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LETTER

Letter to the Editor

Increase of emission and shell features in the spectrum of the FUor V1057 Cyg*

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Abstract. High–resolution échelle spectra of the FUor V1057 Cyg were taken during its minimum brightness in 1996–97. The spectra show the appearance of strong shell–components in the lines of low excitation, an increase of the splitting of the photospheric absorption lines, and the appearance of weak emission lines. It is argued that the mysterious line splitting of the absorption lines in the spectrum of V1057 Cyg, which has been interpreted as originating from an accretion disk, can be explained simply by the presence of central emission cores in the broad absorption lines. This emission spectrum of V1057 Cyg has increased in strength relative to the continuum as the star has faded.

Key words: (stars:) circumstellar matter – stars: individual: V1057 Cyg – stars: pre–main sequence – accretion disks – FUors

1. Introduction

The star V1057 Cyg belongs to the small group of the FU Orionis type stars (FUors), pre–main sequence objects which are undergoing an event of eruptive activity (Herbig 1977). Before its flare–up in 1970, V1057 Cyg was a T Tauri star with the characteristic emission line spectrum. After the rise in brightness, its spectrum changed drastically to an A–F supergiant and later to a G supergiant (G2–5 Ib–II, Herbig 1977). Among the known FUors, V1057 Cyg has the fastest rate of brightness decline during the first two decades after the flare–up.

A characteristic feature of all the FUors is the double profile of the absorption lines. This was one of the reasons to interpret the FUors as objects with accretion disks, where the spectrum is formed not in the atmosphere of a supergiant, but in the atmosphere of an optically thick luminous accretion disk rotating at Keplerian velocities (Hartmann & Kenyon 1985). This interpretation was criticized by Petrov & Herbig (1992), who pointed out that the line doubling phenomenon is observed also in some of the shell–supergiants. It was proposed that the absorption line profiles are split due to the presence of emission components at the center of the absorption lines.

In 1995, V1057 Cyg went into a minimum of its brightness (Ibrahimova & Ibrahimov 1997, Kolotilov & Kenyon 1997) and eventually, in 1997, reached almost its pre–outburst level of brightness in the B band. In this letter we show the most conspicuous changes in the spectrum of V1057 Cyg during the minimum brightness, in 1996 and 1997. At the dates of our observations, the star had nearly the same brightness and colour, V≈ $12\overset{m}{.}5$, B–V≈ $2\overset{m}{.}05$ (E. Kolotilov, private communication).

This is a preliminary report of new observations, with a minimum of interpretation. A more detailed analysis will follow in a later paper.

2. Observations

The high–resolution échelle–spectra of V1057 Cyg were taken on October 30, 1996 and August 15–22, 1997 at the Nordic Optical Telescope (La Palma, Spain) with the SOFIN échelle spectrograph. In October 1996, the spectrum has a S/N ratio of about 100 in the red. In August 1997, a series of exposures with a total exposure time of 24 hours provided a mean spectrum with a S/N ratio of more than 300 in the red. Weak lines of equivalent widths down to 10 mÅ can be identified in the spectrum. The resolution in the average spectrum of August 1997 is about 13 km s^{-1}. The spectra of V1057 Cyg have useful signal in the wavelength range 4800–9000 Å. Spectra of 41 Cyg (F5 II), β Aqr (G0 Ib), 9 Peg (G5 Ib), 40 Peg (G8 II), 84 Her (G2 IIIb) and β And (M0 IIIa) were taken for comparison.

3. Emission lines

A number of emission lines, in addition to H α and the Ca II lines, appeared in the spectrum of V1057 Cyg in August 1997 (cf. Figs. 1 and 2), as compared to the spectrum of 1996 and those previously published. The most conspicuous is the line Fe I (12) λ8047Å. The peak of the emission is at the stellar velocity (–16 km s^{-1}), its width is slightly less than the

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* Based on observations obtained at the 2.56m Nordic Optical Telescope, Roque de Los Muchachos Observatory, La Palma/Spain.

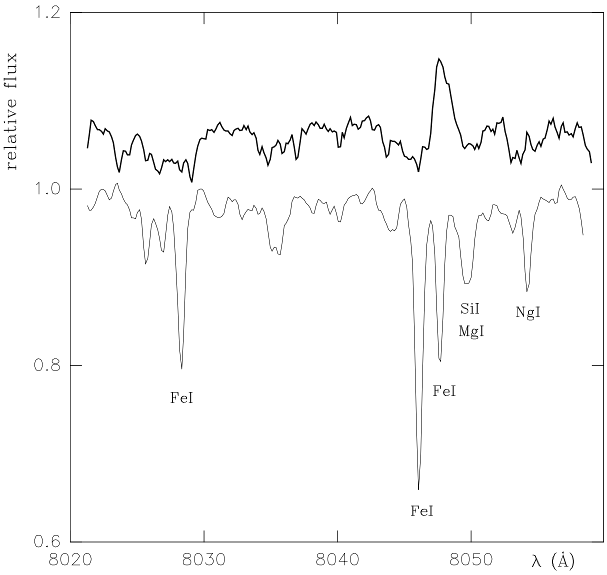

Fig. 1. The emission of Fe I (12) λ8047Å in the spectrum of V1057 Cyg in August 1997 (upper bold curve). The spectrum of β Aqr is shown for comparison, with the identification of a few lines. The spectra are shifted in relative fluxes for clarity.

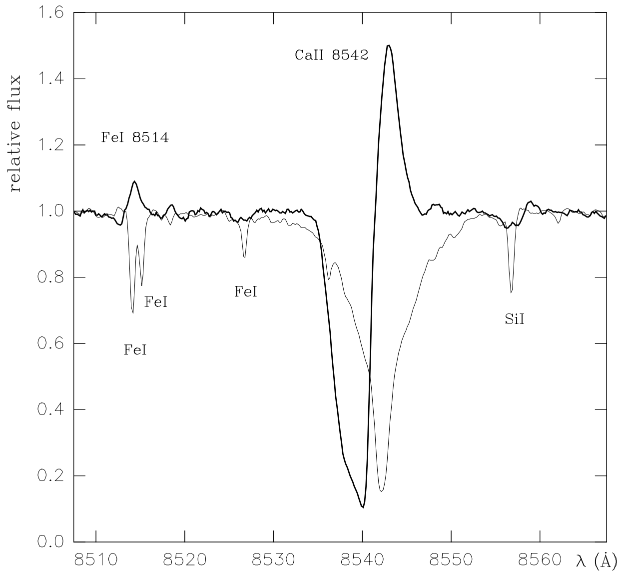

Fig. 2. The emissions of Ca II (2) λ8542Å and Fe I (60) λ8514Å in the spectrum of V1057 Cyg in August 1997 (bold curve). The spectrum of β Aqr is shown for comparison.

width of the photospheric absorption lines. The other emissions are Fe I (60) λ8514Å, Fe II (40) λ6516Å, Ca I (1) λ6572Å and Fe I (12) λ7912Å. It is interesting to note that all of these lines are strong in emission in the spectrum of the pre–main sequence star VY Tau (Herbig 1990). The H α and IR Ca II lines show P Cyg–profiles with the blue–shifted absorption extending up to –380 and –250 km s^{-1}, respectively.

4. Emission components in the photospheric absorption lines

The photospheric absorption lines in the high–quality spectrum of V1057 Cyg obtained in August 1997 are much shallower than in the spectra published so far, which makes a comparison with the spectra of standard stars rather difficult. The ratio of the photospheric line intensities can set limits for the spectral type of F7–G5 Ib–II. The lines of higher excitation potentials, which are supposed to be less affected by emission and shell-components (see below) were used for the spectral classification.

Most of the photospheric absorption lines appear double with an emission–like component at the bottom of the absorption. The wings of the absorption lines near the continuum level (5–7% below the continuum) can be fitted by a rotational profile with v sin i of about 50 km s^{-1}, with a scatter of $\pm$10 km s^{-1} for the individual lines. No systematic trend of this parameter with wavelength was found in the spectral range 5000–8800 Å.

The most interesting finding is that the line doubling, i.e. the velocity separation between the two absorption dips, has increased in October 1996, and even more so in August 1997, as compared to the spectra published so far.

Comparison with the spectra of V1057 Cyg, published by Kenyon et al. (1988)[1] and by Hartmann & Calvet (1995), shows that the line width of the absorption near the continuum level remains the same, but the central emission-like reversal has increased, and the depth of the absorption has been reduced. Due to this effect, some of the weaker lines have almost vanished. At lower S/N ratio, the spectrum would have a "washed out" appearance.

As noted above, several low–excitation lines of Fe I and Ca I have clearly gone over into emission. It is reasonable that the same phenomenon should appear to a lesser degree in other, higher–excitation lines, as a central emission core. This would cause those absorption lines to appear double, precisely as is observed (a typical example is shown in Fig. 3). The strength of the emission spectrum has increased with respect to the continuum as the star has become fainter, so the "line doubling" is now quite striking.

The effect of the line splitting by emission components is most clearly demonstrated by the changes in the profile of Fe I λ6191 Å. The spectra of V1057 Cyg in this region published before were taken in 1988 (Welty et al. 1992) and in 1992 (Hartmann & Calvet 1995). In both spectra the line is not split, with a central depth of about 13% of the continuum level. In October 1996, the line had the same depth, but the weak emission core was already present. In August 1997, the line depth was reduced to 5% and the emission core rose up almost to the continuum level (see Fig. 4). Obviously, this line splitting is entirely due to the rise of the emission core.

[1] The high–resolution spectra published by Kenyon et al. (1988) as well as those by Welty et al. (1992) and Hartmann & Calvet (1995), referred to below, were taken when the star was about 1^{m} brighter, V= 11^{m}.5 – 11^{m}.6, B–V= 1^{m}.7 – 1^{m}.8 (Ibrahimova & Ibrahimov 1997).

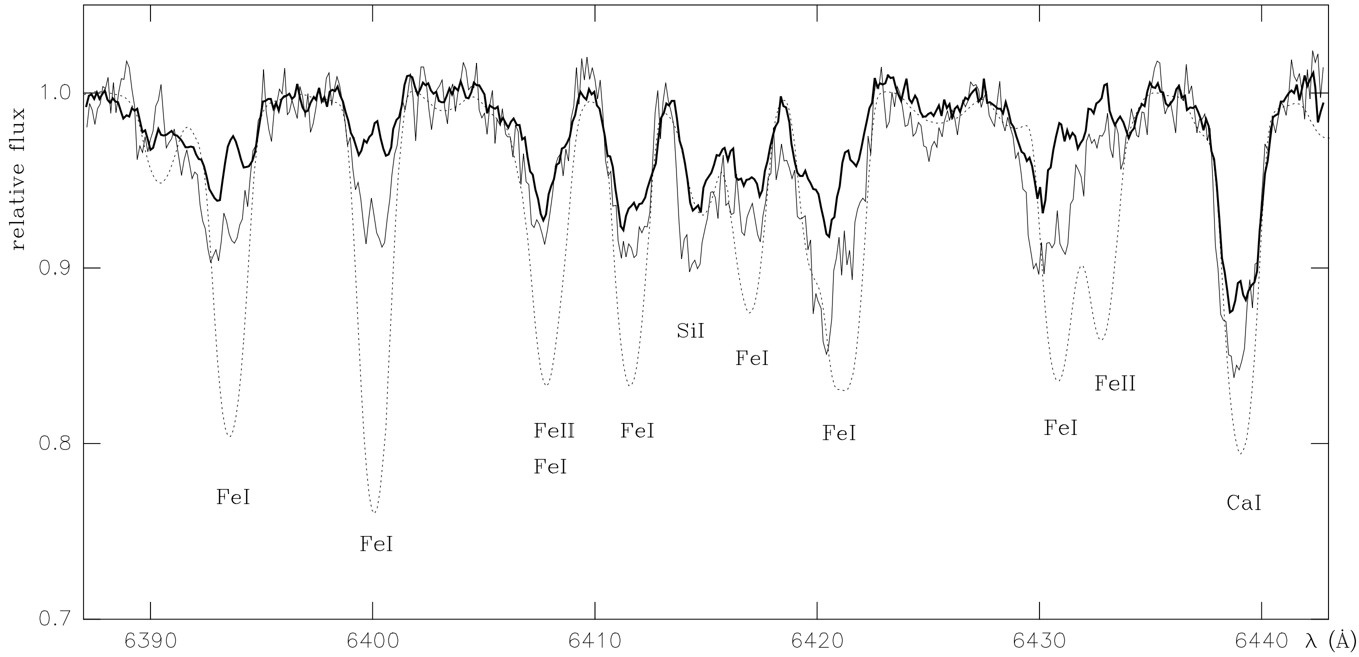

Fig. 3. The bold curve is the spectrum of V1057 Cyg in August 1997, the thin solid curve that in October 1996; the dotted line is the spectrum of β Aqr, spun up to $v \sin i = 50$ km s^{-1}. Note the rise of the emission cores which makes some of the absorption lines appear split.

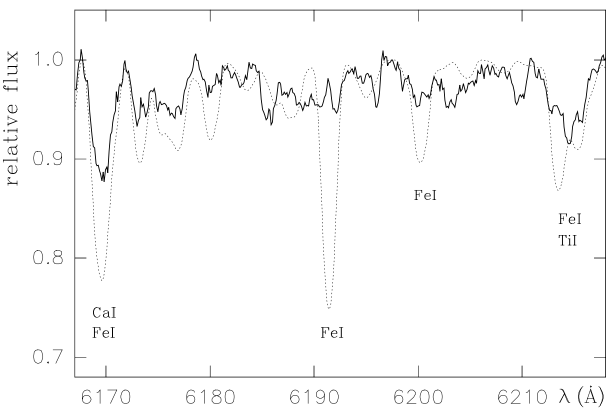

Fig. 4. The bold line is the spectrum of V1057 Cyg in August 1997. The dotted line is the spectrum of β Aqr, spun up to $v \sin i = 50$ km s^{-1}. Note the emission core in Fe I λ6191Å.

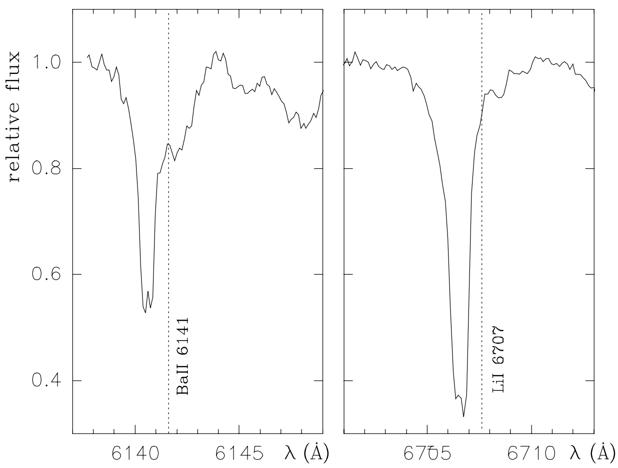

Fig. 5. The blue–shifted shell components in Ba II (2) λ6141Å and in Li I (1) λ6707Å in the spectrum of V1057 Cyg in August 1997. The line positions in the stellar restframe are indicated.

Another argument in favour of this interpretation of the line splitting is that the splitting is *differential*, i.e. the intensities of the emission components at the bottom of the absorption lines are not the same in different lines. The weaker lines of the highest excitation potentials ($>$ 5 eV) are not split, while most of the stronger lines of lower potentials (2–4 eV) are split by an emission component. The velocity separation between the double absorption dips is, on average, 44 km s^{-1} in the red part of the spectrum (as compared to 30 km s^{-1} reported by Hartmann & Kenyon 1985). This value is, however, very different in individual lines: the lines most strongly filled in by emission are split up to 60 km s^{-1} (e.g. Fe I λ6393Å, Fe I λ6400Å).

5. Shell components of the low excitation lines

Another obvious difference in the new spectra of V1057 Cyg as compared to those published before is the appearance of numerous sharp, blue–shifted shell–components of absorption lines of low excitation ($<$ 1 eV) (Figs. 5 and 6). The shell components were stronger in the spectrum of October 1996 than in the spectrum of August 1997. In October 1996, besides the atomic shell–lines, a few weak TiO bands were present in the spectrum, for example the R_1 band of the TiO γ–system near 6781 Å. The sharp head of the TiO band was also blue–shifted,

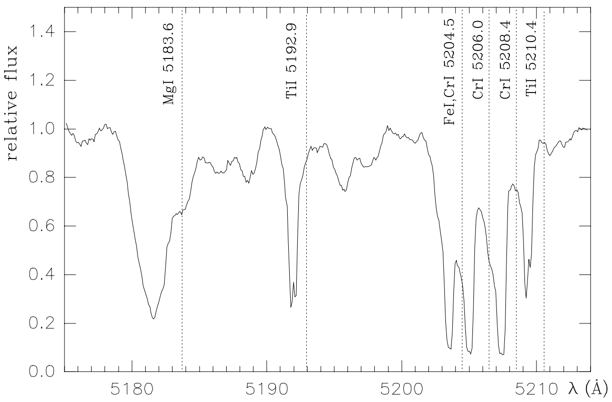

Fig. 6. The shell components in Mg I, Ti I and Cr I lines in the spectrum of V1057 Cyg in August 1997. The line positions in the stellar restframe are indicated.

showing that the bands originate in the expanding shell. In August 1997, the TiO bands have disappeared together with the weaker shell–components of atomic lines.

Some of the blue–shifted shell–lines have no photospheric counterparts at the stellar velocity, because they are too weak in a G–type spectrum, but rather strong in the spectrum of a cool expanding shell.

The radial velocities of the shell components range from –40 to –55 km s^{-1}. The stronger the shell–absorption, the larger its blue–shift. In August 1997, most of the shell–components had two just resolved peaks of absorption separated by 16 km s^{-1} (e.g. Ba II λ6141Å, see Fig. 5). The weak emission line of Ca I (1) λ6572Å is also accompanied by a distinct shell–absorption at –45 km s^{-1}.

6. Discussion and conclusions

The remarkable changes in the spectrum of V1057 Cyg indicate that the fading in brightness, the formation of a cool, expanding shell, and the increase of emission lines may be physically related phenomena.

The dimming of the star, accompanied by the appearance of weak emission lines might be considered as the beginning of the return of the star to its pre–outburst T Tau state. In this case, however, one would expect a change of the spectral type to late K of lower luminosity, which is not observed.

The brightness fading was interpreted by Kolotilov & Kenyon (1997) as due to a dust condensation event in the outflowing wind. The development of the dense cool shell and the absence of appreciable change in spectral type, reported in this letter, seem to support this hypothesis. This implies that the current photometric minimum is temporary, and the star will eventually recover to its previous brightness level.

The presence of emission cores in the broad photospheric absorption lines can quite simply account for the mysterious line splitting in the spectrum of V1057 Cyg (and probably in other FUors as well), as was proposed by Petrov & Herbig (1992) for FU Ori itself. It is the fading of V1057 Cyg, and the consequent enhancement of this emission spectrum, that has made this interpretation so much more persuasive. This is not to deny that FUors may have accretion disks, but only to assert that their absorption line doubling has another explanation. It remains to be investigated whether the emissions are formed somewhere in the wind, which is responsible for the P Cyg–profiles in Ca II and H α.

In any case, these new data put more restrictions on the models of FUors, whose nature is still far from being understood.

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