Weak Solar Activity in Cycle 24 and the Consequent Mild Space Weather

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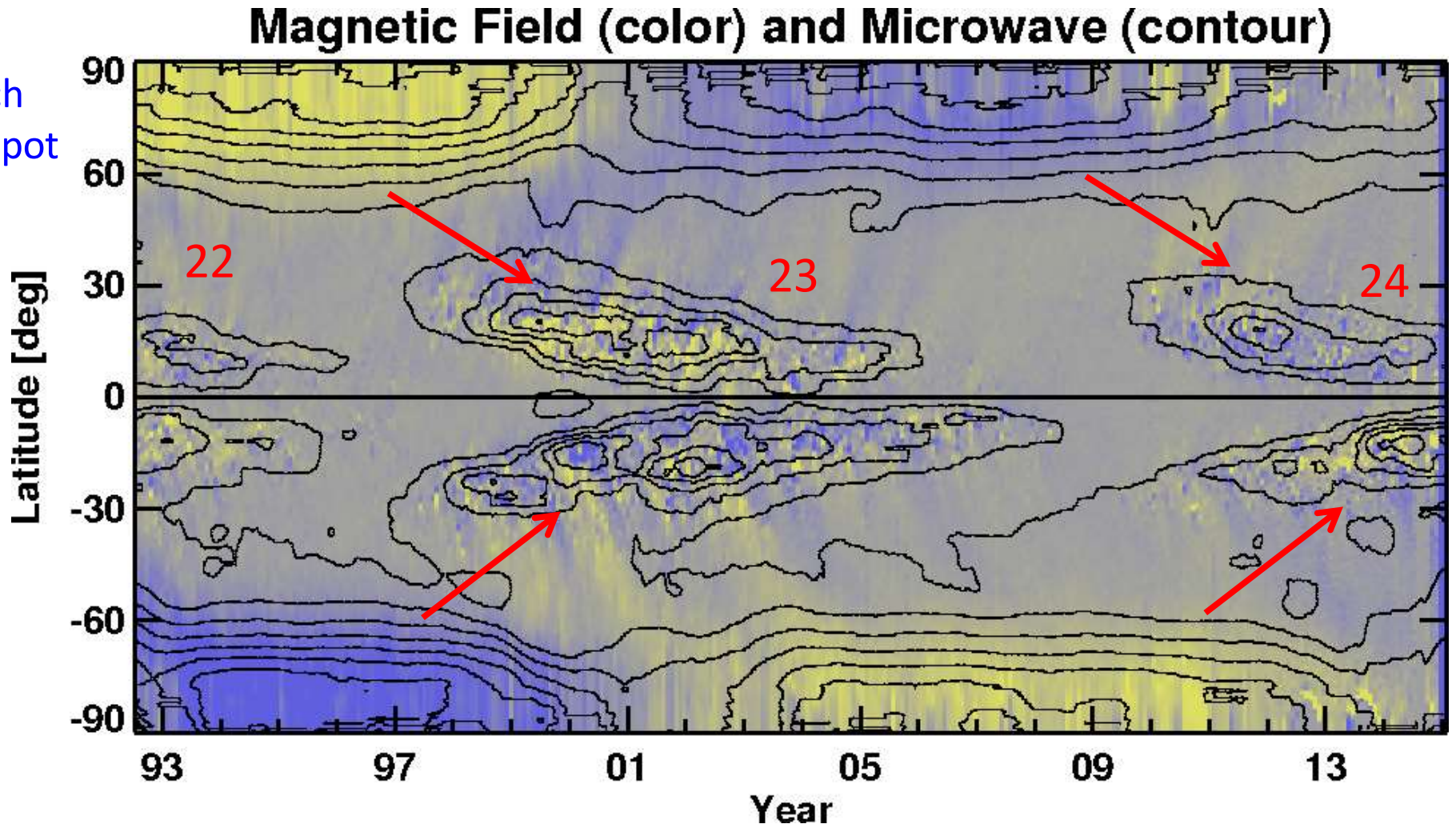
Polar and Equatorial Fields: The Solar Dynamo elements

Polar fields in cycle 23 are much weaker leading to weaker sunspot activity in cycle 24

Will this trend continue?



Weak Solar Cycle 24

The Polar field during cycle 23/24 minimum is smaller than that during 22/23 minimum

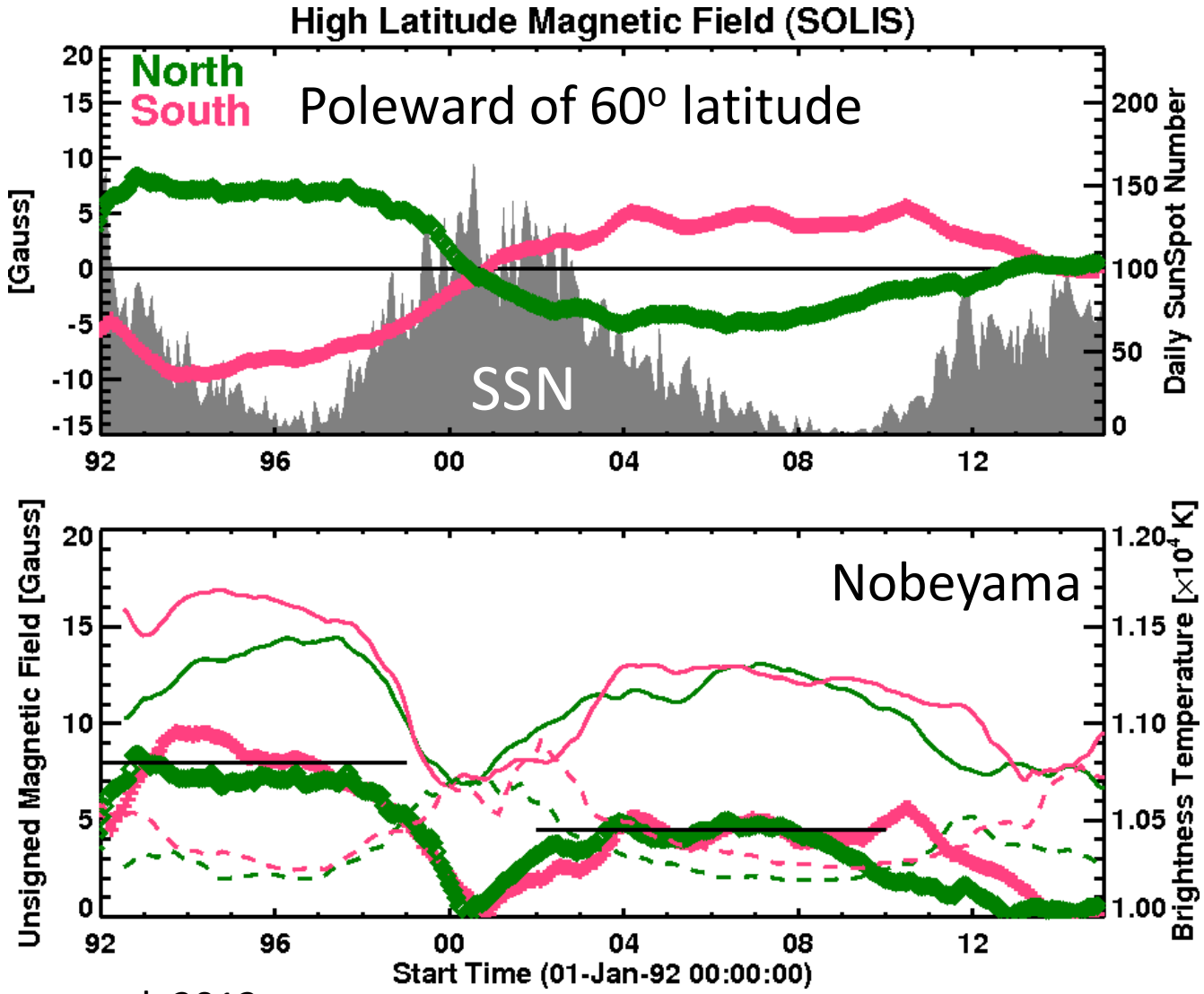
This is also see in microwaves: polar brightness is proportional to polar magnetic field

The low-latitude microwave brightness is from sunspot regions and shows the solar cycle

The Sunspot number and low-latitude microwave brightness are significantly lower in cycle 23

Polar B is not recovering fast in cycle 24

What is the effect on space weather?



updated from Gopalswamy et al. 2012

SEP Rate

SEP Events	Cycle 23*	Cycle24
>10 MeV	58 (0.85/SSN)	35 (0.91/SSN)
>500 MeV	18 (0.26/SSN)	6 (0.16/SSN)
>700 MeV (GLE)	9 (0.52/SSN)	2 (0.05/SSN)

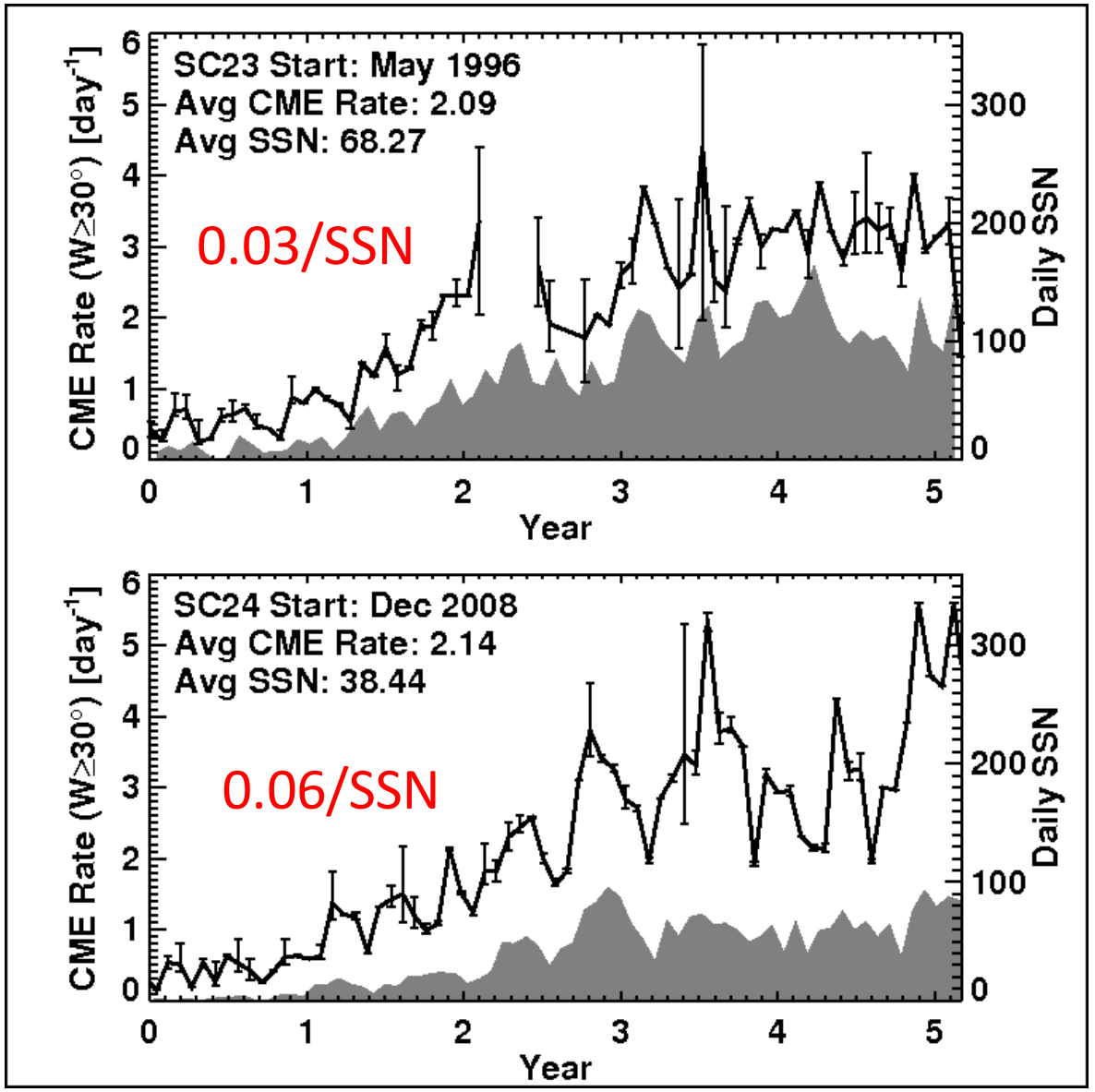
*** Over the corresponding epoch**

>10 MeV SEP Events similar in cycles in 23 &24 when normalized to SSN

>500 MeV Event rate higher in Cycle 23

GLE Event rate much higher in Cycle 23 (lack of high energy SEP Events in cycle 24)

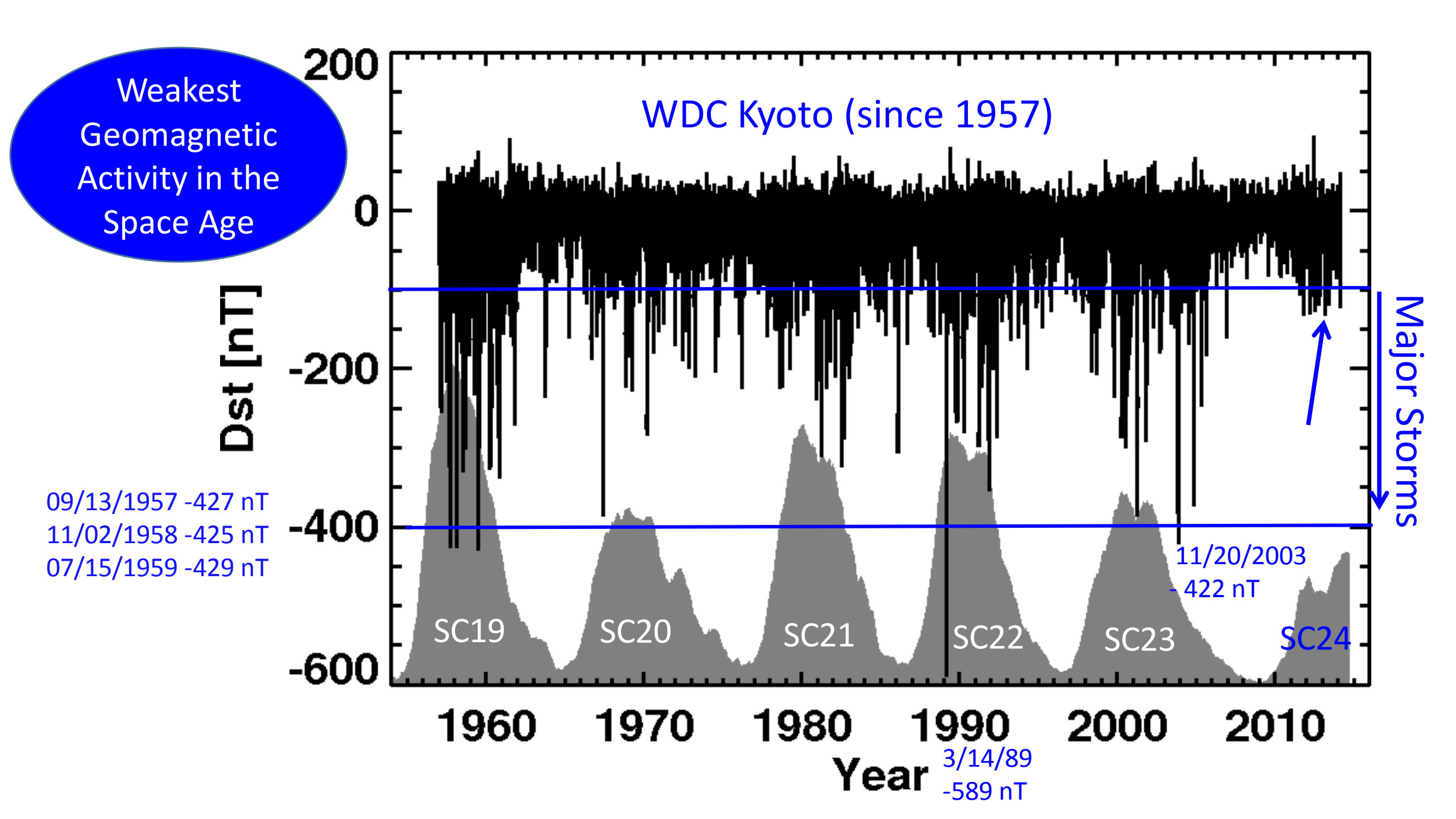
SSN & CME Rate (W≥30°)



Lack of Highest Energy Particles
- Not entirely due to drop in FW CMEs

Property	Cycle 23*	Cycle 24	Ratio
# Large SEP Events	58	35	0.60
# >500 MeV SEP Events	18	6	0.33
# GLE Events	9	2	0.22
Avg CME speed (SEP) km/s	1430	1504	1.08
Halo CME fraction (SEP)	74%	100%	1.35
# FW CMEs	189	142	0.70
Norm. to SSN All/500/GLE	0.85/0.26/0.13	0.91/0.15/0.05	1.1/0.6/0.4

*Same phase as cycle 24 (until 10/2014)


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

Major Geomagnetic Storms of Cycles 23 &24

Weak, Less-frequent Storms
Need more energetic CMEs

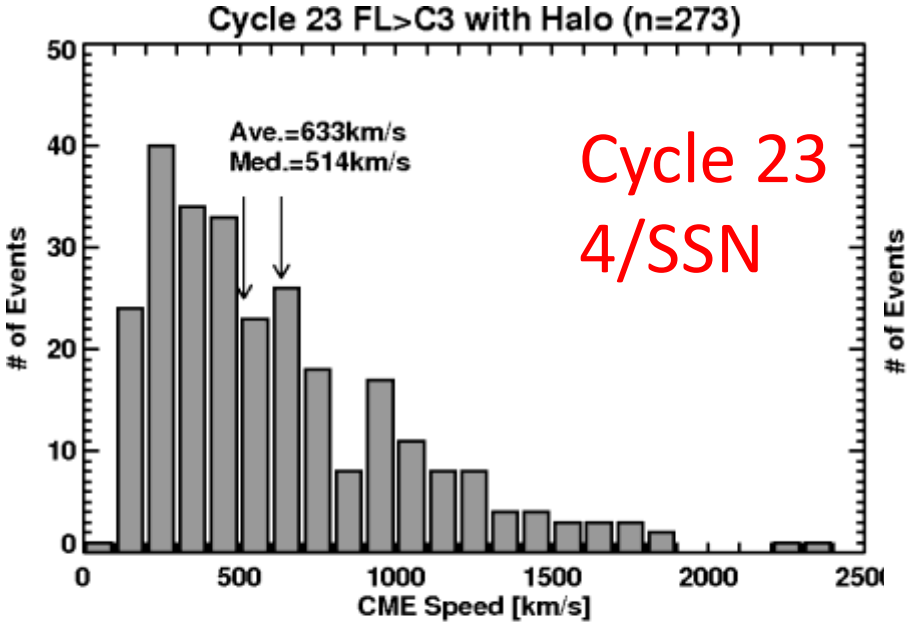
Property	Cycle 23*	Cycle 24	Ratio
# Large magnetic storms	51	12	0.24
# CIR storms	4	1	0.25
# CME storms	47	11	0.23
Avg CME speed (storm) km/s	815	1021	1.25
Halo fraction (storm)	67%	64%	0.96
# FW CMEs	189	142	0.70
Normalized to SSN	0.69	0.29	0.42

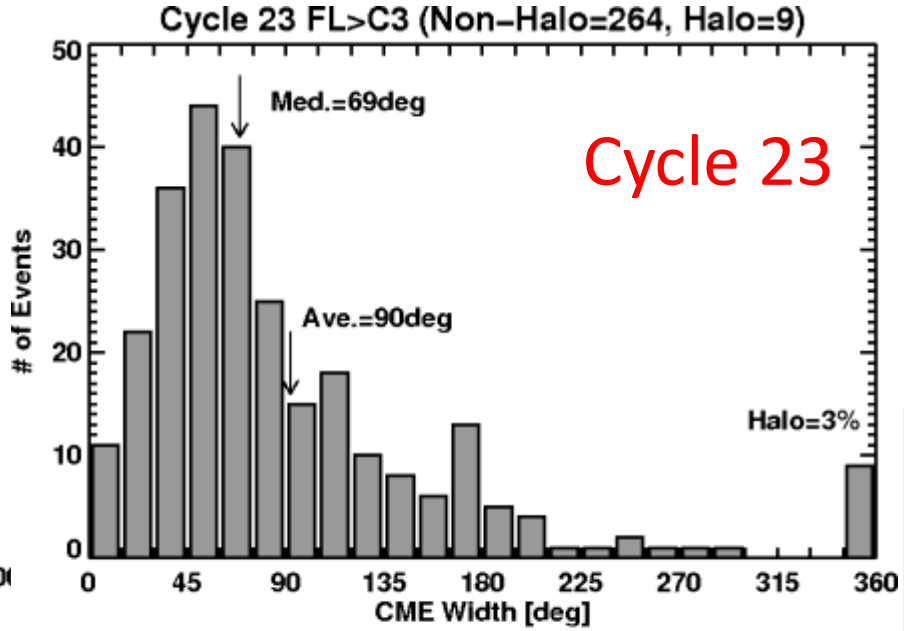
*Over corresponding epoch

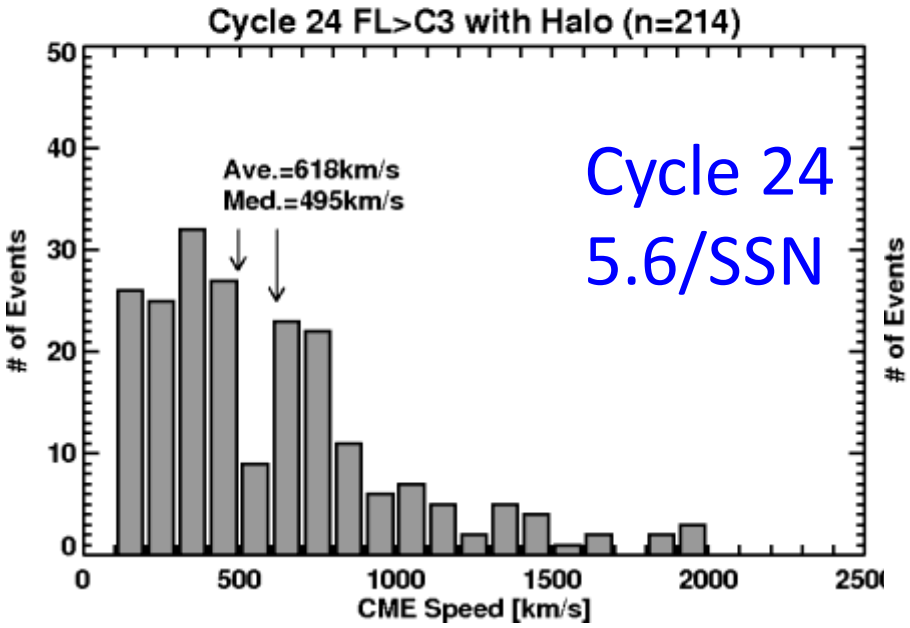
In short…

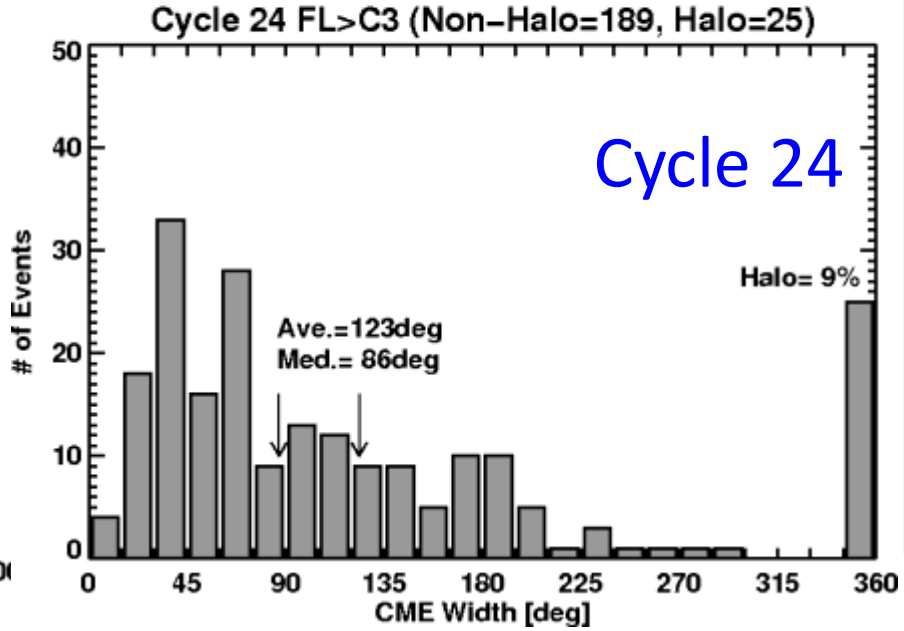
- CMEs are easy on Earth in Cycle 24: Not many high-energy SEP events and major geomagnetic storms
- Number of CMEs relative to SSN is higher in Cycle 24: more weaker CMEs (width $<30^{o}$)
- The solar source (active region) alone cannot explain this mild space weather
- The coronal/IP environment also plays a role
- Clue: All SEP-associated CMEs are halos in Cycle 24

Width distribution is different in Cycle 24









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

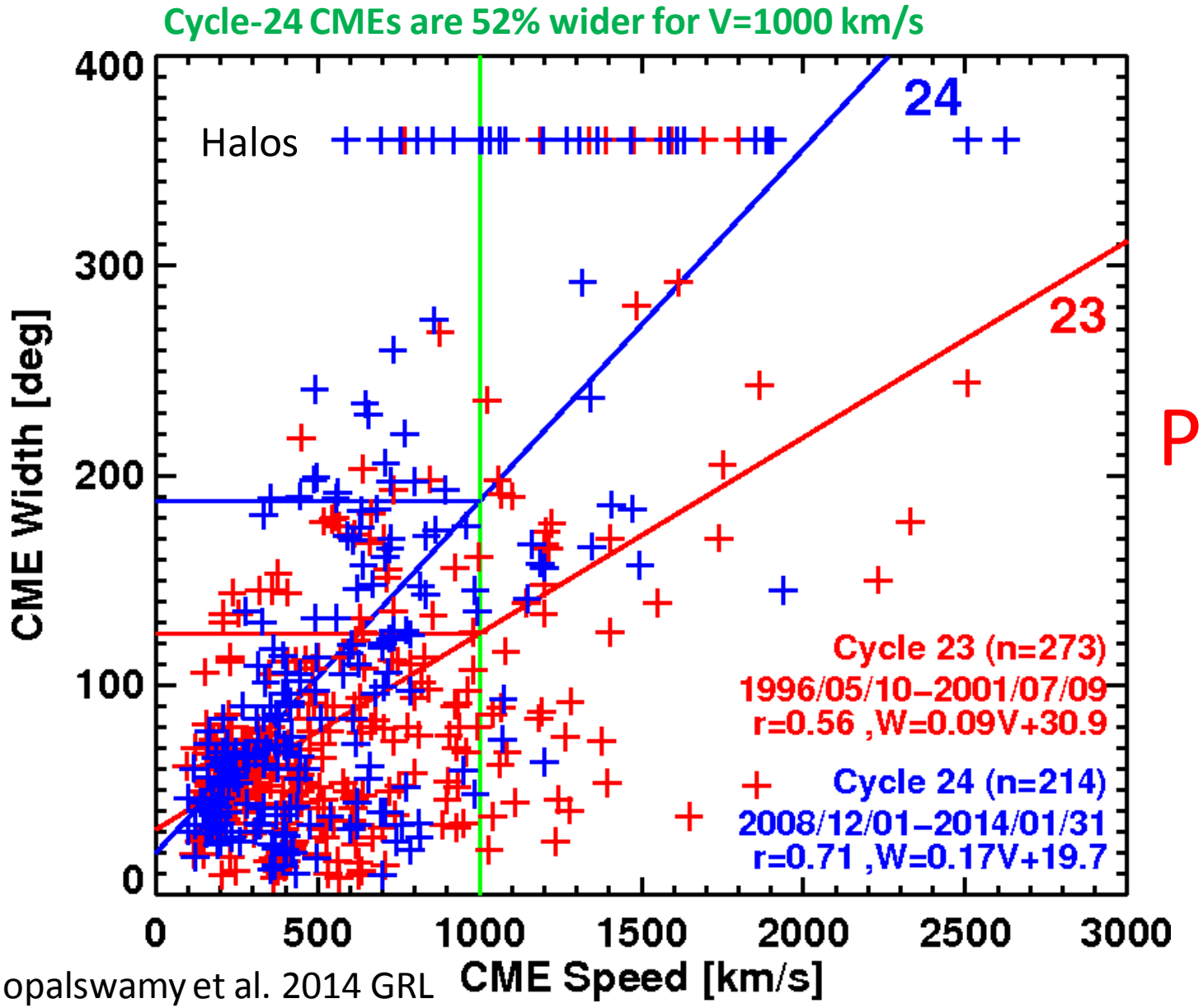
Similar Speed Distributions

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

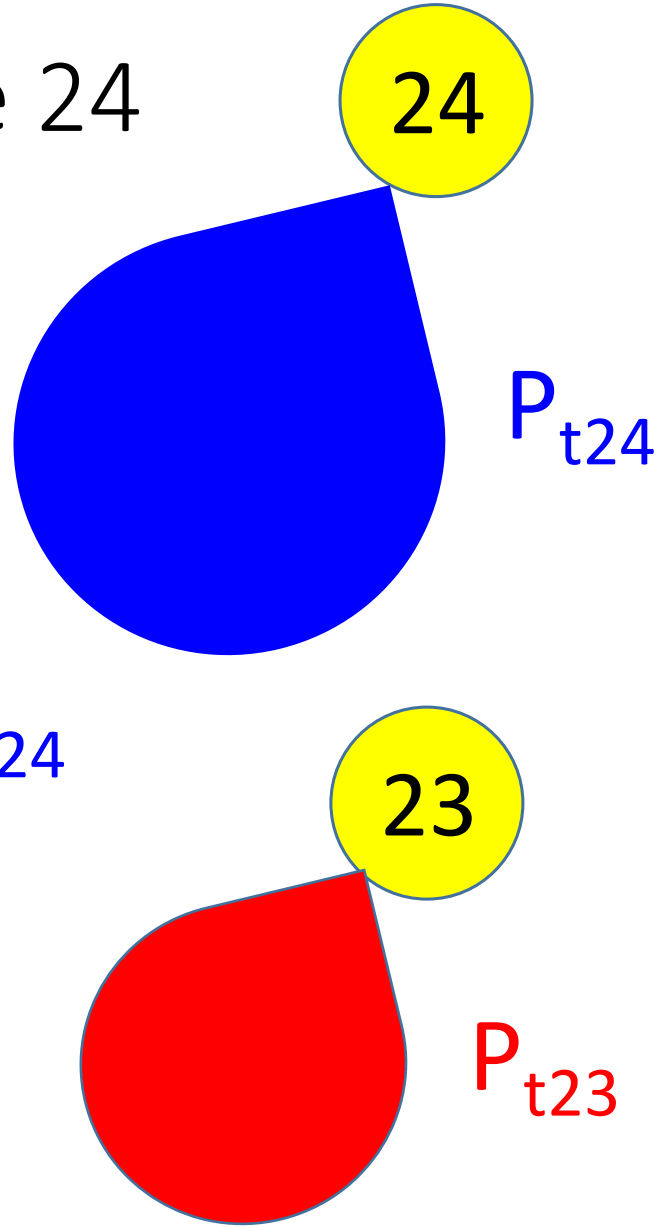
Three times more halos in SC24

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

Anomalous Expansion of CMEs in Cycle 24



Gopalswamy et al. 2014 GRL



Slope is significantly different

For a given speed, cycle 24 CMEs are wider

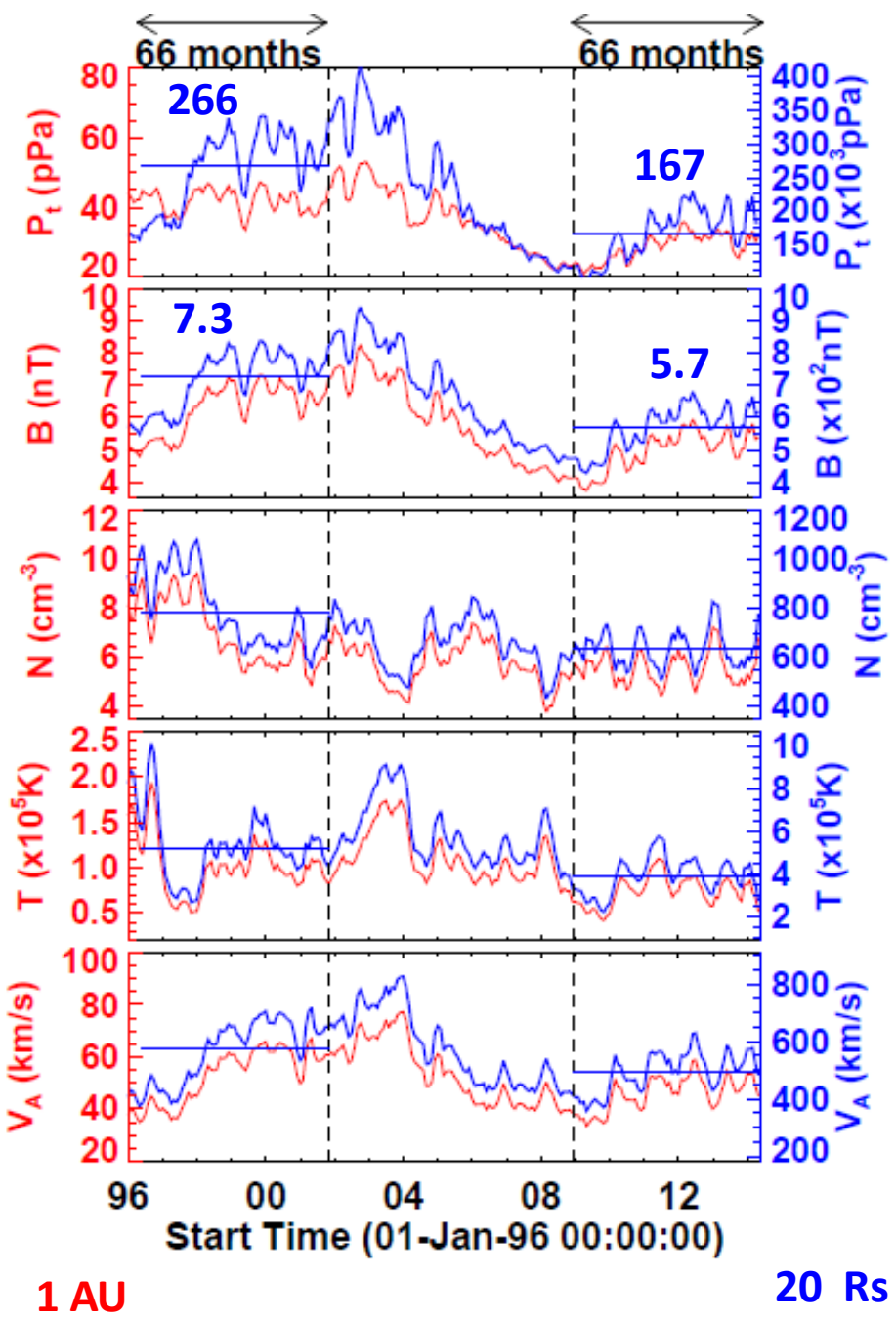
38%

22%

20%

25%

15%



Why do SC 24 CMEs expand more? State of the Heliosphere!

Reduced total Pressure (38%)

→ CMEs expand more

→ This reduces CME magnetic content

→ Cloud storms are weak

Heliospheric Magnetic field is also reduced (22%)

→ Compressed sheath field is weaker

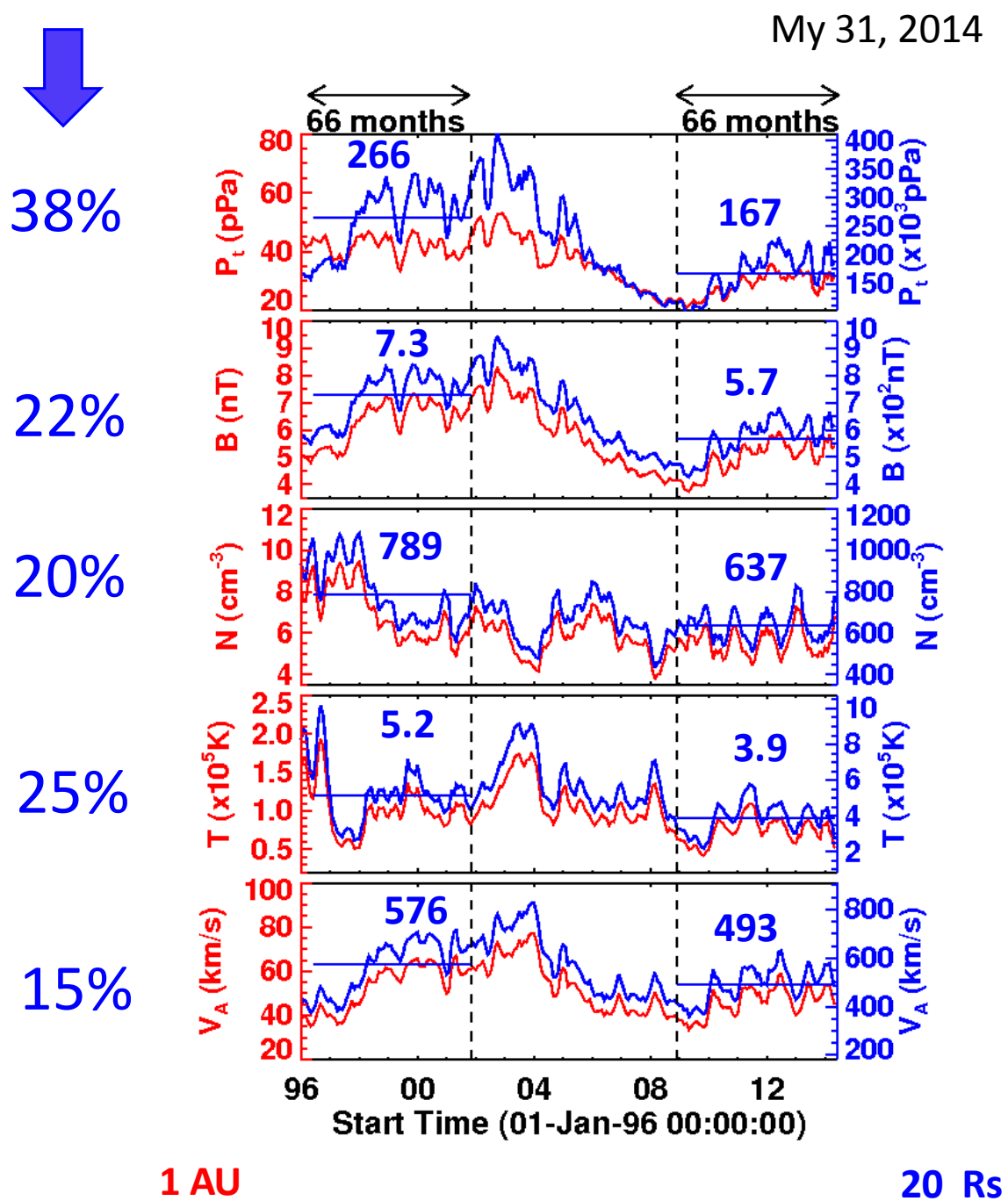
→ This reduces sheath magnetic content

→ Sheath storms are weak

→ CIRs storms are weak

Gopalswamy et al. 2014

State of the Heliosphere



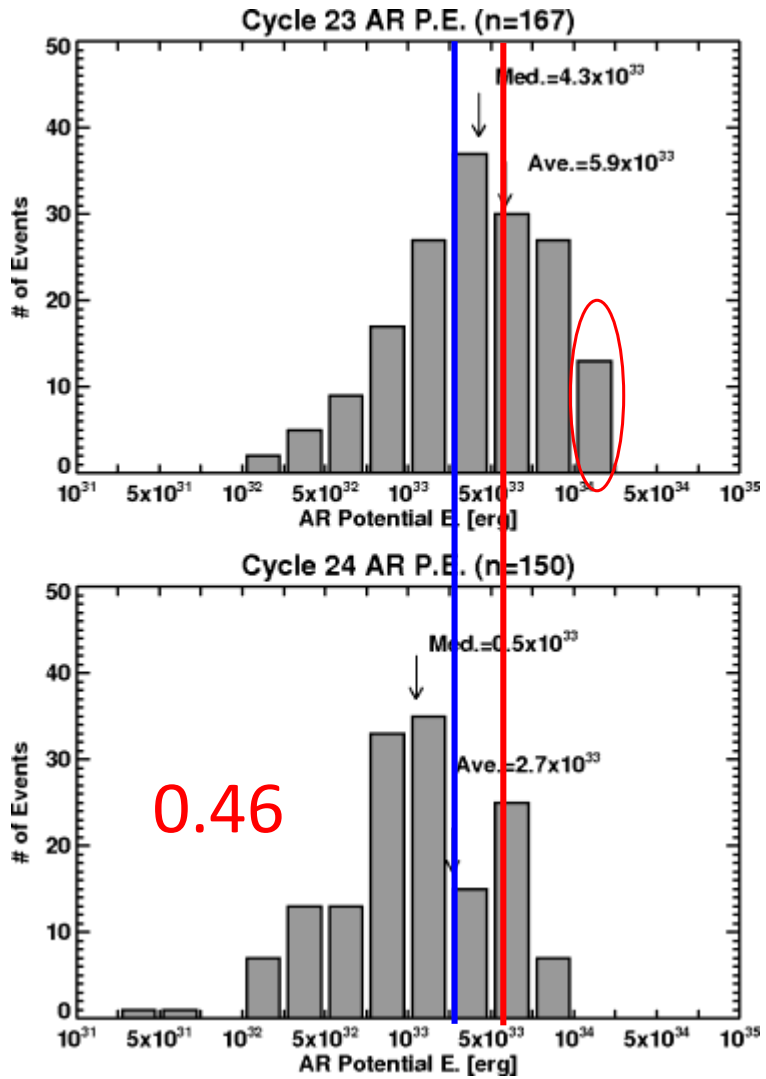
Reduced total pressure
→ CMEs expand more

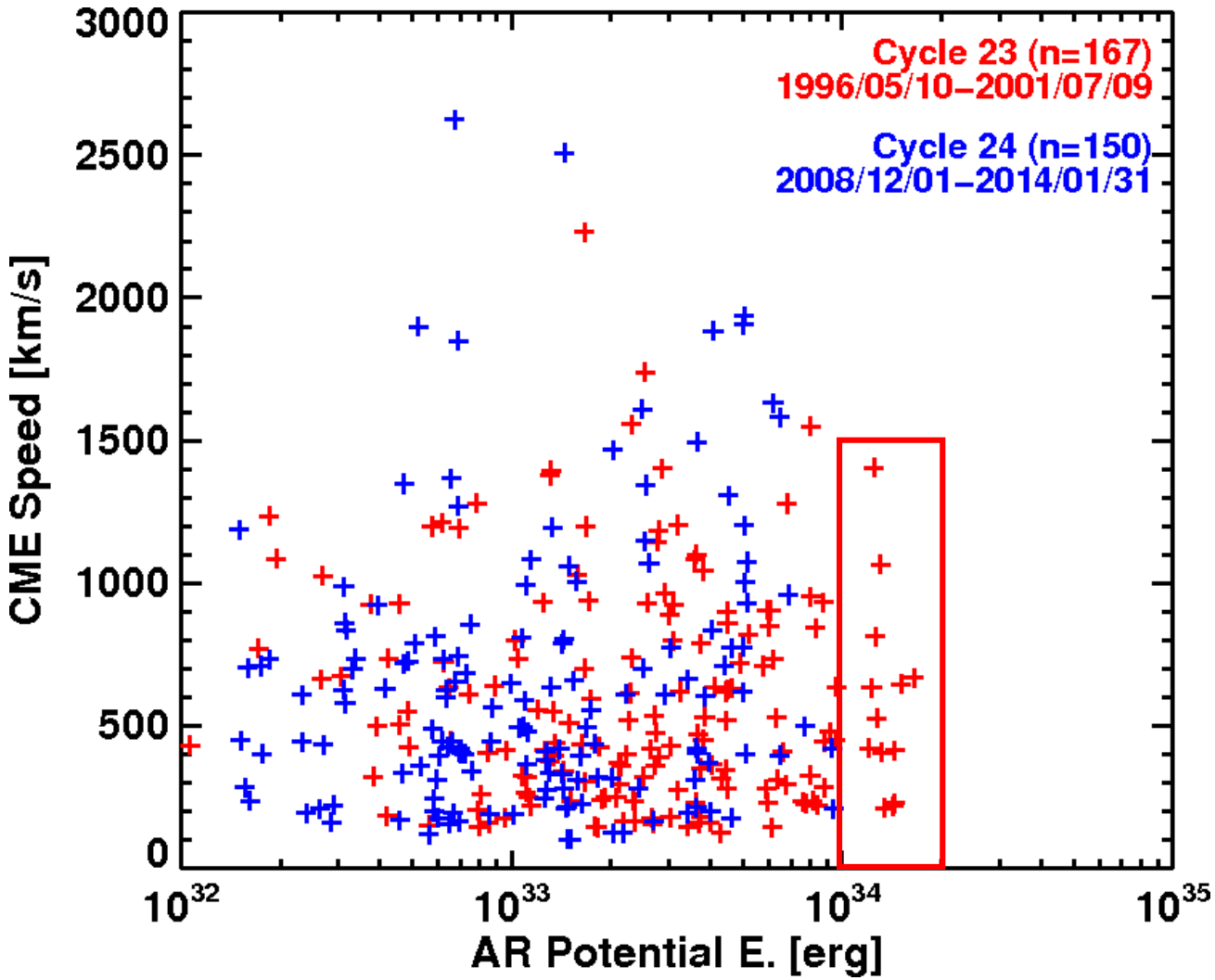
Reduced B
→ Reduced acceleration efficiency (Kirk, 1994)
$dE/dt \propto B$ (rate of energy gain or acceleration time scales $\propto B^{-1}$)
With the available time of ~10 min, it is difficult to accelerate SEPs to GeV energies

Reduced Alfven speed near Sun
→No major reduction in the # SEP Events

Gopalswamy et al. 2014 GRL

AR Potential Energy (Free-energy proxy)



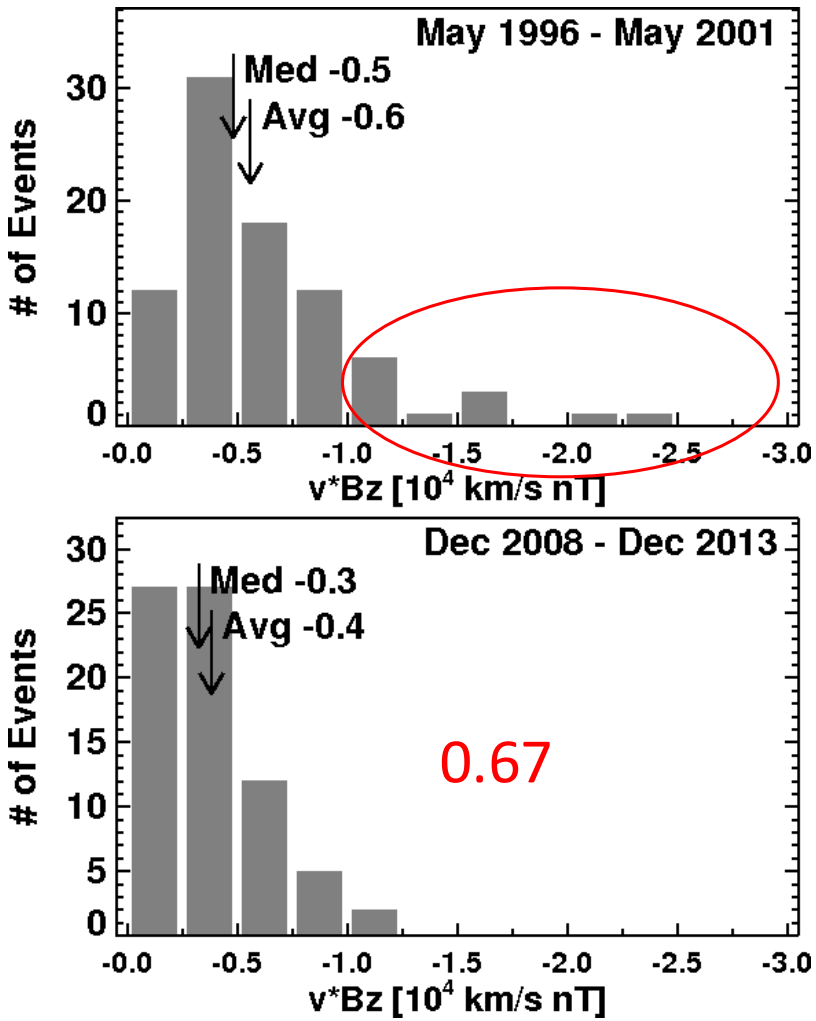


Weak Storm: Due to weak IP field

- 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)



Summary

- Cycle-24 Space Weather is historically mild (space age)
- Weaker CME, sheath, CIR fields
- Weaker CME 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
- Possibility of a further weakness in cycle 25