COMPARING OPTICAL AND NEAR-INFRARED LUMINOSITY FUNCTIONS

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ABSTRACT

The Sloan Digital Sky Survey (SDSS) has measured an optical luminosity function for galaxies in five bands, finding 1.5–2.1 times more luminosity density than previous work. This Letter compares the SDSS luminosity density with two recent determinations of the near-infrared luminosity function based on the 2 Micron All Sky Survey data and finds that an extrapolation of the SDSS results gives a 2.3 times greater near-infrared luminosity density.

Subject headings: cosmology: observations — diffuse radiation — infrared: general

1. INTRODUCTION

The current luminosity density of the universe is an important input into estimates both of the chemical evolution of the universe due to nuclear burning in stars and of the extragalactic background light or cosmic optical and infrared background. The luminosity density is found by an integral over the luminosity function of galaxies, and estimating the luminosity function of galaxies requires photometric measurements of both galaxies and redshifts for distances. The recent release by the 2 Micron All Sky Survey (2MASS; R. Cutri et al. 2000) of near-infrared photometric data covering one-half the sky has led to two recent estimates of the near-IR luminosity function: Kochanek et al. (2001) measured redshifts or used existing redshifts for a bright sample over a large (~2 sr) region on the sky, while Cole et al. (2001) analyze a deeper sample over an effective area of ~0.2 sr using redshifts from the 2 degree Field Galaxy Redshift Survey (2dFGRS). The massive optical photometric and spectroscopic Sloan Digital Sky Survey (SDSS) has also estimated the luminosity function of galaxies in five bands between 0.3 and 1 µm (Blanton et al. 2001). The SDSS luminosity density is 1.5–2.1 times higher than previous estimates of the optical luminosity density, Blanton et al. (2001) go through the exercise of evaluating galaxy fluxes in the ways identical to the methods previously used and found that the larger flux seen by the SDSS was due to the larger apertures employed by the SDSS. This Letter extrapolates this luminosity density comparison of the SDSS to other determinations into the near-infrared.

2. LUMINOSITY DENSITY

While luminosity functions can be defined in many ways, using either parametric models or nonparametric estimators, this Letter only compares the parametric Schechter (1976) luminosity function fits. The Schechter luminosity function is given by

\[ n(L) dL = \phi_\star (L/L_\star) \exp \left(-L/L_\star\right) dL/L_\star, \]

and it gives a luminosity density \( l = 4\pi j = \int L n(L) dL = \phi_\star L_\star \Gamma(\alpha + 2) \). This luminosity density is plotted in Figure 1 as a function of wavelength for the five SDSS bands from Blanton et al. (2001) and the near-infrared \( J \) and \( K \) bands from Cole et al. (2001) along with results from earlier optical and near-infrared studies. Table 1 lists the parameters of the Schechter fits used to compute the luminosity density. Note that the measured luminosity densities scale like the Hubble constant \( H_0 \), so the plotted densities have been divided by a factor of \( h = H_0/100 \). It is clear that there is a large discontinuity between the optical SDSS bands and the near-infrared bands. Also shown in Figure 1 is the mean spiral galaxy spectrum from Dwek et al. (1998). The solid curve in Figure 1 represents a least sum of absolute errors fit to a model that allowed different scaling factors in the optical and near-infrared and that also allowed for an \( l_\star = \text{const} \) tail to the spectrum at short wavelengths. The relative scaling between the SDSS and the 2MASS results was a factor of 2.3. The overall scaling was a factor of 1.7 increase to get the Dwek et al. (1998) luminosity density to match the level of the SDSS data.

In order to study the source of the factor of 2.3 discrepancy between the SDSS and the 2MASS luminosity function, Figure 2 plots both the luminosity density and the three factors that go into the luminosity density as a function of wavelength. This plot clearly shows that the majority of the effect is caused by differences in \( L_\star \). This plot also shows the Kochanek et al. (2001) “all galaxy” fit at 2.2 µm, which is quite consistent with the Cole et al. (2001) fits.

3. DISCUSSION

The local luminosity density differences of a factor of 1.5 between the SDSS and the 2dFGRS (Folkes et al. 1999) and a factor of 2.1 between the SDSS and the Las Campanas Redshift Survey (LCRS; Lin et al. 1996) extend into the near-infrared, where an extrapolated SDSS luminosity density is a factor of 2.3 higher than recent determinations using 2MASS (Cole et al. 2001; Kochanek et al. 2001). The cause of the discrepancies between the SDSS and the LCRS and 2dFGRS optical luminosity density determinations is the use of larger apertures by the SDSS (Blanton et al. 2001), but the cause of the differences in the near-infrared has not been determined. If in fact the optical and near-infrared luminosity density has been underestimated by a factor of about 2, this provides a partial explanation for the high extragalactic background levels seen by Bernstein (1999) in the optical and by Gorjian, Wright, & Chary (2000) and Wright &
Fig. 1.—Luminosity density per unit frequency $l_\nu$, computed from the SDSS (Blanton et al. 2001), LCRS (Lin et al. 1996), 2dFGRS (Folkes et al. 1999), 2dF/2MASS (Cole et al. 2001), Canada-France Redshift Survey (CFRS; Lilly et al. 1996), and Gardner et al. (1997) luminosity functions. Dividing by $h = H_0/100$ makes this quantity independent of the Hubble constant. The dashed curve is the mean spiral spectrum from Fig. 5 of Dwek et al. (1998), but scaled by a factor of 1.7, while the solid curve is the same function with an $l_\nu = \text{const}$ (or $l_\nu \propto \nu^{-2}$) tail starting at 0.8 $\mu$m. The dotted curve shows this function with its original normalization.

Reese (2000) in the near-infrared. The background is given by

\[ 4\pi J_\nu = \int_{l(1+z)p(z)}^\infty \frac{e^{dt}}{dz} \, dz, \tag{2} \]

and while the luminosity functions discussed here only determine $l$ at $z = 0$, one expects that an increase in $l$ at low redshift would propagate smoothly to higher redshifts as well lead to an increased background.

The existing number counts $N(> S)$, where $N$ is the number of sources per steradian brighter than flux $S$, do not give a background $J = \int S \, dN$ as large as the observed backgrounds: $4J_\nu = 8 \pm 2$ nW m$^{-2}$ sr$^{-1}$ at 2.2 $\mu$m from counts (Madau & Pozzetti 2000) versus $20 \pm 6$ nW m$^{-2}$ sr$^{-1}$ from DIRBE (Wright 2001). The number counts for bright sources, in the Euclidean regime with $N(> S) \propto S^{-3/2}$, are related to the local luminosity function by

\[
N(> S) = \frac{1}{3} \int (4\pi)^{3/2} S^{-3/2} \, L^{3/2} n(L) \, dL
= \frac{\phi_1 \Gamma(\alpha + 2.5)}{3} \left( \frac{L_\star}{4\pi} \right)^{3/2} S^{-3/2}. \tag{3}
\]

The bright end of the Madau & Pozzetti (2000) number counts at 2.2 $\mu$m does agree with the Cole et al. (2001) determination of the luminosity function. Increasing the flux of each galaxy by using the larger SDSS apertures would increase $S$ at constant $N$ and thus explain the observed optical and near-infrared backgrounds. The integral under the solid curve in Figure 1 gives a near-IR-to-optical luminosity density of $5.6 \times 10^8 L_\odot$ Mpc$^{-3}$. This value is based on the SDSS data and the extrapolation of the SDSS data into the near-infrared shown in Figure 1.

S. Cole (2001, private communication) suggested that the optical-to-near-IR colors of galaxies in common between the SDSS and 2MASS samples are normal and agree with the shape of the Dwek et al. (1998) curve in Figure 1; he also suggested that he did not expect that the 2MASS magnitudes would miss such a significant fraction of the flux—certainly not a factor of 2.3. If the SDSS luminosity densities are correct, this would suggest that a significant fraction of the galaxies in the SDSS catalog that should have been detectable in the near-infrared were missed by 2MASS.

On the other hand, the SDSS luminosity densities could be too high. If so, the optical and near-infrared background determinations could be too high, or an exotic source such as a decaying elementary particle (see the “DP” curve in Fig. 1b of Bond, Carr, & Hogan 1986) could provide part of the background. If the background determinations are too high, the most likely cause of the error would be the zodiacal light modeling. In the near-IR, replacing the “very strong no-zodi” model (Wright 1997, 1998; Gorjian et al. 2000) with the Kelsall et al. (1998) model would increase the background, making the discrepancy larger. For example, Cambrey et al. (2001) use the Kelsall et al. (1998) model and get $\nu J_\nu = 28 \pm 7$ nW m$^{-2}$ sr$^{-1}$ at 2.2 $\mu$m.

At least some—if not all—of the luminosity function and background determinations discussed in this Letter are incorrect. In order to find out the true luminosity density from galaxies, one will have to measure the total flux from galaxies in

![Graph](image)

**Fig. 2.**—Plot of the three factors in the luminosity density for the SDSS (filled circles), the 2dF/2MASS (filled squares), and the Kochanek et al. (2001; open circles) luminosity functions. The units on the y-axis are arbitrary, and each factor has been scaled to fit on the plot. The thin solid curve is the fit from Fig. 1.

![Graph](image)

**Table 1.** Schechter Luminosity Function Parameters used in Figures 1 and 2.

| Parameter | $u^*$ | $g^*$ | $r^*$ | $i^*$ | $z^*$ | $J_{AB}$ | $K_{AB}$ |
|-----------|-------|-------|-------|-------|-------|---------|---------|
| $\lambda$ (\mu m) | 0.354 | 0.477 | 0.623 | 0.763 | 0.913 | 1.25 | 2.20 |
| $\phi_1$ (Mpc$^{-3}$) | 0.0400 | 0.0206 | 0.0146 | 0.0128 | 0.0127 | 0.0104 | 0.0108 |
| $\alpha$ | -1.35 | -1.26 | -1.20 | -1.25 | -1.24 | -0.93 | -0.96 |
| $M_\star$ | -18.34 | -20.04 | -20.83 | -21.26 | -21.55 | -21.40 | -21.57 |

* Taken from Blanton et al. 2001 and Cole et al. 2001.

* The absolute magnitude at $L_\star$ is given on the AB system.
large apertures that include the low surface brightness fuzzy fringes.

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