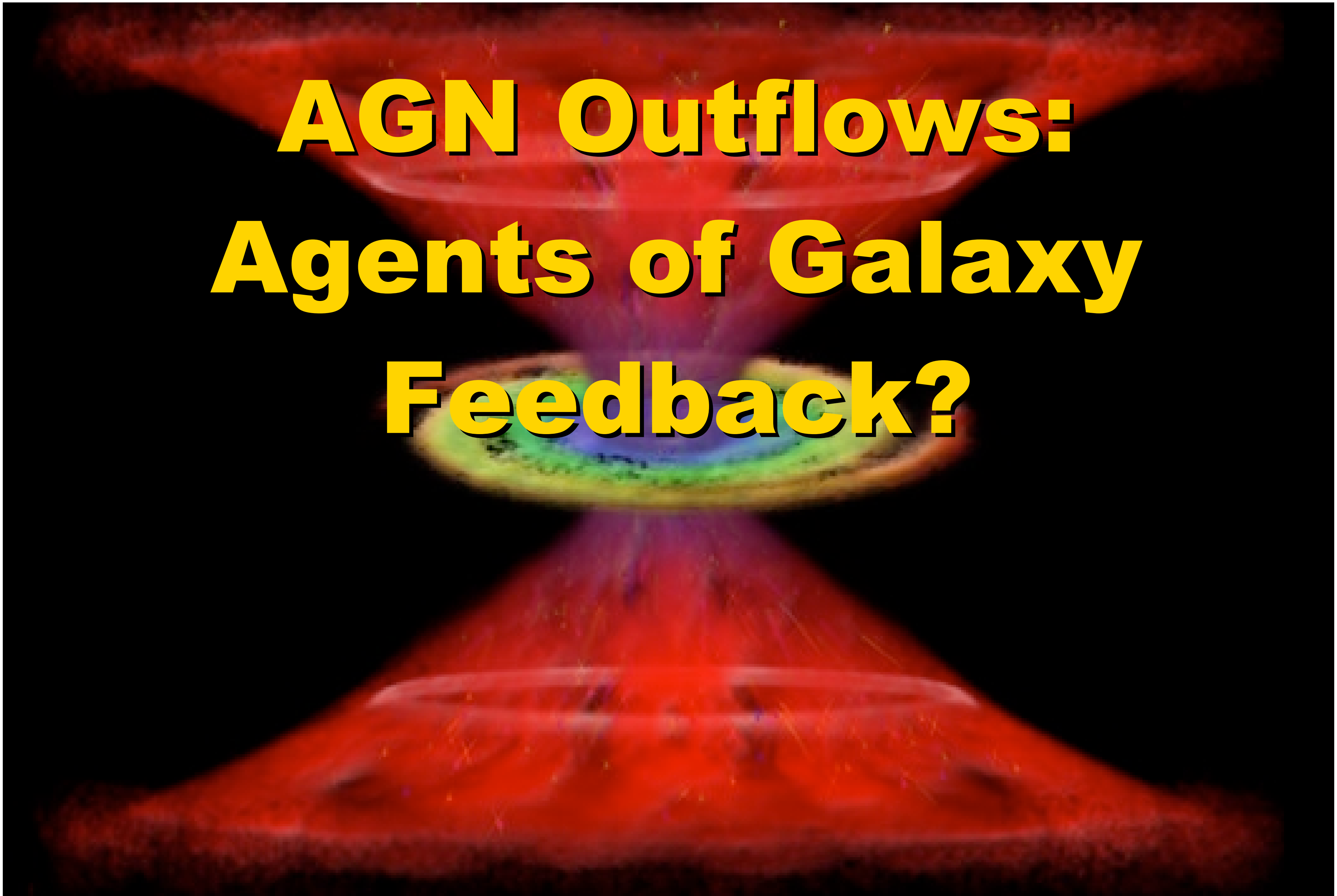
# AGN Outflows: Agents of Galaxy Feedback?



Sarah Gallagher (UCLA)

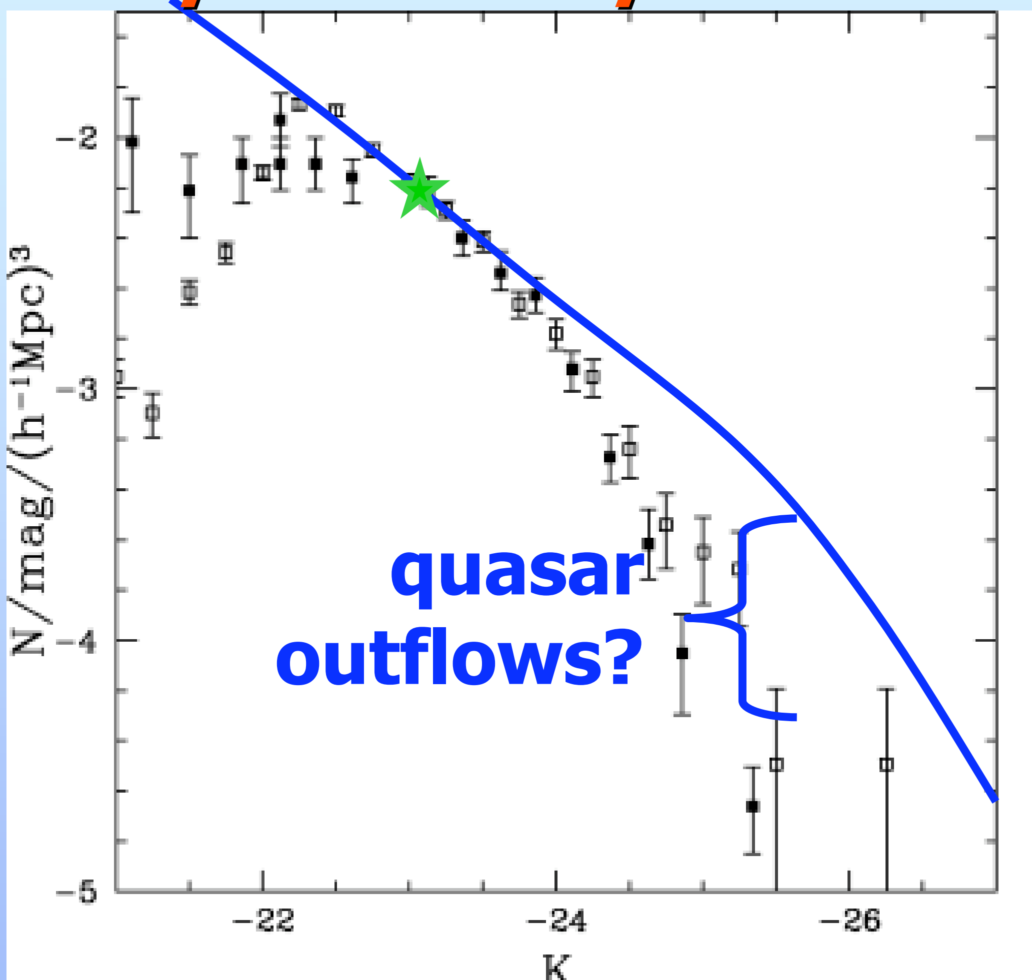
Six Years of Science with *Chandra*

(image credit: NASA/CXC/M. Weiss)

# Quasar Outflows: the new **magnetic fields?**

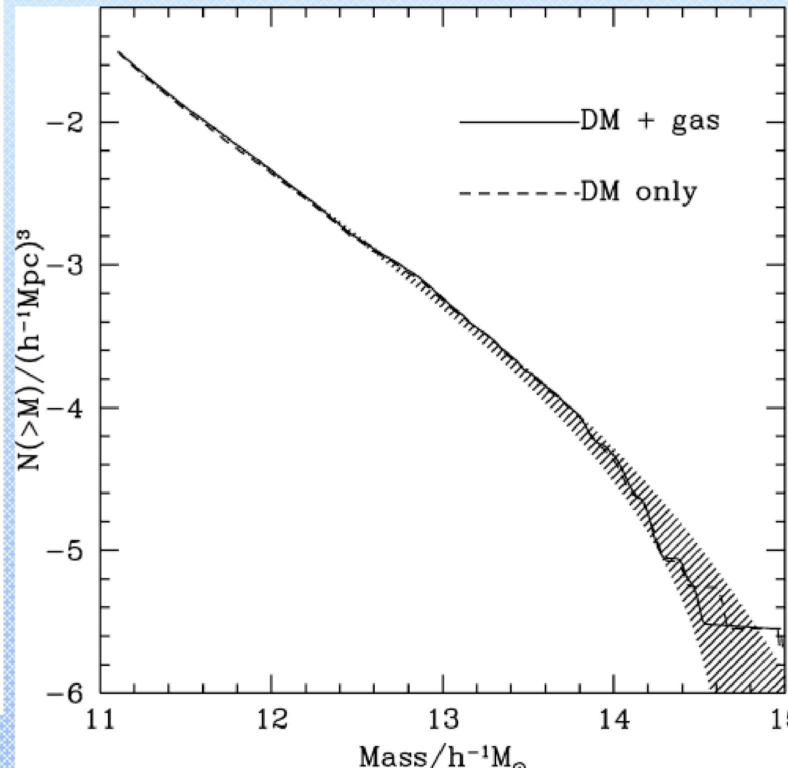
- →Metal enrichment of the intergalactic medium
- →$M_{SMBH}/M_{bulge}$ relation
- →Lack of cooling flows in galaxy clusters
- →End of star formation in massive galaxies

# Galaxy Luminosity Function




$M_K$ → galaxy mass

# Dark Matter Halo Distribution




(Pearce et al. 2001)

## Assumptions:

(1) all bulges have SMBHs

(2) all SMBHs grow during AGN phase

(3) $M_{SMBH} \propto M_{bulge}$

→ ***growth of SMBH & galaxy bulges are related***

# The Scenario

## GRAVITATIONAL COLLAPSE

→ **star formation & SMBH fueling**

→ **AGN outflow**

→ **clears gas supply**

→ **end of star formation & SMBH fueling**

**(e.g., Silk & Rees 1998; Fabian 1999; King 2003; Murray et al. 2005)**

# So, theorists* want quasars outflows…what do we know?

* (e.g., Scannapieco & Oh 2004; Granato et al. 2004; Springel, Di Matteo, & Hernquist 2005; Hopkins et al. 2005a,b)

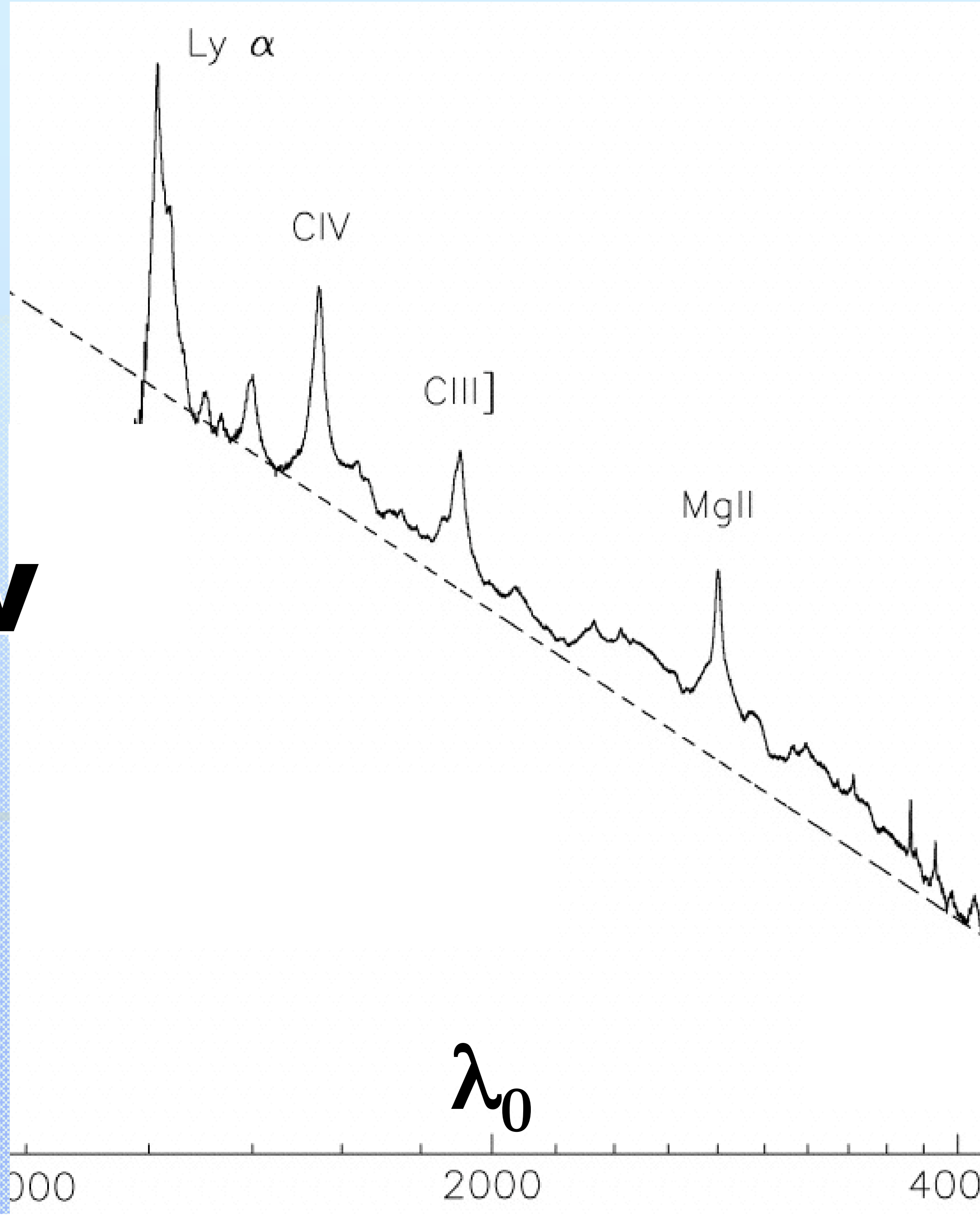
Outflows are *directly* observed in ~20%* of optically selected quasars.

Broad Absorption Line (BAL) Quasars

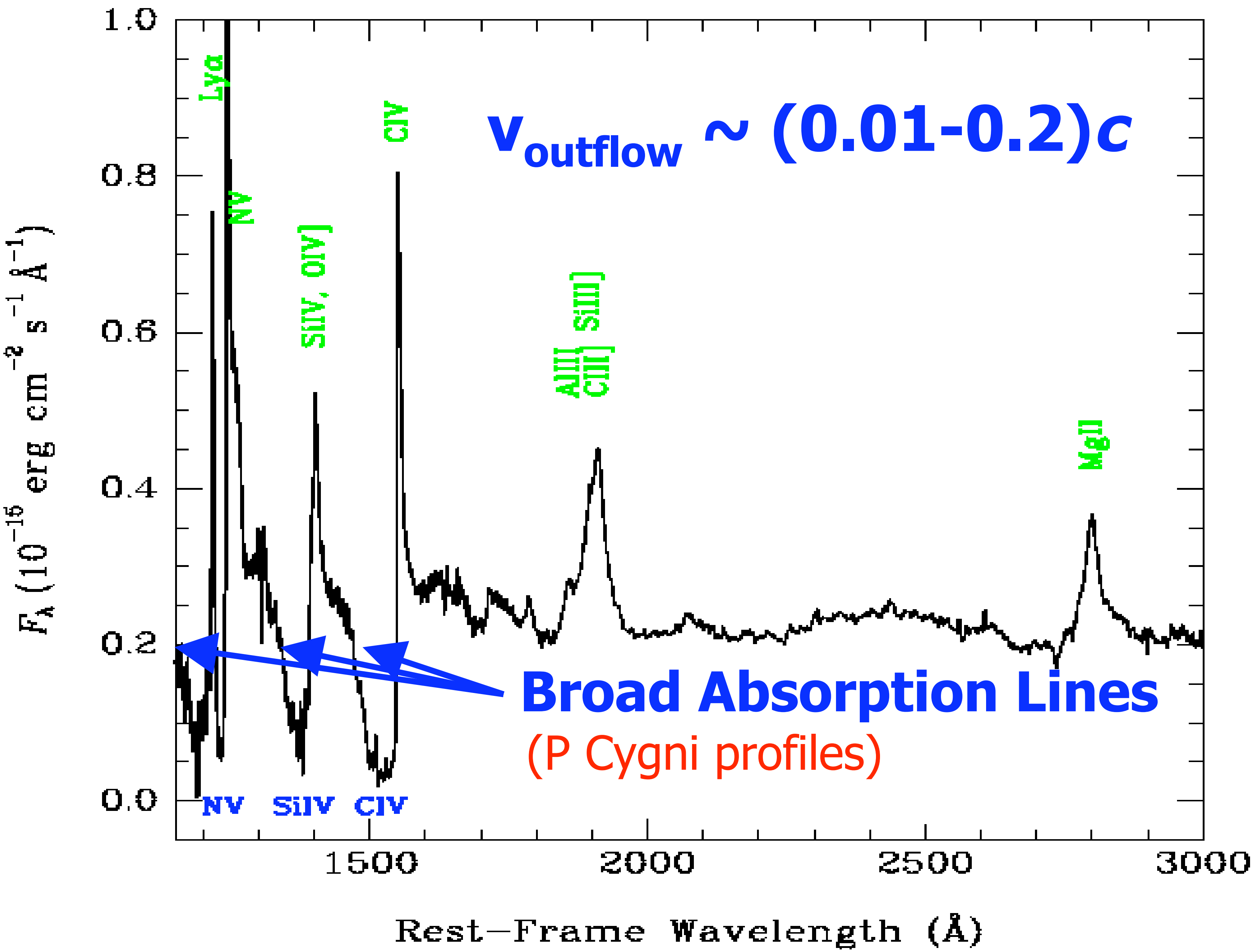
*once selection effects are accounted for

**(e.g., Chartas 2000; Hewett & Foltz 2003; Reichard et al. 2003)**

# Normal Quasar UV Spectrum

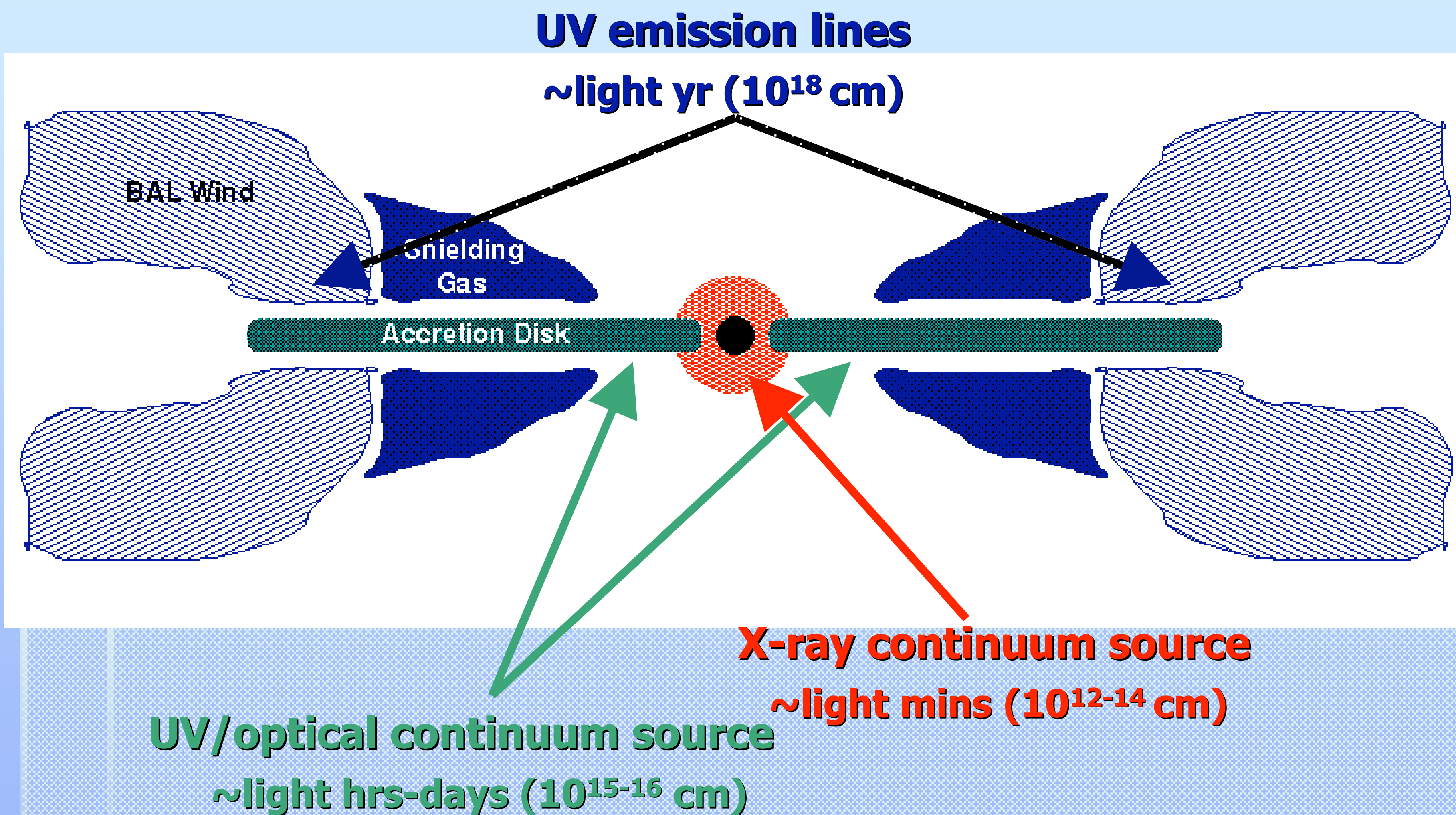



(Vanden Berk et al. 2001)



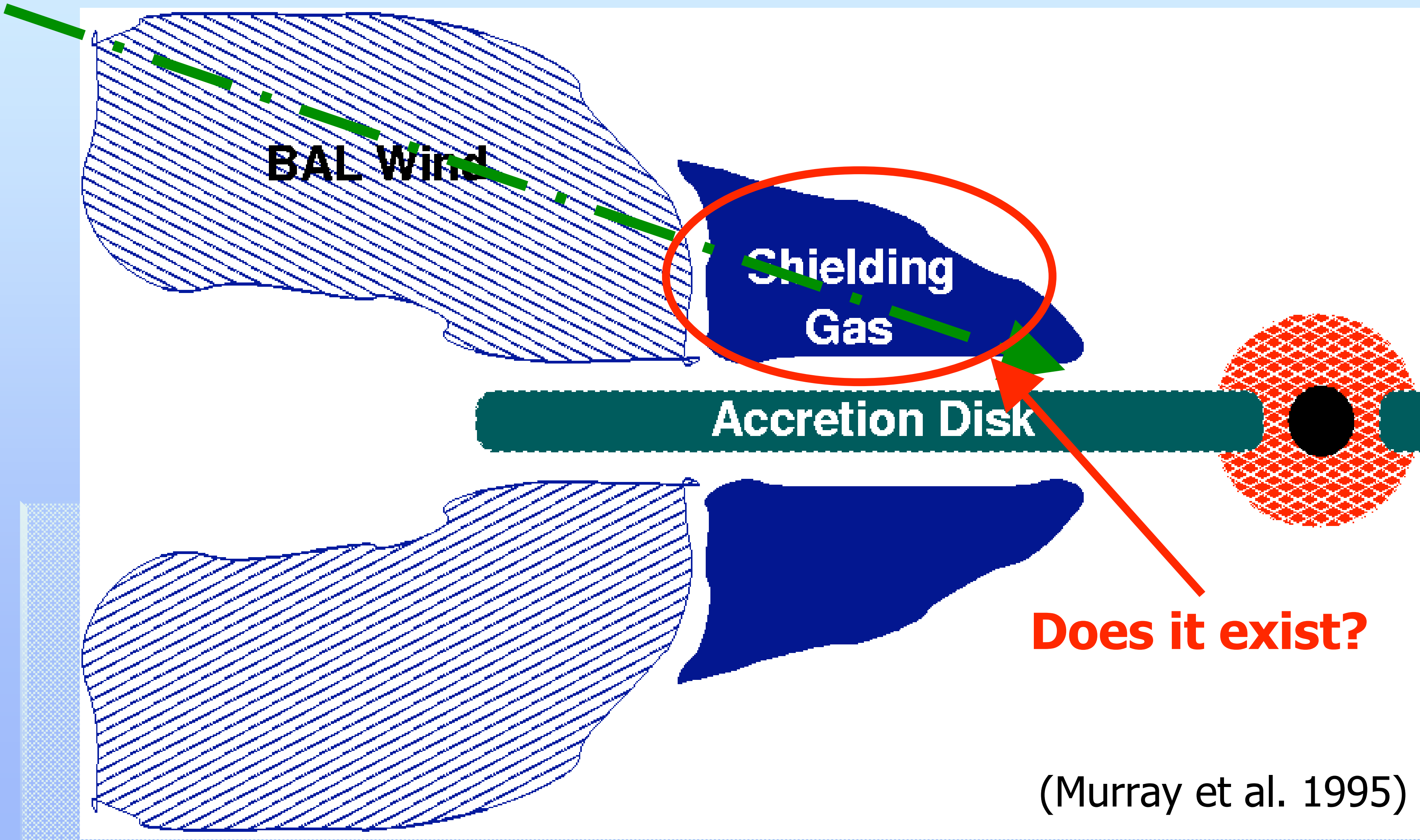
$v_{outflow} \sim (0.01\text{-}0.2)c$
Broad Absorption Lines
(P Cygni profiles)
Lyα
NV
SiIV, OIV]
CIV
AlIII
CIII]
SiIII]
MgII
NV
SiIV
CIV
1.0
0.8
0.6
0.4
0.2
0.0
1500
2000
2500
3000
Rest−Frame Wavelength (Å)
$F_\lambda$ ($10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$)

# A Model for Quasars




(Adapted from Königl & Kartje 1994; Murray et al. 1995)

# The UV View Through the Wind




(Murray et al. 1995)

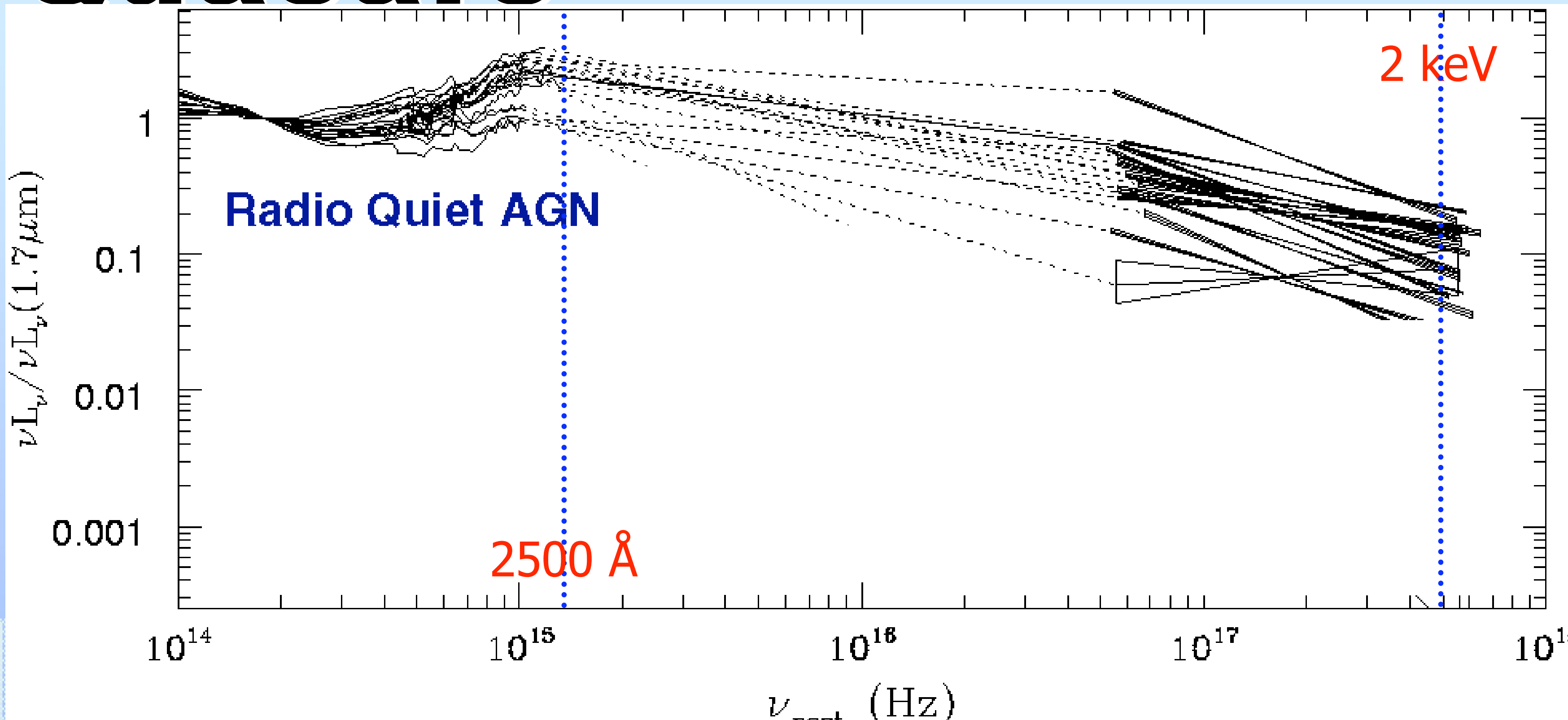
# Evidence for Disk-Wind Quasar Models

- Continuum and emission-line properties of BAL and non-BAL quasars are "remarkably similar"
  - (Weymann et al. 1991)

- From spectropolarimetry and emission-line studies: $f_{cover}$ ~ 10-50%
  - (e.g., Hamann et al. 1993; Hines & Wills 1995; Goodrich 1997; Ogle et al. 1999)

*What do X-ray studies have to offer?*

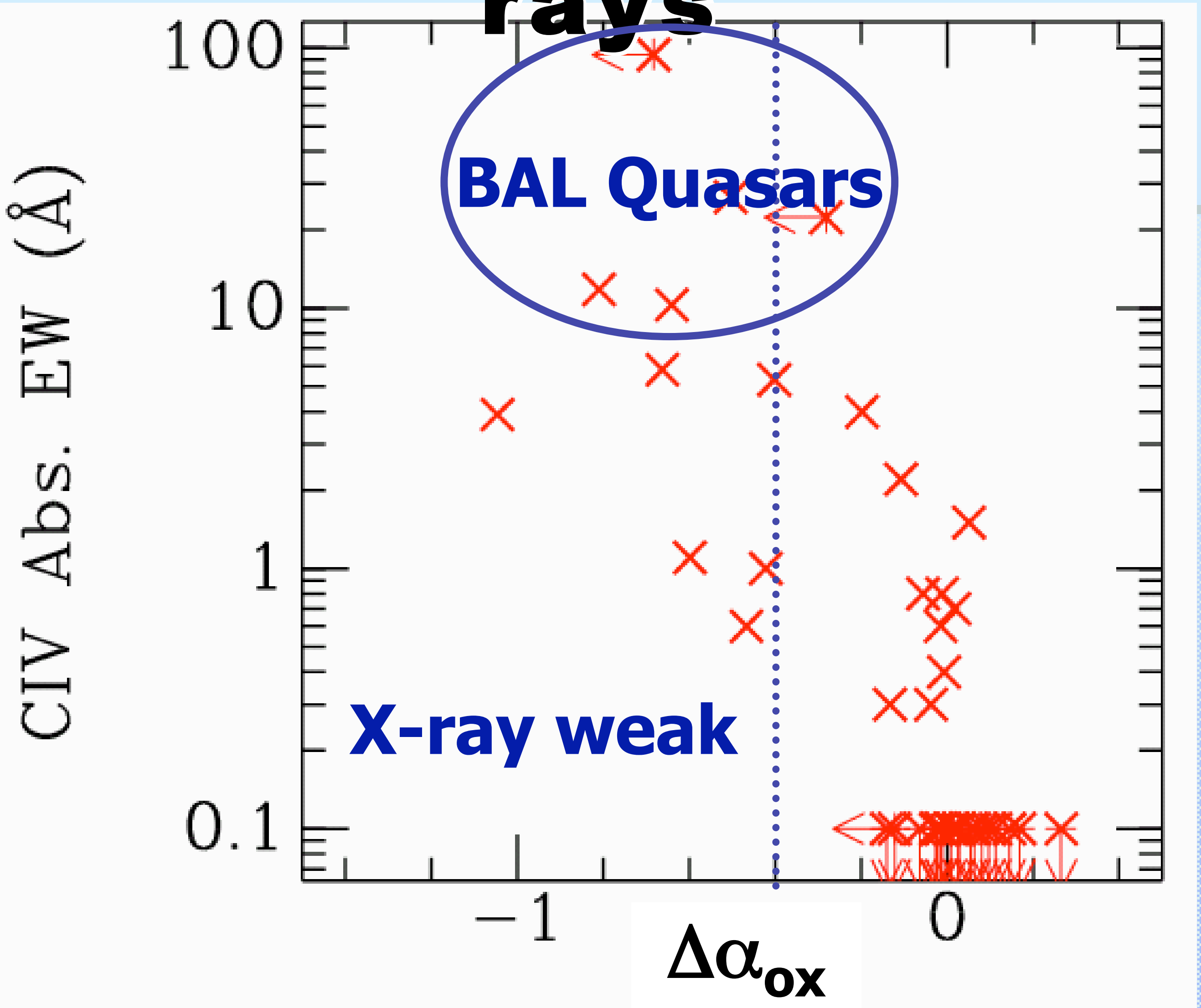
# X-ray Properties of Quasars




**(Laor et al. 1997)**

$$\alpha_{ox} = 0.384 \log (f_{2\,keV} / f_{2500\,Å})$$

# UV Absorbed → Faint in X-rays

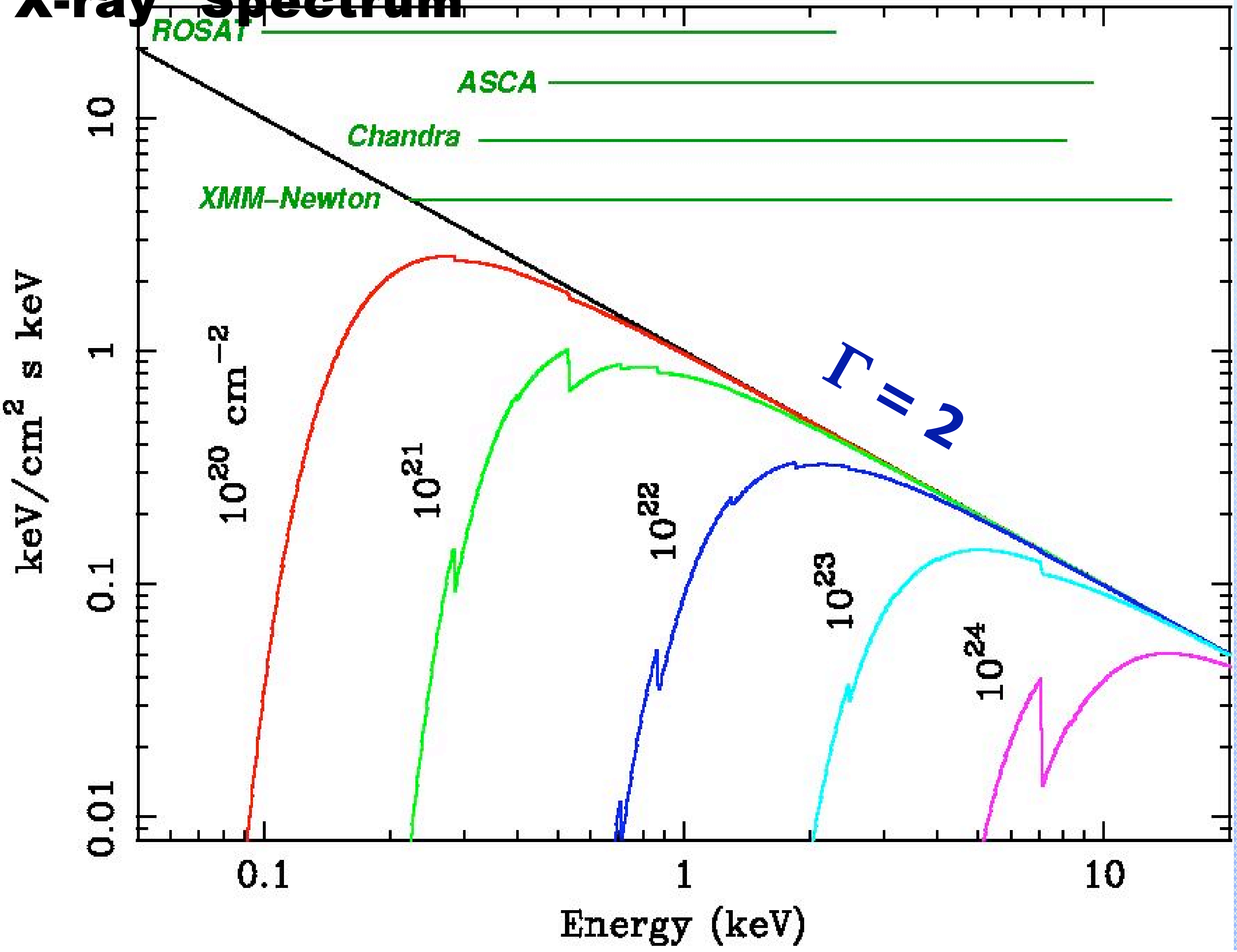



BQS Quasars with z< 0.5 (Brandt, Laor, & Wills 2000)

# X-ray Absorption Studies

- X-ray emission → accretion signature
  - $L_X = 2 – 20\% \; L_{bol}$
- X-rays are highly penetrating
  - up to $N_H \leq 10^{24}$ cm$^{-2}$
  - neutral, moderately ionized, and molecular gas

# Absorption by Neutral Gas of a Quasar X-ray Spectrum



# History of BAL Quasar X-ray Studies

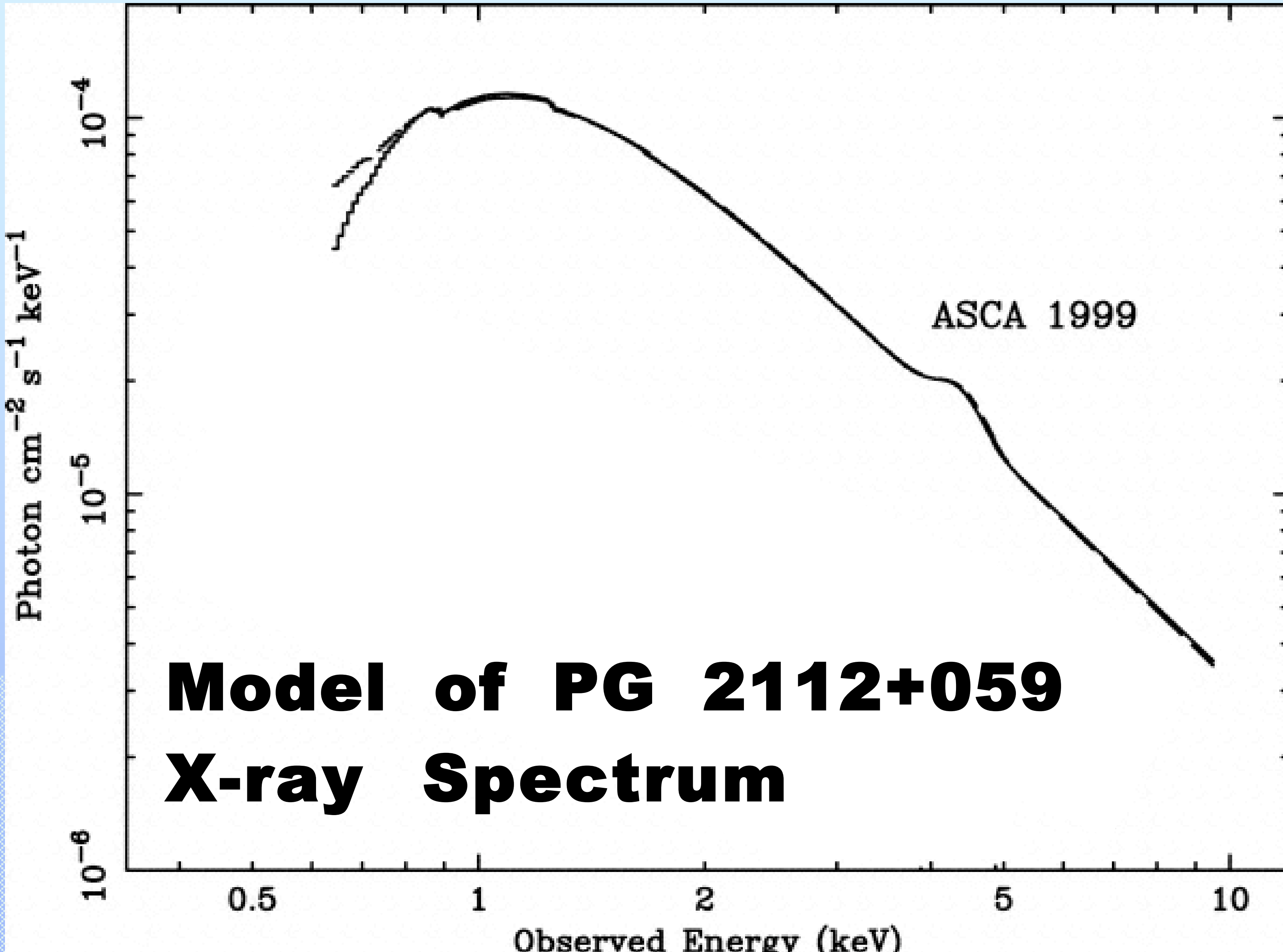
- BAL quasars are *extremely* weak in X-rays

if one assumes weakness is due to absorption...

  - ***ROSAT* studies → $N_H \geq 10^{22.7}$ cm$^{-2}$**
    - **(Kopko, Turnshek, & Espey 1994; Green & Mathur 1996)**
  - ***ASCA* limits → $N_H \geq 10^{23.7}$ cm$^{-2}$ for some**
    - **(Gallagher et al. 1999)**

- Hard-band spectroscopy → solid evidence for absorption as primary cause of X-ray weakness.
    - **(e.g., Green et al. 2001; Gallagher et al. 2001, 2002a)**

# Model of PG 2112+059 X-ray Spectrum




(Gallagher et al. 2001)

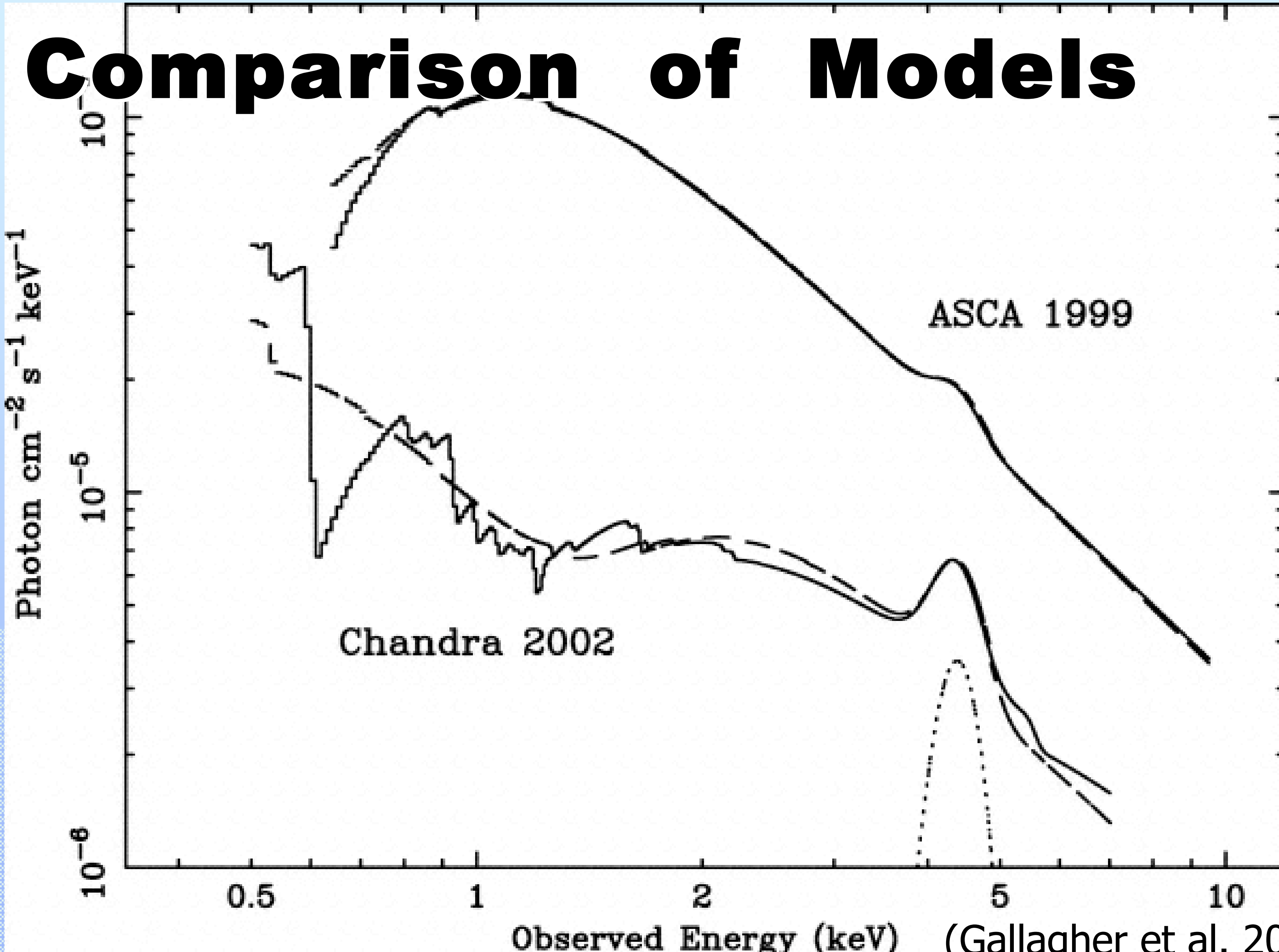
# X-ray Spectroscopy of BAL Quasars

- normal underlying X-ray continua
- significant intrinsic absorption
  - $N_H$ = (0.1-4.0) x $10^{23}$ $cm^{-2}$
- complexity in absorption
  - partial coverage? ionized gas? _*v*?
- from >5 keV continuum:
  - normal $\alpha_{ox}$ (UV/X-ray flux ratio)

(e.g., Gallagher et al. 2002a; Chartas et al. 2002, 2003; Aldcroft & Green 2003; Grupe et al. 2003; Page et al. 2005; Shemmer et al. 2005)

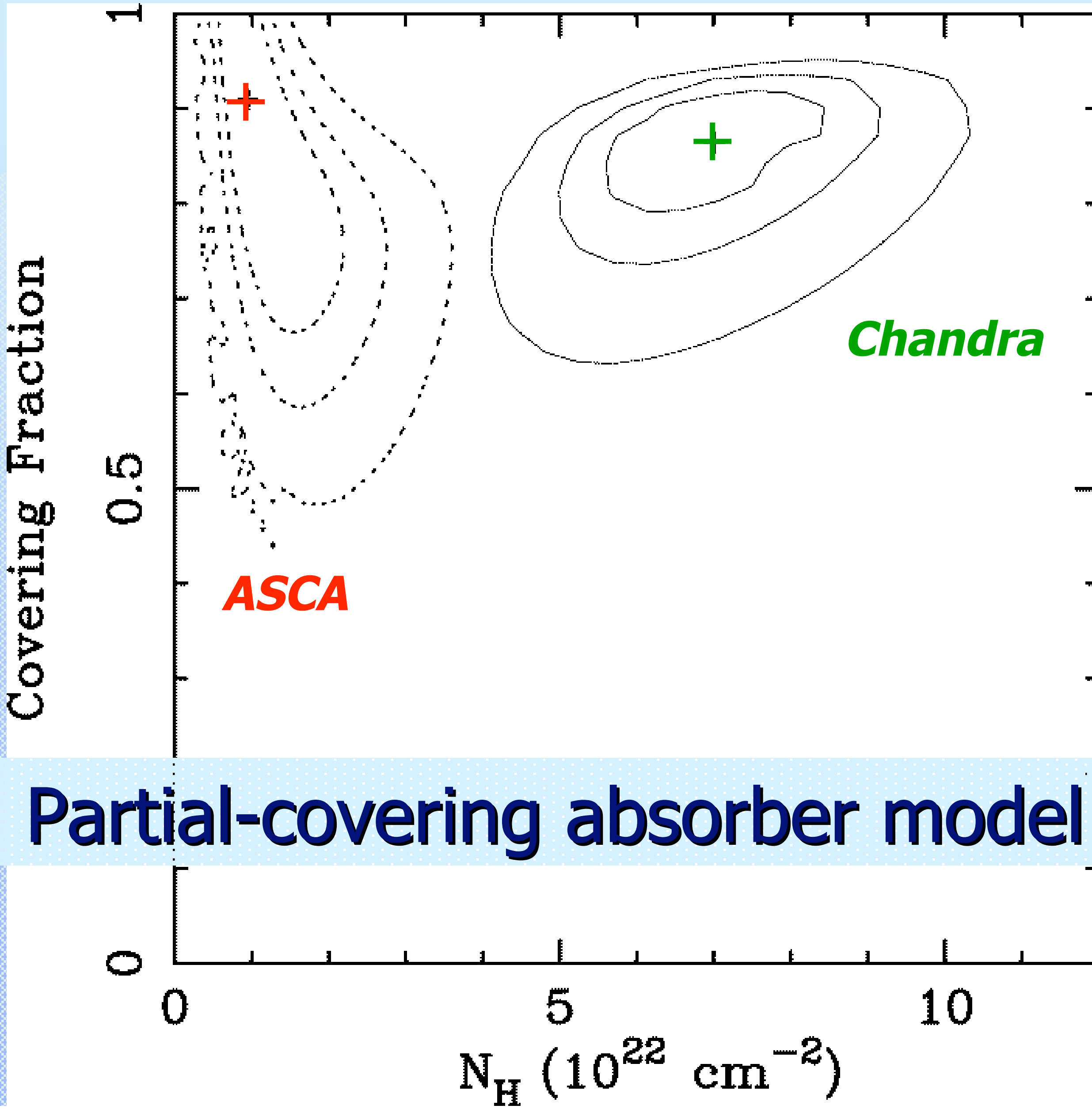
***Conclusion: BAL quasars are typical quasars with absorption.***

# PG 2112+059 Revisited: Comparison of Models



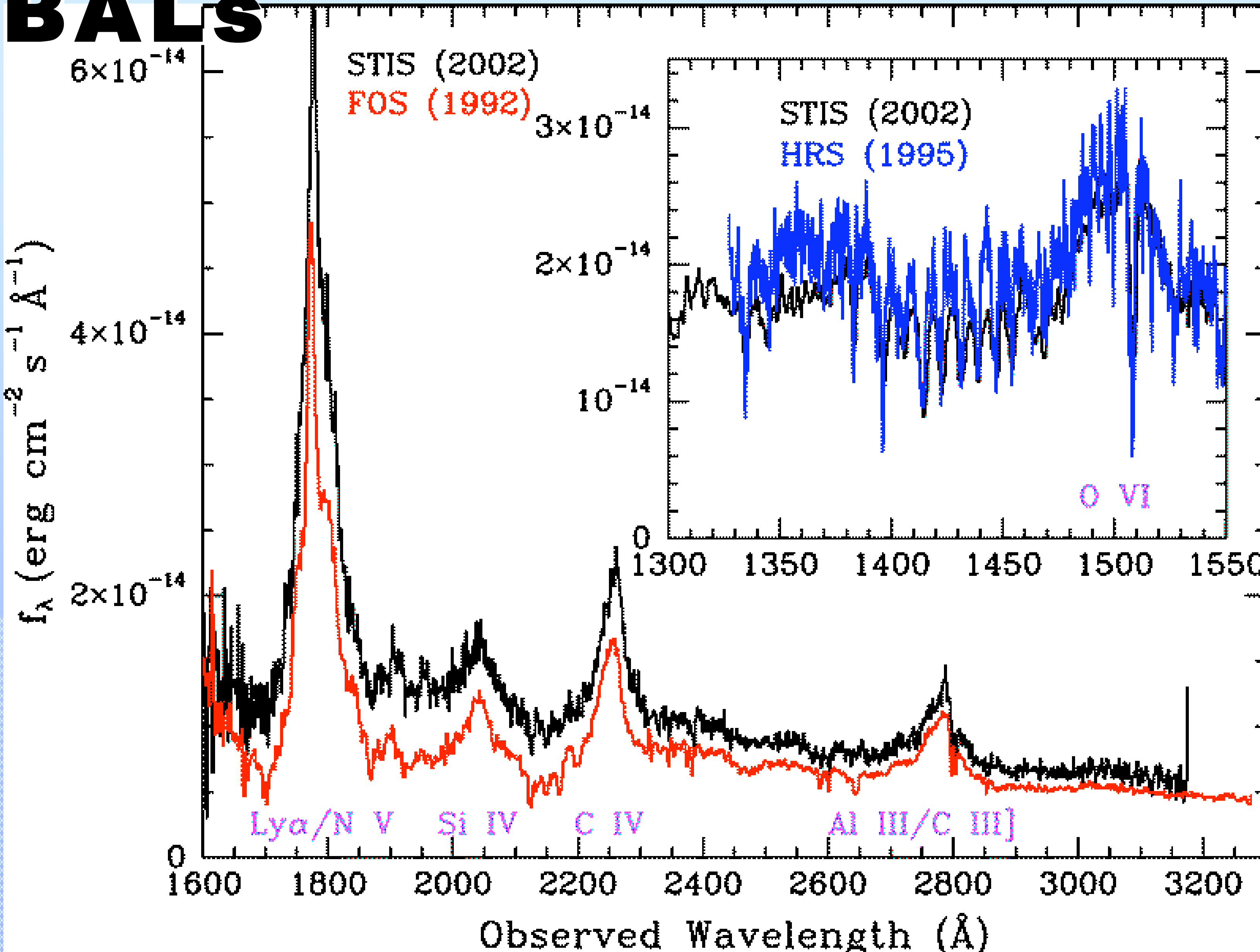

(Gallagher et al. 2004)

# Major Change → Increased $N_H$

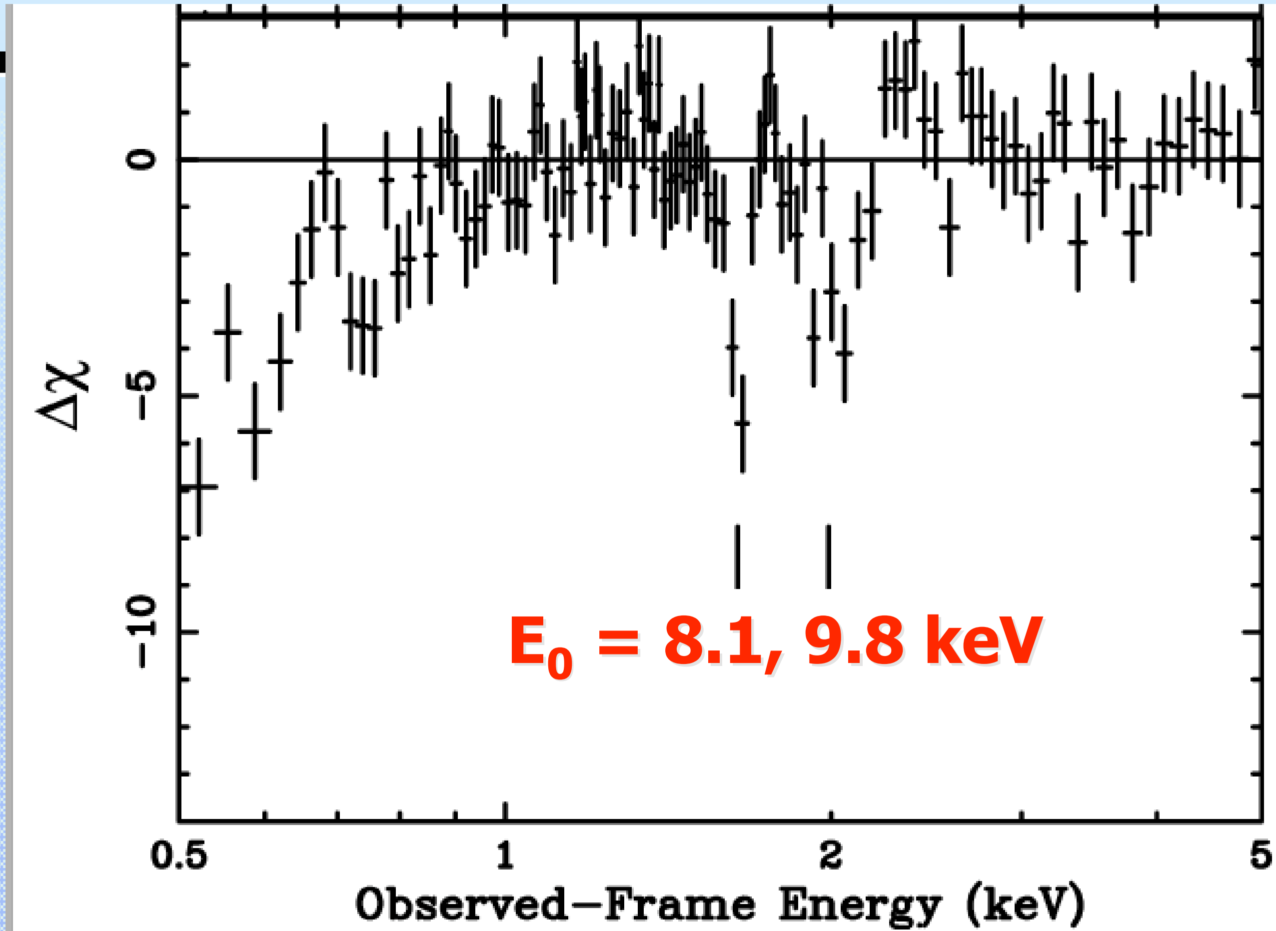



Partial-covering absorber model

# Little Variability in UV BALs



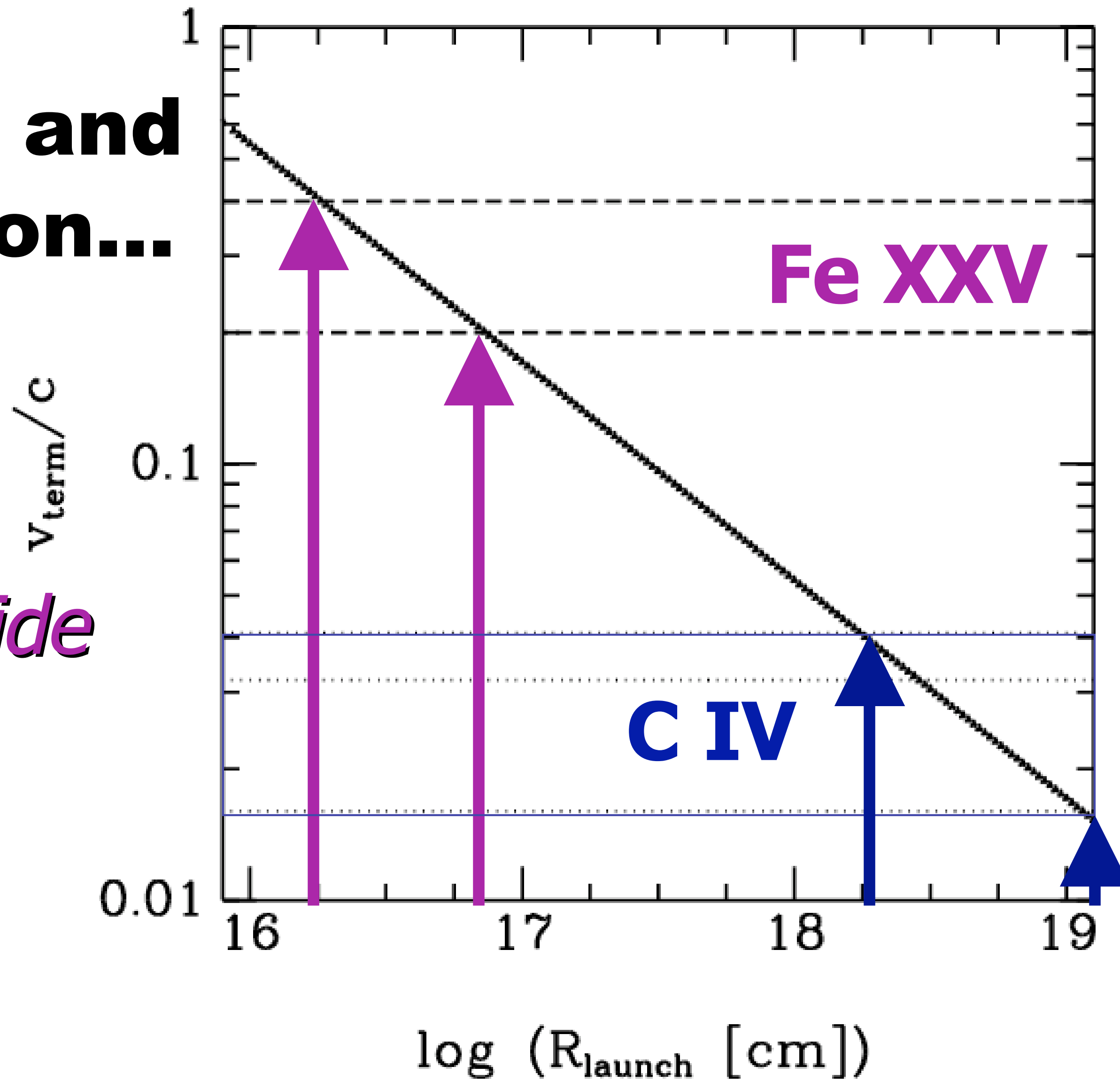
# APM 08279+5255 (z=3.91): first evidence for X-ray BAL




**implied bulk velocities for Fe XXV Kα: 0.2 & 0.4*c***

(Chartas et al. 2002)

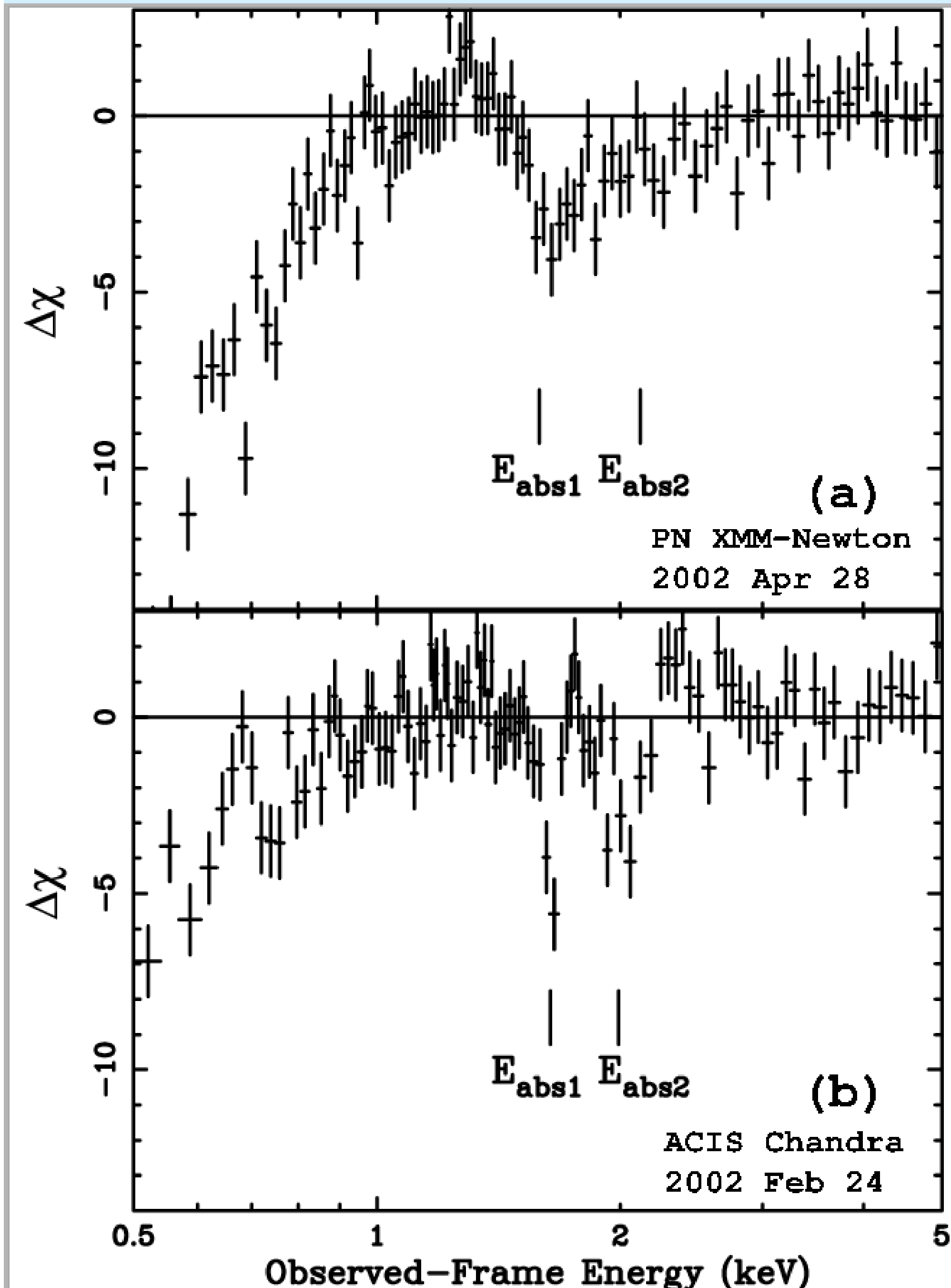
# Small radius and high ionization...




→ *$R_{launch}$ is inside UV BAL region*

(Chartas et al. 2002)

$$v_{term} = \left[ 2GM_{BH} \left( \Gamma_f \frac{L_{UV}}{L_{Edd}} - 1 \right) \left( \frac{1}{R_{launch}} \right) \right]^{1/2}$$




# APM Again

*XMM-Newton* (100 ks)

(Hasinger, Schartel, & Komossa 2002)

*Chandra* (89 ks)

(Chartas et al. 2002)

Clear absorption-line variability on rest-frame timescale of 11 days

(Chartas, Brandt, & Gallagher 2003)

# X-ray BAL Quasar Studies: update

- X-ray data support shielding gas
  - high velocities, high ionization → small launching radius
  - lack of apparent connection between UV and X-ray absorbers
    - mismatches of $N_H$ & $\xi$
- Variability studies offer potential for further insights → short timescales!

$$\dot{E} = \_ \, \dot{m}_{out} \, v^2 = 2\pi \, f_{cov} \, r \, N_H \, m_p \, v^3$$

from UV:

- $f_{cov}$ = 0.1-0.5
- $r = 10^{18}$ cm
- $N_H = 10^{21-22}$ cm$^{-2}$
- $v=10^3$ km/s

from X-ray:

- $f_{cov}$ = 0.1-0.5
- $r = 10^{16}$ cm (?)
- $N_H = 10^{22-23}$ cm$^{-2}$
- $v=10^{4-5}$ km/s (?)

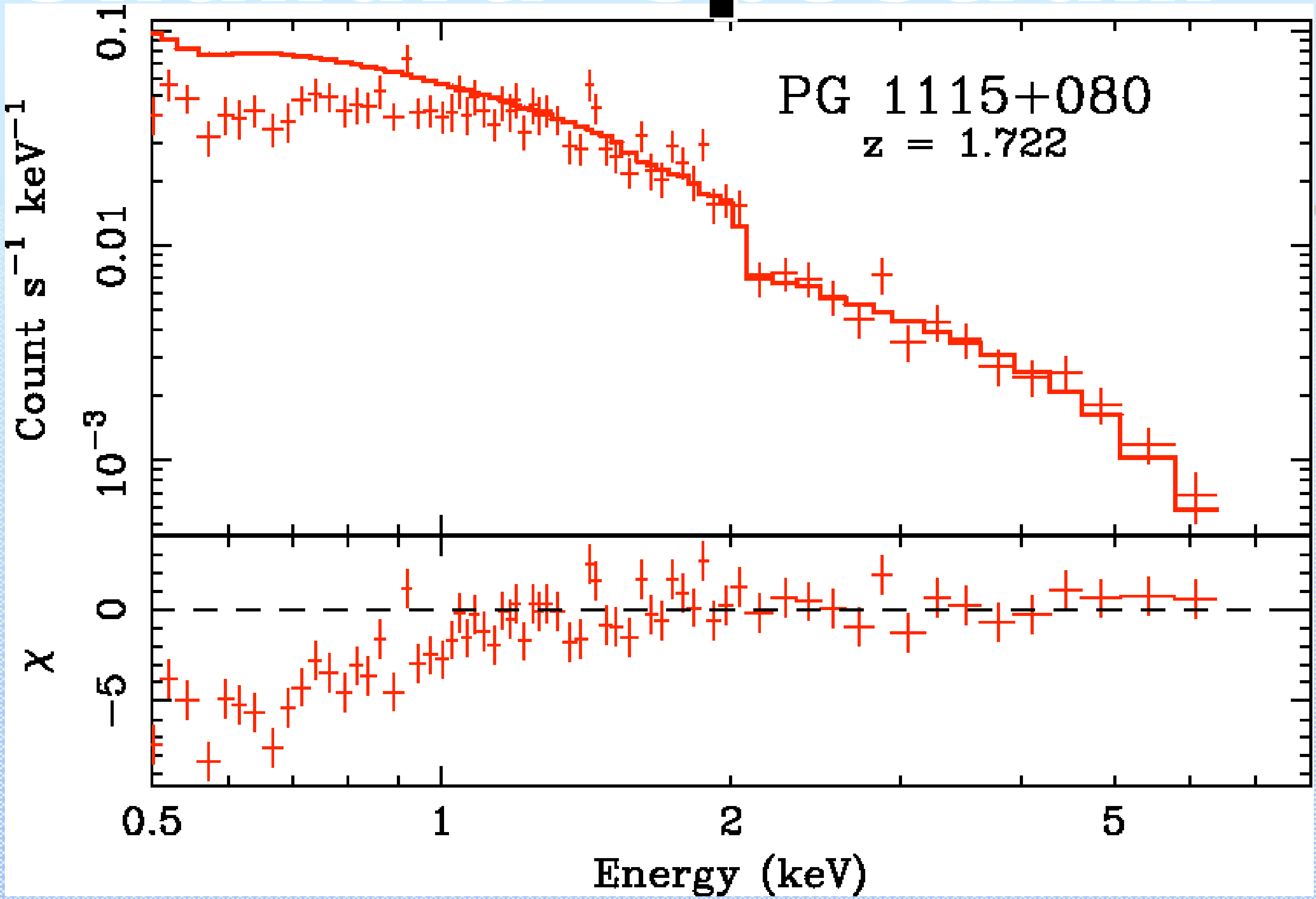
$$\rightarrow \dot{E} = 10^{39}\text{-}10^{45} \text{ erg/s}$$

# Quasar Outflows: status

- X-ray studies of BAL and normal quasars support disk-wind picture
  - → most of the gas seen only in X-rays
  - → gas is likely ionized and compact

- Outflows are probably energetically significant
  - → velocity of X-ray absorbing gas is key

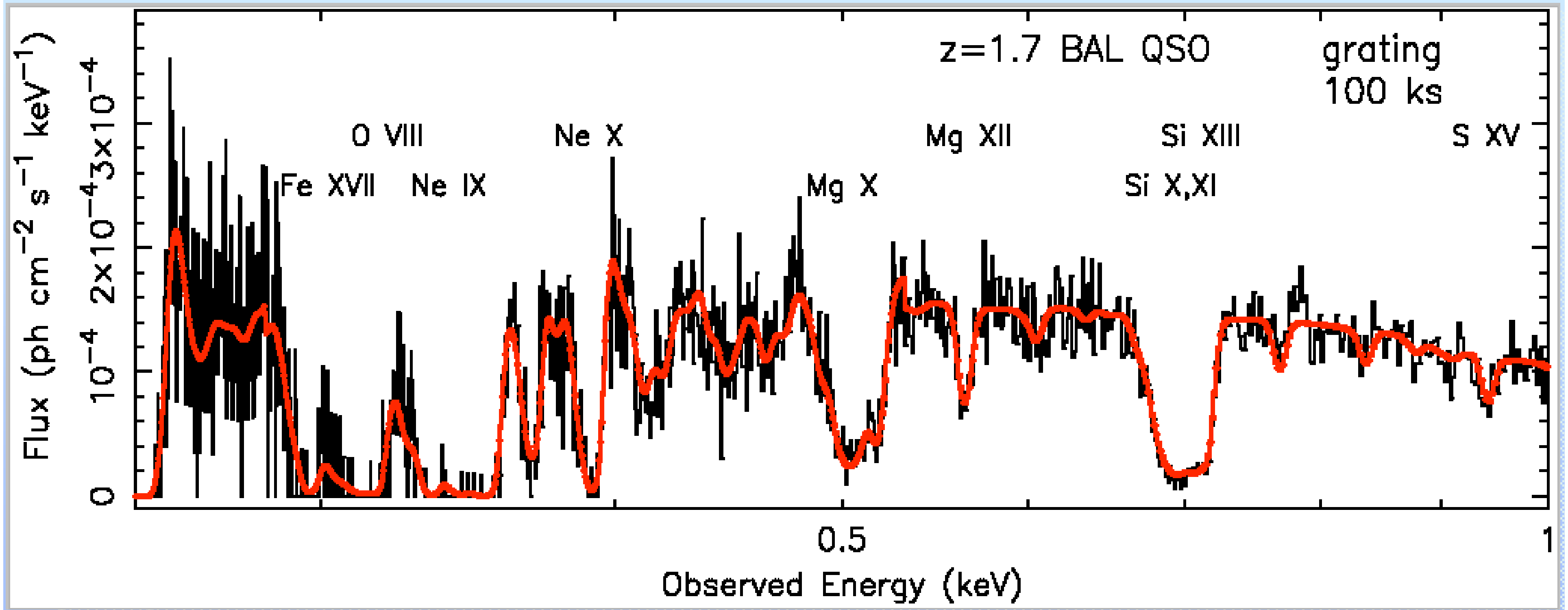
# *Chandra* Spectrum




$\Gamma = 2.0$; $N_H = 3.8 \times 10^{22}$ cm$^{-2}$

(Gallagher et al. 2002)

# Future: *Constellation-X*




**(Model by D. Chelouche)**

Measure $\dot{m}_{out}$ directly!

# Quasar Outflows: status

- X-ray studies of BAL and normal quasars support disk-wind picture
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- Outflows are probably energetically significant
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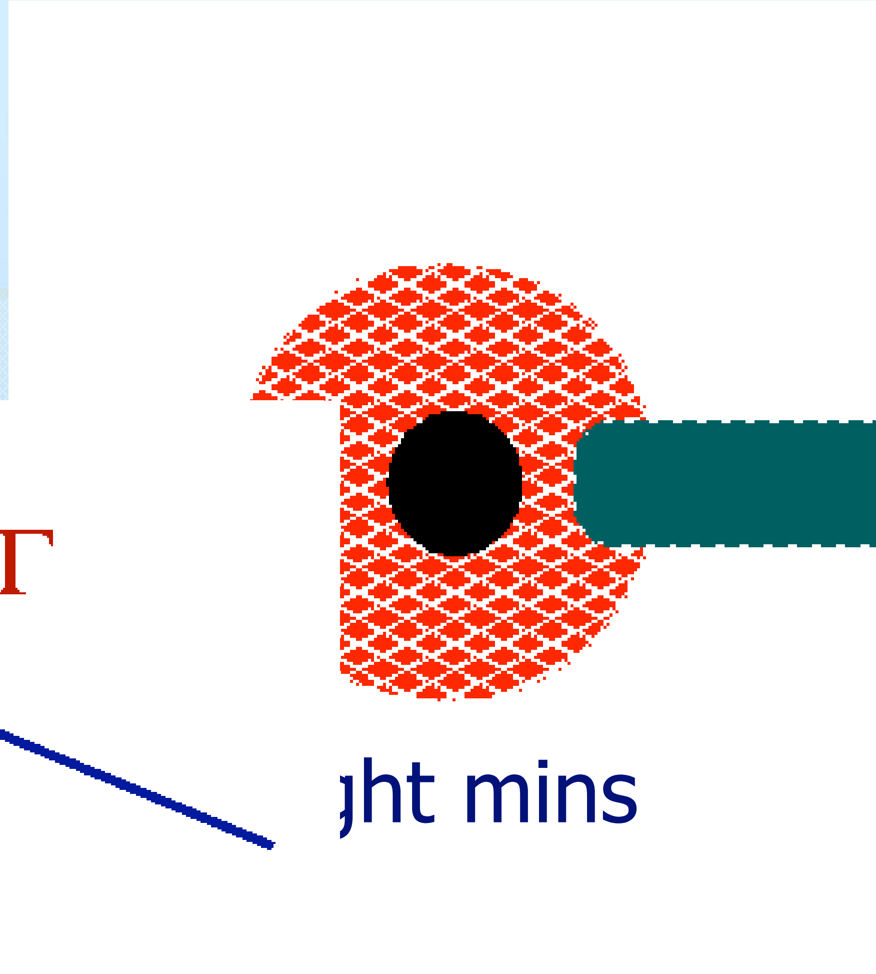
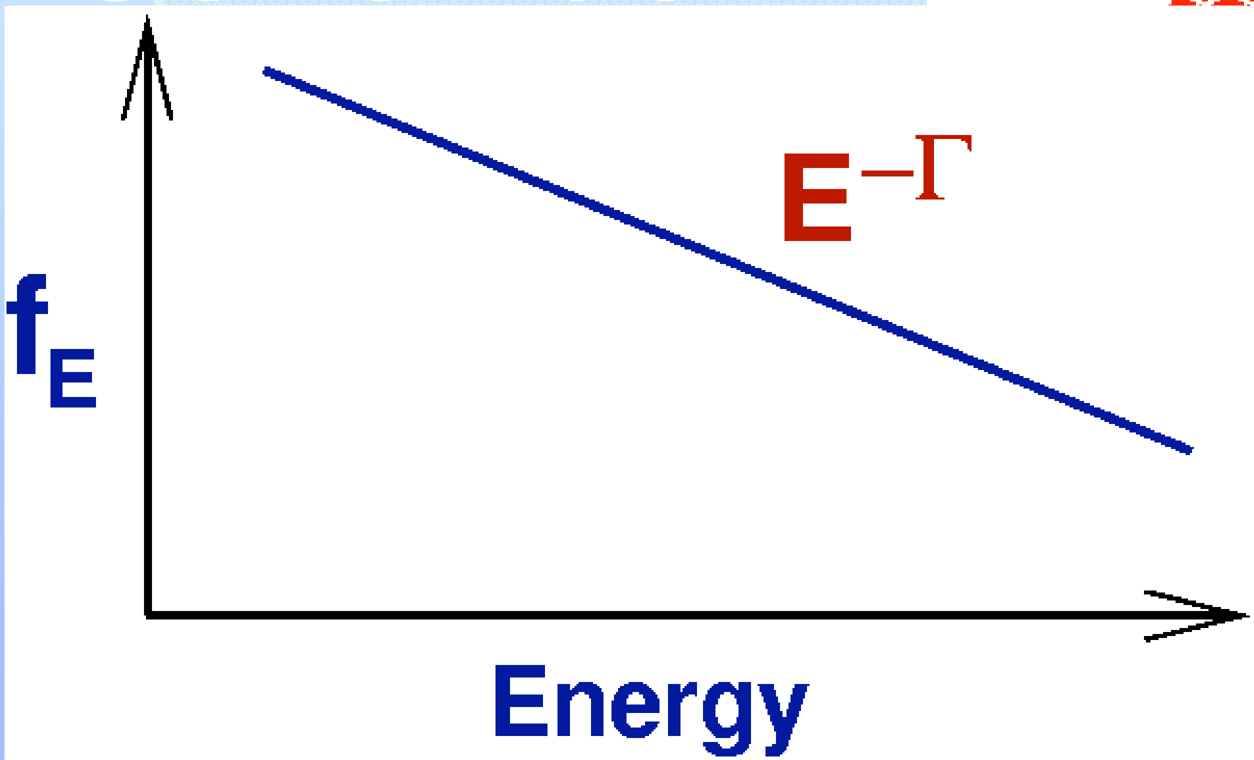
# Do all quasars have strong winds?

- YES! → BAL quasars look like normal quasars
  - (e.g., "remarkably similar" Weymann et al. 1991)
- YES! → UV emission lines are formed in wind
  - (e.g., Königl & Kartje 1994; Proga et al. 2000)
- NO! → only arise when conditions are right
  - (e.g., Hazard et al. 1984; Becker et al. 2000; Leighly 2004)

# Quasar X-ray Continua



# BAL Quasar Close-up

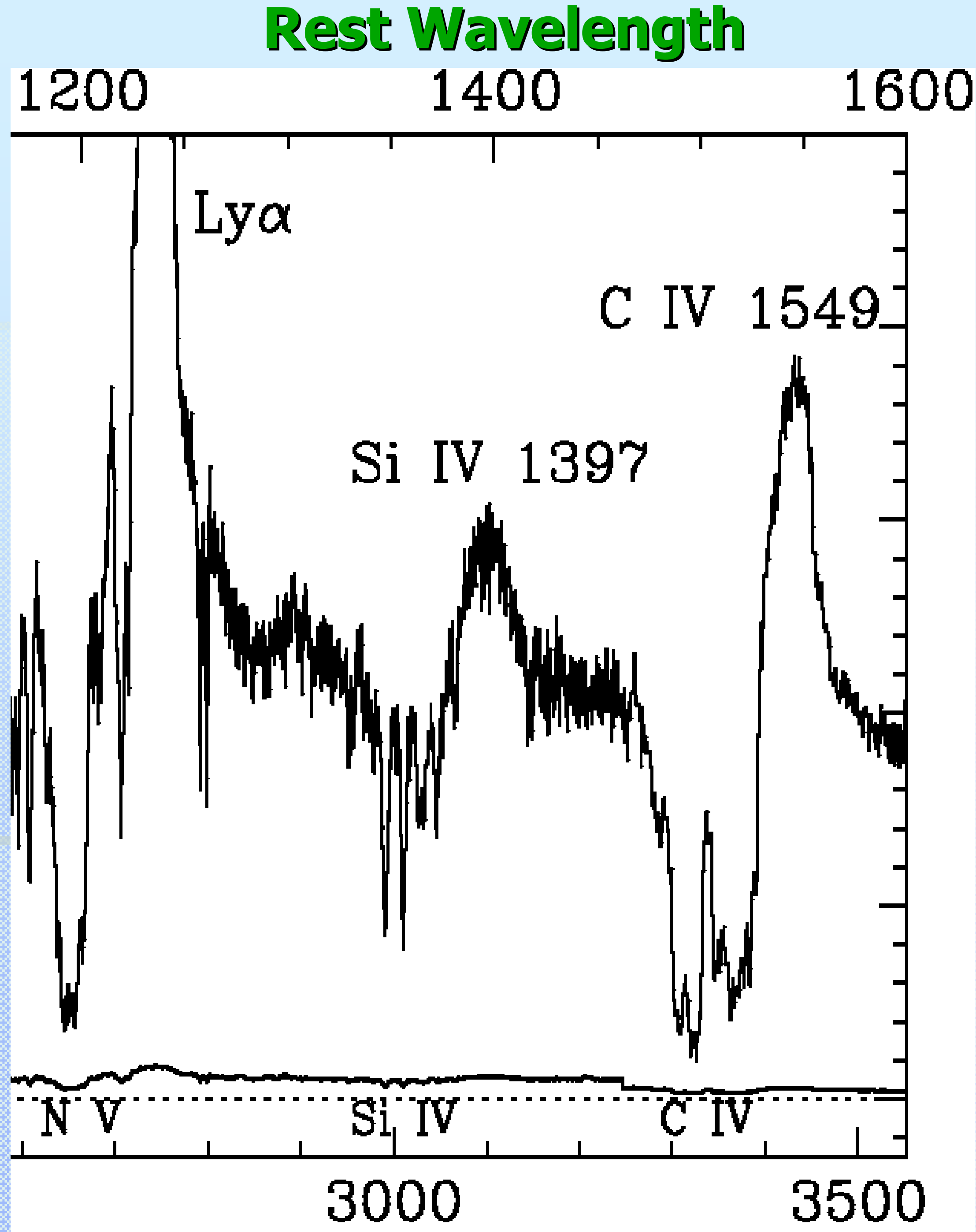
**PG 0946+301**

**z=1.22**

***best estimate of $N_H$:***

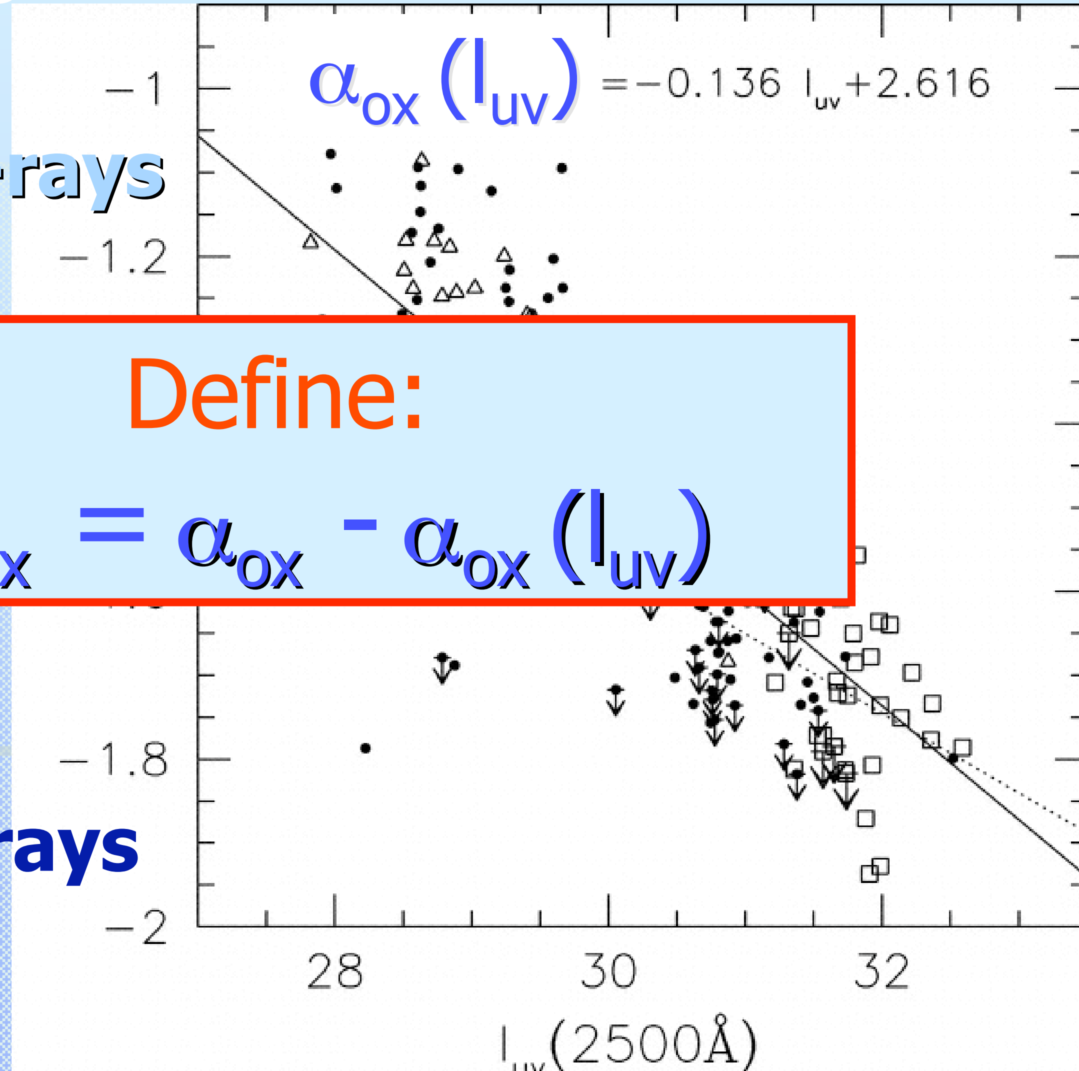
***$\sim 10^{22}$ $cm^{-2}$***

(Arav et al. 2001)



# Relationship of UV luminosity to $\alpha_{ox}$

brighter in X-rays




Define:

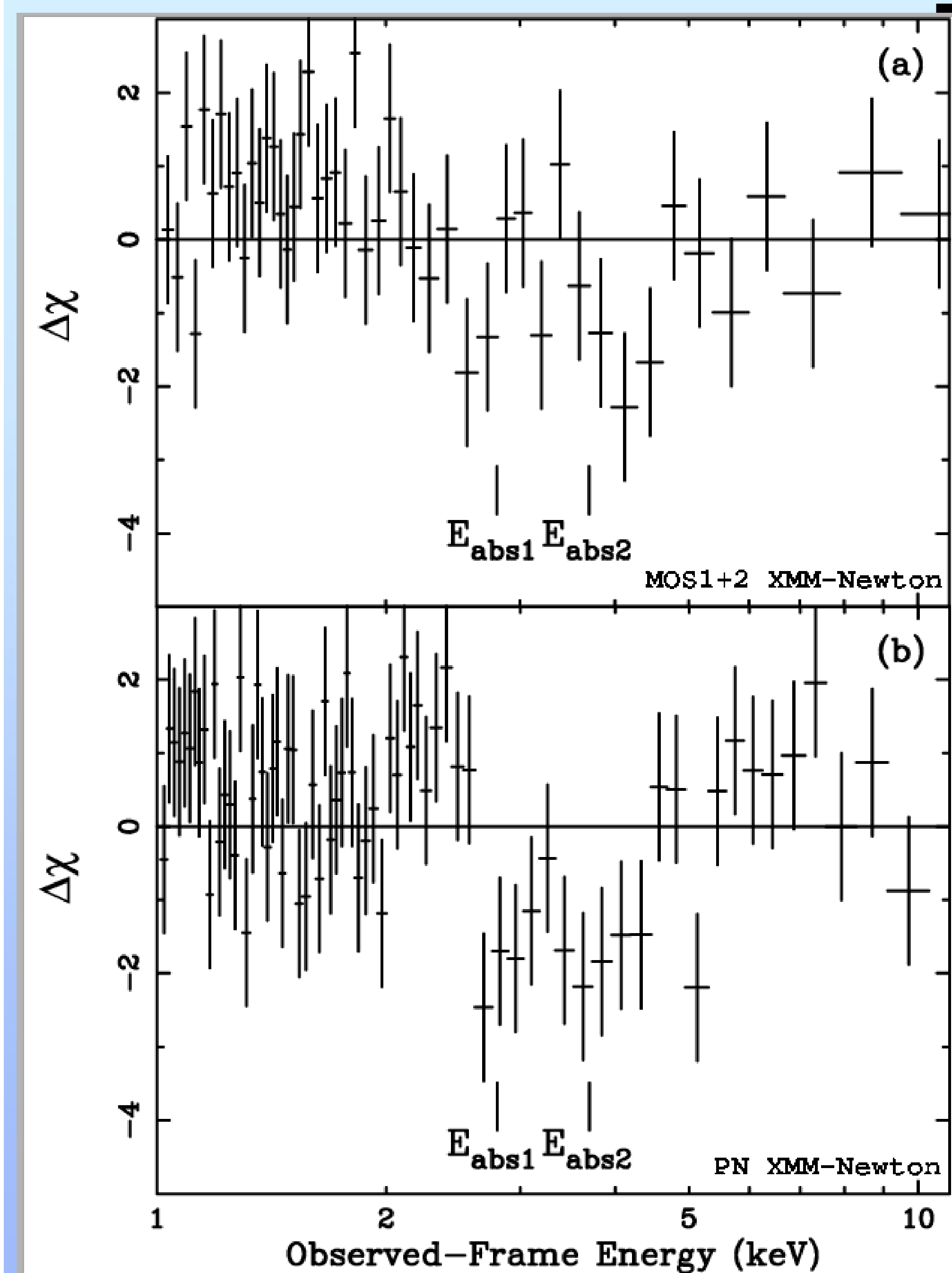
$$\Delta\alpha_{ox} = \alpha_{ox} - \alpha_{ox}(l_{uv})$$

fainter in X-rays

**SDSS Quasars with ROSAT** (Strateva et al. 2005)

# PG 1115+080

*XMM-Newton* (63 ks)

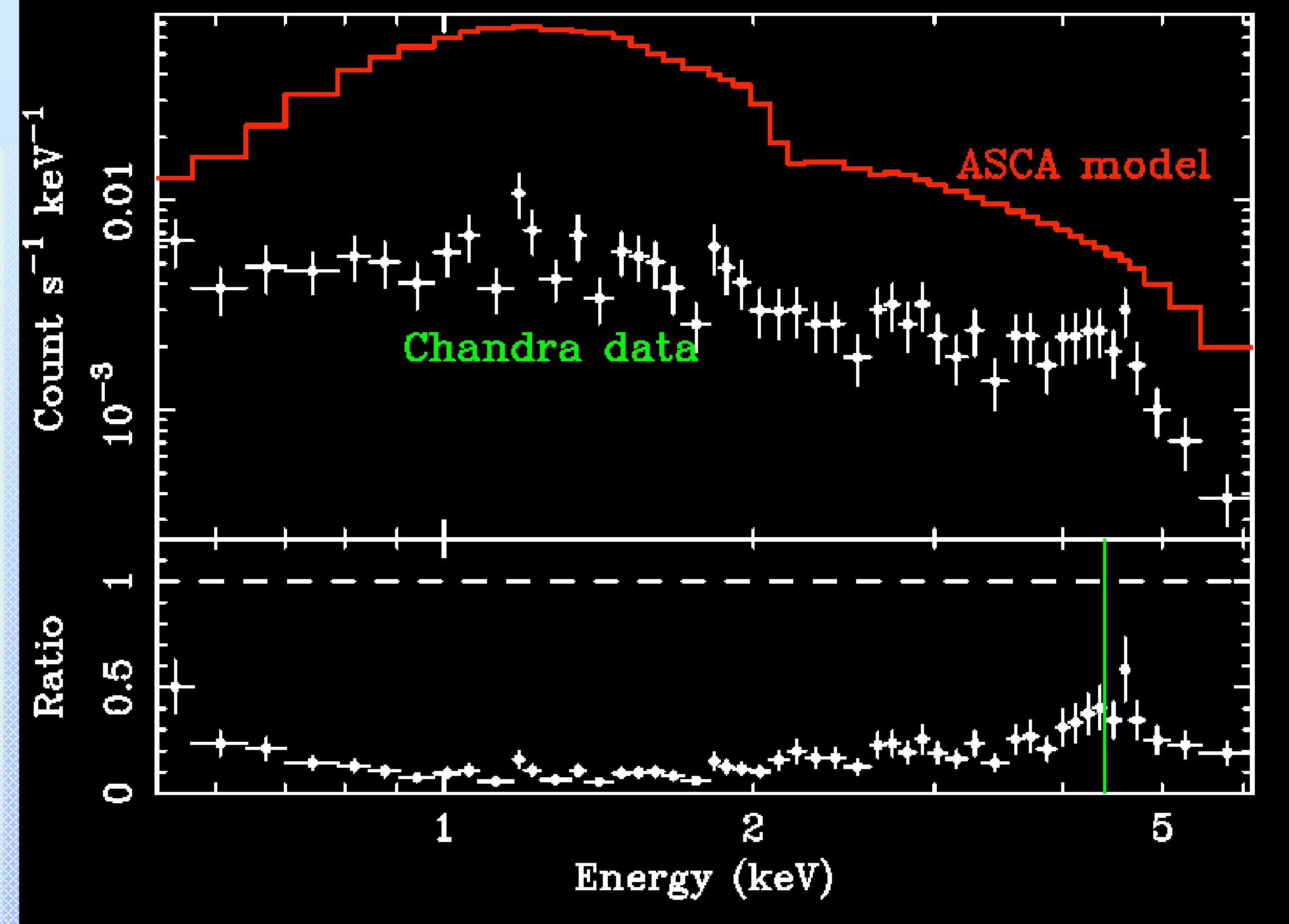



$z$ = 1.72

rest-frame line energies:
7.4 & 9.5 keV → 0.1 & 0.3*c*

(Chartas, Brandt, & Gallagher 2003)

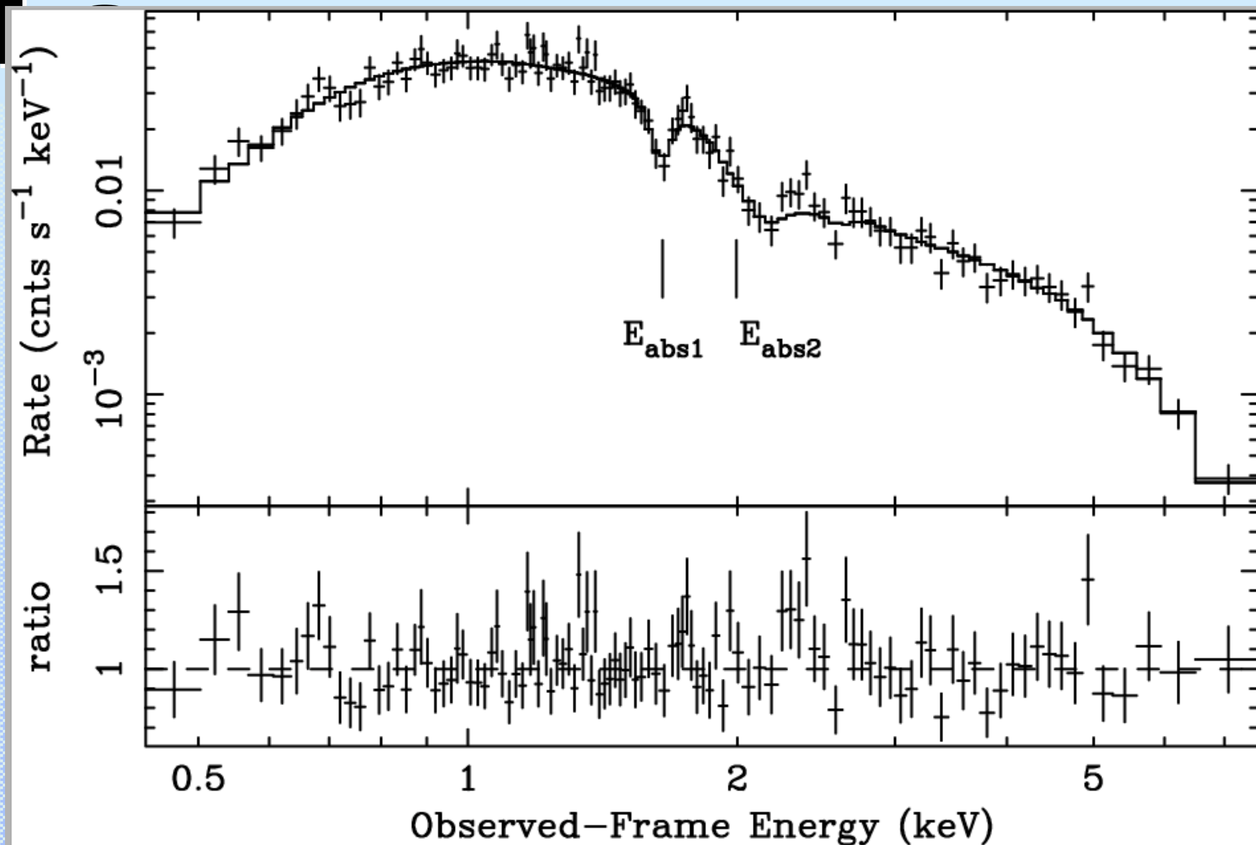
# Dramatic Spectral Variability




PG 2112+059: *ASCA* Oct 1999; *Chandra* Sep 2002

(Gallagher et al. 2004)

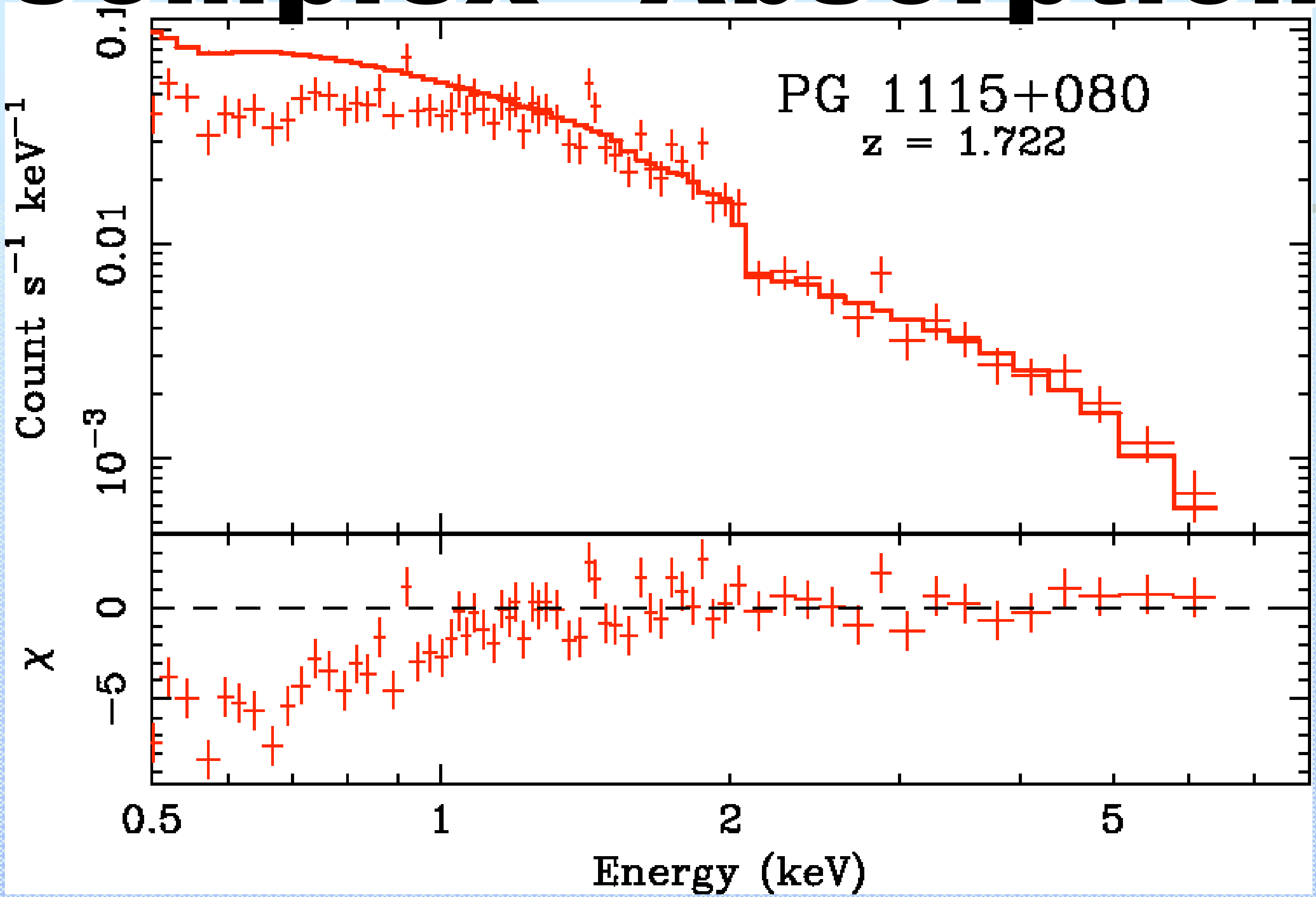
# APM 08279+5255: the first evidence for X-ray BAL…




Rest frame energies of absorption lines: 8.1 & 9.8 keV.

**implied bulk velocities for Fe XXV K$\alpha$: 0.2 & 0.4*c***

# Complex Absorption




$\Gamma$ = 2.0; $N_H$ = 3.8 x $10^{22}$ $cm^{-2}$

(Gallagher et al. 2002)