Solar Wind Magnetic Fluctuations Diagnosing Local Currents

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0) $B_{RMS} \propto \Gamma_w^{0.75}$ over $1 \rightarrow 5$AU

Local Electric Currents are the dominant source of B(t) at spacecraft

1) Pervasive Random Fluctuations

--- Spectrum is random as f^{-1} above 10^4 μHz ($\tau < 100.\text{sec}$)

--- "DC" values ($f < 10.\mu\text{Hz}$, $\tau > 1.\text{day}$) scale as "Mean of random walks"

2) $B_r(t)$ and $B_\theta(t)$ are sometimes *Correlated,* by distinct Fourier components at f_{Rot}

--- Highly variable : 1% - 30% (avg 12%) of B^2 Energy; not a persistent Spiral .

--- Removing *single* f_{Rot} component eliminates (r-θ) Correlation

---?? From gradient of North-South Current, driven by N-S charge imbalance

3) "Dynamical Arcs" are prevalent in the data :

--- Causes Non-random Spectral Energy $10^1 < f < 10^3$ μHz

--- Well-modelled by "Double Filament" radial Currents

--- Similar to PSP "Switchbacks" seen at 0.1 AU

Measurements :
-- ACE @ .99AU
-- Ulysses @ 1 – 5 AU
-- Mariner @ 0.3 – 1 AU

p^+, e^- : $v_w \sim 500.\text{km/s}$

$n_w \sim 10^{6.8}\ \rho^{-2}\ [\#\#/\text{m}^3]$

Flux $\Gamma_w \sim 10^{12.5}\ \rho^{-2}\ [\#\#/\text{s}\cdot\text{m}^2]$

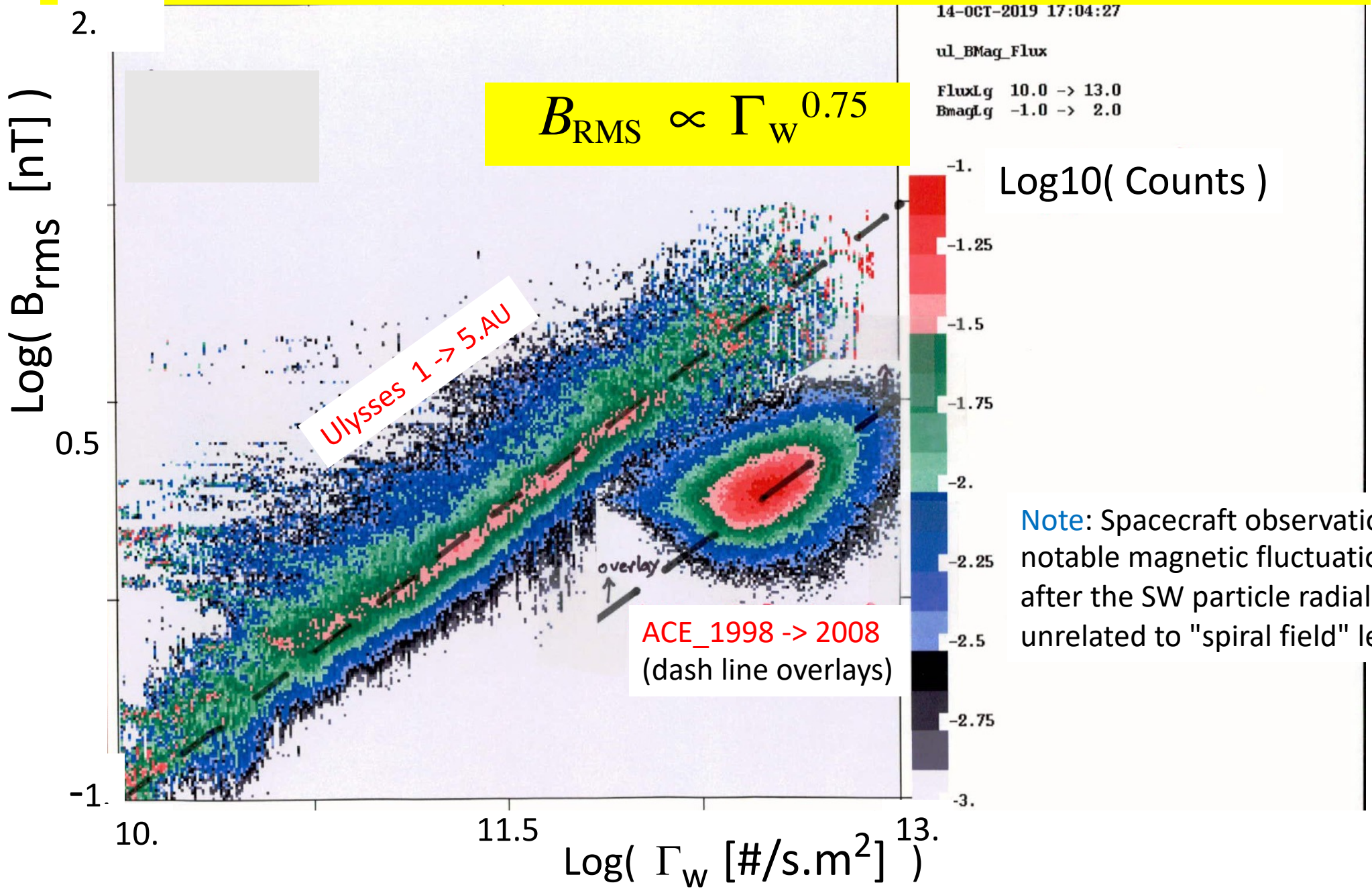
$\rho \equiv r\ /\ 1.\text{AU}$

$\mathcal{E}_{p+} \sim 1.3 keV$

$\mathcal{E}_{e-} \sim 10. eV$

Supported by UCSD and AFOSR

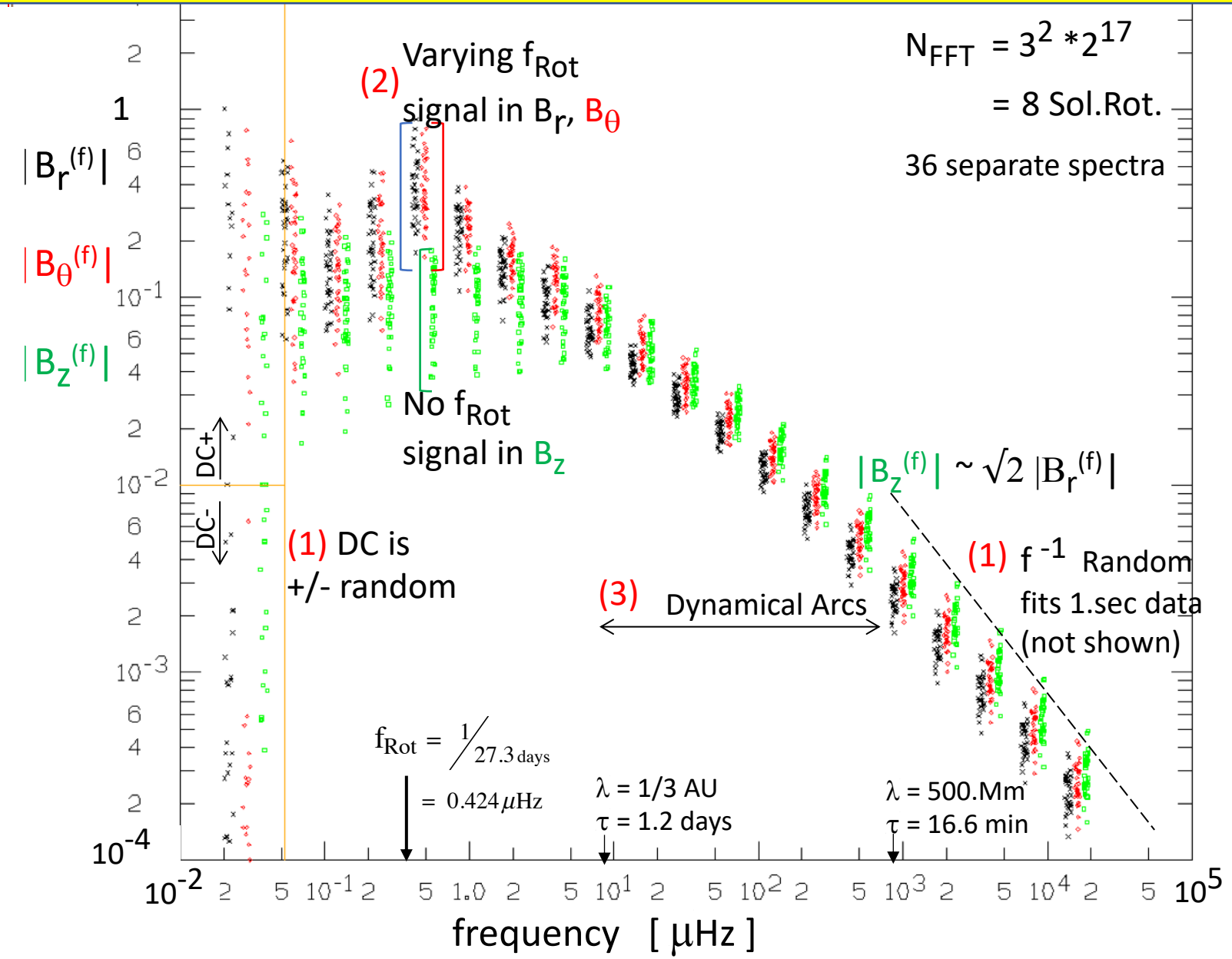
(0) Magnetic Fluctuations Levels are Determined by the Local Solar Wind Flux Γ_w



Note: Spacecraft observations of notable magnetic fluctuations appear after the SW particle radial propagation time, unrelated to "spiral field" lengths .

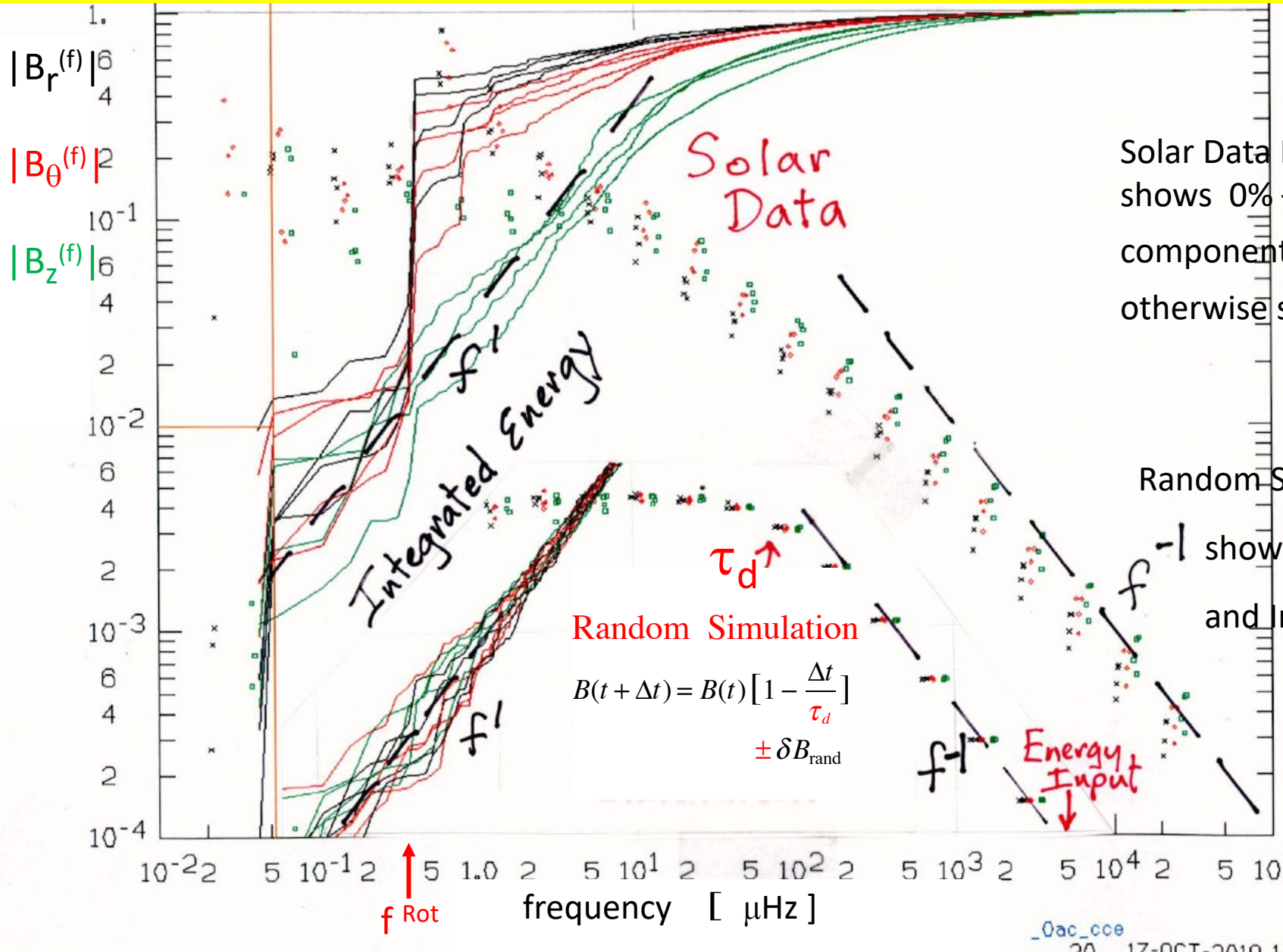
Spectrum of Magnetic Fluctuations : ACE MAG @ 1.AU

16.sec data, 1998.0 -> 2019.4



(1) Low-frequency and High-frequency components show "random walk" spectra

(2) f^{Rot} components are *exceptional* : highly variable, providing sole $B_r - B_\theta$ correlation

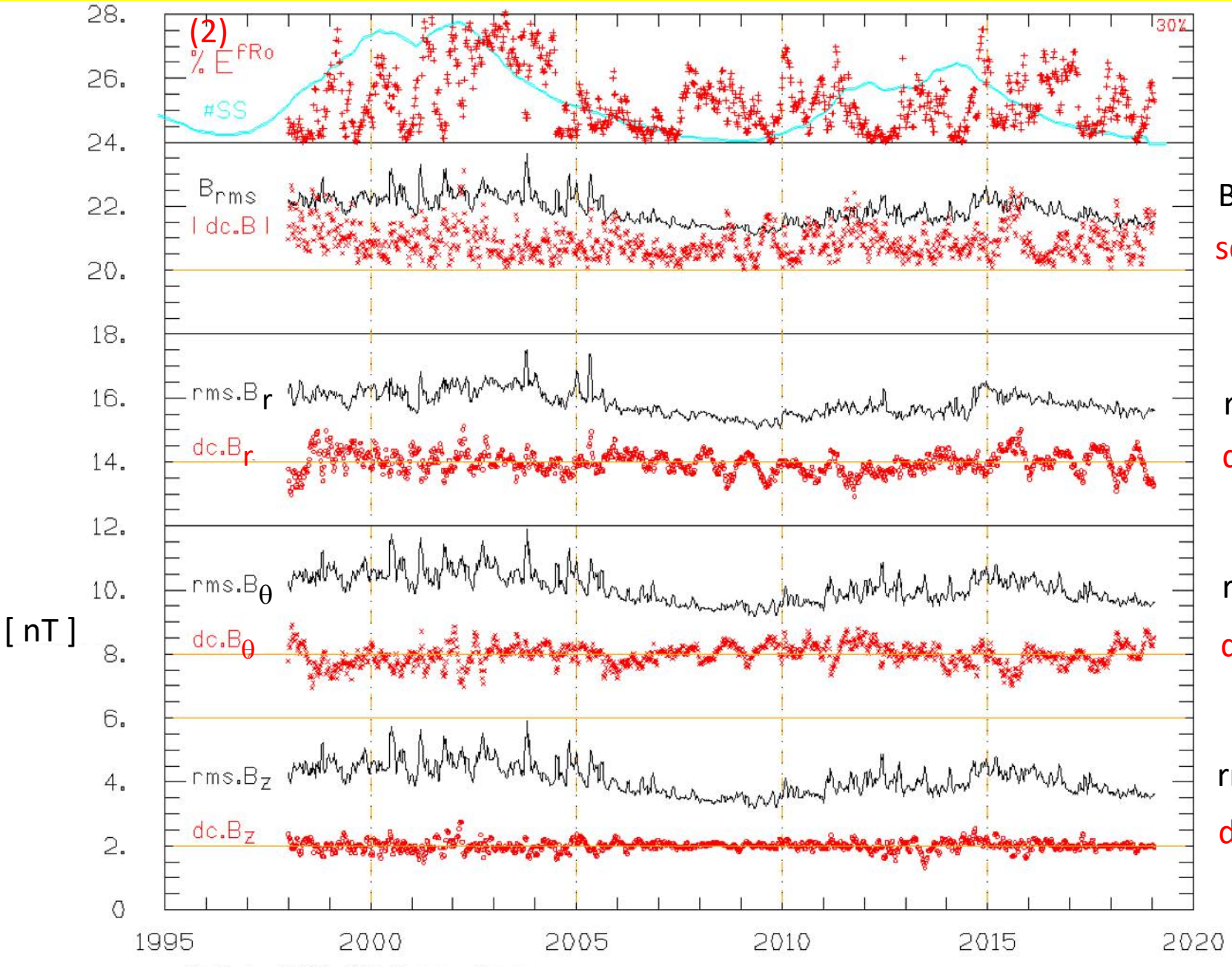


4 spectra

Solar Data Integrated Energy shows 0% – 30% spike in components at f^{Rot} ;and otherwise scales up as f^{1} .

Random Simulation with Dissipation at τ_d shows f^{-1} and f^{0} spectral regions; and Integrated Energy scales as f^{1}.

(1) There are no significant "persistent" magnetic fields at 1.AU :
"DC" levels vary +/- as expected from random higher-frequency "drives"



Tavg = 1.Sol.Rot

B_{rms}

$sqrt(dcB_r^2 + dcB_\theta^2 + dcB_z^2)$

rms. B_r

dc. B_r

rms. B_θ

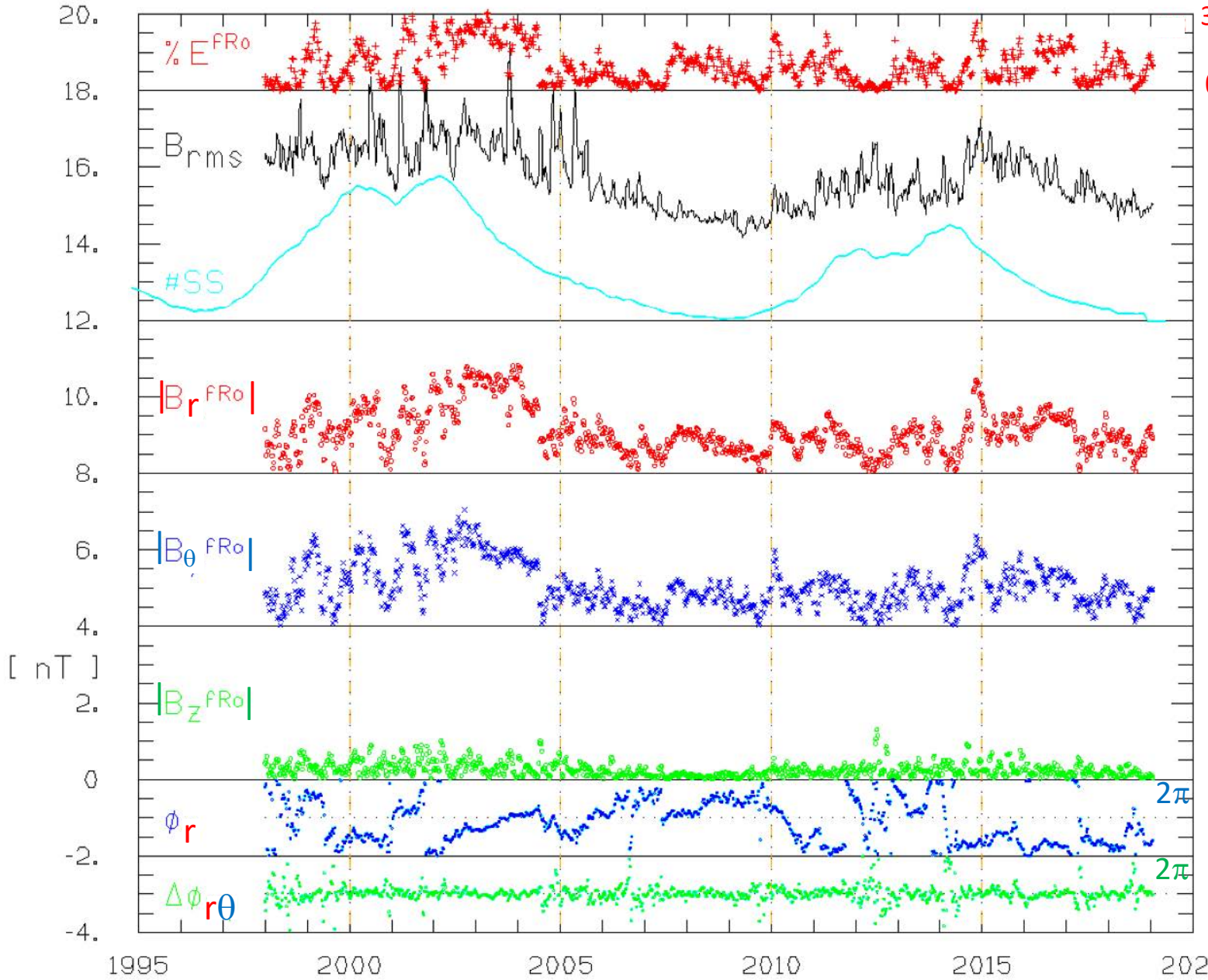
dc. B_θ

rms. B_z

dc. B_z

(2) Fluctuating B_r^{fRot} and B_θ^{fRot} are *phase-Correlated* ; B_z^{fRot} is noise.

0% –> 30% of Magnetic Energy is in B_r^{fRot} and B_θ^{fRot} fluctuations.



30%

0%

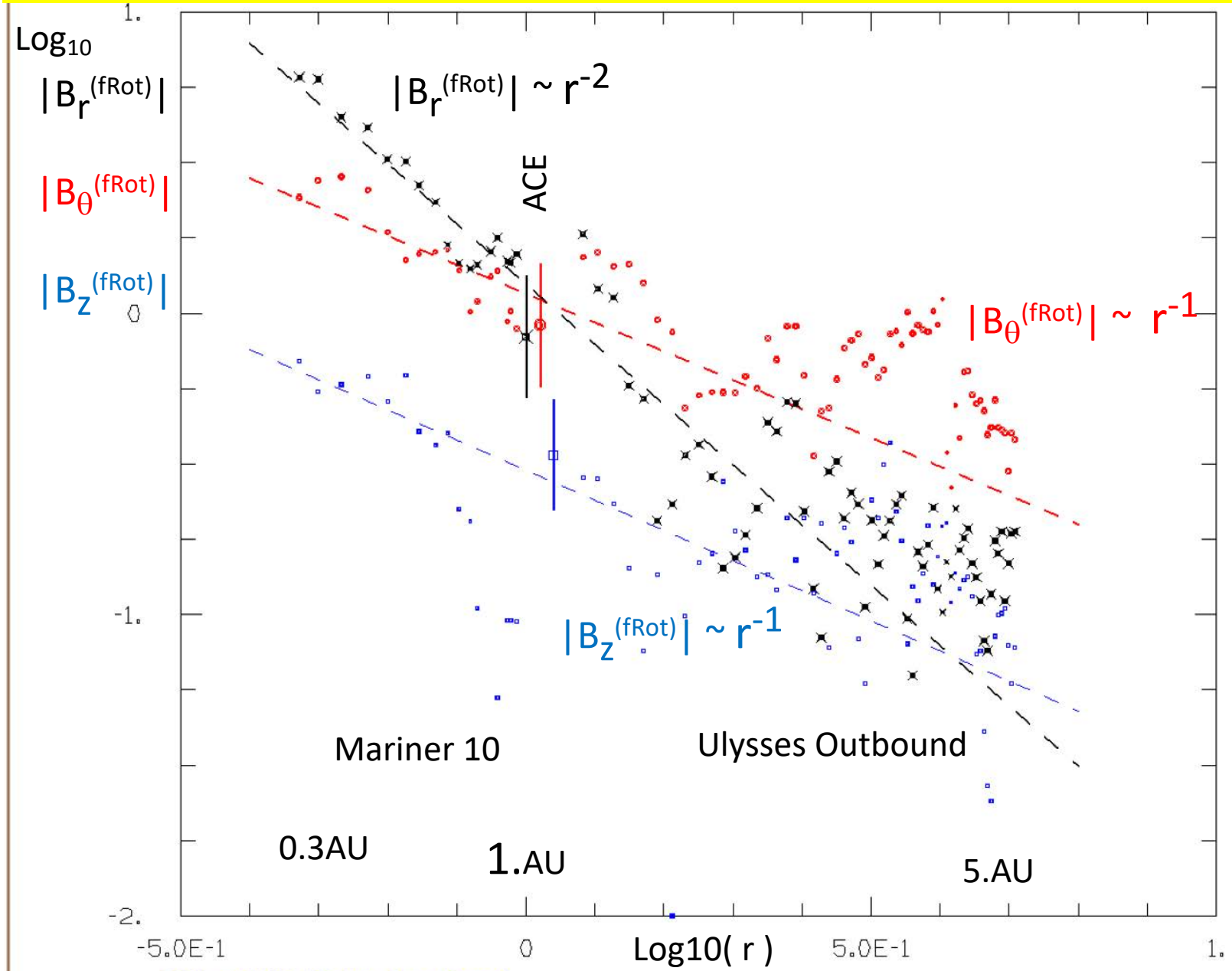
Energy in f^{Rot} components

$|B_r^{fRot}|$ and $|B_\theta^{fRot}|$ both vary on 3-month time scale

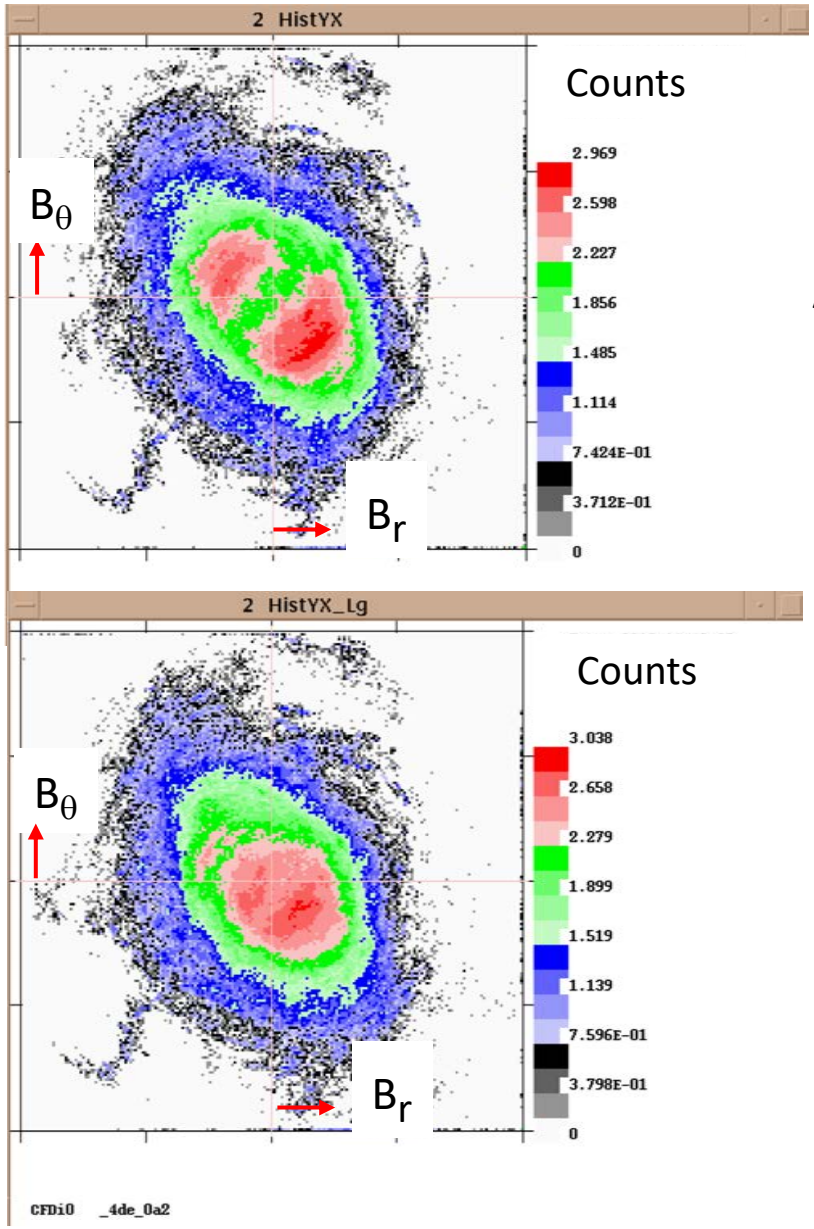
B_r Phase may be "steady" over several solar rotations

$r\theta$:180° phase difference

(2) Radial Dependence of fluctuating components B_r^{fRot} B_θ^{fRot} B_z^{fRot}



(2) $B_r - B_\theta$ anti-Correlation is *Removed* when the Fourier Components at f_{Rot} are *Removed*



Histograms of ($B_r(t)$, $B_\theta(t)$)
temporal occurrences

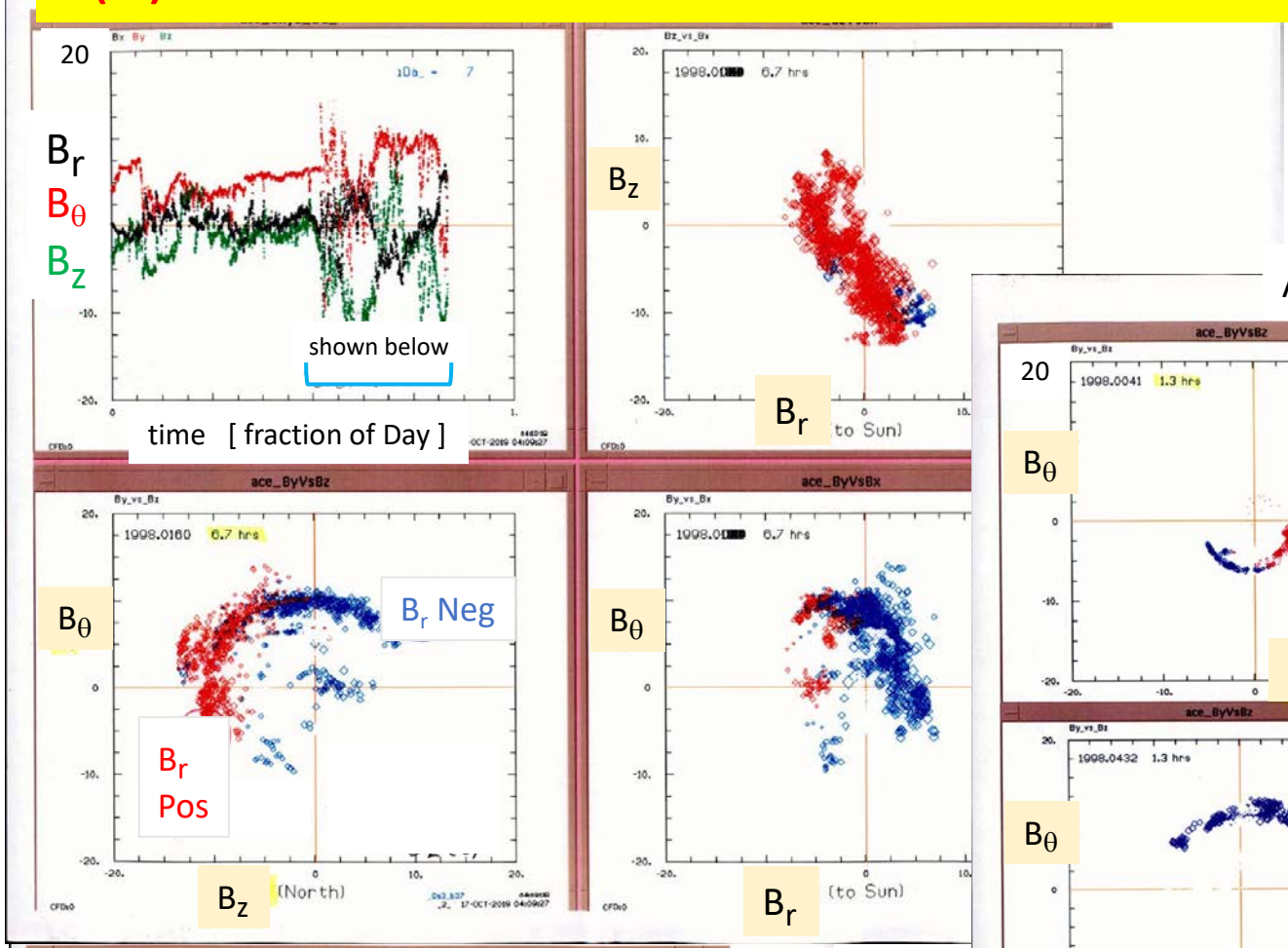
2015.0

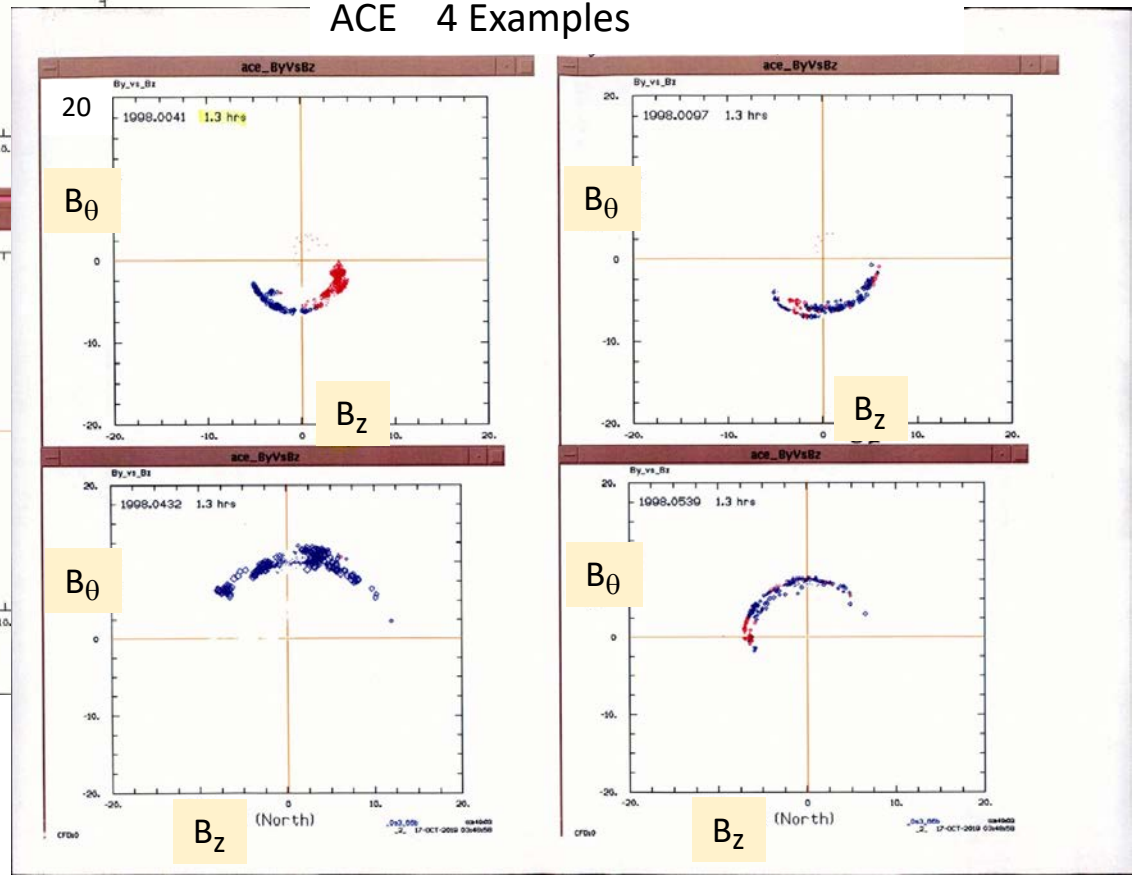
ACE Data, T = 8 Rotations

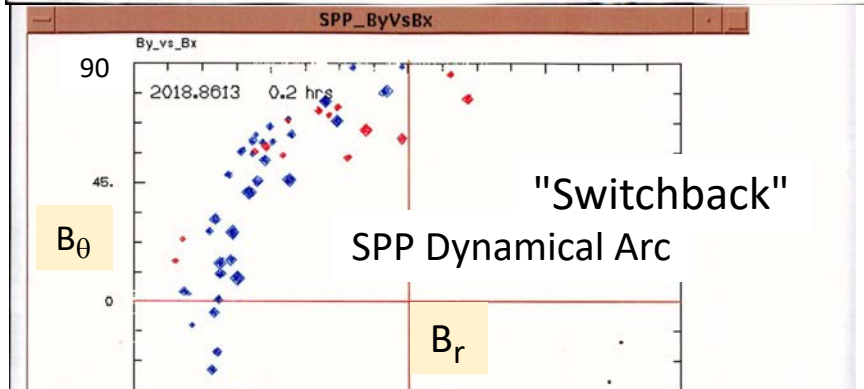
Only in these fRot components is there a variable-strength B_r-B_θ anti-correlation, which can be mis-interpreted as a persistent magnetic spiral.

ACE Data, T = 8 Rotations, with
$B_r^{(fRot)}$ and $B_\theta^{(fRot)}$ components
artificially *Removed* from data

(3) "Dynamical Arcs", Constant Magnitude temporal "arcs" in (B_θ,B_z), (B_θ,B_r), or (B_r,B_z)

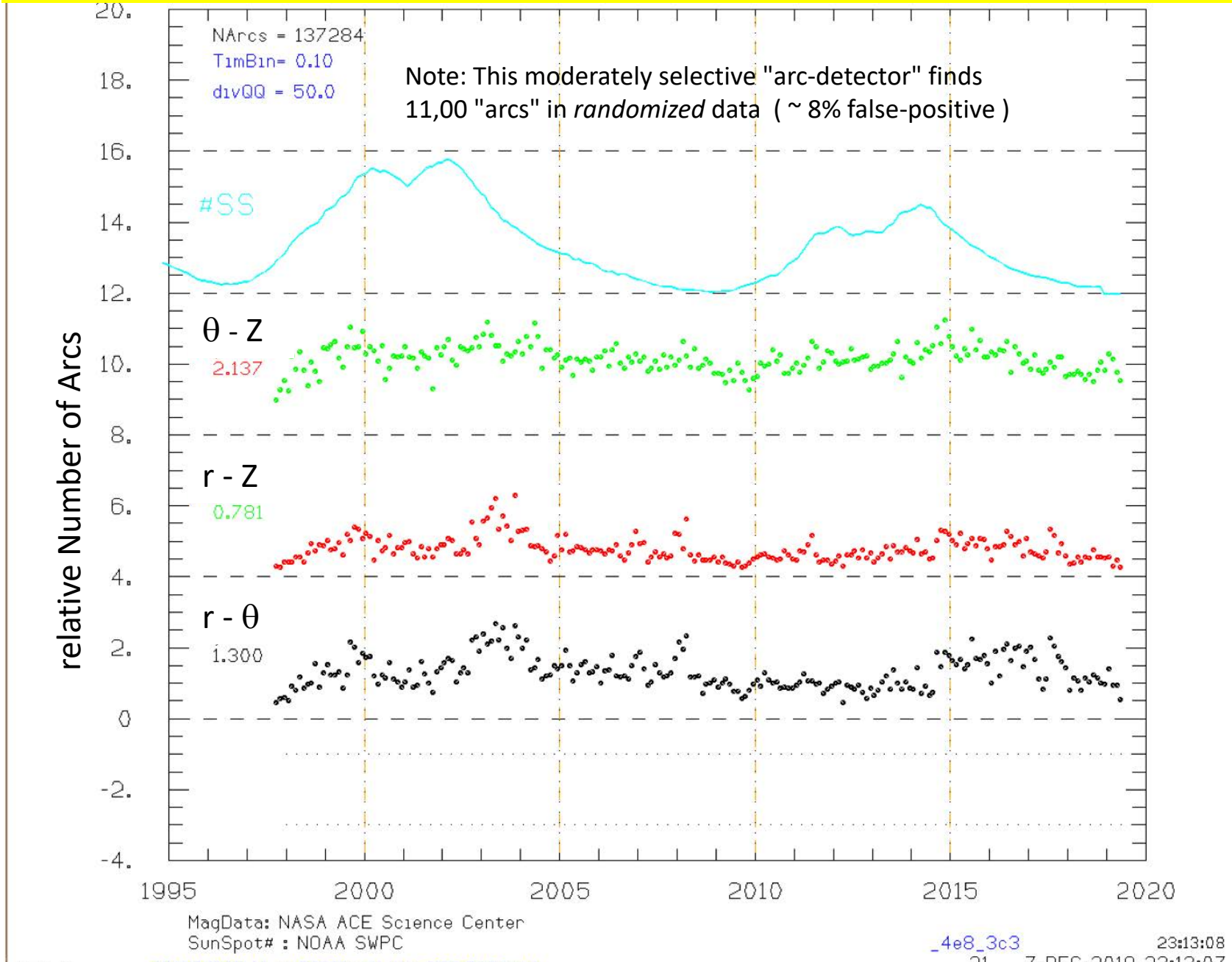




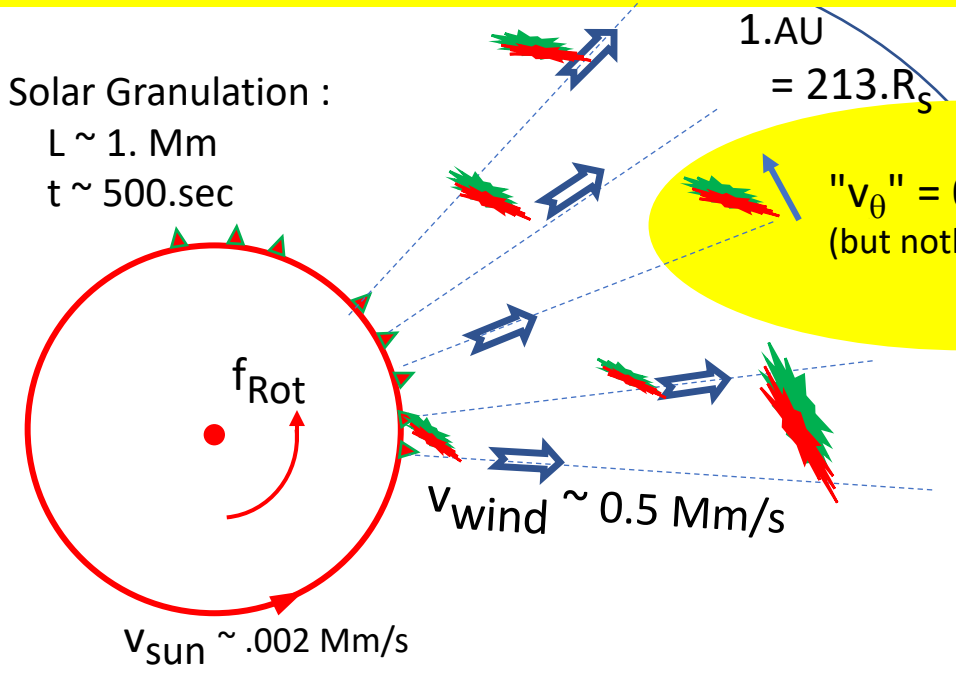


(3) ACE MAG : 137,000 "Dynamical Arcs" in 21 years. T ~ 0.5 hr

All orientations : Bθ–Bz , Br-Bz, Br-Bθ . Rate ~ 18/day



(3) Dynamical Arc Model : Double Electrical Current Filaments



"Neutral" Flow" of { p+ e- }

$n_w \sim 10^{6.8}$ [##/m^3]

$\Gamma_w \sim 10^{12.5}$ [## /s.m^2]

$\sim 10^{24.5}$ [##/s.$(Mm)^2$]

Suppose $\delta n = (n_+ - n_-)$

$== \alpha\ n_w$

from Filamentation, Dynamics, Current Pinch

Then

$$B \approx \frac{2}{cr}(\alpha e n_w v_w)(\pi r_0^2)$$

B ~ 5. nT implies :

α	r_0	$\tau = v_w r_0$
10^{-3}	10^1 Mm	20.sec
10^{-5}	10^3 Mm	0.5 hour

dominant in data

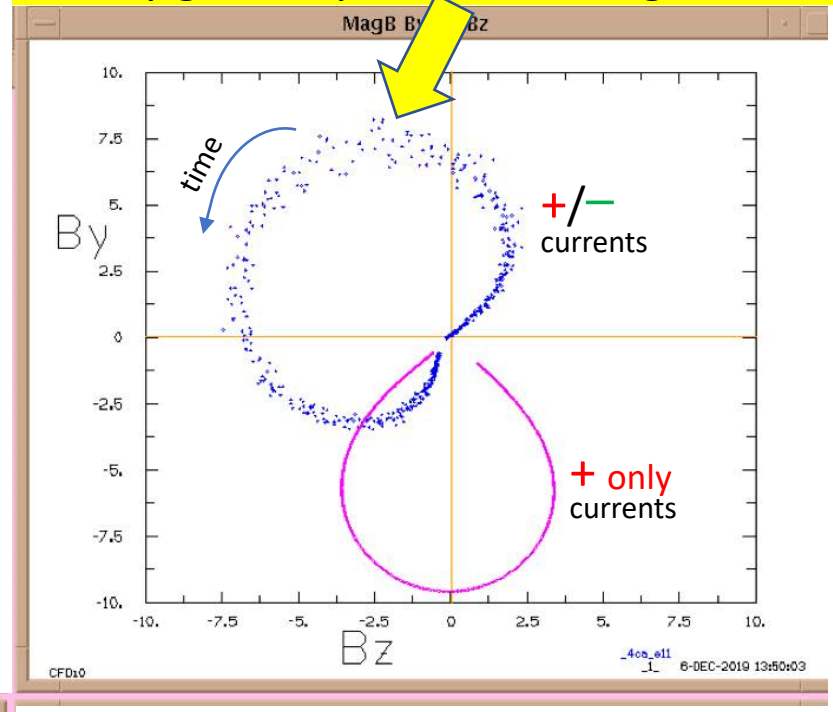
(3) Two Filament Simulation (+ / - Currents) propagating radially gives "Dynamical Arc" signature

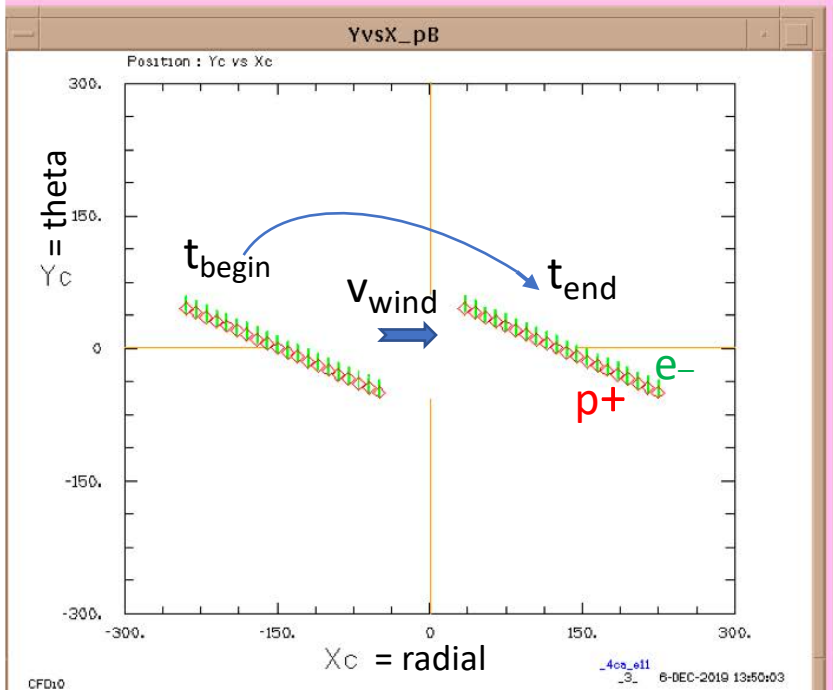
time = 500.sec

length = 200.Mm
Tilt = 30°

+ / - Separation
~ 5.Mm

Currents "fuzzy"
by ~ 10.Mm





SUMMARY : Solar Wind *creates* observed Magnetic Field Spectrum, for r > 0.3AU

0) ➡ $B_{RMS} \propto \Gamma_w^{0.75}$ over $1 \rightarrow 5$AU

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1) Pervasive Random Fluctuations

--- Spectrum is random as f^{-1} above 10^4 μHz ($\tau < 100.\text{sec}$)

--- "DC" values (f < 10.μHz, $\tau > 1.\text{day}$) scale as "Mean of random walks"

2) $B_r(t)$ and $B_\theta(t)$ are *Correlated,* by distinct Fourier components at f_{Rot}

--- Highly variable : 1% - 30% (avg 12%) of B^2 Energy; not a persistent Spiral

--- Removing *single* f_{Rot} component eliminates (r-θ) Correlation

---?? From gradient of North-South Current, driven by N-S charge imbalance

3) $B_\theta(t)$-$B_z(t)$, $B_r(t)$-$B_\theta(t)$, $B_r(t)$-$B_\theta(t)$ "Dynamical Arcs" are ubiquitous

--- Causes Non-random Spectral Energy $10^1 < f < 10^3$ μHz

--- Well-modelled by "Double Filament" radial Currents

--- Similar to PSP "Switchbacks"

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ABSTRACT

The 20 years of ACE satellite measurements of B(t) at 1AU enable detailed spectral and dynamical analyses, here supplemented by radial dependencies from Ulysses and Mariner from 0.3 - 5 AU.

1) Variable-duration spectral analyses clearly show that there is no persistent magnetic "spiral" at 1AU, merely the statistical fluctuations of "random walk" dynamics. Similarly, spectral components B(f) above f≅50μHz clearly show the √N scaling of random noise.

2) The Br and Bθ (but not Bz) spectral components at the solar rotation frequency f^{Rot} are quite exceptional, varying between 0% and 30% (average 17%) of the total $Brms^2$ magnetic energy. In *only* these variable components (with differing radial dependencies) is there a Br-Bθ anti-correlation, which is traditionally mis-interpreted as a persistent spiral. These f^{Rot} components probably reflect z-currents, arising from (θ,z)-dependent electric potentials from exceedingly small differences in e-/p+ ejection from the rotating solar surface.

3) Pervasive dynamical "arc" events are observed on time-scales $10^3 < \tau < 10^5$ sec, presumably related to spiky "switchbacks" observed by PSP at 0.1AU. The dynamics appears as Bθ-Bz, Br-Bz, and Br-Bθ temporal arcs, with occurrence rates differing by direction. The observed dynamics is closely modelled by finite-duration "pinched" +/- current filaments, representing charge non-neutrality of 10^{-5} of the e-/p+ flux over distances d≅10^3Mm and times τ≅2000.s.