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VARIABILITY AND PARAMETER DEPENDENCE OF HARD X-RAY OBSCURATION AROUND SUPERMASSIVE BLACK HOLES IN ACTIVE GALAXIES*

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ABSTRACT

We investigate hard X-ray obscuration of Active Galactic Nuclei (AGN) by considering photoionization processes for a number of simulated accretion-disk winds in our magnetohydrodynamic (MHD) framework. To follow up our earlier work on calculating synthetic AGN obscuration functions, we are motivated in this work to expand our examination of the dependences of obscuration on individual parameters associated with MHD wind and coronal X-ray such as: X-ray luminosity $L_{\rm ion}$, photon index Γ, density of the wind n_o and its radial gradient p where $n \propto n_o r^{-p}$. We find that AGN appear to undergo a relatively drastic transition from more obscured state (e.g. $N_H \gtrsim 10^{22}$ cm^{-2}) to unobscured state (i.e. $N_H \lesssim 10^{22}$ cm^{-2}) as p approaches to ~ 1.1 in these calculations. In the current formalism, luminosity is linearly coupled to wind density (i.e. $L_X \propto n_o$), and our calculations also indicate AGN become more obscured at higher luminosity. We further discuss the plausibility of the current model in comparison with observations.

Keywords: AGN Host Galaxies — X-ray Active Galactic Nuclei — Radiative Magnetohydrodynamics

1. INTRODUCTION

In our earlier note (Reines & Fukumura 2022), we report a general feature of the absorption function predicted by our magnetohydrodynamic (MHD) disk-wind model (e.g. Fukumura et al. 2010) in which many AGN are expected to be unobscured at low X-ray luminosity and low wind density. This is partly consistent with data derived from a large number of X-ray surveys (e.g. Ueda et al. 2003; Buchner et al. 2015), while we also note in our predictions some discrepencies in the obscured AGN populations at intermediate luminosity. For example, those observations suggest the obscuration decreases with increasing L_X ignoring a likely dependence on Γ. In Reines & Fukumura (2022), we were unable to draw a convincing conclusion due to our narrow choice of the parameter ranges in Γ and L_X. In this note, therefore, we exploit the model predictions by focusing on broader parameter

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ranges with a special interest in exploring the exclusive dependences on X-ray property (i.e. L_X and Γ) and wind condition (i.e. n_o and p) as addressed next.

2. METHODS

Our model institutes MHD equations to determine a geometrical structure of magnetized outflows under strong gravity. Plasma is magnetically lifted away from the BH accretion disk through magnetic field lines. By numerically solving MHD equations for this extreme magnetosphere environment, we obtain a set of fiducial solutions for disk winds. To reduce extra degrees of freedom in our model, we fix a given wind morphology throughout the simulations, while considering different wind density structure and radiation field.

By conducting radiative transfer calculations with `xstar` (Kallman & Bautista 2001), we simulate predicted hard X-ray spectra for various sets of the parameters to be fitted with a single power-law model (in $10-50$ keV band), as we constrain the degree of hard X-ray obscuration by obtaining the neutral column density, N_H, as a proxy for obscuration.

In the past work, we have shown the fraction of X-ray obscured AGN, described by an absorption function, is directly related to intrinsic X-ray luminosity L_X, and wind density normalization n_o. Extending the earlier effort with a focus on specific model parameters, the present work further explores unique roles of X-ray luminosity L_X, wind density n_o, radial gradient p, and photon index Γ.

To examine the individual influences of Γ, n_o, L_X, and p, we fix the inclination angle to $\theta = 45°$ throughout these calculations.

3. CONCLUSIONS AND RESULTS

Our speculations about obscuration dependence on L_X and n_o hold in this study. However, our initial findings about Γ are somewhat weak. We find in the current work Γ exhibits a clear trend when the remaining parameters are held constant; i.e. the softer the X-ray continuum is, the more obscuration.

Figure 1 (Left) shows the exclusive dependence of obscuration on Γ for different sets of n_o and L_X. We have found the fraction of obscured AGN increases with increasing Γ unless L_X is sufficiently low. The positive correlation between N_H and Γ is consistent with how X-ray photons in a harder spectrum (i.e. lower Γ) generally have, as a matter of fact, more penetrating power through the wind material. Regardless of Γ, however, n_o and L_X must be sufficiently low to generate Compton-thin AGN spectra.

The effect of L_X on N_H is given in Figure 1 (Upper Right) for different Γ. We have coupled L_X and n_o in our physical formalism; i.e. as plasma accretes, X-ray photons are produced and emitted from the corona of a black hole. Therefore, these parameters are inherently correlated, and we have incorporated this into our computational framework. This result appears to be the most contentious in comparison with the observations (e.g. Ueda et al. 2003), indicating a physical issue with this coupling assumption in our model.

In our wind model, a steeper density profile (i.e. larger p) forces winds to possess a centrally concentrated material along a line of sight; i.e. a more compact density distribution. We find p can also affect the extent of obscuration in Figure 1 (Lower Left); i.e. AGN surrounded by a more centrally-concentrated wind (e.g. $p \gtrsim 1.1$) are more visible, while a wind of spatially more extended density profile (e.g. $p \lesssim 1.1$) can effectively obscure AGN. For $p \lesssim 1.1$, AGN with softer spectrum

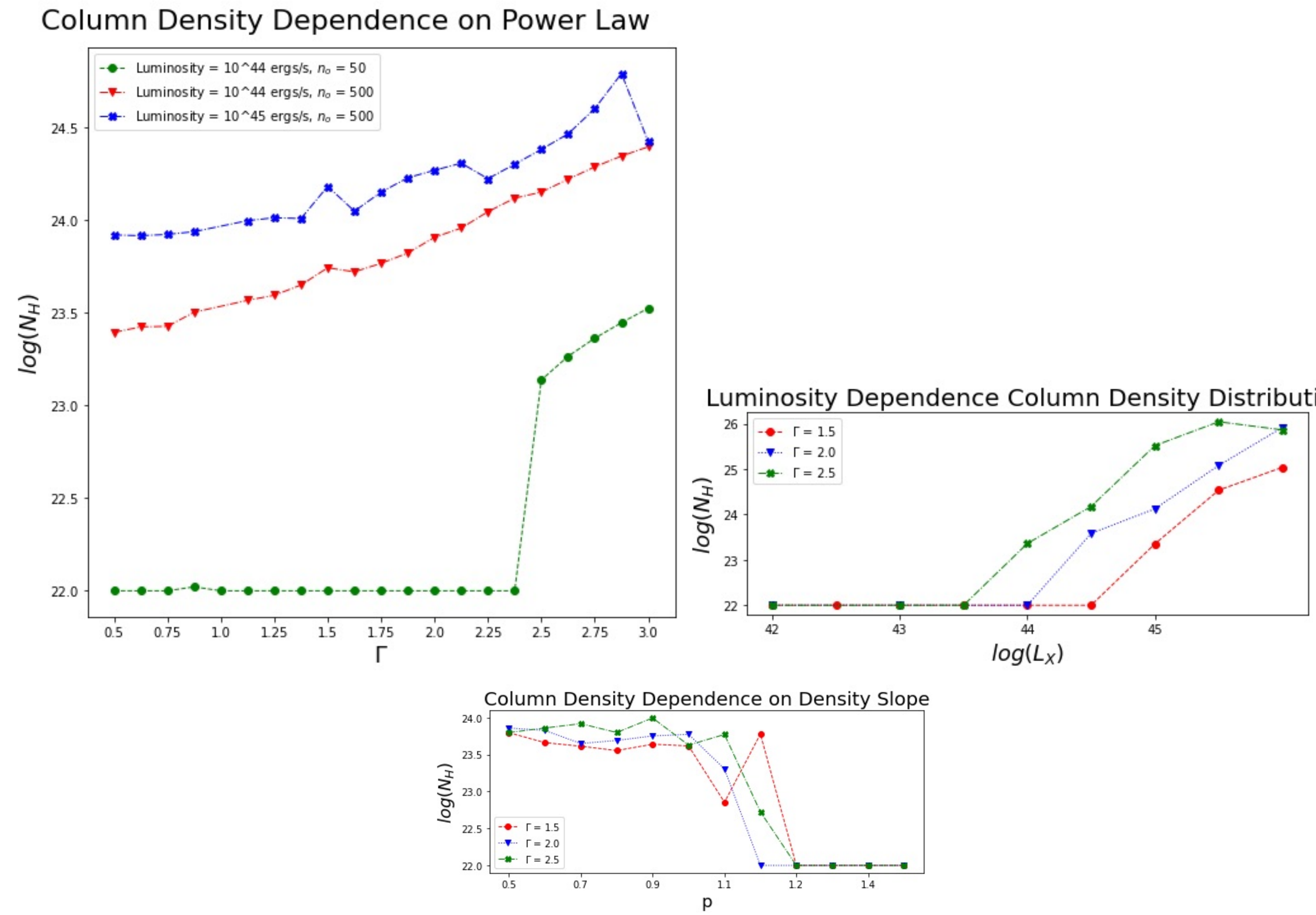

Figure 1. Simulated obscuration with N_H for various model parameters. Left: The effect of Γ for $L_X = 10^{44}$ erg/s and $n_o = 50$ (green), $L_X = 10^{44}$ erg/s and $n_o = 500$ (red) and $L_X = 10^{45}$ erg/s and $n_o = 500$ (blue) for comparison. Any unconstrained low column, $N_H \leq 10^{22}$ cm^{-2}, is readjusted to $N_H = 10^{22}$ cm^{-2} for simplicity. Upper Right: The effect of L_X for $\Gamma = 1.5$ (red), 2 (blue) and 2.5 (green) with $p = 1.0$ and $\theta = 45°$. Lower Right: The effect of p for $\Gamma = 1.5$ (red), 2 (blue) and 2.5 (green) with $p = 1.0$ and $\theta = 45°$.

is more obscured as demonstrated earlier. It is interesting to note there exists a critical p-value at $p \sim 1.1$ separating obscured AGN from unobscured AGN regardless of Γ as if obscuration is suddenly switched off. We call this an obscuration dichotomy within our wind density profile. Such a hypothesis needs to be explored with more thorough simulations in the future work.

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