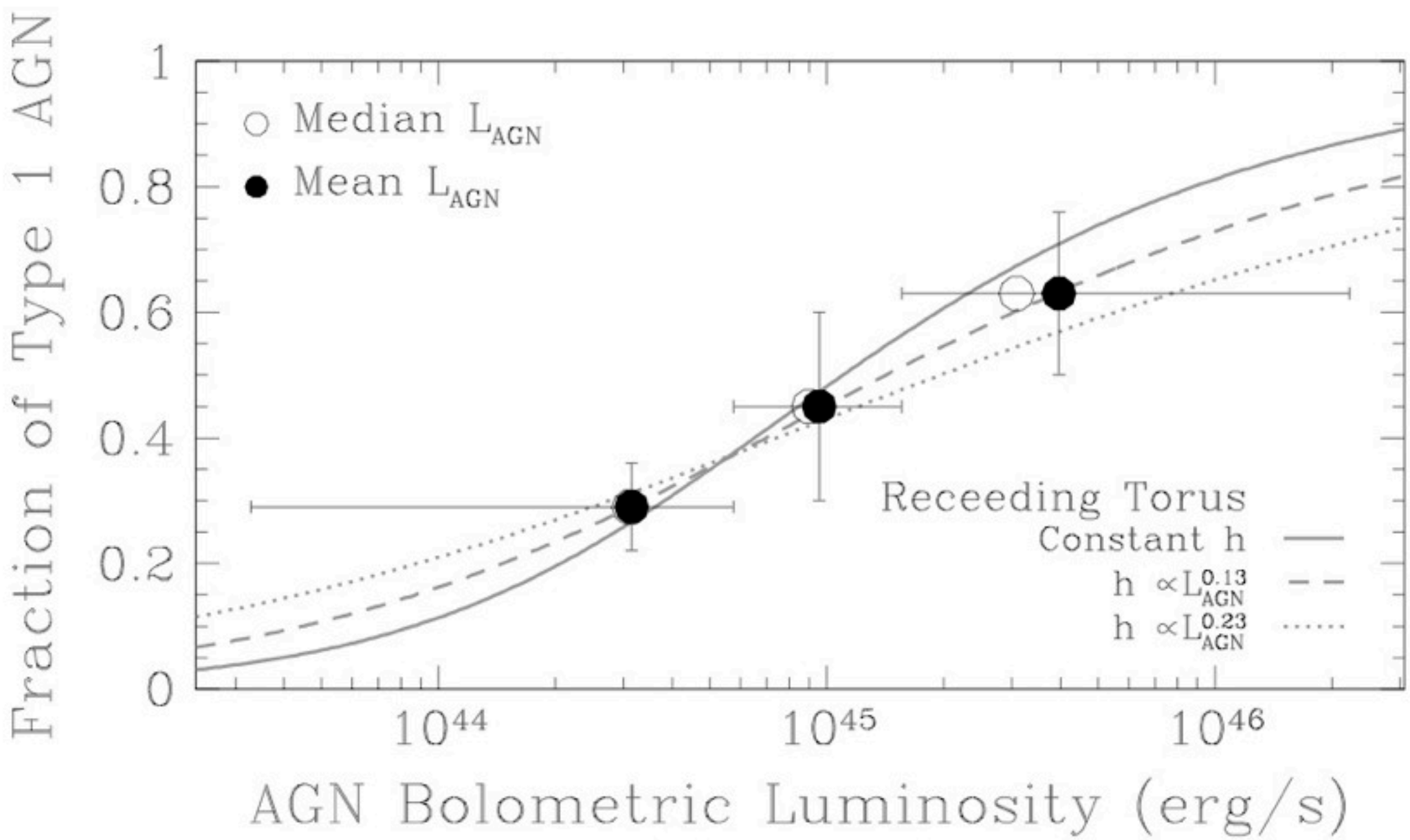
- model broad-band SED as sum of empirical galaxy components + AGN
  - E(B-V): AGN reddening (no reddening applied to empirical galaxy templates)
  - â: fraction of 0.3-30 um luminosity coming from the AGN



Assef, Stern et al. 2013, ApJ, 772, 26

Dust Reddening of WISE AGN (in Boötes)

- more luminous AGN are less likely to be obscured,
- consistent with predictions of the "receding torus" model
- hints of feature in dust distribution at E(B-V) ~ 1



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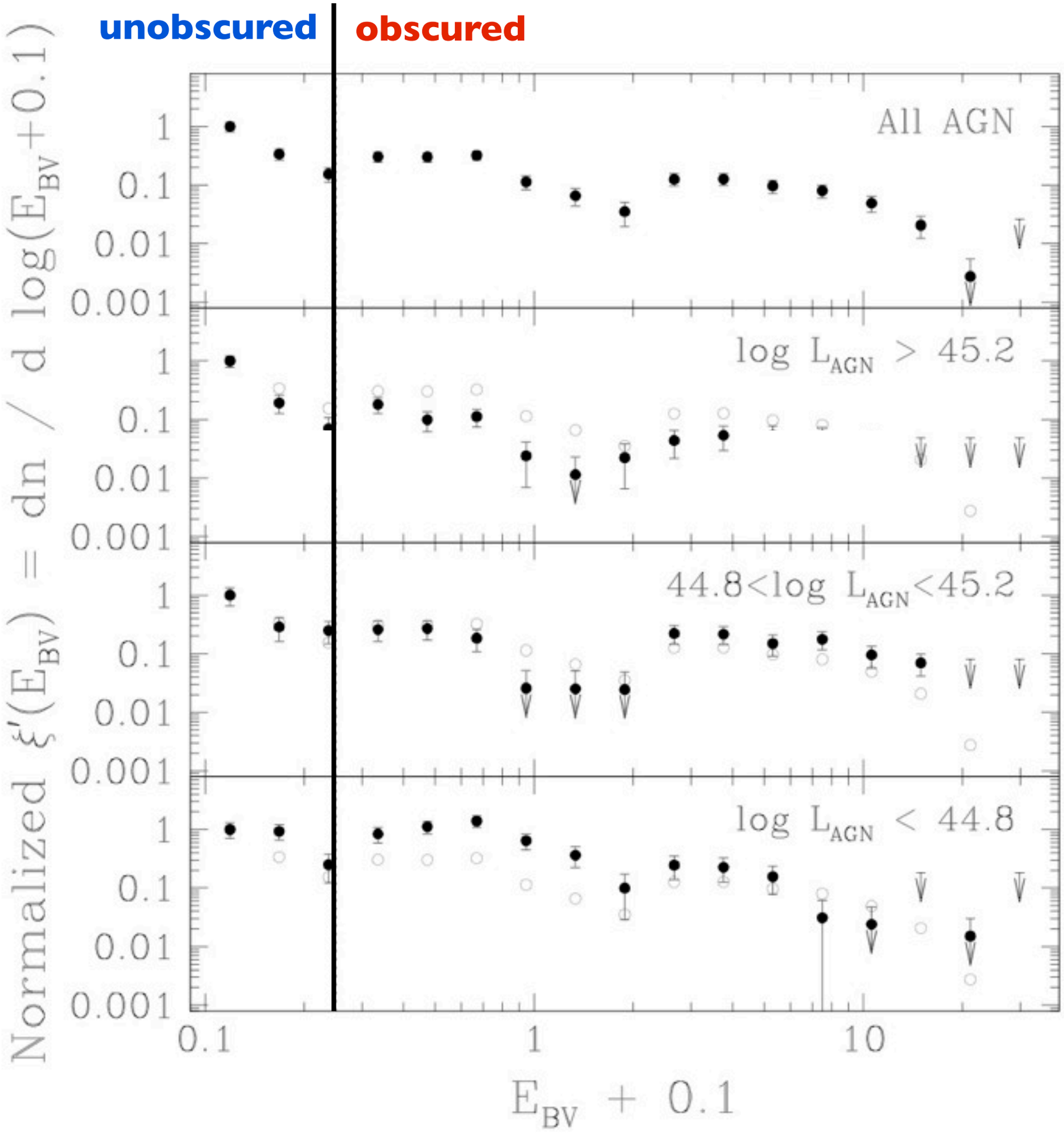
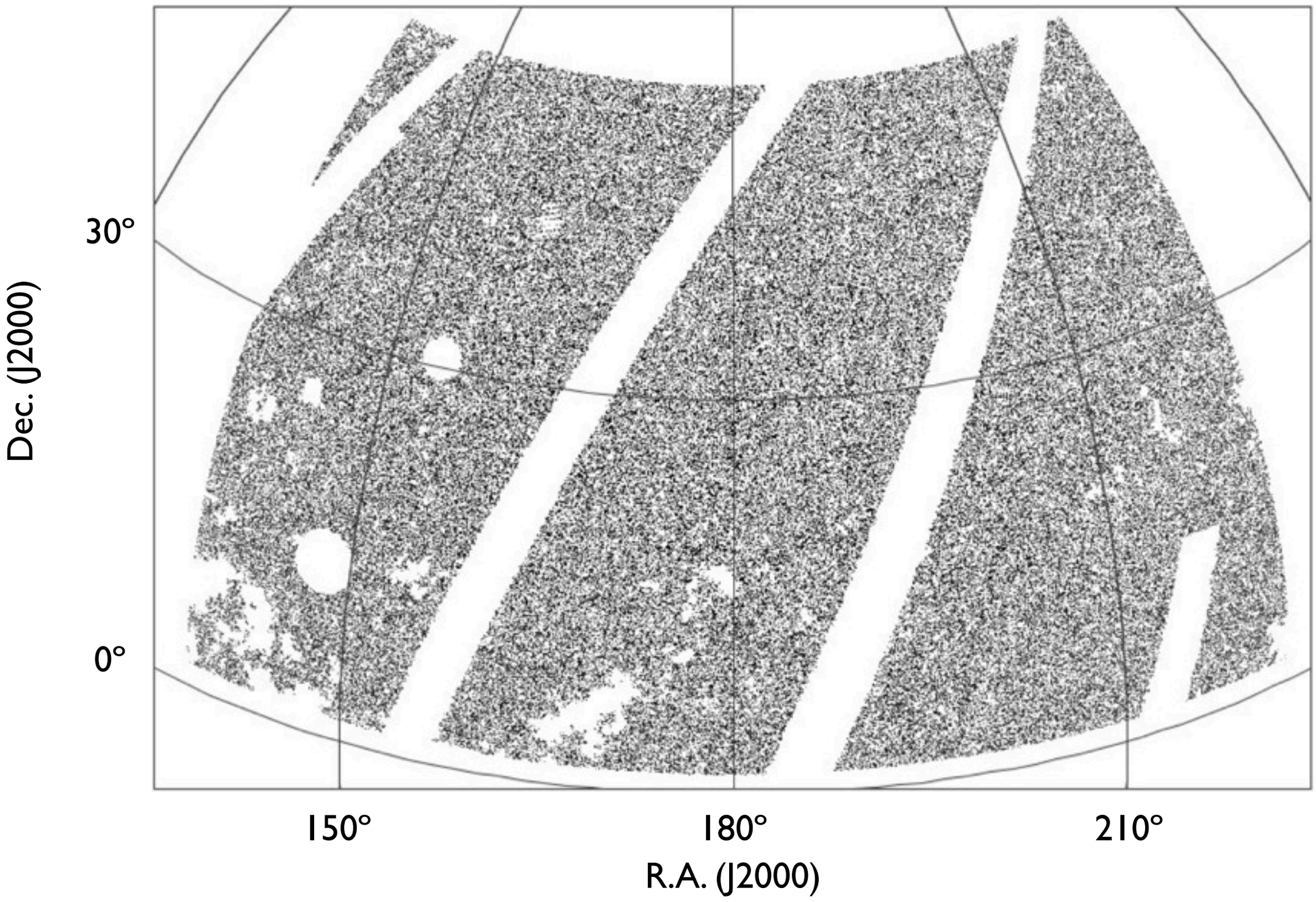


Assef, Stern et al. 2013, ApJ, 772, 26

Angular Clustering of WISE-Selected AGN (in SDSS)

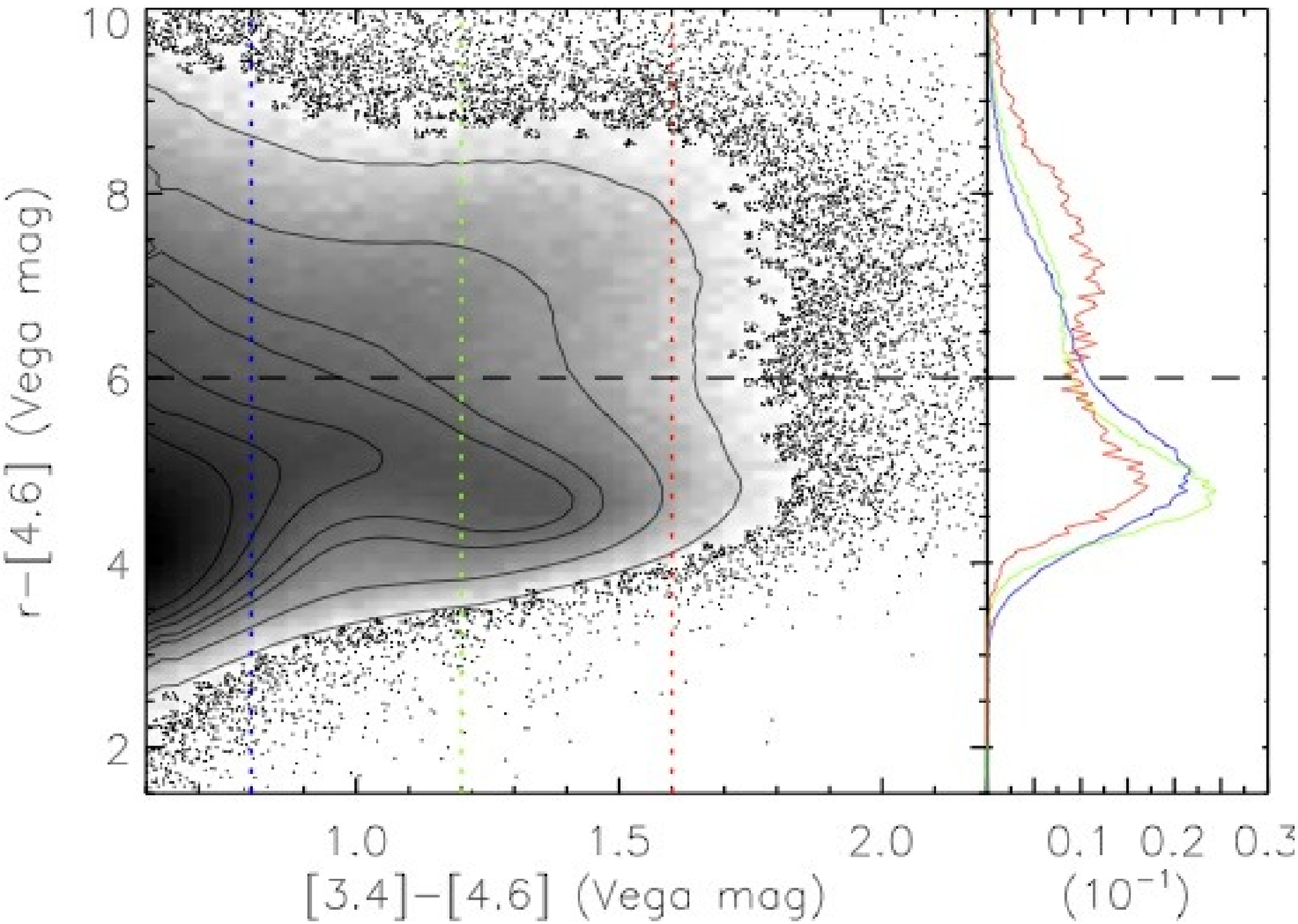
- angular clustering of 170,372 WISE-selected AGN over 3363 deg^2



Donoso, Yan, Stern & Assef et al., ApJ, submitted (arXiv:1309.2277)

Angular Clustering of WISE-Selected AGN (in SDSS)

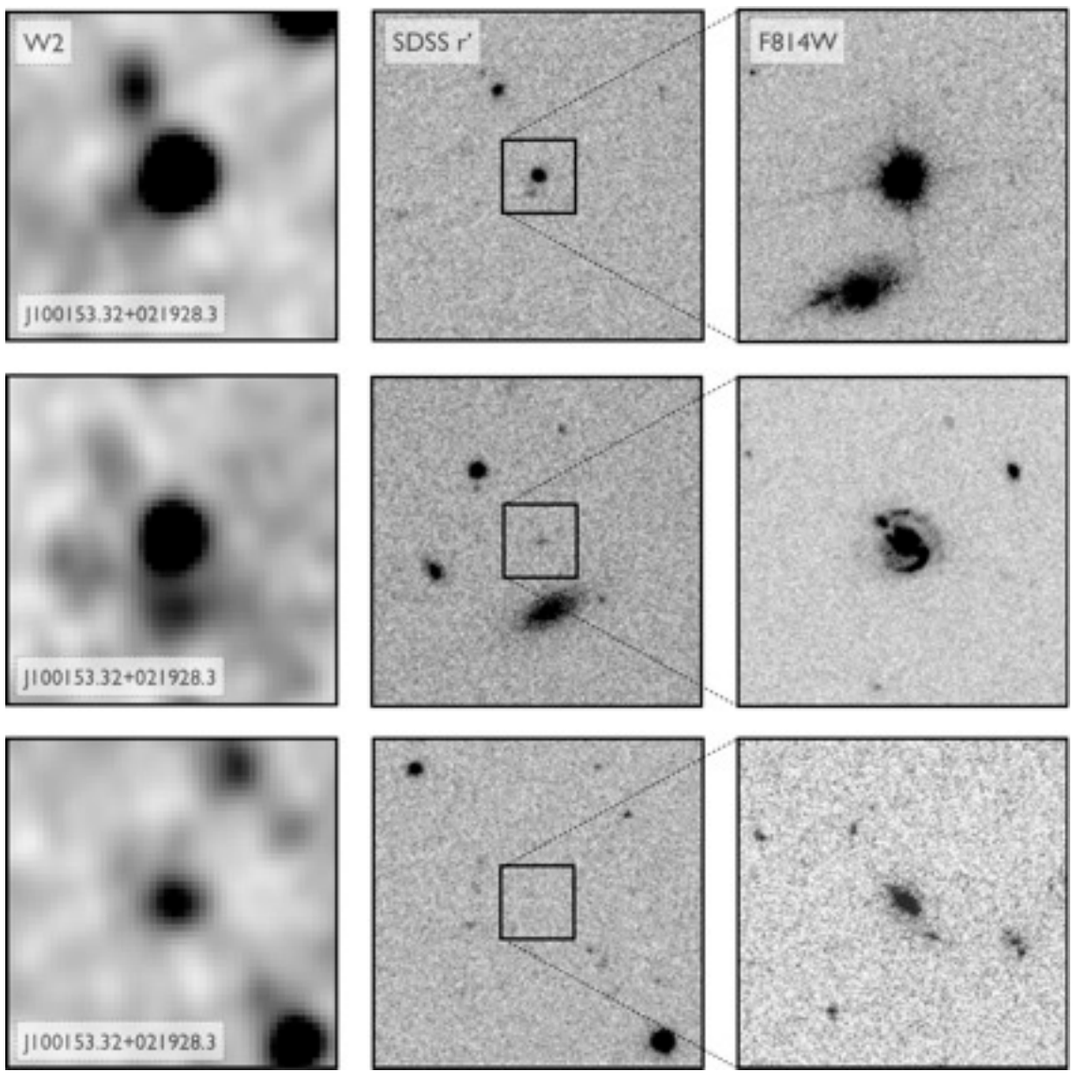
- separate type-1 AGN (unobscured) from type-2 AGN (obscured) using r-W2 color
- note more contamination of red sources into blue selection than vice-versa

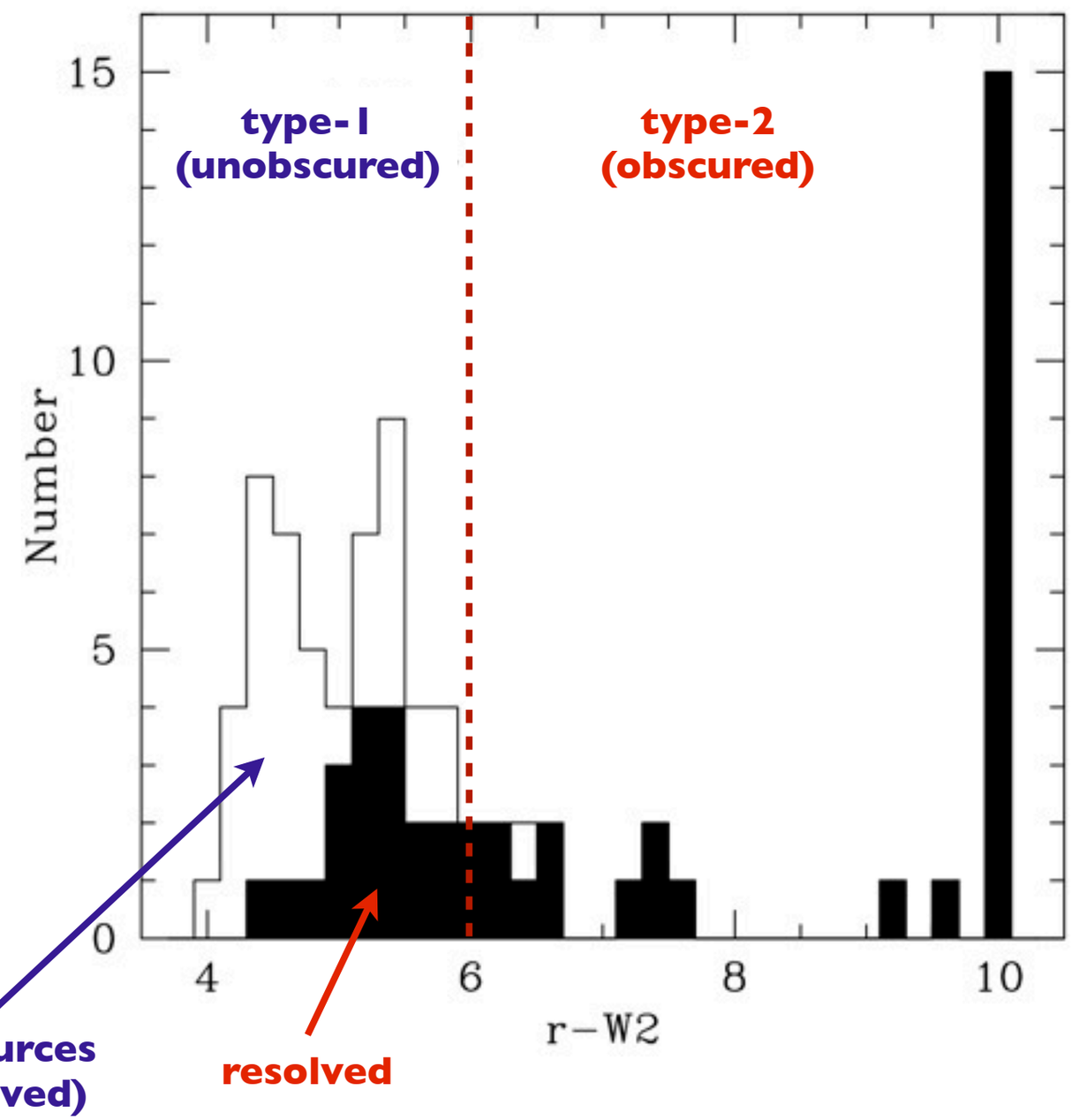


Donoso, Yan, Stern & Assef et al., ApJ, submitted (arXiv:1309.2277)

Angular Clustering of WISE-Selected AGN (in SDSS)

- unresolved AGN have bluer r-W2 colors
- resolved AGN tend to have redder r-W2 colors

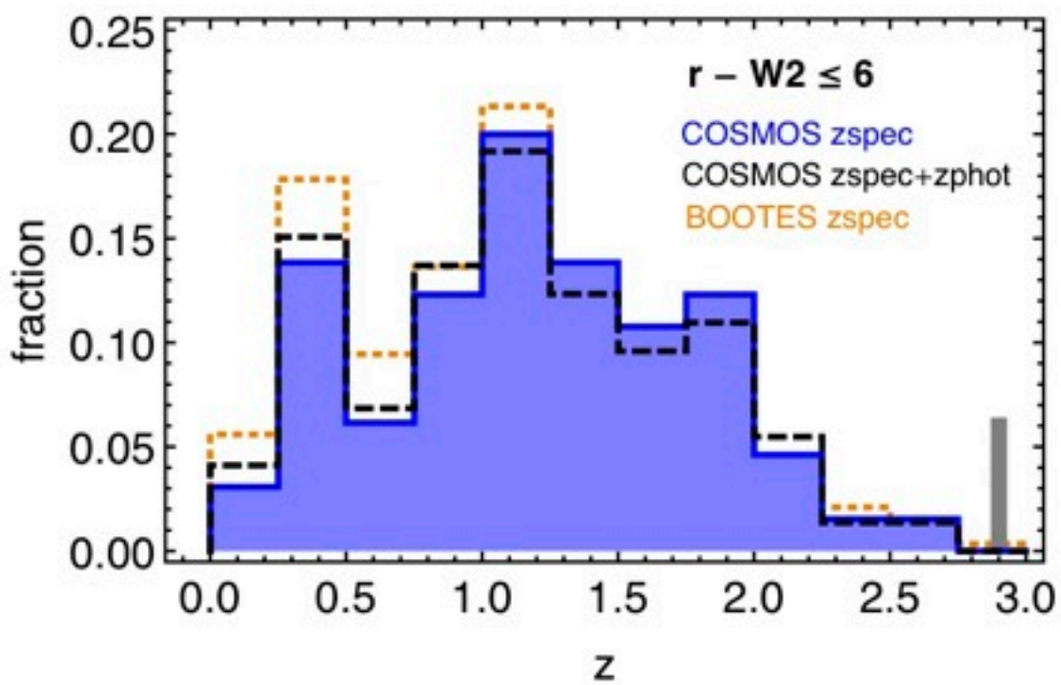


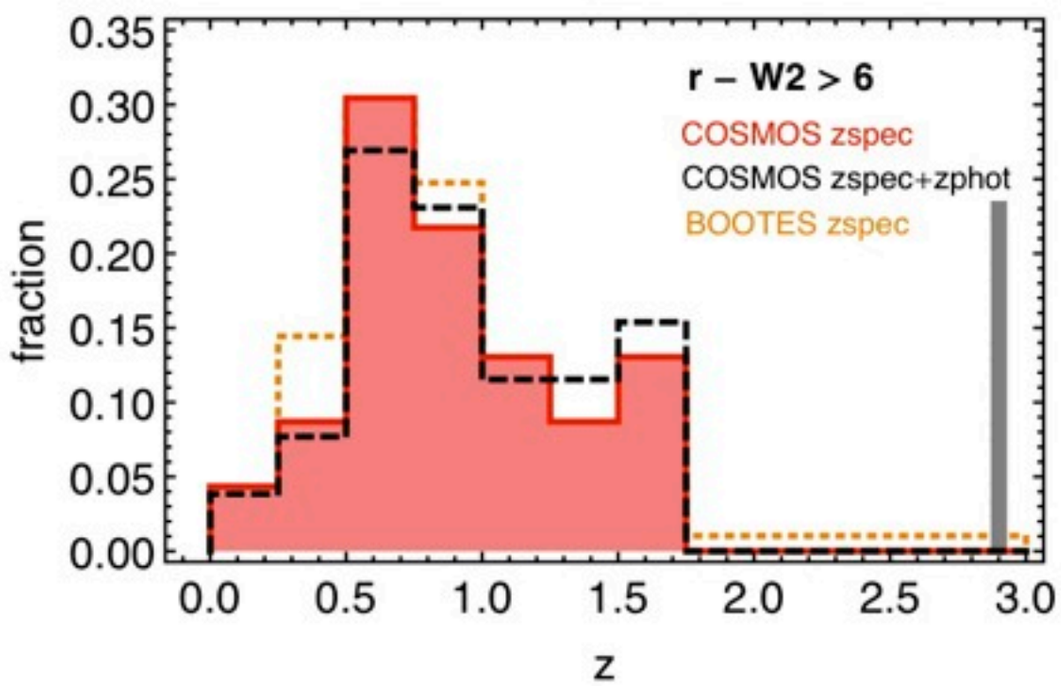


Donoso, Yan, Stern & Assef et al., ApJ, submitted (arXiv:1309.2277)

Angular Clustering of WISE-Selected AGN (in SDSS)

- redshift distribution of unobscured (blue) and obscured (red) WISE-selected AGN
- obscured AGN have a higher bias, implying they reside in richer haloes!

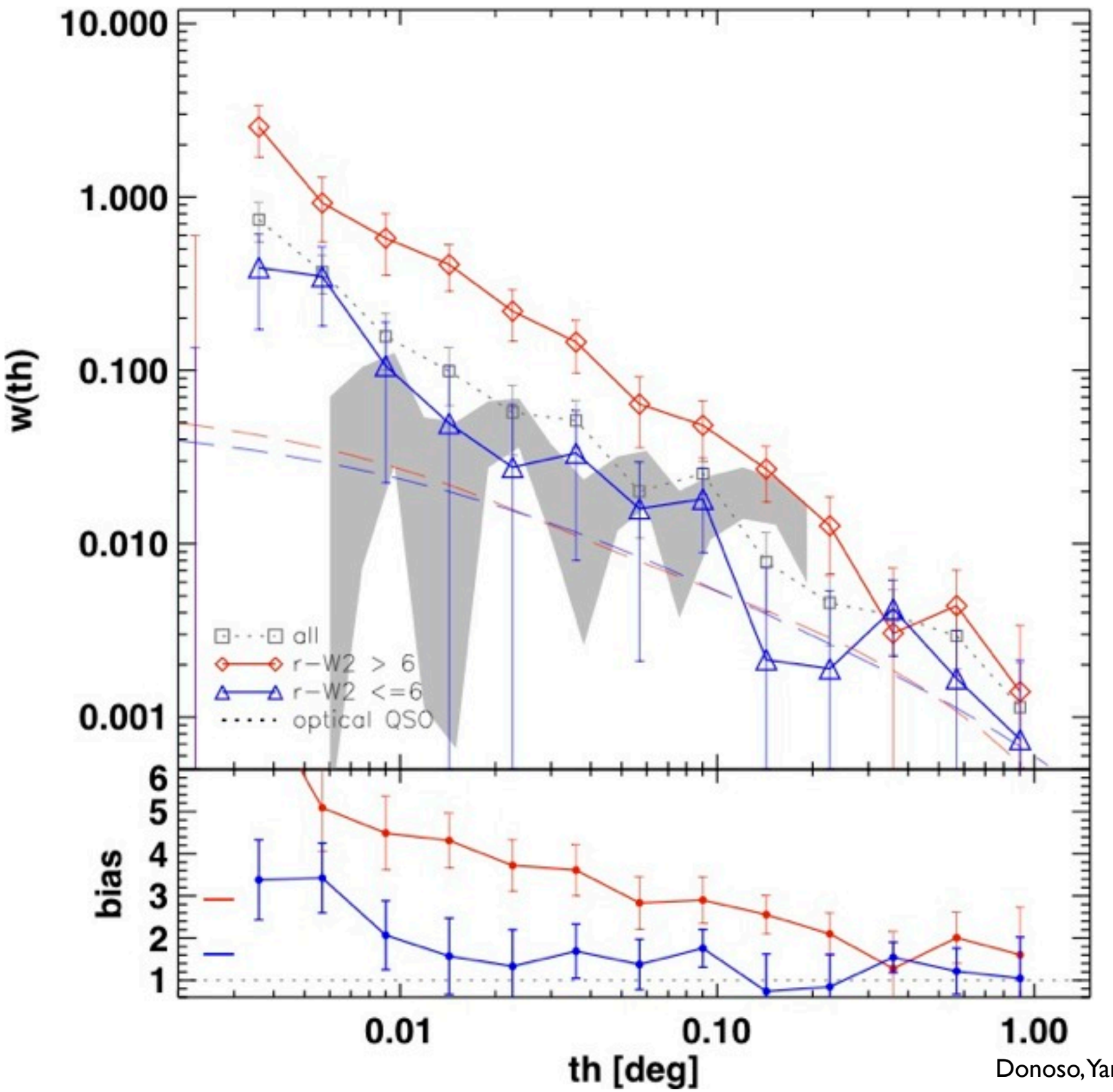




Donoso, Yan, Stern & Assef et al., ApJ, submitted (arXiv:1309.2277)

Angular Clustering of WISE-Selected AGN (in SDSS)

- angular correlation function $w(\theta)$ of blue & red WISE-selected AGN



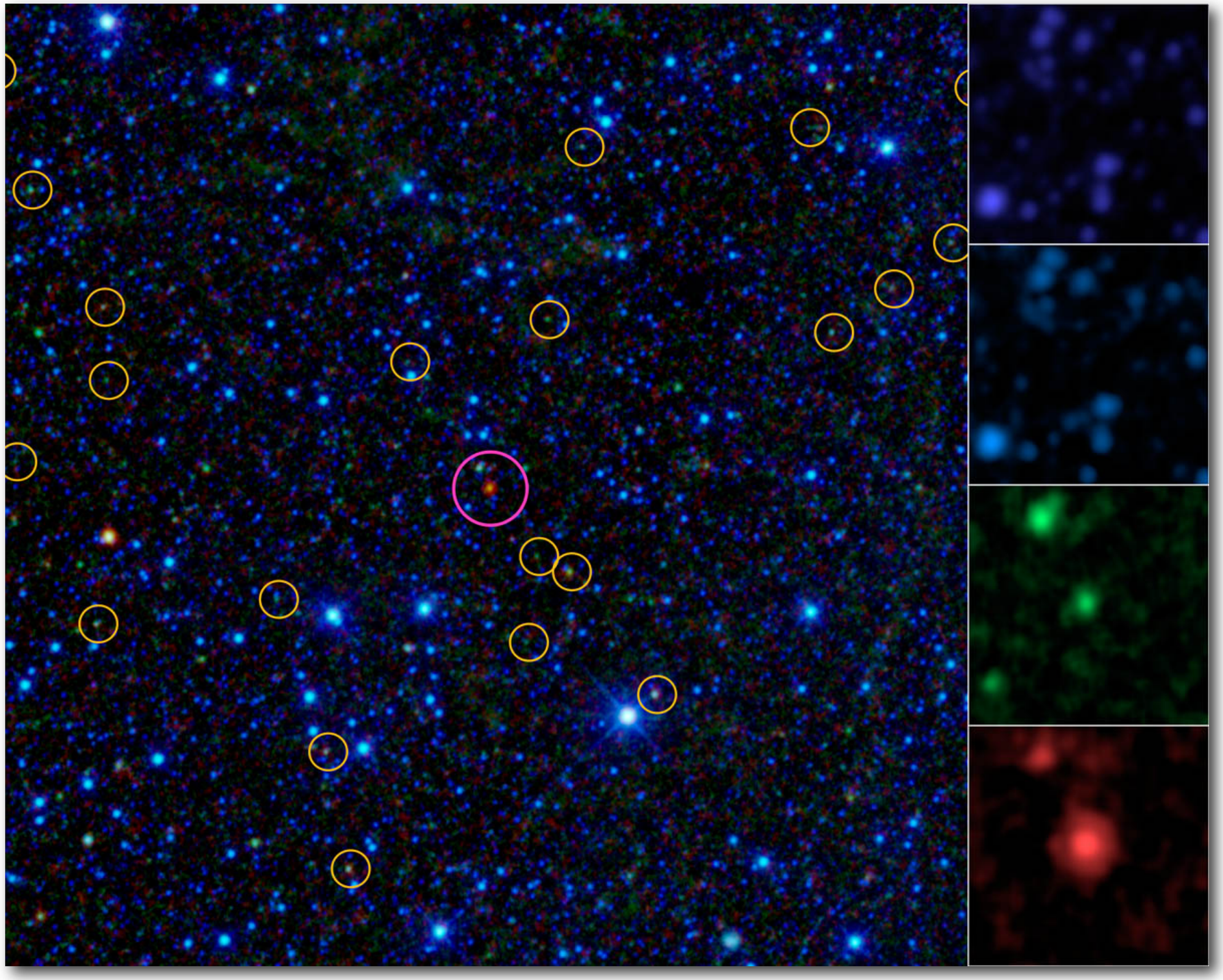
blue AGN:
- b = 1.6 ± 0.6
- M ~ $10^{12.4}$ M(sun)

red AGN:
- b = 2.9 ± 0.6
- M ~ $10^{13.5}$ M(sun)

Donoso, Yan, Stern & Assef et al., ApJ, submitted (arXiv:1309.2277)

The Most Extreme WISE-Selected AGN

- W1W2-dropouts (undetected blue-ward of 12 um)



Eisenhardt et al. 2012, ApJ, 755, 173

The Most Extreme WISE-Selected AGN

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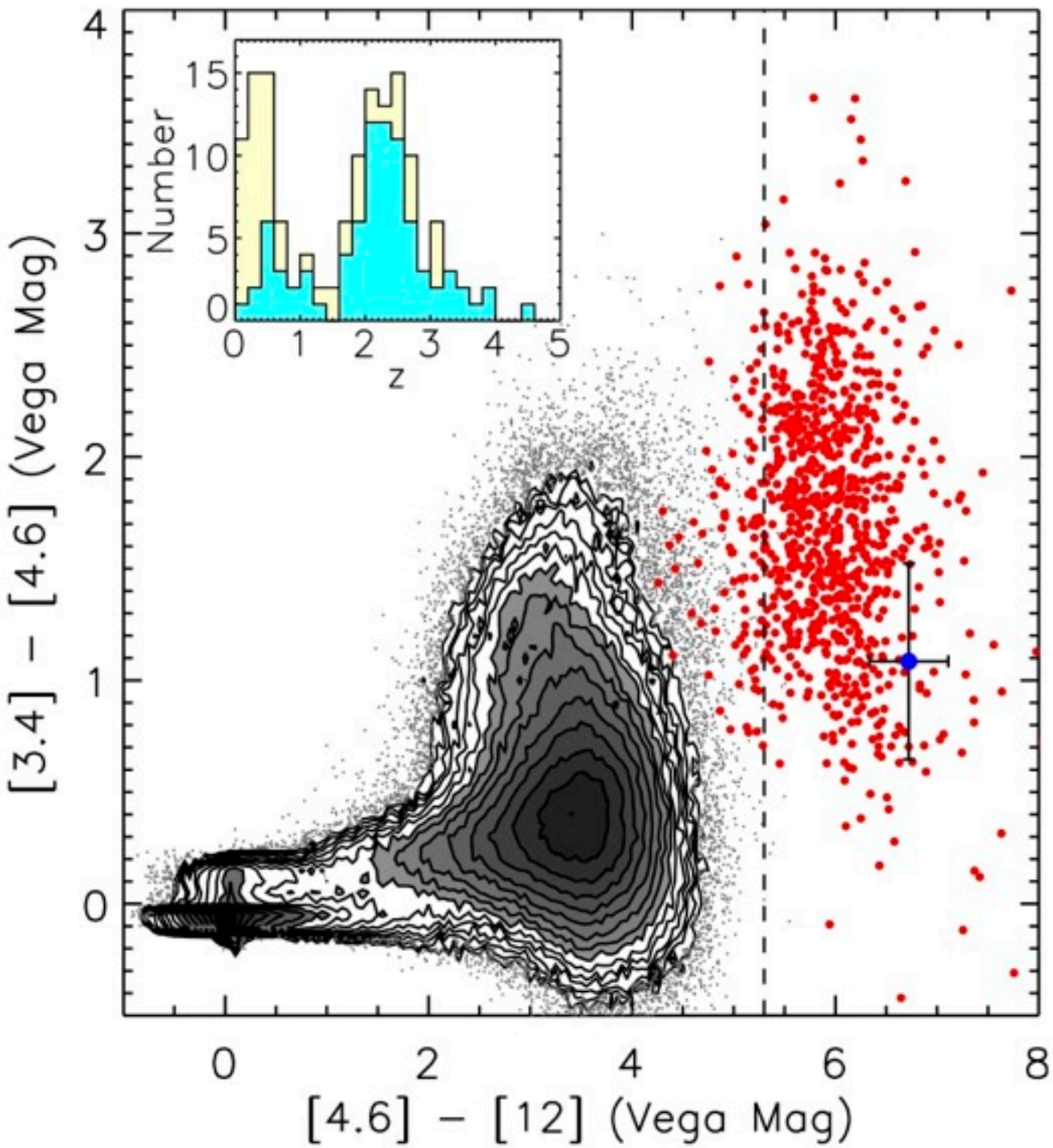
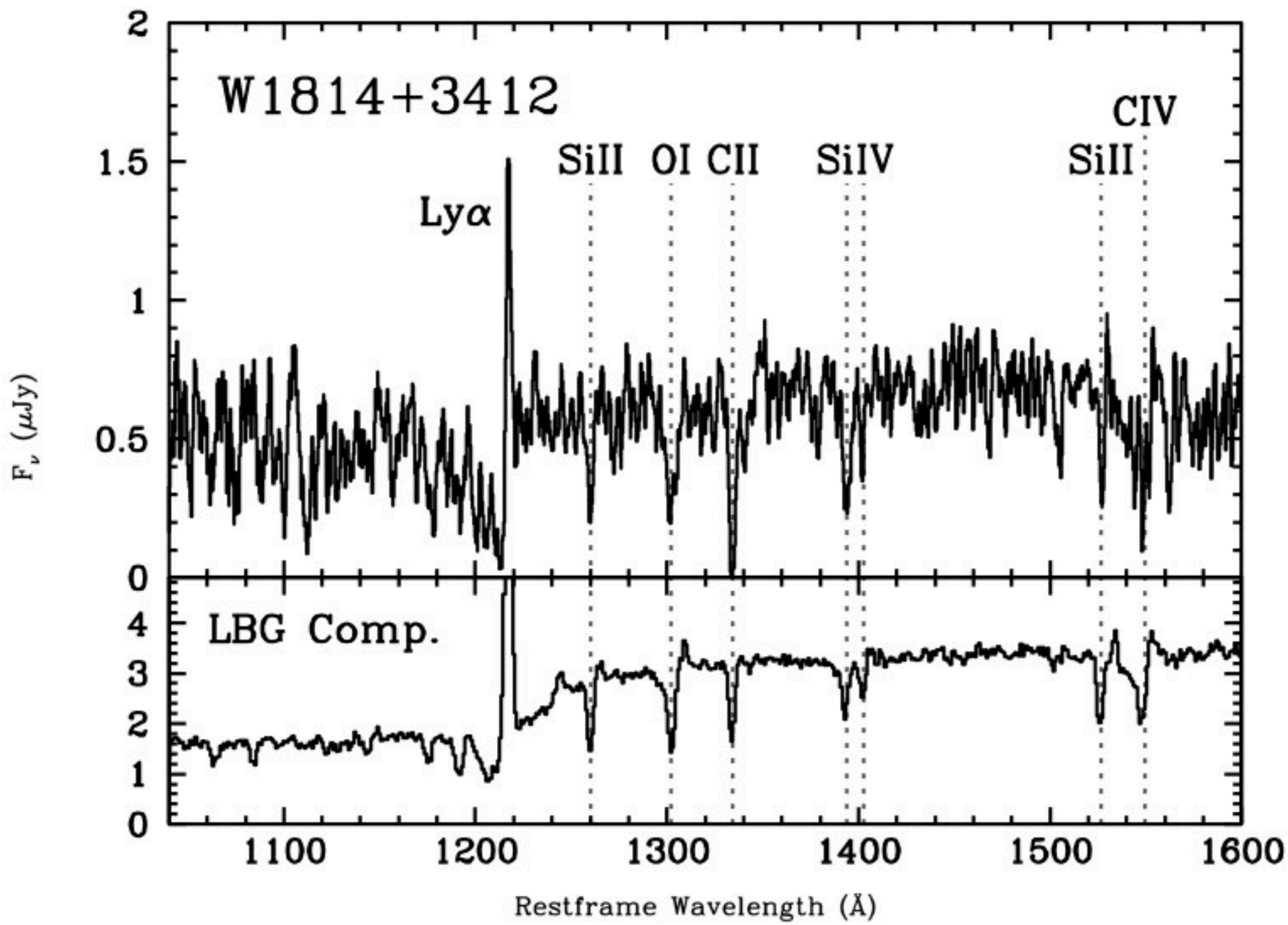


- ~1000 W1W2-dropouts across the extragalactic sky (e.g., only ~1 per 30 deg^2)
- WISE team aggressively studying (e.g., Keck, Gemini, Palomar, WIYN, SOAR, Spitzer, Herschel, XMM-Newton, NuSTAR, CSO, ...)
- <z> ~ 2, with one at z=4.6
- highly luminous
  - L(bol) ~ 1e14 L(sun)
- Lyα blobs common

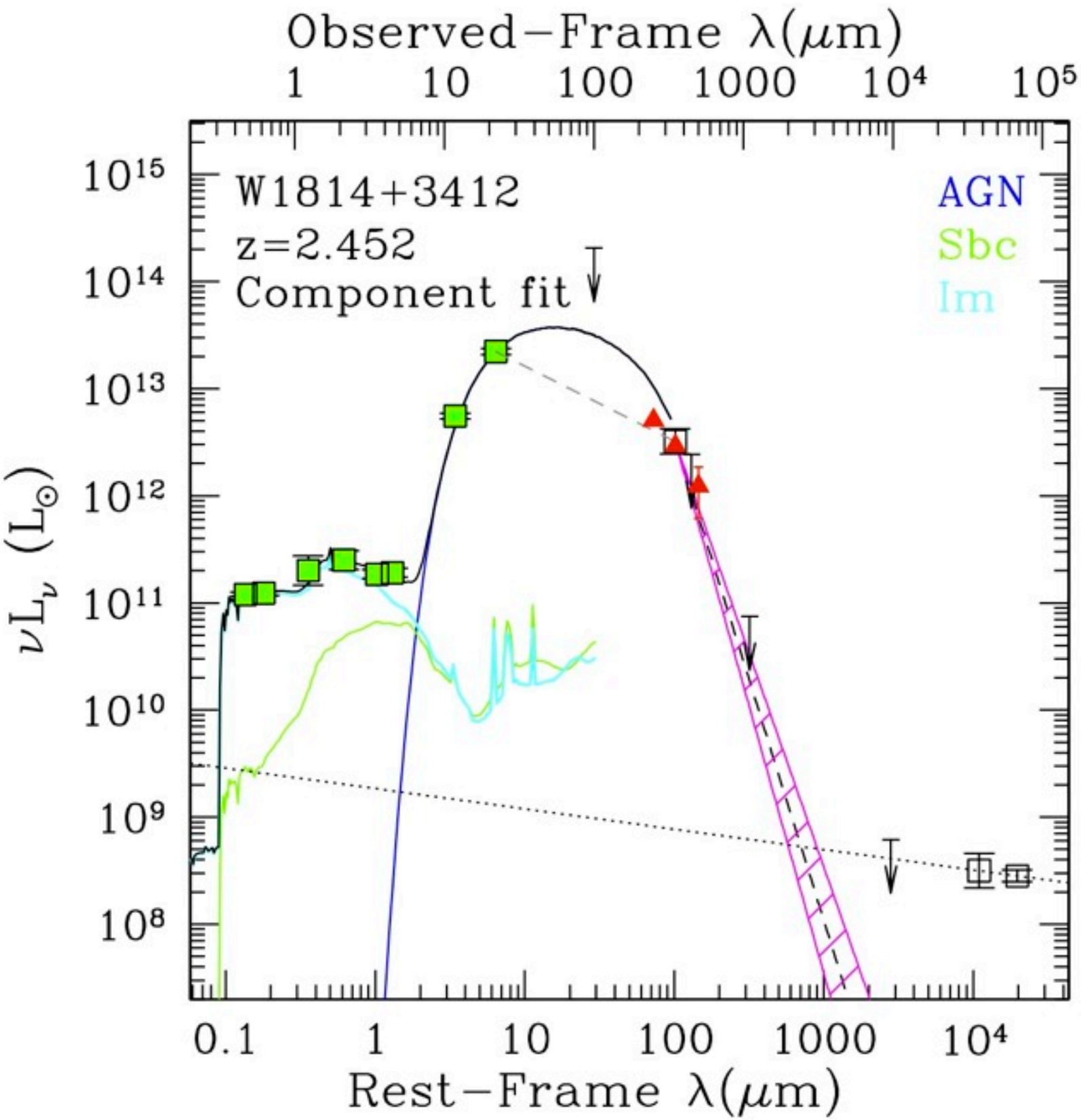
Eisenhardt et al. 2012, ApJ, 755, 173
Wu et al. 2013, 756, 96
Bridge et al.. 2013, ApJ, 769, 91

The Most Extreme WISE-Selected AGN

- Keck spectrum of one of the first W1W2-dropouts (z=2.452)
- (type-2) AGN features turning out to be relatively common (~50%)



Eisenhardt et al. 2012, ApJ, 755, 173

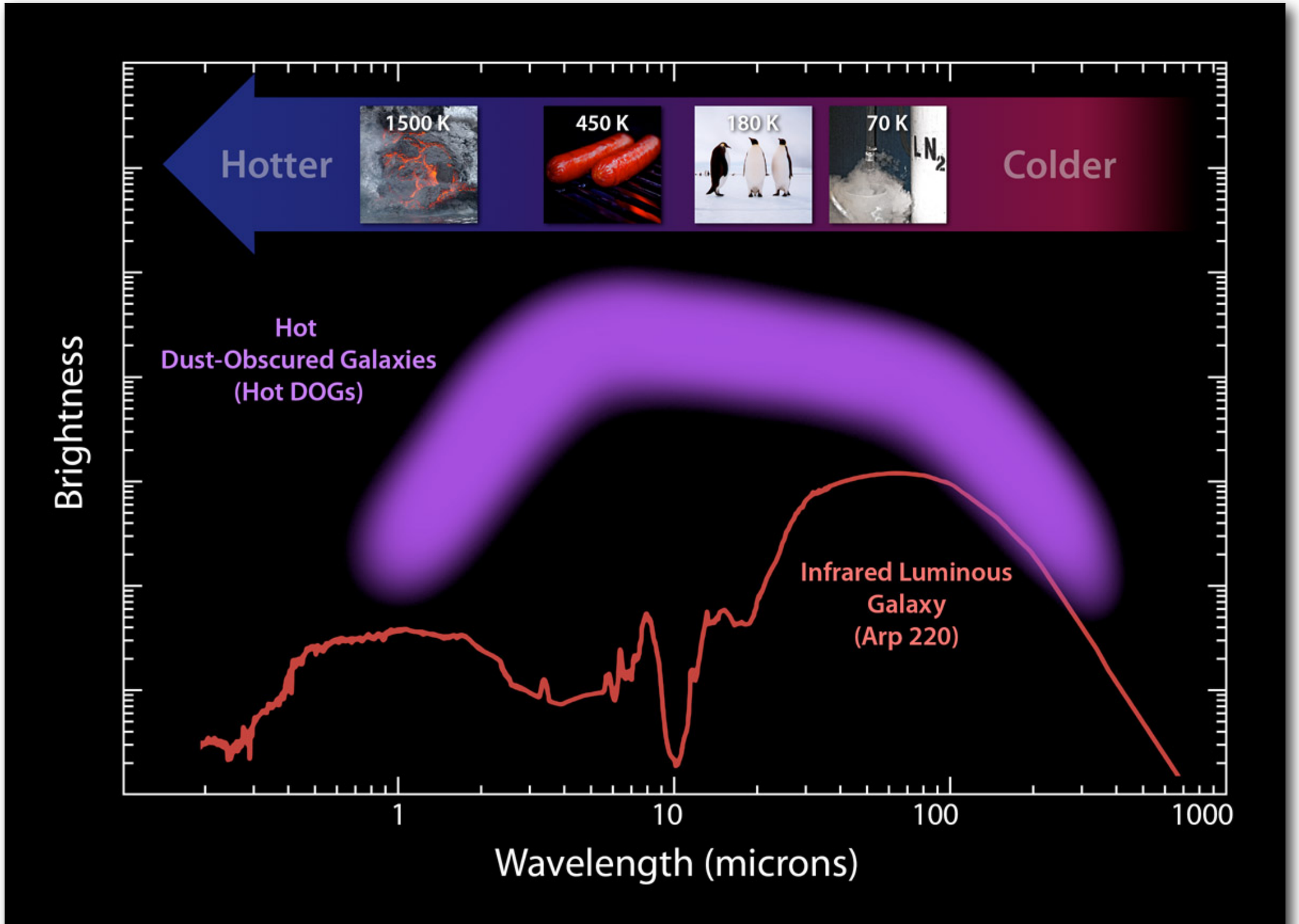


- best fit to SED includes an AGN with ~50 mag of extinction
- for typical dust-to-gas ratios, N(H) ~ 1e24 cm^{-2}
- for Eddington-limited accretion, BH seems big compared to stellar mass
- L(bol) ~ 9e13 L(sun), placing it amongst the most luminous sources known

Eisenhardt et al. 2012, ApJ, 755, 173

Sub-mm Properties of W1W2-Dropouts

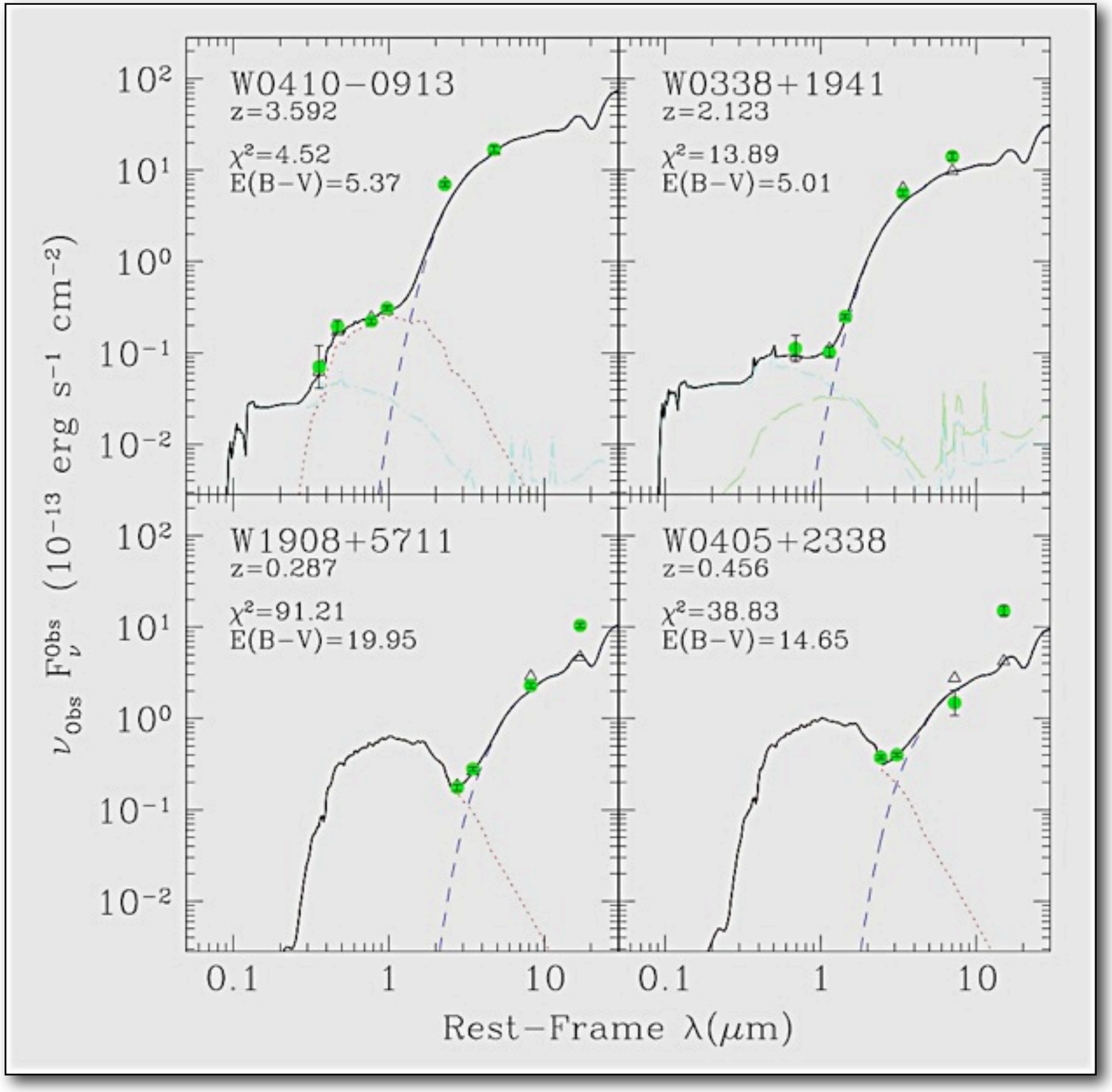
- hotter than SMGs and DOGs -- hot dust-obscured galaxies or "hot DOGs"



Wu et al. 2012, ApJ, 756, 96

The Space Density of Hot DOGs, and Comparison to QSOs

- SED modeling reveals presence of heavily obscured, extremely luminous AGN



Assef et al., in prep.

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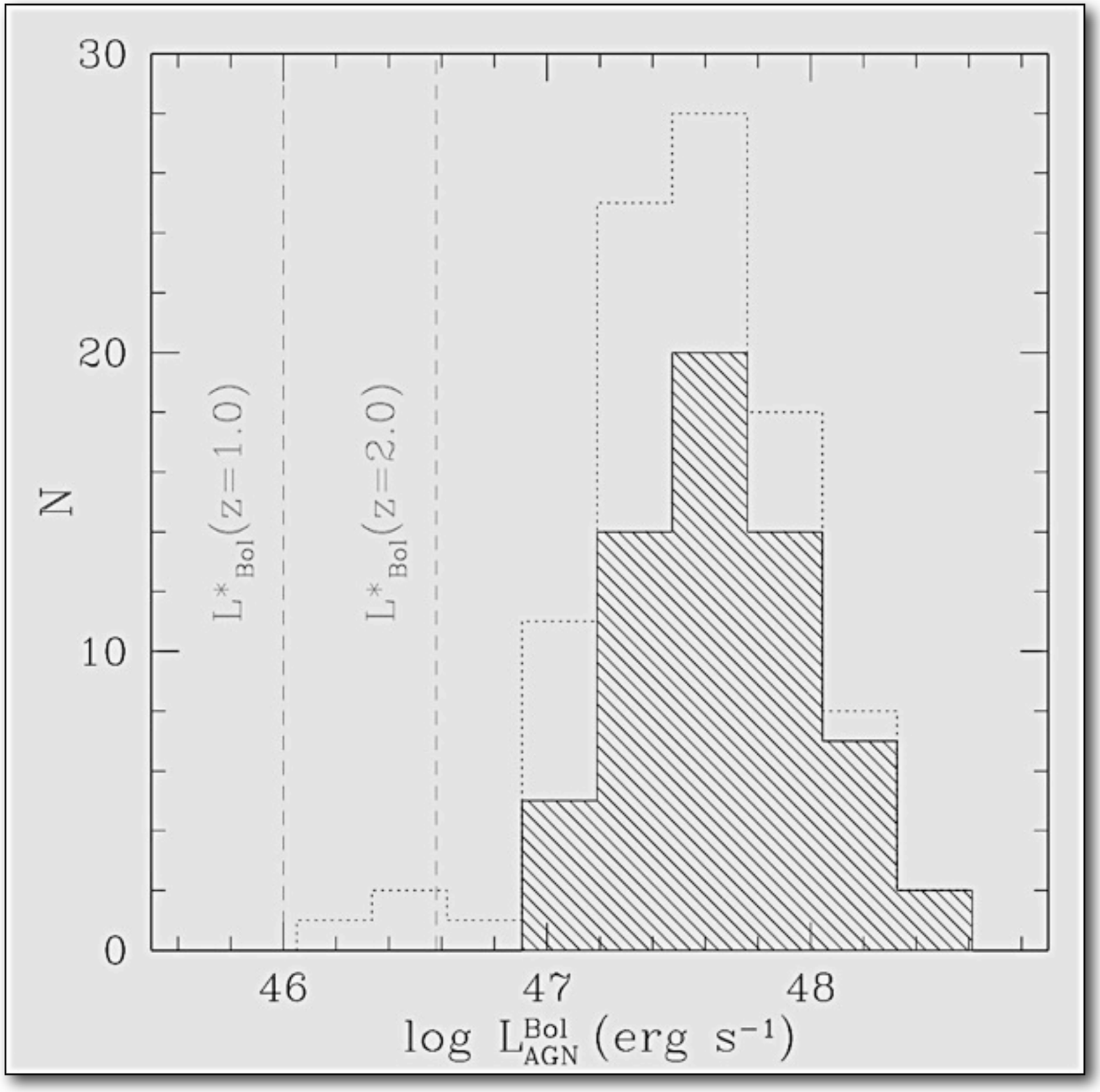


Assef et al., in prep.

Anti-Summary

- the bulk of the quasar population is neither quasi-stellar nor radio-loud

- clustering analysis of WISE-selected AGN sample shows obscured quasars to reside in different (more massive) dark matter haloes than unobscured AGN ➡ hard to reconcile with the traditional orientation-driven, or torus "unified model of AGN" [sorry, Meg]

- WISE is identifying a large population of extremely luminous, extremely obscured AGN ➡ hard to reconcile with the "receding torus" model of AGN, in which more luminous AGN show less obscuration

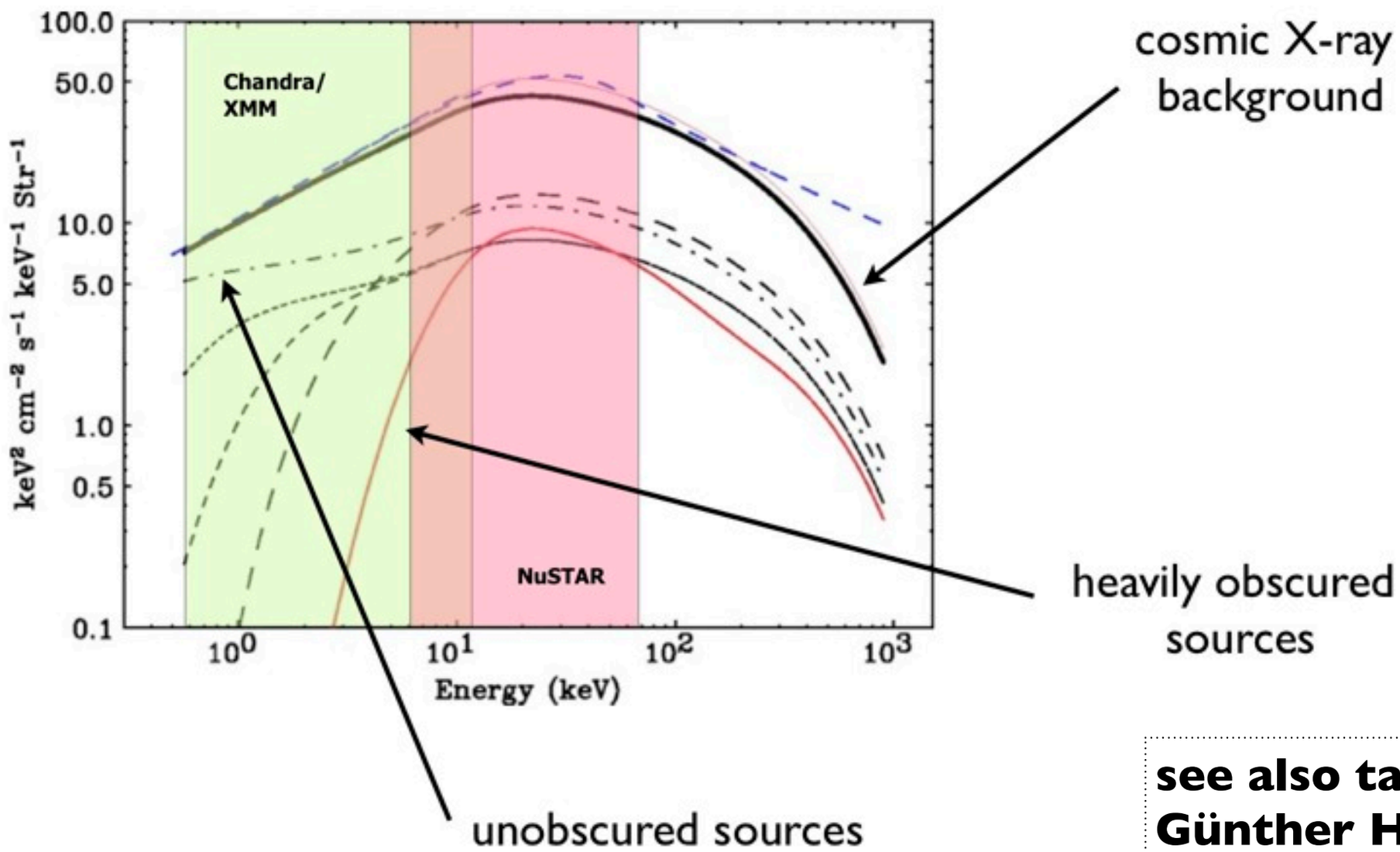
Backup Slides

Asher (6 yr.)
(as 19th-century ninja)

Eden (4 yr.)
(after successful camouflaged kitten hunt)

Why care about the obscured population?

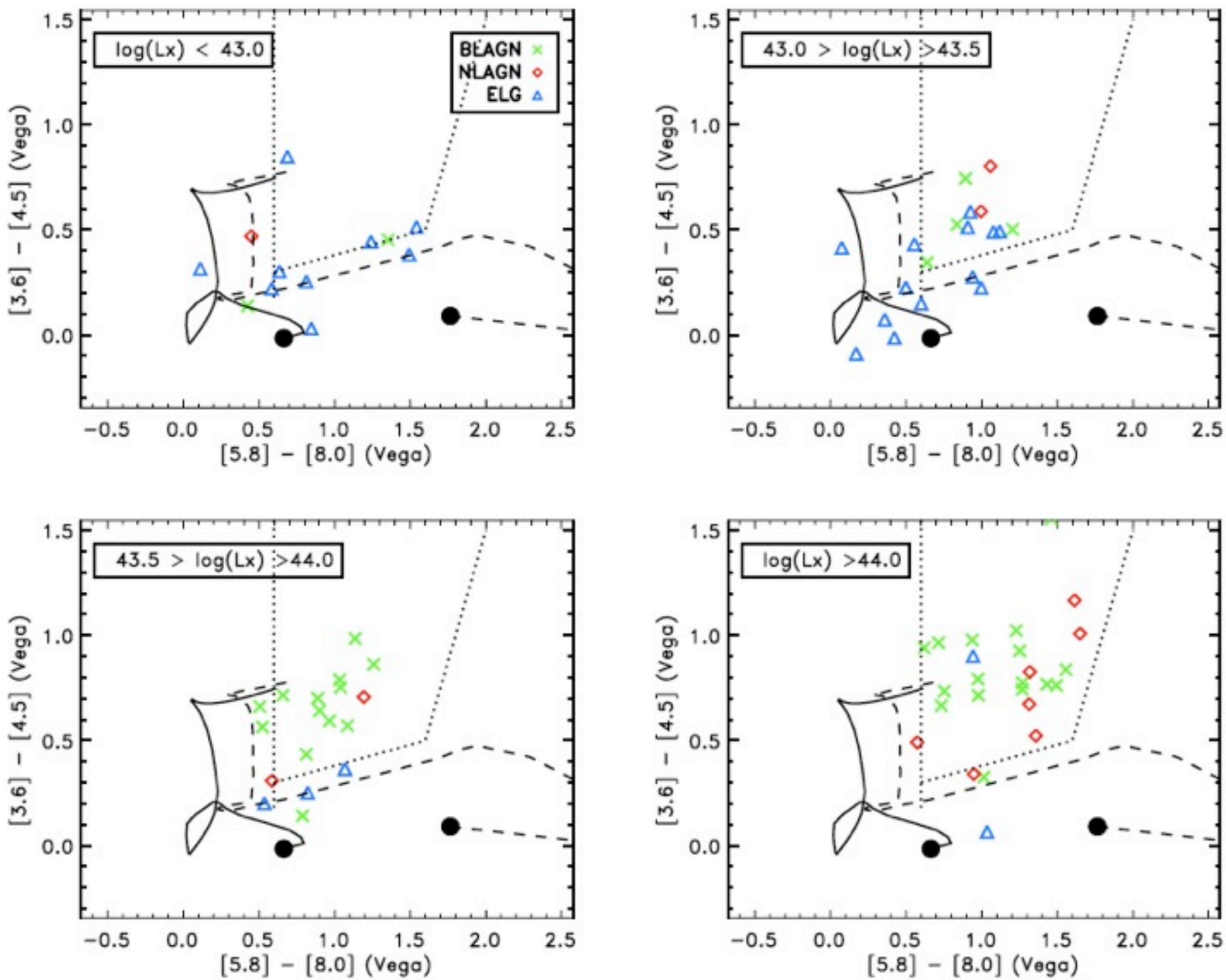
- understand the full census of AGN in the universe
- understand the sources responsible for the cosmic X-ray background
- AGN feedback: clues to galaxy formation & evolution
- important for reionization?



see also talks by:
Günther Hasinger
Fiona Harrison

Ueda et al. 2003, ApJ, 598, 886

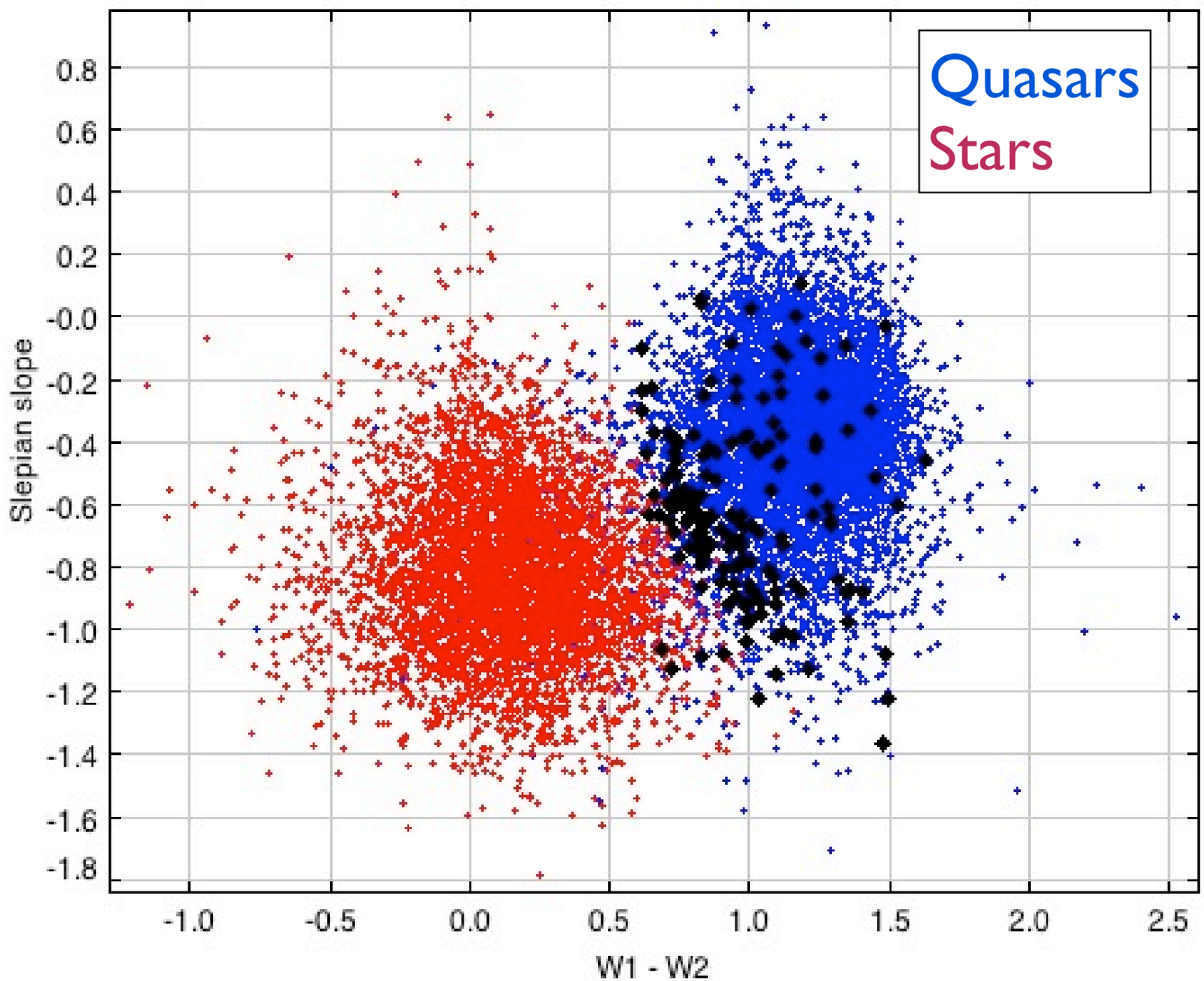
X-Ray Luminosity Dependence



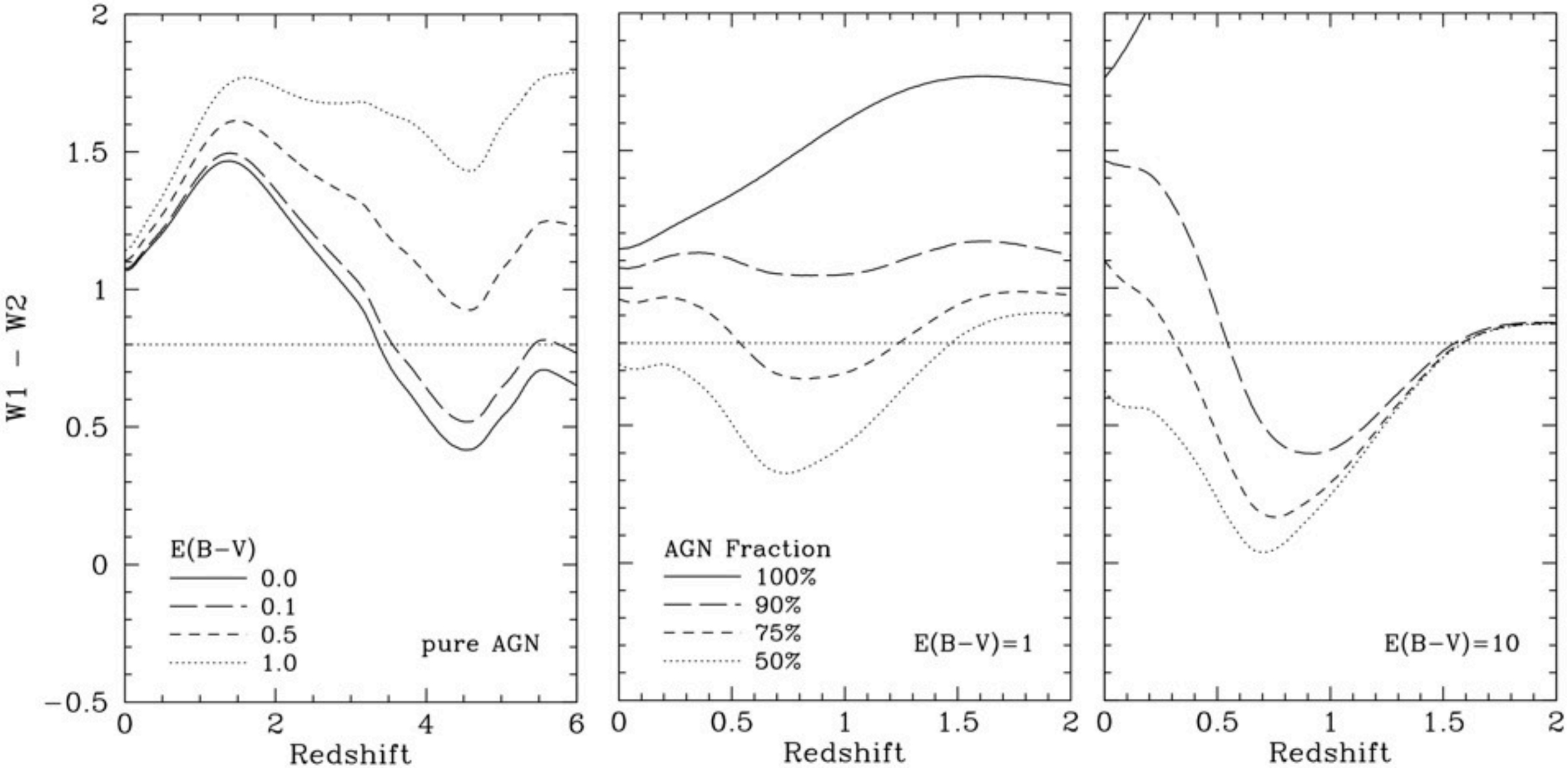
Eckart, McGreer, Stern, Harrison & Helfand 2010, ApJ, 708, 584

Optical Variability + WISE Color Selection of AGN

- optical variability + mid-IR color to identify complete sample of unobscured QSOs
- for stripe 82 QSOs, mid-IR color gets 80.4%; combining w/ variability parameter gets 93.7%



poster by Matthew Graham



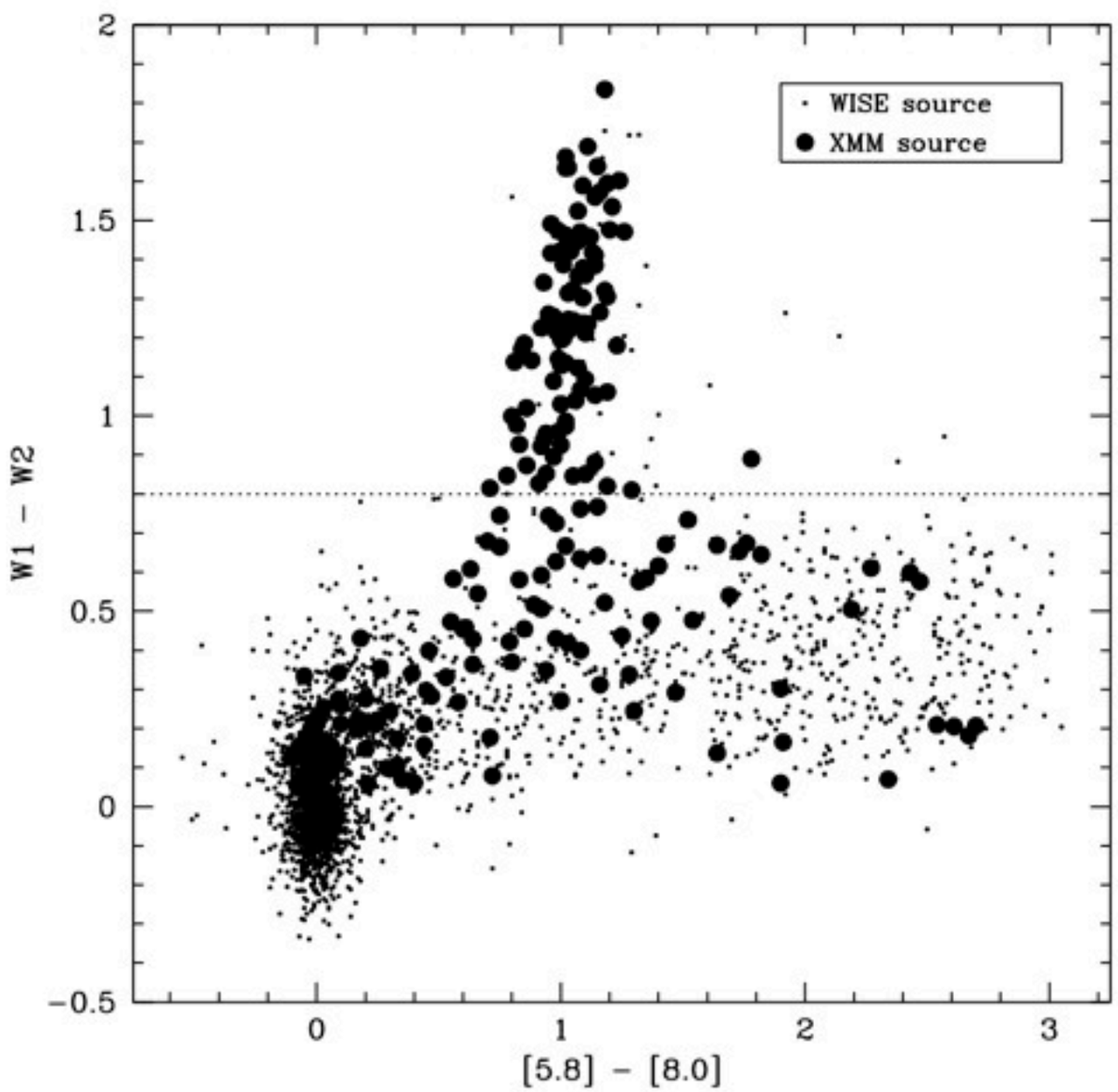
Empirical Galaxy + AGN Templates

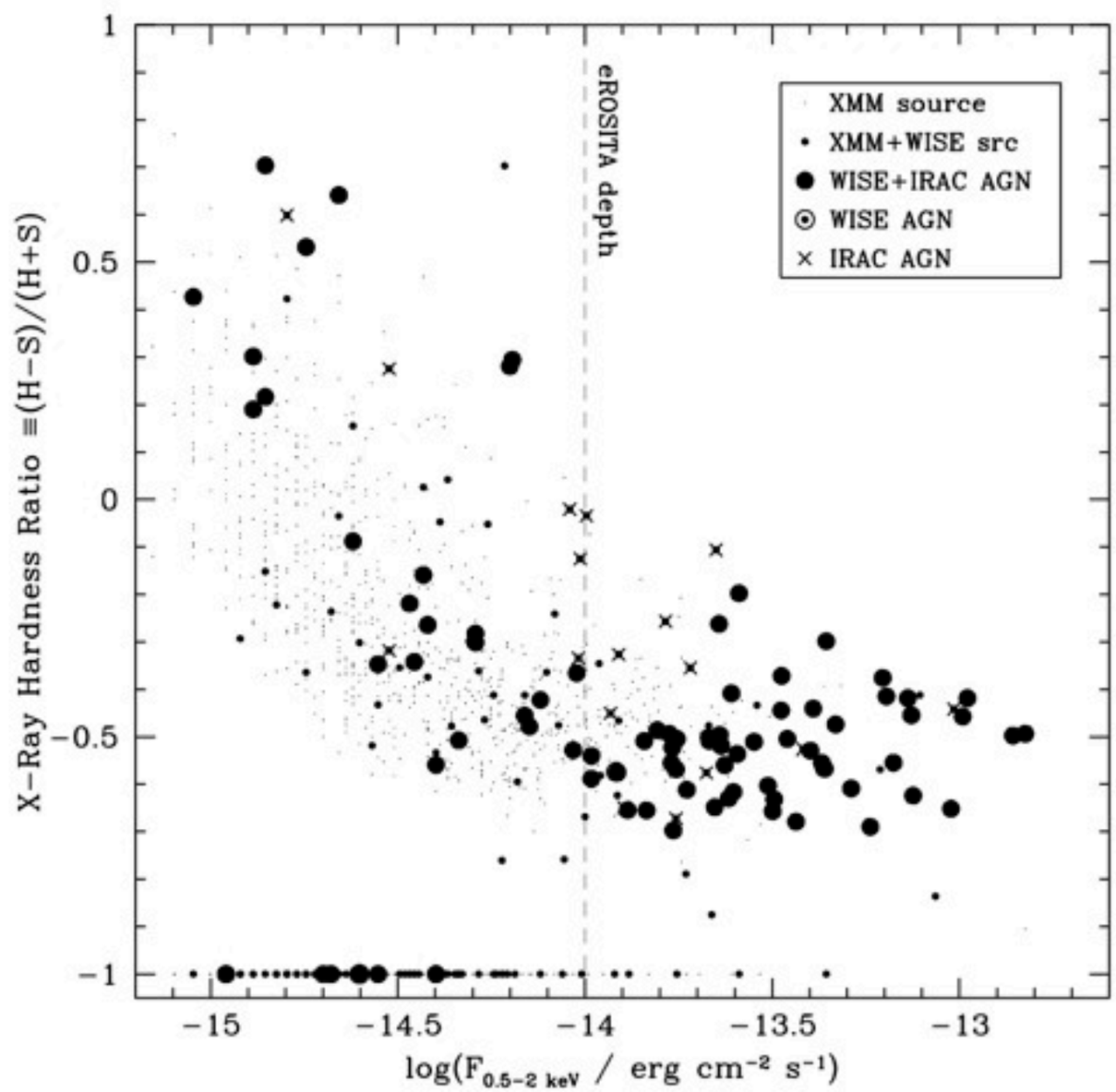
- WISE color selection not good for unobscured QSOs at z>3.5
- heavily obscured AGN more easily diluted by host galaxy
- extremely obscured AGN not detected in W1 and W2

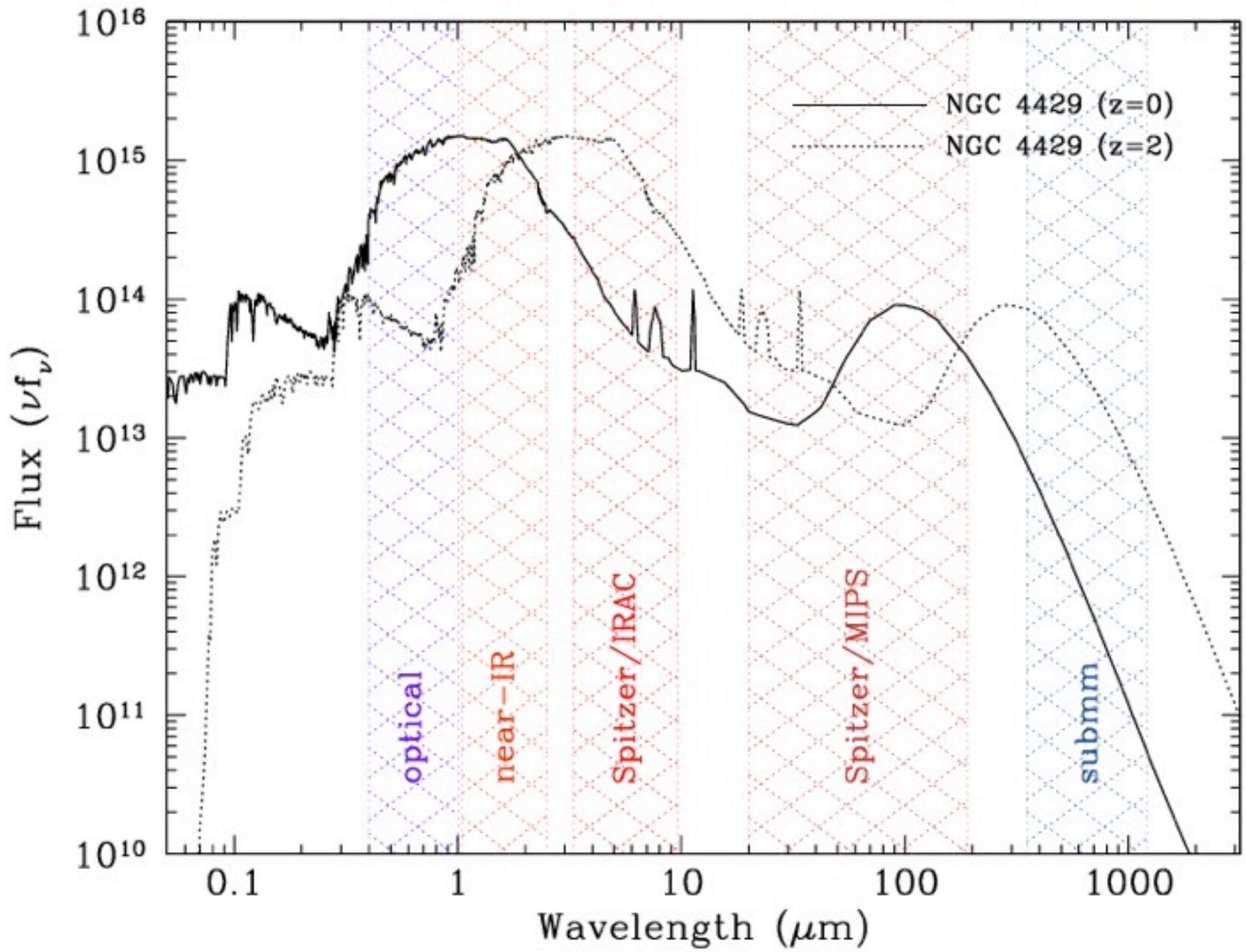
templates from Assef et al. 2010, ApJ, 713, 970

X-Ray Properties of WISE-selected AGN:

- Chandra survey of COSMOS (~100 ks over ~0.9 deg^2)
  - reaches S(0.5-2 keV) ~ $2x10^{-16}$ erg cm^{-2} s^{-1}
  - 6/47 (13%) of WISE+Spitzer AGN candidates **undetected**
- XMM-Newton survey of COSMOS (~60 ks over full ~2 deg^2)
  - reaches S(0.5-2 keV) ~ $5x10^{-16}$ erg cm^{-2} s^{-1}
  - 26/116 (22%) of WISE+Spitzer AGN candidates **undetected**







negative k-corrections in the mid-infrared!