Dust Grain Size Distributions and Extinction in the Milky Way, LMC, and SMC

Weingartner & Draine 2001

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How do you measure the dust size distribution?

You can't.

- No theoretical models for size distribution
- Lots of different ways to generate distributions consistent with observed ISM emission and extinction

Context for WD01

- Spectral features of the diffuse ISM make a strong case for a primarily carbonaceous and silicate dust population
- Spherical carbon+silicate only models successfully reproduce both the extinction and emission features of the diffuse ISM over limited region of spectrum
- Baseline for this kind of analysis due to MRN

MRN Model

Mathis, Rumpl, and Nordsieck 1977

- Extinction observed from 110 nm to 1 μm
- Define $n(a) = \#$(grains at radius a)$/\#$(H nuclei)
- Mie theory gives extinction due to a proposed $n(a)$, given a dielectric function
  - Only works here for $5\,\mathrm{nm} < a < 250\,\mathrm{nm}$
- Least squares $n(a)$ turns out to be $\propto a^{-3.5}$

WD01 Model

- Microwave and IR emission imply significant dust at sizes above and below MRN range
- MRN didn't know about varying $R_V = A(V)/E(B-V)$
- Models of the dielectric functions of PAHs and silicates are much improved by 2001
- WD propose a functional form first, then use it to least squares fit observed $A(\lambda)$
  - Needed to invent numerical codes to get outside of Mie theory regime!

Lacking a satisfactory theory for the size distribution of interstellar dust, we employ functional forms for the distribution which (1) allow for a smooth cutoff for size $a > a_t$, with control of the steepness of this cutoff; and (2) allow for a change in the slope $d\ln n_{\rm gr}/d\ln a$ for $a < a_t$. We adopt the following form:

$$\frac{1}{n_{\rm H}}\frac{dn_{\rm gr}}{da} = D(a) + \frac{C_{\rm g}}{a}\left(\frac{a}{a_{\rm t,g}}\right)^{\alpha_{\rm g}} F(a;\beta_{\rm g},a_{\rm t,g}) \times \begin{cases} 1 \quad , & 3.5\,\text{Å} < a < a_{\rm t,g} \\ \exp\left\{-[(a-a_{\rm t,g})/a_{\rm c,g}]^3\right\} \quad , & a > a_{\rm t,g} \end{cases} \tag{4}$$

for carbonaceous dust [with $D(a)$ from eq. (2)] and

$$\frac{1}{n_{\rm H}}\frac{dn_{\rm gr}}{da} = \frac{C_{\rm s}}{a}\left(\frac{a}{a_{\rm t,s}}\right)^{\alpha_{\rm s}} F(a;\beta_{\rm s},a_{\rm t,s}) \times \begin{cases} 1 \quad , & 3.5\,\text{Å} < a < a_{\rm t,s} \\ \exp\left\{-[(a-a_{\rm t,s})/a_{\rm c,s}]^3\right\} \quad , & a > a_{\rm t,s} \end{cases} \tag{5}$$

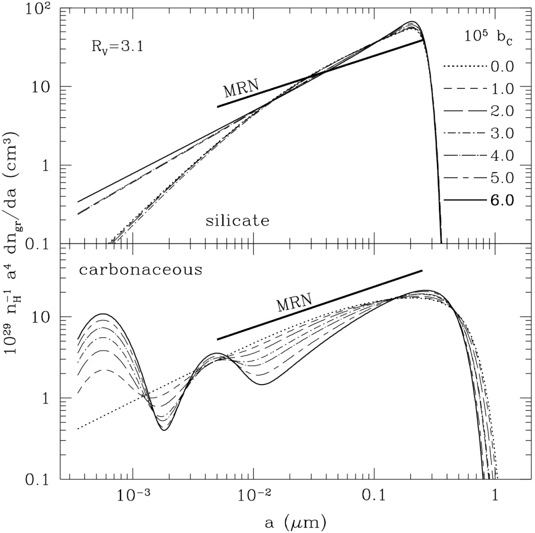
for silicate dust. The term

$$F(a;\beta,a_{\rm t}) \equiv \begin{cases} 1+\beta a/a_{\rm t} \quad , & \beta \geq 0 \\ (1-\beta a/a_{\rm t})^{-1} \quad , & \beta < 0 \end{cases} \tag{6}$$

provides curvature. The form of the exponential cutoff was suggested by Greenberg (1978). The structure of the size distribution $D(a)$ for the very small carbonaceous grains has only a mild effect on the extinction for the wavelengths of interest; we adopt the same values as Li & Draine (2001) for $a_{0,1} = 3.5\,$Å, $a_{0,2} = 30\,$Å, and $\sigma = 0.4$, and the same relative populations in the two log-normal components ($b_{\rm C,1} = 0.75 b_{\rm C}$, $b_{\rm C,2} = 0.25 b_{\rm C}$), but will consider different values of $b_{\rm C}$. Thus equation (4) has a total of six adjustable parameters ($b_{\rm C}$, $C_{\rm g}$, $a_{\rm t,g}$, $a_{\rm c,g}$, $\alpha_{\rm g}$, $\beta_{\rm g}$), with another five parameters ($C_{\rm s}$, $a_{\rm t,s}$, $a_{\rm c,s}$, $\alpha_{\rm s}$, $\beta_{\rm s}$) in equation (5) for the silicate size distribution.

WD01 Model

- Some parameters are constrained by need to match observed microwave emission
  - PAH emission line strengths
  - heating from starlight
  - dipole radiation from spinning grains
- Other parameters just don't yield fits that work outside of certain ranges
- Further required that $n(a)$ approximately reflect solar abundances



R_V=3.1
10^5 b_C
0.0
1.0
2.0
3.0
4.0
5.0
6.0
MRN
silicate
carbonaceous
MRN
10^{29} n_H^{-1} a^4 dn_{gr}/da (cm^3)
a (μm)

WD01 is not the only approach

- Other functional forms
- Maximum entropy method
- Least dust method

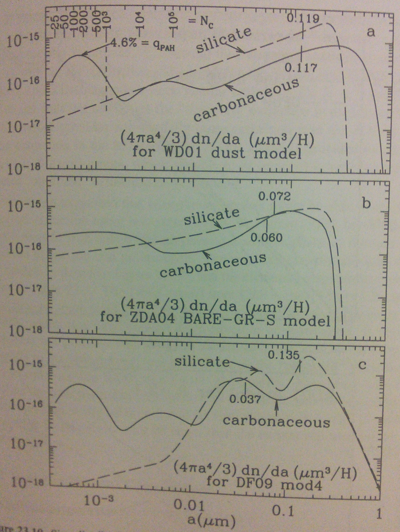


Figure 23.10 Size distributions for silicate and carbonaceous grains for dust models from (a) Weingartner & Draine (2001*a*), (b) Zubko et al. (2004), and (c) Draine & Fraisse (2009). The quantity plotted, $(4\pi a^3/3)dn/d\ln a$ is the grain volume per H per logarithmic interval in a. In each case, tick-marks indicate the "half-mass" radii for the silicate grains and carbonaceous grains.

WD01 Findings

- Use the model to find albedo and scattering parameters for common values of R_V
- Estimate $n(a)$ along SMC, LMC, HD210121 sightlines
- Tension with solar carbon and silicate abundances