On the Optical-to-Silicate Extinction Ratio as a Probe of the Dust Size in Active Galactic Nuclei

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ABSTRACT

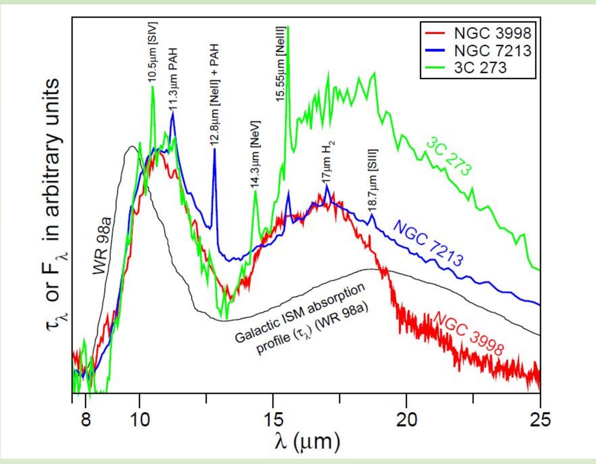
Dust plays a central role in the unification theory of active galactic nuclei (AGNs). Whether the dust that forms the torus around an AGN is tenth micronsized like interstellar grains or much larger has a profound impact on correcting for the obscuration of the dust torus to recover the intrinsic spectrum and luminosity of the AGN. Here we show that the ratio of the optical extinction in the visual band (A_V) to the optical depth of the 9.7 μm silicate absorption feature ($\Delta\tau_{9.7}$) could potentially be an effective probe of the dust size. The anomalously lower ratio of $A_V/\Delta\tau_{9.7} \approx 5.5$ of AGNs compared to that of the Galactic diffuse interstellar medium of $A_V/\Delta\tau_{9.7} \approx 18$ reveals that the dust in AGN torus could be substantially larger than the interstellar grains of the Milky Way and of the Small Magellanic Cloud, and therefore, one could expect a flat extinction curve for AGNs.

INTRODUCTION

Silicate dust is ubiquitously seen in a wide variety of astrophysical environments through the absorption or emission spectral features arising from the Si–O and O–Si–O vibrational modes (see Henning 2010).

In the diffuse ISM, the Si–O and O–Si–O stretching features occur at ~ 9.7 and ~ 18 μm, respectively, and are seen in absorption (e.g., see Siebenmorgen et al. 2014). These features are smooth and lack fine structures, indicating a predominantly amorphous composition (Li & Draine 2001, Kemper et al. 2004).

For AGNs, the situation is more complicated. For type 1 AGNs, the Si–O stretching feature is mostly seen in emission. The peak wavelength of this feature often appreciably shifts from the canonical wavelength of ~ 9.7 μm to longer wavelengths beyond ~ 10 μm.

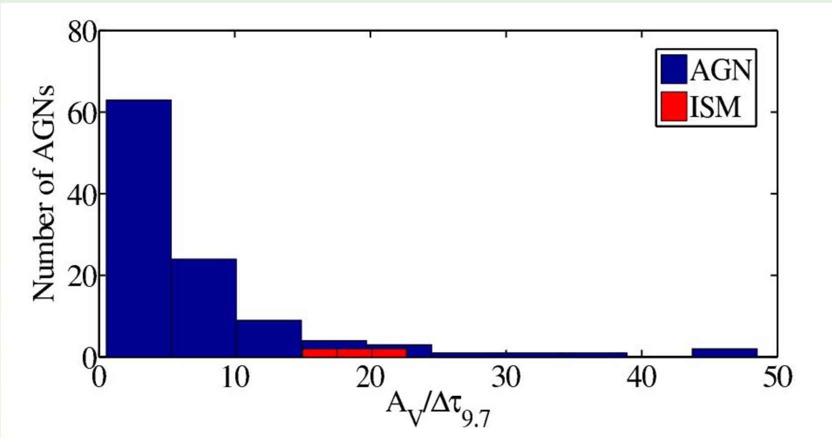


Li et al. (2008) and Smith et al. (2010) attributed this longward wavelength shift of the “9.7 μm” Si–O emission feature to μm-sized silicate grains.
Nikutta et al. (2009) argued that, in the framework of a clumpy dust torus, a mixture of sub-μm-sized interstellar silicate and graphite grains can explain the observed longward wavelength shift of the silicate emission feature. They suggested that the longward wavelength shift could just be caused by radiation transfer effects.
Whether the dust in the AGN torus is sub-μm-sized like its precursor (i.e., interstellar grains) or much larger like that in protoplanetary disks has important impact on correcting for the dust extinction to recover the intrinsic spectra and luminosity of AGNs.

In this work we propose an alternative diagnosis of the dust size in AGN torus, based on $A_V/\Delta\tau_{9.7}$.

The local ISM’s mean ratio of $A_V/\Delta\tau_{9.7} \approx 18$ (Roche & Aitken 1984), the anomalously low ratio of $A_V/\Delta\tau_{9.7} \approx 5.5$ derived for 110 type 2 AGNs (Lyu et al. 2014).

The $A_V/\Delta\tau_{9.7}$ ratio of the AGN sample exhibits that the majority samples have an $A_V/\Delta\tau_{9.7}$ ratio much smaller than that of the diffuse ISM.



$A_V/\Delta\tau_{9.7}$ as a Probe of Dust Size

$$A_\lambda = 1.086\tau_\lambda = 1.086 Cext(\lambda)\cdot N_d$$

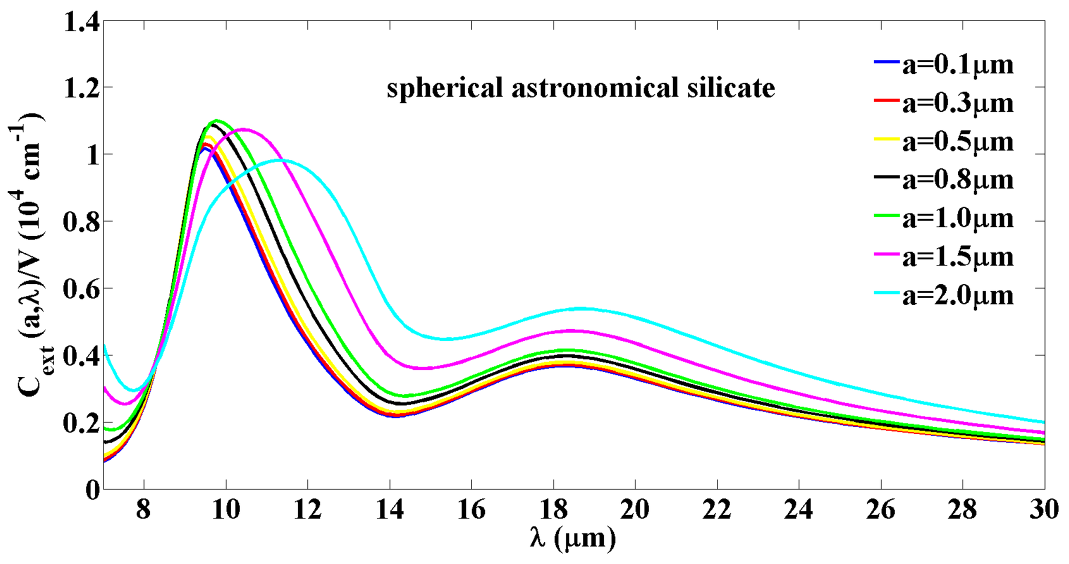
$$\frac{A_v}{\Delta\tau_\lambda} = \frac{1.086\cdot Cext(550nm)}{\Delta Cext(9.7\mu m)}$$

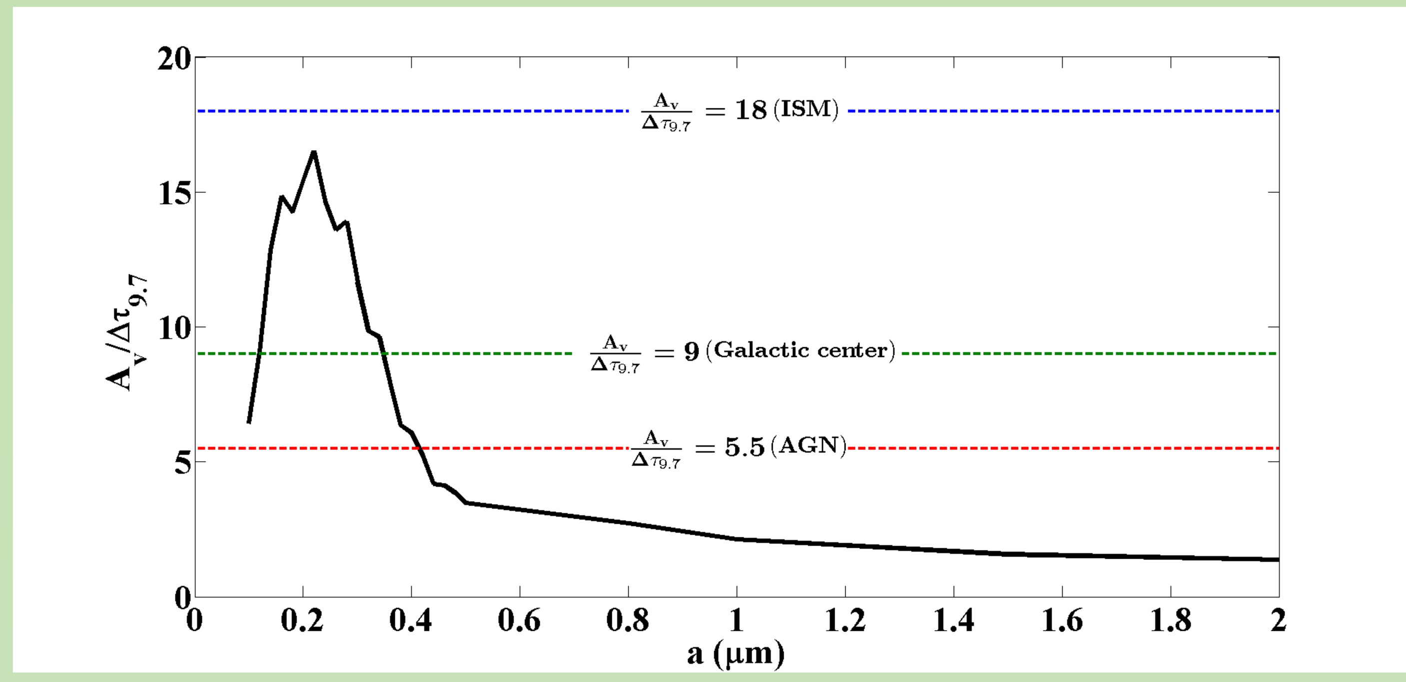
A_V: extinction in V band

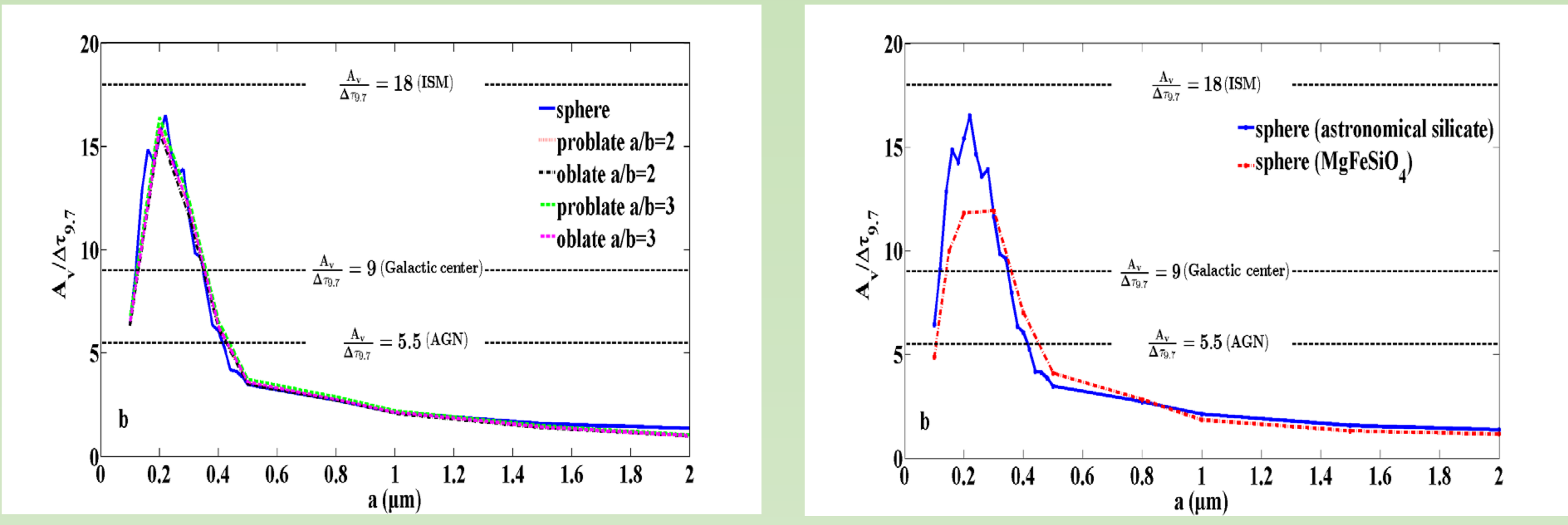
$\Delta\tau_{9.7}$: subtracting the continuum

C_{ext}: extinction cross section

dust type / refraction index / wavelength / dust size → sphere dust grain: Mie theory; spheroid dust grain: Rayleigh approximation → Qext(λ)



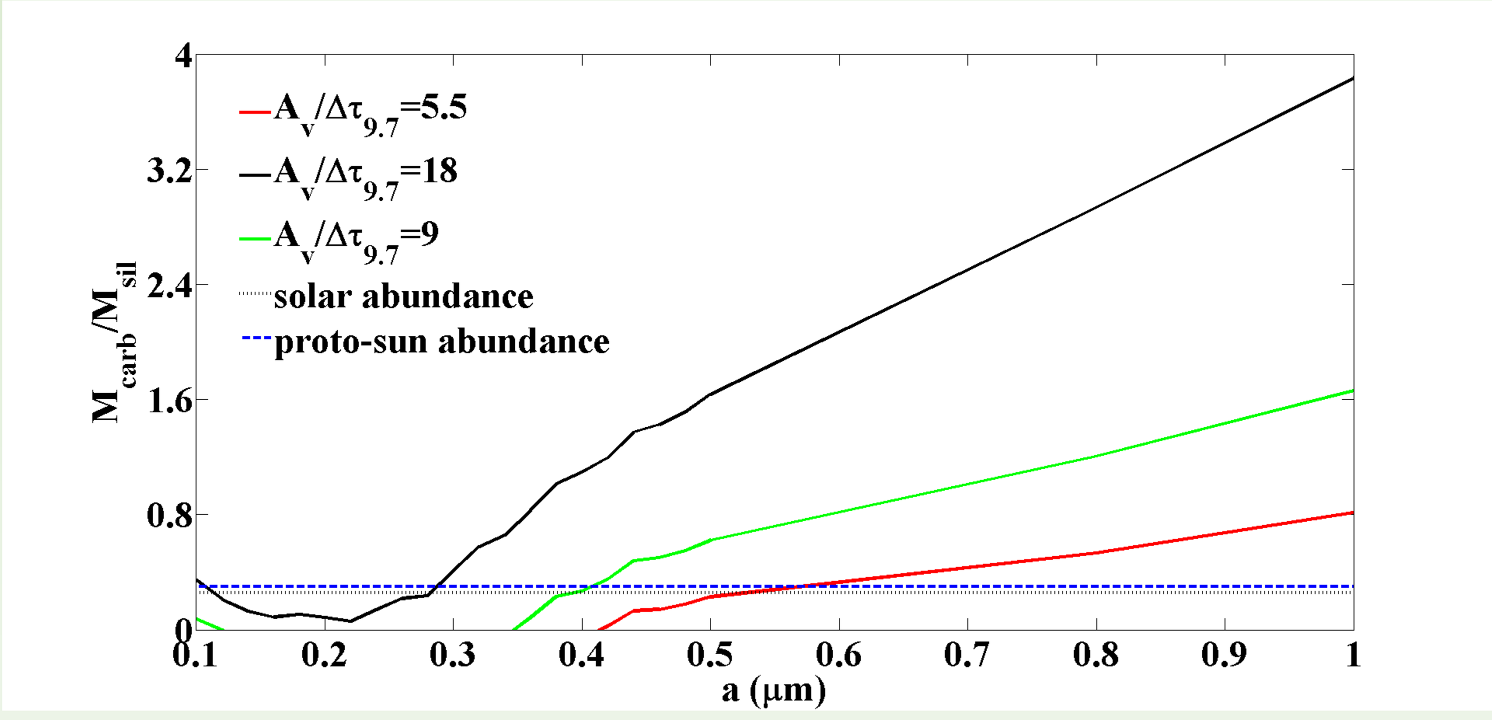




DISCUSSION

$$\frac{A_V}{\Delta\tau_{9.7}} = \frac{\left(N_{sil}C_{ext}^{sil}(V) + N_c C_{ext}^{c}(V)\right)*1.086}{N_{sil}C_{ext}^{sil}(9.7)} = \left(\frac{A_V}{\Delta\tau_{9.7}}\right)_{sil} * \left\{1+\frac{\rho_{sil}}{\rho_c}*\frac{m_c}{m_{sil}}*\frac{C_{ext}^{c}(V)}{C_{ext}^{sil}(V)}\right\}$$

$$\frac{M_{carb}}{M_{sil}} = \frac{\left(\frac{A_V}{\Delta\tau_{9.7}}\right)_{obs}\Big/\left(\frac{A_V}{\Delta\tau_{9.7}}\right)_{sil} - 1}{\left(\frac{\rho_{sil}}{\rho_{carb}}\right)\{C_{ext}^{carb}(V)/C_{ext}^{sil}(V)\}}$$

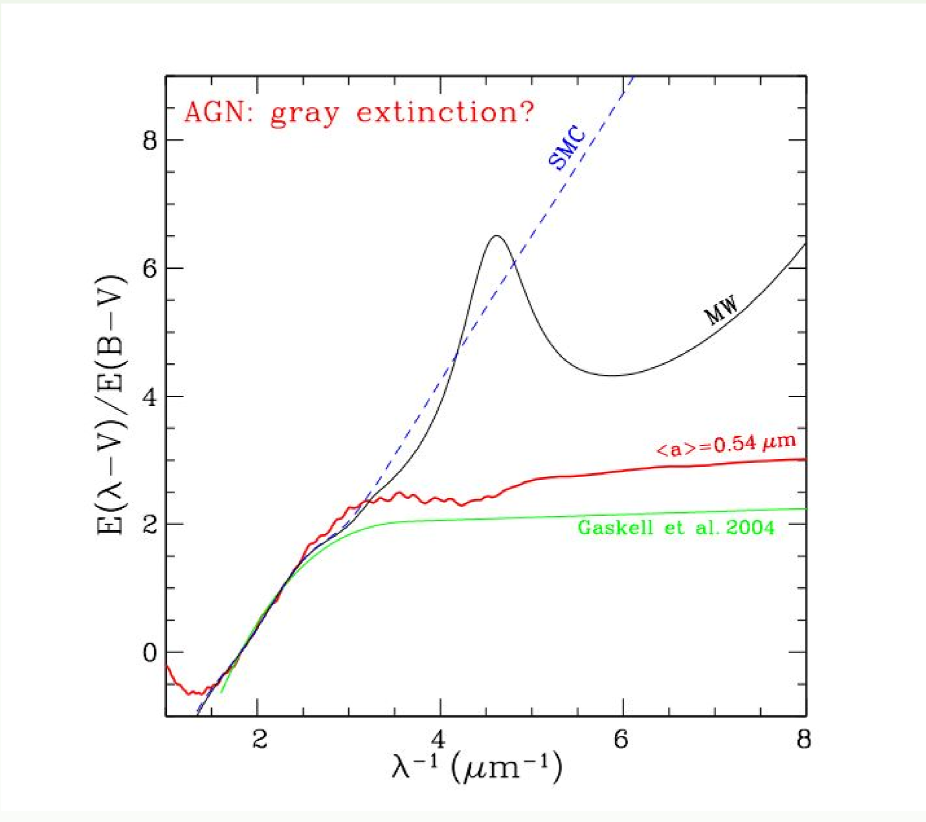


Extinction curve

Dust species: astronomical silicate and spherical amorphous carbon

MRN-type size distribution: $dn/da \propto a^{-3.5}$

size range: $0.2 \le a \le 1.5$ μm
area-weighted mean size: $\langle a\rangle \approx 0.54$ μm



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