

*Letter to the Editor***Properties of *dusty* warm absorbers
and the case of IRAS 17020+4544**Stefanie Komossa¹ and Norbert Bade²¹ Max-Planck-Institut für extraterrestrische Physik, D-85740 Garching, Germany² Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany

Received 4 November 1997 / Accepted 9 December 1997

Abstract. We present a study of the properties of *dusty* warm absorbers and point to some important consequences for the resulting X-ray absorption spectra of AGN. Pronounced effects of the presence of *dust* in *warm* material are (i) an apparent ‘flattening’ of the observed X-ray spectrum in the *ROSAT* band due to a sequence of absorption edges and a shift to lower gas ionization, (ii) the presence of a strong carbon edge at 0.28 keV, and (iii) the expectation of increased time variability of the warm absorber parameters. The first two effects can be drastic and may completely hamper an X-ray spectral fit with a dusty warm absorber even if a *dust-free* one was successfully applied to the data. In order to demonstrate facets of the dusty warm absorber model and test the recently reported important, albeit indirect, evidence for dusty warm material in the Narrow-Line Seyfert 1 galaxy IRAS 17020+4544 we have analyzed *ROSAT* PSPC and HRI observations of this galaxy. The X-ray spectrum can be successfully described by a single powerlaw with index $\Gamma_x = -2.4$ plus small excess cold absorption, or alternatively by a steeper intrinsic powerlaw ($\Gamma_x \simeq -2.8$) absorbed by a *dusty* warm absorber. The findings are discussed in light of the NLSy1 character of IRAS 17020 and consequences for NLSy1s in general are pointed out. In particular, the presence of dusty warm gas results in a steeper intrinsic powerlaw than observed, thus exaggerating the ‘FeII problem’. It also implies weaker potential warm-absorber contribution to high-ionization Fe coronal lines.

Key words: galaxies: active – individual: IRAS 17020+4544 – emission lines – Seyfert – X-rays: galaxies

1. Introduction

Warm absorbers reveal their presence by imprinting absorption edges on the soft X-ray spectra of active galaxies (AGN). Many were found and studied on the basis of observations by *ROSAT* (e.g., Nandra & Pounds 1992, Komossa 1997) and *ASCA* (e.g., Mihara et al. 1994, Reynolds 1997). Within the last year evidence has accumulated that some warm absorbers contain significant amounts of dust. This possibility was first suggested by Brandt et al. (1996) to explain the lack of excess X-ray *cold* absorption despite strong optical reddening of the quasar IRAS 13349+2438.

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Models that explicitly include the dust-gas and dust-radiation interaction using the photoionization code *Cloudy* (Ferland 1993) were calculated by Komossa & Fink (KoFi hereafter; 1996, 1997a-d). Depending on the warm absorber parameters, the presence of dust turned out to have a strong influence on the X-ray absorption structure. The models were applied to several Seyfert galaxies. NGC 3227 (KoFi 1996, 1997b) and NGC 3786 (KoFi 1997c) were shown to be very good candidates for dusty warm absorbers as judged from optical-UV reddening properties as well as *successful X-ray spectral fits*. On the other hand, the bulk of the warm material in NGC 4051 was found to be dust-free (KoFi 1997a). Recently, Reynolds et al. (1997) also presented a *Cloudy*-based dusty absorber model which they successfully applied to the outer warm absorber in MCG 6-30-15. Indirect evidence for the association of some warm absorbers with dust was discussed in Reynolds (1997).

IRAS 17020, which is part of the present study, is a Narrow Line Seyfert 1 galaxy (NLSy1; Moran et al. 1996, Wisotzki & Bade 1997) at redshift $z=0.06$ (de Grijp et al. 1992). Wisotzki & Bade stressed the heavy reddening of the optical spectrum. They also presented a powerlaw fit to the *ROSAT* PSPC spectrum and pointed to the discrepancy between the cold column density derived from optical reddening and the one from the X-ray fit. Leighly et al. (1997; L97) detected an oxygen OVII edge in the *ASCA* spectrum of IRAS 17020 as well as high optical polarization. They also confirmed the strong optical reddening and derived a corresponding gaseous column density of $N_{\text{opt}} = 4 \times 10^{21} \text{ cm}^{-2}$. On this basis they suggested the presence of a warm absorber with internal dust in IRAS 17020.

To test whether the model of a warm absorber that *includes* the presence of dust consistently fits the X-ray spectrum of IRAS 17020, we apply such a model to the (archival) *ROSAT* PSPC spectrum of this source (Sect. 2). Motivated by increasing indirect evidence for the presence of dusty warm absorbers, in the main part (Sect. 3) we point out some important general properties of the dusty material that can result in strong modifications of the X-ray absorption structure as compared to the *dust-free* case, and study consequences. Since the presence of dust influences the X-ray spectrum most strongly at soft energies, one signature being a pronounced carbon edge at 0.28 keV outside the *ASCA* sensitivity range, *ROSAT* (Trümper 1983) is particularly well suited for such a study. To search for time variability of IRAS 17020, and check for the potential contribution to the X-ray spectral complexity of this source from the closeby optically bright star SAO 46462, we also present (PI) HRI observations.

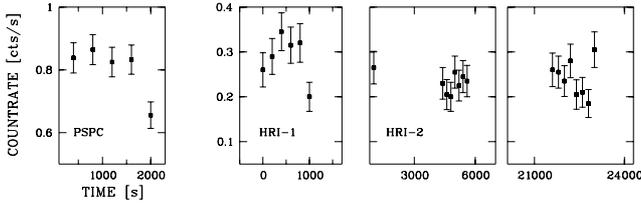


Fig. 1. PSPC and HRI X-ray lightcurve of IRAS 17020. The time is measured in seconds from the start of the individual observations.

2. Data reduction, temporal and spectral analysis

PSPC. A 2.6 ksec pointed observation centered on IRAS 17020 was performed on Aug. 28, 1992. The background corrected source photons were extracted and vignetting and dead-time corrections were applied using EXSAS (Zimmermann et al. 1994). The mean source count rate is 0.80 ± 0.02 cts/s and there are hints for 25% variability during the observation (Fig. 1).

HRI. IRAS 17020 was observed with the HRI on March 4 (1.4 ksec), and April 4-5, 1994 (4.1 ksec). We find mean source count rates of 0.29 ± 0.02 and 0.22 ± 0.01 cts/s, respectively. Again, there are hints for short-timescale variability (Fig. 1; we note that there are no strong variations in the background during the observations). The F8 star SAO 46462 in $108''$ distance from IRAS 17020 is detected in X-rays. However, in the PSPC (HRI), the star is a factor of >50 (80) weaker than the target source and thus does not significantly confuse the spectrum of IRAS 17020.

The conversion of all count rates to *ROSAT* PSPC rates (assuming constant spectral shape) yields values of $CR = 0.91, 0.80, 0.71, 0.93$ and 1.1 cts/s for the *ROSAT* survey, PSPC, HRI-1, HRI-2 and *ASCA* (L97) observation, respectively, revealing small-amplitude long-term variability.

For the spectral analysis source photons in the channels 11-240 were binned according to a signal/noise ratio of 10σ . A single powerlaw (pl) with cold absorption as a free parameter gives a good fit to the PSPC X-ray spectrum ($\chi^2_{\text{red}} = 0.8$) with a photon index $\Gamma_x = -2.4$, absorption of $N_H = 0.35 \cdot 10^{21} \text{ cm}^{-2}$ and a 1-keV photon flux $f = 2.71 \cdot 10^{-3} \text{ ph/cm}^2/\text{s/keV}$. The error ellipses for this model are displayed in Fig. 2.

Application of other spectral models, like a black body or a Raymond-Smith model, yielded no acceptable fits. A pl plus black body and a double pl fit was performed, fixing the cold absorption to the value N_{opt} derived from optical reddening. This was to test whether a low-energy soft excess component could compensate for the stronger cold absorption thus explaining the data without warm absorber. Again, no acceptable fit could be achieved.

We have carefully searched for remaining systematic residuals in the pl fit around the locations of the oxygen absorption edges – none are found. To check whether a dusty warm absorber may nevertheless be present, with a sequence of absorption edges not individually resolved (cf. Sect. 3), we have fit our *Cloudy*-based dusty warm absorber models to the X-ray spectrum of IRAS 17020. The models and the chosen intrinsic continuum are described in more detail in Komossa & Fink (1997a,b,c). In brief, the ionized material was assumed to be of constant density, ionized by a ‘mean Seyfert’ IR to gamma-ray continuum, and in photoionization equilibrium (for cautious notes on the latter assumption see Krolik & Kriss 1995). The dust composition and grain size distribution were chosen like in the Galactic diffuse interstellar medium (Mathis et al. 1977) if not mentioned otherwise, as

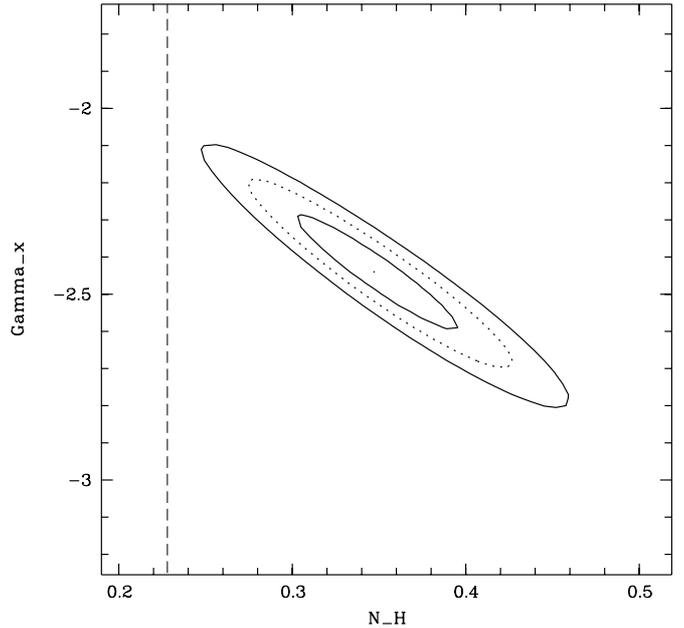


Fig. 2. Error ellipses (confidence levels of 68.3, 95.5 and 99.7%) in Γ_x and N_H (in units of 10^{21} cm^{-2}) for the pl description of the X-ray spectrum. The dashed line marks the Galactic absorbing column density towards IRAS 17020.

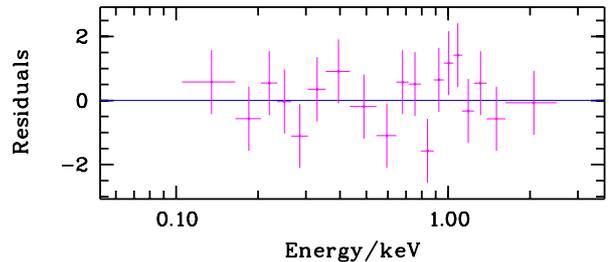


Fig. 3. Residuals for the fit of a dusty warm absorber model with $\Gamma_x = -2.8$ and $N_w = N_{\text{opt}}$ ($\chi^2_{\text{red}} = 0.77$).

incorporated in *Cloudy*, and the metal abundances were depleted correspondingly (see Ferland 1993, Baldwin et al. 1991 for details). The fit parameters of the dusty warm absorber are its column density N_w and the ionization parameter $U = Q/(4\pi r^2 n_H c)$.

In a first step, the photon index was fixed to the value derived from the fit of a single pl, $\Gamma_x = -2.4$. Fitting a warm absorber with free N_H , N_w and U , we are led back to the limit of no warm absorber. A fit with N_w fixed to N_{opt} yields cold absorption consistent with the Galactic value but $\chi^2_{\text{red}} = 1.6$. The fit becomes acceptable if non-‘standard’ dust (i.e., silicate only) is chosen ($\chi^2_{\text{red}} = 1$). Allowing for steeper intrinsic powerlaw spectra, we find satisfactory fits also for dust including the graphite species (cf. Fig. 3). Fixing $N_w = N_{\text{opt}}$, the spectrum can be successfully described by parameters $(\Gamma_x, N_H, \log U) \simeq (-2.6, 0.3 \cdot 10^{21}, 1.0)$ and $(-3.0, 0.45 \cdot 10^{21}, 0.4)$ and values in between for $\chi^2_{\text{red}} \leq 1$. Finally, we checked whether the spectrum could be reconciled with the canonical photon index of $\Gamma_x = -1.9$ and a *dust-free* warm absorber. In this case we find $\log N_w \simeq 23.2$ and $\log U \simeq 0.9$, but $\chi^2_{\text{red}} = 1.2$. Although highly ionized high column density material may provide another explanation for the observed optical polarization via electron scattering, this model predicts a strong OVIII edge (not

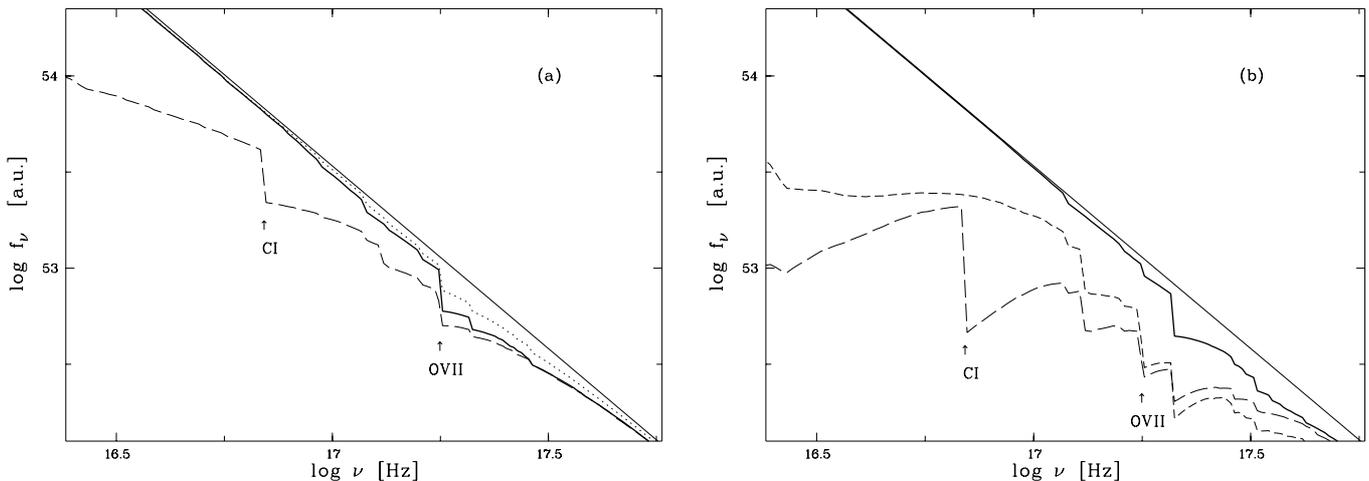


Fig. 4a and b. Influence of dust mixed with the warm absorber on the X-ray absorption structure for two values of the warm column density ($\log N_w = 21.6$ and 22.4). In **(a)** the straight solid line corresponds to the unabsorbed intrinsic spectrum, the heavy solid line to a dust-free warm absorber (WA) with solar abundances, the dotted line to a dust-free WA with the same depleted abundances as in the dusty model, and the long-dashed line to the change in absorption structure after adding dust to the WA. In **(b)** (in addition to the larger N_w a higher U was chosen for presentation purposes) the heavy solid line again corresponds to a dust-free WA with solar abundances, the long-dashed line to a dusty WA (note that, for better presentation, the dust was even depleted by a factor $f_d = 0.5$), and the short-dashed line to the same dusty WA but without the graphite species of dust. Clear changes in the absorption structure are revealed for the models that include dust. The abscissa brackets the *ROSAT* energy range (0.1–2.4 keV); some prominent edges are marked.

observed by *ASCA*; L97) and leaves systematic residuals in the *ROSAT* fit.

3. Discussion

3.1. Properties of dusty warm absorbers

Some general properties of dusty warm absorbers are visualized in Fig. 4. The presence of dust modifies the X-ray absorption structure in two ways:

- (i) Gas-dust interactions influence the thermal conditions in the gas and change its ionization state (e.g. Draine & Salpeter 1979). In particular, for high ionization parameters dust effectively competes with the gas in absorbing photons (Laor & Draine 1993). Adding dust to large column density warm material (cf. Fig. 4b) results in strongly increased soft X-ray absorption, partially due to the stronger temperature gradient across the absorber, with more gas in a cold state.
- (ii) Dust scatters and absorbs the incident radiation (e.g. Martin 1970) and X-ray absorption edges are created by inner-shell photoionization of metals bound in the dust (cf. Figs. 4,5 of Martin & Rouleau 1991). Strong edges are those of neutral carbon and oxygen (Fig. 4a,b). The shift in edge energies due to chemical and solid state effects is only of the order of a few eV (Greaves et al. 1984).

The modifications of the observed X-ray spectrum as compared to the dust-free case can be drastic and are important to take into account when interpreting the observed X-ray properties of AGN. Consequences of the presence of dust are

(A) ‘Flattening effect’: The sequence of individual edges (dust-ones adding to the gas-ones) and the shift to lower ionization lead to a ‘smoothing’ and apparent ‘flattening’ of the observed X-ray spectrum (Fig. 4a). Individual edges are less pronounced as in the dust-free case (where OVII and/or OVIII often dominate). This ‘flattening effect’ of dust (in fact opposite to that of a dust-free warm absorber, which effectively steepens the X-ray spectrum in the *ROSAT* band) has con-

sequences for NLSy1s in general (Sect. 3.3). Another consequence is the possibility to ‘hide’ dusty warm absorbers in the *ROSAT* spectra (as shown by the successful fit to IRAS 17020) if the column densities are not too large¹, although effect (B) has to be taken care of (or else non-standard dust properties allowed; dust in other galaxies may be different from Galactic one, but standard dust properties are also usually assumed to estimate optical reddening).

(B) Carbon edge: Often, the strongest dust-created edge is that of carbon at 0.28 keV, stemming from the graphite species of dust. Its presence may prevent a successful spectral fit and it is important to actually apply the model of a dusty warm absorber to the data. Whereas dust including the graphite species is well consistent with the X-ray spectra of NGC 3227 (KoFi 1997b) and NGC 3786 (KoFi 1997c) and pure graphite was favoured by Reynolds et al. (1997) for MCG 6-30-15, it hampered a successful fit in other cases.

(C) Increased sensitivity to radiation pressure: Material of high ionization parameter and particularly dust particles are strongly subject to radiation pressure (e.g., Laor & Draine 1993, Chang et al. 1987, Binette et al. 1997), causing the gas to outflow (if not otherwise confined) and leading to temporal changes of the absorber properties. Indeed, strong variability in X-ray count rate (of factors 10–15) has been recently detected for the dusty-warm-absorber candidates NGC 3227 and NGC 3786 which could be explained by variability in column density or ionization state of the warm absorber (KoFi 1997b,c).

3.2. The warm absorber in IRAS 17020

Given the potentially strong modifications of the X-ray spectrum in the presence of *dusty* warm material, the successful X-ray spectral fit lends further support to the suggestion (L97) of the presence of a dusty warm

¹ The possibility of the presence of dusty warm material in a sample of NLSy1s to explain their polarization properties is suggested in Grupe et al. (1998).

absorber in IRAS 17020. Although there is evidence for small excess cold absorption (e.g. Fig. 1) no description of the soft X-ray spectrum that involves the *large cold* column inferred from optical observations² could be found.

The successful fit of a dusty warm absorber requires a steep underlying powerlaw of index $\Gamma_x \approx -2.8$ (the data are consistent with a flatter slope, if the graphite component of dust is excluded).

3.3. NLSy1 nature of IRAS 17020

NLSy1s like IRAS 17020 are generally characterized by narrow broad lines, strong FeII emission and steep X-ray spectra (see Brandt et al. 1997 for a recent discussion). Several models were suggested to explain their apparently steep soft X-ray spectra, like a strong soft excess on top of a flat powerlaw (e.g. Puchnarewicz et al. 1992) or a (dust-free) warm-absorbed flat powerlaw (e.g. KoFi 1997d). Recent observations reveal increasing X-ray spectral complexity, with often both, a warm absorber and a soft excess present. The presence of *dusty* warm material adds further to this complexity. In particular, the effective flattening of the observed spectrum implies a steeper intrinsic one, thus exaggerating the problem of producing the strong FeII emission (that in standard models requires hard X-ray photons) in NLSy1s.

The possibility of a warm-absorber contribution to the optical high-ionization lines in Seyferts and NLSy1s was studied by KoFi (e.g. 1997d, Fig. 6). Here, we note that in case the absorber is *dusty*, weaker contribution to line emission is found. In particular, due to the binding of Fe in dust, negligible contribution to high-ionization Fe coronal lines is expected.

Although we find hints for X-ray variability of IRAS 17020 of the order of 25% on timescales from several hundred seconds to years, this amplitude is remarkably small as compared to some other reported cases of Seyfert and NLSy1 variability.

3.4. Concluding remarks

We have shown how the presence of dust in warm absorbers can lead to strong modifications of the observed X-ray spectrum. The model of a dusty warm absorber was successfully fit to the X-ray spectrum of the NLSy1 galaxy IRAS 17020. This corroborates the suggestion of the presence of dusty warm material in this galaxy made on the basis of optical properties (Wisotzki & Bade 1997, L97) and the detection of an oxygen edge in the *ASCA* spectrum (L97). This first good case for a *dusty* warm absorber in a NLSy1-type galaxy, together with the other good candidates in the Sy 1.8 galaxy NGC 3786 (KoFi 1997c), the Sy 1.5 NGC 3227 (KoFi 1996, 1997b), the Sy 1 MCG 6-30-15 (Reynolds et al. 1997), and the quasar IRAS 13349 (Brandt et al. 1996) suggests this component to be common in all types of AGN.

Given the strong X-ray absorption edges of neutral dust-bound metals, dusty warm absorbers will play an important role not only in probing components of the active nucleus, like the dusty torus that is invoked in unification schemes, but also are they a very useful diagnostic of the (otherwise hard to determine) dust properties and dust compo-

sition in other galaxies. Current and future X-ray missions with sensitivity at soft energies and high spectral resolution (like SAX, AXAF and Spektrum-X) will play an important role in studying these issues.

Acknowledgements. The *ROSAT* project is supported by the German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF/DLR) and the Max-Planck-Society. We thank Gary Ferland for providing *Cloudy*, and Hartmut Schulz, Jochen Greiner and Dirk Grupe for a critical reading of the manuscript.

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² Just to recall the assumptions that go into the approach of relating optical reddening by dust with X-ray absorption by cold gas: (i) optical and X-ray continuum reach the observer along the same path, (ii) the extinction is not strongly variable with time, and (iii) the dust/gas ratio is approximately the Galactic value; in modelling the warm absorber we assume (iv) its ionization state to be dominated by photoionization and *Cloudy* to be applicable, and again (v) dust properties similar to Galactic dust.