Active Galactic Nuclei

"What are Active Galactic Nuclei?
And Why Does Anyone Care?"
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Chandra X-ray Center

AGN properties

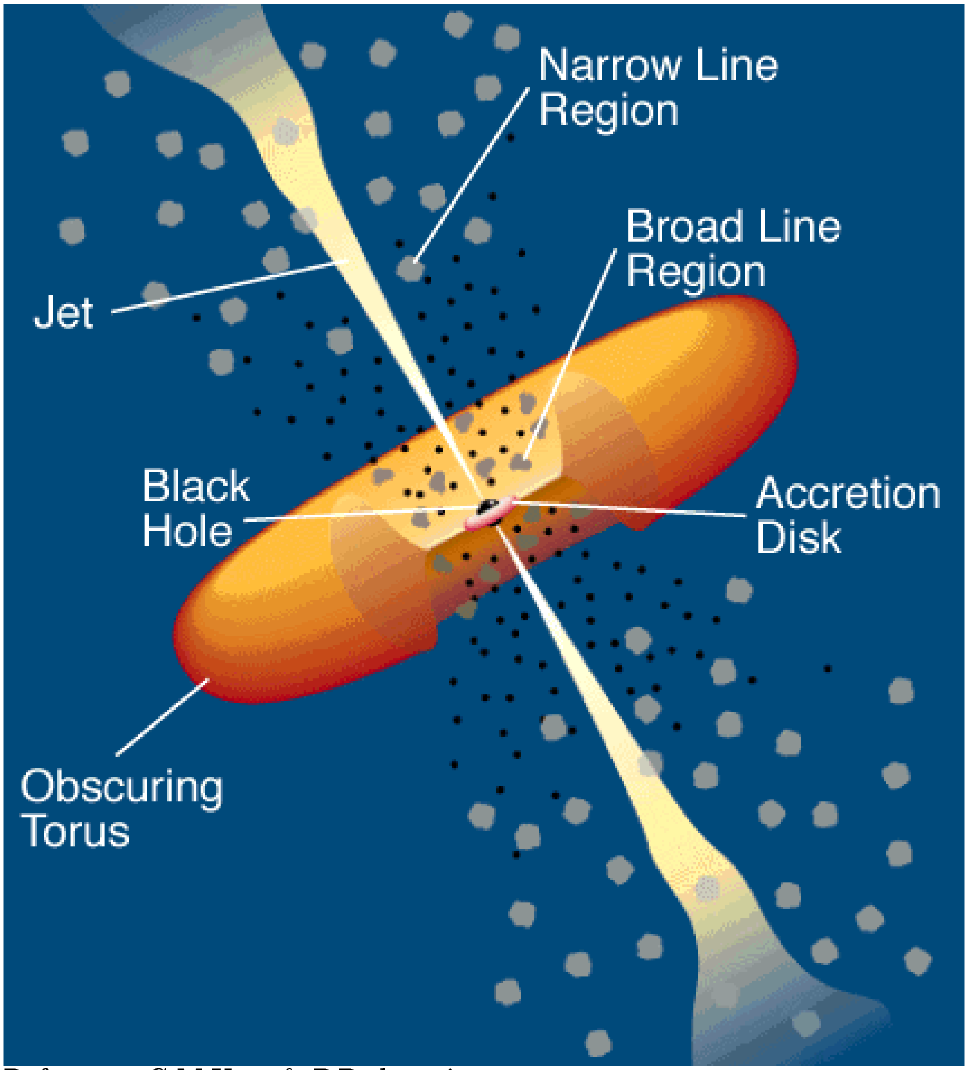
- Highly Luminous: $L_{bol} \sim 10^{42} - 10^{48}$ ergs sec^{-1}
- Compact: size << 1 pc
- Broad-band continuum emission:

$$dL/d\log\nu \sim const.$$

from IR to X-rays and γ-rays

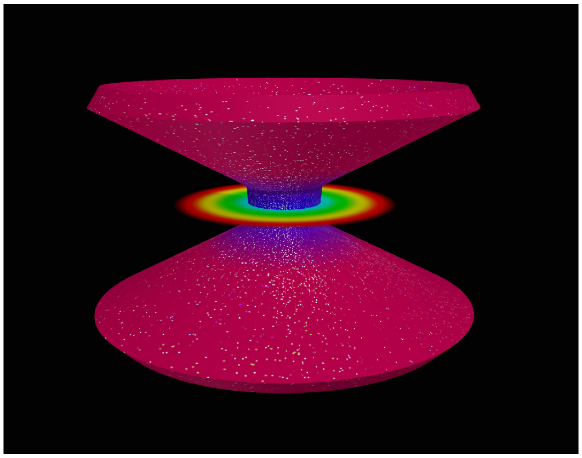
- Variable => *Stronger variations on smaller timescales at shorter wavelengths*
- Weakly polarized: $\sim 1\%$ *linear polarization* but some sources stronger
- Radio emission: *in some sources extended on large scales*

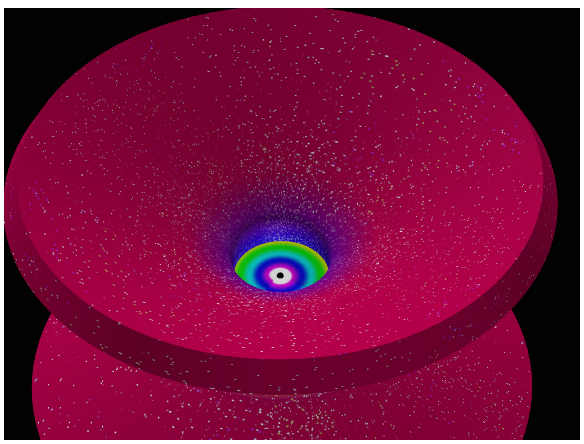
AGN Models

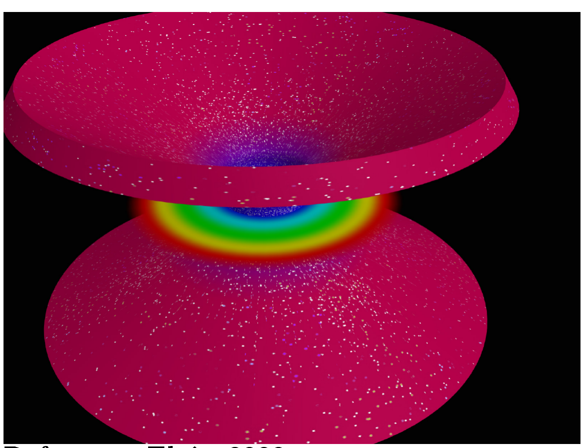


Reference: C.M.Urry & P.Padovani

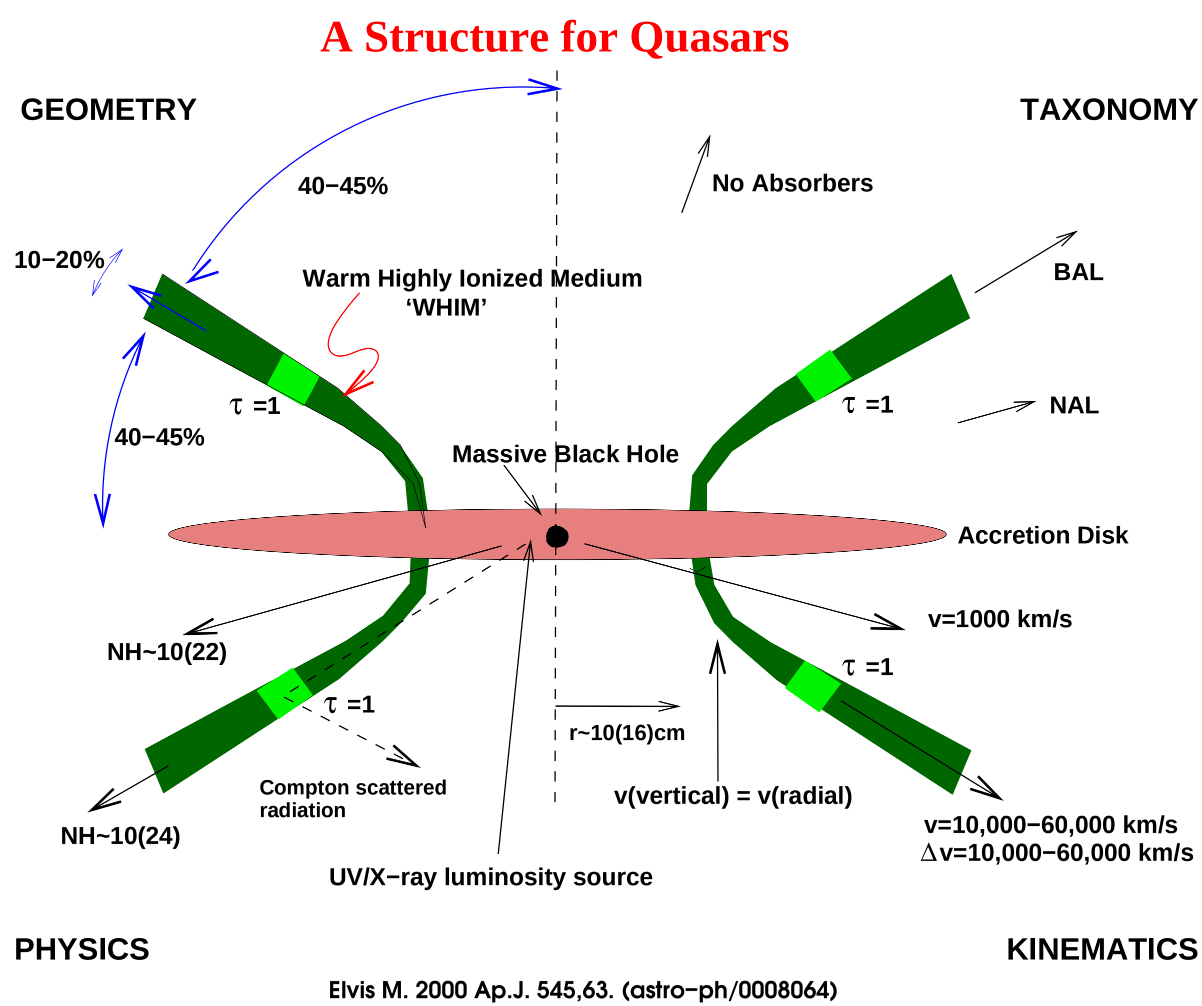
3D Vision



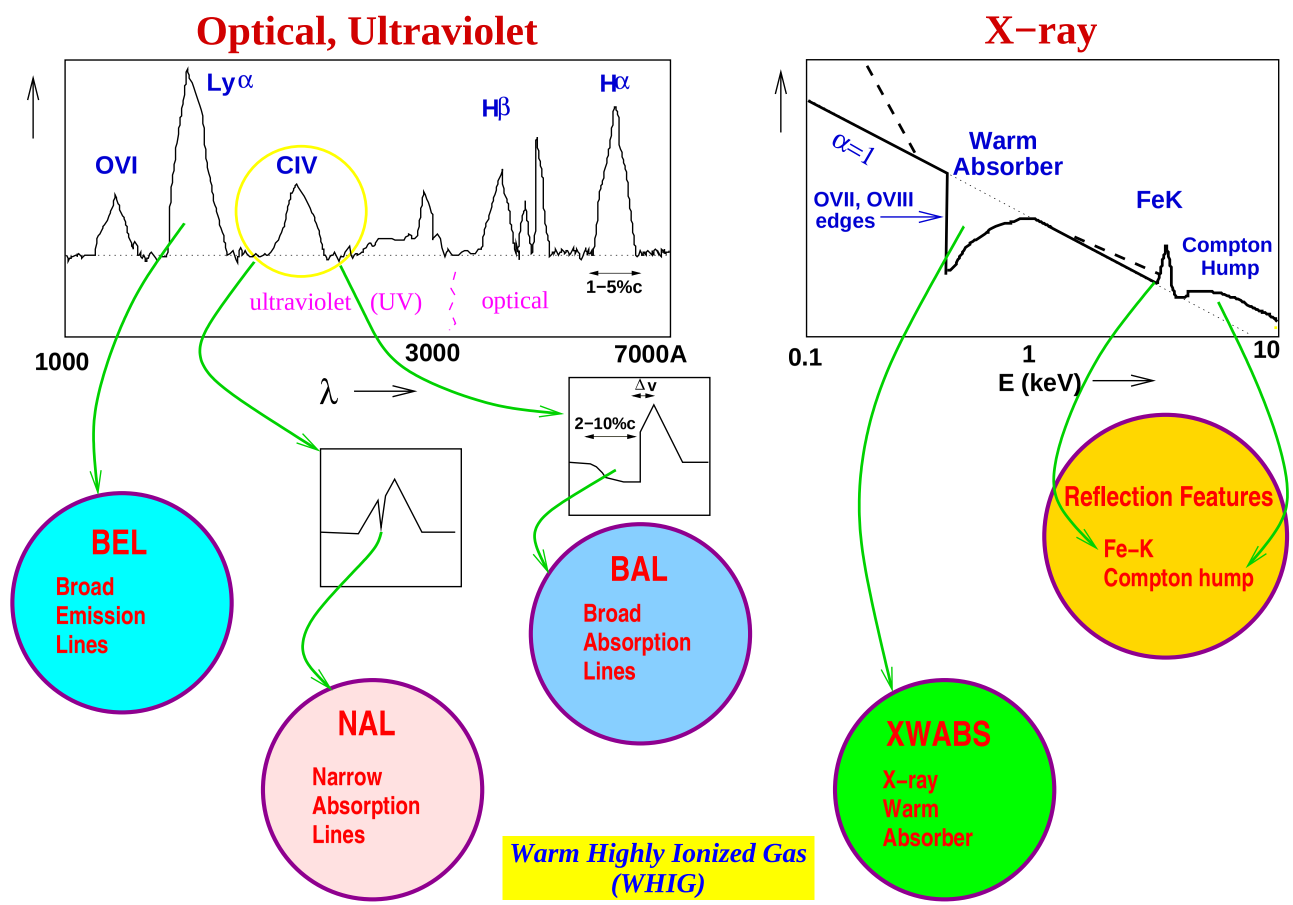




Reference: Elvis, 2000


A Structure for Quasars
GEOMETRY
TAXONOMY
40−45%
No Absorbers
10−20%
Warm Highly Ionized Medium
'WHIM'
BAL
τ =1
τ =1
NAL
40−45%
Massive Black Hole
Accretion Disk
NH~10(22)
v=1000 km/s
τ =1
τ =1
r~10(16)cm
Compton scattered
radiation
v(vertical) = v(radial)
NH~10(24)
v=10,000−60,000 km/s
Δv=10,000−60,000 km/s
UV/X−ray luminosity source
PHYSICS
KINEMATICS
Elvis M. 2000 Ap.J. 545,63. (astro−ph/0008064)

A Quasar Primer



What X-rays can tell us?

- **Thermal emission** from hot gas $T \sim 10^5 - 10^7$ K

  => hot gas is there!

- **Non-thermal emission:** synchrotron, Comptonization

  => relativistic plasma!

- **X-ray emission regions:**

  nucleus - unresolved component

  extended emission on different scales

  => parsec to hundreds kiloparsec

  jets and radio lobes

- **Absorption properties:**

  amount of absorbing material

  outflow/inflow velocity

  cold/warm absorbers

  ionization state

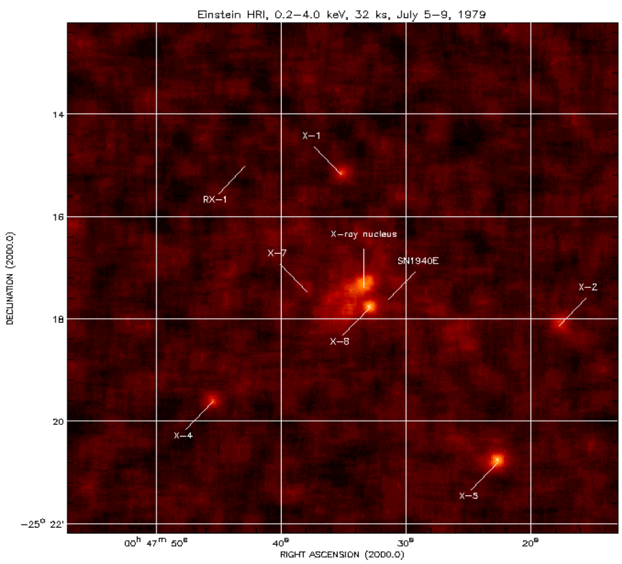
  abundance

- **Variability:**

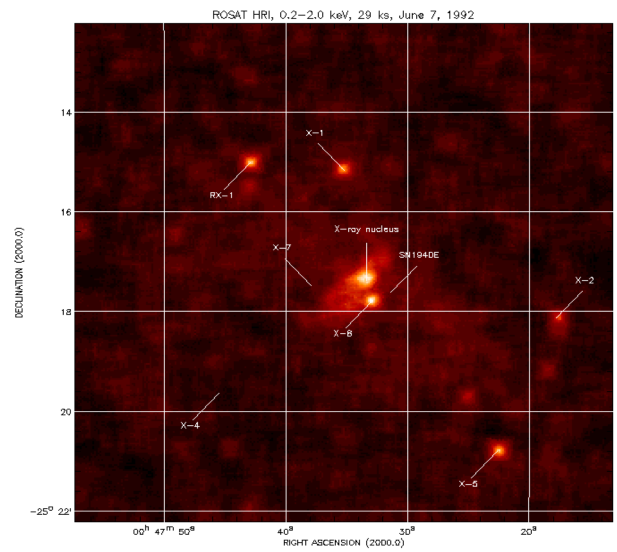
  => scale/size of emitting and reprocessing regions

X-ray observations

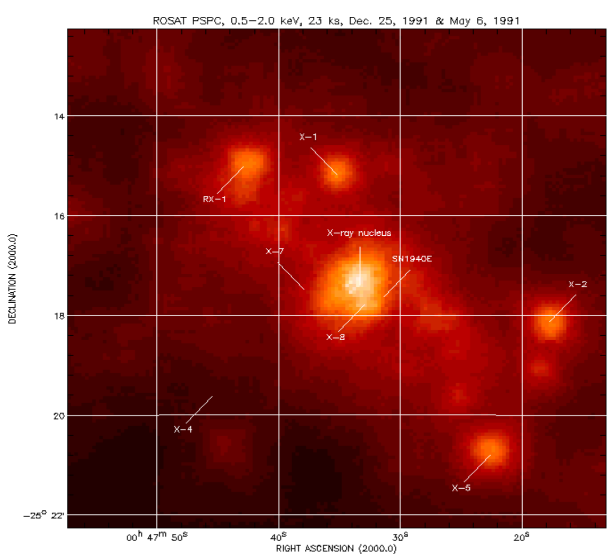
Einstein HRI Image of NGC 253



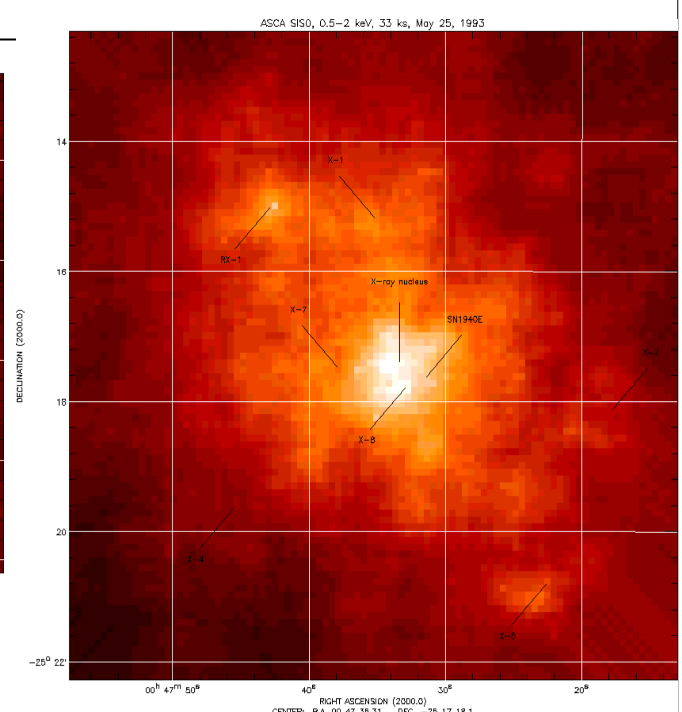
ROSAT HRI Image of NGC 253



ROSAT PSPC Image of NGC 253

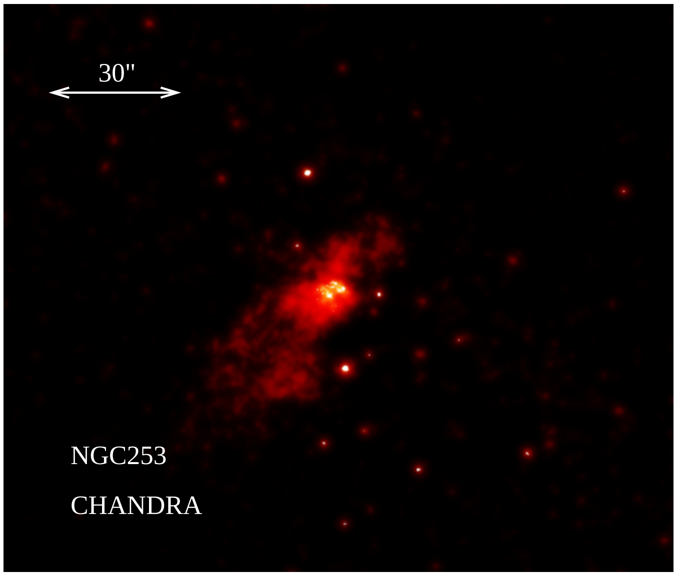


ASCA SIS0 Image of NGC 253



10"x10"

Reference: A.Ptak Web page http://lheawww.gsfc.nasa.gov/ ptak/starburst/m82_n253_images.html



Reference: Chandra press release

Chandra mirrors have exceptional image quality:

=> PSF FWHM ∼0.5 arcsec

compare to ROSAT HRI PSF FWHM ∼ 1.7 arcsec

Chandra can resolve structures on 1 arcsec scale.

Low scattering wings of the PSF => crucial for high dynamic range observations needed when looking at faint structures in vicinity of strong sources

=> quasar jets

Example: X-ray Jets

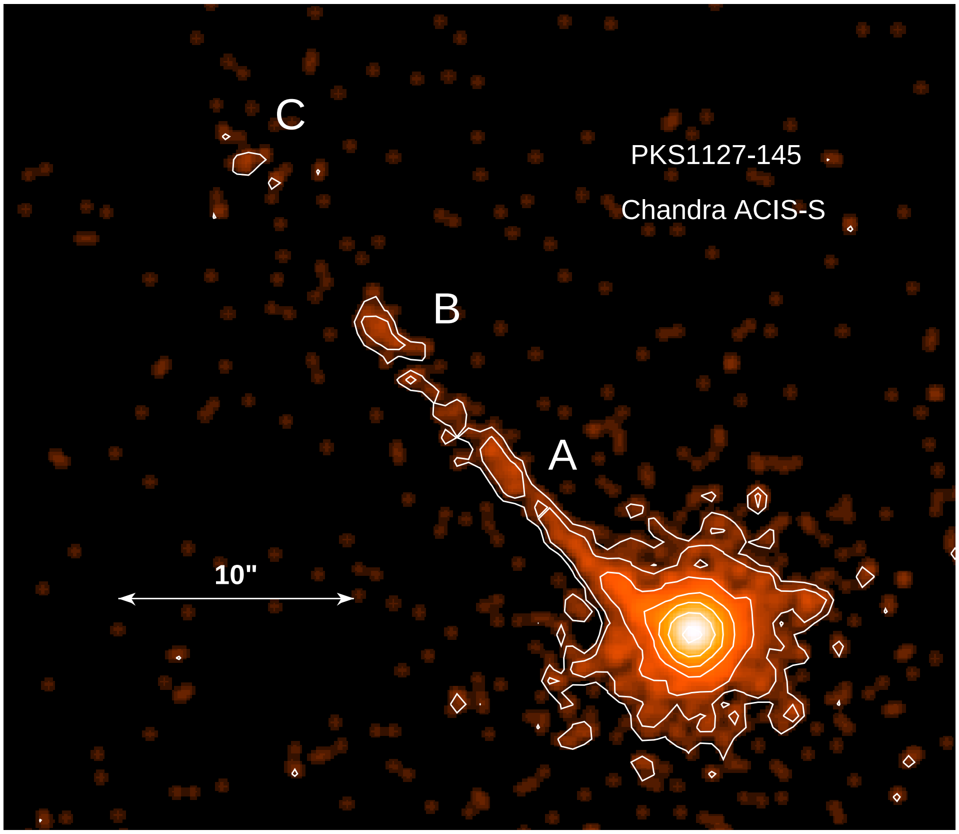
- The main goal of the Chandra observations of two high redshift quasars:

  => study metallicity of the intervening absorption systems

  => evolution of metallicity with redshift

  but you cannot be always certain **what** your new observations will allow you to study!

- Discoveries **happen** even in the 21st century!



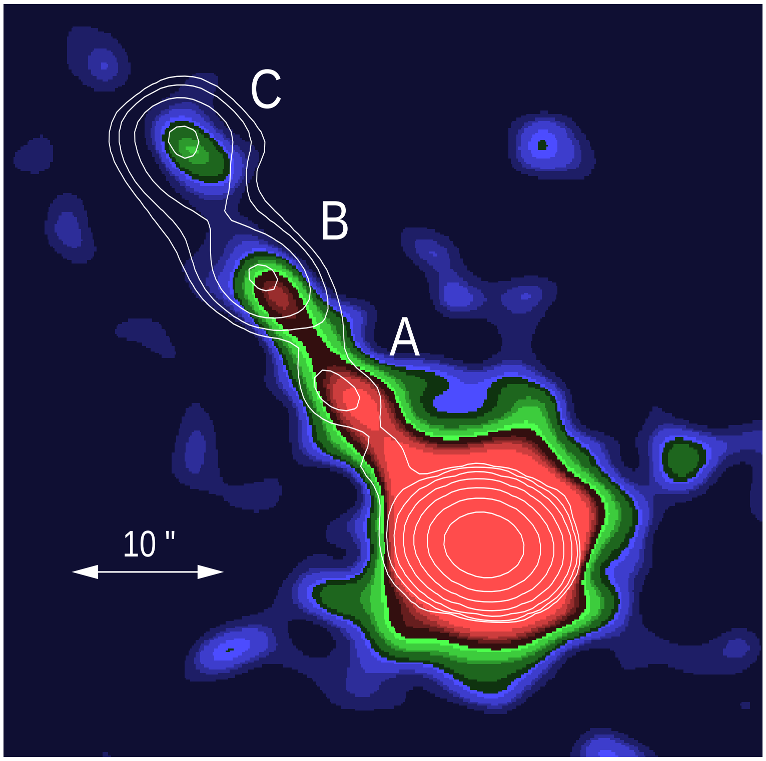
CHANDRA ACIS-S

PKS 1127-145

- X-ray jet is $\sim$ 30 arcsec long => $330h_{50}^{-1}$ kpc at the quasar redshift.
- The jet curves;
- The ratio of individual knots to the core is $\sim 1 : 260 - 460$.

  $f_{2-10keV}(core)$=2.41×10^{-12} ergs cm^{-2} sec^{-1}

  $f_{2-10keV}(A)$=$9.3{\times}10^{-15}$ ergs cm^{-2} sec^{-1}



Chandra/1.4 GHz overlay (3" resolution, Chandra image in color smoothed to match VLA resolution)

- The X-ray knots correspond to the VLA knots only roughly => X-ray peak intensities precede the radio peak intensities by ~1-2" ($\sim 11 - 22 h_{50}^{-1}$ kpc)

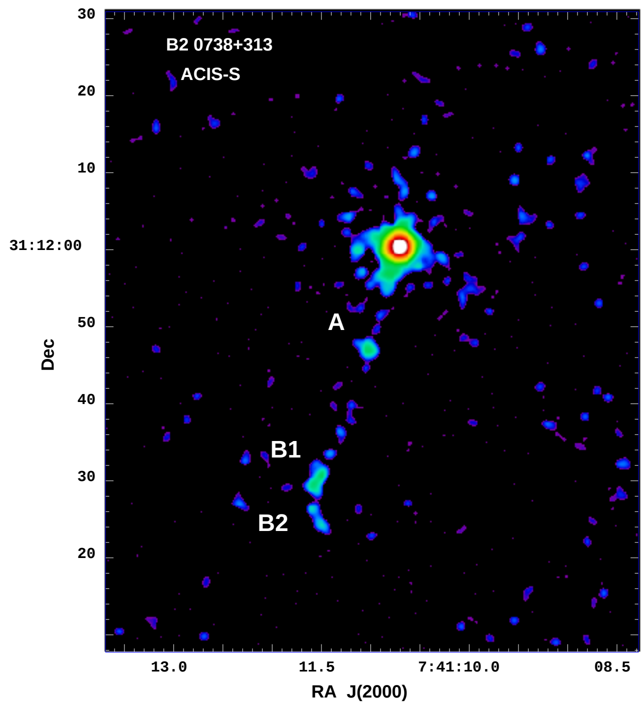


Image smoothed: FWHM=0.75"

Energy: 0.3−6.5 keV

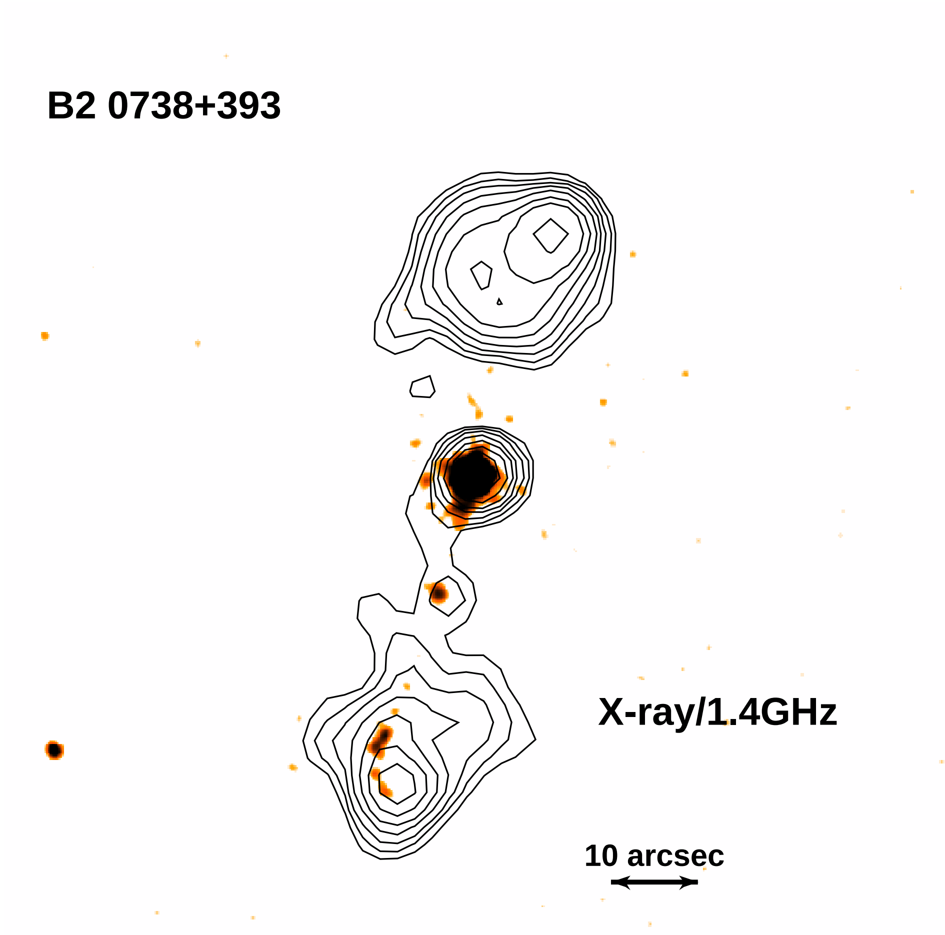
Peak:

4.5e−7 phot/cm^2/s/pix

1pix=0.164"

CHANDRA ACIS-S
B2 0738+313

- X-ray jet is $\sim$ 35 arcsec long => $\sim 300 h_{50}$ kpc.
- The jet is curved with a few enhancements;
- Core to hot spots emission $\sim 1 : 200$



- VLA radio map shows extended radio emission on 1 arcmin scale (the lobes $\sim$ 20 mJy and the core 2 Jy).
- X-ray emission follows the radio emission;
- X-ray is getting fainter moving away from the core, while radio has two hot spots at the end of the Lobes.
- No X-rays to the North at 3σ upper limit of 2×10^{-9} photons cm^{-2} sec^{-1} pix^{-1} (1 pix=0.164")

Jet Models

- Comparison of X-ray, optical and radio data rules out thermal emission, SSC and a simple direct synchrotron emission as primary source of the X-ray jet emission.
- Inverse Compton scattering off Cosmic Microwave Background (CMB) photons can accommodate the observations. Required bluk motion Lorentz factors are higher for lower redshift quasar, $\Gamma_{bulk} \sim 10$ vs. $\Gamma_{bulk} \sim 2-3$.

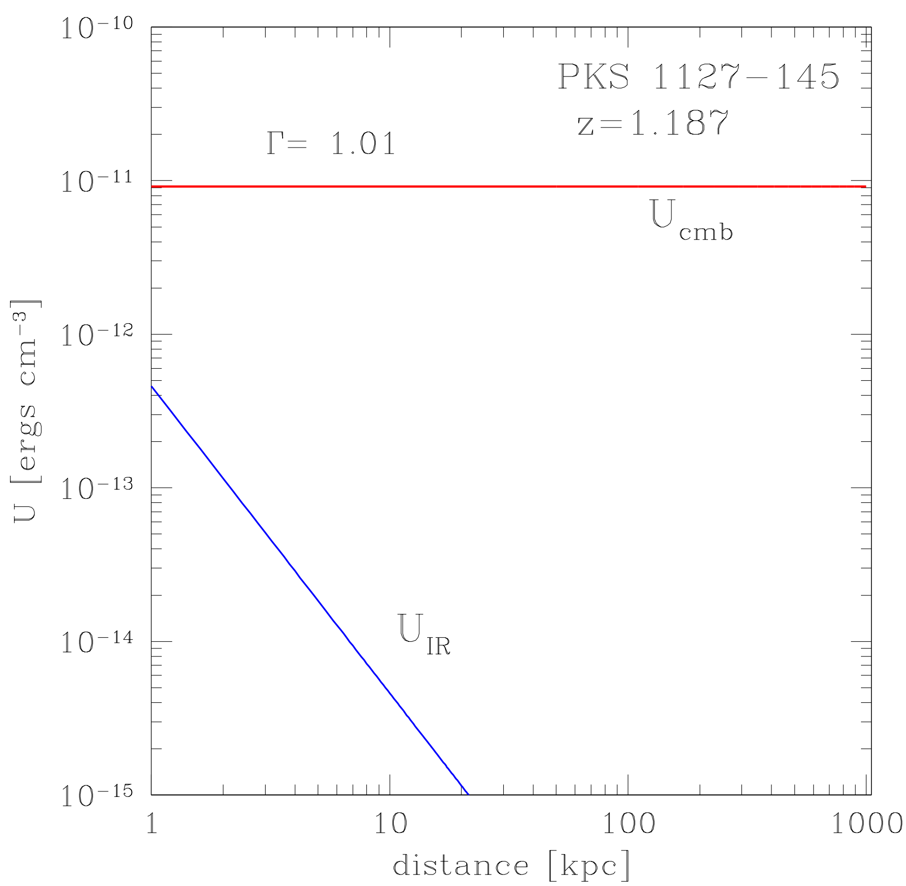


Fig: **Energy density** of the external photon field at z=1.187 as a distance from the quasar core. U_{CMB} - CMB field, U_{IR} - radiation due to the dust in the host galaxy

$$\mathbf{U_{CMB} = aT^4_{CMB}(1+z)^4\Gamma^2} \qquad \mathbf{U_{IR} = \frac{L_{IR}+fL_{NLR}}{4\pi r^2 c\Gamma^2}}$$

A case for the Warm Absorber?
MCG-6-30-15 with XMM and Chandra

◆ High-energy emission of AGN originates from the innermost regions of an accretion flow onto a supermassive object (a black hole?)

◆ The accretion energy is radiated as X-ray and γ-rays with a spectrum which has generally a power-law shape and is absorbed by the interstellar medium in our own Galaxy.

◆ X-ray reprocessing and absorption are the processes generally invoked to interpret deviation from the power-law form. Deviations from a pure power law are seen in many AGNs.

◆ The model generally adopted to match the observations in the 0.5-1 keV energy range is that of a power-law continuum spectrum absorbed by partially ionized material

◆ Many AGNs show absorption edges of ionized oxygen (OVII and OVIII) characteristic of optically thin, photoionized material along the line of sight to the central engine, the so-called *"warm absorber"*.

◆ The origin and location of this warm absorber is still very much a matter of debate.

◆ MCG-6-30-15 (an X-ray luminous Seyfert 1 galaxy) is at the center of this controversy following XMM and Chandra Observations.

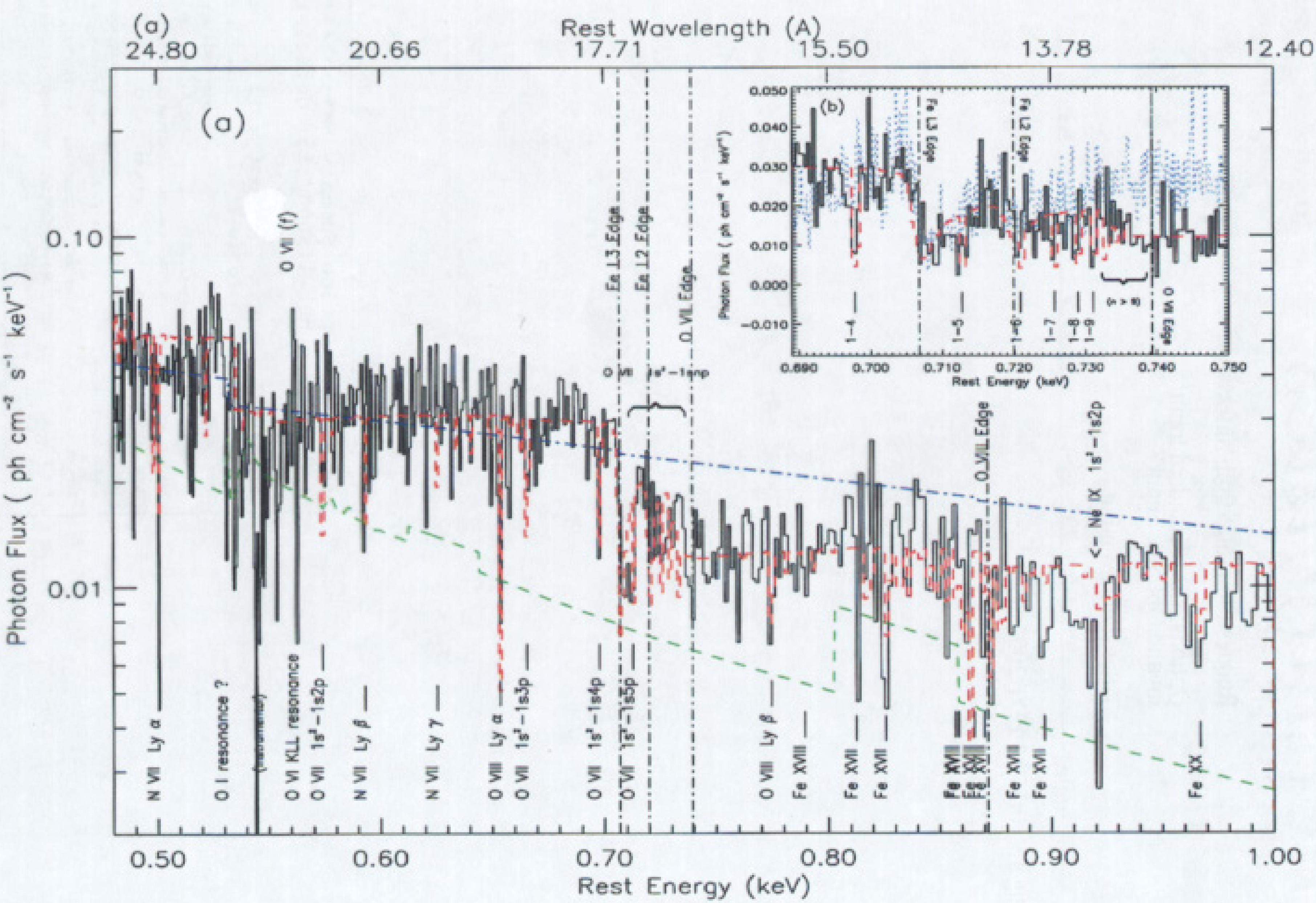
✓ From Lee et al. 2001

"Our Chandra HETG spectrum of MCG -6-30-15 shows that a dusty warbsorber model is not only adequate to describe all the spectral features >0.48 keV (26 Å) but that the data require it."

✓From Branduardi et al. 2001

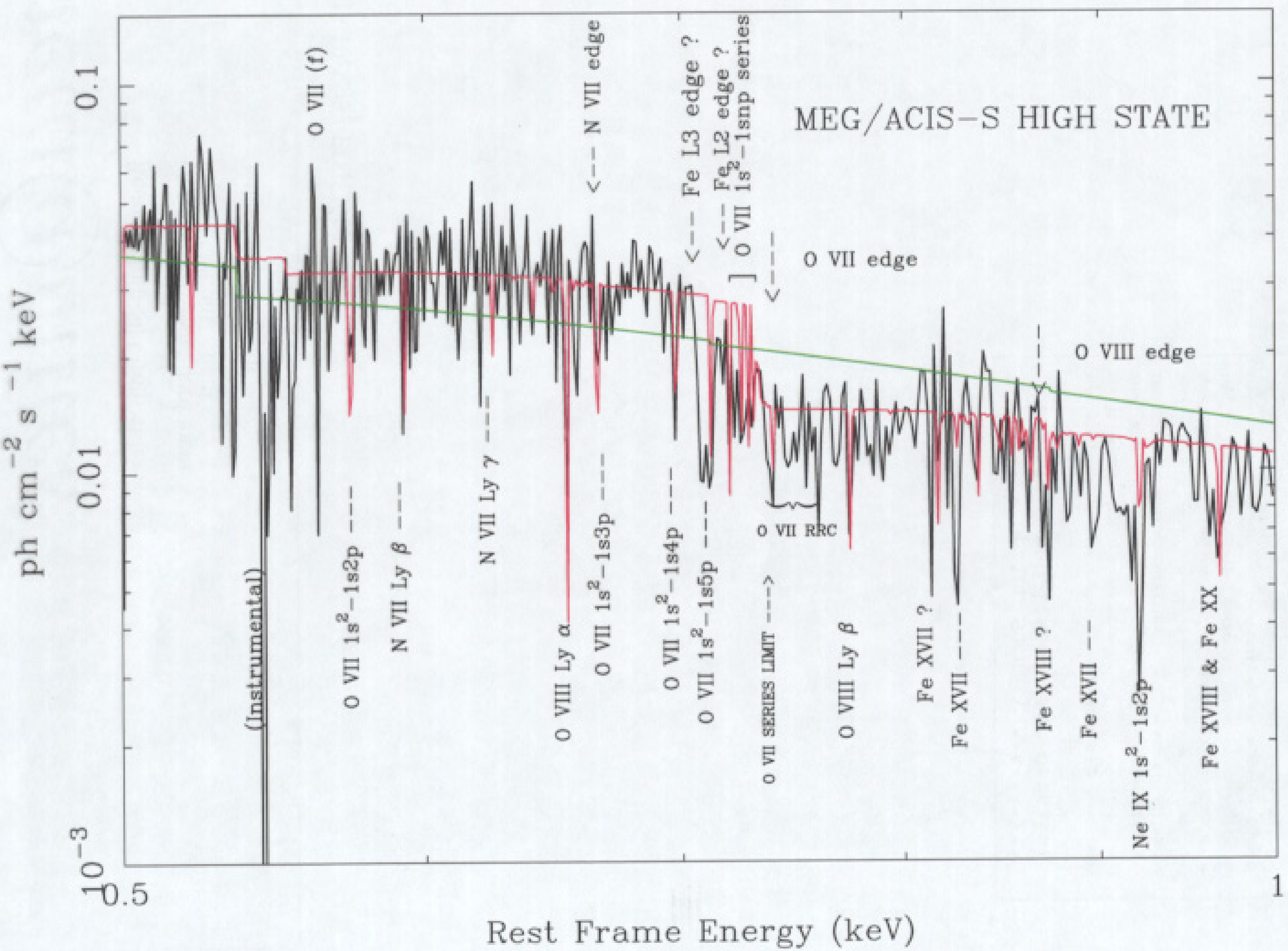
"A simple warm-absorber interpretation of the RGS spectra of MCG-6-30-15 is untenable on spectroscopic grounds. Broad line emission from a relativistic disk surrounding a maximally rotating Kerr black hole seems to explain the data remarkably well."

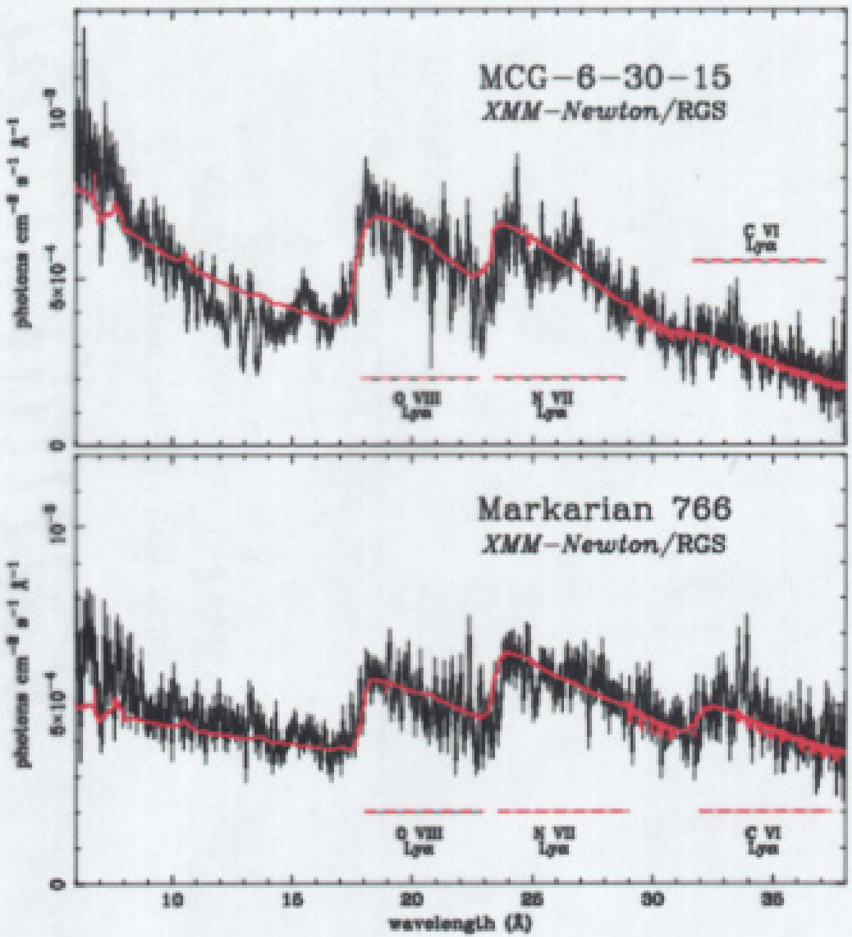
◆ This is what the data show... (note the the mixed use of E and λ by X-ray astronomers!)



LEE et al (2001)

The Warm Absorber Region





BRANDAURi - RAYMONT et. al (2001)

The Narrow Line Region:
Chandra Observations of NGC 4151

(From Ogle et al. 2000)

◆ Direct emission from the nucleus is highly absorbed therefore a good view of its narrow line region is possible.

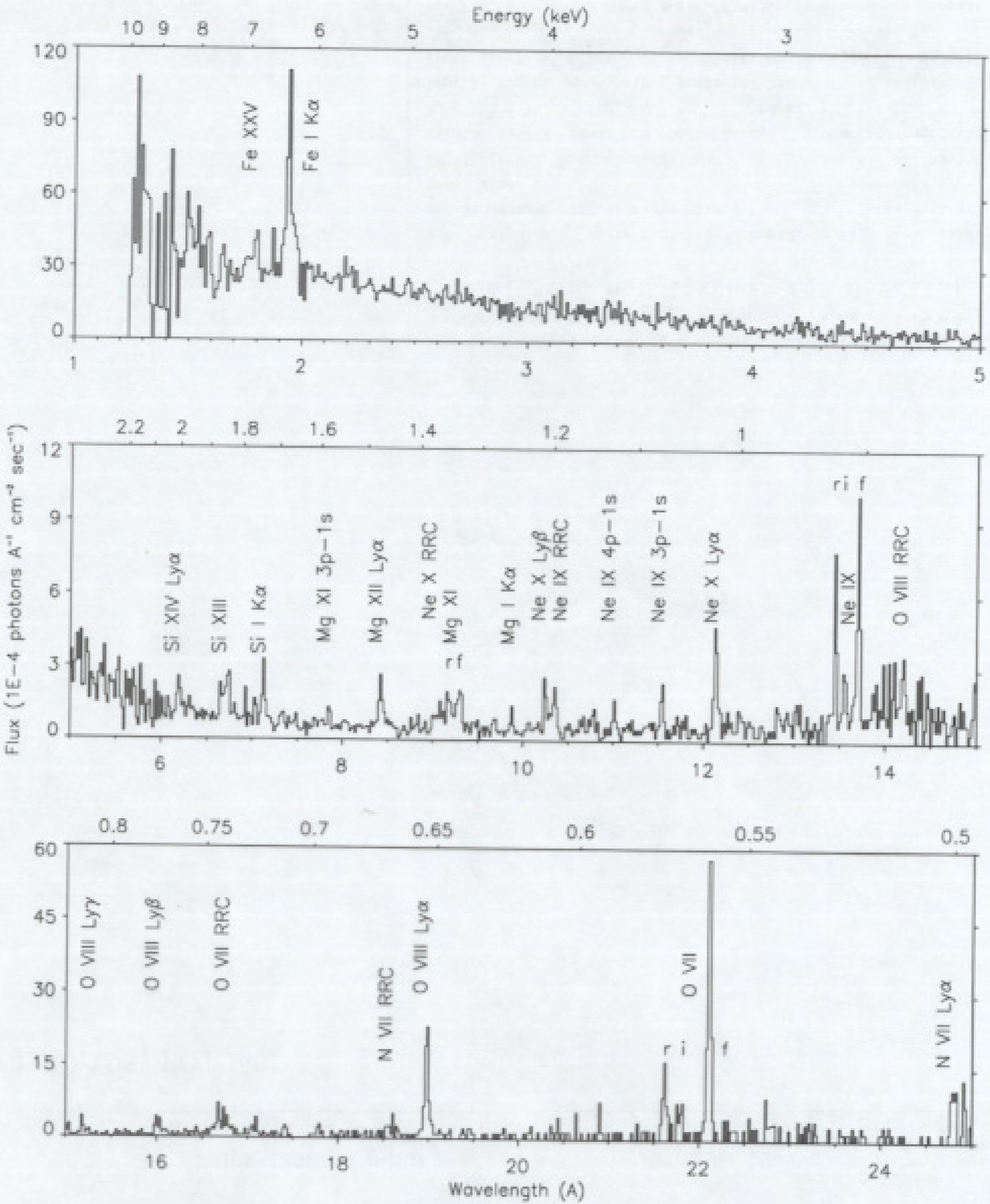
◆ A very weak hard continuum is visible (probably absorbed by local cold material)

◆ The spectrum is dominted by narrow emission lines from a 1.6 kpc highly ionized nebula

◆ X-ray narrow-line region is composite, consisting of both photoionized and collisionally ionized components.

◆ First direct evidence of X-ray line emission from a hot plasma ($T \sim 10^7$ K) that may providepressure confinement for the cooler ($T = 3 \times 10^4$ K) photoionized clouds

◆ And the data...



NGC 4151

Ogle et al

The Iron Line: MCG-6-30-15 again!

◆ A substantial amount of the power in AGNs is thought to be emitted as X-rays from the accretion disk corona in active or flaring regions.

◆ The flares irradiate the accretion disk, which is relatively cold, resulting in the formation of a "reflection" component within the X-ray spectrum

◆ A given incident photon is either absorbed, scattered out or reprocessed into a fluorescent line photon which escapes

◆ These effects give the reflection spectrum a broad humplike shape. In addition, there is an emission line spectrum resulting primarily from fluorescent K lines of the most abundant metals. The iron K line at 6.4 keV is the strongest of these lines.

◆ A narrow Fe K emission line is a common component in Sy 1 galaxies. It is generally interpreted as fluorescence from cold material distant from the inner accretion disc. The exact origin is still debated (molecular “torus”, broad line region, outer disc, dense coulds at smaller radii?).

◆ A broad Fe K emission line is also postulated in several object but is the subject of a much heated debate.

◆ Shape and strenght of the broad component represent a crucial diagnostic of the innermost regions close to the back hole but **depends critically** on the fitting of the underlying continuum

Examples:

XMM EPIC spectra of 6 bright Seyfert 1 galaxies (ratios to 2-10 kev power law).

ASCA Fe K line in MCG-6-30-15

Comparison with Chandra

Other possible ways to fit the data (from Reeves)

XMM/EPIC PN

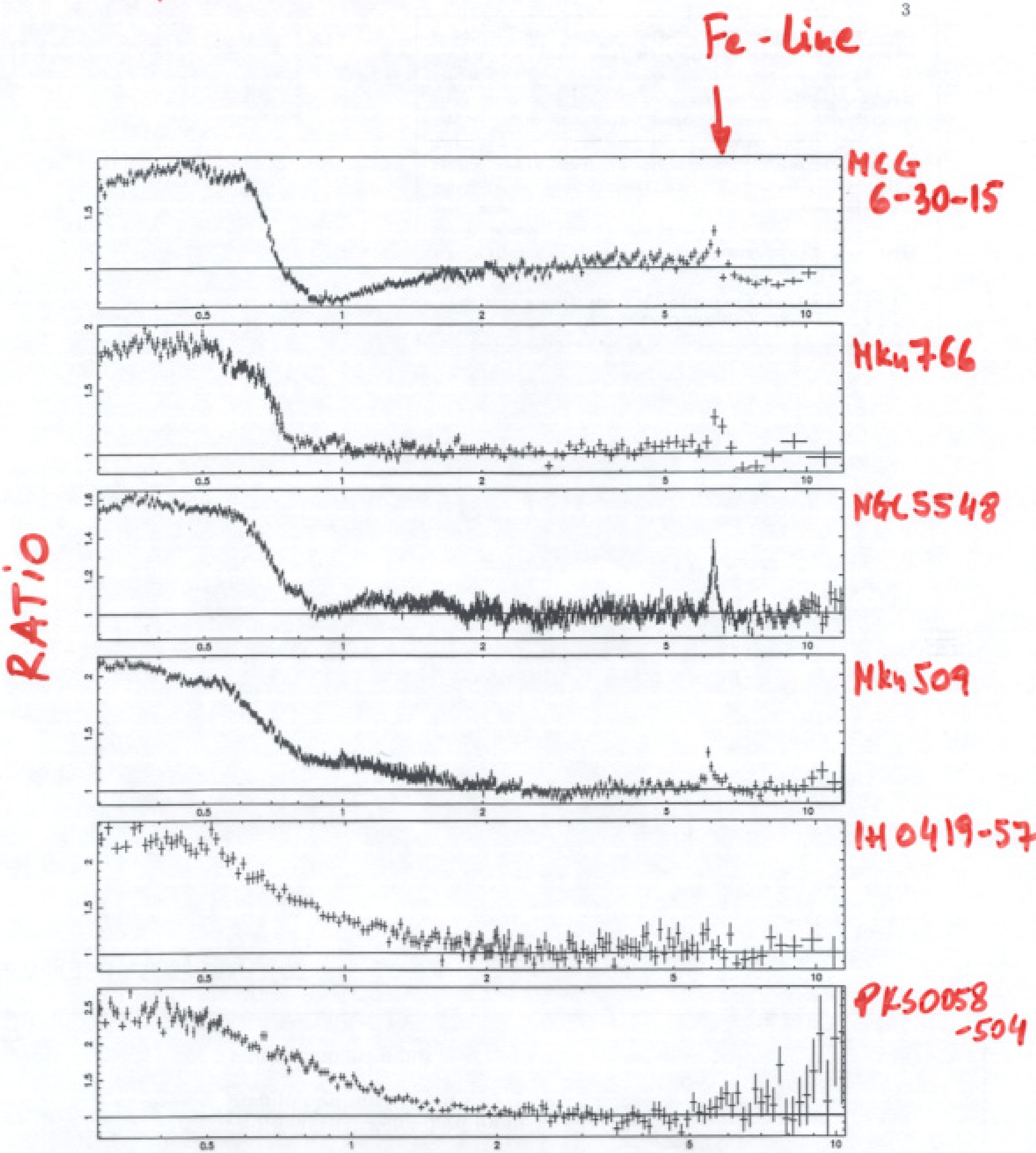
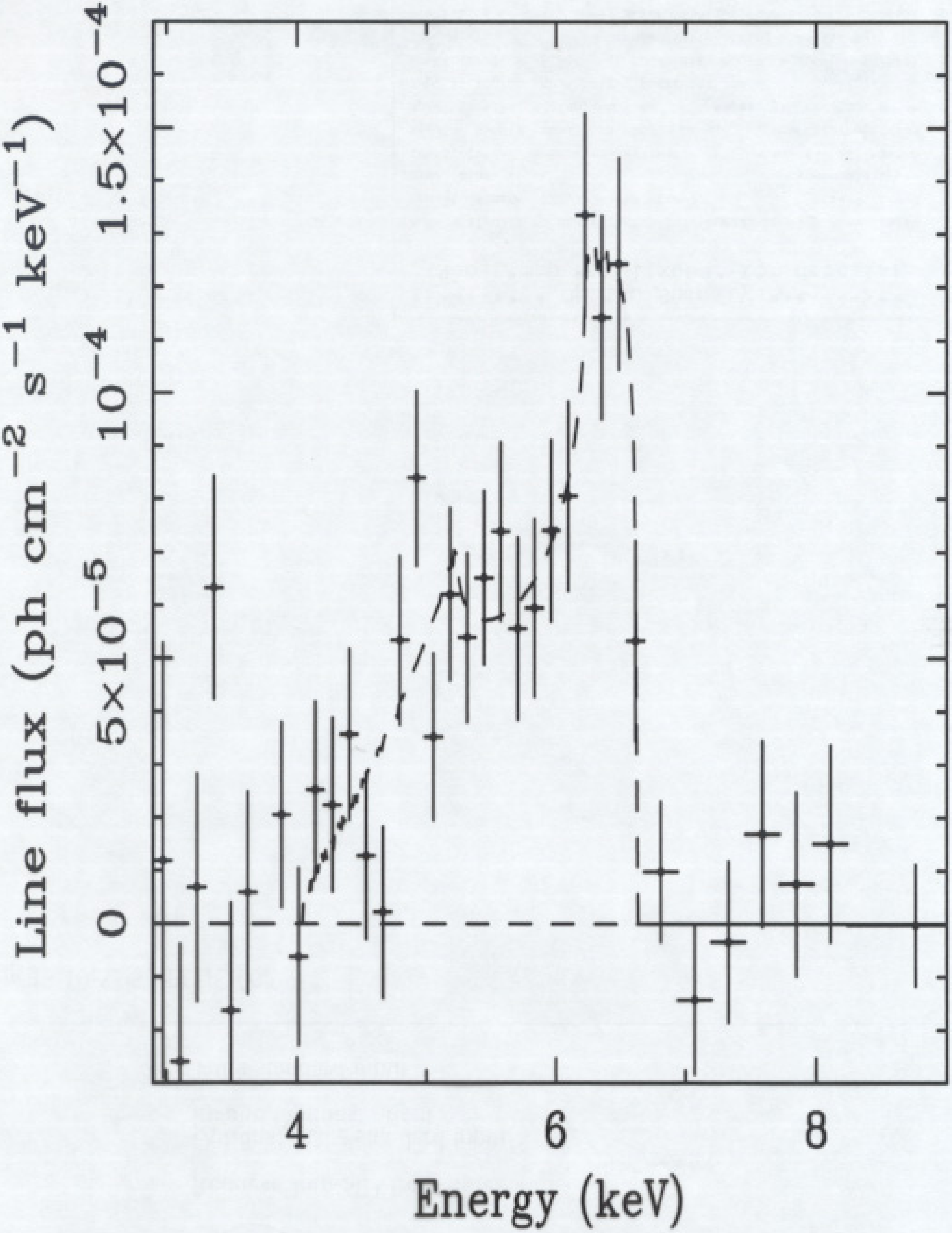
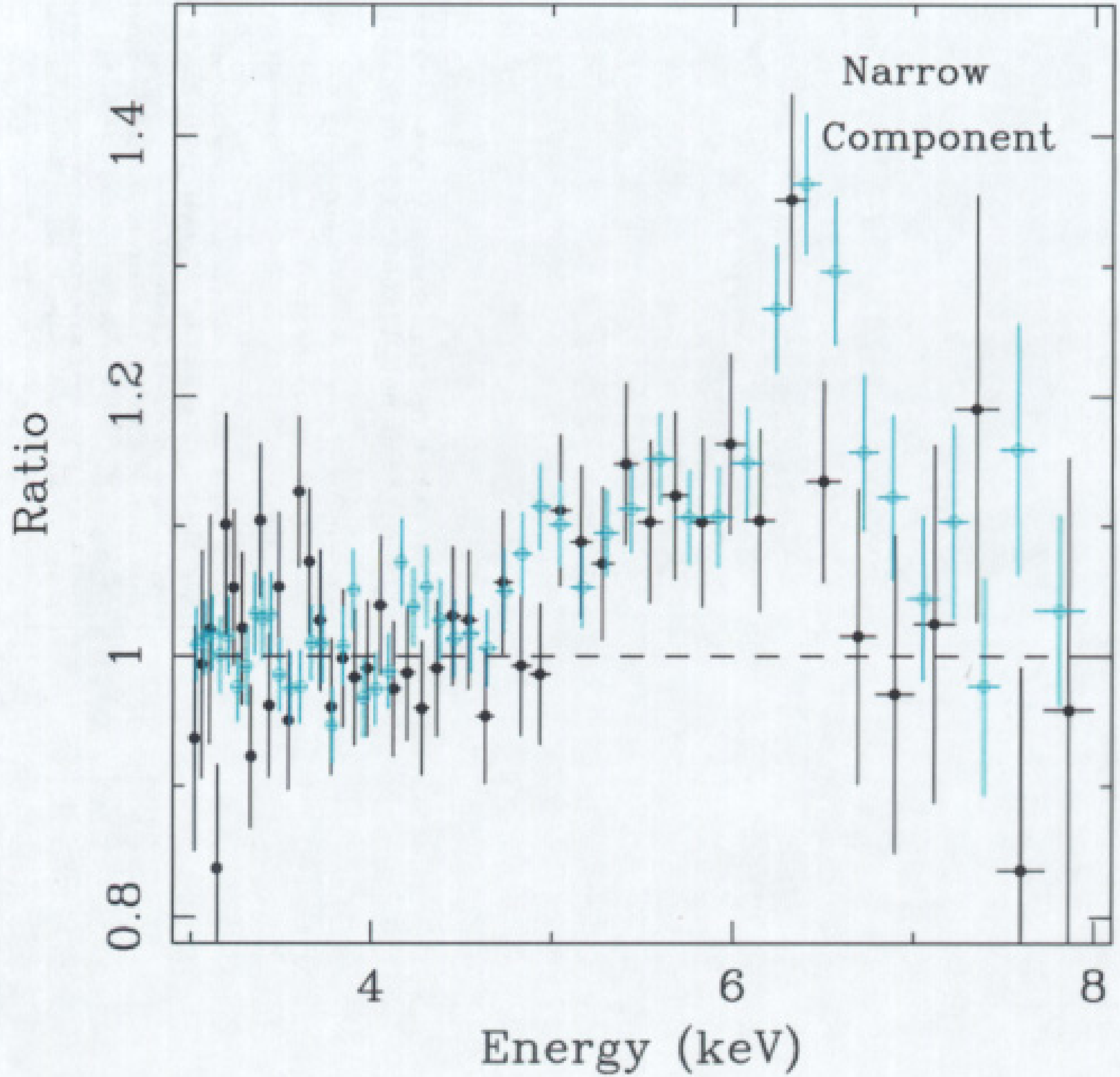


Figure 1. EPIC PN camera spectra for 6 Seyfert 1 galaxies shown as the ratio of measured flux to the 2–12 keV powerlaw fit as listed in Table 1. From the top, in order of increasing 2–10 keV luminosity, are MCG-6-30-15, Mkn 766, NGC 5548, Mkn 509, 1H 0419-577 and PKS 0558-504. The abissca is photon energy (keV) in the observer's frame.

Pounds & Reeves



FABIAN et al (2000)



LEE et al (2002)

POUNDS & REEVES (2002)

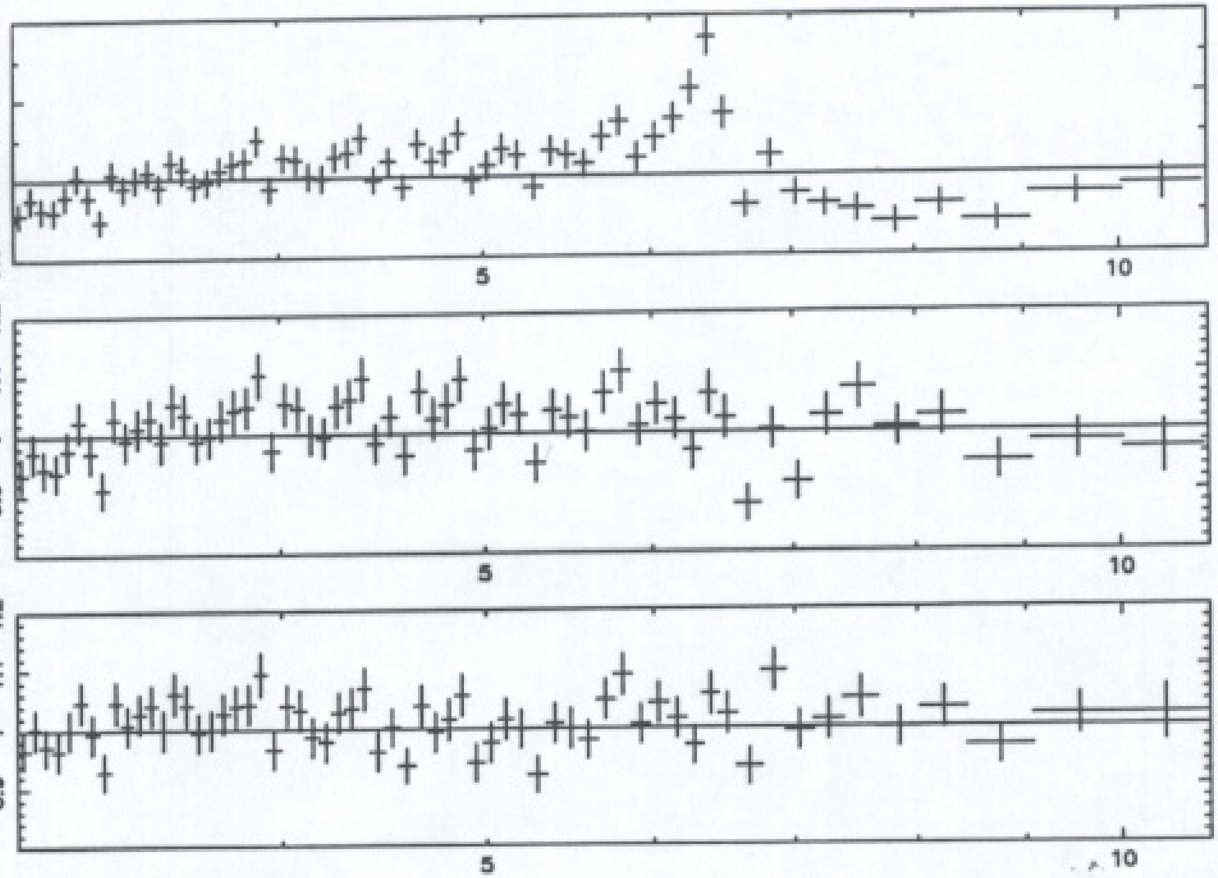


Figure 5. Data/model ratio plots for fits to (a) a power law, (b) a power plus narrow Fe K line and absorption edge, (c) a power law, absorption edge plus narrow and broad Fe K lines fit to the MCG-6-30-15 EPIC data

the previous fit (Figure 5 (b)) suggests the broad line is modelling quite subtle curvature in the EPIC data be-

photons) may be co
by increasingly stron
lower luminosity Sey
6-30-15. We empha
broad-band data fro
from the RGS in pr
elling of the primary
- of absorption and s
unique information c
nuclear environment

One such second
emission line at 6.4
erty across our samp
object PKS 0558-50
tent with reflection
a solid angle of 1–2
Line profile and vari
ing this emission lin
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We suggest the b
or as strong, as it a
servations. A key fac

Radio Loud AGN: not just “Featureless”Spectra

◆ X-ray spectra of radio loud AGN and bright quasars are predominantly “featureless” (pure power-law spectrum absorbed by the Galactic interstellar medium).

◆ X-ray spectra are used for studies of the intergalactic medium (AGN as a powerful “flashlight” shining through the IGM)

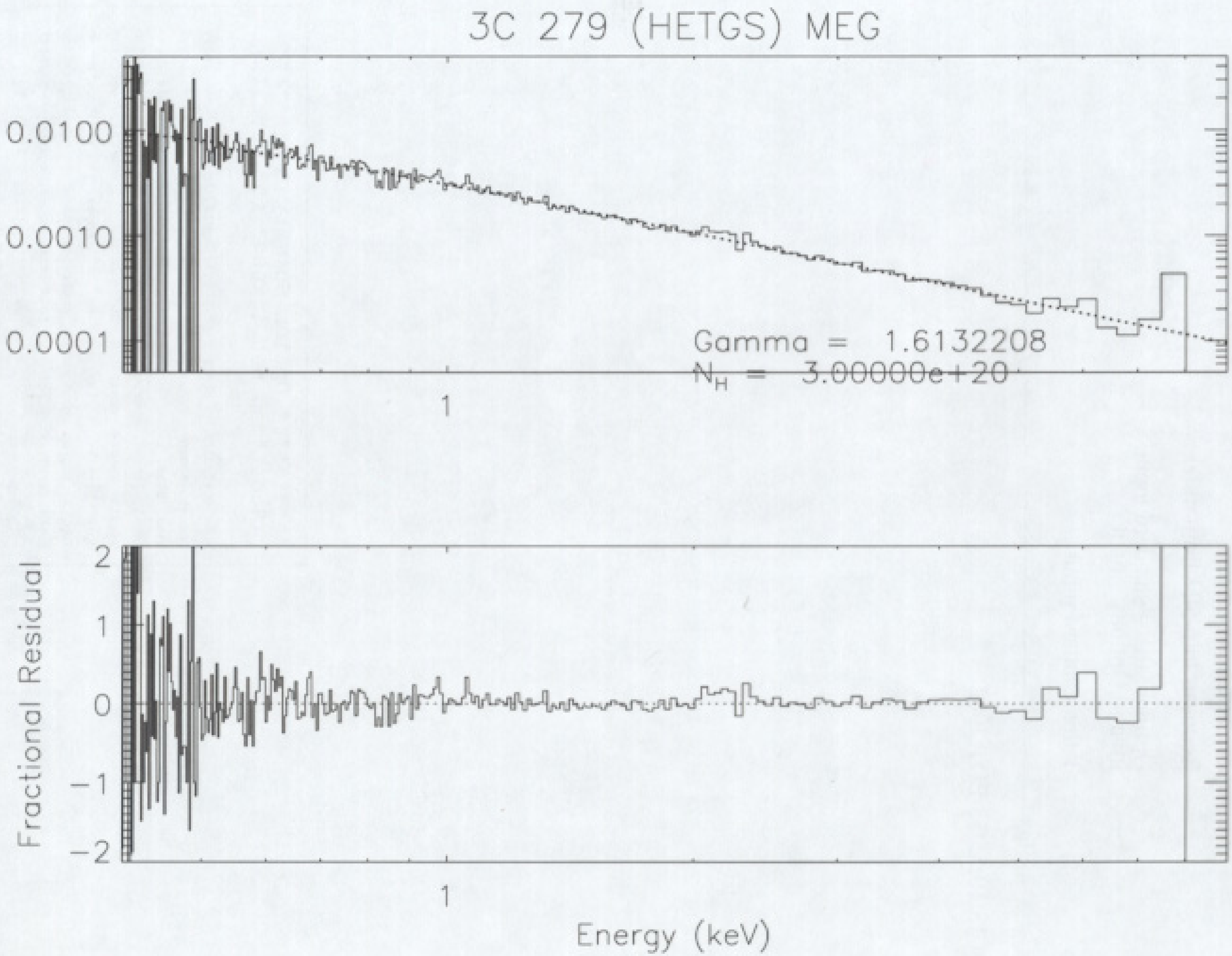
◆ Chandra has detected X-ray absorption lines of OVII, OVIII and NeIX along the line of sight to the bright blazar PKS 2155-304.

◆ The absorption is probably from warm/hot local gas in Intergalactic space surrounding our Galaxy

◆ The dynamical and physical properties derived for the absorbing gas seem consistent with those predicted for the low redshift warm phase of the IGM by hydrodynamical simulations for the formation of structures in the Universe.

Look at the data!

◆ Images show significant structures and jets!


3C 279 (HETGS) MEG
0.0100
0.0010
0.0001
Gamma = 1.6132208
N_H = 3.00000e+20
1
Fractional Residual
2
1
0
−1
−2
1
Energy (keV)

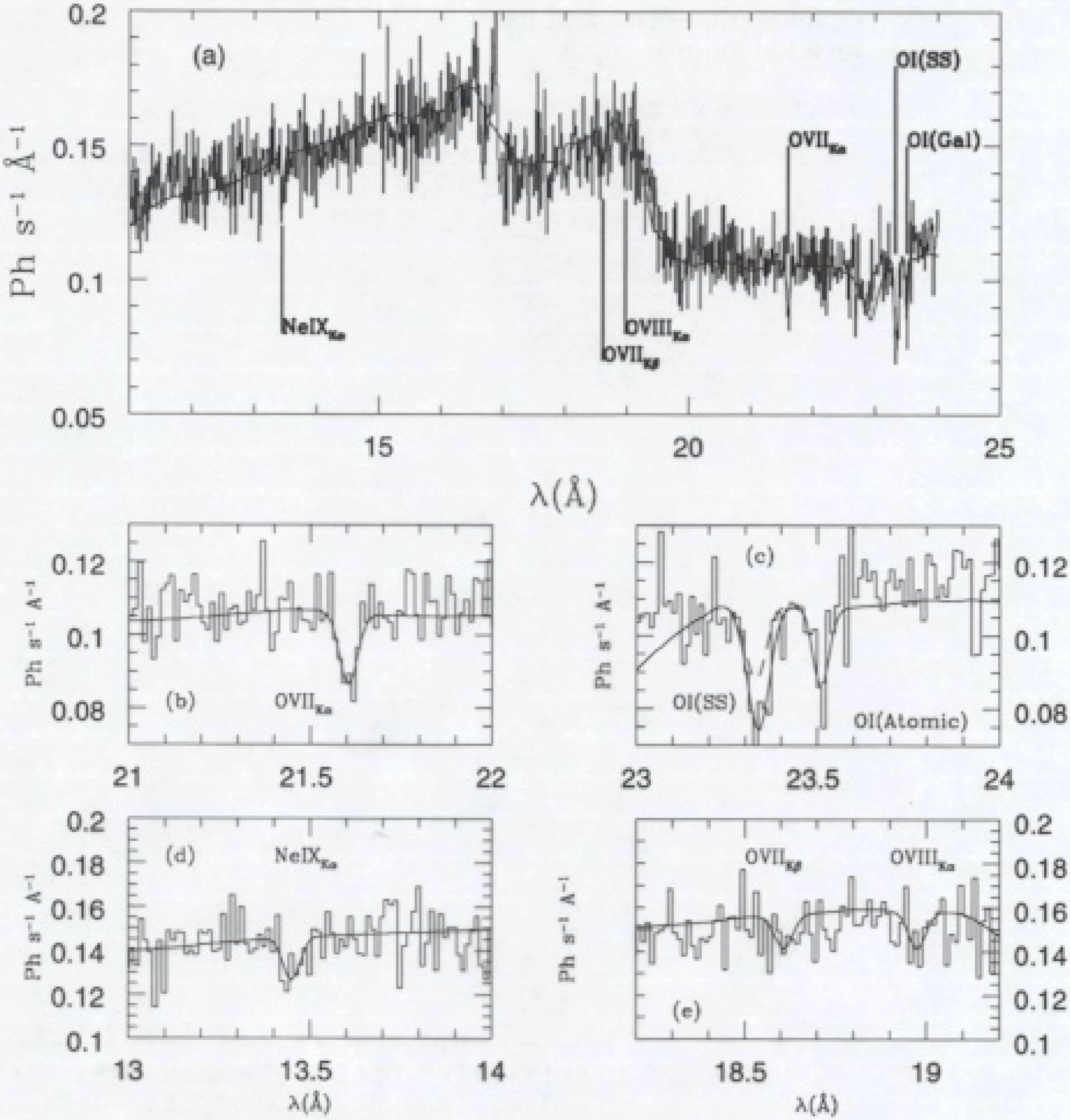


Fig. 1.— Top: (a) X-ray 11-24 Å unbinned ($\Delta\lambda$ = 12.5 mÅ) HRCS-LETG spectrum of PKS 2155-304. The folded best fitting model (power-law plus Galactic absorption, plus 6 absorption lines) is shown as a solid line. The strongest absorption lines are identified. Note that the effective area of the HRCS-LETG has not been corrected for in this plot, in order to show the strong, but large scale, instrumental features. The fitted power-law follows these peaks and dips closely. Bottom: blow-ups of four portions of the spectrum in Fig. 1a: (b) $OVII_{K\alpha}$ (top left); (c) atomic and solid-state (i.e. molecular) OI (top right); (d) $NeIX_{K\alpha}$ (bottom left); (e) $OVII_{K\beta}$ and $OVIII_{K\alpha}$ (bottom right). Vertical lines indicate the rest frame wavelengths of the transitions. The solid-state OI line in Fig. 1c is an effective area feature (dashed line).

Nicastro et al (2002)

10 Questions

M. Begelman, AGN meeting in Paris, July 2002

1. Are black holes fussy eaters?
2. Do AGN have accretion disks?
3. Is the Eddington Limit a limit?
4. Does black hole spin matter?
5. Why are most AGN radio-quiet?
6. What excites the emission lines?
7. Why aren't there BAL Seyferts?
8. Where are the Type II QSOs?
9. How does fuel get to the black hole?
10. Which came first: BH or galaxy?