A Study of Substellar Populations and Mass Functions in the Star-Forming Region S106

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Introduction

Do substellar objects such as brown dwarfs and planetary mass objects ubiquitously form in the star-forming regions?
If any, how many substellar objects are there?
How is their luminosity function and mass function?
Is there any cutoff or turnover in substellar mass function?

S106
- a well-studied massive star-forming region in Cygnus
- Distance : 600pc
- Central star (IRS4) : O9.5V
- Emission nebula (H II region) and Reflection nebula

One of the deepest NIR survey with high spatial resolution in the star-forming regions were accomplished.

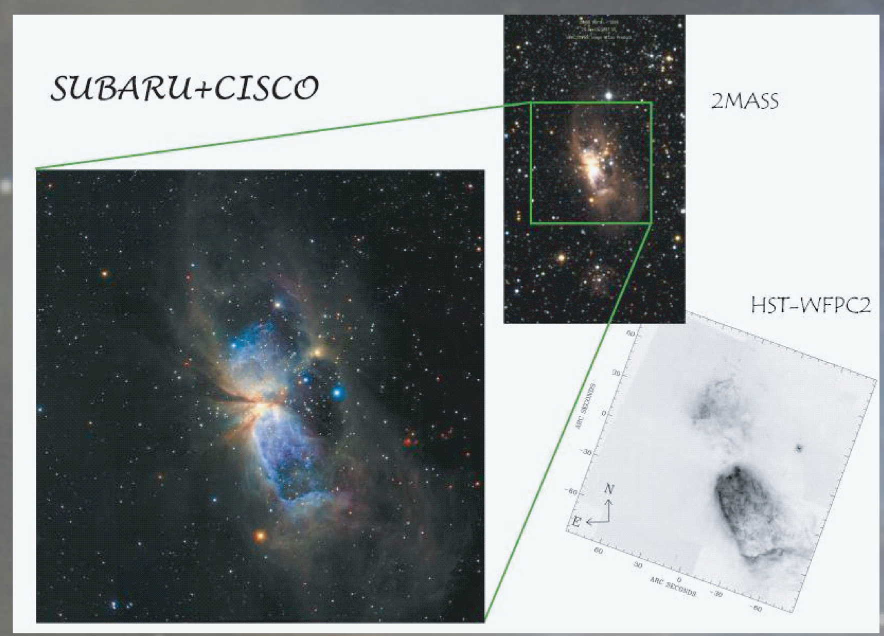

Fig. 1 Images of S106 through different wavelengths. SUBARU and 2MASS observations were carried out at J, H, K'(Ks), while HSTobservation was conducted at optical H α line.

Telescope	SUBARU 8.2m
Instruments	CISCO
Wavelengths	J, H, K'
Date of Obs.	1999.5.25,6.5-6
Total Exp. Time	6min.(J),4min(H,K')
Seeing	0.2-0.4"
Area of Coverage	5' x 5'
Standard Stars	FS27 & FS29
Identified Sources(10 σ)	～1700
Limiting Mag (10 σ)	21-21.5(J),20-20.5(H&K')

Identification and Properties of YSOs

☆Classification of sources: (Figure 2)
Locus of the observed color on the NIR color-color diagram
← **YSOs = Objects with NIR excess, indicative of disks**
In particular, only the sources whose colors are similar to reddened Class II objects is discussed.

☆Estimate of Luminosity for YSOs:
Dereddened absolute J-band luminosity (Jo-luminosity)
← Extinction= difference between the observed color and the intrinsic color of Class II object (CTTS; Meyer et al. 1997) on the color-color diagram

☆Population of YSOs: (Figure 2,3)
The S106 cluster is classified into 3 groups.
←Detailed inspection of Cloud properties with the aid of radio observations and Stellar proerties (NIR excess, extinction, fraction, surface density, spatial location of YSOs)

☆Luminosity Function (LF) of YSOs: (FIgure 3)
No cutoff is shown down to completness in LFs of 3 groups
LF of each group appears different.

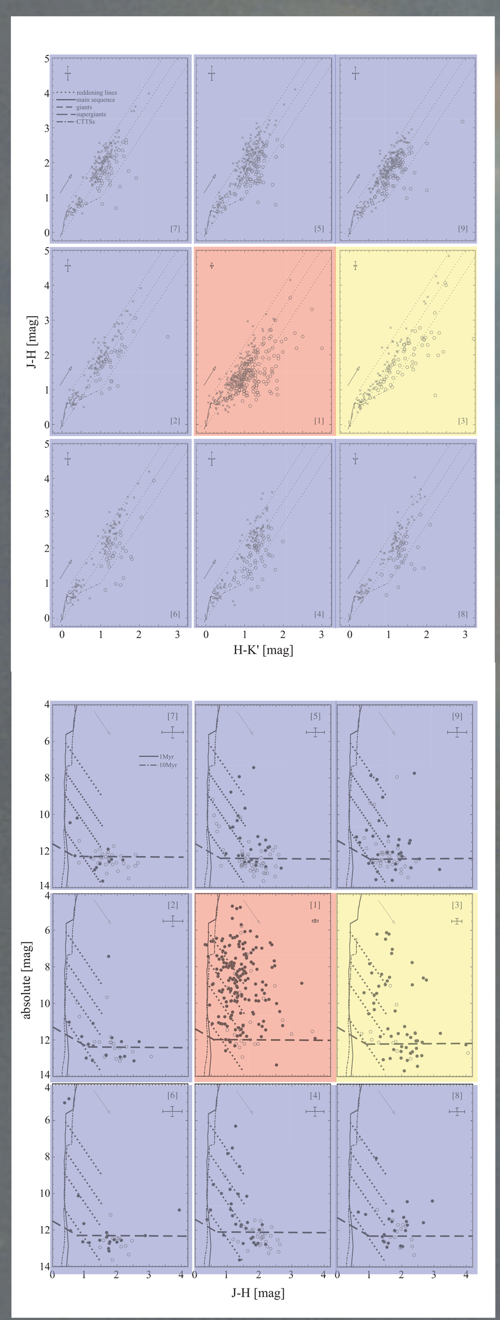

Fig. 2 [top]Color-color diagram of all sources identified in the JHK bands with K error <0.1. This figure enables us to discriminate YSOs(○) and field stars(×).[bottom] Color-magnitude diagram of YSO candidates. For reference, the 1, 10 Myr iisochrone of the latest models (Ballaffe et al. 1998,2003) and the boundary of star/ brown dwarf, brown dwarf/planetary mass object along reddening vector (4 dotted lines) and detection limits (dashed lines) are also shown.

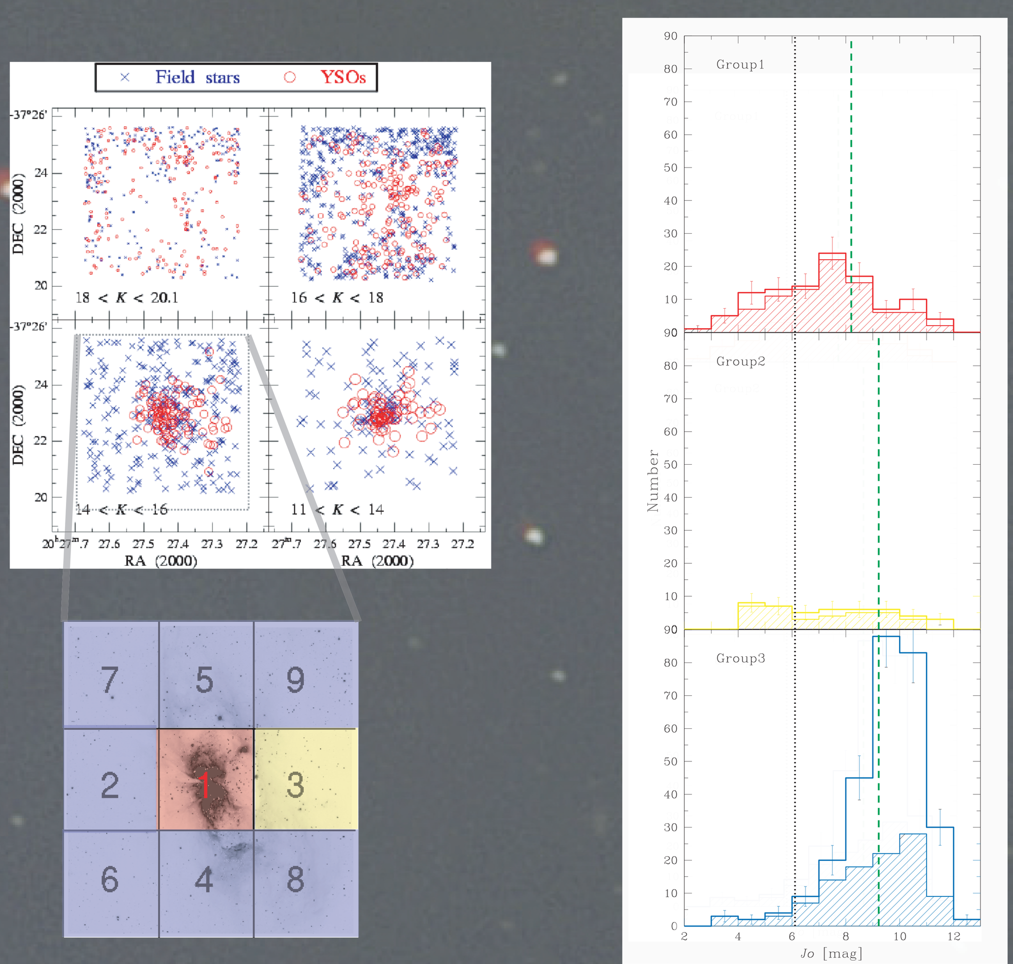

Fig. 3 [upper left] Stellar distribution of YSOs(red circle) and field stars (blue cross) within various K-luminosity range.Bright YSOs are concentrated at center, while faint YSOs are distributed over.[lower left]Schematic representation of regions and 3 groups.[right] LF of YSO candidates in 3 groups. Hattched region presents better Class II candidates.

Mass Function of YSOs

★Estimate of Mass for YSOs:
Combination of the unreddened luminosity and mass-luminosity relation, assuming of age
← Relationship of mass and Jo-luminosity is derived from the recent evolutionary models (Ballafe et al.1998,2003; Burrows et al. 1997)
← Assumption of ages, 1 Myr (typical), 0.3 Myr (younger), and 10 Myr (maximum)
Total number of identified young stellar object candidates～600,
young brown dwarf candidates～400

★Mass Function (MF) of YSOs: (Figure 4)
- There is a substantial fraction of substellar object candidates.
- No turnover occurs below the hydrogen-burning limit at any age.
- MFs steadily increase or appear flat toward completeness, which is near and below the deutelium-burning limit.
- Differences in the different evolutionary models are not significant in the global shape of MFs.
- MFs locally varies on a parsec scale within the S106 region.
- The S106 MFs are different from the other young cluster such as Trapezium and IC348 regardless of age.
- MFs at very low mass side would not only be universal.

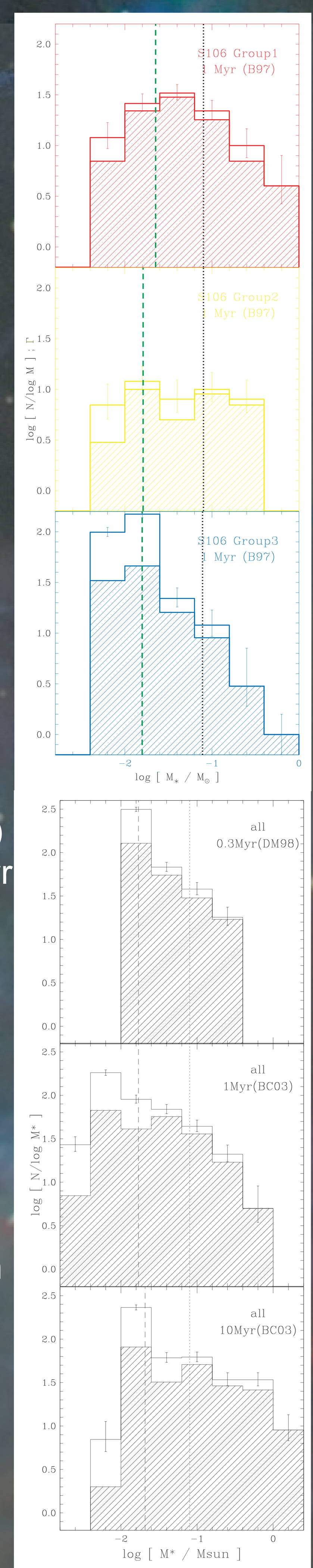

Fig. 4.[top] MFs for Class II object candidates of Groups, 1,2,and 3, assuming age of 1Myr. Black and green lines represent the star/brown dwarf boundary and completeness limits. Our MFs are represented by the number of stars per unit logarithmic mass interval.

Summary

- Deep NIR imaging survey identified ～ 1700 sources in the JHK f band with the 10 σ limiting magnitude > 20.
- Hundreds of very low-luminosity YSO candidates are revealed and most of them (～400) are likely to be young substellar objects. Furthermore, ～100 YSO candidates have an estimated mass of giant planets. These young substellar objects appear to be ubiquity.
- The YSO clusters in S106 are not represented by one population.
- Luminosity functions and mass functions of the YSO candidates are locally varying on a parsec scale within S106, but all of them do not appear any turnover down to the completeness limits.
- Mass functions at very low mass side may be dependent on the star-forming environments.

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