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Unexplained light variations of the F0 V star 9 Aurigae

In this paper we discuss photometry of 9 Aur that can be found in IAU file 218 of unpublished photometry of variable stars (Breger *et al.*1990). This file contains 85 broad-band differential V magnitudes and 6 Δ(B-V) colors of 9 Aur, using BS 1668 (V = 5.68, B-V = 0.42) as comparison star, obtained on 19 nights by Krisciunas, primarily at the 2800-m level of Mauna Kea on the Island of Hawaii, using a 15-cm reflecting telescope, photometer, DC amplifier, and strip chart recorder. File 218 contains 65 ΔU, 66 ΔB, and 66 ΔV observations by Guinan, obtained with a 25-cm automatic photoelectric telescope (APT) on 52 nights at Mt. Hopkins, Arizona. The APT data are differential magnitudes of 9 Aur vs. BS 1561, with the check star being BS 1568 (V = 4.47). Each APT differential magnitude represents three 10 second digital integrations: 1) on the star in question; 2) on the comparison star; and 3) on the sky. The APT data are inherently more accurate than Krisciunas' data.

Other data in File 218 relevant to this paper are measurements of α Aur (Capella) vs. 9 Aur, obtained before 9 Aur was suspected to be variable; also, infrared photometry of 9 Aur and two other F0 V stars (through broad-band filters JHKLL' and narrow-band M; λ = 1.25 to 4.67 μm).

9 Aur has been used as the comparison star for photometry of α Aur (Krisciunas 1984). Subsequent photometry of January 1987 to November 1988 by Krisciunas, when analyzed with the Discrete Fourier Transform algorithm of Deeming (1975, 1976), indicates a period of 39.4 days and an amplitude of ΔV ≈ 0.08 mag (Fig. 1). Guinan found no such *regular* variations for α Aur vs. BS 1668 at that time, so we naturally suspected that 9 Aur is variable.

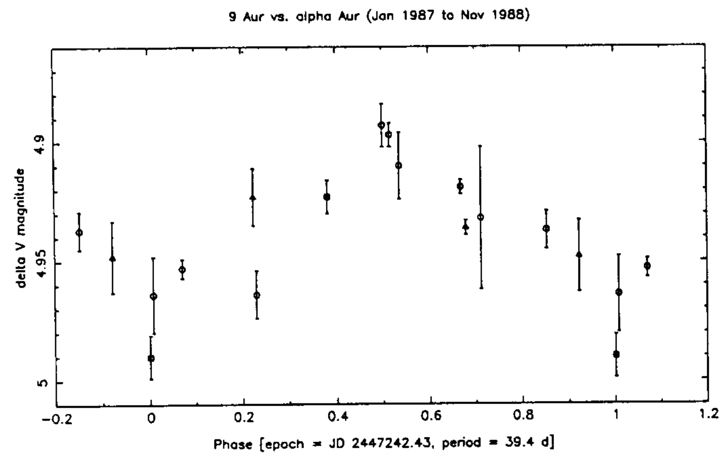

Fig. 1 ΔV differential magnitudes of 9 Aur vs. α Aur, folded with a period of 39.4 days. Triangles: data of January to March 1987. Circles: data of October 1987 to March 1988. Squares: data of September and November 1988.

Fig. 2 shows data of 9 Aur from September 1988 to April 1990, using BS 1668 as the comparison star. Data from two nights have been excluded: 17 Feb 1989 UT, when the data were reduced from ammeter readings rather than strip chart tracings; and 23 Apr 1989, when only one ΔV was obtained

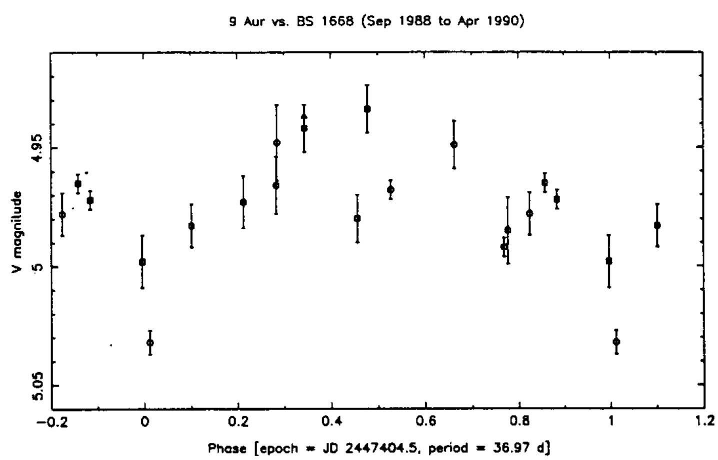

Fig. 2 V magnitude of 9 Aur, using BS 1668 as comparison star. Circles: data of September 1988 to March 1989. Squares: data of September 1989 to April 1990. Triangle: data of 12 Feb 1990 (average of first and third measurements only - second, anomalous (?) datum of V = 4.828 has been excluded from nightly mean.)

before fog and rain occurred. The wave evident in Fig. 2 results from having folded the data with a period of 36.97 days, derived from Deeming's DFT algorithm.

Guinan's data of 9 Aur vs. BS 1561 (12 Nov 1989 to 28 Mar 1990 UT) show a definite wave in the U, B, and V bands from Julian Dates 2447896 to 926 (Fig. 3). The B-band data, in particular, show evidence for a wave preceding and following these dates. Deeming's DFT algorithm gives frequency components of 34.3, 35.8, and 36.5 days for the U, B, and V data, respectively. There are other peaks in the power spectrum, but the points folded with other periods give graphs that look like scattergrams. It should be noted that APT observations of BS 1568 vs. BS 1561 show a scatter consistently half as large, with no suspected periodicity, compared to the 9 Aur vs. BS 1561 data.

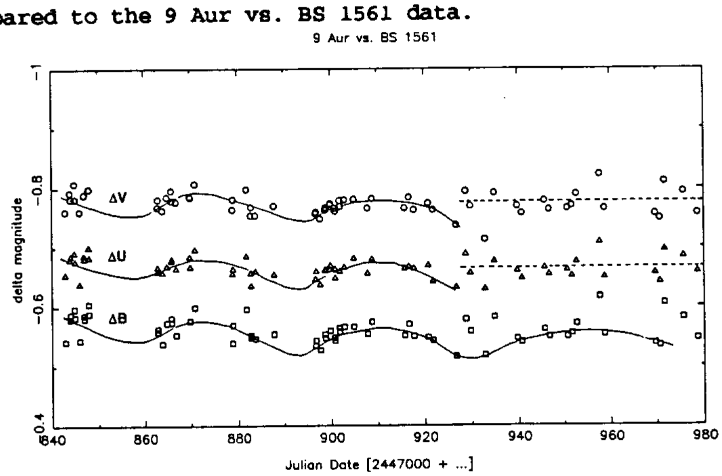

Fig. 3 Differential UBV photometry of 9 Aur vs. BS 1561, from Mt. Hopkins "Phoenix-10" telescope (November 1989 to March 1990).

The 9 Aur data (using α Aur, BS 1668, and BS 1561 as comparison stars) allow us to state that 9 Aur can exhibit sinusoidal variations with a period of 36 to 39 days.

9 Aur (= BS 1637 = Gliese 187.2) has a spectral type of F0 V (Hoffleit and Jaschek 1982) or F1 IV/IV-V (Gray and Garrison (1989). Abt (1965) found it to be a single line spectroscopic binary, but a subsequent paper by Abt and Levy (1974) "did not confirm the previous orbit," concluding that 9 Aur has a constant radial velocity and is a single star. However, if we believe the errors of the radial velocities of Abt and Levy (1974), as well as data of Takeda (1984), there are radial velocity variations of 5 or 6 km/sec. From

speckle data, Hartkopf and McAlister (1984) found no evidence for a close companion at the 0.030 arcsec level. (9 Aur does have a 12th magnitude companion 5 arcsec away, and a V = 9.43 red companion 90 arcsec away, according to Gliese's *Catalogue of Nearby Stars* (1969).) We summarize some of the observational characteristics of 9 Aur in Table I.

Table I

Some Observed Properties of 9 Aur

Spectral type: F0 V or F1 IV/IV-V

$\langle V \rangle = +4.98$	$(b-y) = +0.217$
$B-V = +0.34$	$m_1 = +0.152$
$U-B = +0.04$	$c_1 = +0.642$
	$\beta = 2.723$

$M_V = +3.4$ (Gliese 1969)
$= +2.94$ (from $c_1 - (b-y)$)

v sin *i* = 14 km/sec (upper limit?)

$V_{rad} = -2.1 \pm 0.5$ to 3.4 ± 0.7 km/sec

Light Amplitude (ΔV) ≈ 0.04 to 0.08

Period ≈ 36-39 days (and < 1 hour?)

What could be the cause of the light variations of 9 Aur? Below we make some suggestions, in order of *increasing* likelihood.

1) A low mass companion in a highly eccentric orbit causes tidal distortions of 9 Aur.

2) A lumpy ring of dust orbits 9 Aur at the distance required for a 36-39 day orbit, causing prolonged eclipses (somewhat like ε Aur). That orbit size would be about 0.3 AU, and the dust would be heated to about 800 °K. If this were the case, we might measure an infrared excess at $\lambda \approx 4$ μm. To test this we carried out infrared photometry of 9 Aur and two other F0 V stars (BS 1869 and BS 2228) with the United Kingdom Infrared Telescope on 25 Aug and 6 Sep 1989 UT. (Beam sizes of 7.8 and 5.0 arc seconds were used in order to

keep all *known* companions of 9 Aur out of the beam.) Because simple black body curves can fit the data, there is no evidence for an infrared excess in any of the three stars.

3) Could 9 Aur be a spotted star? If so, we might expect variations with a period comparable to the rotational period of the star. According to *The Bright Star Catalogue*, 9 Aur has a rotational rate of v sin i = 14 km/sec. If it is indeed an F0 V star, then its *maximum* rotational period (letting $i = 90^\circ$) would be 4.9 days (assuming log (R/R_{Sun}) = +0.13, given by Allen (1973, p. 209)). The 36-39 day variations tend to rule out the standard spotted star model, *if* the v sin i value is correct. However, the value of 14 km/sec originates in the list of measures of Huang (1953, wherein 9 Aur = PGC 1202), and may only be an upper limit.

4) In Fig. 4 we show Krisciunas' V-band data from four nights (4 Sep 1989 to 9 Nov 1989 UT), folded with a period of 33.8 *minutes*. (10 measurements obtained on 5 Dec 1989 UT over 50 minutes indicate a somewhat longer period.) Given the spectral type of 9 Aur, the evidence for photometric variations on time scales of tens of minutes, and the small observed variations of the radial velocity of the star, it could be that 9 Aur is a δ Sct star (i.e. short-period pulsator). While δ Sct stars can have multiple periods, there are no δ Sct stars with periods like 36-39 days. We note that 9 Aur is outside the right hand edge of the instability strip in the color-magnitude diagram (Breger 1979).

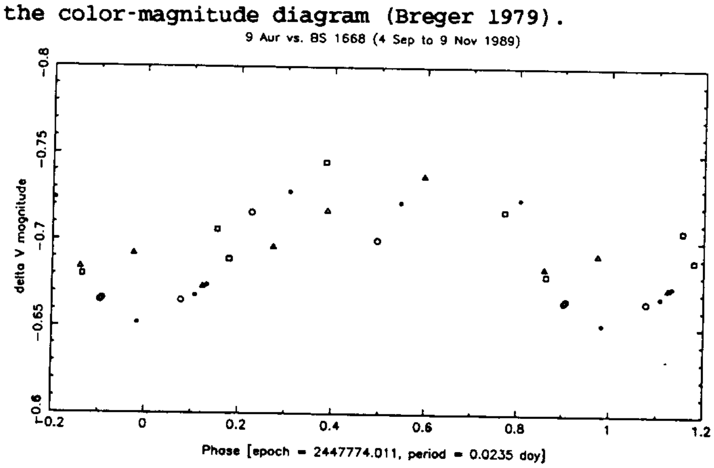

Fig. 4 ΔV data of 4 Sep 1989 UT (open circles), 12 Sep 1989 (squares), 21 Sep 1989 (triangles) and 9 Nov 1989 (dots), folded with a period of 0.0235 days = 33.8 minutes.

5) Provost and van't Veer-Menneret (1969) state: "The most striking result of [our] study is the strong microturbulence velocity, similar to that of an Am star, found in 9 Aur whose F0 m[ain] s[equence] type is well confirmed by this study." We suggest that this microturbulence could manifest itself, in an observational sense, in variations of luminosity, with or without star spots. Short-term variations could be explained by non-radial oscillations, such as those discovered in α^2 CVn stars (Wolff 1983).

Regarding stars of similar spectral characteristics, Conti and Strom (1968) list three 8th magnitude stars in the Pleiades (HD 23194, 23607, and 23924), of spectral type (A5 to A7 V) similar to 9 Aur, which have high microturbulence velocities. Breger (1972) found HD 23607 (= TR 390) to be a δ Sct star with period ≈ 0.049 day and amplitude 0.01 mag. He found the other two stars to be constant. Further photometry on HD 23607 is reported by Seeds and Stephens (1977). It is not known if any of Conti and Strom's three stars show longer-term (≈ 40 day) variability.

We need several hours of continuous data on 9 Aur with an APT or two-channel photometer (on one or more nights) to confirm if it has short-term variations like a δ Sct star. The rotational rate of 9 Aur should be remeasured. Stars of similar spectral type with high microturbulence velocities should be checked for short-term (≈ 1 hour) *and* longer-term (≈ 40 day) photometric variability.

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