Fast Ionized X-ray Absorbers in AGNs

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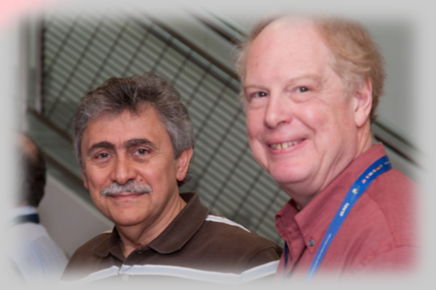

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Ehud Behar (Technion, Israel)
Ioannis Contopoulos (Academy of Athens, Greece)

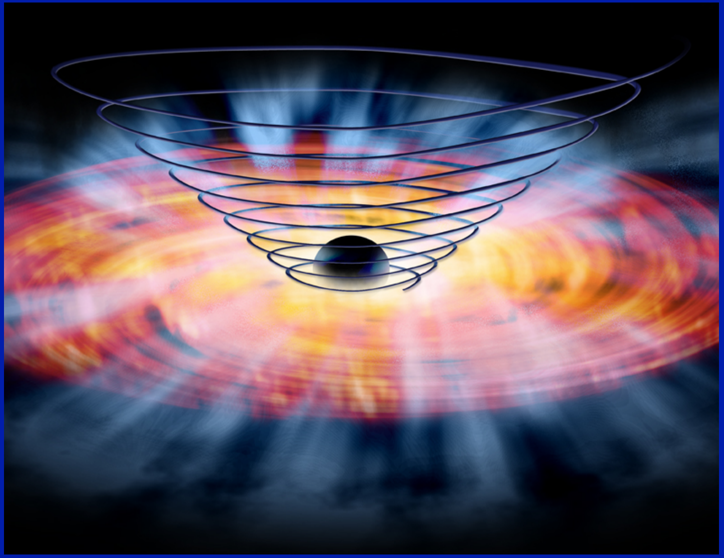
Illustration: Wind from Accretion Disk Around a Black Hole

Outline

(1) WAs (~sub-pc) vs. UFOs (<1000R_S) in X-ray

(2) MHD-driven Wind Model

(3) Outlook

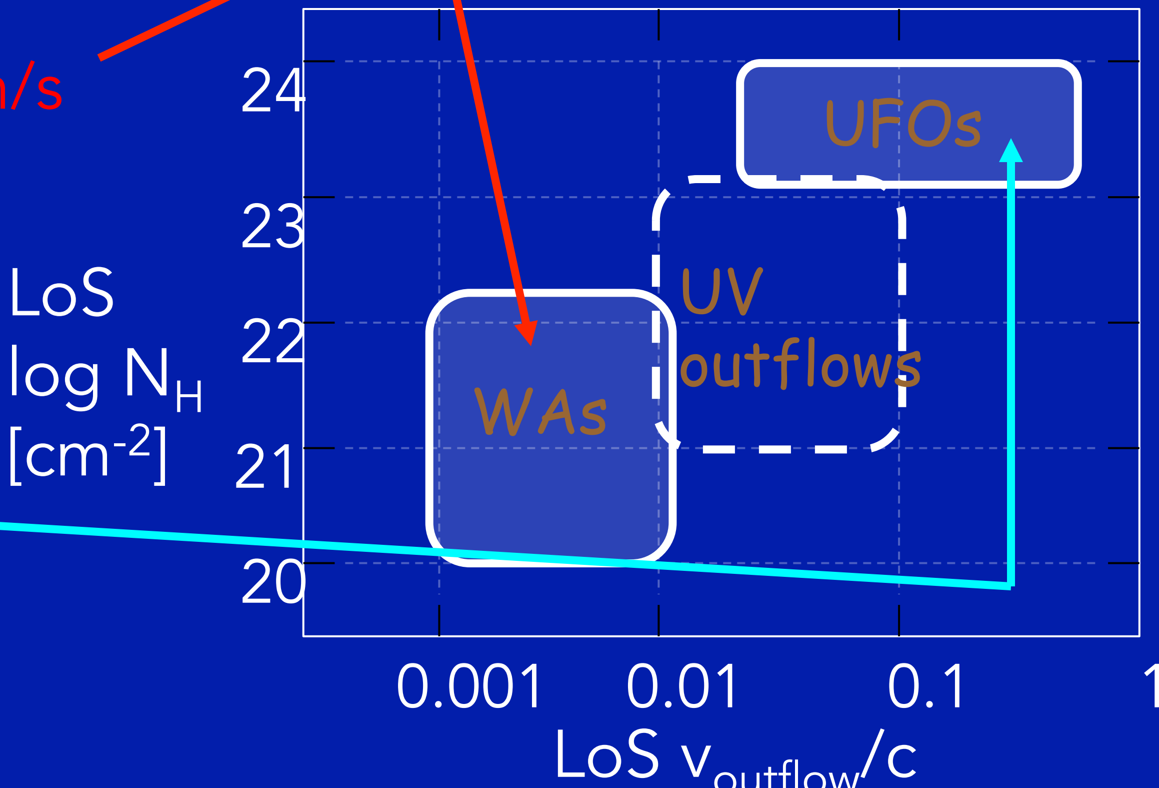


Ionized X-ray Winds
(i.e. Warm Absorbers & Ultra-Fast Outflows)

- ❑ (Soft) X-ray-bright Seyfert AGNs
- ❑ Distant QSOs
- ❑ Soft X-ray & Fe K band

- ❑ v_{out} ~100 - 1,000 km/s
- ❑ log ξ ~ -1 to 4
- ❑ $N_H \sim 10^{20-22}$ cm^{-2}

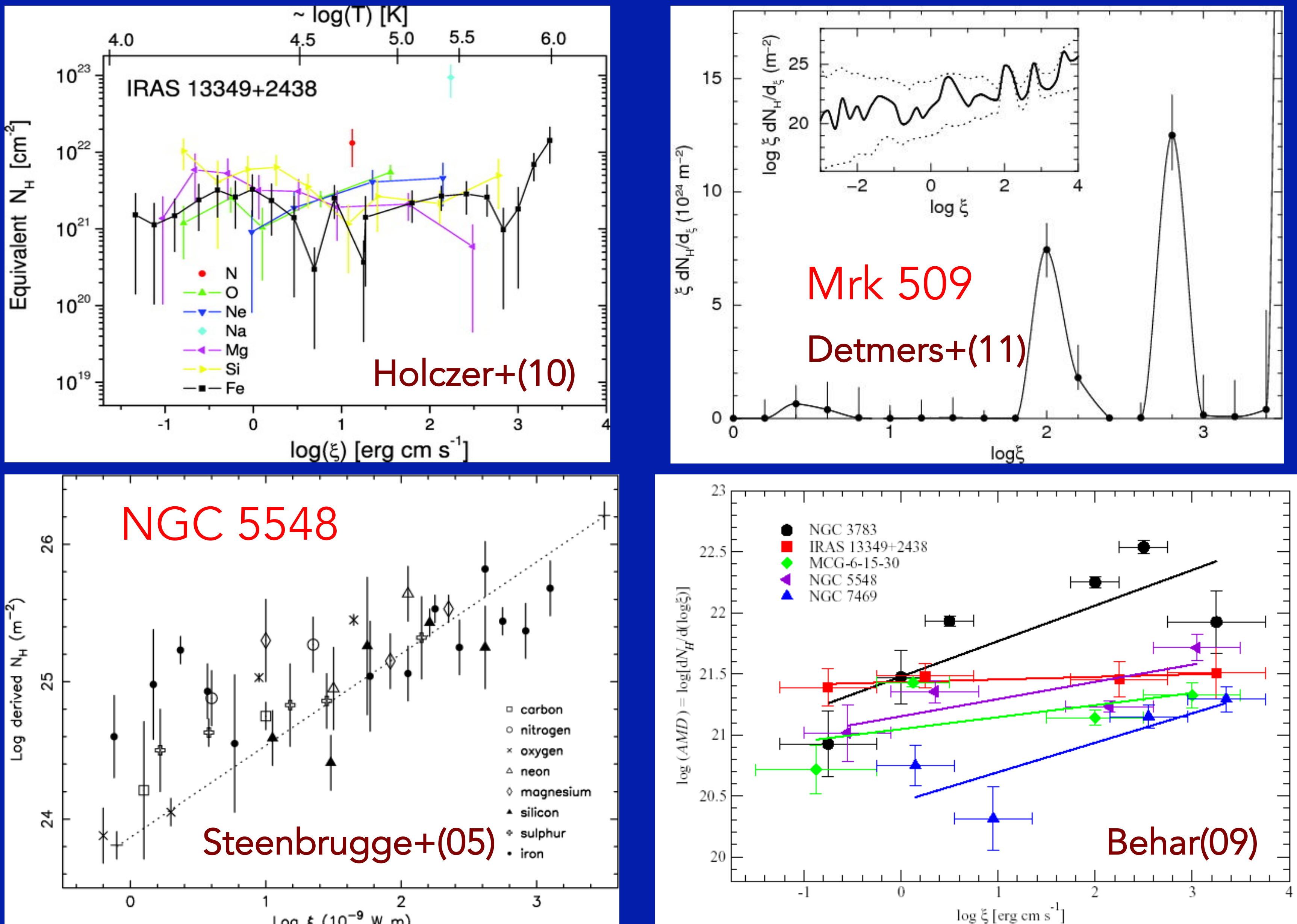
- ❑ v_{out}/c~0.1 - 0.8
- ❑ log ξ ~ 3-6
- ❑ $N_H \sim 10^{23-24}$ cm^{-2}



Outstanding Questions

- Spatial location?
- Geometry?
- Continuous/Patchy flows?
- Defining quantities?

Absorption Measure Distribution (AMD)



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 $n \sim r^{-2}$!

Then

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

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

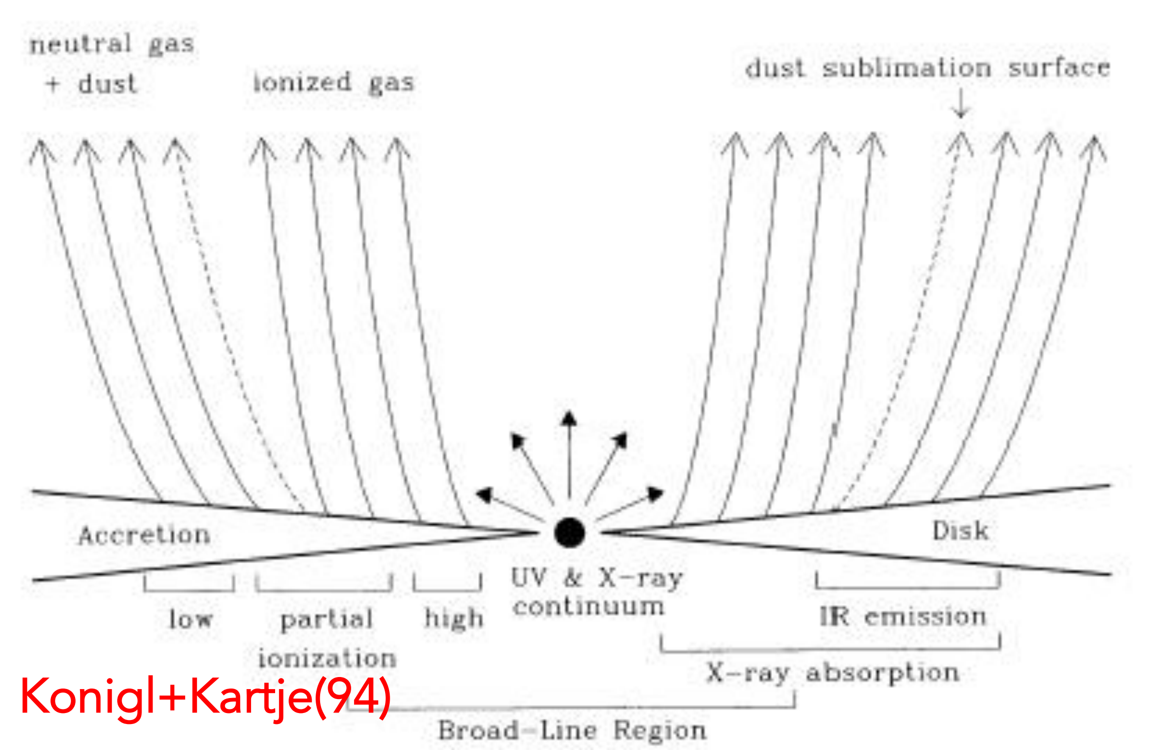
Therefore, the flow is 2D
(e.g. Blandford+Payne82, Contopoulos+Lovelace94, Konigl+Kartje94…etc.)

outflow mass ← exterior
kinetic power ← interior

Absorbers as Disk-Wind

- Outflows necessary for accretion process
- Driven by "some" acceleration process(es)
- AGN X-ray photoionizing wind materials

Matter (gas) + photon (AGN SED) fields
➔ Absorption features



(1) Thermal-driven models:
Begelman, McKee&Shields(83)
Proga&Kallman(02)

(2) Radiation-driven models:
Castor+(75), Murray+(95;98)
Proga+Kallman(04)
Higginbottom+(14)

(3) MHD-driven models:
Blandford+Payne(82)
Konigl+Kartje(94)
Contopoulos(95), Everett(05)
Takeuchi+(13), Ohsuga+(11)
Fukumura+(10a;b,14,15)

Others (Phenomenological):
Blandford+Begelman(99)
Schurch+Done(07,08)
Sim+(08;10)

& more…

MHD-Driven Disk-Wind Model with $n \sim 1/r$

(e.g. Fukumura+10a,b,14,15)

(1) Steady-state, axisymmetric ideal MHD eqns. ($P_{rad}=0$)

Disk treated as BC

$$\nabla \cdot (\rho \mathbf{v}) = 0 \quad \text{(mass conservation)} ,$$

$$\nabla \times \mathbf{B} = \frac{4\pi}{\mathbf{c}} \mathbf{J} \quad \text{(Ampere's law)} ,$$

$$\mathbf{E} + \frac{\mathbf{v}}{\mathbf{c}} \times \mathbf{B} = 0 \quad \text{(ideal MHD)} ,$$

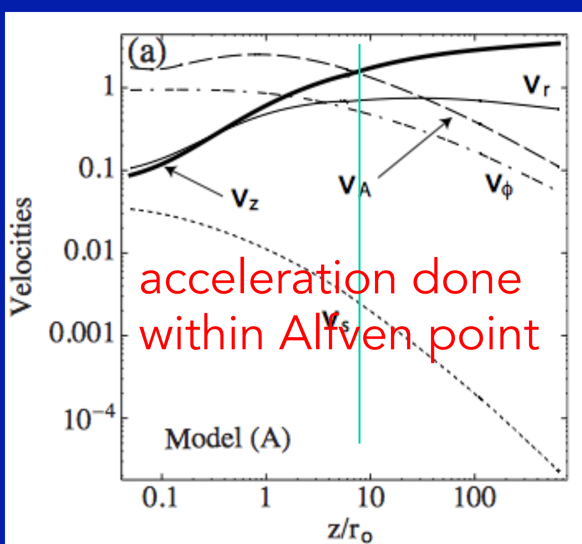
$$\nabla \times \mathbf{E} = 0 \quad \text{(Faraday's law)} ,$$

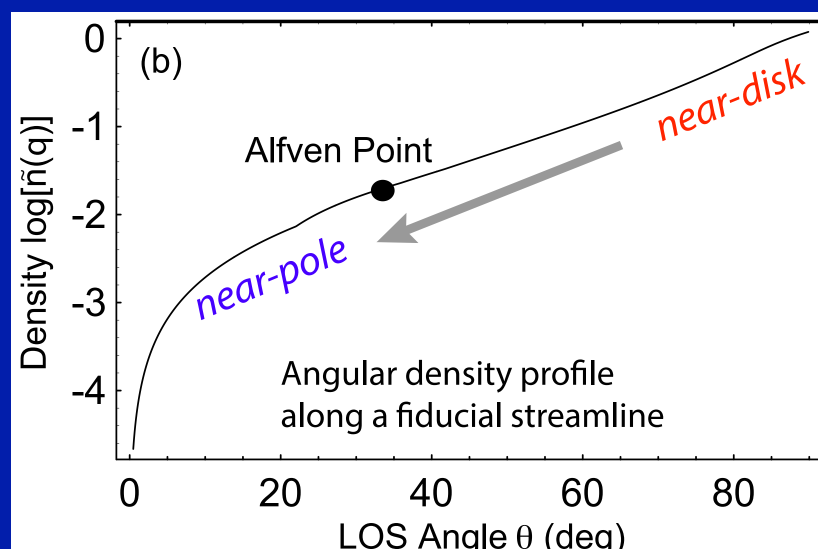
$$\rho (\mathbf{v} \cdot \nabla) \mathbf{v} = -\nabla \mathbf{p} - \rho \nabla \Phi_{\mathbf{g}} + \frac{1}{\mathbf{c}} (\mathbf{J} \times \mathbf{B}) \quad \text{(momentum conservation)} ,$$

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

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

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





MHD wind is 2D!

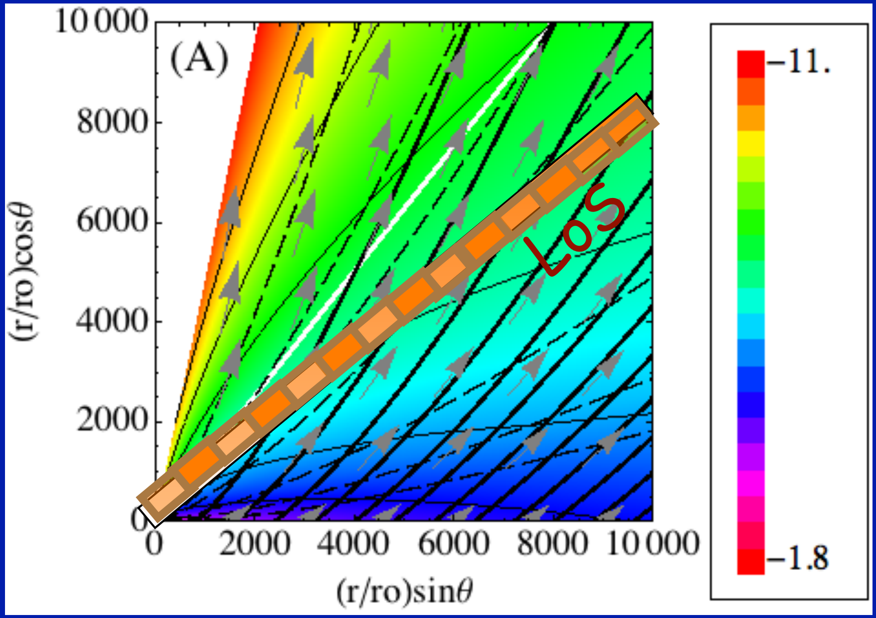
Solving Grad-Shafranov eqns. with self-similar radial profiles in MHD framework.

➔ Toroidal (Keplerian) to poloidal motion transition.

MHD-Driven Disk-Wind Model with n ~ 1/r

(e.g. Fukumura+10a,b,14,15)

(2) Solve radiative transfer along LoS with xstar photoionization code by discretizing wind in radius



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

Solve ionization balance under heating-cooling equilibrium in each cell:

- ➔ Initial SED assumed
- ➔ Solve ionization balance in i^{th} cell
- ➔ Obtain transmitted SED from i^{th} cell
- ➔ Inject it to $(i+1)^{th}$ cell
- ➔ Repeat this process

while also keeping track of columns for ions in each cell.

Then, calculate a global ionization structure.

$$\xi(r,\theta) \equiv \frac{L}{n(r,\theta) r^2}$$

MHD-Driven Disk-Wind Model with n ~ 1/r

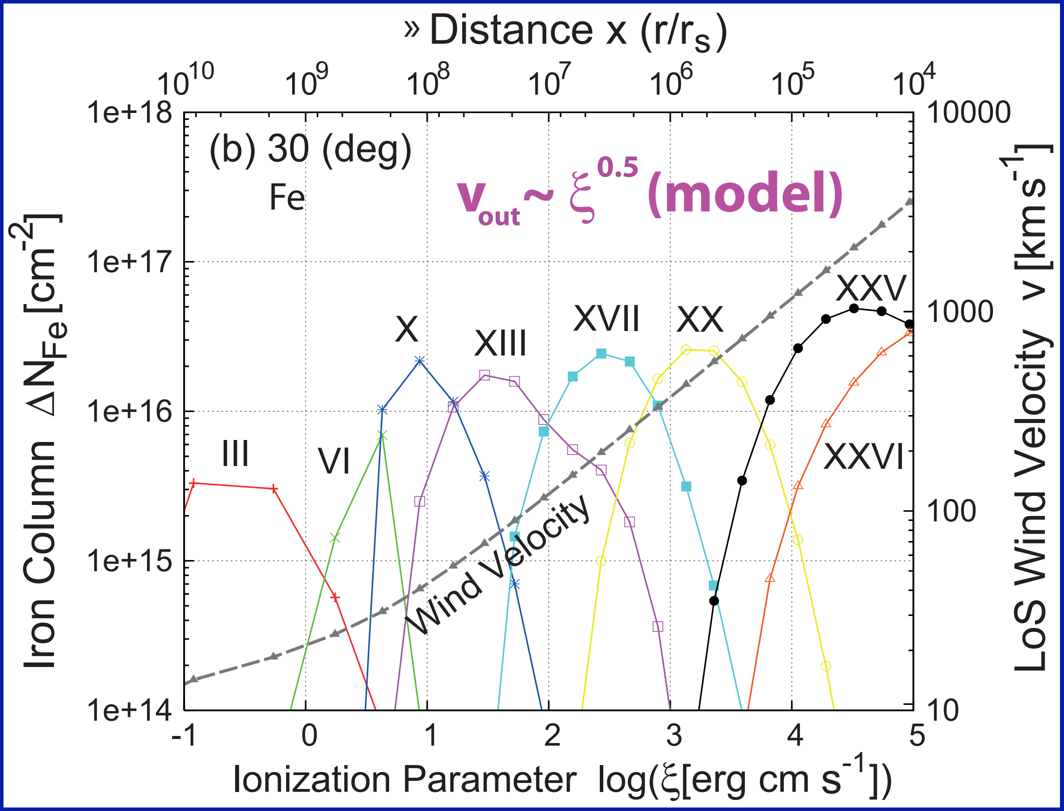
(e.g. Fukumura+10a,b,14,15)

Test1:

RQ Seyfert 1:

Single PL: $\Gamma = 2$
$L_{ion} = 3x10^{42}$ erg/sec
$M = 10^{6}$ Msun

→ calculating AMD for Seyfert WAs



- ❑ Constant AMD for 4 decades in ξ (all ions)
- ❑ Velocity profile (c.f. $v \sim \xi^{0.65}$ for WAs+UFOs)

Tombesi+13

MHD-Driven Disk-Wind Model with n ~ 1/r

(e.g. Fukumura+10a,b,14,15)

Test2: Applying to the UFO in PG 1211+143

PG 1211+143:

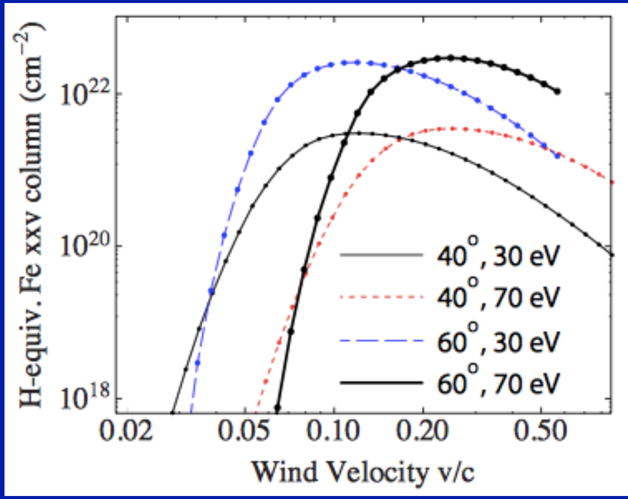
$\Gamma = 2$ and $\alpha_{OX} = -1.5$
$L_{ion} = 1.3\times10^{44}$ erg/sec
$M = 10^8$ Msun

A grid of wind model parameters

Model Grid of the mhdwind Component

Primary Parameter	Range
Viewing Angle θ (degrees)	30°, 40°, 50°, 60°, 70°
BBB Disk Temperature $kT_{\rm bbb}$ (eV)	10, 30, 50, 70
Disk Truncation Radius $\log f_t \equiv \log(R_t/R_o)$	0, 0.3, 0.6, 0.9, 1.2, 1.5, 1.8

1D radiative transfer along LoS for various elements →



Calculated Fe XXV columns

MHD-Driven Disk-Wind Model with n ~ 1/r

(e.g. Fukumura+10a,b,14,15)

- ❑ From radiative transfer calculations one finds columns.
- ❑ With atomic/plasma physics one computes cross section

$$\sigma_{\mathrm{photo},\nu} \equiv 0.001495 \, \frac{f_{ij} H(a,u)}{\Delta\nu_D} \quad \mathrm{cm}^2$$

which yields optical depth of wind.

$$\tau_\nu(r,\theta) = \sigma_{\mathrm{photo},\nu}(r,\theta) N_{\mathrm{ion}}(r,\theta)$$

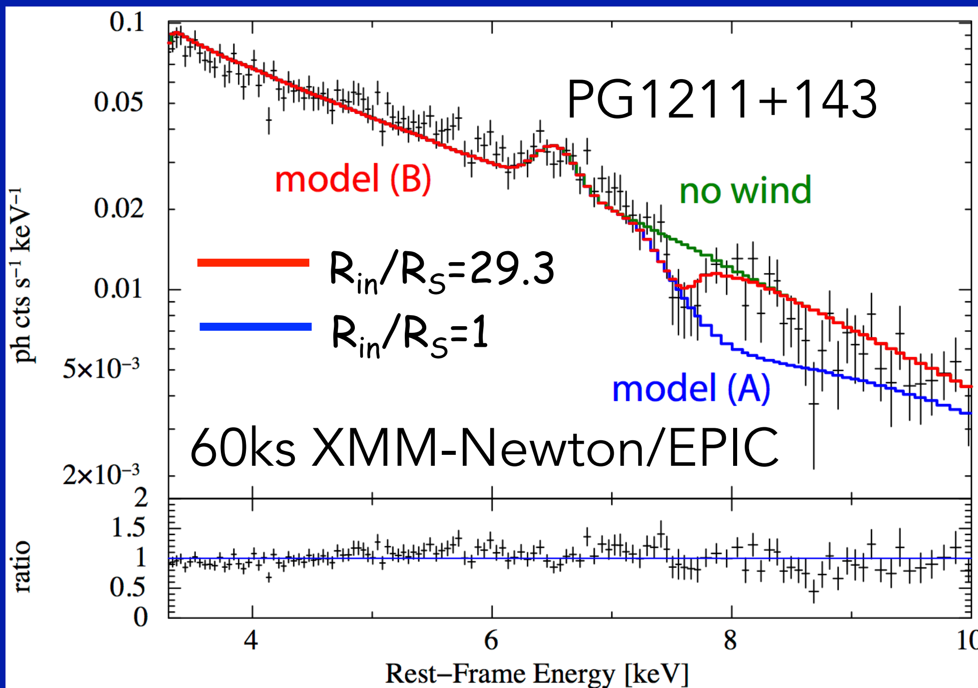
- ❑ Spectral shape is computed with Voigt profile H(a,u)

MHD Wind Characteristics

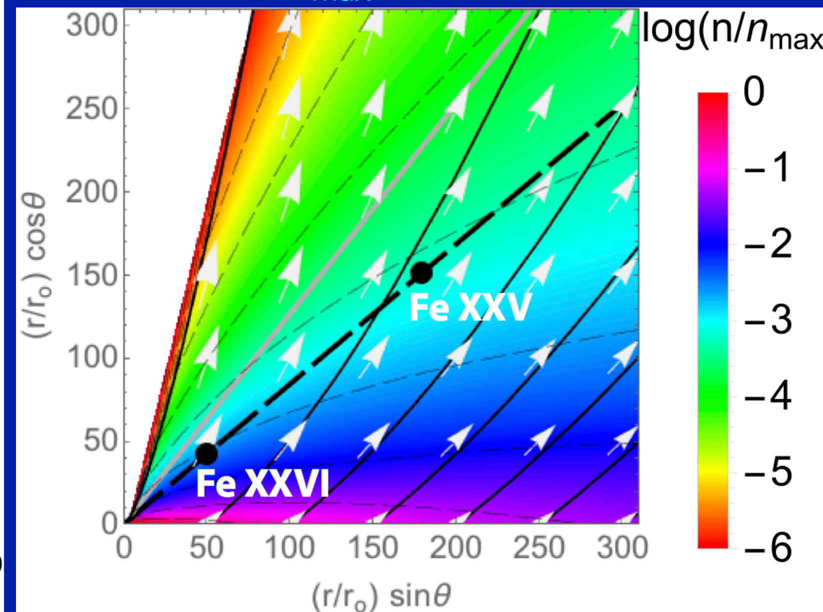
- ✓ There is always near-relativistic fast wind components at smaller radii
- ✓ SED will determine whether "spectroscopically" visible or not to us

MHD-Driven Disk-Wind Model with n ~ 1/r

(e.g. Fukumura+10a,b,14,15)



n_{max} = 5e11 cm^{-3}



Best-fit model:

kT_{in} = 38 eV and θ_{obs} = 49°

N_H(FeXXV) = 1.2x10^{23} cm^{-2}, log ξ_c = 5.3, v/c = 0.115

R(FeXXV) = 235 R_S , R_{trunc} = 29.3 R_S

M_{out}(FeXXV) = 2.56Msun/yr

χ^2/ν = 198.54/128

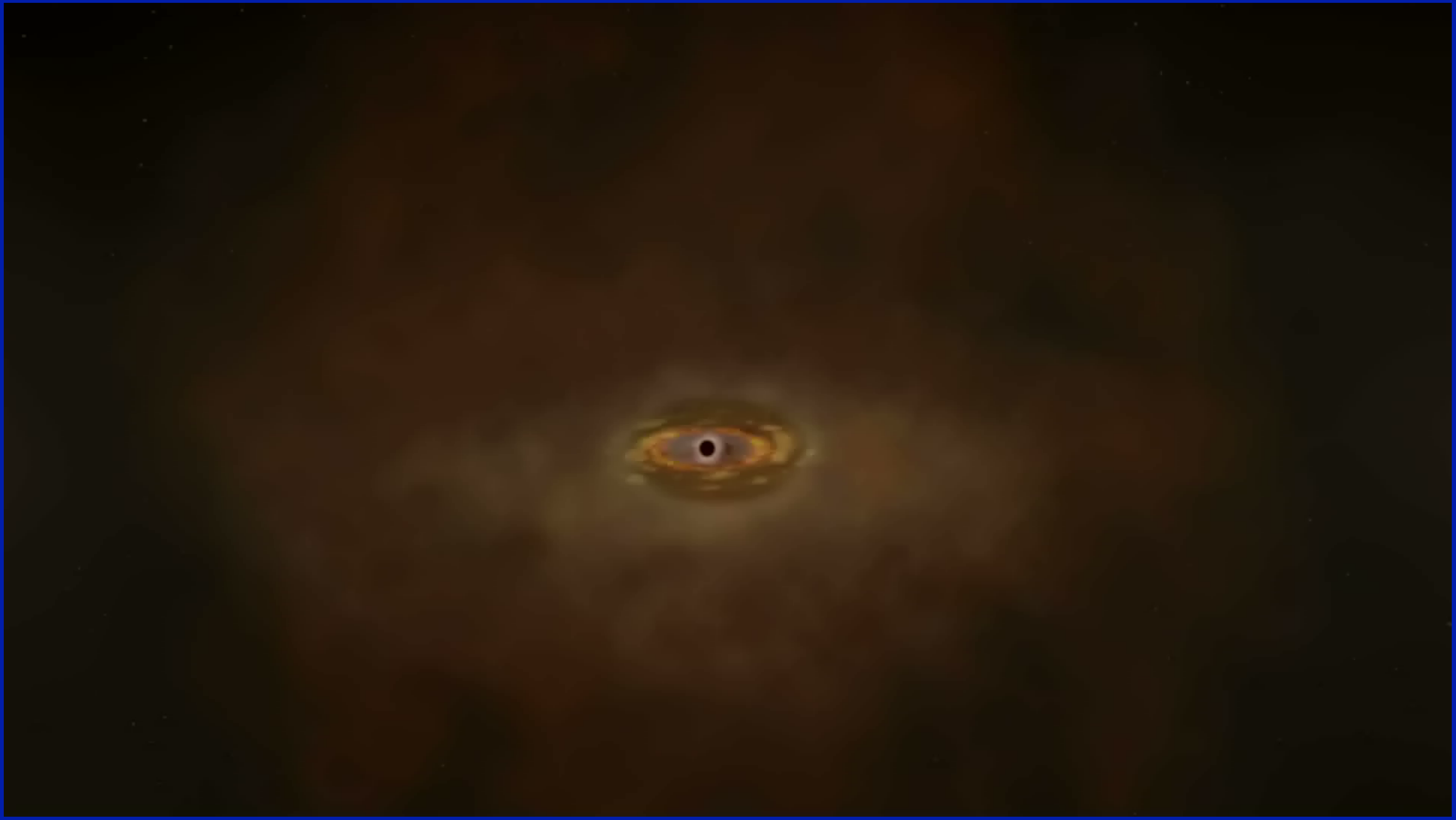
Brief Outlook

- ❑ X-ray absorbers can tell us outflow physics
  phenomenology (micro) ➔ many progress!
  global perspective (macro) ➔ ???

- ❑ Launching mechanism(s)
  Thermal? Radiation? MHD?
  ➔ need some "smoking gun" evidence…
  (e.g. high-ξ & high-N_H wind ➔ MHD?)

- ❑ Contribution to AGN feedback process
  How much power can be delivered?

Thanks!



NASA's Goddard Space Flight Center