Developing ISM Dust Grain Models with Precision Elemental Abundances from IXO

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Introduction

Interstellar dust grain models rely heavily on constraints provided by the measured UV/optical absorption and scattering, IR emission, and polarization, and the assumed dust-phase elemental abundances. However, several models exist which can satisfy these constraints (Zubko et al. 2004), so additional limits must be placed on models so that we may distinguish among them. An obvious choice is to better determine the dust-phase elemental abundances. Until now, the most common method has been through indirect measurements: measuring the gas-phase abundances and subtracting them from the assumed total (solid + gas phase) ISM abundances (so-called "cosmic" elemental abundances). Until now, the method most commonly used is indirect measurements: measuring the gas-phase abundances and subtracting them from the assumed total (solid + gas phase) ISM abundances (so-called "cosmic" elemental abundances), with the result being the amount that is locked away in dust particles. The gas-phase component of the local ISM is fairly well-known (Cardelli et al. 1996; Sofia et al. 1997; Cardelli & Meyer 1997; Sofia et al. 1998) and seems relatively constant; however, the total ISM elemental abundances are not known, and proxies are often used instead.

Historically, the Sun has been used as the standard for ISM abundances. However, while most solar abundances have remained more or less constant over the years, those of the main dust-forming elements have dropped considerably (Anders & Grevesse 1989; Grevesse & Sauval 1998; Asplund et al. 2005), as seen in Fig. 1. With the latest revision downward, solar O abundances are now in better agreement with those of B stars (Sofia & Meyer 2001; Andre et al. 2003; Asplund et al. 2005), which have been thought to better represent the ISM, but there is now far too little material in the solid phase for the models to reproduce the observables (Li 2005). Further, B stars are subject to element stratification due to dilution, so abundances measured at their surfaces do not necessarily reflect the abundances of the clouds from which they formed.

[X-ray spectroscopy offers a way out of the quagmire with direct measurements of gas and solid phase abundances, letting us tightly constrain dust grain models without introducing the uncertainties that are inevitable when using indirect methods. This has been done with data from Chandra and XMM-Newton (e.g. Paerels et al. 2001; Takaki et al. 2002, Juetzt et al. 2004; Liedtke et al. 2005) but there is significant variation in the results. Some of these spectra have anomalous abundance ratios, indicative of circumstellar material, making them poor representatives of the diffuse ISM. Others have uncertainties which are too large to provide meaningful constraints on grain models.

The Importance of IXO

High signal-to-noise measurements coupled with multil wavelength data along diffuse ISM sightlines are crucial to building comprehensive grain models. IXO will provide high quality photometric observations of the absorption edges of dust-forming elements in short exposures. Fig. 2a compares modeled spectra from Chandra, XMM, and IXO of the nearby galaxy NGC 6822. IXO (modeled with a power law $N_{\alpha} = 2 \times 10^{21} \text{ cm}^{-2}$, $Y = 1.1$, flux = $10^{46}$ erg s$^{-1}$ cm$^{-2}$). Exposure times are as indicated. Even assuming the very low solar abundances of Wilms et al. (2000), IXO (Ultra) can recover O, Mg, Ni, and Fe abundances to better than 10% (Table 1).

IXO will be able to examine abundances in different environments in the ISM, thus opening a window on the study of grain evolution and cycling between diffuse and dark clouds. In Fig. 4, we have plotted the percent error of abundance measurements for a source, modeled again as X.Per, with exposure times of 50 ks for Chandra and XMM, and 20 ks for IXO. We used the solar abundances of Wilms et al. (2001) and set $N_{\alpha}$ to different values: $\alpha = 10^{21}$, $\alpha = 10^{20}$, and $\alpha = 10^{19}$ cm$^{-2}$. The uncertainties for Chandra and XMM tend to be around 20% or higher, even along relatively diffuse sightlines; as the density increases, the uncertainty does as well, to 100% in many cases. Along very dense sightlines ($\alpha = 10^{19}$ cm$^{-2}$), XMM cannot detect any of these elements in the given exposure time. In stark contrast, the uncertainties with IXO are far lower -- less than 3% for both diffuse and dense sightlines.

IXO will provide us with high precision data, over a wide range of environments, that has not been available with previous missions. By providing us with high quality abundances both total and gas-phase, over a wide range of environments, IXO will revolutionize interstellar dust modeling.

References: