Diurnal anisotropy enhancement due to non-local effects of coronal mass ejections

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Key points: In neutron monitor data at cutoff rigidity ~17 GV, short-term modulation events in Jan. & July 2012 exhibited two-week, symmetric decreases in count rate and sharp increases in diurnal anisotropy along –*y*, due to non-local effects of CME shocks and diffusive cross-field inflow leading to count rate recovery.

Neutron monitor count rates
at low cutoff vs.
high geomagnetic cutoff:

At high cutoff, sporadic &
long-term variations are much weaker,
but diurnal variation remains and often
dominates.

An 18NM64 at high altitude & cutoff,
such as the Princess Sirindhorn Neutron
Monitor at Doi Inthanon, Thailand (cutoff
~17 GV), provides a clean measurement
of solar diurnal anisotropy.

Station
(geomagnetic
cutoff, GV)

South Pole NM

& bares (0.1)

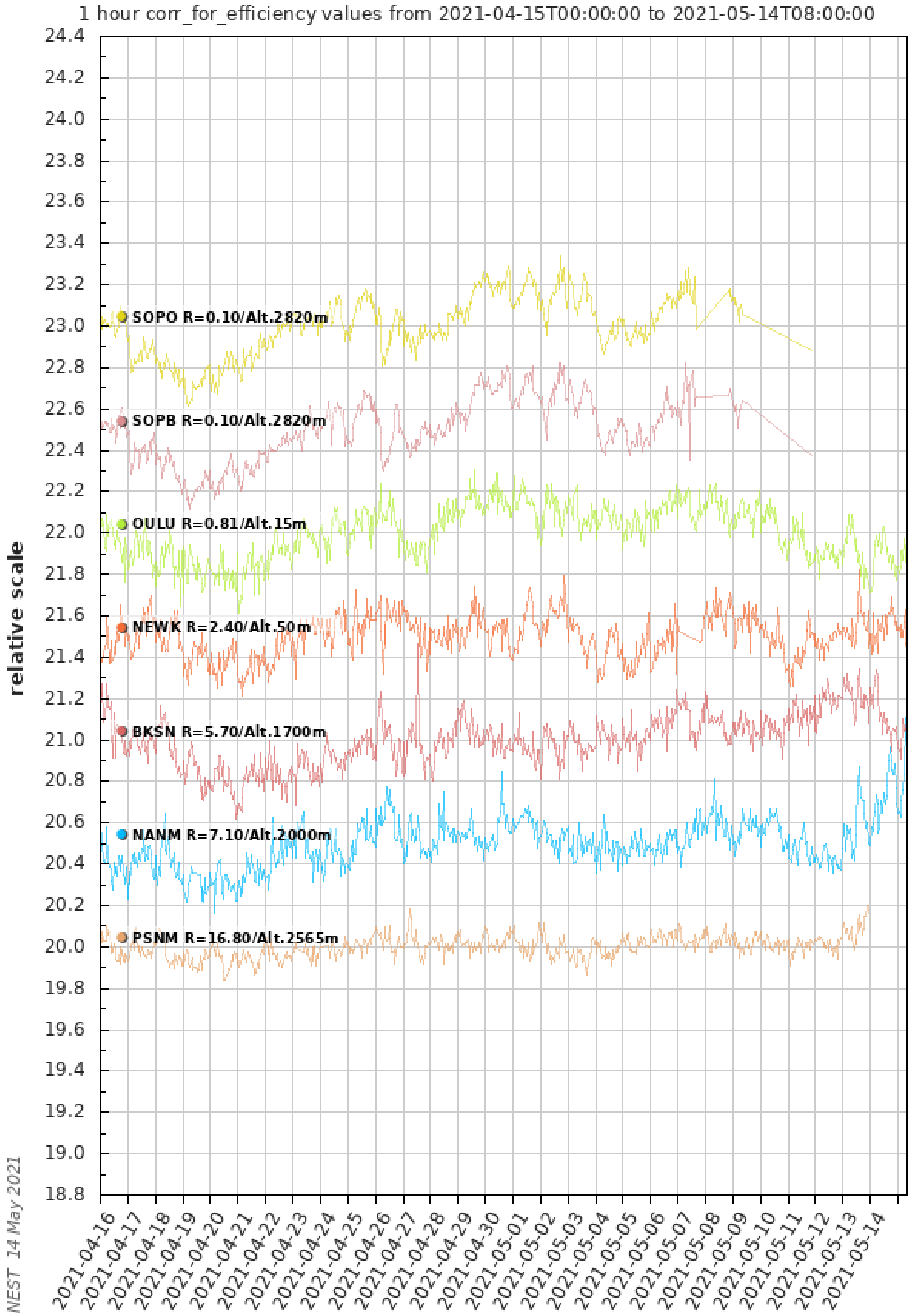
Oulu (0.81)

Newark (2.4)

Baksan (5.7)

Nor-Amberd (7.1)

Doi Inthanon (16.7)



Plotted with https://www.nmdb.eu/nest/

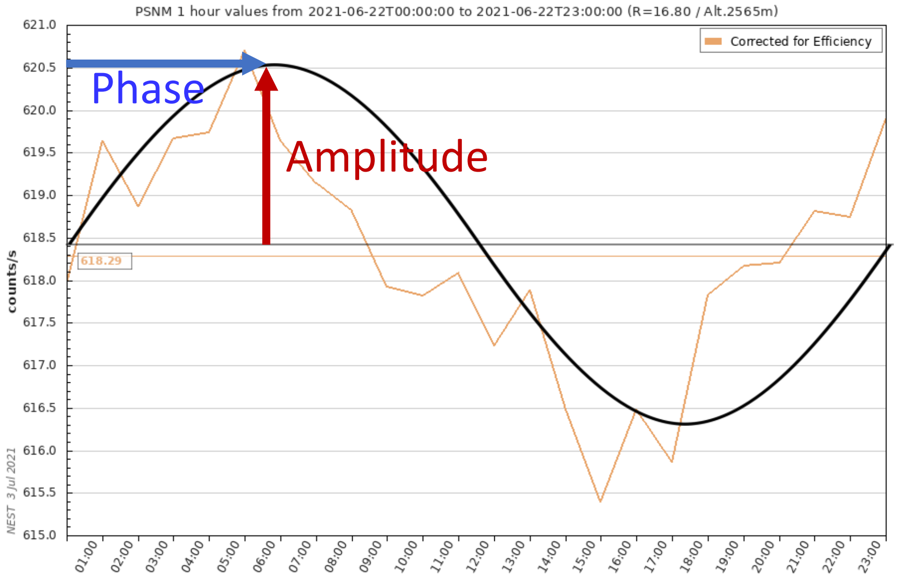
Solar diurnal anisotropy

	Mechanism	*Associated with*	*Depends on sign of **B**?*
1.	Parallel diffusion	rapid flux changes	No
2.	Parallel flow	rapid flux changes	No
3.	Perpendicular diffusion	slow flux changes	No
4.	Perpendicular drifts	solar magnetic polarity	Yes
5.	Gradient anisotropy	$\mathbf{B} \times \nabla n$	Yes

Observation at higher cutoff rigidity

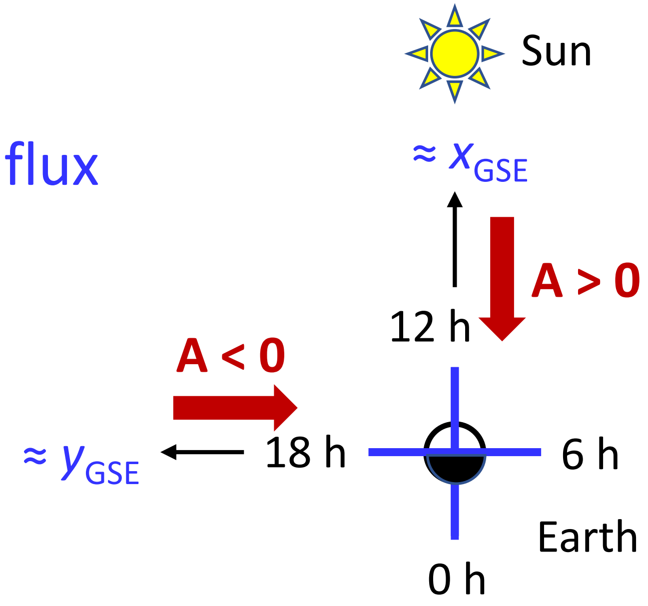
- Particles have large gyroradius (at 17 GV, *R* ~ 0.07 AU or 4 degrees heliolongitude/latitude)
- More sensitive to gradient anisotropy, e.g., from latitudinal cosmic ray gradient
- Less sensitive to small structures (ICMEs)
- Still sensitive to large structures (shocks)

1^{st}-order harmonic analysis of diurnal anisotropy



Data plotted with https://www.nmdb.eu/nest/

- Excess over 24-h running average is fit to a sinusoidal curve (vary day boundary to estimate uncertainty)
- Consider set of asymptotic viewing directions: matrix of coupling coefficients
- Convert to local time at the station
- Report phase as local time of max. cosmic ray flux
- Obtain flow vector ***S***:
  - S_x component (from 0 h local time, roughly along x_{GSE})
  - S_y component (from 6 h local time, roughly along y_{GSE})



Doi Inthanon diurnal anisotropy & count rate, and solar wind parameters, 2008-2019 (7-day averages)

Anisotropy (flow) vector

Mostly varies along –y (corotational) direction

Phase *is close to 18 h for A>0, close to 12 h for A<0*

Anisotropy magnitude

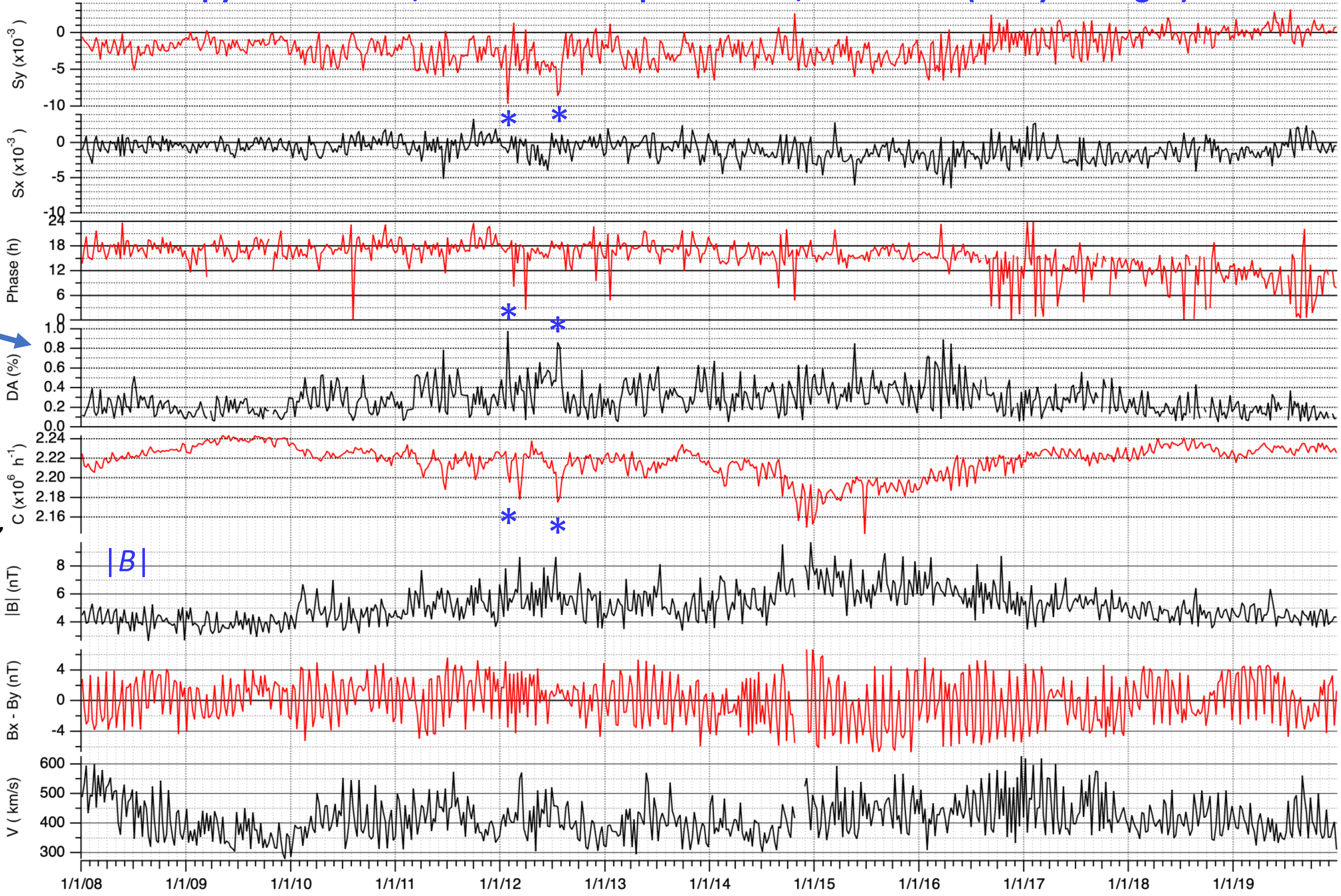
Moderate variation with sunspot cycle, interesting shorter-term phenomena

Count rate

varies 3% with sunspot cycle, Forbush decreases, short-term modulation events, 27-day variations

B_x-B_y *indicates sectors; affects gradient anisotropy*

Solar wind speed



Sunspot min., *A* < 0 ... Sunspot max. ... *A* > 0, Sunspot min.

Doi Inthanon diurnal anisotropy & count rate, and solar wind parameters, 2012 (7-day running averages)

Short-term modulation events (non-local shock effects)

Anisotropy (flow) vector
Mostly varies along –y (corotational) direction

Phase *is close to 18 h for A>0 (corotational)*

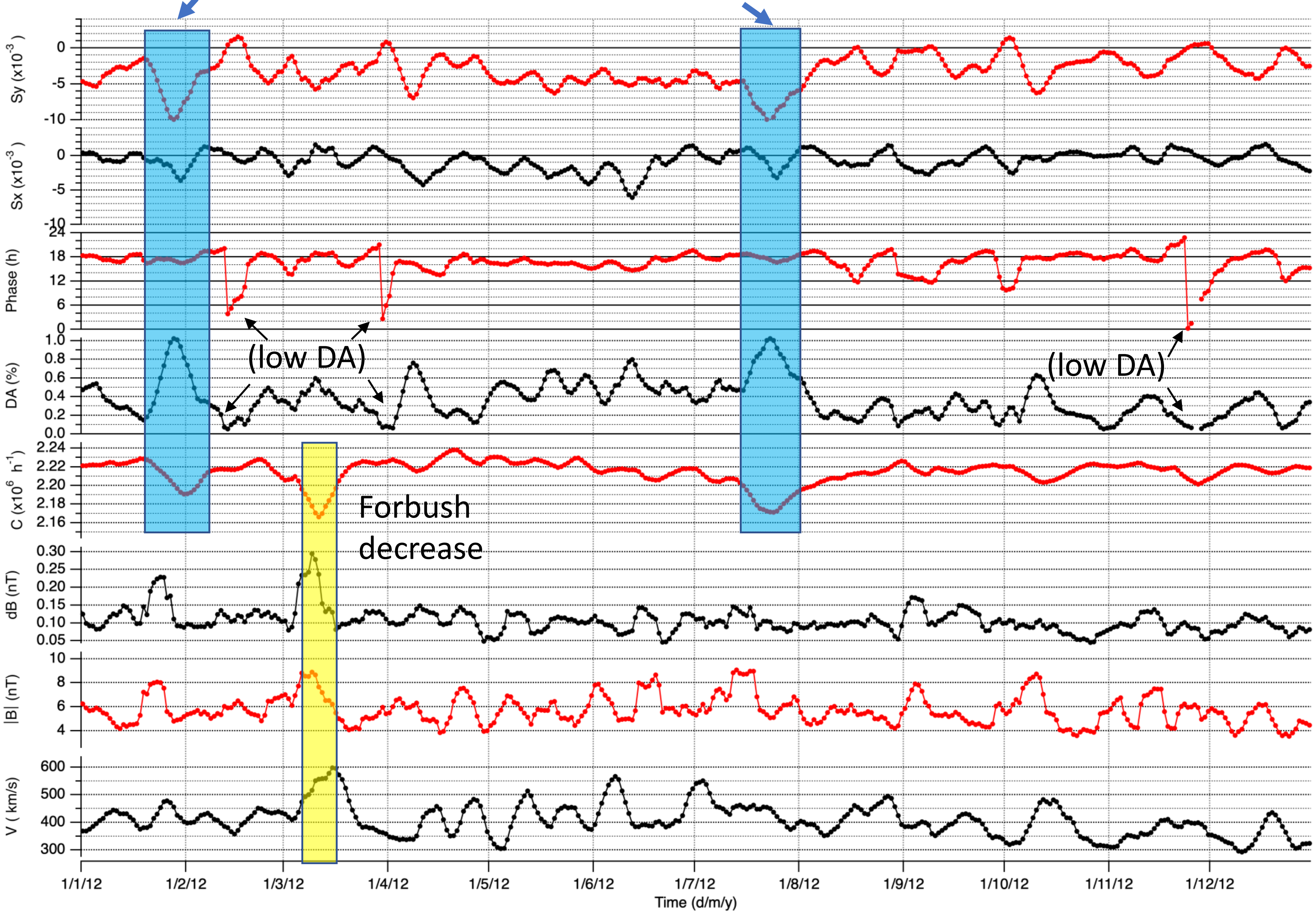
Anisotropy magnitude
(if very low, then phase is not meaningful)

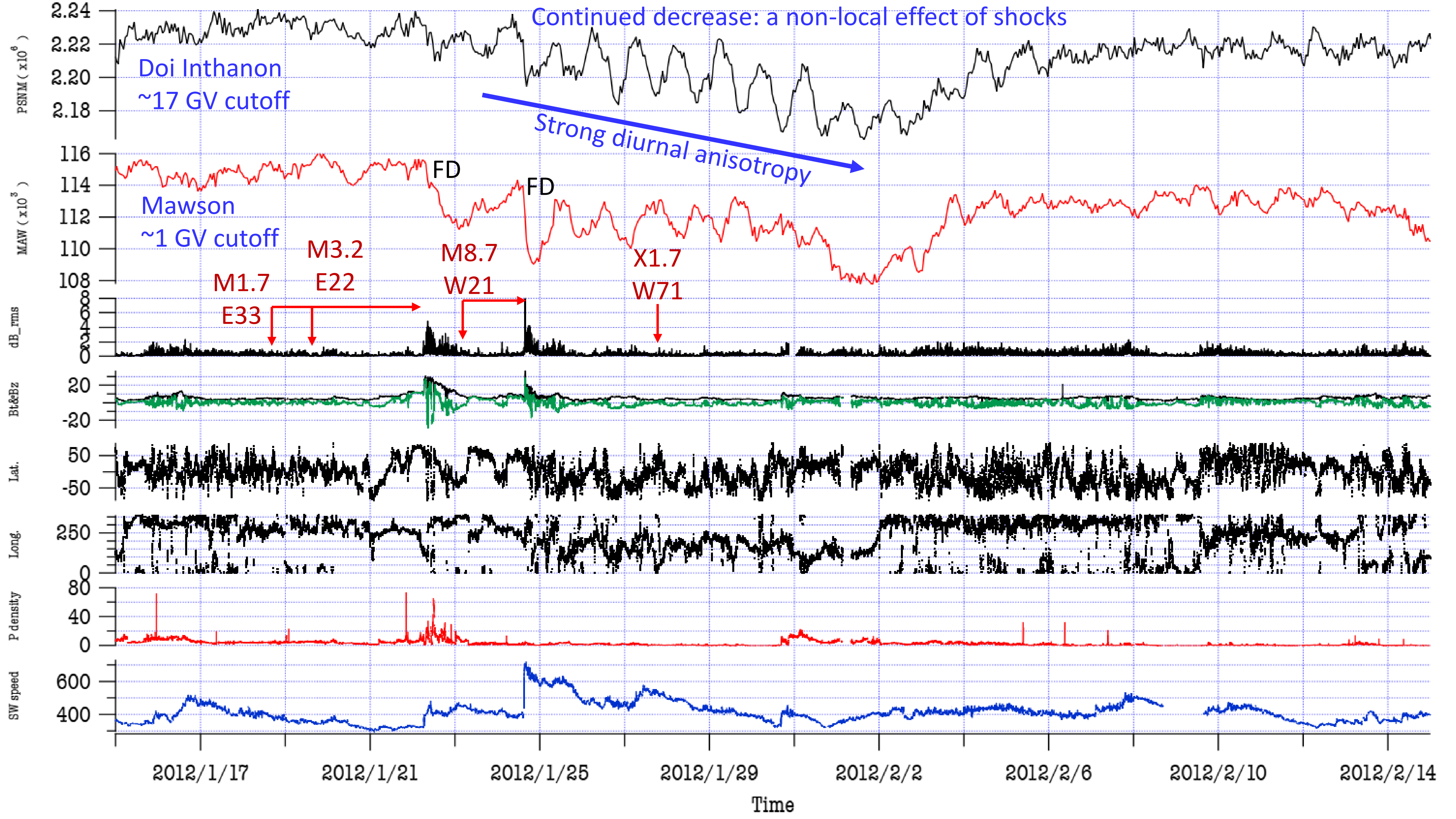
Count rate

Magnetic fluctuation

Magnetic field magnitude

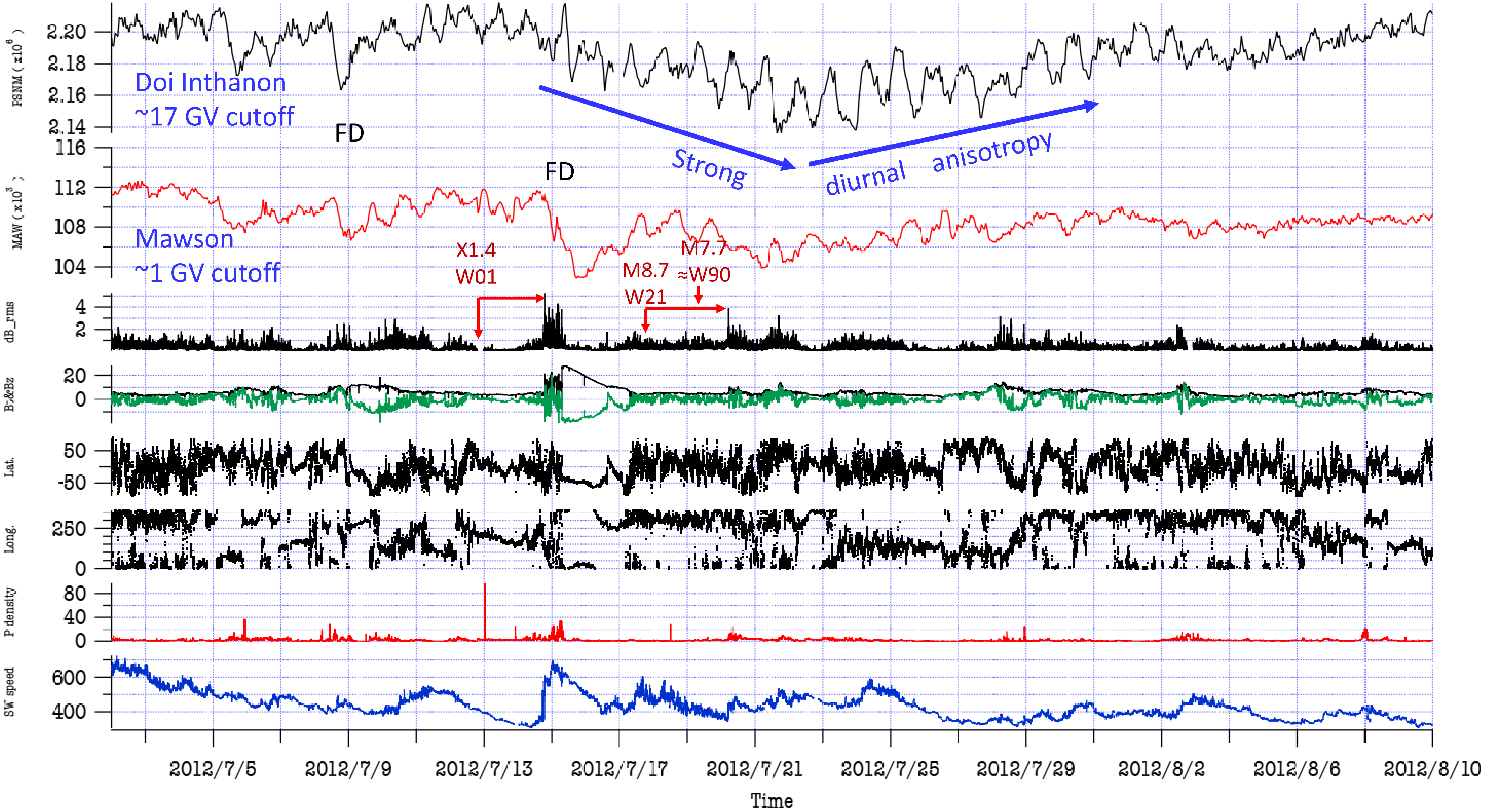
Solar wind speed





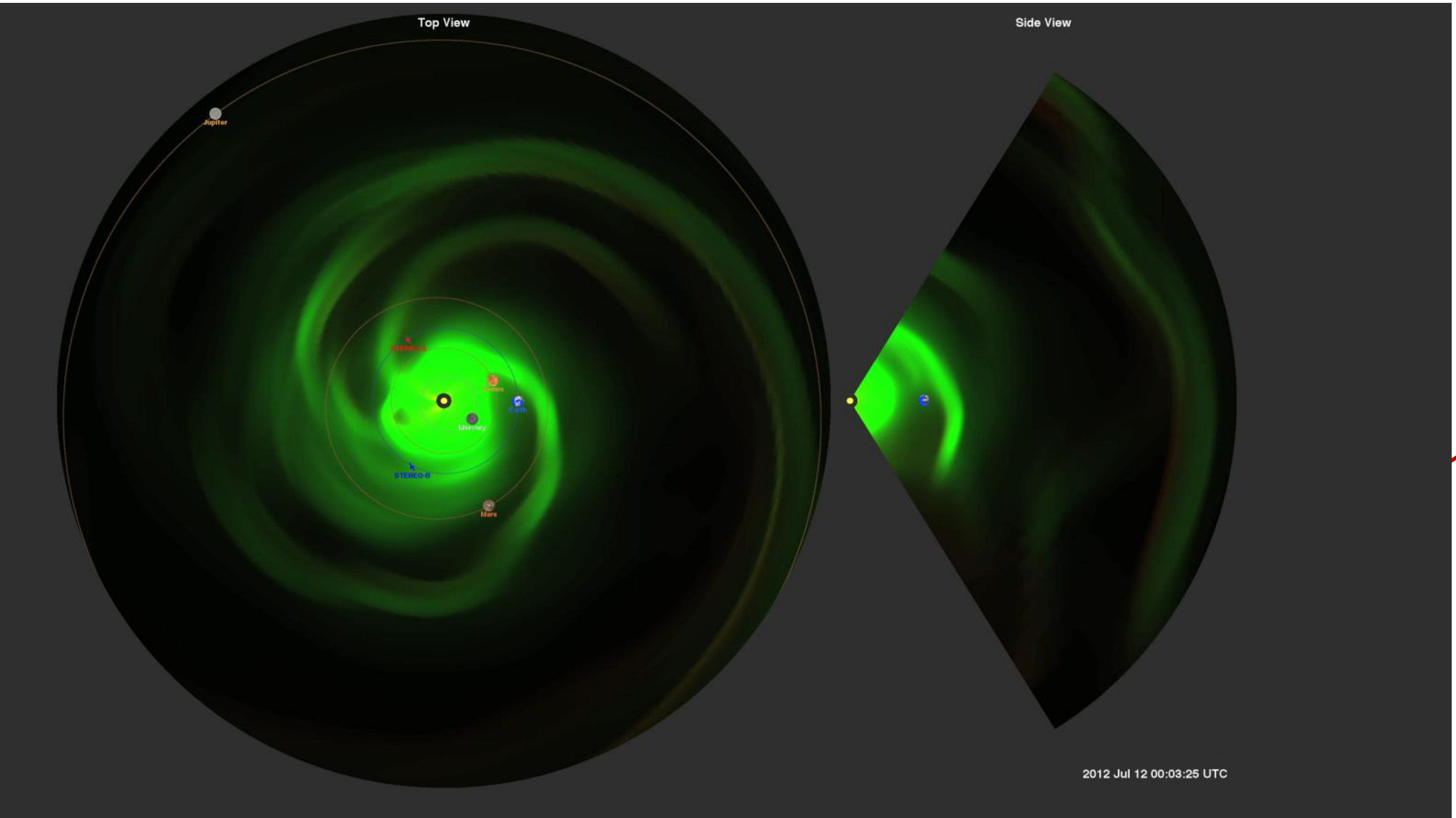
Continued decrease: a non-local effect of shocks
Doi Inthanon
~17 GV cutoff
Strong diurnal anisotropy
Mawson
~1 GV cutoff
FD
FD
M1.7
E33
M3.2
E22
M8.7
W21
X1.7
W71
PSNM (x10^6)
MAW (x10^3)
dB_rms
Bt&Bz
Lat.
Long.
P density
SW speed
2012/1/17
2012/1/21
2012/1/25
2012/1/29
2012/2/2
2012/2/6
2012/2/10
2012/2/14
Time

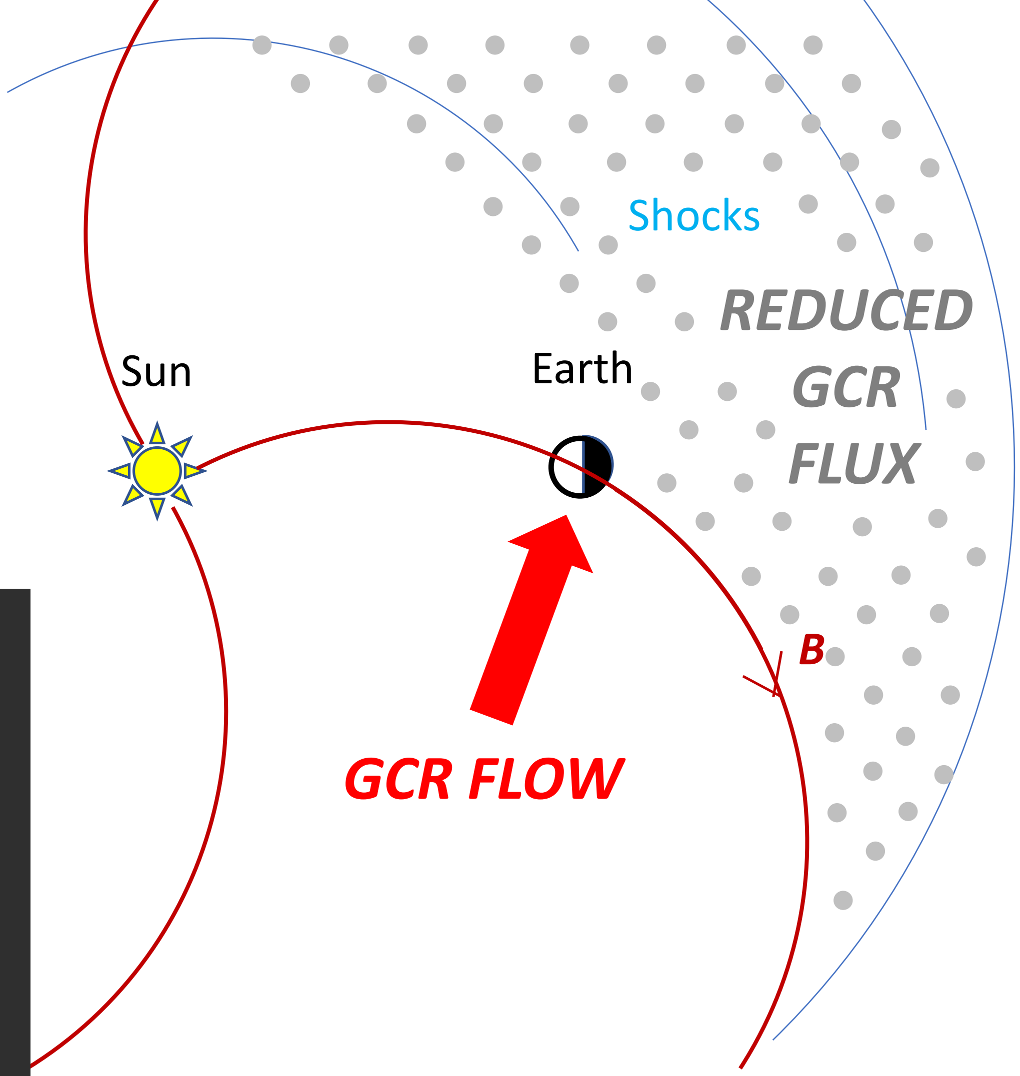
Continued decrease: a non-local effect of shocks



Two-week modulation events of 2012 Jan & Jul:

- Sequence of CMEs & interplanetary shocks
- High rigidity -> Large-scale structures
- Enhanced anisotropy along –*y* (corotating) & late/gradual flux recovery explained by perpendicular diffusion, $\lambda_\perp \sim 10^{-3}$ AU (Ruffolo et al. 2012 theory & sim.: $\lambda_\perp \approx 3 \times 10^{-3}$ AU)





Enlil simulation of solar wind density (green), views from N & E, 2012 July 12-26

https://svs.gsfc.nasa.gov/4167

Summary

- We examine the diurnal anisotropy (DA) over 2008-2019 from the Princess Sirindhorn Neutron Monitor at Doi Inthanon, Thailand, at effective vertical cutoff rigidity of 16.7 GV

- DA time series has moderate effect from solar modulation (mainly on phase) and strong short-term effects of gradient anisotropy, short-term modulation events, and Forbush decreases

- Two short-term modulation events in 2012 exhibited a two-week symmetric decrease in count rate and sharp increase in diurnal anisotropy along –*y*, due to non-local effects of CME shocks and diffusive cross-field inflow leading to recovery.