Chapter 8

Research in Progress

While I have thus far carried out several in-depth studies utilizing the Quest-2 photometric and follow-up spectroscopic surveys, I have only begun to scratch the surface of the analysis that this vast dataset is capable of producing. In this chapter, I highlight some of the projects that I have already begun to pursue beyond the work presented in this thesis.

8.1 Hydra Spectroscopic Observations

In chapter 3, I present spectroscopic observations taken with the Hydra multifiber spectrograph at CTIO as follow-up to the photometric survey in USco. As mentioned, in total the observations produced $\sim$1150 spectra (of varying quality) yet I only discussed results for $\sim$100 stars in chapter 5. The reason for lack of inclusion of the remaining spectra was twofold. 1) Because I ultimately wished to derive the age and mass distributions for this region, I needed a data set selected in a manner consistent with itself. Thus, I chose to include only those stars observed with Hydra that met the same selection criteria as that applied to stars observed spectroscopically at Palomar. The remaining Hydra targets met less strict selection criteria in an attempt to place as many fibers on stars as possible during a single pointing. 2) We applied for time with Hydra early during analysis of the Quest-2 observations. As such, the photometry changed several times both before and after these observations were made, and several candidates thought to be 'top tier' candidates (i.e., those meeting all of the selection criteria applied to the single slit Palomar observations) at the time of observation would no longer have made the cut. Additionally, at the time of the proposal, I did not have a full appreciation for the spatial density of top tier candidates. Because the photometric survey region is so large, while I have >1000 top tier candidates in this region, perhaps only ∼5 could be observed in each 40'×40' field of view. These observations were still *extremely* beneficial to this work in that I was able to observe at ∼5 times the rate of the Palomar observations; however, they did not yield as many new PMS stars as expected.

Of the stars with Hydra spectra not discussed in chapter 5, ∼400 have spectral types late-K through M-types, which I will refer to as 'late-types'. Another ∼650 have spectral types late-F through mid-K which I will refer to as 'mid-types.' I show histograms of magnitudes for these two samples at r-band (figure 8.1) and at J-band (figure 8.2) along with the range of magnitudes expected for members of USco at these spectral types. I have assumed for this calculation that all members of USco are 5 Myr-old, 145 pc away, and have $0 \leq A_V \leq 2$. As can been seen from figures 8.1 & 8.2, most of the stars classified as late-type *could* be bona fide members of USco. However, since most of the spectral types are earlier than ∼M3, I cannot use the strength of the Na I doublet (λ8190 Å) to determine surface gravity and must therefore rely on an alternative criteria for youth. Most of the stars classified as mid-type, do not appear to be members of USco based on their observed magnitudes and spectral types. This sample is likely dominated by reddened field dwarfs and background giants.

I intend to analyze the spectra of all stars observed with Hydra (not already presented in chapter 5) more thoroughly. Based on initial classification, ∼100 stars exhibit Hα emission, most of them late-type objects. I do not see evidence of significant Li (λ6707 Å) absorption for more than a handful of stars, despite the fact that the spectra are of high enough resolution to detect it for mid-type stars. This result provides further evidence that most of the stars in the mid-type sample are field stars. For late-type stars with strong TiO molecular absorption, Li absorption becomes diluted with TiO absorption and much higher resolution is required for detection. This project will be my first priority when I begin my postdoc position, and I intend to

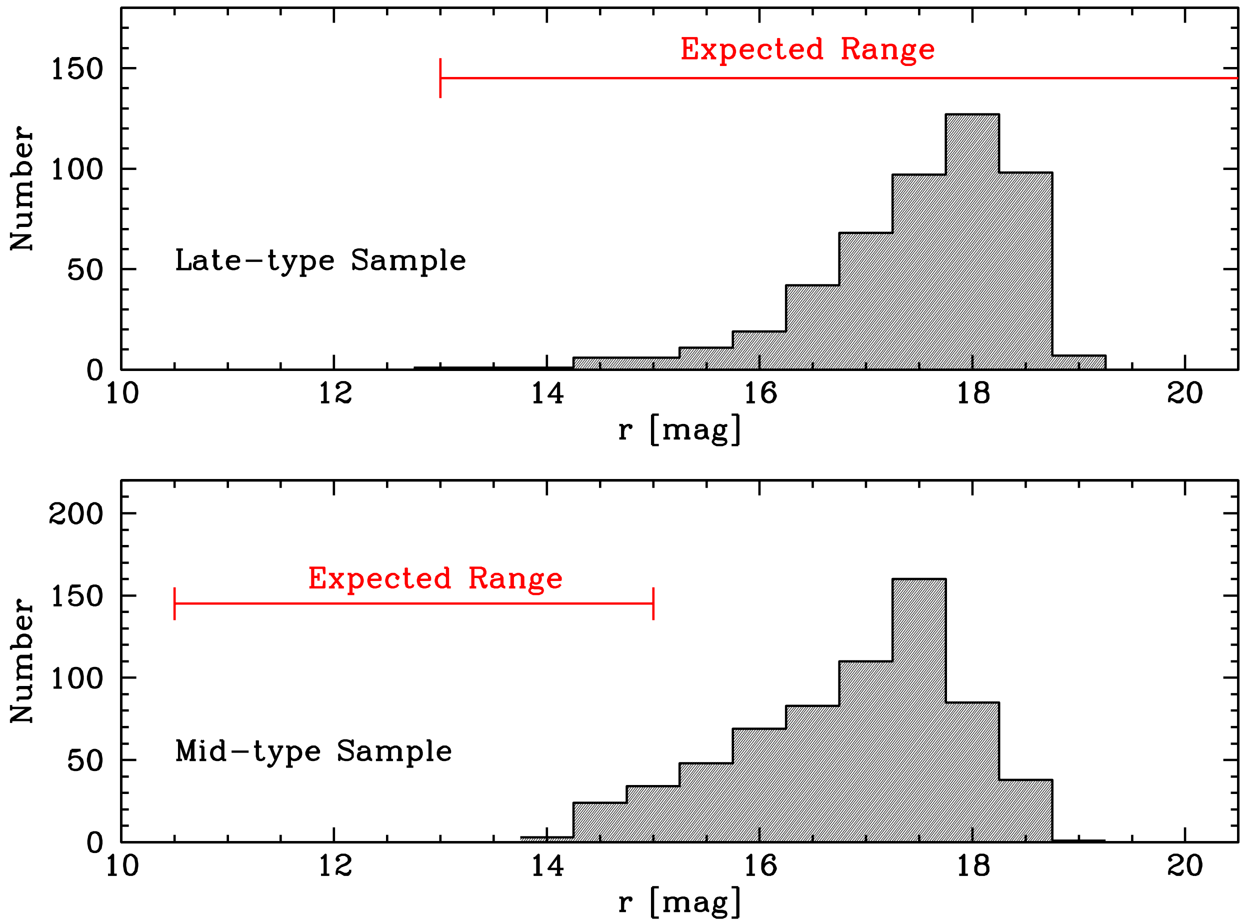

Figure 8.1 Histograms of r-band magnitudes for targets of the Hydra spectral observations not discussed in chapter 5. The top histogram shows data for stars classified as spectral type late-K to M; the bottom histogram shows data classified as spectral type late F to early-K. Shown in both panels is the expected range of magnitudes for 5 Myr-old stars of those spectral types at the distance of USco.

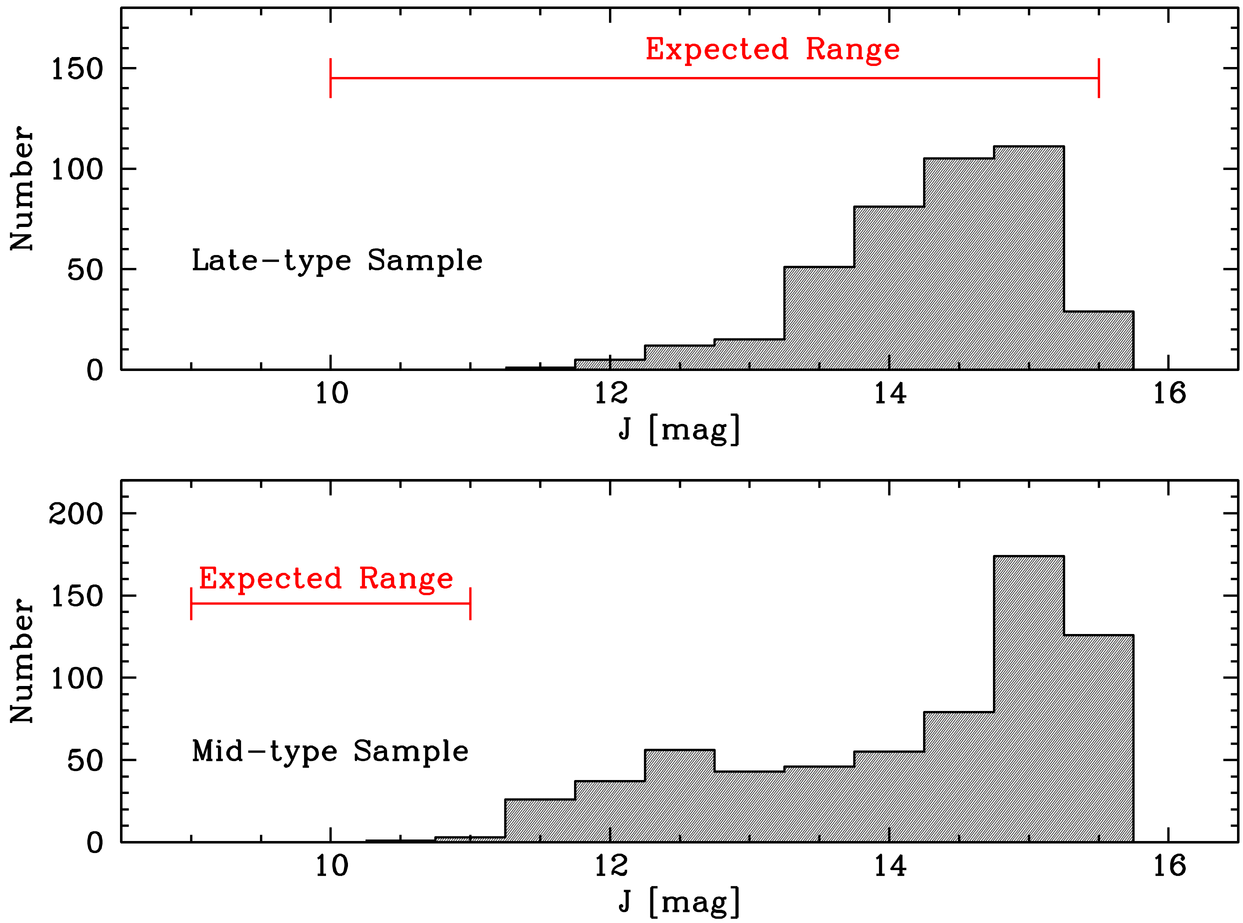

Figure 8.2 Histograms of J-band magnitudes for targets of the Hydra spectral observations not discussed in chapter 5. The top histogram shows data for stars classified as spectral type late-K to M; the bottom histogram shows data classified as spectral type late F to early-K. Shown in both panels is the expected range of magnitudes for 5 Myr-old stars of those spectral types at the distance of USco.

present the results along with results from remaining Palomar spectra (chapter 5) in an upcoming publication (chapter 9, last paragraph).

8.2 Palomar Spectra of High-Variability Stars

The ultimate form of the Quest-2 survey to look for new PMS stars near USco and Taurus was/is quite different from that envisioned when the proposal to obtain the observations was written. The original intent had been to identify candidate PMS stars based on their colors and magnitudes *and* photometric variability. Thus the reason for taking 12 to 24 monitoring observations in each region. As described in chapter 1, young PMS stars have systematically more magnetic activity than do older stars at equivalent masses. This activity causes increased photospheric activity in the form of cool star spots which can be observed as photometric variability. This technique has been successfully used by Briceño et al. (2005) to identify ∼200 new members of the ∼5–10 Myr-old regions of Orion OB 1a and Orion OB 1b using Quest-1 in Venezuela.

However, because the CCDs used in Quest-2 are not scientific grade, at the time we initially received the photometric data, repeatability was not sufficient to identify low mass PMS variable stars. The Briceño et al. (2005) survey finds an average value of $< \Delta V > \sim 0.26$ mag for non-accreting PMS stars. These stars were identified above a noise of $< \Delta V > \sim 0.005$ at $V < 17$ to $< \Delta V > \sim 0.09$ at $V < 20$. The Quest-2 data had average repeatability at several times this level at the time when the spectroscopic follow-up program began. Because the photometry for each source (in the monitoring regions) was an average of multiple observations, the colors and magnitudes in the photometric catalog were much more accurate than any single measurement. Thus, the photometry for a given star was relatively accurate, even when its magnitude had a high RMS (i.e., photometric repeatability). The RMS value, however, was artificially high because I had not yet worked out all the bugs in the photometry (see chapter 2 for more details). Therefore I chose to select candidate PMS stars only from colors and magnitudes listed in the source catalog and largely ignored a star's photometric variation.

During the past 3–4 years that I have been working on this project, the photometry reduction and calibration has gone through several iterations. The results discussed in §2.3 are for the final version of the photometry and are at a precision where I could now begin to select candidate PMS stars based on photometric variability. To this end, I was awarded 3 nights at Palomar to begin taking spectra of variable stars newly identified in the USco region. Because photometric precision was determined to be *very* CCD dependent, I assessed the repeatability plot of each CCD separately before deciding which stars to include in the variability sample.

In figures 8.3 & 8.4 I show photometric repeatability as a function of r-magnitude for the 28 r-band CCDs. Only stars observed in more than half of the 24 monitoring scans (i.e., >12 times) are considered as variable candidates. Red lines indicate the empirical boundary between variable and non-variable stars in each column. I did not consider any stars in column 19 as variables. This procedure produced $\sim$1300 candidate variable stars. Of these, $\sim$250 were red in all colors and thus, possible young PMS stars. During the three nights at Palomar in May 2007, I was able to observe $\sim$20% of this list. Because these data were taken only a few months before my defense, I have not yet analyzed the spectra. However, I am hopeful that they will yield tens of additional PMS stars in this region.

8.3 HIRES Spectra of PMS Stars near Taurus

In chapter 4, I presented results from my photometric/spectroscopic survey of $\sim$200 deg^2 in and near the Taurus molecular clouds. As part of this work, I identified 42 new low mass PMS stars of which approximately half have spectral signatures that indicate they are as young as members of the known $\sim$1 Myr-old Taurus subclusters while the other half was determined to be slightly more evolved, $\sim$5–10 Myr-old. From assessment of the spatial and proper motion distributions, I argued in chapter 4 that the new pre-main sequence stars identified far from the clouds cannot have originated from the vicinity of the 1–2 Myr-old subclusters which contain the bulk of

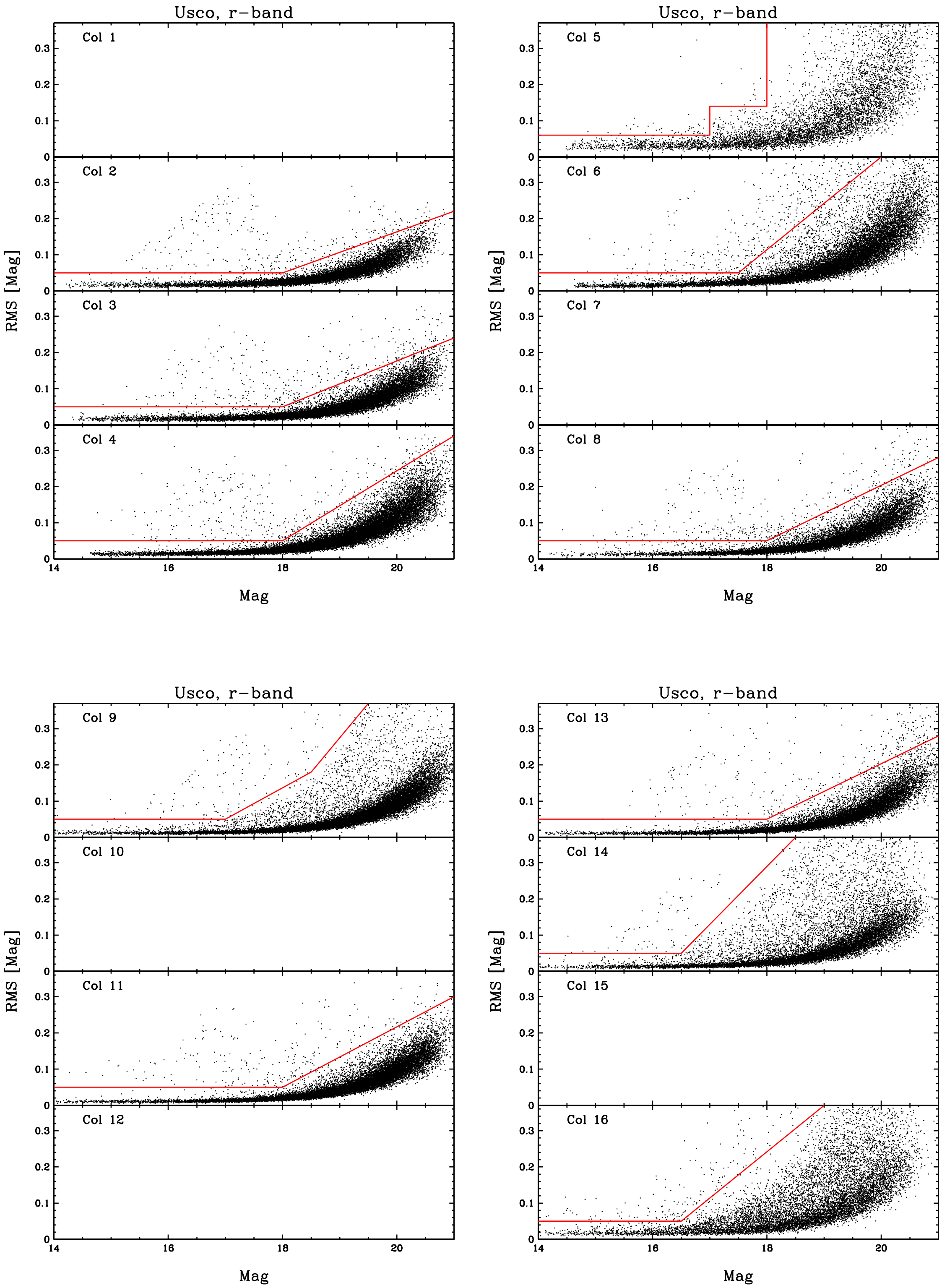

Figure 8.3 Photometric repeatability as a function of magnitude for all stars detected in more than half of the monitoring scans (i.e., >12) in USco.

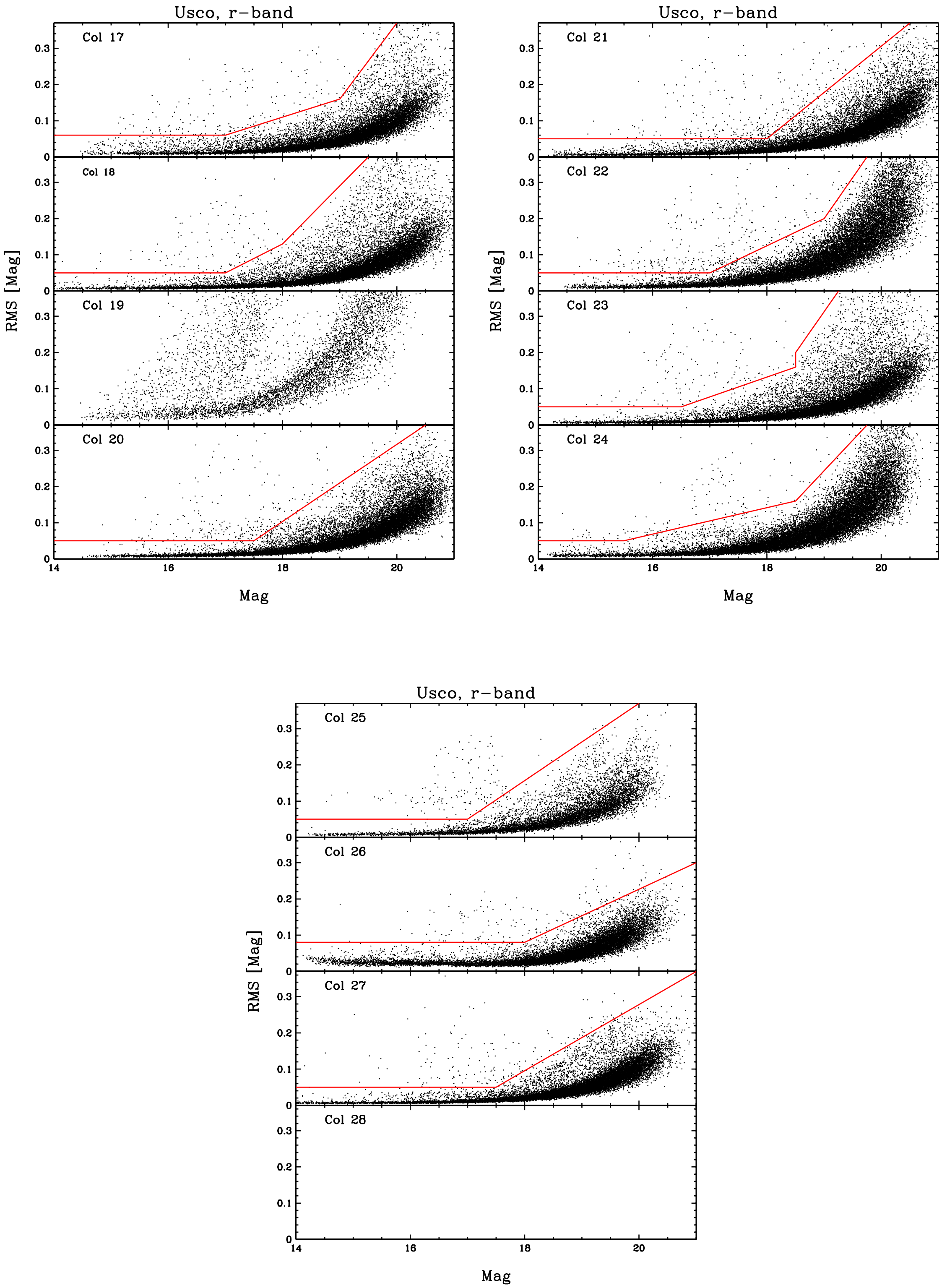

Figure 8.4 Photometric repeatability as a function of magnitude for all stars detected in more than half of the monitoring scans (i.e., >12) in USco.

the identified Taurus members, but instead represent a newly identified area of recent star formation near the clouds.

I was awarded 3 nights on Keck with HIRES in the 2006B season to take high-resolution spectral observations of these stars. Thus far, I have observed ∼2/3 of the sample in this manner, and have time this fall to observe the remaining stars using the Magellan Inamori Kyocera Echelle (MIKE) on the Magellan Clay Telescope. Once the observations have been completed, I will use the high resolution spectroscopic data to derive additional information on the kinematics (i.e., radial velocities) and ages (i.e., Li equivalent widths) of the newly identified PMS stars which will help solidify their origin and relationship to Taurus. The radial velocity distribution of Taurus is tightly peaked at V_R ∼-18.7 km/s with a small dispersion of ∼1.7 km/s (e.g., Frink et al. 1997). I will use high resolution spectroscopy to measure the radial velocities for new PMS stars at a precision of $\lesssim$1 km/s which I will combine with more robust measurements of proper motion (derived from existing catalogs). Following the methods of Frink et al. (1997), I will assess whether the space motions and distances of the sources can simultaneously be consistent with stars in Taurus, thus providing a compelling argument for or against these stars being part of the 'missing' PTTS population.

In addition to kinematic information I will also measure Li equivalent widths. Li depletion occurs slowly over >100 Myr for F and G type stars and is therefore not suitable for distinguishing PTTSs from older Pleiades-age objects. For K to mid-M type stars that are fully convective, Li depletion occurs over much faster timescales (∼10 Myr; D'Antona & Mazzitelli 1994) and is a more robust indicator of youth. In this spectral range Li can only be measured with high resolution spectroscopy due to broad molecular absorption features present in the spectra. Detecting Li in these objects will serve as an independent check of the surface gravity assessment and further confirm youth. I will also investigate secondary indicators of youth such as rapid rotation and weak accretion (i.e., broad wings in the Hα emission line) which are known to evolve on timescales of ∼10 Myr.