1986JAVSO..15...36P

V2022 SAGITTARII: AN EXAMINATION OF THE EVOLUTION OF A BL HERCULIS STAR

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Abstract

V2022 Sagittarii was confirmed to exhibit characteristics of a BL Herculis star. A peculiar period increase was derived for V2022 Sgr from observations covering the interval 1926 - 1985.

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1. Introduction

V2022 Sagittarii was discovered by Hoffleit (1964), who classified it as a Population II Cepheid. Population II Cepheids are now divided into two subclasses: W Virginis stars, with periods greater than three days, and BL Herculis stars, with periods less than three days. The light curves of each group are distinctly different. W Vir stars show light curves with broad, round maxima, a rising branch less steep than the descending branch, and a small hump at the base of the rising branch. A BL Her star's light curve is characterized by a steep rising branch, a sharp maximum, a secondary shoulder or bump on the descending branch, and a large amplitude (Kwee 1967). V2022 Sgr's short period indicates that it fits into the subclass of BL Her stars. Figure 1 shows a light curve for V2022 Sgr. The characteristics of a BL Her star are evident.

The theory behind BL Her stars is summarized in Gingold (1975). They are thought to be stars with $M < 1 M_{\odot}$, evolving on the asymptotic giant branch following the exhaustion of helium in their cores. Helium burning occurs in a shell surrounding the core, which progressively narrows and grows in luminosity. This causes the overlying layers, including the hydrogen-burning shell, to expand. Thus, the hydrogen-burning shell begins to decrease its energy output. This causes the surface luminosity to decline. The entire envelope contracts, the density rises, and, on an HR diagram, the star moves toward the blue and into the instability strip. This motion is halted when the hydrogen-burning shell begins to regain its former strength. The period is inversely proportional to the square root of the density, so, during this phase, there will be a decreasing period. As the hydrogen-burning shell increases its luminosity, the star will begin to move back up and to the right, towards the red. It will expand and cool, the density will drop, and the period will increase. The evolutionary models given by Gingold (1975) show that the number of times these adjustments of the two shells cause the star to enter the instability strip is dependent on the mass of the star. These motions occur on a relatively short time scale, so the possibility exists that any period change detected may be due to evolution.

2. Determination of Physical Characteristics

Physical parameters were derived for V2022 Sgr to see how well they agreed with the general characteristics for BL Her stars. The results, as well as general characteristics of BL Her stars and classical Cepheids, are given in Table I. The luminosity was derived from the period-luminosity relation given by Shu (1982), and the other parameters from relationships given by Smith *et al.* (1978) and Strohmeier (1972). The results, from an examination of Table I, seem to fit well with the Population II Cepheid instability strip as defined by Demers and Harris (1974). It must be emphasized that these quantities are very rough.

3. Determination of Period Change

V2022 Sgr was then investigated for any period changes. I examined over 300 NA plates taken at the Maria Mitchell Observatory as well as over 100 RH and RB patrol plates from the Harvard Observatory, all spanning the years 1926 to 1985. The original elements determined by Hoffleit (1964) are:

$$JD_{max} = 2437146.678 + 1.533160\ E. \qquad (1)$$

The magnitudes of the comparison stars were based on the sequence 1826-2728 by Warren et al. (1976). Brightness estimates were then made using these magnitudes. Light curves for 30 time intervals spanning 1926 to 1985 were then determined. The length of each time interval was chosen according to the number of observations available. A mean light curve was derived, and used to determine the O-C value for each interval. Assigning an O-C value involves the determination of the observed maximum for each light curve, and the measurement of its deviation from the calculated maximum. Figure 2 shows the O-C values as well as the line and parabola determined by a least squares fit. The error bars indicate the greatest possible range for a fit between the average light curve and each individual curve.

The line implied the new elements:

$$\begin{aligned} JD_{max} = 2446270.609 &+ 1.533169\ E. \qquad (2) \\ \pm 0.023 &\pm 0.000004 \end{aligned}$$

The mean error, based on the residuals of the line, was 0.0034.

The parabola implied the new elements:

$$\begin{aligned} JD_{max} = 2446270.742 &+ 1.533223\ E + 3.9 \times 10^{-9}\ E^2. \qquad (3) \\ \pm 0.023 &\pm 0.000008 \quad\ \pm 6 \quad \times 10^{-10} \end{aligned}$$

The mean error, based on the residuals of the parabola, was 0.0020.

The parabola implied a rate of change in the period of = +1.88 days/10^6 years.

There is a significant reduction of the mean error from the line to the parabola. Inspection of Figure 2 reveals that the parabola does indeed seem to be the better fit. The test described by Pringle (1975) has applied to test the significance of the parabolic term. The term was found to be significant at the 99.9% confidence level, implying only a 0.1% chance that the square term is due to chance deviation from the line.

4. Conclusions

V2022 Sgr is a BL Her star with an increasing period. The luminosity, using Table I from Gingold (1975), implies a star of M~0.527 $M_\odot$, undergoing a type-three crossing of the instability strip. A type-one crossing takes place when the star crosses the instability strip coming off the horizontal branch. A type-two crossing occurs when the star moves to the blue off the asymptotic branch as described above, and the type-three crossing occurs after the star has halted its blueward movement and is moving up and to the right, back to the red. Atype-three crossing, then, implies an expanding, cooling star, a decreasing density, and an increasing period. The value for the rate of period change calculated by Wehlau and Bohlender (1982) for a star of M~$M_\odot$ undergoing a third crossing is 2 days/10^6 years. This is very close to what I found.

5. Acknowledgements

I would like to thank Dr. Emilia P. Belserene for her guidance throughout this project. I would also like to thank the National Science Foundation and the Dorrit Hoffleit Assistantship Fund for the financial suppport of this research.

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TABLE I

Physical Parameters of V2022 Sgr, BL Her Stars, and Classical Cepheids

	V2022 Sgr	BL Her stars	Pop. I Cepheids
Luminosity ($L/L_\odot$)	262	100-300	380-31000
M_V	-0.375	-	-
Distance (parsecs)	6000	-	-
Effective Temperature	6560	6840	5400-6900
Mass (limit)	$1M_\odot$	$1M_\odot$	$3-14M_\odot$
$B-V_\odot$	0.338	-	-

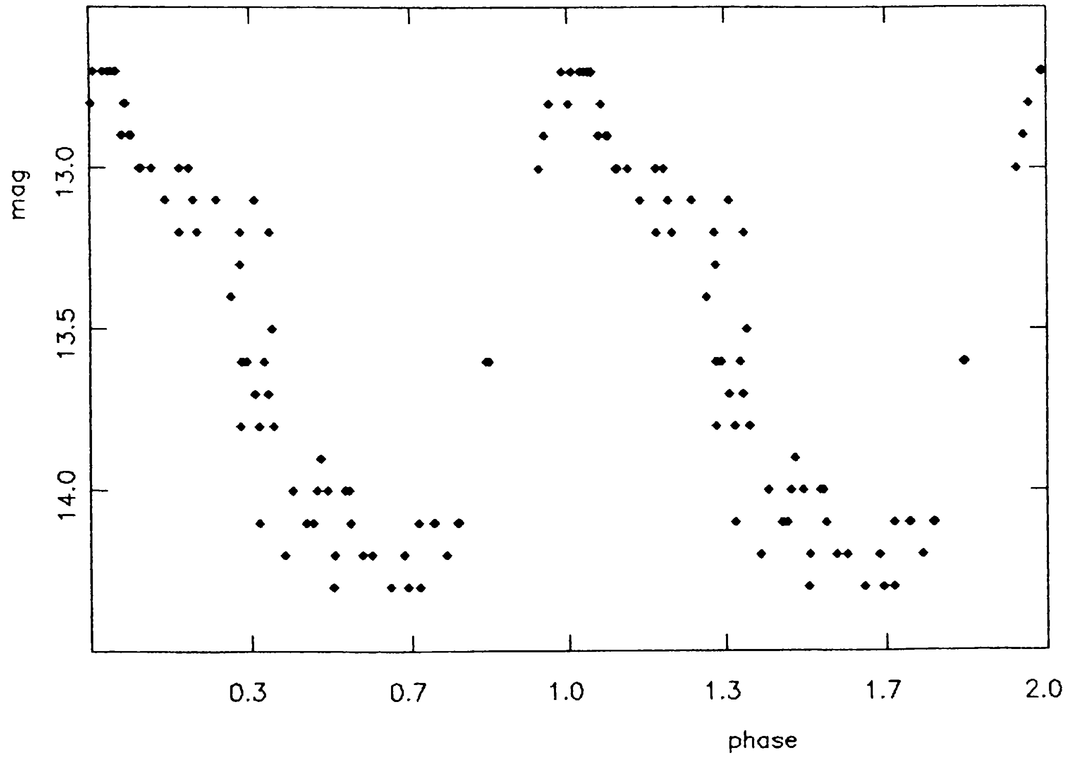

Figure 1. Photographic light curve, spanning 1980-1985, for V2022 Sgr. Phases were computed using the ephemeris JD 2437146.678 + 1.553160 E.

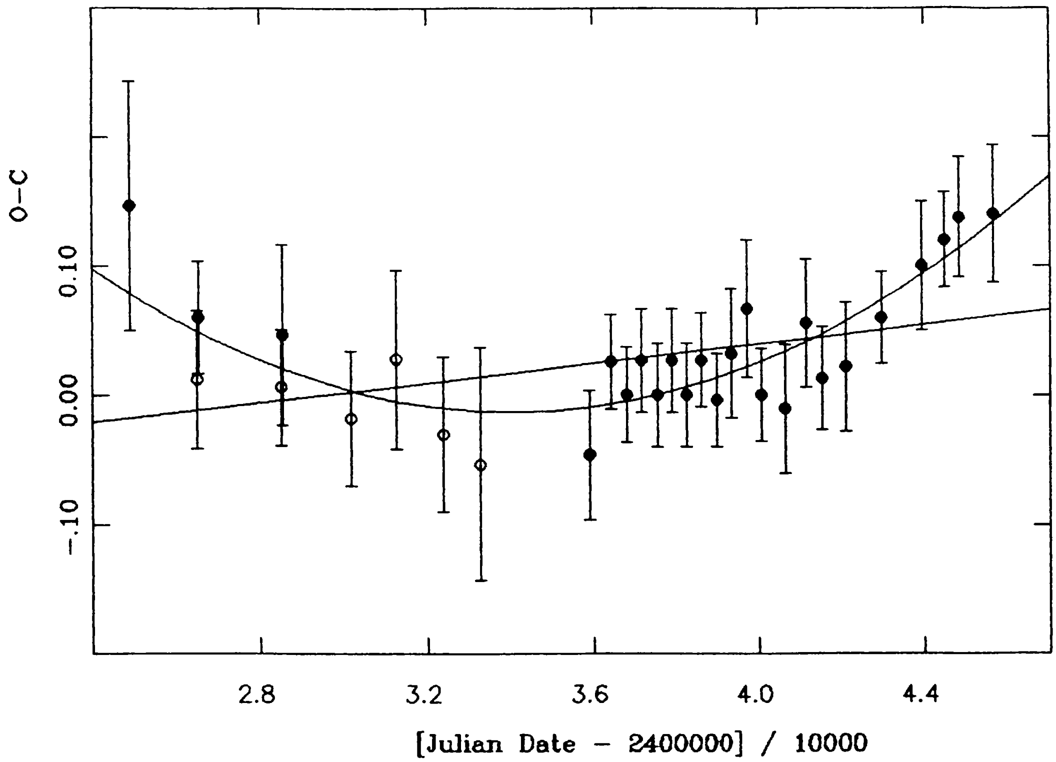

Figure 2. O-C graph for V2022 Sgr for the years 1926 to 1985, calculated from the ephemeris JD 2437146.678 + 1.533160 E. The closed circles are points derived from MMO plates, and the open circles are from Harvard plates. The bars indicate the greatest possible uncertainty in the observed times of maximum. The parabola and the line represent the best least squares fit.