OBSERVING REQUEST
University of Arizona Observatories

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

A Search for New Pre-Main Sequence Binaries in the Cepheus OB3b Young Cluster

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Abstract of Scientific Justification

Using a combination of Spitzer, Chandra and ground-based measurements, we have recently performed a census of young stars in the Cep OB3b cluster. These data show that CepOB3b is one of two known massive ($>$ 1000 members), young ($<$ 5 Myr), clusters within 1 Kpc of the Sun. Compared to the Orion Nebula Cluster, Cep OB3b has a similar number of members, but it has largely dispersed its natal gas. Ages in the literature are typically given as 3-4 Myr (Mayne et al. 2007; Littlefair et al. 2010), and it has a disk fraction of 30% (compared to 80% in the Orion Nebula Cluster). These three characteristics indicate that the Cep OB3b is a more evolved counterpart to the Orion Nebula Cluster. We are now engaged in a large multi-wavelength study of Cep OB3b designed to study disk and cluster evolution. We propose Hectochelle observations of a sample of potential pre-main sequence spectroscopic binaries. These observations will greatly expand the known population of pre-main sequence spectroscopic binaries while allowing us to analyze the dynamics of the emerging cluster, providing a unique snapshot of a massive young cluster emerging from its natal cloud. This is a continuation of NOAO Proposals 2009B-0449, 2010B-0436, 2011B-0472 and 2013A-0423.

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	Sept-Oct	Aug-Nov	no	no

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	Cep OB3b	22:54:40	62:32:00	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

Introduction: We propose MMT Hectochelle observations of the Cep OB3b cluster at 712 pc (Figure 1, Moscadelli et al. 2009) to search for pre-main sequence (pre-MS) spectroscopic binaries (SBs). Our Spitzer observations have revealed a cluster of $\sim$1000 low mass stars with disks (Allen et al. in 2012). We have also obtained 150 ks Chandra observations of Cep OB3b and detected $\sim$700 X-ray luminous young stars. From these data, we estimate that Cep OB3b has a total of 3000 young stars, making it one of two massive ($>$ 1000), young ($<$ 5 Myr) clusters known within 1 kpc of the Sun (Allen et al. 2012). Although similar in size to the Orion Nebula Cluster (the other massive cluster within 1 kpc; hereafter: ONC), Cep OB3b appears to be in a later stage of evolution. In contrast to the ONC, Cep OB3b has largely dispersed its molecular gas and most stars are found in a cleared cavity of low extinction ($A_V < 5$) with two molecular clumps on the edge of the cavity (Figure 1). There is still ongoing star formation in the molecular clumps. Interestingly, Cep OB3b can be subdivided into two sub clusters (Figure 1), the East sub-cluster and the West sub-cluster, which have different properties. In particular the disk fraction is clearly distinct between the sub-clusters with a 30% disk fraction in the East and a 50% disk fraction in the West. Further, the West sub-cluster has an excess of fast rotators compared to the East (Figure 2). This work will establish the Cep Ob3b cluster as a laboratory for studying both the early evolution of young stars, the evolution of disks and the evolution of young clusters post gas dispersal.

Program: We propose MMT Hectochelle observations of CepOB3b region to search for binarity. In all nearby ($<$ 800 pc) star forming regions, there are only about 80 confirmed pre-main sequence (pre-MS) spectroscopic binaries (SBs) (see Mathieu 1994; Melo et al. 2001; Prato 2007; Maxted et al. 2008) with an additional 90 candidates in the ONC (Tobin et al. 2009). We have obtained to date 5 configurations with Hectoschelle and measured radial velocities for 162 members of Cep Ob3b (Figure 2), over 85% of which have spectral classifications, thus mass and age estimates. Out of these 162 members there are 63 candidate SBs based on their change in R_V with epoch or a double peaked cross-correlation function (Figure 3). If many of our targeted objects turn out to be multiples, this would greatly extend the known population of pre-MS SBs. These systems are one of the best means for directly measuring the masses of pre-MS sequence stars, and increasing the number of known pre-MS SBs is essential for testing and refining models of pre-MS evolution. These models are in turn the cornerstone of many studies that require the ages and masses of young stars, such as the determination of the initial mass function and star formation history in young clusters.

Obtain radial velocities: Radial velocity measurements of younger, more embedded clusters shows complex velocity structures, where the stellar velocities often follow the complex velocity structure of the natal gas (Furesz et al. 2006; Tobin et al. 2009). This initial structure may be important in determining whether a cluster survives gas dispersal (Smith et al. 2011). The gas dissipation and relaxation times of young clusters are similar, leading us to believe Cep OB3b will inherit the complex dynamics of its formation and not be virialized or relaxed. With these data, we can determine whether Cep OB3b exhibits complex velocity structure or whether relaxation has erased the initial conditions. Further, we can search for kinematic segregation of the different age populations present in the cluster, and estimate if the kinetic energy of the cluster exceeds its potential energy.

Study the Evolution of Accretion: Velocity resolved Hα emission lines are a powerful diagnostic of accretion from disks onto pre-main sequence stars. Hectochelle allows us to separate narrow nebular lines from Hα generated in accretion flows and measure the accretion rate onto the star (Flaherty & Muzerolle 2007). This measurement requires a mass for the star which we can estimate from the Hectospec spectral classifications in hand. The change in accretion rate with age gives us unique insight into the evolution of the gas surface density of disks between 1-10 Myr (Calvet et al. 2005).

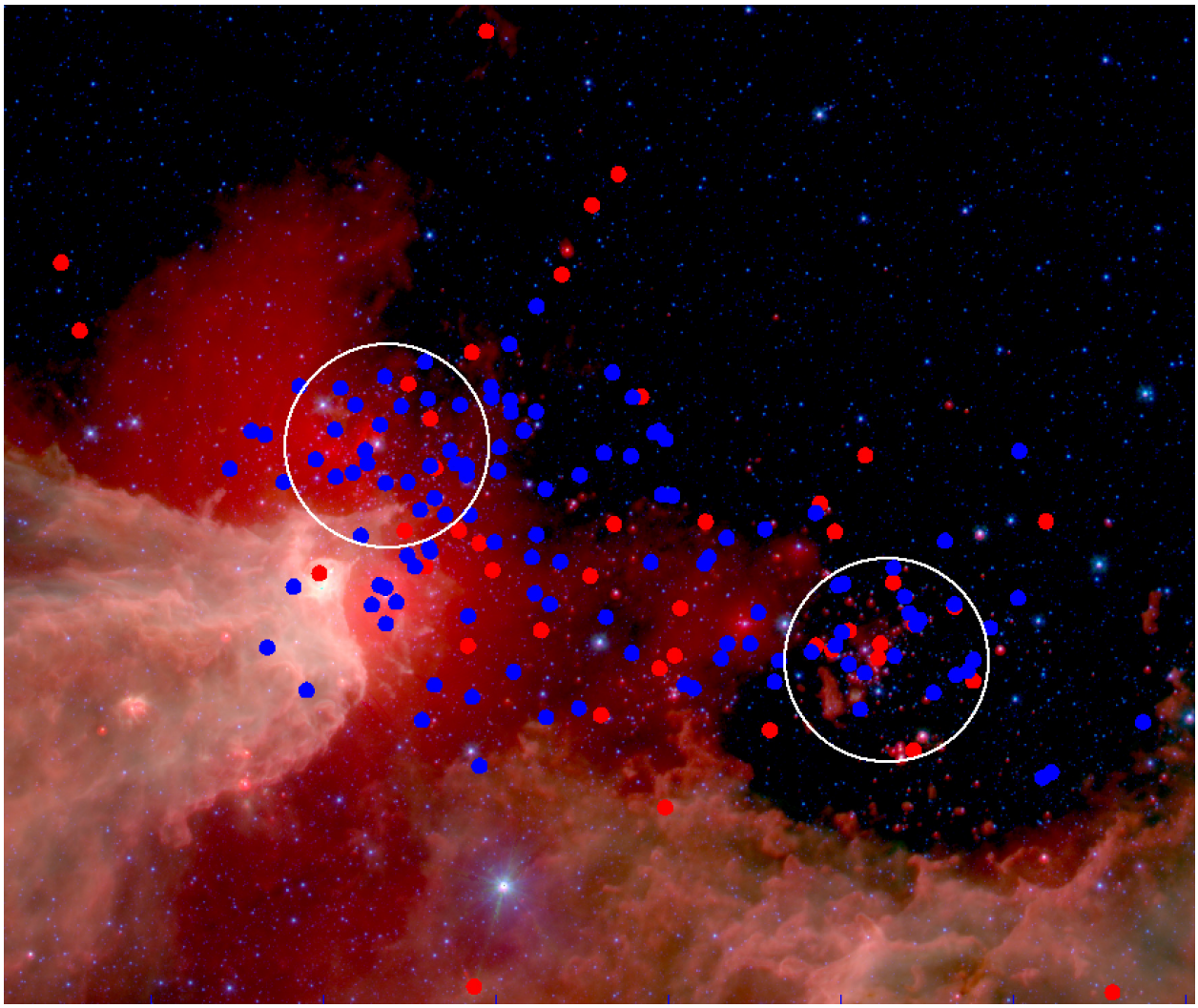

Figure 1: *Spitzer* 3.6 (blue), 8 (green) and 24 μmm (red) image of the Cep OB3b cluster. The surfaces of the cavity surrounding Cep OB3b are clearly delineated by the pink emission. The circles are the sample of cluster members with measured RVs with the young stars with protoplanetary disks in red and the young stars without disks in blue. The white circles denote the centers of the sub-clusters.

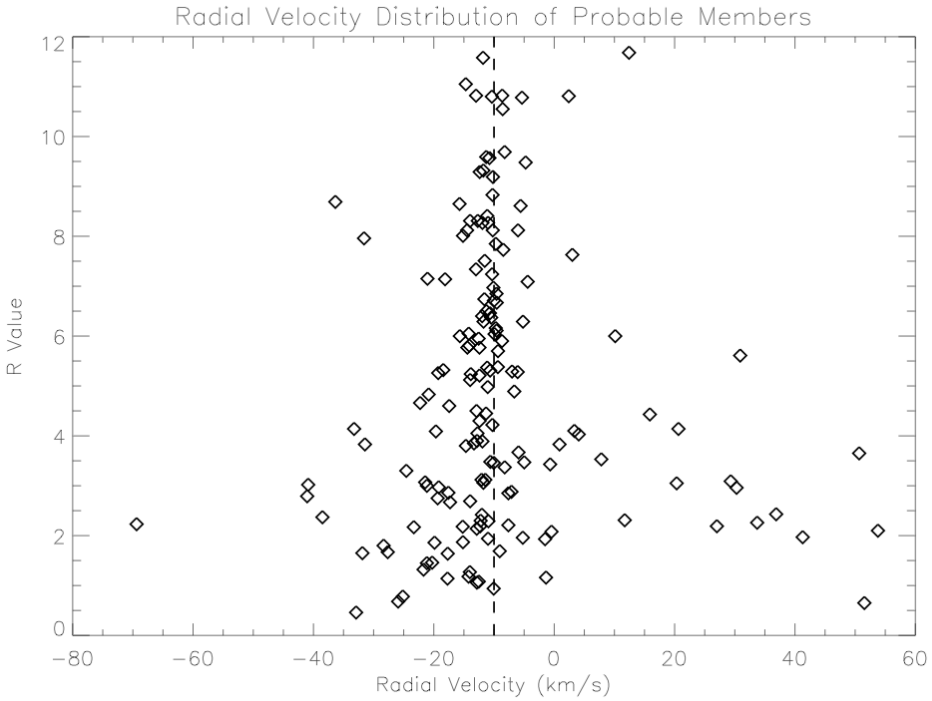

Figure 2: Distribution of the Hectochelle measured RVs for the young members of Cep OB3b. The vertical line denotes the CO gas velocity in the nearby Cep B molecular clump as measured by Heyer et al. (1996).

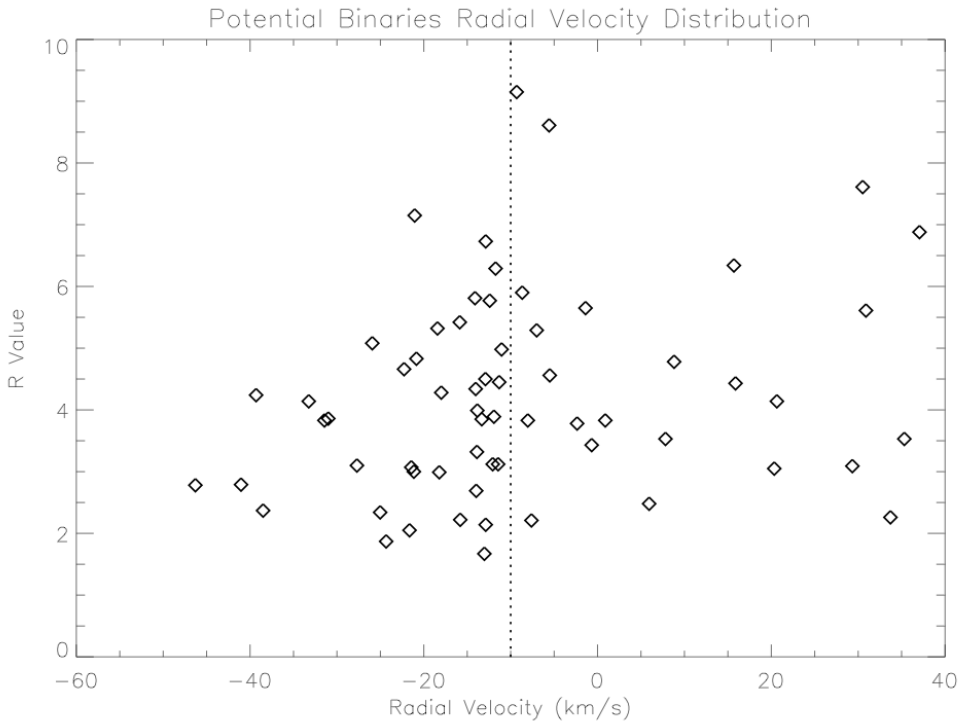

Figure 3: Sample of candidate binaries based on their change in R_V with epoch or a double peaked cross-correlation function

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)***

Our team has used Hectochelle to reliably obtain radial velocities in young clusters and Hectospec to obtain spectral types (Furesz et al. 2008, Winston et al. 2009, Figures 1 and 2). We use this experience to design these observations, and we will analyze the data in a similar manner to achieve the goals discussed in the scientific justification.

Hectochelle Source Selection and Set Up: We will select our sample to include the 63 potential binaries. The remaining fibers will be placed on other known young members of the cluster. We expect that with integration times of 340 minutes (binned 2 2) we can go to 16.5 mag in V with an accuracy of 500 m/s. We will focus on the wavelength regime around the Hα (6500 Å) emission line. This gives us the useful information about accretion through the profile of Hα emission, and still gives the radial velocity (Furesz at al 2006, 2007) based on Ca and Fe lines outside of the hydrogen emission. Furesz et al (2007) used a library of calculated spectra (Munari et al, 2005), which at a resolution of R = 20,000 seems to be a good match for the 2×2 binning mode of Hectochelle. In order to have proper subtraction of the nebular emission from the spectra we propose for an offset sky exposure for each fiber configuration.

We plan four separate observations of the same pointing, the first two early in the observing period (early September), and separated by a couple days, while the last two are later in the observing period (late october), and also separated by a couple days. This will allow us to sample both short and medium period SBs. This amounts to one total night of observing time, spread out over four quarter nights.

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**)*

Observing time awarded toward this project include the following programs through NOAO: Allen was PI on the program: 2009B-0449, 2010B-0436, 2011B-0472 and 2013A-0423. The Hectospec and Hectochelle data was reduced and analyzed as part of the PhD thesis for Allen. Megeath was a Co-I on the programs 2009B-0449, 2010B-0436 2011B-0472 and 2013A-0423. Megeath was PI on the programs 2009B-0549 and 2012B-0514

Data collected through UAO time will greatly enhance the existing dataset by allowing it to serve a new purpose as a catalog of young pre-MS SBs and refine its original purpose as the binary systems are accounted for in the analysis of the Cep OB3b cluster kinematics.

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 as reported in this proposal.