Heliospheric Magnetic Fields Generated by Solar Wind Current Fluctuations

DPP2023 / UO04.15
NNP.ucsd.edu/Solar

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

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

0) The Solar Wind originates in the Photosphere,
as ~~ 10^7 Electric "Lightning" Jets. --> UM09.03

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.μHz, $\tau > 1.\text{day}$) are "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

Work supported by NSF Phy21-06332, DoE, AFOSR, ONR

(0) Show us the Energy, Ulysses !!

Summary :

(1) The Sun is charged, by +460. Coulombs,
mainly resident in the plasma sheath at Rsun.

(2) The resulting electric energy is 6.keV at Rs,
whereas the proton gravitational "well" is 2.keV at Rs.

(3) The 4.keV excess electric energy can accelerate
proton Jets to 880.m/s ,
when not slowed by ecliptic-plane gas & dust.

(4) The Ulysses proton data shows a "hard limit"
at 880.km/s, over all directions and decades in time,
away from the ecliptic.

(5) This 460.C of charge is ***quantitatively determined*** by the
"virial" equality of gravity & electric energies (10.keV) at $r = 0$.

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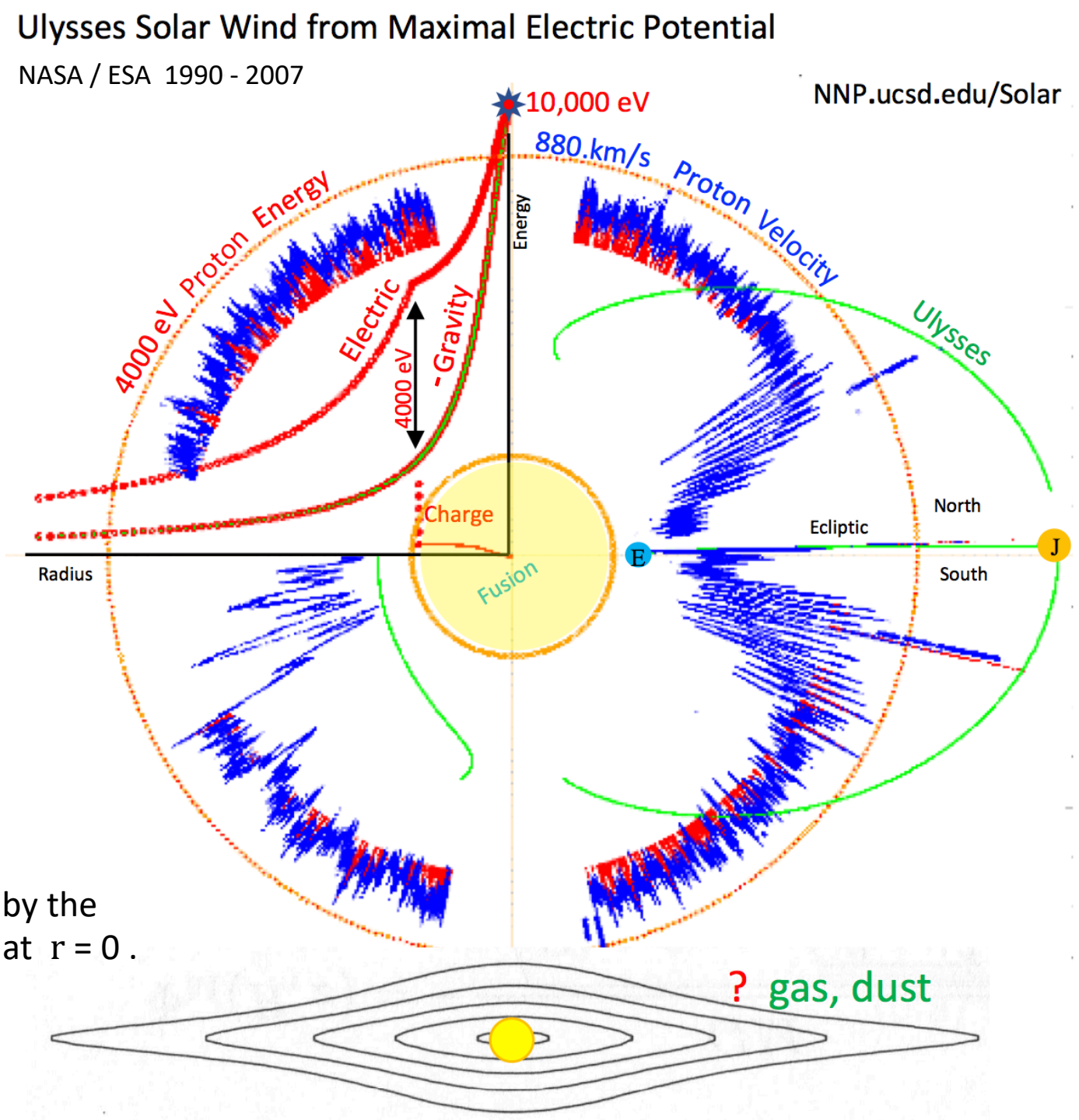
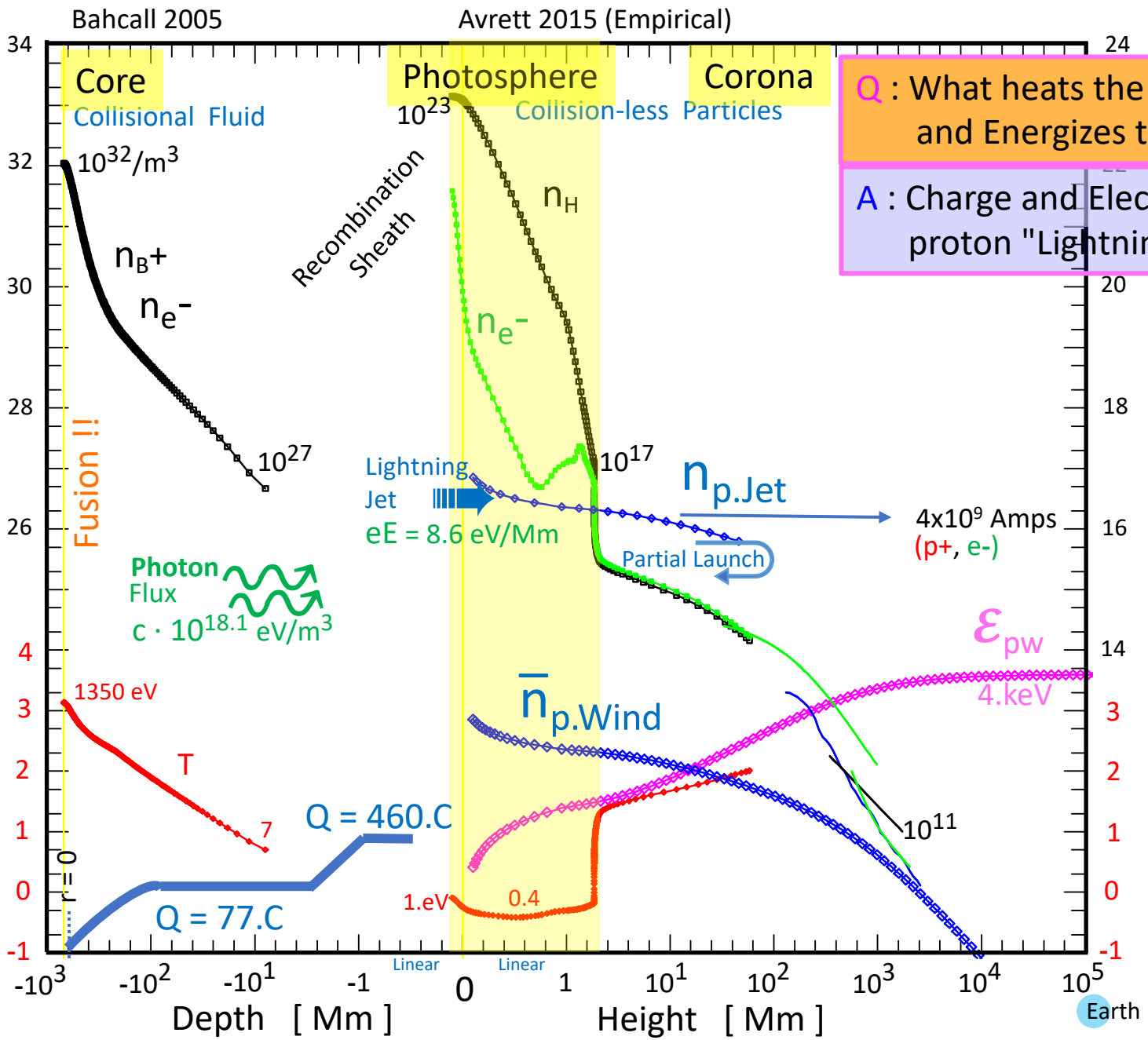


The Sun, In & Out



Q : What heats the Corona and Energizes the Solar Wind ?

A : Charge and Electric Fields, which accelerate proton "Lightning Jets" through the Photosphere.

The **Core** is described as a highly collisional, fully ionized fluid of baryons and electrons, with a central temperature T ~ 1350.eV = 1.6 x10^7 Kelvin .

Fusion energy diffuses out to R_{sun} as a **Photon Flux** of magnitude 64.MW/m^2 .

A plasma **Recombination Sheath** forms where the temperature drops below 1.eV ; here, no model exists.

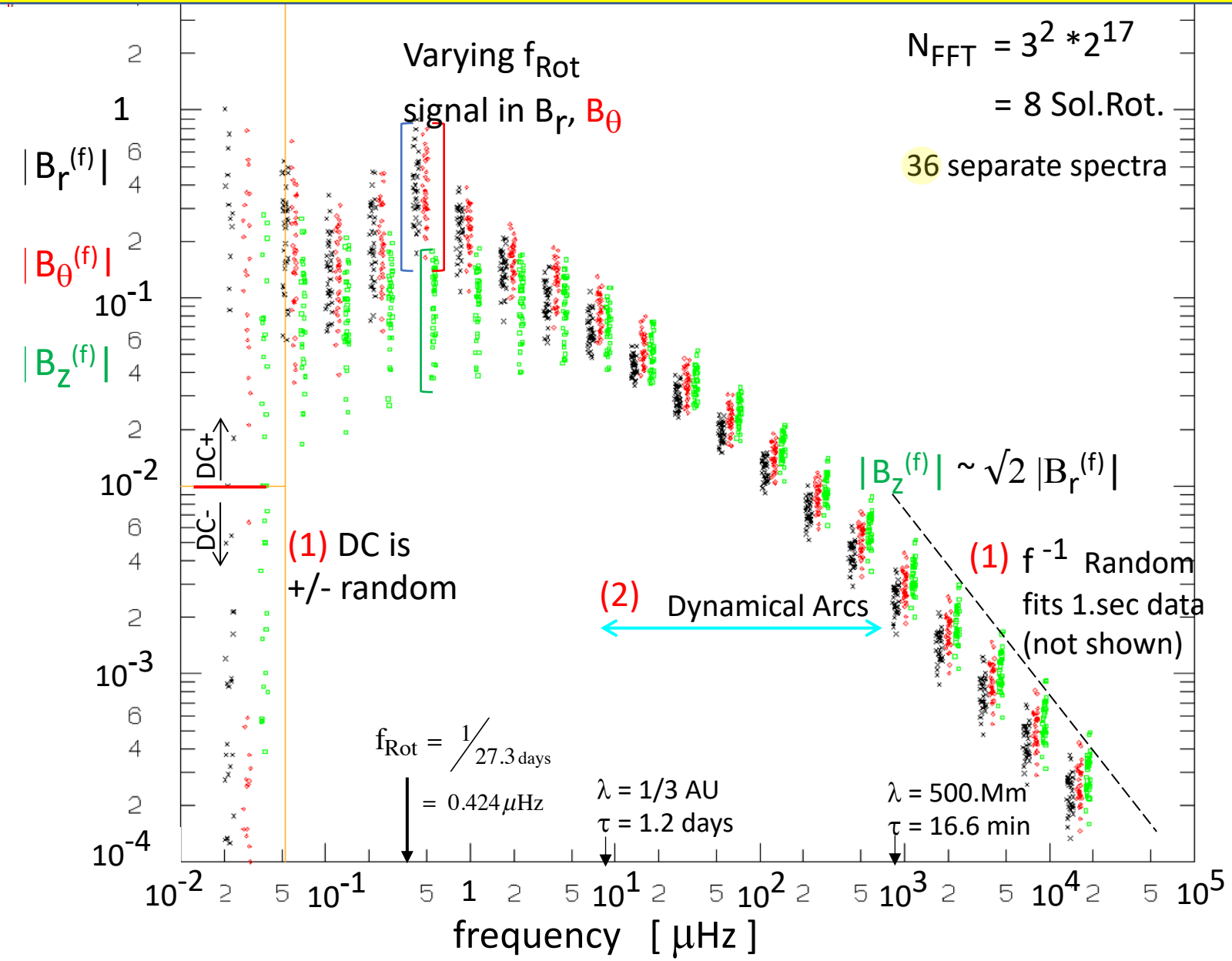
A weakly-ionized **Photosphere** ~2.Mm thick (yellow). covers the interior plasma. Here, the description must change from a collisional fluid to collision-less particles.

The **Corona** is a very low density, collisionless plasma, with empirical energy of about 100.eV per particle.

The proton/electron Solar **Wind** is an energetic, pervasive, persistent, low-density flux Γ of particles.

(1) 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

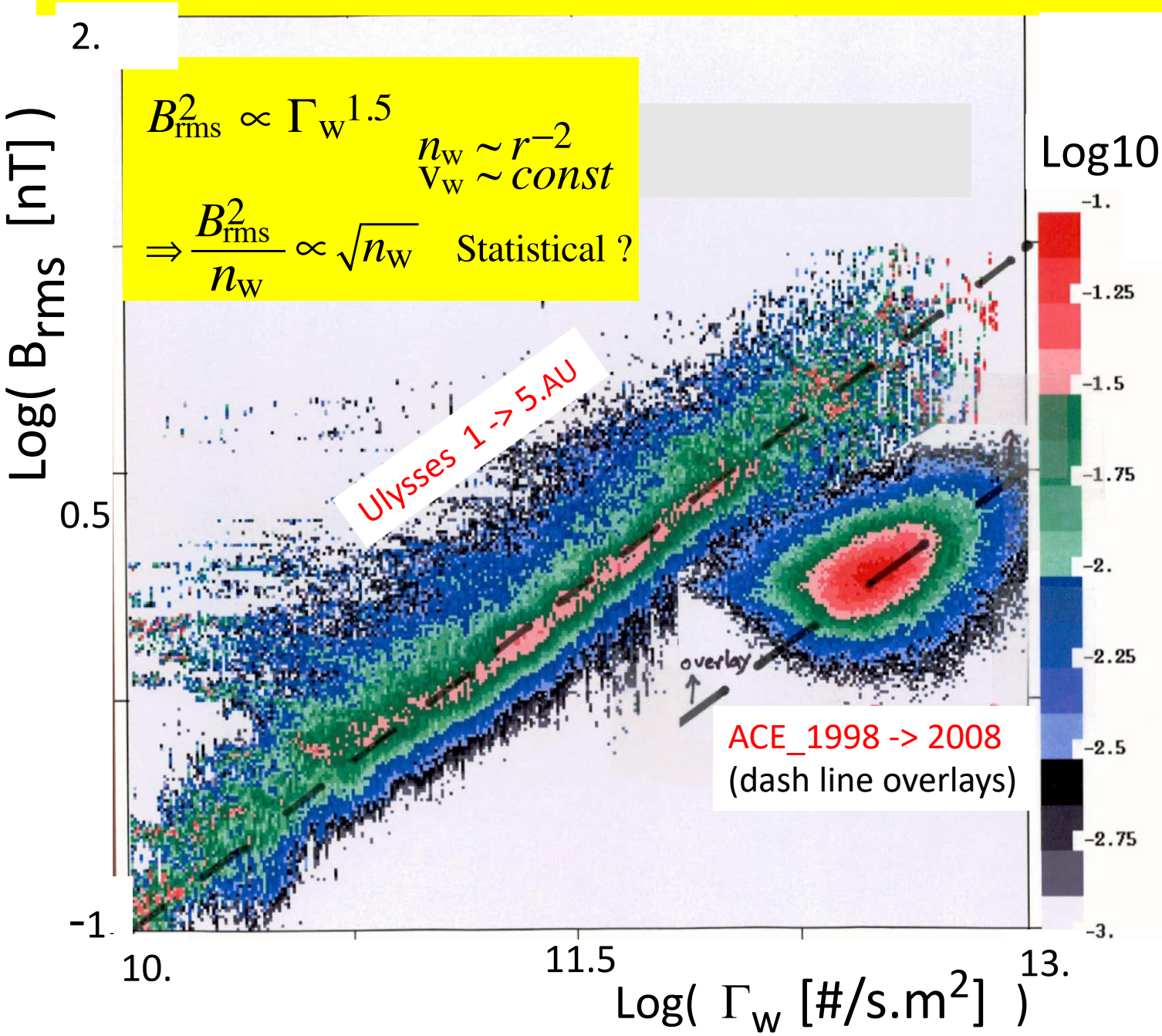
--- Similar to PSP "Switchbacks" seen at 0.1 AU

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

$$B_{rms}^2 \propto \Gamma_w^{1.5}$$

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

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



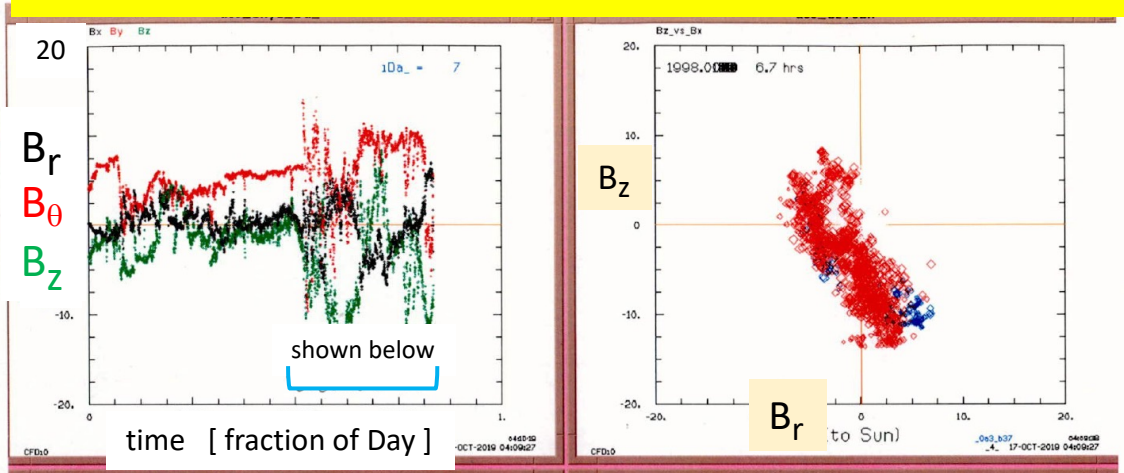
The measured magnetic fluctuations are created by the local electrical-currents of the Solar Wind, including any global currents from global charge separation.

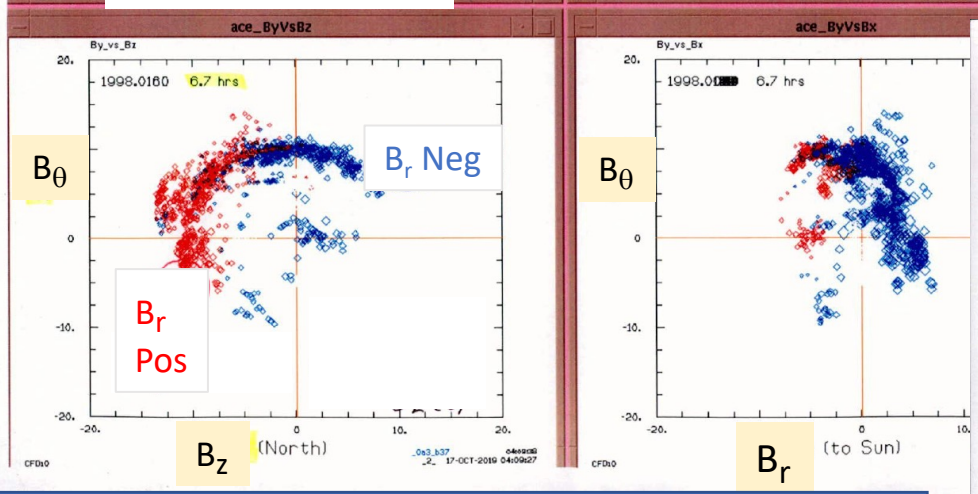
Moreover, major Solar surface events cause spacecraft detections of enhanced fluctuations after the SW particle *radial* propagation time, unrelated to "rooted spiral magnetic field" lengths.

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)

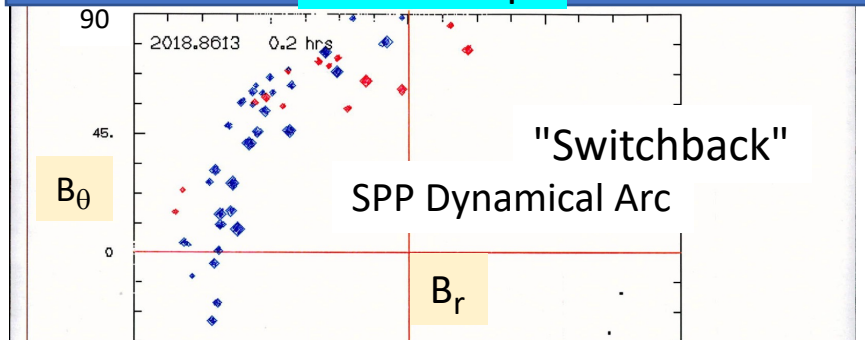




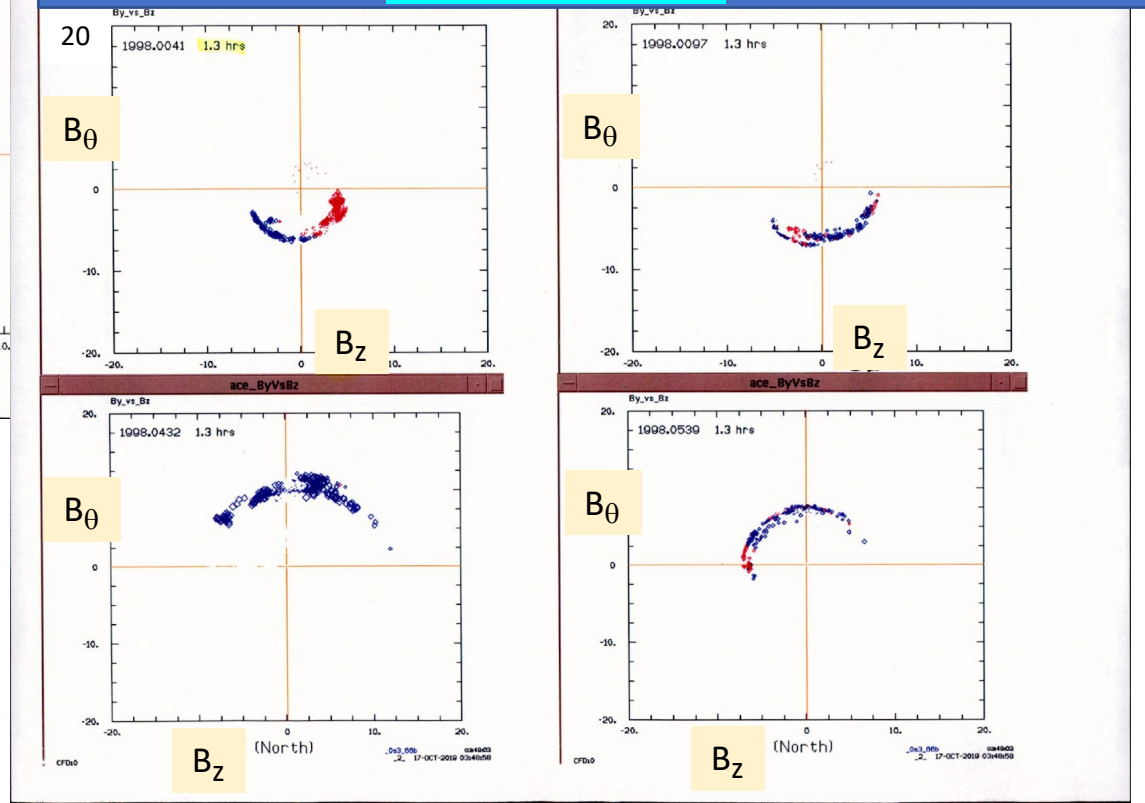
At left, a {Bθ,Bz} constant magnitude Arc appears in 6.7 hours MAG temporal data, unrelated to the sign of Br (red/blue). Other pairs {Bz,Br} and {Bθ,Br} show no Arc during this time, but are equaly prevalent in general. Below are 4 Arcs of 1.3 hrs duration, selected for their "clean" appearance.

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

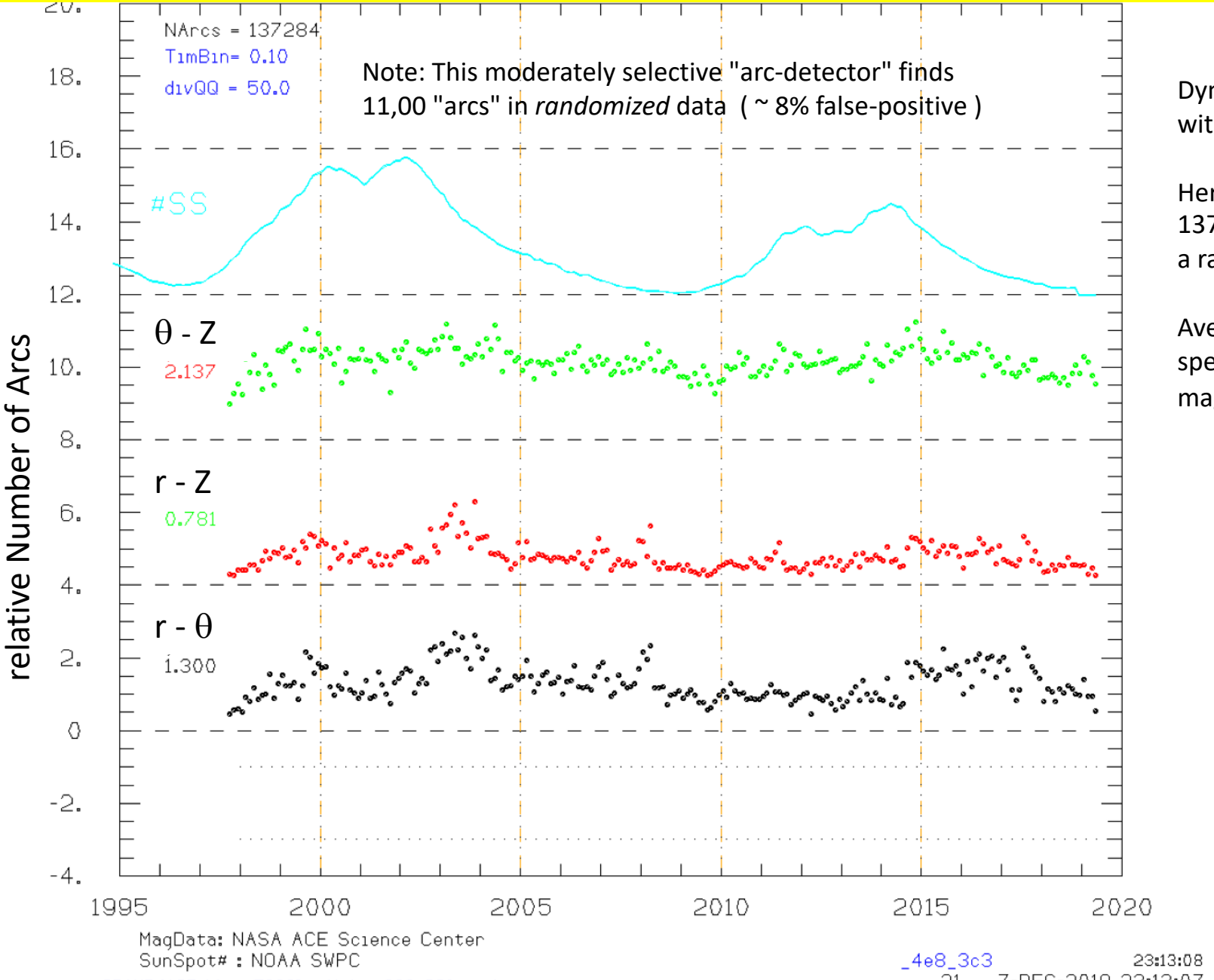
SPP Example



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

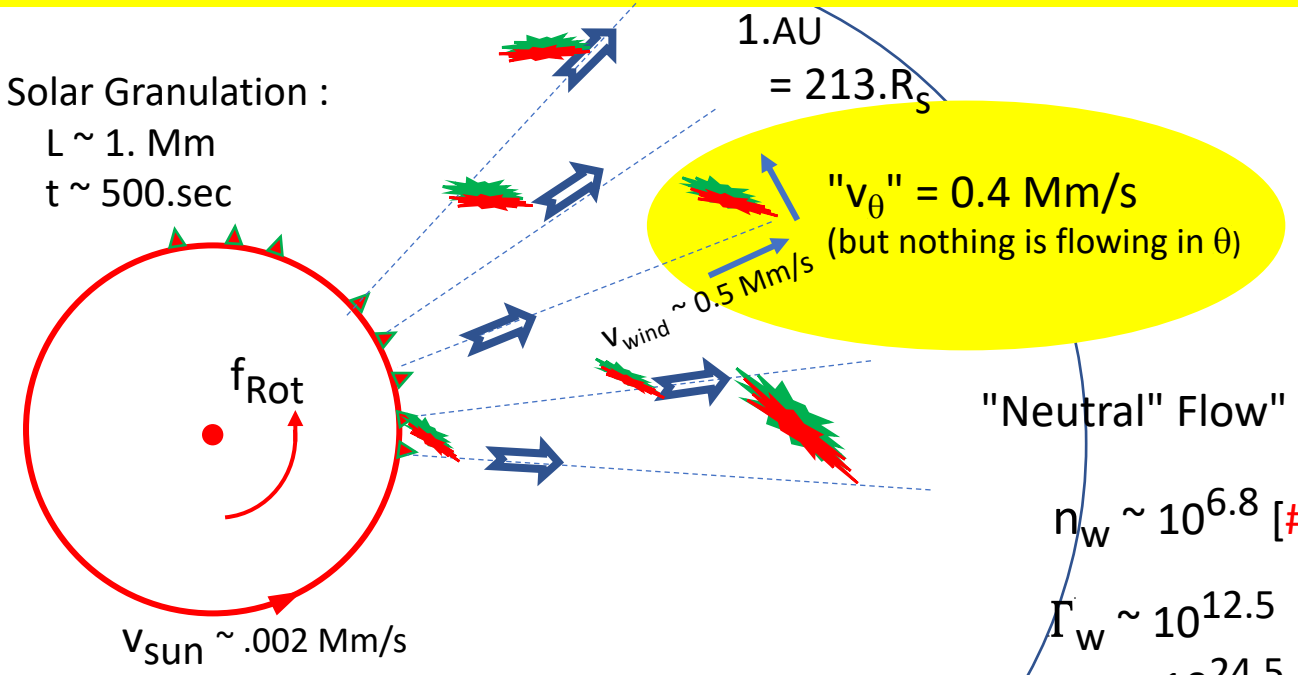


Dynamical Arcs appear in all pairs of {Br, Bθ, Bz}, with similar rates of occurence.

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

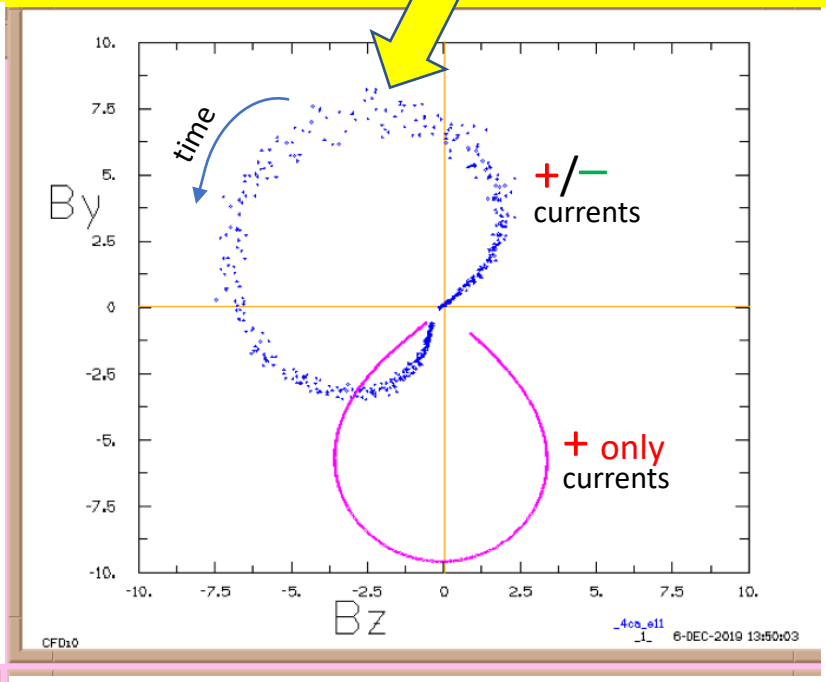
time = 500.sec

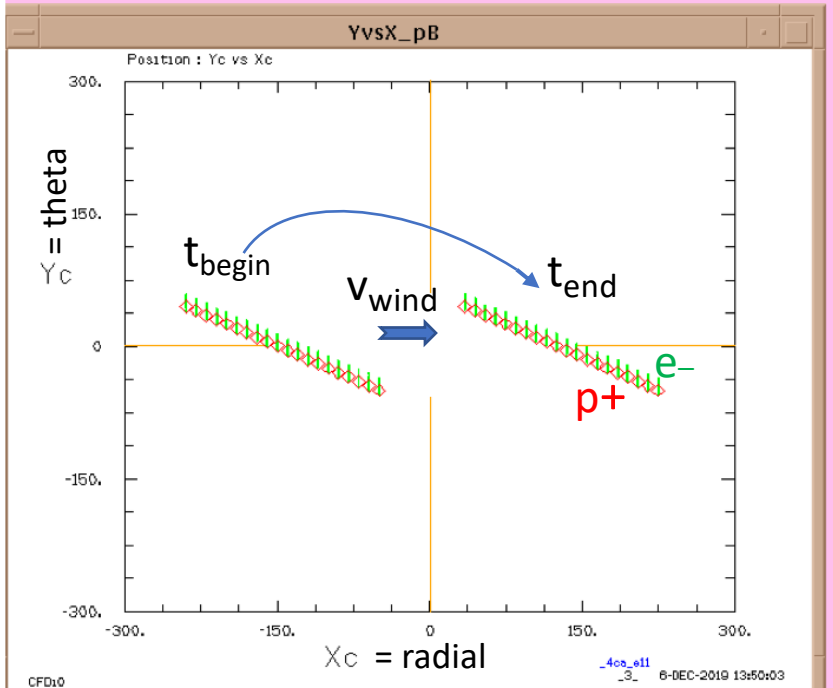
length = 200.Mm

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.

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