Statistical Behavior and Solar Cycle Variation of Coronal Mass Ejections

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- CME Rate
- Solar Cycle Variations

Difficulty to determine the CME rate



CME Quality Index

5. Excellent

- 4. Good
- 3. Typical
- 2. Fair
- 1. Poor
- 0. Unable to measure

• Fractions of extremely poor CMEs have increased from 2004.

CME Identification Procedure

Yashiro et al. 2004 stated "LASCO operators maintain a log, which contains notes (CME direction, flare association, data gap, and so on) on most of the CMEs observed daily. We use this log (available at http://lascowww.nrl.navy.mil/cmelist.html) as a guide for our measurements. We also run movies of LASCO images and identify **any missing CMEs**."

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Team and Operations Resources LASCO(C1 at MPAe (Germany) LASCO at LAS (France) LASCO Handbook Technical Notes Detailed Documentation Acronyms	Hello CMEs In 2002 (Jp) Hello CMEs In 2003 (Jp) Hello CMEs In 2003 (Jp) Hello CMEs In 2004 (Jp) Hello CMEs In 2005 (Jp) Hello CMEs In 2005 (Jp) Hello CMEs In 2007 (Jp)										
Related Units Solvin Uneges and CNEs SOHO Morre page SOHO and SOHO Indruments Other Solar Satellites and Observatories	PRELIMINARY LISTS A preliminary list of events has been general divided by year. These lists are provided for: Over the course of the mission, the research • Dr Chris St.Cyr Mission start (Dec 1 • Dr Simon Plunket October 1998 our • Or Garett Lewrence Bunary 1, 20 • Dr Guillerno Stenborg January 1, 20 Preliminary CME list for 1/1999 - 12/1999 Preliminary CME list for 1/1999 - 12/2091 Preliminary CME list for 1/1990 - 12/2001 Preliminary CME list for 1/1990 - 12/2001 Preliminary CME list for 1/1900 - 12/2001 Preliminary CME list for 1/2001 - 12/2001 Preliminary CME list for 1/2005 - 102/001	ad with the LASCO deta. This is not necessarily complete, but should o researchers with complementary data who wish to collaborate with me scientists have maintained the CME lists. They are listed below: 995) thru October 1996 til January 2001 til Anuary 2001 Junuary 2005 Old thru the present	ntain	e all of th	f the t	ligges CO te	st eve	ents. 1	The li	st is	
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In 2004, the LASCO operator changed to G. Stenborg. He identified extremely faint and narrow CMEs, which were not listed as previously.

Difficulty to determine the CME rate



CME Quality Index

5. Excellent
4. Good
3. Typical
2. Fair
1. Poor
0.5 Extremely Poor
0. Unable to measure

• Extremely poor CMEs should be excluded for proper comparison.

CME Rate



The average sunspot number has declined by ~40% but CME occurrence rate did not drop in cycle 24 unlike SSN.

Possible Bias: LASCO Cadence 3 frames/hour → 5 frames/hour



12 minutes cadence

24 minutes cadence

Automated CME Detection



• The CME Rate in SC24 is comparable to or higher than that in SC23.

Nobeyama Radio Heliograph (NoRH)

Since April 2015, NoRH has been operated by International Consortium for Continued Operation of Nobeyama Radioheliograph (ICCON=一献; a cup of sake)



- Disadvantage
 - Low Spatial Resolution (~10")
 - 16 hrs data gap because of the ground observation
- Advantage
 - High time resolution (1 sec 0.1 sec)
 - Constant Data Quality for 23 years

A Prominence Eruption



Limb events (prominence activities) are automatically detected (Shimojo+ 2006, PASJ). http://hinode.stelab.nagoya-u.ac.jp/ICCON/

Prominence Eruption Rate



• NoRH PE Rate is comparable.

Magnetic Cloud



Gopalswamy+ 2015, JGR

Flare Rate



The flare occurrence rate dropped in cycle 24 like SSN.

Flare and Fast CME Rate



The number of fast CMEs dropped in cycle 24.

Flare Intensity Distributions



CME Speed Distributions



 On average, the CMEs in the 23 maximum are slower than those in the 24 maximum.

Annual Averaged CME Speed



CME Width Distributions



• The CMEs in SC24 are wider.

Cycle Variation: CME Width



Gopalswamy+ 2014, GRL

CME and Flare Latitudes



• Compared to the flare latitudes, the CME latitudes are more widely distributed.

CME Mass Measurement

Mass measurement assumes that the CME material is in the sky-plane (Vourlidas et al. 2000).

Mass measurement is accurate for limb events.

- Previously we did not provide the mass of partial and full halos.
 - But we know there are limb halo CMEs.

CME Mass Distributions



• The median mass of the SC24 max is approximately half of the SC23 max.

CME Kinetic Energy Distributions



• The median K.E in SC24 decreased 76%.

CME Kinetic Energy: Cycle Variation



CME Source Regions

- CMEs originate from sunspot (active regions; ARs) and non-sunspot regions (quiet regions; QRs).
- What fractions of the CMEs do originate from QRs?
- Starting Point: Wide CMEs (W≥60°) observed by SOHO/LASCO.
- We use STEREO/COR1 to exclude backside CMEs.
- We use SDO/AIA, Ha, and Hinode/XRT to identify the surface signatures of the CME, e.g. flares, filament eruptions, and dimmings.
- We analyzed 233 CMEs occurred in 2011.

CME Source Regions

Active Regions	Quiet Regions	No Surface Signature Identified (Stealth CMEs)
55%	41%	4%

- Significant fractions of the CMEs originates from the QRs.
- We could not identify the surface signature of the 10 (4%) CMEs.

CME Speed Distribution

- The speed distributions are highly overlapped.
- On average, the AR CMEs are faster than QR CMEs.
- Fast and wide CMEs (V≥900 km/s; W≥60°) originate from active regions only.



CME-associated Flares

- Approximately 60% of the wide CMEs are associated with B-class or below.
 - Many of them are associated with filament eruptions.
 - Note: Backside and limb event (Lon>85°) are excluded to avoid the possible X-ray occultation.
- Only 17% of the wide CMEs are associated with M- and X-class flares.

- Approximately 30% of the fast and wide CMEs are associated with Cclass flares.
- For space weather purpose, we need to keep watch the C-class flares also.



Summary

- The CME occurrence rate did not drop in cycle 24 unlike SSN.
 - Significant number of the CMEs originate from QRs.
- On average, the CMEs in cycle 24 are less energetic because of the decrease of the CMEs from ARs.
- On average, the CMEs in cycle 24 are wider because of the decrease of ambient pressure.

	SC23 Max	SC24 Max
Speed	503 km/s	411 km/s
Width	89°	97°
Mass	1.0x10 ¹⁵ g	4.8x10 ¹⁴ g
Kinetic Energy	9.0x10 ²⁹ erg	2.2x10 ²⁹ erg