The effects of radiation pressure on the absorption in the Chandra Deep Fields

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The presence of absorbing gas around the central engine of Active Galactic Nuclei (AGN) is a common feature of these objects. Recent work has looked at the effect of the dust component of the gas, and how it enhances radiation pressure such that dusty gas can have a lower effective Eddington limit than ionised gas. In this work, we use data from the 2 Ms exposures of the *Chandra* Deep Field North and *Chandra* Deep Field South surveys, to characterise the AGN in terms of their Eddington ratio (λ) and hydrogen column density (N_H). We find that most of the AGN in our sample tend to be found at low Eddington ratios (typically $10^{-4} < \lambda < 10^{-1}$) and high N_H (> 10^{22} cm^{-2}), with black hole masses in the range (10^7 - 10^9) M_{Sun}. Their distribution is in agreement with that expected from the enhanced radiation pressure model, avoiding the area where we would predict the presence of outflows.

Introduction

The obscuring material around AGN will be under the effect of the inward gravitational force of the supermassive black hole and the outward pressure of the emitted radiation. By investigating the balance between these two forces, one can predict the behaviour of the gas on the scale of tens of parsecs. The Eddington ratio ($\lambda = L/L_{Edd}$), is a measure of the ratio between the luminosity of the source (L) and the luminosity at which the radiation pressure balances the gravitational force (L_{Edd}). In the presence of dust, the gas couples with the dust grains, increasing the effective cross-section and lowering L_{Edd}. The effective Eddington ratio, written as a function of the standard Eddington ratio is then (Fabian et al. 2006):

$$\lambda_{eff} = \frac{L}{L_{Edd}} \frac{\sigma_D}{\sigma_T} = \lambda \frac{\sigma_D}{\sigma_T}$$

where σ_T is the cross-section for Thomson scattering and σ_D is the effective cross-section including dust. AGN that are below their standard Eddington limit ($\lambda < 1$) can be above the effective limit ($\lambda_{eff} > 1$) when considering dusty gas. **Fig. 1** shows the different states for AGN. In the white region ($\lambda_{eff} > 1$) we expect to have objects experiencing outflows or variable absorption; in the grey area, AGN will have long-lived absorption. The pink region represents column densities due to dust lanes further out in the galaxy. In any case, their N_H is expected to be lower than 5 x 10^{21} cm^{-2} .

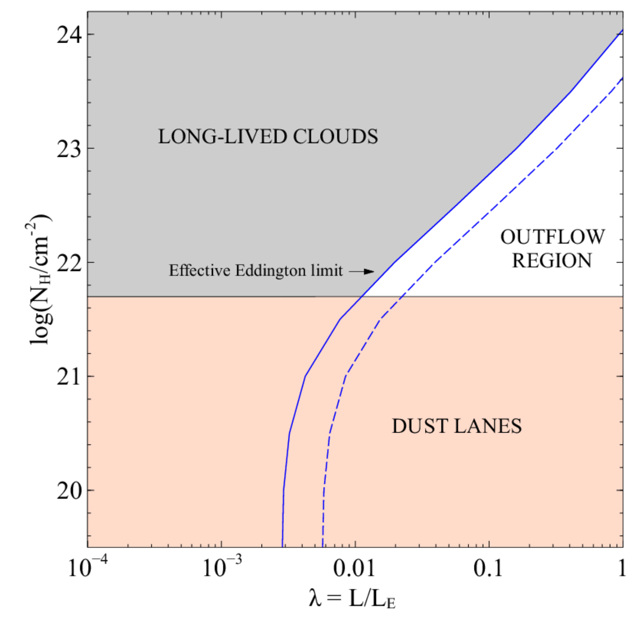

Fig. 1) Hydrogen column density vs Eddington ratio plot. The solid line represents the effective Eddington limit for dusty gas. The dashed line indicates the effective limit when the mass of the enclosed stars is considered.

Results

To test the model described above, we use data from the 2Ms exposures in both *Chandra* Deep Fields. The N_H and luminosities for the sample are determined from X-ray spectral fitting (Bauer et al. 2010, in prep). Spectroscopic redshifts were compiled by Luo et al. 2010 (CDF-S) and by Rafferty et al. 2010 (CDF-N). For the sources without spectroscopic redshifts, photometric redshifts obtained from multi-wavelength SED fitting were used (Xue et al. 2010). AGN are selected based on their luminosity ($L_{2\text{-}10\,keV} > 10^{41}$ erg/s) and their masses are obtained with a $M_{BH} - M_{K\text{-}band}$ scaling relation (Graham et al. 2007).

Fig. 2 shows our results for the 160 AGN with z < 1 in both fields. Most of our objects lie in the upper left region of the plot. More than 95% of the sources with $N_H > 5\times10^{21}$ cm^{-2} avoid the area where we would expect to see outflows (white region), which means that the absorbing clouds around them are long-lived.

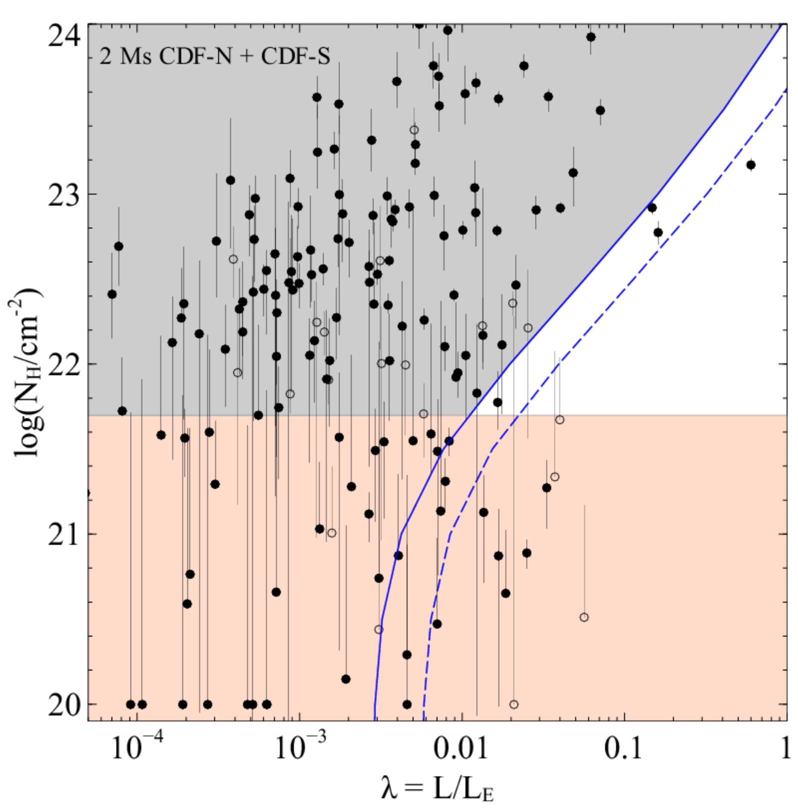

Fig. 2) Distribution of our sample of z < 1 AGN in the regions from Fig.1. Filled circles represent AGN with spectroscopic redshifts, and open circles AGN with photometric redshifts only. The sources tend to be obscured and to avoid the outflow region. Errors in Eddington ratios are of the order of 30%.

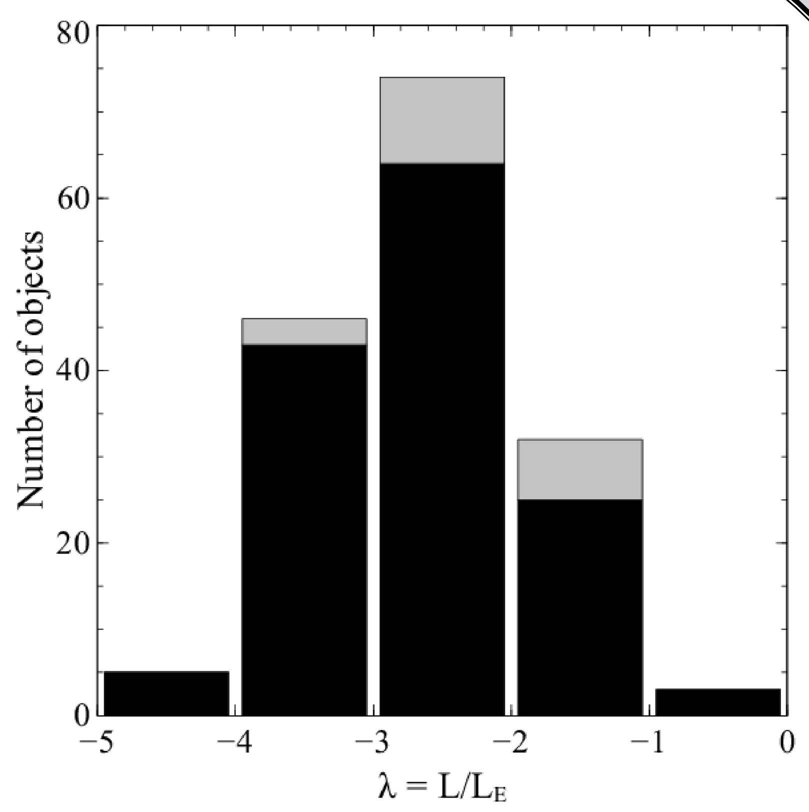

Fig. 3) Eddington ratio distribution. Black histogram represents sources with spectroscopic redshifts, grey histogram adds the sources with photometric redshifts only. AGN have a wide range of Eddington ratios, varying mainly between 10^{-4} – 10^{-1}, as also found by Babić et al. 2007.

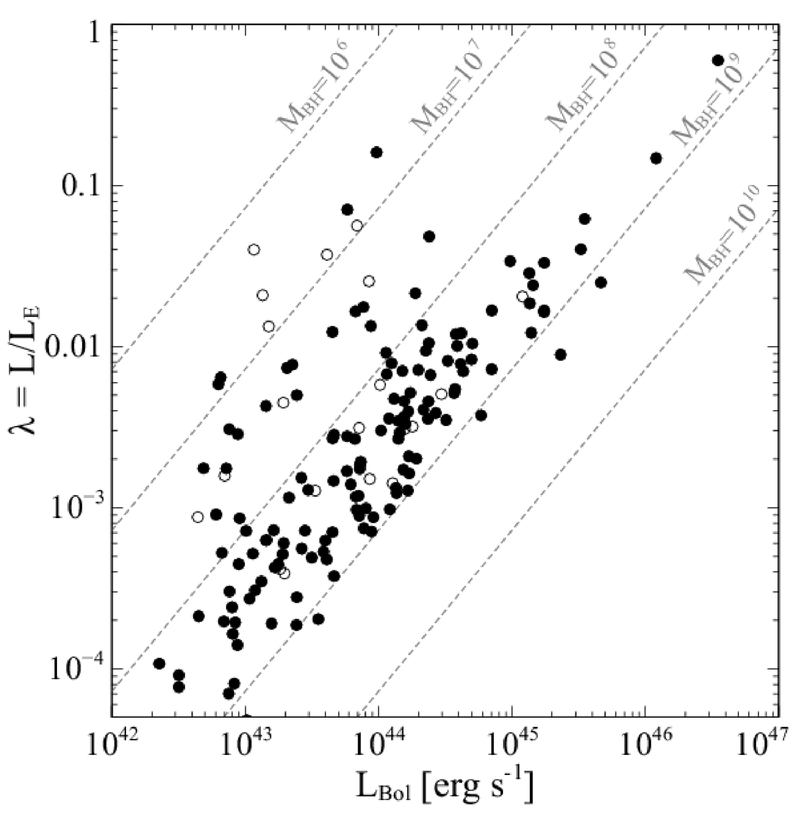

Fig. 4) Eddington ratio as a function of bolometric luminosity. Filled circles represent AGN with spectroscopic redshifts, and open circles AGN with photometric redshifts only. The dashed lines separate between different black hole masses (in units of M_{Sun}).

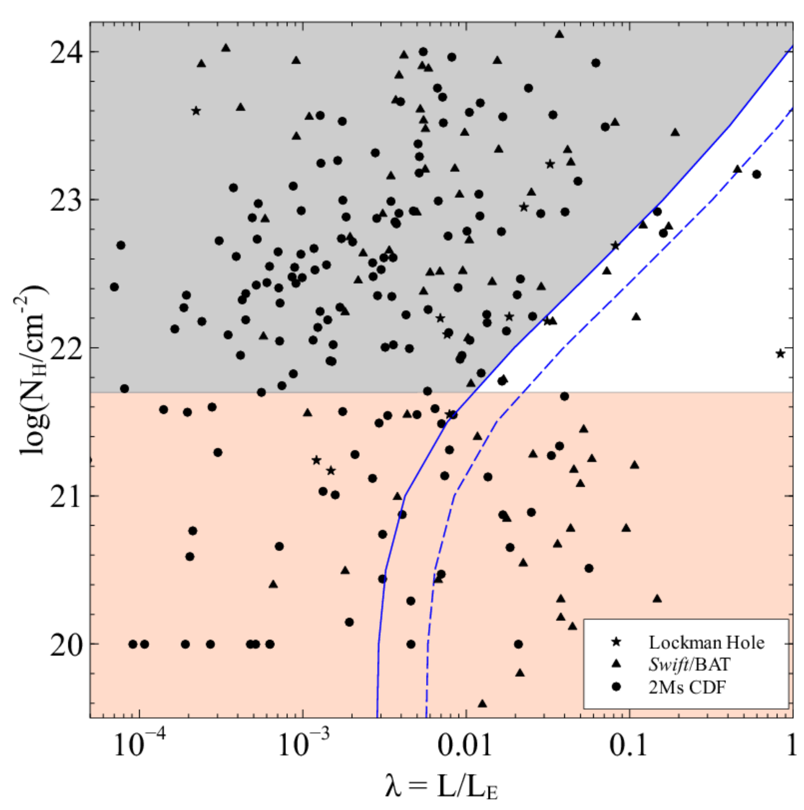

Fig. 5) Summary plot of results from the Lockman Hole, *Swift*/BAT and CDF (this work). Dashed line considers an increase of the enclosed mass by a factor of 2 M_{BH} when calculating L_E

Fig. 3 and **Fig. 4** present the general properties of our sample. In **Fig. 5** we compare our results with previous works on this subject (Fabian et al. 08; Fabian et al. 09). Compiling data from local AGN (Swift/BAT), Lockman Hole and Chandra Deep Fields (the present work), we reinforce our conclusion on a wider redshift range.

The planned *International X-Ray Observatory* (IXO), will be able to detect outflows at high redshifts, due to its high spectral resolution at low X-ray energies (< 2 keV) and large effective area. The sources lying close to the effective Eddington limit in **Fig. 2**, and in particular, the ones clearly above it, are very good targets for future spectroscopic studies like those.

Conclusions

- We have analysed a large sample of AGN in the CDF-S and CDF-N and shown that in general they have large column densities (log N_H > 22) and a wide distribution of Eddington ratios.
- These objects tend to lie below their effective Eddington limit, spending most of their time obscured.
- More than 95% of the AGN with N_H > 5 x 10^{21} cm^{-2} avoid the outflow region.
- Our conclusions are in agreement with previous results, and are applicable to not only deep CDF samples but also to local AGN.
- The AGN lying close to the effective Eddington limit are likely to present outflows. These objects are primary candidates for future spectroscopic studies.

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