NASA INFRARED TELESCOPE FACILITY (IRTF) APPLICATION FOR OBSERVING TIME (rev. Aug. 2008)	IRTF USE ONLY:
OBSERVING PERIOD: February, 2010 - July, 2010	App. No.: 2010A065
	Date Recvd: 10/01/2009 08:25

Investigator(s)	PI	Grad. Stud.	E-mail	Phone number
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(1) Title of application:

Dynamical Observations of Hyades Cluster Spectroscopic Binaries

(2) Number of runs and hours requested:

Run No.	Night(s) per run	# Hours per Night	Day(s) per run	# Hours per Day	Remarks
1	2	6 hrs	0	0	1st half nights

(3) Range of dates which are acceptable

Run 1: 02/01/2010 - 02/18/2010, HST

Additional Run Information:
Targets are all near 4h 30m, so can only be observed this semester during the first half of the night in early February.

(4) Scientific category: stellar

(5) Phase of moon required: any

(6) IRTF instruments required: CSHELL

(7) Primary observer first-time instrument user? No, 0 years since last observed

(8) Remote observing required? Yes

State College, PA

(9) List any special requirements:

(10) Estimate how many more days or nights to complete the project:

We estimate two additional half nights in the Fall 2010 semester will be required. Additional time requests beyond that will be determined based on the outcome of our 2009B scheduled observations and 2010A request.

(12) ABSTRACT (less than 100 words):

We continue our ongoing program to measure fully dynamical masses for a large sample of low-mass Hyades binaries by combining double-lined velocity curves measured with CSHELL at the IRTF with visual orbits from the CHARA interferometer. Our Spring 2010 request is concentrated on sample members with long periods; these observations will provide velocity measurements at orbital phases that are absent from our current solutions. When complete, this program will produce a fully dynamical initial mass function for cluster stars with known age, covering the mass range from $\sim 0.1 - 1.0\mathrm{M}_{\odot}$.

(13) LIST IRTF OBSERVING TIME DURING THE LAST 2 YEARS, STATUS OF DATA, AND PUBLICATIONS. COPY AND PASTE FOR AS MANY SEMESTERS AS NEEDED.

Semester 08B Dynamical Observations of Hyades Cluster Spectroscopic Binaries (2008B052)
These observations are part of the current program. Two half-nights were awarded in October 2008. We observed nine program targets in good conditions, two of these on both nights. Results from these observations for vB 40 and vB 68 are shown in the Figures section of the Scientific Justification.

Semester 09A Dynamical Observations of Hyades Cluster Spectroscopic Binaries (2009A072)
These observations are part of the current program. Two half-nights were awarded in February 2009; both were severely affected by poor weather. We observed a single program target through thick clouds on one night, but the resulting spectra are of poor quality. We did not obtain any observations on the other night.

Semester 09B Dynamical Observations of Hyades Cluster Spectroscopic Binaries (2009B066)
These observations are part of the current program. Four half-nights have been awarded and are scheduled for December 2009. If observing conditions are favorable, these observations will allow us to complete several of the short period binaries on our target list.

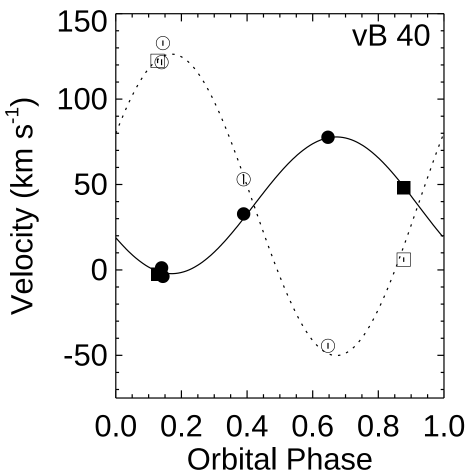
(14) SCIENTIFIC CASE. Maximum of one single-spaced page of text, 11-pt. or larger, plus one page for figures and tables. References and the Object List can take additional pages if necessary.

Dynamical observations of binary stars in clusters can directly address many fundamental problems in star formation and stellar evolution. Clusters provide well defined stellar populations, with memberships that have a common formation history and evolution. High-resolution infrared spectroscopy combined with long-baseline interferometry of cluster binaries can measure true masses (e.g. Schaefer et al. 2008) for a large sample of co-evolved stars over a wide range of stellar mass. Such results lead directly to a localized initial mass function for star formation in the cluster, that is independent of theoretical models and does not suffer from the binary contamination commonly present in photometric surveys (Bonnell et al. 2007; Kroupa 2002). The distributions of orbital parameters, masses, and mass ratios distinguish between the effects of fragmentation, dynamical interaction, and accretion in theories of binary star formation (Ballesteros-Paredes et al. 2007). In addition, the orbital parallax measurements that result from fully dynamical orbits provide an independent cluster distance and, when combined with a mass-luminosity relationship (e.g. VandenBerg et al. 2006; Baraffe et al. 1998), the cluster age (e.g. Armstrong et al. 2006).

We are continuing our long-standing IRTF program carrying out dynamical observations of Hyades cluster spectroscopic binaries (Bender & Simon 2008; Bender 2006). The Hyades is a good laboratory to study binary star formation because, although it is an older cluster, it retains its cluster identity and cluster properties such as age and metalicity are well determined. Orbital parameters of Hyades binaries have been precisely measured from decades of visible light spectroscopy (D. Latham & R. Stefanik, *private communication*). However, most secondaries are not detected at visible wavelengths, where the secondary-to-primary flux ratio becomes very small for mass ratios much less than one. In the infrared, this flux ratio is significantly larger, so we are using CSHELL to convert these single-lined systems into double-lined systems. In October 2008, we began intensive CSHELL observations of 11 binaries that are within the sensitivity limits of the CHARA interferometer at the Mount Wilson Observatory. CHARA can observe targets as faint as K$\sim$ 7.0 mag and ΔK$\sim$3 mag, and has an angular resolution of 0.7 mas in the K-band on the longest baselines, which is sufficient to resolve even the shortest period Hyades binary. Our intent is to combine the spectroscopic and visual orbits to measure the component masses of these 11 binaries to better than a few percent. When complete, these measurements will produce a fully dynamical initial mass function for the Hyades, covering the mass range from $\sim 0.1 - 1.0\mathrm{M}_\odot$.

We are currently scheduled for four half-nights in December 2009 with CSHELL. During this run we will intensively observe the short period binaries in our sample, obtaining up to four epochs per binary. We will observe each of the long period binaries at least once. Also during December, we are scheduled for five nights at CHARA, with both the PAVO and Classic beam combiners, to obtain visual orbits for these systems. If our December IRTF run is successful, we anticipate that the four short-period binaries in our sample (L20, vB 40, vB 62, & vB 121) will be complete to our target precision of $\sim$ 1%. Fig. 1 & 2 show the current status of vB 40; our spectroscopic observations have measured its mass ratio, $\mathrm{M}_2/\mathrm{M}_1$, to $\lesssim$ 2%.

During the spring 2010 semester, we propose to obtain an additional epoch of CSHELL observations for each of the seven long period binaries in our sample. These observations will provide double-lined velocity measurements at new orbital phases. They are particularly critical for the three binaries in our sample that have periods nearly equal to integer numbers of years (vB 68, vB 102, & vB 142), which cannot be adequately measured using only observations during Fall semesters. Figures 3 & 4 present the current state of one of these binaries, vB 68. During our early observations from 2004 – 2006, this binary was only constrained by a single double-lined spectroscopic observation. We obtained a second observation in October 2008. Poor weather prevented us from obtaining a 3rd observation in February 2009. Measuring the masses in this system, and in the other long period systems in our sample, to $\sim$ 1% will require several additional observations over the next few years.



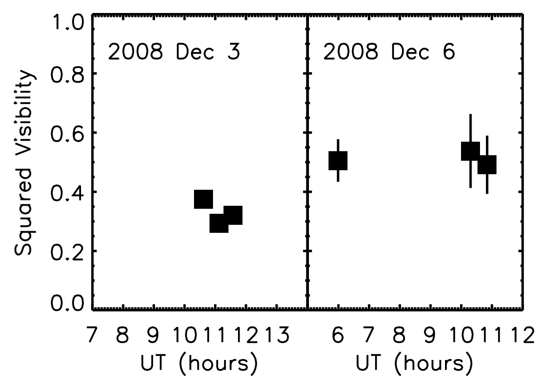
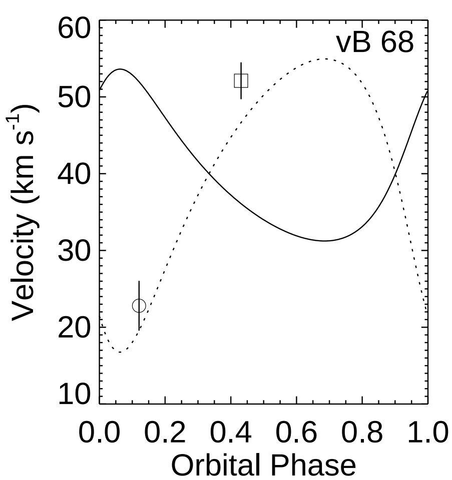


Figure 1: Velocity vs. phase curve for sample binary vB 40, showing primary velocities (*solid symbols and curve*) and secondary velocities (*open symbols and dashed curve*) measured with CSHELL. Circles are from our 2004–2006 program; squares were obtained in October 2008 as part of the current program. Uncertainties are plotted, but are generally smaller than the plotting symbols. Our current SB2 solution yields a mass ratio of $q = 0.45 \pm 0.01$.

Figure 2: Visibilities (fringe amplitudes) of vB 40 measured at CHARA in the broadband K filter. The binary is clearly resolved (visibilities significantly less than 1.0). Preliminary modeling of the sparsely sampled data is consistent with a binary that has a separation of ~ 1 mas. Continued observations with better sampling in the 2009 will allow us to compute an orbit model for this system.



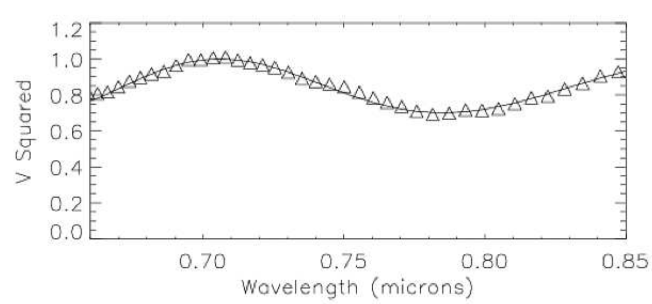


Figure 3: Same as Fig 1, for vB 68. The primary is a rapidly rotating F star ($V_{rot} \sim 80\,\mathrm{km\ s^{-1}}$) and our infrared spectroscopy is not able to measure its velocity. The plotted primary velocity curve is from visible light SB1 observations. The measured secondary uncertainties are larger than typical (see *Tech. Just.*)because the underlying spectra have low signal-to-noise.

Figure 4: Spectrally dispersed visibilities of vB 68 measured at CHARA in the R-band. These results from a 4-minute exposure show the periodic visibility curve representative of a binary system. The separation between the peaks is proportional to the binary separation while the minimum estimates the flux ratio. A fit yields a projected separation of 24 mas along the interferometer baseline and a contrast ratio of 2.6 magnitudes (M. Ireland, private comm.).

(15) TECHNICAL CASE. Justify the observing time requested for this proposal. Your justification should include source magnitudes (or fluxes) and estimates of the exposure times and Signal-to-Noise ratios required to meet the goals of your project. Your guiding requirements should also be discussed. **Maximum of one single-spaced page of text, 11-pt. or larger. Note that proposals which lack adequate technical justification may be rejected.**

Our target binaries for this program are given in the *Object List*, along with observational details and the current number of SB2 observations we have for each system. For the current request, we have removed from our target list two short period systems (vB 40 & L20) that we expect to complete in December 2009, and assigned two additional short period systems (vB 62 & vB 121) to a lower priority; we will observe these systems if time allows, but they are not primary targets in the current proposal. We use CSHELL with the 0.5" slit, at a single grating position centered at 1.55 μm. This provides a free spectral range of ~ 40 Å and a spectral resolution of $\sim 30,000$. The 1.55 μm region contains numerous stellar atomic and molecular lines, and is relatively free of telluric absorption. CSHELL is one of the few instruments available to the US community that can provide these near-IR observations, and we have used it successfully in this program during past semesters. Spectra are wavelength calibrated using internal Ar and Kr lamps, distributed across the array with the CVF.

Each binary spectrum contains the blended light from the primary and secondary. We disentangle these using a two-dimensional cross-correlation algorithm with observed template spectra, which provides radial velocities for each star and an estimate of the flux ratio (Bender & Simon 2008). We have an existing suite of observed templates, covering spectral types from late F through early L (Bender 2005). CSHELL's small free spectral range limits the number of stellar lines we observe. This restricts the velocity precision of our correlation analysis to $\sim 1/4$ of a pixel, or about 0.7 km s^{-1}. This is less than we could achieve using an echelle spectrograph with larger spectral range, but is adequate for measuring Hyades binaries.

The correlation analysis is effective in detecting a faint companion in a blended spectrum, even if the individual lines from the companion are below the observed noise level. During our 2004–2006 program, we measured flux ratios for our target binaries (Bender 2006). We use these results to determine the minimum signal-to-noise required for each binary to ensure a detection of the secondary, while retaining velocity precision and using observing time efficiently. CSHELL can achieve a signal-to-noise of ~ 100 in 45 minutes on targets with H$\sim$6.5 mag, using the 0.5" slit. Based on this, we have calculated the exposure times provided in the *Object List* for each of our targets.

Our intent this semester is to concentrate on the long period systems in our binary sample. Observing each of these (designated *1st priority*) will require about 10 hours under good conditions, inclusive of all overheads. The targets are concentrated near RA $4^h\ 30^m$. During the spring semester they are visible at the IRTF only during the first half of the night, and only for the first ~ 2.5 weeks of February. Consequently, we request two half nights between February 1 and February 18. If time allows, we will also revisit the two short period systems vB 62 and vB 121.

Armstrong et al. 2006, AJ, 131, 2643
Ballesteros-Paredes, et al. 2007, in PPV, 63
Baraffe et al. 1998, A&A, 337, 403
Bender et al. 2005, AJ, 129, 402
Bender 2006, Ph.D. Thesis, Stony Brook University
Bender & Simon 2008, ApJ, 689, 416
Bonnell, et al. 2007, in PPV, 149
Kroupa, P. 2002, Science, 295, 82
Schaefer et al. 2008, AJ, 135, 1659
VandenBerg et al. 2006, ApJS, 162, 375

Object List

Object	Coordinates	H-Mag	Time	N_{obs}	Comments
1st priority					
vB 68	$04^h\ 28^m\ 23.4^s$, $+14^\circ\ 44'\ 27.5''$	5.2	50	2	P∼1 yr
vB 77	$04^h\ 29^m\ 20.6^s$, $+17^\circ\ 32'\ 41.8''$	5.8	70	2	
vB 81	$04^h\ 30^m\ 18.0^s$, $+19^\circ\ 50'\ 26.1''$	5.9	45	1	
vB 96	$04^h\ 33^m\ 58.5^s$, $+15^\circ\ 09'\ 49.0''$	6.6	30	2	
vB 102	$04^h\ 37^m\ 32.0^s$, $+15^\circ\ 08'\ 47.2''$	6.1	90	4	P∼2 yr
vB 142	$04^h\ 46^m\ 30.4^s$, $+15^\circ\ 28'\ 19.4''$	6.8	120	4	P∼3 yr
vB 113	$04^h\ 46^m\ 45.6^s$, $+09^\circ\ 01'\ 02.7''$	5.9	70	2	
2nd priority					
vB 62	$04^h\ 26^m\ 18.5^s$, $+21^\circ\ 28'\ 13.6''$	6.2	60	4	short period
vB 121	$04^h\ 50^m\ 48.5^s$, $+16^\circ\ 12'\ 37.6''$	6.2	120	5	short period