Precise Optical-Infrared Spectroscopic Extinction Curves

Kenji Emerson[1], Adwin Boogert[2]

1 Institute for Astronomy at Hilo -- 640 North Aʻohōkū Place Hilo, HI, USA

2 Institute for Astronomy at Mānoa -- 2680 Woodlawn Drive Honolulu, HI, USA

Introduction

Interstellar extinction curves are a prime diagnostic of dust grain properties in the ISM; reflecting grain size and composition distributions. They are also used for spectral foreground extinction correction.

Variations in the shape of the extinction curve, characterized by R(V)=A(V)/E(B-V) and the power law index α in the infrared, trace variations in grain size distribution and composition, where larger R(V) values imply larger grains [1,5,6].

Broad-band photometry extinction curves have low resolving power, limiting photospheric continuum and line absorption corrections. Spectroscopic extinction curves focus on subsets of the optical-infrared range.

We derive opto-infrared spectroscopic extinction curves using the pair method: where an observed reddened star is divided by an non-reddened companion with similar stellar properties.
We focus on singular early-type main sequence stars, with a foray to cooler later-type stars.

Methods & Data

We observed OBA-type stars reddened by diffuse dust or the edges of dense clouds or shocked regions: 0.2 ≤ E(B-V) ≤ 2. Corresponding non-reddened OBA-type stars were observed.
We determined extinction pairs by self-similar spectral lines, mostly H and He, minimizing their Pearson χ^2 criterion.

We obtained optical (0.32 μm ≤ λ ≤ 1.0 μm) spectra using the UH88 SNIFS spectrograph, with near-infrared (0.7 μm ≤ λ ≤ 4.2 μm) spectra from IRTF SpeX in SXD and LXD_short modes.

We derive extinction curves similar to Decleir 2022 [1]. To derive A(V), we fit E(λ-V) (normalized based on F(550 nm), a proxy of V) to a power law [A(λ)/A(V) ~ $S\lambda^{-\alpha}$] in the infrared to derive A(V) and extinction A(λ)/A(V). Multi-chain MCMC is used to derive these values and uncertainties.

$$A(V) = -\lim_{\lambda\to\infty} A(V)\left(\frac{A(\lambda)}{A(V)} - 1\right) \qquad \frac{A(\lambda)}{A(V)} = \frac{E(\lambda - V)}{A(V)} + 1$$

Due to SNIFS B-channel calibration issues, we estimate R(V) by fitting our curves to Gordon 2023 [2] curves. We also define an alternative shape indicator similar to R(V): R(X), Fig 2.

$$R(X) = \frac{A(1\mu\mathrm{m})}{A(0.66\mu\mathrm{m}) - A(1\mu\mathrm{m})}$$

Results

We present our first results using 10 of our extinction curves, with 4 sight lines associated with the edges of molecular clouds ("Dense") and 1 associated with a supernova remnant ("Shocked").

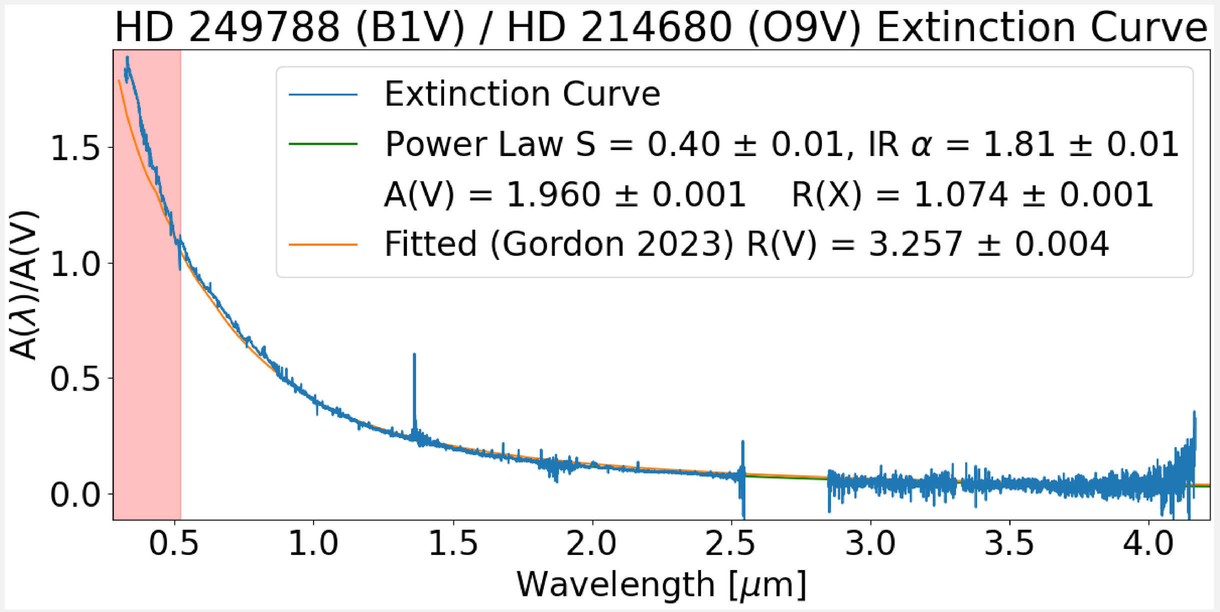

Fig 1. One of our diffuse extinction curves; masked areas have poor atmospheric transmission, the shaded red area is unreliable due to SNIFS B-channel. We find that our extinction curves match well to other results from the literature [1,2].

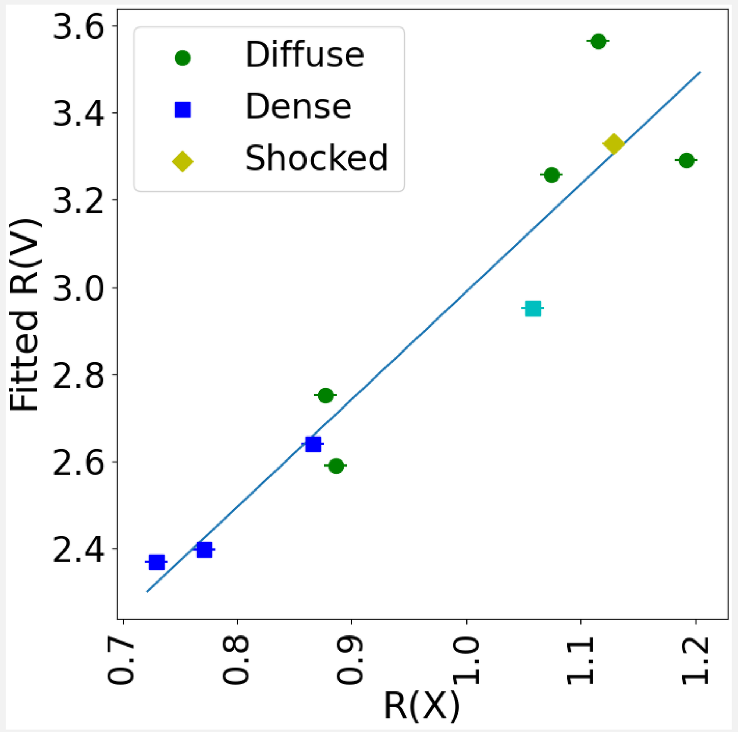

Fig 2. We use R(X) as a more direct measure of the extinction curve shape, in addition to fits with the Gordon 2023 R(V) curves.

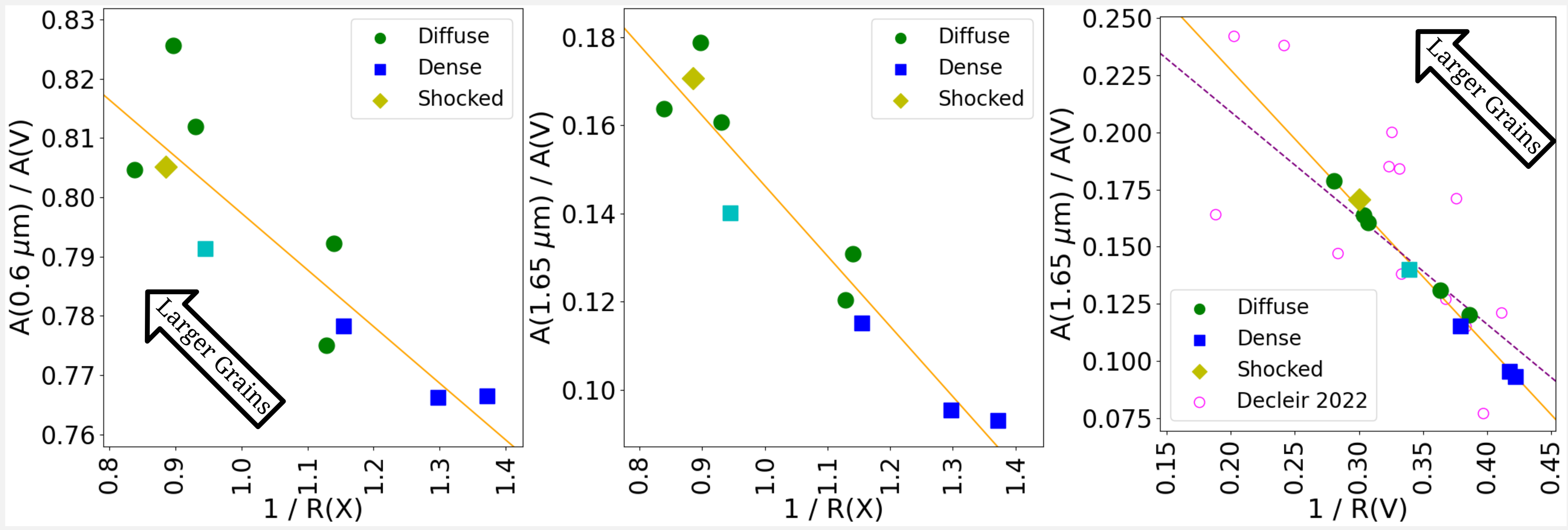

Fig 3abc. The shape of our extinction curves have a correlation with 1/R(X) or 1/R(V) (as estimated [2]). This correlation holds with both diffuse and dense/shocked sight lines. For comparison, we over-plot data from Decleir [1] Fig. 13; marked is the average galactic diffuse R(V) = 3.1 [3]. Linear fits are for our data (orange) and Decleir (pink) as published. The cyan "dense" sight line has a 3.1 μm ice feature [4].

Cooler Types

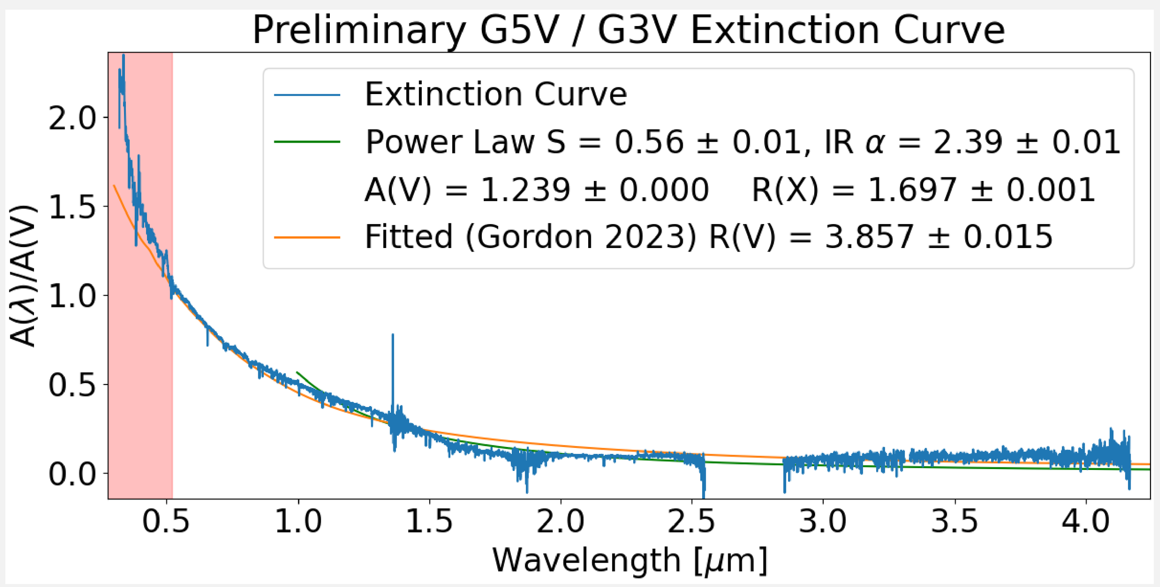

Fig 4. A preliminary extinction curve of G-type stars, plotted similar to Fig 1, shows promise for extinction curves using cooler type stars.

Summary

- **We obtained optical and near-infrared (0.32 μm ≤ λ ≤ 4.2 μm) spectra, deriving extinction curves for 10 sight lines (Fig 1).**

  Four sight lights are associated with edges of molecular clouds and one with a supernova remnant. Our extinction curves have good agreement between other studies using subsets of the optical-infrared range [1] and studies synthesizing them [2].

- **We find correlations between our extinction curve and R(X) (and R(V), by proxy) Fig 3abc; the tight correlation aligns with literature [1] results on the R(V)-dependence of extinction curves [3].**

  These correlations, along with the R(X) and R(V) correlation, show that R(V)-dependence of extinction curves affect a wide range of wavelength regions, not just the defining B and V bands for R(V). This supports literature [1] that extinction curves are a family of functions based mainly on R(V).

- **We tentatively find lower R(V) values (smaller grains) at dense cloud edges and higher R(V) near shocked regions. This is opposite of expectations [5], and analysis of the larger sample is warranted.**

- **Deriving extinction curves with the pair-method using cooler stars (FGK-type) show promise (Fig 4), although it is complicated by the numerous metal lines present.**

- **Future work in this project is to determine if any trends of R(V) with line of sight conditions can be found.**

- **SPECTRE, an upcoming IRTF integral-field-unit spectrograph instrument [7], instantaneously covers the same optical-infrared wavelength range and can derive extinction curves with improved accuracy.**

Contact:
Kenji Emerson: kemerson@hawaii.edu
Adwin Boogert: aboogert@hawaii.edu

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