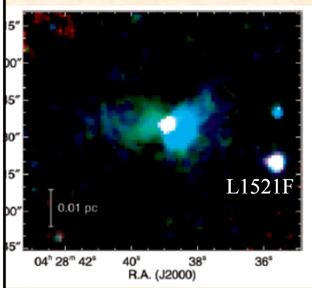
Diversity of Star/Planet Formation with Subaru/GLAO

Yumiko Oasa (Saitama Univ.)

Open questions about Star/Planet formation
@Extreme-Subaru & TMT-era

- What key physical processes govern the formation of stars?
  - that of Brown dwarfs (BDs), the least massive objects (planetary-mass objects; PMOs) and most massive stars, especially?
- How and when BDs and PMOs form?
  - Is the process same as "star" or "planet"?
- Whether the IMF is universal or not? If not, what determines it?
  - Do they have turn-over?
  - Very lower-mass and upper-mass end
  - Over a range of mass, metallicity, stellar density, and environment

Formation of Brown Dwarf & Planetary Mass Objects



Very Low Luminosity Objects (L < 0.1 Lo)
Earliest stage of accretion
or Proto-BD ?

Spitzer/IRAC 3.6/4.5/8.0

5.5'

Chamaeleon I cloud

- How and when BDs form?
- They form like stars (miniature star)?
- They form like planets? Formed as binary and then ejected ?

JHK photometry have revealed "Planetary Mass Objects" (Oasa et al. 1999)

Do such lower-mass objects form in the similar way?

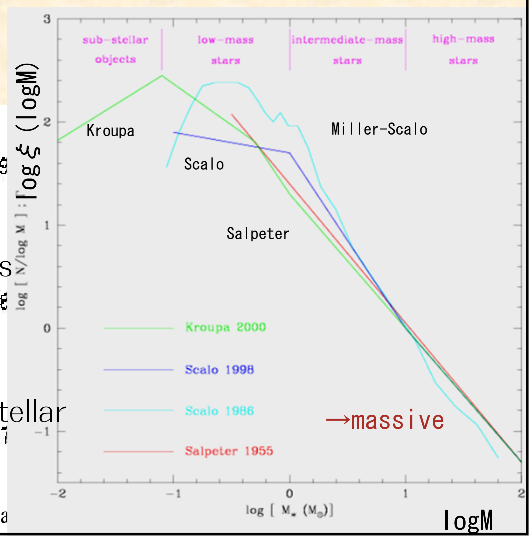
Initial Mass Function

- Stellar evolution depends on its mass
- 10〜0.4Mo: Salpeter-like IMF appears almost anywhere: the number of stars increase with decreasing mass

- Salpeter's law
  - Increase monotonously
- Scalo's law
  - Peark around 0.3Mo
  - data incompleteness… ?
- Kroupa et al…

- For much lower-mass objects such as BDs and PMOs, is their number increasing?

- Its slope is shallower at substellar (increase、flat、or decrease…)
→ possible evidence for IMF variations



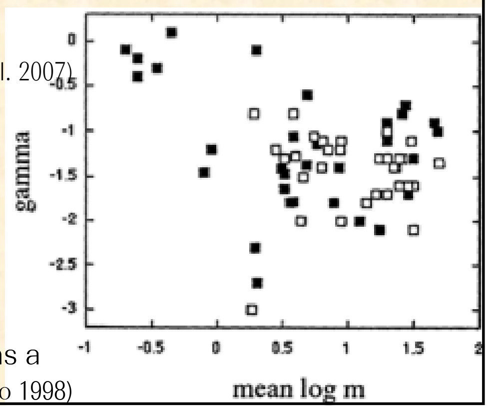
(Non)Universal IMF?

Is the IMF universal anywhere?

- IMF does not appear the "same" IMF (Scalo 1998)
- Its form is local variable among clouds/cluster (S106: Oasa et al. 2006, Trapezium: Hillenbrand 1997, NGC 3603: Harayama et al. 2008)
- Cloud core MFs are consistent with stellar IMF (NGC1333: Oasa et al. 2008, Pipe: Alves et al. 2007)

Salpeter's IMF

$$\Gamma(m) = \frac{\partial \log F(\log m)}{\partial \log m}, \qquad \Gamma \approx -1.3$$

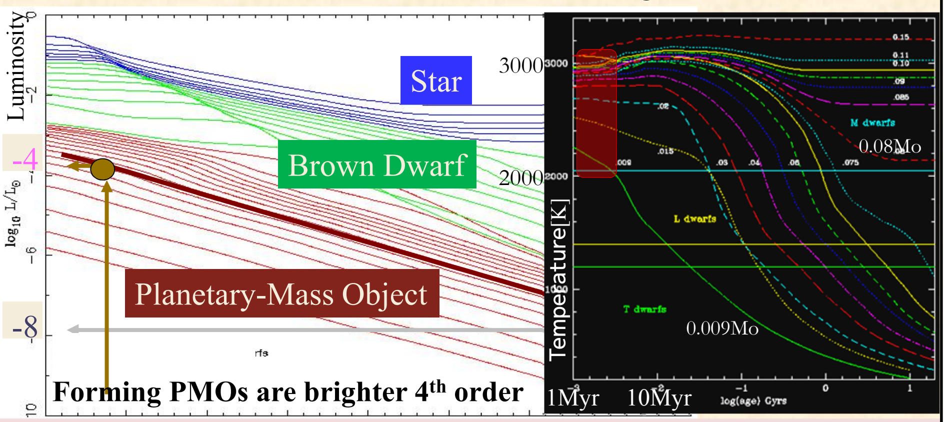


Galactic and LMC IMF index as a function of average mass (Scalo 1998)

Characteristics of Young Stellar Object (YSO)

BDs and PMOs are extremely faint, but..

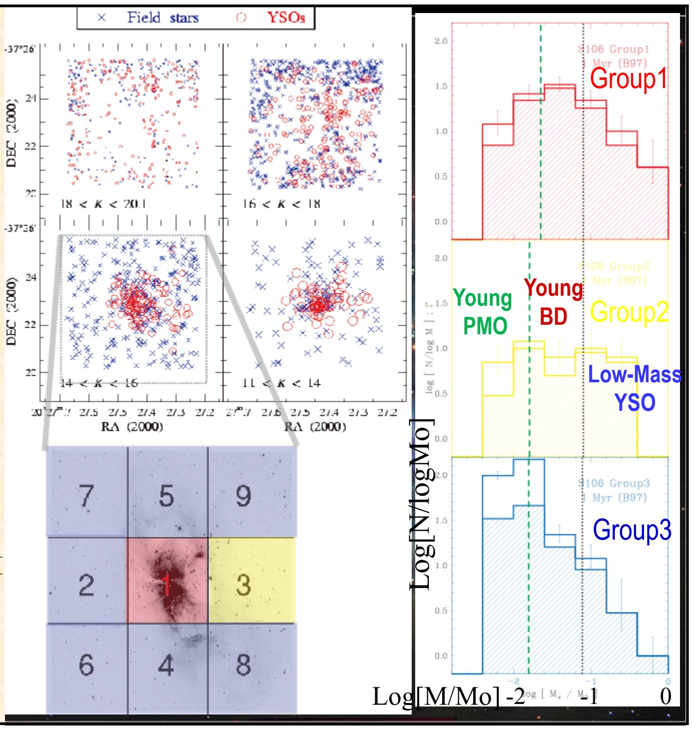
- They are brighter at earlier evolutionary stage.
- Embedded and very low-mass YSOs → bright at NIR
- YSOs in cluster have almost the same age, distance



Identify substellar YSOs embedded in cloud → NIR survey

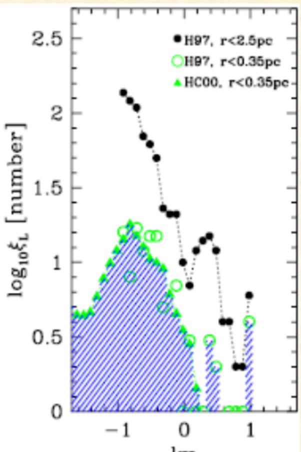
Mass Function -S 106-

- MFs at lower-mass end are increasing or flat?
- It locally varies on a parsec scale, indicating not universal.

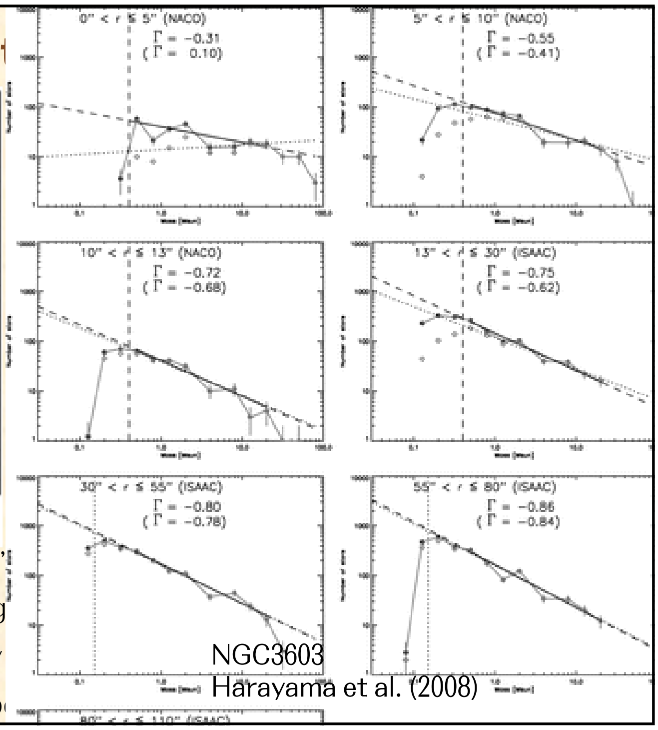


S106: Oasa et al. 2006

Mass Funct

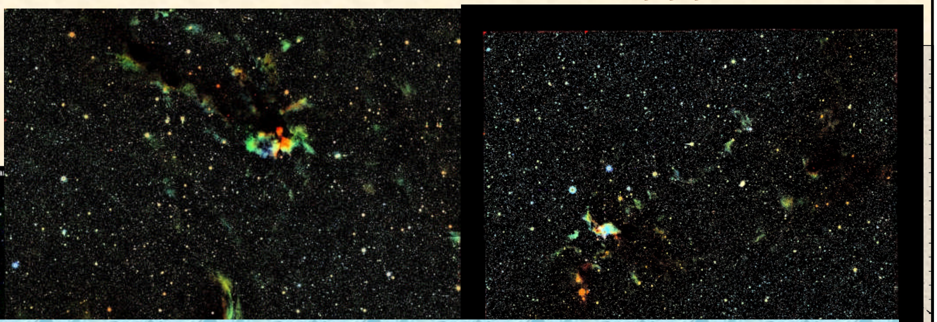


Trapezium: Hillenbrand 1997,



- MFs are increasing
- In Trapezium, they
- In NGC3603, it app

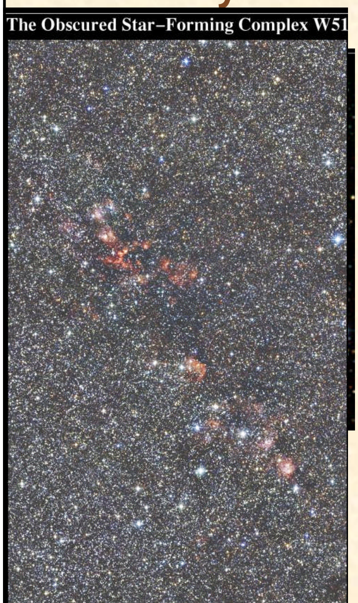
Mass Function -NGC1333-



However, there are still many open questions…

- Depends on environment, such as cloud conditions, UV radiation and metallicity?
- At the lower/upper-end ?
- Taking into account of ambiguous binarity, ••• ?
- Serpens @200pc with Subaru/MOIRCS (14' x14') J~23 and so on .

Planetary-mass objects in the various SFRs!



Very deep NIR imaging enough to detect young BDs and PMOs

To detect embedded planetary mass objects @ NGC7538 (~2.7kpc; Av>15)

JHK photometry(J=25) → massive PMOs with Av=15 @1Myr

For comparison… with WISH, TMT

W51 (~7.5kpc; Av>25)

JHK photometry(J=27) → massive BDs with Av=25 @1Myr

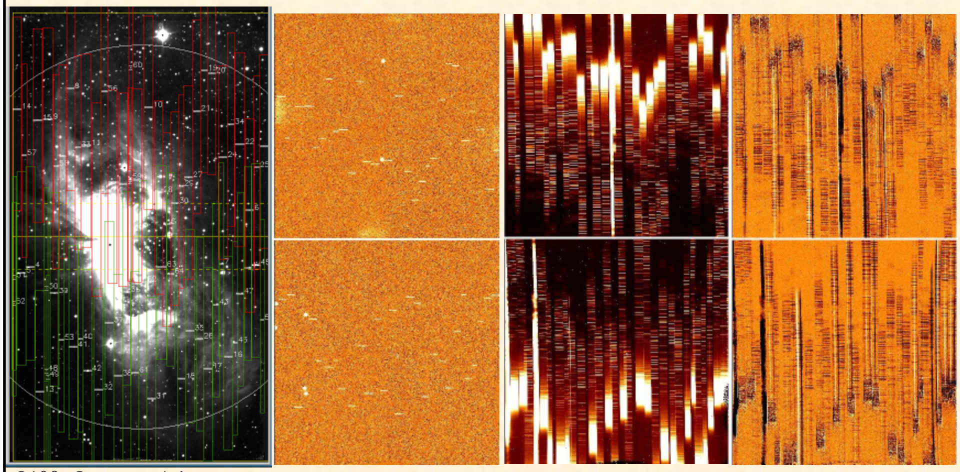
Investigation of low-mass IMF with various environments

Are they bona fide young BDs/PMOs?

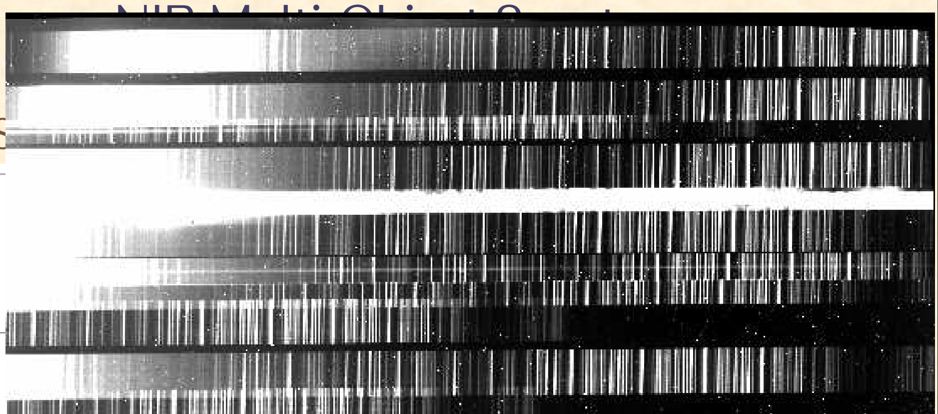
NIR Multi-Object Spectroscopy : Temperature and Mass Estimate

Subaru+MOIRCS(2048x2048x2 HgCdTe FoV～4x7’)

Preimage+mask　Maskimage　Rawdata　A-B subtracted



S106: Oasa et al. in prep.

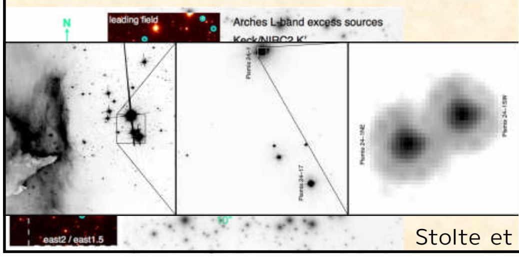


We took this data at seeing～0.3-0.4“. However, there are some problems…

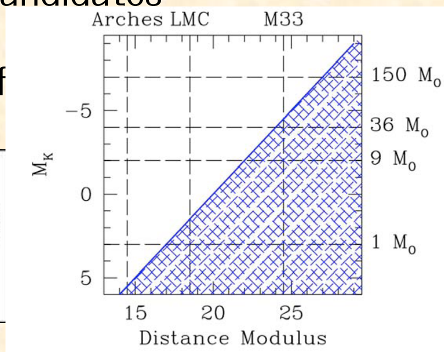
- Spectra is overlapped with the neighboring stellar one. → the number of slit is too much? (57)
- Misalign? (furthermore, flat problem)

Massive star formation studies

Massive stars form in dense clusters, most of which are formed with companion
Do the most massive stars form through accretion?
What is disk life-time?
Is there any mass segregation?
JHK (L) photometry → disk candidates
Proper motion → cluster
Trace IMF across full range of



Stolte et



Questions on instrument specifications for Star/Planet formation studies

Recent works for low-mass young stellar populations with deep NIR observations for various SFRs provide possible evidence for IMF variations

⇓

1. Baseline specifications of NIR instruments

Wide-Field NIR Imager and Multi-Object Spectrograph!!

If Integral Field Spectrograph is available, we can observe the disk/jet structure, in the following…

2. What is the optimal plate scale / FoV for your science cases?

Wider is better! But, 0.1”/pixel seems good.

3. Can you highlight synergies between this instrument and the TMT?

Yes, TMT will allow us to detect much fainter targets, i.e. lower - mass objects or in farther regions. TMT L-photometry and high-resolution spectroscopy will enable us to determine the disk structure, age and mass for substellar objects unambiguously.

Questions on instrument specifications for Star/Planet formation studies

4. Does this instrument have competitive (or complementary) capabilities with planned NIR space missions such as JWST, Euclid and WISH?

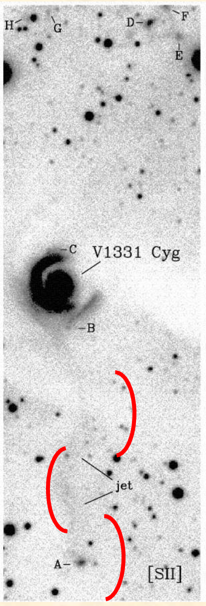
Yes, other NIR missions, especially WISH, are complementary tool for our aims.

5. Do you need spectroscopic capability? If yes, is it possible (or strong enough) to carry out with FoV of the current MOIRCS (4' x 6') but with GLAO or do you need much wider FoV? If the latter is the case, why?

Yes, we need NIR spectroscopy strongly. MOIRCS is a powerful tool.
If possible, we request multi-object spectroscopy with wider FOV (10').
Rather, we prefer "uncontaminated spectra"

In summary, we hope the wider field imager and MOS with GLAO, but the upgraded MOIRCS will also benefit our studies.

Large scale structure of jets



FOV=5.5' x 2' (Mundt & Eisloffel 1998)

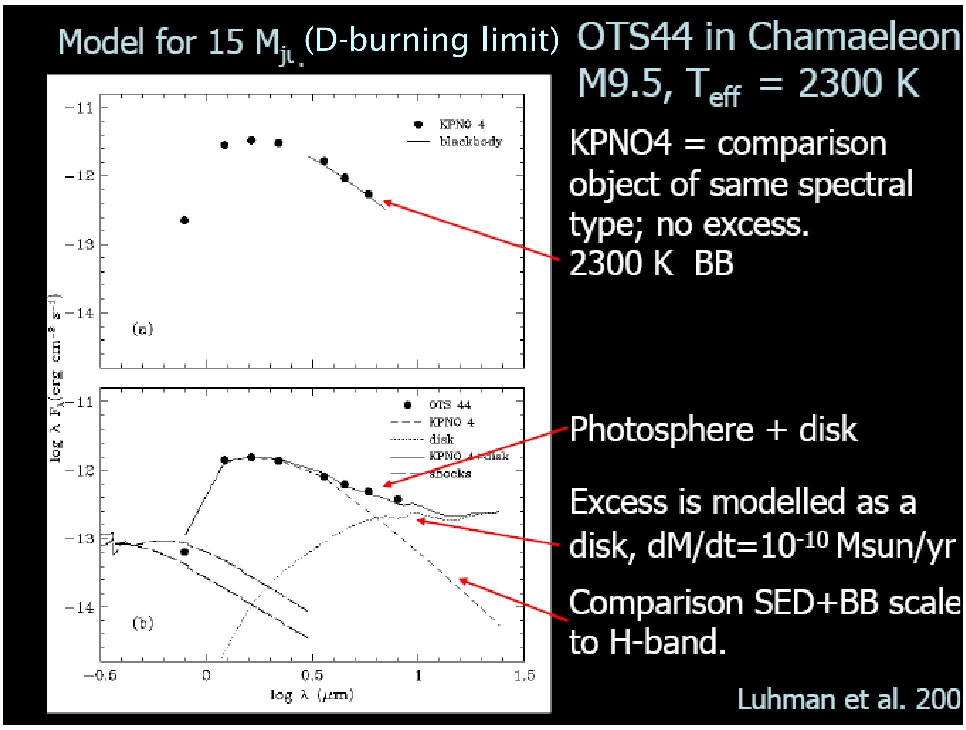
IFU spectroscopy will make clear the origin of the launching mechanism of the outflows/jets.

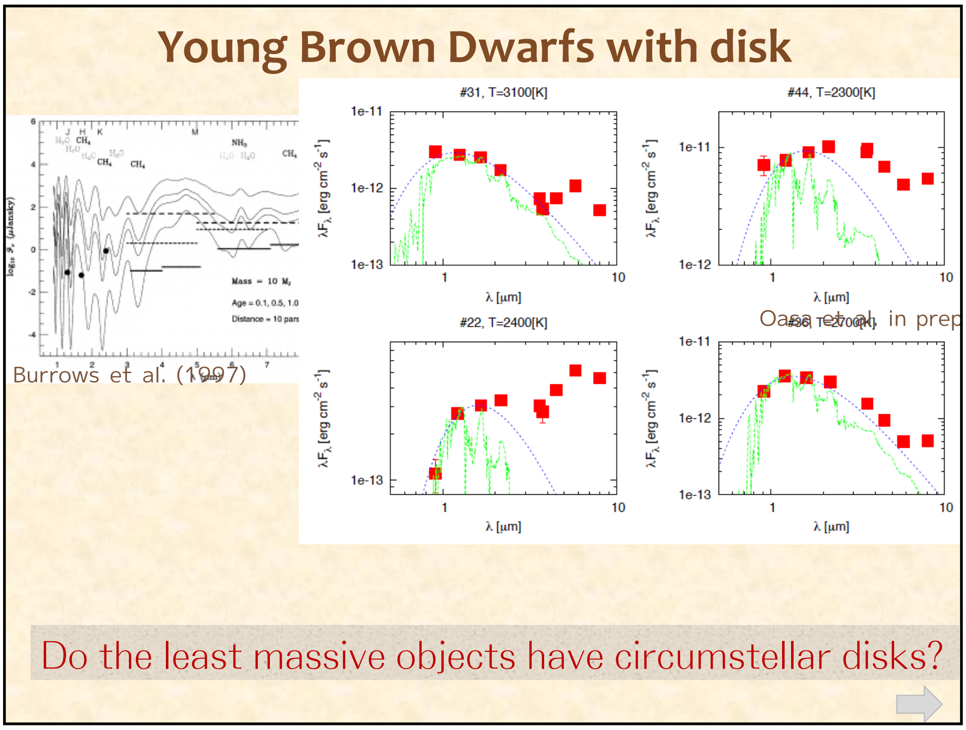
- Jets emanating from YSOs are often twisted.

V1331 Cyg case (binary)

  - Precession (Terquem+ 1999)
  - Twisted magnetic field (Uchida & Shibata 1985)
  - Interaction with dense ISM

- If Jets are twisted with ～150 km/s, we can determine kinematics, temperature, and ionization in larger scale using mid-resolution spectroscopy (R～1000).


Model for 15 Mjup (D-burning limit)
OTS44 in Chamaeleon
M9.5, Teff = 2300 K
KPNO4 = comparison object of same spectral type; no excess.
2300 K BB
Photosphere + disk
Excess is modelled as a disk, dM/dt=10-10 Msun/yr
Comparison SED+BB scale to H-band.
Luhman et al. 200
KPNO 4
blackbody
(a)
OTS 44
KPNO 4
disk
KPNO 4 + disk
shocks
(b)
log λ F_λ (erg cm⁻² s⁻¹)
log λ (μm)


Young Brown Dwarfs with disk
Burrows et al. (1997)
#31, T=3100[K]
#44, T=2300[K]
#22, T=2400[K]
Oasa et al. in prep
λ [μm]
λF_λ [erg cm⁻² s⁻¹]
Mass = 10 M_J
Age = 0.1, 0.5, 1.0
Distance = 10 parsecs
Do the least massive objects have circumstellar disks?