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# On the problem of very energetic flares in binary systems

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**Abstract.** Observations of several RS CVn and other late-type binary systems have revealed the occurrence of extremely energetic flares ranging from $10^{34}$ up to $10^{38}$ erg. The energy of these flares has commonly been explained by the presence of a filament that can, due to the binary nature of the system, store much more energy than a filament on a single star for the same surface field strength.

Here, we show that this explanation is based on an unphysical model and we briefly analyse different mechanisms that could in principle account for these flares. Following previous authors, we suggest that either the flares are scaled-up versions of solar type flares due to a larger amount of magnetic flux involved in the eruption, or they are resultant from the interaction between the magnetospheres of the two stars.

**Key words:** stars: binaries: close – stars: activity – stars: flare – stars: magnetic fields

## 1. Introduction

The total energy released in a large solar flare is of the order of $10^{32} - 10^{33}$ erg which is only a small fraction of the magnetic energy contained in a large sunspot group (Priest 1982; Kopp & Poletto 1984). The problem is therefore not so much the origin of the energy but the detailed physical mechanism responsible for the release of magnetic energy stored in a highly conducting plasma in such a short time-scale.

On the other hand, stellar flares can be several orders of magnitude more energetic than their solar counterparts which does raise the problem of finding a capable energy source to explain them (Byrne 1990). Stellar flares have generally been interpreted as scaled up versions of solar flares so that the energy is also of magnetic origin and its larger content is due to a larger volume and/or a higher field strength involved in the process. There are theoretical predictions and several other observational evidences supporting these views. The stronger flares are most commonly observed on synchronous rapidly rotating binary systems from which theory predicts an enhanced dynamo effect. This is in agreement with the observation of very spotty photospheres and magnetic measurements that find a very large fraction of the stellar surface covered with strong magnetic fields (Strassmeier & Linsky 1996). Also, eclipse observations have provided evidence for an extended corona either in the form of closed loop like structures that reach heights of several stellar radii or in the form of interconnecting loops between the two stars (Siarkowski 1996).

In order to determine the field strength necessary to account for the estimated energy release in the flare, the usual procedure is to use some observational parameters and theoretical considerations to approximately determine the flare volume (e.g. van den Oord & Mewe 1989; Doyle et al. 1992) so that the relation $E \approx B^2.V$ can be used to derive a minimum field strength. This is a rough estimate not only due to the uncertainties in the flare volume and energy release but also because not all magnetic energy is available to be dissipated. Only the *free* energy, i.e., the energy above the minimum energy state, can in principle be dissipated.

A problem arises when the estimated minimum field strength necessary to account for these flares is much higher than expected, either from direct surface field measurements (e.g. Donati et al. 1990) or from equipartition arguments, and an alternative explanation seems necessary (Foing et al. 1994; Doyle et al. 1992). In other works, the application of a solar type model of two-ribbon flares is unable to explain the observed behaviour of the flare (Graffagnino et al. 1995), or it requires an unlikely high surface field strength (Pagano et al. 1997; Doyle et al. 1989; Doyle & Mathioudakis 1990; Doyle et al. 1994). In all these cases, the observations have been interpreted on the basis that the magnetic energy that can be stored in a filament is much higher on a binary system than on a single star for the same surface field (van den Oord 1988). Our purpose is to show that although the binary nature of the systems is likely to be important for the large energy content of these flares, the scenario conceived and physical modelling are incorrect and cannot therefore be used, as they have been, to explain the observations (Sect. 2). In Sect. 3 we analyse different mechanisms that could account for the energy of these flares. We conclude in Sect. 4.

## 2. Prominences and their association with flares

### *2.1. Solar case*

The eruption of a filament, or prominence, is very often associated with a two-ribbon flare. It is not known, however, whether the prominence eruption is a consequence of the destabilization of the whole magnetic structure in which it is supported, or it is the driver of the flare itself, in spite of the fact that it may not be its main energy source.

Quiescent prominences are usually divided into two main categories: Normal (N) or Inverse (I) polarity. In the former case, exemplified by the Kippenhahn-Schlüter model (Kippenhahn-Schlüter 1957, K-S), the magnetic field transverses the body of the prominence in a way similar to a simple arcade. In the latter case, this two fields point in opposite directions.

In the I-polarity model of Kuperus & Raadu (1974, K-R), the prominence is represented by a massive line current, $I$, in force equilibrium between gravity and Lorentz forces. They show that the field due to the line current cannot penetrate into sub-photospheric layers and so induces surface currents. The interaction between the photospheric currents and the current filament provides an upward repulsive force that can help support the prominence against gravity. In the K-S type of models of N-polarity prominences, the current flowing along the prominence is small so that the support is mainly due to the background field with little contribution from this repulsion force. For I-polarity, however, the current flows in the opposite direction which causes the background field to exert a downward force. In this case, equilibrium is only possible for large currents so that the repulsion force can balance both gravity and the Lorentz force due to the background field. Mathematically, vertical equilibrium can be expressed as

$$\frac{I^2}{4\pi h} - IB(h) = mg, \tag{1}$$

where $B(h)$ is the horizontal background field, $m$ the prominence mass per unit length and $h$ the vertical distance from the photosphere to the prominence. Van Tend & Kuperus (1978) considered a background field obtained from extrapolation of various solar active regions and studied the case of I-polarity prominences. They find that the equilibrium current, given by the solution of Eq. (1), attains a maximum at a certain height. If the current flowing along the prominence increases beyond this critical value, there is no nearby equilibrium and the prominence erupts, possibly originating a flare. This point occurs where $B(h)$ starts to decrease faster than the repulsion force, i.e., faster than $1/h$. These line current models have been generalised to more detailed and realistic configurations (e.g. Anzer 1989; Priest, Hood & Anzer 1989; Démoulin & Priest 1993; Low 1993; Low & Hundhausen 1995; Schönfelder & Hood 1995).

Although a line current is a very simplified model of a prominence, it captures the essence of global support and can in principle be used to investigate the properties of prominences in binary stars to which we now turn our attention.

### *2.2. Binary case- van den Oord model*

#### 2.2.1. Equilibrium solutions

In the last decade convincing evidence has been gathered for the presence of prominence-like material in the coronae of active stars. Although the best studied prominence system is the rapidly rotating single star AB Doradus (Collier Cameron 1996), several flaring binary systems have been observed to show prominences (Jeffries 1996; Hall & Ramsey 1992, 1994). This suggests that, as in the Sun, there is an association between prominences and flares.

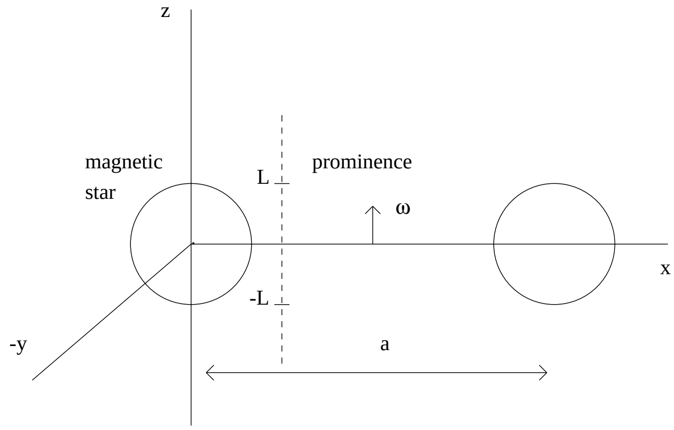


**Fig. 1.** Schematic representation of a prominence in a binary system. The stars are separated by a distance $a$ and have equal radius ($\mathrm{R}_* = 2\,\mathrm{R}_\odot$). The filament is infinitely long but the mass is concentrated between $z = \pm L$. After van den Oord (1988).

This scenario has been investigated by van den Oord (1988). In his model a prominence is represented by a straight, infinite line current lying parallel to the binary rotation axis with its mass delimited between $-L$ and $L$, where $L = \mathrm{R}_* = 2\,\mathrm{R}_\odot$. He considers that one star has a strong dipole magnetic field whose axis lies perpendicular to the rotation axis, along the $-y$ direction, while the other star has no appreciable field. The geometry of this model is depicted in Fig. 1.

In order to determine stable equilibrium locations for the filament, he builds the generalised potential energy, $U$, that includes the magnetic and the effective gravity contributions. We point out that although the Coriolis force does not contribute to the static force balance it is important in the stability of the equilibrium. As shown by Rogers & Sonnerup (1986), the effect of Coriolis force is always stabilizing. Therefore, the minima of energy can only indicate locations where sufficient stability conditions exist.

Van den Oord finds that in general two stable configurations are possible. One close to the magnetic star where the repulsion force of this star balances the force of the background field with a negligible contribution from the mechanical forces and the repulsion force of the second star, i.e., a solar type K-R prominence. The other equilibrium occurs close to the non-magnetic star where its repulsion force balances the mechanical forces with a negligible contribution from the other forces and it owes its existence to the binary property of the system. As the current $I$ increases, the equilibrium close to the non-magnetic star disappears while the other solution moves closer to the non-magnetic star and its repulsion force becomes important.

Within this model there are no solutions of the type where the mechanical forces are balanced by the Lorentz force of the background field with a negligible contribution from the repulsion forces. But close to the L1 point material is pushed away from the magnetic star by the generalised gravity and one would expect to find solutions of the N-type. To explain this contradiction we note that with the energy principle of this model, a solution is stable only if it is stable under the condition of constant current perturbation. On the contrary, Ferreira & Jardine (1995) showed that when studying the stability of the equilibrium the current $I$ cannot be taken as a constant during the perturbation, but instead ideal MHD constrains the magnetic flux between the prominence (of small but finite radius) and the surface to be conserved which has a stabilizing effect (see also Anzer & Ballester 1990). In other words, the calculation of the magnetic energy of the system does not incorporated the ideal MHD condition and therefore misses the most relevant solution resultant from the binary nature of the system.

#### 2.2.2. Energy stored in the filament

In this model, equilibrium in the x-direction can be written in dimensionless units as

$$I^2 H(x) - I^2 H(1-x) - Im\frac{2}{x^2} = 0, \quad (2)$$

where the mechanical forces acting on the filament are neglected. The first term of the equation represents the repulsion force due to the surface currents on the magnetic star, the second term the repulsion force of the other star and the third term the Lorentz force due to the background dipole field of moment $m$. In this geometry, the function $H(x)$ varies, to first order, as $1/x^3$. It must be noticed that this decrease is faster than the variation of the dipole force. If we were to consider the case of a single star, the variation of current with height would be a monotonically increasing function with no non-equilibrium point. In this case, the current could increase up to infinity. This is only possible because in line current models the physical mechanism creating the current is not incorporated.

The inclusion of the binary component introduces an extra repulsion force with the effect that the equilibrium current can reach infinity in between the two stars. Before this occurs, instability in the y-direction sets in, which puts a limit on the maximum current that can flow along the filament. Van den Oord finds that this maximum current increases with increasing binary separation and he gives an expression for the maximum energy stored as $W \propto a^2$, where $a$ is the binary separation. This expression is counter intuitive as one would expect the binary nature of the system to become more important as the binary separation decreased, and not the other way around. But this is obviously a consequence of the fact that as $a$ increases, the binary system becomes wider and tends to a single star where the maximum energy goes to infinity. It must also be pointed out that the requirement that at the equilibrium locations the Lorentz forces still dominate the mechanical forces

$$\frac{I}{c} > \frac{1}{2}\omega\lambda^{1/2}(aL)^{1/2}\left(\frac{a}{\mathrm{R}_*}\right)^{3/2}, \quad (3)$$

as imposed by van den Oord, does not pose any real constraint. Deducing from his Eq. (22), $(I/c) \approx 0.5\, aB_0$, where $B_0$ is the surface external dipole field, and using Kepler's third law, one verifies that if the condition above is verified for a given binary, it is verified for any binary with the same total mass but greater binary separation.

Clearly, there is not enough physical content in the model to allow one to estimate the maximum energy content that is possible to store in a filament. A more detailed model that includes the mechanism responsible for increasing the current may not allow very high values of the filament current. Therefore, we do not expect these I-polarity type prominences to be very different from the ones found on the Sun or other late-type single stars, if they form in similar background fields.

On the grounds that for the same surface magnetic flux a prominence in a binary *cannot* store much more energy than a prominence on a single star, we conclude that this flare model is unphysical and cannot explain the energetic flares observed on binary systems. Equally, it cannot be used to discard the possibility that some flares are a consequence of the binary nature of the system. Catalano & Frasca (1994) observed a flare lasting about six days. Due to the fact that this system is a rather separated binary they find that the maximum energy contained in an interbinary filament is several orders of magnitude larger than that observed for the flare. From this they conclude that the binary nature of the system does not play a fundamental role in the energetics of this flare. Evidently, the use of this model renders their conclusions invalid and hence the nature of the flare remains undetermined.

## 3. Interbinary flares

It must be realised that whatever model is considered, if magnetic energy is the main source of the flare, it inevitably requires either a strong magnetic field, or a large volume, or perhaps both. Indeed, the maximum magnetic energy available for dissipation is given by

$$E_{\mathrm{free}} = \int \frac{\left(B^2 - B_{\mathrm{pot}}^2\right)}{8\pi} dV \quad (4)$$

where $B_{\mathrm{pot}}$ represents the potential field resulting from the same base flux distribution as the true field, $B$. This expression obtains if the magnetic flux is frozen rigidly into the stellar surface boundary. Further restrictions on the amount of free energy result if the field can only relax to a linear force-free state due to the constraint of helicity conservation (Berger 1984).

Let us now analyse the energy contained in a force-free field on a single star which satisfies

$$(\boldsymbol{\nabla} \times \boldsymbol{B}) \times \boldsymbol{B} = 0, \quad (5)$$

$$\boldsymbol{\nabla} . \boldsymbol{B} = 0. \quad (6)$$

Denote the energy of a force-free state by $E_{\mathrm{ff}}$, and define the unique minimum energy state with an open configuration and same surface flux distribution by $B_{\mathrm{open}}$ and its energy by

$E_{\rm open}$. Aly (1984) conjectured that $E_{\rm ff} < E_{\rm open}$ for all simply connected force-free fields with all field lines anchored to the boundary. This conjecture is supported by more recent analytical and numerical analysis (e.g. Aly 1991, Sturrock 1991, Lynden-Bell & Boily 1994, Mikic & Linker 1994). For the case of a force-free field with the same surface flux distribution as a dipole, the maximum energy is $E_{\rm open} \approx 1.66\, E_{\rm dip}$ so that at most $0.66\, E_{\rm dip}$ is available to be dissipated (for a derivation of this result see Low & Smith 1993). If non force-free fields are considered, they can store free energy in the form of cross-field electric currents that can exceed this limit (Low & Smith 1993). This then allows for eruptive events like solar flares and coronal mass ejections to be achieved with the transition from a closed to a totally open configuration. Alternatively, there can be a transition from an initially force-free closed field to a partially open state with a lower energy (Wolfson & Low 1992). The physical processes that can be responsible for triggering a solar flare are very diverse and range from what can be referred as internal causes, for example when a critical twist or shear of the field is exceeded, to external causes like the interaction of bipolar fields pushed together by converging motions (Sweet 1958), or the interaction of new emerging flux with existing magnetic structures (Heyvearts et al. 1977).

It is plausible that many stellar flares are very similar to solar ones. In this case the contribution of the binary component to the flare event is an indirect one; the binary nature of the system enhances the dynamo process and consequently the stellar surface is covered with a higher magnetic flux. It is well known that on the Sun new flux does not emerge randomly on the surface but rather concentrates into regions with pre-existing flux. On these stars one expects a similar behaviour with the formation of very extended active regions. This idea is corroborated by magnetic measurements and by the detection of very large spots, or clusters of spots, on the stellar surfaces of several binary stars. Also, these large flares are very likely composed of several smaller flare events, that may occur in the same or in different active regions. The events may be related, i.e, one flare can trigger others, this phenomenon being known as sympathetic flares, or unrelated and in this case the flares are accounted for under the assumption of random occurrence of flares. This has the practical effect of increasing the volume where magnetic energy is being dissipated. To make a rough estimate of the energy contained in a solar type flare that involves a larger magnetic flux consider the average magnetic field and linear size[1] on an active region of these stars with respect to the Sun to be $B = 3 - 10 B_\odot$ and $L = 10 L_\odot$. It then results a flare energy $E = 10^4 - 10^5 E_\odot$, where $E_\odot$ denotes the energy of a typical solar flare, which is capable of explaining most stellar flares.

It is also possible that the binary nature of the system plays a direct role in driving flares. Let us consider both stars to have their own magnetic field. Some aspects of the interaction of magnetic fields in binary stars have been studied by Vahia (1995) where it is shown that in a single rotation the field of one star can change from completely enclosing the other star to completely excluding it. However, this author assumes that the fields are immersed in a vacuum and can therefore change their topology instantaneously. But, if we consider the field to be immersed in a quasi-perfect conducting plasma, the connectivity of the field lines can change on a short time-scale only in the presence of very large current regions (current sheets). The interaction and mutual compression of the two stellar magnetospheres provides an ideal situation for these current sheets to form and constitutes a viable way to originate energetic interbinary flares which was first explored by Uchida & Sakurai (1983). Let us consider that the magnetic fields evolve to a configuration where a neutral current sheet separates the two magnetospheres that are compressed against each other (Fig. 2b). This is a favourable situation for reconnection of field lines to occur between the two opposing fields that could also trigger energy release contained in currents of the much larger surrounding magnetic structure. Indeed, this is supported by observations showing that solar flare activity encompasses two or more interacting magnetic bipoles but most of the energy seen in X-rays is released inside one of the bipoles rather than at the interaction site between them (Machado et al. 1988). This process would naturally lead to a flare like event (i.e. particle acceleration and associated radio and X-ray bursts, formation of very hot loops and chromospheric evaporation) but on a very large scale and with the formation of interconnecting loops between the two stars (Fig. 3). The field could then evolve to a situation similar to the initial one driven by the emergence of new flux, surface motions and differential rotation or if the binary is not in perfect synchronous rotation.

The mathematical problem of calculating the magnetic field in this physical situation is rather involved and will not be attempted. For the qualitative discussion intended here, it suffices to analyse the energy content of a much simpler situation which

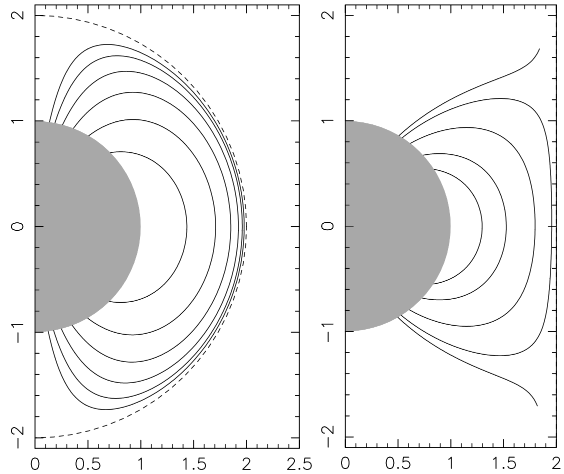


**Fig. 2. a** Idealised situation of a stellar dipole field compressed by an external sphere represented by the dashed line. **b** Approximate solution of the problem of two stellar dipoles of equal strength compressed against each other in a binary system separated by $4\,R_*$. In this example, the field close to the pole is open, simulating the effect of a stellar wind. Only the plane defined by the dipole axis and the axis connecting the two star centres is shown.

[1] The increase in linear size can also be partially attributed to the larger radii of these stars when compared to the Sun.

contains the relevant physics and has an immediate solution. The magnetic field resultant from an isotropic compression of an initial dipole field is represented in Fig 2a. The axisymmetric nature of the field allows one to express the magnetic field in terms of a stream function $A$

$$\boldsymbol{B} = \frac{1}{r\sin\theta}\left(\frac{1}{r}\frac{\partial A}{\partial\theta}\boldsymbol{e_r} - \frac{\partial A}{\partial r}\boldsymbol{e_\theta}\right). \tag{7}$$

The fact that the field remains potential in between the star and the compressing sphere of radius $\mathrm{R}_s$ results in the equation

$$\frac{\partial^2 A}{\partial r^2} + \frac{\sin\theta}{r^2}\frac{\partial}{\partial\theta}\left(\frac{1}{\sin\theta}\frac{\partial A}{\partial\theta}\right) = 0 \tag{8}$$

which subject to the boundary conditions

$$\begin{aligned} A &= \left(B_0\,\mathrm{R_*}^2\right)\sin^2\theta \qquad , \quad r = \mathrm{R}_* \\ B_r &= \frac{1}{r^2\sin\theta}\frac{\partial A}{\partial\theta} = 0 \quad , \quad r = \mathrm{R}_s \end{aligned} \tag{9}$$

has the solution

$$A = \left(B_0 R_\star^3\right)\sin^2\theta\left[\frac{R_s^3}{R_s^3 - R_\star^3}\frac{1}{r} - \frac{1}{R_s^3 - R_\star^3}\,r^2\right] \tag{10}$$

After calculating the field components from Eq. (7) one finds the magnetic energy to be

$$E_\circ = \frac{1}{8\pi}\int B^2 dV = \frac{B_0^2 R_\star^3}{3}\left(\frac{2R_\star^3 + R_s^3}{R_s^3 - R_\star^3}\right), \tag{11}$$

where $B_0$ is the surface equatorial field strength. In the limit $R_s \to \infty$ this energy reduces to that of a dipole field, $E_\circ = E_{\text{dip}} = B_0^2 R_\star^3/3$, while in the limit $R_s \to \mathrm{R}_*$ it diverges to infinity. To determine the minimum energy field in this closed volume we write

$$A(r,\theta) = \left(B_0 R_\star^3\right)\sin^2\theta\left(\frac{a}{r} + br^2\right) \tag{12}$$

where $a$ and $b$ are parameters to be determined. The lower boundary condition is then used to eliminate the unknown $b$ so that we can calculate the magnetic energy as a function of $a$. Minimizing this energy shows that the field obeys the boundary condition $B_\theta = 0$ at $r = R_s$ and has an energy

$$E_{\circ\text{min}} = \frac{2}{3}B_0^2 R_\star^3\left(\frac{R_s^3 - R_\star^3}{2R_s^3 + R_\star^3}\right), \tag{13}$$

so that the free energy is

$$E_{\circ\text{free}} = E_\circ - E_{\circ\text{min}} = 3B_0^2 R_\star^3\frac{R_s^3 R_\star^3}{(R_s^3 - R_\star^3)(2R_s^3 + R_\star^3)}. \tag{14}$$

Due to its geometry, the energy of this idealised configuration (Fig. 2a) constitutes an upper bound to the physical situation we intend to model. We can estimate the free energy contained in the current sheet between the two magnetospheres to be

$$E_{\text{free}} \approx 2 \times \frac{1}{6} \times \frac{4\pi}{24}E_{\circ\text{free}} = \frac{\pi}{18}E_{\circ\text{free}} \tag{15}$$

where the factor 2 results from having two magnetospheres being compressed, the factor $1/6$ is due to the fact that the compression is only along one direction and the factor $4\pi/24$ is due to the volume difference between a sphere and a cube. These factors are somewhat uncertain but we think they give a correct answer up to a factor of two. If the stars are sufficiently separate for $R_s^3 \gg \mathrm{R_*}^3$ to hold, then we can write $E_{\text{free}} \approx 2B_0^2 R_\star^6/a^3$, which is twice the mutual energy of two parallel dipoles separated by a distance $a$ along the direction perpendicular to their axes.

The validity of our estimate of the free energy depends on the particular binary system we want to study, as it requires both stars to be magnetic, and on complex physical processes (e.g. how much compression can occur until the current sheet gets unstable and triggers reconnection). Also, stellar fields will in general be inclined with respect to each other at some angle other than $180°$ and not well represented by two dipoles of equal strength, but annihilation of such fields is still possible. In this case, we expect that an upper limit to the free energy can be given by twice the mutual energy of the two fields.

Although the studies of Aly (1984, 1991) discussed earlier are only applicable to single systems, it is still useful to compare the free energy in this model with Aly's limit. For typical binary separations, the free energy contained in the current sheet is below Aly's limit although it can be a significant fraction of this limit. An extra source of energy could be present due to currents generated by photospheric shearing motions acting on the footpoints of field lines. In the idealised situation represented in Fig. 2a there is no limit to the energy of the field resultant from shearing of field lines as the field is unable to expand and approach the fully open state. In the case of a binary the field is free to expand in every direction but in the direction of the stellar companion. This means that the energy of the force-free fields present in the binary can exceed twice the value of Aly's limit and this energy *increases* by some as yet unknown amount as the binary separation *decreases*. This problem deserves further study but it will not be pursued here. However, we expect that for typical binary separations the maximum amount of free energy in this scenario can be expressed as $E_{\text{free}} = pE_{\text{dip}}$ with $p$ a numerical factor of order one. We emphasize that this is in direct contrast with the model of van den Oord where the maximum free energy *increases* with *increasing* binary separation and can attain values much larger than the energy of a potential dipole field. Calculating an upper limit of the available free energy to be that of a dipole divided by the fraction of stellar surface occupied by the active region still seems a reasonable estimate and independent of the type of flare present, if this energy is contained in force-free currents. Therefore, although the interaction of the two magnetospheres may be a source of non-solar type flares, one still requires large surface magnetic fluxes to explain the energy budget of energetic stellar flares.

Naturally, there are sources of energy other than the magnetic energy contained in force-free currents which could play an important role in the energy budget of a flare. The interbinary region provides a favourable location for the existence of loops with high density and pressure. For the present discussion it is not relevant whether this material is in the form of cold prominence clouds or hot coronal plasma. This material will in general distort the magnetic field and originate cross-field currents that

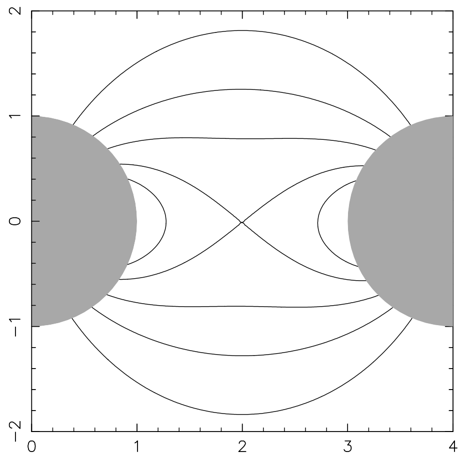


**Fig. 3.** A possible magnetic configuration after a reconnection event between two opposing fields as seen in the plane defined by the dipole axis and the axis connecting the two star centres. Notice the presence of interconnecting loops and a X-type neutral point.

increase the amount of free magnetic energy available for dissipation. Moreover, if the field evolves, through reconnection, from a configuration similar to that depicted in Fig. 2b to one with interconnecting loops (Fig. 3), the dense material will tend to be accreted to one of the stars and release its generalised gravitational energy as it penetrates into the chromosphere. After the accretion of this interbinary material, the base gas pressure at the interconnecting loops footpoints will in general be incompatible with a static equilibrium, and a siphon flow will be driven from one star to the other. This process can continue until the magnetic topology connecting the two stars is modified or until the loop base pressure change and allows for a static equilibrium. These three associated processes; magnetic reconnection, accretion of interbinary plasma and accretion driven by a siphon type mechanism, may together represent a good candidate to explain the very long duration flares observed in some binary systems: CF Tucanae (Kürster & Schmitt 1996), AR Lacertae (Ottmann & Schmitt 1994), HR 5110 (Graffagnino et al. 1995) and HU Virginis (Endl, Strassmeier and Kürster 1997).

It is possible that the main source of energy for these flares is gravitational and centrifugal (associated with the material at the L1 point), and thermal (associated with the siphon flow) while the magnetic field, necessary for the stability of the material at the L1 point and to channel the siphon flow, has a comparatively small contribution. A similar explanation was already considered by Foing et al. (1994) to explain the $10^{38}$ erg released during a flare. These authors invoked the destabilization of an arcade of loops extending up to the L1 point and containing dense and cool plasma which represents a N-polarity prominence. However, in the case of this particular flare, for the interbinary plasma to be the main source of energy, it requires an extremely high density plasma filling a large volume, for which there appears to be no evidence.

Let us also note that in the Sun a coronal mass ejection (CME) liberates an energy of the order of $10^{31-32}$ erg which is comparable to that of a large flare. But while in the case of a flare most of its energy manifests itself as thermal energy, in the case of a CME most of the energy liberated is in the form of work done to lift its mass against gravity and to produce the kinetic energy of the expelled mass. This implies that a typical solar CME occurring on a single star other than the Sun is difficult to detect. However, if a CME occurs in a binary system in the region between the two stars, the ordered form of energy carried by the CME can be transformed to the final form of thermal and dissipative energy as the CME is accreted by the other star and interacts with its magnetic field. This could result in a violent energy release identifiable as a stellar flare. The observations of Jeffries & Bromage (1993) of the active binary system Gliese 841A revealed the occurrence of flares on possibly both the component stars. The triggering of a CME associated with the flare on the secondary is a possible mechanism to drive the flare on the primary a few hours later.

The possibility that interbinary magnetic field interactions are responsible for most of the energetic flares observed can in principle be observationally tested by searching for flares occurring preferentially between the two stars in eclipsing binaries. Some evidence for this has already been reported (Doyle & Mathioudakis, 1990). However, binary flares could also result if a star that has a large-scale magnetic field interacts with the wind of the other star, forming a magnetospheric tail. This magnetotail can then release its energy and magnetic flux through flare like events in many ways similar to the substorms that occur in the Earth's magnetosphere (e.g. Dolginov 1988).

## 4. Summary and conclusion

In the present work we have shown that a mechanism commonly proposed to explain very energetic flares in late-type binary systems is invalid due to the unphysical nature of its non-equilibrium points. We have also explored the possibility that the interaction of the magnetic fields of the two stars can trigger long duration and energetic flares and presented an estimate of the free magnetic energy that can be released in this process. The reconnection of the two stellar fields can initiate energy release on a much larger scale and also induce accretion flow from one star to the other along interconnecting flux tubes. Therefore, the main source of energy for some flares may be kinetic, gravitational and thermal instead of magnetic. Another possible process of originating interbinary flares consists in a coronal mass ejection initially generated in one star accreting and interacting with the other star and releasing energy in the event. Alternatively, these stellar flares can be physically similar to solar flares but occurring in a larger volume and with a stronger mean magnetic field. Whatever model one considers, if the flare energy source is magnetic, then one cannot avoid the need for very high surface magnetic fluxes on at least one of the binary components to explain the very energetic flares.

It is likely that these and other mechanisms are applicable to different flares in the same or different binary systems. The ability to discern the physical mechanism responsible for a particular flare will depend on the amount of information provided by the observations and equally important on developing these qualitative ideas further into detailed models.

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**Note added in proof:** It has been pointed out to us that Simon, Linsky and Schiffer (1980) suggested that the interaction of stellar magnetospheres and the ensuing flows might be a source of very long duration binary flares.