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A Study of V356 Sagittarii and Other Algols in the Ultraviolet Spectral Range

Thesis submitted to the
International School for Advanced Studies, Trieste, Italy
- Astrophysics Sector -
in partial fulfillment of the requirements for the degree of

Magister Philosophiae

Candidate:
Regina M. Daly

Supervisor:
Prof. Roberto Stalio

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Abstract

In this work I present a review of Algol binary systems and their behavior in the ultraviolet spectral region. Many Algols display absorption and/or emission lines which require temperatures much greater than the photospheric temperatures of either component in the system. Thus a region of high temperature must exist in the system. I begin with a review of Roche lobe equipotentials and binary star evolution and nomenclature used in binary star astrophysics. Algol systems are part of the semidetached binary systems. I discuss work we have done on one system in particular: V356 Sagittarii. Following my review of binary star physics, I discuss the work which has been done on V356 Sgr including the model proposed for the system in 1978. I discuss work which has been done on several Algol systems in the ultraviolet. Since all these systems have been observed with the IUE telescope, I give a brief description of the IUE instrument. I have tried to demonstrate the various theories concerning the location of the high temperature region. Some authors have put it near the secondary component, others have suggested two regions and others have suggested only one region surrounding the primary component. I compare the spectra we have taken of V356 Sgr with IUE with previous works. I show the differences and similarities in the high temperature lines in V356 Sgr and those other studied. I suggest reasons for the differences. I also analyze photospheric lines to see if the presence of the high temperature lines affect the photosphere of the primary.

To my advisor,
my confidant,
my friend,
my grandmother Mary Margaret Palmer

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I would like to thank my family who encouraged me while I was living out of the US. I would like to thank a few people at SISSA; Phil Cuddeford who helped me when I arrived in Trieste and tried to improve my English, Hugo Morales Técotl, who always offered me his quiet, strong friendship though his research is at the other end of the universe from mine, Mike Smith, who gave me long conversations and Saturday nights filled with Twin Peaks and chocolate, Noboru Takeuchi for entertaining meal times and nights at El Gaucho and Miguel Chávez Dagostino for teaching me useful Spanish and for being such a close friend. I will miss them all.

I would also like to thank Adrian Jones for simply being a friend during times when all I needed was a friend eventhough I was thousands of miles away. Be the Buddha.

Contents

1 Introduction

In this work, I present a discussion of interacting binary stars or, more specifically, the system V356 Sagittarii and similar binary systems classified as Algols. V356 Sgr consists of a B main sequence primary star and an A-type giant. It has a period of 9.8 days with an 11-hour eclipse. The B star is the more massive, though smaller, component by a factor of approximately 3. This is a characteristic of Algols. It has been shown that circumstellar material surrounds the primary star in V356 Sgr. (Plavec et al. 1984) I will discuss recent work on other Algols and follow this with a discussion of results from six days of high resolution IUE observations of V356 Sgr taken out of eclipse in May 1990. During primary eclipse, the IUE spectra of V356 Sgr is a pure emission spectra with the N V lines the strongest emission line. (Plavec 1984) This system has been studied in both low and high resolution IUE spectra during eclipse, but no studies have been done o the out of eclipse spectra. Peters and Polidan (1984), studied four Algol systems out of eclipse and found the lines of Si IV, N V and C IV lines to be highly variable within one period and also variable over several periods. The systems they studied were all systems with a B main sequence star and a F or G subgiant. Another study of the absorption spectra by of U Cep Plavec (1983b) (a B main sequence star and G subgiant) also showed high variations of these lines within a period and between periods. Since V356 Sgr is slightly different from those studied previously, *i.e.* the primary is critically rotating and the secondary is an A giant rather than an a late subgiant, the object of this study was to search for similarities and differences in the circumstellar material with those studied and to discuss the nature of the the circumstellar matter as seen by the behavior of the absorption lines of N V, Si IV and C IV. I will discuss the effects of this circumstellar material on the photospheric lines of Si II and C III. These results will be compared to work done on similar systems as well as examination of changes in the photosphere of the B star due to mass influx.

In 2, the theory and background of binary systems and Algol systems is discussed. Included are discussions of Roche lobes, nomenclature in interacting binary systems, the definition of Algols systems and W Serpentis systems and the behavior of Algol-type systems in the ultraviolet. I also include a brief discussion of binary star evolution. I will conclude this section with a detailed description of the Lubow and Shu (1975) model for gas dynamics in interacting binary systems. This model is the most widely accepted model for the accretion process and the presence of circumstellar material in semidetached binaries.

In section 3, I will discuss the work which has been done on V356 Sgr. One of the original works was done by Popper (1956), who observed V356 Sgr, published the light curves and determined the parameters for the system. The parameters for this system are considered some of the best determined parameters in Algols. The parameters he published are the parameters used today with some small changes. The parameters I use here have been taken from Popper (1980). Next, I will summarize a model constructed by Wilson and Caldwell (1978) based on Popper's published light curves. They postulated a thick disk around the primary star in V356 Sgr to fit the optical light curves of the system. I will discuss an attempt by Ziółkowski to determine the evolutionary state of V356 Sgr. I will conclude this section with work done with IUE low resolution data on V356 Sgr as part of a study of Algol systems.

In section 4, I will discuss the current work in Algol systems and try to express the conflicting theories in the formation of high temperature ionization lines in Algol systems. In particular, I will discuss the high temperature lines of N V, Si IV and C IV seen in both emission and in absorption in the far ultraviolet spectra. All the systems I present have been observed with IUE. I will begin with a brief description of the IUE instrument and its capabilities. I will discuss the work on γ_1 Velorum, AU Monocerous, and Algol (also known as β Persei) in which researchers suggested two high temperature regions within the systems. I will talk about work on U Cephei, RW Tauri and SX Cassiopeae. For these systems it has been proposed that only one high temperature region exists induced by accretion within the system. Plavec and his collaborators also compare the emission lines strength in the three systems. I will discuss in detail Plavec's (1983b) discussion of the high temperature region in U Cep, both in emission and absorption and his work to determine the nature of this high temperature region. This will be followed by the work done by Peters and Polidan (1984) who studied the absorption lines of Si IV, C IV, and N V in four Algols, AU Monocerous, CX Draconis, U Corona Borealis, and TX Ursae Majoris with high resolution IUE data and postulated the presence of a "high temperature accretion region" surrounding the primary component in their systems.

In section 5, I will return to V356 Sgr. I will begin with a description of the IUE data and give a brief outline of the data analysis. I will show results of high resolution spectra taken by Polidan (1989) during primary eclipse of these lines. I will follow this with a discussion of the high temperature lines of Si IV, C IV and N V in V356 Sgr as seen in the high resolution IUE spectra and their behavior throughout the period. We have fairly good coverage of the whole period. For the 8.9 day period we have data from 6 days with two observations per day. I will compare these also with historical observations. I will discuss the similarities/differences of the high temperature lines in V356 Sgr with those studied by Peters and Polidan (1984). Next, I will discuss various photospheric lines in V356 Sgr to determine if the high temperature region associated with the Si IV, C IV and N V has an effect on the photosphere of the B-star. To my knowledge, this sort of study has not been done in these systems.

Finally, in section 6, I will present the conclusions and possible further research to be done on this system. This system warrants a more quantitative study of the high temperature region than I will give here. As I will show, V356 Sgr has a high temperature region surrounding the primary component which is more stable and spherically symmetric that those previously studied. Since the primary star is rotating at critical velocity, this system also provides a good test for the theory of rapidly rotating stars.

2 Background

2.1 Roche Lobe Equipotentials

The theory of binary stars revolves around the theory of equipotential surfaces known as Roche lobes. In order to discuss interacting binary stars a qualitative derivation of Roche surfaces must be presented. For a more quantitative discussion see Pringle(1985). If one begins with two spherically symmetric stars separated by a distance a, they will be governed by Kepler's third law:

$$P^2 \propto a^3 \tag{1}$$

However, if the two components have sizes on the same order as their separation distance, they are close, then the tidal forces can serve to affect the motion. These tidal forces act like a frictional force and tend to circularize the orbital motion and synchronize the spins. For a given mass distribution and total angular momentum, a system has the least mechanical energy when it rotates as a rigid body . Thus the minimum energy state requires that the components have circular orbits and synchronous spins (see Shu and Lubow, 1981 and references therein). Using the equations of motion in rotating coordinates one can show that the gravitational potential satisfies Poisson's equation:

$$\nabla^2 \phi_G = 4\pi G \rho(r) \tag{2}$$

Here, ϕ_G is the gravitational potential and ρ is the density distribution of the star. Incorporating the assumptions of circular orbits and synchronous rotation one can show that at the surface of a star, where pressure and density tend to zero, the total potential is constant. The total potential in the system is the sum of the gravitational potential and the centrifugal potential, ϕ_C

$$\Phi = \phi_G + \phi_C \tag{3}$$

It would seem that one could then solve the Φ equation to find the equipotential surfaces. However, since the gravitational potential ϕ_G depends on the distribution of density throughout the star, the solution requires complex numerical techniques. The Roche solution is an approximate solution to the Poisson equation assuming that the gravitational field due to each star acts as if the mass of each star were located in the center. This assumption is reasonable since stars are centrally condensed objects. The Roche approximation leads to a simple solution of the Poisson equation and then to the calculation of the equipotential surfaces.

$$\phi_G = \frac{GM_1}{|\mathbf{r} - \mathbf{r_1}|} - \frac{GM_2}{|\mathbf{r} - \mathbf{r_2}|} \tag{4}$$

where r_1 and r_2 are the center of star 1 and 2 respectively and the origin is the center of mass. In the orbital plane where $z = 0$ and $y = 0$ one can compute the critical points on the x-axis connecting the center of the components. One critical point, the inner Lagrangian point or L_1, lies between the two stars. (See figure 1) The Roche equipotentials have been computed assuming circular orbits, synchronous rotation, and centrally condensed stars. Due to the presence of tidal

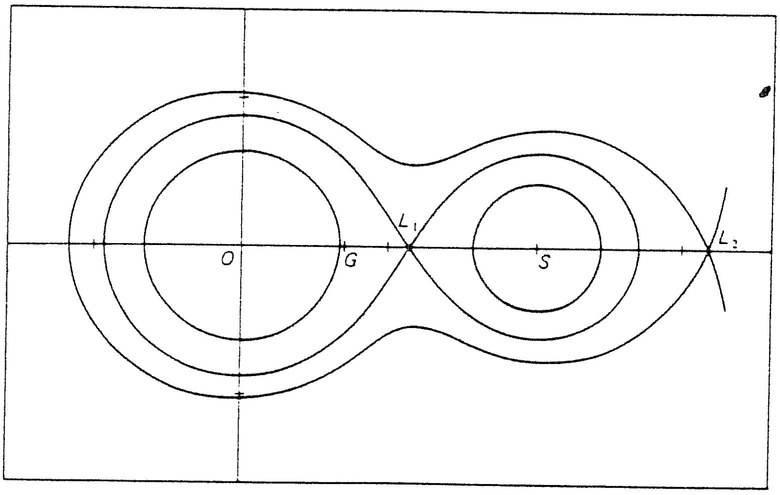

Figure 1. Roche equipotentails in the orbital plane of the binary system. THe center of star 1 is a 0 and star 2 is at S. The Roche lobes have been computed for $M_1/M_2 = 2$ (Pringle, 1985)

interactions which tend to circularize the orbit and promote synchronous rotation, it is reasonable to expect that in most close binaries, the orbit is circular and at least one of the components rotates synchronously. The assumption that the stars are centrally condensed is supported by stellar theory.

2.2 Types and Nomenclature in Binary Stars

Close binary systems are generally divided into three categories based on their Roche lobe configurations. These are *detached, semidetached and contact* binary systems. These are often further subdivided into more specific classes. In all classes, it is generally assumed that the components are close enough that the orbits are circular and at least one component (the less massive) rotates synchronously. The "detached" binary is defined as those systems in which both components are smaller than their Roche lobe. If one ignores the effects of stellar winds then the components do not transfer enough mass to effect stellar evolution. The second class is the "semidetached" binaries. According to theory, when a star begins to exhaust its core, it leaves the main sequence and expands. If this star is a member of a close binary system then the Roche lobe serves as a volume limit for expansion. (Shu and Lubow, 1981) When the star has filled its Roche lobe, it begins to transfer mass through the inner Lagrangian point to the other component. At the inner Lagrangian point, the effective gravity becomes zero and the material is pushed toward the detached component where it is gravitationally captured. Common subdivisions of semidetached binaries are "Algol", "W Serpentis" and "β Lyrae" systems. These will be discussed later. The third class is the "contact" binaries. These arise if both components overfill their Roche lobes. The two stars physically touch and have a common photosphere. One type of contact binary systems are the W Ursae Majoris systems. These consist of two main sequence stars that posses photospheres exhibiting the same effective temperature for the two components despite the fact that the mass ratio between them is 0.5. The semidetached and the contact binaries are often described as "interacting" binary systems.

In binary stars, generally the more massive component is termed the "primary" star and the less massive the "secondary" component. In Algols the secondary is the component that fills its Roche lobe, and is also called the "contact" component. The primary is called the "detached" component or the "gainer" or the "accreting" star since it gains mass through Roche lobe overflow and accretion. The primary eclipse occurs when the secondary star passes in from of the primary star along our line of sight. Often in discussions of binary stars, the term "following hemisphere" and "preceding hemisphere" is used. The preceding hemisphere is that side we see coming toward us during the first half of the period and the following hemisphere is that side we see during the second half of the period as the star moves away from us. Throughout this work, I will be denoting phases as fractions of the period. Primary eclipse is phase 0 or 1 secondary eclipse is phase 0.5. Also instead of using "phase", I will use ϕ.

The Algol variables are, obviously, those similar to their namesake Algol. They generally consist of a normal B-type or A-type main sequence star and a late type subgiant with no wind outflow velocities. (McClusky and Sahade 1987). They are identified by deep primary eclipses where the light flux may drop to a few percent of the normal flux. This behavior is impossible to obtain if both components are on the main sequence. The flux would only drop by about one-half. On the main sequence, the luminosity, surface brightness and radius all increase monotonically with mass. Deep eclipses also cannot occur when the more massive star is evolving away from the main sequence. In this case, the luminosity increases and a smaller portion of the star can be eclipsed. Therefore for deep eclipses the less luminous component must be the larger star. Less luminous implies less massive, but according to stellar evolution theory, the more massive star should be first to leave the main sequence. (Plavec 1983a) In the 40s this apparent contradiction with single star evolution was termed "the Algol paradox". This paradox was solved satisfactorily in the 50s. The theory states that initially the present subgiant in the system was the more massive component. It evolved, filled its Roche lobe and began to transfer mass through Roche lobe overflow to the main sequence component. In Algol systems, the main sequence star is the more massive star and the subgiant is the less massive sometimes by a factor on the order of 10. According to evolutionary theory, these systems undergo a phase of very rapid mass transfer and then settle into a phase of little or no mass transfer. Sometimes "classical Algols" is used to describe Algol systems which have undergone rapid mass transfer in the past. The classifications "β Lyrae" and "W Serpentis" are systems closer to the rapid mass transfer phase. Plavec describes W Ser systems as those which differ from classical Algol systems due to a large amount of circumstellar material. Generally there is so much circumstellar material that the primary component is difficult to identify. The UV spectra of W Ser systems is an emission spectrum throughout the period. The large amount of circumstellar material is may be due to a higher rate of mass transfer and/or a larger volume for the Roche lobe of the accreting star. I will use the terms "Algol" and "W Ser" system interchangeably throughout this work since the definitions between the types is fairly fuzzy and some of the systems are classified by their researchers as "active Algols" or "weak W Ser" stars.

2.3 Binary Star Evolution

In close binary systems, the evolution of the components is affected by the mass transfer between the two stars. From the review of Paczyński (1971), he enumerates the various assumptions employed in studies of the evolution of binary systems. The first assumption is that the components can be treated as spherically symmetric even if one of them fills its Roche lobe. Paczyński gives references for those who have shown that the effects of tidal distortion are small. The next assumption is that there is a critical radius such that the mass exchange takes place when the star exceeds this critical radius. This critical radius is taken to be the Roche lobe radius. Another assumption is that the orbit of the binary is circular. The Roche lobe formulation assumes a circular orbit and a solution does not exist for the elliptical case. Also Paczyński states that no semidetached systems are known to have definitely noncircular orbits. The radius of the star is assumed to be less than, or equal to the Roche lobe. The star is assumed to be in a hydrostatic equilibrium. The most controversial, and probably inaccurate, assumption is that the total mass of the binary and the orbital angular momentum is conserved during evolution. This assumption is in conflict with observations of binary systems which show large amounts of circumstellar material.

Binary star evolution is divided into three phases. Case A is associated with hydrogen burning in the core of the primary. In this case, the primary refers to the more massive star and thus the star that fills its Roche lobe. Case B is caused by rapid core contraction and case C is carbon ignition. In general, case A occurs in binary systems with short initial orbital periods on the order of days. Case B occurs in those systems initial periods of days to months and C occurs on the order of months to years. The actual ranges depend on the mass ratio in the system. In all cases, the mass transfer occurs in two steps. The first is a phase of rapid mass transfer, followed by a phase of less, though still significant, mass transfer. In all cases, the primary star fills it Roche lobe and transfers mass to the less massive component. The rapid mass transfer phase is characterized by changes in the period and the mass ratio of the system. The mass ratio may be more than inversed during this phase.

2.4 Gas Dynamics in Binary Systems

Lubow and Shu (1975) analyzed the gas dynamics in semidetached binaries. They began by assuming synchronous rotation of the contact component, isothermal flow and steady conditions. The argument of their paper rests on the use of a small parameter ϵ, defined as the ratio of the thermal sound speed to the ordered velocity.

$$\epsilon = \frac{a}{\Omega d} \tag{5}$$

$$a = (\frac{kT}{m})^{1/2} \tag{6}$$

where a is the isothermal sound speed, Ω the angular velocity and d the separation distance. They show that the width of the stream scales as ϵd and the density of the gas stream scales as $\frac{\epsilon^{-2}\dot{M}}{\Omega d^3}$ and $\dot{M}$ is the mass transfer rate. They find that the only relevant parameter for the gas flow under these assumptions is the mass ratio of the components.

$$\mu \equiv \frac{M_D}{M_C + M_D} \tag{7}$$

M_C and M_D are the masses of the contact and the detached component respectively.

In the region near the L_1 point the gas leaves the contact component by accelerating from subsonic speeds to supersonic speeds. Lubow and Shu find that the sonic point of the mass-carrying streamlines must occur within an order ϵ neighborhood of the L_1 point. All matter-carrying streamlines must cross in an ϵ of L_1. Thus, all the material leaving the contact component form a narrow jet of material at the L_1 region. The flow is governed by Bernoulli's equation which states, roughly, that the velocity is highest where the pressure is lowest, although this can be complicated by gravity and the presence of strong Coriolis forces. The angle of this narrow stream of material forms as it leaves the L_1 region and heads toward the detached component is determined only by the mass ratio of the two components. (See figure 2.)

$$\cos 2\theta_s = \frac{-4}{3A} + (1 - \frac{8}{9A})^{1/2} \tag{8}$$

$$A \equiv \frac{\mu}{|X_{L_1} - 1 + \mu|^3} + \frac{1-\mu}{|X_{L_1} + \mu|^3} \tag{9}$$

The angle is between 19.5° and 28.4° with respect to the line joining the centers of the components. As the flow leaves the L_1 region and moves toward the detached component, it is described by a two dimensional flow. Hydrostatic equilibrium is maintained in the z-direction and the gas is confined to the orbital plane. In this orbital region, the pressure effects are negligible and the flow can be roughly described by ballistic trajectories of free particles. As the flow leaves the L_1 point, its motion is a straight line well past L_1. This is due to the opposing pulls of the Coriolis force and the gravitational force of the detached component. If the detached component is large enough, the incoming stream would intercept the star on its trajectory. Otherwise, the stream would continue asymmetrically around the star to restrike itself and form a disk. Lubow and Shu define $\tilde{\omega}_{min}$ as the distance of closest approach of the stream to the center of the detached component. If the radius of the detached component, scaled by the separation distance, is greater than $\tilde{\omega}_{min}$ then the stream will directly impact the star.

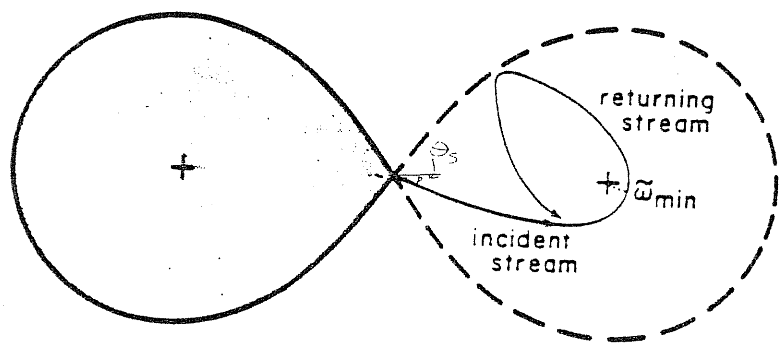

Figure 2. Illustration of the Lubow and Shu (1975) stream of material leaving the lobe-filling component. $\tilde{\omega}_{min}$is the distance of closest approach to the center of the detached component.

3 History of V356 Sagittarii

3.1 System Parameters

Observational work on V356 Sgr can be traced back to 1930, but the seminal paper on this system was done by Popper (1956). In this work, he sets the parameters which are used today. Using spectrograms obtained at McDonald Observatory in 1946 and photometric observations taken at Lick Observatory in 1951, he published the light curves and determined the parameters of the system. He sets the spectral type as B3V and A2II. These are still the parameters, though Polidan (1989) has reclassified the B-star as a B1V star rotating rapidly so that in the optical, it looks like a B3 star with an utraviolet excess. The masses are set at 12.1 and $4.7 M_{\odot}$ for the B and the A star respectively. Note the difference of a factor ~ 3. Popper sets the radii at 4.9 and $12.7 R_{\odot}$. These values have been changed and in his 1980 review of stellar masses, the radii are put forth as 6.0 and 14.0 radii. In his work, he

	V356 Sgr	
Period (days)	8.896106	
Spectrum	B3V	A2II
Mass ($M_{\odot}$)	12.1±1.1	4.7±0.6
Radius ($R_{\odot}$)	6.0±0.7	14.0±1.5
Log g	3.96±0.10	2.82±0.10
V_{escape} (km s^{-1})	877±65	358±30
V sin i (km s^{-1})	350	90
V_{sync} (km s^{-1})	33	77
T_{eff} (K)	16500±750	8600±300
$\dot{P}$	4 x 10^{-9}	
$\dot{M}$ ($M_{\odot}$ yr^{-1})	4 x 10^{-7}	

Table 1. System parameters for V356 Sgr as given by Popper (1980) (Polidan, 1989)

states that "these [spectrographic] observations are in qualitative agreement with the hypothesis that the periods of axial rotation and of orbital revolution of the A star are equal ... while the rotation period of the B-star is considerably shorter." It has been show that the B-star is rotating almost critically at 350 km/s. He also states that "the orbital eccentricity, if different from zero, is too small to be significant." These support the theory of synchronization and circularization in close binary systems and allows one to employ the Roche model as an accurate model. He sets the period as 8.89610 days, a refinement to earlier works which today has only been changed by the addition of a further decimal place. In his published light curves, he points out the large difference between the depths of the light curves (a characteristic of Algols) and explains it as a result of tidal interaction, gravity darkening, and limb darkening. From his analysis, Popper concludes that the B star is a normal main sequence star but that the A-star is an unusual object due to the discrepancy between its mass and radius.

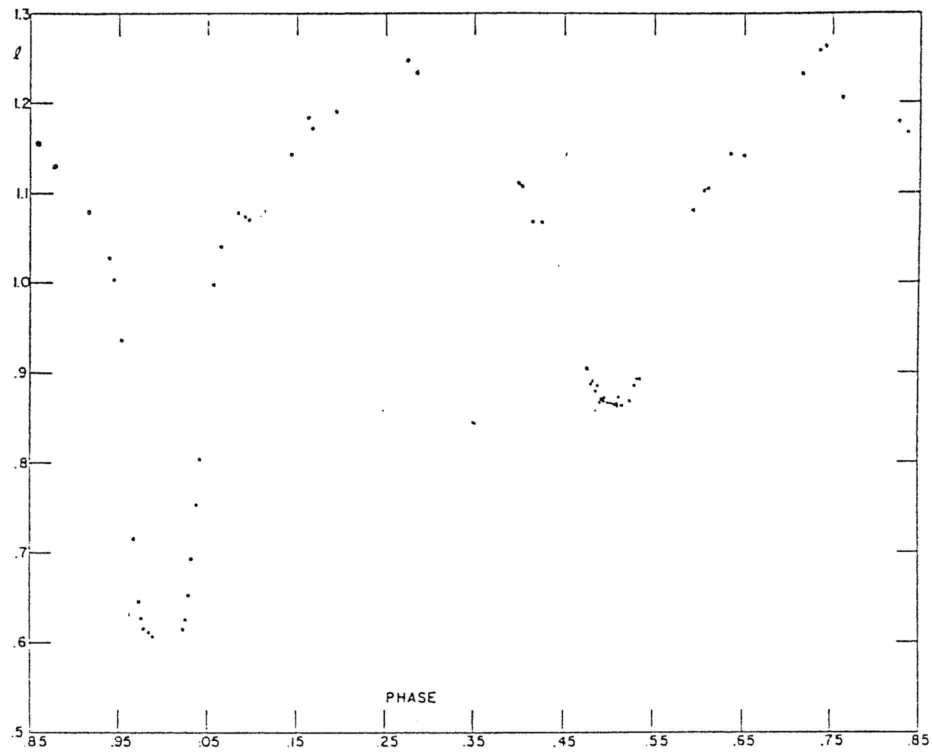

Figure 3. Light curve for V356 Sgr as published by Popper (1956). The y-axis is luminosity units and the x-axis is phase.

3.2 Model of V356 Sgr

In 1978, Wilson and Caldwell reexamined the light curves of Popper and developed a model to account for peculiarities described by Popper in his work. The four anomalies Wilson and Caldwell point out are:

1. The ratio of the eclipse depth is less than it should be as indicated by spectral type.
2. There is a small reflection effect which should be greater.
3. The duration of the secondary eclipse is longer than the primary eclipse.
4. The primary eclipse is not total – the light curve should be flat at the bottom and it is not.

They also point out three observational problems. The first is the absolute mass determination. The second is the absence of emission line activity in the system. Emission lines activity in the optical would indicate the presence of circumstellar material. Since this paper was written, emission line activity has been found in the far ultraviolet regions of the spectra. The third problem is the period change due to mass transfer. Since period changes are not seen in this system, then there is no evidence of rapid mass transfer. Wilson and Caldwell stat that mass transer has been completed in this system. However, small period changes have been indentified. So V356 Sgr is classified as a classical Algol which has passed its rapid mass transfer phase and thus an older system. Wilson and Caldwell attempt to fit the Popper's light curves with the system. They find that the two components alone cannot fit the light curve and explain the anomalies in the system. They propose:

> a thick, opaque circumstellar disk of recently transferred material [which] surrounds the primary. This disk blocks the star and makes it appear underluminous for its mass, but does not alter the spectral type.

They computed the light curves for these two stars using a procedure developed for tidally eclipsing binaries. They needed some means of reducing the light of the primary star without reducing its surface brightness, so they postulated the existence of the this disk about the star. In their model, they have ignored the rapid rotation of the B-star. This thick, opaque disk would serve to geometrically block part of the light of the primary and deepen the secondary eclipse. They begin with a self luminous disk in contact with the star and find that this cannot explain the observed light curves. Thus they propose an extreme case and adopt a completely non-luminous disk surrounding the primary and leave it to further research to propose a more physical model. Using their disk, they adjust the physical dimensions of the disk and adjust slightly the inclination angle until they produce a light curve which agrees with Popper's light curves. They consider the fact that the rapid rotation of the primary could be a more physical model by distorting the primary star without invoking the disk model. They cite the absence of reflection effect which cannot be explained by rapid rotation. However, the presence of circumstellar matter has been observed in V356 Sgr and this could also reduce reflection effect. That state that: "it seems difficult to avoid the conclusion that a geometrical and optically thick disk ...is present around the primary star." As stated earlier, they did not account for the rapid rotation of the B-star. The model they used assumes spherically symmetric stars distorted by tidal interaction. According to Stalio and Polidan (1990), if the B-star is rotating at nearly its critical velocity, it would be significantly rotationally distorted and have a vertical temperature gradient between the poles and the equator. It would be cooler at the equator and hotter at the poles. I believe that in shape this would be similar to a star surrounded by a disk and provides a more physical explanation than a completely non-luminous disk of material. Wilson and Caldwell conclude with: "V356 Sgr cannot be understood as a normal , uncomplicated, example of an Algol-type system", but it does show very similar behavior to other Algols, as will be demonstrated later. Wilson and Caldwell is the most widely quoted model for V356 Sgr, however, as has been shown, the model is largely unphysical and seems to be a fitting of the parameters to the light curve. Subsequent observations have shown no evidence for a disk of material surrounding the primary in V356 Sgr. The Wilson and Caldwell model will not work without the disk.

3.3 Evolutionary Model of V356 Sgr

Since V356 Sgr has well defined parameters, Ziółkowski (1985) attempted to determine the evolutionary status of the system. Ziółkowski classified V356 Sgr as a system which is evolving in case B of binary evolution and thus he predicts a rapid increase of the orbital period as a consequence of mass transfer. The Wilson and Caldwell (1978) model stated that the mass transfer had ceased. Ziółkowski citing the presence of circumstellar material in V356 Sgr, proposes that the mass loss is non-stationary but not substantial. The goal of Ziółkowski was to "construct the theoretical evolutionary sequences leading to the present state of V356 Sgr."

Ziółkowski begins with the standard assumptions enumerated previously for binary star evolution, including the fact that the initially less massive component is able to handle mass inflow and that both components are of normal compositions. He begins with the conservative case of conserved total mass of the system and conserved total orbital angular momentum. He justifies this showing that there are no good observations to describe the mass loss from the system. Using these assumptions, he is left with only one free parameter–that describing the initial state of the system, *i.e.* the initial masses of the components of the system. He adjusts the free parameter to obtain agreement for the masses of both components, radius of the contact component as well as the luminosity and effective temperature of the contact component. The values can be checked against the present day rate of mass transfer. Using four values for the initial mass of the primary star (now secondary) Ziółkowski found that in each case the system follows case B of binary evolution, but the rate of mass transfer was very high ($\sim 10^{-3} M_{\odot}/yr$) and not supported by the observations.

Since the conservative evolution did not work for V356 Sgr, Ziółkowski turned to non-conservative models. He introduced two arbitrary parameters for the loss of mass and angular momentum. He tested both core helium burning models and core hydrogen burning models. In the core helium burning models he finds that he cannot reproduce the present masses of the components. In the core hydrogen burning models, Ziółkowski finds that the now secondary is too advanced to be a core hydrogen burning star. Next Ziółkowski turns to shell hydrogen burning models. He can satisfactorily reproduce the system only for very low values for the parameter describing loss of angular momentum . In other words, he finds that though there might be significant mass loss from the system, there cannot be significant loss of angular momentum. Ziółkowski states this "cannot be justified from a physical point of view".

Finally, Ziółkowski concludes that the contact component burns hydrogen in a shell and excludes the other models he tested. The system cannot be described by conservative evolution. The evolutionary status requires rapid mass transfer which is in contrast with observation. Ziółkowski can produce the present state of V356 Sgr with non-conservative evolution with no angular momentum loss, but substantial mass loss.

3.4 Ultraviolet Spectra of Algols

In 1983 and 1984, Plavec studied the ultraviolet spectra of several Algol systems in emission and their emission line spectra. Plavec has defined a subclass of Algols called the "W Serpentis" stars . These are systems in which there is strong emission activity in the ultraviolet. In the W Serpentis systems, emission line activity of high temperature lines is seen throughout the period accompanied by period changes. This is in contrast with Algols which if the emission lines are seen they are seen only during the eclipse. The W Ser systems seem to represent a phase of rapid mass transfer, while more classical Algols have passed this phase. A transition phase between the W Ser and the classical Algols –active Algols–has been proposed. In this work, I will be using the terms Algol and W Ser interchangeably. In Plavec (1983a), he studied the eclipse spectra of 11 Algol systems (including V356 Sgr) in the UV to search for emission line activity seen in W Ser stars. Since the secondary in these systems are later than B-type, the flux in the UV from the secondary is very small. He finds that 7 of the 11 show emission lines of Si IV, N V and C IV. For the remaining four, he suggests that perhaps the exposure times for the observation were inadequate to find the emission. For these 7 there are widely differing emission line signatures. For some of the systems, the C IV is by far the strongest line and in others, the N V is the strongest. For V356 Sgr, (Plavec 1983a) the C IV is much weaker than the N V. (See figure 3) Since this system is believed to be an old system, (Wilson and Caldwell, 1978) it could represent a transition phase between rapid mass transfer and the end of mass transfer. Also V356 Sgr is different than the others studied by Plavec in that the secondary is not a subgiant,

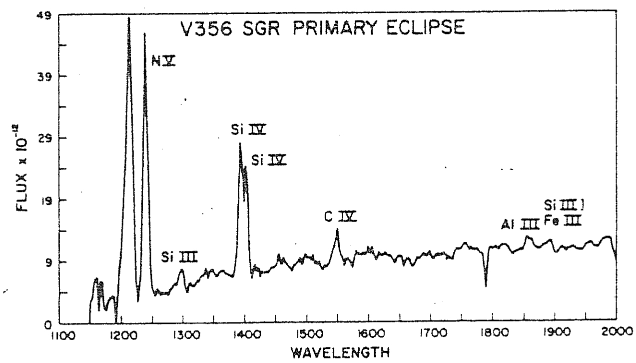

Figure 4. Low resolution IUE spectra of V356 Sgr (Plavec 1983). Note the strength of the N V line in comparison with the other lines. The strong line next to N V is interstellar Lyman α.

but a real giant and also it is not a late-type star, but an A star. Of the seven stars studied by Plavec, the emission line strengths also varied between them, up to a factor ~ 100. These changes in the emission lines could be due to the different geometries in the systems, their ages and the mass transfer rates. Changes in the geometry would change the volume of the Roche lobes and allow different volumes for the the formation of circumstellar material. Plavec et al.(1984) suggests that these hot emission lines are formed in a stellar wind induced by the accretion of Roche lobe overflow material. This conversion of energy would form in a region surrounding the gainer star.

4 Current Work in Algols

4.1 Introduction

Since this work deals mainly with the far ultraviolet observations in Algol systems, the place to begin is with the launch of IUE in 1978. I will first discuss a little about the IUE instrument and its capabilities. I will follow this by a discussion of work which has been done in the IUE spectral range on various systems, including with the observation of high temperature ionization lines in U Cephei by Kondo *et al.* (1978) and similar systems such as γ_1 Velorum and β Persei. This will be followed by discussion of work done on SX Cassiopeae, RW Tauri and U Cephei by Plavec. Plavec and his collaborators compare the emission line regions in all three systems, discuss the absorption lines in U Cep and the nature of the line-forming region. I will discuss Plavec's (1983b) work on U Cep in detail. Peters and Polidan (1984) studied four Algol systems, AU Monocerous, TX Ursae Majoris, U Corona Borealis, and CX Draconis whose primaries are large enough that the Lubow and Shu (1975) stream directly impacts the surface. In this work, Peters and Polidan, using high resolution IUE data, studied the absorption lines of C IV, N V, and Si IV throughout the period and also against historical observations. I will also go into detail in this work because I will later compare the lines of C IV, N V, and Si IV in V356 Sgr to the work done by Peters and Polidan.

system name	primary spectral type	secondary spectral type	period (days)
β Per	B8V	G-K III	2.87
γ_1 Vel	B2III		1.482
SX Cas	A6III	G6III	36.37
U Cep	B7V	G8III	2.49
RX Tau	B9V	K0III	2.7
AU Mon	B6p	F0	11.11
CX Dra	B2.5e	F	6.7
U CrB	B6V	F8III-V	3.45
TX UMa	B8V	F8III	3.06
V356 Sgr	B1V	A2II	8.90

Table 2. A list of the stars discussed in this section

4.2 The IUE Satellite

The International Ultraviolet Explorer (IUE) was launched on 26 January 1978 and has been operating consistently since. IUE was designed to function only for a maximum of five years, and now has been functioning for more than thirteen years and will continue if funding continues. It is one of the most successful instruments in history. For a complete description of the IUE instruments see Boggess *et al.* (1978). IUE is an echelle spectrograph designed to be able to view the spectral range 1150Å–3200Å and to view this range in a high resolution of 0.2Å for bright objects or a low resolution of 6Å for faint sources. In order to fulfill these requirements, the spectrum is split into two ranges: 1150Å–1950Å and 1900Å–3200Å. The former spectral range is often called the SWP (for "short wavelength prime") and the latter the LWP or LWR ("long wavelength prime" or "long wavelength redundant"), this referring to the camera which has taken the data. IUE in geosynchronous orbit, allowing real-time observations from ground control centers. The observer can view his own target on a television screen as the instrument is pointed and can adjust his own observing schedule if necessary. All objects observed with IUE become public domain after six months, allowing astronomers to use the now extensive archive freely. The IUE is an international instrument operated eight hours a day by ESA near Madrid and sixteen hours a day by NASA at Goddard Space Flight Center.

4.3 β Persei

β Persei (also known as Algol) is the namesake of all this classification. It has a period of 2.87 days and a slight inclination of 81.2 degrees. The primary star is a B8V and the secondary is a G or K III. There is evidence of circumstellar material. Sahade and Hernández (1985) took many high resolution spectra in 1978 and 1979 achieving a fairly complete coverage of the period. They found a purely absorption spectra including the resonance lines of N V, Si IV and C IV.

They cannot positively identify the N V lines. The Si IV is strong in some phases, and stronger near primary minimum. The C IV lines are weak and blended with Fe III and do not undergo any noticeable changes in the intensity. The lines of Si II at $\lambda1409$ and $\lambda1410$ seem to vary in antiphase with Si IV, but the resonance lines of Si II do not show any changes. The lines of Si IV and C IV are seen both in emission and in absorption. Sahade and Hernández reason that they are seen in one or the other might be connected with the dimensions and/or the opacity of the responsible regions. The existence of these lines imply the existence of an envelope of $\sim 10^5 K$ electron temperatures. Thus in β Per there must be sources of non-thermal energy. Similarly with work that has been done with AU Mon (Sahade and Ferrar 1982), Sahade and Hernández suggest two regions of high temperatures (see figure 5). The C IV originates close to the primary component while Si IV and N V arise further out in an extended envelope. They state:

> in β Per the ultraviolet lines, including the resonance lines of Si IV and excluding the C IV originate in regions that share the motion of [the primary component] of the system and should be located not very far from the star itself.

From the velocity behavior of C IV, it is determined that C IV is formed in a region of extended envelope surrounding the whole system. Thus, there exists two distinct regions characterized by high electron temperatures , in agreement with the interpretation for AU Mon and γ_1 Vel. The origin of the high temperature region probably results as a dissipation of shock waves produced when the Lubow and Shu stream interacts with a ring or disk surrounding the secondary component and the matter being lost interacts with the outer envelope. Sahade and Hernández concluded that there are non-thermal sources in the system and all UV lines are produced within the gravitational domain of the B8V primary component. They show evidence for the existence of two high electron temperature regions resulting from the dissipation of shock waves.

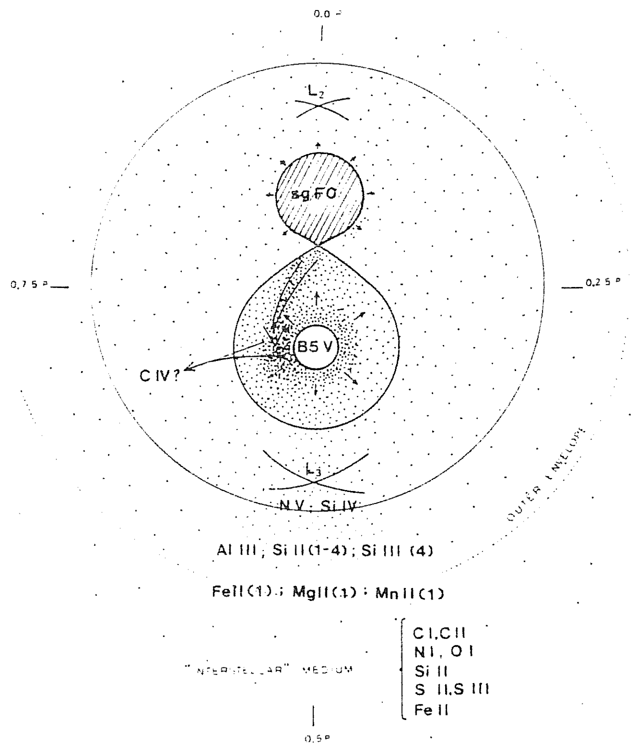

Figure 5. A model of the system AU Mon (Sahadè and Ferrer 1982) showing the two high temperature regions; one where C IV is formed and one where N V and Si IV are formed.

4.4 γ_1 Velorum

Sahade and Hernández (1984) also studied the IUE spectra of γ_1 Vel. The period of this system is 1.482 days and the primary is a B2 III and the secondary component is unknown–no ground-based or IUE spectra shows its existence. The inclination of the system is 70 degrees and so does not undergo total eclipses. Sahade and Hernández have taken IUE high dispersion data on γ_1 Vel in January and July 1979. They find that there is a difference between the lines taken at phases 0.376 and 0.298 taken six months later. Once again, the spectra shows the presence of ions requiring electron temperatures between $10^5 K$ and $10^3 K$. An extended gaseous envelope is suggested with layers or regions of different physical conditions. Despite the fact that the resonance lines of C IV and Si IV require nearly the same temperatures their line widths are quite different, suggesting two different regions for formation. The IUE lines are symmetrical with no radial velocity shifts. According to Sahade and Hernández the study of AU Mon, β Persei, and γ_1 Vel show very similar behavior in the Si IV and the C IV and they have concluded that they are formed in two regions of similar temperature, but differing physical conditions. These regions would be formed from gas stream interaction with disks or clouds of material.

4.5 SX Cassiopeae

Plavec and Weiland (1982) have studied SX Cas and have labelled it as a W Ser type system because of its strong emission line activity. The emission lines in SX Cas can be seen throughout its period. Plavec and Weiland state that SX Cas is similar to the systems β Lyrae and KX And. As a point of reference, they compare SX Cas to β Lyrae. In both systems there is no evidence for intercombination lines with the exception of possibly Si III] λ1892. Though weak intercombination lines should not be seen above the noise in the spectra, strong lines such as N IV] λ1486.8 and O III] λ1666.15 should be detectable. Since they are not, Plavec and

Weiland set a value for the electron density in the emission line region to

$$n_e \sim 4 \times 10^{12} cm^{-3} \tag{10}$$

from the ratio: Si III]1892/ Si III 1299 although in their low resolution observations both lines are blended. From the dependence of the Si III lines on electron density, Plavec and Weiland are able to rule out densities $n_e < 5 \times 10^{11} cm^{-3}$. These values for n_e are typical for stellar atmospheres. Therefore it is natural to assume that these emission lines are formed in the late- type star. Previous investigators have placed the emission line formation region surrounding the secondary star since they are predominantly seen in the UV during the primary eclipse when the flux of the primary is neglible. Plavec and Weiland put forth three arguments against this hypothesis. First, using the values for the electron density given above, Plavec and Weiland compute that the emitting region would have to have a height on the order of kilometers. This would be consistent with the theory that these lines are formed in a transition layer surrounding the secondary. Plavec and Weiland compare the emission lines of SX Cas with known cases of chromospheric radiation and show that the emitting powers and fluxes are several orders of magnitude greater in SX Cas. Their second argument is that in stellar chromospheres, the C IV(λ1550):Si IV(λ1403):N V(λ1240) are very similar and have a ratio of 3:1:0.3, however for SX Cas the value is 10:10:18. This can also be explained in terms of mass loss in the secondary component and perhaps the star has undergone some sort of CNO processing. These two previous arguments do not show definitively if these lines are formed near the secondary star. However, Plavec and Weiland point to the behavior of the emission lines outside of eclipse. If the lines were formed in the secondary star the lines should be the strongest during the primary eclipse. Plavec and Weiland show that the emission lines become stronger outside of totality by a factor of $\sim$ 2.2 (see figure 6). They demonstrate that all lines are enhanced when the region surrounding the hotter component is observable. Thus, they conclude: "The emitting region is more likely associated with the accreting star". They do not propose any explanation for the emitting region other than saying the it is probably related to the accretion process in the system.

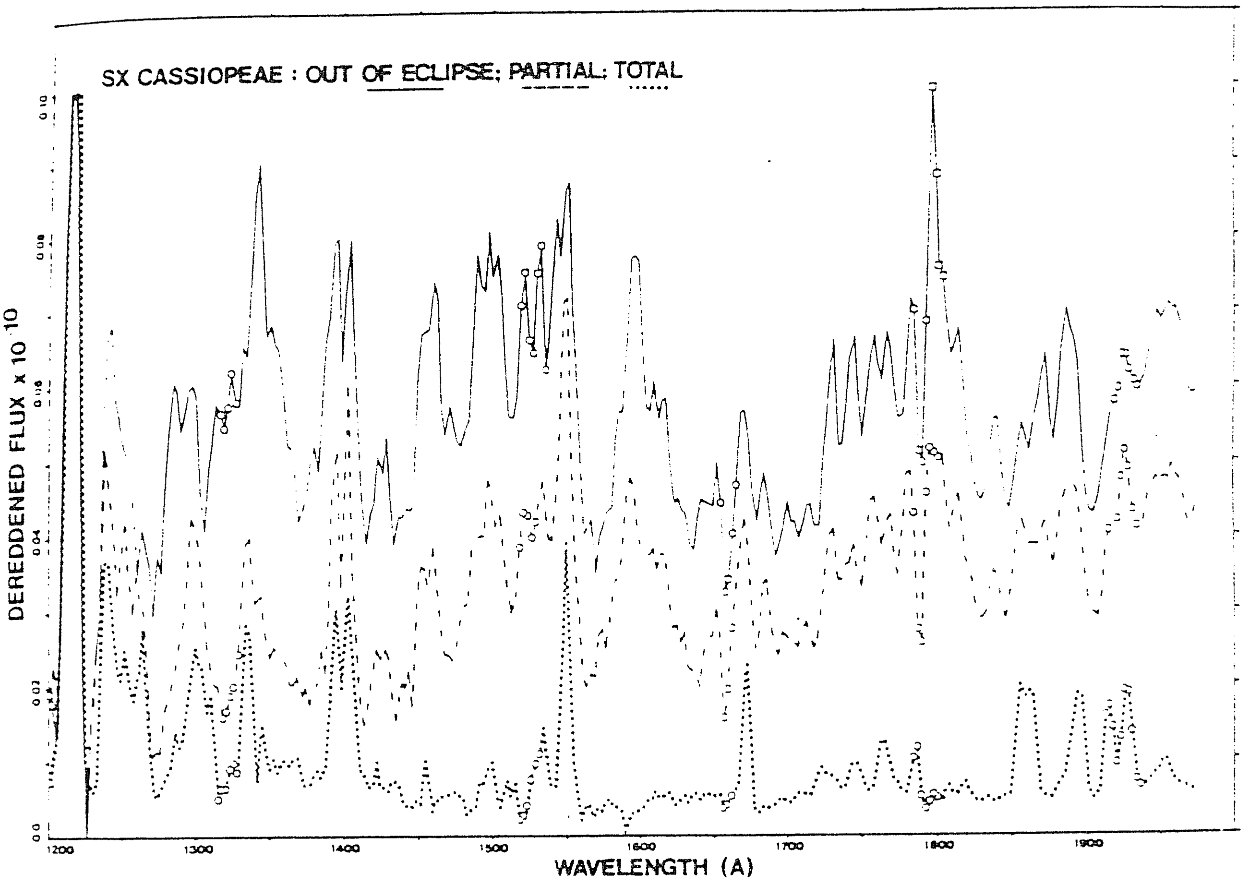

Figure 6. SX Cas from Plavec (1983). A plot of SX Cas out of eclipse, partial eclipse and total eclipse. Note that the emission lines are stronger out of eclipse.

4.6 U Cephei

The eclipsing binary system U Cephei was observed by Kondo *et al.* (1979) out of eclipse with the IUE satellite. They took nine high resolution spectra in the long wavelength (LWR) camera ($\lambda\lambda$1900–3200Å) and one short wavelength (SWP) camera ($\lambda\lambda$1200–1900Å). In the SWP spectra, they identified the C IV ($\lambda\lambda$1548,1550Å) and the Si IV ($\lambda\lambda$1394,1402Å) At the the effective temperature of the B7 primary star of 13,000K, from the Saha equation carbon should be predominantly the form of C II and no significant amounts of Si IV or C IV should be present. Kondo *et al.* proposed a region of a hot spot on the primary star. Since they had only one observation of the SWP region they conclude their discussion there.

Kondo *et al.* (1981) returned to U Cep with more observations. In this work, they have 3 SWP observations and 21 LWR observations. Once again, they show the unusual presence of the absorption lines of Si IV and C IV. These features indicate the presence of non-LTE conditions or conditions other than those in the stellar photosphere.. They suggest:

> The C IV and S IV lines arise from the region above the conventional photosphere where the infalling matter from the gas stream gives rise to a pseudo-photosphere whose temperature is higher than that of a photosphere observed from the ground. This pseudo-photosphere may exist primarily along the equatorial regions of the B star.

They also point out that the velocities of the Si IV and the C IV lines have deviations from the velocity of the primary star and these lines are clearly phase dependent.

Plavec (1983b) studied U Cephei in the low dispersion IUE SWP spectra. See figure 7. He examined the emission line spectra and compared his results with those for SX Cas. He also studied the absorption spectra of U Cephei and proposed a model for the formation region of these high temperature lines in emission and absorption. The emission line spectrum in U Cep is visible only during

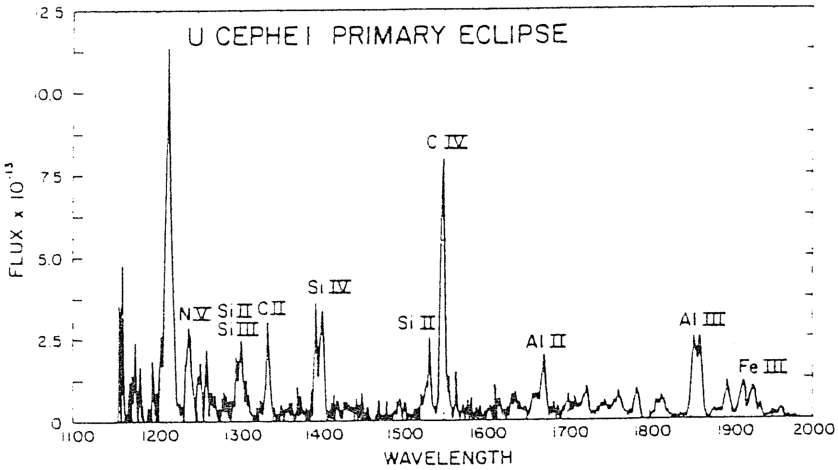

Figure 7. U Cep from Plavec (1983b) during total eclipse.

the primary eclipse, unlike SX Cas which shows its emission lines throughout the period. The emission line spectrum of both systems is a pure emission spectra with a low flat continuum. The flux of the secondary contributes very little in the far ultraviolet region. As with SX Cas, Plavec points out that the intercombination lines of O III]λ1663, N III] λ1750 and C III]λ1909 would be distinguishable if they had sufficient intensity, but they have not been found. Since these intercombination lines cover a wide rand of electron temperatures and critical electron densities, once again, Plavec is able to set a value of:

$$n_e \geq 5 \times 10^{11} cm^{-3} \tag{11}$$

for the electron density which is in agreement with the density found in SX Cas. In examination of SX Cas and U Cep, Plavec has observed these stars with the low dispersion mode since the system is too dim during primary eclipse to be seen with IUE. But the two systems are very similar to β Lyr which has been observed with high resolution IUE spectra. In β Lyr, Plavec was able to set a value of $n_e \geq 5 \times 10^{12} cm^{-3}$. In all three systems, there is a definite lack of intercombination lines with the possible exception of Si III]λ1892.

With the low resolution spectra of both SX Cas and U Cep, Plavec compares the emission lines in both systems. SX Cas is classified by Plavec as a W Ser system due to the presence of emission lines throughout the period and also the Balmer lines in emission in the optical. U Cep is classified as a weak W Ser star or an active Algol system. It shows no evidence of Balmer lines and Hα has been reported only once. Comparing the two spectra, Plavec finds that the same emission lines are found with "few insignificant exceptions". The emission lines are narrower in U Cep than SX Cas. In SX Cas the Si II line is stronger compared to Si III, but there may be a contribution from O I. Comparing line intensities, a fairly rough process since the spectra are low dispersion, Plavec find that the mean ratio between the lines is 138 (see table 3). In his table he uses

COMPARISON OF U CEPHEI WITH SX CASSIOPEIAE

LINE		POWERS, $P(\lambda)$ $(10^{-3} L_\odot)$		RATIOS OF POWERS		
				$P(\lambda)/P(1671)$		
Ion	λ(A)	U Cep	SX Cas	U Cep	SX Cas	$P(SX)/P(U)$
N V	1240	1.90	316	1.7	3.1	166
Si II (4)	1264	0.48	177	0.4	1.75	369
Si III (4)	1298	0.53	165	0.5	1.6	311
Si II (3)	1303	1.15	155	1.0	1.5	135
C II (1)	1336	1.56	181	1.4	1.8	116
Si IV (1)	1394	1.43	186	1.3	1.85	130
Si IV (1)	1403	2.21	174	2.0	1.7	79
Si II (2)	1533	1.24	101	1.1	0.9	81
C IV (1)	1550	5.69	174	5.1	1.7	31
Al II (2)	1671	1.11	105	1.0	1.0	95
Al III (1)	1854	1.87	94	1.7	0.9	50
Al III (1)	1862	1.26	76	1.1	0.75	60
Fe III[a] (34)	1895	0.84	145	0.8	1.4	173
Fe III (34)	1915	0.74	101	0.7	1.00	136
Fe III (34)	1926	0.73	105	0.7	1.0	144

[a] Possibly blended with Si III] 1892 A.

Table 3. A comparison of emission lines in U Cep with SX Cas and a ratio of their powers (Plavec 1983b)

the Al II 1617Å line as a reference. Notice that the intensity ratio between the systems is comparable. The emission lines of SX Cas are stronger than U Cep by an average factor of more than 100. This explains why the emission lines can be seen throughout the period in SX Cas and not in U Cep. The primary component in U Cep is stronger than the emission lines. In SX Cas the N V , Si IV, C IV lines reach $4 \times 10^{-12} erg\, cm^{-2}\, s^{-1}\, \AA^{-1}$ with the continuum flux at nearly the same level. In U Cep , the C IV reaches $7 \times 10^{-13} erg\, cm^{-2}\, s^{-1}\, \AA^{-1}$. The continuum flux is $3 \times 10^{-11} erg\, cm^{-2}\, s^{-1}\, \AA^{-1}$, 40 times higher. The situation is similar in the optical region. In SX Cas, the first 6 Balmer lines are always seen while in U Cep, the Hα has been recorded only once. The power emitted in the emission lines in the SWP region (1230–1950Å) is $2.8L_{\odot}$ and $0.026L_{\odot}$ for SX Cas and U Cep respectively. The integrated flux in the continuum is $3.5L_{\odot}$ and $0.020L_{\odot}$. Therefore, during the primary eclipse the emission lines contributed $\sim 50\%$ to the total energy output in the region in both systems. Since the flux ratios are very similar between the two systems, Plavec concluded that the continuous radiation in the UV region is powered by the same mechanism. Plavec asks the question: Why is the far ultraviolet radiation in SX Cas so much stronger than in U Cep? A first explanation is that the emitting volume is much larger in SX Cas. The emitting volume scales as the the volume of the Roche lobe. The Roche lobe is determined by the geometry of the system. The separation distance in SX Cas is $87R_{\odot}$ and $15R_{\odot}$ in U Cep. If the emitting volume scales with the volume of the Roche lobes then the emission ratios should be ~ 300. If the emission lines are optically thick or the emitting region disk shaped, *i.e.* a classic accretion disk, the emission ratios should be $\sim$ 50. If only the volume seen during the eclipse contributes to the emission, that part of the lobe between the stellar radius and the Roche lobe then the emission ratios would be ~ 100. This is similar to the ratios calculated above, but may be a coincidence. The difference in the far ultraviolet radiation could be due to a larger energy input in SX Cas, a higher rate of mass influx due to Roche lobe overflow; a different stage of binary evolution. Plavec concludes that:

> ...it is clear that the primary components are not involved since their powers in the same spectral regions are $30.9L_{\odot}$ and $19.8L_{\odot}$ [for SX Cas and U Cep respectively]

Comparing the high temperature lines of Si IV, C IV and N V in both stars, the C IV is the most interesting. C IV is by far the strongest line in U Cep, although in SX Cas its strength is similar to Si IV. The strongest line in SX Cas is the N V line. In both systems the C II is roughly the same strength (relatively), but the C IV is enhanced in U Cep. The differences in these lines could be due to different temperatures in the emitting layer and/or the presence of CNO processed material which would affect the C/N ratio. As has been stated previously, the presence of these lines are unusual in a main sequence B star. A B star does not have the stellar radiation to ionize lines of C IV, Si IV and N V. At least not to the strength seen in the spectra. Plavec suggests that

> The absence of any other powerful photoionizing source contrasted with the presence of strong emission lines of C IV and N V suggests that ionization is predominantly collisional.

Next, Plavec attempted to locate the line emitting region in U Cephei. To do this, he ran several spectra through one eclipse. He obtained 3 SWP spectra and 2 LWR spectra. From previous work done on U Cep (Olsen, 1980), he assumes that the disk thickness is about 80% of the stellar radius or 0–2.2$R_\odot$. He cannot use observations from older eclipses since he shows changes over time of the line strengths. During a single eclipse, the changes in the line intensities must be due to the changing geometry of the visual regions as they become eclipsed by the cool star. There are perceptible differences in these spectra. The pre-totality spectra has higher peak intensities and higher total fluxes than the totality spectra. This provides more arguments against the formation of these lines in the secondary component. It is obvious that the lines undergo eclipses and are much weaker during totality. Therefore, considering the arguments presented for SX Cas and the changing intensity of the U Cep lines, it seems reasonable to conclude that this line-forming region surrounds the primary star. The differences in line intensities between the pre-totality and the total eclipse implies that more radiation was coming from the pre-totality region (*i.e.* the following hemisphere) of the star. The emitting region must be quite close to the surface of the B star and Plavec shows that if the vertical extent is 0.0–2.2$R_\odot$ or 0.0–0.8R_B then the surface area is $3 \times 10^{22} cm^2$ and a radiating volume of

$$V = 1 \times 10^{34} cm^3. \tag{12}$$

He has no reliable estimates for the electron density and uses the value previously derived from the lack of intercombination lines $n_e \geq 5 \times 10^{11} cm^{-3}$.

Following the analysis of the emission spectra, the location of the line emitting region, Plavec turned to the absorption lines in the system. For the absorption lines, it is possible to observe U Cep in IUE high resolution. From the results given by Kondo *et al.*(1981), Plavec shows that most of the absorption lines are shallow and broad implying a high velocity of axial rotation. The presence of the Si IV and C IV lines must originate in a different, much hotter region. According to Plavec "We claim that all the lines as emission lines have their counterparts in the absorption spectrum " and have profiles distinctly different from photospheric lines. These lines cannot be fit with gaussian profiles. I will show later that V356 Sgr behaves similarly. The N V, Si IV and C IV lines would have very little contribution from the photosphere and it can be assumed that they are generally formed in a hot region. Plavec explained that the absorption spectrum is simply the emission spectrum as we look toward the primary component. Most likely different segments of this hot region is seen in absorption and emission. From the central residual intensities of the high temperature lines, Plavec computes the optical thickness of the hot layer above the photosphere, using r_c, the central residual intensity :

$$\tau_0 = \frac{4}{3}\left(\frac{1}{r_c} - 1\right) \tag{13}$$

Assuming a uniform layer:

$$\tau_0 = \alpha H R_i A_{el} N_H = 0.8 \alpha H R_i A_{el} N_e \tag{14}$$

where H is the geometrical thickness, A_{el} is the fractional abundance of the species with respect to hydrogen, R_i is the fraction of atoms of the element in ionization state i and α is the absorption coefficient per atom. Since the lines studied here are resonance lines, the absorbing atoms would be in the ground level. The absorption then is:

$$\alpha = \frac{(\pi)^(1/2)e^2}{mc^2}\lambda^2 f\Delta\lambda_D \qquad (15)$$

The Doppler width $\Delta\lambda_D$ is:

$$\Delta\lambda_D = \frac{\lambda}{c}\left(\frac{2kT_e}{\mu m_H} + {v_t}^2\right) \qquad (16)$$

where v_t is the turbulent viscosity. It is assumed that there is considerable turbulent viscosity since the lines are broad but not gaussians. Thus v_t dominates the above equation. The gas temperature then enters in the ionization calculations of R_i. The ionization fractions R_i can be computed assuming solar abundances and collisional equilibrium. Plavec uses published results. Plavec shows that the "disk" of material actually has thickness on the order of a stellar radius. If a fraction b of visible disk is obscured then the residual intensity is given by

$$r_c = (1 - b) + b/(1 + \tau_o) \qquad (17)$$

Plavec demonstrates that for $r_c = 0.28$ for Si IV, $b \geq 0.72$ which is consistent with the earlier assumption that 80% of the disk is obscured. He used four lines to fit the profiles, two Si IV lines, and one N V and C IV line, (those fairly free of blends) and the parameters τ_0, v_t and v_{rot} varied over a wide range of values. Since turbulence and rotational velocity are not easy to separate and both affect τ_o, and combined with the low signal-to-noise of the data, then results are fairly crude. However, he was able to show there is a fairly large optical thickness in the region. The shape of the line profiles make the assumption of large turbulent velocities safe. He points out that with the four lines fit, there is good agreement in the value of the turbulent viscosity which point to the fact that all four lines are formed in the same region. This differs from the argument by others of two different regions in Algols. The rotational velocity computed is less than the the rotational velocity of the photosphere of the primary star. Hn_e is defined as the effective column density. Assuming that all lines are formed in the same region of constant temperature T_e, it becomes impossible to fit all four lines. The discrepancy is probably due due to the initial assumption of a homogeneous isothermal reversing layer. However, the discrepancy can also be reduced if some CNO processing is assumed. Using this the

$$\log T_e = 5.0 \tag{18}$$

and

$$Hn_e = 5 \times 10^{21} cm^{-2} \tag{19}$$

for the mean column electron density. Since

$$n_e \sim 5 \times 10^{11} cm^{-3} \tag{20}$$

from above then the scale height is

$$H = 10^{10} cm = 0.14 R_\odot \tag{21}$$

which is in serious contrast with the value of the observed extent of the circumstellar material:

$$2.2 R_\odot = 1.5 \times 10^{11} cm \tag{22}$$

which in turn requires

$$n_e \sim 10^{10} cm^{-3} \tag{23}$$

Plavec, in order to solve this discrepancy, proposes that the highly ionized material exists in blobs or thin shells formed as a consequence of numerous shocks. This idea of shocks is in concordance with Kondo *et al.*(1981)

Following these computations, Plavec attempted to determine the nature of the line emitting region. Assuming that the emission lines are optically thin and the ionization equilibrium collisional, then the emission line intensity during totality should be given by:

$$P = \epsilon(T_e) n_e^2 V \tag{24}$$

where V is the emitting volume and ϵ is the emissivity per unit volume and electron density. Assuming an emitting region homogenous in electron temperature and density then the ratio of the observed fluxes is equal to the ratio of the emissivities. The ratio of the C II and C IV lines are dependent only on electron temperature:

$$\frac{P(CIV)}{P(CII)} = f(T_e) = 38 \tag{25}$$

which leads to a value of $T_e = 10^5$ since the ratio is a steep function of temperature. This is in agreement with the value obtained using the absorption lines. The ratio of C IV and N V is a function of electron temperature and abundance.

$$\frac{P(CIV)}{P(NV)} = f(T_e, Y) \tag{26}$$

where Y is the relative abundances which has been effected by CNO processing. For $T_e = 1 \times 10^5$ $Y = 0.75$ or 75% of the material has been CNO processed. However if $T_e = 1.2 \times 10^5$ then $Y = 0$ and there has been no CNO processing. Therefore, there is no concrete agreement for CNO processing. EM is the emission measure.

$$EM = n_e^2 V \tag{27}$$

From the emissivities, combined with the observed line intensities then

$$EM \approx 3 \times 10^{55} cm^{-3} \tag{28}$$

$$V = 1.2 \times 10^{32} cm^3 \tag{29}$$

A factor of 80 times smaller than the earlier the estimate from the geometry of the system $V = 10^{34} cm^3$ which lead to $n_e \approx 6 \times 10^{10} cm^3$. Once again Plavec shows that the volume participating seems smaller than the available area and this supports the theory of blobs or filaments of material.

Plavec concludes his discussion with the fact that the line emitting region definitely does surround the primary star and not the secondary star as argued by other authors. The energy powering and ionizing this region comes comes gravitational energy release in accretion. This accretion process can be explained by the Lubow and Shu (1975) model. Perhaps most of the gravitational energy is released at the hot spot when the stream penetrates photosphere of the

B8 star, leading to absorption lines which change within one period. At this point, it is not understood what mechanism creates the circumstellar hot layer, but there is little doubt that it exists. Plavec puts forth five properties of the hot layer in U Cep:

- It is optically thick in both absorption lines and emission lines.
- The hot layer surrounds the whole star along the equator with variable intensity of the absorption lines.
- The thickness of the layer is one the order of a stellar radius—it is not a thin accretion disk.
- The radial extent is uncertain and may be lumpy
- The circumstellar material probably is not of solar composition, but partially CNO processed.

4.7 RW Tauri

Following the works on SX Cas and U Cep, Plavec (1983) then studied RW Tauri, labelling it a weak W Ser star. Like W Ser systems, RW Tau shows conspicuous changed in period and similar emission lines. Plavec observed RW Tau in September 1982 with IUE. It consists of a B8V and K0IV secondary. Plavec was unable to get a total eclipse spectra and in the spectra and the light from the primary dominates the far UV spectra (see figure 8). Emission lines of Si IV and C IV can still be identified. He gives a table of "safely identified lines" and a comparison with the line strengths of SX Cas and U Cep (see table 4). The values given in the table are very uncertain, probably by a factor of 2 and represent lower limits. The total energy emitted in the UV by RW Tau is only a few thousandths of a solar luminosity and very similar to U Cep. Once again for RW Tau, Plavec suggests that the high ionization emission lines derived their energy from the accretion process.

RW Tau and U Cep have similar periods and similar structures and the mean ratio of the emission lines is 3 ± 1

SAFELY IDENTIFIED EMISSION LINES IN RW TAURI

LINE				POWERS, $P(\lambda)$ ($10^{-3} L_\odot$)			RATIOS OF POWERS, P_r	
Ion (1)	λ(Å) (2)	FLUX[a] (3)	SURFACE FLUX[b] (4)	RW Tau (5)	U Cep (6)	SX Cas (7)	P(UC)/P(RW) (8) (9)	P(SX)/P(RW) (10) (11)
Si IV (1)	1394	5.06	8.1	1.16	1.43	186	1.2	160
Si IV (1)	1403	2.14	3.4	0.49	2.21	174	4.5	355
C IV (1)	1550	5.87	9.4	1.35	5.69	174	4.2	129
Al III (1)	1854	3.41	5.5	0.78	1.87	94	2.4	120
Al III (1)	1862	2.12	3.4	0.49	1.26	76	2.6	156
Fe III[c] (34)	1895	0.94	1.5	0.22	0.84	145	3.9	674
Mg II (1)	2799	7.14	11.4	1.64	3.71	> 126	2.3	> 77

[a] Units: 10^{-13} ergs cm^{-2} s^{-1}.
[b] Units: 10^{6} ergs cm^{-2} s^{-1}.
[c] This line is probably blended with Si III] 1892 Å.

Table 4. A comparison of emission lines in SX Cas, RW Tau, and U Cep. Plavec and Dobias (1983) state that RW Tau is very similar to U Cep.

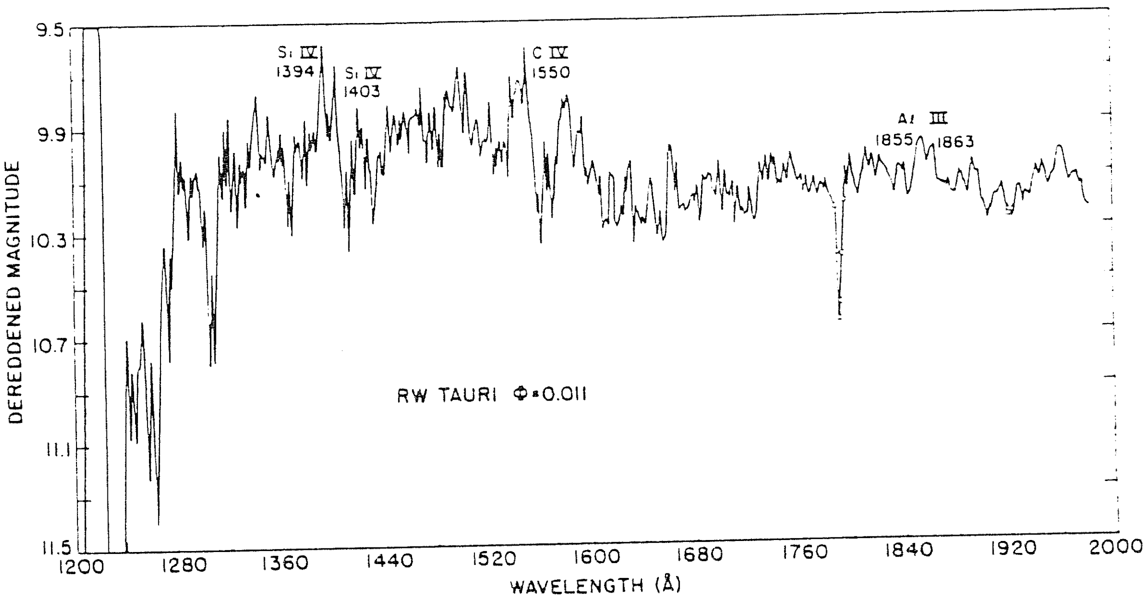

Figure 8. IUE spectra fo RW Tauri (Plavec and Dobias, 1983). The system is not in total eclipse and light from the primary dominates the spectrum.

4.8 AU Monocerous, CX Draconis, U Corona Borealis, TX Ursae Majoris

Sahade and Ferrer (1982) presented ground-based and IUE observations of AU Mon. AU Mon is a B5 primary with an F0 companion. The high resolution IUE material was taken at two different epochs with phases of 0.5 and 0. 667. The spectra display only absorption lines, including broad Si IV, N V, and narrow (comparatively) C IV lines. The Si IV lines at 0.5 are strongly asymmetric to the blue, but at 0.66 the asymmetric effect is absent. Due to blending, it was not possible to compare the N V lines in this manner. Sahade and Ferrer suggest that the IUE high temperature lines are formed in different regions characterized by different physical conditions. Since they had only two observations, they did not have enough data to say where the different lines originate. The Si IV and N V lines require a temperature of 10^5 and must form in a region with a density much less than those characteristic of streams or disks. Sahade and Ferrer, noting the differences between C IV and the other lines, propose another high temperature region in the spectrum. Shock waves could be produced in interacting close binaries when the stream interacts with an accretion disk. In AU Mon, Sahade and Ferrer propose that shock waves are also produced in an envelope surrounding the whole system. The behaviour of the Si IV lines suggests that there is flow of matter through the L_3 point. The C IV is formed in a different region, probably close to the components. (see figure 5.)

Peters and Polidan (1984) (hereafter PP84) studied the absorption lines of four Algol systems whose primary was larger than the Lubow and Shu parameter $\tilde{\omega}_{min}$. (See figure 9). Recall, $\tilde{\omega}_{min}$ is the distance of closest approach of the Lubow and Shu stream to the center of the detached component. If the detached component has a radius smaller than $\tilde{\omega}_{min}$, the stream will continue around the star and form a disk, otherwise it will impact the star.

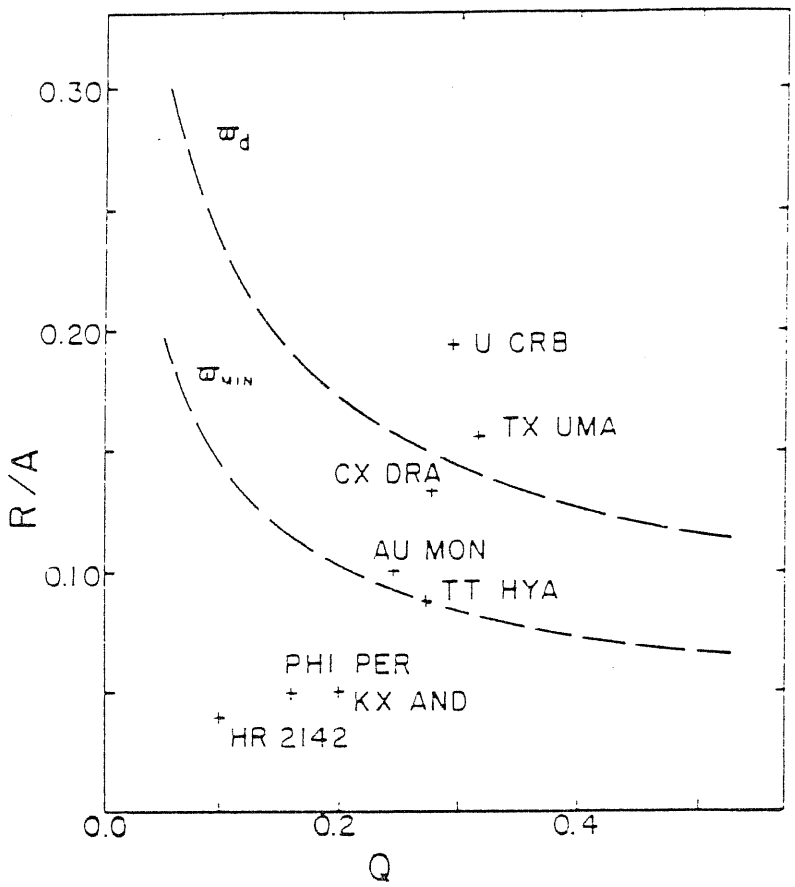

Figure 9. From PP84. A plot of 8 systems with $\tilde{\omega}_{min}$(Lubow and Shu 1975). Those systems with R/A (radius of the primary scaled by the separation distance) below $\tilde{\omega}_{min}$should form disks while those with R/A larger than $\tilde{\omega}_{min}$, the stream should directly impact the star.

In the systems studied by PP84, the flow due to Roche lobe overflow should directly impact the primary. PP84 point out that in those systems with radius less than $\tilde{\omega}_{min}$ there is evidence of stable disks as indicated by optical emission lines. The four systems studied by PP84 were AU Monocerous, CX Draconis, U Corona Borealis and TX Ursae Majoris. In all these systems it has generally been concluded in previous works that a high temperature region exists around these stars and that mass transfer accretion process is responsible for the heating of this region. From the phase dependence in the strength of these lines and the radial velocity of the features, PP84 have attempted to locate this hot region. The depths and the widths of the absorption lines give information on the vertical extension of the gas out of the orbital plane. In this work, using an ionization equilibrium code PP84 determine the column densities. They also estimate the temperature, density and abundance in the line formation region.

PP84 studied the N V, C IV and Si IV lines in all four systems and found them to be quite variable and prominent on the 0.4 – 0.9 phase. The S III and Al III also vary with these lines. These lines formed in the high temperature region also contain contributions from the photosphere, the gas stream, the interstellar medium and other sources. The lower ionization species do not display variation parallel to the high temperature lines. PP84 do not discuss the lower ionization lines since they do not seem to be formed predominantly in this high temperature region.

They begin with AU Mon. (See figure 10). In all systems they study they removed the wavelength shift due to the motion of the primary. In this way, the lines should correspond to their laboratory wavelength. The N V lines show striking phase dependent variations throughout the period. It is strong at phase 0.95 but completely disappears by phase 0.32. The C IV lines, though much weaker, parallel the N V lines. There seems to an asymmetric distribution of the high temperature region around the star. The Si IV lines are formed in the same region as N V. Normal B5 stars do not display Si IV lines, but late Be stars do.

The strength of the Si IV lines are much stronger than any seen in Be stars. They are asymmetrical at certain phases, indicating a wind. Due to these lines, there is a suggestion of non-radiative heating in the outer atmosphere. Both the Al III and the S III lines show contributions from the high temperature regions.

CX Dra (B2.5e + F period = 6.7 days) shows the variable N V features and is similar to AU Mon in the phase dependence. (See figure 11) They show the lines at phase 0.57 and 0.86. The N V lines are broader and less symmetrical than AU Mon. There is a sharp redshifted component. The behavior of C IV, Si IV, Al III, and S III paralleled N V. Once again a wind profile is seen in the Si IV lines, but it is different than in AU Mon. An addition absorption on the redward wing indicated mass flow toward the primary.

In U CrB (B6V + F8III-IV, period = 3.45 days), the N V and C IV lines are present at phase 0.88, but are absent at 0.32 and 0.62. (See figure 12.) The C IV is much weaker than the N V. The Si IV lines completely disappear at 0.32 and has its maximum strength at phase 0.88 . The Al II varies similarly with the Si IV lines.

TX UMa (B8V + F8III, period = 3.06 days) is the latest system in spectral type studied and the one with the lowest total systematic mass in this study. In this system, the N V and the C IV are not observed at all and the the Si IV shows phase dependence similar to the other stars. (See figure 1)3. The Si IV lines are not always present. One very dissimilar feature in comparison with the other systems is the behavior of the Si IV lines are that they are seen both just before and just after the eclipse. The 0.92 spectra seems to have a component due to the gas stream. PP84 suggest that perhaps in TX UMa the high temperature region, when present is more globally distributed.

For each system the centroids of each line was measured and compared with ground based radial velocity curves. The phase dependent velocities follow the primary component's orbital motion putting the line formation region close to the primary component. Using the lines of S III(λ1206), N V ($\lambda\lambda$1239,1243), Si IV ($\lambda\lambda$1394,1403) and C IV ($\lambda\lambda$1548,1551) PP84 measure the column densities in the lines by fitting them with theoretical lines profiles. They found that there was not a wide range in column densities between individual ions, differing stars and between observations. They have called the high temperature region where these lines are formed the "High Temperature Accretion Region" (HTAR). Between the stars studied, they find that the conditions in the HTAR did not change significantly between observations. The widths of the lines of the highly ionized species are either comparable to the photospheric lines or broader. PP84 and Plavec propose only one high temperature region. As shown, others propose two different high temperature regions. The main argument is that the shape of the C IV lines is different than the Si IV lines. PP84 suggest that this is due to depletion of carbon due to CNO processing while the others explain it as different regions of similar temperature, but differing physical conditions.

PP84 analyzed the approximate conditions in the HTAR. The radiation field of the primary star for the ionization. The HTAR requires a gas temperature which is higher than the photospheric temperature. Also, from these lines, carbon is underabundant. This is derived from the fact that the column density ratio of N V/C IV $\sim$ 10. Using the size of the Roche lobe and the computed column densities, PP84 put a lower limit on the particle density of

$$n_e > 10^7 cm^{-3} \tag{30}$$

significantly lower than the value given by Plavec for U Cep. Plavec calculated his value using the lack of intercombination lines to set a lower limit to the density. This by PP84 calculation is independent of any assumption of ionization source and the actual density must be substantially higher. PP84 carried out an ionization calculation. Estimating the physical conditions in the HTAR, they assumed that the gas is in equilibrium, there is an optically thin continuum. They found that models for the line formation region which involved a hot stellar radiation field could not reproduce the observations. Collisionally dominated models were much more successful. Collisional ionization by electrons dominated the photoionization for the highly ionized species. For CX Dra, using the ratio of the S III/N V and the Si IV/N V, PP84 found a $T_e = 117,000 \pm 15,000$ for solar abundances or $T_e = 105,000 \pm 15,000$ for a region that is nitrogen enriched. Using the ratio S III/Si IV which is unaffected by CNO processing, the ratio gives a $T_e = 105,000 - 117,000$. The ratio of S III/C IV which is not unaffected by CNO processing, has a value of 1.8 ± 0.3 much different than the expected value of 1.1 for solar abundances. The C IV/Si IV = 0.4 ± 0.2 whereas the expected value is 2.3. These ratios can be brought into agreement if carbon in depleted in CX Dra. If it is assumed that fully CNO processed material is observed, then nitrogen is enriched by a factor of ~ 5. In the other systems studied: the HTAR in AU Mon is similar in carbon abundance and temperature to CX Dra. In U CrB, there is a slightly lower temperature for the gas than CX Dra. In TX UMa, the gas is of a significantly lower temperature and PP84 do not rule out solar abundances in this system.

Next, PP84 compute the total particle column density and deduce the total particle number density. Using the ionization calculations PP84 determine the ionization fractions for $T_e \sim 10^5$. Assuming that S and Si have solar abundances and that N is enhanced by a factor of 4.5, then the total column densities for AU Mon, CX Dra and U CrB are similarly. This supports the assumption that ionization equilibrium prevails in the HTAR. The density is computed to be

$$n_e \sim 10^9 cm^{-3}. \tag{31}$$

Following these calculations PP84 attempt to determine the size and the geometry of the HTAR and discuss the role of turbulence. Due to the changing strength of the lines there seems to be a non-spherical distribution in phase. The HTAR is located preferentially on the hemisphere of the star receiving the gas stream. The likely source of heating is the shock from the collision. In AU Mon and CX Dra, N V is strong over a wider phase interval than U CrB. The rotationally velocity of the primary may influence the distribution of matter. The vertical extent of the HTAR must be at least a stellar radius since the lines are quite deep. There is no obvious correlation between PP84's b-parameter (a measure of line width) and $v \sin i$ of the primary, so the region does not seem to be in corotation with the primary. Turbulence could form the broadening of the lines. Since the lines are seen even when the region of gas stream impact is not, an ionization source must exist and be maintained throughout the HTAR. PP84 propose turbulence as the principle ionization source, but how this turbulence is maintained is unknown.

In conclusion, PP84 have studied the high ionization lines of Si IV, N V, C IV, S III and Al III in four Algols whose primary component is larger than Lubow and Shu's $\tilde{\omega}_{min}$ parameter. For all four systems they find evidence for a high temperature accretion region, HTAR. For CX Dra, AU Mon, U CrB there seems to be only small differences between the HTAR. The mass of the HTAR is small ($< 1\%$) compared with the theoretical mass for the gas streams. In Plavec's study of U Cep, he suggests a higher density region than PP84. Plavec uses the absence of intercombination lines to set the density and PP84 disagree with his method. In all systems the Si IV lines show the clear presence of a wind with phase dependence. The lack of N V in TX UMa implies that the HTAR is cooler than the other systems. PP84 show that the variability of the HTAR is not surprising if it is formed as a by product of mass exchange. The mass exchange in Algol binaries has been known to be quite variable.

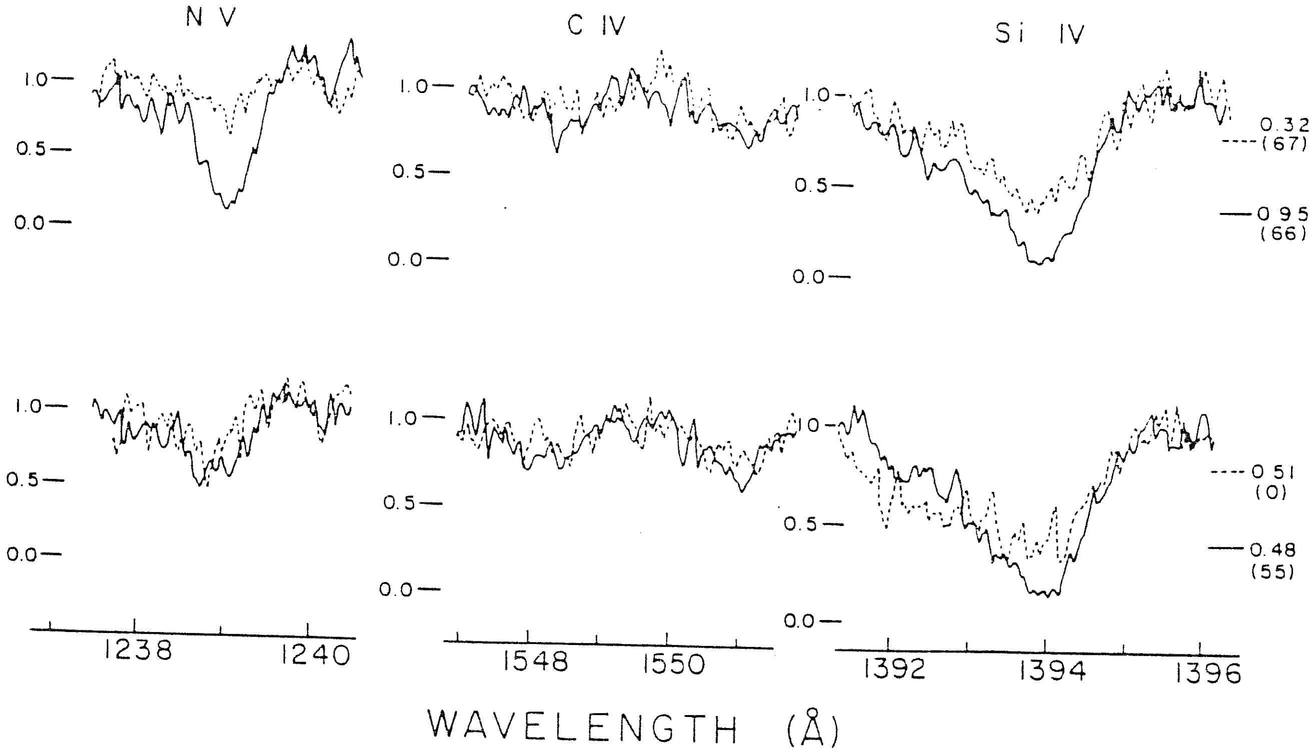

Figure 10. N V, C IV and Si IV in AU Mon. The upper plots are those taken during one period at the phases 0.32 and 0.95. The lower plots are those taken at nearly the same phase separated by 55 cycles.

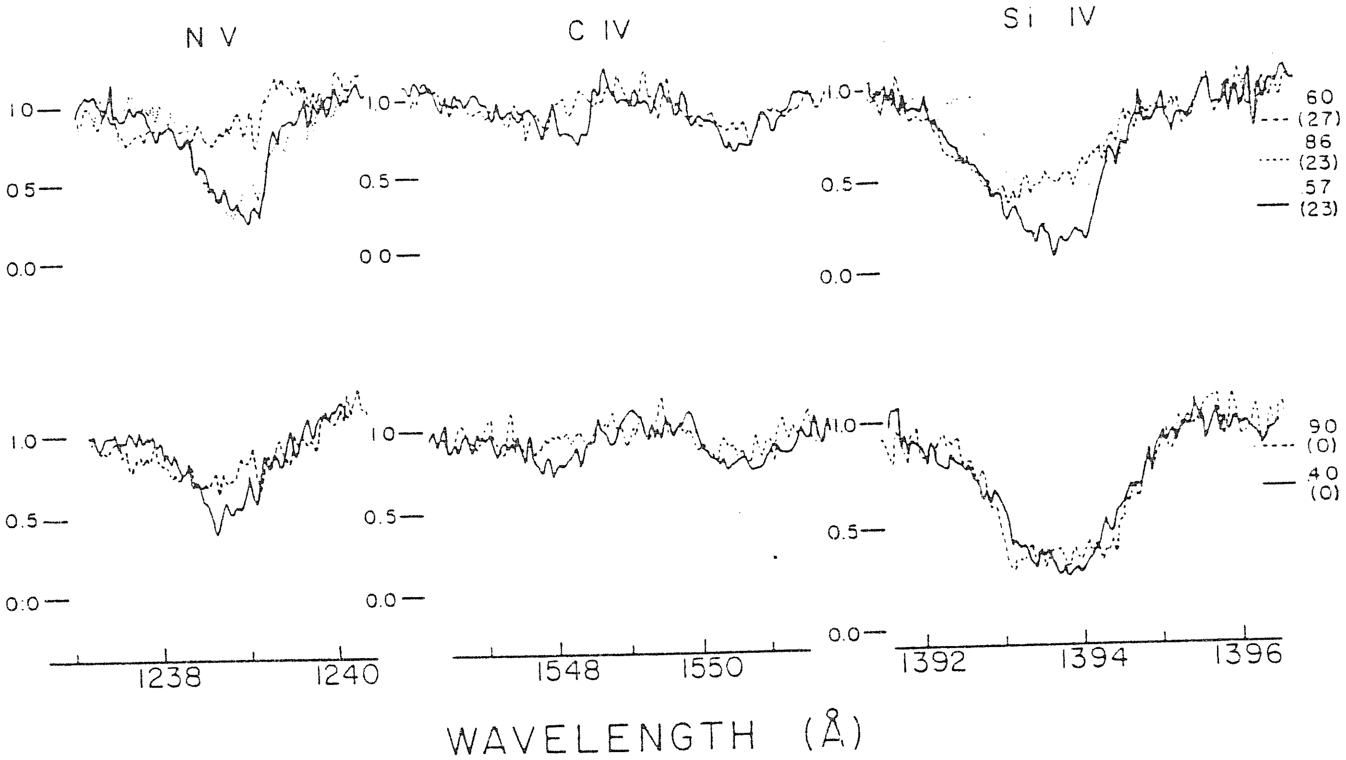

Figure 11. N V, C IV and Si IV for CX Dra. The lower pair differ by only a half a period.

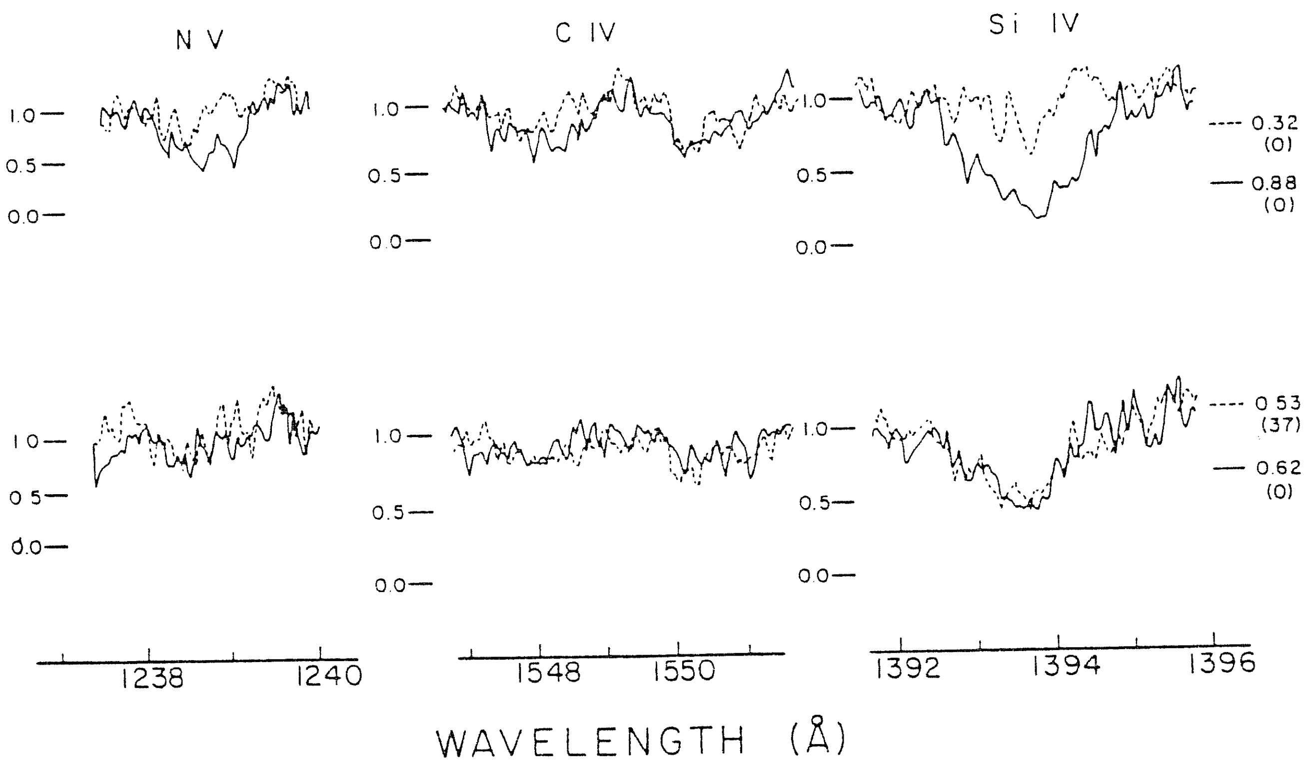

Figure 12. N V, C IV and Si IV for U CrB for two phases during the same period and for two similar phases which differ by 37 periods.

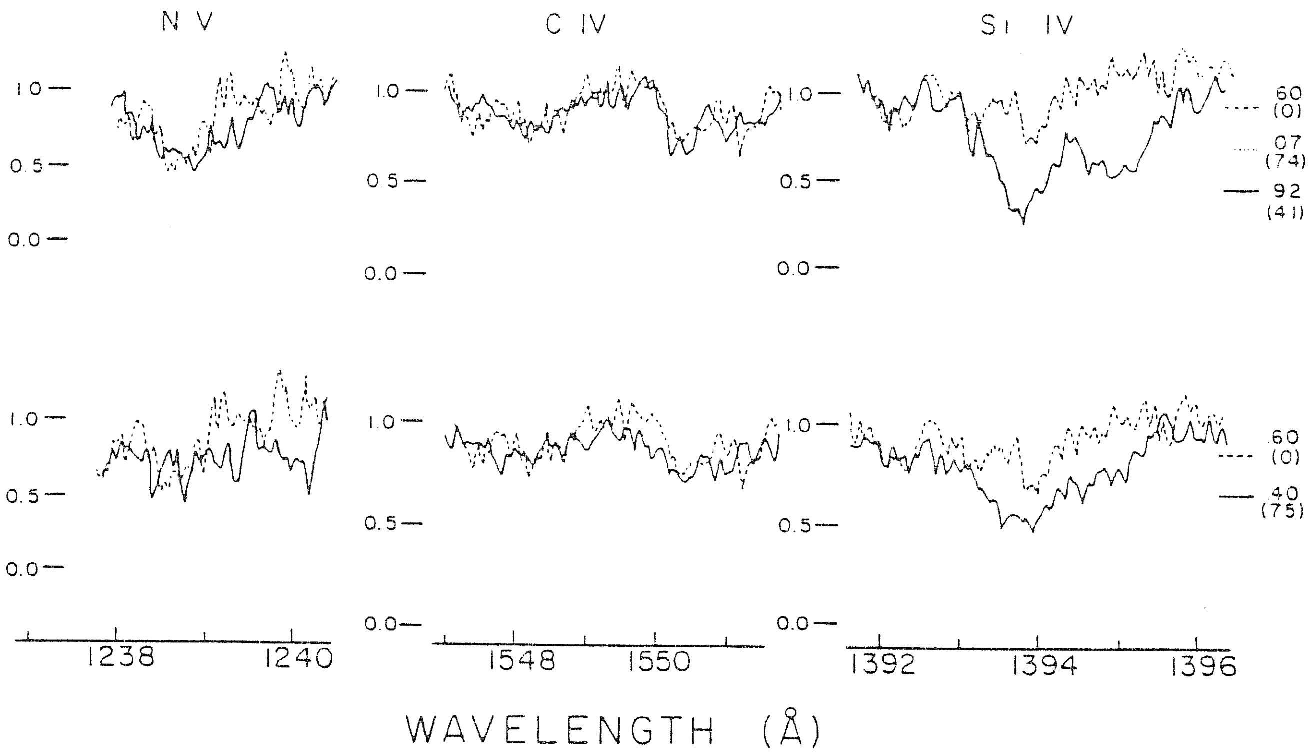

Figure 13. N V, C IV and Si IV for TX UMa as before.

5 Discussion of work on V356 Sgr

This is a discussion of the preliminary work we have done on V356 Sgr. I will discuss our data analysis and compare our work to that which has been done before. In Table 4, I list the observations taken in May 1990. I have included the SWP number, the date of observation and the phase. I will begin with a work done by Polidan (1989) who studied the high temperature lines with high resolution IUE of the eclipse data. I will also describe the IRAF package used to analyze the data. I will then discuss our first results. I will begin with a discussion of the high temperature lines formed in the HTAR described by Peters and Polidan. I will compare them to the lines published in PP84. I include a section on the absorption lines of Si II and C III. These lines should be formed predominantly in the photosphere. Comparing them to reference stars, we try to determine if the presence of the impact stream affects the stellar photosphere. In all plots that I will show, the spectra have been normalized to 1 and have been shifted for the motion of the B-star. In this way, the spectra can be directly compared with the other spectra and with the laboratory wavelength of the line. In many cases, interstellar lines appear on the spectra. These lines appear shifted, but this is simply an effect of shifting the spectra for the star movement, they are not real effects.

name	date of observation	phase
SWP38790	15 May 1990	0.88
SWP38791	15 May 1990	0.89
SWP38810	17 May 1990	0.09
SWP38811	17 May 1990	0.10
SWP38823	18 May 1990	0.19
SWP38824	18 May 1990	0.19
SWP38826	18 May 1990	0.22
SWP38827	18 May 1990	0.23
SWP38843	21 May 1990	0.53
SWP38844	21 May 1990	0.54
SWP38850	22 May 1990	0.65
SWP38851	22 May 1990	0.66

Table 4. A list of the observations taken in May 1990 with IUE of V356 Sgr. The first column is the SWP designation, the second the date of observation and the third column is the phase at that observation.

5.1 Emission line spectra of V356 Sgr

Polidan (1989) studied the emission lines during eclipse with high resolution IUE data and data from the Voyager Ultraviolet Spectrometer. Plavec classifies V356 Sgr as a system similar to RW Tau and U Cep–an active Algol system–a transition system between Algols and W Ser stars. Polidan reclassifies the primary from a B3V star to a rapidly rotating B1V star which looks like a B3 star in the optical. He describes the UV emission lines as: "extremely broad FWHM$\sim$ $1100 km\, s^{-1}$, almost symmetrical emission with weak slightly blue shifted absorption components." (See figure 14). The C IV emission identified by Plavec in low resolution spectra becomes instead numerous weak emissions of perhaps Fe III. Polidan finds no evidence of any carbon in emission in the eclipse spectra of V356 Sgr. He also find no evidence for carbon is found in the photosphere of the A2II secondary. This implies that the secondary has undergone CNO processing. In comparison, the B star seems to have normal carbon abundance. Since all emission lines can be fit with the same line shape parameters, Polidan states that there is no evidence for a stratified line formation region. He concludes this work with the suggestion for further research on the geometrical distribution of the gas. I will show some progress in this in my treatment of the absorption lines of V356 Sgr. Since Polidan describes this as a B1 star and it is classified as a B3 star, I have used as reference stars, both a B1 and a B3 star. The B1 star is a B1e star, 60 Cyg with $v \sin i = 350 km/s$. The B3 star is HD168905 a B2.5V star with $vsini = 290 km/s$.

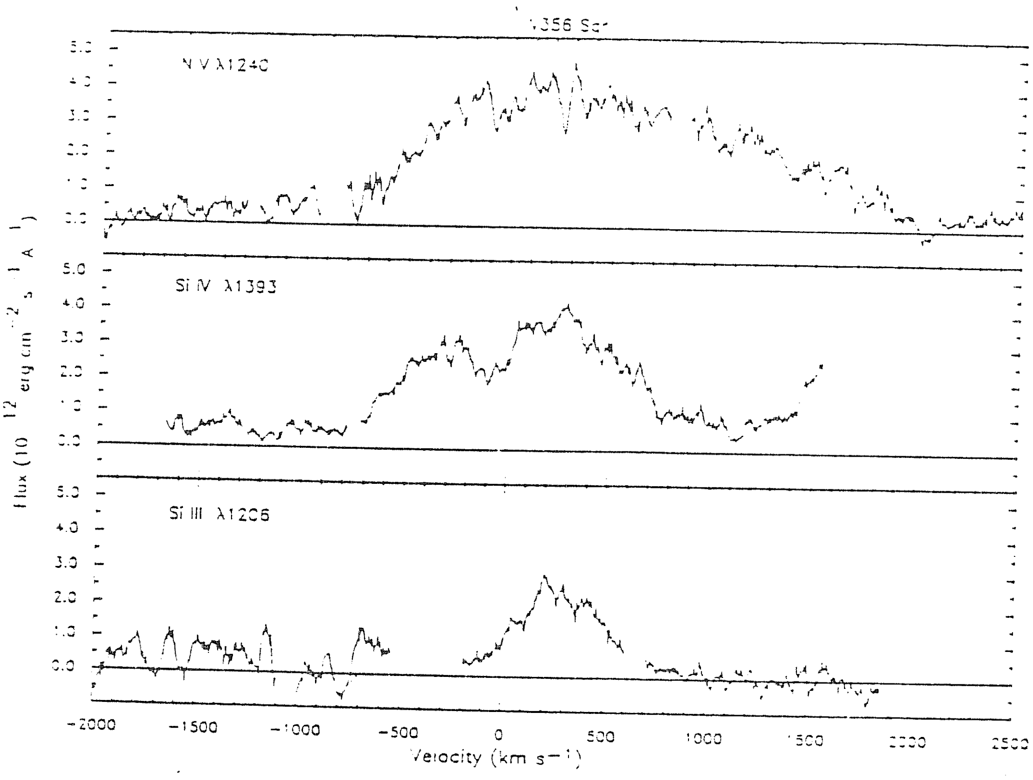

Figure 14. Emission lines of N V, Si IV and Si III in V356 Sgr (Polidan 1989) from high dispersion IUE data taken during eclipse.

5.2 IRAF

To analyze this data, I have used the NOAO/IRAF (Image Reduction and Analysis Facility) software package developed by the National Optical Astronomy Observatories to reduce CCD data. It can easily be used to reduce other types of data. IRAF is divided into several packages and subpackages to perform various tasks. I was able to extract data from the archive as ascii files and using the IRAF package *noao.onedspec.sinterp* to make an image which could be manipulated by other IRAF tasks. In this case, *noao* refers to the package I used, *onedspec* refers to the subpackage under the *noao* package which analyzes one-dimensional data and *sinterp* is the task used to interpolate ascii files into an image. I normalized all the spectra to a unit continuum with the *noao.onedspec.continuum* task which fits a continuum to a spectra, rejecting points more than a given sigma value from the mean, and divides the spectra by this continuum. I shifted all the spectra to account for the movement of the B star around the center of mass. I computed the velocity values from the parameters given by Popper (1956) for the various phases. I then converted the velocity values into pixel values and used the *noao.onedspec.shiftline* to shift the lines appropriately. IRAF was designed to work on CCD images and thinks that each point given is a pixel value. This can easily be worked with, but must be remembered. I measured equivalent widths and line shifts using the *noao.onedspec.splot* task which is a general purpose task designed for analysis of one dimensional data. All of the plots seen in this section have been plotted using *noao.onedspec.specplot* or the *graph* task.

5.3 Comparison with previous works

In figures 15-18 I show the absorption lines of Si IV, N V, C IV and Al III throughout the period for V356 Sgr. Polidan (1989) in his study of the emission lines showed that there was little if any carbon in the emission spectrum. This is consistent with the carbon in absorption. Note that the C IV has been shown at a scale half that of the other lines. In figure 19, I have overplotted the C IV with a B3 reference star. Since the B1 reference star is a Be star, I cannot compare the C IV lines. Be stars have unusually high C IV abundances. The C IV is slightly stronger than the reference star, but not significantly. Due to the high signal-to-noise of the C IV lines, we have not done any detailed analysis of them. The Si IV, N V and Al III lines all behave similarly. Simply by looking at these lines, one can see a distinct difference with PP84. In PP84, the lines became significantly weaker or disappear altogether on the side of the star not receiving the mass stream. In figure 20, I present a simplified diagram of the geometry of these systems. Only the primary component is shown. The secondary would be in the center of the diagram. The Lubow and Shu (1975) gas stream impacts the star on the quarter indicated by the hatch marks. For the phase 0–0.5 the region is not seen, but the second half the region is seen by the observer, represented by the eye symbol. In all the Algols studied the gas stream hits at approximately the same place. In V356 Sgr, the lines do definitely change shape and shift with respect to the laboratory wavelength (indicated by the vertical line on the plot), but the intensity is similar. Also for U Cep, Plavec describes the lines as highly variable over the period.

In figures 21c, 22c, 23c I show a comparison of the Si IV, N V, and Al III with historical spectra. Very little has been done with this system out of eclipse, but two high resolution spectra are in the IUE archives. SWP9139 is an older observation and is phase 0.73. The phases we observed are 0.66 and 0.88. Since this phase falls between these and, as I will show later, this part of the phase is the most variable, we elected not to use it. The other historical observation is from 1988, SWP33161 and is phase 0.18. This can be directly compared with our spectra at 0.19. In PP84, they show that over time, the HTAR is also variable. In our Si IV and Al III lines, the match is very close, implying very little change in the HTAR. The N V lines do not show this same behavior, but still seem very similar.

So as a preliminary conclusion simply comparing the spectra of V356

Sgr and those presented by PP84, we can surmise that a HTAR does exist in V356 Sgr because of the strong presence of the Si IV and N V and lines. The weakness of the C IV lines concur with Polidan's (1989) study of the emission lines. However, in V356 Sgr the HTAR seems to be more evenly distributed around the star and not concentrated on the side of the star receiving the mass stream. The comparison with historical observations indicate that this region is more stable that those studied by PP84 or U Cep. Why is the high temperature region in V356 Sgr more stable and symmetric than those seen in previously studied stars?

5.4 Analysis of the high temperature lines

In order to understand the high temperature region in V356 Sgr we did some analysis of the lines of Al III, Si IV, and N V. In figures 21-23 we compared the lines at phases 0.22 and 0.65 for all three lines. At phase 0.22 the region where the stream impacts the star would not be visible, whereas at 0.65 the region would be facing the observer (see figure 20). Changes between 0.22 and 0.65 could be indicative of a gas stream or changes in the high temperature region due to the gas stream impact. Notice that in all three figures the line at 0.65 is shifted to the blue or perhaps simply has a blue component. Measuring the velocity shift, for Si IV, N V and Al III, the shifts are:

$$Si\,IV : \sim 80 km/s$$

$$N\,V : \sim 90 km/s$$

$$Al\,III : \sim 60 km/s$$

The value of the Al III lines could be closer to 70 km/s since it does not have a distinct minimum. Therefore all lines shift to the blue by an average of $\sim$ 70 km/s. velocity.

Next we compared the lines at 0.22 and 0.88. In general these lines are very similar. (see figures 21-23) The N V line has a distinct blue component at 0.88 and the Si IV and Al III also seen to have a blue component though the component is much smaller.

$$Si\,IV : \sim 40 km/s$$

$$N\,V : \sim 80 km/s$$

$$Al\,III : \sim 50 km/s$$

In all three plots the phase 0.88 is slightly wider than the phase 0.22 plot.

In order to try to determine any changes in the lines, we computed the equivalent widths for each line. For each data point, we have added a 10% error bar on each side to account for such errors as bad continuum determination, incorrect identification of the line wings and others. (See figure 24). Then points taken at the same observing time were averaged to reduce the error bars. In all three cases, the equivalent widths seem constant through the period. The average equivalent for each line is:

$$SiIV \;:\; 2.013 \pm 0.126$$

$$NV \;:\; 0.7150 \pm 0.0864$$

$$AlIII \;:\; 1.1470 \pm 0.1430$$

So there seems to be a fairly symmetric high temperature region with evidence of the stream or the stream impact at phase 0.65. Although the high temperature lines seem to change shape and shift throughout the period, the equivalent width seems to remain fairly constant.

5.5 Analysis of photospheric lines

We have also analyzed the photospheric lines of Si II and C III to determine if there are changes in the photosphere of V356 Sgr due to the high temperature region or the gas stream impact. A study of the photosphere has not been done in any of the works I encountered on the high temperature regions in Algol systems. It has been shown (Stalio and Polidan) that rapidly rotating stars would have regions of differing temperature, the equatorial region being cooler and more extended due to centrifugal motion than the polar regions. For the primary in V356 Sgr the polar region would have a spectral type of B1 and the equatorial region would be closer to B3.

Note the lines of C III in figure 25. Throughout the period, the lines do not appear to change significantly. Comparing the spectra of phases 0.22 and 0.65, there is no line shift or line shape change (See figure 26). Comparing the phases of 0.22 and 0.88, again there is no discernable difference. Comparing with the B1 reference star, the line is nearly identical. Comparing it to the B3 star it is stronger, but only slightly. From the C III lines, it would seem that carbon is formed both in the regions that have temperatures representing a B1 star and a B3 star and that nothing is happening in the photosphere of the primary star due to the gas stream. The equivalent width plots (see figure 27) do not show any surprizing changes either.

See figure 28 and 29 of the Si II lines. The lines do seem to change through the period. They seem to begin blue-shifted with respect to the laboratory wavelength and then become centered. This almost seems opposite to the high temperature lines of Si IV and N V which seem to be centered and then become redshifted. The Si II lines then behave in anti-phase with the high temperature lines. If we compare the lines at phase 0.22 and 0.65, there seems to be a difference in the lines of $\sim$ 110km/s. The phase 0.22 line seems to be stronger than the 0.65 line. Comparing the spectra at 0.22 and 0.88 we find another difference with the high temperature lines. The difference between the high temperature lines and the Si II lines is that the high temperature lines are centered and then become blue shifted during the period. The Si II lines are redshifted and then become more centered. In the high temperature lines the line at 0.88 was slightly wider than the 0.22 spectra. In Si II the 0.88 spectra is definitely more narrow than the

0.22 spectra, whereas in the high temperature lines, the 0.88 spectra was wider than the 0.22 spectra. The velocity difference between the edges is $\sim$ 60km/s. Comparing the Si II lines with the B1 standard, we see a large difference. There is no significant Si II in the reference star. Comparing the Si II lines with the B3 standard, the lines fit except for a line shift. The equivalent width plots of Si II show a definite trend to lower equivalent widths with period.

Why is there such a difference between the two photospheric lines? The key could lie in the rapid rotation of the B star. From published spectra in the *Copernicus* catalog (Jenkins and White, 1977) of the far ultraviolet it seems that in B1 stars, C III is present, but Si II is absent. In B3 stars C III is weak and Si II is definitely strong. We see the C III lines in our B3 star at nearly the same strength as the B1 star, if slightly weaker. If the equatorial regions look like a B3 star then the impact of the gas stream could be responsible for the change in the Si II lines. The Si II lines become weaker at phase 0.65 when the gas stream impacts the equator. Perhaps the impact of the gas stream heats the photosphere, suppressing the formation of Si II lines. If this effect between the Si II and the C III lines is real it would be the first confirmation of rapidly rotating star theory and the first time it has been possible to show lines which are formed in different regions of a star. At this point, more research needs to be done on more photospheric lines to confirm this effect.

5.6 Conclusions on V356 Sgr

Returning to the high temperature lines, I will try to discuss the behavior of the system. A high temperature region exists in this system but it is different than those previously studied. The high temperature lines in U Cep and those studied by PP84 showed strength variations throughout the period and also over several cycles. The strength of the lines for V356 Sgr seem to stay fairly consistent, though they do change shape through the period. PP84 say that the high temperature region in their systems has a large vertical extent from the large depth of the lines. We can assume a similar structure in the high temperature region in V356 Sgr. The region seems to be more evenly distributed in V356 Sgr than the others. The question is why? The first supposition would be that the rapid rotation of the primary spreads the region around the star. However, U Cep also has a fairly rapidly rotating primary and it is one of the most variable systems. The other major differences between V356 Sgr and other systems studied is that the secondary in V356 Sgr is an A giant whereas the others are later subgiants. A stars have radiative atmospheres and later type stars have more convective atmospheres. How would the presence of a radiative atmosphere, as opposed to a convective atmosphere, affect the mass transfer and the high temperature region? How would a subgiant secondary or a giant secondary change the system? Unfortunately, Algols with A-type secondaries have not yet been investigated.

We seem to see evidence of the gas stream and/or the region where the gas stream impacts in the spectra at phase 0.65. The blue shift of the line could indicate that the material is moving toward the observer. The gas stream would impact the star the through conservation of energy heat the photosphere. This could induce a wind and the blue shift we see at phase 0.65. This could also explain why the Si II lines are weaker at 0.65; the heating of the photosphere could suppress the formation of Si II.

At this point, these theories are partially unsubstantiated. We plan to continue research on this system and formulate a quantitative model. More research needs to be done on those systems with early type secondaries and those with giant secondaries to understand this system.

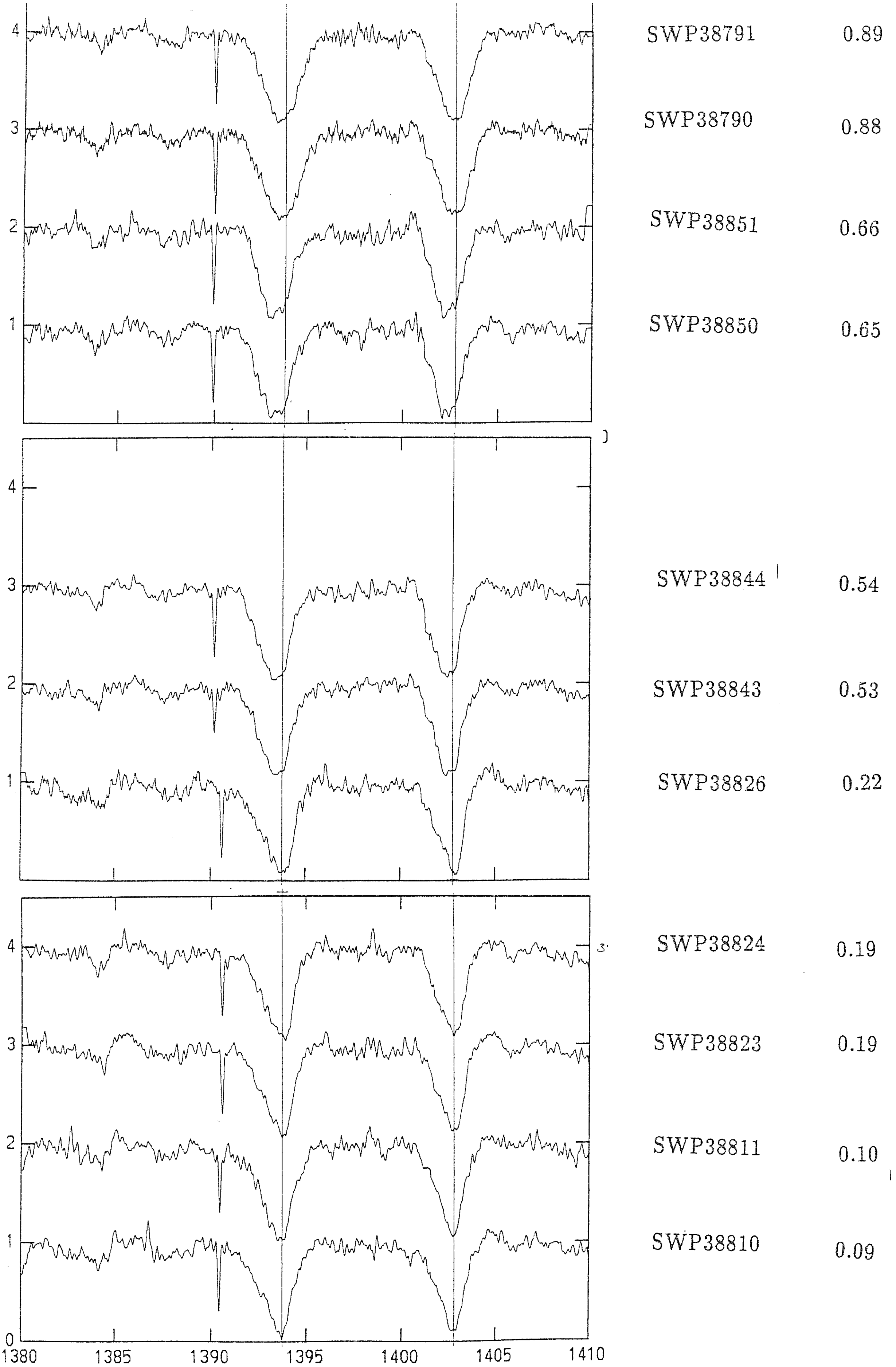

Figure 15. A plot of Si IV lines throughout the period. Next to each observation is the SWP number and the phase. The horizontal lines represent the rest wavelength for the species. The lines have been normalized to a continuum of 1.

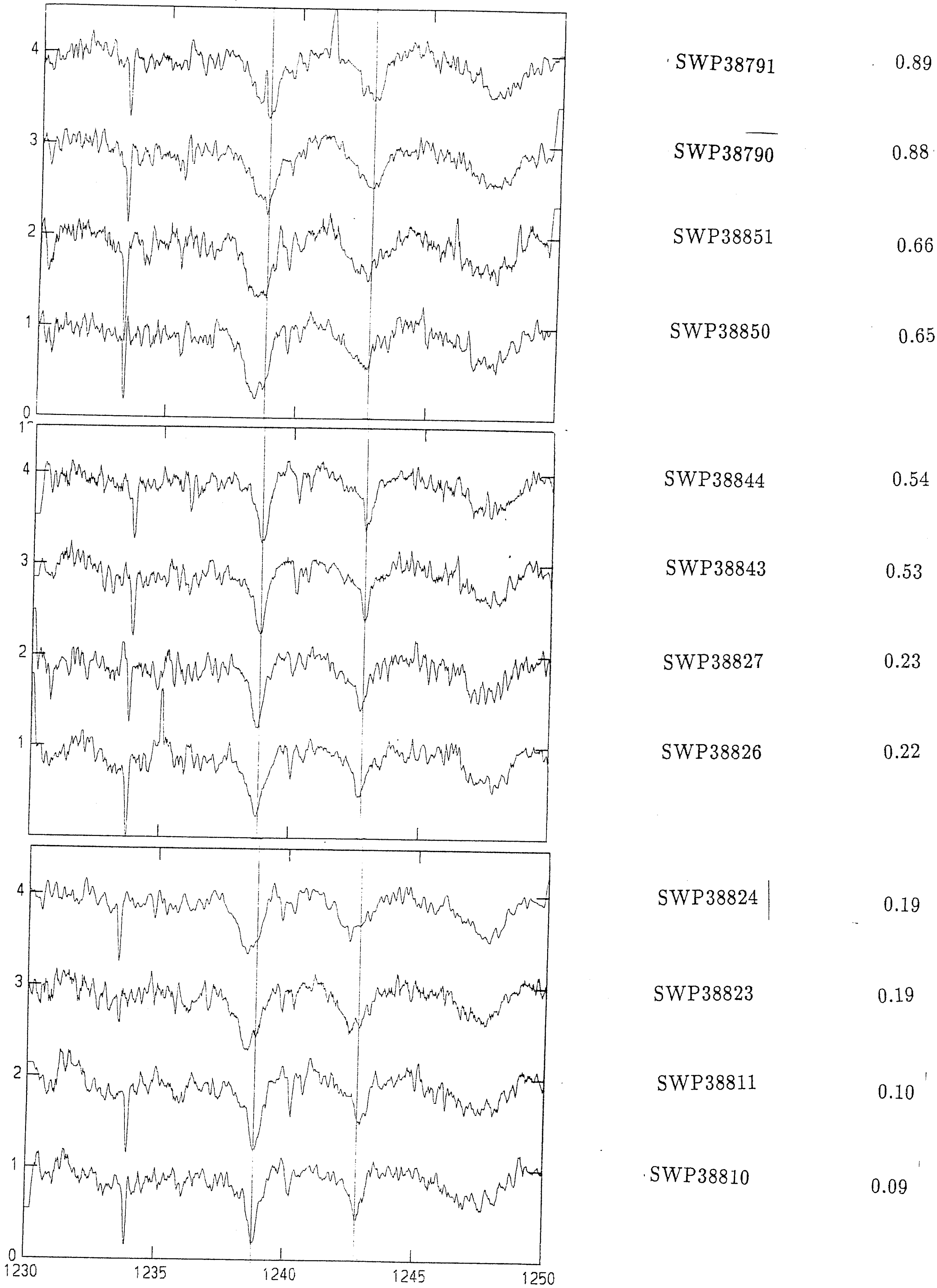

Figure 16. N V lines throughout the period.

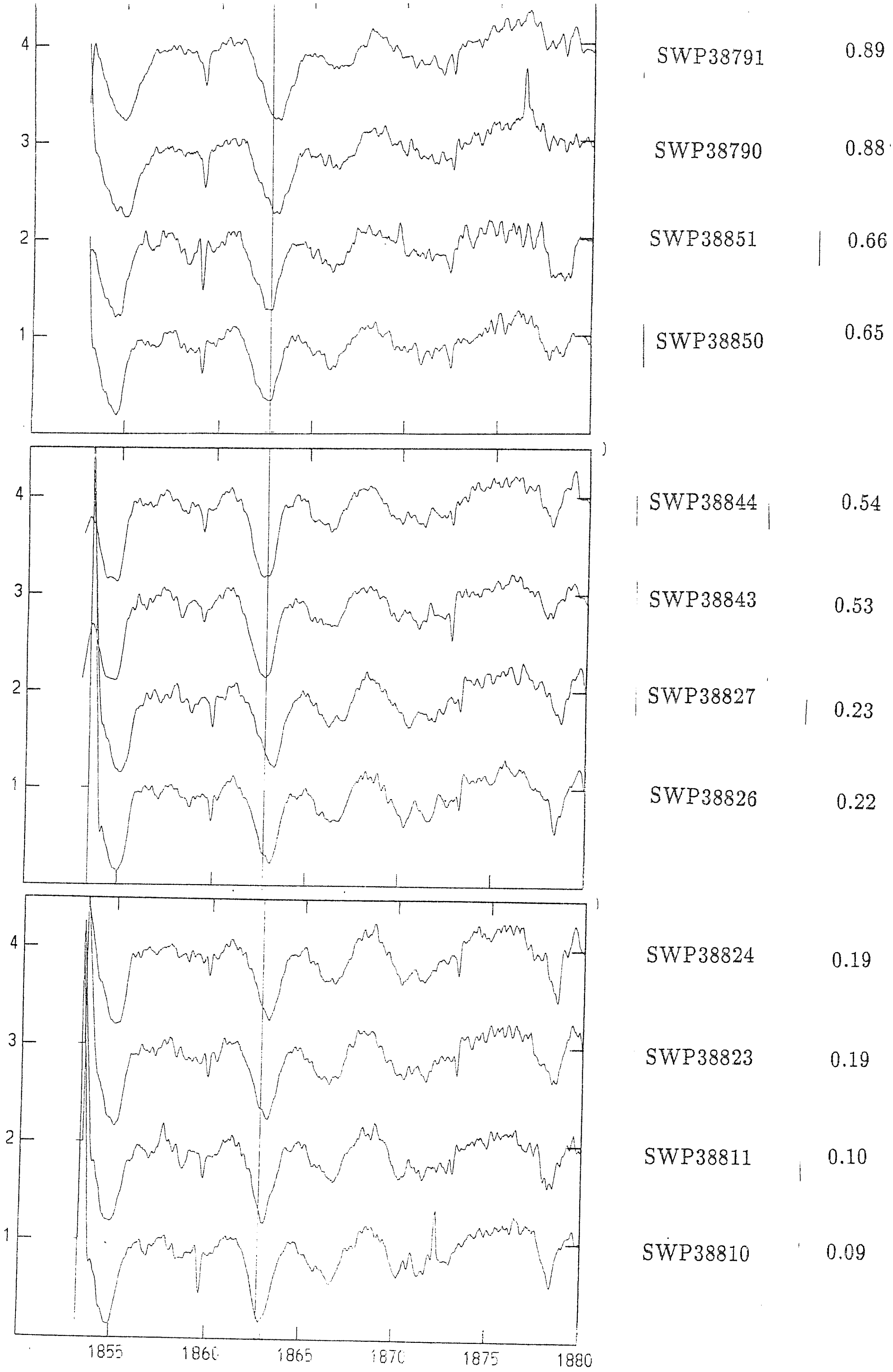

Figure 17. Al III lines throughout the period.

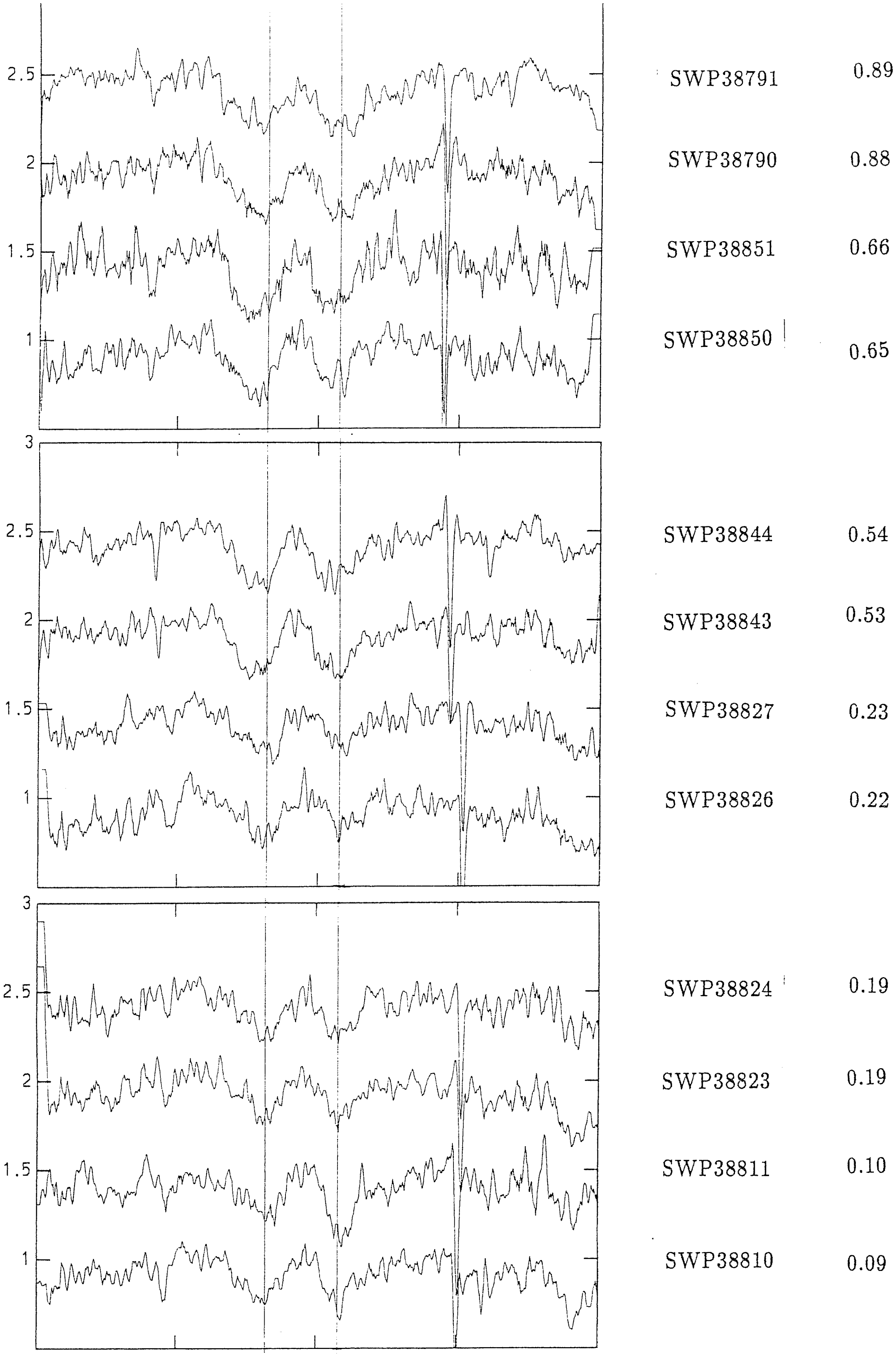

Figure 18. C IV lines thoughout the period.

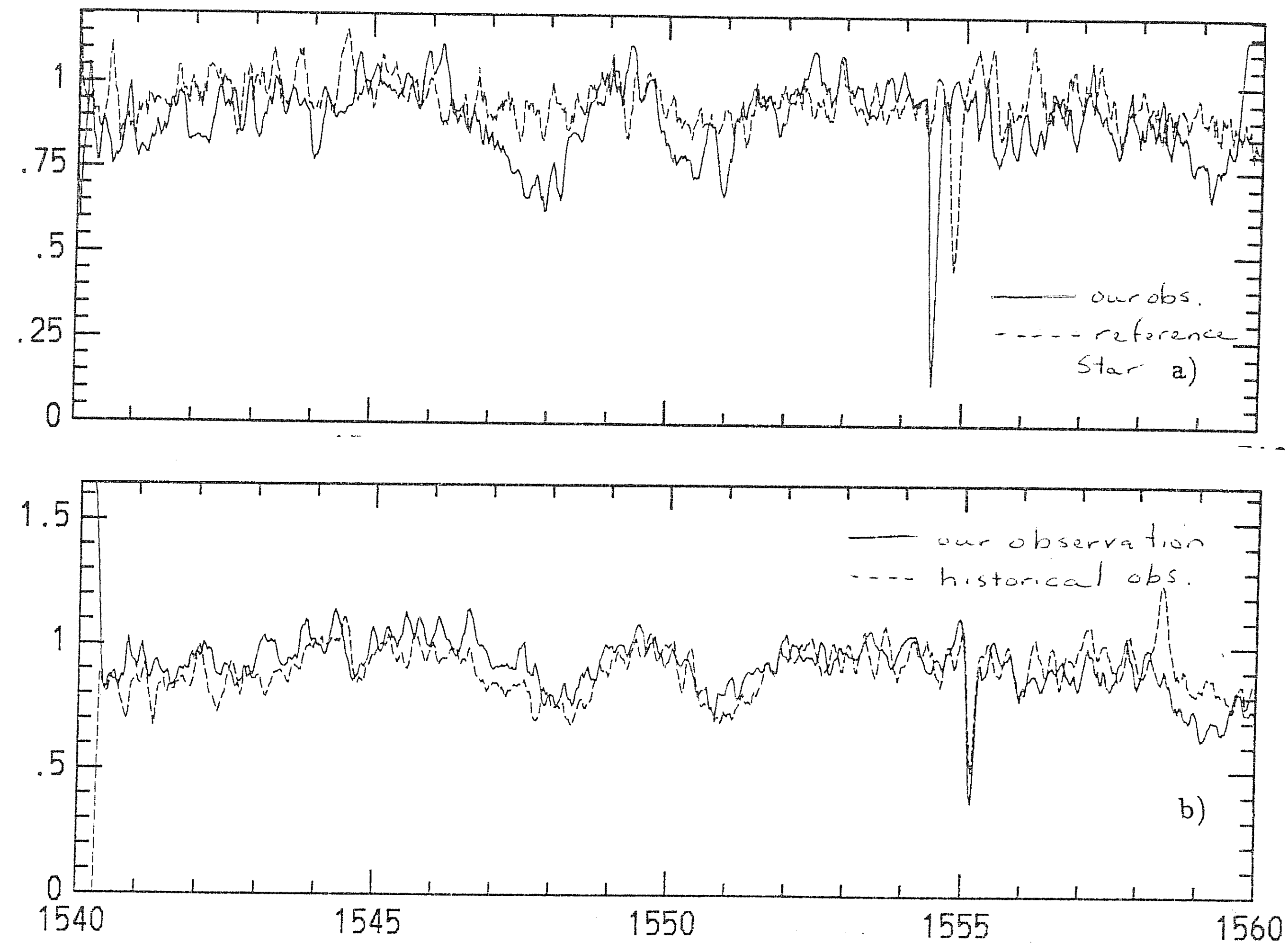

Figure 19. a) a comparison of the C IV with a B3 reference star. b) a comparison of C IV with historical observations.

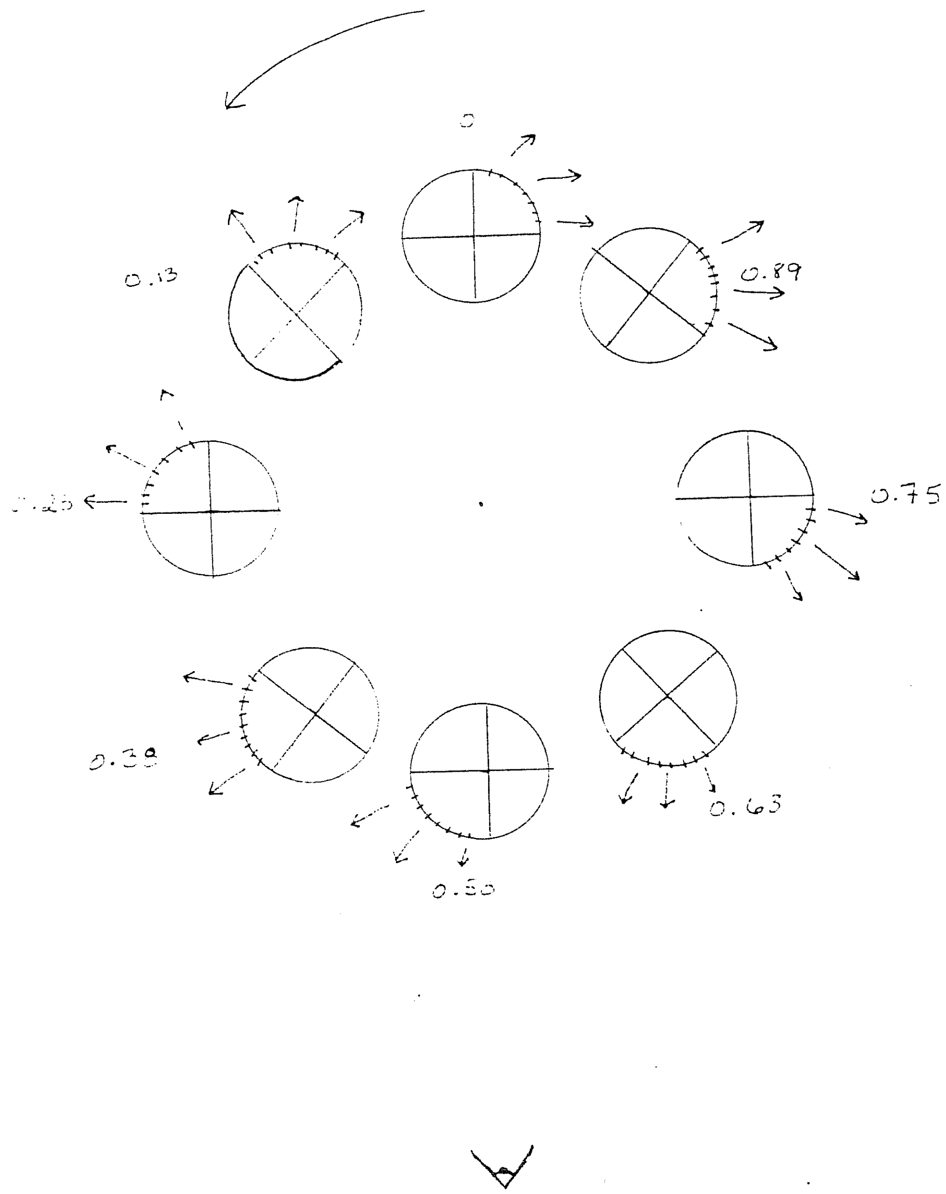

Figure 20. A simplistic drawing of the primary in Algol systems and V356 Sgr. The hatched quarter indicates the part of the star receiving the gas stream. The various phases are marked. The eye symbol indicates the location of the observer. The secondary is not shown and the center of the drawing is the center of mass of the system.

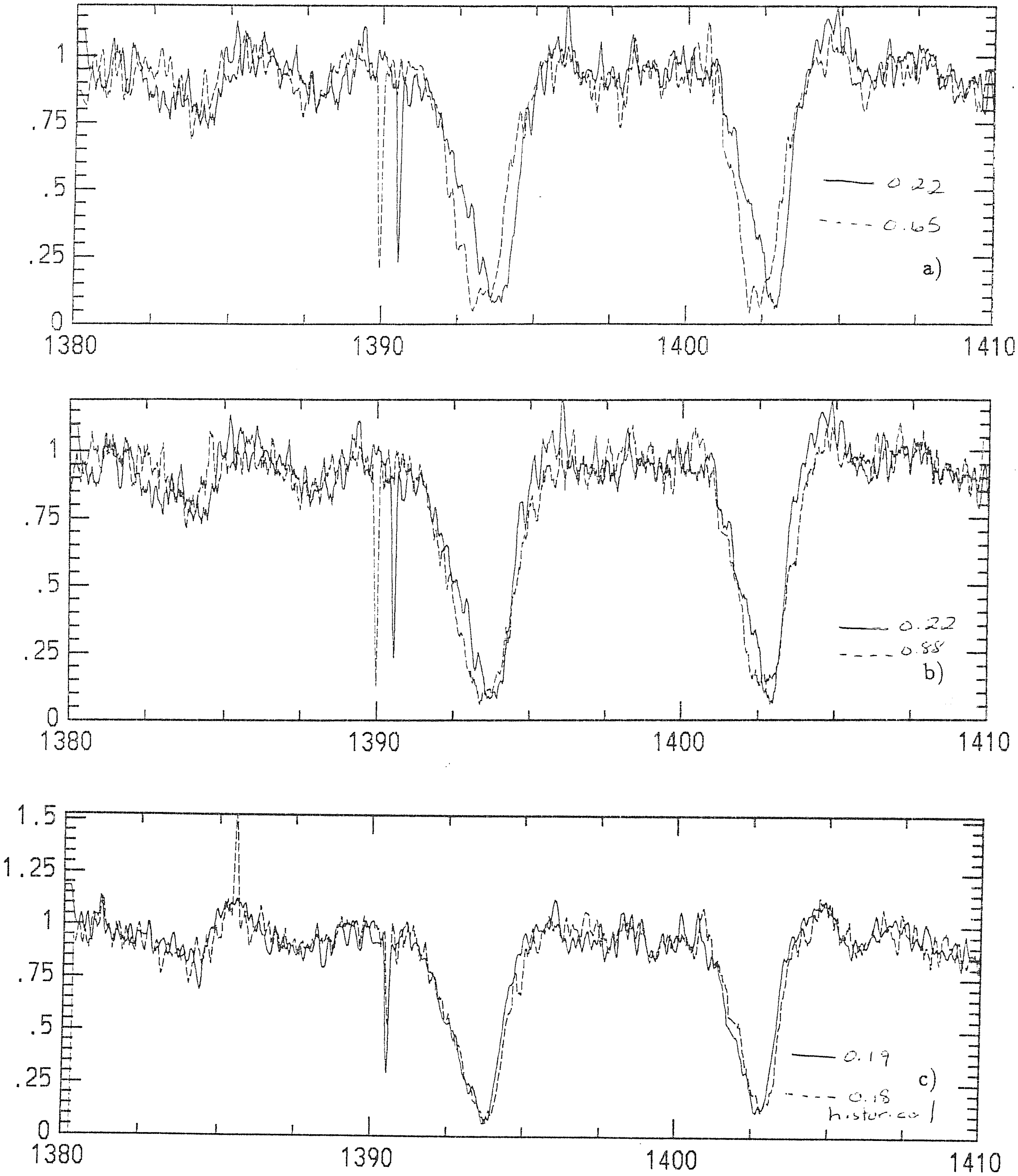

Figure 21. Si IV a) phases 0.22 and 0.65 compared. b) phases 0.22 and 0.88 compared. c) phase 0.19 compared with a historical spectra (98 cycles).

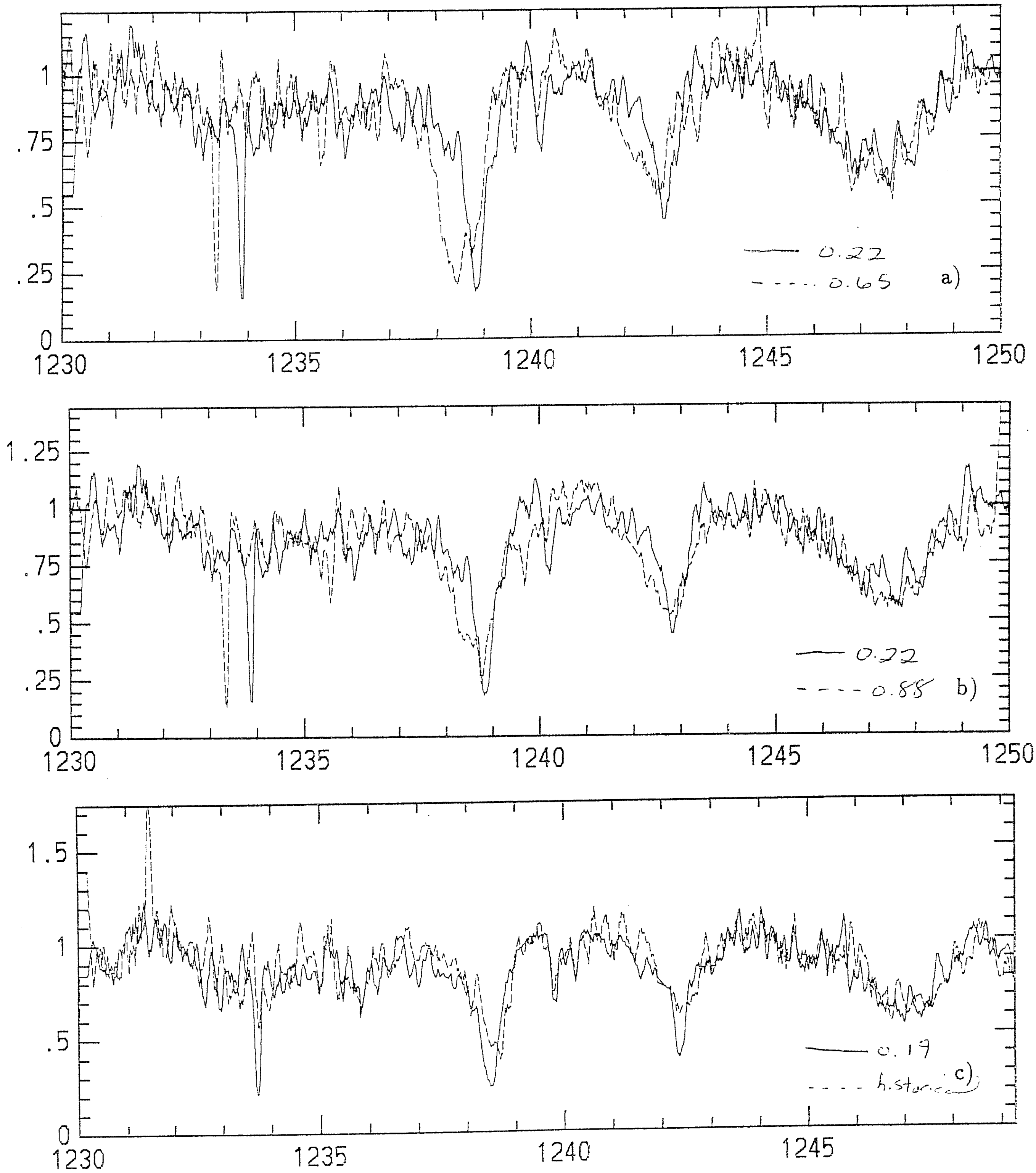

Figure 22. N V a) phases 0.22 and 0.65 compared. b) phases 0.22 and 0.88 compared. c) phase 0.19 compared with a historical spectra (98 cycles).

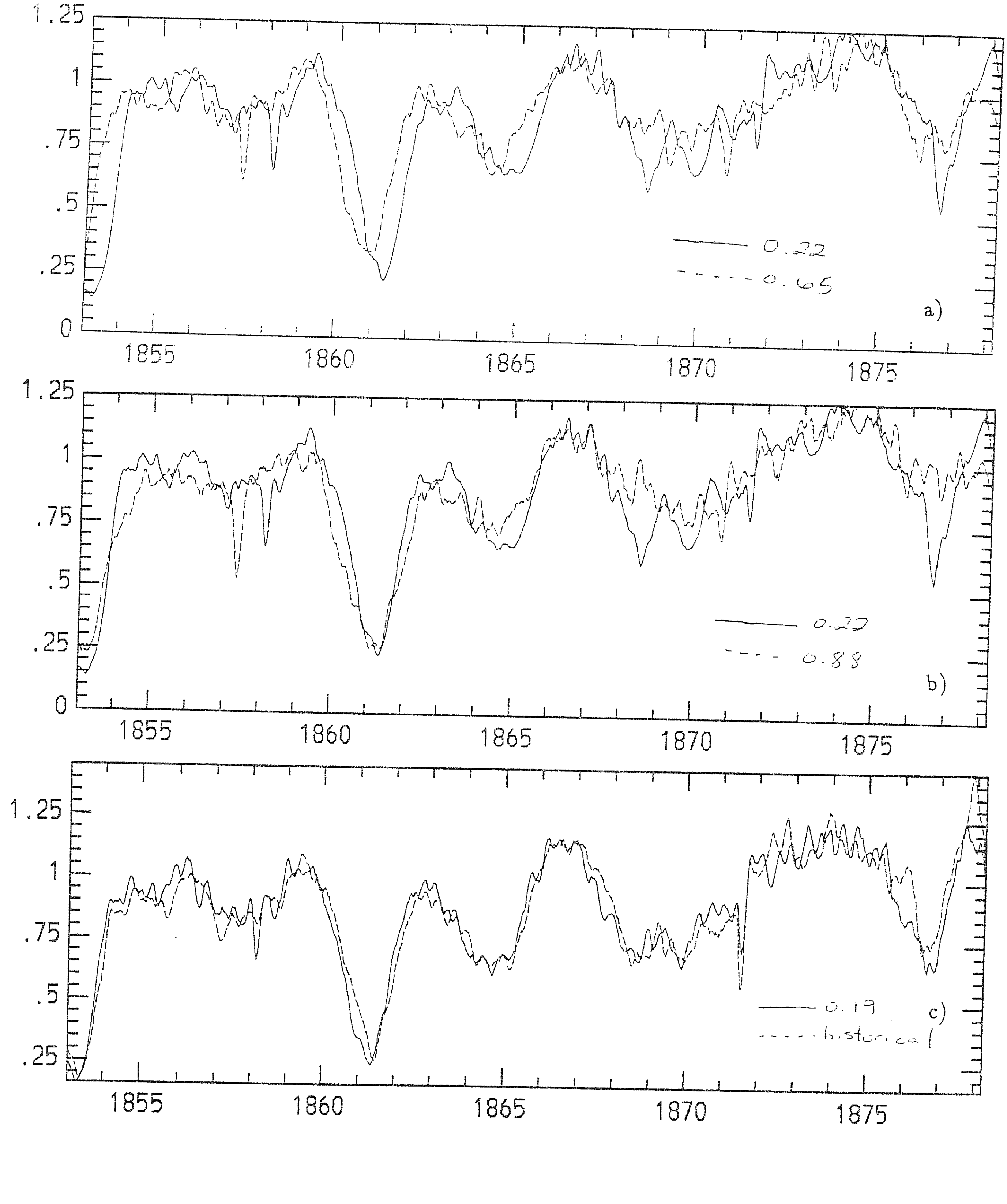

Figure 23. Al III a) phases 0.22 and 0.65 compared. b) phases 0.22 and 0.88 compared. c) phase 0.19 compared with a historical spectra (98 cycles).

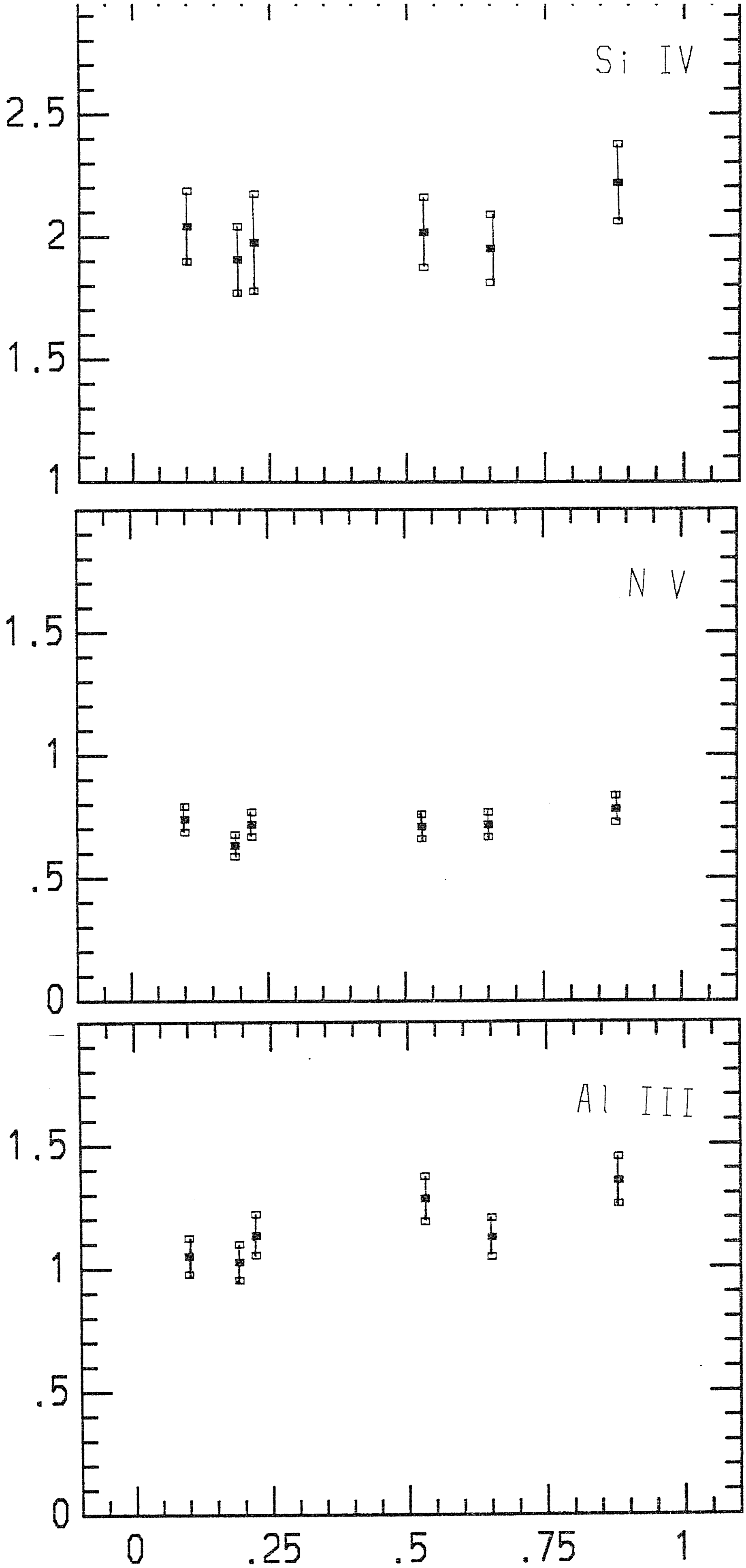

Figure 24. Equivalent width plots for Al III, Si IV and N V. The observations taken on the same day have been combined to reduce the error.

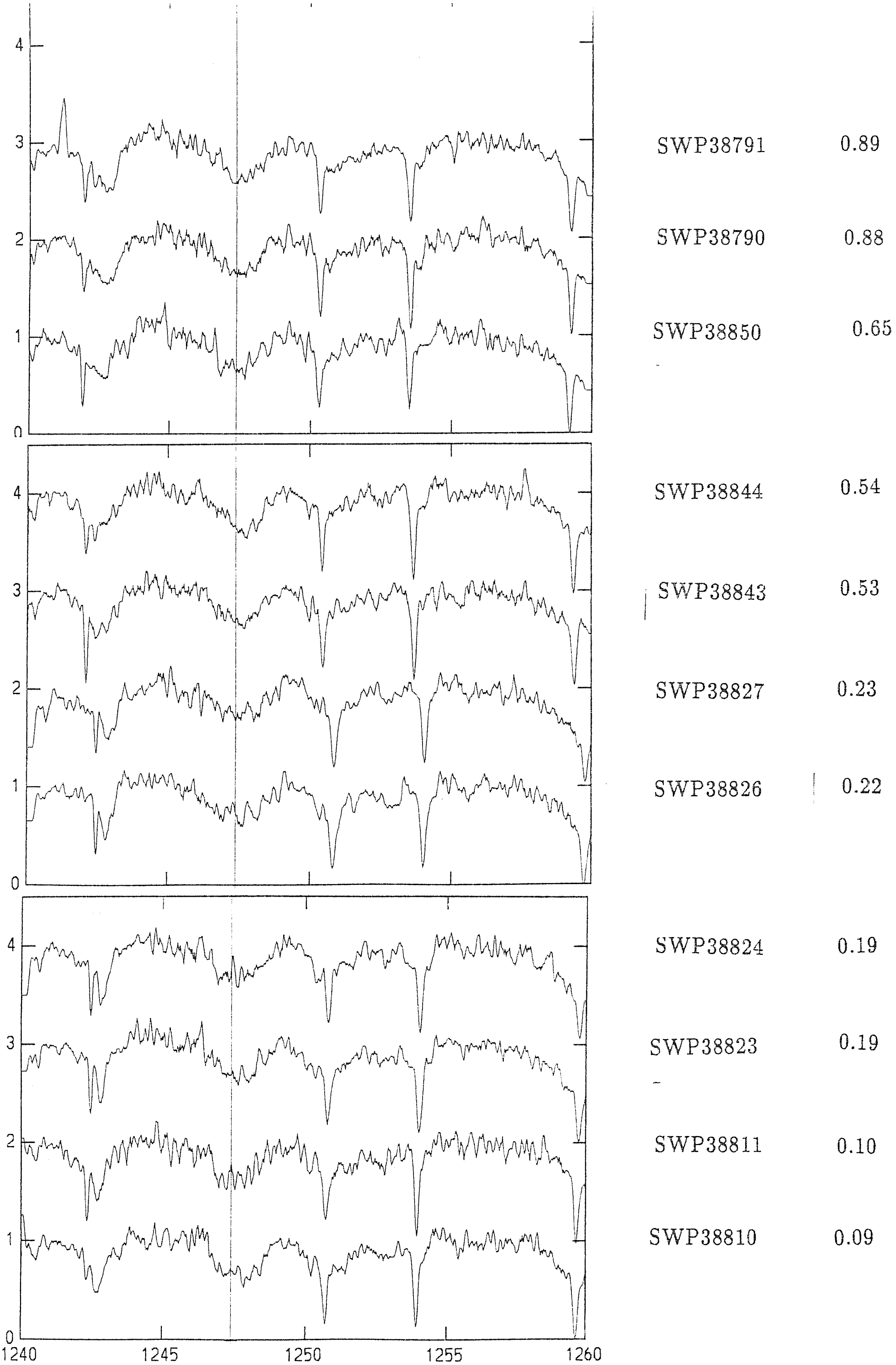

Figure 25. C III lines throughout the period.

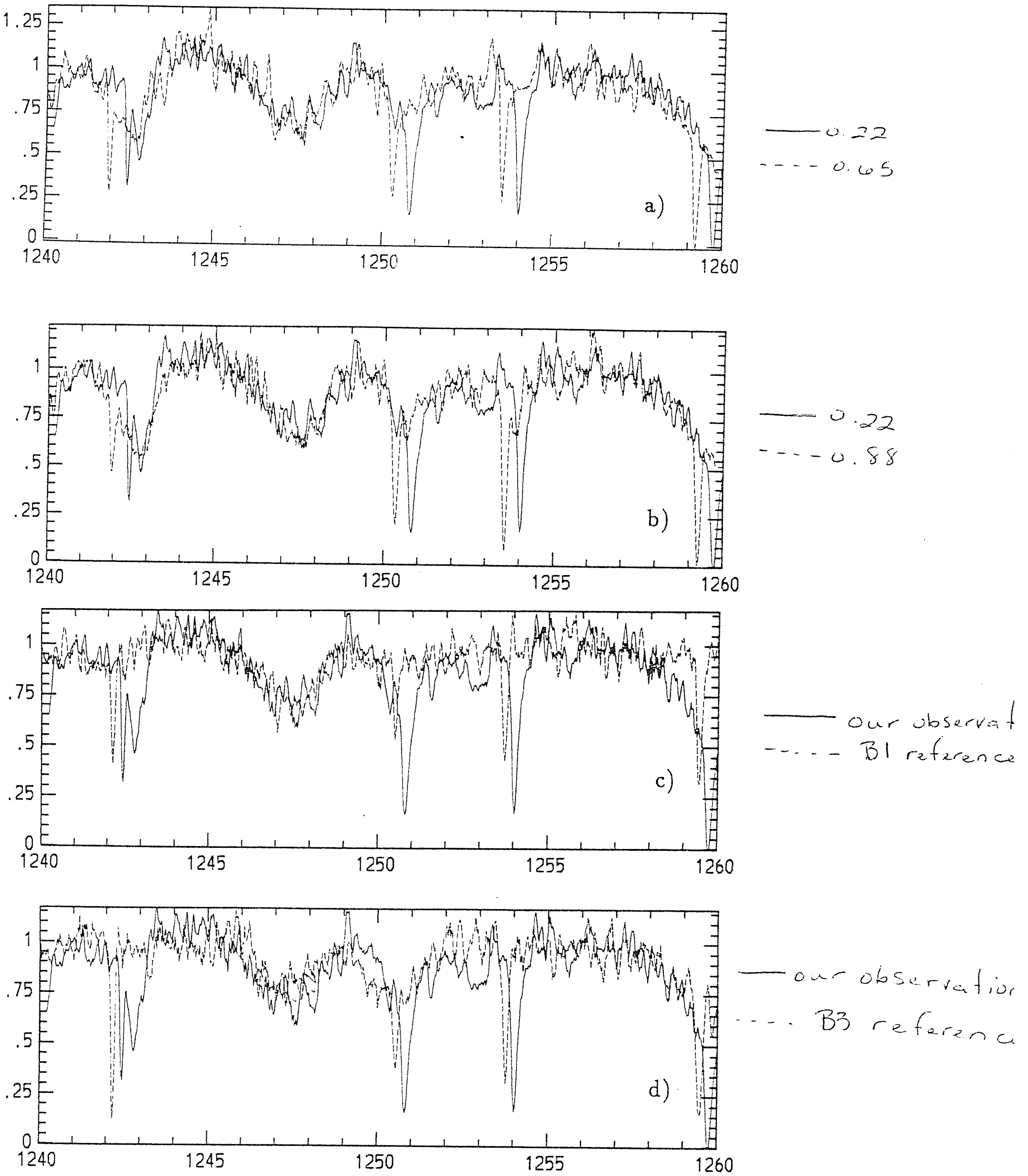

Figure 26. C III a) phases 0.22 and 0.65 compared. b) phases 0.22 and 0.88 compared. c) C III compared to B1 reference star d) C III compared to B3 reference star.

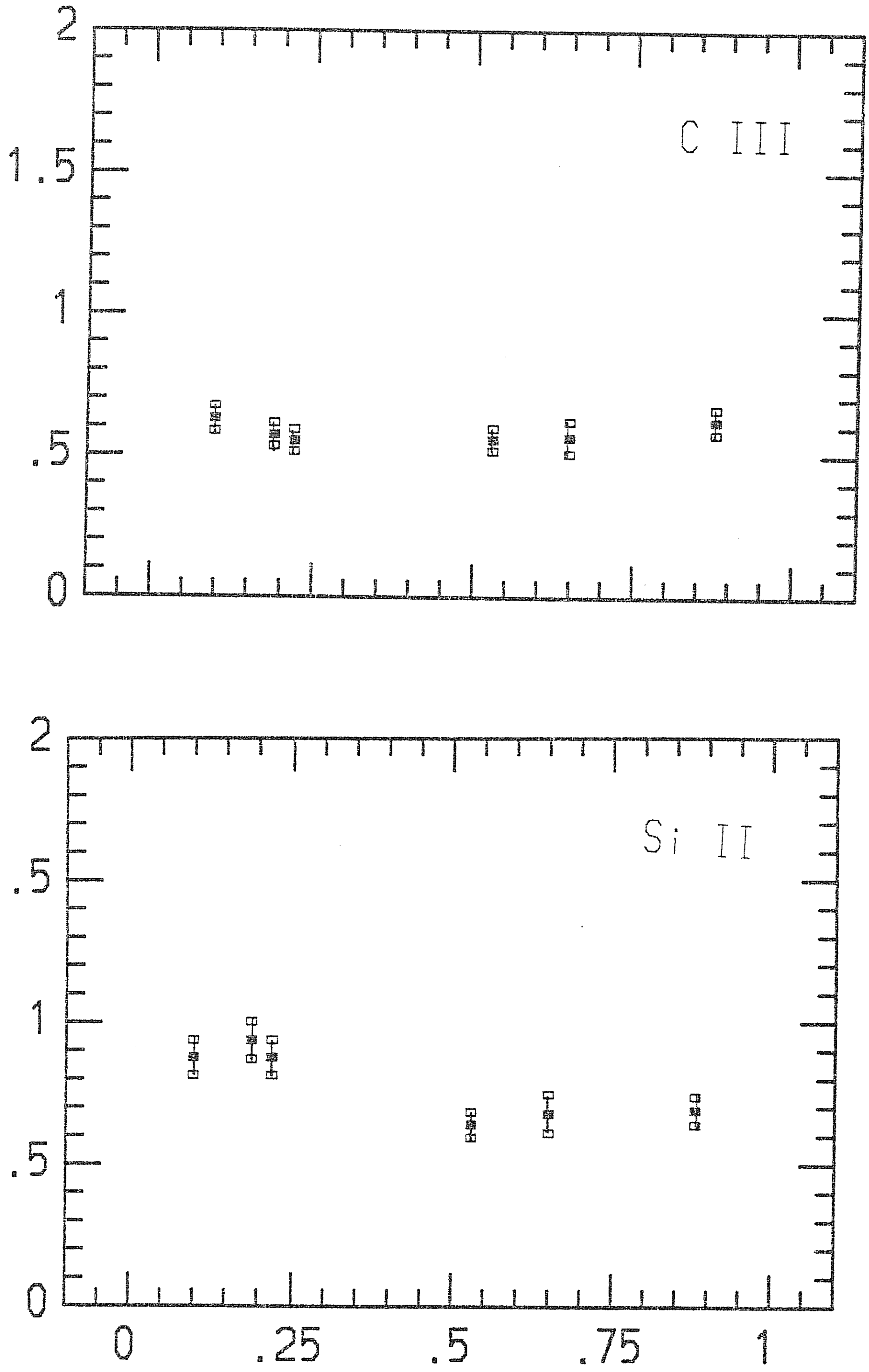

Figure 27. Equivalent width plots of Si II and C III.

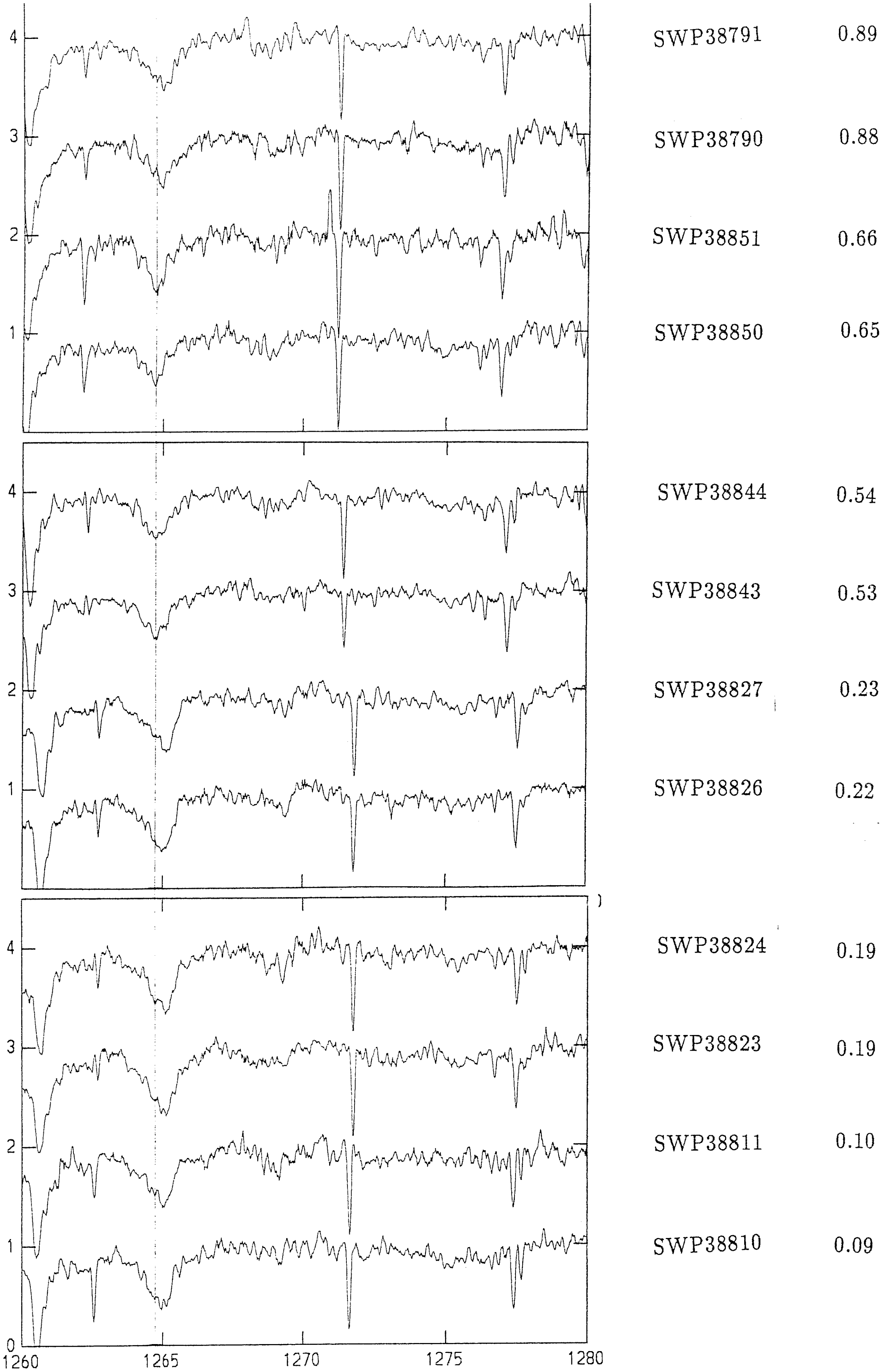

Figure 28. Si II lines throughout the period.

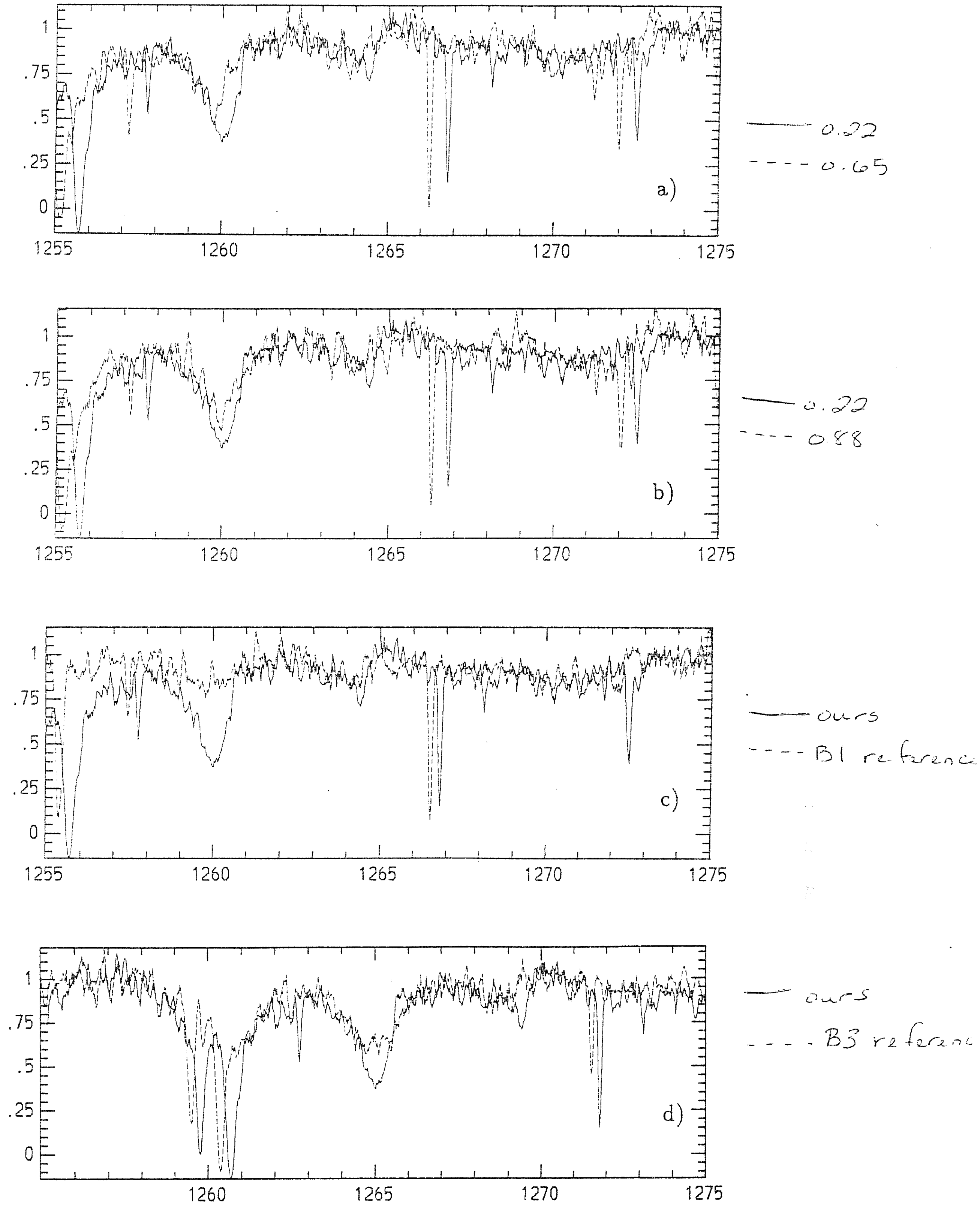

Figure 29. Si II a) phases 0.22 and 0.65 compared. b) phases 0.22 and 0.88 compared. c) C III compared to B1 reference star d) C III compared to B3 reference star.

6 Conclusion

In this work, I have tried to put forth a review of the high temperature ionization lines observed in the Ultraviolet region in Algol systems. In many of these systems, these high temperature emission lines are seen only during primary eclipse. This led investigators to believe that these emission lines were formed near the secondary component as perhaps a transition zone in the chromosphere. Plavec and Weiland (1983), in a study of SX Cas showed that this cannot be the case. They gave three reasons, the strongest being that the emission lines (seen throughout the period in SX Cas) become stronger by a factor of more than two outside of the eclipse. Those Algol systems which show the emission line spectra throughout the period, Plavec has dubbed "W Ser" systems.

Work done on the high temperature absorption lines by Sahade and Ferrar and Sahade and Hernández identified two high temperature regions in Algols. These investigators have justified two regions by demonstrating the shape difference in the C IV and Si IV lines. Others have explained it as an underabundance of carbon due to CNO processing. This is still being debated. In Plavec's (1983b) analysis of U Cep, he states that the high temperature emission lines and the high temperature absorption lines are the same material seen under different circumstances. Plavec studied both the emission and the absorption lines in U Cep and tried to describe the nature of this high temperature region. It is generally thought that these high temperature regions are the result of mass transfer within the system. The lobe-filling star transfers mass through the inner Lagrangian point to the primary according to the Lubow and Shu (1975) model. If the primary component is larger than the parameter $\tilde{\omega}_{min}$ (dependent on the scaled primary radius and the mass ratio of the two components) then the stream will impact the star. Otherwise, the stream will continue around the star and for a disk of material similar to the classical thin accretion disks. Peters and Polidan (1984) did a study of the high temperature absorption lines of four stars whose primary is larger than $\tilde{\omega}_{min}$. All four showed evidence of the high temperature lines in absorption. They demonstrated that other systems whose primary was smaller that $\tilde{\omega}_{min}$ showed evidence of stable disks. It is thought that the Lubow and Shu gas stream impacts the photosphere and through conservation of energy, heats the material and formed a hot region above the stellar photosphere. It is not understood how these regions are maintained, though turbulence has been suggested. In those stars studied by Peters and Polidan, they showed that this "high temperature accretion region" (HTAR) was highly asymmetric and in cases disappeared altogether on the side of the star not receiving the gas stream. Their HTAR also changed over several phases. This was concurrent with results found by Plavec on U Cep. We found, however, from out data that V356 Sgr did not behave this way. The high temperature absorption lines are strong throughout the period and seem to remain very similar over several cycles. Polidan (1989) studied the high temperature lines in eclipse and found that there were strong Si IV, N V and S III emission lines, but no discernible carbon in emission. He states that the secondary star in V36 Sgr is carbon deficient due to CNO processing. Out analysis agrees with this. We find very little C IV in absorption in the system. Fro out analysis of the high temperature lines, we are able to conclude that the lines are fairly constant in strength but do change shape through the period. This shape change, however is not manifest in the equivalent width measurements. If there are changes in the equivalent width of the lines, it is small. So V356 Sgr is somehow different than those studied previously. The HTAR is more spherically distributed and the more stable over time. The physical differences between V356 Sgr and other studied systems are:

- The rapid rotation of the primary star
- The presence of an A star as opposed to a later type (F,G or K) star
- The secondary is a giant as opposed to a subgiant

The first item can be rejected since the next most rapidly rotating star, U Cep, also shows some of the most drastic changes in the lines. So, perhaps the presence of the A giant leads to a more uniform HTAR.

We also studied the photospheric lines of C III and Si II. The primary photosphere has not been studied much in Algol systems. We found a surprising result. The C III is constant throughout the period. There is no difference throughout the period. The Si II, however is highly variable with a distinct change in the equivalent width change over the period. Since the primary is rotating rapidly the star should, according to theory, have a vertical temperature gradient. The star should look like a B1 star at the poles and a B3 star at the equator. We compared C III and Si II to reference stars, also rotating rapidly, of spectral type B1 and B3. The C III was very similar to both the B1 and B3 stars. The B1 reference star showed no Si II and the B3 star showed a much better agreement. We think that the Si II has been formed only in the region near the equator, but the C III has been formed throughout the star, but probably mainly in the poles. More work needs to be done on this part of the project, however if this behavior is real this star is a good test of rapidly rotating star theory. This also may be the first time that we can show where lines are formed in a star.

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