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DEEP INFRARED SURVEYS OF STAR FORMINGREGIONS IN THE MWG AND LMC

YASUSHI NAKAJIMA
National Astronomical Observatory of Japan, Osawa 2-21-1, Mitaka, Tokyo, 181-8858, Japan
E-mail: yas@optik.mtk.nao.ac.jp
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ABSTRACT

On behalf of the IRSF/SIRIUS group, I introduce some recent results from our deep near-infrared surveys (J, H and Ks bands, limiting magnitude of Ks=17) toward star forming regions in the Milky Way Galaxy (MWG) and Large Magellanic Cloud (LMC) with the near-infrared camera SIRIUS. We discovered a rich population of low-mass young stellar objects associated with the W3 and NGC 7538 regions in the MWG based on the near-infrared colors and magnitudes. The high sensitivity of our survey enables us to detect intermediate-mass pre-main sequence stars, i.e. HAEBE stars, even in the LMC. We detected many HAEBE candidate stars in the N159/N160 complex star forming region in the LMC with the IRSF 1.4-m telescope. Spatial distributions of the young stellar objects indicate the sequential cluster formation in each star forming region in the complex and large scale (a few × 100 pc) sequential cluster formation over the entire complex.

Key words : infrared: stars — stars: formation — stars: pre-main-sequence

I. IRSF/SIRIUS

SIRIUS (Simultaneous-color InfraRed Imager for Unbiased Surveys) is a near-infrared (NIR) camera (Nagashima et al. 1999, Nagayama et al. 2003) developed by Nagoya University and National Astronomical Observatory of Japan. It is designed for deep and wide JHKs-bands simultaneous surveys. SIRIUS is equipped with three HAWAII (1024×1024) arrays, J(λ=1.25 μm), H(1.63 μm), and Ks(2.14 μm) band filters, and two dichroic mirrors which enable simultaneous observations at the three bands. Simultaneous observations at the three bands provides us with accurate color information.

The purpose of SIRIUS is deep and high-resolution survey of large areas, but not the whole sky like 2MASS or DENIS. SIRIUS is mainly used with a dedicated 1.4-meter telescope, IRSF (InfraRed Survey Facility), at the South African Astronomical Observatory. The survey of southern sky began in November 2000. When it is attached on the IRSF 1.4-meter telescope, the field of view is 7.7 arcmin by 7.7 arcmin with the pixel scale of 0.45 arcsec. With a typical integration time of 15 minutes, the 10 σ limiting magnitudes are J=19.2, H=18.6, Ks=17.3.

SIRIUS was also used on the University of Hawaii 2.2-meter telescope at Mauna Kea for three times in August 2000, October 2000, and September 2001. When SIRIUS is attached on the UH 2.2-meter telescope, the field of view is 4.9 arcmin by 4.9 arcmin with the pixel scale of 0.28 arcsec. With a typical integration time of 15 minutes, the 10 σ limiting magnitudes are J=20.3, H=19.2, Ks=18.3. Surveys of several northern sky areas were done.

II. STAR FORMATION STUDIES

Star formation is one of the major subjects for SIRIUS. SIRIUS is powerful in revealing pre-main-sequence (PMS) stars, because it is sensitive to PMS stars due to thermal emission from circumstellar matter and embedded PMS stars suffer less extinction in the wavelengths.

Many star formation studies are therefore done so far (Sugitani et al. 2002, Jiang et al. 2002, Nakajima et al. 2003, Nagashima et al. 2003, Jiang et al. 2003, Ojha et al. 2004a, Baba et al. 2004, Ojha et al. 2004b, Nakajima et al. 2005) I introduce two topics in this manuscript.

III. N159/N160 IN THE LMC

(a) LMC Survey

The main purpose of SIRIUS at IRSF is an unbiased deep survey toward 6 degree square area of the Large Magellanic Cloud (LMC). The survey began in December 2000 and we have completed for the whole area. The integration time for each field is 5 minutes and the limiting magnitude is Ks ~17 mag.

Star formation in the LMC is one of the most important researches in this survey. With the limiting magnitude of Ks ~17 mag, a large fraction of the population of intermediate mass pre-main sequence star [Herbig Ae/Be (HABE) star] can be detected at the distance of the LMC, if the luminosity function in the LMC is the same as the Galactic one. Covering 6 degree

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square area and detecting most of the HAEBE stars, LMC survey of SIRIUS will be unique in the survey of star forming region in the LMC. Here, I introduce one of the results from the LMC survey.

(b) Cluster Formation in N159/N160

The N159/N160 complex is one of the most interesting cluster forming regions in the LMC. Previous optical, far-infrared and radio observations suggested that the N159/N160 complex consists of three distinct and spatially well separated regions (Bolatto et al. 2000). The northern region N160 is associated with massive cluster formation at a relatively evolved stage. The central region N159 is at a younger stage of cluster formation, being wrapped in molecular gas. The southern region N159S harbors the N159S giant molecular cloud (GMC), however, the absence of any star forming activity was indicated. Thus, the N159/N160 complex shows a diversity of cluster status.

We aimed at detecting HAEBE stars and embedded protostars in the N159/N160 complex with the NIR LMC survey and at revealing cluster status in the pre-main sequence stage. We discovered a total of 338 and 424 candidates of HAEBE and OB stars, respectively, based on the NIR colors and magnitudes. The HAEBE candidates are 10 clusters, while the OB candidates are 13. We discovered an embedded HAEBE cluster in a GMC associated with the N159 region and a HAEBE cluster at a tip of the N159S GMC. This is the first indication of cluster formation in the N159S GMC. Together with neighboring two HII regions, the HAEBE cluster at a tip of the N159S GMC indicates a hint of the beginning of sequential cluster formation in N159S. Spatial distributions of the HAEBE, OB and previously known optical clusters and embedded massive stars indicate that (1) sequential cluster formation within each of the N159 and N160 regions, and (2) large scale sequential cluster formation over the entire region from N160 to N159S. Possible triggers for the large scale sequential cluster formation are a supergiant shell SGS19 and an expanding superbubble. More details are found in Nakajima et al. (2005).

IV. NGC 7538 AND W3 IN THE MWG

We have investigated many massive star forming regions in the MWG with SIRIUS. As they are located close to us, we can detect low mass PMS stars, i.e. T-Tauri stars, as well as massive PMS stars. We can discuss luminosity functions of PMS stars by detecting a wide luminosity range of PMS stars, which lead us to a clue to the initial mass function (IMF). Here, I introduce two results, NGC7538 (Ojha et al. 2004b) and W3 (Ojha et al. 2004a), from the observations of SIRIUS with the University of Hawaii 2.2 meter telescope.

The HII region NGC 7538 at a distance of 2.8 kpc harbors massive stellar objects in various early stages of development (Campbell & Persson 1988). There are three luminous far-infrared (FIR) sources, IRS 1-3, in NGC 7538. They are known to have star formation activities such as maser and outflow. We observed an area of 24 arcmin^2 centered on IRS 1-3. Based on the NIR colors and magnitudes, we identified a rich population of young stellar objects (YSOs); 268 T-Tauri stars, 18 protostar-like objects, and 46 probable massive YSOs. Most of the YSOs are arranged from the north-west toward south-east in three distinct regions, forming a sequence in age: the diffuse HII region (north-west, oldest: where most of T-Tauri and protostar-like objects are detected); the compact aggregation of IRS 1-3 (center); and the regions with the extensive IR reflection nebula and a cluster of probable massive YSOs (south-east and south). The K-luminosity function (KLF) shows a power-law slope : 0.30±0.03, which is lower than the typical values reported for the embedded clusters.

The W3 Main star forming region is at a distance of 1.8 kpc and contains HII regions and embedded FIR sources. We observed an area of 24 arcmin^2 centered on the W3 Main star forming region. We identified a rich population of YSOs, which constitute a cluster also in the W3 Main. The KLF shows a power-law slope : 0.25±0.02, which is also lower than the typical values as in NGC 7538. The property of KLF and IMF will be investigated for more star forming regions with SIRIUS.

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