



# dust\_extinction: Interstellar Dust Extinction Models

Karl D. Gordon <sup>1</sup>

<sup>1</sup> Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD, 21218, USA

DOI: [10.21105/joss.07023](https://doi.org/10.21105/joss.07023)

## Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 

---

Editor: [Ivelina Momcheva](#)  

## Reviewers:

- [@TheSkyentist](#)
- [@keflavich](#)

Submitted: 22 May 2024

Published: 25 August 2024

## License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).

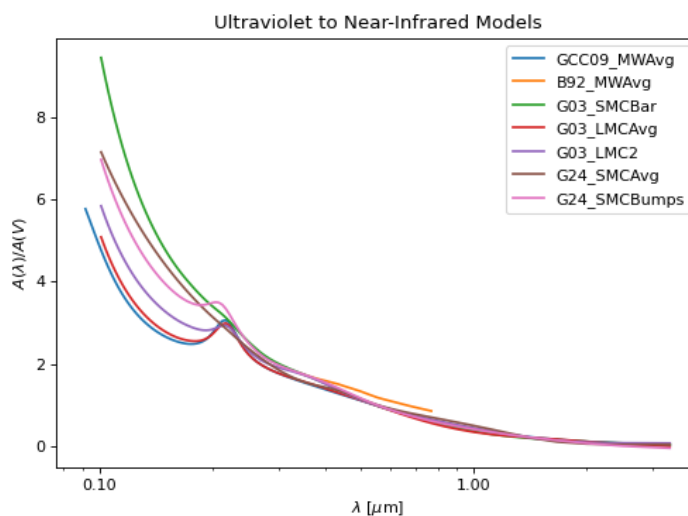
## Summary

Extinction describes the effects of dust on observations of a single star due to the dust along the line-of-sight to the star removing flux by absorbing photons and scattering photons out of the line-of-sight. The wavelength dependence of dust extinction (also known as extinction curves) provides fundamental information about the size, composition, and shape of interstellar dust grains. In general, models giving the wavelength dependence of extinction are used to model or correct the effects of dust on observations. This Python Astropy-affiliated package ([Astropy Collaboration et al., 2022](#)) provides many of the published extinction models in one place with a consistent interface.

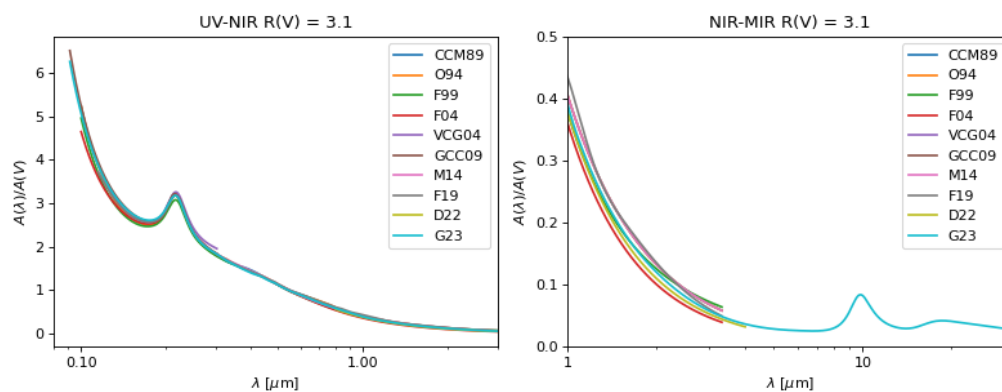
## Statement of need

Many observation- and theory-based extinction curves have been presented in the literature. Having one Python package providing these models ensures that they are straightforward to use and used within their valid wavelength and parameter (where appropriate) ranges. Other packages provide extinction curves, but they generally provide one or a small number of curves for specialized purposes (e.g., [Barbary, 2016](#)).

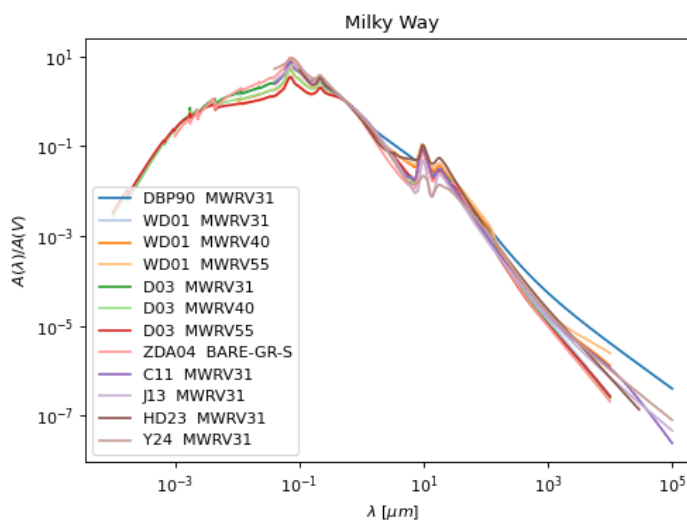
The types of extinction models supported are Averages, Parameter Averages, Grain models, and Shapes. The Averages are averages of a set of measured extinction curves and examples are shown in [Figure 1](#). The Parameter Averages are extinction curve averages that depend on a parameter, often  $R(V) = A(V)/E(B - V)$  which is the ratio of total to selective extinction. [Figure 2](#) shows examples of such models. The Grain models are those extinction curves computed using dust grain models ([Figure 3](#)). Note that only these models provide dust extinction predictions from X-ray through submm wavelengths. The final type of models are Shapes that provide flexible functional forms that fit selected wavelength ranges (see [Figure 4](#) for examples).



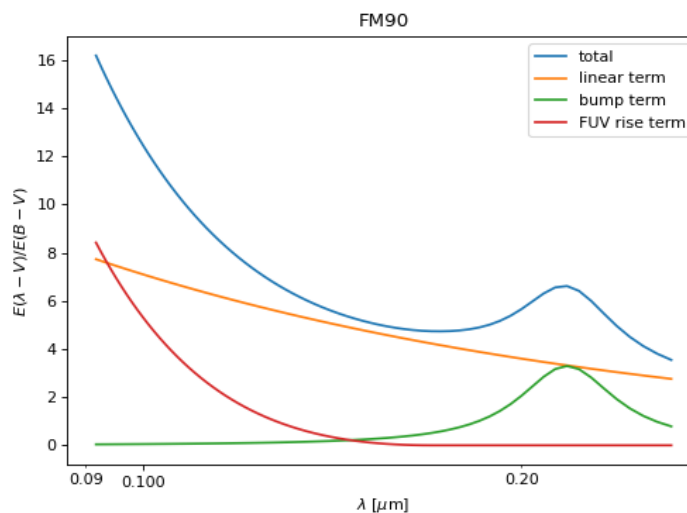
**Figure 1:** Examples of Average models based on observations in the Milky Way, Large Magellanic Cloud (LMC), and Small Magellanic Cloud (SMC) (Bastiaansen, 1992; Gordon et al., 2003, 2009, 2021, 2024).



**Figure 2:** Examples of Parameter Average models (Cardelli et al., 1989; Declair et al., 2022; Fitzpatrick, 2004, 1999; Fitzpatrick et al., 2019; Gordon et al., 2009, 2023; Maíz Apellániz et al., 2014; O'Donnell, 1994; Valencic et al., 2004).



**Figure 3:** Examples of Grain models that are based on fitting observed extinction curves as well as other dust observables (e.g., emission and polarization) (Compiègne et al., 2011; Desert et al., 1990; Draine, 2003; Hensley & Draine, 2023; Jones et al., 2013; Weingartner & Draine, 2001; Ysard et al., 2024; Zubko et al., 2004).



**Figure 4:** Example of a Shape model that is focused on decomposing the UV extinction curve (Fitzpatrick & Massa, 1990).

The wavelength dependence of extinction for a model is computed by passing a wavelength or frequency vector with units. Each model has a valid wavelength range which is enforced, as extrapolation is not supported. The model output is in the standard  $A(\lambda)/A(V)$  units where  $A(\lambda)$  is the extinction in magnitudes at wavelength  $\lambda$  and  $A(V)$  is the extinction in magnitudes in the V band. Every model has a helper extinguish function that alternatively provides the fractional effects of extinction for a specific dust column (e.g.,  $A(V)$  value). This allows for the effects of dust to be modeled for or removed from an observation.

This package does not implement dust attenuation models<sup>1</sup>. Dust attenuation results when

<sup>1</sup>See [karllark/dust\\_attenuation](#).

observing more complex systems such as a star with nearby, circumstellar dust or a galaxy with many stars extinguished by different amounts of dust. In both cases, the wavelength dependence of effects of dust are dependent not just on the dust grain properties, but also the effects of the dust radiative transfer (Steinacker et al., 2013). Specifically, these effects are the averaging of sources extinguished by differing amount of dust and the inclusion of a significant number of photons scattered into the observing beam.

Any published dust extinction model is welcome for inclusion in this package. I thank Kristen Larson and Aidan McBride for model contributions and P. L. Lim, Brigitta Sipocz, Soham Gaikwad, Clement Robert, and Adam Ginsburg for smaller much appreciated contributions.

## References

- Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., Earl, N., Starkman, N., Bradley, L., Shupe, D. L., Patil, A. A., Corrales, L., Brasseur, C. E., Nöthe, M., Donath, A., Tollerud, E., Morris, B. M., Ginsburg, A., Vaher, E., Weaver, B. A., Tocknell, J., Jamieson, W., ... Astropy Project Contributors. (2022). The Astropy Project: Sustaining and Growing a Community-oriented Open-source Project and the Latest Major Release (v5.0) of the Core Package. *Astrophysical Journal*, 935(2), 167. <https://doi.org/10.3847/1538-4357/ac7c74>
- Barbary, K. (2016). *extinction v0.3.0*. Zenodo. <https://doi.org/10.5281/zenodo.804967>
- Bastiaansen, P. A. (1992). Narrow band multicolor photometry of reddened and unreddened early-type stars. *Astronomy and Astrophysics*, 93, 449–462.
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. (1989). The relationship between infrared, optical, and ultraviolet extinction. *Astrophysical Journal*, 345, 245–256. <https://doi.org/10.1086/167900>
- Compiègne, M., Verstraete, L., Jones, A., Bernard, J.-P., Boulanger, F., Flagey, N., Le Bourlot, J., Paradis, D., & Ysard, N. (2011). The global dust SED: tracing the nature and evolution of dust with DustEM. *Astronomy and Astrophysics*, 525, A103. <https://doi.org/10.1051/0004-6361/201015292>
- Decleir, M., Gordon, K. D., Andrews, J. E., Clayton, G. C., Cushing, M. C., Misselt, K. A., Pendleton, Y., Rayner, J., Vacca, W. D., & Whittet, D. C. B. (2022). SpeX Near-infrared Spectroscopic Extinction Curves in the Milky Way. *Astrophysical Journal*, 930(1), 15. <https://doi.org/10.3847/1538-4357/ac5dbe>
- Desert, F.-X., Boulanger, F., & Puget, J. L. (1990). Interstellar dust models for extinction and emission. *Astronomy and Astrophysics*, 237, 215–236.
- Draine, B. T. (2003). Interstellar Dust Grains. *Annual Reviews of Astronomy and Astrophysics*, 41, 241–289. <https://doi.org/10.1146/annurev.astro.41.011802.094840>
- Fitzpatrick, E. L. (2004). Interstellar Extinction in the Milky Way Galaxy. In A. N. Witt, G. C. Clayton, & B. T. Draine (Eds.), *Astrophysics of dust* (Vol. 309, p. 33). <https://doi.org/10.48550/arXiv.astro-ph/0401344>
- Fitzpatrick, E. L. (1999). Correcting for the Effects of Interstellar Extinction. *Publications of the Astronomical Society of the Pacific*, 111(755), 63–75. <https://doi.org/10.1086/316293>
- Fitzpatrick, E. L., & Massa, D. (1990). An analysis of the shapes of ultraviolet extinction curves. III - an atlas of ultraviolet extinction curves. *Astrophysical Journal*, 72, 163–189. <https://doi.org/10.1086/191413>
- Fitzpatrick, E. L., Massa, D., Gordon, K. D., Bohlin, R., & Clayton, G. C. (2019). An Analysis of the Shapes of Interstellar Extinction Curves. VII. Milky Way Spectrophotometric Optical-through-ultraviolet Extinction and Its R-dependence. *Astrophysical Journal*, 886(2), 108. <https://doi.org/10.3847/1538-4357/ab4c3a>

- Gordon, K. D., Cartledge, S., & Clayton, G. C. (2009). FUSE Measurements of Far-Ultraviolet Extinction. III. The Dependence on  $R(V)$  and Discrete Feature Limits from 75 Galactic Sightlines. *Astrophysical Journal*, 705, 1320–1335. <https://doi.org/10.1088/0004-637X/705/2/1320>
- Gordon, K. D., Clayton, G. C., Declair, M., Fitzpatrick, E. L., Massa, D., Misselt, K. A., & Tollerud, E. J. (2023). One Relation for All Wavelengths: The Far-ultraviolet to Mid-infrared Milky Way Spectroscopic  $R(V)$ -dependent Dust Extinction Relationship. *Astrophysical Journal*, 950(2), 86. <https://doi.org/10.3847/1538-4357/accb59>
- Gordon, K. D., Clayton, G. C., Misselt, K. A., Landolt, A. U., & Wolff, M. J. (2003). A Quantitative Comparison of the Small Magellanic Cloud, Large Magellanic Cloud, and Milky Way Ultraviolet to Near-Infrared Extinction Curves. *Astrophysical Journal*, 594, 279–293. <https://doi.org/10.1086/376774>
- Gordon, K. D., Fitzpatrick, E. L., Massa, D., Bohlin, R., Chasteney, J., Murray, C. E., Clayton, G. C., Lennon, D. J., Misselt, K. A., & Sandstrom, K. (2024). Expanded Sample of Small Magellanic Cloud Ultraviolet Dust Extinction Curves: Correlations between the 2175 Å Bump,  $q_{PAH}$ , Ultraviolet Extinction Shape, and  $N(H\ I)/A(V)$ . *Astrophysical Journal*, 970(1), 51. <https://doi.org/10.3847/1538-4357/ad4be1>
- Gordon, K. D., Misselt, K. A., Bouwman, J., Clayton, G. C., Declair, M., Hines, D. C., Pendleton, Y., Rieke, G., Smith, J. D. T., & Whittet, D. C. B. (2021). Milky Way Mid-Infrared Spitzer Spectroscopic Extinction Curves: Continuum and Silicate Features. *Astrophysical Journal*, 916(1), 33. <https://doi.org/10.3847/1538-4357/ac00b7>
- Hensley, B. S., & Draine, B. T. (2023). The AstroDust+PAH Model: A Unified Description of the Extinction, Emission, and Polarization from Dust in the Diffuse Interstellar Medium. *Astrophysical Journal*, 948(1), 55. <https://doi.org/10.3847/1538-4357/acc4c2>
- Jones, A. P., Fanciullo, L., Köhler, M., Verstraete, L., Guillet, V., Bocchio, M., & Ysard, N. (2013). The evolution of amorphous hydrocarbons in the ISM: dust modelling from a new vantage point. *Astronomy and Astrophysics*, 558, A62. <https://doi.org/10.1051/0004-6361/201321686>
- Maíz Apellániz, J., Evans, C. J., Barbá, R. H., Gräfenner, G., Bestenlehner, J. M., Crowther, P. A., García, M., Herrero, A., Sana, H., Simón-Díaz, S., Taylor, W. D., van Loon, J. Th., Vink, J. S., & Walborn, N. R. (2014). The VLT-FLAMES Tarantula Survey. XVI. The optical and NIR extinction laws in 30 Doradus and the photometric determination of the effective temperatures of OB stars. *Astronomy and Astrophysics*, 564, A63. <https://doi.org/10.1051/0004-6361/201423439>
- O'Donnell, J. E. (1994).  $R$ -dependent Optical and Near-Ultraviolet Extinction. *Astrophysical Journal*, 422, 158. <https://doi.org/10.1086/173713>
- Steinacker, J., Baes, M., & Gordon, K. D. (2013). Three-Dimensional Dust Radiative Transfer\*. *Annual Reviews of Astronomy and Astrophysics*, 51, 63–104. <https://doi.org/10.1146/annurev-astro-082812-141042>
- Valencic, L. A., Clayton, G. C., & Gordon, K. D. (2004). Ultraviolet Extinction Properties in the Milky Way. *Astrophysical Journal*, 616, 912–924. <https://doi.org/10.1086/424922>
- Weingartner, J. C., & Draine, B. T. (2001). Dust Grain-Size Distributions and Extinction in the Milky Way, Large Magellanic Cloud, and Small Magellanic Cloud. *Astrophysical Journal*, 548, 296–309. <https://doi.org/10.1086/318651>
- Ysard, N., Jones, A. P., Guillet, V., Demyk, K., Declair, M., Verstraete, L., Choubani, I., Miville-Deschênes, M.-A., & Fanciullo, L. (2024). THEMIS 2.0: A self-consistent model for dust extinction, emission, and polarisation. *Astronomy and Astrophysics*, 684, A34. <https://doi.org/10.1051/0004-6361/202348391>

Zubko, V., Dwek, E., & Arendt, R. G. (2004). Interstellar Dust Models Consistent with Extinction, Emission, and Abundance Constraints. *Astrophysical Journal*, 152, 211–249. <https://doi.org/10.1086/382351>