*The Magellanic System: Stars, Gas, and Galaxies*
*Proceedings IAU Symposium No. 256, 2008*
*Jacco Th. van Loon & Joana M. Oliveira, eds.*

DOI: 00.0000/X000000000000000X

# The IRSF Magellanic Clouds Point Source Catalogue

**Daisuke Kato**[1]

[1]Department of Astronomy, Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan
email: kato@astron.s.u-tokyo.ac.jp

**Abstract.** We present a near-infrared (JHKs) photometric catalog. This is the most sensitive in all NIR catalogs covering large portions of the Magellanic Clouds; the $10\sigma$ limiting magnitudes are 18.8, 17.8, and 16.6 at J, H, and Ks, respectively, about 2 mag deeper than those for 2MASS. It includes about 18 million point sources distributed over 40 deg$^2$ of the LMC, 11 deg$^2$ of the SMC, and 4 deg$^2$ of the Magellanic Bridge. The photometric and astrometric accuracies for bright sources are 0.03−0.04 mag and 0.1 arcsec, respectively. Color-color and color-magnitude diagrams for the sources show features of giants, AGB stars, OB stars and Herbig Ae/Be stars in the Magellanic Clouds. This indicates that the catalog is quite attractive for studying star formation and evolution in the Magellanic Clouds. Catalog data are available at http://pasj.asj.or.jp/v59/n3/590315/ .

**Keywords.** Magellanic Clouds, catalogs, surveys, infrared: stars

## 1. Introduction

The Magellanic Clouds (MCs) consist of two irregular galaxies, the Large and Small Magellanic Clouds (LMC and SMC, respectively). The LMC and SMC are embedded in a common H I envelope; the region between the Clouds, called the Magellanic Bridge (MB), also includes stellar components. The proximity of the MCs (50−60 kpc) allows us to study individual stars in them. Compared to our Galaxy, the MCs are characterized by lower metallicity, lower dust-to-gas ratio, and stronger radiation field. Under these different circumstances, the stars in the MCs may follow different formation and evolution paths from those in the Galaxy.

Within the last decade, two near-infrared (NIR) large-area surveys have been carried out; the Two Micron All Sky Survey (2MASS) has completed a full-sky $JHK_s$ survey (Skrutskie et al. 2006) and the Deep Near Infrared Survey of the Southern Sky (DENIS) has also surveyed the southern sky at $IJK_s$ (Cioni et al. 2000). These surveys have given the first comprehensive NIR views of the MCs (e.g., 2MASS: Nikolaev & Weinberg 2000, DENIS: Cioni, Habing, & Israel 2000). However, as their photometric limits ($\sim 14$ mag at $K_s$) and spatial resolutions (2−3 arcsec) were chosen to facilitate large-area coverage, the data include only the brightest sources in the MCs: AGB stars, supergiants and the brightest red giants and dwarfs.

We have carried out a new extensive NIR survey at $JHK_s$ for the MCs with higher sensitivities and finer spatial resolutions than previously available. Thanks to these advantages, our survey has reached objects fainter by $\sim$2 mag than those observed in 2MASS and DENIS and resolved neighboring objects situated more than $\sim 0.3$ pc apart. The homogeneous data set will provide a comprehensive census of stars for studies of the formation and evolution of stellar systems in the MCs.

## 2. Catalogue

In this section, we present only a cursory description of the observation, data reduction procedure, and quality assurance for the catalog. The details are presented in Kato et al. (2007). We have carried out an imaging survey of the MCs in the NIR bands $J$ ($\lambda_c = 1.25$ $\mu$m), $H$ (1.63 $\mu$m), and $K_s$ (2.14 $\mu$m). The observations were made from 2001 October to 2006 March with the SIRIUS camera ("Simultaneous three-color InfraRed Imager for Unbiased Survey") on the InfraRed Survey Facility (IRSF) 1.4 m telescope at Sutherland, the South African Astronomical Observatory. The SIRIUS camera is equipped with three 1024 pixel $\times$ 1024 pixel HAWAII arrays to enable simultaneous observations in the three bands (Nagashima et al. 1999, Nagayama et al. 2003). The IRSF/SIRIUS pixel scale is 0.45 arcsec, yielding a field of view of 7.7 $\times$ 7.7 arcmin$^2$.

We surveyed the main part of the LMC and SMC, and a portion of the western MB. A total of 4455 pointings were required to cover the 55 deg$^2$ of the MCs. The total integration time was 300 sec for each position. A subset of the standard stars from the faint NIR standard star catalog (Persson et al. 1998) was observed. The average seeing throughout this survey was 1.3, 1.2, and 1.1 arcsec, Full Width at Half Maximum (FWHM), at $J$, $H$, and $K_s$, respectively.

We applied the standard procedure for NIR array image reduction: dark subtraction, flat-fielding, sky subtraction, and dithered images combination, based on NOAO's IRAF software package. We performed source detection with IRAF's DAOFIND and photometry with IRAF's DAOPHOT packages (Stetson 1987). Pixel coordinates ($x$, $y$) of the detected sources were converted to equatorial coordinates ($\alpha$, $\delta$) based on the International Celestial Reference System (ICRS) via the 2MASS Point Source Catalog (Skrutskie et al. 2006). Finally, we constructed the final Point Source Catalogs by selecting sources with S/N $\geqslant$ 4 in at least one band. The resulting source counts in the catalogs are 14 811 185 in the LMC, 269 682 in the SMC, and 434 145 in the MB.

The quality of the catalog was evaluated as follows:
(1) We confirmed the photometric accuracy for bright sources is 0.03−0.04 mag in all bands, by checking the dispersion of magnitude differences between duplicate sources in overlapping regions of adjacent fields observed under different observing conditions. This is consistent with that between 2MASS sources and our counterparts of about 0.04 mag.
(2) By the same procedure for estimating the photometric accuracy, we confirmed the astrometric accuracy for bright sources is 0.1 arcsec.
(3) The $10\sigma$ limiting magnitudes and the averages of the 90% completeness limits are 18.8, 17.8, and 16.6 mag, and 18.5, 18.2, and 17.4 mag at $J$, $H$, and $K_s$, respectively.

## 3. Color-Color and Color-Magnitude Diagrams

We present the color-color ($H-K_s$ vs. $J-H$) and the color-magnitude ($J-K_s$ vs. $K_s$) diagrams for the LMC in Figures 1(a) and (b). Plotted sources, whose source counts are 1 936 123, have photometric uncertainties $\leqslant$ 0.11 mag, or S/N $\geqslant$ 10, with a "point-like" PSF-profile, and no bright adjacent sources in all bands. As well as those toward the SMC and the MB, their spatial distributions and luminosity functions are presented in Kato et al. (2007).

In Figure 1(a), we present the color-color ($H - K_s$ vs. $J - H$) diagram (hereafter CC diagram) for the LMC. In the CC diagram, we labeled six features, "CC1" to "CC6". Of these features, "CC2" and "CC4" are clearly seen in the 2MASS CC diagram (in Figure 2 of Nikolaev & Weinberg 2000), but the others are not seen or are merged with "CC2".

"CC1" to "CC6" can be assigned to populations classified by Nakajima et al. (2005)

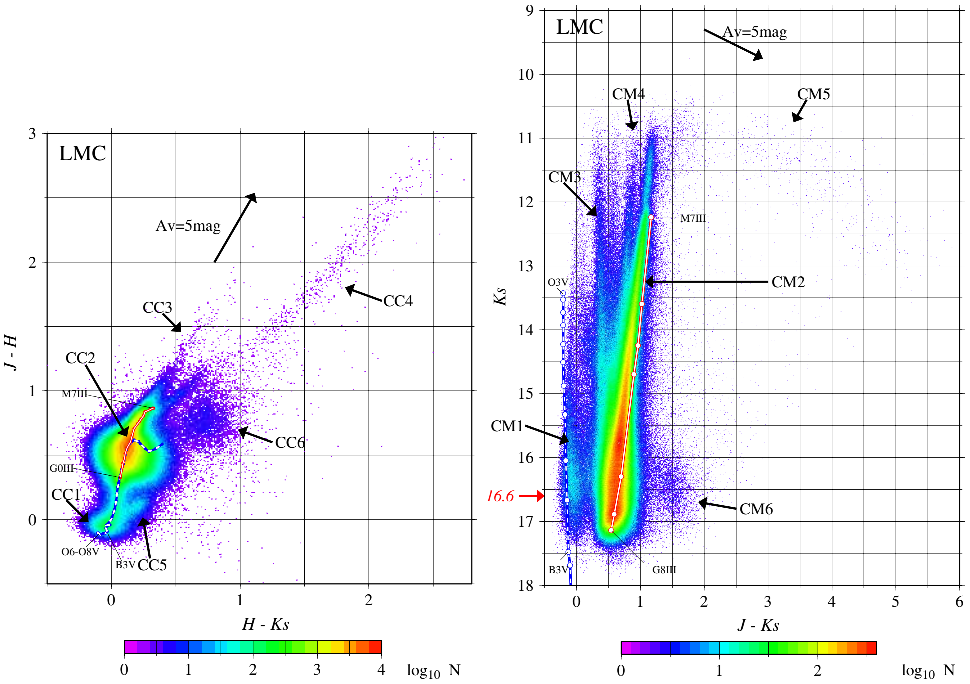


**Figure 1.** The color-color ($H - K_s$ vs. $J - H$, a) and the color-magnitude ($J - K_s$ vs. $K_s$, b) diagrams for the LMC. Each plane is binned by 0.01 mag and the number density levels are logarithmic. The blue dashed and red solid lines are the loci of dwarfs and giants, respectively. Red number indicates the $10\sigma$ limiting magnitude.

in the CC diagram for the N159/N160 region of the LMC (see their Figure 8) as follows:
"CC1": OB stars and supergiants (corresponding to "OB" and "S" in Figure 8 of Nakajima *et al.*).
"CC2" and "CC3": giants ("GNT").
"CC4": AGB variables with dust shells ("V").
"CC5": Herbig Ae/Be (HAeBe) stars and Classical Be stars ("Y").
"CC6": HAeBe stars and galaxies with z > 0.1 ("Y").

In Figure 1(b), we present the color-magnitude ($J - K_s$ vs. $K_s$) diagram (hereafter CM diagram) for the LMC. The CM diagram shows four fingers ("CM1" to "CM4"), a horizontal extension "CM5", and a loose cluster "CM6". Of these features, "CM1" to "CM5" are seen in the 2MASS CM diagram (Figure 3 of Nikolaev & Weinberg 2000), but "CM6" is not seen because it is below the 2MASS 10 $\sigma$ limiting magnitudes.

Based on classification by Nikolaev & Weinberg (2000) and correspondence between "CM6" and "CC6", "CM1" to "CM6" can be assigned to populations as follows:
"CM1": the main sequence (corresponding to "region A" designated by Nikolaev & Weinberg).
"CM2": the RGB ($K_s \gtrsim 12$) and the AGB ($K_s \lesssim 12$) ("E", "F", and "G").
"CM3": Galactic foreground sources ("B").
"CM4": the vertical red clump ("I").
"CM5": AGB stars ("J" and "K").
"CM6": HAeBe stars and galaxies with z > 0.1 (no counterparts in the 2MASS CM diagram, but corresponding to "CC6").

Our higher sensitivity enables to detect HAeBe stars, whose lifetimes are $\sim 1$–$3$ Myr, yielding evidence of ongoing star formation. With our limiting magnitudes, we can detect HAeBe stars down to $\sim 3$ $M_\odot$ in the LMC (see Appendix A in Nakajima et al. 2005). Since the HAeBe and OB star candidates can be selected based on their positions on the CC ($H - K_s$ vs. $J - H$) diagram (see Fig. 1, a), these are useful probes for studies of star formation in the MCs.

Using our survey data, star formation in some areas of the MCs have already been analyzed. Based on spatial distributions of HAeBe and OB star candidates, Nakajima et al. (2005) and Hatano et al. (2006) suggested large-scale triggered star formation in two active star-forming regions, N159/N160 and N11 in the LMC. In the Magellanic Bridge region, Nishiyama et al. (2007) found more than 200 HAeBe star candidates, indicating ongoing star formation.

## 4. Future Work: Release of Images

We plan to release the IRSF MCs survey images on the web site of Japanese Virtual Observatory (JVO). Fits and 3-color images will be released. These images are useful to identify extended sources such as nebulae and galaxies, and estimate their surface brightness. All the survey images will be released by March 2009.

## Acknowledgements

The "IRSF Near-Infrared Magellanic Clouds Survey" is a joint program of Nagoya University, the National Astronomical Observatory of Japan, the University of Tokyo, and the South African Astronomical Observatory. The IRSF/SIRIUS project was financially supported by the Sumitomo Foundation, Grants-in-Aid for Scientific Research on Priority Area "A" (Nos. 10147207 and 10147214), and the Ministry of Education, Culture, Sports, Science, and Technology of Japan. DK is supported by Grant-in-Aid for Scientific Research (18204014) from the JSPS.

## References

Cioni, M.-R., Loup, C., Habing, H.J., et al. 2000,
Cioni, M.-R.L., Habing, H.J., & Israel, F.P. 2000, *A&A*, 358, L9
Hatano, H., Kadowaki, R., Nakajima, Y., et al. 2006, *AJ*, 132, 2653
Kato, D., Nagashima, C., Nagayama, T., et al. 2007, *PASJ*, 59, 615
Nagashima, C., et al. 1999, in T. Nakamoto, *in Star Formation 1999* (Nobeyama, Japan: NRO), p. 397
Nagayama, T.,Nagashima, C., Nakajima, Y., et al. 2003, in M. Iye & A.F.M. Moorwood, *Proc. SPIE*, 4841, p. 459
Nakajima, Y., Kato, D., Nagata, T., et al. 2005, *AJ*, 129, 776
Nikolaev, S., & Weinberg, M.D. 2000, *ApJ*, 542, 804
Nishiyama, S., Haba, Y., Kato, D., et al. 2007, *ApJ*, 658, 358
Persson, S. E., Murphy, D.C., Krzeminski, W., Roth, M., Rieke, M.J. 1998, *AJ*, 116, 2475
Skrutskie, M.F., Cutri, R.M., Stiening, R., et al. 2006, *AJ*, 131, 1163
Stetson, P.B. 1987, *PASP*, 99, 191