



Black Hole Cosmic Evolution

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Scuola Nazionale di Astrofisica
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2. Deep X-ray Surveys
3. Optical Identifications
4. Luminosity Function
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6. Future Missions

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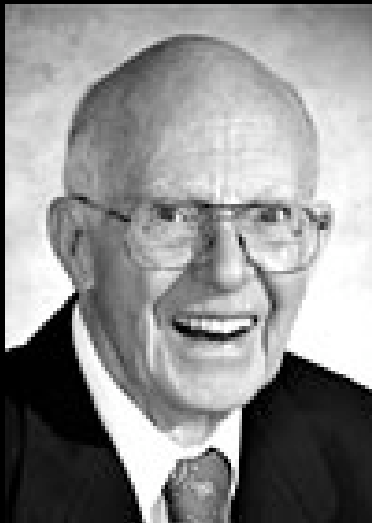
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Nobel Prize in Physics 2002

for pioneering contributions to astrophysics, in particular for the detection of **cosmic neutrinos**

for pioneering contributions to astrophysics, which have led to the discovery of **cosmic X-ray sources**



Raymond Davis Jr.

(1/4)



Masatoshi Koshihara

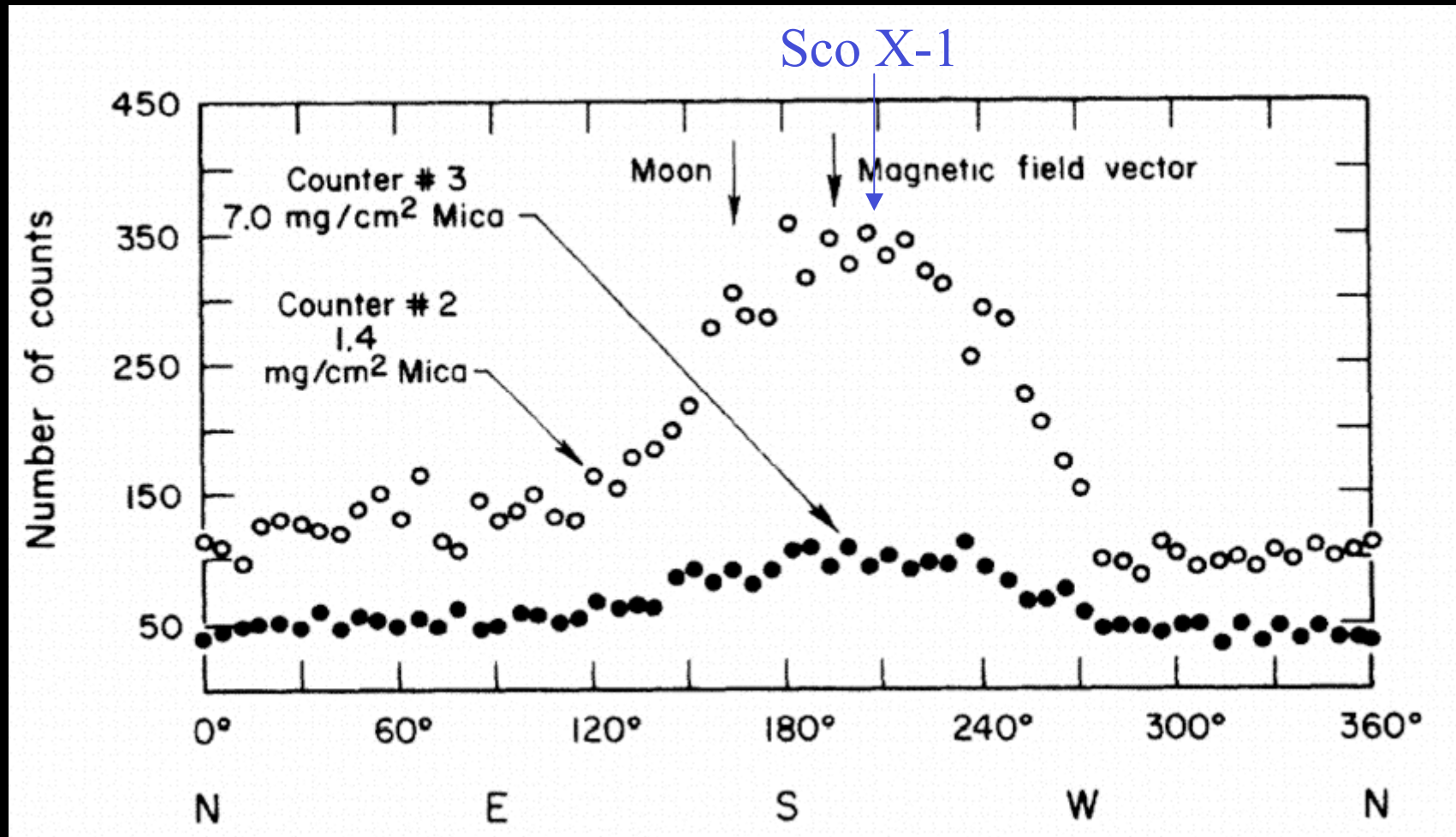
(1/4)



Riccardo Giacconi

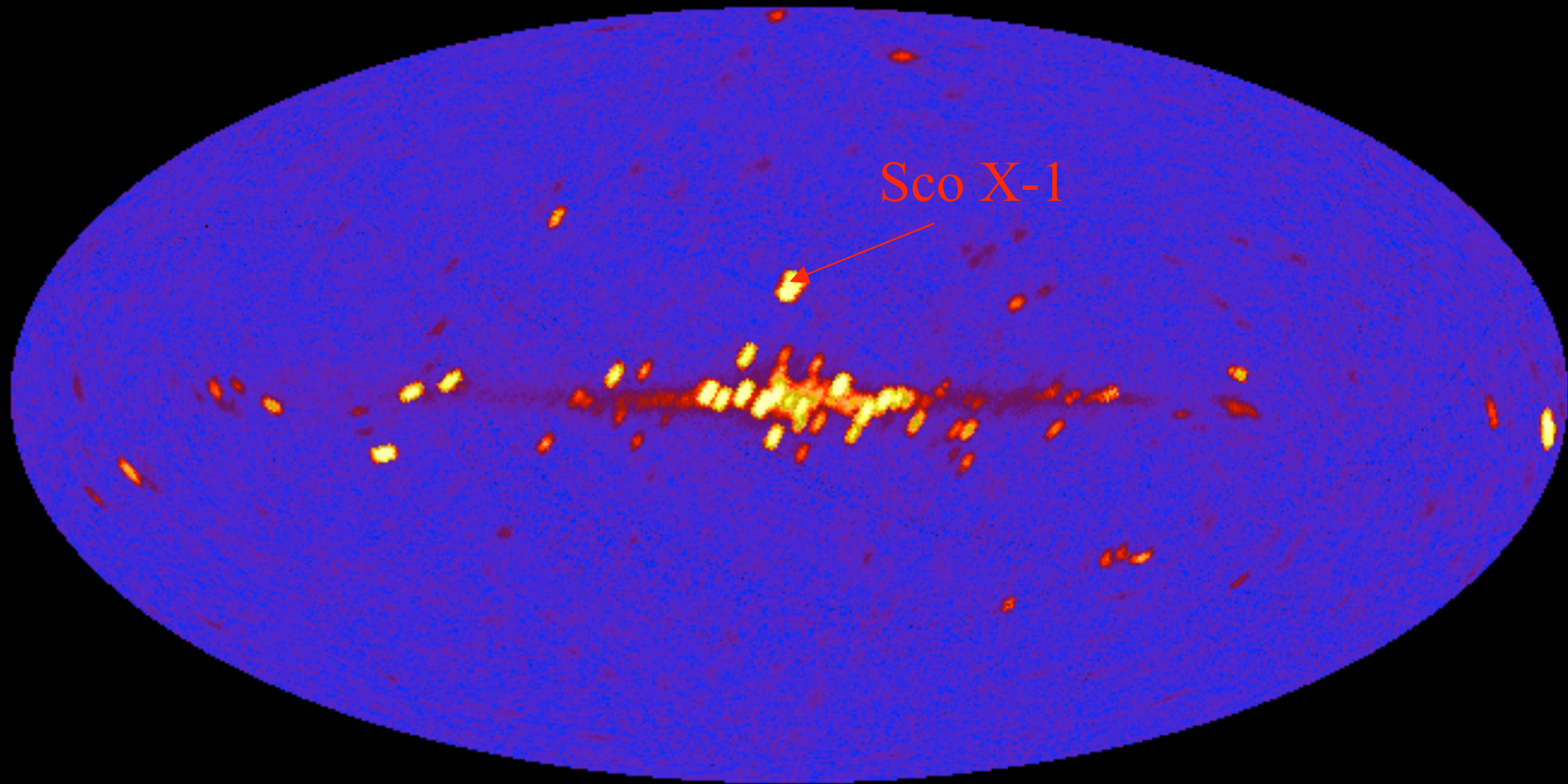
(1/2)

The XRB discovery



Giacconi, R., Gursky, H. Paolini, F., & B. Rossi, 1962, Phys. Rev. Lett. 9, 439

HEAO-1 All-Sky Map

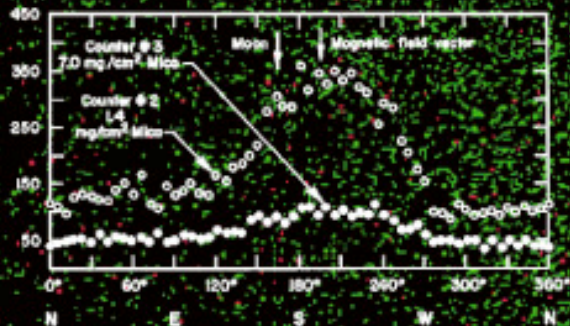


⇒ XRB is isotropic

⇒ Dipole consistent with cosmic microwave background

⇒ Extragalactic (cosmological origin?)

„Historical“ Moments



ROSAT Observation
of Sco X-1 behind the
Moon (Predehl)

HEAO-1 XRB Spectrum

Power Law fits

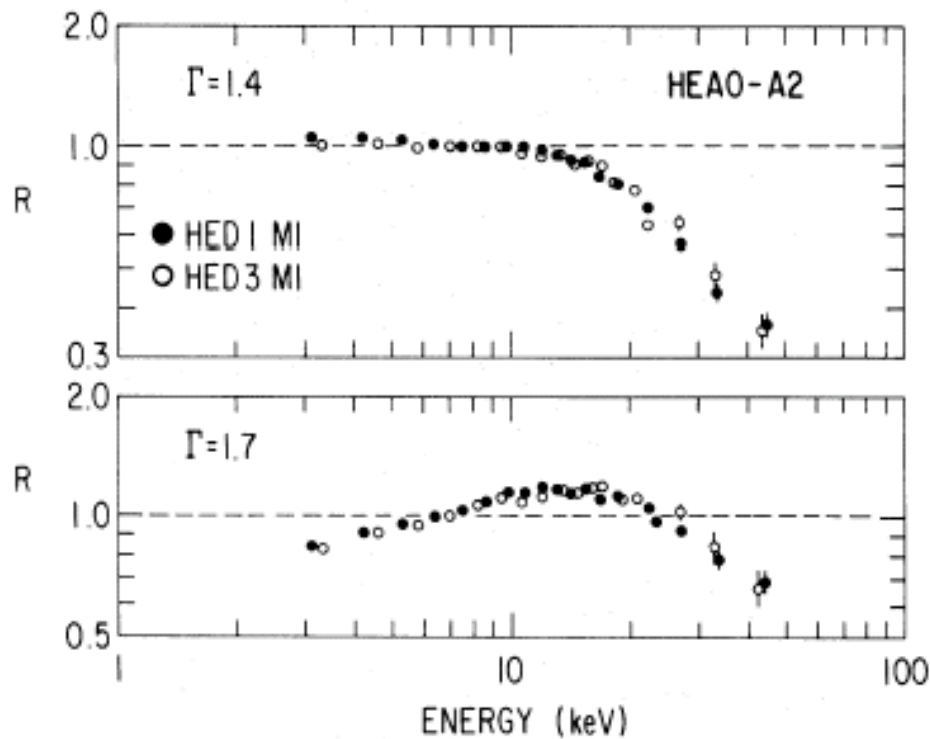
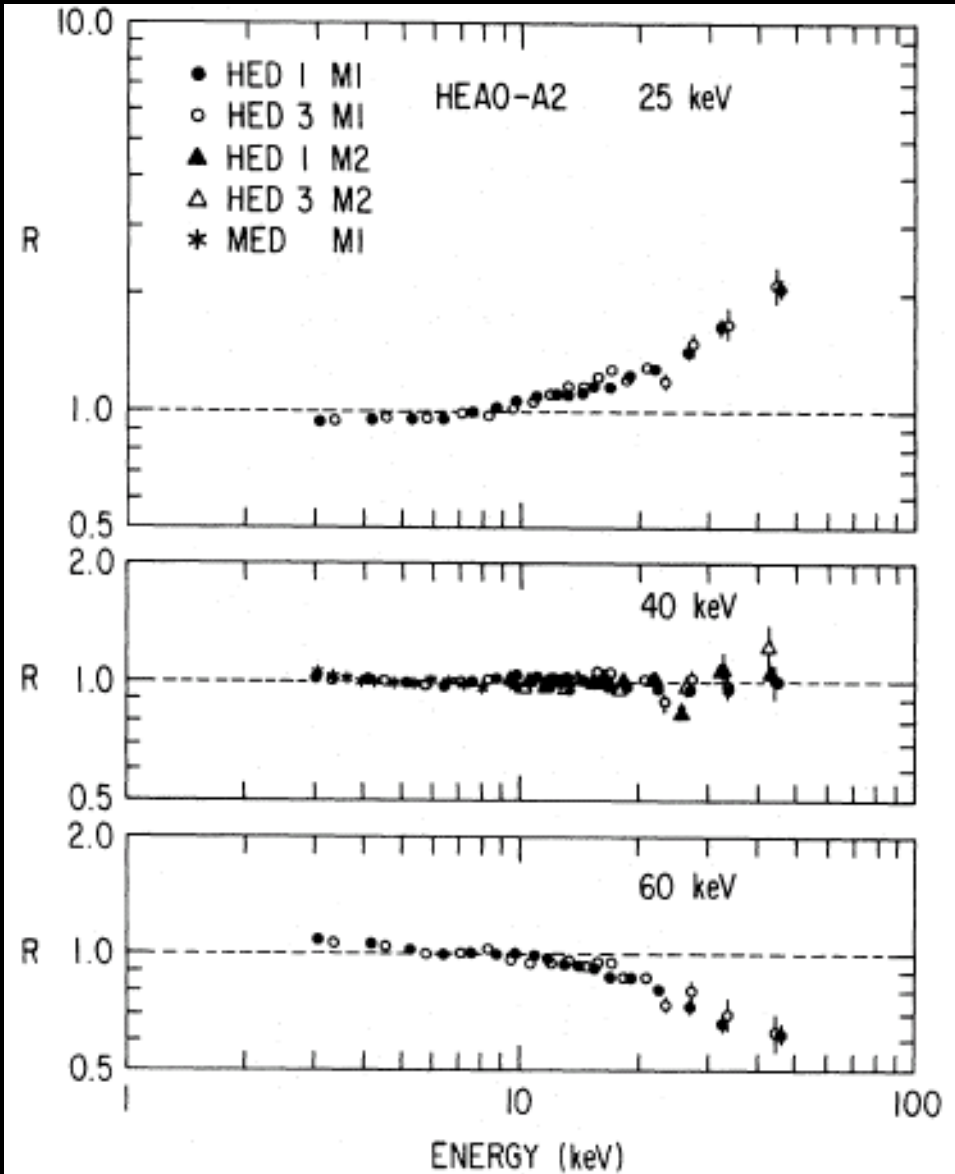
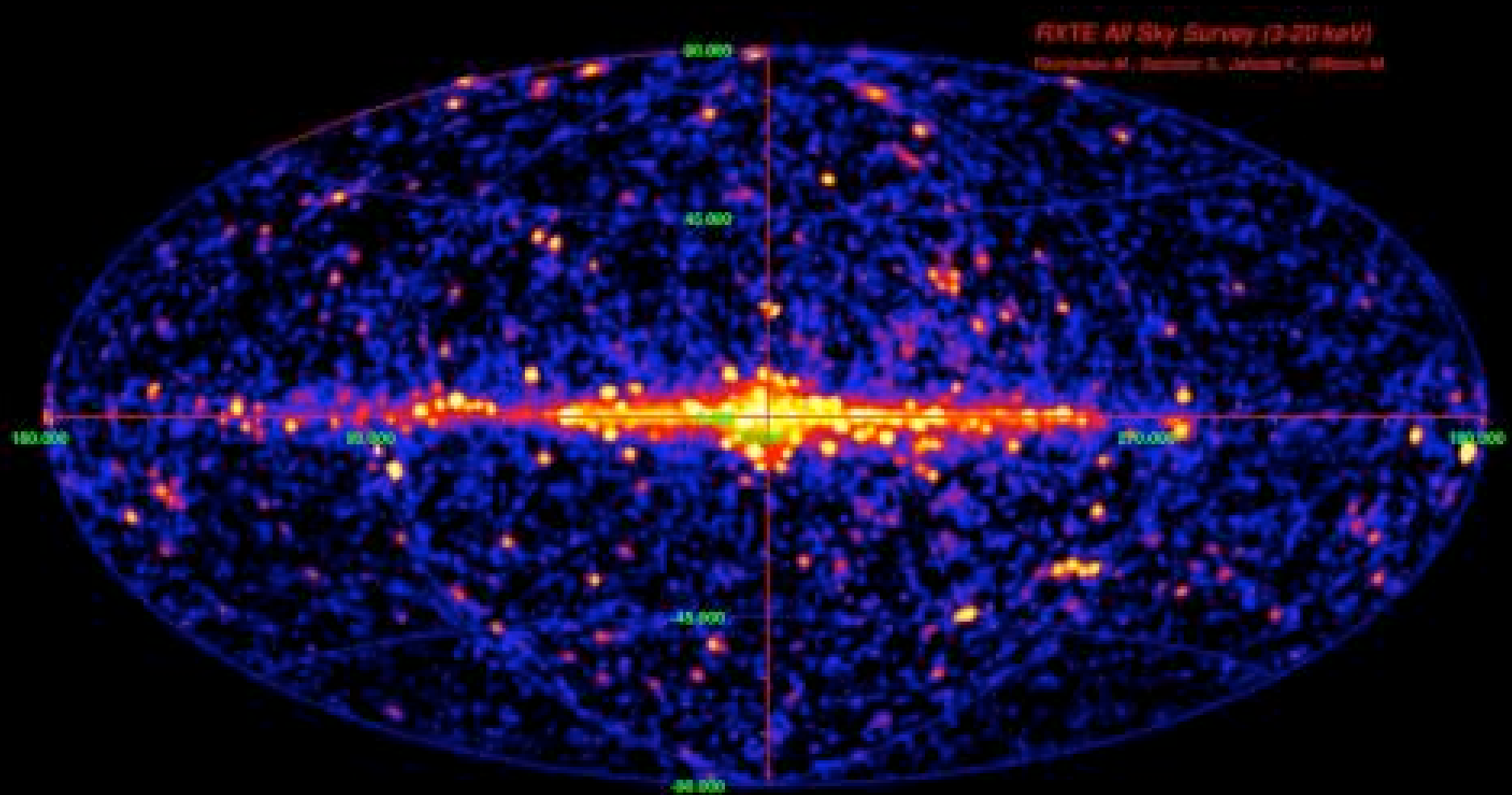


FIG. 3.—The ratio of the observed counts for the XRB to that predicted for power-law incident spectra. Statistical errors are shown when larger than the size of the symbols.

Bremsstrahlung fits

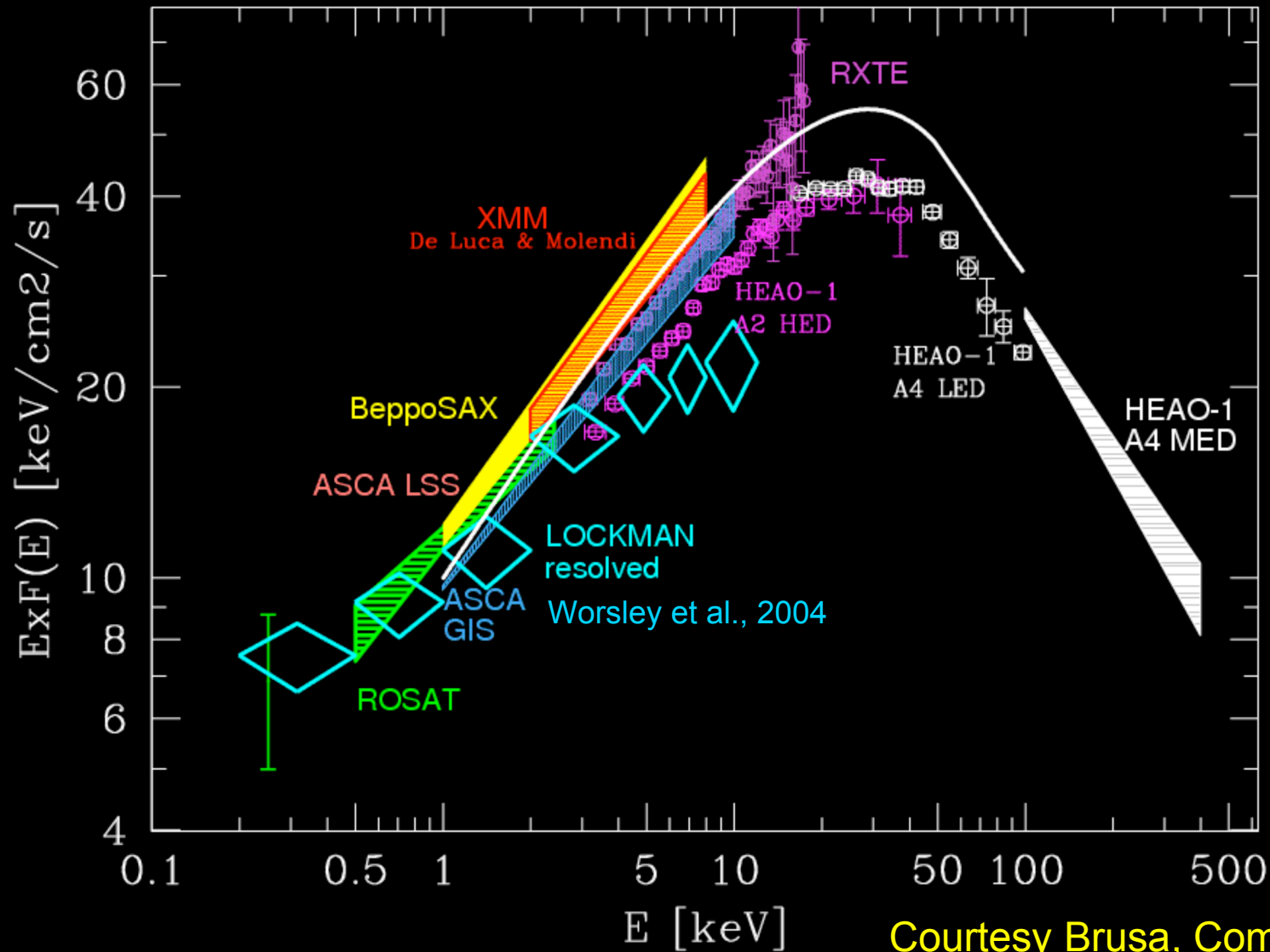


RXTE Slew Survey Map



RXTE All-Sky Map in the 2-10 keV band (Revnivtsev et al.)

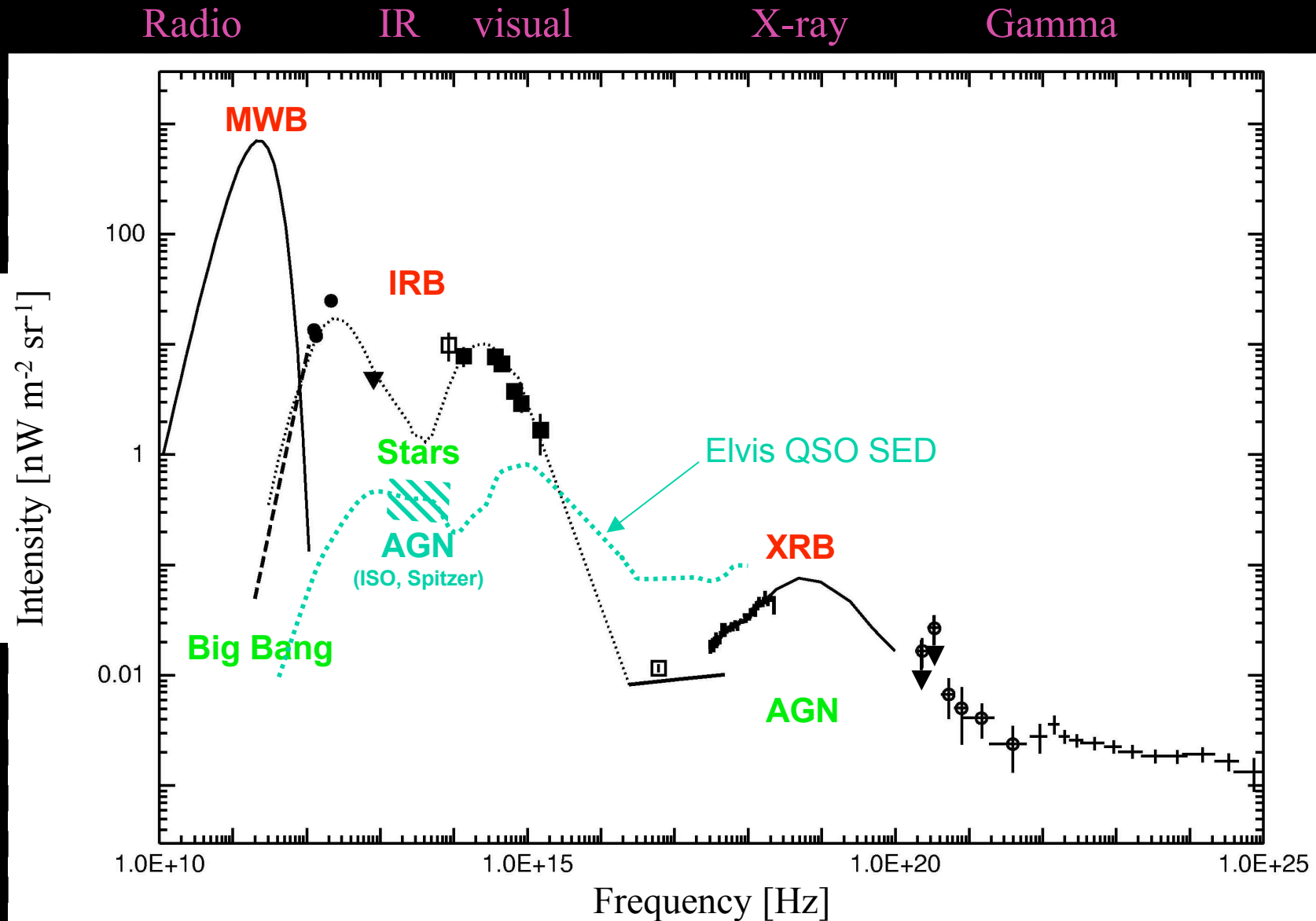
X-ray Background Spectrum



Courtesy Brusa, Comastri, Gilli

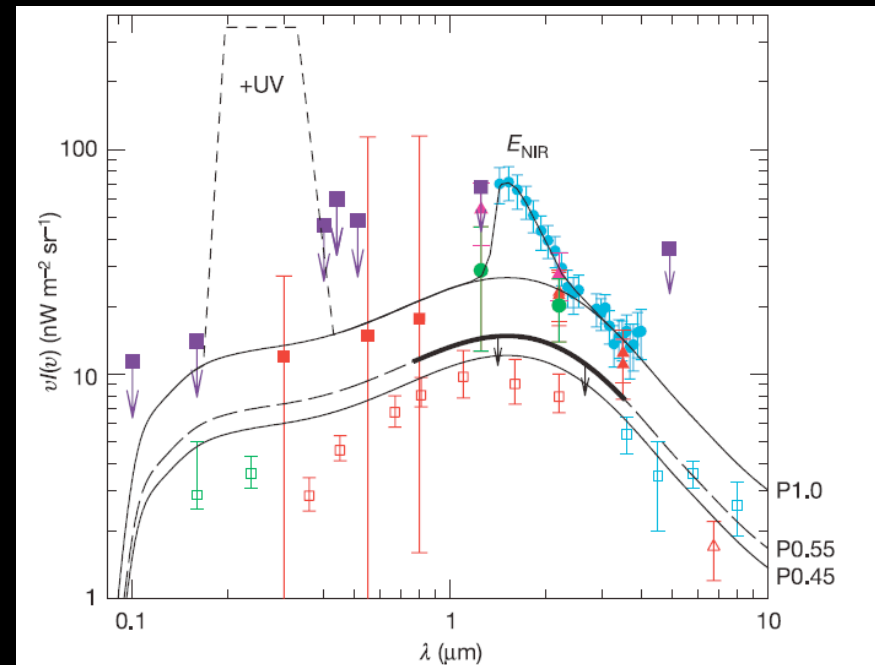
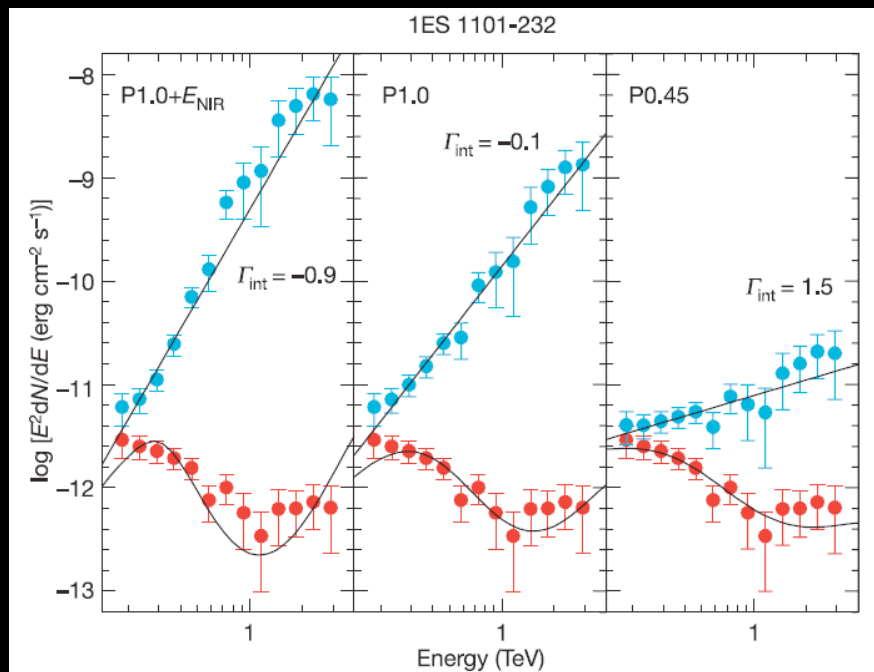
=> $E < 2$ keV XRB resolved; at $E > 5$ keV still very much work to do!

Cosmic Energy Spectrum



Optical EBL by TeV absorption

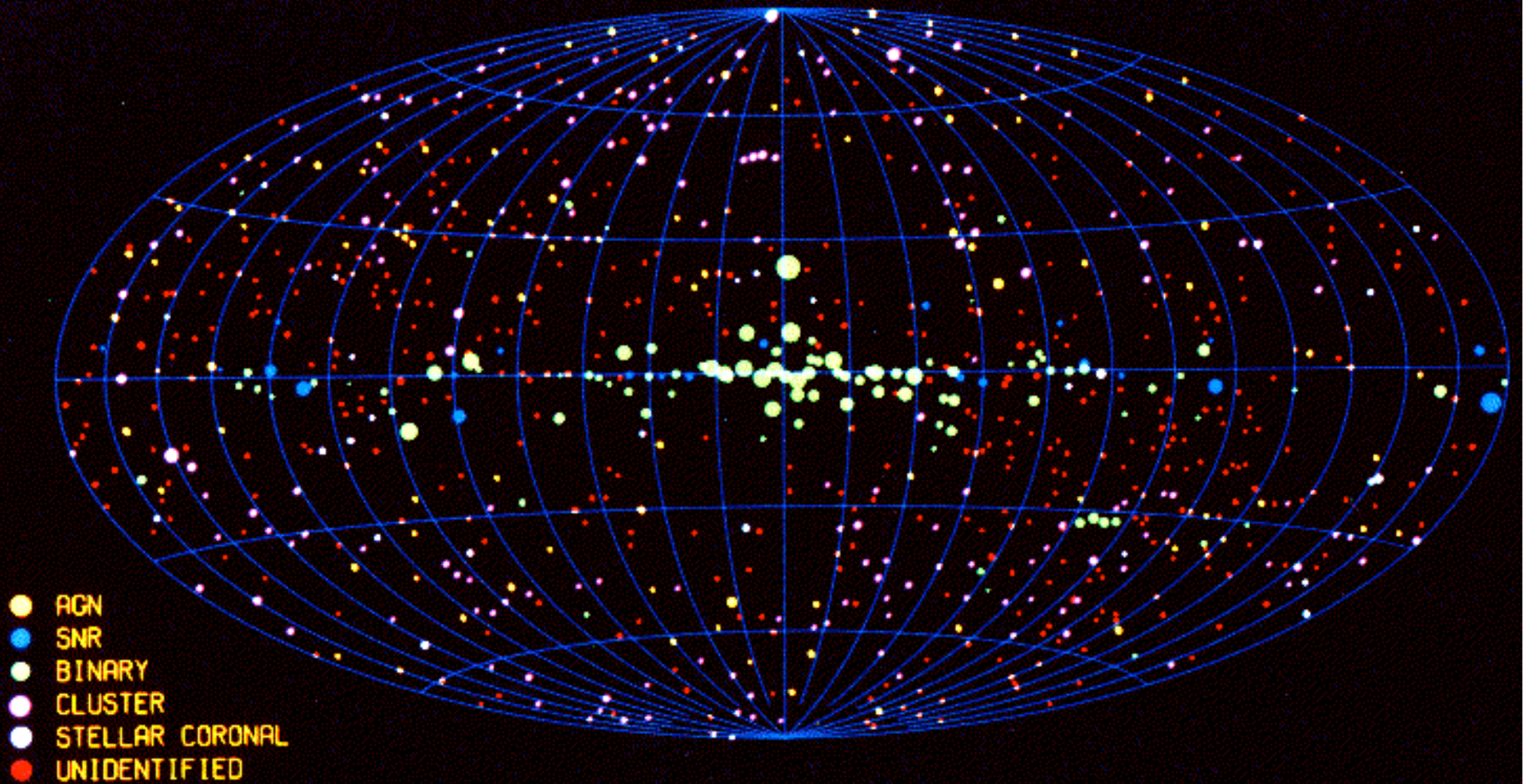
H.E.S.S. data on 2 blazars at $z=0.17-0.19$



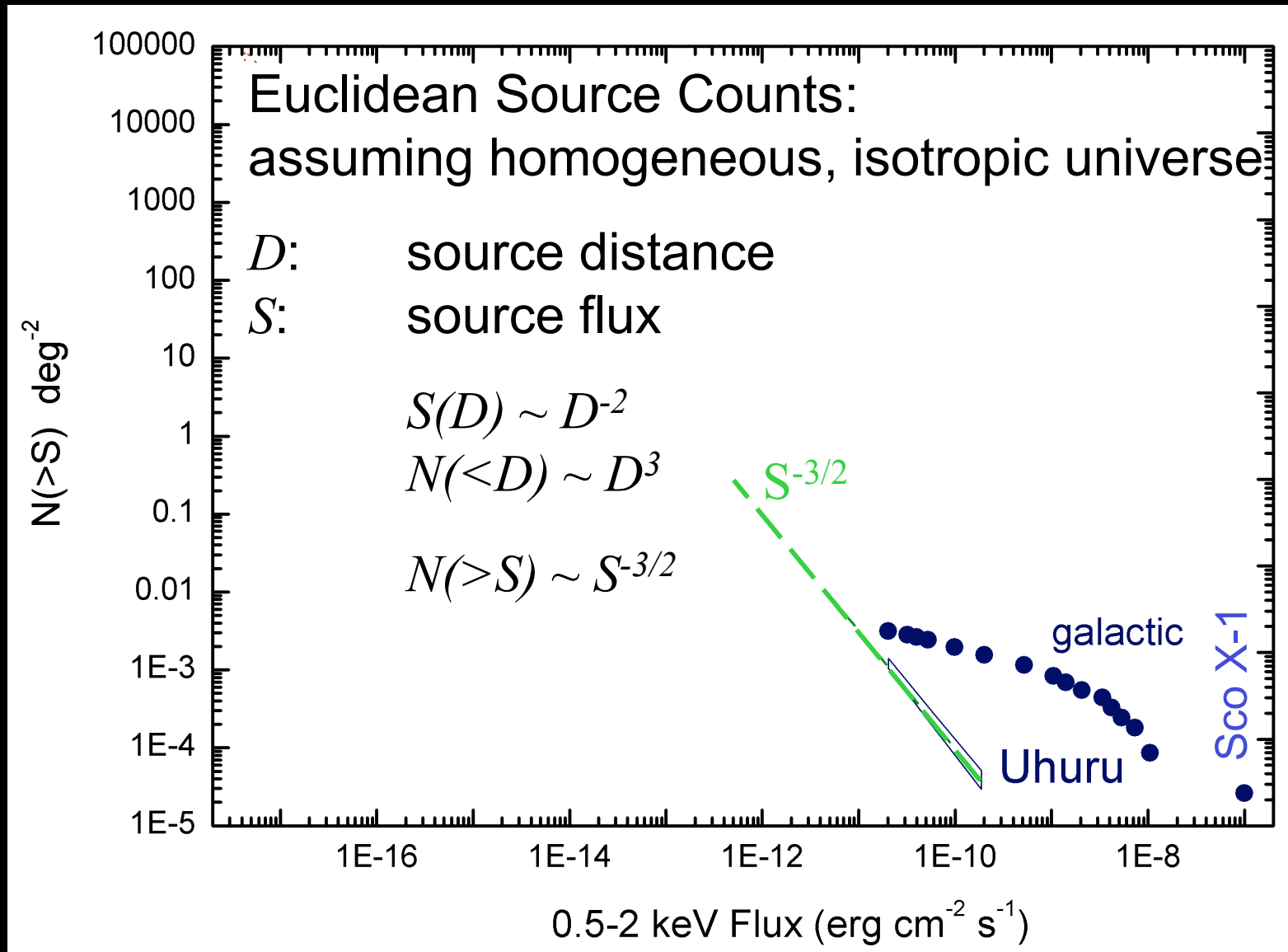
Aharonian et al., 2006, Nature 440, 1018

It is very hard to measure a cosmic background !

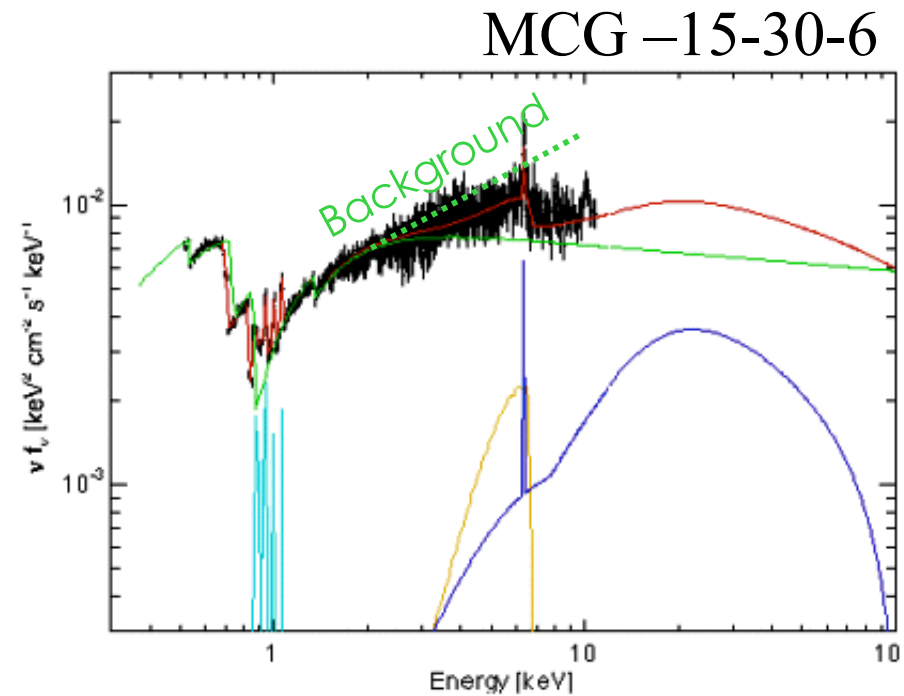
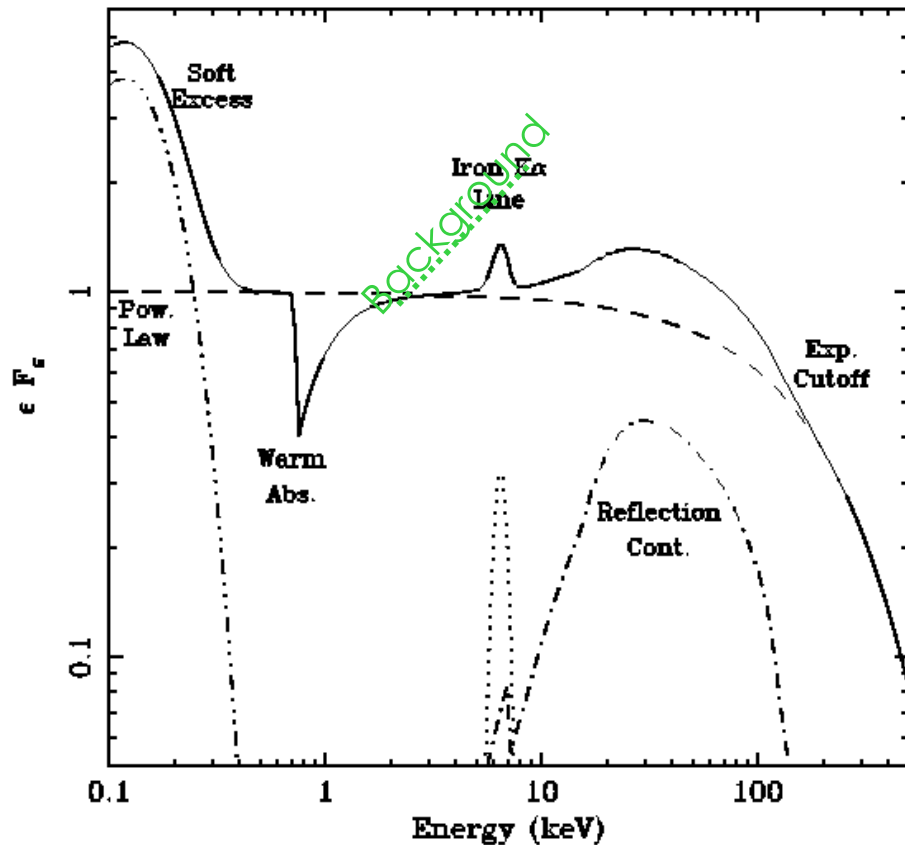
HEAO-1 All-Sky X-ray Catalog



Source Counts

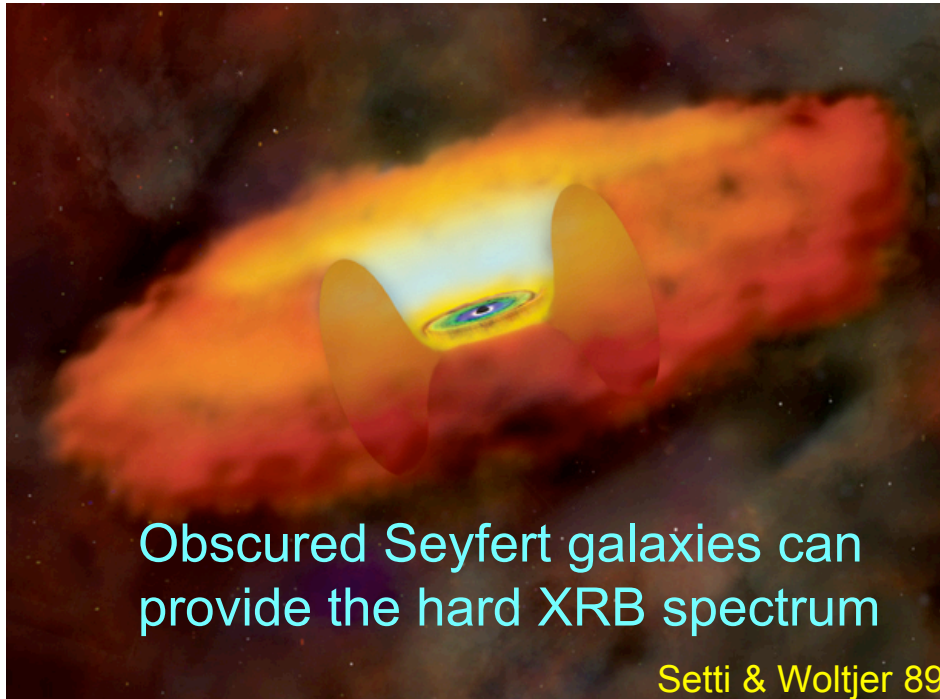


Typical AGN spectra

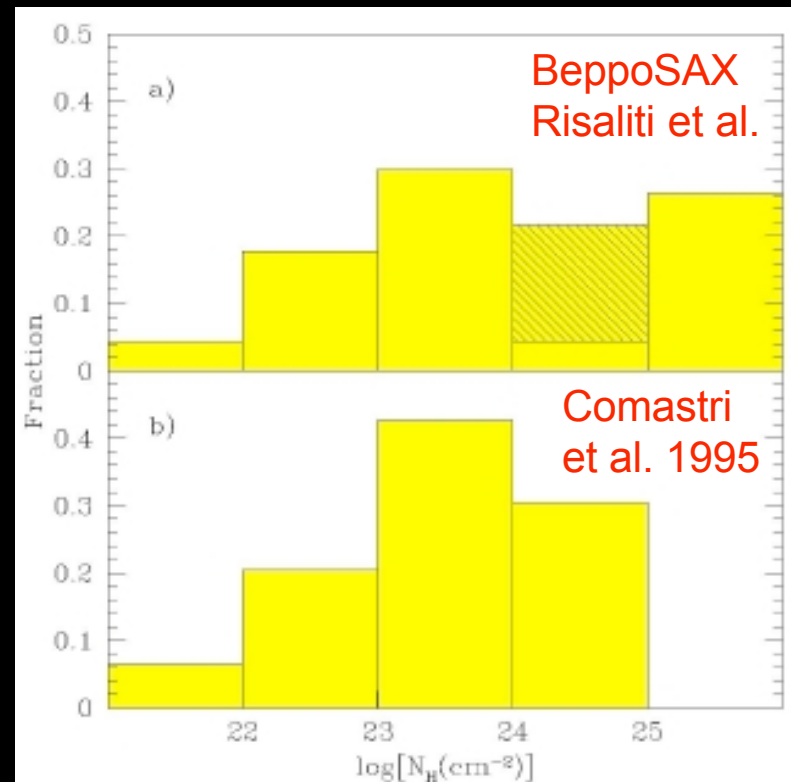
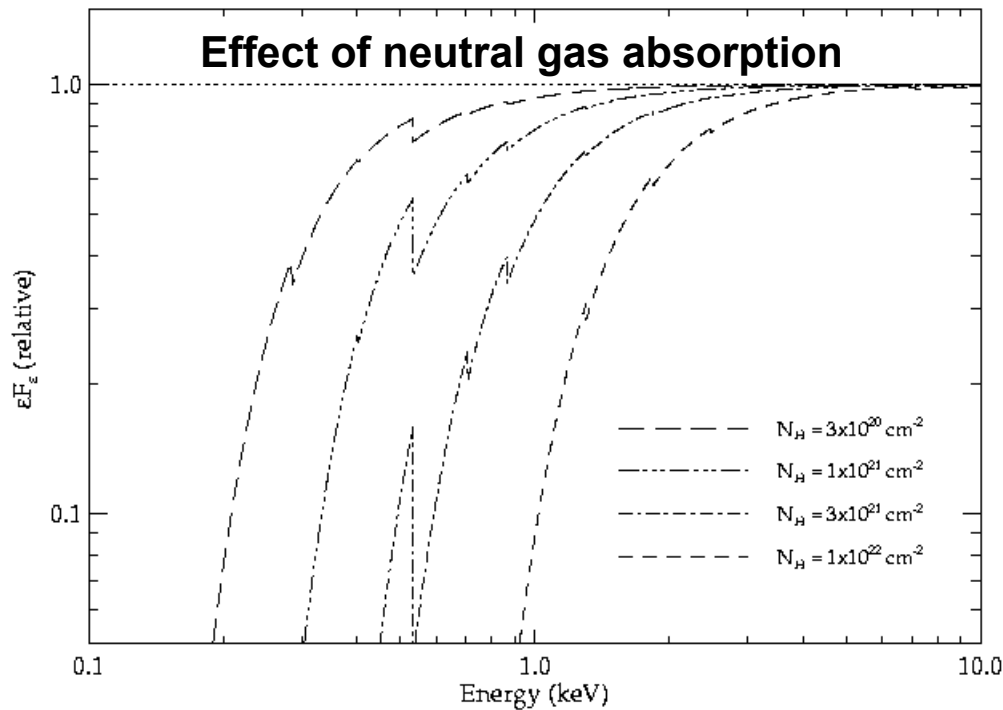


⇒ Spectral paradoxon @ 2-10 keV: $\Gamma_{\text{AGN}}=1.7$; $\Gamma_{\text{XRB}}=1.4$

Obscured AGN XRB model



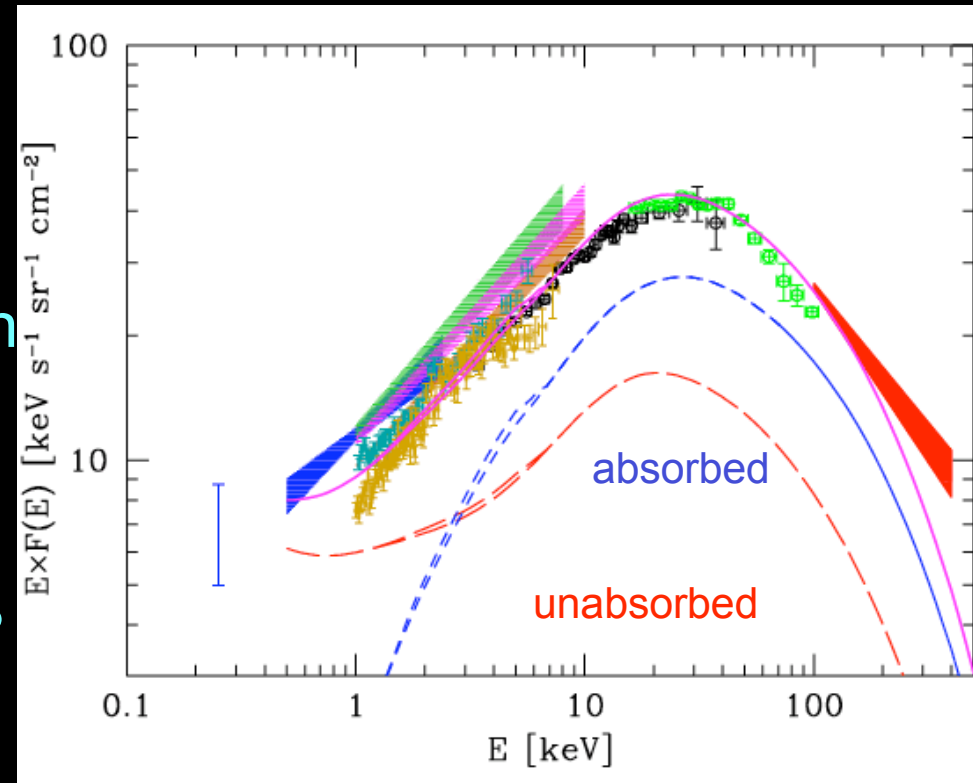
AGN Absorption distribution



Background Synthesis Model

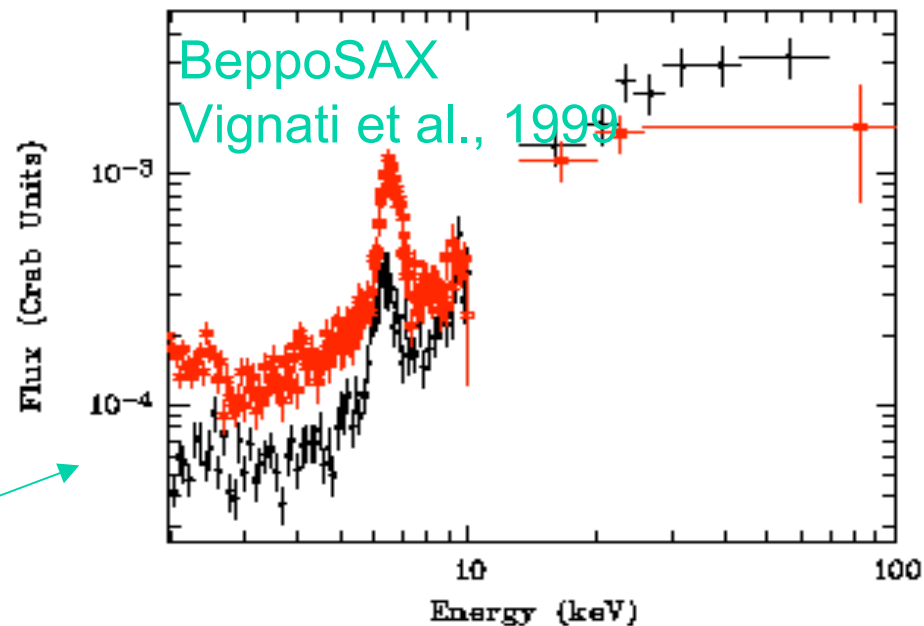
Ingredients:

- AGN X-ray luminosity function
- AGN cosmological evolution
- canonical AGN spectrum
- AGN absorption distribution
- variation of type1/type2 ratio?



- ⇒ Many different models can fit the XRB spectrum
- ⇒ Need other constraints
- ⇒ Prediction: hard sources in Chandra/XMM surveys; type-2 QSO!
- ⇒ Uncertainty in background spectrum important

Obscured AGN NGC 6240

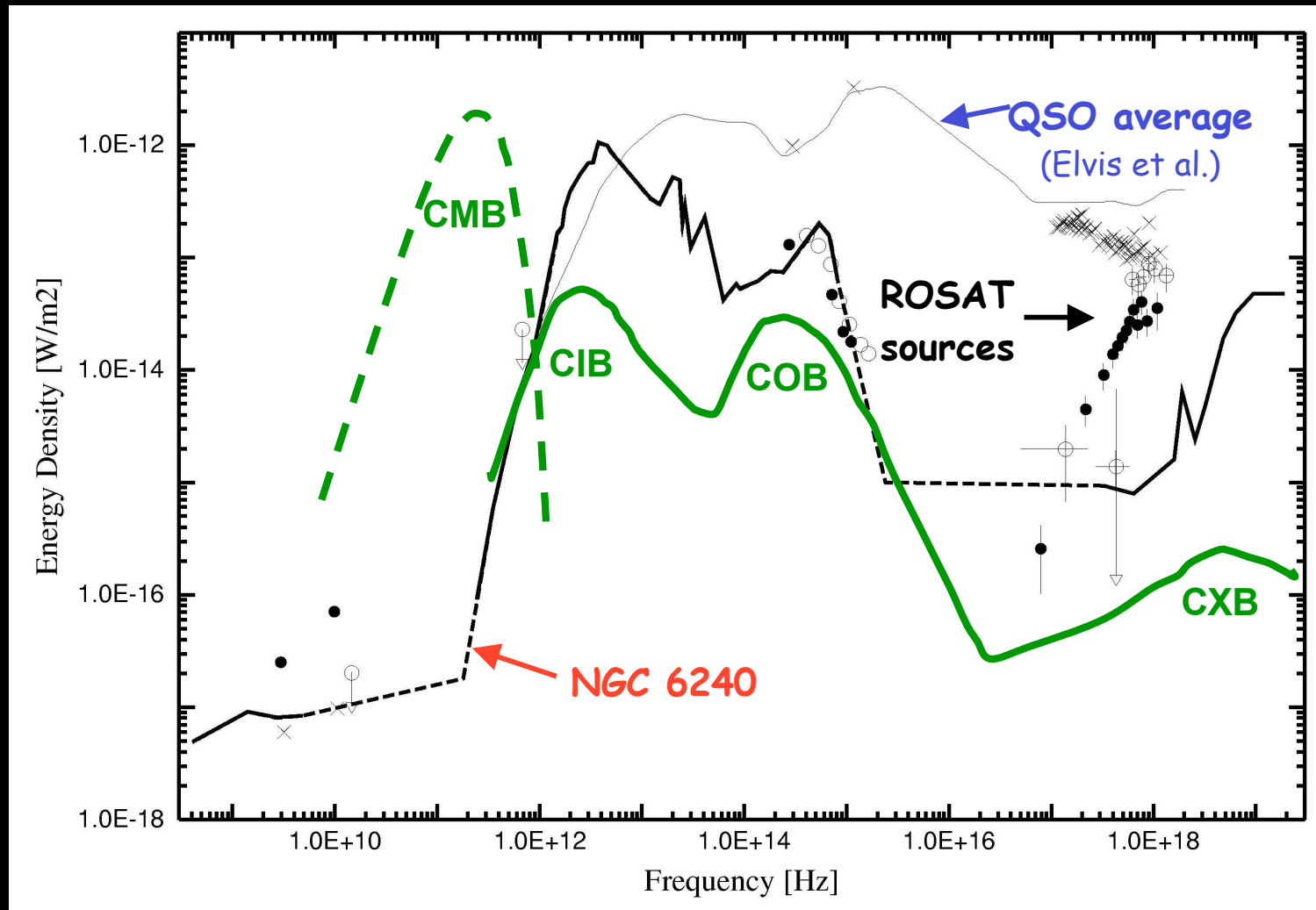


Visual/ESO 2.2m
Keel et al. 1995

First X-ray active binary AGN
+ type-2 QSO !!!

X-ray/Chandra Komossa et al., 2002

Spectral Energy Distributions



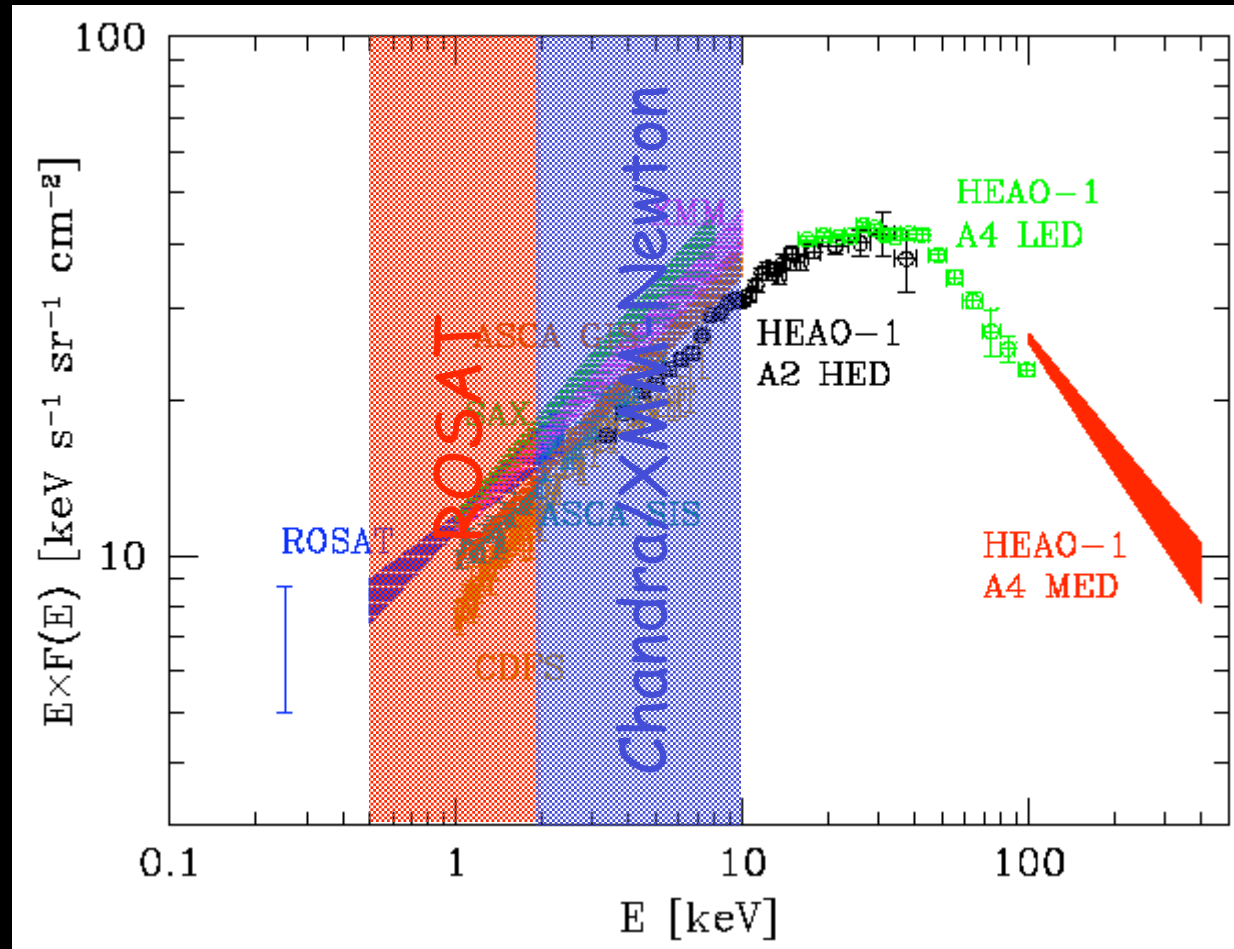
- ⇒ X-ray background reflects obscured black hole growth
- ⇒ 80-90% of accretion energy is obscured

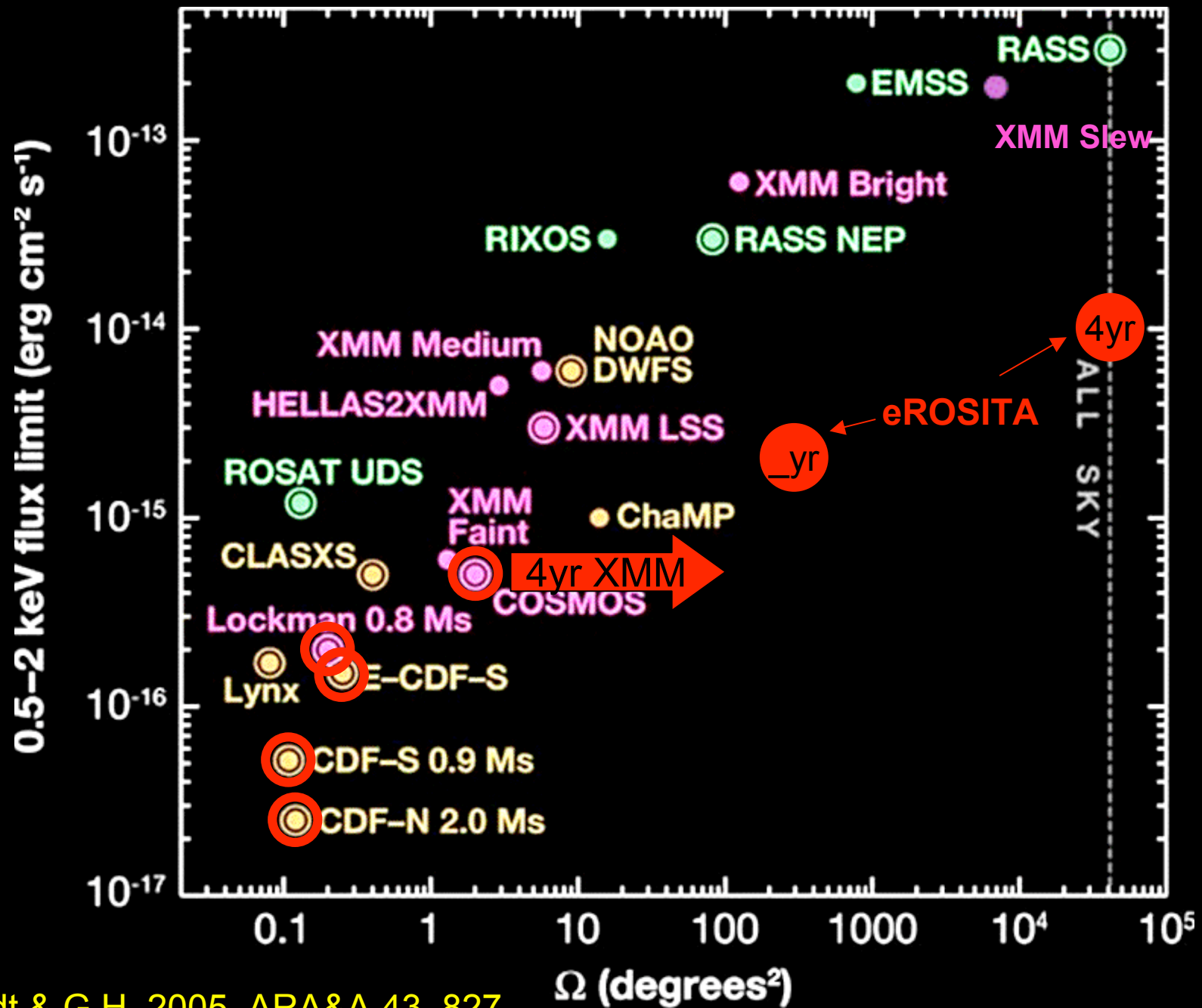
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Review: Brandt, W. N. & G. Hasinger, ARAA 43, 827 (2005)

Deep X-ray Surveys

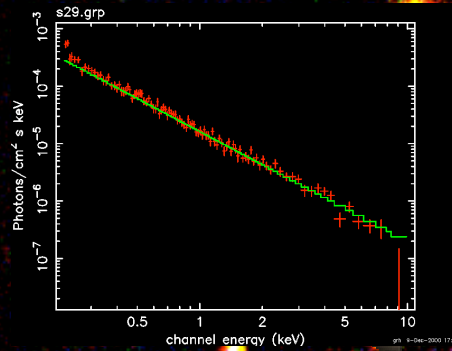




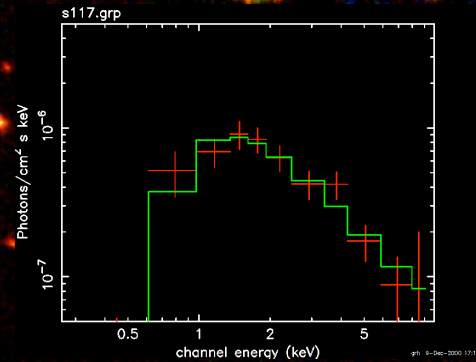
The Lockman Hole Survey(s)

Lockman Hole: X. Barcons, H. Böhringer, H. Brunner, A. Fabian, A. Finoguenov, Y. Hashimoto, P. Henry, I. Lehmann, V. Mainieri, S. Mateos, I. Matute, M. Schmidt, A. Streblyanskaya, G. Szokoly, M. Worsley

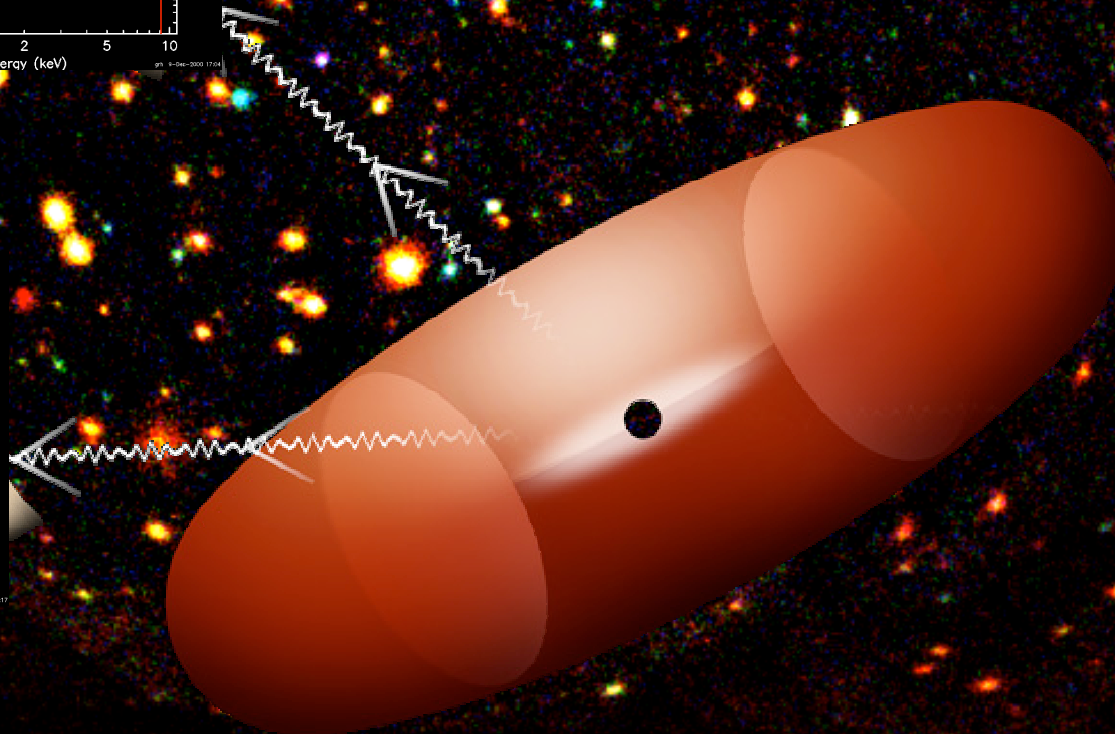
Lockman Hole

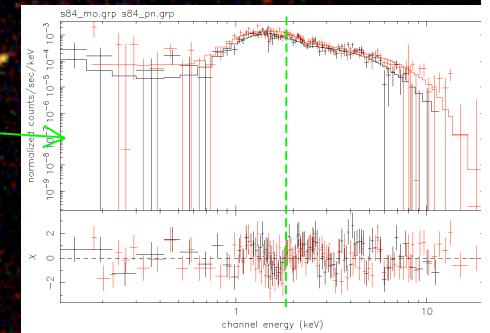
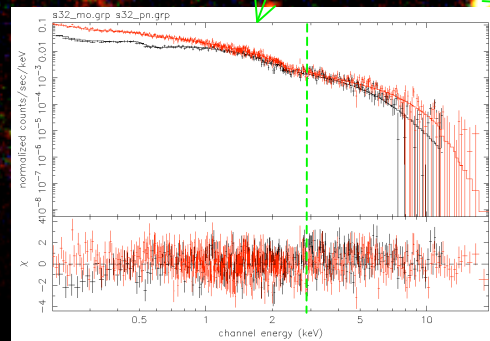
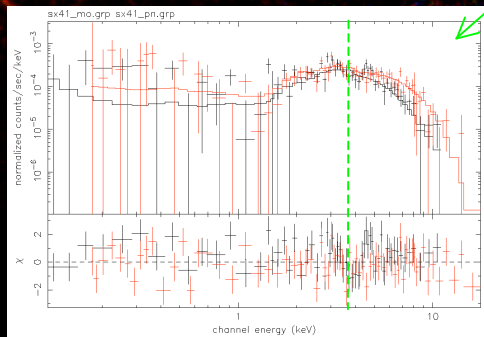
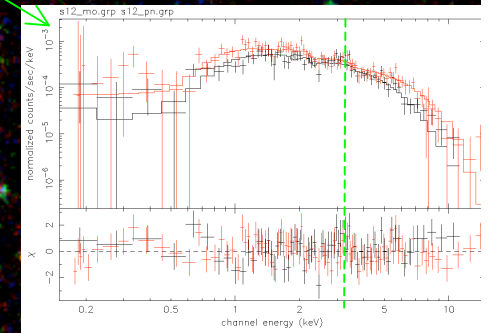
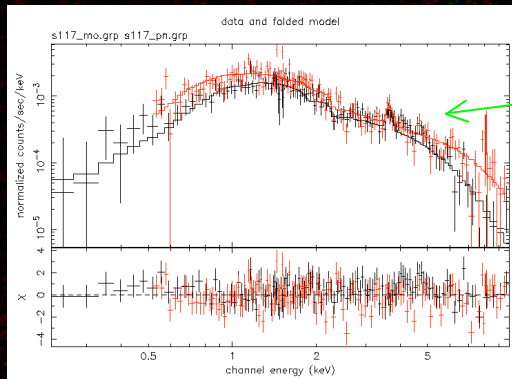
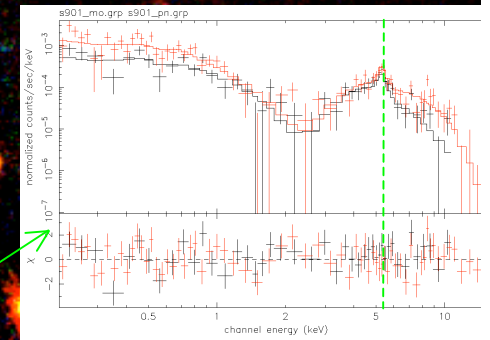
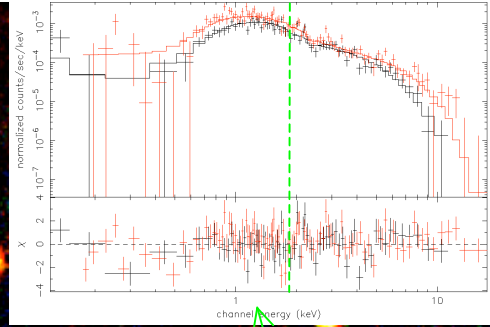
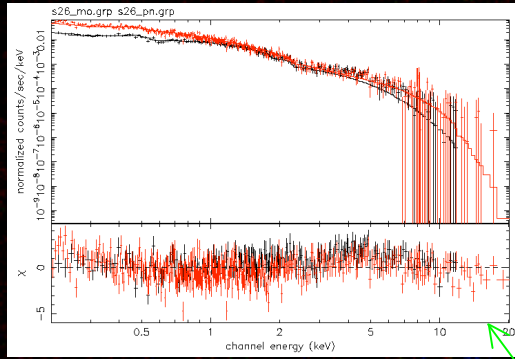


Red (more soft
X-rays)



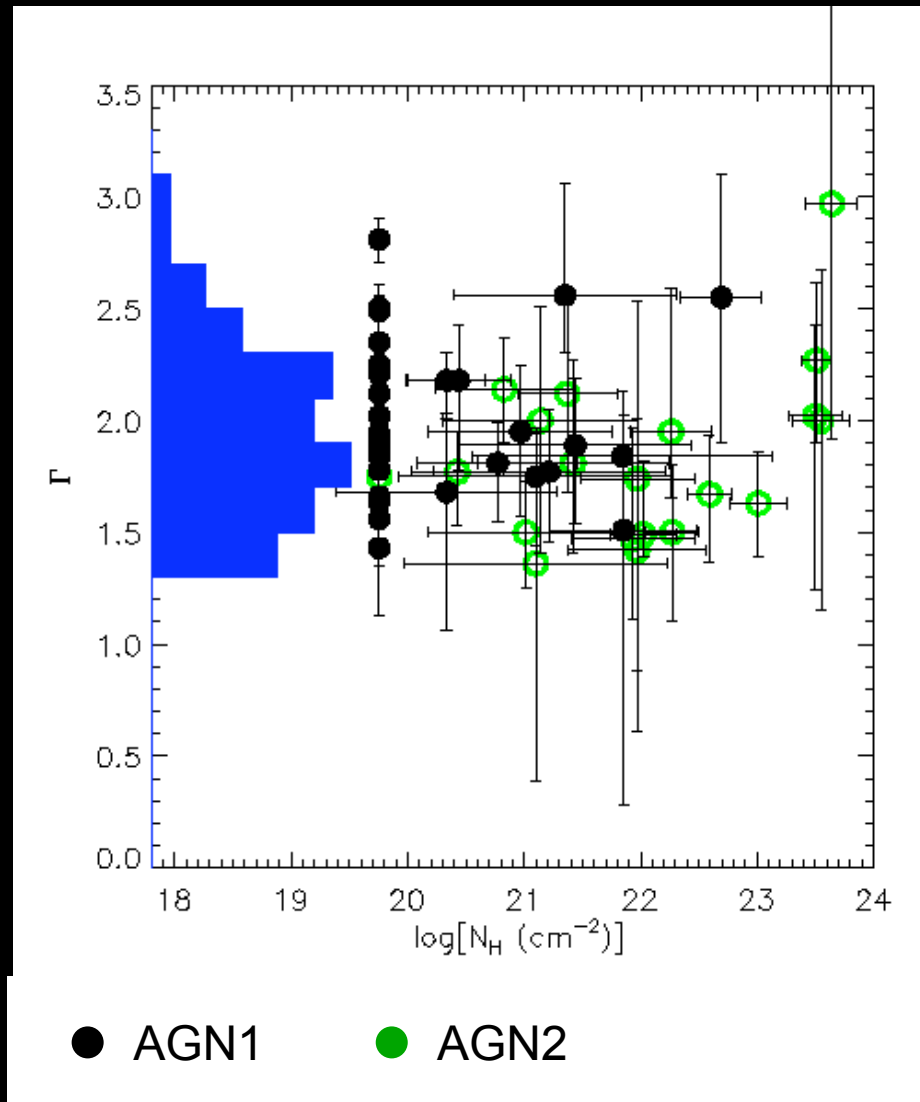
Blue (only hard
X-rays)





XMM PN+MOS

XMM LH Spectral Diagnostic



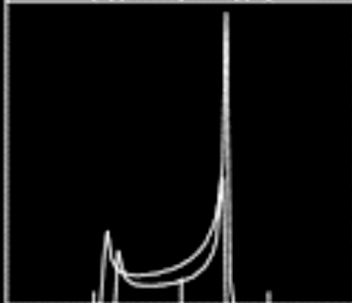
⇒ Confirming predictions of XRB synthesis models

Fe-line diagnostic

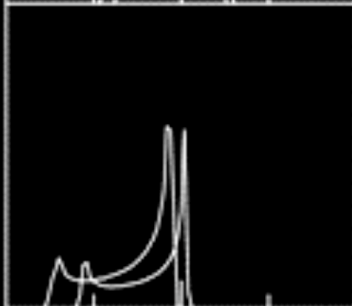
Newtonian



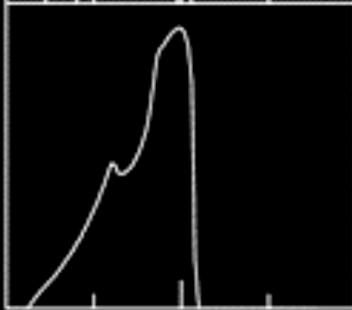
Special Relativity:
Transverse Doppler
and Beaming



General Relativity:
Gravitational
Redshift

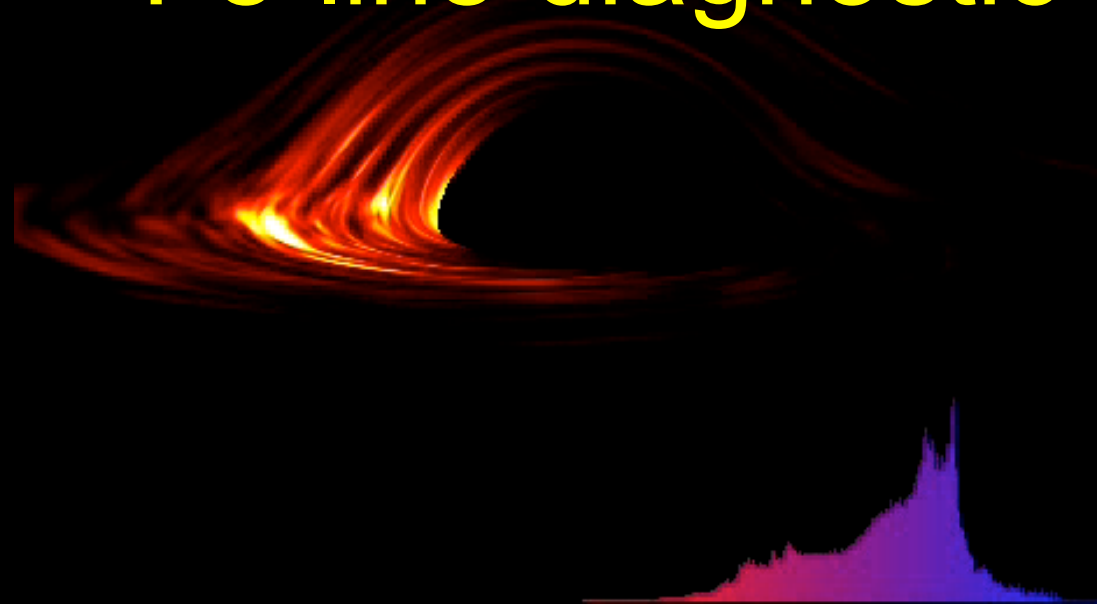


Disk Emissivity

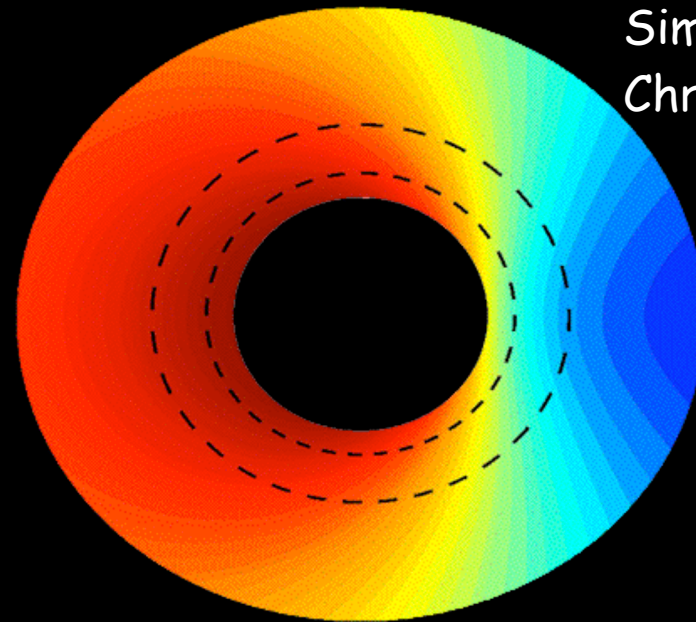


0.5 1 1.5

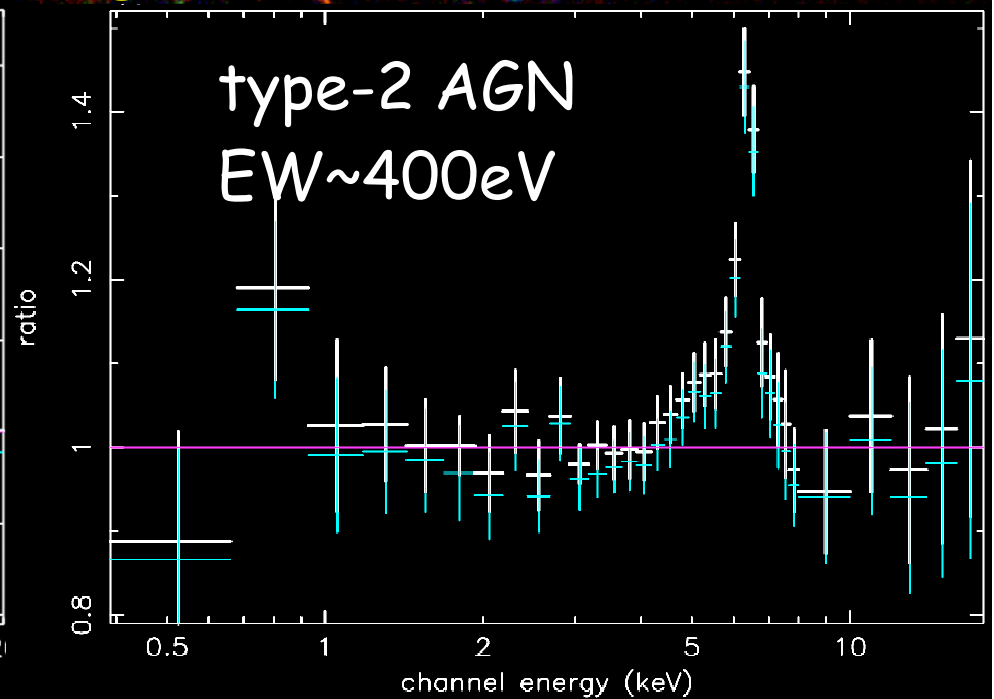
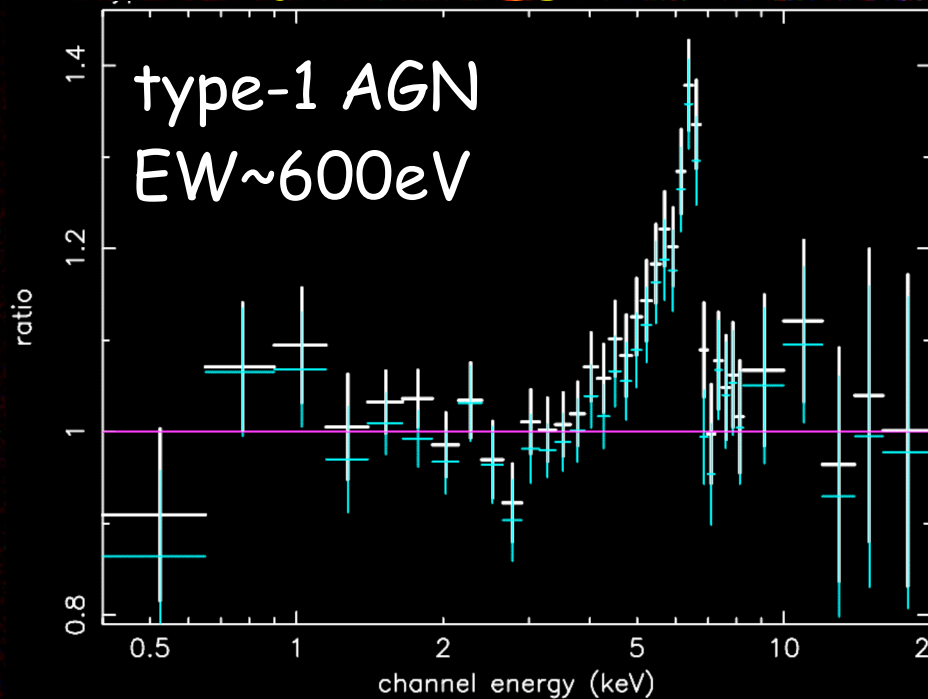
$\nu_{\text{obs}}/\nu_{\text{em}}$



Simulation by
Chris Reynolds



X-ray Background average rest-frame spectra



Streblyanskaya et al., 2004

Large equivalent width can be explained by 3 x solar metallicity.

BH spin within reach.

Good news for Next Generation X-ray Observatory !

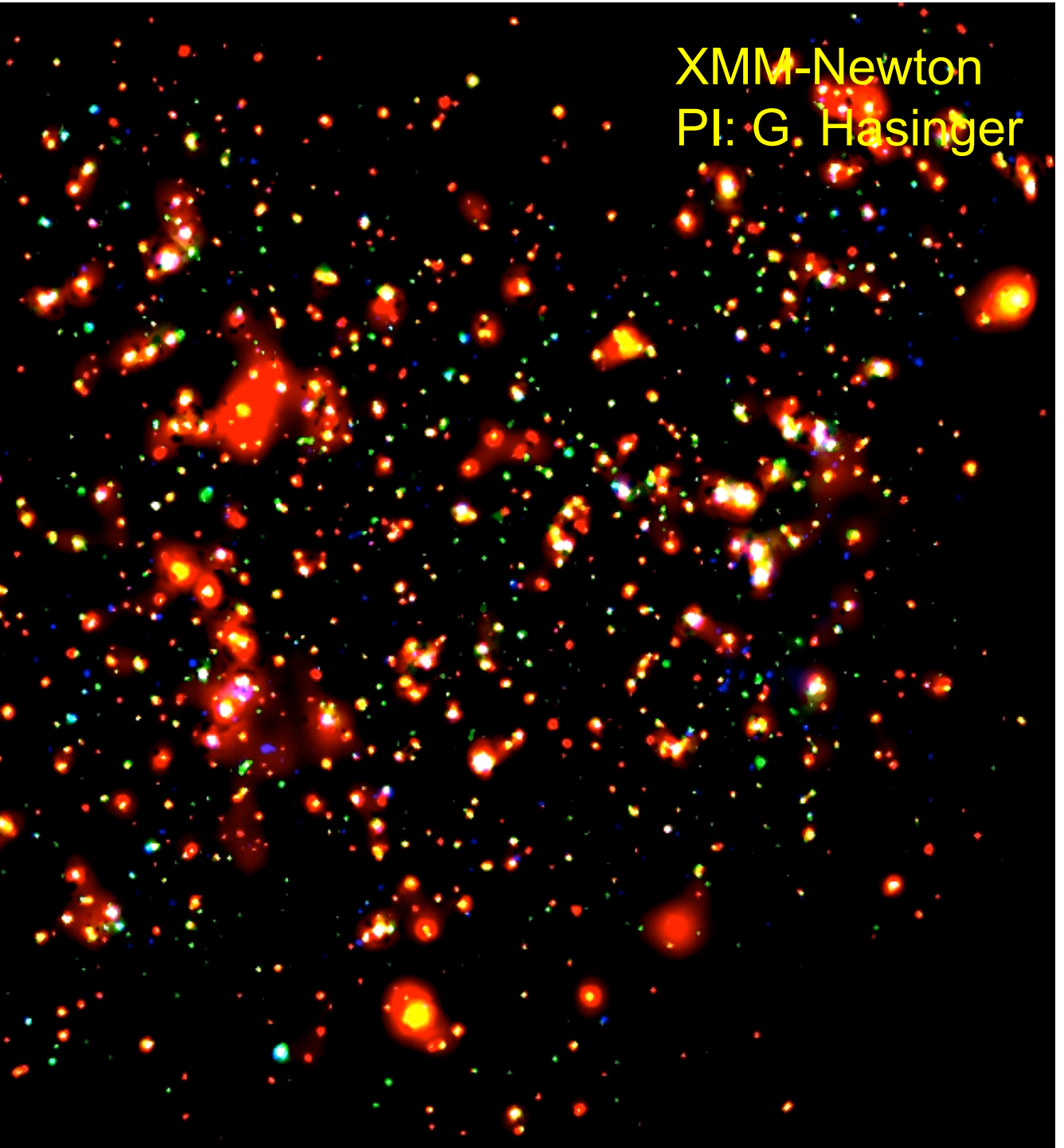
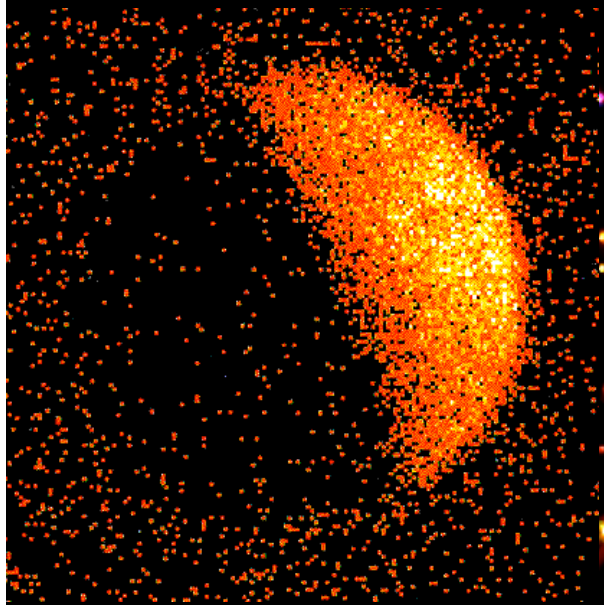
The XMM-COSMOS Survey

COSMOS: H. Böhringer, H. Brunner, M. Brusa,
N. Cappelluti, F. Civano, A. Comastri, M. Elvis,
A. Finoguenov, F. Fiore, A. Franceschini, R. Gilli,
R. E. Griffiths, C. Impey, I. Lehmann, S. Lilly, V. Mainieri,
G. Matt, I. Matute, T. Miyaji, S. Molendi, S. Paltani,
D. B. Sanders, N. Scoville, J. Silverman, L. Tresse,
M. Urry, P. Vettolani, G. Zamorani

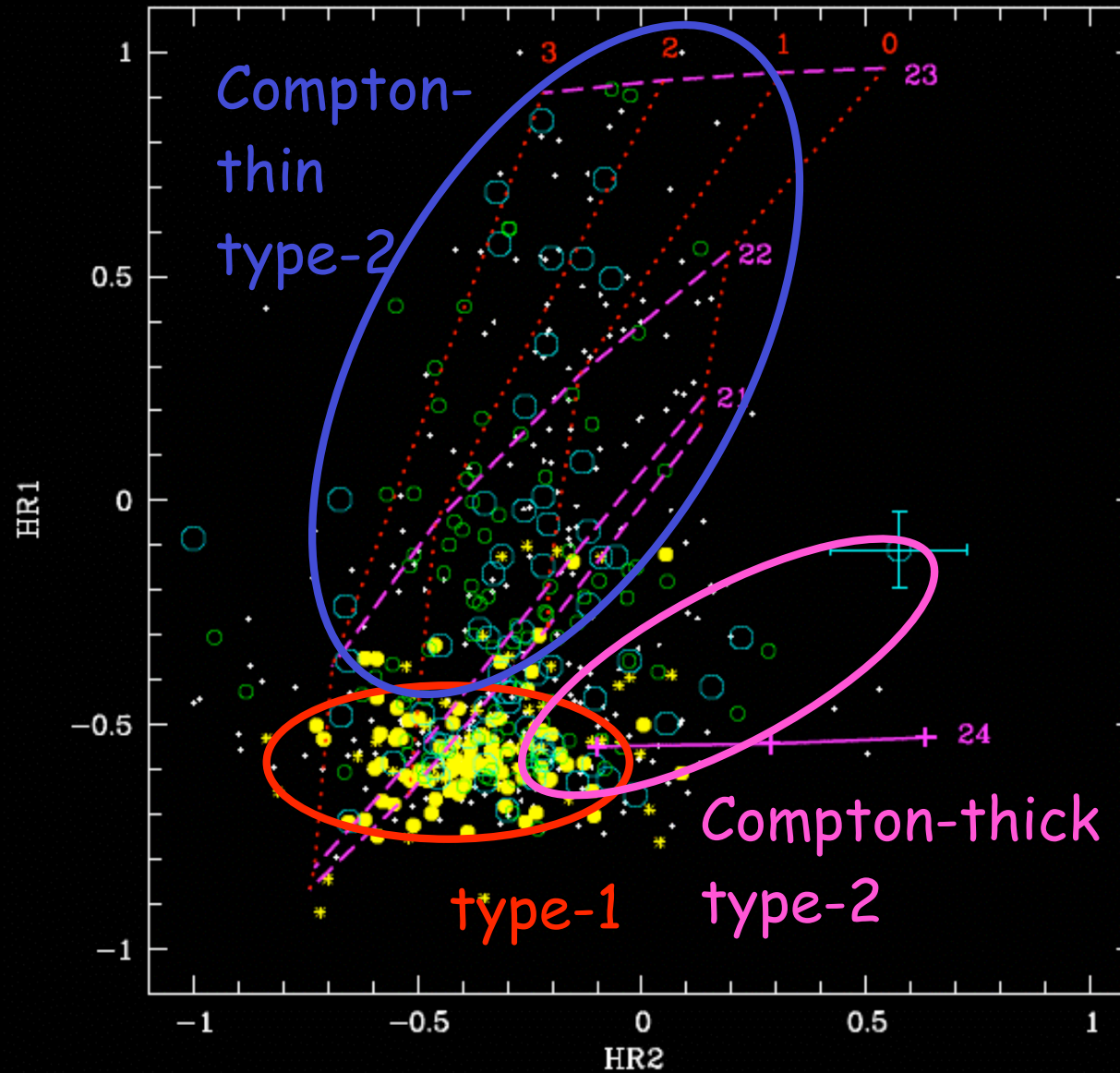
Cosmos Survey

2 deg²

XMM-Newton
PI: G. Hasinger

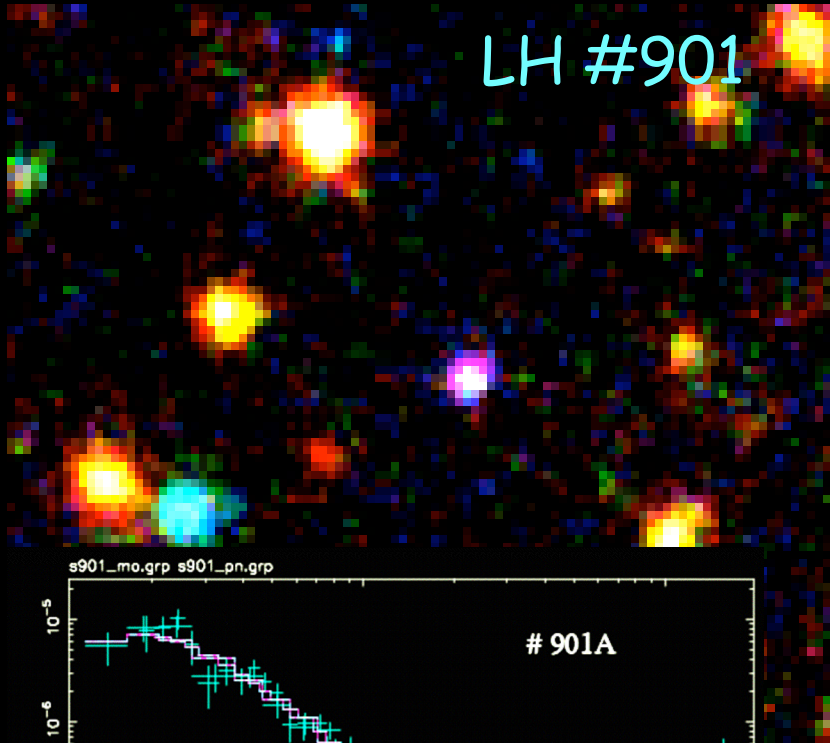


X-ray color-color diagnostic

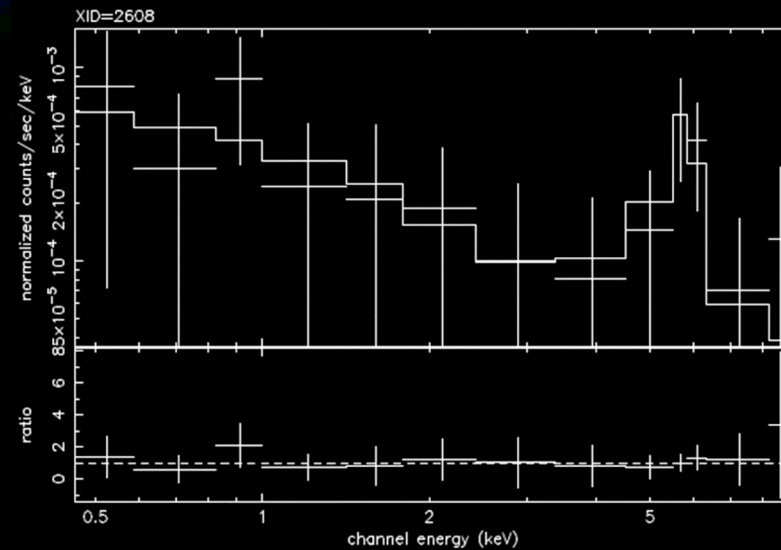
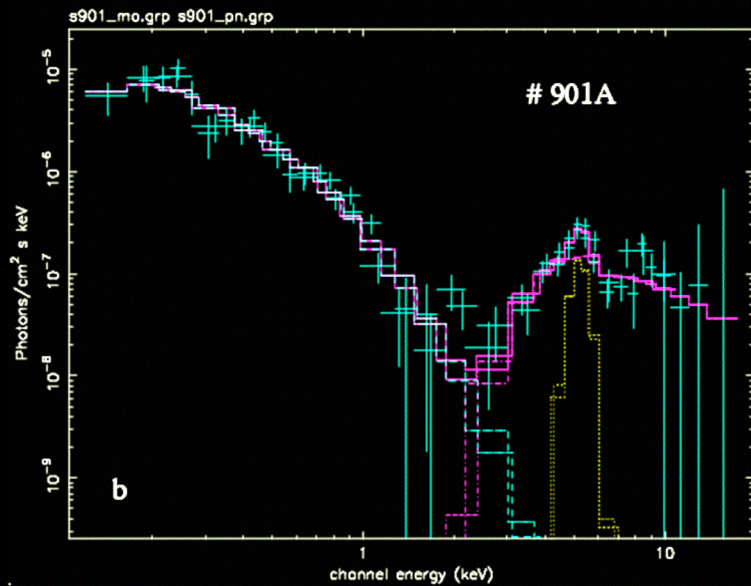
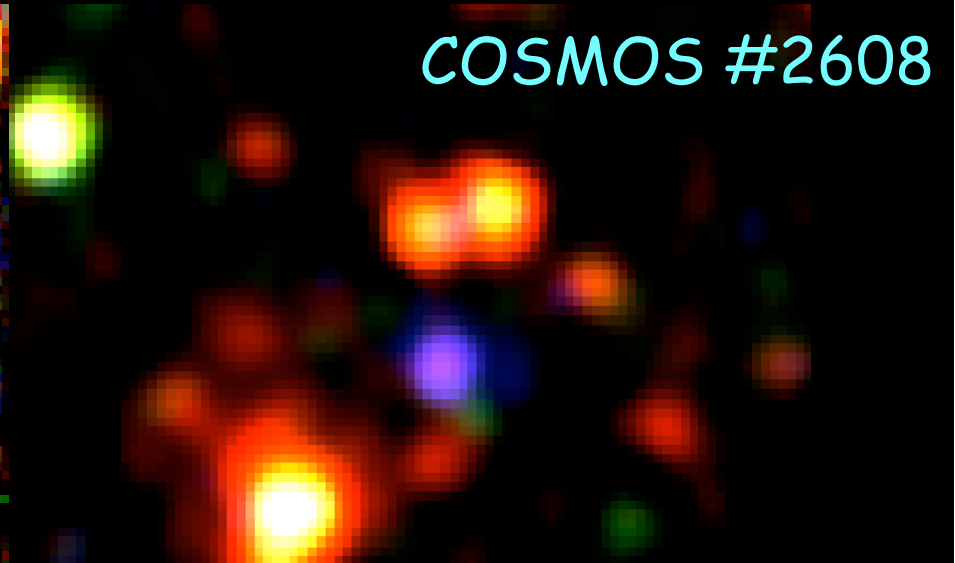


„Pink Sources“

LH #901

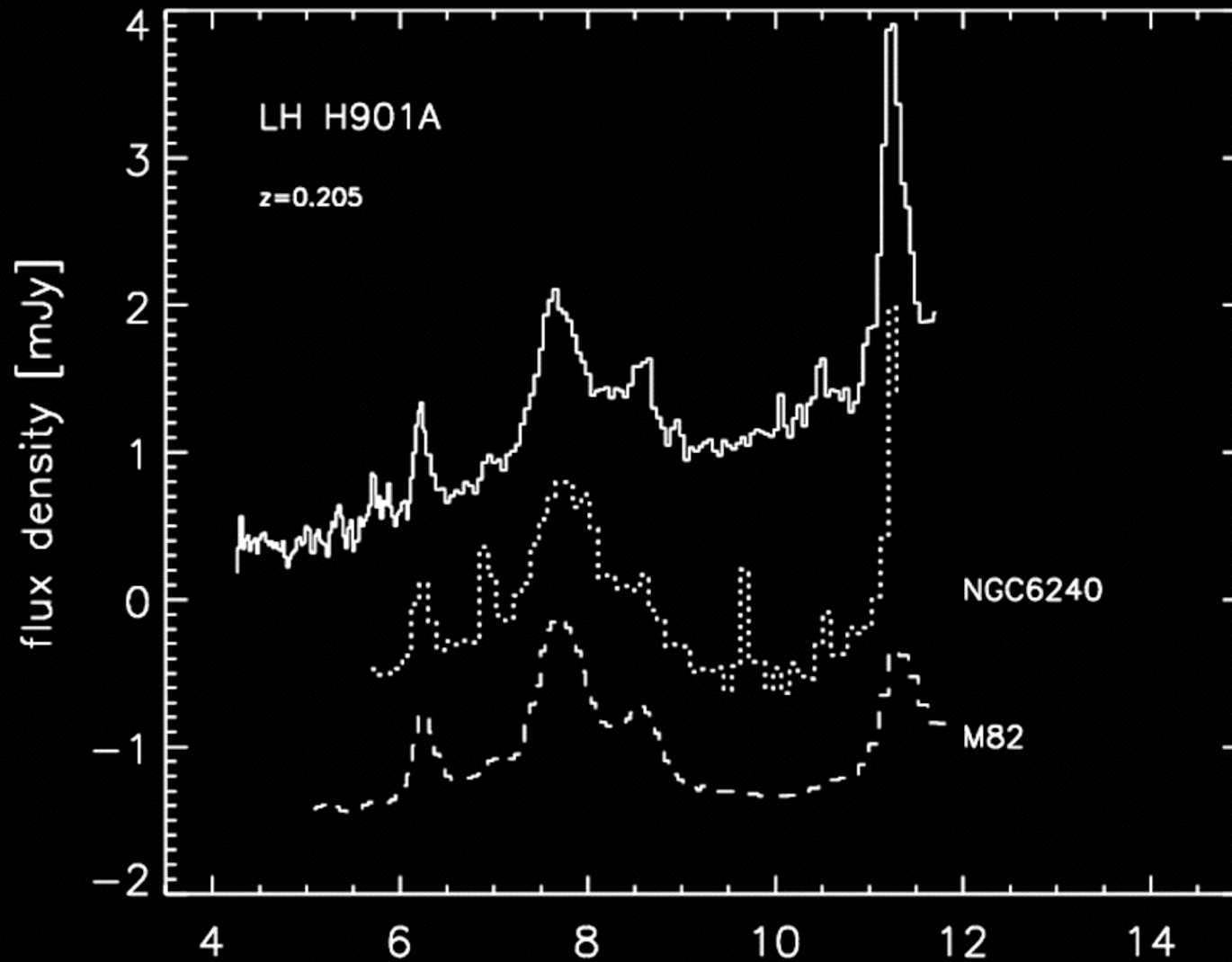


COSMOS #2608

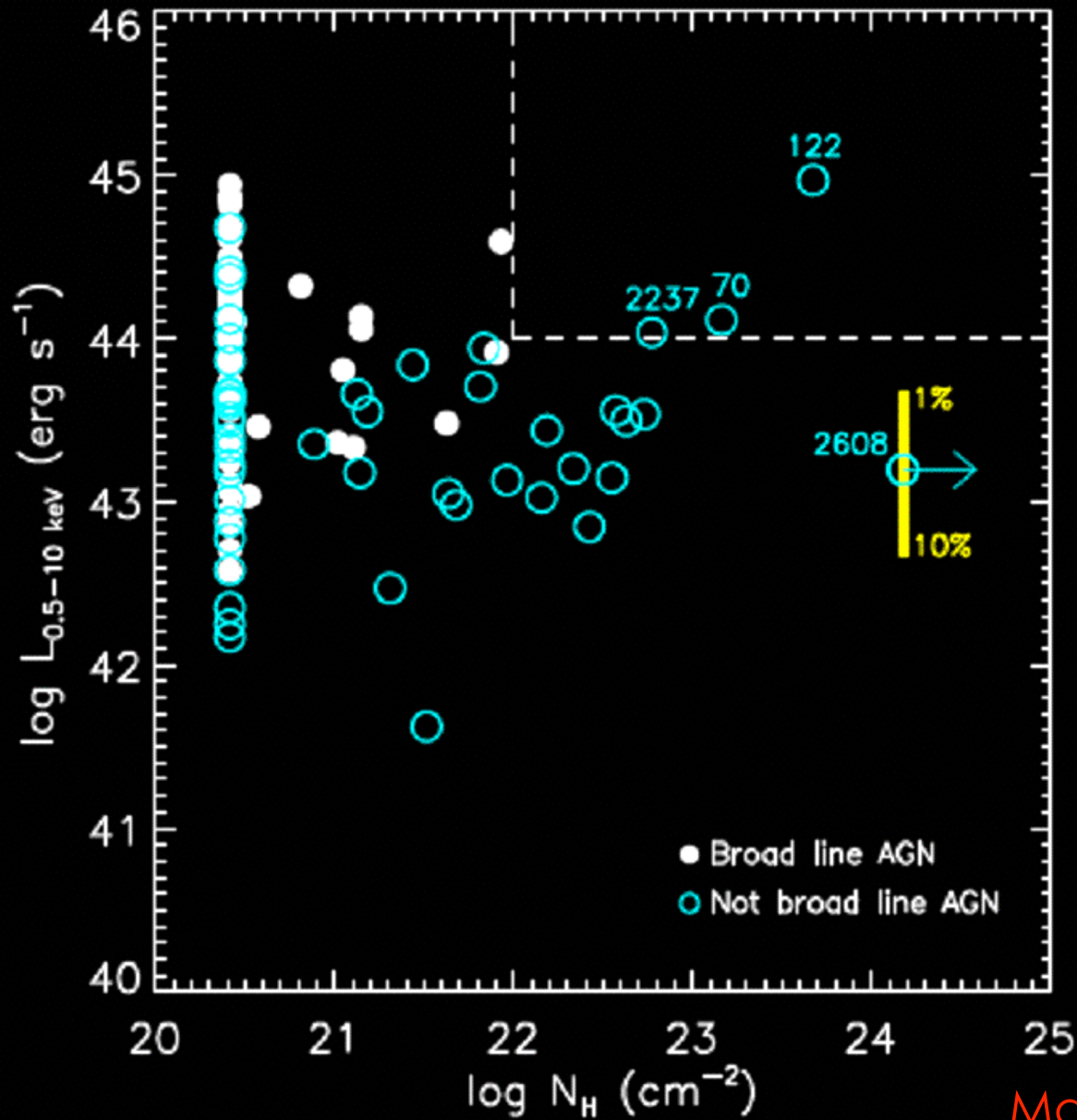


Compton-thick AGN spectra!

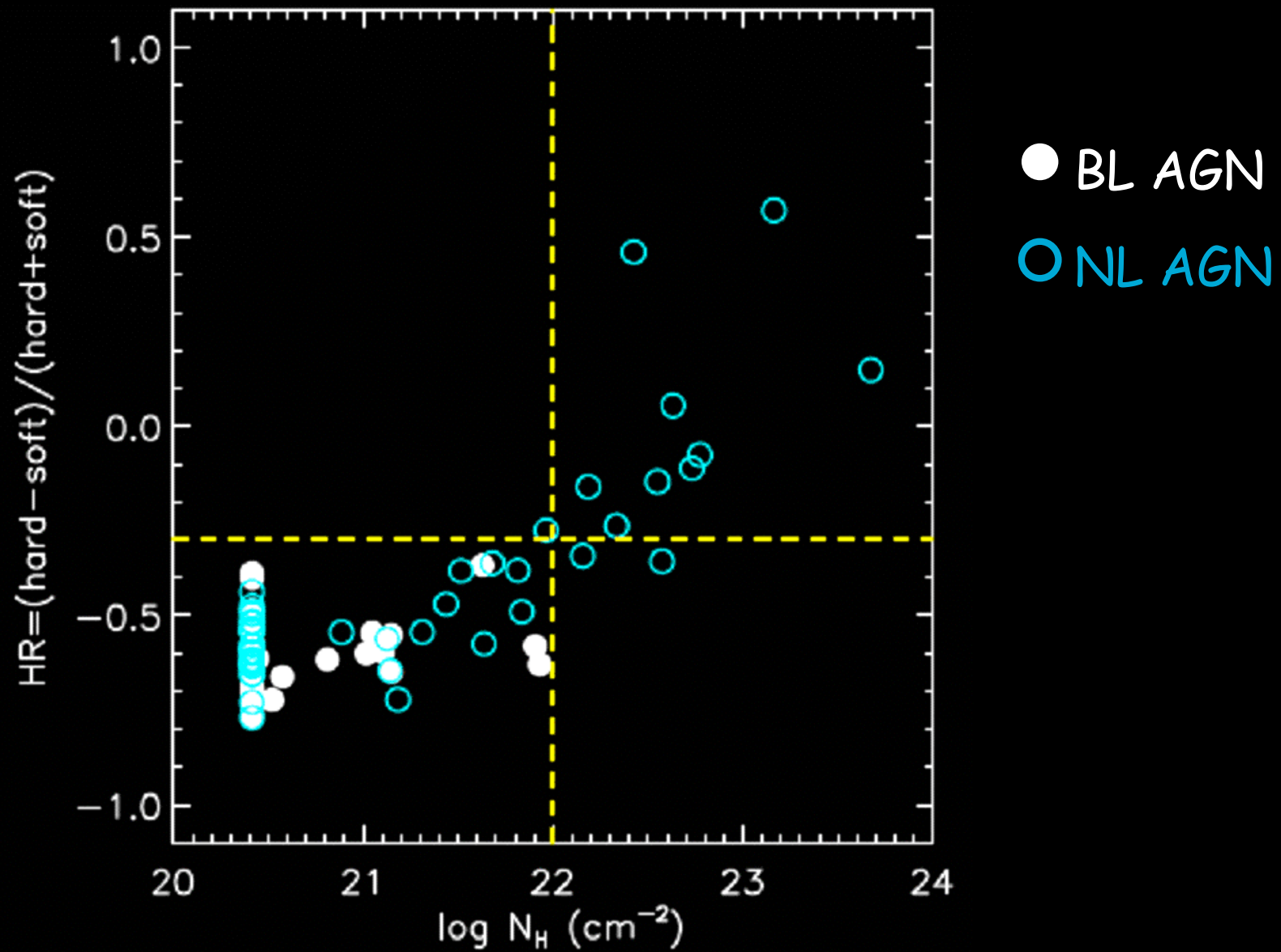
Spitzer IRS (mid-IR) spectroscopy



COSMOS: NH vs. Luminosity



HR as proxy for N_H



The Chandra Deep Field South

CDFS: J. Bergeron, S. Borgani, A. Finoguenov, R. Giacconi, R. Gilli, R. Gilmozzi, K. Kellerman, L. Kewley, A. Koekemoer, I. Lehmann, V. Mainieri, M. Nonino, C. Norman, M. Romaniello, P. Rosati, E. Schreier, A. Streblyanskaya, G. Szokoly, P. Tozzi, J.X. Wang, W. Zheng, A. Zirm

E-CDFS: D. Alexander, F. Bauer, E. Bell, J. Bergeron, W. N. Brandt, E. Fomalont, R. Gilli, K. Kellermann, A. Koekemoer, B. Lehmer, V. Mainieri, T. Miyaji, H.W. Rix, P. Rosati, D. Schneider, J. Silverman, G. Szokoly, P. Tozzi

Chandra Deep Field South

Chandra 4x250 ksec
(PI: N. Brandt)

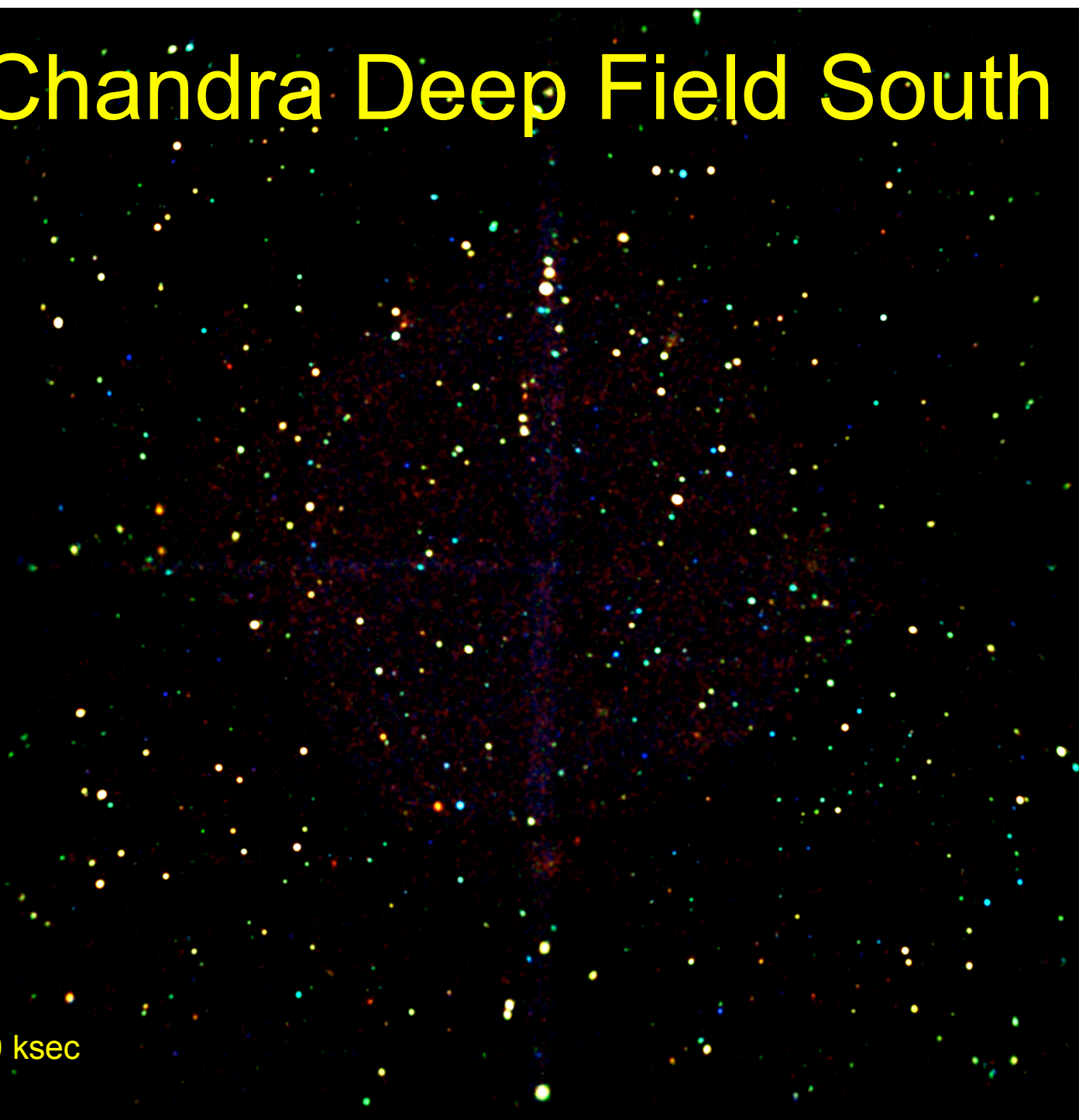
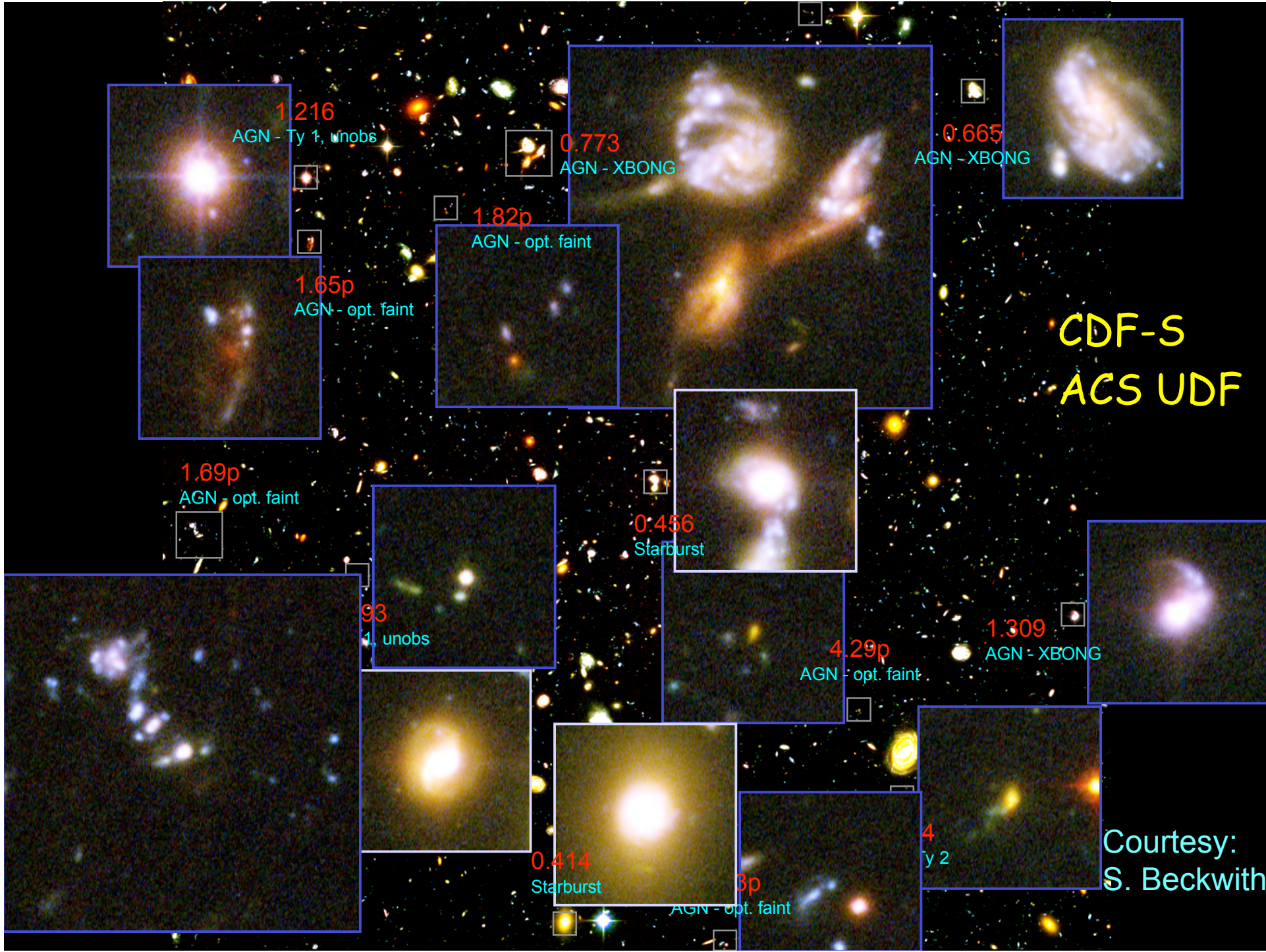


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CDF-S
ACS UDF

1.216
AGN - Ty 1, unobs

0.773
AGN - XBONG

0.665
AGN - XBONG

1.82p
AGN - opt. faint

1.65p
AGN - opt. faint

0.456
Starburst

1.69p
AGN - opt. faint

93
1, unobs

4.29p
AGN - opt. faint

1.309
AGN - XBONG

4
y 2

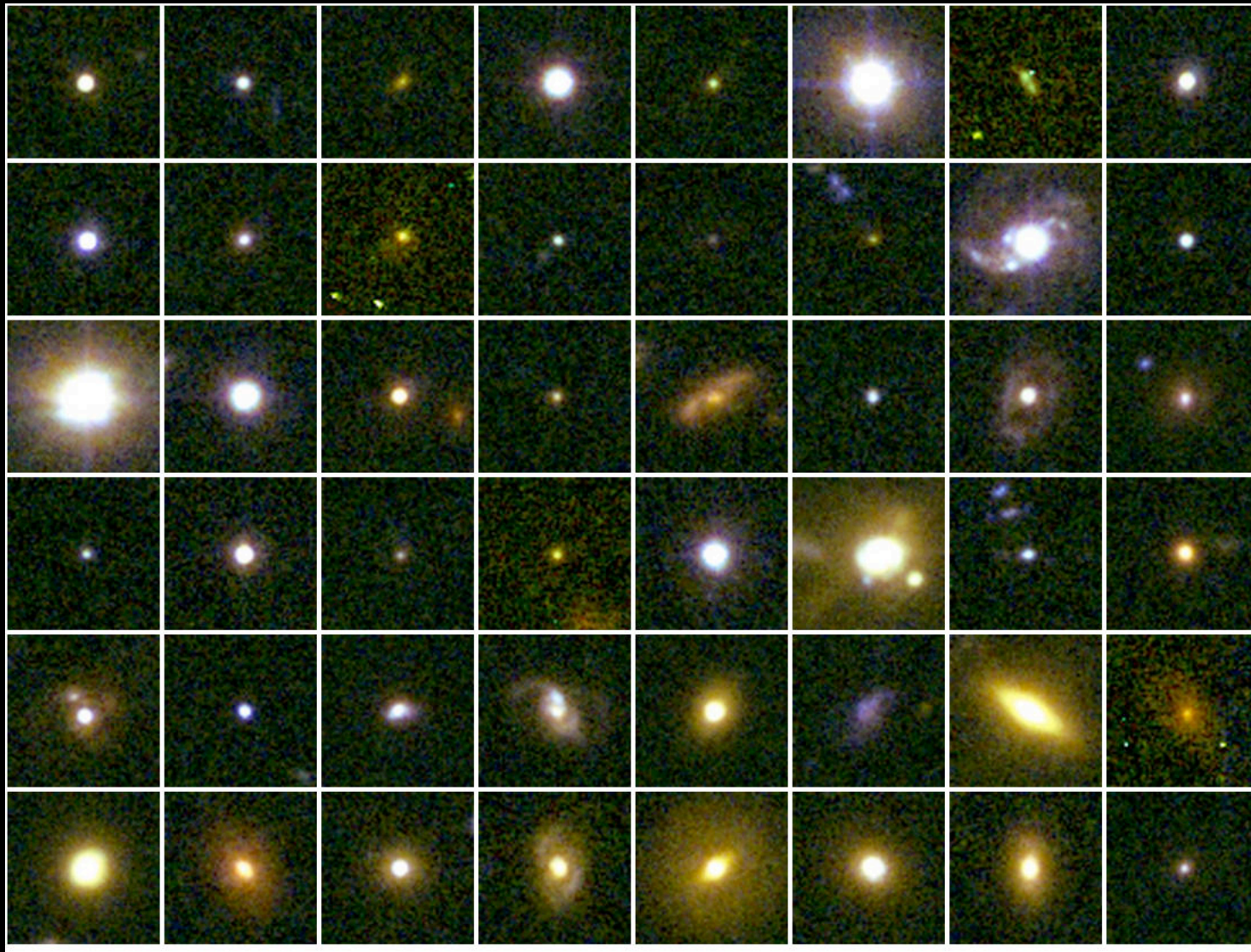
0.414
Starburst

3p
AGN - opt. faint

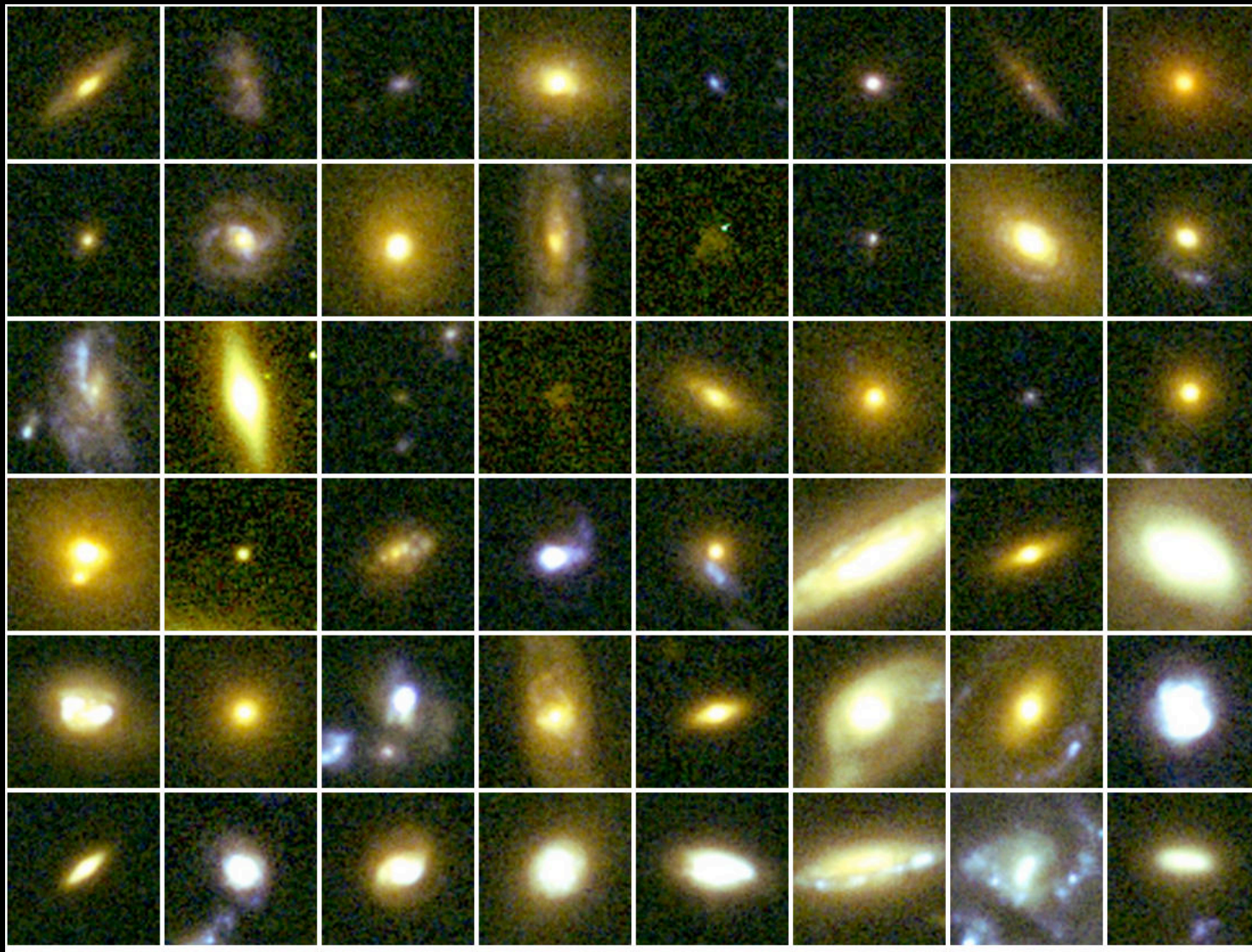
4
y 2

Courtesy:
S. Beckwith

AGN zoo

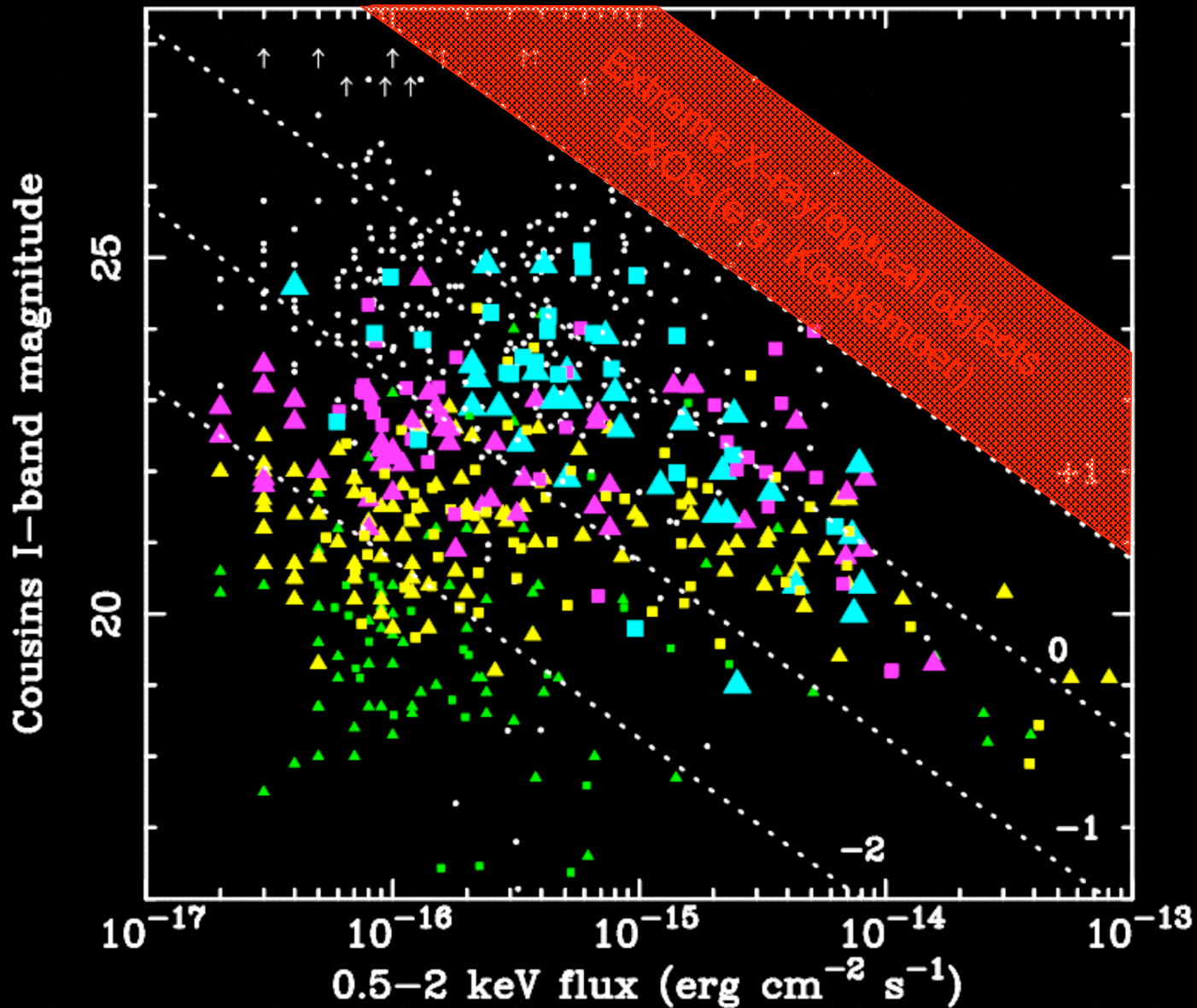


AGN zoo



B V i z

Chandra Deep Field IDs



CDFN: Triangles
CDFS: Squares
dot: unidentified

$0 < z < 0.5$
 $0.5 < z < 1$
 $1 < z < 2$
 $2 < z < 6$

Spectroscopic Identifications



VLT (ESO)

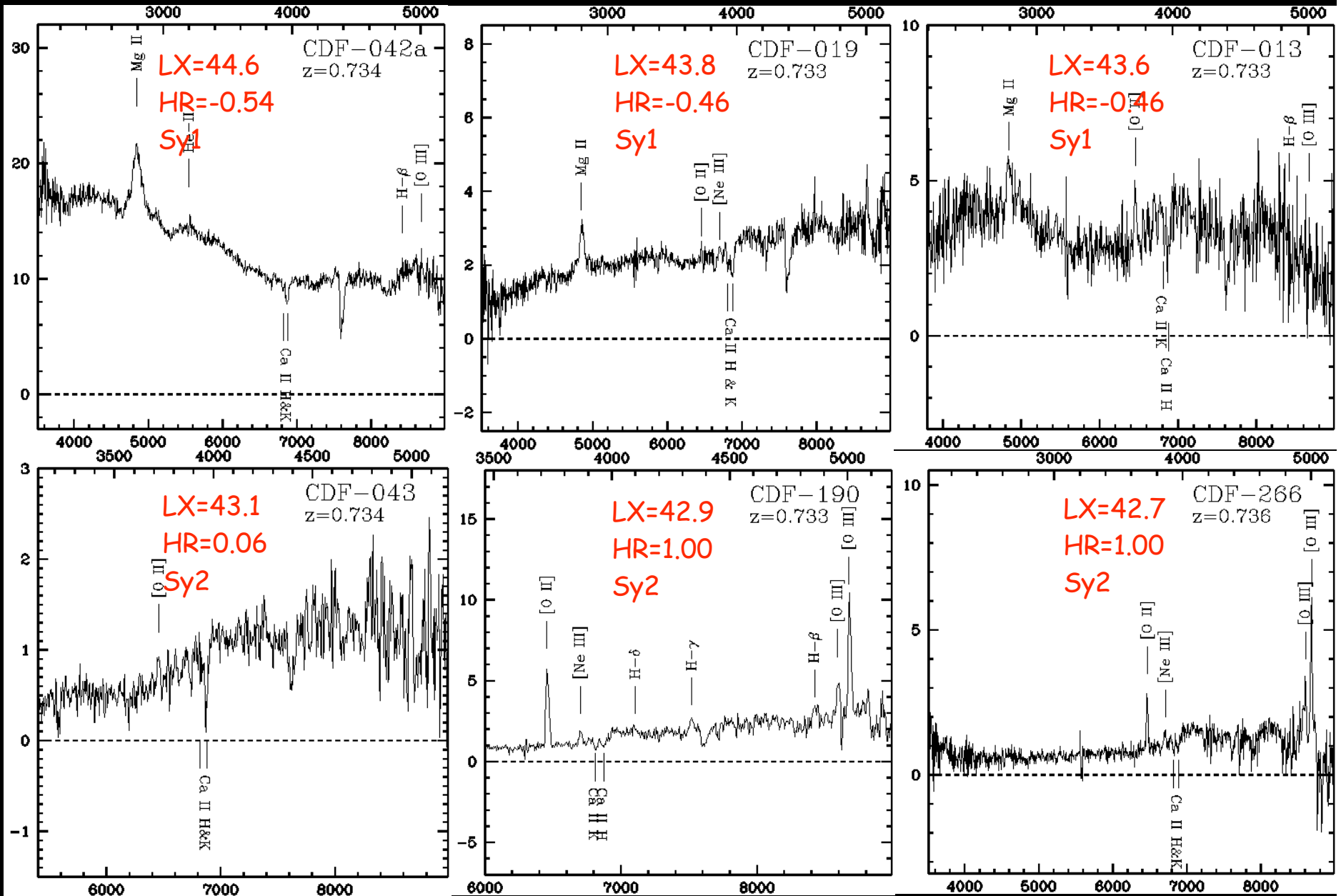
VLT FORS multiobject spectroscopy: 11 nights (2000-2001)

1-5 hrs exposures (PI: G. Hasinger, MPE)

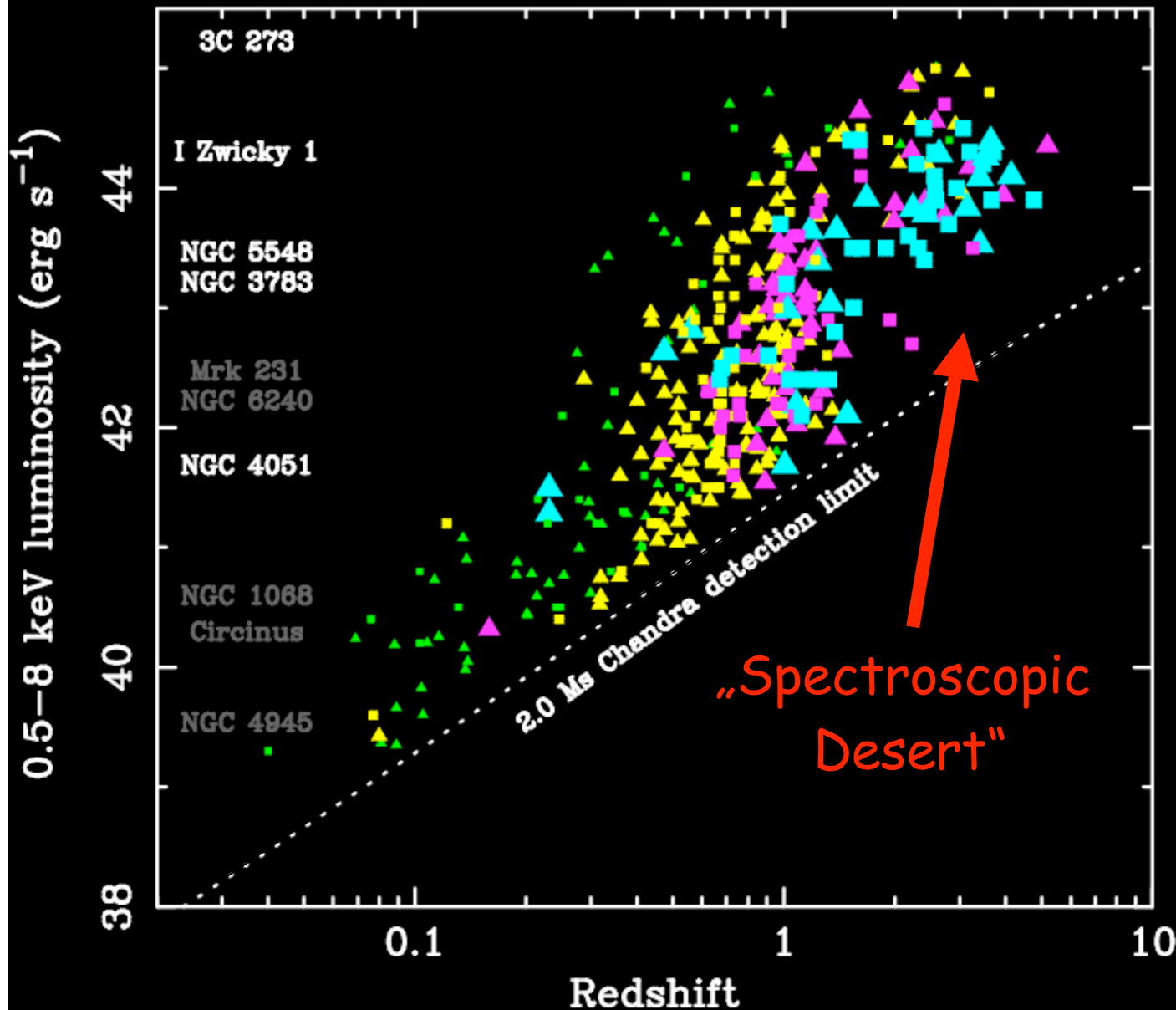
Szokoly et al., 2004 (ApJS)

ISI citation classic 04/06!

Type 1/Type 2 at the same Redshift



L_x vs. redshift



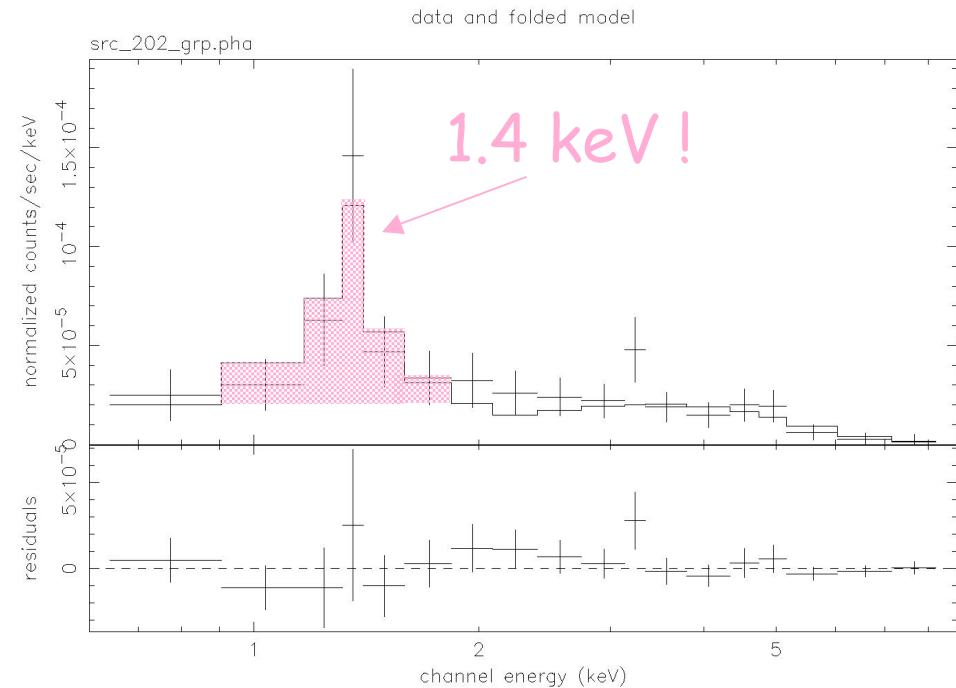
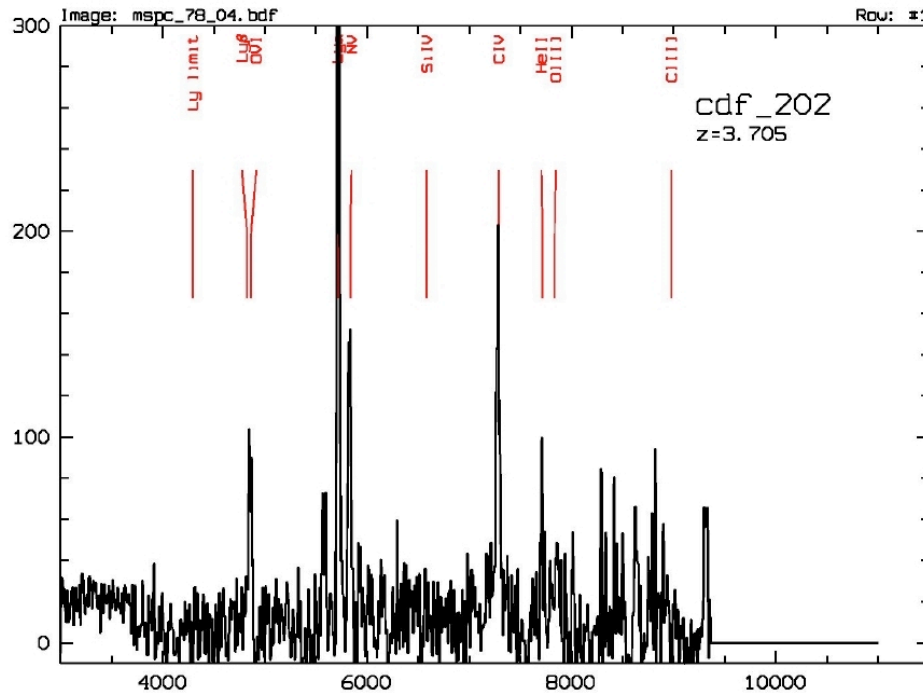
CDFN: Triangles
CDFS: Squares

I=15-20
I=20-22
I=22-23
I>23

QSO-2 detected

CDFS #202: type-2 QSO
 $z=3.705$
narrow high-excitation lines
VLT-spectrum

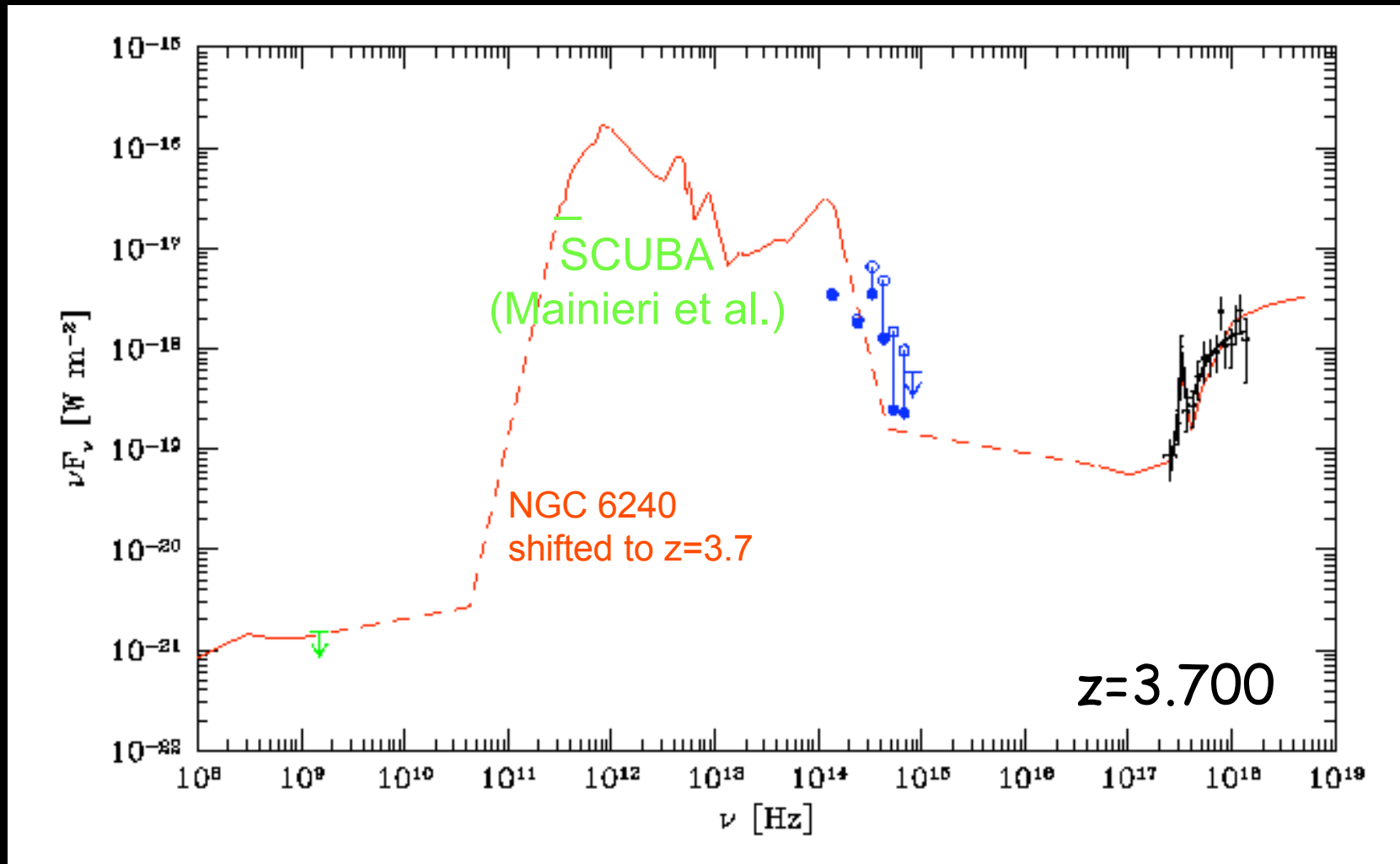
$L_x | 10^{45}$ erg/s
 $N_H | 10^{24}$ cm⁻²
Fe-line @ 6.4 keV
Chandra spectrum



Norman et al., 2001

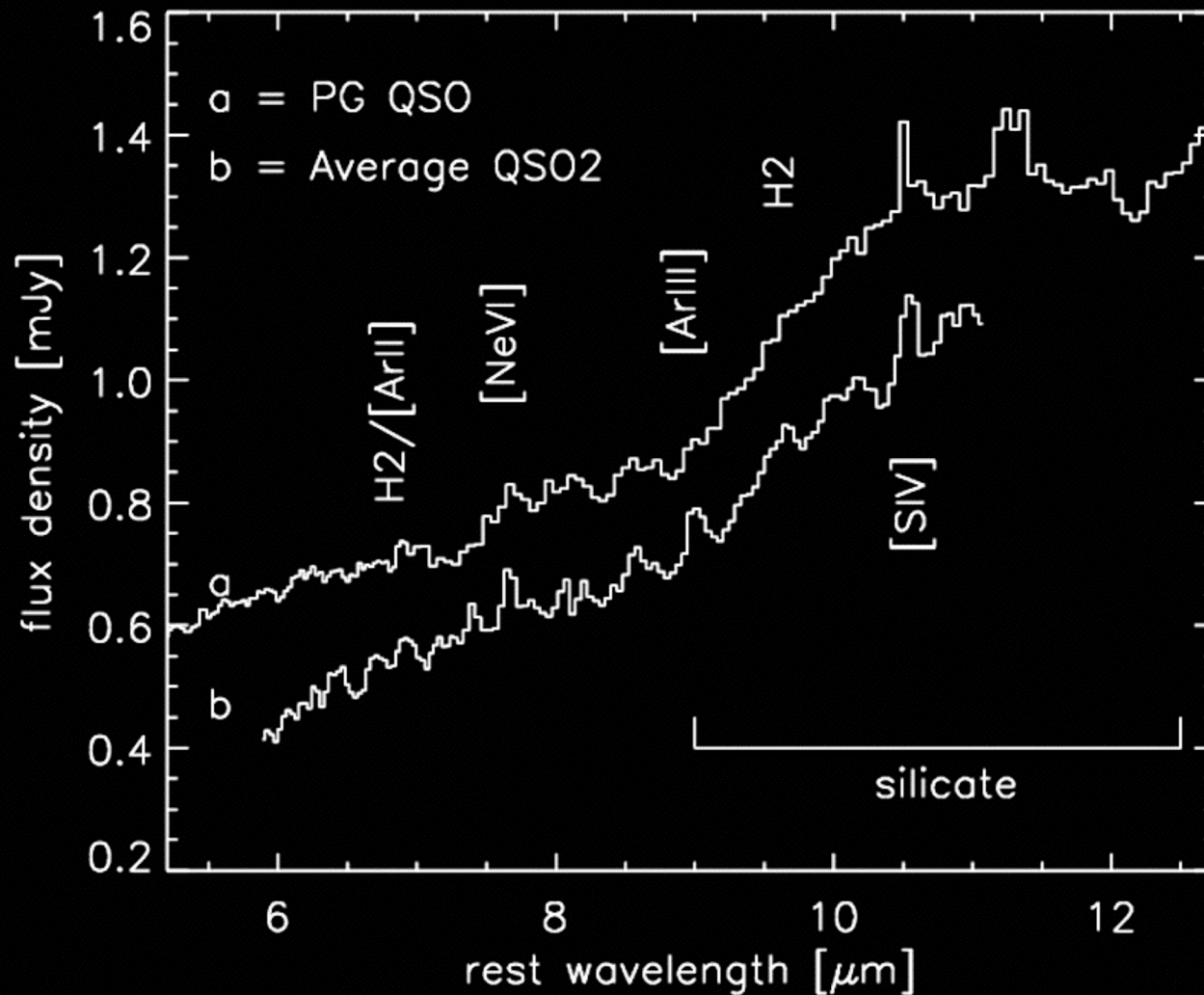
→ Confirmation of 1995 Comastri et al prediction!!!

Prototypical QSO2 CDFS #202



⇒ High-redshift carbon copy of NGC 6240 !

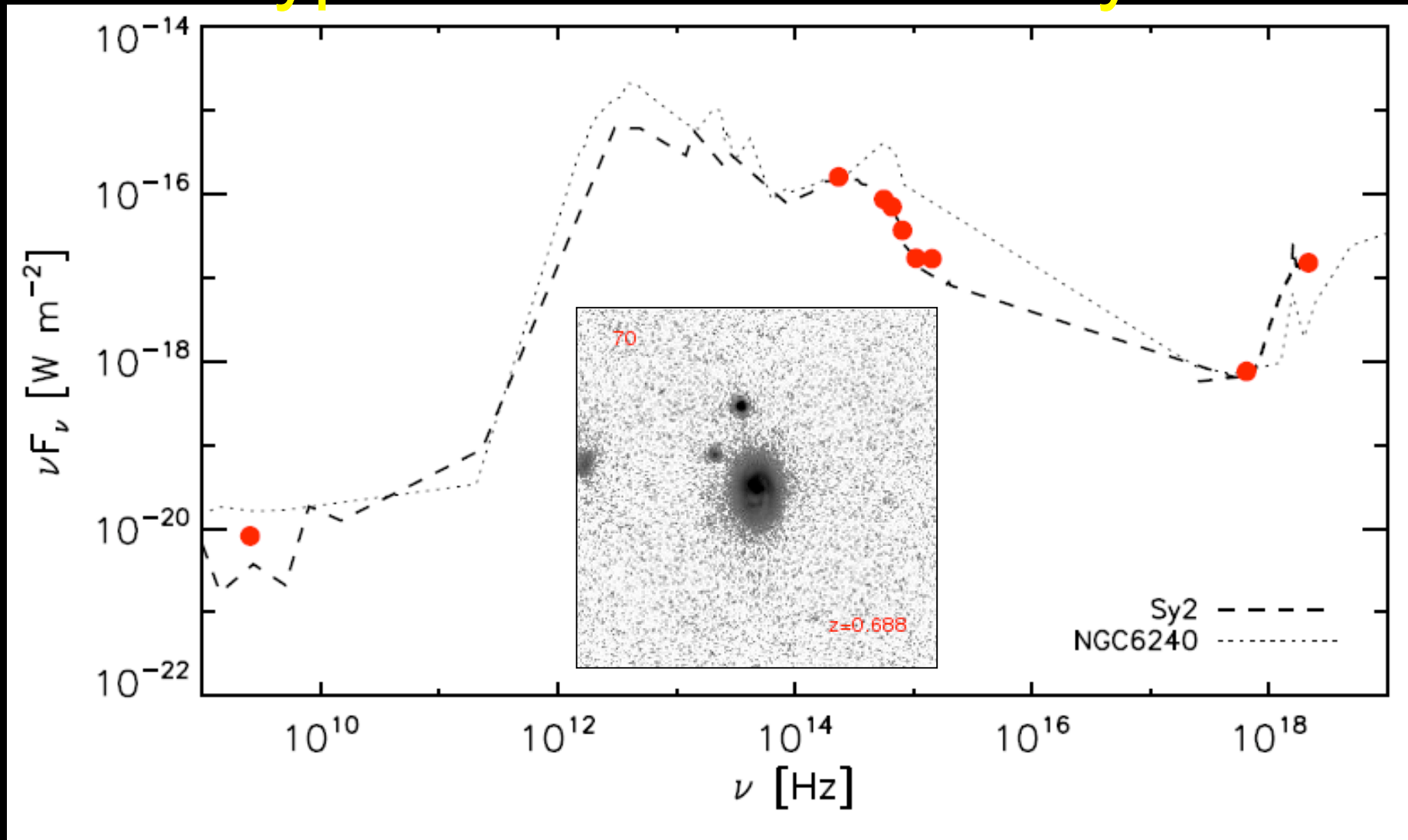
Average QSO-2 IRS spectrum



X-ray selected QSO-2 show silicate emission, no PAH!

Sturm et al., 2006, ApJ

Typical QSO-2 SED ~ Sy2



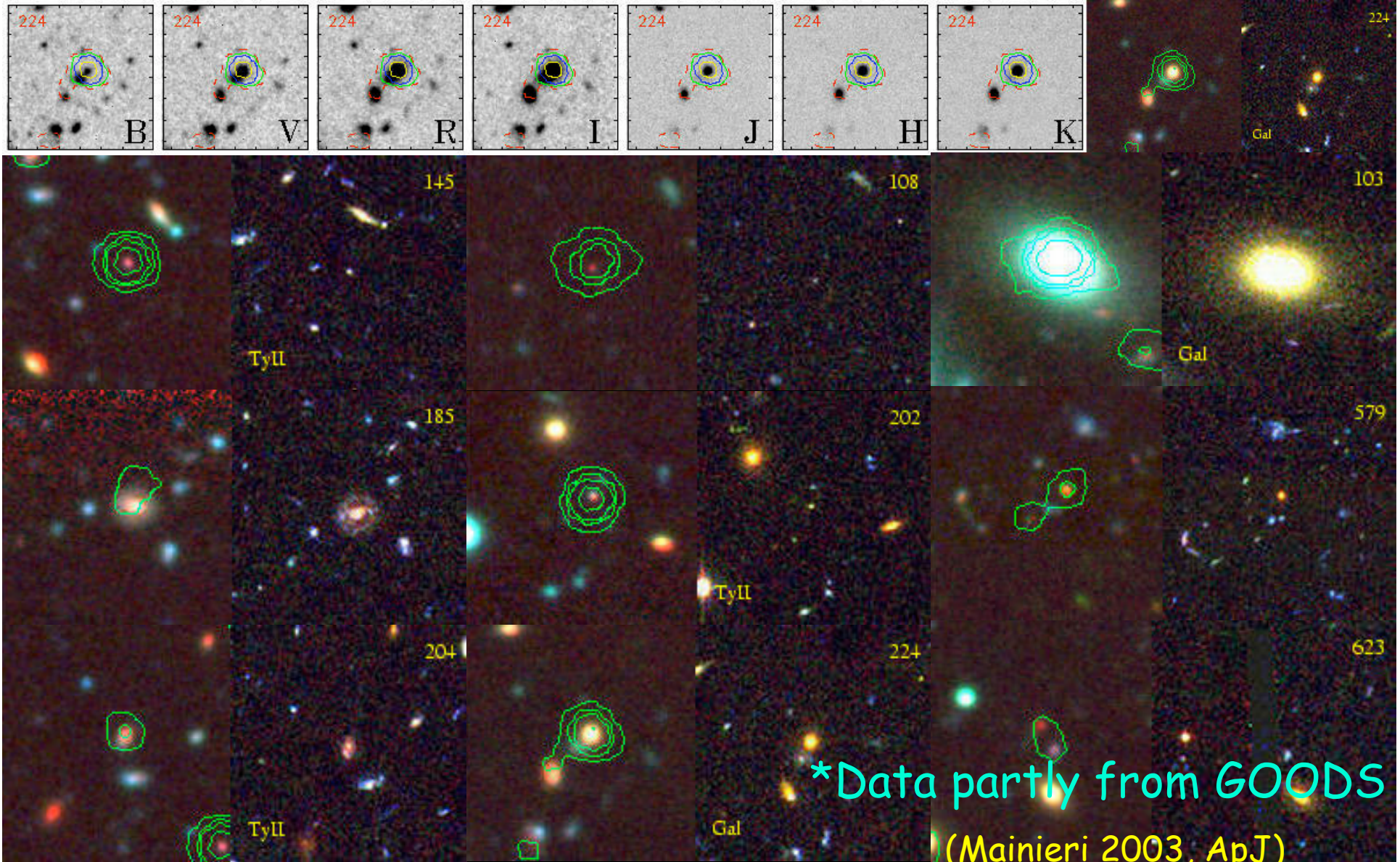
X-ray selected QSO-2 are NOT ULIRGS - and viceversa!

Sturm et al., 2006, ApJ

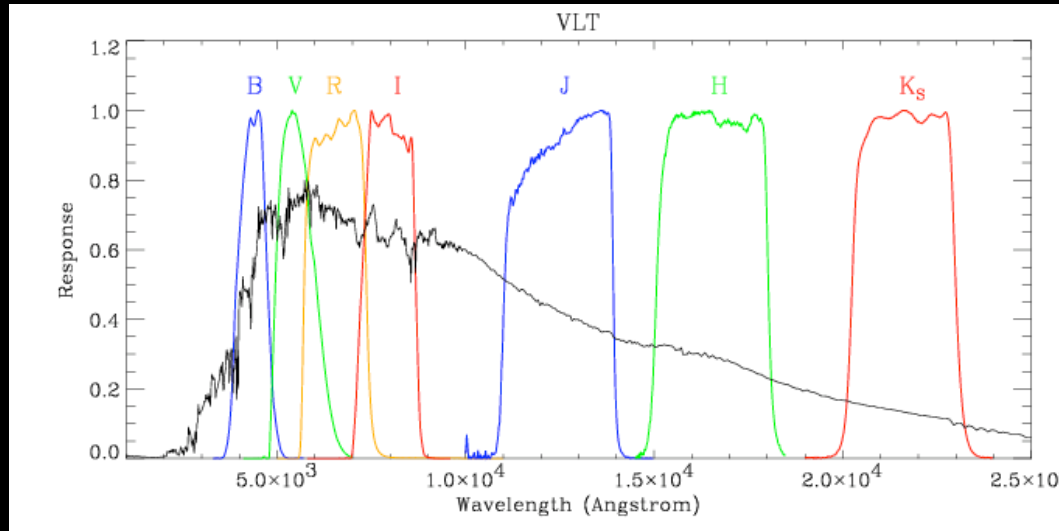
Photometric Redshifts

VLT*

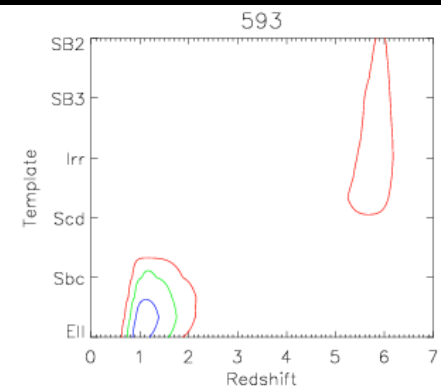
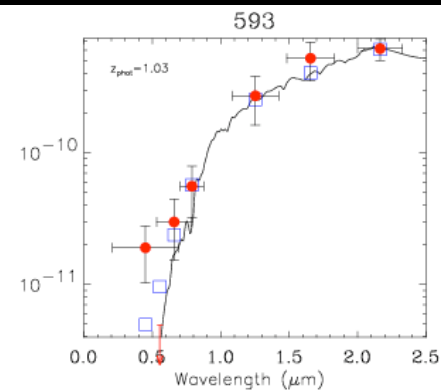
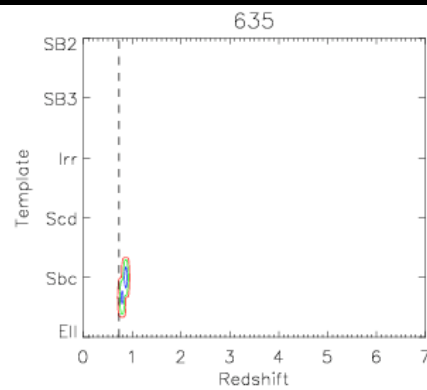
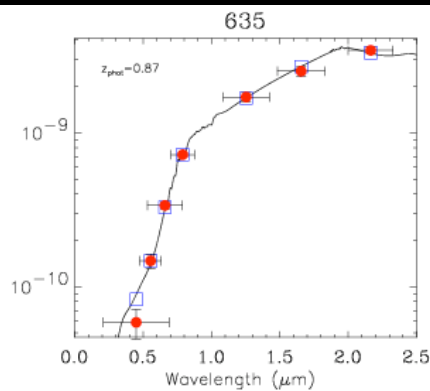
HST*



Template Fitting



- Works well for galaxies ($\Delta z \sim 0.1$)
- Some problems with type-1 AGN
- Template SEDs critical



Mainieri et al., 2003; Zheng et al., 2003

Combo-17 Redshifts

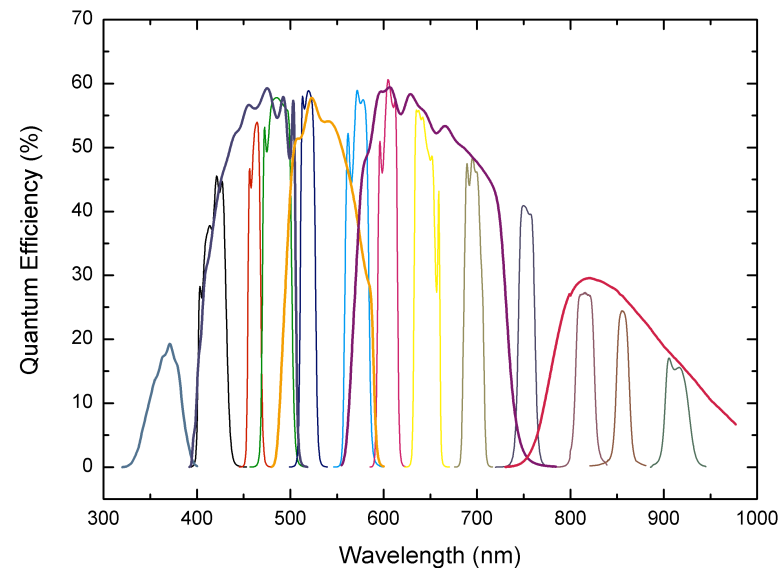
- ESO/MPI 2.2m+WFI
- 1 degree Field of View
- UBVRI broadband +
- 12 narrow-band filters
- limiting magnitude: $R \sim 24$

- no NIR info!
- QSOs modelled very well

Wolf C. et al., 2001, *A&A* 377, 442

Wolf C. et al., 2003, *A&A* 401, 73

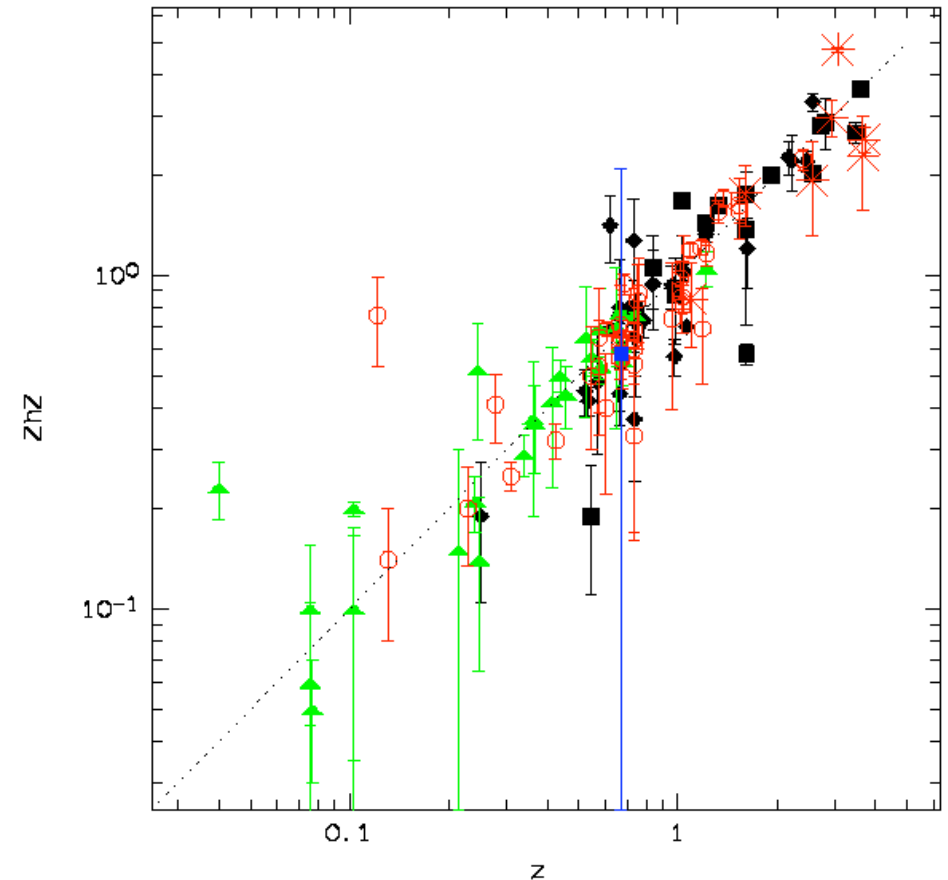
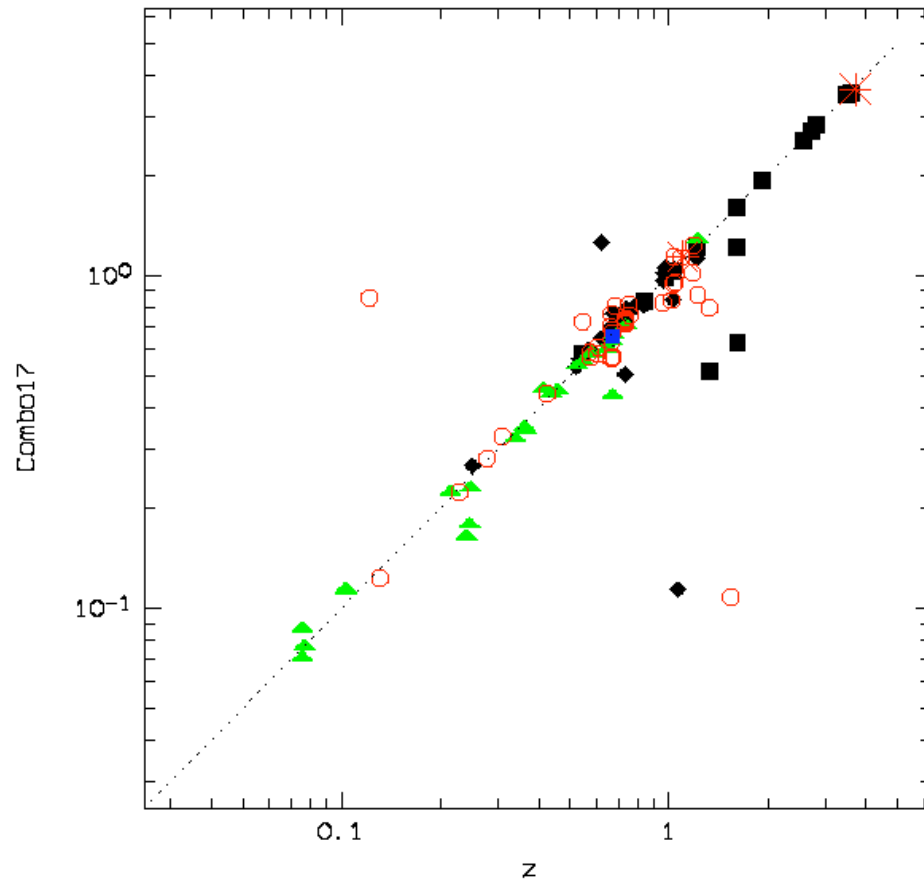
Wolf C. et al., 2004, *A&A* 421, 913



Comparison of Photo-zs

COMBO-17

VLT+HST Photometry



Black: type-1 AGN; Red: type-2 AGN Green: galaxies

Wolf et al., 2003

Zheng, Mainieri et al., 2003

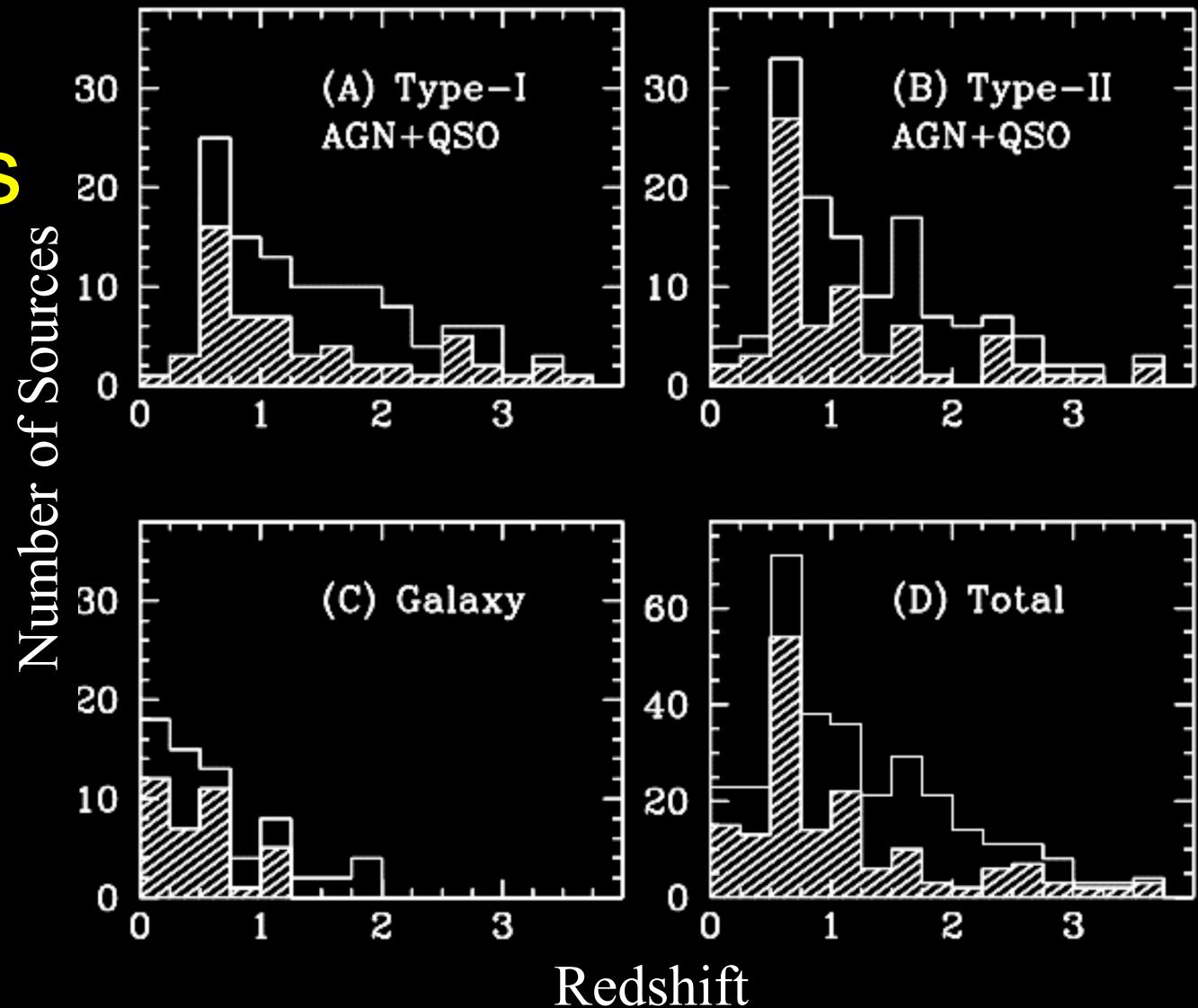
CDFS Optical IDs

Combining all forces:

FORS Spectro-z
(Szokoly et al., 2004)

Combo-17 multiband
(Wolf et al., 2004)

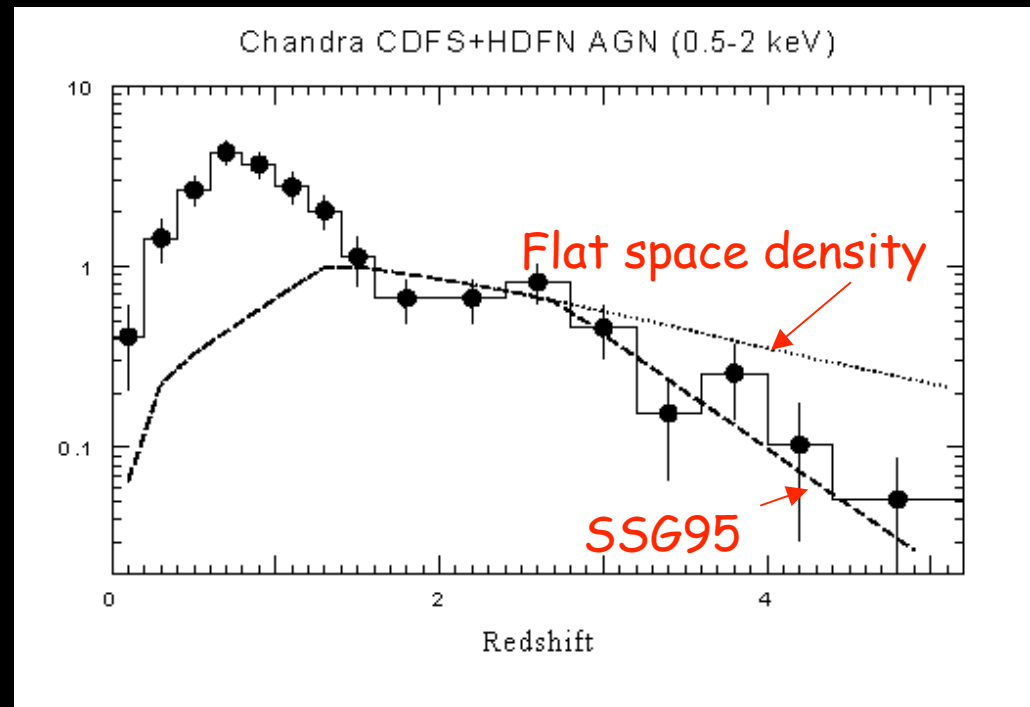
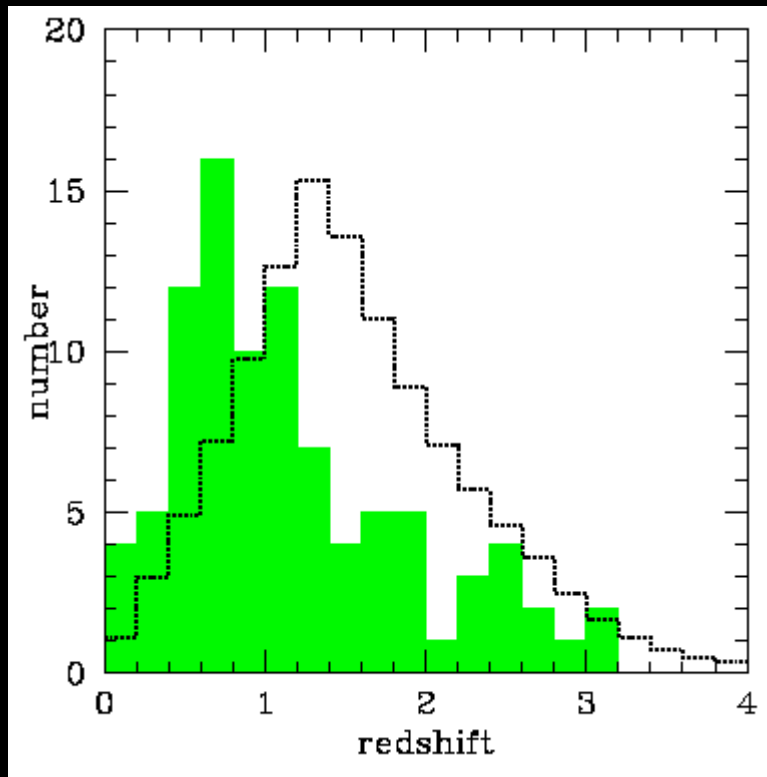
FORS/ISAAC photo-z
(Zheng et al., 2004
Mainieri et al., 2004)



> 95% have spectro- or photo-z thanks to VLT, GOODS, GEMS, ACF UDS etc. (only possible in CDFS !!!)

Photo-z fill in spectroscopic desert, but still peak at $z \sim 0.7$

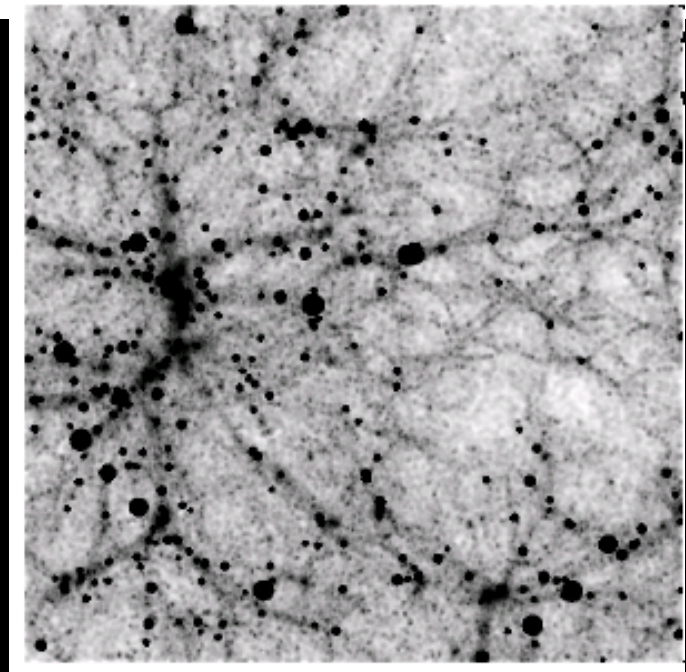
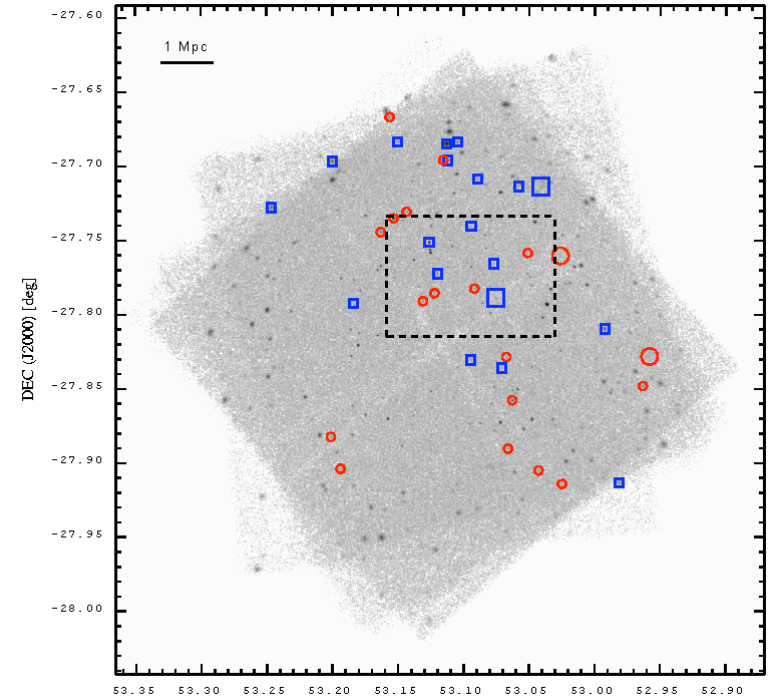
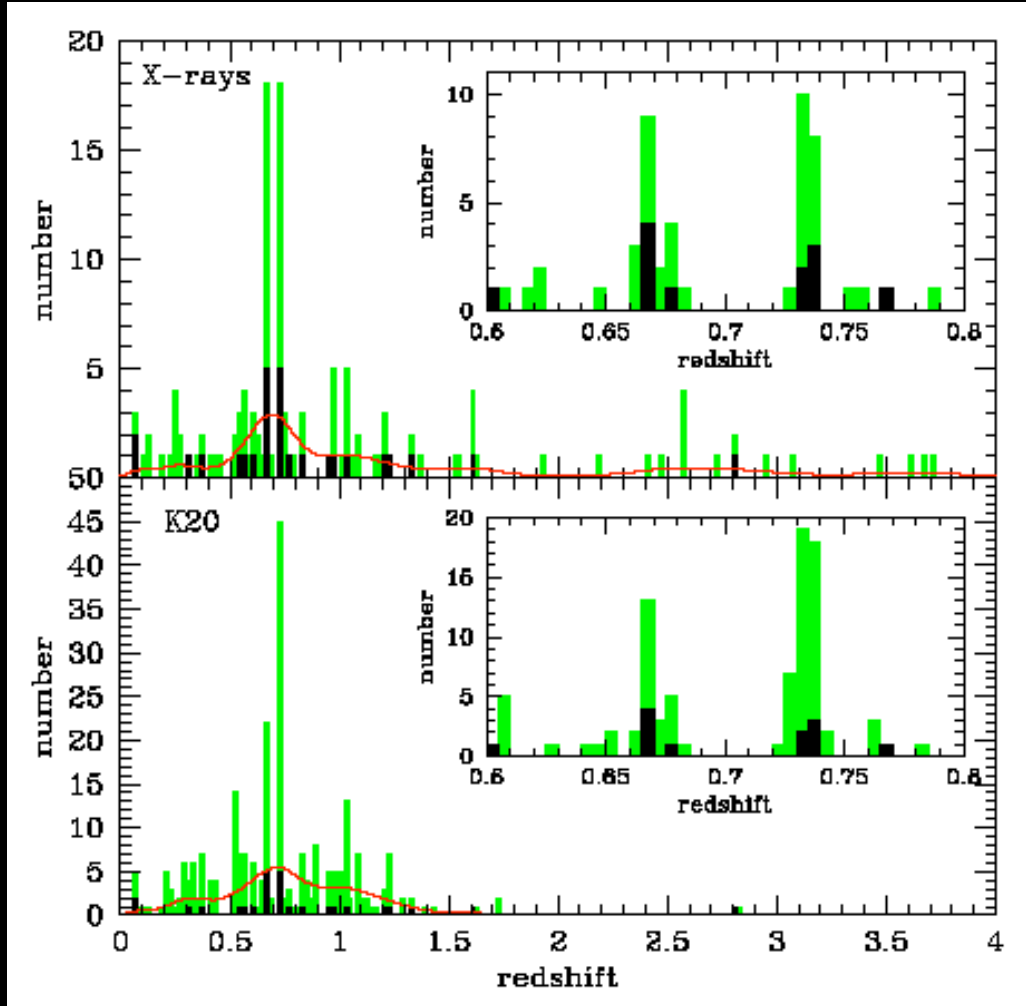
Redshift Distribution



Gilli, Salvati & Hasinger 2001 models

- Chandra AGN peak at much lower z than expected
- AGN space density decline at high z likely

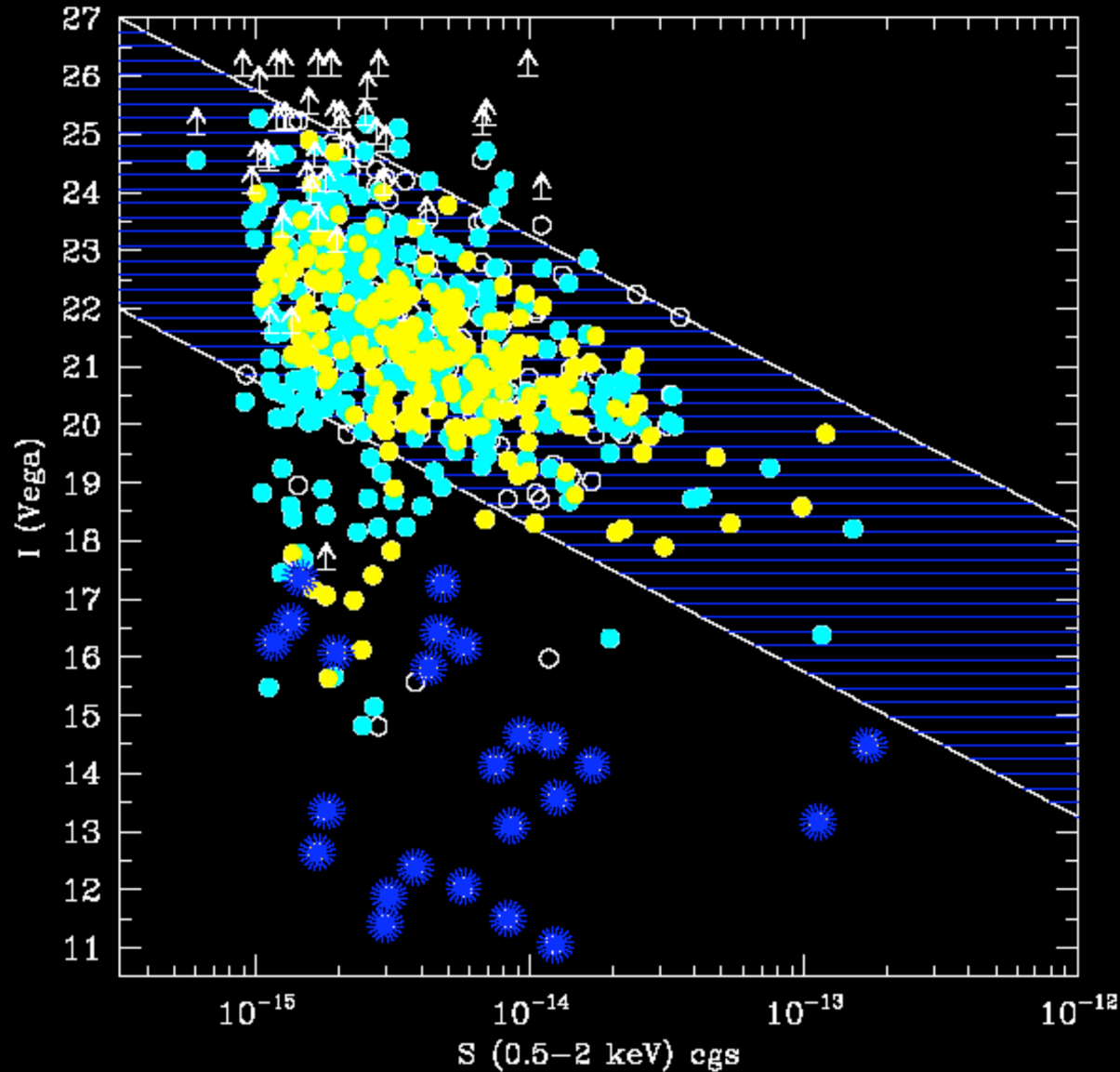
AGN in Sheets



Gilli et al., 2003, CDF-S results

XMM-COSMOS: Optical Identifications

Brusa et al. (2006)



— ACS point-like

— ACS extended

* candidate star

XMM-COSMOS: First results on optical identifications (12 pointings)

Brusa et al. (2006)

N(X-ray sources)

695

N(with opt ID)

626 (mostly within 3")

90%

N(ambiguous opt ID)

28

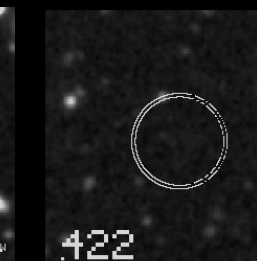
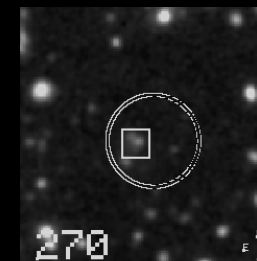
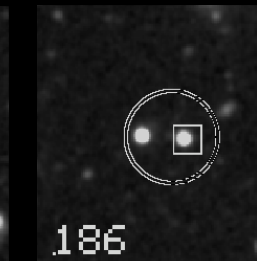
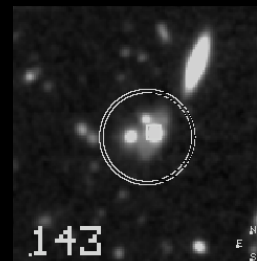
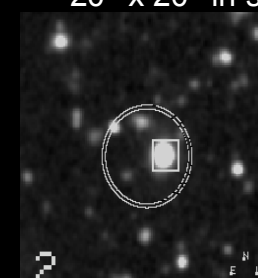
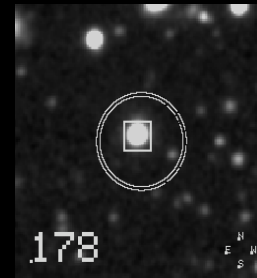
4%

N(no opt ID)

41

6%

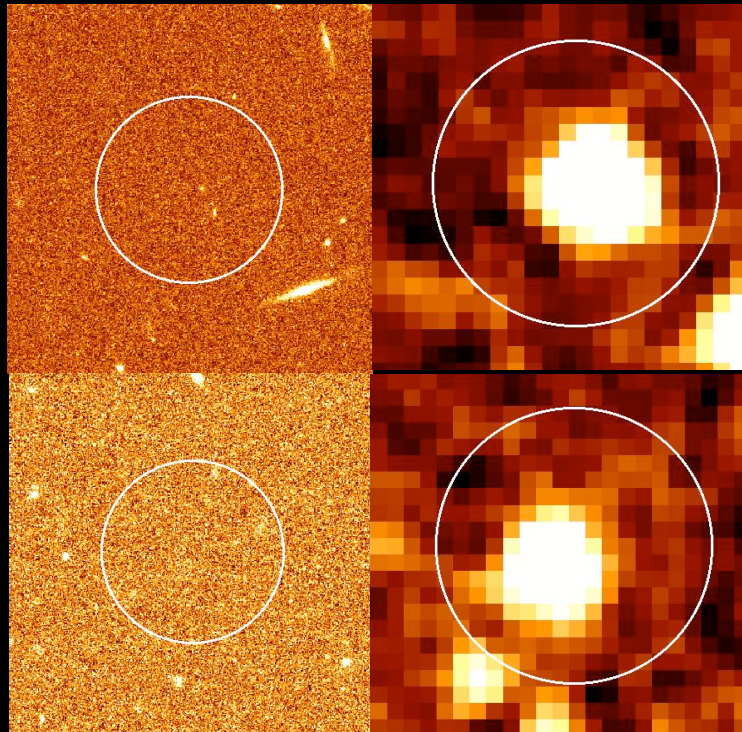
Images: Subaru R-band
20" x 20" in size



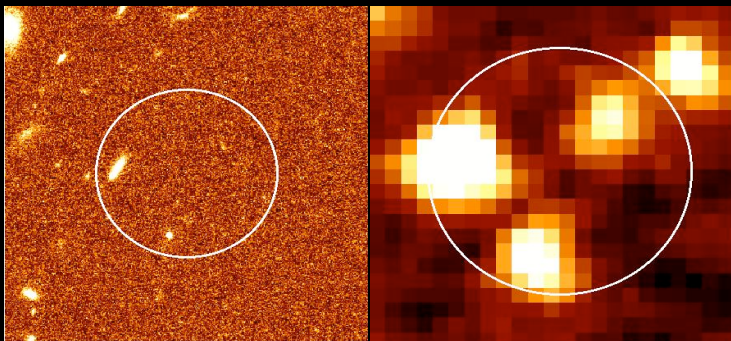
Empty fields
or very faint objects

XMM-COSMOS + Spitzer/IRAC

- “Visual” test on ~220 optically faint/very faint sources:



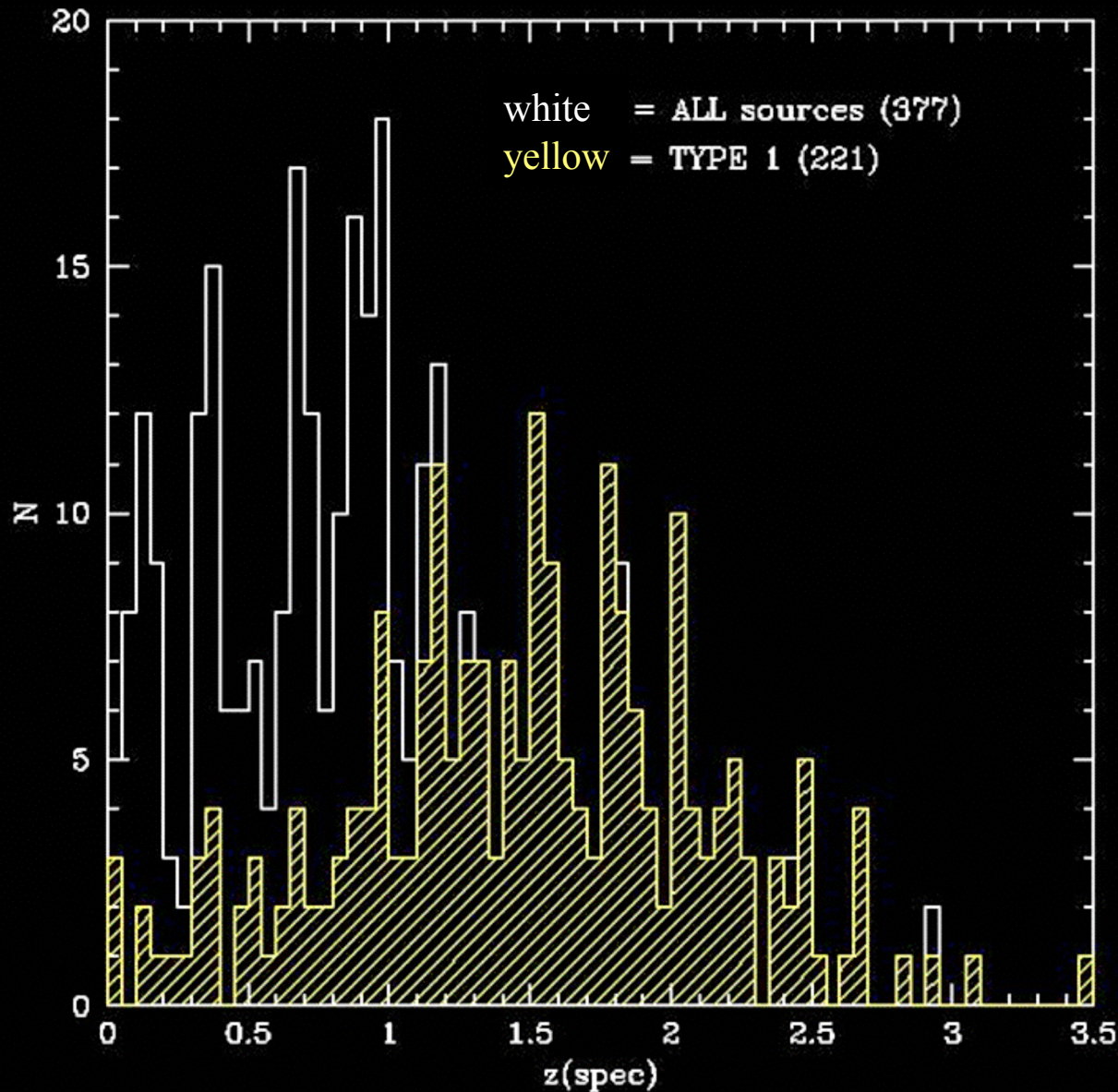
~50% of the sources associated to a unique, IRAC source



~50% have multiple sources in XMM error box or nothing

Brusa, Civano et al.

COSMOS Redshift distribution



Red-shifts:

89 from SDSS

204/187 from Magellan
IMACS (Trump et al.,
2006)

41/24 from zCOSMOS
(Lilly et al., 2006)

40/24 from VLT P73
(Kneib et al.)

92/42 from MMT
(Prescott et al.)

XMM-COSMOS

Photo-z for X-ray sources

Preliminary check of photo-z for X-ray selected AGN

Current photo-z work well
for type-2 AGN
dominated by galaxy light

Do not work well for
Broad-line AGN

→ need more work!

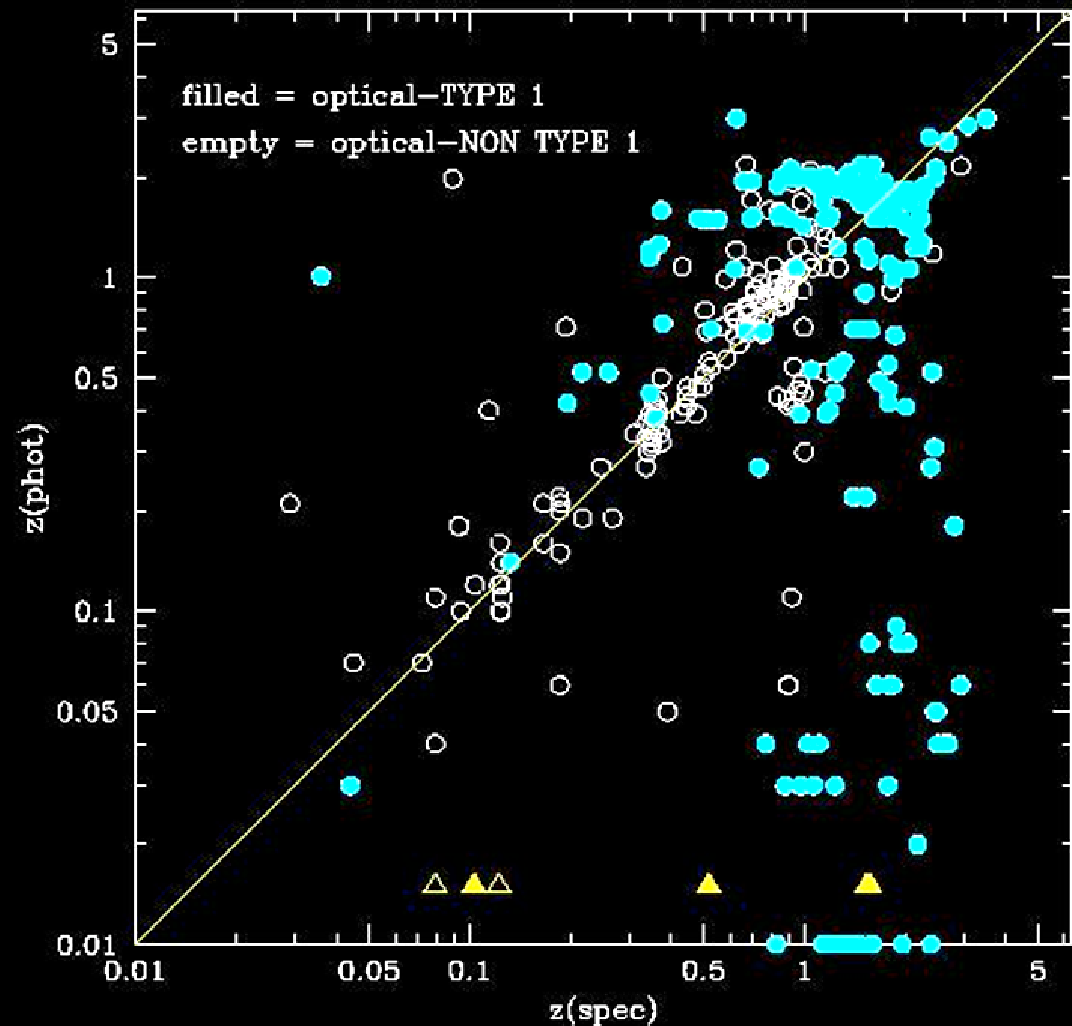


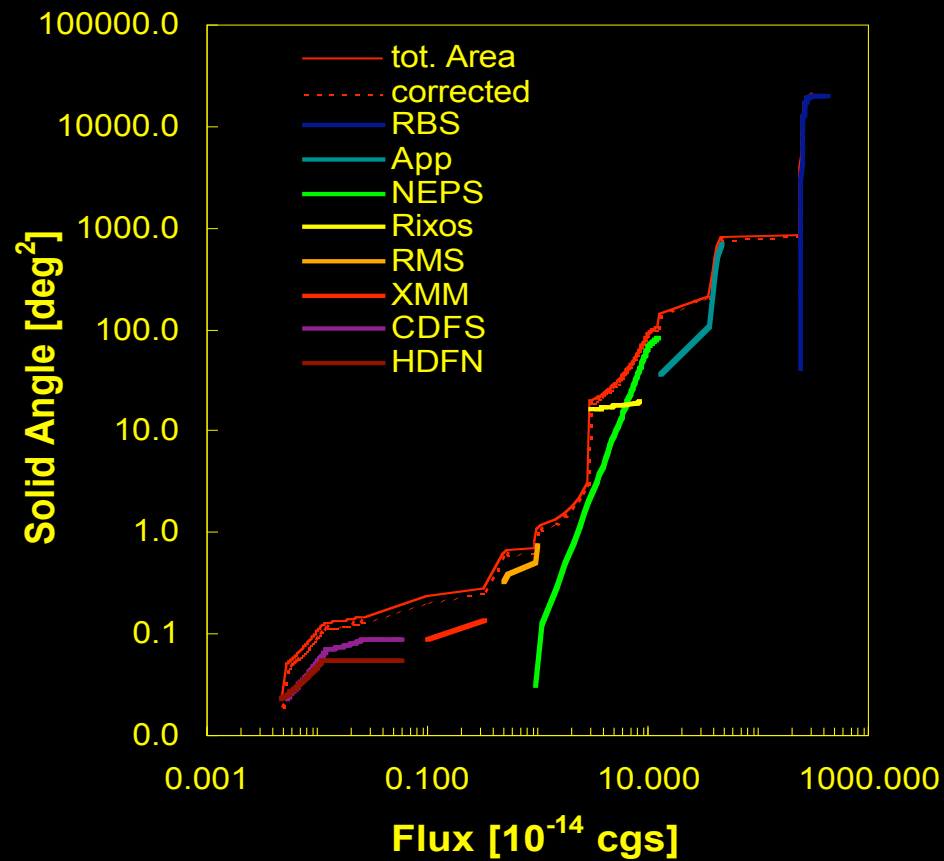
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1. The X-ray Background
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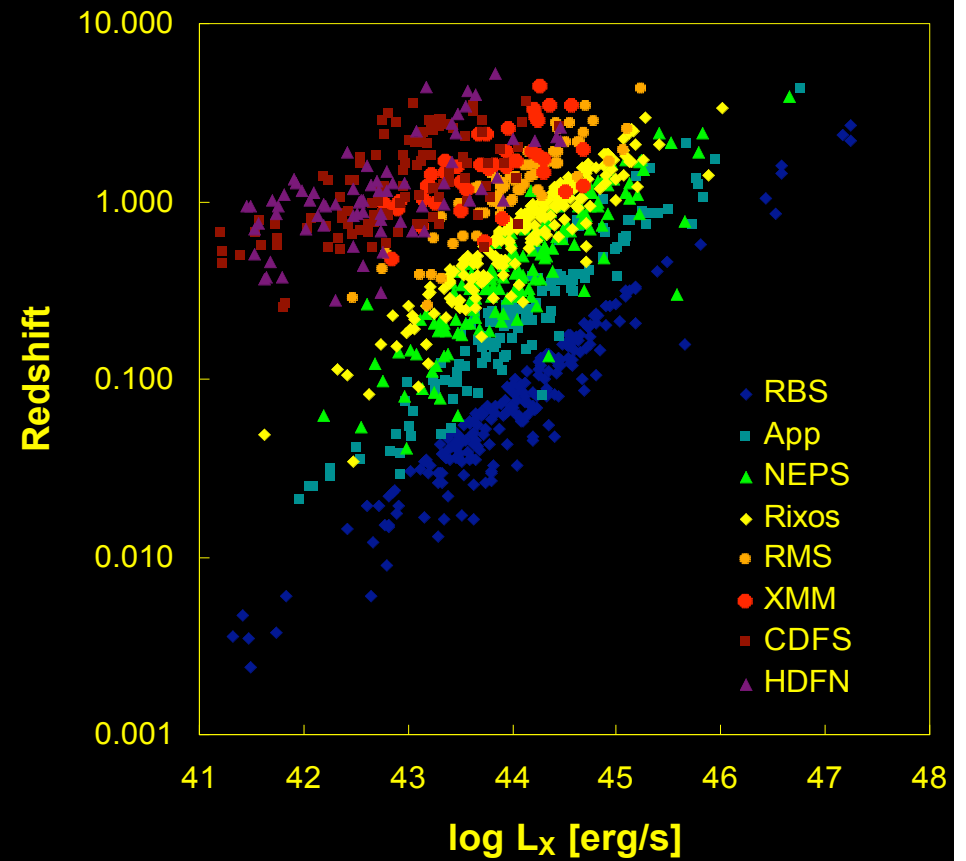
XLF & XrB Model: A. Comastri, R. Gilli, T. Miyaji, M. Schmidt, Y. Ueda

Multi-Cone Surveys

Survey Area



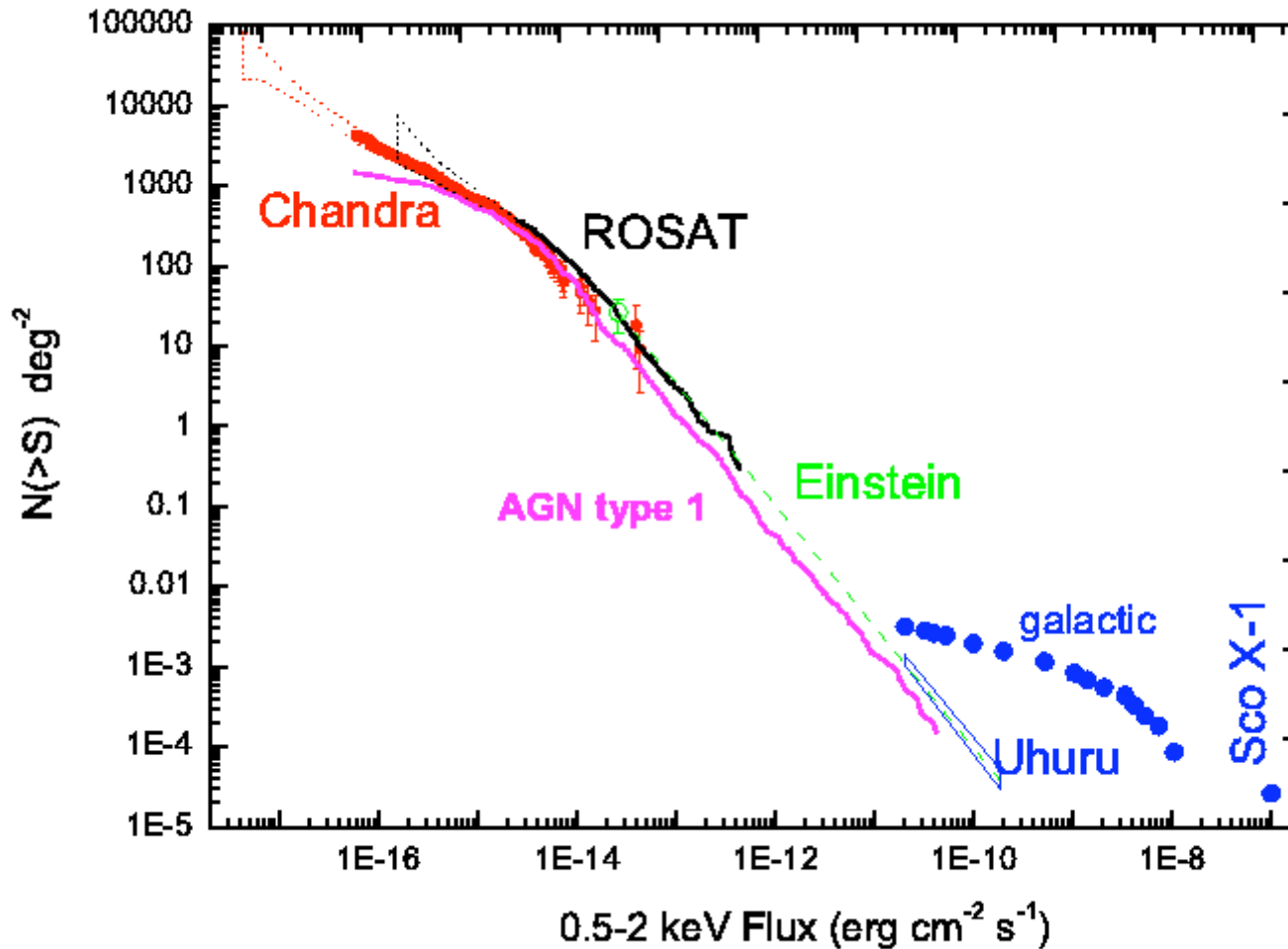
Hubble Diagram



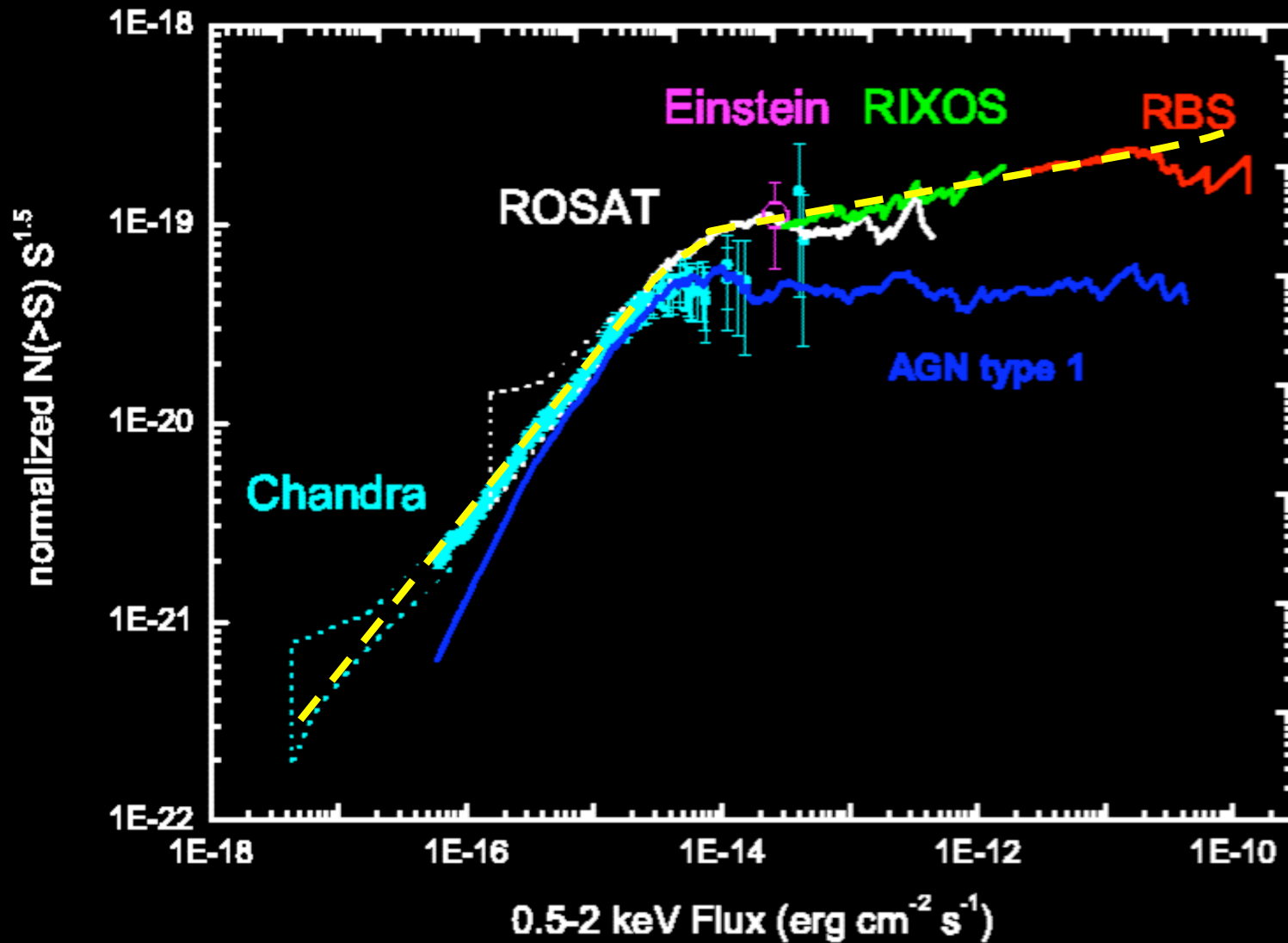
Multi-Cone Surveys

- Type-1 AGN in the 0.5-2 keV band
 - Continuation of ROSAT work, most sensitive & complete
- ROSAT Samples (Miyaji et al., 2000)
 - ROSAT Bright Survey: 203 (0) AGN (Schwope et al., 2000)
 - RASS Selected North: 134 (5) AGN (Appenzeller et al., 1996)
 - RASS NEP Survey: 101 (9) AGN (Gioia et al., 2003)
 - RIXOS serendipitous: 194 (14) AGN (Mason et al., 2000)
 - ROSAT Deep Surveys: 84 (7) AGN (e.g. Schmidt et al., 1998)
- XMM Deep Survey (Mainieri et al., 2002)
 - Lockman Hole: 48 (8) AGN (Lehmann et al., 2001 ++)
- Chandra Deep Surveys
 - CDF North/HDF-N: 67 (21) AGN (Barger et al., 2003)
 - CDFS spec.+phot.: 113 (1) AGN (Szokoly, Zheng et al. 2003)
- Total: 944 (65) AGN¹ Yellow: unidentified

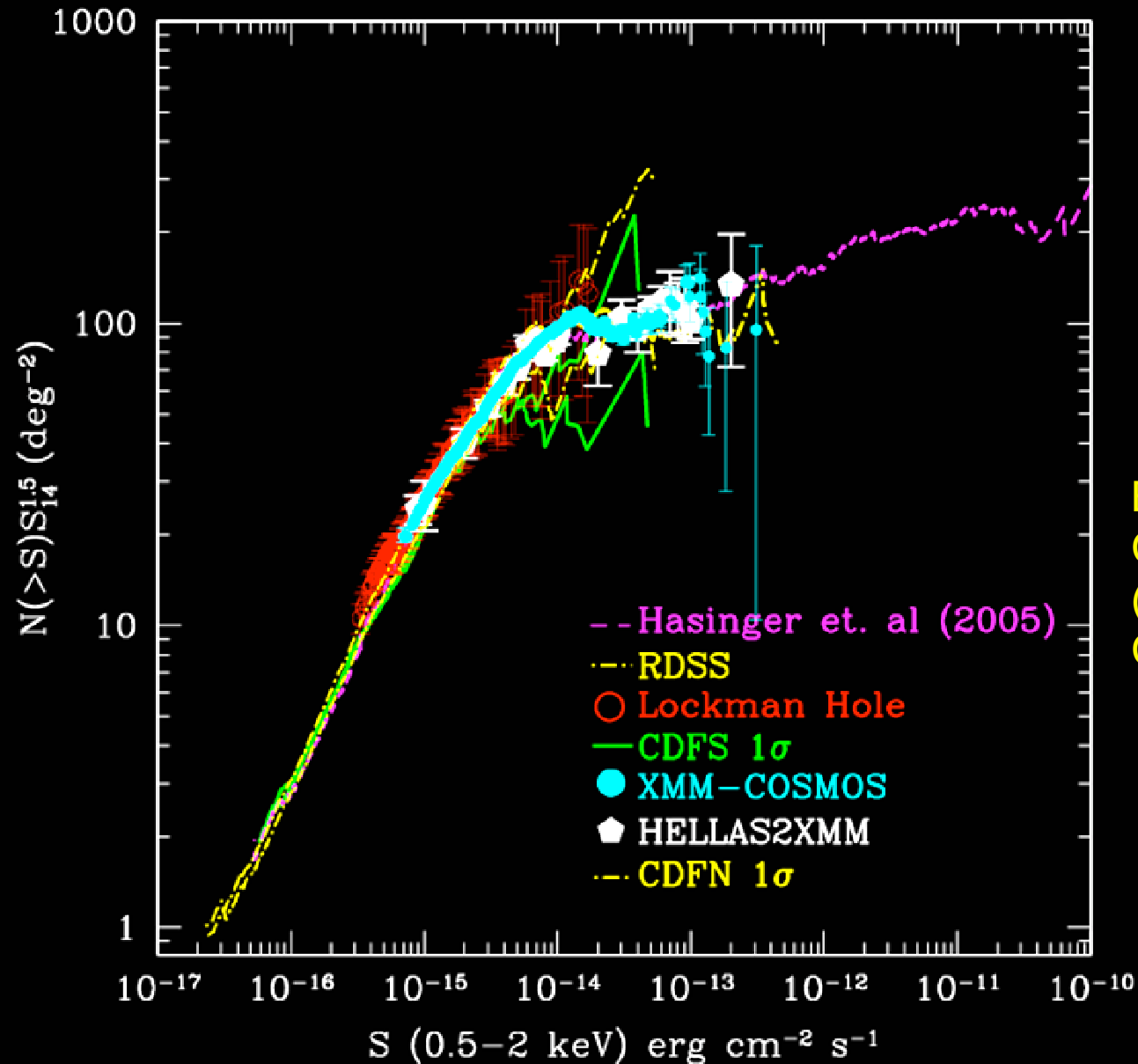
Number counts



Multi-cone logN-logS

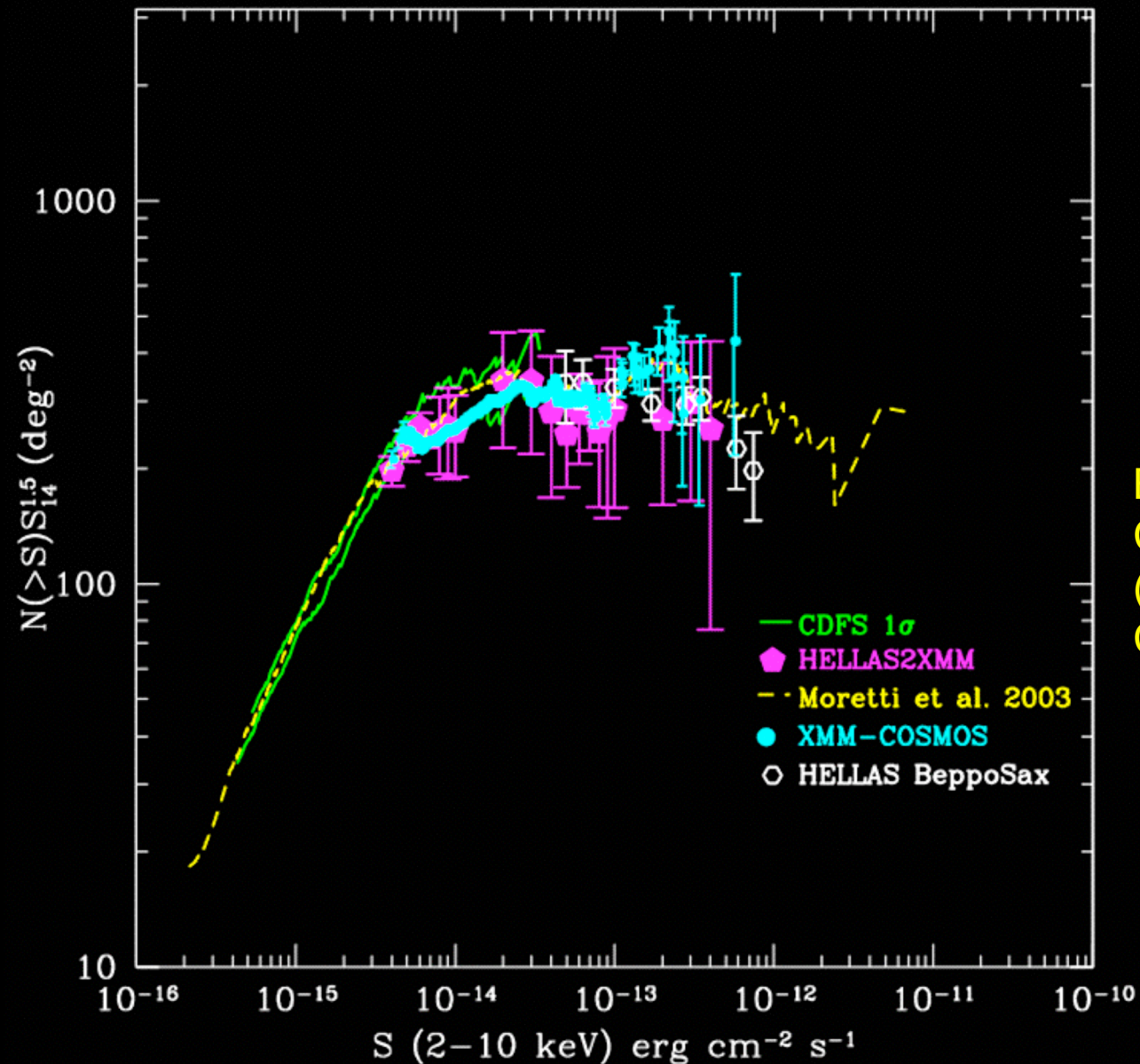


COSMOS logN-logS 0.5-2 keV



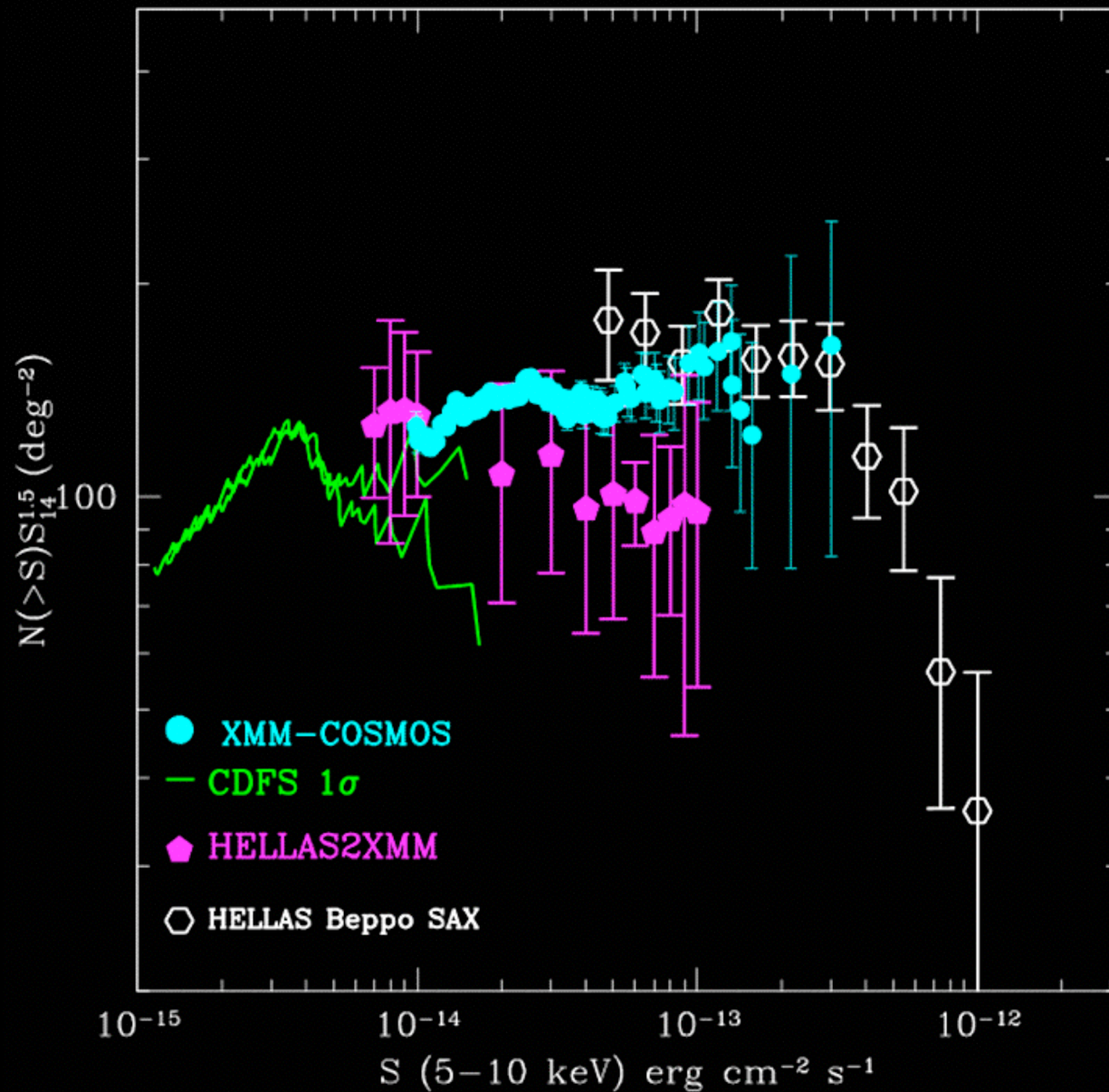
Based on 25 XMM
COSMOS pointings
(~60% of final data)
Cappelluti et al., 2006

COSMOS logN-logS 2-10 keV



Based on 25 XMM
COSMOS pointings
(~60% of final data)
Cappelluti et al., 2006

COSMOS logN-logS 5-10 keV

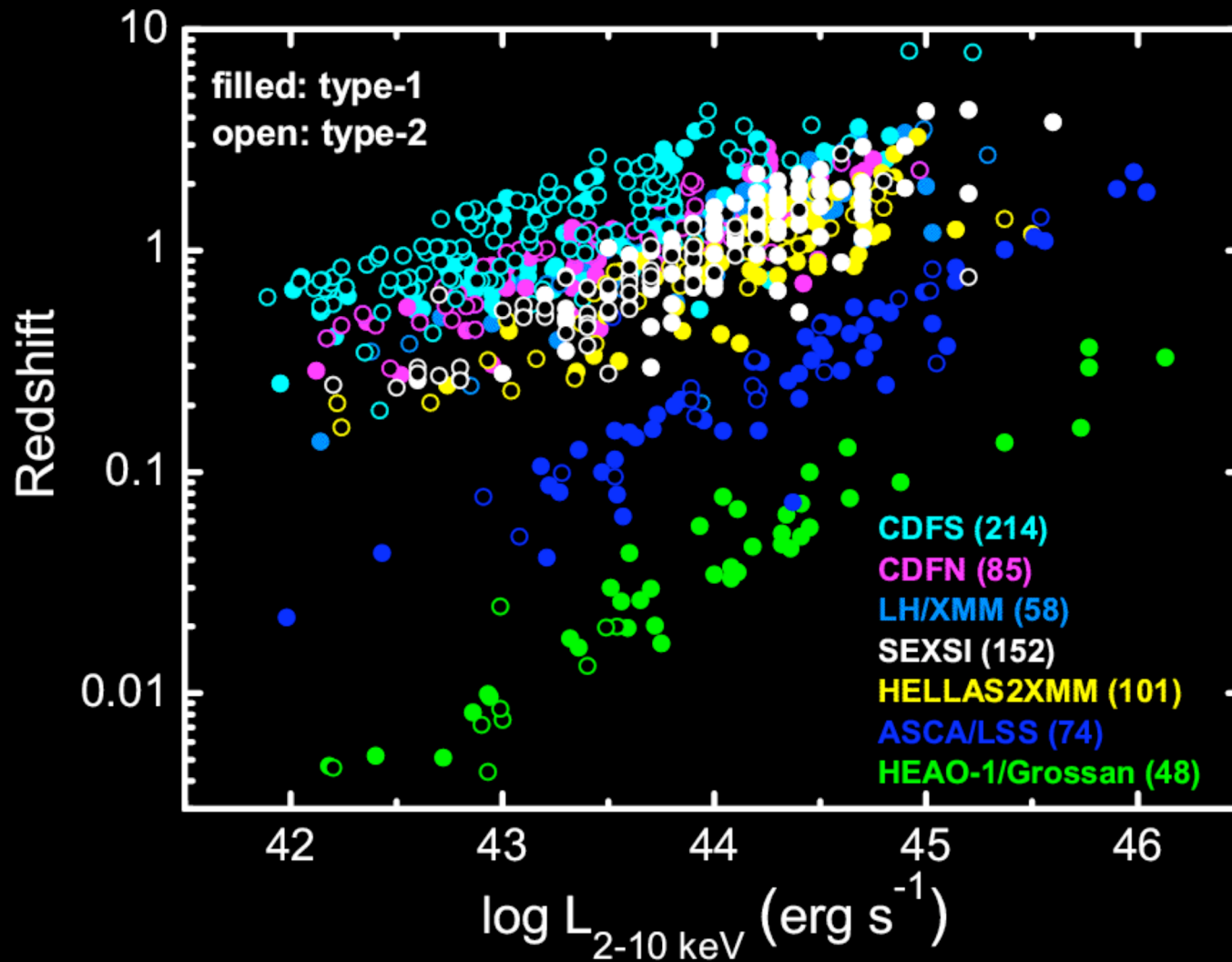


Based on 25 XMM
COSMOS pointings
(~60% of final data)
Cappelluti et al., 2006

Optically identified hard samples

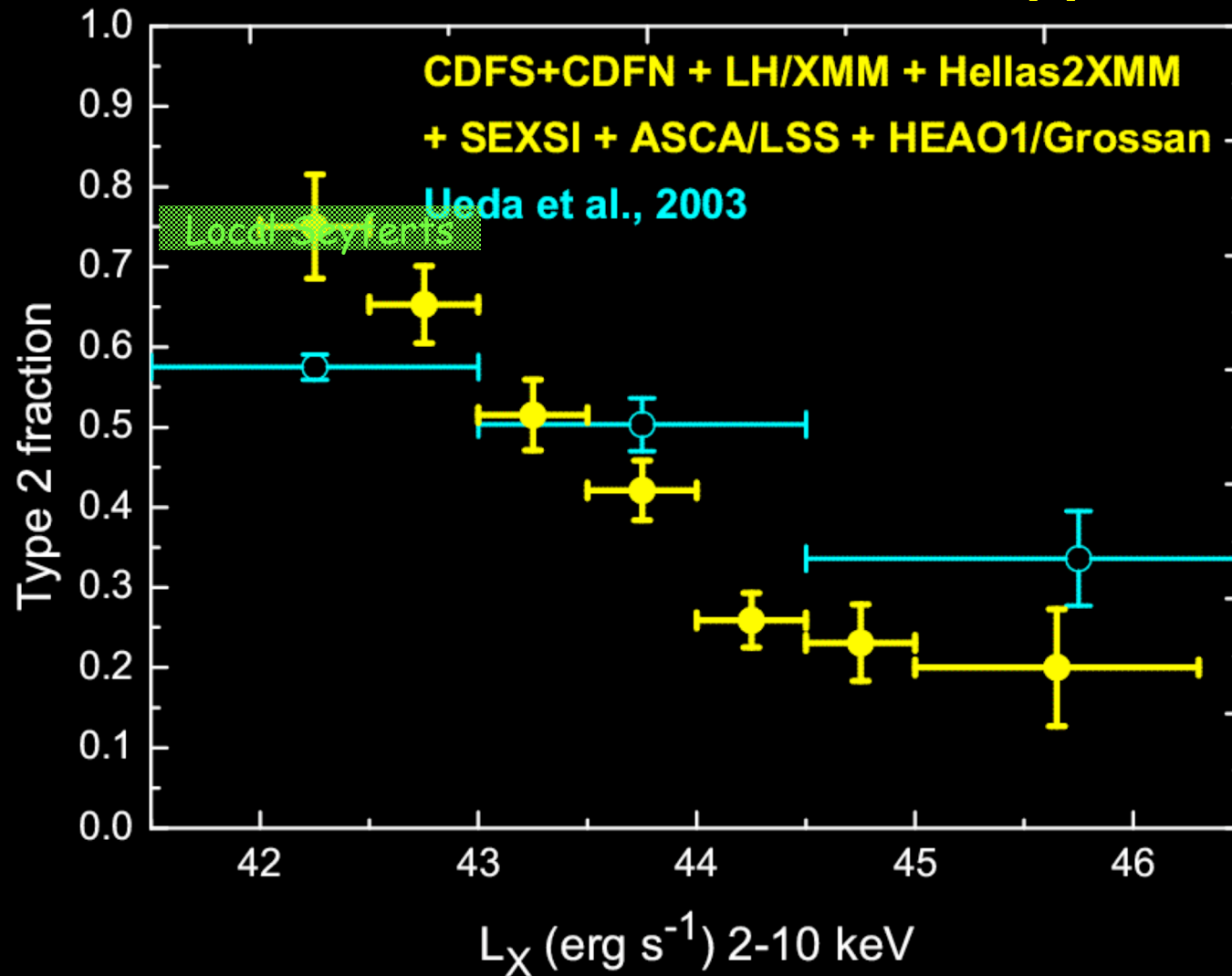
type-1: optical BLAGN, or galaxy with $L_x > 42$, $HR < -0.2$

type-2: optical NLAGN, or galaxy with $L_x > 42$, $HR > -0.2$



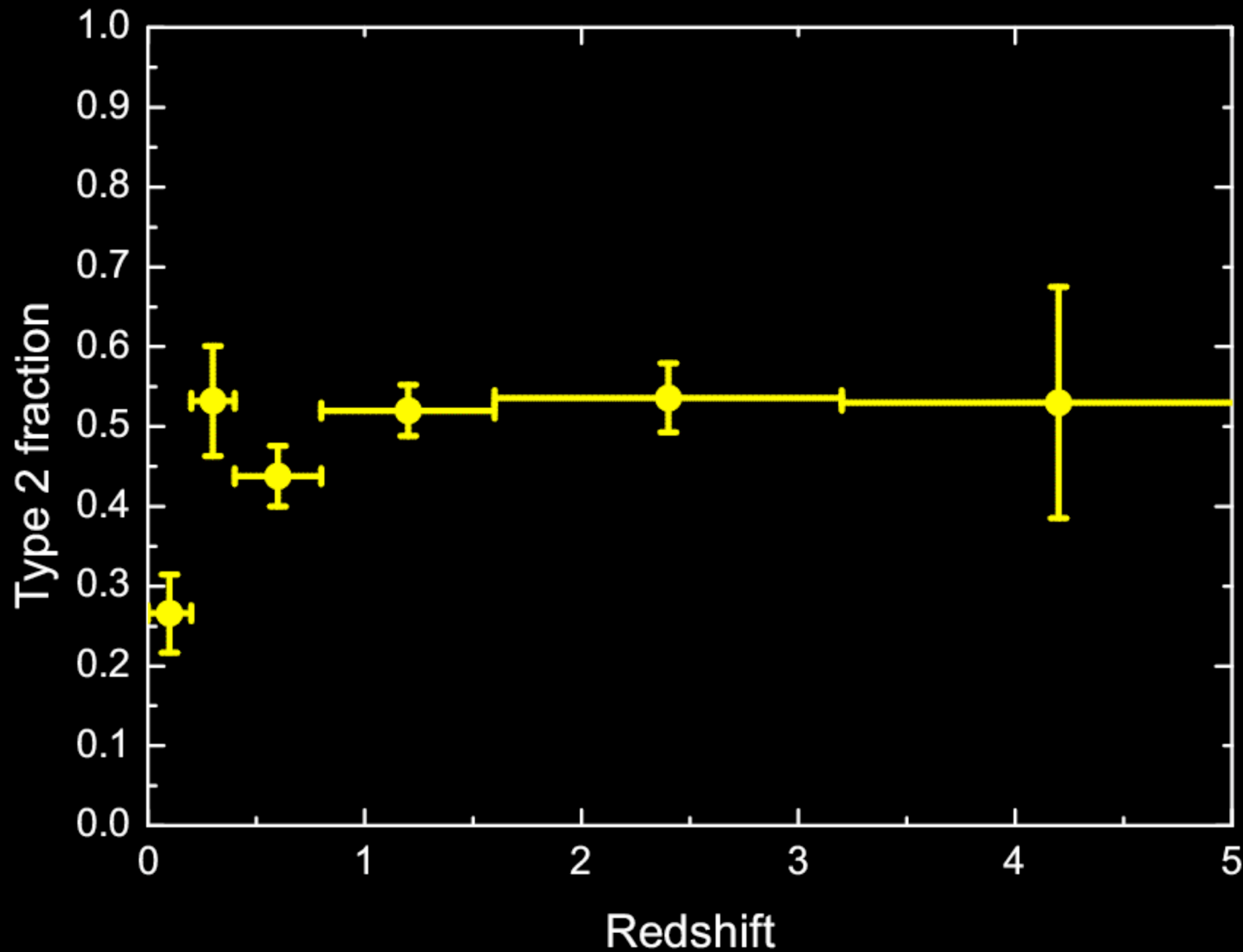
729 AGN,
optical/NIR
completeness
~80-90%

Type 2 fraction $f(L_X)$



Fraction of type-2's decreases with luminosity.
Strong AGN can „clean out“ their environment!

Type 2 fraction $f(z)$

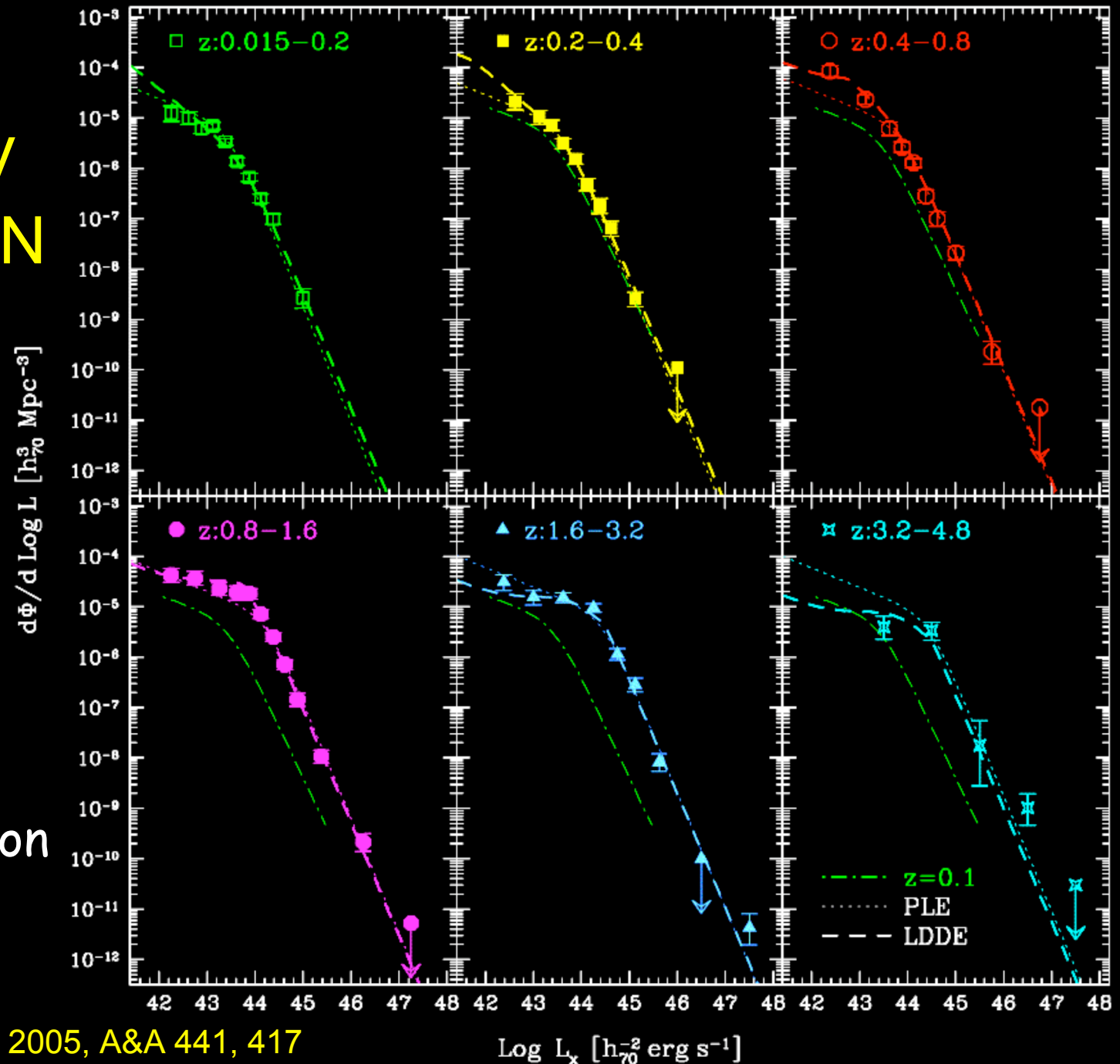


No significant evolution in absorption fraction detected

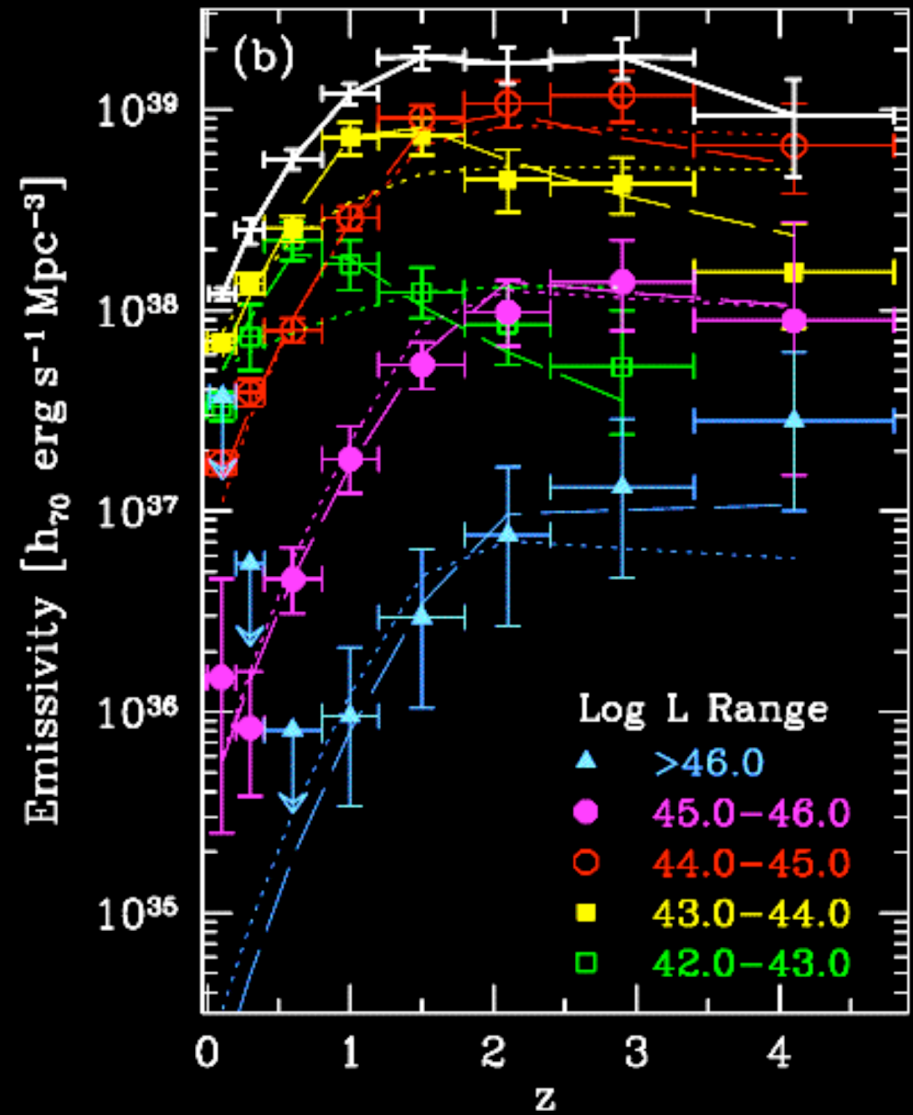
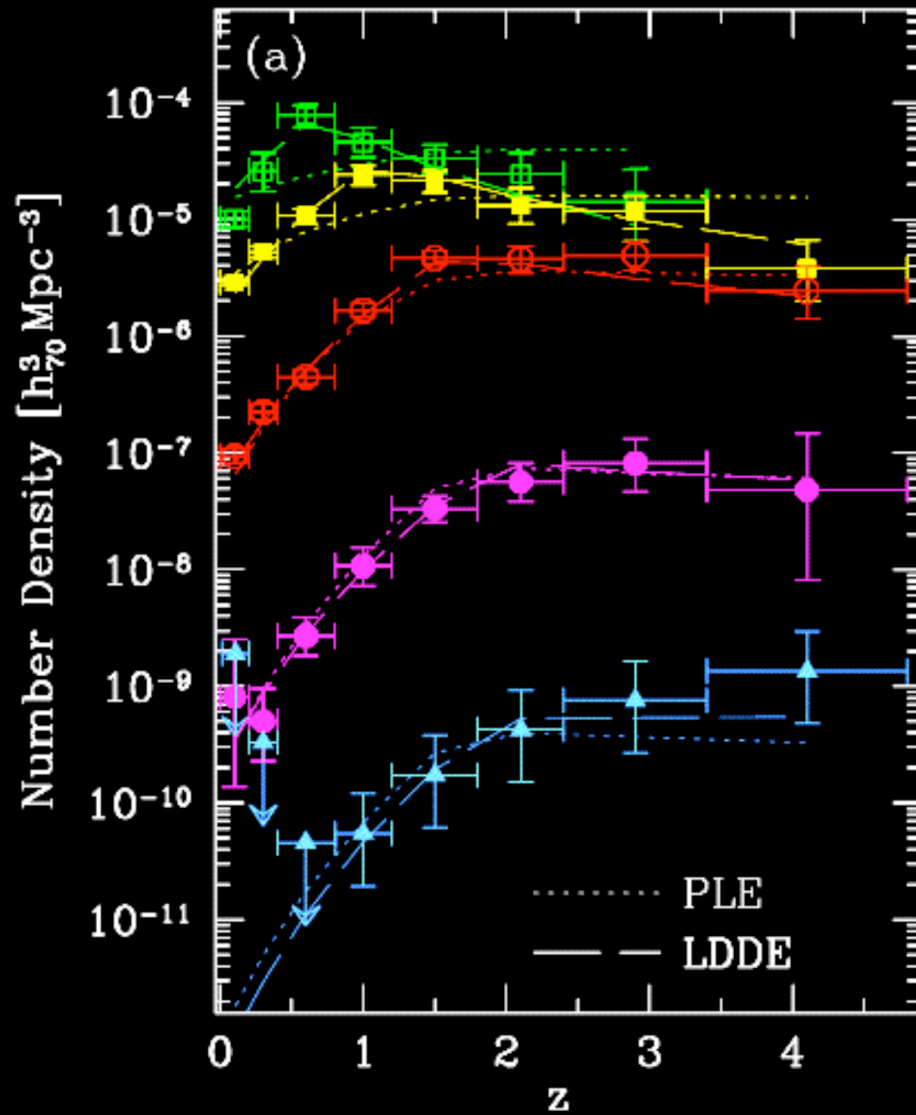
XLF

0.5-2 keV
type-1 AGN

Luminosity-
dependent
density evolution
(LDDE)
confirmed

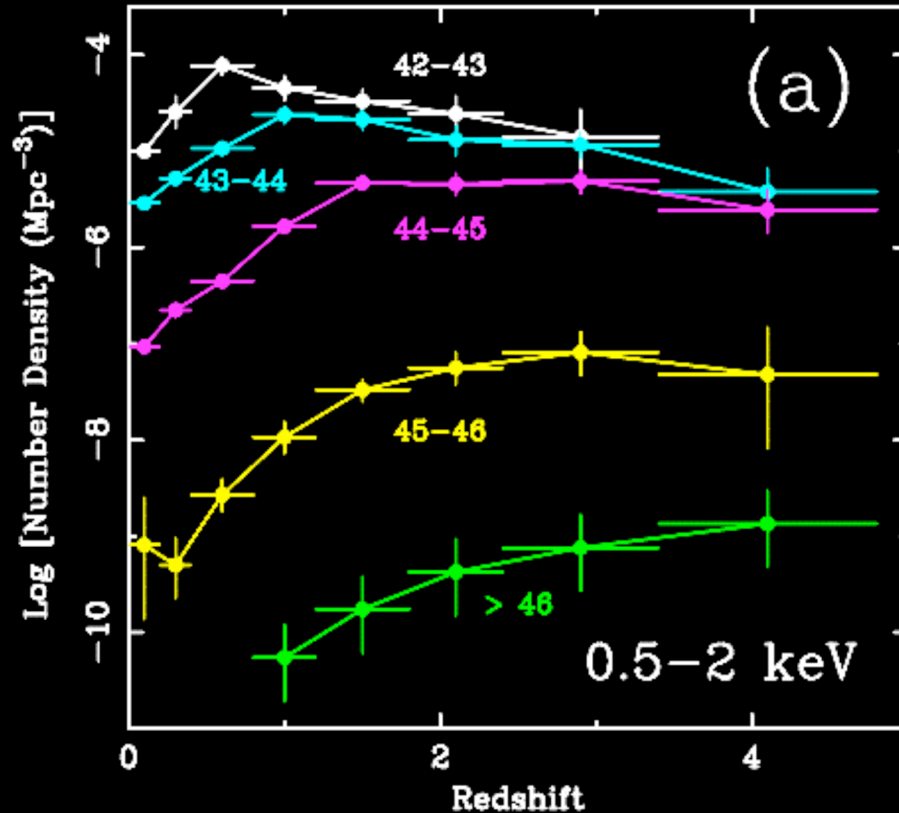


Space/Luminosity density evolution

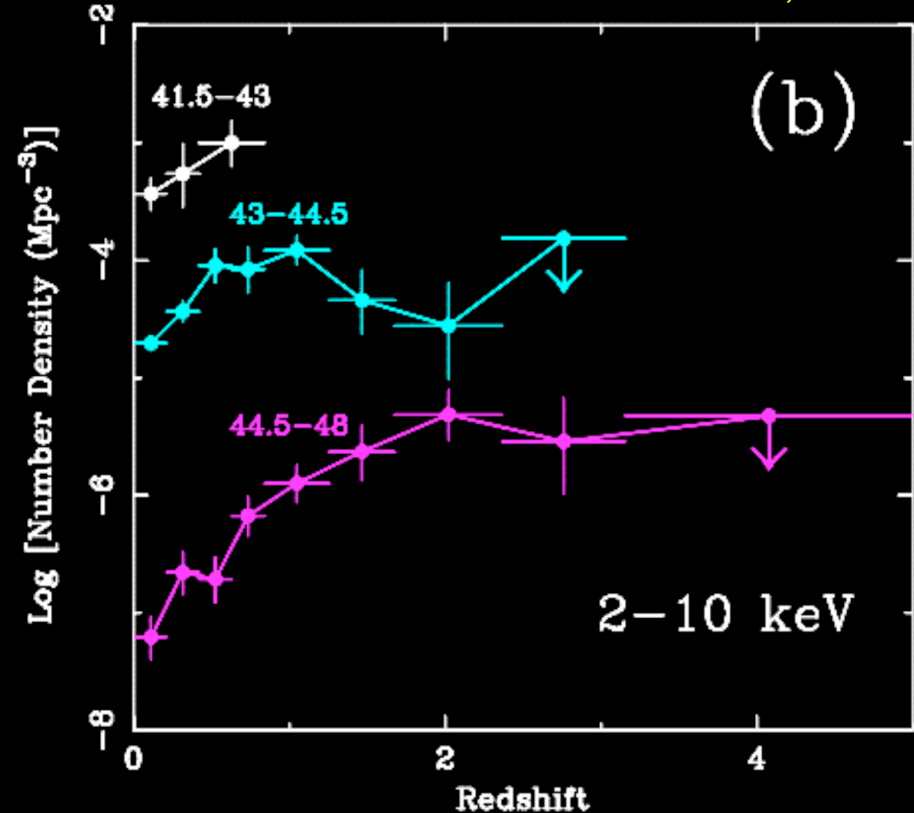


Densities in soft and hard band

Brandt & G.H., 2005



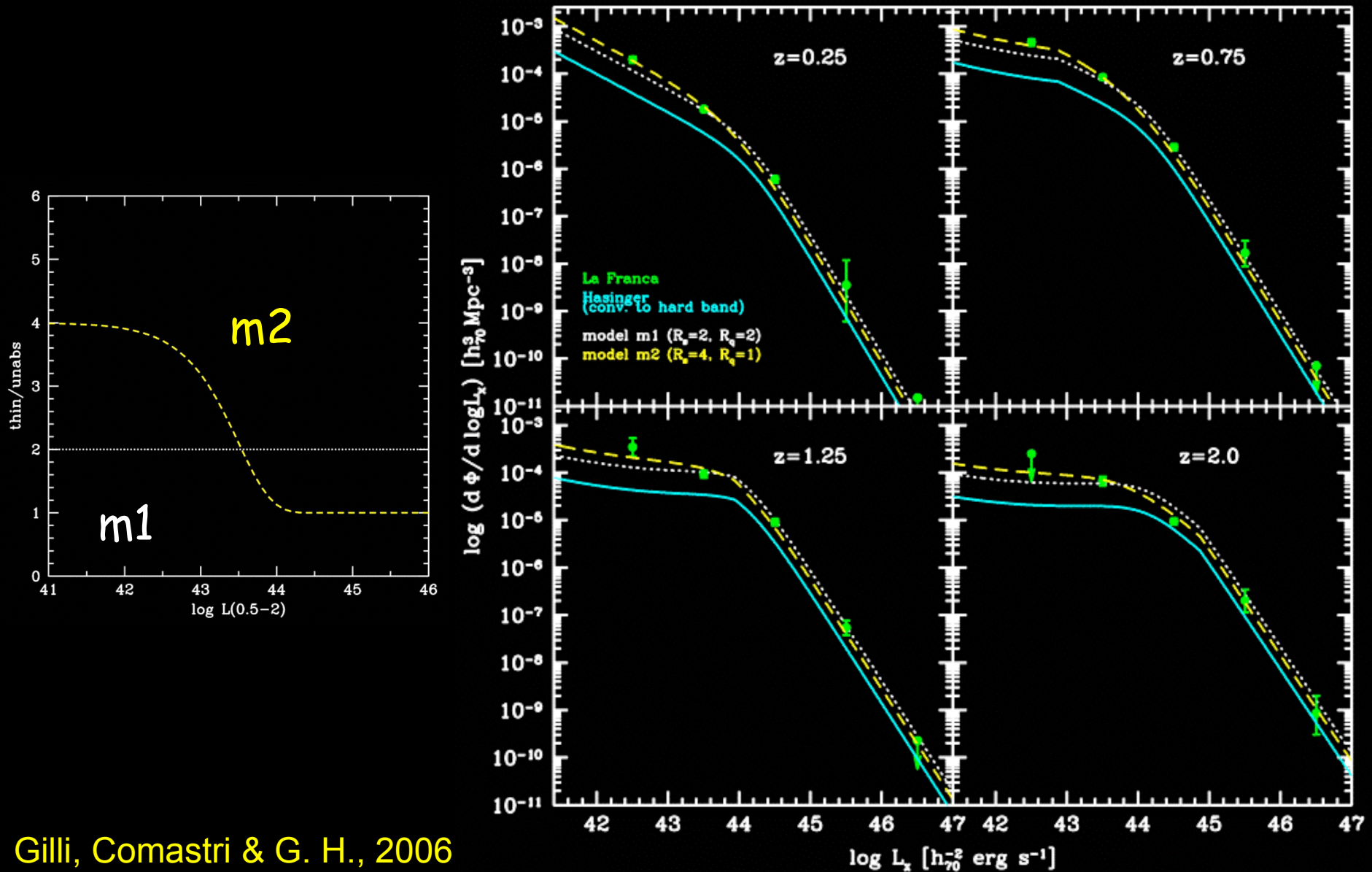
G.H., Miyaji & Schmidt, 2005
based on ~1000 AGN-1



Ueda et al., 2003,
based on ~250 AGN

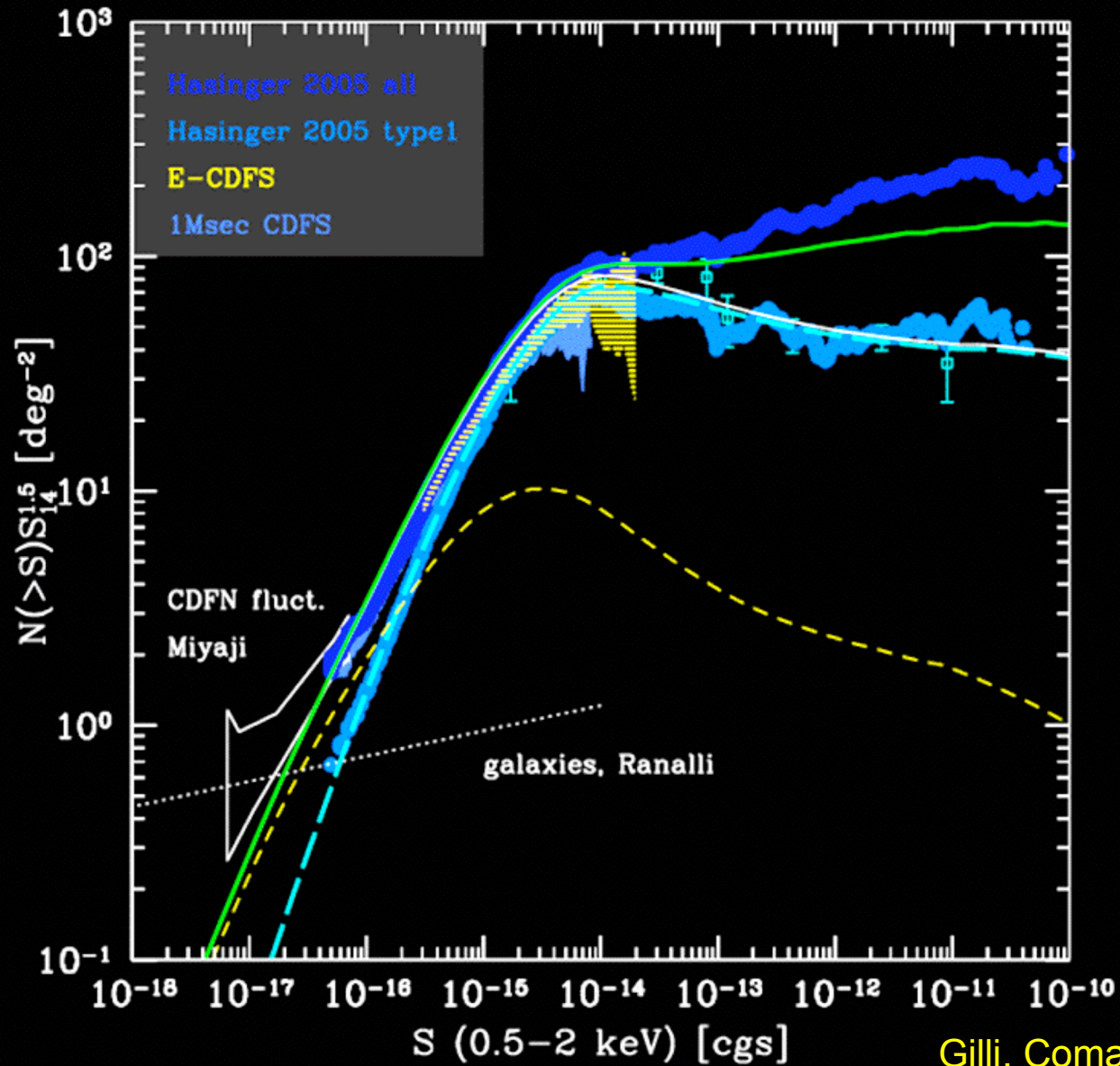
Very similar behaviour in hard and soft band.
Soft samples go deeper and are more complete.

Direct comparison of hard vs. Soft XLF



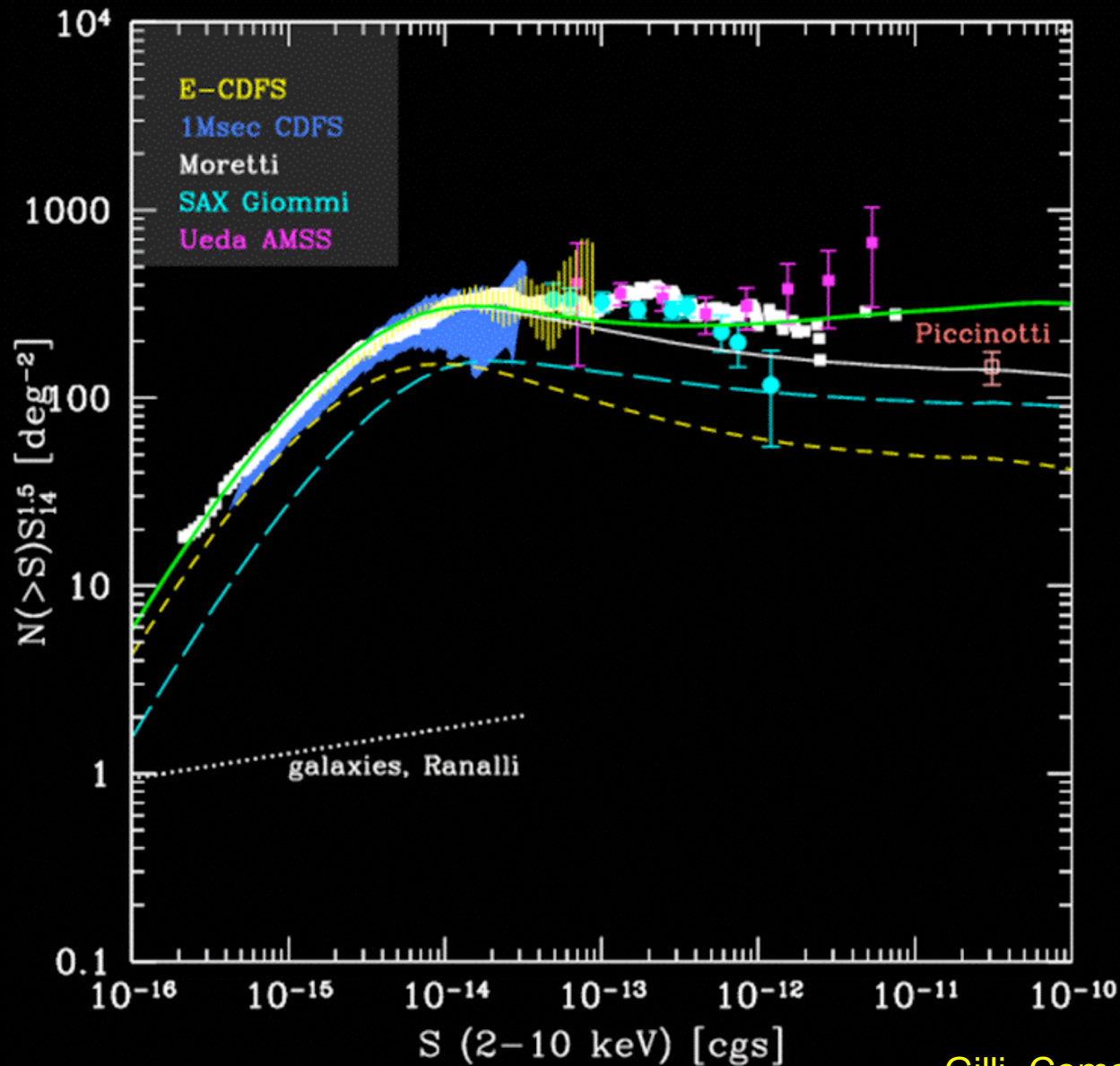
Gilli, Comastri & G. H., 2006

Most recent Population Synthesis Model

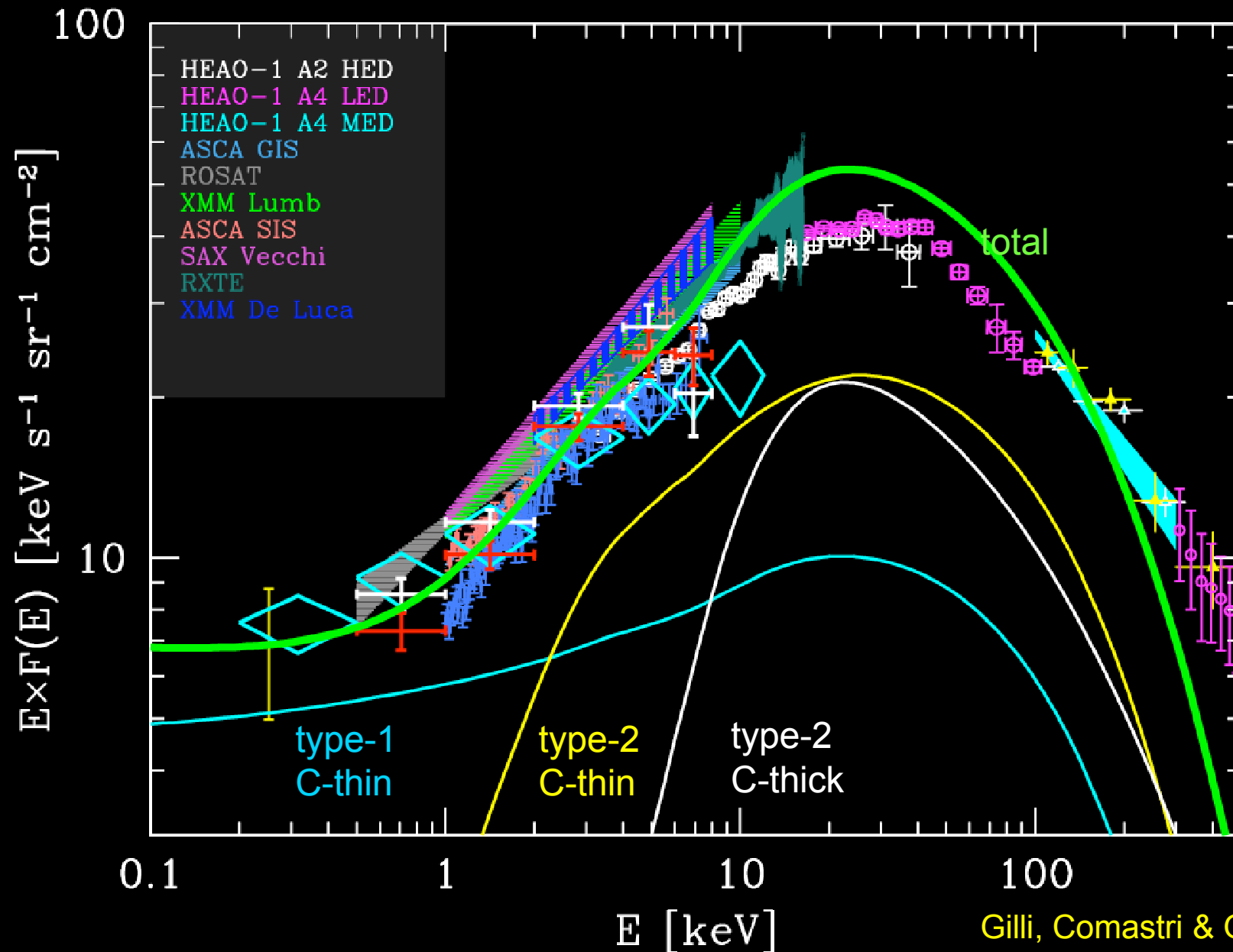


Gilli, Comastri & G.H., 2006

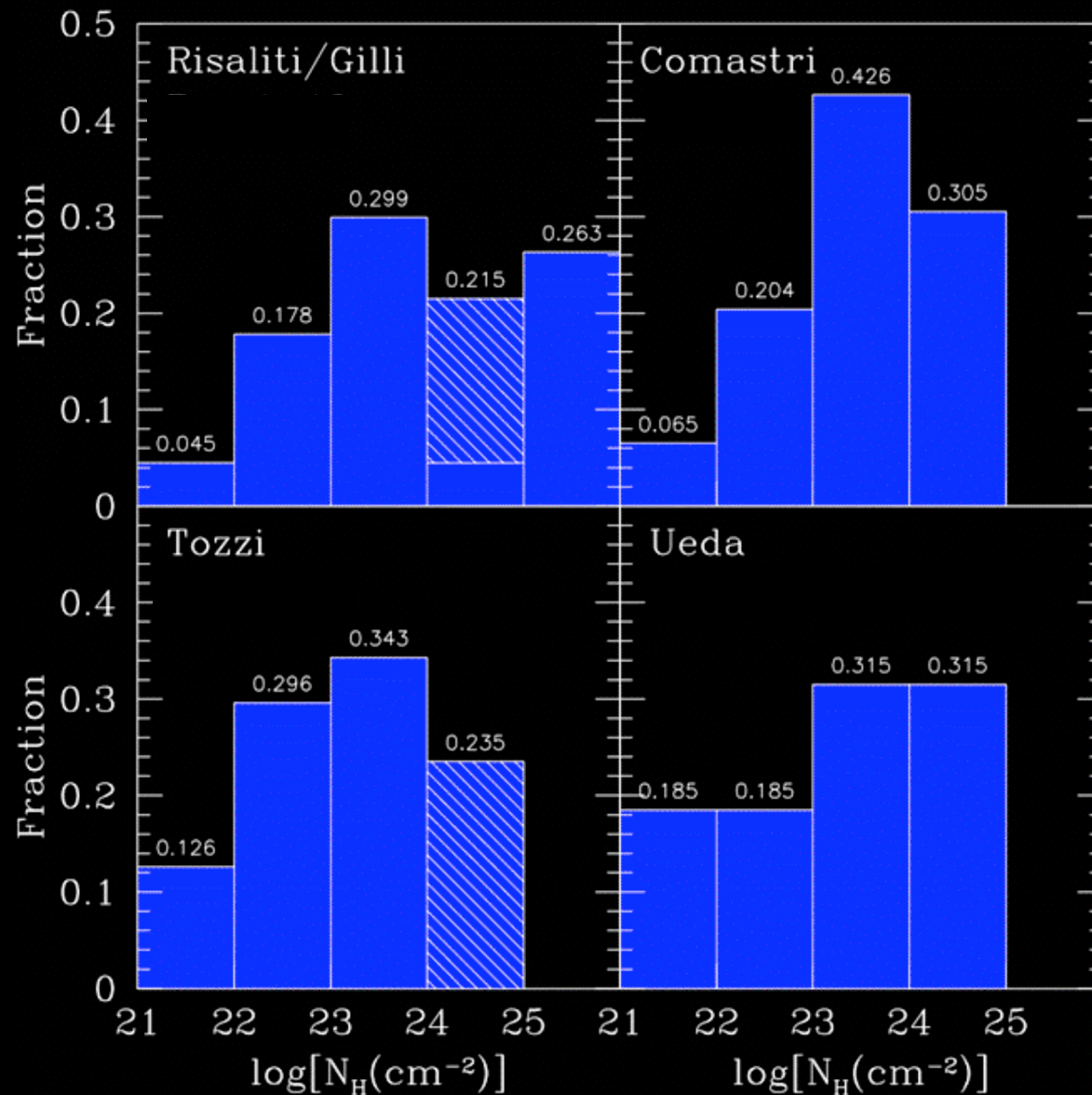
Most recent Population Synthesis Model



Most recent Population Synthesis Model



Constraining the N_H distribution



→ still significant uncertainties and limited predictive power

Need: identified samples of 10-30 keV sources

Better determination of 20-40 keV

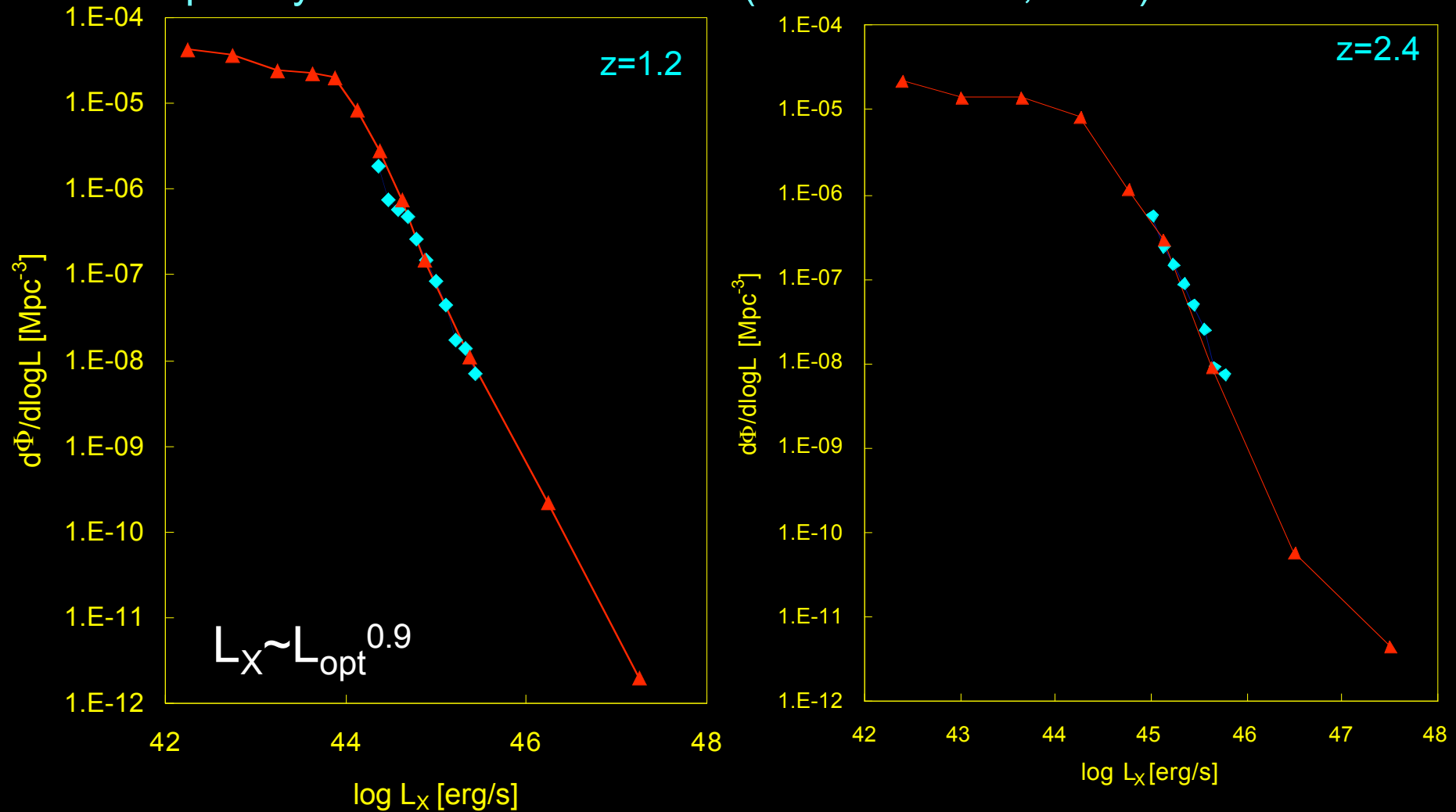
See Dwelly et al. 2005

background

Comparison X-ray/optical (SDSS)

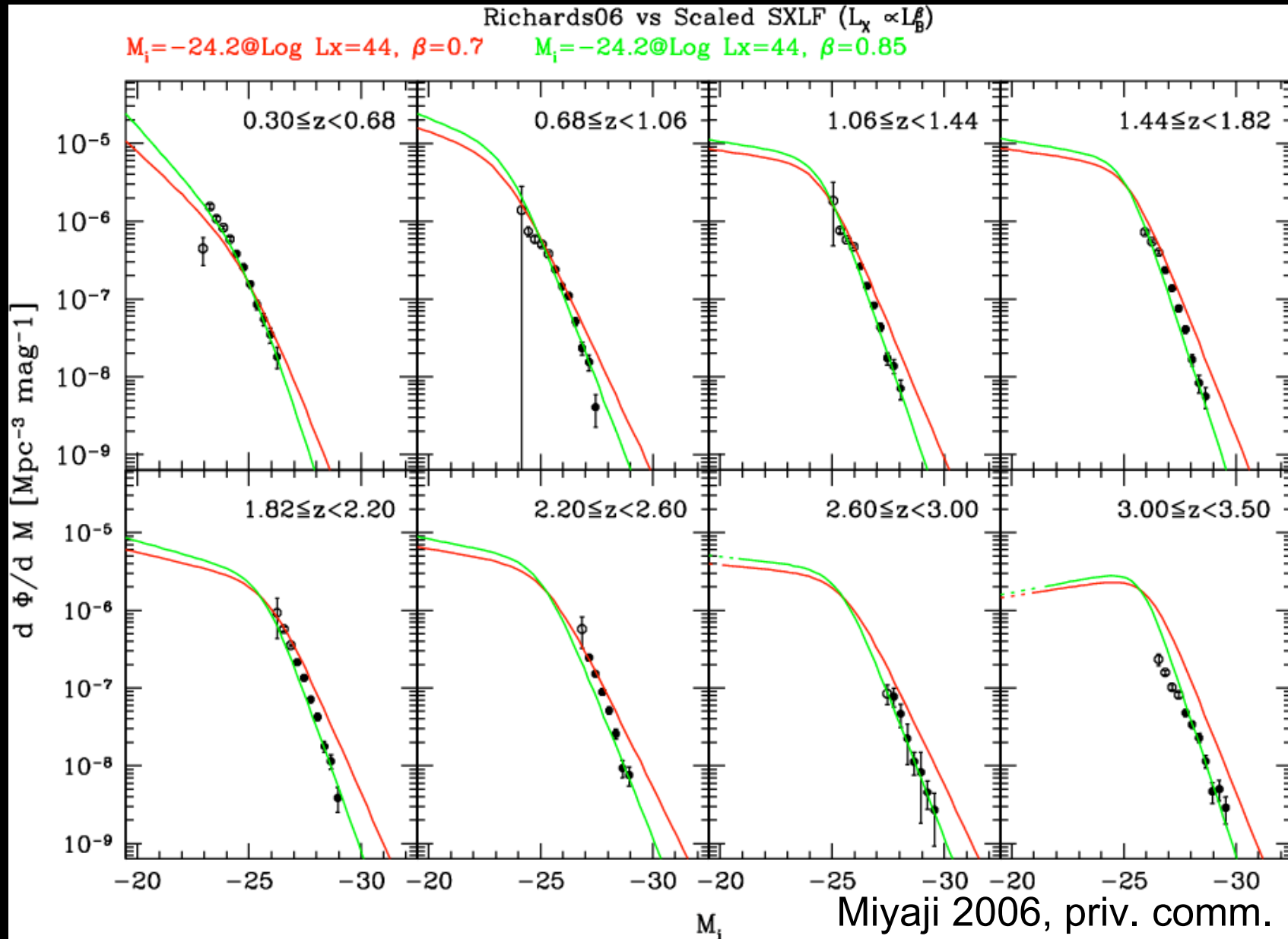
type-1 soft X-ray selected AGN (G.H., Miyaji, Schmidt, 2005)

Optically selected SDSS QSOs (Richards et al., 2005)



Perfect match! But X-ray surveys sample
a much wider range of luminosities!

Comparison soft X-ray/SDSS



2dF/SDSS Comparison

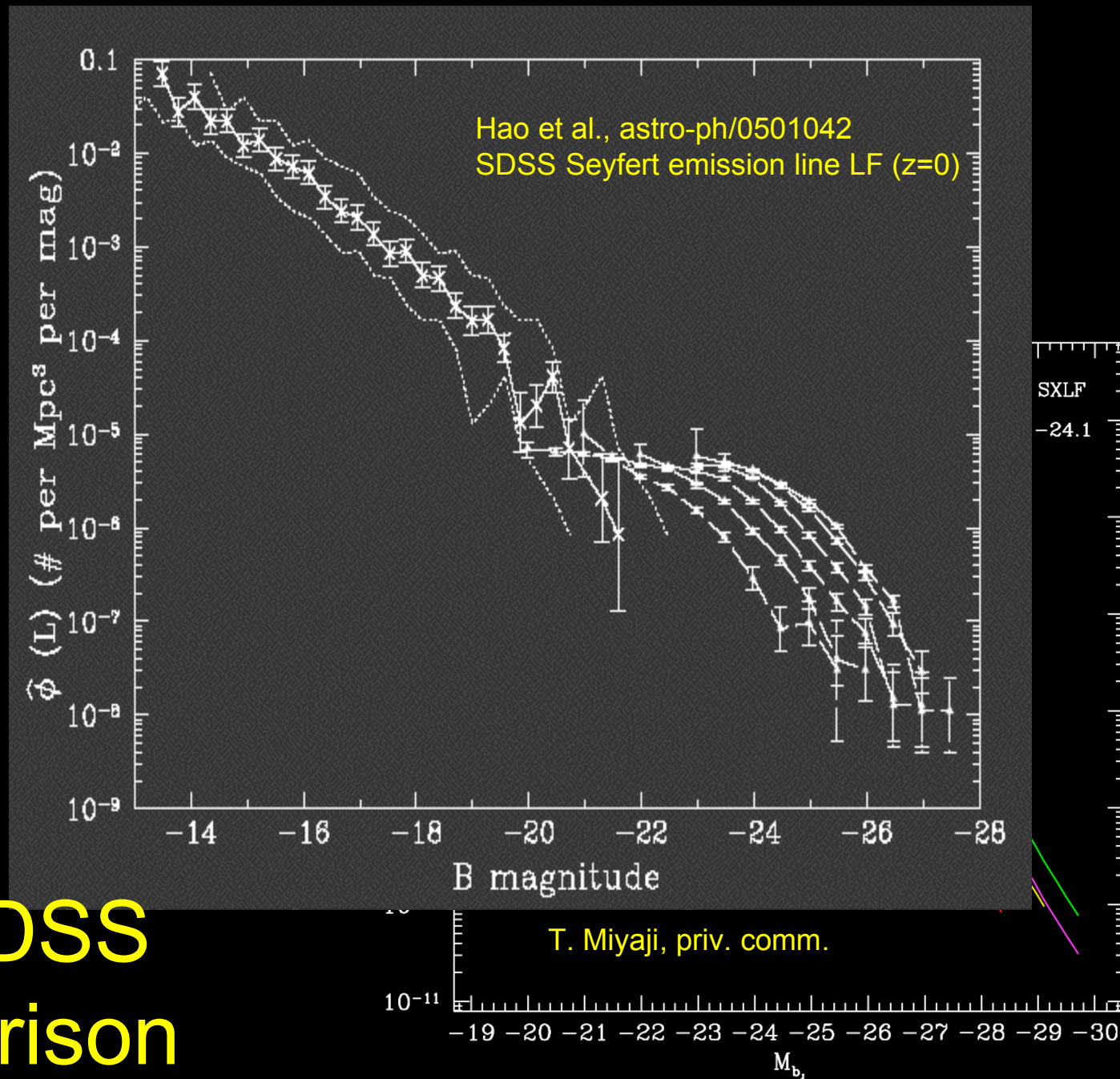
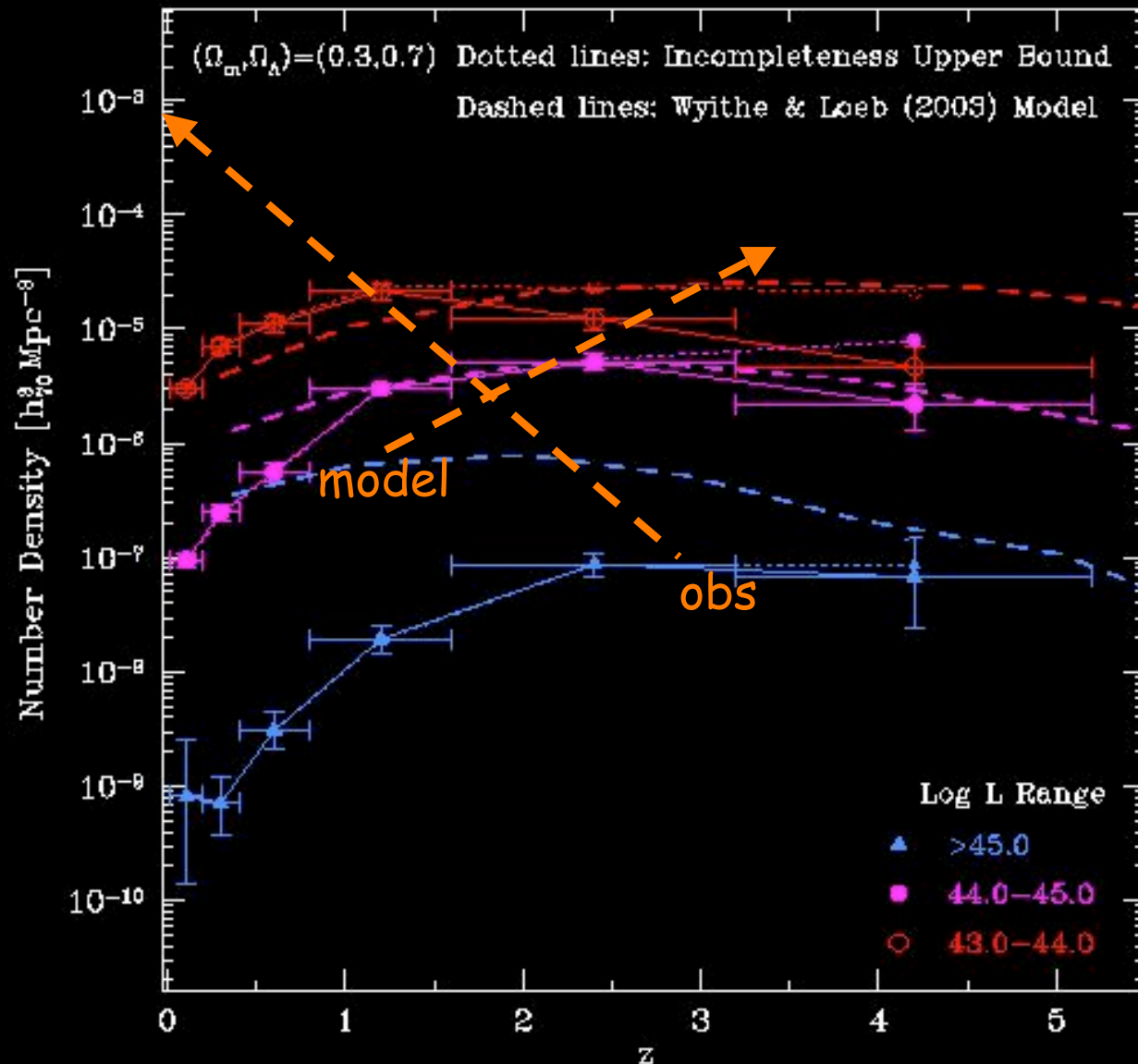


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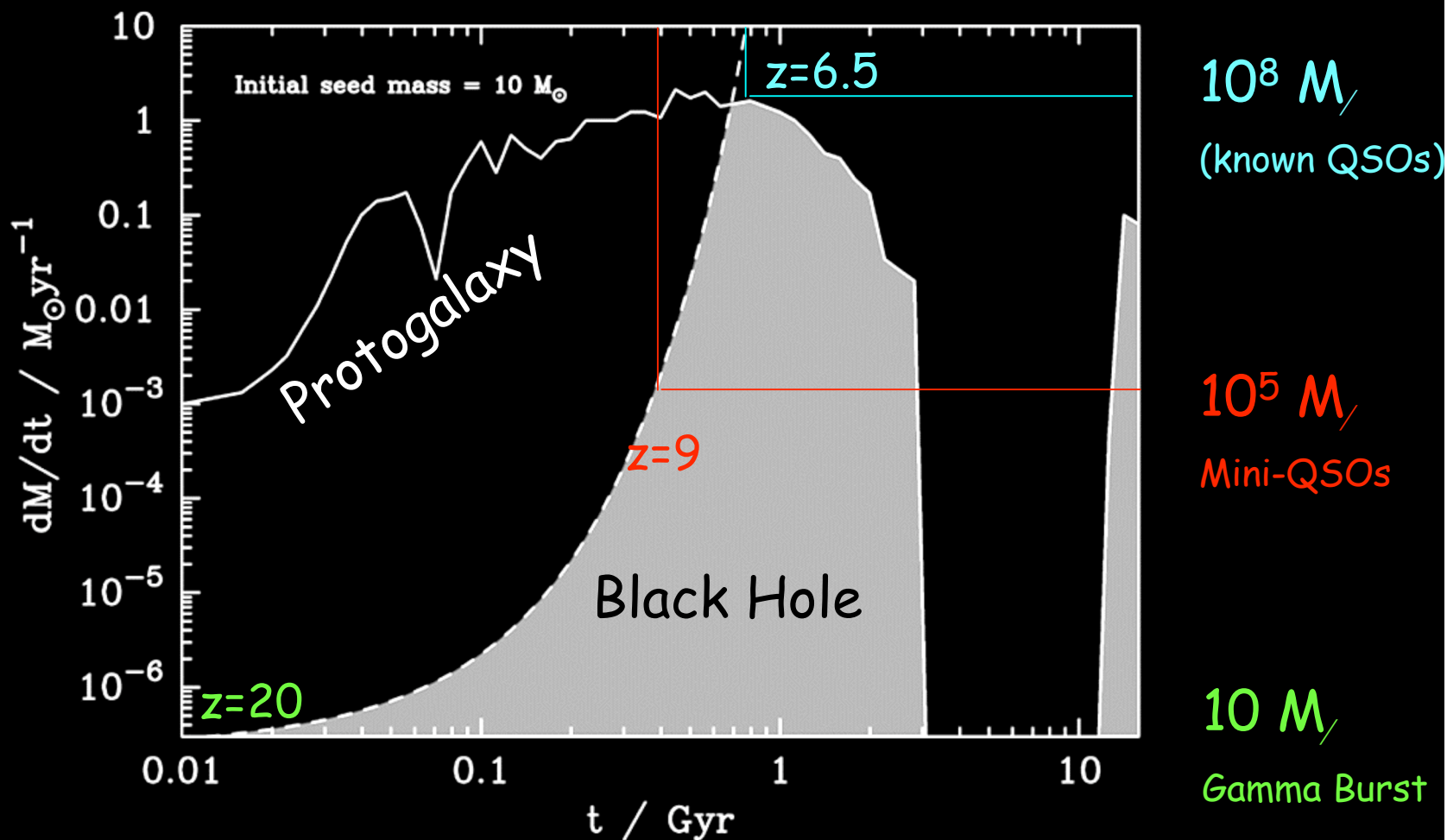
Model Comparison



→ BH Growth/Merger Models need major revision

QSO exponential feeding

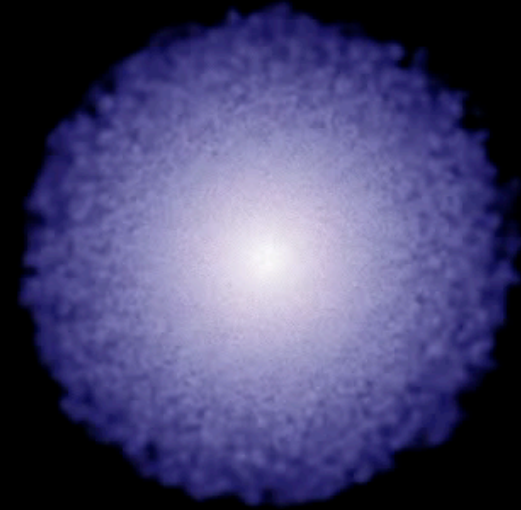
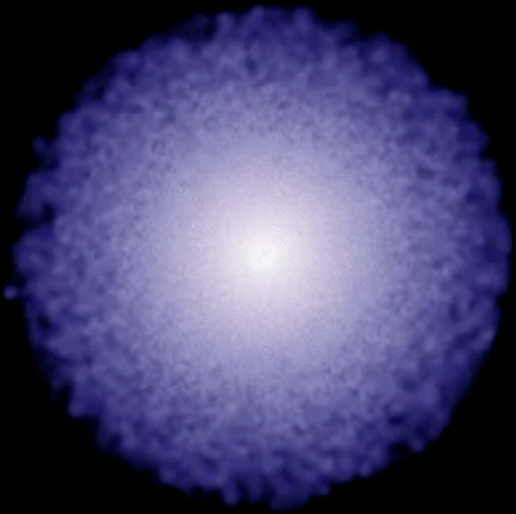
Archibald et al. 2001



Need New Generation X-ray Telescope to detect and study BH in conjunction with forming galaxy ($S_{\text{min}} \sim 10^{-18} \text{ erg cm}^{-2} \text{ s}^{-1}$).

$10^5 M_{\odot}$ @ redshift 9 detectable.

T = 0 Myr



10 kpc/h
|-----|

Simulation by Tiziana de Matteo, Volker
Springel (MPA) & Lars Hernquist (Harvard)

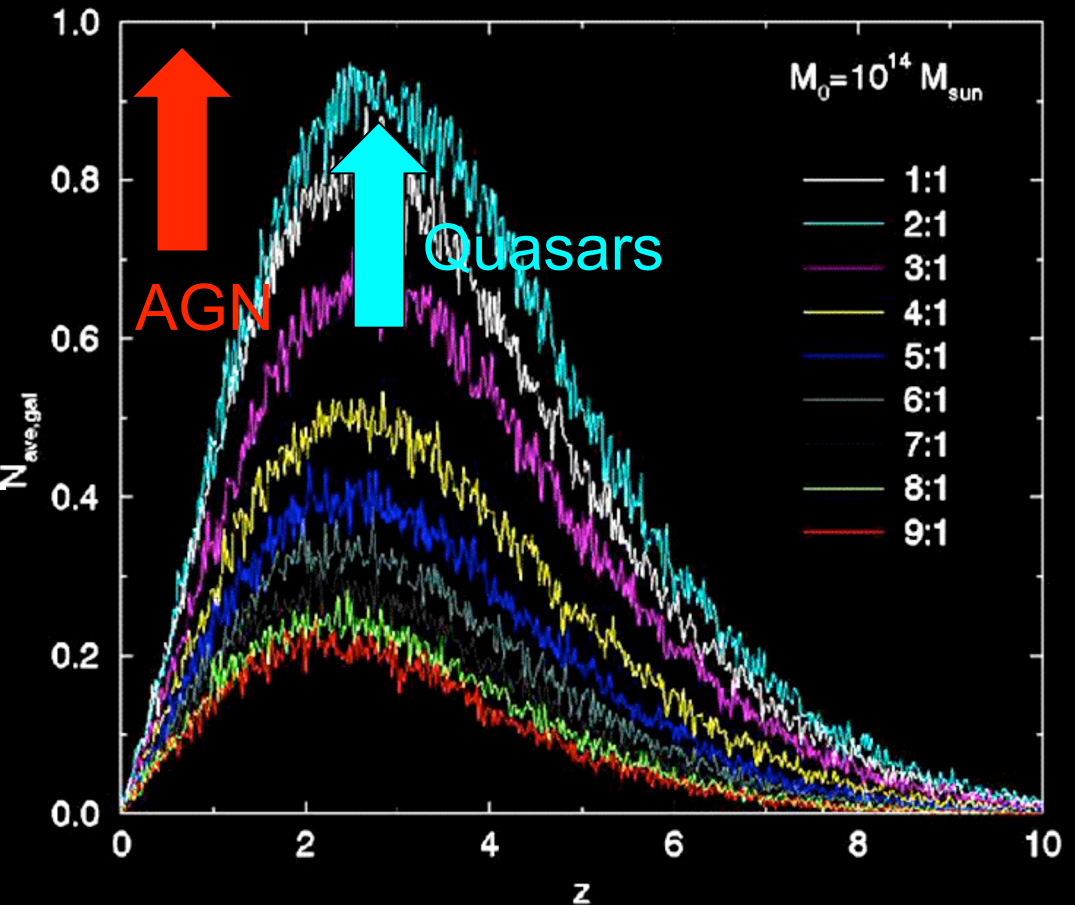
History of Merger-Events

Burkert et al., 2004

In the early universe there are more mergers, because the galaxies were closer to each other.

Also galaxies still contain more gas to feed black holes

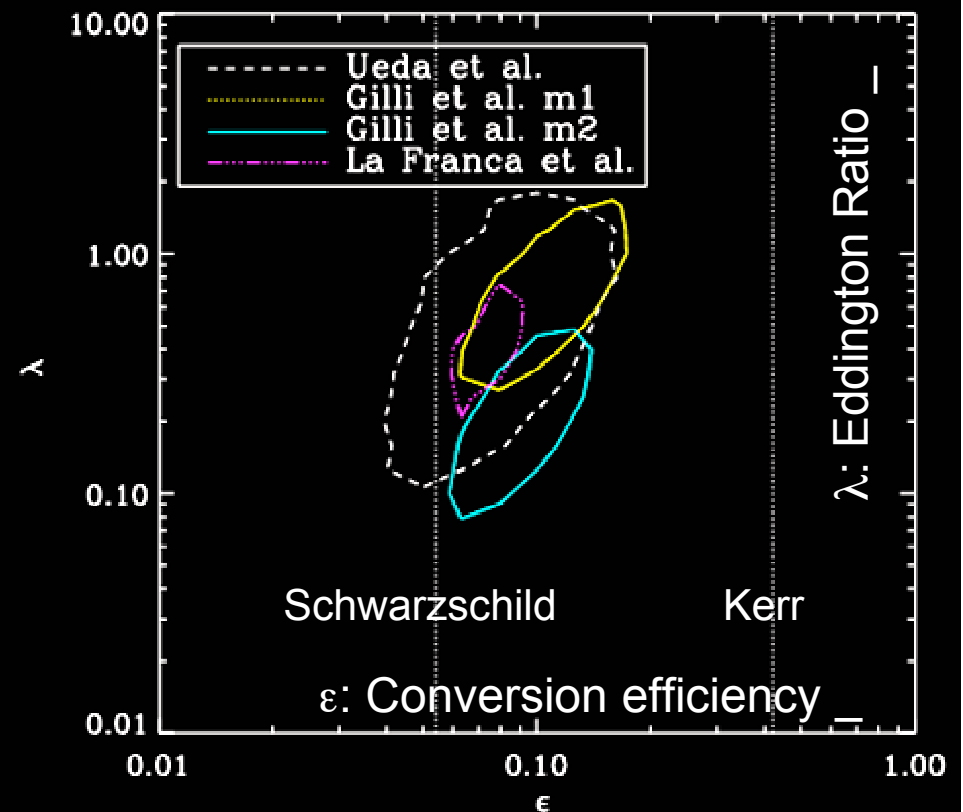
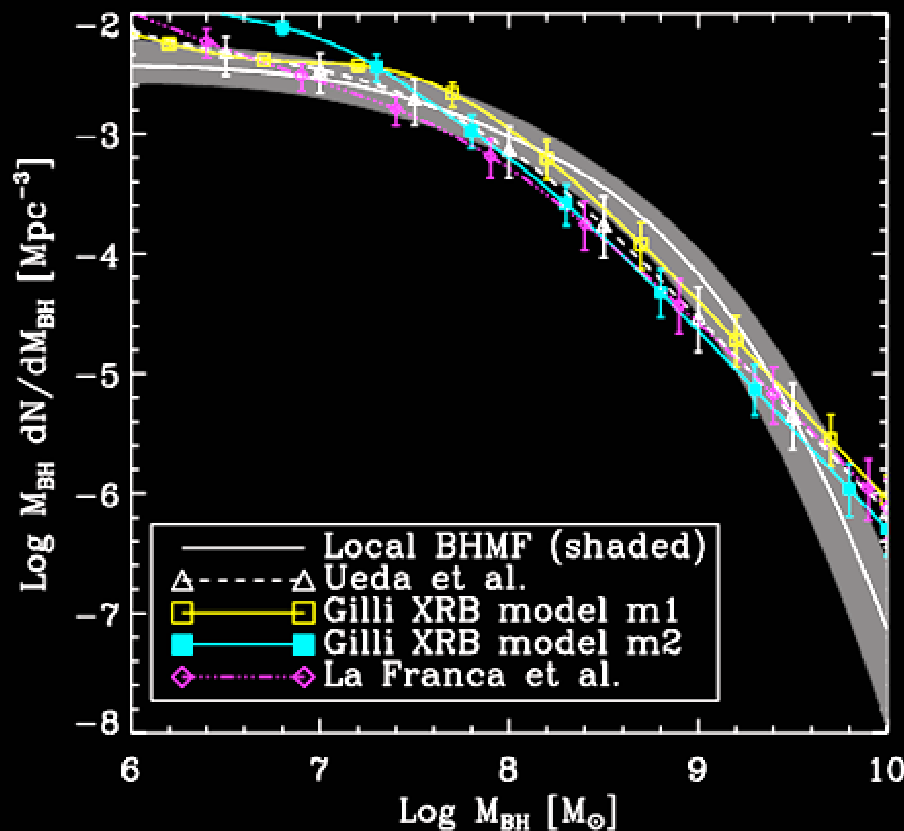
The calculated merger rate can very well describe the rise and fall of quasars in the early universe.



Why the bulk of the black holes, which produce part of the X-ray background, are formed so much later, is still not understood and needs further theoretical work. Maybe due to late triggering of small BH formed in early mergers.

Local BH mass vs. accreted BH mass function

- Accreted Black Hole mass function derived from X-ray background can be compared with the mass function of dormant relic black holes in local galaxies (Soltan 1982).
- These two estimates can be reconciled, if an energy conversion efficiency of $\epsilon=0.1$ is assumed. Such high efficiency requires a Kerr-BH!

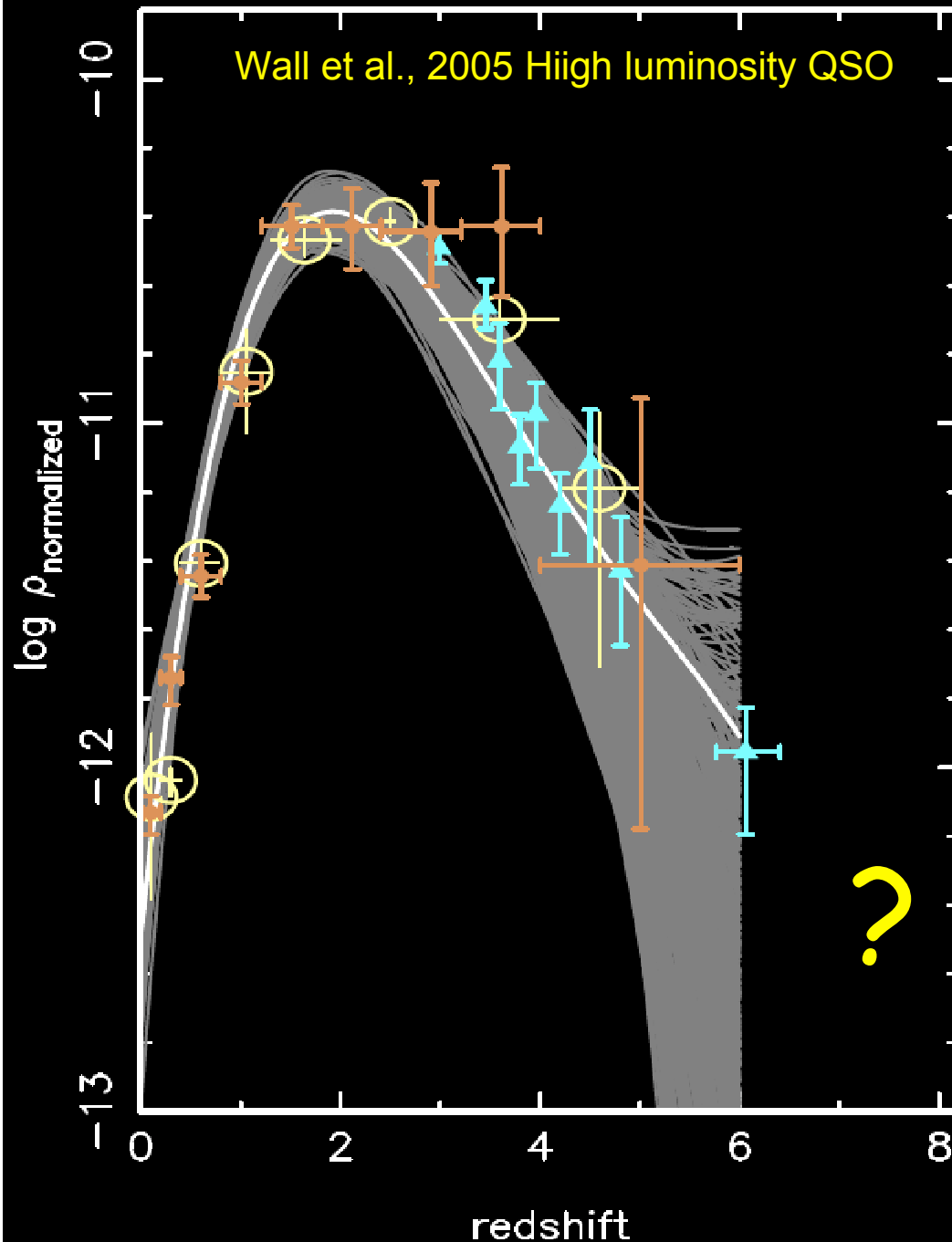


Marconi et al., 2006, MNRAS

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High-z QSO



- Radio QSO (Wall et al., 2005)
- Soft X-ray ROSAT/Chandra/XMM (G.H., Miyaji & Schmidt 2005)
- Chandra/ROSAT (Silverman et al. 2004)
- Optical QSOs (Schmidt et al., 1995, Fan et al. (2001, 2004))

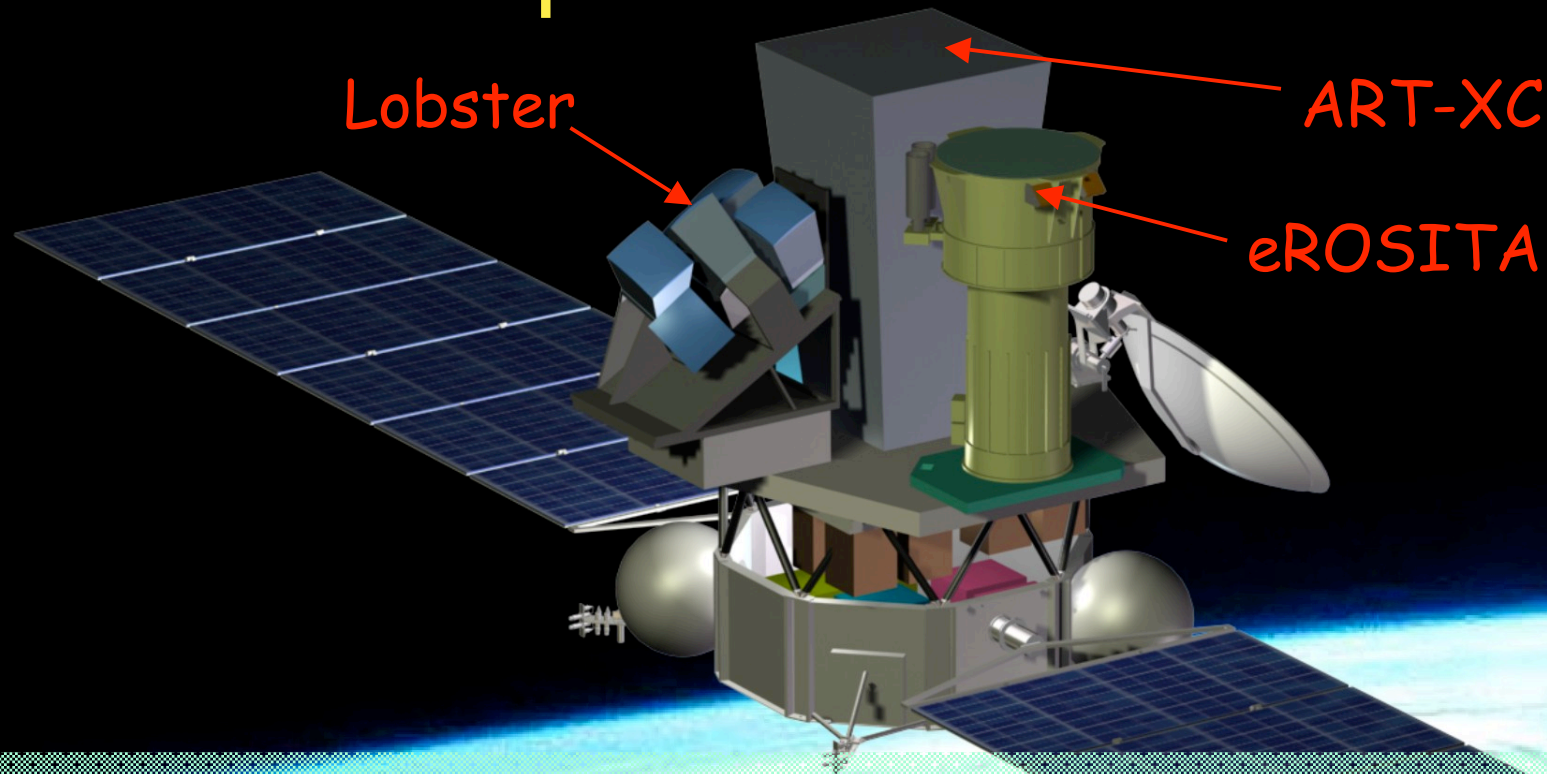
Very large solid angle & deep surveys required to study $z > 5$ QSOs

E-CDFS

XMM/COSMOS

eROSITA

The new Spectrum-X-Gamma Mission

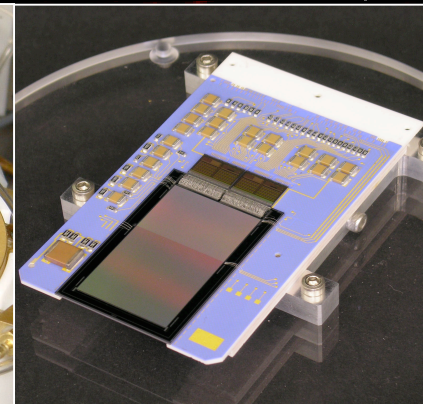
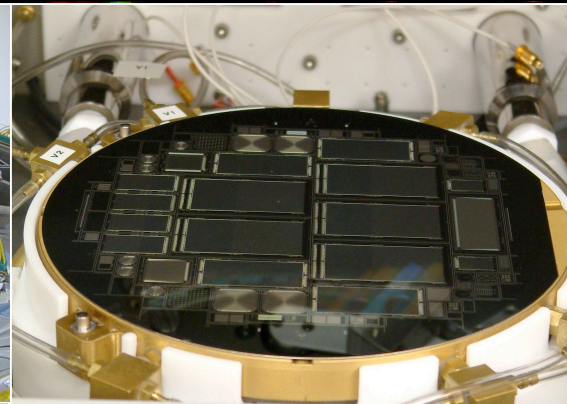
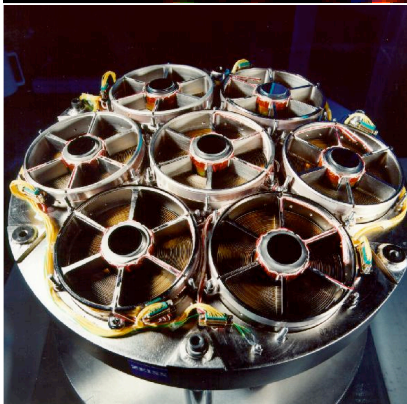
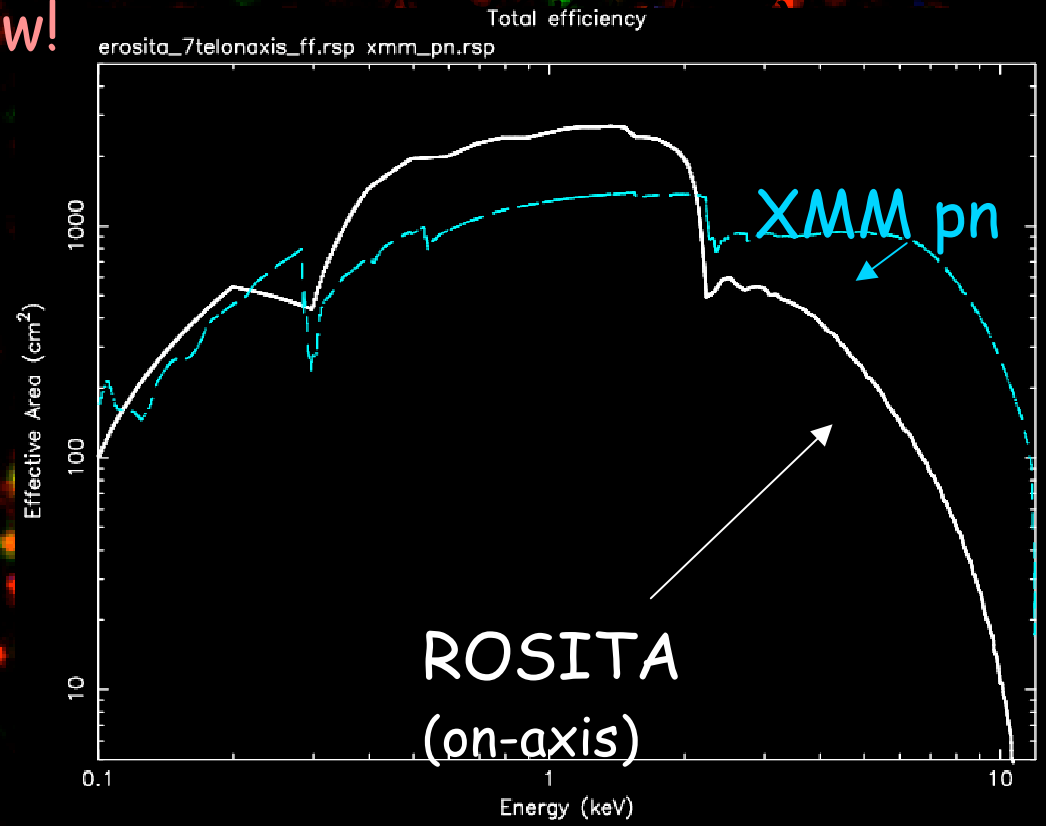


- Mission is approved on the Russian side. Launch possible on Soyus/Fregat from Kourou or Baikonur in 2010/11.
- Equatorial LEO orbit guarantees excellent background, other orbits still under discussion.
- eROSITA costs about 45 Mio €; DLR has earmarked funding profile for ~25 Mio €; rest through MPG
- Mission will be proposed for PPARC & ESA funding in 2006.

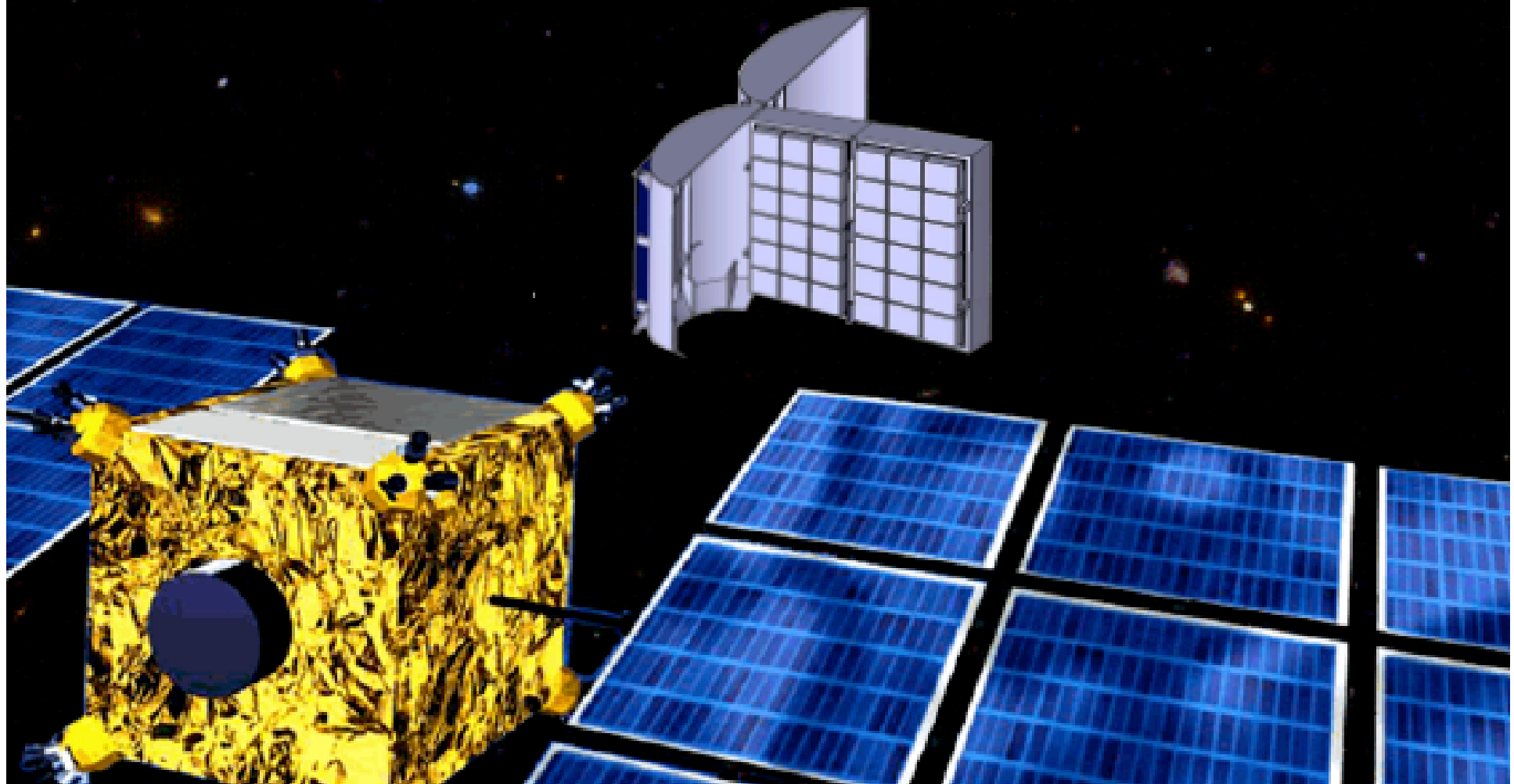
eROSITA



Instrument is in Phase-B now!

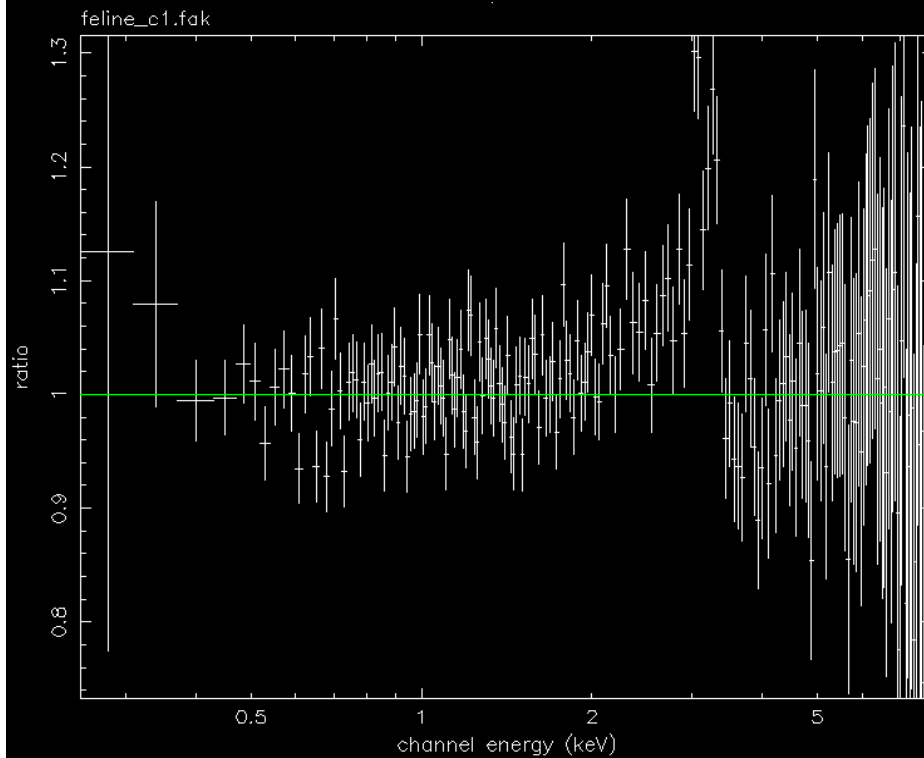


... and the final goal: XEUS

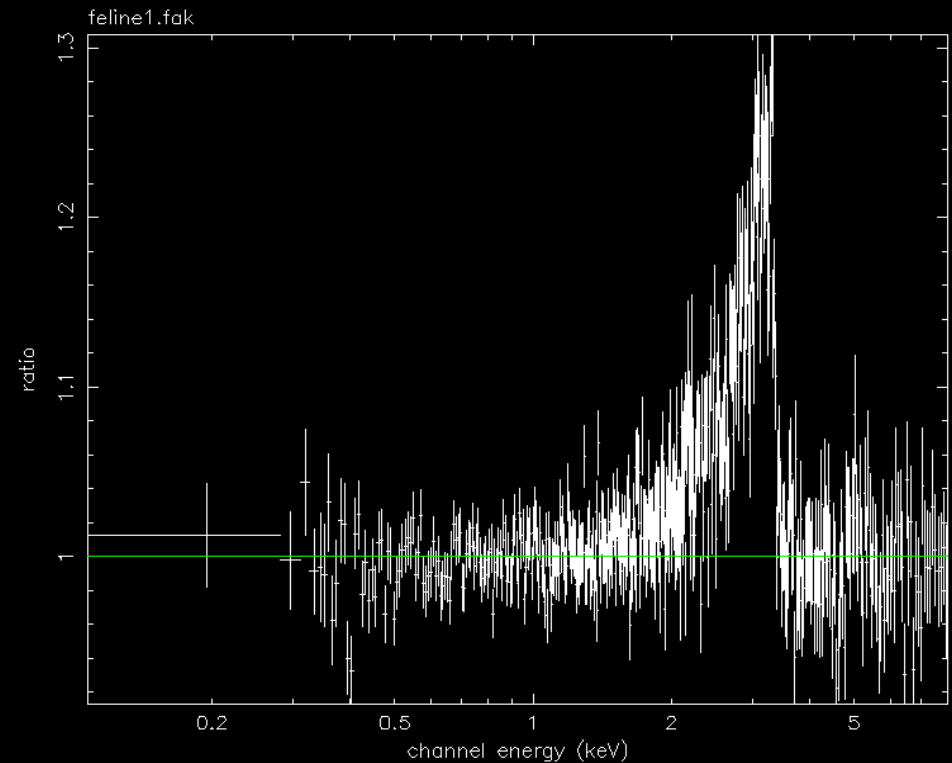


Throughput Matters!

$z=1$ $L_x=10^{44}$ erg/s $F_x=3.6 \times 10^{14}$ cgs



1 Msec Con-X TES



1 Msec XEUS WFI

Thank you very much!

