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GD 428: AN EXTREME DWARF CEPHEID

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ABSTRACT

During a recent series of observations of white dwarfs, we discovered a $0^d.039088$ periodicity in GD 428. The combined set of observational data available to us—including apparent magnitude, proper motion, five-color photometry, spectra, and both the light and color curve—suggest identification of this star as a dwarf Cepheid. If this identification is correct, then GD 428 is the shortest-period star of this class, has the lowest intrinsic luminosity of all known dwarf Cepheids, and occupies a unique position on the H-R diagram.

Subject headings: stars: δ Scuti — stars: individual

I. OBSERVATIONS

Observations of GD 428 ($\alpha_{1977} = 3^h45^m3$, $\delta_{1977} = +63°18'.6$) were made at the No. 2, 91 cm telescope at Kitt Peak National Observatory in 1976 December. One-second simultaneous integrations were made in two colors. Continuous recording of these data over times as long as $1\frac{1}{2}$ hours enabled us to study quantitatively the light curve of GD 428. This star was one of several selected for study as possible variable white dwarfs whose light curves we were to analyze for periodicities in the range of 5 s to about 1000 s. The bandpasses of the two channels were defined by the Johnson V filter in the red and the combined effects of the dichroic beam splitter and the response of the photomultiplier tube in the blue. A journal of observations is given in Table 1. Raw data have been corrected for extinction and transformed to the UBV system. The transformation errors are ± 0.024 mag in V and ± 0.019 mag in $B-V$.

The light curve in V for the first run is given as Figure 1. The light curve is similar in shape to that of the pulsation variables such as the Cepheids, RR Lyrae stars, or dwarf Cepheids, with a fairly rapid rise to maximum followed by a somewhat longer decay time. The asymmetry parameter (for definition see Tsesevich 1975) is $\epsilon = 0.31$, the mean visual magnitude is 13.0 mag, and the peak to peak variability is 0.33 mag. The color curve, $B-V$, is also shown in the figure. Although the shape of the light curve resembles that of the RRc stars, the period of GD 428 is far shorter than is shown by those stars. The period is more consistent with those of the δ Scuti and dwarf Cepheid variables. In our observations of six cycles accrued over 5 days the light curves are reproducible from cycle to cycle, a feature which is not characteristic of the δ Scuti variables.

We have derived the times of maximum light by drawing several lines at constant magnitude through the light curves, bisecting these lines, and connecting those bisectors with a smooth curve. The intersection of that curve with the observed light curve defines the time of maximum. The uncertainty in the times of maximum light are estimated to be $\pm 0^d.0001$. A least squares fit to the six times of maximum light produces the following ephemeris:

$$\mathrm{HJD}_{\text{maximum V}} = \underset{\pm 31}{2443125^d.80476} + \underset{\pm 51}{0^d.0390883}E$$

We have attempted to fit a quadratic ephemeris to our data. An F-test for such an ephemeris (see Pringle 1975) gives a null result indicating no significant improvement in fit. The period of GD 428, over our limited 5 day span, is constant and is one of the shortest of the pulsationally driven stars.

II. DISCUSSION

In order to determine what kind of star GD 428 is, we have collected all other available information on this star. The information comprises proper motion, five-color photometry, and low-dispersion spectroscopy.

The proper motion of GD 428 is given as class 2 (Giclas, Burnham, and Thomas 1970), indicating a value of approximately $0''.17\ \mathrm{yr}^{-1}$. A more recent estimate gives $\mu = 0''.145\ \mathrm{yr}^{-1}$ (Thomas 1977). The motion is in position angle 105°. At its galactic coordinates $l^{II} = 142°$, $l^{II} = +7°$, the proper motion carries this star parallel to the galactic equator in the direction of increasing galactic longitudes. As we shall show below, the observed proper motion makes it implausible that GD 428 is on the main sequence.

Five-color photometry of GD 428 was obtained on 1976 December 15 UT (Weistrop 1976). These observations were made while we were simultaneously observing the light curve. They correspond in phase to a time in our figure of HJD 2443128.839. The photometric data are reproduced in Table 2. Based on the observed $B-V$, a classification of F4 V is indicated. There is a pronounced ultraviolet deficiency, which suggests that the star is reddened. GD 428 lies in the direction of Perseus, where Johnson (1968) has indicated that the value of R is ambiguous. An A7 V star with about 0.2 mag of red-

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TABLE 1

JOURNAL OF OBSERVATIONS

Date (UT)	Start (UT)	No. Bins	HJD_{MAX} (2443120.+)	Cycle
1976 Dec. 13.....	06:48:27	6231	5.80456	0
			5.84420	1
1976 Dec. 13.....	06:36:19	2386	5.88348	2
1976 Dec. 15.....	04:57:40	6219	7.71964	49
			7.75848	50
1976 Dec. 18.....	07:03:40	2154	10.80848	128

TABLE 2

FIVE-COLOR PHOTOMETRY OF GD 428 ON HJD 2443127.754

Color Index	Value
$U-B$.....	0.26±0.032
$B-V$.....	0.43±0.013
V.....	12.93±0.018
$V-R$.....	0.24±0.016
$V-I$.....	0.30±0.007

dening or a B9.5 V star with about 0.4 mag of reddening will give the observed $U-B$, $B-V$ colors. Spectra of GD 428 have been obtained by Cowley and Crampton (1977). At about 100 Å dispersion, they see only hydrogen lines in absorption, no metal lines or K-line, and a radial velocity less than 40 km s^{-1}. A classification of late B or early A is indicated. Similar conclusions regarding classification have been made by Greenstein (1977), who also indicates a $\log g = 4.4 \pm 0.4$. The classification as a white dwarf is thus unlikely.

While the combined spectral and photometric evidence would favor a late B-type main-sequence classification, the proper motion makes such an assignment highly unlikely. For an absolute magnitude 0.0 and a maximum absorption ($R = 6$) of 2.4 mag, the distance modulus would be 10.6 mag. At a distance of 1300 pc, its transverse velocity would be 900 km s^{-1}—an extremely high and improbable value.

The dwarf Cepheids (also referred to as AI Velorum stars) are pulsating variables characterized by periods between $0^d.05$ and $0^d.25$, median spectral types between A2 and F2, and amplitudes greater than about 0.3 mag. On the other hand, δ Scuti variables, whose period and spectral types cover a similar range, have generally lower amplitudes (less than 0.2 mag) and are distinguished by irregularities in both light curves and periodicity. Period-luminosity relations have been given by Frolov (1969) for δ Scuti stars and by Frolov (1965) for both RR Lyrae and AI Velorum stars. The δ Scuti period-luminosity relation indicates an absolute visual magnitude of +2.2 for $P = 0^d.039$, while the general period-luminosity curve for RR Lyrae and AI Velorum stars extrapolates to an estimated absolute magnitude of +5.5. A δ Scuti identification would give a true distance modulus (with 2.4 mag of absorption removed) of 8.4 mag, a distance of 475 pc, and a transverse velocity of about 325 km s^{-1}. On the other hand, a similar calculation for an AI Velorum identification gives a distance of 100 pc and a transverse velocity of 70 km s^{-1}, placing GD 428 considerably below the main sequence. On the basis of the high transverse velocity, reinforced by the stability of the period and the light curve, we reject the identification of GD 428 as a δ Scuti variable.

Many AI Velorum stars lie considerably below the main sequence though not quite by the 5.5 mag indicated here. GD 428, with the indicated AI Velorum properties, would lie well below all other known dwarf Cepheids. It would be within but close to the blue edge of an extension of the instability strip. Dziembowski and Kozlowski (1974) have considered low-mass models (0.2–0.25 $M_\odot$) for AI Velorum stars characterized by a degenerate helium core with hydrogen envelopes. They find pulsational instabilities in the range we observe. According to these authors a star of 0.2 $M_\odot$ will pulsate either in the fundamental radial mode with a period of

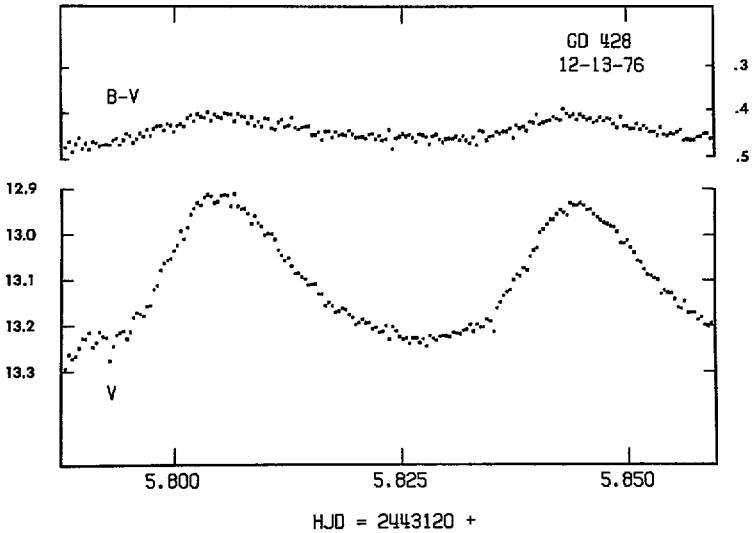

FIG. 1.—The light and color curve of GD 428. Each plotted point is the average of 32 s of data. The median color is +0.44 with a peak-to-peak variation of 0.08 mag in phase with the light curve.

$0^d.04$ or in the first overtone at $0^d.03$ for log $T_e = 3.9$. The observed period of GD 428 is in agreement with these authors' 0.2 $M_\odot$ calculation. Considerable mass loss from the progenitor of such a star is required, and it is not at all clear what evolutionary sequence is involved.

It seems that the best fitting parameters for GD 428 place it, as a dwarf Cepheid, at $M_v = 5.5$ and at a distance of 100 pc, Determination of accurate reddening and absorption in the direction of this star is required to add confidence to this designation, as are continued observations to verify stability of the period and light curve.

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