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Simultaneous Visible and Near-Infrared Variability of Classical T Tauri Stars

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Abstract. Temporal structural changes of protoplanetary disks surrounding T Tauri stars (TTSs) can cause magnitude variations of TTSs. On the other hand, variability is also expected due to cool spots and/or hot spots on the surface of the star, thus it is important to distinguish the causes of the observed variability. Our sample consists of 23 TTSs (22 classical T Tauri stars, 1 weak-lined T Tauri star) and 4 Herbig Ae/Be stars. The observations were performed over a period of about 3 months in the V, J, and K_S band, simultaneously. We detected variability for all stars in the three bands (>0.05 mag in V, >0.09 mag in J, >0.09 mag in K_S). Color-magnitude relations obtained between V, J, and K_S bands suggest that stellar spots are not the only cause of variability for most of our targets. In addition, the data implies that six stellar systems contain larger grains than in the interstellar medium if the variability is only caused by extinction due to circumstellar matter.

Keywords. stars: pre-main-sequence, (stars:) planetary systems: protoplanetary disks, stars: variables: other.

1. Sample, Observations, and Data Reduction

Observations were carried out using TRISPEC, a simultaneous optical and near-infrared imager mounted on the *Kanata* telescope of Hiroshima University. We obtained photometric data in the V, J, and K_S band for 22 CTTSs, 1 WTTS, and 4 Herbig Ae/Be stars between November 2007 and February 2008, with a coverage of at least one observation every five days.

Magnitudes were measured by aperture photometry relative to the comparison stars located in the same field of view ($7\overset{\prime}{.}0 \times 7\overset{\prime}{.}0$). The photometric accuracy spans from 0.03 to 0.05 mag in the three bands.

2. Results

We detected significant variability in all three bands. The amplitude of the variability ranged 0.05–3.14 mag in V, 0.09–1.58 mag in J, and 0.09–0.75 mag in K_S.

Periodicity analysis. Fourteen out of 27 stars were analyzed for periodicity in the V band. Six stars showed quasi-periodic variability with periods between 3.6 and 10 days.

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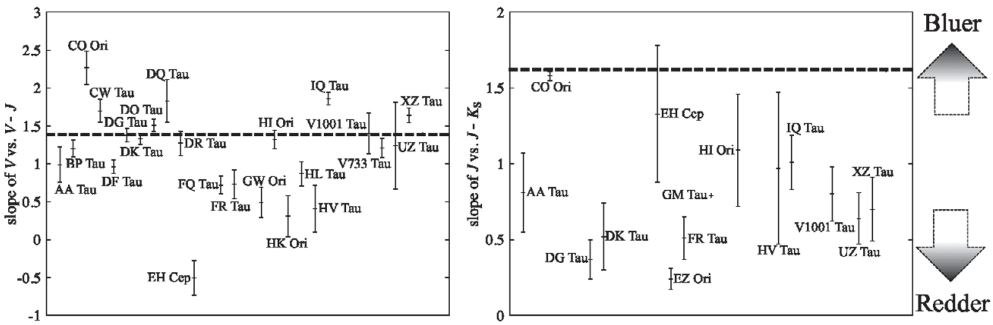

Figure 1. Slopes of variation in the color-magnitude diagrams. Left: V vs. $V - J$, right: J vs. $J - K_S$. The dashed lines represent extinction by dust grains of $R_V = 3.1$. (Some stars are not included in this plot because they did not show the relation expressed by a linear function in the color-magnitude diagrams.)

Color-magnitude diagram. Targets appear to be redder when they are dimmer in V (J). Excluding data with errors larger than 0.2 mag, we performed least-squares fitting for the color-magnitude variations (Fig. 1). First, we calculated the slope of variation on J vs. $J - K_S$ based on a scenario that the cause of the variability is a cool spot (T_{spot} = 1000–3500 K, $Area_{spot}/Area_{star}$ = 0.05–0.5) or a hot spot (T_{spot} = 4500–10000 K, $Area_{spot}/Area_{star}$ = 0.01–0.05), and found that it is larger than 2.0. This is inconsistent with our observations (Fig. 1 right), suggesting that stellar spots are not the only cause of variability for most of our targets. Another possible cause is variable extinction by circumstellar matter. Slopes of V vs. $V - J$ for CO Ori, CW Tau, DO Tau, DQ Tau, IQ Tau, and XZ Tau are larger than 1.39 ($R_V = 3.1$, Mathis, 1990), implying grain growth occurred in these systems. However the slope of J vs. $J - K_S$ is lower than in the case of pure extinction. While extinction plays a role in determining the K_S flux, the dominant factor in this wavelength range is the near-infrared excess from the disk. Taking this into account it is possible to explain the observations by assuming that the near-infrared excess itself is variant over time.

Disk Modeling. Assuming a protoplanetary disk with a warp, we used the Monte Carlo radiative transfer code of Whitney *et al.* (2003a, 2003b) for investigating the relation between extinction and the thermal radiation from the disk. The magnitude varies due to disk rotation. Stellar mass, radius (= R_{star}), and temperature, as well as the mass, inner and outer radius of the disk were taken from Bouvier *et al.* (1999). The scale height of the warp (= w) was varied between 0.5 and 2.7 R_{star}. We found that a larger w yields a larger slope of V vs. $V - J$ for a disk with an inclination of 73 degrees. A higher warp leads to a shift toward bluer colors which can be explained by a shadow cast onto the region where J flux is dominant. On the other hand, the slope of J vs. $J - K_S$ becomes smaller, because infrared excess from the warp increased. However, slopes predicted from any of the warp models were not consistent with our observations which showed smaller slopes. We therefore conclude that additional near-infrared emission sources are needed.

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