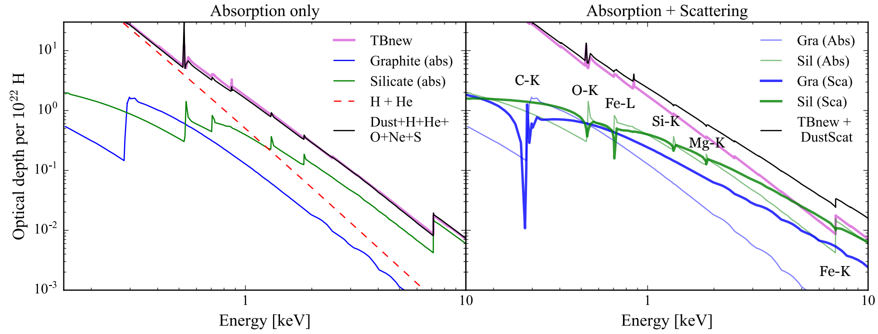
The Effects of Dust Scattering on High Resolution Absorption Edge Structure

MIT KAVLI INSTITUTE

Lia Corrales(1), J. García(2), J. Wilms(3), F. Baganoff(1)

(1) MIT Kavli Institute for Astrophysics and Space Research
(2) Harvard-Smithsonian Center for Astrophysics
(3) University of Erlangen-Nuremburg
lia@space.mit.edu

High energy studies of astrophysical dust complement observations of dusty interstellar gas at other wavelengths. With high resolution X-ray spectroscopy, dust scattering significantly enhances the total extinction optical depth and alters the shape of photoelectric absorption edges. This effect is modulated by the dust grain size distribution, spatial location along the line of sight, and the imaging resolution of the X-ray telescope. At soft energies, the spectrum of scattered light is likely to have significant features at the 0.3 keV (C-K), 0.5 keV (O-K), and 0.7 keV (Fe-L) photoelectric absorption edges. This direct probe of ISM dust grain elements will be important for (i) understanding the relative abundances of graphitic grains or PAHs versus silicates, and (ii) measuring the depletion of gas phase elements into solid form. We focus in particular on the Fe-L edge, fitting a template for the total extinction to the high resolution spectrum of three X-ray binaries from the Chandra archive: GX 9+9, XTE J1817-330, and Cyg X-1. We discuss ways in which spectroscopy with XMM can yield insight into dust obscured objects such as stars, binaries, AGN, and foreground quasar absorption line systems.



Left: A 60/40 mix of silicate/graphite grains is representative of the average extinction properties of Milky Way dust. After accounting for abundant gas-phase neutral ISM elements, our model agrees with the absorption curve from TBnew [1].

Right: At X-ray wavelengths, **the magnitude of dust scattering is equal to or greater than dust absorption**. Not only does scattering increase the total extinction opacity of the ISM, it also alters the shape of the photoelectric absorption edge.

When to apply dust scattering

Compact dust scattering halos are less likely to contribute to extinction because they will have a high enclosed fraction. Scattering halos become more compact with higher energiy, larger dust grains, or when dust is closer to the source.

Energy Range:

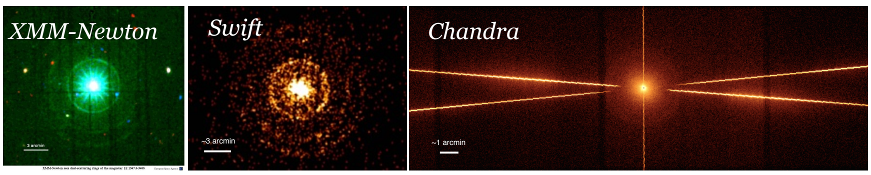
<6 keV	6-10 keV
All telescopes (encl frac < 70%)	*Chandra, Swift, XMM-Newton* ~~*NuSTAR, Hitomi*~~

Dust intrinsic to a source will contribute to extinction **if the geometric covering is smaller than the typical scattering angle**.

Dust Location:

intrinsic to source	intermediate dust
~~*dust enshrouded T-Tauri stars*~~ *dust clumps in AGN torus (maybe)* ~~*stellar winds*~~ *(probably not)*	*quasar foreground systems (e.g. DLAs, MgII absorbers) Galactic ISM*

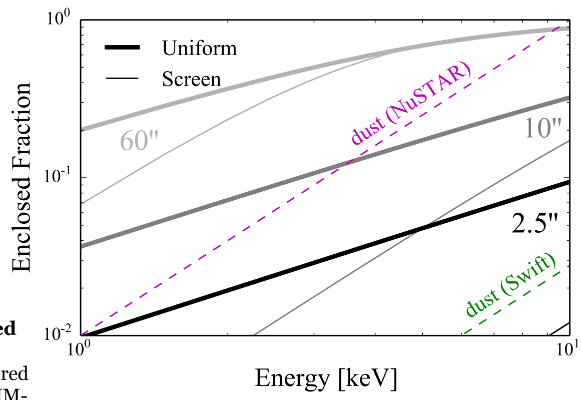
Scattering Halo Enclosed Fraction



IE 1547.0-5408 (ESA) SGR J1550-5418 Cyg X-1 (ObsId 107)

Dust in the foreground of X-ray objects produces a dust scattering scattering halo image on arcminute scales. The scattering component contributes to the total ISM extinction cross section. However, the contribution from dust extinction is modulated by the imaging resolution of the telescope, because some fraction of the scattering halo image is captured within the point source extraction aperture: ~2.5" (*Chandra*), ~10" (*Swift, XMM-Newton*), and ~60" (*NuStar, Hitomi*).

The extinction cross-section at the Fe-L photoelectric absorption edge is highly influenced by dust scattering, which adds structure to the low energy side of the edge. The dust scattering contribution also depends on the resolution of the telescope, because some scattered light will be captured within the source extraction aperture. The curves below show the edge modified for a 10" (Swift or XMM-Newton) aperture and for a 60" (Astro-H) aperture, which capture some fraction of the scattering halo (enclosed fraction).

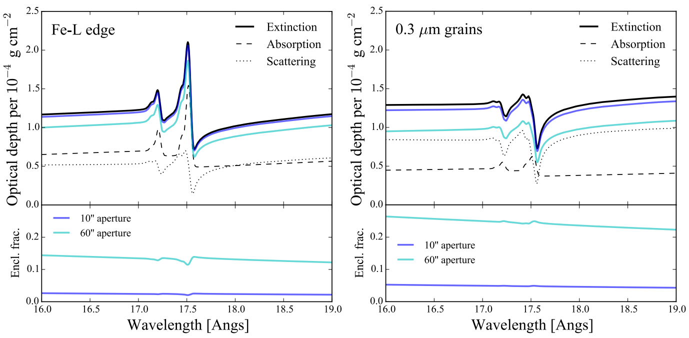


The figure above shows what fraction of the scattering halo is enclosed by a source extraction aperture of various radii. The **thick lines** show the scattering halo calculated from **dust distributed uniformly on the sight line**. The **thin lines** show the same but for a situation where **all the dust is located in a screen** half way between the X-ray source and observer. Many dust scattering halos can be fit with a single dust wall [2].

For comparison, the `XSPEC` model **`dust`** assumes that all of the scattered flux is spread uniformly in a disk with radius that depends on 1/E. This model implies an E^2 dependence for the enclosed fraction, which is vastly different from reality.

The recently released **`xscat`** model [3] addresses scattering from various dust grain sizes and spatial distributions.

Fe-L extinction edge



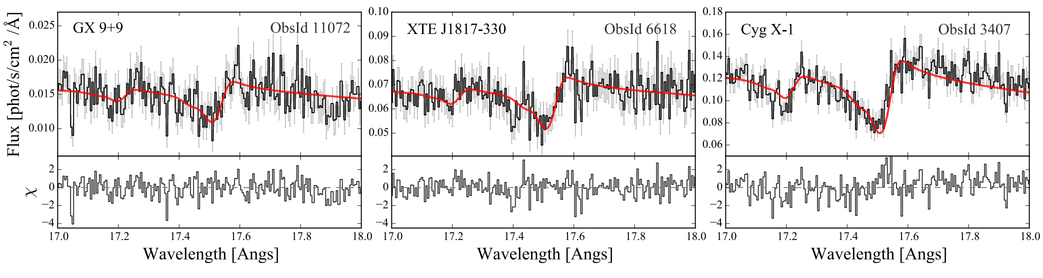
Left: Extinction is comparable in magnitude to absorption for a powerlaw distribution of dust grains, typical of the Milky Way. This will alter the perceived Fe column by a factor of two.

Right: Dust scattering is highly sensitive to grain size, as demonstrated by a hypothetical distribution of singly sized 0.3 μm grains. In this case, scattering dominates absorption and the total extinction curve does not have a step-like shape characteristic of edge models.

Fe-L extinction template fits to three bright Galactic X-ray binaries

We used the template above (left) to fit the high resolution spectra from three objects in the *Chandra* archive (TGCat [4]). The values are in rough agreement other ISM absorption measurements [5], but converting to neutral Fe column requires assumptions about dust grain mineralogy. Dust extinction **templates for the full *Chandra* band are available** as an `XSPEC` local model, **`ISMdust`** [6].

Object	Dust mass (10^{-4} g cm^{-2})
GX 9+9	0.34 ± 0.04
XTE J1817-330	0.27 ± 0.03
Cyg X-1	0.52 ± 0.03



References

[1] Wilms, Allen, & McCray (2000) - ApJ 542, 914
[2] Valencic & Smith (2015) - ApJ 809, 66
[3] Smith, Valencic, & Corrales (2016) - ApJ 818, 143S
[4] Huenemoerder et al. (2011) - AJ 141, 129H
[5] Gatuzz et al. (2015) - ApJ 800, 29

[6] **`ISMdust`** model downloadable from http://github.com/eblur/ismdust