OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Aug–Dec **Proposal type:** short-term

Mass Ratios of Young Spectroscopic Binaries in Orion

P.I.: Lisa Prato (Lowell Observatory / NAU; *lprato@lowell.edu*; 928 233 3213)
CoI(s): Thomas Allen (Lowell Observatory), Andrew Szentgyorgyi (CfA), Guillermo Torres (CfA)

Abstract of Scientific Justification

We propose to observe candidate pre-main sequence binaries in the Orion Nebula Cluster with Hectochelle. With a modest time commitment of less than one night spread over the course of semester 2015B, and a matching allocation in 2016A, we will confirm the binary nature of these young systems and determine mass ratios for a third to half of the systems. A large sample of pre-main sequence binary mass ratios is necessary to test and refine the pre-main sequence evolutionary models that are central to the determination of properties such as the initial mass function and star formation history in young clusters.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/5	Hectochelle			1	grey	Nov–Dec	Oct–Dec	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*:

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	Orion Nebula Cluster	05:34:00	−05:30:00	Cluster

Approval for Instrument Use from PI: _____

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

Absolute masses of T Tauri stars lay the foundation for low-mass stellar astrophysics. Once composition is established, a star's mass determines all subsequent properties and the very nature of its life and death. Stellar mass dictates the environment for planet formation and the suitability for, and sustainability of, potential life on exoplanets. Over the last decades, young (1 to a few Myr) star masses have been approximated by measuring stellar luminosity and effective temperature, mapping these quantities onto the Hertzsprung-Russell (H-R) diagram, and comparing the results with models of star formation and evolution (e.g., Weinberger et al. 2013). However, models for low-mass stars suffer from the lack of a reliable observational framework and incomplete knowledge of molecular opacities, and diverge on choice of equation of state and somewhat arbitrary initial conditions (Baraffe et al. 2015). Simon (2008) illustrated the discrepancies between five sets of low-mass tracks (Figure 1).

Dynamically measured mass ratios number $\sim$4 dozen (Figure 2). Most stars in the Solar neighborhood reside in binary or multiple systems, but we do not yet have a satisfactory picture of how they form, especially the shortest period systems. Theory has reached a point where simulations of entire clusters of young stars yield mass ratio distributions for sub-samples of various primary star mass (e.g., Bate 2012). Unfortunately, there are no homogeneous young star mass ratio distributions for comparison. The systems shown in Figure 2 are culled from several different investigations, vary in precision from a few to a few tens of percent, and include an assortment of results from half a dozen star forming regions with ages $1-25$ Myr.

We propose to spectroscopically determine mass ratios in a sample of $\sim$120 pre-main sequence (PMS) spectroscopic binaries in the Orion Nebula Cluster (ONC), identified by Tobin et al. (2009, 2013). Although these systems are angularly unresolvable with current ground-based technologies, high-precision astrometry such as that being carried out by the GAIA all-sky mission, will provide the visual orbit parameters required to determine absolute masses for all the individual stars in our target binaries with the completion of the GAIA mission; a partial tally will be possible by 2018 with the early GAIA data releases.

Our approach to this program is two-fold. In the first stage we will obtain a series of four visible light spectra of each candidate spectroscopic binary in Tobin et al. (2013). High-resolution ($>$30,000) visible light spectroscopy is adequate for identifying binaries through RV variability, and the multiplexing available with the Hectochelle instrument at the 6.5-m MMT telescope (Szentgyorgyi et al. 2011) greatly increases observing efficiency. About a third to a half of the systems we expect will be identifiable as double-lined binaries on the basis of the Hectochelle data alone. Following Wilson (1941), it is possible to determine the mass ratio and center of mass velocity of a spectroscopic binary on the basis of at least 3 radial velocity measurements of both the primary and secondary (e.g., Mace et al. 2012).

For other systems confirmed with the Hectochelle+MMT data as spectroscopic binaries, but single-lined, we will in the second stage of this project apply to use the IGRINS high-resolution infrared spectrograph at the McDonald Observatory 2.7-m telescope. Infrared observations make it possible to measure the radial velocity of the secondary star in small mass ratio binaries (Prato et al. 2002). This is because flux scales as a steeper function of mass in visible light than in the near-IR (Figure 3). PI Prato is a member of the IGRINS science team and has already successfully obtained IGRINS nights in November, 2014, and upcoming in May and June of 2015.

Baraffe et al. 2015, A&A, in press
Bate 2012, MNRAS, 419, 3115
Mace et al. 2012, AJ, 144, 55
Prato et al. 2002, ApJ, 569, 863
Simon 2008, The Power of Optical/IR Interferometry, 227
Szentgyorgyi et al. 2011, PASP, 123, 1188
Tobin et al. 2009, ApJ, 697, 1103
Tobin et al. 2013, ApJ, 773, 81
Weinberger et al. 2013, ApJ, 762, 118
Wilson 1941, ApJ, 93, 29

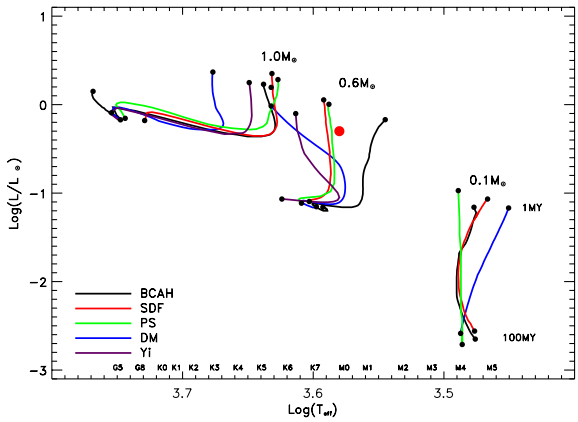

Figure 1: Simon (2008)'s illustration of scatter in low-mass evolutionary tracks (Baraffe et al. 1998; Siess et al. 2000; Palla & Stahler 1999; D'Antona & Mazzitelli 1994; Yi et al. 2003). The red dot shows typical values of L and T_{eff} for a young M0.

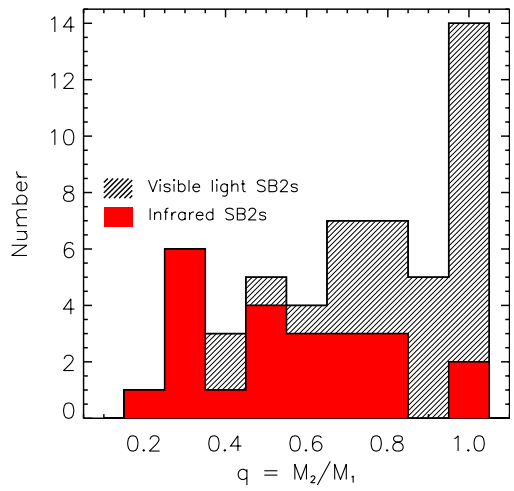

Figure 2: Mass ratio distribution for all known young double-lined spectroscopic binaries.

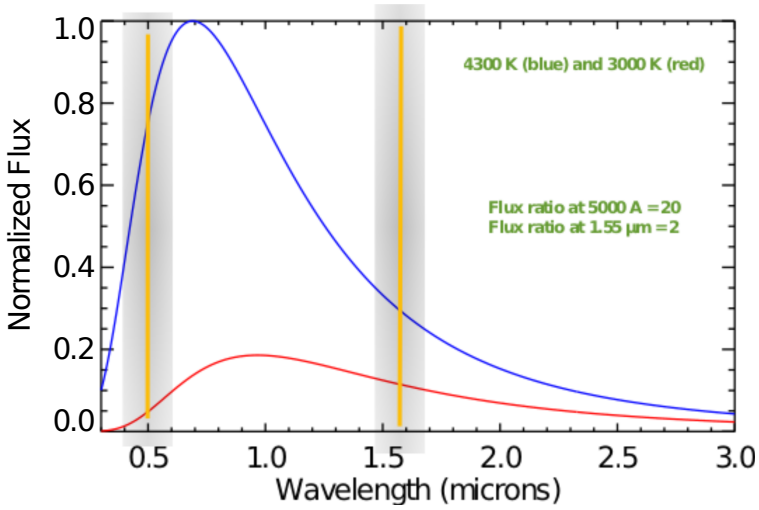

Figure 3: Black body curves for 4300 K (blue, late K) and 3000 K (red, late M) stars. Vertical gold lines indicate the V and H bands.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

The Hectochelle multi-fiber instrument is capable of recording up to 240 spectra simultaneously at R=38,000 over a 1 degree field of view (Szentgyorgyi et al. 2011). The spectral range is 150Å in width. By focussing on the order containing the MgI lines around 5225 Å, precision of 0.5 km/s is attainable with a signal-to-noise ratio (S/N) of $\sim$20. For targets of magnitude V$<$16 mag, S/N=20 or better can be accomplished in $\lesssim$4 hours, divided into four or five 45-minute integrations. The remarkable efficiency of Hectochelle will allow all 120 targets in the ONC candidate sample to be observed simultaneously at the desired S/N in a 3$-$4 hour period.

Our observing strategy will be to obtain 2 sets of spectra separated by a few days in the autumn of 2015 and another set in January or February, 2016. This will allow for the confirmation of both short and medium period spectroscopic binaries in the first year of the project with a modest investment of 16 hours of observing time, a little over one night total on the MMT, divided between semesters 2015B and 2016A.

Team member Allen is an experienced Hectochelle user, team member Szentgyorgyi is the Hectochelle PI, and team member Torres is an expert in stellar radial velocity measurements for spectroscopic binaries. Our team possesses the expertise and software resources for the expeditious reduction and analysis of the data.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

No Steward Observatory time has been allocated to this project, although the targets are drawn from a project (Tobin et al. 2009) which used Hectochelle to identify candidate spectroscopic binaries in Orion. We are currently requesting 8 hours of observations in the autumn of 2015. In January−February, 2016, we will request another 8 hours. In future semesters we may request additional time in order to fully characterize the orbits of confirmed binaries but that would comprise a separate effort.

Observing time with the IGRINS high-resolution infrared spectrograph at the 2.7-m telescope at McDonald Observatory will complement the program proposed here by capitalizing on spectroscopic binaries identified by Hectochelle to determine their mass ratios in the infrared. PI Prato is a member of the IGRINS science team and has already been successful in obtaining time on that new facility in November of 2014 and upcoming in May and June, 2015.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

PI Prato has never before used Steward Observatory facilities. Co-I Allen is an experienced user of the MMT and more information is given on this in detail in our Cep OB3b proposal.