UV OBSERVATIONS OF γ Cas: INTERMITTENT MASS-LOSS ENHANCEMENT

H.F. HENRICHS
Astronomical Institute, University of Amsterdam
Roetersstraat 15, 1018 WB Amsterdam.

Introduction

Twenty one high resolution IUE observations made over a two year interval revealed remarkable changes in the profiles of the resonance lines of C IV, N V and Si IV in the B 0.5 IVe star γ Cas. Narrow (FWHM < 100 km s^{-1}), blue shifted (v < 1500 km s^{-1}), absorption components of varying strenghts are observed in addition to the broad, asymmetric, low-velocity absorption lines which seem to be steady.

An earlier proposed model to explain this phenomenon (the "UV-shell model" by Henrichs et al. 1980, Paper 1) has now been tested and probably confirmed by new observations which were taken with high time resolution, as was suggested in Paper 1.

We arrive at the following conclusions:

1) Intermittent enhancement (factor >> 2) of the stellar wind mass-loss rate (duration < 1 day) gives rise to a rapidly expanding (thin), high-density shell. A higher density might be correlated with a lower terminal velocity of the shell, which is less than the terminal velocity of the wind.
2) The decay of the column density of these shell lines is expected to be proportional to $(\text{time})^{-2}$ (Paper 1). This means that they are observable only during a few weeks.
3) The "UV-shell" phases of the star occur very frequently, typically on timescales of a week to a month. The strength and/or duration is variable. No periodicity has been found in γ Cas.
4) It is suggested that these UV-shell lines are <u>not</u> necessarily associated with the Be nature of γ Cas, but rather they may be common property of all early-type stars. This conclusion is based additionally on a statistical study of 26 OB stars with Copernicus (Lamers et al. 1981) where the majority of this sample shows more or less similar UV-shell lines.
5) A spin-off conclusion of the present work is that in OB binary X-ray sources the often observed irregular X-ray variability might well be explained by the UV-shell model: intermittent enhancement of the X-ray flux will be observed if the high-density shell passes through the orbit of the compact object. Simultaneous UV and X-ray observations of γ Cas might reveal its binary nature (see Paper 1).

M. Jaschek and H.-G. Groth (eds.), Be Stars, 431–435.

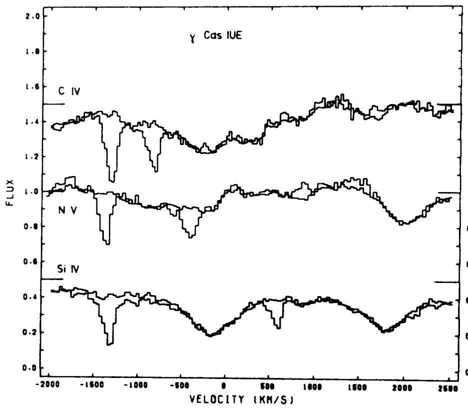

Fig.1. Spectra with and without "UV-shell" lines

A detailed paper containing much of the observational material and the line profile analysis will appear elsewhere (Henrichs et al. 1981). Here we describe only a few important observations leading to some of the conclusions mentioned above.

Line profile analysis

Figure 1 shows the strongest UV-shell episode ever recorded from γ Cas (26 may '80) superposed on a "quiet" spectrum near the resonance lines of C IV, N V and Si IV. The horizontal velocity scale is relative to the principal line of each doublet. Fluxes are normalized to the stellar continuum (indicated by horizontal lines). The "quiet" spectrum is a mean of 4 spectra which were taken between different UV-shell episodes in 1978 and 1979. A mass-loss rate of about 10^{-8} $M_{\odot}$ $year^{-1}$ was derived from this spectrum (Paper 1). Note that the centers of the broad absorptions are all shifted by −200 km s^{-1}, indicating mass outflow.

In fig. 2 a time sequence of 19 days duration is shown. The

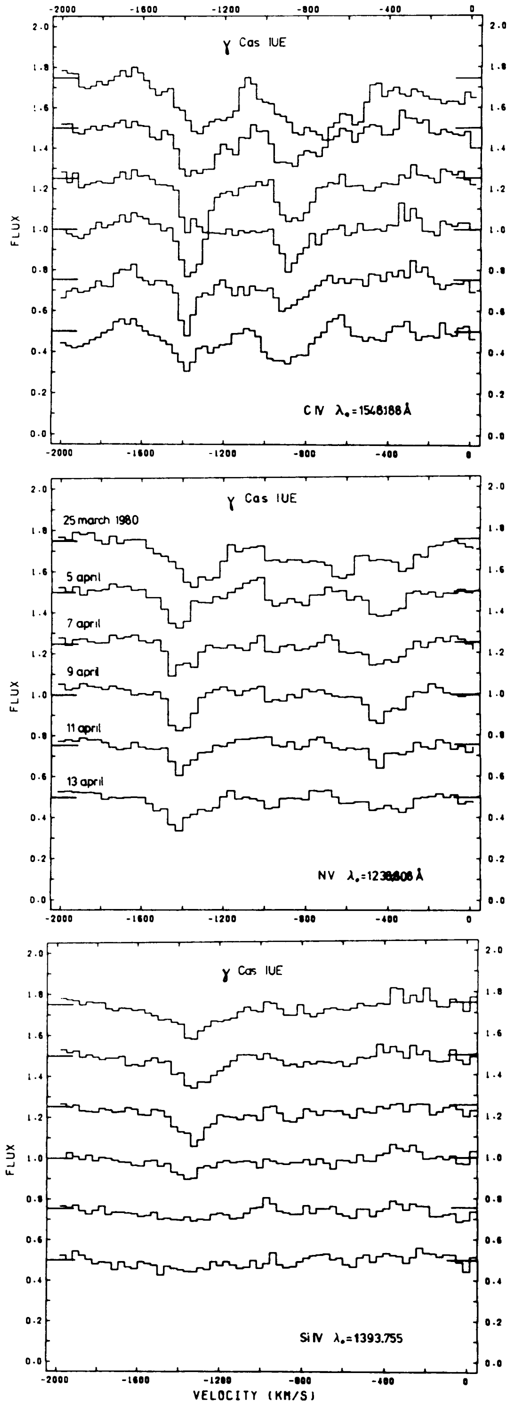

Fig.2. Normalized shell spectra of the april 1980 UV-shell episode.

https://doi.org/10.1017/S0074180900038171 Published online by Cambridge University Press

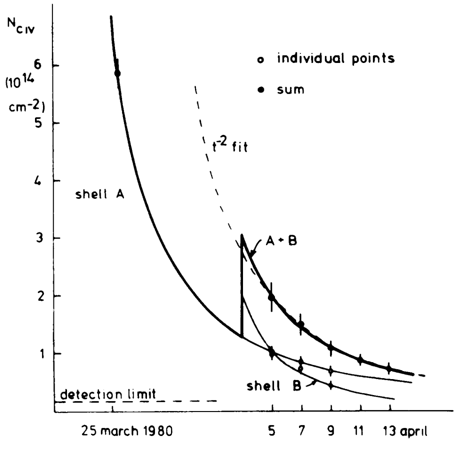

Fig.3. C IV column density decay and possible t^{-2} behaviour.

scales are those of fig.1. Here the spectra are normalized to the local underlying stellar + line flux. These UV-shell spectra are therefore ready for direct comparison with theoretical predictions. It is clear from fig.2 that all three ions do indeed show equal (sometimes several) shell velocities. In complicated cases the identification is aided by the presence of both doublet lines from all three ions.

Spectral line fits (corrected for the IUE instrument) were made to derive the column density according to profiles of the type

$$F(v) = \exp(-\tau_o \exp(-((v-v_c)/v_t)^2))$$

where F is the flux, τ_o the central optical depth of the line, v_c the central velocity and v_t the "turbulent" width, respectively. If necessary, more lines were included in the fit.

The resultant C IV column densities (not corrected for abundance) are displayed in fig.3. The dashed curve is a t^{-2} fit through the last 5 datapoints, suggesting that at 25 March we are dealing with not the same shell. For the first four datapoints the sum of more components was used. Therefore a more appropriate description would be with two sets of shell lines, which are observed at v_A = -1400 kms^{-1} and at v_B = -1300 kms^{-1}. A two shell fit based on 4 free parameters and 9 points (solid line in fig. 3) gives a very good agreement with the observed behaviour, implying that the second UV-shell episode should have started a few days before 5 April.

Shell parameters

From the observed column density we may estimate the mass M in a shell using $M = 4\pi r_s^2 m_H N_H$. Here r_s is the inner radius of the shell, which is estimated from its velocity and the length of time it has been visible. We assumed that 10% of Si is in Si IV. This prescription yields $\sim 3.10^{24}$ g for shell A and $\gtrsim 3.10^{23}$ g for shell B. If we express the formation time τ of the shell in days and the mass-loss enhancement by p (Paper 1) we obtain $\tau p \simeq 50$ and 5 for shell A and B respectively. No attempt has yet been made to solve the ionization balance to obtain the density in the shell (giving the thickness and formation time). In any case the high values of τp indicate a very strong mass-loss enhancement.

References

Lamers, H., Gathier, R., & Snow, T., 1981, in preparation.

Henrichs, H., Hammerschlag-Hensberge,G.,Howarth,I.,Barr,P., in preparation.

Henrichs, H., Hammerschlag-Hensberge, G., & Lamers,H.,Proc. 2nd European IUE Conference,Tübingen,Germany, ESA Sp-157, 147,April 1980(Paper 1)

https://doi.org/10.1017/S0074180900038171 Published online by Cambridge University Press

DISCUSSION

Stalio: For some of the O stars you mentioned as having shells we started a program of monitoring their shell variability with IUE. From the observations already made we found several other O stars having shells. The most striking evidence of changes is found in HD 175754 (O8 III) (Carasco, Costero, Stalio, 1981, A&A in press).

Snow: Many Be star observers are not familiar with the observations of O star winds. The more we learn about winds in Be stars, the greater the similarity that can be seen between O and B stars. Whether or not the winds are the underlying-cause of the Be phenomenon, they are clearly of great importance, and the comparison with the O stars is constructive.

Doazan: I want to emphasize 3 points:
1. Your term of "shell" lines to designate the narrow absorption superionized lines is confusing because this term designates the low excitation lines observed in shell spectra in the visible. To avoid needless confusion it would be better to find an other designation.
2. The variability exhibited at the present epoche in the UV in γ Cas, the high velocity component remains at almost the same velocity, the variability affects principally the strength of the line. In 59 Cyg we observe large velocity changes simultaneously with profile changes.
3. Your model tries to explain only the superionized region surrounding the star and I see no way of explaining the low velocities observed in the H_α emission with the velocity law you have adopted. The Be phenomenon is defined by the presence of this cool and low velocity atmosphere and UV observations show that we have in addition a high velocity expanding region. Any realistic model should explain both regions.

Henrichs: 1. I propose: ultraviolet, high-velocity, high-excitation, narrow absorptions as sometimes has been observed in γ Cas, in order to avoid any possible confusion... Perhaps we might abreviate it to high-velocity (shell) lines because they only appear at high velocity.
2. If you look closer to the γ Cas data you would find in several cases (for instance in the 25 March and 13 April spectra) absorptions at velocities between 600 and 800 km/s, just what you observed in 59 Cyg. I argued that during one "hight-velocity shell" episode the probability is rather low to observe the absorptions at low velocity, simply because the acceleration goes very fast (paper 1). So in 59 Cyg apparently the episodes occur very frequently. They are observed not to have such a high strength as in γ Cas. The latter point is in favour of this interpretation: the ratio formation time/ decay time is higher for 59 Cyg than for γ Cas, which is expected for "weak" and "strong" episodes, respectively.
3. Olson (1980, priv. communication) calculated the H_α emitted by the "high velocity shells" of the type I described. The result was that the effect on H_α is completely neglegible. So you may form your H_α whenever you like: this "high velocity shells" are not going to

effect this. In other words: I have no model for the H_α emission, the only thing I know is that it does not come from these high velocity shells. But I agree definitely with you that ultimately it is still the same which displays so many phenomena which has to fit together in one model.

Thomas: We shall emphasize that γ Cas is in the "quasi-steady" bright Be phase; while 59 Cyg is in the minimum, but presently low-level Be phase. So, that one observes always the same 1400 $\pm$ 200 km/s for γ Cas can equally be interpreted as a stationary velocity pattern, with density rising and falling, and not an outward moving shell. If it is an outward moving shell, then it must interact with the "storage bubble", which produces the H_α emission. Further, if the shell is continously accelerated, why is then not a similar acceleration acting on this "ambient H_α medium" through which the shell moves?

Henrichs: I agree completely on the first point; the Be phase might be very important. For your second point I refer to my answer to the question (2) of Dr. Doazan. I think that it is really difficult to construct a temperature distribution from which you would observe lines of ions with 1. a wide spread in ionization potential at exactly the same velocity, independent of the density, and 2. multiple structure, i.e. two or more sets of different (high) velocities. Both of these properties have frequently be seen. The last point you mentioned is true. It would probably be observable, but don't forget the short time scales (hours). How strong this effect will be is not calculated: it would be extremely interesting to know the magnitude of this effect.

Endal: Can you estimate from the velocity dispersion within a blob, the time duration of an enhanced mass loss event?

Henrichs: The problem is that a velocity dispersion cannot be disentangled from a density gradient. Otherwise this would give indeed an estimate for the thickness of these shells.
Assuming a Lamers and Morton velocity law we arrived at a lower limit: $p \gtrsim 2$(see paper 1), based on the assumption that there is no density gradient. I am afraid that we really have to solve the ionization balance to obtain the density. This is however a difficult task.

https://doi.org/10.1017/S0074180900038171 Published online by Cambridge University Press