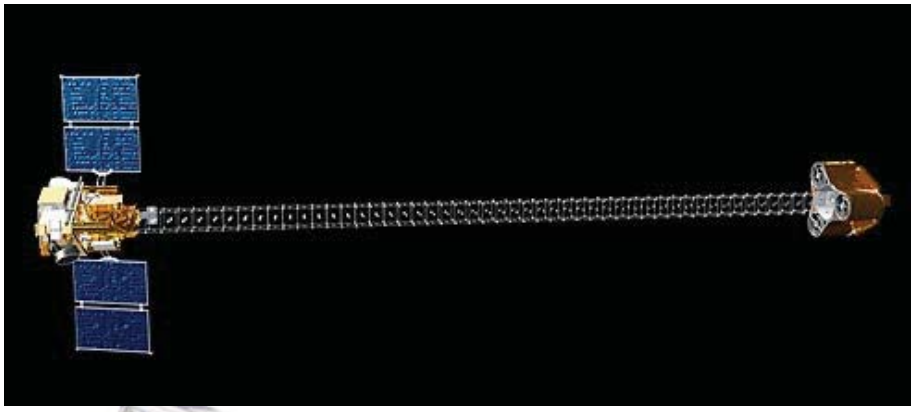
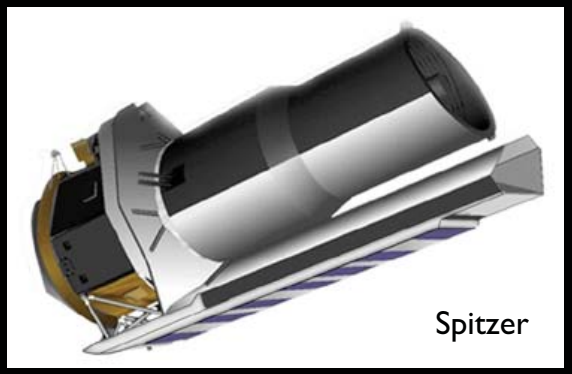
Obscured AGN at High Redshift

Daniel Stern, Project Scientist for NuSTAR
(JPL/Caltech)



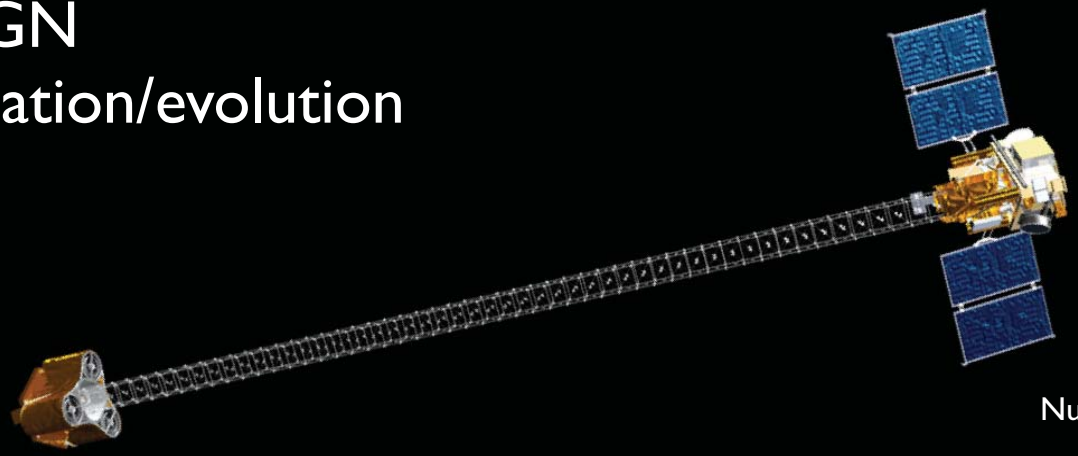
Univ. of Toronto
2008 Apr. 7



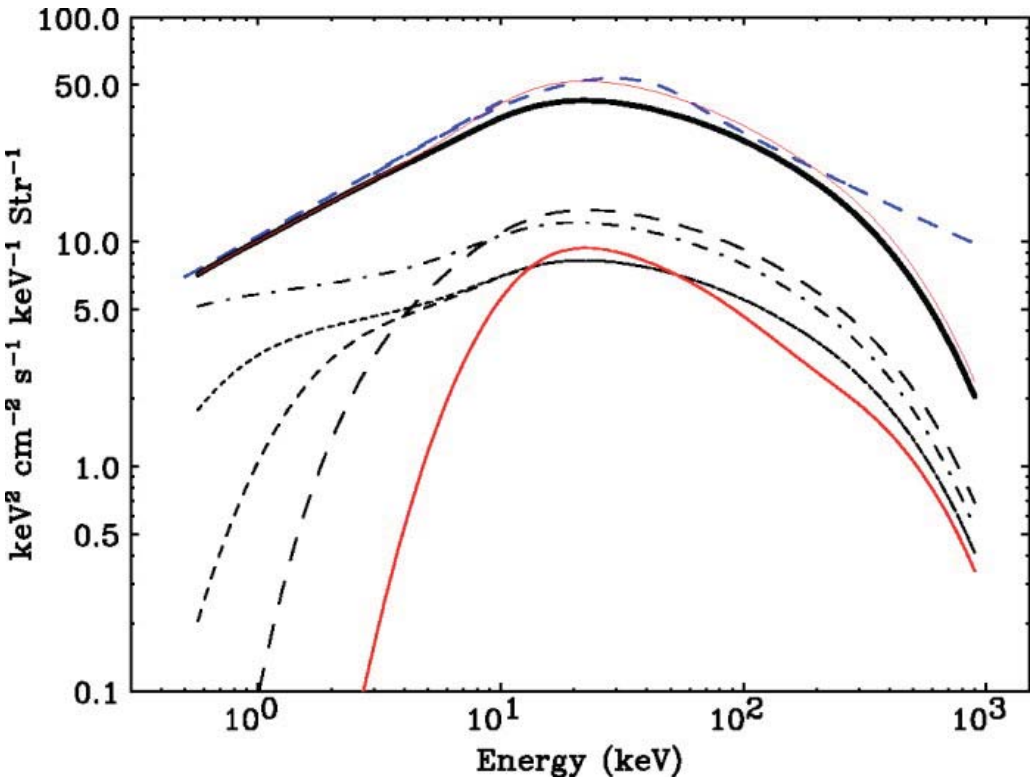
Motivation:

an unbiased census of AGN in the Universe

- cosmic X-ray background
- unified models of AGN
- clues to galaxy formation/evolution



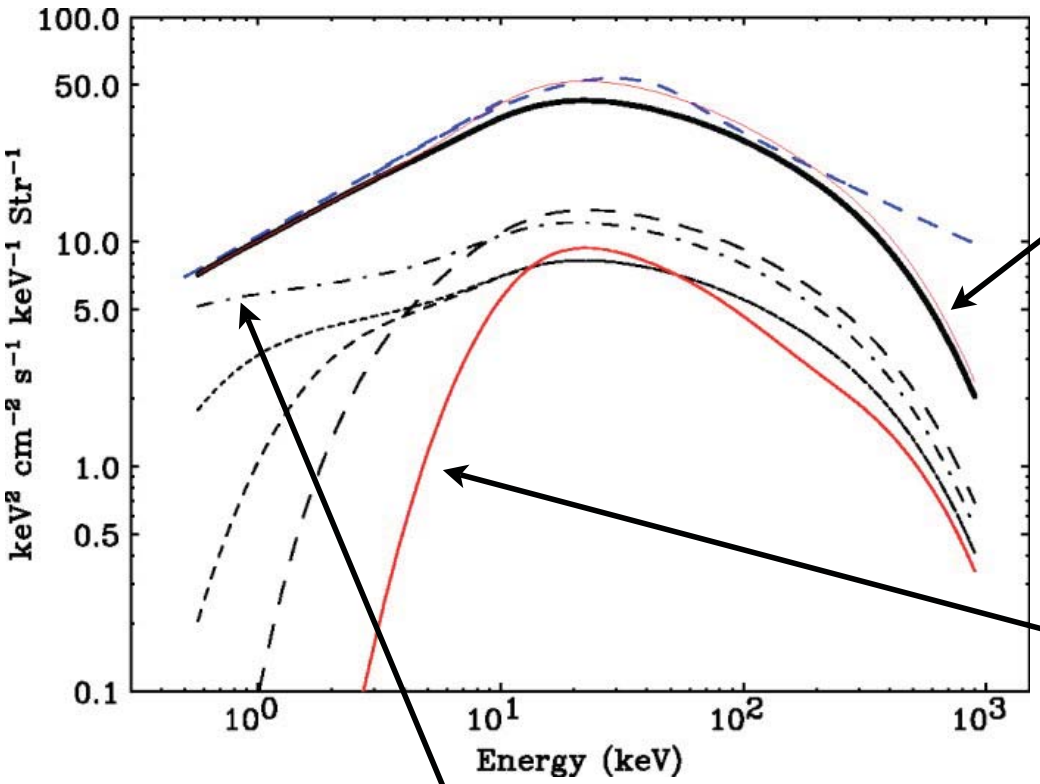
Motivation: Cosmic X-Ray Background



- peaks at ~30 keV
- constrains the accretion history of the universe, e.g., the formation history of supermassive black holes
- requires a population of heavily obscured AGN

Ueda et al. 2003, ApJ, 598, 886

Motivation: Cosmic X-Ray Background



cosmic X-ray background

heavily obscured sources

unobscured sources

Ueda et al. 2003, ApJ, 598, 886

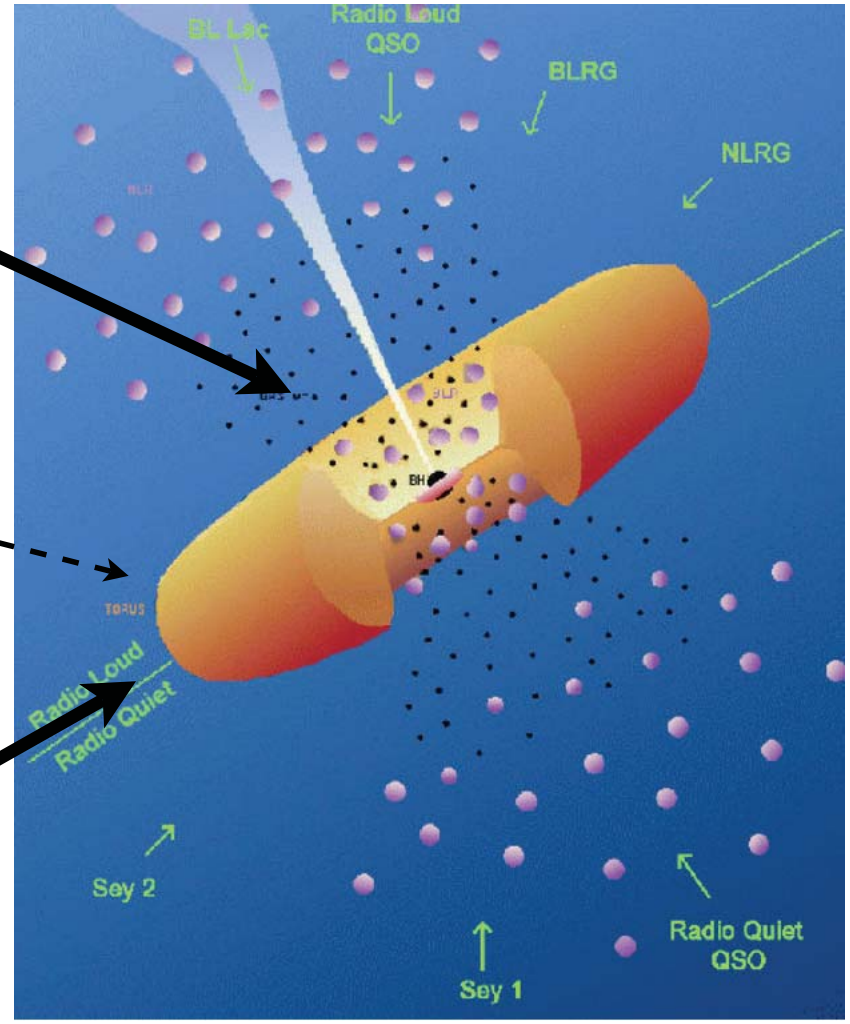
Motivation: Unified Models of AGN

Orientation Model

unobscured AGN
(type 1)

torus

obscured AGN
(type 2)

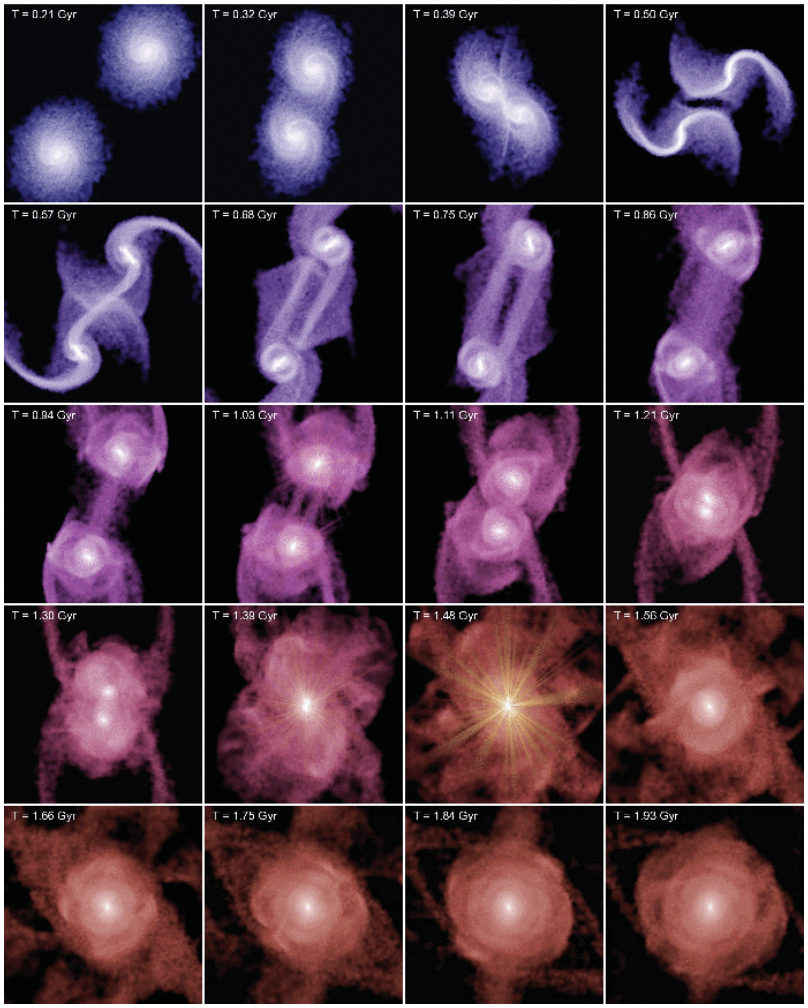


Urry & Padovani 1995, PASP, 107, 803

Motivation: Unified Models of AGN

Dynamical Model

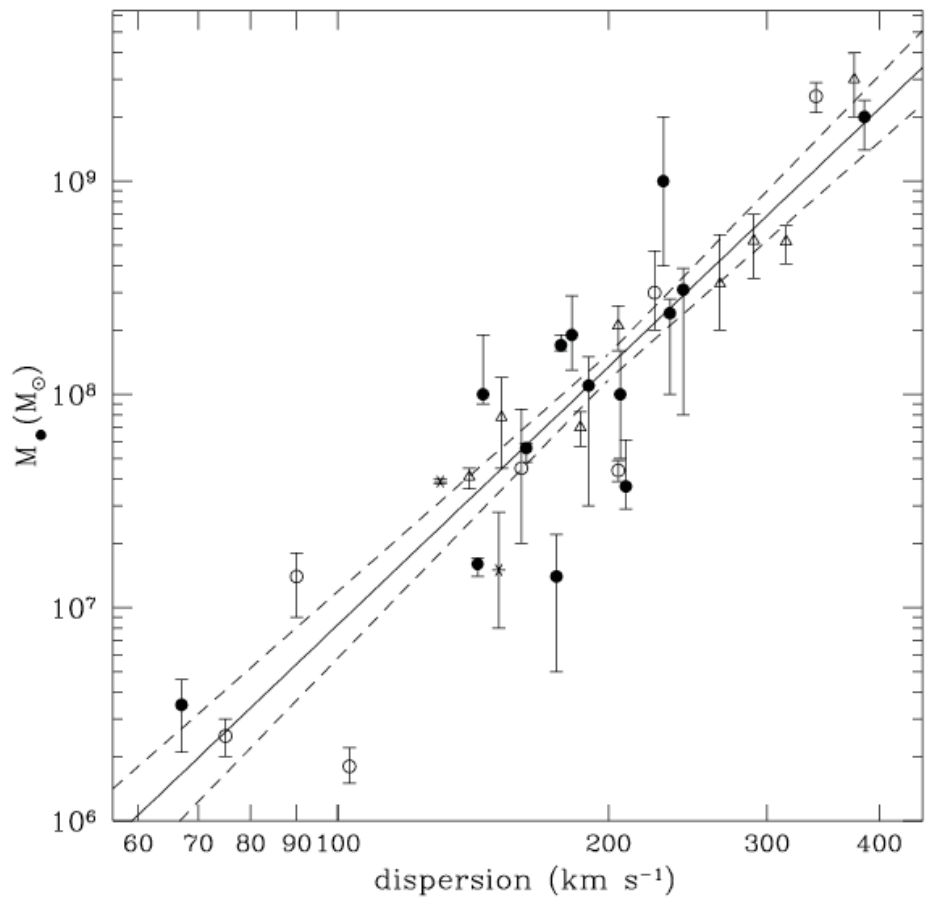
rather than **orientation**, posits **time** as the central variable which differentiates the broad zoology of AGN classifications



Hopkins et al. 2006, ApJS, 163, 1

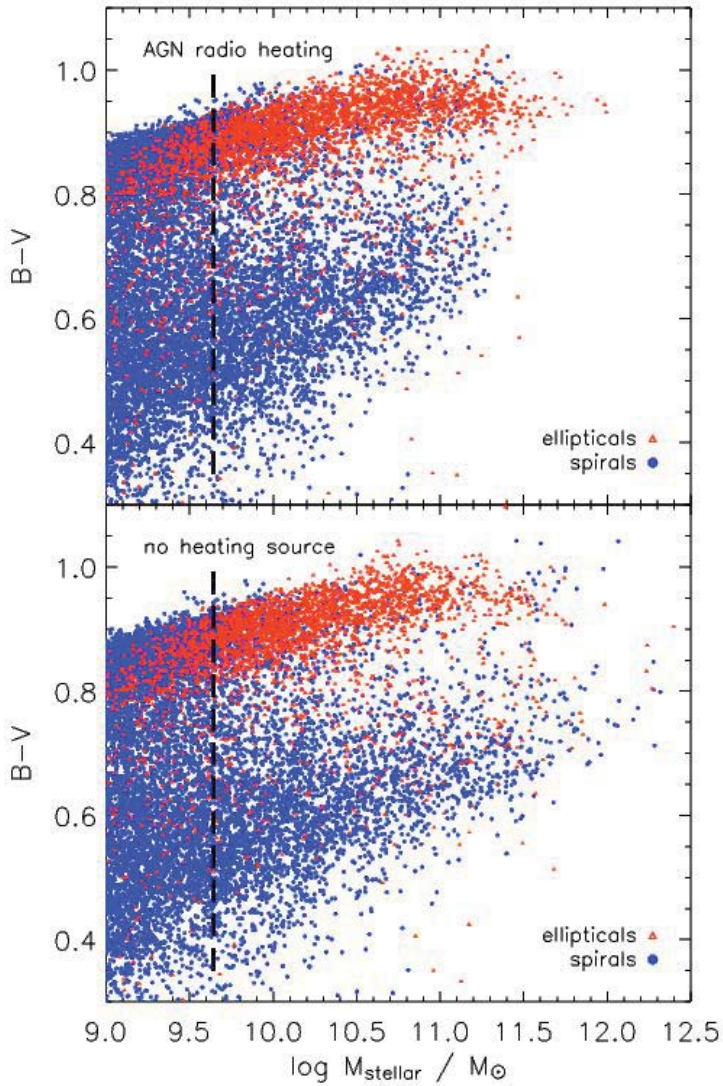
Motivation: Black Hole - Bulge Relation

- black hole mass correlates tightly with bulge velocity dispersion
- implies intimate connection between accretion-driven and fusion-driven energy production in the universe



Tremaine et al. 2002, ApJ, 574, 740

Motivation: AGN Feedback + "Downsizing"



- AGN feedback can quench star formation in massive galaxies
- models have it explaining the lack of massive blue galaxies, bimodality, downsizing, etc...

Croton et al. 2006, MNRAS, 365, 11

Big Questions:

- What and where are the obscured sources which are needed to explain the X-ray background?
- What is causing their obscuration?
- How does this relate to galaxy formation & evolution?

The Most Distant Obscured Quasar

THE ASTROPHYSICAL JOURNAL

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TYPE 2 QSO

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GYULA SZOKOLY,[3] PAOLO TOZZI,[7] JUNXIAN WANG,[1] WEI ZHENG,[1] ANDREW ZIRM,[1]
JACQUELINE BERGERON,[8] ROBERTO GILMOZZI,[8] NORMAN GROGIN,[2]
ANTON KOEKEMOER,[2] AND ETHAN SCHREIER[2]

Received 2001 February 21; accepted 2002 January 25

ABSTRACT

In the Chandra Deep Field–South 1 Ms exposure, we have found, at redshift 3.700 ± 0.005, the most distant type 2 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 $3\,\sigma$ 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 $\sim$700–2300 km s^{-1} with an average of approximately $\sim$1500 km s^{-1}. The emitting gas is metal-rich ($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 $\sim$6.4 keV and $\sim$1 keV, respectively, in agreement with the obscuration scenario, is detected at a $2\,\sigma$ 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

The Most Distant Obscured Quasar

THE ASTROPHYSICAL JOURNAL, 518:L61–L64, 1999 June 20
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A RADIO GALAXY AT $z = 5.19$[1]

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HUUB RÖTTGERING,[3] AND GEORGE MILEY[3]
Received 1999 March 11; accepted 1999 April 19; published 1999 May 5

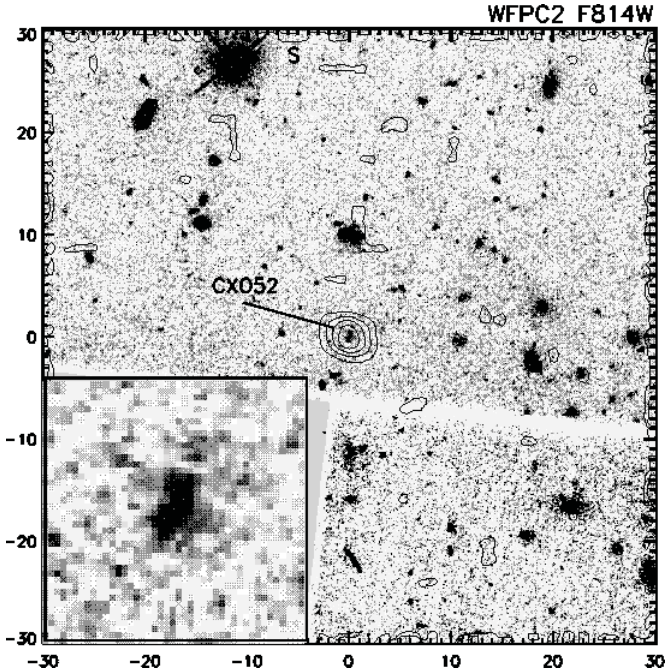
ABSTRACT

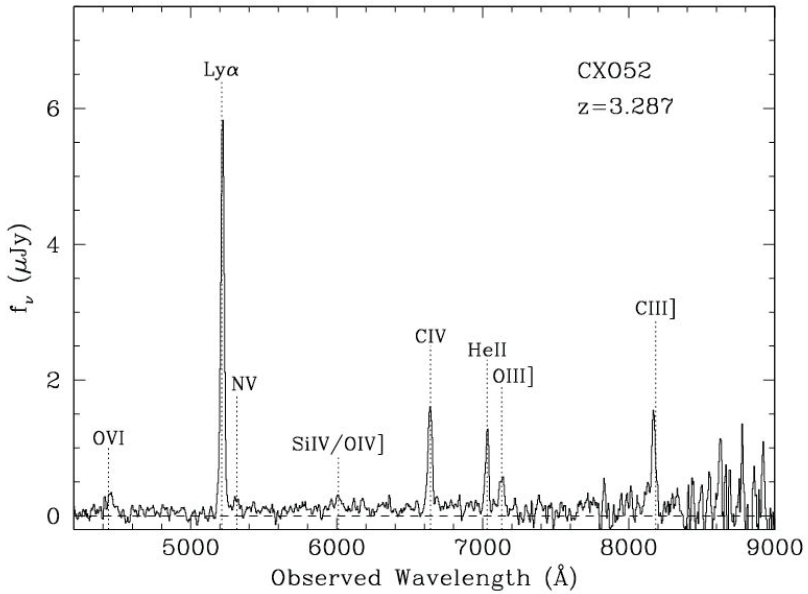
We report the discovery of the most distant known active galactic nucleus, the radio galaxy TN J0924−2201 at $z = 5.19$. The radio source was selected from a new sample of ultrasteep spectrum sources, has an extreme radio spectral index $\alpha_{365\,\mathrm{MHz}}^{1.4\,\mathrm{GHz}} = -1.63$, and is 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)

Identifying Obscured AGN at High Redshift

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





Stern et al. 2002, AJ, 123, 2223

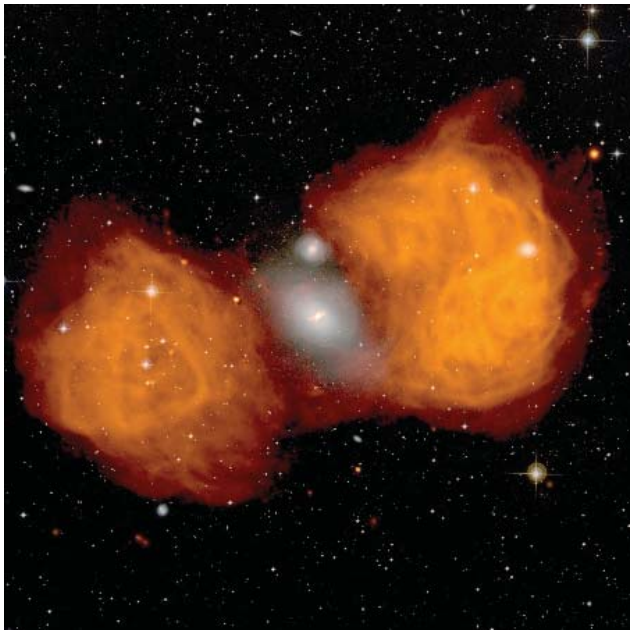
Radio Selection of (Obscured) AGN

Advantages:

- low frequencies are isotropic
- radio provides extra information
  - AGN lifetimes (~10^7 - 10^8 yr)
  - duty cycle (e.g., "double doubles")
  - jet axis stability

Disadvantages:

- only seeing ~10% of AGN



Fornax A

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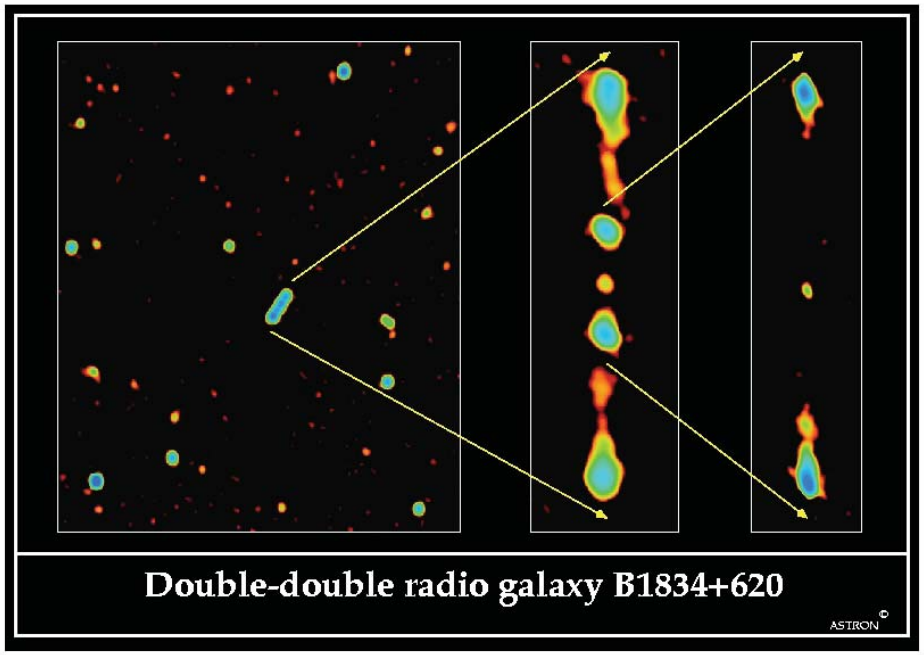


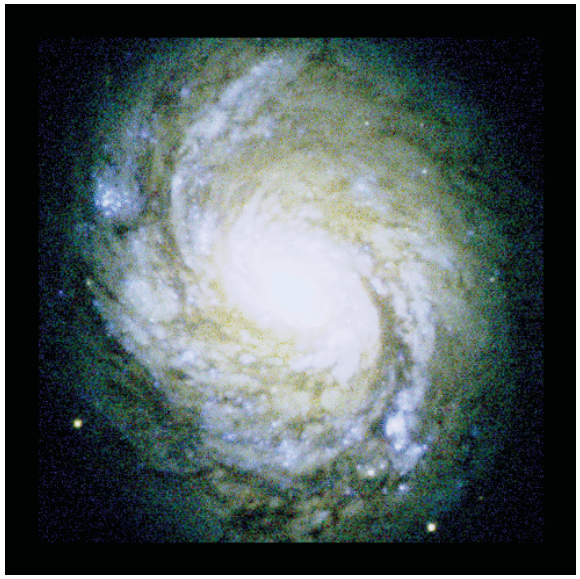
X-Ray Selection of (Obscured) AGN

Advantages:

- hard X-rays are isotropic
- probing XRB directly
- even low activity levels have high contrast over stellar X-ray emission

Disadvantages:

- Chandra & XMM don't probe the hard X-rays
- Compton thick AGN missed at even moderate redshifts (Ms w/ Chandra only detects NGC 1068 to z=0.4)



Optical Selection of (Obscured) AGN

Advantages:

- (optical) spectroscopy potentially very robust

Disadvantages:

- (optical) spectroscopy potentially very fickle:
  - extinction
  - dilution from host galaxy light

Mid-IR Selection of (Obscured) AGN

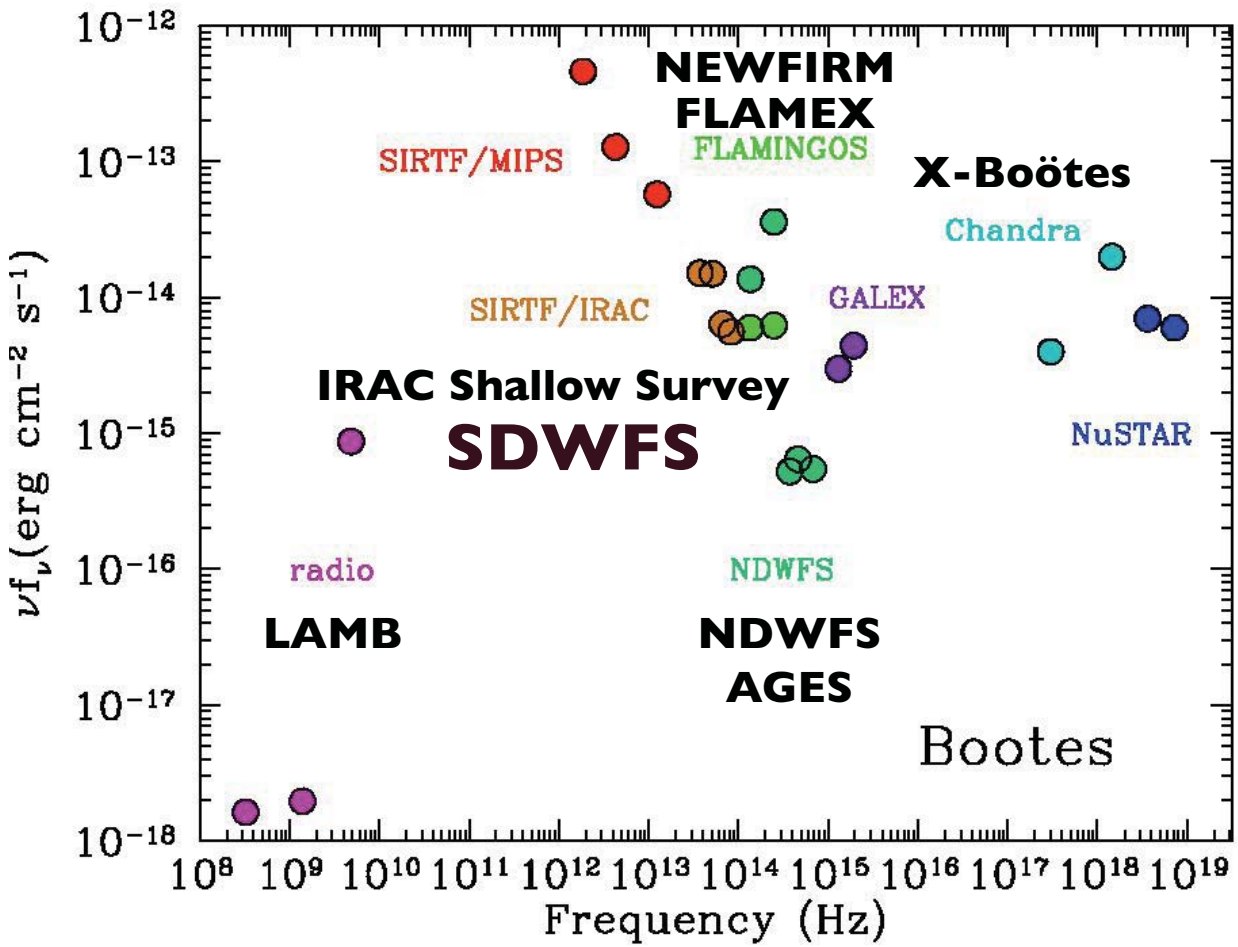
Advantages:

- mid-IR emission is isotropic
- identifies all luminous AGN
- sensitive to even Compton thick AGN
- Spitzer is very efficient at mapping large areas deeply

Disadvantages:

- insensitive to low-luminosity AGN

The Boötes Field

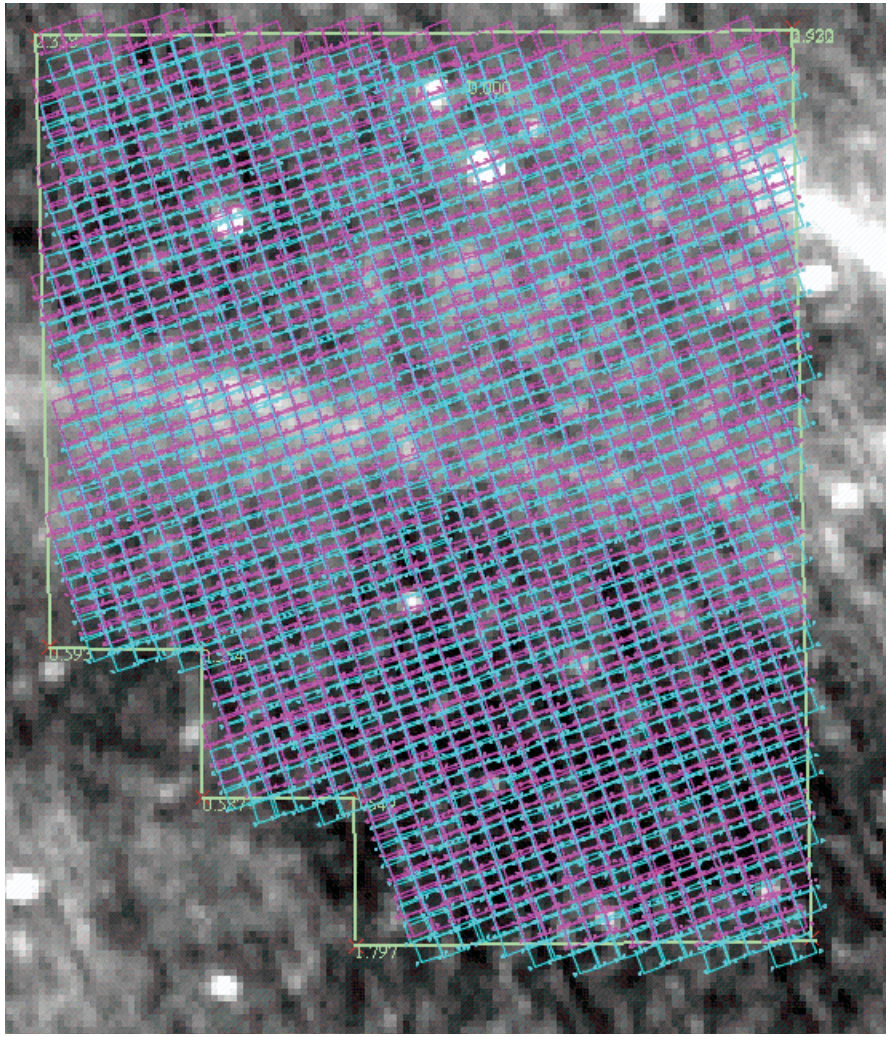


The IRAC Shallow Survey

AKA "Epoch 1 of SDWFS"

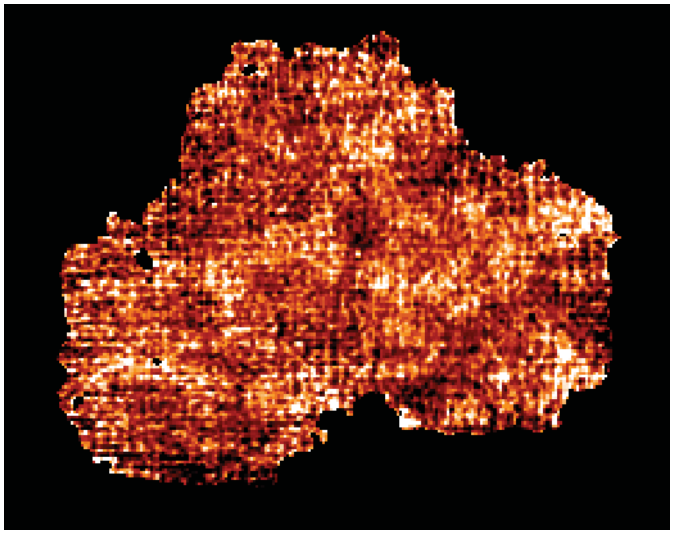
- 8.5 square degrees in NDWFS Boötes field
- 60 hours of observatory time, obtained 2004 January 10-14
- 90 seconds/position
- 18,000 images
- reaches depths of 6.4-50 microJy at 3.6-8.0 microns

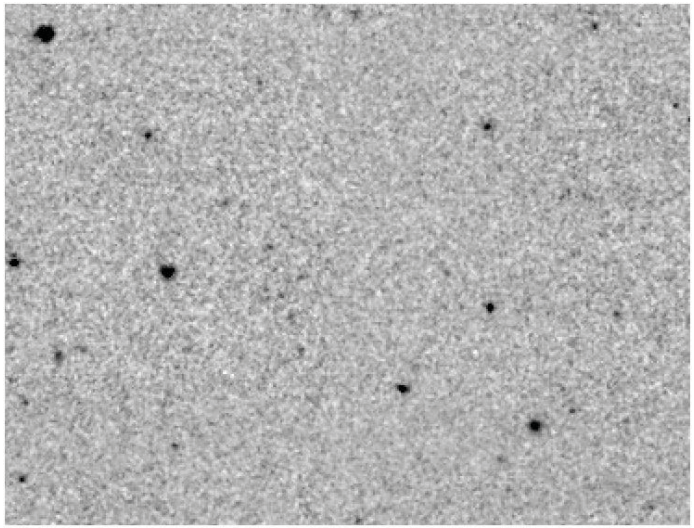
- SDWFS: 3 more epochs being obtained between August 2007 and March 2008

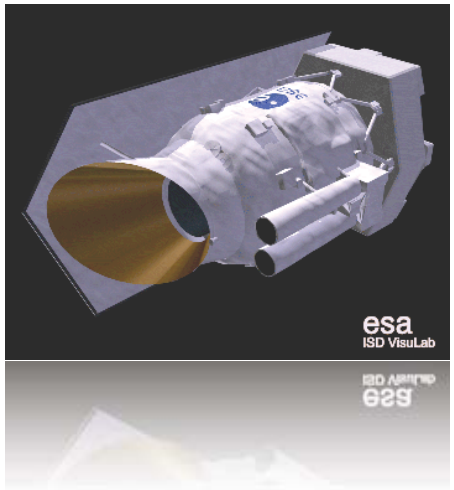


Eisenhardt, Stern et al. 2004, ApJS, 154, 44

ISO vs. Spitzer



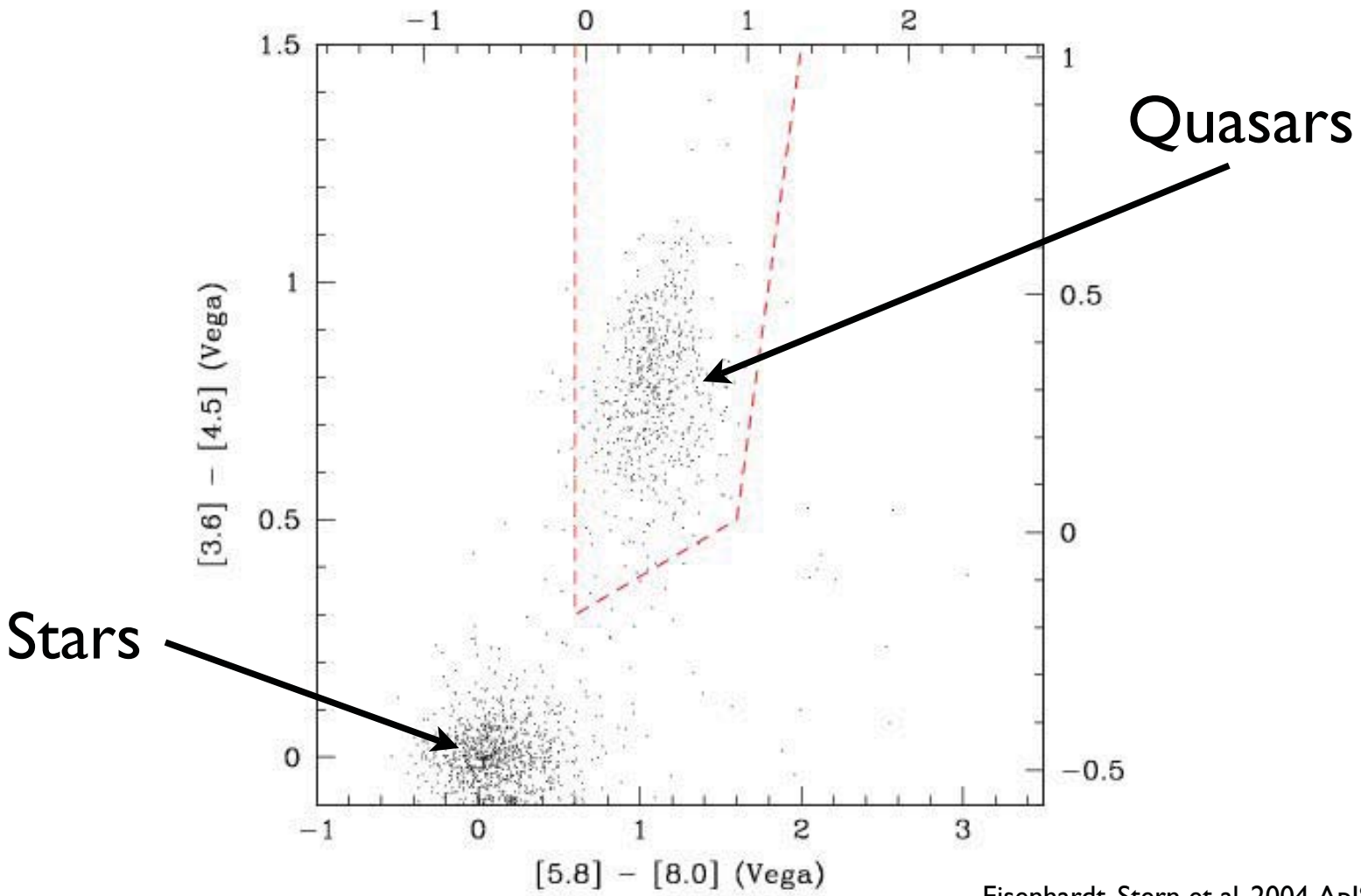




7 microns
reaches ~30 μJy
~15 hr

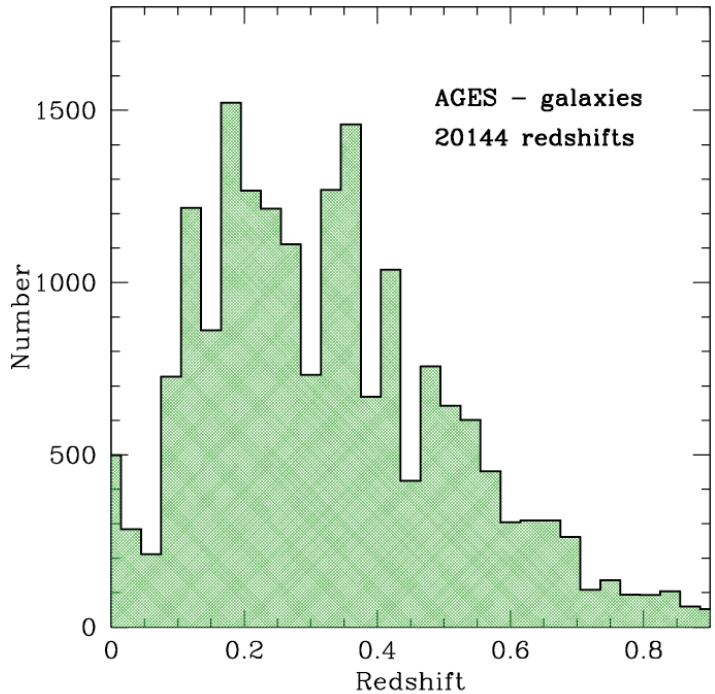
8 microns
reaches ~30 μJy
90 s

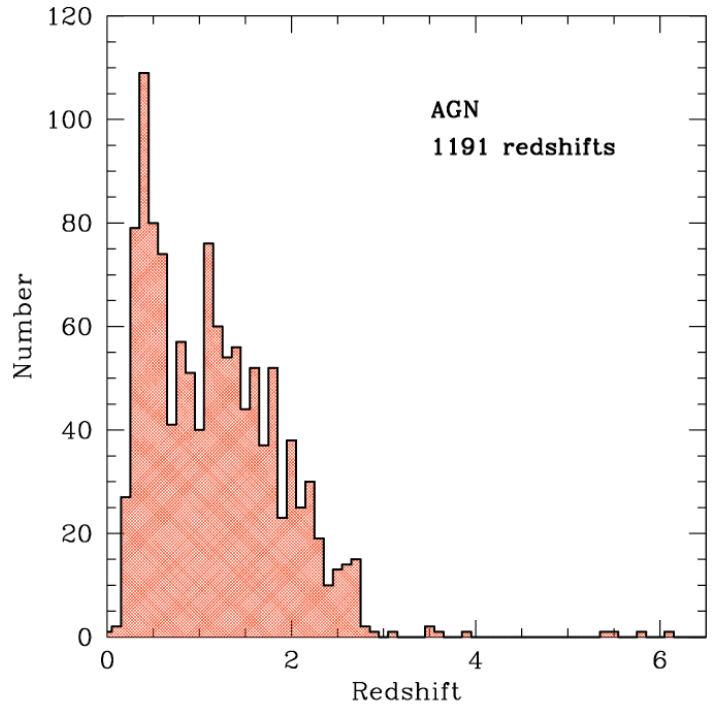
Mid-IR Colors of Point Sources



Eisenhardt, Stern et al. 2004, ApJS, 154, 44

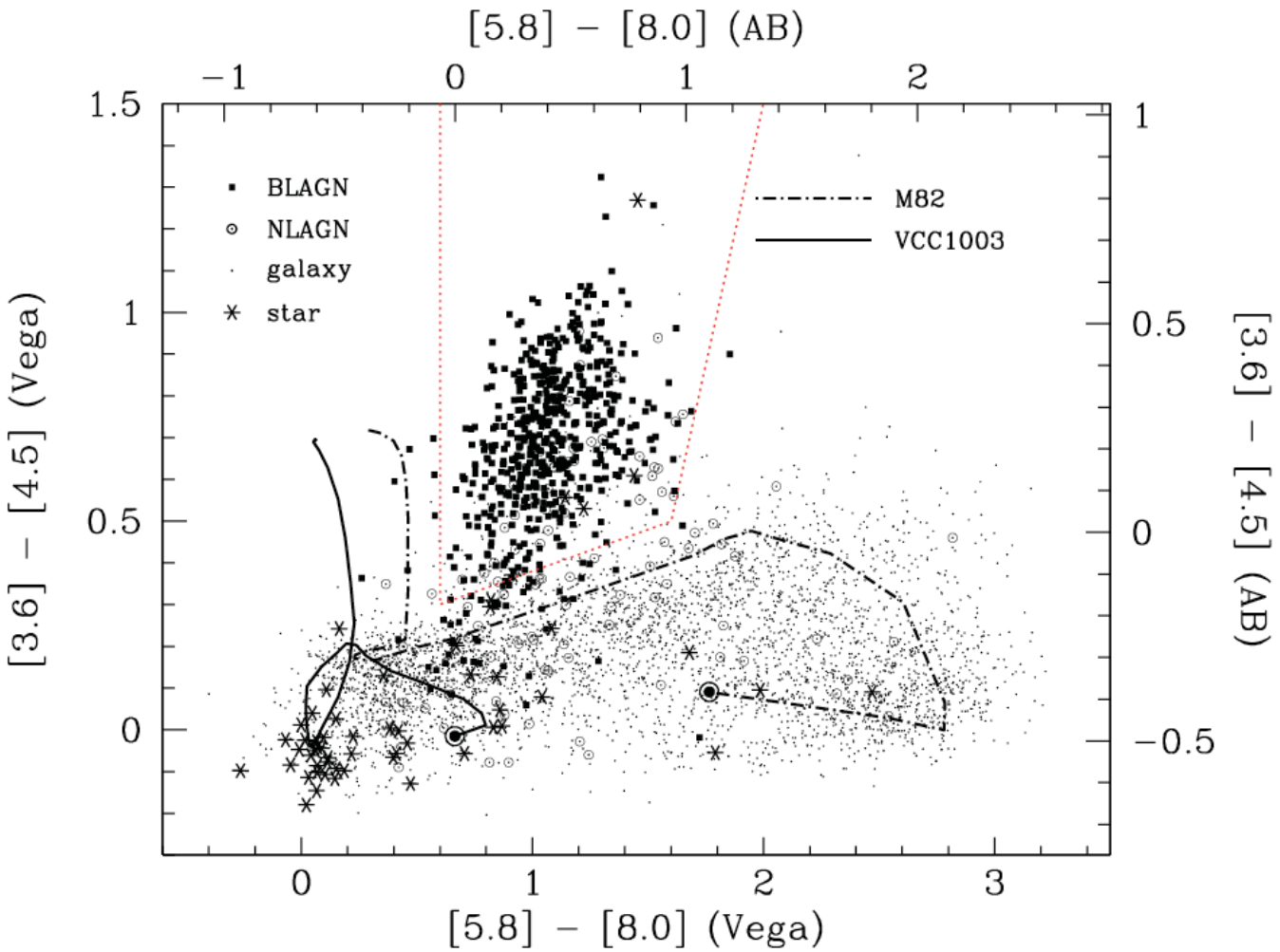
AGES: AGN & Galaxy Evolution Survey



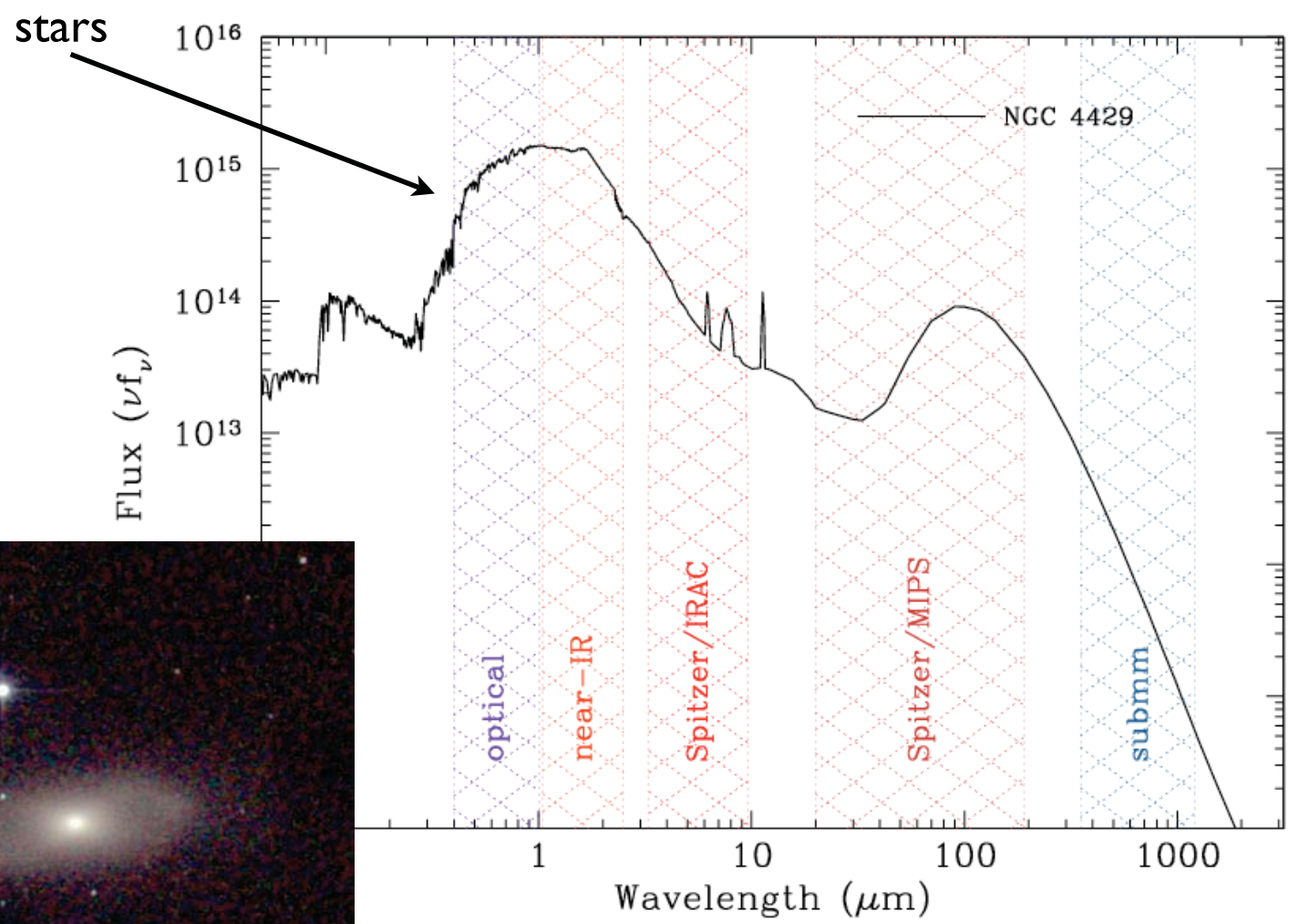


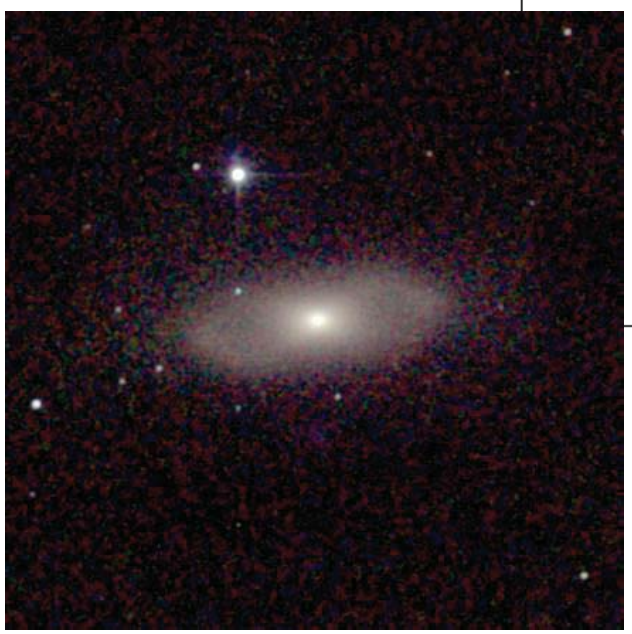
- AGES 1& 2 (PI's Kochanek & Eisenstein) has >20,000 spectroscopic redshifts in the Bootes field, mostly R<20.5 using Hectospec at MMT
- additional programs add another ~2000 redshifts (mostly Keck)
- AGES 3 (PI's Kochanek, Murray & Stern) goes fainter; data almost fully processed

Mid-IR Colors of AGES Sources



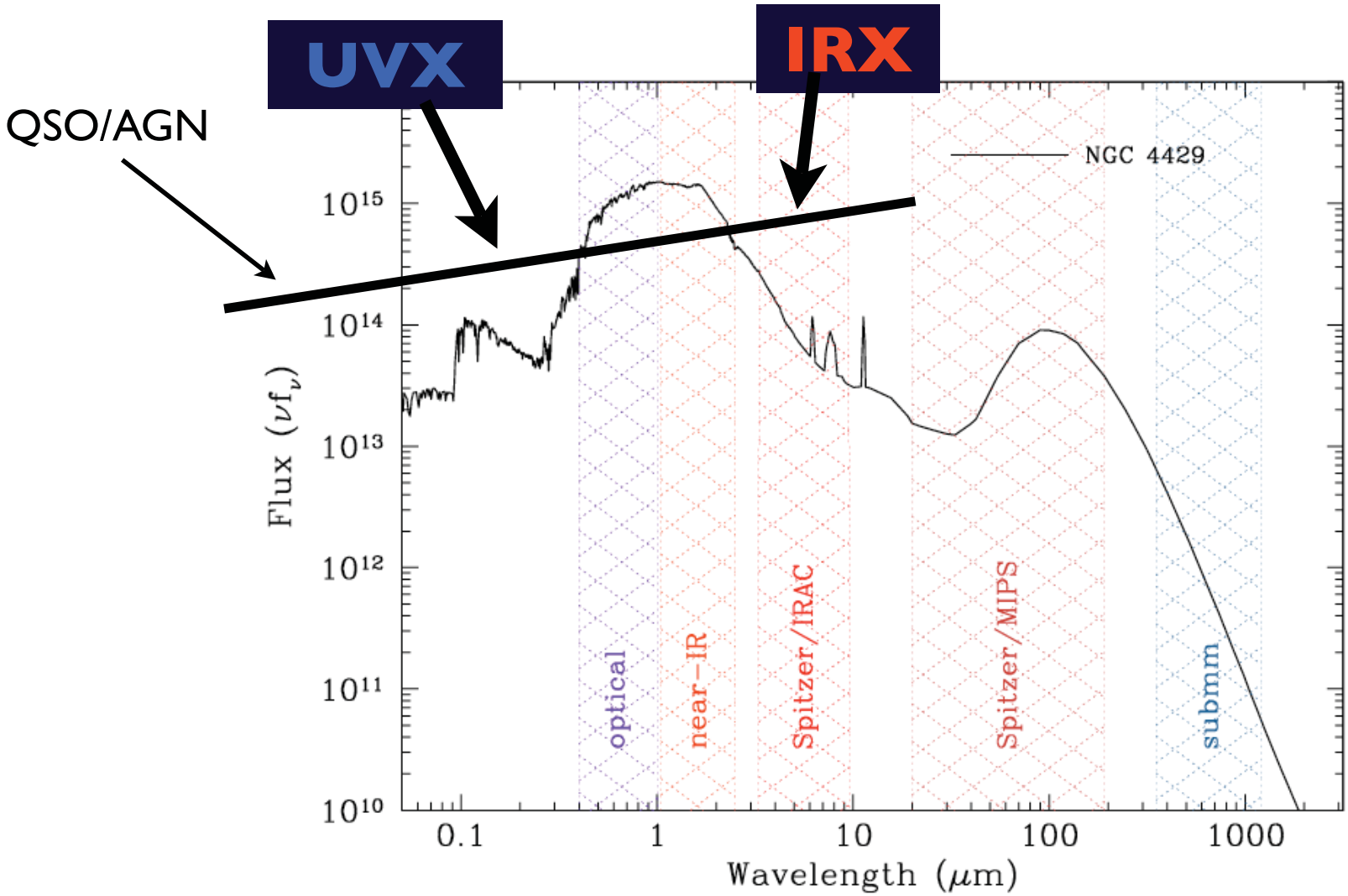
Stern et al. 2005, ApJ, 631, 163



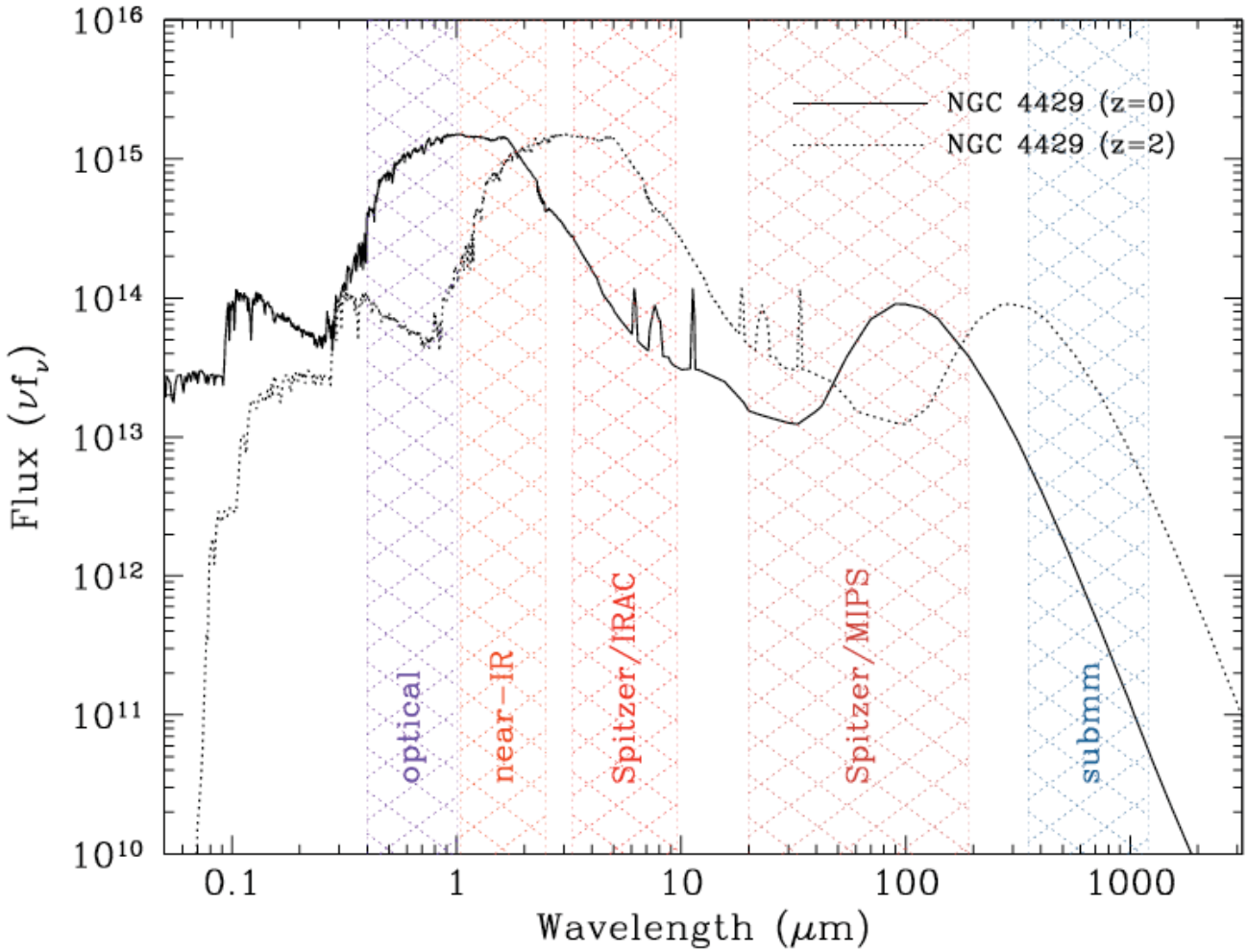


NGC 4429 (SA in Virgo)

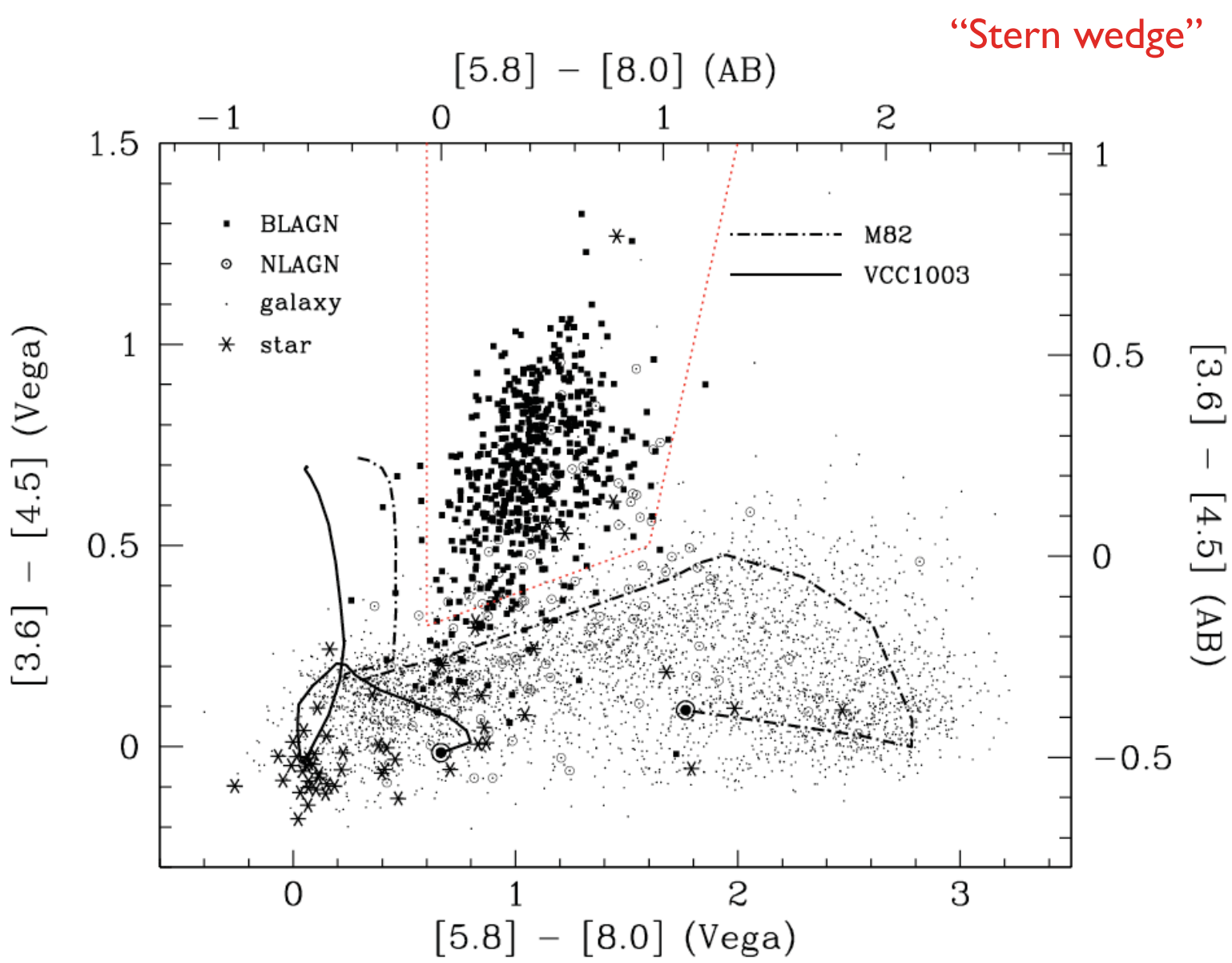
stellar emission:
dominated by sum of blackbody spectra



quasar/AGN emission:
dominated by a power-law

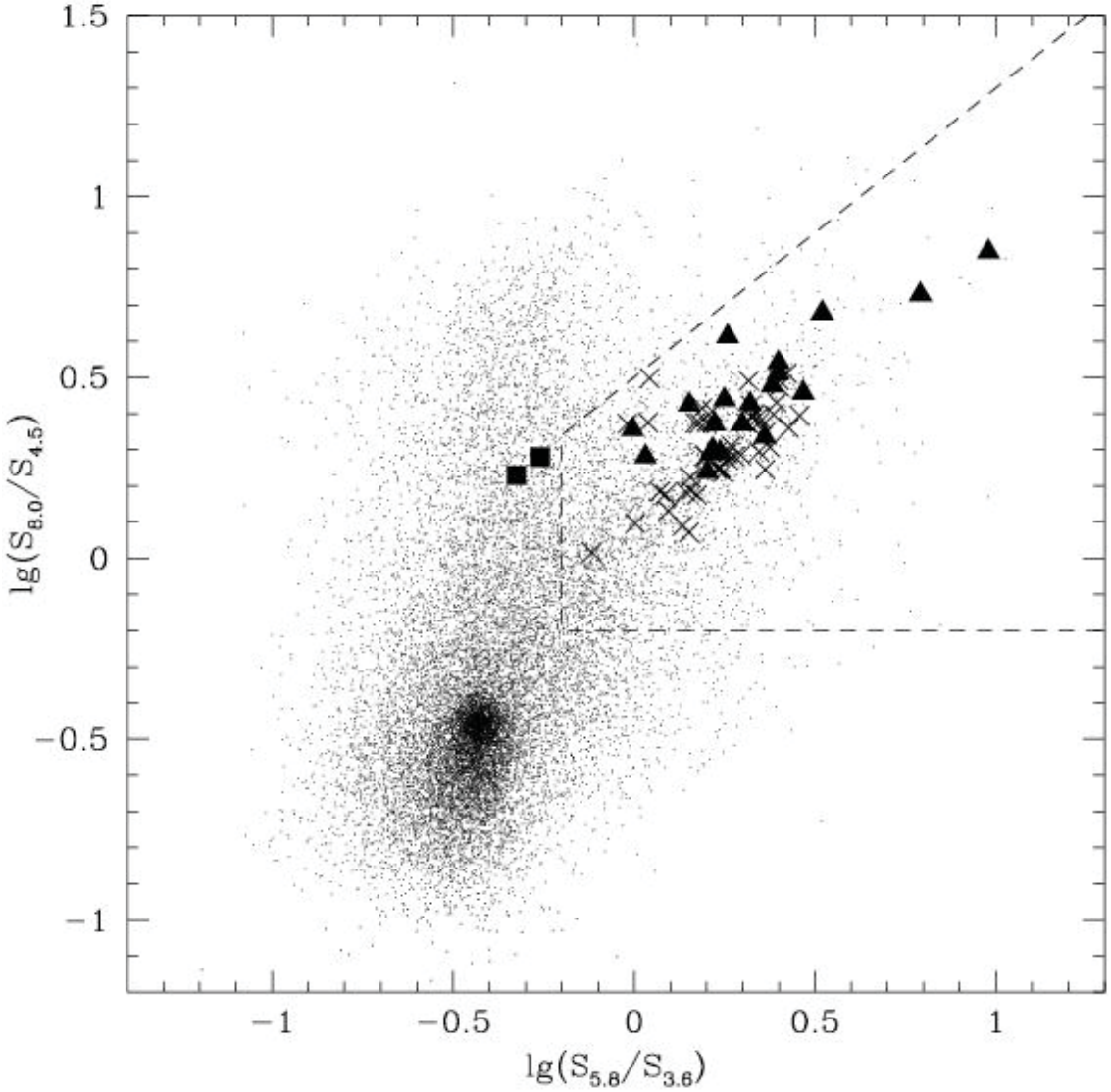


negative k-corrections in the IRAC bands!

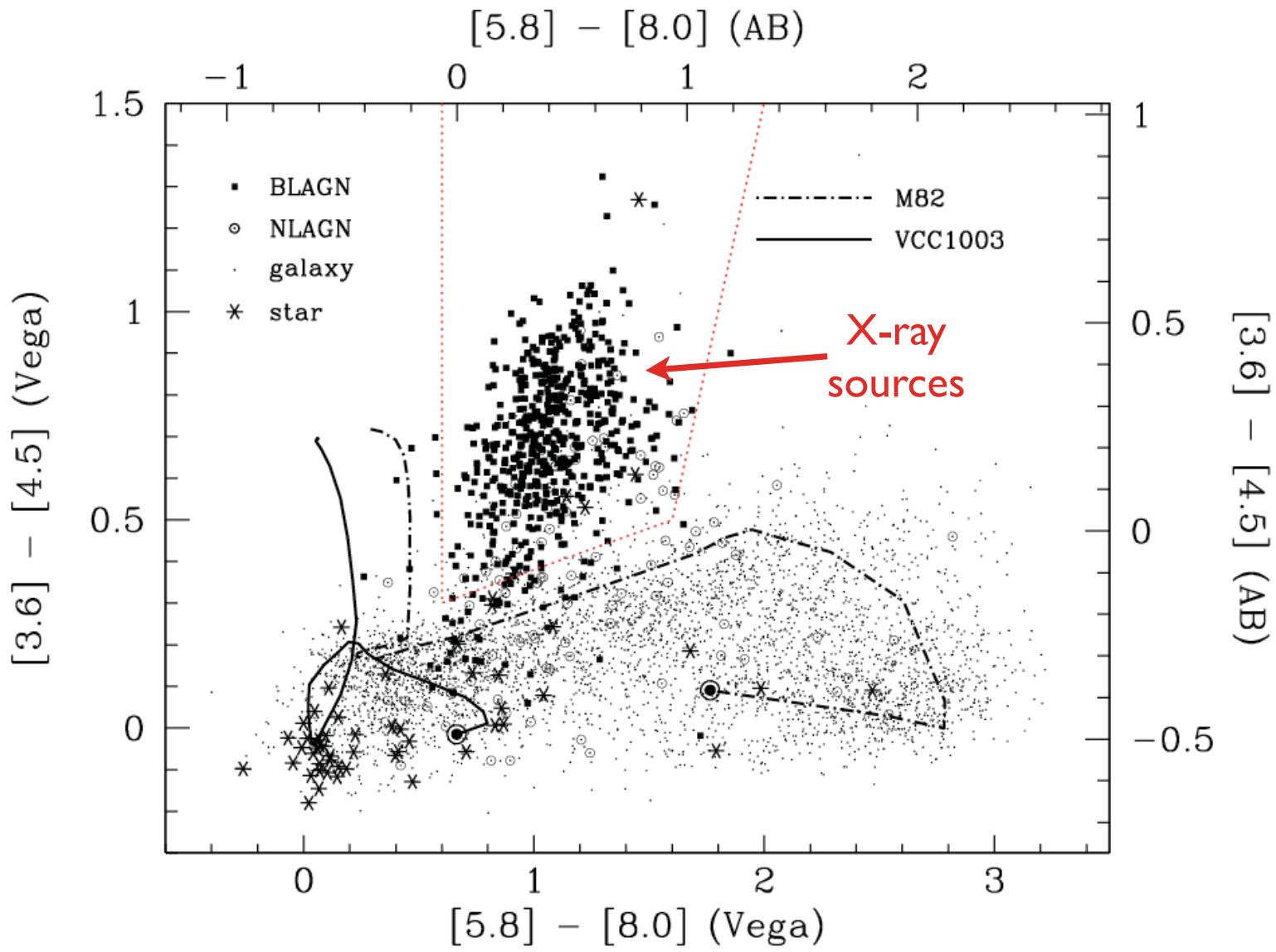


Stern et al. 2005, ApJ, 631, 163

"Lacy wedge"



Lacy et al. 2004, ApJS, 154, 166



Gorjian et al., ApJ, in press

Mid-IR AGN Selection: Robust & Complete

681 sources in the AGN wedge with spectra (circa 2005):

522 (77%) broad-lined AGN
40 (6%) narrow-lined AGN
113 (17%) "normal" galaxies
6 (1%) stars

→ little contamination

576 broad-lined AGN with 4-band IRAC colors in AGES (c. 2005):

522 (91%) selected by IRAC wedge
~85% X-ray sources
~45% MIPS 24 micron sources

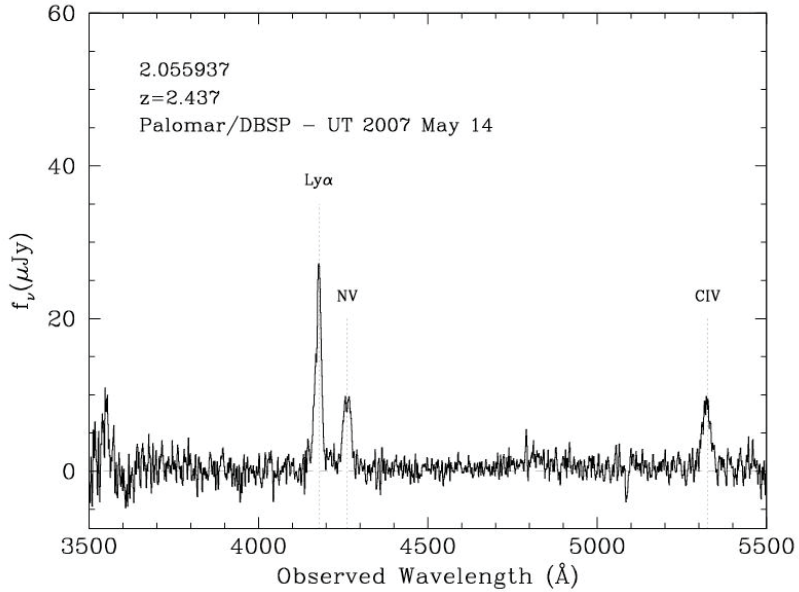
→ highly complete
(for unobscured/luminous AGN)

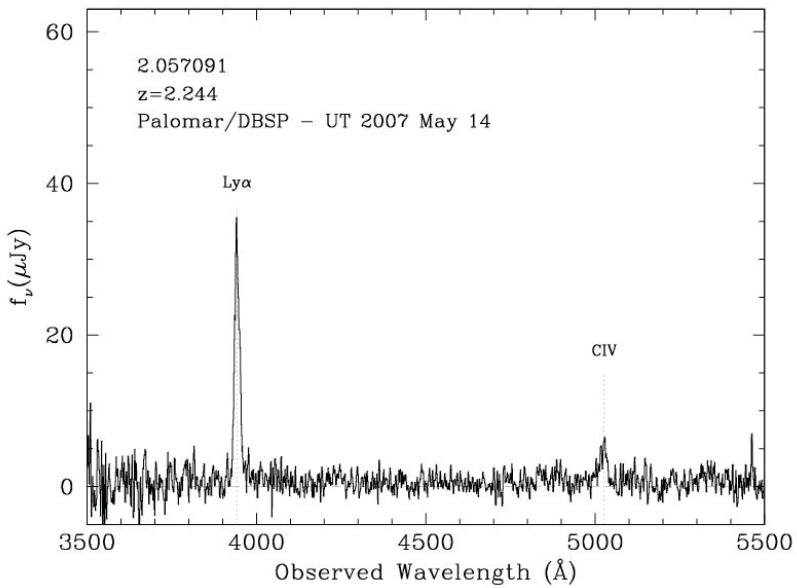
Mid-IR AGN Selection: Demographics

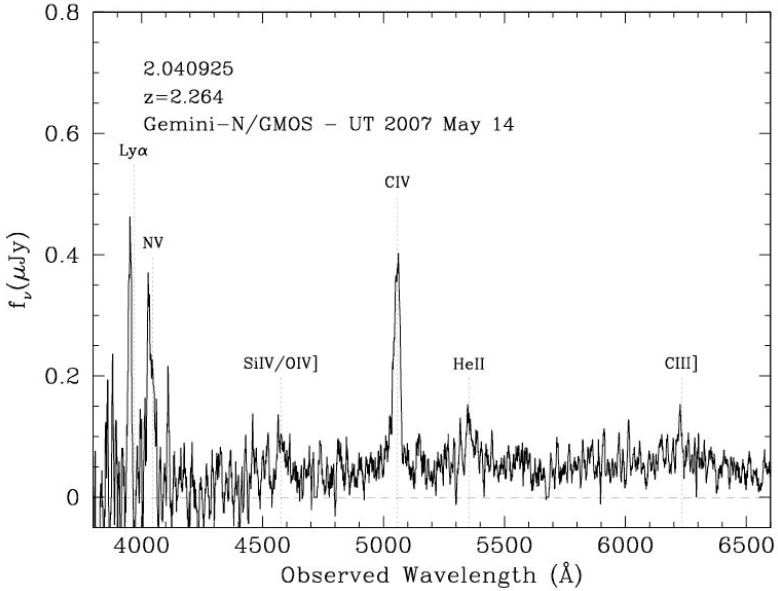
- 8 μm depth, for typical quasar SED, corresponds to R~21.5
- COMBO-17 QLF finds ~65 quasars per sq.deg to R=21.5 (Wolf et al. 2003)

IRAC Shallow Survey finds ~275 AGN per sq. deg.

Type 2:Type 1 ratio is ~3:1

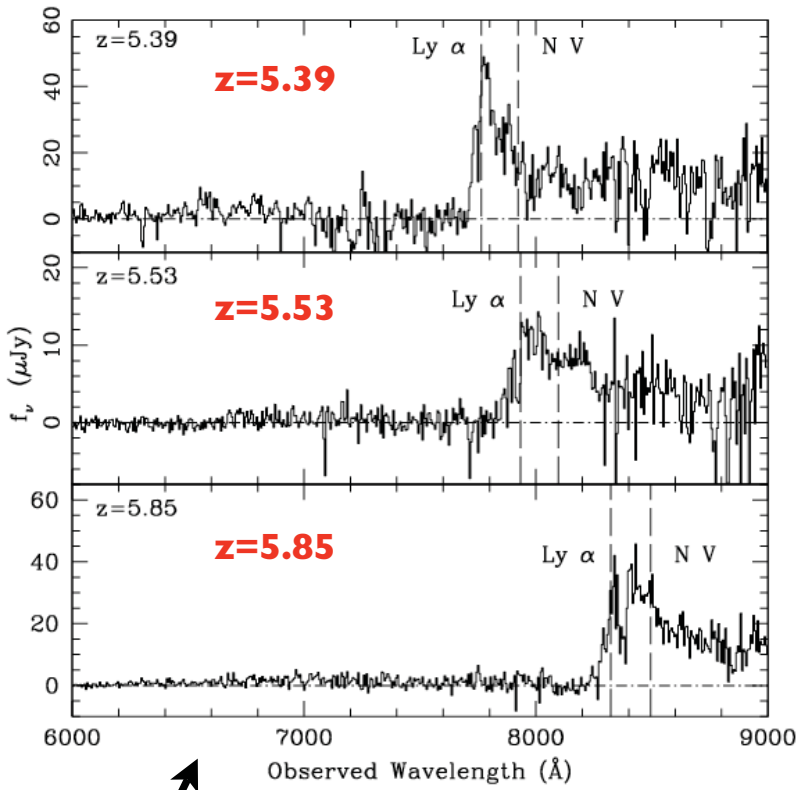






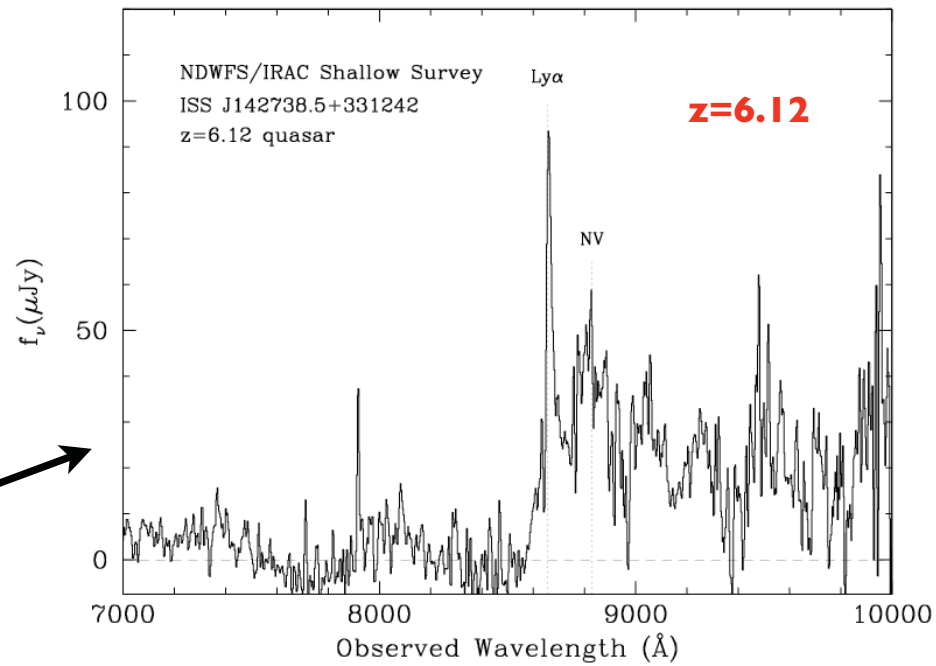
Radio Quiet Radio Galaxies

Boötes High Redshift Quasars



selected using mid-IR criteria

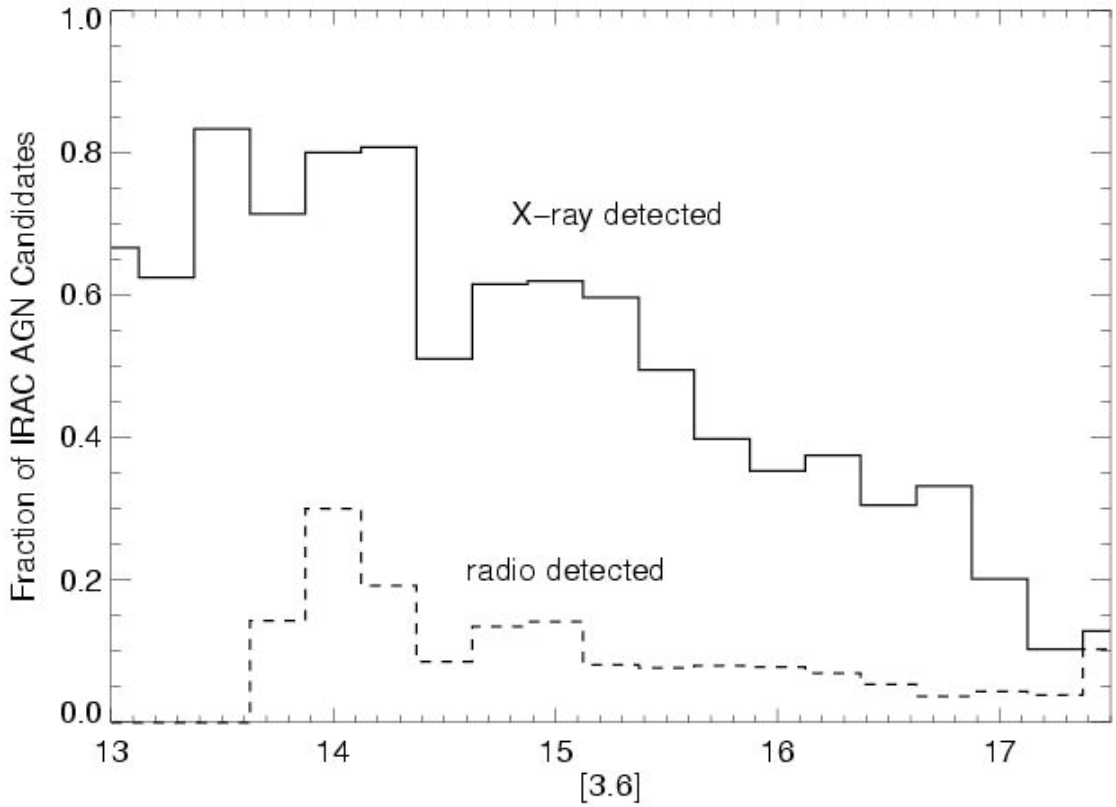
highest redshift radio source



Cool et al. 2006, AJ, 132, 823

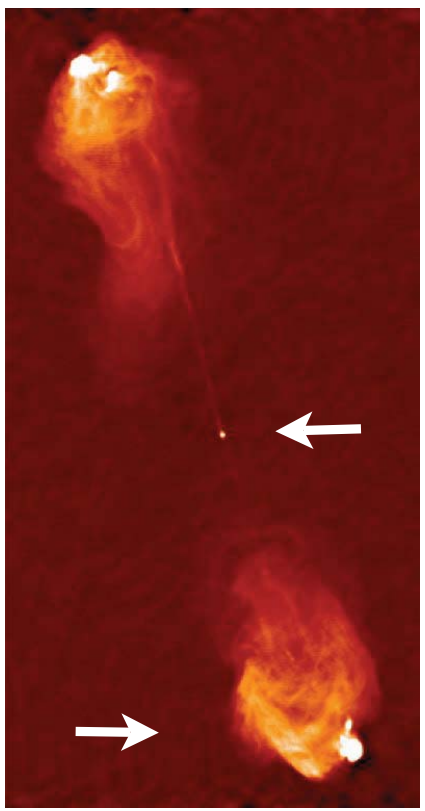
Stern et al. 2007, ApJ, 633, 677

Fraction of IRAC AGN Detected in the Radio and X-ray

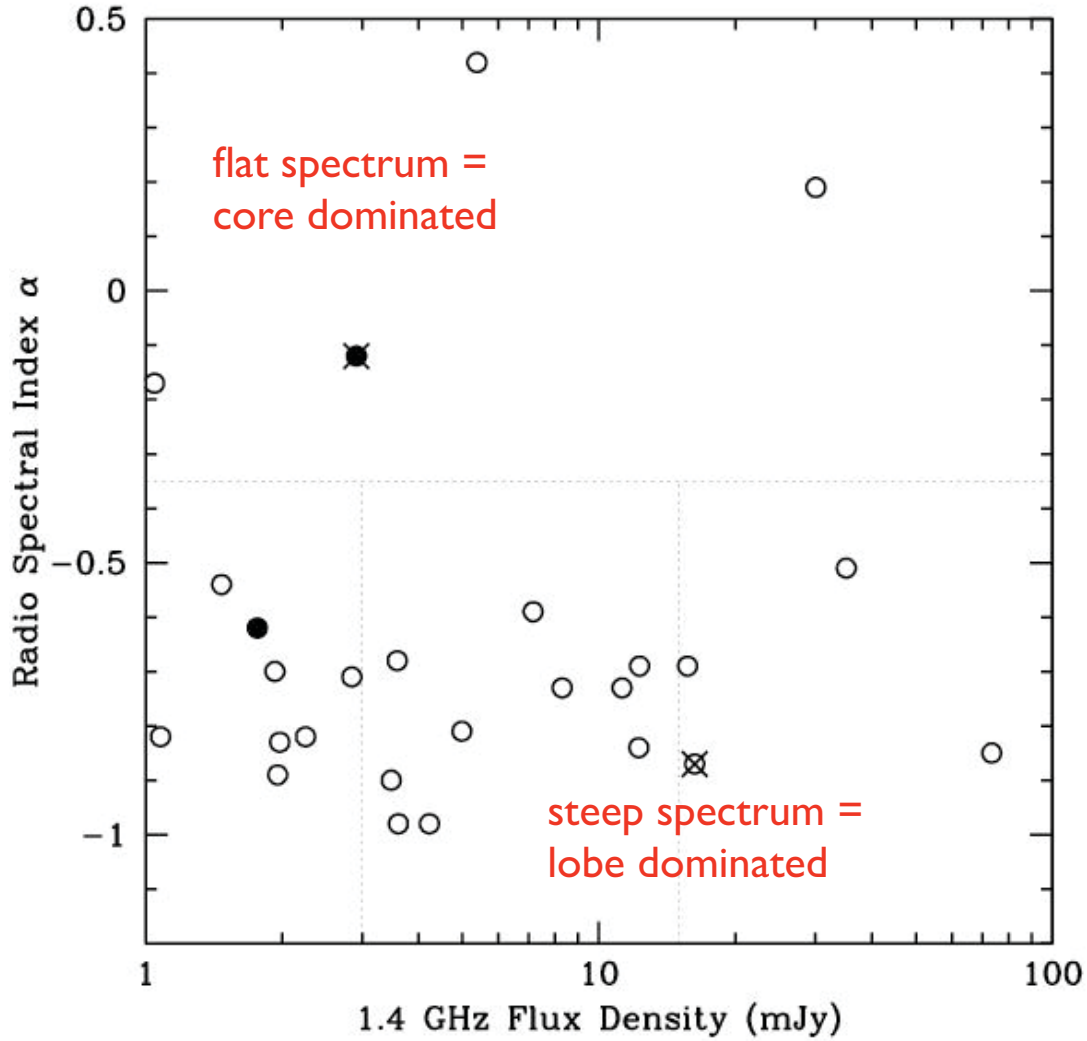


Radio Properties of IRAC AGN

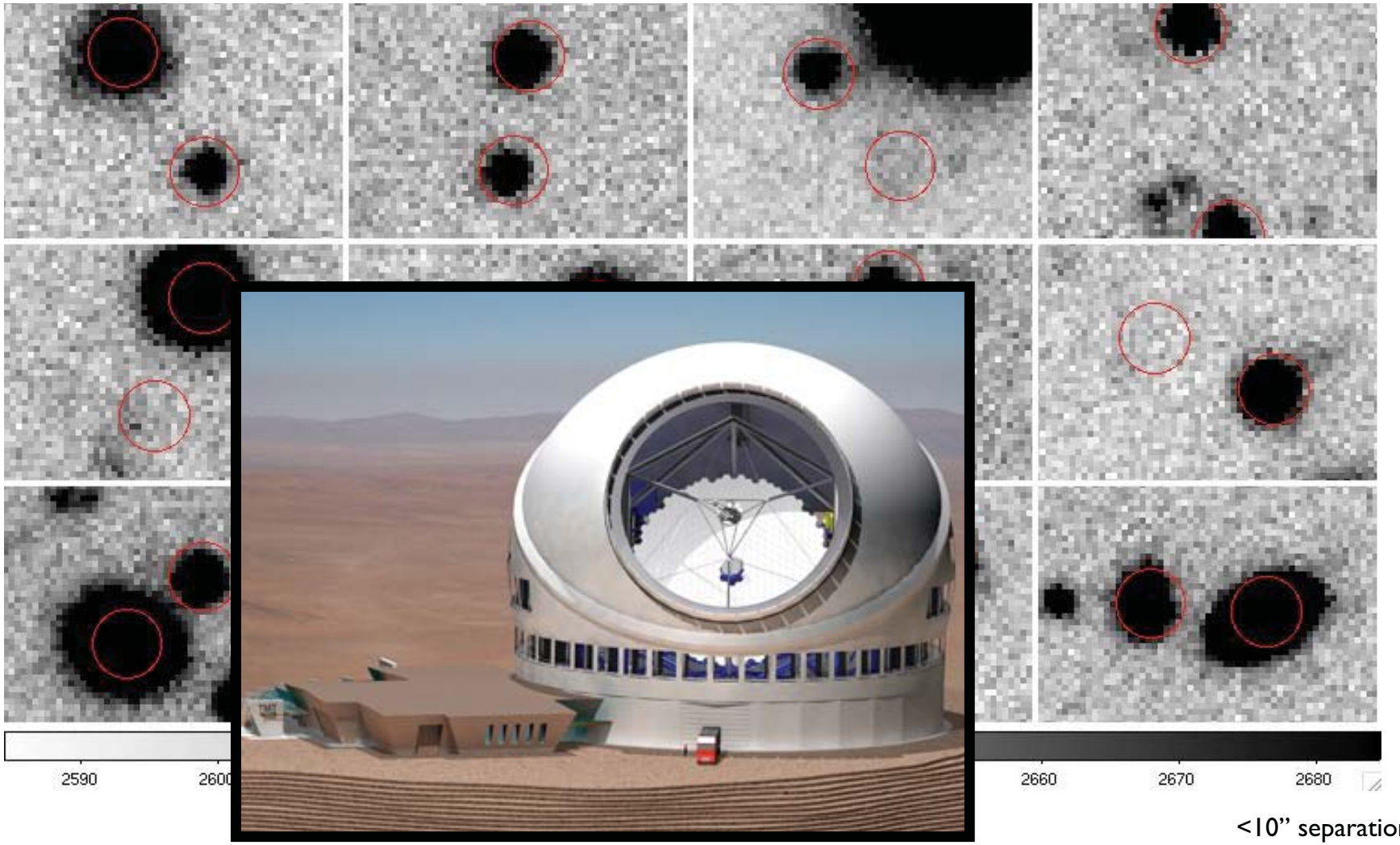
optically faint IRAC AGN
(Bw,R,I > 24.5)



Cygnus A



Close Pairs of IRAC AGN



<10” separation

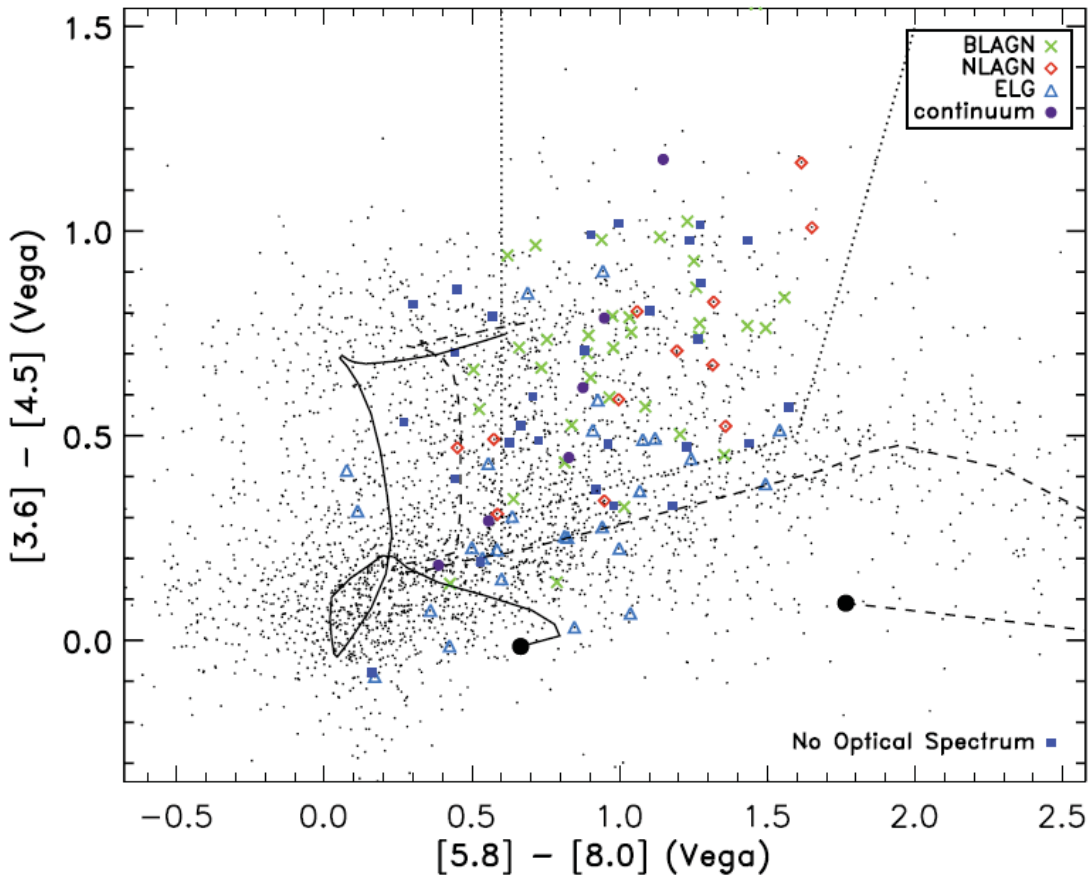
Serendipitous, **E**xtragalactic, **X**-ray **S**ource **I**dentification Survey

Megan Eckart, Fiona Harrison, David Helfand, DS

- 27 archival, deep Chandra pointings (2 deg^2)
- 1034 hard (2-10 keV) X-ray selected sources
- 438 spectroscopic redshifts from Keck:
  - 211 type 1 AGN (BLAGN)
  - 32 type 2 AGN (NLAGN)
  - 176 'normal' galaxies (ELGs, or XBONGs)

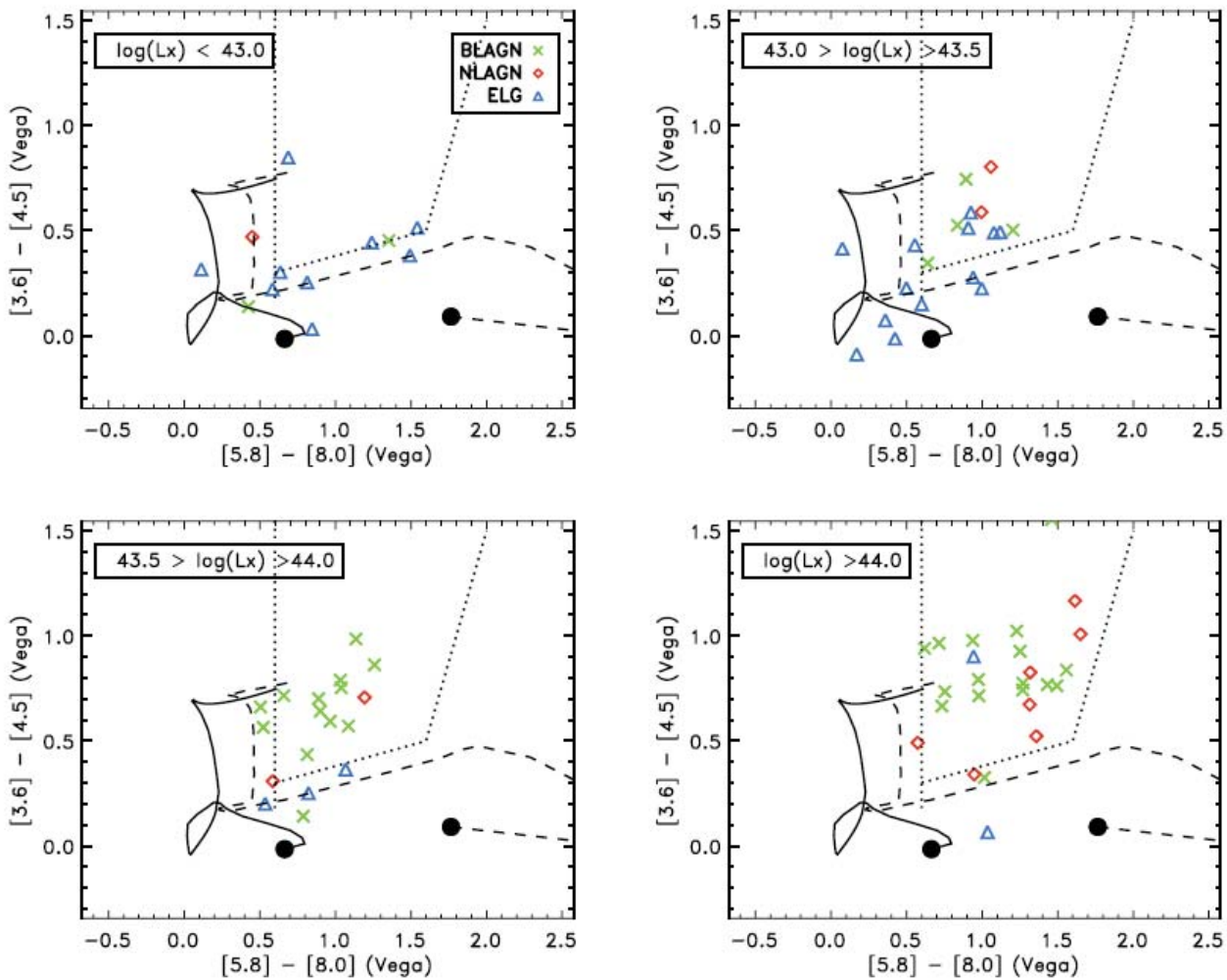
Mid-IR Colors of Hard X-Ray Sources

- 6 fields with Spitzer data
- 250 hard X-ray sources
- 140 with redshifts
- in mid-IR wedge:
  - 86% of the BLAGN
  - 67% of the NLAGN
  - 28% of the ELGs



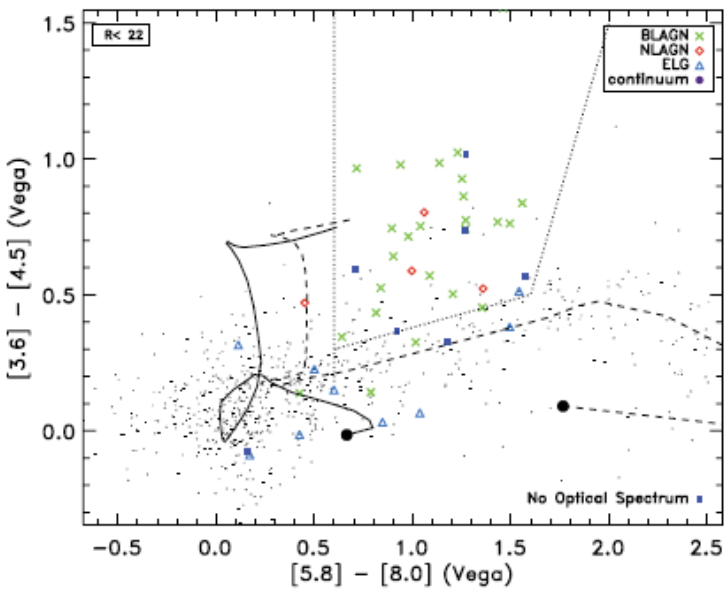
Eckart et al., in prep.

X-Ray Luminosity Dependence

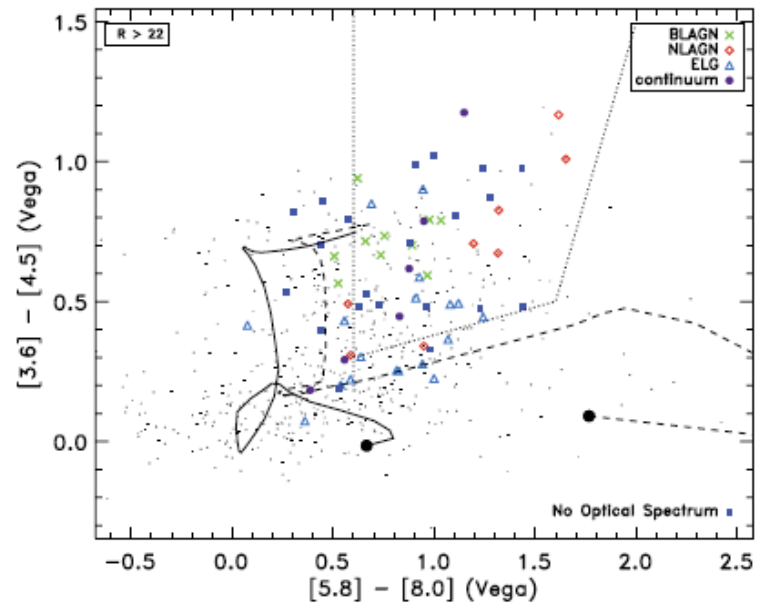


Eckart et al., in prep.

Optical Brightness Dependence



R<22
31/40 (78%) X-ray det'd



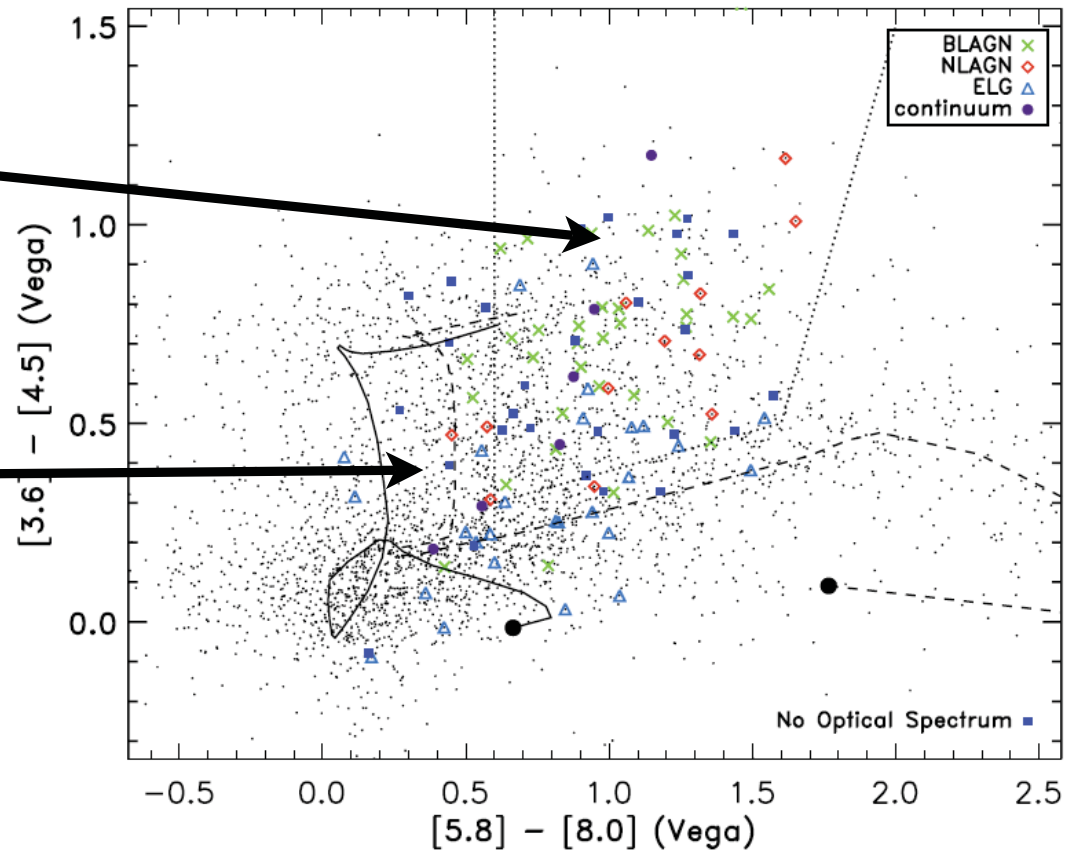
R>22
37/121 (31%) X-ray detected

Eckart et al., in prep.

Stacking X-Ray Non-Detections

Inside Wedge
- 288 sources
- <0.5-2 keV>= 0.47 ± 0.04 cts.
- <2-8 keV> = 0.42 ± 0.05 cts.

Outside Wedge
- 1500 sources
- <0.5-2 keV>= 0.22 ± 0.01 cts.
- <2-8 keV> = 0.06 ± 0.02 cts.



Eckart et al., in prep.

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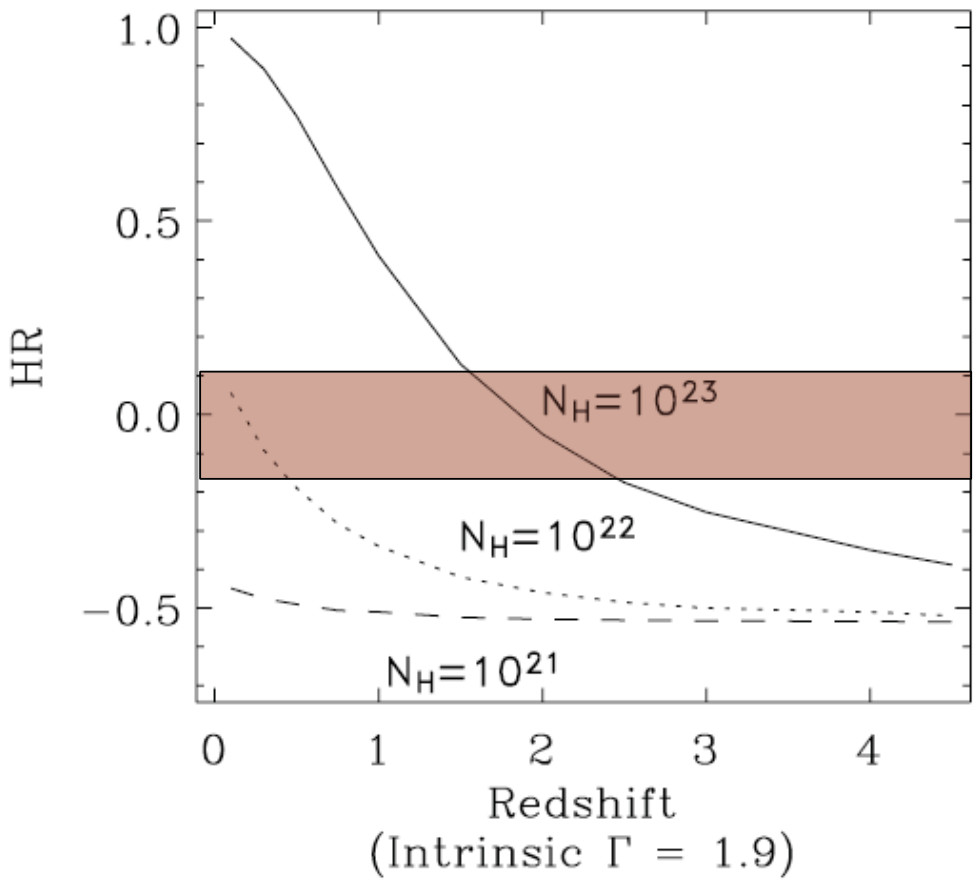
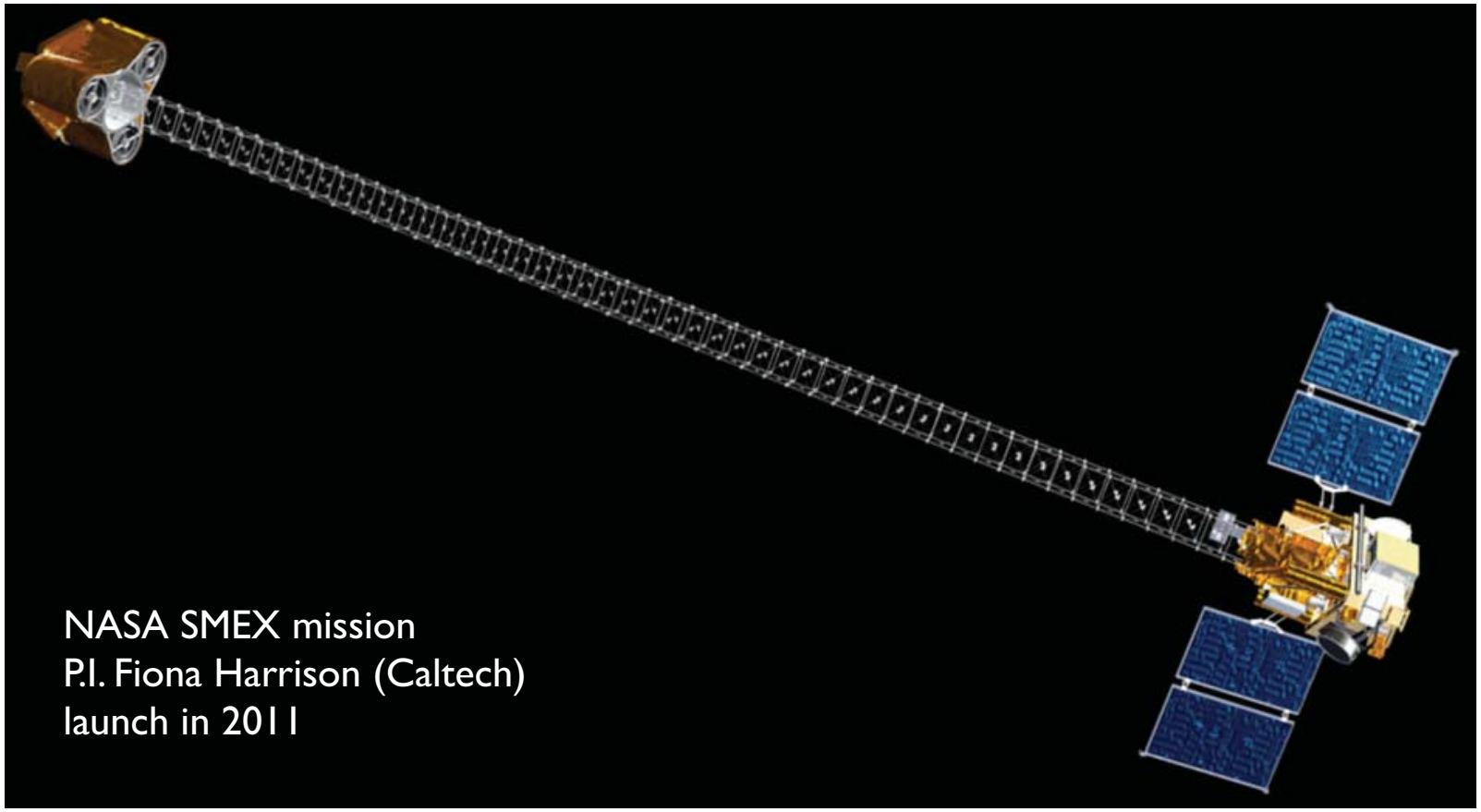


Eckart et al., in prep.

NuStar:

Nuclear Spectroscopic Telescope Array

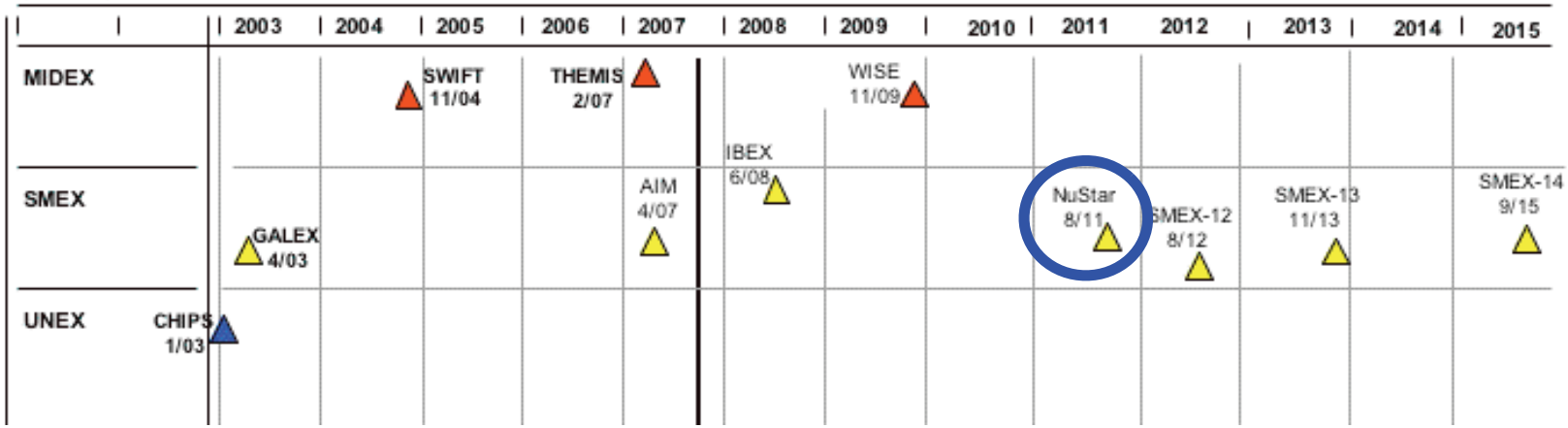


the first focusing mission above 10 keV

EXPLORERS PROGRAM

CODE 410

Launch Schedule



Fiona Harrison (P.I., Caltech)

Steve Boggs (UC-Berkeley)

Finn Christensen (DSRI)

Lynn Cominsky (EPO, Sonoma State)

Walter Cook (Caltech)

William Craig (Inst. Manager, Livermore)

Charles Hailey (Columbia)

Greg Madejski (Stanford)

David Meier (JPL/Caltech)

Daniel Stern (Proj. Sci., JPL/Caltech)

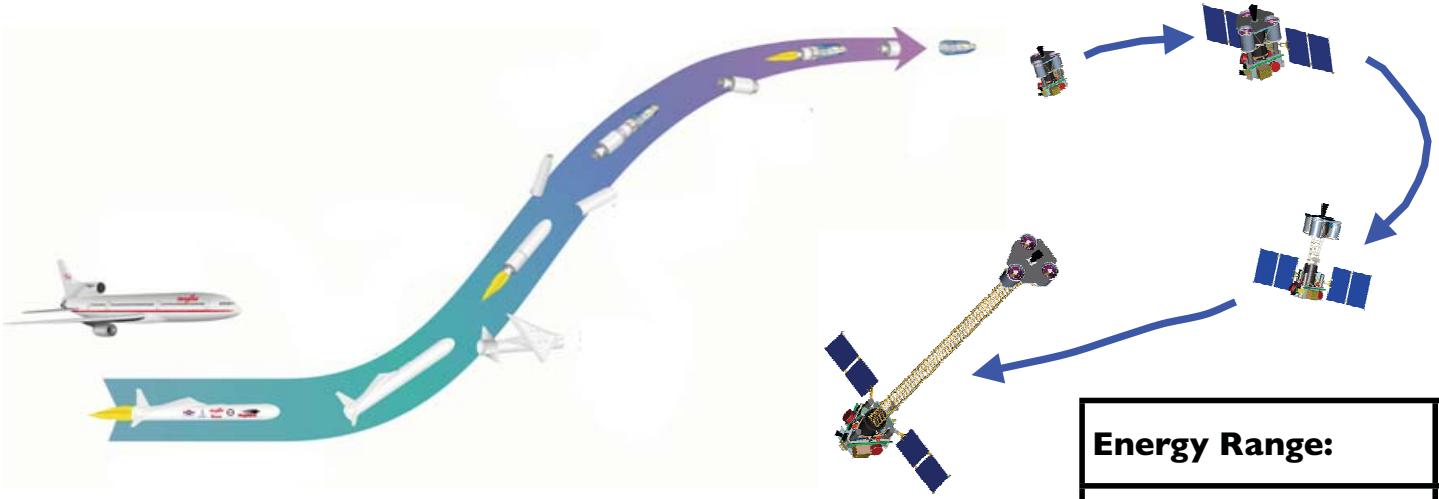
Stephen Thorsett (UC-Santa Cruz)

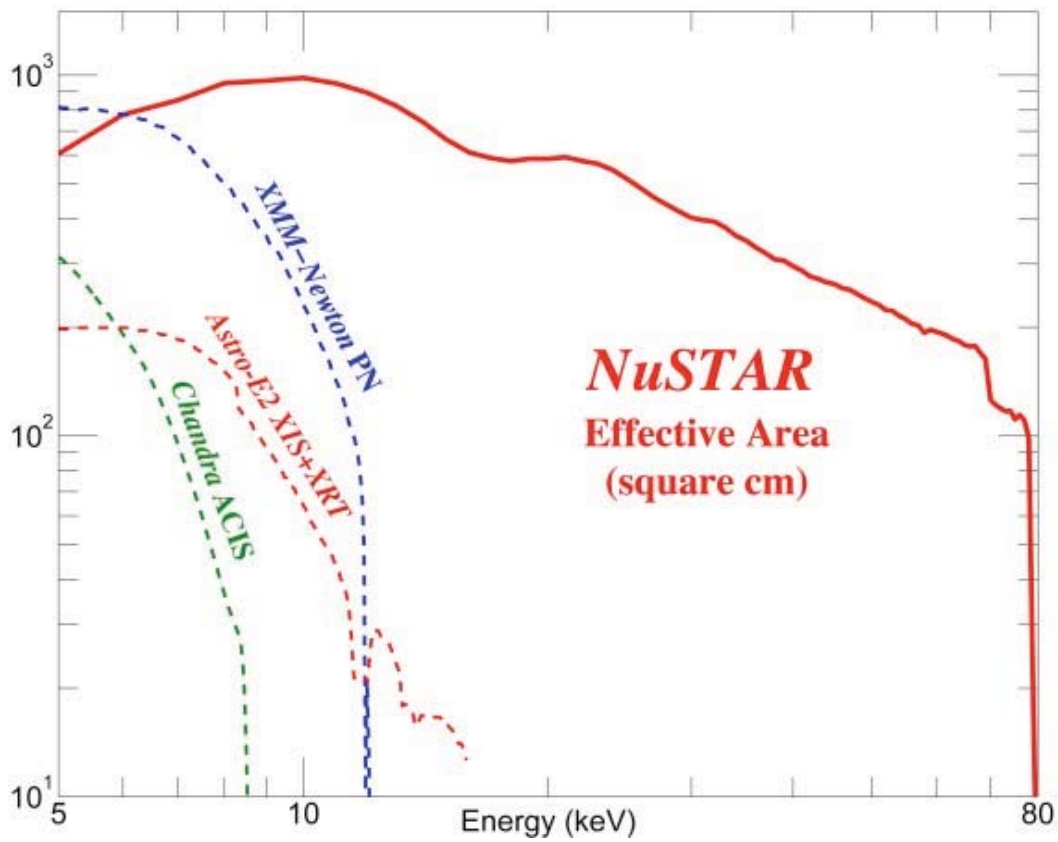
Stan Woosley (UC-Santa Cruz)

Yunjin Kim (Proj. Manager, JPL/Caltech)

Will Zhang (GSFC)

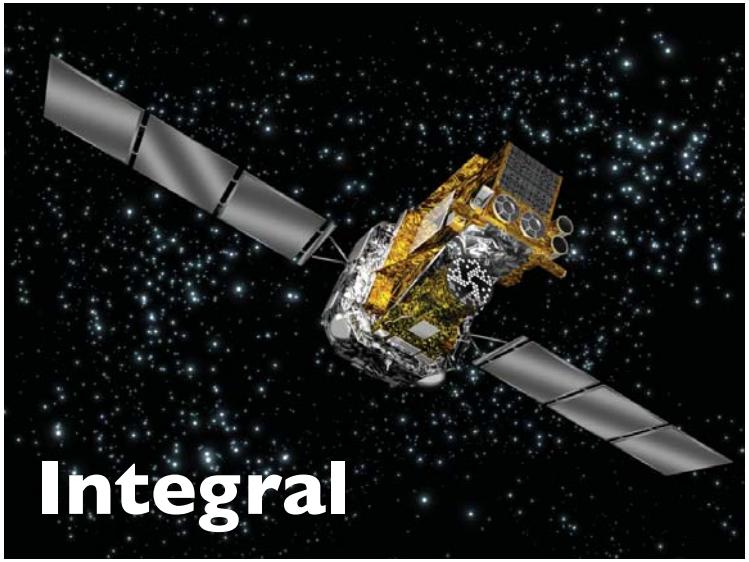
Andrea Razzaghi (GSFC)

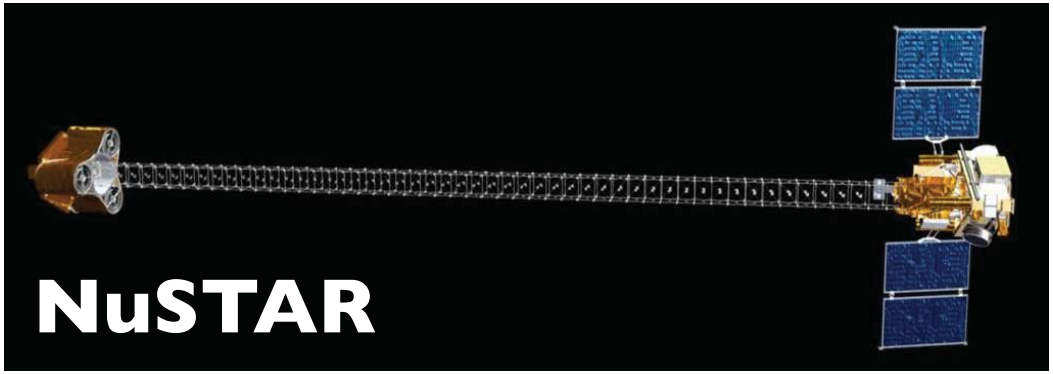




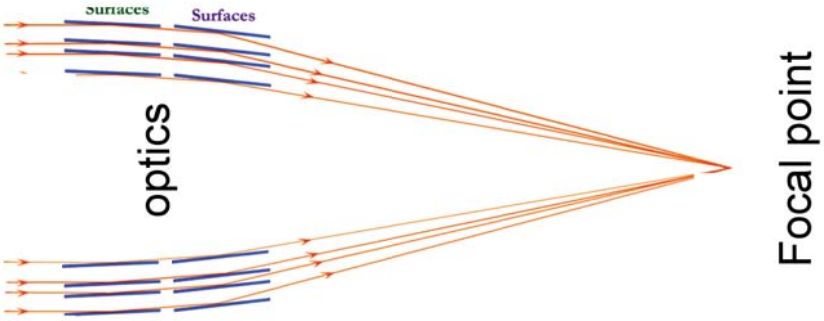
Energy Range:	6-80 keV
Angular Resolution:	40 arcsec (HPD)
Field of View:	13.4 x 13.4 arcmin
Spectral Resolution:	1 keV at 68 keV
Sensitivity (3σ, 1 Ms):	1 μCrab (20 keV) 10 μCrab (60 keV)
Timing Resolution:	1 msec
ToO Response:	<24 hr
Launch Date:	August 2011
Orbit:	27 degrees 525 km
Orbit Lifetime:	84 months (nominal)

NuSTAR's **breakthrough** is the first use of focusing optics in the hard X-ray band





Pinhole Camera:
high background, large detector

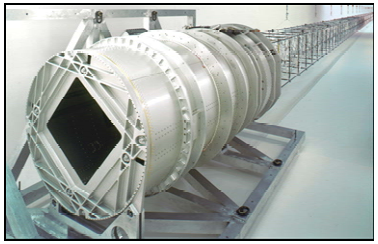


Focusing Telescope:
low background, compact detector

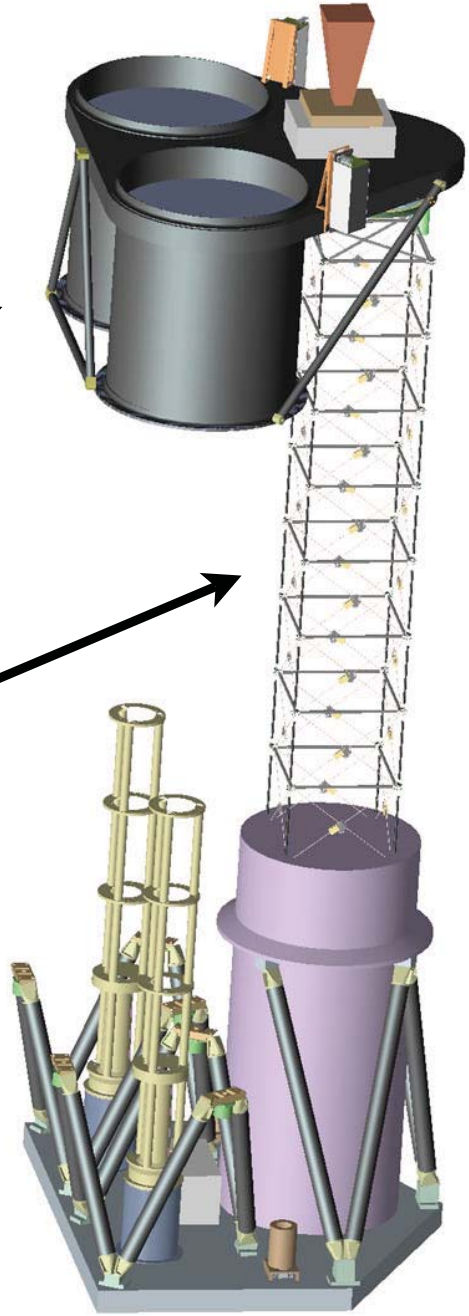
Three Key Technologies

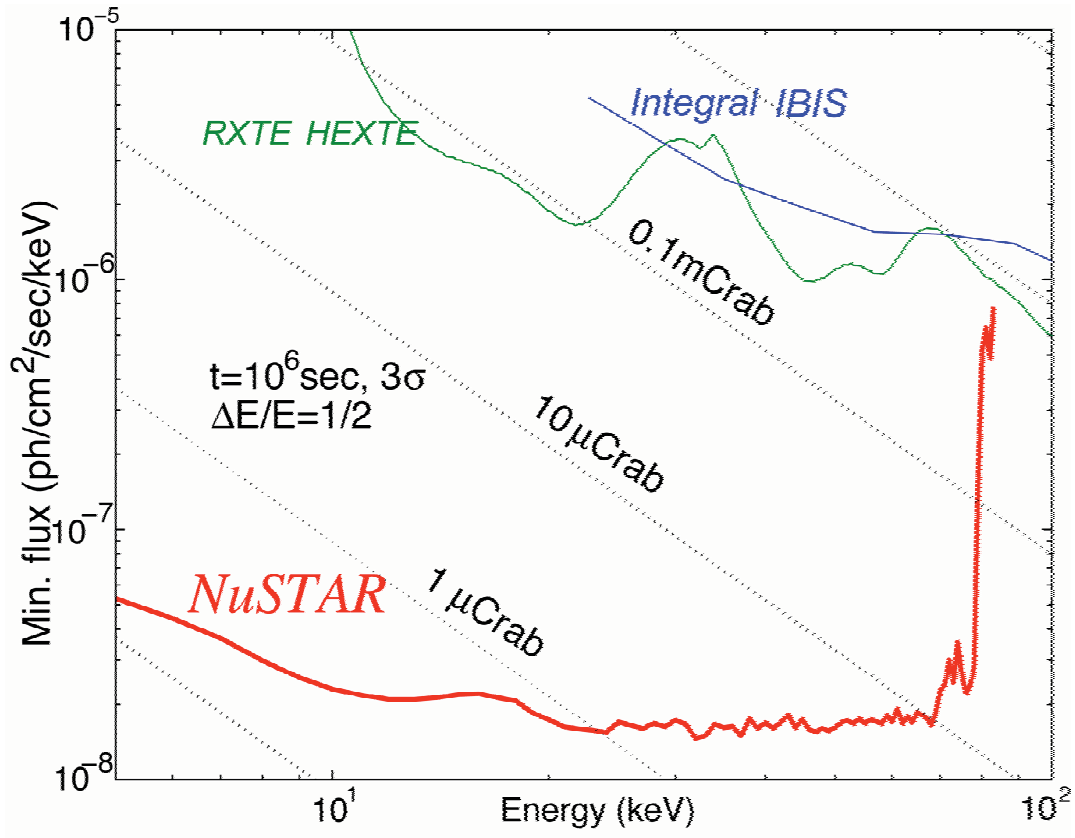
hard X-ray optics
(HEFT balloon)

deployable mast
(SRTM: Shuttle Radar Topography Mission)



solid state
hard X-ray detector
(HEFT balloon)

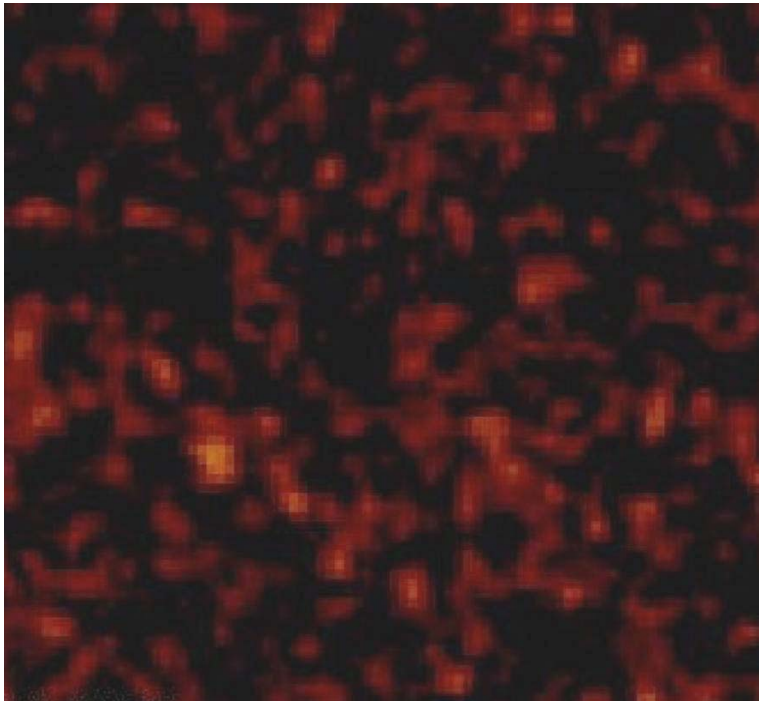




More than an order of magnitude advance in spatial and spectral resolution!

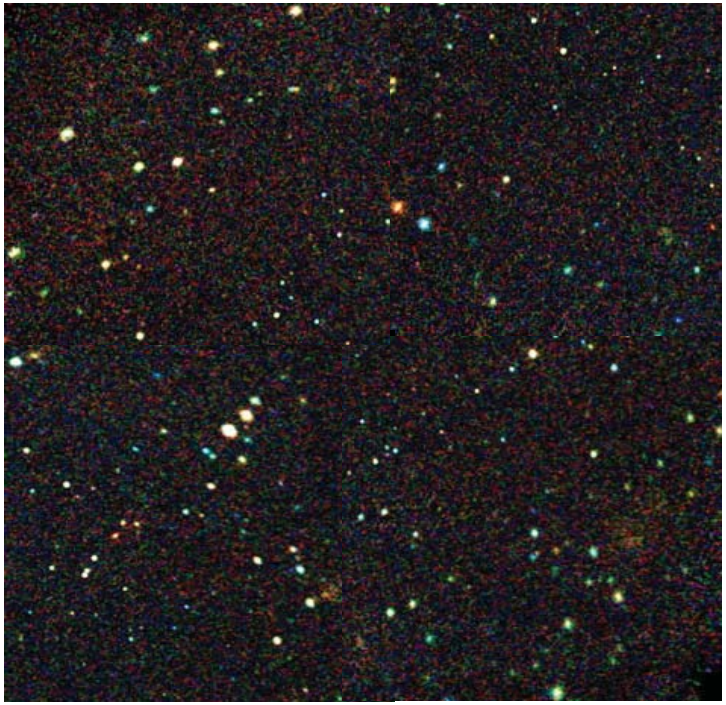
More than 2 order of magnitude advance in sensitivity!

Integral



2x2 degrees, 20-40 keV
1.5 month w/ IBIS

NuSTAR



2x2 degrees
simulated NuSTAR image

study the X-ray background at its peak!

Big Questions:

- What and where are the obscured sources which are needed to explain the X-ray background?
    - Mid-IR is detecting many of them; await NuSTAR to see their hard X-ray spectra and identify both the lower luminosity sources and the most heavily obscured sources
- What is causing their obscuration?
    - Definately some obscuration on galactic scales
- How does this relate to galaxy formation & evolution?
    - TBD

THE END

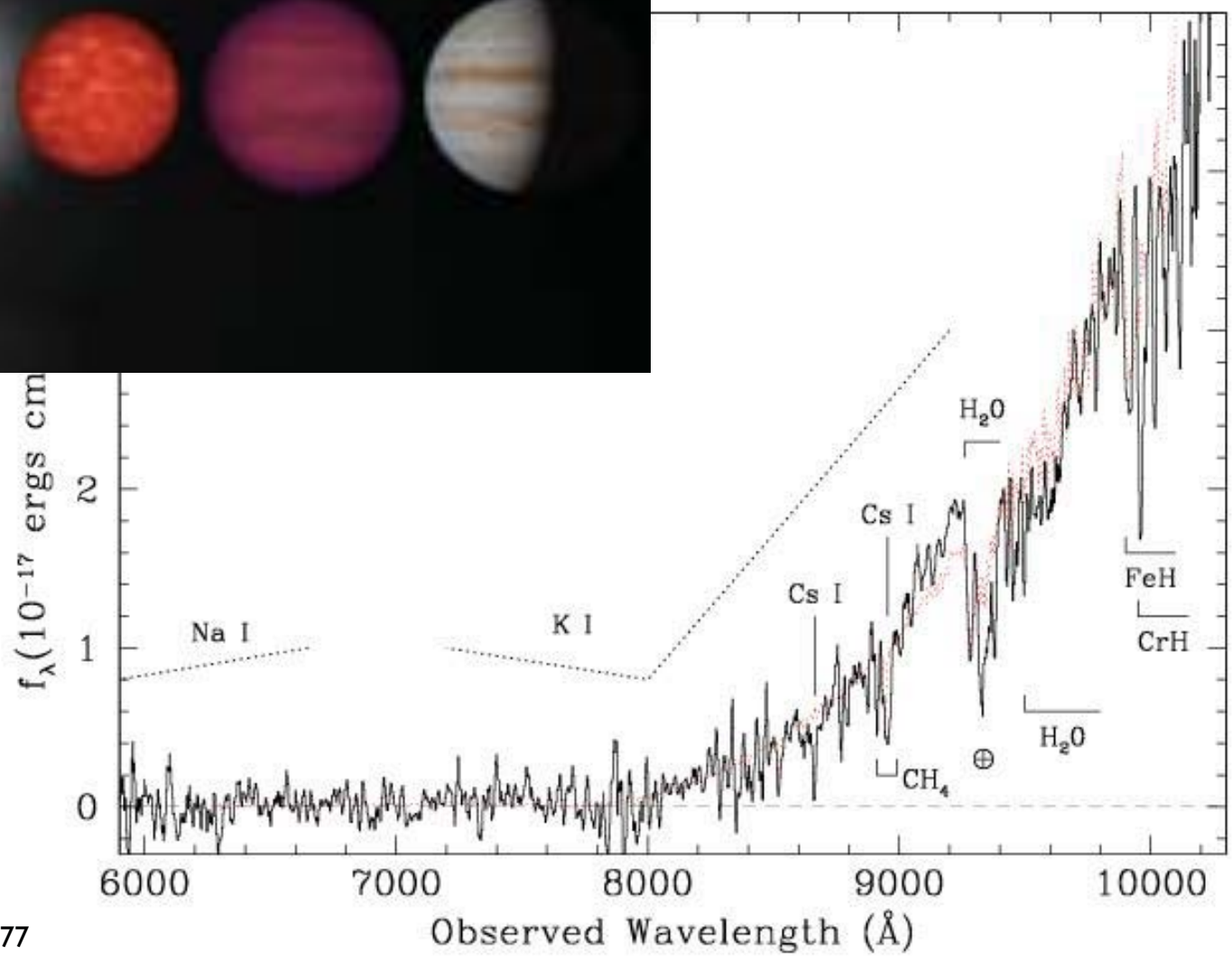
Other IRAC Projects in Boötes:

from the **IRAC Shallow Survey**

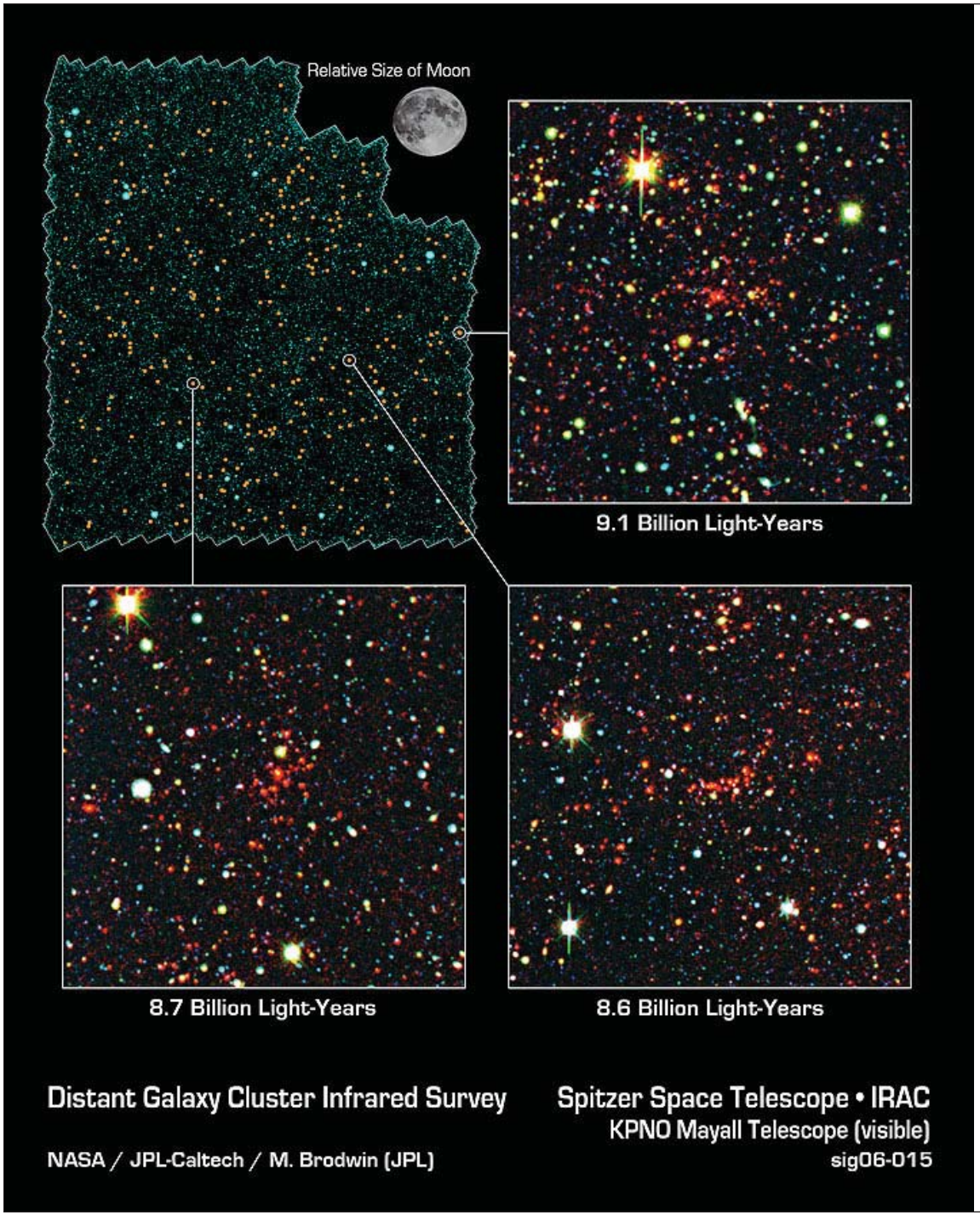
& the **Spitzer Deep, Wide-Field Survey**

(**SDWFS**)

brown dwarfs



Stern et al. 2007, ApJ, 633, 677

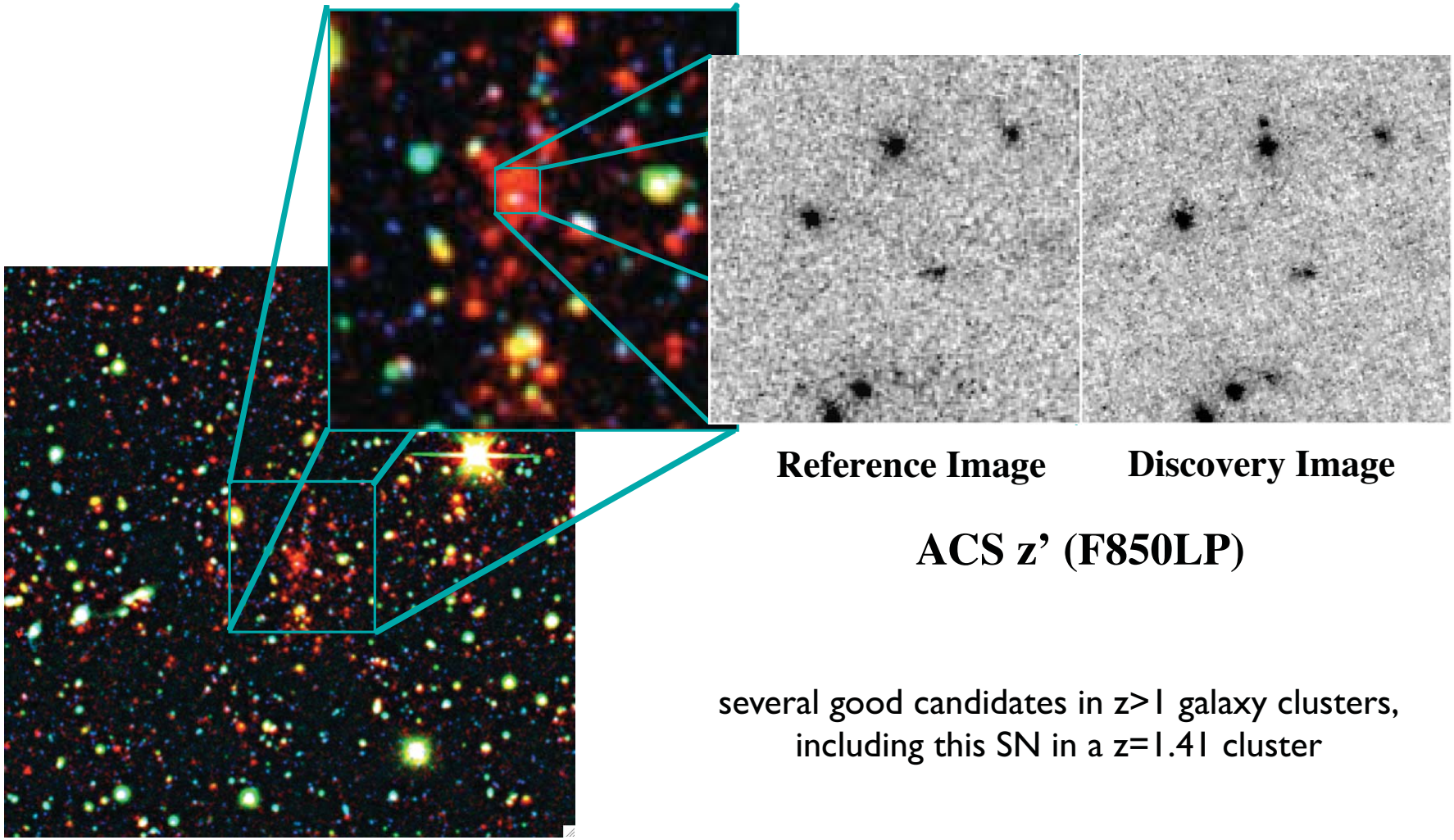


High-Redshift Galaxy Clusters

10 **confirmed**
galaxy clusters at z>1

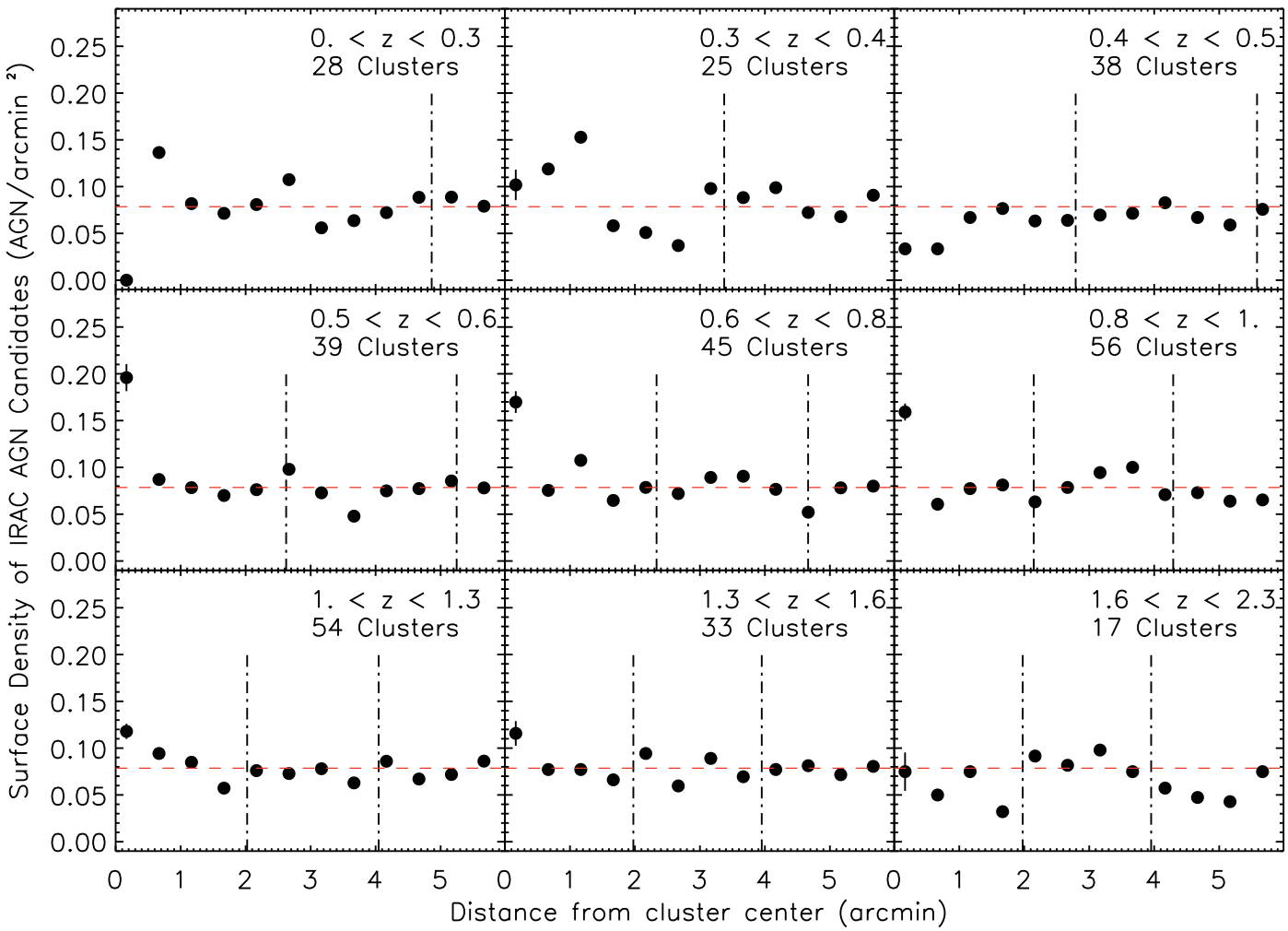
- Stanford et al. 2005, ApJL, 634, L129
- Elston et al. 2006, ApJ, 639, 816
- Brodwin et al. 2006, ApJ, 651, 791
- Eisenhardt et al. 2007, ApJ, submitted
- Brodwin et al. 2007, ApJL, submitted

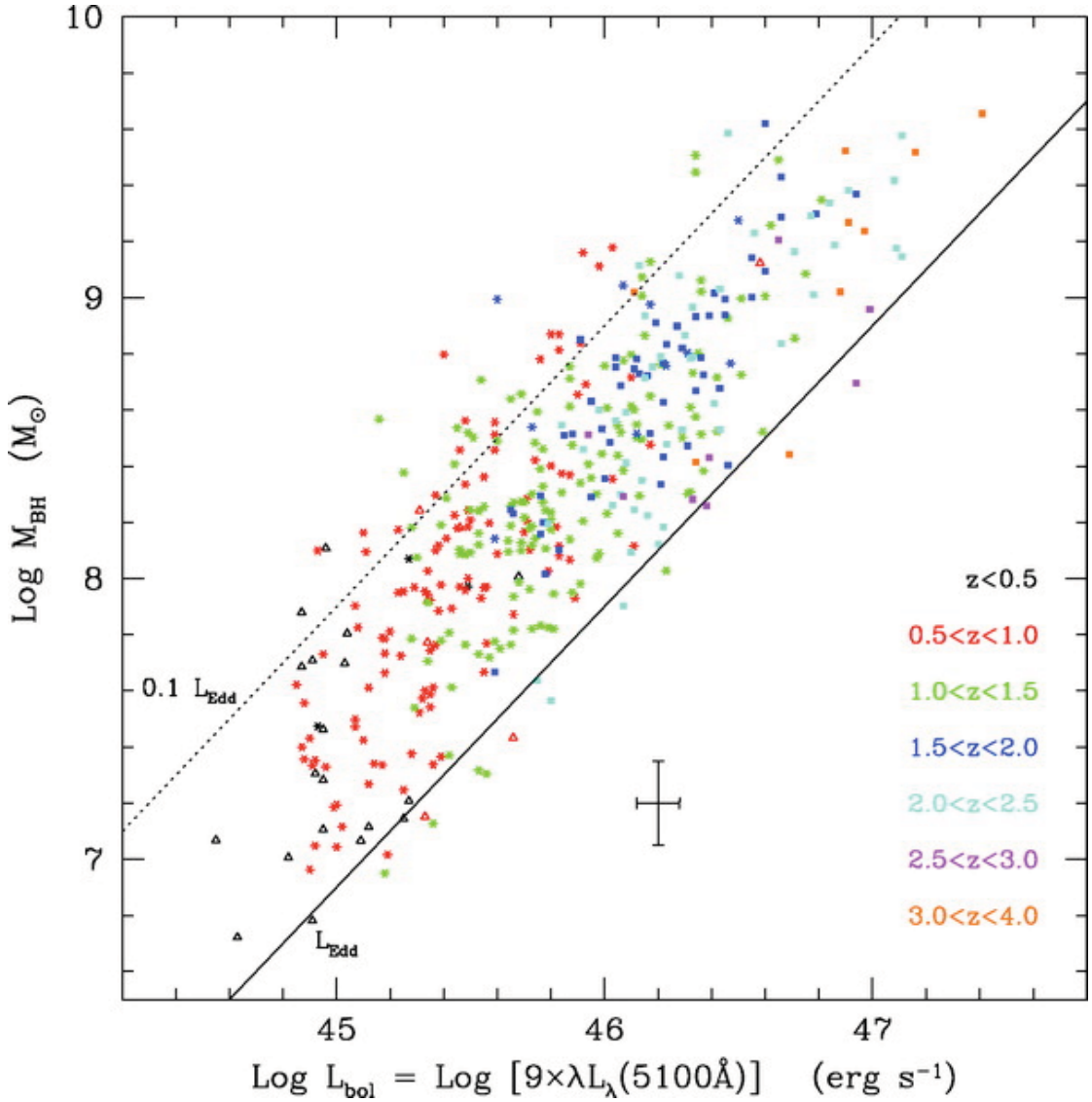
Galaxy Cluster SN Cosmology



several good candidates in z>1 galaxy clusters,
including this SN in a z=1.41 cluster

AGN Butcher-Oemler Effect





Quasars (Unobscured)

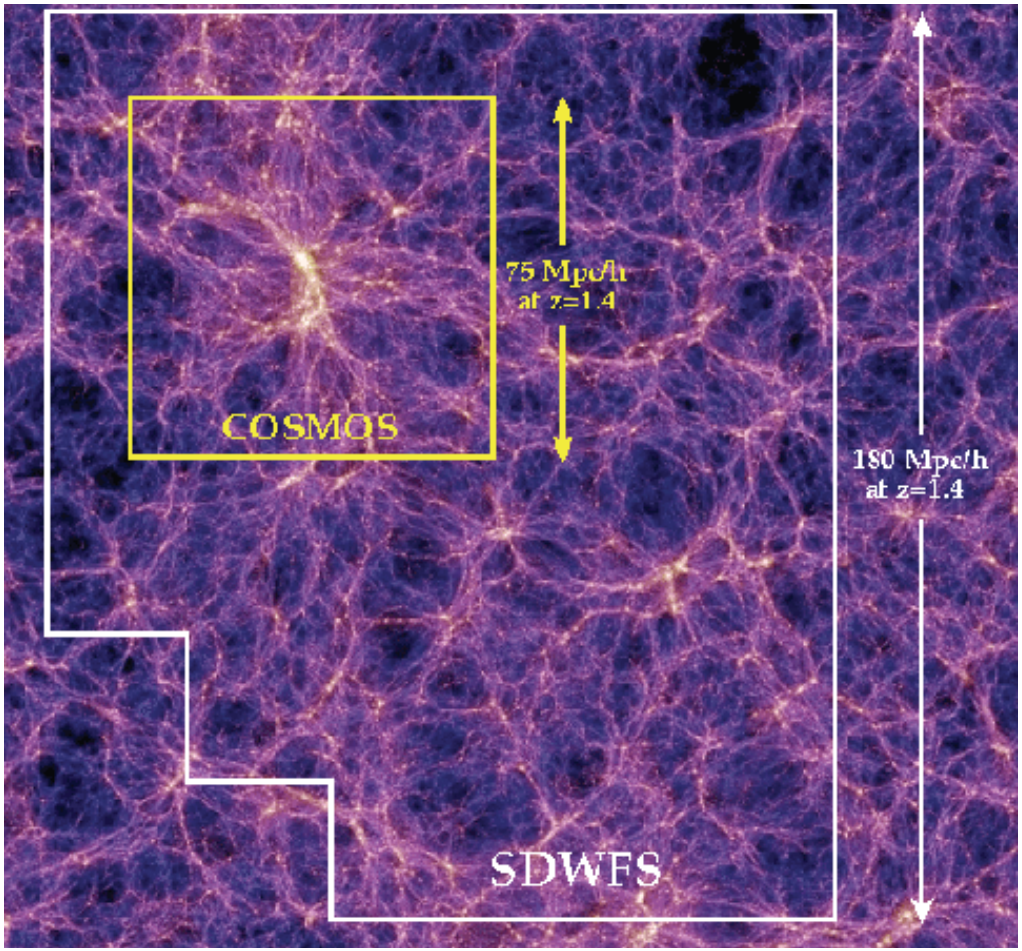
- Eddington ratios for large set of sources with spectroscopic redshifts from AGES:
- most broad-lined AGN are emitting at ~30% the Eddington ratio

Kollmeier et al. 2006, ApJ, 648, 128

SDWFS

quadruple the depth of the IRAC Shallow Survey:

- diffuse infrared background from population III stars
- clusters/clustering of massive galaxies out to z~2.5
- AGN studies
- mid-IR variability
- rare objects, e.g. the coldest brown dwarfs



Wide-Field Infrared Survey Explorer

- NASA/MidEx mission, led by JPL & UCLA
    - P.I. - Ned Wright (UCLA)
    - Project Scientist - Peter Eisenhardt (JPL)
- launch scheduled for November 2009
- full-sky 3-24 micron survey
- compliments SDSS/2MASS, JWST, LSST, PanSTARRS, ...
- ~50 mid-IR AGN / sq. deg.