OBSERVATIONS OF THE GAS STREAM IN THE MASS TRANSFER BINARY HR 2142[1]

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ABSTRACT

The mass transfer binary system HR 2142 has been observed at selected phases with the high resolution spectrograph on IUE. The observations were scheduled throughout the interval $0.91 < \phi < 0.00$ in order to permit us to view the light of the primary star through the gas stream as it presents different orientations to our line of sight. Numerous UV lines formed in the gas stream have been identified. The strengths and velocity variations displayed by these lines are compared with those observed in the ground-based spectral region. As part of a preliminary analysis of the IUE data, column densities and velocities from Si III (4), Si IV (1), and Ti III (1) are used to deduce electron densities in the gas stream as well as its thickness. Possible evidence for stratification in the gas stream is presented.

INTRODUCTION

HR 2142 (HD 41335) is a 5th magnitude Be star which is also a mass transfer binary system (references 1 and 2). With a period of 80.86 days and a systemic mass of about 15 $M_\odot$, it is a high mass counterpart of the familiar Algol type binary system.

In order to investigate the physical properties of the gas stream, a series of high resolution IUE observations were completed throughout the phase interval $0.91 < \phi < 0.00$, when we view the light of the primary star through the gas stream. The journal of the observations is presented in table I. The phase, ϕ, which is listed for each observation, is obtained from a recent orbit solution for this single lined spectroscopic binary system (reference 2). According to this solution, if the period is fixed at $80^{d}.86$, K = 9.4 km s^{-1}, V_o = 24.1 km s^{-1}, and conjunction occurred on JD 2441990.6. Also included in table I is a list of phases based solely upon spectroscopic observations (reference 1) in which Φ_s = 0.0 when the Balmer gas stream lines peak in strength.

In this paper, a preliminary analysis of the IUE data is presented. Phase dependent observations of features in the spectral region λλ1295 - 1310 [which contains Si III (4), Si II (3), and Ti III (1)] and the Si IV resonance lines are analyzed and compared with earlier ground-based and *Copernicus* ultraviolet observations.

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ABOUT THE MODEL

Details about the model for HR 2142 can be found in references 1 - 4. In figure 1, we show the model which has been developed over the past seven years from both ground-based and Copernicus ultraviolet observations. The phase interval over which the IUE observations were made is indicated. Some features of the model which are shown in figure 1 are: 1) the presence of a well-defined gas stream and counter stream which apparently have large inclinations with respect to the line of centers in the system; 2) the existence of an extended, rotating, low-density ($N_e \simeq 10^{10}$ cm^{-3}) accretion disk positioned about the primary star; and 3) the existence of an overall stellar wind from the primary star and/or the disk which appears to be enhanced at $\phi = 0.5$. Since the system does not undergo an eclipse and the projected rotational velocity of the primary is high (about 400 km s^{-1}, reference 5), we assume that the inclination of the system is about 70°. Therefore, the physical parameters we deduce for the gas stream pertain to relatively high latitudes. Since the spectral type for the primary is B1IV, the total mass in the system is about 15 $M_\odot$.

DESCRIPTION OF THE OBSERVATIONS

In figures 2 and 3, we show the phase dependent spectral variations observed in two selected regions. Between λλ1295 and 1310 we observe lines of Si III (4), Si II (3), Ti III (1), and O I (2). The O I line is entirely an interstellar feature and is used as an aid in calibrating the wavelength scale. Si II 1304 is a blend of interstellar and gas stream lines. Superimposed on broader photospheric features are sharper lines of Si III (4) and Ti III (1) which are formed in the gas stream. In figure 3, it can be seen that the SiIV resonance lines have gas stream components which are redshifted by about 100 km s^{-1} relative to the centers of the photospheric lines.

From an inspection of figures 2 and 3, it can be seen that the sharp, shell-type absorption lines which are formed in the gas stream are already present in the earliest spectrum taken at $\phi = 0.91$. In fact, the strongest members of Si III (4), as well as other gas stream features seen in other spectral regions, are saturated at this phase! The gas stream lines peak in strength between $0.95 < \phi < 0.96$. However, the intensities of the gas stream lines decline rapidly after $\phi = 0.96$. It should be noted, though, that the intrinsically stronger features persist at conjunction.

From $\phi = 0.91$ through 0.96, the gas stream lines show a positive velocity shift (50 - 100 km s^{-1}) relative to the photosphere of the primary star. However, at conjunction, the gas stream lines which remain appear to be at rest relative to the photosphere.

The ultraviolet observations described above are compatible with earlier ground-based and Copernicus UV observations of this star. In the visible spectrum, the Balmer gas stream features reach maximum strength at $\phi = 0.96$ but disappear completely at conjunction. Furthermore, the Balmer features show a large velocity shift (80 km s^{-1}, reference 1) relative to the photosphere at $\phi = 0.92$ but this shift decreases to zero by conjunction. Copernicus observations (references 3 and 4) revealed that gas stream lines of

C II, N II, Si III, S III, and Fe III were present at conjunction whereas weaker lines of Si II and S II were absent. The latter study did show that all of the gas stream lines in the ultraviolet were weaker at conjunction but it also revealed that the profiles of the lines are complex and contain multiple components. One of these components is a highly saturated feature which remains relatively fixed in velocity from $\phi = 0.90$ through $\phi = 0.96$. The other components are unsaturated and show more positive velocities. The total equivalent width for the unsaturated components is comparable to that of the main component. At conjunction, the strengths of the higher velocity components are much reduced. We now believe that the velocity variations displayed by the gas stream lines can be understood in terms of the variable multiple components.

The most numerous gas stream features in the UV spectrum of HR 2142 are lines of Fe III. Lines of C I, C III, N I, N III, O I, O III, and Fe II are not observed. Ultimately, all of the gas stream lines which can be identified and reliably measured will be analyzed to refine the model for the gas stream. However, in view of the complexity already observed in the gas stream lines (reference 4), the preliminary analysis of the IUE data presented in this paper is restricted to lines which are unsaturated and presumably unblended with other features.

ANALYSIS

The fact that Fe II gas stream lines are not observed suggests that the temperature in the gas stream is above 18,000°K. From the ratio of Fe III 1032/1130 (reference 4), we conclude that the temperature in the gas stream is close to 19,000°K. Therefore, in the analysis presented below, we adopt a gas stream temperature of 19,000°K.

As stated in the last section, the complex nature of the gas stream lines renders any analysis of saturated features highly uncertain. Although the Fe III lines are the most numerous gas stream lines, all of these features which have reliable f-values are quite saturated. Upon inspection of the data, it was determined that Ti III (1) 1296 was especially suitable for analysis.

As seen in figure 2, Ti III λ1295.88 begins to show at $\phi = 0.92$. By $\phi = 0.96$, it has reached a maximum strength of 0.2 A. Other stronger members of this multiplet are blended with Si III (4) $\lambda\lambda$1295 and 1299. The Ti III features appear to have disappeared completely by $\phi = 0.98$. For the analysis of the line strength, the f-value was obtained from Wiese and Fuhr (reference 6) while the partition functions for Ti were computed from data in Drawin and Felenbok (reference 7). The column density from Ti III 1296 observed at $\phi = 0.96$ is 1.8×10^{14} cm^{-2}. The column density for Ti III becomes 10^{15} cm^{-2}. If $T \simeq 19{,}000$°K and $N_e \approx 10^{12}$ cm^{-3}, then Ti III/Ti = 5×10^{-3}. Since hydrogen is 10^7 times more abundant than Ti, the Ti III 1296 observation implies a hydrogen column density of 2×10^{24} cm^{-2} at a phase of 0.96. Therefore, with a density about 10^{12} cm^{-3}, a path length of 10 to 20 $R_\odot$ (or 1 - 2 R_*) is implied. This result is compatible with the theoretical calculations for the structures of gas streams by Lubow and Shu (reference 8). Finally, it should be emphasized that such large column densities persist for a very short interval of time ($0.93 < \phi < 0.96$). Densities are at least ten times lower outside of the above stated phase interval.

The Si IV gas stream lines (figure 3) are also unsaturated and, therefore, suitable for analysis. The column density of Si IV is 3×10^{13} cm^{-2} at a phase of 0.96. At $\phi = 0.91$, it is half of this value while at conjunction the column density is reduced by two-thirds. If the temperature in the Si IV region is about 19,000°K and the electron density is between $10^{11} - 10^{13}$ cm^{-3}, then most of the silicon must be triply ionized. Since the abundance ratio between hydrogen and silicon is 3×10^{4}, a hydrogen column density of about 10^{18} cm^{-2} is implied. Therefore, either a low electron density or a small path length is implied. Neither are compatible with analyses of other spectral features formed in the gas stream. The low column density from the Si IV lines suggests that these features are formed in a different portion of the gas stream than are the lines of Ti III, Fe III, and the Balmer lines. Perhaps it should be noted that the Si IV lines show a larger velocity shift (about 120 km s^{-1}) relative to the photosphere than do the above mentioned lines as well as the gas stream lines of Si III.

The weaker, unblended members of Si III (4) were also analyzed. These lines suggested a Si III column density of 5×10^{14} cm^{-2}. If the path length is about 10 $R_\odot$, an electron density of 10^{11} cm^{-3} is implied for the Si III region. Some of the Si III lines remain saturated throughout the interval of the observations. The velocities from the Si III lines are compatible with those from the Balmer lines.

In this paper, a preliminary analysis of the IUE observations has been presented. Ultimately, the analysis of the saturated lines as well as the acquisition of additional observations should allow us to develop a detailed model for the mass flow in the system.

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TABLE I - JOURNAL OF IUE OBSERVATIONS OF HR 2142

Image No.	Date (U.T.)	Julian Date (244+)	Phase (ϕ)	Phase (Φ_s)
SWP 8596	1980 March 30	4328.51	0.91	0.95
SWP 8597	1980 March 30	4328.55	0.91	0.95
SWP 8604	1980 March 30	4329.21	0.92	0.96
SWP 8616	1980 March 31	4330.14	0.93	0.97
SWP 6962	1979 October 23	4169.99	0.95	0.99
SWP 8637	1980 April 2	4332.50	0.96	0.00
SWP 6996	1979 October 25	4172.03	0.98	0.02
SWP 7007	1979 October 27	4173.78	0.00	0.04

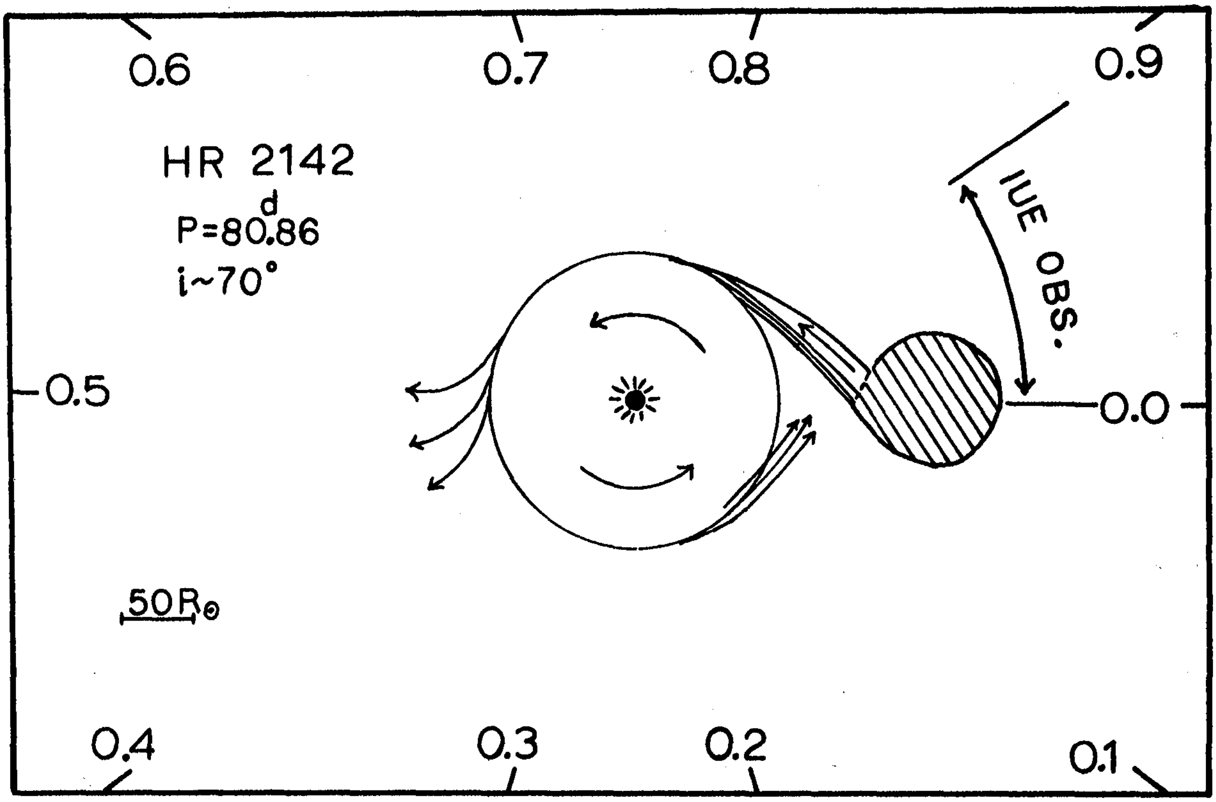

Figure 1: A model for the binary HR 2142. The interval in phase during which the IUE observations were obtained is indicated.

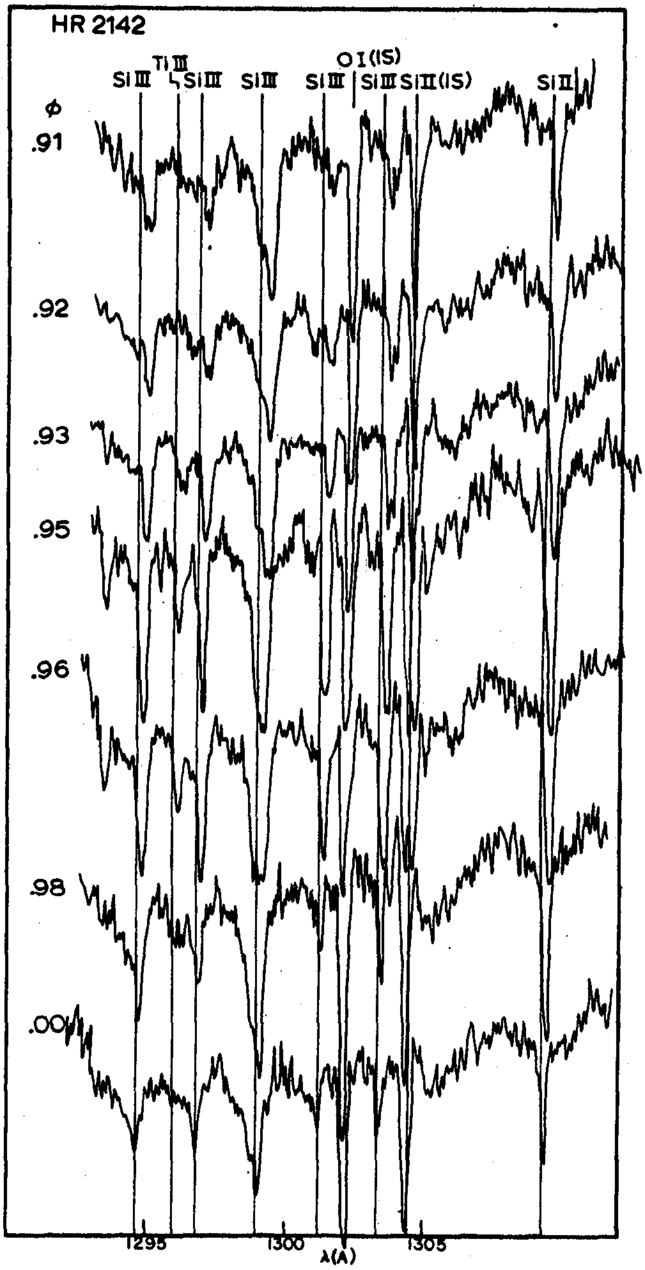

Figure 2: Phase dependent spectral variations in the strengths of the gas stream lines observed between 0.91 < φ < 0.00. The major features are labeled and the vertical lines indicate the locations of the corresponding photospheric lines.

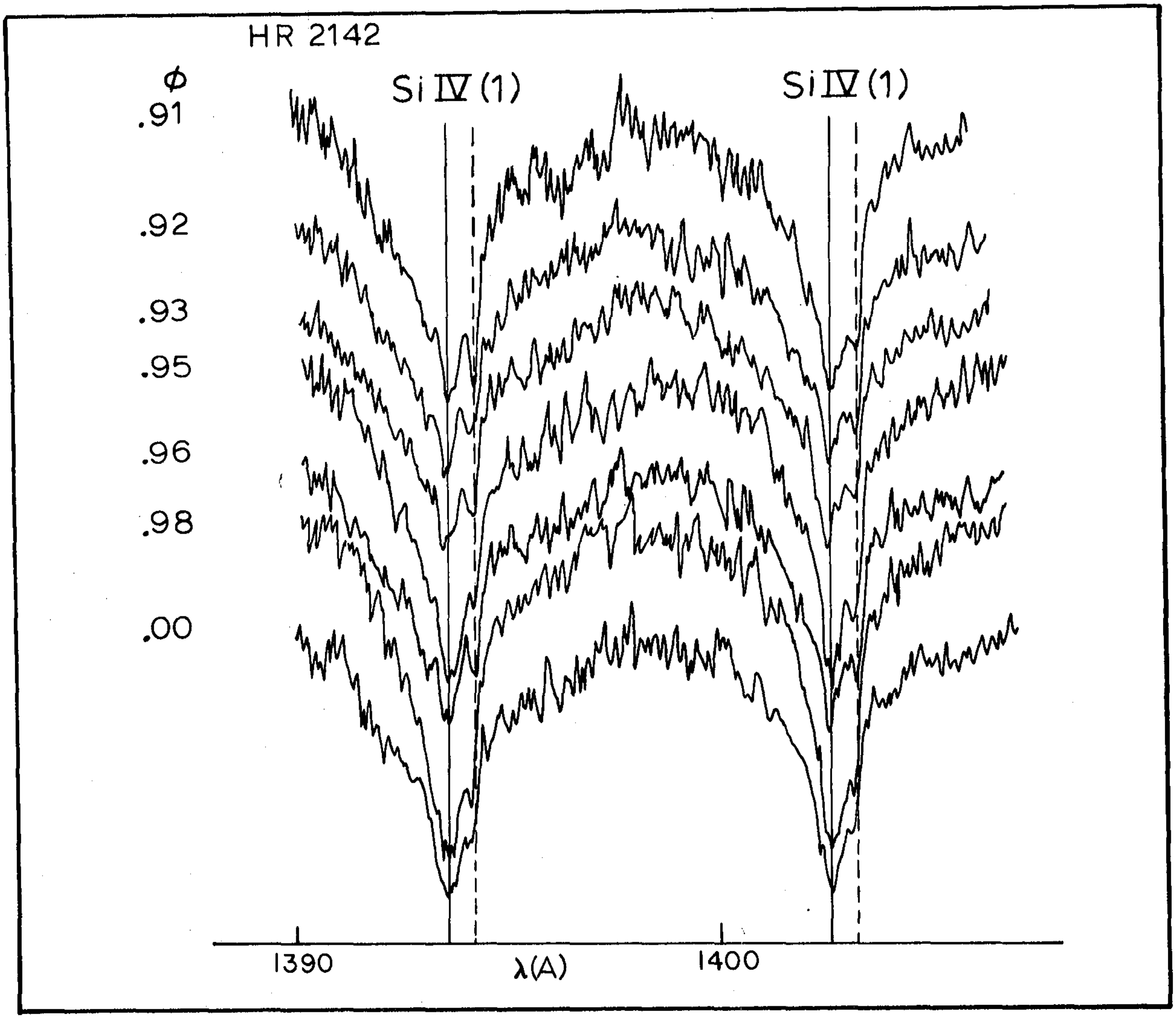

Figure 3: Phase dependent spectral variations in Si IV (1). The vertical dashed lines indicate the location of the gas stream component.