The Electric Field of the Sun and Solar Wind

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Q : How can a Solar Photon Flux of $\Gamma_{\varepsilon\gamma} \sim 60.\,\mathrm{MW/m^2}$
possibly create a Solar Wind with $\Gamma_{\mathrm{KE}} \sim 60.\ \ \mathrm{W/m^2}$?

A : With Electric Fields

(at surface)

Gravi-Thermo-Electric $eE_G \sim +1.4\,\mathrm{eV/Mm}$ <--- Eddington, Rosseland (1924)

and Photo-Electric $eE_\gamma \sim +4.6\,\mathrm{eV/Mm}$ from average $\sigma_{\gamma e} \sim 3\mathrm{x}10^{-24}\,\mathrm{m}^2$ modeled here

thereby dominating gravity $m_p\,g \sim -2.8\,\mathrm{eV/Mm}$

and "levitating" Protons to keV energies.

Note : Photon-electron cross-section $\sigma_{\gamma e}$ varies broadly; photons heat the Wind; maintaining a "self-consistent drive"; additional theory is needed.

: "Runaway" protons escape H0 background, requiring a kinetic analysis.

: The un-neutralized charge Q is *exceedingly* small (~ 10^{-36});

: This "global spherical" model identifies the Electric energetics; but structures on the mega-meter scale are evident the the data.

Here: Diagnosing ACE, Ulysses, and Mariner10 *magnetic fluctuations* characterizes the *electric currents* in the (globally neutral) Wind.

We find : 1) pervasive Noise Fluctuations 2) Global North-South Currents and 3) "Double Filament Currents" creating "Bx(t) - By(t) Dynamical Arcs"

But : ~~MHD~~ These processes are *precluded* by the assumptions of MHD.

Stellar Hydro Eqns: mass charge photons

$m_p\ m_e$ $\quad e^-\ p^+$ $\quad \gamma$

$$1 \quad \nabla^2\Psi(r) = G\, m_p\, n_p(r)$$ Gravity

$$2 \quad \nabla \bullet \Gamma_{\varepsilon\gamma}(r) = \frac{d}{dt}\varepsilon(r)$$ Energy Generation

$$3 \quad -\frac{d}{dT}(aT^4)\ T'\, l_\gamma = \frac{4}{c}\Gamma_{\varepsilon\gamma}$$ Thermal Diffusion

$$4a \quad [n_pT]' + n_p m_p \Psi' + (+e)n_p\Phi' = 0$$ Proton Fluid

$$4b \quad [n_eT]' - \frac{\Gamma_{\varepsilon\gamma}}{c\, l_{\gamma e}} + \cancel{n_e m_e}\Psi' + (-e)n_e\Phi' = 0$$ Electron Fluid

$$\underline{4a+4b} \quad [(2n)T]' - \frac{\Gamma_{\varepsilon\gamma}}{c\, l_{\gamma e}} + n\, m_p\Psi' = 0$$ Hydro Forces

$$\underline{4a-4b} \quad \frac{\Gamma_{\varepsilon\gamma}}{c\, l_{\gamma e}\, n} + m_p\Psi' + (2e)\,\Phi' = 0$$ Electric Field

(0) Photon Drive of Solar Wind : γ p+, e-, H*, $H^{(-)}$

$$\frac{\Gamma_{\varepsilon\gamma}}{c}\sigma_{\gamma e} - \frac{1}{n_e}[n_e T]' + e\Phi' = 0$$

Gravi-Electric (hydro)

$$\sigma_{\gamma e} = 1 / n\, l_{\gamma e}$$

Photo-Electric

$$\sigma(H^*) \sim \pi a_0^2 = 0.6\,\mathrm{x}10^{-20}\,\mathrm{m}^2$$

$$\sigma(H^- bf) \sim 0.5\,\mathrm{x}10^{-20}\,\mathrm{m}^2$$

$$\sigma(H^{(-)} ff) \sim 0.5\,\mathrm{x}10^{-20}\,\mathrm{m}^2$$

$$\sigma_{\gamma e} \sim 3.4\,\mathrm{x}10^{-24} = Model$$

$$\sigma_{\mathrm{T}} = 0.7\,\mathrm{x}10^{-28}\,\mathrm{m}^2$$

Photo-Electric:

When Electric Field on Protons
Exceeds Collisional Drag from H^0

Runaway p+ :

$$\frac{d}{dr}\varepsilon_p = -m_p\Psi' - e\Phi' - \nu_c(p^+, H^0)$$

$$\varepsilon_{p+}(\rho) \sim \varepsilon_0 + (1.3\mathrm{keV})\left[1 - 1/\rho\right]$$

$$\mathrm{v_p}(\rho) \sim (500.\mathrm{km/s})\left[1 - 1/\rho\right]$$

$$n_\mathrm{p}(\rho) \sim 3\mathrm{x}10^{11}\ \rho^{-2}\ \mathrm{m}^{-3}$$

$$\Gamma_\mathrm{p}(\rho) \sim 1.6\mathrm{x}10^{17}\ \rho^{-2}\ \mathrm{s}^{-1}\mathrm{m}^{-2}$$

$$\rho \equiv r / R_s$$

Hydro: Protons Electrons

2.8 eV /Mm

$m_p g$ $+eE$ $n_p T$

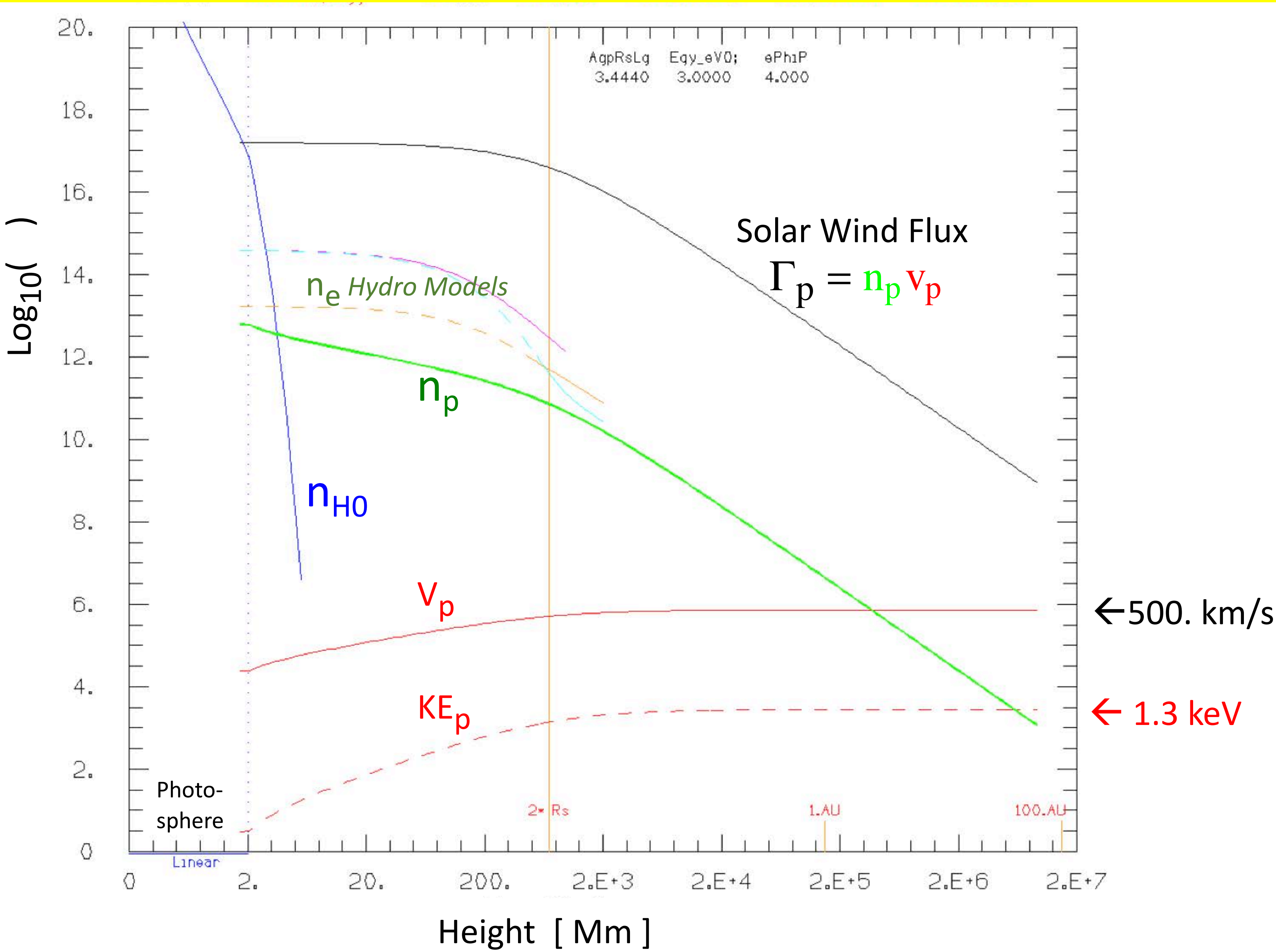
$m_e g$ $-eE$ $n_e T$

$E_{PhEl} \sim 4.6$ eV/Mm

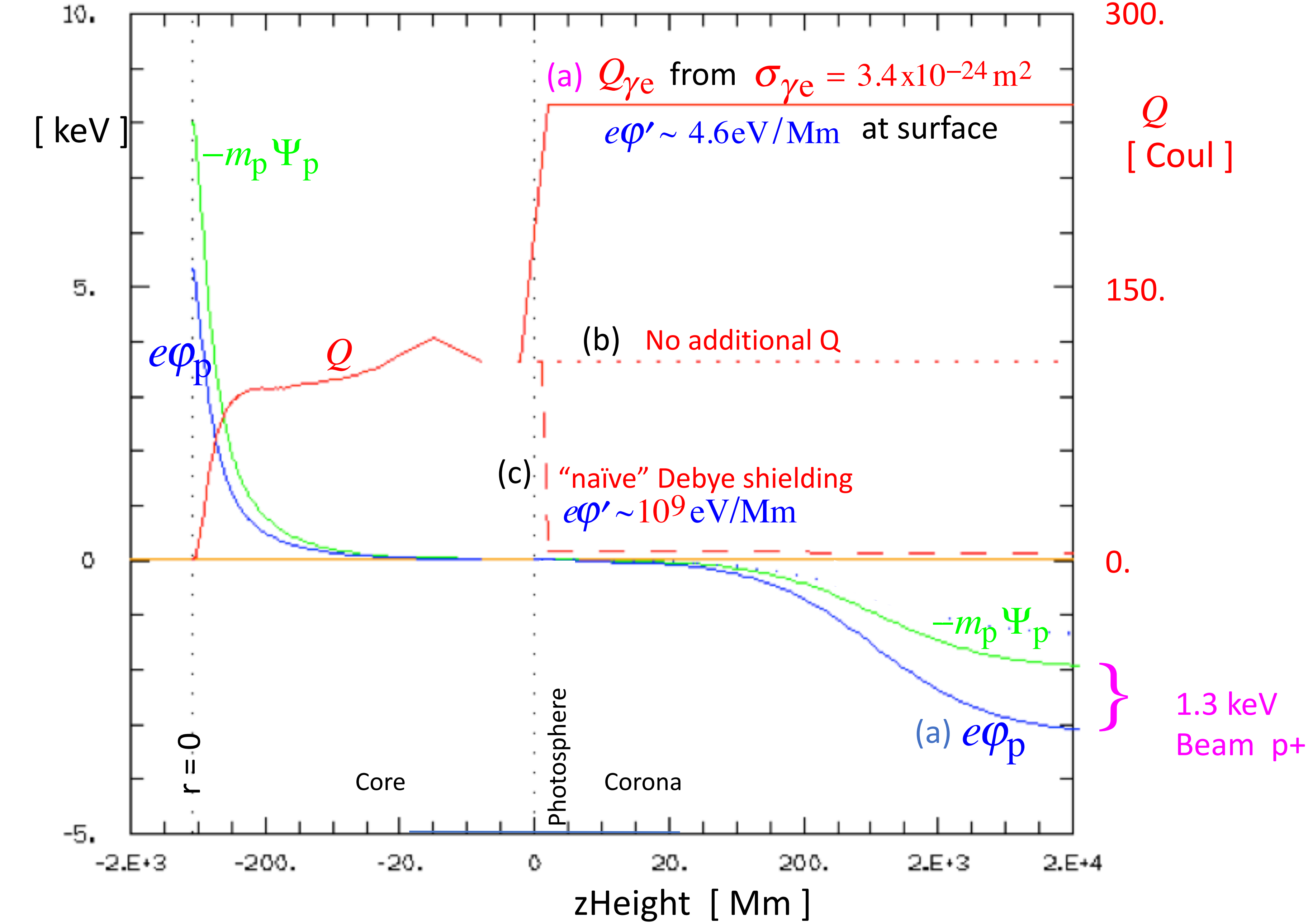
from

$$\Gamma_{\varepsilon\gamma} = 60.\,\mathrm{MW/m^2}\ \rho^{-2}$$

Photon-Driven Solar Wind p+ Flux, Density, Velocity, Energy
assuming average $\sigma_{\gamma e} = 3.4\text{x}10^{-24}\,\text{m}^2$

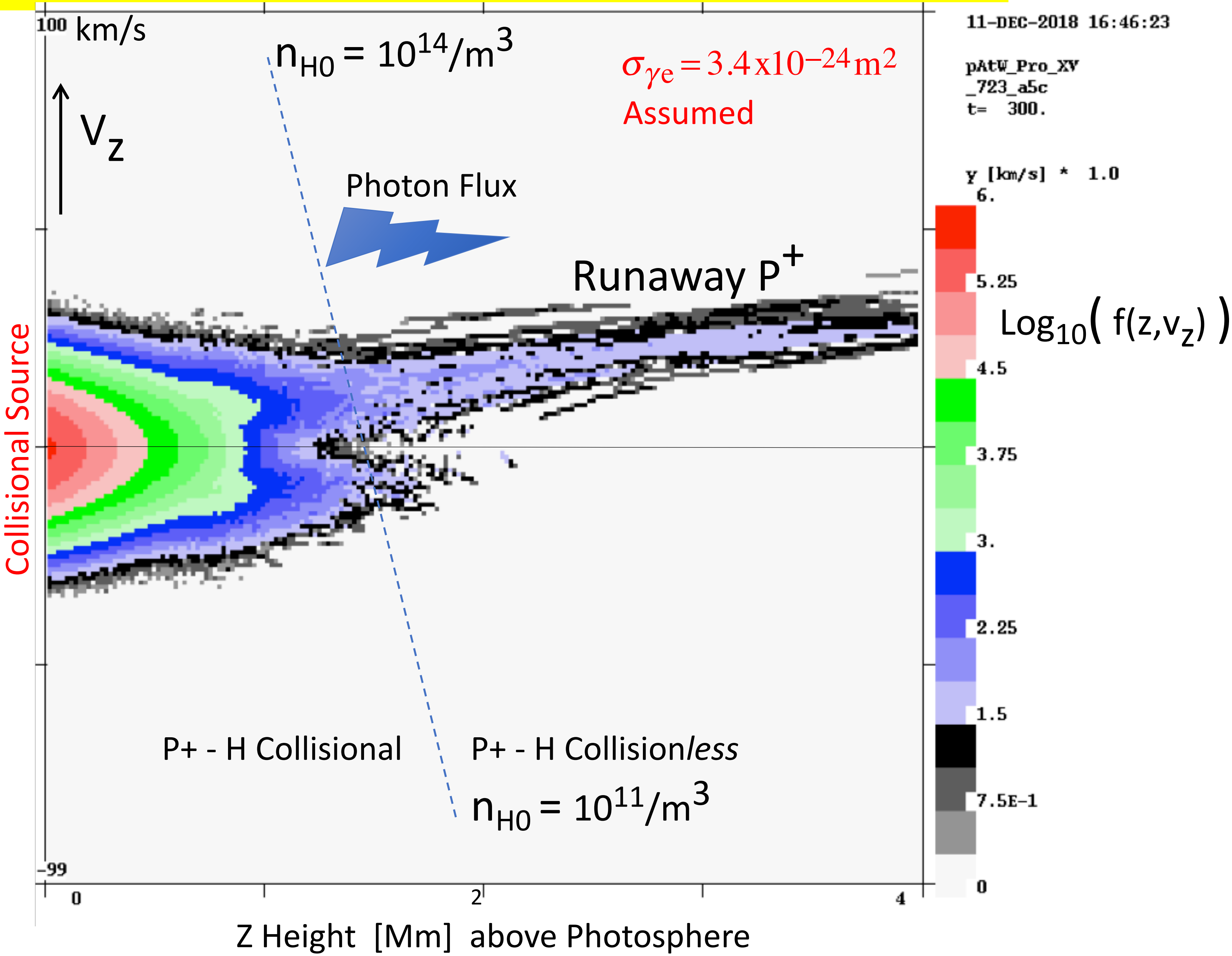


Q, φ, Ψ from (a) Photon-driven charge separation, giving 1.3keV Solar Wind;
(b) No additional charge; (c) "naïve" Debye shielding, giving 10^9 eV/Mm

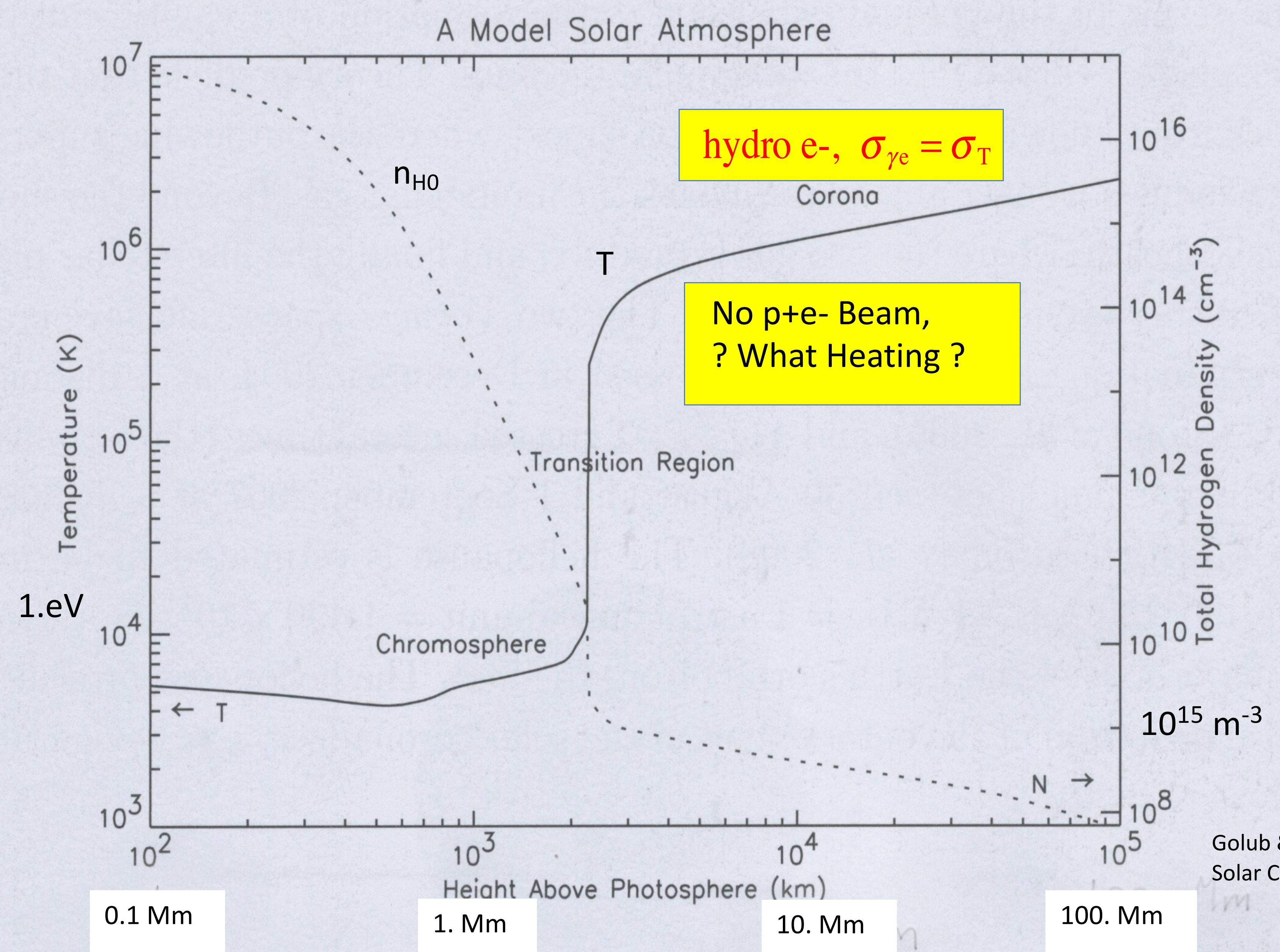


0.5

"1-d PIC Sim" : Collisional e-p+ Source, Photon Force, H^0 Drag, e- p+ Kinetics, Poisson Eqn => e- p+ Beam



Traditional MHD Models : Coronal Heating and Solar Wind Energetics remain elusive



Golub & Pasachoff,
Solar Corona

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

1) Random Fluctuations 2) f_{Rot} Signature from Global N/S Currents

3) Dynamical Bx-By Arcs from "Double Filament" Currents

p^+, e^- : $v_w \sim 500.\mathrm{km/s}$ $\mathcal{E}_{p+} \sim 1.3\,keV$

$n_w \sim 10^{24.8}\ \rho^{-2}\,[\#\#/\mathrm{Mm}^3]$ $\mathcal{E}_{e-} \sim 10.eV$

Flux $\Gamma_w \sim 10^{24.5}\ \rho^{-2}\,[\#\#/\mathrm{s}\cdot\mathrm{Mm}^2]$

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

$B_{RMS} \propto \Gamma_W^{0.75}$ over $1 \rightarrow 5\mathrm{AU}$

$B_{radial} == B_x$
$B_{theta} == B_y$
$B_{north} == B_z$

$\rho \equiv r / 1\mathrm{AU}$

$f_{Rot} = {}^{1}\!/_{27.3\,\mathrm{days}}$

$= 0.424\,\mu\mathrm{Hz}$

1) Pervasive Random Fluctuations

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

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

2) $B_x(t)$ and $B_y(t)$ are *correlated,* by distinct Fourier components at f_{Rot}

--- Highly variable : 1% - 40% (avg 12%) of B^2 Energy

--- Removing *single* f_{Rot} component eliminates Correlation

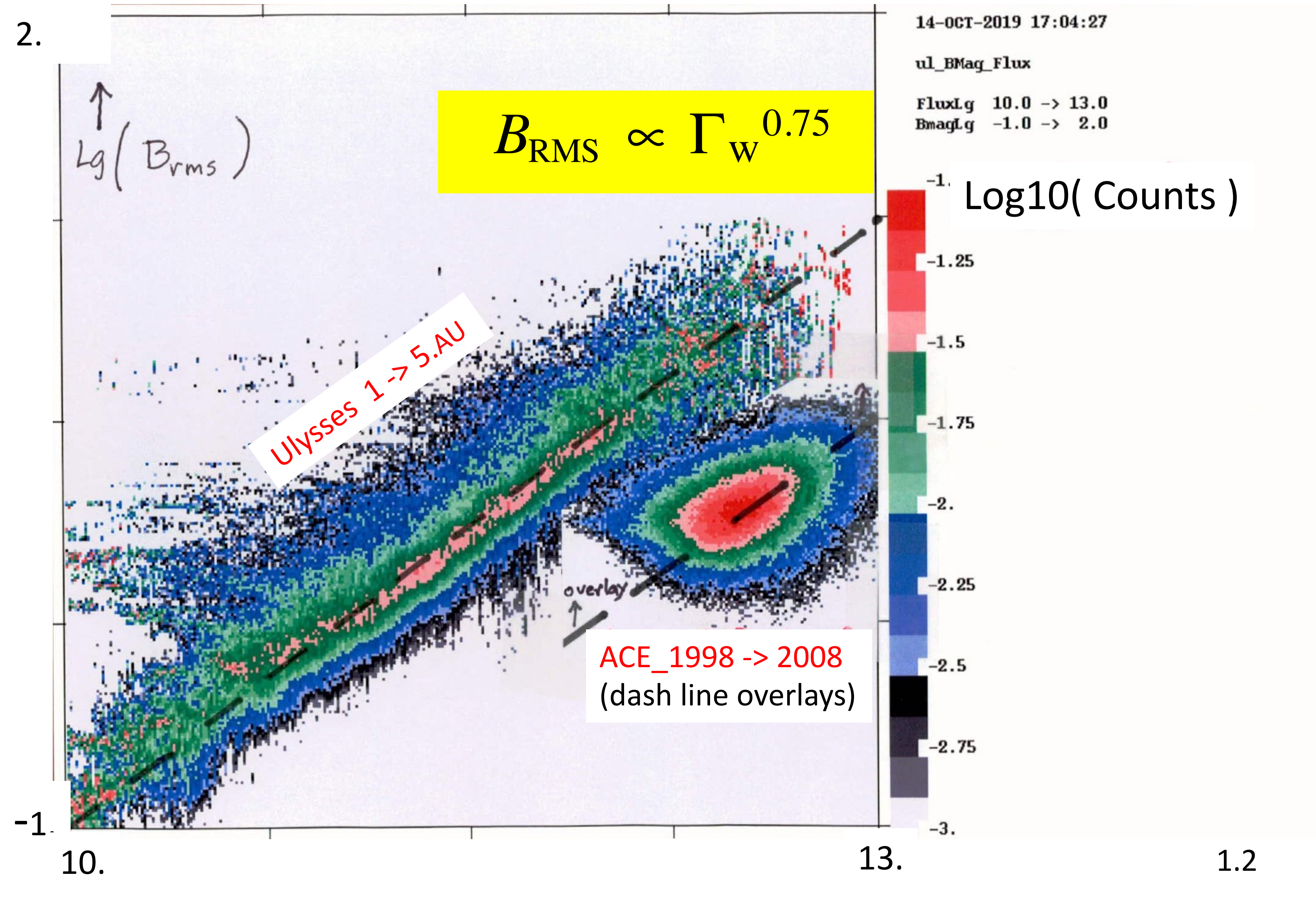
---?? From gradient of North-South Current, driven by N-S charge imbalance

3) $B_y(t)$-$B_z(t)$, Bz(t)-Bx(t), Bx(t)-By(t) “Dynamical Arcs” are ubiquitous

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

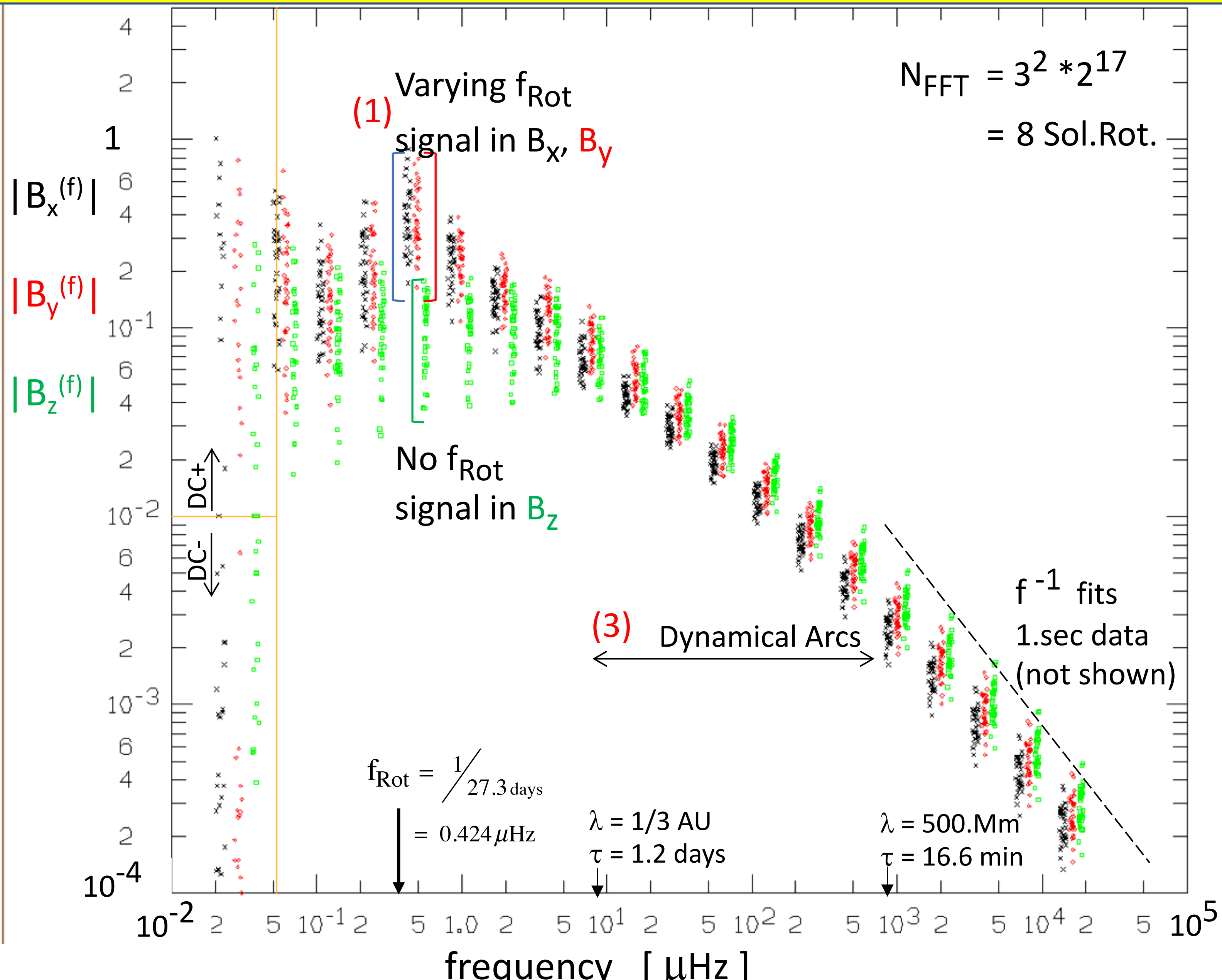
--- Non-random Spectral Energy $10^1 < f < 10^3$ μHz

Magnetic Fluctuation Level depends on Solar Wind Flux



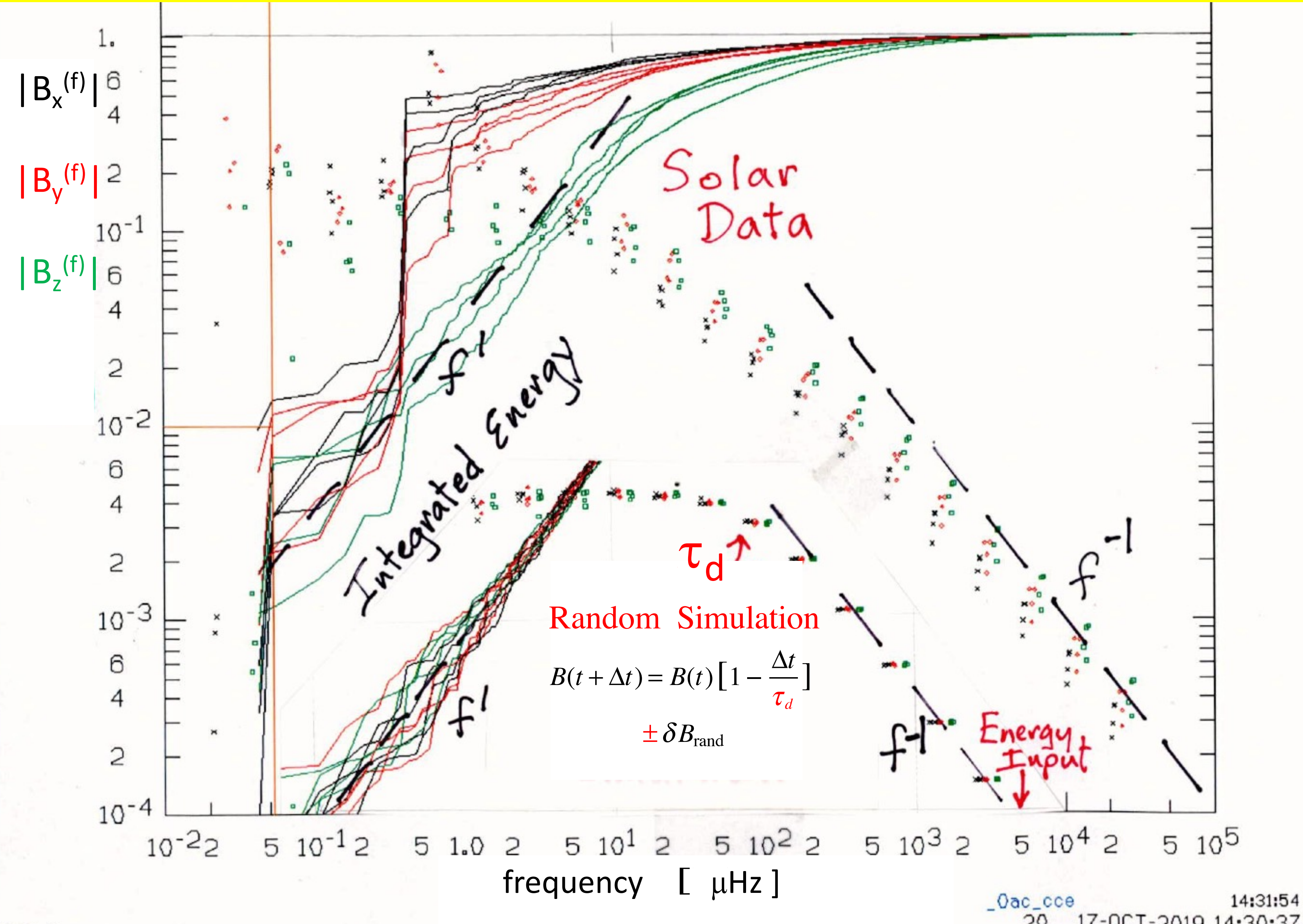
(1) Spectrum of Magnetic Fluctuations : ACE MAG @ 1.AU

16.sec data, 1998.0 -> 2019.4

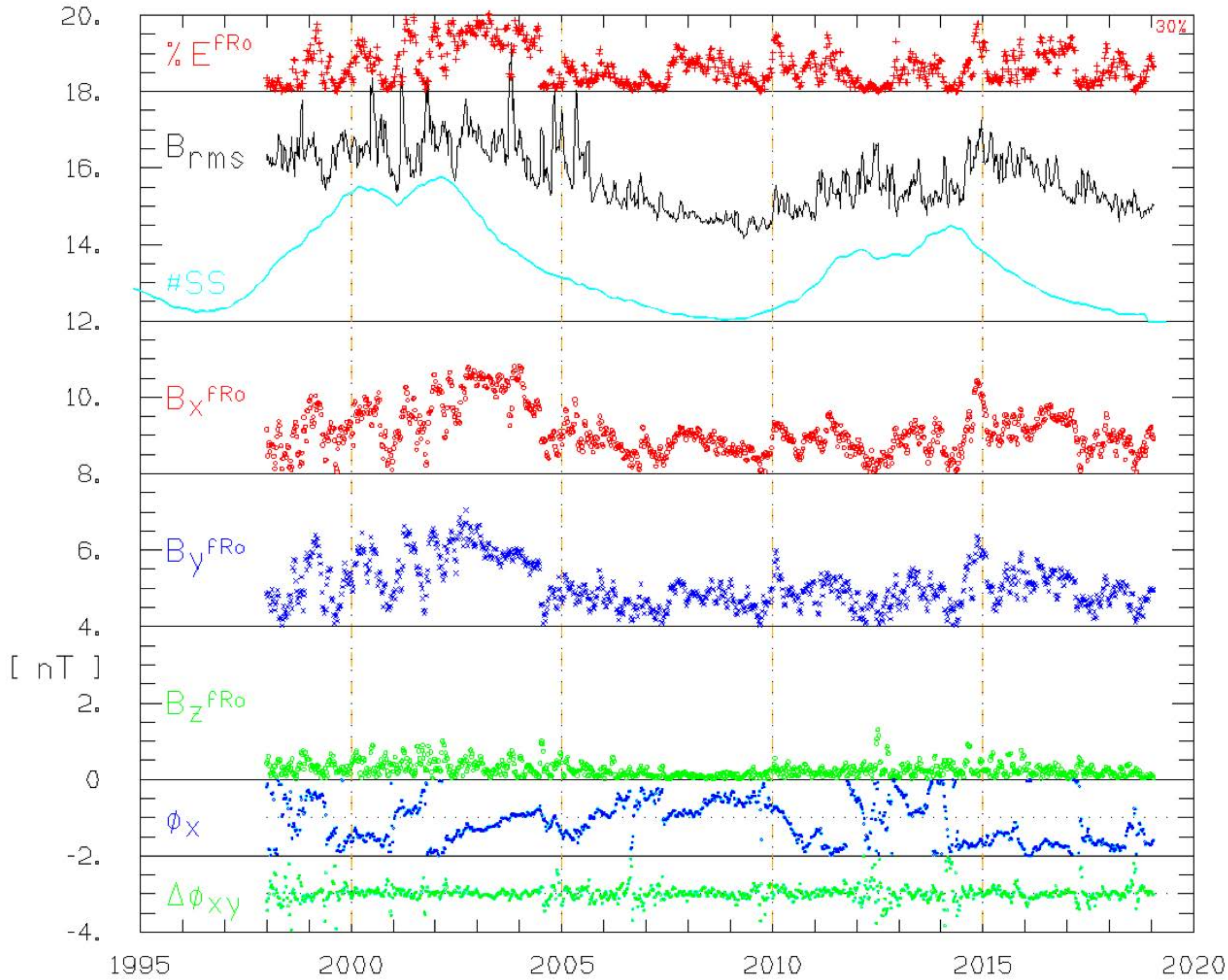


(2) f^{Rot} components are *exceptional* : larger-than-random variations over months

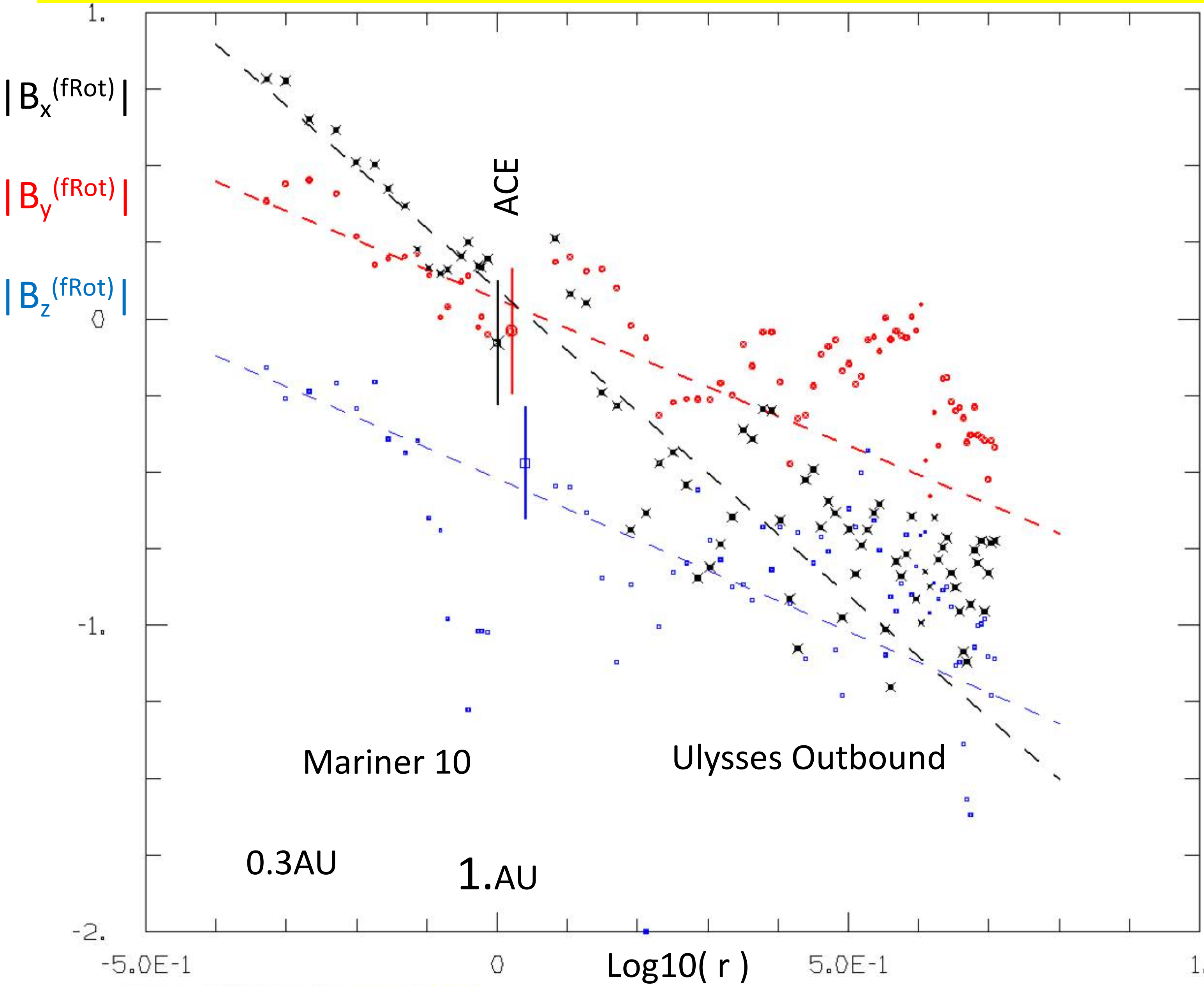
: provide 180° correlation between Bx and By



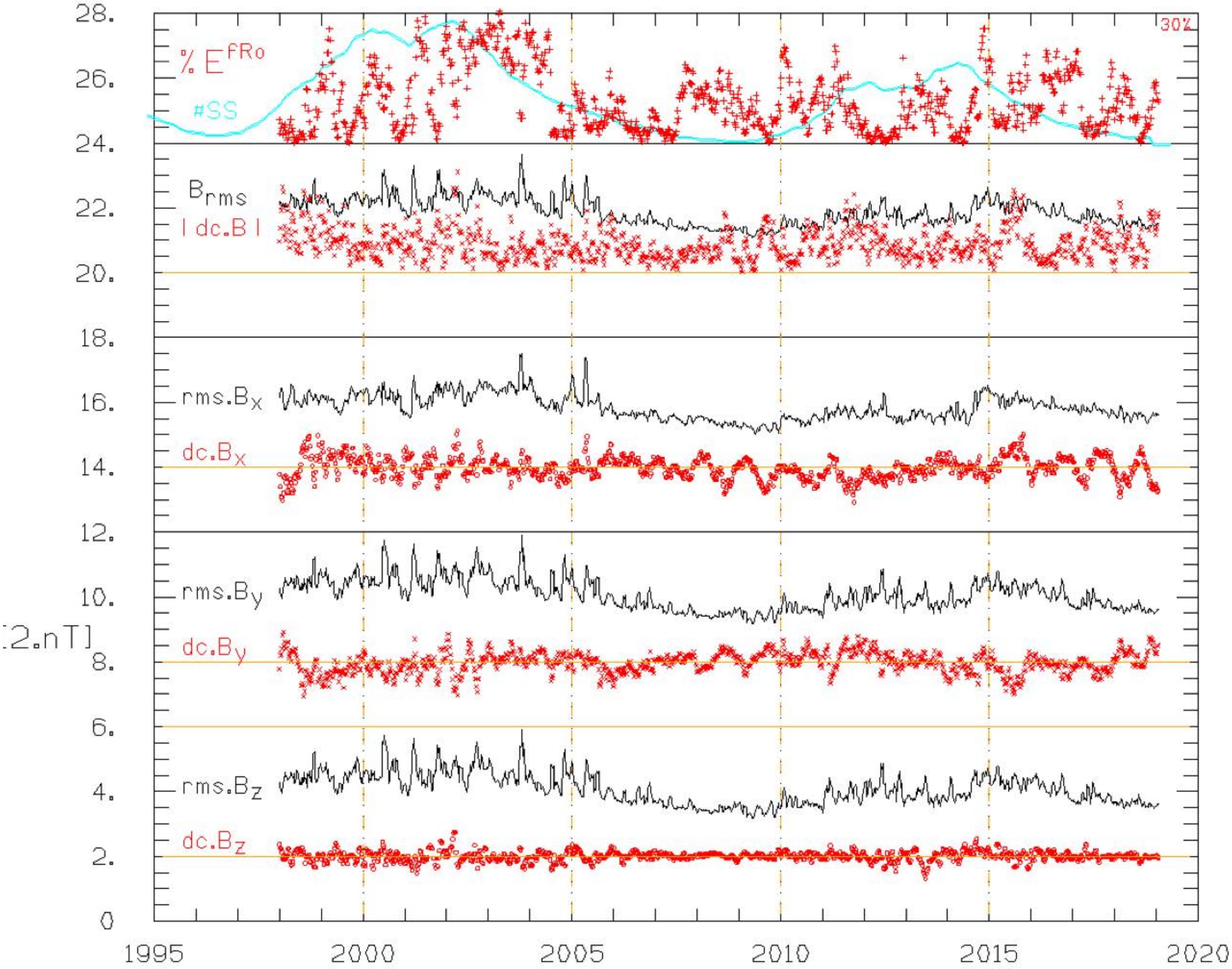
(2) Fluctuating B_x^{fRo} and B_y^{fRo} are *Correlated* ; B_z^{fRo} is noise.
0% –> 30% of Magnetic Energy is in $B_{x,y}^{fRo}$ fluctuations.



Radial Dependence of fluctuating components B_x^{fRot} B_y^{fRot} B_z^{fRot}



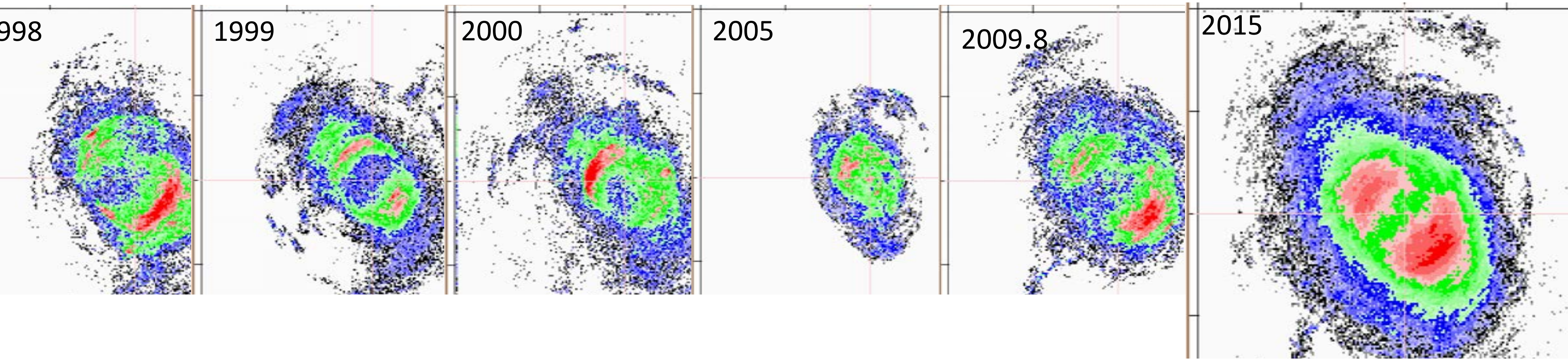
There are no significant "persistent" magnetic fields at 1.AU :
"DC" levels vary +/- as expected from random higher-frequency "drives"



$B_x - B_y$ Correlation is *Removed* when the Fourier Components at f_{Rot} are *Remove*

ACE Data, T = 1 Rotation

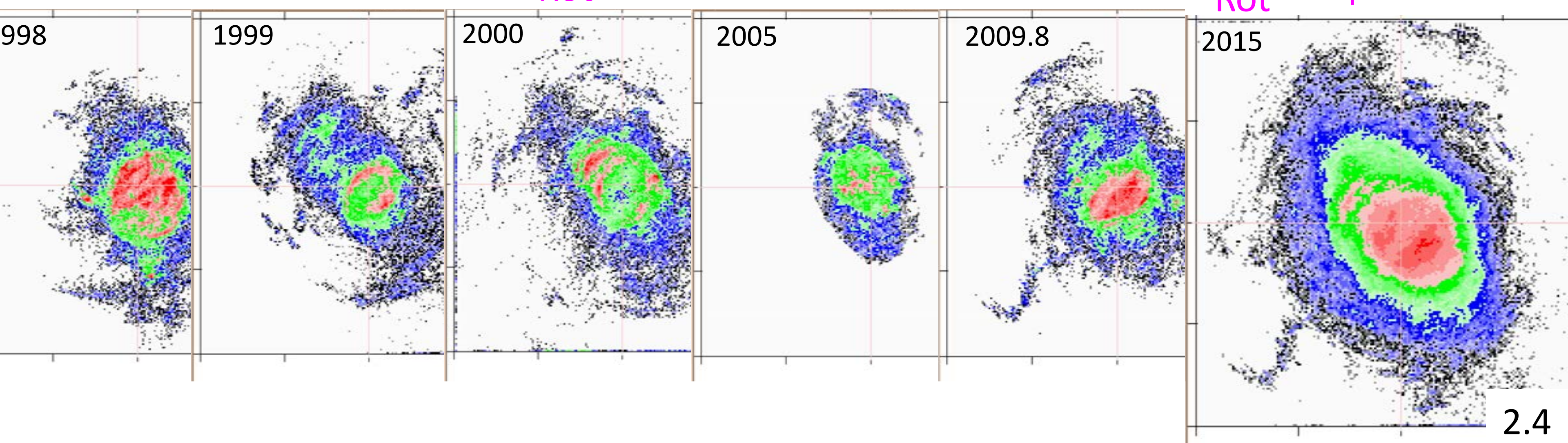
ACE Data, T = 8 Rotatio



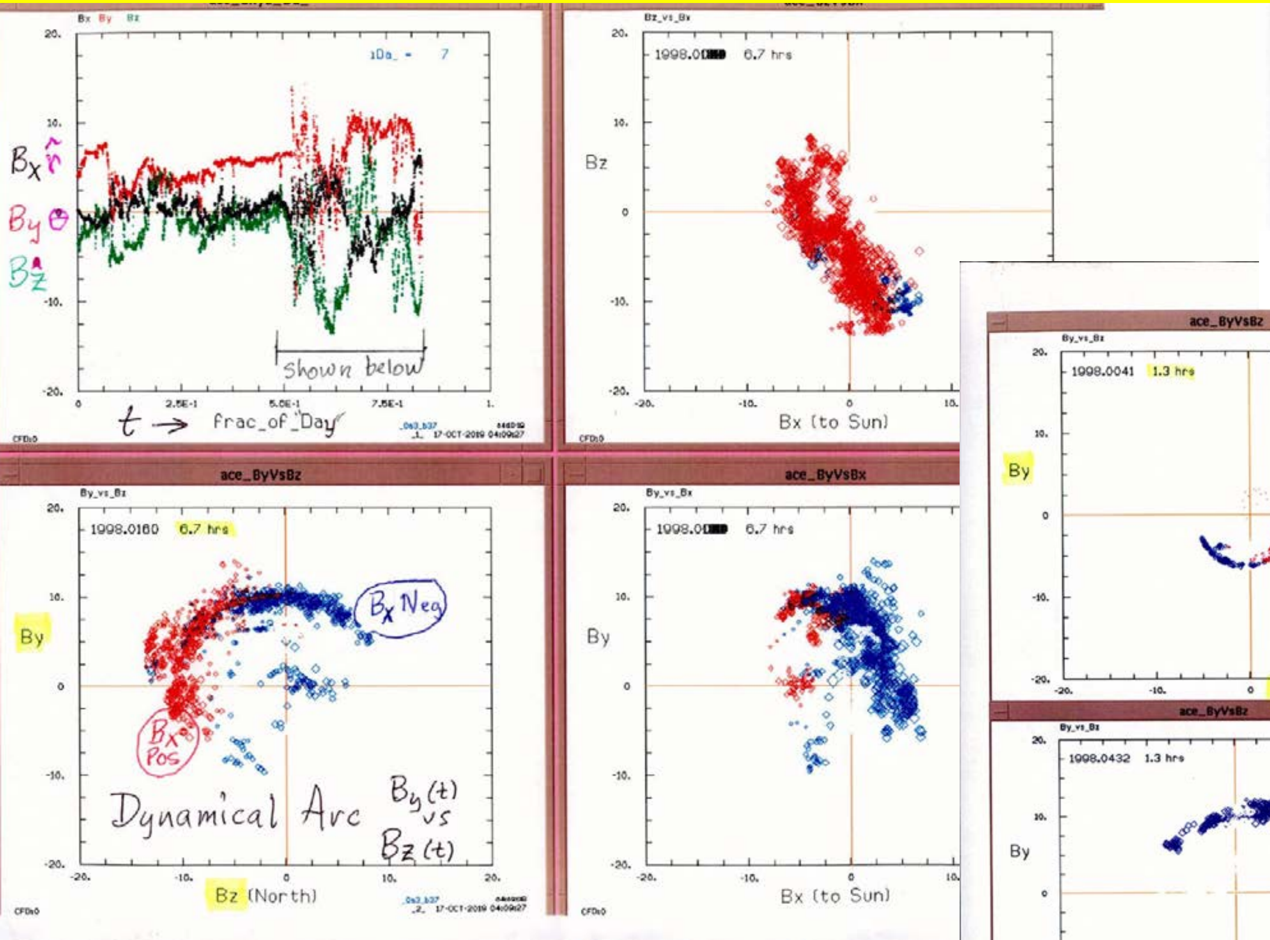
ACE Data, T = 1 Rotation, f_{Rot} components *Removed*

ACE Data, T = 8 Rotatio

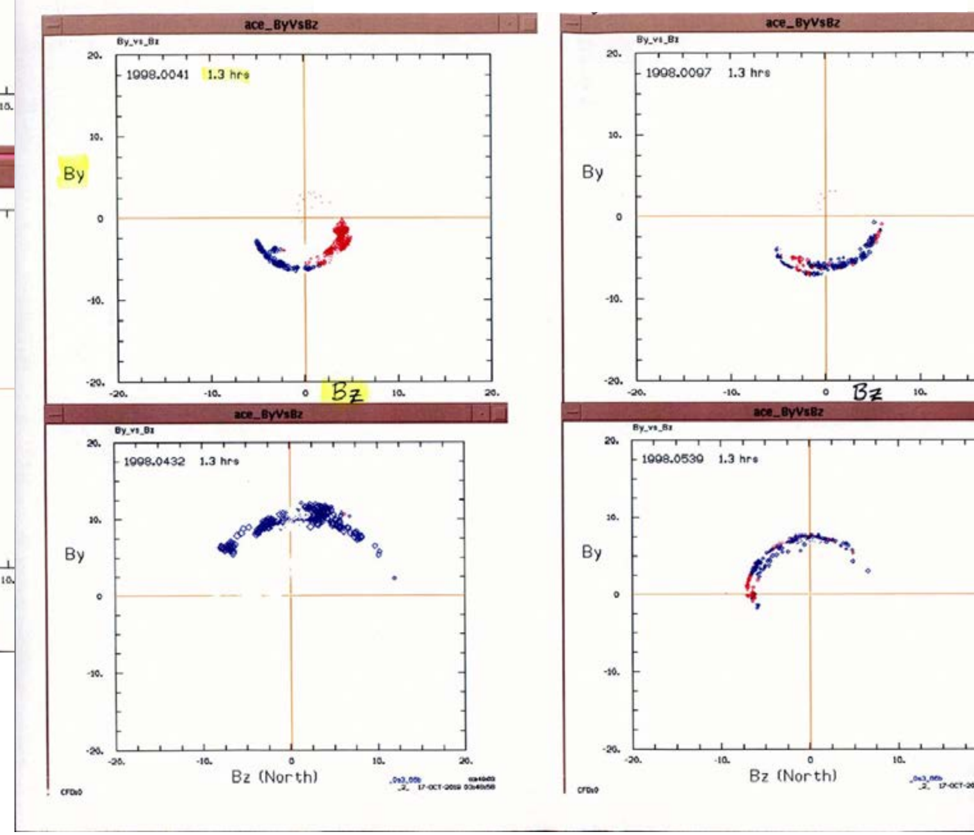
f_{Rot} components *Remo*

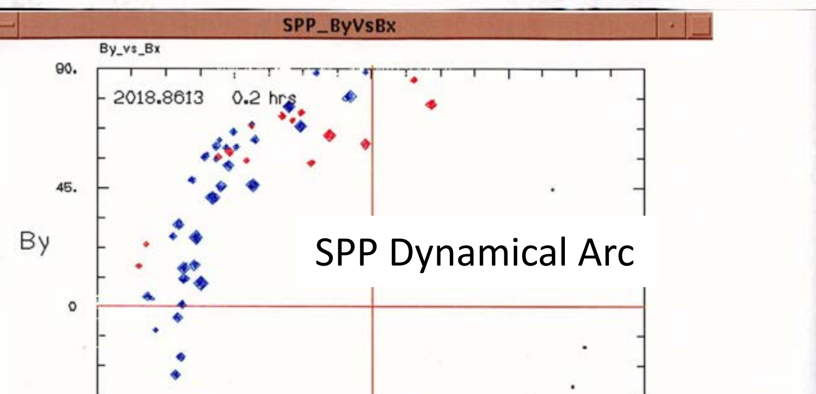


(3) "Dynamical Arcs", apparently from Double Current Filaments



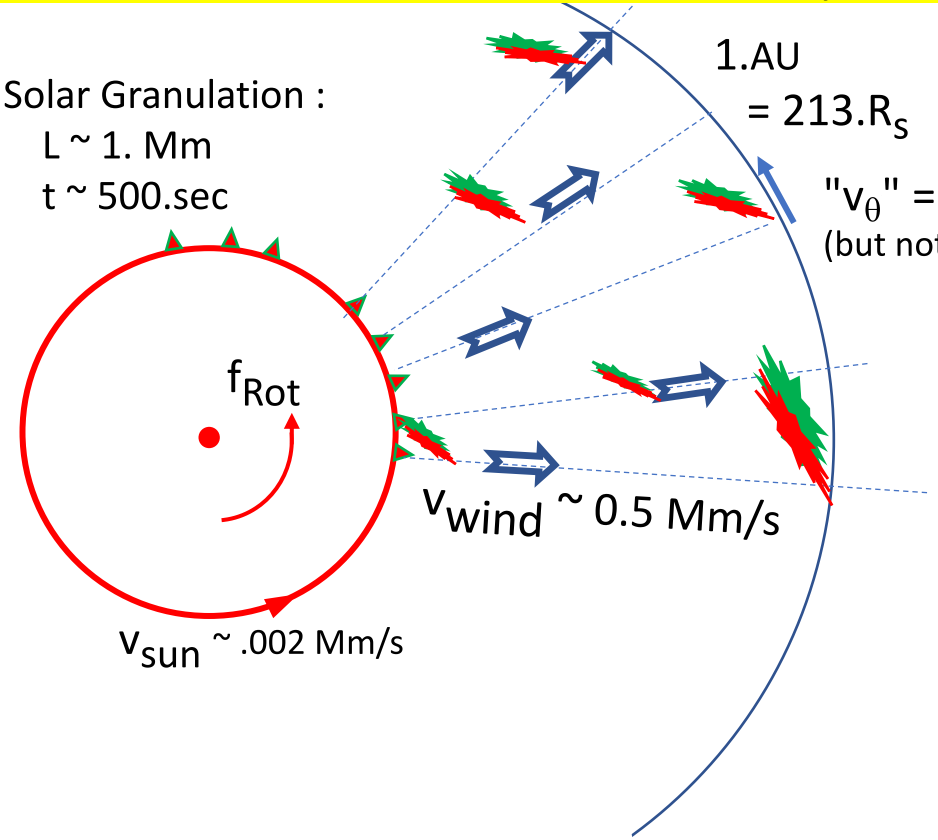
ACE 4 Examples





SPP Dynamical Arc

Model : Double Current Filaments => $B_y(t)$ vs $B_z(t)$ "Dynamical Arcs"



"Neutral" Flow" of $\left\{ \begin{matrix} p+ \\ e- \end{matrix} \right\}$

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

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

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

Suppose $\delta n = \alpha \; n_w$

$= (n_+ - n_-)$

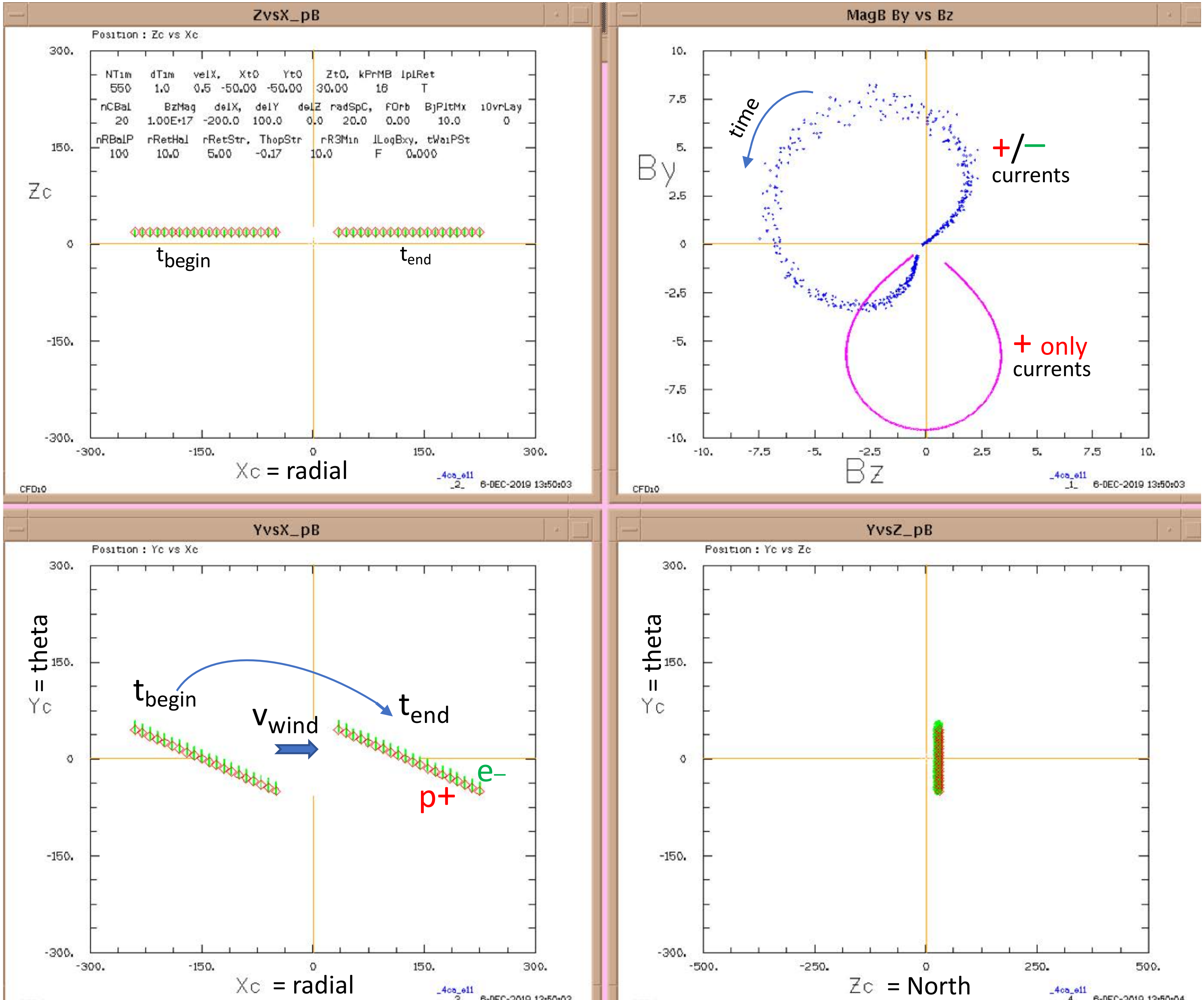
from
Shot Noise,
Filamentation,
Dynamics,
Current Pinch

Then

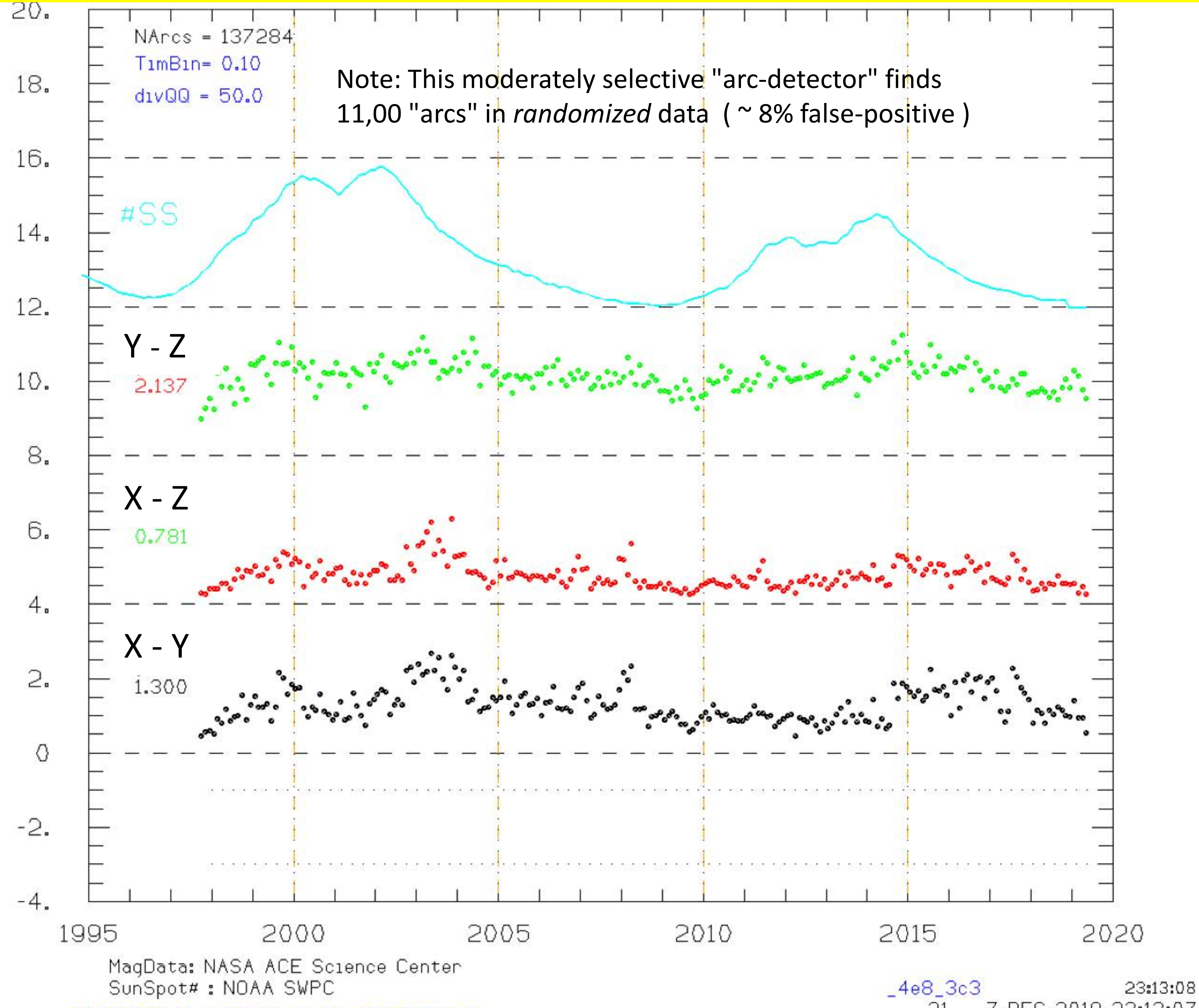
$$B \approx \frac{2}{c\,r}(\,\alpha\, e\, n_w\, v_w\,)(\pi\, r_0{}^2)$$

B ~ 5. nT implies :

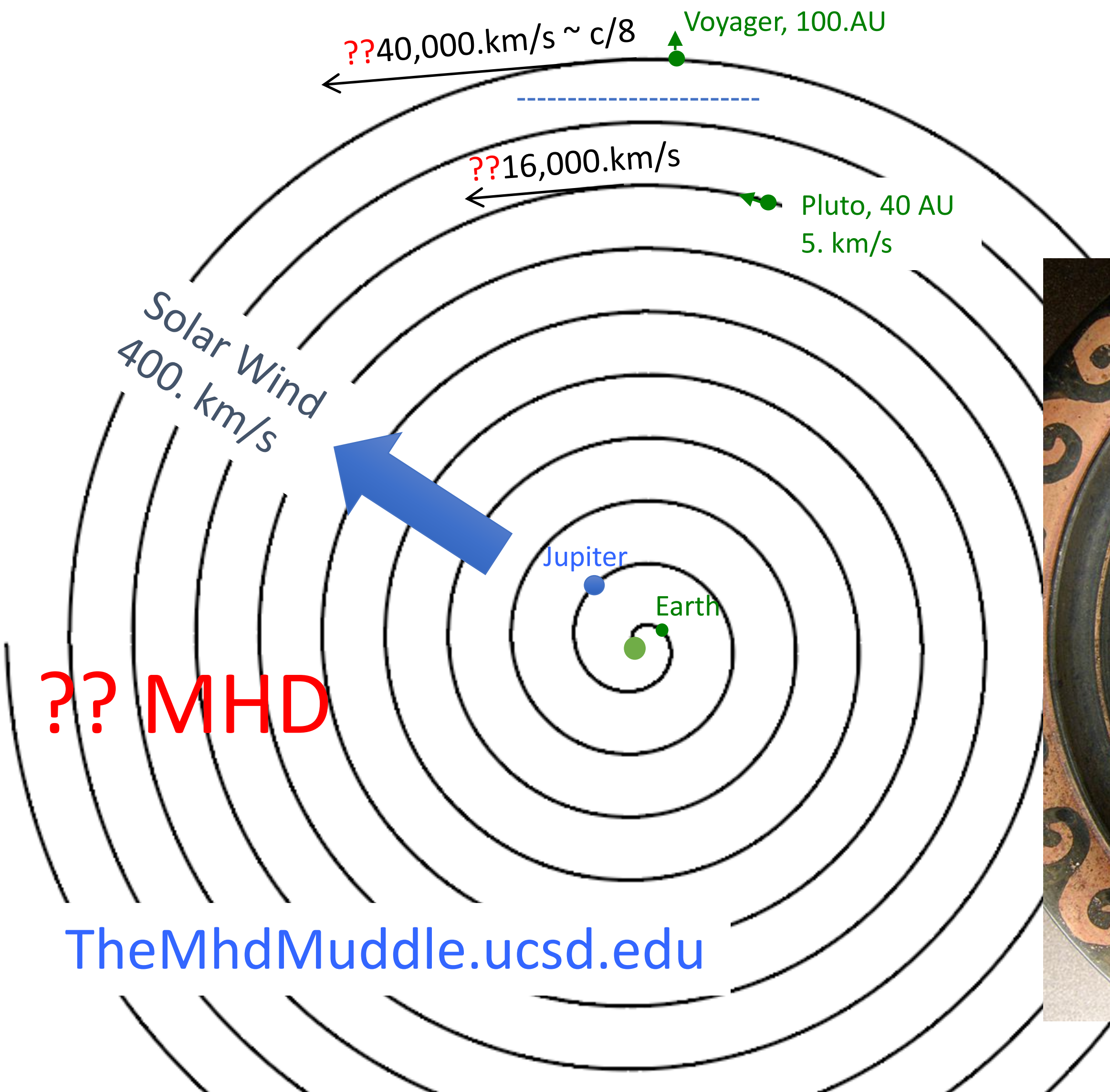
α	r_0	$\tau = v_w\, r_0$
10^{-3}	10^1Mm	20.sec
10^{-5}	10^3 Mm	0.5 hour


ZvsX_pB
Position : Zc vs Xc
NTim dTim velX, Xt0 Yt0 Zt0, kPrMB lplRet
550 1.0 0.5 -50.00 -50.00 30.00 18 T
nCBal BzMag delX, delY delZ radSpC, fOrb BjPltMx iOvrLay
20 1.00E+17 -200.0 100.0 0.0 20.0 0.00 10.0 0
nRBalP rRetHal rRetStr, ThopStr rR3Min lLogBxy, tWaiPSt
100 10.0 5.00 -0.17 10.0 F 0.000
Zc
tbegin
tend
Xc = radial
MagB By vs Bz
time
By
+/−
currents
+ only
currents
Bz
YvsX_pB
Position : Yc vs Xc
Yc = theta
tbegin
tend
vwind
e−
p+
Xc = radial
YvsZ_pB
Position : Yc vs Zc
Yc = theta
Zc = North
6-DEC-2019 13:50:03
6-DEC-2019 13:50:04
CFD:0

ACE MAG : 137,000 "Dynamical Arcs" in 21 years. T ~ 0.5 hr
All orientations : By-Bz , Bx-Bz, Bx-By . Rate ~ 18/day



Fluctuating B-fields measured by Spacecraft are generated by Filamentary Currents in the outward-flowing Solar Wind;
NOT BY the Chimera of a Rotating Dipolized Monopole Magnetic Spiral



Chimera Apulia (Louvre)

MHD Assumptions :

: Longitudinal, Transverse
or : Irrotational, Solenoidal

$$\begin{Bmatrix} E \\ B \\ J \end{Bmatrix} \equiv \begin{Bmatrix} E_L \\ B_L \\ J_L \end{Bmatrix} + \begin{Bmatrix} E_T \\ B_T \\ J_T \end{Bmatrix}$$

$$\nabla \times \begin{Bmatrix} E_L \\ B_L \\ J_L \end{Bmatrix} = 0 \qquad \nabla \cdot \begin{Bmatrix} E_T \\ B_T \\ J_T \end{Bmatrix} = 0$$

J_T is "curling" or "spin" current

$$\nabla \bullet E_L = 4\pi \cancel{\rho_Q} = 0$$

$$\nabla \bullet B_L = 0$$

$$\boxed{\begin{aligned} c\nabla \times E_T &= -\dot{B}_T \\ c\nabla \times B_T &= \cancel{\dot{E}_T} \end{aligned}}$$ photons

$$c\nabla \times B_T = \cancel{\dot{E}_T} + \underbrace{\dot{E}_L + 4\pi J_L}_{\text{cancel}} + 4\pi J_T$$

$$F = \cancel{\rho_Q E} + (\cancel{J_L} + J_T) \times B_T / c$$

$$\nabla \bullet J = -4\pi \cancel{\dot{\rho}_Q} = 0$$

$\rho_Q = 0$ **:** No Charges

$E_L = 0$ **:** No Elec.Pot.Egy

No Thermo.Elec

No Gravi.Elec

No Capacitance

No Photons

No Causality

(Simultaneous)

No E // B

$J_L = 0$ **:** No Convective Current

$$J_T = \sigma_T E_T$$ Induction of J_T *only*

$$\sigma_T = \infty \quad \text{(Ideal)}$$

?? Spin Currents do not dissipate

?? Moving B-lines live forever

?? B-lines "Frozen-Into" Plasma

?? Plasma "Stuck on" B-lines

?? Particle Streamline $\equiv$ B-line

Dissipation of ~~Particle~~ Current

$$\nu_{ei} = n\, \bar{v} \left(\frac{e^2}{T}\right)^2 \ln\Lambda$$

$$m\, \Delta v_{ei}\, \nu_{ei} = e E_Q \quad \text{(momentum)}$$

$$\sigma = \frac{e^2 n}{m \nu_{ei}} \approx (10^{14}\,\mathrm{s}^{-1})\, T_{eV}^{3/2}$$

Hydro : $\nu_{ei} \nearrow \Rightarrow T \searrow, \sigma \searrow$

Magnetic: $\sigma \nearrow \Rightarrow T \nearrow, \nu_{ei} \searrow$

* Contradictory