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PHOTOMETRY OF CAPELLA (Dec 1981 TO Apr 1990)

Capella (= α Aurigae = BS 1708 = Gliese 194) is part of a multiple star system, the two brightest components of which make up a spectroscopic binary composed of a G6 III and an F9 III star (Ayres and Linsky 1980). According to Fekel *et al.* (1986, on p. 570), the G6 star has a rotational rate of v sin i = 5 ± 2 km/sec, while the F9 star has v sin i = 36 ± 3 km/sec.

The orbit of the bright Capella components has been investigated by interferometric methods. Bagnuolo and Hartkopf (1989) find an orbital period of 104.02 days and an inclination of the orbit of 136.6 degrees. (If the position angle increases with time the inclination is between 0 and 90 degrees, where 0 degrees means we view the orbit face on. By convention, if the position angle decreases with time $90 < i < 180$.) Assuming that the rotational axes of the Capella components are perpendicular to the plane of their orbit, angle i for v sin i is 46.6 degrees.

Ayres, Marstad, and Linsky (1981) derive apparent angular diameters of 8.81 and 5.00 milli-arcsec for the G6 and F9 stars, respectively. Adopting a parallax of 0.0768 arcsec for Capella (Bagnuolo and Hartkopf 1989, quoting van Altena data), we obtain diameters of 11.5 and 7.0 D_{Sun} for the G6 and F9 stars. Given the observed values of v sin i and i = 46.6 degrees, we can obtain expected rotational periods for the stars. For the F9 star we obtain P_{rot} = 7.2 ± 0.6 days. For the G6 star we obtain a "best guess" value of 84 days, but the large relative error of its v sin i allows P_{rot} to be anywhere between 60 and 130 days. Given the semi-major axis orbit size of 0.05523 arcsec (Bagnuolo and Hartkopf 1989), equivalent to 155 R_{Sun}, we note that the two stars are separated by many times their diameters. (Tidal distortions of the two stars, giving rise to different projected surface areas, would result in variability of about 0.003 mag, much smaller than our observational error.)

From ultraviolet observations Ayres and Linsky (1980) indicate that the F star is chromospherically active.

Consequently, one might expect it to exhibit star spots, and as it rotates there could be measurable light variability. Hoffleit and Jaschek (1982) give ΔV = 0.03 for Capella's variability, but no further details are given.

Recently, Shcherbakov *et al.* (1990) have found that the equivalent width of the He 10830 Å line of Capella varies with a period of 104 days, equal to that of the orbital period. They attribute this to the G9 star. This is to say that the *source of chromospheric helium absorption* on the G9 star faces the F6 star at all times, but it is possible that the G6 star could be rotating at a somewhat different rate.

In this paper we present photometry of Capella that can be found in IAU file 218 of unpublished photometry of variable stars (Breger *et al.* 1990). This file contains photometry of Capella vs. BS 1668 (V = 5.68, B-V = 0.42; Hoffleit and Jaschek 1982), obtained by Guinan using the Villanova 38-cm reflector and narrow-band b, y, and r filters at effective wavelengths of 4530, 5500, and 6600 Å, respectively. He also employed a neutral density filter which attenuated the b-band light of Capella by 5.262 mag, the y-band light by 5.200 mag, and the r-band light by 5.150 mag. His data are shown in Fig. 1. We note that at times Capella *is* constant: Guinan's r- and b-band data from 5 nights in Dec 1981 exhibited no variations greater than ±0.005 mag. Guinan believes that the fading by a few hundredths of a magnitude after JD 2447000, most notable in the r-band data, is real, rather than due to any instrumental effect such as the alignment of his neutral density filter.

File 218 also contains broad-band differential V magnitudes and B-V colors of Capella vs. 9 Aur and Capella vs. BS 1668. A small sample of previous photometry of Capella vs. 9 Aur (Krisciunas 1984) showed no significant variations from Feb 1980 to Mar 1981, but more recently we have found that 9 Aur exhibits variability of ΔV ≈ 0.04 to 0.08 with a period of 37.5 ± 2.0 days (Krisciunas and Guinan 1990) and suspected short-term periodic variability as rapid as 34 minutes. Krisciunas' photometry shown here was primarily obtained at the 2800-m elevation of Mauna Kea, Hawaii, using a 15-cm reflector and a photometer employing an uncooled RCA 931A photomultiplier tube, standard UBV filters, a DC amplifier, and a strip chart recorder. Beginning in January 1989 (JD 2447545) Krisciunas made his observations of Capella, 9 Aur, and BS 1668 using a Hartmann screen on the front of the telescope, which diminished the stars' light by

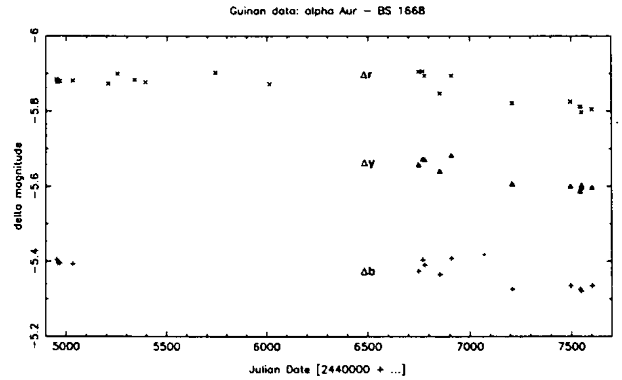

Fig. 1 - Differential magnitudes of Capella vs. BS 1668 by Guinan. X's: Δr data (6600 Å). Triangles: Δy data (5500 Å). +'s: Δb data (4530 Å).

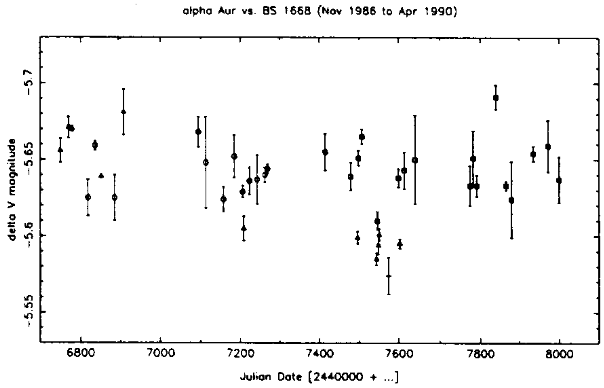

Fig. 2 - Differential photometry of Capella, primarily with respect to BS 1668.
Triangles: Δy data (5500 Å) by Guinan. Squares: ΔV data of Krisciunas, reduced from strip chart tracings. +: Krisciunas ΔV datum reduced from ammeter readings. Circles: Krisciunas ΔV data of Capella vs. 9 Aur, corrected for 39.4 day, ΔV = 0.07 variations of 9 Aur and adjusted for <ΔV> of 9 Aur vs. BS 1668.

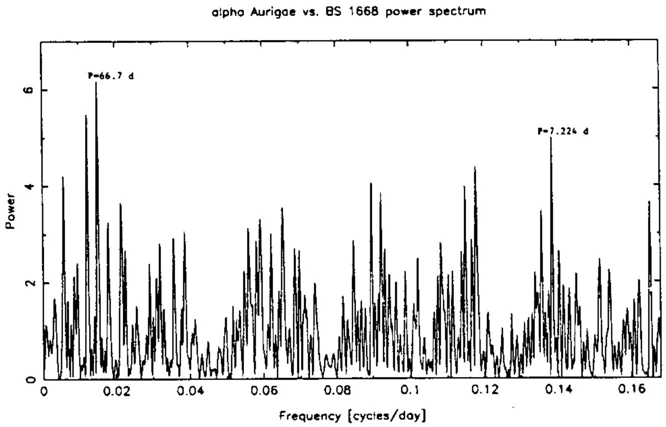

Fig. 3 - Power spectrum of data from Fig. 2, using the Lomb-Scargle algorithm. The 5 points of Guinan from JD 2447495 to 2447602, and the Krisciunas datum reduced from ammeter readings, have been eliminated from the analysis.

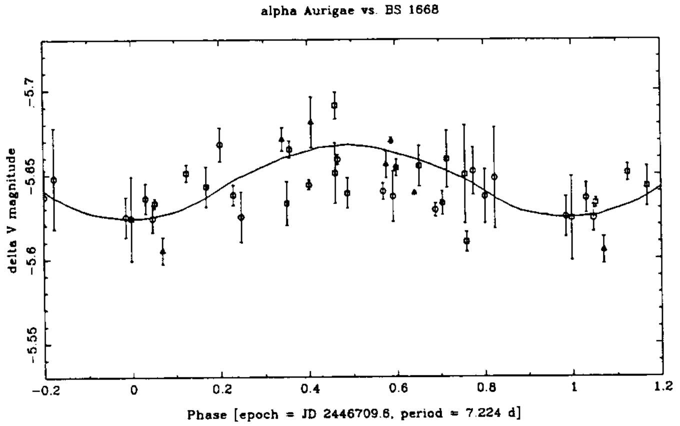

Fig. 4 - Data of Fig. 2 (excepting 5 points of Guinan from JD 2447495 to 2447602 and Krisciunas datum reduced from ammeter readings), folded with a period of 7.224 days. Epoch of minimum = JD 2446709.6.

about 1 magnitude. This was to ensure that Capella did not saturate the photomultiplier tube.

Fig. 2 shows Guinan's Δy data and Krisciunas's ΔV data for Capella vs. BS 1668. It also includes data of Capella vs. 9 Aur, obtained from Jan 1987 to Apr 1988 (JD 2446817 to 2447268), reduced to the "Capella vs. BS 1668 system" as follows: an epoch of minimum of JD 2447242.43 and period of 39.4 days was adopted for 9 Aur, with a peak to peak amplitude of $\Delta V = 0.07$ mag. The mean $\Delta V = -0.708 \pm 0.004$ for 9 Aur vs. BS 1668, obtained from 84 measurements of 9 Aur vs. BS 1668, made from Sep 1988 to Apr 1990, was then added to obtain the equivalent "Capella vs. BS 1668" values.

We note that the Capella vs. 9 Aur photometry, along with the mean ΔV of 9 Aur vs. BS 1668 and $V = 5.68$ for BS 1668, gives us $\langle V \rangle = +0.041$ for Capella from Jan 1987 to Apr 1988. This compares well with $\langle V \rangle = +0.039 \pm 0.006$ from Krisciunas' Capella vs. BS 1668 photometry of Sep 1988 to Apr 1990. Thus, Krisciunas' data show no evidence of a discontinuity of the mean brightness after JD 2447000.

We have investigated the data of Fig. 2 with the Discrete Fourier Transform algorithm of Deeming (1975, 1976), and by means of the Lomb-Scargle algorithm for unevenly spaced data (see Press and Teukolsky 1988 and references therein). The latter is to be preferred, because it is not only more adept at extracting correct periods from noisy data, but allows one to assign a "false alarm probability" to any peaks in the power spectrum (i.e. the probability that a peak is just due to random noise) even for frequencies much higher than the Nyquist frequency (the reciprocal of twice the average sampling internal). A false alarm probability of 0.01 or less is considered good evidence that a particular frequency is not due to noise.

Given the 41 points in Fig. 2, both algorithms give a peak of the power spectrum corresponding to a period of about 28.1 days, but this may hinge on a gain change inherent in Guinan's data of JD 2447495 to 2447602, which appear as the minimum if the data are folded with that period. If we eliminate those 5 points and the datum of Krisciunas reduced from ammeter readings instead of strip chart tracings, and investigate all frequencies up to 2 times the Nyquist frequency, there are peaks in the power spectrum corresponding to periods of 81.96 and 66.66 days, both comparable to the rotation rate of the G6 III star; the false alarm probabilities are 0.251 and 0.137, respectively. A peak corresponding to a period of 104 days is *not* found. If we investigate frequencies up to 12 times the Nyquist frequency (Fig. 3), the likelihood that the 82 and 67 day periods are spurious increases significantly (to 0.823 and 0.586), but we obtain a peak in the power spectrum at F = 0.1384 cycles/day, or a period of 7.224 days, equal to the expected rotation rate of the F9 III star.

In Fig. 4 we show the data of Fig. 2, excluding the 6 points mentioned above, folded with a period of 7.224 days. A sinusoid with peak to peak amplitude $\Delta V \approx 0.04$ is suggested, but the average sampling rate is too long, and the photometric accuracy too poor, for us to claim that such a period has been conclusively demonstrated. Also, if we are to believe the error bars, there is more happening to Capella than variability attributable solely to the rotation of the F9 III star. In any case, we now have a much better *upper bound* to the level of Capella's apparent variability, based on several years of measurements.

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