The Morphological Type Dependence of K-band Luminosity Functions

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Abstract.
Differential 2.2$\mu$m (K-band) luminosity functions are presented for a complete sample of 1570 nearby ($V_{\text{gsr}} \leq 3000$ km/s, where $V_{\text{gsr}}$ is the velocity measured with respect to the Galactic standard of rest), bright ($K \leq 10$ mag), galaxies segregated by visible morphology. The K-band luminosity function for late-type spirals follows a power law that rises towards low luminosities whereas the K-band luminosity functions for ellipticals, lenticulars and bulge-dominated spirals are peaked with a fall off at both high and low luminosities. However, each morphological type (E, S0, S0/a-Sab, Sb-Sbc, Sc-Scd) contributes approximately equally to the overall K-band luminosity density in the local universe, and by inference, the stellar mass density as well.

1. Introduction

The Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006) constitutes a unique resource that has been exploited in recent years to produce near-infrared luminosity functions for galaxies with ever greater precision (Cole et al. 2001; Kochanek et al. 2001; Bell et al. 2003; Eke et al. 2005; Jones et al. 2006). The K-band luminosity function provides a key constraint in understanding galaxy evolution in the context of Lambda Cold Dark Matter ($\Lambda$CDM) cosmology by virtue of the fact that the zero redshift K-band luminosity function traces the stellar mass accumulated in galaxies at a wavelength where interstellar extinction is minimal (Devereux, Becklin & Scoville 1987; Bell & de Jong 2001; Bell et al. 2003).

The current paradigm, constrained, in part by the K-band luminosity function (e.g., Benson et al. 2003) has galaxy disks forming through a combination of cold gas accretion and feedback (e.g., Dutton 2008) with bulges resulting from mergers (e.g., Masjedi, Hogg & Blanton 2008). Thus, the diversity of visible morphologies seen today among galaxies represents the culmination of multiple evolutionary paths. These end points in galaxy evolution are captured in a taxonomy devised by Hubble (1936) and refined by de Vaucouleurs (1959),...
that is based on the relative prominence of the stellar bulge and the degree of resolution of the spiral arms.

Nearby galaxies were identified using HYPERLEDA; a web-based interface (http://leda.univ-lyon1.fr) that provides access to the Principal Galaxy Catalog (Paturel et al. 2003). The 2MASS counterparts were identified on the basis of positional coincidence with the Extended Source Catalog (XSC, Jarrett et al. 2000). A volume-limited sample was defined for further study, hereafter the K10/3000 sample, comprising 1604 galaxies with $K \leq 10$ mag, $V_{\text{gsr}} \leq 3000$ km/s, and $|b| > 10$ degrees. The adopted K-band magnitudes are those measured within the $20 \text{mag}/(\text{arc sec})^2$ elliptical isophote; the parameter $k_m-k_{20\mu e}$ in the 2MASS XSC.

The principal aim of this project, described in more detail in Devereux et al. (2009), is to use nearby galaxies to define the first benchmark K-band luminosity functions for galaxies segregated by visible morphology. The luminosity function calculation employs the non-parametric maximum likelihood method of Choloniewski (1986). Our study improves on Marzke et al. (1994, 1998); Binggeli, Sandage & Tammann (1988); Efstathiou, Ellis, & Peterson (1988); Kochanek et al. (2001) and Bell et al. (2003) by limiting the sample to include only nearby galaxies, which have the most reliable morphological assignments, and by using the most recent galaxy distance determinations in conjunction with near infrared K-band magnitudes that correlate with stellar mass.

![Figure 1](image-url)  

**Figure 1.** K-band isophotal luminosity functions for 1345 galaxies in the K10/3000 sample segregated by visible morphology. The error bars reflect statistical uncertainties only. The binning procedure inherent to the Choloniewski method excludes some galaxies which is why the total number of galaxies is not the sum of the number of galaxies within each Hubble type, and why the total number of galaxies in the plot is less than the total in the sample.
2. Morphological Type Dependence of the K-band Luminosity Function

Figure 1 shows that galaxies of different morphological type have different luminosity functions and no type mimics the shape of the total luminosity function. Ellipticals dominate the space density at high luminosities, whereas late-type (Sc - Scd) spirals dominate the space density at low luminosities. Lying between these two extremes are the lenticular galaxies and the bulge-dominated spirals (S0/a - Sbc).

The total K-band luminosity density, calculated by integrating the total luminosity function yields \((5.8 \pm 1.2) \times 10^8 \, h \, L_\odot \, Mpc^{-3}\). Elliptical galaxies contribute \(\sim 16 \pm 3\%\) of the total. Lenticulars and bulge-dominated spirals combined contribute \(\sim 68 \pm 14\%\) of the total, or \(\sim 22 \pm 4\%\) for each subgroup (S0, S0/a-Sab, Sb-Sbc). Finally, the late-type spirals contribute \(\sim 16 \pm 3\%\) of the total. Overall, to a good approximation, one could say that each Hubble type \((E, S0, S0/a-Sab, Sb-Sbc, Sc-Scd)\) contributes equally to the overall K-band luminosity density in the local universe. Using information provided in Bell et al. (2003), one can predict that the M/L ratio measured in the K-band will not vary systematically by more than \(\sim 7\%\) between E and Scd galaxies. Consequently, each morphological type contributes approximately equally to the stellar mass density as well.

As far as the shape of the luminosity functions, late-type spirals follow a power law that rises towards low luminosities, whereas the ellipticals, lenticulars and bulge-dominated spirals (S0/a - Sbc) are peaked with a fall off at both high and low luminosities. Our results concerning the morphological type dependence of K-band luminosity functions differ from previous studies. Kochanek et al. (2001) and Bell et al. (2003) divided their sample into just two broad categories; early and late, based on visual classifications and the SDSS light concentration index. They found little difference in form between the luminosity functions for the different types, which reflect that of the total luminosity function. Our results, based on a more comprehensive segregation according to the visual morphological classification scheme of de Vaucouleurs (1959), reveal significant differences between the luminosity functions for the different types, none of which mimic the shape of the total luminosity function.

3. Discussion

Our principal new result is that the shape of the K-band luminosity functions depend significantly on galaxy visible morphology. It may be more than a coincidence that the functional forms distinguish between bulge dominated and disk dominated systems. Evidently, there are at least two quite distinct galaxy formation mechanisms at work to produce the diversity of morphological types seen in the local universe. The next step, of course, is to establish what the formation mechanisms are exactly, which will require modeling the differential luminosity functions in the context of hierarchical clustering scenarios (e.g., Cole et al. 2000; Benson et al. 2003).

Semi-analytic models have already revealed that a combination of cold gas accretion (Weinberg et al. 2004) and feedback (Oppenheimer & Davé 2006)
can flatten the slope of the halo mass function to match that seen for galaxy
disks. Such models are also able to reproduce the peaked luminosity functions
observed for ellipticals and bulge-dominated spirals by incorporating ma-
jor mergers ([Barnes & Hernquist](#) 1992; [Hopkins et al.](#) 2008). Thus, there is
promise that the morphological dichotomy revealed by the K-band luminosity
functions may be understood within the context of ΛCDM cosmology (Benson
2008, private communication). On the other hand, dwarf ellipticals pose a prob-
lem; even though they may be structurally related to their more luminous coun-
terparts ([Kormendy et al.](#) 2008), our results show that they have a distinct
luminosity function as noted previously by [Binggeli, Sandage & Tammann](#)
(1988).

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