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X-RAY OBSCURATION AROUND SUPERMASSIVE BLACK HOLES IN ACTIVE GALAXIES*

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ABSTRACT

We investigate obscuration of Active Galactic Nuclei (AGN), identified as Supermassive Black Holes (BH) in luminous galaxies. In this model, winds of plasma particles launched from the accretion disk are photoionized by hard X-ray continua from the AGN's corona, resulting in obscuration in the X-ray band. Many X-ray spectroscopic observations suggest a majority of AGN are obscured by an intervening gas along our line of sight. Through photoionization calculations for selected wind solutions, we simulate the observed AGN obscuration distribution. We discuss the plausibility of the model by comparing our theoretical obscuration distribution to X-ray data by producing a library of synthetic absorption spectra of X-ray continua. Using our model's obscuration findings, we show how the obscuration distribution is dependent on the model parameters.

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

1. INTRODUCTION

Observational hard X-ray studies suggest the fraction of X-ray obscured AGN decreases with the intrinsic luminosity. The amount of obscured AGN is often described by an absorption function with the obscuring column density, N_H. (Ueda et al., 2003)

We model a Magnetohydrodynamic (MHD) phenomenon responsible for the outflow of plasma particles and ions launched from the accreting disk. By utilizing magnetized disk wind models, we develop and construct a computational scheme facilitating the calculation of absorption features for AGN hard X-ray spectrum (i.e. 5keV – 50keV). (Fukumura et al., 2010) Plasma particles and ions flow along magnetic field lines away from the BH accretion disk. By numerically solving MHD equations for this extreme magnetosphere environment, we validate our model which may explain the physics of the observed surveys of AGN obscuration in the context of accretion disk winds. We compute a swath of disk-wind solutions for scenarios of varying parameter values. Our model parameter space includes luminosity - $42 \leq \log(L_X\ [\mathrm{ergs{\cdot}s^{-1}}]) \leq 46$, normalized density of plasma wind - $10^{13} \leq n_o\ [\mathrm{cm^{-3}}] \leq 10^{14}$, observation angle - $\theta = 30°$, $45°$, $60°$, and power law of transmitted X-ray spectrum - $\Gamma = 1.5$, 2.0 (X-ray spectra of AGN are described as power law spectra, characterized by the photon index Γ).

Our method determines the obscuration of hard X-ray photon continuum: the measurement of intervening matter along a line of sight through outflowing disk-wind.

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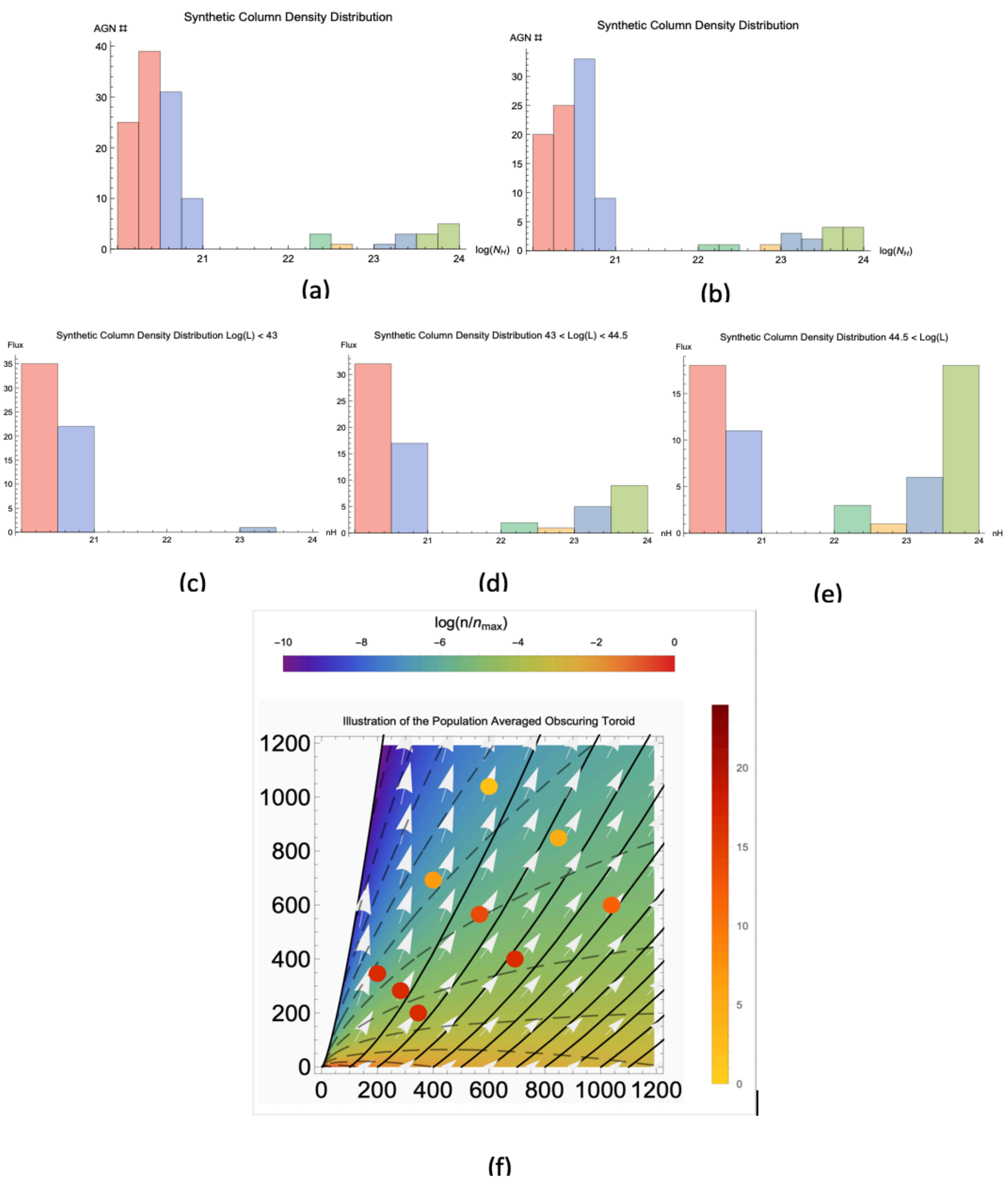

Figure 1. Distribution of our synthetic column density for (a) $\Gamma = 1.5$ and (b) $\Gamma = 2.0$ along with the luminosity-dependence for (c) $L_X < 10^{43}$, (d) $10^{43} < L_X < 10^{44.5}$ and (e) $10^{44.5} < L_X$. (f) Angular distribution ($\theta = 30^\circ$, 45°, 60°) of the mean obscuring column densities N_H in our model for three luminosity regimes with the innermost dot being corresponding to (c), the middle dot to (d) and the outermost dot to (e). Color depicts the mean value of N_H. Superimposed is the color-coded density distribution (normalized) of the disk-wind. White vector arrows denote the velocity field, thick curves denote magnetic field lines, and dashed curve for the density contours.

2. RESULTS

Hard X-ray surveys of a large sample of AGN show many AGN are obscured by a circumnuclear material. As a result, the observed hard X-ray spectra are partially absorbed by the intervening matter. (Ueda et al., 2003) By conducting radiative transfer process (RTP) calculations using the simulated wind solutions and X-ray radiation from a corona, we show ionized winds launched magnetically from an accretion disk can account partly (if not fully) for the observed obscuration. For the range of the model parameters (primarily given by X-ray luminosity L_X, inclination θ, and wind density n_o), we calculate the column density N_H of X-ray-absorbing plasma (i.e. ionized winds) to construct a distribution of N_H as a function of L_X known as an absorption function. The calculated absorption function suggests high-inclination AGN (i.e. larger θ) are obscured the most, while a peak of AGN obscuration exists at the column of $N_H \approx 10^{23\text{-}24}$ cm^{-2} from the luminosity-averaged result. Our theoretical absorption function is in broad agreement with data from literature, while some quantitative details in the model remain to be improved for better explanation.

Figure 1 (a and b) is a distribution of N_H for individual AGN simulations in units of number per bin, normalized to unity in $\log(N_H) = 20$ to 24 cm^{-2}; Figure 1a for $\Gamma = 1.5$ and Figure 1b for $\Gamma = 2.0$. Here we illustrate the number of unobscured AGN at N_H of 10^{20} cm^{-2} and highly obscured AGN at N_H of 10^{24} cm^{-2}. We discovered, using our model simulations, Γ has a negligible effect on our obscuration findings: N_H. Our method for plotting our histogram in Figure 1 (a and b) is analogous to distributions of surveys by Ueda et al, 2003. We identified a vast allotment of essentially unobscured AGN of $N_H \approx 10^5 - 10^{20}$ cm^{-2}. Unobscured AGN derive from simulations with low density and luminosity values. Scenarios with moderate to high luminosity result in greater obscuration of $N_H \approx 10^{22} - 10^{24}$ cm^{-2}. This is also reflected in observed surveys. This majority of unobscured AGN have low normalized density and luminosity values. In the current framework of our model, moderately obscured spectra are the rarest of all populations. Further research is necessary to understand the physical meaning of this dip. In our present philosophy, a threshold - particular set of parameter values - exists where highly energetic X-ray photons become absorbed quickly, resulting in the 'gap' illustrated in Figure 1(a and b).

When examining the upper to lower panels of Figure 1 (c, d, e) we view different luminosity ranges of $42 \leq \log(L_X) \leq 43.5$, $43.5 \leq \log L_X \leq 44.5$, and $44.5 \leq \log L_X \leq 46$. As luminosity is raised, we view an increase of obscuration. Although simple and preliminary (due to limitations of collating and computing the same sample range of AGN), the agreement or our findings with observed surveys is encouraging.

In Figure 1 (f) we show the predicted angular distribution of obscuring column density (filled dots) in our calculations along with the wind density structure (color-coded) and its contours (dashed curves). Magnetic field lines are denoted in thick dark curves and wind velocity vector field is given by white arrows. This cross-sectional view is intended to illustrate the changes in multiple parameters/variables of obscuration phenomenon surrounding the BH. (e.g. Buchner et al., 2015) We examine a geometric distribution of calculated absorption functions. Each point represents N_H value (in log) averaged over a set of different wind density values at varying θ (30°, 45°, 60°). Points closest to the origin correspond to a low luminosity regime. The set of midpoints correspond to intermediate regime. The points furthest from origin correspond to high regime. The contour colors in the background show the wind density distribution as a function of (r, θ) ranging from high (red) near the accretion disk (at $\theta = 90°$) to low (blue) near the innermost wind layer.

This angular distribution plot illustrates the simple trend of increasing obscuration close to the accretion disk. The density and luminosity parameters are coupled in the computation of our model. Therefore, we shall discuss the inverse relation of these parameters, the direct relation of these parameters and the dependence of these parameters on observation angle. When the normalized density and luminosity are inversely related, density high and luminosity low - and vice versa, N_H is low. When normalized density and luminosity are directly related at reciprocal high values, N_H is high, as illustrated also by Figure 1c and 1e. Physically, coronal X-ray photons are absorbed/obscured close to an accretion disk in all luminous AGN.

Notably, obscuration increases with luminosity L_X through the base of the wind at $\theta = 60°$. The wind becomes optically thick with increasing L_X, whereas optically thin with decreasing θ at 30° because of the photoionization balance phenomenon. At low L_X regime, this trend is reversed because the ionization parameter is much lower. This is our finding in this program.

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