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A CONVECTIVE FLARE THEORY
КОНВЕКТИВНАЯ ТЕОРИЯ ВСПЫШЕК

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Abstract. This paper attacks the still unresolved problem of the origin of flares. We give here a picture which is able to present for us the ultimate process causing the flares and at the same time it gives also the sequence of events which eventually leads to the development of the rich family of phenomena associated with flares. In reviewing firstly the popular flare-theories, it is pointed out that they could not give us answers for these problems. Then, by the theory of sound-speed convection and related phenomena, we outline a general picture of the sequence of flare-associated phenomena. We point out, that this convective flare theory, while it involves much of the favours of the popular flare theories, can be used very fruitfully in answering such kind of problems as the energetics of flares, the flare «build-up», extreme blue coloured flares etc. We investigate some details of this theory and compare it's consequences with the observational data.

Резюме. Этот доклад рассматривает пока еще не решенную проблему происхождения вспышек. Мы здесь даем картину, которая в состоянии представить первичный процесс, вызывающий вспышки. В то же время она дает последовательность событий, которая в конечном итоге ведет к развитию богатого семейства явлений, связанных со вспышками. В начале, рассматривая популярные теории вспышек, указывается, что они не могут дать ответы на эти вопросы. Затем посредством теории конвекции со звуковой скоростью мы набрасываем общую картину последовательности явлений, связанных со вспышкой. Мы указываем, что эта конвективная теория вспышек вместе с тем, что содержит большую часть преимуществ популярных теорий вспышек, может быть использована очень плодотворно для решения такого рода задач, как энергетика вспышек, «образование» вспышки, экстремально синие цвета вспышек и т. д. Мы исследуем некоторые детали этой теории и сравниваем ее последствия с наблюдательными данными.

Introduction. Nowadays it is a standard belief that the entire energy of a flare is stored above the photosphere and probably also above the chromosphere and it is supplied by the energy of the present magnetic fields [1]. Nevertheless, the recent work of Zirin and his co-workers and especially the paper of Rust [2] proves, that—perhaps with the exception of the largest flares—enduring changes of magnetic fields

associated with flares are undetected. Moreover, as pointed out by Harvey and Harvey [3], we have to interpret the observed magnetic field changes occurring co-spatially and simultaneously with flares as a result of seeing effects rather than real magnetic field changes. Regarding these results, for the magnetic origin of flares we have to assume, that there exist a mechanism working in the high outer atmosphere of stars which is able to create continuously magnetic energy as well as to transform their energy to flare energy. Because the effectivity of transormation of magnetic energy into flare energy is lower than 10% [4], this means that one has to assume that—in the case of a large flare of the Sun, $E_f = 10^{32}$ ergs—there have to exist in the choromosphere conditions leading to a continuous creation of magnetic field with an average strength B=2000 Gauss in a sphere the diameter of which is larger than 10^5 km. On deriving the flare energy e. g. from the reconnection of the antiparallel field lines, we need this kind of very special package of field lines in this whole volume. In this way, it seems to us that the basic assumption of the standard magnetic flare theory is a very artificial one.

We would like to point out, that even in the case of the Sun the flares are not always connected with magnetic fields. There exist such cases when the flares occur outside from the 100 000 km region around a spot group [5]. The work of Dodson and Hedeman [6] showed that roughly a 7% of the large flares occurs far from any active region. Nevertheless, this kind of flares seems the same as the others within a magnetic region. Postulating that these flares possess a unique physical nature, we can see the basic unability of the standard magnetic flare theories at the interpretation of flare energetics.

Further difficult points of the magnetic flare theories are the problem of a fast triggering mechanism [7, 8]; the unresolved problem of the continuous energy supply of flares [9]; the sequence of the results showing the photosperical origin of flares [10, 11]; etc., (see aso later). In general, we can say that the analogue of the lightnings in the atmosphere of the Earth with the flare phenomena is misleading. At the same time, the magnetic flare theories suffer from basical arbitrariness without giving us any clear picture about the main processes associated with the flares or any prophecy.

Regarding the non-magnetic theories we mention first the hypothesis presented by Ambartsumian [12, 13], in which he points out to the difficulties of the interpretation of the observational data with the conventional theories and suggests a non-thermal way for the origin of flare radiation by the hypothetical action of prestellar material. Gorbackij [14] has made more concrete this theory by his bubble-model in which hot bubbles, similarly to the convective cells, transport the suddenly released surplus heat arising from point explosions from the inner region of stars. Gurzadian [15, 16] has investigated the observable consequences of these theories by assuming that a cloud of «fast electrons» suddenly appears in the high atmospheres of these stars as a consequence of the above phenomenon. Nevertheless, no clear determination of the connection between the active phenomena taking place in the deeper regions of the star and the parameters of the fast electron clouds has been given.

Independently from the above conceptions, the «hot cloud» and «hot spot» models have been developed for the interpretation of flare phenomena by Kunkel [17] and Gershberg [18, 19]. Unfortunately, a common character of these works is that they are somewhat «ad hoc» models in a sence that they start with the input hypotheses of the presence of «hot plasma cloud» without deriving it from some physiual processes. While they work more or less well for flares with usual colors, they are not able to interpret such a non-thermal phenomena at which the observed color indices are U—B = −3.0 [20].

To surmount the above difficulties we developed an all-embracing convective flare theory with the help of an overall convective theory [21]. In this picture we have tried to follow the development of convection from the ultimate onset to the ultimate end.

In the energy liberating regions of the stars the energy production does not go on in an exactly spherical symmetry because of the chemical inhomogenities and the individual concretness of the single reactions. Because of the very strong temperature-dependence of the energy producing reactions there exist a positive feedback for these reactions. Nevertheless, regarding the basic (almost)—constancy of the overwhelming majority of the stars, it is usual to postulate that the energy production goes on in an exactly balanced manner. While this postulation seems to be from the observational side as a plausible one, in the detailed calculations of stellar models it works well in order to simplify the calculations and the basic equations and to use it in the assumption of the dynamical equilibrium of the stellar cores and to assume, that it is not necessary to follow the individual reactions [22].

Nevertheless, we can mention from the observational side, that even He-flash does not produce always observable consequences [23]; and what concerns the basic assumptions of the theoretical nature [24], we want to point out, that the time scales of the negative feedback (volume expansion) are finite and therefore in local regions at the stellar cores one can actually develop from time to time a local thermal runaway which leads to an explosive primal convection [25]. This primal convection thus produces «jets» in the form of high-speed individual primal convective cells which can penetrate within proper conditions into the stellar subphotospheric regions. These long-living primal convective cells could so accelerate to the local sound speed near the surface and thus they are able to produce a sonic boom [26] which disrupts the cells. It is plausible to assume that these primal convective cells approaching the photosphere frequently push in front of them magnetic flux tubes which then appear at the surface as bapolar structure. If the primal convective cell approach the surface in the region in which the gradient of the magnetic field is very high, then this magnetic field could have a similar effect to the convective cell as the sonic boom: it disrupts suddenly the convective cell in an explosive manner.

The energy of this explosion is supplied by the kinetic energy of the convective cell and by the surplus inner energy of it. These two quantities can be regarded as roughly equal at the speed of sound. At the disruption of the convective cell the liberating energy trasforms mainly to the kinetic energy of the particles because the energy density is very. high. Other forms of the transformed energy are the ionization energy

the energy of different kind of waves etc., all of which has a very limited ability to absorb energy. This means that it develops a cloud of «fast electrons» together with a cloud of «fast protons» and eventually all the matter contained in the primeval convective cell dissolves into the surroundings. After the thermalization we also have a «hot cloud» or «hot spot». The kinetic energy of the particles could be some MeV because the transformation of the energy of convective cell can go on in a very little volume in the shock front, therefore a negligible part of its energy is enough for all kind of ionization. This involves that the bulk of energy has no other possibility than to trasform into the kinetic energy of the protons and electrons and other particles. These high energy particles then loose their energy by subsequent cascade-trasitions until which they are not observable directly, i. e. they can cause the observed preflare phenomena—and therefore the dominant part of the energy could appear in the visible spectra gradually from the UV side as a «non-thermal wall» [20]. Therefore this model is able to reproduce the phenomena assumed as an input hypotheses in the models of Gurzadian, Kunkel and Gershberg at the same time as it preserves some feature of the Ambartsumian's and Gorbackij's picture.

Results and Discussion. The flare energies can be obtained in this picture by the following formula:

$$E_f = n\rho V v_s^2, \tag{1}$$

where n is the number of convective cells being disrupted by the sonic boom or by the magnetic field gradient; ρ is the density of the convective cell at the level of disruption; V is its volume and v_s is the local sound speed. For the application of the formula (1), wee need realistic stellar atmosphere models for the depth dependence of the local sound speed, and density. We have to choose two parameters as a free parameter: the depth of the disruption (d) and the lineaar size of the convective cell at this depth (L).

The formula (1) is not sensitive to the probably small density differences. For example, in the photosphere of a dMe star with T=4200 K, $\rho = 4\times10^{17}$ cm^{-3}, if we choose d=0 km and L=1000 km, we get from the formula (1) that $E = 2\times10^{29}$ ergs. But, if we choose for the disruption depth d=500 km below the level of photosphere, with L=1000 km we get for $E = 10^{34}$ ergs, i. e. the formula is very sensitive to he disruption depth, and of course to the total mass of the convective element. For the energies of very large flares, observed in some stars in the Orion-aggregate, we have to consider the disruption of supergranulae instead of granulae. For supergranulae flares our formula easily gives 10^{38}—10^{39} ergs. It has to note here, that just at these young stars dominate the supergranulation over the granulation even at the photospheres [27].

We can use also our formula to estimate the depth-dependence of the primary explosion and its relation to the time-characteristics of the flare's light curve. If we think about a fixed mass convective cell, it reaches the local sound speed deeper when its inner energy is larger. Therefore, the time characteristics of the consequently developing flare will be slower because of the deeper explosion. It is well known, observationally, that the flares with the largest energy develop more slowly while the fast flares generally have lower total energy. We think that our picture gives a simple interpretation for this relation.

Moreover, we show a derivation of the time scale of the flash phase of the flares by our picture. We interpret this time as the time during which the disruption of the convective cell develops and reaches its maximum rate. When a convective cell reaches the sound speed, it does not disrupt suddenly: there exist a certain time interval, until which the cell moves with the sound speed and the density-and presure perturbations accumulate to a certain, critical rate. At this time the disruption of the convective cell as a whole, suddenly starts. Because of the very transient character of this disruption, we can get very short time scales for these phenomenon. Of course, the deeper the level of the primary explosion, the larger the smoothing out in the photosphere.

We can deduce by our picture, that there exist an other time scale for the total time of the flares, during which a continuous energy supply is assured by the continuous disruption of the remaining parts of the convective cell. The characteristic time of this process can be given by the following formula:

$$t_f = L/v_s. \qquad (2)$$

With $L=1000$ km and $v_s=6$ km/s this estimation gives $t_f=167$ s. This value can be regarded as being in a good agreement with the necessary time scale of the continuous energy supply firstly pointed out by Doschek et al [9].

Regarding the direct observational confirmation of the interpretation of the primary explosion of flares as a disruption of convective cells, we have to mention the observations in which blue shift of the photospheric material are detected before the explosive phase of the flare [3, 28—30]. Here we have to note that if we don't see in the slit the place directly under which the primary exprosion occur, then it is less probable to detect any blue shift [9]. Woodgate et al [31] also observed upflows immediately prior to the impulsive phase of the solar flares.

Other observations also confirm our picture. The ovserved red and blue asymmetries at the solar flares show a definite outward motion in the flash phase of the flares [32-34]. Red asymmetries could be observed at motions directed outwards also [35, 36]. Doschek et al [9] by SKYLAB observations of 1973 June 15 flare observed only blue shifts and not red-shifts.

The pre-flare phenomena detected at the flare-build-up phase can be easily interpreted by our picture as photospheric and chromospheric phenomena developing as a consequence of the disruption of convective cells in viewing the fact that the flash phase of the flares are reached only when filament activation already occurs. During the time until which the high speed particle beams do not interact strongly with the surrounding material, one cannot detect flares. In this way we can also interpret the coronal flares or the solar noise-storms.

Baziljevskaya et al. [37] have shown that there exist a significant correlation between the solar activity indices, solar neutrino fluxes and solar cosmic ray radiation. This result show a clear connection between the energy production and the surface activity, already suggested by Sheldon [38] and Kocharov [39]. We think that this result confirms our picture in which the flare energy is ultimately supplied by the energy production in the interior of stars. Because of this untimate connection between flares and energy production, we can suggest an interpretation of the well-known fact that the flare luminosity correlates with the total luminosity of the flare stars [40].

The interpretation of the observed Balmer-jump in flares by the models of Gershberg [19] and Grinin and Sobolev [41] involves an explosive high-speed motion of the chromospheric material. We interpret this high-speed motions as consequences of the disruption of the convective cells.

The strong UV exesses, the strong blue continuum, the strengthening and widening of emission lines, the presence of absorbing and hot clouds, the photospheric origin of the continuum emission, the presence of high-speed particle beams, the fact that the continuum emission sometimes precedes significantly the flash phase can be easily interpreted by our picture. Nevertheless, it needs further theoretical and observational work for more detailed results.

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DISCUSSION FOLLOWING PAPER BY A. GRANDPIERRE

K. Kodaira. 1. How do you explain the observational facts about majority of solar flares that they begin with impulsive phase of nonthermal nature?

2. How can the magnetic configuration remain undisturbed by the energetic explosion of the convection package?

A. Grandpierre 1. The primal atmospheric convective explosion occurs in subphotospheric regions, therefore we can see only the secondary etc. processes of the subsequently developing cascade of events and these—in the impulsive phase of flares—are of course, mainly or only nonthermal processes.

2. The phenomena developing as a consequence of the convective explosion, leads to course to some kind of modification of the co-spatial magnetic field. But these changes do not lead to a significant enduring changes of magnetic field structures if there are no conditions for proper instabilities or annihilation.

ОПТИЧЕСКИЙ КОНТИНУУМ ПРИ ВСПЫШКАХ НА КРАСНЫХ КАРЛИКАХ КАК РЕЗУЛЬТАТ ИМПУЛЬСНОГО НАГРЕВА ХРОМОСФЕРЫ

OPTICAL CONTINUUM DURING FLARES ON RED DWARFS AS A RESULT OF THE CHROMOSPHERIC IMPULSIVE HEATING

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Резюме. Появление оптического континуума при вспышках на звездах типа UV Кита связывалось нами ранее с тепловым излучением низкотемпературного источника, образующегося в ходе газодинамического процесса при впрыскивании ускоренных электронов в хромосферу. В рамках этой модели обсуждается вопрос о форме кривой блеска для импульсных вспышечных событий. Проведено сравнение наших теоретических выводов с наблюдениями вспышек на 6-м телескопе с высоким временным разрешением. Отсутствие на фазе роста кривых блеска временных особенностей длительностью несколько миллисекунд является независимым аргументом в пользу развиваемой газодинамической модели.

Abstract. The appearance of the optical continuum of flares on UV Ceti-type stars was related earlier by us with the thermal emission of the low-temperature source, forming during gasdynamic processes originating due to ejection of the accelerated electrons into the chromosphere. In the framework of this model, we discuss a shape of the light curve of impulsive flaring events. We compare our theoretical conclusions with the results of observations of the flares carried out with a very high time resolution with 6-m telescope. The absence of millisecond-timescale features on the rising part of the light curves is considered as an independent argument for the flare gasdynamic model developed by us.

Доклад посвящен вспышкам на красных карликовых звездах. Физика [illegible] их нестационарных явлений весьма сложна. Последние успехи