NEAR-INFRARED VARIABILITY IN YOUNG STARS IN CYGNUS OB7

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ABSTRACT

We present the first results from a 124 night J, H, K near-infrared monitoring campaign of the dark cloud L 1003 in Cygnus OB7, an active star-forming region. Using three seasons of UKIRT observations spanning 1.5 years, we obtained high-quality photometry on 9200 stars down to $J = 17$ mag, with photometric uncertainty better than 0.04 mag. On the basis of near-infrared excesses from disks, we identify 30 pre-main-sequence stars, including 24 which are newly discovered. We analyze those stars and find that the NIR excesses are significantly variable. All 9200 stars were monitored for photometric variability; among the field star population, $\sim$160 exhibited near-infrared variability (1.7% of the sample). Of the 30 young stellar objects (YSOs), 28 of them (93%) are variable at a significant level. Of the 30 YSOs, twenty-five have near-infrared excess consistent with simple disk-plus-star classical T Tauri models. Nine of these (36%) drift in color space over the course of these observations and/or since Two Micron All Sky Survey observations such that they cross the boundary defining the NIR excess criteria; effectively, they have a transient near-infrared excess. Thus, time-series JHK observations can be used to obtain a more complete sample of disk-bearing stars than single-epoch JHK observations. About half of the YSOs have color-space variations parallel to either the classical T Tauri star locus or a hybrid track which includes the dust reddening trajectory. This indicates that the NIR variability in YSOs that possess accretion disks arises from a combination of variable extinction and changes in the inner accretion disk: either in accretion rate, central hole size, and/or the inclination of the inner disk. While some variability may be due to stellar rotation, the level of variability on the individual stars can exceed a magnitude. This is a strong empirical suggestion that protoplanetary disks are quite dynamic and exhibit more complex activity on short timescales than is attributable to rotation alone or captured in static disk models.

Key words: accretion, accretion disks – infrared: stars – stars: formation – stars: pre-main sequence – stars: variables: T Tauri, Herbig Ae/Be

Online-only material: color figures

1. INTRODUCTION

Near-infrared studies of young stars allow for the direct detection of optically thick disks around these stars via excess K-band flux (Lada & Adams 1992; Lada et al. 2000). The intrinsic colors of these disk-bearing young stars occupy a well-defined locus in $(J - H)$ versus $(H - K)$ two-color space (henceforth called JHK space), and their position along this locus is determined by physical parameters such as their inclination angle, disk inner hole size, and accretion rate (Meyer et al. 1997; Robitaille et al. 2006). This technique of identifying young stellar objects (YSOs) using their near-infrared colors has been used extensively to characterize populations of young stars associated with star-forming regions in Orion, Taurus, Ophiuchus, Chamaeleon, and others for nearly two decades (e.g., Strom et al. 1993, 1995; Itoh et al. 1996; Hillenbrand et al. 1998; Oasa et al. 1999; Haisch et al. 2000; Robberto et al. 2010).

Disk-bearing young stars, also known as classical T Tauri stars (CTTSs), have long been identified as optically variable (Joy 1945; Herbig 1962). At a minimum, the variability is due to a combination of (1) cold starspots, (2) hot accretion spots, and (3) circumstellar dust occultations (Herbst et al. 1994). Optical variability can be used to effectively identify young low-mass stars, even in regions lacking other tracers of star formation such as molecular clouds (Briceño et al. 2005).

The variability of T Tauri stars in the near-infrared has been less thoroughly studied. One of the first projects was carried out by Skrutskie et al. (1996) who sampled bright T Tauri stars, mostly members of the Taurus cloud, over the course of a few nights. They found nearly all the stars varied significantly and the amplitude of K-band source variability was weakly correlated with $(K - L)$ excess—a reliable disk diagnostic. From a multi-epoch study of the Serpens cloud core, Kaas (1999) found the IR variability to be a strong indicator of youth. Variability across 14 epochs was used to reveal new YSOs in the ρ Oph cluster (Alves de Oliveira & Casali 2008). In the early part of the last decade, Carpenter et al. (2001) used 16 observations of a 0.84 × 6° region over 19 days to study NIR variability toward the Orion Nebula Cluster, and Carpenter et al. (2002) used 15 observations of a similarly sized field in the Chamaeleon I star-forming region over 4 months; the typical peak-to-peak amplitude of variability seen was around 0.2 mag in each band. These studies found near-IR (NIR) variability most commonly arose from cold starspots, hot accretion spots, and variable extinction. However, among stars with a near-infrared excess (~25% of the variable stars possessed NIR excess), changes in the accretion disk were required to explain the observed variability. Eiroa et al. (2002) combined optical and NIR data of 18 bright stars and found 12 had correlated optical and NIR variability trends, suggestive of a common physical origin such as spots and/or variable extinction. An investigation of long-term NIR variability in a large sample of T Tauri stars using two to three epochs covering baselines of six to eight years was carried out by Scholz et al. (2009) (see also Scholz 2012). They find the fraction of large-amplitude variables increases...
for progressively longer baselines. They derived a 2500 year upper limit on the duty cycle for large-scale episodic accretion events. The YSOVAR survey of an 0.9 deg² region of the Orion Nebula Cluster (Morales-Calderón et al. 2011) obtained 81 epochs of mid-IR Spitzer photometry over 40 consecutive days, in conjunction with 32 epochs of J-band images from the United Kingdom InfraRed Telescope (UKIRT) and 11 epochs of $K_s$ photometry from the Canada–France–Hawaii Telescope. In that study of disk-bearing young stars, various phenomena were observed, including periodic variability and disk occultation events.

In this paper, we present a survey in which the photometric variability of objects in the Braid Nebula star-forming region within Cygnus OB7 was monitored for nearly two years. Our goal is to detect high-confidence YSO candidates with precision photometry, study their variability, and analyze the stability of the near-infrared disk diagnostic.

The constellation Cygnus contains several rich and complex star-forming regions including Cygnus X as well as the North American and Pelican nebulae (Reipurth & Schneider 2008). Nine OB associations have been found in Cygnus, with Cygnus OB7 the nearest at a distance of around 800 pc (Aspin et al. 2009; distance modulus $\mu = 9.5$). Within Cygnus OB7 lies a complex of several dark clouds collectively known as Kh 141 (Khavtasi 1955) that have been individually identified in the Lynds catalog (Lynds 1962). The dark cloud LDN 1003 in Cyg OB7 has been identified as a site of active star formation, having first been studied in the optical by Cohen (1980) who found a diffuse red nebula he named RNO 127. This nebula was later determined to be a bright Herbig-Haro (HH) object by Melikian & Karapetian (2001, 2003; HH 428). Further study in the optical and near-infrared identified a number of HH objects (Devine et al. 1997; Movsessian et al. 2003) and multiple IRAS sources (Dobashi et al. 1996) that reveal the presence of a young stellar population and significant star formation activity.

The presence of two FUors in this region (Reipurth & Aspin 1997; Greene et al. 2008; Aspin et al. 2011), which has come to be known as the Braid Nebula region (Movsessian et al. 2006), led to a focused, multi-wavelength effort to study the young stars in this dark cloud, which is currently ongoing. A narrowband optical and near-infrared survey of HH outflows observed using the Subaru 8 m telescope (Magakian et al. 2010) found 12 outflows that have identifiable originating/exciting sources and many more nebulous objects not yet associated with identified sources. Aspin et al. (2009) carried out a near-infrared integral field spectroscopic survey to identify actively accreting sources such as T Tauri stars, which studied 16 sources in the field and identified 12 young stars among them. Using the Caltech Submillimeter Observatory, a 1.1 mm map of cold gas and dust associated with these young stars was obtained (Aspin et al. 2011), identifying 55 cold dust clumps, 11 of which were associated with IRAS sources. The wide range of evolutionary states encountered in this region, from starless clumps to optically visible T Tauri stars, suggests that star formation here is an ongoing process rather than a one-time occurrence.

In this paper, we describe a $JHK$ monitoring survey of the Braid Nebula star-forming region in Cygnus OB7. We plan to present first results from this survey in two papers; this is Paper I of two. Our goal in Paper I is to identify disk-bearing young stars, to broadly characterize the variability properties of these stars using sensitive, long-baseline, nightly cadence time-series photometry, and to investigate the reliability of the near-infrared excess criterion itself with respect to time. In the second paper (S. J. Wolk et al. 2012, in preparation, hereafter known as Paper II), we will describe the specific phenomena seen in the light curves, carefully analyze the variability and periodic nature of specific stars, and present variability statistics for the field star population.

In Section 2, we outline the UKIRT observations and data reduction procedures. In Section 3, we describe our method of identifying stars with near-infrared excesses and studying their variability. In Section 4, our results are presented, and in Section 5 we discuss the broad implication of these results on infrared studies of young stars.

## 2. DATA

### 2.1. Observations and Data Processing

The $J$, $H$, and $K$ observations of a $0.9 \times 0.9$ region in Cygnus OB7 were obtained using the Wide Field Camera (WFCAM) instrument on the UKIRT, an infrared-optimized 3.8 m telescope atop Mauna Kea, Hawaii at 13,800 feet elevation. These data consist of WFCAM observations taken from 2008 April 26 to 2009 October 11 (Figure 1) in three observing seasons as part of a special observation program described in C. Aspin et al. (2012, in preparation). The first season was in spring of 2008 and covered 26 nights. The second season was during fall 2008 and lasted 71 days. The third season was approximately one year later and lasted 75 days. During the monitoring runs, data were taken once per night on a total of 124 nights in all three bands. Atmospheric seeing was between $0.5$ and $1.0^\prime$ on any given night. The $J$, $H$, $K$ filter bands on WFCAM comply with the $JHK$ broadband filters from the Mauna Kea Observatories Near-Infrared filter set (Casali et al. 2007; Tokunaga et al. 2002); WFCAM’s photometric system is described in Hewett et al. (2006).

Detailed specifications for the WFCAM instrument are given in Casali et al. (2007). The instrument has four $2048 \times 2048$ Rockwell Hawaii-II PACE arrays with a scale of 0.4 arcsec pixel$^{-1}$, giving a combined solid angle of 0.21 deg$^2$ per exposure. The four detectors are widely spaced, at 94% of one detector’s width apart (see Figure 2). We used a standard effective integration time of 40 s per pointing. In a stepping...
Figure 2. Footprint of WFCAM consists of four detectors spaced by (94%) of their width, covering a non-contiguous 0.21 deg$^2$; four pointings are required to fill the observing field. In this figure, we show how the 16 tiles in this observing field are imaged: the four tiles marked “A,” called “footprint A,” are observed in a simultaneous imaging, then the telescope is slewed south by 15$'$ to observe the “B” tiles, west by 15$'$ to observe “C” tiles, and finally back north by 15$'$ to observe the “D” tiles. Underlaid is a map of star counts across the field, showing clearly the structure of the dark cloud L 1003, which causes the mean extinction in each tile to vary.

pattern, WFCAM can scan a nearly complete square degree of the sky in four pointings (A, B, C, D in Figure 2). The pointings have a minor overlap on their edges such that stars in the overlapping region were observed twice per night.

Data from the survey were pipeline reduced and processed by the WFCAM Science Archive System (Irwin 2008; Hambly et al. 2008), which is also used for the UKIDSS survey described in Lawrence et al. (2007). Near-infrared observations are calibrated against Two Micron All Sky Survey (2MASS) sources in the field which have extinction-corrected color 0.0 $\leq$ $J$ $-K$ $\leq$ 1.0 and 2MASS signal-to-noise ratio >10 in each filter. For the target stars, total uncertainties in photometry are typically 2% down to $J = 16.5$, $H = 16$, and $K = 15$, and errors are less than 4% at $J = 17$ (Hodgkin et al. 2009). In processing such a wide field of view, a large number of data quality issues arise and are typically dealt with by the pipeline by assigning photometric error flags for issues such as bad pixels, deblending, saturation, and other effects.

2.2. Data Retrieval and Cleaning

We retrieved the processed photometry data from the WFCAM Science Archive Web site via an SQL interface. All 124 nights of data were retrieved, cross-matched, and merged together into a single catalog containing columns for object ID, observation date, sky coordinates, $JHK$ photometry, and various photometric processing flags. Our initial query was for data that satisfied the criteria $J < H < K < 18$; $J$, $H$, $K$ $> 9$; and photometric uncertainty $\sigma_{(J,H,K)} < 0.1$, in order to include all possibly relevant data on young stars in this region (see Section 3.2 on magnitude cuts) while keeping the downloaded catalog file at a manageable size.

Hodgkin et al. (2009) present an empirically derived correction from the pipeline-estimated photometric error to the true, measured error:

$$M^2 = cE^2 + s^2,$$

where $M$ is the measured total error, $E$ is the estimated photometric uncertainty given by the pipeline, the constant of proportionality $c = 1.082$, and the systematic component $s = 0.021$. We applied this update to the estimated photometric uncertainties after retrieving the data and confirming that night-to-night variations at the 2% level were typical even for high signal-to-noise stars.

To assess the photometric integrity of this data set, we calculated the mean $JHK$ colors for each pointing on each night, averaged over all stars. We excluded observations where the mean colors showed significant deviations. For each night, we computed the mean $J - H$ and $H - K$ color of all reliable stars within each detector footprint (here, “reliable” denotes stars with photometric uncertainties less than 0.1 mag in each band and no processing error flags, while avoiding bright stars). In practice, this translated to stars between $13 < J < 18$, $12 < H < 17$, and $11.5 < K < 16.5$. Typically, 25,000 stars met this criterion every night. We find that systematic night-to-night color deviations of the ensemble on each footprint are indeed about 2% (as expected), but a significant minority (~15%) of nights exhibit large offsets in color space (see Figure 3), likely due to non-uniform extinction from thin clouds. We applied a form of iterative outlier clipping to select and
Figure 3. Illustration of our procedure to reject suspicious observations. On each night, we calculated the mean color of a large sample of stars in each footprint. Each nightly mean color is plotted as one point for footprints A, B, C, and D (see Figure 2). The dashed blue ellipses enclose the nightly mean colors for observations considered “reliable.” Nights with mean colors outside that region were rejected.

(A color version of this figure is available in the online journal.)

remove anomalous nights from our analysis, leaving only the
nights whose mean colors lay within 3\$\sigma\$ of the outlier-clipped,
time-averaged global mean color.

We also note that the mean color in each footprint is
significantly different. This is because each footprint samples
regions of different visual extinction, as seen in Figure 2.
Instrumental effects are not expected to cause this, as all four
derectors are included in each footprint.

Out of the 124 nights in the original survey, 24 nights were
rejected due to significant deviations in the mean color, leaving
100 nights for our analysis (Figure 1).

3. DISK IDENTIFICATION AND ANALYSIS

Our scientific goal in this project is to detect young stars that
possess disks by their \textit{K}-band excess, to briefly characterize the
variability of these disked stars, and to investigate the stability
of these \textit{K}-band excesses with respect to time.

3.1. The Near-infrared Excess

To detect optically thick disks around young stars, we use
the near-infrared excess criterion developed by Lada & Adams
(1992) and the CTTS locus reported by Meyer et al. (1997). We
consider stars to have a near-infrared excess consistent with an
optically thick disk at \textit{K} band (hereafter referred to simply as a
“\textit{K}-band excess”) if their colors fall significantly to the right of
\textit{JHK} space demarcated by the main-sequence reddening band
and within the CTTS locus. To ensure the disk signatures are
significant, we require the sources to be 4\$\sigma\$ redward of the
reddening vector associated with the reddest, non-disk-bearing
stars (Lada & Adams 1992):

\[
(J - H) \leq 1.714 \times (H - K) \quad (2)
\]

and not more than 4\$\sigma\$ below an empirically derived locus of
the de-reddened location of about 30 CTTS on the near IR
color–color diagram (Meyer et al. 1997):

\[
(J - H) \geq 0.58 \times (H - K) + 0.52. \quad (3)
\]

We show the distribution of stars within \textit{JHK} space in
Figure 4. Underplotted is the locus of main-sequence star
intrinsic colors (Koornneef 1983) as a solid curved line, and
the CTTS locus (Meyer et al. 1997) as a solid straight line that
terminates near (1.0, 1.0) in \textit{JHK} space, corresponding to the
highest accretion rates and smallest disk hole sizes found by
Meyer et al. (1997). Reddening vectors using the extinction law
presented in Rieke & Lebofsky (1985) are plotted out from the
tip of the CTTS locus and the main-sequence curve. Loosely
following Itoh et al. (1996), we partition the inhabited areas of JHK space into three regions: “P,” “D,” and “E,” meaning “photosphere,” “disk,” and “extreme,” respectively, demarcated by these reddening vectors.

Region “P” is inhabited by stars whose NIR emission is dominated by their photosphere. This includes main-sequence stars, giants, and some pre-main-sequence (PMS) stars with a small or negligible K-band excess, including CTTS with small K-band excess, as well as weak T Tauri stars. Single-epoch or time-averaged near-infrared colors cannot distinguish between main-sequence stars and YSOs that lie in this region.

Region “D” is occupied by stars whose NIR emission originates from both a photosphere and a disk, and is consistent with simple models of an accreting, optically thick disk at K band (Meyer et al. 1997). All stars in “D” are definite disk-bearing stars, but disked stars can also occupy regions “P” or “E,” so stars in Region “D” are not a complete sample of disk-bearing stars.

Region “E” contains stars with more excess at K band than can be accounted for by an accreting, geometrically flat disk. These stars will be hereafter referred to as “extreme K-excess stars,” and are expected to be less evolved; their redder colors may be due to emission from a circumstellar envelope. Class I protostars have been found to inhabit this region due to their redder colors (Lada & Adams 1992; Robitaille et al. 2006).

3.2. Study Depth

Our goal is to search for high-confidence PMS stars in Cygnus OB7. We chose a J = 17 brightness cut. This limits errors in J to about 4% with similar errors in H and K for typical stellar colors. This reduced our input catalog to 9200 stars. At the published distance of Cyg OB7 (800 pc; distance modulus μ = 9.5), we can estimate to what stellar mass depth this survey reaches by using PMS isochrones calculated from Siess et al. (2000). For these isochrones, we assume a typical YSO age of 10^6 yr.

The most extinguished YSO in this sample is seen through about 11.5 mag of visual extinction, as estimated by tracing its JHK color back to the CTTS locus and measuring the resulting color offset in units of AV. Assuming a maximum extinction of AV = 12, this survey reaches a nominal depth of 0.3 M⊙, and in less extinguished regions where AV < 7 we should reach down to the hydrogen-burning limit (∼0.1 M⊙). However, since the deepest part of the clouds has not been penetrated by the survey, we have no knowledge of the maximum extinction, nor any depth to which we can be assured we are complete.

3.3. Variability

We identify a star as “variable” if it is seen to change at a level greater than its photometric noise. To quantitatively select stars that are variable in this data set, we use the Stetson variability index S (Stetson 1996; Carpenter et al. 2001). The Stetson index is useful for multi-wavelength simultaneous observations, as it assumes that true variability will cause observations at different wavelengths to rise or fall in unison; its usefulness as a criterion for variability has been established by multiple time-series studies (e.g., Carpenter et al. 2001, 2002; Plavchan et al. 2008; Morales-Calderón et al. 2011). The Stetson index identifies variables even among stars whose variability is comparable to photometric noise without any assumptions about the type of variability seen, except that true variability should cause all channels to vary.

The Stetson index is computed by the following equation:

$$S = \sum_{i=1}^{p} \text{sgn}(P_i) \sqrt{|P_i|},$$

where p is the number of pairs of simultaneous observations of a star. $P_i = \delta_{j(i)}\delta_{k(i)}$ is the product of the relative error of two observations. The relative error is defined as

$$\delta_i = \sqrt{\frac{n}{n-1}} \frac{m_i - \bar{m}}{\sigma_i},$$

for a given band. The size of the bias is $\sqrt{(n - 1)/n}$, where n is the total number of observations contributing to the mean. The second term is the standard error term, where $m_i$ is the measured magnitude, $\bar{m}$ is the mean magnitude, and $\sigma_i$ is the intrinsic error of the individual measurement.

Formally, the Stetson index is designed to identify stars as variable when S > 1 if photometric uncertainties are properly estimated. After applying the error correction described in Section 2.2 and calculating S for all 9200 stars, we find the outlier-clipped mean S value to be 0.2, with the outlier-clipped distribution having a standard deviation of 0.16. Therefore, stars with S ≥ 1 can be considered 5σ variables, and we use S ≥ 1 as our criterion for variability (Figure 5).

All stars brighter than J = 17 with no photometric processing error flags were analyzed for variability. Among these 9200 field stars, we recover ~160 that are variable according to the Stetson index S > 1. The positions of these 160 stars are plotted in Figure 6 as blue squares. In this paper, we focus on the identification and variability characteristics of the disked population; the variability characteristics seen in the non-disked stars will be discussed in Paper II.

3.4. Transient Excesses

If a star exhibits a K-band excess in only a fraction of its observations, then we consider its K-band excess to be transient.
Figure 5. Value of the Stetson index for all 9200 stars. As a function of $H$ magnitude, the distribution is flat with a typical value of about 0.2. The threshold of 1 is about a $4\sigma$ deviation and is exceeded by $\sim 160$ sources.

We do not expect the circumstellar disks of such stars to actually disappear and reappear; rather, the disks in such systems are likely undergoing physical changes that cause their $H - K$ colors to vary back and forth across the line demarcating unambiguous disked stars (region “D”) from ambiguous main-sequence stars (region “P”). Such a change could feasibly be induced by starspots (hot or cool), impulsive heating events such as stellar flares, changes in (inner) disk inclination, local extinction, central hole size, or a varying accretion rate (Bouvier & Bertout 1989; Meyer et al. 1997; Scholz 2012).

To identify and characterize stars with transient $K$-band excess, all data satisfying our quality filter were evaluated against Equations (2) and (3) (see Section 3.1). Stars that showed a $K$-band excess according to these criteria were tallied, producing a table of stars with $K$-band excess in at least one observation, along with the number of times that star was observed and the fraction of nights that the star displayed a $K$-band excess.

We find 528 stars that show a $K$-band excess on at least one night. Given our $4\sigma$ cutoff, we expect a substantial number of single-night false positives due to photometric noise assuming Gaussian statistics in $\sim 920,000$ individual observations. We filter most of these false positives by removing all stars that show a near-infrared excess in fewer than 15% of nights or those that met our measurement criteria on 25 or fewer nights. (See Figure 7, inset.) This cut makes us insensitive to any YSOs who genuinely possess a disk that contributes to a significant $K$-band excess in less than 15% of observations, but it filters out virtually all false positives while allowing us to remain sensitive to stars with small and moderate, but stable, $K$-band excesses.

Figure 6. Spatial distribution of disked and variable stars detected in our analysis. Disked stars are plotted as red circles; variable stars that lack $K$-band excess are plotted as blue squares. Most (90%) disked stars lie within the boundaries of the dark cloud, while variables are found uniformly in the field. (A color version of this figure is available in the online journal.)
These criteria identify 42 disked candidates out of the original 9200 stars. We individually inspected the remaining light curves. If a star was selected by these criteria but (1) had no photometric variability greater than noise (i.e., $S < 1$), (2) had a $JHK$ color trajectory consistent with Gaussian noise around a mean value, and (3) on average, lay on or to the left of the boundary between region “P” and “D” in $JHK$ color space (see Figure 4), then we concluded it was not clearly a CTTS that possessed a $K$-band excess, and removed it from our analysis. Twelve stars were removed this way.

4. RESULTS

After applying these criteria, we recover 30 PMS stars, whose properties we present in Tables 1 and 2. We designate them RWA 1–30.

4.1. Identification of Pre-main-sequence Stars

Based on the method presented in Section 3, we report the identification of 30 YSOs that possess a near-infrared excess consistent with an optically thick disk at $K$ band (a “$K$-band excess”). Of these, five were previously reported as actively accreting YSOs by Aspin et al. (2009) based on $Br\gamma$ emission and other spectral signatures, and one was reported as a possible but unconfirmed YSO; the remaining 24 are new discoveries.

The positions of stars identified with $K$-band excess were checked against the IPAC database; all had a 2MASS counterpart within 0.2 arcsec, except for RWA 28 which had no counterpart within 2″. Two stars were also found as IRAS sources, and seven are AKARI sources. Six stars have been discussed by Aspin et al. (2009). 2MASS photometry corroborates the presence of a $K$-band excess at a significant level for 15 stars. In 10 more, the colors are within 2.5σ of the line separating regions “P” and “D;” so would be considered ambiguous. Four stars have 2MASS colors indicating a significant lack of $K$-band excess. The YSOs CN 3S (RWA 5) and CN 7 (RWA 13) did not show NIR excess at 2MASS epoch but were identified as $K$-band excess sources in these observations; the classification of CN 3S was inconclusive based on its spectrum at 1.4–2.5 μm, but our identification of it as a variable star that possesses a $K$-band excess in these 2008–2009 observations supports its status as a YSO.

With the exception of source CN 3N, we recovered all of the YSOs identified in Aspin et al. (2009) that our search was sensitive to—the only other stars that we missed were either too bright or too faint for our search, or did not show an NIR excess at the time of the 2MASS observations presented in Aspin et al. (2009). The recovery of spectroscopically confirmed young stars in our analysis provides a useful indication that our search is finding real YSOs. However, this is not expected to be a complete sample of all of the young stars in the field for three reasons. First, not all stars that possess an accreting circumstellar disk (Class II stars) are identifiable in a $JHK$ color–color diagram, especially those seen at unfavorable inclination angles, low accretion rates, and/or large inner disk holes (Meyer et al. 1997). Many of these disked stars can be recovered using longer-wavelength observations (Haisch et al. 2000; Lada et al. 2000). Second, the brightness cutoffs used in this study to guarantee reliable photometry exclude the brighter PMS stars and, if they exist, fainter or more substantially extincted ($AV > 7$) low-mass stars. Three stars in this field (CN 3N, Cyg 19, IRAS 15N) have been confirmed as YSOs based on spectroscopic and 2MASS observations (Aspin et al. 2009), but are saturated in the WFCAM images; two confirmed PMS stars (the Braid Star and IRAS 14) are likewise fainter than our cutoff. Finally, in this analysis, we removed all stars that showed any photometric error flags, such as from deblending or bad pixels, that may in fact have useful photometry sufficient to identify a $K$-band excess. Nonetheless, our goal in this paper was not a complete determination of the YSO population, but rather a high-confidence sample of $K$-excess stars whose NIR variability properties could be reliably studied.
4.2. Variability of Pre-main-sequence Stars

Of the 30 YSOs, 28 (93%) are variable at a significant level. Values of $S$ among these stars range from $S = 2$ to $S = 60$. Variable stars typically vary in all three bands, with most stars also showing color variations. J-band rms variability in these stars ranged widely from 0.02 mag to 0.70 mag, peak-to-trough variability ranging from near the photometric noise limit to greater than two magnitudes at $J$ (Table 3). The median $J$-band rms on these variable YSOs was $\sim0.1$ mag, corresponding to a median variability index $S \sim 10$. YSOs varied significantly on all timescales studied. Many varied noticeably from one night to the next. However, the manner of the variations differed among the stars with some showing slow and steady changes, while others were more abrupt. Figure 8 shows the K-band light curves from season 2 for two “typical” stars, RWA 15 and RWA 17. In the case of RWA 15, the global range is about 0.75 mag with night-to-night changes of nearly 30%. The data also seem to have a pattern of peaks and troughs separated by about 10 days (these will be discussed further in Paper II). RWA 17 is a little chaotic in the beginning, but in general, it shows a slow steady
The only two $K$-excess sources which are not identified as variable, RWA 28 and 30, are both at the faintest end of our search near $J = 17$ with the largest photometric uncertainties, typically around 4% at $J = 17$; hence, the 2% variability noted in some brighter stars could go undetected here. RWA 30 is plausibly variable under its photometric noise: its photometric uncertainty is higher than four disked stars. RWA 28's photometric noise causes it to drift near the border between “P” and “D” (in similar fashion to the 12 excluded stars rejected from our source list as described in Section 3.4). It was not excluded from our source list because of these UKIRT observations but show no significant extra-K-excess may arise from warm, infalling circumstellar material that is not in a disk. Indeed, three of these stars are detected as $AKARI$ (9–200 μm) sources, and the brighter two are also $IRAS$ (25–100 μm) sources. Spectral energy distribution (SED) fits support the interpretation that they are less-evolved “Class I” protostars. Two of these stars also give indications of being eruptive variables (S. J. Wolk et al. 2012, in preparation).

### 4.4. Transient NIR Excesses

Of the 25 simple $K$-excess stars, seven vary in color space such that they spend more than 15% of their time in region “P” and would not be detected by near-infrared excess criterion at these epochs (see Figure 7). Figure 9 shows examples of two such stars. Furthermore, three of these seven stars have mean colors that lay in region “P”; these YSOs would be undetected in a search of time-averaged $JHK$ color. Finally, comparison with 2MASS data shows two stars that possess a $K$-band excess in all of these UKIRT observations but show no significant $K_s$-band excess at the 2MASS epoch. These nine stars (nearly 1/3 of our

| Object ID | Observed rms | Color rms | Stetson Index | P/D/E | Transient Excess? |
|-----------|--------------|-----------|---------------|-------|------------------|
|           | $J$          | $H$       | $K$           | $J - H$ | $H - K$ | $S$ (On Average) |
| RW A 1    | 0.473        | 0.379     | 0.278         | 0.099  | 0.103  | 42.96 D           |
| RW A 2    | 0.698        | 0.746     | 0.493         | 0.191  | 0.361  | 59.95 E           |
| RW A 3    | 0.022        | 0.022     | 0.019         | 0.021  | 0.019  | 3.78 D            |
| RW A 4    | 0.086        | 0.085     | 0.087         | 0.028  | 0.041  | 8.59 P            |
| RW A 5    | 0.064        | 0.051     | 0.054         | 0.023  | 0.028  | 7.72 D            |
| RW A 6    | 0.020        | 0.023     | 0.031         | 0.013  | 0.013  | 2.23 D            |
| RW A 7    | 0.241        | 0.276     | 0.295         | 0.059  | 0.068  | 30.81 D           |
| RW A 8    | 0.101        | 0.056     | 0.067         | 0.050  | 0.068  | 2.77 D            |
| RW A 9    | 0.066        | 0.078     | 0.094         | 0.017  | 0.021  | 8.65 D            |
| RW A 10   | 0.028        | 0.032     | 0.043         | 0.016  | 0.021  | 3.33 D            |
| RW A 11   | 0.029        | 0.027     | 0.041         | 0.014  | 0.016  | 3.40 D            |
| RW A 12   | 0.154        | 0.133     | 0.134         | 0.037  | 0.042  | 14.45 D           |
| RW A 13   | 0.093        | 0.087     | 0.091         | 0.030  | 0.042  | 7.95 D            |
| RW A 14   | 0.265        | 0.201     | 0.184         | 0.050  | 0.072  | 25.05 P           |
| RW A 15   | 0.248        | 0.199     | 0.184         | 0.104  | 0.110  | 16.58 E           |
| RW A 16   | 0.127        | 0.112     | 0.091         | 0.028  | 0.048  | 11.50 D           |
| RW A 17   | 0.287        | 0.194     | 0.137         | 0.098  | 0.070  | 24.21 D           |
| RW A 18   | 0.135        | 0.115     | 0.112         | 0.037  | 0.053  | 11.53 D           |
| RW A 19   | 0.135        | 0.182     | 0.145         | 0.067  | 0.057  | 16.15 E           |
| RW A 20   | 0.128        | 0.126     | 0.144         | 0.030  | 0.032  | 10.80 D           |
| RW A 21   | 0.245        | 0.190     | 0.136         | 0.062  | 0.068  | 19.91 D           |
| RW A 22   | 0.062        | 0.067     | 0.093         | 0.019  | 0.034  | 7.59 D            |
| RW A 23   | 0.054        | 0.056     | 0.073         | 0.022  | 0.043  | 6.74 D            |
| RW A 24   | 0.052        | 0.048     | 0.061         | 0.014  | 0.023  | 5.51 D            |
| RW A 25   | 0.075        | 0.055     | 0.067         | 0.032  | 0.042  | 6.50 D            |
| RW A 26   | 0.270        | 0.244     | 0.205         | 0.097  | 0.078  | 15.87 E           |
| RW A 27   | 0.247        | 0.181     | 0.132         | 0.070  | 0.058  | 34.58 P           |
| RW A 28   | 0.035        | 0.019     | 0.015         | 0.036  | 0.025  | 0.18 D            |
| RW A 29   | 0.037        | 0.042     | 0.052         | 0.022  | 0.020  | 3.61 D            |
| RW A 30   | 0.033        | 0.020     | 0.022         | 0.032  | 0.019  | 0.76 E            |

Notes. Typical photometric errors are ~2%. Refer to Table 1 for more details.

* Transient $K$-excess classification based on 2MASS data.

Increase of 25% over the course of a month, followed by a decline.
Figure 9. JHK color trajectories for RW A 4 and 23, two of the nine YSOs identified in this analysis as having a transient near-infrared excess. RW A 4 has a significant near-infrared excess in only 41% of observations, and its time-averaged mean JHK colors lie in region “P.” RW A 23 exhibits a significant NIR excess in 59% of observations. Colored circles indicate the progression of time from early 2008 (dark blue) to late 2009 (dark red). Solid line: CTTS locus. Dashed line: reddening vector. The plus (+) in the bottom-right corner illustrates the typical uncertainty on each individual JHK measurement.

Table 3

| Variability Extrema |
|---------------------|
| Object ID | Median K | ΔJ | ΔK | ΔJ − H | ΔH − K | ΔJ − K |
|------------|----------|----|----|--------|--------|--------|
| RWA 1      | 10.98    | 1.85 | 1.13 | 0.45   | 0.50   | 0.93   |
| RWA 2      | 11.90    | 2.74 | 1.78 | 1.19   | 1.36   | 1.64   |
| RWA 3      | 12.21    | 0.35 | 0.30 | 0.13   | 0.13   | 0.12   |
| RWA 4      | 10.82    | 1.23 | 0.55 | 1.10   | 0.51   | 0.84   |
| RWA 5      | 10.78    | 0.67 | 0.48 | 0.19   | 0.22   | 0.40   |
| RWA 6      | 12.74    | 0.09 | 0.11 | 0.07   | 0.06   | 0.09   |
| RWA 7      | 12.69    | 0.81 | 0.93 | 0.20   | 0.25   | 0.39   |
| RWA 8      | 14.40    | 0.43 | 0.32 | 0.47   | 0.44   | 0.52   |
| RWA 9      | 12.87    | 0.26 | 0.36 | 0.10   | 0.10   | 0.14   |
| RWA 10     | 13.19    | 0.15 | 0.31 | 0.09   | 0.11   | 0.19   |
| RWA 11     | 10.96    | 0.14 | 0.18 | 0.07   | 0.12   | 0.12   |
| RWA 12     | 10.74    | 0.73 | 0.57 | 0.28   | 0.24   | 0.35   |
| RWA 13     | 10.63    | 0.58 | 0.43 | 0.20   | 0.25   | 0.44   |
| RWA 14     | 14.07    | 1.49 | 0.73 | 0.42   | 0.70   | 0.99   |
| RWA 15     | 12.43    | 1.27 | 0.89 | 0.47   | 0.59   | 1.02   |
| RWA 16     | 11.25    | 0.61 | 0.41 | 0.18   | 0.22   | 0.39   |
| RWA 17     | 10.38    | 0.94 | 0.51 | 0.37   | 0.25   | 0.59   |
| RWA 18     | 11.12    | 0.66 | 0.61 | 0.18   | 0.22   | 0.40   |
| RWA 19     | 10.61    | 0.71 | 0.60 | 0.26   | 0.40   | 0.40   |
| RWA 20     | 9.76     | 0.87 | 0.89 | 0.17   | 0.15   | 0.20   |
| RWA 21     | 11.17    | 1.20 | 0.67 | 0.28   | 0.32   | 0.60   |
| RWA 22     | 11.24    | 0.73 | 0.45 | 0.51   | 0.14   | 0.52   |
| RWA 23     | 13.48    | 0.48 | 0.35 | 0.12   | 0.25   | 0.34   |
| RWA 24     | 11.01    | 0.28 | 0.29 | 0.07   | 0.12   | 0.12   |
| RWA 25     | 10.61    | 0.49 | 0.32 | 0.22   | 0.22   | 0.31   |
| RWA 26     | 13.71    | 1.33 | 1.05 | 0.49   | 0.35   | 0.71   |
| RWA 27     | 12.83    | 1.99 | 1.37 | 0.33   | 0.50   | 0.79   |
| RWA 28     | 15.08    | 0.17 | 0.10 | 0.22   | 0.13   | 0.19   |
| RWA 28     | 14.24    | 0.17 | 0.23 | 0.16   | 0.10   | 0.25   |
| RWA 30     | 13.78    | 0.22 | 0.11 | 0.22   | 0.11   | 0.20   |
| Median     | 0.66     | 0.46 | 0.22 | 0.23   | 0.23   | 0.40   |
| Maximum    | 2.74     | 1.78 | 1.19 | 1.36   | 1.36   | 1.64   |
| Minimum    | 0.09     | 0.10 | 0.07 | 0.06   | 0.06   | 0.09   |

sample) have been identified as exhibiting a transient K-band excess.

Among the variable CTTS candidates, many show JHK color–color variability parallel to either the CTTS locus (Meyer et al. 1997) or to a combination of the CTTS locus plus extinction; the two remaining show chaotic behavior in JHK space. In Figure 10, we show the trajectories of the 30 YSOs. The upper-left panel shows the simple-disked variables which show small (<0.5 mag in color) variations which, for the most part, appear to move the star parallel to the main-sequence track or directly along the CTTS locus. The lower-left panel shows the extreme variables, plus a few stars which move parallel to the main sequence. The upper-right panel shows eight trajectories which appear to be indicative of systematic changes in the disk structure. Theoretical models of the CTTS locus (Meyer et al. 1997) derive its slope as owing to different accretion rates, disk hole sizes, and inclination angles. Among the extreme K-excess stars, color-space variability is largely chaotic, but in two cases seems to roughly follow the same pattern of positive color slope that seems to contain contributions from the CTTS track and from the dust reddening track. Of course, there are more than just three parameters (accretion rates, disk hole size, and inclination angle) that determine the final location. By varying 14 parameters in their radiative transfer-based models, Robitaille et al. (2006) calculate 200,000 model SEDs in evolutionary stages. Additional model parameters that appear susceptible to short timescale variations include the effective stellar temperature, which can change due to flares or spots, as well as parameters relating to the disk structure such as the scale height of the inner disk.

While we see stars regularly cross between “P” and “D,” no stars cross between “D” and “E.” Our sample is very small and

4 Robitaille et al. (2006) use “stages” as a theoretical equivalent to the observational “classes,” but the mapping is not exact since stages 0–III cover Classes 0–II. The Class of an object can depend both on stage and, for example, viewing angle.
not cleanly defined in terms of Class. Thus, the results are more open to speculation than interpretation. The YSOs in this sample seem to separate into simple-disked Class II stars that inhabit regions “P” and “D,” and more extreme sources that inhabit region “E.” Models describe all but one of the stars in the “E” region as stage I (Robitaille et al. 2006). There is a paucity of stage I models which occupy the “D” region. This supports speculation that these are Class I sources and we infer from Robitaille et al. (2006) that changes in the various accretion parameters in these stars lead to changes in $J - H$ and $H - K$ color which are mediated by an envelope which is more complex than the thin disk surrounding Class II (Stage III) objects.
5. DISCUSSION

5.1. YSOs are Variable in the Near-infrared

As found in Section 4.2, virtually all of the detected YSOs showing a K-band excess also exhibit near-infrared variability. Importantly, our search did not include variability as a selection criterion except to disambiguate close cases. As noted in Section 3.2, our study is not complete. For example, only 6 of the 12 YSOs discussed in Aspin et al. (2009) were recovered by our study. Furthermore, the stars in our sample were subject to both brightness and faintness cuts to ensure sensitivity to photometric variations on the order of $\sim 2\%$. Nonetheless, it is clear that near-infrared variability is a behavior common to all disked PMS stars bright enough to be measured at $>2\%$ accuracy and possessing a K-band excess. This is consistent with previous NIR variability studies of young stars (Carpenter et al. 2001, 2002) and also consistent with optical studies (Herbst et al. 1994; Briceño et al. 2005).

It seems likely that NIR variability alone could be used to identify young stars, as seen in the optical (e.g., Briceño et al. 2005; Parihar et al. 2009). Parihar et al. (2009) noted that long-term monitoring increased the variability detection rate in the optical by about 50% for periodic variables. We do not find the effect of extended monitoring as pronounced. Of the 30 stars, 26 were found to be variable via the Stetson index in the 26-night first observing season. For the 70+ nights of seasons two and three, the results were 25/30 and 27/30, respectively. Even the inclusion of all three seasons only leads to the detection of 28/30 as variables. Because it was consistently the same stars which were detected as non-variable (RWA 6, 8, 11, 28, and 30), it appears the detection of variability on the longer data sets was not an effect of long-term periodicity, but rather the increase in signal to noise enabled by the additional data. We suspect that using the specific trajectories in JHK color space seen in these 30 stars (Section 4.4) as an additional selection criterion could be useful in detecting disked stars within the “P” portion of the reddening band. This would also be consistent with variability seen in Carpenter et al. (2001) where stars that lack near-infrared excess, but that are associated with the Orion A molecular cloud, are seen to vary at a level significantly higher than field stars. This means that Class III stars should be detected as NIR variables (e.g., Parihar et al. 2009; S. J. Wolk et al. 2012, in preparation).

5.2. On the Variability of the NIR Disk Diagnostic

While other studies have used time-series JHK photometry to investigate young stars with disks, the use of time-averaged NIR colors to identify disked stars (e.g., Carpenter et al. 2002) will still miss some YSOs. In this study, we found three stars whose time-averaged colors showed no infrared excess, but whose variability carried them into region “D” of JHK space in 20%–50% of observations, revealing the presence of a circumstellar disk around these stars. Therefore, simply searching through time-averaged colors is not a sufficient YSO detection technique in time-series observations.

JHK observations are known not to be sensitive to 100% of disks around young stars. The CTTS locus is partially degenerate with reddened main-sequence colors in JHK space (Meyer et al. 1997), and previous infrared studies of young stellar populations show L-band (3.5 $\mu$m) observations can detect disks around $\sim 85\%$ of young stars at age $\sim 0.3$–1 Myr, while JHK-only single-epoch surveys see disks around only $\sim 50\%$–60% of the same sample of stars (Haisch et al. 2000; Lada et al. 2000). We have used our data set to determine the improvement in disk sensitivity for time-series versus single-epoch JHK observations: we summed up the probability of seeing a disk around each of the RWA stars on a given night. The probabilities range from $\sim 18\%$ through 80% with many stars that always showed disks (100%). We then calculated an expectation value of how many disked stars we expect to see on a single night. For our data, this came out to about 25, i.e., on an average night we expect to see 25 of the 30 RWA stars in the “D” or “E” region of the diagram. Multiple observations gave us 30 stars, i.e., an $\sim 20\%$ increase. If our results are typical, then a direct consequence of this study is that 20% ± 5% more disked stars may be found by using multiple JHK observations spread out over about a month, increasing JHK disk sensitivity to roughly 60%–70%. In situations where it is significantly more practical to obtain multiple JHK observations than to acquire L-band imaging or to carry out a spectroscopic survey to investigate accretion, this approach could prove a useful way to simultaneously increase the number of identified circumstellar disks and study variability of young stars.

5.3. On the Underlying Cause for NIR Variability in YSOs

Of the 30 YSOs, 28 are variable at a significant level. As seen in the upper portion of Figure 10, about half of these vary along linear tracks. Some YSOs parallel the CTTS locus of Meyer et al. (1997), while others seem to follow a somewhat steeper slope. As presented in Section 4.4, the aggregate color–domain variability behavior is consistent with changes in mass accretion rate, inner hole size, and inclination angle, in some cases combined with changes in extinction or starspot coverage. Other variability mechanisms exist. These were summarized recently by Scholz et al. (2009). The dominant process can be indicated by the range of magnitude and color changes exhibited by the stars (summarized in Table 3). Among these mechanisms are rotationally modulated changes due to cool spots or hot spots on the stellar surface, extinction changes, and changes in the inner disk. Our goal in this section is to discuss possible factors that may induce the observed variability, not to distinguish among them.

Changes in the overall extinction may be the simplest to imagine. Perhaps induced by the disk, extinction can cause unlimited changes in the apparent flux of the stars. However, such changes should move the star in the direction of the reddening vector. Figure 10 shows no pure examples of this. However, there are many cases where the data appear to move predominantly in this direction (see Figure 10, upper right). RWA 17 and RWA 26 show some of the clearest examples of changes in reddening (Figure 11). However, it is clear from the color–magnitude plots that the observed changes are not due to reddening alone.

Cool spots, like those on the Sun, were first identified as a contributor to the variability of PMS stars in the 1980s (Vrba et al. 1985). Even static stellar spots induce variability because of the rotation of the star. Starspots have been used regularly as a method of measuring stellar periods (e.g., Attridge & Herbst 1992). But there is a limit to the variability cool spots can induce, since the spot is typically only 1000–1500 K cooler than the nominal photosphere. In the J band, the luminosity change is typically <15% (Cohen et al. 2004). The implied color change due to a lower effective temperature is <5%. All the stars in our sample exceed a color range of 9% in J – K (Table 3).

Hot spots, thought to arise from accretion, can cause a larger signal than cool spots since the temperature difference
is typically larger (a factor of two or three hotter than the surrounding photosphere). These can induce signals as high as 1 mag at $J$ and color changes of 40% in $J-K$, even with a filling factor as small as 1% (Scholz et al. 2009). However, over 1/3 of our sample exceeds this color range, so hot spots alone cannot account for this variability. Of the remaining 20 stars, half of them have color changes in excess of 25% in $J-K$, indicative of very active hot spots or a combination of variable hot spot and other effects.

The CTTS locus is derived from models of T Tauri stars with accretion rates spanning two orders of magnitude, disk hole sizes spanning 1–10 $R_\star$, and a full range of observable inclination angles (see Meyer et al. 1997; Robitaille et al. 2006, esp. Figure 3 and Figure 18, respectively). That most of the $IHK$ variability we see in CTTS candidates is focused along this track is evidence that changes in the overall accretion structure—disk inclination, hole size, and accretion rate (the size of the hot spots)—are the primary cause for $IHK$ variability in about half of the stars. This is especially true for the subset of stars in Figure 10 (upper left), which move right along this track, and those in Figure 10 (upper right), which appear to follow a hybrid of this track plus reddening.

Because of the degeneracy between the three parameters (disk inclination, hole size, and accretion rate), it is not possible to easily disentangle the contributions from each of these three parameters. That said, it is easy to imagine ways that they might co-vary. For example, a decreasing (or increasing) inner disk hole size might naturally be simultaneous with an increasing (or decreasing) accretion rate. The line-of-sight inclination of the innermost edge of the disk—not the inclination of the entire disk—might reasonably vary due to warping in response to a strong, misaligned stellar magnetic field and the rotation of the star. Observational and theoretical evidence for warped accretion disks has been provided by Bouvier et al. (2003) and Espaillat et al. (2011). For the data presented here, we do not attempt to model the individual stars to identify the specific mechanisms of variability.

5.4. Individual Variability

In addition to the aggregate color-domain variability just analyzed, we have identified a number of striking patterns of variability in individual stars' light curves. Periodic, quasi-periodic, and eruptive variability is seen among the identified YSOs, mirroring previously studied classes of variable YSOs such as the periodic disk eclipses of AA Tau (Bouvier et al. 2003), and the eruptive, large-scale accretion events of EX Lup and V1118 Ori (Aspin et al. 2010; Audard et al. 2010). Many classes of variability including eclipsing and contact binaries, and "long-period" ($P \sim$ weeks) pulsating stars are seen among the $\sim$160 variable field stars. In one case, one of the disked stars appears to be part of an eclipsing system. A detailed investigation of these variable stars will appear in Paper II.

6. SUMMARY

We observed a star-forming region in the dark cloud L 1003 in Cyg OB7 on more than 100 nights spanning 1.5 years using NIR wide-band photometry. Using the $K$-band excess diagnostic, we found 30 candidate PMS stars, including 25 disked objects (CTTS candidates) and 5 young stars with extreme $K$-band excess (Class I candidates). Among the 25 CTTS candidates, nine (36%) cross the main-sequence reddening band cutoff, indicating that single-epoch observations are insufficient to identify all YSOs that show $K$-band excess. Even time-series observations may miss some stars if they only select using time-averaged $JHK$ colors. Additionally, the pattern of variability in color space seen in the variable CTTS candidates is a strong indication that NIR variability in young stars arises from a combination of variable extinction and changes in the inner accretion disk. While some of the variability may be due to rotationally modulated starspots, other possibilities include changes in accretion rate, inner hole size, and/or disk inclination. None of the extreme $K$-band excess stars are seen to cross into the "disked" region of the NIR color–color space.

To summarize our results:

1. The 30 PMS stars discussed in this paper include 24 newly identified YSOs.
2. Overall, >90% of the young stars with disks are variable. Over 80% are variable on a timescale of about 1 month.
3. YSOs can be separated into "simple-disk" or "extreme" classes based on degree of $K$-band excess.
4. 36% of "simple-disk" $K$-band excess sources have a transient $K$-band excess.
5. The color behavior of many of the "simple-disk" YSOs is consistent with changes in disk geometry and/or accretion rate.

In this paper, we have presented an analysis of a unique data set containing multi-season NIR monitoring for variability of young stars. A follow-up paper (S. J. Wolk et al. 2012, in preparation) will discuss the variability of field stars, and a phenomenological categorization of NIR variability seen in YSOs. Further observations, at both IR and X-ray wavelengths, are planned to better characterize the overall PMS population in this field.

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