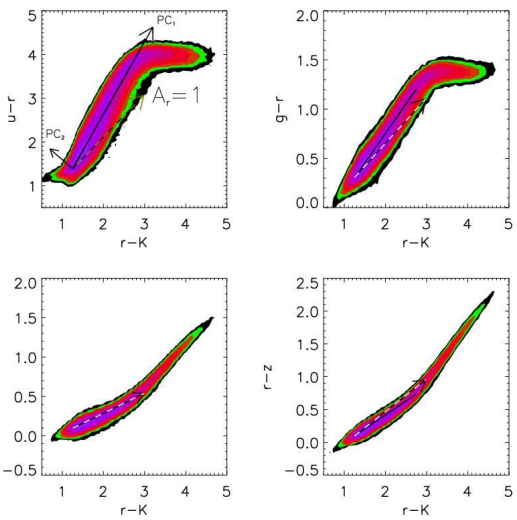
Dissecting the Milky Way with SDSS - III: The properties of interstellar dust

J.M. Meyer[1], Ž. Ivezić[1], D.P. Finkbeiner[2], D.J. Schlegel[3], K.R. Covey[1], A. Seth[1], M. Jurić[2], R.H. Lupton[2], C.M. Rockosi[4], Gillian R. Knapp[2], James E. Gunn[2]

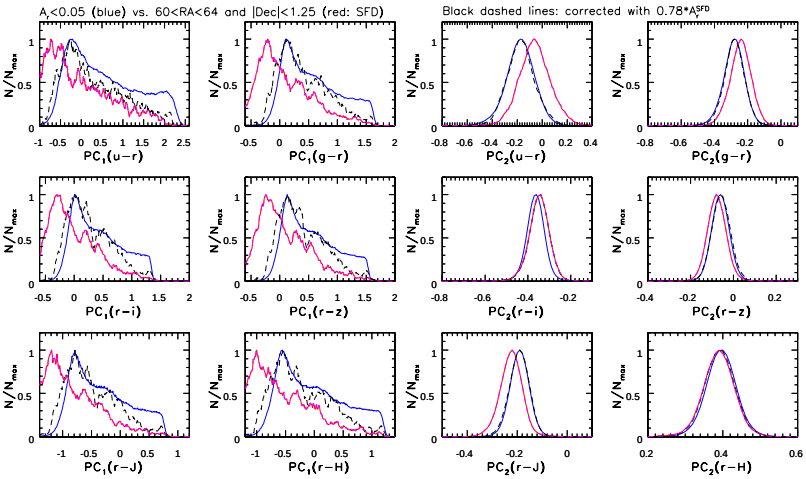
[1]University of Washington, [2]Princeton University, [3]Lawrence Berkeley National Laboratory
[4]University of California - Santa Cruz

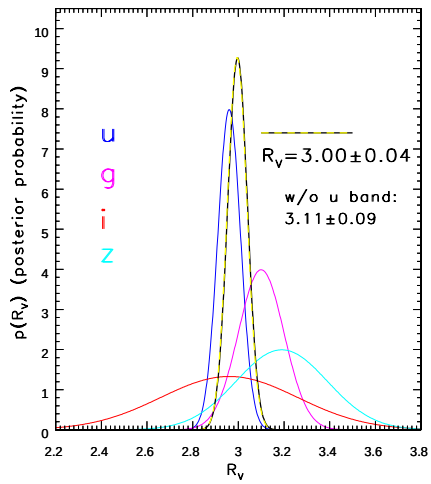
Abstract. We use the distribution of 1.7 million point sources detected by both SDSS and 2MASS in 7-dimensional color-color space to study the effects of interstellar extinction. This method provides constraints on both the amount of extinction and its wavelength dependence, and thus allows us to independently test the accuracy of the Schlegel, Finkbeiner and Davis (1998, SFD) maps, and the conversion coefficients used to generate extinction corrections in the five SDSS bands. While we find a few regions on the sky where the SFD maps probably overestimate extinction by up to ∼20%, the discrepancies are below our sensitivity limit of 5% for most of the sky observed by SDSS. We find that the published SDSS conversion coefficients for computing extinction from the SFD maps need to be adjusted by a few percent due to the slightly incorrect filter transmission curves that were used to compute these coefficients prior to the beginning of the SDSS. The corrected values constrain the slope of the extinction curve to $R_V = 3.00 \pm 0.04$, with less than 0.1 variation over the analyzed sky regions.



The Method

We use the distribution of 1.7 million point sources detected at high galactic latitudes ($|b| > 30$) by both SDSS and 2MASS in the 7-dimensional color-color space to study the effects of interstellar extinction. The seven colors span the wavelength range from 0.3 μm (SDSS u band) to 2.2 μm (2MASS K band). The sample is K-band limited ($K < 14$), and the flux limits in all other seven bands are faint enough that if a star makes the K band cut, it is bright enough to be detected in all other bands (for the moderate, <1 mag, extinction considered here). The interstellar extinction reddens the stellar colors and thus shifts the position of the stellar locus. Both the amount of extinction and its wavelength dependence can be determined by measuring the locus position. We measure the locus position in six two-dimensional projections spanned by the $r-K$ and $m-r$ colors, where $m = u, g, i, z, J$ and H. Since the extinction in the 2MASS K band is small ($A_K/A_r = 0.133$) the locus shifts in the $r-K$ direction provide robust constraints for A_r ($A_r = 0.887\,A_V$ for $R_V = 3.1$). The shifts in the $m-r$ directions then provide constraints for the extinction wavelength dependence. We measure the shifts using principal colors, PC_1 and PC_2, with PC_1 parallel to the blue part of the stellar locus, and PC_2 perpendicular to it (see solid lines in **the figure to the right**). The blue part of the stellar locus at the probed faint magnitudes ($14 < r < 17$) includes mostly thick disk stars with distances of the order 1 kpc or larger, which are thus beyond all the dust. The locus shifts (illustrated by dashed arrows for $A_r = 1$) are defined relative to its position determined using stars with $A_r < 0.05$, as given by the SFD maps (see the figures below). Any plausible errors in the SFD maps have negligible effects on this "dereddened" position of the stellar locus.





The Main Results for A_λ

Using stars with $A_r < 0.05$ (median $A_r \sim 0.02$), as given by the SFD maps, we determine the "dereddened" position of the stellar locus, shown as blue histograms in **the above two figures**. If the errors in the SFD maps were negligible (∼ 0.01 mag or less), and the wavelength dependence of the extinction perfectly known, then such idealized extinction corrections would always produce a stellar locus at the same position in the 7-dimensional color-color space (assuming that the interstellar dust properties do not vary greatly, and that the effects of changing stellar population mix are not large). The measurable discrepancies between the "predicted" and observed stellar locus position can then be attributed to the errors in the SFD maps (i.e. A_r) and assumed shape of the extinction curve, A_λ/A_r.

The shape of the extinction curve, A_λ/A_r, in the SDSS bands was initially computed (prior to the beginning of the survey, to enable spectroscopic targeting) using the standard parametrization of the extinction curve (Cardelli, Clayton & Mathis 1989; O'Donnell 1994) with $R_V = 3.1$. These values of A_m/A_r (1.87,1.38,0.76,0.54, with $m = u, g, i, z$) are commonly used to compute the extinction in the SDSS bands using the SFD maps. The analysis of the position of the stellar locus described above suggests that these values need to be changed to (1.84,1.40,0.78,0.57). These changes can be traced to the slightly incorrect filter transmission curves that were used to compute the conversion coefficients prior to the beginning of the SDSS.

The SFD extinction map errors larger than ∼5% can be easily detected using the stellar locus shifts. While we find a few regions on the sky where the SFD maps probably overestimate extinction by up to ∼20%, the discrepancies are below our sensitivity limit for most of the sky observed by SDSS. The largest discrepancy is found towards a 10 deg^2 large patch centered on RA=62 deg and Dec=0 (l=191.4, b=-35.6). The red histograms in the above two figures show the predictions for the locus position based on the SFD maps – they are clearly offset from the blue histograms which correspond to the "dereddened" position of the stellar locus. When the SFD map values for A_r are multiplied by 0.78, the resulting stellar locus (black dashed histograms) agrees well with the predictions (blue histograms).

Implications for R_V

Each new value of A_λ/A_r required to properly deredden stellar colors implies a nearly independent constraint on the slope of the extinction curve parametrized by R_V. We generate values of A_λ/A_r for a grid of R_V using the standard parametrization of the extinction curve, and from the measured values of A_λ/A_r and corresponding errors obtain constraints for R_V shown in **the above figure**.

For the source spectral energy distribution we have used an F0V spectrum which is a fairly close match to the spectra of blue stars analyzed here. Using a mean galaxy spectrum instead has a negligible effect on the results, while adopting the mean spectrum of low-redshift (<2.2) quasars introduces an offset in the implied value of R_V of ∼0.1.

Assuming that four measurements (in the u, g, i and z bands) are independent, we obtain the dashed curve which implies that $R_V = 3.00 \pm 0.04$. This value is compatible with all the four individual measurements, as discernible from the figure. When the shortest-wavelength u band measurement is ignored, the best value becomes $R_V = 3.11 \pm 0.09$. We find that R_V varies by less than 0.1 (root-mean-square) over the analyzed sky regions. However, we emphasize that all these regions are at fairly high galactic latitudes ($|b| > 30$).

Future work

The method described here can be used to produce extinction maps in the five SDSS bands with a spatial resolution of about 1 deg^2, which is comparable to the resolution of the SFD maps. Hence, in addition to an essentially independent test of the SFD maps, it will be possible to study the variation of the shape of the interstellar extinction curve with an unprecedented spatial resolution, and over a wide wavelength range.