Heliospheric Magnetic Fields Generated by Solar Wind Current Fluctuations

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

1) Satellite B(t) data shows 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) "Dynamical Arcs" are prevalent in the data :
   --- Appear as Non-random Spectral Energy $10^1 < f < 10^3$ μHz
   --- Well-modelled by Polarized Neutral Plasma Flows
   --- Similar to PSP "Switchbacks" seen at 0.1 AU

3) $B_r(t)$ 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 rotation-time persistence in Solar surface emission, as seen inF some Sunspots.

0) The Solar Wind originates in the Photosphere,
   as ~~ 10^7 Electric "Lightning" Jets. --> YO07.008 (Friday)

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

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

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

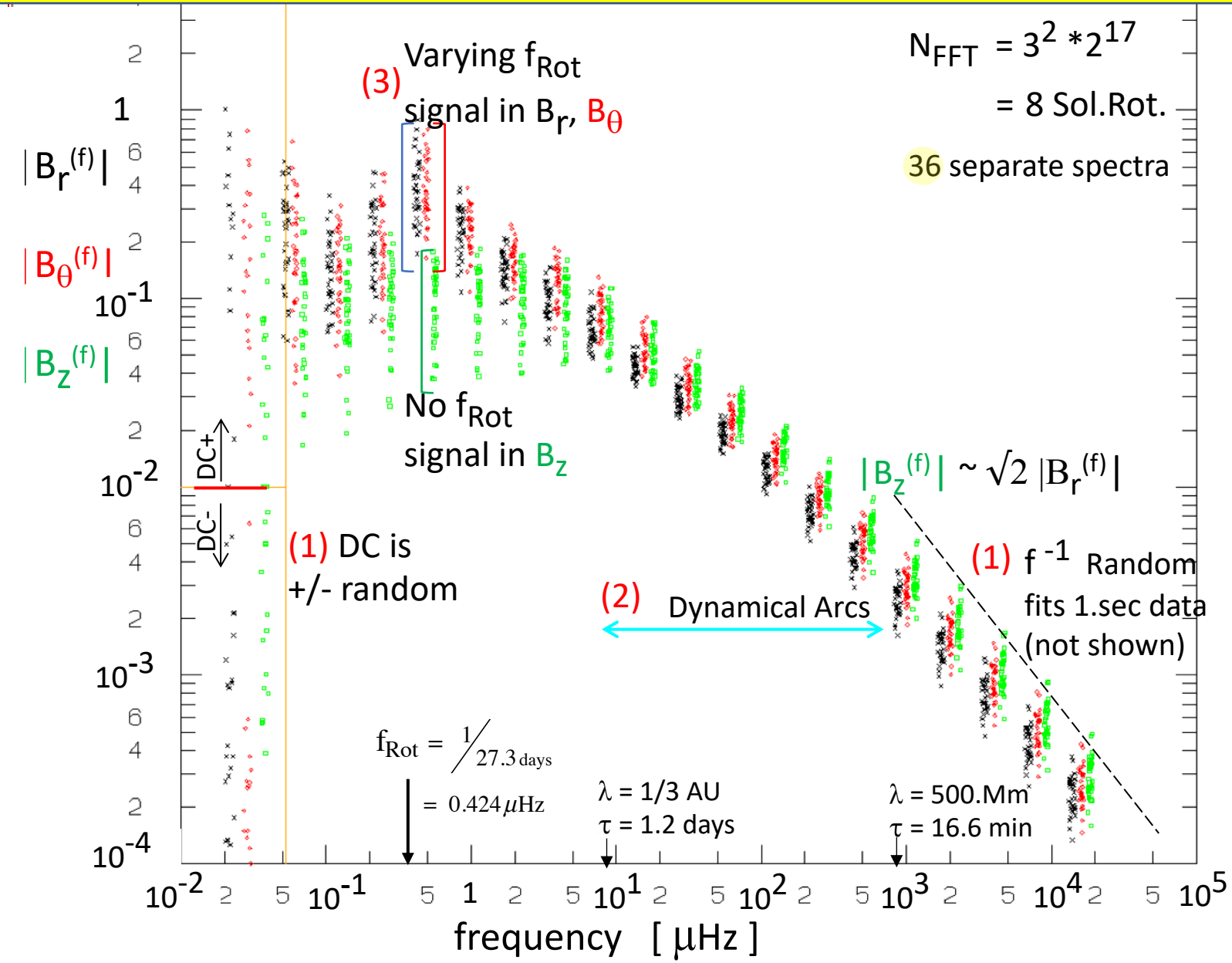
$\mathcal{E}_{e-} \sim 10. eV$

Supported by UCSD and AFOSR
PDFs at NNP.ucsd.edu/Solar

v2

Spectrum of Magnetic Fluctuations : ACE MAG @ 1.AU

16.sec data, 1998.0 -> 2019.4



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"

[+/- magnitude of f_1 is distance above/below 10^{-2}]

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

--- Determine Spectral Energy $10^1 < f < 10^3$ μHz

--- Modelled by "Double Filament" radial Currents

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

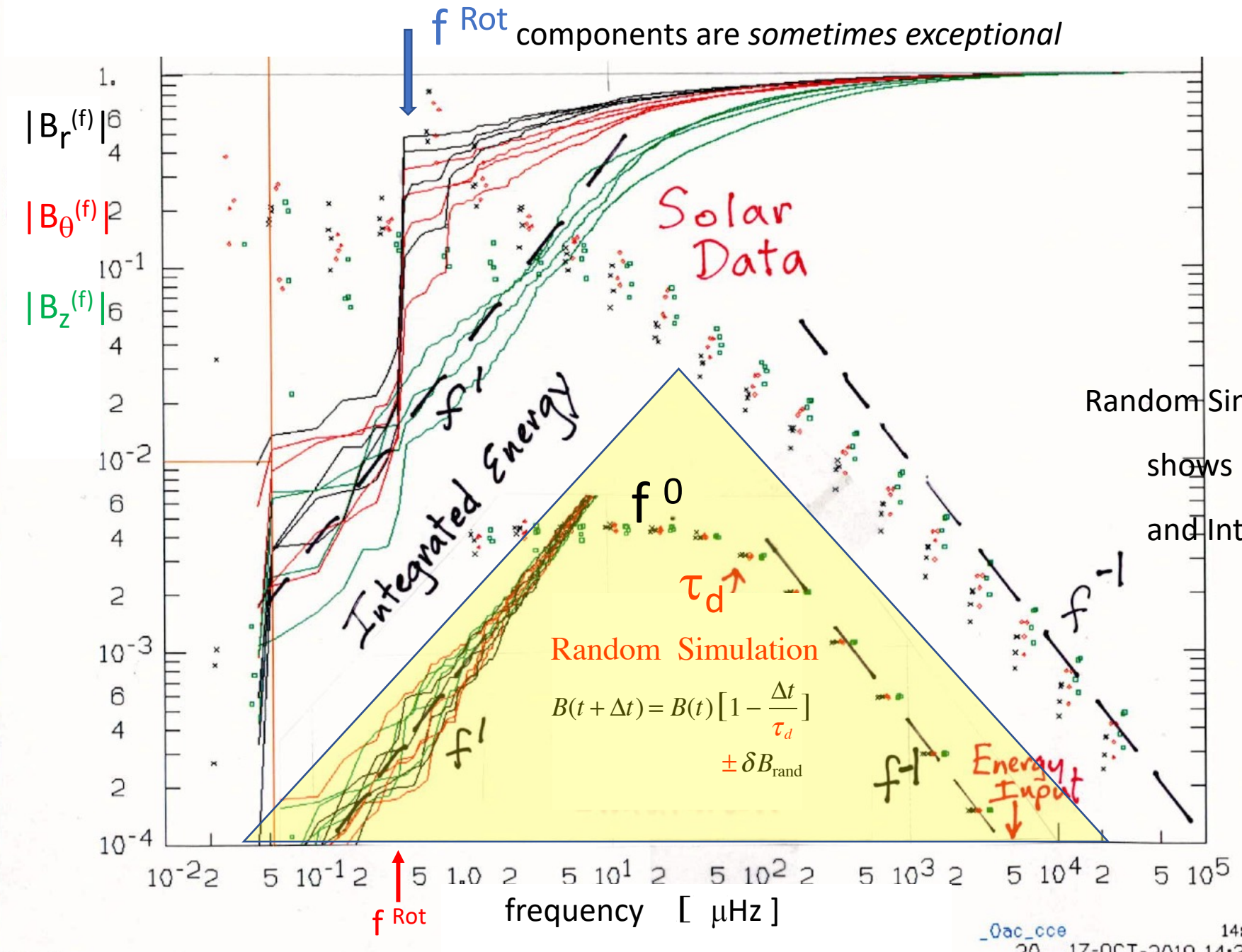
3) $B_r(t)$ and $B_\theta(t)$ are sometimes *Correlated,* by a distinct Fourier component at f_{Rot}

--- Highly variable : 1% - 30% (avg 12%) of B^2 Energy

--- *Not* a persistent Spiral .

--- From rotation-scale persistence in surface emission, as with strong Sunspots.

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

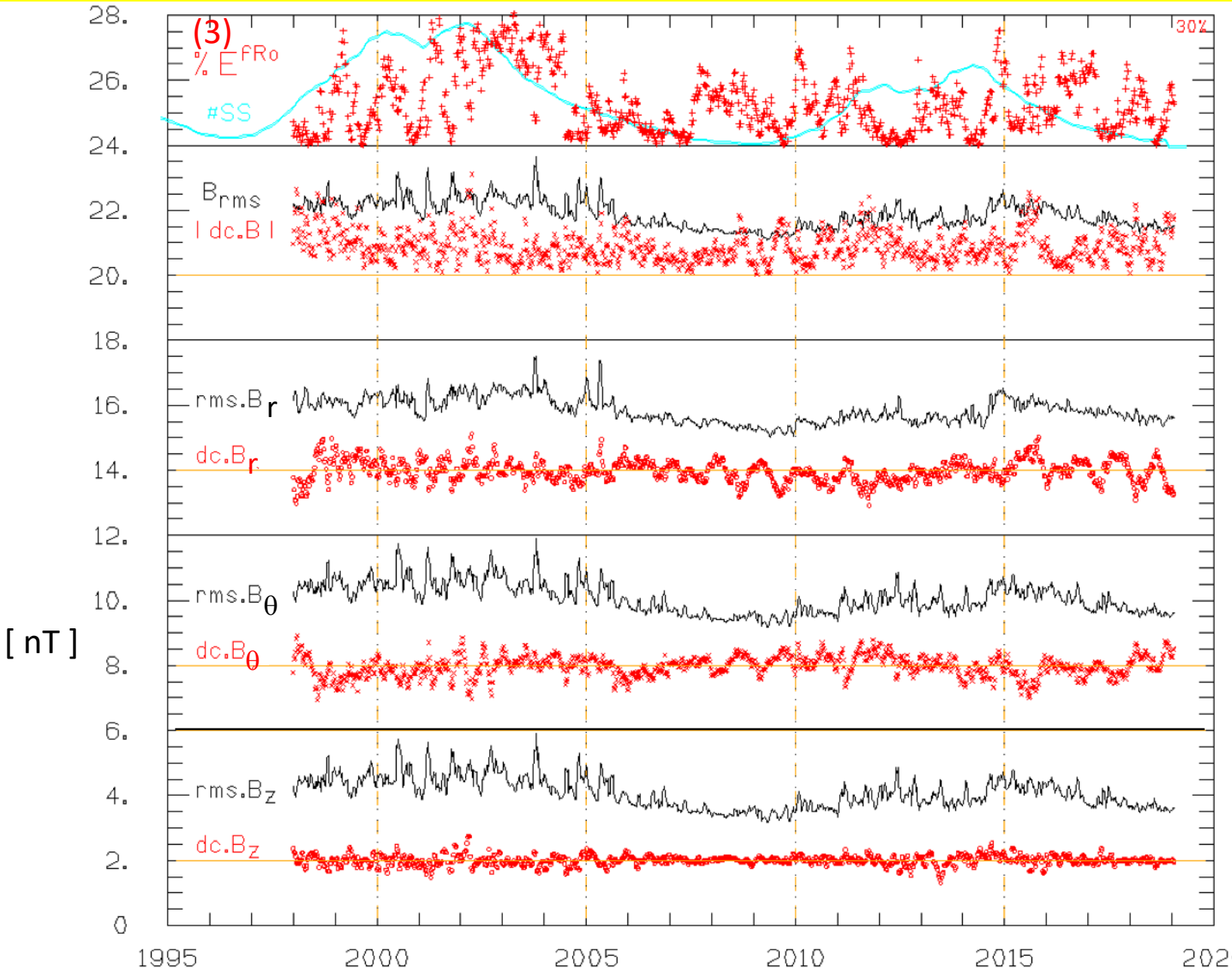


4 spectra

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



Tavg = 1.Sol.Rot

Energy @ f_{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

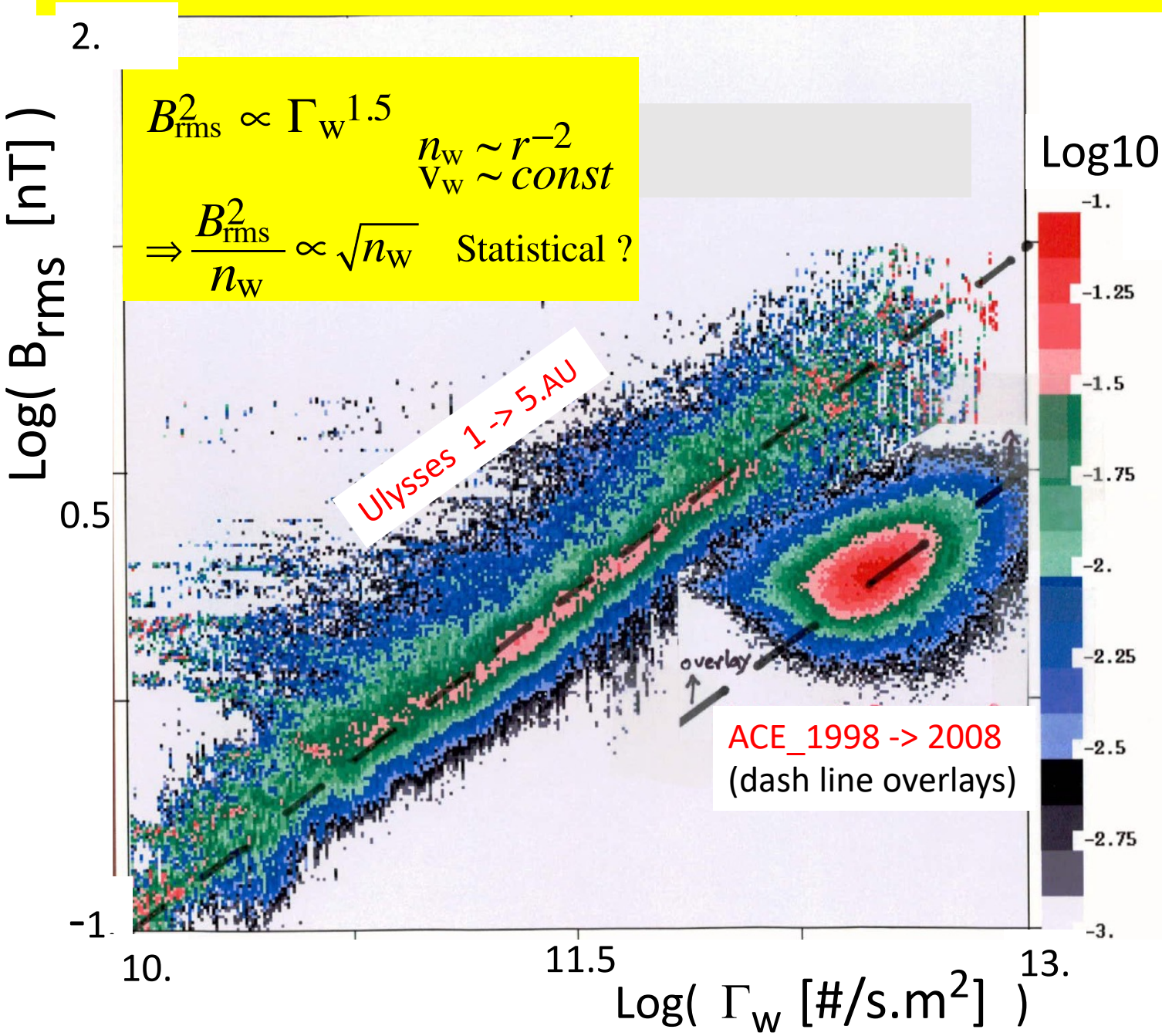
dc. B_z

(1c) Magnetic Fluctuations Levels are Determined by the Local Solar Wind Flux Γ_w

$$B^2_{rms} \propto \Gamma_w{}^{1.5}$$

$$n_w \sim r^{-2}$$
$$V_w \sim const$$

$$\Rightarrow \frac{B^2_{rms}}{n_w} \propto \sqrt{n_w}$$ Statistical ?



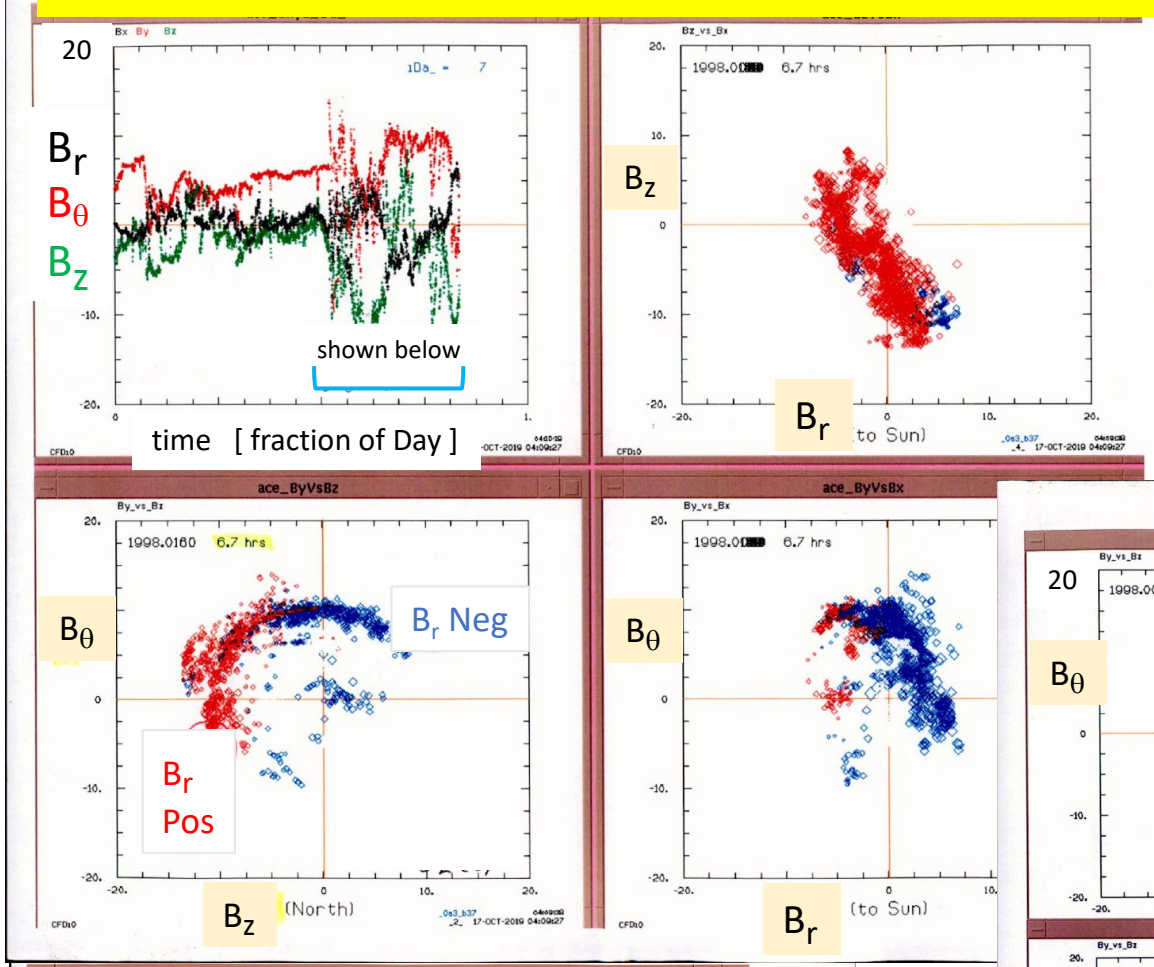
The measured magnetic fluctuations are created by the local electrical-currents of the Solar Wind, including any global currents from global charge separation.

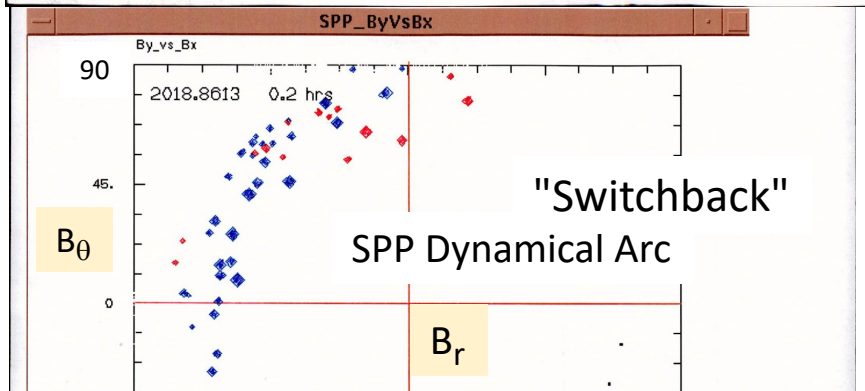
Moreover, major Solar surface events cause spacecraft detections of enhanced fluctuations after the SW particle *radial* propagation time, unrelated to "rooted spiral magnetic field" lengths.

The $B_{rms}{}^2 \propto r^{-3}$ scaling is widely observed, and interpreted as hydro—agnetic fluctuations.

Here, we note that the magnetic energy per particle scales as the square-root of particle number, consistent with statistical fluctuations.

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

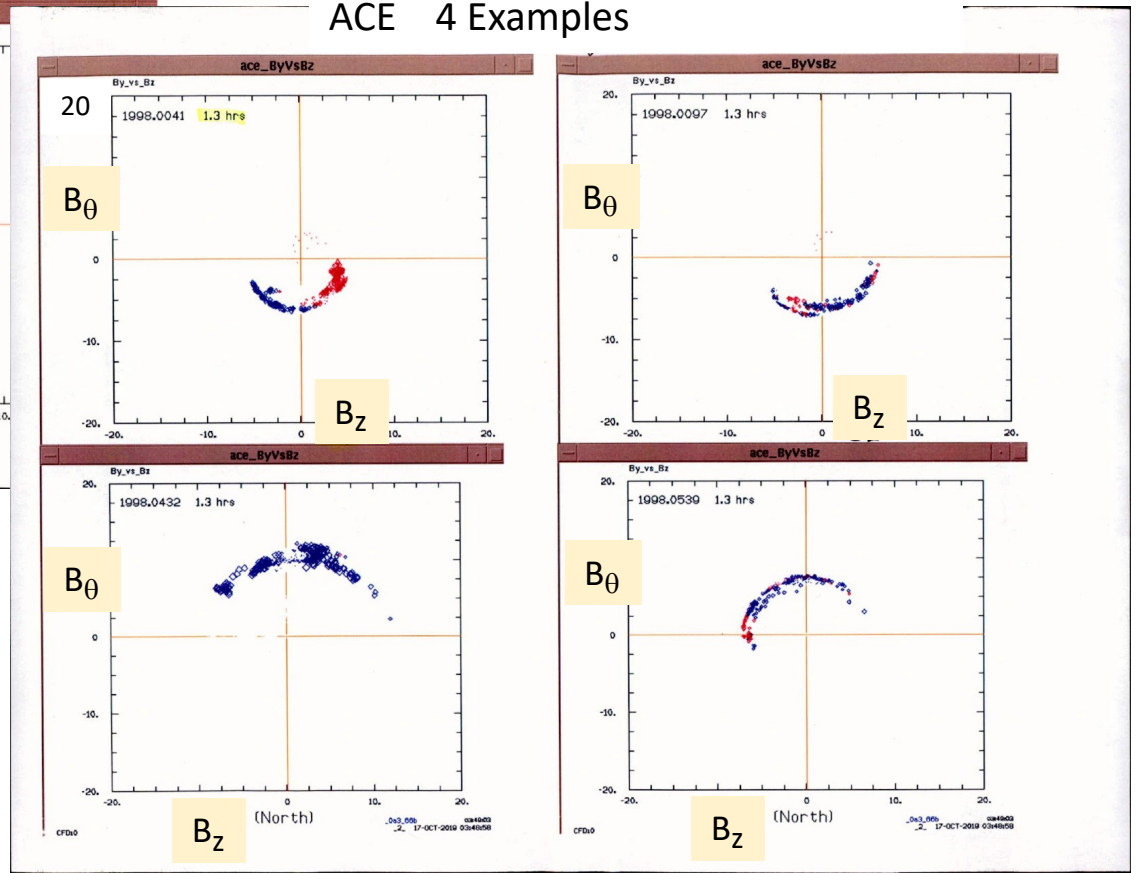




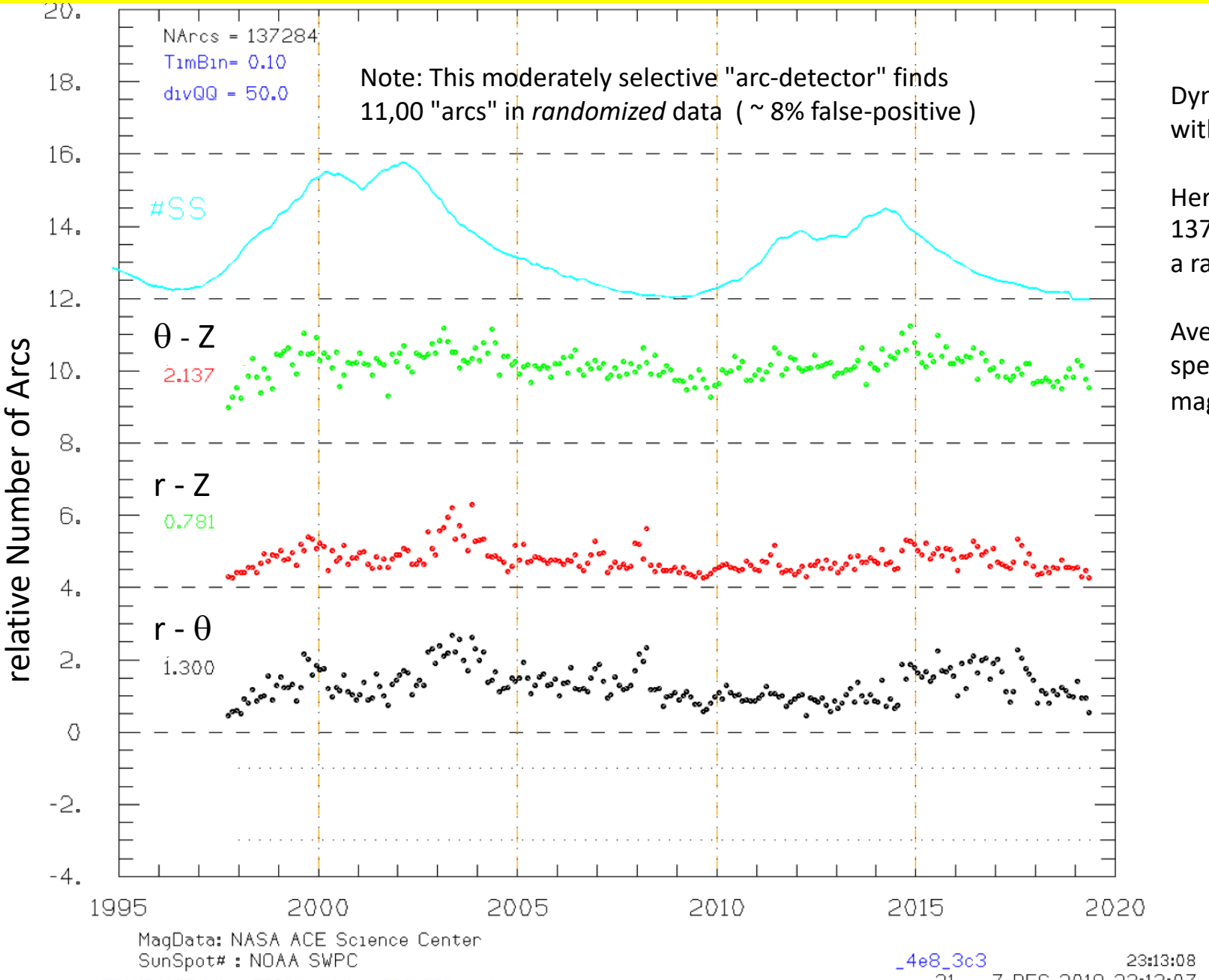
At left, a {Bθ,Bz} constant magnitude Arc appears in 6.7 hours MAG temporal data, unrelated to the sign of Br (red/blue). Other pairs {Bz,Br} and {Bθ,Br} show no Arc during this time, but are equaly prevalent in general. Below are 4 Arcs of 1.3 hrs duration, selected for their "clean" appearance.

Below left is a 0.2 hr segment from PSP data showing similar behavior, albeit at 20x larger field magnitudes.

ACE 4 Examples



(2) ACE MAG : 137,000 "Dynamical Arcs" in 21 years. T ~ 0.5 hr
All orientations : Bθ–Bz , Br-Bz, Br-Bθ . Rate ~ 18/day

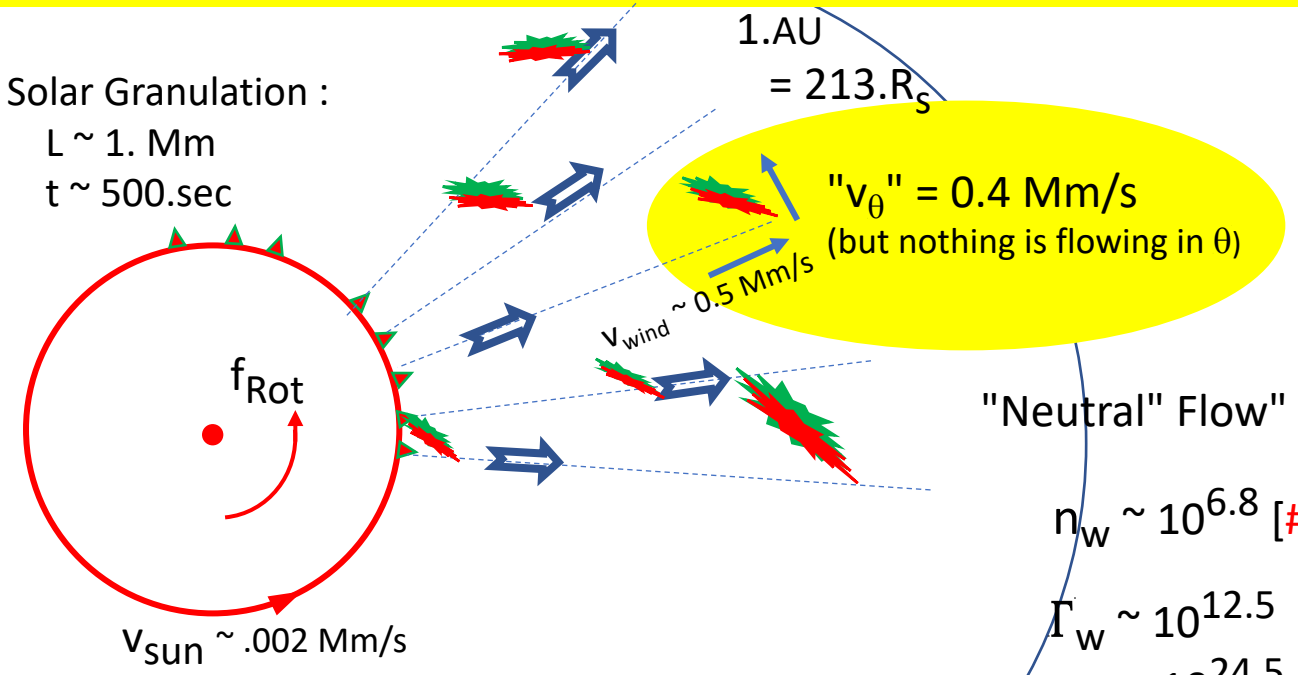


Dynamical Arcs appear in all pairs of {Br, Bθ, Bz}, with similar rates of occurence.

Here a moderately selective computer filter counts 137 000 Arcs (+/- 10%) with periods T~0.5hr, giving a rate of 18/day.

Averaging over multiple Dynamical Arcs contributes to the spectral region of $10 < f < 1000$ μHz, where field magnitudes fall off more slowly than the "random" f^{-1} .

(2) 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.$(Mm)^2$]

Spacecraft measurements establish that the Solar Wind e-/p+ particle flux is basically radial , and global charge conservations requires that it is basically charge-neutral.

However, small deviations from charge neutrality ($\alpha \sim 10^{-5}$ here) can create currents which create the 5.nT magnetic field magnitudes observed at 1.AU.

Here, the spatial scale of $r_0 \sim 10^3$ Mm is suggested by the 0.5 hr time scale for major B-field magnitude changes.

The "challenge" is to characterize propagating structures of low-collisionality globally-neutral flows, with weak electric currents generating self-consistent and Electric and Magnetic fields.

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

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

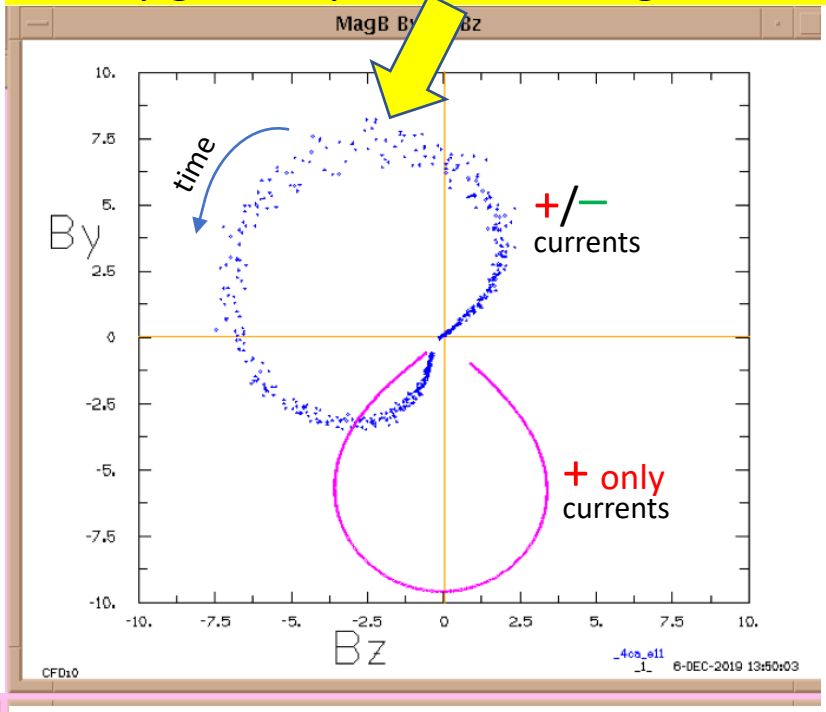
time = 500.sec

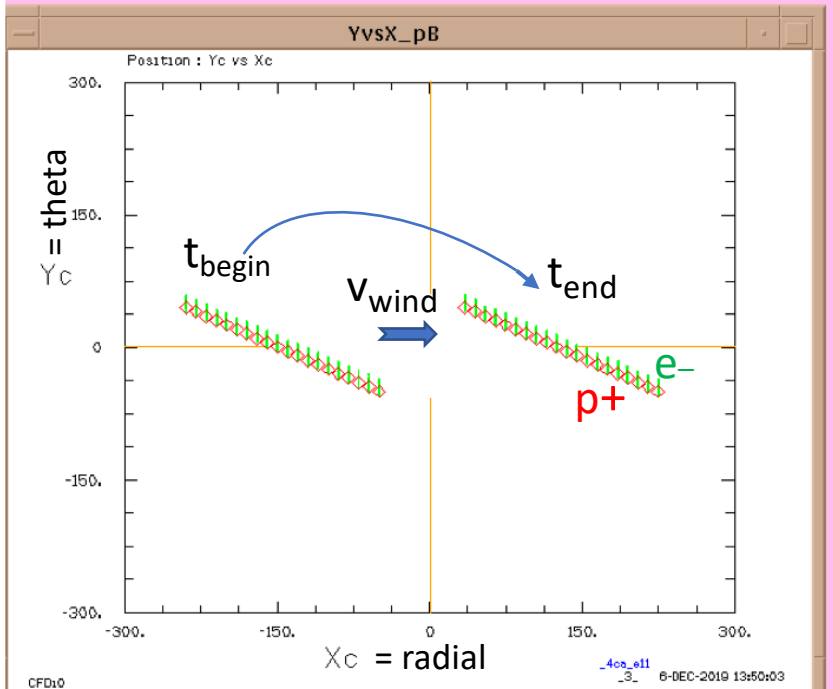
length = 200.Mm

Tilt = 30°

\+ / - Separation ~ 5.Mm

Currents "fuzzy" by ~ 10.Mm





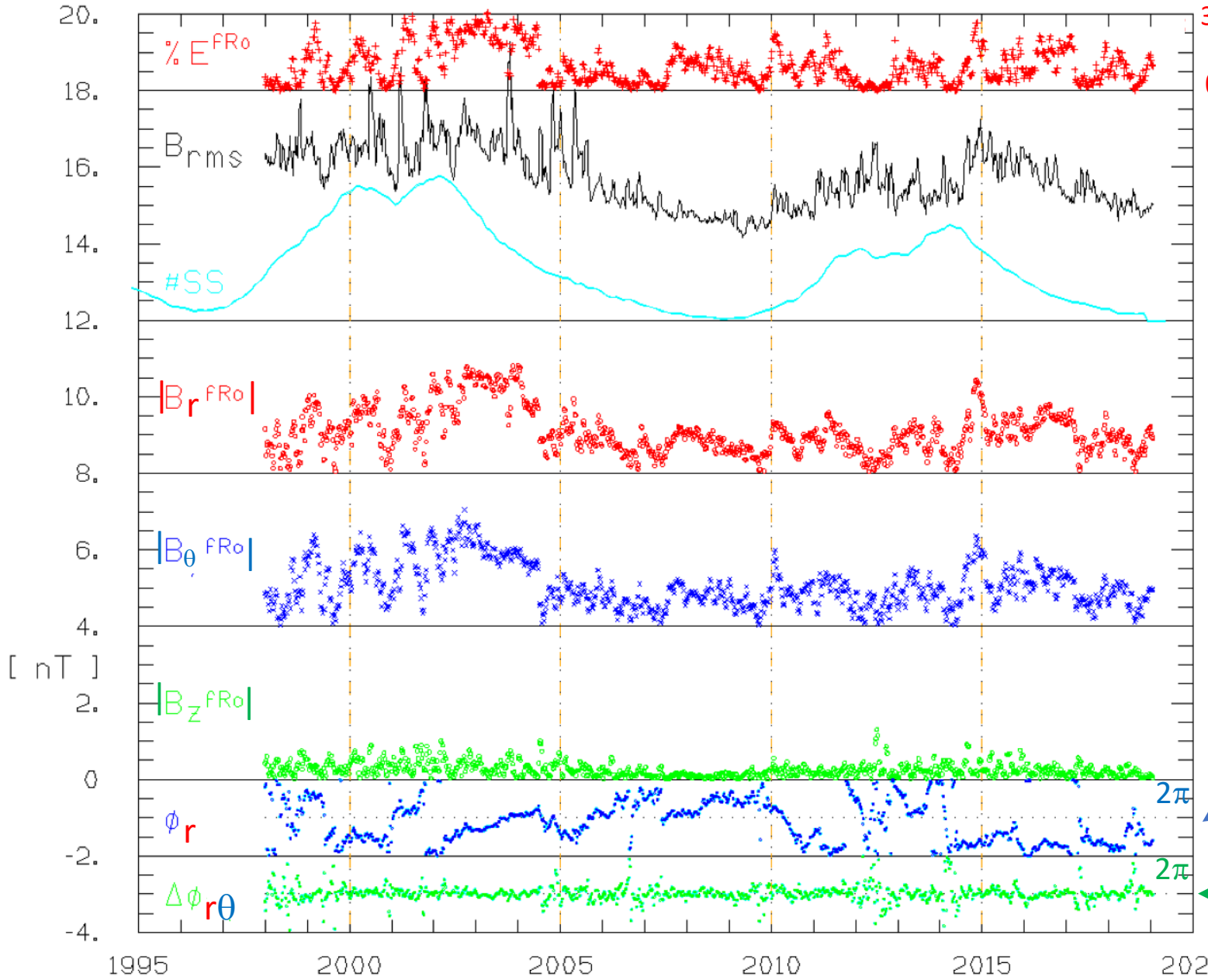
A simple "geometric" calculation of magnetic fields shows that Dynamical Arcs in pairs of {Br, Bθ, Bz} will arise from radially propagating charge separations.

Here, 200.Mm long filaments of +/- charge, separated by 5.Mm, propagate radially past the spacecraft with v_r = 0.5Mm/s .
The currents are modelled by hundreds of particles, each "fuzzy" over 10.Mm.

The broad Dynamical Arc signature is obtained when the total charge is Zero; but not when only one sign of current is included.

(3) 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%

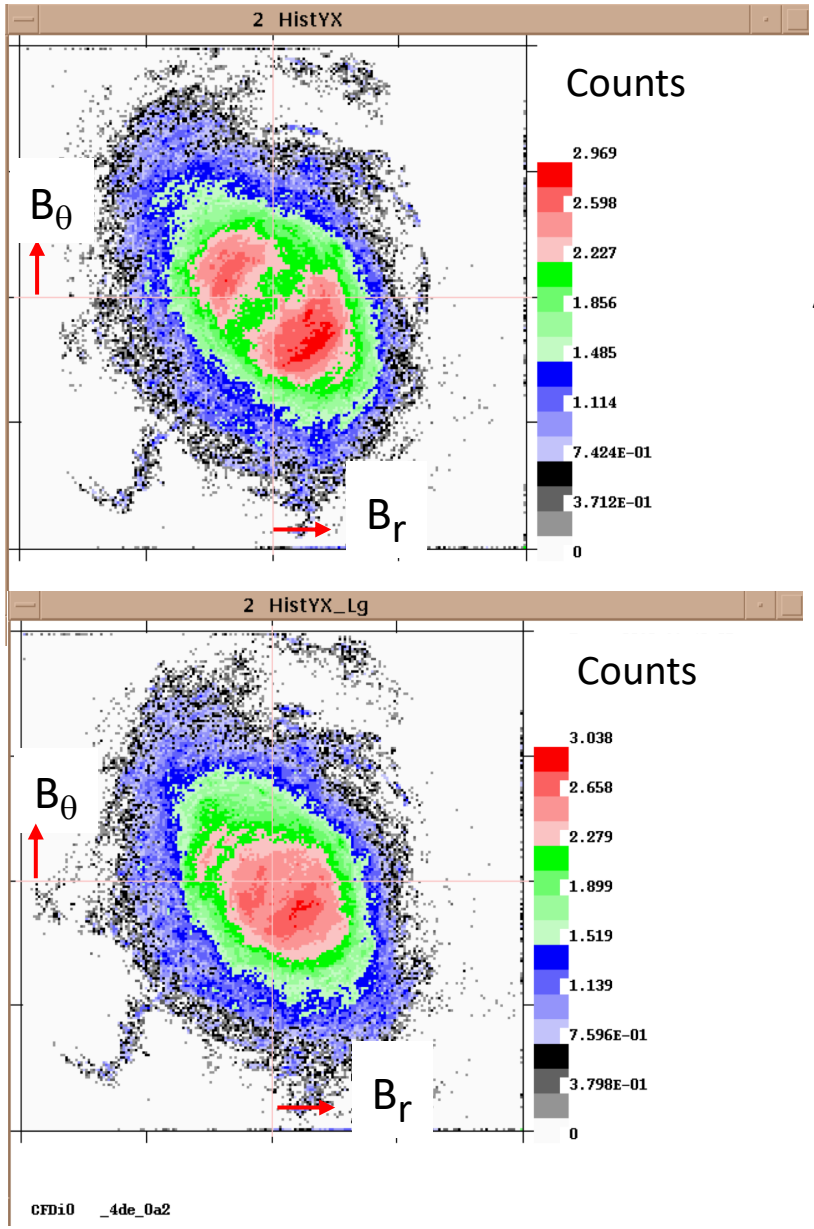
Energy in f^{Rot} components

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

B_r Phase may be "steady" over several solar rotations

Pha(B_r) - Pha(B_θ) : persistent 180° difference

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



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

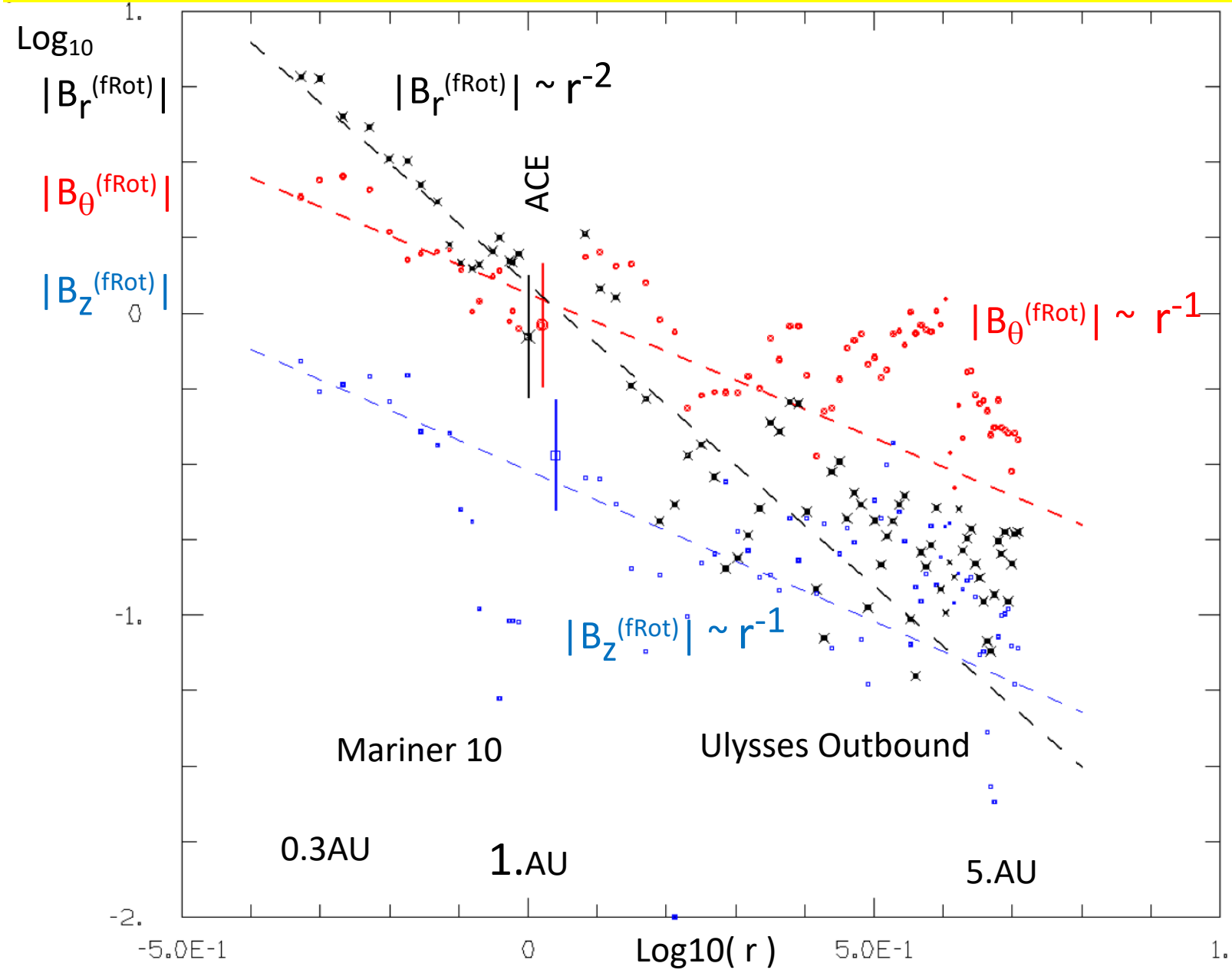
2015.0

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

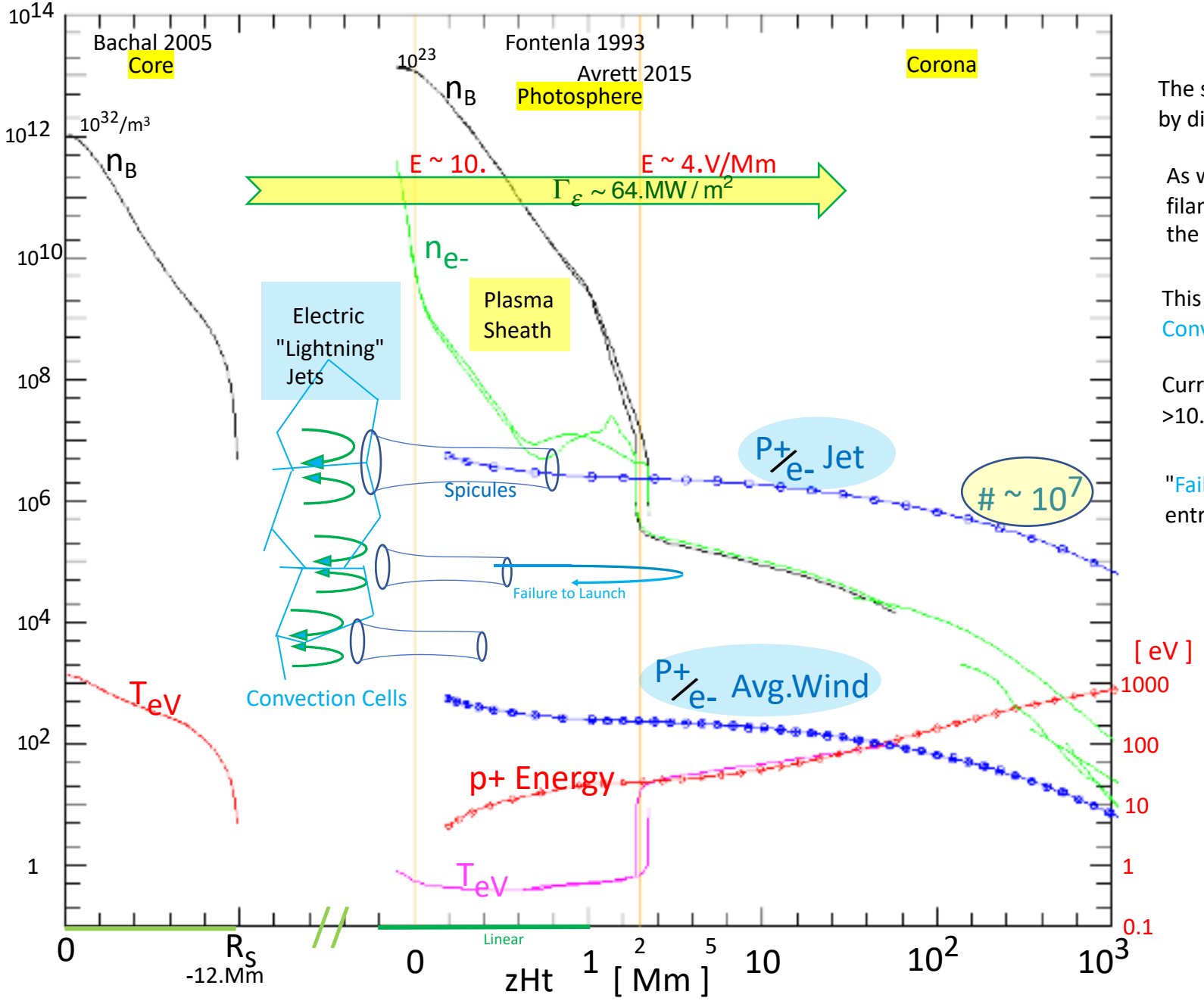


Sparse data from Ulysses outbound and Mariner 10 allows estimates of the radial dependence of the fRot components, albeit polluted by the (unknown, quasi-random) temporal variations.

The 20-year ACE averages and standard deviation levels are shown at 1.AU

Solar wind dynamic and fluctuation characteristics probably determine $|B_r^{(fRot)}| \sim r^{-2}$, $|B_\theta^{(fRot)}| \sim r^{-1}$, and $|B_z^{(fRot)}| \sim r^{-1}$.

0) Electric "Lightning" Jets Form the K-Corona Glow and the Solar Wind



The strong outward Solar energy flux Γ_ε induces weak electric fields E, by displacing a small fraction (~10^{-36}) of the plasma electrons outward.

As with Earth lightning, this electrical energy is released in episodic filamentary Jets, by an avalance breakdown of electrical resistivity in the weakly ionized Photosphere.

This breakdown occurs readily along the cool edges of surface Convection Cells (# ~10^7, A_{cell}~$(0.5Mm)^2$, lifetimes ~5.min).

Current "pinch" effects will favor small Jets (~5.km)^2 with energies >10.eV, glowing in the neutral background as "spicules" and"campfires".

"Failure to Launch" would result from too much neutral mass entrained in an accelerating Jet.