On the Location and Composition of the Dust in the Warm Absorber Dust in the MCG–6-30-15 warm absorber

D. R. Ballantyne, Joseph C. Weingartner and N. Murray

Canada Research Chair in Astrophysics

D. Ballantyne

Canadian Institute for Theoretical Astrophysics, McLennan Labs, 60 St. George Street, Toronto, Ontario, Canada M5S 3H8

The warm absorber observed in the Seyfert 1 galaxy is known to consist of at least two zones and very likely contains dust. Hubble Space Telescope images show a dust lane crossing the galaxy just below the nucleus. In this paper, we argue that this dust lane is responsible for the observed reddening of the nuclear emission and the Fe i edge hinted at in the Chandra spectrum of . We further suggest that the gas within the dust lane can comprise much of the low ionization component (i.e., the one contributing the O vii edge) of the observed warm absorber. Moreover, placing the warm absorbing material at such distances (hundreds of pc) can account for the small outflow velocities of the low ionization absorption lines as well as the constancy of the O vii edge. Photoionization models of a dusty interstellar gas cloud (with a column appropriate for the reddening toward ) using a toy Seyfert 1 spectral energy distribution show that it is possible to obtain a significant O vii edge (τ ∼ 0.2) if the material is ∼150 pc from the ionizing source. For , such a distance is consistent with the observed dust lane. We emphasize the point first made by Kraemer : dusty interstellar material will likely contribute to the warm absorber, and should be included in spectral modeling.

The current data on is unable to constrain the dust composition within the warm absorber. Astronomical silicate is a viable candidate, but there are indications of a very low O abundance in the dust, which is inconsistent with a silicate origin. If true, this may indicate that there were repeated cycles of grain destruction and growth from shocks in the interstellar medium of . Pure iron grains are an unlikely dust constituent due to the limit on their abundance in the Galaxy, yet they cannot be ruled out. The high column densities inferred from the highly ionized zone of the warm absorber implies that this gas is dust-free. dust, extinction — galaxies: active — galaxies: Seyfert — galaxies: individual() — X-rays: galaxies — X-rays: ISM

Introduction sect:intro

Soft X-ray absorption by photoionized gas was first used by hal84 and psp90 to explain the unusual spectrum of the quasar MR 2251–178. This “warm absorber” was characterized by ROSAT spectra of Seyfert 1s which showed absorption edges due to O vii and O viii np92,nan93,fio93,tur93. Warm absorber studies matured with the launch of the more sensitive ASCA observatory, which allowed more detailed spectral modeling [e.g.,][fab94,gtn95,rf95]. Analysis of a large sample of Seyfert 1s observed by ASCA showed that approximately 50% exhibit absorption features from photoionized gas in their soft X-ray spectra rey97,geo98. Currently, the study of the warm absorber is being revolutionized with observations from the dispersion gratings onboard Chandra and XMM-Newton which have been able to resolve individual absorption lines from a myriad of metals and charge states in the warm gas [e.g.,][kaa00,koa01,coo01,lee01,kas02]. Photoionization modeling has then shown that, in many cases, more than one ionization parameterThere are some objects which can still be modeled adequately with only one ionization parameter, e.g., Mrk 509 yaq03.s needed to describe the observed spectrum [e.g.,][mfr00,ko01,kaa02]. Also, the positions of the lines point toward outflow velocities on the order of a few hundred to a few thousand km s−1. Thus, this warm absorbing gas seems to be in the form of an outflowing wind [cf.,][bks00,elv00]. However, there remains a major uncertainty in the location of the gas, with many models considering the broad-line region [e.g.,][rf95,net96,geo98] or the putative obscuring torus [e.g.,][kk01,ko01] as the most likely origin for the warm absorber.

A possible constraint on the location of at least some of this warm gas may be provided if it contains any dust, which sublimes at the radius of the broad-line region bar87 for a typical active galactic nucleus (AGN). Dusty warm absorbers (hereafter, DWA) were first considered for the quasar bfp96,skb99 and the Seyfert 1 galaxy rwfc97. In both of these AGN, the column of neutral H inferred from the reddening is significantly larger than that inferred from the neutral absorption in the soft X-ray band, but is of the same order as the column of ionized gas inferred from the warm absorber rwfc97. This sug-
gests that the dust is similar to Galactic dust and resides within the warm ionized gas, and may signifi-
cantly affect the observed soft X-ray spectrum (kf97 and references therein; kb98). Spectroscopic evidence
for dust in X-ray warm absorbers has now been found by lee01 in the Chandra gratings observation of
(this seems to have been confirmed by the very recent XMM-Newton data of tur03). This high resolu-
tion spectrum exhibited a sharp drop. An alternative explanation for this drop (based on XMM-Newton
data) is that it is the blue edge of a relativistically broadened O viii Lyα line bran01,sak02. However,
this interpretation has been challenged from both observational lee01 and theoretical brf02 points of view. A
\[ \tau_V \approx 3E(B - V) = 1.8; \text{rwfc97} \], assuming Galactic-type dust located within the warm absorber.

Rather than place the DWA near the central engine of the AGN, kra00 (see also ck01) argued for the
existence of a “lukewarm absorber” outside the narrow-line region. This gas would have sufficient column
to explain the observed reddening, and has been ionized to the point where hydrogen is fully stripped, but
the metals would only be moderately ionized and would exhibit strong UV absorption lines rather than
O vii or O viii edges. Thus, this model requires an inner warm absorber to account for the highly ionized
oxygen features kra00. The lukewarm absorber has been shown to be consistent with the X-ray kra00 and
UV cren01 data of NGC 3227, as well as the UV spectrum of Ark 564 cren02.

In the case of \( z = 0.008, L_{2-10\,keV} \approx 10^{43} \text{ erg s}^{-1} \); see Table tab:columns for a summary of the
absorbing columns), it was clear from early ASCA variability studies that a multi-zone warm absorber was
needed [e.g.,] ot96,mfr00. table A summary of the absorbing columns toward . Reference 1 = ewl89, 2 =
rfc97, 3 = lee02b. tabularcccc Type \( N_H (\text{cm}^{-2}) \) Derived from Origin Ref.

A Hubble Space Telescope (HST) image of shows a distinct dust lane that cuts across the southern
part of the galactic disk (Fig. fig:hst; mgt98; see also fwm00). figure !f1.eps Hubble Space Telescope image
of mgt98. A dust lane is apparent crossing the southern part of the galactic disk. fig:hst