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Deep Near-Infrared Surveys and Young Brown Dwarf Populations in Star-Forming Regions

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Abstract. We are currently conducting three kinds of IR surveys of star forming regions (SFRs) in order to seek for very low-mass young stellar populations. First is a deep JHKs-bands (simultaneous) survey with the SIRIUS camera on the IRSF 1.4m or the UH 2.2m telescopes. Second is a very deep JHKs survey with the CISCO IR camera on the Subaru 8.2m telescope. Third is a high resolution companion search around nearby YSOs with the CIAO adaptive optics coronagraph IR camera on the Subaru. In this contribution, we describe our SIRIUS camera and present preliminary results of the ongoing surveys with this new instrument.

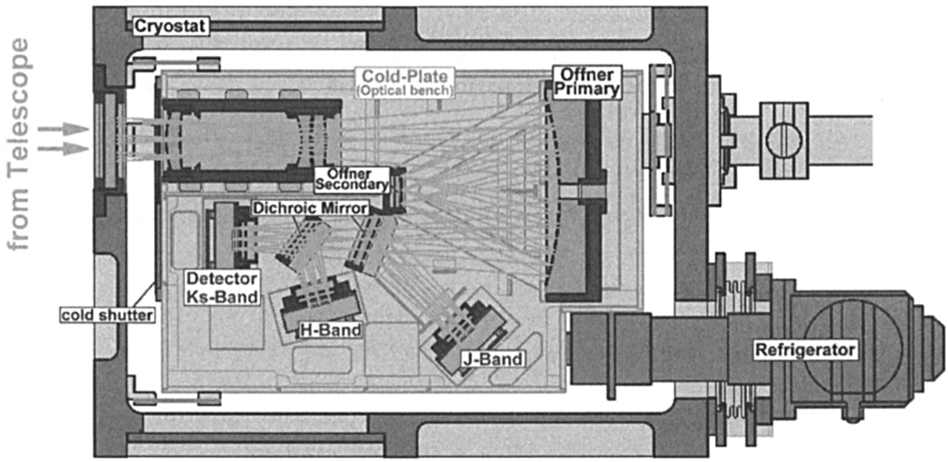

Figure 1. Layout of the SIRIUS IR camera

1. SIRIUS Near-IR Surveys of Star Forming Regions

1.1. SIRIUS IR camera

SIRIUS is a near-infrared simultaneous three-band (J, H, and Ks) camera developed jointly by the Nagoya University and the National Astronomical Observatory of Japan (PI: M. Tamura). The design of SIRIUS is optimized to deep and large area surveys in the three near-IR bands. In fact, its another main purpose is a deep whole area survey of the Large Magellanic Cloud. It is equipped with three science-grade 1024x1024 HgCdTe arrays manufactured by the Rockwell. The optics is composed of the F conversion lens system which enables the camera to attach any F$\sim$10 telescopes, the Offner catadioptric system, two dichroic beam splitters, and the three fixed filters (see Figure 1). SIRIUS obtained its first light on the University of Hawaii 2.2m telescope in 2000 August and is now under regular operation on the IRSF 1.4m telescope in Sutherland, South Africa. The latter telescope was constructed by the Nagoya University in 2000 September. The performance of SIRIUS on these telescopes is summarized in Table 1. This instrument is one of the most efficient IR cameras for deep and wide area imaging in star forming regions. More details of the SIRIUS camera can be found in Nagashima et al. (1999) and Nagayama et al. (2002).

Table 1. SIRIUS performance measured on the telescopes

Telescope	J_{limit} (mag)	H_{limit} (mag)	Ks_{limit} (mag)	Pixel Scale (arcsec pixel^{-1})	F.O.V. (arcmin square)
IRSF 1.4m	19.2	18.6	17.3	0.47	8.1
UH 2.2m	20.6	19.2	18.3	0.28	4.8

1.2. Star Forming Region Surveys

So far we have covered the following areas of low-mass, intermediate-mass, and high-mass SFRs. The regions, areas, and the limiting J magnitudes (15 minute integration, 10σ) of the surveys are summarized in Table 2. Typical seeings were 0.6 - 1 arcsec on the UH 2.2m and better than 2 arscec on the IRSF 1.4m. Similar surveys toward other regions are also in progress.

Table 2. Surveyed SFRs

Name	Region (sq. arcmin.)	J_{limit} (mag)
Chamaeleon I	2484	19.1
Chamaeleon II	1872	19.1
Ophiuchus	3087	19.1
Lupus	64	20.0
NGC1333	22	20.1
M17	204	18.7
S235	22	20.5
M16	22	19.5
S255	22	20.2

2. Our Aims and Strategies of the Surveys

One of our main aims of these surveys is a systematic search for very low-mass young stellar populations in SFRs including young brown dwarfs (YBDs) and young planetary mass objects (YPMOs). The abundance and the origin of these very low mass objects are one of the most important questions of the low-mass star formation studies. The ongoing near-infrared (1-2.5 micron) searches make selection of these sources based on their JHKs colors (e.g., Tamura et al. 1998). However, there is some ambiguity in this method: some percentage of field stars are confused with the YSOs with small IR excesses and vice verse (e.g., Muench et al. 2001). Although the more definite identification of each source as YSO awaits for further confirmation, the fraction of source contamination is considered to be constant among regions. Therefore, we could discuss statistically the luminosity functions and mass functions of these young low-mass populations.

Follow-up spectroscopy with fiber or multi-object spectrometers such as FMOS or MOIRCS on the Subaru Telescope will be important and deep thermal imaging from space such as ASTRO-F will be conducted in several years for the candidates we discovered during the current surveys.

3. Comparison of Luminosity Functions and Populations of Young Brown Dwarfs in SFRs

Our surveys are in fact deep enough to make a census of young, very low-mass stars including YBDs and YPMOs (e.g., Tamura et al. 1998; Oasa et al. 1999;

Lucas & Roche 2000; Luhman et al. 2000). The absolute completeness limit for the Chamaeleon and Ophiuchus clouds is about J=12 mag, deeper than the expected J magnitude of a 1 Myr, 0.01 solar mass object.

We have found that a significant number of YBD populations in the low-mass SFRs. However, there appears to be a variation of YBD population among SFRs. For example, the ubiquity of YBDs within one cloud complex has been shown in the N and SW cores of the Chamaeleon I cloud. Their luminosity functions down to YPMOs are similar to each other (see also Oasa et al. 1998). In contrast, surprisingly no YBD and YMPO candidates have been found in the core of the Lupus cloud except for one class I like object in spite of a much deeper search than before (see also Nakajima et al. 1999).

Even in the massive SFRs, our SIRIUS surveys are deep enough to make a census of YBDs near the stellar-substellar boundary mass. Also note that our surveys with the Subaru telescope are deep enough ($K > 20$) to include all YBDs and some planetary-mass YSOs in the massive SFRs even though they are relatively distant compared with the low-mass SFRs (Oasa et al. 2002, in prep.; also in this proceedings for S106).

We have calculated the number of YBD candidates relative to that of low-mass "stellar" YSOs for the massive and intermediate SFRs. The ratio, N(YBD)/N(LMYSO), ranges from 0.5 to 3. Therefore, the population of YBDs seems to be comparable to that of T Tauri stars within the same regions.

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