J. Astrophys. Astr. (2019) 40:1
https://doi.org/10.1007/s12036-018-9570-1

© Indian Academy of Sciences

Relation between solar flares and halo coronal mass ejections

V. KOTESWARA RAO[1,2,*], K. RAMA GOPAL[1], R. RAMAKRISHNA REDDY[1],
K. AMARESWARI[2] and K. SANKARASUBRAMANIAN[2,3]

[1]Department of Physics, Sri Krishnadevaraya University, Anantapur, India.
[2]U R Rao Satellite Centre, Indian Space Research Organisation, Bengaluru, India.
[3]Indian Institute of Astrophysics, Bengaluru, India.
*Corresponding author. E-mail: vkrao.isro@gmail.com

MS received 15 June 2018; accepted 26 November 2018; published online 19 January 2019

Abstract. Solar flares and coronal mass ejections (CMEs) are two very important active events from Sun. Inspite of several theoretical and statistical analyses, the relation between solar flares and CMEs is so far not well established, and strong opinions and arguments still continue. Statistical approaches use a lot of data available from many measurements by space and ground instruments. They try to map the measured parameters of one event to that of another event and try to establish the relation between them. Halo CMEs are a kind of special CMEs in the sense that they are directed towards Earth and hence can influence Earth's atmosphere. For a scientist interested in Sun–Earth interactions and the effect on Earth's atmosphere, study of Halo CMEs is extremely important. In this paper the relation between solar flares and Halo CMEs is studied. The data sets used are for the period from October 2006 to March 2017. For the first time, the Halo CMEs are categorized into four different groups based on the relative time of occurrence with respect to the flares and the relation between the flare and Halo CME parameters is studied. It is shown that: (a) there is a good correlation between certain flare parameters (like flare flux and peak intensity) and CME parameters (like kinetic energy, linear speed, and mass) especially when the Halo CME occurs during the flare; (b) For the same set of CMEs, the correlation is poor with flare duration; and (c) For CMEs before or after the flare, the correlation is lesser than the CMEs occurring during the flare.

Keywords. Solar flares—coronal mass ejections—halo CMEs.

1. Introduction

The subject of relation between solar flares and Coronal Mass Ejections (CMEs) and their association is well debated and argued since many years. There are arguments based on theory and statistical evidence for and against the association between flares and CMEs. There are various schools of thought which probably can be consolidated into four categories: (1) Flares and CMEs are activities caused by independent mechanisms and hence there is no relation between them, (2) Flares are the source and initiate CMEs, (3) Flares are the result of CMEs, and (4) Flares and CMEs are bimodal.

Gosling (1993) outlined the rationale for a different paradigm of cause and effect that removes solar flares from their central position and assigns the central role of cause to CMEs. He concluded to say that it is time to lay 'the solar flare myth' to rest. Harrison (1995) presented an analysis of solar X-ray flares associated with CMEs for the period 1986–87 and said that the analysis supports the view that the flare and CME are signatures of the same magnetic activity but represent the responses in different parts of the magnetic structure. They do not drive one another, but are closely related. Dryer (1996), after a critical examination of the claims that the single cause of the CMEs lies in their close connection with large scale closed magnetic structures in the corona, has suggested that the CME associations (flare or non-flare) are at least bimodal and the bimodal set of associations is fundamental to the eventual understanding of the cause of the CMEs. Yashiro and Gopalaswamy (2008) examined the CME association of flares from 1996 to 2007 and found that the CME association rate clearly increases with the flare's peak flux, fluence and duration. The launch of Coronagraph on SOHO and the processing of data to catalog the CMEs and their properties opened up many new studies on the relation between flares and CMEs. Aarnio *et al.* (2010) derived a relation between the CME mass and the flare flux stating that the stronger the associated flare is, the more massive the CME is. Youssef (2012) studied the CMEs (recorded by SOHO) and their associated solar flares (flare events observed by GOES) during the period from 1996 to 2010. He found that 67% of the 778 CME–flare associated events (530 events) ejected from the solar surface after the occurrence of the associated flare and this result sustains the idea that flares produce CMEs as suggested by Dryer (1996), not the idea that flares are byproducts of CMEs as postulated by Hundhausen (1999). Nitta *et al.* (2013) studied the association of solar flares with CMEs during the deep, extended solar minimum of 2007–2009, using extreme-ultraviolet (EUV) and white-light (coronagraph) images from the Solar Terrestrial Relations Observatory (STEREO). He concluded that we still cannot rely on low coronal observations alone to detect and characterize CMEs. Different manifestations of CMEs in the low corona suggest that there may be more than one mechanism or a particular magnetic topology for launching CMEs. Schmieder *et al.* (2014) stated that flares and CMEs belong to the same magnetically-driven event and shown that 75% of the CMEs are strongly related with flares detected by GOES as well as their onset is related with the impulsive phase of flares.

Halo CMEs are of particular importance to be studied as they are directed towards Earth and hence can influence the weather more directly. The characteristic of a Halo CME, is that its measured brightness appears to be surrounding the entire solar disk. In other words, the CME with a measured sky plane width of 360° is called a Halo CME. This paper presents a study of the relation between solar flares measured in X-rays and the Halo CMEs measured by Coronagraph.

2. Data used

The CME data is obtained from the catalog containing all CMEs manually identified since 1996 from the Large Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory (SOHO) mission. Data from this catalog is available from the year 1996 to March 2017 (at the time of writing this paper). The catalog gives information on date and time of occurrence of CME in the Field of View of LASCO, the Central Position Angle (CPA), sky plane width of the CME, Linear Speed (LS), acceleration, mass, kinetic energy, etc. CMEs of an apparent width of 360° are marked as ‘Halo’ in the CPA.

Table 1. Entries available from the Flare and CME catalogs.

Period	20-10-2006 to 31-03-2017
Total number of flares	15,394 (Hinode) 14,514 (GOES)
Total number of CMEs	16,958
Number of Halo CMEs	323

The solar flare data is taken from the catalog generated using X-ray Telescope (XRT) on-board Hinode (Solar-b) satellite launched in September 2006. Data from this catalog is available from 20 October 2006 to 31 March 2017. Description and details about the preparation of the Hinode flare catalog can be found in Watanabe *et al.* (2012).

The common data available period from the two catalogs is limited by the solar flare catalog which is from 20 October 2006 to 31 March 2017. Accordingly, the data used for analysis in this paper is from October 2006 to March 2017. Table 1 shows the available entries from these two catalogs.

X-ray flare data from GOES X-ray Sensor (XRS) for the same period is also used to compare the results obtained with Hinode flare data. This data is available from National Centres for Environmental Information (NCEI) of National Oceanic and Atmospheric Administration (NOAA).

3. Methodology and analysis

The flare data from XRT and XRS and the CME data from SOHO are extracted for a common period from 20 October 2006 to 31 March 2017. From the CME catalog, the Halo CMEs are extracted and the total number is found to be 323. To establish the relation between flares and CMEs, normal practice is to apply time and spatial nearness between the two events. Time nearness criteria for this study is set as

$$|\text{Time of flare} - \text{Time of occurrence of Halo CME}| < 2\,\text{h}$$

Time of occurrence of CME is the observed time in the field of view of the LASCO instrument. Time of flare is defined depending on the way the flare occurred with respect to the Halo CME. All the Halo CMEs are categorized into four groups depending on their occurrence with respect to the Flare.

Table 2. Definition of time of flare for each group of Halo CME.

S. no.	Group	Time of flare defined as
1	Group 1	Not defined
2	Group 2	Midpoint of start and end times of the flare (start time + end time) divided by 2
3	Group 3	End time of the flare
4	Group 4	Start time of the flare

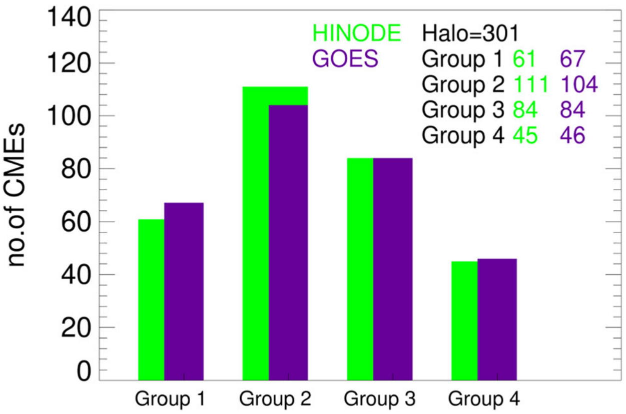

Figure 1. Group-wise distribution of the Halo CMES.

Group 1: No flare association
Group 2: CME occurred during (between start and end of) the flare
Group 3: CME preceded by a flare
Group 4: CME followed by a flare

Time of flare definition for all the four groups is given in the Table 2.

The sky plane width of a Halo CME is 360° and hence will not serve any purpose to impose a condition with respect to the position of the flare. Youssef (2012) in his work "On the relation between the CMEs and the solar flares" used the following criteria for spatial association.

$$| \psi_{\mathrm{CME}} - \psi_{\mathrm{F}} | < \phi$$

where 'ψ_{CME}' is the position angle of the CME (the angle measured on the solar disk between the solar north pole and the line directed to the ejection of the CME), 'ψ_{F}' is the flare's position angle and 'ϕ' is the angular width of the CME as detected by SOHO.

In this condition, for Halo CMEs, 'ϕ' happens to be 360° and hence has no meaning. Any flare location can be associated with the observed CME that satisfies temporal association condition. Therefore no criteria is set for spatial relation between the flare and Halo CME. However, a statistical analysis is also performed on the data sets by setting spatial nearness criteria between the flares and the Halo CMEs. The details are presented under Section 4. The total Halo CMEs are 323 out of which 22 are back side CMEs. The group wise distribution of the remaining 301 front side CMEs is given in Figure 1. It can be seen that the time relation results from both GOES and Hinode catalogues match quiet well with a little difference. This difference is not significant to affect any of the results presented in the paper. Most of the study is carried out using Hinode flare catalog.

About 20% front side Halo CMEs (61 out of 301) are observed to be not associated with any flare within a time period of +/− 2 h. In this 20%, CMEs associated with flare may not be observed by HINODE or Flare can be back side. Having Noted this, further study is done on the remaining 240 Halo CMEs categorized under Group2, Group 3 and Group 4. Using the definition of time of flare as given in Table. 2. time difference between the flare and the Halo CME for each pair is computed. If the flare occurs before the CME, the time difference is designated as positive and if the flare occurs after the CME, it is designated as negative. The occurrence of CMEs in terms of numbers with respect to the computed time difference (30 min intervals), for the three groups, are given in Figure 2.

The 240 flares associated with Halo CMEs are distributed over the four quadrants of the Sun Disk. The quadrant wise distribution of the flares on the Sun Disk is shown in Figure 3. It is noted that the distribution is fairly equal over the four quadrants. The distribution of the Halo CME associated flares on the Sun Disk with respect to longitude and latitude (represented in arc sec) is shown in Figure 4.

The relation between the number of Halo CMEs associated with the flares and the latitude of the flare origin is studied. Figure 5. shows the results for the three groups of Halo CMEs and also for all the groups together. The latitude information is in terms of arc seconds. Negative numbers indicate South and positive numbers indicate North on the Sun Disk.

The relation between some of the flare properties and the Halo CME properties is carried out to visualize their possible association. Figure 6 gives the relation between the flare peak Intensity (I) and the Kinetic Energy (E) of the Halo CME. Note the plots are in log-log format.

Relation between another property of the Halo CME, the Linear Speed (LS) and the flare peak intensity is presented in Figure 7. Note X axis is in log scale denoting the class of the flare. One more important characteristic of a Solar flare is its duration. The relations between

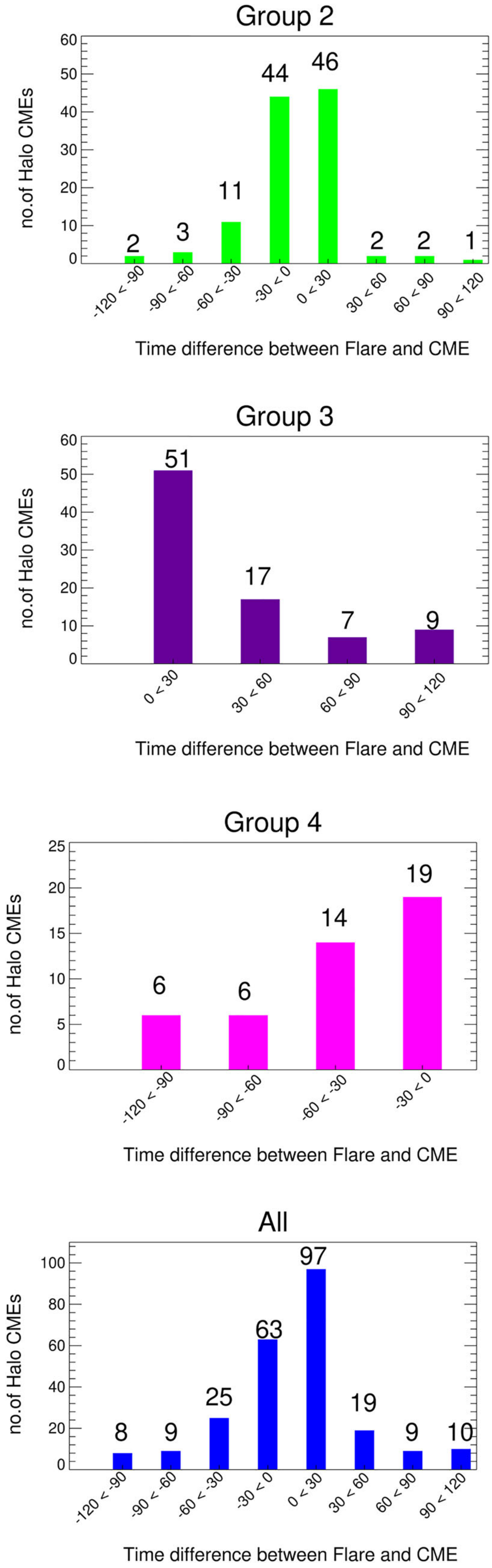

Figure 2. Time difference between the Flare and the Halo CME.

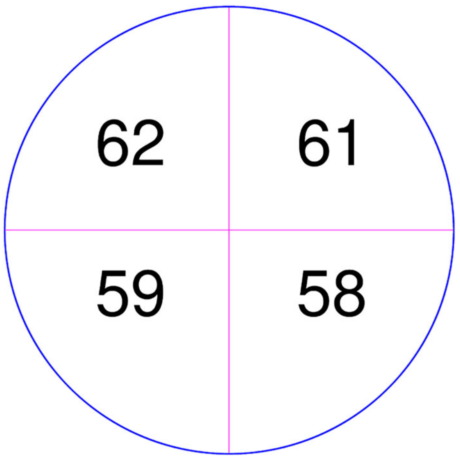

Figure 3. Quadrant wise distribution of flares associated with Halo CMEs.

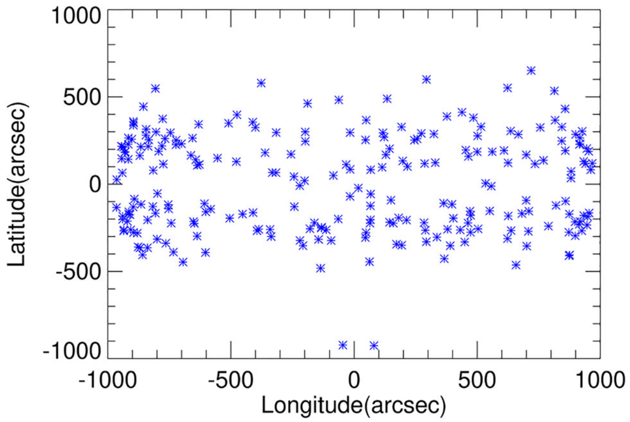

Figure 4. Longitude and Latitude wise distribution Flares associated with Halo CME.

Kinetic Energy and the Linear Speed of the Halo CMEs with respect to the duration of the associated flares are shown in Figures 8 and 9. respectively. Here the duration means the time between flare pea to flare end, as given in catalog.

The relation between the logarithm of Halo CME mass and logarithm of its associated flare Flux (GOES) is shown Figure 10. 214 out of 240 Halo CMEs associated with flares have mass and flux values. The 214 CME–flare pairs are binned into 20 equal sets of 10 pairs each. For these 20 sets, the mean values of logarithmic CME mass and logarithmic flare flux values are computed. The mean values are used to study the relation between flare flux and Halo CME mass. The error values are calculated in each set both for logarithmic mass and logarithmic flux as $\sigma/\sqrt{}(N)$ (Here in N 1s 10.). For the reaming four pairs mean values are calculated separately and error is calculated as $\sigma/\sqrt{}\ (4)$.

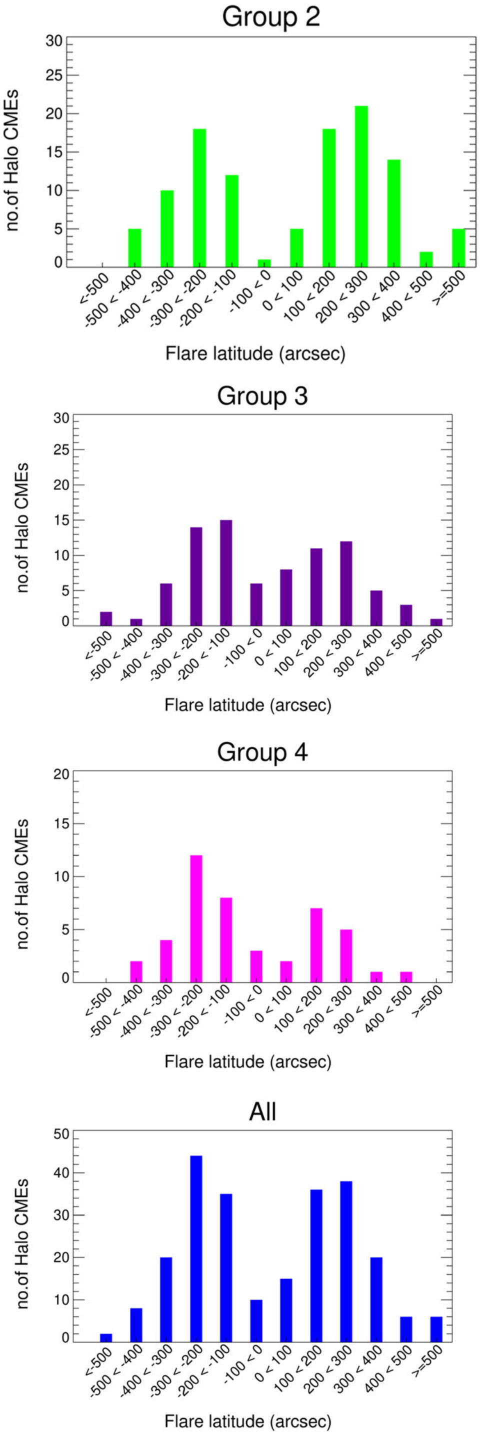

Figure 5. Latitude distribution of flares associated with Halo CMEs, on the sun disk.

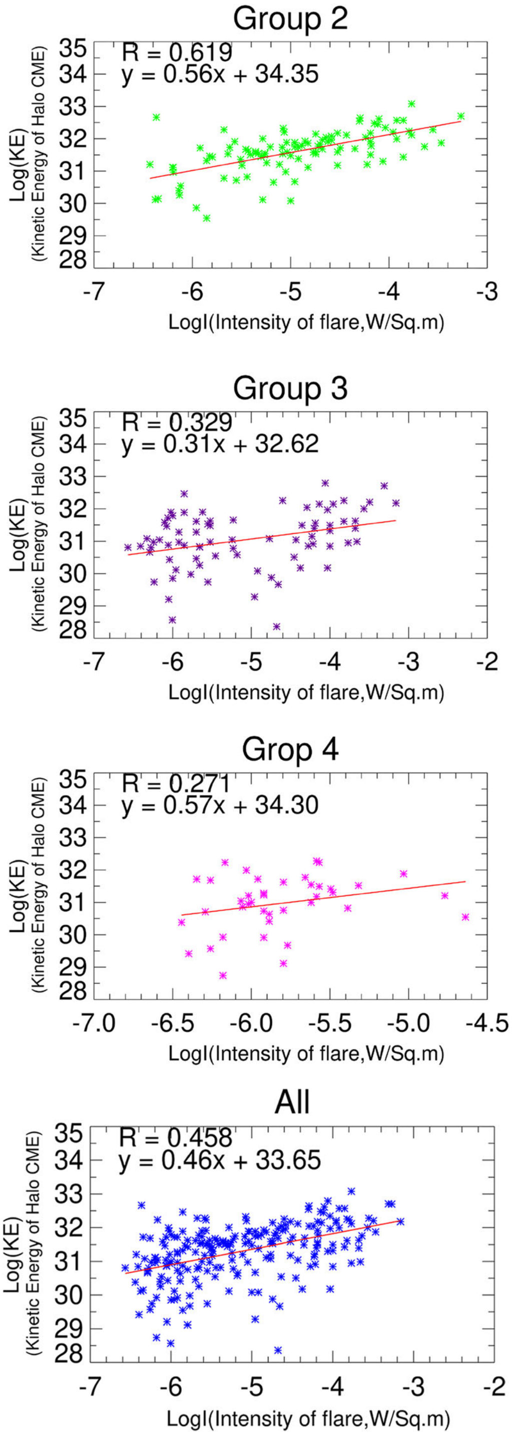

Figure 6. Relation between flare peak Intensity (I) and Halo CME Kinetic Energy (E).

In Group 2, 95 out of 111 pairs have both CME mass and flux values. For 90 pairs same procedure is used as above. For the reaming five pairs mean values are calculated separately and error is calculated as $\sigma/\sqrt{(5)}$. The same procedure is followed or other groups also.

4. Results and discussion

With the criteria of the time association between the Solar Flares and the Halo CMEs is applied, it is observed that about 205 of the Halo CMEs have no flares associated, which could be due to lack of observational data.

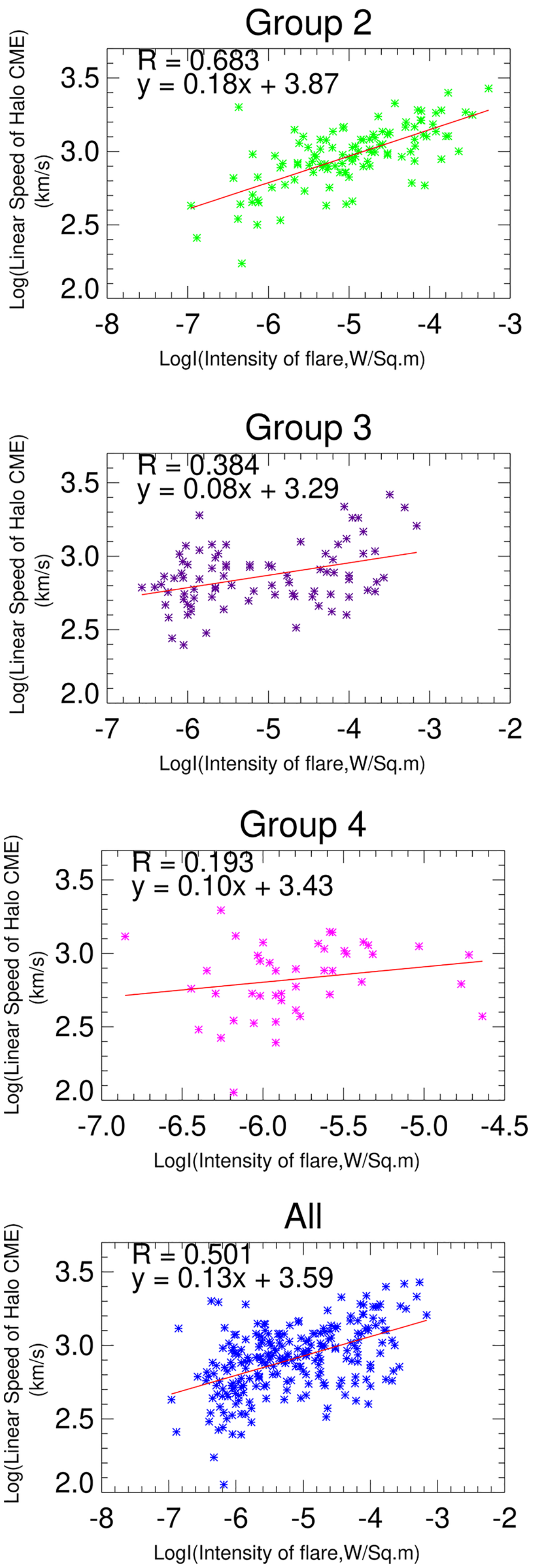

Figure 7. Relation between Peak flare Intensity and halo CME Linear Speed.

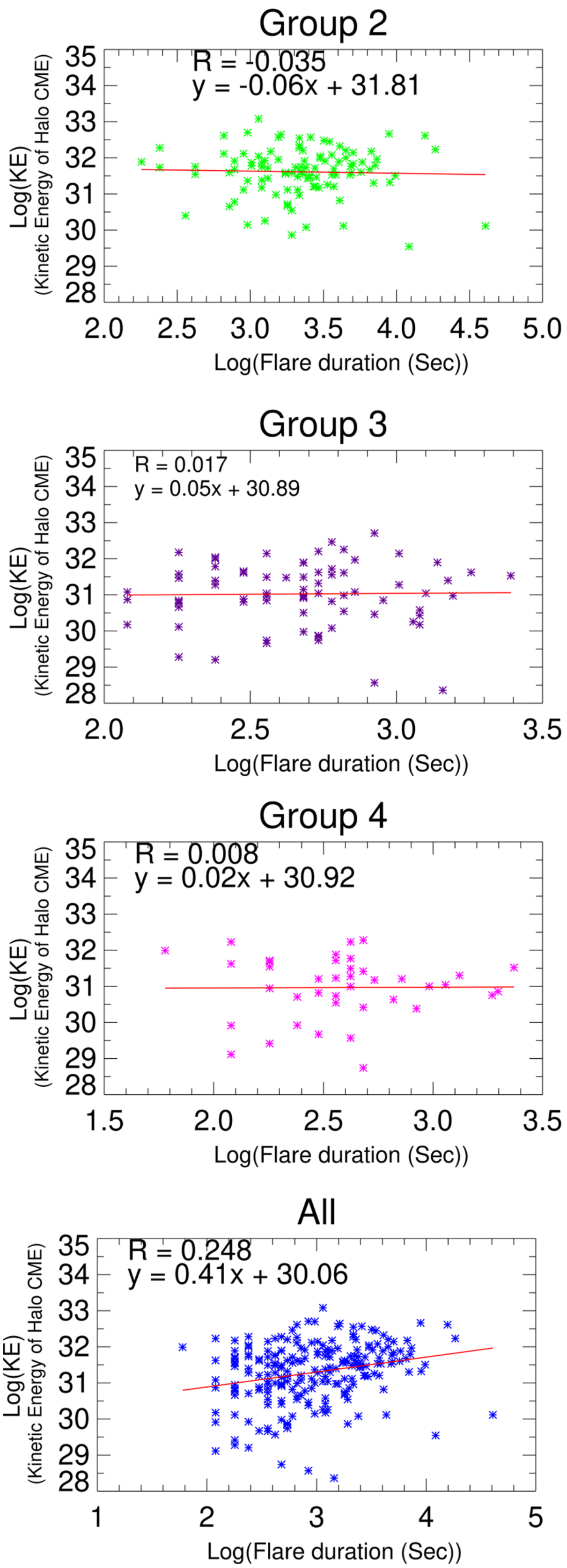

Figure 8. Relation between flare duration and kinetic Energy of Halo CME.

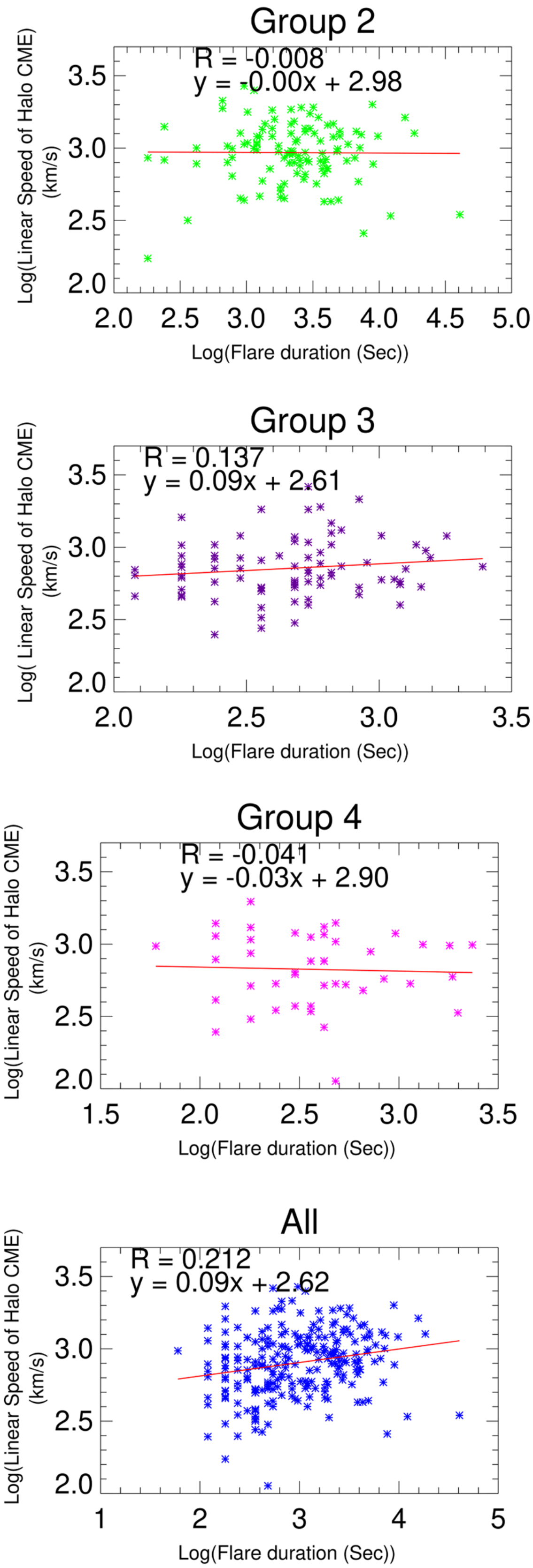

Figure 9. Relation between flare duration and Halo CME Linear Speed.

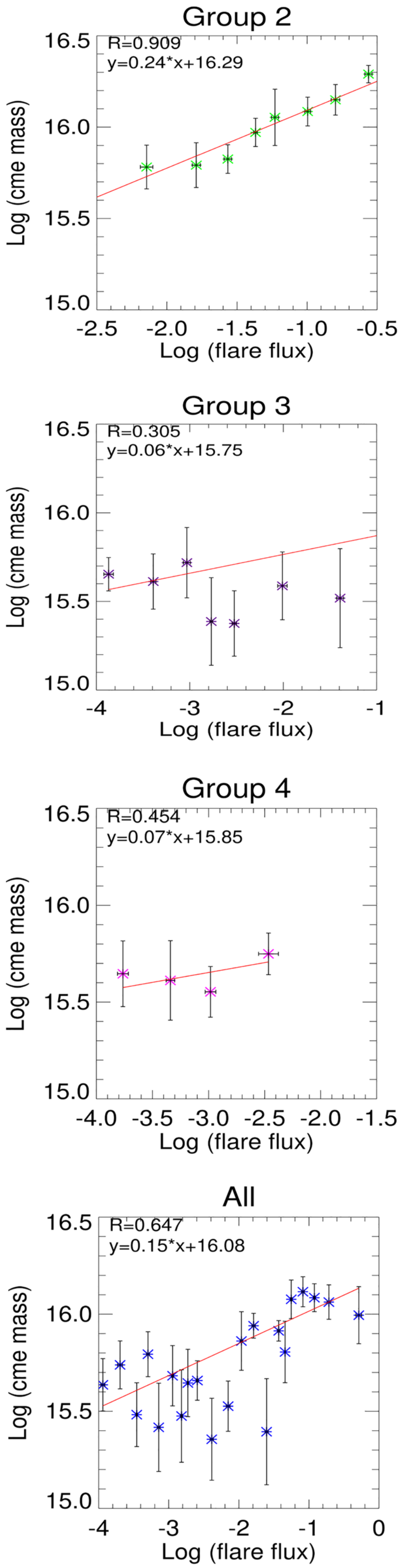

Figure 10. Relation between Integrated flare Flux and halo CME Mass.

Out of the remaining 240 CMEs 195 (111 from Group 2 + 84 from Group 3) are preceded by start of a Flare. This represents a high percentage of 81.25%. Group 4 consisted of 45 CMEs followed by Flare. This represents a low percentage of 18.75%. A major percentage of the CMEs associated with the flares are preceded by the initiation of the flares. Another interesting observation is that there are no high intensity flares (higher than M3.5) in Group 4 (where CME is followed by a flare) that are associated with Halo CMEs.

Study of the time difference between the flare and CME (Figure 2.) reveals the following facts. 90 Halo CMEs out of 111 (81%), in Group 2, occurred within +/− 30 min. For Group 3 Halo CMEs 51 out of 84 (60%) occurred within 0–30 min, whereas 80% have occurred within 0–60 min. For Group 4 Halo CMES, 19 out of 45 (42.22%) occurred within −30 to 0 min, whereas 73% have occurred within −60 to 0 min. Over all for 80% of the Halo CMEs the time difference between the flare and the Halo CME is within 60 min. This indicates a good time association for all three groups of the Halo CMEs.

The positional significance of the Solar Flares associated with the Halo CMEs is explored. The first attempt is whether a particular quadrant of the Sun Disk contributes differently in comparison with other quadrants. Figure 3 clearly shows that there is no dominance of any particular quadrant as the quadrant wise distribution is fairly equal. The next attempt is on the Longitude and Latitude distribution. The distribution as seen from Figure 4 reveals that the distribution over Longitudes is equal whereas that is not so with Latitude. Almost all (232 out of 240 representing 96%) of the flares associated with the Halo CMEs are within the Latitudes from −500 to +500 arc sec. A significant percentage (90%) is within the Latitudes of from −400 to +400 arc sec. This is expected as CMEs originate from active regions and the active regions fall in this latitude band. Almost one half of the Solar Disk, near to the poles is not contributing to the Halo CMEs. Figure 5 gives the Latitude distribution of the Flares associated with all groups of Halo CMEs. The distribution and concentration of the flares for all groups of Halo CMEs appear to be similar.

The relation between the Kinetic Energy of the CME and its associated flare peak intensity shows an average level of correlation between them. Group 2 shows a better correlation (R = 0.6) than Group 3 (R = 0.3) and Group 4 (R = 0.2). The relation between the Linear Speed of the CME and its associated flare peak intensity also shows an average level of correlation between them. Group 2 shows a better correlation (R = 0.6) than Group 3 (R = 0.3) and Group 4 (R = 0.19). Yashiro and Gopalaswamy (2008) reported on the statistical relationships between solar flares and coronal mass ejections (CMEs) observed during 1996–2007. The correlation coefficient between the CME kinetic energy and the flare peak intensity is found to be 0.48. This closely matches with the correlation coefficient of 0.458 all 3 groups in our study. Similar is the case with CME linear speed also. Yashiro's study reported the correlation coefficient between CME speed and flare peak intensity to be 0.50. The correlation coefficient of 0.501 for all the three groups in our study is also same as this. It is evident from Figure 6 that X class flares always are associated with CMEs with Kinetic energy of 10^{31} or higher. It can also be seen from Figure 7 that CMEs with Linear Speeds higher than 2000 km/s are always associated with either high intensity M class or X class flares. These two observations suggest that the flares and Halo CMEs may not always be independent of each other.

The relation between the Kinetic energy and the flare duration shown in Figure 8 and the relation between the Linear speed of Halo CME and the flare duration shown in Figure 9 indicate that the correlation is very weak between these parameters. Harra *et al.* (2016) explored characteristics of 42 X-class flares during the period 2011–2014 for a clear signature to differentiate the flares that have association with CMEs from those which do not have association. 9 out of 42 flares were not having association with CME. They observed no clear discrimination of flare duration (FWHM) between events with and without CMEs. Our observation of weak correlation between the kinetic energy and the linear speed of the CME, and the flare duration also is similar. Our observation is not limited to X-class flares alone. However in Figure 8 the Kinetic Energy plot for Group2 shows a slight negligible slope indicating lower energies with higher duration of the Flare.

Figure 10 shows the log–log relation between Integrated flare flux from (integrated from flare start to end time) obtained from GOES flare catalog, and Halo CME mass. This is similar to that, for all CMEs of large sample events, reported by Compagnino (2016). Group 2 shows a better correlation (R = 0.9), whereas group 3 and 4 show weak correlation. The log-log relation appears more valid for the Group 2 Halo CMEs (Occurred during the flare).

Analysis is also carried out using the spatial nearness of the flare and CME. To do this analysis, source location of CME is obtained from the catalog of Halo CMEs provided by CDAW. The criteria set for this analysis is that the latitude difference between flare and CME is less than ±10° and longitude difference is less than

Table 3. Comparison of statistical parameters between two analyses, one using only time nearness and the other using both time and spatial nearness.

	Only time association	Both time and spatial association
Number of HALO CMEs		
Total	301	301
Group 1	61	155
Group 2	111	81
Group 3	84	54
Group 4	45	11
CME kinetic energy (log E) versus flare peak intensity (log I)		
Group 2	$R = 0.619$	$R = 0.599$
	$Y = 0.56\ X + 34.35$	$Y = 0.59\ X + 34.52$
Group 3	$R = 0.329$	$R = 0.511$
	$Y = 0.31\ X + 32.62$	$Y = 0.63\ X + 33.93$
Group 4	$R = 0.271$	$R = 0.179$
	$Y = 0.57\ X + 34.30$	$Y = 0.39\ X + 33.25$
All	$R = 0.458$	$R = 0.466$
	$Y = 0.46X + 33.65$	$Y = 0.56\ X + 34.05$
CME log linear speed versus log I		
Group 2	$R = 0.683$	$R = 0.667$
	$Y = 0.18\ X + 3.87$	$Y=0.18x+3.86$
Group 3	$R = 0.384$	$R = 0.495$
	$Y = 0.08\ X + 3.29$	$Y=0.13x+3.48$
Group 4	$R = 0.193$	$R = -0.24$
	$Y = 0.1\ X + 3.43$	$Y = -0.12x+2.25$
All	$R = 0.501$	$R = 0.497$
	$Y = 0.13\ X + 3.59$	$Y=0.14x+3.6$
Log E versus log flare duration		
Group 2	$R = -0.035$	$R = -0.143$
	$Y = -0.06\ X + 31.81$	$Y = -0.26\ X + 32.62$
Group 3	$R = 0.017$	$R = -0.103$
	$Y = 0.05\ X + 30.89$	$Y = -0.37\ X + 32.01$
Group 4	$R = 0.008$	$R = 0.055$
	$Y = 0.02\ X + 30.92$	$Y = 0.18\ X + 30.65$
All	$R = 0.248$	$R = 0.234$
	$Y = 0.41\ X + 30.06$	$Y = 0.42\ X + 30.12$
CME log linear speed versus log flare duration		
Group 2	$R = -0.008$	$R = -0.261$
	$Y = -0.00\ X + 2.98$	$Y = -0.14\ X + 3.5$
Group 3	$R = 0.137$	$R = 0.061$
	$Y = 0.09\ X + 2.61$	$Y = 0.04\ X + 2.74$
Group 4	$R = -0.041$	$R = 0.066$
	$Y = -0.03\ X + 2.9$	$Y = 0.05\ X + 2.8$
All	$R = 0.212$	$R = 0.158$
	$Y = 0.09\ X + 2.62$	$Y = 0.07\ X + 2.74$
CME mass (log M) versus flare fluence (log F)		
Group 2	$R = 0.909$	$R = 0.763$
	$Y = 0.24\ X + 16.29$	$Y = 0.35\ X + 16.37$
Group 3	$R = 0.305$	$R = 0.896$
	$Y = 0.06\ X + 15.75$	$Y = 0.49\ X + 16.38$
Group 4	$R = 0.454$	$R = 1$
	$Y = 0.07\ X + 15.85$	$Y = 0.056\ X + 16.99$
All	$R = 0.647$	$R = 0.817$
	$Y = 0.15\ X + 16.08$	$Y = 0.44X + 16.43$

±20°. It may be noted that this is in addition to the time matching.

The results summarized in the form of comparison between two analyses, one with only time nearness and the other with both time and spatial nearness, are presented in Table 3.

The results show that the correlations are not improving after considering the spatial nearness for Halo CMEs.

5. Conclusion

The study is focused on the relation between the solar flares and the Halo CMEs. After establishing the 'Time association' between them it was imperative to Group the CMEs based on their time of occurrence with respect to the time of occurrence of the Flare. The fact that 61 out of 301, representing <21%, indicates either it is due to the non-availability of observational data of the flares or due to CMEs really have no flares associated with them. If it is due to the second reason, then it indicates that some of the CMEs are not the result of any flare, at least as measured in X-ray domain. Neither these CMEs are the cause for producing any flares. They also may not be the result of a single physical phenomenon that produces both flare and CME. On the other hand 195 out of 240 (representing >80%) Halo CMEs have shown relationship with flares by means of 'Time Association' and appear to be initiated by the flares. The Linear Speed and Kinetic Energy show a reasonably good correlation with the peak intensity of the flare. The duration of the flare has no correlation with the Linear Speed and the Kinetic Energy of the Halo CME. 45 out of 240 Halo CMEs are followed by flares. These results clearly show that a single theory would not explain the relation between the flares and the Halo CMEs, at least at the present juncture. The 'Bimodal' approach suggested by some authors also may not be adequate to explain the statistical observations. A 'Trimodal' or 'Multimodal' approach is called for. As this holds good particularly for the Halo CMEs by this study, it may be true for all CMEs in general.

Acknowledgements

The authors are thankful to the management of Sri Krishnadevaraya University, Anantapur; Particularly the Head, Department of Physics; for facilitating this work. The authors also acknowledge the unstinting support provided by Dr. M. Annadurai, Director, U R Rao Satellite Centre, Bengaluru. We Profoundly thank Dr. K. Sivan, Chairman, ISRO for his encouragement and support for this research work. We acknowledge CDAW Data Center by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory for usage of the CME Catalog derived from LASCO coronagraph on SOHO. SOHO is a project of international cooperation between ESA and NASA. We acknowledge the usage of the flare catalog from Hinode–XRT. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and the NSC (Norway). We acknowledge NGDC for the GOES flare catalog.

References

Aarnio A. N., Stassun K. G., Hughes W. J., McGregor S. L. 2010, Solar Phys. 0, 22

Compagnino A. 2016, A statistical study of CME properties and of the correlation between Flares and CMEs Over the Solar Cycles 23 and 24

Dryer M. 1996, Solar Phys. 169(2), 421–429

Gosling, J. T. 1993, Solar Syst. Plasma Phys. JGR 98(Issue A11), 18397–18950. https://doi.org/10.1029/93JA01896

Harra, K. et al. 2016, Solar Phys. 291, 1761–1782. https://doi.org/10.1007/s11207-016-0923-0

Harrison, R. A. 1995, Astron. Astrophys. 304, 585–594

Hundhausen A. 1999, in Strong K. T., Saba J. L. R., Haish B. M., Schmelz J. T., eds, The many faces of Sun, Springer, New York, NY, pp. 143–200, https://doi.org/10.1007/978-1-4612-1442-7_5

https://cdaw.gsfc.nasa.gov/CME_list

https://cdaw.gsfc.nasa.gov/CME_list/halo/halo.html

https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs

http://xrt.cfa.harvard.edu/flare_catalog

Nitta, N. V., Aschwanden, M. J., Freeland, S. L., Lemen, J. R., Wulser, J. P., Zarro, D. M. Solar Phys. Accepted 5 August 2013

Schmieder, B., Aulanier, G., Vrsnak, B. 2014, Solar Phys. 19, 05

Watanabe, K., Masuda, S., Segawa, T. 2012, Solar Phys. 279, 317–322. https://doi.org/10.1007/s11207-012-9983-y

Yashiro, S., Gopalaswamy, N. 2008, Statistical Relationship between Solar Flares and Coronal Mass Ejections, Universal Heliophysical Processes Proceedings, IAU Symposium No. 257

Youssef, M. 2012, NRIAG J. Astron. Geophys. 1, 172–178