SHINING THROUGH THE FOG: POLARIZATION AND THE ORIGIN OF THE MID-ECLIPSE LIGHT OF KH 15D.

Jennifer L. Hoffman, Department of Astronomy, University of California at Berkeley,
601 Campbell Hall, Berkeley, CA 94720-3411, USA (jhoffman@astro.berkeley.edu).

Introduction: KH 15D is an unusual variable star in the young cluster NGC 2264. Its light curve shows a 48-day period and features stellar eclipses that have varied in depth and shape over the past century [1–4]. Recent studies suggest that the object is a pre–main sequence binary system surrounded by a precessing circumbinary disk inclined to our line of sight [5–7]. The peculiar eclipse behavior results from occultation of varying portions of the stellar orbits by the opaque edge of the disk. At the current mid-eclipse phase, when both stars are occulted in this model, KH 15D still emits a small amount of flux, ~5% of its maximum light [8]. The fact that this light is ~2% polarized [9] suggests that it arises from scattering of incident starlight either from the circumbinary disk or from nebular or coronal regions surrounding one or both of the stars [10–11]. These scenarios should produce distinct polarimetric signatures. I have used a multiple-scattering radiative transfer code to calculate the flux and polarization contributions of these scenarios and to investigate the effects of each on the mid-eclipse brightness and polarization of the system. In this poster, I will present the results of this project, assess the likely relative contributions of disk-like and nebular/coronal scattering regions to the mid-eclipse light of KH 15D, and predict the polarimetric signatures that should be observed at other phases in each case. Because the polarization variations of a binary-disk system can strongly constrain the characteristics of its scattering regions [12], further polarimetric observations of KH 15D will provide an invaluable source of information about the circumstellar environment of this important young binary.

Previous polarimetric modeling results: There are two potential mechanisms by which mid-eclipse light originating from the stars may become polarized by the disk. The light may scatter once off the far face of the disk before reaching the observer, or it may travel through the disk (Fig. 1). Models of the first scenario, assuming single scattering from large grains with an isotropic phase function and an albedo of unity, cannot reproduce the mid-eclipse light (Fig. 2; [13]). This suggests that the disk must have a very large and physically implausible warp in order for such a “reflective” scenario to be the only cause of the mid-eclipse light [13].

In preliminary radiative transfer models [13], I considered the scenario in which mid-eclipse light reaches us by multiply scattering through a disk of electrons. Although [9] consider electron scattering an unlikely mechanism for the opacity in the KH 15D disk, their argument assumes a scattering region that is nearly spherically symmetric. Flattened electron-scattering disks can produce polarization of up to a few percent, depending on the scattering albedo [14]. In the case of KH 15D, I assumed a disk with an electron density varying as r^{-4} and linearly with polar angle [15]. For simplicity, I considered a single central point source of light. For various disk opening angles, I varied the scattering albedo and total optical depth until the ratio of emergent light at a viewing angle of 90° (corresponding to an out-of-eclipse phase) to that at 0° (fully eclipsed) matched the 5% observed fractional eclipse depth [8]. Mid-eclipse polarization for the resulting models ranged from 0.5% to 12%, with larger values for larger albedos and wider opening angles but only weak dependence on optical depth (Fig. 3). I concluded that an electron-scattering disk with a small opening angle could reproduce the observed ~2% mid-eclipse polarization [9] with intermediate optical depths ($\tau < 10$) and low scattering albedos ($a < 0.4$) [13]. No additional scattering regions were required to match this polarization magnitude.

Current work: Since published polarimetry exists for only two epochs, one in eclipse and one out of eclipse [9], these models are not well constrained by observational data. The fact that a disk model of the sort I investigated in [13] *could* produce the observed polarization at mid-eclipse does not imply that it is the *only* possible solution. In fact, as models based on photometry and spectroscopy become more sophisticated, new propositions are emerging for the source of the scattered light at mid-eclipse. One such suggestion proposes that the blue peaks seen at phases ±0.17 in the color curve are caused by a hot, dense component (perhaps an extended chromosphere or accretion column) associated with one of the stars [10]. Another possibility, based on analysis of the light curves during eclipse ingress and egress and the photometric reversal during eclipse, is that the scattering region could have the form of a low-density “nebula” or “corona” surrounding each star [11]. In this poster, I will present the polarization predictions of Monte Carlo numerical radiative-transfer models of these scenarios and compare them with previous and updated disk results. In particular, the behavior of the polarized light during eclipse ingress and egress should help distinguish between different scenarios for the geometry of the scattering region. I will use these results to argue for future polarimetric observations of KH 15D and to show how such observations can distinguish between model scenarios to reveal the unseen structure of this enigmatic binary system.

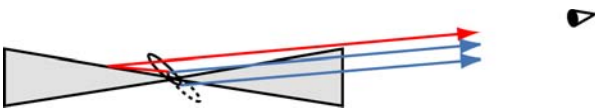

Fig. 1. Schematic diagram showing different paths by which light from one or both stars may reach us during mid-eclipse. The red arrow illustrates the "reflective" scenario, in which light scatters once off the far disk face before reaching the observer. The blue arrows represent the scenario in which light reaches the observer after scattering through the disk. Both scenarios may create polarization.

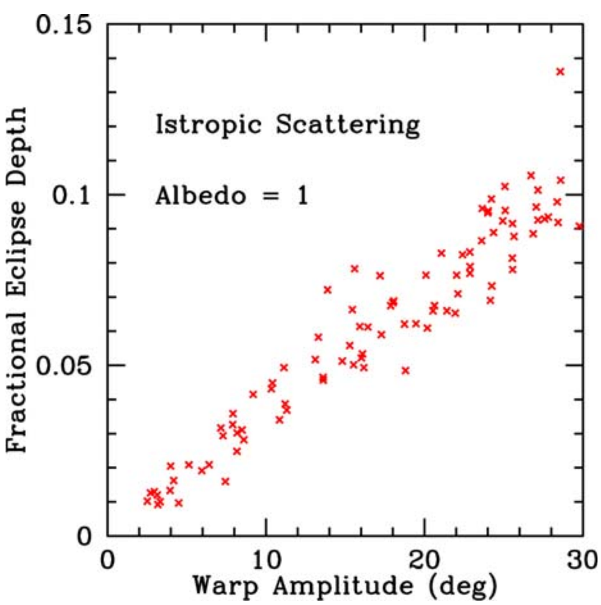

Fig. 2, from [13]. Eclipse depths resulting from a model of the "reflective" scenario, assuming large grains and an isotropic scattering phase function. Even for the maximum possible albedo and very large warp amplitudes shown here, this model cannot reproduce the observed fractional eclipse depth of ~5% [8].

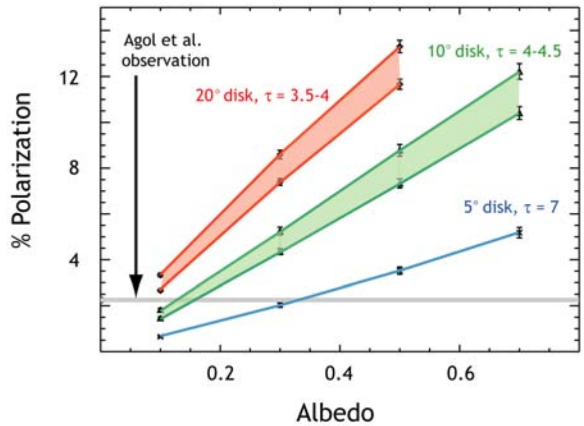

Fig. 3., from [13]. Polarization results from numerical models of mid-eclipse light reaching the observer after multiple scattering through disks with several different values of optical depth and albedo. Scattering is by electrons whose density varies as r^{-4} and θ. All models shown reproduce the correct eclipse depth in the total flux; most reproduce [9]'s observed polarization at mid-eclipse for intermediate optical depths and low albedos.

References: [1] Kearns, K. E. & Herbst, W. (1998) AJ, *116*, 261. [2] Winn, J. N., Garnavich, P. M., Stanek, K. Z., & Sasselov, D. D. (2003) ApJ, *593*, L131. [3] Johnson, J. A. & Winn, J. N. (2004) AJ, *127*, 2344. [4] Johnson, J. A. et al. (2005) AJ, *129*, 1978. [5] Winn, J. N. et al. (2004) ApJ, *603*, L45. [6] Chiang, E. I. & Murray-Clay, R. A. (2004) ApJ, *607*, 913. [7] Johnson, J. A., et al. (2004) AJ, *128*, 1265. [8] Herbst, W. et al. (2002) PASP, *114*, 1167. [9] Agol, E., Barth, A. J., Wolf, S., & Charbonneau, D. (2004) ApJ, *600*, 781. [10] Hamilton, C. M. et al. (2005), astro-ph/0507578. [11] Winn, J. N. et al. (2005) in prep. [12] Hoffman, J. L., Whitney, B. A, & Nordsieck, K. H. (2003) ApJ, *598*, 572. [13] Ford, E. B., Hoffman, J. L. 2005, & Chiang, E. I. (2005) AAS, *205*, 1612. [14] Wood, K., Bjorkman, J. E., Whitney, B., & Code, A. (1996) ApJ, *461*, 847. [15] Ford, E. B., priv. comm.