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AN OLD EVOLVED BINARY IN THE GALACTIC HALO

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ABSTRACT

The faint blue star HZ 22 is shown to be a very short period binary with properties which suggest that it is highly evolved. It is probably more than 1500 pc above the galactic plane, and is either a very old disk Population I or a halo Population II star.

I. INTRODUCTION

The results of one of several surveys for faint blue stars at high galactic latitudes were reported by Humason and Zwicky (1947). Their original list contained 48 stars, of which the twenty-second ($\alpha = 12^h12^m16^s$, $\delta = +36°56'$, 1950) is the subject of this investigation. Greenstein discovered large-amplitude variations in the radial velocity of this star on spectrograms obtained at the Hale Observatories. The spectral classification appeared to be that of a reasonably normal B3 star, but the faint apparent magnitude of 13 suggested a great distance above the galactic plane. Gaposchkin (1962) discovered light variation for HZ 22 on Harvard Patrol plates, and determined a light curve photographically. Using Greenstein's spectra, he found a period of $3^d.5821$, and deduced a mass sum on the order of 12 $M_\odot$ and a distance of 16,000 pc above the galactic plane. The star was the subject of much discussion at the First Conference on Faint Blue Stars, held at Strasbourg, and reported by Luyten (1965). That discussion called attention to the seeming anomaly of such a youthful star so far from the galactic plane, with the large mass indicated by its membership in a close binary system.

In a rediscussion of Gaposchkin's paper, Smak (1969) pointed out that a shorter period would improve the velocity curve, and he suggested a considerably different structure for the system. The discoveries reported in our paper largely confirm Smak's speculations.

II. OBSERVATIONS

HZ 22 was observed photometrically at the Mount Laguna Observatory during 1971 March, April, and May with the intent of improving the light curve sufficiently to redetermine the period. Observations were made on 10 nights in that interval, and the reduced differential magnitudes are available upon request. The observations were made with a 16-inch (41 cm) telescope and a refrigerated 1P21 photomultiplier. Because of the faint apparent magnitude of HZ 22 no filters were used, and integration of 30 s was required. The comparison stars used were the same as those used by Gaposchkin. The cell response and the high temperature of HZ 22 convolute to a magnitude similar to the *U*-band of the *UBV* system, but not sufficiently for a simple transformation to be performed. HZ 22 was found to vary continuously in brightness, contrary to Gaposchkin's report of an Algol-type light curve. Repetition of the variation pattern on each fourth night suggested an integral or half-integral day period, and explained why Gaposchkin had found a period close to four days. Further analysis revealed that the period is much shorter than four days. Greenstein's radial velocities quickly sorted out an unambiguous period from our data. The ephemeris for HZ 22 may now be computed from

$$JD = 2441096^d.183 + 0^d.573703E .$$

Greenstein's spectroscopic observations since 1953 extend over 11,632 cycles, and have therefore extended the accuracy of our period. The light curve is shown in figure 1, and is seen to be similar to that of a β Lyrae system. The minima are of unequal depth, and the maxima are similarly unequal. Preliminary analysis has shown that this light curve can be understood as the result of a rotating, tidally distorted star, with no eclipses. The depth and height asymmetry may be due to differential gravity darkening, but further analysis and more observations are being performed to deal with this problem. Photometry of HZ 22 by Kowal (kindly communicated in advance of publication) gives values of colors and magnitudes at maximum light transformed to the UBV system of

$$V = 13.07\,, \quad B - V = -0.29\,, \quad U - B = -1.05\,,$$

with no significant variation in the colors throughout the cycle.

More than 40 spectrograms of HZ 22 were secured by Greenstein at the Hale Observatories. Most are in the blue region, and the dispersions are 38, 90, and 190 Å mm^{-1}. Two more at 103 Å mm^{-1} were secured by us at the Kitt Peak National Observatory.[1] The spectrum is that of an early B star with rotational broadening. Reproductions of it have been published by Greenstein (1969). Lines of the Balmer series and of He I were used to determine radial velocities. The velocity curve which results from these spectrograms is shown in figure 2 with the kind permission of Dr. Greenstein who made all of those observations and measurements. The theoretical curve shown in figure 2 was computed from elements based upon our solution using the program published by Wolfe, Horak, and Storer (1967). These elements are

$$P = 0^{d}.573703\,, \quad K = 130 \pm 3 \text{ km s}^{-1}\,, \quad e = 0.09 \pm 0.02\,, \quad \omega = 340° \pm 12°\,,$$

$$a_p \sin i = 1.02 \times 10^6 \text{ km} \pm 2 \times 10^4 \text{ km}\,, \quad \gamma = -1 \pm 1 \text{ km s}^{-1}\,.$$

The eccentricity is somewhat large for such a short-period system, and its reality is questionable in view of the ability of short-period systems to distort a velocity curve with complications due to the proximity of the components. No spectroscopic evidence for the secondary star has been observed, and no emission features have been found from Hα to 3400 Å.

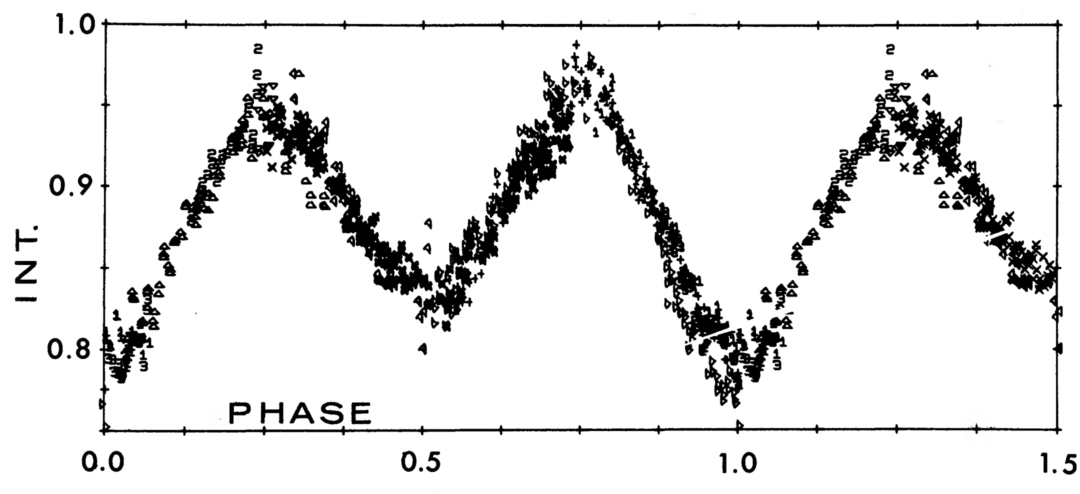

FIG. 1.—The light curve of HZ 22 as observed with an unfiltered, refrigerated 1P21 photomultiplier. The vertical scale is in units of intensity.

[1] Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

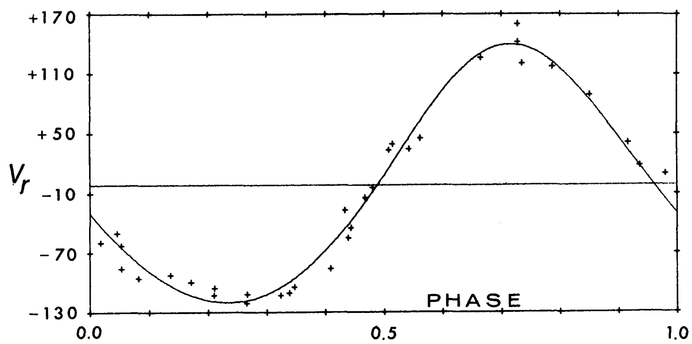

FIG. 2.—The velocity curve of HZ 22. Phase 0.0 is taken as the time of the deepest minimum of the light curve.

Greenstein has analyzed the hydrogen line profiles and has deduced a surface gravity of log g = 3.9 in cgs units. A proper motion of $\mu_\alpha = +0\rlap{.}''030$ year^{-1} and $\mu_\delta = -0\rlap{.}''021$ year^{-1} is reported by Luyten and Miller (1951). Pels and Perek (1951) give very similar values of $\mu_\alpha = 0\rlap{.}''04$ year^{-1} and $\mu_\delta = -0\rlap{.}''014$ year^{-1}.

III. ANALYSIS OF DATA

The mass function of HZ 22 is 0.13 $M_\odot$, which for equal masses of the components gives 0.5 $M_\odot$ apiece if sin i is taken as unity. The *UBV* colors, corrected for reddening, lead to a temperature of 28,000° K (θ = 0.18). If the surface gravity is due entirely to the mass and radius of the star (i.e., negligible tidal potential from the secondary, and negligible centrifugal effect), the expression

$$M_{\rm bol} = \tfrac{5}{2}\log g + 10\log\theta - 2.5\log M - 5.82$$

leads to a value of −2.8 for the bolometric absolute magnitude. A bolometric correction of −2.95 leads to a distance modulus of 13, and a tangential velocity of >600 km s^{-1} relative to the Sun. The latter seems too large, and implies that the luminosity may be overestimated.

In an attempt to delineate the boundaries upon the possible structure of this unique system we have generated a table (see table 1) of possible configurations based upon observed parameters and simplified assumptions. This table, although somewhat crude because of the assumptions, permits us to infer an upper limit for the mass of the primary star, and to infer some of the system properties which such a limit would imply. The simplifying assumptions made are that the orbit is circular, with sin i = 1.0, and

TABLE 1

POSSIBLE CONFIGURATIONS FOR THE STRUCTURE OF THE BINARY SYSTEM HZ 22

M_p	M_s	(a_p+a_s)	R_p	R_A	$M_{\rm bol}$	M_v	(m_v-M_v)
0.10	0.25	2.1	0.52	0.63	−0.69	+2.26	10.8
0.20	0.32	2.4	0.72	0.81	−1.40	+1.55	11.5
0.30	0.40	2.6	0.86	0.93	−1.79	+1.16	11.9
0.50	0.50	3.0	1.08	1.13	−2.28	+0.67	12.4
0.70	0.60	3.2	1.24	1.25	−2.58	+0.37	12.7
1.00	0.75	3.5	1.44	1.41	−2.91	+0.04	13.0

that the primary star may be approximated by a spherical blackbody. Our interpretation of the light curve leads us to believe that the tidal distortion from sphericity amounts to no more than a 10 percent difference between polar and equatorial (along the bulge) radii. Table 1 was then generated by using the mass of the primary as the independent variable, and the surface gravity measured by Greenstein as the observed parameter to be reproduced. For each value of the primary mass, the mass function was solved for the secondary mass and the separation between the stars. The surface gravity at the substellar point on the inner hemisphere of the primary star was then expressed by

$$g_1 = g_* - g_{T_1} + g_{c_1} - g_c \,. \tag{1}$$

At the antipodal point the expression for the surface gravity is

$$g_2 = g_* - g_{T_2} - g_{c_2} - g_c \,. \tag{2}$$

With the stellar masses, stellar radius, and separation between stars expressed in units of the solar mass and radius, the surface gravity is in terms of that of the Sun. Each of the terms in these equations is defined in terms of the quantities M_p (mass of the primary star), M_s (mass of the secondary star), R_p (radius of the primary star), a_p (radius of the orbit of the primary star about the center of mass), a_s (radius of the orbit of the secondary star about the center of mass), and ω (angular velocity of the orbital motion). Each term then has the following form and interpretation:

$g_* = M_p/R_p^2$, self-induced surface gravitv of the primary star ; (3)

$g_{T_1} = M_s\left[\frac{1}{(a_p + a_s - R_p)^2} - \frac{1}{(a_p + a_s)^2}\right]$, contribution due to the tidal coupling ; (4)

$g_{T2} = M_s\left[\frac{1}{(a_p + a_s)^2} - \frac{1}{(a_p + a_s + R_p)^2}\right]$, contribution due to the tidal coupling ; (5)

$g_{c_1} = k\omega^2(a_p - R_p)$, centrifugal (orbital) contribution in the rotating coordinate frame ; (6)

$g_{c_2} = k\omega^2(a_p + R_p)$, centrifugal (orbital) contribution in the rotating coordinate frame ; (7)

$g_c = k\omega^2 R_p$, centrifugal (stellar rotation) contribution in the rotating coordinate frame . (8)

The constant k is a unit correction factor designed to preserve all g-values in terms of the surface gravity of the Sun. It has the value

$$k = R_\odot/g_\odot \,.$$

The IBM 1130 computer was used in the pair of equations (1) and (2) to solve for R_p by forcing the average value $\frac{1}{2}(g_1 + g_2)$ to be equal to the observed surface gravity which is 0.29 in units of the solar gravity. This procedure does not consider the contribution to observed gravity at phases other than 0.0 and 0.5. Recent results by Rucinski (1971) indicate that the entire variation is not more than 15 percent, which is certainly less than the error in the measured log g. The quantity R_A, also in units of the solar radius, is the effective radius of action for the inner Roche contact lobe as defined by Kuiper and Johnson (1956). Comparison of the value of R_A with R_p constitutes one argument for setting an upper limit to the primary mass. Since no evidence for mass transfer in the form of emission lines has been observed, we infer that $R_p < R_A$ and thus that $M_p < 0.7\ M_{\odot}$. A second argument is that reasonable space motion for HZ 22 as an old disk-population star occurs when the distance modulus is on the order of 11. From table 1 this implies that M_p may be as little as $0.2\ M_{\odot}$.

The surface gravity for a white dwarf that has a mass of $0.2\ M_{\odot}$ and lies upon the mass-radius relation for pure He stars is 500 $g_{\odot}$, and so it appears that the primary star is not now a white dwarf. The nature of the secondary star is wholly a matter of conjecture. For a working hypothesis we have assumed that it is a white dwarf and is therefore not detectable by direct observation.

IV. CONCLUSIONS

The original dilemma of a youthful upper-main-sequence star 16,000 pc up in the halo is now resolved by our discovery of its short period. HZ 22 is apparently an object of very small mass, one-tenth as distant as previously believed. It appears to reside on the left side of the H-R diagram, as a consequence of great age and nearly completed evolution. Presumably much mass has been lost from this system, and we may now be observing the cinder core of a dying star on its way to becoming a white dwarf.

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