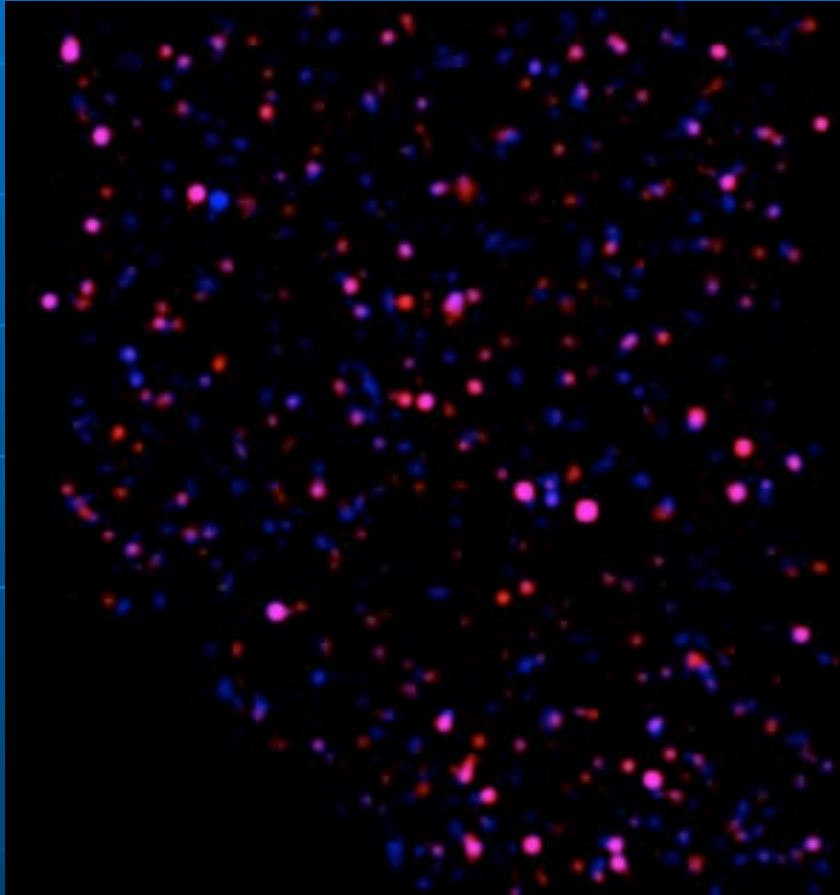


Xboötes: the 9.3 square degree Boötes field



“false-color” 0.5-7 keV X-ray image

* X-ray and infrared properties of
AGN

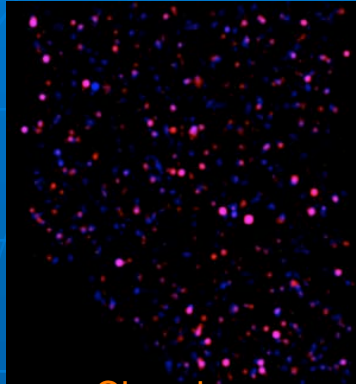
* Using AGN to Map Cosmic
Structure

Stephen Murray and the XBoötes
Team

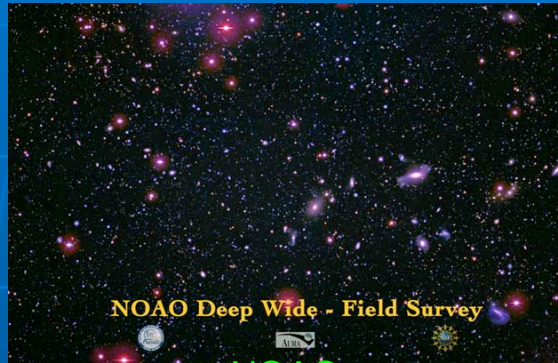
Harvard-Smithsonian
Center for Astrophysics



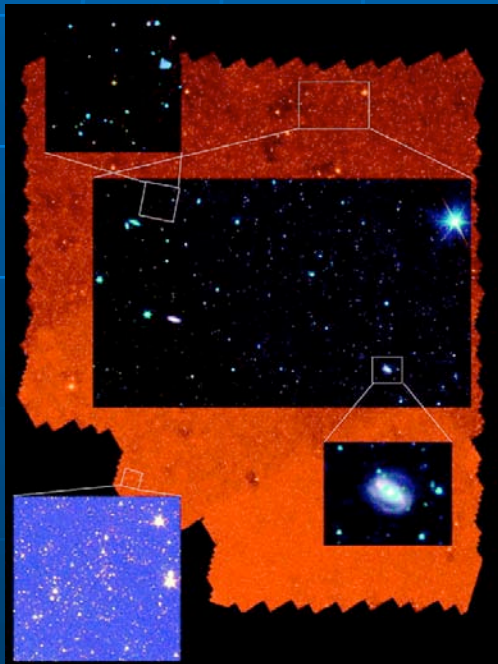
Collaborators



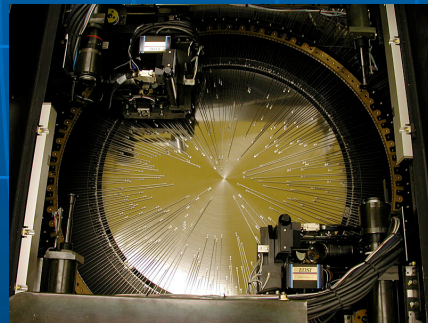
Chandra



NOAO



Spitzer



MMTO

- **Chandra (CfA)**
 - S. Murray, W. Forman
 - A. Kenter, N. Caldwell
 - R. Hickox, C. Jones
- **Spitzer (JPL/Caltech/CfA)**
 - P. Eisenhardt, M. Brodwin
 - V. Gorjian, M. Pahre
 - and the IRAC Shallow Survey Team
- **Optical spectroscopy (OSU/Arizona)**
 - K. Kochanek, D. Eisenstein
 - and the AGES Team
- **Optical photometry (NOAO)**
 - B. Januzzi, A. Dey, K. Brand
 - and the NDWFS Team
- **and more...**

Outline of Talk

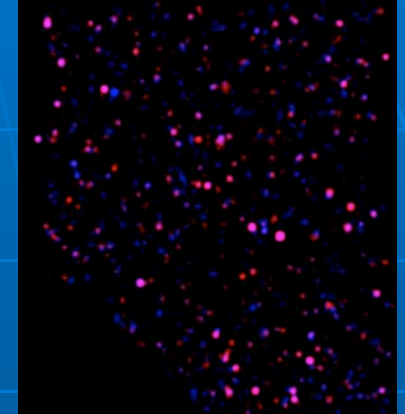
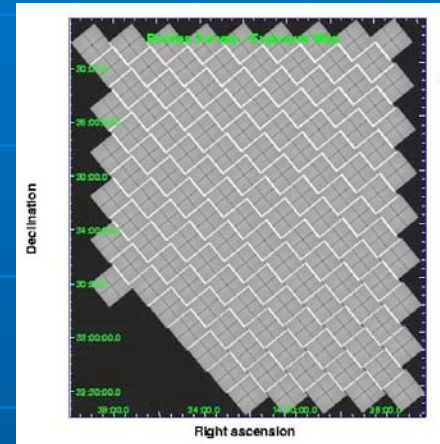
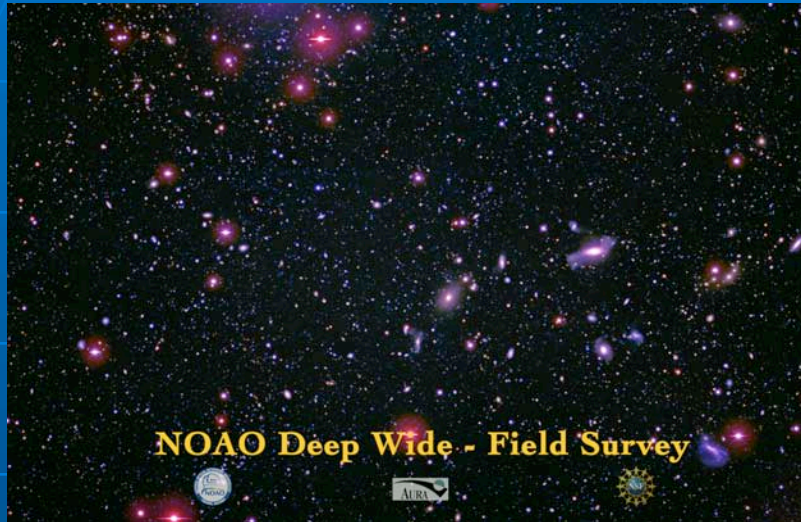
- Introduction
- What is the Xbootes Survey?
- Using Hectospec, Chandra, Spitzer to characterize AGN
- X-ray and IR properties of BLAGN
- Mapping the cosmic web with AGN
- The local environment of AGN
- Work in Progress

Multiwavelength Observations of the Boötes Field

VLA P-band	90 cm	7 sq. deg	100 μ Jy	100% complete
VLA L-band	21 cm	1 sq. deg.	15 μ Jy	100% complete
VLA (FIRST)	21 cm	9 sq. deg.	1mJy	100% complete *
Westerbork	21 cm	7 sq. deg.	8 μ Jy	100% complete
Spitzer/MIPS	24,70,160 μ m	9 sq. deg.	3.0,30,100mJy	100% complete *
Spitzer/IRAC	3.6,4.5,5.8,8.0 μ m	9 sq. deg.	6.4,8.8,51,50 μ Jy	100% complete *
NOAO	J,Ks	5 sq. deg.	23 mag	100% complete *
NOAO	K,Ks	9 sq. deg.	19.2 mag	100% complete *
NOAO	J,H	9 sq. deg.	21 mag	40% complete
NOAO	B _w ,R,I	9 sq. deg.	25.5–26.6 mag	100% complete *
NOAO	U	9 sq. deg.	25 AB mag	100% complete
NOAO	U	1 sq. deg.	26 AB mag	100% complete
GALEX	FUV,NUV	1 sq. deg.	26 AB mag	100% complete
GALEX	FUV, NUV	9 sq. deg.	25 AB mag	in progress
Chandra	0.5–2.0 keV	9 sq. deg.	4,7 $\times 10^{-15}$ erg s ⁻¹ cm ⁻²	100% complete *
Chandra	2.0 –7.0 keV	9 sq. deg.	1.5 $\times 10^{-14}$ erg s ⁻¹ cm ⁻²	100% complete *
NOAO/Keck	spectroscopy	sparse	24 mag	in progress
MMT/Hectospec	spectroscopy	9 sq. deg.	R~20.5 mag	100% complete
Spitzer/IRS	spectroscopy	sparse		in progress

Bootes Survey Imaging Data

Optical photometry: NOAO DWFS
photometry B,R,I,J,K (Januzzi & Dey 1999)

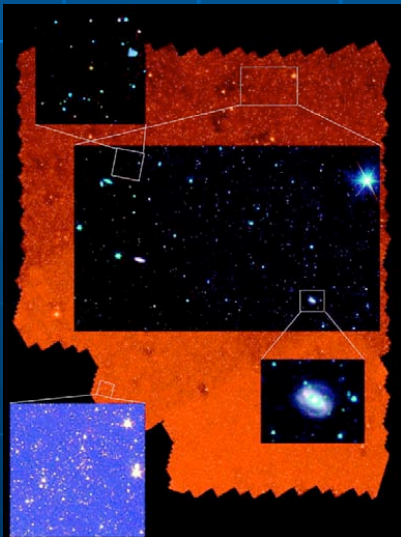


X-ray: Chandra XBootes survey (Murray et al. 2005, Kenter et al. 2005) 126 ACIS fields @ 5 ksec each
> 3000 X-ray sources

Infrared: Spitzer IRAC Shallow Survey (Eisenhardt et al. 2004)

The Bootes field was observed with the IRAC camera on Spitzer in four bands: 3.6, 4.5, 5.8, 8.0 microns.

~30,000 sources are detected in all four IRAC bands



The XBoötes Survey

- Xboötes:
- 126 Chandra ACIS pointings
- 5 ksec each field (630 ksec)
- Joint GTO and GO program
- $14^{\text{h}} 32^{\text{m}} + 34^{\circ} 06'$
- 4642 sources detected (≥ 2 cts)
 - 625 spurious
- 3293 sources detected (≥ 4 cts)
 - 22 spurious
- 42 extended sources (≥ 10 cts)
- $f_{\text{min}} = 4(8) \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$ (0.5-7 keV)
- 98% sources ≥ 4 cts matched to NDWFS candidates ($R \leq 26$)

Murray et al. ApJ S 161, 1 (2005)

Kenter et al. ApJ S 161, 9 (2005)

Brand et al. ApJ, 641, 140 (2006)

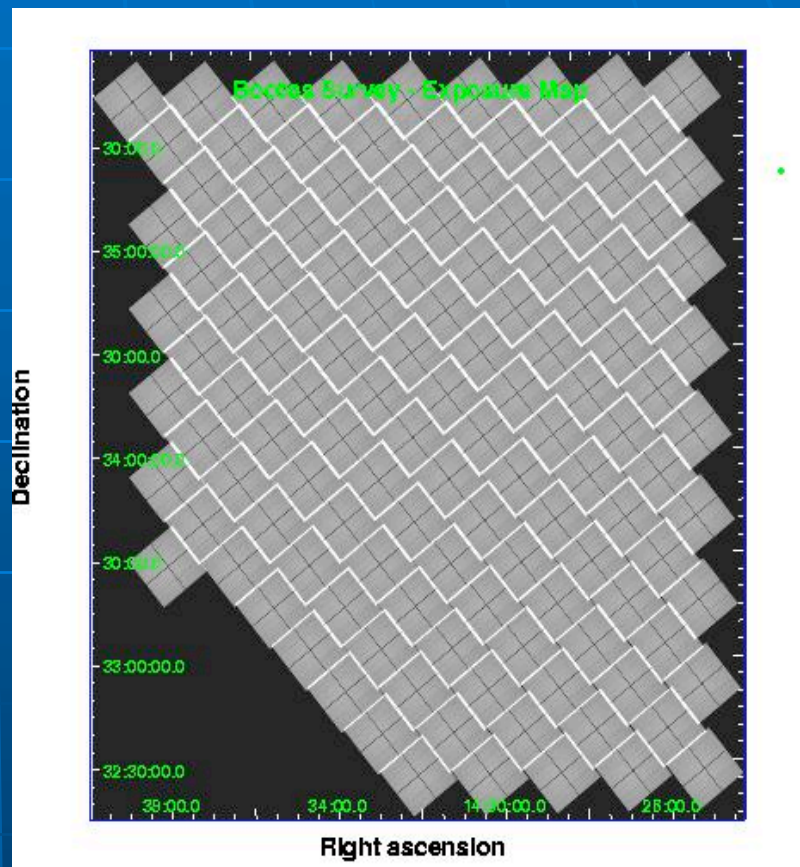
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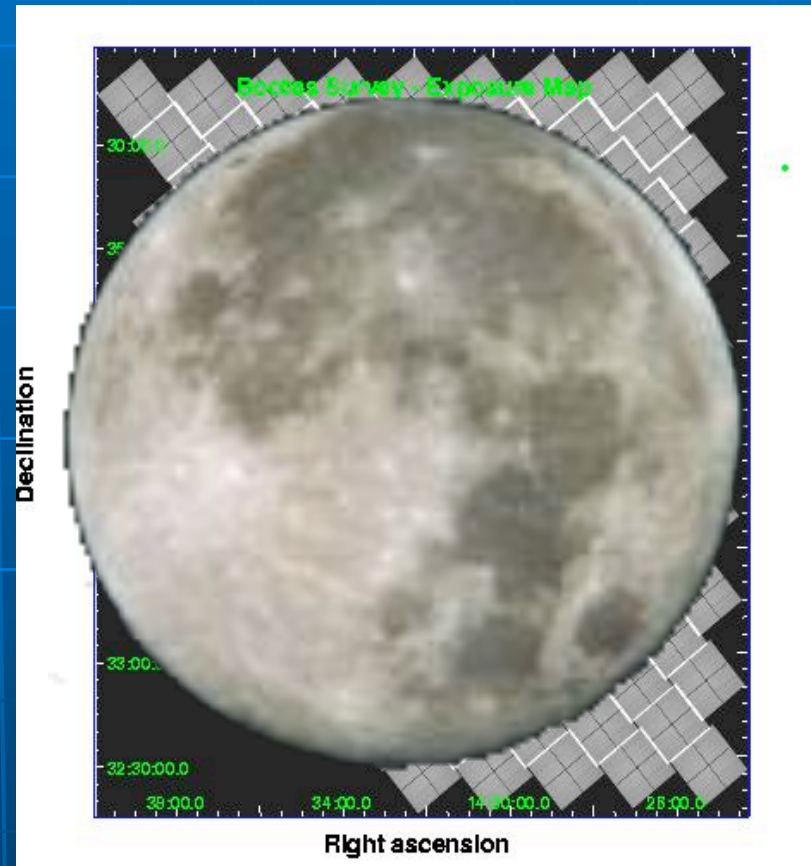
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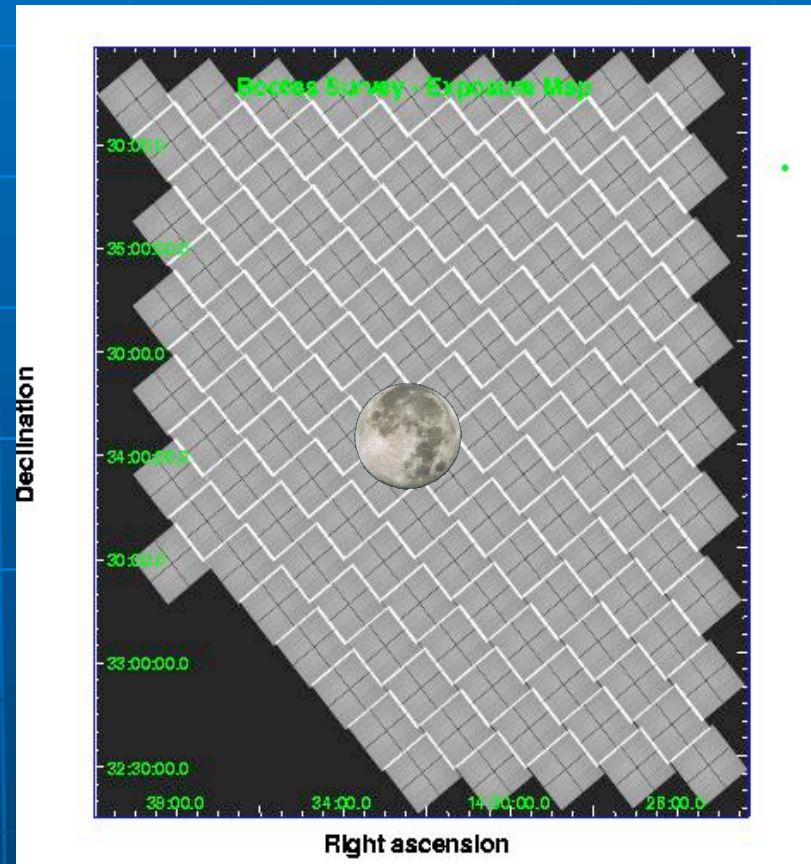
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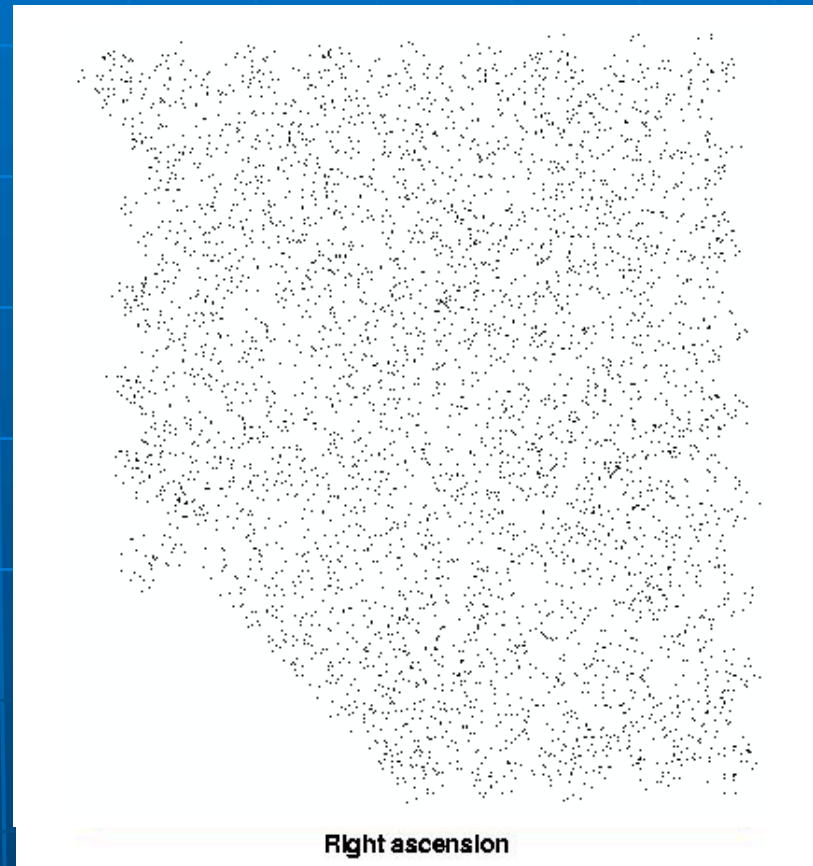
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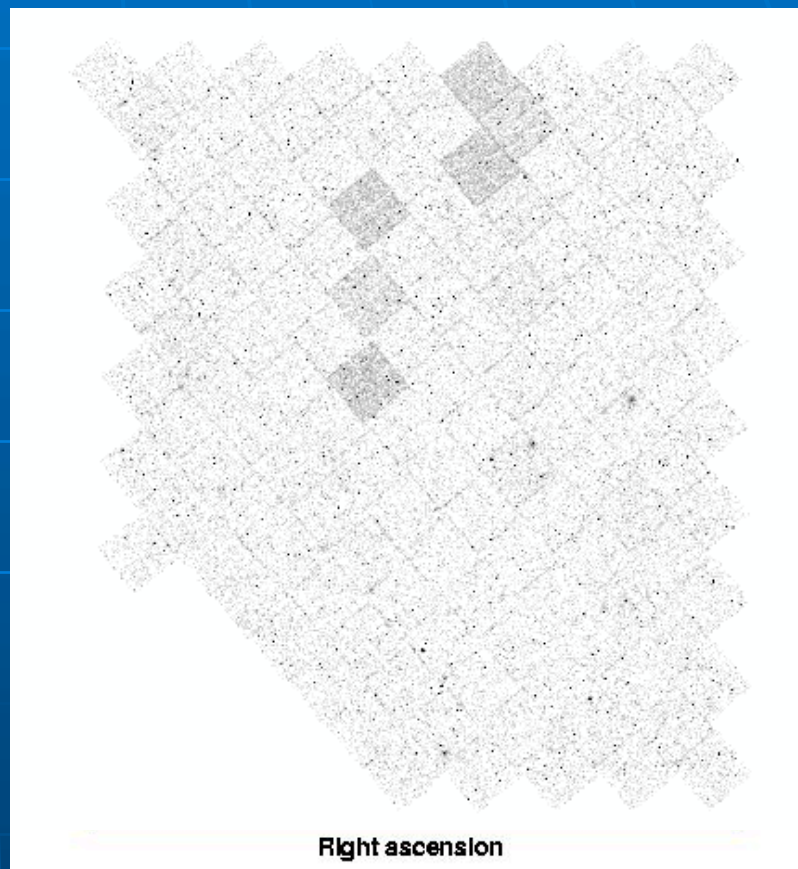
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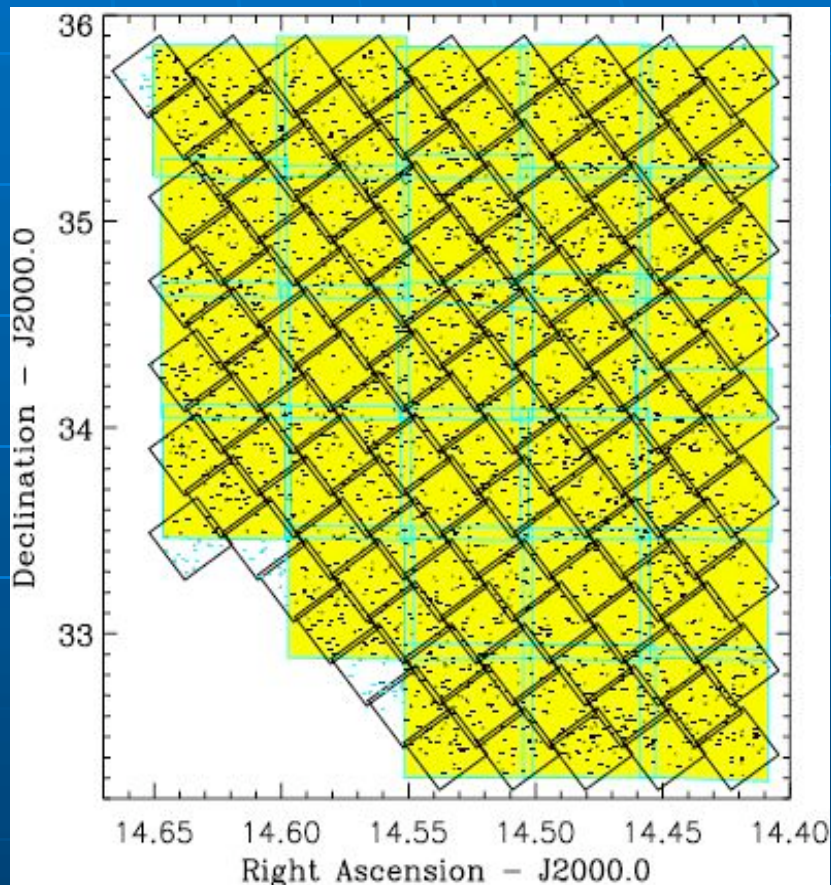
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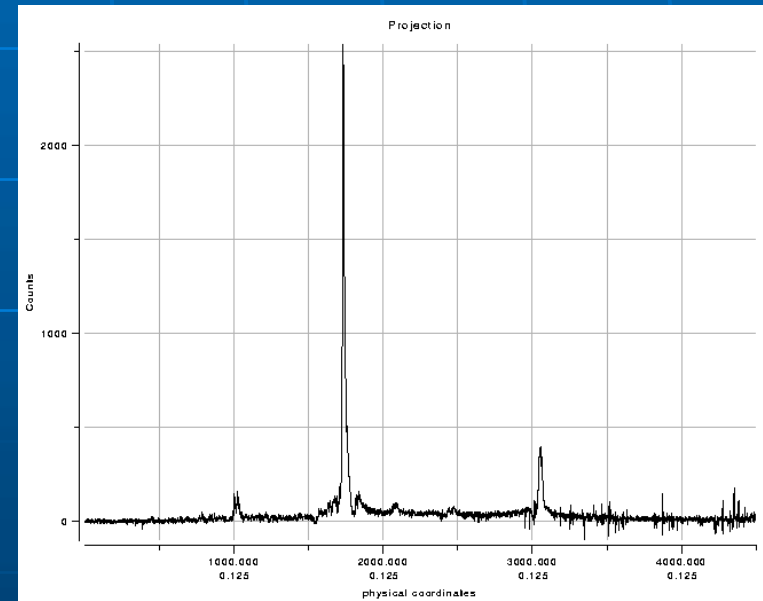
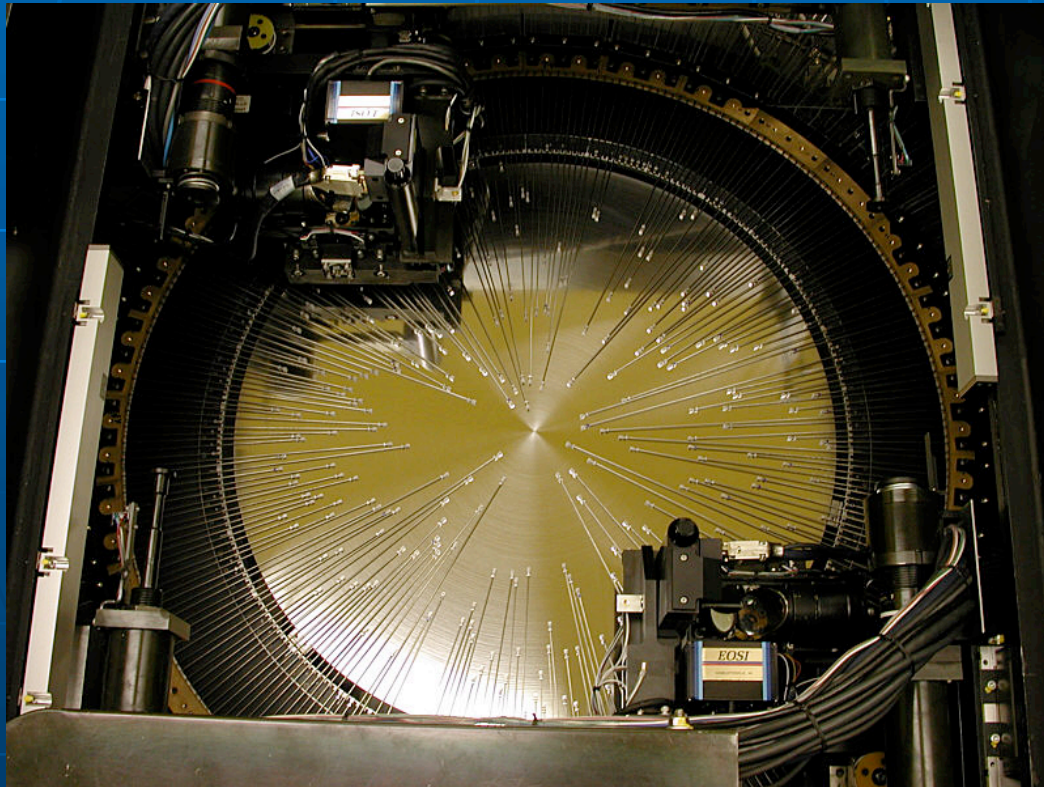
Brand et al. ApJ, 641, 140 (2006)



MMT Bootes Survey

Optical spectroscopy: AGES survey w/ MMT/Hectospec

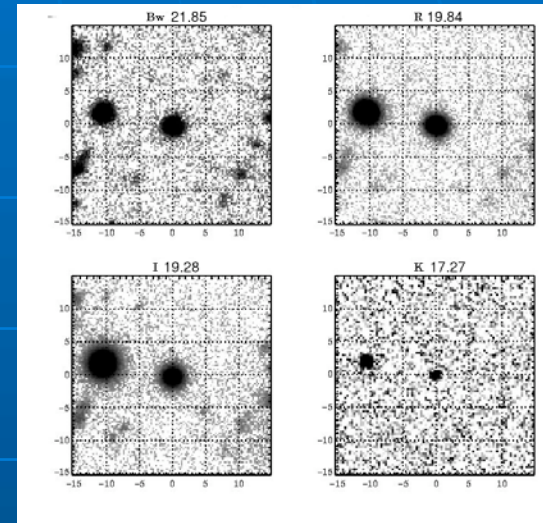
The first sample contains ~2000 **broad line AGNs**,
80 **narrow-line AGNs**, and 19,000 “normal” galaxies.



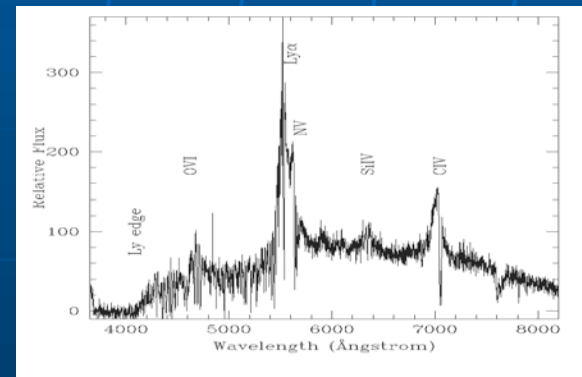
AGN and Galaxy Evolution Survey (AGES)

- MMT/Hectospec fiber spectrograph
- 300 fibers/field
- Complete galaxies $I < 19.5$
- Complete X-ray > 4 cts and $I < 21.5$
- $\sim 27,000$ targeted galaxies
- $\sim 1,500$ targeted X-ray selected

- E.g., $z=3.53$ AGN with 12 X-ray counts. $I=19.28$,
 $L_x = 3 \times 10^{45} \text{ erg s}^{-1} (0.5 - 7 \text{ keV})$

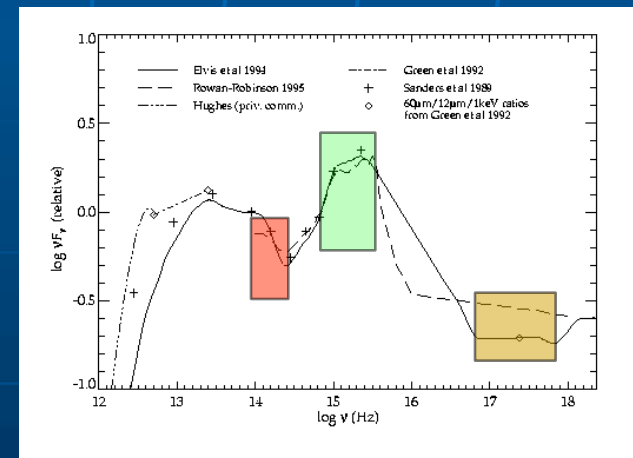
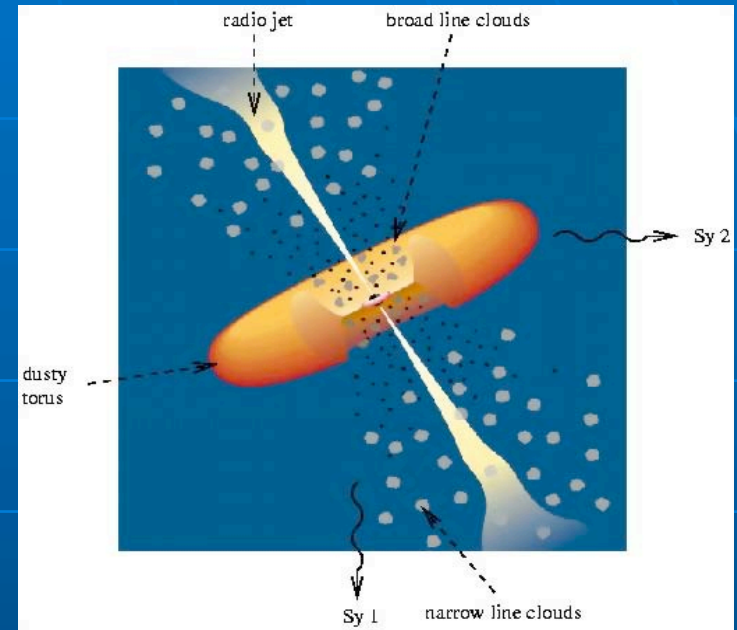


CXOXB J142547.4+352719



Multiwavelength Studies of AGN

(Urry & Padovani 1995)

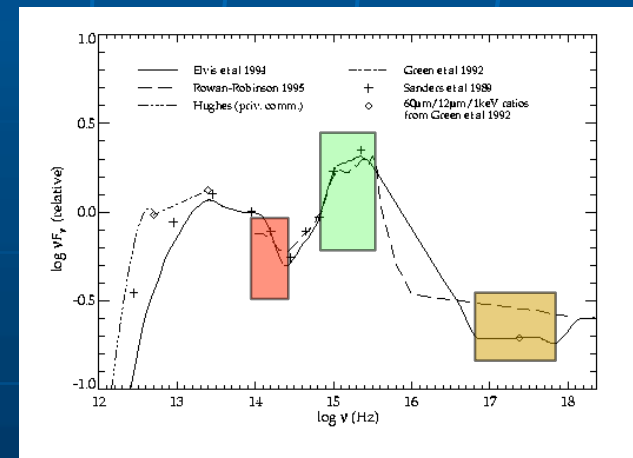
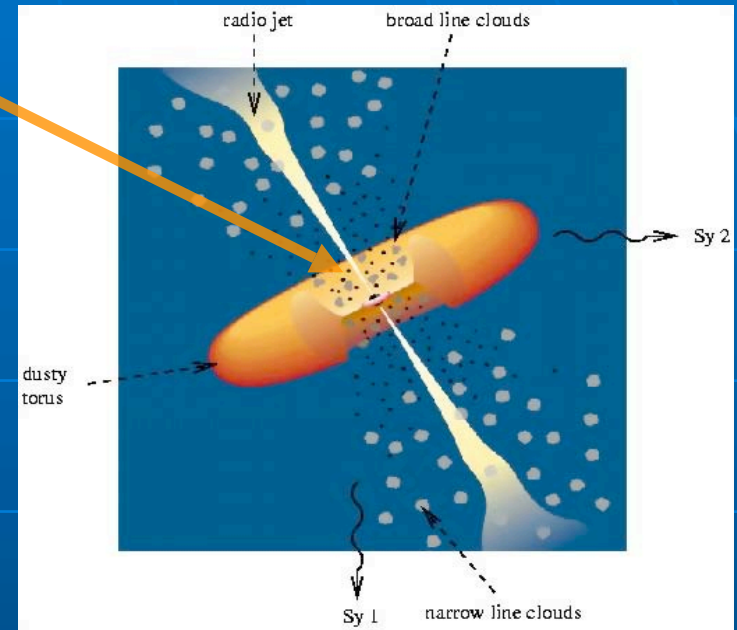


(Manners 2002)

Multiwavelength Studies of AGN

X-rays: direct probe of central engine and accretion luminosity (~ 3200 in Boötes)

(Urry & Padovani 1995)



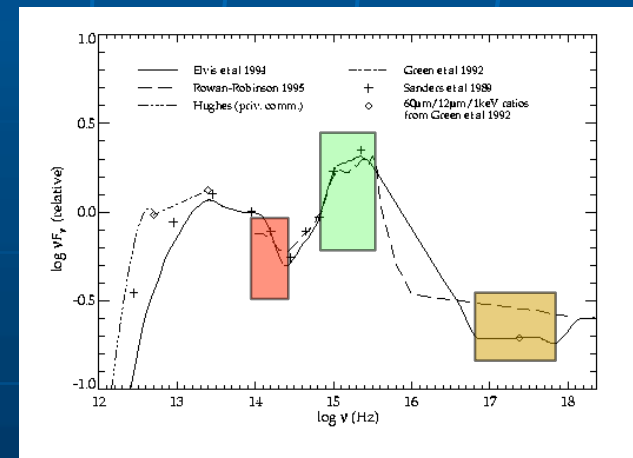
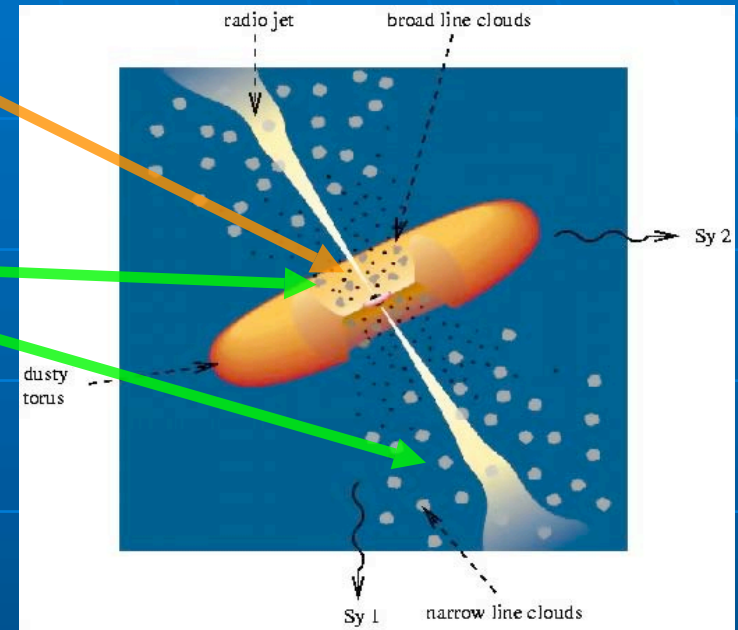
(Manners 2002)

Multiwavelength Studies of AGN

X-rays: direct probe of central engine and accretion luminosity (~ 3200 in Boötes)

Optical/UV: probe of regions close to (BL) or farther from (NL) the black hole; most affected by extinction (~ 2000 in Boötes)

(Urry & Padovani 1995)



(Manners 2002)

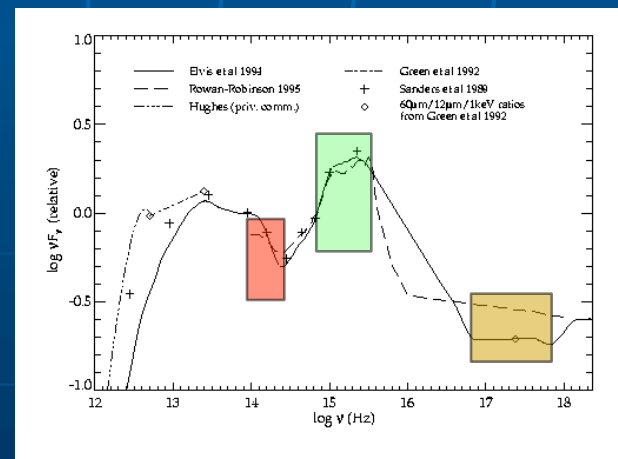
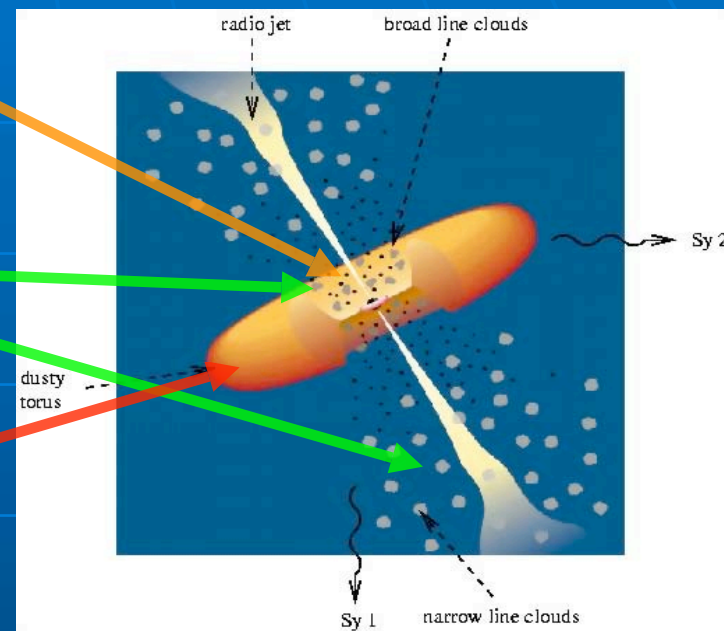
Multiwavelength Studies of AGN

X-rays: direct probe of central engine and accretion luminosity (~ 3200 in Boötes)

Optical/UV: probe of regions close to (BL) or farther from (NL) the black hole; most affected by extinction (~ 2000 in Boötes)

Infrared: due to reprocessed emission from dust, heated by the central engine (~ 2000 in Boötes)

(Urry & Padovani 1995)



(Manners 2002)

Multiwavelength Studies of AGN

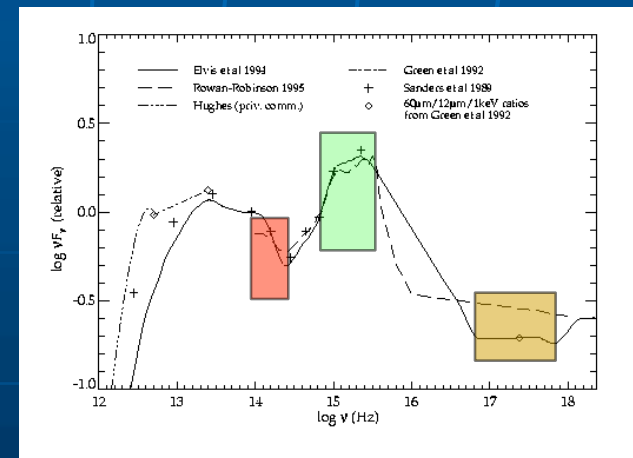
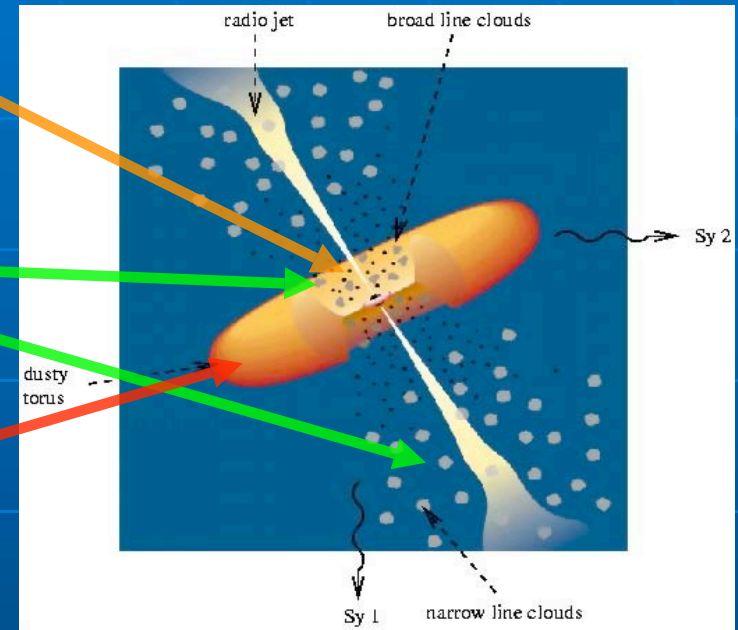
X-rays: direct probe of central engine and accretion luminosity (~3200 in Boötes)

Optical/UV: probe of regions close to (BL) or farther from (NL) the black hole; most affected by extinction (~2000 in Boötes)

Infrared: due to reprocessed emission from dust, heated by the central engine (~2000 in Boötes)

Total AGN Density ~600 deg²

(Urry & Padovani 1995)



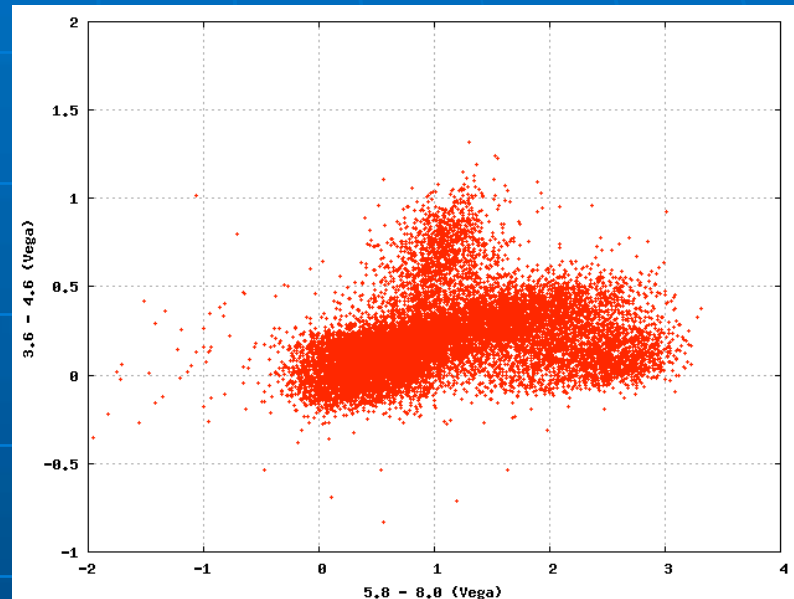
(Manners 2002)

Multiwavelength Studies of AGN

Spitzer IRAC Color-Color Selection of AGN

Multiwavelength Studies of AGN

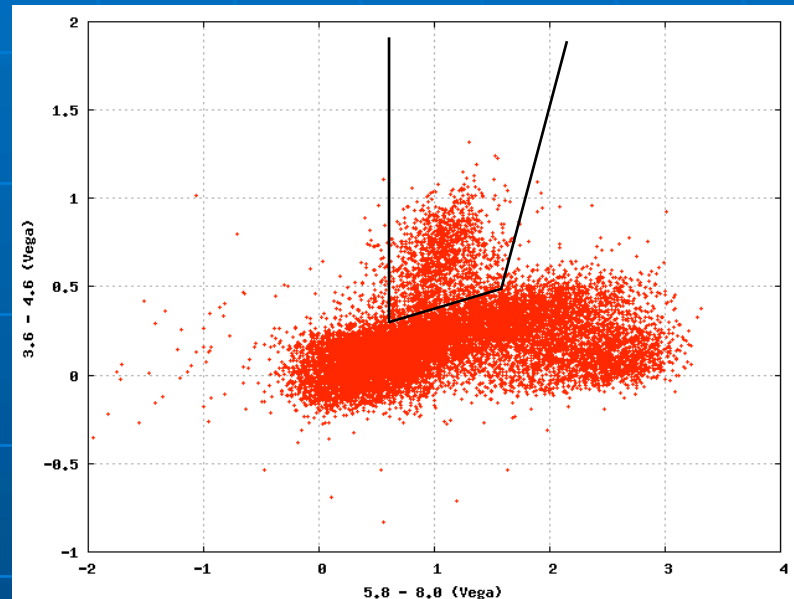
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Multiwavelength Studies of AGN

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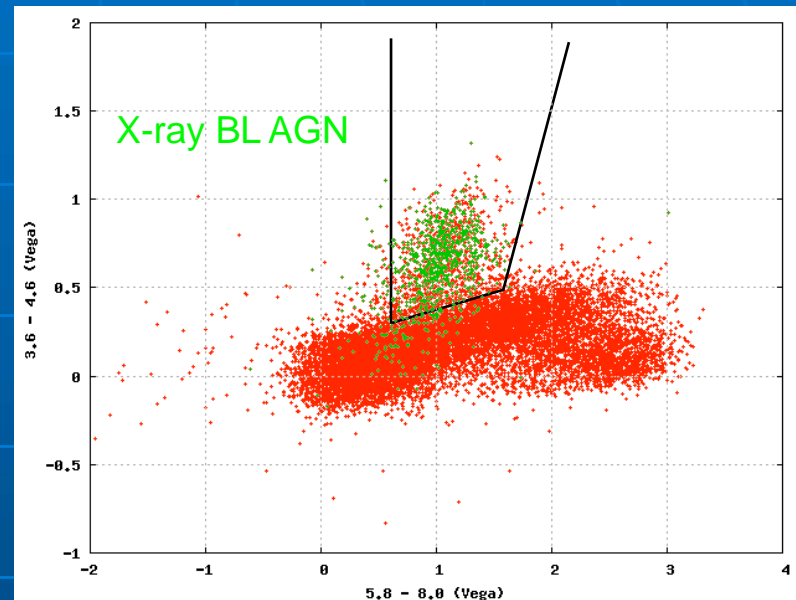
IRAC AGN 'Wedge'
Stern et al 2005



Multiwavelength Studies of AGN

Spitzer IRAC Color-Color Selection of AGN

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Multiwavelength Studies of AGN

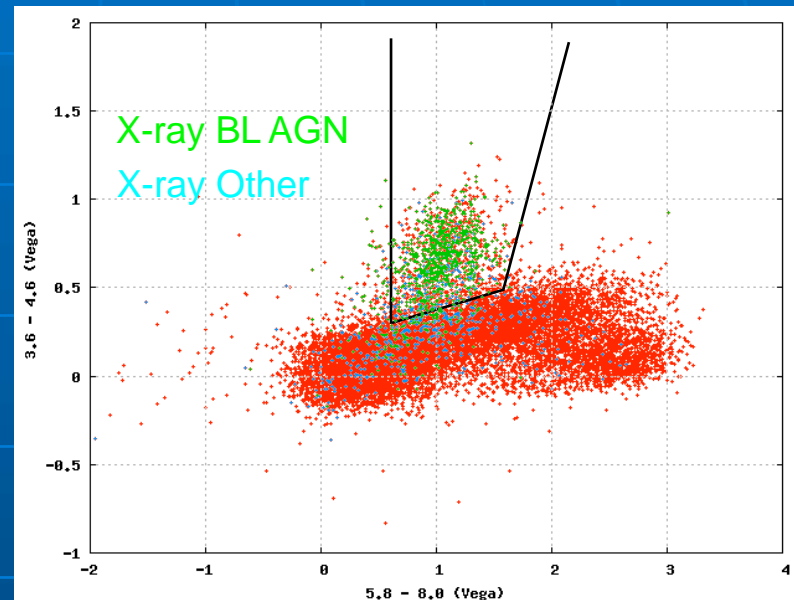
Spitzer IRAC Color-Color Selection of AGN

IRAC AGN 'Wedge'
Stern et al 2005

X-rays: ~3300 in Bootes sample
(≥ 4 counts, ~1/2 in wedge)

Optical/UV: ~2000 in sample
(~1/2 X-ray selected)

Infrared: ~2000 in sample
(~1/2 X-ray selected)



Multiwavelength Studies of AGN

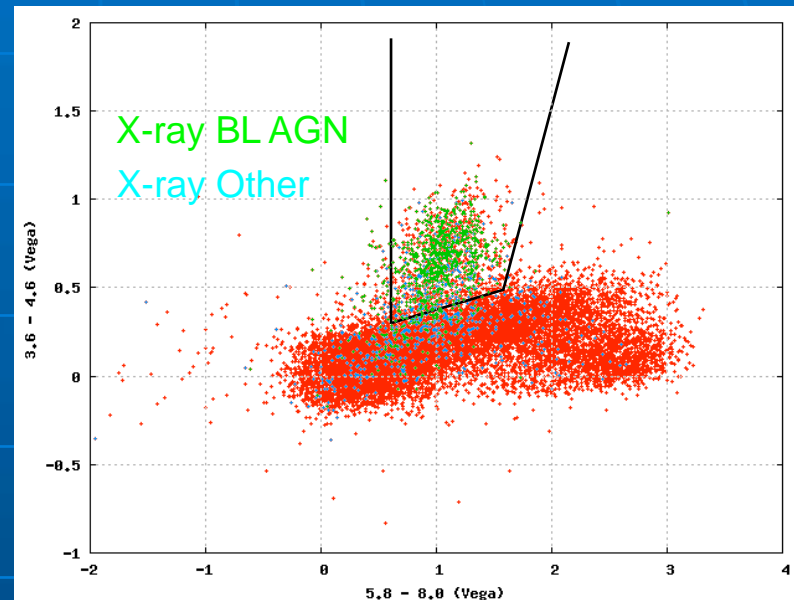
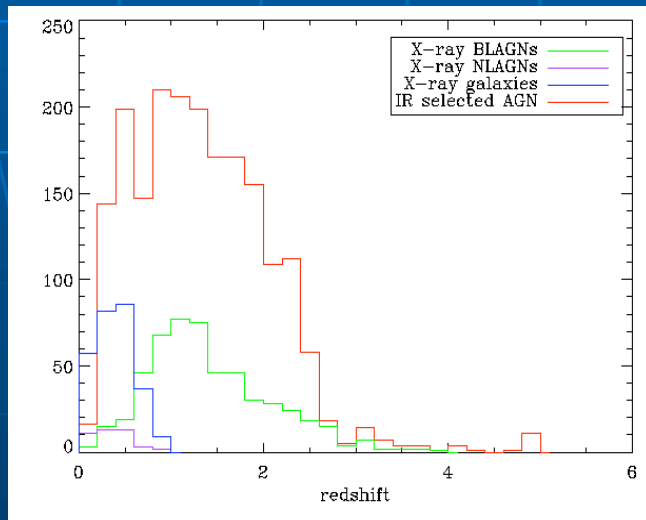
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(~1/2 X-ray selected)

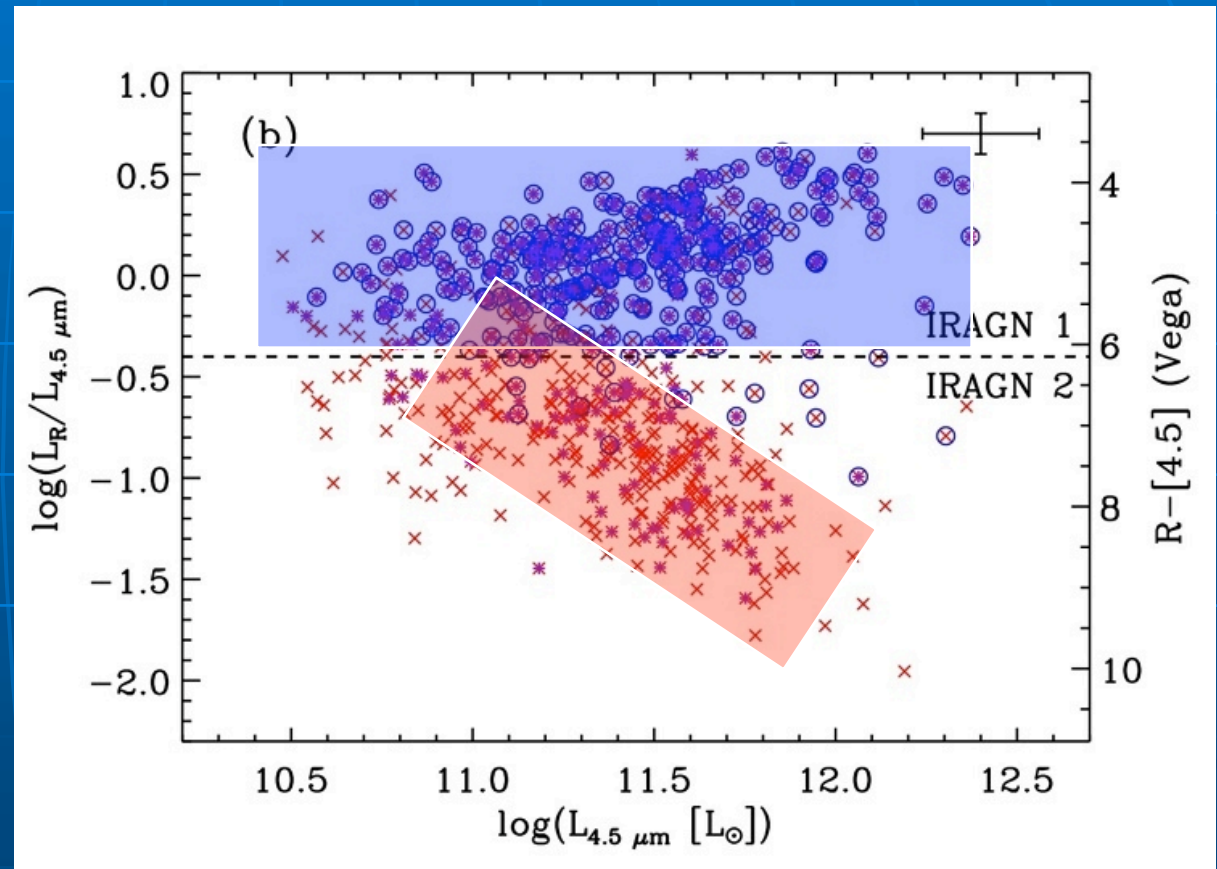


Color-Selection of Obscured AGNs

Selection Criteria:

- 5σ in all IRAC bands
- In IR AGN Wedge
- NOAO R-band flux (1915 total)
- Redshift > 0.7
- Spectroscopic or Photo-z (1410)

~1/2 X-raydetected



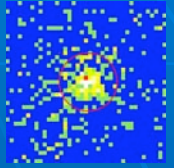
X-ray Spectral Shapes

Hardness ratio:

$$HR = (HB - SB) / (HB + SB)$$

crude measure of X-ray spectrum

Average X-ray
fluxes from
stacking analysis



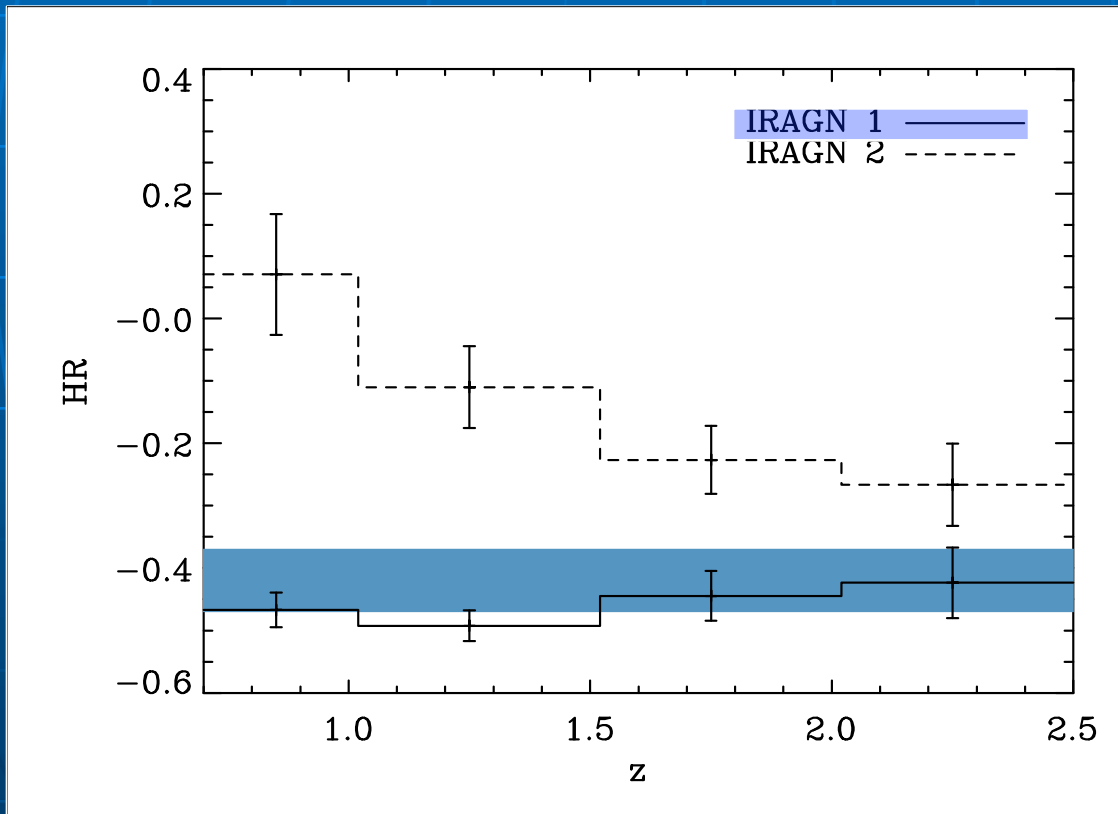
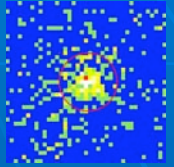
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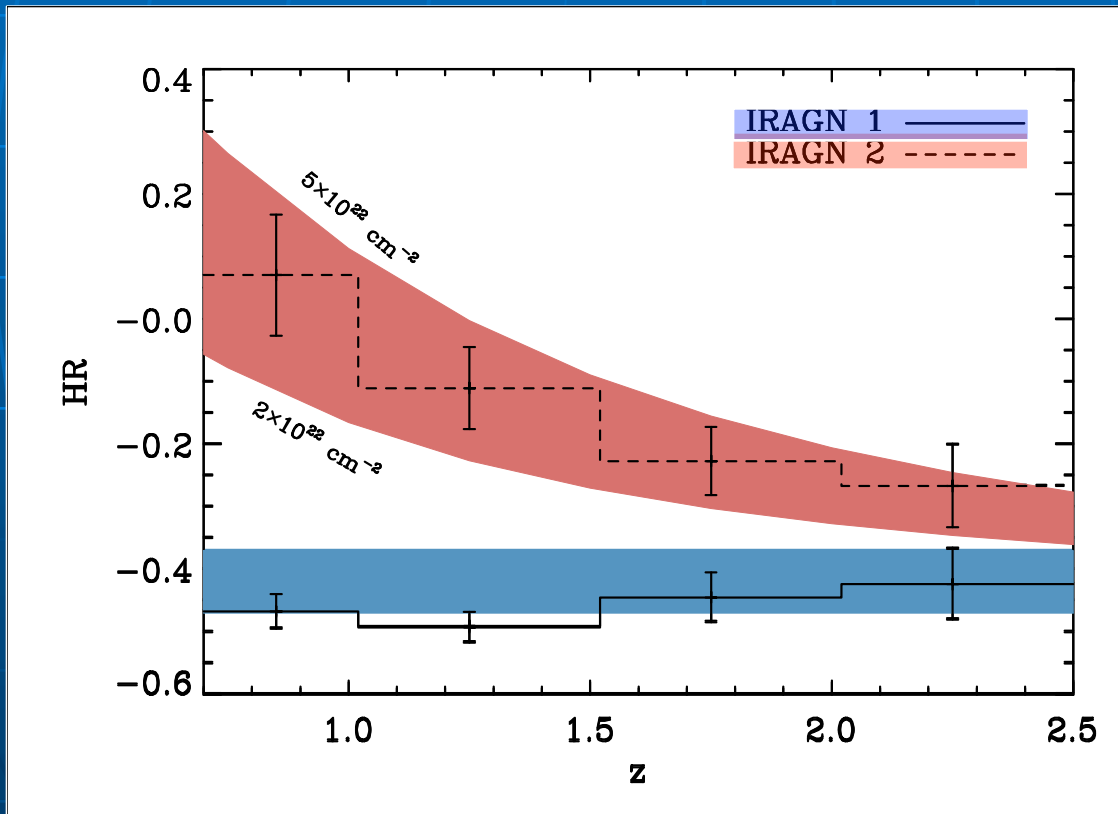
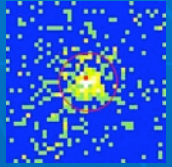
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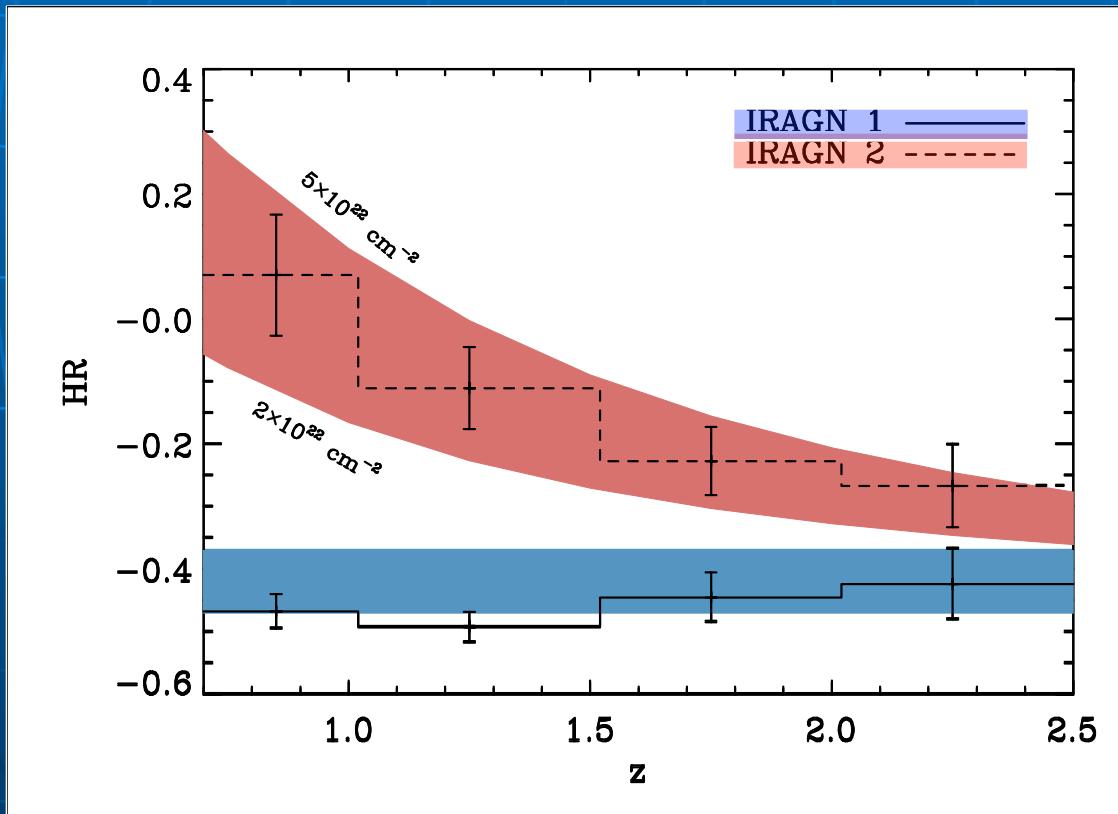
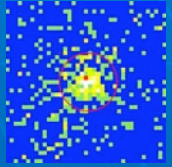
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X-ray Spectral Shapes

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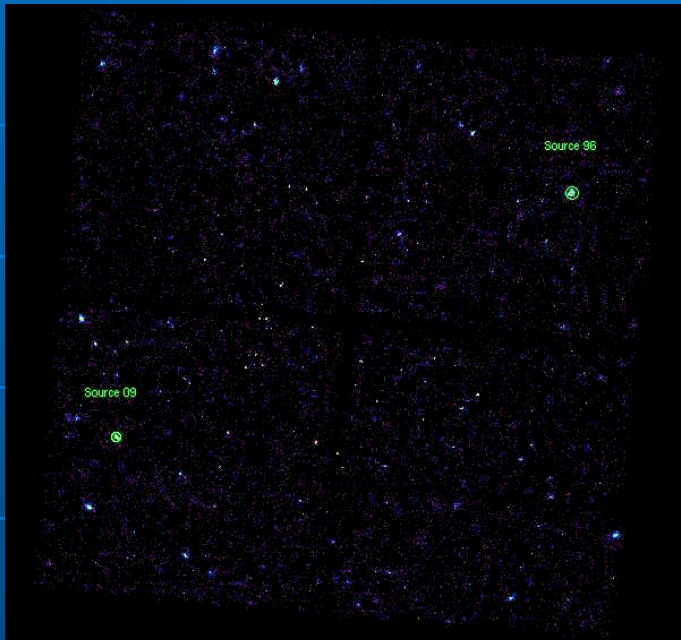


HR for IRAGN 2s
corresponds to
moderate obscuration,
 $N_H \sim 3 \times 10^{22} \text{ cm}^{-2}$

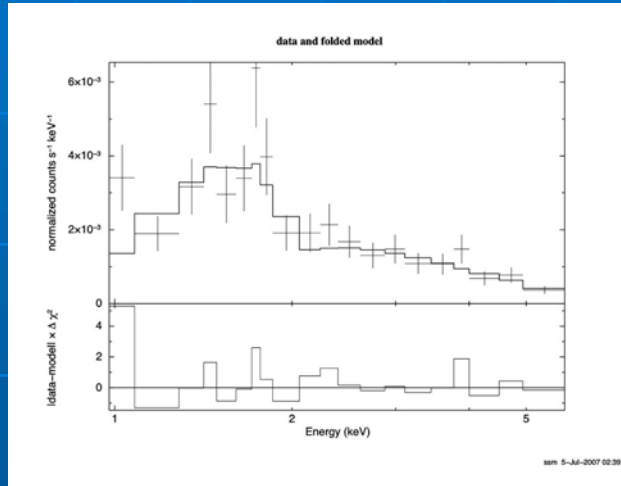
HR ~ -0.5 for IRAGN 1s
corresponds to a spectrum
typical of Type 1 AGNs
(photon index $\Gamma = 1.8$)

Follow up Observations of IRAGN2

Source 96

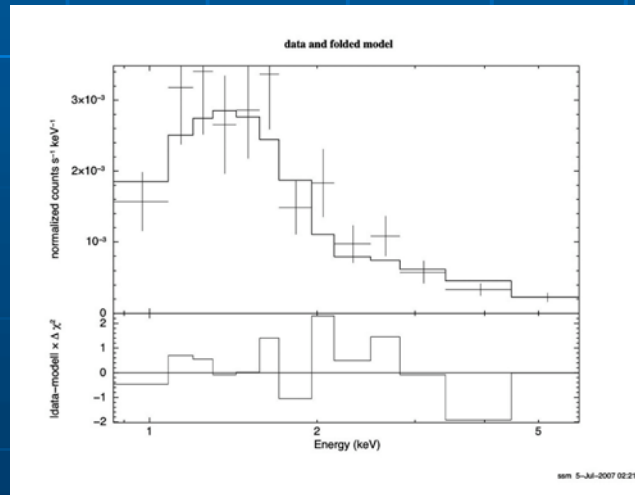


40 ksec ACIS-I
~250 cts/IRAGN



$z=0.92$
 $nH=4.1\pm 0.6\times 10^{22}\text{ cm}^{-2}$
 $\Gamma=1.70$

Source 09



$z=1.58$
 $nH=2.9\pm 1.0\times 10^{22}\text{ cm}^{-2}$
 $\Gamma=1.70$

* Using AGN to Observe the Cosmic Web

Xbootes 9.3 Square Degree Survey

Large Scale Structure

- Other Surveys

- DEEP2

- $0.7 < z < 1.4$
- 4 x 1 sq. deg
- 40,000 redshifts

OCDM

- 2dF

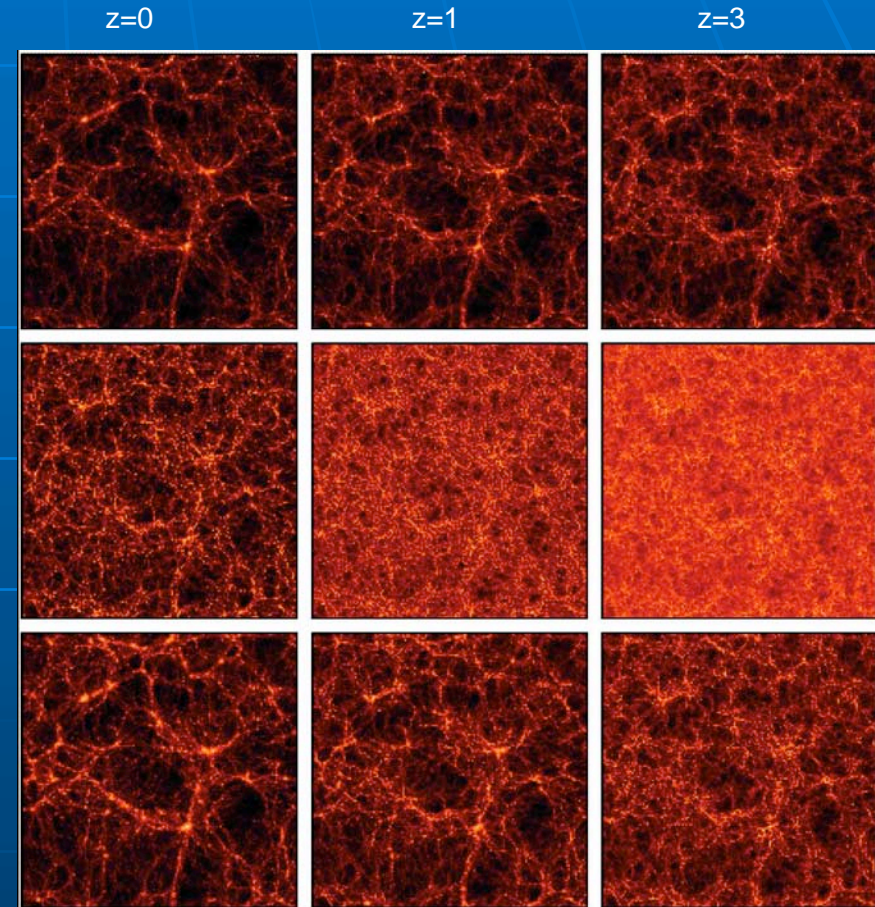
- $z < 0.2$
- 1500 sq. deg
- 200,000 redshifts

SCDM

- SDSS (~12 AGN /sq deg)

- $z < 2.3$
- 6600 sq. deg
- 850,000 redshifts

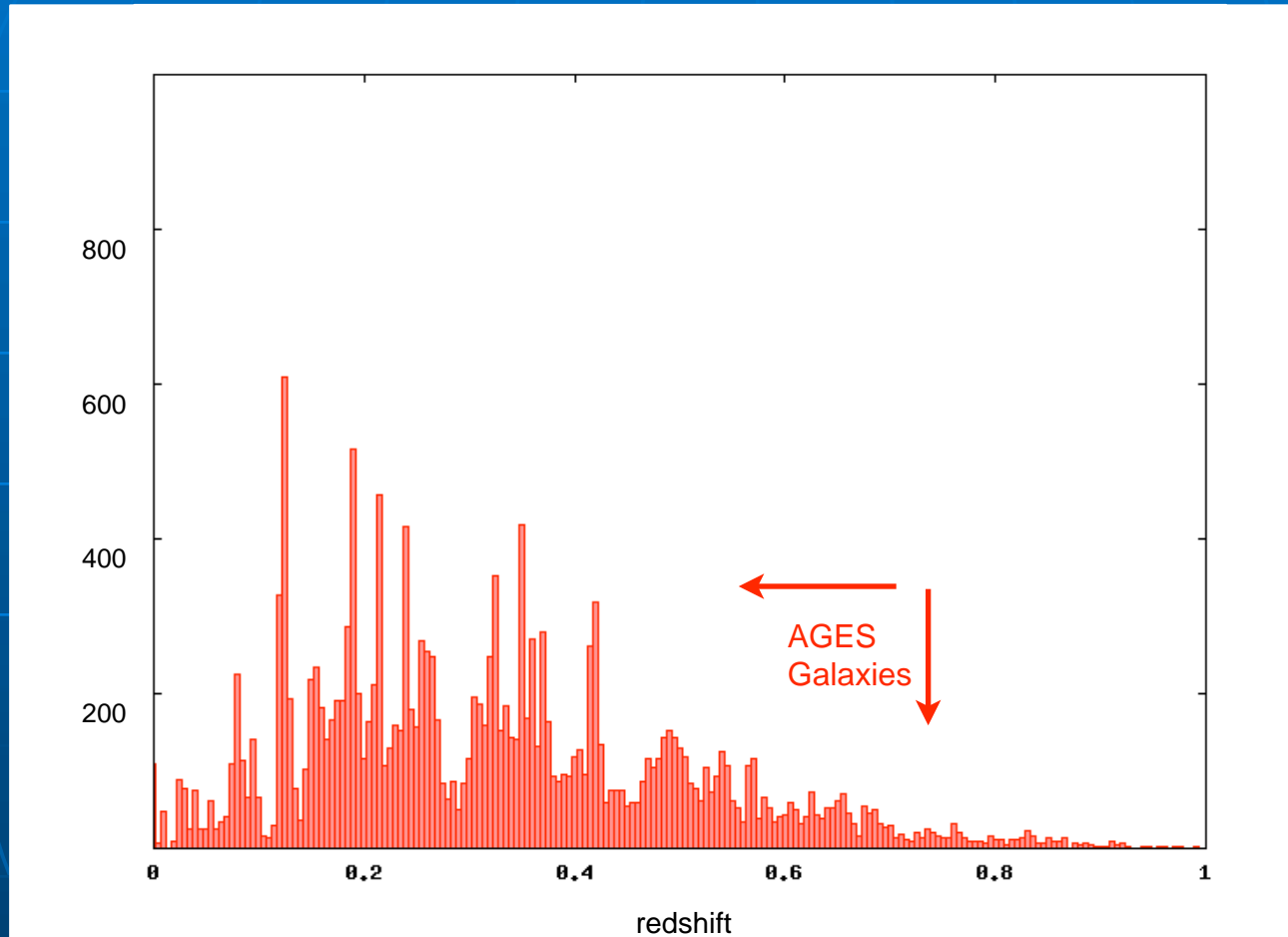
LCDM



Jenkins et al., 1998 (ApJ, 499, 20-40)

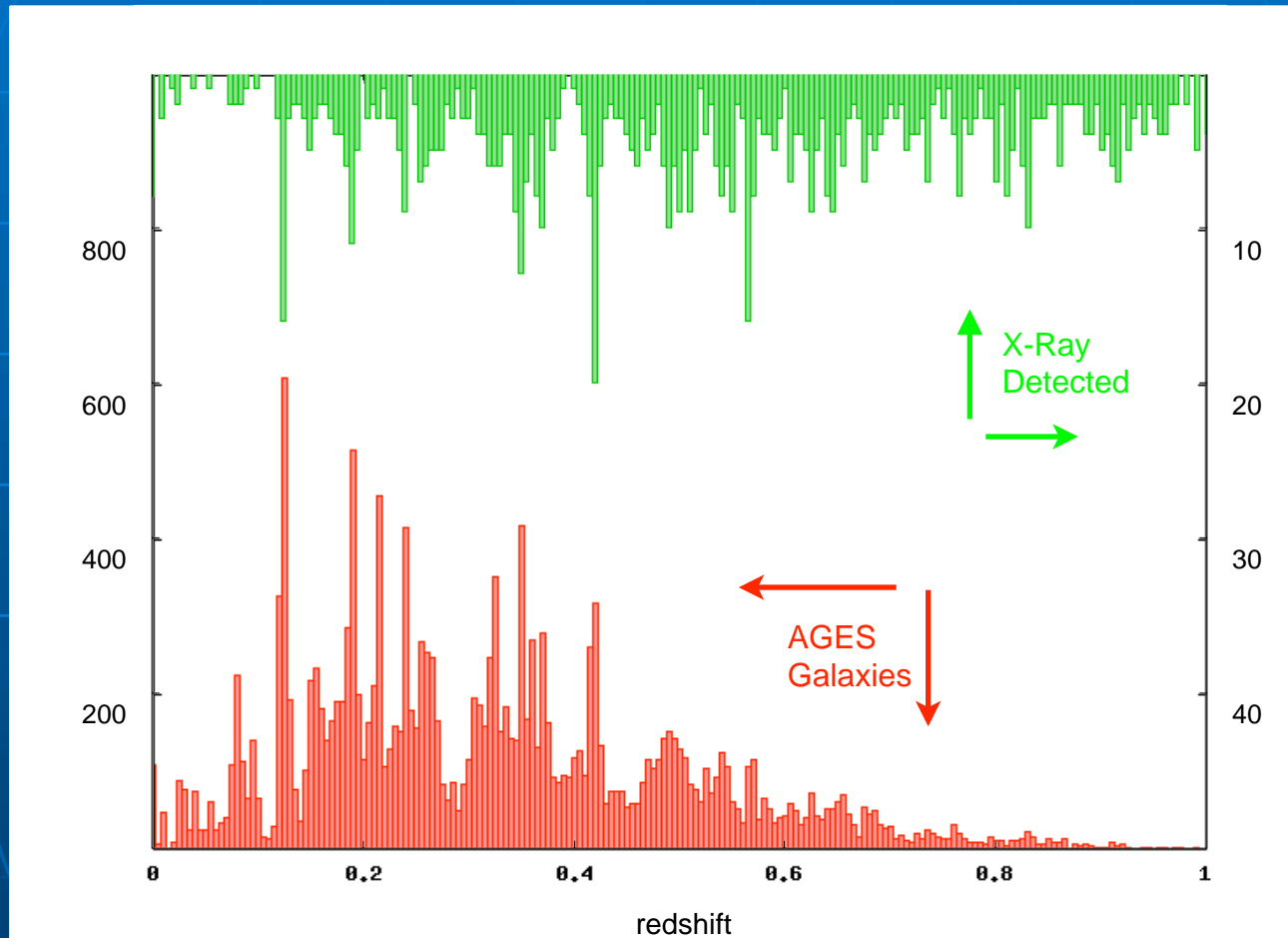
Large Scale Structure

Enabled by the high surface density of AGN in XBoötes Survey



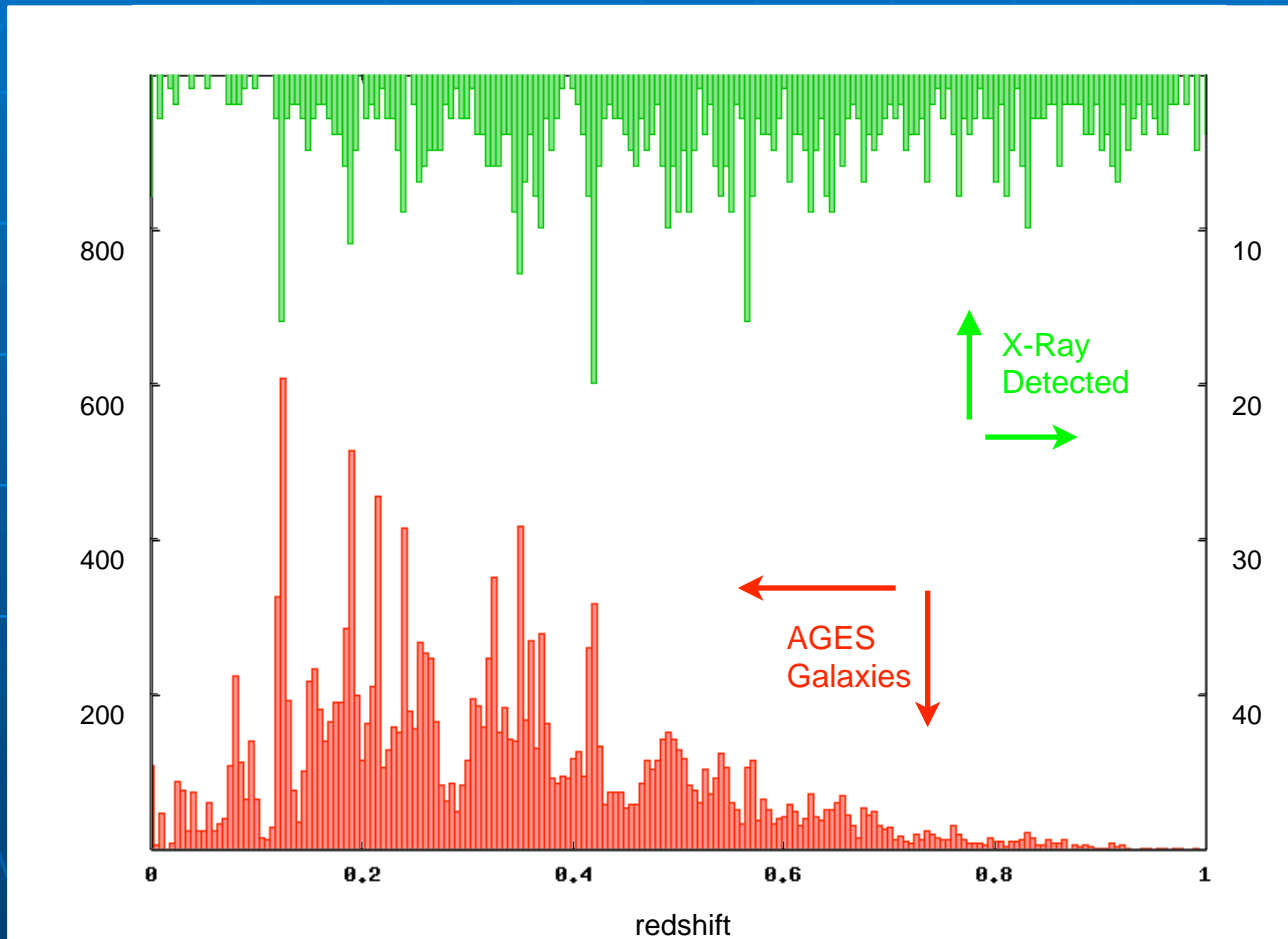
Large Scale Structure

Enabled by the high surface density of AGN in XBoötes Survey



Large Scale Structure

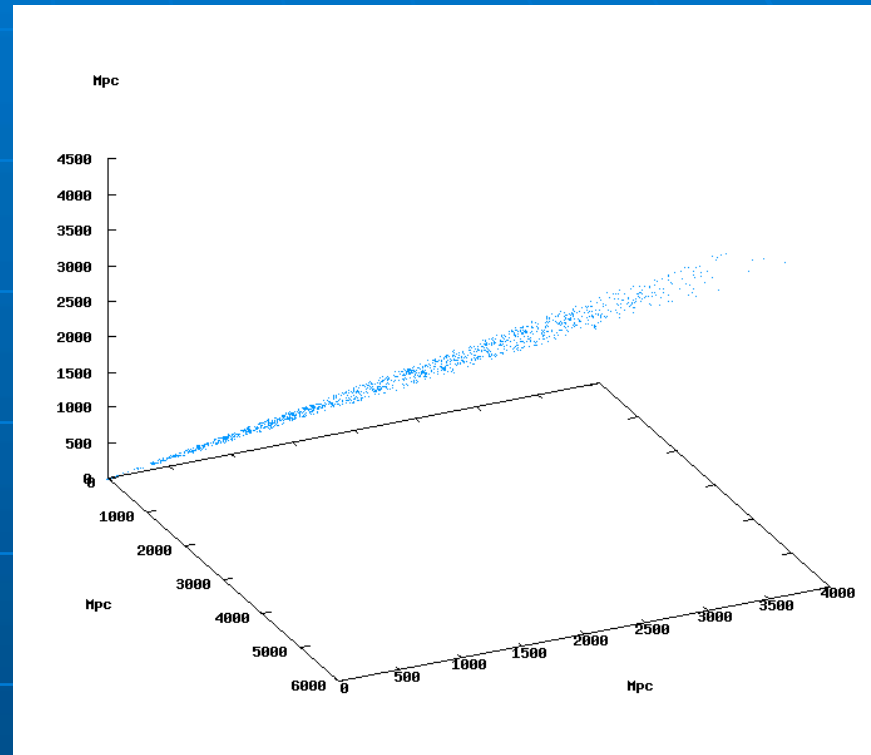
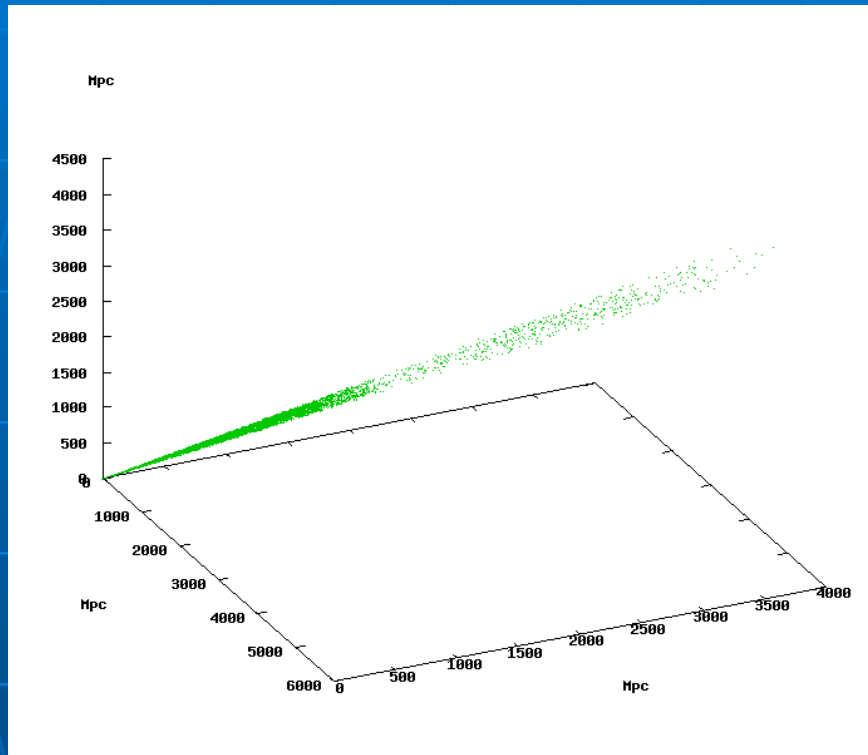
Enabled by the high surface density of AGN in XBoötes Survey



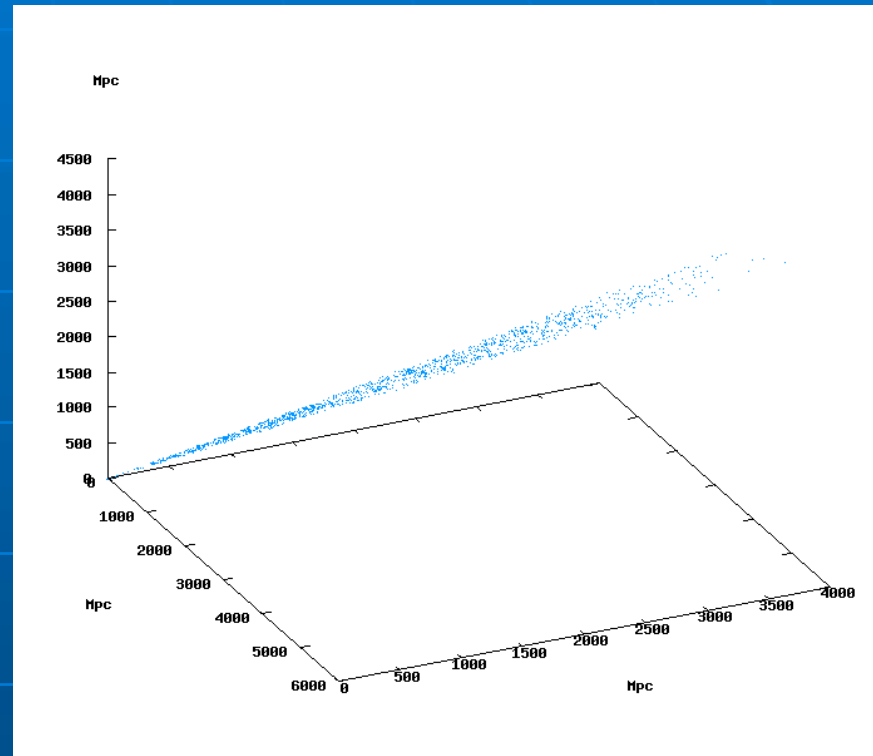
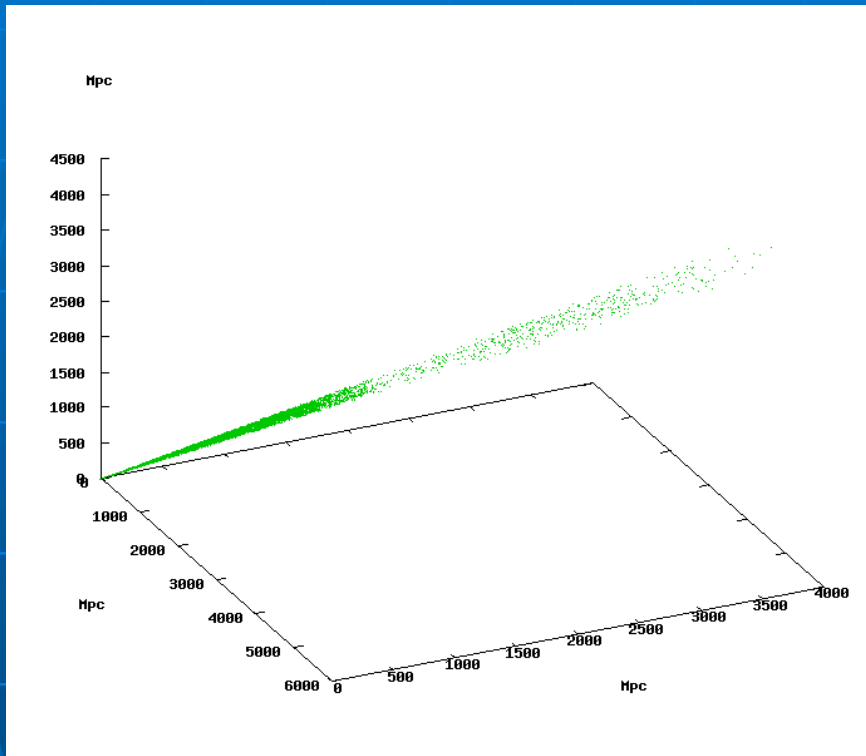
X-Ray selected AGN and galaxies trace same structure at $z < 0.7$
X-Ray sources continue to trace structure at $z > 0.7$

Survey Results ($0 < z < 5$)

Survey Results ($0 < z < 5$)

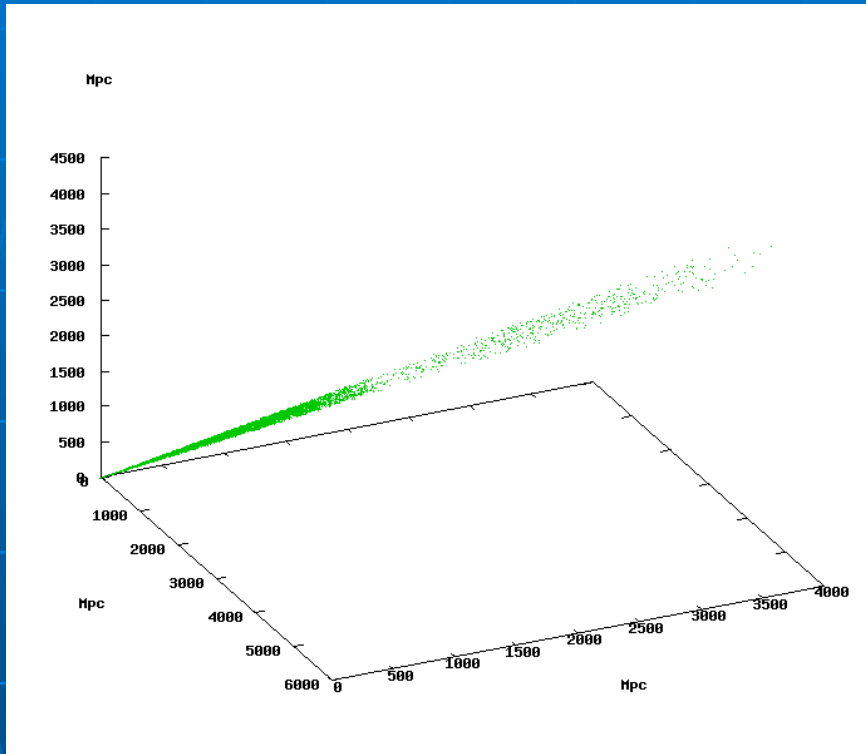


Survey Results ($0 < z < 5$)

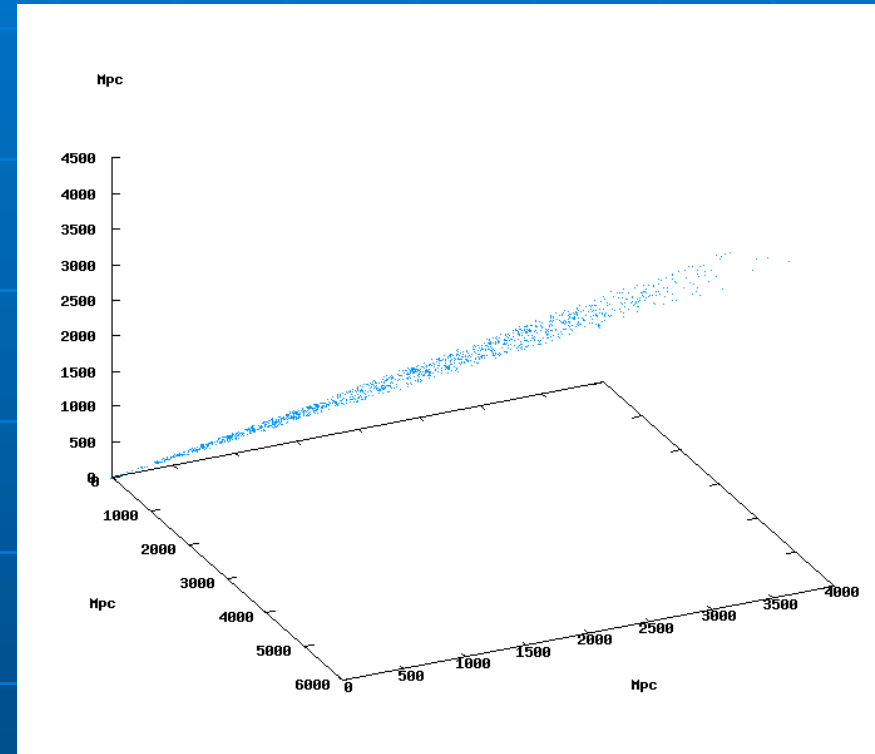


- Not X-ray Selected (18,820)
- Most galaxies with $z < 0.7$
- 531 $z > 1$, must be AGN, but not detected in shallow x-ray survey

Survey Results ($0 < z < 5$)

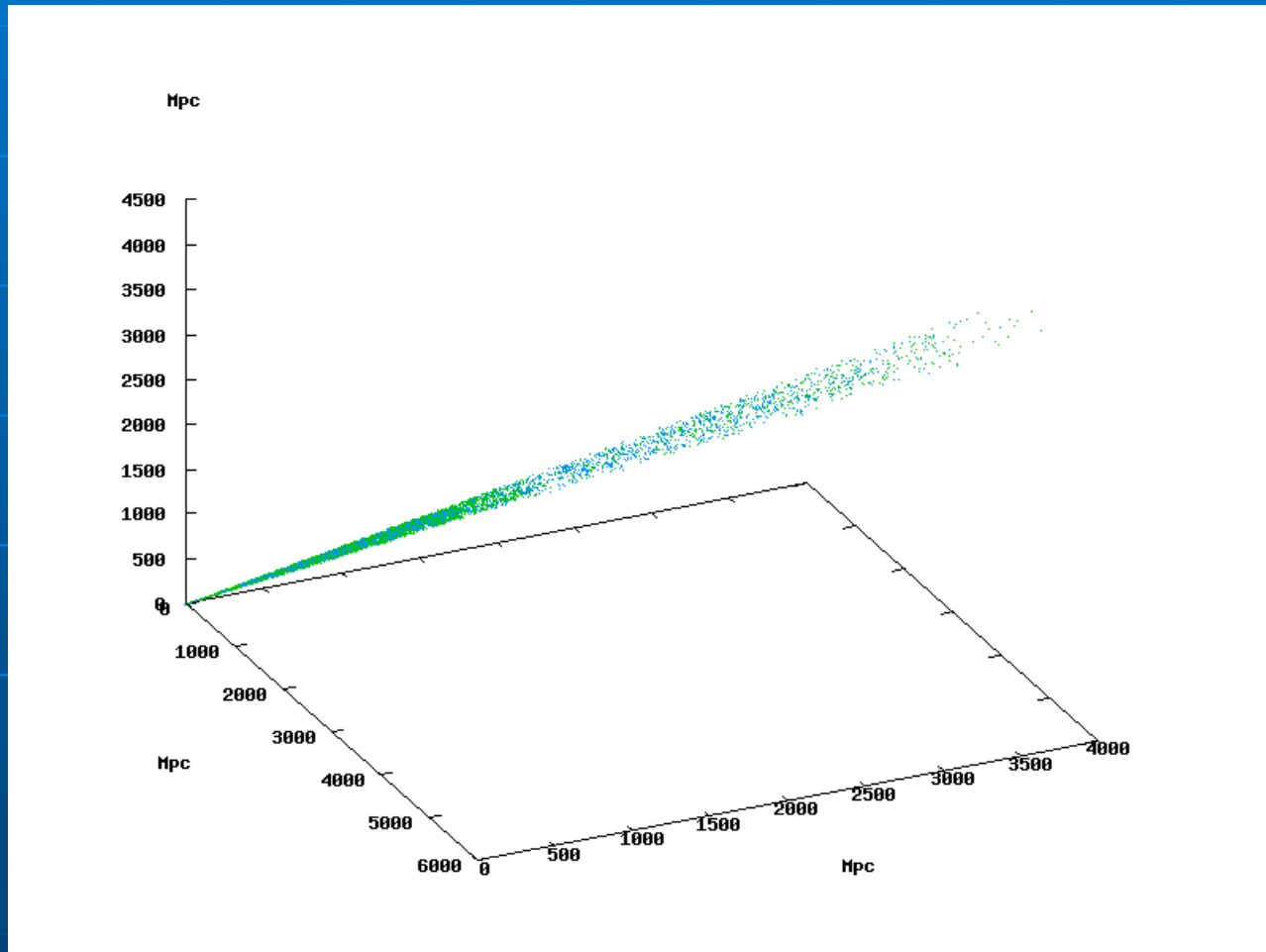


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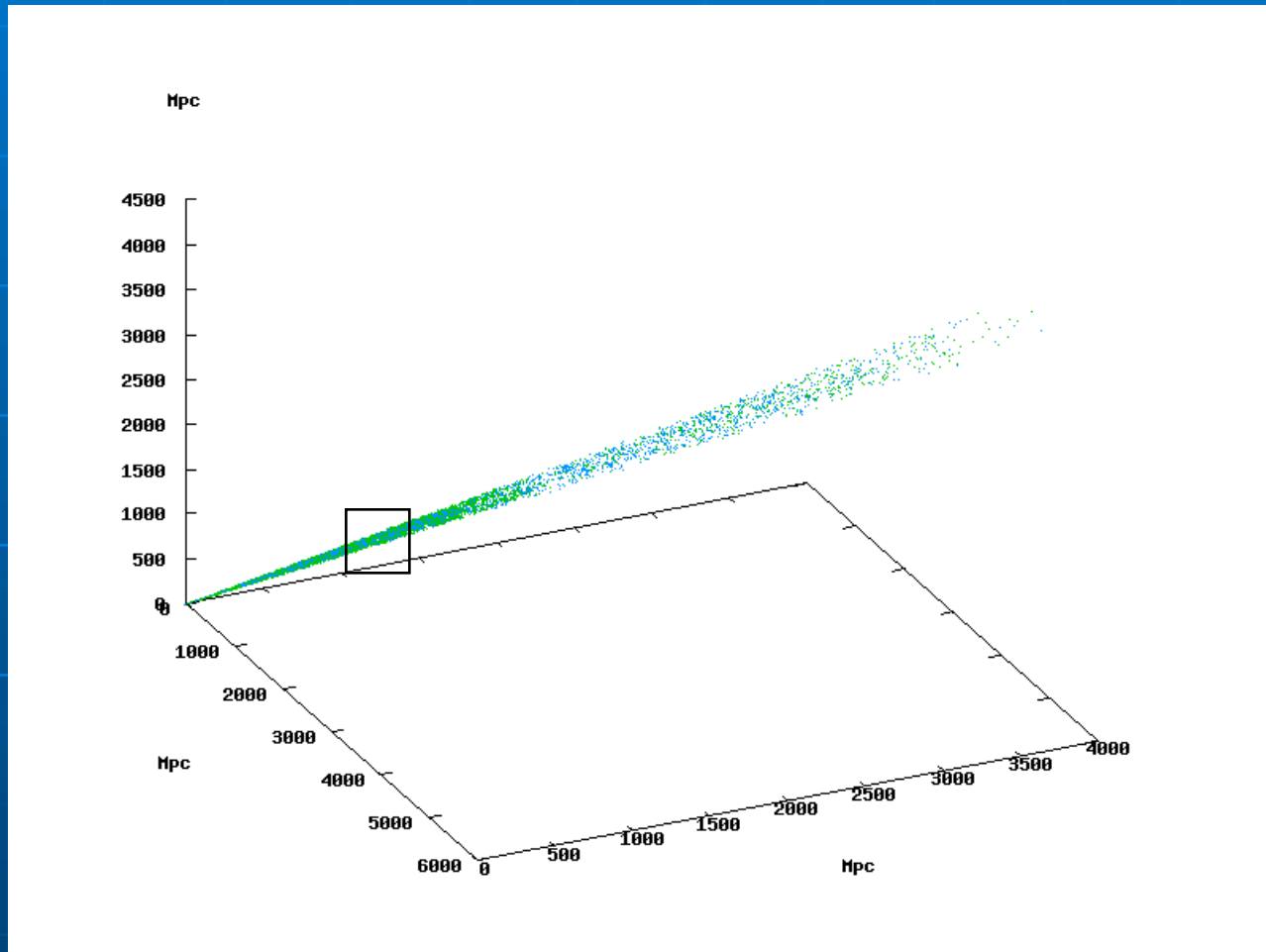


- X-ray Selected (1531)
- ~250 “galaxies”
- ~80 “narrow emission line”
- ~1200 “AGN”

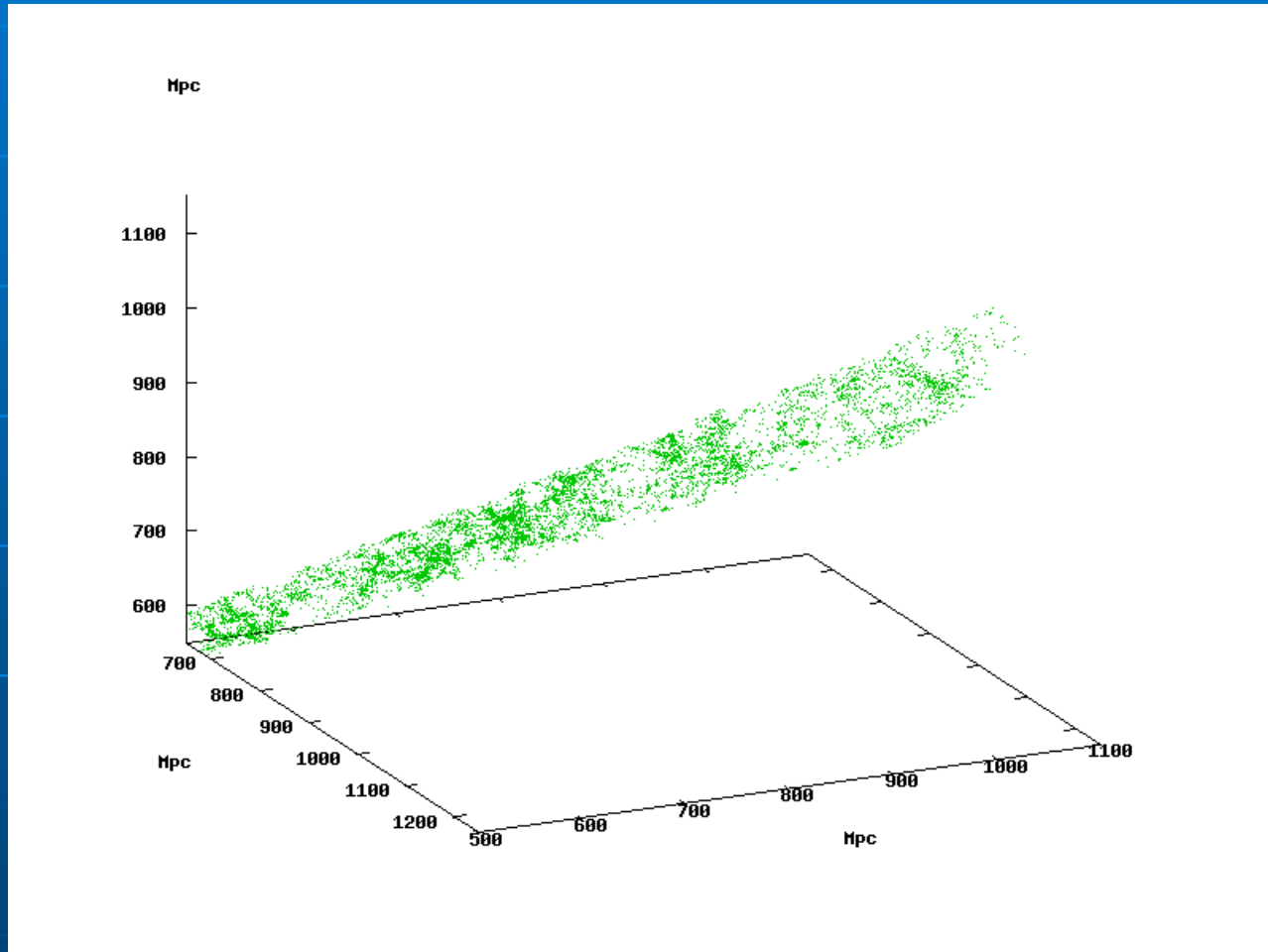
Structure ($0.25 < z < 0.50$)



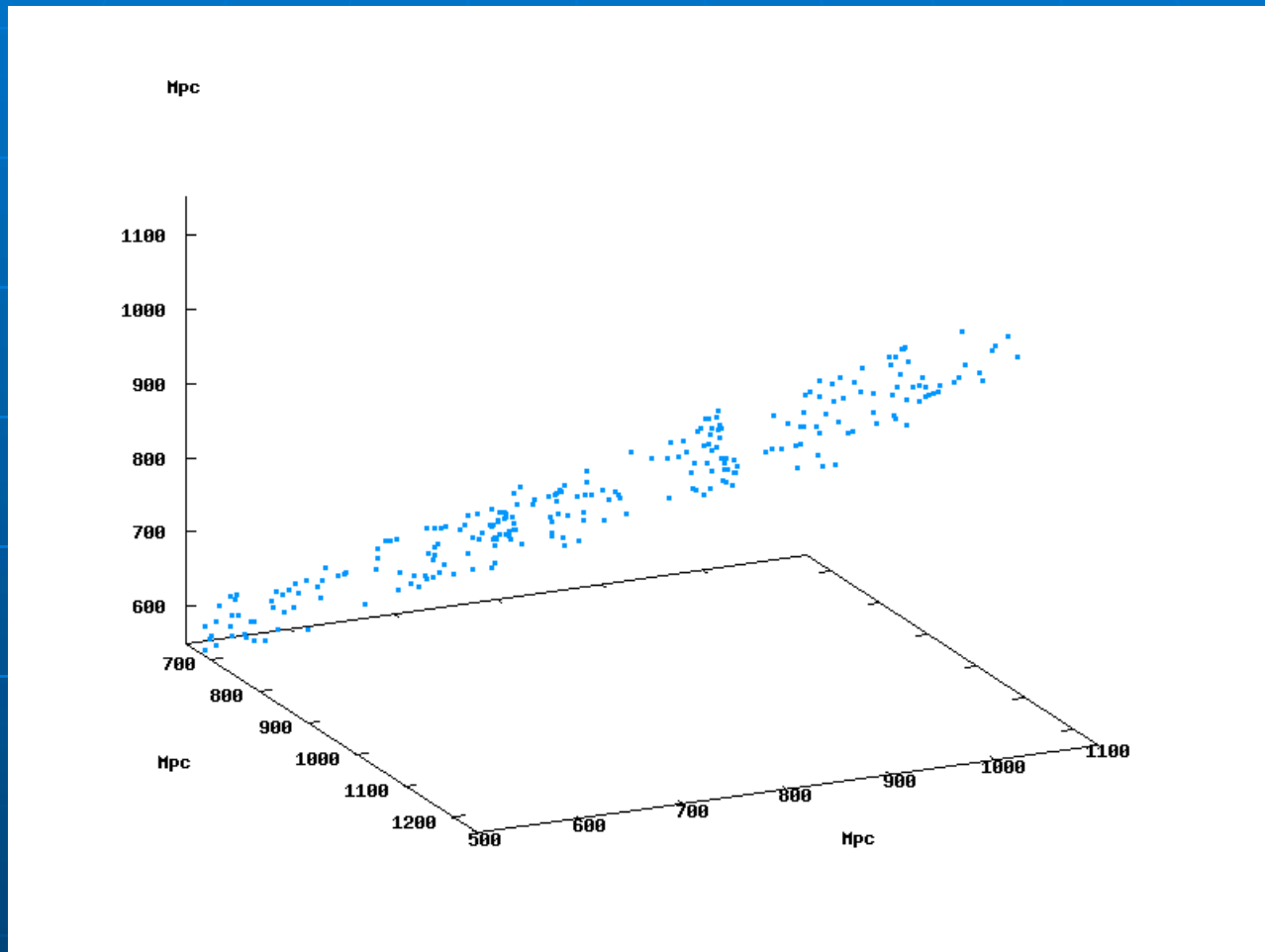
Structure ($0.25 < z < 0.50$)



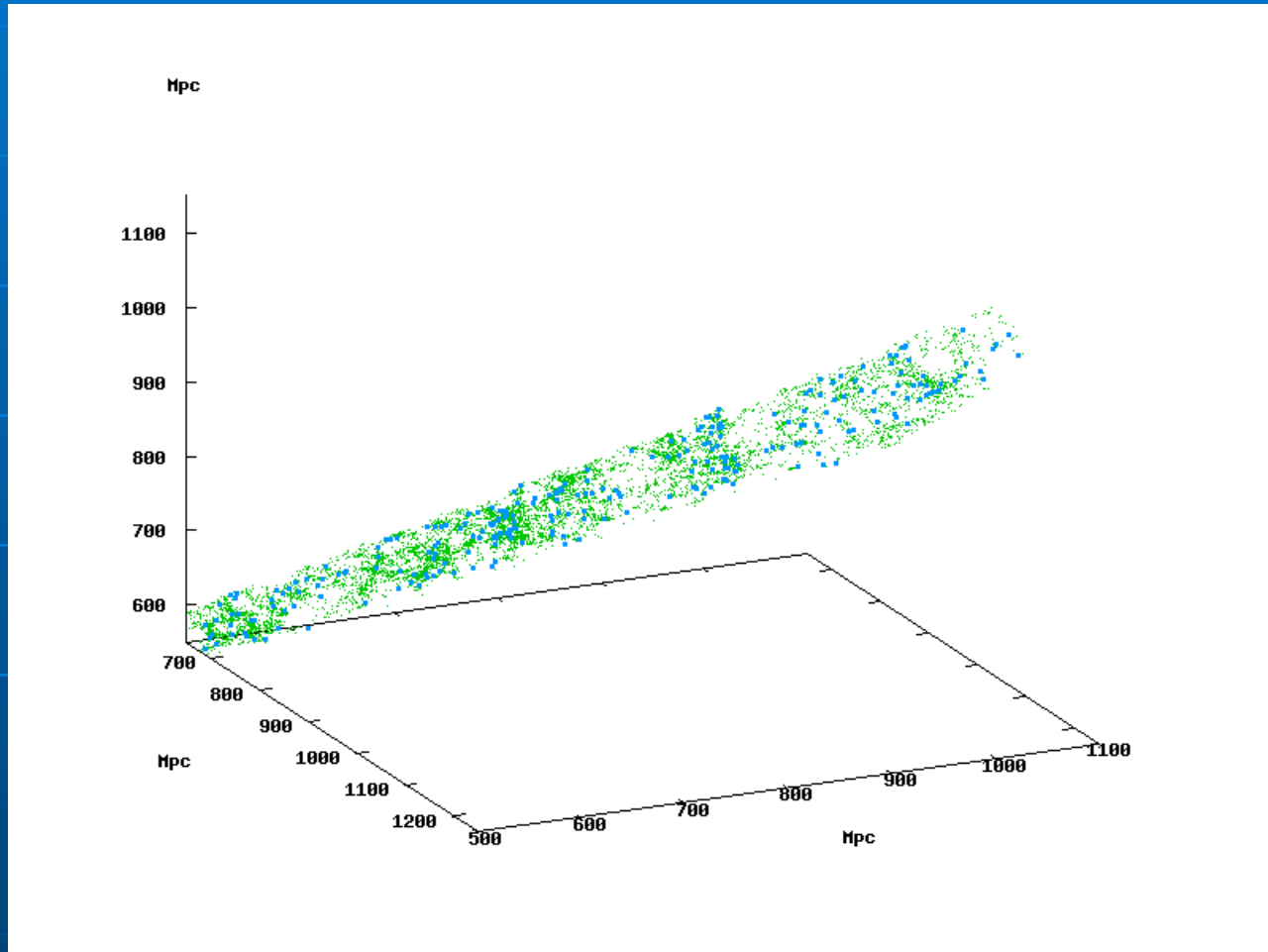
Structure ($0.25 < z < 0.50$)



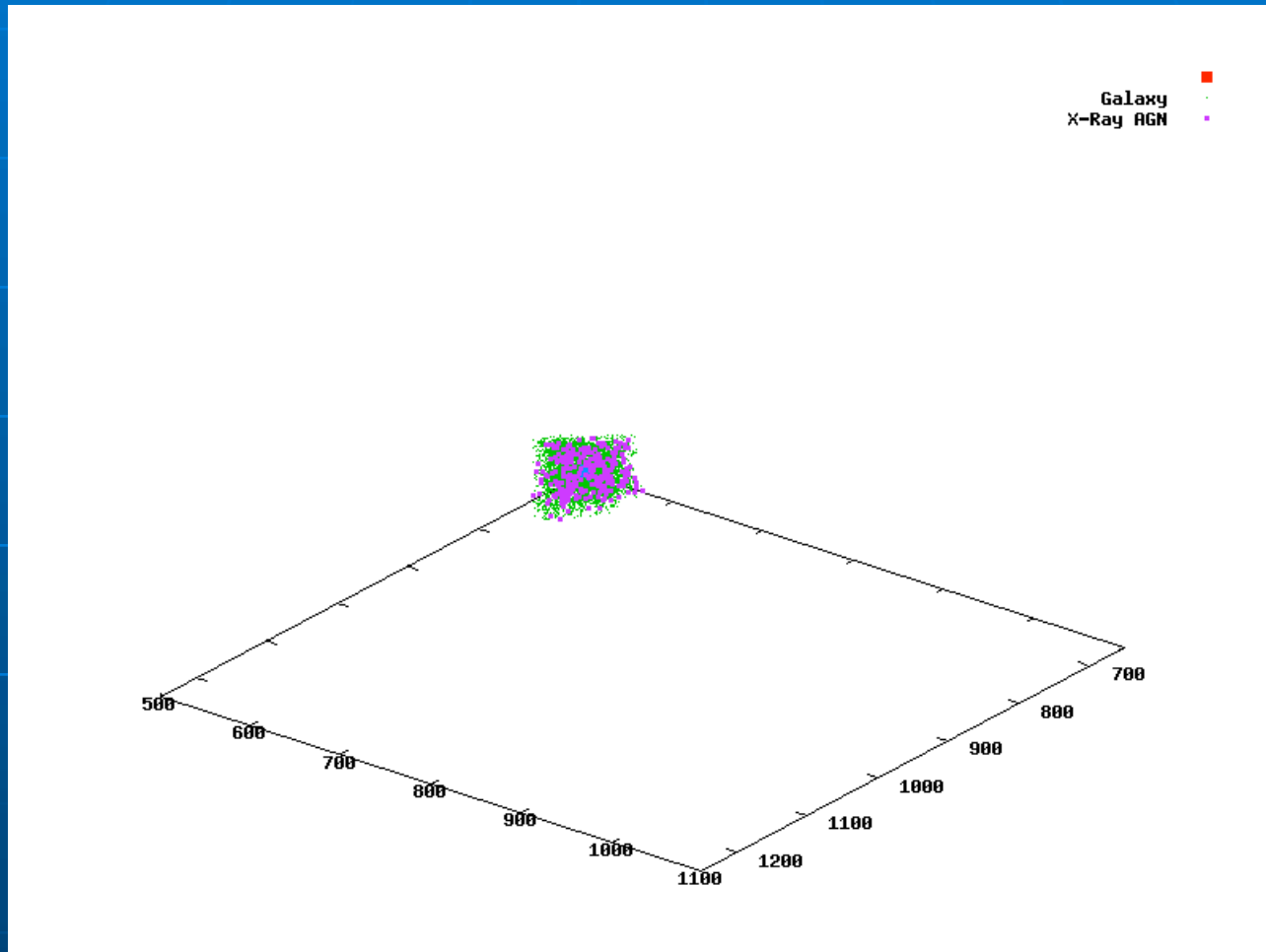
Structure ($0.25 < z < 0.50$)



Structure ($0.25 < z < 0.50$)

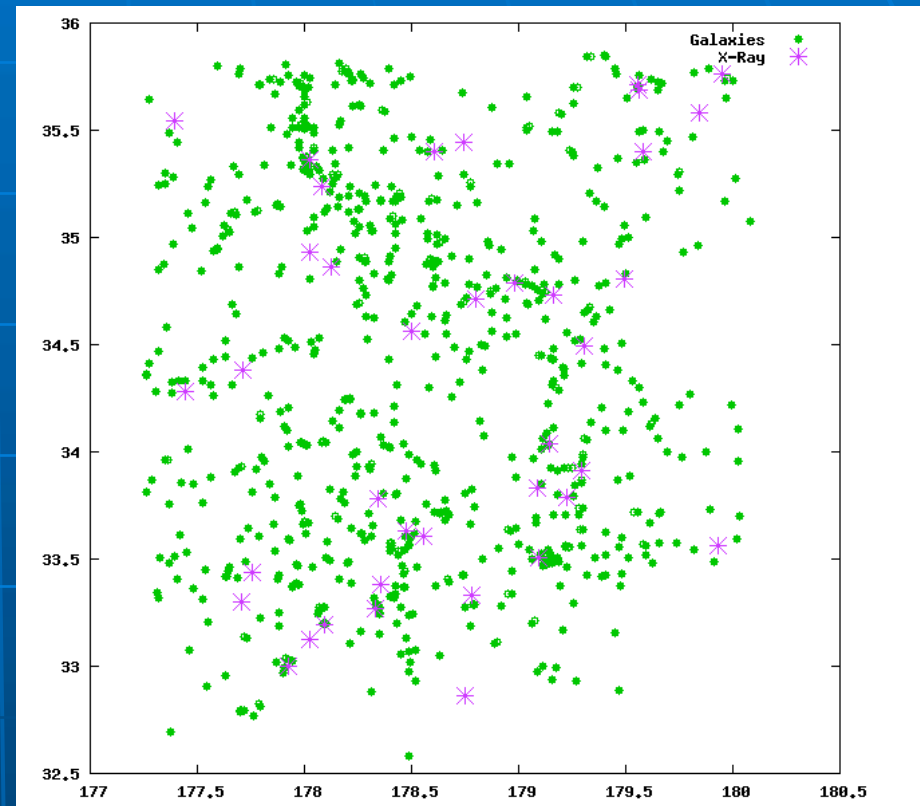


Structure ($0.25 < z < 0.50$)



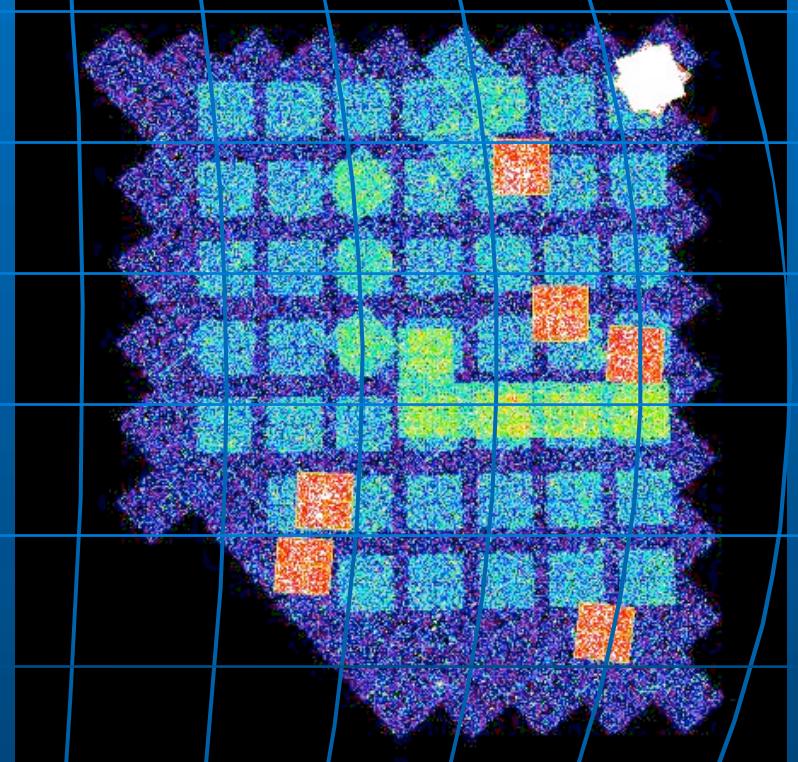
AGN Environment

- Local Galaxy Density may impact:
 - Activity
 - Type
 - Luminosity
 - ...



Redshift Slice $0.41 < z < 0.43$

Work in Progress



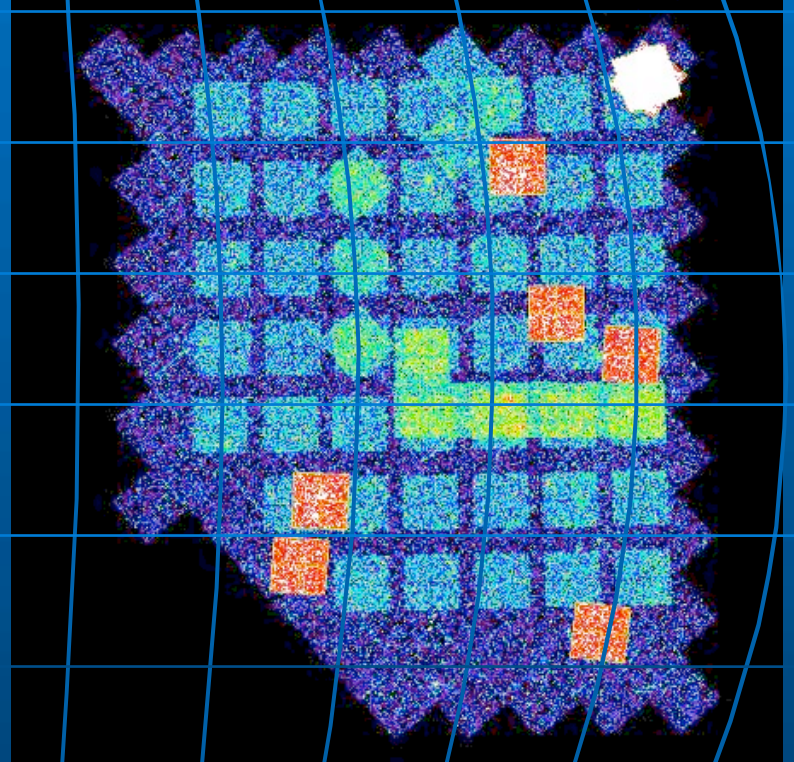
Work in Progress

- Re-survey 1/2 of Bootes to increase the number of AGN and measure variability
- Deeper exposures to extract spectra of IRAGN
- Shallow Survey in DEEP2

How does environment affect the AGN (XBONGS vs BLAGN)?

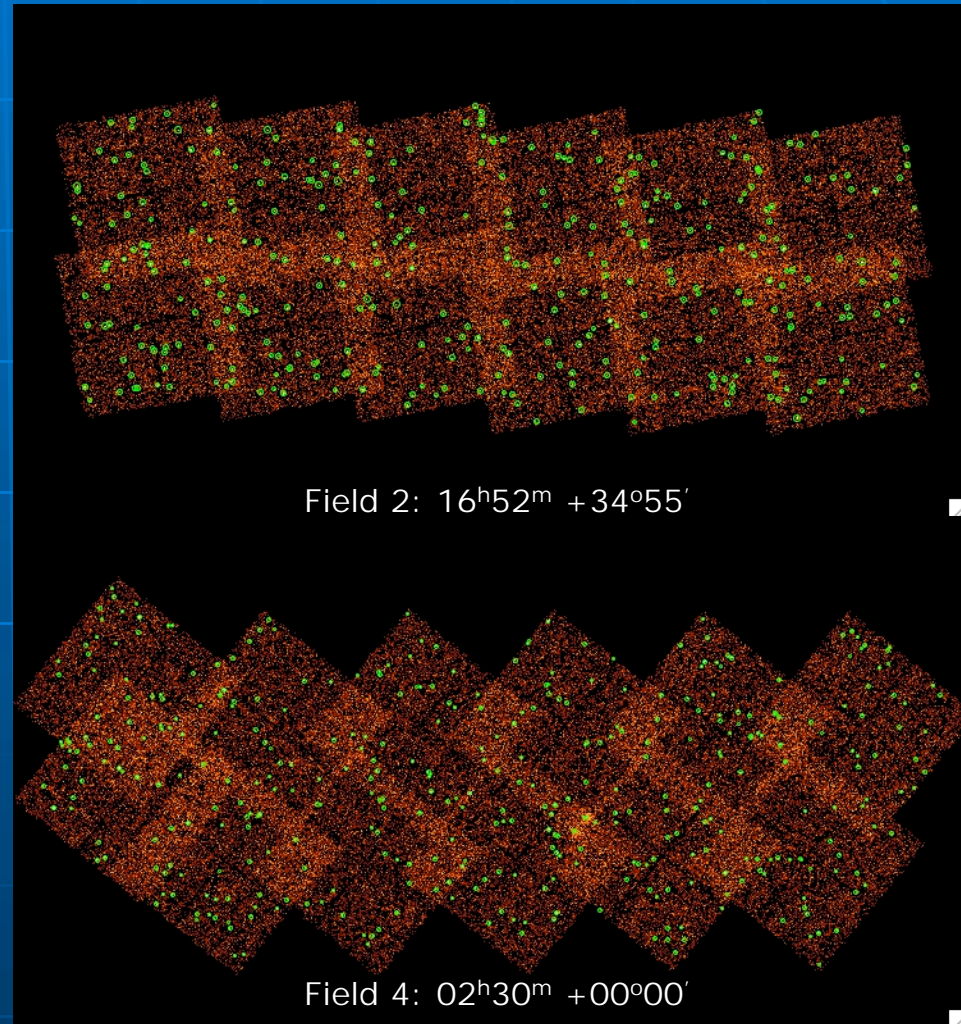
Why is X-ray emission less for IR brighter galaxies?

Does cosmic structure change with redshift?



Chandra DEEP2 Observations

- Fields 2 and 4
 - 12 x 10 ksec exposures for each field
 - some overlaps give 20-30 ksec total (not considered yet)
- Use wavelet source detection
 - 543 Field 2, 578 Field 4 to $\sim 3 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$
 - 347 Field 2, 388 Field 4 to $\sim 5 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$



DEEP2 Matches

Field 2

- X-ray to photometric catalog¹
 - 360/543 (within 2 arc-sec) 0.663
 - 244/347 (≥ 5) = 0.703
- X-ray to Zcat_dr3_v1.0²
 - 72 ($z > 0$); 57 ($0.7 < z < 1.4$)
- Potential w/hectospec $I < 22$
 - 174
 - 136 (≥ 5)

Field 4

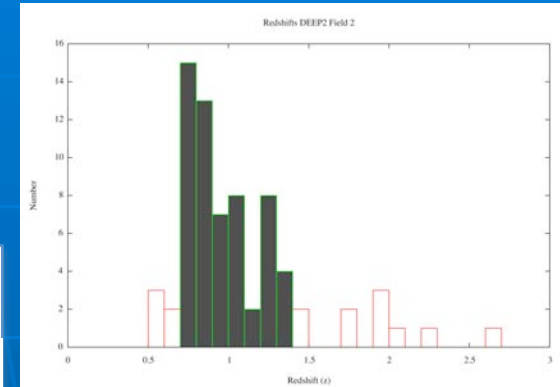
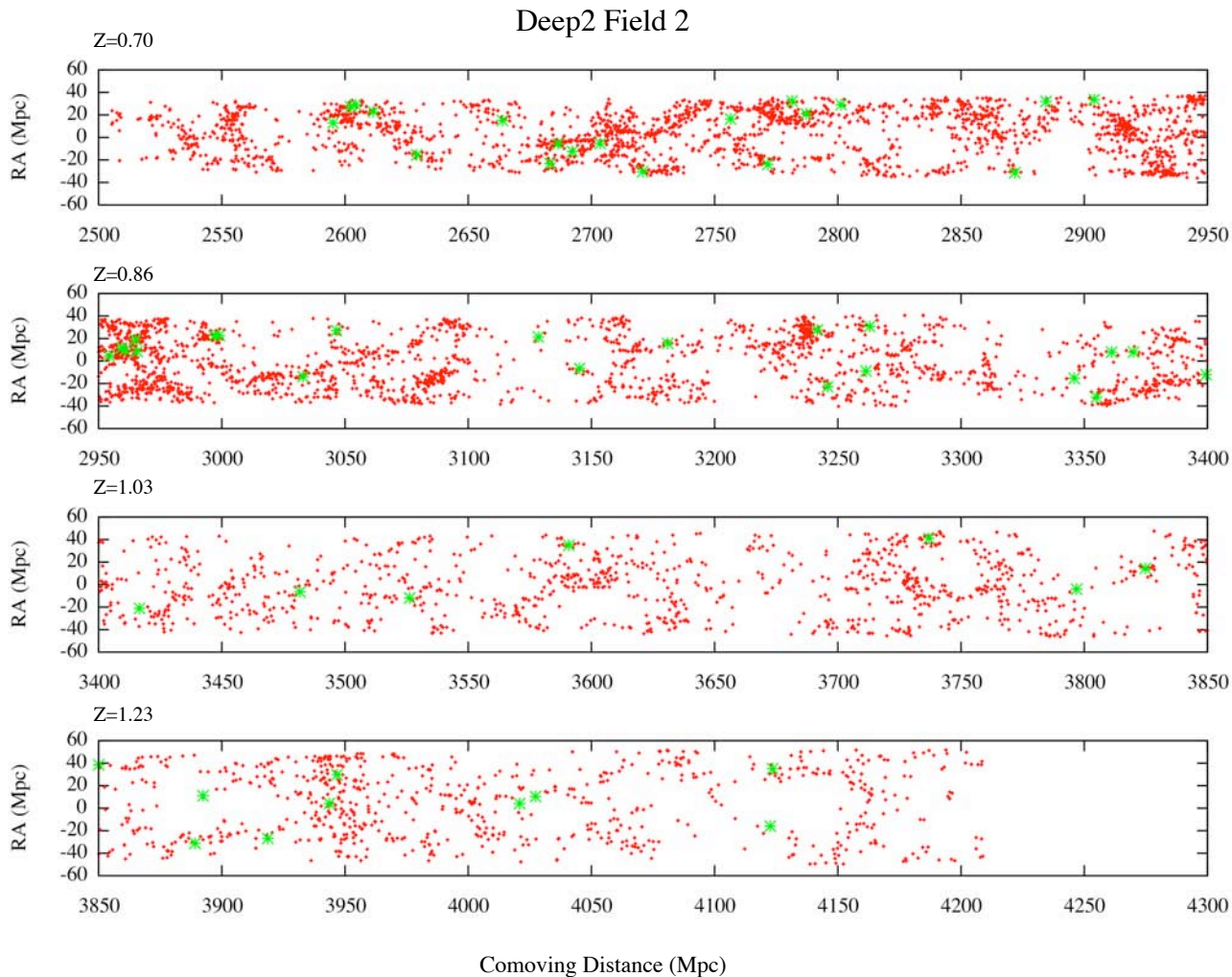
- X-ray to photometric catalog¹
 - 390/578 (within 2 arc-sec) 0.675
 - 292/388 (≥ 5) = 0.753
- X-ray to Zcat_dr3_v1.0²
 - 86 ($z > 0$); 60 ($0.7 < z < 1.4$)
- Potential w/hectospec $I < 22$
 - 188
 - 162 (≥ 5)

¹ Coil et al. 2004

² Davis et al. 2003

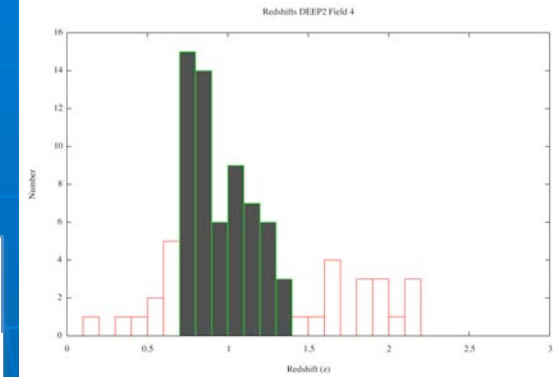
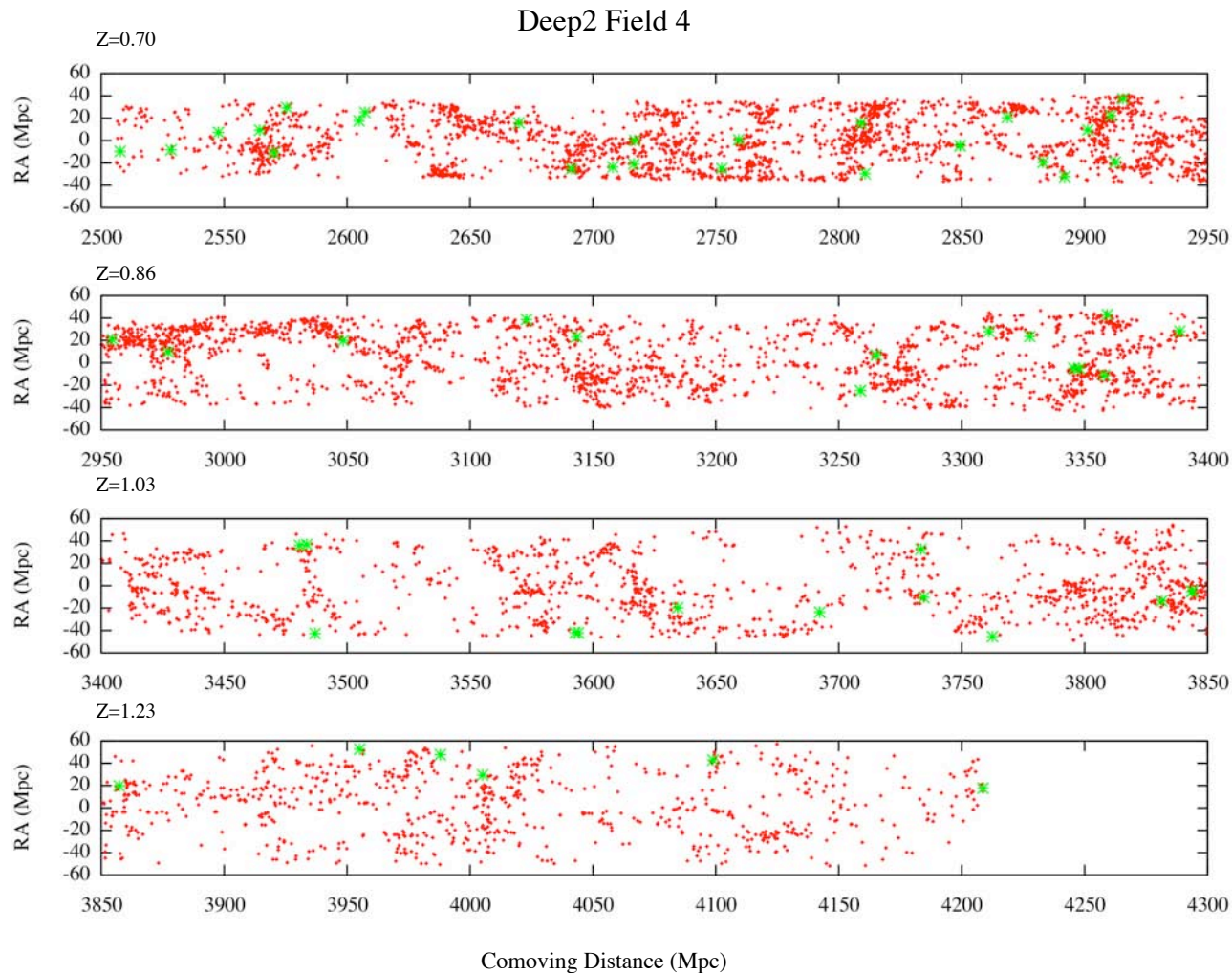
² Davis et al. 2007

AGN and LSS



Field 2

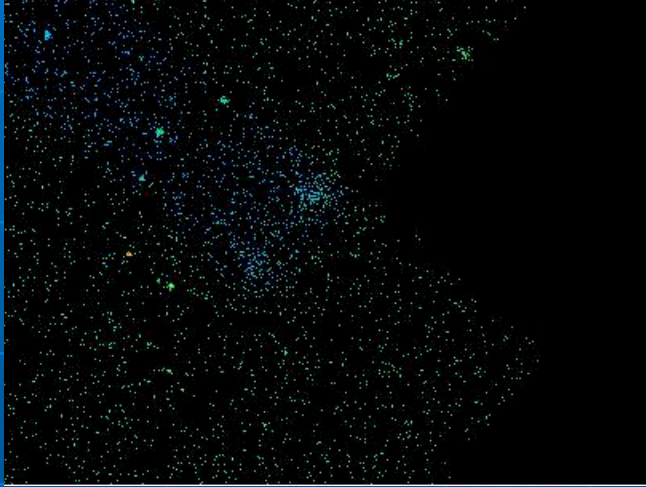
AGN and LSS



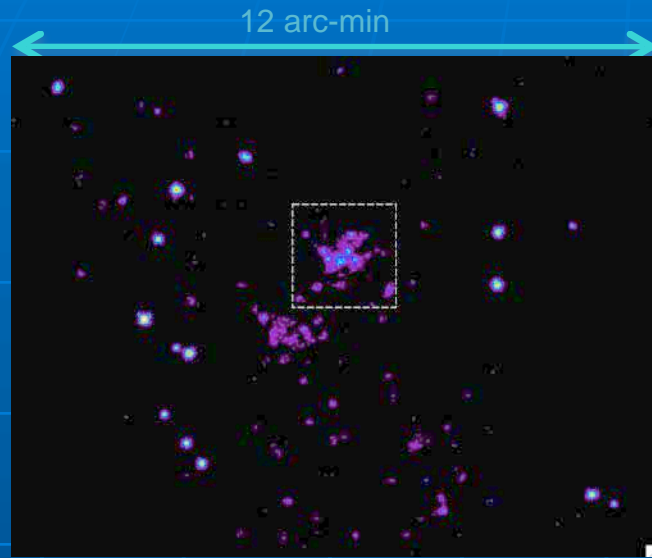
Field 4

Merging Clusters?

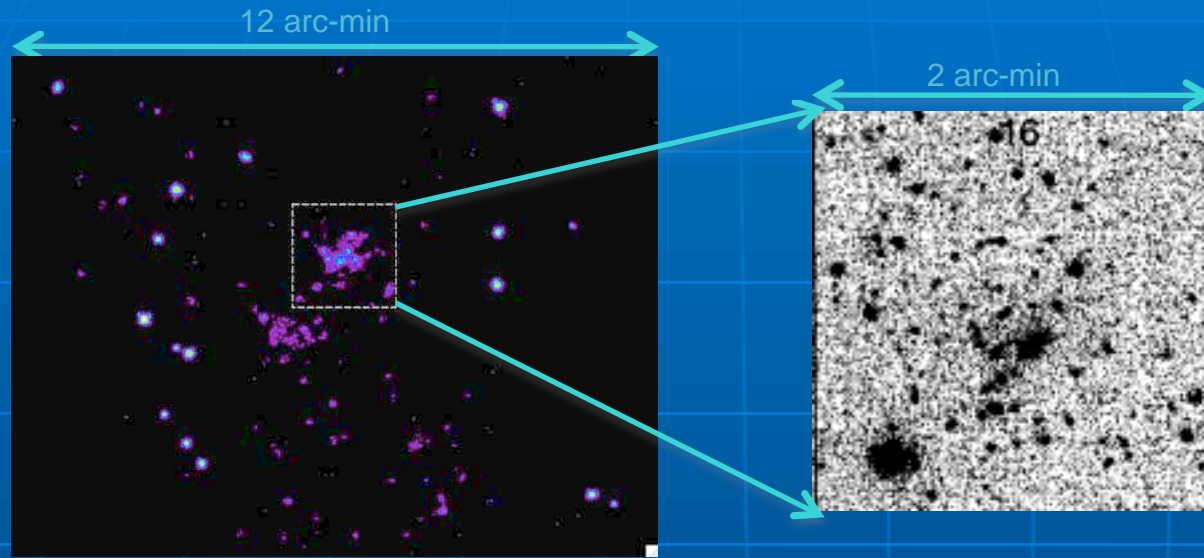
Merging Clusters?



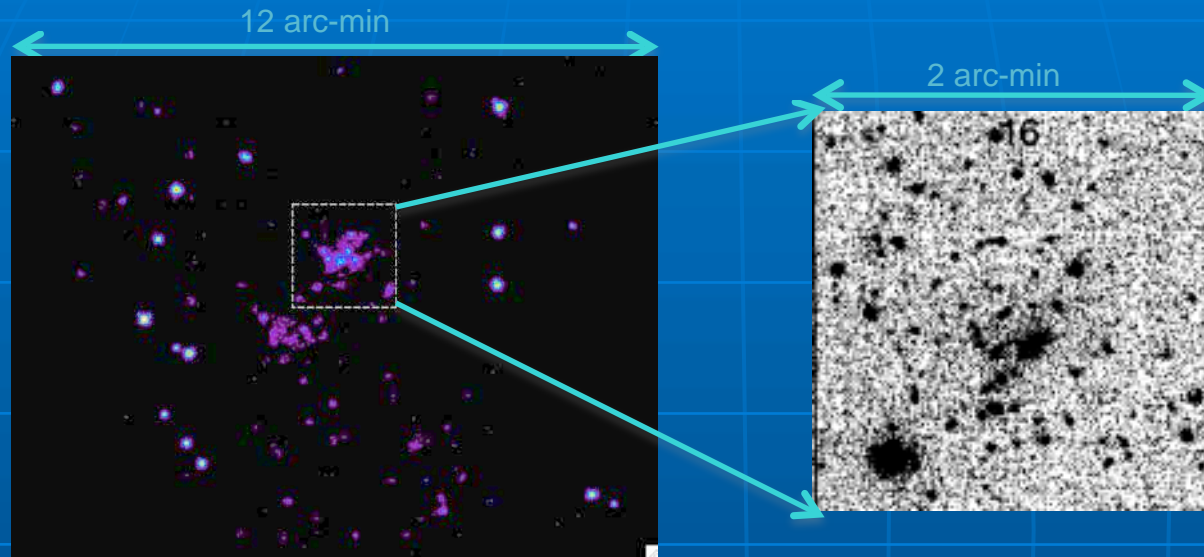
Merging Clusters?



Merging Clusters?



Merging Clusters?

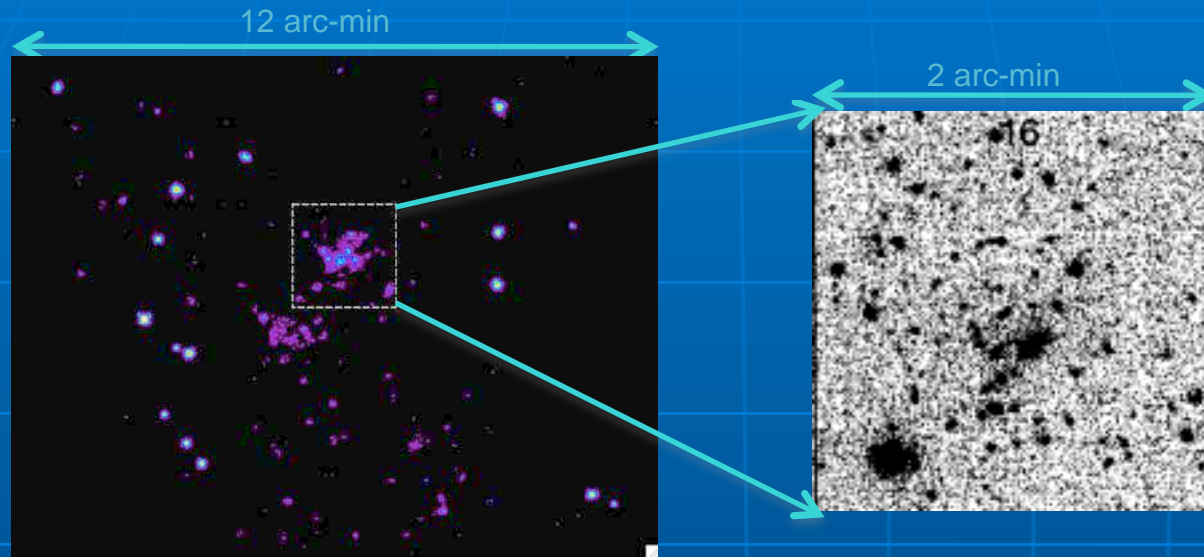


PDCS-1 Postman et al. (1996)

016 02 28 26.5 +00 32 20 119 0.50 0.75 4.26 87.8 32± 4 90± 9 178 0.50 1.94 6.48 108.6 35± 6 110±16

redshift

Merging Clusters?



PDCS-1 Postman et al. (1996)

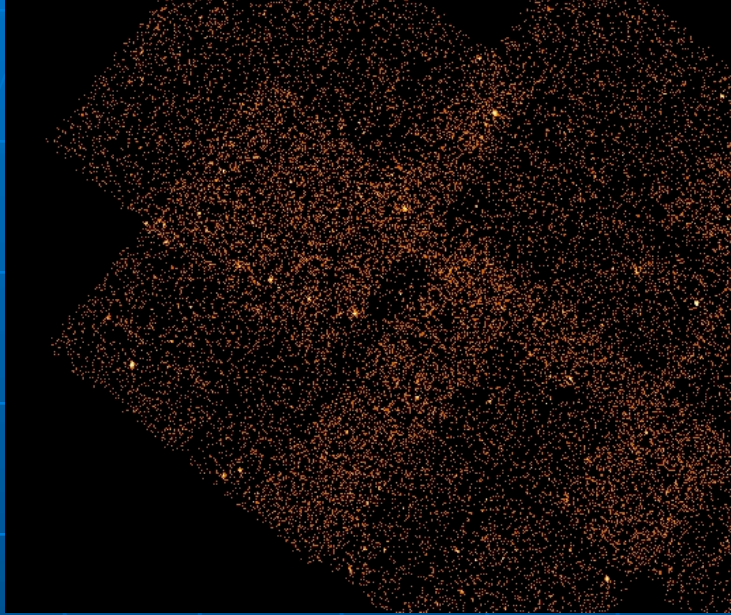
016 02 28 26.5 +00 32 20 119 0.50 0.75 4.26 87.8 32± 4 90± 9 178 0.50 1.94 6.48 108.6 35± 6 110±16

$L_x = 4 \times 10^{43} \text{ erg cm}^{-2} \text{ s}^{-1}$ (0.5 – 7.0 keV)
($L_x = 2 \times 10^{43} \text{ erg cm}^{-2} \text{ s}^{-1}$)

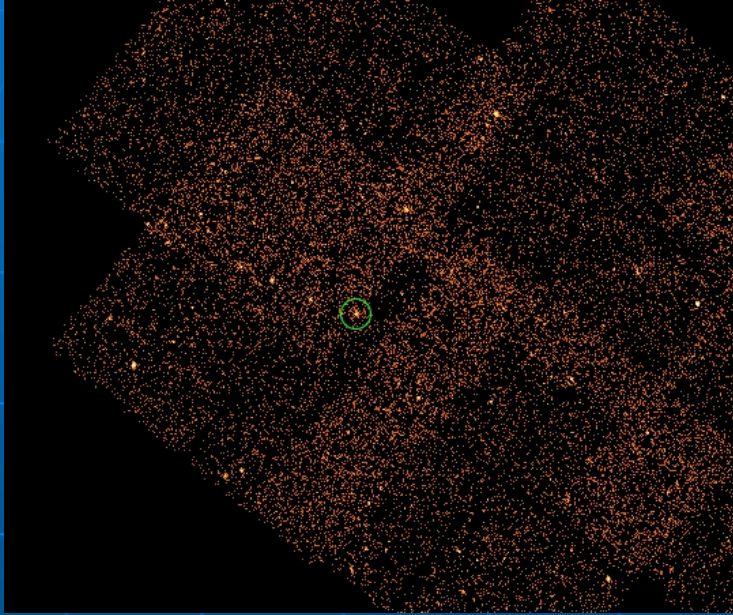
redshift

XDEEP2 AGN

XDEEP2 AGN

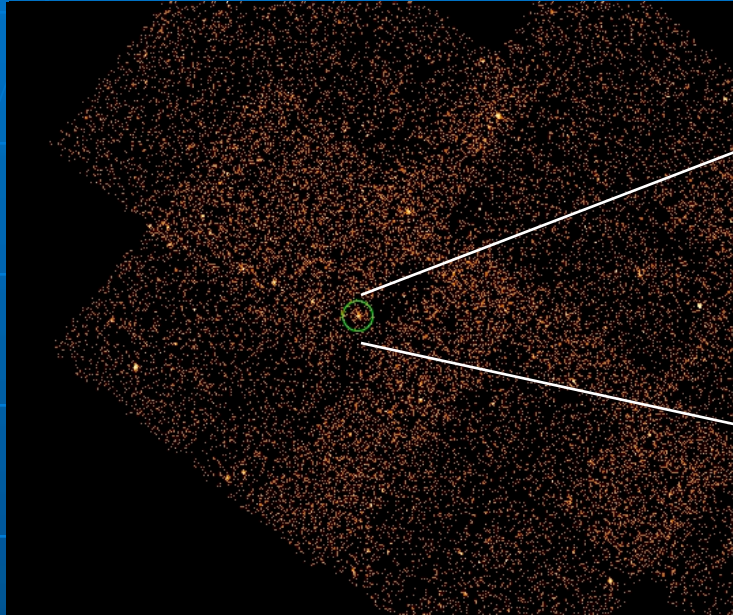


XDEEP2 AGN



Brightest matched X-ray source (62 photons)

XDEEP2 AGN

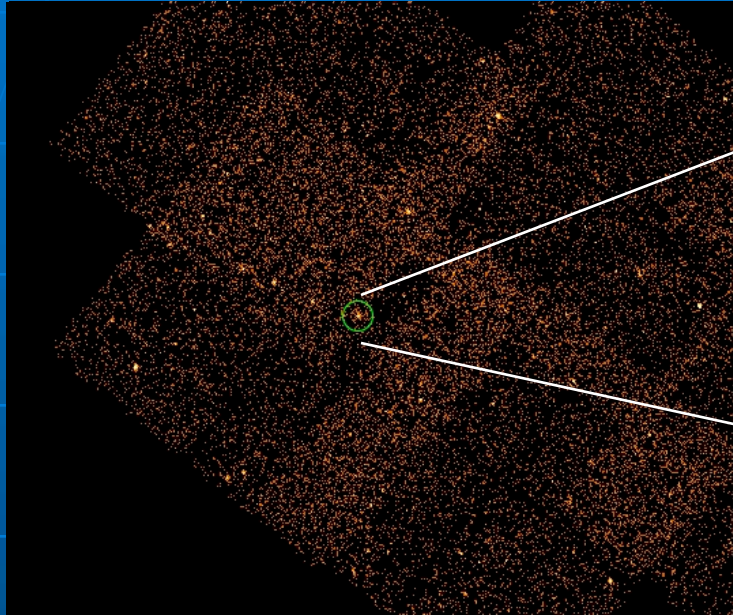


Brightest matched X-ray source (62 photons)

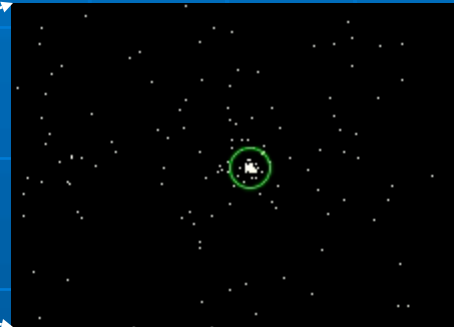


5 arcsec

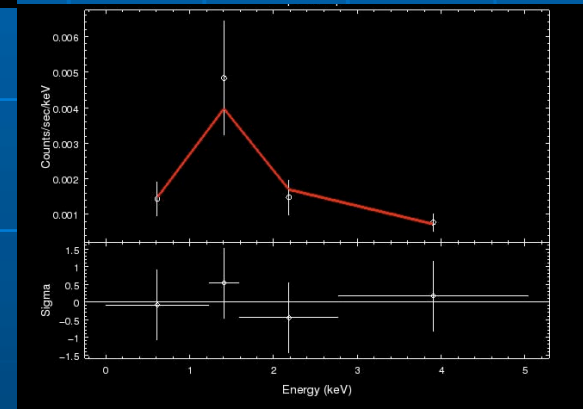
XDEEP2 AGN



Brightest matched X-ray source (62 photons)

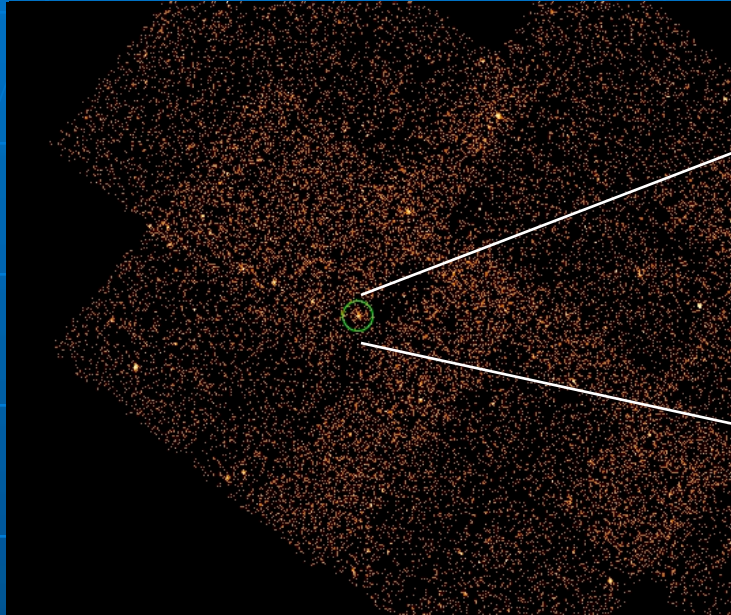


5 arcsec



Power law 1.7

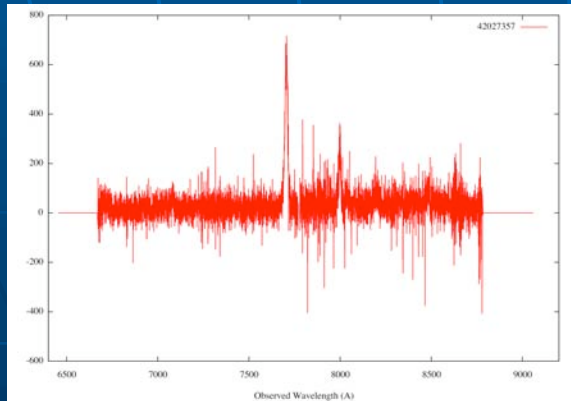
XDEEP2 AGN



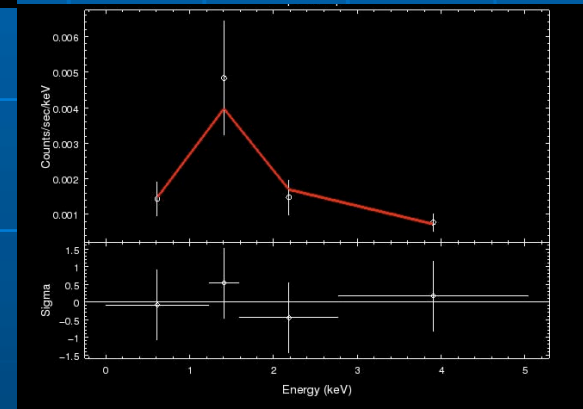
Brightest matched X-ray source (62 photons)



5 arcsec

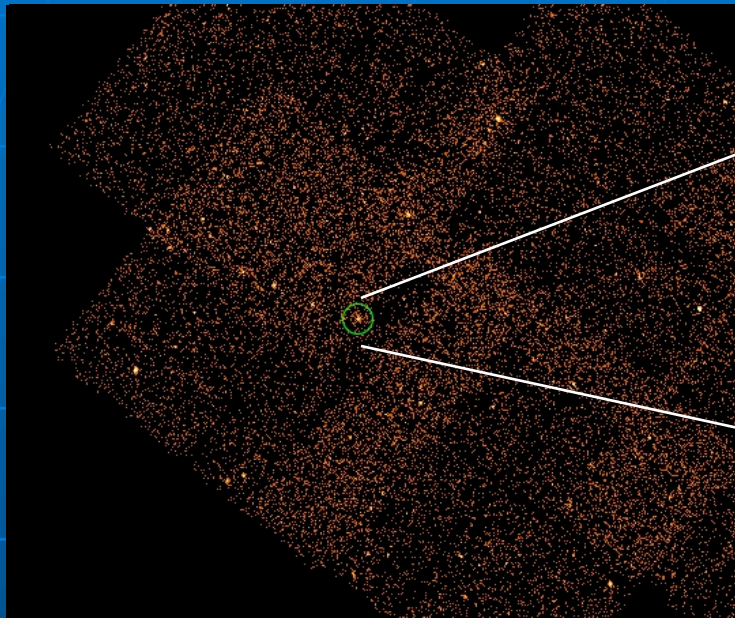


Deep2 spectrum



Power law 1.7

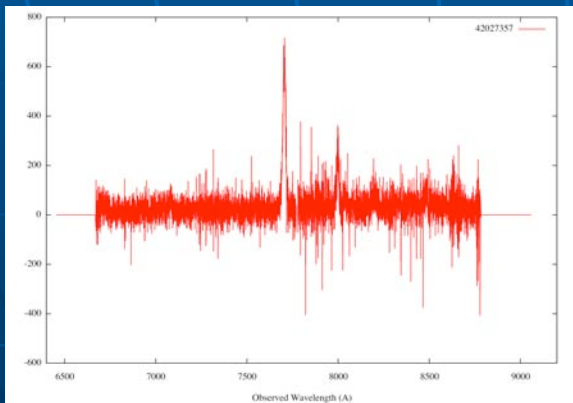
XDEEP2 AGN



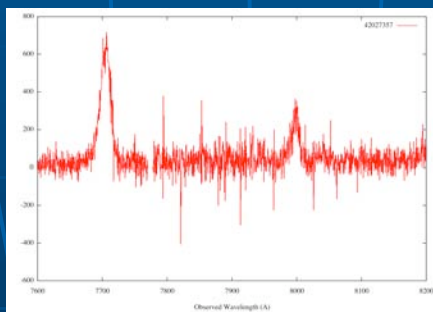
Brightest matched X-ray source (62 photons)



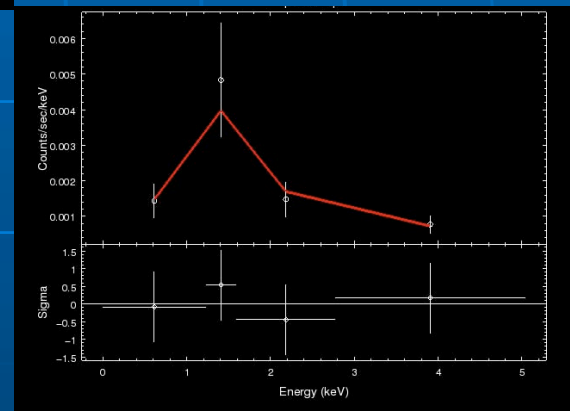
5 arcsec



Deep2 spectrum

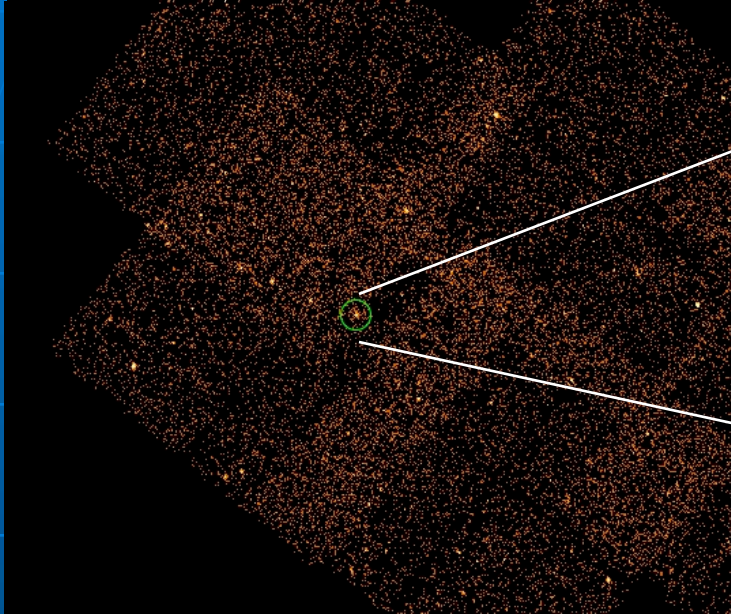


O II (3727) Ne III (3869)

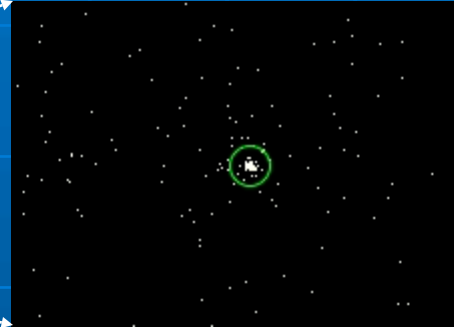


Power law 1.7

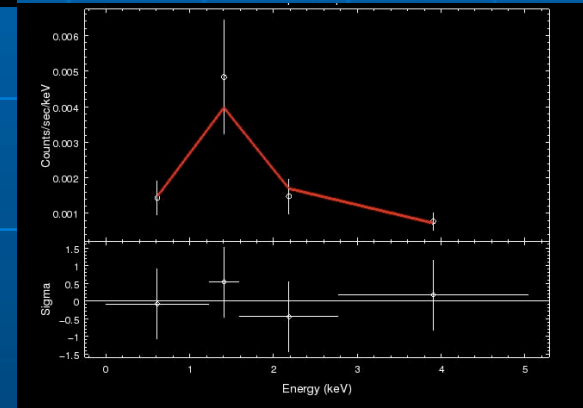
XDEEP2 AGN



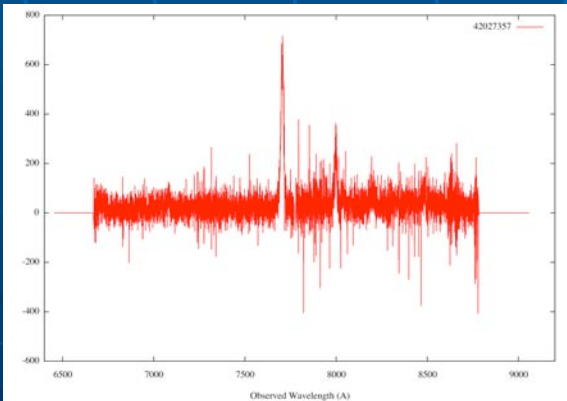
Brightest matched X-ray source (62 photons)



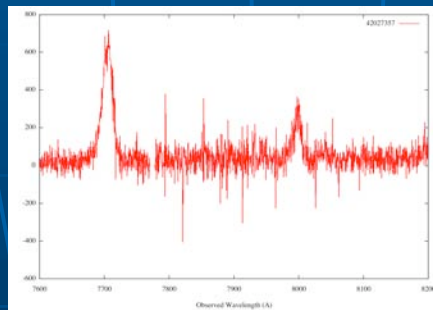
5 arcsec



Power law 1.7



Deep2 spectrum



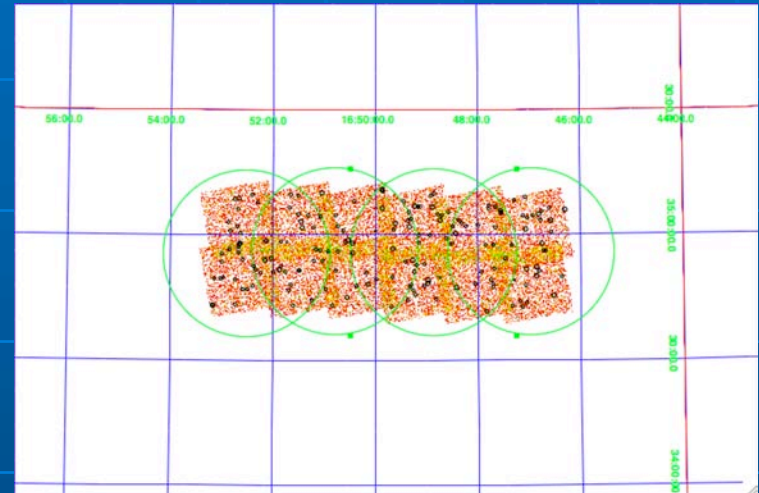
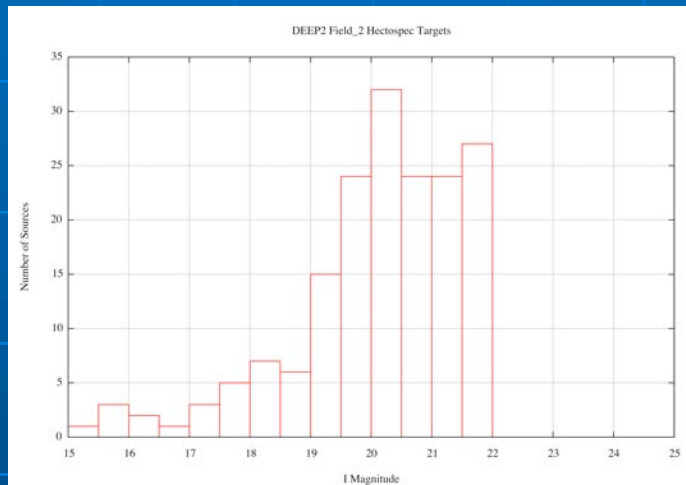
O II (3727) Ne III (3869)

Flux (0.5-7 keV) = $7 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$
 Redshift $z=1.07$
 $L_x = 4.4 \times 10^{44} \text{ erg s}^{-1}$

Future Plans

More Optical Spectra for X-ray AGN

- Hectospec at MMTO



- 174 + 188 possible new spectra to go with the 158 already in hand =>520
- AGN accretion modes, host galaxies, and clustering (XBootes - Hickox 26.03)
- Spitzer IRAC survey fields 2 and 4

STAY TUNED