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Small Variation of the NIR and MIR Interstellar Extinction Laws

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Abstract. Using the data from *APOGEE*, *WISE*, and *GLIMPSE*, we explored the variation of the near-infrared (NIR) and mid-infrared (MIR) interstellar extinction laws of the Milky Way. We derived the IR extinction laws towards a number of different sightlines, including 24 bins along Galactic latitude (b) and 592 plates observed by *APOGEE*. Our results indicate that E(J-H)/E(J-K) show only subtle variation along b, Galactic longitude (l), or the depth of E(J-K). This suggests that the NIR extinction law can be considered as universal. Similarly, E(K-W1, W2, W3, [3.6], [4.5], [5.8], [8.0])/E(J-K) also show only small variation along b, l, or the extinction depth. The MIR extinction curve is flat, indicating that the MIR extinction law is likely universal.

Keywords. dust, extinction, galaxies: ISM, Galaxy: disk, infrared: ISM

1. Introduction

It is well known that the extinction laws in the UV and optical bands are not universal, and vary with interstellar environments. In the infrared range, the near-IR (NIR) extinction curve can be described using a universal power law $A_\lambda \propto \lambda^{-\beta}$, with $1.6 < \beta < 1.8$ (Draine 2003). However, this has been challenged by a number of recent works, which have derived $\beta > 2.0$. Meanwhile, the mid-IR (MIR) extinction curve is rather flat, and consistent with the modeled extinction curve of $R_V = 5.5$ (Draine 2003). This flat MIR extinction curve is also questioned by Chapman *et al.* (2009), who propose that the MIR extinction law will significantly change with extinction depth and become consistent with that of $R_V = 3.1$ when the absolute extinction is small.

Therefore, we would like to investigate: 1. Is it true that there is a universal extinction law in the NIR? 2. And does the MIR extinction law stay flat towards all sightlines?

2. Method and Tracers

Based on the stellar parameters provided by *APOGEE*, we have established a new method which is called "intrinsic color method" to derive the extinction laws. Applying this method to all *APOGEE* data, we have derived the average IR color excess ratios and thus the average NIR and MIR extinction laws (Wang & Jiang 2014, Xue *et al.* 2016). However, in order to really understand the variation of the IR extinction laws, it is very necessary to do systematic studies along a sufficient number of different sightlines.

The data used in this work come from *APOGEE* DR12, with the IR photometric survey data from all-*WISE* and *Spitzer/GLIMPSE*. We adopted the criteria similar to those used by Xue *et al.* (2016) and selected "G K" Type giants as extinction tracers. With these tracers, we derived new relations between effective temperature $T_{\rm eff}$ vs. IR colors, and specially considered the possible effect caused by different metallicities [M/H]. After deriving intrinsic color indices based on the relation of $T_{\rm eff}$ vs. IR color, we could obtain the IR color excesses and then the extinction laws.

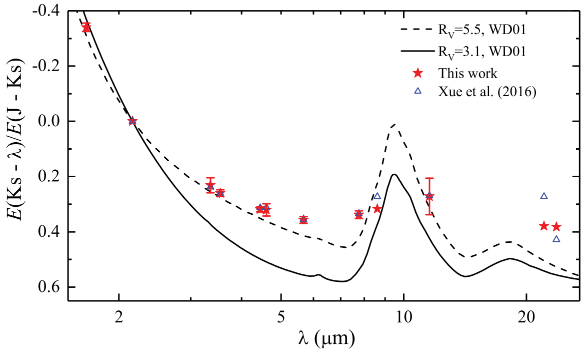

Figure 1. The universal NIR and MIR extinction law/curve of the Milky Way

3. Results

In order to explore the behavior of extinction laws along different sightlines, we divided the Galactic latitude (b) into 24 bins, and also selected 592 *APOGEE* plates as the sightlines to probe the possible variation along the direction of Galactic longitude (l). Meanwhile, a number of unreliable sightlines with large uncertainties have been excluded.

Our NIR extinction map of E(J-K) is quite consistent with that of A_K provided by *APOGEE*. The map of NIR color excess ratio E(J-H)/E(J-K) has a similar pattern with the R_V map derived by Schlafly *et al.* (2016), however, our map covers more sightlines and is much smoother, indicating small variations in NIR extinction laws. The results also indicate that E(J-H)/E(J-K) only show slight variation along b and l, and there is no apparent pattern for this variation. A very subtle variation has found between E(J-H)/E(J-K) and extinction depth E(J-K).

The maps of MIR excess ratios [E(K-W1, W2, W3, [3.6], [4.5], [5.8, and [8.0])/E(J-K)] show smooth distributions within $|b| < 20$. The results of sightlines located in higher b are absent because of large uncertainties. Similar to the distribution of NIR extinction law, the MIR color excess ratios also vary a little along l and b. Only very subtle variations have been found between the MIR extinction laws and the depth of E(J-K).

By using a Gaussian function to fit the histograms of E(J-H)/E(J-K) and E(K-λ)/E(J-K), we obtained the FWHMs of the distributions for each band. In Figure 1, the average color excess ratios derived in this work are denoted in red stars, with half of FWHM plotted as error bars for each band. The MIR extinction curve is flat and consistent with the modeled extinction curve of $R_V = 5.5$. Except for the W3 band, the variations of color excess ratios are very small, indicating that the IR extinction law (from 1μm to 8.0μm) can be considered to be very close to universal.

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