ON ACTIVITIES OF UV CET-TYPE FLARE STARS AND OF T TAU-TYPE STARS

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Comparisons of the activities of UV Cet-type flare stars and of T Tau-type stars with solar activity permits the conclusion that non-stationary processes in the UV Cet-type stars and in the Sun are of an indentical physical nature but that they differ qualitatively from active events in the T Tau-type stars. The identity of the activity in flare stars and the Sun makes it possible to study successfully stellar activity with the help of known models of various solar events and, on the other hand, to have a more general approach to the physics and evolution of solar activity on the basis of established features of numerous flare stars of different ages and masses. The hypothesis on hydromagnetic activity of the T Tau-type stars is sketched; within this framework, one supposes that the main feature of such stars is an occurrence at every point of the stellar surface, of conditions necessary for the existence of dark spots, i.e. a lowering of the photospheric brightness due to strong local magnetic fields. It is noted that the total energy losses from non photospheric radiation of flare stars are comparable in power to the total radiation deficit of dark spots on such stars. This fact confirms the possibility of transmitting effectively a significant part of a subphotospheric layers energy into higher regions of the stellar atmosphere by hydromagnetic waves and is an important argument in favour of the proposed hypothesis on the nature of T Tau-type stars.

As is known, the T Tau-type and the UV Cet-type variables were discovered by Joy and by Luyten practically simultaneously, in the middle of the forties, and are often considered as related objects physically and generically. Indeed, these eruptive stars have many common features: low luminosities, non-periodic brightness variations with amplitudes up to several magnitudes, advanced spectral classes at brightness minima and strong emission spectra that are seen even in the quiet state and correspond to a rather low, chromospheric, degree of excitation. It is

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a widespread opinion that young T Tau-type stars are immediate predecessors of older flare stars of the UV Cet type. This opinion is based on series of observable facts: flare stars do not show a relation with diffuse matter, but such a relation is very characteristic for T Tau-stars and is an important argument in favour of their youth; many flare stars have been found in stellar clusters but T Tau-stars are no longer there; flare and chromospheric activity in UV Cet-stars involves processes that are of several magnitudes lower in energy than similar processes in T Tau-stars, and the abnormally high abundance of Li that is inherent in T Tau-stars is found only in one flare star. However, there are considerations that cast doubt on a thesis that observable T Tau-stars are immediate predecessors of typical flare stars. Thus, T Tau-stars belong to the flattest component of the Galaxy but among flare stars we have objects of the galactic disc and even of the galactic halo. Then, masses of T Tau-stars are evaluated to be about 1-3 solar masses but masses of flare stars are an order of magnitude lower and observations do not show such a strong outflow which could diminish a stellar mass so much in 10^6 - 10^7 years, the time scale of T Tau phase of stellar evolution. Therefore, the problem of the generic relation between eruptive variables of T Tau-type and of UV Cet-type requires more careful study. However, problems of stellar evolution are outside the scope of this Colloquium. So now let me turn your attention to a comparative consideration of the observable activities of these stars.

In the very beginning of investigations of T Tau and UV Cet stars there were noted some common features in their activities and those of the Sun: emission spectra in the quiet state of variables of both types lead to ideas about strong stellar chromospheres and short-lived flares suggest an analogue with the solar chromospheric flares. However, these original general considerations evolved into very different model conceptions.

1. After a lot of observational data on the UV Cet star flares and on the features of photospheres, chromospheres and coronae of such stars had been accumulated, the identity of the physical nature of activities of these variables and of the Sun was proposed (Gershberg, 1975). Direct discoveries of the transition region between chromospheres and coronae (Hartmann et al., 1979; Haisch and Linsky, 1980), of thermal radiation from stellar coronae (Johnson, 1981; Vaiana et al., 1981), recordings of stellar flares in the EUV range (Butler et al., 1981) and in the X-ray range (Kahn et al., 1979; Haisch et al., 1980) converted this suggestion into an obvious statement. A useful aspect of this suggestion should be stressed.

Firstly, the identity of the physical nature of active processes in the Sun and in flare stars permits us to use models of solar events to understand the nature of events observed in red dwarfs. An excellent example of a successful application of solar physics to the study of flare stars is the recent paper by Katsova et al. (1980). Developing the Pickel'ner-Kostyuk model for the solar chromospheric flares, they have carried out refined calculations of a strong hydrodynamical disturbance in the solar atmosphere subjected to impulsive heating with a fast electron flux. Calculations showed that in such a situation a strong shock propagation downward to the photosphere is formed, and intensive radiation of hydrogen must originate in a thin layer behind the shock front. In extreme cases the optical thickness in the continuum of this layer can approach unity, and such a layer can be responsible for a white light flare. Apparently, an application of this scheme to flare stars gives a solution of a problem of the short-lived continuum emission in stellar flares. According to calculations, in the denser atmospheres of K-M stars the downward propagating shock practically always approaches the conditions where the optical thickness of the compressed gas is of order of unity, i.e. white light flares must be rather ordinary events in flare stars and not extraordinary events as they are in the Sun. It should be noted that calculation of the chromospheric response to the initial temperature disturbance, including the formation and propagation of a shock within an essentially heterogeneous medium with variable radiation losses, is rather a complex subject. For instance, it is hard to evaluate flare color indices or to compute a set of theoretical light curves. All such photometric characteristics can be found only with a numerical integration over a very non-homogeneous disturbed volume. However, the physical clarity of this scheme makes it much more attractive than numerous homogeneous models (e.g. a hot photospheric spot, a hot gas at chromospheric or subcoronal temperature, relativistic or subrelativistic particles) or simple combinations of such models, that have been used for a long time to represent observable flare color indices, to compute theoretical light curves and to understand the short-lived continuum radiation from the UV Cet star flares (see Gershberg, 1978). It is not possible to uniquely pick out the best homogeneous model or simple combination of such models to represent this continuum emission, but the two best models (optically thin gas of subcoronal temperature (Gershberg, 1975; Mullan, 1976; Kodaira, 1977) and gas of chromospheric temperature and of a significant optical thickness in the Balmer continuum (Grinin and Sobolev, 1977)) are natural components of the non-homogeneous model by Katsova et al.

Secondly, the identity of the physical nature of the activity of flare stars and of the Sun does not mean that problems of the physics of these eruptive stars become problems of the solar physics. In reality, we have here a two-way fruitful interaction. For instance, it is obvious that the observations of a number of flare stars of different masses, sizes and ages give a lot of data for a more general approach to the solar activity phenomenon, e.g. finding new regularities in this activity or possible evolution of the activity, in total. The total stellar flare radiation energy can be obtained with a rather simple observation and therefore flare energy spectra in the UV Cet-type stars have been investigated in much more detail than in the Sun. In Shakhovskaya's (1979) paper updated for this Colloquium, the most complete description of the stellar flare energetics is given based on such a spectral-energetic approach. A similar analysis of the solar data would be valuable. Then, if flares on the Sun and on red dwarfs are physically identical, only a theory of solar flares may be correct, which can represent successfully, by varying the magnitudes of essential parameters, the much more powerful and faster flares of the UV Cet-type stars. It is a rather strict criterion for correctness of a solar flare theory, but it seems to me that solar physicists have not realized in full the importance of this criterion yet. Only when it was found that thermal radiation from flare star coronae contributes several percent of the stellar luminosity, was the necessity to revise the tradition concept of stellar (and solar) coronae realized.

2. Relations between the T Tau-type stars and the Sun are of quite another character. As we know more about these variables we find less place for a direct analogue between the activities of these stars and of flare stars and the Sun. Actually, emission spectra of typical T Tau-stars are similar to the solar chromospheric spectrum in excitation but contain a noticeable amount of stellar optical radiation while the solar chromospheric contribution does not exceed 10^{-4} of the total luminosity of the Sun. Then, time-averaged variable components of T Tau-star luminosities are comparable in power to their constant component while flares in the Sun and in flare star give negligible contributions to their total luminosities. These quantitative differences are so large that we have no practical hope of describing T Tau-star activity with known schemes of the solar activity, using variations of the magnitudes of essential parameters. The most important fact is that in T Tau-stars we observe events that give evidence of qualitative differences between these variables and the Sun. In some T Tau-stars, infrared emission exceeds noticeably the photospheric radiation in power while no infrared excess has been found either in the Sun, or in flare stars. During the FU Ori-type flares that are inherent in T Tau-stars stellar luminosities increase up to two orders of magnitudes and remain at such a high level for decades. Neither the Sun, nor flare stars show such powerful processes.

As is known, in spite of a large volume of accumulated data on the T Tau-type stars, we have no common model for the activity of these stars yet. We do not know a physical mechanism that may be certainly regarded as responsible for irregular variations of stellar brightness. There is no commonly accepted interpretation for the emission line spectra of these variables. There exist different hypotheses on excitation sources, on structure and kinematics of irradiated gas. The nature of the blue continuum emission is not clear. There exist many qualitative schemes to explain separate features of T Tau-stars. Recently Lynden-Bell and Pringle (1974) have proposed the quantitative model of disc accretion and within this framework they have represented some photometric features and infrared radiation of these variables: Larson (1980) has worked out quantitative model of rotational non-stability to explain the FU Ori-type flares. The close relation of these models with current ideas on the youth of T Tau-stars and their quantitative nature make them very attractive. They are not however sufficient to represent all the main observable features of the T Tau-type stars and are unlikely to be mutually compatible.

Dr Petrov and myself (Gershberg and Petrov, 1976) have attempted to understand the whole variety of observable features of these stars within the framework of a common scheme based on a decisive role of stellar magnetism. In the most complete version this hypothesis on hydromagnetic activity of the T Tau-type stars is published in the Astronomische Nachrichten N 4, 1982. There are two suggestions that are the basis of this hypothesis:

a) at the phase of minimum brightness, at practically every point of a stellar surface conditions similar to those in Sunspots are found where the presence of a strong magnetic field leads to a significant suppression of the photospheric brightness; the whole stellar surface is supposed to be a mosaic consisting of magnetic spots.

b) the degree of suppression of optical radiation in these stellar spots exceeds that in the Sunspots and approaches 100%.

In spite of the exotic character of these suggestions, apparently, they do not contradict to observations and known laws of physics (Gershberg, 1982), and in the framework of current ideas on stellar evolution an essential role for magnetic fields at early phases of stellar life is very probable (Mestel, 1977; Lynden-Bell, 1977). In the framework of the proposed hypothesis, observed irregular light curves of the T Tau-stars should be considered a result of numerous quasi-independent processes "dark spot-normal bright photosphere", which take place due to magnetic field strength variations in different areas of the stellar surface. The FU Ori-type flare corresponds to a rare phase when practically the whole stellar surface is free from dark spots. Infrared excess and intense chromospheric emission spectra are related in this scheme to strong fluxes of non-radiative energy that supply most of the stellar energy losses at the minimum brightness phase. Recently discovered very fast brightness variation in T Tau-stars that are similar to the UV Cet-type flares arise in a natural manner from the proposed hydromagnetic situation at the T Tau-star surfaces. However, these stars flares which are much more powerful and much slower than the UV Cet-type flares do not permit us to reduce them to superpositions of short-lived flares of red dwarf type.

The proposed hypothesis on hydromagnetic activity of the T Tau-type stars is a development of Danielson's (1965) idea on the outflow of the sunspot radiation deficit beyond the photosphere by hydromagnetic waves. As is known, this idea had been developed by Mullan (1974a) and by Parker (1974) and then applied to flare star dark spots by Mullan (1974b). This model is not commonly accepted and the problem of sunspot radiation deficit is being hotly debated (Cowling, 1976; Parker, 1977; Sreenisavan, 1977; Obridko and Teplitskaya, 1978). However, recent observations by Willson et al. (1981) give an important argument in favour of this model. Our hypothesis is supported as well by Bray's (1981) results: he has found that in one sunspot center the surface brightness is equal to 14% of the quiescent photospheric value, much less than previously found.

3. Thus, as the observations are accumulated, it becomes more clear that the UV Cet-type flare star activity is identical to the solar activity but has essential qualitative differences from the T Tau-type star activity. In such case a question arises: why are we actually discussing the T Tau-stars at the Colloquium on the UV Cet-stars?

In a paper published in the Memorie della Società Astronomica Italiana (49, 781, 1978) I have suggested that stellar magnetism is a decisive factor in the evolution and physics of activities of variables of both types and, in particular, that this is a distinguishing factor for flare and non-flare stars. Powerful coronae of flare stars have since been found by the Einstein Observatory which do not fit the traditional models of stellar coronae supported with acoustic waves are the most important argument in favour of such a suggestion. Correlation between the BY Dra syndrome and axial rotation rates (Bopp and Espenak, 1977) and between the X-ray luminosity and axial rotation rates (Katsova, 1981) suggest that magnetic fields in flare stars are of a secondary nature. However, independent of the relation between fields and stellar rotation, it is clear that magnetic loops carrying stellar coronae are supported on extended active regions in photospheres. The problem of dark spots in active regions of flare stars seems to be the main un-resolved problem in flare star physics. Just in this point - in the problem of dark stellar spots connected with strong local magnetic fields - there is a deep physical relation between flare stars and T Tau-stars. It should be noted that the origin of magnetic fields of these variables may be quite different. In T Tau-type stars, that are young objects, the relic fields can be dominant while in older UV Cet-type stars the fields originated during the stellar evolution can be dominant. Since similar local events in these stars - dark spots, short-lived flares, chromospheric emission - are defined mainly by the strengths of local magnetic fields, the noted similarity in observed events does not exclude essential differences in the global structure and evolution of magnetic fields of these stars.

According to observation, the total radiation deficit of flare star spots approaches 10% of the stellar luminosities. The problem of so large a deficit has been discussed in details by Hartmann and Rosner (1979). They have concluded that neither the traditional Biermann-Cowling conception with a space redistribution of the sunspot radiation deficit, nor the Danielson-Mullan-Parker scheme with a transformation of the electromagnetic into hydromagnetic radiation gives a successful solution for the problem of the large radiation deficit. They proposed the idea of a temporal redistribution of the stellar luminosity due to a possible effect of the magnetic field on the convective transfer efficiency. In connection with such an idea it should be noted that the current theory of convection accounting for magnetic fields does not predict the existence of structures where the energy could be accumulated and which, in the end, could be responsible for temporal variations of stellar luminosities. However, since this theory is a phenomenological one only, we cannot reject the possible appearance of such structures in a future complete physical theory of stellar convection that might be constructed on the basis of the principles of the thermodynamics of open systems. It is the only possibility that gives hope of the correctness of the Hartmann-Rosner hypothesis. On the other hand, as Shakhovskaya and myself find, the sum of the energy losses of a flare star for short-lived flares to occur and for maintenance the stationary stellar chromosphere, corona and stellar wind turns out to be compatible in order of magnitude with the total radiation deficit of dark stellar spots. This circumstance removes the main objections by Hartmann and Rosner against the Danielson-Mullan-Parker scheme, since similar values of energy losses mentioned and total radiation deficits of stellar spots can be interpreted as observable evidence of a transmission of a significant part of the subphotospheric layers' energy into higher regions of the stellar atmosphere by hydromagnetic waves; although a mechanism for such a transmission is not clear yet. Therefore, it is very desiderable to carry out X-ray observations for different degrees of spottedness of flare stars and long-term bolometric monitoring for several flare stars and T Tau-type stars similar to the solar experiment ACRIM (Willson, 1981).

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DISCUSSION

Vaiana: I did not quite understand where the luminosity of these stars would appear in your picture. Would it be in X-rays, in the optical, in the infra-red or where?

Gershberg: I have not time to go into this fully. However it is possible to explain in this hydromagnetic theory the problems of the brightness variations, of the chromospheres, the darkness and FU Ori. In the minimum brightness state the surface is completely covered in spots. When these separate into several individual spots the magnitude increases to some critical level at which one sees a normal photosphere. When the star is free from any spots we have the FU Ori-type stars. So the normal state of the star is that of maximum brightness.

Rodonò: In your slide showing flare frequency spectrum as a function of luminosity the anomalous behaviour of EQ Peg is due to the fact that both stars flare. This applies also to UV Ceti. I also have almost the same question as Dr.Vaiana, that is, where is the energy flux missing from the spots deposited? We can for instance have deposition temporally, leading to variability or we can have deposition into another spectral band. Which do you think occurs?

Gershberg: In my model there is no energy storage. An any moment the total energy flux is constant. However depending on the total strength of the magnetic field it acts as a regulator. If the field is weak we have a normal photosphere. If the field is strong we have the spotted condition and the energy flux is carried in hydromagnetic waves.

Feldman: Do you have an explanation for the strong bipolar mass flows that are observed in the CO line in many T Tauri stars? There is a lot of energy in those flows.

Gershberg: May I discuss this with you later?