Poster contributions of the "Advanced Lectures on the Starburst-AGN Connection", Eds. R. Mújica, I. Aretxaga & D. Kunth, 2001, INAOE Electronic Edition (http://www.inaoep.mx/∼agn00/posters.html), pp. 13-15

Radiation Pressure Acceleration by X-rays in Active Galactic Nuclei

D. Chelouche[1] and H. Netzer[1]

School of Physics and Astronomy and the Wise Observatory, The Beverly and Raymond Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel

Abstract. We present calculations of the dynamics of highly ionized gas clouds that are confined by external pressure, and are ionized by AGN continuum. We focus on the gas that is seen in absorption in the X-ray spectrum of many AGN and show that such gas can reach hydrostatic equilibrium under various conditions. The principal conclusion is that the clouds can be accelerated to high velocities by the central X-ray source and that the acceleration by X-rays is mainly due to bound-free absorption which is efficient for $L/L_{\rm Eddington} \gtrsim 0.1$. The typical velocity for a flow that originates at $R = 10^{17}$ cm in a source with $L = 10^{45}$ erg s^{-1} is $\sim$ 1000 km s^{-1}, i.e. similar to the velocities observed in several X-ray and UV absorption systems.

1. Introduction

Highly ionized X-ray gas (HIG) is common in both types of active galactic nuclei (AGN). The strongest observed features in type-I (Seyfert 1) galaxies are absorption features at around 1 keV, mostly due to O VII(0.74keV) & O VIII(0.87keV). Recent *Chandra* observations reveal the presence of numerous absorption and emission lines (e.g., Kaspi et al. 2000) in some of these sources. The deduced hydrogen column densities range from 10^{21} to 10^{23}cm^{-2} (e.g., George et al. 1998) and the absorption lines are narrow ($\sim$ 300 km s^{-1}) and exhibit outflow velocities of $\sim$ 500 km s^{-1}. Currently, there is no indication of the location and the mass of this component. Objects which show HIG features also show UV absorption systems with similar line properties (Crenshaw et al. 1999).

In this work we investigate the effect of radiation pressure force on HIG clouds and their observed velocities. This involves also the ionization and thermal structure of the gas.

2. The Model

In this work we treat the HIG as a single cloud that is photoionized by a standard AGN continuum. To prevent evaporation, we assume magnetic confinement (Rees 1987; Sivron & Tsuruta 1993) with a chosen radial dependence. We resort to the general method described in Mathews & Blumenthal (1977) in which the cloud structure obeys a hydrostatic equation that includes radiation pressure force and gravity. We assume spherical symmetry and a thin shell configuration of the cloud.

We obtain a self-consistent hydrostatic structure by solving for the ionization and thermal structure and by calculating the radiation pressure force profile in the cloud.

3. Results

Fig. 1 presents the contribution of the different absorption and scattering processes to the total radiation pressure force for a 10^{22} cm^{-2} column density cloud with an ionization parameter, $U_x = 10^{-0.8}$ (see Netzer 1996). While bound-bound processes contribute the most at the illuminated surface, their contribution diminishes into the cloud due to optical depth effects. Bound-free processes are next in importance and are closely related to the ionization structure of the gas. Their contribution is more uniform across the cloud with a tendency to rise towards the non-illuminated surface due to changes in ionization and the shape of a typical AGN continuum. Free-free absorption is, in general, negligible.

Several cases of cloud structure are presented in Fig. 2. A common feature is the rising density towards the non-illuminated surface due to the imposed external pressure boundary condition and the temperature decrease towards the non-illuminated surface. Clouds which are more ionized or have lower column density attain a more uniform structure due to the smaller optical depth. The cloud structure is insensitive to the density up to $n_H \sim 10^{12}$ cm^{-3} above which the micro-physics changes considerably.

The cloud dynamics is described by a ballistic equation of motion, as long as the hydrostatic approximation holds. The acceleration is described by a single parameter - the average force multiplier, $\langle M \rangle$. This is defined as the cloud's bulk acceleration due to radiation pressure force divided by the force due to Compton scattering pressure (see also

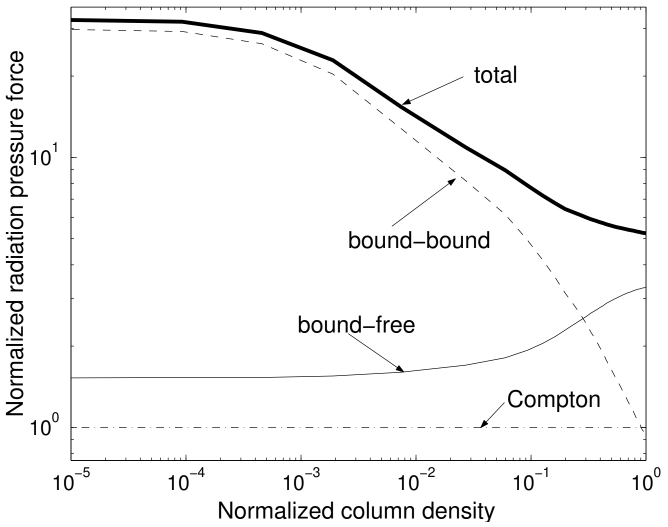

Fig. 1. Contribution of the various radiative processes to the normalized radiation pressure force. 10^{22} cm^{-2} column density is assumed

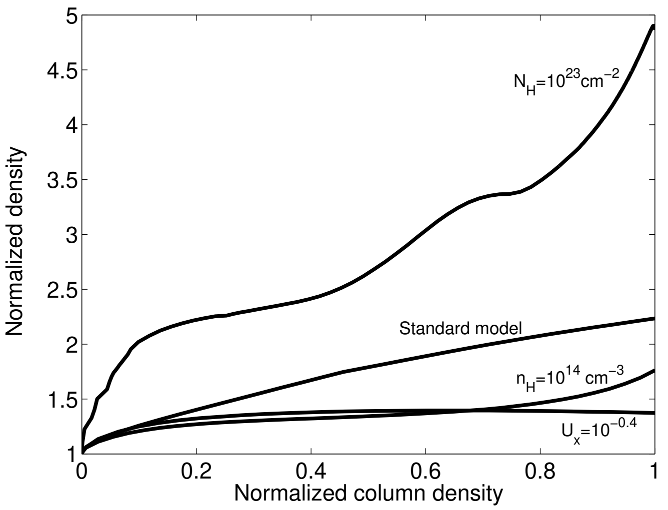

Fig. 2. Cloud density profiles. The standard model is $U_x = 10^{-0.8}$, $N_H = 10^{22}$ cm^{-2}, $n_H = 10^8$ cm^{-3}. This is assumed unless otherwise specified. Note the density rise towards the non-illuminated surface in all models.

Netzer 2000, Chelouche & Netzer 2001). This parameter is related to the cloud structure and depends strongly on N_H and U_x (Table 1). $\langle M \rangle$ decreases with U_x since absorption in highly ionized gas is less efficient and as a result of the typical AGN ionizing flux, being lower at higher energies ($\langle M \rangle \gtrsim 1$ for $U_x > 1$). For $N_H < 10^{22}$ cm^{-2}, $\langle M \rangle$ decreases due to self-shielding (absorption) of the ionizing flux. Above $N_H \sim 10^{22}$ cm^{-2} the cloud becomes less ionized and absorbs the ionizing continuum more efficiently.

Apart from $\langle M \rangle$ which is related to the cloud properties, the dynamics is also affected by external conditions such as the external pressure profile, the AGN luminosity,

Table 1. $\langle M \rangle$ values*

	$N_H = 20$	$N_H = 22$	$N_H = 23$
$U_x = -1.6$	60.	20.	60.
$U_x = -0.8$	20.	10.	12.

* U_x and N_H are in log units.

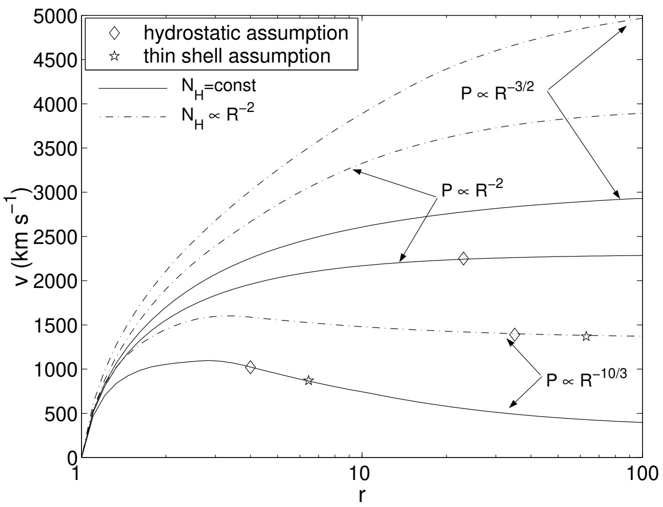

Fig. 3. Velocity profiles for N_H = const and $N_H \propto r^{-2}$ (constant mass) clouds for several external pressure profiles with $L_{45} = R_{17} = 1$, $l = 0.3$. Constant mass models obtain larger final velocities. Pressure profiles where $\log(P_{\rm ext})/\log(r) > -2$ are most efficient in accelerating HIG clouds. Distances at which the hydrostatic approximation and thin-shell geometry are no longer valid are designated.

the launch point of the cloud and the central mass. For $P_{\rm ext} \propto R^{-2}$ the solution of the equation of motion is

$$v(r) = 1350\sqrt{\left(\frac{L_{45}}{R_{17}}\right)\left(\langle M(r)\rangle - \frac{1}{l}\right)\left(1-\frac{1}{r}\right)}\ {\rm km\ s^{-1}} \quad (1)$$

where R_{17} is the launching radius in units of 10^{17} cm, r is the cloud location divided by R_{17}, L_{45} is the source luminosity in units of 10^{45} erg s^{-1}, and $l = L/L_{\rm Eddington}$.

In Fig. 3 we present several dynamical models for constant column density ($N_H(r)$ = const) and constant mass clouds ($N_H \propto r^{-2}$), each with several different assumed $P_{\rm ext}$ (see Netzer 1990). Constant mass clouds are less massive and are therefore accelerated to higher velocities. Rapidly declining pressure profiles are less efficient since the clouds expand and become highly ionized.

4. Conclusions

Photoionized highly ionized gas (HIG) clouds in AGN environment can be accelerated to the outflow velocities inferred from UV and X-ray observations. Such clouds can achieve hydrotstatic equilibrium structure. The dynamical models predict that the HIG lies within or just beyond the broad line region (BLR). Much larger velocities ($\sim 20,000$ km s^{-1}) can be obtained from material that evaporates from the inner accretion disc. The acceleration is most effective for $L/L_{\rm Eddington} > 0.1$ since the clouds are driven mainly by bound-free absorption.

References

Chelouche D., Netzer H., 2001, MNRAS, submitted
Crenshaw D. M., Kraemer S. B., Bogess A., Maran S. P., Mushotzky R. F., Wu C., 1999, ApJ, 516, 750
George I. M., Turner T. J., Netzer H., Nandra K., Mushotzky R., Yaqoob, T., 1998, ApJS 114, 73
Kaspi S., Brandt W. N., Netzer H., Sambruna R., Chartas G., Garmire G. P., Nousek J. A., 2000, ApJ 535, L17
Mathews W. G., Blumenthal G.R., 1977, ApJ 214, 10
Netzer H., 1990, in Courvoisier T.J.-L.& Mayor M., eds., Active Galactivc Nuclei. eds., Springer-Verlag, Berlin, p. 57
Netzer H., 1996, ApJ, 473, 781
Netzer H., 2000, In: Proc. of the "Advanced Lectures on the Starburst-AGN Connection", World Scientific
Rees M. J., 1987, MNRAS 228, 47
Sivron R., Tsuruta S., 1993, ApJ 402, 420