Substellar Objects in Nearby Young Clusters

SEARCHING FOR THE BOTTOM OF THE IMF

Vincent Geers University of Toronto

Aleks Scholz, Ray Jayawardhana (PI), Laura Fissel, Eve Lee, David Lafrenière, Motohide Tamura

MOTIVATION

- Understanding the origins of the stellar initial mass function is one of the main goals for a theory of star formation.
 - Upper-mass slope (Salpeter 1955) remarkably unchanged after more than 50 years
 - Understood and reproduced by various star formation theories with fragmentation and core accretion
 - Low mass end of IMF predicted to extend to M=0.001-0.01 M_☉, with more physics involved:
 Dynamical interactions, turbulence, photo-erosion, etc.
 - Discovery of population of "Isolated Planetary Mass Objects" (IPMOs) in σ Ori and ONC with:
 - Mass at or below Deuterium burning limit (≤ 13 Mjup)
 - Confirmed cluster membership

WHERE STAR FORMATION MEETS PLANET FORMATION

- How do these IPMOs form? As a star or by fragmentation in / ejection from a disk?
- What is the minimum mass limit for objects forming like stars, i.e. opacity limit of fragmentation?
- How common are IPMOs relative to low mass stars and brown dwarfs (BDs)?
- Do IPMOs undergo their own T Tauri phase?
- Studies of the bottom of the IMF:
 - Frequency and physical properties poorly known
 - So far no evidence for cut-off in mass function
 - Only few regions (ONC, σ Ori) studies systematically down to Deuterium limit; follow-up challenging (400 pc)
 - Unbiased surveys of ChaI (Luhman et al. '07) down to 0.01 M_☉, and USco (Lodieu et al. '08)

SONYC PROJECT GOALS

- Characterizing the Substellar Objects in Nearby Young Clusters
 - Extremely deep imaging / spectroscopy with 8m telescopes, aiming to detect photosphere in broad-band photometry from 0.8-2.2 micron
 - Unbiased extinction limited sample
 - Imaging survey for substellar candidates:
 o multiple clusters: NGC 1333, ChaI, ρ Oph
 - all nearby 125-300 pc with moderate extinction
 - ultra-deep => aim to be complete down to 3 Mjup
 - large scale => at least 1000 arcmin² in each region
 - multi-band => covering i, z, J, K
 - Spectroscopic confirmation of spectral type
 Low-res. zJHK-band multi-object spectra

SONYC: NGC 1333

- Young (≈1 Myr), nearby (300 pc) rich cluster in Perseus
- ~20 known Brown Dwarfs previously
- Subaru SuprimeCam/ MOIRCS i', z, J, K-band images of entire cluster (0.25 sq. degrees)
- Survey complete down to 24.7 in i'-band and 20.8 in J-band



NGC 1333: CLUSTER POPULATION



NGC 1333 : SUBSTELLAR MASS CANDIDATES

- Very low mass (VLM) objects are faint and red => color-magn. diagrams for candidate selection
- 196 selected candidates izJK photometry, with colors consistent with young BDs and VLM objects



- Optically selected candidates consistent with evolutionary tracks Baraffe ('98, '03), Chabrier ('00)
 - Recover BDs from Wilking et al. 2004, Greissl et al. 2007
- Possible contamination by late field M dwarfs & background giants => need spectroscopic confirmation

SPECTROSCOPIC CONFIRMATION





• Subaru MOIRCS MOS spectra of 53 objects

- Compare with AMES DUSTY model spectra (Allard et al. 2001)
- 28 objects show peak in H band due to H_2O absorption bands, sharpness through CIA => young => cluster membership
 - Consistent with BD spectra in other regions (e.g. Brandeker et al. '06, Muench et al. '07)
- $_{\odot}$ Confirm 19 obj. with $T_{\rm eff}$ = 2500-3000K (M6-M9), 7/19 from Wilking et al. '04

MINIMUM MASS IN NGC1333?



- Coolest objects 2500 ± 200 K => 0.012-0.02 M_{\odot}
 - no planetary mass objects in spectr. confirmed sample
 - survey complete to 0.004-0.008 M_{\odot} (Av ~ 5–10 mag)
- Expected 8-10 substellar mass objects, found none!

SUMMARY OF FINDINGS IN NGC 1333

- Survey:
 - 196 candidate substellar mass candidates
 - 28 spectroscopically confirmed as late M-type with Teff = 2500-3900 K
 - 19 of these Teff = 2500-3000K ± 200K (M6-M8.5)
 - Low-mass limit of confirmed BDs is $0.012-0.02 \text{ M}_{\odot}$, possible detection of cut-off of IMF in this cluster?
- Other findings:
 - 11 late type objects confirmed as class II with disks
 - Overabundance of BDs in NGC1333
 - 33 spec. conf. BDs vs. 50 stellar members
 - stellar/substellar ratio is factor 2-5 lower than in other surveyed regions
 - No companions found within 1.0" (300 AU)

Disks around substellar mass objects



- 16 / 28 N1333 candidates detected with Spitzer IRAC (3-8 micron), 10 even with MIPS (24 micron)
 - 11 / 16 are found to have IRAC excess, classified as Class II objects with disks, results consistent with Gutermuth et al. (2008)

SONYC: RHO OPH SUMMARY

- SupCam, MOIRCS, i', J, K imaging complete to 24.2, 20.9, 19.4 magn.
- 180 candidates selected from (i', i'-J), MOIRCS-MOS spectra for 58, incl. 1 known BD from Natta '06
- MOS spectra for some candidates in hand, under analysis, one confirmed new BD with $T_{eff} = 2500$ K
- Variable extinction is a complication in Rho Oph



SONYC PROJECT STATUS

- Surveys
 - NGC 1333
 - Scholz et al. (2009): imaging, spectroscopy, Spitzer excess
 - ρ Oph and Cha I
- This is just the groundwork...
 - Improve spectral type determination
 - High res. spectra of atomic lines in photosphere (e.g. Gemini GNIRS)
 - Detailed characterization of physical properties
 - disks, binarity, atmospheres, accretion, activity