

Solar Charge Electric Fields and Jets, in Quantitative Agreement with Ulysses and PSP

or: What Heats the Corona and Energizes the Solar Wind ?

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A fully consistent plasma model of the Sun mandates a stable, steady-state net charge of **+460.Coulombs** .

The resulting electric potential is **$e\Phi = +10. \text{ keV}$** at $r=0$, decreasing to **$e\Phi = + 6. \text{ keV}$** at R_S .
The proton gravitational "well" is **$m_p\Psi = -10. \text{ keV}$** at $r=0$, decreasing to **$m_p\Psi = - 2. \text{ keV}$** at R_S .

This charge and electric potential is **quantitatively determined** by the "virial" equality of gravity and electric energies at $r = 0$, with **no free parameters**.

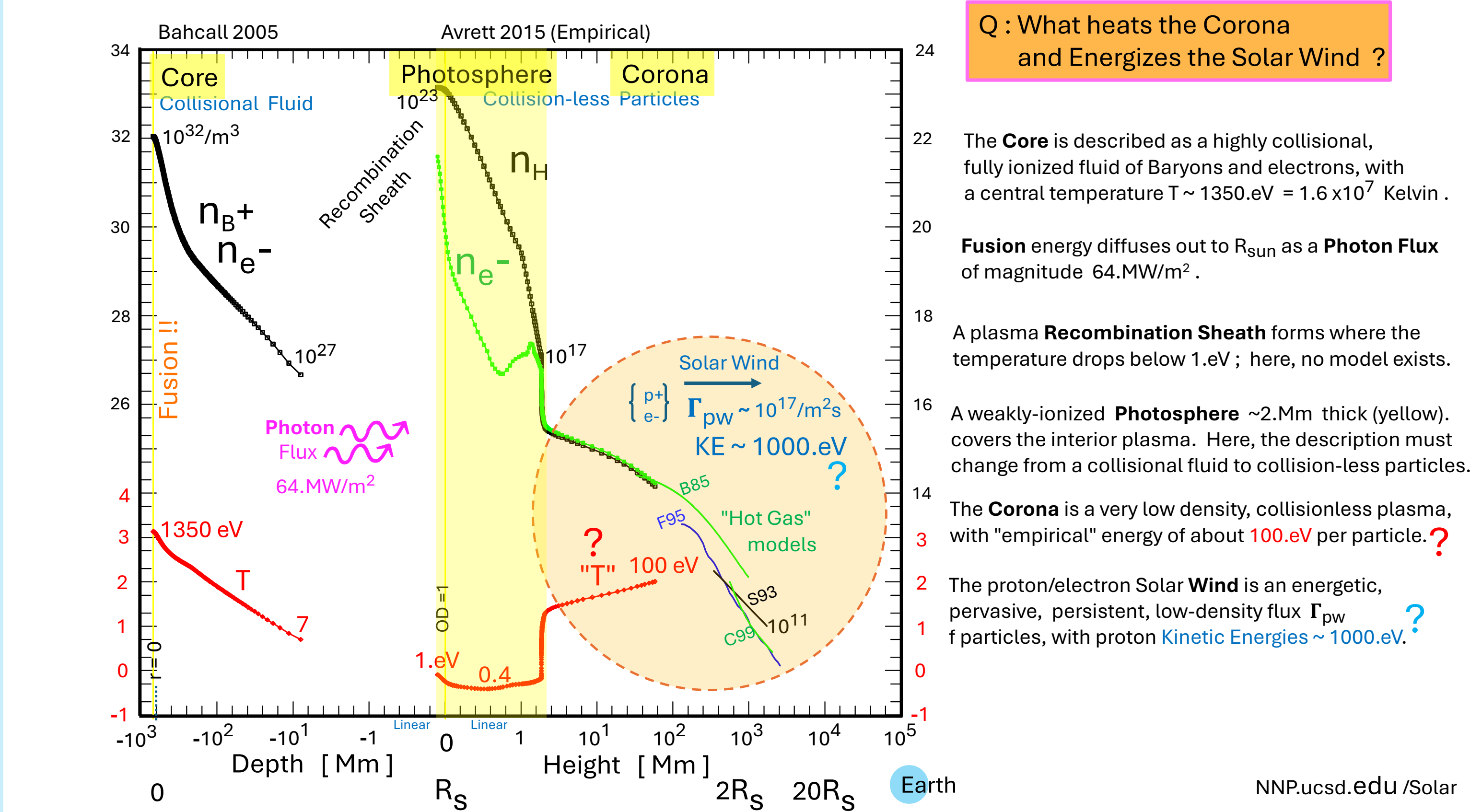
The **4.keV** excess electric energy can accelerate proton Jets to **880.m/s** , when not slowed by ecliptic-plane gas & dust & turbulence.

Recent **Parker Solar Probe** eVDF data analyses show space potentials in close agreement with **$\Phi = + 6. \text{ kV}$** (R_S / r) , over $15 < r < 80 R_S$.

The **Ulysses** proton data over 15 years shows a "hard limit" at **880.km/s**, over all directions away from the ecliptic .

The electric energy produces electron and proton Jets, appearing as surface Spicules, surface Flares, and glowing currents in bouyant Prominences.

The surface electric field makes H- more strongly bound, and H3+ neutrally bouyant, with complementary opacity characteristics.



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

The **Core** is described as a highly collisional, fully ionized fluid of Baryons and electrons, with a central temperature $T \sim 1350. \text{ eV} = 1.6 \times 10^7 \text{ Kelvin}$.

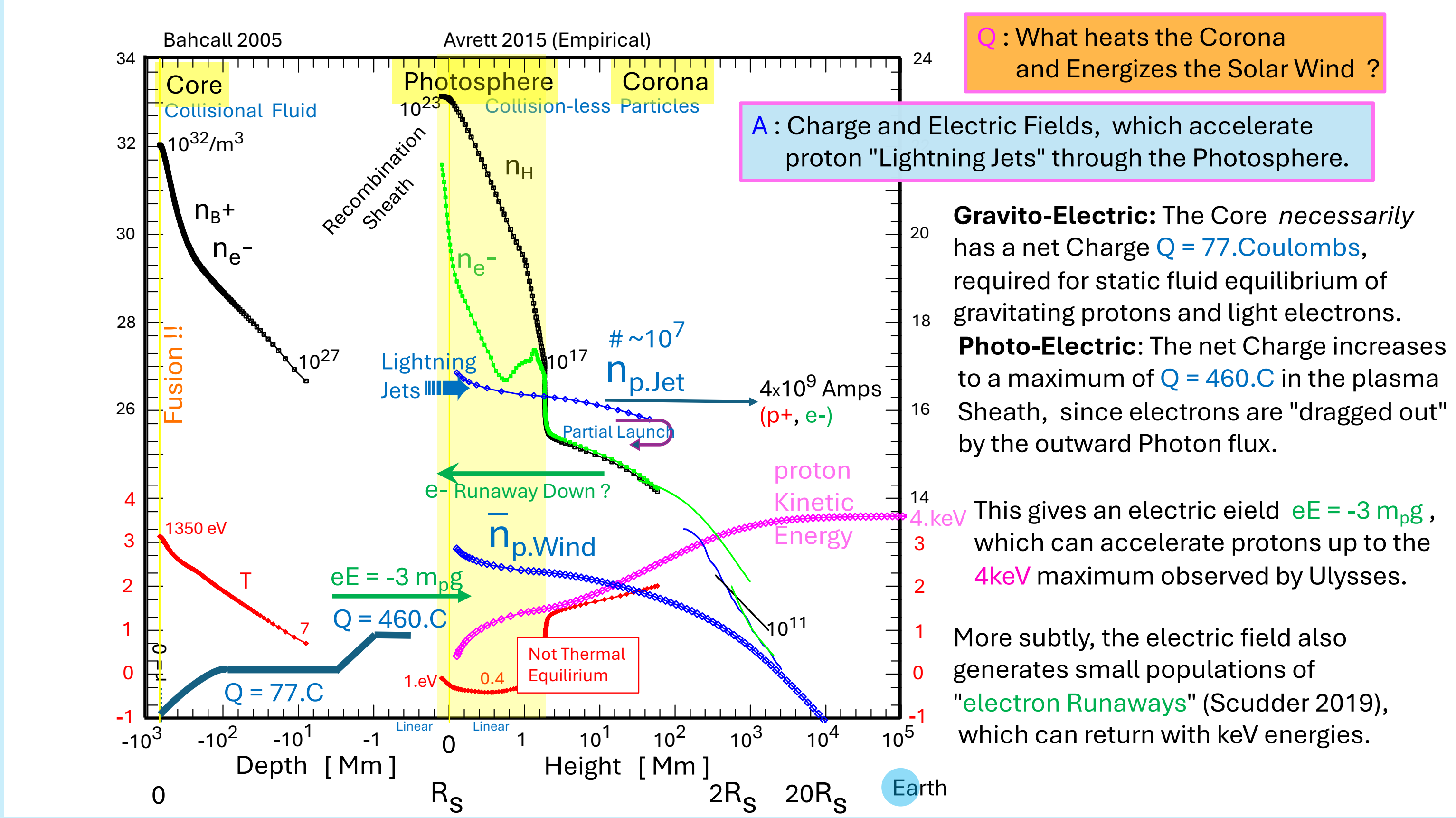
Fusion energy diffuses out to R_{sun} as a **Photon Flux** of magnitude $64. \text{ MW/m}^2$.

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

A weakly-ionized **Photosphere** $\sim 2. \text{ Mm}$ 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 $100. \text{ eV}$ per particle. ?

The proton/electron Solar **Wind** is an energetic, pervasive, persistent, low-density flux of particles, with proton **Kinetic Energies** $\sim 1000. \text{ eV}$. ?



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

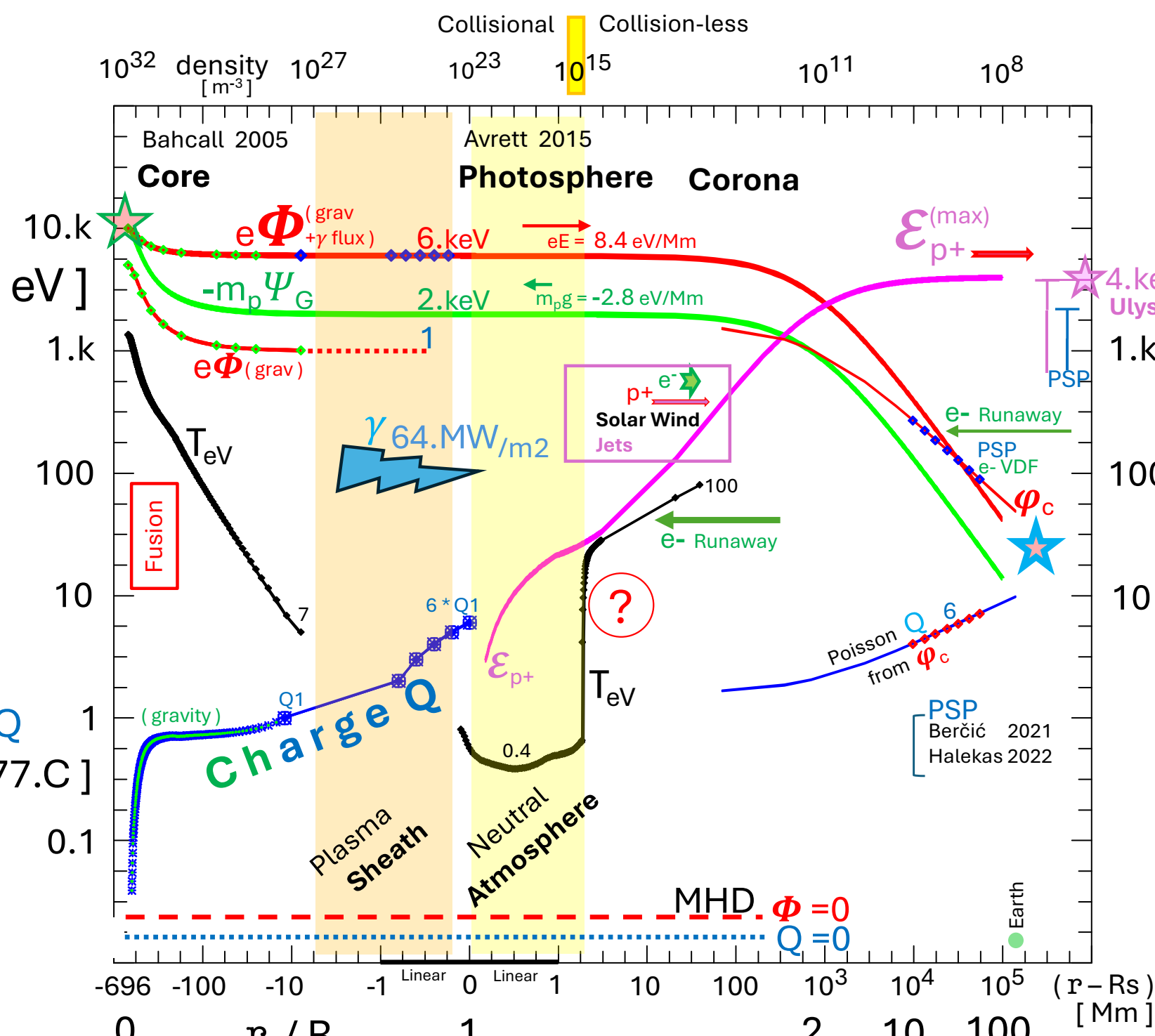
A : Charge and Electric Fields, which accelerate proton "Lightning Jets" through the Photosphere.

Gravito-Electric: The Core *necessarily* has a net Charge **$Q = 77. \text{ Coulombs}$** , required for static fluid equilibrium of gravitating protons and light electrons.
Photo-Electric: The net Charge increases to a maximum of **$Q = 460. \text{ C}$** in the plasma Sheath, since electrons are "dragged out" by the outward Photon flux.

This gives an electric field **$eE = -3 m_p g$** , which can accelerate protons up to the **4keV** maximum observed by Ulysses.

More subtly, the electric field also generates small populations of "electron Runaways" (Scudder 2019), which can return with keV energies.

Charge-Electric Solar Model Uniquely Determines Solar Wind Energetics



What heats the Corona and energizes the Solar Wind ?
>>> The coherent radial electric field arising from net **Charge Q** within the Sun .

Standard Solar models give **$-m_p\Psi_G (r=0) = 10. \text{ keV}$** "Gravito-electric" equilibrium in the collisional Core *requires* **$Q = 77. \text{ C}$** of electrons to escape outward.

The Solar heat flux of $64. \text{ MW/m}^2$ "drags" additional electrons out from the plasma Sheath, limited by a "virial limit" of **$e\Phi < -m_p\Psi_G$** .

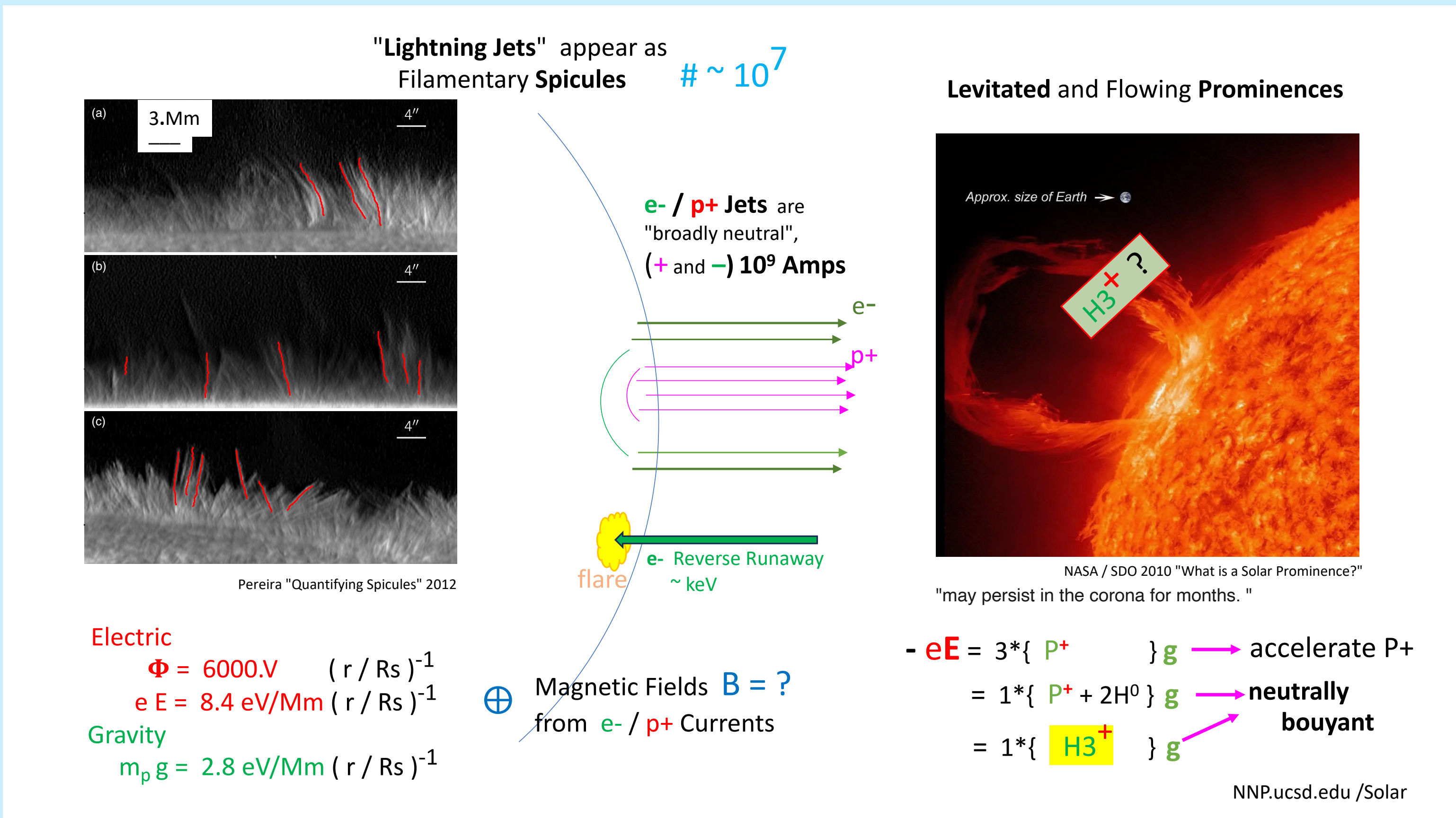
The total charge of **$Q = 460. \text{ C}$** gives **$e\Phi = 10. \text{ keV}$** at $r=0$, and **$e\Phi = 6. \text{ keV}$** at $r=R_S$.

This gives **4.keV** of excess electric energy to accelerate surface protons out of the **-2.keV** gravity "well" .

15 years of Ulysses proton velocity data shows a "hard limit" of **4.keV = 880.km/s** , when out of the ecliptic plane.

Recent analyses of PSP electron VDF data reveals a potential **ϕ_e** versus radius, which agrees closely with the energy **$e\Phi$** available for "reverse runaway" electrons (Scudder 2019).

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"Lightning Jets" appear as Filamentary Spicules # ~ 10^7

e^- / p^+ Jets are "broadly neutral", (+ and -) **10^9 Amps**

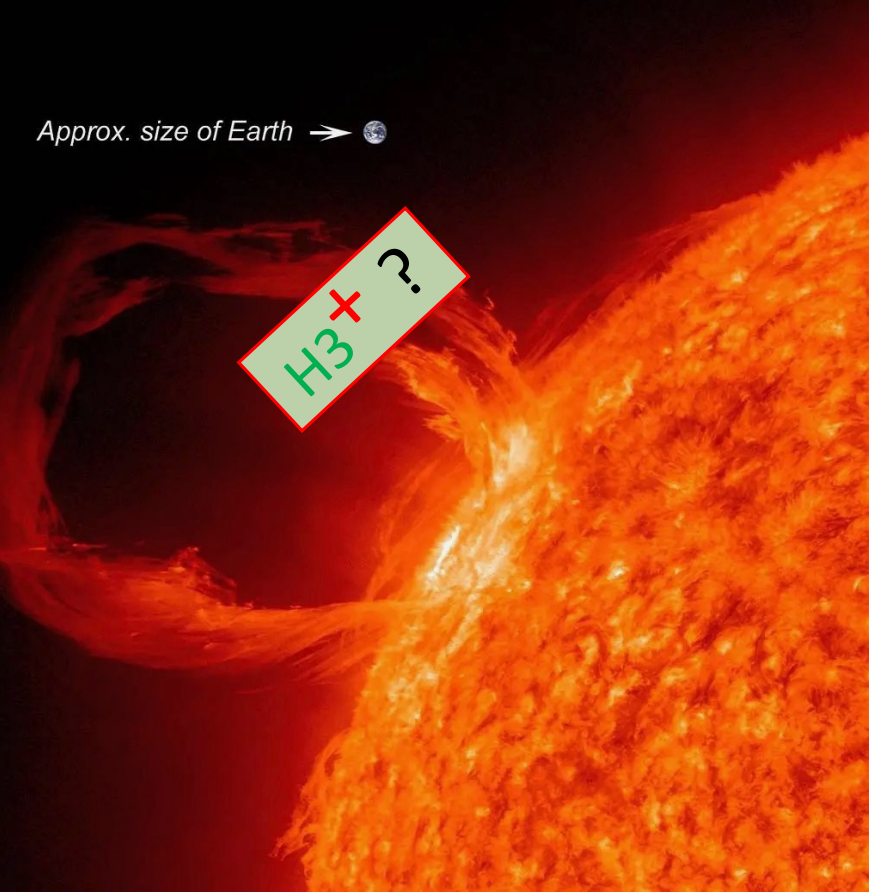
e^- Reverse Runaway ~ keV

Magnetic Fields $B = ?$ from **e^- / p^+ Currents**

Electric $\Phi = 6000. \text{ V}$ (r / R_S)⁻¹
 $eE = 8.4 \text{ eV/Mm}$ (r / R_S)⁻¹

Gravity $m_p g = 2.8 \text{ eV/Mm}$ (r / R_S)⁻¹

Levitated and Flowing Prominences



NASA / SDO 2010 "What is a Solar Prominence?"

"may persist in the corona for months. "

$-eE = 3\{ p^+ \}$ g **accelerate P^+**
 $= 1\{ p^+ + 2H^0 \}$ g **neutrally bouyant**
 $= 1\{ H3^+ \}$ g

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Equilibrium Stellar Fluid Eqns: mass charge photons
 m_p, m_e, e, p^+, γ

1a $\nabla^2 \Psi(r) = G m_p n_p(r)$ Gravity
1b $\nabla^2 \Phi(r) = -k_l e (n_p - n_e)$ Electric Potential
2 $\nabla \cdot \Gamma_e(r) = \frac{d}{dt} \mathcal{E}(r)$ Fusion Energy Flux
3 $-(4aT^3) T'(r) l_y = \frac{4}{c} \Gamma_e$ Thermal Energy Diffusion
4a $[n_p T]' + n_p m_p \Psi' + (+e) n_p \Phi' = 0$ Proton Fluid Momentum
4b $[n_e T]' - \frac{\Gamma_{ey}}{c l_{ye}} + n_e m_e \Psi' + (-e) n_e \Phi' = 0$ Electron Fluid Momentum
4a+4b $[(2n)T]' - \frac{\Gamma_{ey}}{c l_{ye}} + n m_p \Psi' = 0$ Total Fluid Momentum
4a-4b $\frac{\Gamma_{ey}}{c l_{ye} n_e} + m_p \Psi' + (2e) \Phi' = 0$ Electric Field

Gravito-Electric in high-density collisional regime
 $A. \text{ Pannekoek } S. \text{ Rossetland (1924) } A.E. \text{ Eddington}$
 $-\frac{1}{2} m_p g(r) \approx eE(r)$
 $@ R_S \approx 1.4 \text{ eV / Mm}$

Photo-Electric : γ/e - cross-section is large for correlated e^-/p^+
 $(1 < \sigma_{\gamma e} < 10^8) \times 10^{-28} \text{ m}^2$
 $@ R_S = 8.4 \text{ eV/Mm}$

$\sigma_{\gamma e} = \frac{1}{l_{ye} n_e}$

Magneto-Hydro Assumptions

$\nabla \cdot E_L = 4\pi (\rho_+ - \rho_-) = 0$

$\nabla \cdot B = 0$

$c \nabla \times E_T = -\frac{\partial B}{\partial t}$

$c \nabla \times B = \frac{\partial E_L}{\partial t} + 4\pi J_L + 4\pi J_T$

$Force = \cancel{p} E_L + (\cancel{J_L} + J_T) \times B / c$

$\nabla \cdot J_L = 4\pi \cancel{\frac{\partial \rho}{\partial t}} = 0$

No Charges
No Electric Energy
No $E \parallel B$
Yes: Inductance, B^2 Energy

Conductivity $\sigma \rightarrow \infty$ (Ideal)

? Moving B-lines live forever
? B-Lines "Frozen-Into" Plasma
? Plasma "Stuck-on" B-Lines
? Particle Streamline = B-Line

Show Us the Electric Potential, PSP

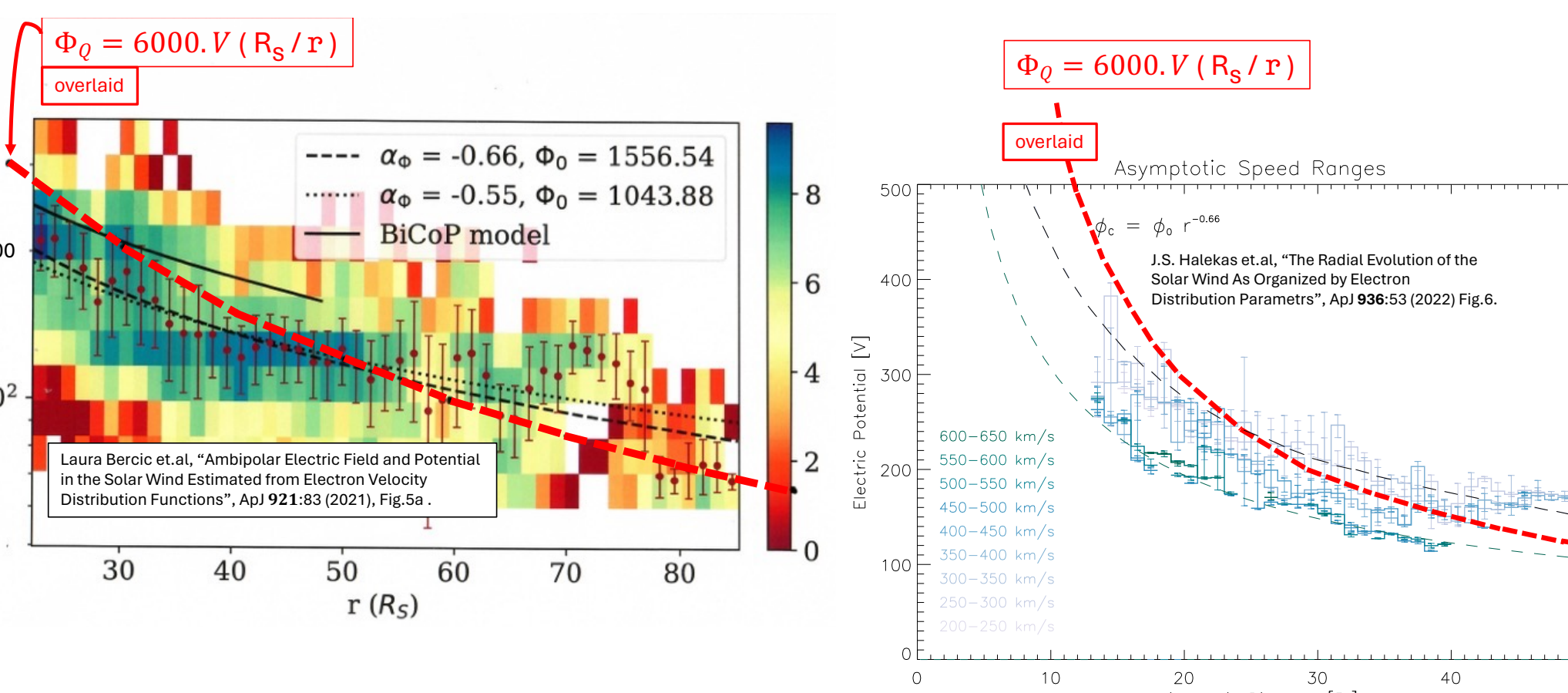
The Sun is an immense spherical ball of gravitationally bound plasma, generating copious fusion energy. This energy is emitted in all directions, mainly as electro-magnetic waves (light and heat). The Sun also emits about one-millionth as much energy in beams of energetic protons with accompanying electrons, called the Solar Wind. This Wind energizes the Earth's magnetosphere, causes our atmospheric auroras, and can negatively impact satellite communications.

One of the NASA /ESA big questions for satellite missions is, "What heats the Solar Corona and energizes the Solar Wind?" A new charge-electric model now provides a strikingly simple answer: "The permanent electric field originating below the Corona." A new electric model shows quantitative agreement with satellite data, from both the **Parker Solar Probe** and the older **Ulysses** mission.

The requisite net charge is **$Q = 460. \text{ Coulombs}$** , quantitatively determined by a new "plasma virial limit". This gives the maximal electric potential in terms of the well-known gravitational potential, with **no adjustable parameters**.

Outside the Sun, the potential is **$\Phi_0 = 6000. \text{ V} * (R_S / r)$** ; and this accelerates surface protons out of the **2,000 eV** gravitational "well", and up to a maximum kinetic energy of **4,000 eV**.

PSP Two research teams have published analyses of measured electron VDFs, obtaining distinctive signatures of static electric potentials. (Bercic 2021, Halekas 2022) . Surprisingly, the simple electric model for **Φ_0** [shown as **Red dashed Overlays**] agrees broadly with these inferred potentials, over radii of 15 to $80 R_S$.



C.F. Driscoll, "The Electric Fields and "Lightning Jets" of the Sun and Solar Wind", Physics of Plasmas, **30**, 102903 (2023) , doi:10.1063/5.0139215 . NNP.ucsd.edu / Solar

Ulysses: The maximal proton energy of **4,000.eV** at **880.km/s** agrees closely with the "hard" upper limit measured over the 15 years of Ulysses data. (McComas, 2000) This is the *only* data out of the dusty and turbulent ecliptic plane of the planets,

Moreover, the persistent electric field energy explains many puzzling "non-thermal" structures. The pervasive outward proton jets may interact with energetic "reverse runaway electrons" (Scudder, 2019), together forming the ubiquitous "spicules" the occasional surface "campfires" and flares, as well as the fluctuating current-induced magnetic fields. Electro-kinetic chemistry may impact the pervasive **H-ions** which dominate the solar opacity, and provide the **H3+ cations** which are neutrally bouyant above the surface. More broadly, charge-electric energy and stability may be crucial for understanding the birth, stable burning, unstable oscillation (Maia), and final collapse of the myriad star species.

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