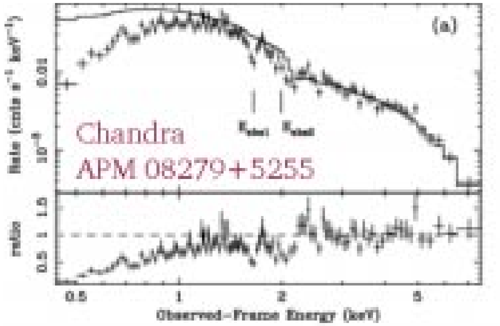
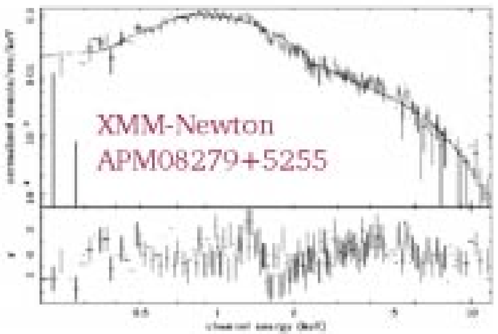
X-ray AGN
(Active Galactic Nuclei)



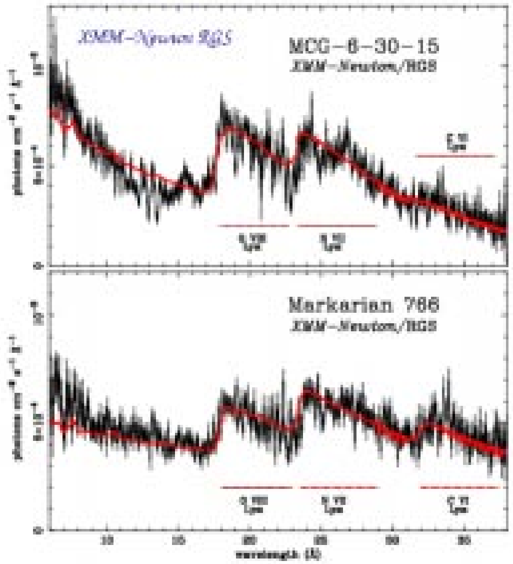


X-Ray Astronomy School V

7 August 2007

Dan Schwartz

SAO/CXC



Based on course material by

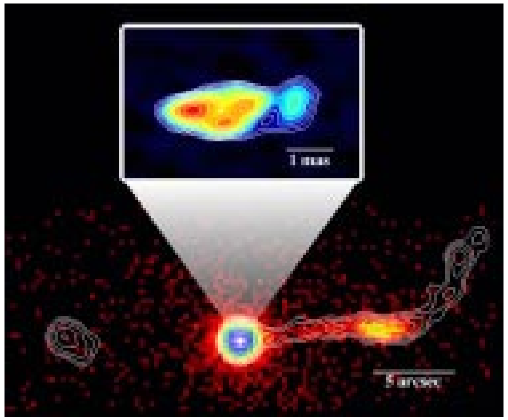
Tom Aldcroft

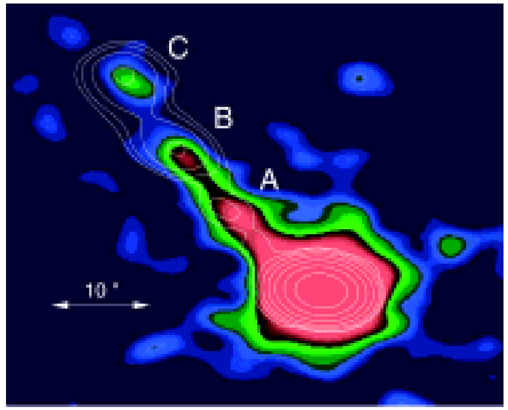
Antonella Fruscione

Aneta Siemiginowska

and references therein

and original material on Quasar Jets

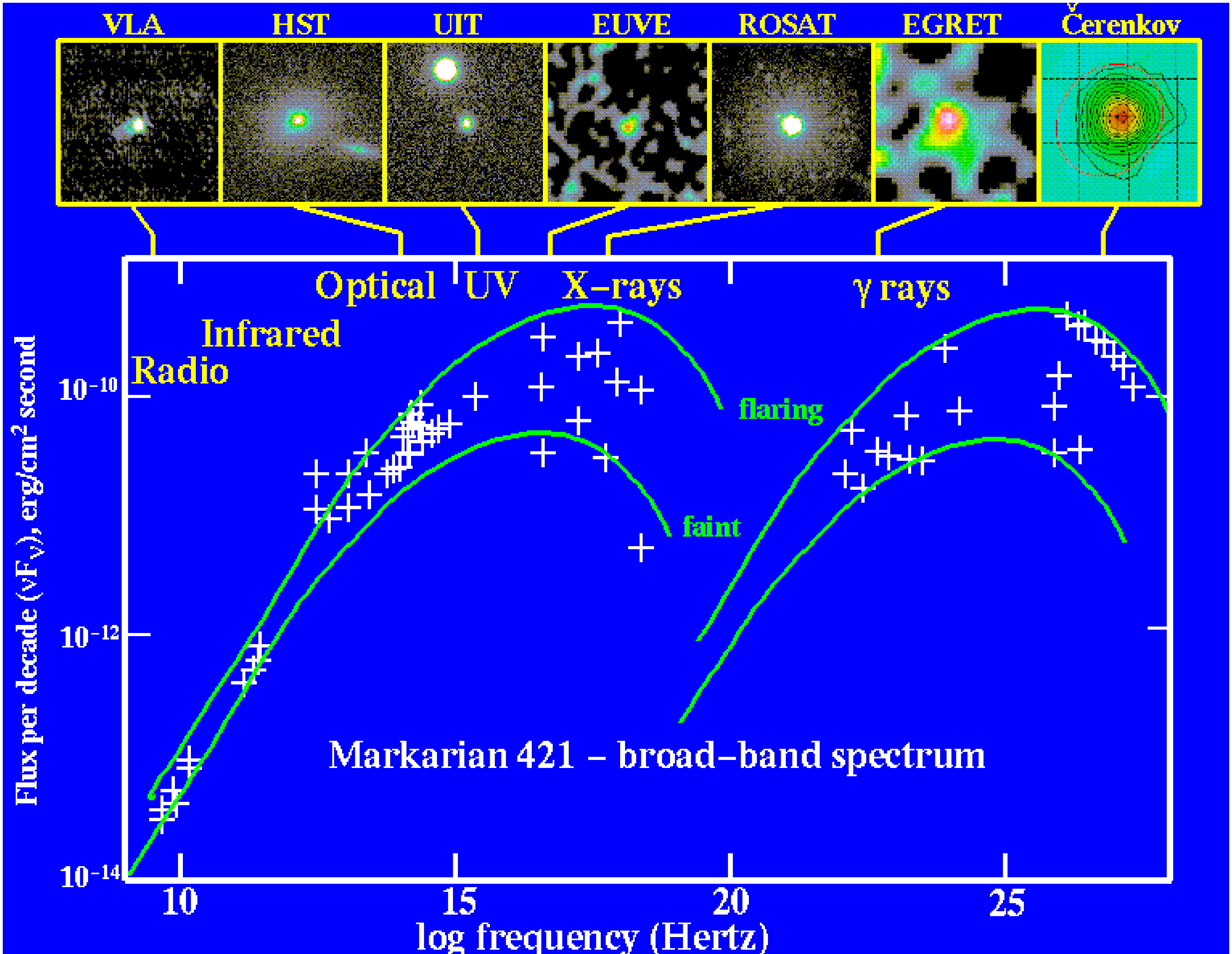




What are AGN?

Phenomenological:

- **Highly luminous:** $L_{bol} \sim 10^{42} - 10^{48}$ ergs s^{-1}
- **Compact**: size << 1pc
- **Broad-band** continuum emission:
  $dL / dlog\, \nu$ = roughly constant
  From IR to X-rays and γ-rays
- **Variable:** stronger variations on smaller timescales at shorter wavelengths
- **Polarized:** typical 1% linear in optical
- **Radio emission:** Common, but wide range
- **Emission/abs. lines:** High velocity, non-stellar



VLA
HST
UIT
EUVE
ROSAT
EGRET
Čerenkov
Radio
Infrared
Optical
UV
X-rays
γ rays
flaring
faint
Markarian 421 – broad-band spectrum
Flux per decade (νFν), erg/cm2 second
10-10
10-12
10-14
10
15
20
25
log frequency (Hertz)

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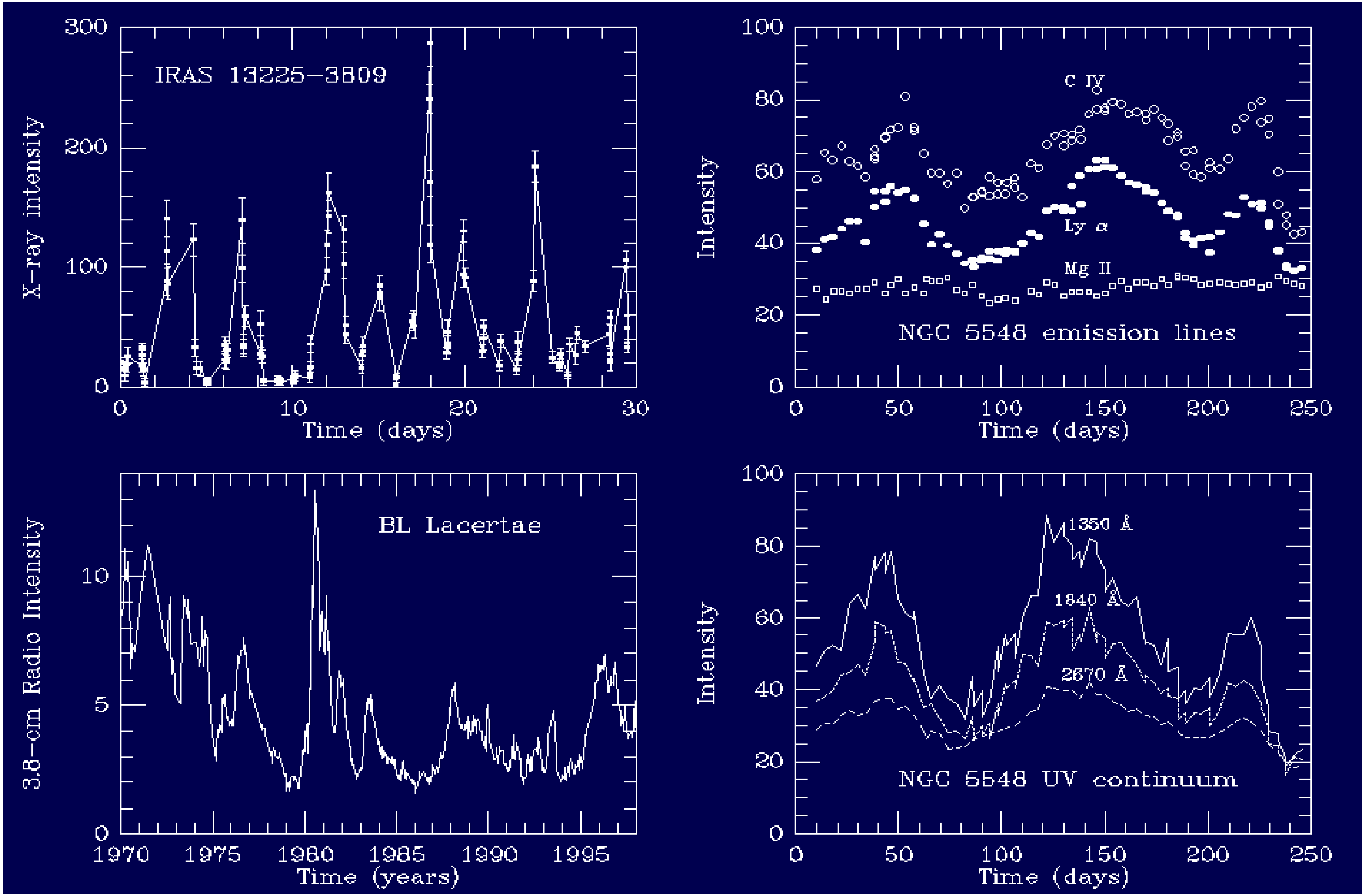
Time variable in all bands



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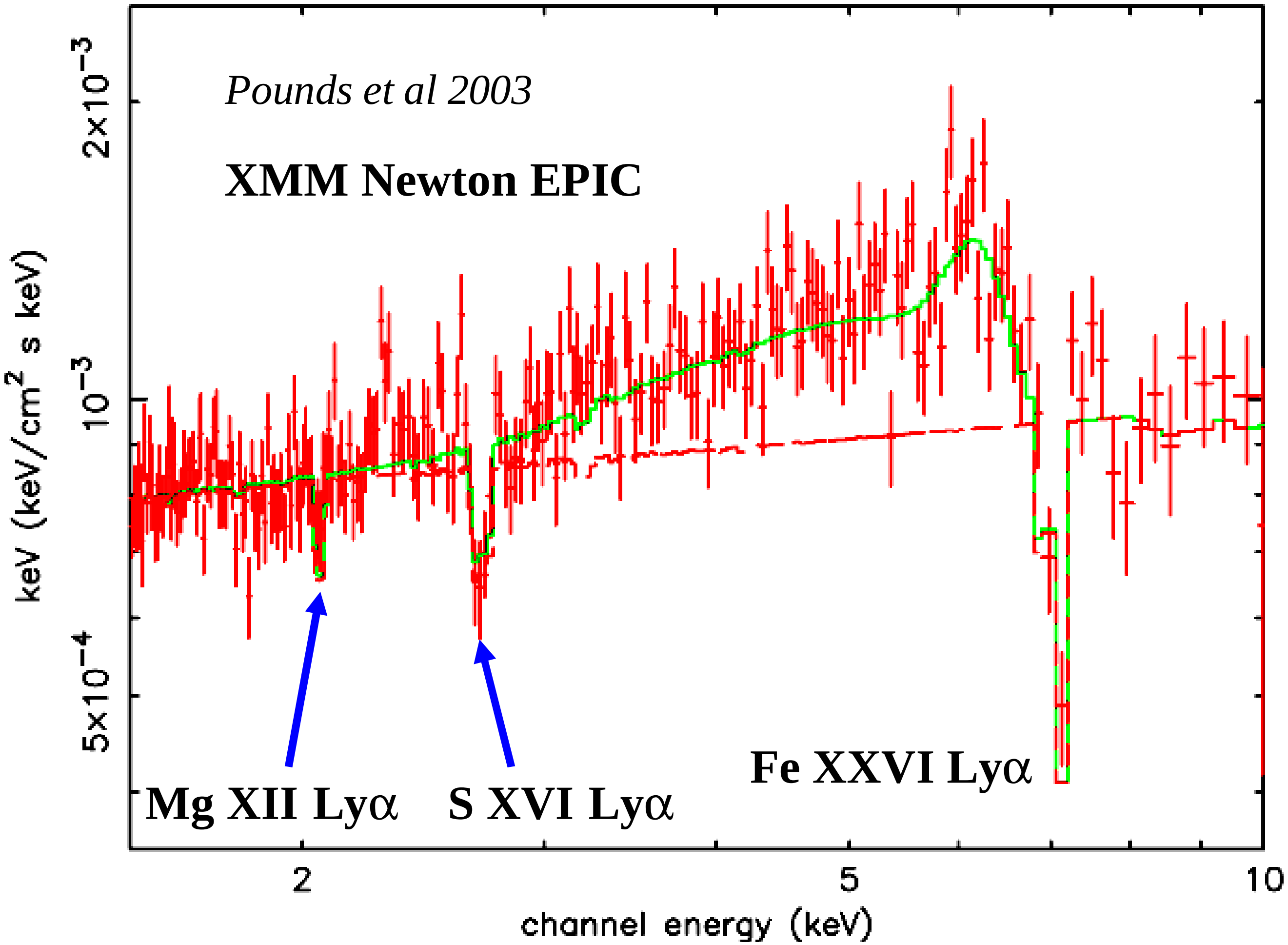
X-Ray absorption: High velocity outflow in PG 1211+143



Velocity of outflowing ionized gas based on observed line broadening
~ 0.09-0.1c

What is an AGN?

Physical:

- **Supermassive Black Hole: $M \approx 10^5$ to $10^{10}\ M_\odot$**
- **In the center of a galaxy**
- **Powered by Accretion: $L = \eta\ d\,(Mc^2)\,/dt$**
- **Scale: Eddington Luminosity: $F_{radiation}=F_{gravity} \Rightarrow L_{Edd} \approx 1.3\times10^{38}\ (M/M_\odot)$ ergs s^{-1}**
- **Scale: Schwarzschild radius: $R_g=2GM/c^2=2.95\times10^5(M/M_\odot)$ cm**

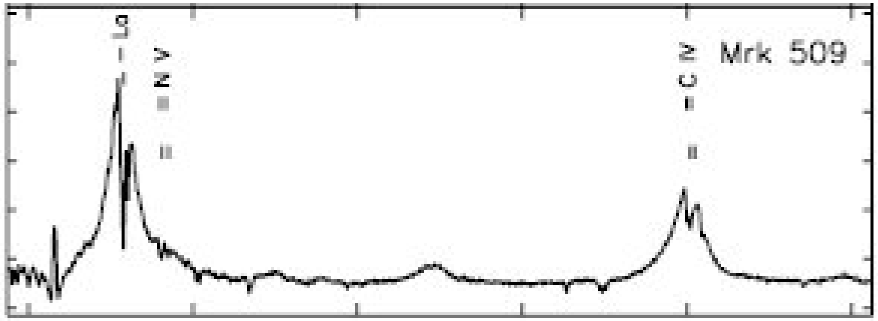
What are AGN called?

- **Quasars (quasi-stars)**
- **QSO's (quasi-stellar objects)**
- **QSRS's (quasi-stellar radio sources)**
- **BL Lac objects**
- **Blazars (BL Lac type quasars)**
- **OVV (Optically Violent Variables)**
- **Seyfert Galaxies (which may be Type 1, Type 2, Type 1.x, Narrow line type 1)**
- **Narrow Emission Line galaxies**
- **LINER's (Low ionization nuclear emission region)**
- **LLAGN (Low Luminosity AGN)**

What can X-rays tell us?

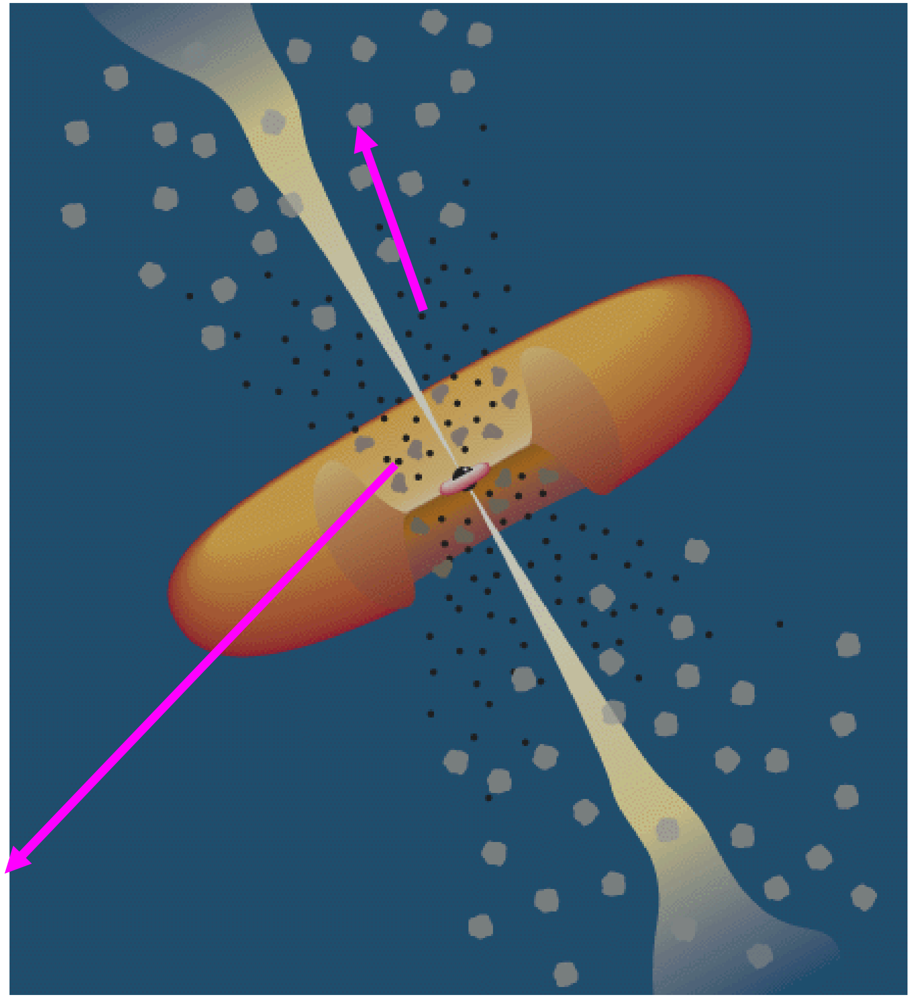
- Time Variability:
  - **Scale/Size** of the emitting and reprocessing regions
- X-ray Spectra:
  - Absorption:
    - Amount of **absorbing** material
    - Outflow/Inflow **velocity**
    - **Cold/Warm** absorbers
    - **Ionization** State
  - Thermal emission from hot gas: 10^5-10^7 K **=> hot gas is there!**
  - Non-thermal emission: synchrotron, Comptonization **=> relativistic plasma!**
  - Emission lines
    - **General Relativistic effects**
- X-ray Imaging:
  - **Nucleus** – unresolved component
  - **Extended emission** on different scales: parsec to hundreds kpc
  - **Jets and radio lobes**

Structure of AGN

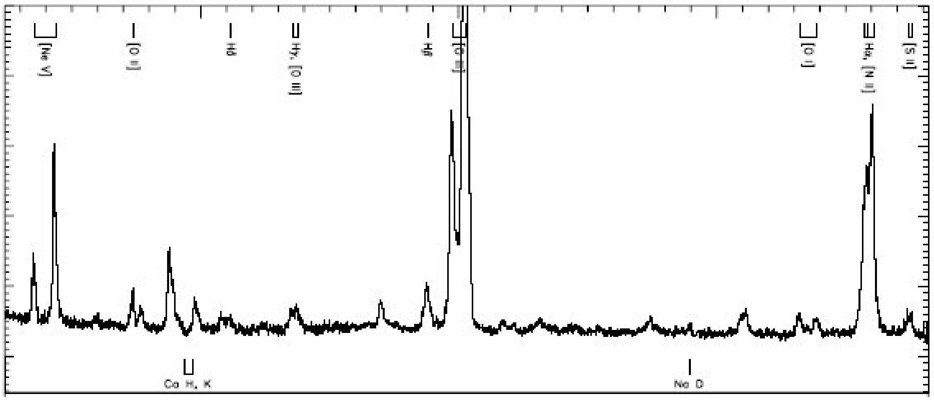


Scales for M= 10^8 $M_\odot$

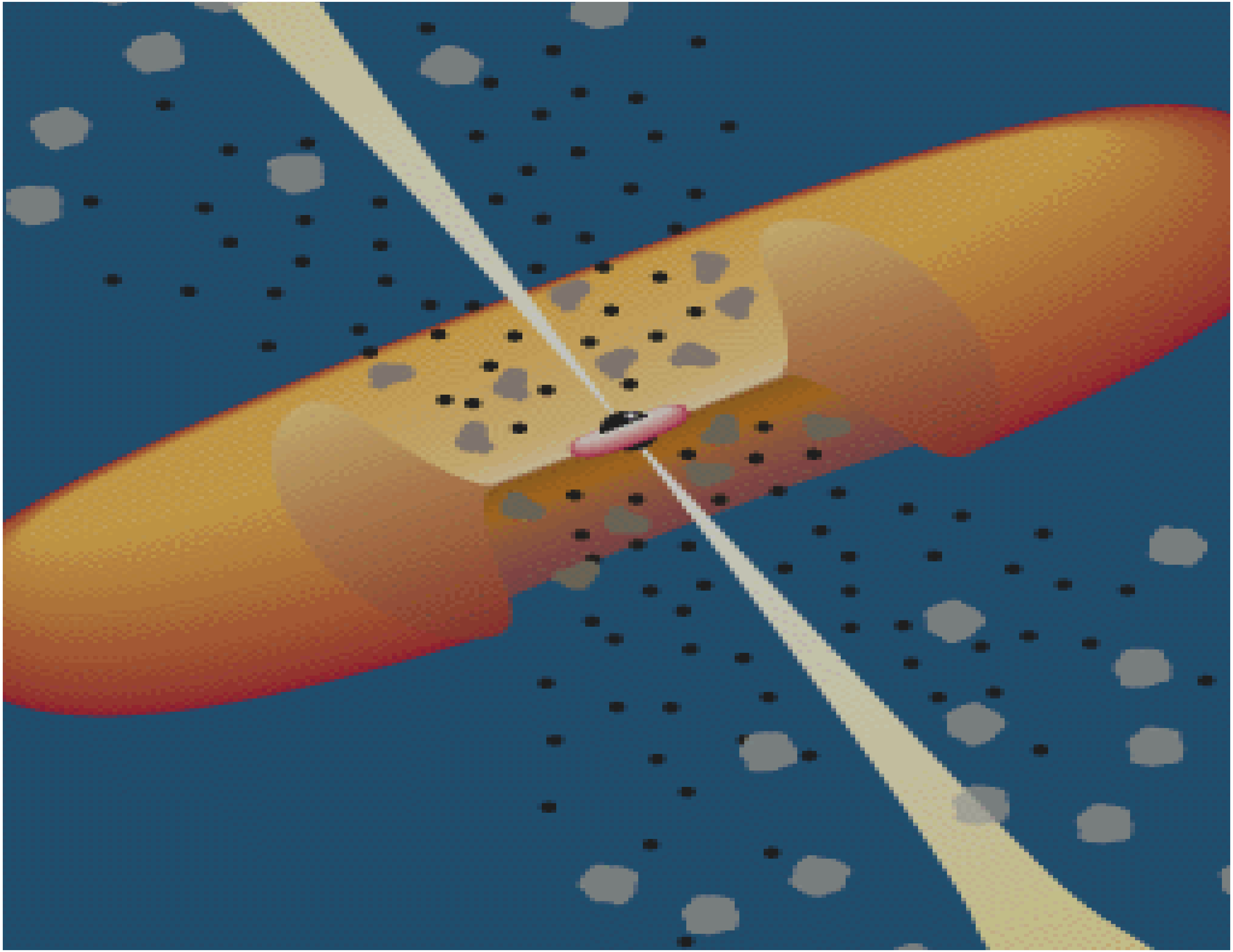
Black hole	3×10^{13} cm
Accretion disk	$1\text{-}30\times10^{14}$ cm
BLR	$2\text{-}20\times10^{16}$ cm
Torus	10^{17} cm ??
NLR	$10^{18}\text{-}10^{20}$ cm
Jets	$10^{17}\text{-}10^{24}$ cm



- This picture based on integrated emission is only part of the story!

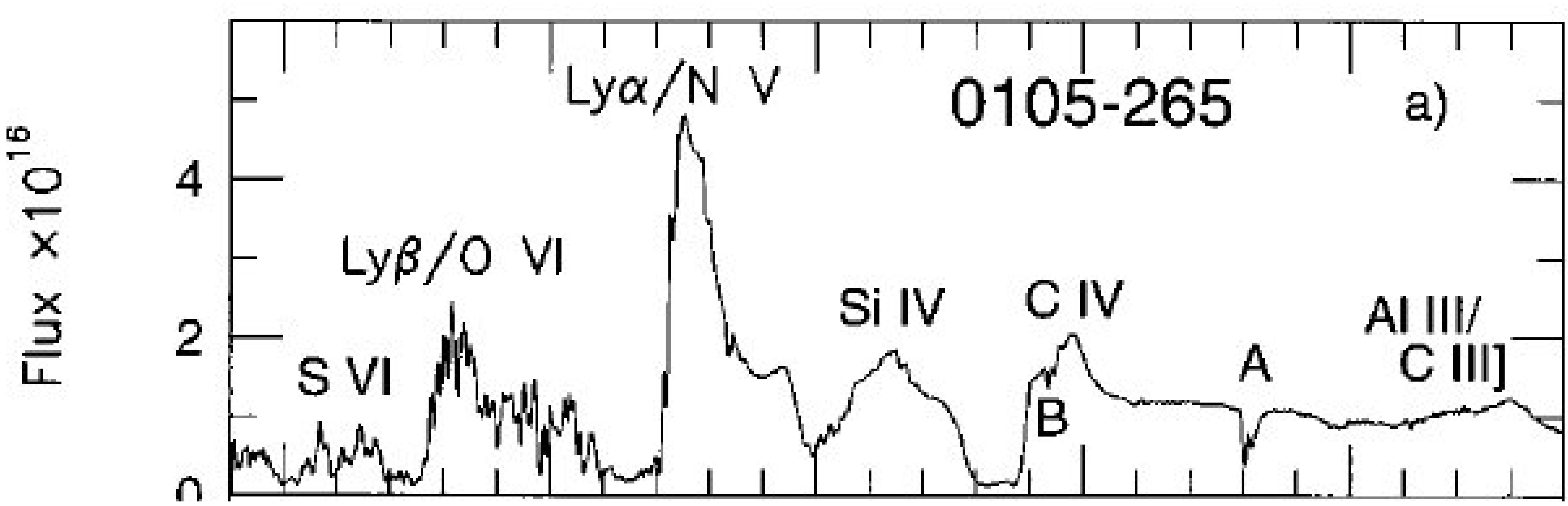


Urry C.M. & Padovani P. 1995 PASP, 107, 803.

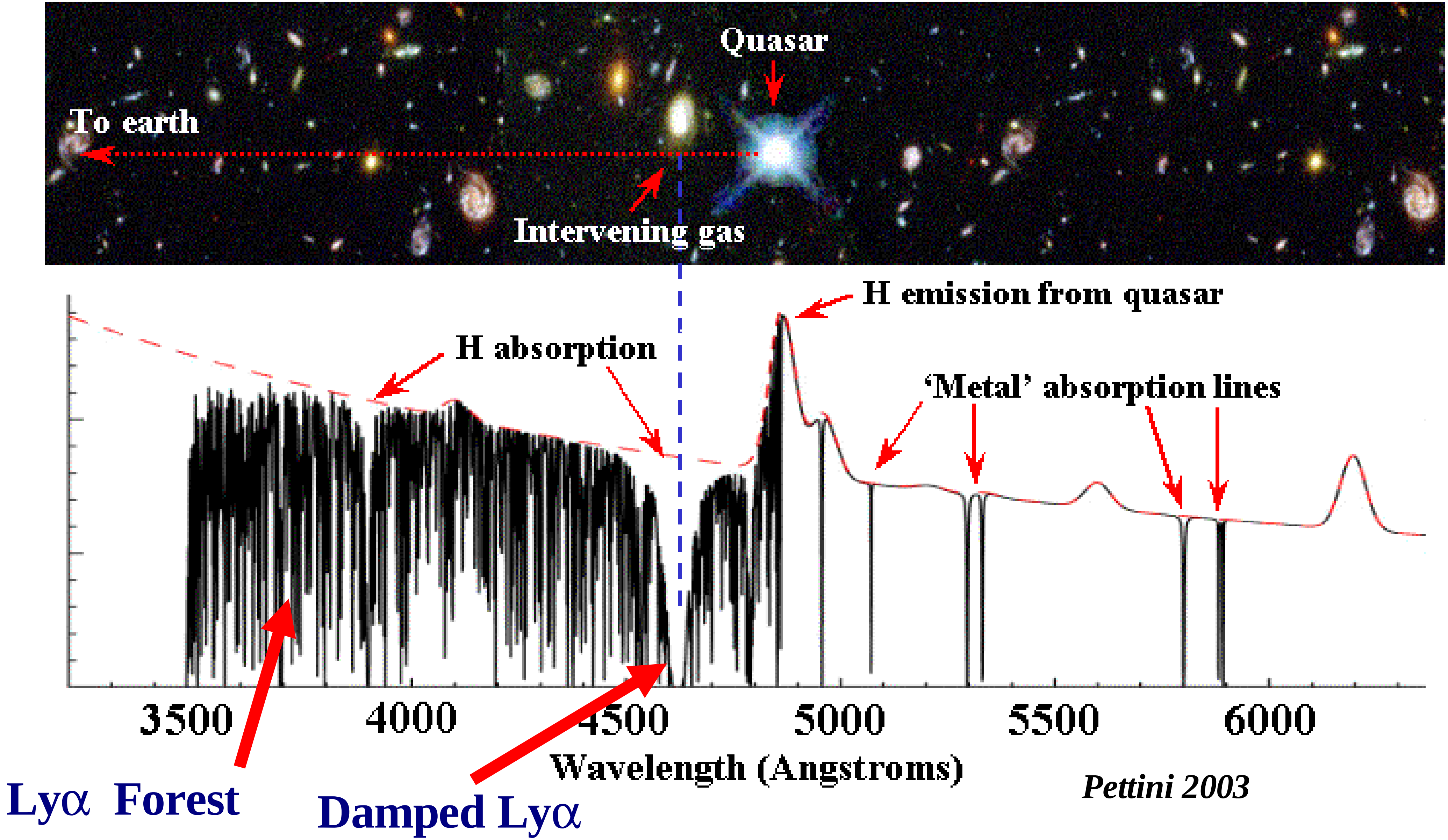


Absorbing outflows in AGN

- AGN of all stripes show absorption in optical through X-ray
- Outflowing material with ejection velocities up to ~0.2*c* in extreme BALQSOs, but typically narrow with v_{out} ~few 1000 km/s in Seyferts
- Absorption presents opportunity for detailed physical analysis along a single sightline (vs. integrated emission)

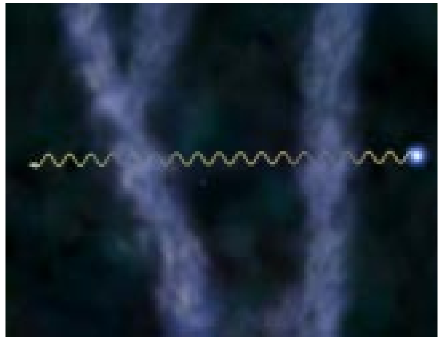


Optical/UV Absorption due to IGM
=> Studies of Matter in the Universe



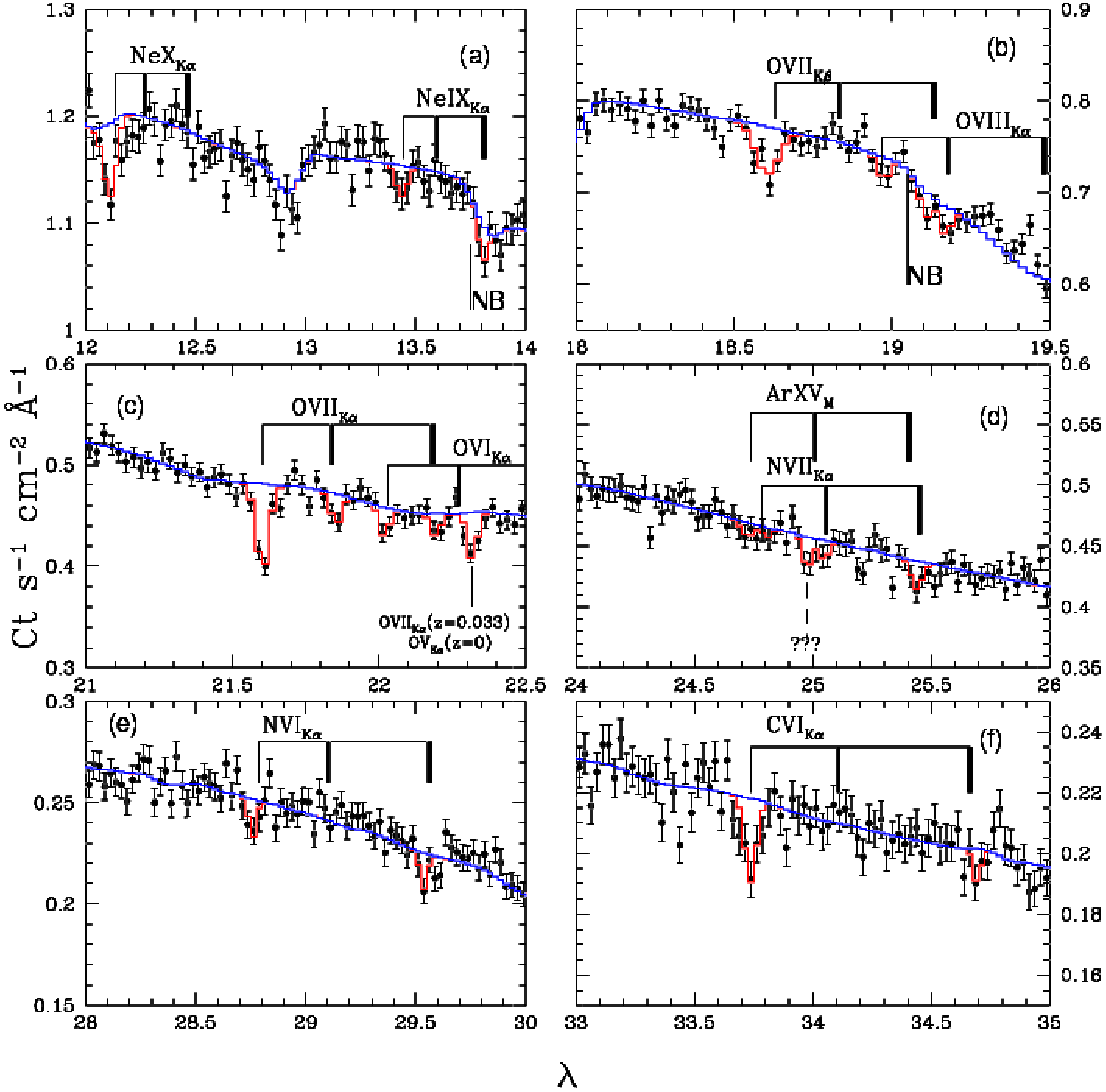
Pettini 2003

X-RAY ABSORPTION: the intergalactic medium



Credit:CXC

Nicastro et al. 2005

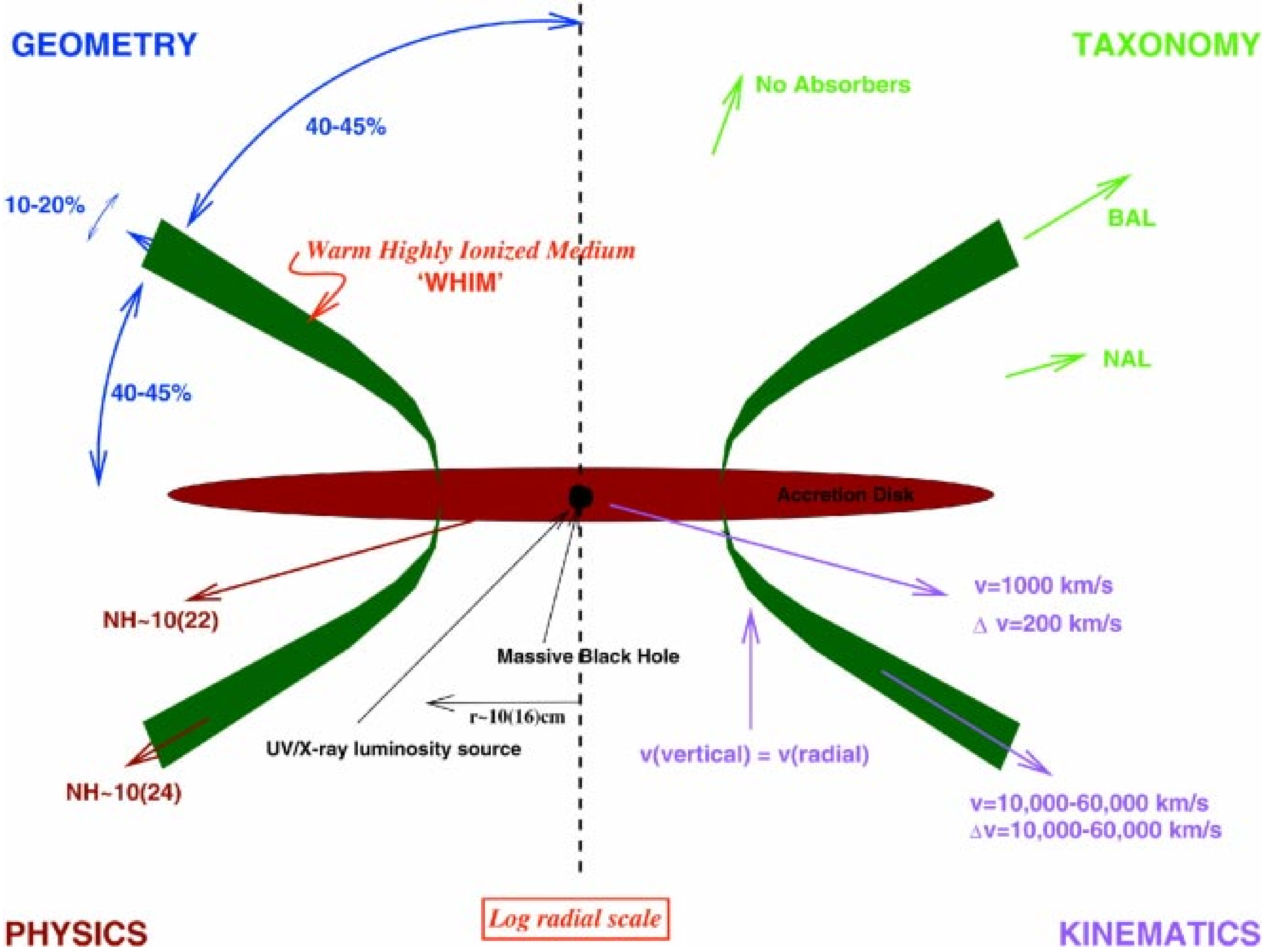


Mrk 421 (z=0.03) observed by Chandra ACIS/HRC-LETG as a powerful "background" light source.

X-ray emission absorbed by intervening filaments of gas - the warm-hot intergalactic medium (WHIM)

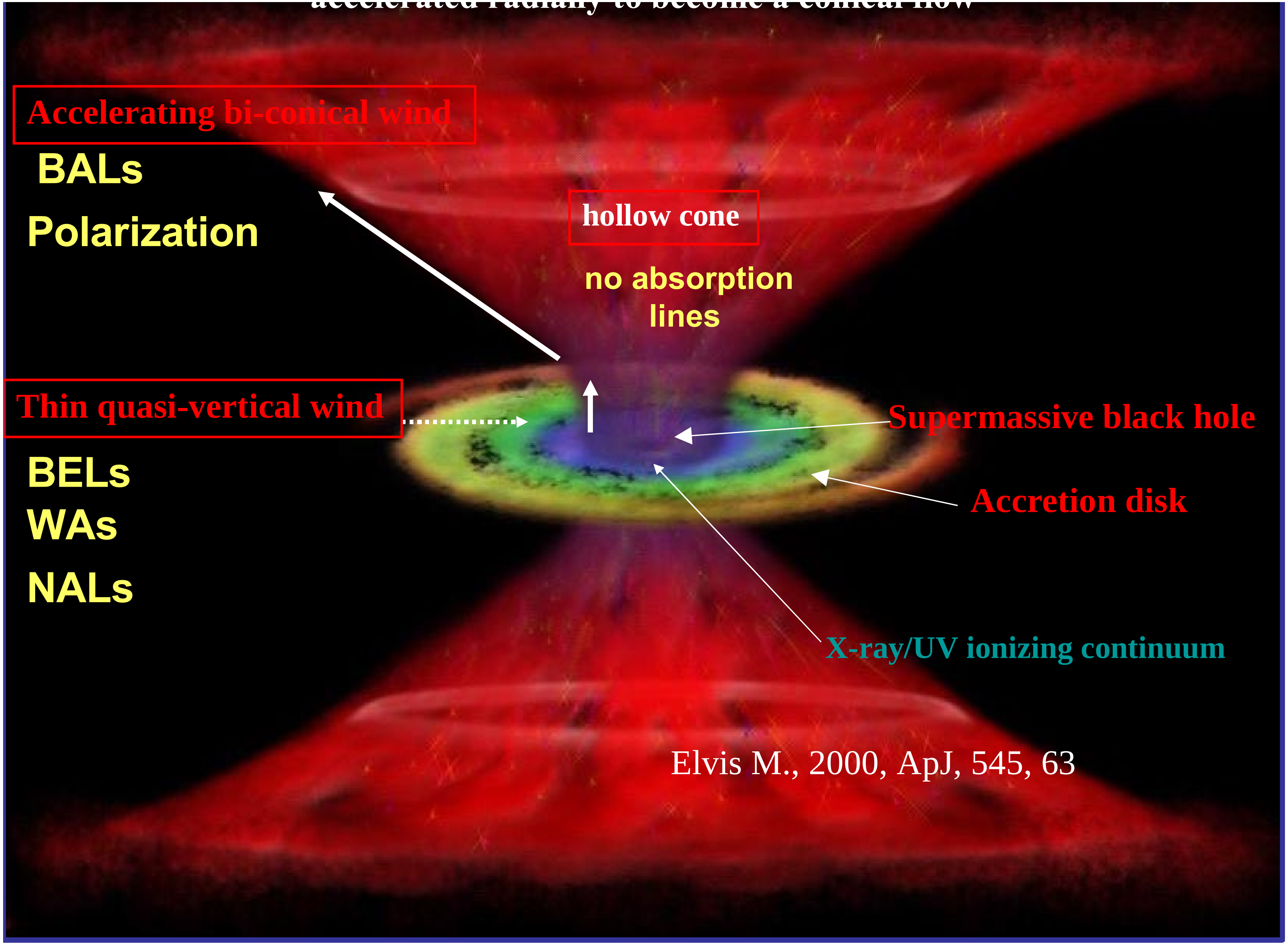
Detection two intergalactic ionized absorbers at redshifts z=0.011 (NVII,OVII,OVIII) and z=0.027 (CIV,NVI,NVII,OVII and NeIX)

Elvis Structure for Quasars

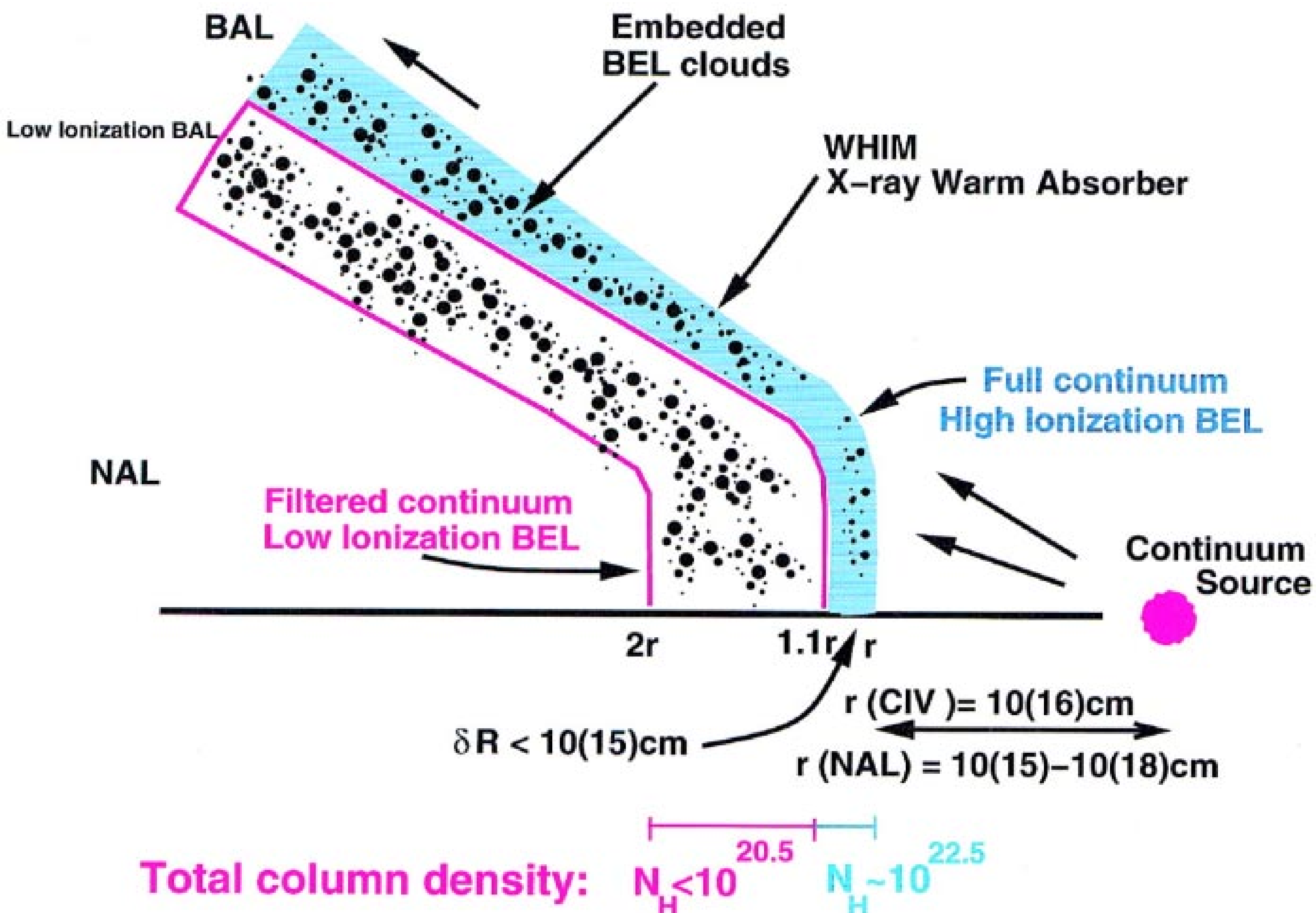


Elvis 2000

accelerated radially to become a conical flow



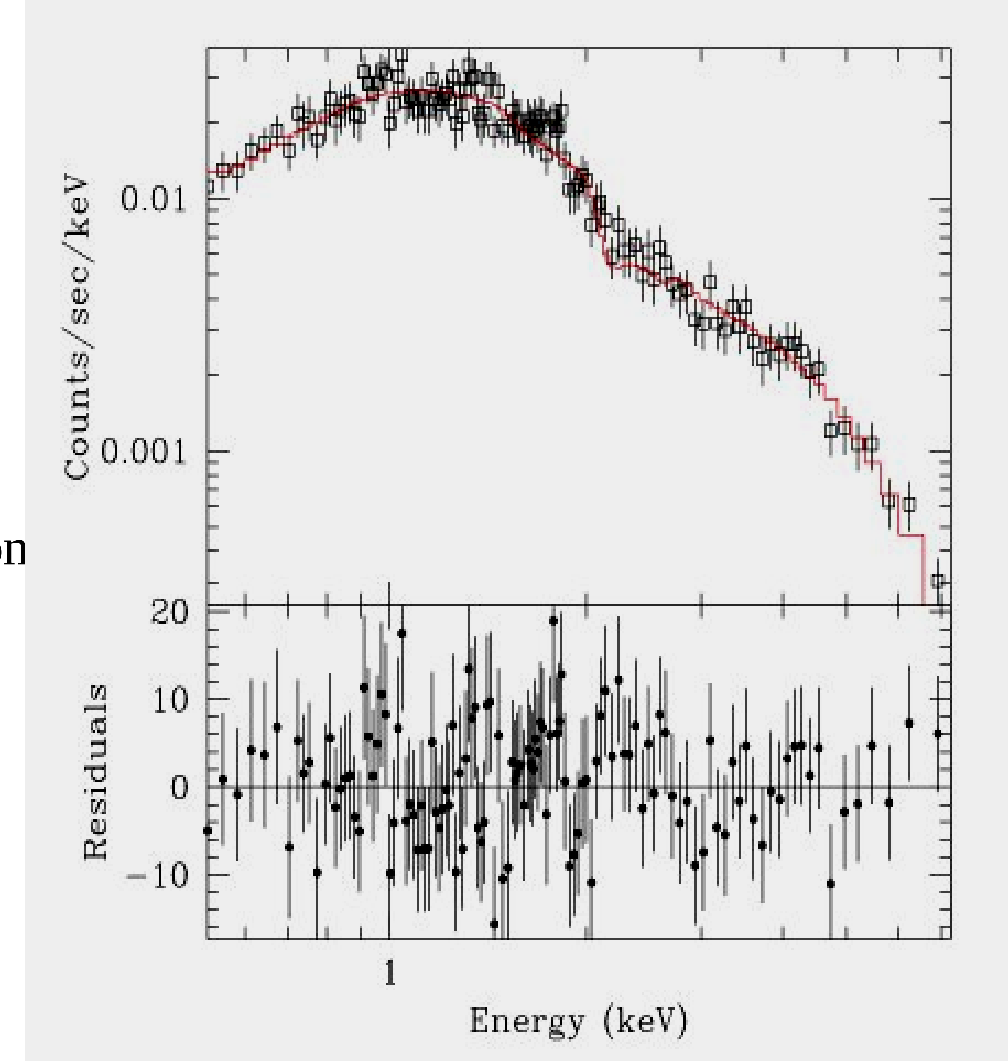
Elvis Structure for Quasars



Low Resolution Spectral Analysis – High Counts

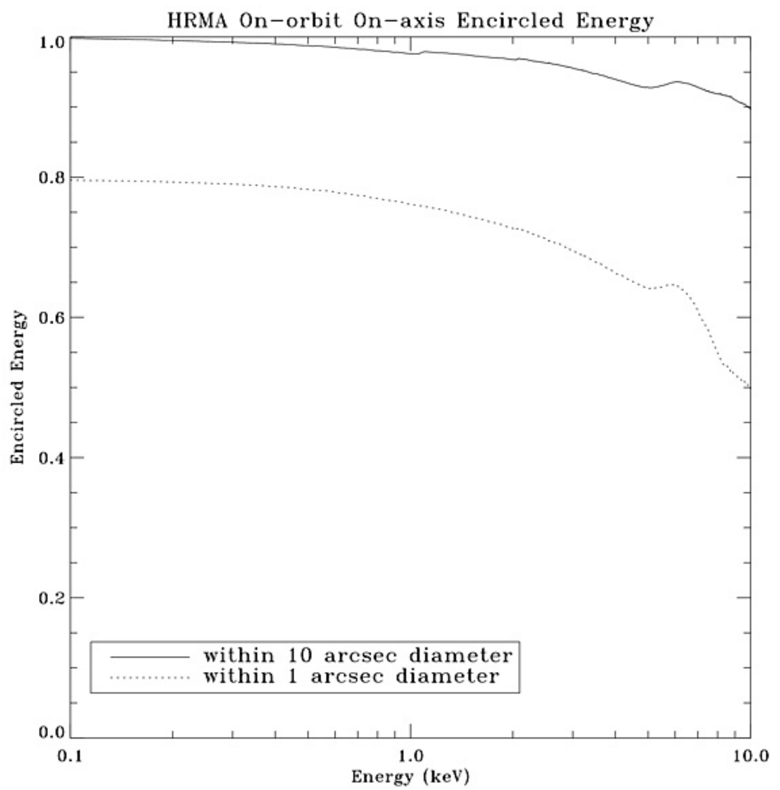
Case Study: Spectrum of UM425A

- First goal: understand the X-ray spectrum of the bright UM425A
- With ~5000 counts this is one of the highest S/N X-ray observations of a BALQSO
- Science drivers
  - Is the hard powerlaw a typical z~1 RQ QSOs?
  - What is the intrinsic absorbing column?
  - Is the absorption "warm" or "cold"?
- Analysis issues
  - Source and background extraction region
  - Pileup
  - Fit models
  - Fit statistics and minimization methods



Source and background extraction regions

- Source extraction region is commonly set to include ~95% of source photons near 1-2 keV
- X-ray mirror PSF is broader for hard photons (scattering)
- For XMM the analysis tools calculate ARF based on extraction region
- For Chandra, standard tools currently do not account for extraction region size
  - Need to be aware of this effect
  - 1” diameter (on-axis) => $\Delta\Gamma \sim 0.10$
  - 10” diameter (on-axis) => $\Delta\Gamma \sim 0.02$
  - User tools exist to correct ARF[1]



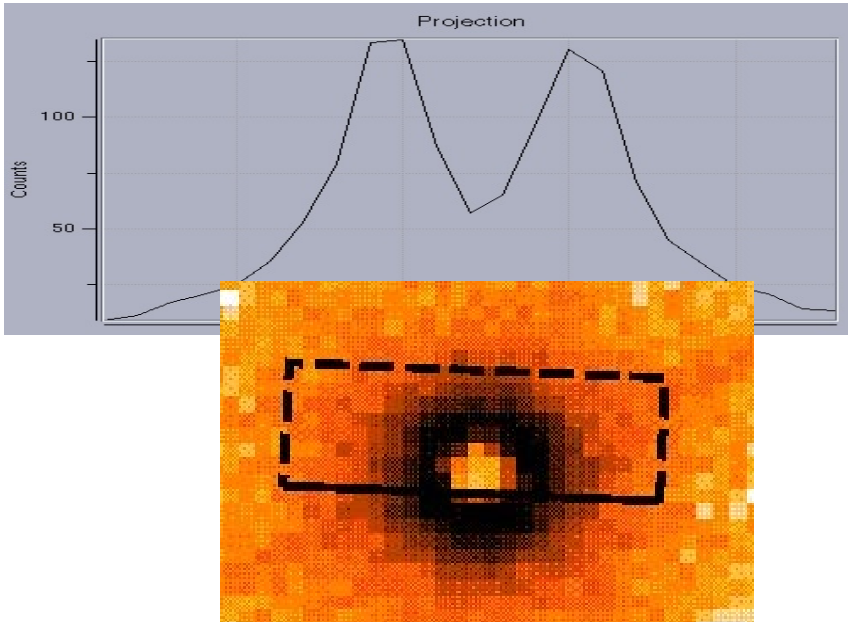
- For background, usually choose a large source-free annulus. If not available use pre-made background files

- Evaluate source contamination

[1]http://www.astro.psu.edu/xray/acis/recipes/non_www_scripts/xpsf/xpsf.pro

PILEUP

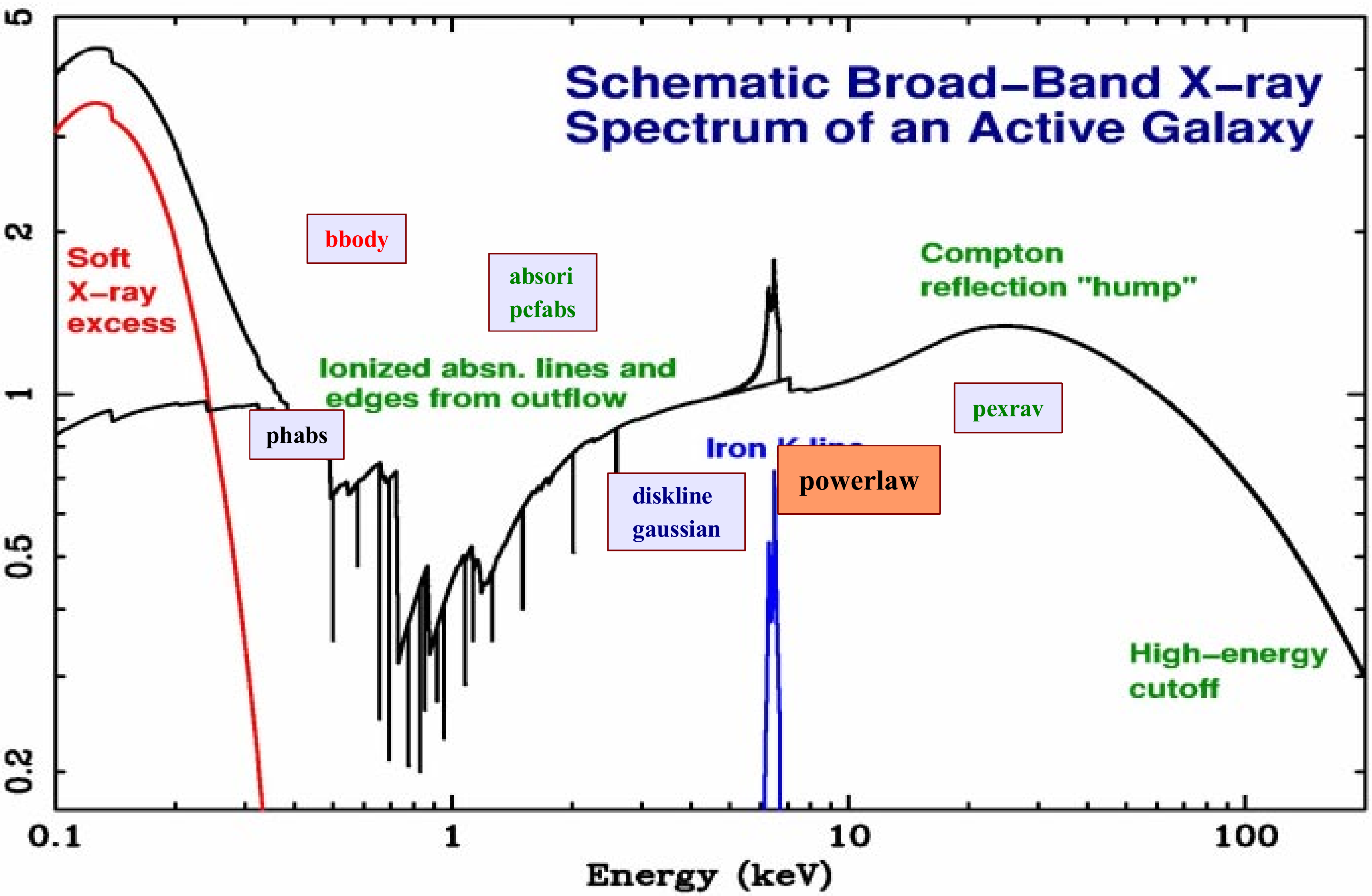
- Multiple photon events within a single or adjacent pixels during a single readout can cause either energy or grade migration
- For bright sources this causes distortion in the image and spectrum
- An initial estimate of pileup for ACIS can easily be made with PIMMS. For XMM the SAS tool epatplotcan be used as a diagnostic.
- For moderate pileup in ACIS there is a CIAO thread[1] that gives details of how to include the jdpileup model[2] in fitting
- For strong pileup, the only option may be to excise the core and fit using only the wings. This introduces serious issues related to PSF energy dependence, assumptions in ARF generation, and grade selection of acis events .



[1]http://cxc.harvard.edu/sherpa/threads/pileup

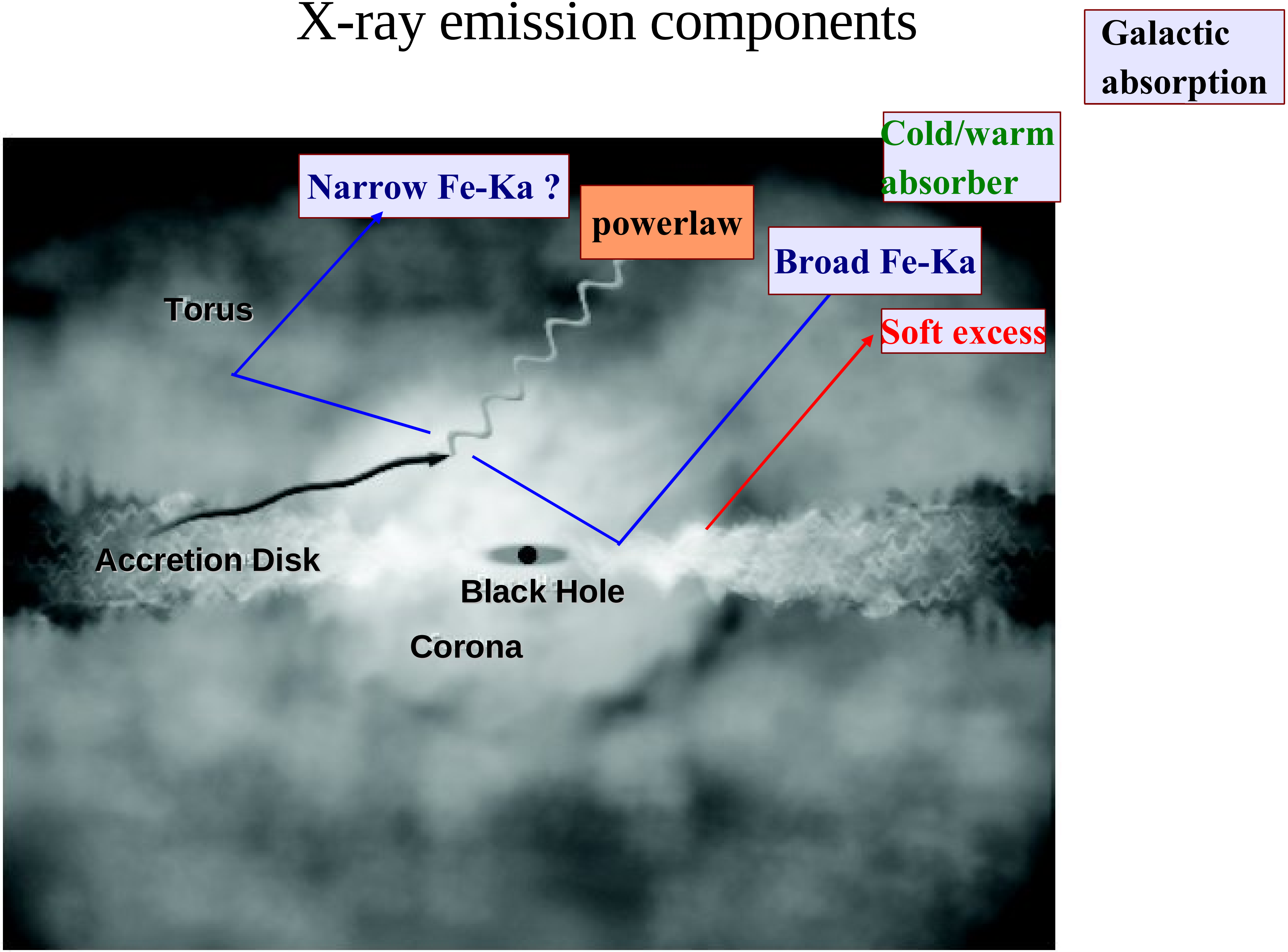
[2]http://space.mit.edu/~davis/pileup2001.html

Common “Off the Shelf” low-resolution models for AGN

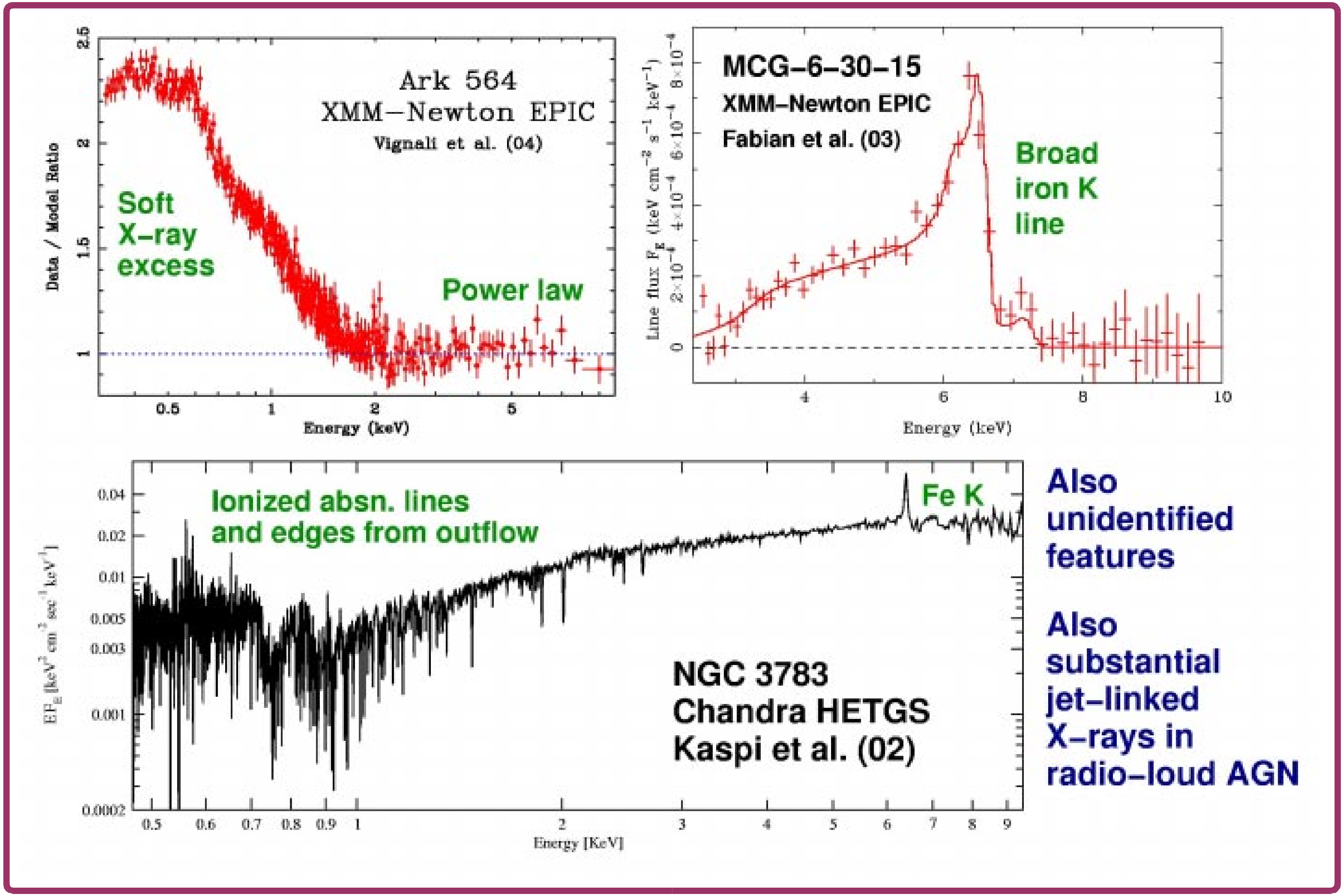


Adapted from http://www.astro.psu.edu/users/niel/papers/aas204-invited.pdf by N. Brandt

X-ray emission components



AGN spectral features



http://www.astro.psu.edu/users/niel/papers/aas204-invited.pdf

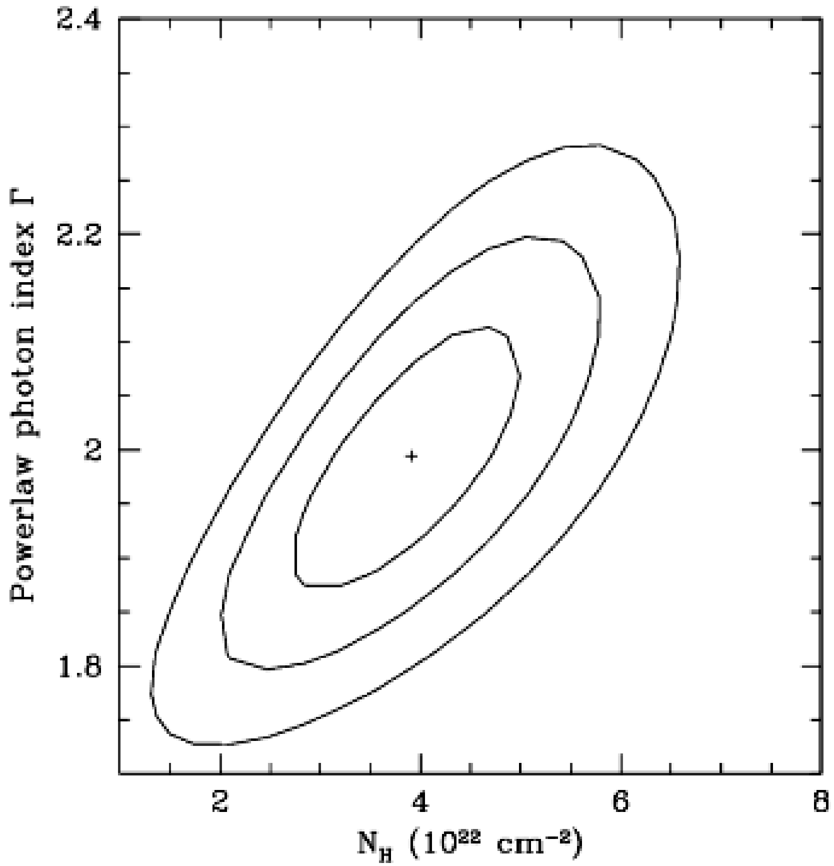
Spectral fitting options

- Common options for X-ray spectral analysis are XSPEC and Sherpa
- As for other analysis tasks, scripting all fits and plot generation will save much time in the long run
- Fit statistic (e.g. Chi Gehrels, Chi Primini, Model Variance, Data Variance, Cash, C-stat, etc)
- Optimization method
- Binned or unbinned?

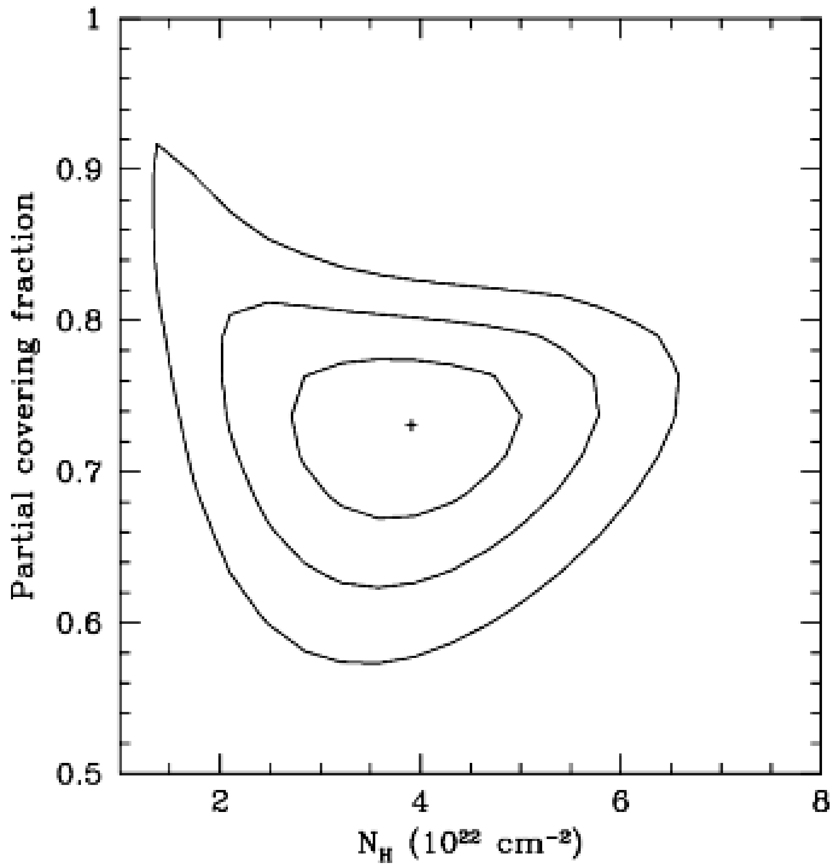
Binned	Unbinned
Subtract background	Model background
Well-defined goodness of fit	C-stat
Intuitive visual plot of model vs. data	Not easy
Gaussian assump. invalid < ~20 cts/bin	No restrictions
Fit statistic needs consideration	Cash is robust, unbiased
Generally faster	Slower

UM425A spectral fit conclusions

- UM425 is a very typical $z \sim 1.5$ radio-quiet QSO
  - Power law photon index 2.0 ± 0.1
  - Optical to X-ray flux ratio index is $\alpha_{ox} = 1.6$
- This argues against the hypothesis that BALQSOs are a special evolutionary state of AGN
- The ionization state of the X-ray obscuring material is not constrained.



Warm absorber



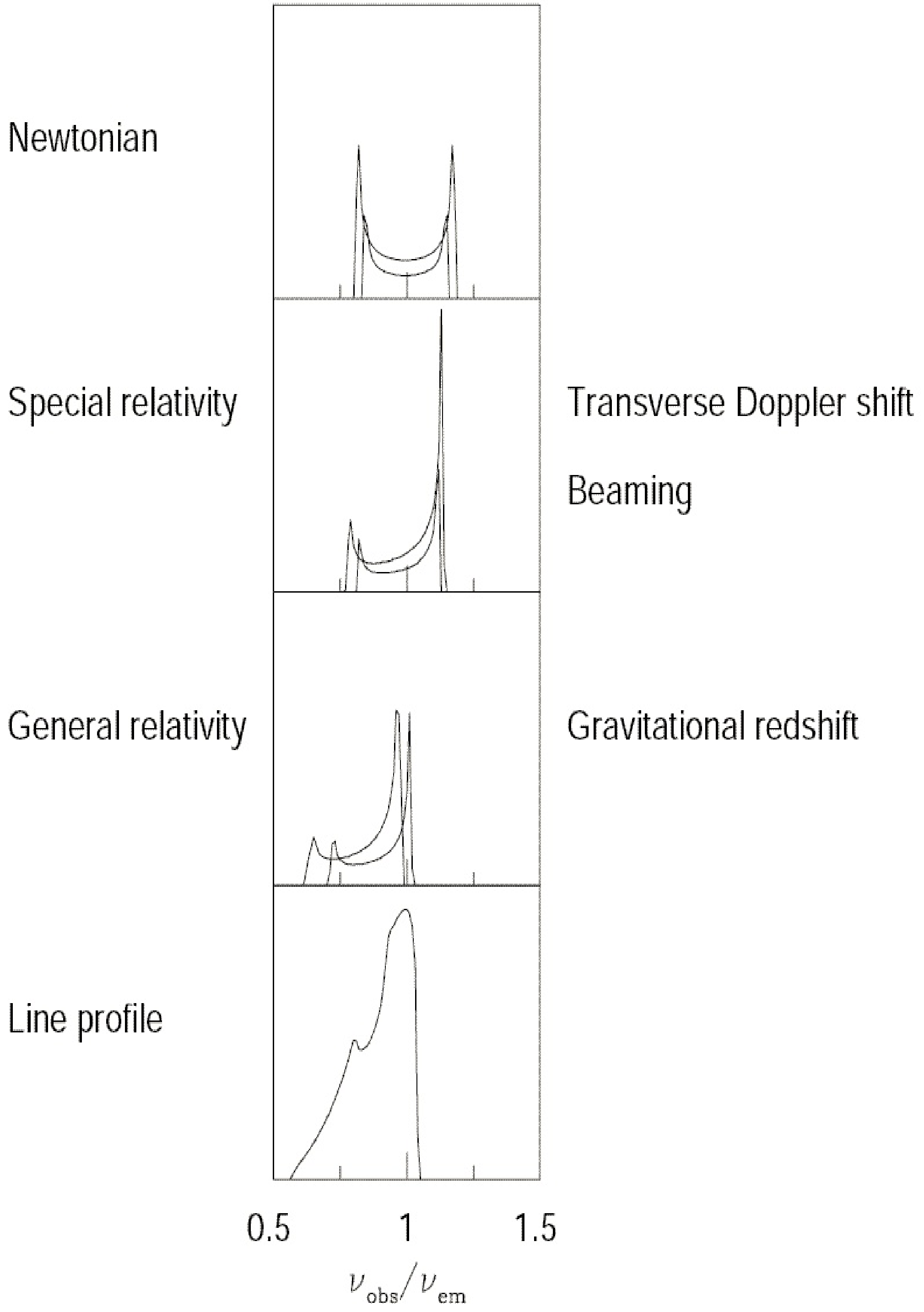
Neutral Absorber

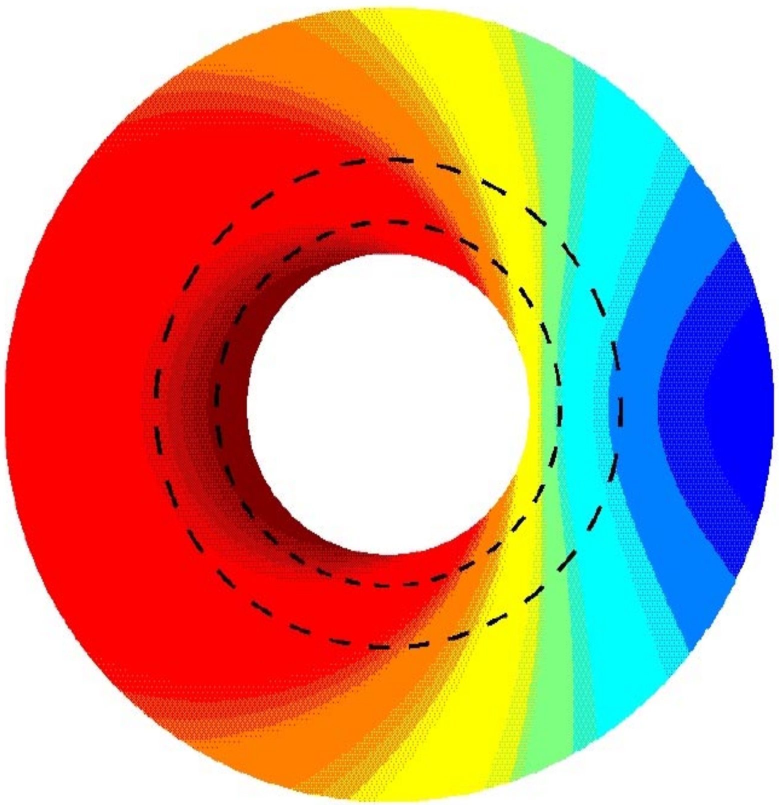
Emission Lines

- ***Originate in the nucleus:***
  - ***Accreting matter***
  - ***Relativistic broadening – Fe-line***
  - ***BLR clouds***
- ***Originate in the hot gas away from the nucleus – NLR in Seyfert 2***

Fe-Line Profile

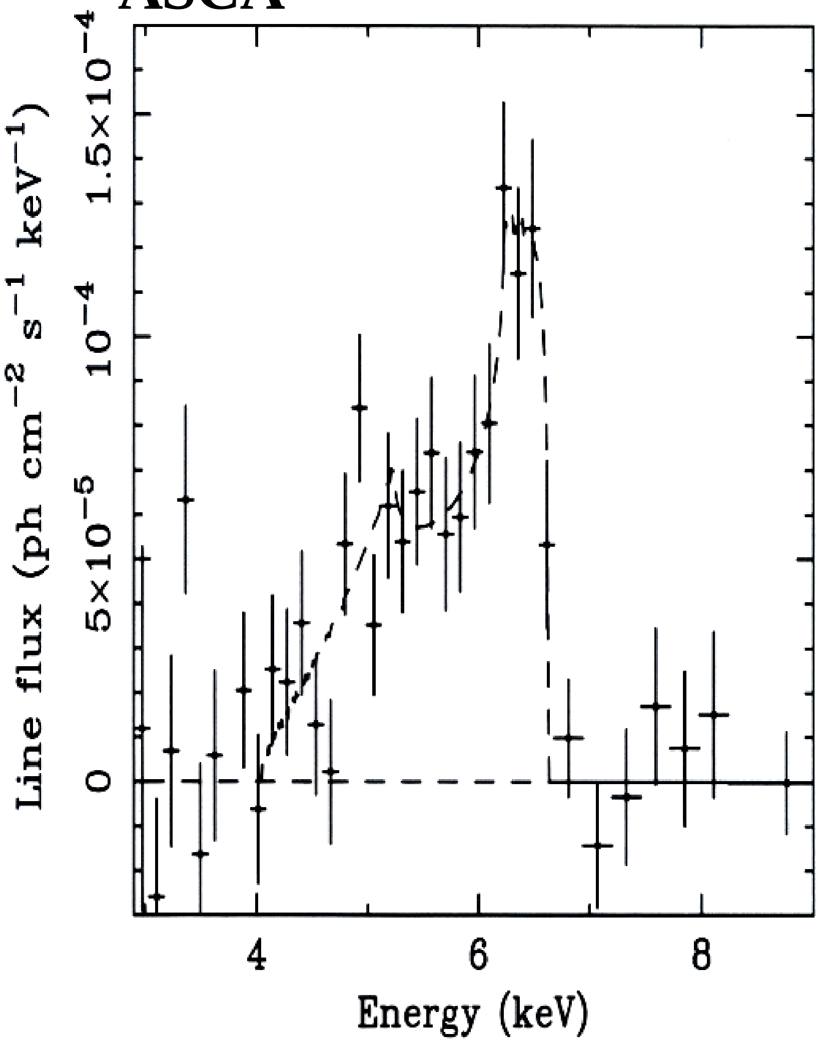
Fabian et. al., 2000, PASP, 112, 1145



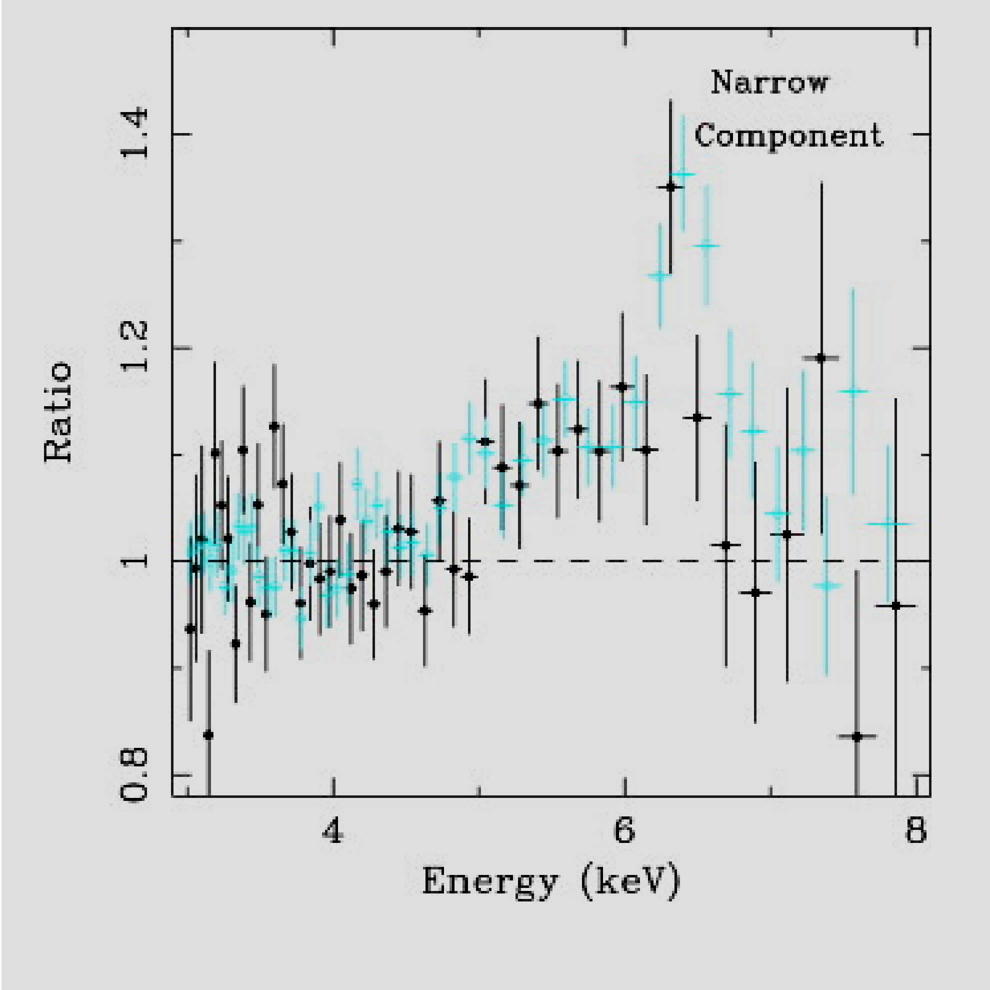


A case for a broad line in MCG 6-30-15?

ASCA *Tanaka et al. (1995)*



Chandra *Lee et al. (2002)*



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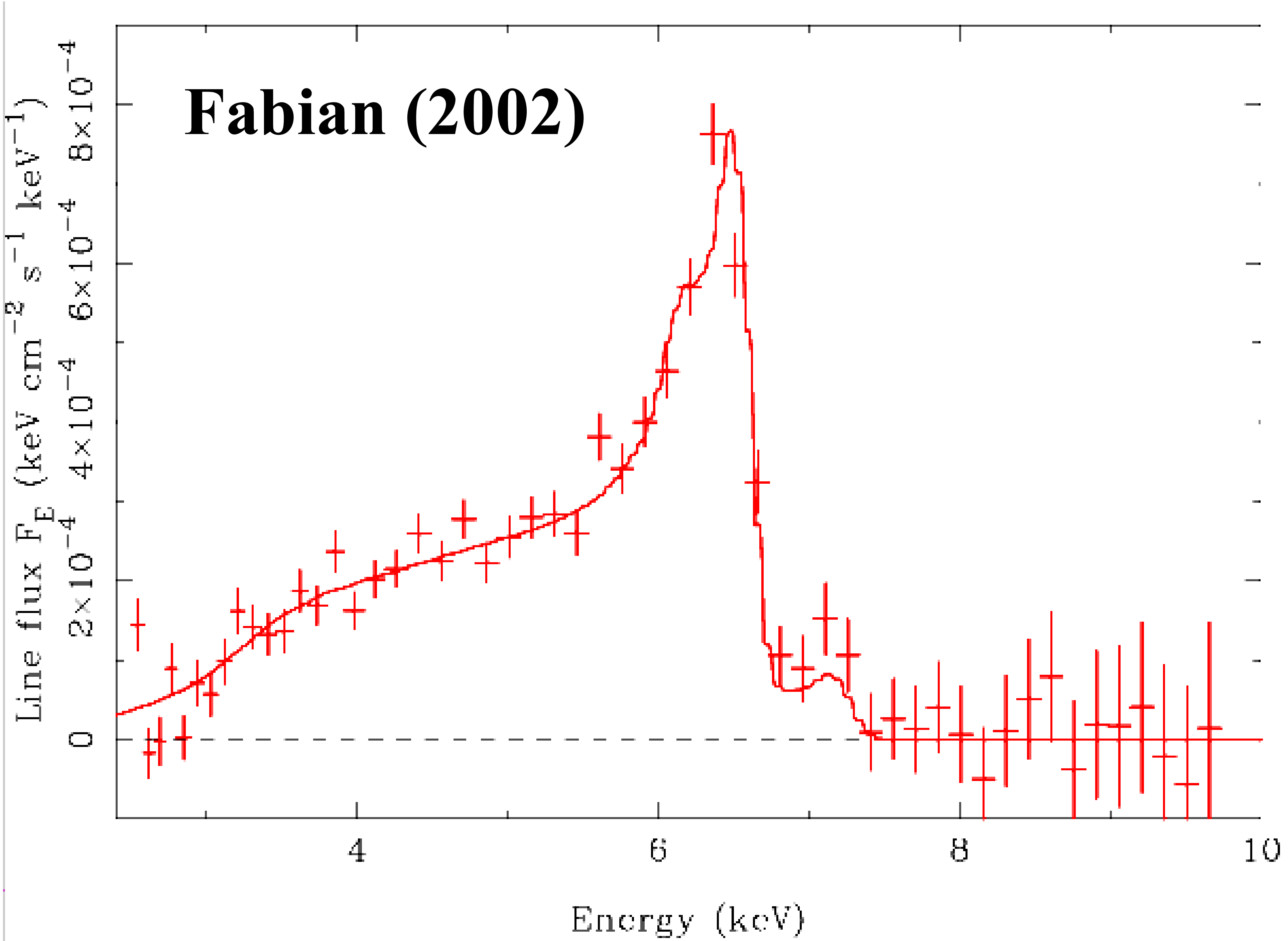
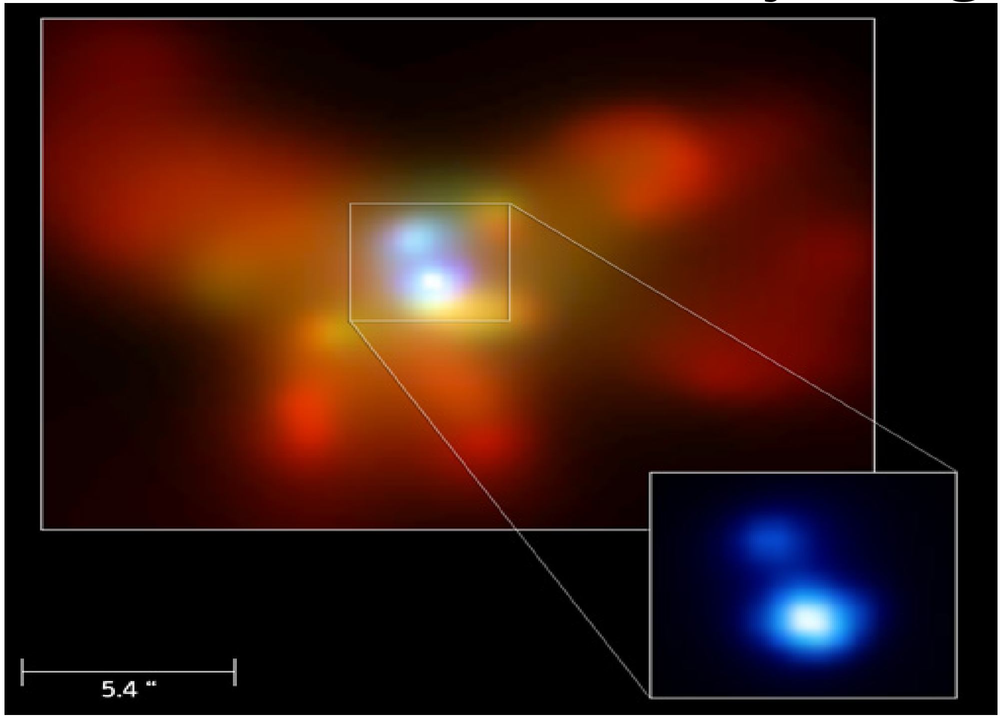
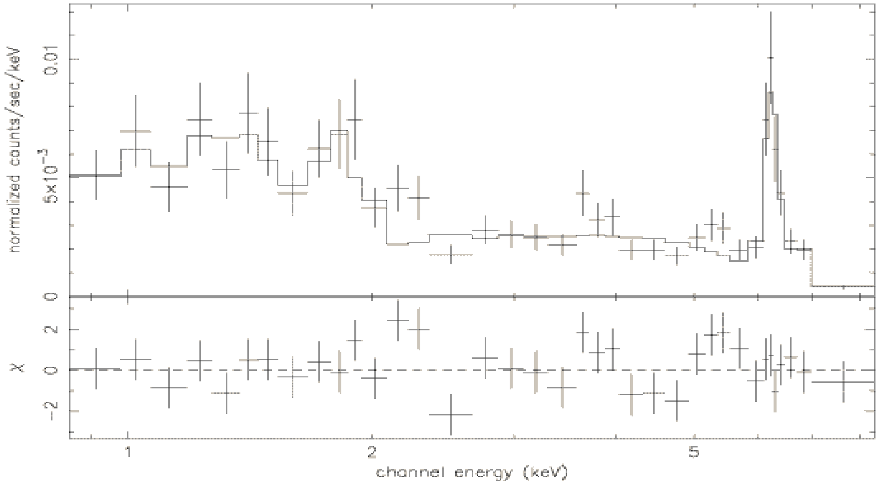


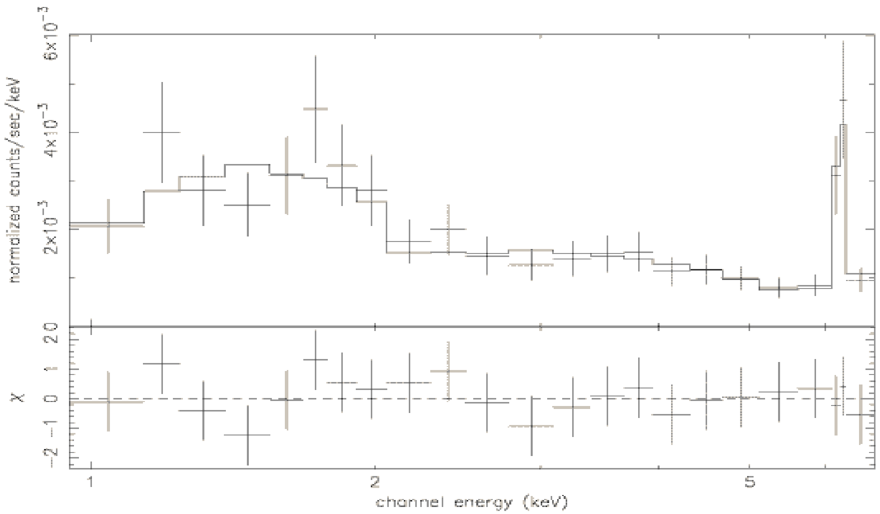
X-ray Imaging



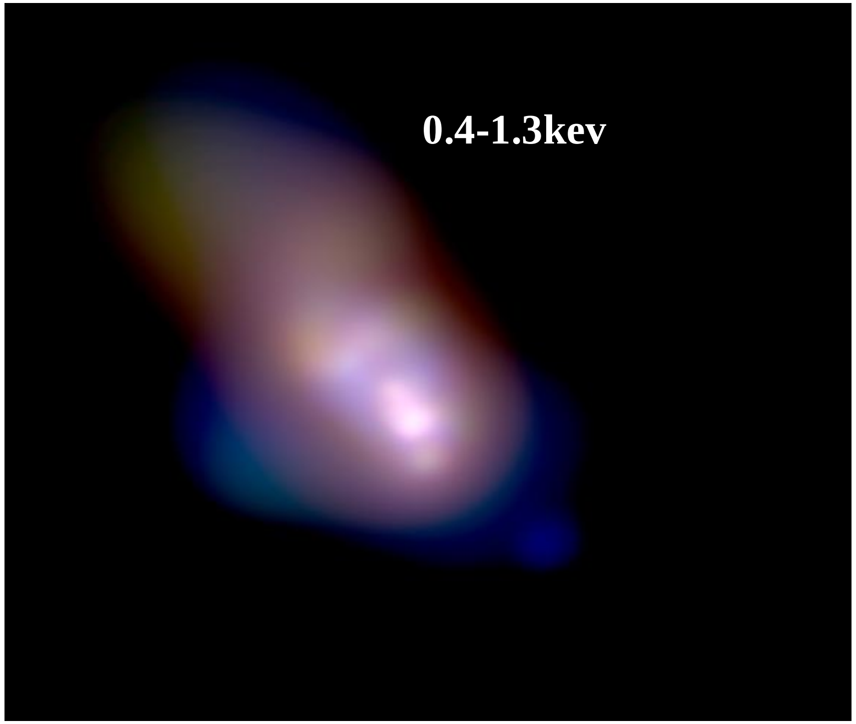
*“The Chandra image of **NGC 6240**, a butterfly-shaped galaxy that is the product of the collision of two smaller galaxies, revealed that the central region of the galaxy (inset) contains not one, but two active giant black holes.”(Chandra press release)*

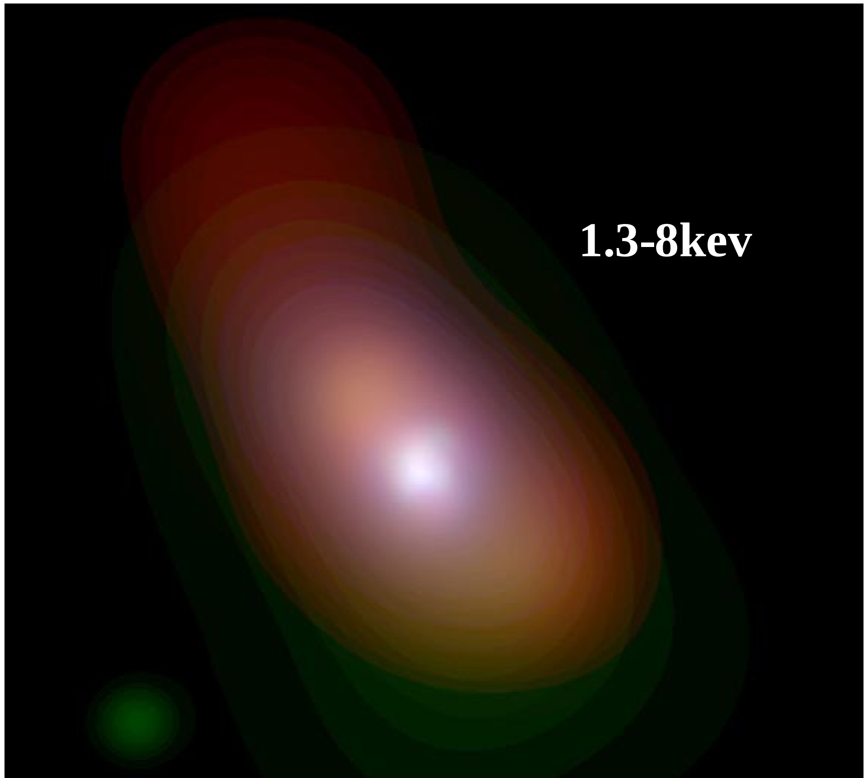
Credit:NASA/CXC/MPE/S.Komossa et al., 2003, ApJ 582, L15





Extended Emission: NGC 1068





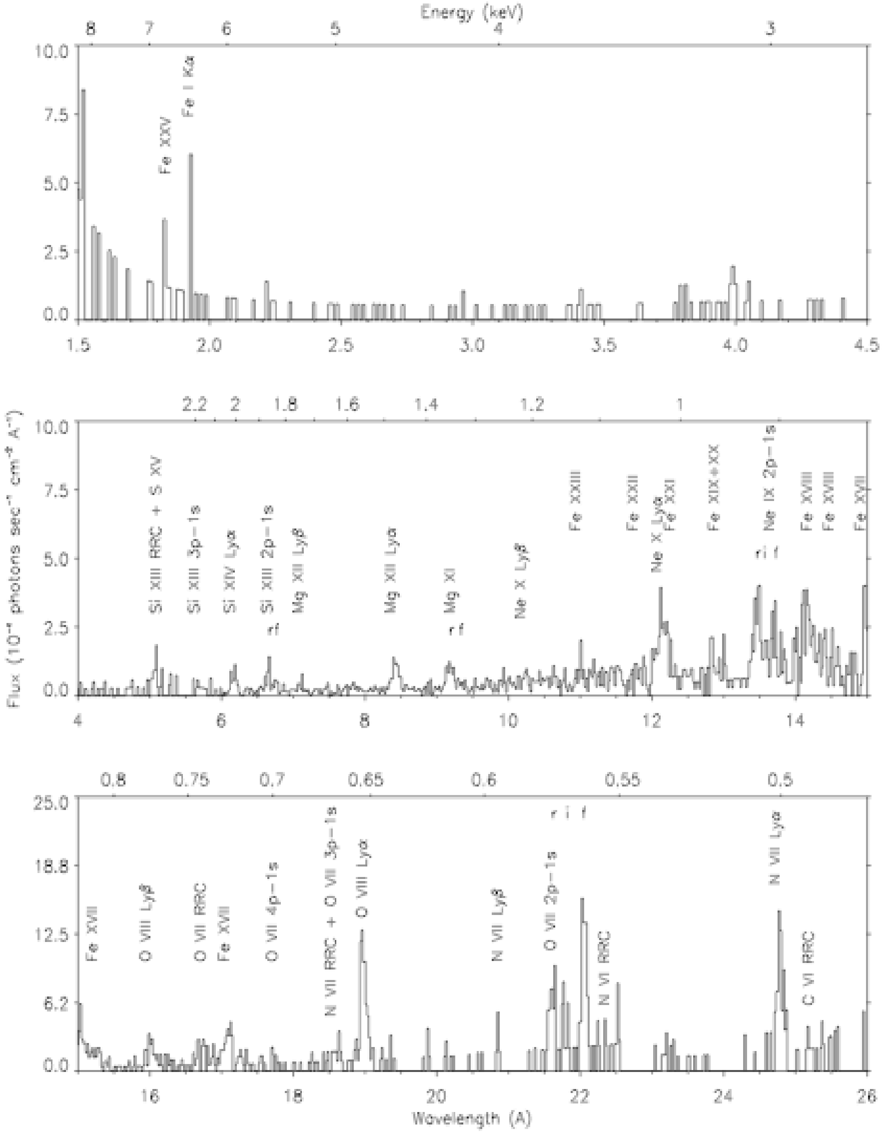
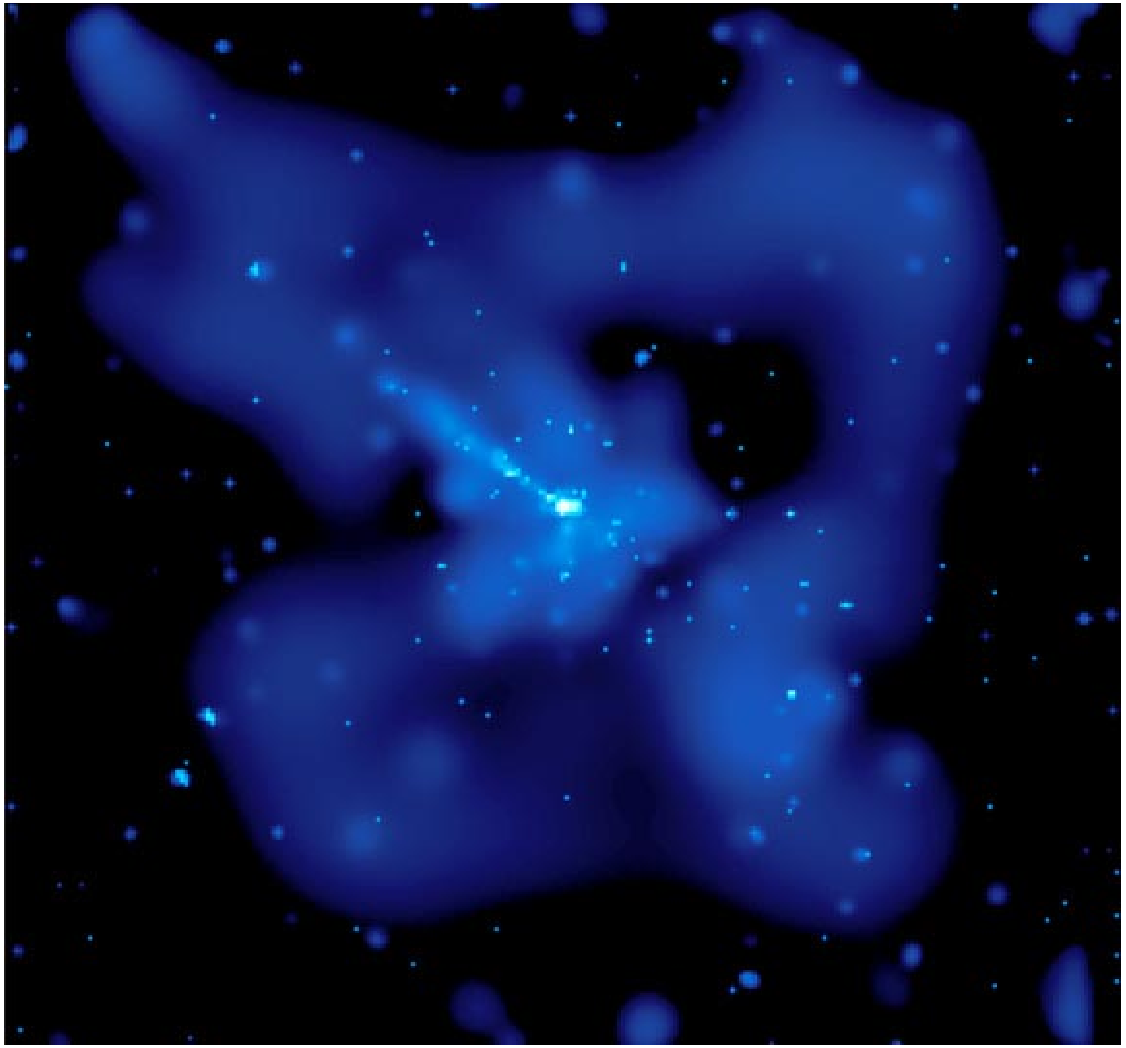


Fig. 2. *Chandra* HETGS spectra of the NE cloud, centered 3″.1 NE of the nucleus. Binning is the same as in Fig. 1. The forbidden lines (f) and RRCs are weaker than in the nuclear region (Fig. 1), due to lower column density. The H-like and He-like resonance lines are relatively stronger from photoexcitation. The Fe L emission lines are stronger, indicating a greater Fe abundance. Fe Kα emission is weaker because there is relatively little neutral matter in this region.



Karovska et al 2002

Centaurus A

- arclike soft X-ray structures, extending to ~8 kpc in the direction perpendicular to the jet.
- diffuse X-ray and the optical emission in the arcs could originate in a region of interaction (possibly a shock) between the infalling material from the outer regions of the galaxy and the cool dust and H I-emitting material in the center or from an equatorial outflow resulting from an outburst of nuclear activity ~10^7 yr ago.

Observations of Extragalactic X-ray Jets

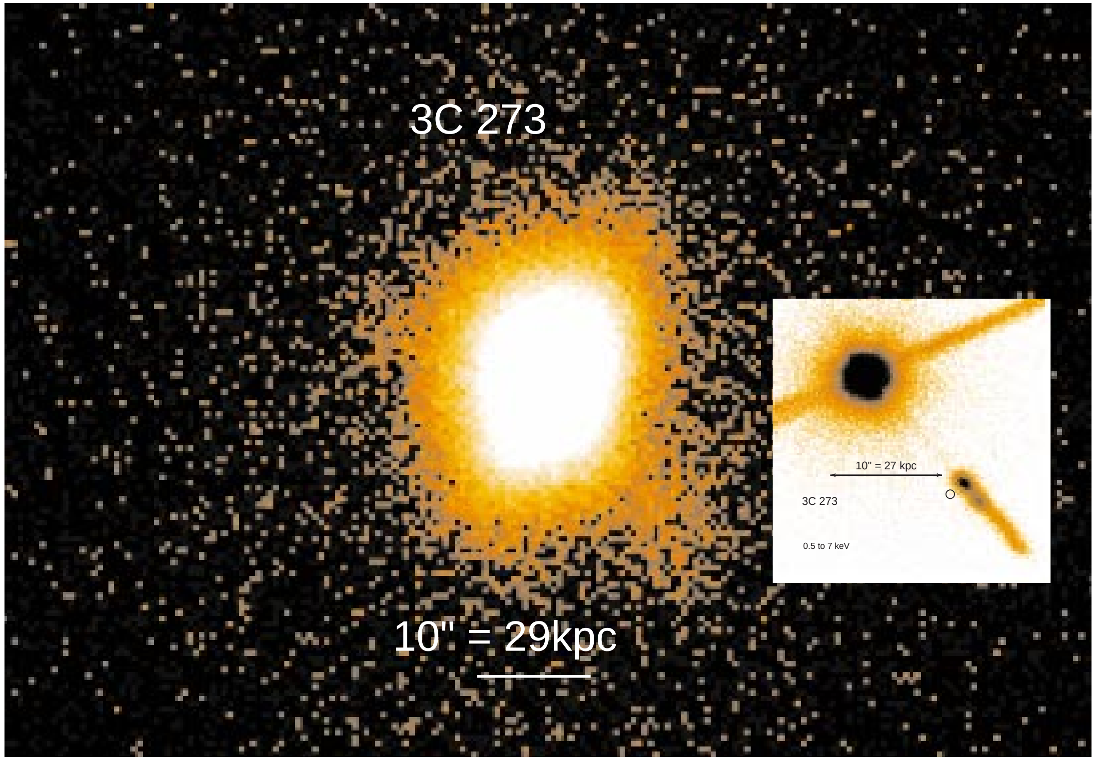
Before Chandra:

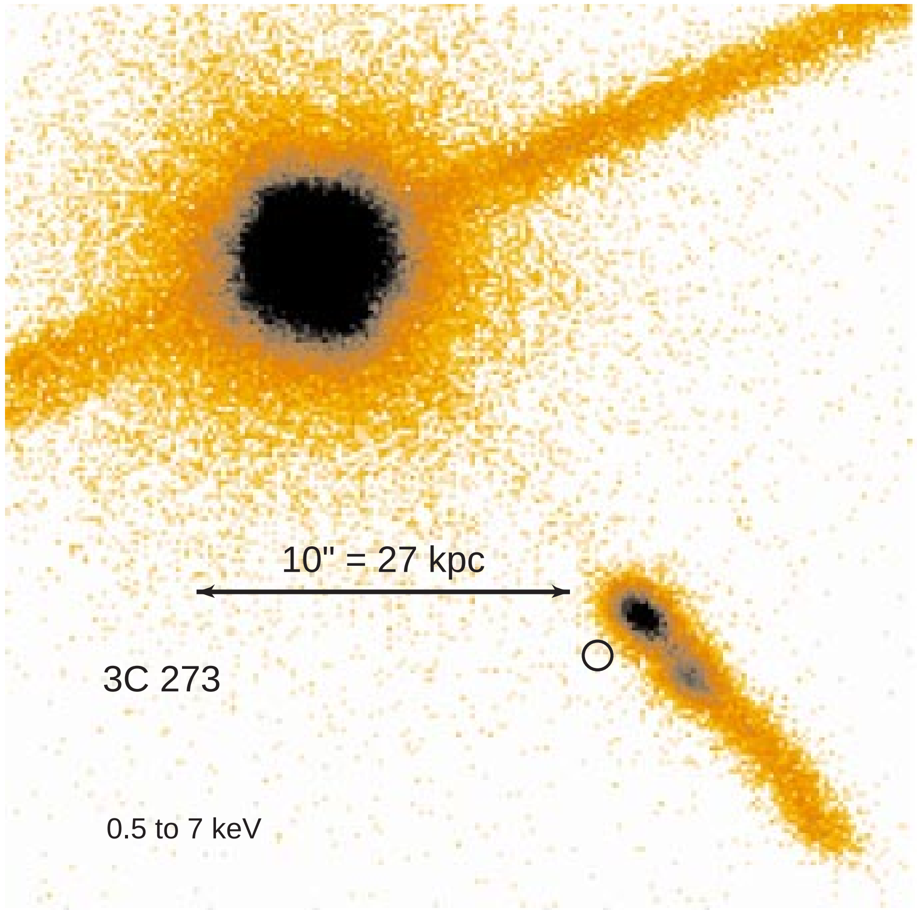
WHY?

Only 3 Certain Detections; M87, Cen A, 3C 273

Chandra Launched:

Large numbers of jets detected.

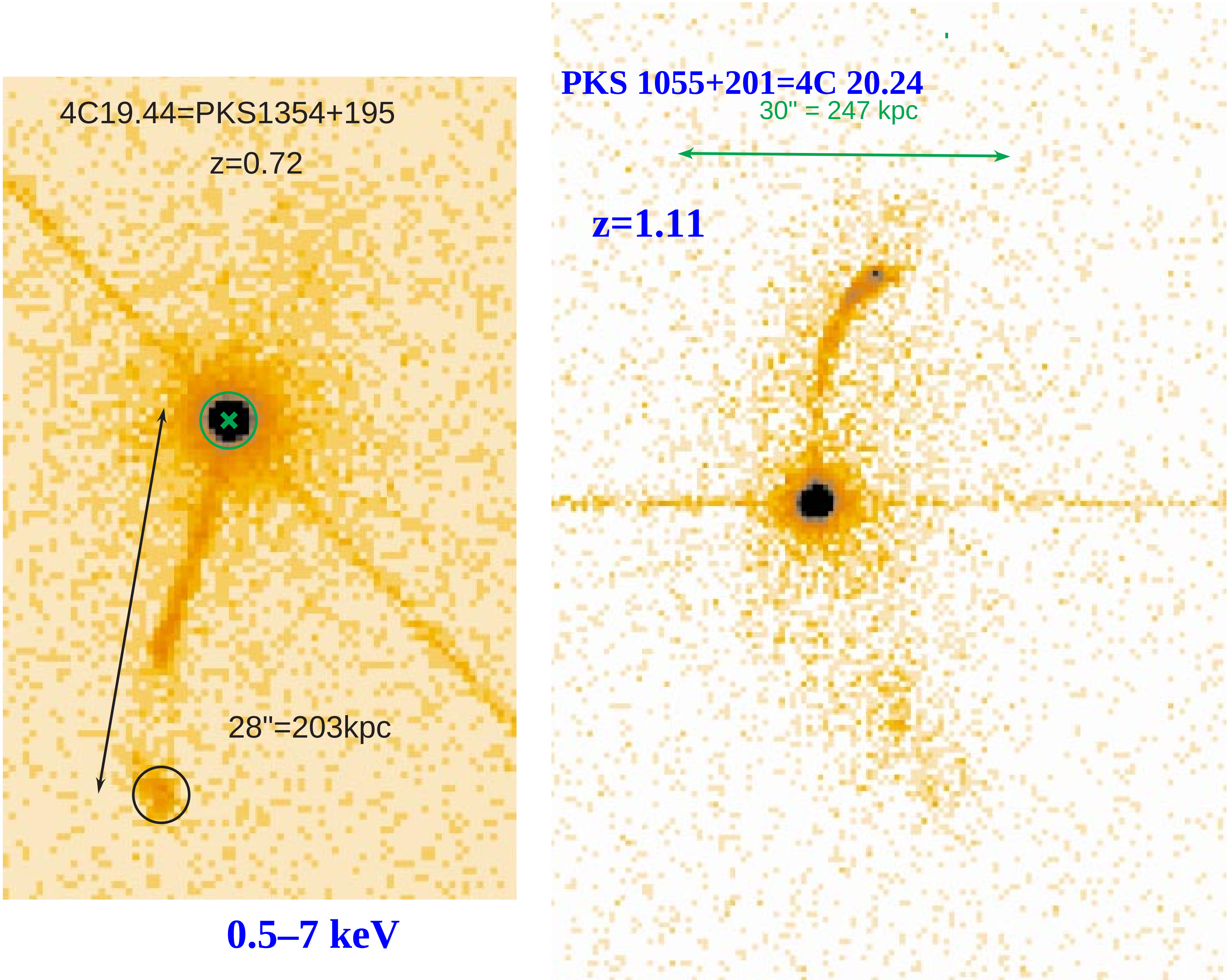




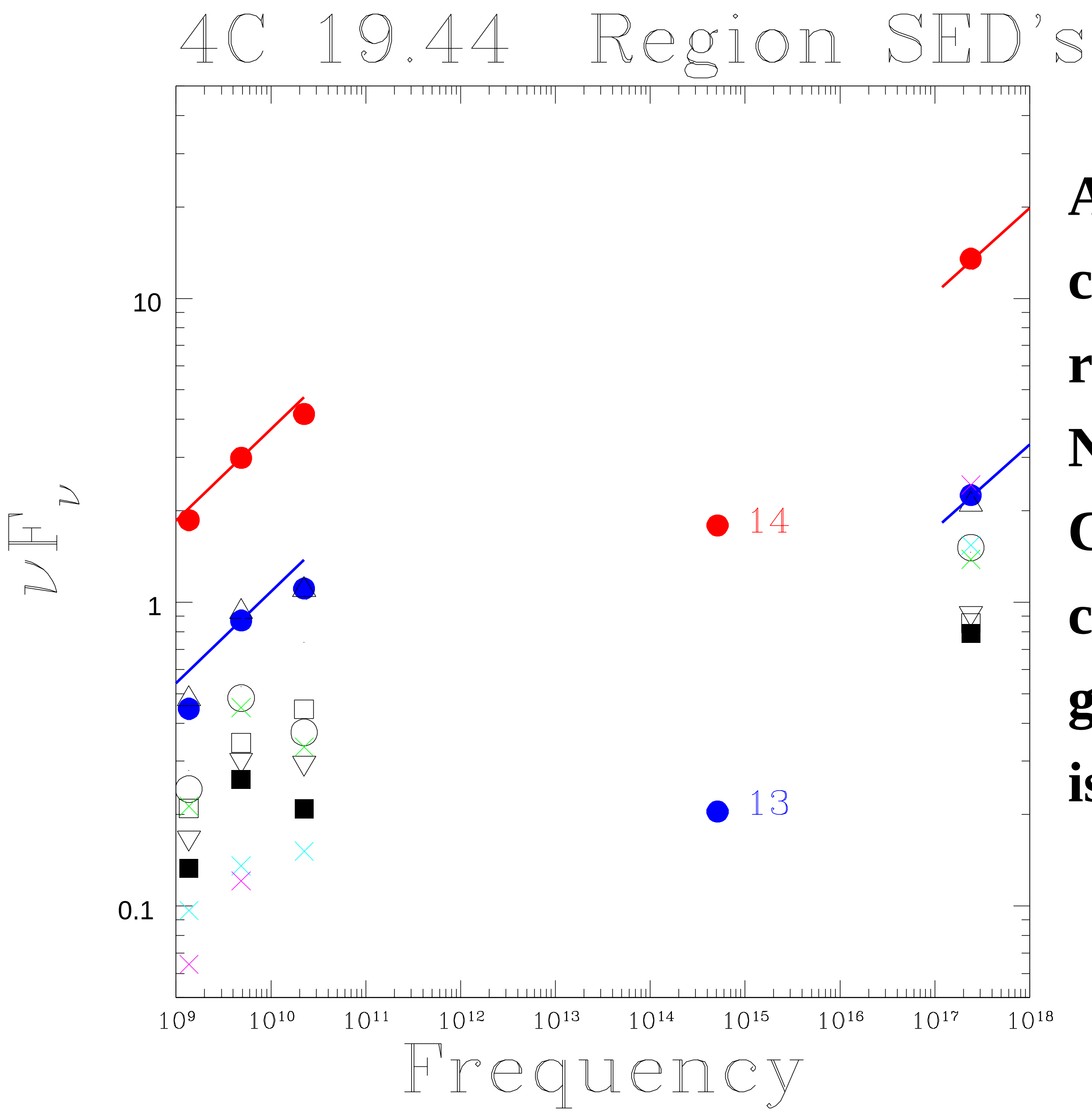
Angular Resolution!

Importance of Jets

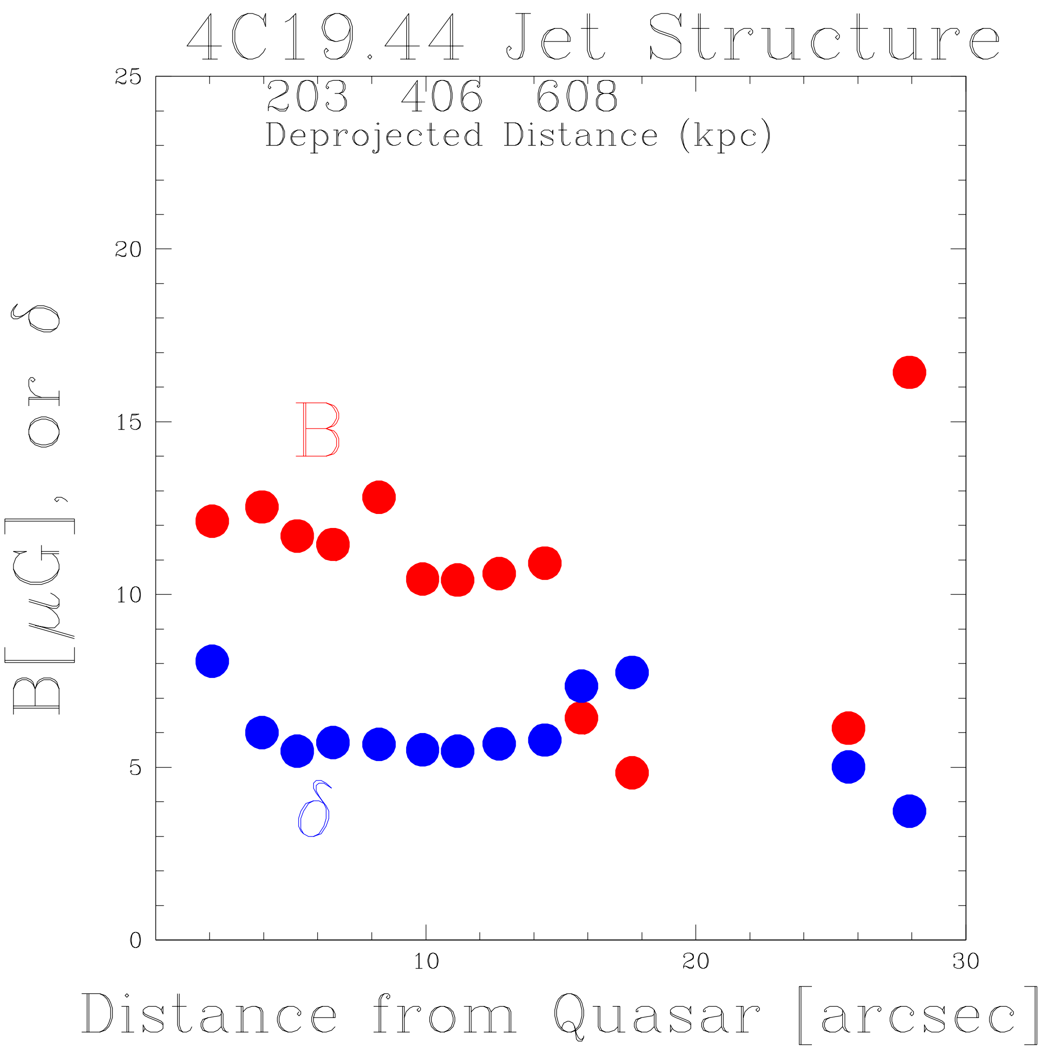
- **What Do Jets Do?**
  - **Carry large quantities of energy, to feed radio lobes**
  - **Significant part of black hole energy generation budget**
  - **Interact with gas in galaxies and clusters of galaxies**
- **What Do We Want to Learn**
  - **Particle composition and acceleration**
  - **Jet acceleration and collimation**
- **Why Do We Need X-Ray Data?**
  - **Spectral Energy Distribution (SED) gives mechanism**
  - **Particle lifetimes change with observed band**

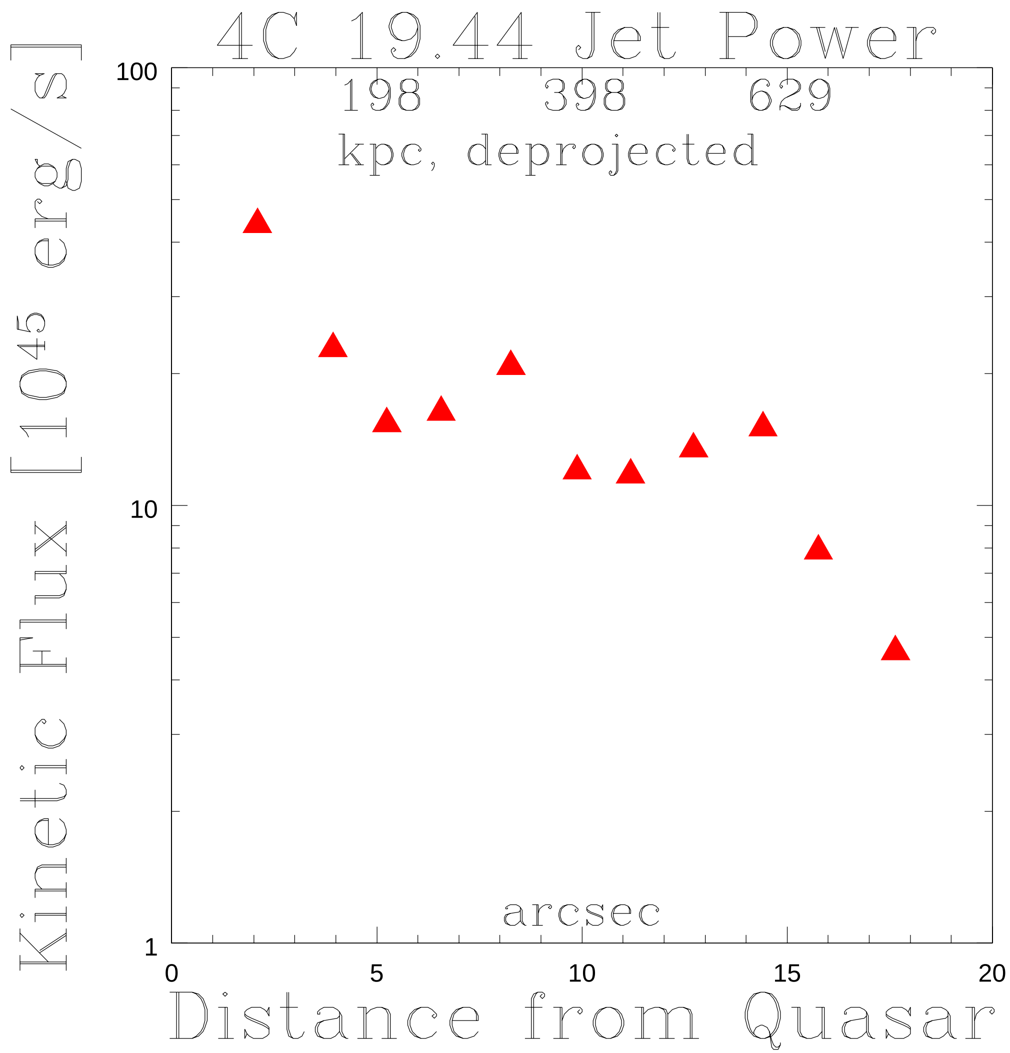

4C19.44=PKS1354+195
z=0.72
28"=203kpc
PKS 1055+201=4C 20.24
30" = 247 kpc
z=1.11

0.5–7 keV



A synchrotron spectrum cannot extend from the radio to the X-ray region. Next simplest is inverse Compton scattering on the cosmic microwave back-ground. Implies that the jet is in relativistic motion.


4C19.44 Jet Structure
203 406 608
Deprojected Distance (kpc)
B
δ
B[μG], or δ
Distance from Quasar [arcsec]
0
5
10
15
20
25
10
20
30


4C 19.44 Jet Power
198 398 629
kpc, deprojected
arcsec
Kinetic Flux [10^45 erg/s]
Distance from Quasar
1
10
100
0
5
10
15
20

Implications of the AGN Jets

- **Eddington Luminosity might not limit Accretion Rate**

- **Jets may Power Cluster Cavities – Stop Cooling Flows**

- **IC/CMB X-ray jets Maintain Constant Surface Brightness vs. z. We will detect them at Arbitrarily Large Redshift.**

Related Topics

We were not able to cover

1. **AGN number counts. Gives information on the cosmic evolution of various AGN types. Apply the continuity equation:**

$$\frac{\partial\ N(L,t)}{\partial t} + \frac{\partial(dL/dt\ N(L,t))}{\partial L} = S(L,t) \qquad (1)$$

2. **Type II AGN and spectral synthesis**
   How do the AGN spectra add up to make the diffuse X-ray background?

3. **Hardness ratios for low count spectral information**

4. **Gravitational lensing**

5. **Different models and modes of accretion**

6. **Role of AGN outbursts in clusters, to reverse cooling flows.**