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Trigger process in solar flare as disruption of percolated current network by external disturbance

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Abstract. We present analysis of the possible triggers-external disturbances for solar flares. We consider flare process, as phase transition in current system percolated through resistors network. We show that in the percolation' approach, unlike to standard MHD consideration, trigger action of external disturbances may be effective. If, in result of trigger disturbance it will be disrupt last infinity clusters of the high conductive elements in any local region of current sheet then phase transition of the global current system as whole into new "flare" state will became.

We analyze possible sources of the external disturbances-triggers and show that most probable sources are: a) instability of cold quiescence prominences, b) instability of hot coronal arc-like plasma structures, c) shock-wave and accelerated cosmic rays from another flare. We show that these possible triggers allow to explain naturally well known phenomena of: a) preflare activity of filaments-prominence above neutral kin of active region 1 hour before flare, b) swinging of the 20-40 min oscillation X- and radio emission 3-10 hour before flare and c) sympathetic flare phenomena, correspondently. We compare our analysis with experimental and numerical simulation of triggers of phase transition in percolation networks.

1 Introduction

All accepted approach to solar flare process considers it as extra fast (100-1000 sec) dissipation of the magnetic field in very compact (at least in one dimensions) current structure. Standard MHD theory (Priest, 1982) explains this process as result of instantaneous excitation of small-scale plasma turbulence in all current volume. Resulted step-like increasing of electrical resistance to "anomalous" value ($R_* > 10^{5-9} R_{coronal}$) lead to explosion increasing of the energy release by Joule dissipation with power $Q \propto I^2 R_*$. From another side, plasma turbulence excitation is considered as result of current density increasing up to critical level $\mathbf{j_{cr}=nev_{cr}}$, with critical velocity value equal to phase velocity of plasma waves (Kaplan, Pikelner, Tsytovich, 1974) wave resonance condition). For this standard approach any external disturbances from corona can't be effective as trigger of flare because its energy is negligible relative magnetic energy of global coronal current structure. So, its influence on the global current in corona will be negligible, too. Standard approach suggests that only very slow (days) generation of the global current by magnetic spots motion on the photosphere level may be considered both as energy source and as trigger mechanism.

At the same time real observations of the numerous groups demonstrated absolutely another situation - different kinds of preflare activity coronal structures precede to the flare itself:
activation of quiescence prominence-filaments 1 hour before flare (Smith, Ramsey, 1964, 1966);
excitation of coronal emission oscillations some hours before strong proton flares (Kobrin et.al., 1978)
short time bursts-precursors in hard X-ray and radio emission preceded flare 0.25÷1 hour (Tappin, 1991).

Progress in the physics of current sheet based on the consideration of the current propagation as percolation through random resistor's network allows considering of trigger problem from another position (Pustil'nik, 1997, 1998). Percolation approach leads us to understanding of flare as phase transition in percolated system like to semiconductor-conductor transition, superconductor - normal state transition, crystallization,...). This approach explains correspondent phase transition as disruption of any last infinity clusters of the good conductive resistors in the resistors network what force current propagate through regions with low conductivity and dissipate there currents energy. It is evident, that current conservation in these "bad resistors" domains will lead to generation of the numerous electrostatic double layers with strong electric fields and to run-away of the charged particles into acceleration process.

This phase transition near percolation threshold is object of long-term investigations (both theoretical, experimental and numerical) in different applications and

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we use some their results illustration of our consideration.

Unlike to standard MHD paradigm, current system in percolation approach is very sensitive to external disturbances when it is in the state near threshold of percolation. It is caused by ability of the small amplitude external disturbances to change conditions in the local region of current sheet with concentration of "bad" resistors near threshold n_c. Here small change of the local current will convert plasma of "normal" domains to turbulent state, in result it will disrupt last high conductive clusters permitted "normal" current percolation and will start phase transition to flare state.

2 Trigger sources, threshold conditions, and manifestations – precursors.

Trigger machines:

Solar corona has only two kinds of the stable plasma formation what are observed during long time in the quit state of active region. It is:

a) Quite prominences – curtain-like thin sheet of the very cold and dense plasma ($T<10^4$K, $n=10^{11-12}$ cm^{-3}) in very hot and rarified corona ($T=10^6$K, $n=10^{8-9}$ cm^{-3}) with very specific geometric ratio thickness:height:length equal for most prominences $10^{8.5}$cm:$10^{9.5}$cm:10^{10}cm (0.01:0.1:1).

b) Steady state coronal condensations – arc-like structures with very hot and dense plasma ($T=(1.5\text{-}2)10^6$K, $n=10^{10}$ cm^{-3}).

Both coronal condensations and quite prominences need in magnetic field support/confinement for equilibrium with surrounded corona (the first for confinement from expansion by inner pressure, the second one for support of heavy weight of prominence, what is suspended in the empty corona for a long time (weeks at least)).

Both them are situated in the nearest neighborhood of the future flare energy release – region of magnetic fields interaction where magnetic shear and current concentration are maximal. Prominence hangs above photosphere neutral line and correspondent strong current region in corona, where new magnetic flux emerges from under photosphere and interacts with old magnetic configuration. Coronal condensation is situated under Y-like magnetic singularity and its current sheet in the base of coronal helmet structure, formed by stretching of coronal magnetic flux into solar wind.

Equilibrium of these plasma structures based on the magnetic pressure and tension and suggests specific magnetic geometry for them: magnetic hole (sagging) for prominences and stressed magnetic arcs for coronal condensations. It may be obtained from equation for magneto-static equilibrium:

$$\vec{\nabla}(nkT\ ) + \rho \cdot \vec{g} = [\vec{H} * \mathrm{rot}\,\vec{H}]/4\pi$$

From another side this equilibrium (as all kinds of magnetic confinement) has some problem with stability. Namely, both for prominences and for coronal condensations its evolution (condensation of the matter into prominences or heating and evaporation plasma into coronal condensation) will leave this structure to loss of stability.

Instabilities of the trigger machines:

Main mode of the instabilities is well-known interchange (or Raleigh-Taylor) flute instability. This instability has place when "heavy" (dense) matter is confined by regular magnetic field in the effective field of gravity with g_{eff}. For cold dense matter of the prominence effective gravity is the solar gravity $g_{eff}=g_\odot$ and its direction is down. For hot dense matter of coronal arcs effective gravity is centrifugal acceleration $g_{eff}=V^2{}_T/R_c$ of hot ions in the curved magnetic lines with curvature radius R_c and it is directed up.

In result of this instability flutes of dense matter creep between magnetic field lines in the gravity direction. In the linear stage of flute instability (when size of the flute is negligible relative its wide or wide of transition layer "plasma-field") $\lambda_z<\lambda_y,d_z$, then size of flutes and its velocity will increase as exponential law: with increment: but later on the non-linear stage velocity of the flute asymptotically increase to free-fall law

$$\gamma_g \approx \sqrt{\frac{g_{eff}}{d_z}} \text{ for } d_z > \lambda_y, \text{or } \gamma_g \approx \sqrt{\frac{g_{eff}}{\lambda_y}} \text{ for } d_z < \lambda_y$$

$$v_z \Rightarrow v_{ff} = \sqrt{\frac{2\lambda_z}{g}}$$

The time of disruption of prominences and coronal arcs by flute modes is very short: 10÷20 minutes for prominences and 20÷40 minutes for coronal condensations, but real time of its observed life is days÷weeks. It is mean that some stabilization factor for these flute instabilities has place in solar corona and save it.

Stabilization factors and threshold – trigger:

It was shown earlier (Pustil'nik,1974) that from three main stabilization factors of flute' instabilities (shear of the surrounded magnetic field ≡ rotation of the magnetic field with distance from the plasma; account of finiteness of ion Larmor radius with its additional effective elasticity, ballooning of the flute caused by tension of the magnetic field lines freeze in the stable surrounded region ≡ account of finiteness of the field line in the instability region) the last is the most effective for stabilization of flute modes in the solar coronal structures. Increment of the balloon mode for region with length along the field L_x is :

$$\gamma_b = \sqrt{\gamma_g^2 - V_A^2 \cdot (2\pi / L_x)^2} \qquad (1)$$

where $V_A=H/(4\pi\rho)^{1/2}$ – Alven velocity. Physical mean of this stabilization and threshold character of its action is quite evident from (1) – if time of magnetic tension $\tau_A=L_x/V_A$ is shorter then time of the flute ejection $\tau_g=1/\gamma_g$, then flute will be stopped after time of stabilization on the distance $\lambda_z \approx g_{eff}\ (\tau_A)^2$ and will be returned back by magnetic tension. For opposite case, when time of the flute development is shorter then stabilization time, magnetic tension will not have time to stop it. Condition of the equality of this times give threshold for trigger process, caused by ballooning mode of flute instabilities:

$$L_x \cdot n \cdot g_{eff} = \pi \cdot H^2 \cdot d_z \quad (2)$$

Prominence' trigger scenario:

When density or depth of the quiescence prominence will increase above limit of stability, prominence will reach unstable state in any local part, there is flute of dense prominence plasma will start develop down (Pustil'nik,1974). Flutes will oscillate during its development with Alven time 10-20 min. For observation in narrow spectral filter (like to H_α) it will leave to disappearance prominence manifestation in the center of line with increasing it in red and blue wings. After stage of swinging with some oscillations (about 30-60 min) flute will impact into lower percolated current and will disturb it. If current sheet is near the percolation threshold, small external disturbances are able to disrupt last infinity clusters of high conductive domains and convert current system to "flare" state.

Comparison with observations shows that prominence' trigger scenario has place in really. As it was shown by Smith and Ramsey (1964, 1966) for more the 53% of the 293 strong flare (>2B), its preflare behavior includes stage of the prominence activation during 1 hour before flare itself. Typical preflare evolution for these flares included several phases: Widening and/ darkening (30-50 min before flare), break-up with visual disintegration of filament (15-20 min before flare), transition from absorption to emission (flare itself) with next ejection of matter – in good agreement with prominence' trigger prediction. One from the observed flares from Smith and Ramsey (1964) we demonstrate as example in Fig.1.

Coronal arc' trigger scenario.

The same behavior we may wait for coronal condensations, too. Coronal heating of the arcs has to increase density and temperature (and g_{eff} directed up) in it. It will lead to increasing of amplitude of flute's oscillation on the upper surface of coronal condensations. When flute will reach to Y-like singular point with helmet' coronal sheet above coronal arcs it will disturb it. If this current structure is in the state near percolation threshold – it will destroy "normal" state and switch on "flare" regime. So, main manifestation of the condensation' trigger mechanism have to be swinging of flutes oscillations and correspondent quasi-periodical variation in coronal emission (Pustil'nik, 1978) with Alven times (20-40 min) and amplitude in X-rays about 10-100% and in radio waves about 1-10%. Specific feature of this kinds of flares is its realization on the "open" magnetic field lines with obligatory effect of "proton events" – direct and immediate ejection of the accelerated cosmic rays from current sheet into the solar wind. Comparison with observation was made systematically for radio manifestations by Kobrin et al. (1978) and showed that for all observed proton events this swinging of quasi-periodical oscillation with time 20-40 min) had place during tens hours before flares. We illustrate this manifestation and burst in the maximums of oscillations by the example of recent strong proton event in April 2001 with flux variation in X-ray (GOES 8-10) and in radio (our data from radio telescope RT-2.5 of Sea of Galilee Astrophysical Observatory, Israel).

Discussion and conclusion.

We see that flare process in percolated current sheet may be switched on by external disturbance from surrounded coronal plasma. We described two simplest trigger's scenarios and show that they are realized in the real solar condition in the large part of flares.

We would like to remember that these scenarios doesn't exhaust list of possible trigger's disturbances. It is evident that some combinations of these two scenarios are possible (fore example: coronal flare stimulate prominence flare by fast particle input).

Another possibility is stimulation of the described trigger mechanisms by any another external agents (emergence of new magnetic flux from atmosphere, stimulated prominence' trigger scenario; shock wave from another distanced flare what disturb prominence and coronal arcs and may destabilize it,...).

We would like to note here, that the same flute instability of hot and dense flare plasma and cosmic ray flare arc is possible effective way for its ejection into Solar wind as Coronal Mass Ejection (Pustil'nik,1974, Shibasaki,1998).

Interesting manifestation of these trigger mechanisms is possible stimulation of the sequence of short-time burst-precursors by swinging flutes in the initial start of current sheet disturbance, when current percolation in local region of flute influence still may be restored by current redistribution and will not destroy current propagation as whole. It may explain observed sequences of bursts-precursor with time interval 15-20 min preceded to strong flare about 20÷60 min (Tappin,1991). Direct manifestations of these bursts-precursors on the maximal disturbances of radio flux before flare itself is shown in the Fig.2.a. in the example of coronal scenario for stromg flare 02 April 2001 (marked by arrows).

Main question for using of this approach for flares prediction is: what is probability for different trigger schemes in real conditions of the solar corona? Answer on this question demand statistical analysis of observational data from the point of view of preflare activations.

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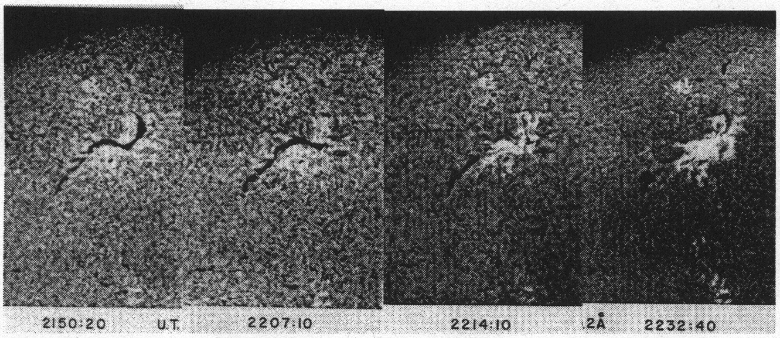
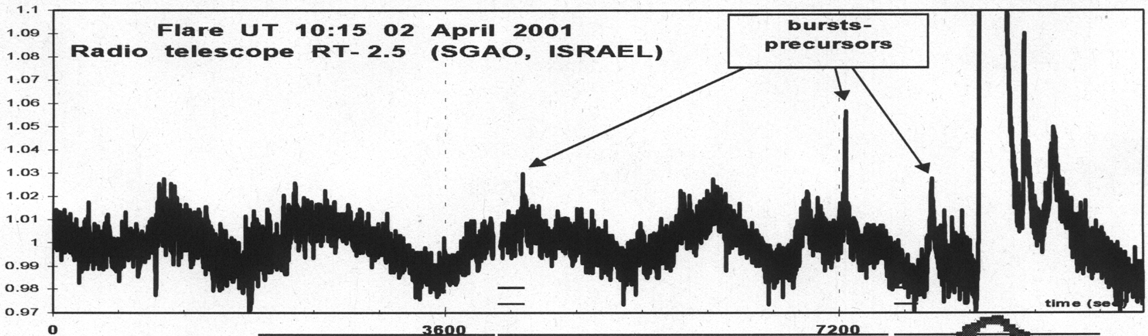


Fig.1.a. Fig.1.b. Fig.1.c. Fig.1.d.

Fig. 1.a-1.d.:Example of the preflare activation of quiescent prominence on the disc, observed as dark filament: 1.a. 21:50– widening and darkening of marked part of filament; 1.b. 22:07 – visual disappear of activated filament in the narrow spectral line; 1.c. 22:14-start of the emission; 1.d. 22:32 - flare itself

Fig.2.a. Radio flux quisi periodical fluctuations with period 20-30 min preceded to flare 02 April 2001 at least 2 hours before flares with bursts-precursors on the maximums of flux oscillation (τ = 1 sec).



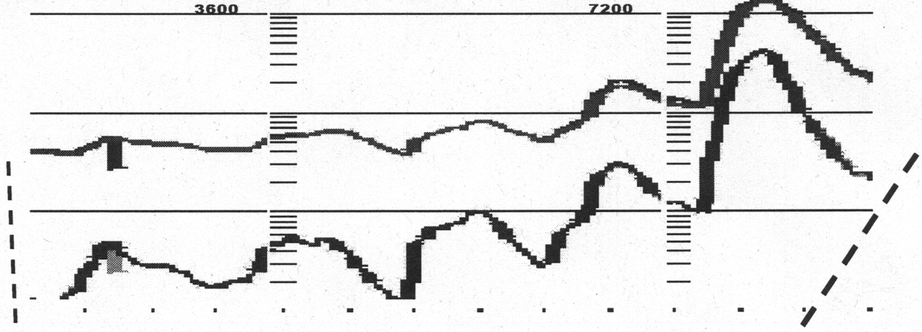


Fig. 2.b. Fragment with X-ray flux preflare oscillation with time scale and zero point the same as in the radio record above (Fig.2.a) demonstrated high correlation between X-ray and radio oscillations (τ = 1 min)

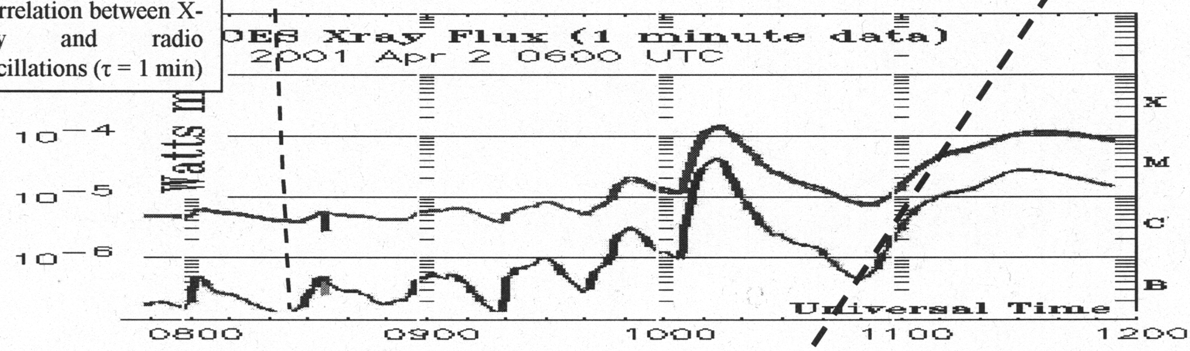


Fig. 2.c. -hour fragment of the X-ray record from GOES detectors with exitation of preflare X-ray oscillation with period 15-30 min and time preceding – some hours