DUSTY WARM ABSORBERS: THE CASE OF IRAS 13349+2438

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Abstract. Warm absorbers are an important new probe of the central region of active galaxies (AGN). Observing and modeling this component provides a wealth of information on the nature of the warm absorber itself, its relation to other components of the active nucleus, and the intrinsic AGN X-ray spectral shape.

We briefly review the general properties of dusty warm gas. For the first time, we then apply such a model to the IR loud quasar IRAS 13349+2438. It was the first to be suggested to host a dusty warm absorber (Brandt et al. 1996), but has not yet been modeled as such.

1. Dusty warm absorbers
1.1. INFLUENCE OF DUST ON THE X-RAY ABSORPTION STRUCTURE

So far, warm absorbers revealed their existence mainly in the soft X-ray spectral region by imprinting absorption edges on the X-ray spectra of many AGN. This highly ionized material provides an important new diagnostic tool to investigate the physical conditions in the nuclei of active galaxies.

Recently, evidence has accumulated that some warm absorbers contain significant amounts of dust. This possibility was first suggested by Brandt et al. (1996, B96 hereafter) to explain the lack of excess X-ray cold absorption despite strong optical reddening of the quasar IRAS 13349+2438. A point emphasized by Komossa & Fink (KoFi hereafter, e.g. 1997a,b) and Komossa & Bade (KoBa; 1998) is the strong influence of the presence of dust on the X-ray absorption spectrum which becomes drastic for high column densities.
TABLE 1. Properties of the dusty warm absorber in IRAS 13349 derived from X-ray spectral fits. For comparison results for a dust-free warm absorber are shown. The derived properties of the ionized material and the intrinsic continuum are rather different in this case.

|            | warm absorber | single powerlaw |
|------------|---------------|-----------------|
|            | $\Gamma_x$   | $\log U$        | $\log N_w$ | $\chi^2_{\text{red}}$ | $\Gamma_x$ | $\chi^2_{\text{red}}$ |
| dusty WA   | $-2.9$        | $-0.4$          | $21.2^{(1)}$ | 1.2 | $-2.8$ | 1.3 |
| dust-free WA | $-2.2$     | 0.7             | 22.7       | 0.8 |

$^{(1)}$ fixed to the value $N_{\text{opt}}$ determined from optical reddening

$N_w$. Signatures of the presence of (Galactic-ISM-like) dust, as opposed to the dust-free case are, e.g.,
- a strong carbon edge in the X-ray spectrum,
- a stronger temperature gradient across the absorber with more gas in a ‘colder’ state, shifting the dominant absorption edges to more lowly ionized species
- increased sensitivity of dusty gas to radiation pressure, which may drive strong outflows of the warm material.

The first two effects lead to an effective flattening of the observed X-ray spectrum. Thus, for both, the derivation of the physical properties of the warm absorber as well as the intrinsic spectral shape it is important to apply self-consistent models that take into account the presence of dust.

2. The IR-loud quasar IRAS 13349+2438

This quasar received a lot of attention, recently. A detailed optical study was presented by Wills et al. (1992). In a thorough study of the ROSAT X-ray spectrum of IRAS 13349+2438, B96 suggested the presence of a dusty warm absorber. Brinkmann et al. (1996) detected changes in the ASCA spectrum as compared to the earlier ROSAT data; the warm-absorption features remained present (Brandt et al. 1997). Further candidates for dusty warm absorbers quickly followed, including NGC 3227 (KoFi 1996, 1997b), NGC 3786 (KoFi 1997c), and IRAS 17020+4544 (Leighly et al. 1997, KoBa). Whereas the model of a warm absorber that includes the presence of dust has been successfully fit to these objects, it has not yet been applied to IRAS 13349+2438 (first results of the present study were reported by Komossa 1998, and Komossa & Greiner 1999). Given the potentially strong modifications of the X-ray absorption spectrum in the presence of dust, it is important to scrutinize whether a dusty warm absorber is consistent with the observed X-ray spectrum. Since some strong features of
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Figure 1. Residuals after applying different spectral models to the ROSAT X-ray spectrum of IRAS 13349+2438. Left: simple powerlaw model, middle: dust-free warm absorber, right: dusty warm absorber (see text for details). Systematic residuals around 0.8 keV, the location of the OVII and OVIII absorption edges, are better removed by the dust-free warm absorber due to the presence of a much stronger OVIII edge in the best-fit model as compared to the dusty case. Fine-tuning in the dust-properties or the oxygen metal abundances with corresponding changes in the heating-cooling balance might alleviate this problem.

Dusty warm absorbers appear outside the ASCA sensitivity range, ROSAT data are best suited for this purpose; we used the two pointed PSPC observations of IRAS 13349+2438 of Jan. 1992 and Dec. 1992.

As ionizing continuum illuminating the absorber we adopted a mean Seyfert spectrum of piecewise powerlaws (as in KoFi 1997b) with $\alpha_{\text{EUV}} = -1.4$. We use as definition for the ionization parameter $U = Q/(4\pi r^2 n_{\text{H}} c)$, where $Q$ is the rate of photons above the Lyman limit. The photoionization calculations were carried out with Ferland’s (1993) code Cloudy.

In a first step, we fit a dust-free warm absorber (as in B96, but using the additional information on the hard X-ray powerlaw available from the ASCA observation, $\Gamma_{x}^{2-10\text{keV}} \sim -2.2$). This gives an excellent fit with log $N_w = 22.7$ ($\chi^2_{\text{red}} = 0.8$). If this same model is re-calculated by fixing $N_w$ and the other best-fit parameters but **adding dust** to the warm absorber the X-ray spectral shape is drastically altered and the data can not be fit at all ($\chi^2_{\text{red}} = 150$). This still holds if we allow for non-standard dust, i.e., selectively exclude either the graphite or silicate species.

Whereas this first approach was mainly to demonstrate the strong influence of the presence of dust, it has to be kept in mind that the expected column density $N_{\text{opt}}$ derived from optical extinction is less than the X-ray value of $N_w$ determined under the above assumptions. Therefore, in a next step, we allowed all parameters (except $\Gamma_x$) to be free and checked, whether a dusty warm absorber could be successfully fit at all. This is not the case (e.g., if $N_w$ is fixed to log $N_{\text{opt}} = 21.2$ we get $\chi^2_{\text{red}} = 40$).

The bad fit results can be partially traced back to the ‘flattening’ effect of dust. In fact, if we allow for a steeper intrinsic powerlaw spectrum, with $\Gamma_x \sim -2.9$ much steeper than the ASCA value, a dusty warm absorber with $N_w = N_{\text{opt}}$ fits the ROSAT spectrum well ($\chi^2_{\text{red}} = 1.2$, Tab. 1). We also analyzed the ROSAT all-sky survey data of this source and, again, a steep intrinsic spectrum is required.

At present, there are several possible explanations for the ROSAT-
ASCA spectral differences: (i) Variability in the intrinsic powerlaw. We con-
sider this solution unlikely, since the spectrum is steep in all three ROSAT
observations taken at different times. (ii) Remaining ROSAT-ASCA cross-
calibration uncertainties. This is well possible, given previous reports of
a tendency of steeper ROSAT spectra when compared with ASCA data
of the same object. (iii) Variability in a two-component warm absorber.
There are increasing indications of more than one X-ray warm absorber in
MCG 6-30-15, and IRAS 13349+2438 might be a similar case.

In summary, the presence of a dusty warm absorber in IRAS 13349+2438
seems consistent with the data if one allows for some spectral differences
between the ROSAT and ASCA data. The necessity of dust survival then
locates the ionized material outside the bulk of the broad line region (BLR)
of IRAS 13349+2438.

3. Prospects for the study of dusty WAs with XMM and AXAF

Clear signatures of the presence of dust are the carbon edge at 0.28 keV and
the oxygen edge at 0.56 keV (not yet individually resolved by current X-ray
instruments), and the confirmation and study of dusty warm absorbers will
certainly be a prime goal of future X-ray satellites like AXAF and XMM.
In particular, dust-created absorption edges will play an important role
not only in probing components of the active nucleus, like the dusty torus,
but also are they a very useful diagnostic of the dust properties in other
galaxies\(^1\). Further, measurements of edge energies and widths will allow to
determine the dynamical state of the warm absorber.

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\(^1\)Note that, if the dust was mixed with cold gas instead, the soft X-ray spectrum
would be completely dominated by hydrogen absorption (in warm absorbers, H and
He are nearly fully ionized). Further, gas-phase absorption would be very difficult to
distinguish from dust-absorption, since the differences in edge energies of neutral atoms
due to solid-state effects in the dust are only on the order of a few eV (cf. the discussion
in KoFi 1997a and KoBa).