# Properties of Coronal Holes Causing Intense Geomagnetic Storms in Solar Cycles 23 and 24

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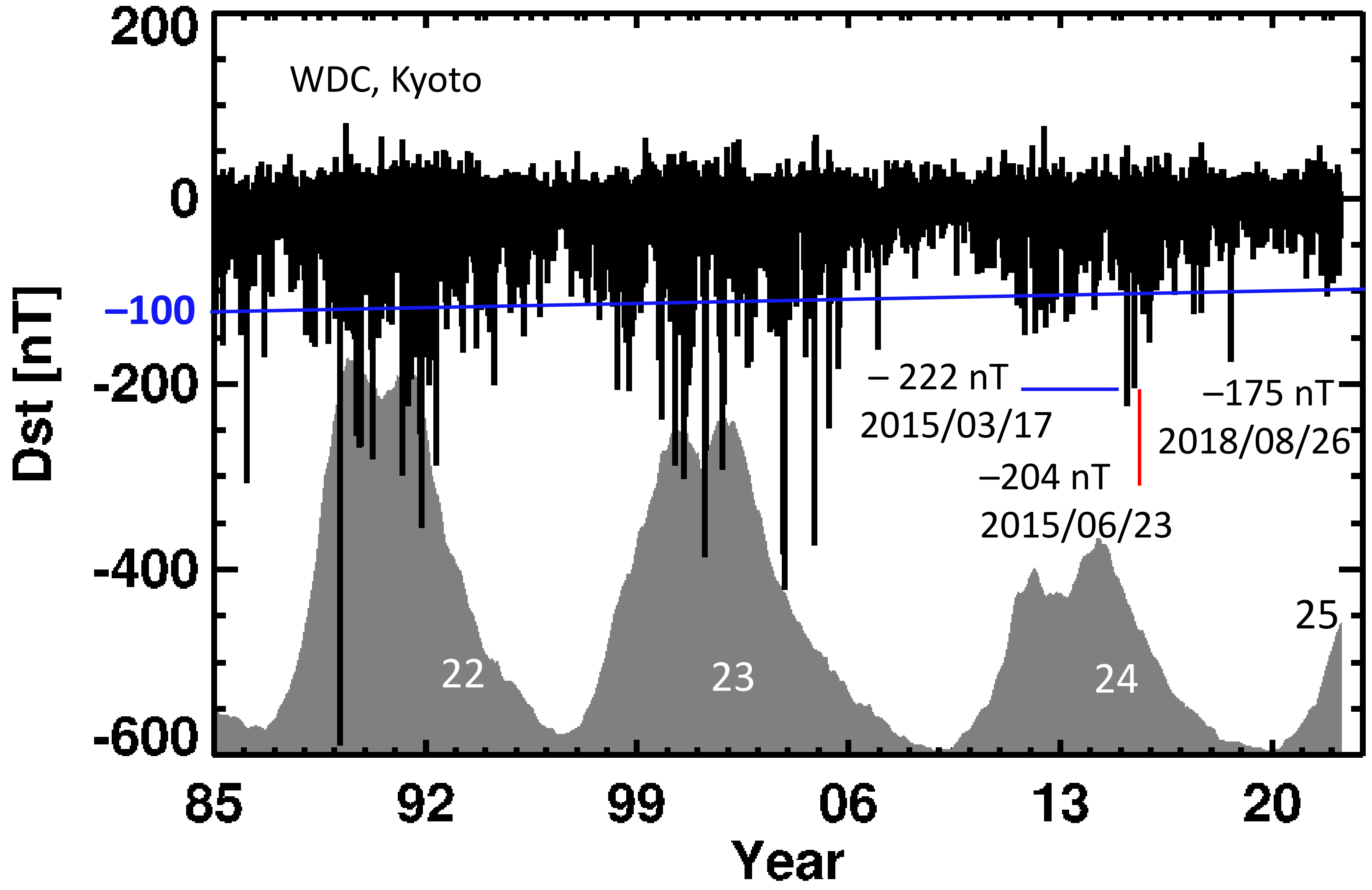
# Cycle 24 has weaker and less frequent storms

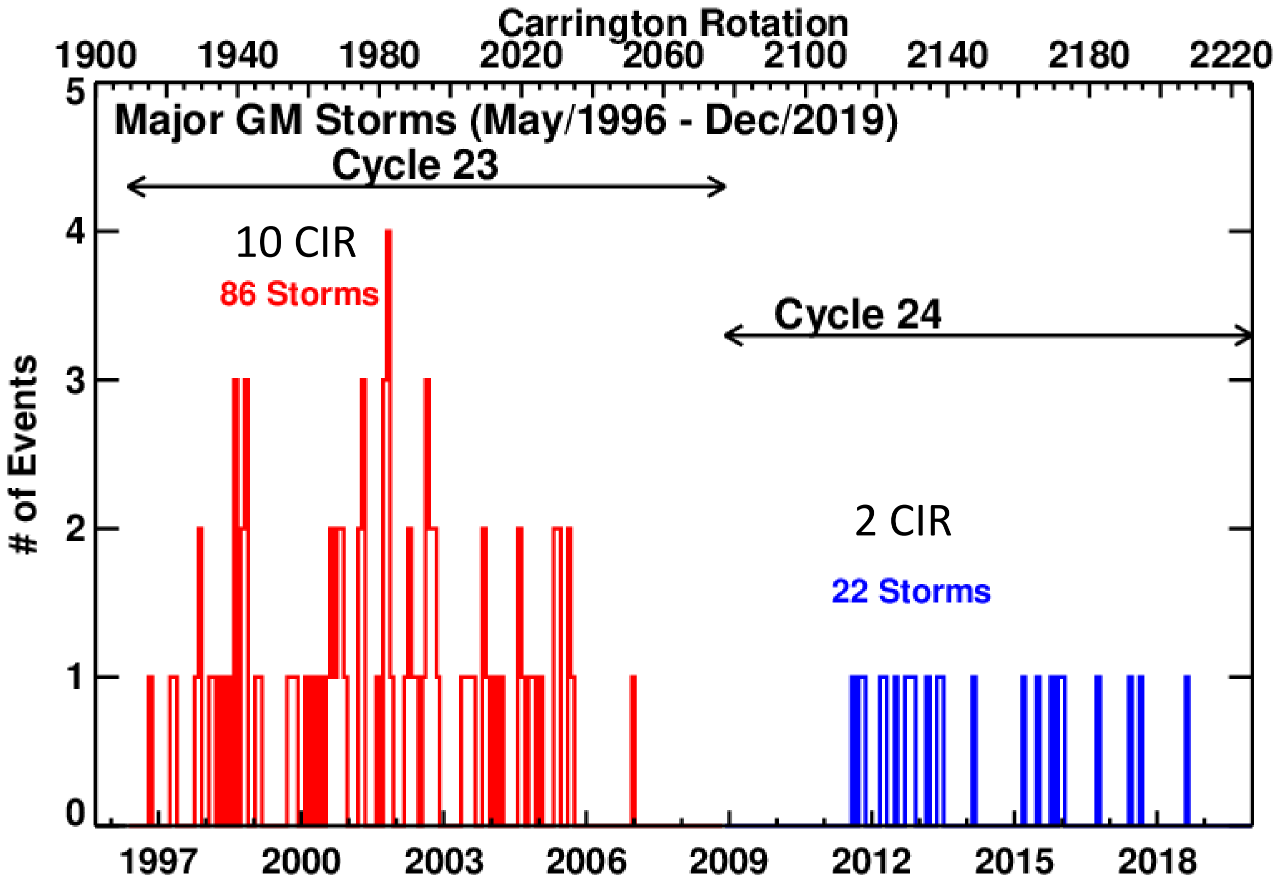



Cycle 24 is the weakest cycle in the space age

Mild space weather
Weak solar activity combined with backreaction of the heliosphere on solar wind structures.

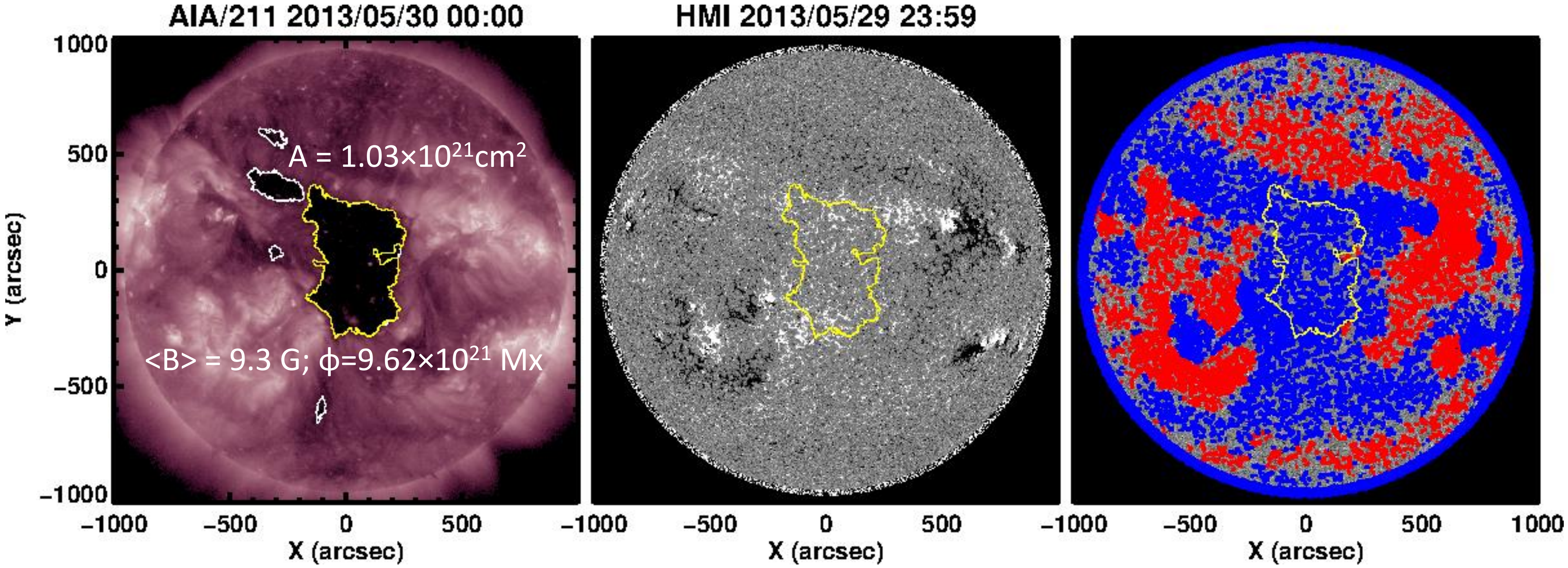
Gopalswamy 2012; Richardson & Cane 2013; Gopalswamy et al. 2014; 2015; Kakad et al. 2019; Hajra 2021

# GM Storms of cycle 24: low intensity, less frequent




Intense storms (Dst ≤ -100 nT)

All storms: 74% reduction
CME storms: 74% reduction
CIR storms: 80% reduction

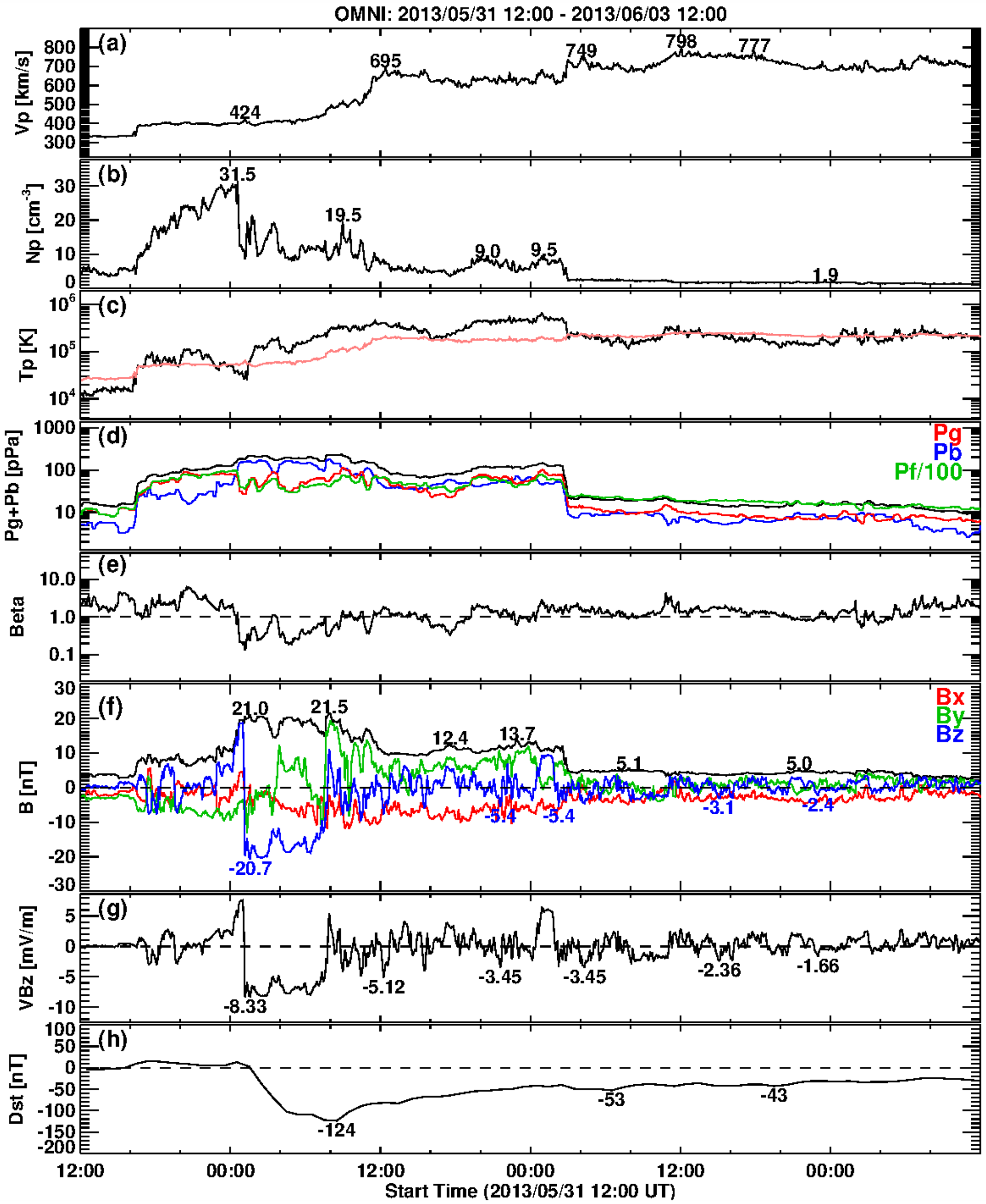

AIA/211 2013/05/30 00:00
HMI 2013/05/29 23:59
A = 1.03×10^21 cm^2
<B> = 9.3 G; ϕ=9.62×10^21 Mx
Y (arcsec)
X (arcsec)
X (arcsec)
X (arcsec)
1000
500
0
−500
−1000
−1000
−500
0
500
−1000
−500
0
500
−1000
−500
0
500
1000

# CIR/HSS

Vpk = 695 km/s
Vint = 424 km/s
Bz = -20.7 nT
Dst = -124 nT

$\int vBsdt = I(Ey) = 151$ Wb/m
$\int Qdt = I(Q) = -200$ nT
$Q(t) = -4.4\,(VBs - 0.49)(P_f/P_0)^{\gamma}$ , VBs > 0.49 mV/m

Murayama 1982; Fenrich &Luhmann 1998; Wang et al. 2003; Xie et al 2008; Le et al. 2020; Zhao et al. 2021



# CIR Storms of cycles 23 and 24

**Table 2**. List of intense storms in cycle 23 and 24 and the associated coronal hole properties

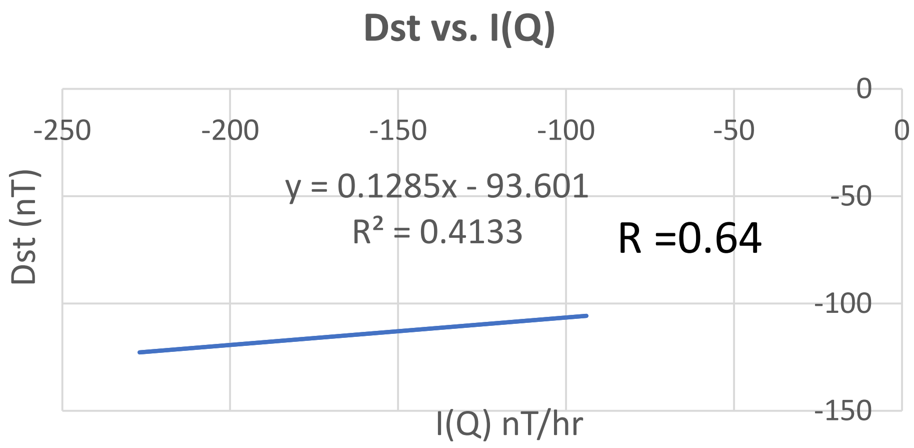
| Dst Date | Time | Dst (nT) | CH Date & Time | Loc. | Pol. | Area ($10^{20}cm^2$) | <\|B\|> (G) | Flux ($10^{21}$ Mx) |
|---|---|---|---|---|---|---|---|---|
| Cycle 23 | | | | | | | | |
| 1996/10/23 | 05:00 | -105 | 1996/10/20 07:03 | N00 | + | 7.33 | 7.3 | 5.35 |
| 1998/03/10 | 21:00 | -116 | 1998/03/08 09:03 | S30 | - | 1.86 | 11.9 | 2.22 |
| 1998/08/07 | 06:00 | -108 | 1998/08/04 04:14 | ??? | + | ---- | ---- | ---- |
| 2002/09/04 | 06:00 | -109 | 2002/08/31 06:48 | S15 | + | 9.39 | 15.6 | 14.7 |
| 2002/10/07 | 08:00 | -115 | 2002/10/05 01:48 | S07 | + | 24.6 | 20.0 | 49.2 |
| 2002/10/14 | 14:00 | -100 | 2002/10/11 02:39 | N25 | - | 8.50 | 18.9 | 16.1 |
| 2002/11/21 | 11:00 | -128 | 2002/11/18 13:21 | S04 | + | 8.40 | 12.5 | 10.5 |
| 2003/07/12 | 06:00 | -105 | 2003/07/07 21:40 | N04 | - | 6.61 | 10.9 | 7.20 |
| 2004/02/11 | 18:00 | -93 | 2004/02/10 09:24 | N02 | - | 17.6 | 11.2 | 19.7 |
| 2005/05/08 | 19:00 | -110 | 2005/05/07 01:36 | N10 | - | 20.6 | 16.5 | 34.0 |
| 2005/08/31 | 20:00 | -122 | 2005/08/29 10:48 | S12 | + | 18.0 | 17.0 | 30.6 |
| 2006/04/14 | 10:00 | -98 | 2006/04/12 17:59 | N02 | - | 4.77 | 9.2 | 4.41 |
| Cycle 24 | | | | | | | | |
| 2013/06/01 | 09:00 | -124 | 2013/05/30 00:00 | N00 | + | 10.3 | 9.3 | 9.62 |
| 2015/10/07 | 23:00 | -124 | 2015/10/05 08:00 | S05 | + | 9.60 | 7.3 | 7.03 |
| 2016/03/06 | 22:00 | -98 | 2016/03/02 17:15 | S08 | - | 1.70 | 8.0 | 1.36 |

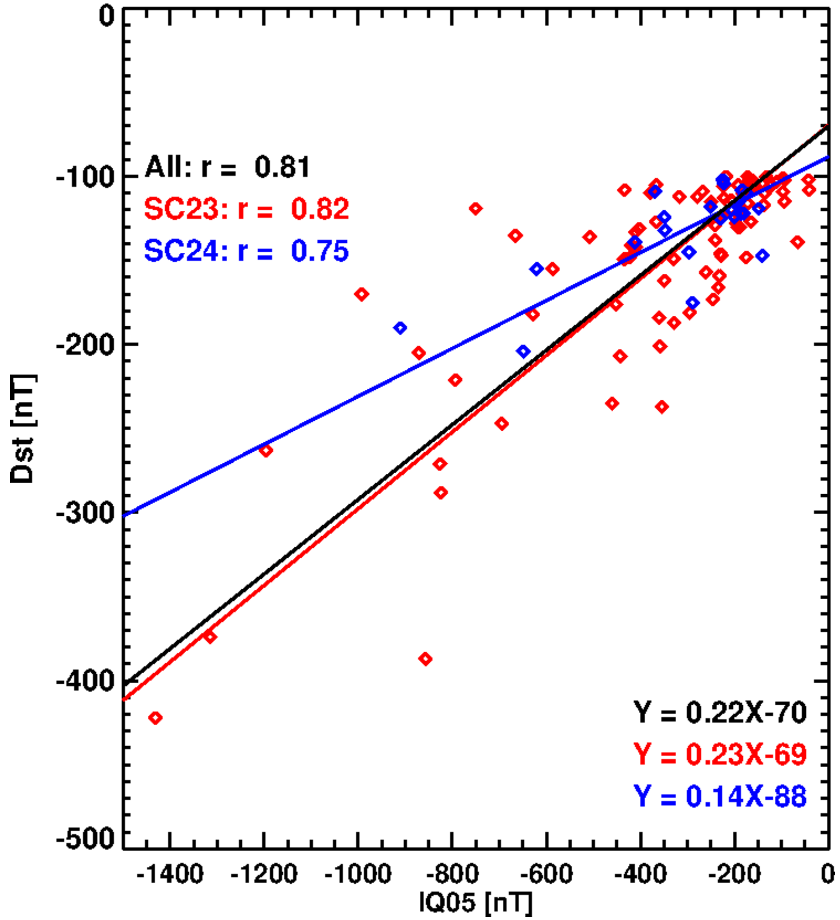
Average B 8.2 G vs 13.7 G (-40%)
Area 7.2x$10^{20}$ $cm^2$ vs 11.6 x$10^{20}$ $cm^2$ (-38%)
Flux 6.0×$10^{21}$ Mx vs. 1.76x$10^{22}$ Mx (-66%)
Vpk 712 km/s vs. 643 km/s (10%)
Vint 408 km/s vs. 450 km/s (-9%)

Nakagawa et al. 2019 (A, V smaller)
Grandin et al. 2019
(lower geoeffectiveness)

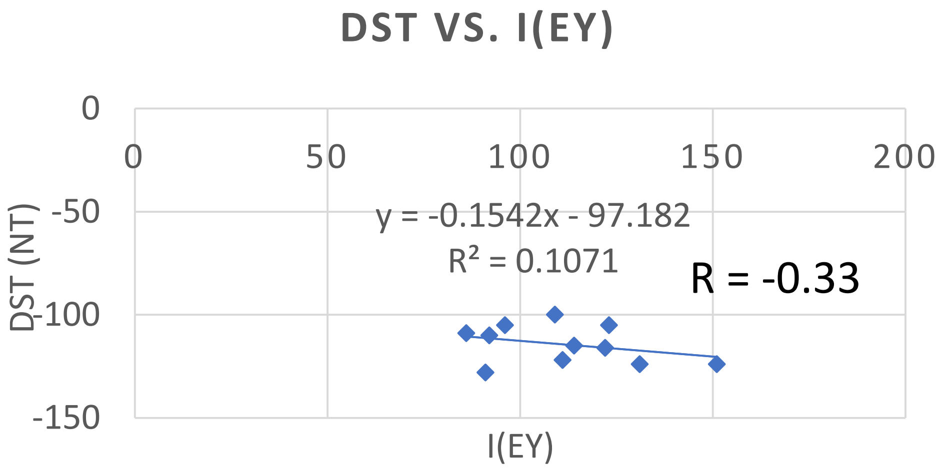
Heliospheric state weaker in cycle 24

# Comparison with CME Storms

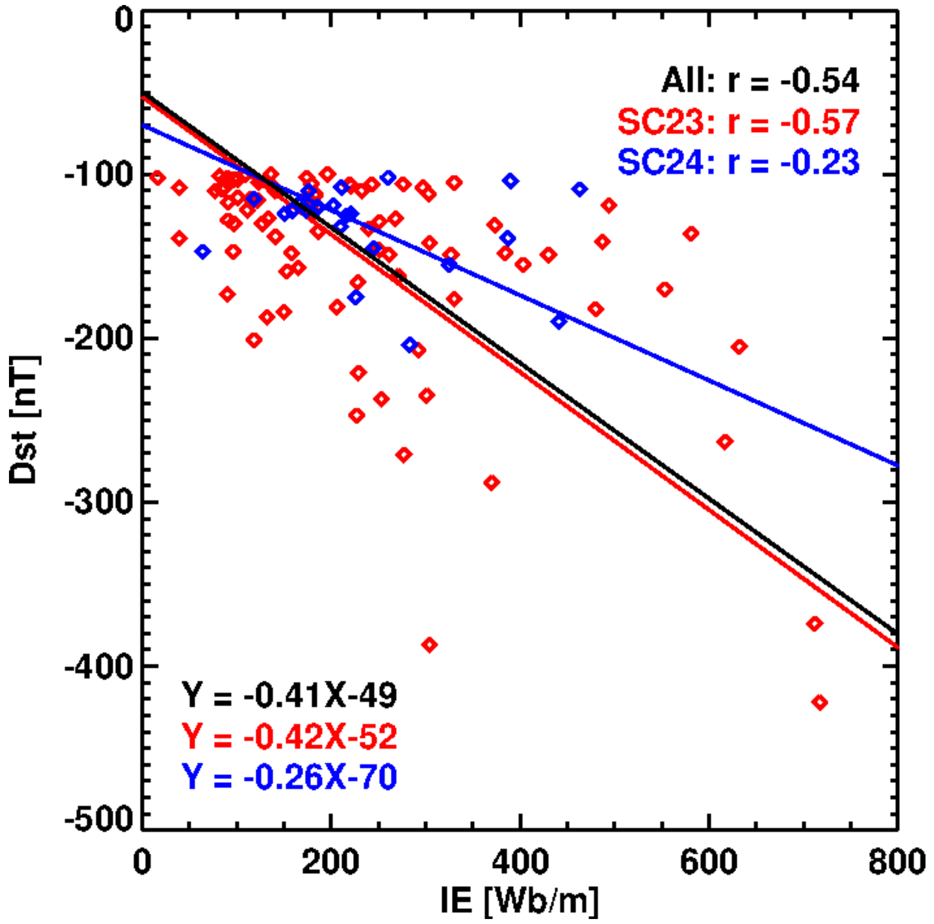


# Weaker Correlation between I(Ey) and Dst



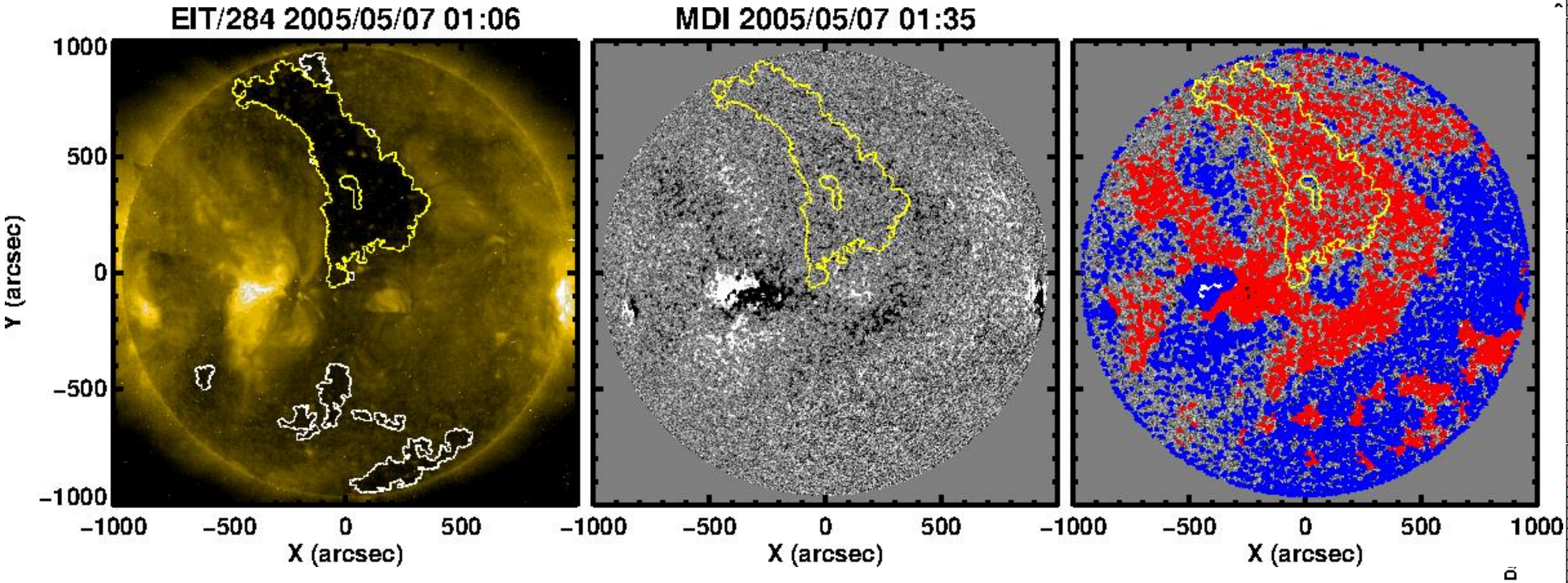

CIR Storms

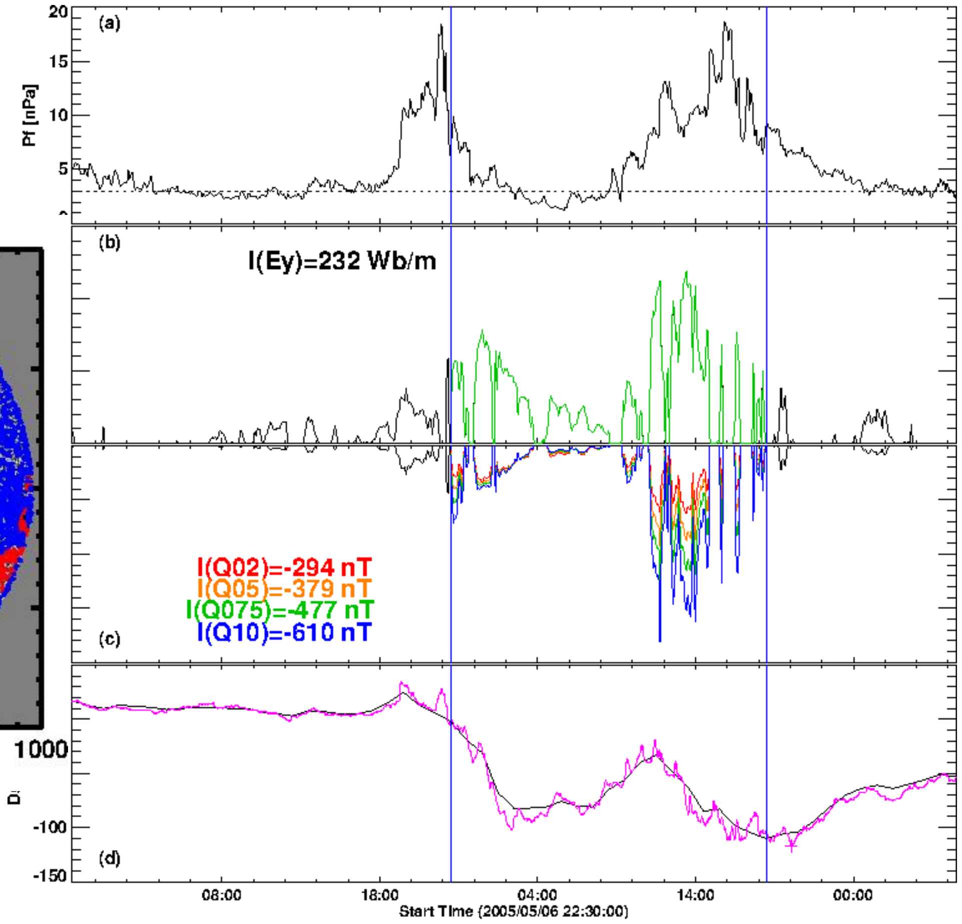



All Storms

# Double Dip CIR Storms

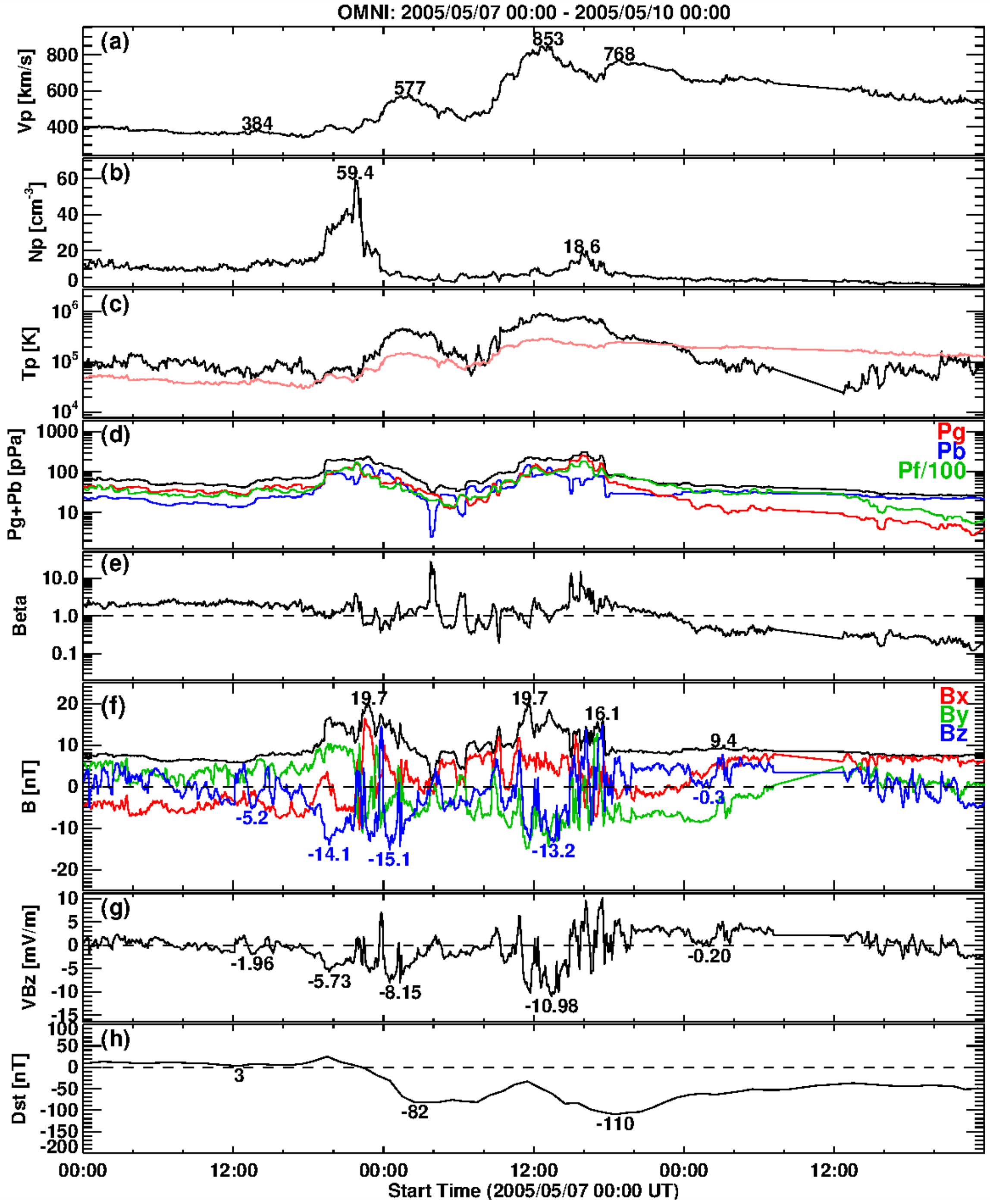
Longitudinal structure of the coronal hole seems to be responsible for the double dip




Kamide et al. 1998; Zhang et al. 2008 double dip due to sheath & cloud storms

# Two Dips due to two Bz<0 intervals



# Summary

- There was a reduction in the number of intense storms in SC 24
- The number of CIR storms dropped from 10 to 2 (-80%)
- CH area, average magnetic field dropped by ~40% in cycle 24
- The storm-causing HSS speed is similar in the two cycles → only occasionally the compression is high enough to cause intense storms
- Dst – I(Q) correlation is significant, but lower than that for CME storms
- Dst – I (Ey) correlation is much weaker, but the trend is similar to CME storms
- Confirms the importance of dynamic pressure in enhancing the ring current energy