X-ray Emission from Active Galactic Nuclei

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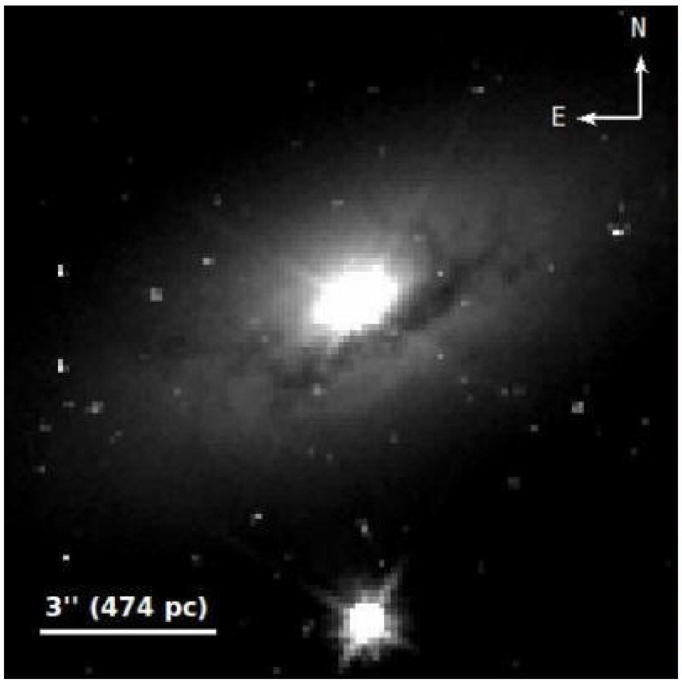
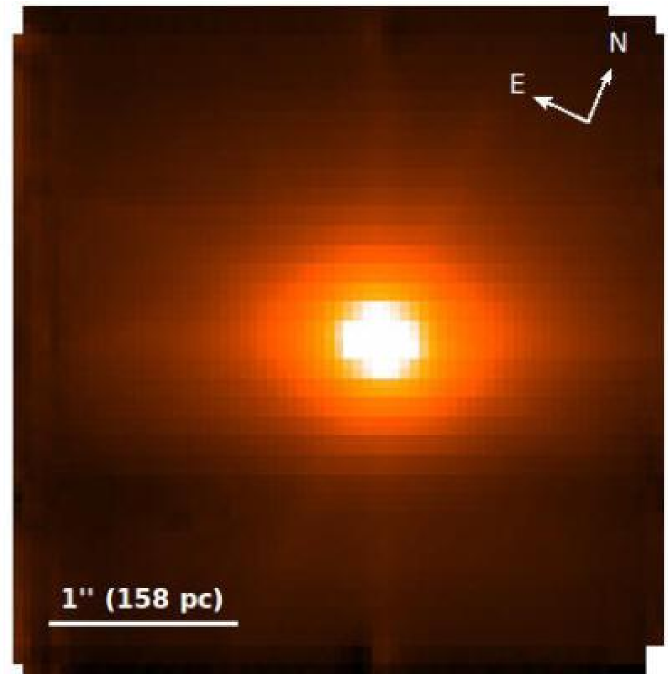
IUCAA

Chandra Workshop, NCRA, 25 October 2017

Active Galactic Nuclei





Nuclei of galaxies that are active - an energy source other than stars
Called AGN if the activity is substantial in some characteristic determined observationally e.g., Strong X-ray Variability, Jets from nuclei, Broad emission lines, etc.

Active Galactic Nuclei

(Phenomenological description)

- **Large luminosity:** *~$10^{42\text{-}48}$ erg/s*
- **Compact:** *size << 1pc*
- **Broadband Continuum emission**
- d*L* / d*log ν ≈ constant (IR to X-rays and γ-rays)*
- **Strong emission lines** in the optical/UV
- **X-ray & gamma-ray Emission**
- **Strong variability** over the EM spectrum on a range of time scales: *minutes to days and months*
- **Jets & lobes in radio-loud AGN:** sizes ~ kpc — Mpc

AGN – Physical picture

high luminosities

highly variable

Eddington limit
=> large mass

small size

Accretion onto SMBH

Artist's impression

Central SMBH

$$(M_{\rm BH} \sim 10^5 - 10^{10} {\rm M}_\odot)$$

Powered by accretion

$$(L = \eta \dot{M} c^2)$$

Size scale : Swarzschild radius

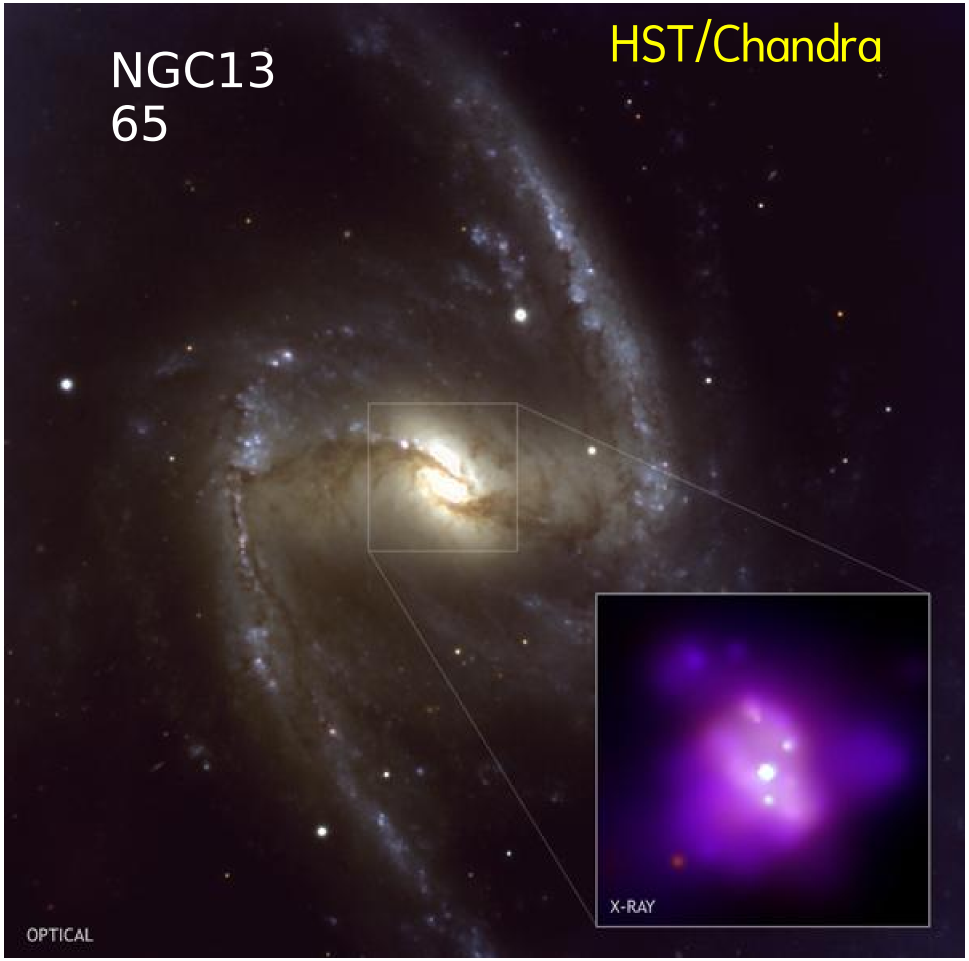
$$(R_S = \frac{2GM_{BH}}{c^2})$$

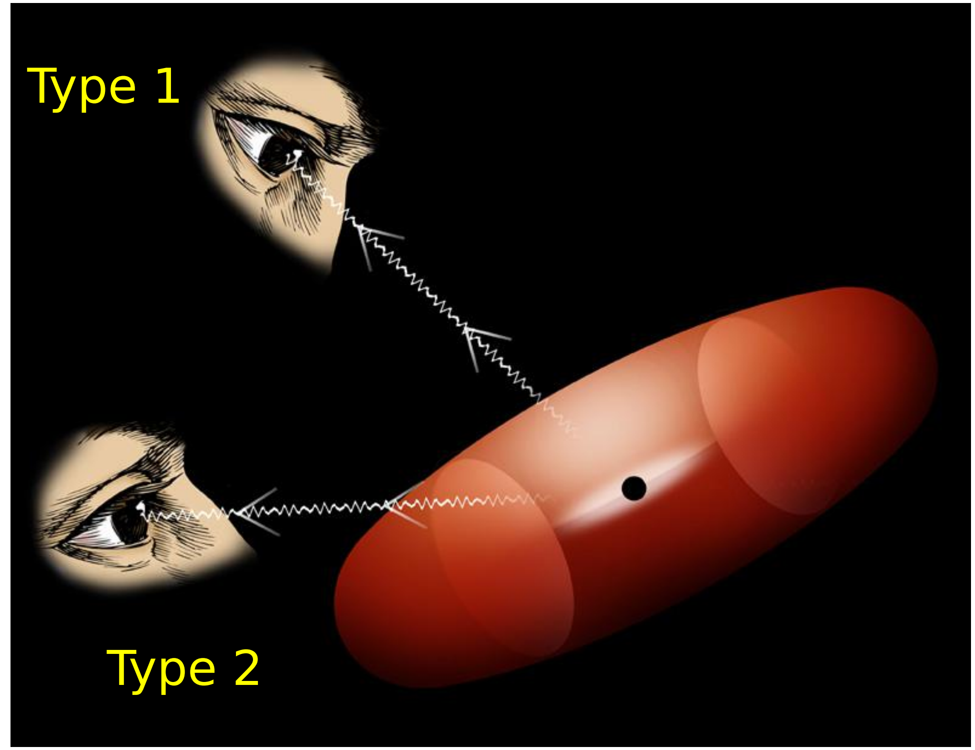
Luminosity : Eddington luminosity :

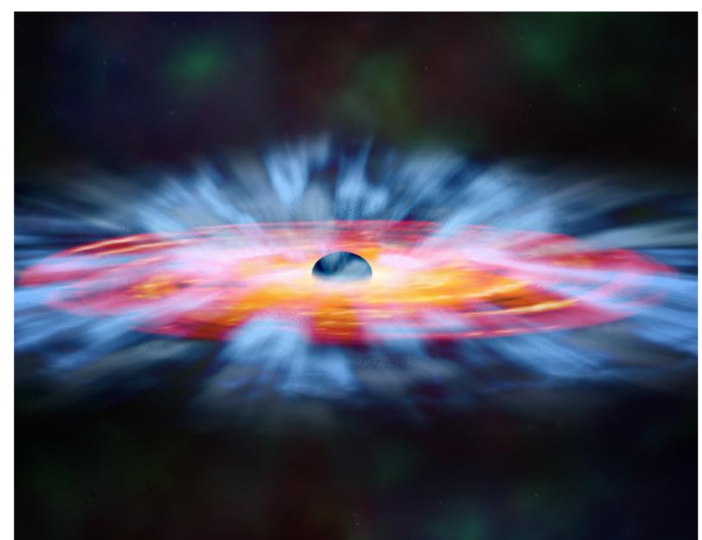
$$F_{rad} = F_{gravity}$$

$$=> L = 1.38 \times 10^{38} \left(\frac{M_{BH}}{M_\odot}\right) {\rm erg\ s}^{-1}$$

Observer's View of RQ AGN







Direct view of central engines in RQ type 1 AGN such as nearby bright Seyfert 1 galaxies

Why are X-rays important probes of RQ AGN?

Optical/UV: $\Delta t_{obs} \approx 1\text{–}10$d => $\ell \approx 0.001\text{–}0.01$ pc

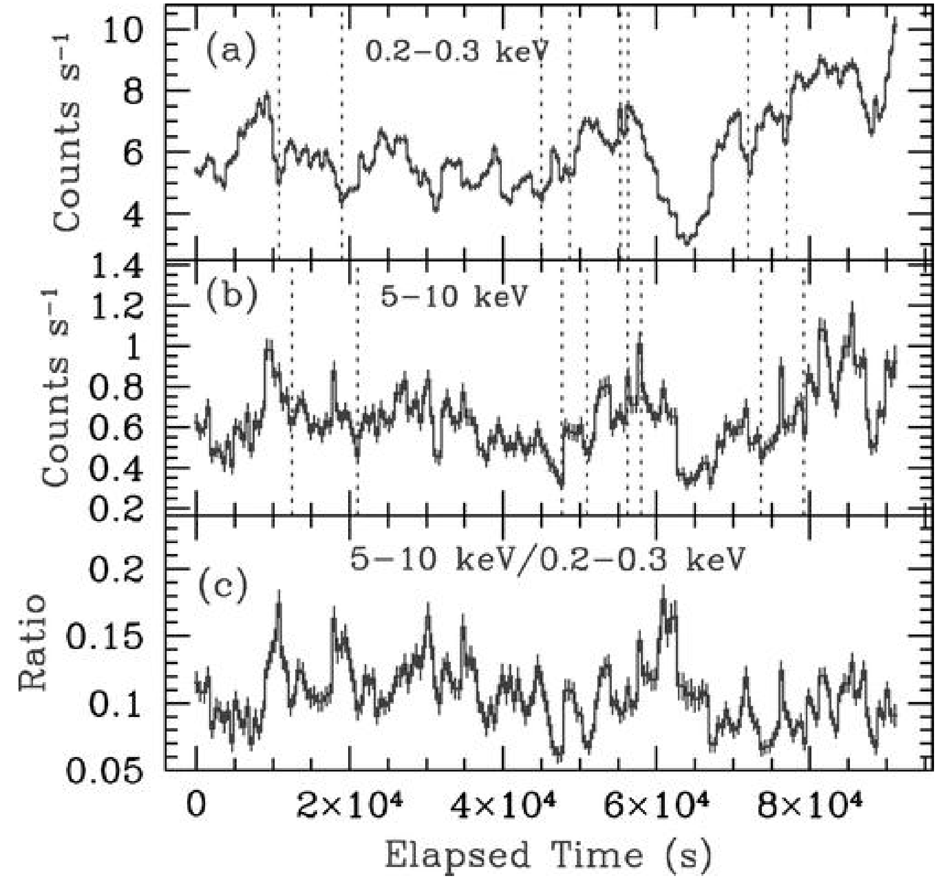
X-ray: $\Delta t_{obs} \approx 1$ hour => $\ell \approx 10^{-5}$ pc

In comparison:

Schwarzschild radius $R_S = \frac{2GM}{c^2}$

$M/M_\odot$	R_S
10^6	10^{-7} pc
10^8	10^{-5} pc
10^9	10^{-4} pc

Akn 564 (Dewangan et al. 2007)

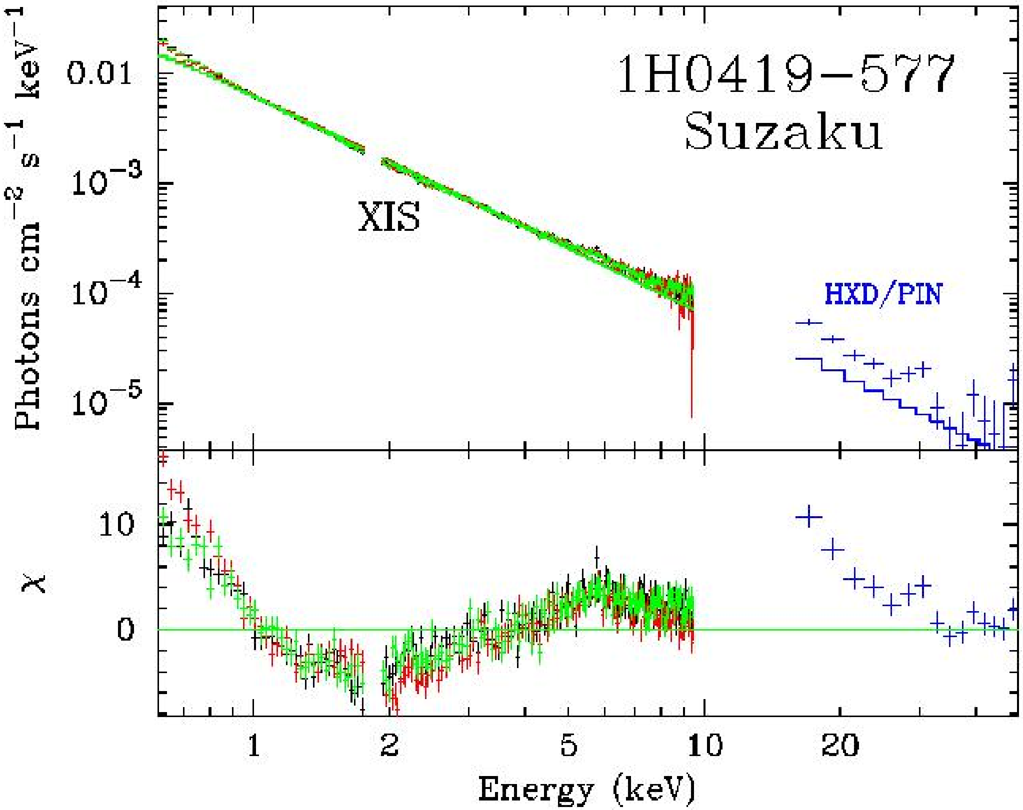


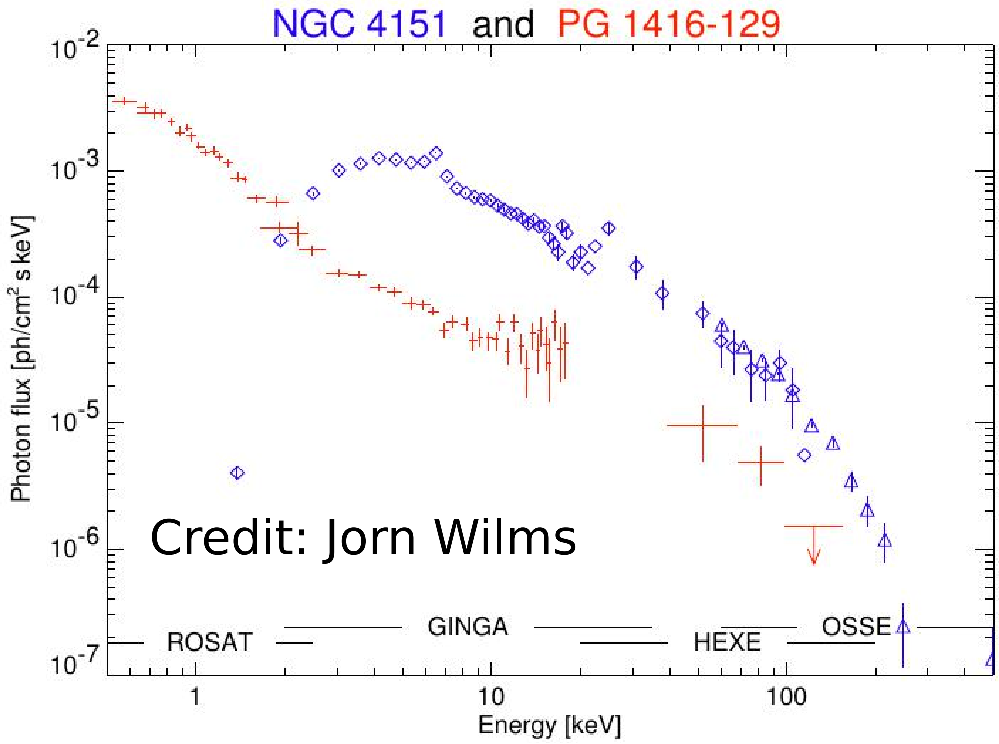
X-ray Variability in the vicinity of SMBH

X-rays probe immediate environment of SMBH

X-ray continuum of AGN

Powerlaw : N_E (photons cm^{-2} s^{-1} keV^{-1}) $= AE^{-\Gamma}$





Powerlaw continuum with a high energy cutoff at ~100 keV

Origin : Comptonization in a hot corona

X-ray powerlaw continuum

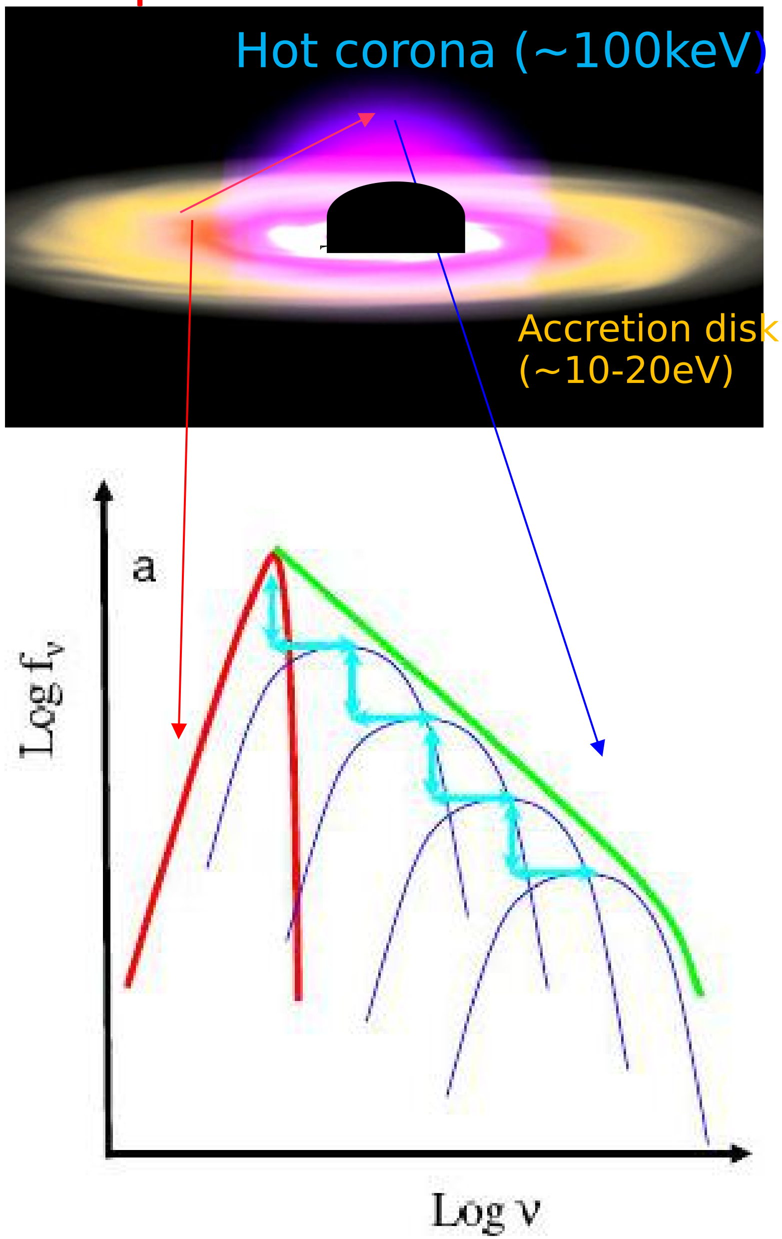
Compton up-scattering of soft photons from a cool accretion disk (<50eV) in an optically thin hot corona (100keV, $\tau < 1$)

A fraction τ of seed photons get upscattered to energies by a factor $1 + \frac{4kT_e}{m_e c^2}$

Repeated upscattering => powerlaw with a cutoff

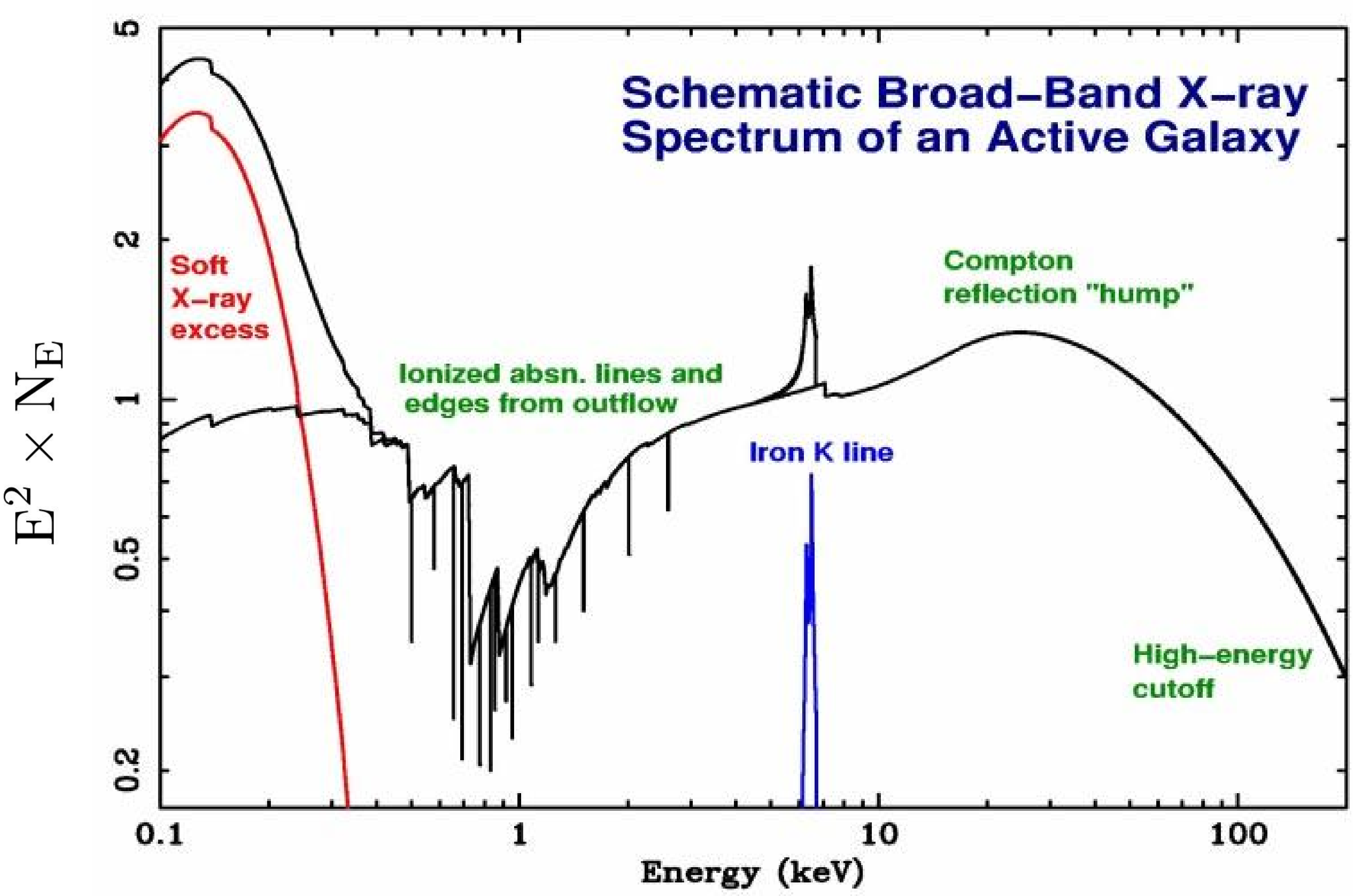
$$E_{cut} \sim kT_e$$

Two phase model



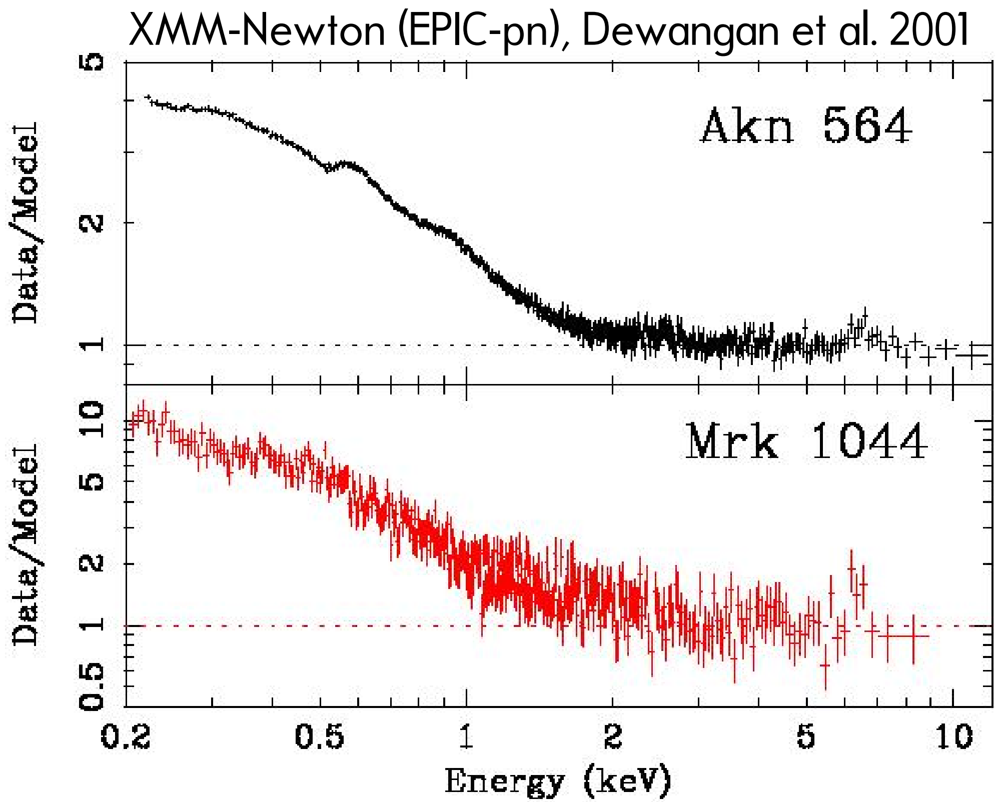
Haardt & Maraschi (1991, 1993), Done (2010)

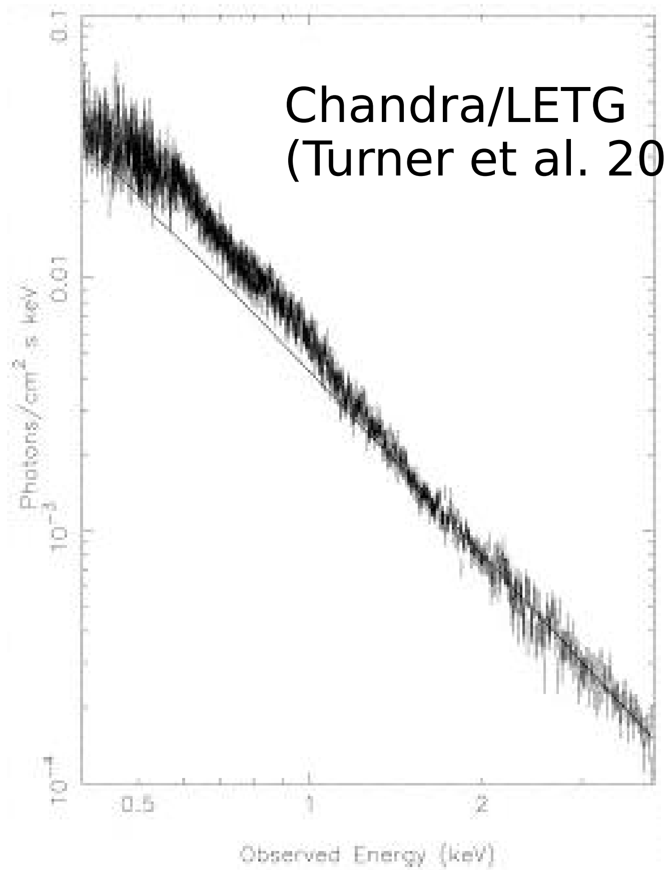
Schematic X-ray SED of type 1 AGN



Credit: Neil Brandt

Soft X-ray Excess Emission





Soft X-ray excess emission (disevered by Singh et al. 1985, Arnaud et al. 1985)

Single or multiple BB kT~100-300eV

Optically thick emission from an accretion disk – NO

Origin not clearly understood - blurred reflection?

Broad iron line and reflection hump

MCG-5-23-16: Suzaku observations

Observed Flux

$$\mathbf{f_{2-10keV} = 9 \times 10^{-11}}\mathrm{ergs\ cm^{-2}s^{-1}}$$

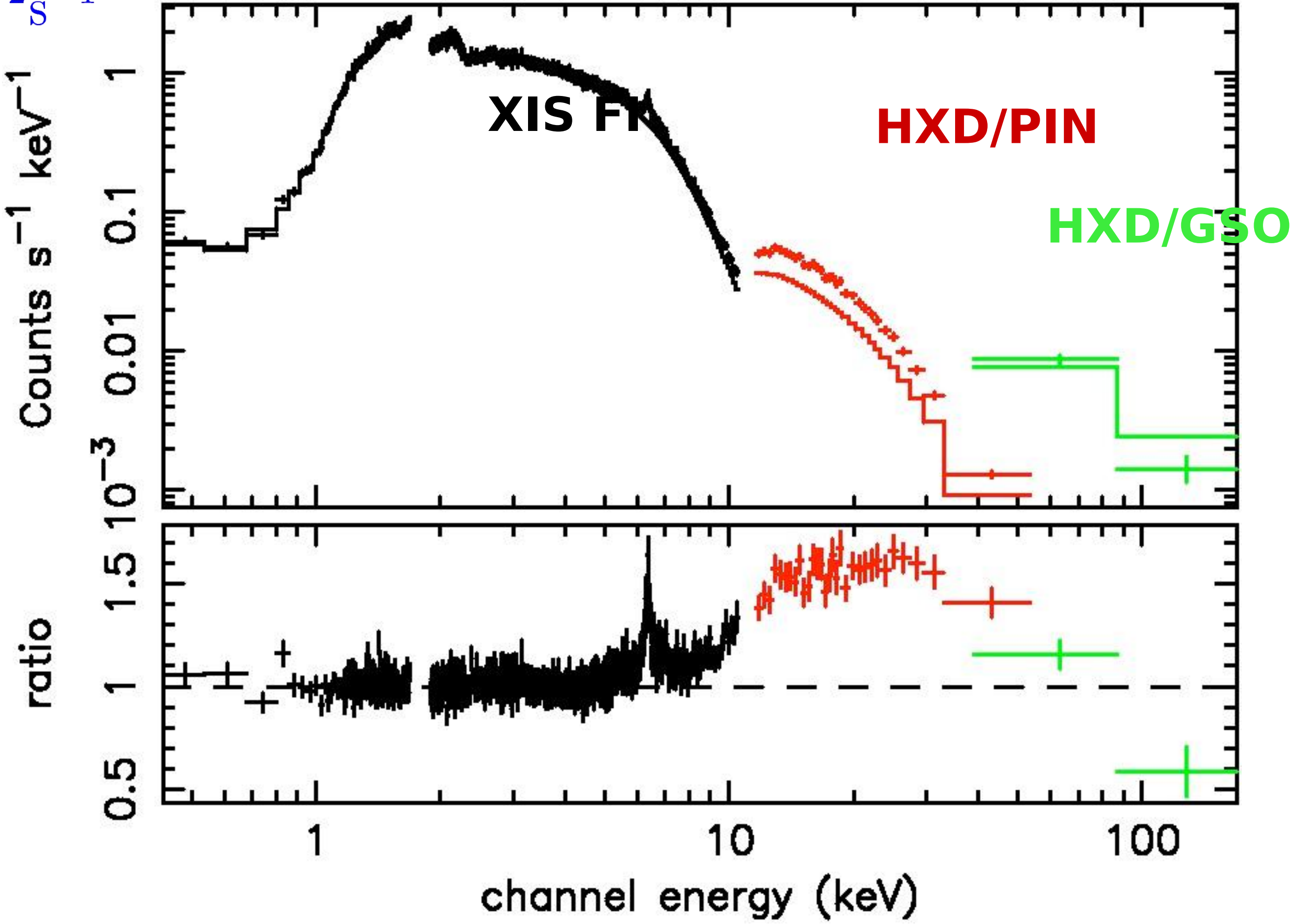
$$\mathbf{f_{15-100keV} = 2 \times 10^{-10}}\mathrm{ergs\ cm^{-2}s^{-1}}$$

Absorbed powerlaw (N_H=1.65×$10^{22}$$cm^{-2}$, Γ=1.95)

Iron K line between 6-7 keV

Reflection hump above 12 keV

(Reeves, Awaki, Dewangan, etal. 2007)

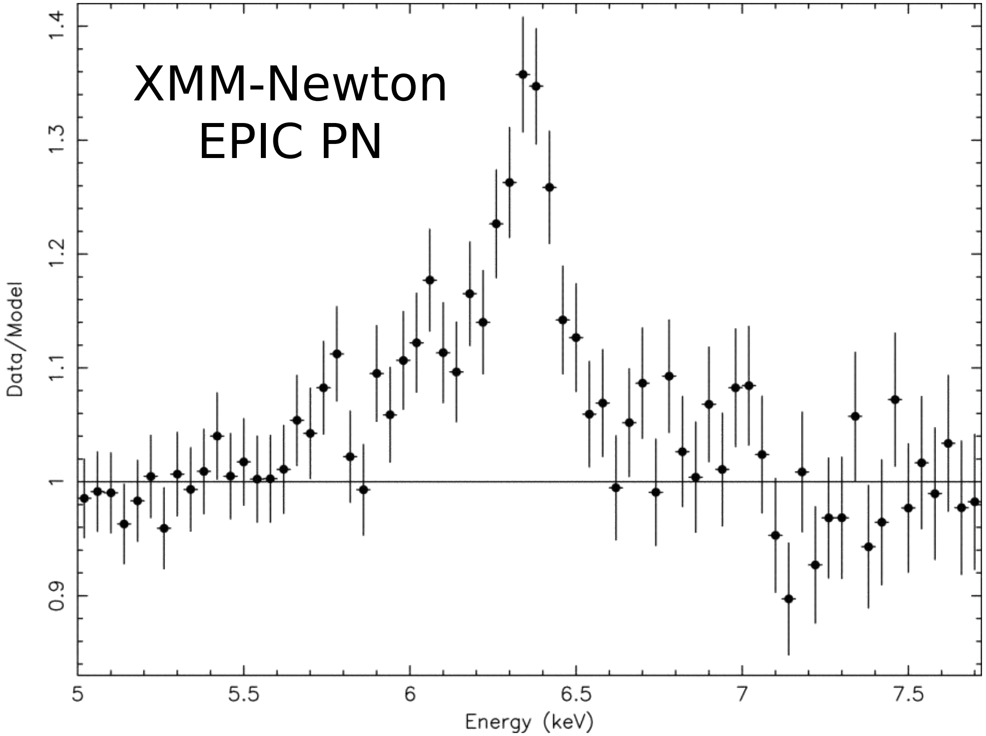


MCG-5-23-16: Broad Iron K line

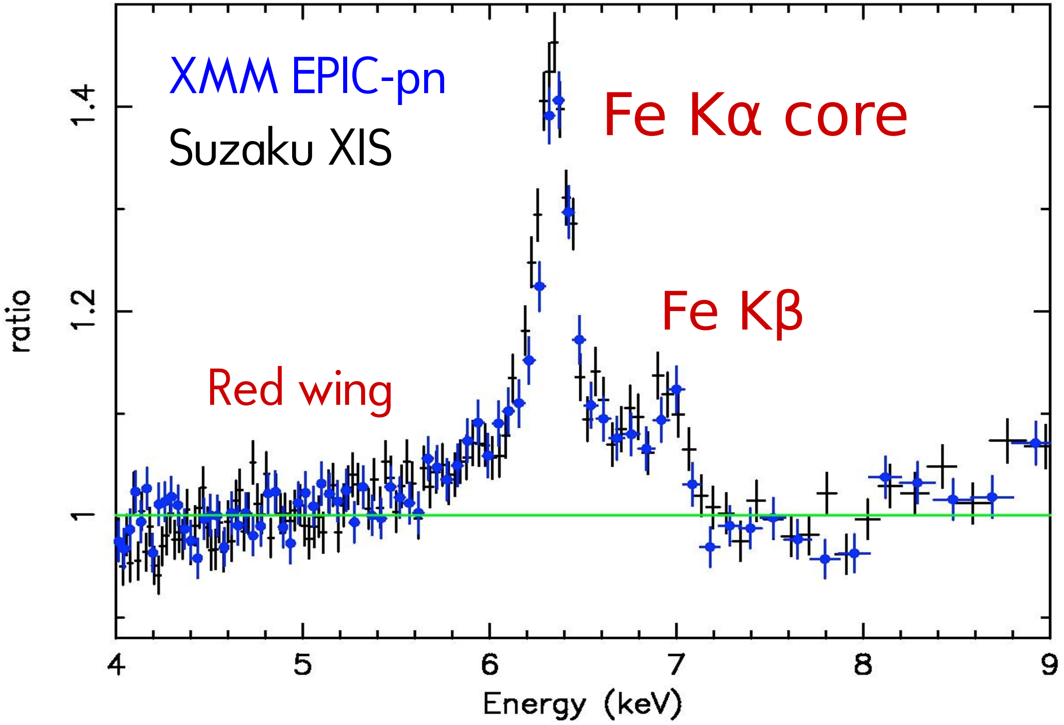
(XMM & Simultaneous XMM/Suzaku)

Iron K line shape – Data to 3-5keV best-fit PL ratio

(Dewangan et al. 2002)



(Reeves, Awaki, Dewangan, etal. 2007)



Narrow and broad iron K lines

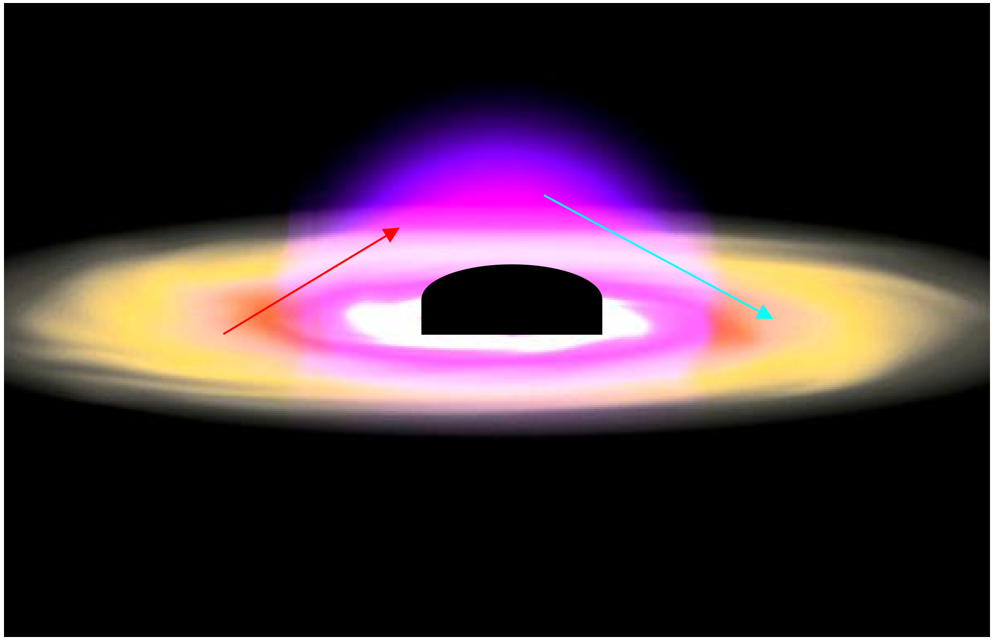
Broad component: FWHM ~ 50000 km/s

X-ray Reflection

Hot corona – powerlaw spectrum

Some of the high energy photons from the hot corona re-enter the accretion disk

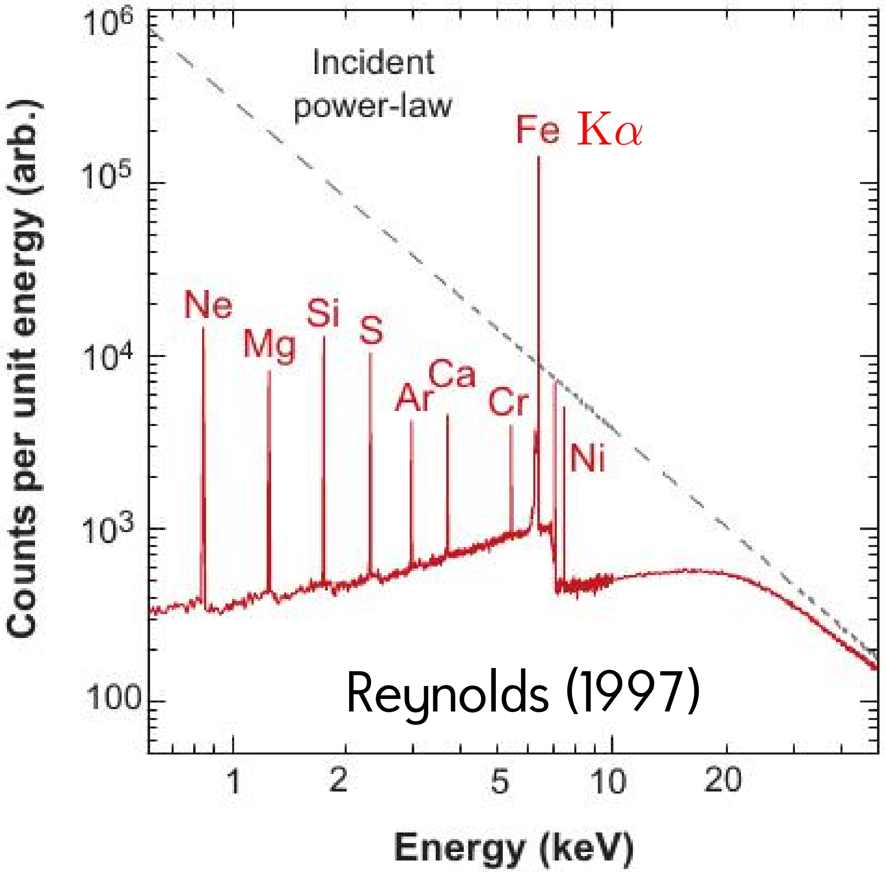
Two possible fates of the incident high energy photon



Compton scattering by free electrons in the disk

Photoelectric absorption by metals in the disk and fluorescent line emission

X-ray Reflection Spectrum



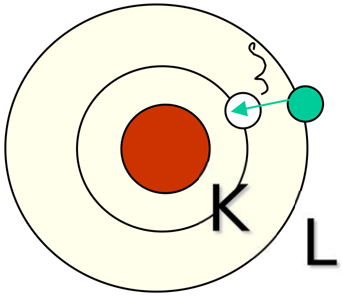
At soft X-ray energies, reflection is small due to photoelectric absorption by lighter elements

At hard X-rays, Incident photons are Compton back-scattered from the disk

A spectrum of fluorescent emission lines arises from the photoionization of metals in the disk

Iron Kα line at 6.40 keV the most prominent due to

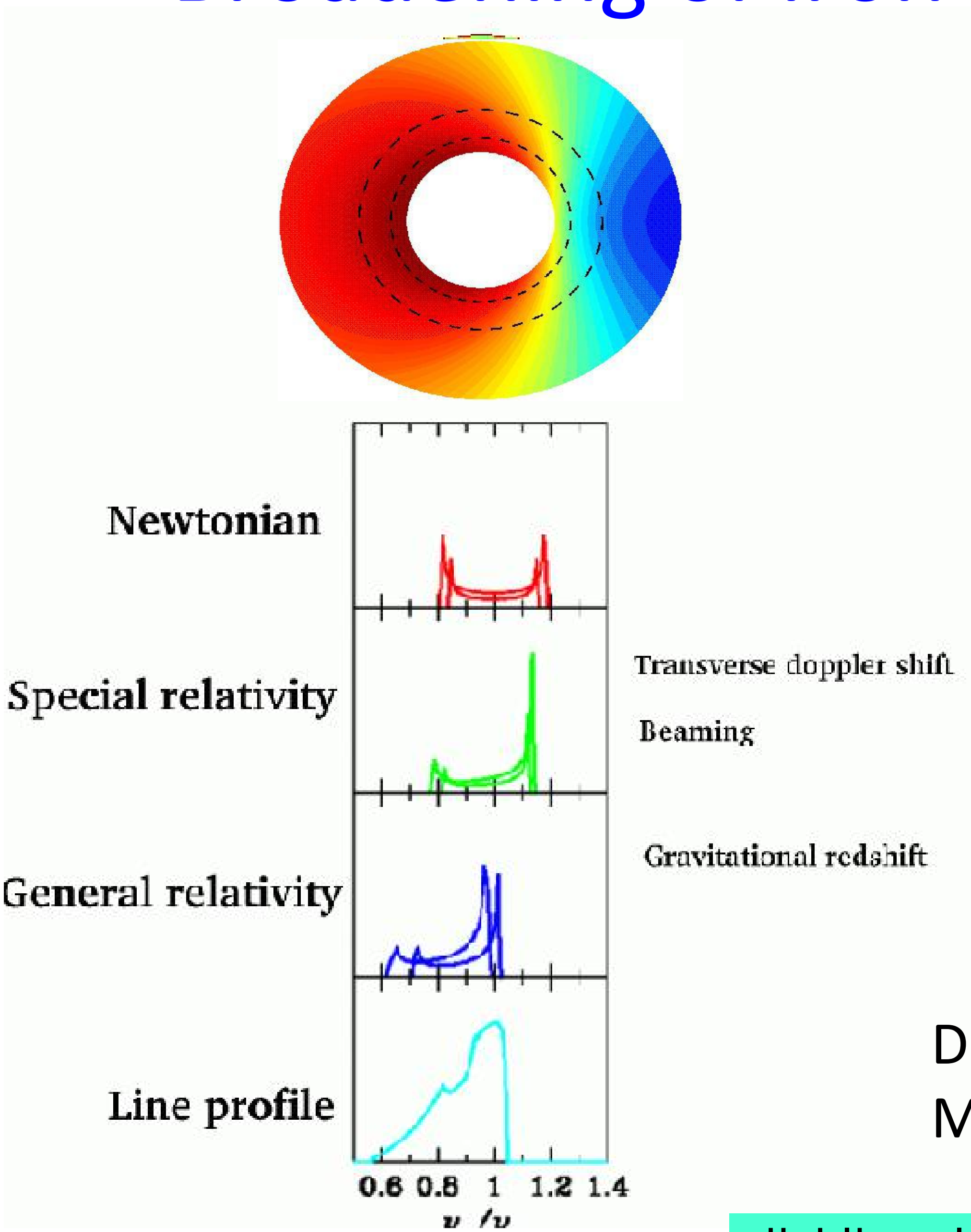
- high fluorescence yield
- large cosmic abundance.



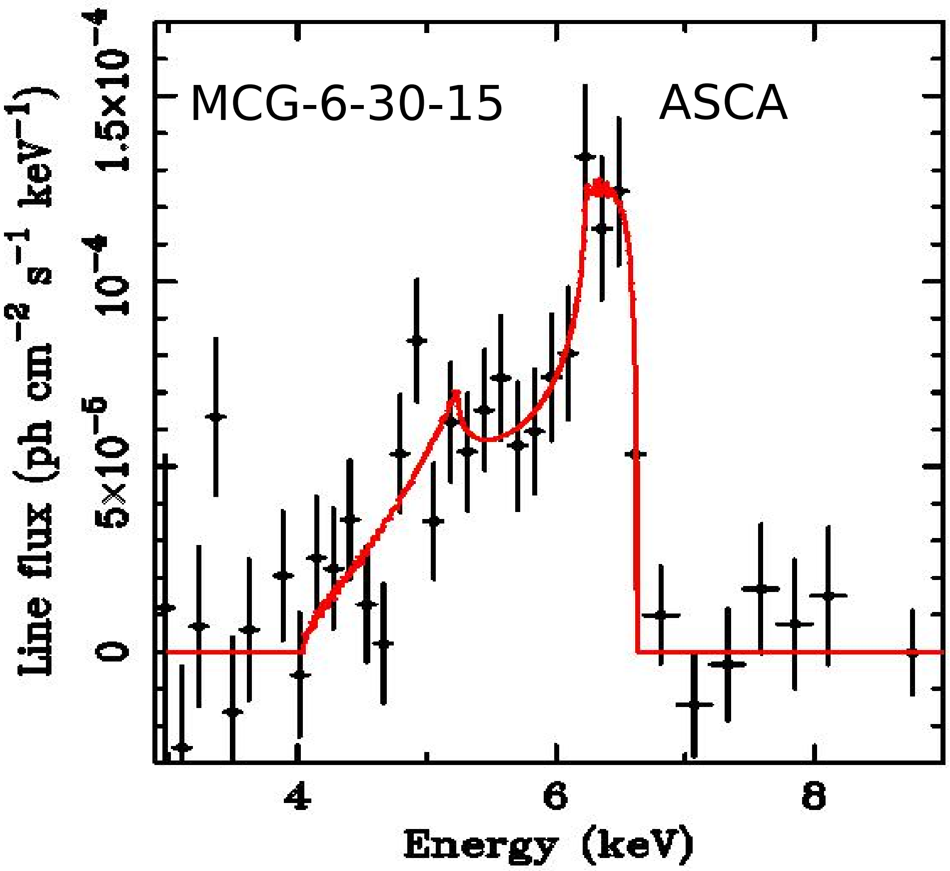
K α line

X-ray reflection : Xillver, reflionx table models

Broadening of iron line – Strong gravity



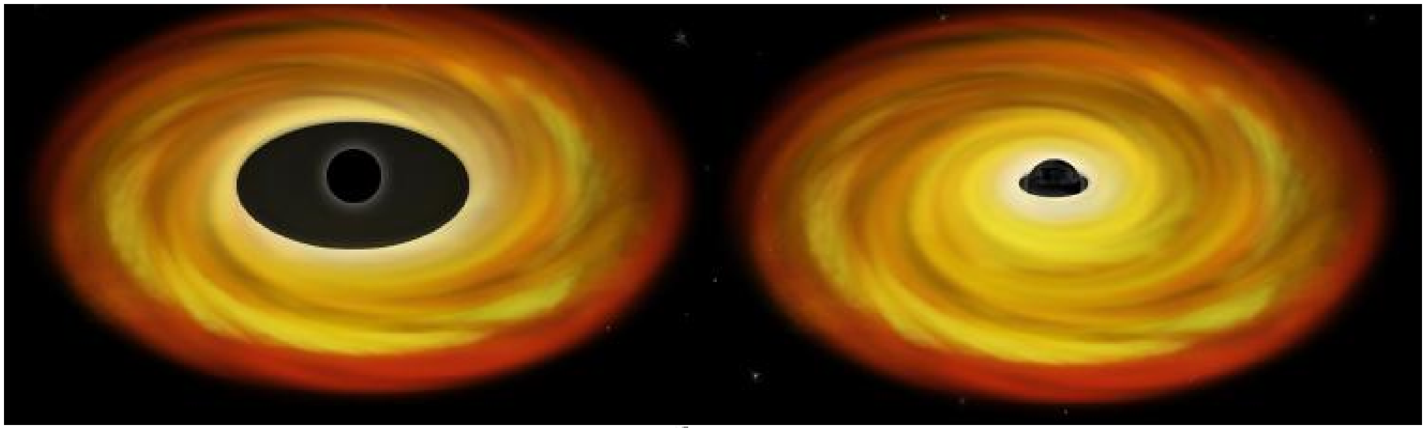
Fabian et al. (2000)

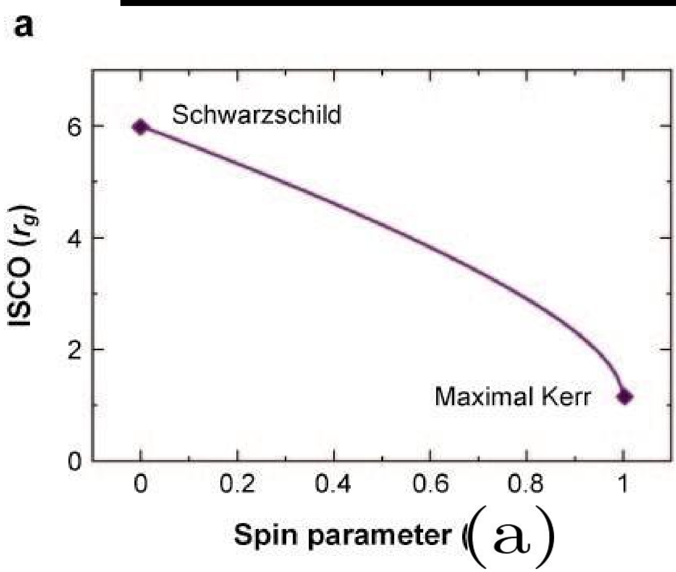


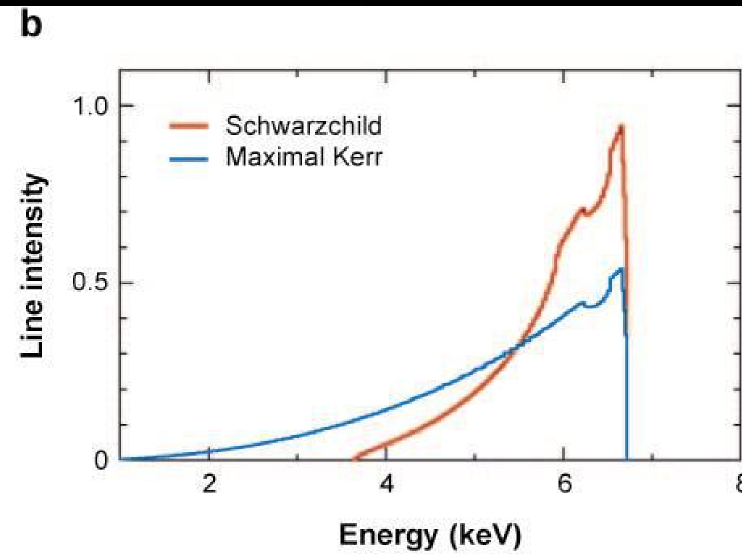
Discovery of broad Iron line profile in MCG-6-30-15 (Tanaka et al. 1995, Nature)

diskline, laor, relline models in XSPEC/ISIS/Sherpa

Broad Iron Line – Measuring BH spin







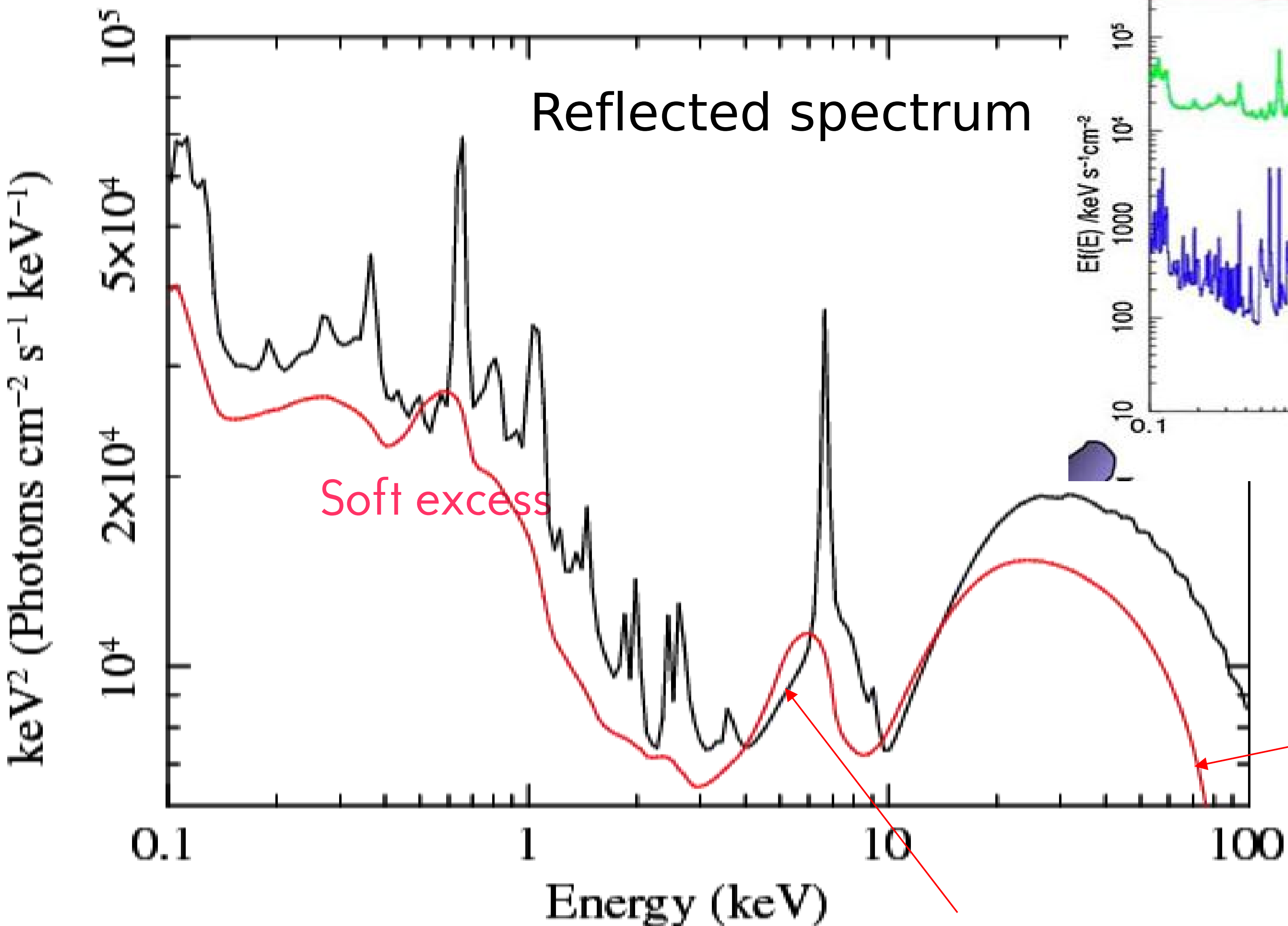
Miller JM. 2007.
Annu. Rev. Astron. Astrophys. 45:441–79

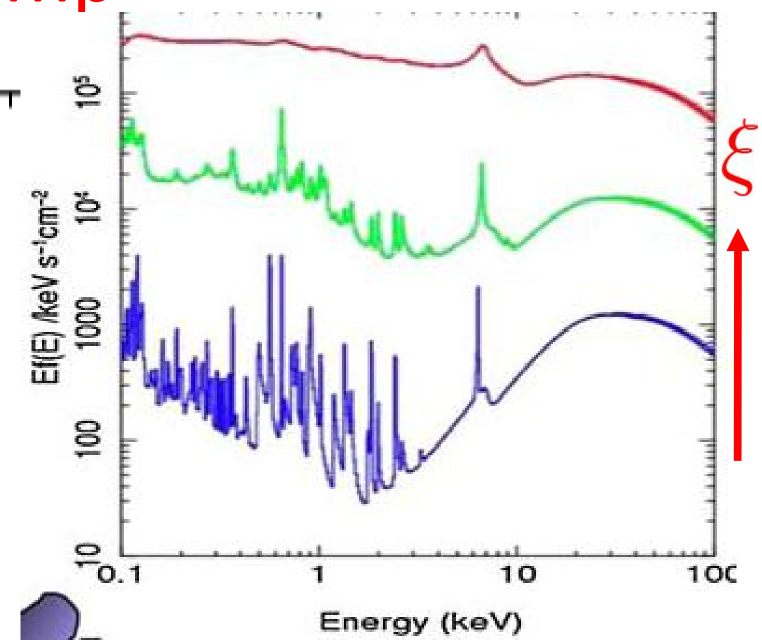
Dimensionless BH spin parameter

$$a = \frac{cJ}{GM^2)}$$

Reflection & Relativistic blurring

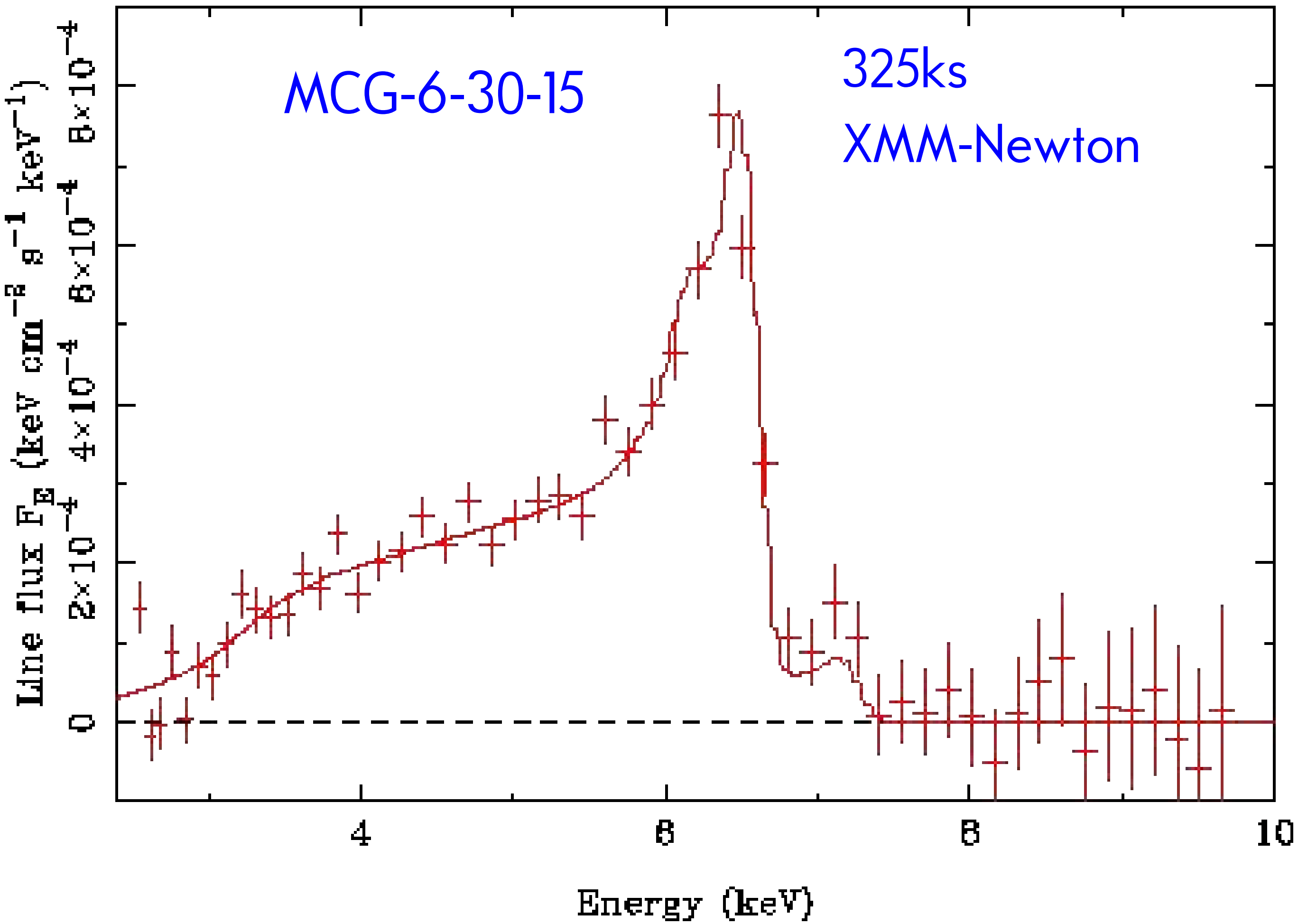
SE + broad line + hump





Relativistic reflection : relxill model

BH Spin from broad iron line



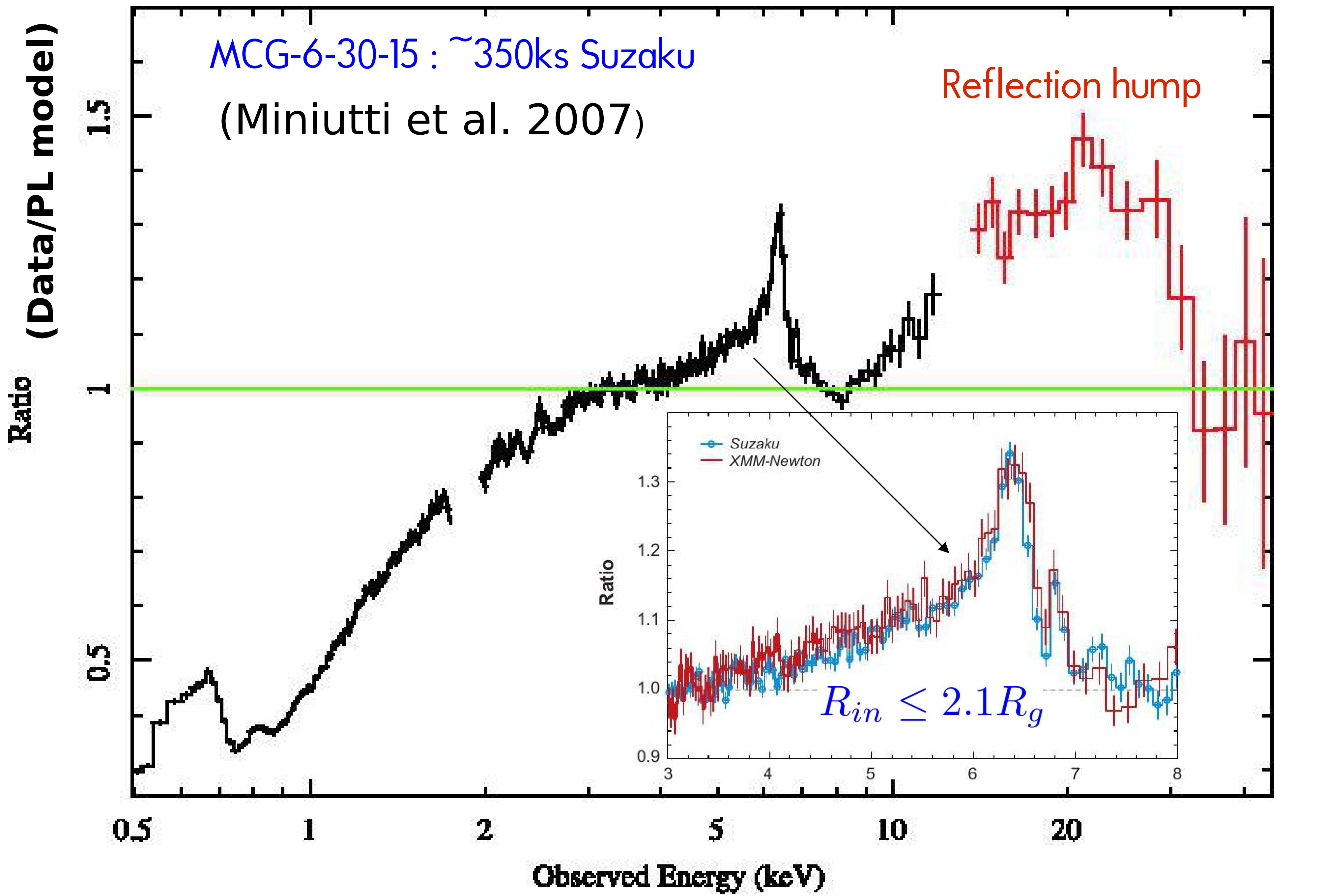
(Fabian et al 2002)

Extreme red-wing requires emission from below $6R_g$

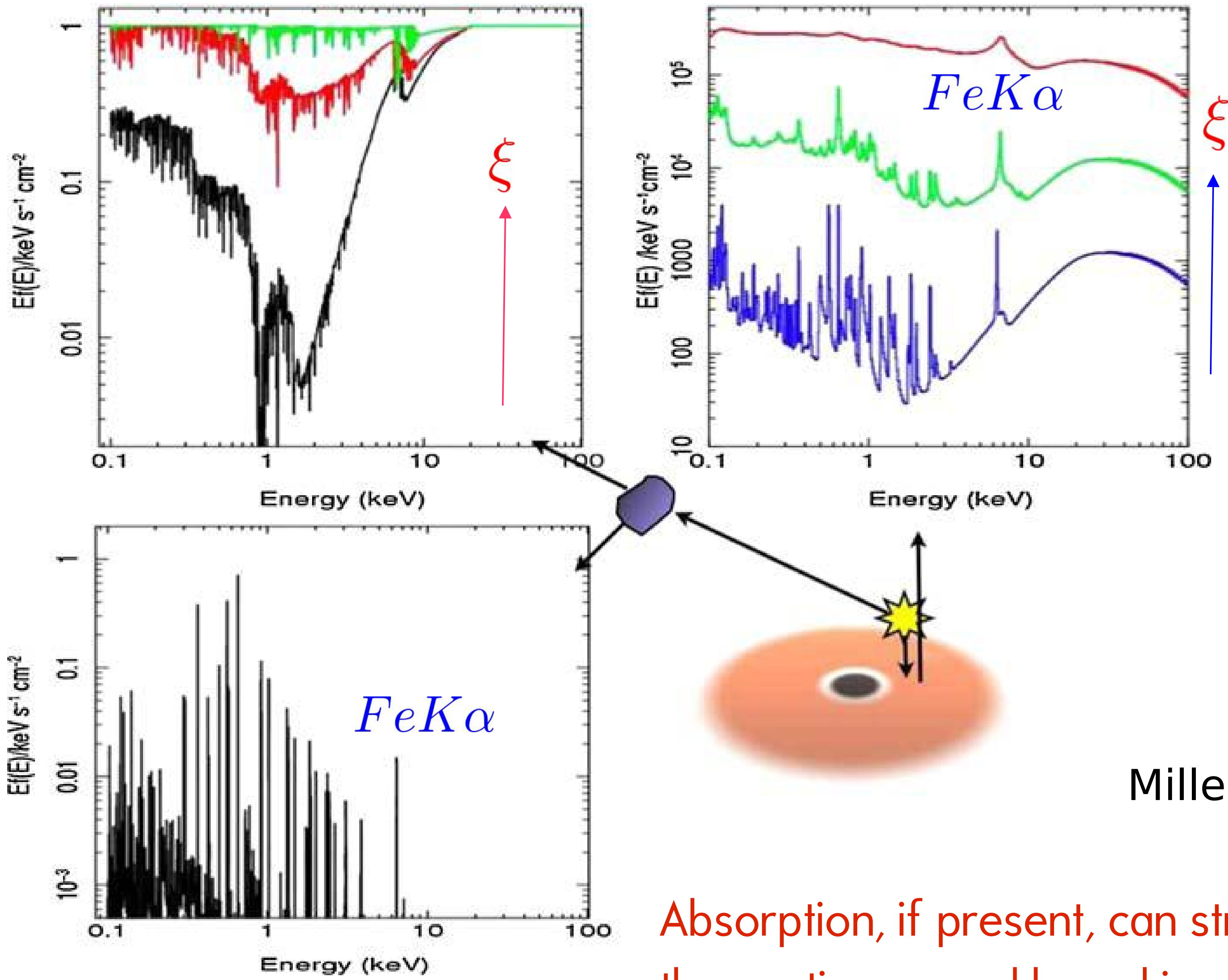
Inner disk radius at $\sim 2R_g$

➡ Highly spinning BH

Broad Iron line and Reflection hump



Reflection & Absorption



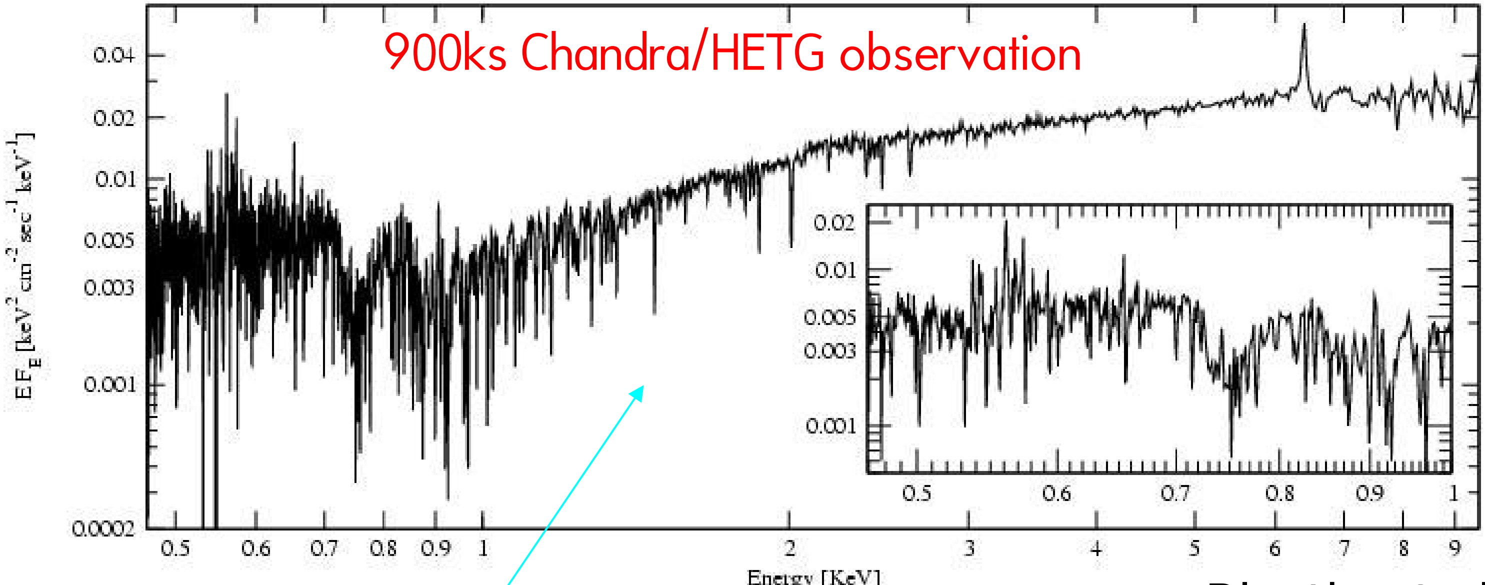
Simulated Spectra

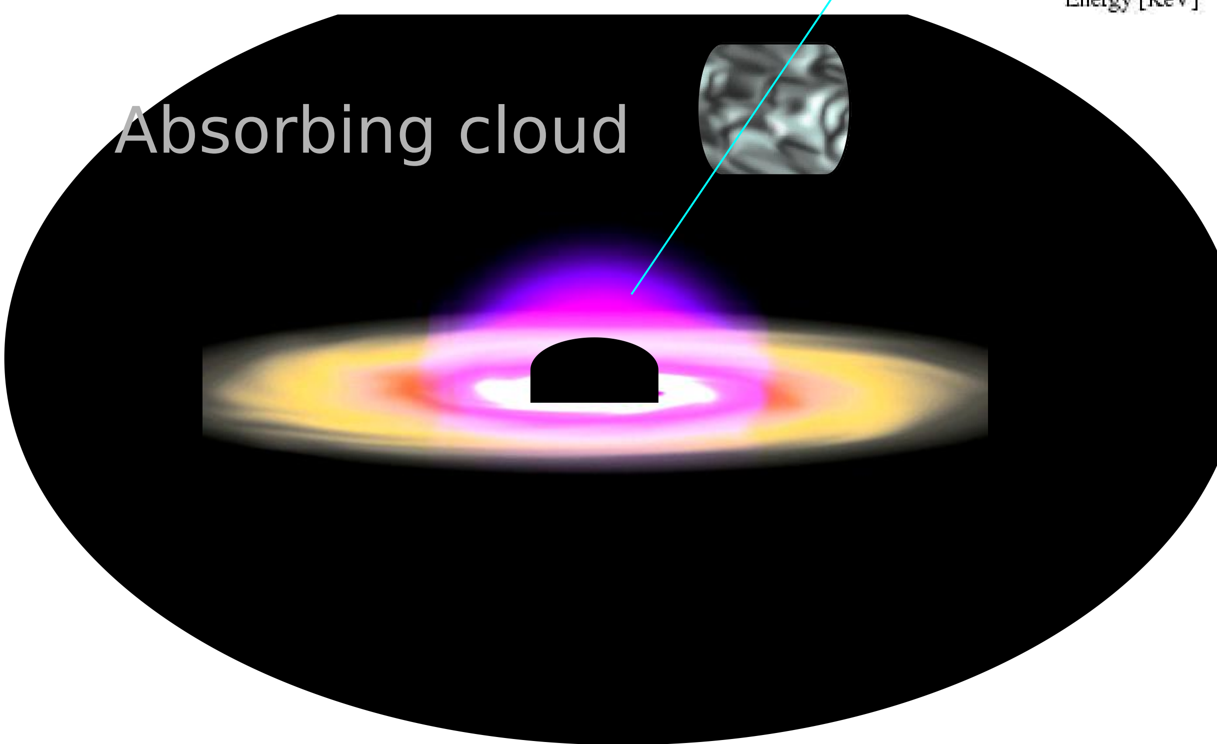
Miller & Turner 2009

Absorption, if present, can strongly affect the continuum and broad iron line

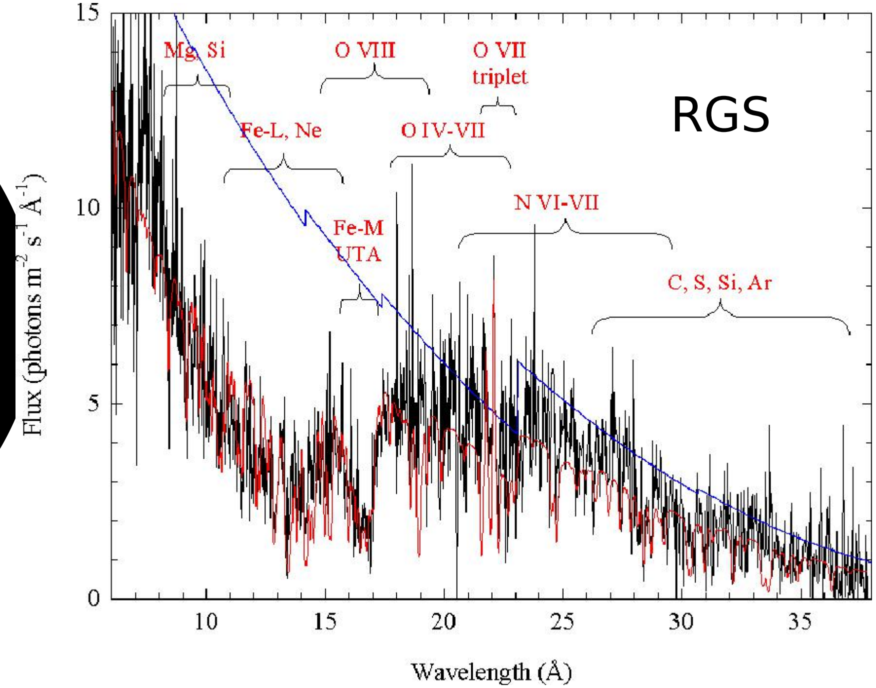
X-ray Absorption

Kaspi et al. (2002)





Blustin et al. 2002



Absorption in the X-ray band

K and L bands
Of abundant
elements

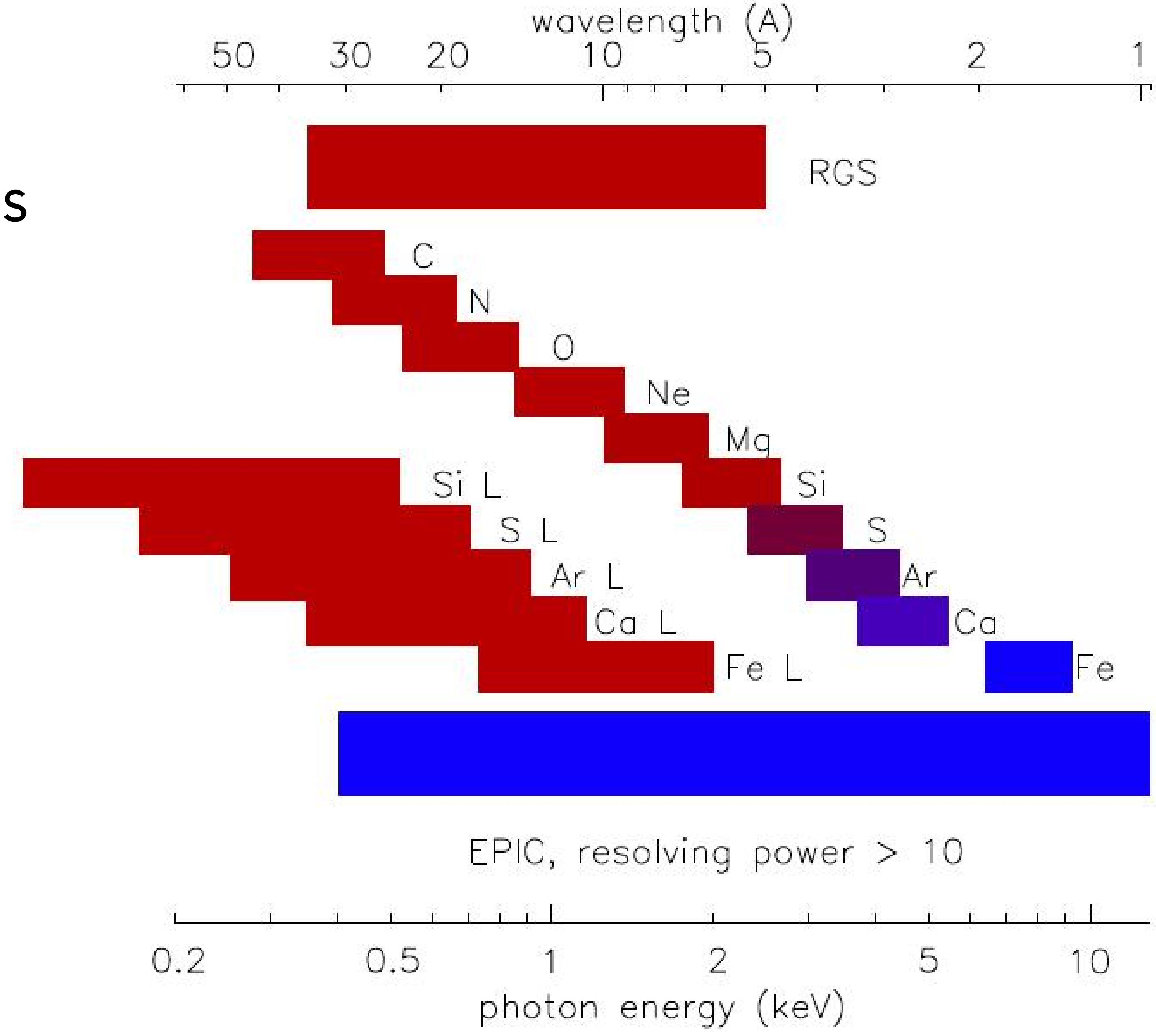
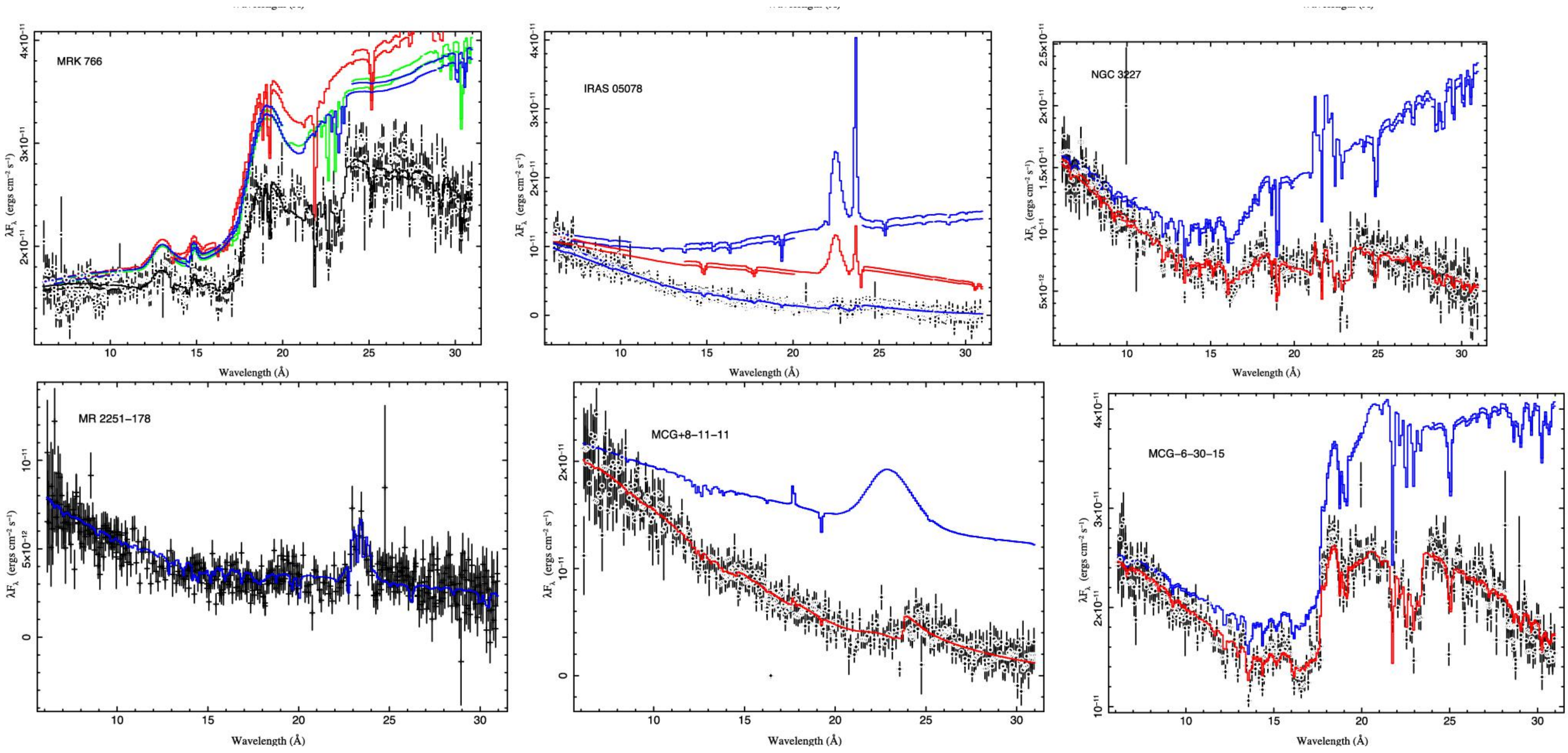


Image credit: Frits Paerels

X-ray Warm Absorbers in Seyfert 1s (XMM RGS)



Laha, Guainazzi, GCD+2014

Cloudy-based Warm absorber models

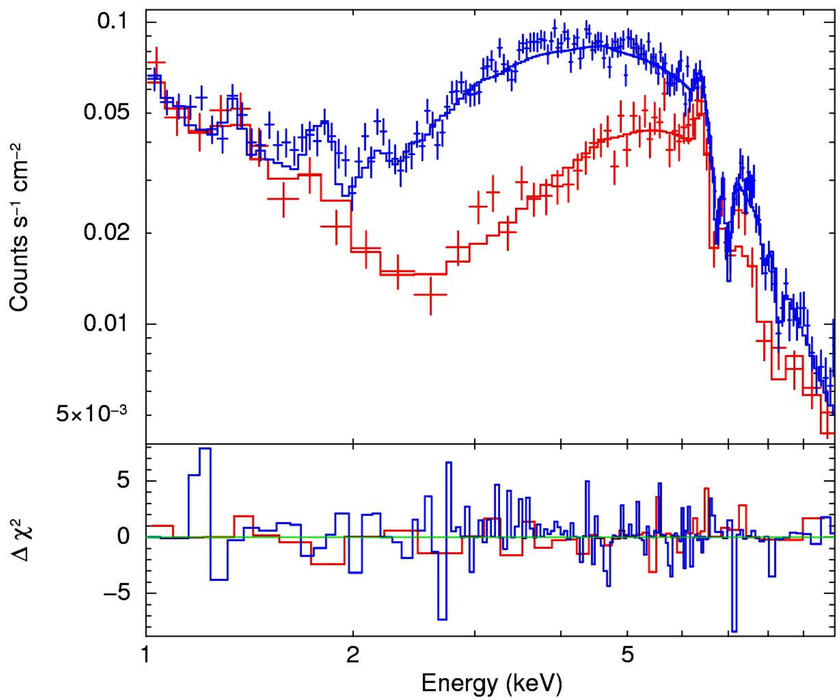
Complex & Variable Absorption

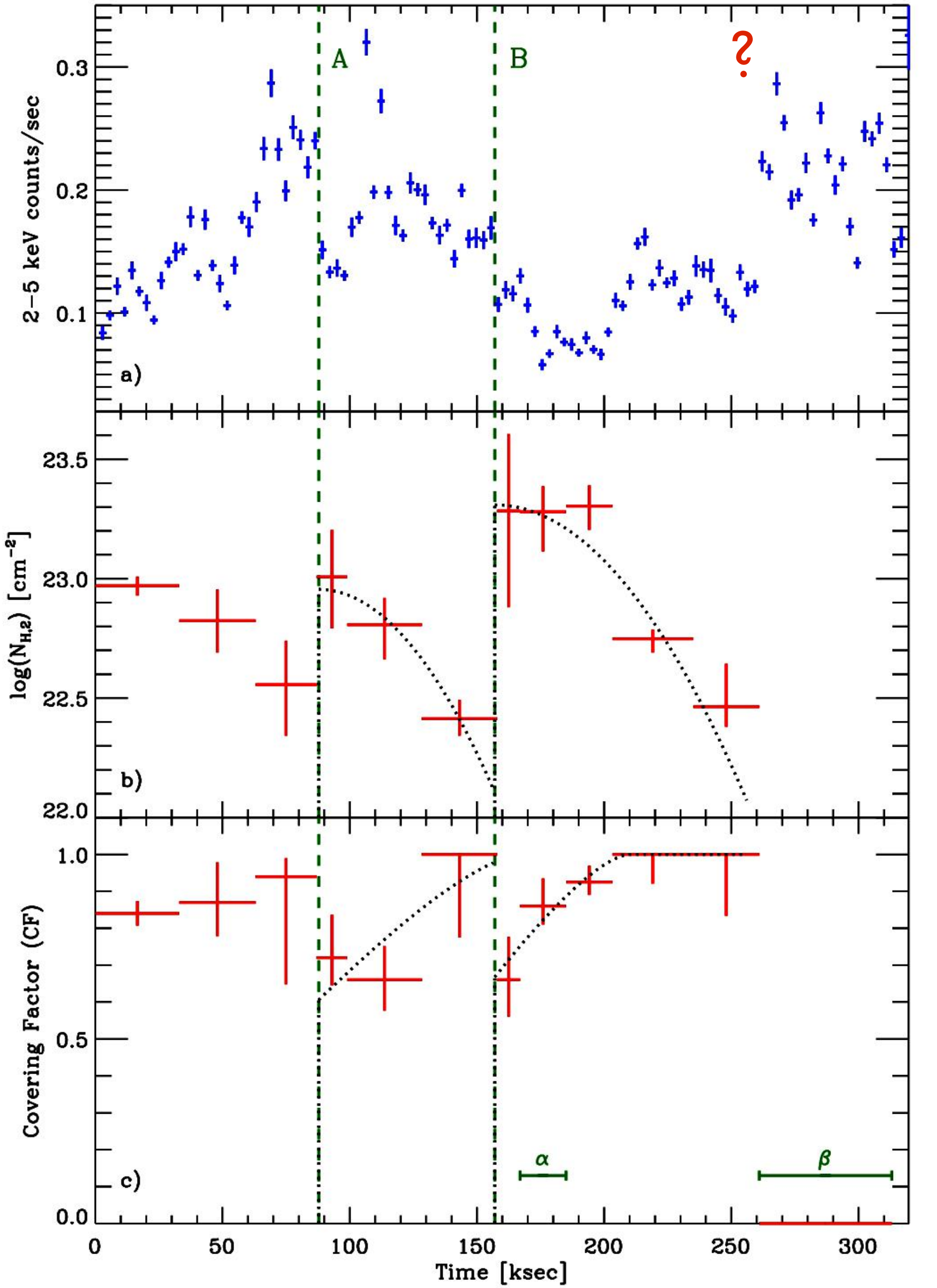
(Risaliti et al. 2009; Mailino et al. 2010)

Variable neutral partial covering absorption on hours-days scale.

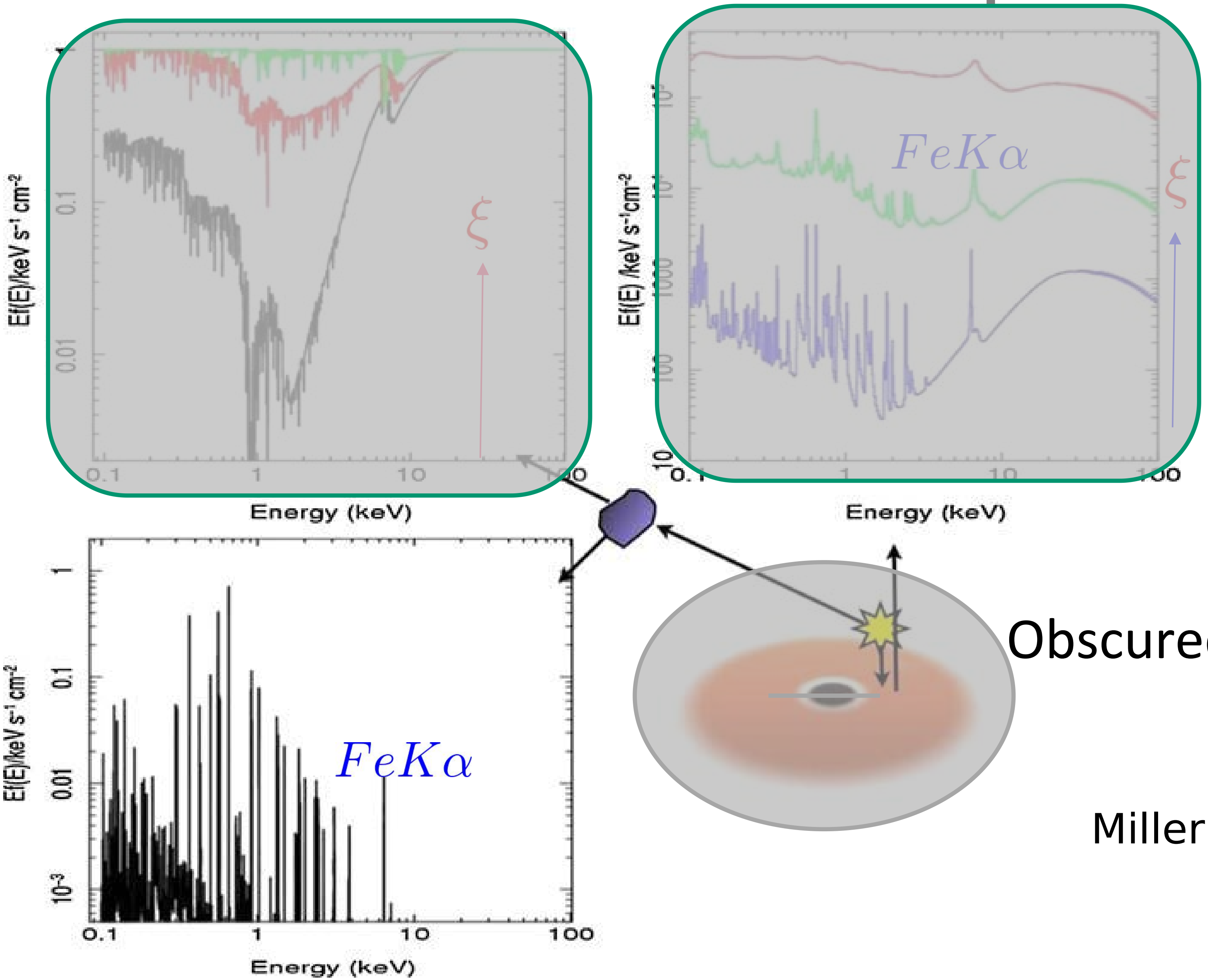
Both N_H and CF vary on short time scales. Cometary-shaped BLR clouds crossing the line of sight.

NGC 1365





Reflection & Absorption



Simulated Spectra

Obscured from view

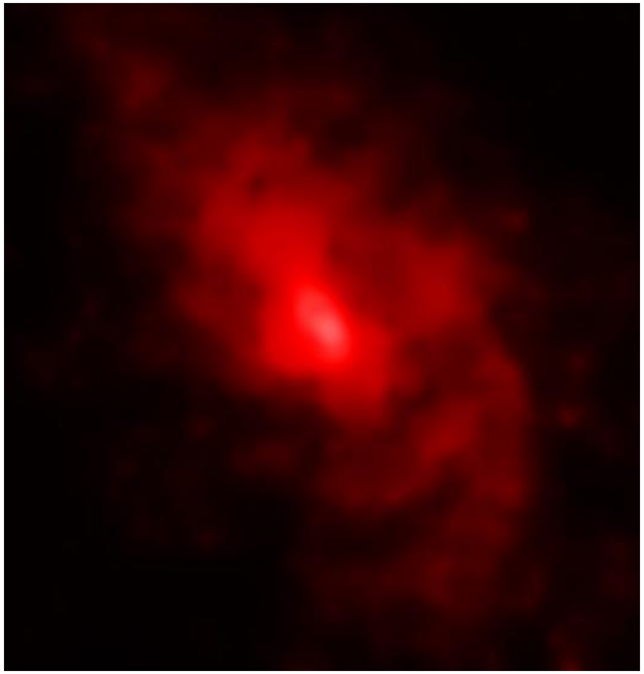
Miller & Turner 2009

Photoionized emission

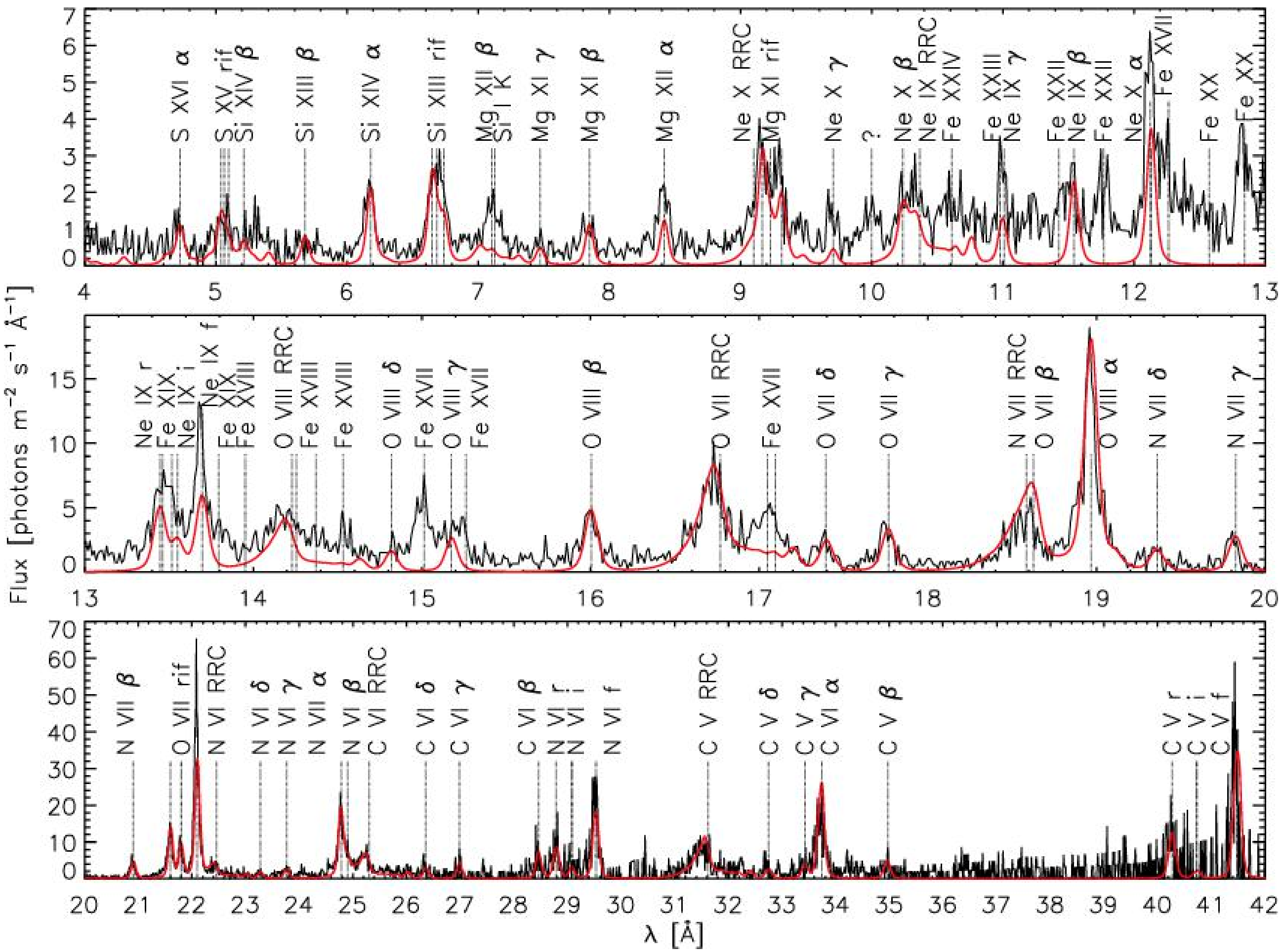
X-ray narrow-line region

NGC1068: Compton-thick Seyfert 2

Chandra



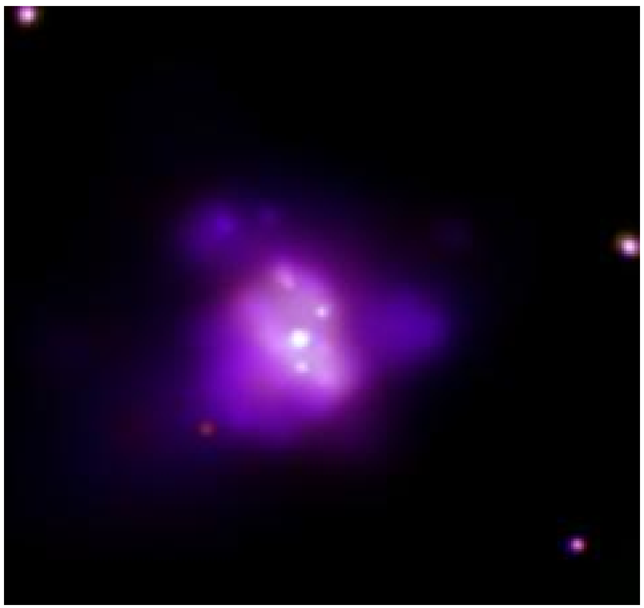
XMM RGS : Kinkhabwala et al. 2002, Brinkmann et al. 2002



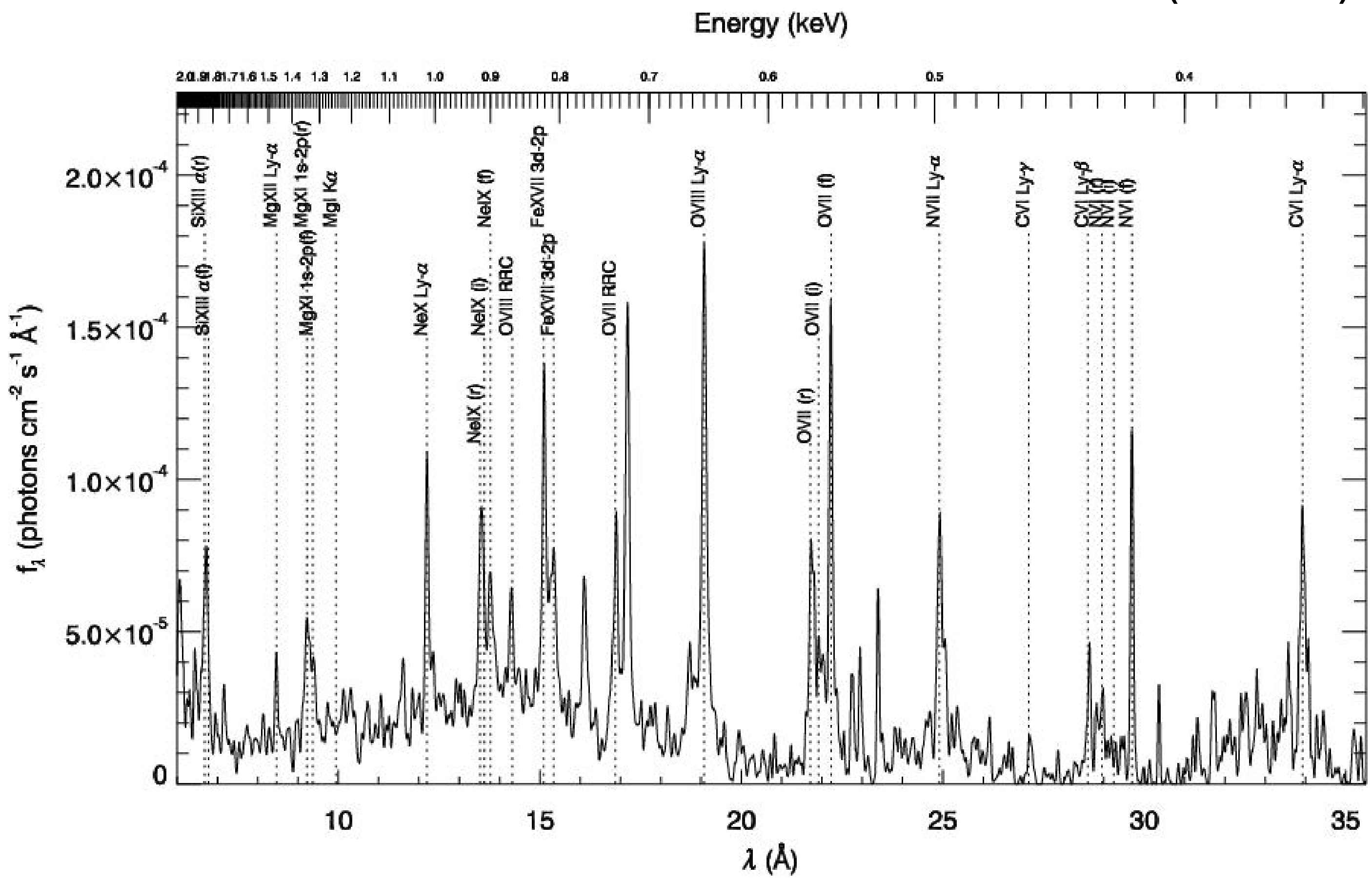
Photoionized Plasma

NGC1365 : Photoionized+ Colliosionally ionized Plasma

Chandra

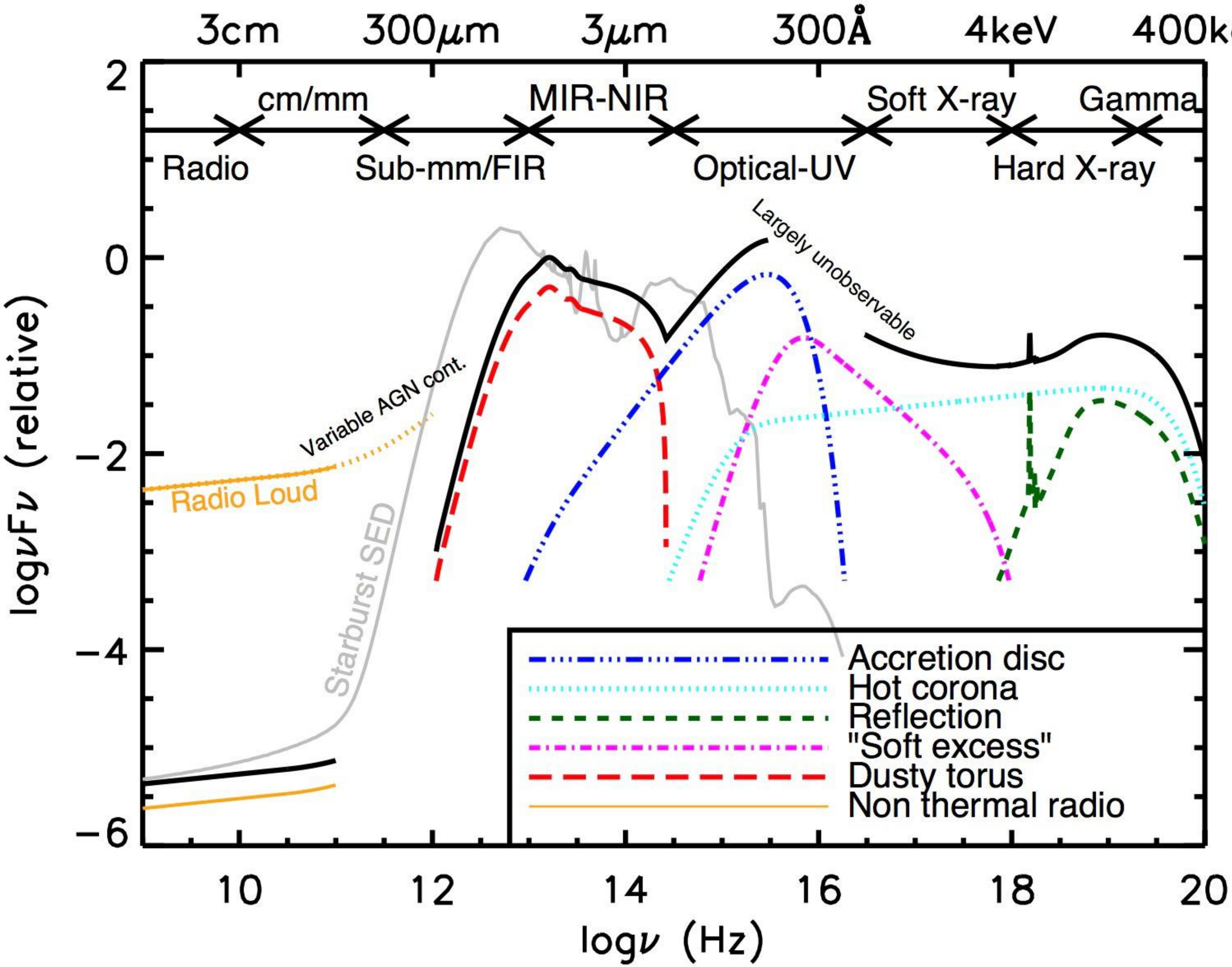


XMM RGS (0.5 Ms)



Guainazzi et al. 2009

Multi-wavelength SED of AGN



Simultaneous MW observations are important!

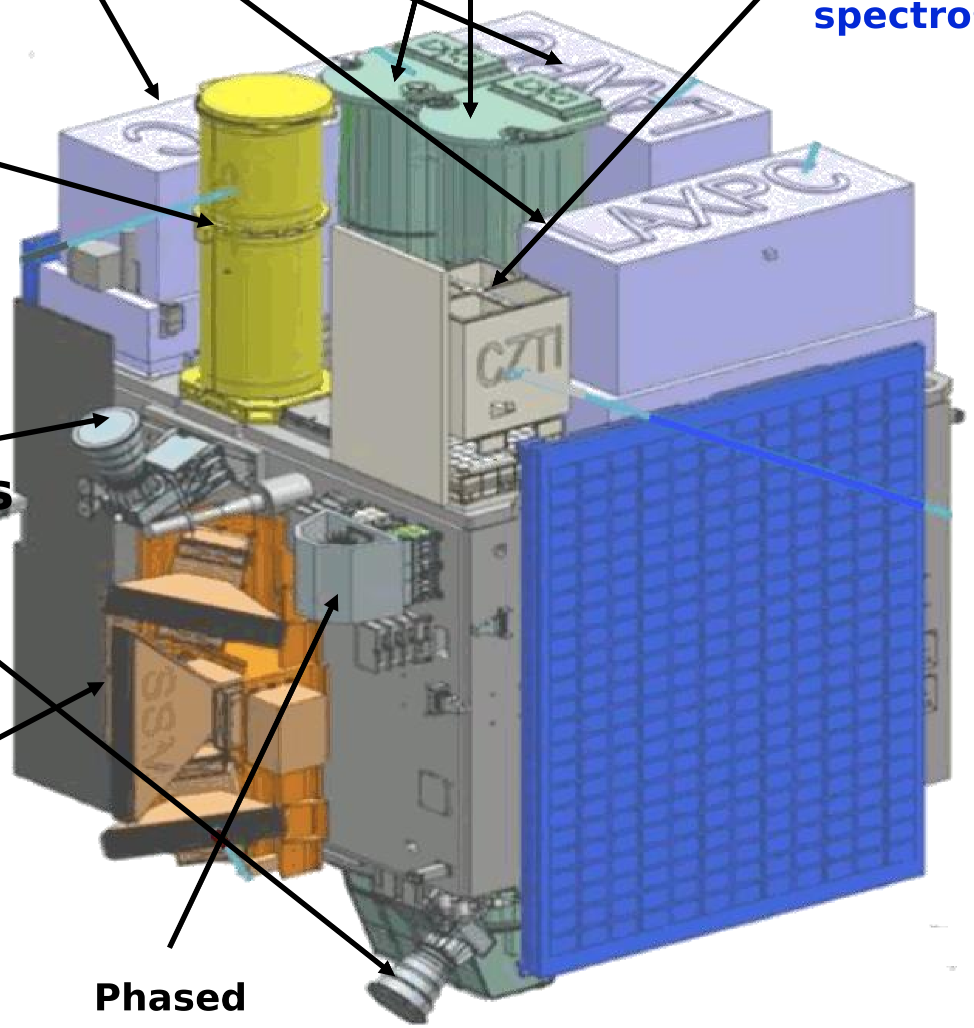
ASTROSAT

LAXPC
3-100 keV X-ray Timing, broadband spectroscopy

UVIT
1.4” UV imaging

CZTI
10-250 keV hard X-ray imaging, timing, spectroscopy

SXT
0.2-8 keV imaging & line spectroscopy



Star Sensors

SSM
rotating 2-10 keV monitor

Phased Array Antenn a

PI: S. Seetha (ISRO)
PMs: S.N. Tandon (UVIT),
J.S. Yadav (LAXPC),
K.P. Singh (SXT)
A.R. Rao (CZTI)
M.C. Ramadevi (SSM

LAXPC: TIFR, RRI
SXT: TIFR, ISRO, UoL
CZTI: TIFR, ISRO, IUCAA, RRI, PRL
SSM: ISRO, IUCAA, RRI
UVIT: IIA, ISRO, IUCAA, CSA

Spacecraft: ISRO
Operations: ISRO
Ground software: ISAC, SAC, TIFR, RRI, IIA, IUCAA, NCRA, PRL

Integrated AstroSat before launch

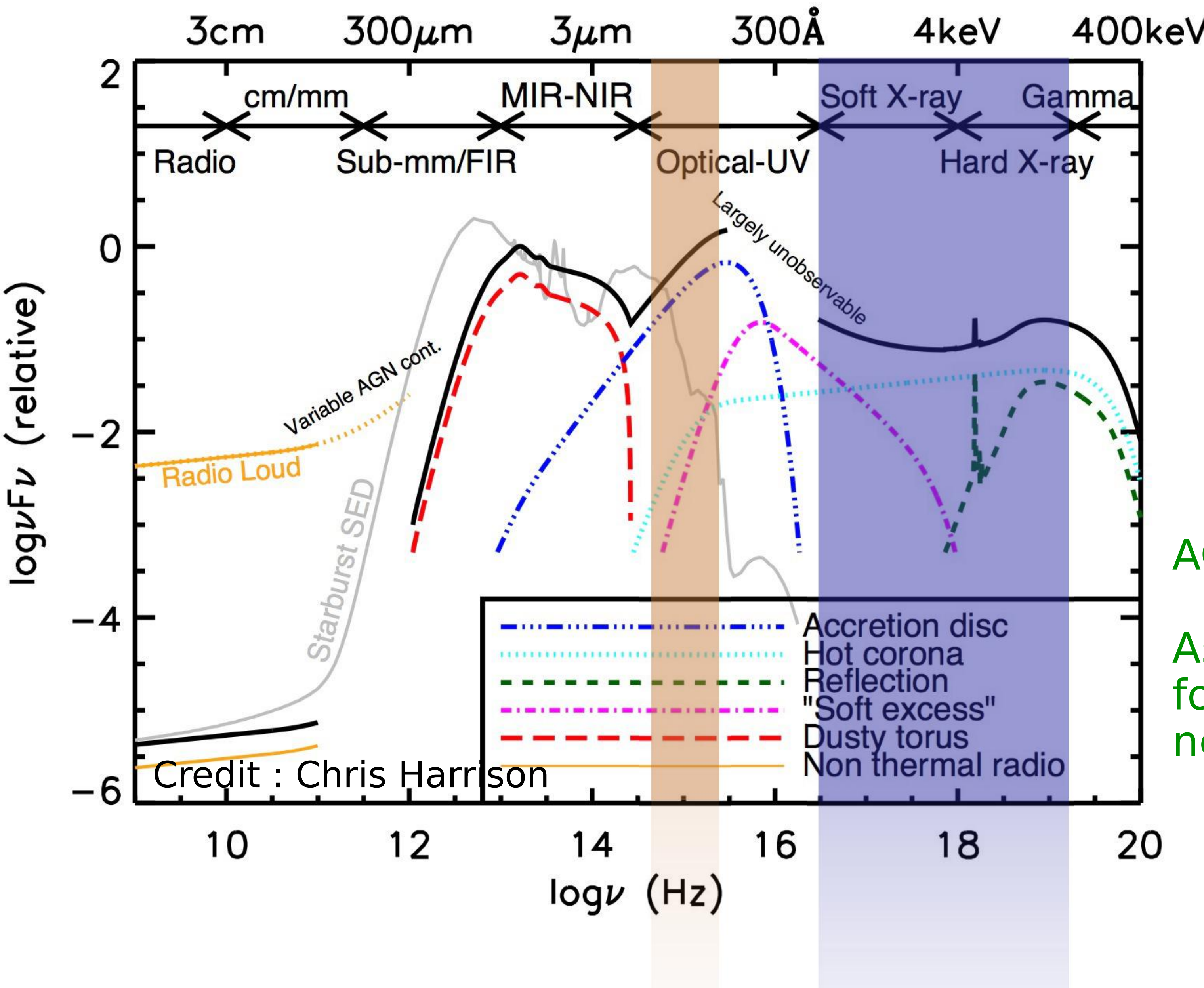
weight: 1.5 ton

PSLV XL Rocket

Launched: 28 Sept. 2015

isro tifr iia IUCAA PRL RRI CSA ASC University of Leicester

AGN SED & Astrosat coverage



UVIT : FUV/NUV/VIS
15 optical/UV filters
(1300 - 5500A)

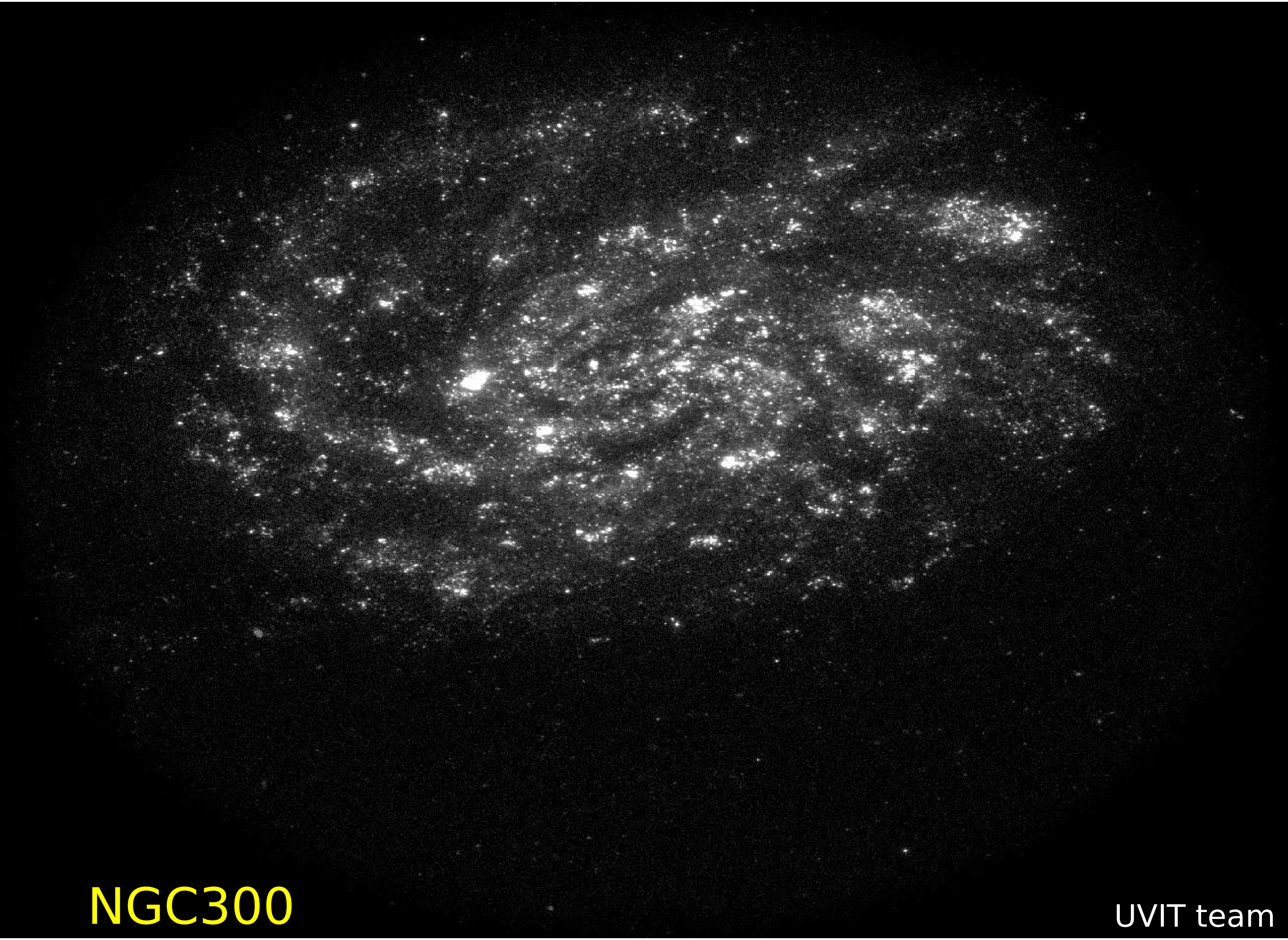
SXT (0.2-8 keV)

LAXPC (3-80 keV)

CZTI (10-100 keV)

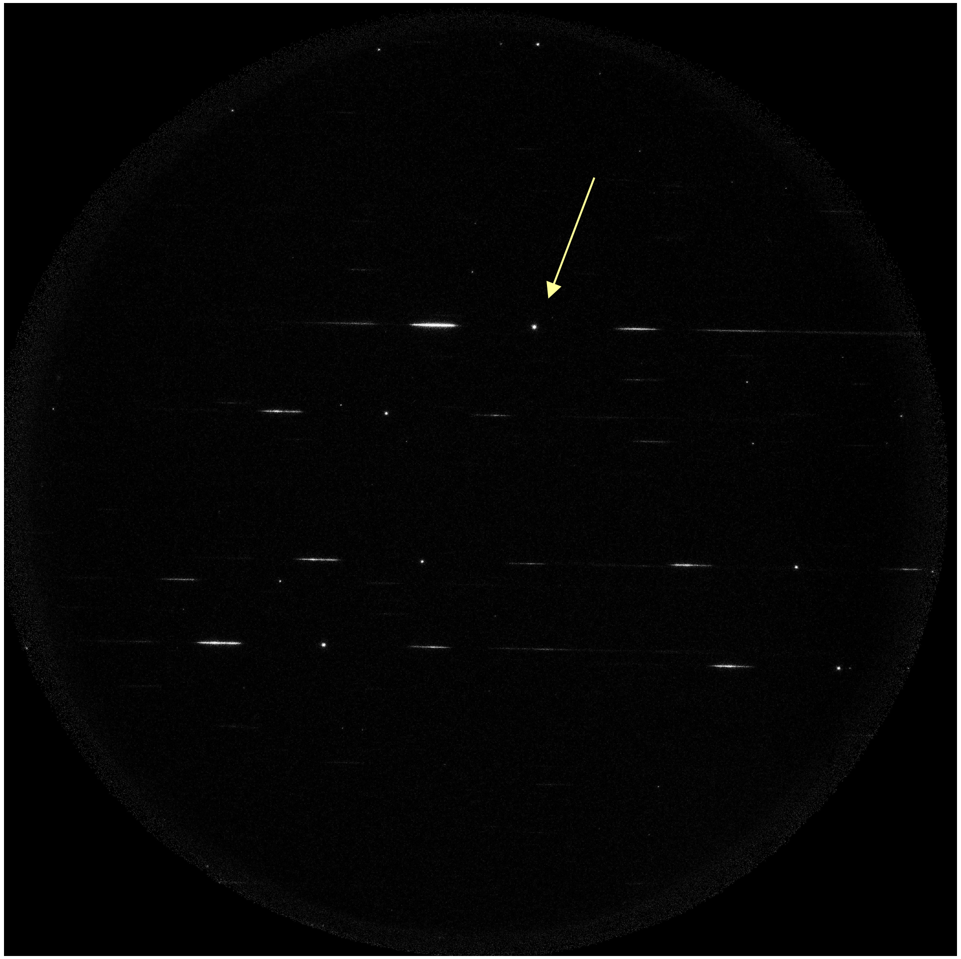
AGN truly MW objects

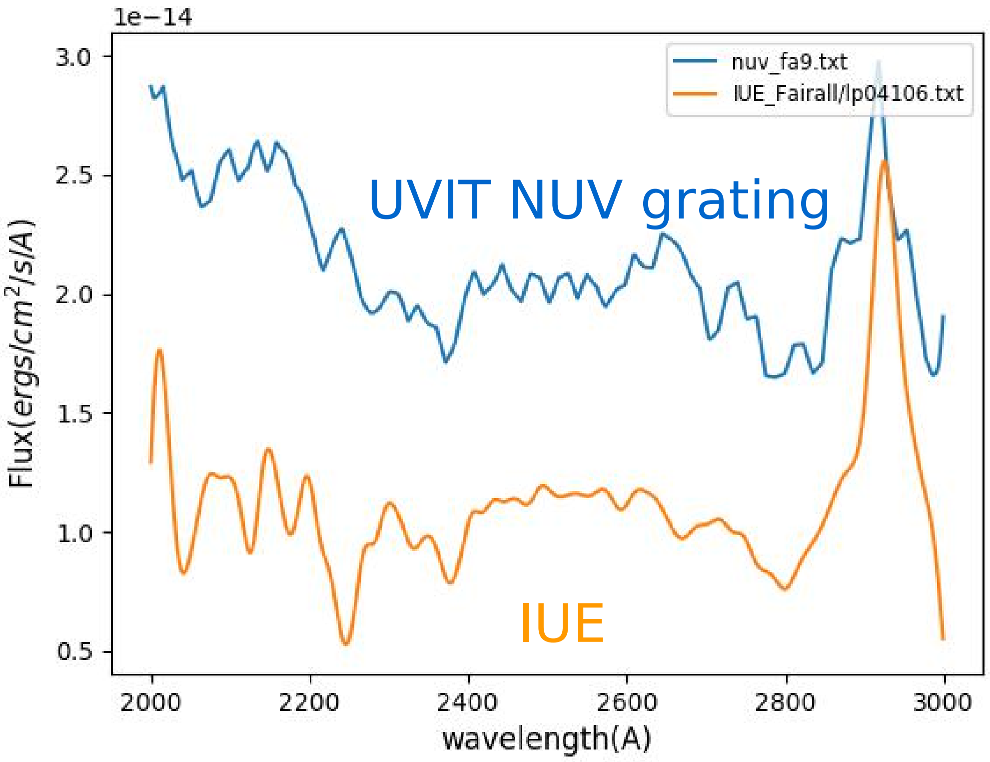
Astrosat well suited for MW study of nearby bright AGN


NGC300
UVIT team

Fairall 9: UVIT observations

NUV Grating exposure : 6000s

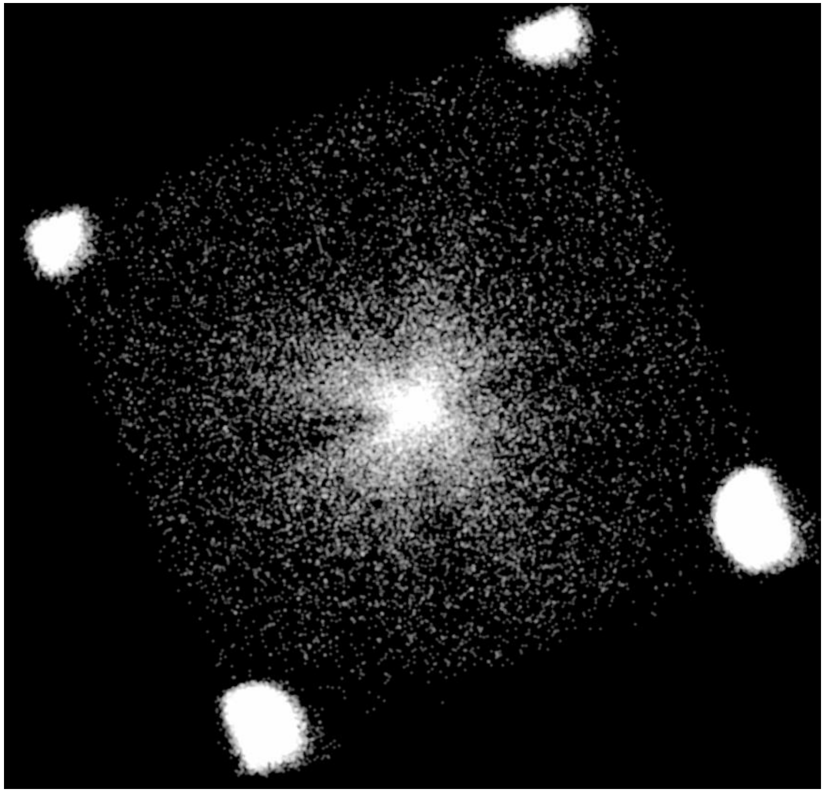


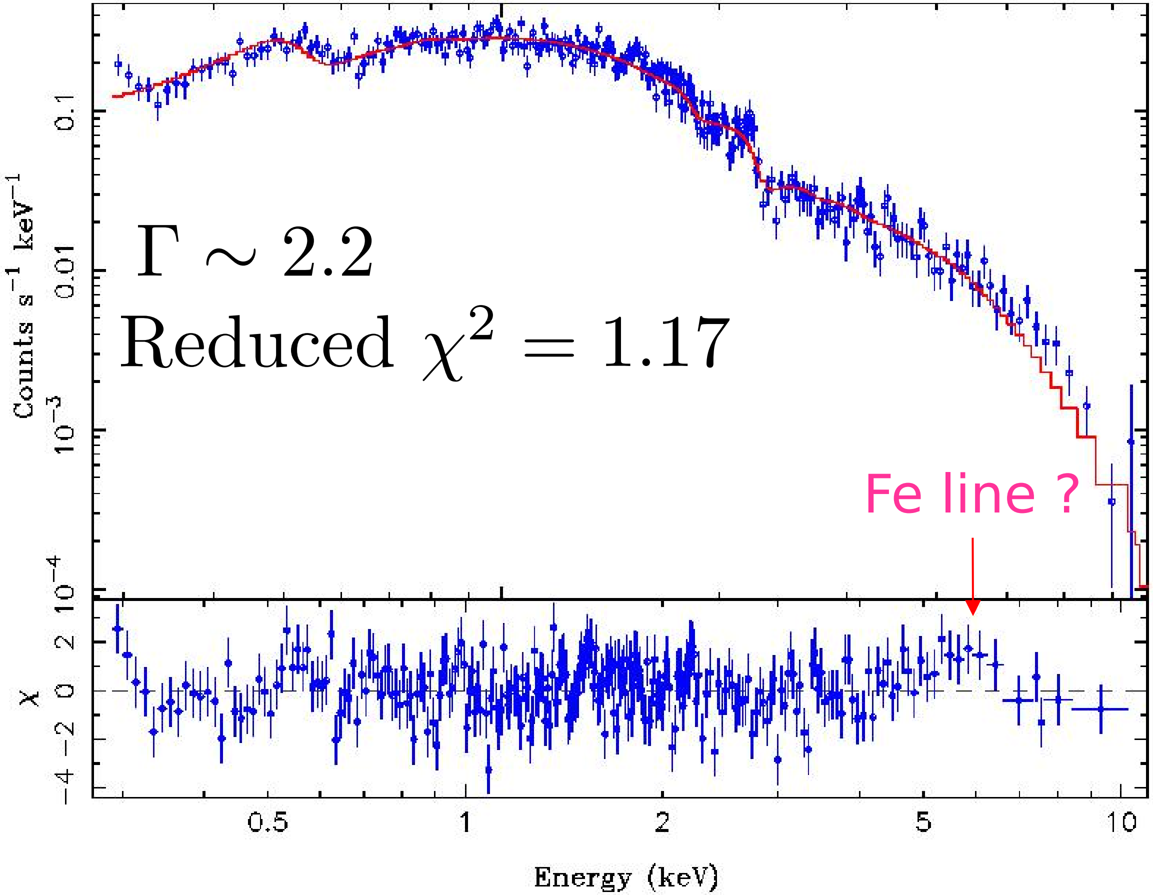


Sriram, 2017

Fairall 9 : SXT Data

Net exposure : 25.8ks, source : 0.46 counts/s

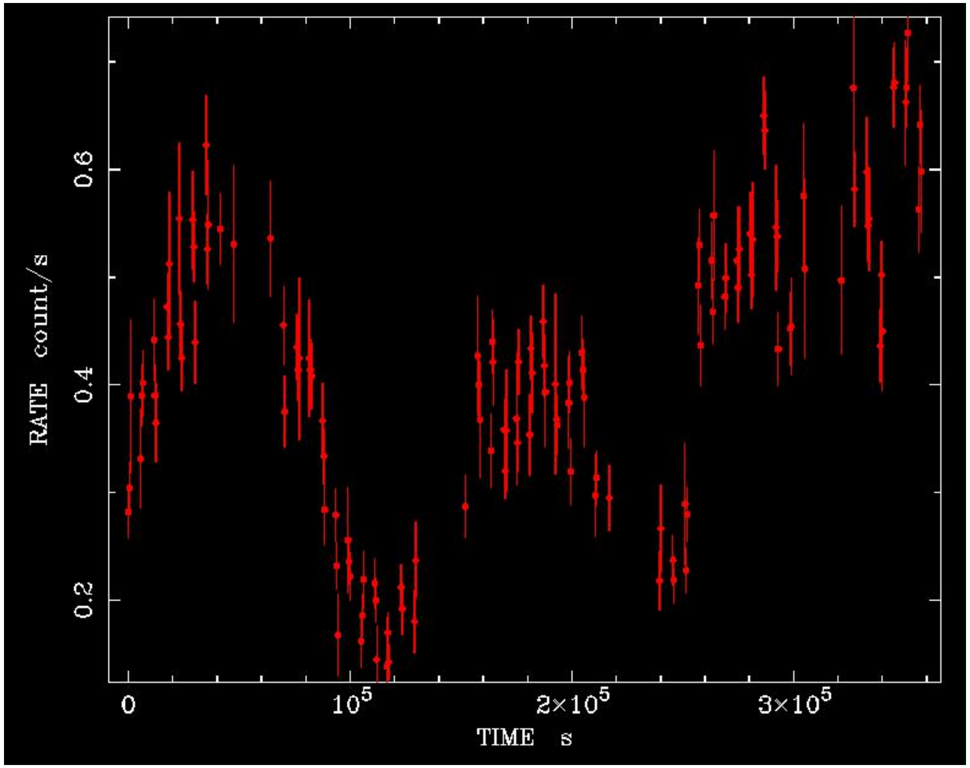


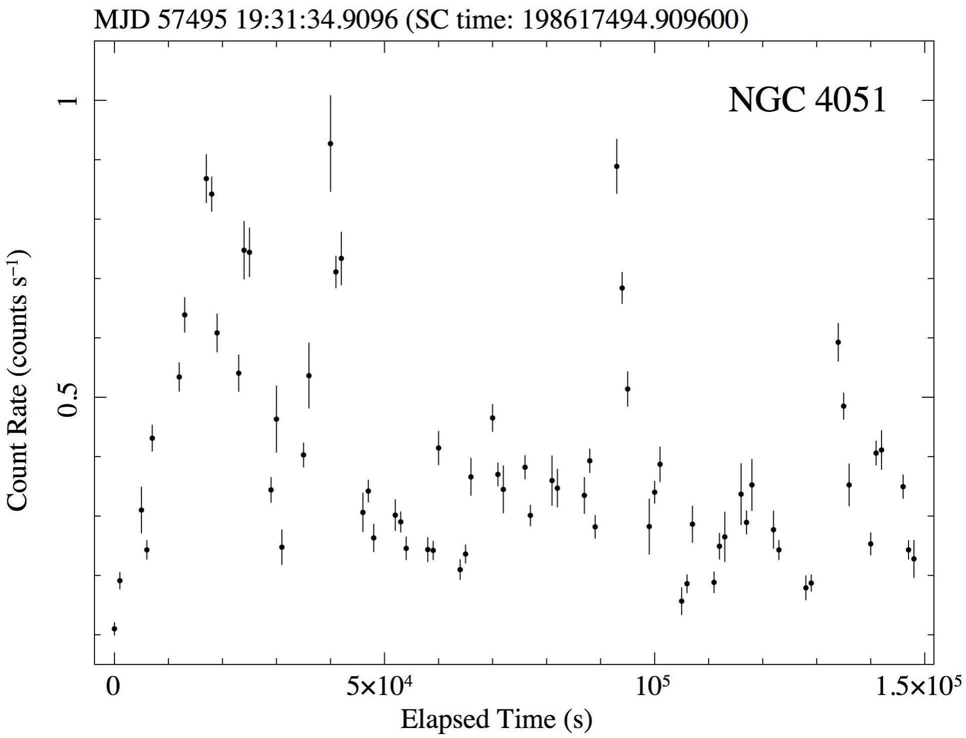


SXT Observations of AGN

BH mass : $6x10^6$ solar mass
Flux (2-10keV) ~1e-11 cgs

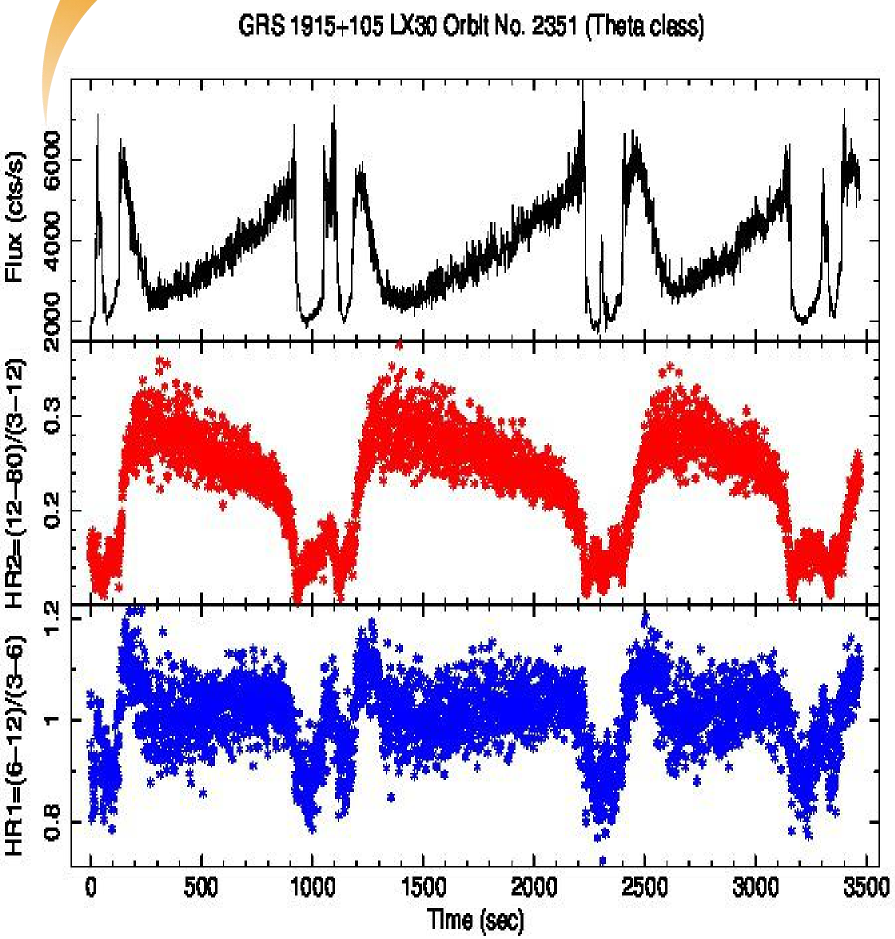
NGC4051 (~1.7 days long)



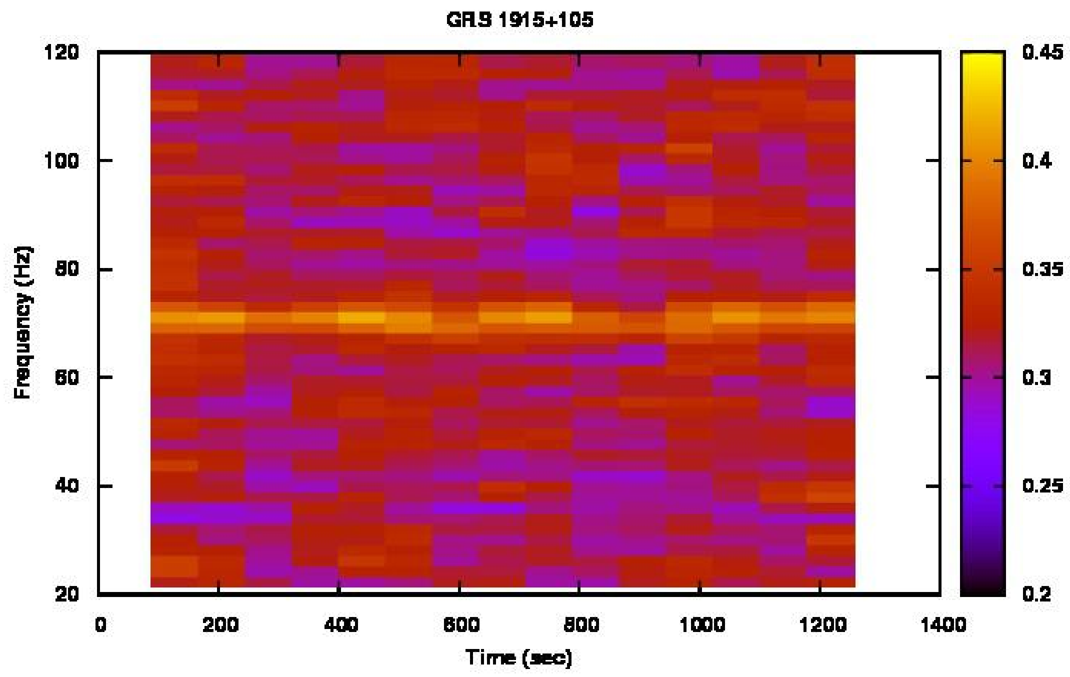


Timing capability of LAXPC: GRS1915+105

Very large count rates

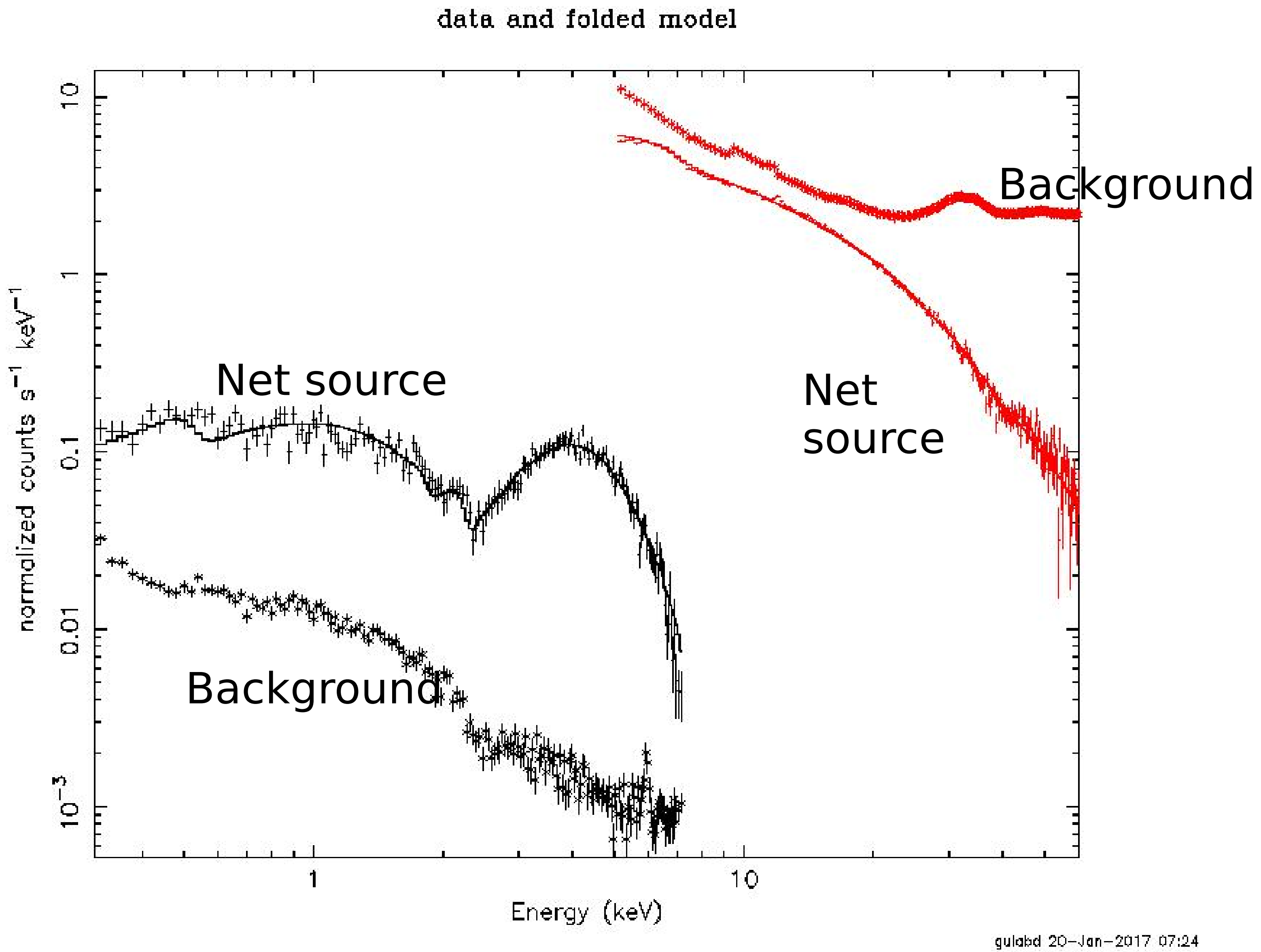


Rare High frequeny QPOs detected with LAXPC



Courtesy: J. S. Yadav

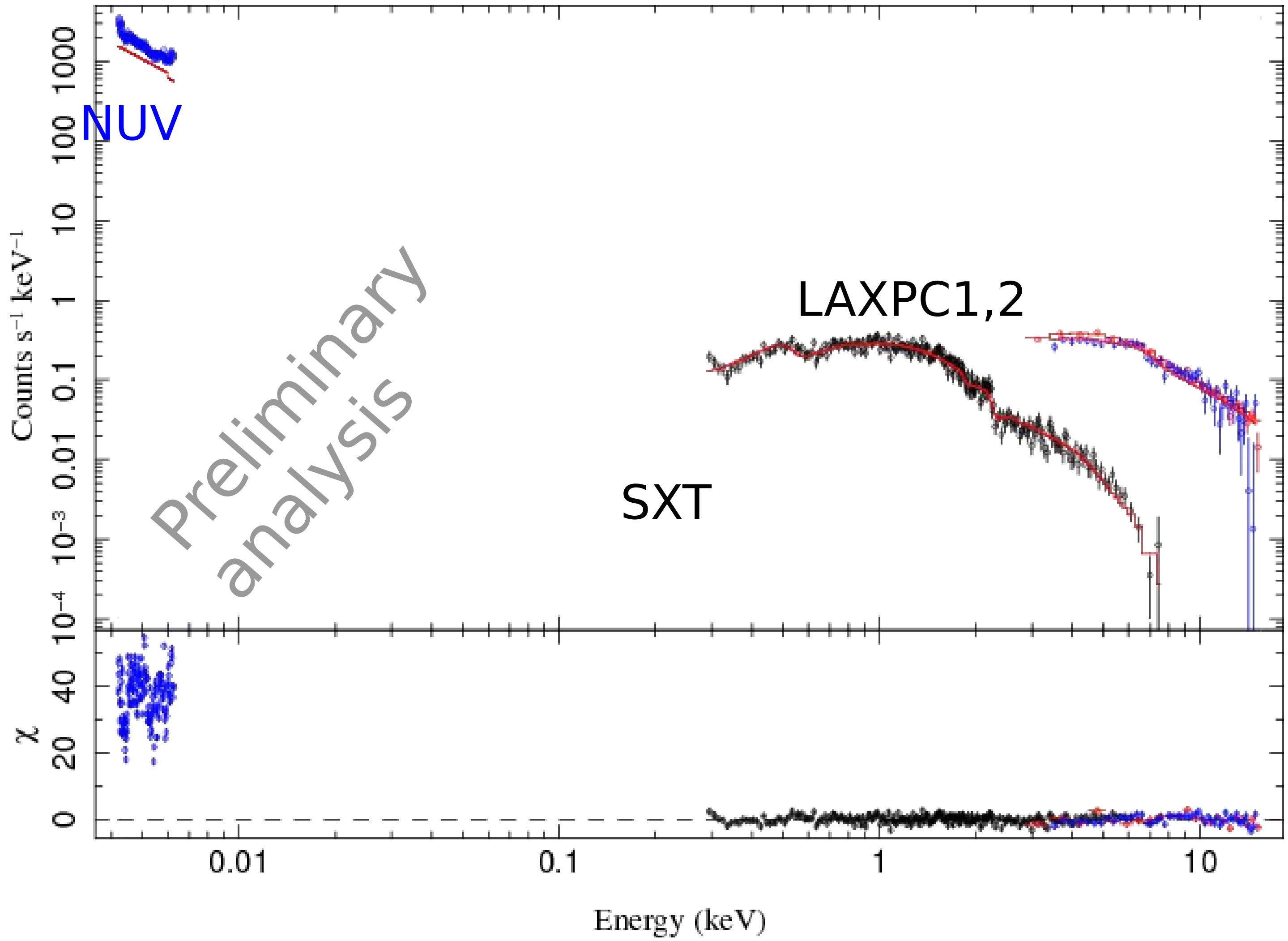
NGC4151 : AstroSat SXT/LAXPC broadband continuum



Fairall 9: Spectral Energy Distribution

AstroSat SXT+LAXPC+UVIT/NUV grating data

Excess NUV emission



Thank You