RECENT RESULTS FROM THE SATELLITES CHANDRA AND XMM-NEWTON

Ingo Lehmann & Günther Hasinger
Max-Planck-Institut for extraterrestric Physics, Garching/Munich, FRG

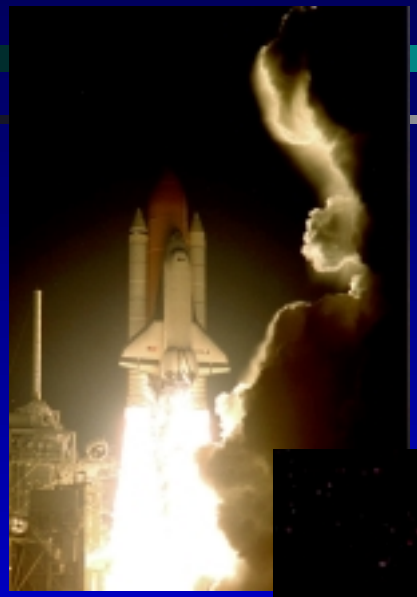
EPS-12: “Physics in Space Symposium“, Budapest, August 29, 2002

Schedule

- The XMM-Newton & Chandra Observatories
- Imaging of Active Galactic Nuclei and galaxies
- Moderate and High Resolution X-ray Spectroscopy of Active Galactic Nuclei
- Cosmic X-ray background – Deep X-ray Surveys
- Summary

The XMM-Newton and Chandra satellites

Chandra X-ray observatory (CXO)



Juli 1999

X-ray component of NASA‘s four Great Observatories: Hubble telescope, Compton Gamma-ray observatory, Space Infrared Telescope Facility

High resolution imaging X-ray telescope (1/2 arcsec) with a suite of advanced imaging and spectroscopy instruments

- **high elliptical orbit**
- **operated by the NASA Space flight center**

Instruments onboard of Chandra

High Resolution Mirror Assemble (HRMA)

- focal length: 10 m, largest diameter: 1.2 m
- nested set of four parabolic/hyperbolic grazing-incidence X-ray mirror pair (Wolter-A type)
- PSF FWHM ~0.5 arcsec, FOV ~ 30 arcmin (ghostfree)

Four focal plane instruments:

- Advanced CCD Imaging Spectrometer (ACIS)
- High Resolution Camera (HRC)
- Low/High Energy Transmission Grating (LETG/HETG)

Properties of the Chandra instruments

ACIS (PI: Garmire, Penn State)

- two CCD arrays with 4/6 chips (ACIS-I/S), 1024^2 pixel
- ACIS-I: 16.9 x 16.9 arcmin
- ACIS-S: 8.3 x 50.6 arcmin
- energy range: 0.4-6/7 keV

HRC (PI: S.S Murray, CFA)

- two micro channel plate imaging detector (30 x 30 arcmin)
- energy range: 0.08-10 keV
- angular resolution: 0.5 arcsec
- Similar to ROSAT‘s HRI

LETG (MPE/Netherlands)

- operated with HRC-S
- energy range: 0.08-0.2 keV
- high resolution soft X-ray spectroscopy

HETG (PI: Canizeres, MIT)

- operated with ACIS-S
- energy range: 0.4-10 keV
- high spectral resolution: E/? E~1000

The XMM-Newton observatory

ESA‘s fourth cornerstone mission
defined in the Horizon 2000 programme

- three Wolter-A type X-ray telescopes with different detectors
- 30 cm optical/UV telescope
- simultaneous operation of all telescopes

- launched in December 1999

Simultaneous X-ray/optical/UV observations

Instruments onboard of XMM-Newton

European Photon Imaging Camera (EPIC)

- 3 CCD cameras for imaging and moderate-resolution spectroscopy: 2 x MOS, PN (0.15-12/15 keV)
- Angular resolution ~5/6 arcsec, FOV ~ 30 arcmin

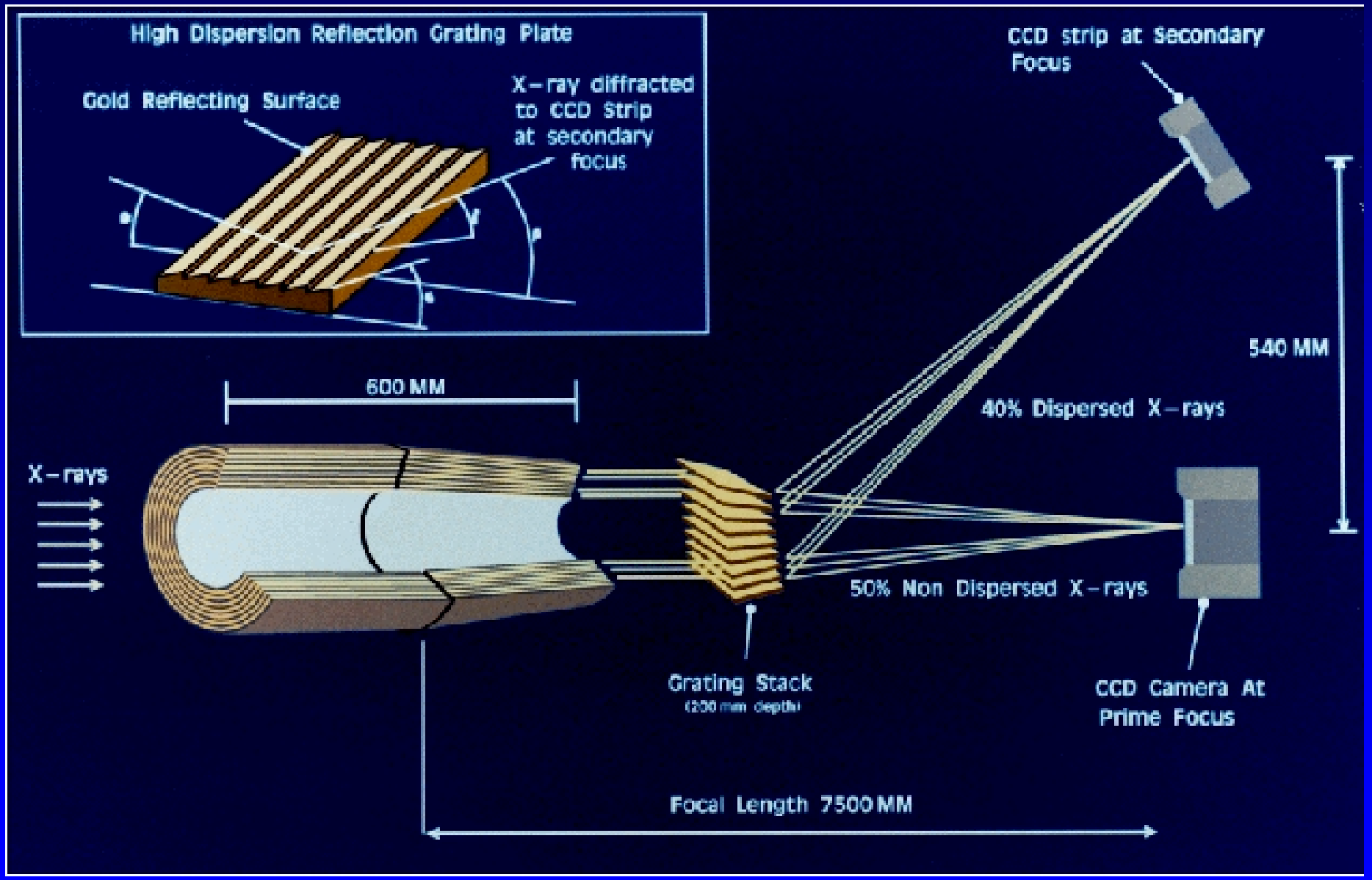
Reflection Grating Spectrometer (RGS):

- Soft X-ray spectroscopy (0.35-2.5 keV, $E/\Delta E$ ~ 200-800)

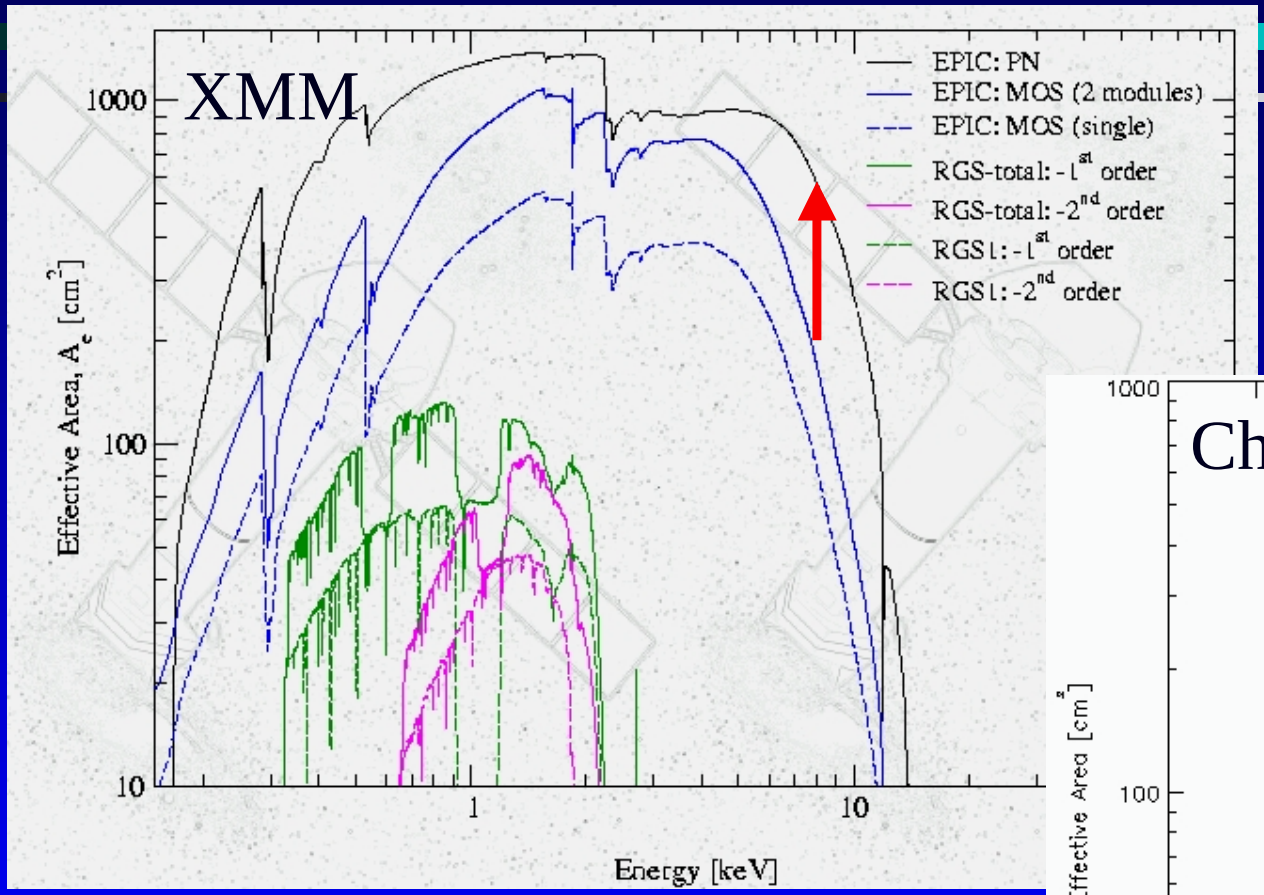
Optical Monitor (OM):

- Optical imaging in the 160 to 600 nm bands

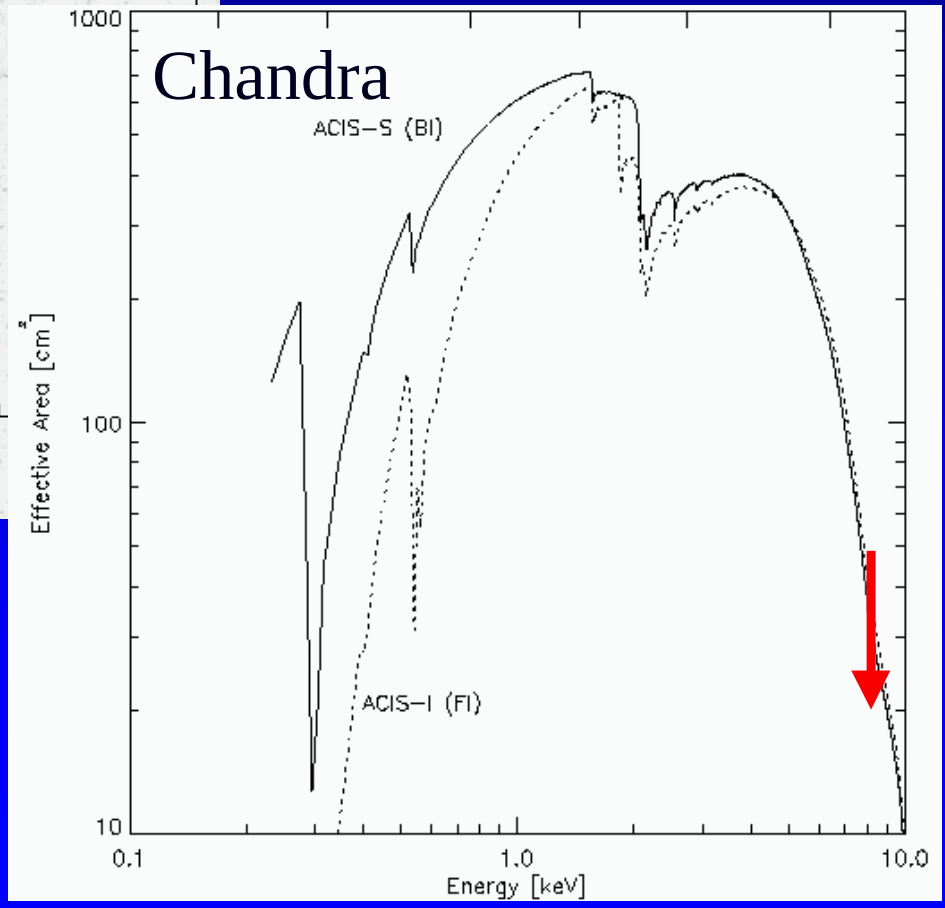
XMM light path (with gratings)



Effective area



At 8 keV: factor of ~30 more efficient



XMM-Newton has much higher sensitivity compared to Chandra !

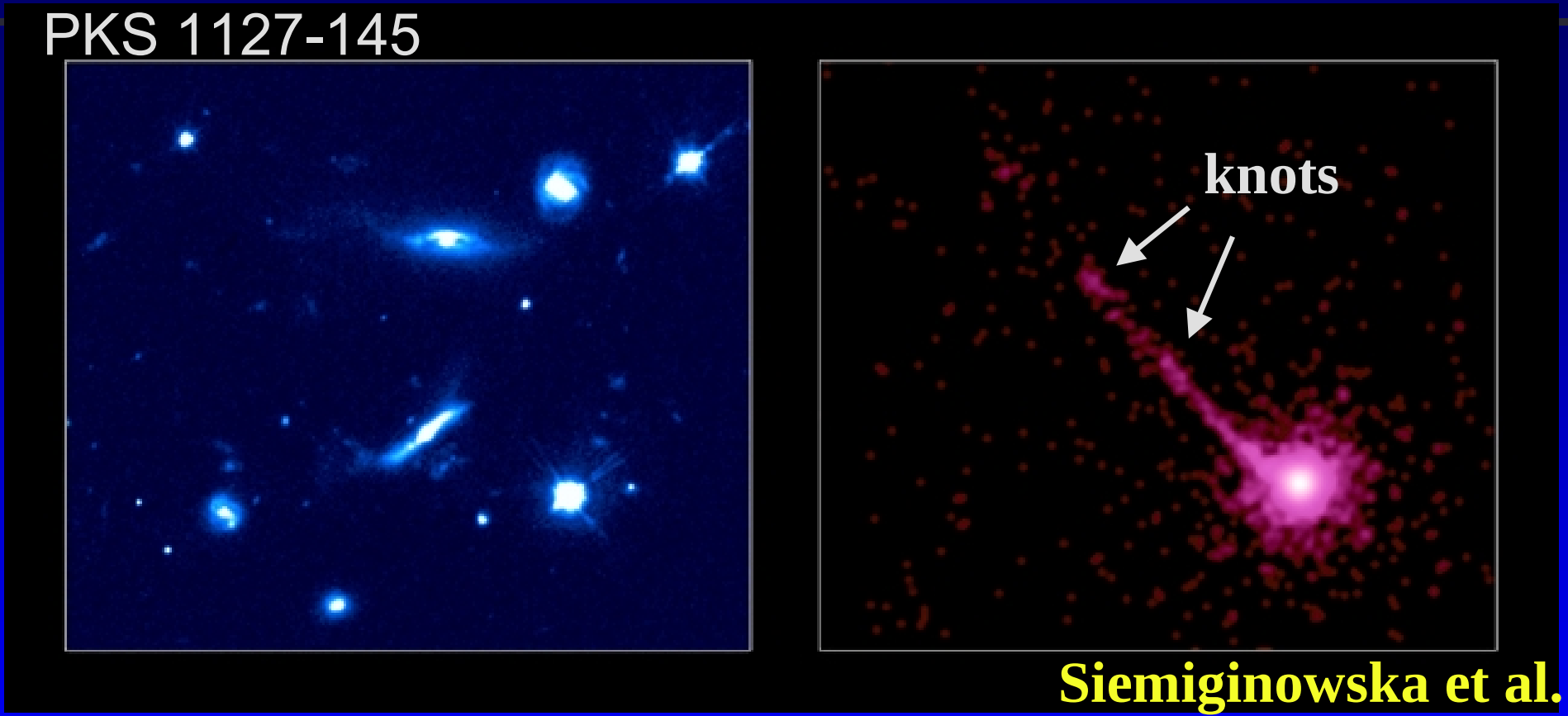
Comparison

	XMM-Newton	Chandra
Faintes sources:	3e-16 erg/cm^2/s	3e-17 erg/cm^2/s (2 Msec)
Confusion limit reached within:	~200 ksec	~ 10 Msec observation
Angular resolution:	~5-6 arcsec	~0.5/ 1 arcsec
Energy response:	highest	no response above 7 keV
Particle background:	medium effected	less effected

Powerful combination for imaging and spectroscopy !!!

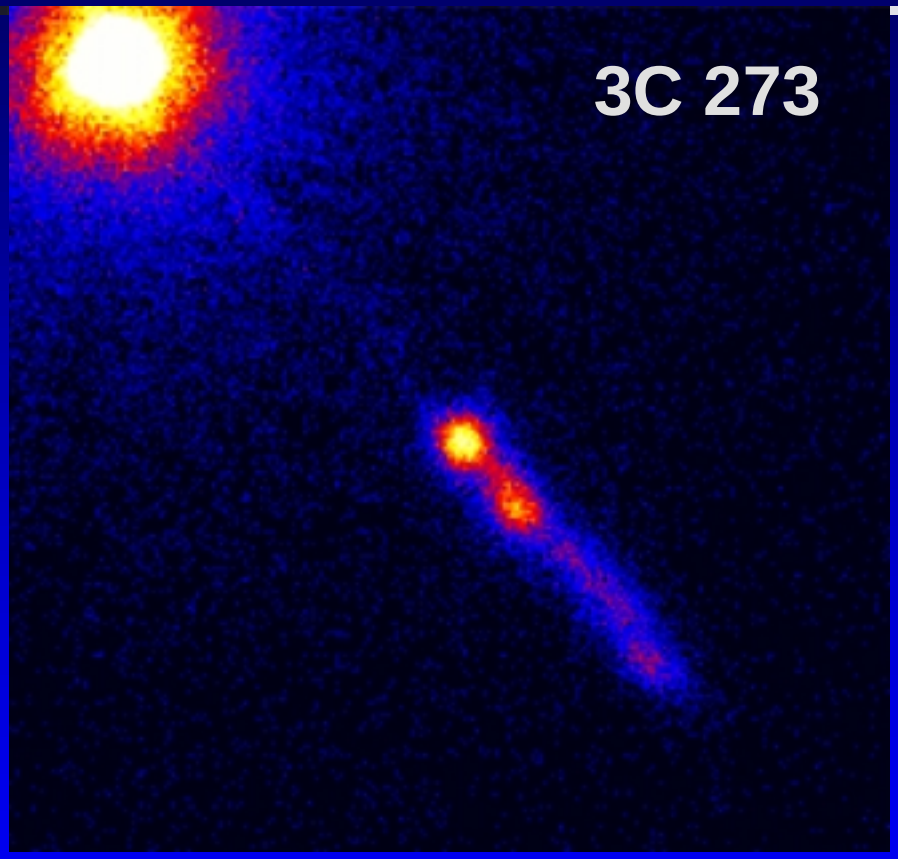
High angular resolution imaging of galaxies and Active Galactic Nuclei

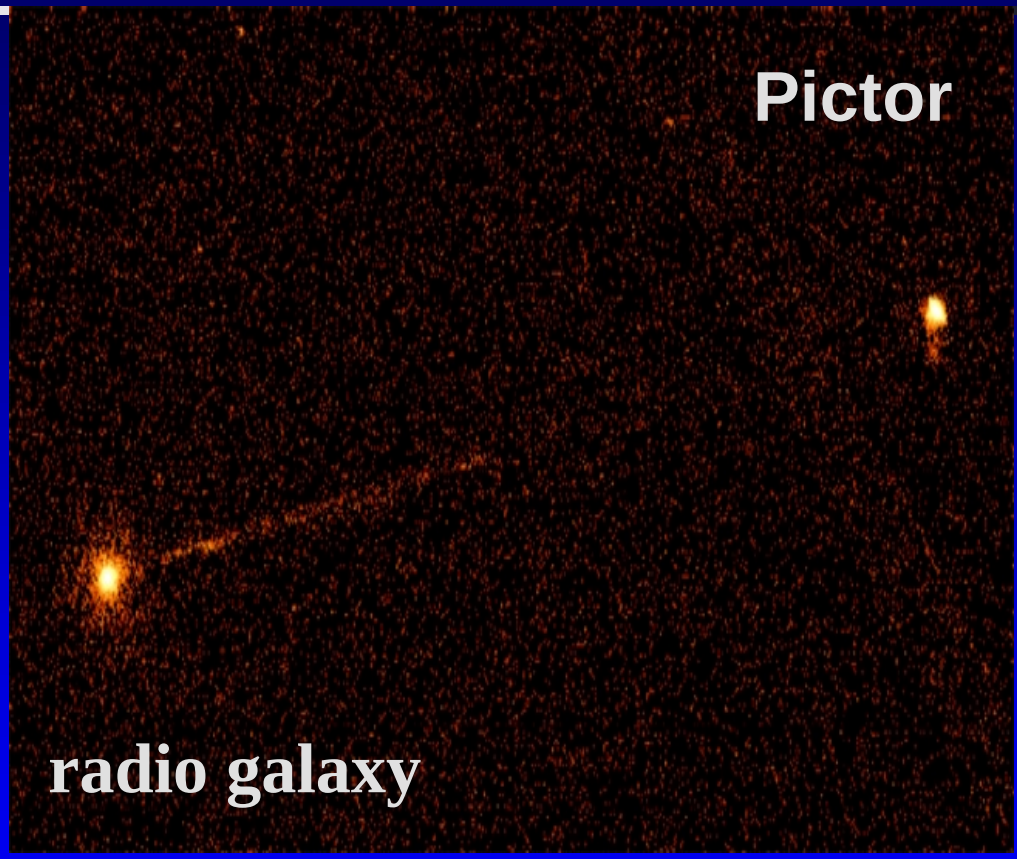
X-ray jet from PKS 1127-145



- enormous jet extends over 1 million light year from the quasar
- high energy beam produced by the collision of high energy electrons with microwave photons
- explosive activity related to gas swirling around a supermassive BH

X-ray jets

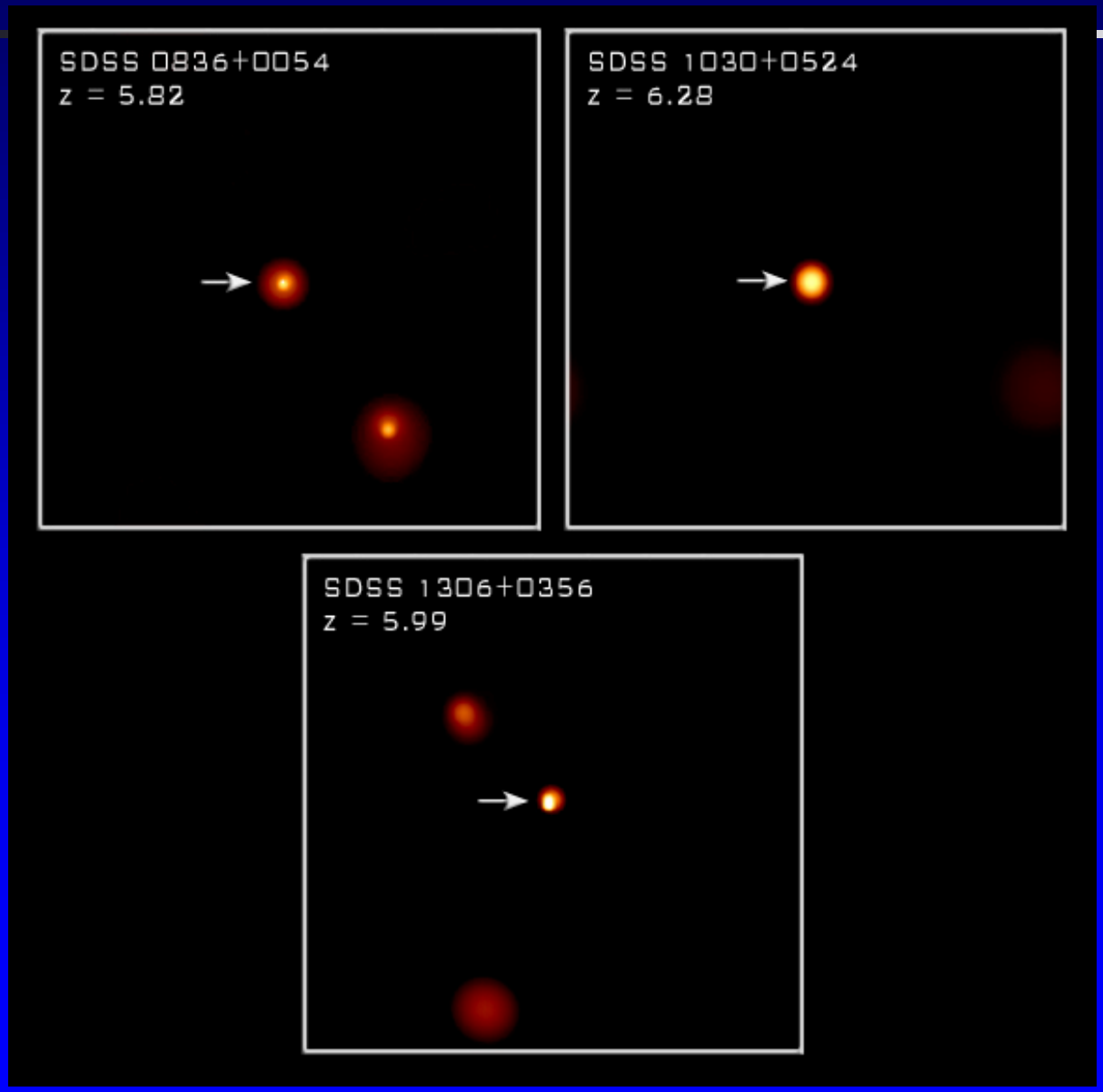




- image of the area between the core and the beginning of the jet
- velocity very close to the speed of light

- 360000 light years long jet with a hot spot
- shock wave along the head and the side of the jet boosting electrons

Detection of high-z Quasars

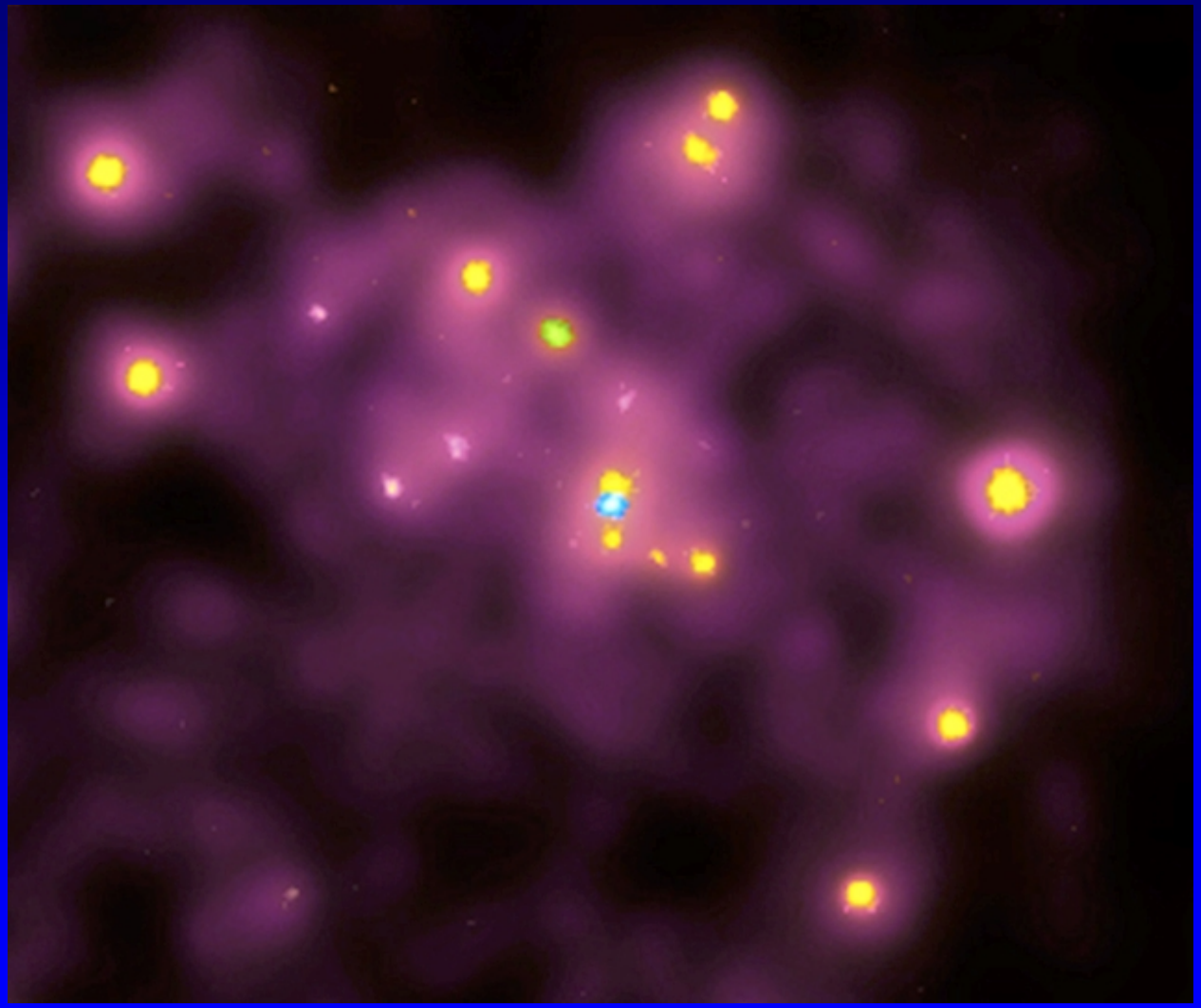


Mathur et al. 2001, Brandt et al. 2001

- **13 billion light years from earth**
- **universe at 7 % of its present age**
- **similar power output and properties as low-z quasars**

Similar conditions around supermassive black holes !!!

Andromeda galaxy (M 31)



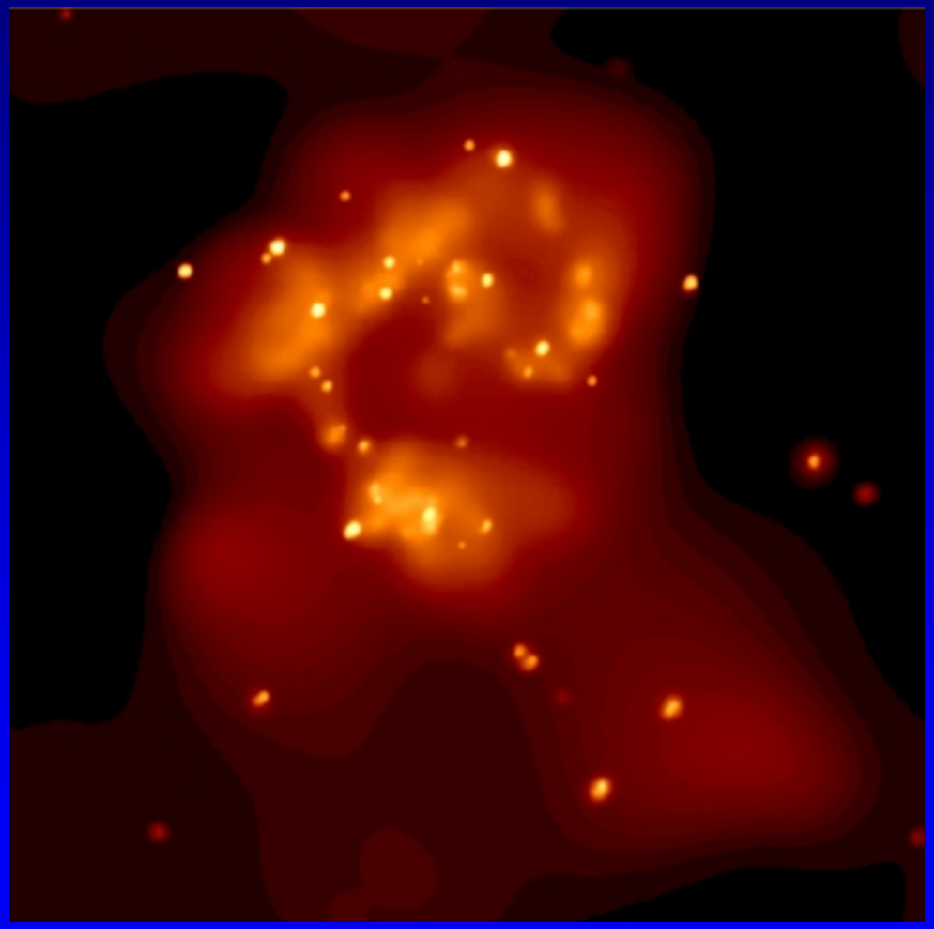
S.S. Murray et al. 2001

- central position of the M 31 galaxy of our local group
- several X-ray binaries
- a „cool“ million degree X-ray source in the center

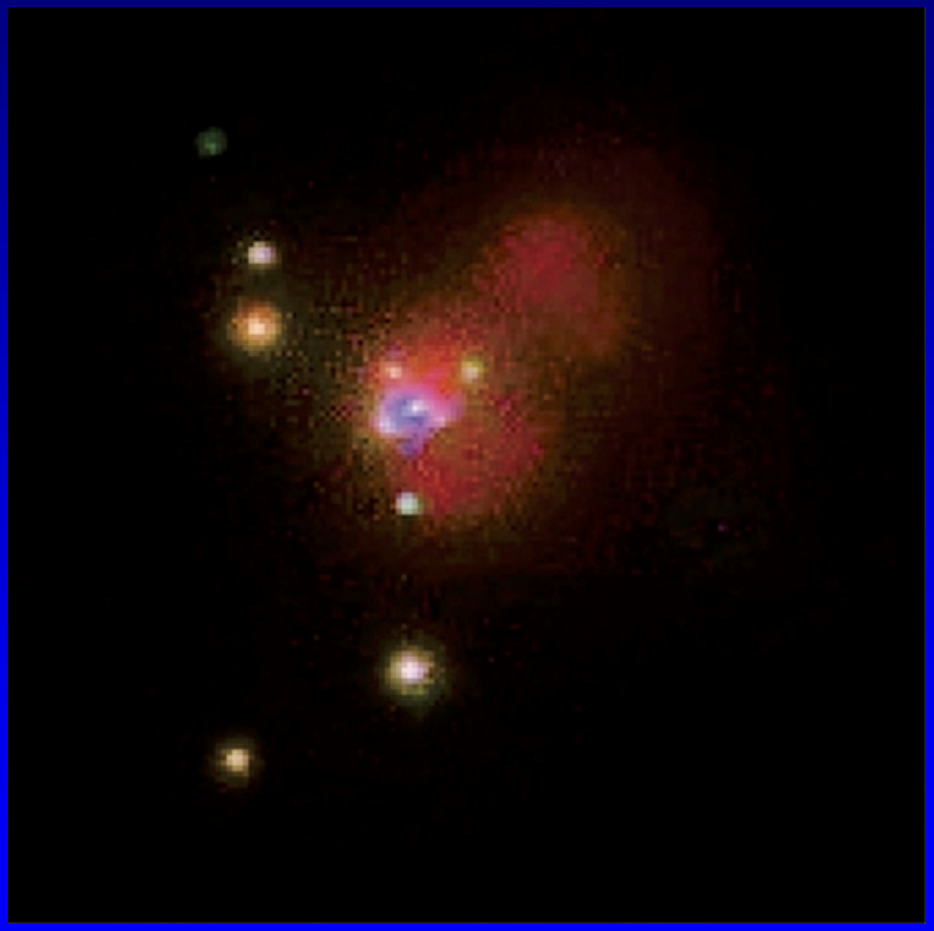
Supermassive BH with 3 million M

AGN in nearby galaxies

Antenna: Superbubbles, binaries

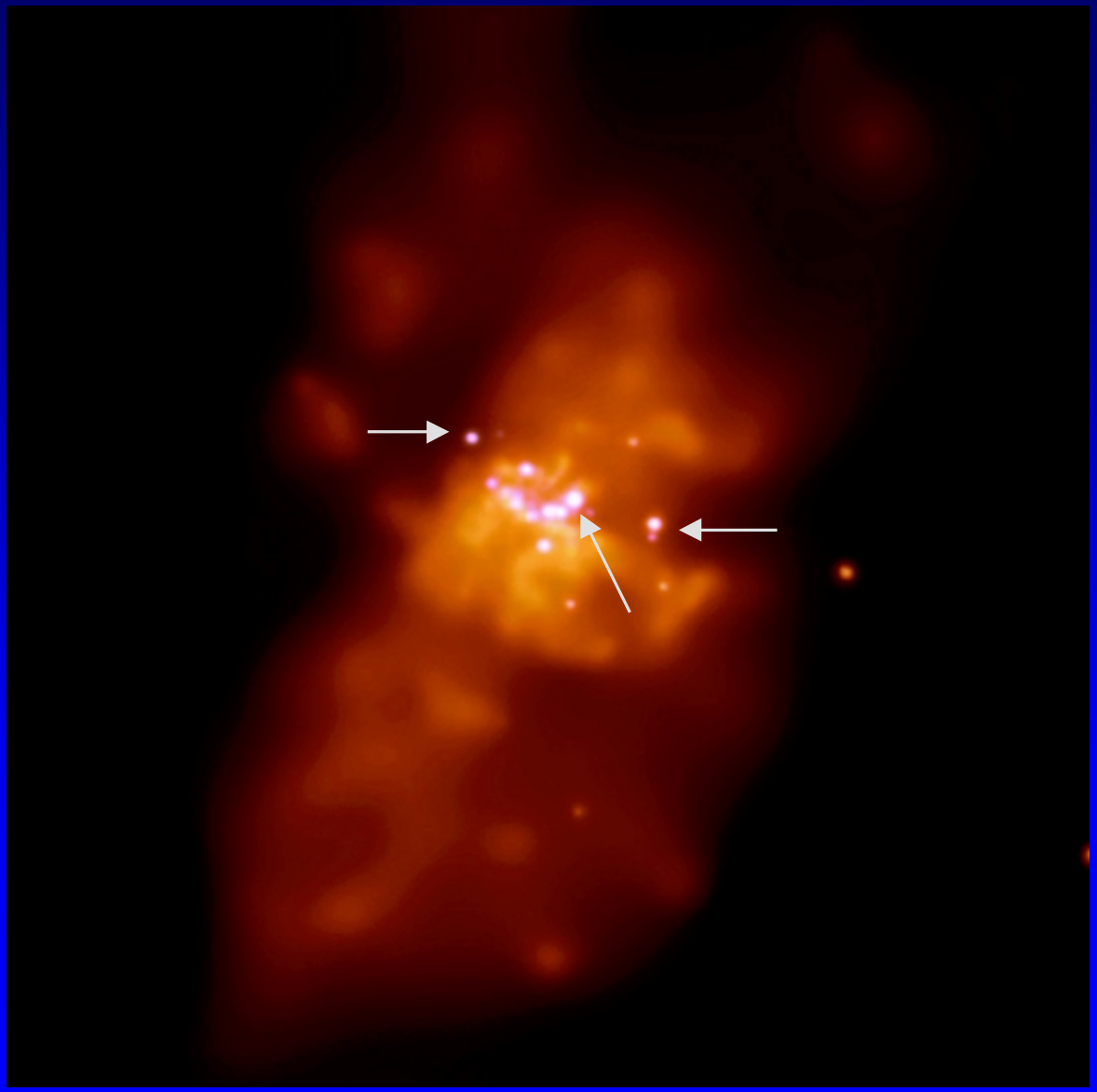


Circinus: Supereddington sources



Intermedium BH mass studies (L_X=10^{39} erg/s)
Disentangle starburst from nuclear emission regions

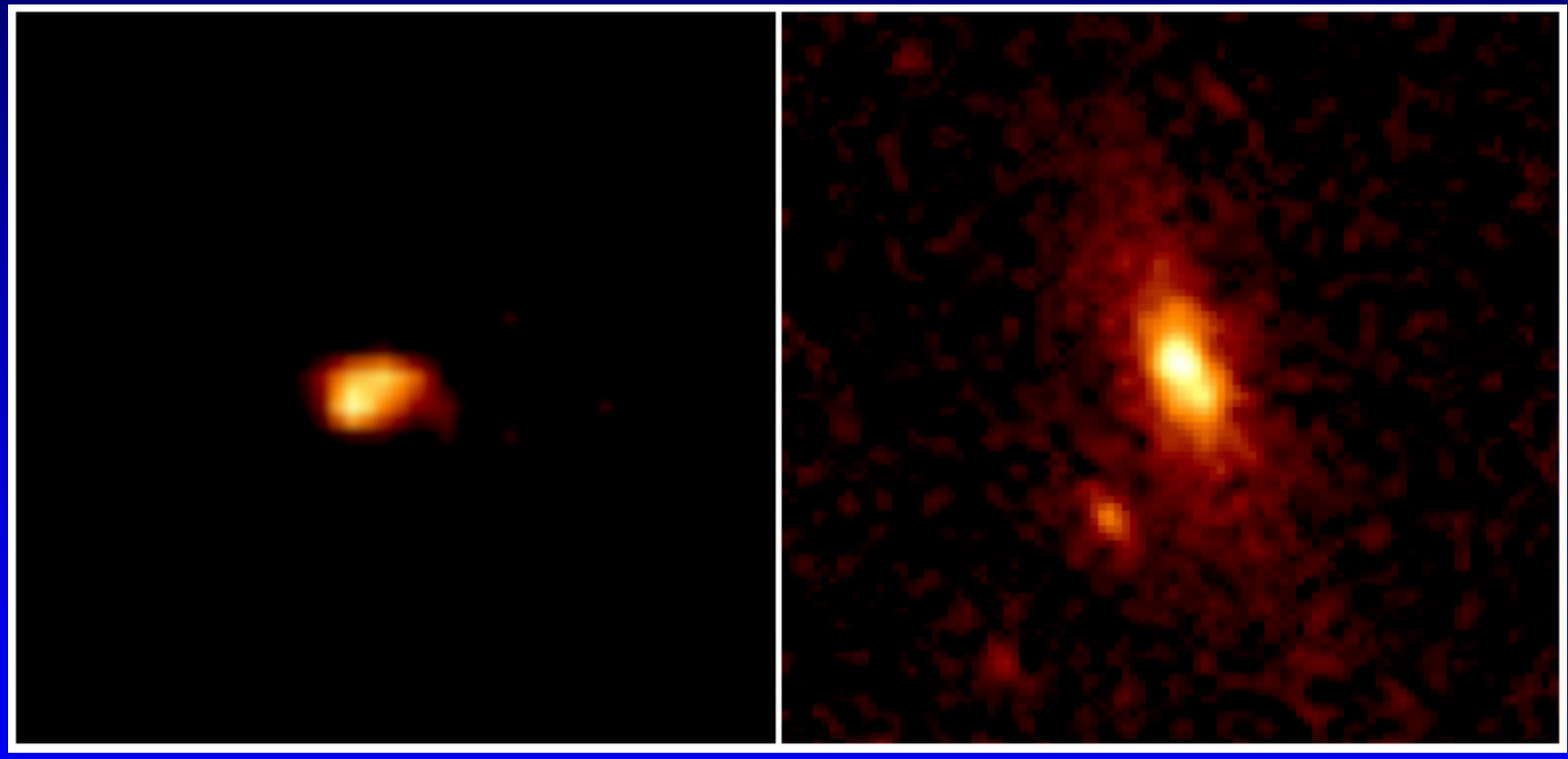
M82 – nearest starburst galaxy



- 11 million light years from the earth
- Massive starformation
- Diffuse emission and a large number of ultraluminous X-ray sources

Massive black holes ~100 solar masses or beamed black holes

Images of type-2 Quasars

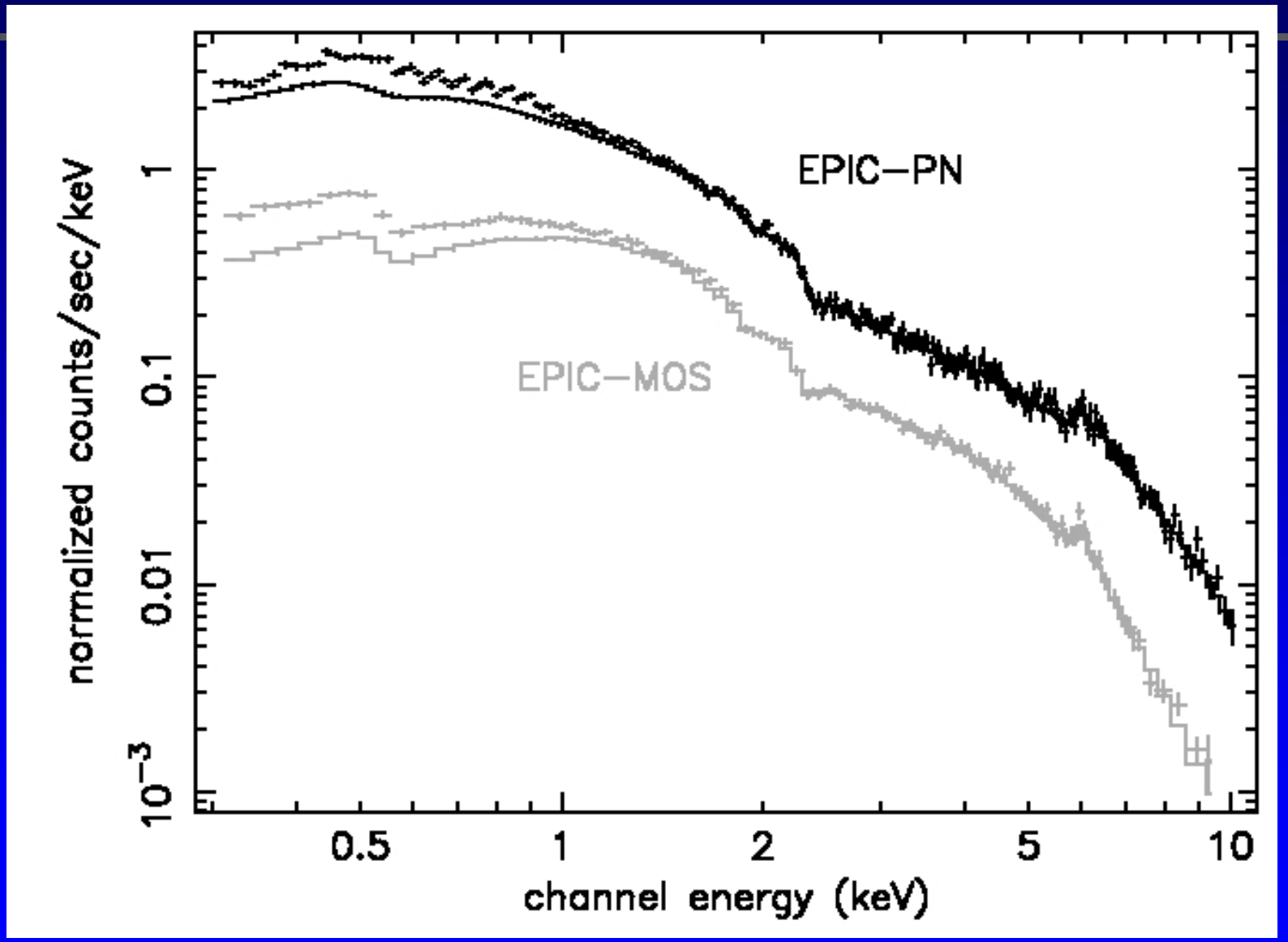


- **Hard X-ray images of obscured Quasars, hidden by gas and dust at other wavelength**

Fabian et al. 2001

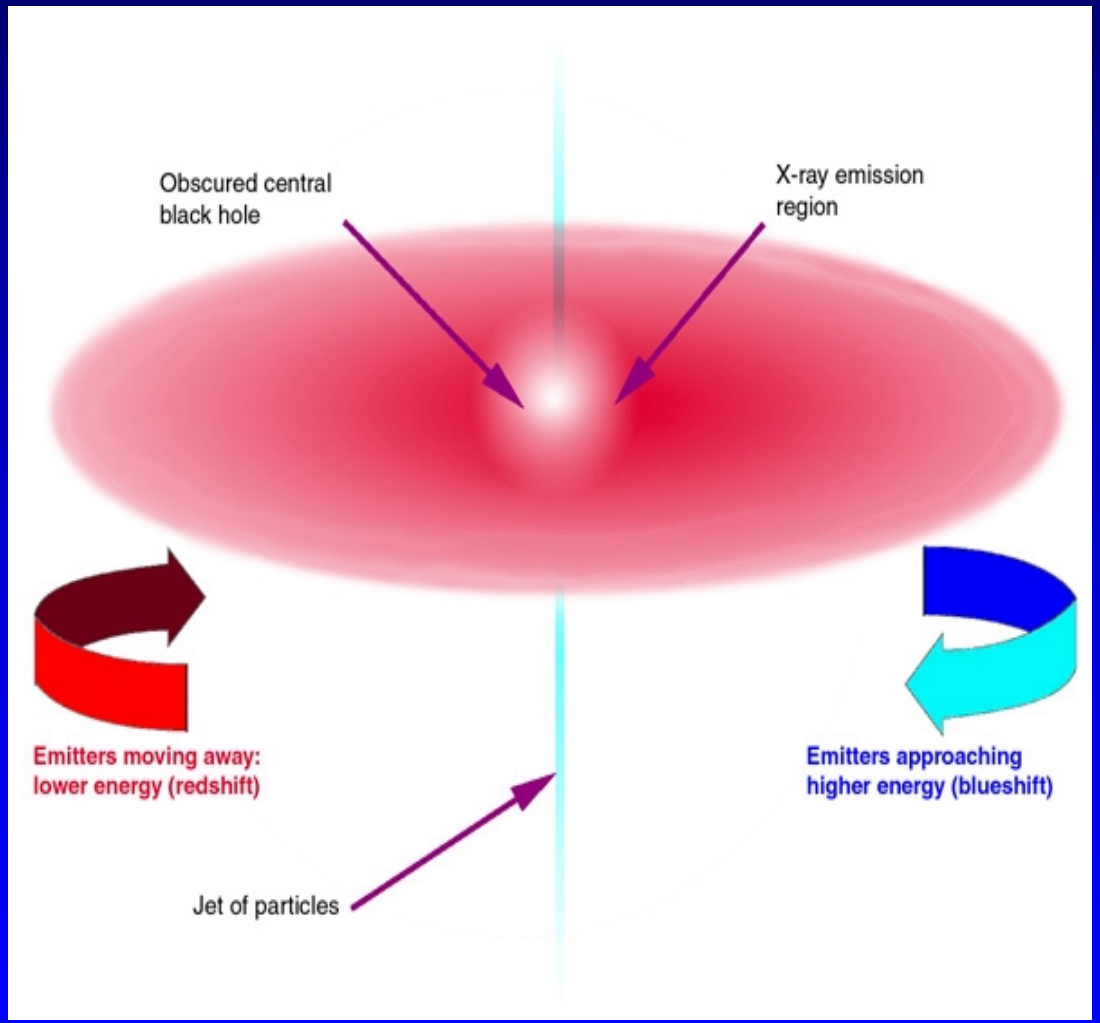
X-ray spectroscopy of Active Galactic Nuclei with XMM-Newton and Chandra

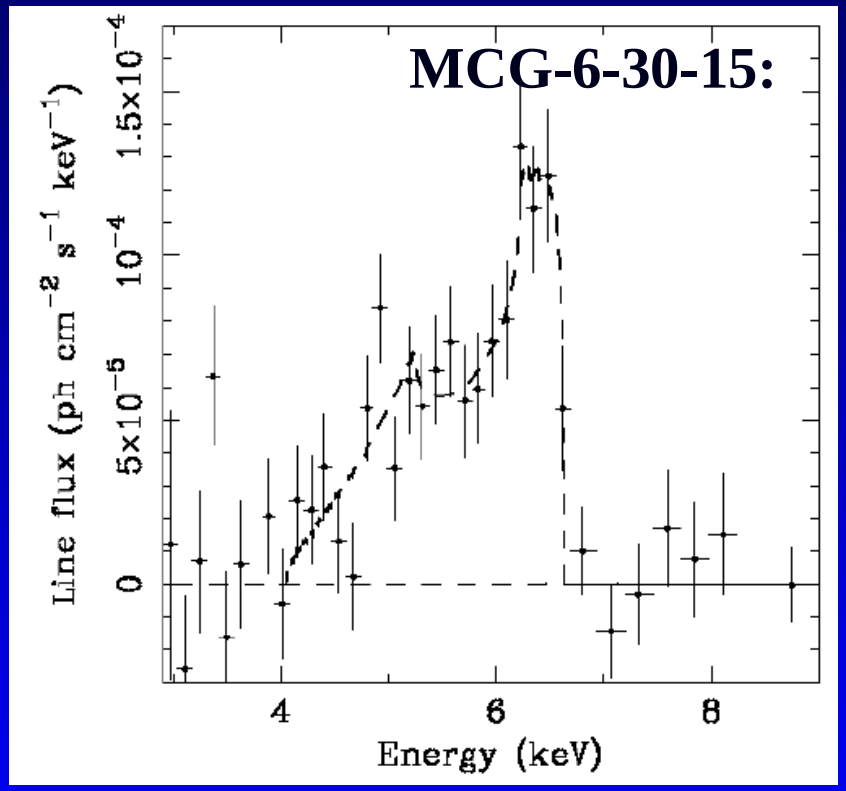
XMM broad-band spectra of AGN



Power-law extrapolation: ~15 % soft excess emission (0.5-2 keV)

Relativistic Iron Line Profiles



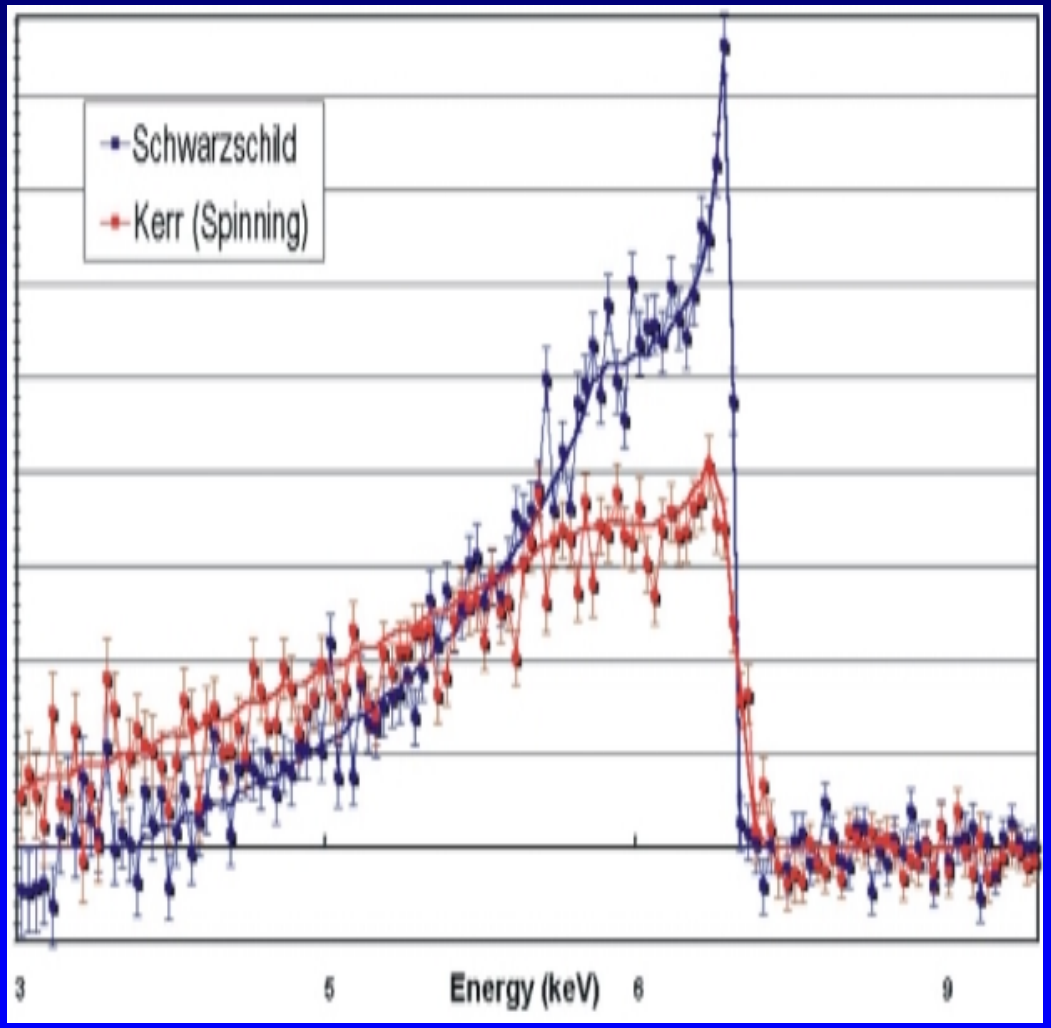


Hard X-rays illuminate ‘cold’ inner accretion disc

Broad Iron Kα seen by Reflection

Tanaka et al. 1995

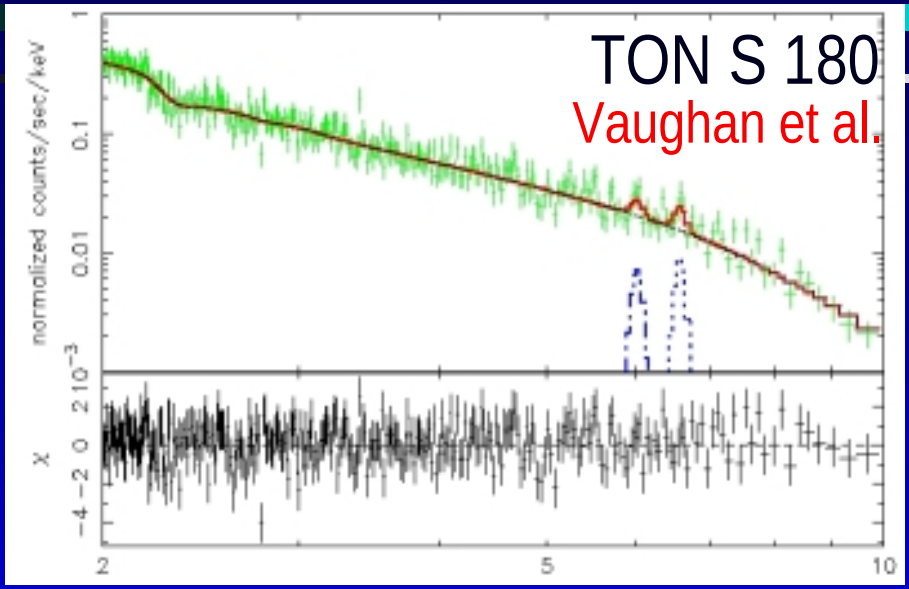
Black hole diagnostics



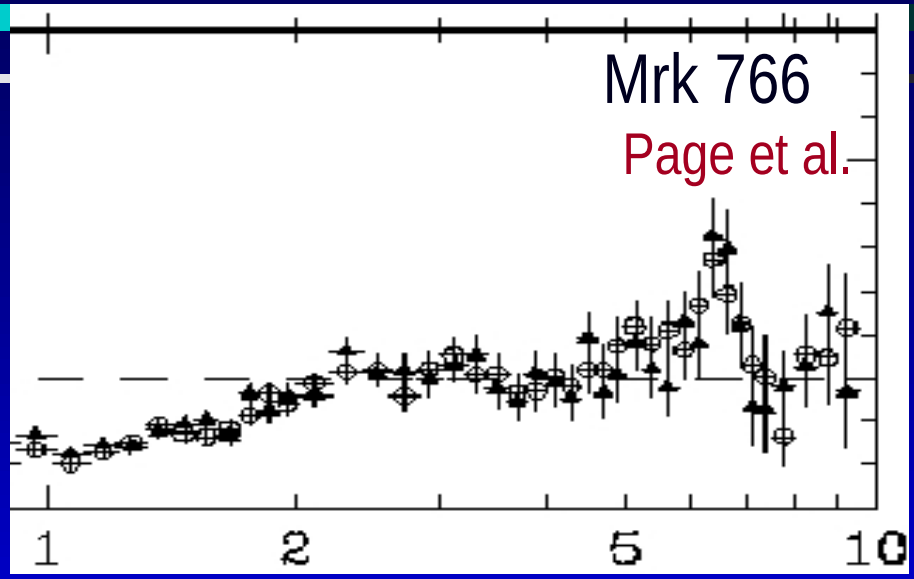
- ASCA showed iron K-lines to be often very broad and redshifted
- Relatively few high SNR profiles
- Some doubts have been raised about data and interpretation

XMM-Newton Fe K line profiles

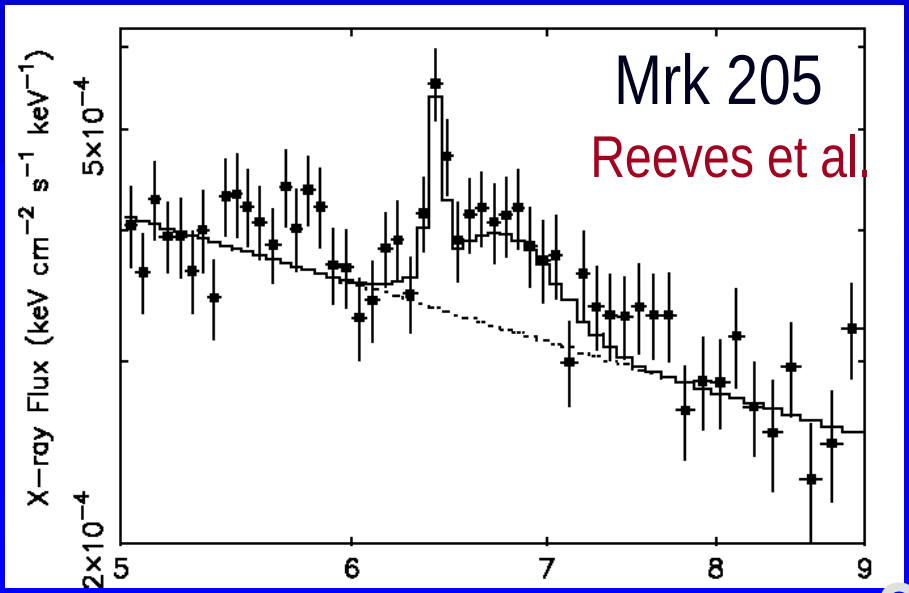
Narrow unresolved Fe K lines



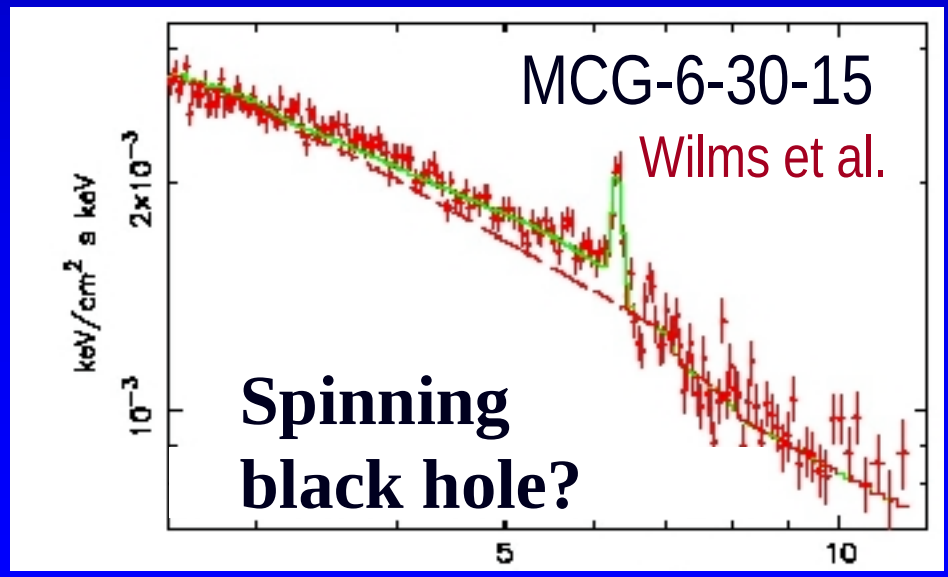
Indications for red wings



Narrow neutral and broad ionized



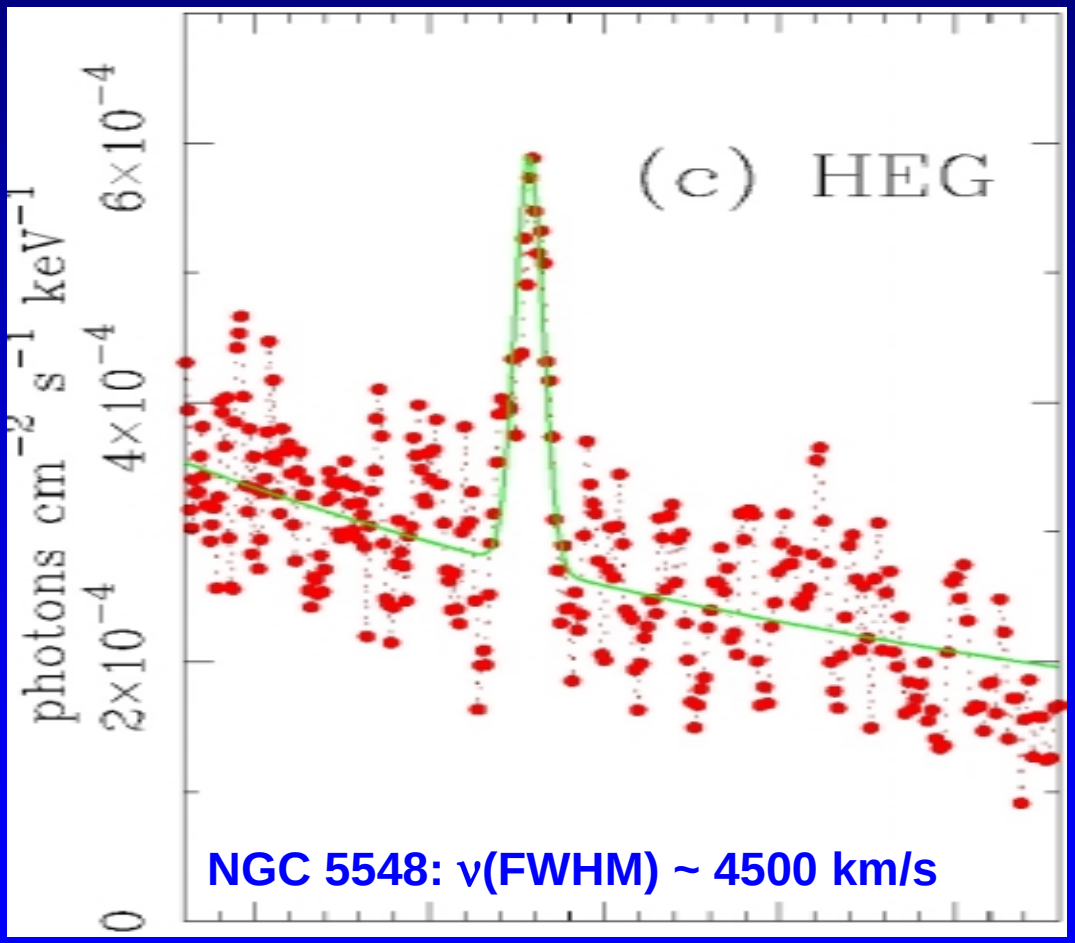
Red wing, above an uncurved continuum

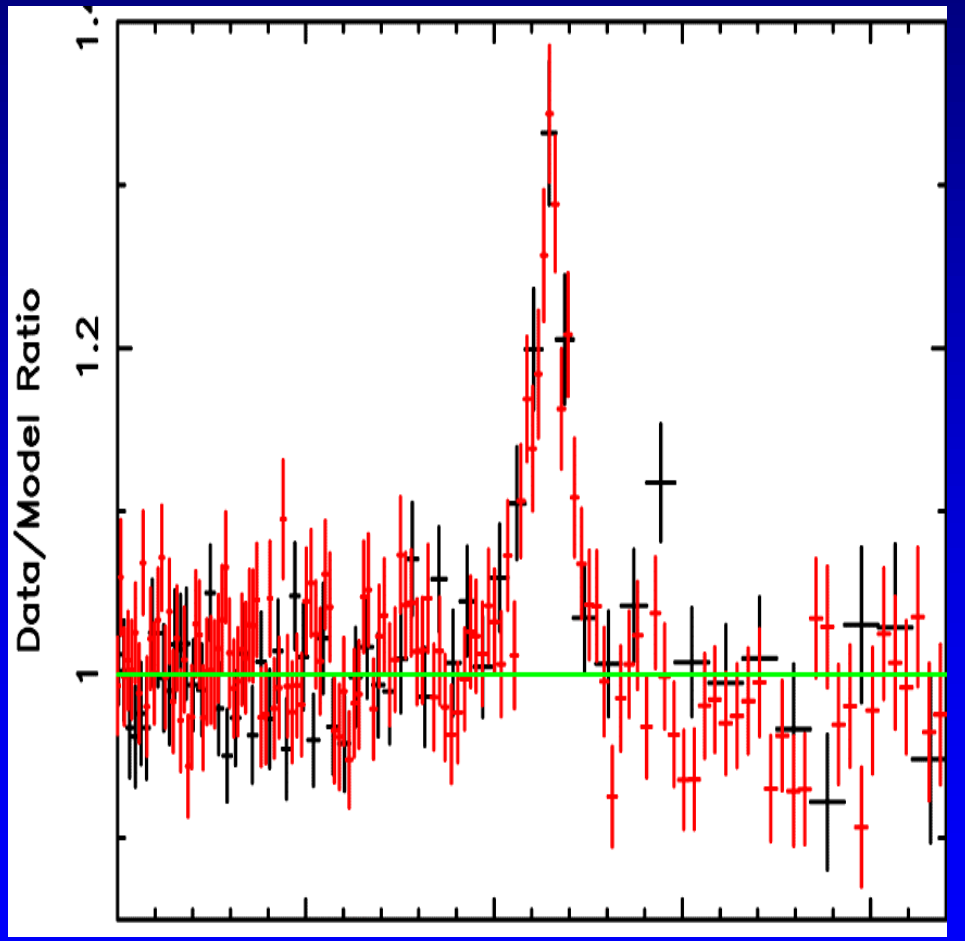


Chandra

Narrow Iron Kα line in NGC 5548

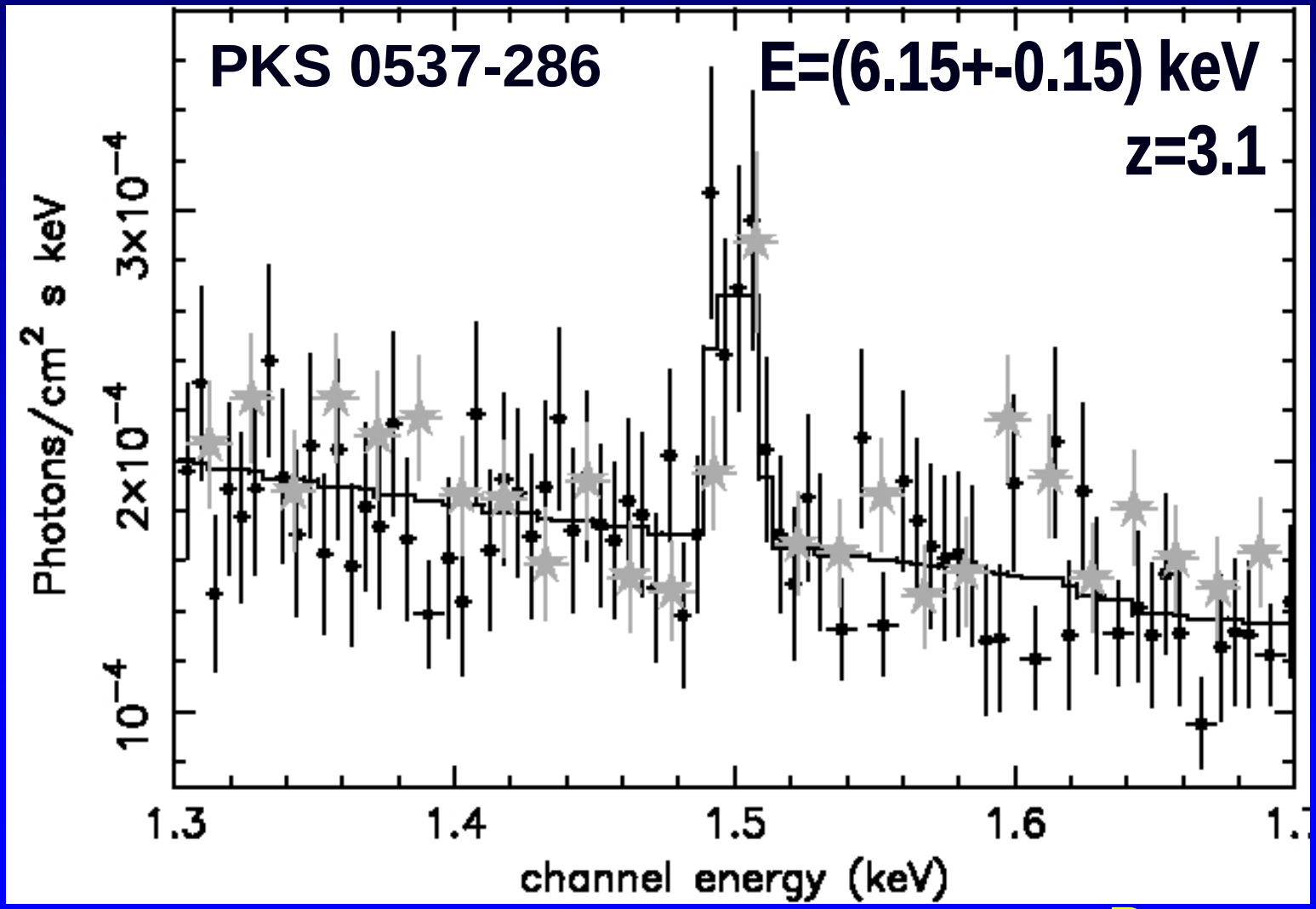
Chandra HETG Yaqoob *et al.* 2001 ***XMM-Newton EPIC***





Fe K line in a high z quasar

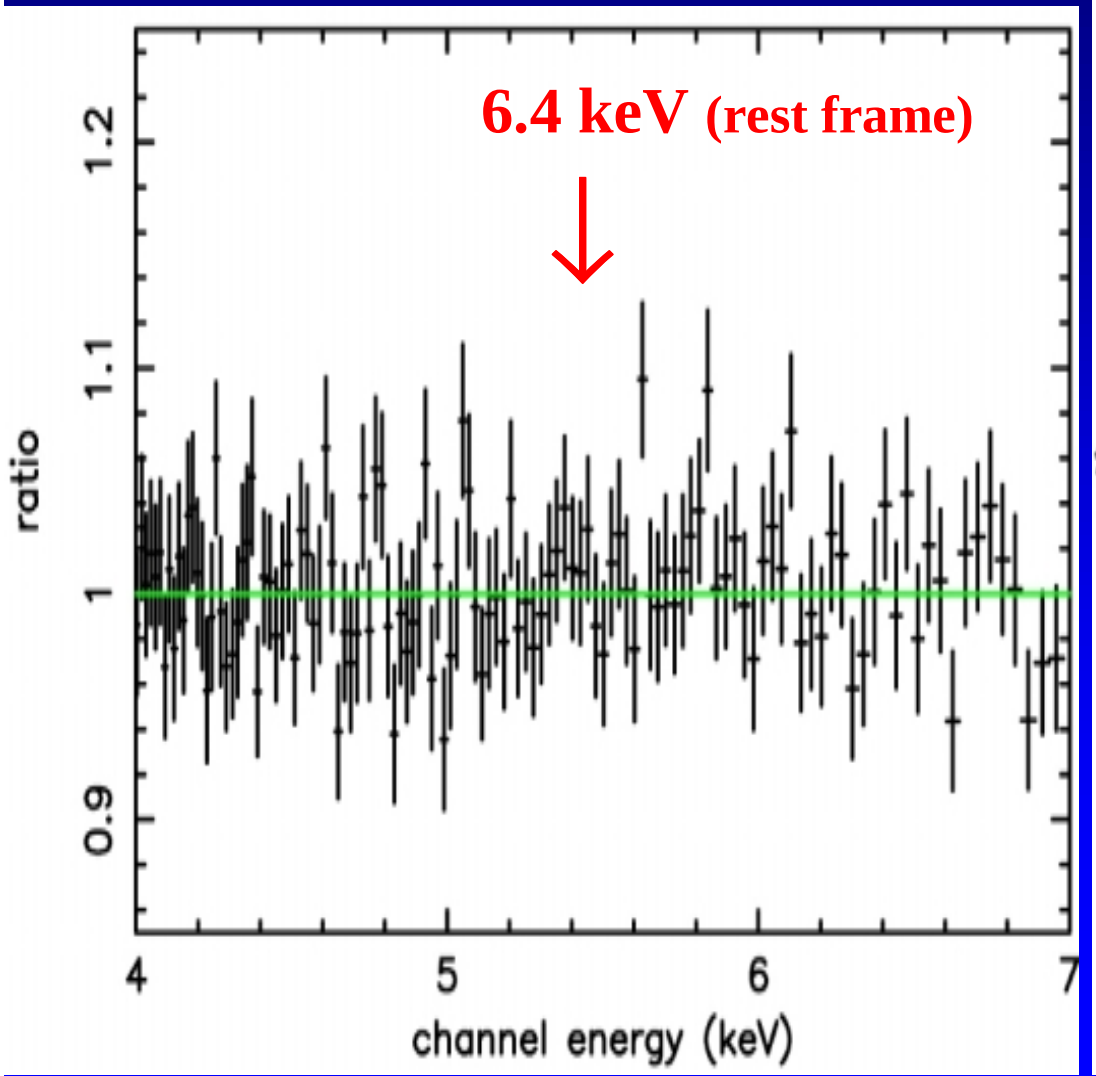
First detection:



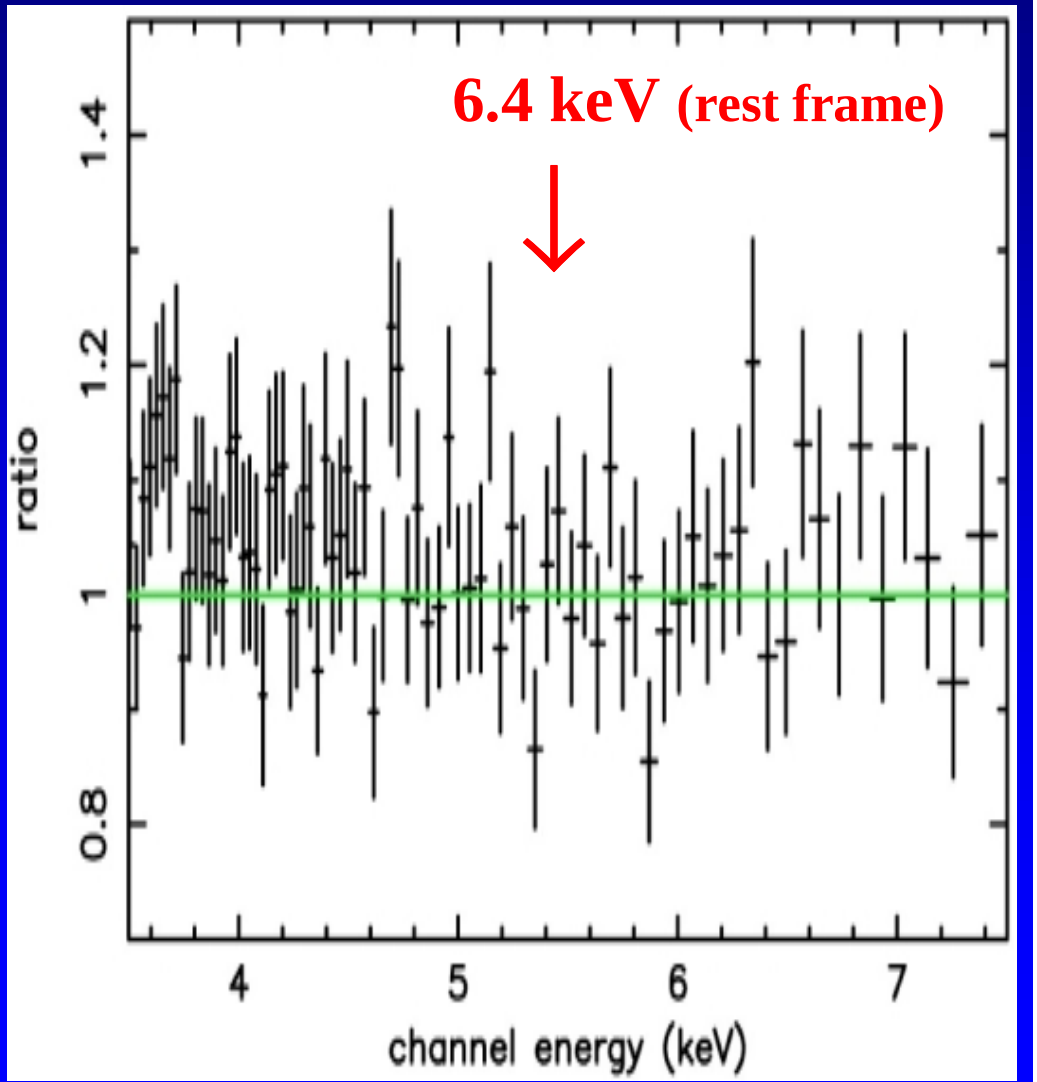
Reeves et al. 2001

Luminous Quasars – No Fe K lines?

3C 273; Iron Kα Line, EW<10eV

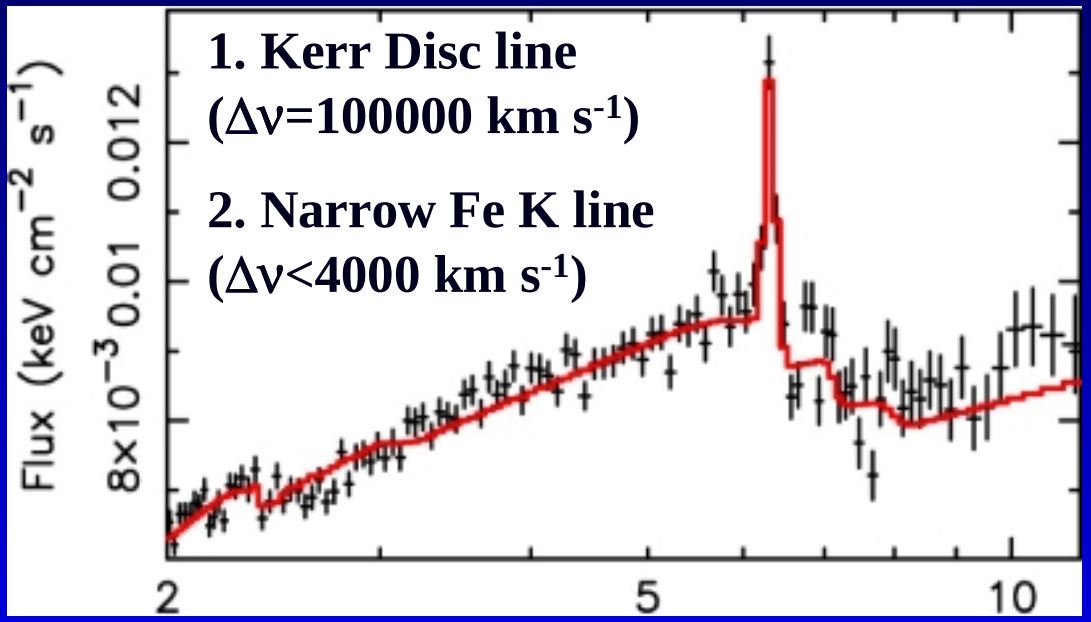


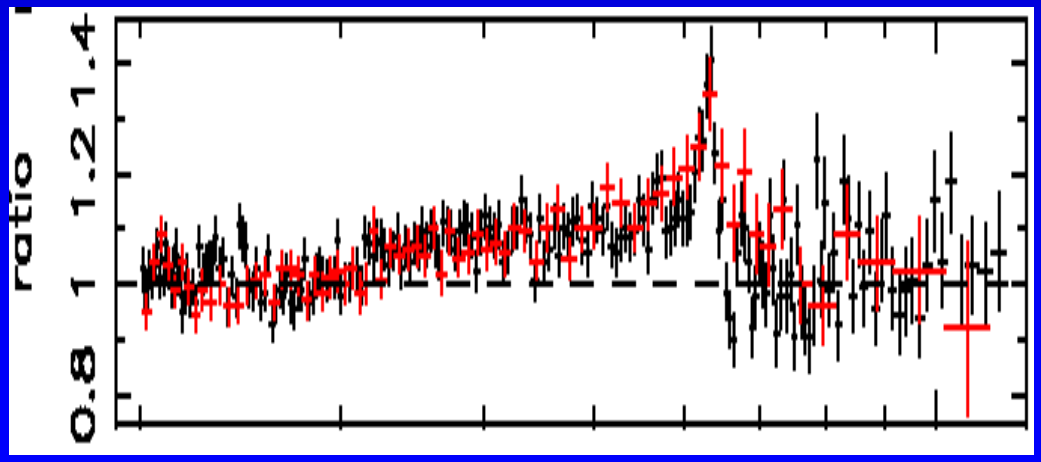
PDS 456; Iron Kα Line, EW<12eV



MCG-6-30-15 – spinning BH?

XMM-Newton EPIC



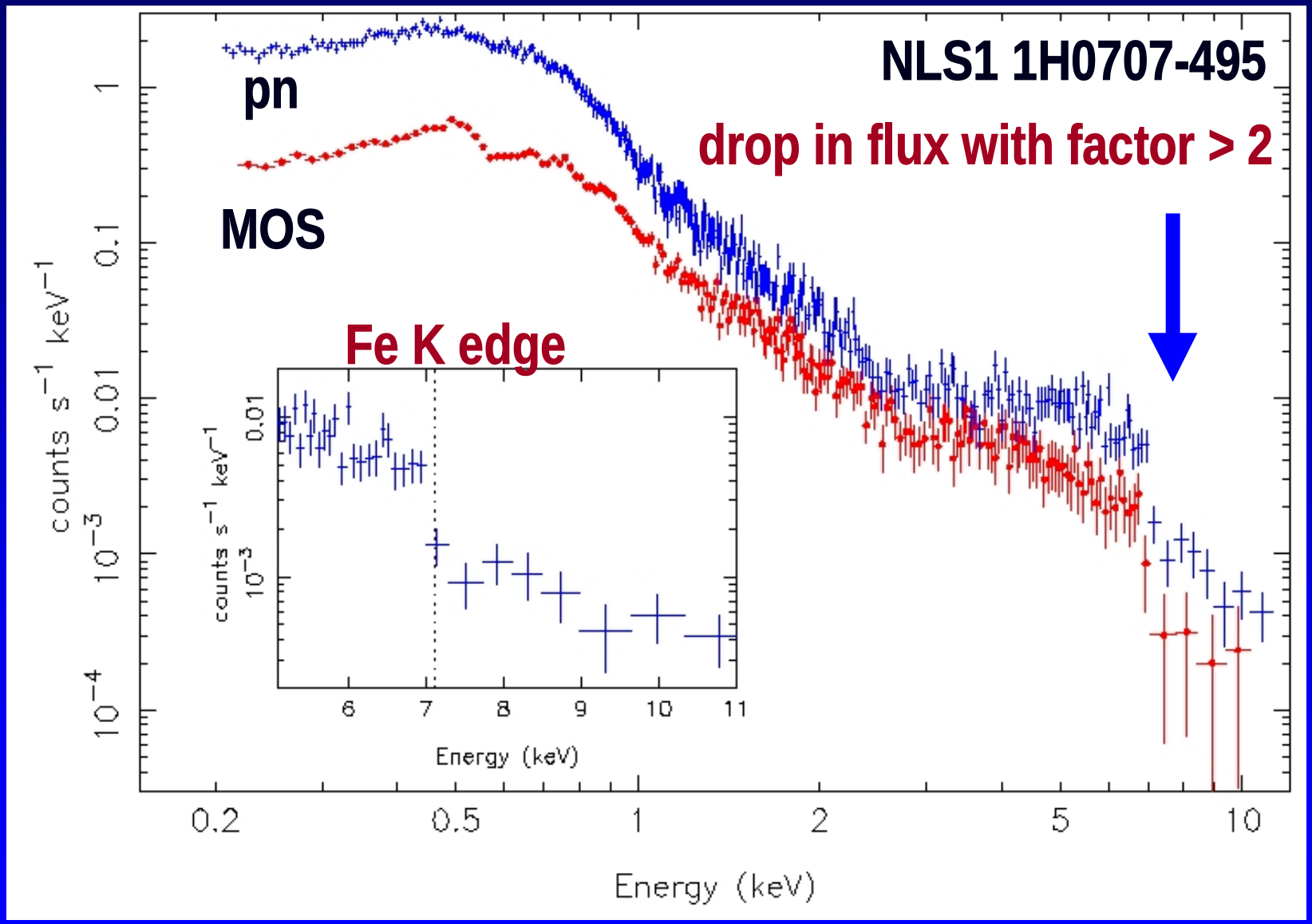


Spinning black hole?

Wilms *et al.* (2001)

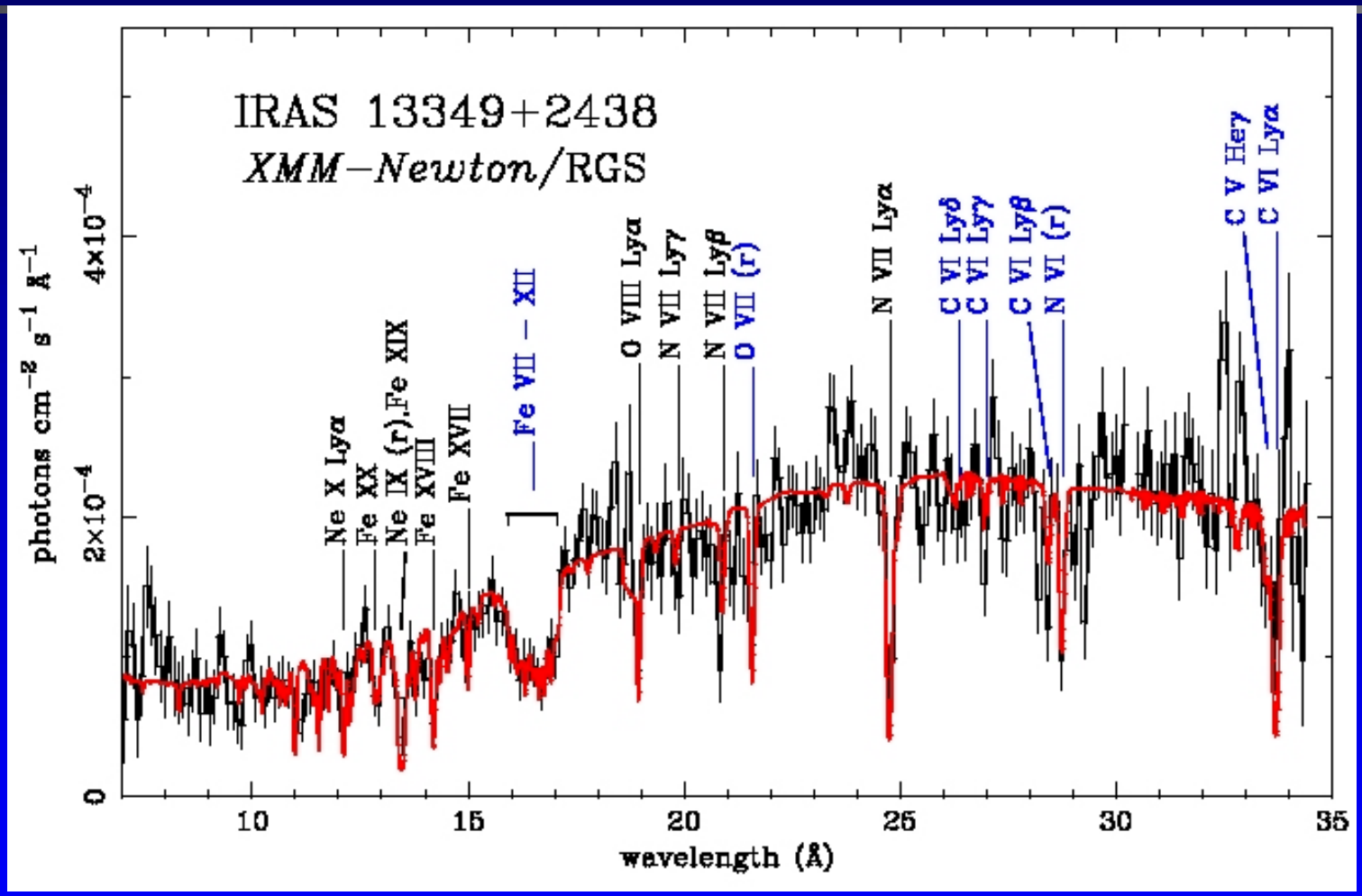
Sharp spectral feature at ~7.1 keV

XMM-Newton



Boller et al. 2002

Complex resonance absorption



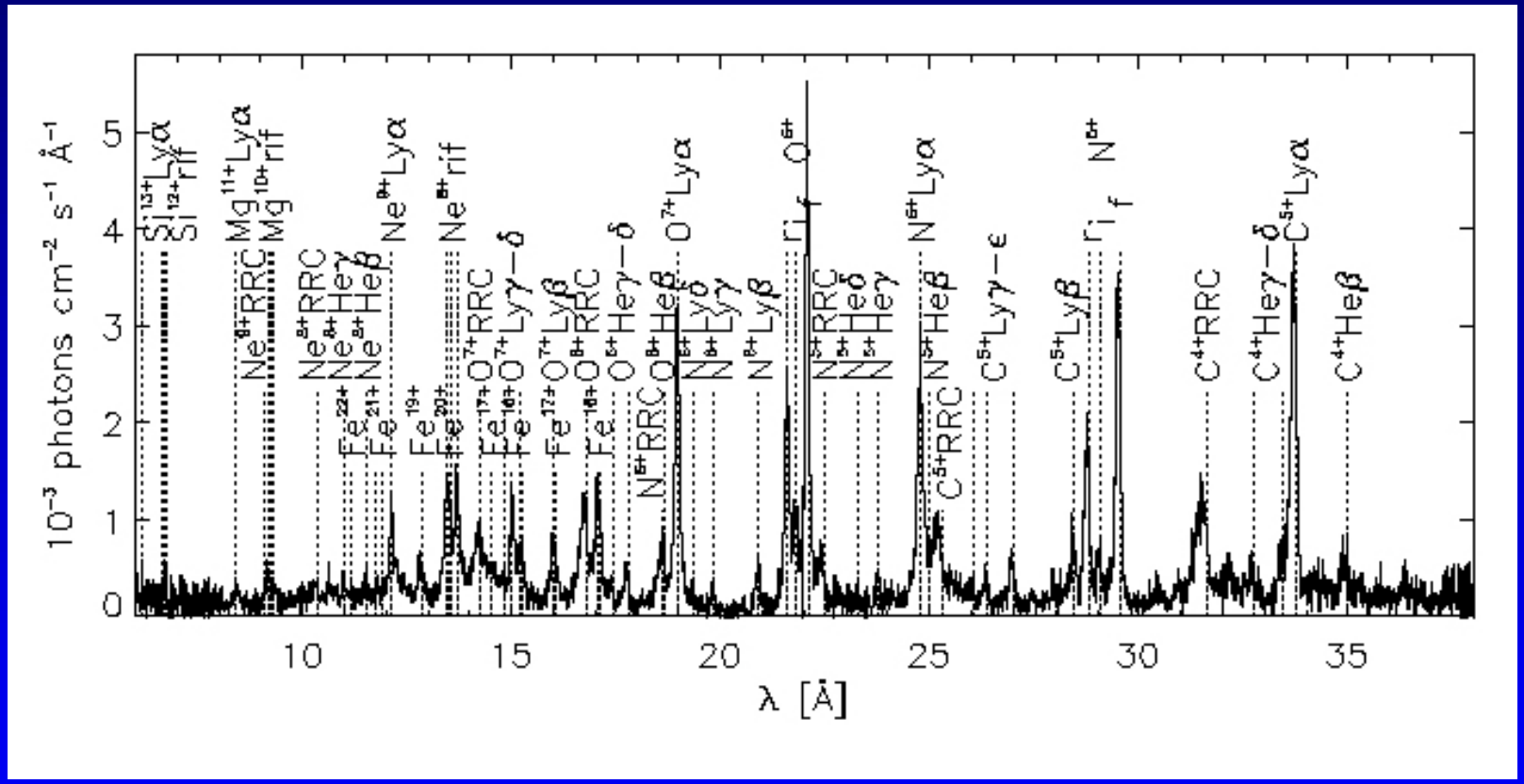
Sato et al. 2001

High/low ionization lines: Ne X, Fe XVII-XX, OVIII, NVII/ Fe VII-XII, CV-VI, OVII

Broad absorption feature between 16-17 A (730-770 eV)

Soft X-ray spectroscopy of AGN

XMM-Newton RGS spectrum of NGC 1068



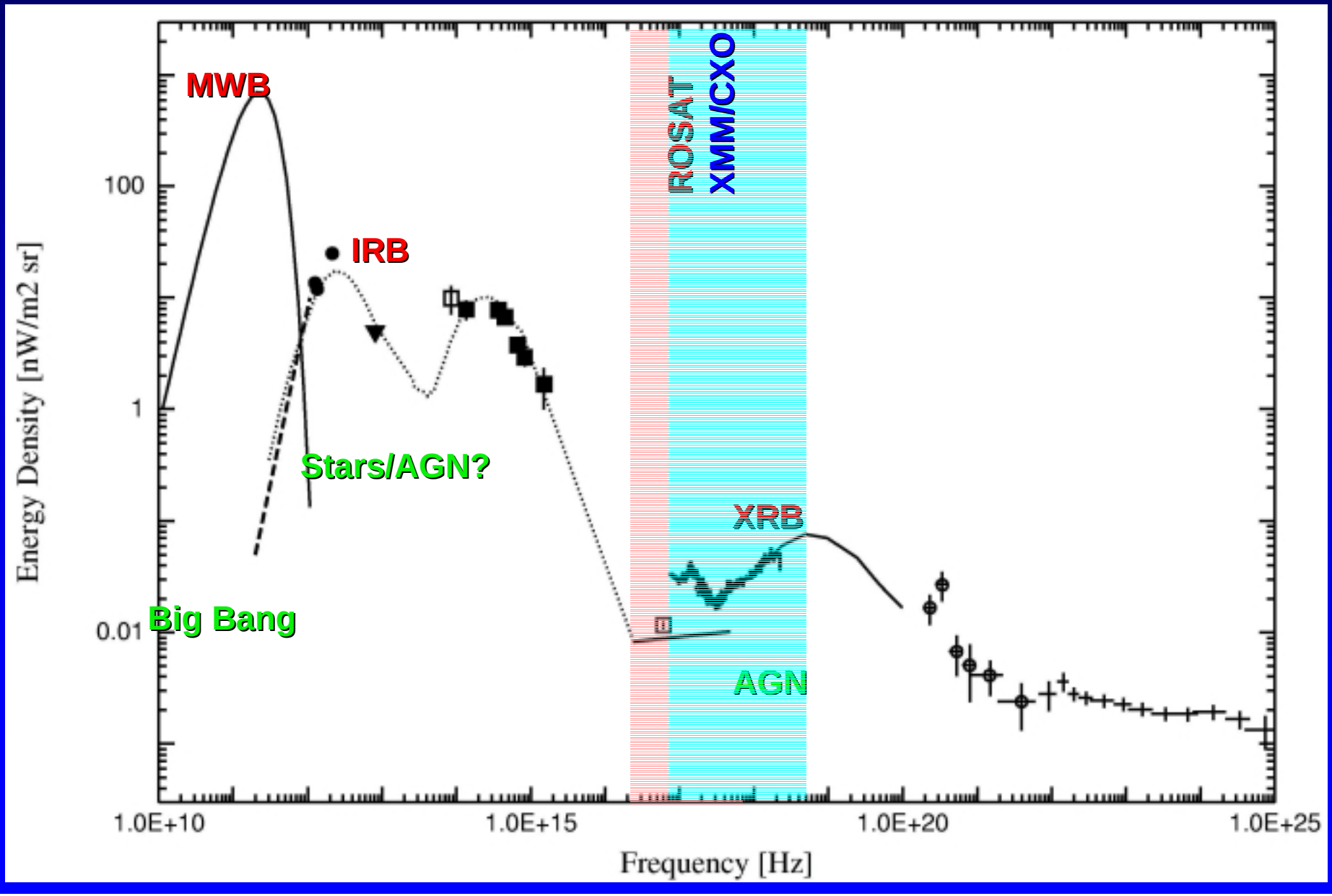
Increasing the number of spectral features from 2-3 to 30-60 !

Kinkhabwala et al. 2001

Similar result from Chandra HETG for NGC 3783 **Kaspi et al. 2000**

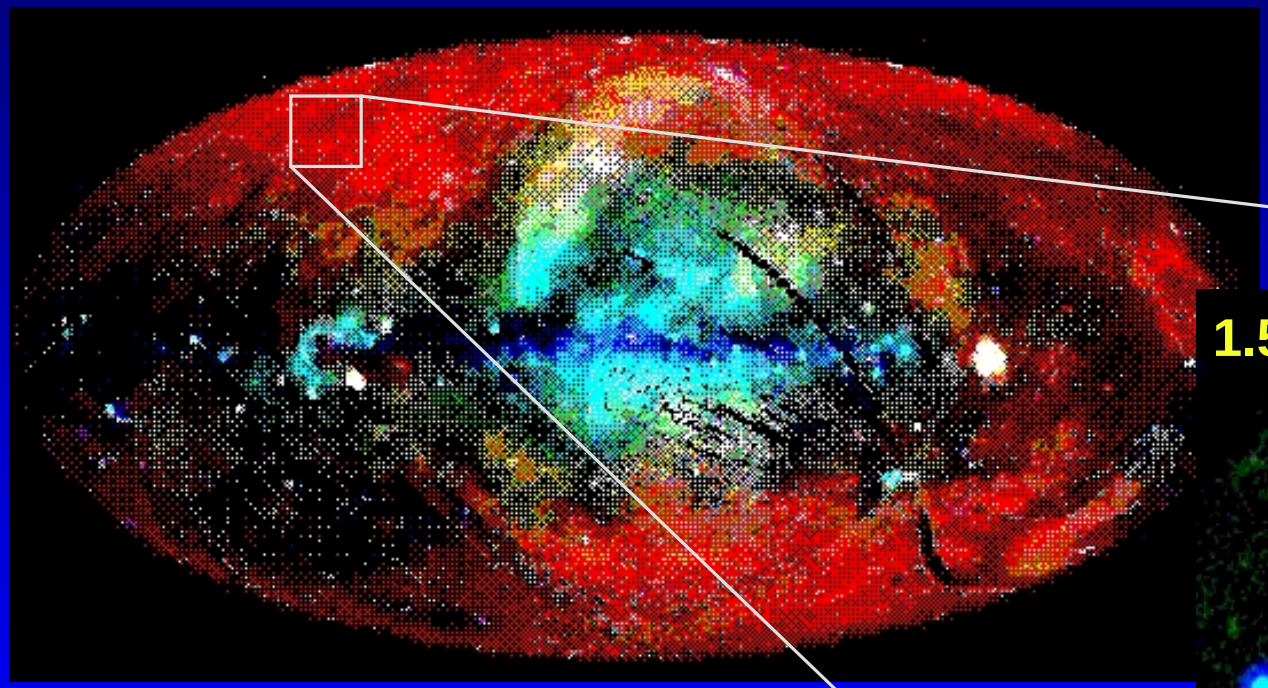
The Cosmis X-ray background – Chandra and XMM-Newton Deep Surveys

Cosmic Energy Density



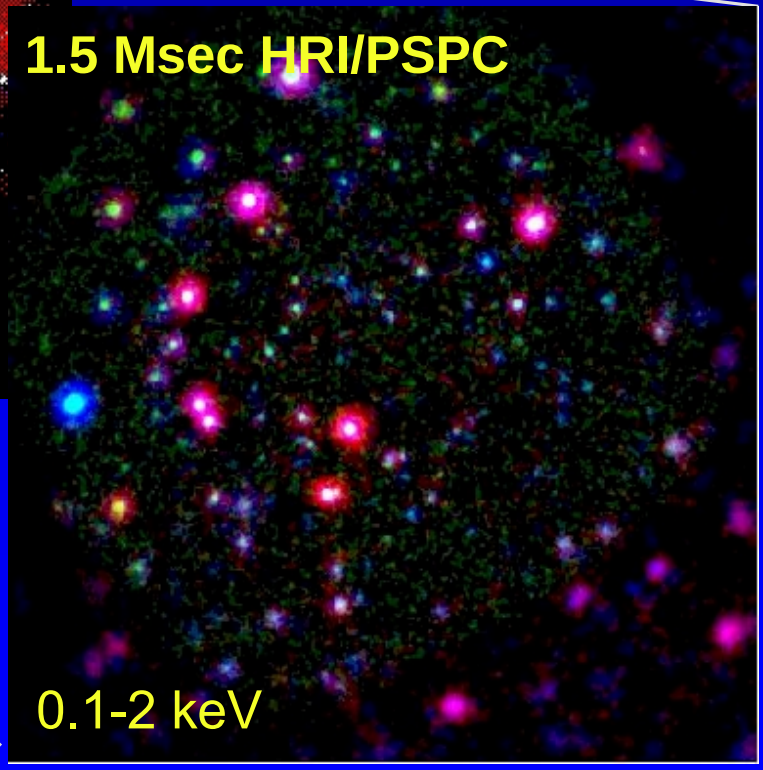
Motivation for Deep Surveys

ROSAT All Sky Survey



Lockman Hole Field

(N_H=5.9 x 10^{19} cm^{-2})

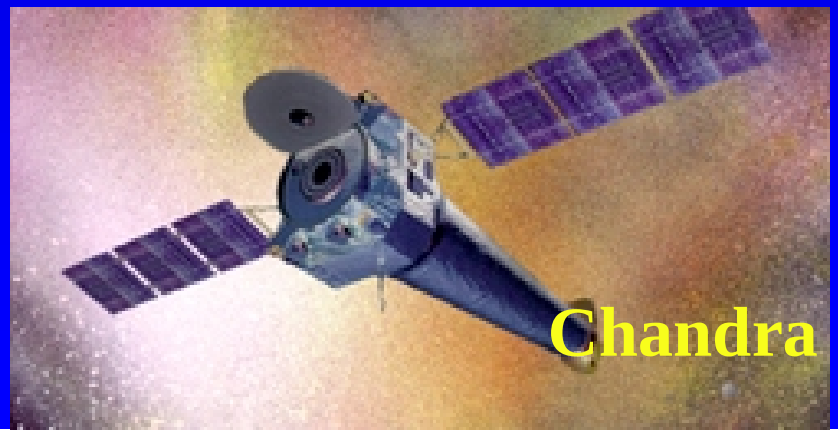


Resolve the XRB!
Nature of the sources?

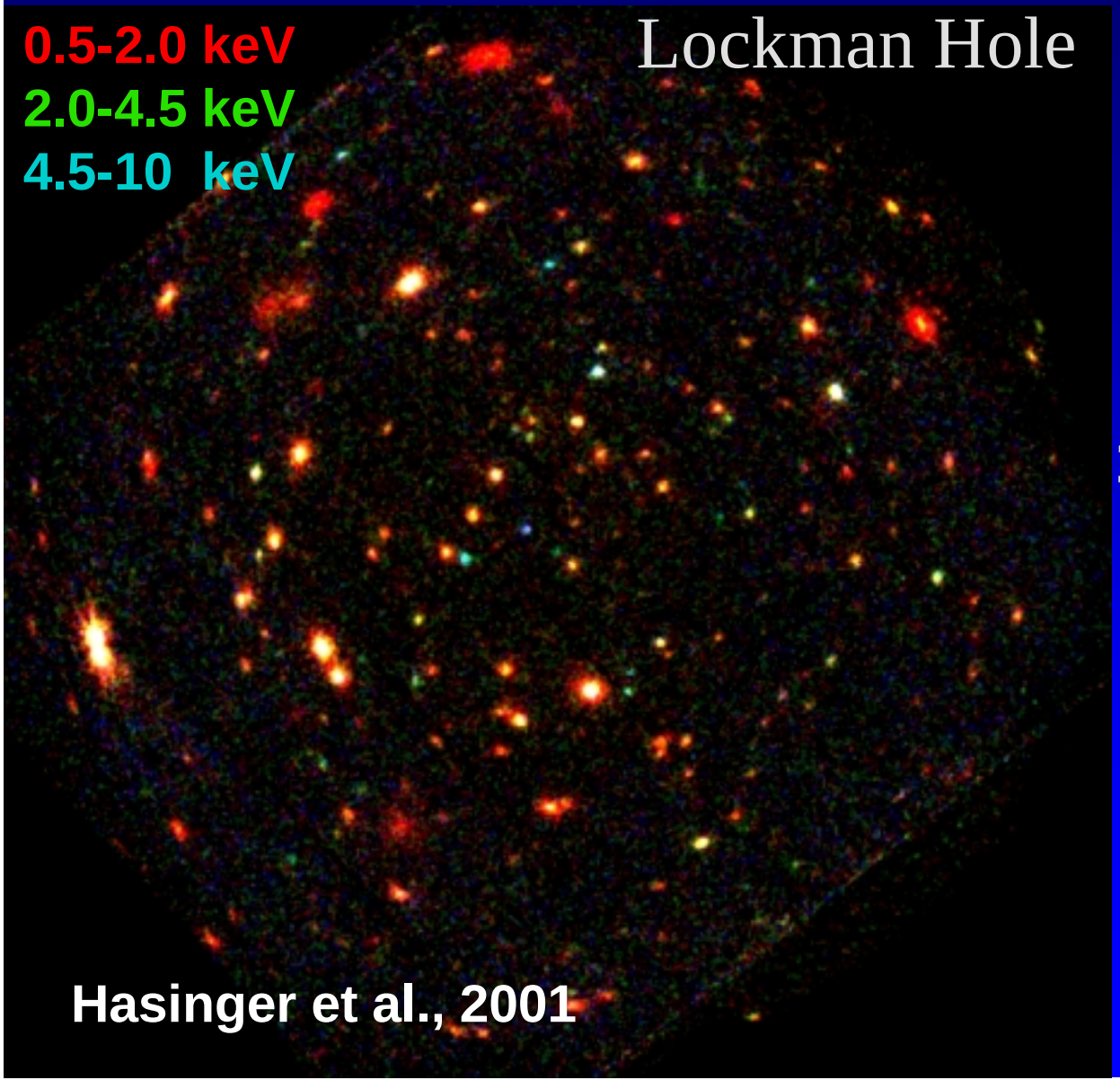
Hasinger et al. 1998, Lehmann et al. 2001

Deep X-ray Surveys

Survey	N/S	AXAF	XMM	ASCA SAX	ROSAT	HST	ISO	SIRTF (plan)	SCUBA	RADIO	PI
CDFS	**S/N**	X	X			X		X		X	**Giacconi**
HDF-N	N	X	X		X	X	X	X	X	X	Garmire
Lockman	**N**	X	X	X	X	X	X	X	X	X	**Hasinger/Murray**
Lynx3.A	N	X	X	X	X	X				X	Stanford
ELAIS N1	N	X	X				X		X		Almaini
Hawaii 13h	N	X			X	X	X	X	X	X	Mushotzky
UKDS	N		X		X	X		X		X	Mason
CFRS	N/S		X			X			X	X	
SUBARU	S/N		X								Watson
Groth strip	N		X		X	X		X		X	Griffiths
Marano	S		X	X	X	X	X			X	Zamorani
SA 57	N				X		X				Miyaji



XMM-Newton Deep Survey



Soft/Hard and Ultrahard samples

↓

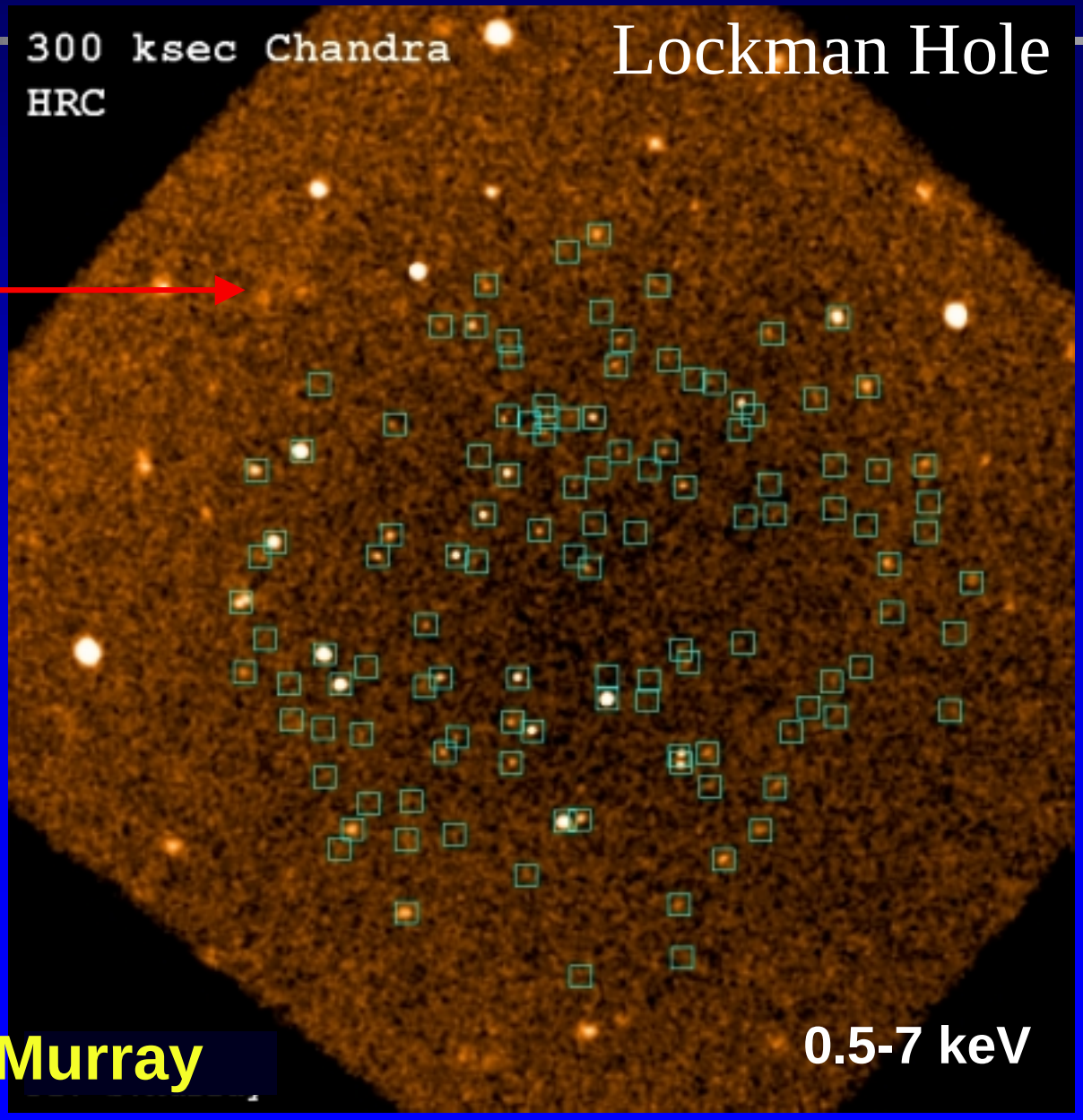
106 sources: $3.8*10^{-16}$ cgs

69 sources: $2.1*10^{-15}$ cgs

34 sources: $3.2*10^{-15}$ cgs

→ **12 / 7 sources not detected in the soft band**

300 ksec Chandra HRC



High-z cluster

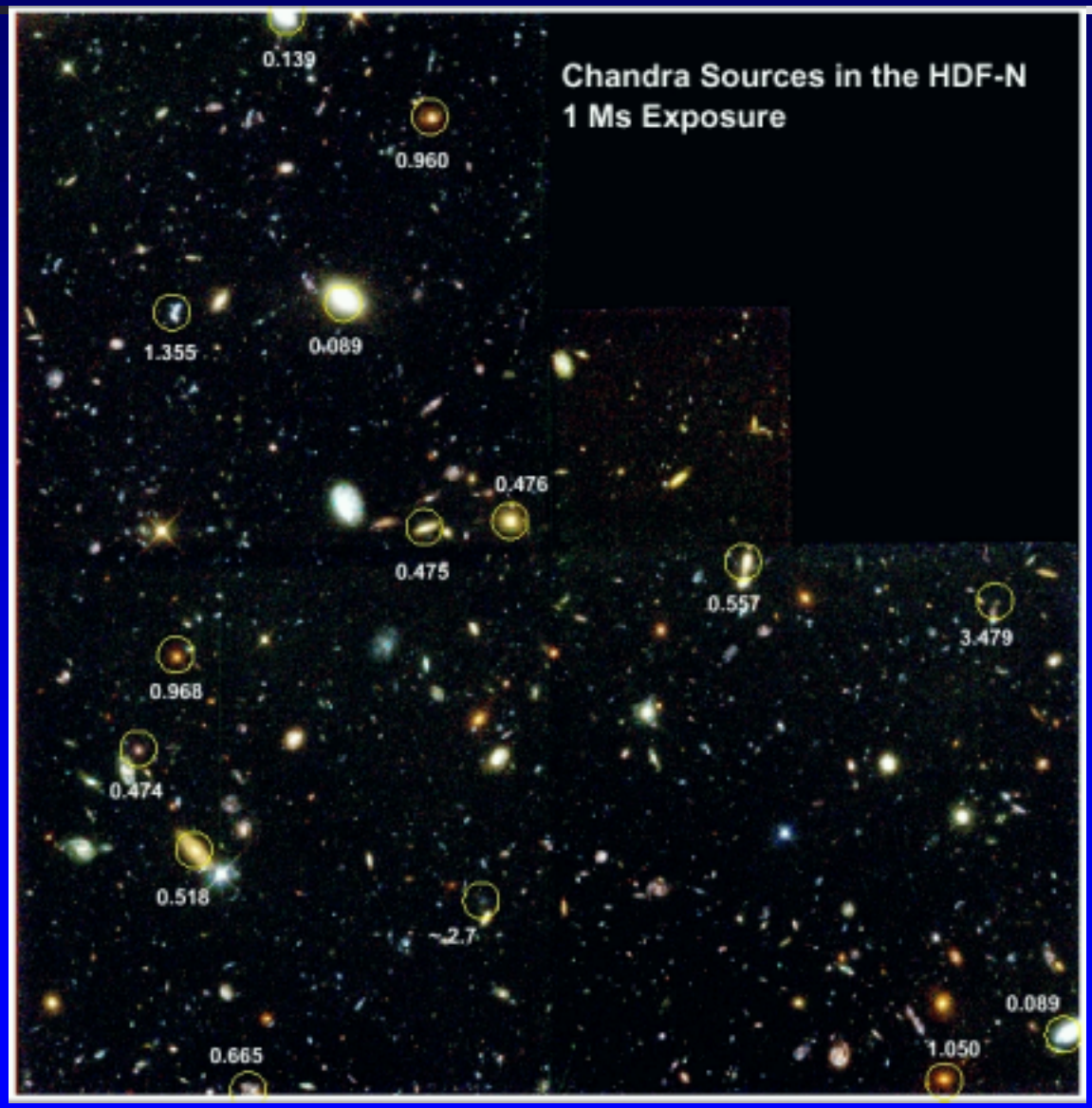
Similar 0.5-2.0 keV flux limit

Extremely accurate postions

XMM sources overplotted

PI: Steve Murray

Hubble Deep Field-North



Brandt et al. 2001, Hornschemeier et al. 2001

2 Msec exposure

400 detected sources

population of relatively normal galaxies detected

Two classes:

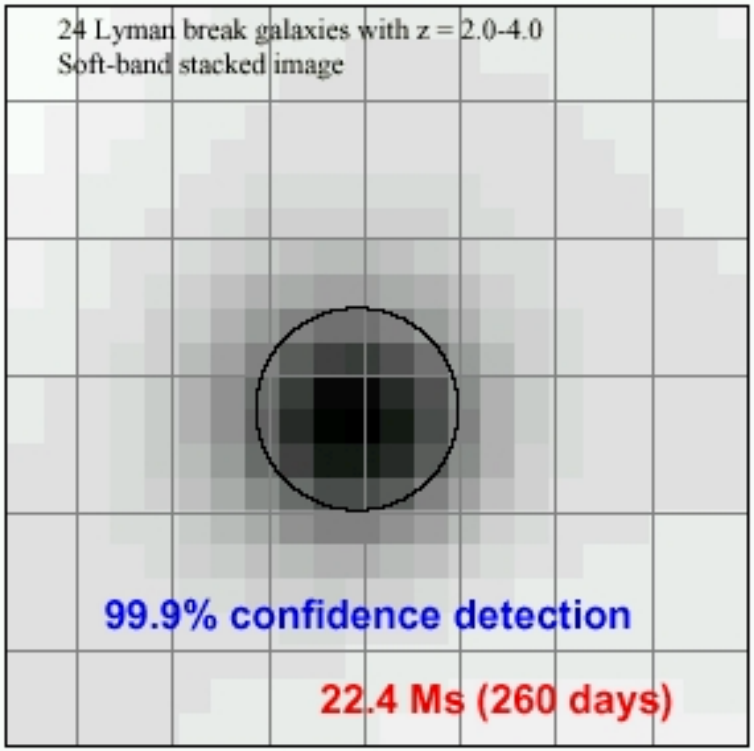
- obscured AGN
- relatively normal elliptical galaxies at z~1

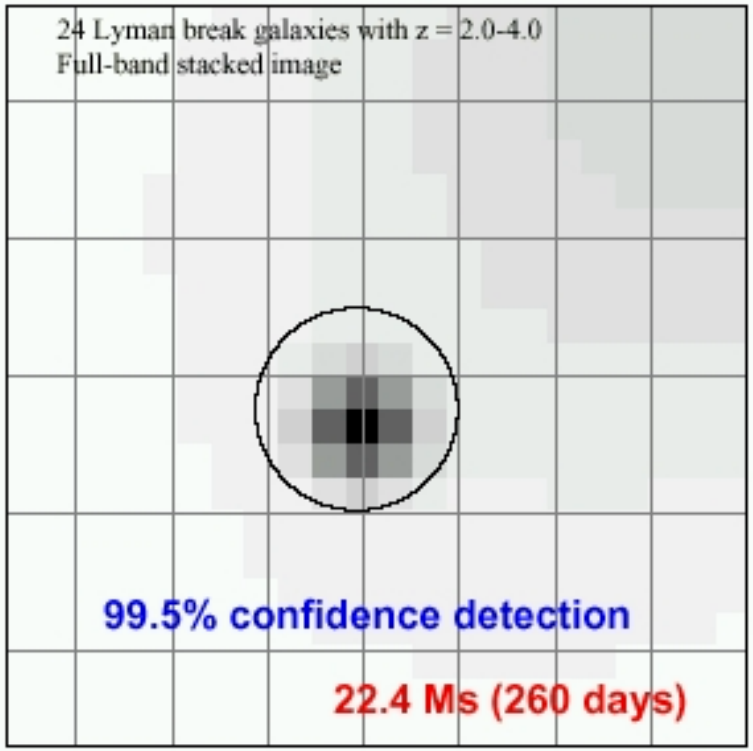
excellent correlation between X-ray sources and ISO sources

Detection of high-z galaxies

Stacked Lyman Break Galaxy Images

Star-formation rates ~ 30-50 solar masses / year +





4×10^{-18} erg cm^{-2} s^{-1}

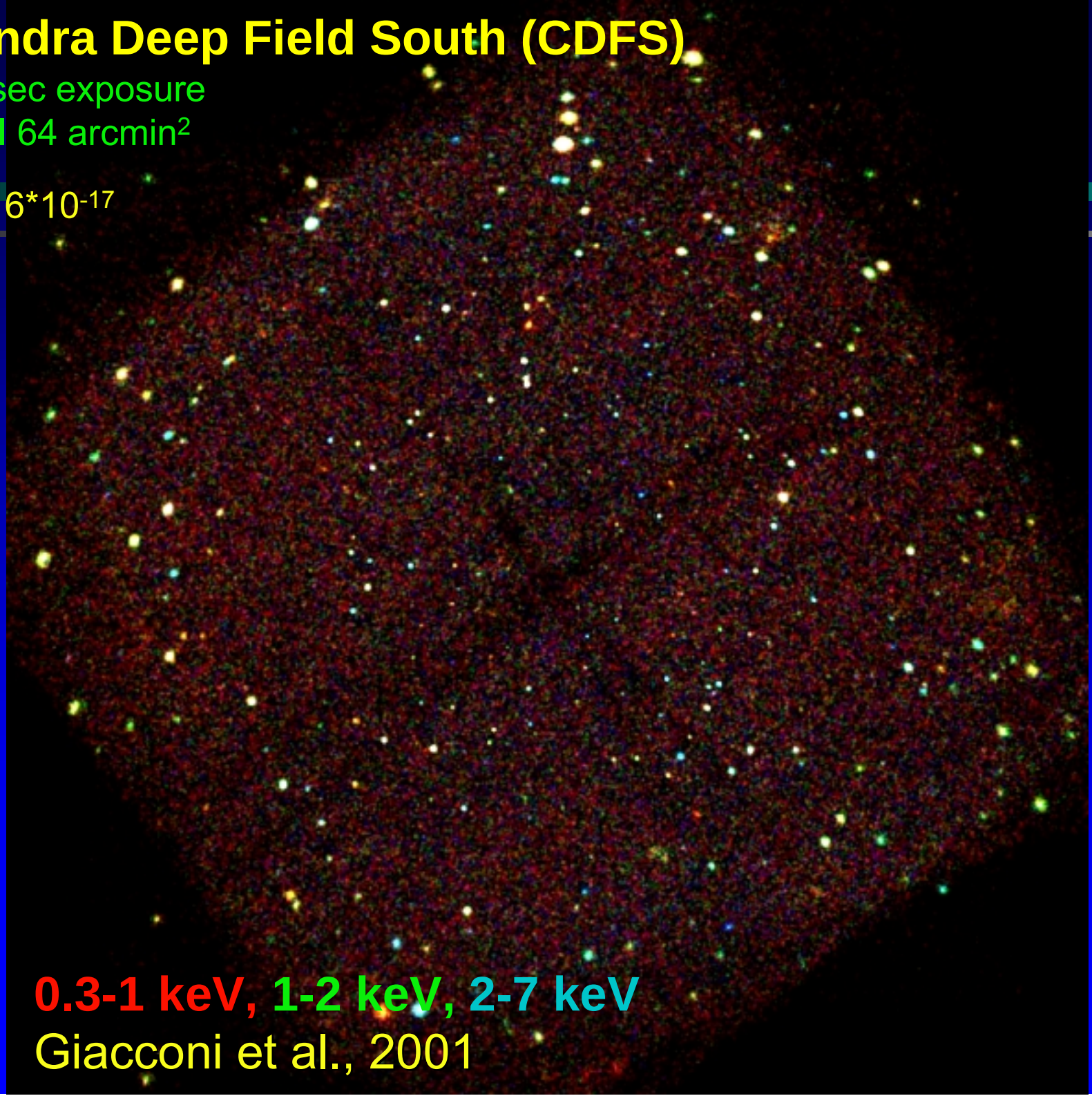
Brandt et al. 2001

Chandra Deep Field South (CDFS)

940 ksec exposure

ACIS-I 64 arcmin^2

$S_{min} = 6*10^{-17}$

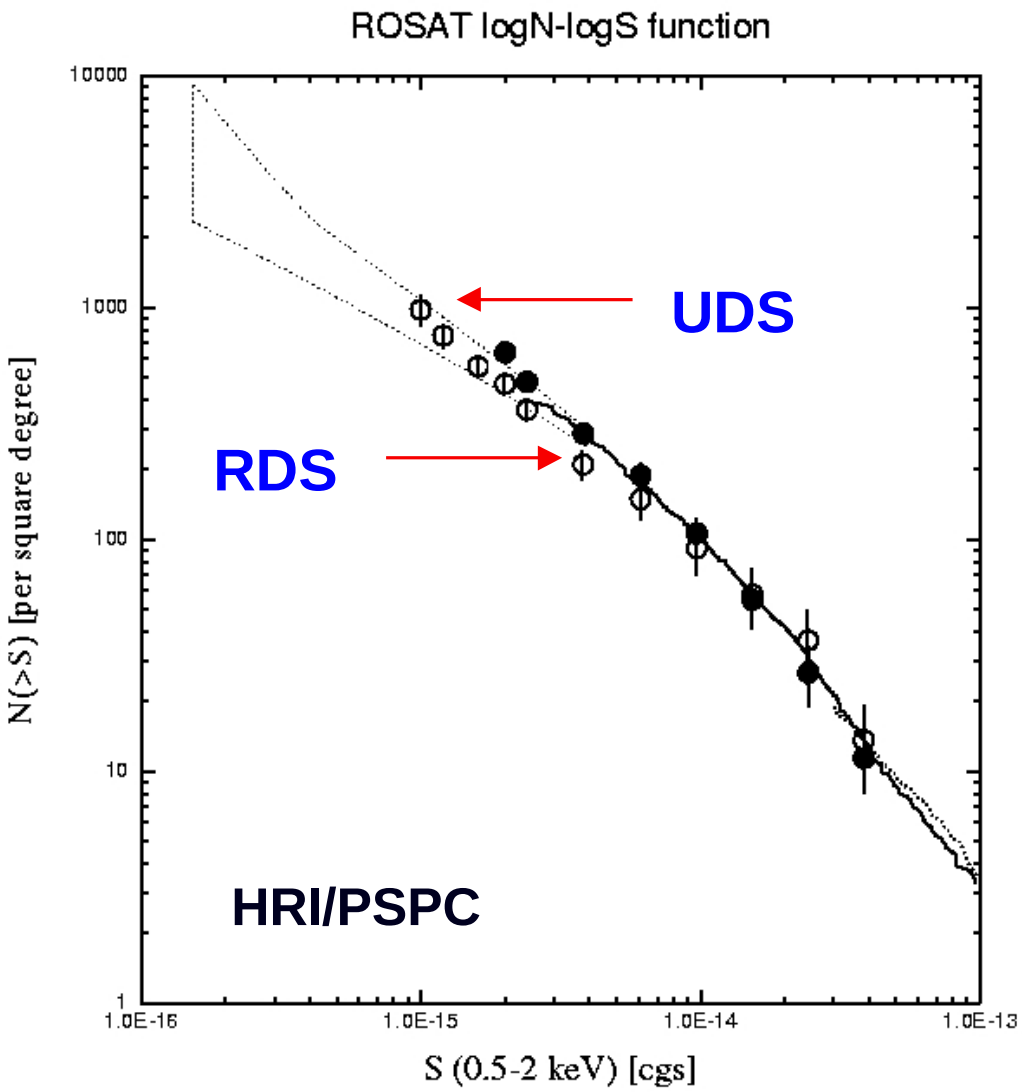


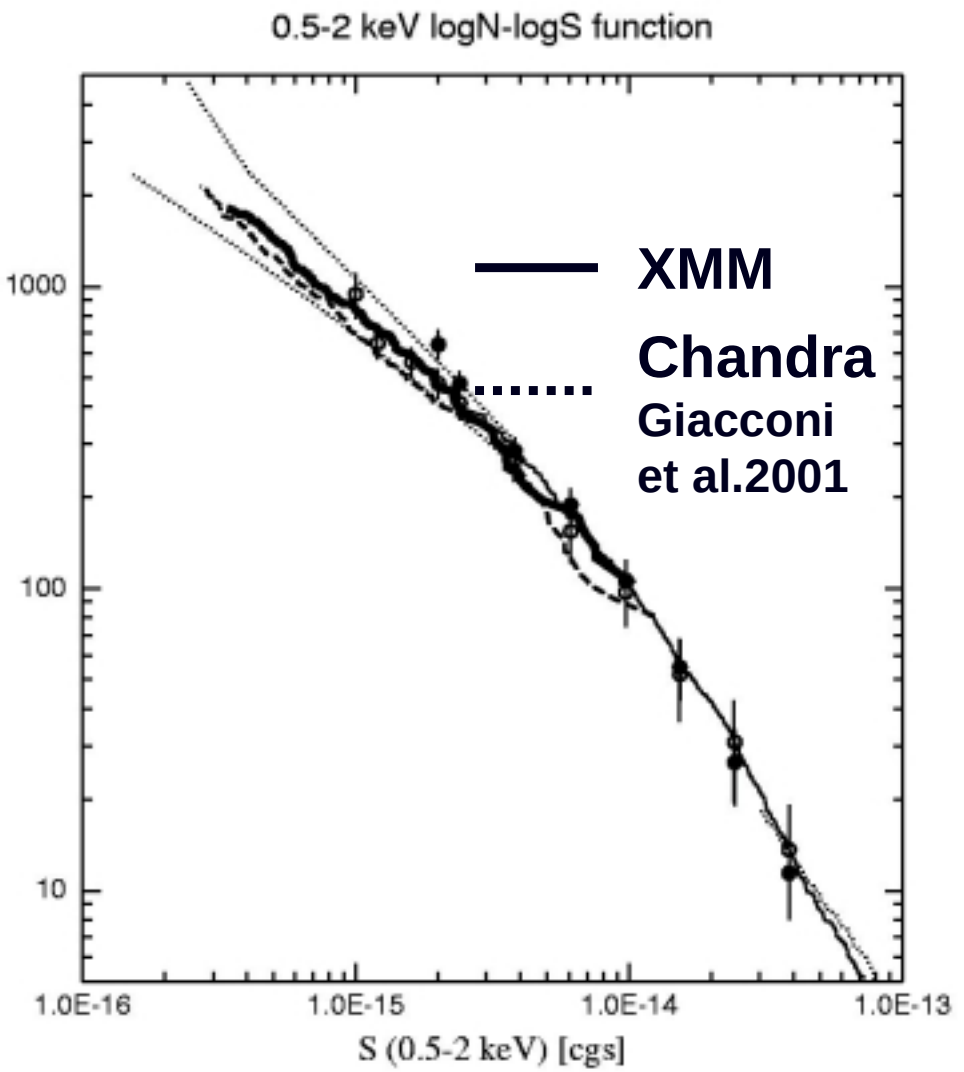
0.3-1 keV, 1-2 keV, 2-7 keV

Giacconi et al., 2001

Giacconi
Bergeron
Borgani
Chen
Gilli
Gilmozzi
Hasinger
Lehmann
Kellermann
Kewley
Nonino
Norman
Rosati
Schreier
Szokoly
Tozzi
Zheng

Soft logN-logS (0.5-2 keV)

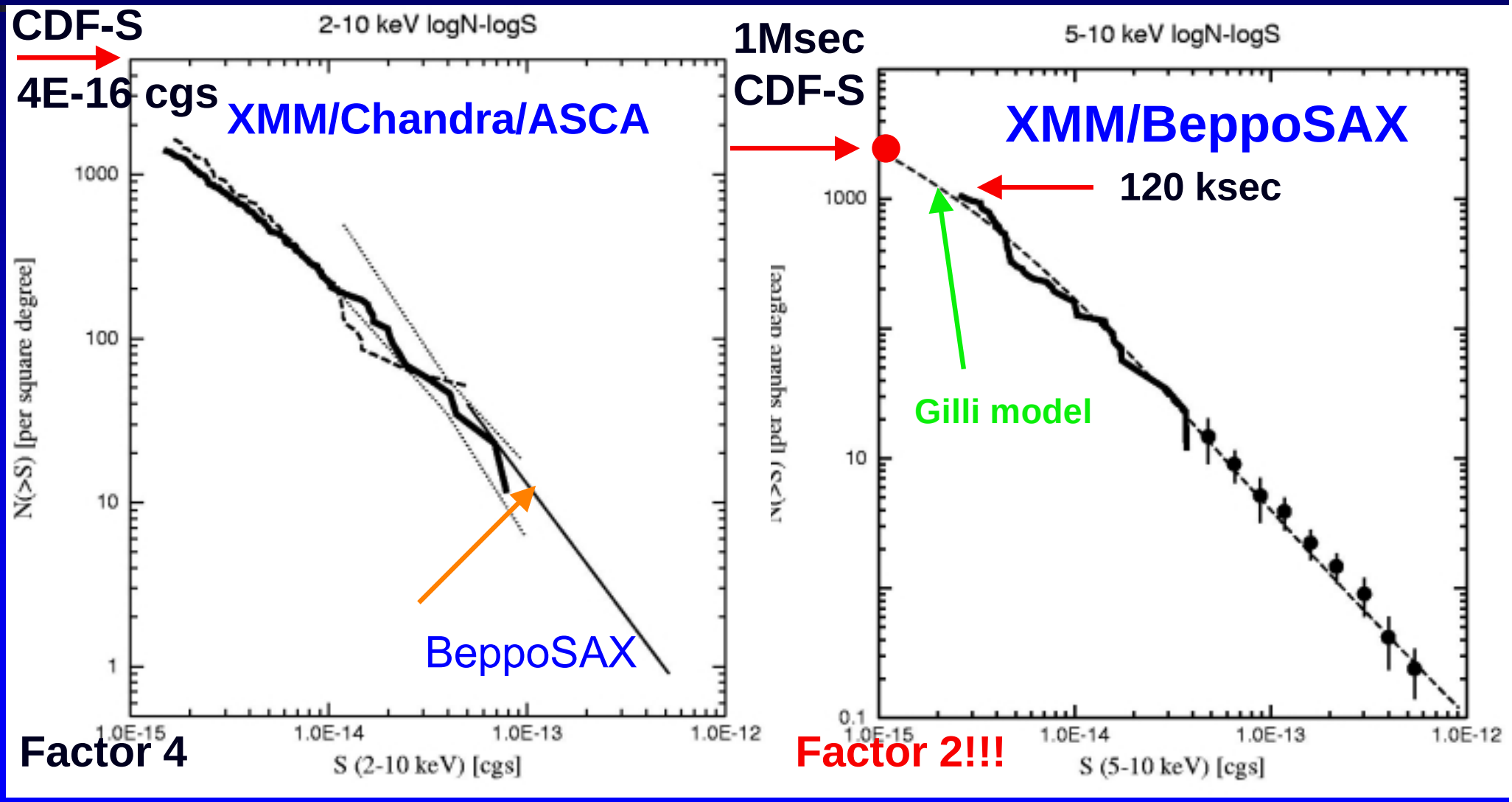




Hasinger et al. 1998

70-80% of the 0.5-2.0 keV XRB !

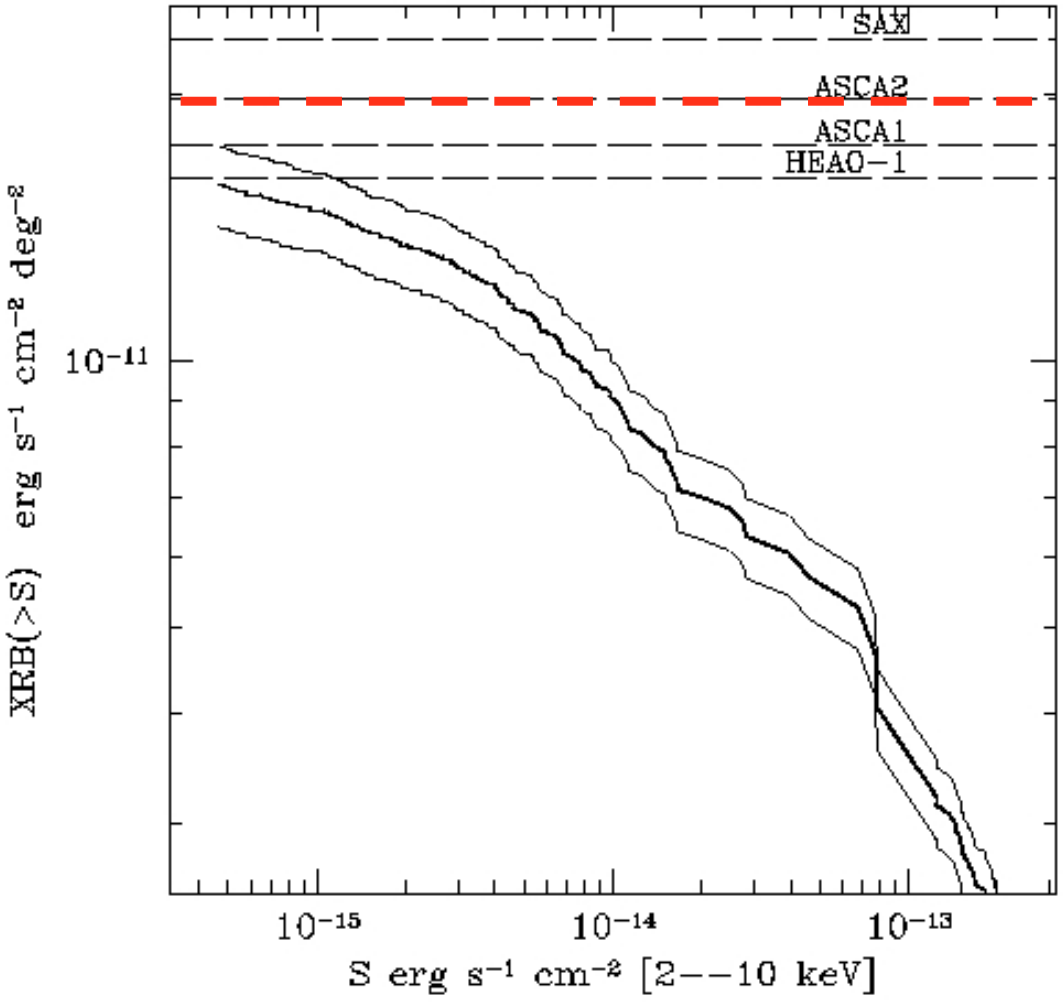
Hard logN-logS (2/5-10 keV)

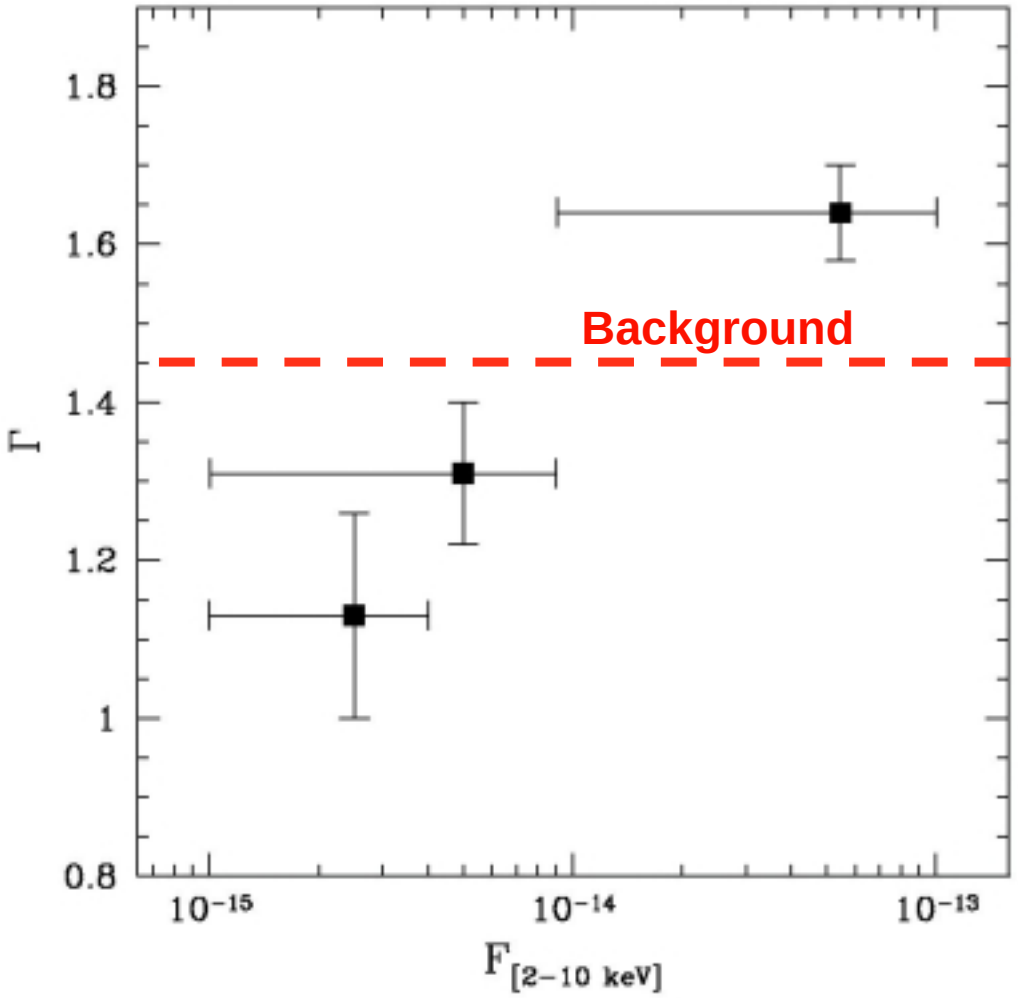


Hasinger et al., 2001
Tozzi et al. 2001

~60% of the 5-10 keV XRB!

Contribution to XRB (CDFS)





70-100% resolved with the right spectral shape!

... but uncertainty lies in the absolute background flux

LH Optical/NIR coverage

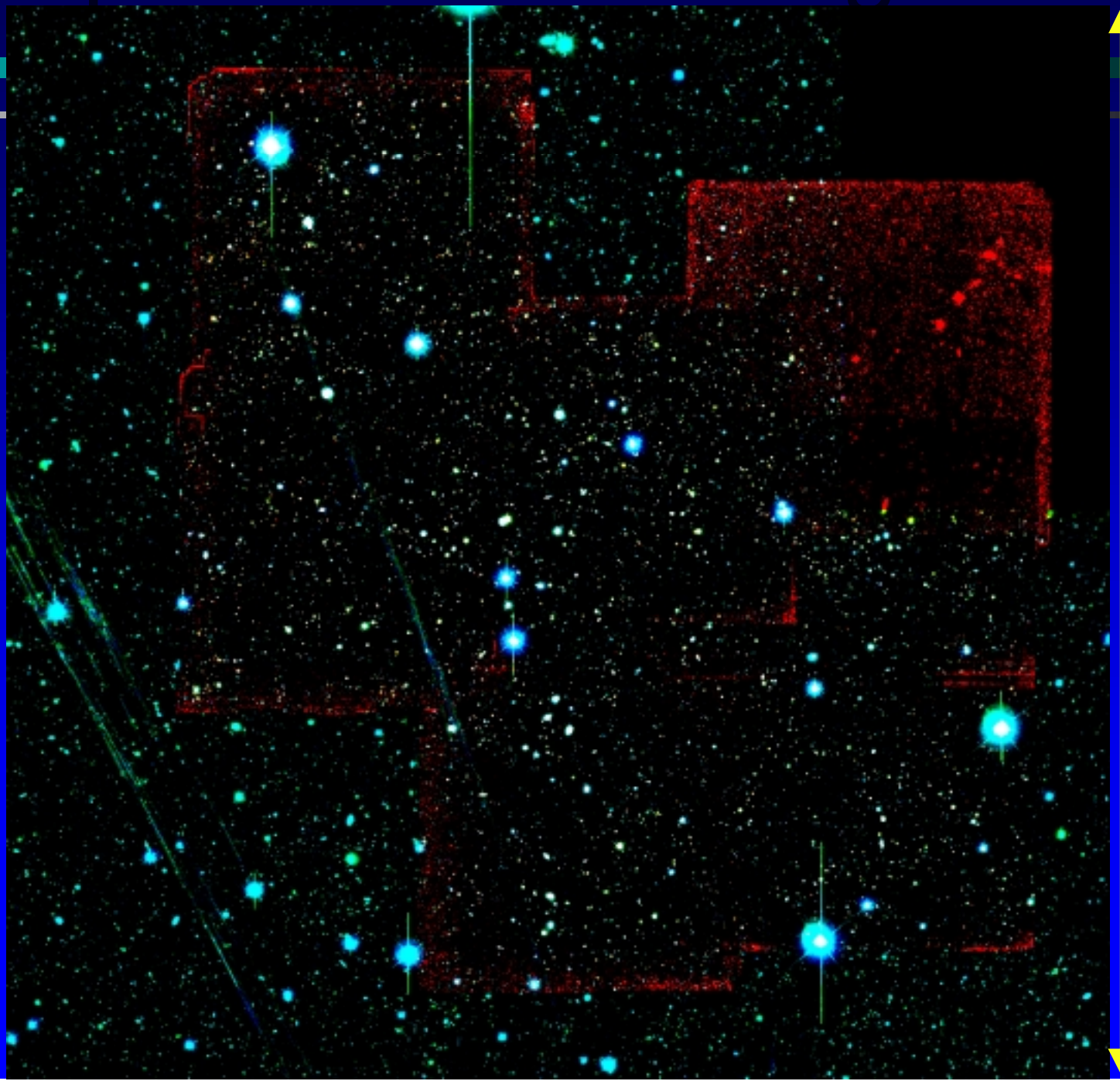
V, I: UH 8K
< 25.5 mag*

R: Keck LRIS
< 25 mag

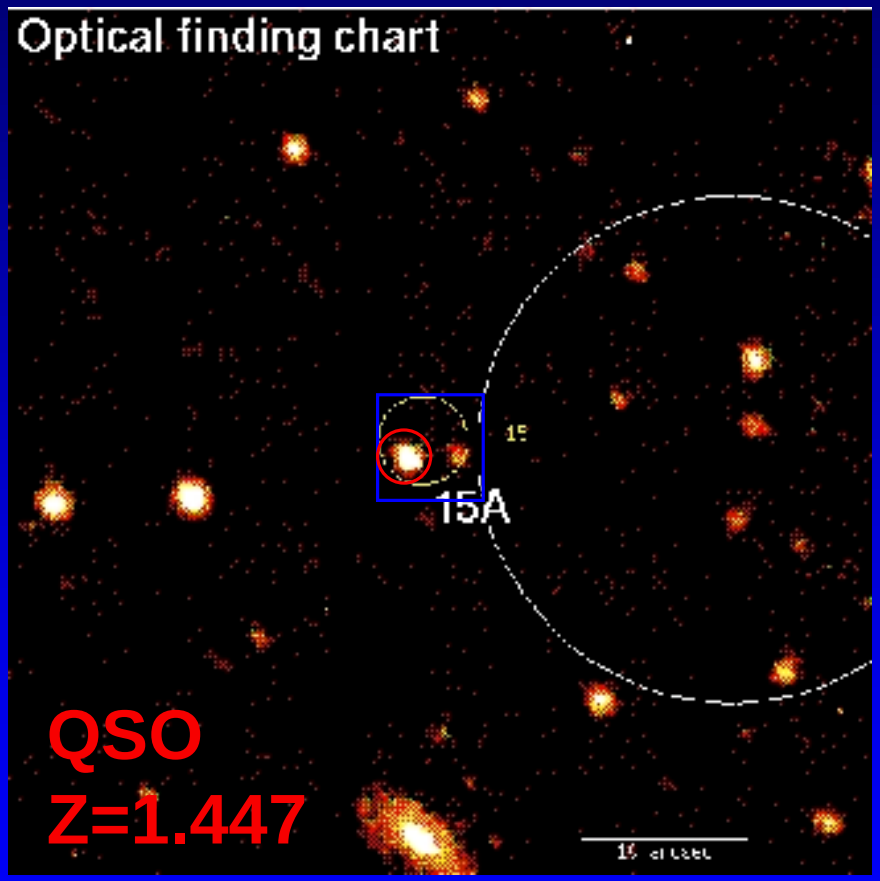
K: Calar Alto Ω‘
< 20 mag**

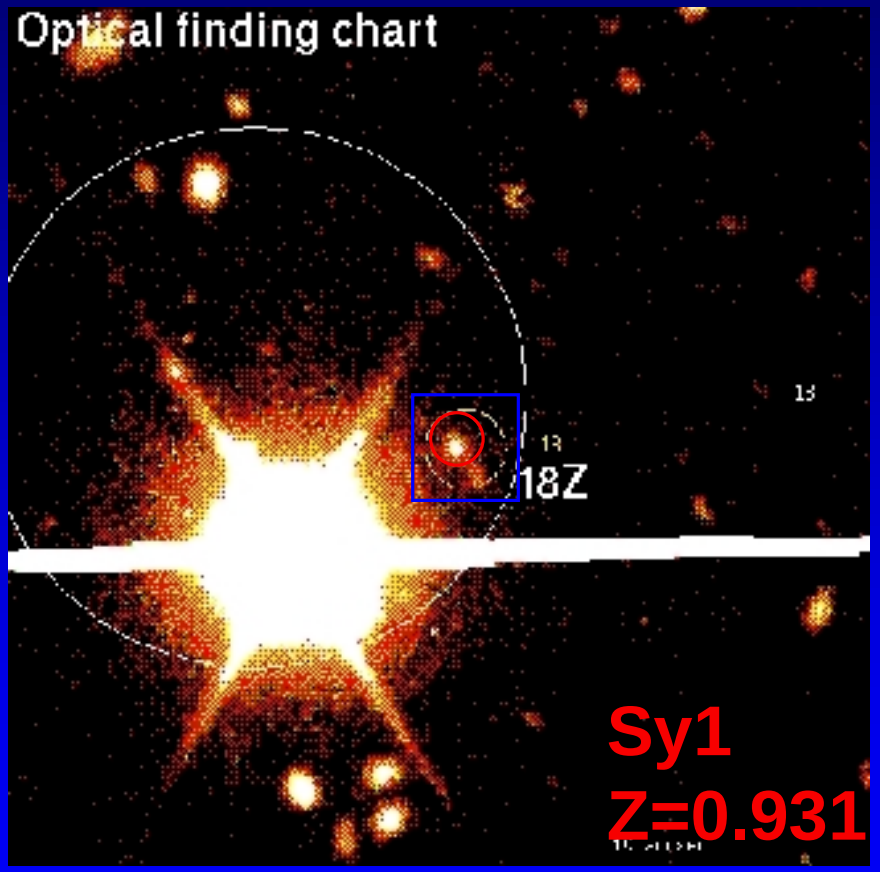
Keck/SUBARU

G. Hasinger (MPE)
M. Schmidt (Caltech)
P. Henry (Hawaii)
M. Akiyama (Subaru)
Y. Hashimoto (AIP)
G. Szokoly (AIP)



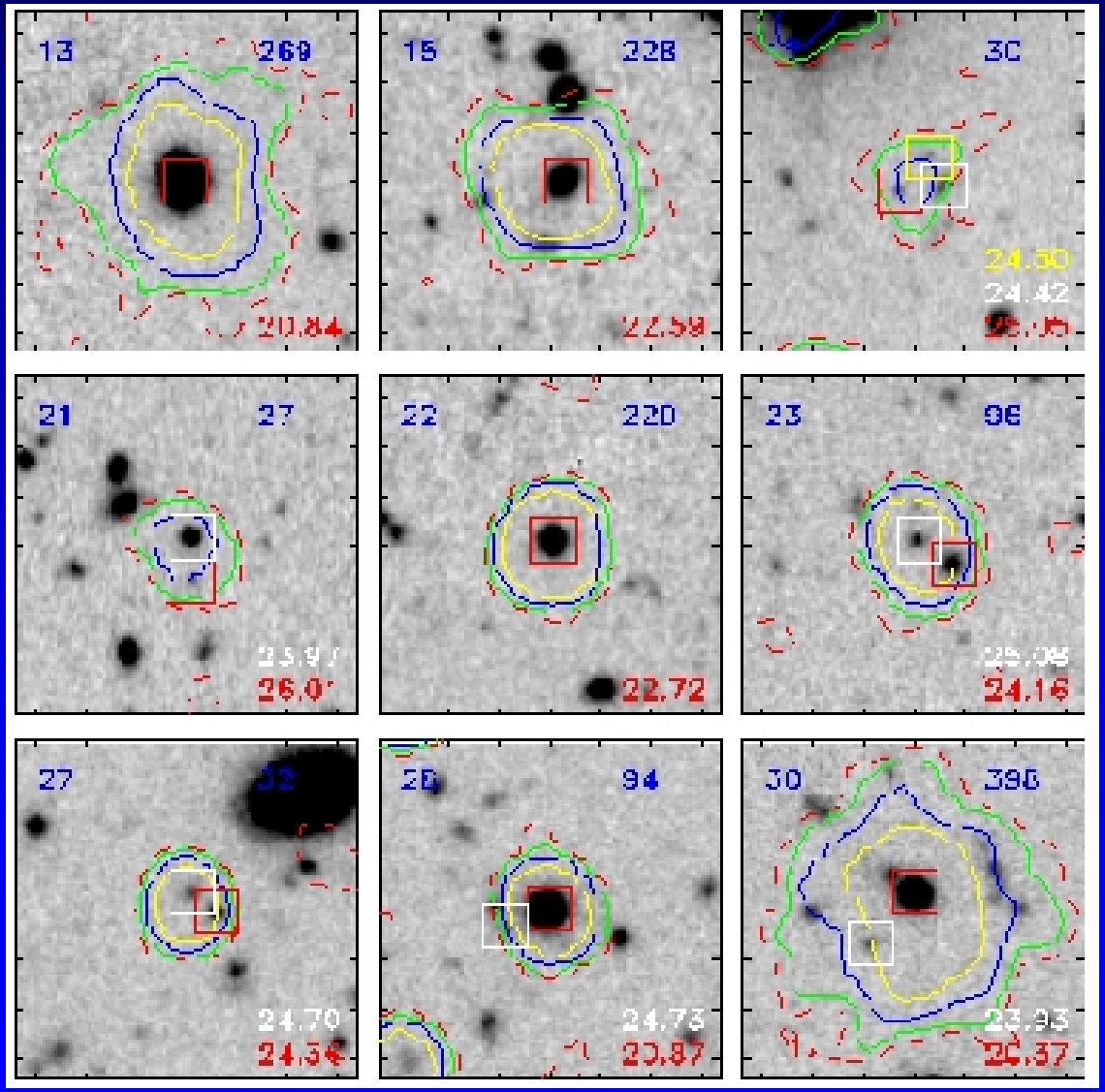
Optical Follow-up





ROSAT PSPC/HRI ~25/5`` XMM ~6`` Chandra HRC~0.5``

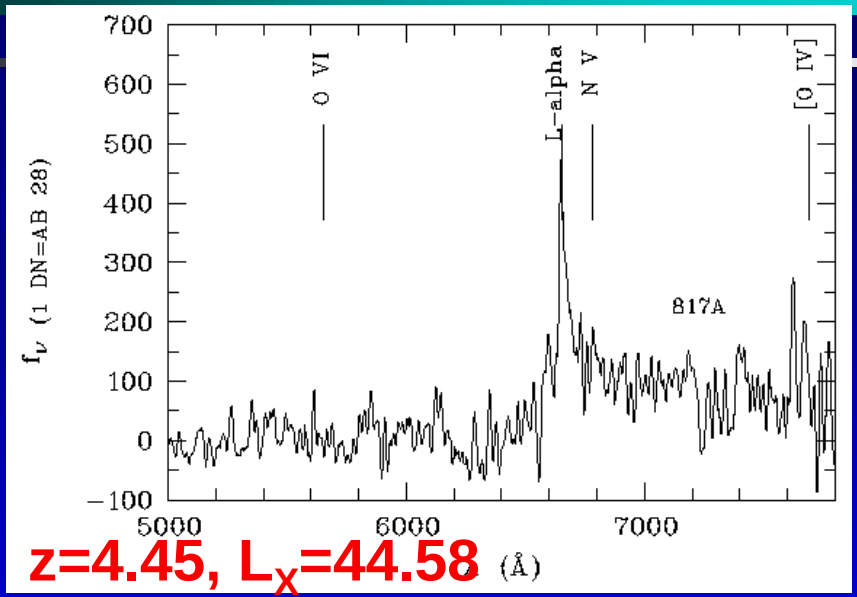
Finding charts CDF-S



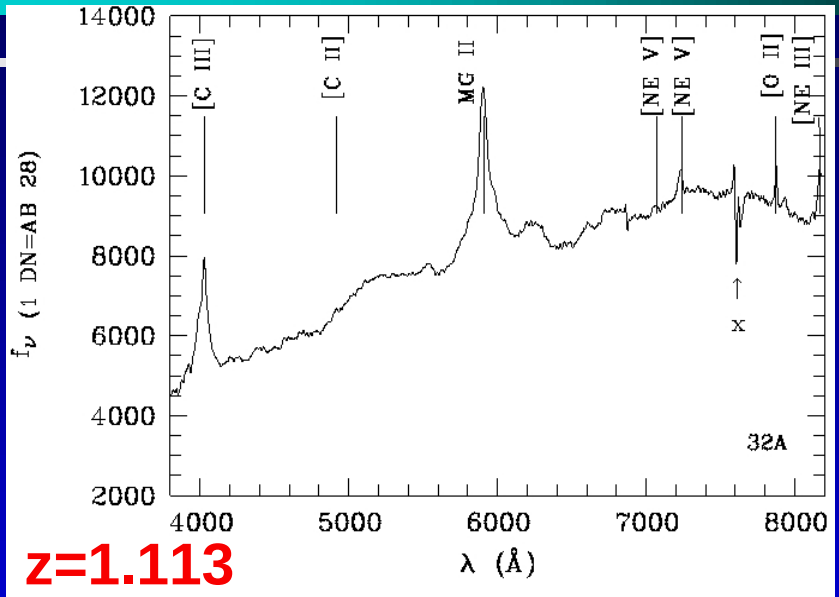
Only one optical counter-part within the 90 % error box

ROSAT → 60% AGN type I

QSO

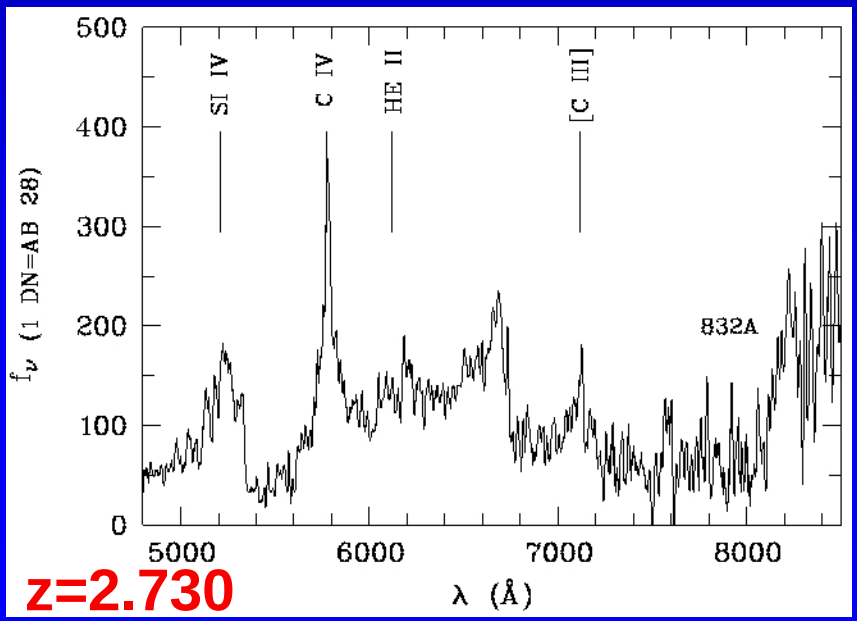


z=4.45, L_X=44.58

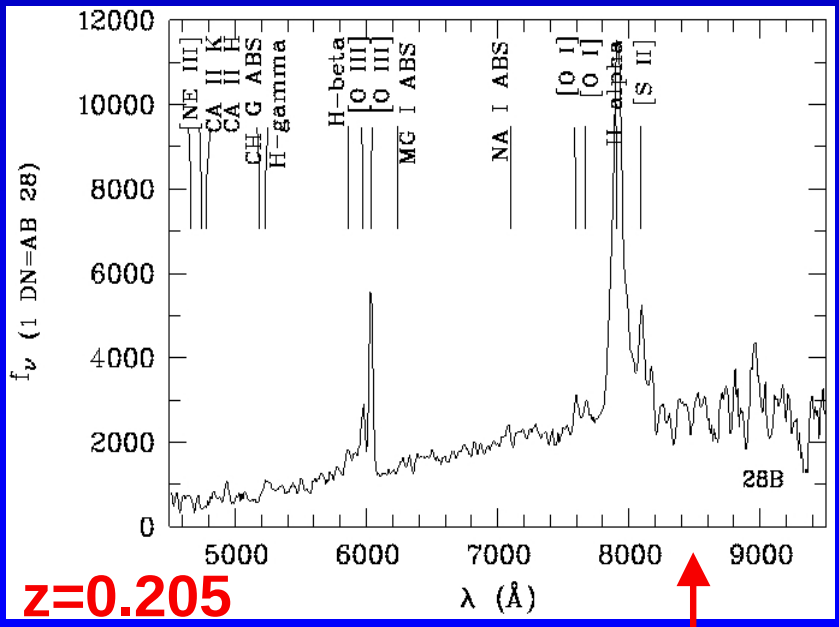


z=1.113

BAL-QSO



z=2.730



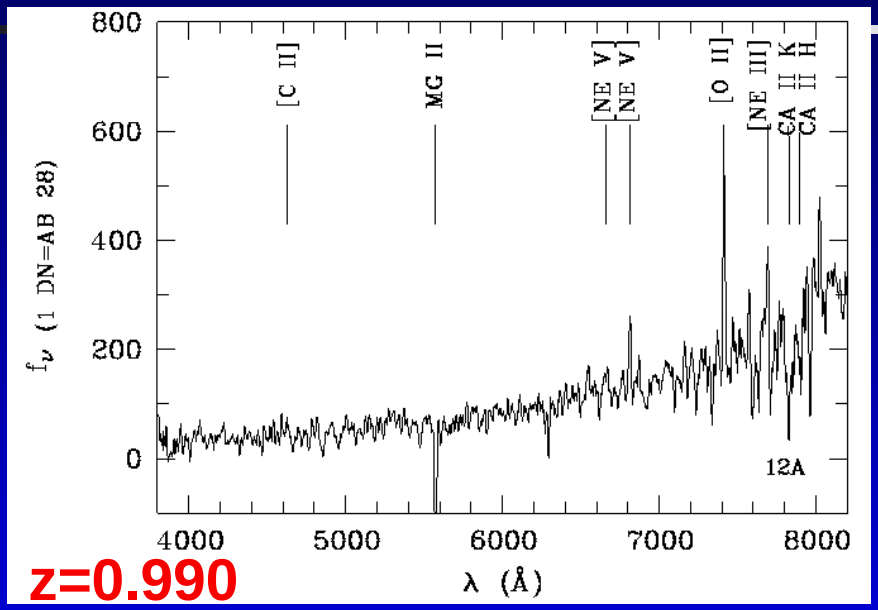
z=0.205

Sy 1.5 (type II)

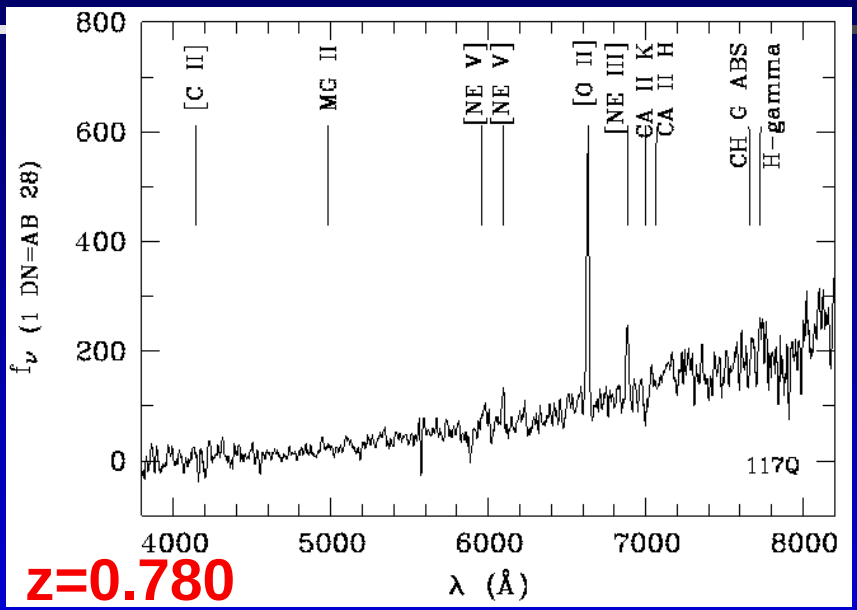
Schmidt et al. 1998/Lehmann et al. 2000/2001

Large Balmerdecrement

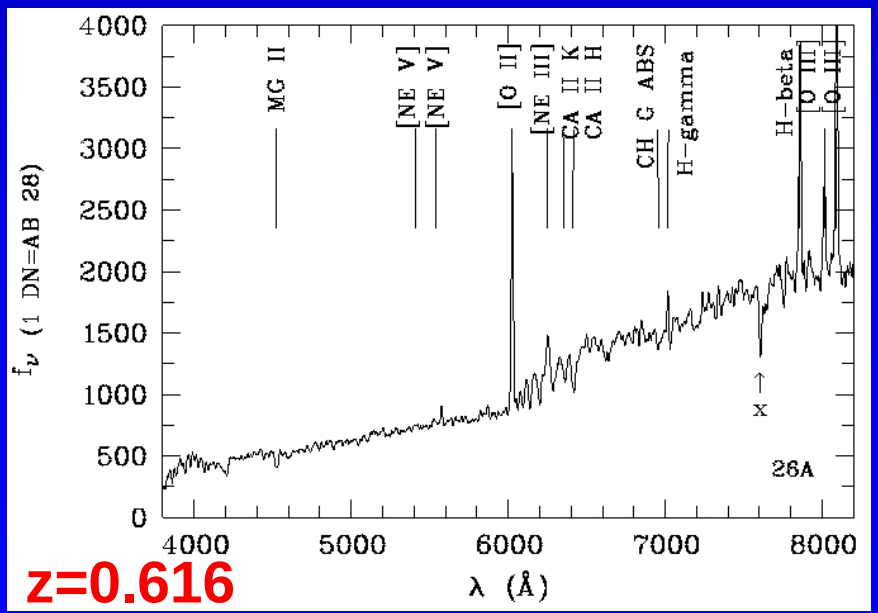
ROSAT → 15% AGN type II



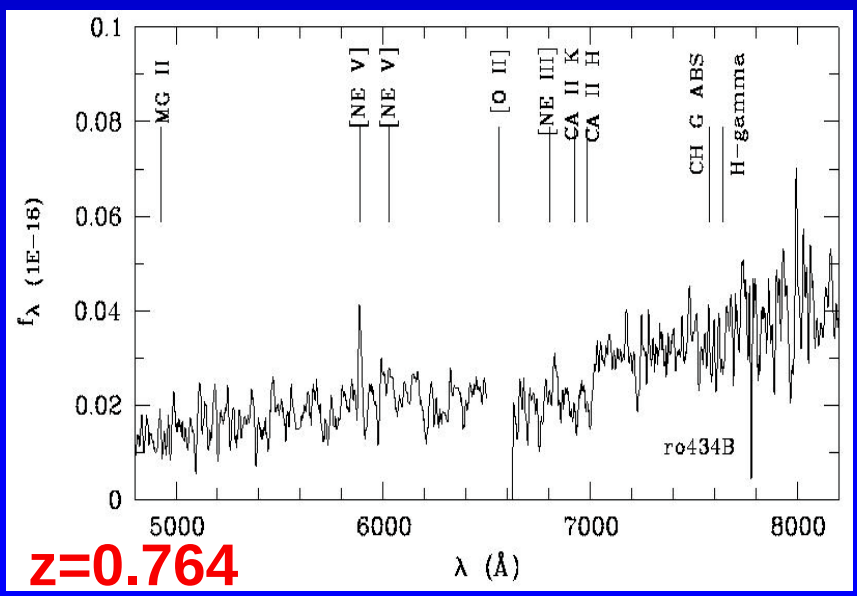
z=0.990



z=0.780



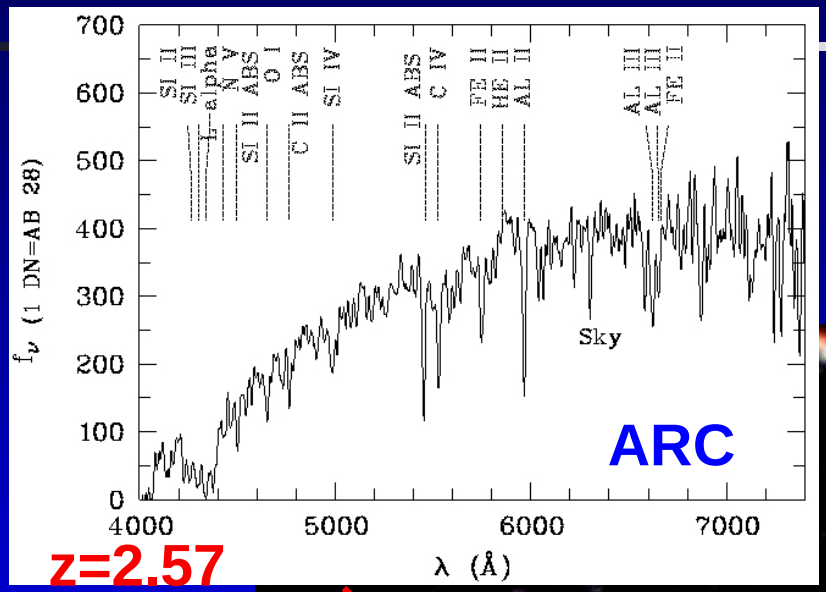
z=0.616

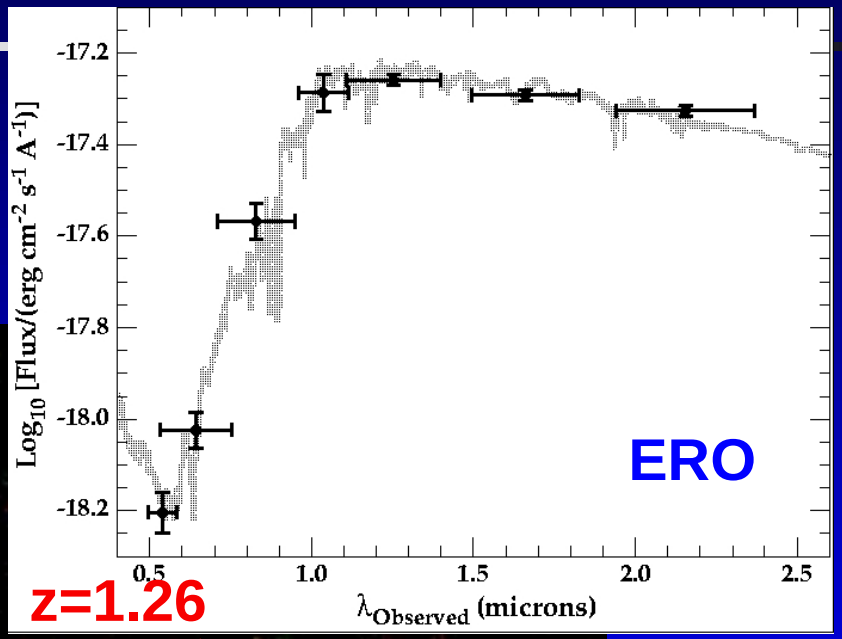


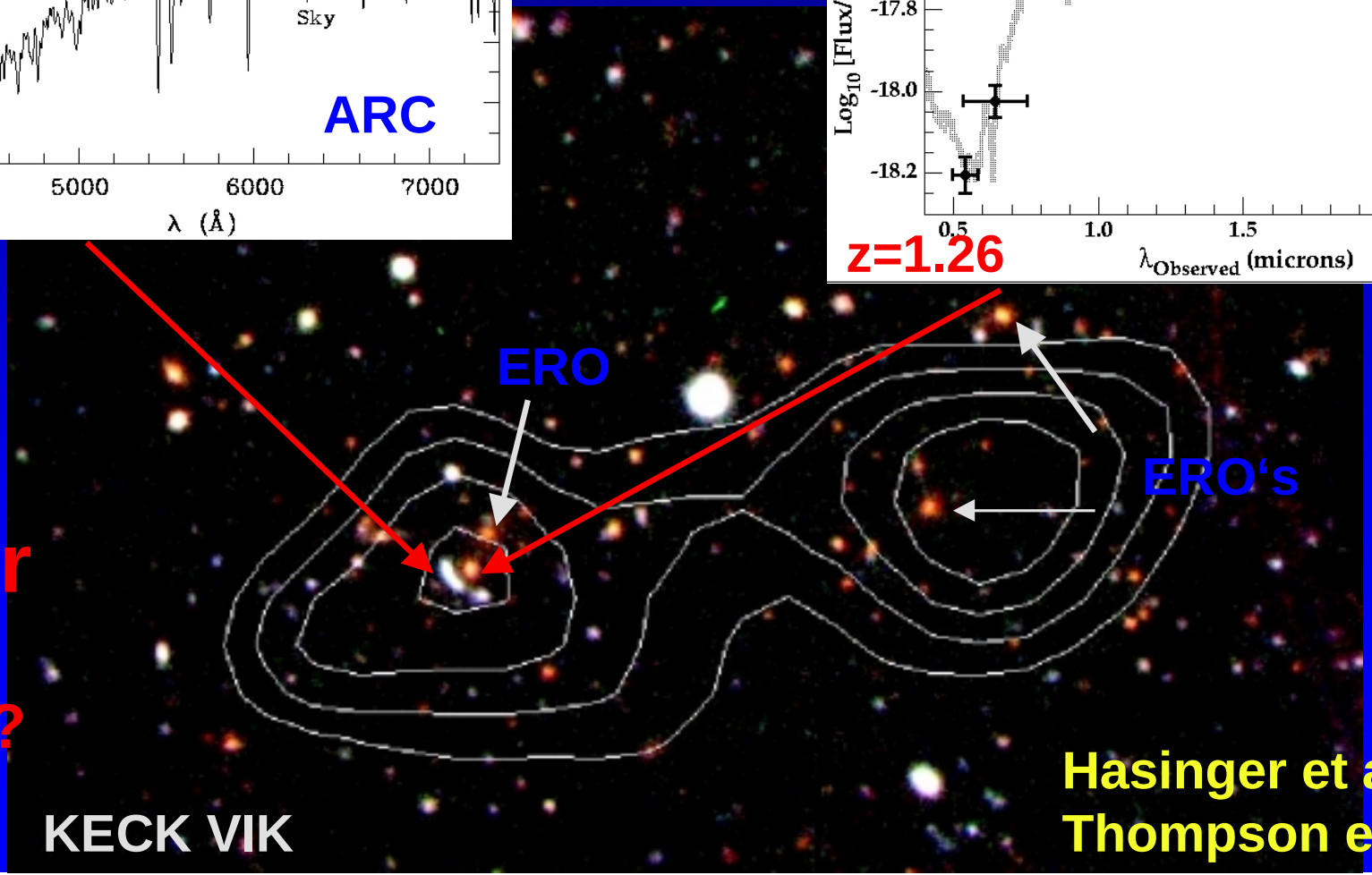
z=0.764

➔Log L_x=41.4-43.7 (0.5-2.0keV)

10% Groups/cluster of galaxies





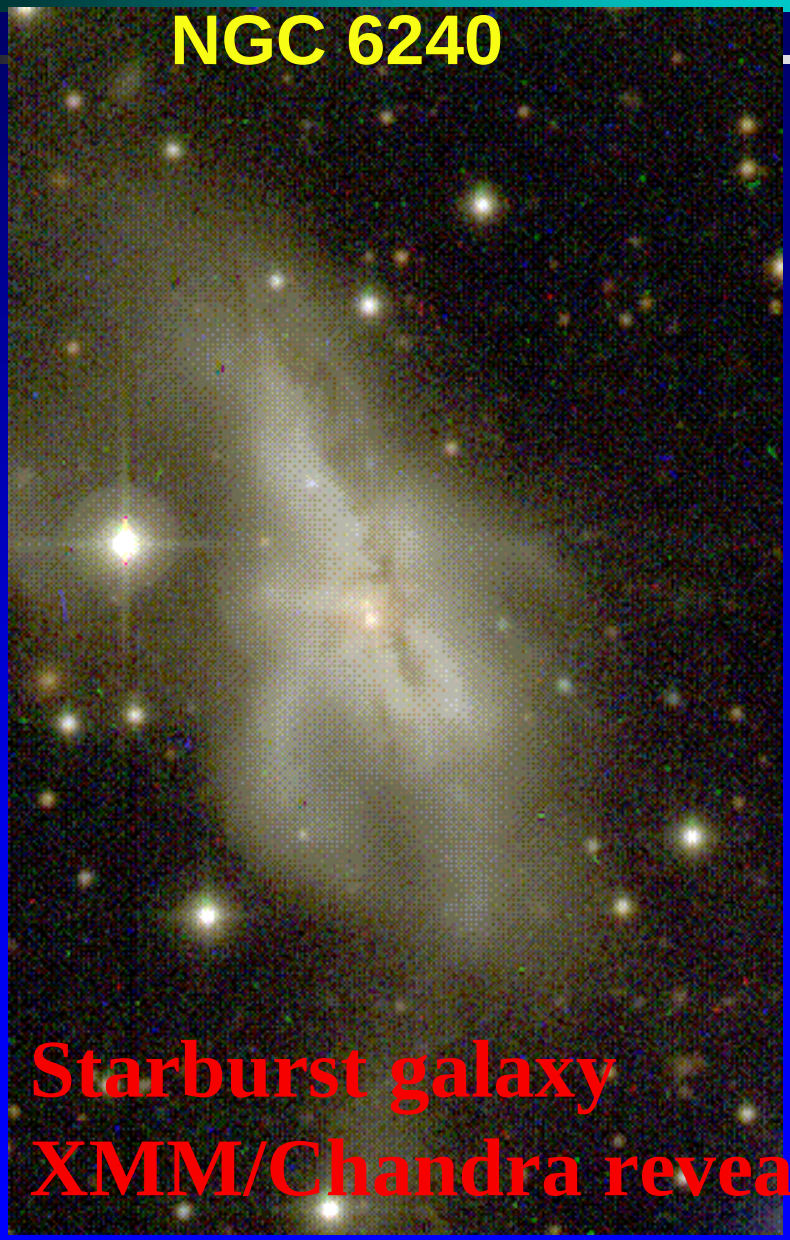


High-z Cluster

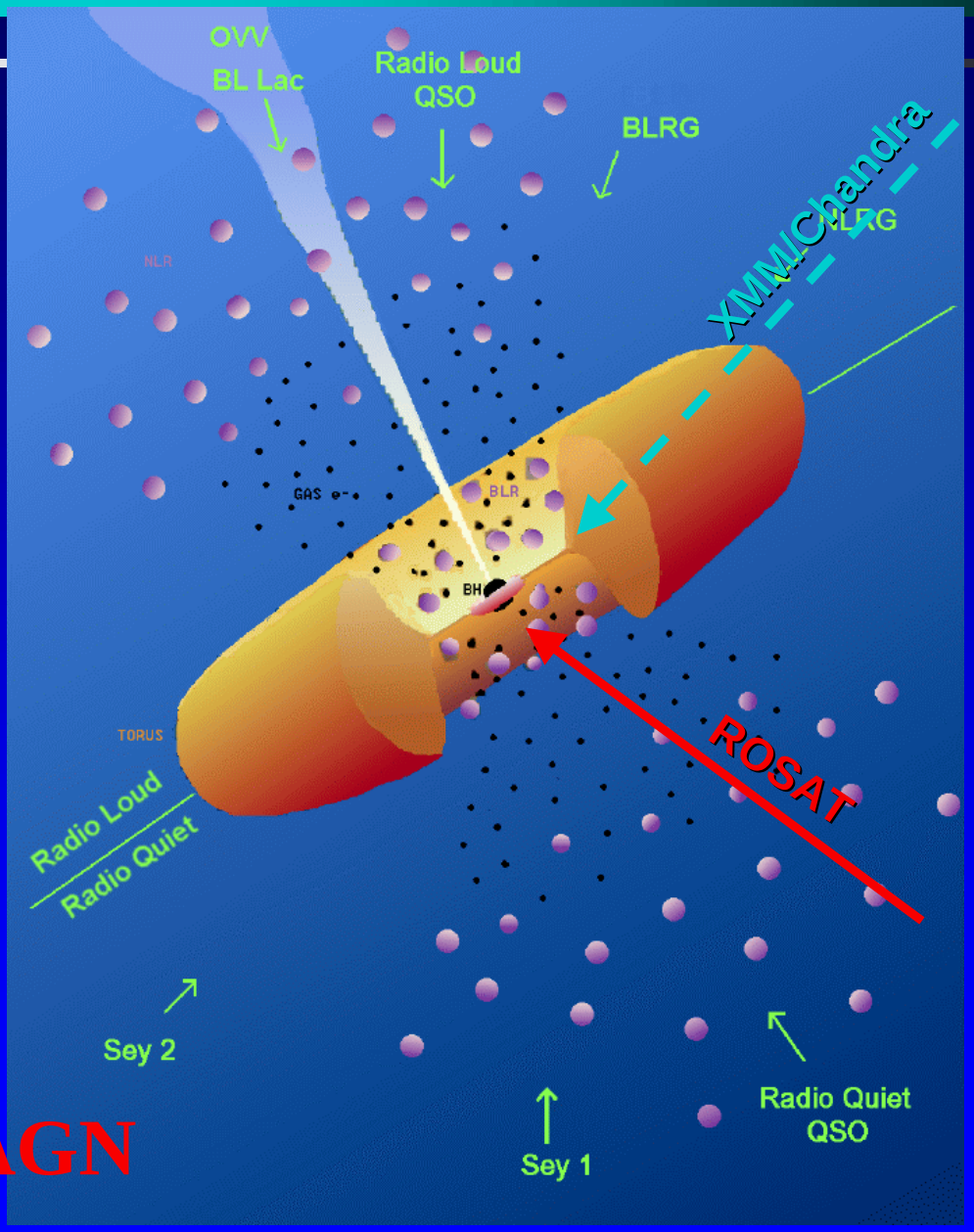
Merging?

Hasinger et al. 1999
Thompson et al. 2001

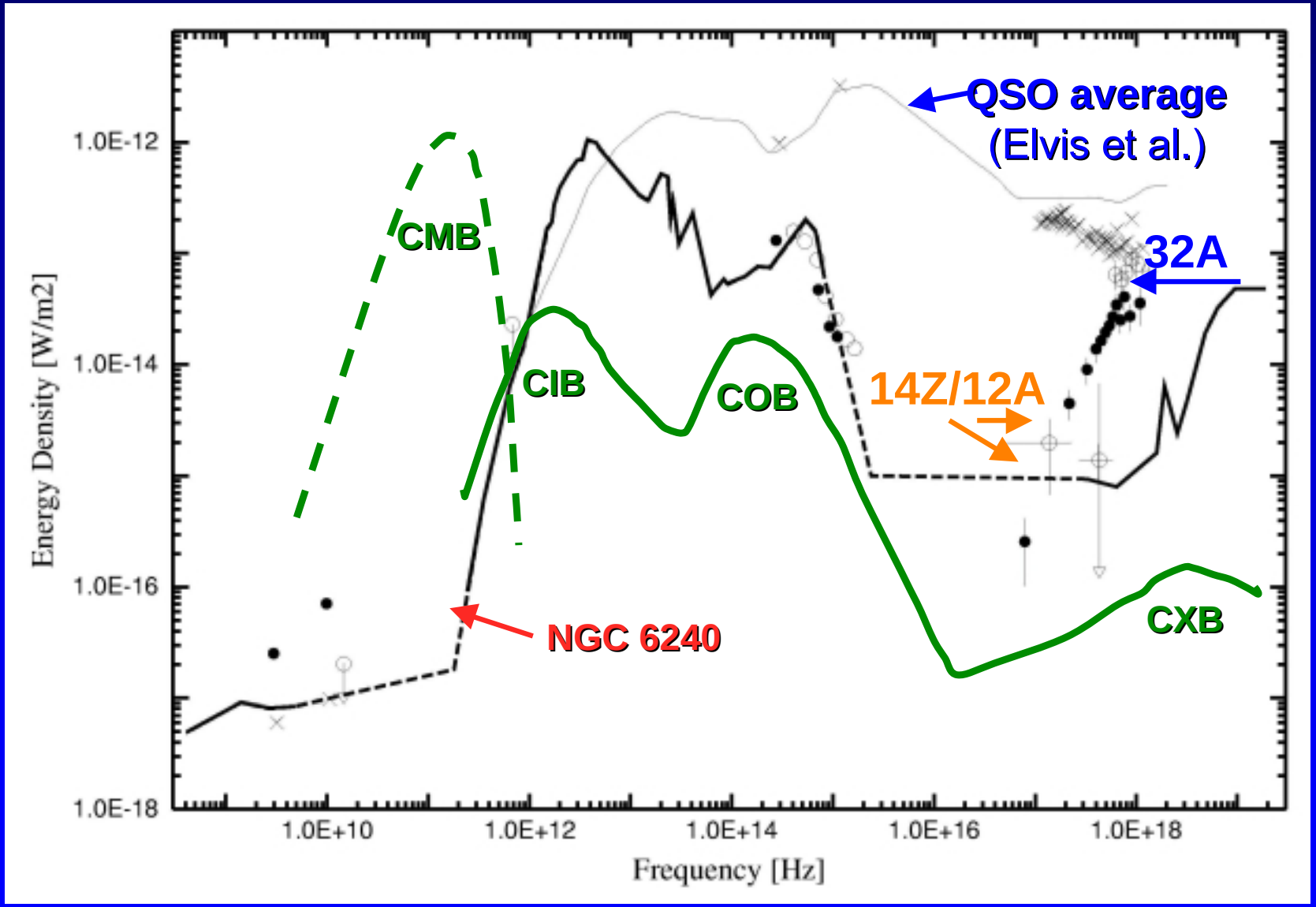
AGN model – absorbed AGN (II)



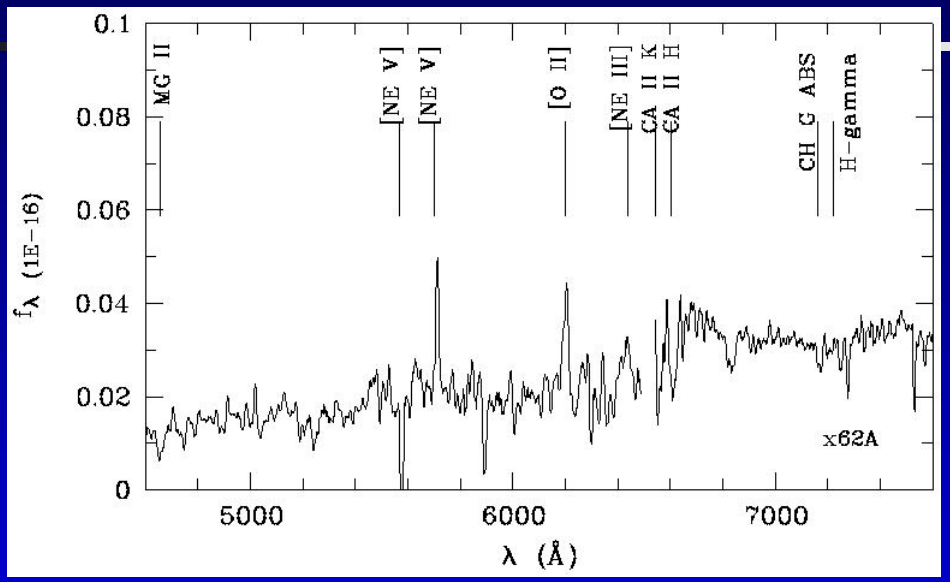
Starburst galaxy
XMM/Chandra reveal AGN



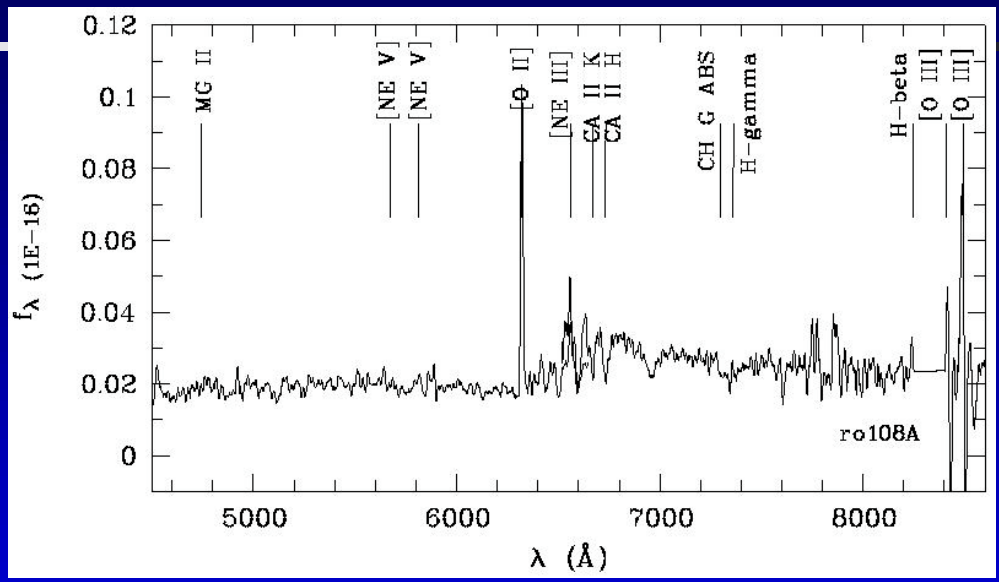
Absorbed AGN



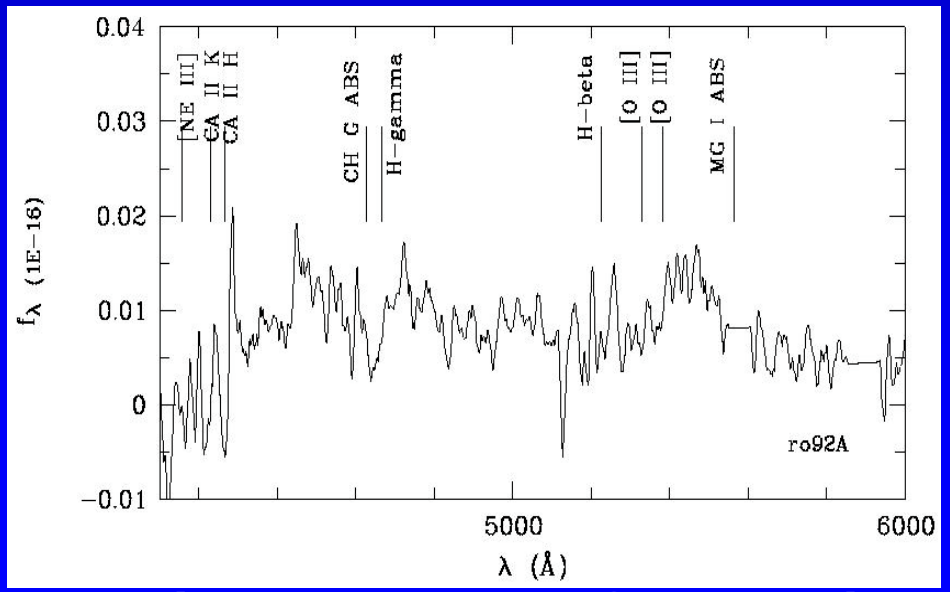
New sources → type II AGN



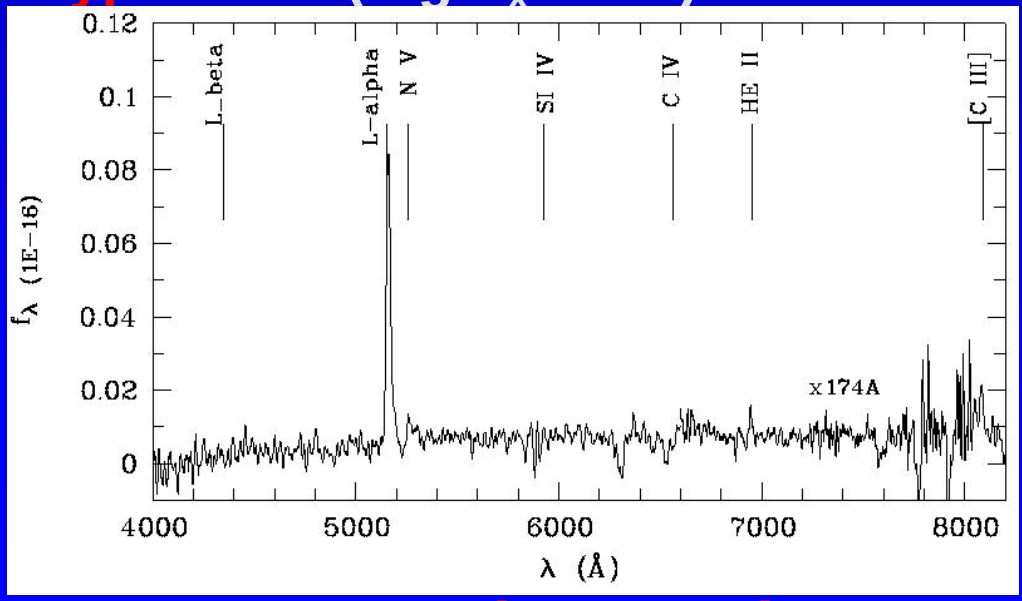
type II AGN



type II/Gal (log L_x~42.0)



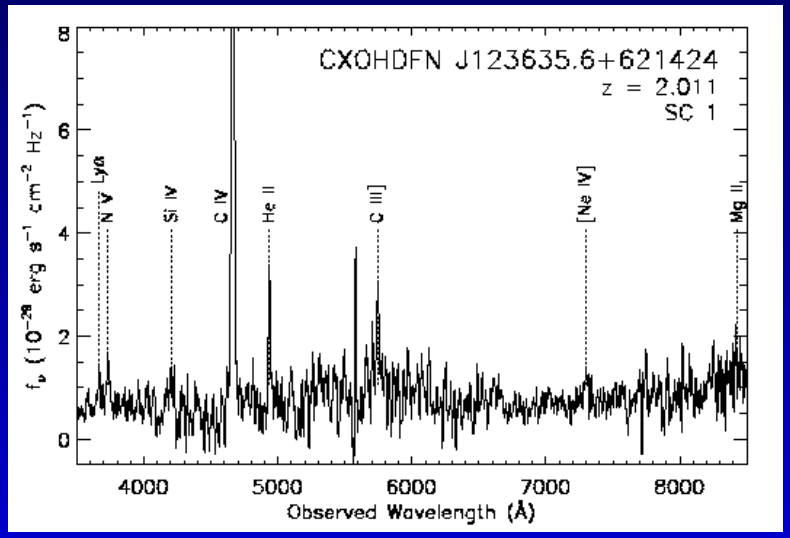
GAL (log L_x=40.2, soft source)



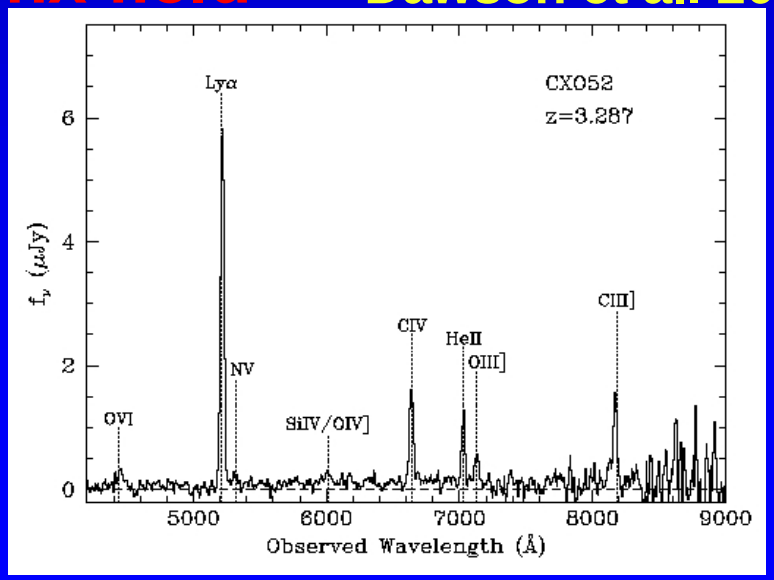
type II QSO (z=3.240)

Chandra ➔ type-2 Quasars

HDF-N*

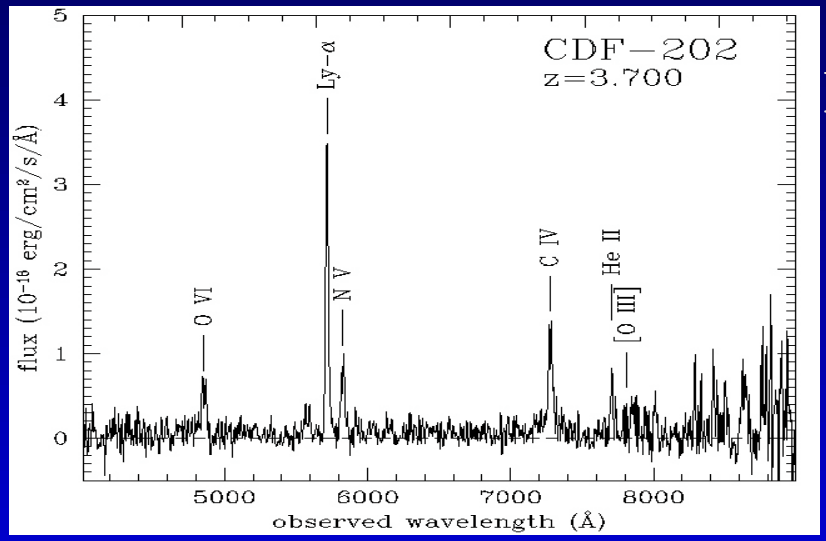


Lynx field **Dawson et al. 2002**



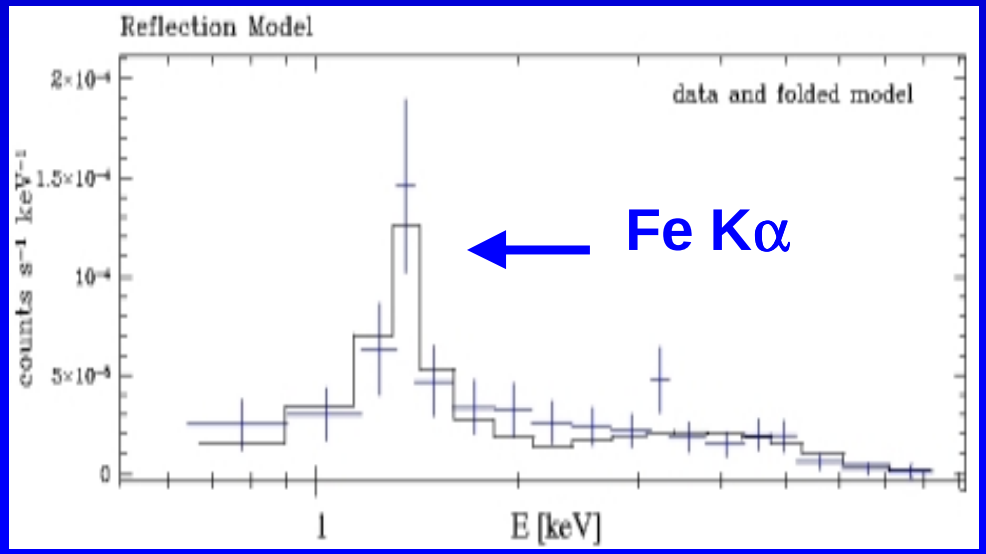
Stern et al. 2001

CDFS



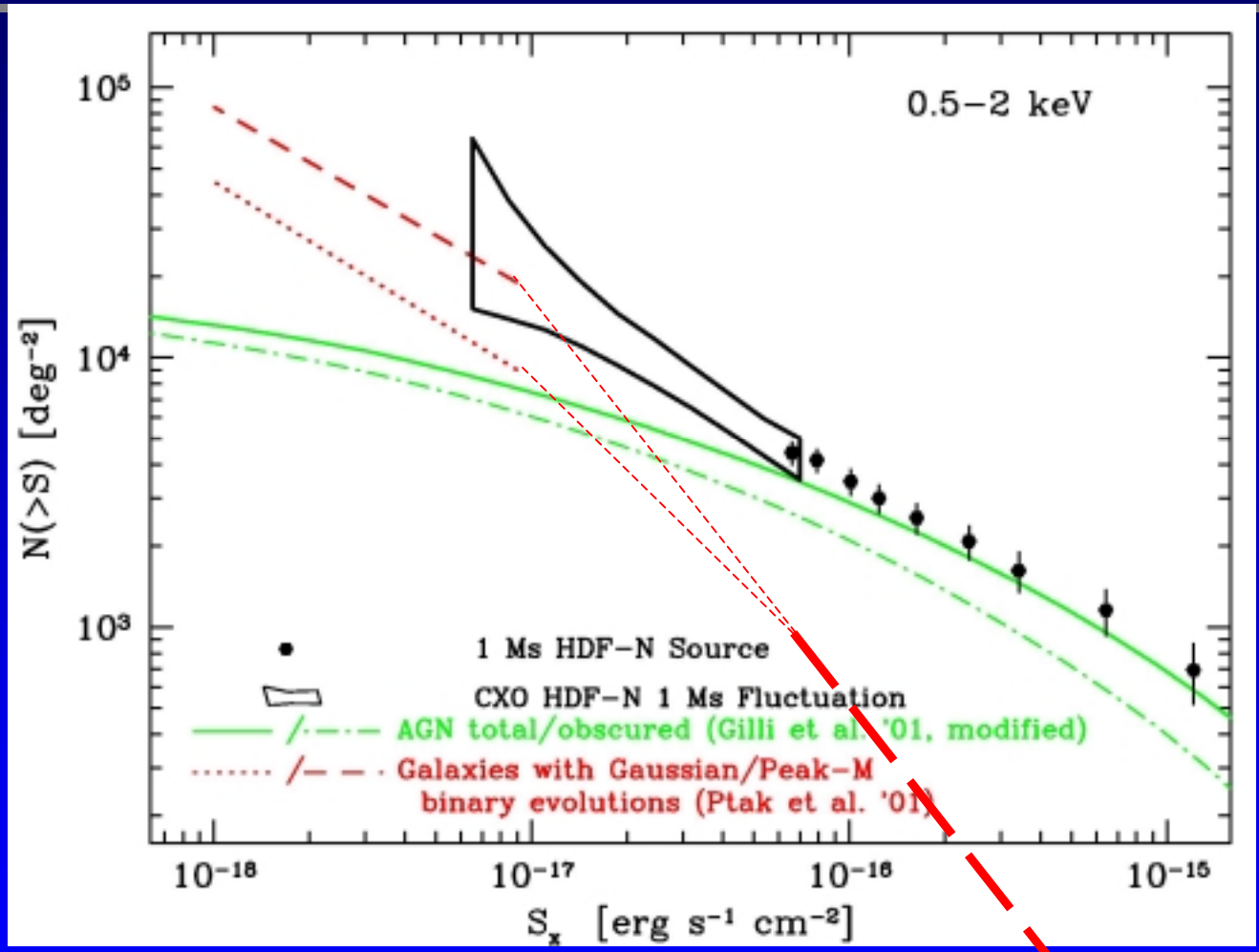
Γ=0.51±0.27
N_H~10^{24} cm^{-2}
R-Ks=2.5
L_{2-10}=$10^{45±0.5}$
Radio quiet
$EW_{Kα}$~1keV

Norman et al. 2001



radio gal. z=3.395 **Fabian et al. 2002**

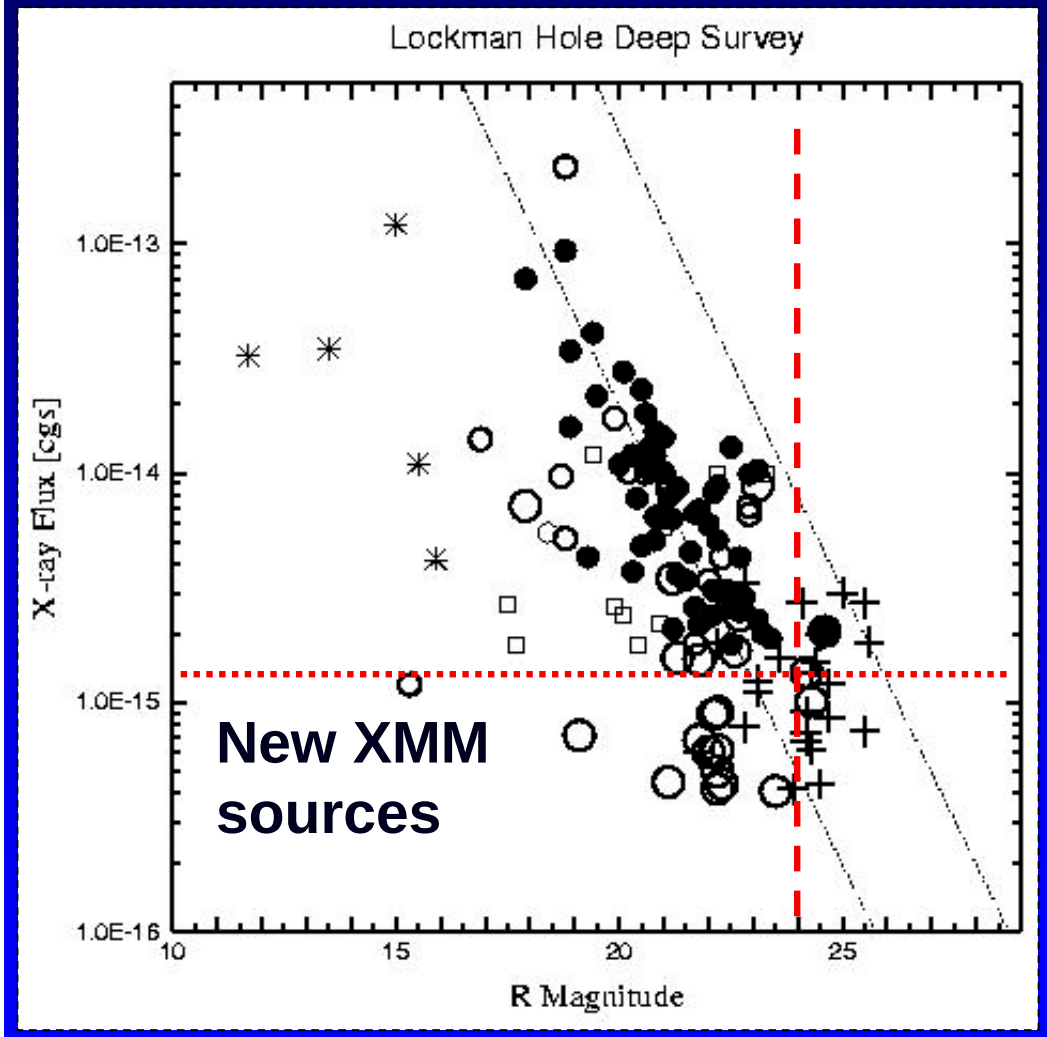
Contribution of Galaxies

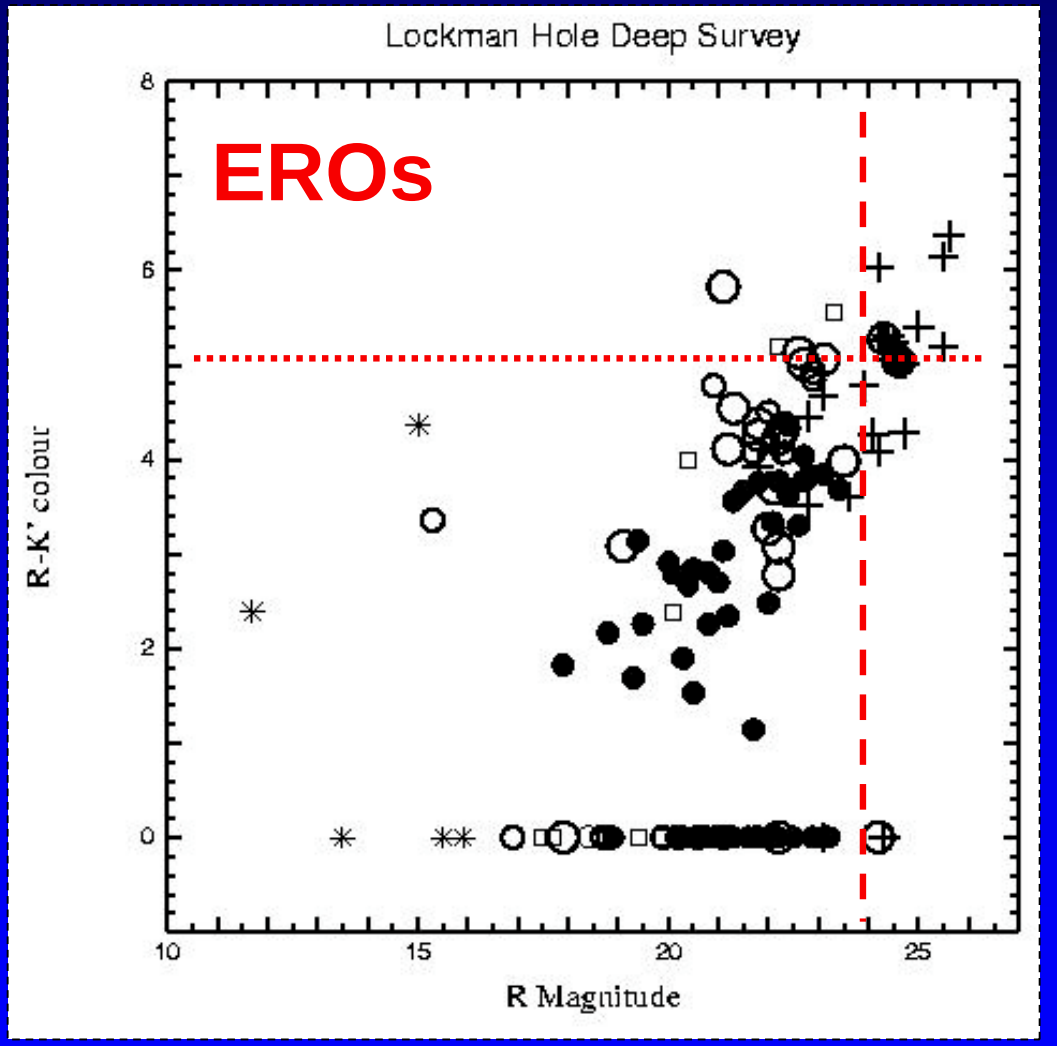


Miyaji+Griffiths 2001

Normal Galaxies

ROSAT/XMM optical/NIR IDs

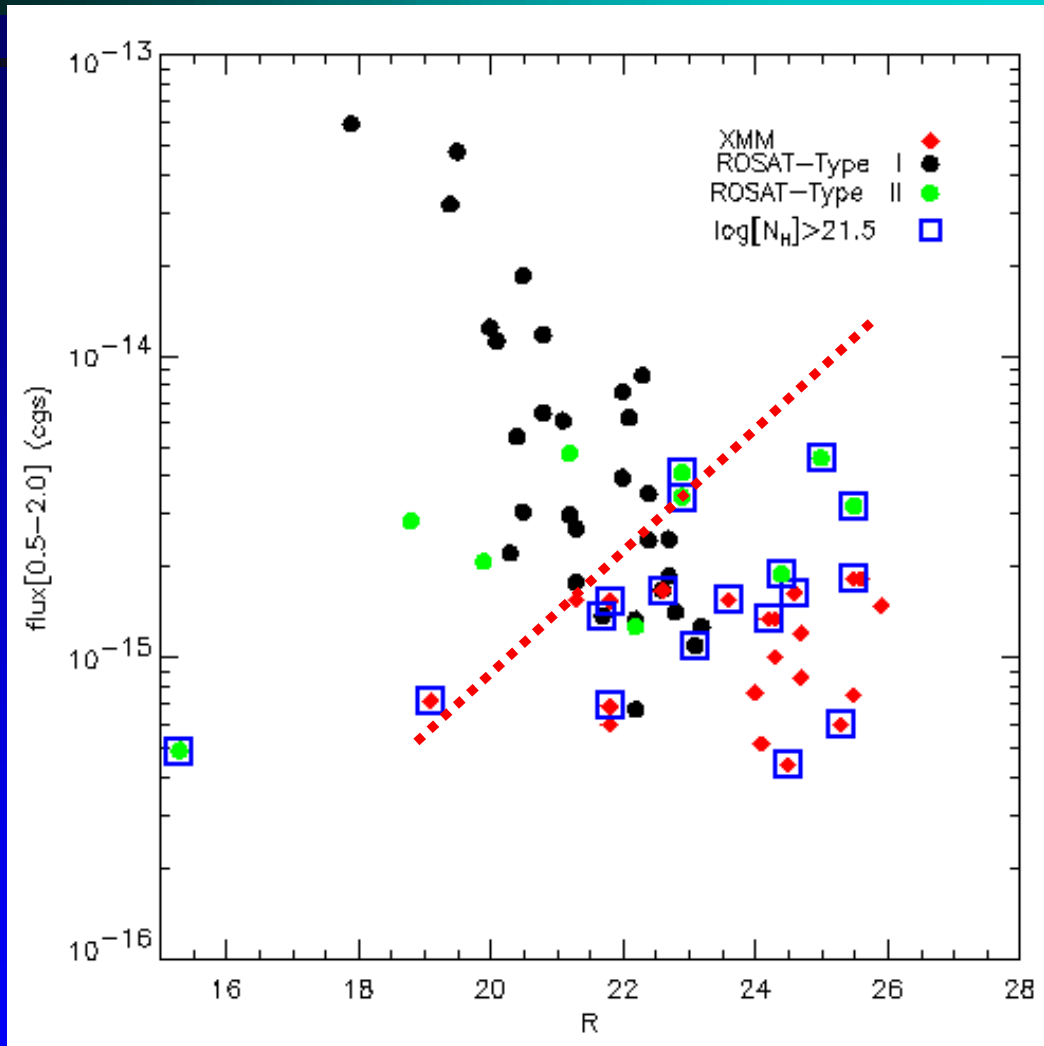


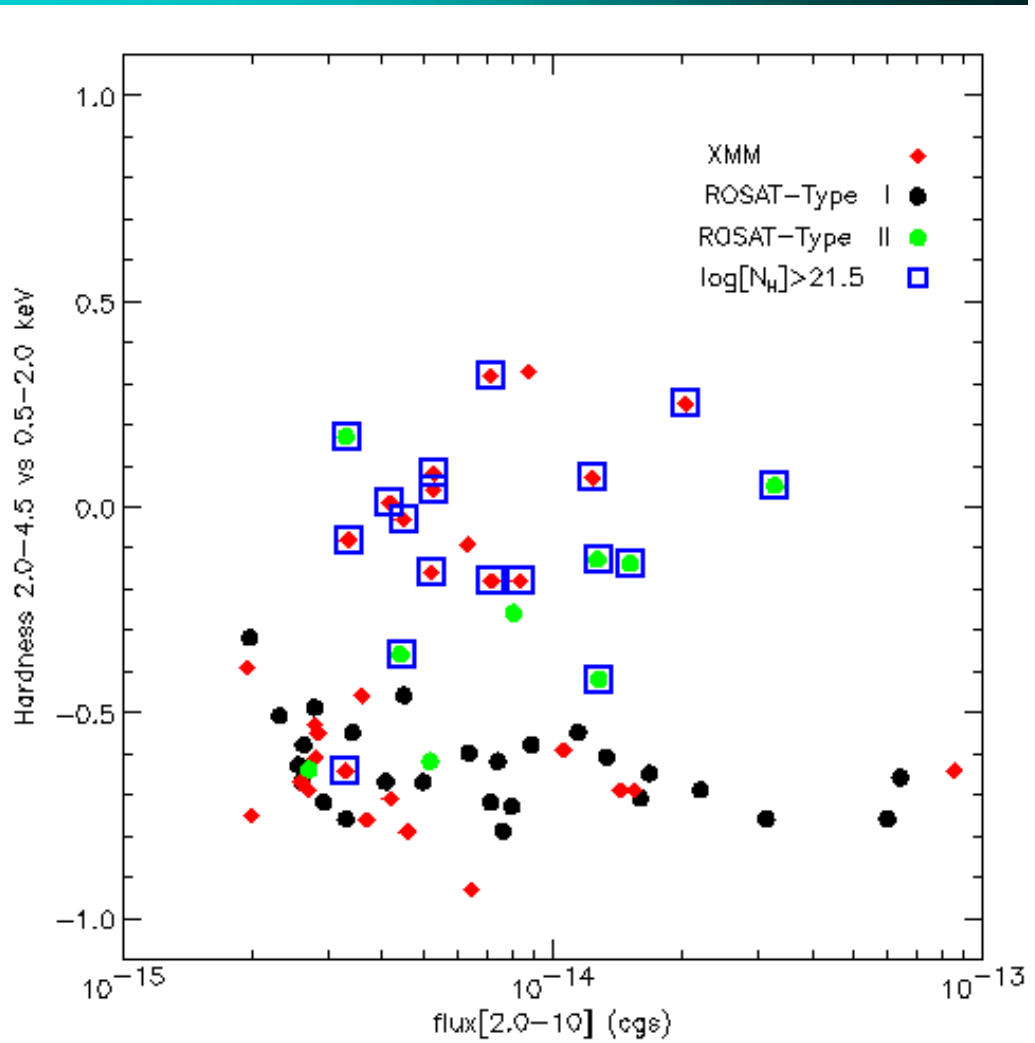


Schmidt et al. 1998/Lehmann et al. 2001

● AGN type1 ○ AGN type2 □ Cluster/group ✸ Star + unidentified

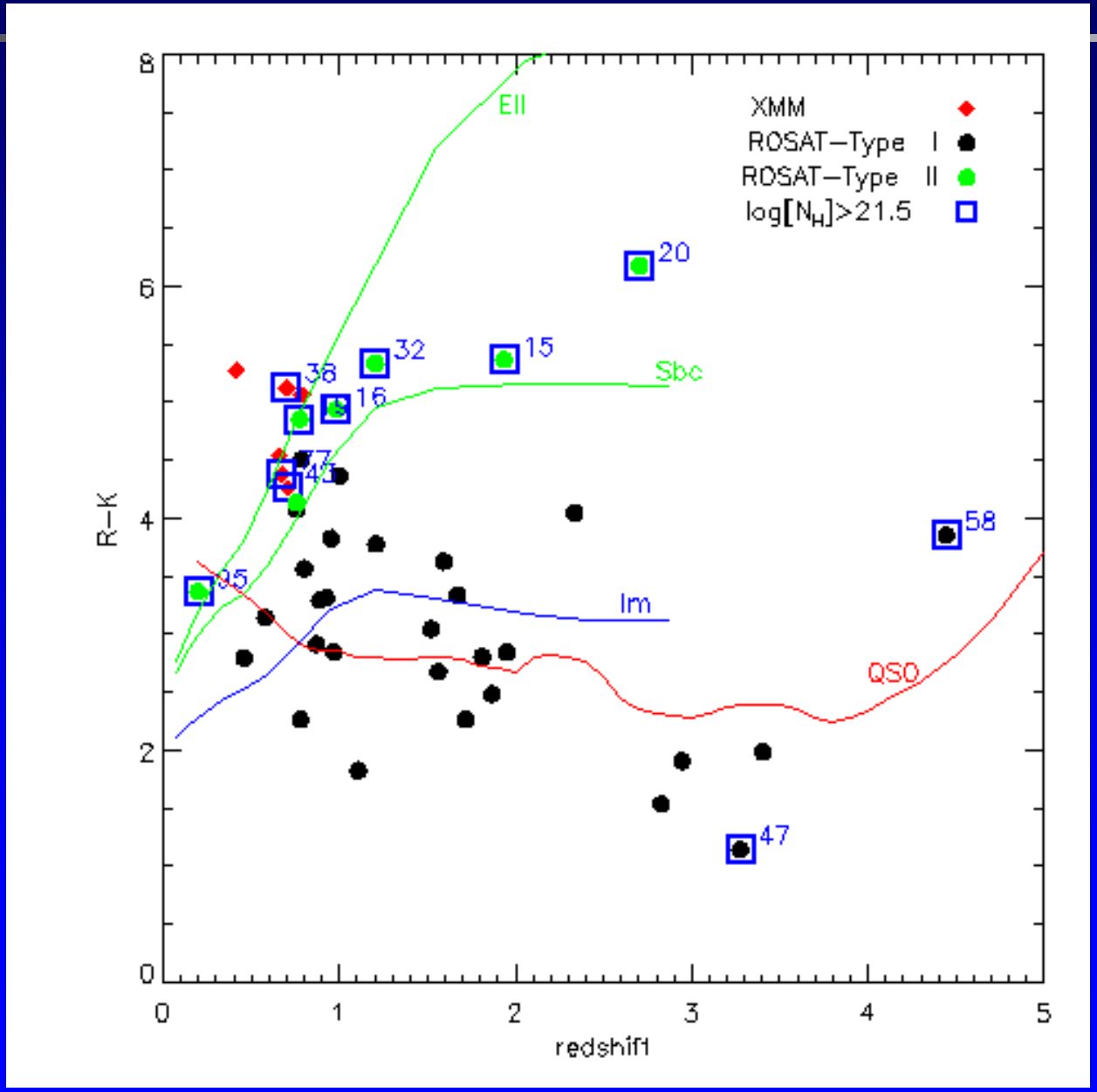
Absorption vs. optical type





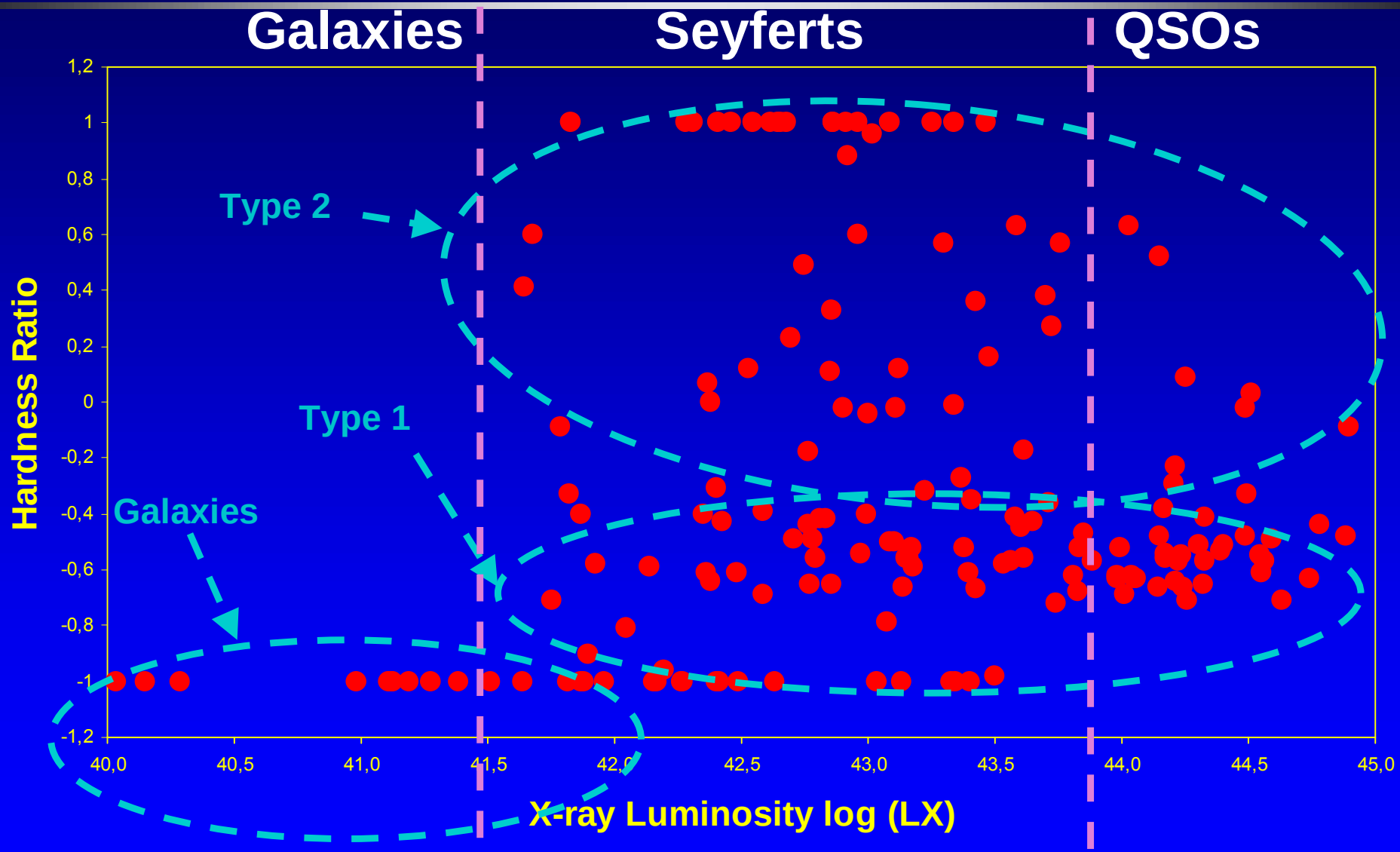
V. Mainieri et al. 2001

Spectral diagnostic vs. optical type



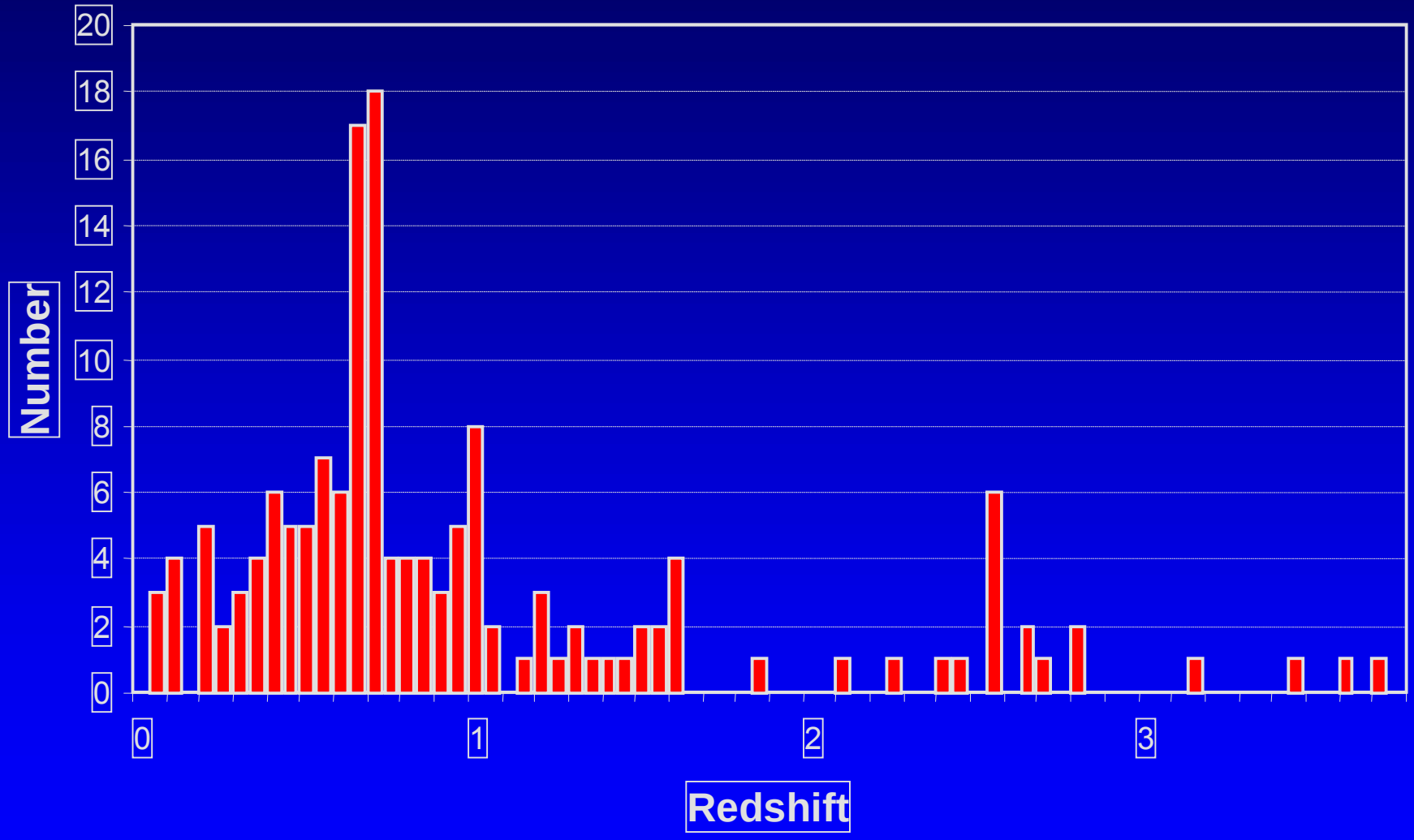
Lehmann et al. 2001
Mainieri et al. 2001

XMM and Chandra IDs



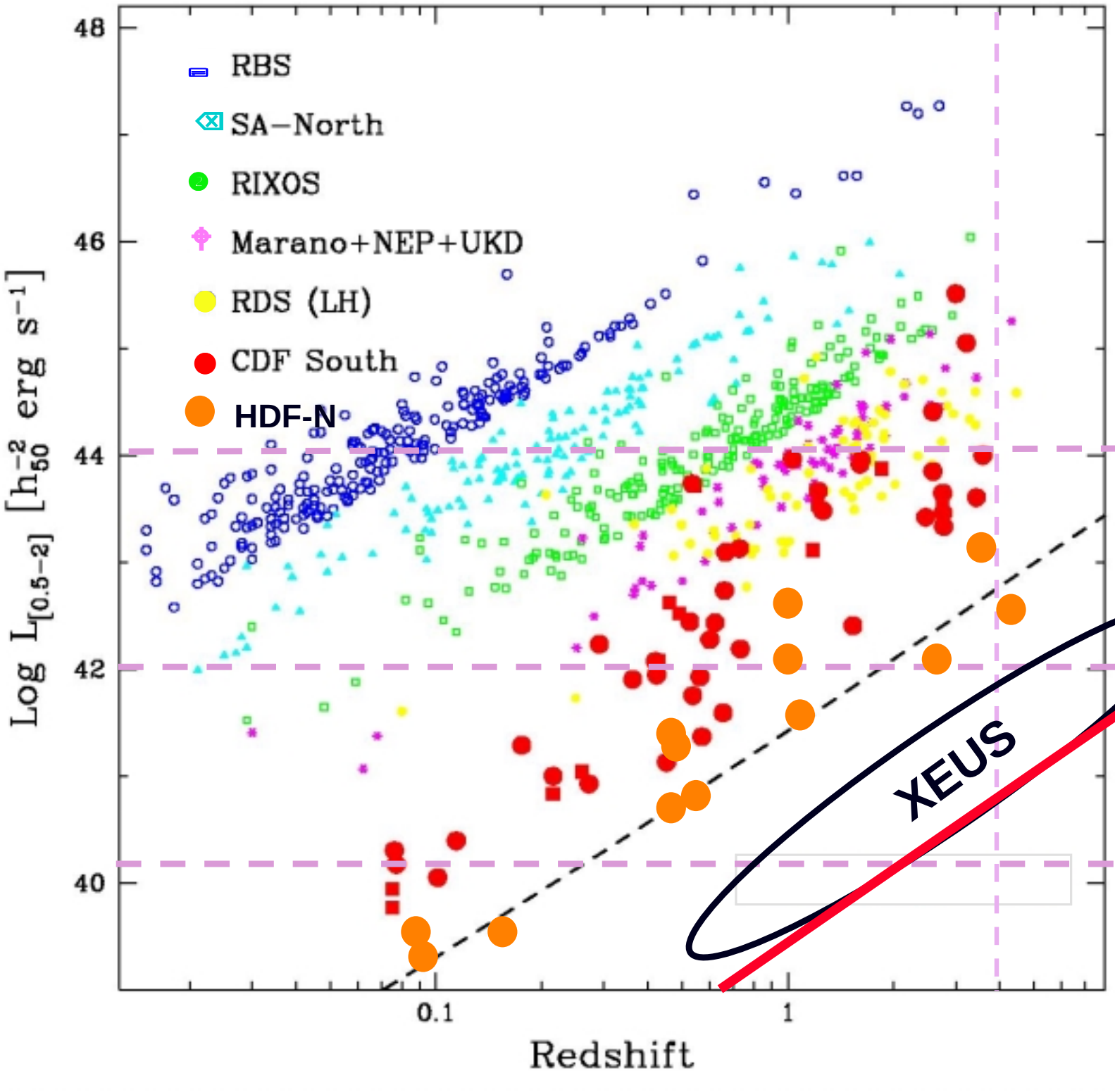
180 redshifts, ~60% complete

CDFS Redshift Distribution



Most X-ray sources at lower redshift (z<1)

Hubble Diagram



QSOs

Sy1/Sy2

10^{-18} erg/cm^2 s

LLAGN
SB-Gal.

Normal Gal
single XRB

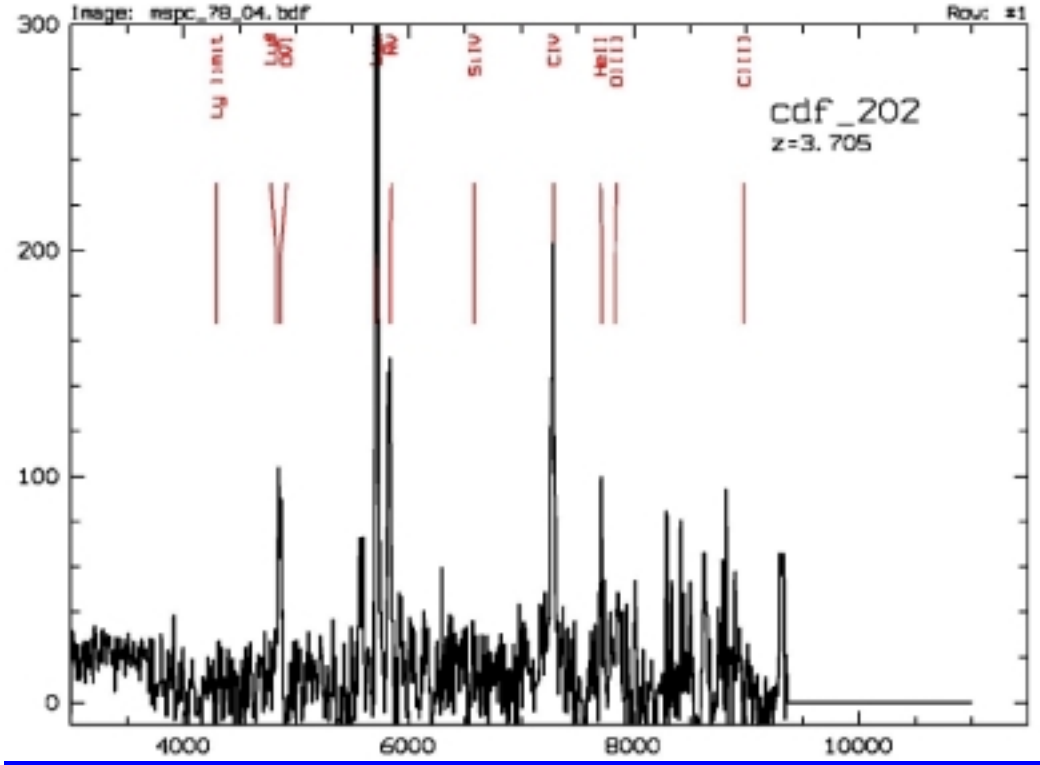
XEUS

Highest-redshift Fe-line

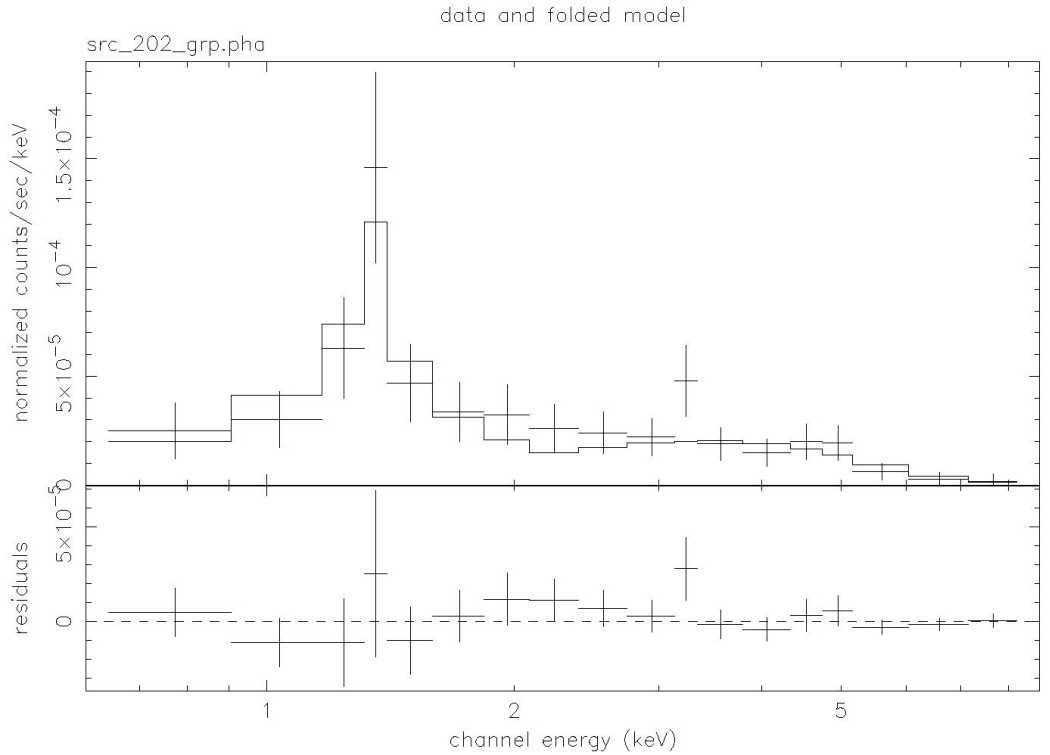
CDFS #202: **type-2 QSO**
z=3.705
narrow high-excitation lines

L_X ~10^{45} erg/s
N_H ~10^{24}cm^{-2}
Fe-line @ 6.4 keV

VLT-spectrum



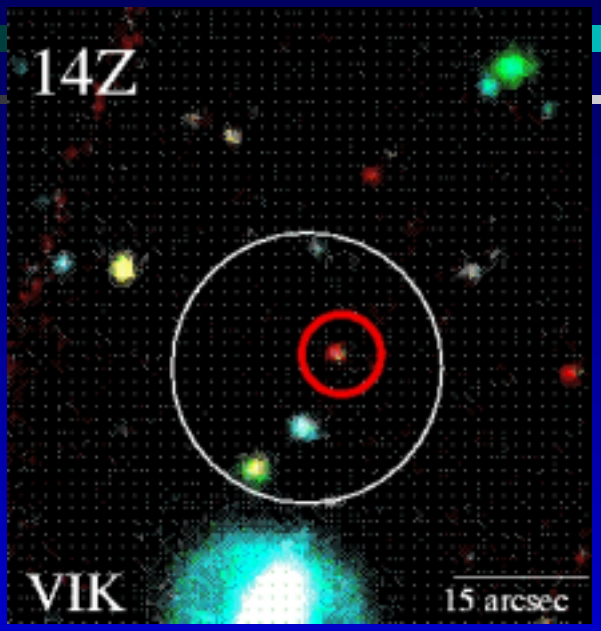
Chandra spectrum

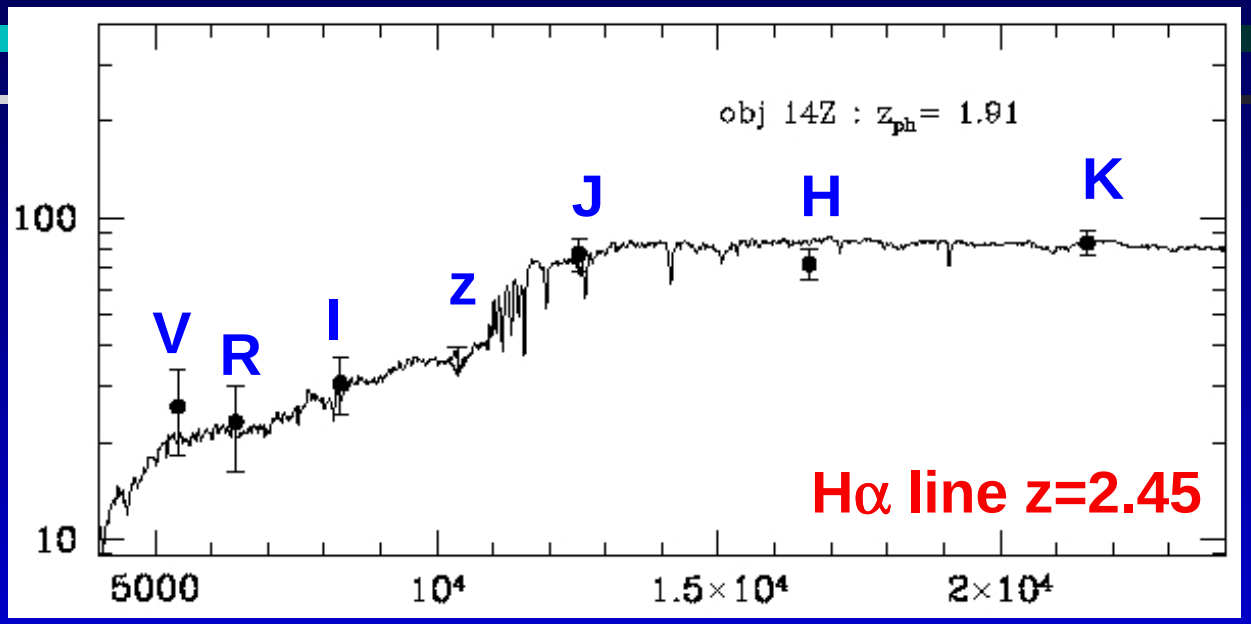


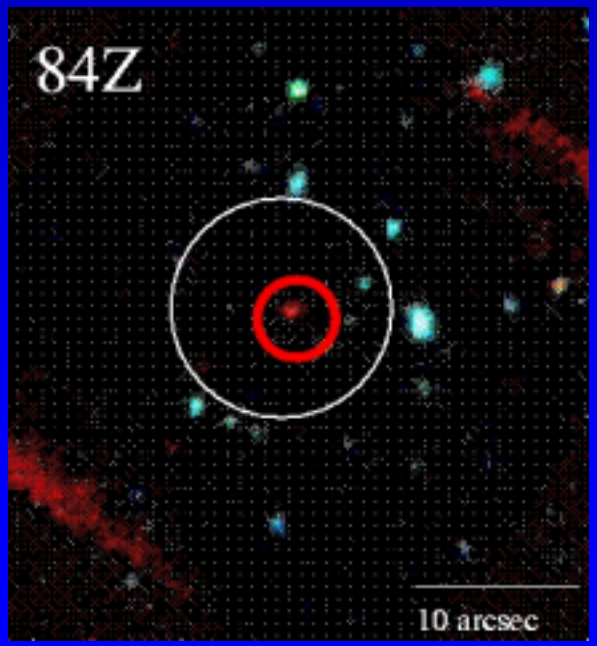
=> Rosetta-Stone for X-ray Background !!! **Norman et al., 2001**

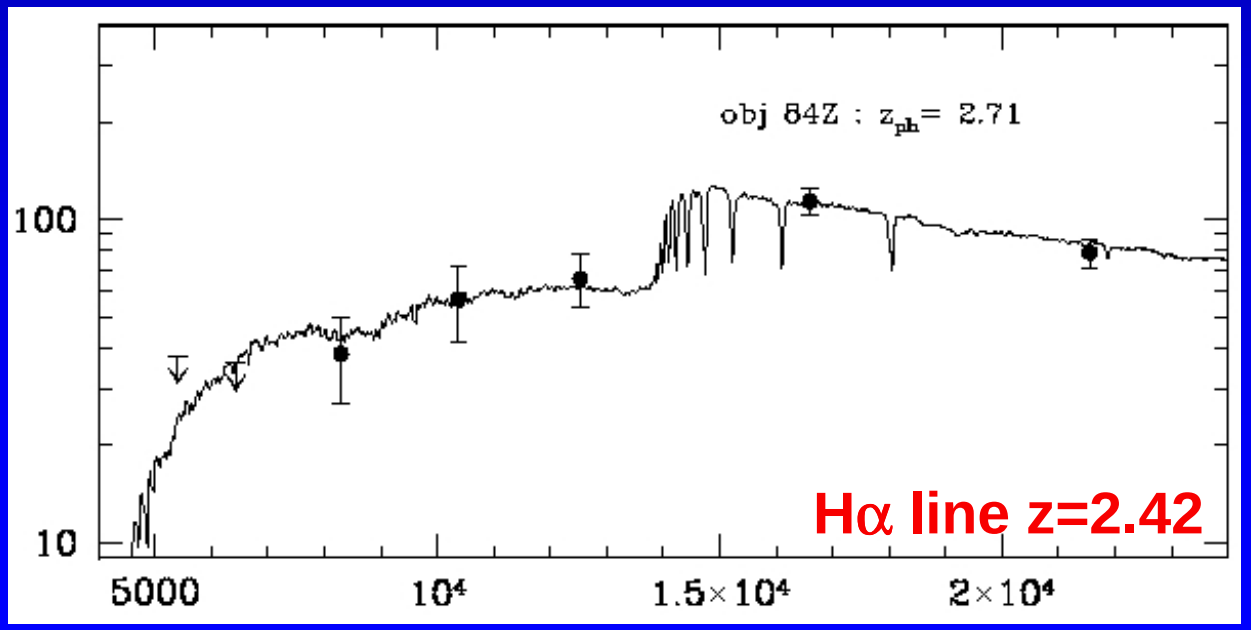
Photometric redshifts

R-K'>5.0 EROs





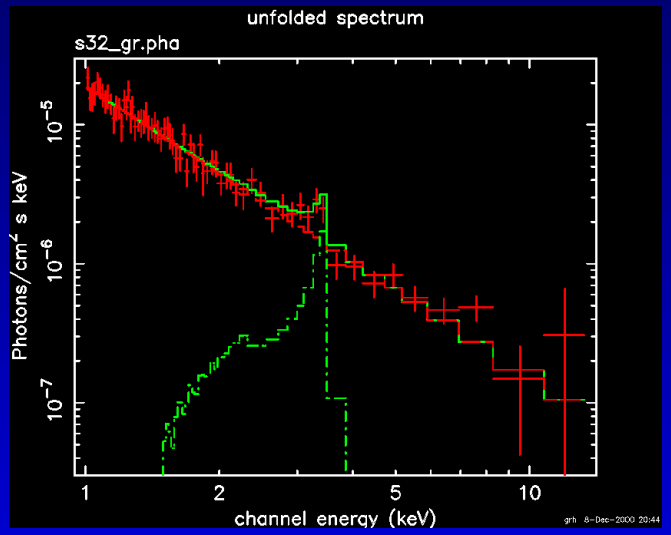




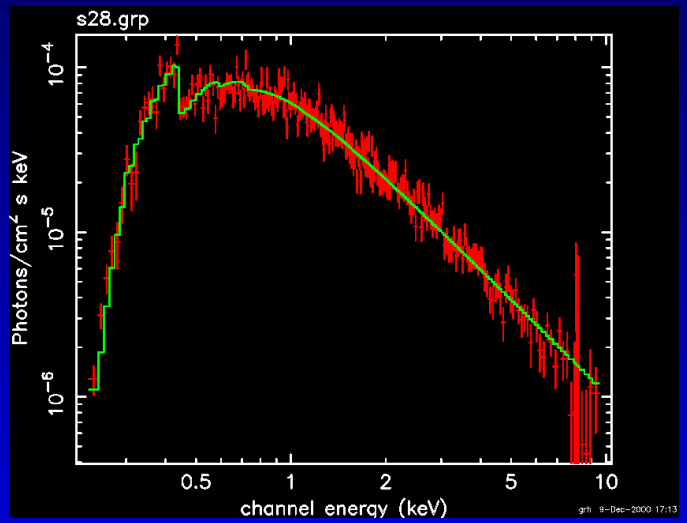
Lehmann et al. 2001 (L. Pozzetti)

Subaru ICRS Pat Henry

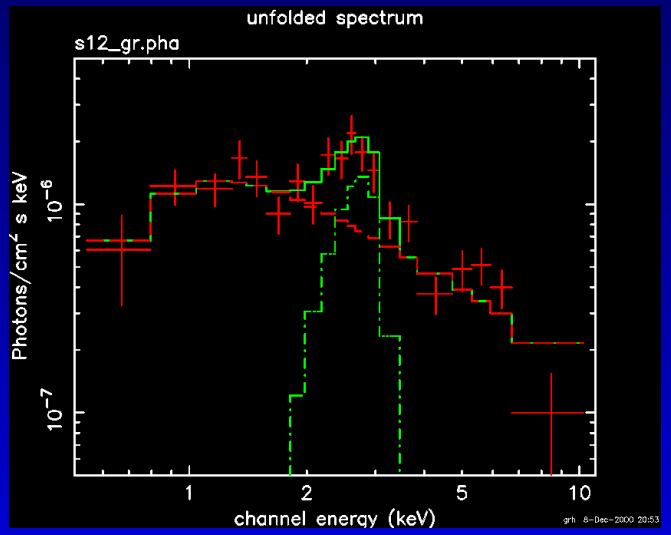
XMM Absorbed AGN spectra



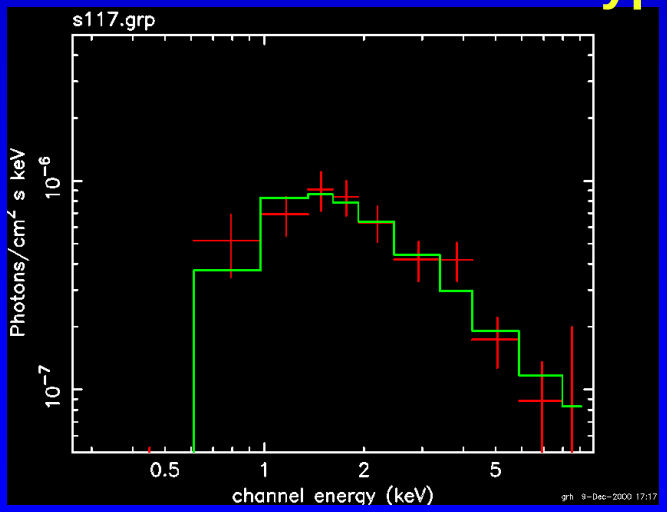
AGN type I

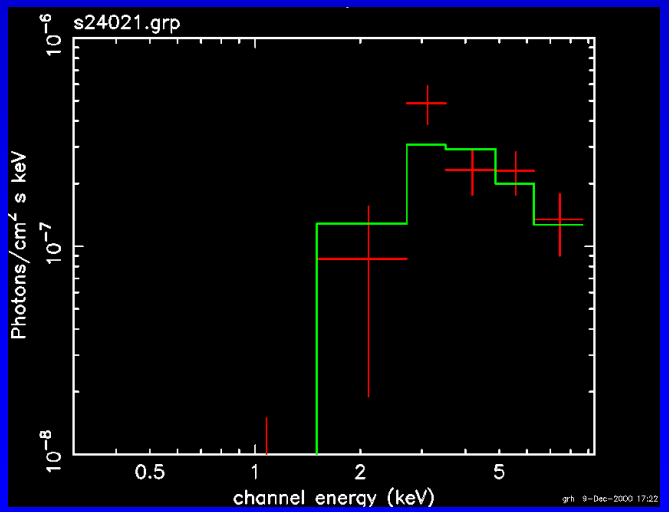


AGN type II



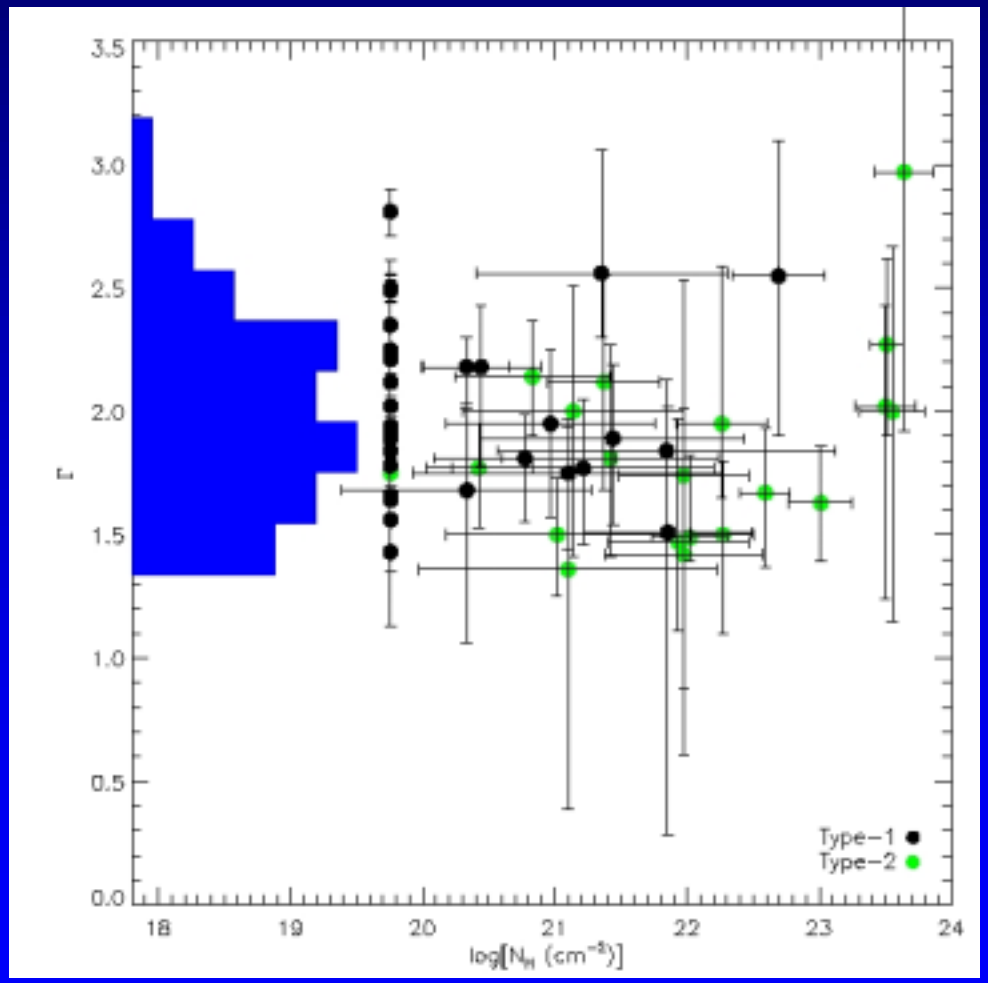
Fe II K line



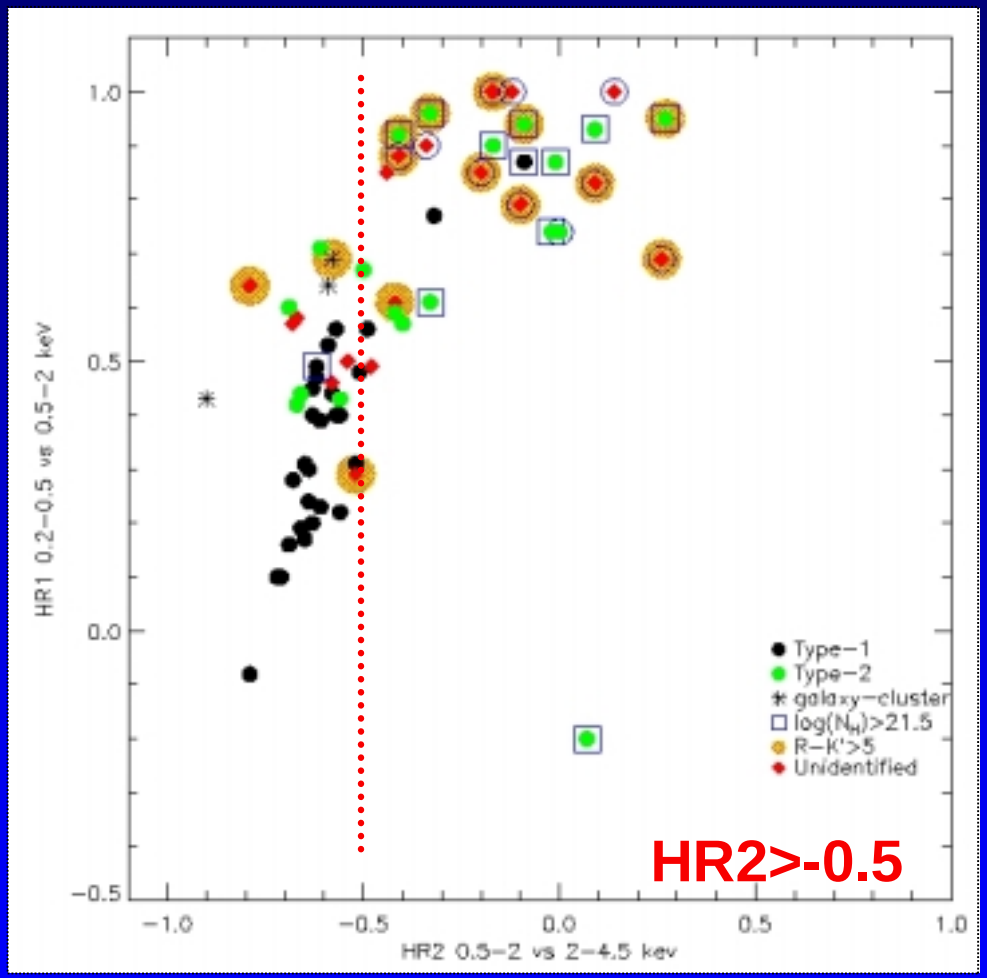


AGN type II – intrinsic absorption (10^{21}-10^{24} cm^{-2})

X-ray properties



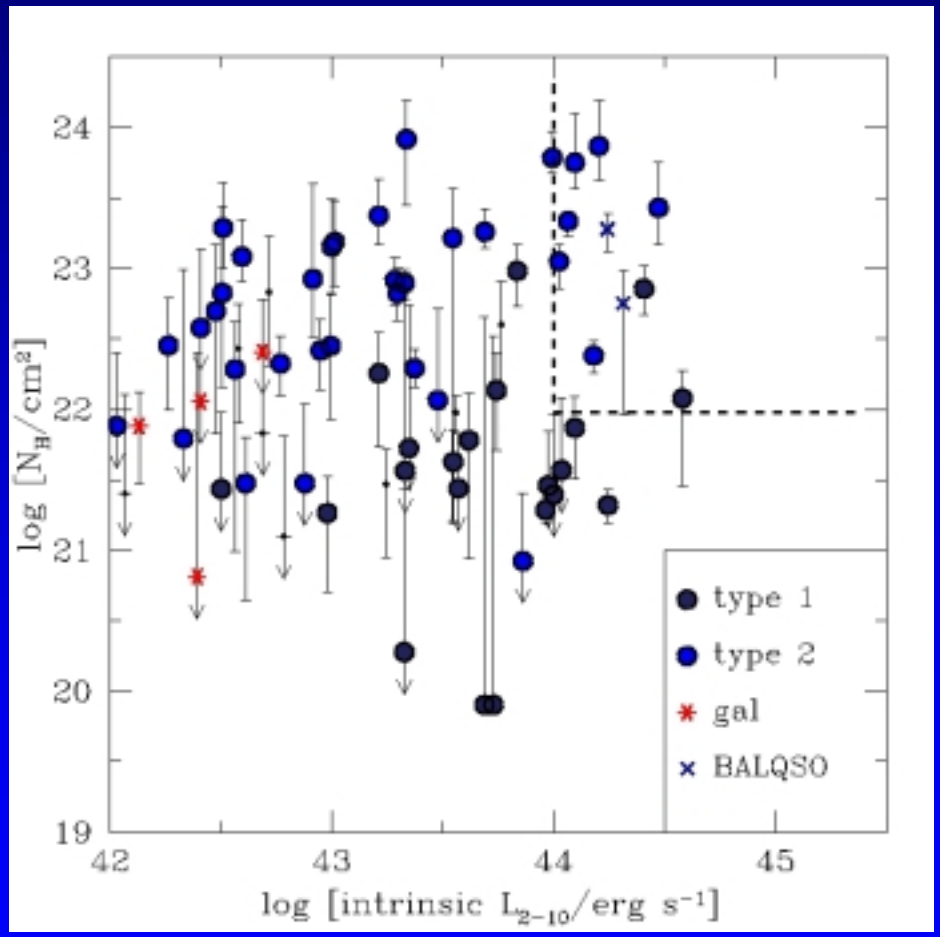
Mainieri et al. 2002



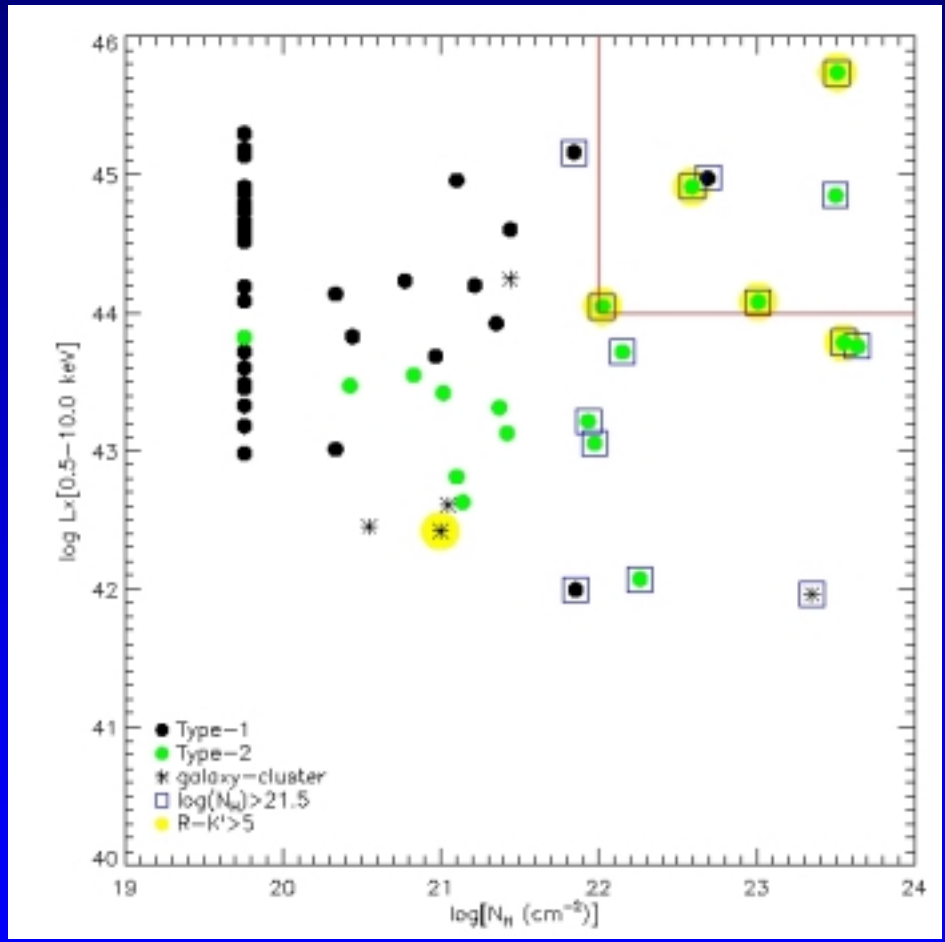
Hardness ratio selection !

Fraction of type-2 QSOs

CDFS

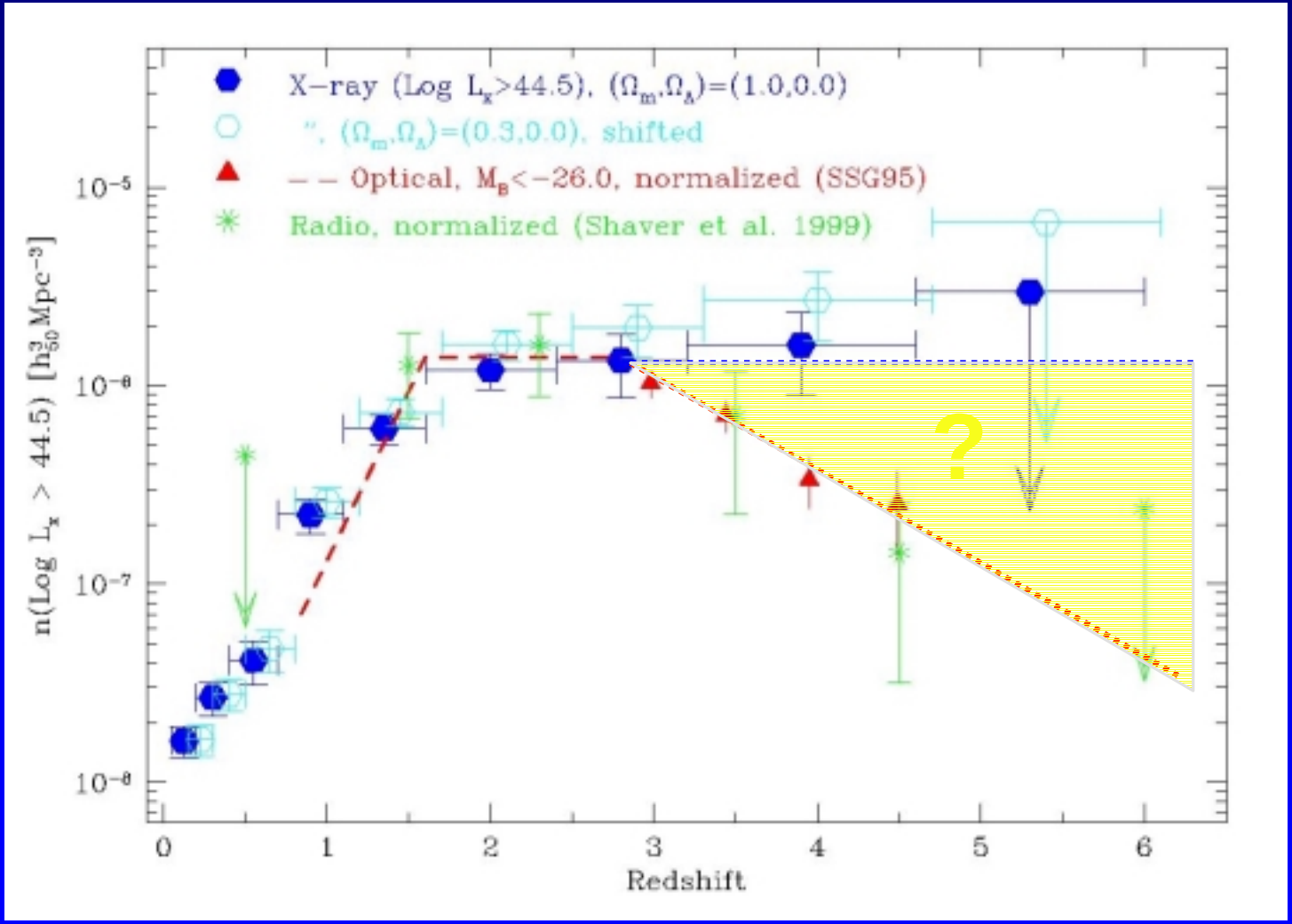


Lockman Hole



~10 % (11 objects) ➔ Significant population!!!

AGN Space Density



Miyaji et al., 2000

Summary

- High angular resolution images of AGN & galaxies
- X-ray diagnostics of supermassive black holes
- Detection of new spectral features of AGN
- ~100 % of the cosmic hard X-ray background resolved
- XMM-Newton/Chandra sources – hard, intrinsically abscured AGN (N_H=$10^{21\text{-}24}$ $cm^{-2)}$, mainly at z<1,but significant number of type-2 Quasars found