Periodic NIR Behavior in Young Stars

Scott J. Wolk (CfA), T.S. Rice (Harvard), C.A. Aspin (IfA)

arxiv.org/abs/1206.0759 arxiv.org/abs/1306.2326

Introduction

Our goal is to study the near-infrared variability of young stars. IR studies are the foundation for understanding early stellar and disk evolution. Young stars are also the sites of active planet formation. We have analyzed WISE mid-infrared photometry and time-series near-infrared UKIRT/ WFCAM photometry of a region of active star formation in the Cygnus OB7 association. These data will allow us to investigate their variability on time scales of days to a few years.

Cyg OB7

This is the closest (800pc) of the Cygnus OB associations and includes several dark clouds including Lynds 1003 and 1004 (shown at the right). It contains at least two FU Ori objects. Khanzadyan et al. (2012) identified 28 outflows and 18 protostars in this region. It is clearly one of the youngest and most active near by OB associations.

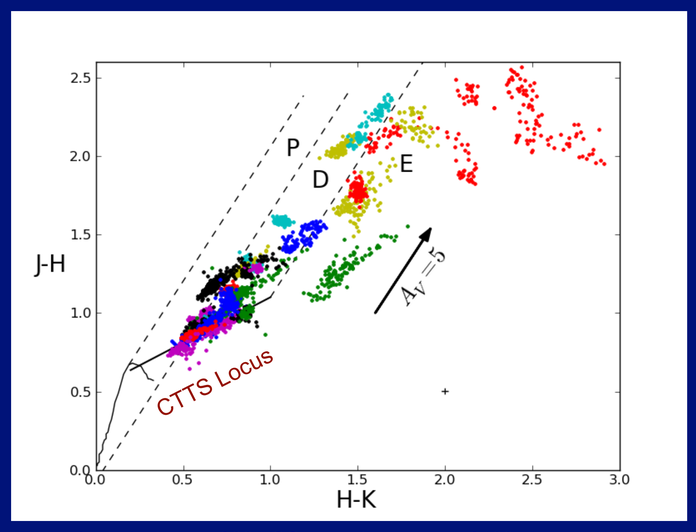
NIR Monitoring Program

Observations were taken using UKIRT from early 2008 to late 2009. Using WFCAM, we took photometric observations in the J, H, and K near-infrared bands over a 1-square-degree field on about 100 nights spread across 3 observing seasons. Our data were reduced automatically using the WFCAM Science Archive processing. Over 9,200 sources had photometry better than 4% (K~16) in all three channels on over 75 nights. We searched this database for any variability and all stars which showed K band excesses consistent with a disk.

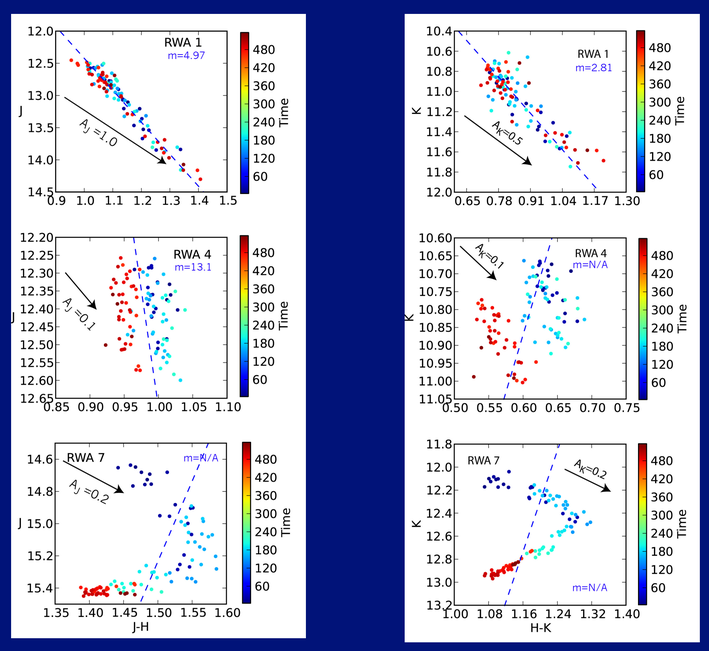
Results

The WISE data reveal 96 YSO candidates of which 49 were monitored.

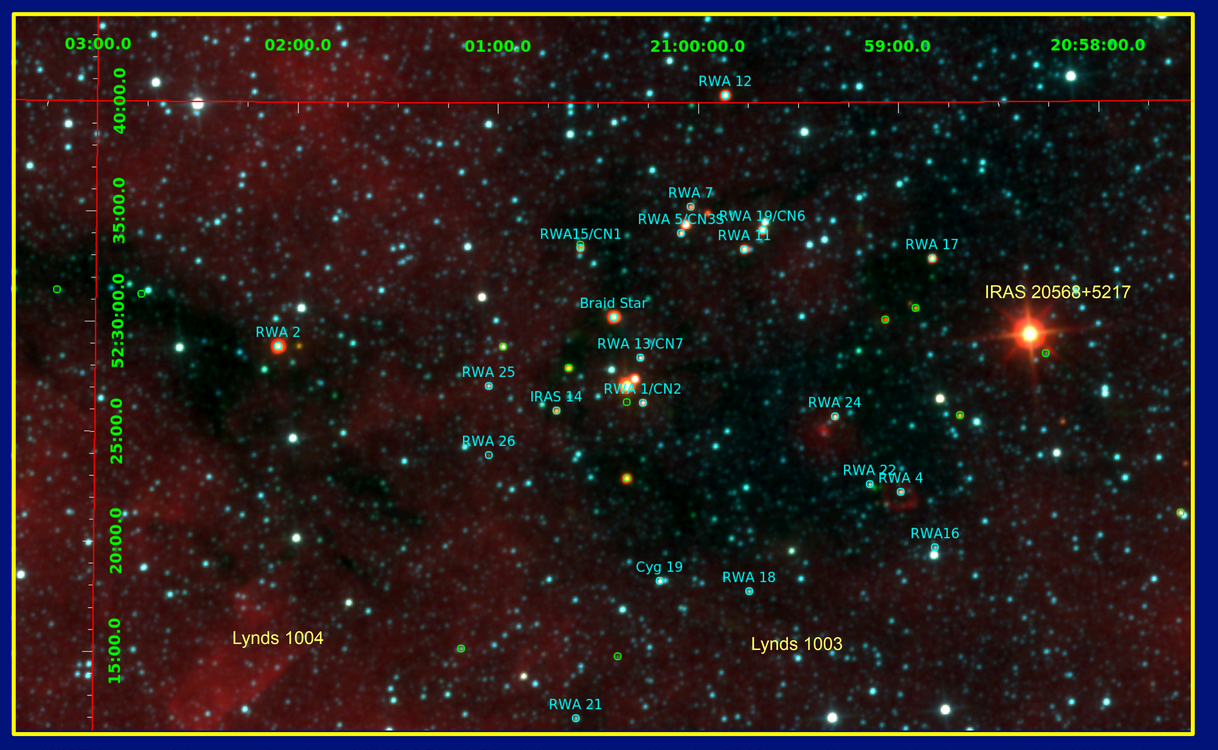
- >80% of the YSO were variable at a significant level. The data are consistent with 100% variability on time scales of 10 yrs.
- 36% of the YSOs varied such that they crossed between the photospheric and disked regions of the IR color magnitude diagram.
- The lightcurves could be classified into 4 principle classes – Periodic, quasiperiodic, long duration & stochastic – which appear indicative of different physical processes.
- We detect changes in the photometric signatures which we map to changes in specific physical conditions – including accretion rate, hole size & inner edge inclination (outlined by Carpenter et al. 2001).



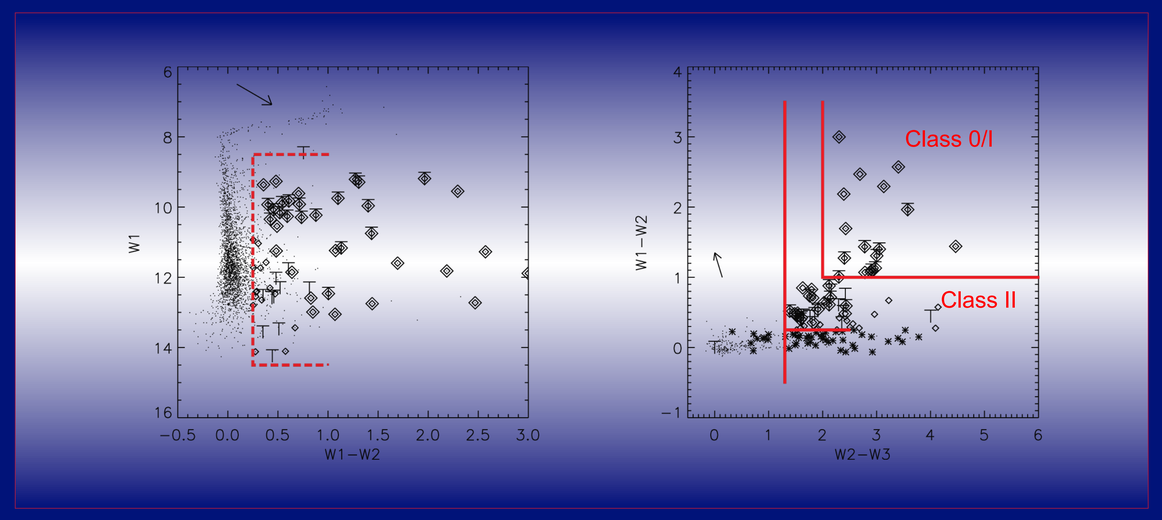
The color trajectories of 30 YSOs over the course of 100 observations. Each star's trajectory is plotted in a different color; some colors are repeated. Nine YSOs drift between regions "P" (photosphere) and "D" (disk). Many of the trajectories are coherent, tracing the CTTS locus (Meyer et al. 1996) or a combination of the CTTS locus and reddening.



Examples of fitted color–color diagrams. A linear model is not always representative (e.g. RWA 7). The direction and length of the ISM reddening vector is indicated in each window as is the fitted slope (m).



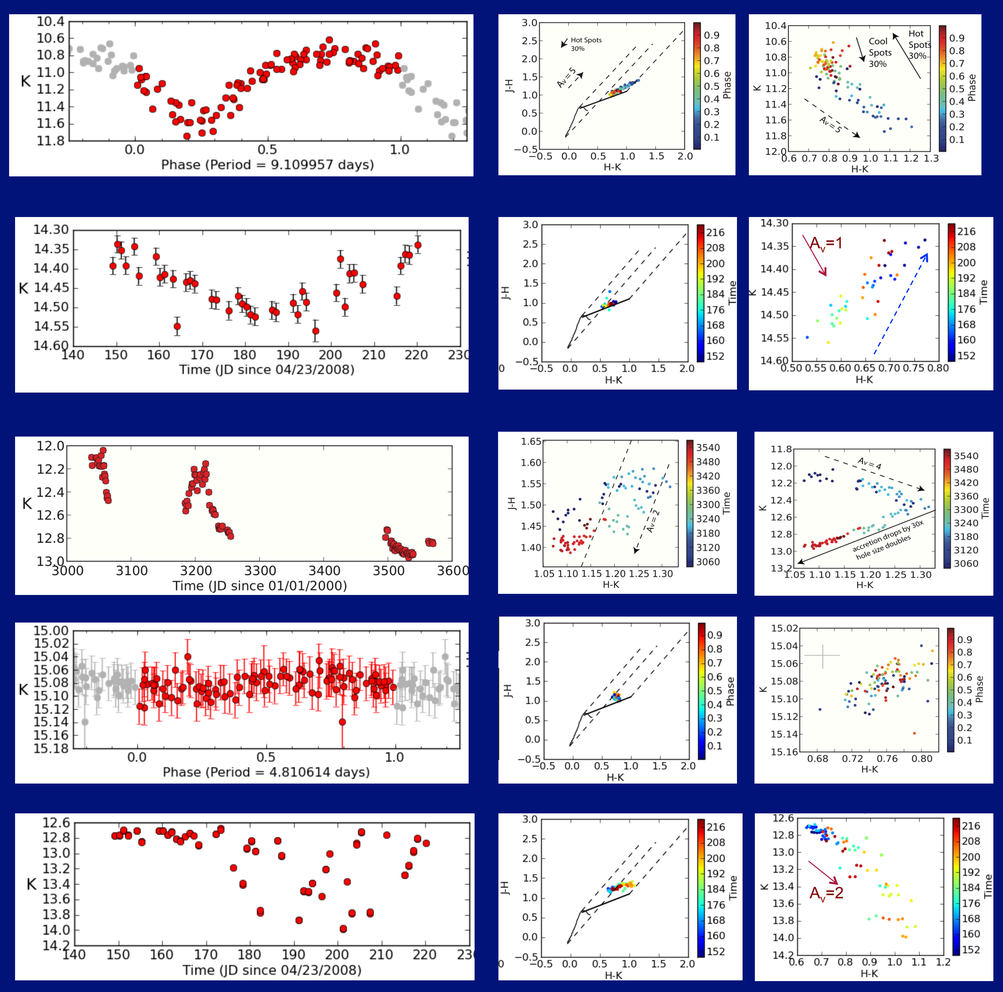
WISE image of the central region of CYG OB7 (BGR=3.6μm,4.8μm, 22μm). PMS stars discussed by Aspen et al. (2009) and Rice et al. (2012) are circled in Cyan. Newly identified YSOs from the WISE survey are marked in green. Two of the selection color diagrams are shown below. "T" indicates a previously known YSO. Diamonds indicate newly identified YSOs. Stars in the upper-right portion of the W1-W2, W2- W3 ([3.6]-[4.8], [4.8]-[12]) diagram are probable Class 0/I protostars.



Light Curves

Examples of the typical light curves seen from YSOs:

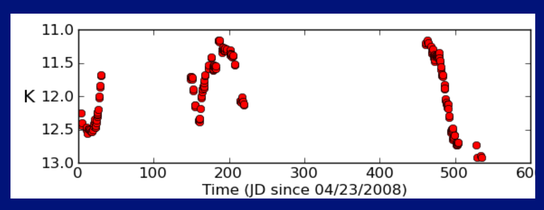
1. About 25% are like the top one - very periodic, with variability within the periodic signal. Many appear to move along the CTTS locus in the 2-color diagram (TCD) and are reddening dominated in the color-magnitude diagram (CMD).
2. About 25% are similar to line 2. Quasiperiodic, they appear to move along the CTTS locus in the 2 color diagram and move in a direction indicating changes in the disk structure (cf. Carpenter et al. 2001; hole size, accretion rate or inclination) in the TCD and CMD.
3. Class 0/I protostars tend to resemble line 3. Huge changes which have a long duration. They appear to move chaotically in the TCD. While there are patterns in the CMD, they are complex.
4. At least one of the stars that is not formally variable appears periodic.
5. A few stars defy classification.
6. By contrast, the 140 eclipsing binaries don't exceed 0.7 mag, and show nearly no color change (ΔH-K>0.1) (Wolk et al. 2013).

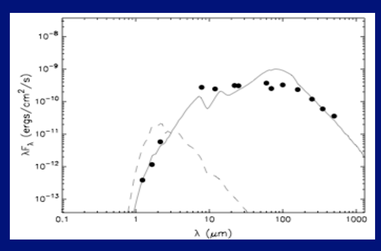


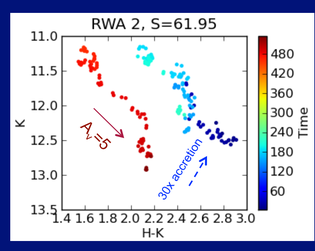
A sample of the different types of light curves and color-space trajectories. First panels are light curves, some are phase folded. Second panels are JHK TCDs. Reddening band and CTTS locus are indicated. The third panels are KHK CMDs. In addition to showing the reddening vector, the color trajectories of disk changes such as accretion rate and hole size are indicated in blue when meaningful.

RWA 2

RWA 2 exhibits changes of 5 mag. at J and full period cycles on time scales of months. The J-K color varies by 2.1 and is reddest when the star is at its faintest. The trajectory of the star in JHK color-color and color magnitude space is indicative of changes in both reddening by 15 A_V (red vector in right most plot) and changes in accretion rate by a factor of 10 (the blue vector in right most plot). K band spectroscopy show RWA~2 has strong H_2 and Brγ emission. L' imaging resolves a binary (700 AU [0.9"] separation) with a very red companion. We have obtained mid and far-IR data on this source from WISE, IRAS, IRAC, AKARI, PACS and SPIRE and fit an SED model (Robitaille et al. 2007) to the source and find the star has a disk and massive envelope.

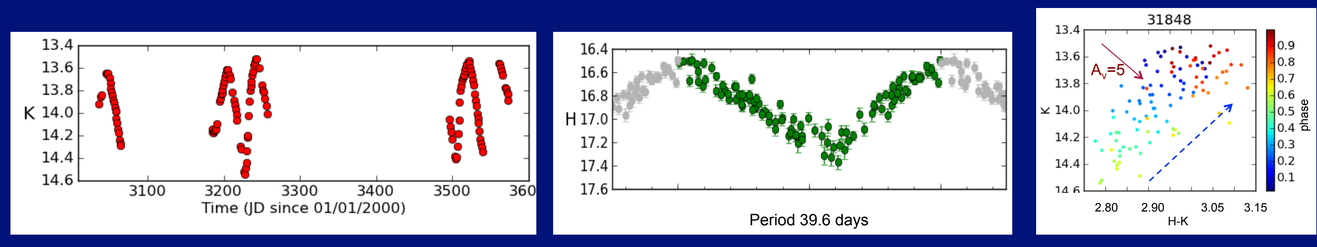






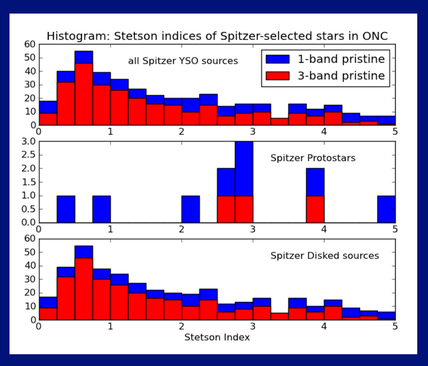
WISE 31848

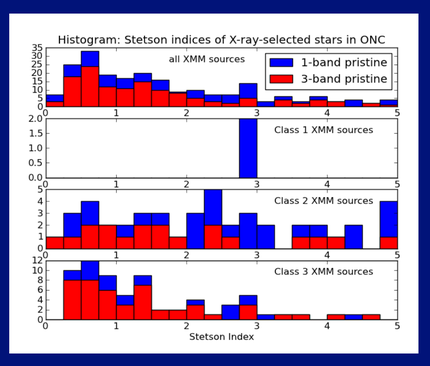
This source was recently revealed as a YSO. WISE data were required for the identification as it is J>20 in most of the UKIRT data. WISE shows [3.6]-[22] > 8 while [3.6]-[4.5]=2.6 – this is clearly a Class 0/I source. Khanzadyan et al. (2012) find this object drives a small outflow. We find a very strong and regular 40 day period, which we believe is associated with accretion based on the K, H-K colors. Studies of YSO periods indicate rotation periods are usually < 10 days. This implies a 40 day period must be associated with something in the disk or the influence of a binary companion. Changes in dust extinction by 5 A_V are independent of the 40 day period.



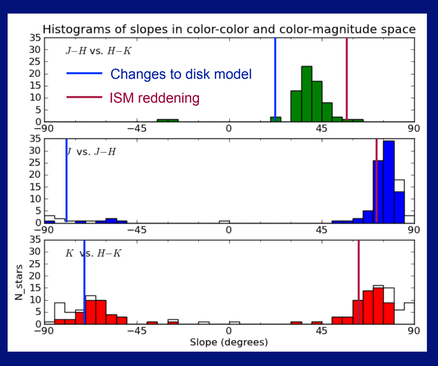
Statistical Results

We are following up this project with a similar project in Orion (L1641; Rice et al. 2014). Over 1200 stars have been identified as variable with over 500 identified as periodic. The size of the sample allows statistical analysis.





Above we plot the distribution of Stetson indices as a function of Class for IR (left) and X-ray (right) selected samples. The value of the Stetson indices are larger for the less evolved objects. However, the fraction of variables is statistically very close, ~70% for the Class III, ~80% for Class II and ~90% for Class I. "Pristine" indicates the number of bands with observational errors < 2%.



The distribution of fitted slopes show that most cluster near the reddening vector. Reddening is usually steeper than ISM models predict. A substantial fraction are 90° opposed indicative of changes in the accretion structure.