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Results of an International Monitoring Campaign on the Peculiar Object KH 15D

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Abstract. Results of an international campaign to monitor the unique pre-main sequence eclipsing variable KH 15D are reported. Excellent coverage was achieved on three eclipses during the last season. It is interesting that the first and last of these were more similar in shape, while the middle one was somewhat different. This raises the possibility that the true period of the system is twice the interval between eclipses (48.36 days). Possible models for the system are briefly discussed.

1. Introduction

KH 15D is a weak-lined T Tauri star (WTTS) that undergoes an amazing eclipse every 48.36 days. Over a time span of about 4 days it fades from its normal brightness of I=14.5 mag to about I=18, where it stays for about 18 days before re-emerging, again on a $\sim$ 4 day time scale. The minimum is not precisely flat but shows structure on hourly time scales as well as a general brightening of variable amount near the time of central eclipse. The star was discovered by Kearns et al. (1997); further observations are reported by Kearns & Herbst (1998) and Hamilton et al. (2001). The eclipses are strictly periodic but the precise shape of the light curve changes slightly from eclipse to eclipse and has evolved more dramatically over the six years that we have been following the star.

While a detailed understanding of this unique object is still emerging, some things are already clear. Out of eclipse, KH 15D looks like an ordinary low-mass (0.5-1 $M_\odot$), pre-main sequence (PMS) star at an age of 2-4 My (Sung, Bessel & Lee 1997). It has a spectral type of K7, weak Hα emission ($\sim$ 2 Å EW) and strong LiI absorption. It has ordinary colors for its spectral type, with little reddening and no infrared excess or mm emission. In short, it looks exactly like the other WTTSs in NGC 2264, which are generally recognized as solar-like stars in their early PMS phase and are excellent candidates to harbor forming solar systems, some presumably analogous to our own. An international campaign was organized to follow the star during the 2001/2002 observing season, with emphasis on the eclipse in Dec., 2001. Some results of that campaign are described here. Further details are reported by Herbst et al. (2002).

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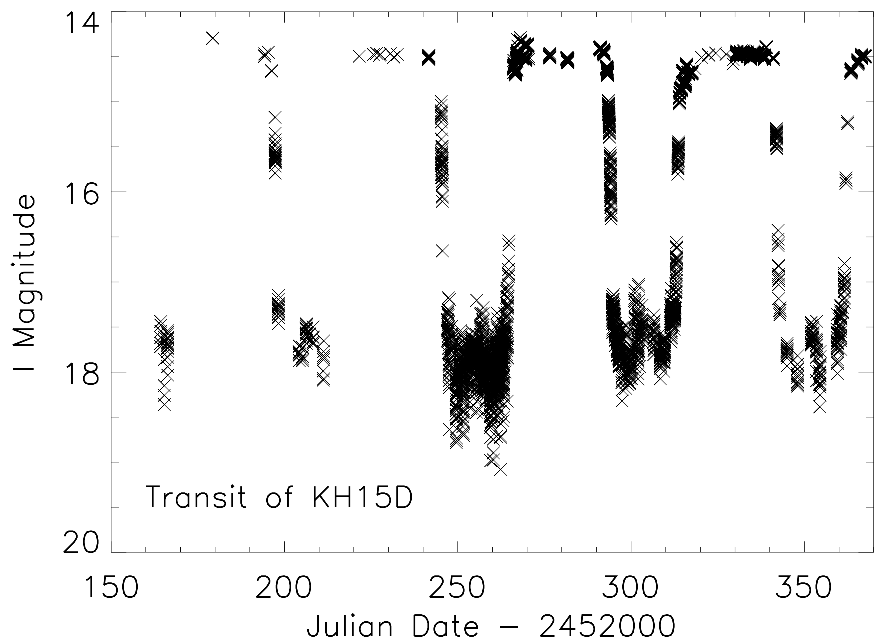

Figure 1. The light curve of KH 15D during the 01/02 observing season.

2. Observations

The participants in the campaign and the observing sites were as follows: F. Vrba (Flagstaff Station of the U.S. Naval Obs.), M. Ibrahimov (Maidanak Obs. in Uzbekistan), C. Bailer-Jones, R. Mundt, M. Lamm, A. Scholz and A. Riffeser (European Southern Obs. in Chile and Calar Alto Obs. in Spain), T. Mazeh (Wise Obs. in Israel), K. Haisch (Infrared Telescope Facility in Hawaii), Z. Webster (Owens Valley Radio Observatory millimetre-wave array in California) T. Balonek (campus telescope at Colgate University in New York). In addition, the authors, along with E. Williams and A. Rhodes obtained data at Van Vleck Observatory, on the campus of Wesleyan University in Connecticut and at Kitt Peak National Observatory in Arizona. Again, we note that a more complete description of the observing strategy and results is given by Herbst et al. (2002).

3. Results and Models

The light curve obtained from this study is shown in Fig. 1. It may be seen that the duty cycle for an eclipse is currently $\sim$ 40% of the orbital cycle, which is much too large for any stellar eclipsing object; the eclipse events must be caused by an extended distribution of non-luminous matter in the close vicinity of the star. There is also no spectral type change and little systematic color change during an eclipse, although at minimum light the median color in V-I is about

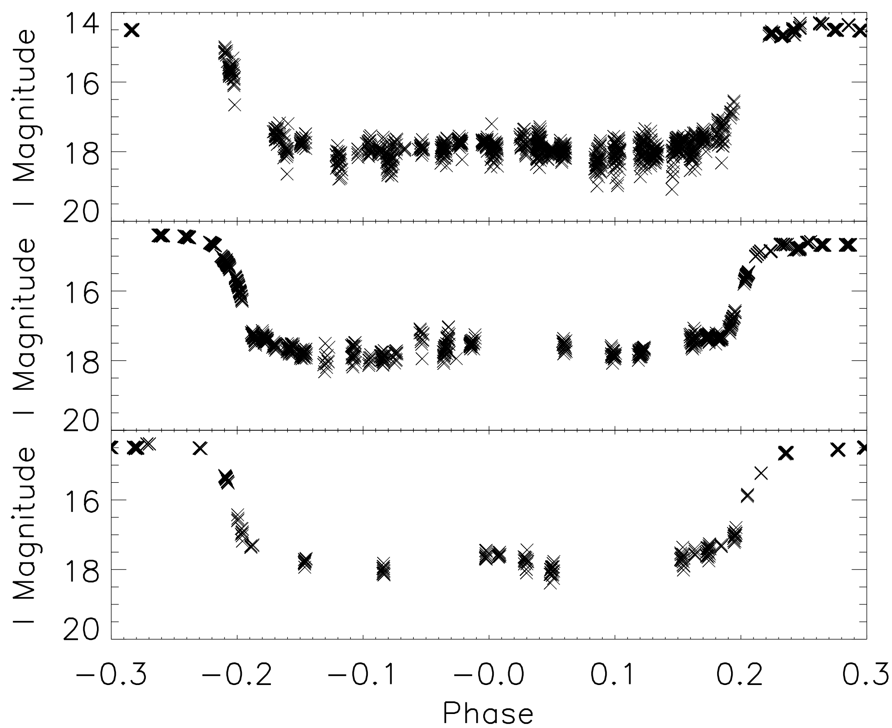

Figure 2. The last three eclipses of the 01/02 observing season are shown enlarged.

0.1 mag bluer than at maximum (Hamilton et al. 2001; Herbst et al. 2002). A "knife edge" advancing (or retreating) across the face of a limb-darkened K7 star describes the shape of ingress (and egress) quite well. We believe that the unique property of KH 15D is that it is oriented in just the right way to be eclipsed by structured circumstellar matter as close as 0.2-0.3 AU to the star.

An intriguing result from this campaign is that the eclipses do not always have the same over-all shape or symmetry. In Fig. 2 we show enlargements of the three eclipses during the 2001/2002 season for which we obtained good photometric coverage. It is apparent that the first and last of these eclipses (shown in the top and bottom panels of the figure, respectively) look about the same, while the middle eclipse of the set has a somewhat different shape. This raises the possibility that the true period for this object is not the 48.36 days between eclipses, but the 96.7 day period between *alternate* eclipses. Obviously, this needs to be confirmed by detailed observations in subsequent seasons. Having only three well-sampled eclipses is not enough for any firm conclusion on this matter.

Models of KH 15D fall into two categories, depending on whether the K7 star is the dominant mass in the system or not. So far, we do not have sufficient radial velocity data to say for sure whether it is or is not. If it is, then the basic model involves occulting matter orbiting the star. In this case, the eclipse is caused by a feature or features orbiting the K7 star with a period of 48 (or 97) days, so we can apply Kepler's third law to derive a semi-major axis for the orbit of the occulting matter of 0.21 (or 0.32 AU). Therefore, if this model is correct, we are probing a region of the circumstellar environment closer to the star than Mercury is to the Sun. The occulting feature appears to have a very sharp edge, such that a knife-edge model fits the data well. However, the transit time for an object orbiting at 0.2-0.3 AU from the K7 star is only $\sim$ 0.5 d, much less than the time of ingress or egress ($\sim$ 2-2.5 d). Therefore, if the star is eclipsed by a sharp-edged orbiting feature, its occulting edge must be inclined by about 15^o to its direction of motion. Such an eclipsing structure could be caused by density waves or a corrugation of a disk driven by an embedded planet or brown dwarf, as Bryden et al. (2000), for example, have modeled.

If, on the other hand, KH 15D is a binary star system and the unseen component has a mass comparable to or larger than the K7 star, then the observed phenomena could be caused wholly or in part by the motion of the visible star with respect to a circumbinary disk. In this case, the bright state would correspond to the K7 star peeking above the obscuration and, possibly alternately below it. Such a scenario might even explain the "mirror image" symmetry of alternate eclipses seen in Fig. 2. If the star passed behind a structured occulting screen alternately from two different directions, one might get the sort of behavior observed. A high precision radial velocity study is clearly required to make progress on understanding this unique object. Further information on this object may be obtained from the World Wide Web site at: http//www.astro.wesleyan.edu/kh15d.

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