Investigation of the Initial Mass Function at Low-Mass End: Is it uniform?

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Objects whose mass are giant planet have been discovered in isolation. They are "Planetary Mass Objects (PMOs)". what you call, "Free-Floating Planets" (Cha; Oasa et al. 1999, σ Ori; Zapatero-Osorio et al. 2000, Trapezium; Lucas & Roche 2000).

- Salpeter’s law
  + Increase monotonously
- Scalo’s law
  + Peak around 0.3Mo
  + But, data incompleteness
- Kroupa’s law
  + Peak around 0.1 Mo?
  + But, data incompleteness

Do IMFs decrease or increase for much lower-mass objects?

Is the IMF universal anywhere, at very low-mass side?
How to search Planetary Mass Objects
NIR Photometry & Spectroscopy

Wireless 0855-0714 is the nearest (2.2pc) Ydwarf. old
"Planetary Mass Objects".

OT44: T_eff=2300 K, M~6-17M_j, ~2x10^6yr (Oasa et al. 1999; Jergens et al. 2014)

Multi-object spectroscopy to measure the water absorption
depth is very useful for hundreds of PMO and BD candidates.
NIR Multi-Object Spectroscopy: Temperature and Mass Estimate

Subaru HK spectroscopy detects H$_2$O absorption.

Oasa et al. in prep.

IMF - Massive SFR S106-

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

Oasa et al. 2006
IMF – Massive SFRs Orion, NGC3603 -

- IMF in the inner Trapezium (Ori A) appears to turn over, while IMF in Ori B increase toward substellar mass.
- IMFs between the inner and outer Trapezium and NGC3603 are different, similar to one in S106.

IMF – Intermediate mass SFRs Serpens -

- Most of Spitzer/SMM sources (=Class I/II in our NIR obs.) are located in the dense cloud.
- Total MF appears to rise steadily toward PMOs.

Spatial Distribution (left) and Total MF (right) of very low-mass YSOs (Blue:PMO, Red:BD, Green:TTS)

Hillenbrand 1997,2000
Harayama et al. (2008)
Oasa et al. in prep.
All the MFs are increasing toward the lowest mass source. In Group 3, there appears to be a deficit of BDs. Outside Groups, the slope of MSs shows steep.

Within the same cloud, the MFs appear “not universal”. There exist a significant population of PMOs. Most of PMOs are distributed outside dense core.

①Do PMOs form in the thin clouds?
②Do PMOs move outward dense cloud cores?

- MFs exhibit increasing shapes toward completeness, regardless of age.
- The clump MF (Sandell & Knee 2001) is very consistent with the stellar MF, especially assuming ages of 0.3 Myr.

Oasa et al. (2008)
There exist ~2000 PMOs/BDs within L1689/L1709 cloud. BDs are located around dense cloud core and TTS, while PMOs are distributed over the entire cloud. Both IMF appears also increasing toward substellar mass regime, but their slope are different each other.

All the results are limited within <1kpc. Thus, there are still many open questions...

★ Depends on environments, such as cloud conditions, UV radiation and metallicity?
★ Taking into account of ambiguous binarity, ⋯?
Proposal: Planetary-mass objects form everywhere?

Very deep NIR imaging enough to detect young BDs and PMOs
To detect embedded PMOs @ NGC7538 (~2.7kpc; Av>15)
JHK phot. (J=25) with ULTIMATE → massive PMOs with Av=15 @1Myr
W51 (~7.5kpc; Av>25)
JHK phot. (J=27) with TMT → massive BDs with Av=25 @1Myr
For comparison…M31 (~780kpc)
J=30 photometry with TMT → 0.8Mo with Av=10 @1Myr

Are PMOs common everywhere? How abundant?
Investigation of low-mass IMF with various environments

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

Questions on ULTIMATE for SF studies

1. What do you think is the “KEY” science/observations for ULTIMATE?
If only using the wide-field imager, it is survey for both very low-mass and massive YSOs, binarity frequency and inspection of IMF.

2. Which instrument (WFC/MOS/IFU) do you think is 1st priority for ULTIMATE?
WFC is best. Survey at 1st step, then multi-spectroscopy at 2nd step is preferred. Wider is better! About 0.1"/pixel appears good.

3. Do you have good science cases to be done with GLAO+MOIRCS?
Yes, we have experienced studies using MOIRCS.
Wide NIR survey with good image quality thanks to GLAO will discover numerous, lower-mass PMOs and YBDs in farther SFRs.

4. Which survey design sounds best for you?
I agree that WFC is 1st step and MOS is 2nd step. Most PMOs are too faint to be followed-up spectroscopy with TMT, if possible.