X-ray Diagnostics of MHD-driven Accretion Disk Winds in the Era of Microcalorimeters

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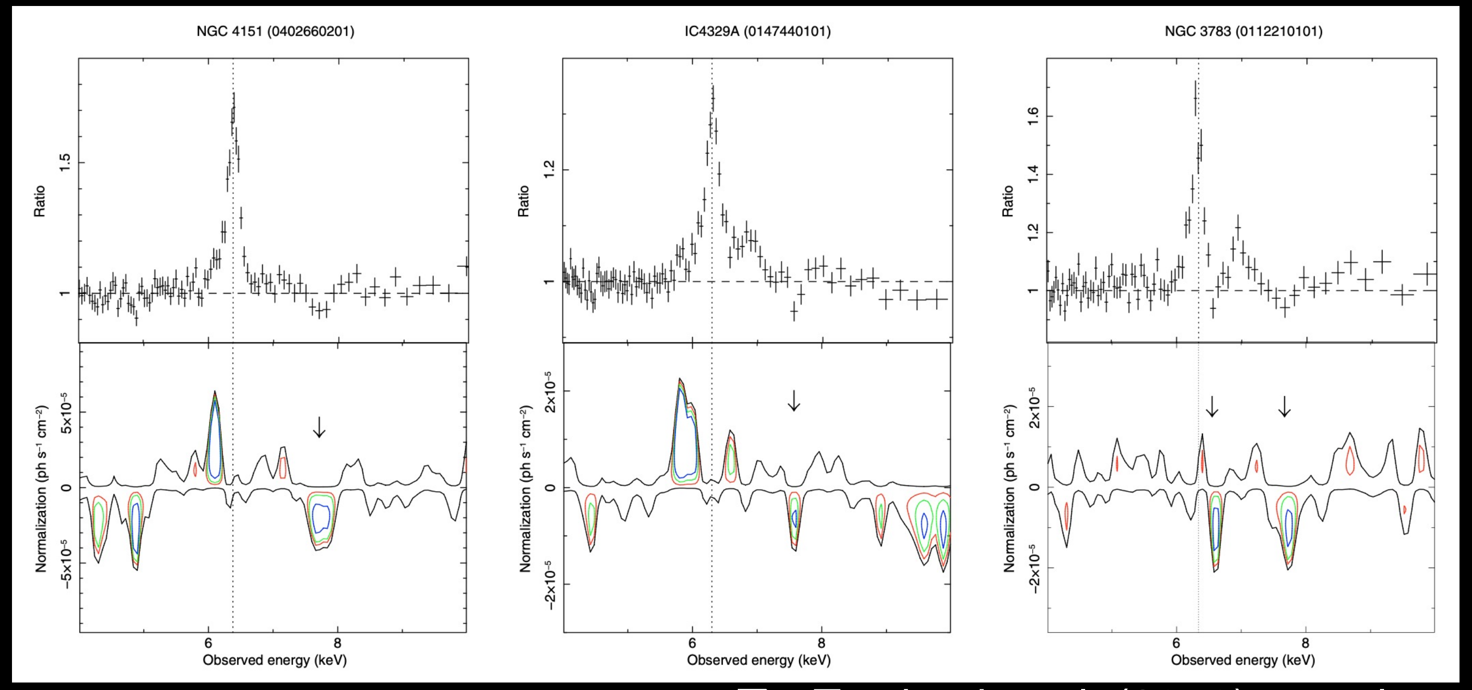
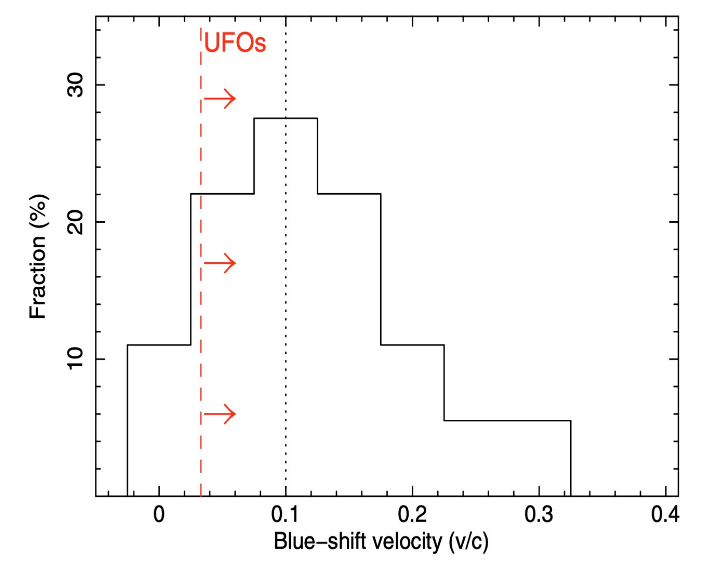
Abstract :
We explore spectral signatures of the predicted multi-ion ultra-fast outflow (UFOs) in the broadband AGN X-ray spectra by exploiting an accretion disk wind model in the context of magnetohydrodynamic (MHD) framework. Expected UFO properties depend on (1) **inclination θ**, (2) **X-ray photon index Γ**, (3) **optical/UV-to-X-ray strength α_{OX}**, (4) **wind density gradient along a line of sight p**, (5) **wind density factor f_D** and (6) **Eddington ratio λ_E**. With an emphasis on radio-quiet Seyferts in sub-Eddington regime, multi-ion UFO spectra are systematically calculated as a function of these parameters to show that MHD-driven UFOs are likely to imprint a unique "tell-tale" asymmetric absorption line profile with a pronounced blue tail structure "on average". Such a characteristic line signature, being almost generic to MHD disk winds due to the intrinsic wind kinematics, can be utilized as a diagnostic proxy to potentially differentiate MHD-driving from other launching scenarios. We also present high fidelity microcalorimeter simulations in anticipation of the upcoming *XRISM*/Resolve and *Athena*/X-IFU instruments to demonstrate that the suggested "tell-tale" sign may be immune to a spectral contamination due to the presence of additional warm absorbers and partially covering gas.

[1] Seyfert UFOs (e.g. Fe XXV/FeXXVI absorbers)



❑ Tombesi et al. (2010) sample

- ❖ ~ 35% of radio-quiet Seyfert 1s
- ❖ v_{out}(mean) ~ 0.14c
- ❖ N_H (mean) ~ 10^{23} cm^{-2}
- ❖ log ξ (mean) ~ 4.2



[2] Generic Characterization of MHD-Driven UFO Model

- ➢ Steady-state, axisymmetric, ideal MHD equations to describe outflows
- ➢ Numerically solve Grad-Shafranov equation with radial self-similarity
- ➢ Thin accretion disk assumed on the equatorial plane (i.e. q_{obs} ~ 90°)
- ➢ Efficient **JxB** acceleration along a poloidal field line
- ➢ No radiation field is assumed (i.e. pure magnetic winds)

$$\rho(\vec{v}\cdot\nabla)\vec{v} = -\nabla p - \rho\nabla\Phi_g + \frac{1}{c}(\vec{J}\times\vec{B}) \quad (\textit{momentum conservation})$$

$$\nabla\cdot(\rho\vec{v}) = 0 \quad (\textit{mass conservation})$$

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

$$\vec{E} + \frac{\vec{v}}{c}\times\vec{B} = 0 \quad (\textit{ideal MHD condition})$$

$$\nabla\times\vec{E} = 0 \quad (\textit{Faraday's law})$$

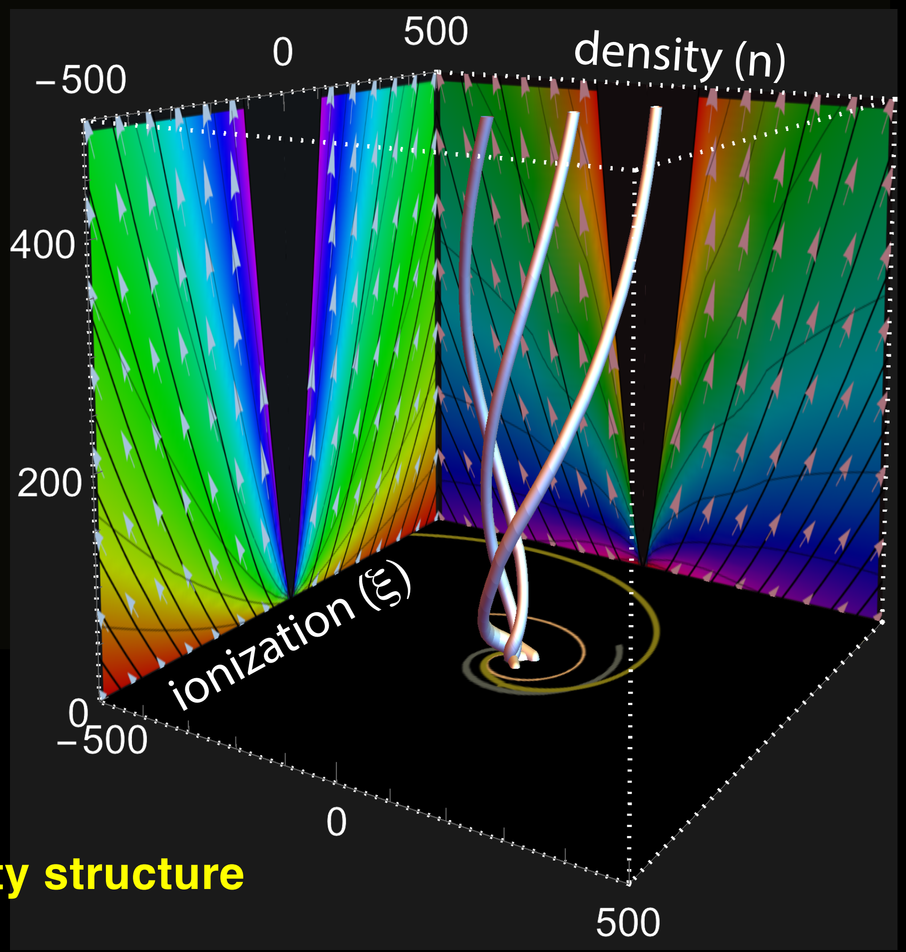
$$n(r,\theta) \equiv n_o f_D \left(\frac{r}{R_{\rm in}}\right)^{-p} h(\theta) \quad \text{and} \quad v_r(r,\theta) \sim v_{\rm K,in}\left(\frac{r}{R_{\rm in}}\right)^{-1/2} g_r(\theta),$$

$$L_{\rm ion} \equiv \int_{13.6\rm eV}^{13.6\rm keV} f_E(\Gamma, \alpha_{\rm OX}, \lambda_E)\, dE\ ,$$

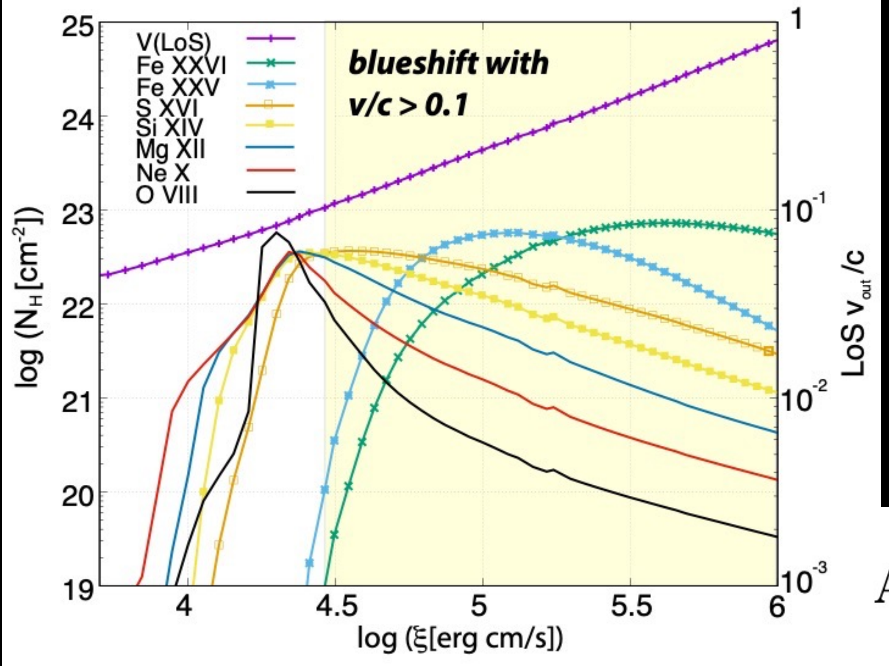
[3] MHD Wind Morphology and Absorption Features

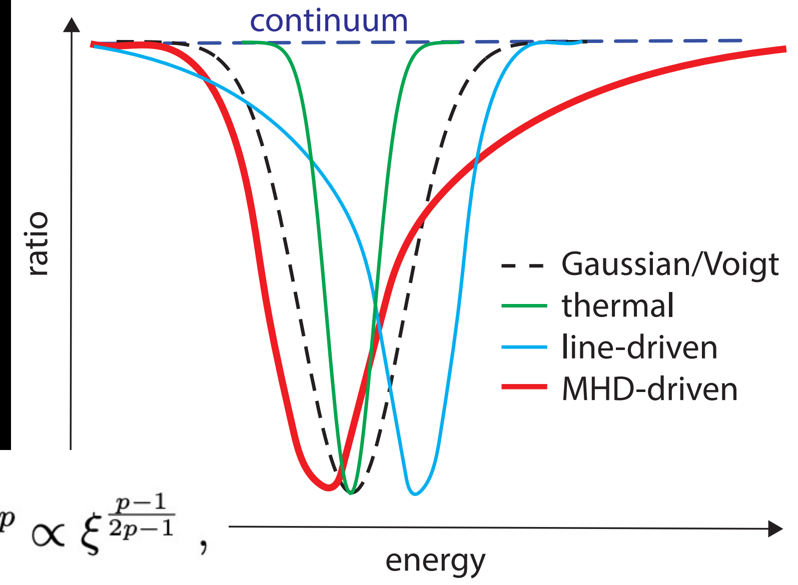
Table 1. Primary Parameters in MHD UFO Model (mhdwind)

	Parameter		Range of Value
1	Inclination [deg]	θ	20° – 50°
2	X-ray Photon Index	Γ	1.5 – 2.5
3	Optical/UV-to-X-ray Strength	$\lvert\alpha_{\rm OX}\rvert$	1.5 – 1.8
4	Wind Density Gradient	p	1.2 – 1.7
5	Wind Density Factor	f_D	10^{-3} – 1
6	X-ray Luminosity	λ_E	0.05 – 0.5



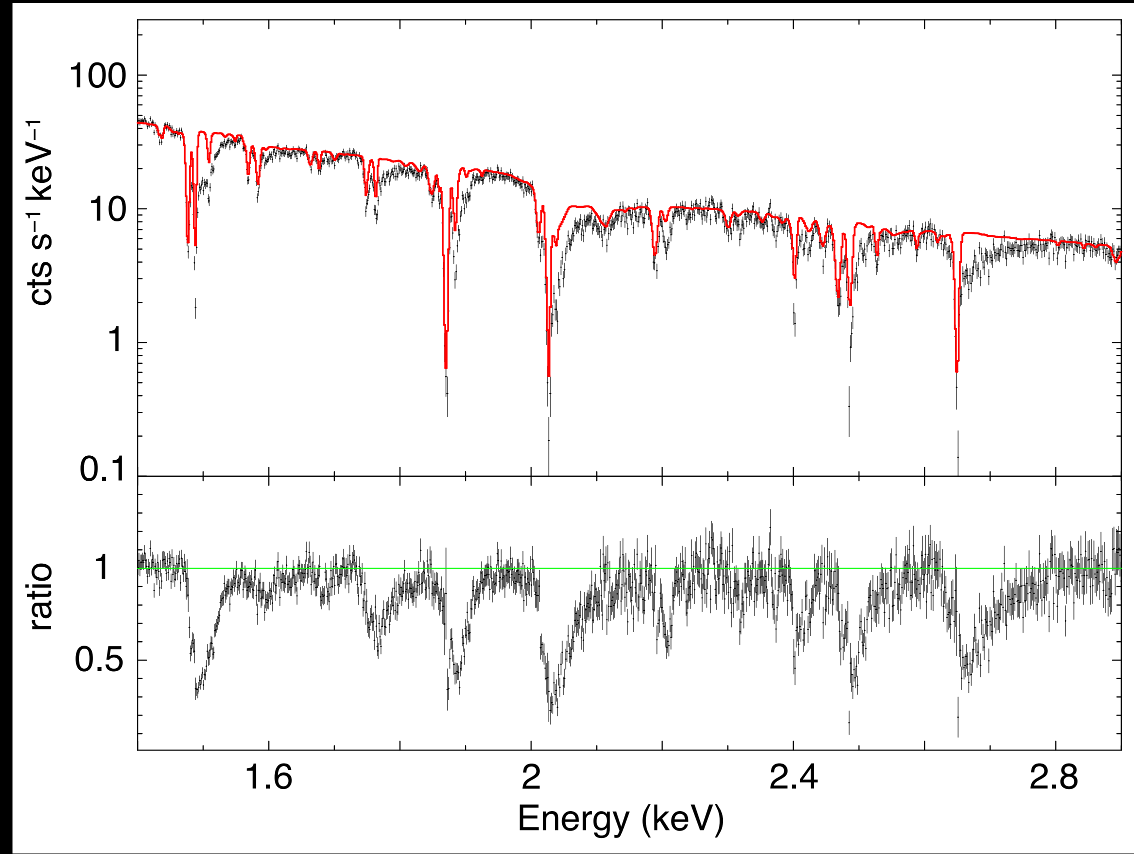
❑ **Asymmetric blueshifted line shape "on average" ⇐ UFO velocity structure**

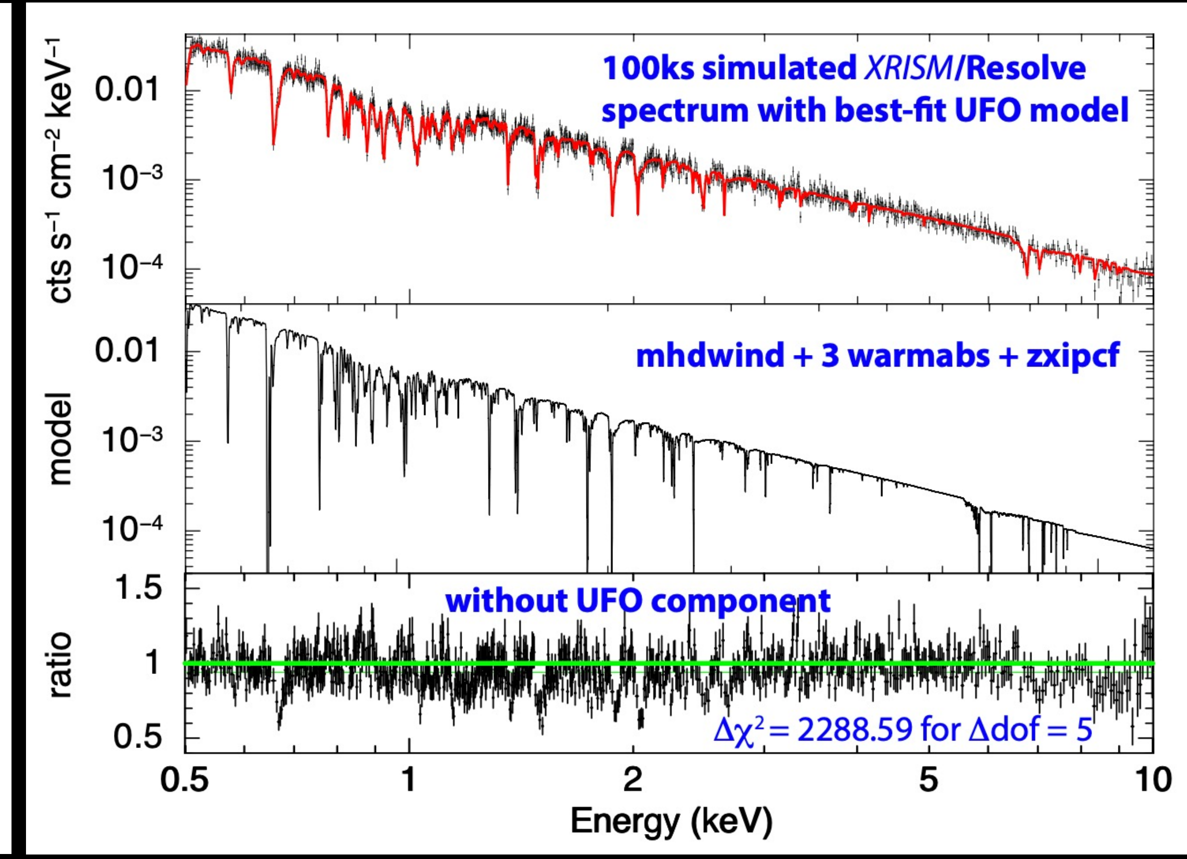




$$\mathrm{AMD}(p) \equiv \frac{d\left[N_{\rm ion}^i(r,\theta)\right]}{d\left[\log\xi(r,\theta)\right]} \propto r^{1-p} \propto \xi^{\frac{p-1}{2p-1}}\ ,$$

❑ **Microcalorimeter Simulations** **See Fukumura et al. (2022), ApJ, 940, 6**





Conclusion - Microcalorimeter has potential to reveal the tell-tale "magnetic sign" in UFO features.