A Global View: AGN Ionized Winds

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Illustration: Wind from Accretion Disk Around a Black Hole

Ubiquitous presence of outflows!

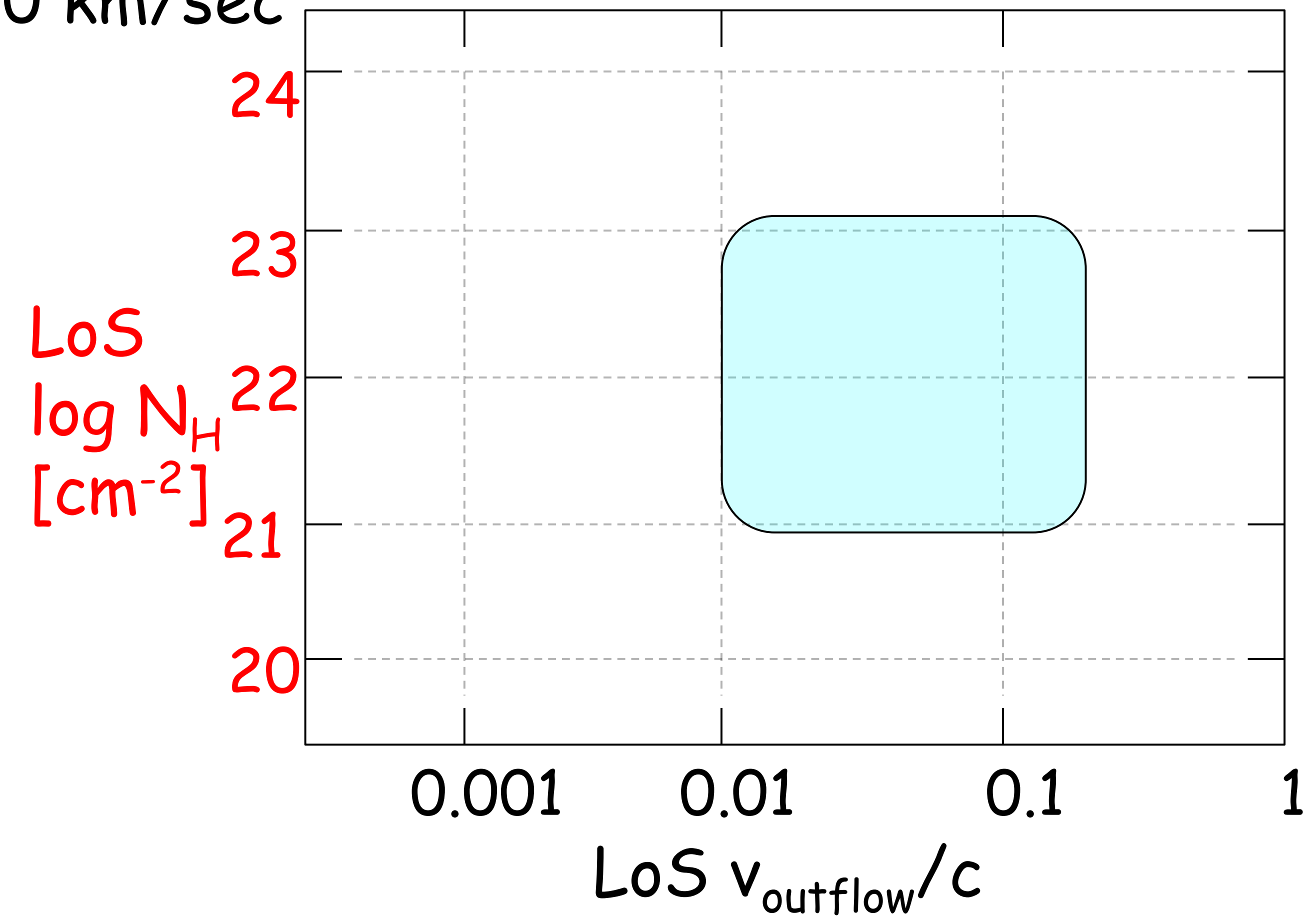
i.e. Absorption features in Seyfert/QSOs/Binaries

➔ Observational evidence of "irradiated plasma" along line-of-sight (LoS)

➔ Useful to probe:
column density, *ionization state*, *LoS velocity* and *demographic/geometrical properties*

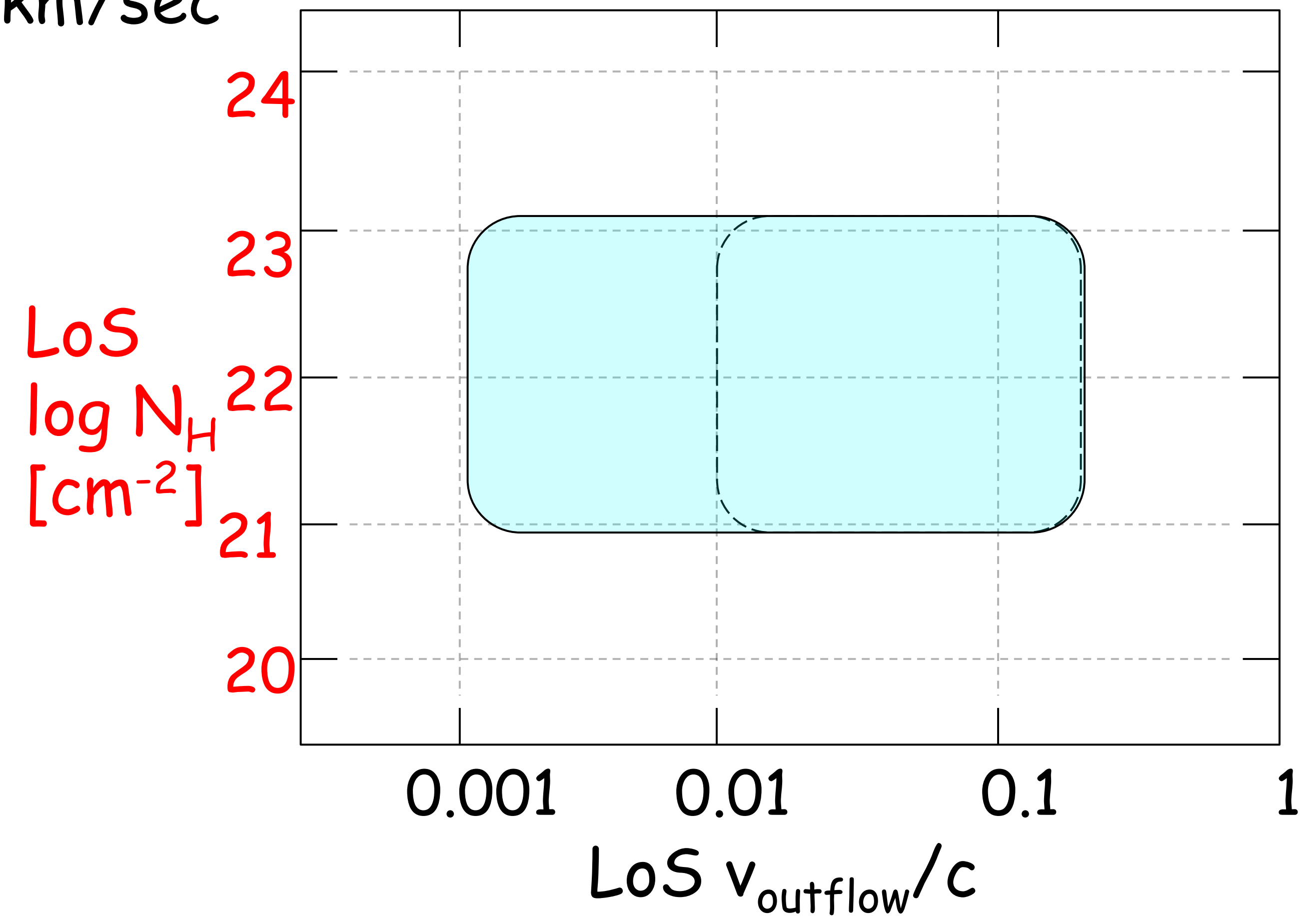
UV BALs (e.g. C IV): X-ray-faint QSOs

- 10-20% of optically-selected QSOs
- log $\xi \sim 0$
- FWHM > 2,000 km/sec



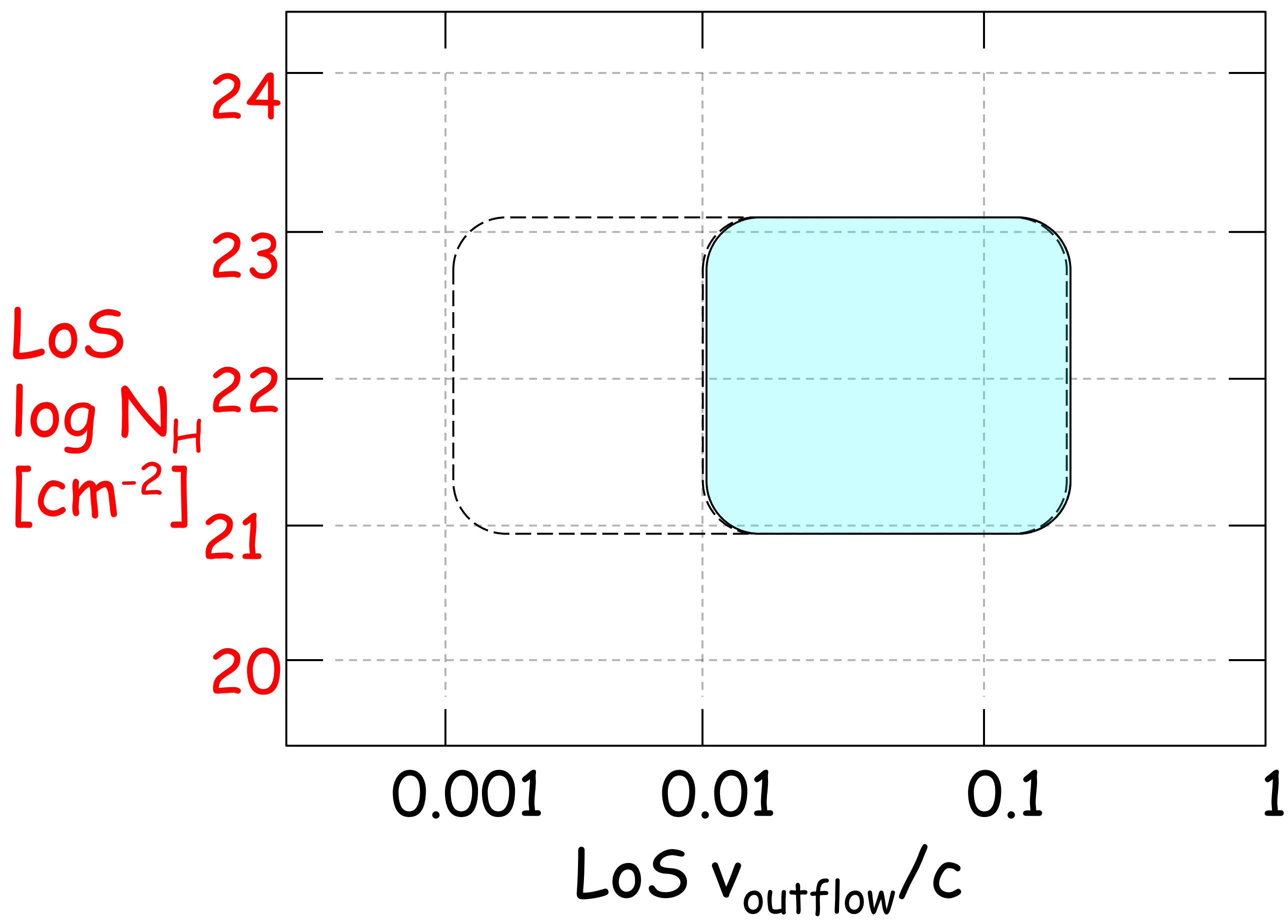
UV NALs (e.g. C IV): X-ray-faint QSOs

- < 50% intrinsic feature
- log $\xi \sim 0$
- FWHM < 500 km/sec



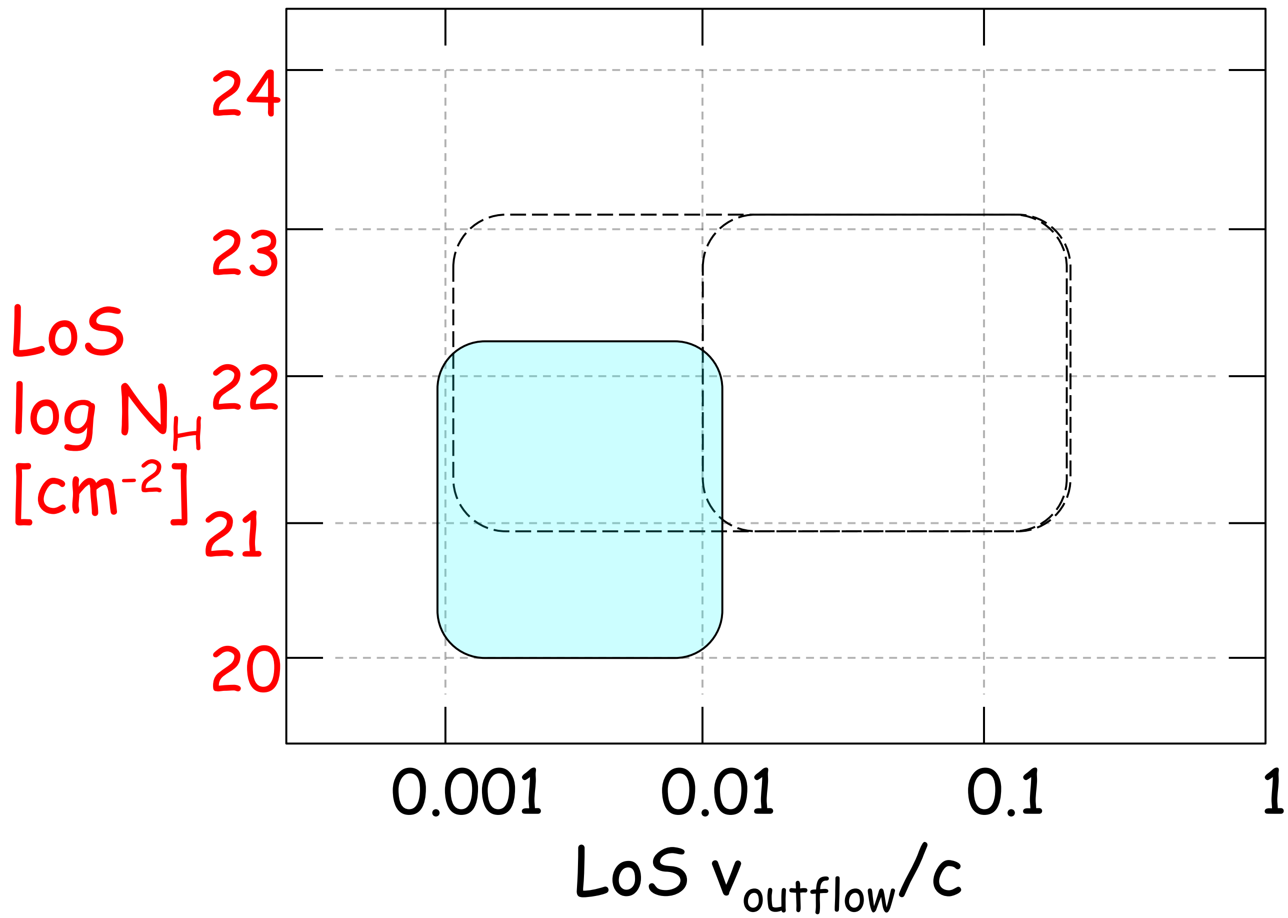
UV mini-BALs (e.g. C IV): X-ray-faint QSOs

- < 50% intrinsic feature
- 500 km/sec < FWHM < 2,000 km/sec
- log $\xi \sim 0$



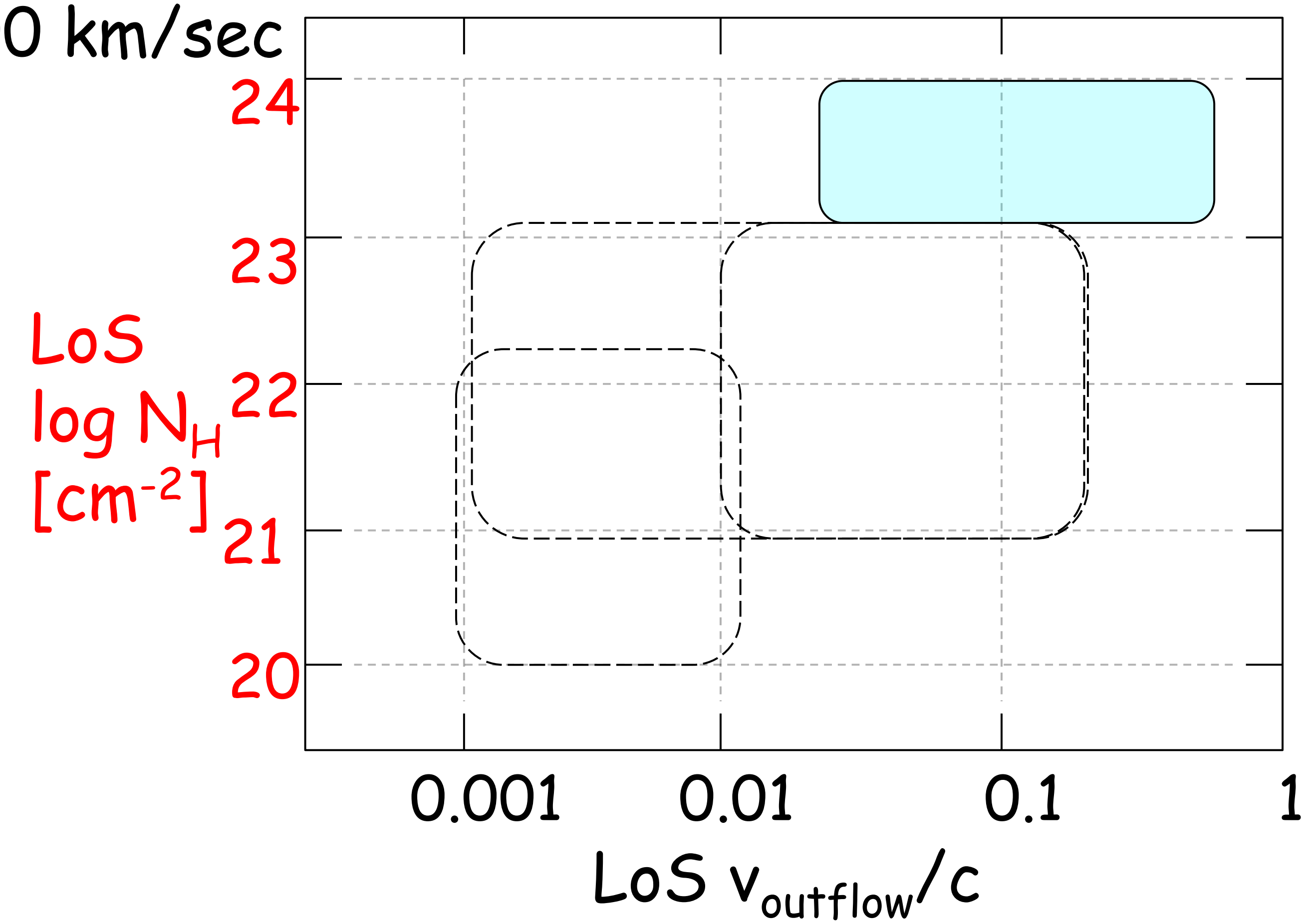
X-ray wimpy-outflow (warm absorbers):

- X-ray-bright AGNs (Seyferts + QSOs)
- ~ 50% of X-ray-bright Seyferts
- 300 km/sec < FWHM < 2,000 km/sec
- log ξ ~ -1 to 4



X-ray massive fast-outflows: (highly-ionized ions)

- Soft-X-ray-bright Seyfert AGNs (e.g. PG QSOs)
- X-ray-faint BAL QSOs
- FWHM > 5,000 km/sec
- log ξ ~ 3-5

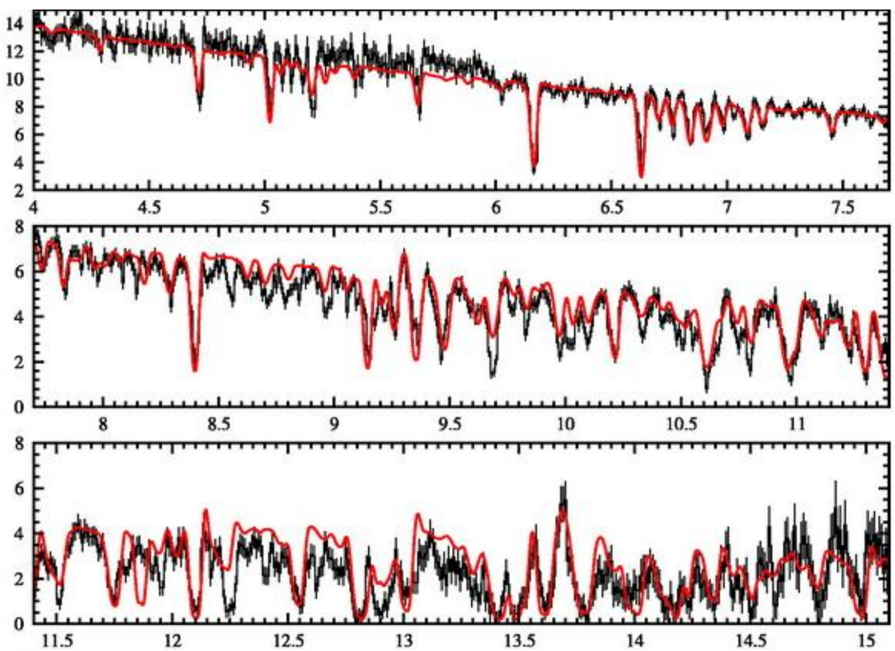


Outstanding Questions:

- Properties?
- Spatial location?
- Geometry?
- Physical origin?

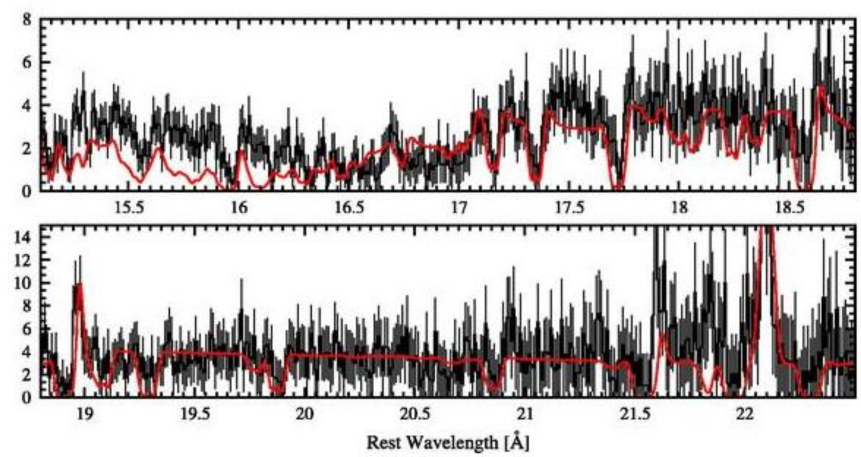
Data seems to point to…

- UV & X-ray absorbers related (in v & ξ space)
- Possibly related to X-ray-weakness (SED)
- Spatial N_H distribution not (completely) random

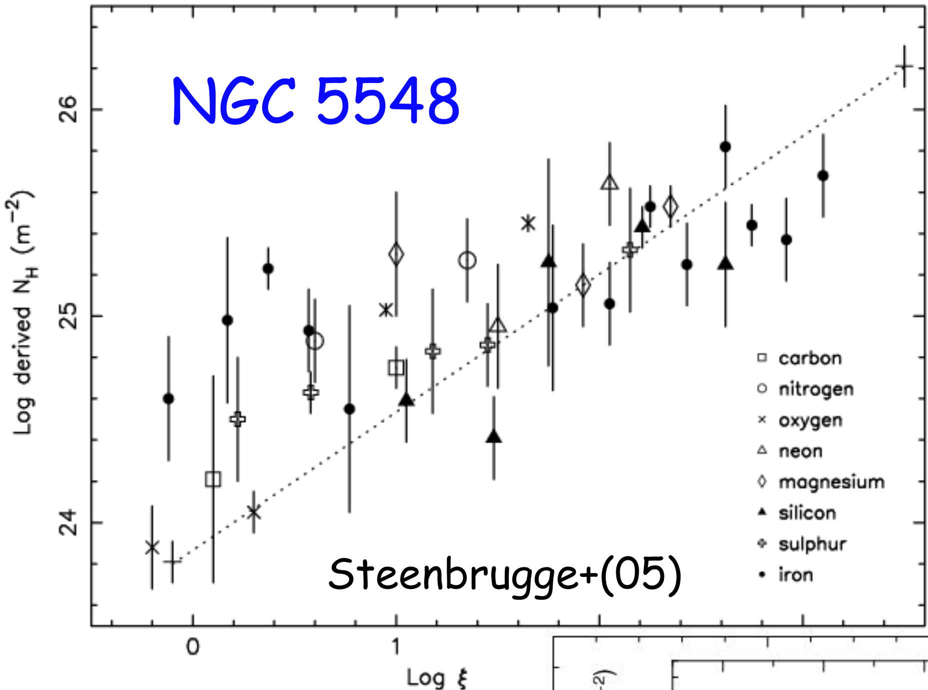


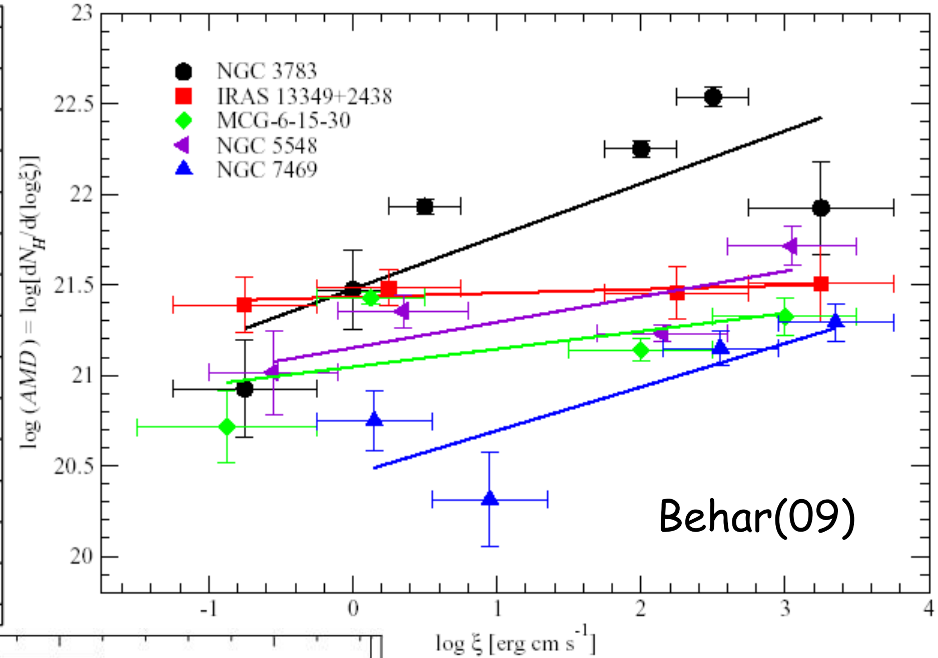
Chandra spectrum of NGC 3783

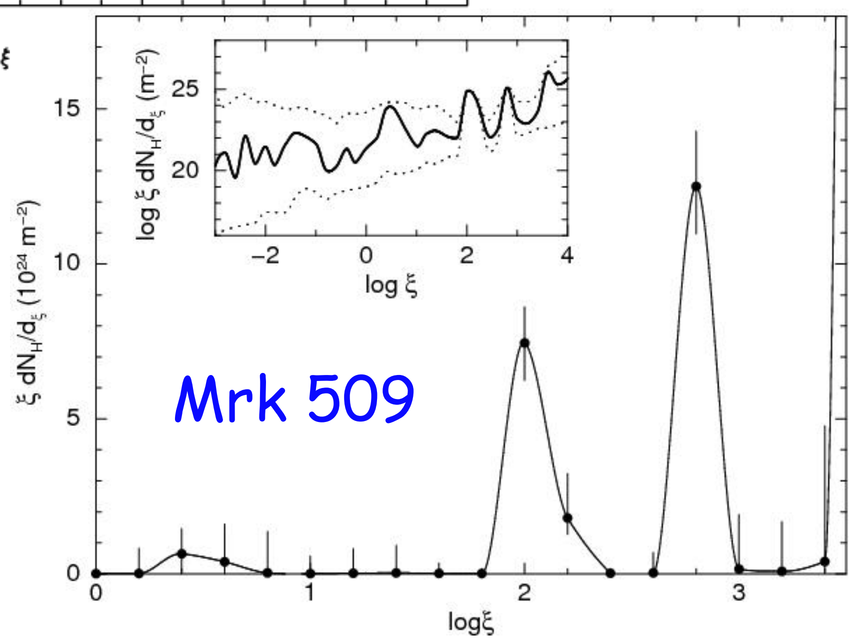
Netzer+(03)



Absorption measure distribution (AMD)







Detmers+(11)

AMD ~ constant…so what?

$$\xi \equiv \frac{L}{nr^2} = \frac{L\Delta r}{r^2 N_H} \Rightarrow N_H = \frac{\Delta(\log \xi)}{\Delta \xi}\frac{\Delta r}{r^2}L,$$

$$AMD \equiv \frac{N_H}{\Delta(\log \xi)} = \frac{\Delta(1/r)}{\Delta \xi}L,$$

$$\therefore \frac{\Delta(1/r)}{\Delta \xi} \approx const. \Rightarrow \xi \propto \frac{1}{r} \Rightarrow n \propto \frac{1}{r}$$

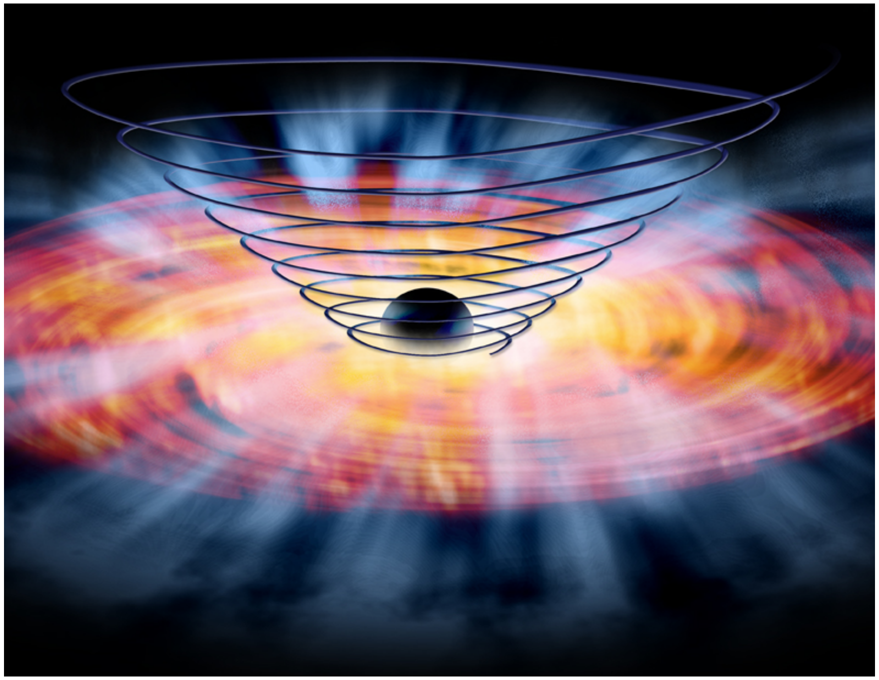
Not n ~ $1/r^2$!

Then $\dot{M} \approx nr^2 v \approx r^{-1} r^2 r^{-1/2} \approx r^{1/2}$

Therefore, the flow is two-dimensional…
(e.g. Blandford+Payne82, Contopoulos+Lovelace94, Konigl+Kartje94…etc.)

$$\dot{M} \propto r^{1/2}, \dot{E}_k = \dot{M} v^2 \propto r^{-1/2}, \dot{P} = \dot{M} v = const.$$

Attempt with Disk-Wind



Previous work:
(incomplete list)

Blandford+Payne(82)
Konigl+Kartje(94)
Contopoulos(95)
Murray+(95;98)
Blandford+Begelman(99)
Proga+Kallman(04)
Everett(05)
Schurch+Done(07,08)
Sim+(08;10)
& more...

- Accretion disks necessarily produce outflows/winds
- Driven by "some" acceleration process(es)
- Local X-rays heat up and photoionize plasma along the way

Matter (gas) + *photon* (SED) fields will tell us its coupling
➔ Absorption features

Disk-Wind Solutions with n ~ 1/r

(Contopoulos+Lovelace94)

- Self-similar prescription for radial-profiles

  Magnetic flux: $\Psi(r,\theta) \;=\; (r/r_o)^q\psi(\theta)\Psi_o\ ,$

- Steady-state, axisymmetric MHD solutions: (P_{rad}=0)

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

MHD disk-wind model (Contopoulos+Lovelace 94)

Density $$n(r,\theta) \equiv \frac{\rho(r,\theta)}{\mu m_p} = n_o x^{2q-3} \mathcal{N}(\theta) \quad n_o = \frac{\eta_W \dot{m}}{2\sigma_T r_S}$$

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

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

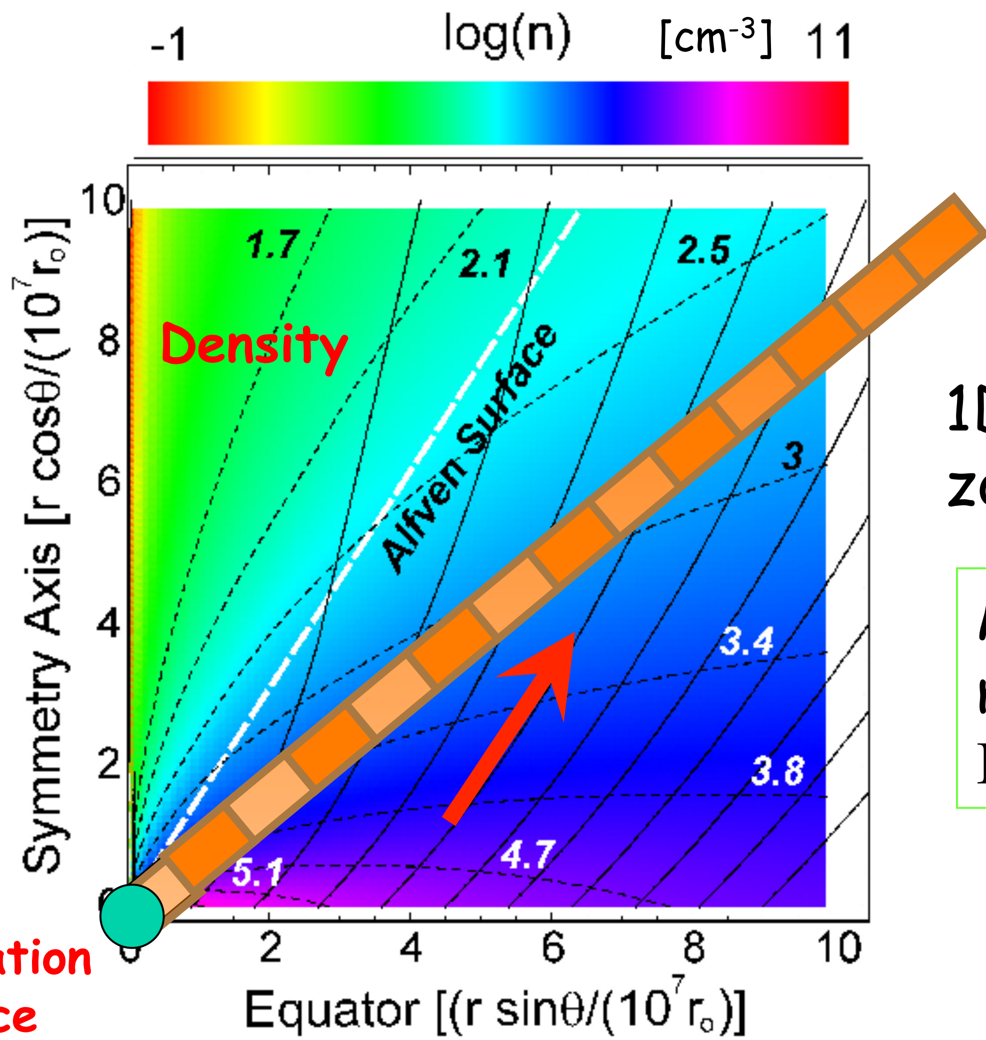
- $B(r,\theta) \sim N(\theta)/r$ ← Grad-Shafranov equation
- $n \sim 1/r$ (i.e. equal column per decade in radius)
- LOS $v \sim 1/r^{1/2}$ (can be a good fraction of c at small radii)
- $\xi \sim 1/r$ (ignoring local absorption)

LoS Radiation Transfer

Photoionization with XSTAR code (e.g. Kallman+Bautista01)

(http://heasarc.nasa.gov/lheasoft/xstar/xstar.html)

Density Map



LoS

1D computational zones

Radiation Source

M(BH) =10^6 Msun
mdot ~ 0.1-0.3
Γ ~ (2-10 keV) ~ 1.5

Computation of Radiation Field in Radial Direction

- Input SED progressively interacting with LoS gas
- Call XSTAR to compute opacity/emissivity for the (i+1)-th zone
- Luminosity exiting the (i+1)-th zone consists of:
  1) transmitted luminosity thr. i-th zone
  2) locally produced continuum within (i+1)-th zone
  3) locally produced lines within (i+1)-th zone

$$L_{i+1} = L_{i+1}^{(\mathrm{tr})} + L_{i+1}^{(\mathrm{cont})} + L_{i+1}^{(\mathrm{line})} \ ,$$

where

$$L_{i+1}^{(\mathrm{tr})} = L_i e^{-\tau_{(i+1)}} \ ,$$

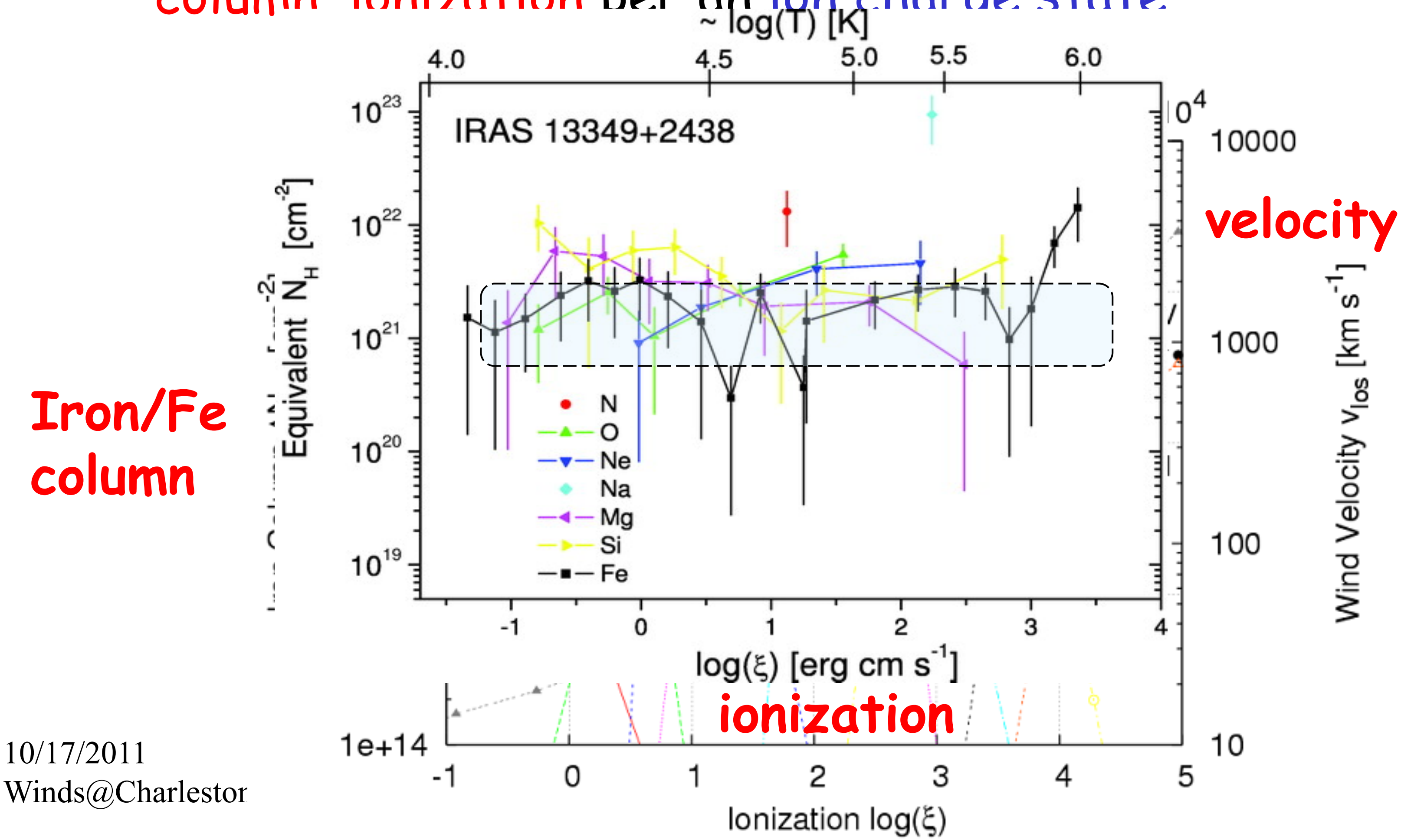
L_i is the luminosity exiting the i-th zone.

c.f. XCORT (Schurch +Done 07,08)
QWIND (Risaliti+Elvis+10)

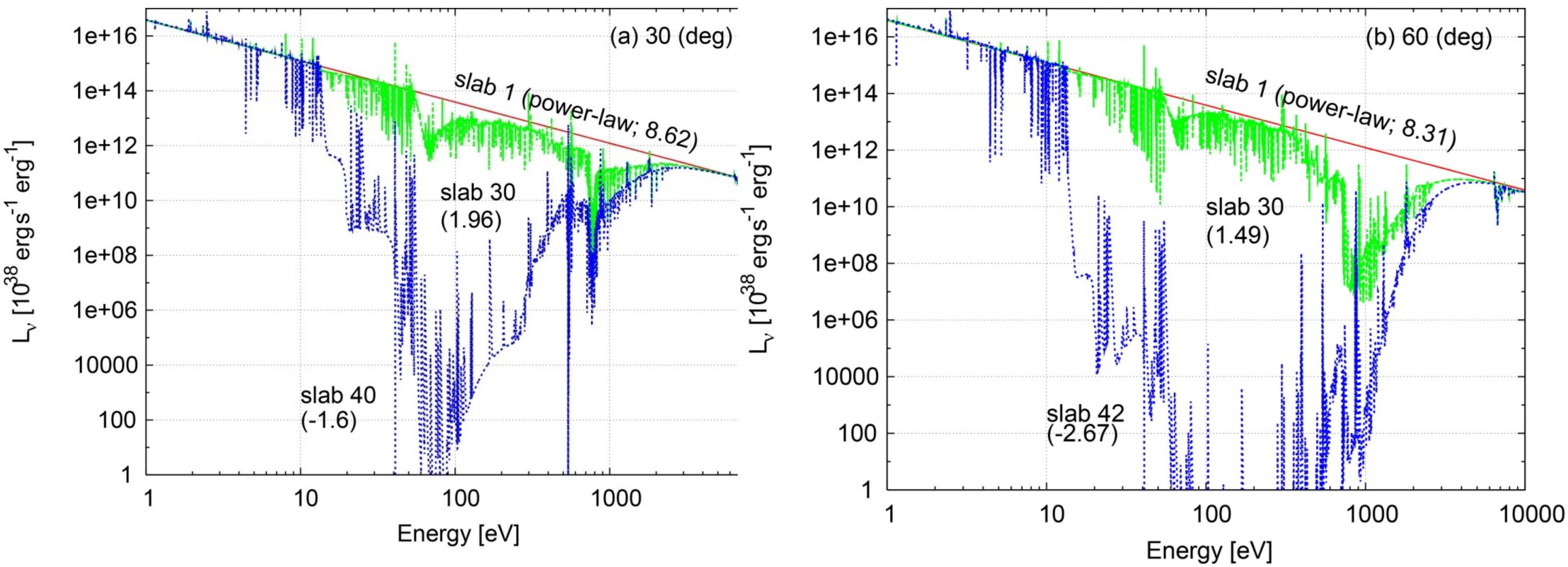
Absorption Measure Distribution (AMD)

Radiation transfer is solved in LoS with XSTAR photoionization code
➔ AMD = Distribution of ionic column against ionization state

The model allows for correspondence among velocity, column, ionization per an ion charge state



Examples of spectrum transferred through two different depths in the wind for 30/60 deg LoS

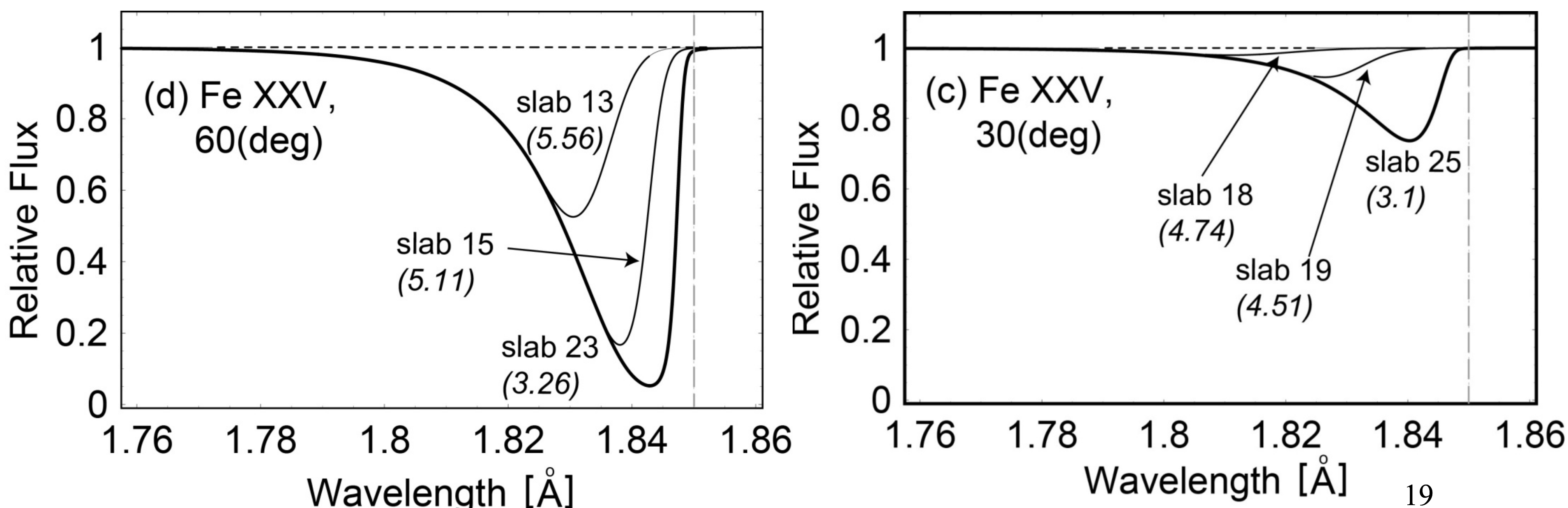


Synthetic disk-wind absorption spectra with Voigt Profile

We use ***local shear velocity*** for transfer of the resonance lines instead of XSTAR's turbulent velocity.

$$\tau(\nu) = \sigma(\nu) N_H(\nu) \ , \ \ \sigma = 0.01495(f_{ij}/\Delta\nu_D) H(a,u) \ ,$$

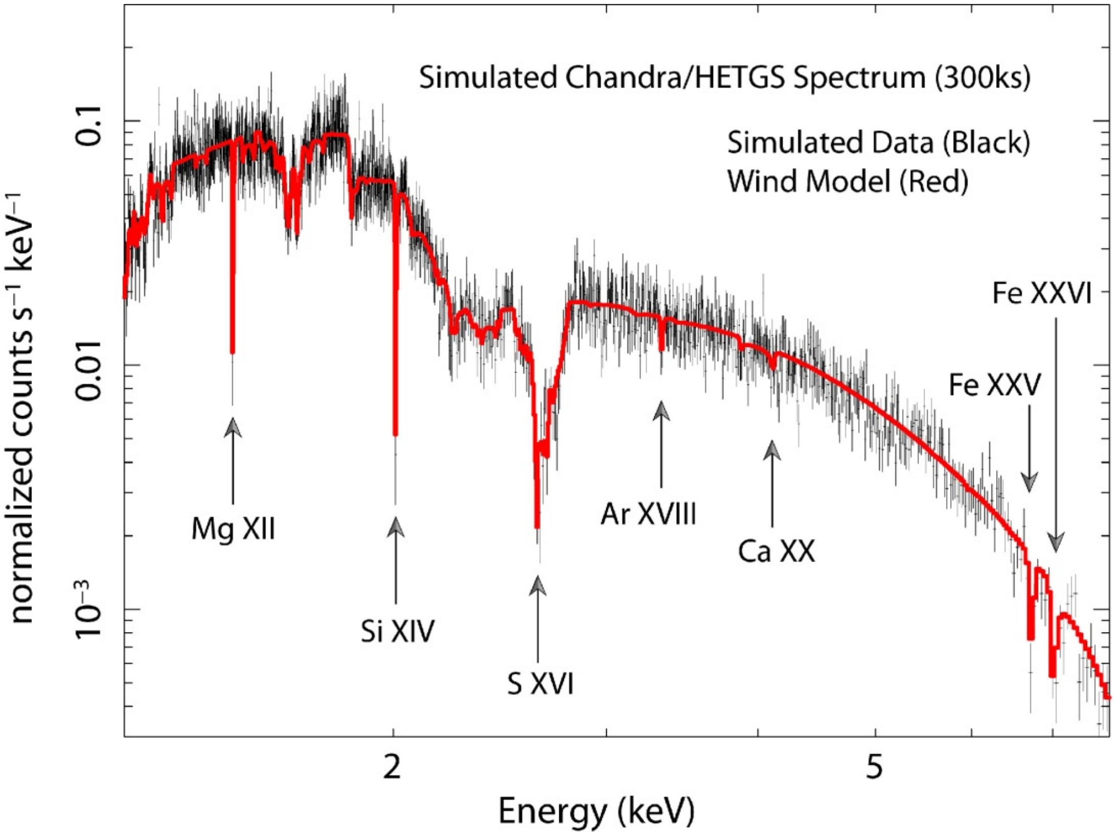
$$H(a,u) \equiv \frac{a}{\pi}\int_{-\infty}^{\infty} \frac{e^{-y^2}dy}{(u-y)^2+a^2} \ . \quad u(x,\theta) = \frac{\nu/\nu_0 - 1/[1-v_{\rm los}(x)/c]}{\Delta v_{\rm sh}/c} \ .$$



Fukumura+(10a)

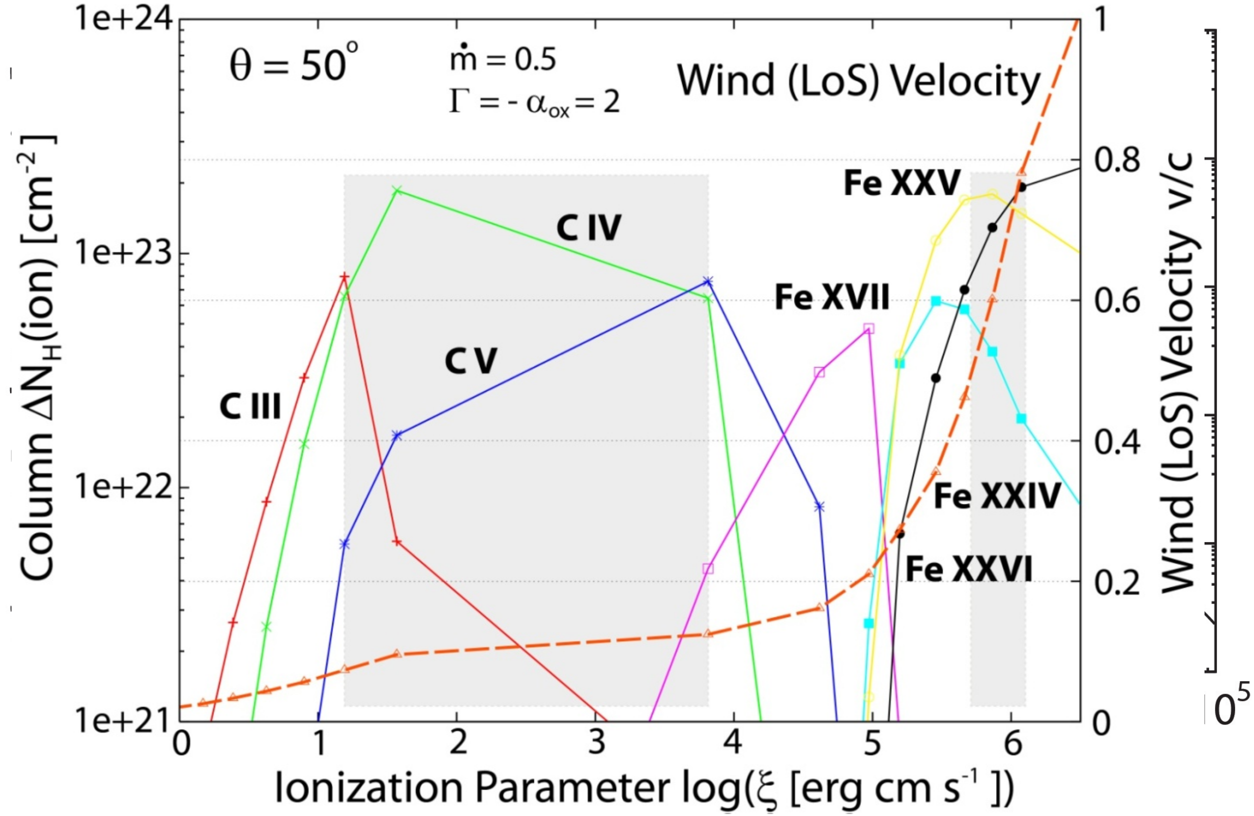
XSPEC mtable model with *Chandra*/HETGS response matrices

We plan to implement absorption spectra from our MHD-disk wind into XSPEC.



$$F_\nu \equiv \mathtt{phabs} \times (\mathtt{po} + \mathtt{bbody/MCD}) + \Sigma_i \mathtt{ga}_i) \times \mathtt{WindAbs}$$

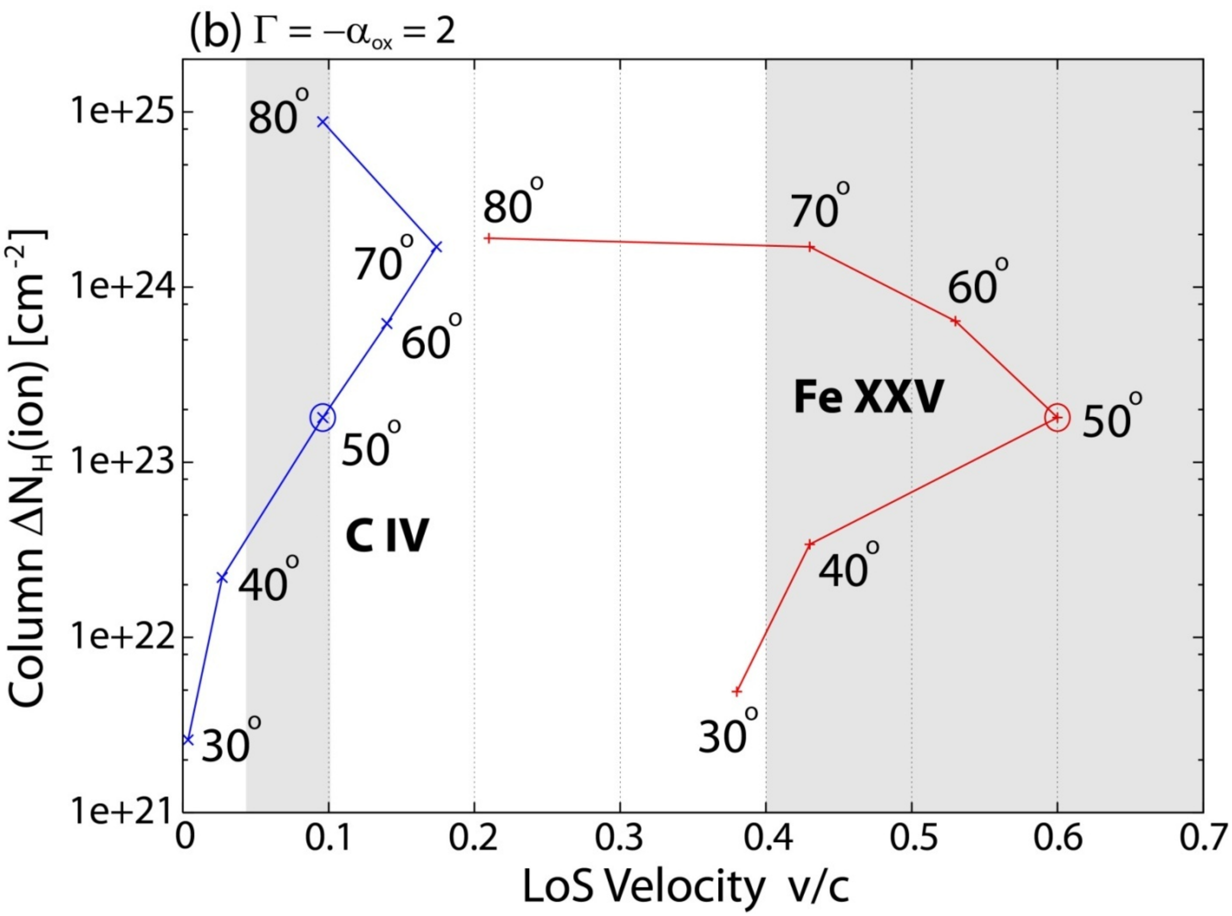
Putting AGNs in a perspective of α_{OX}

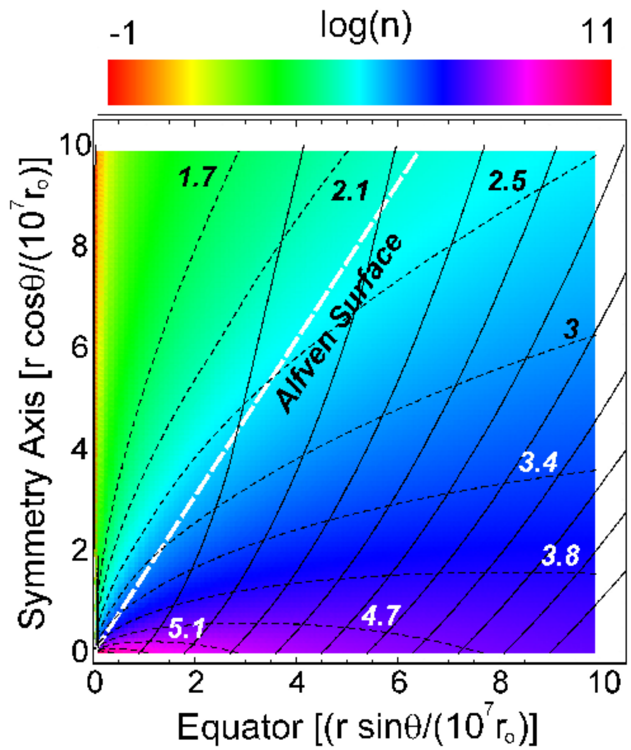


α_{ox} = 0.384 log ($f_{2\ keV}$ / $f_{2500\ Å}$)

➔ tells you X-ray weakness

Velocity-dependence on LoS angle





Summary

We propose a simplistic MHD disk-wind model:

- Key ingredients = **LoS angle**, **mdot**, **SED**

X-ray-bright AGNs:

- Observed AMD (i.e. local column distribution N_H as a function of ξ)
- Observed wind kinematics and outflow geometry (e.g. ~100-300 km/s for FeXVII; ~1,000-4,000 km/s for FeXXV)

Optically-bright QSOs and soft-X-ray-bright Seyferts:

- Softer SED ➔ higher outflow velocity (i.e. $v/c > 0.1$)

α_{OX} is "the" defining parameter to control the outflow properties

Fukumura et al. (2010a), ApJ, 715, 636
Fukumura et al. (2010b), ApJL, 723, 228

end

A simple estimate…

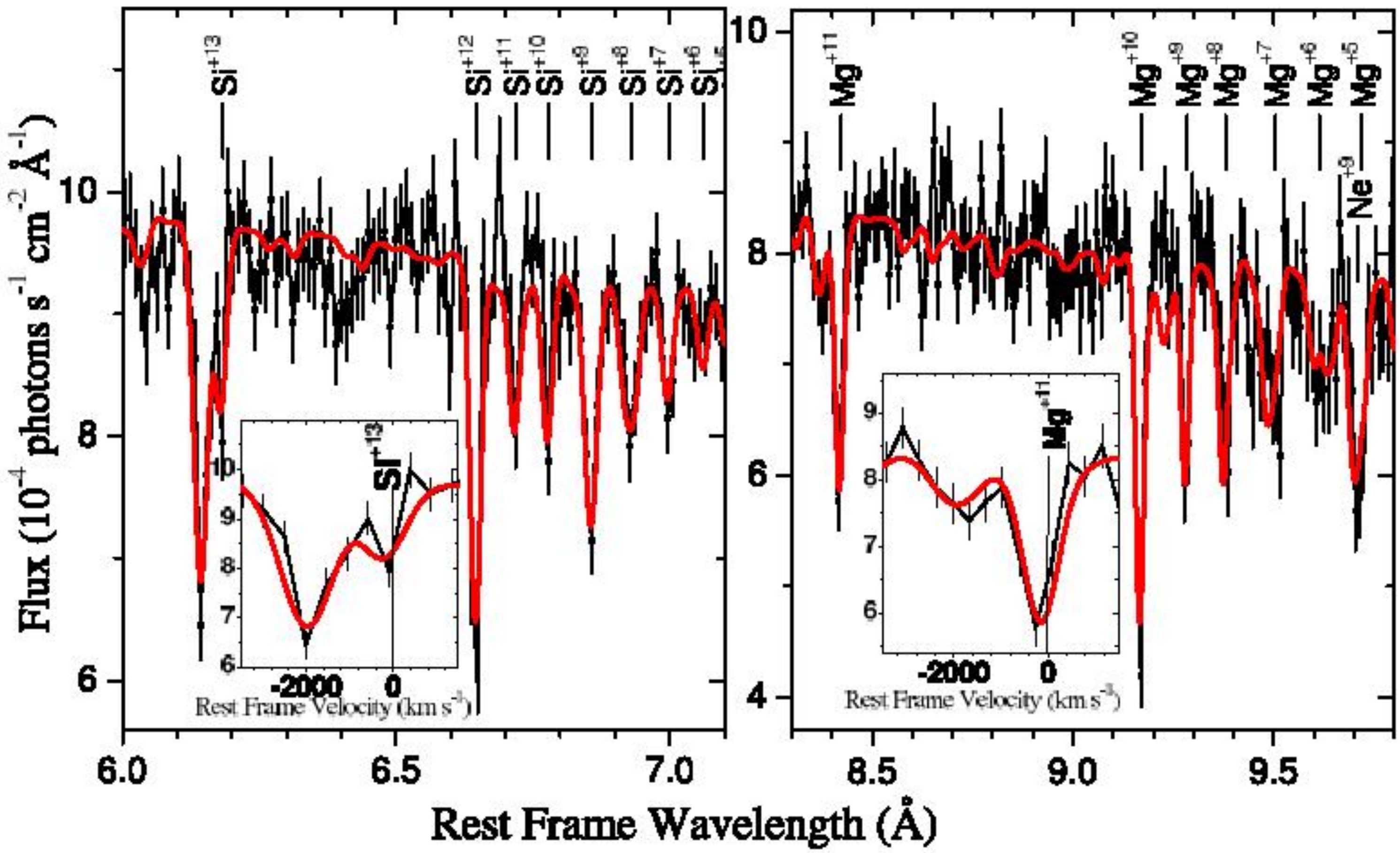
When integrated over wind between Rin and Rout we find

$$\dot{M}_{out} \sim$$

$$\dot{E}_{out} \sim$$

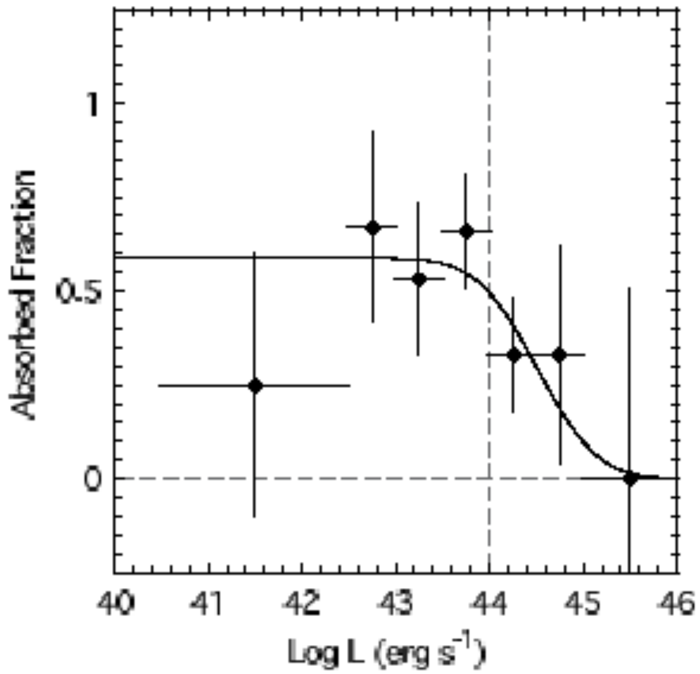
Side Notes1

MCG 6-30-15



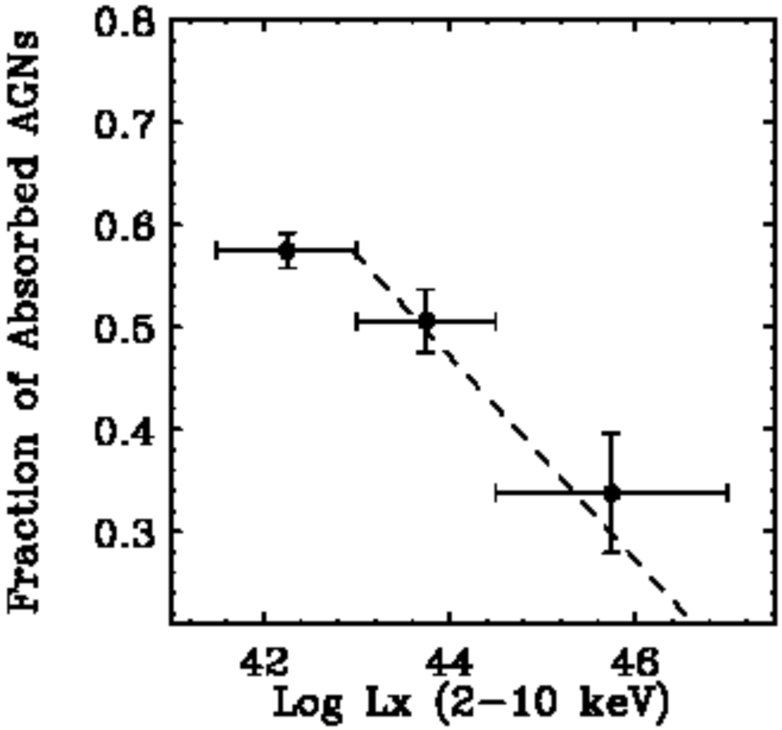
Holczer+(10)

Side Notes2



Swift/BAT selected AGNs

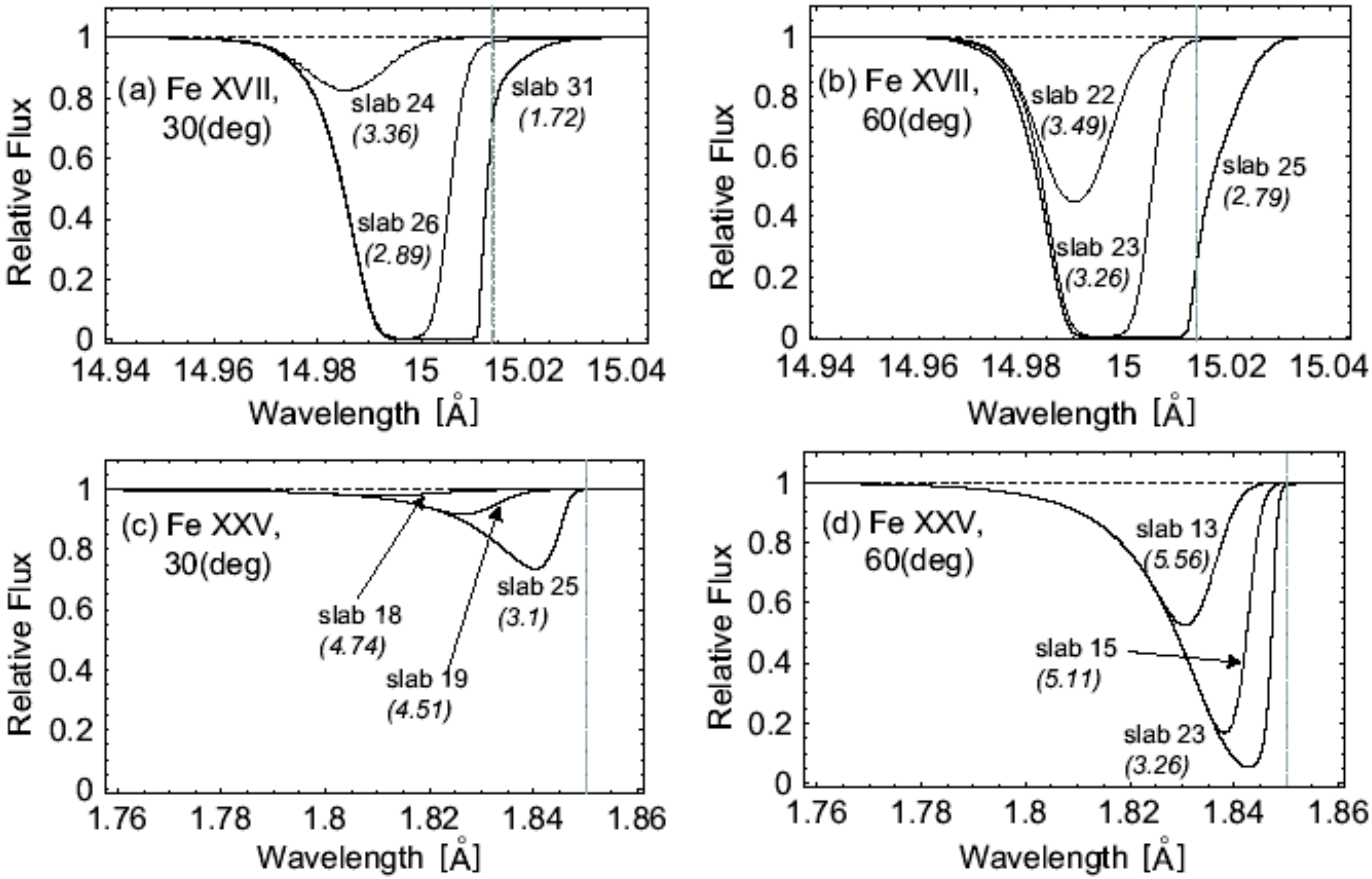
Tueller+(08)



Compiled AGN surveys

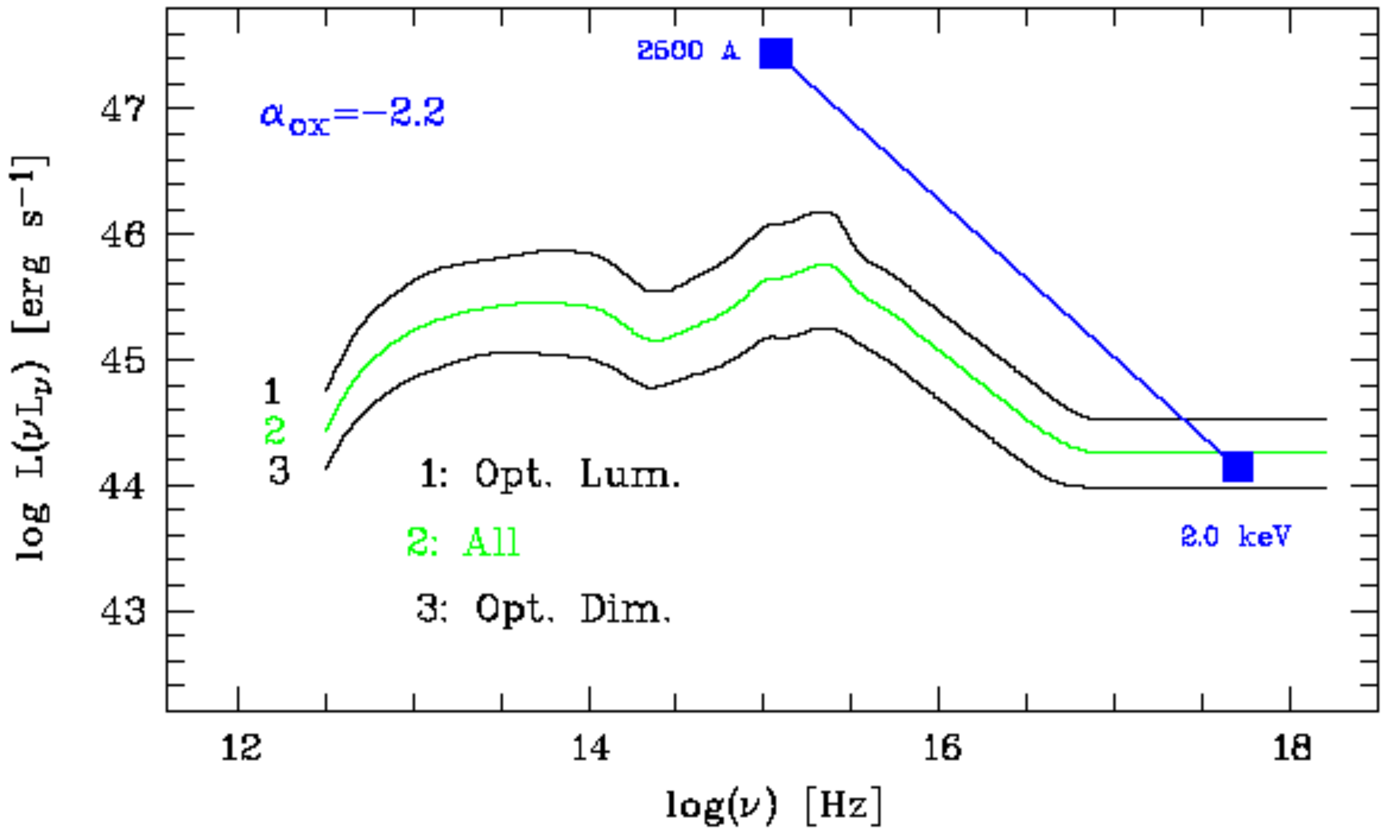
Ueda+(03)

Side Notes3



(a) Fe XVII,
30(deg)
slab 24
(3.36)
slab 31
(1.72)
slab 26
(2.89)
Relative Flux
Wavelength [Å]
(b) Fe XVII,
60(deg)
slab 22
(3.49)
slab 25
(2.79)
slab 23
(3.26)
(c) Fe XXV,
30(deg)
slab 18
(4.74)
slab 19
(4.51)
slab 25
(3.1)
(d) Fe XXV,
60(deg)
slab 13
(5.56)
slab 15
(5.11)
slab 23
(3.26)

Side Notes4

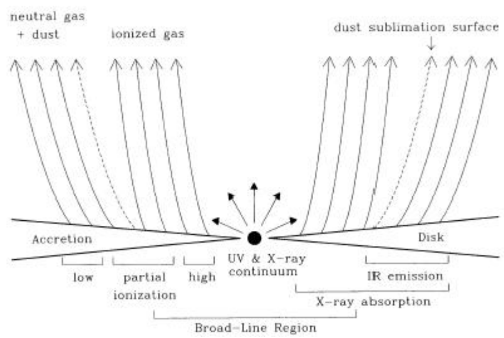


2500 A
α_{ox}=−2.2
1
2
3
1: Opt. Lum.
2: All
3: Opt. Dim.
2.0 keV
log L(νL$_\nu$) [erg s^{-1}]
log(ν) [Hz]

Outflow Type	Objects	velocity v/c	column N_H [cm^{-2}]	Ionization parameter log ξ [$erg\ cm\ s^{-1}$]
UV BAL	QSOs	~ 0.01-0.2		~ 0
UV NALs	QSOs	~0.001-0.2		~ 0
UV mini-BALs	QSOs Seyferts	~0.01-0.2		~ 0
X-ray WAs	Seyferts	~0.001-0.03		~ 0 - 4
	Binaries			
X-ray UFOs	Seyferts	~0.1-0.7		

Attempt to describe (N_H, $v_{outflow}$, ξ) with MHD disk-wind

Konigl+Kartje(94)



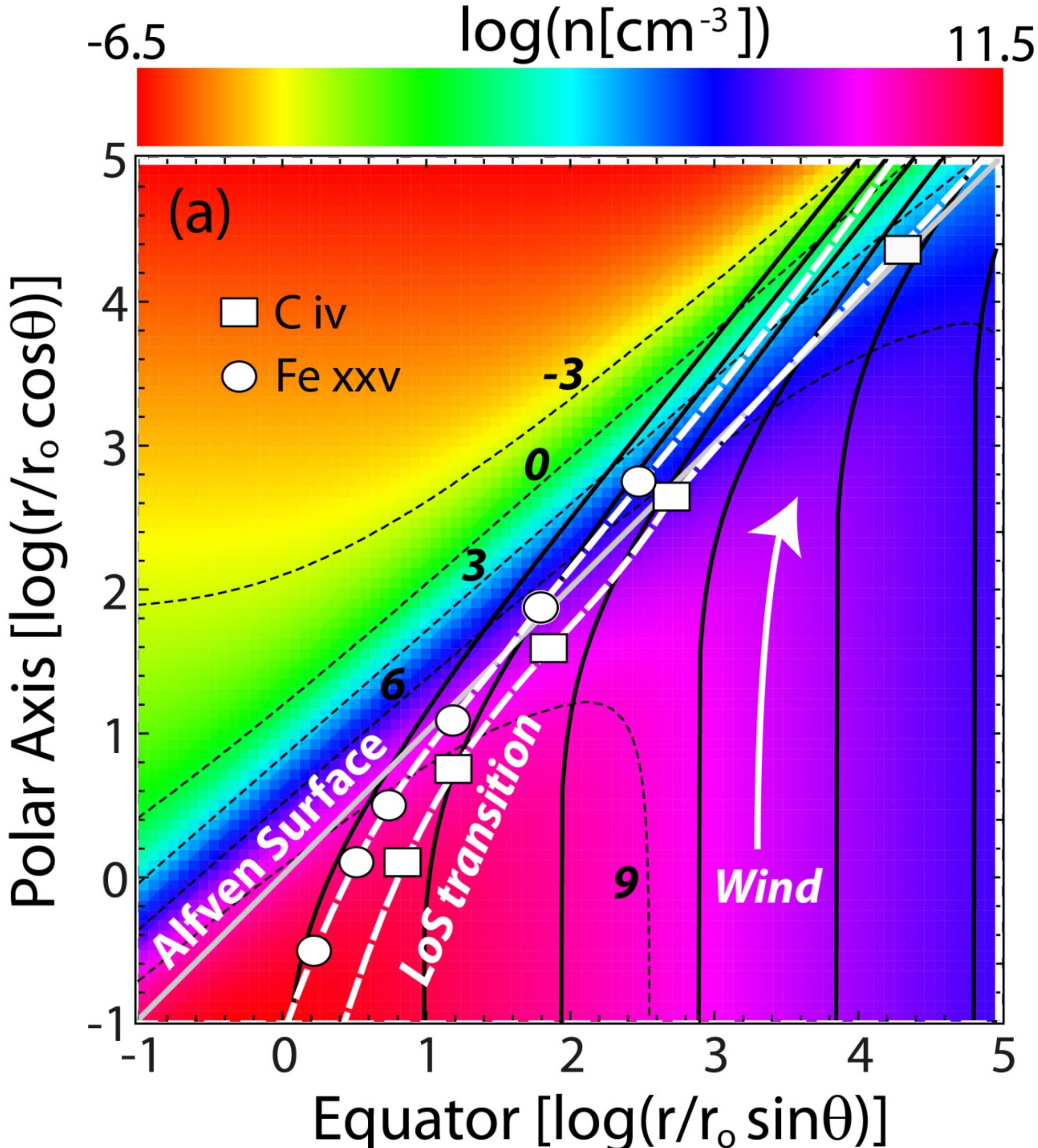
Earlier work:

Blandford+Payne(1982)
Contopoulos(1994,1995)
Konigl+Kartje(1994)
Blandford+Begelman(1999)
and more …

- Accretion disks (necessarily) produce outflows/winds
- Large-scale poloidal B-field guides plasma
- Local X-rays heat up and photoionize winds

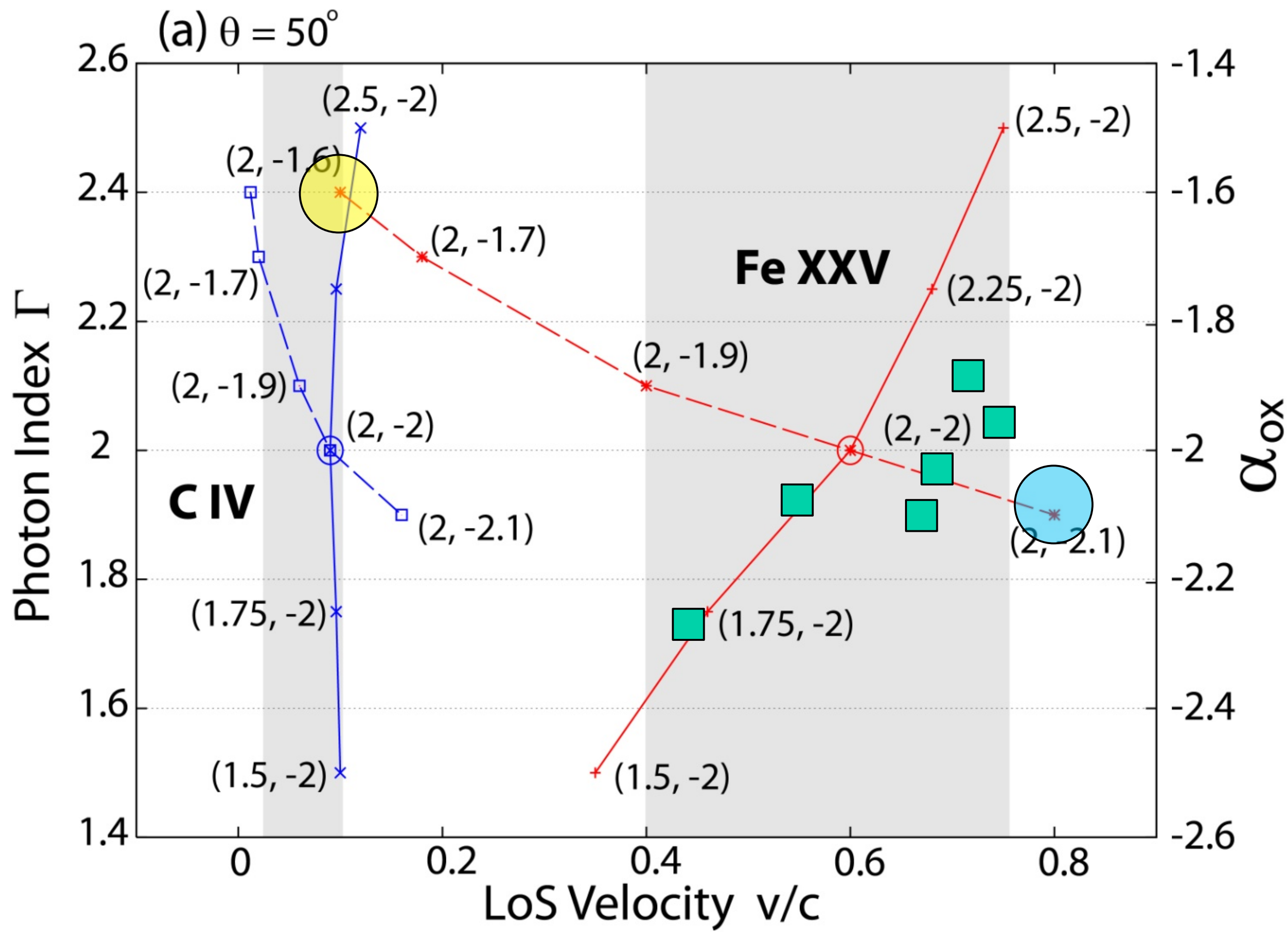
➔One can ask what charge-state of ions would peak in (ξ, v) space via mutual interact between photon and matter fields

➔ LoS absorption lines spectra

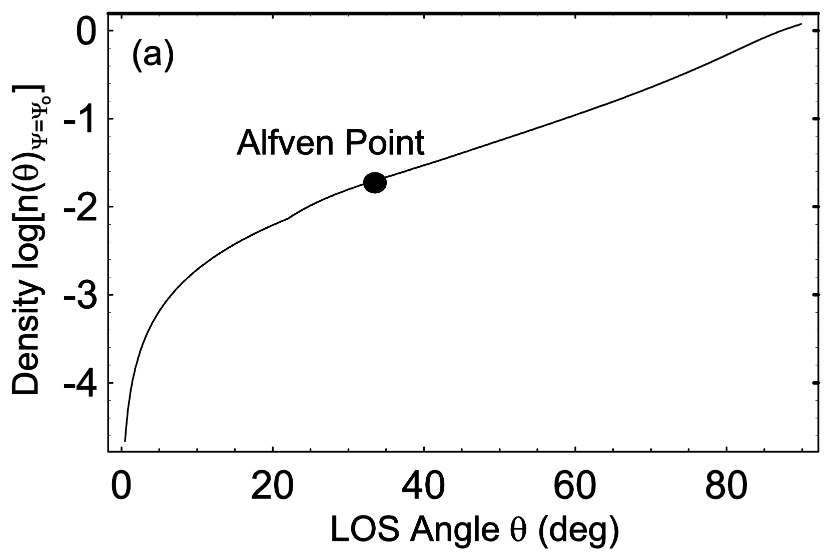

log(n[cm^{-3}])
-6.5
11.5
(a)
C iv
Fe xxv
-3
0
3
6
9
Alfven Surface
LoS transition
Wind
Polar Axis [log(r/r$_o$ cosθ)]
Equator [log(r/r$_o$ sinθ)]
-1
0
1
2
3
4
5

Fiducial correlations from model

Velocity-dependence on SED (hard X-ray weakness)



Squares = X-ray data of APM 08279+5255 from Chartas+(09)
Curves = MHD disk-wind model from Fukumura+(2010b)


(a)
Alfven Point
Density $\log[n(\theta)_{\Psi=\Psi_o}]$
0
-1
-2
-3
-4
0
20
40
60
80
LOS Angle θ (deg)