Absorption and scattering properties in polarized bright soft X-ray selected ROSAT AGN

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Abstract. We have surveyed the optical linear polarimetric properties of 65 soft X-ray selected ROSAT Active Galactic Nuclei (AGN). Most of these sources show low polarization (<1\%) and no optical reddening. This is in agreement with the X-ray results suggesting a direct view on the center. However, two of our AGN show polarization as high as 7–8\% and high reddening. This optical reddening suggests a high column of dusty gas, but why does this gas not absorb the soft X-rays? We suggest that the dusty gas is actually ionized. There is evidence for these ‘warm’ absorbers from X-ray absorption features seen in ROSAT and ASCA spectra.

1. Introduction

It is commonly accepted by most astronomers that all Active Galactic Nuclei (AGN) are powered by the same type of engine: accretion of matter though an accretion disk onto a super-massive black hole. What kind of matter is it that fuels the engine and how is it distributed? In order to try to answer this question we have to apply different observational techniques, such as the study of the X-ray properties and optical linear polarimetry.

Our study of soft X-ray selected AGN (Grupe et al. 1998a,b) has shown that AGN with steep X-ray spectra tend to have relatively narrow Broad Line Region (BLR) emission lines, weak Narrow Line Region (NLR) emission lines, and strong FeII emission (see also the article by Thomas Boller about Narrow-Line Seyfert 1 galaxies in these proceedings). Two hypotheses to explain the narrowness of their H\(\beta\) are (i) that the systems are seen at high inclination, so the highest velocity BLR is obscured by a dusty torus. This is suggested by unified schemes for Seyfert 2s, in which a ‘hidden’ Seyfert 1 nucleus is revealed by its scattered (polarized) spectrum (e.g. Antonucci & Miller 1985, Cimatti et al. 1993), and (ii) that the narrower H\(\beta\) is the result of a lower mass black hole – with the strong, rapidly variable soft-X-rays arising from an unobscured view of the hotter inner regions of the accretion disk (Boller et al. 1996, Grupe et al. 1998a). The former hypothesis predicts scattering polarization, while the latter predicts zero polarization. If this is so, we can expect to see very broad lines and continuum in scattered, polarized light. This was the original motivation for our polarization survey. On the other hand, our X-ray studies have shown that there is little or no absorption of soft X-rays by neutral elements in these AGN (Grupe et al. 1998a). This lack of absorption suggests a direct view to the center, which means we would not expect these sources to be polarized.

2. Sample and Observations

The AGN sample we used for the X-ray and optical spectral studies (Grupe et al. 1998a, b) was based on complete identifications of all bright soft X-ray sources from the ROSAT All-Sky Survey (RASS, Voges et al. 1993, 1998, Thomas et al. 1998). The RASS used the position sensitive proportional counter (PSPC), sensitive between 0.2 and 2 keV. Our selection criteria were: PSPC count rate > 0.5 cts s\(^{-1}\), hardness ratio 1 < 0.0, and |\(b\)| > 20\(^\circ\). Adopting these criteria led to a sample of 110 AGN. In addition to the PSPC X-ray spectra, our database includes medium-resolution spectroscopy obtained at ESO, La Silla, Chile, and McDonald Observatory, Texas. Details of data reduction, and the results are given by Grupe et al. (1998b).

For the polarimetry survey, we used a broad-band polarimeter on the 2.1m telescope at McDonald Observatory. More details about the observations can be found in Grupe et al. (1998c), where we presented results for the sample defined above. We have complete polarization data for 65 objects. The sample is complete for the northern hemisphere plus some objects of southern declination that are accessible from McDonald or from which information can be found in the literature. All in all, two thirds were observed by us, and for 1/3 we took data from the literature (mainly Berriman 1989, Berriman et al. 1990). For those objects that turned out to be highly polarized we also obtained spectropolarimetry at the 2.7m telescope at McDonald.

We compared the results for our soft X-ray AGN sample with those from the optically selected Narrow-Line
Seyfert 1 galaxies (NLSy1s) sample that Goodrich (1989) studied by spectropolarimetry. For the Goodrich sample we also collected optical spectroscopic and ROSAT X-ray data. While his sample is biased towards optical properties, it is unbiased with respect to soft X-ray properties, e.g. cold absorption.

3. Survey Results

Figure 1 displays the distribution of the degree of polarization for the 65 objects of our soft X-ray selected sample. Most of these show no or only low degrees of polarization, \( p < 1\% \). One object was found with \( p \approx 1\% \) (CBS 126), three objects showed \( p \approx 2\% \) (NGC 1068, H0439-272, Mkn 766), and two sources with \( P > 4\% \) were found (IRAS F12397+3333, IRAS 13349+2438). While IRAS 13349+2438 has been extensively studied before (e.g. Wills et al. 1992, Brandt et al. 1996, 1997), IRAS F12397+3333 is new.

We were curious to find out if there were any differences between polarized and unpolarized AGN. We did not find any differences in their line widths or X-ray spectral indices compared with the rest of the sample. However, the polarized AGN turned out to be the ones with high Balmer decrements and steep (reddened) optical continua. These objects seem to be affected by dust.

3.1. The polarized AGN

Six objects of the sample have shown polarization above 1%: CBS 126, NGC 1068, Mkn 766, H 0439-272, IRAS F12397+3333, and IRAS 13349+2438. The degree of polarization of CBS 126 turned out to be wavelength independent. Probably this can be explained by polarization through aligned dust grains and not by scattering, which would show a stronger wavelength dependence in the degree of polarization. Scattering polarized AGN show a wavelength dependence because we look for the dilution of the polarized light by unpolarized light. In the case where the unpolarized light absorbed by dust, the unpolarized spectrum is reddened. Therefore, the signature of scattering is an increase of the degree of polarization towards the blue. NGC 1068 is a special case in our sample, included because of its extended soft X-ray emission. Mkn 766 is also one of the sources in Goodrich’s NLSy1 sample. We found H 0439-272 to be polarized during our 1998 McDonald observations, so detailed spectrophotometry is not yet available. We concentrate here on the two ‘highly polarized’ AGN IRAS 13349+2438 and IRAS F12397+3333. Both objects show a strong wavelength dependence in the degree of polarization (see Grupe et al. 1998c). This is a sign of scattered light. We observed both objects by spectropolarimetry. While the results of this study have been already published for IRAS 13349+2438 (Wills et al. 1992), we are preparing the results of the IRAS F12397+3333 data for publication now.

The results of our spectropolarimetry observation of IRAS F12397+3333 show that there is a slightly higher degree of polarization in the broad lines and a much lower degree of polarization can be seen in the narrow lines. We discuss the significance of this later.

As noted before, the polarized AGN are those that are highly affected by dust reddening. The question is, should they not be affected by cold, neutral absorption in soft X-rays as well? Why do we see soft X-rays from these highly reddened objects? Objects such as IRAS 1509-21 from Goodrich (1989)’s sample shows both high reddening and attenuation of soft X-rays by neutral absorption. The answer may be that the absorption is by dusty, ionized ‘warm’ gas (extra ionized absorbers in there). This gas absorbs at intermediate X-ray energies (~ 0.5-3.0 keV), but is transparent to soft X-rays. If our objects are affected by warm absorbers we can expect to see their characteristic absorption features around 0.7-0.9 keV, caused by highly ionized oxygen ions (O VII at 0.74 keV and O VIII at 0.87 keV). Brandt et al. (1996, 1997) have intensively studied the ROSAT and ASCA data of IRAS 13349+2438 and found exactly those features in the X-ray spectra. Fortunately, IRAS F12397+3333 had been observed serendipitously, in a long ROSAT ‘pointed’ exposure of a nearby source. We found warm absorber features in the ROSAT spectrum of this source (see Figure 2). In order to get a more significant result we had ASCA observations of this source in 1998 June just a few days before this conference. From a quick look at these new data, we also find warm absorber features in the ASCA spectra. The details of the ROSAT and ASCA data as well as the spectropolarimetry results will be presented in detail (Grupe, Leighly & Wills; Wills, Grupe, Leighly & Wang in preparation).

4. Discussion

Most of the AGN we studied have shown polarization < 1%. This favors a direct, unobscured view to the nucleus.
Fig. 2. ROSAT PSPC spectrum of the pointed observation of IRAS F12397+3333. The upper panel shows a single power law fit to the data ($\alpha_X = 2.0$, $N_H = 2.8 \times 10^{21} \text{ cm}^{-2}$, $\chi^2/\nu = 1.8$). The fit can be significantly improved by adding an absorption edge of OVII at 0.74 keV (rest frame). We find an optical depth of $\tau = 0.9 \pm 0.2$, $\chi^2/\nu = 1.0$. The ratio of this fit is given in the lower panel.

This is in agreement with our finding of no cold absorption of soft X-rays and the flat optical, unreddened spectra and the low Balmer decrements. We can therefore rule out the hypothesis that the relatively narrow BLR lines found in NLSy1s are a result of obscuration of the inner high velocity BLR clouds.

However, the situation in the polarized AGN might be different. All those AGN have shown high Balmer decrements and reddened optical spectra. This suggests that they are affected by dust. Their polarization is wavelength dependent. The explanation is that the scattered and therefore polarized light is diluted by a redder unpolarized component. The direct light must go through some dust. We can ask where the scatterers, warm absorbers, and dust are located. The answer to this question may be found by spectropolarimetry. We find that the BLR lines are only slightly more polarized than the continuum, but the NLR lines are much less polarized. Therefore we can conclude that the dust must be located somewhere between the BLR and us, but it does not affect the NLR emission. It must be inside or just outside of the BLR.

The observation of central soft X-ray emission in these highly reddened AGN can be explained by the presence of warm, ionized absorbers. We find those features in the X-ray spectra of our polarized AGN. Leighly et al. (1997) have even shown that scattering polarized AGN tend to show warm absorber features in their ASCA data. On the other hand, objects that do not show ‘warm’ absorber features in their ASCA spectra, turn out to be low or unpolarized. ASCA observations in connection with HST observations of objects that have shown a warm absorber in their ASCA spectra even reveal UV absorption features – suggesting ionized outflows from AGN (e.g. Mathur et al. 1997). Further studies of these polarized soft X-ray selected AGN can help us to understand the structure, kinematics, and physical conditions on scales less than a few pc in AGN. With the new upcoming X-ray satellites a more detailed study of the absorption features will be possible to get more information about the kinematics of these absorbers.

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