The Mild Space Weather in Solar Cycle 24

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Mild Space Weather

- Historically weak and infrequent geomagnetic storms
- Paucity of high-energy solar energetic particle events
- Both are caused by coronal mass ejections
- The CME rate has not declined significantly
- SSN down by ~40%
- How can all these be tied together?

Solar Activity Variation

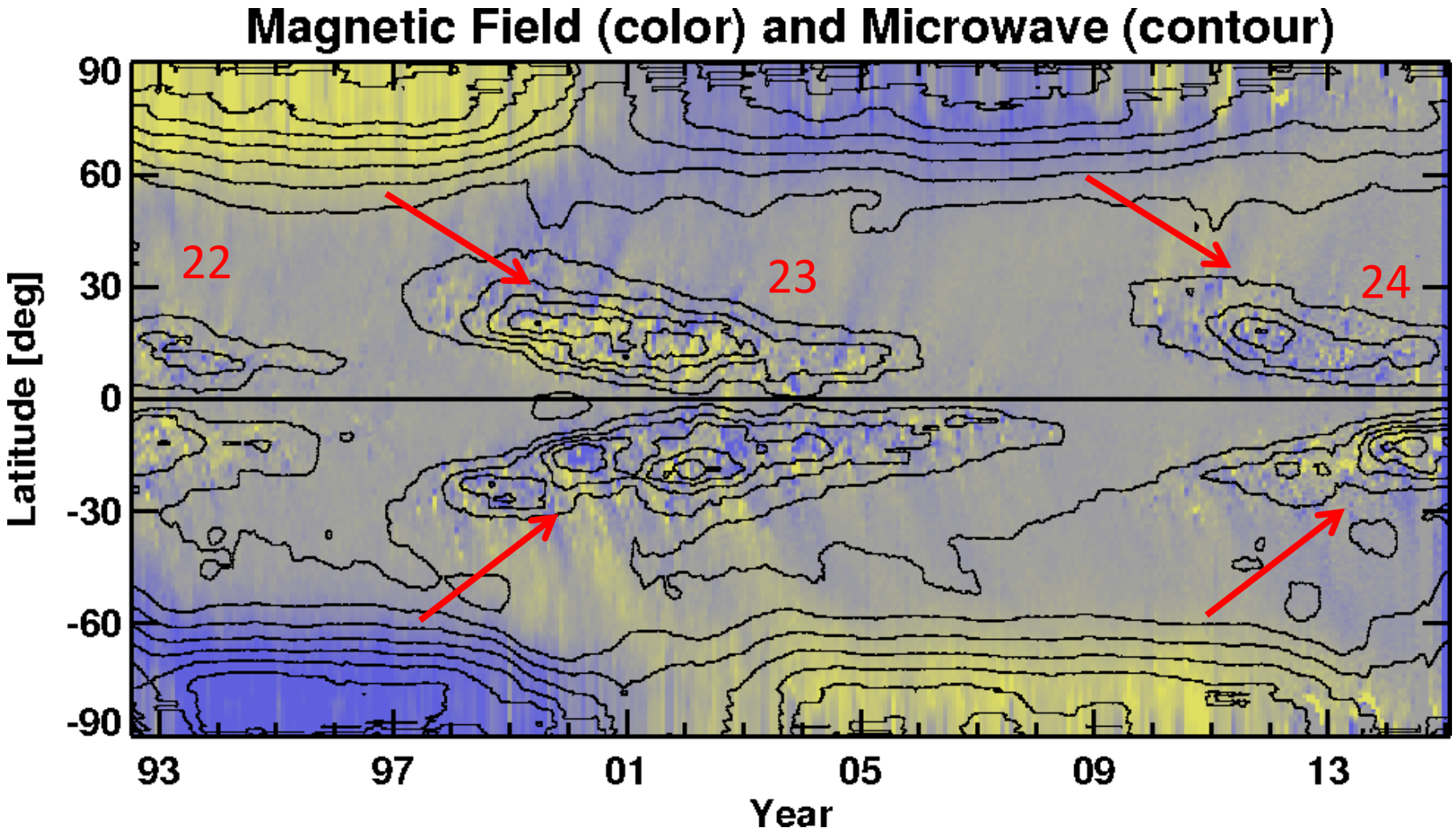
Yellow: positive Blue: negative polarity

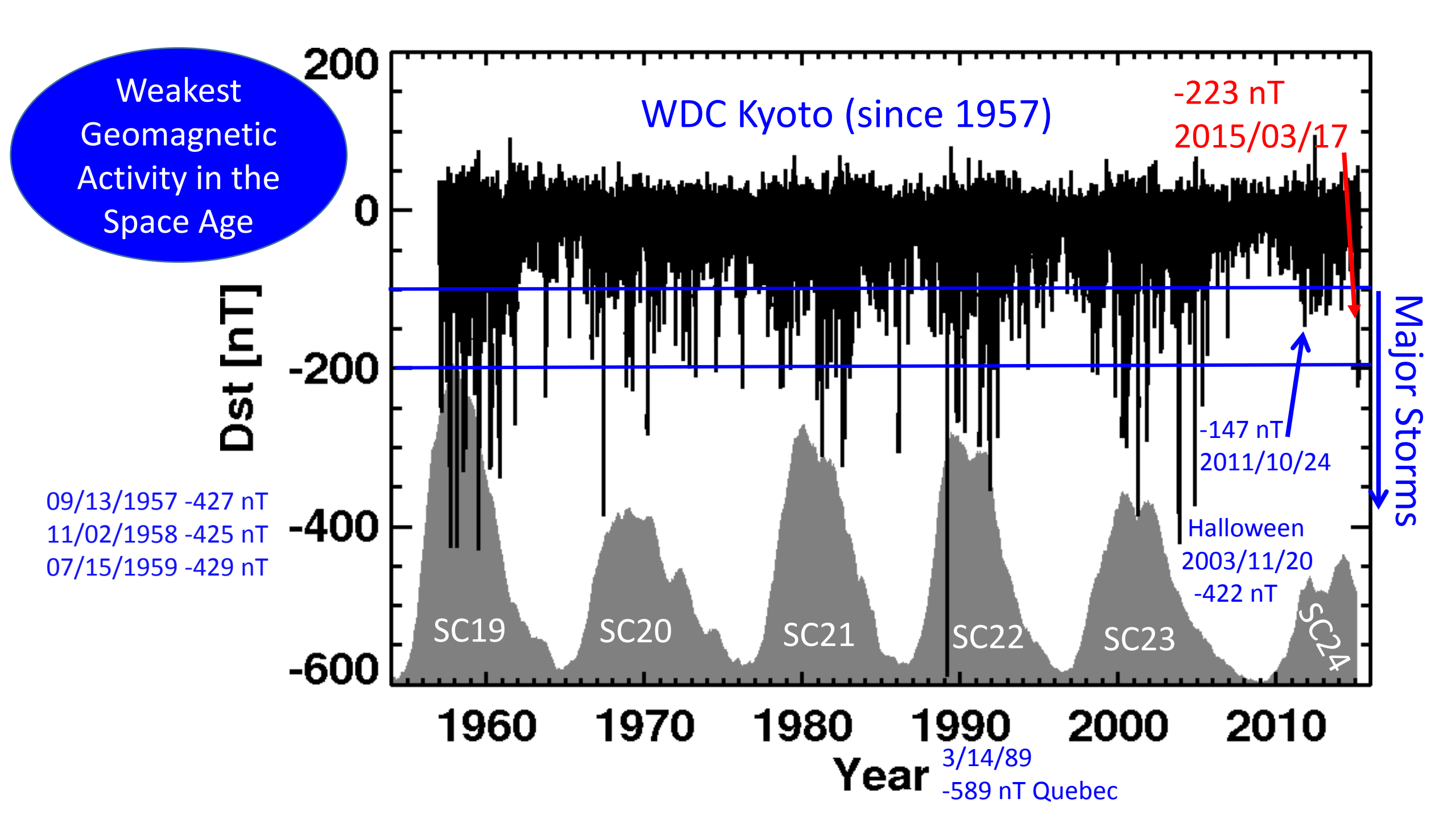
Solar activity variation is a property of the solar dynamo

The dynamo converts poloidal field into toroidal field (i.e., sunspot field) and vice versa

Polar fields in cycle 23 were weak leading to low sunspot activity in cycle 24

What is the impact on space weather?



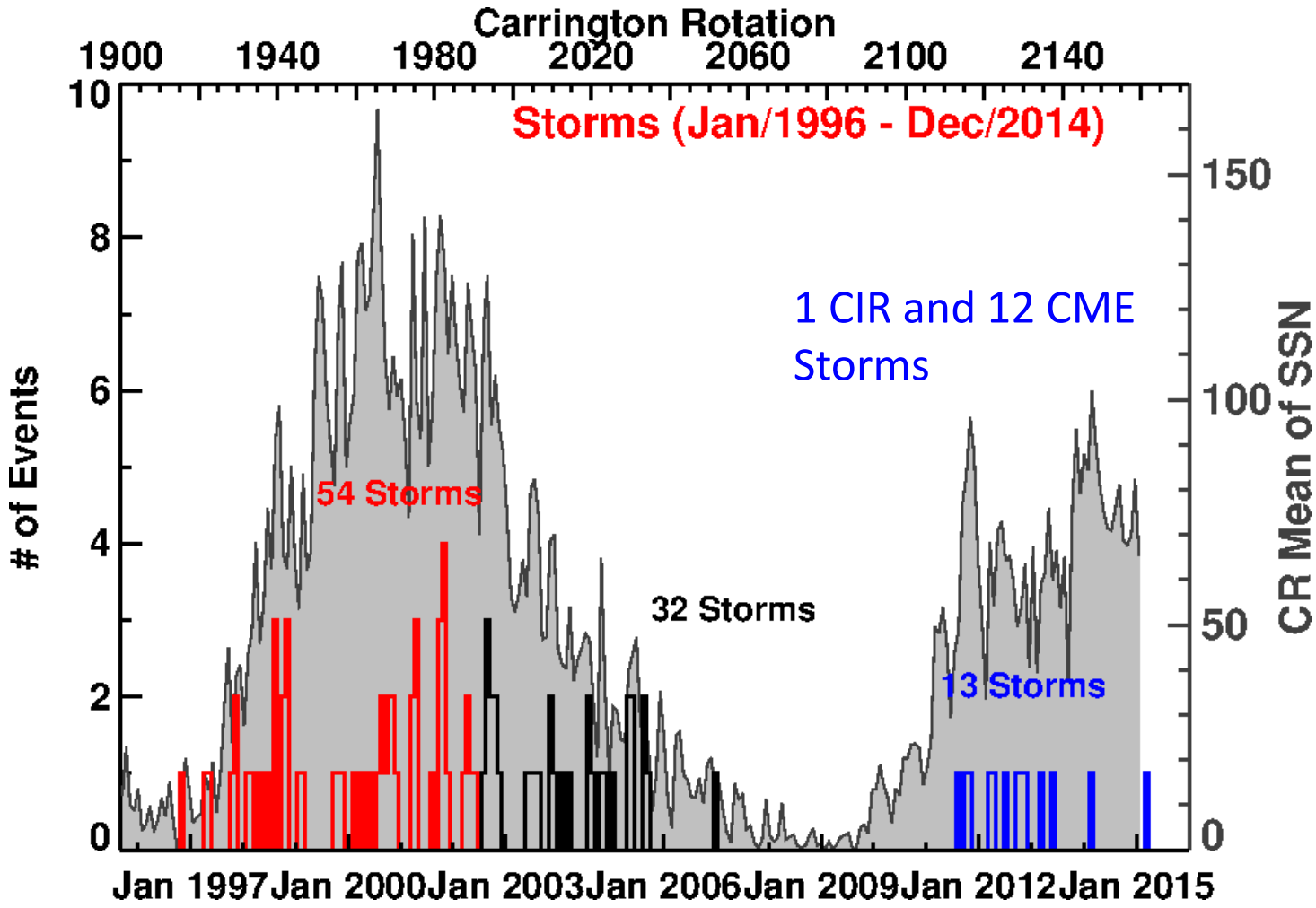

Weakest Geomagnetic Activity in the Space Age
WDC Kyoto (since 1957)
-223 nT
2015/03/17
Dst [nT]
200
0
-200
-400
-600
Major Storms
-147 nT
2011/10/24
Halloween
2003/11/20
-422 nT
09/13/1957 -427 nT
11/02/1958 -425 nT
07/15/1959 -429 nT
SC19
SC20
SC21
SC22
SC23
SC24
1960
1970
1980
1990
2000
2010
Year
3/14/89
-589 nT Quebec

Comparing Cycles 23 and 24

	Cycle 23	Cycle 24	Ratio
Dst< -100	54	12	0.22
SSN	68.27	38.45	0.56
FW CMEs	3.32/mo	2.33/mo	0.70

The 78% drop in the number of major storms is much larger than the
44% drop in SSN or
30% drop in fast and wide CMEs

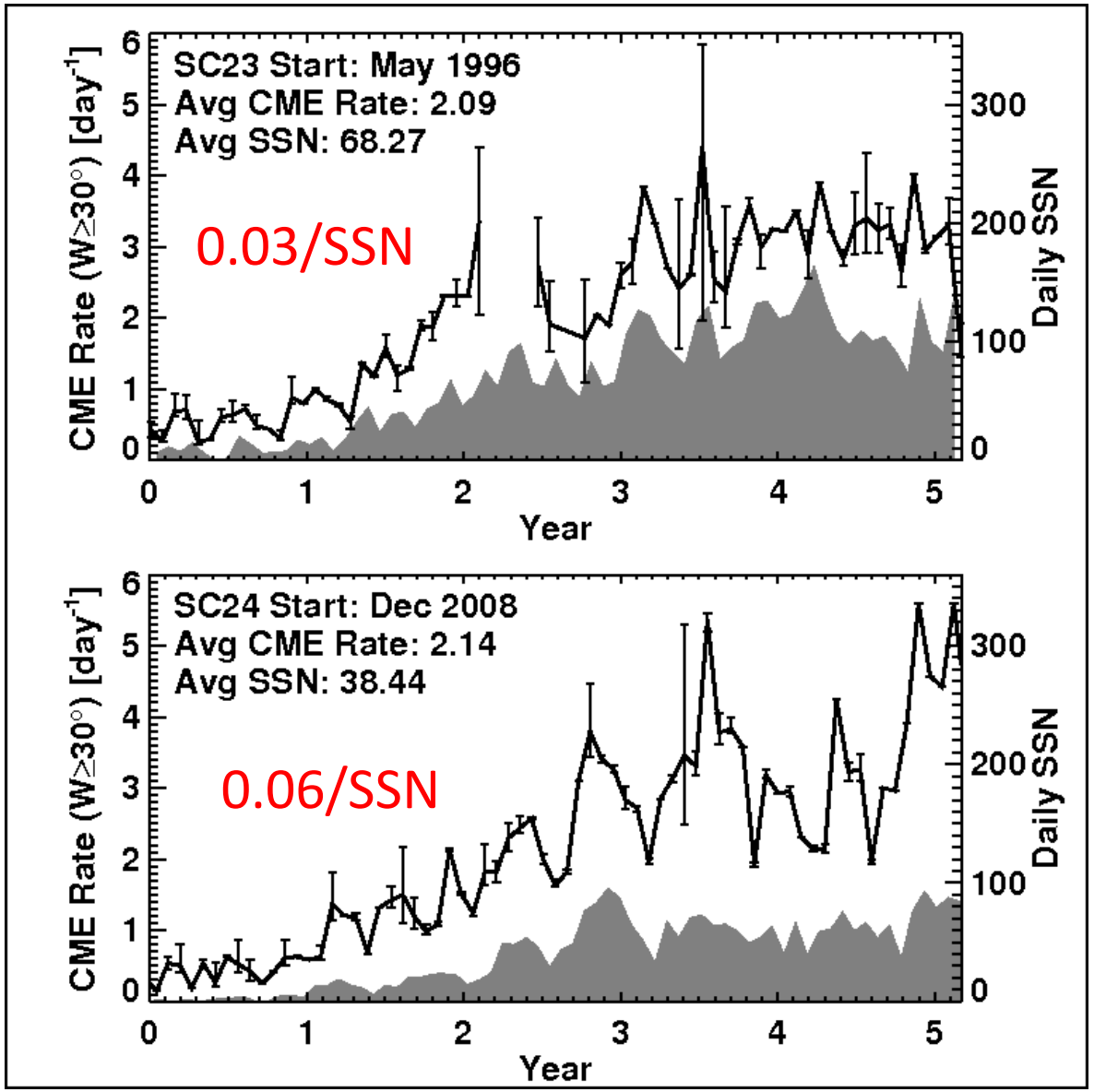
Fast (V≥900 km/s) and wide (W≥60deg) typically cause major storms



SSN & CME Rate (W≥30°)

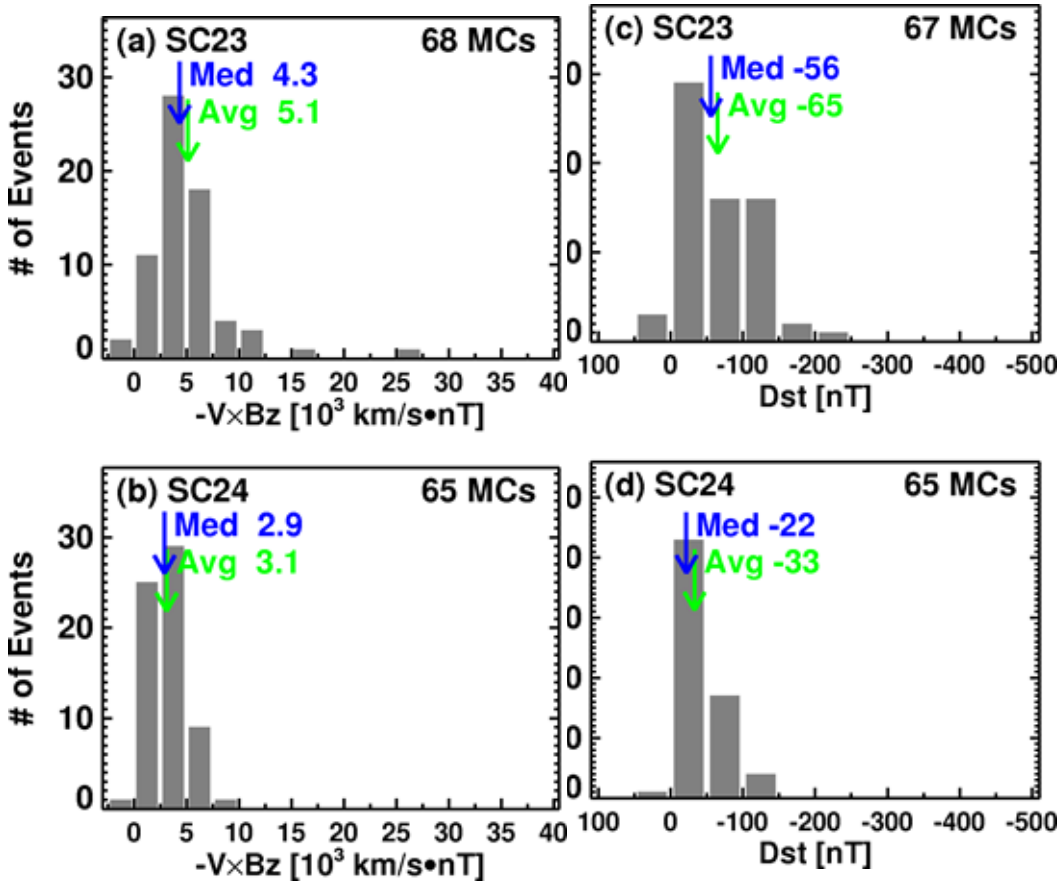
CME rate did not decline in cycle 24

- Higher when normalized to SSN
- Halo CMEs are similar
- Only fast and wide CMEs declined by 30%
- Not enough to account for 78% drop in the number of major storms



Why Low Geoeffectiveness?

- Dst = -0.01VBz – 32 nT (Gopalswamy 2010) (cycle 23)
- Reduction in VBz should lead to weaker storms
- We considered magnetic clouds that were detected at L1
- 68 in SC 23; 65 in SC 24
- Measured V and Bz for SC 23 &24
- VBz is down by 39%
- Dst is down by 49%

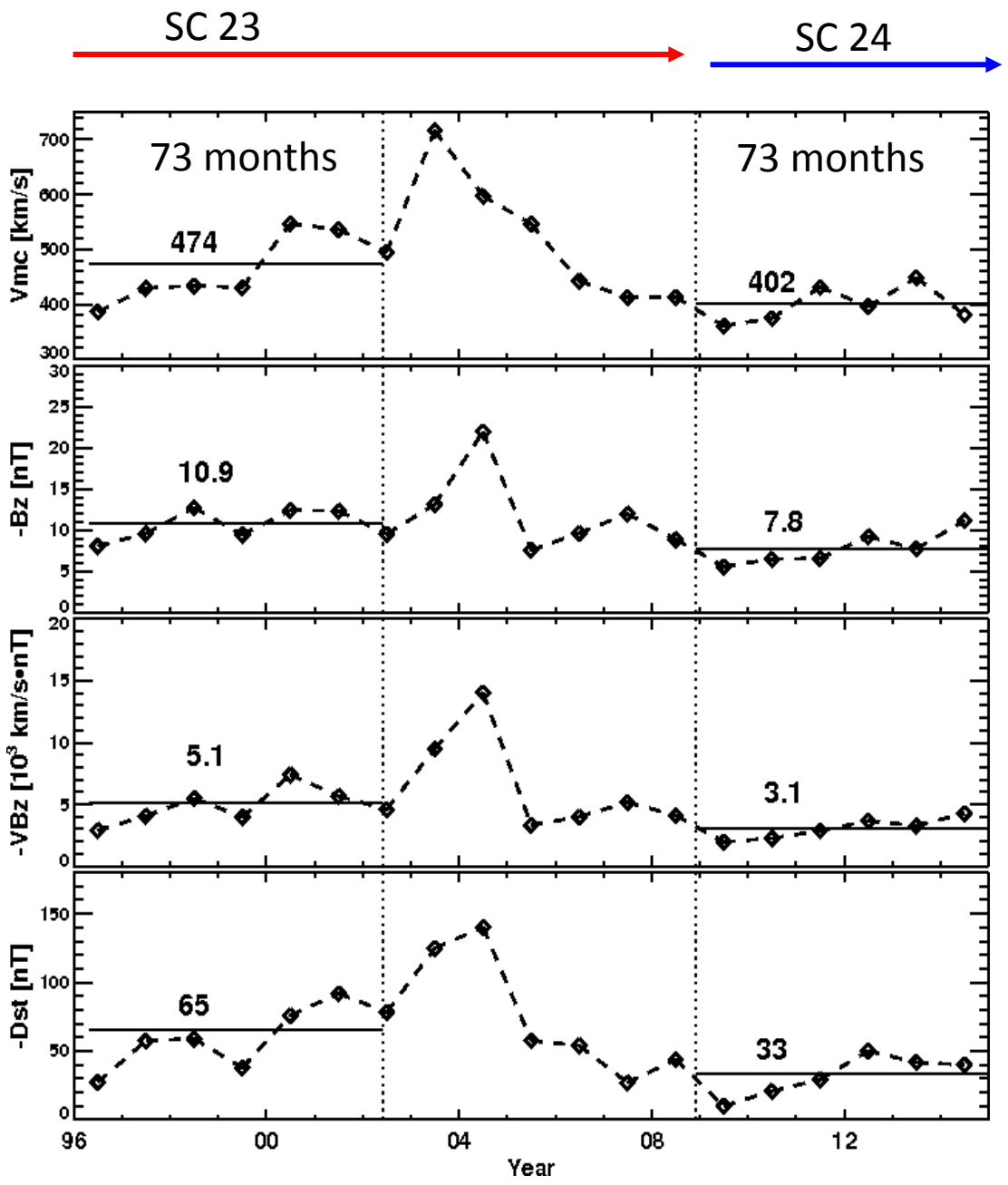


For Cycle 24: Dst = -0.017VBz + 16 nT

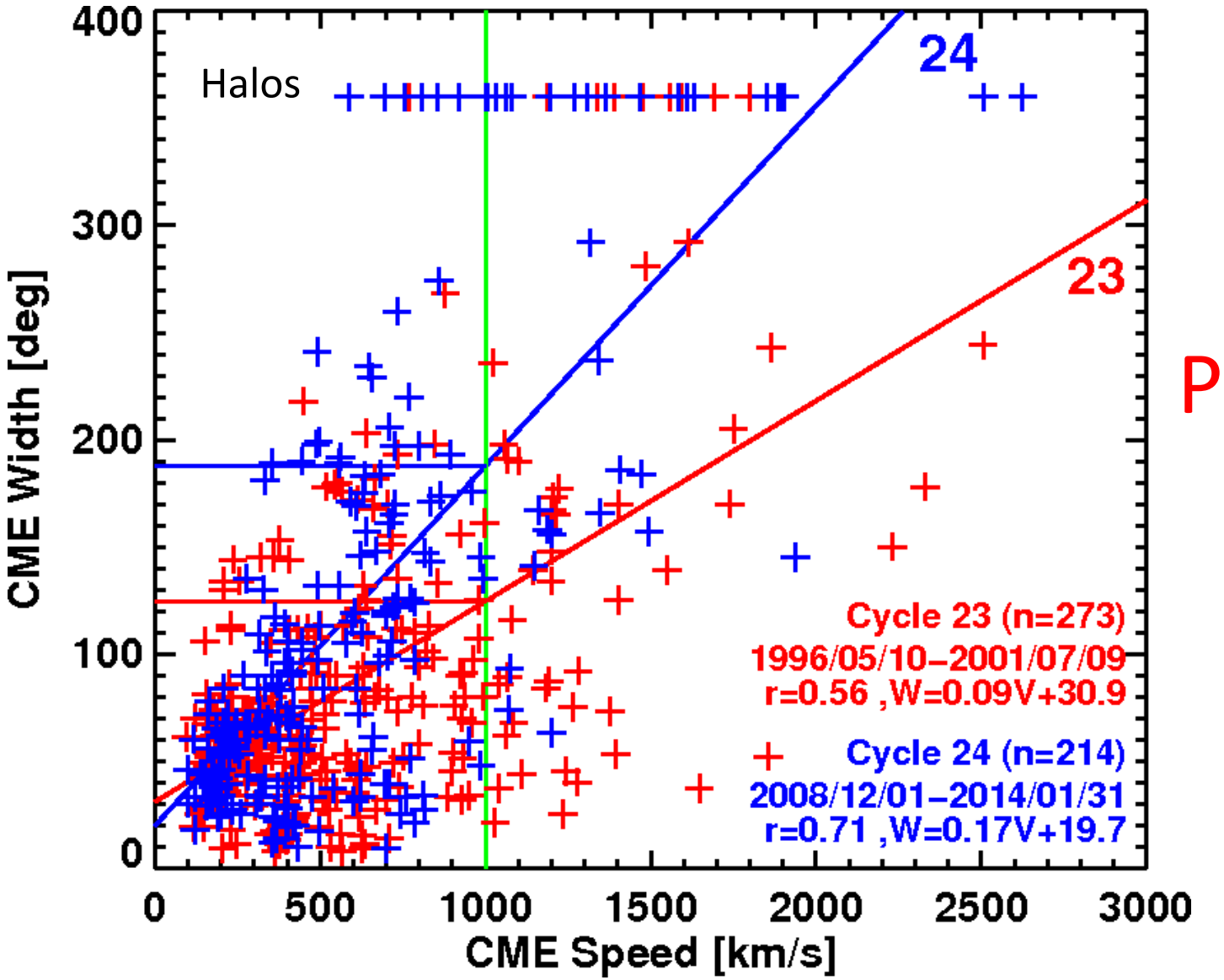
Decline in V and Bz

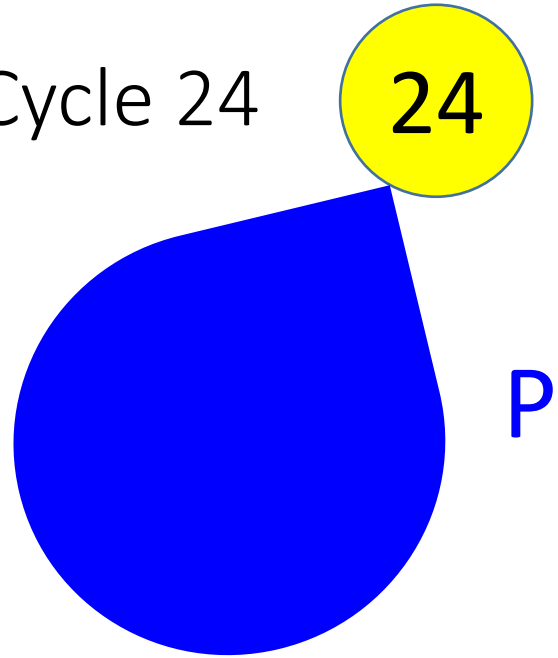
→ Decline in VBz

→ Decline in Dst

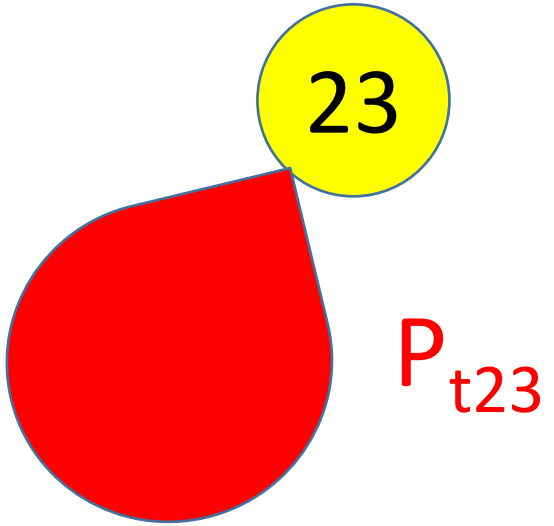


Why Low VBz? Anomalous Expansion of CMEs in Cycle 24





$P_{t23} > P_{t24}$

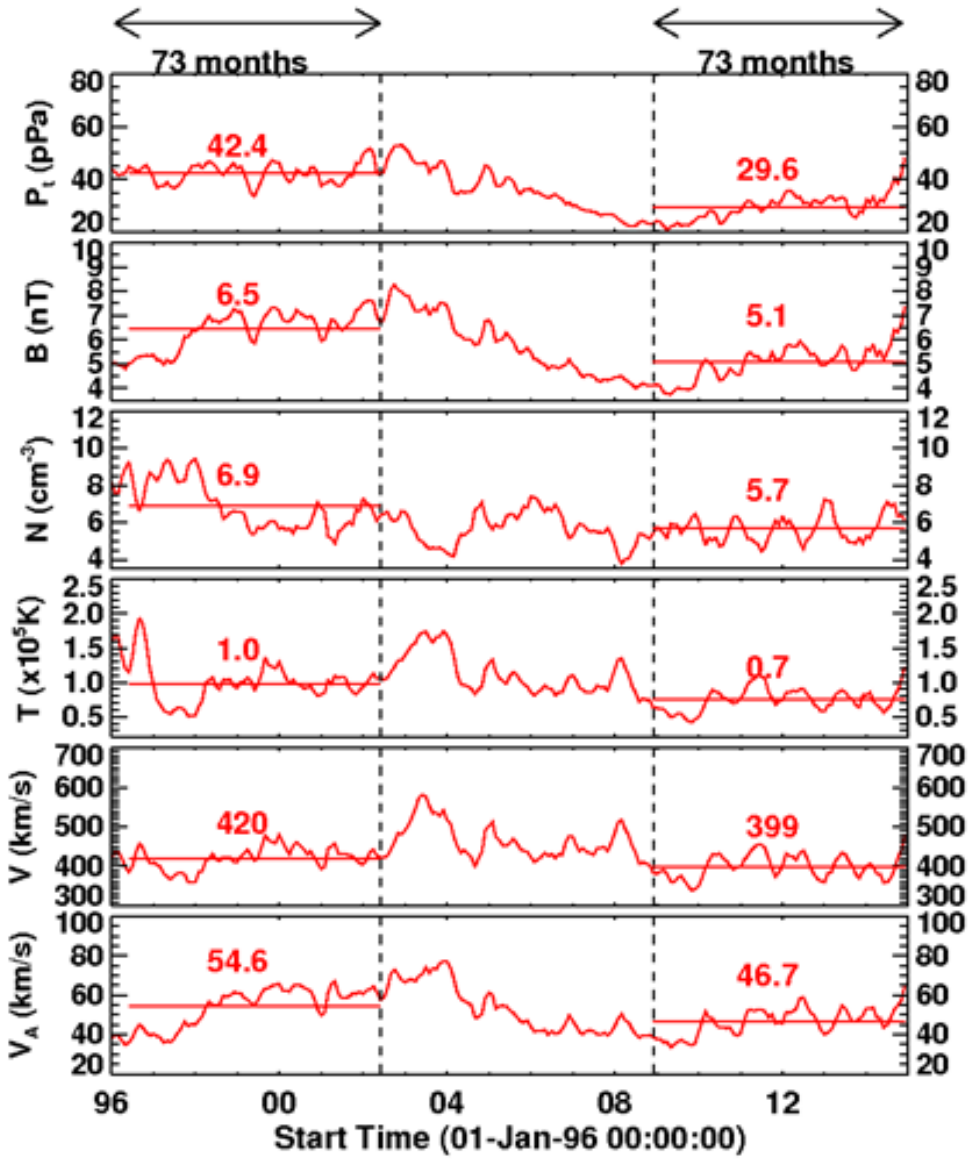


Slope is significantly different

For a given speed, cycle 24 CMEs are wider

30%

22%



Gopalswamy et al. 2014 GRL (updated)

Why do SC 24 CMEs expand more? Low ambient total pressure!

Reduced total Pressure (30%)

→ CMEs expand more

→ This reduces CME magnetic content

→ Cloud storms are weak

Heliospheric Magnetic field is also reduced (22%)

→ Compressed sheath field is weaker

→ This reduces sheath magnetic content

→ Sheath storms are weak

→ CIRs storms are weak

Solar Energetic Particles

SEPs	Cycle 23*	Cycle24	Ratio
>10 MeV	58 (0.85/SSN)	35** (0.91/SSN)	1.07
>500 MeV	18 (0.26/SSN)	6 (0.16/SSN)	0.62
>700 MeV (GLE)	9 (0.52/SSN)	2 (0.05/SSN)	0.10

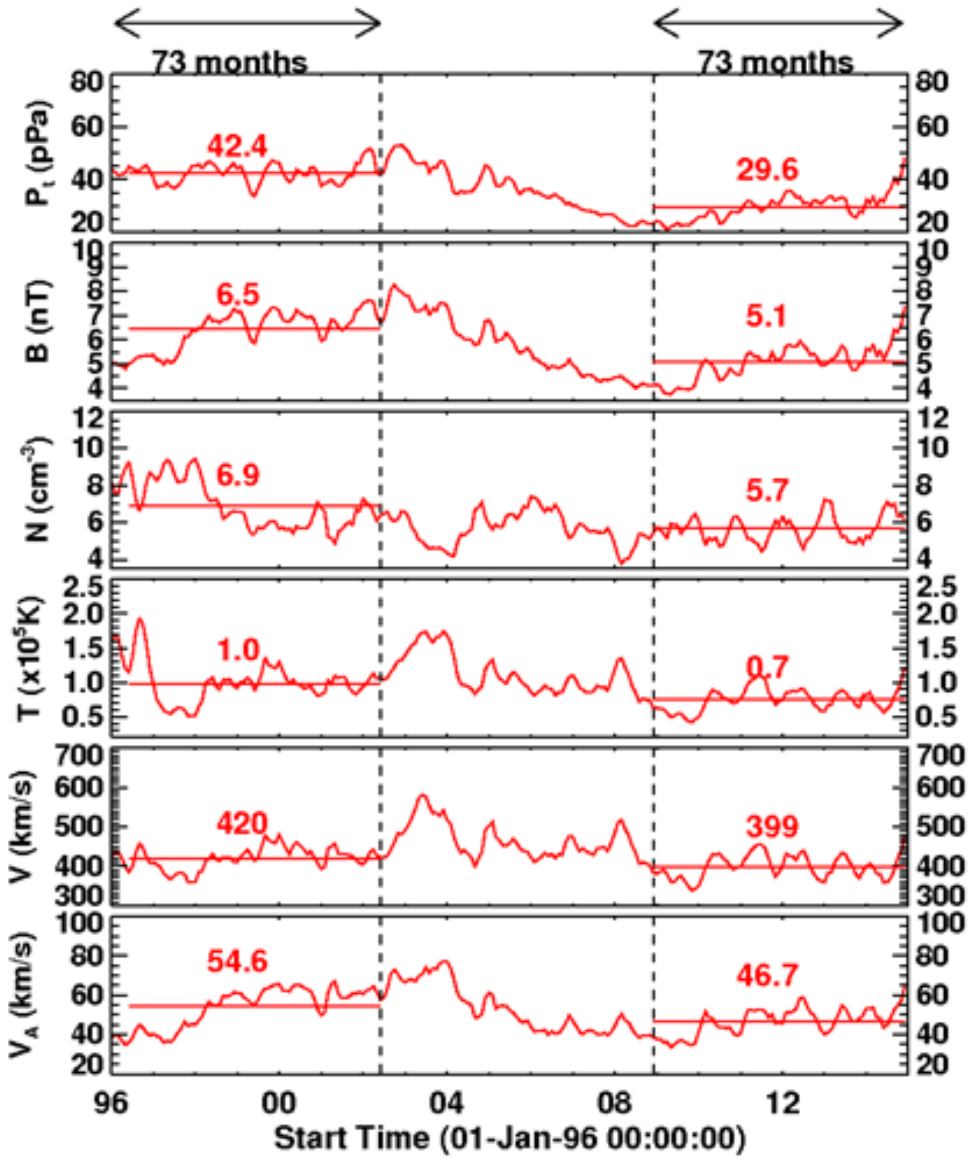
Ratios normalized to SSN

- Low-energy SEP events did not drop
- >500 MeV SEP events dropped by 38%
- >700 MeV SEPs dropped by 90%

- These cannot be explained by the 30% drop in FW CMEs

30%

22%



Gopalswamy et al. 2014 GRL (updated)

Why do SC 24 CMEs expand more? Low ambient total pressure

Reduced B

→ Reduced acceleration efficiency (Kirk, 1994)

$dE/dt \propto B$ (rate of energy gain or acceleration time scales $\propto B^{-1}$)

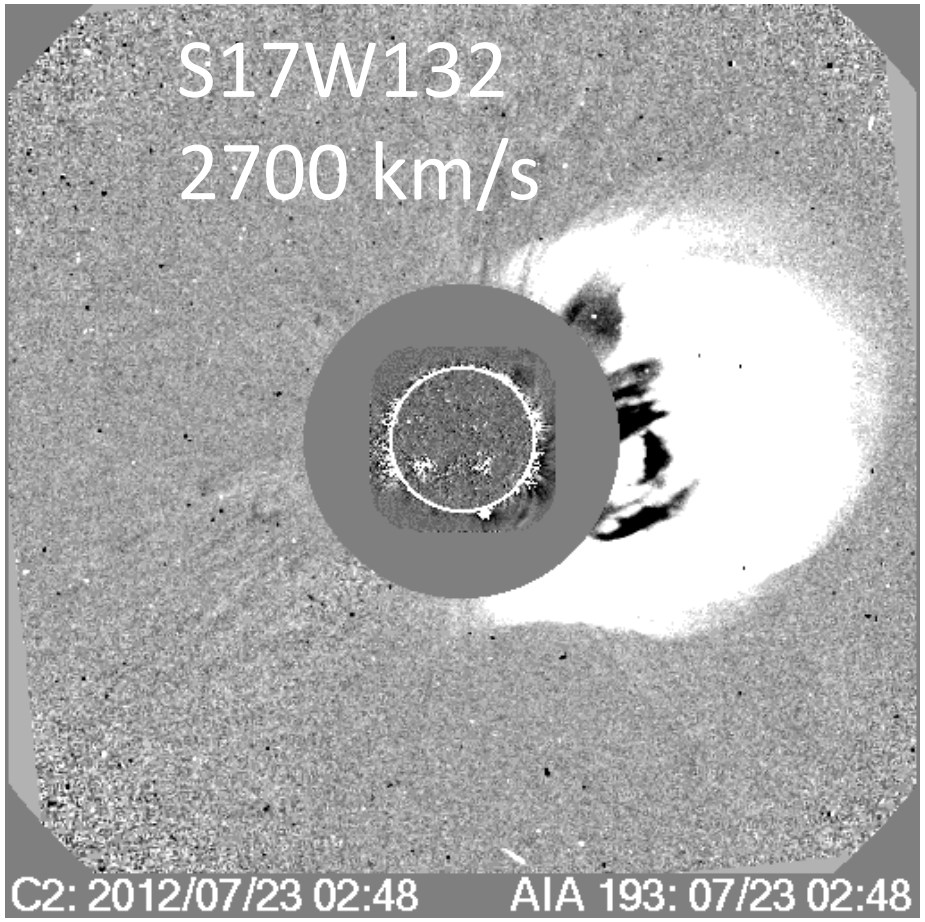
With the available time of ~10 min, it is difficult to accelerate SEPs to GeV energies

Reduced Alfven speed near Sun

→No major reduction in the # SEP Events

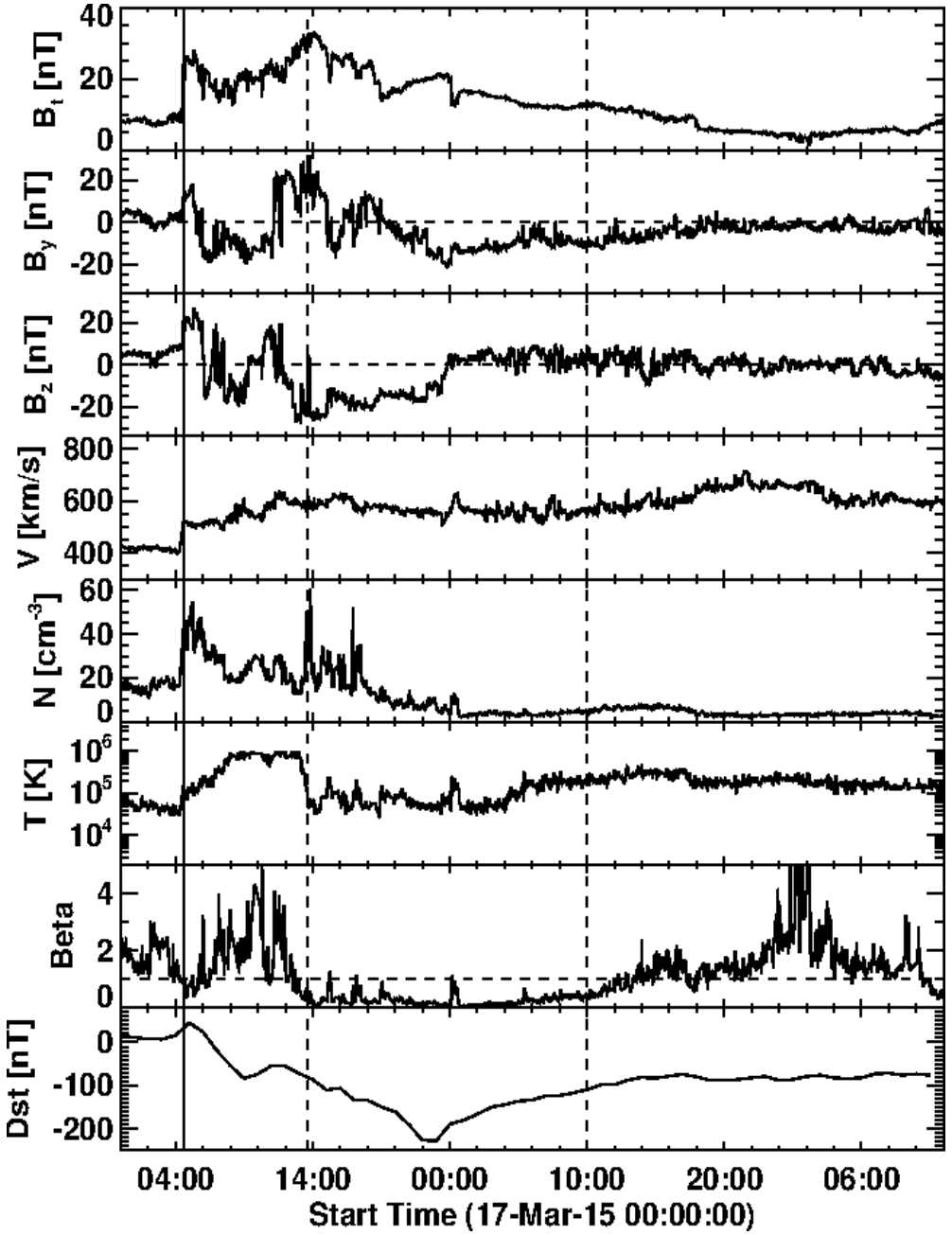
Caveat: Extreme Event

- July 23, 2012 CME with a speed of ~2700 km/s (back-sided)
- The magnetic cloud arrived at STEREO A with a speed of ~1500 km/s and a Bz of -52 nT
- If Earth-directed, it would have produced a storm with a Dst of -812 nT (Dst = -0.01VBz-32 nT)
- If there were no expansion, VBz would be larger by 1/0.6 and the Dst would be as high as -1332 nT



2015 March 17 Storm

- March 15, 2015 CME with a speed of ~1120 km/s (S18W39); Earthward speed ~1025 km/s
- The magnetic cloud arrived at L1 with a speed of ~600 km/s and a Bz of -25 nT
- Observed Dst = -223 nT
- Dst = -0.017VBz +16 nT → -239 nT
- If there were no expansion, VBz → VBz/0.6 and the Dst would be -409 nT

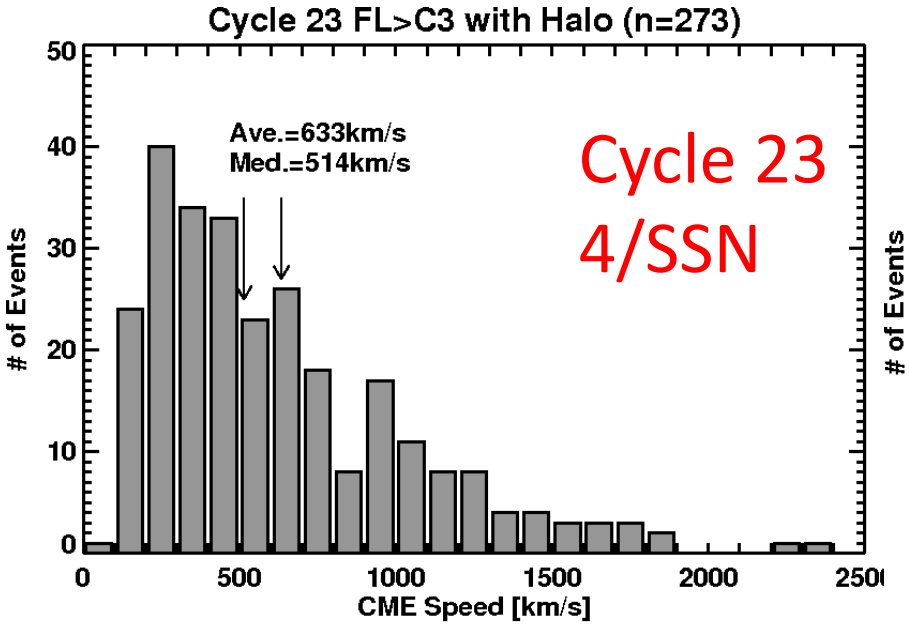


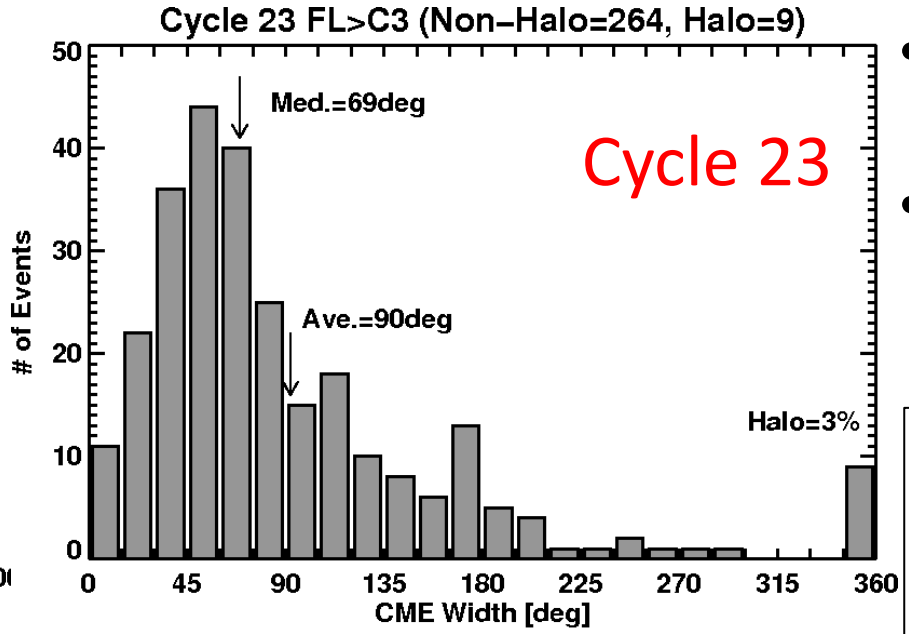
Summary

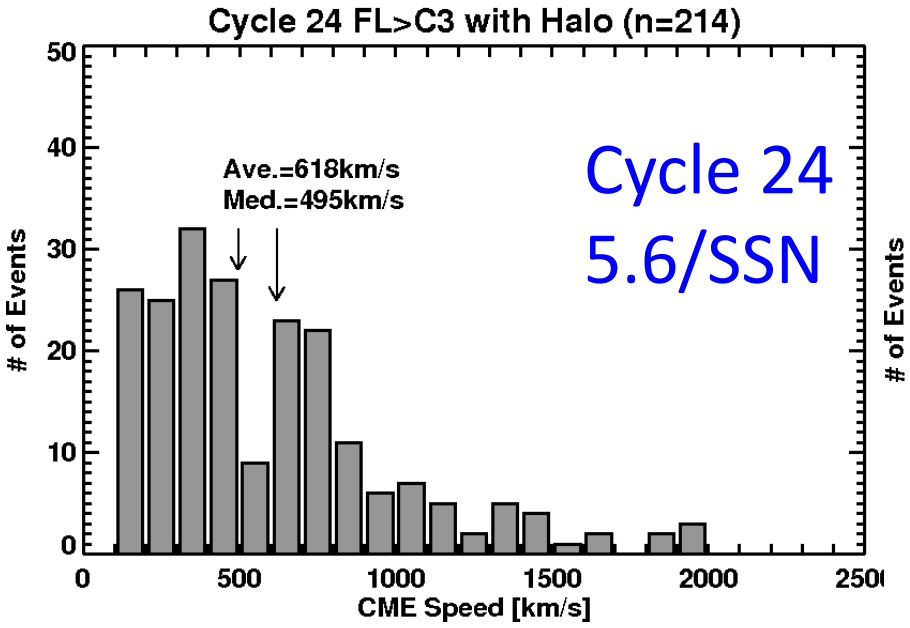
- Cycle-24 Space Weather is the mildest in the space era
- Weaker MC, sheath, CIR fields
- Weaker MC field is due to weaker heliospheric total pressure
- Weaker sheath, CIR fields due to weaker heliospheric B
- No drastic reduction of low-energy (>10 MeV) SEP events because of reduction in Alfven speed
- Severe reduction in high-energy (>500 MeV, GLE) SEP events due to diminished efficiency of shock acceleration
- Dst – VBz relationship holds, but VBz range is small in cycle 24
- Extreme events do occur in weak cycles, but the severity is subdued

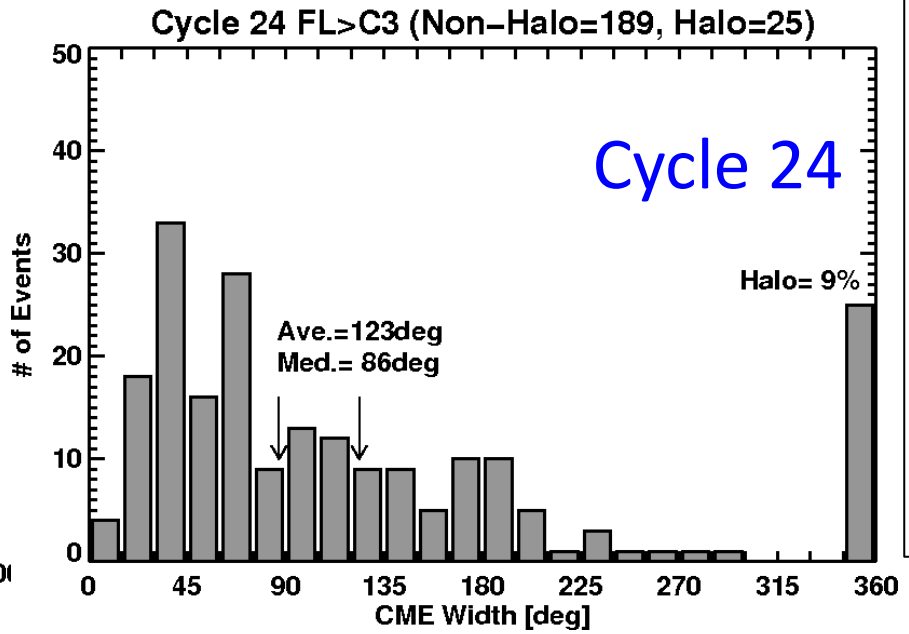
Backup slides

Width distribution is different in Cycle 24









- Limb CMEs to avoid projection effects
- CMEs associated with ≥C3.0 flares

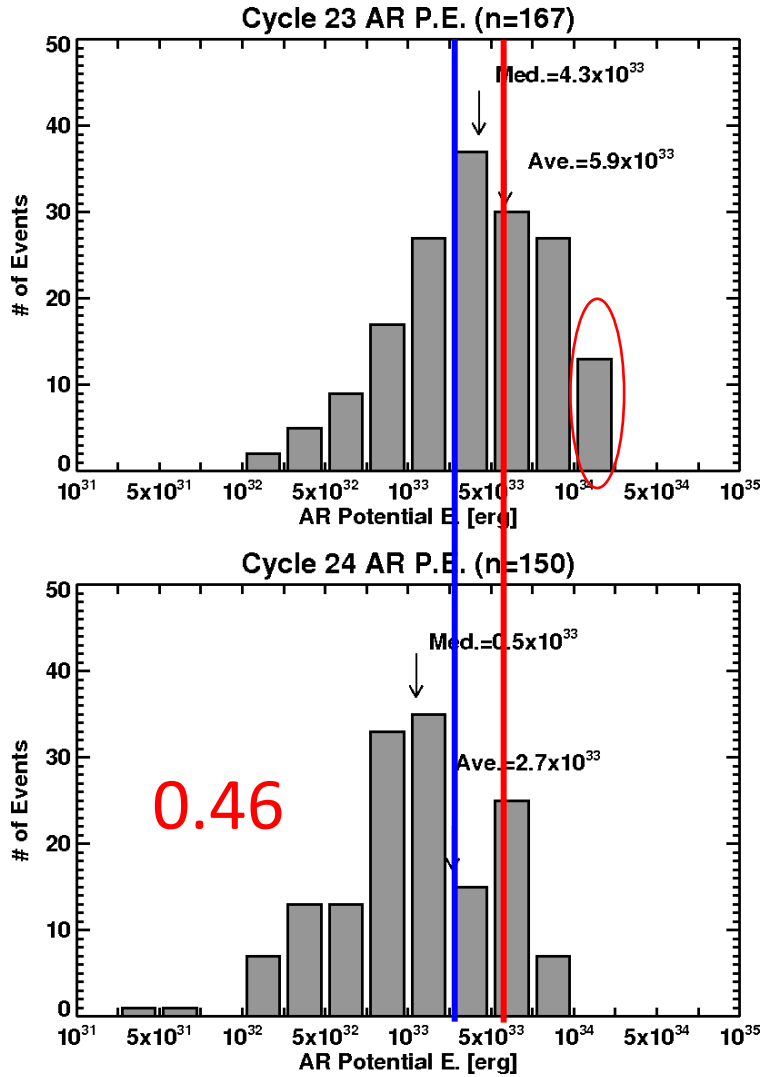
Similar Speed Distributions

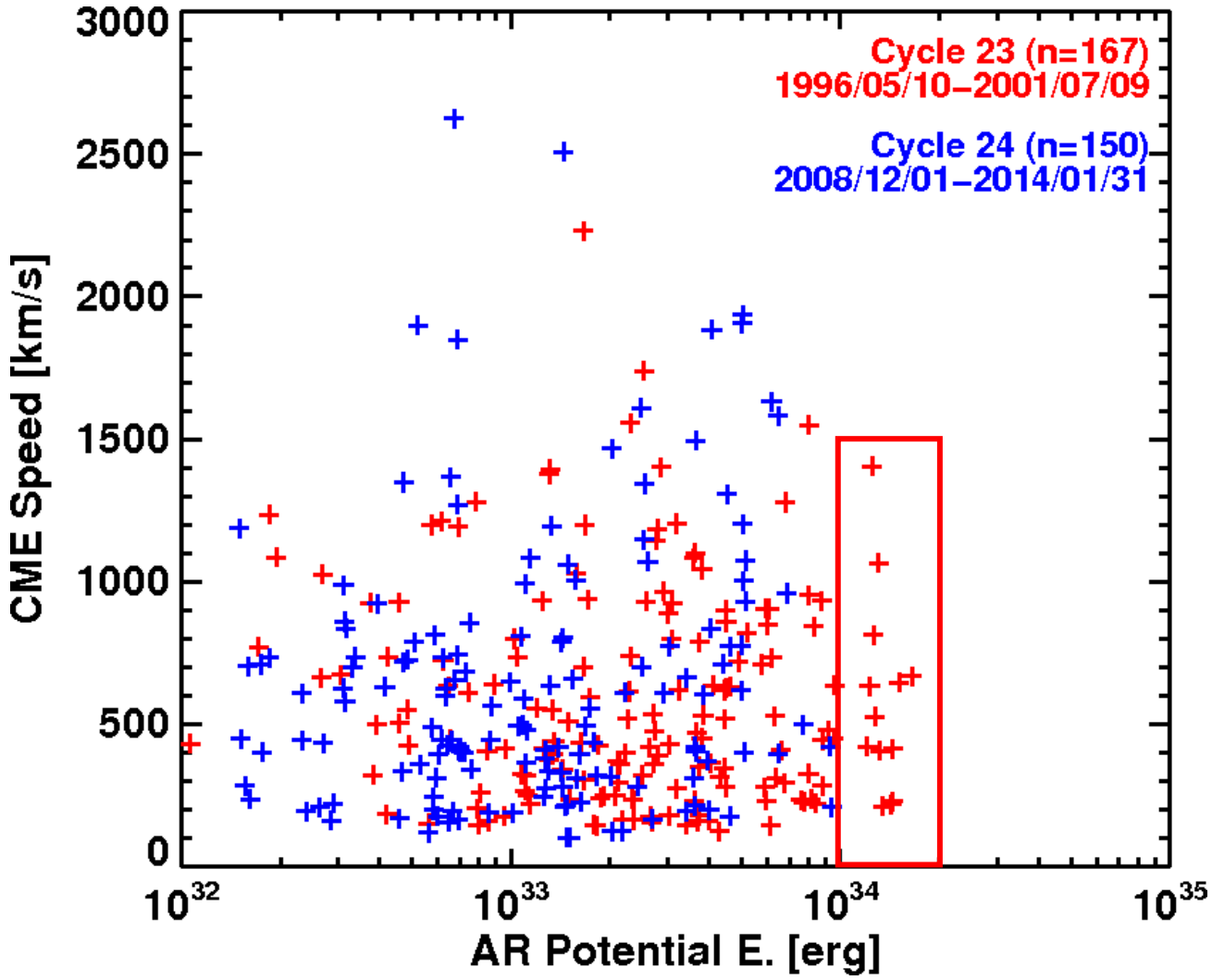
Different Width Distributions; Average width of non-halos is 37% higher in cycle 24

Three times more halos in SC24

Reduction in # CMEs
~ 27%
-a lot less than SSN drop

AR Potential Energy (Free-energy proxy)





Weak Storm: Due to weak IP field

- Dst = 0.01 VBz – 32 nT (Gopalswamy 2010)

- Dst = - 140 nT (Most intense storm in cycle 24)
- VBz = -108/0.01 = - 1.08x10^4 km/s nT

- VBz = - 2.5x10^4 km/s nT (max value in cycle 23)
- Dst = - 282 nT (stronger storms in cycle 23)