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THE STORY OF HD 47129: THE MASSIVE O-TYPE BINARY

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RESUMEN. Se presenta una descripción del comportamiento de HD 47129 basada en observaciones terrestres y una relación preliminar del comportamiento del doblete de resonancia de Si IV en el ultravioleta. Se hace énfasis en la importancia del objeto, desde el punto de vista evolutivo y del interés de un esfuerzo observacional concentrado y cooperativo en un rango de longitud de onda lo más amplio posible, a través de todo el ciclo orbital.

ABSTRACT. A description of the behavior of HD 47129 on ground-based observations and a preliminary account of the behavior of the resonance doublet of Si IV in the ultraviolet are presented. The importance of the object from the evolutionary point of view and the desirability of a concentrated, cooperative observing effort in as wide a wavelength range as possible and throughout the orbital cycle, are stressed.

Key words: **STARS-BINARIES – STARS-EARLY TYPE**

I. INTRODUCTION

At the CTIO 25th Anniversary Symposium I put forward the idea (Sahade 1988), which must have certainly been already advanced by others, to plan "for telescopes to be devoted to specific types of work, like following interacting binaries throughout their orbital period" in order to "obtain good coverage of a complete cycle and also perhaps to have observations repeated at several cycles". The old Lick Expedition telescope that the Astrophysics Group of the Chilean Pontifical Catholic University possess at San Cristóbal is, in a way, a facility devoted, at least partly, to such kind of a program. One important outcome of this good observational policy of the Group was the study of the 78-day period Wolf-Rayet binary γ_2 Velorum (Moffat et al. 1986) which provided a strong confirmation of Niemela and Sahade's (1980) results that had been questioned in an investigation based on a small number of, not well distributed phasewise, observations.

When I was invited to give a paper at this multi-celebration Colloquium, I was suggested to talk about Be stars in general, or about a particular Be object, because this is a subject Nikolaus Vogt and his collaborators are mainly working on here. But I thought that the present occasion was an excellent one to bring out the problem of the very massive O-type system HD 47129 because it may perhaps induce the Group to devote telescope time to the continuous observation of the object, although it is not exactly a southern one. Moreover, it may induce the Group to speed up providing the telescope with a modern detecting system and the possibility of observing the Hα region which is so important particularly in peculiar objects. At the same time, the meeting offered a good opportunity to mention some results that Estela Brandi and myself are working out from the archival IUE images, and perhaps try to discuss them in the framework of the ground-based observations.

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There are, of course, other objects that ought to be tackled by observing them continuously during an appropriate interval of time but we shall confine ourselves to the most massive system so far known, only.

II. THE OBJECT

HD 47129 = HR 2422 = BD +6º 1309 = GC 8631 = V640 Mon [$\alpha = 6^h37^m24^s.0$, $\delta = +6º08'07''$ (2000.0); $m_v = 6.06$] is a spectroscopic binary with a period of 14.3961 days, usually called Plaskett's Star on account of the fact that it was J.S. Plaskett (1922) who, in 1921, at Victoria, discovered the binary character of the object and the large masses of the components.

HD 47129 is in the constellation of Monoceros, and is a member of the Mon OB2 association, which is located in a H II region near the young open cluster NGC 2264. Abhyankar (1959) has estimated an average value for the distance which places the object at some 1140 parsecs from us.

Abhyankar and Spinrad (1958) found that HD 47129 undergoes irregular light fluctuations which may become as large as 0.08 magnitudes and appear to be real. The nature of such variations, however, are not readily understood.

The object also displays variable, intrinsic polarization, in u, B, V, R, (Hayes 1975; Pfeiffer 1975; see also Pfeiffer and Koch 1977), which is synchronous with the orbital cycle (Rudy and Herman 1978). From their observations, Rudy and Herman (1978) determined that i= 70º ±9º.

III. GROUND-BASED SPECTROSCOPY

The spectrum of Plasketts's star displays five sets of lines, four in absorption and one (should we say two?) in emission, as follows.

1. A set of relatively strong absorption lines corresponds to one of the components of the system, the component that has been usually known as "the primary component" and was classified as Oe 5 by Plaskett (1922) and later as O8 V (cf. Sahade 1962). These lines are easy to measure and yield a velocity distribution with little scatter from a mean velocity curve (Plaskett 1922; Struve 1948; Stickland 1987) but <u>the velocity values at maximum velocity of recession were systematically different by some 30 km s^{-1} in two different cycles (Struve 1948).</u>

Abhyankar (1957) derived orbital elements by combining all available radial velocity measurements and the derived parameters are given in Table 1.

TABLE 1. Orbital Parameters of HD 47129

γ_1	+24.9	± 0.8	km s^{-1}
K_1	205.2	± 1.0	km s^{-1}
e	0.011	± 0.005	
ω	22.4	±26.9	degrees
T_p	8.07	± 1.07	days
a sin i	40.62 x10^6		km
f($\mathfrak{M}$)	12.88		$\mathfrak{M}_\odot$

2. A set of fainter absorption lines which are normally described as those arising in the "secondary" component of the system, that is, in the companion to the O8 V star.

Plaskett (1922) stated that these lines are "very weak and the measures very difficult and uncertain", and added that "the Pickering helium lines 4542 and 4200 seem relatively the strongest in this spectrum indicating possibly a slightly earlier type, but the stronger helium lines 4026, 4472, 4713, 4922 also appear and have been measured". "Hβ and Hγ in the second spectrum have generally been measured but were only given low weight on account of faintness and breadth". No N lines were seen by Plaskett.

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Struve (1948) found the lines of the "second component" easily detected but "weak" and more diffuse than... those of the principal component". He normally measured lines of H and He I, and, at variance with Plaskett's, on Struve's plates the He II lines are relatively weak. Struve noticed night-to-night large intensity variations in the phase interval that corresponds to velocities of approach. Fig. 1 shows a reproduction of Struve's (1948) spectra.

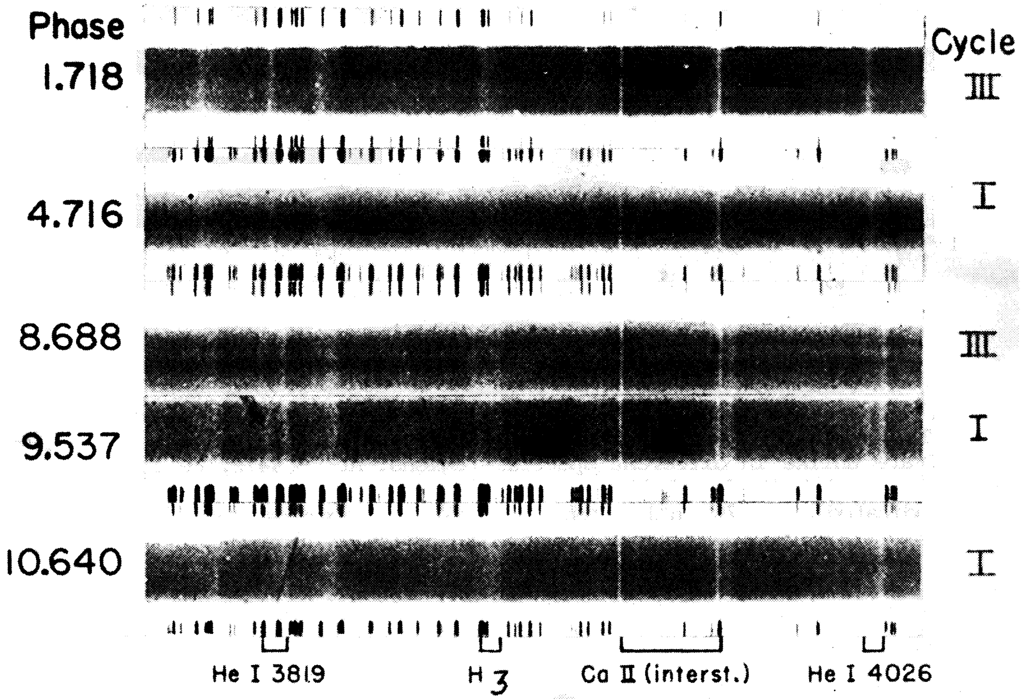

Fig. 1. Reproduction of Struve's (1948) spectra of HD 47129; the phases in terms of the value of the period and taking as the origin the conjunction at which the O8 V star is farthest away from us would be, from top to bottom, 0.37, 0.58, 0.85, 0.91 and 0.99 P, respectively. The original illustration was reproduced as it was published; the lines are absorption lines.

The next set of spectra was taken at Mount Wilson in 1956-57 (Struve, Sahade and Huang 1958) and the surprising result was that then the lines of the "secondary component" were present only in the red portion of the spectrum, displaying He I 5876 and He I 6678, the former being very weak and the latter as strong as the corresponding line of the primary component of the system (Fig. 2).

Struve's (1948) observations led to the belief that the system of HD 47129 was actually formed by two stars of the same spectral type, the "secondary" being smaller in size than the "primary" to account for the relative weakness of its spectrum. But the 1956-57 Mount Wilson observations posed the question as to whether the "secondary" was indeed an O8 object. It was then thought that the "secondary" was really a later type object but that its spectrum, somehow, mimics that of the companion.

It is clear that what has usually been described as the spectrum of the secondary component is certainly not that of a star, it may be that of a star distorted by something that is variable in nature and in some epochs becomes opaque in the photographic region of the spectrum. On spectrograms taken in the interval 1969-1975 the lines of the "secondary" component are weak but seen again in the blue-violet region of the spectrum (Hutchings and Cowley 1976).

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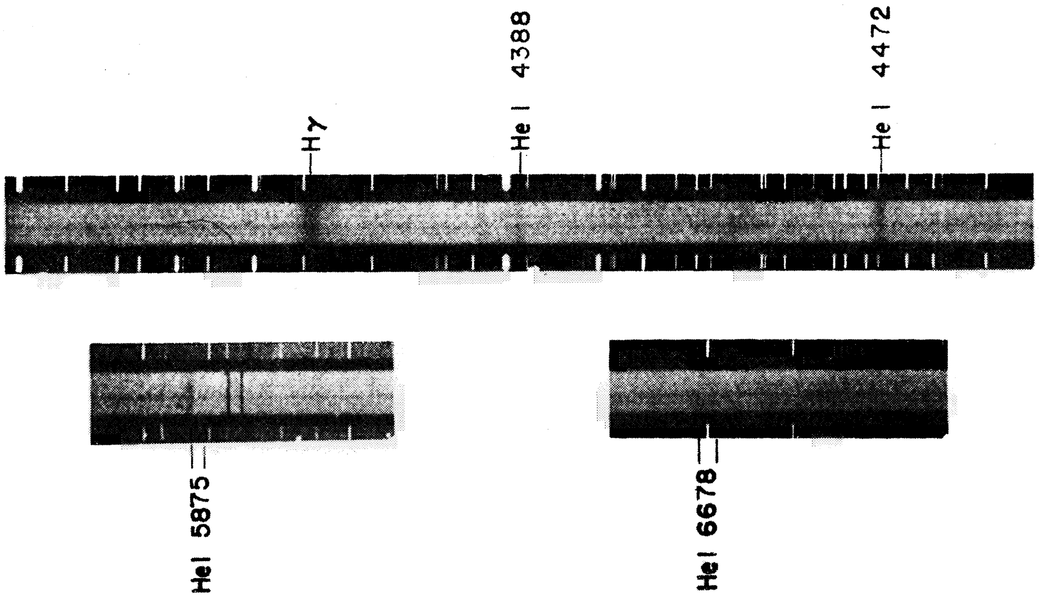

Fig. 2. The spectrum of HD 47129 in 1956-57 (from Struve, Sahade and Huang 1958). The original caption reads "The relative intensities of the components of He I are unlike in different spectral regions. At λ 4472, He I shows only one strong violet-displaced line (primary component); at λ5876 (by an oversight indicated by 5875 in halftone) a weak, red component is also present; and at λ6678 the two components are of about the same intensity."

The behavior of the radial velocities from the spectrum we are discussing does not suggest orbital motion, shows systematic differences from one epoch to another and yields a value of γ_2 which is 100 km s^{-1} more negative than γ_1 . Abhyankar (1957) has illustrated such a behavior by plotting the radial velocities from all the available observations together, with appropriate symbols for each epoch; his plot is reproduced in Fig. 3.

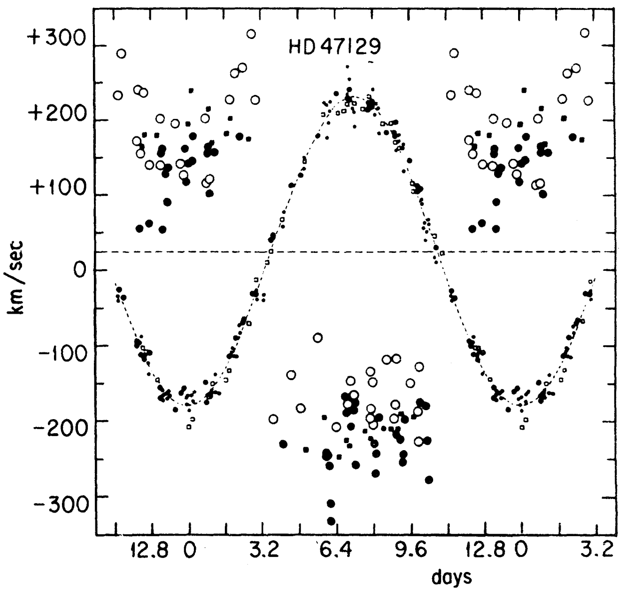

Fig. 3. Abhyankar's (1957) plot of all radial velocities of HD 47129. The phases are indicated in days and the origin was taken at the quadrature where the O8 V component had velocities of approach. Symbols are as follow: Victoria (1922): primary, open squares, secondary, filled squares. Mc Donald (1947-1948): primary, small open circles, secondary, large filled circles. Lick and Mount Wilson (1956-1957): primary, small filled circles, secondary, large open circles.

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3. A set of sharp lines of the triplet series of He I (3888, 4472, 5876) that are violet-displaced by some 700 km s^{-1} and suggests the existence of an expanding shell (see Fig. 4). The He I 6678 line, which belongs to the singlet series, seems to behave similarly but the feature is very much weaker.

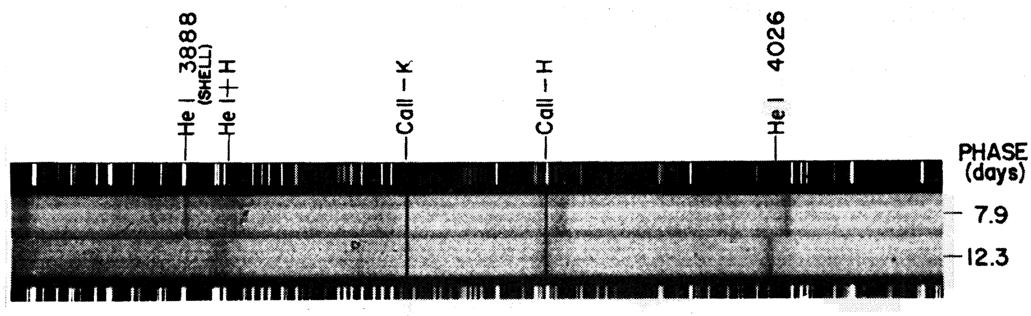

Fig. 4. Diluted radiation at the He I triplet series in HD 47129 in 1956-57 (Struve, Sahade and Huang 1958). The phases in terms of the value of the period and taking as the origin the conjunction at which the O8 V star is farthest away from us would be, from top to bottom, 0.80 and 0.10 P, respectively.

The presence of these violet-displaced lines that suggest dilution of radiation was discovered on the material taken at Mount Wilson in 1956-57 (Struve, Sahade and Huang 1958; Struve 1957). At such time the diluted lines were present in a narrow range of phases, namely, 0.73P-0.94P, and also on a plate taken at about 0.5P. For the phases that we are giving we have preferred to take as the origin the conjunction at which the O8 V component is farthest away from us; this permits us to visualize more easily what we are talking about. For some reason, in the earlier papers the origin was the quadrature at which the O8 V star has velocities of approach.

The observations were understood in terms of an envelope the density of which was higher on the side where the primary component is receding from us.

4. A set of extremely sharp absorptions of Ca II-H and -K and Na I-D, that are of interstellar origin.

5. The fifth set of lines present in the spectrum of HD 47129 is in emission, and it is shown in several lines, particularly in Hα and in He II 4686 (Struve, Sahade and Huang 1958; Struve, Sahade and Abhyankar 1958). The features are variable with phase.

Fig. 5 reproduces the region of Hα as it appears on the material taken by Sahade and by Struve at the Mount Wilson Observatory in 1956-57. We distinguish an underlying broad feature the width of which corresponds to velocities of 600-700 km s^{-1}. The emission appears to be bordered by a violet, somewhat diffuse absorption, which suggests that we are dealing with a P Cygni profile. This feature seems to form in the extended gaseous envelope in which the system is embedded.

We also distinguish a narrow emission superimposed upon the broad emission feature, that gives rise to the radial velocity plot that is reproduced in Fig. 6. The interpretation of the behavior of the narrow emission suggested that it arises in a stream deflected towards one side of the system perhaps by radiation pressure from the O8 V star.

In addition, Hα is cut into by absorption features that appear to arise in the two components of the system, but while the absorption that arises in the "primary" is strong, the other one is weak and, sometimes, difficult to measure. In the phase interval where the diluted lines are present, the absorptions appear as only one broad feature.

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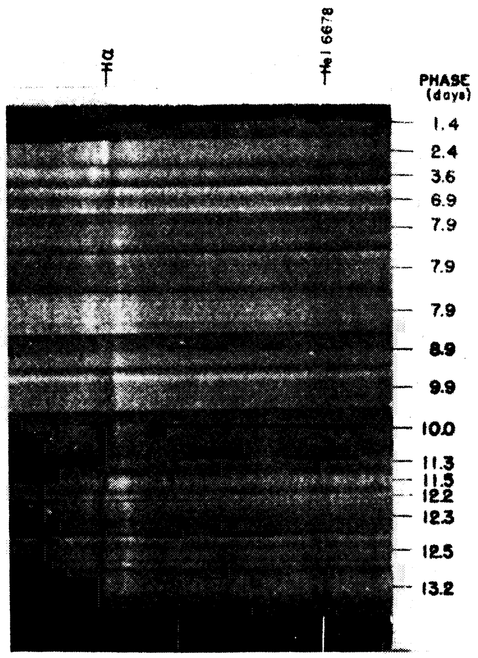

Fig. 5. The region of Hα in 1956-57 (Struve, Sahade and Huang 1958). The phases in terms of the value of the period and taking as the origin the conjunction at which the O8 V star is farthest away from us would be, from top to bottom, 0.35, 0.42, 0.49, 0.73, 0.80, 0.80, 0.80, 0.87, 0.94, 0.94, 0.03, 0.05, 0.10, 0.10, 0.12, 0.17 P, respectively.

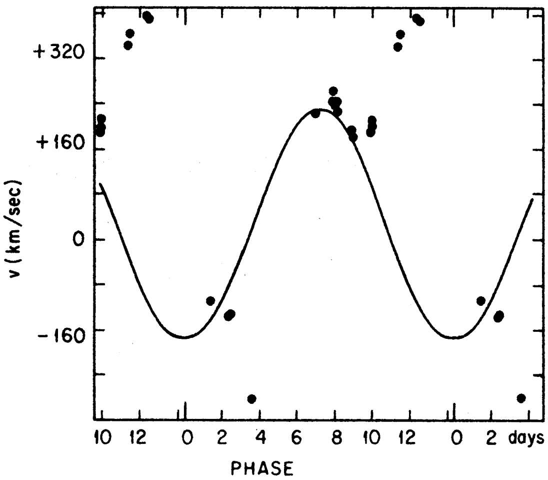

Fig. 6. Plot of the radial velocities from the narrow emission at Hα (Struve, Sahade and Huang 1958). The phases are indicated in days and the origin was taken at the quadrature where the O8 V component had velocities of approach.

IV. THE LINES OF THE "SECONDARY SPECTRUM"

The examination of Fig. 3 suggests that the spectrum of the "secondary" component must be highly distorted by the presence of matter being shed by the star, and we surmise this from the fact that

$$\gamma_2 - \gamma_1 \sim -100 \text{ km s}^{-1}$$

(cf. Sahade 1959). Mass loss takes place presumably in an irregular fashion but perhaps with spherical symmetry.

The question then arises as to whether we can actually determine the masses of the components from a plot such as that of Fig. 3. Almost thirty years ago, Sahade (1962) pointed out that although it is true that the velocity distribution that is yielded by the "secondary" spectrum is erratic, shows some trends that are different at different times, displays a large scatter and looks hopeless particularly in the phase interval when the star is receding from us, the average velocity values at quadratures are always about the same, and are probably the star's velocities at quadratures. The acceptance of this argument leads to the result that the mass of the "secondary" star must be larger than the mass of the O8 V component. If we take into account the value of i from the polarization measurements, the mass-function derived by Abhyankar (1959) and the mass-ratio of 0.8 (Sahade 1962), then we have

$$\left.\begin{aligned} \mathfrak{M}_1 &= \mathfrak{M}_{O8\ V} = 40\ \mathfrak{M}_\odot \\ \mathfrak{M}_2 &= 50\ \mathfrak{M}_\odot \end{aligned}\right\} \text{ if } i = 70^\circ$$

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but the uncertainty in i makes the value of 60º, considered earlier, also a good possibility; in such a case,

$$\left.\begin{aligned} \mathcal{M}_1 &= 51\ \mathcal{M}_\odot \\ \mathcal{M}_2 &= 64\ \mathcal{M}_\odot \end{aligned}\right\} \text{if } i = 60º$$

As it was also pointed out by Sahade (1962), a similar type of behavior, as far as the distribution of the velocities from the "secondary" spectra is concerned, is shown by the early type binaries AO Cassiopeiae, V448 Cygni and β Scorpii.

Apart from the peculiar and variable spectral behavior of HD 47129, the object appears to be very important also from the evolutionary point of view, because we may be dealing with an interacting binary caught at or about the stage of rapid mass loss before mass-reversal has taken place (Sahade 1987). This possibility would emphasize the importance of understanding the object and of scrutinizing the behavior of the mass loss process.

V. THE IUE ARCHIVAL DATA

Recently, Brandi, Ferrer and Sahade (1989) undertook a study of the archival IUE images of the 78.5 day-period Wolf-Rayet binary γ_2 Vel to try to reanalize the variations in the line profiles that were discovered several years earlier (Willis and Wilson 1976), and to decide whether or not we could advance a different explanation from the ones that were offered before (Willis and Wilson 1976; Willis et al. 1979; Sahade and Zorec 1981).

In our work we found evidence for an effect of the collission of the winds from the two components of the system, and we immediately thought that it would be highly desirable to check whether or not we could find similar effects in other early type binaries and, if so, see what kind of general conclusion could be drawn, if any.

HD 47129 appeared to be a good candidate to work with because Sara Heap (1981), on the basis of five IUE images, thought she might have found evidence for the effect of colliding winds in the binary. As a consequence, we decided to scrutinize the whole of the available material on the object that existed in the IUE archives.

For our analysis we have used hard copies of selected spectral regions of the ultraviolet spectra of HD 47129 obtained at the Regional Data Analysis Facility of NASA's Goddard Space Flight Center during a short stay in 1983. The selected regions were 40-50A wide and contained the following lines

N V	1239, 1243 A
Si IV	1394, 1403 A
C IV	1548, 1551 A
He II	1640 A
Mg II	∿2800 A

Unfortunately, most of the images were taken in the small aperture mode, as it was usually the case at the first IUE episodes, when the object was bright. When using small aperture it is not possible to determine absolute fluxes nor to compare the continua of two images because the position of the star relative to the spectrograph entrance slot may be different during different exposures.

VI. THE RESONANCE LINES OF SI IV

The analysis of the IUE spectra is still under way but I shall attempt a preliminary description of the behavior of the resonance doublet of Si IV. Figures 7 and 8 reproduce the region at different phases of the orbital cycle.

The profiles of the doublet are P Cygni profiles with very broad violet absorptions, actually much broader than the separation of the two components; therefore, they partially overlap. Over such very broad profiles we see superimposed

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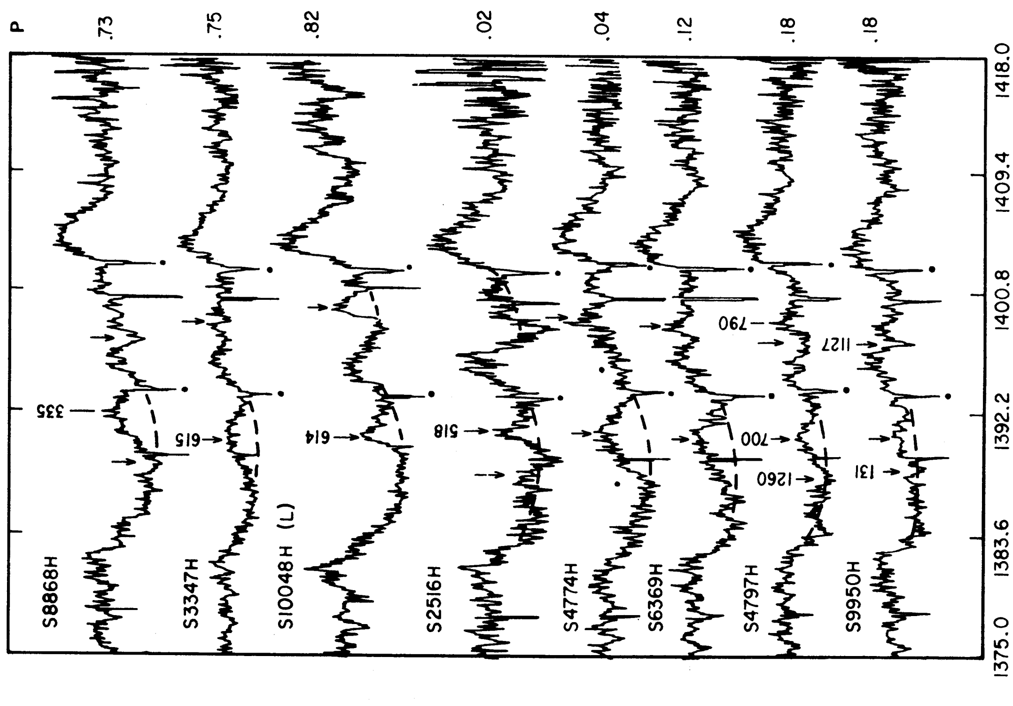

Fig. 7. The region of the resonance doublet of Si IV in the IUE spectrum of HD 47129.

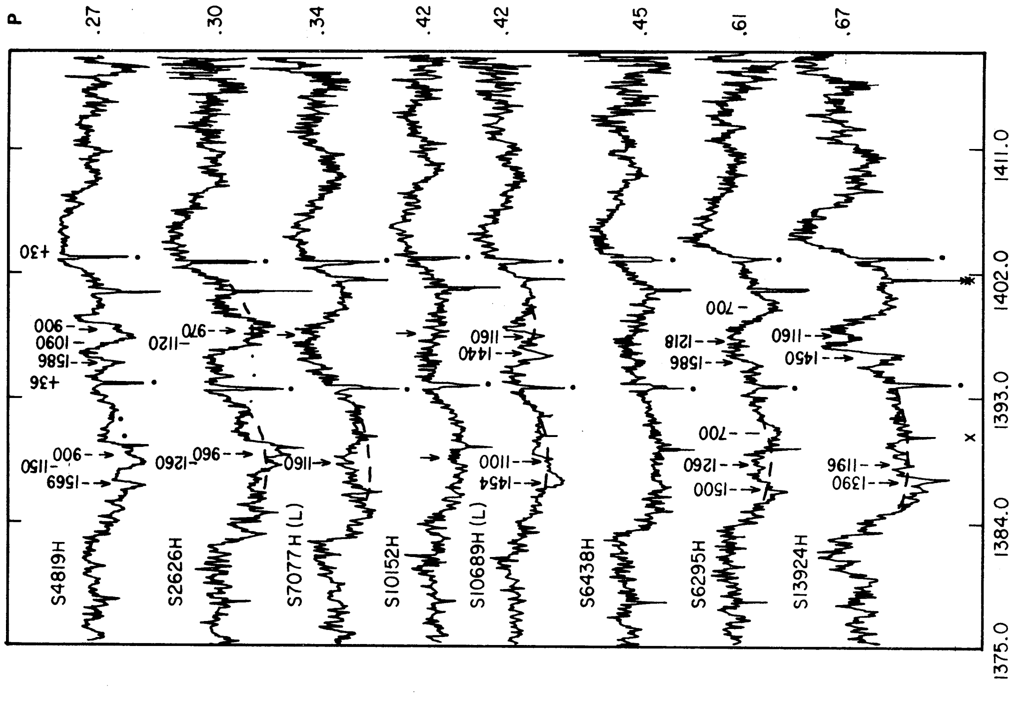

Fig. 8. The region of the resonance doublet of Si IV in the IUE spectrum of HD 47129.

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TABLE 2. Broad Emission and Absorptions Superimposed upon Violet Absorption Profile of Si IV

Phase (P)[a]	Radial Velocity from Emission Center (in km s^{-1})[b]	Radial Velocities from Absorptions (in km s^{-1})		
0.02	- 518:*	-800	......	......
0.04	- 700	......	......	......
0.12	- 700	......	......	......
0.18	- 700	......	-1200	......
0.18	- 700	......	-1200	......
0.27	- 700*	-900	-1100	-1600
0.30	- 700*	-900	-1100	......
0.34	-1160	......	......	......
0.42	no emission: normal abs.	......	......	......
0.42	......	......	-1100	-1450
0.45	no emission: normal abs.	......	......	......
0.61	......	-700	-1200	-1600
0.67	......	......	-1150	-1400
0.73	- 335	......	-1100	......
0.75	- 615	......	......	......
0.82	- 614	-900	......	......

[a] The origin of phases is the conjunction at which the O8 V is farthest away from us.
[b] The asterisk indicates a P Cygni profile.

a) very sharp absorptions, at about the laboratory wavelengths, that must arise in the outermost layers of the extended envelope;

b) an emission of some 600-700 km s^{-1} width which is absent at least in the phase interval 0.42P-0.67P;

c) one or more absorption features.

Table 2 lists the radial velocities derived from the measurement of features under b) and the most conspicuous under c); there may be other absorption features and we are trying to ascertain whether or not it is so.

In general, the emission superimposed upon the very broad absorption of the P Cygni profile of Si IV yields a velocity of about -700 km s^{-1}. It appears as though there are profile variations with phase and also with the cycle in the orbital motion. Similar types of profile variations in the photographic region may result in the varying distortion effects that are displayed by the ground-based observations. But we need to secure observations with the IUE in the large aperture mode before we can ascertain the pattern of behavior in the ultraviolet and then try to correlate such a behavior with the behavior of lines that are observed in the photographic region.

The fact that the P Cygni profiles of the superimposed emission correspond to velocities of the order of -900 km s^{-1}, probably mean that Si IV is formed further out than Hα. As for the rest of the absorptions, they may arise in other layers of the extended envelope.

The point to make, particularly in the context of the meeting, is that it would have certainly been very helpful for the interpretation of the IUE observations to have at disposal contemporaneous ground-based material that would provide additional pieces of information about the gaseous envelope that could help in our understanding of HD 47129.

If the evolutionary stage of the binary is actually the one we believe it is at, a concentrated cooperative observing effort in as wide a wavelength range as possible may be giving us answers regarding the mechanisms and the physics of evolutionary mass loss in close binaries.

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