Sub-Stellar Mass Objects in Orion OB1b

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Abstract. Since most stars in the galaxy were formed in OB associations, most field brown dwarfs are also likely to have formed in OB associations. Observations of very low mass members of OB association hold the promise of revealing whether sub-stellar mass objects form as small stars, or are underdone, with masses limited by photoevaporation or by dynamical ejection. Observations of young associations can also directly reveal the truly initial Mass Function, before low mass objects have had the opportunity to evaporate from the association. Our ongoing program to map the Orion OB1b association has revealed over 7000 photometric candidate sub-stellar mass objects. Near-IR spectroscopic followups of 22 candidates show that 70% have characteristics of M5-M8 objects with very low gravity. At an association age of 2 Myr, these are sub-stellar mass objects.

1. Star Formation in OB Associations

Most low mass stars and sub-stellar mass objects (SSMOs) are born in OB associations (e.g., Briceño et al. (2007)), which provide a more representative view of low mass star formation than do the better studied T associations. Our ongoing study (Walter et al. 2009) of the Orion OB1 association is designed to show how and where the very lowest mass objects, brown dwarfs and free-floating planets, form. We seek to measure the spatially-resolved mass function (MF) and by characterizing their spatial distribution, to determine whether SSMOs form as merely small stars, or are underdone, with masses limited by photoevaporation or by dynamical ejection. At the few million year (Myr) ages of OB associations, the SSMOs are still warm and bright, and readily detectable.

Orion OB1 is the largest nearby OB association, with 4 subassociations.

OB1a is the oldest (10 Myr) and closest (330 pc) subassociation.

OB1c is at comparable age and distance, and may be physically related to OB1a.

OB1b (2-5 Myr; 450 pc) lies between and behind these.

OB1d (∼1 Myr) is the Orion Nebula Cluster.

Béjar et al. (1999) have reported 171 SSMOs within a 1 $\deg^2$ region centered on σ Ori, a dense part of Ori OB1b. Sherry et al. (2004) showed that the MF down to 0.2$M_\odot$ was indistinguishable from the galactic MF. Our preliminary results (Walter et al. 2009) suggest a large population of very low mass objects in this direction - many more than are found in T associations.

2. Photometry - the CPAPIR Survey

We obtained JHK images using the CPAPIR imager on the SMARTS/CTIO 1.5m telescope between Oct 2006 and Jan 2008. The CPAPIR images a 35' field of view. Images were astrometrically and photometrically calibrated against 2MASS stars in the field. We extrapolated to fainter magnitudes assuming a linear response. The median completeness of [16.35, 16.35, 15.55] mag, respectively, in $[J, H, K]$ (assuming log N-log S$\approx$ 3/2) corresponds to a 0.02$M_\odot$ in either Orion OB1a or b (OB1a is closer but older, so the objects are intrinsically fainter). The completeness in individual fields differs by up to $-0.4/+1.6$ mag depending on conditions. We go deeper than the 2MASS completeness by [0.2, 0.9, 0.9] mag in $[J, H, K]$, respectively. There are 146,905 point sources in the full map. A crude cut for SSMO candidates ($K > 14.4; 0.8 < J - K < 1.0$) finds 7838 candidates brighter than the completeness limit.

3. Spectroscopy

We observed 19 photometrically-selected targets with IRTF/SpeX in 2008 in prism (R=200) mode. We observed 7 targets with the Palomar/TripleSpec (R=2600) in December 2013. There are 4 objects in common. The photometric selection criteria for the spectroscopic targets are $K > 14.4, 0.75 < J - K < 1.0$. All spectra were reduced using the SpeXTool software.

We used the indices defined by Allers & Liu (2013) to determine the optical spectra types and to estimate the surface gravity. Thirteen of the SpeX targets have spectral types consistent with M5–M8. All of these have low gravity indicators (gravity score > 1). All 7 TripleSpec targets have spectral types consistent with M5-M8, and all 7 have low gravity indicators (gravity score > 1).

The spectra (Figure 1) show the triangular H band shape expected of low gravity objects, however the peak seems to be shifted to longer wavelengths than is seen in older objects. This is illustrated in Figure 2.

The TripleSpec spectra have sufficient resolution to reveal the gravity sensitive alkali absorption lines. The K I lines are weaker than seen in main sequence stars (Figure 3), again suggestive of low surface gravity. The radial velocities of these targets are consistent with the velocity of the Orion OB1 association, further cementing the association of these targets with Ori OB1, and indicating that the ages must indeed be of order 10^6 years.

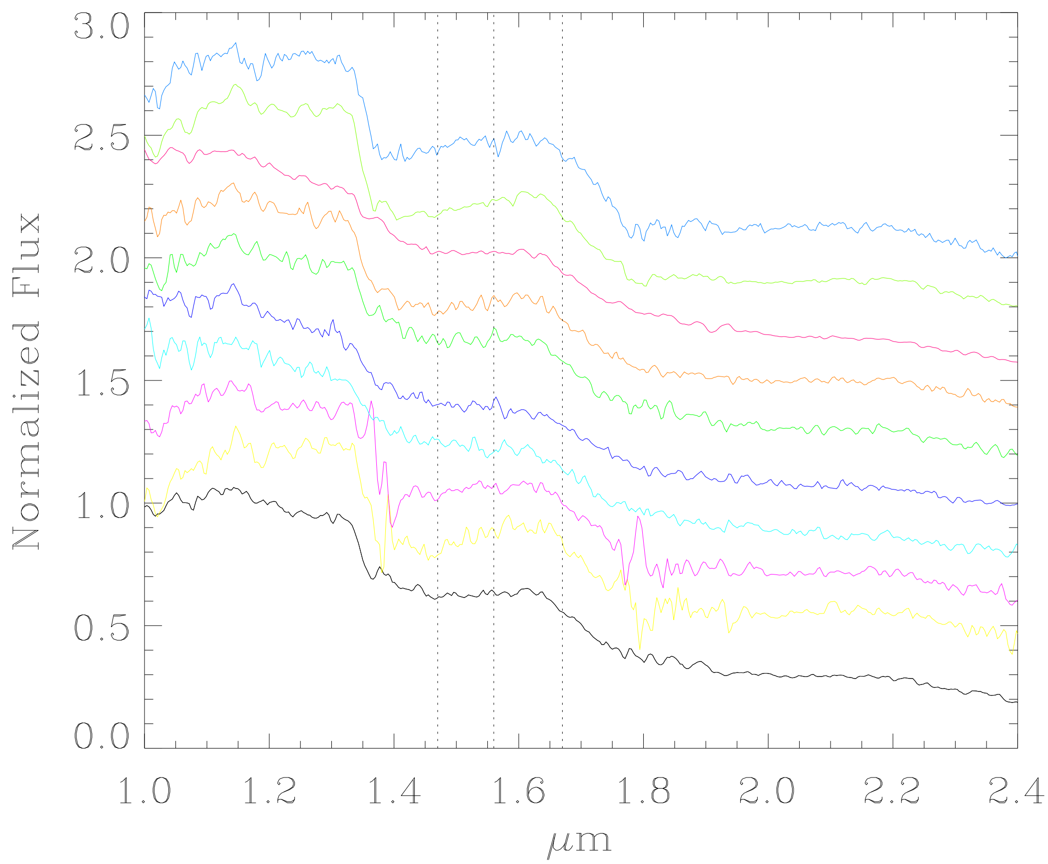

Figure .1: The triangular H band shape is evident in these 10 SpeX prism spectra. The vertical dotted lines are the wavelengths Allers & Liu use to define the H-band index. In all cases the long wavelength continuum is well past the peak. Not surprisingly, none of these H-band indices suggest low gravity. However, other indices do.

4. Upcoming

The high fraction of low gravity objects in the photometric sample suggests a very large number of association members are of sub-stellar mass. Based on population synthesis models and observations of the galactic population (Bochanski et al. 2010), there should be significant foreground contamination from early-mid M dwarfs in any near-IR-selected sample. We can break this degeneracy, and derive a much less-contaminated sample using optical photometry.

The next step in this study will be to obtain a uniform, deep sampling of the region at optical wavelengths. As is evident in Figure 4, the near-IR colors are largely degenerate among the M spectral classes. It is challenging to discriminate between M6 SSMOs and foreground early M stars. We have time at CTIO in December 2014 to use DECam to obtain uniform deep imaging to g ∼25 mag.

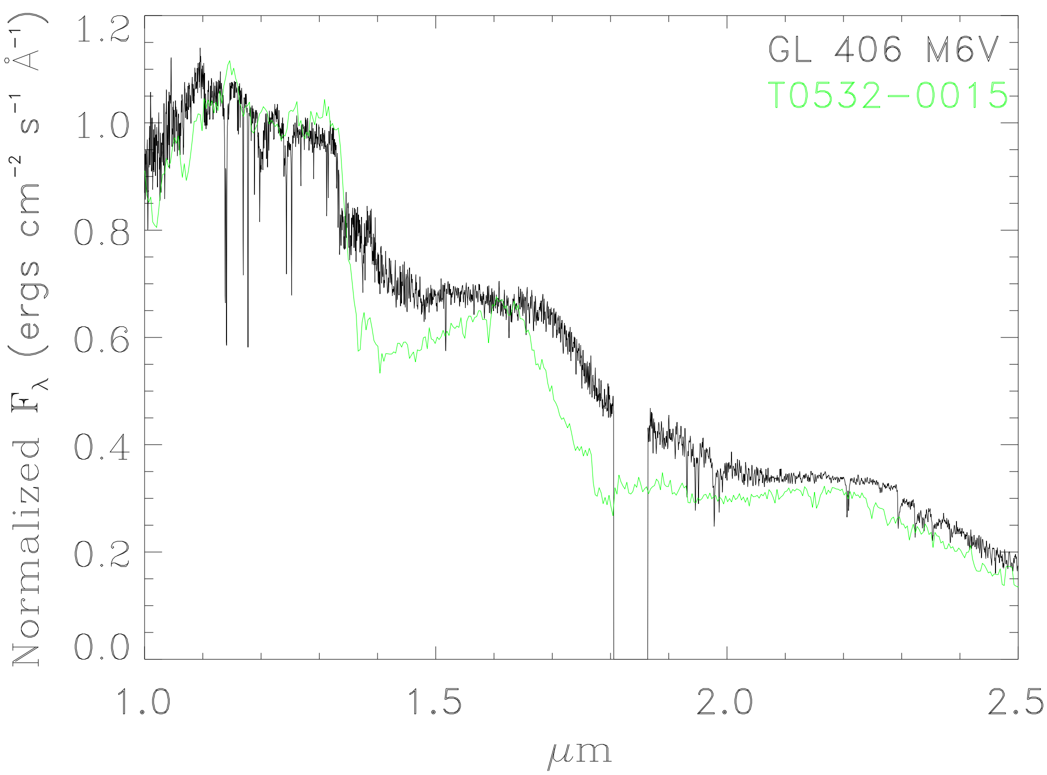

Figure .2: Comparison of the spectrum of an old M6V standard (Gl 406), from the IRTF Spectral Library (Rayner et al. 2009) in black, with the spectrum of one of the SSMO candidates (green). Note the narrow and strongly peaked H band. It appear narrower than similar features in other "young" SSMOs.

5. Conclusions

Near-IR spectroscopy of 22 SSMO candidates strongly suggests an abundance of SSMOs in the Orion OB1b association. Sixteen objects appear to be M5 or later, with low gravity scores. This suggests that the foreground contamination from galactic M dwarfs is of order 30%. This implies a population of about 5000 sub-stellar mass objects, which is comparable to the ∼ 10,000 stars in the association.

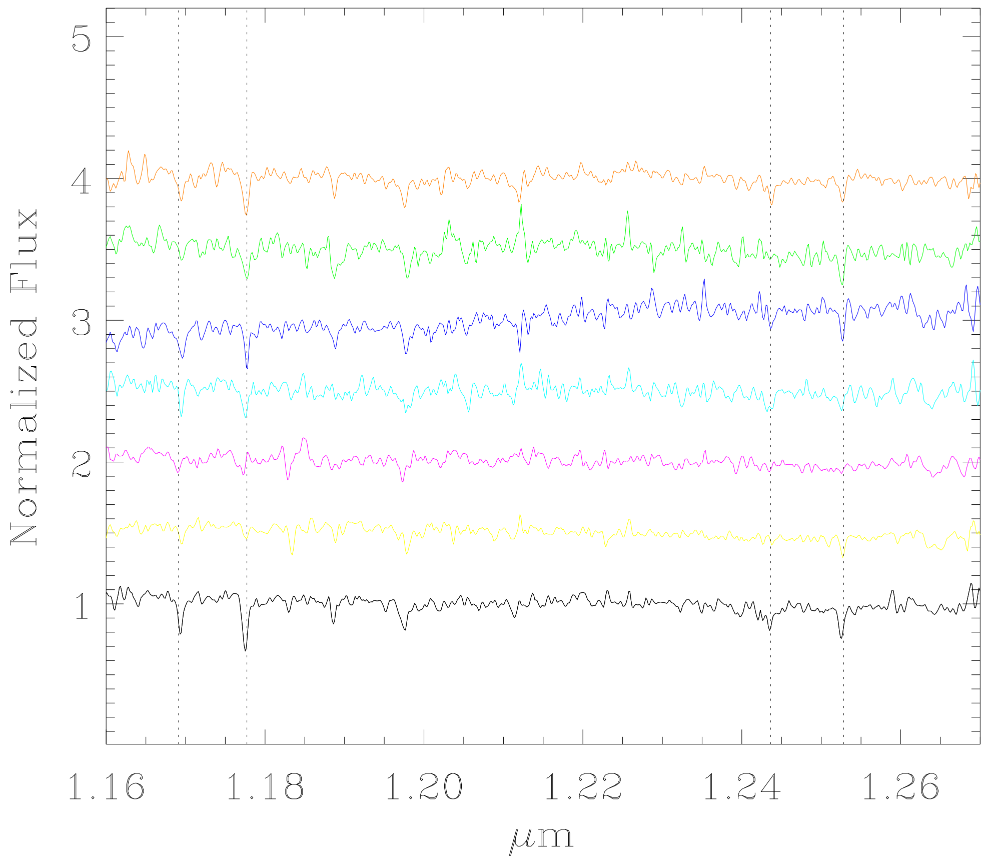

Figure .3: K I lines in the TripleSpec data. Based on the Allers & Liu indices (Allers & Liu 2013), all these stars have gravity scores of 1.5-2, indicating low gravity. The vertical dotted lines are the air wavelenths of the K I lines, shifted by -22 km/s to match the radial velocity of Orion OB1b.

6. Citation Instructions

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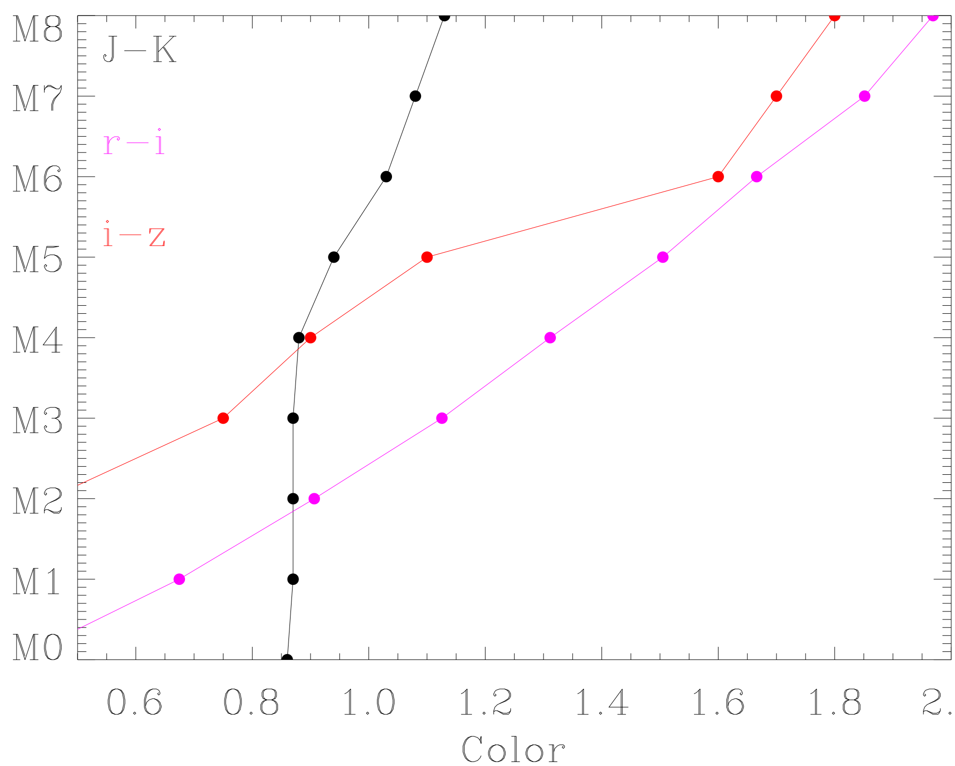

Figure .4: Why you shouldn't completely trust the nIR photometry. J-K varies only slowly among the M stars; 2-10 Myr old SSMOs are expected to have M6-M8 spectral types. Optical colors provide much greater discrimination.

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