Measuring the Gas and Dust Phases in the ISM

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3. CONCLUSIONS AND SUMMARY

3.1. Results

Using equation (1) and the assumptions described above, we compute the results are shown in Figure 1, where we display the X-ray absorptivity as to emphasize deviations from the $E^{-3}$ proportionality. By reading the plot as a "bar diagram," it is easy to estimate the relative importance of the contributors to $\rho_{\text{ISM}}$. For energies above the oxygen K edge at $D = 0.5$ keV (see Table 2), the X-ray opacity is dominated by the metals and H and He are relatively unimportant. Below 1 keV, C, N, O, and Ne are the important absorbers, while above 1 keV, Si, S, and Fe are important.

Also clear from Figure 1 is that the effect of grains on $\rho_{\text{ISM}}$ is small for a standard MRN distribution. The effect of grains is found to be less than previous estimates such as MM83 in part because our grain model consists of lower density porous grains and in part because we calculate for an MRN distribution of grain sizes rather than by choosing an average grain size such as $0.3 \mu m$ as used by Fireman and others. Thus, the greatest number of grains lies in very small grains with $q > 1$ above $D = 1$ keV, so self-shielding is not important in these grains. Consequently, for an MRN distribution there are only small differences between the optical depth of an entirely gas-phase ISM and the optical depth for an ISM in which some of the gas atoms have been depleted into grains. This is illustrated in Figure 2, where we plot the grain optical depth as a function of energy for grains of radius $0.25$ and $0.025 \mu m$, as well as for an MRN distribution of grains. These optical depths are calculated using Appendix A and considering a hydrogen column density of $1.0 \times 10^{-20} \text{ cm}^{-2}$. The total mass in $N_{\text{H}}$ grains is the same for all three grain models shown. Clearly, the self-blanketing factor affects the opacity more for low energies and larger grain sizes. Since the change in grain $F_{\text{IG}}$. 1.-Absorptivity per hydrogen atom of the ISM using the assumptions described in the text. The dotted line is the absorptivity including grains with an MRN distribution, and the dashed line is the absorptivity assuming that all grains are of radius $a = 0.3 \mu m$. The inset shows the cross section without the multiplication by $E^3$. We also illustrate the contribution of hydrogen and hydrogen plus helium to the total cross section. The contribution of the $H_2$ cross section to the total hydrogen cross section is indicated by the dot-dashed line.
Fig. 2.— Cross sections per Hydrogen nucleus for the Weingartner & Draine (2001) ($R_V = 3.1$) dust model. Scattering contributes significantly to the extinction, with significant variation across the O K and Fe L absorption edges.
Fig. 7.— Two random aggregates used to investigate the effects of grain geometry and porosity on dust extinction. Both figures are from Shen et al. (2008). Left: a porous BA grain composed of $N = 256$ monomers. Right: a less porous random aggregate produced by the BAM2 algorithm, also containing $N = 256$ monomers.

3.2.1. An application of GGADT: effect of grain geometry on X-ray extinction

The geometry of dust grains is not currently well constrained. Polarization of starlight implies that dust grains are not spherically symmetric. The next simplest grain geometry is the spheroid; spheroidal grain models are able to reproduce observations of starlight polarization and extinction (Kim & Martin 1995; Draine & Fraisse 2009).

However, for plausible dust evolution scenarios, dust grains are likely more complicated than single-material spheroids or even ellipsoids. ISM grains could have irregular geometries as well as inhomogeneous composition. Some authors (e.g. Mathis & Whitten 1989; Henning & Stognienko 1993; Stognienko et al. 1995) have argued for highly porous geometries.

To illustrate the possible effects that grain geometry might have on abundance measurements based on X-ray extinction, we employ GGADT to compute the extinction cross sections for five example grain geometries. The size is specified by the radius of an equal-volume sphere, $a_{\text{eq}}(3V/4\pi)^{1/3}$, where $V$ is the volume of the solid material. The five grain geometries used are (1) a sphere, (2) an oblate spheroid, (3) a prolate spheroid, (4) a BAM2 aggregate, and (5) a BA aggregate, each with the same mass ($a_{\text{eq}} = 0.2$ µm) and silicate composition. For an EMT sphere representing material of porosity $P$, $a_{\text{EMT}} = a_{\text{eq}}(1 - P)^{1/3}$.

Ballistic agglomeration (BA) aggregates are constructed by single-size spherical monomers arriving on random trajectories and adhering to their initial point of contact; BAM2 aggregates allow for arriving monomers (after the third) to migrate until coming into contact with three monomers (prior to the arrival of the next monomer) resulting in structures with porosity significantly less than for BA aggregates. A detailed description of these ballistic agglomeration aggregates is given by Hoffman & Draine 2015, arXiv:1509.08987v1:

Fig. 9.— Orientation-averaged $Q_{\text{ext}}$ for equal-mass $a_{\text{eff}} = 0.2$µm silicate grains with different geometries. A $256 \times 256$ grid was used for the shadow function in all cases, and calculations were averaged over 64 random orientations. Porous, extended grain geometries significantly alter the fine structure of the absorption edges (except for the Fe K edge). Moderately prolate/oblate spheroidal grains, on the other hand, have $Q_{\text{ext}}$ very similar to spherical grains.
Typical source in Milky Way:

Flux: $10^{-9}$ ergs cm$^{-2}$ s$^{-1}$ (∼ GX 9+9)
NH: $3 \times 10^{21}$ cm$^2$
Model: powerlaw + ngauss(16)
Abundance: solar

The black simulation shows an LYNX exposure for 1 ks in the relevant band-pass between 13 and 43 Angstrom showing expected line absorption from C V, C VI, N VI, N VII, O I–IV, O VII, O VIII, Ne I, Ne II, Ne III

The red simulation shows the same for a 100 ks exposure with the HETG onboard Chandra. The HETG bandpass usually cuts off below 30 Angstrom

From Chandra to Lynx, Cambridge, MA, Aug. 8 2017
measure Fe $L_{\text{II\&III}}$ shape/depths

$\Delta E/E$ of MEG

@ Fe $L_{\text{III}} \sim 1$ eV

Lynx gratings $<< 1$ eV

From Chandra to Lynx, Cambridge, MA, Aug. 8 2017
Schulz, Corrales & Canizares 2016:

![Graph showing scattering, silicate K edge, atomic Si K edge, and Si XIII transitions.](From Chandra to Lynx, Cambridge, MA, Aug. 8 2017)
Obtain a highest resolved edge structure at sufficient statistic in the smallest possible data bin:
GX 3+1: 213ks
From Chandra to Lynx, Cambridge, MA, Aug. 8 2017
Fig. 1. Si K-edge XANES spectra of some representative silicate minerals with different degree of polymerization.

Fig. 2. Si K-edge (peak C) of representative silicate minerals of Fig. 1 in an expanded scale. The Si K-edge shifts to higher energy by 1.3 eV with increase in the polymerization of SiO$_4^{2-}$ clusters, from nesosilicates to tectosilicates.
So why Lynx?
Si K edge in GX 340+0 in 6 ks

From Chandra to Lynx, Cambridge, MA, Aug. 8 2017
Lynx allows X-Ray Absorption Surveys

X-ray absorption spectroscopy is a powerful tool to study existing forms of matter in our Universe. LYNX allows us to perform high resolution X-ray absorption surveys as effectively as surveys are now or in very near future quite common in astronomy pursued in other wavelength bands such as optical, IR, and sub-mm.
Neutral (cool) vs. lowly ionized (warm) ISM phases: C K, O K, Ne K $\delta E < 0.5$ eV

Dust composition and variability in the Milky Way: Fe L, Mg K, Si K, Fe K $\delta E < 2$ eV

Gas to dust ratio across the Milky Way: Mg K, Si K $\delta E < 2.5$ eV

The Fe K / L depth ratio across the Milky Way; Fe L, Fe K $\delta E < 2$ eV

~5000 Galactic Sources:
Log $f_x = [-9, -13]$ <exposure> > 1 ks

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