Infrared Variability in Young Stars

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Abstract. We present an analysis of near-infrared UKIRT photometry and mid-infrared time-series photometry for several clusters taken as part of the Spitzer Young Stellar Object VARiability program (YSOVAR). In the clusters L1688, IRAS 20050+2720 and GGD 12-15 we identify variability in several hundred stars ranging from Class I to Class III. The data have photometric uncertainties less than 0.05 mag down to [4.5] ∼15.5. We study the light curves and color trajectories of the sources in the monitored fields. We investigate the variability and periodicity of the YSOs and find that they divide into observational classes which at a the least include: 1) stochastic variables, 2) long-term variables, 3) periodic stars which vary in frequency or amplitude and 4) stars with periodic variability which is stable over long timescales. Some YSO variability defies simple classification.

1. Introduction

Our goal is to study the 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 time-series near-infrared photometry of regions of active star formation in the Cygnus OB7 and the ONC using UKIRT/WFCAM data. We have also obtained time-series IRAC data from the warm Spitzer mission (3.6 and 4.5 μm) for GGD12-15, IRAS 20050+2720 and the ρ Oph star forming region (L 1688; Günther et al. 2014) as part of the YSOVAR Spitzer large program. These data will allow us to investigate the long and intermediate timescale variability of the stars and their disks.

1.1 Different types of physics lead to different variability in the IR

For young stars, variability has several sources. The stellar photosphere can have large dark star spots or hot spots caused by accretion. These can have impacts on the flux in the J and H bands but these variations lead to little color change since they are reflective of 3000–10,000 K blackbodies. Class II objects have an inner disk that is typically optically thick in the IRAC bands; about 20% of the Class II objects also have optically thick disks at K band. Changes to the emission from the disk can occur due to responses to changes in the stellar emission, changes in the disk structure due to accretion, or dynamically induced changes to the structure of the disk. Each of these can have different color signatures. Extinction suppresses the total flux, especially blue-ward of 3 μm. In this wavelength region, changes in any of the five components (star, extinction, accretion, disk or envelope) can lead to significant changes of flux and color.

2. Observations

2.1 Near-IR Monitoring Program

NIR Observations were taken of the ONC using UKIRT from October 2006 to April 2009. Using WFCAM, we took photometric observations in the J, H, and K near-infrared bands over a 1-square-degree field on about 120 nights spread across 3 observing seasons. Our data were reduced automatically using the WFCAM Science Archive processing. Over 14,000 sources had photometry better than 4% (K$\sim$16 mag) in all three channels. We confirmed over 1200 of these as strong variables with Stetson Index >1 (see Figure .1; Rice et al. in prep; Stetson 1996).

2.2 Mid-IR Monitoring Program

YSOVAR is a Spitzer program which obtained time series photometric monitoring at 3.6 and 4.5 μm data of nearby star forming regions. IRAS 20050+2720 was observed over about 100 epochs (sampled approximately twice per day for 50 days, less frequently at longer timescales). Overall, 550 stars, including 180 YSOs, have good light curves (Poppenhaeger et al., in prep.). GGD12-15 data include over 1000 light curves including more than 350 objects observed in both IRAC channels. Over 200 variables are detected and the vast majority are identified with YSOs (Figure .2; Wolk et al., in prep.). The data were taken during Summer 2010. There are over a dozen clusters covered in the YSOVAR project including Orion, NGC 1333 and Ceph C (Rebull et al. 2014).

3. Analysis

Variability is usually assessed by correlated changes (i.e. Stetson index; Stetson 1996). We also calculated the mean absolute and standard deviations; the various criteria give similar, not identical results. Each star is visually checked for contamination. Period searches are

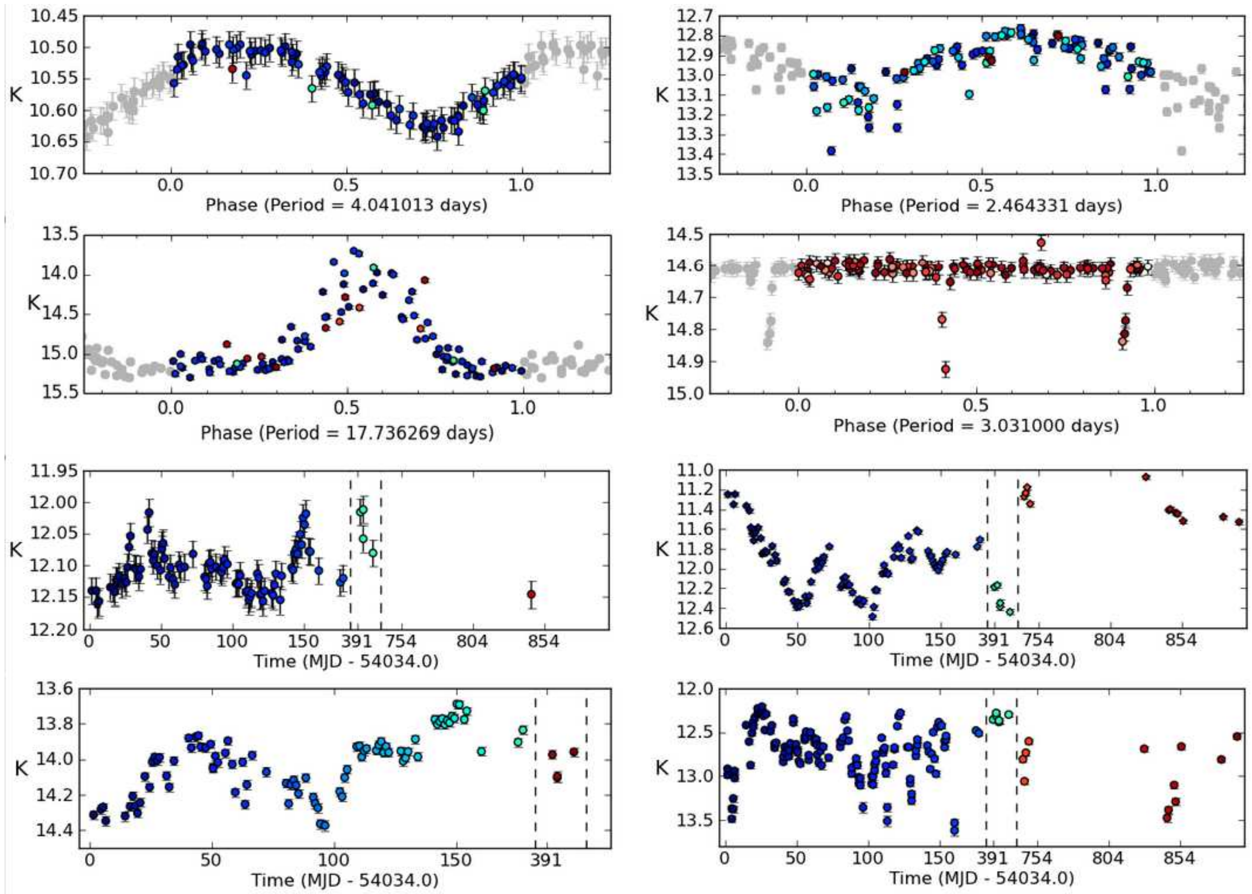

Figure .1: Example K-band lightcurves from the ONC (Rice et al. 2014 in prep.). From left to right, top to bottom we show: two periodic sources, a periodic bursting source, an eclipsing binary, a bursting source, an aperiodic source and two sources eclipsed by their disks (dippers; Stauffer et al. 2014)

conducted on all lightcurves. Data were folded over strong periods. We also fit a vector to the color change (i.e $\Delta[3.6]/\Delta[3.6\text{-}4.5]$ and $K/H-K$).

4. Results

Among the 1200 strong variables from the ONC, most near-IR light curves could be easily classified. About 25% are clearly periodic, with variability within the periodic signal. They appear to move along the CTTS locus in the 2 color diagram and are reddening dominated in the CMD. About 25% are quasi-periodic, they appear to move along the CTTS locus in the 2 color diagram and move in a direction indicating changes in the disk structure (hole size, accretion rate or inclination) in the CMD. Many Class I protostars showed long, slow changes. Huge changes ($>$ 1 mag) can occur. While there are patterns in the two-color diagram and color-magnitude diagram they are complex. Several stars that are not formally

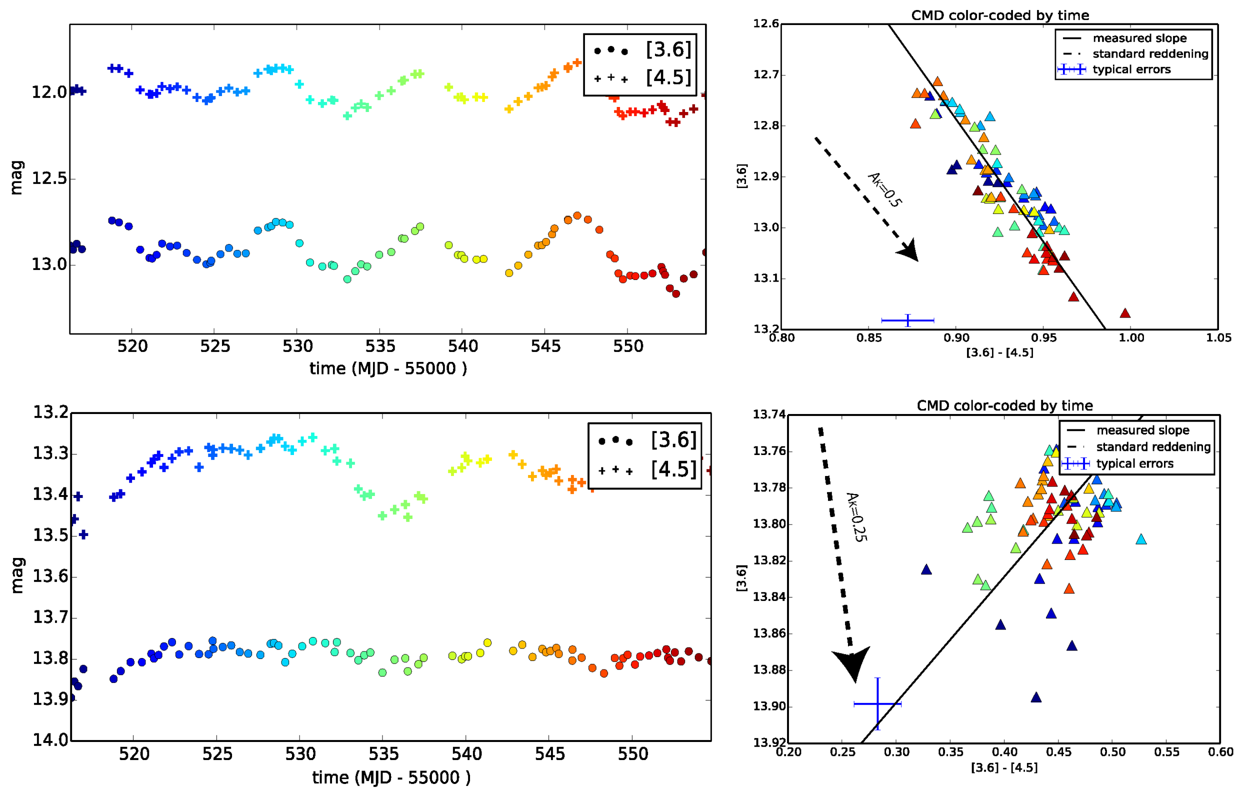

Figure .2: Two example Mid-IR light curves from GGD12-15. The panels on the left show the raw lightcurves in the [3.6] and [4.5] bands – color indicates time. The right side uses the same colors to indicate time in a [3.6], [3.6-4.5] color-magnitude plot. In the top plot, the star (SSTYSV J061056.75-061101.7) changes color in correspondence to the reddening vector. In the bottom plot,(SSTYSV J061054.97-061136.1) the color changes are nearly orthogonal to the reddening vector.Indebetouw et al. (2005)

variable, via the Stetson index, are still periodic. This is because the choice of Stetson index was to to ensure the detection of highly statistically significant variability. Emphasis was not placed on weak, but possibly statistically significant, lightcurves. Still, some variables defy classification.

While there are many similarities with NIR lightcurves, mid-IR lightcurves are different. About 85% of the known YSOs vary significantly in both IRAC channels. While about 20% are periodic, many Class I-II objects with defined periods have significant variability within the periodic signal. The largest fraction are quasi-periodic – meaning they rise and fall with changing amplitude and/or period (Cody et al. 2014). A significant difference between the near– and mid-IR light curves is that long, slow trends are much more common in the mid-IR, and about 10% of stars show change of up to 0.5 mag, but dramatic changes (>0.7mag) are very rare. Most stars have color changes compatible with extinction being the dominant cause, but there is still a significant fraction that show systematic shifts or get bluer as they get fainter.

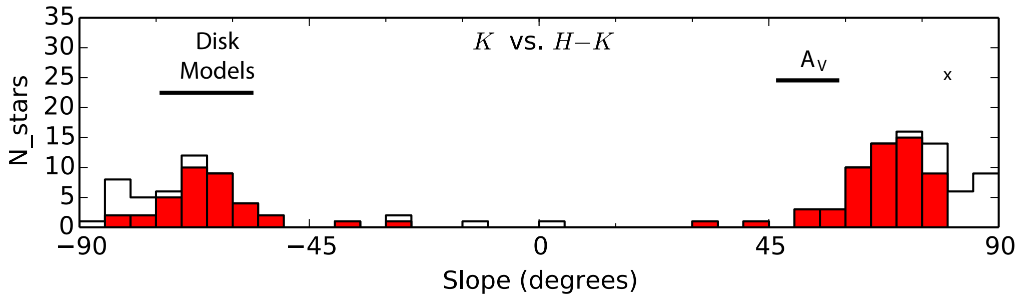

Figure .3: Distributions of the fitted slopes in color-magnitude space in K, $H - K$. As in Carpenter et al. (2001), only stars showing color slopes with greater than 20% accuracy from the ONC sample are shown. Those on the right hand side show reddening as they get fainter, those on the left hand side show "blueing".

5. Conclusions

Overall, over 80% of the known YSOs were variable at a significant level. In the NIR, most of the stars show color changes consistent with changes in reddening, but over 1/3 of the YSOs varied such that they crossed between the photospheric and disked regions of the IR color magnitude diagram (Figure .3). We attribute these variations to changes in the accretion and disk structure (Espaillat et al. 2010; Wolk, Rice, & Aspin 2013; Günther et al. 2014). The observed variability varies widely, including periodic, quasi-periodic, monotonic and stochastic types. Less evolved stars vary more.

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