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Relation between angular width and speed of coronal mass ejections observed during 23rd solar cycle

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A B S T R A C T

The study of observed relation between angular width and speed of normal or partial coronal mass ejections (CMEs) observed at *Large Angle and Spectrometric Coronagraph (LASCO)* on board the *Solar and Heliospheric Observatory (SOHO)* during 23rd solar cycle are statistically analyzed. Normal or Partial CME is defined as CME having angular width $\geq 120^\circ$ and Halo CMEs having angular width = 360°. Total 1601CMEs were observed during 23rd solar cycle out of these 1119 normal or partial CMEs (71.59%).The maximum number of partial CMEs observed at 140° angular width during every year. Most of the partial CMEs have speeds in the range of 200 - 800 kms^{-1}.

Introduction

CMEs were first detected in the 1970s by the *Orbiting Solar Observatory (OSO-7)* on 1971 Dec. 14 (Tousey R., 1973). Since their discovery CMEs have been observed by several space-borne instruments, namely the seventh *OSO-7* coronagraph, the *Apollo Telescope Mount (ATM)* coronagraph on board Skylab, the Solwind coronagraph on board the P78-1 satellite, the LASCO on board the SOHO, and Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) on board Solar TERrestrial RElations Observatory (STEREO). The ground-based instruments, e.g. the Mauna Loa K-Coronameter, have also observed CMEs. For more than three decades, the identification of the CMEs has been carried out by human eye and the event catalogs have been compiled manually (Gopalswamy *et al.*, 2009). CMEs are eruptions of plasma from the Sun that range in speed from 10 kms^{-1} to more than 3300 kms^{-1} (Gopalswamy *et al.*, 2004). These solar phenomena are episodic expulsions of mass and magnetic field from the solar corona, which involve large scale reconfigurations of the corona and significant disturbances in the solar wind. Changes in the large scale coronal structure caused by mass ejections typically occur on timescales ranging from several minutes to several hours (Hundhausen *et al.*, 1994) and are associated with solar wind disturbances that typically reach Earth in 3–4 days.

Since its launch in 1996, the number of CMEs detected by *SOHO/LASCO* exceeds more than 12000. The median apparent angular width of CMEs observed in the *LASCO* field of view is about 50° (St. Cyr *et al.*, 2000), but the values have a broad distribution. CMEs with maximum apparent width of 360° are commonly known as Halo CMEs and are very important for space weather applications (Gopalswamy *et al.*, 2000). CMEs with apparent angular width ≥120° are taken as partial CMEs. Many CMEs originate from the disruption of a helmet streamer. When viewed near the solar limb such CMEs typically have a form characterized by a bright leading shell of material surrounding a dark cavity within which an erupted prominence is found (Hundhausen, 1993).

The CMEs are categorized using images taken by the *Solar Maximum Mission (SMM)* coronagraph based on geometric characteristics exhibited by them. These are loop/cavity/core, stack, blob, jet, tongue and fan. From *P78-1* observations CMEs are classified into loop, curved front, halo, spike, double spike, multiple spike, streamer blowout, fan and complex. Normal or Partial CMEs are likely to have the well known three part structure and can be explained as resulting from the expansion of flux tubes.

Gopalswamy (2010) summarized the kinematic properties of CMEs. The statistical properties of halo CMEs were studied and obtain the average value of speed of halo CMEs is 466 kms^{-1} (Gopalswamy *et al.*, 2010). Yashiro *et al.* (2003) investigated the properties of narrow CMEs and found that the population of normal or partial CMEs increased towards solar maximum. During solar minimum partial CMEs originate from the equatorial region, while during solar maximum partial CMEs are ejected from all latitudes like partial CMEs. They showed that the average speed of partial CMEs increases from 300 kms^{-1} during solar minimum to 550 km/ s^{-1} at solar maximum.

In this paper we analyze kinematical properties like speed and angular width of partial CMEs, Halo CMEs and Halo CMEs with SPEs and we compare the results between them.

Data

The data used is collected from *SOHO LASCO* CME catalogue at http://cdaw.gsfc.nasa.gov/CME_list. *SOHO LASCO* CME CATALOG contains list of all CMEs manually identified since 1996 from the *LASCO* on board the *SOHO* mission. Over the past 18-years the *SOHO LASCO* instrument has been detecting CMEs. The *LASCO* instrument consists of three coronagraphs C1, C2 and C3 that span the fields of view 1.1–3R_S, 2–6R_S and 4–30R_S, respectively. Both C2 and C3 are externally occulted white light coronagraphs; while C1 was designed for spectrometric purposes but has been out of operation since 1998 June.

The CMEs are classified on the basis of angular width i.e. normal or partial CMEs are having angular width ≥120° and Halo CMEs having angular width = 360°. From Jan. 1996 to Dec. 2008, more than 12000 CMEs have been observed by *SOHO/LASCO*, which have a large range of angular widths. We define a normal or partial CME as one whose measurable apparent angular width is ≥120°.

A three months data gap occurred in 1998 from 24 June to 22 October due to an unexpected loss of contact with the spacecraft. Subsequent failure of all three gyroscopes caused an interruption from 21 December 1998 to 6 February 1999. A third data gap occurred in June 2003, when *SOHO*'s main antenna became stuck. This problem was overcome and nominal observations resumed on July 10. Additionally, regular gaps of a few days through the whole mission's lifetime occur during the *SOHO* keyhole periods.

The relation between angular width and speed of normal or partial CMEs are studied during 23rd solar cycle (1996 to 2008).

Angular Width distribution

The CMEs are classified according to the angular width. CMEs with angular width≤20° are known as narrow CMES. The intermediate CMEs have the angular width in between 20° to 200°, while wide CMEs observed with angular width ≥ 200° [Y. Wang *et al.,* 1998]. The CMEs with the angular width ≥ 120° are known as partial CMEs. The CMEs with the angular width 360° are known as halo CMEs. Halo CMEs appear to surround the occulting disk in the sky plane projection.

Note that halo CMEs, with an apparent angular width of or close to 360°, are simply due to that the CMEs, probably with an angular width of tens of degrees, propagate near the Sun-Earth line, either toward or away from the Earth. Many CMEs show an increase in angular width as they move out, so measurements are made when the angular width appears to approach a constant value. Halo CMEs constitute only ~3% of all CMEs. Halo CMEs are very important, as these are the earth directed and geoeffective i.e. causes for the large solar proton events and geomagnetic storms.

The histograms of the number of partial CMEs against angular width of CMEs observed during the year 1996 to 2008 are illustrated in figure 1. During the solar minimum of 23rd solar cycle 1996-2001, the number of CMEs are maximum in the year 1996 - 1997 at angular width ~ 180° and minimum at ~ 260° and ~ 300°, during 1998–1999 the number of CMEs are maximum at an angular width between 130° to140° and minimum at ~ 320° and ~ 270°, during 2000 and 2001 the number of CMEs are maximum at an angular width between 130° to 140° and minimum at ~ 300°. During solar maximum 2002-2004 in the year 2002 - 2004 the number of CMEs are maximum at an angular width of between 130° to 140°and minimum at ~ 300°. In the final phase 2005-2008 solar minimum, the number of CMEs maximum at angular width between 130° to 140°and minimum at ~ 280°, ~ 300°, ~ 360°.

Speed distribution

Mass motion is a basic characteristic of CMEs and quantified by their speeds. Coronagraphs obtain images with a preset time cadence and when a CME occurs, the leading edge moves to a greater heliocentric distance. On measuring the heliocentric distance of the leading edge of a CME in each LASCO image, one obtains CME height as a function of time. Height-time measurements are made in the sky plane, so all of the derived parameters such as speed etc. are the lower limits to the actual values (Gopalswamy *et al.,* 2006]. The height-time plots are then fitted to first order polynomials which give an average speed within the LASCO field of view. The CME velocity general means the radial propagation speed of the top part of a CME frontal loop.

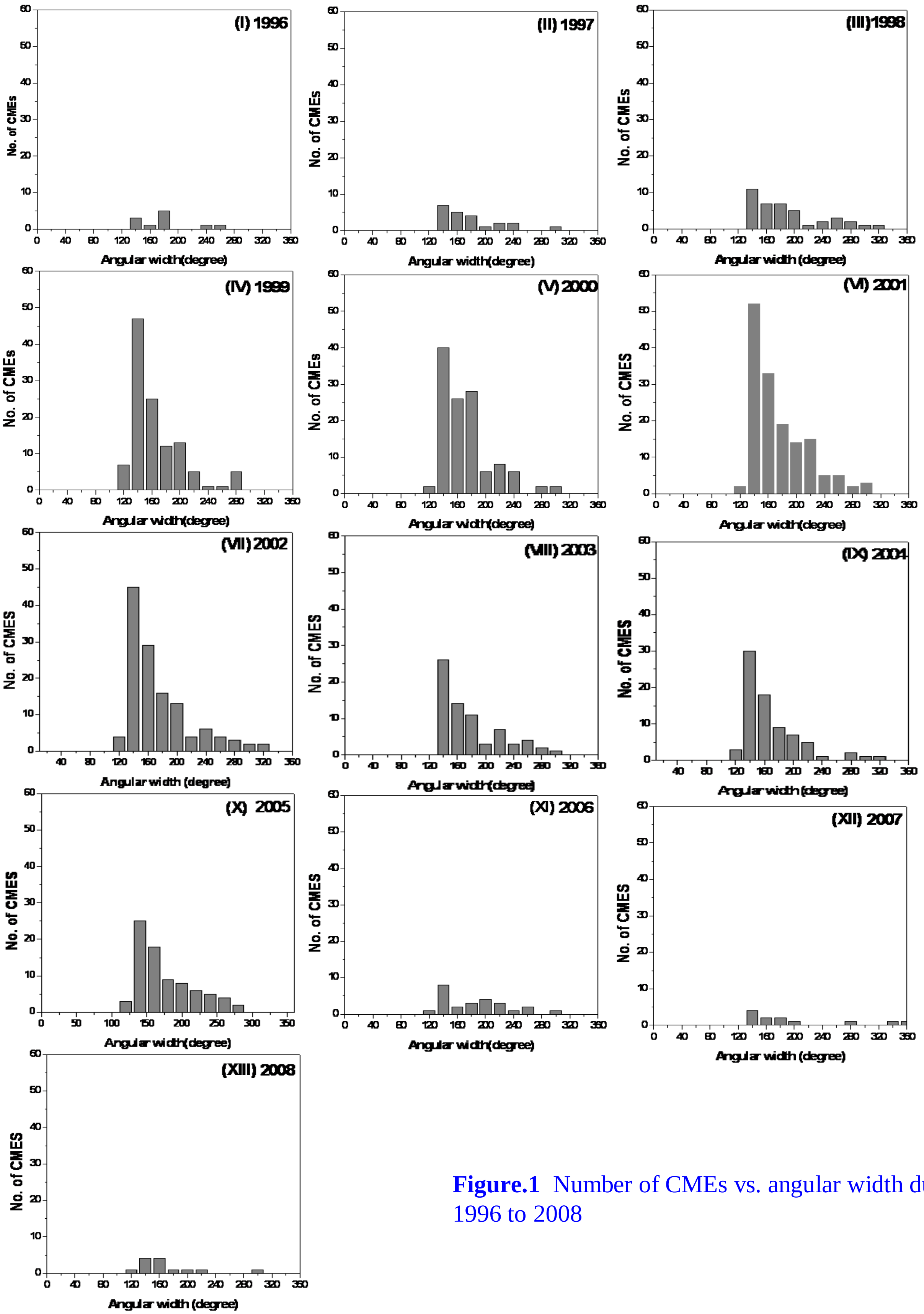

Figure.1 Number of CMEs vs. angular width during 1996 to 2008

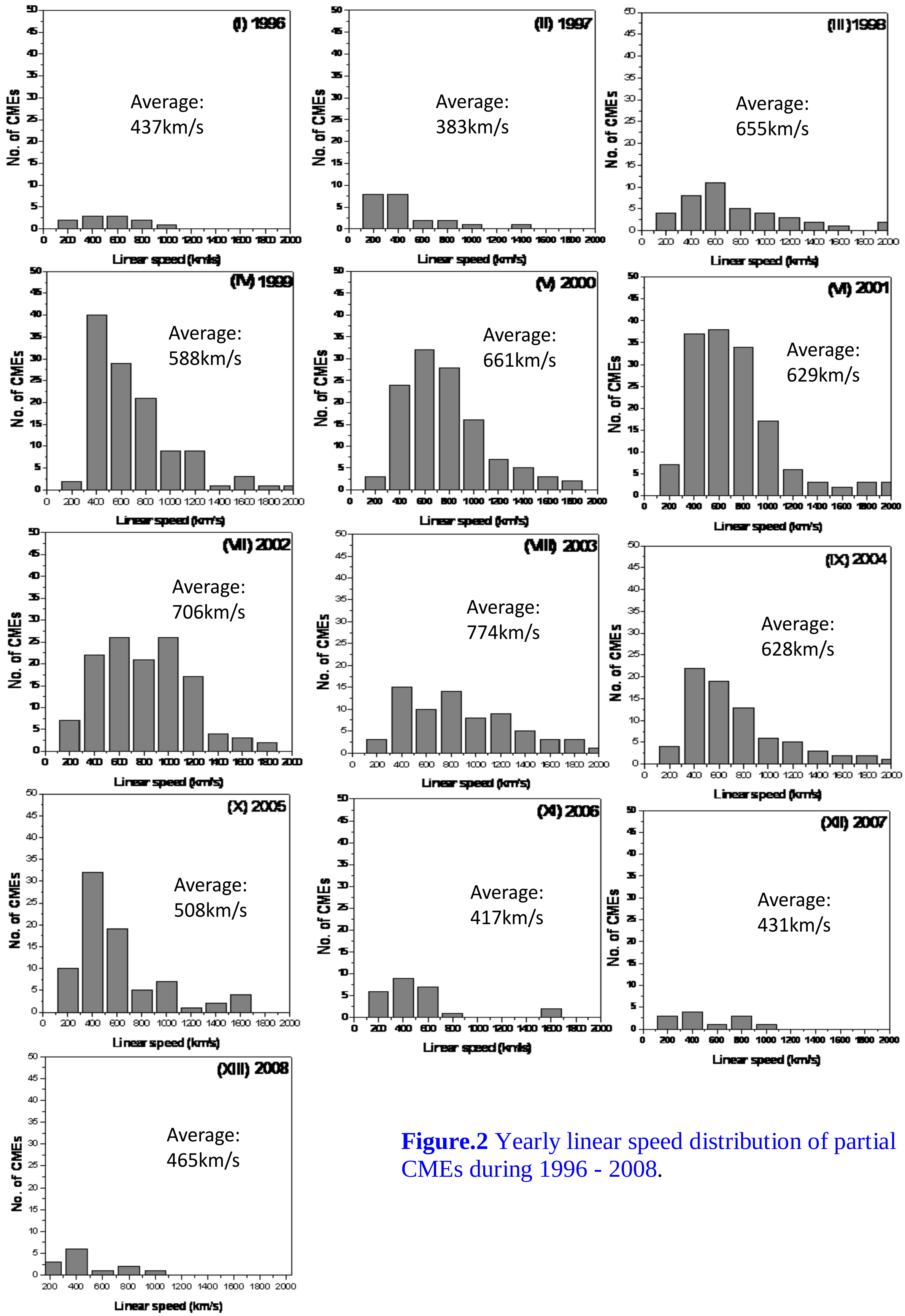

Figure.2 Yearly linear speed distribution of partial CMEs during 1996 - 2008.

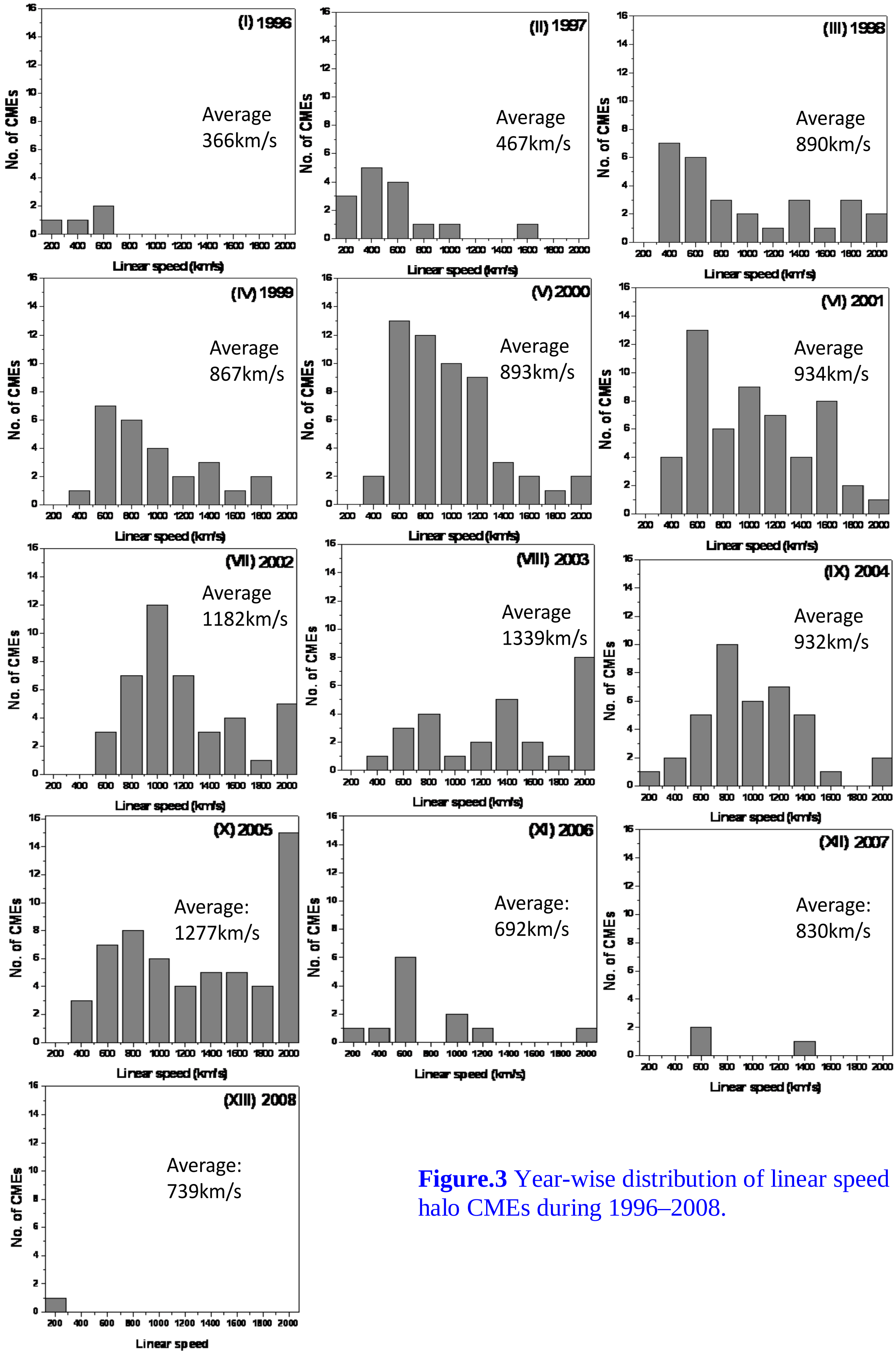

Figure.3 Year-wise distribution of linear speed of halo CMEs during 1996–2008.

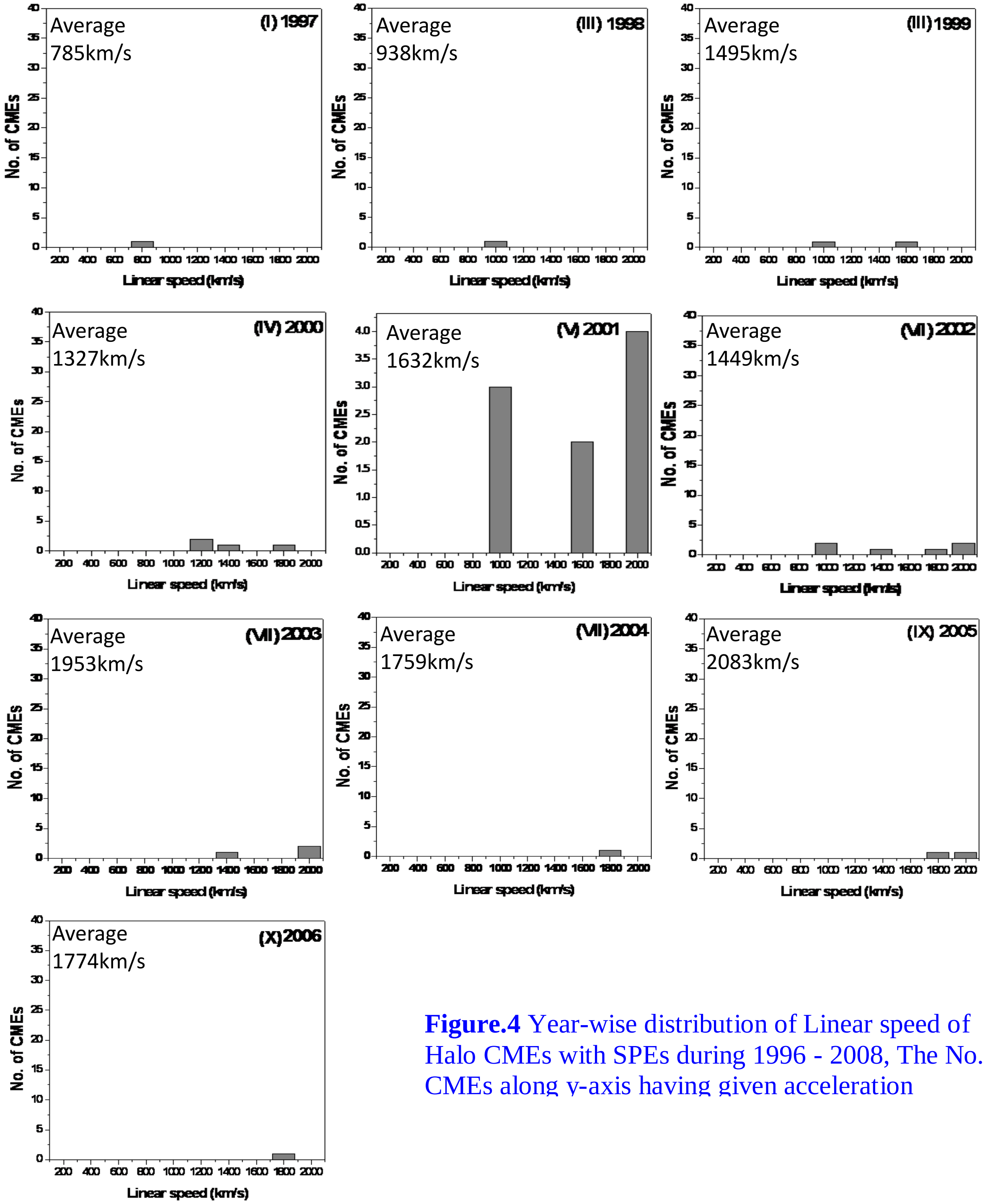

Figure.4 Year-wise distribution of Linear speed of Halo CMEs with SPEs during 1996 - 2008, The No. of CMEs along y-axis having given acceleration

However, it should be noted that this velocity measures the motion of the CME frontal loop projected in the plane of the sky, therefore, it can be called projected velocity. There are continuous attempts trying to correct the propagation velocity for the projection effects. The CME projected velocity ranges from ~ 20 km s^{-1} to > 2000 km s^{-1}, occasionally reaching 3500 km s^{-1}. The averaged velocity increases from 300 km s^{-1} near solar minimum to 500 km s^{-1} near solar maximum. Second, all the plasmas within the CME cavity are also moving outward, not just the material along the frontal loop, as implied by spectral observations in the dimming region under the CME (Harra *et al.*, 2001). The speed is close to the actual speeds only for CMEs propagating in the sky plane. CMEs ejected at an angle to the sky plane are subject to projection effects, the CME speed varies over two orders of magnitude from 57 km s^{-1} to more than 3387km s^{-1}, with an average value of 730 km s^{-1}. Figure 2, 3 and 4 shows year wise speed distribution of partial CMEs from 1996 to 2008. The last bin in each plot consists of all CMEs with speed >2000km s^{-1}, along y- axis gives the number of CMEs. Figure 2 illustrates the variation linear speed distribution of partial CMEs observed during 23rd solar cycle.

Conclusion

The properties of CMEs in which width and speed, In this the study of 1119 partial CMEs (having widths > =120°), 444 of Halo CMEs (having widths = 360°) and 30 of Halo CMEs with solar proton flux (having widths = 360°) observed during the period 1996 – 2008 and come to conclude that the majority of the partial CMEs have widths in between 120°and 359°. The corresponding widths for Halo and Halo with solar proton flux CMEs lie in the range 360°. Most of the partial CMEs have speeds in the range of 200–800 kms^{-1}. The corresponding speeds for Halo CMEs lie in the range of 200–600 kms^{-1}.

The maximum speed of Halo CMEs (3387 kms^{-1}) are much greater than that of and Halo with solar proton event CMEs (2684 kms^{-1}) and partial CME (2505 kms^{-1}).

Acknowledgments

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