Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 38, 2026, Sofia

DOI: https://doi.org/10.3897/arb.v38.e06

STATISTICAL STUDY OF EJECTIVE FILAMENT/PROMINENCE ERUPTIONS DURING SOLAR CYCLE 23

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Key words: *CMEs, flare, filament, ejective eruption, Solar Cycle 23*

Abstract

Filament/prominence eruptions in the solar atmosphere are one of the most important solar events that drastically affect space weather. The formation, evolution, and eruption of filaments are directly linked to the Sun's magnetic activity. Herein, 159 filament eruptions that occurred during 1998–2011 have been statistically analysed to distinguish between the different types of filament eruptions – confined or ejective. This is performed using the List of interplanetary (IP) Shocks Observed during Solar Cycle 23 (May 1996 – January 2008) and their Source Information Environmental Satellites (GOES) X-ray plots [1]. We have found that 69% of filament eruptions are confined, while 31% are ejective. We have examined confined filament eruptions (110 events) during the 23rd solar cycle (1996–2008) in Khaled et al. [2] and found that 21% are due to active filaments and 48% to disappearing filaments. Here we present a statistical investigation of the ejective filament/prominence eruptions. The relationships among filament eruptions, flares, and CMEs (coronal mass ejections) for each type have been studied separately. We have found a significant probability of CME occurrence in M and X flare classes. It has also been observed that the predominant X-ray energy of ejective eruptions is M-class. We have found that the CME velocity associated with active filaments ranges from 775 to 975 km/s, whereas that associated with disappearing filaments is much higher (up to 1800 km/s). Finally, our study shows that 40% of the events have an angular width of 360 degrees (Halo CME), indicating they can significantly impact Earth's upper atmosphere and cause changes in space weather.

Introduction

Filaments are gigantic arcs of hot plasma that extend above the photosphere of the Sun [3]. They are a collection of many threads that form an apparent loop. In the solar disk, they appear as stretched, dark features, which extend up to halfway across the solar disk. Because this plasma is slightly cooler than the solar surface below, they appear dark against the hotter background. When it is seen at the solar limb, it appears as a light, bright loop against the dark outer space behind hence it is called a prominence. So the filaments and the prominences are two words that describe different perspectives of the same thing.

Decades of study have shown that it is very difficult to characterise filament properties. Filaments show differences in morphology, lifetime, position on the solar disk, complexity of their magnetic field environments, etc. The formation of a filament is quite a slow process. It takes a few days, especially when it is located far from an active region. Understanding the origin of such variety and attaining better knowledge of these structures and their environment during the different phases of their life can provide valuable information on the physics of the solar atmosphere [4].

Many studies in the literature have shown that flares and filament eruptions are the two main solar phenomena that may be associated with CMEs. Some of these studies address the relationship between prominences, which could be easily detected, observed, and measured against the dark sky background and CMEs. Moreover, CMEs associated with prominences are not difficult to detect. Gilbert et al. [5] examined 54 Hα events to identify characteristics of active prominences (APs), eruptive prominences (EPs), and disappearing filaments (DFs) to study the relationship between prominence activity and CMEs. They found that 94% (17 of 18) of the EPs have an associated CME compared to only 46% (12 of 26) for APs. Also, they found that 70% of the events (seven of 10) are DFs.

Mouradian et al. [6] showed that the sudden disappearance (SD) of the filaments can be either dynamic (DSD) or thermal (THD). They showed that only DSDs are associated with CMEs, while THDs are only local disturbances in the lower corona.

We aim to investigate Filament/Prominence eruptions and their close relation with CMEs and flares, and to study whether a clear signature X-ray flare class could be associated with either confined or ejective eruptions. We classified the Filament/Prominence list (for 159 complete observations of the filament eruptions for the period 1998–2011) into two main categories: (1) confined eruption and (2) ejective eruption. This period is in the frames of the 23rd Solar cycle, which lasts 12.6 years, beginning in August 1996 and ending in December 2008. The maximum smoothed sunspot number observed during the cycle is 180.3. During the minimum transit from 23rd to 24th, there were a total of 817 days with no sunspots [7]. 23rd Solar cycle is medium in activity, but it is interesting that it is the last cycle before the deep minimum after it. We have conducted a statistical study of eruptions to identify precursors for each type of eruption. The data set and method of research are described in detail in Khaled et al. [2], where we consider only confined eruptions (69.2% of 159 filament eruptions).

In this paper, we investigate the signature X-ray flare class associated with ejective eruptions and some properties of CMEs (speed and angular width).

Relationship between X-ray flares and CMEs associated with ejective eruptions

Some properties of the X-ray flares and CMEs associated with ejective eruptions are analysed and displayed in this section. Table 1 summarises the X-ray flare classes associated with active and disappearing ejective filaments. It was found that the dominant X-ray flare energy of ejective eruptions is that of M class (15 events), or 30.6% from 49 data points selected. In addition, the number of X-ray flares in class B, C, and M associated with disappearing filaments is always higher than that associated with active filaments. On the other hand, A-class does not produce any associated filaments [8], while the energetic X-class only produces disappearing filaments. It was noticed that the percentage of M class in ejective eruption (30.6%) is higher than the percentage of M class in the confined eruption (18.2%) [2]. Additionally, disappearing filaments need more X-ray energy than active filament activations: namely, M, X, and EP (defined as eruptive prominence).

Table 1. Summary of the number of X-ray flares associated with active and disappearing ejective filaments

X-ray Flare class	Active filament type	Disappearing filament type
A	0	0
B	2	3
C	2	11
M	4	11
X	0	5
EP	1	10

Fig. 1 shows the number of ejective eruptions associated with different classes of X-ray flares, the distribution of ejective eruption events compared to filament extent, and the distribution of ejective eruption events compared to flare duration.

We have obtained that most of the ejective eruptions have a filament field extent between 5 and 20 degrees. And in some cases, only one event has an extent of more than 40 degrees, which represents about 4% of all the events. We have noticed that as the filament length increases on the solar disk, the probability of ejective eruption is higher (Fig. 1b)

Finally, we have also found that the most common X-ray flare durations for ejective eruptions are between 33 min and 1 hour 40 min. About 73.3% of all the ejective eruption events have a duration ranging between 33 min and 2 hours. And there is a duration of more than 3 hours, which represents about 11.8% of all data (Fig. 1c).

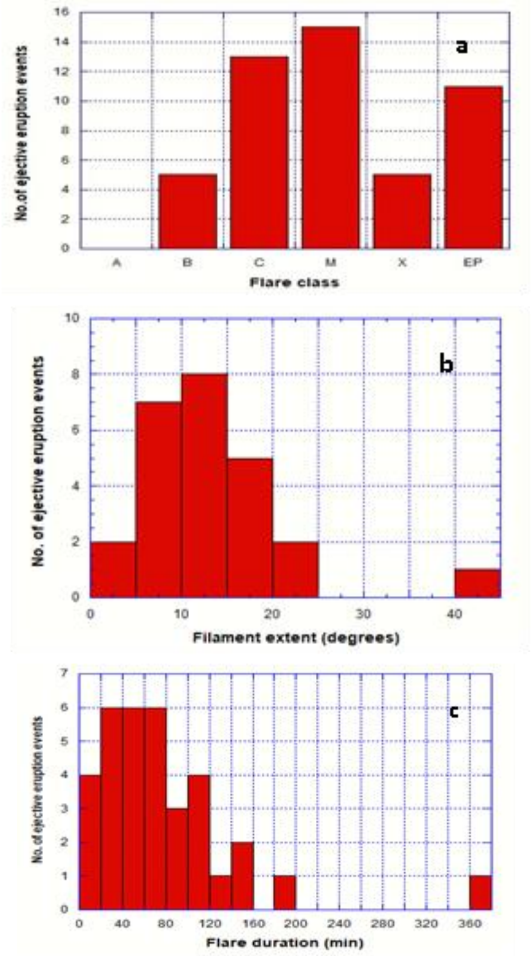

Fig. 1. a) Number of ejective eruptions associated with different classes of X-ray of flare; b) Distribution of ejective eruptions compared to filament extent, and c) Distribution of ejective eruptions compared to flare duration that result from ejective eruptions

CMEs properties (speed and angular width) resulting from ejective eruptions from active and disappearing filaments

Fig. 2 shows the histogram plot of CMEs speed resulting from ejective eruptions and the histogram plot of the angular width of CMEs associated with ejective filaments (Disappearing and Active filament eruptions).

Fig. 2a displays the distribution of CMEs speed of all ejective filaments used. It was found that the maximum speed reached 1800 km/s, while the minimum speed detected was about 300 km/s. This difference in speeds may be due to the amount of energy that the CME gained to be ejected.

From Fig. 2b one can see that CMEs speeds, which are associated with ejective eruptions, are in the range from 200 to 1800 km/s. Maximum speed with a value of 1600 km/sec is recorded for 3 events out of a total of 40 events, which represents 7.5%. Another 7.5% have a speed of 1200 km/s. This means that about 15% of the disappearing eruptive filaments have high speeds.

For eruptions resulting from active filaments, as shown in Fig. 2c, we see that each event (only 5 events found) in the data has its own distinct velocity. Speed ranges from 775 to 975 km/sec. It should be noted that CMEs with higher speeds are more likely to be formed due to disappearing filaments, not active filaments.

A histogram plot of the angular width of CMEs associated with ejective filaments (Disappearing and Active filament eruptions) is shown in Fig. 2d. One can see that the angular width of the CMEs associated with ejective filaments lies in the range of 60–360 degrees. About 40% of the events have an angular width of 360 degrees (Halo CME), which indicates that most CMEs resulting from ejective filaments have a high probability of reaching the Earth (they are geoeffective).

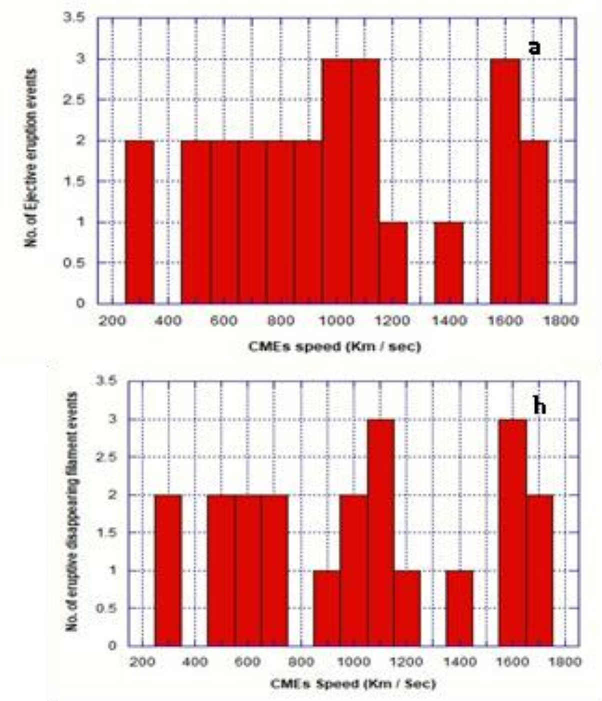

Fig. 2. a) Distribution of CMEs speed resulting from ejective eruptions;
b) The Distribution of CMEs speed of ejective eruptions in the case of disappearing

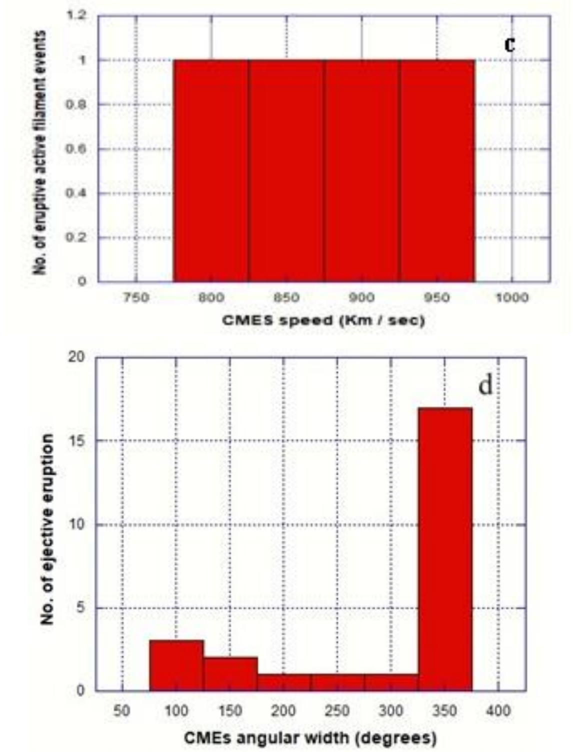

Fig. 2. c) For active filament eruptions;
d) Distribution of CMEs' angular width that results from ejective filaments

Regression analysis

Using regression analysis/curve fitting, we tried to find any relationships between the different parameters of confined and ejecting eruptions to use in forecasting.

Fig. 3 shows the weakness of the pairwise relationship among the considered variables (flare duration vs filament extent, eruption duration vs filament extent, and eruption duration vs flare duration). The maximum Correlation coefficient between any pair is always less than 0.4. So, we rely on the previous analysis to predict the behaviour of flares and CMEs ejections based on filament/prominence eruptions.

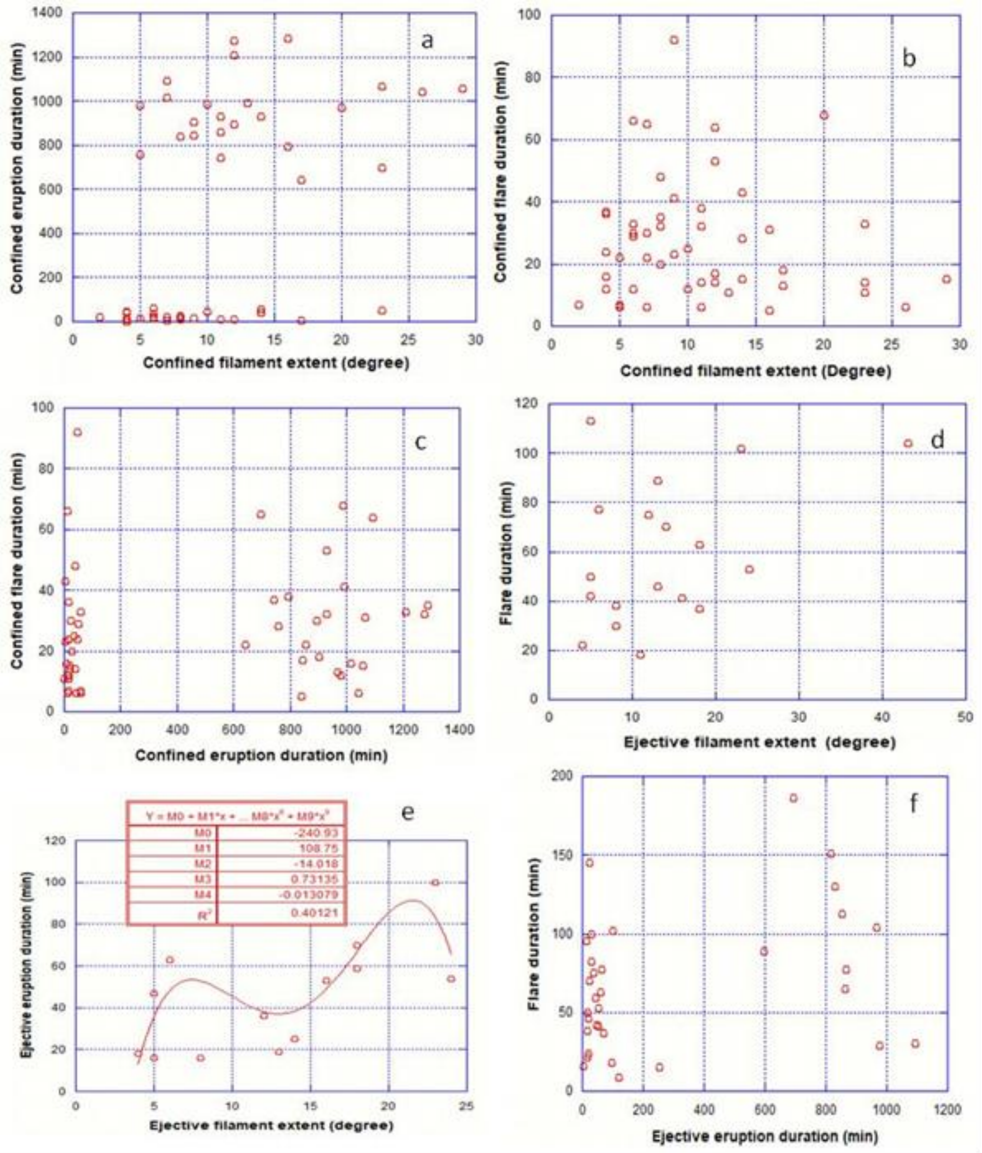

Fig. 3. Relationship between filament extent and flare duration and eruption duration for both confined and ejective eruptions (a, b) for confined eruption and (d, e) for ejective eruption. The relation between the eruption duration and flare duration in minutes for confined and ejective eruptions (c, f, respectively) is also shown.

Conclusion

In this work, we statistically examine ejective eruptions during the 23rd Solar cycle (1996–2008). They are 31% (49 events) of 159 filament eruptions that occurred in the period 1998–2011. Nine events (6%) are active filaments, and the other 40 (25%) are disappearing filaments.

The dominant X-ray flare energy of ejective eruptions is that of M class (15 events) or 30.6% from 49 data points selected. It is higher than the percentage of M class in the confined eruption (18.2% or 20 from 110 selected events). Additionally, disappearing filaments need more X-ray energy to be activated than active filaments: namely, M, X, and EP classes. This means that the M and X flare classes are highly likely to have CME ejection.

The distribution shows that the most common filament field extent is located between 5 and 20 degrees. We can use filament length as a good Predictor parameter. The shorter the filament length on the solar disk, the higher the probability of confined eruption [2], while the longer the filament length on the solar disk, the higher the probability of ejective eruption.

The most common flare duration is between 33 minutes and 2 hours for ejective eruption. It should be noted that besides filament/prominence eruptions, high-energy (relativistic) particles of solar and galactic origin, i.e., protons and heavier nuclei of galactic and solar cosmic rays, are important for space weather and space climate [9–11]. They cause complex nuclear-electromagnetic-lepton cascades in the Earth's atmosphere, which lead to ionisation of the surrounding air and the entire environment. Cosmic ray-induced ionisation is associated with effects on atmospheric chemistry and physics and is principal for radiation safety in spaceflight [12–15].

Studying properties of the CMEs (speed and angular width) resulting from ejective (active and disappearing) filament eruptions, we have found that:

1) CMEs speeds detected from the selected data range from 200 to a maximum of 1800 km/s.

2) About 15% of the disappearing eruptive filaments have high speeds – from 1200 km/sec to 1600 km/sec.

3) We have obtained that the CME velocity associated with active filaments varies between 775 and 975 km/s, and the CME velocity associated with disappearing filaments is much higher (up to 1800 km/s).

4) Finally, our study shows that 40% of the events have an angular width of 360 degrees (Halo CME), which indicates that they are geoeffective and can influence space weather.

The results of this work are essential for the analysis and prediction of processes in solar-terrestrial relations and space physics [16–20].

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СТАТИСТИЧЕСКО ИЗСЛЕДВАНЕ НА ИЗХВЪРЛЯЩИ ИЗРИГВАНИЯ НА НИШКИ/ПРОТУБЕРАНСИ ПО ВРЕМЕ НА 23-ИЯ СЛЪНЧЕВ ЦИКЪЛ

С. Халед, А. Шимеис, М. Хюсеин, М. Семейда, П. Стоева, А. Стоев

Резюме

Изригванията на нишки/протуберанси (filament/prominence) в слънчевата атмосфера са едни от най-важните слънчеви събития, които драстично влияят на космическото време. Формирането, еволюцията и изригването на нишките са пряко свързани с магнитната активност на Слънцето. В настоящата работа са статистически проучени 159 изригвания на нишки, случили се в периода 1998–2011 г., за да се разграничат различните видове изригвания на нишки – ограничени или изхвърлващи. Това е извършено с помощта на Списъка с междупланетни (interplanetary IP) шокове, наблюдавани по време на 23-ия слънчев цикъл (май 1996 г. – януари 2008 г.) и техните рентгенови диаграми от изходната информация за околната среда (GOES) [1]. Установихме, че 69% от изригванията на нишки са ограничени изригвания, докато 31% са изхвърлящи изригвания. Изследвахме ограничени изригвания на нишки (110 събития) по време на 23-ия слънчев цикъл (1996–2008 г.) в Khaled et al. [2] и установихме, че 21% от тях се дължат на активни нишки, а 48% – на изчезващи нишки. Тук представяме статистическо изследване на изригванията на изхвърлящи нишки/протуберанси. Връзката между изригванията на нишки, изригванията и свойствата на изхвърляния на маса от короната (CME) за всеки тип е изследвана поотделно. Установихме, че има значителна вероятност за CME с класове на изригвания M и X. Също така е наблюдавано, че преобладаващата рентгенова енергия на изхвърлените изригвания е от клас M. Получихме, че скоростта на CME, свързана с активните нишки, варира между 775 и 975 km/s, а скоростта на CME, свързана с изчезващи нишки, е много по-висока (до 1800 km/s). Накрая, нашето проучване показва, че 40% от събитията имат ъглова ширина от 360 градуса (Halo CME), което показва, че те могат да окажат значително въздействие върху горните слоеве на земната атмосфера и да причинят промени в космическото време.