Physics – Uspekhi **41** (8) 807 – 814 (1998)

PHYSICS OF OUR DAYS

PACS numbers: 96.60.Qc, **97.10.–q**, **97.20.–w**, **97.30.–b**

Flaring red dwarf stars: news from Crimea

R E Gershberg

Contents

Abstract. **Important phenomena are briefly described which have recently been discovered in the Crimean studies of flaring red dwarf stars believed to be the most common type of variable stars in the Galaxy. These phenomena include (i) long-lived radiation from a blueshifted component in the ionized-helium λ 4686 Å emission line in the active state of one such star, (ii) a long-lived absorption component in the stellar flare light curves with a lifetime exceeding that of the conventional flare emission, and (iii) solarcycle-like activity periodicity of the star EV Lac, whose mass is only 0.3 solar masses. In theoretical terms, a red dwarf star spot model is constructed which, in contrast to the commonly accepted model, agrees well with the solar spot picture.**

1. Introduction

Flaring red dwarf stars are the most numerous variable objects in the Galaxy. These stars show activity similar to the Sun. So solar phenomena which are available for very detailed studies serve as a guide in understanding non-stationary processes occurring in such stars. On the other hand, an analysis of a large number of flare stars, among which there are objects of different ages and masses, single and binary star components, provides a possibility for a more general approach to solar activity problems and, in particular, to a choice of decisive factors in the appearance and development of this activity in the course of stellar evolution.

Solar activity and the activity of flaring red dwarf stars are ultimately due to the magnetism of stars of low and intermediate masses with convective energy transfer in the subphotospheric layers and significant rotation. Both these factors change slowly on a time scale comparable with the stellar evolution, so the activity considered should appear over the whole stellar lifetime. This is a distinctive feature of such activity in comparison with young T Tauri stars with masses and temperatures similar to the Sun, and with different variabilities of old objects like supernovae, novae and various cataclysmic systems, whose lifetime is many orders of magnitude shorter. The dominance of flaring red dwarf stars among all variable stars is due to the long duration of solar-type activity and the rapid increase in the number of low-mass stars. However, their low absolute luminosity makes the number of known such stars in the solar neighborhood only slightly higher than 200, whereas more luminous variable stars like cepheids are discovered even in other galaxies and the number known is a few thousand.

A joint astrophysical consideration of solar activity and flaring red dwarf stars is a branch of stellar-solar physics that has formed and obtained significant results in the last decades. It has been intensively developed in the Crimean Astrophysical Observatory (CrAO) over the last 30 years based on both their own observations and broad international co-operation involving ground-based optical telescopes in many observatories, radio telescopes, and space-borne devices.

In this paper four new results obtained in the Crimea in the last 2 – 3 years are presented. Two of them are directly concerned with flares in such stars, one dealing with the statistical properties of their activity, and the last referring to surface inhomogeneity of such objects.

2. Ionized helium in the spectra of stellar flares

A sporadic increase in brightness is the phenomenon that allowed the stellar activity considered to be discovered. Objects with such variability are called UV Cet-type stars. As in solar flares, during flares in such stars significant energy is released over comparatively small areas of the stellar surface and the subsequent relaxation processes develop over the total height of the stellar atmosphere including the upper photospheric layers, the chromosphere, the corona, and apparently the adjacent circumstellar space. Such flares on the Sun result in fluxes of energetic particles and magnetic perturbations in interplanetary space, which are detected by space-borne devices and by geophysical methods on Earth. However, no direct evidence for stellar flare effects on the circumstellar medium is known.

R E Gershberg Crimean Astrophysical Observatory,
334413 Nauchny, Crimea, Ukraine
E-mail: gershberg@crao.crimea.ua

Received 2 February 1998
Uspekhi Fizicheskikh Nauk **168** (8) 891 – 897 (1998)
Translated by K A Postnov; edited by A Yaremchuk

During sporadic flares in dwarf stars, the optical spectrum is known to change essentially: emission lines of hydrogen and ionized calcium are strongly enhanced, neutral helium emission and a strong blue continuum appear. On some occasions, a short-lived emission λ 4686 A of ionized helium has been detected. Many characteristics of stellar flare emission at optical, radio, ultraviolet, and X-ray wavelengths have been explained by complex gas-dynamic motions emerging in the stellar (and solar) atmosphere as a result of a powerful local energy release [1 – 3], although it would be premature to speak about a completed theory of these phenomena.

In the framework of international cooperative observations of one such star, EV Lacertae, organized by CrAO in 1994, over 6 nights at the Shain 2.6 meter telescope, a continuous spectral patrol of the star was performed [4]. The most interesting results were obtained on the night of August 31 – September 1. They are presented in Fig. 1.

In the top panel of the figure the light curve of the star on this night is shown as a count rate in the U photometric band depending on time. A half dozen characteristic fast flares with different amplitudes and durations of several minutes are clearly visible. Also seen is a long-lived glow that started at UT 20:46 and lasted at least until the strongest flare of the

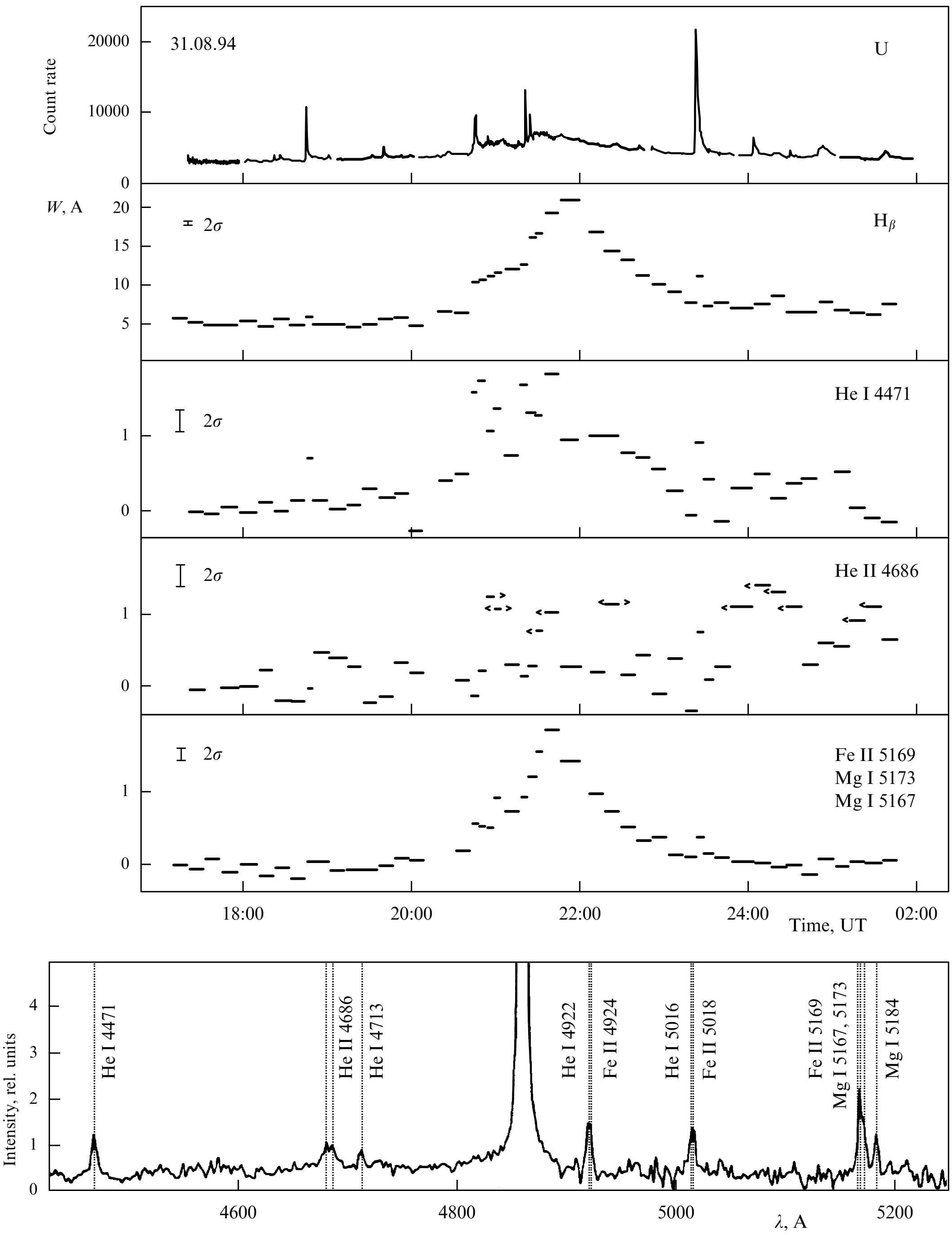

Figure 1. Results of photometrical and spectral monitoring of the flare red dwarf star EV Lac obtained on August 31 – September 1, 1994. Shown are the count rate in violet light, the equivalent width of the emission lines H_β, HeI λ 4471 A, HeII λ 4686 A, FeII λ 5169 A + MgI λ 5167/73 A blend, and the spectrum of active states of the star.

night at UT 23:24. The next panel demonstrates the equivalent widths W_{H_β} of hydrogen H_β emission, which are proportional to the total energy emitted in this line. A close inspection of these two plots reveals the reaction of H_β emission on separate flares. But the main feature of the temporal behavior of W_{H_β} is a dominating maximum connected with the enhanced stellar brightness over almost three hours. The equivalent width of the emission blend Fe II λ 5169 A and Mg I λ 5167/73 A shown in the fifth panel of the figure shows behavior similar to W_{H_β}; the correlation coefficient $r(W_{H_\beta}, W_{\text{blend}}) = 0.94$.

The third panel of the figure displays the equivalent width of neutral helium λ 4471 A. The comparison of this plot with the previous two shows that this line reacts more clearly to separate fast flares than H_β, although both these lines generally correlate with each other: $r(W_{H_\beta}, W_{\lambda 4471}) = 0.76$.

The most interesting and unexpected results were obtained by patrolling the helium λ 4686 A emission line (see the fourth panel of the figure). Formally, this line does not correlate with the emission considered above, the correlation coefficient lying within the range 0.2 to 0.3. However, a closer comparison of $W_{\lambda 4686}$ with the stellar light curve reveals that almost all spectra with enhanced ionized helium emission were obtained 15 – 30 minutes after the fast flares. The second feature of He II λ 4686 A emission is presented in the bottom panel of the figure, where the added spectrum of all active states of the star registered by us during the 1994 campaign is shown. A sharp splitting of He II emission is clearly seen in the plot: the long-wavelength component has a normal wavelength, while the short-wavelength one is shifted by −400 km/s. Among the spectra obtained on the night 31.8/1.9, eight spectra demonstrate only the short-wavelength component, two spectra show both components, and one spectrum has only the long-wavelength component. These features are marked in the figure by $<$, $< >$, and $>$, respectively.

The meaning of these observations is not yet completely clear. Probably, a similar enhancement of He II lines occurred during the flare of AD Leo observed by Byrne and Gary [5] on 2.2.84 in a spectrum obtained by the IUE satellite with 20-min exposure started 8 min after the maximum of a rapid flare. In this spectrum, a double time growth in intensity of He II λ 4686 A line was detected which appears in the He II recombination spectrum during a successive cascade transition after a λ 4686 A quantum emission. Apparently, the short-wavelength component of this line we discovered may emerge in a transition region between the stellar chromosphere and corona or inside the lower part of the corona during the formation of moving structures, whose solar analogs produce transients in interplanetary space. If this is the case, a systematic spectrography of stellar flares near He II λ 4686 A line would allow one to evaluate the kinetic component of the total energy of stellar flares, which is practically unknown, although the ratio of the kinetic to radiative energy of flares is an important parameter for a general theory of these processes.

3. Absorption effects during stellar flares

At the end of the 60s, when performing patrol photoelectric observations of flaring red dwarf stars in blue and green wavelengths (photometrical system B and V, respectively), the Italian astronomers Cristaldi et al. [6] were the first to note that often the brightness of a star before the beginning of a flare somewhat decreases, and all EV Lac flares occurred at minima of slow fluctuations of the quiet brightness with a depth of about 0.1 mag. During observations of UV Cet in October 1968, a fairly strong flare was also detected in the minimum of a slow brightness variation [7]. During the flare of EV Lac on 9.10.73 observed by Flesch and Oliver [8] with violet, blue, and red filters simultaneously, a pre-flare decrease in the stellar brightness by 0.1 mag in red light for 15 s was detected without a visible effect in violet and blue light. Andersen [9] observed a similar phenomenon for this star on 7.10.75: a pre-flare brightness decrease in the red part of the spectrum with a less pronounced effect in the blue part. Moffett et al. [10] discovered the pre-flare decrease of the H_β line during a flare in UV Cet 6.1.75. Rodono' et al. [11] detected a flare in YZ CMi on 5.1.78 in the blue light with a two-channel photometer and the pre-flare brightness weakening is very clear in the records. This feature was seen most distinctly in the light curve of the flare of EQ Peg on 19.7.80 observed by Giampapa et al. [12] in the violet light, with the pre-flare dimming continuing almost 3 min. The deepest pre-flare brightness weakenings were registered in BD + 22° 3406 by Mahmoud and Soliman [13] on 25 and 28.5.80.

Shevchenko [14] was the first to carry out a statistical study of the pre-flare dips of flare stars. Among the data published, he selected 144 reliably registered light curves of four UV Cet stars and found that half of the light curves revealed no pre-flare brightness variations, and then another half flares, with a pre-flare brightness increase (i.e. with a smooth growth in brightness immediately before the rapid outburst) occurred practically as frequently as those with pre-flare fading, with possible evidence for the pre-flare dips being observed predominantly in weaker flares. Later Cristaldi et al. [15] analyzed the light curves of 277 flares in seven red dwarf stars, detected in Catania in 1968 – 1976, and found that 61% of the flares revealed no pre-flare brightness variations, 30% of the flares demonstrated the pre-flare brightness increase, and 9% showed pre-flare fading. In the same paper it was shown that during a pre-flare rise in brightness the star blues while during a pre-flare dip it reddens.

The observations by Flesch and Oliver [8] stimulated the first theoretical model for the pre-flare brightness decrease: Mullan [16] suggested that the observed fading in the red light relates to a rapid transition of a powerful H_α emission into absorption. However, the subsequent spectral observations of the flares have not confirmed this model.

An alternative model by Grinin [17, 18] was based on the fact that, as follows from calculations, during rapid heating of the atmosphere of a cool star, its transparency must decrease thus temporarily decreasing the emergent radiative energy flux. The source of the rapid heating may be the impulse phase of a flare, which, by analogy with solar flares, should start with the appearance of short-lived hard radiation in the chromosphere.

In addition to this detailed developed model of the anomalous relaxation of a cool star atmosphere after a temperature perturbation, Grinin [19] put forward a general idea for the suppression of radiation from an active area at the beginning of the stellar flare. One interpretation of observations suggested by Roizman and Kabichev [20] is consistent with this concept: a smooth, slow brightness growth before the flare practically always occurs, but is not always detected photometrically, and the decrease in brightness of the star registered immediately before the rapid increase is due to a transient disappearance of the additional source producing the slow brightness growth. In this scheme there is no absolute decrease of stellar brightness below its ordinary level. However, this scheme has not been developed further.

Grinin's model of the anomalous relaxation of a stellar photosphere has predicted that the most notable pre-flare dimming of a star should take place at a wavelength of about 1 μm, so beginning from the mid-70s observations of this effect have been carried out mainly in the near-IR region.

Bruevich et al. [21] analyzed about 150 near-IR light curves of flares in three red dwarfs and found that practically all strong optical flares were accompanied by synchronous IR flares; in nearly 70% of the flares they detected pre-flare brightness fadings and confirmed that such fadings occur preferentially before comparatively weak flares. These conclusions were completed and made more precise by the subsequent observations of the Tashkent group [22].

During a strong outburst of AD Leo on 28.3.84, Rodono' et al. [23] discovered a long-lived dimming in the IR K-band with a very insignificant pre-flare decrease in brightness of the star in this band. To explain the IR-emission weakening during the optical flare of the star the Gurzadian's concept [24] was involved. According to this model, the flare's optical emission is a by-product of the emergence of a powerful relativistic electron flux from inside the star: due to Compton scattering, they give energy to some fraction of infrared photospheric photons thus producing ultraviolet and optical quanta. But this model predicts only synchronous counter-phase changes in the IR and optical and does not provide an explanation of the pre-flare brightness fadings, and there are serious doubts as to its physical justifiability in total [25].

In the course of co-operative studies of EV Lac in 1991, 1992, and 1993, the star was monitored simultaneously in the near-IR K-band at the Canary Islands by M Kiger, and in all standard bands of the UBVRI photometric system, covering the wavelength range from the violet to near-IR, by I Yu Alekseev and N I Shakhovskaya in the Crimea. Of six comparatively weak flares registered simultaneously in both observatories in 1991 and 1992, only in one outburst in the violet band is a brightness weakening in the K-band observed at the 2σ level. In 1993, both observatories observed the powerful optical flare on 10.9.93, but only marginal weakening in the K-band is seen at the 3σ level (see Fig. 2); however, several such fadings were detected before the flare as well. During 1994 and 1995, in addition to UBVRI observations in the Crimea, an IR patrol in the K-band was carried out in Catania. In one of six flares registered in the optical one can suspect a small smooth weakening 20 – 30 minutes after the flare maximum in the IR brightness of the star.

From this list it follows that rather numerous photometrical long-wavelength observations have not led to any definite and clear picture of pre-flare weakening in the brightness of flare stars. In this situation, it is worth mentioning one comparatively weak flare in EV Lac registered at CrAO on 5.10.96 by D N Shakhovskoy in the UBVRI photometric system during observations of this star with a high time resolution organized by B E Zhilyaev.

Figure 3 shows the light curves of this flare obtained by Zhilyaev et al. [26] after having processed the original data using the sliding averaging method with a Gaussian window of width 5 to 12.5 s. Two components of the flare are clearly seen in this figure: the traditionally registered emission component best seen in the violet band U, and a broad absorption component which is more distinguished toward the long-wavelength part of the spectrum. This clearly two-component model — 'an emission peak in an absorption saucer' — gives rise to the possibility of considering some seemingly independent photometric characteristics of stellar flares from a unified point of view.

1. As already mentioned, since the end of the 60s it had been noted by observers that fast flares occur during the slow minima of stellar brightness. Later such observations have disappeared. Apparently, this is due to the fact that the first observations we done mainly in blue and green light (the B and V photometric band), and later observers passed onto monitoring in violet light (the U-band) thus increasing the sensitivity to the emission component but simultaneously

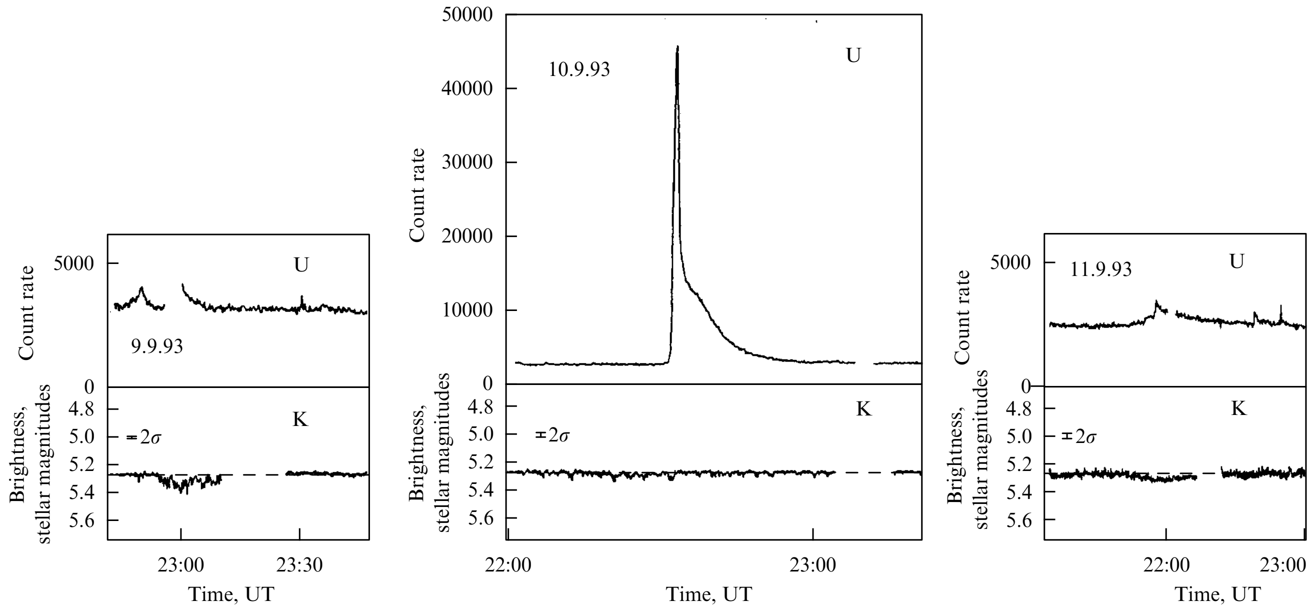

Figure 2. Light curve of flares of EV Lac obtained in 1993 simultaneously in violet light (the U-band) in the Crimea and in the infrared K-band in the Canary Islands.

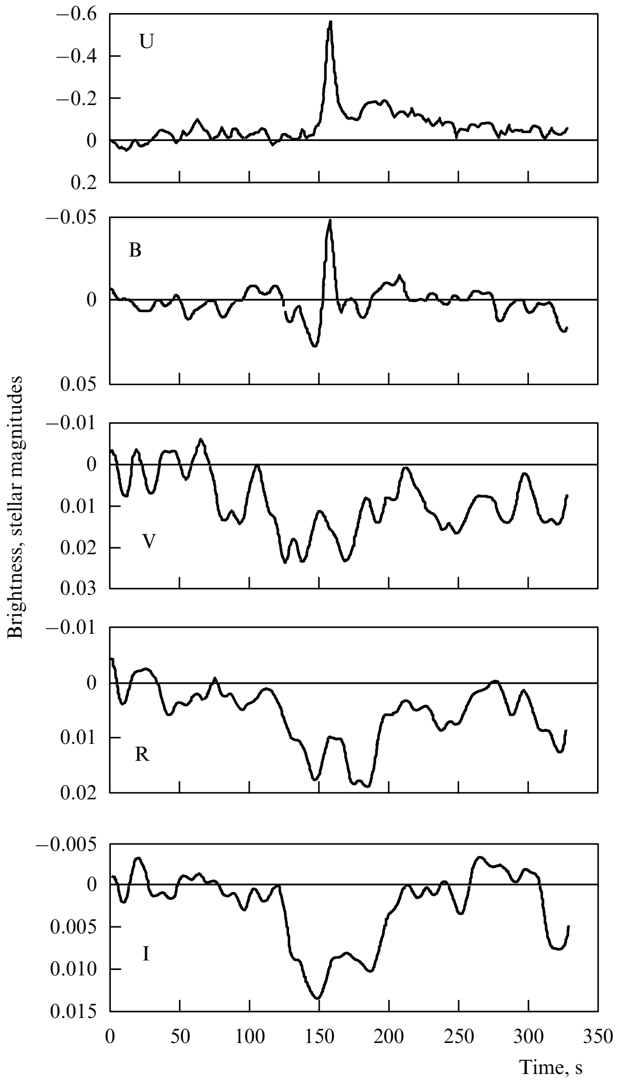

Figure 3. Light curves of the flare of EV Lac detected on October 5, 1996, in the Crimea in the UBVRI photometric bands.

decreasing the probability of discovering the 'absorption saucer'.

2. The blueing of the star during a pre-flare brightness rise and its reddening during a pre-flare brightness weakening discovered in Catania [15] provides reasons to believe that these photometric variations are caused by different mechanisms and are independent to a significant degree. Since the amplitudes of the absorption component are small (see Fig. 3 and the estimates of the depths of local minima in Refs [6, 7]), the emission component more probably dominates the absorption during strong flares, which results in the preferential discovery of pre-flare weakenings before less violent flares noted by Shevchenko [14], Cristaldi et al. [15] and Bruevich et al. [21].

3. The pre-flare dip of EV Lac discovered on 9.10.73 by Flesch and Oliver [8] was registered with a high signal-to-noise ratio, had a large amplitude, and is usually cited as one of the most obvious examples of such a phenomenon. However, on closer inspection of the total light curve obtained after the emission component has faded, one can suspect the presence of a final fragment of the absorption component with a depth comparable with the pre-flare brightness weakening. Thus, this flare with a 'template' pre-flare brightness decrease also conforms to the 'emission peak in the absorption saucer' scheme.

4. Turning back to the observed behavior of EV Lac in the K-band during optical flares, an examination of two low-amplitude flares registered in 1993 both in Crimea and the Canary Islands reveals the possible presence of a shallow 'saucer' in the IR K-band (see Fig. 2).

These facts provide grounds to believe that the 'emission peak in an absorption saucer' scheme possesses some essential properties of stellar flares and deserves special theoretical consideration. In other words, this scheme substantially changes the setting of the problem of stellar flare theory: instead of explaining the short-lived stellar brightness weakenings immediately before the flare, one should look for a mechanism for the weakening of the apparently photospheric emission that in duration is comparable or even exceeds the flare observed in the violet light.

As already mentioned, the rich and various phenomena of the solar activity provide a clue for interpreting many flare activity phenomena in the UV Cet stars. However, it is difficult to find on the Sun any analogs of the comparatively long-lived 'absorption saucers'. The disappearance of filaments detected on the Sun at the very beginning of solar flare development, suggested by Giampapa et al. [12] as a cause for the pre-flare decrease in the violet emission of the star they registered, could hardly have a notable effect in the long-wavelength region. Besides, with all the variety of solar observations, nothing among them is adequate to the broad-band photometric observations of stars which register with high precision the flux emanating from the whole visible stellar hemisphere containing an active region together with spots and flares. Here an experiment like ACRIM [27] with filters registering only the photospheric solar emission would be very desirable.

4. On the periodicity of activity of EV Lac

The solar cycle is the most prominent feature of solar activity. The structure of the solar magnetic field and all related characteristics change with a typical period of about 11 years, including the number and location of dark spots and bright active regions on the solar surface, the frequency and power of flares, and all geoactive processes. A deep physical similarity between solar phenomena and the activity of flaring red dwarf stars provides grounds to expect solar-like cyclicity in such stars. However, it has not been verified so far. The point is that among 111 stars, subjected by O Willson and his colleagues to multi-year spectral monitoring to discover chromospheric emission variations, there is only one flare star of UV Cet type — Laland 21185 (Gliese 411) of the spectral class dM2.1e, but the emission variations observed in its spectrum are determined by powerful sporadic flares, so it has been impossible to distinguish a weak cyclic component against their background [28]. So the search for cyclicity in the activity of flare star EV Lac has been carried out in Crimea using the statistics of the photometric properties of its flares [29].

As is well known, a statistical analysis of UV Cet star flares revealed a power-law character for the energetic spectrum in the optical [30], after which a similar relation was established for optical flares on the Sun [31]. Then Kasinsky and Sotnikova [32, 33] showed the validity of this relation for low-energy X-ray emission from solar flares and found a distinctive change of the power-law spectral index of the flares with the solar cycle phase: from − 0.95 at the solar maximum epoch to − 0.52 at the minimum. This fact served as a reason for a similar analysis of the flare activity of EV Lac.

In the top panel of Fig. 4, the spectral power-law index of the optical flares of EV Lac over the last 20 years is presented. A sinusoidal best-fit has a period of 7.3 years. The Pelt algorithm, which finds the most probable period without fixing the form of the best-fit periodic curve, gives a period of 7.1 years for the same data. In the bottom panel the energy release in flares in units of the quiet stellar luminosity in the U-band during different observational seasons is shown. The sinusoidal best-fit for these data has a period of 7.5 years. The sinusoids are phase-shifted by about one year. A similar situation exists for different characteristics of solar activity. For example, the correlation coefficient between the Wolf numbers, which characterize the level of spots on the Sun, with the spectral power-law index of the flares in the soft X-ray band is 0.62 for simultaneously measured quantities and increases up to 0.84 for data shifted by one year with respect to each other.

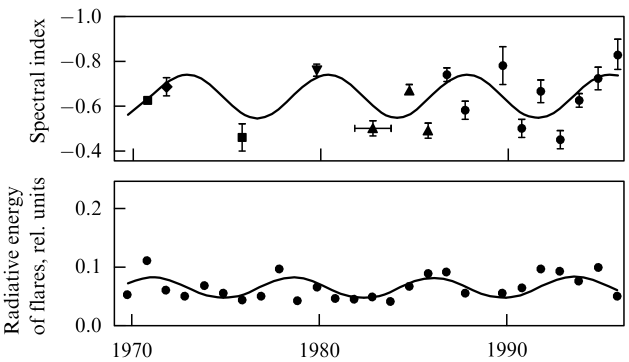

Figure 4. Manifestations of periodicity in the activity of EV Lac: the upper panel shows the spectral power-law index of the flares; the bottom panel displays the mean radiative energy of the flares emitted in violet light in units of the quiet stellar luminosity.

Thus, two characteristics of the flare activity of EV Lac lead to the conclusion that cyclic activity with a characteristic time close to 7.3 years exists in this star. This conclusion is of principal importance.

Indeed, the most spectrally late star found by Baliunas et al. [28] to have cyclic activity is a K7 dwarf HD 201092. EV Lac has a substantially lower mass. According to the current discussion on stellar magnetism [34], in fully convective stars with masses smaller than 0.3 solar masses, the boundary between the convective envelope and radiative core, where the solar-like large-scale magnetic field is generated, disappears, and a turbulent dynamo mechanism starts to act which should not display any cyclicity. EV Lac has just this critical mass. So the discovery of a periodicity in the activity of this star may be a very important observational fact for the general concepts of magnetism in dwarf stars.

5. Surface inhomogeneity of flaring red dwarf stars

G Kron, who more than 50 years ago discovered the spottedness of the red dwarf in the YY Gem system, evaluated the size of a cold spot that could produce the photometric effect he found. Since then, about ten different algorithms have been suggested for the estimation of stellar spot parameters using photometrical measurements and all of them have solved the problem set by Kron, viz. to determine the parameters of the minimum number of spots that could produce the observed brightness variations. Since the number of free parameters rapidly increases with the number of spots considered, all observations have been successfully described. This fact, however, has not given confidence to the adequacy of the calculations in reality. The point is that the picture of spottedness obtained has not conformed with the known properties of solar spots. First of all, in this picture one main spot has been introduced, then one or two less photometrically significant spots have been added, whereas such a hierarchy is not inherent to the Sun. Secondly, in such calculations high-latitude cold spots appear as a rule, which are not observed on the Sun.

To remove these contradictions, a so-called zonal model of spottedness was suggested in Crimea two years ago, in which the general properties of the total spotted region are determined, but not the parameters of individual spots. As for the Sun, it is assumed that these regions form two symmetric bands relative to the equator, and in the simplest form such a model is described by four free parameters: the distance of the bands from the equator and their width, a parameter of inhomogeneous filling of the bands with spots by longitude, and the relative brightness of the cold spots and the unperturbed photosphere. The model has been published in detail in several papers by Alekseev and Gershberg [35 – 38]. The observations considered in the framework of the zonal model have led to the following results.

1. The proposed model describes all the available observations of red dwarf flare stars without using the hypothesis of large cold near-polar spots, whose very existence contradicts to the known picture of solar activity and meets difficulties from the point of view of the theory of magnetism in slowly rotating stars.

2. In the framework of the zonal model of spottedness, an increase of the mean stellar brightness from season to season may be accompanied by both an increase and decrease in the brightness amplitude modulation, which is really observed, whereas in the traditional model, a decrease in the rotational modulation amplitude must be accompanied only by an increase in the mean brightness.

3. All the observed variety of the main parameters of light curves of spotted red dwarf stars (the mean seasonal brightness, the rotational brightness modulation amplitude, and the brightness amplitude ratio in different photometric bands) can be described in the framework of the simplest four-parametrical model of zonal spottedness; the total spottedness of such stars reaches tens of percent of their total area, which is tens of times higher than the maximum solar spottedness.

Recently, Alekseev and Bondar' [39] and Alekseev [40] carried out observations and analyzed the spottedness of some more red dwarfs. So in total the analysis now includes 23 red dwarf stars of 70 such objects with known photometrical effects due to spottedness, i.e. a sufficiently representative sample of the spotted stars. Figure 5 shows the model parameters found with the global characteristics of the corresponding stars, viz. their temperatures and Rossby numbers, in those cases when a correlation between them has been found. The main result of such a comparison is that the properties of solar spots correspond well to the correla-

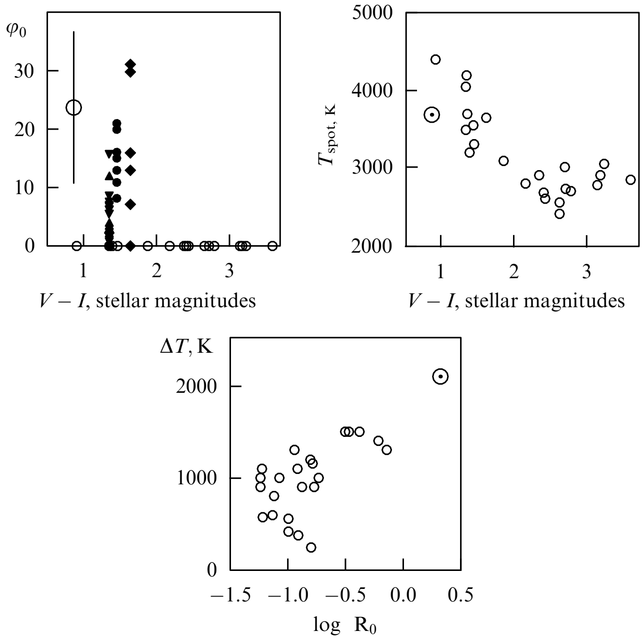

Figure 5. Correlations of the spottedness parameters of red dwarf stars calculated in the zonal spottedness model with their global characteristics: φ_0 is the lower latitude boundary of the spottedness bands, $T_{\rm spot}$ is the spot temperature, ΔT is the temperature difference between the photosphere and spots, $V-I$ is the color index related to the effective stellar temperature, R_0 is the Rossby number (the ratio of the convective mixing velocity to the rotational velocity of the star).

tions observed. This fact definitely supports the proposed zonal model of spottedness of red dwarf stars.

6. Conclusions

The results listed above give only some specific examples of stellar-solar studies which encompass very different magnetohydrodynamic and plasma phenomena. These include magnetic field generation at the bottom of the convective zone, the formation of surface structures with dark photospheric spots and active chromospheric regions on the Sun and stars, rapid sporadic outbursts, and quiet and sporadic X-ray and radio coronal emission. Each of the listed phenomena displays very different appearances.

For example, the fact that the maximum solar spottedness registered in one and a half centuries of observations has not exceeded 0.5% of its total surface, while it reaches tens of percent on red dwarfs, implies that on such stars regions with strong local magnetic fields (the dark spots) are much closer to each other. This leads to more frequent and more powerful flares: the maximal energy in solar flares never exceeds 10^{32} erg, whereas the most violent flares in red dwarfs attain 10^{35} or even 10^{36} erg. Ordinarily registered stellar flares correspond to the most powerful solar flares in white light with strong continuum emission. Weak flares with energies of $10^{27}-10^{28}$ erg corresponding to the typical solar flares have been detected only during observations of the weakest flare stars (with minimal interference from their quiet photosphere) on the 6-m telescope of the Special Astrophysical Observatory in the North Caucasus with a unique photometrical system MANIA (Beskin et al., 1988). Apparently, the notable difference in the energetics of the solar and stellar flares is mainly due to the difference in areas encompassed by such processes, while the energy release per unit surface area is comparable [29].

The richness and diversity of physical processes and activity phenomena studied on the Sun and in red dwarf stars with the methods of stellar-solar physics enable one to consider this field of astrophysics as one of the most perspective to understand the structure and evolution of low- and intermediate-mass stars.

References

1. Kostyuk N D, Pikel'ner S B *Astron. Zh.* **51** 1002 (1974)
2. Livshits M A, Katsova M M, in *Astrophysics in the Extreme Ultraviolet* (Eds S Bowyer, R F Malina) (Dordrecht: Kluwer Academic Press, 1996) p. 171
3. Katsova M M et al. *Astron. Astrophys.* **321** 549 (1997)
4. Abranin E P et al. *Astron. Astrophys.Trans.* (1999) (in press)
5. Byrne P B, Gary D E, in *Solar and stellar flares* (Eds B M Haisch, M Rodono) (Reprinted from Solar Physics, Vol. 121) (Dordrecht: Kluwer Acad. Publ., 1989) p. 63
6. Cristaldi S et al., in *Non-periodic phenomena in variable stars* (Ed. L Detre) (Dordrecht: D. Reidel Publ. Co., 1969) p. 149
7. Chugainov P F et al. *Inf. Bull. Var. Stars* N 343 (1969)
8. Flesch T R, Oliver J P *Astrophys. J.* **189** 127 (1974)
9. Andersen B N *Inf. Bull. Var. Stars* N 1084 (1976)
10. Moffett T J, Evans D S, Ferland G *Monthly Not. RAS.* **178** 149 (1977)
11. Rodono' M et al. *Astron. Astrophys.* **76** 242 (1979)
12. Giampapa M S et al. *Astrophys. J.* **252** L39 (1982)
13. Mahmoud F M, Soliman M A *Inf. Bull. Var. Stars* N 1866 (1980)
14. Shevchenko G G *Astron. Tsirk.* (792) 2 (1973)
15. Cristaldi S, Gershberg R E, Rodono' M *Astron. Astrophys.* **89** 123 (1980)
16. Mullan D J *Astron. Astrophys.* **40** 41 (1975)
17. Grinin V P *Izv. Crimean Astrophys. Obs.* **48** 58 (1973)
18. Grinin V P *Izv. Crimean Astrophys. Obs.* **55** 179 (1976)
19. Grinin V P, in *Vspykhivayushchie Zvezdy, Fuory i Ob'ekty Kherbiga-Aro* (Flaring Stars, Fuors, and Herbig-Aro Objects) (Ed. L V Mirzoian) (Erevan: Izd. AN Armyanskoĭ SSR, 1980) p. 23
20. Roĭzman G Sh, Kabichev G I *Astron. Zh.* **62** 1095 (1985) [*Sov. Astron.* **29** 639 (1985)]
21. Bruevich V V et al. *Izv. Crimean Astrophys. Obs.* **61** 90 (1980)
22. Kilyachkov N N, Shevchenko V S, in *Vspykhivayushchie Zvezdy, Fuory i Ob'ekty Kherbiga-Aro* (Flare Stars, Fuors, and Herbig-Aro Objects) (Ed. L V Mirzoian) (Erevan: Izd. AN Armyanskoĭ SSR, 1980) p. 31
23. Rodono M et al., in *Solar and stellar flares* (Eds B M Haisch, M Rodono) (Reprinted from Solar Physics, Vol. 121) (Dordrecht: Kluwer Acad. Publ., 1989) p. 53
24. Gurzadian G A *Astrophys. Space Sci.* **48** 313 (1977)
25. Gershberg R E *Astrofizika* **16** 375 (1980)
26. Zhilyaev B E et al. *Astron. Astrophys.* (in press)
27. Willson R C, Hudson H S *Astrophys. J.* **244** L185 (1981)
28. Baliunas S L et al. *Astrophys. J.* **438** 269 (1995)
29. Alekseev I Yu, Gershberg R E, in *The Earth and the Universe* (Eds G Asteriadis, A Bantelas, M E Contadakis, K Katsambalos, A Papadimitriou, I N Tziavos) (Thessaloniki: Ziti Editions, 1997) p. 43.
30. Gershberg R E *Astrophys. Space Sci.* **19** 75 (1972)
31. Kurochka L N *Astron. Zh.* **64** 443 (1987) [*Sov. Astron.* **31** 231 (1987)]
32. Kasinsky V V, Sotnikova R T *Issled. po Geomagnetizmu, Aeronomii i Solnechnoj Fizike* (87) 43 (1989)
33. Kasinsky V V, Sotnikova R T *Issled. po Geomagnetizmu, Aeronomii i Solnechnoj Fizike* (104) 15 (1996)
34. Drake J J et al. *Center for EUV Astrophys. Publ.* (734) (1996)
35. Alekseev I Yu, Gershberg R E *Astron. Zh.* **73** 589 (1996) [*Astronomy Rep.* **40** 538 (1996)]
36. Alekseev I Yu, Gershberg R E *Astron. Zh.* **73** 579 (1996) [*Astronomy Rep.* **40** 528 (1996)]
37. Alekseev I Yu, Gershberg R E *Astrofizika* **39** 67 (1996)

38. Alekseev I Yu, Gershberg R E *Astron. Zh.* **74** 240 (1997) [*Astronomy Rep.* **41** 207 (1997)]
39. Alekseev I Yu, Bondar' N I *Pis'ma Astron. Zh.* **23** 294 (1997) [*Astronomy Lett.* **23** 257 (1997)]
40. Alekseev I Yu *Astron. Zh.* **75** (in press) (1998)
41. Beskin G M et al. *Izv. Crimean Astrophys. Obs.* **79** 71 (1988)