UV/X-ray Absorbers in the Context of MHD Accretion-Disk Winds

~ Galactic Black Holes (GBHs) to Active Galactic Nuclei (AGNs) ~

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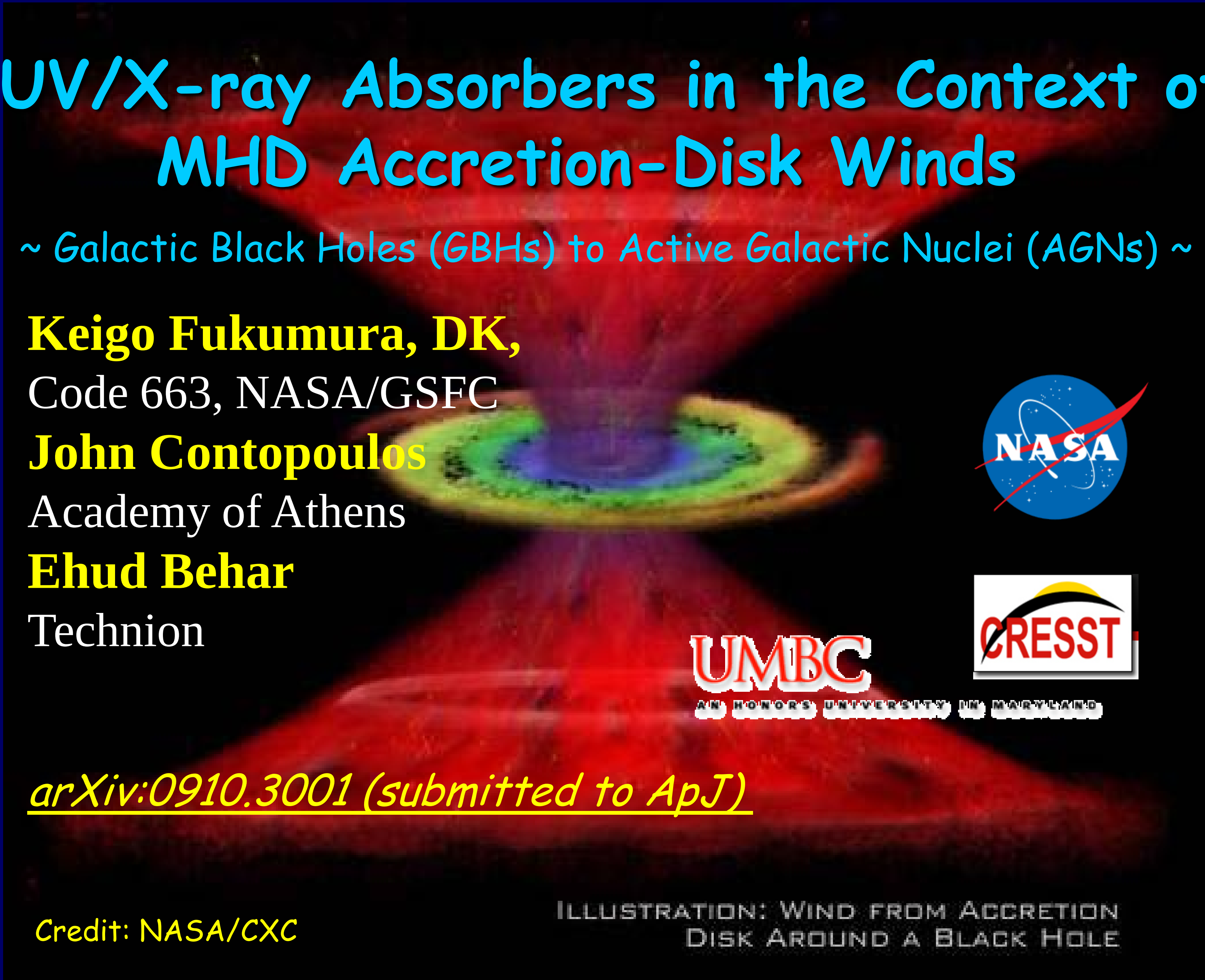
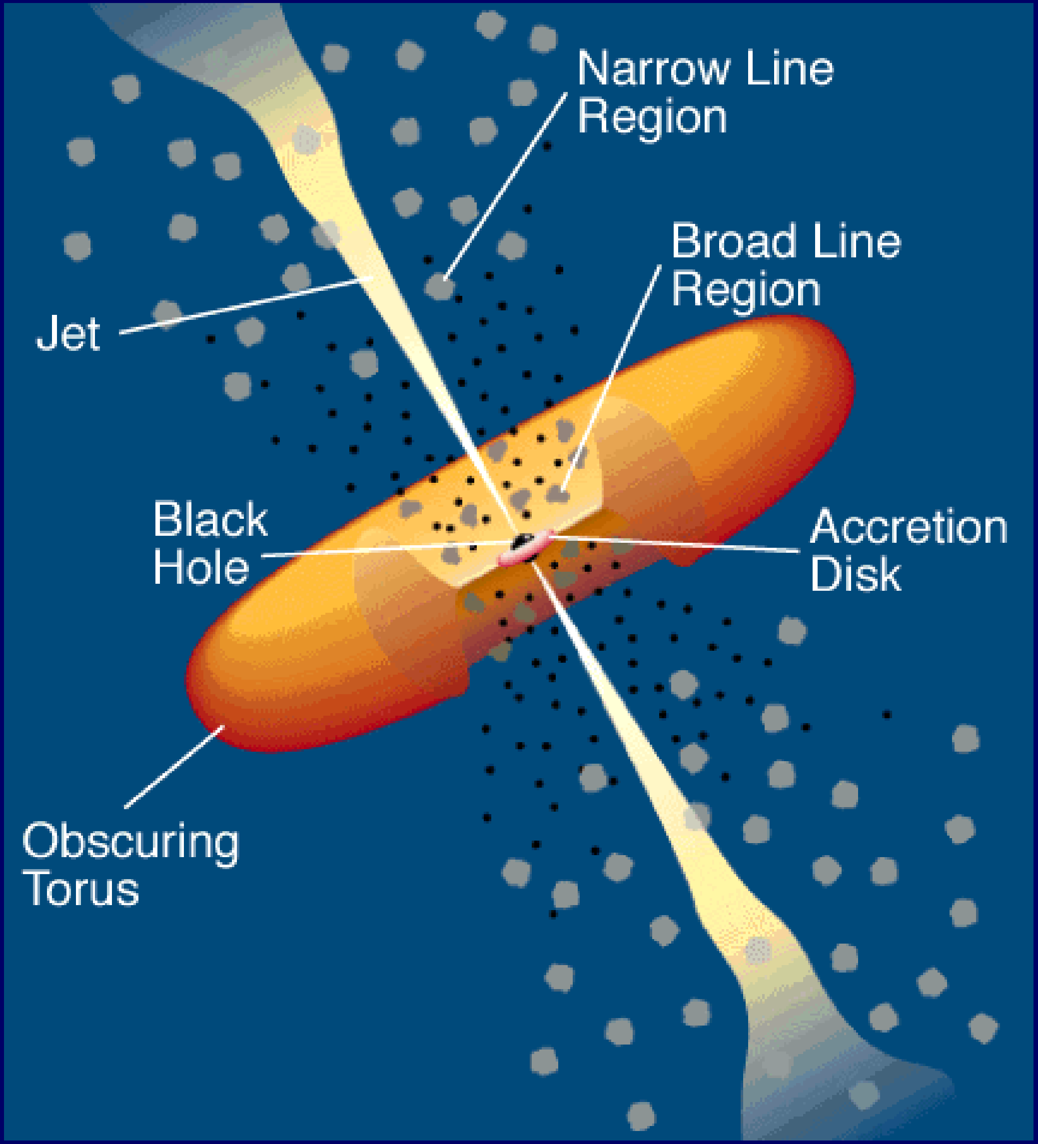
CRESST

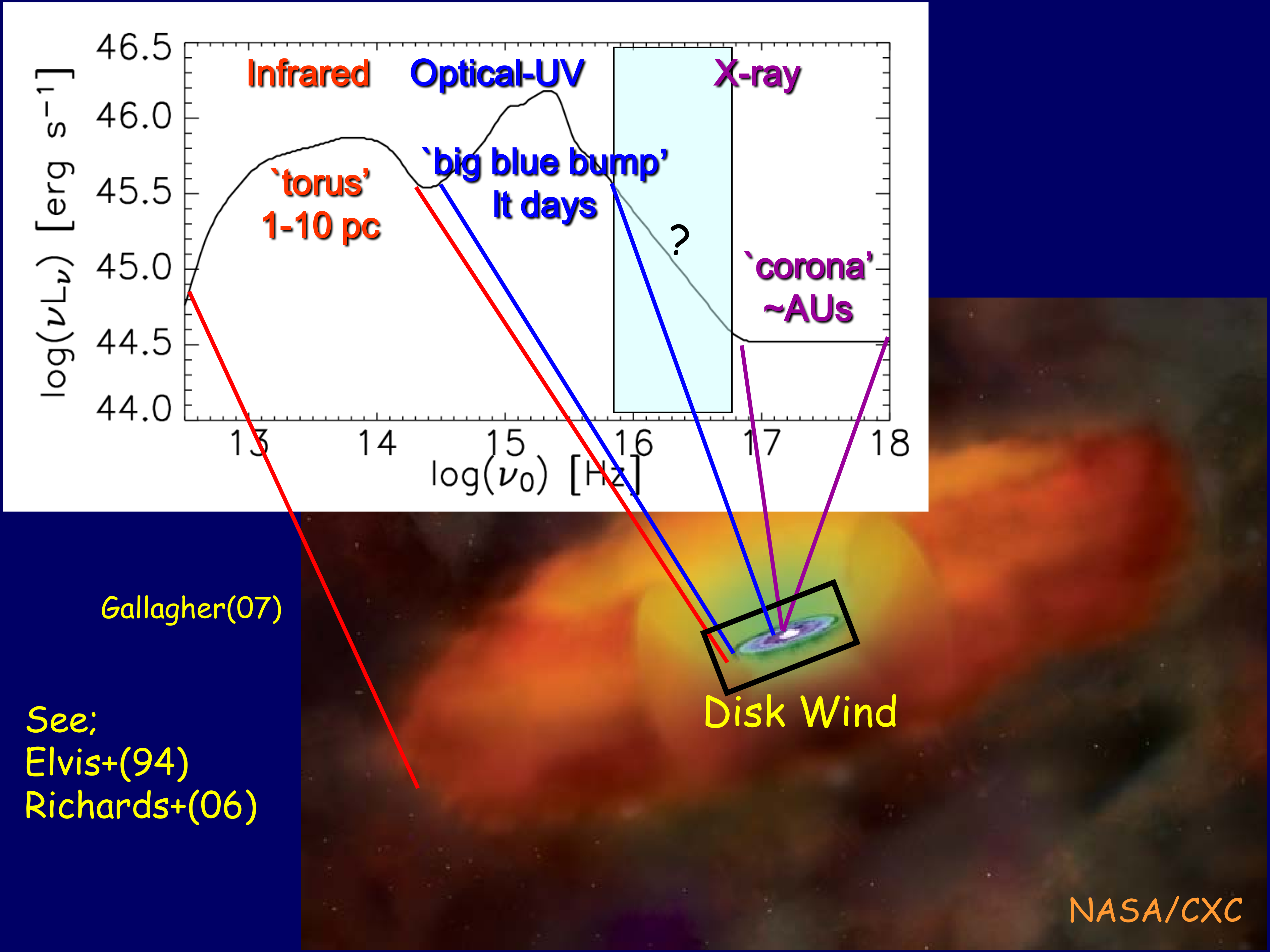
arXiv:0910.3001 (submitted to ApJ)



Credit: NASA/CXC

ILLUSTRATION: WIND FROM ACCRETION DISK AROUND A BLACK HOLE


Narrow Line
Region
Broad Line
Region
Jet
Black
Hole
Accretion
Disk
Obscuring
Torus



See;
Elvis+(94)
Richards+(06)

- Observations of Ionized Absorbers (AGNs/Seyferts/Quasars; Binaries)

- Seyferts/Quasars (MCG-6-30-15/IRAS 13349+2438)
  - ➔ Low/High-velocity outflows (~100-3,000 km/sec)
  - ➔ Absorption Measure Distribution (~Flat AMD)

- Broad Absorption Line Quasars (APM 08279+0255)
  - ➔ High-velocity C IV in UV (~ 0.04c-0.1c)
  - ➔ Near-relativistic Fe XXV in X-ray (~ 0.4c-0.8c)
  - ➔ High columns (>~ 10^{22-24} cm^{-2})

- Summary

- Issues

1 . Blueshifted Absorption Signatures

- Ubiquitous absorption lines from low to high ionization states (e.g. **X-rays** in AGNs/GBHs; **UV** in bright quasars)
- Observational evidence of "**irradiated plasma**" in line of sight (LoS)
- **Blueshifted** absorption lines (winds/outflows toward us)

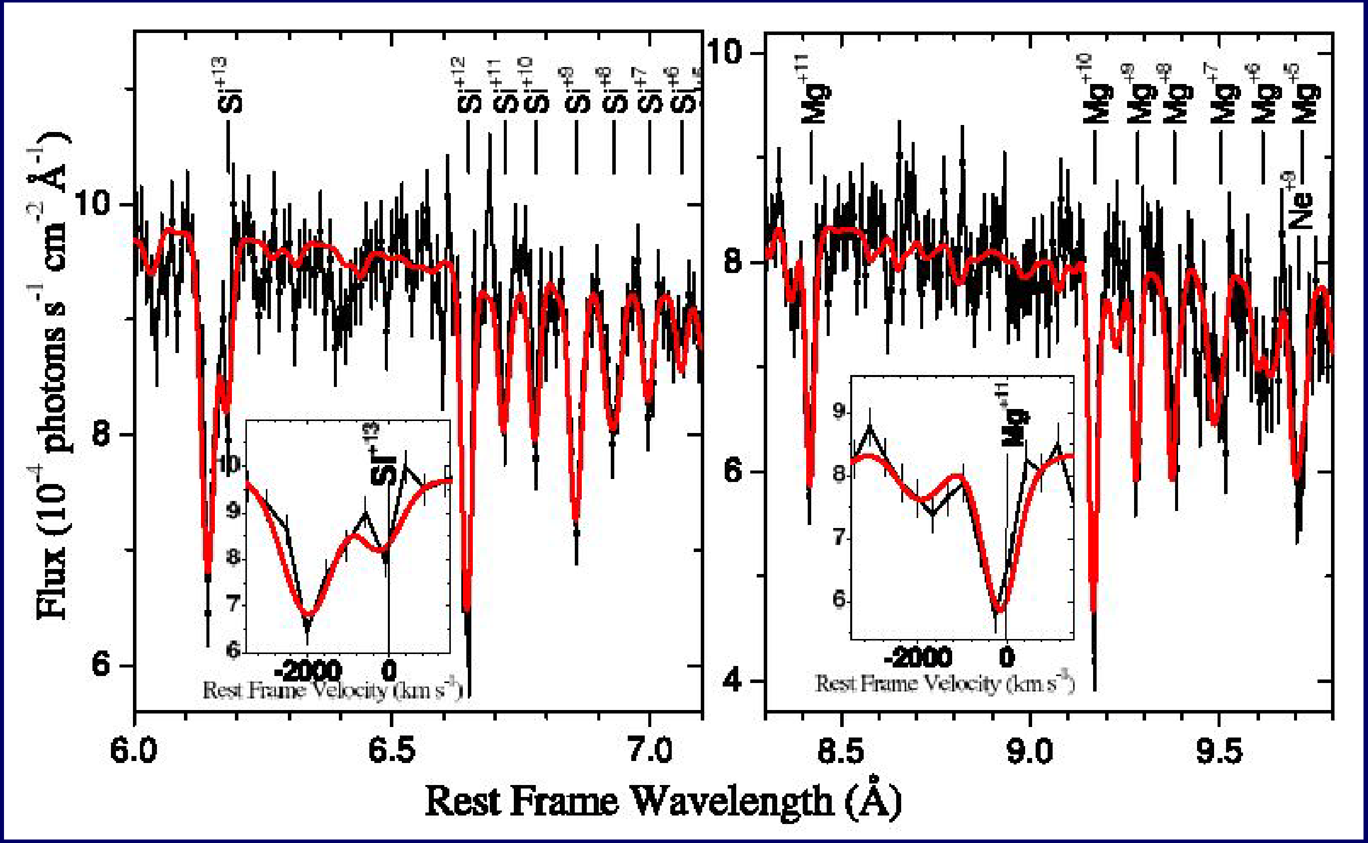
➔ Useful diagnostics for probing absorber's physics;

i) *column density,* N_H [cm^{-2}]
ii) *ionization parameter,* $\xi = L/(n\ r^2)$ [$erg\ cm\ sec^{-1}$]
iii) *LoS velocity,* v/c
iv) *demographic/geometrical properties*

2a. Example – AGNs/Seyferts

MCG-6-30-15:
(z = 0.007749)

- *ROSAT*
- *ASCA*
- *Chandra*
- *XMM-Newton*
- *Suzaku*



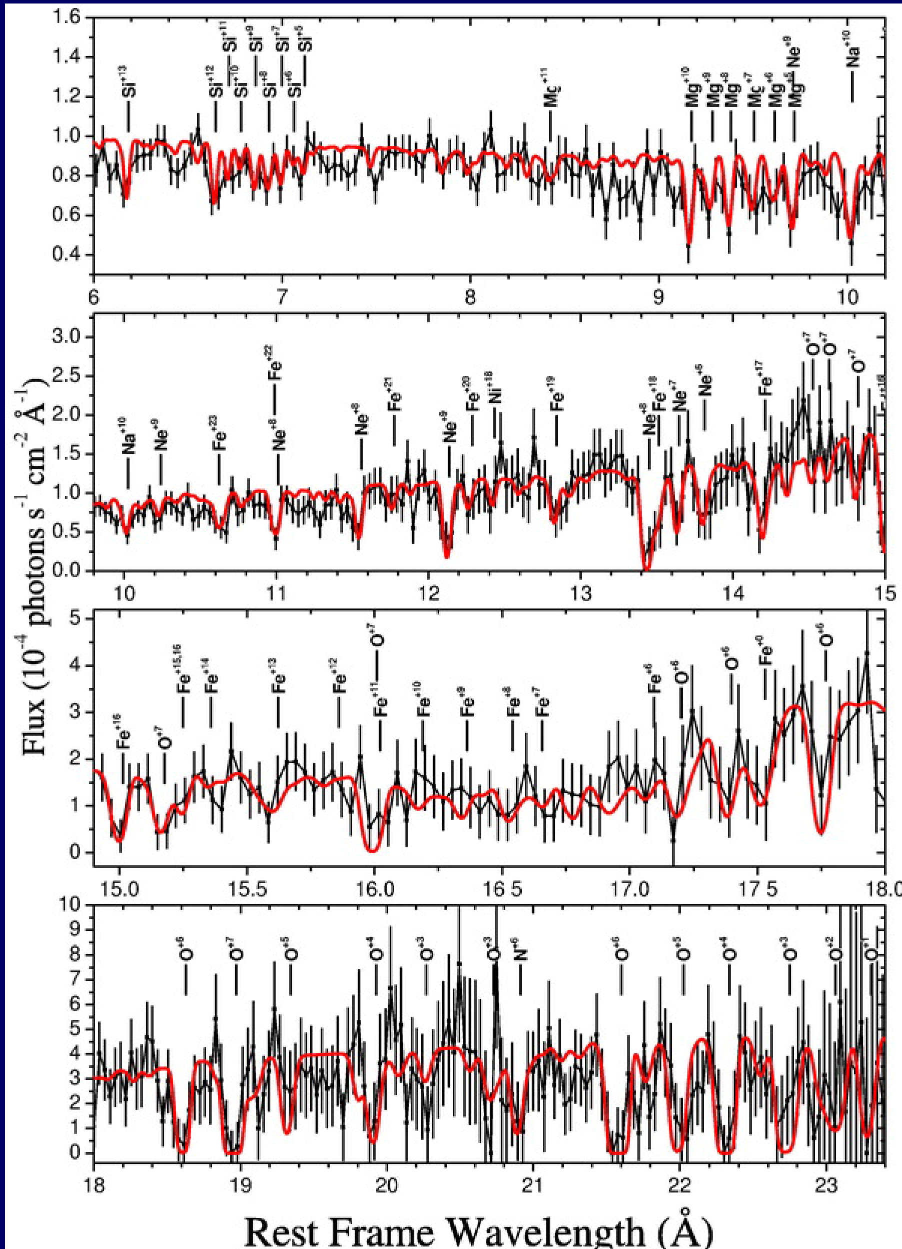
Holczer+(10)

- Broad Fe Ka line
- ~ 1ksec doubling time

- Fe XVII ~ 100 km/sec @ low-ξ
- Fe XXV ~ 1,900 km/sec @ high-ξ

(e.g. Otani+96, Reynolds+97, Sako+03, Miller+08)

2b. Example – AGNs/Quasars



IRAS 13349+2438:
(z = 0.10764)

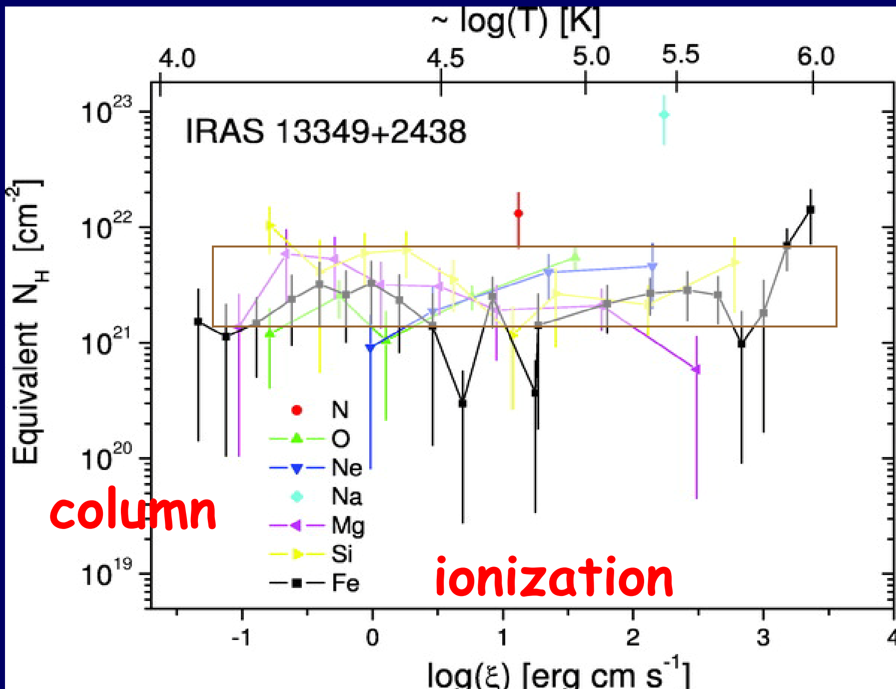
- Infrared-loud/radio-quiet QSO
- X-ray obs. with *ROSAT*, *ASCA*, *Chandra*, *XMM-Newton*

- Broad absorption lines of many ions
- Fe XVII ~ 300 km/sec
- Fe (HI) ~ higher velocities
- Integrated N_H ~ 10^{22} cm^{-2}

Chandra data
Holczer+(07)

2c. Absorption Measure Distribution (AMD)

$AMD(x) = dN_H / d\log\xi \sim x^p$ where $\xi = L/(n\,r^2)$



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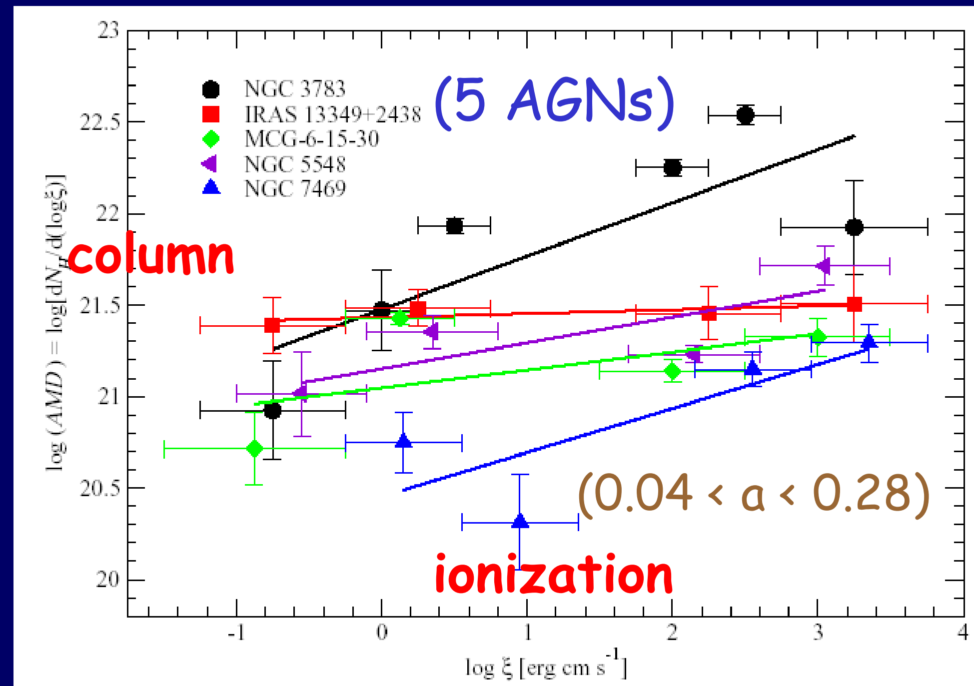
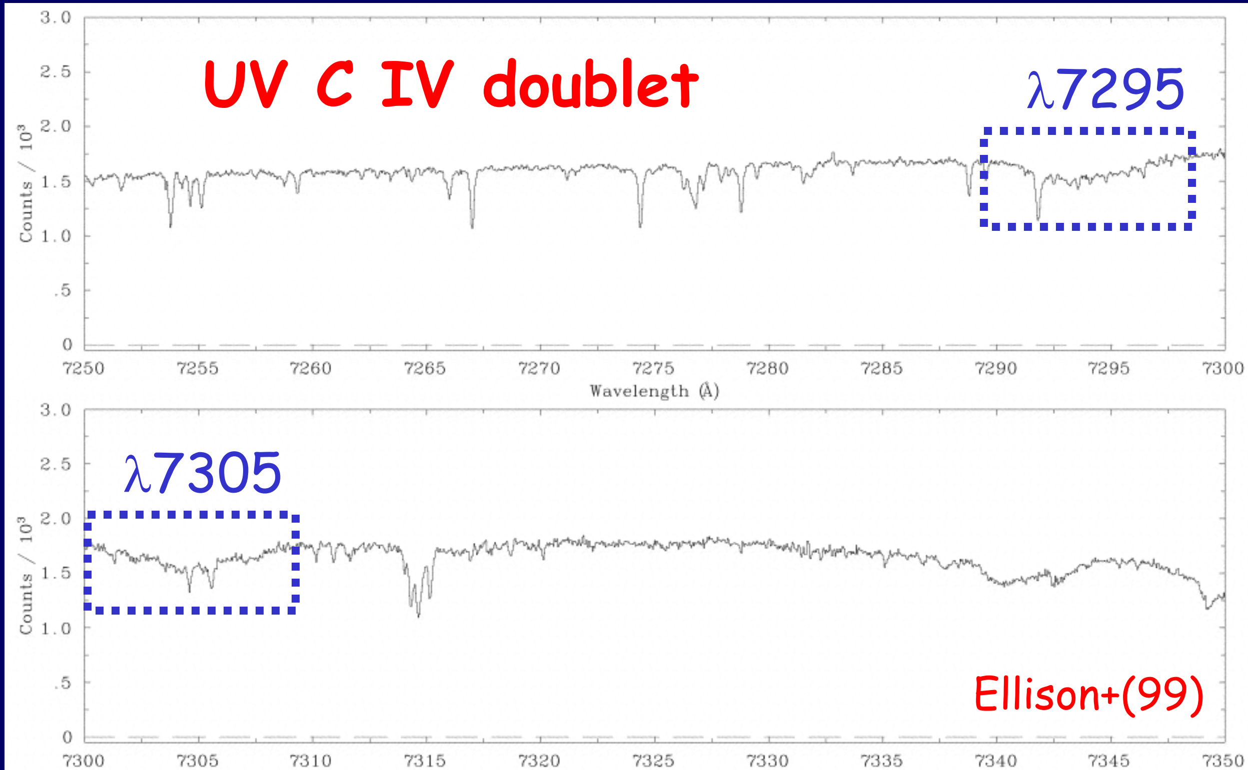


Behar(09)

Observational implication (i.e. almost "flat" AMD):

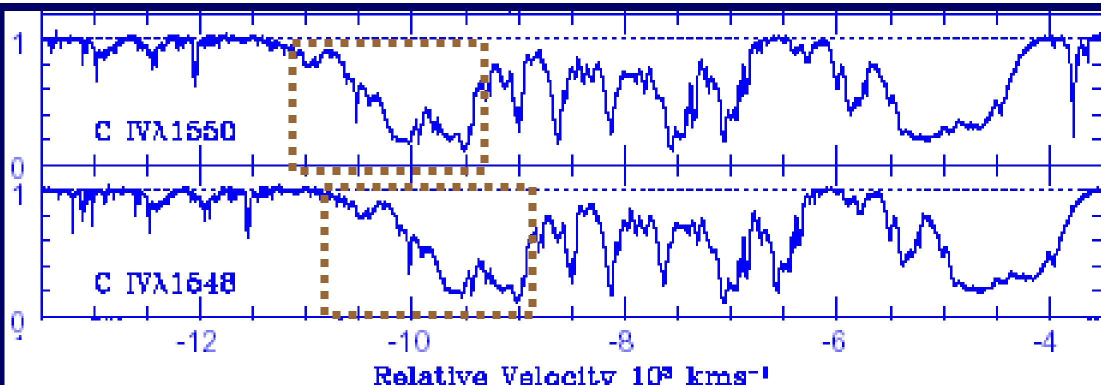
➔ presence of nearly equal N_H over 4-5 decades in ξ (p~0.04)

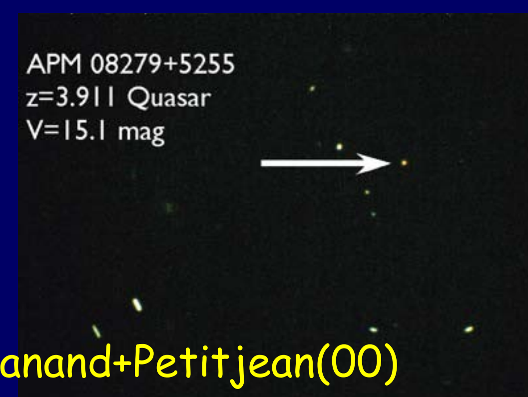
2d. Example – Broad Absorption Line (BAL) Quasars



APM 08279+5255:
(z = 3.91)

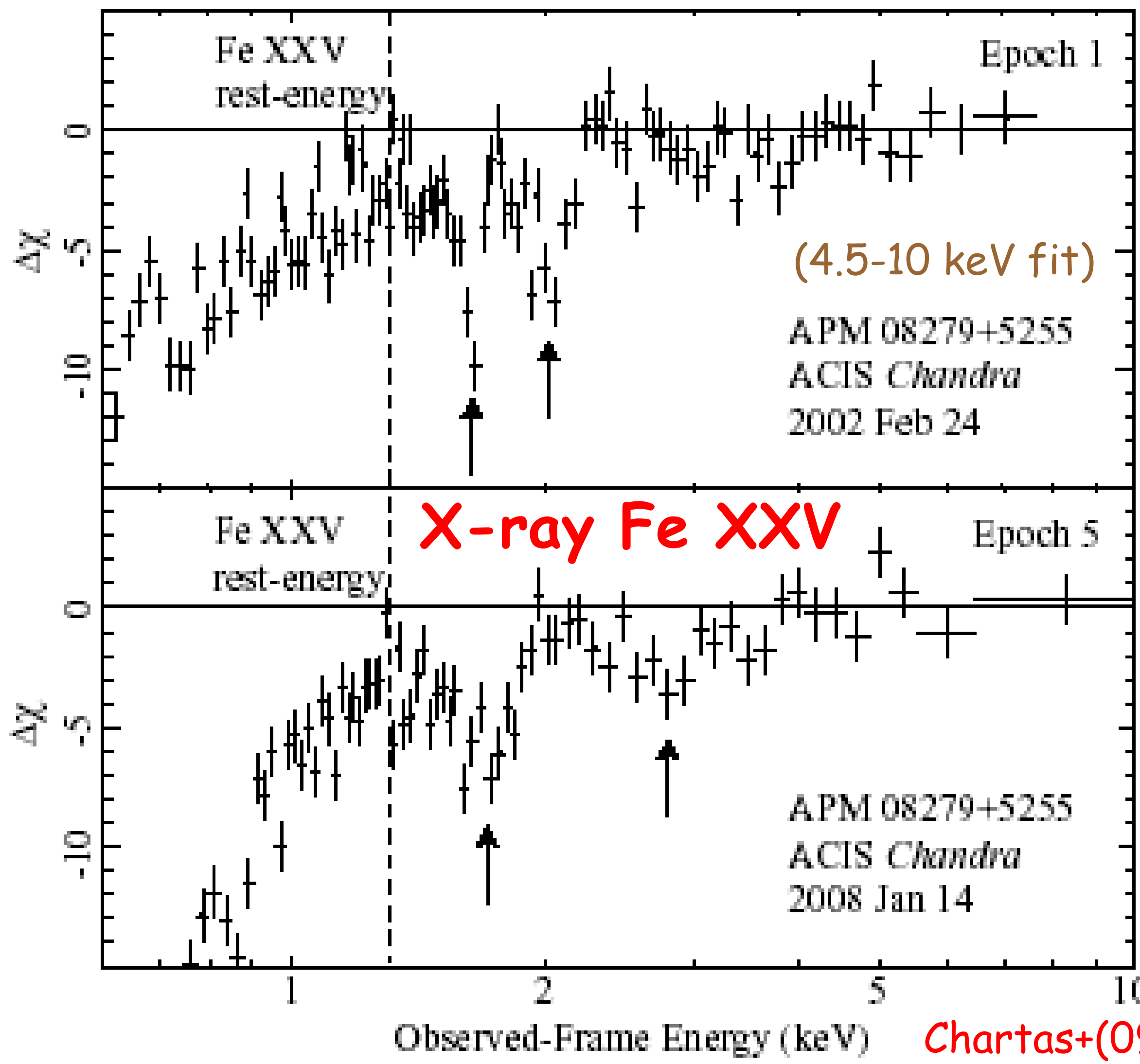
- Lensed QSO (x100)
- Infrared-loud, radio-quiet
- High-velocity outflows v/c~**0.04-0.1 in C IV** (UV: Keck/HIRES)





Srianand+Petitjean(00)

2d. Example - Broad Absorption Line (BAL) Quasars



Chartas+(09)

APM 08279+5255:
(z = 3.91)

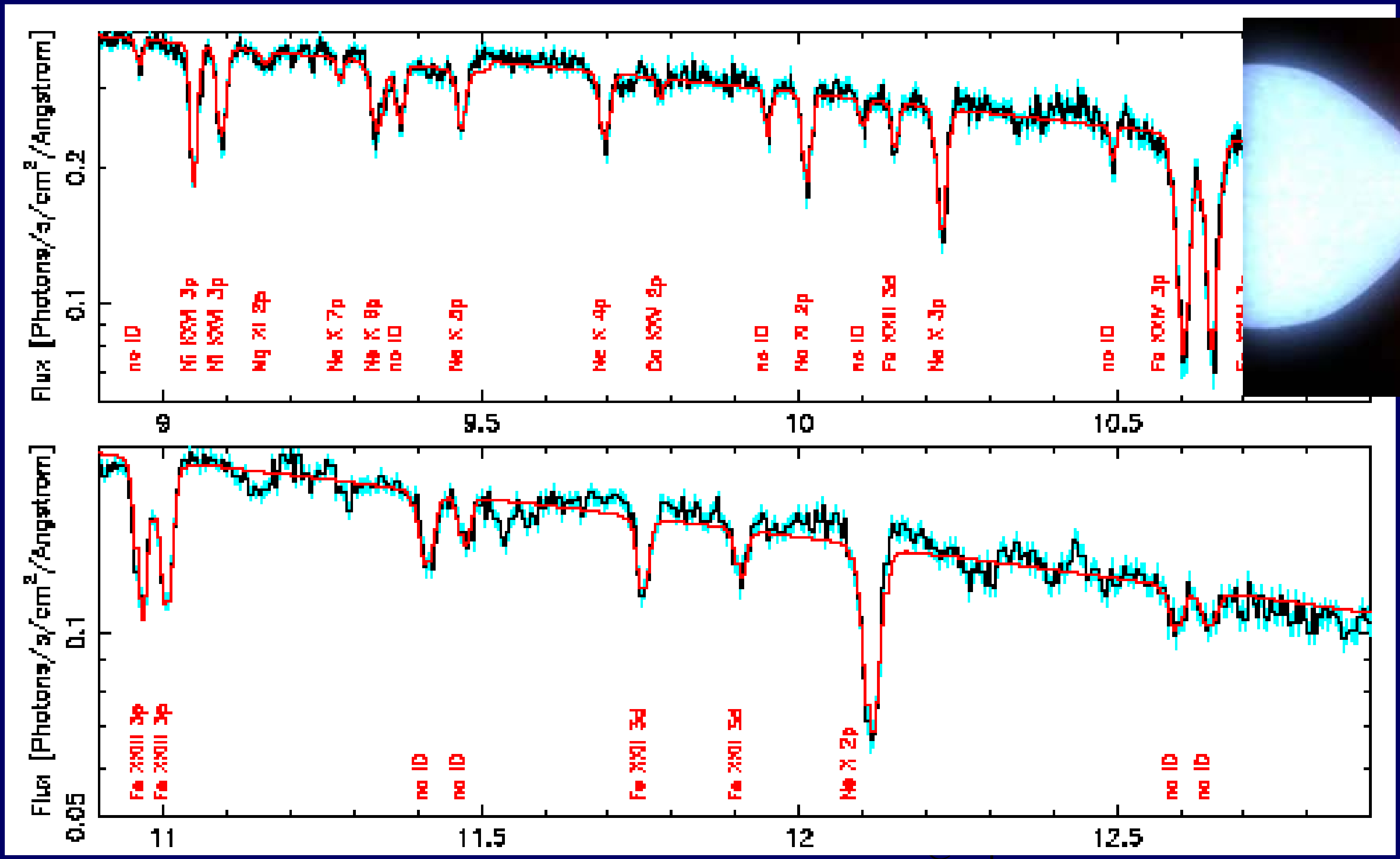
- Lensed QSO (x100)
- Infrared-loud, radio-quiet
- High-velocity outflows v/c~0.04-0.1 in C IV (UV: Keck/HIRES)
- Near-relativistic outflows **v/c~0.4-0.8 in Fe XXV** (X-ray: *Chandra/XMM/Suzaku*)

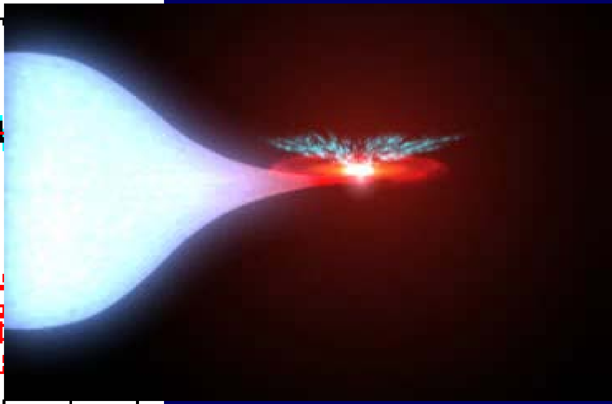
2d. Example – Galactic Black Hole (GBH) Binaries

GRO J1655-40:

- M(BH)~7Msun
- M(2^{nd})~2.3Msun

- High ionization: log(ξ[erg cm s^{-1}]) ~ 4.5 - 5.4
- Small radii: log (r[cm]) ~ 9.0 - 9.4
- High density: log(n[cm^{-3}]) ~ 14

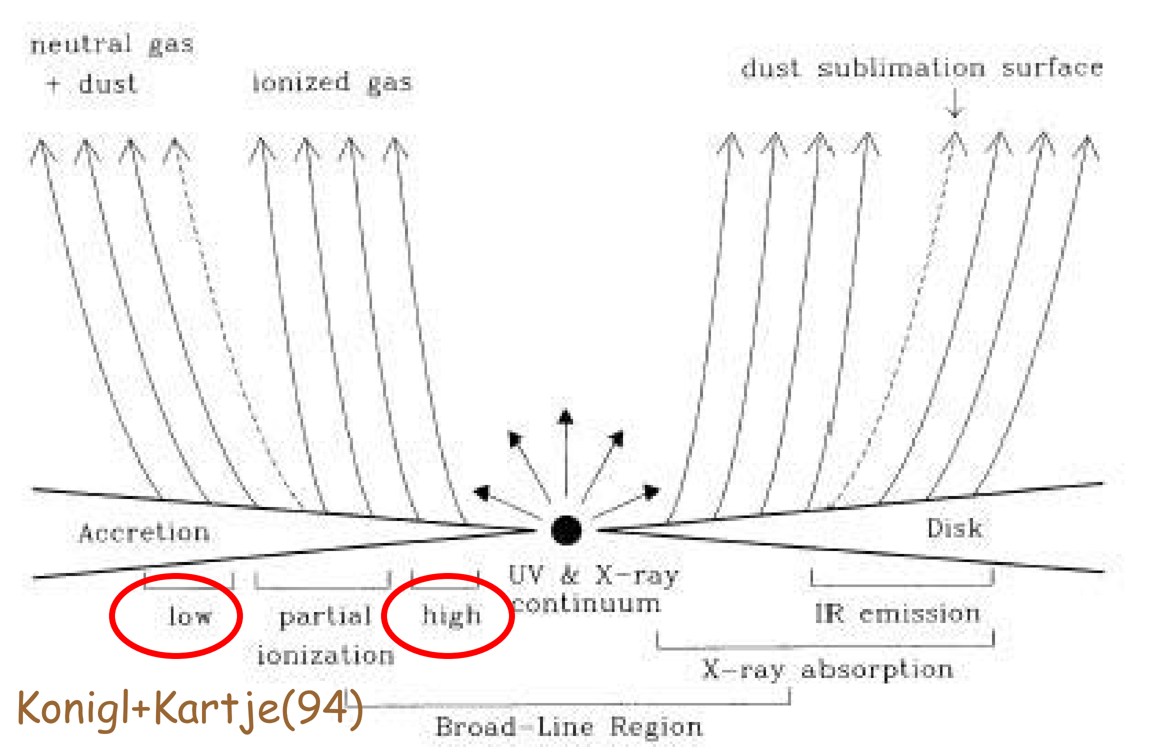




NASA/CXC/A.Hobart

Chandra Data
Miller+(08)

3. Previous Attempt with Disk-Wind



Previous work:

Blandford+Payne(82)
Konigl+Kartje(94)
Contopoulos(95)
Blandford+Begelman(99)
Proga+Kallman(04)
Everett(05)
Schurch+Done(07,08)
Sim+(08)
& more…

✓ Accretion disks (necessarily) produce outflows/winds (launched initially with Keplerian rotation)
✓ Large-scale poloidal B-fields accelerate plasma*
✓ Local X-rays heat up and photoionize plasma along the way

➔ *Need to simulate mutual interactions between ions & radiation*

*Acceleration Process(es)

1. **Compton-heated wind** (e.g. Begelman+83, Woods+96)
   " Central EUV/X-ray ➔ heating a disk ➔ thermal-wind"
   Issue ➔ *Too large radii…*

$$R_c \sim 10^{10}(M/M_{\odot})/T_{c8}\ \mathrm{cm}$$

2. **Radiatively-driven (line-driven) wind**
   (e.g. Proga+00, Proga+Kallman04)
   "UV radiation pressure ➔ accelerate plasma"
   Issue ➔ *Overionization @ smaller radii…*

3. **Magnetocentrifugally-driven wind**
   "Large-scale B-field ➔ accelerate plasma"
   Issue ➔ *Unknown field geometry…*

4a. Self-Similar Disk-Wind Solutions: (Contopoulos+Lovelace94)

✓ Self-similar prescription for radial-dependence of a field-line

$$\Psi(r,\theta) = (r/r_o)^q \psi(\theta) \Psi_o \ ,$$

"q" = radial scaling

✓ Steady-state, axisymmetric MHD solutions (2D): (Newtonian; P_{rad}=0):

$$\begin{aligned}
\nabla \cdot (\rho \mathbf{v}) &= 0 && \text{(mass conservation)} \ , \\
\nabla \times \mathbf{B} &= \frac{4\pi}{\mathbf{c}} \mathbf{J} && \text{(Ampere's law)} \ , \\
\mathbf{E} + \frac{\mathbf{v}}{\mathbf{c}} \times \mathbf{B} &= 0 && \text{(ideal MHD)} \ , \\
\nabla \times \mathbf{E} &= 0 && \text{(Faraday's law)} \ , \\
\rho(\mathbf{v} \cdot \nabla)\mathbf{v} &= -\nabla \mathbf{p} - \rho \nabla \Phi_{\mathbf{g}} + \frac{1}{\mathbf{c}}(\mathbf{J} \times \mathbf{B}) && \text{(momentum conservation)} \ ,
\end{aligned}$$

✓ 5 conserved quantities: *Energy, Ang.Mom., Flux, Ent., Rot.*

4b. Self-Similar Disk-Wind Solutions: (Contopoulos+Lovelace94)

Density

$$n(r,\theta) \equiv \frac{\rho(r,\theta)}{\mu m_p} = n_o x^{2q-3} \mathcal{N}(\theta)$$

$$n_o = \frac{\eta_W \dot{m}}{2\sigma_T r_S}$$

LoS column density

$$N_H(\Delta r, \theta) \equiv \int_{\Delta r} n(r,\theta) dr$$

x = r/rs

Ionization parameter

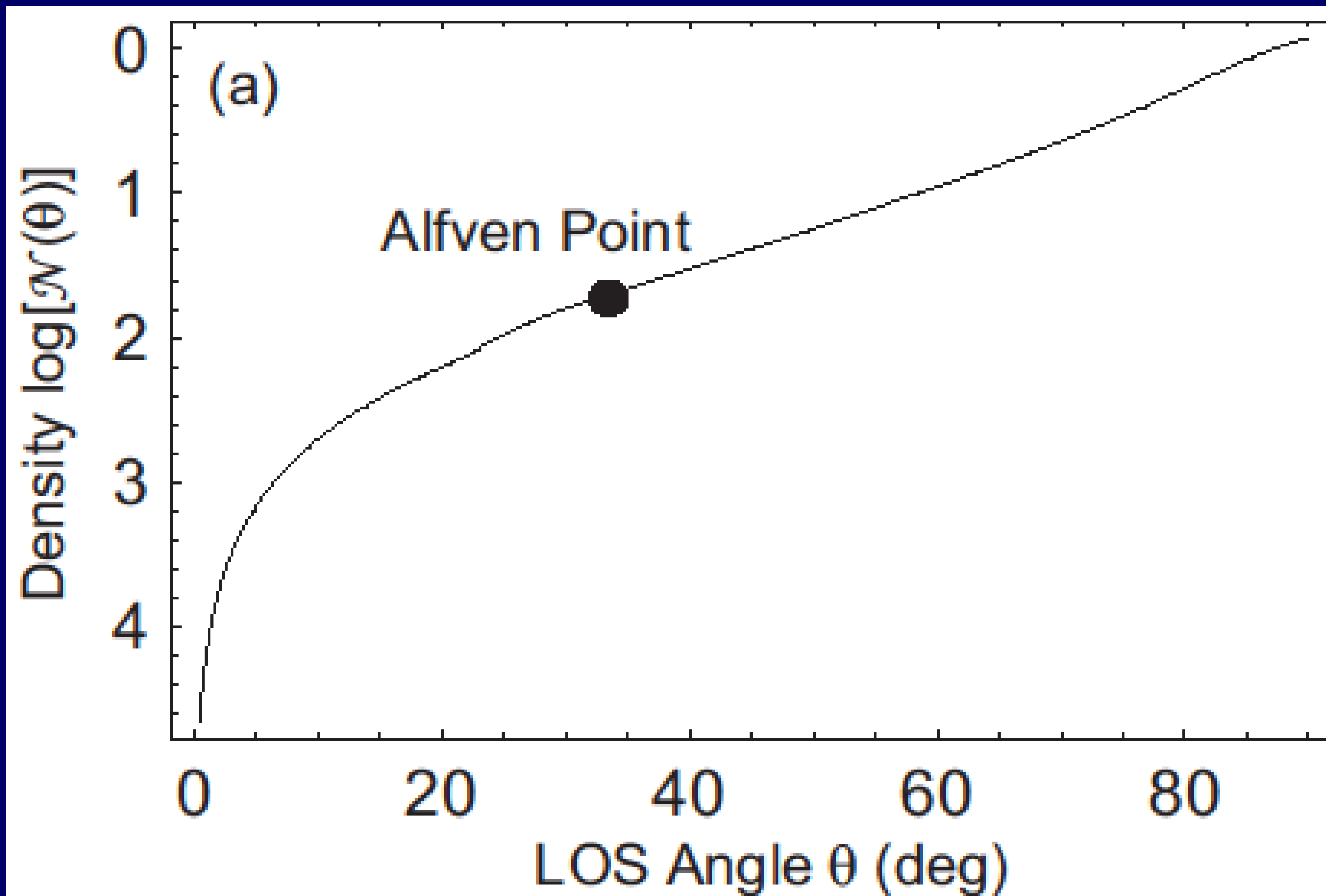
$$\xi(r,\theta) \equiv \frac{L}{n(r,\theta) r^2} \simeq \frac{\epsilon}{\mathcal{N}(\theta)\eta_W} \frac{3 \times 10^8 \dot{m}}{x^{2q-1}}$$

(c.f. Ueda+03; Tueller+08)

We seek "q=1" self-similar wind solution:

- ✓ B(r,q) ~ N(q)/r
- ✓ Wind density ~ 1/r (i.e. equal column per decade in radius)
- ✓ LoS velocity ~ $1/r^{1/2}$ (can be a good fraction of c at small radii)
- ✓ Ionization parameter ~ 1/r (ignoring local absorption)

Angular Density Distribution

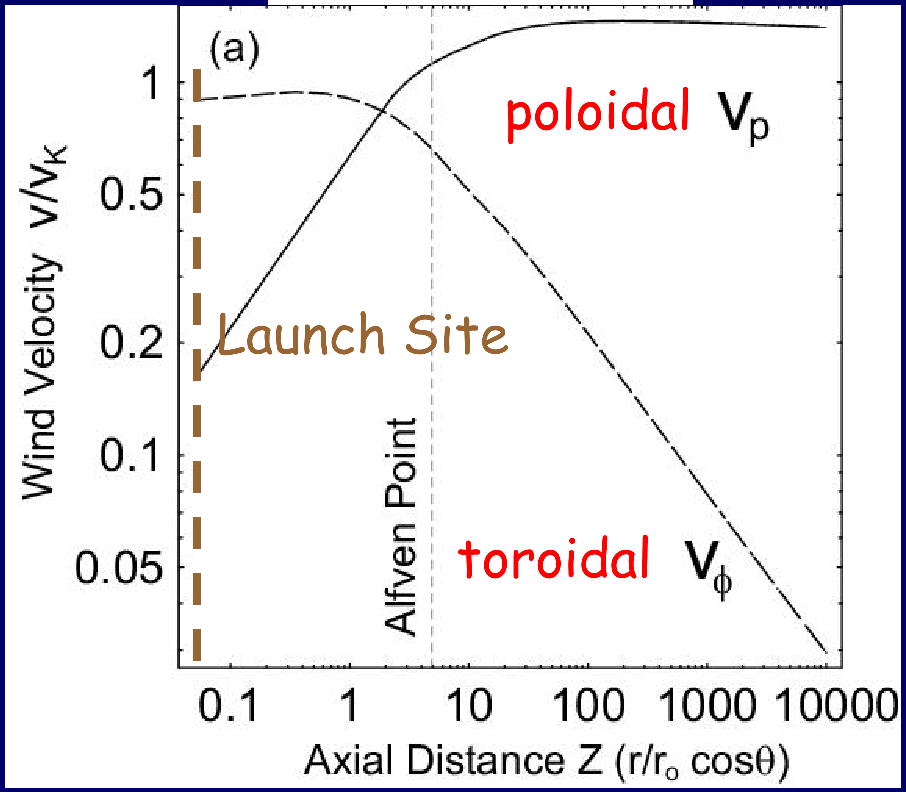


5. Simple Wind Solutions with q=1

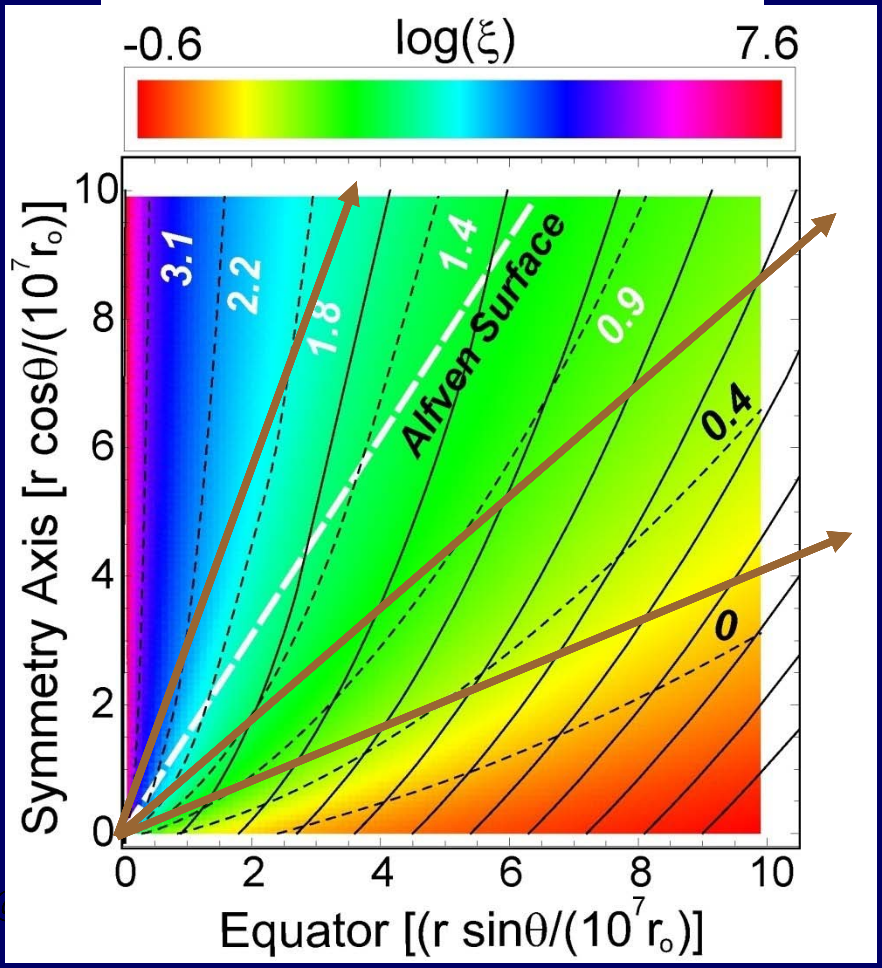
Assume:
M(BH) = 10^8 Msun, Γ ~ 2 (single power-law), mdot ~ 0.5,
rad. eff. ~ 10%, r(in) ~ Schwarzschild radius, n(in) ~ 10^{10} cm^{-3}

Fukumura+(09)

Velocity Field

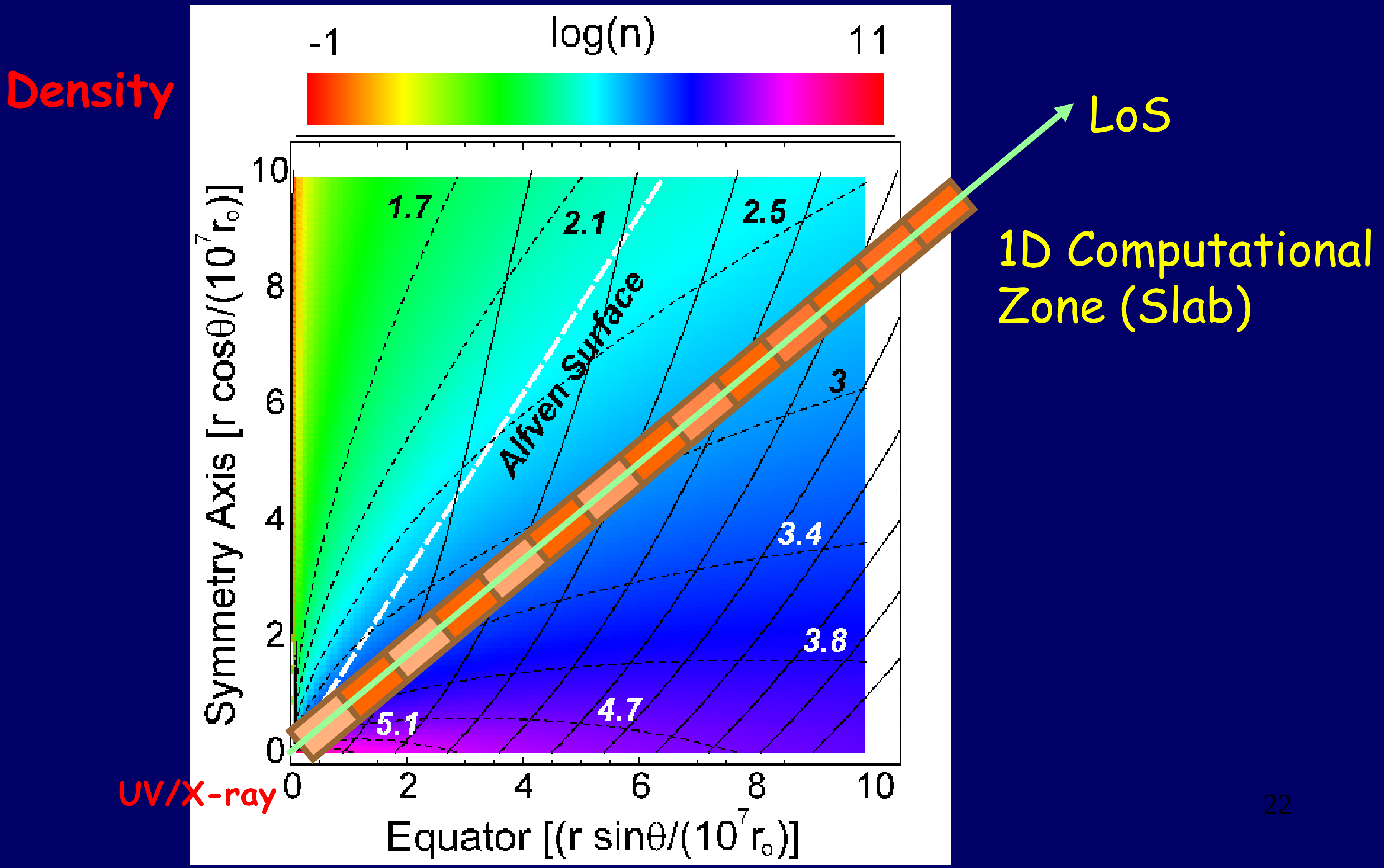


Ionization Parameter

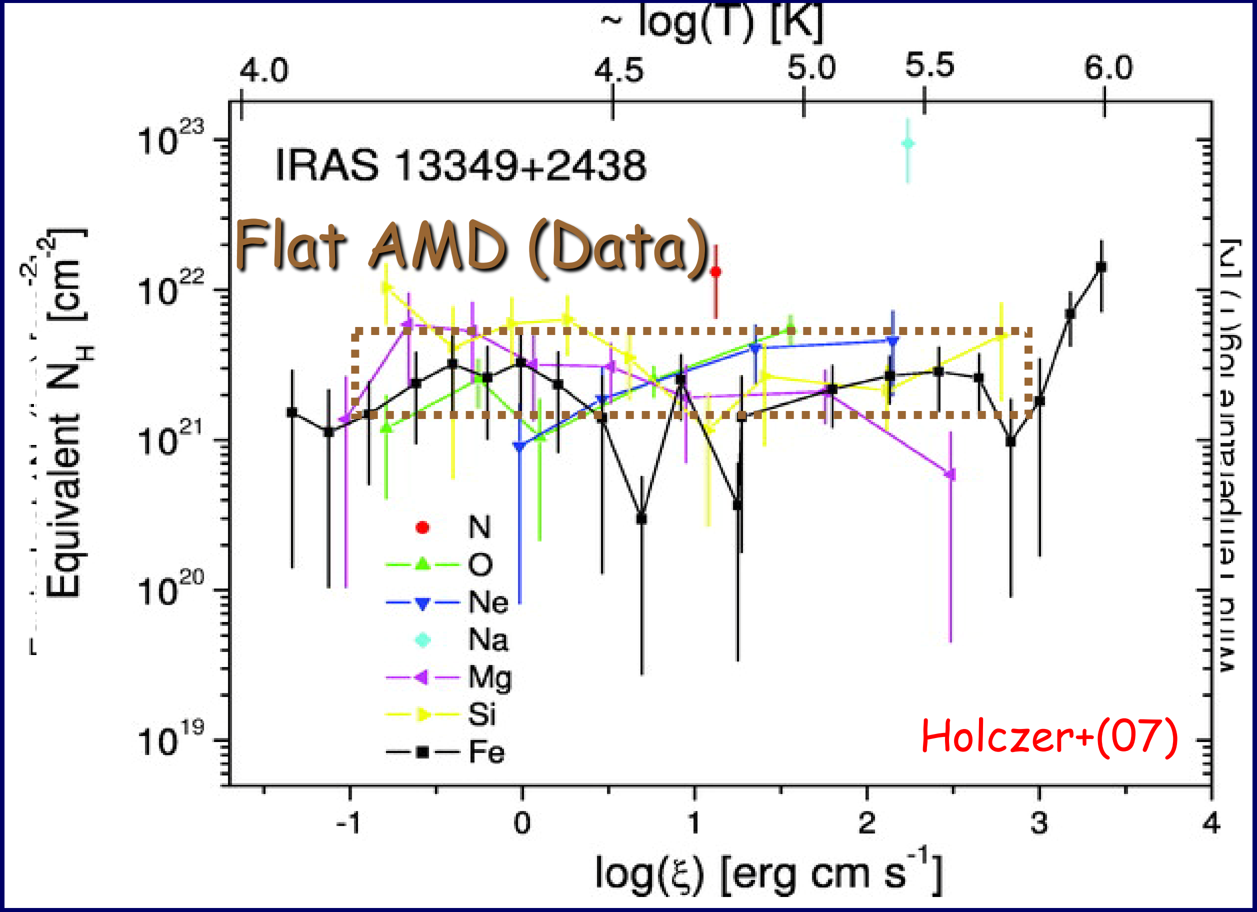


6. Radiation Transfer (1D)

Computations of radiative transfer (1D) with photoionization code XSTAR (assuming local thermal equilibrium): (e.g. Kallman+Bautista01)



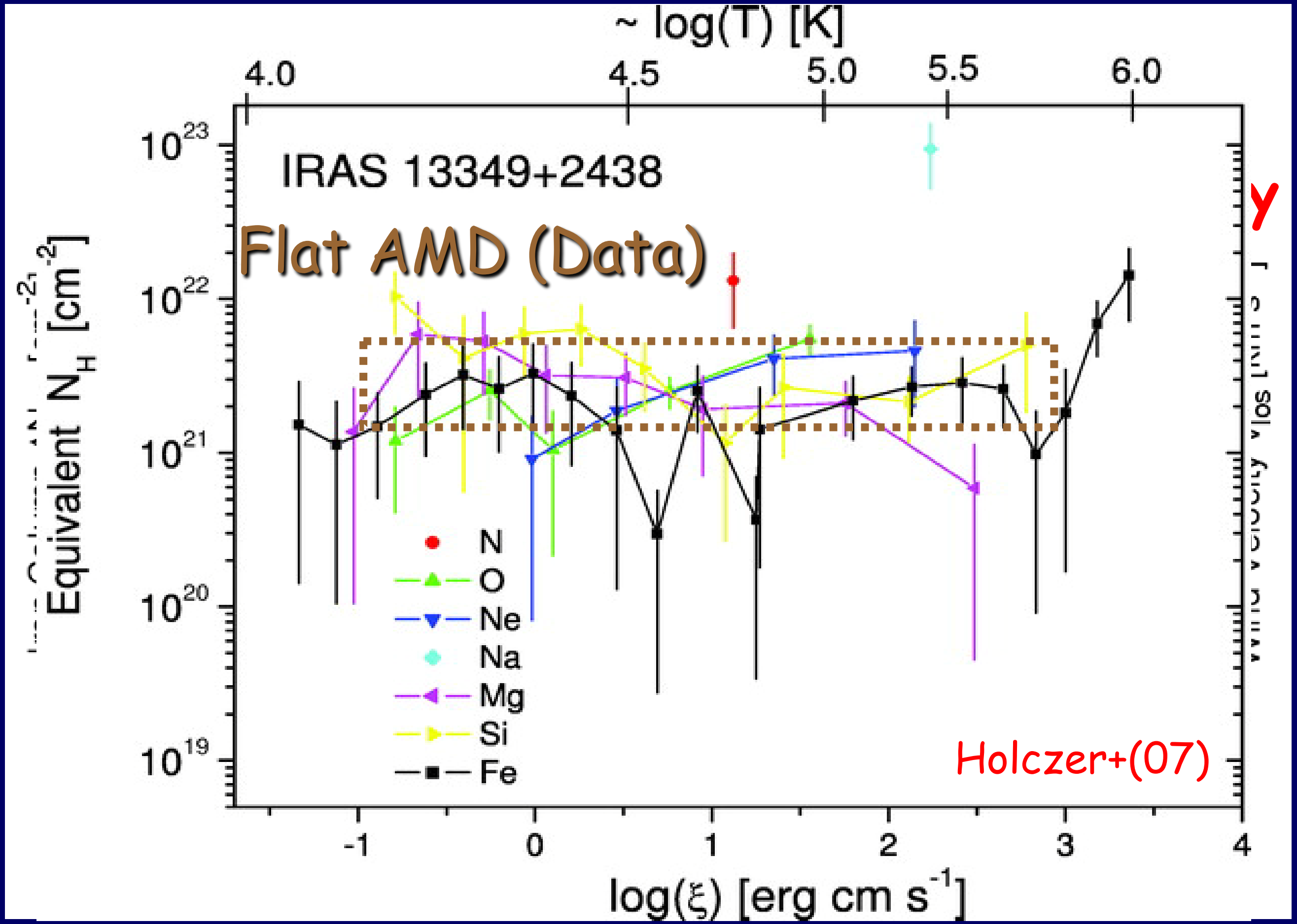
7. Modeled AMD with q=1



✓ Local N_H being constant over a wide range of ξ (e.g. IRAS 13349)

(Note: BP82 model: q=3/4 ➔ AMD ~ ξ ➔ ruled out)

8. Modeled AMD (Fe) with q=1



Fe XVII:
~100-300 km/sec
@ low ionization

Fe XXV:
~1,000-3,000 km/sec
@ high ionization

➔ Agree w/ data

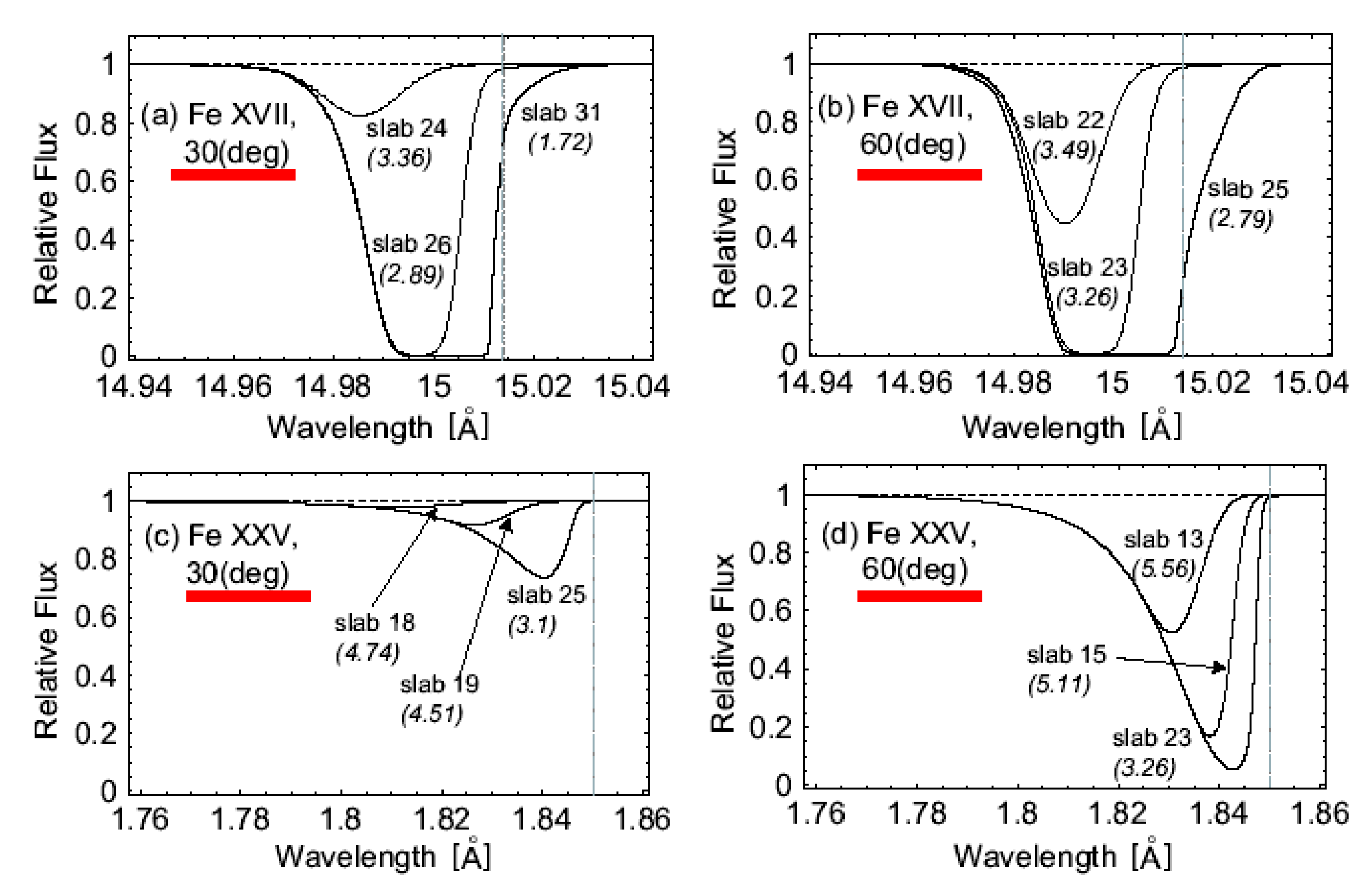
✓ Correspondence among wind velocity, column, & charge state

9. Modeling of Absorption Spectra

Column + (LoS) velocity + cross-section
→ modeling progressive absorption lines

Wind optical depth $\tau(\nu) = \sigma(\nu) N_H(\nu)$

Line photoabsorption cross-section $\sigma = 0.01495 (f_{ij}/\Delta\nu_D) H(a,u)$



f_{ij} = oscillator strength

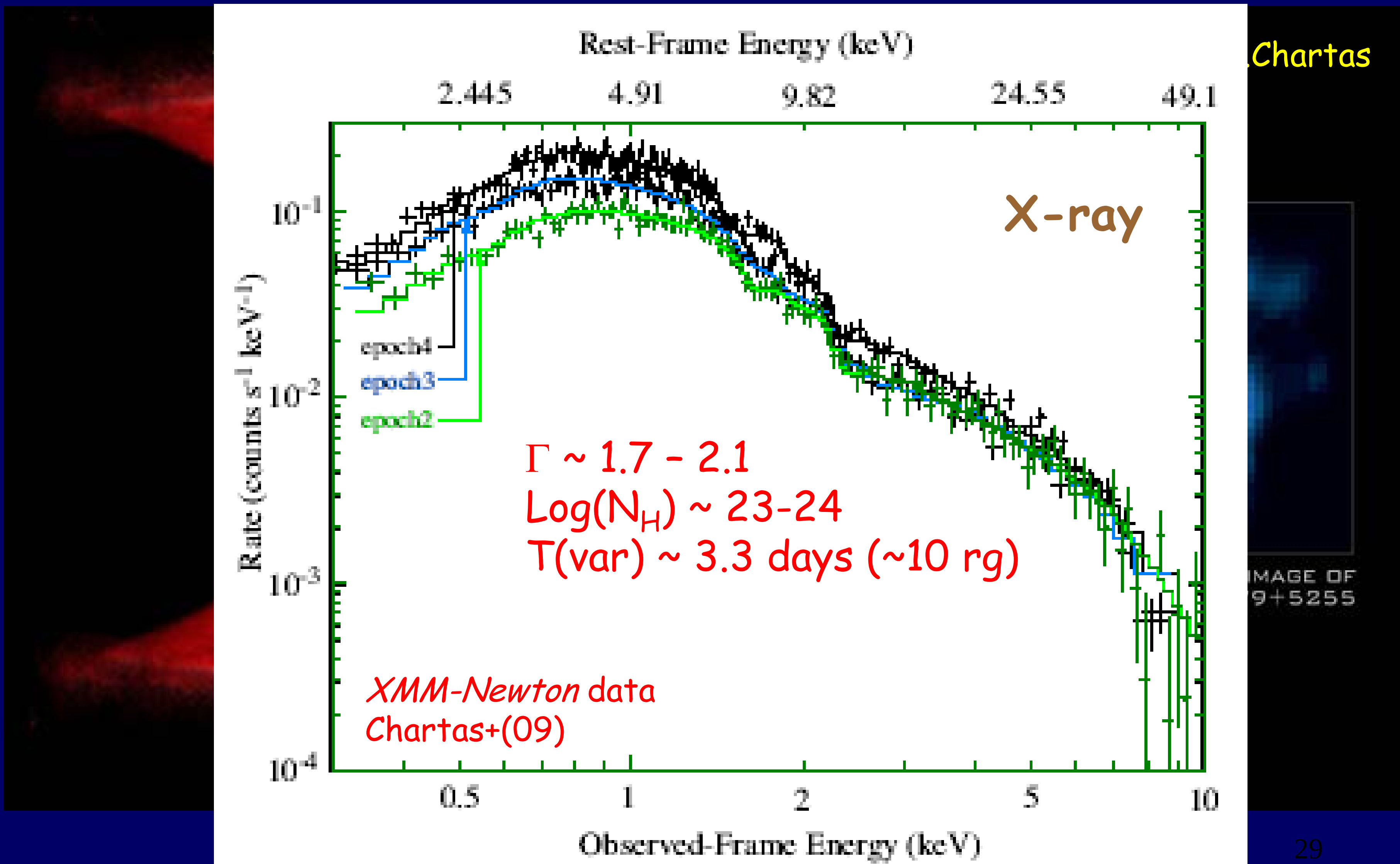
$\Delta\nu_D$ = broadening factor

H(a,u) = Voigt function

(Mihalas78)

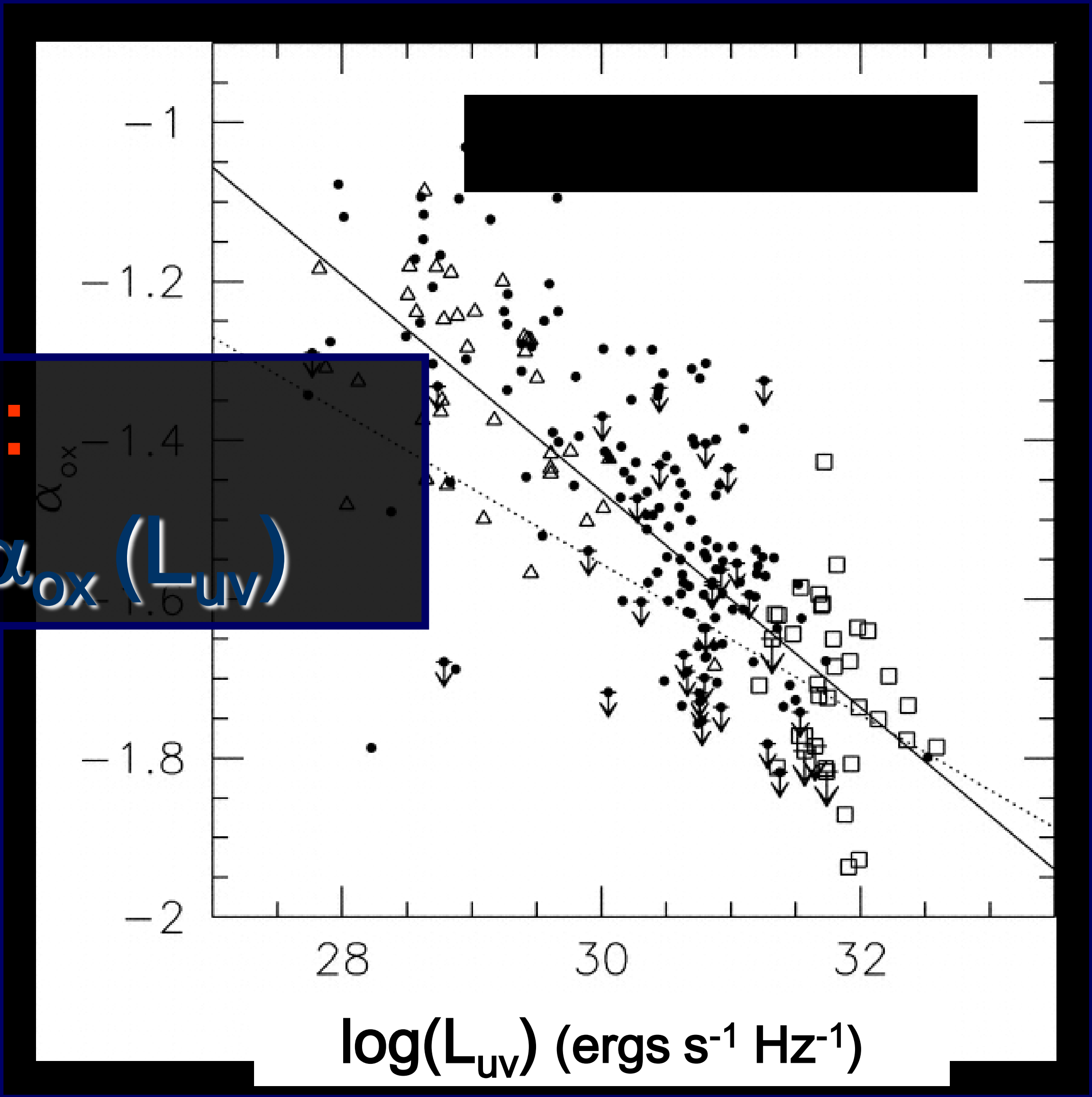
13. Example - APM 08279+5255 (lensed quasar)

z = 3.91



UV Luminosity vs. α_{ox}

brighter in X-rays



Define:

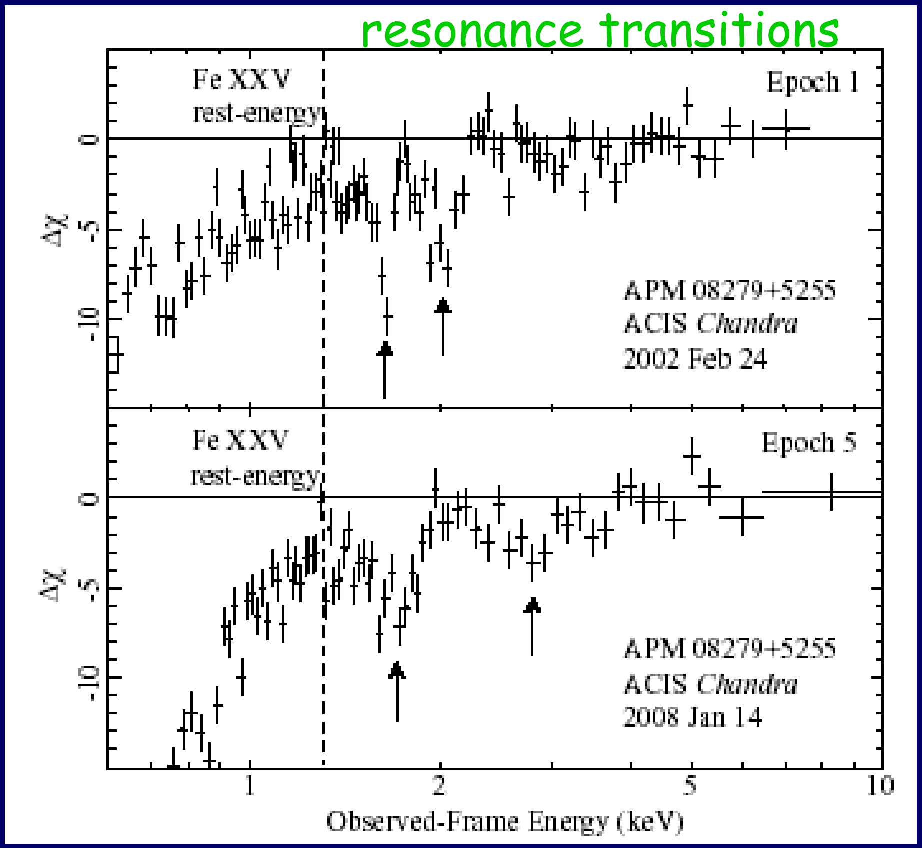
$$\Delta\alpha_{ox} = \alpha_{ox} - \alpha_{ox}(L_{uv})$$

fainter in X-rays

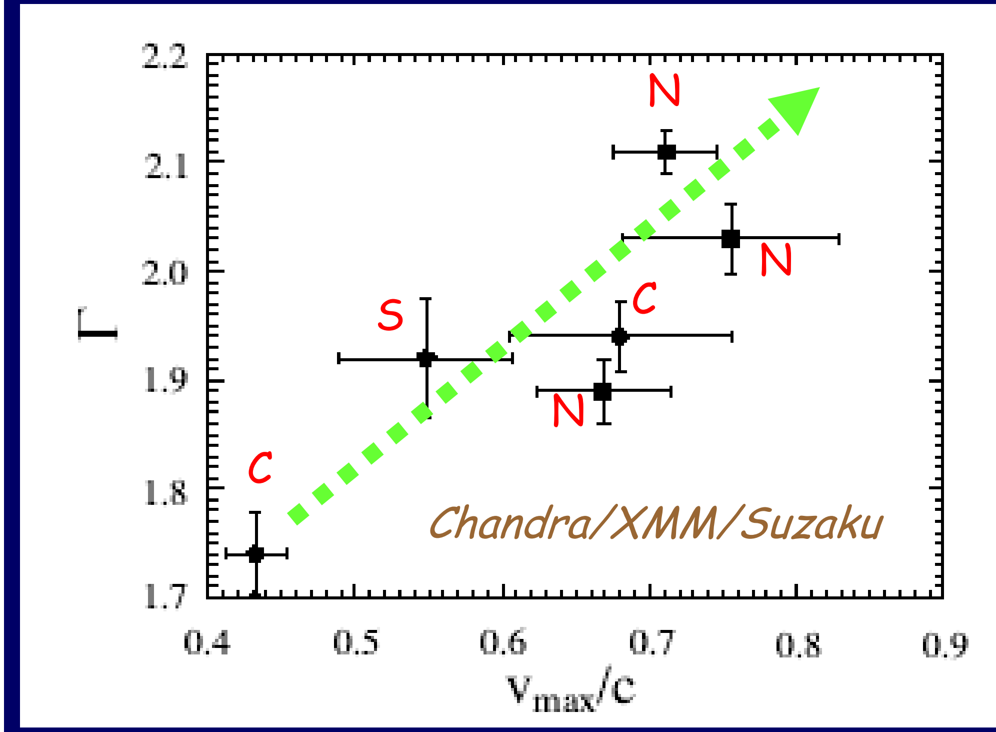
228 SDSS Quasars with ROSAT (Strateva et al. 2005)

14. Example - APM 08279+5255 (Near-relativistic outflows)

X-ray Absorption line (Fe XXV)



spectral index vs. wind velocity

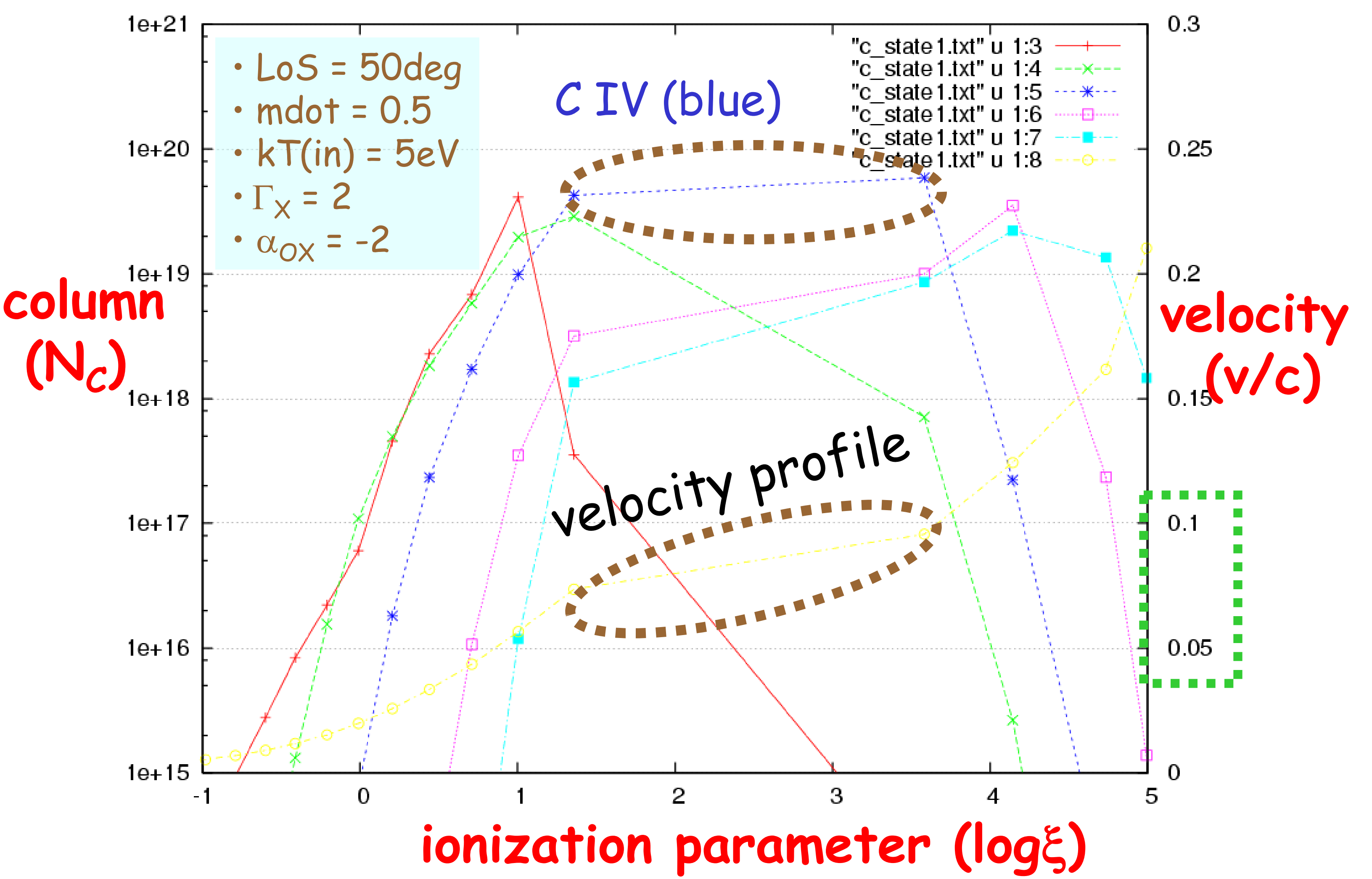


Effect of ionizing spectrum(!?)

Chartas+(09)

15. Modeling UV BALs (C IV) - Preliminary

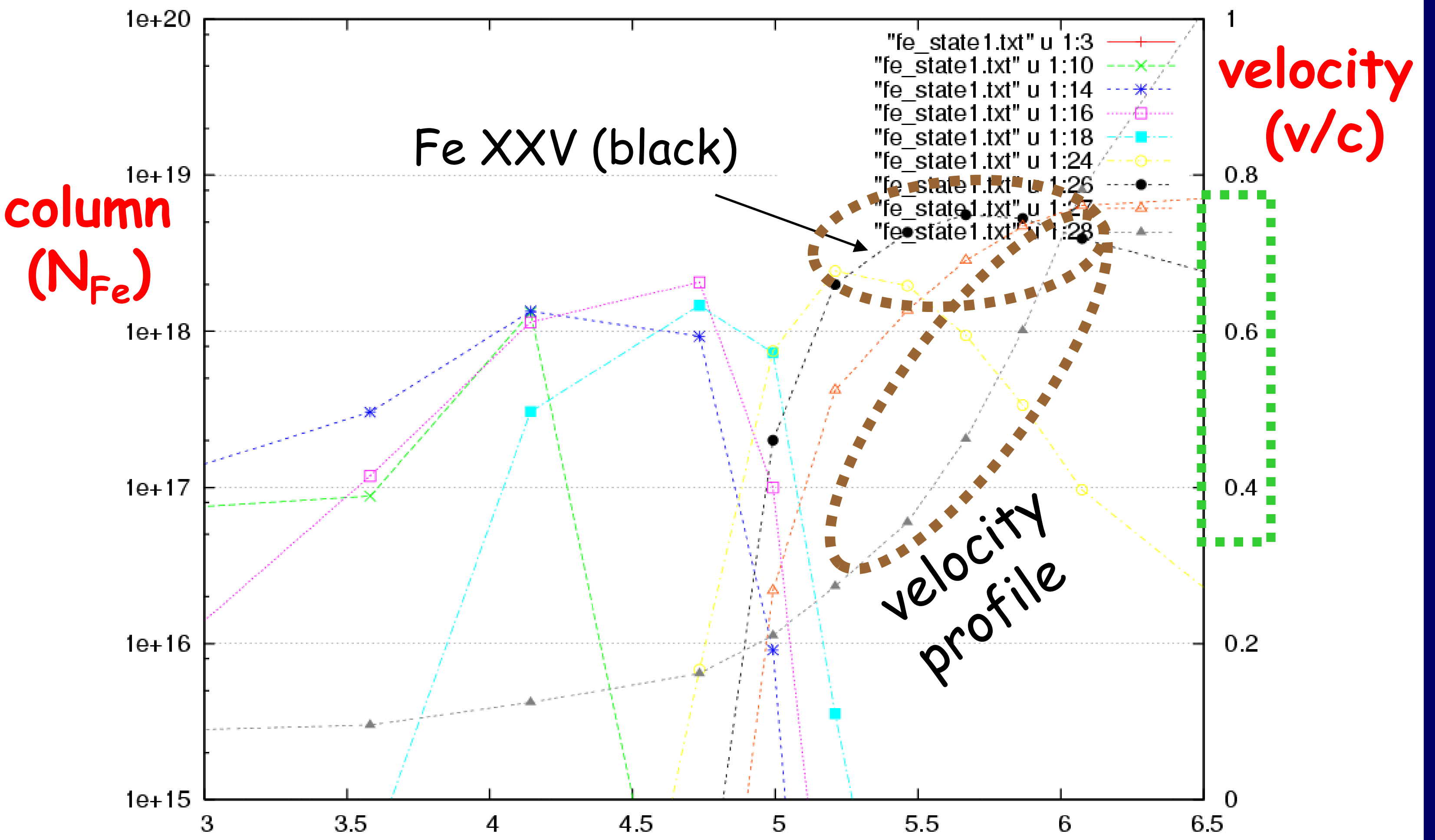
Our model can achieve v/c(C IV) ~ 0.05-0.1



Constraint for, e.g., SED, q, LOS...etc.

16. Modeling X-ray BALs (Fe XXV) - Preliminary

Our model can achieve v/c(Fe XXV) ~ 0.4-0.8



Constraint for, e.g., SED, q, LOS...etc.

Summary

We propose a simple-minded MHD (self-similar) disk-wind model:

✓ Key ingredients ➔ **mdot** (column)
LOS angle (velocity)
F_ν (SED; Γ, α_{OX}, MCD…etc.)
q (field geometry)

This model can (in part) explain/reproduce some interesting observables:

✓ Observed AMD (i.e. local column distribution N_H as a function of ξ)
✓ Observed wind kinematics and outflow geometry:
Seyferts ➔ ~100-300 km/s (Fe XVII); ~1,000-3,000 km/s (Fe XXV)
BAL QSO ➔ ~ 0.04-0.1c (UV C IV); ~ 0.4-0.8c (X-ray Fe XXV)

➔ These wind configurations, viewed globally, incorporate all the requisite properties of the parsec scale "torii" invoked in AGN unification schemes.

Issues (Future Work)

Wind Solutions (Plasma Field):

- ✓ (Special) Relativistic wind
- ✓ Radiative pressure (e.g. Proga+00, Everett03, Proga+Kallman04)

Radiation (Photon Field):

- ✓ Realistic SED (particularly for BAL quasars)
- ✓ Different LoS between UV and X-ray (i.e. $R_{UV} > R_X$ by x10…)
- ✓ Including scattering/reflection (need 2D radiative transfer)

(Ultimate) Goals:

✓ Comprehensive understanding of ionized absorbers within a single framework (i.e. disk-wind)

➔ AGNs/Seyferts/BAL/non-BAL QSO with high-velocity outflows (e.g. PG 1115+080, H 1413+117, PDS 456 and more…)

➔ Energy budget between radiation and kinetic energy…

Review on Absorption Features:

- Crenshaw, Kraemer & George 2003, ARAA, 41, 117 (Seyferts)
- Brandt et al. 2009, arXiv:0909.0958 (Bright Quasars)

<u>END</u>