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Evidence for a Precessing Disk in the Extreme Binary ϵ Aurigae

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Abstract. Among the longest known eclipse durations and binary periods is that of the star ϵ Aurigae, which exhibits 2-year long eclipses every 27.1 years. Oddly, the nature of the secondary in the system continues to elude ready identification. In 1965, Huang proposed a massive disk as the eclipsing body, and study of the 1984 eclipse led Lissauer and Backman to suggest an embedded B star binary in the disk to maintain it. A collaboration of observers allows me to present recent optical photometry and spectroscopy, near-IR spectroscopy and Spitzer space telescope IRS and MIPS observations of ϵ Aurigae as it approaches its next eclipse. These data argue for current detectability of the embedded binary, and precession of the disk axis, suggesting a radical change is possible for the next mid-eclipse brightening. An international monitoring campaign for the 2009-2011 is being organized, and participation invited via website http://www.du.edu/~rstencel/epsaur.htm .

Keywords. stars: epsilon Aur, binaries, eclipsing, supergiant, circumstellar matter, accretion disks, infrared, photometry, polarimetry, interferometry

1. Introduction

The prevailing hypothesis concerning the nature of the long period eclipsing binary HD 31964 (ϵ Aurigae) features a (contact?) B star binary embedded in a massive, 20 AU diameter cold disk [475K], all of which orbits an F-type supergiant star (Carroll et al. 1991). Total system mass is approximately 29 solar masses, with an orbital separation of 27.6 AU and period of 27.1 years. Flat-bottomed eclipses of two years duration and 0.7 mag depth optically suggest that the cold disk covers half the surface area of the F star (Huang, 1965). The next eclipse is predicted to start in 2009. Kemp et al. (1986) analyzed polarimetry of the 1984 eclipse and argued that the disk is inclined 2 to 5 degrees from its orbital plane. Together with a central eclipse brightening that has varied over the past 3 eclipse events, disk tilt could signal precession of its orientation. Disk precession could also affect view-ability of the disk-centered B-star binary. New observations are being sought to test this possibility.

Key to testing this model is assembly of an observational spectral energy distribution (SED). In addition to UBV photometry described below, recent non-eclipse near and mid-IR spectra have been obtained with MIMIR and Spitzer instruments, respectively. These fluxes seem at odds with IRAS photometry reported by Backman and Gillett (1985) during the last eclipse. The prominent 475K IR excess appears to have been replaced by a hydrogen emission line source and power law extension of the mid-IR spectrum.

2. Recent Observations

Optical photometry in the UBV system has been resumed by J. Hopkins at Hopkins Phoenix Observatory as of 2003 (www.hposoft.com/Astro/PEP.html), which sup-

Table 1. SPITZER Space Telescope observations of ϵ Aur

Date	MJD	Instrument	Mode
2005 Sep 25	53639	MIPS	PHOT and SED
2005 Oct 19	53663	IRS	Stare/HiRes
2006 Feb 23	53790	MIPS	PHOT and SED
2006 Mar 17	53812	IRS	Stare/HiRes

plements his 1982-88 coverage of the past eclipse. From these recent UBV photometry, he found the mean V magnitude was 3.05 with a cyclic variation range of 0.132 magnitude, having a basic period of 66.2 days (based on Peranso/ANOVA software analysis). V band also shows a brightening trend over the 2003-2006 seasons. Low amplitude variability of ϵ Aur out of eclipse has long been known (Shapley 1928), and its detectability may be orbital phase dependent. Mean B magnitude is 3.625 with a variation of 0.175 magnitude and similar period. Mean U band is 3.725 with a variation of 0.35 magnitude and similar period. The B-V and U-B colors both show a redder trend, ranging from 0.54 to 0.58 magnitude and 0.10 to 0.14 magnitude, respectively, corresponding to F8 supergiant colors, comparable to SED fitting results. These colors are significantly redder than the canonical F0 I spectral type assigned ϵ Aur, and may represent spectral evolution during the 20th century.

A minor revolution in CCD cameras and small spectrometers allows accomplished amateurs to obtain spectra with modest telescopes. Both Mais and Schanne have reported variations in Hα profiles, including transient double peaked emission wings, in spectra obtained during 2004-2006 (cf. Hopkins 2006). Mais utilizes an SBIG spectrometer/ST10XME on a C-14/Paramount, yielding 0.4 Åper pixel resolution. Schanne's home-built spectrometer on a 5 inch Maksutov-Newtonian achieves somewhat higher resolution. Schanne reports variation of the intensities of the wings. The red wing is increasing, while the blue one is decreasing with time, during spring 2005.

New JHKLM region spectra were obtained with the 1-5 micron MIMIR instrument on 20 January 2006 [MJD 53756] by D. Clemens and A. Pinnick with the 1.83 m Perkins telescope near Flagstaff, Arizona, with NSF PREST program sponsorship. The spectra were obtained during an interval when V band magnitude was approaching a local minimum in brightness. The spectra show many lines of neutral hydrogen, including Brα [5-4, weakly in emission], Pfγ [5-8, in absorption] and many of the Hu series [6-n, strongly in absorption] between 3.35 and 4.15 microns. Unidentified emission features are seen at 3.87, 3.89 and 3.99 microns.

Clemens noted that hydrogen lines dominate the spectra, with helium and metals absent. Brackettα is in emission, all others are in absorption - including the rest of the Brackett series, the Humphreys series, and the maybe an occasional Pfund line. The only stars in a paper by Hanson, Conti and Rieke (1996) that show Brα emission without He I 2.05 micron emission are X-ray binary stars (mass transfer systems). Clemens reports that Paschenβ is absent, which is normally a very strong line in other sources (in absorption in stars and emission in PN, both from prior Mimir observations). The Paβ line could be optically thick (perhaps self-absorbed, like Lyα).

Under Spitzer cycle 2 observing time, I obtained IRS high resolution mid-IR spectra and MIPS photometry of ϵ Aur on the following dates (Table 1): The spectra show a continuum with weak emission lines, consistent with the MIMIR spectra. The MIPS photometry reveals some variation between observational epochs. These data are being combined to establish an overall spectral energy distribution. A complete report is being prepared for publication elsewhere.

Table 2. Predicted contact times for the 2009-2011 eclipse of ϵ Aur

Contact	MJD	Date	Duration
First	55050	2009 Aug 06	137 d
Second	55187	2009 Dec 21	223 d
Mid	55410	2010 Jul 09	...
Third	55633	2011 Mar 11	223 d
Fourth	55897	2011 May 15	64 d

While the opaque cold disk remains the working hypothesis to explain the eclipse behavior and apparent infrared excess during the last eclipse, Dana Backman (private communication) has been advocating a bright spot model to account for behavior between eclipses - namely, a heated sub-stellar point on the disk, facing the F supergiant. Visibility of this bright spot will vary with orbital phase, and possibly other factors. Details regarding these sets of observations, and updates, can be found at the webpage mentioned below.

3. An international campaign for the 2009-11 eclipse

Given the remarkable suite of astronomical facilities on earth and in orbit, it should be feasible to obtain excellent multi-wavelength coverage of the upcoming eclipse phenomena. Table 2 shows the predicted times of eclipse, based on analysis of previous eclipsing timings, by J. Hopkins (private communication). We have set up a campaign website to enlist collaborators and collate results, much as we did for the prior eclipse cycle (Stencel 1985). The website is: http://www.du.edu/∼rstencel/epsaur.htm, and we invite interested persons to share in this multi-generational adventure.

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List of Objects