SEARCH FOR COLLIDING STELLAR WINDS IN PLASKETT'S STAR (HD 47129)

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ABSTRACT

High-dispersion spectra of Plaskett's star (HD 47129) were obtained with the short-wavelength spectrograph on IUE at five phases of the binary cycle. The unsaturated wind profiles, particularly those of Si IV λ1400, show complex, phase-dependent structure. Two interpretations for the structure are suggested, neither of which is entirely satisfactory: (1) the structure is a consequence of directed streams, and (2) the structure is a consequence of colliding winds from the primary and secondary.

INTRODUCTION

In the past 15 years, two observational discoveries from space have changed our way of thinking about OB stars. The first discovery, made by Morton (Ref. 1) and his colleagues at Princeton, was that OB giants have high-velocity winds. The second discovery, made by scientists using the Uhuru satellite (Ref. 2) was that some close binaries having an OB component emit x-rays. The interpretation of these observations is that the secondary is a compact object embedded in the wind of the OB giant, and x-rays are generated in the wake of the wind accreting onto the compact object. I don't think there is any doubt today that the massive x-ray binaries are associated with accretion by a compact object. Nevertheless, it is useful to think of other mechanisms of x-ray emission that do not involve a compact object. Prilutskii and Usov (Ref. 3) have, in fact, considered how x-rays might be generated in close binaries containing two O stars. They suggest that x-rays could be generated behind a shockfront formed where the wind of the primary collides either with the secondary itself, or with the wind of the secondary. It is this latter possibility -- the phenomenon of colliding winds -- that I wish to use as a framework for discussing Plaskett's star (HD 47129).

Let me first review the evidence that the two components of Plaskett's star do, in fact, have winds which may interact. Detailed studies of the visual spectrum (Ref. 4, 5, 6) indicate that Plaskett's star is a double-line spectroscopic binary whose components are both

O-giants. Table I summarizes some of the properties of the two components (Ref. 6). Although the spectral types are approximately the same (O7 I), their flux distributions differ, with the secondary appearing slightly cooler. In the red region of the spectrum, the primary and secondary are of approximately equal brightness, while in the blue spectral region, the primary is at least three times brighter. Spectra obtained with IUE indicate that in the ultraviolet, only the primary is visible, as indicated by the fact that "photospheric" lines like N IV λ1718 show radial-velocity variations which follow the radial-velocity curve of the primary (although shifted to shorter wavelengths by about 200 km/sec). The IUE observations also indicate that the primary has a wind typical of those of O giants with a terminal velocity of 2500 km/sec. Since the visual spectrum of the secondary is similar to that of the primary, and since the mass and radii of the two stars are similar (Ref. 6), I assume that the secondary also has a high-velocity wind.

Consequences of Colliding Stellar Winds

If this is the case, it seems worthwhile to develop the observable consequences of colliding stellar winds and to compare these predictions with observation. One potentially observable consequence of colliding stellar winds is, of course, the generation of x-rays. Cooke, Fabian and Pringle (Ref. 7) have predicted measurable x-ray luminosities of six binaries, including HD 47129, in which both stars are thought to be O stars undergoing mass-loss. Fabian, in fact, has observed Plaskett's star with HEAO-2, and I just found out yesterday the outcome of these observations: HD 47129 is an x-ray source with an x-ray luminosity of 6×10^{32} ergs per sec. This luminosity is two orders of magnitude below Cook et al.'s predictions. In fact, it is equivalent to x-ray luminosities of garden-variety single stars. Another potentially observable consequence of colliding winds is the alteration of the properties of the winds. The theory has not been developed in any quantitative manner, but it is not hard to see at least qualitatively how this alteration might go. In the absence of a companion, the O giant has an accelerating wind. The predominant species in the wind are ions like N V, Si IV, C IV which scatter stellar photons, thereby producing the P Cygni-type features typical of O-type ultraviolet spectra. Now consider how a companion with a wind modifies the situation (Figure 1). According to Prilutskii and Usov, a highly ionized cavity will form where the two winds collide. The presence of the cavity may be detectable through its effect primarily on the ionization law and secondarily, on the velocity law of the stellar wind. The ionization law describes how the number of ions capable of scattering varies with velocity in the wind. Because N^{+4}, Si^{+3}, C^{+3} are ionized to higher stages in the cavity, the P Cygni profiles of N V, Si IV, C IV are modified at the wavelengths corresponding to the velocities of the cavity. The velocity law describes how the velocity increases with distance. It may also be modified by the high-ionization cavity since the ions in this cavity have

TABLE I

PROPERTIES OF HD 47129
(taken from Ref. 6)

Period = 14.439601 days

$K = \begin{cases} 200 \text{ km/s (He II, Si IV, He I lines)} \\ 162 \text{ km/s } (H\gamma) \end{cases}$

$M_1 \approx M_2 \approx 55\ M_\odot$ or more

$R_1 \approx R_2 \approx 20\text{-}25\ R_\odot$

Distance between stars $\gtrsim 100\ R_\odot$

$\dot{M} \approx 2$ to $8 \times 10^{-6}\ M_\odot$ per year

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no resonance transitions accessible to the stellar photons and hence, radiatively-driven acceleration is not possible in the cavity. The main effect, then, of the high-ionization cavity is the appearance of structure in a P Cygni profile. Furthermore, the appearance of structure should be phase-dependent: the profile should remain unaltered at phases 0.5 to 1.0 since the line of sight from the primary to the observer does not pass through the cavity, while it should be altered at phases 0.0 to 0.5.

IUE Observations

The IUE spectra show evidence for phase-dependent structure in some of the wind profiles, most notably Si IV and C IV. These two features are formed by scattering material over the full range of velocities, but because they are not fully saturated, they are still sensitive to anomalies in the ionization law. Figures 2 and 3 show the profiles of the Si IV and C IV wind features at four phases covering nearly half of the orbital cycle. (I should note that a good deal of care was taken in deriving the observed profiles so as to insure that the reduction process itself would not be a source of spurious structure. In particular, the interorder background was smoothed by a 31-point median filter followed by two 15-point running averages before it was used to obtain the net fluxes. In addition, the echelle ripple "constants" were derived for each profile by trial and error until the three orders containing a given profile overlay one another in the wavelength intervals where they overlapped. In no case did the constants used in the standard reduction procedure suffice!) For comparison, the top of each figure shows the profiles of these two features as calculated from the formulae and tables of Castor and Lamers (Ref. 8). Examination of Figures 2 and 3 shows the development of structure in the Si IV wind profile until at phase, $\phi = .47$, three sets of absorption features are visible, or alternatively, until two sets of "lack-of-absorption" features are visible. The radial velocities of these features are given in Table II. Although less dramatic, the C IV feature shows the development of "lack-of-absorption" midway in its profile at phase, $\phi = .64$.

The structure of these lines is open to several interpretations, none of which is entirely satisfactory. One, which follows along the lines of Struve, Sahade and Huang's interpretation of the visual spectrum, is that the wind of the primary contains directed streams which account for the sharp absorption components of the Si IV profile. If the velocity law for the components is the same as for the rest of the wind, then these streams extend out to 1.6 stellar radii. It is hard to understand how these streams could remain so contained with so little velocity dispersion out to such large distances. Another interpretation, which follows along the lines of the colliding wind hypothesis, is that the structure of the wind profiles is due to the "lack of absorption" caused by the erasure of Si^{+3} and C^{+3} in the high-ionization cavity. A simple model for the high-ionization cavity, such as that shown in

TABLE II

Measured Radial Velocities from SWP 4819 (ϕ = .37)

ID	Velocity (km/s)	Remarks
Si IV λ1393.755	-1550	Sharp
	-1190	Sharp
	-370	Broad
	+48	Sharp, interstellar
Si IV λ1402.769	-1570	Sharp
	-1140	Sharp
	-460	Broad
	+45	Sharp, interstellar

Figure 1, does not explain the observed phase-variations, but surely the geometry of the cavity must be more complicated than this simple model. The development of a more realistic model that includes the angular momentum of the system and possibly unequal rates of mass-loss from the two components would appear to be a fruitful line of research.

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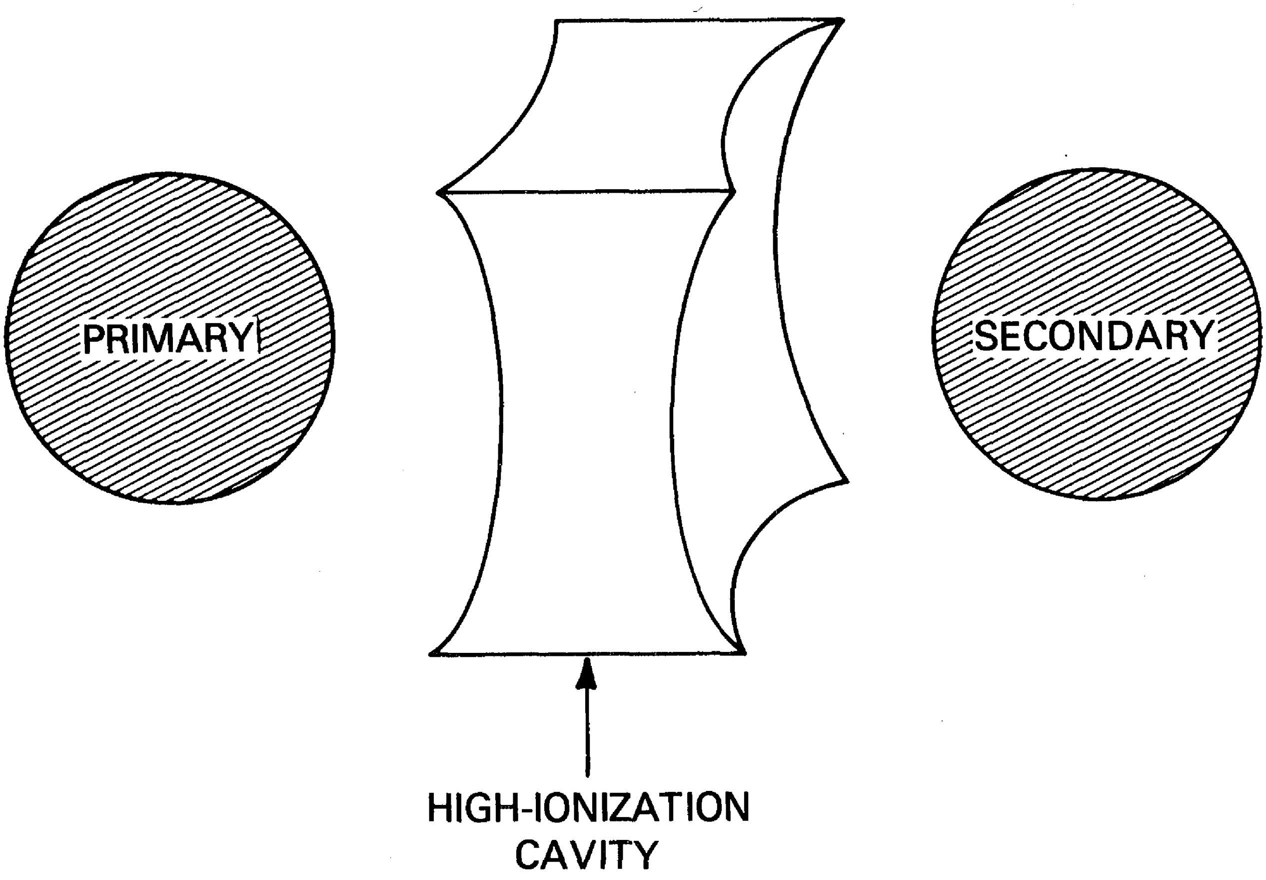
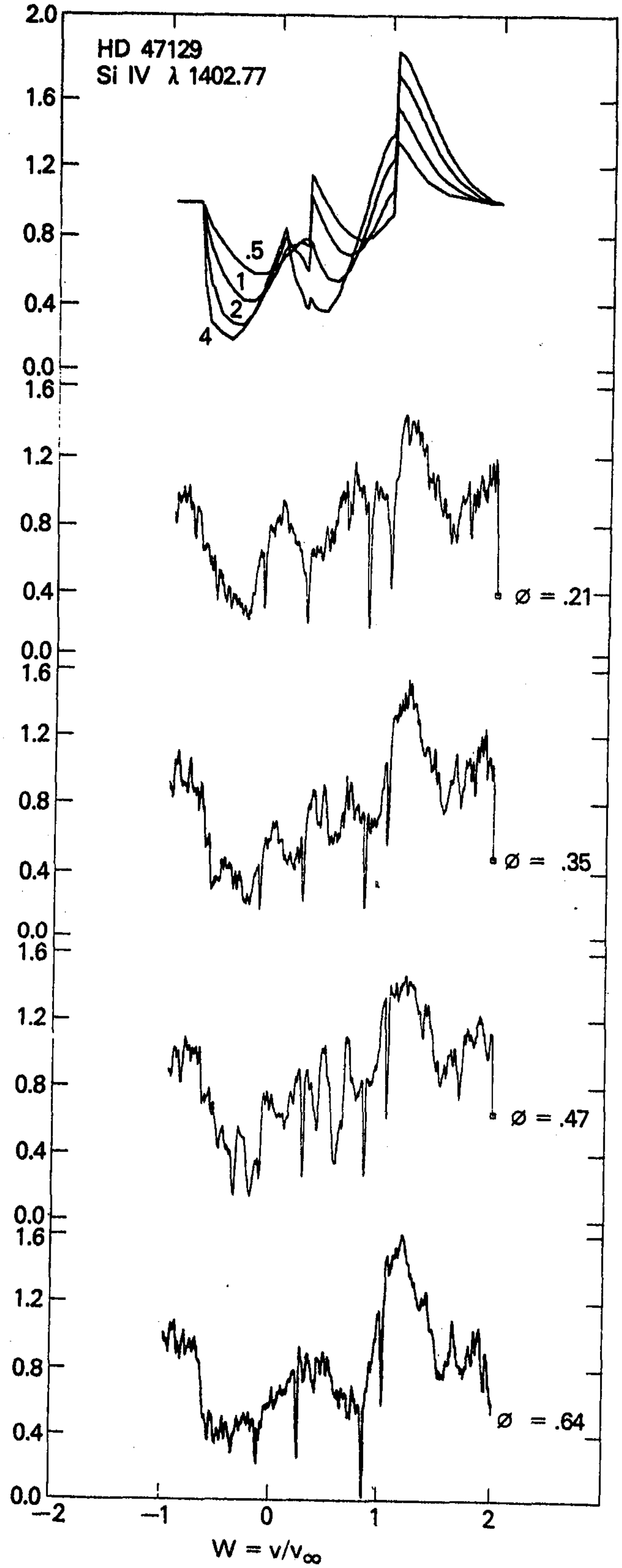


Figure 1



HD 47129
Si IV λ 1402.77
.5
1
2
4
Ø = .21
Ø = .35
Ø = .47
Ø = .64
2.0
1.6
1.2
0.8
0.4
0.0
−2
−1
0
1
2
W = v/v∞

Figure 2

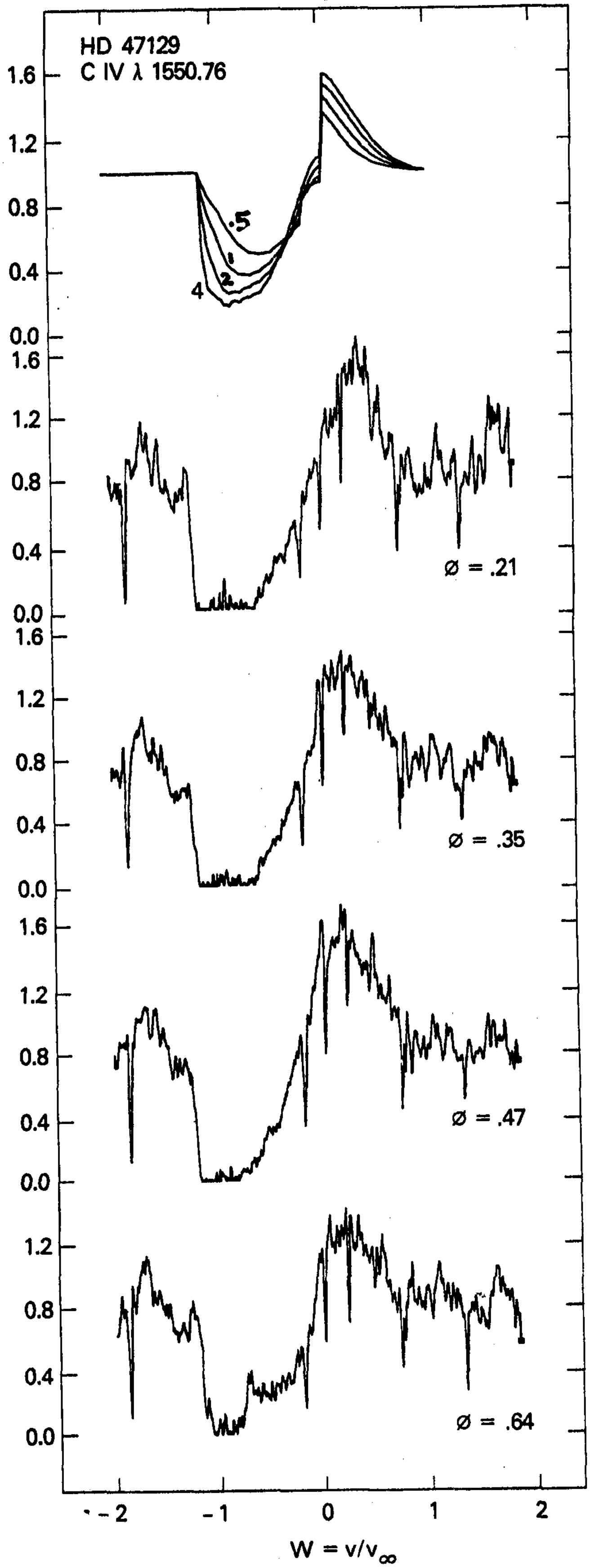

HD 47129
C IV λ 1550.76
1.6
1.2
0.8
0.4
0.0
.5
1
2
4
ø = .21
ø = .35
ø = .47
ø = .64
-2
-1
0
1
2
W = v/v∞

Figure 3