# Statistical Behavior and Solar Cycle Variation of Coronal Mass Ejections

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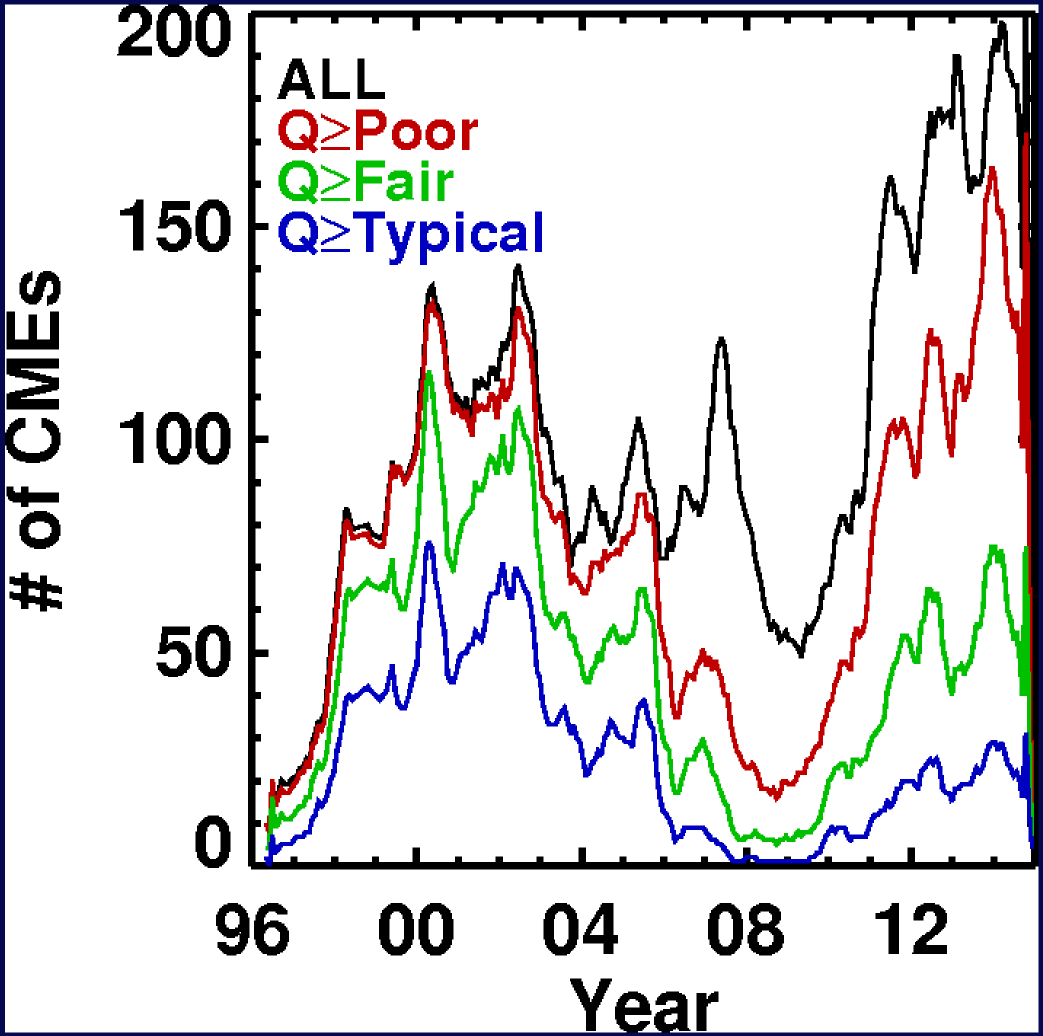
- CME Rate
- Solar Cycle Variations

# Difficulty to determine the CME rate



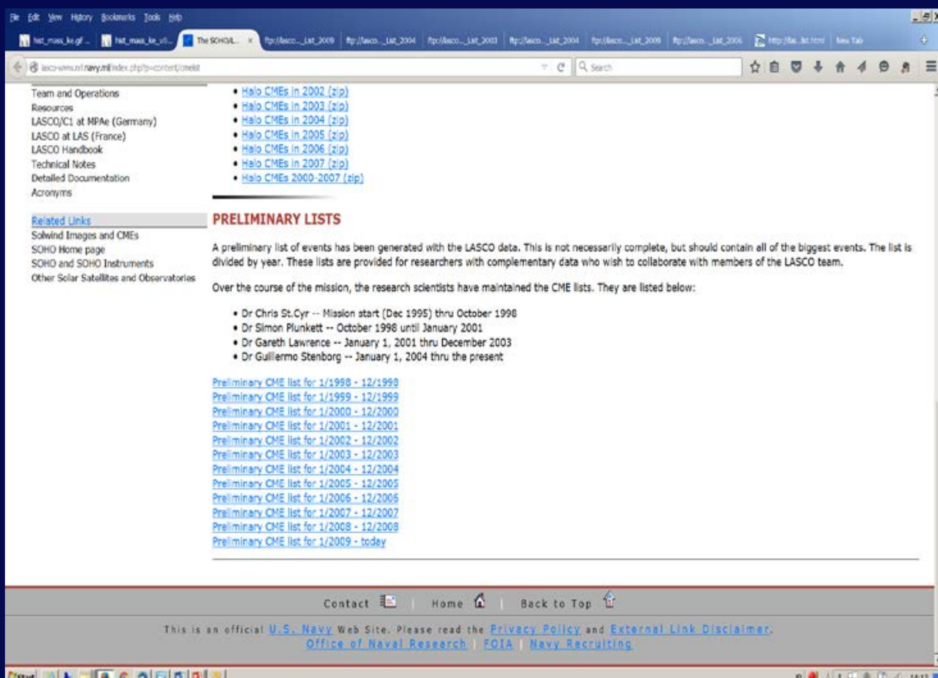

CME Quality Index

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

- Fractions of extremely poor CMEs have increased from 2004.

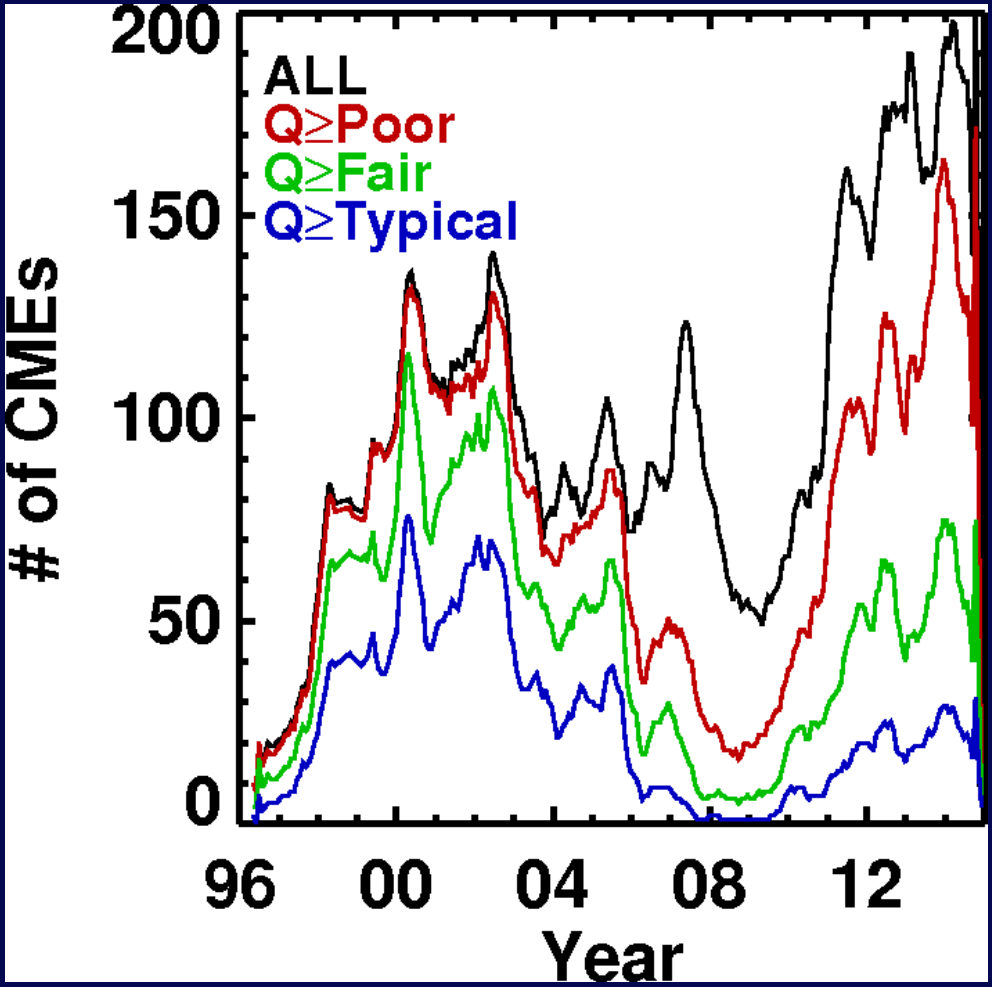
# CME Identification Procedure

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://lasco-www.nrl.navy.mil/cmelist.html) as a guide for our measurements. We also run movies of LASCO images and identify **any missing CMEs**."




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

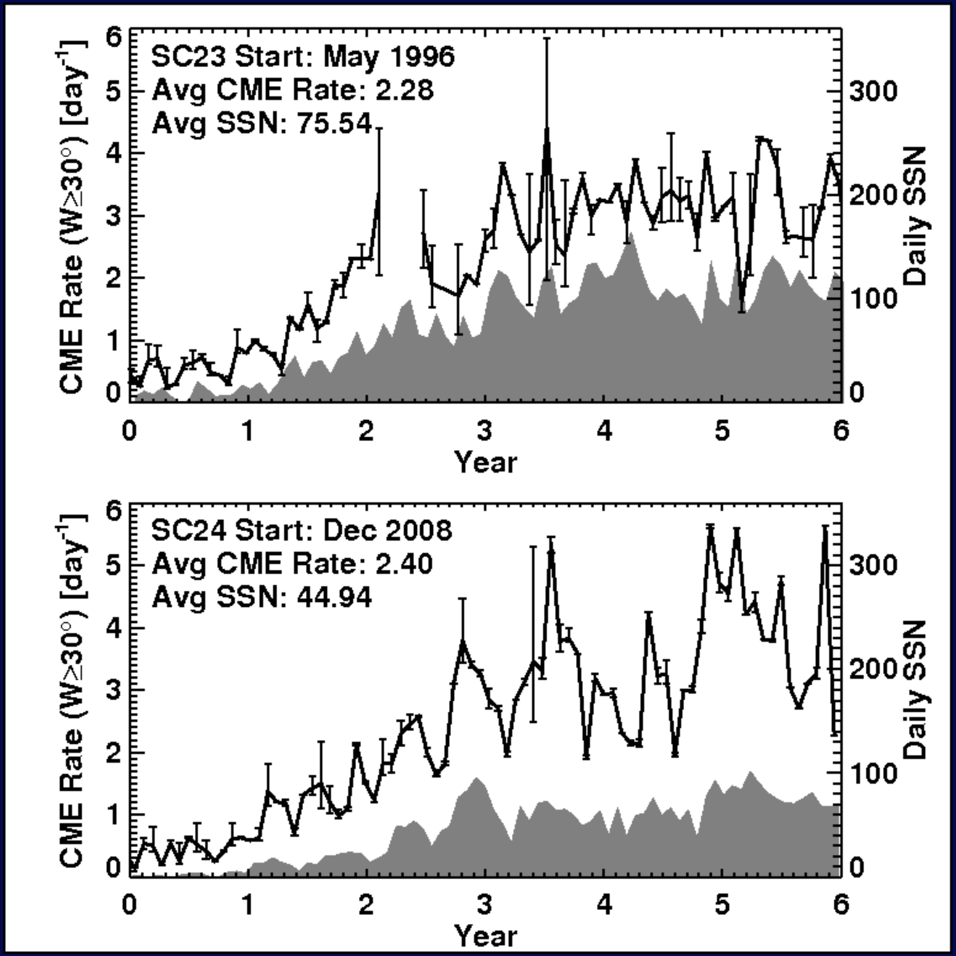
5. Excellent
4. Good
3. Typical
2. Fair
1. Poor

0.5 Extremely Poor

0. Unable to measure

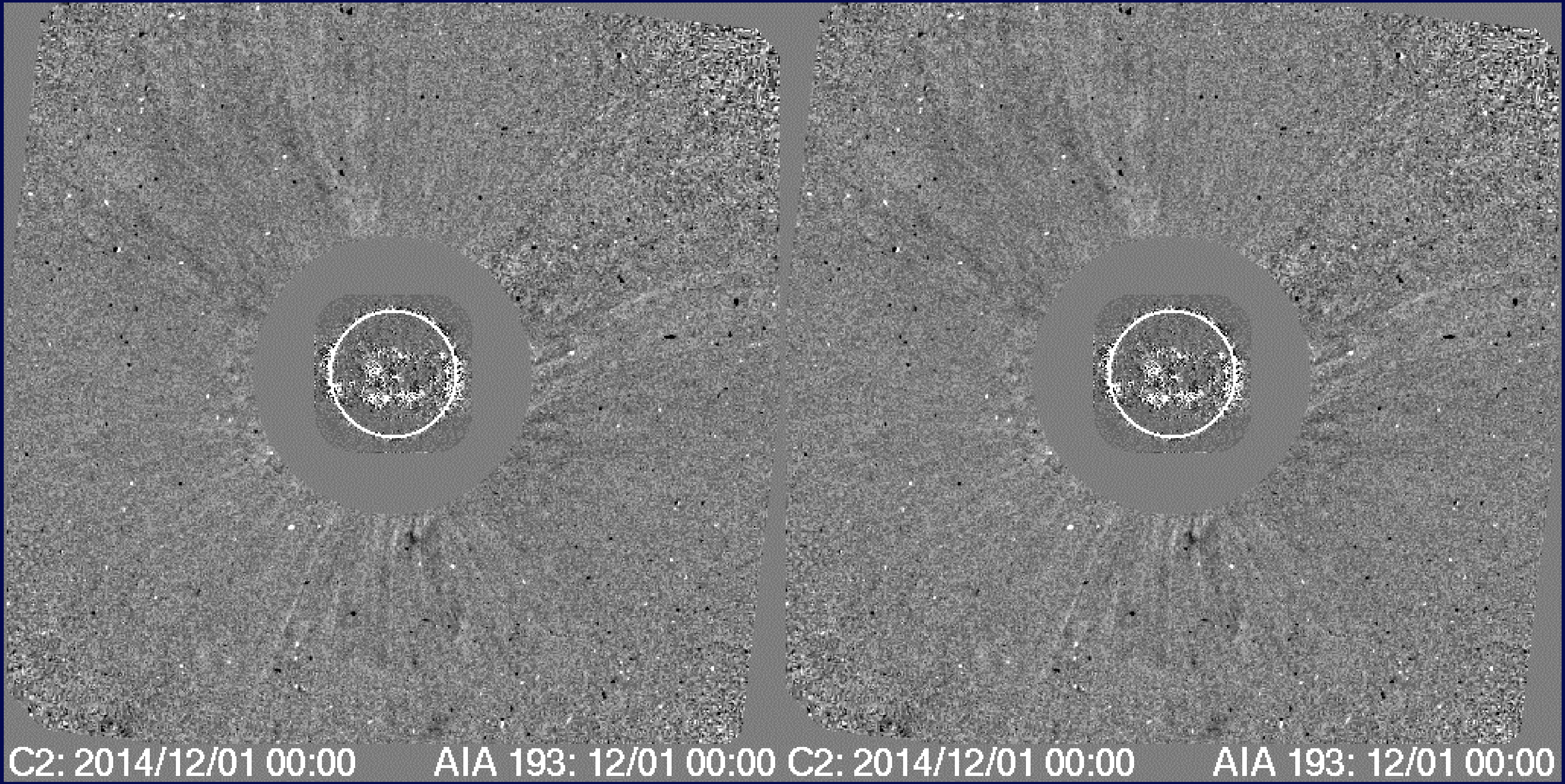
- Extremely poor CMEs should be excluded for proper comparison.

# CME Rate




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

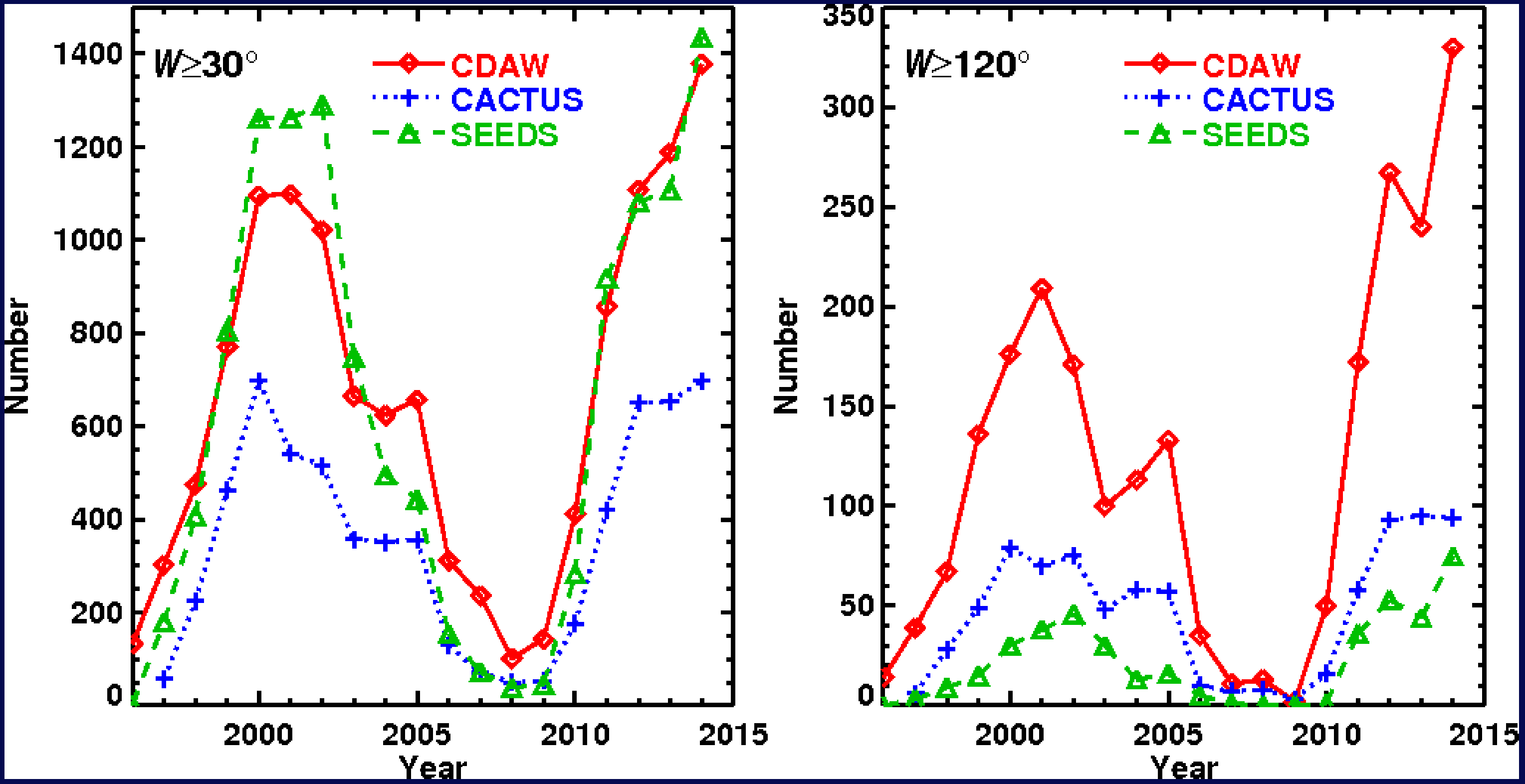
# Possible Bias: LASCO Cadence
# 3 frames/hour → 5 frames/hour




12 minutes cadence

24 minutes cadence

# Automated CME Detection



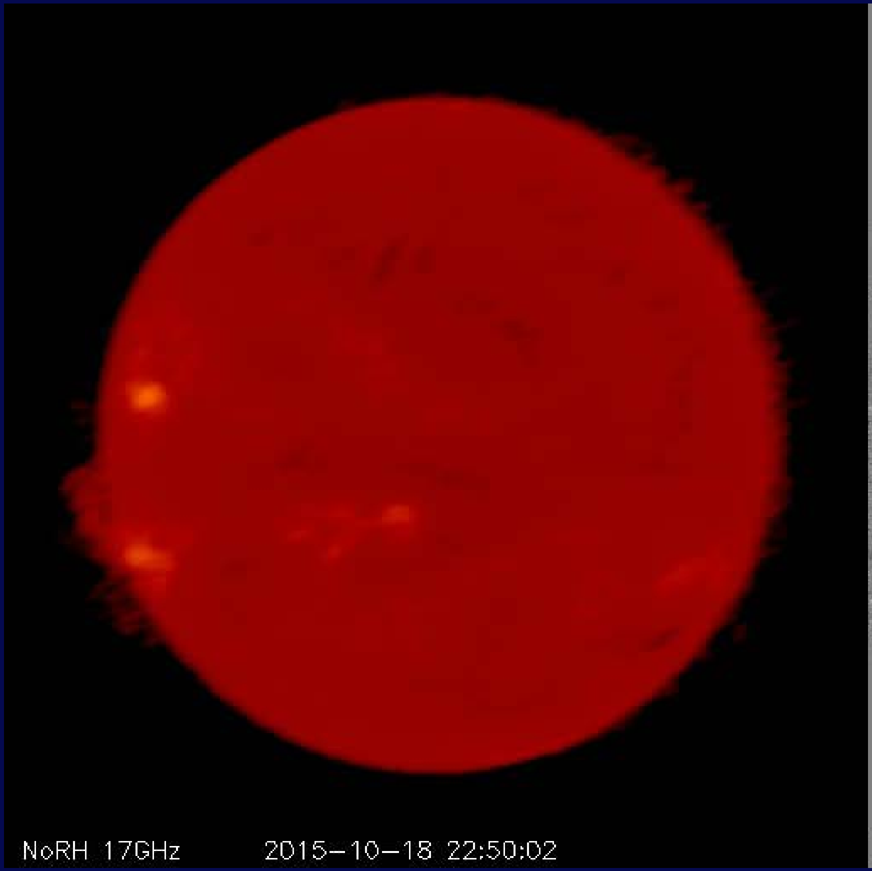

- The CME Rate in SC24 is comparable to or higher than that in SC23.

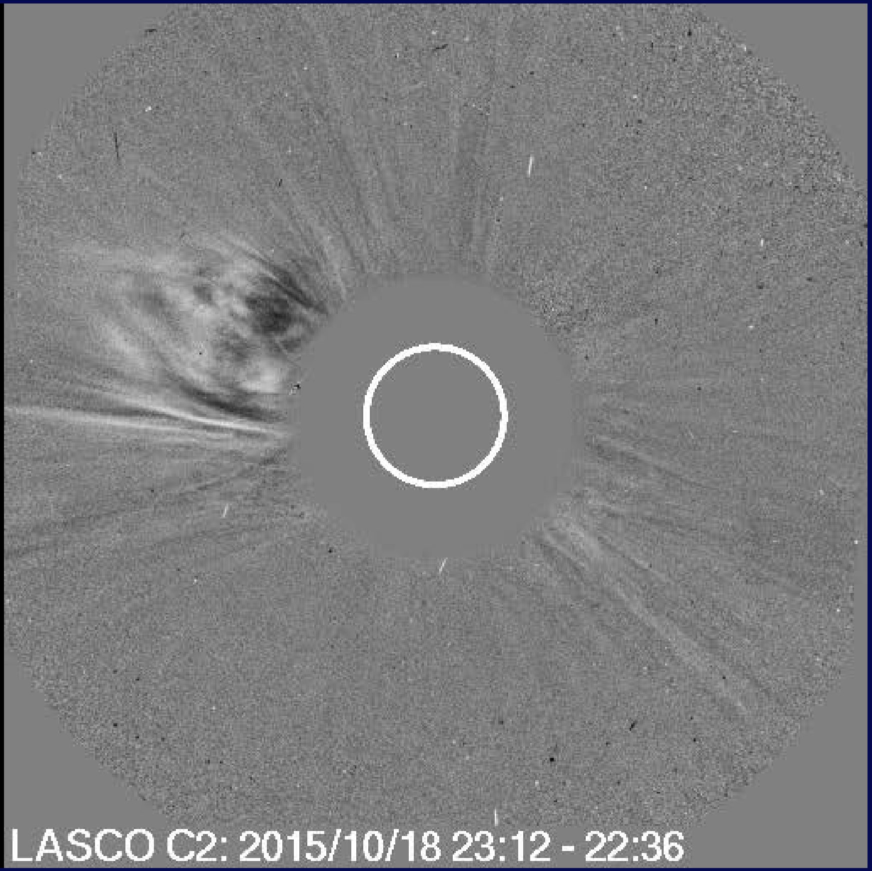
# Nobeyama Radio Heliograph (NoRH)

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

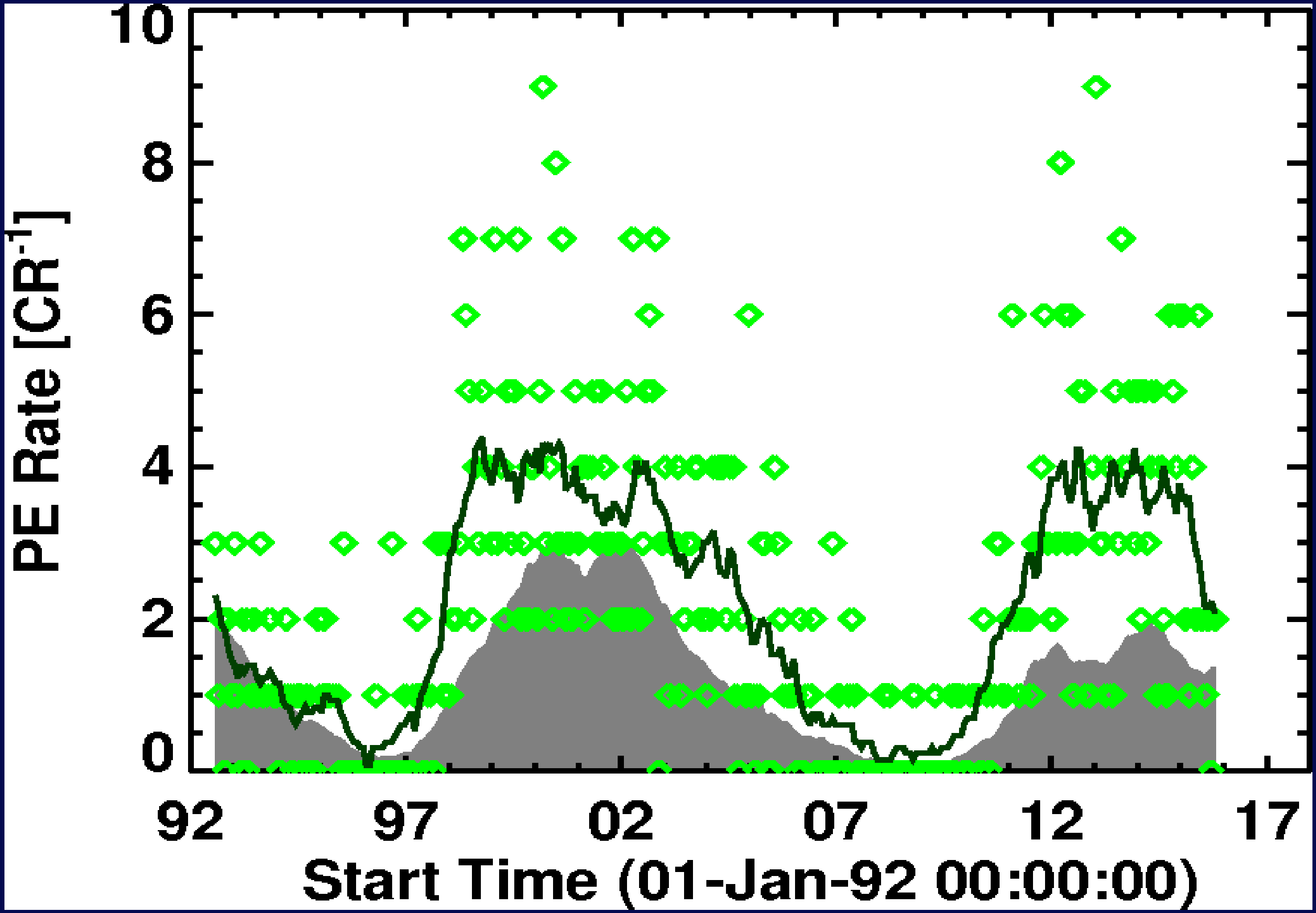
# A Prominence Eruption



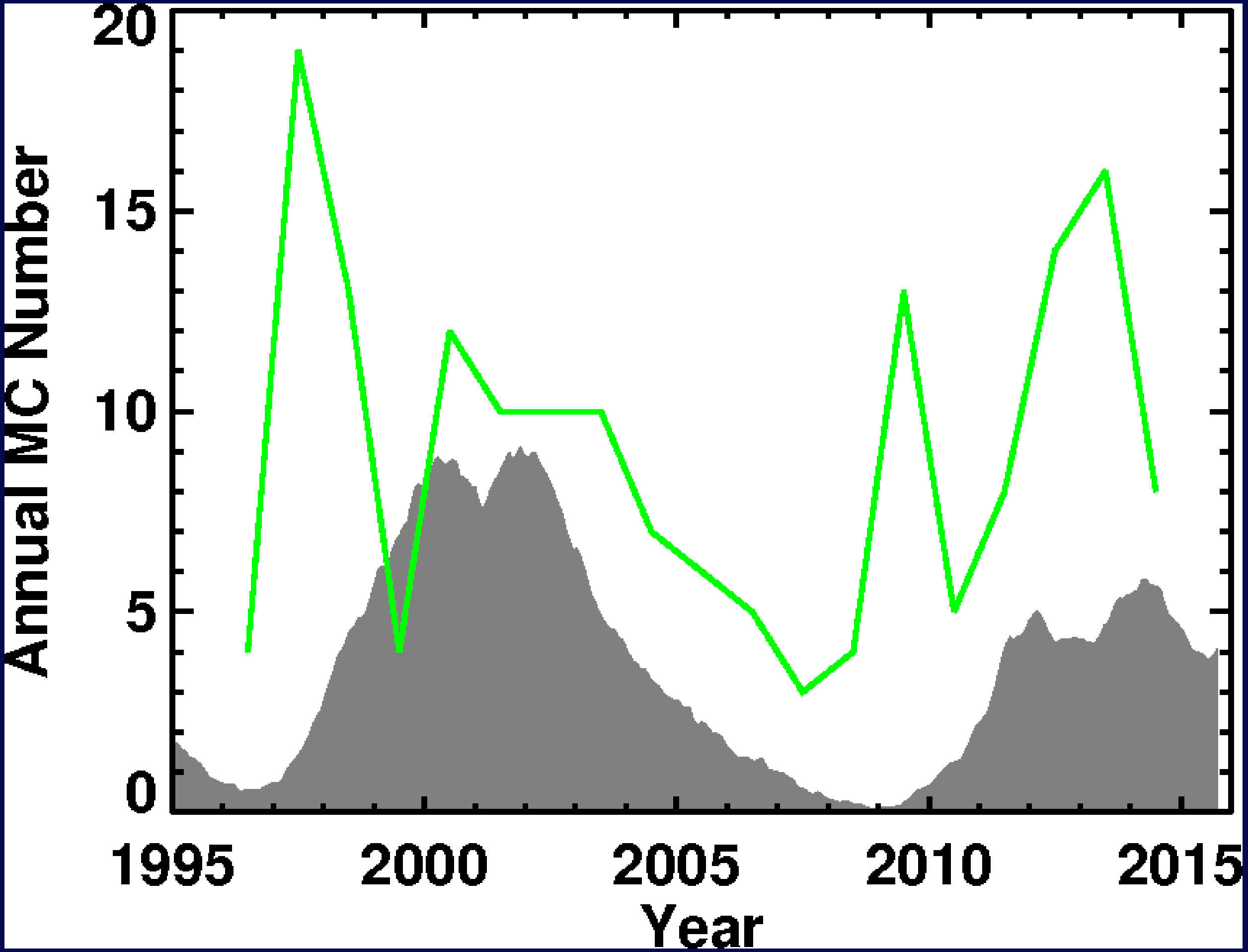

Limb events (prominence activities) are automatically detected (Shimojo+ 2006, PASJ).
http://hinode.stelab.nagoya-u.ac.jp/ICCON/

# Prominence Eruption Rate



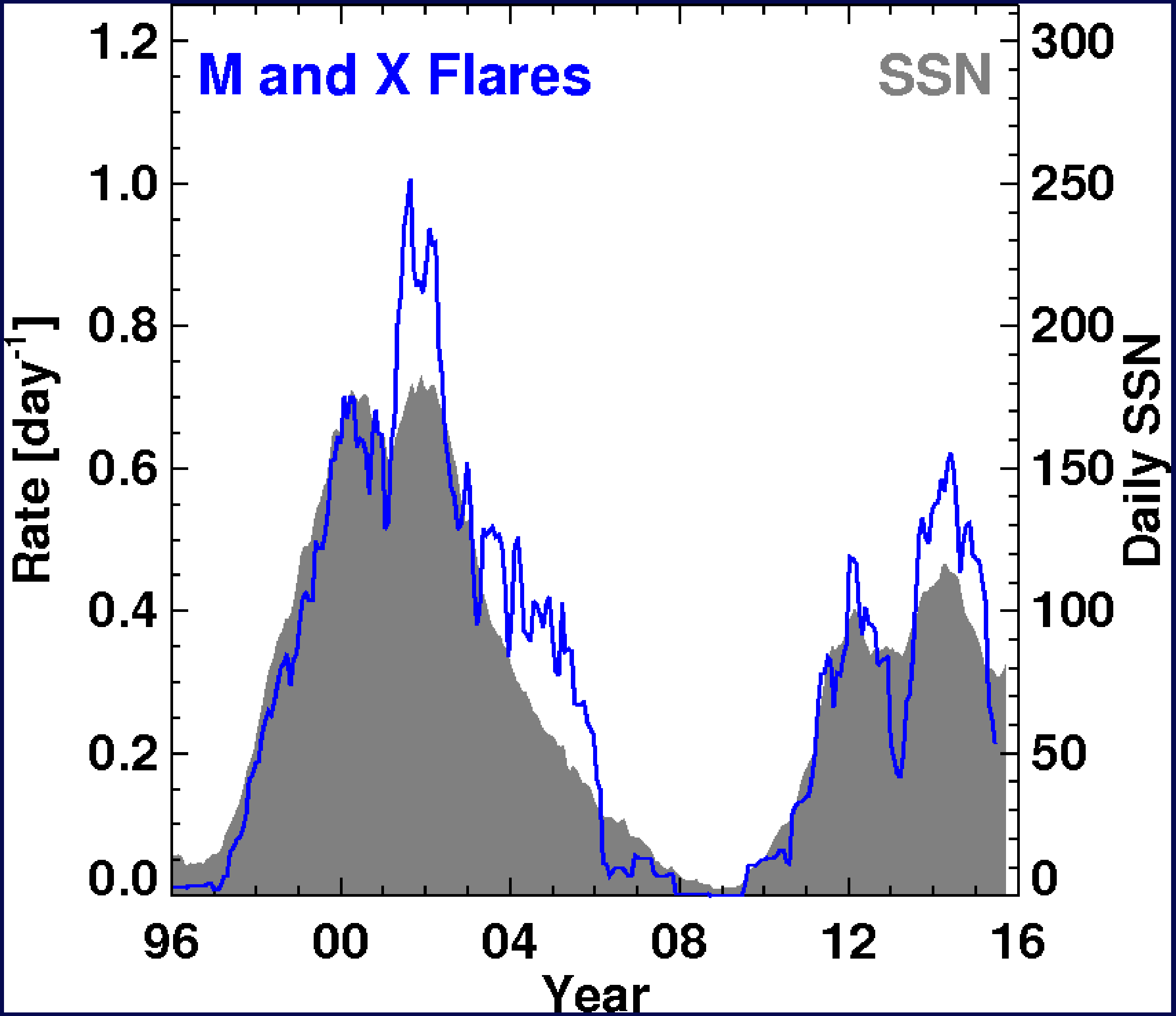

- NoRH PE Rate is comparable.

# Magnetic Cloud



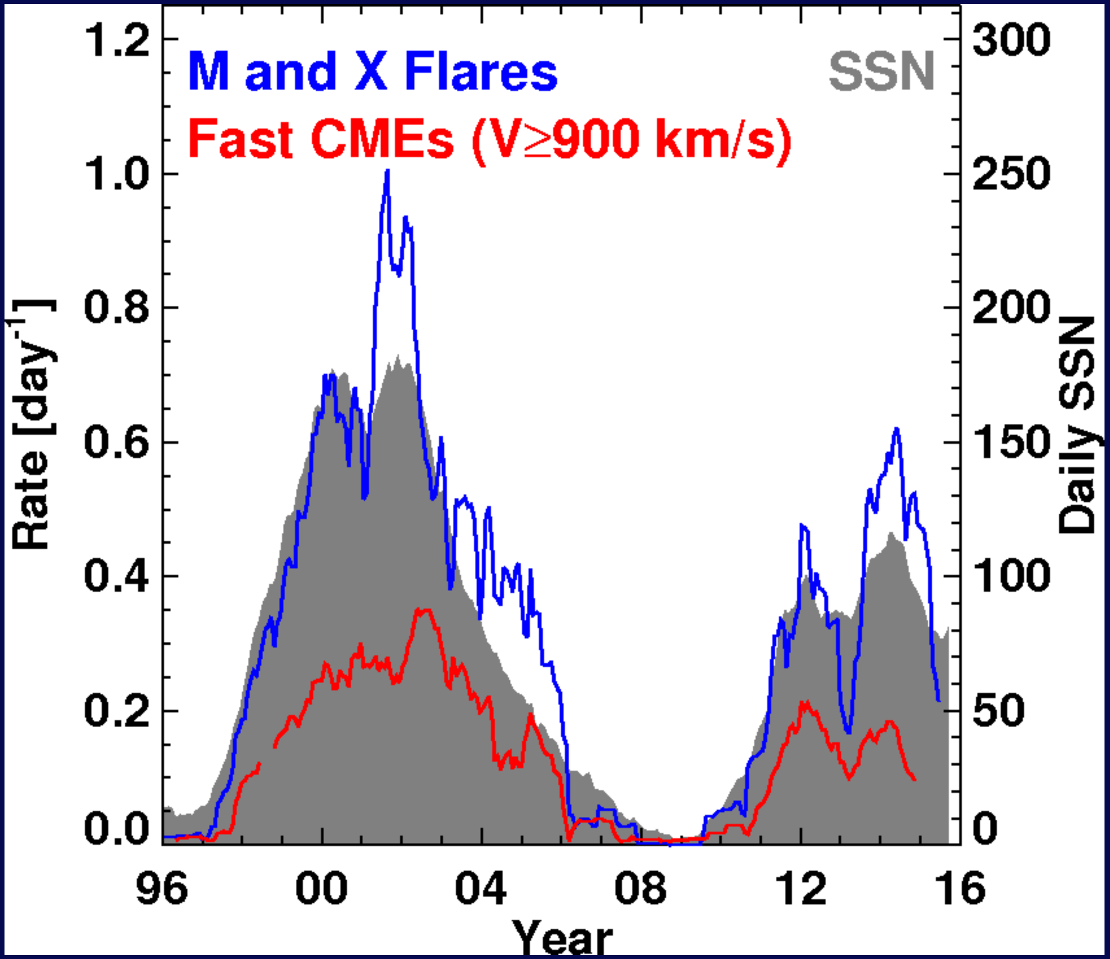

Gopalswamy+ 2015, JGR

# Flare Rate



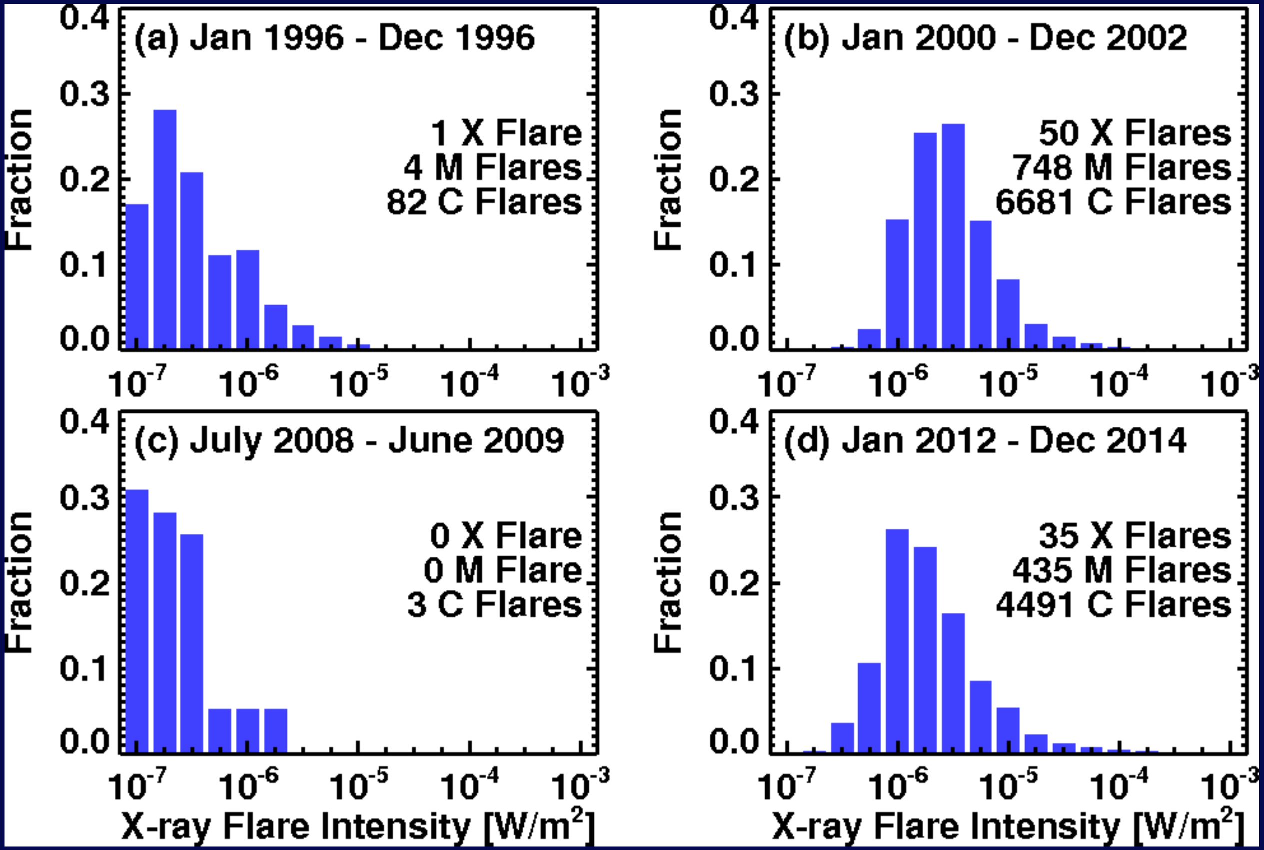

The flare occurrence rate dropped in cycle 24 like SSN.

# Flare and Fast CME Rate

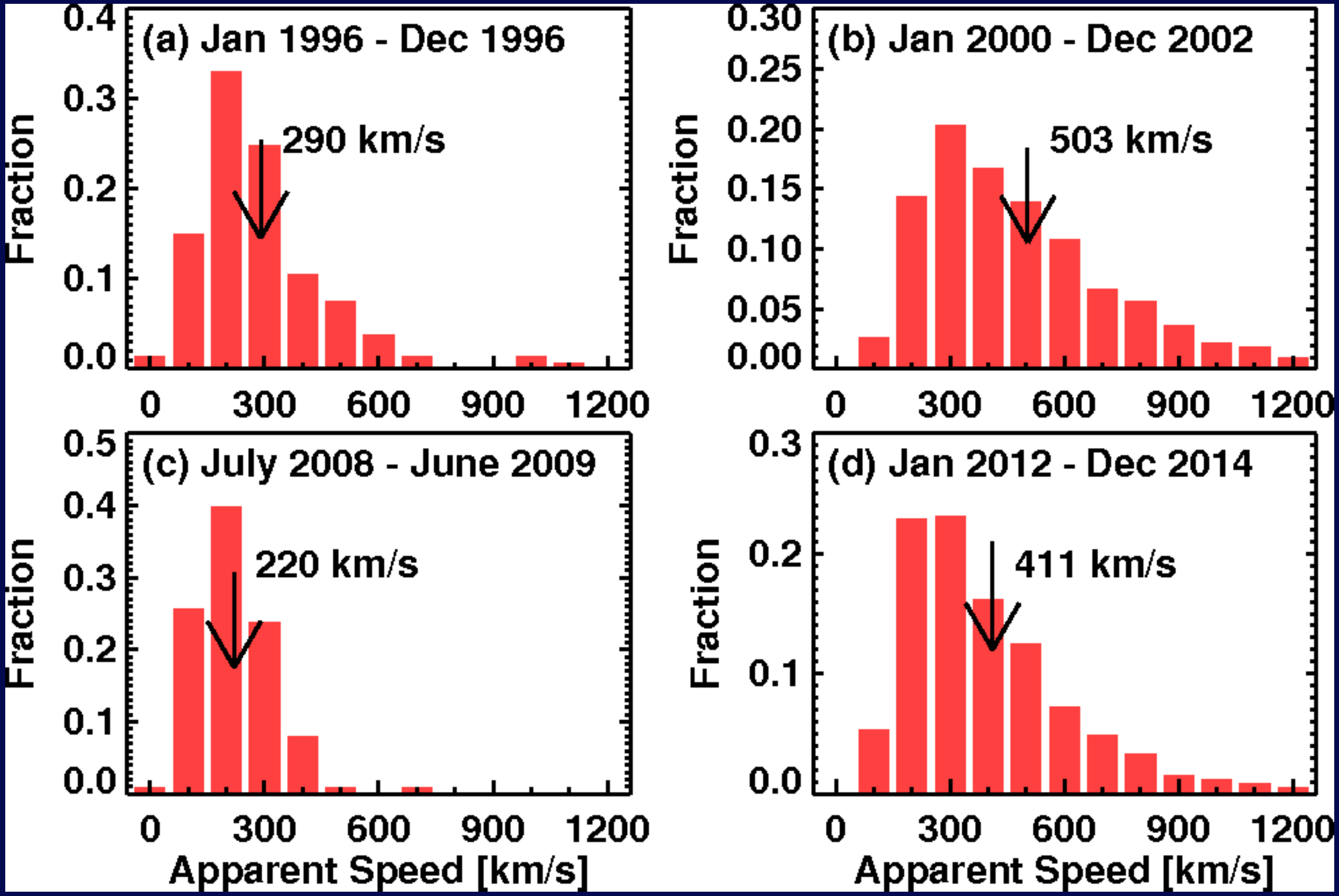



The number of fast CMEs dropped in cycle 24.

# Flare Intensity Distributions

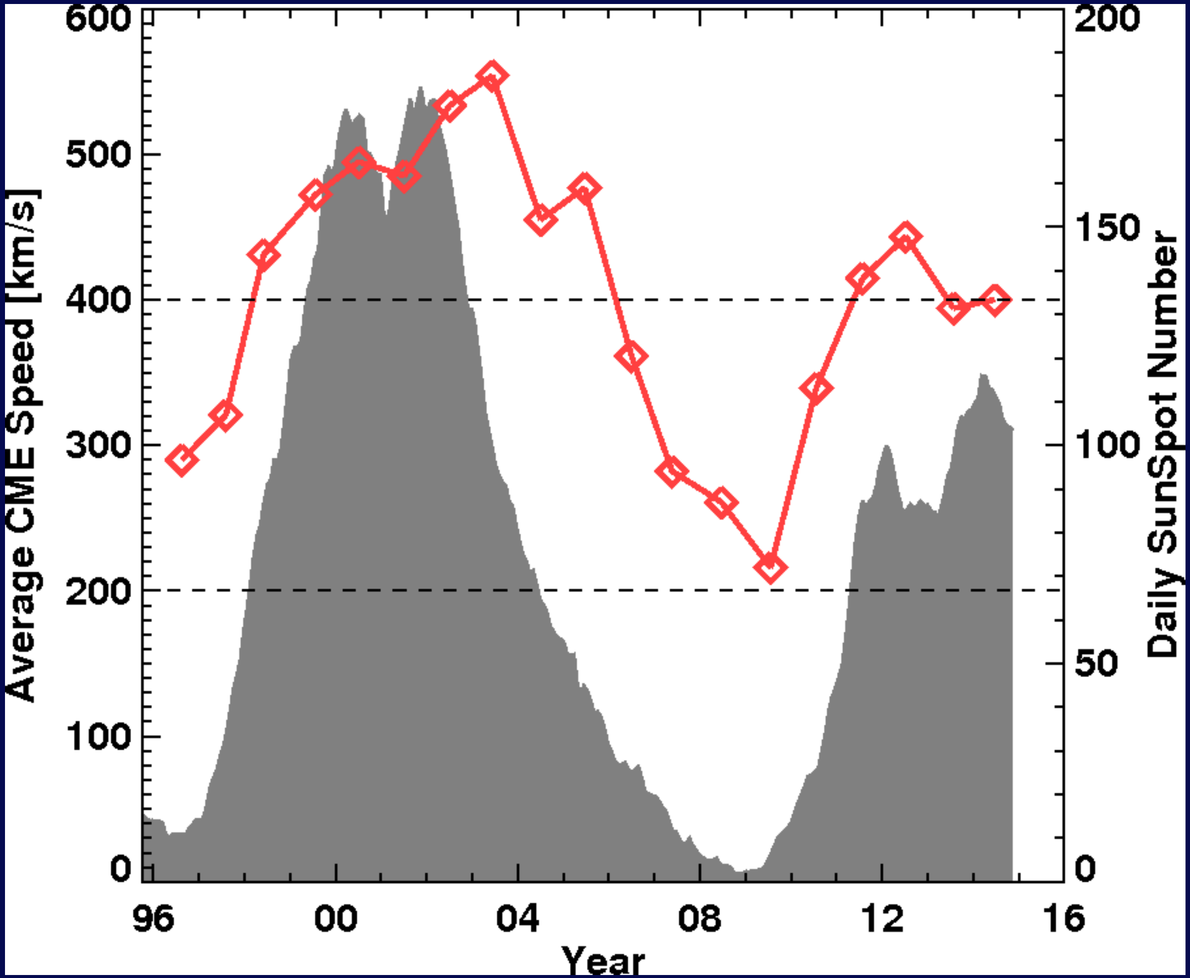


# CME Speed Distributions

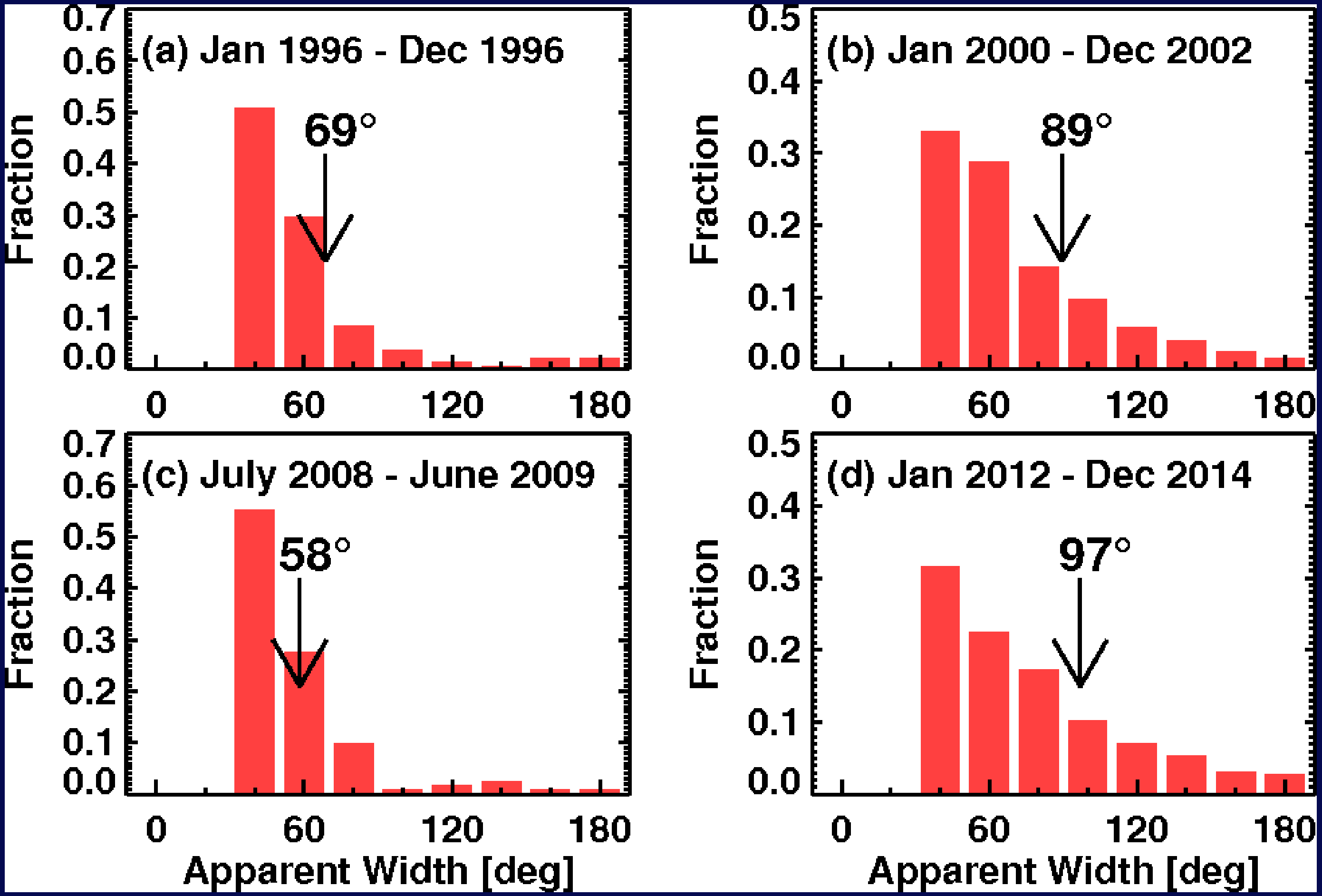



- On average, the CMEs in the 23 maximum are slower than those in the 24 maximum.

# Annual Averaged CME Speed

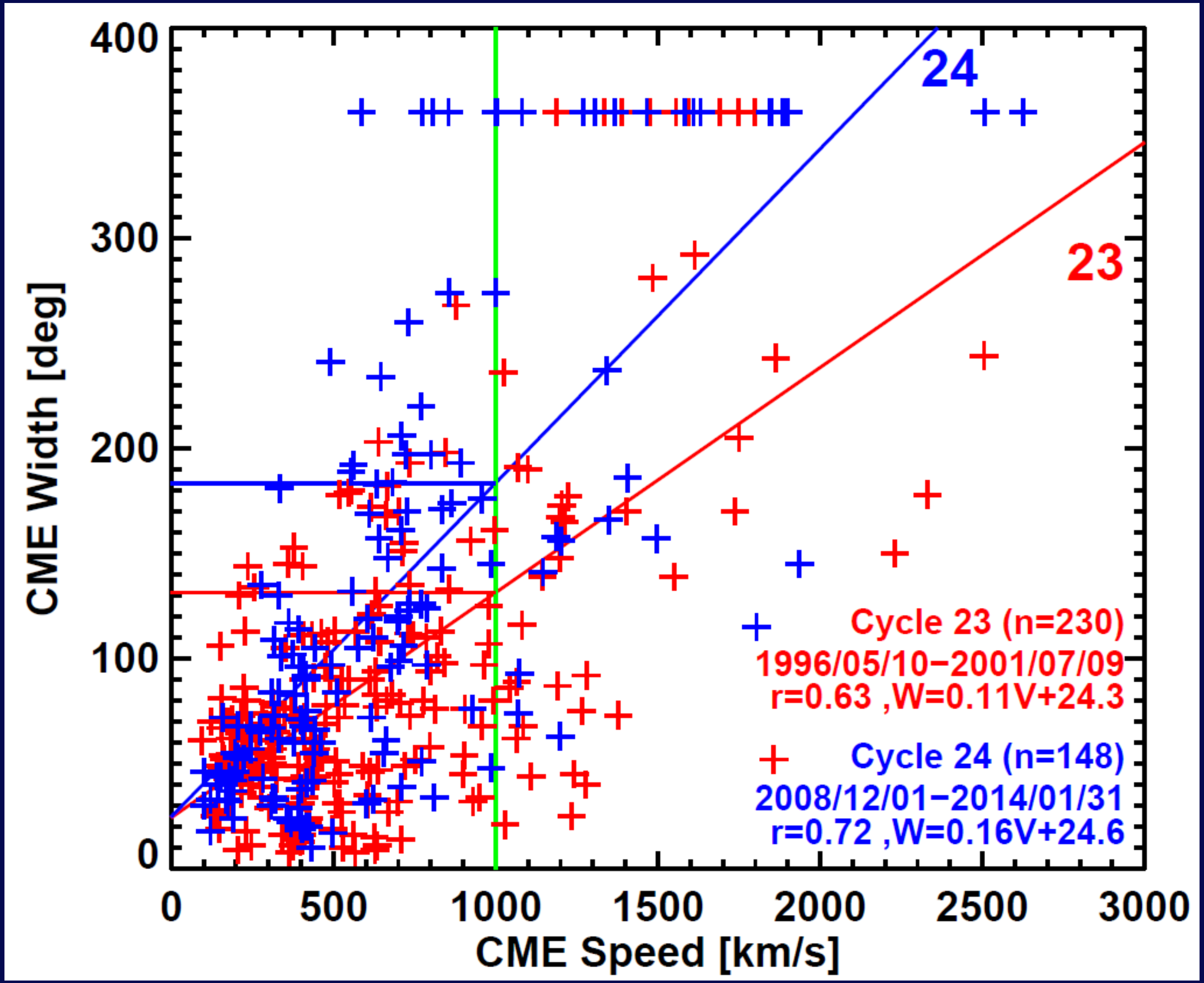


# CME Width Distributions



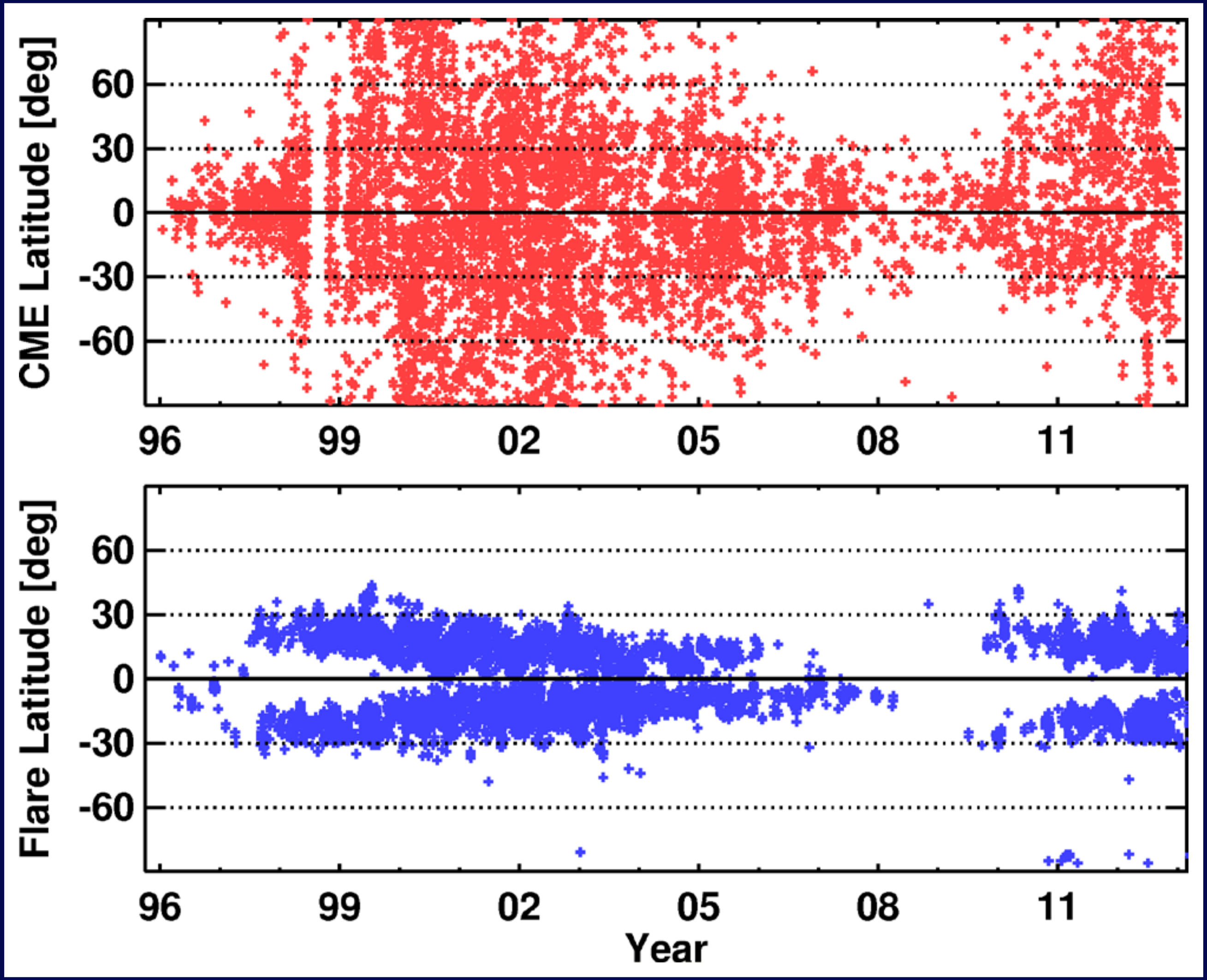

- The CMEs in SC24 are wider.

# Cycle Variation: CME Width




Gopalswamy+ 2014, GRL

# CME and Flare Latitudes

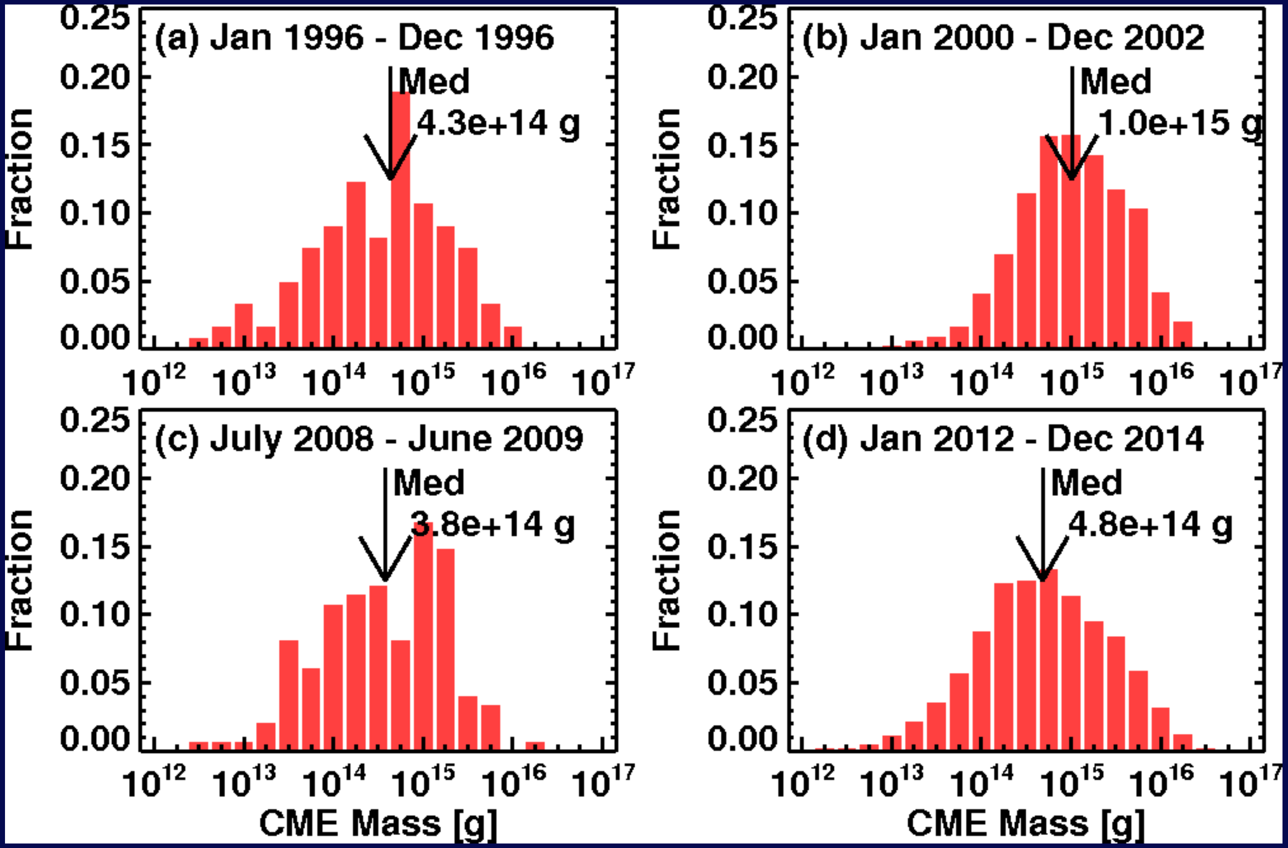



- Compared to the flare latitudes, the CME latitudes are more widely distributed.

# CME Mass Measurement

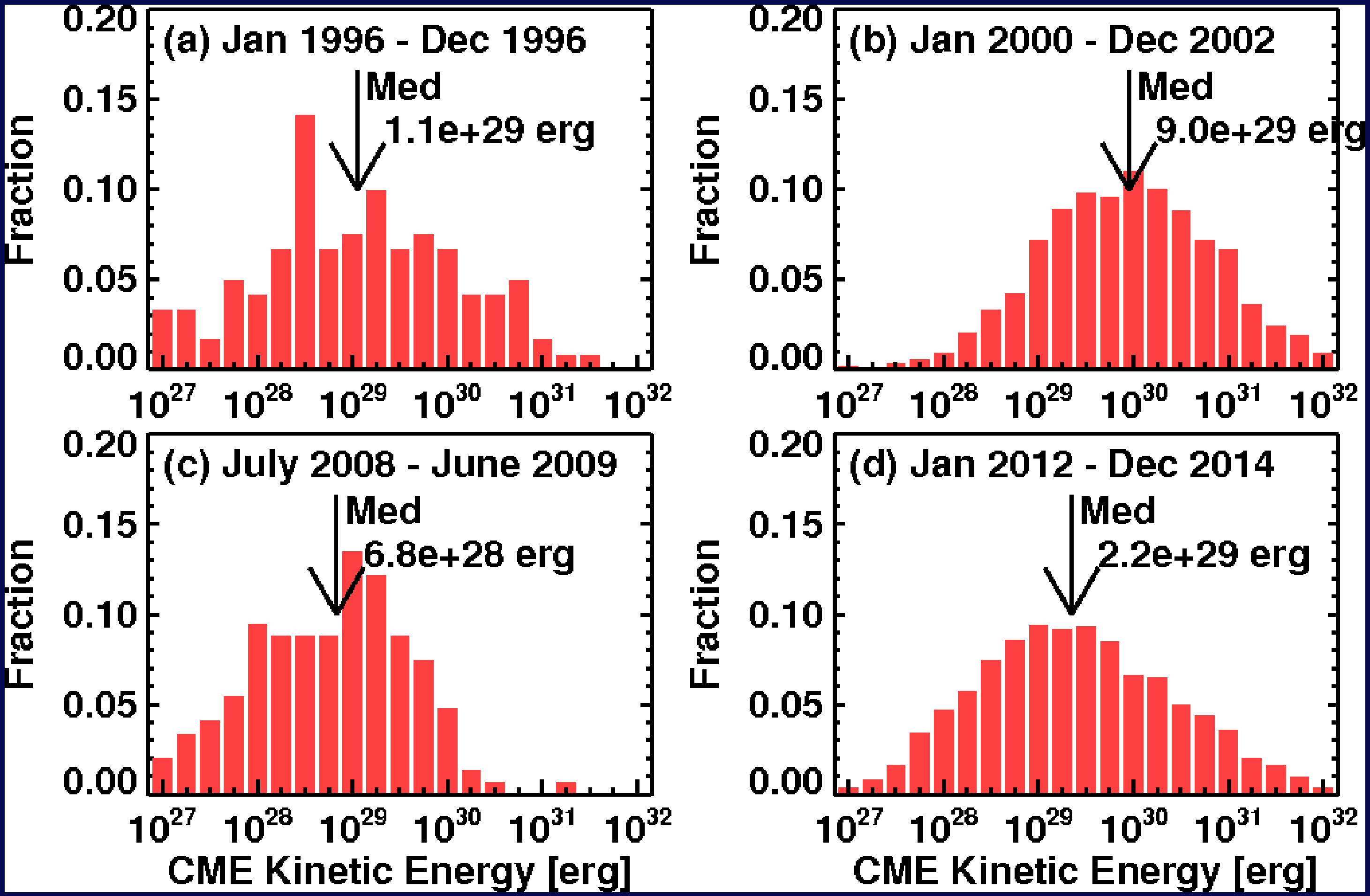
- Mass measurement assumes that the CME material is in the sky-plane (Vourlidas et al. 2000).
  - Mass measurement is accurate for limb events.
- Previously we did not provide the mass of partial and full halos.
  - But we know there are limb halo CMEs.

# CME Mass Distributions



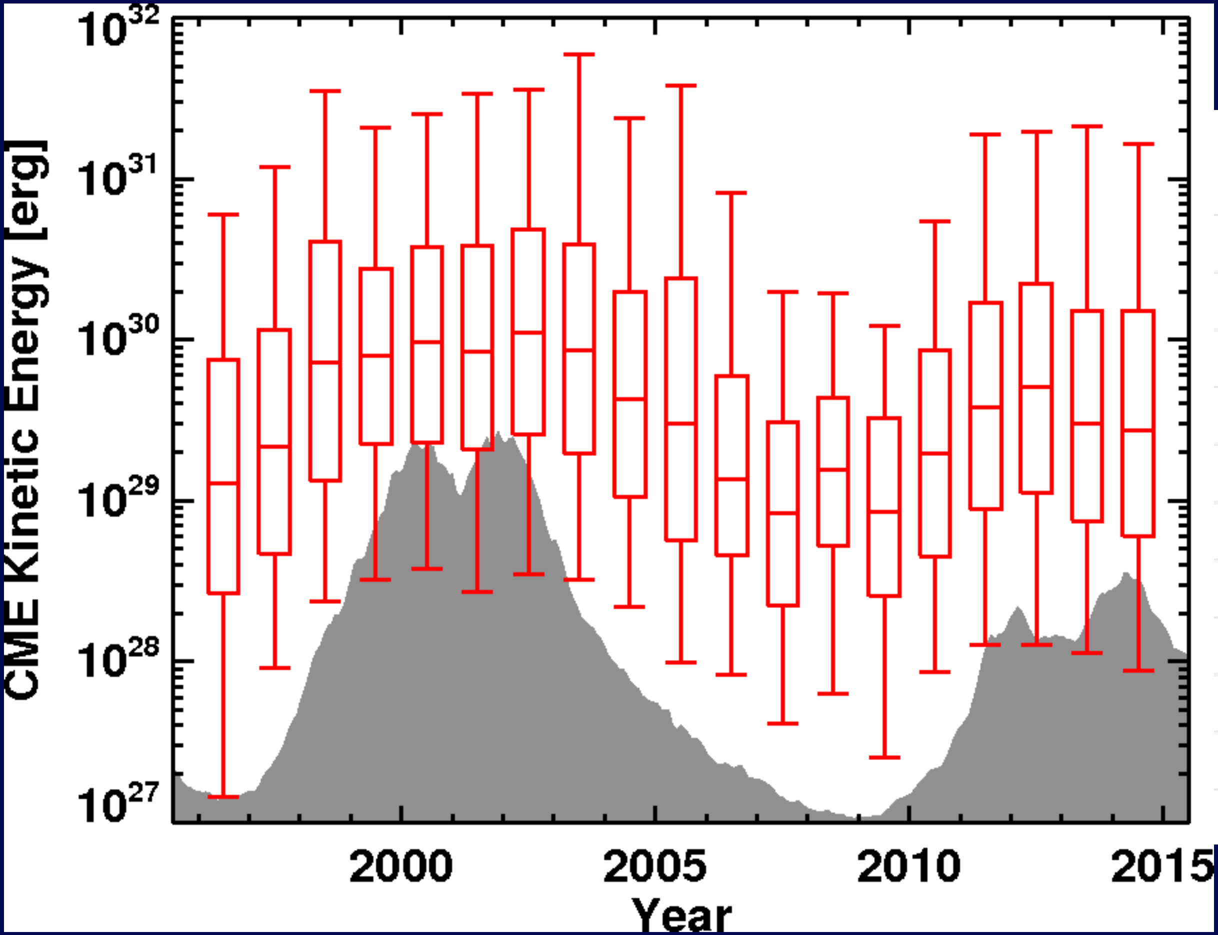

- The median mass of the SC24 max is approximately half of the SC23 max.

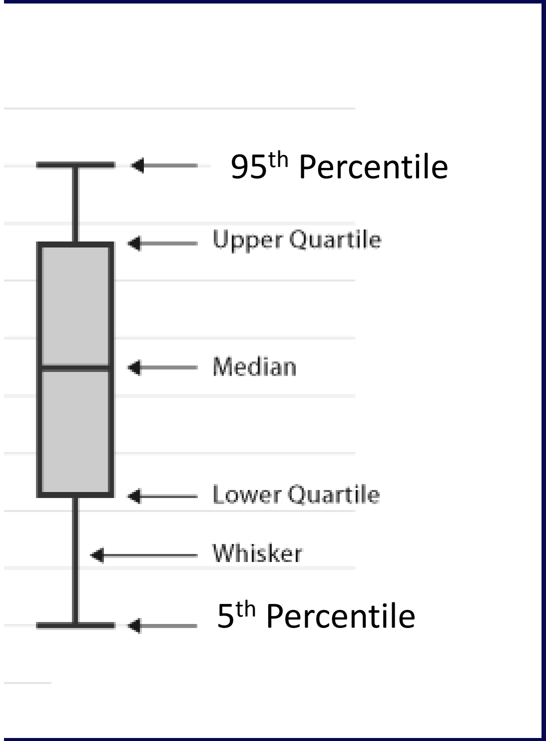
# CME Kinetic Energy Distributions




- 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 ($W \geq 60^\circ$) observed by SOHO/LASCO.
- We use STEREO/COR1 to exclude backside CMEs.
- We use SDO/AIA, Hα, 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

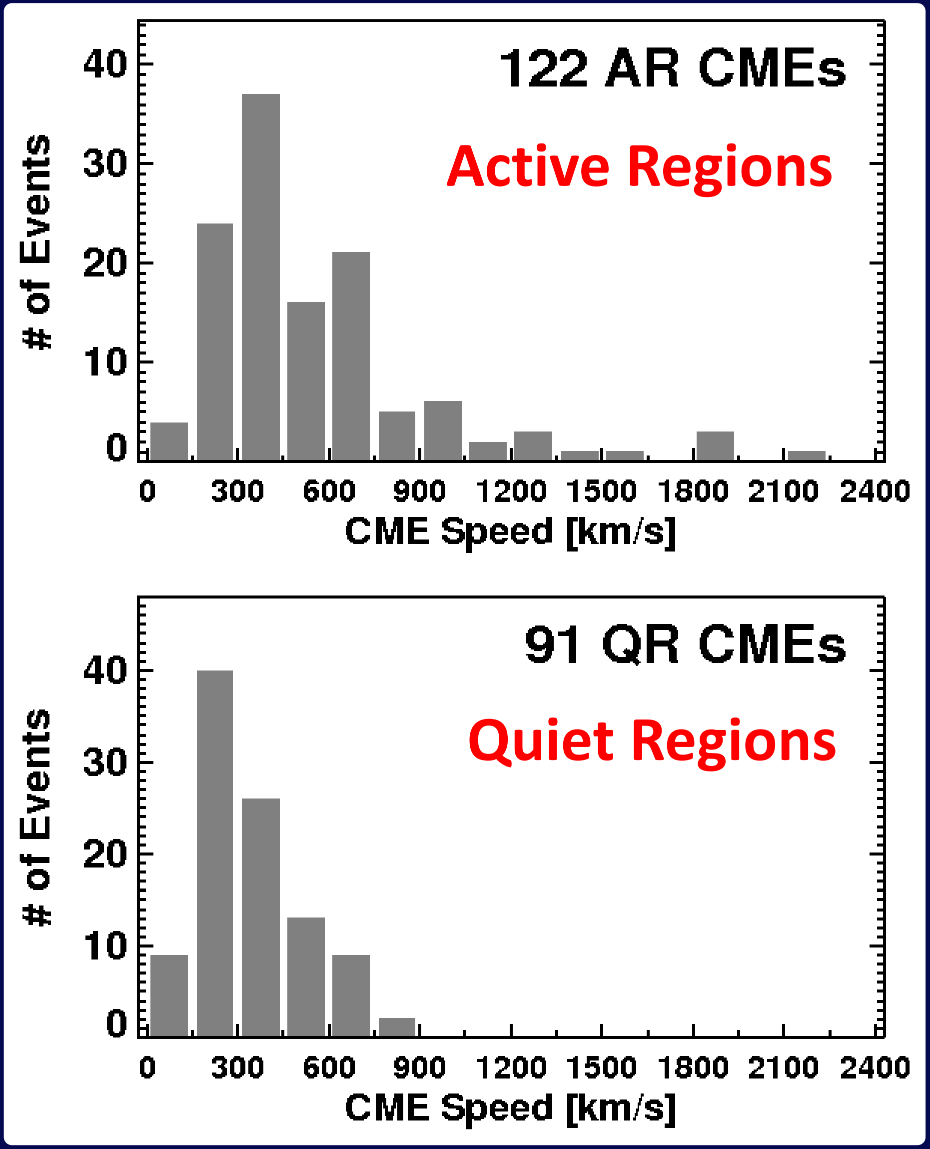
| Active Regions | Quiet Regions | No Surface Signature Identified (Stealth CMEs) |
|---|---|---|
| 55% | 41% | 4% |

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

# CME Speed Distribution

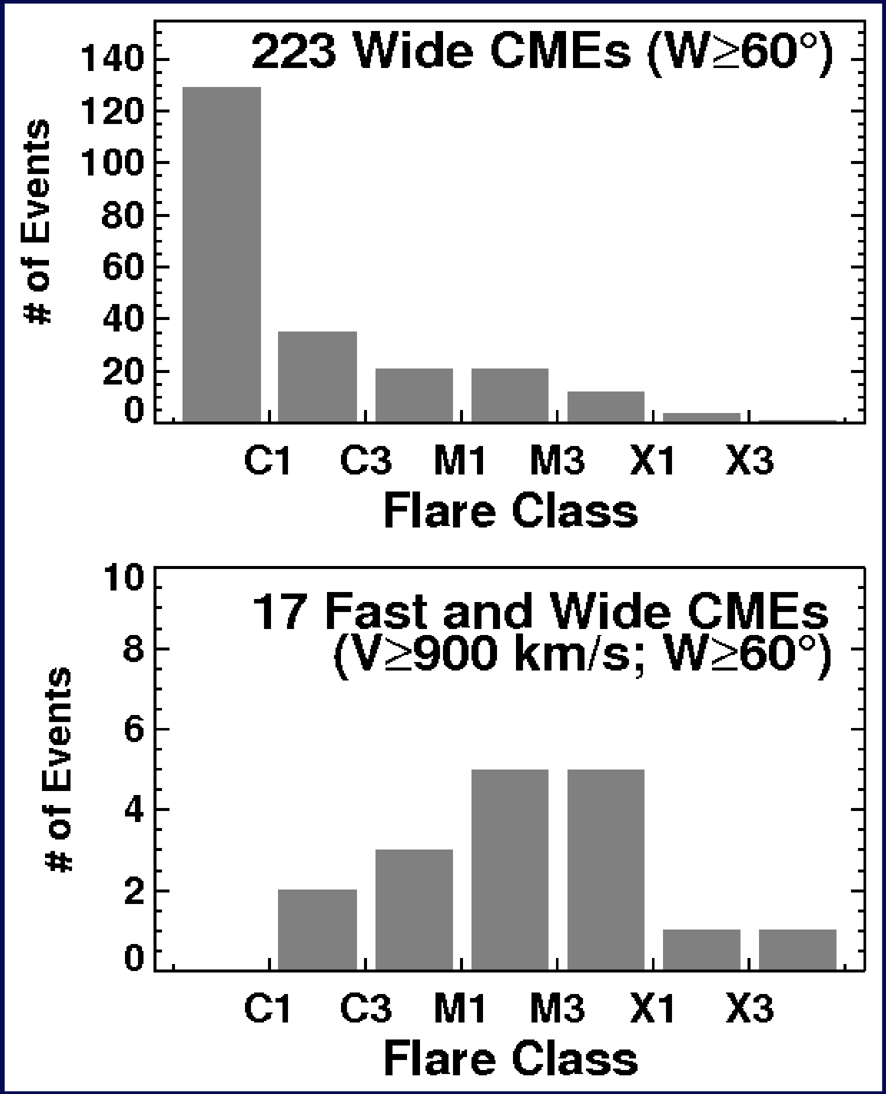
- The speed distributions are highly overlapped.
- On average, the AR CMEs are faster than QR CMEs.

- 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 C-class 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 | $1.0 \times 10^{15}$ g | $4.8 \times 10^{14}$ g |
| Kinetic Energy | $9.0 \times 10^{29}$ erg | $2.2 \times 10^{29}$ erg |
| | | |