SDSS Quasars and Dust Reddening

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Abstract. The Sloan Digital Sky Survey can be used to detect and characterize red and reddened quasars. In Richards et al. (2003), we showed that 6% of SDSS quasars have red colors consistent with significant dust reddening by an extinction curve similar to that of the Small Magellanic Cloud (SMC). We estimate that a further 10% of the luminous quasar population is missing from our magnitude-limited SDSS sample. More recent work (Hopkins et al., in preparation) confirms the conclusion that dust reddening is the primary explanation for SDSS quasars in the red tail of the color distribution. Fitting orthogonal first- and second-order polynomials to SDSS quasar photometry measures the slope and curvature of each object’s UV/optical spectrum. The slope vs. curvature distribution is elongated along the axis predicted for SMC-like reddening, while the axes predicted for LMC- or MW-like reddening provide significantly poorer fits. Extension to longer wavelengths using a smaller sample of SDSS/2MASS matches confirms this result at high significance.

1. Introduction

The SDSS Quasar Survey is very well suited to the detection and characterization of moderately reddened quasars. Quasar candidates are selected in the $i$-band, which is less affected by dust extinction than traditional $B$-band selection. It is large (~30,000 quasars to date) and relatively deep ($i \leq 19.1$ and $i \leq 20.2$ for low- and high-redshift quasar candidates, respectively). It includes high-quality ($\sigma_{\text{phot}} \leq 0.05$), five-band photometric data for all quasar candidates plus high-quality, moderately high-resolution ($R \sim 2000$) spectra for most of them. In this contribution we highlight some results of our initial study of reddened quasars (Richards et al. 2003), as well as some more recent results from work in progress.

2. Using Relative Colors to Identify Red and Reddened Quasars

The left-hand panels in Figure 1 show the observed colors of SDSS quasars as a function of redshift in $u-g$, $i-z$, and $g-i$. Calling a quasar ‘red’ based on an observed color cut (e.g., $u-g>0.6$, upper left) is subject to redshift-dependent systematic errors. Instead, we subtract the median quasar color at $z<2.2$ and plot the resulting histograms of relative colors $\Delta(u-g)$, $\Delta(i-z)$, and $\Delta(g-i)$.
in the right-hand panels in Figure 1. The $\Delta(i-z)$ histogram (middle right) is nearly Gaussian, but shorter wavelength colors such as $\Delta(u-g)$ (top right) have increasingly prominent red tails. Intrinsic red power laws would produce identical histograms in each color, while synchrotron emission cutoffs would produce redder colors at longer wavelengths. Therefore, dust reddening must be responsible for the red tails in the histograms.

Figure 2a shows the distribution of $\Delta(g-i)$ vs. $z$ for $\sim$15,800 SDSS quasars. Solid lines show the effect of SMC reddening with the indicated $E(B-V)$ as a function of $z$ on a quasar with intrinsic $\Delta(g-i)=0.2$. Unambiguously dust-reddened quasars lie to the right of the leftmost line. From them, we estimate that our sample misses only 10% of the quasar population due to dust extinction with $E(B-V) \leq 0.28$. Figure 2b shows composite quasar spectra as a function of $\Delta(g-i)$; the moderately dust-reddened composite is made from quasars lying between the darker lines in Figure 2. As expected, each dust-reddened composite has significant curvature — a power-law connecting continuum windows at 1450 and 4000 Å (dotted line) overpredicts the observed flux longward of 5000 Å.

3. Spectral Slope and Curvature at Ultraviolet-Optical Wavelengths

In Hopkins et al. (in prep.), we fit orthogonal first- and second-order polynomials to the relative magnitudes (see above) of $\sim$15,800 SDSS quasars. This procedure yields the 'slope' and 'curvature' of each object’s 'photometric spectrum' via the
Figure 2. Top (a): Distribution of SDSS quasars in relative color $\Delta(g-i)$ versus redshift. Contours show normal quasars, distributed between $-0.3 < \Delta(g-i) < 0.3$ due to the dispersion in power-law spectral indices. Outside this range (points), the excess of redder quasars over bluer ones is due to dust reddening (plus host galaxy contamination at $z<0.9$). Solid lines show the effects of dust reddening with the indicated SMC extinction curve $E(B-V)$. Bottom (b): Composite spectra as a function of $\Delta(g-i)$ color, plus attempted fits to underlying power-law continua.
coefficients $c_1^*$ and $c_2^*$ of the fitted first- and second-order Chebyshev polynomials. We fit the photometry because it has higher S/N, better calibration, and a longer wavelength baseline than the spectra. We extend the wavelength baseline by a factor of $\sim 3$, at the expense of larger photometric uncertainties, using a subsample of $\sim 2,600$ SDSS quasars also detected by the Two-Micron All-Sky Survey.

Figure 3 shows that the slope vs. curvature distribution for matched SDSS-2MASS quasars (contours and squares) is elongated along the axis predicted for SMC-like reddening (plus signs and line), while the relations predicted for the LMC (diamonds) or MW (crosses) extinction curves provide significantly poorer fits. SMC-like extinction is more common than LMC-like extinction along our lines of sight to quasars, and MW-like extinction is rare along such sightlines.

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References

Richards, G., et al. 2003, AJ, 126, 1131