Plasma Sheath Electric Fields and Jets of the Sun and Solar Wind

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Cool Stars 22

A new global "charge-electric" model builds on standard *fluid* models for the solar Core (Bahcall 2005) and Photosphere (Averett 2015) , now balancing gravity with electrostatics. The electrostatic energy then explains the anomalous Coronal heating and energization of the Solar Wind.

The electric model starts with +77.C of Core charge as *quantitatively required* for static proton balance with gravity ; and additional plasma Sheath charge for electron containment against the outward photon drag.

A novel "virial" relation between gravitational and electric energies *limits* the *total* charge to +460.C and potential to $\Phi(0) \leq 10.\text{keV}$, giving $\Phi(R_S) \leq 6.\text{keV}$; and this upper limit appears to be the global *stable state* for the Sun.

This electric potential can accelerate a surface proton to an kinetic energy of 4.keV, when not dissipated by gas, dust, or electro-magnetic turbulence.

1) The **Ulysses** proton data shows a 15-year "hard limit" of 4.keV (880.km/s), over all directions above and below the ecliptic, during low sunspot activity.

2) Two analyses of the **PSP** electron VDF data for $15 < r/Rs < 80$ obtain electric potentials in close agreement with $\Phi = 6.\text{keV}\ (r/R_S)^{-1}$.

The electric model explains many puzzling surface effects, including fluctuating magnetic fields from surface currents. The electric field of 8.4 eV/Mm (3x gravity) can create proton "Lightning Jets" penetrating the hydrogen atmosphere, appearing as the ubiquitous **Spicules**, heating the **Corona**, and forming the Solar Wind. A "neutrally levitated" cloud of 1/3 ionized hydrogen can form **Prominences** and **Arcs**, glowing from internal currents driven by surface potential variations.

More broadly, the electric model may inform theory perspectives on the gaseous birth, plasma ionization, stable burning, and unstable collapse of the myriad types of stars.

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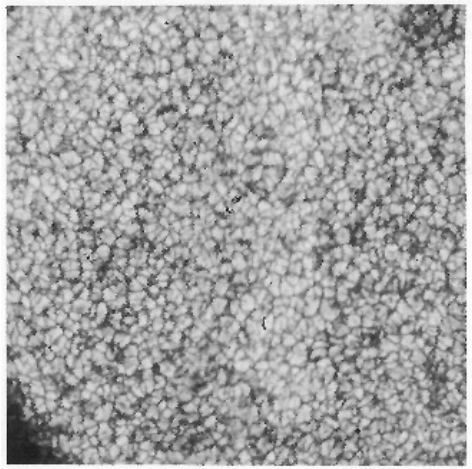
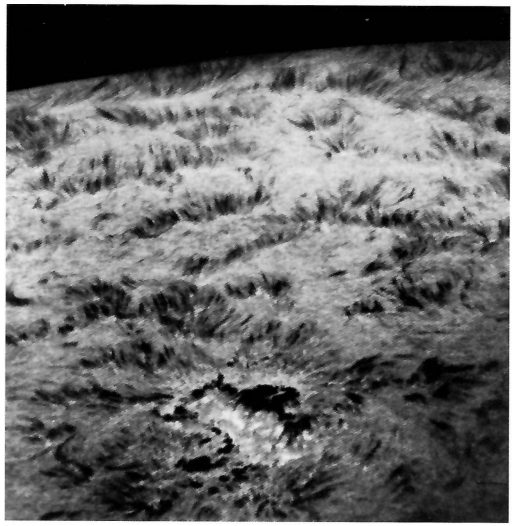
Surface **Convection Cells**,
A ~ $(1.Mm)^2$, τ ~ 5.min. # ~ 10^7



Brandt 1970

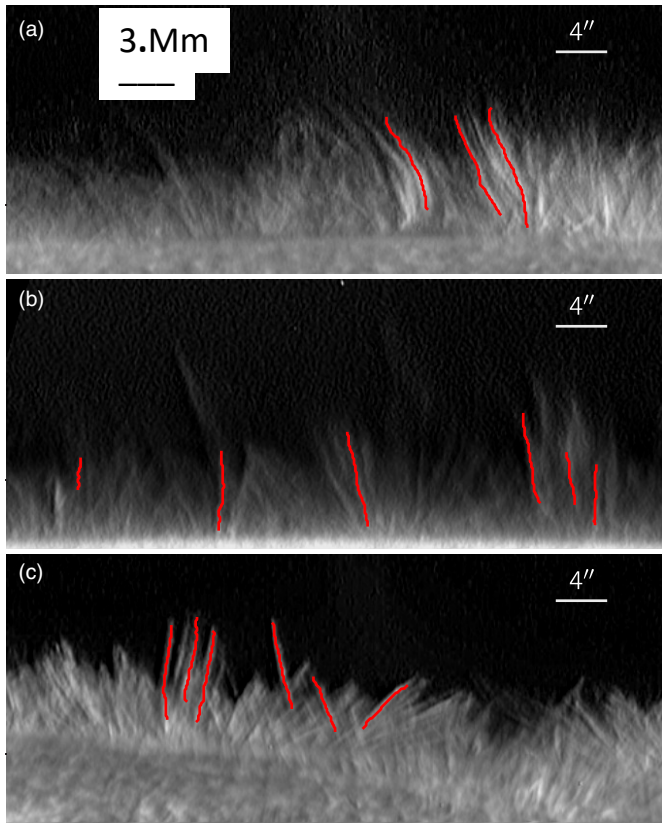
? Initiation points for Jets ?



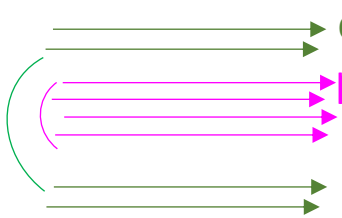
λ = 656.µm

Lang 1995

"**Lightning Jets**" appear as
Filamentary **Spicules**

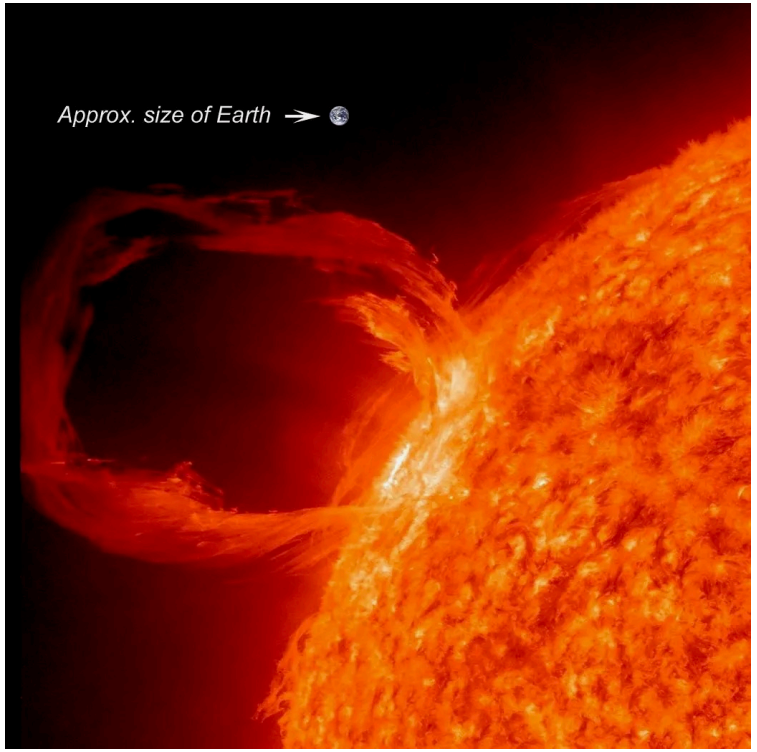


Pereira "Quantifying Spicules" 2012



Jets are
"broadly neutral",
(+ and –) 10^9 **Amps**

Levitated and Flowing **Prominences**



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

"Prominences, anchored to the Sun's surface.
Forms in about a day ; and may persist in the
corona for months. "

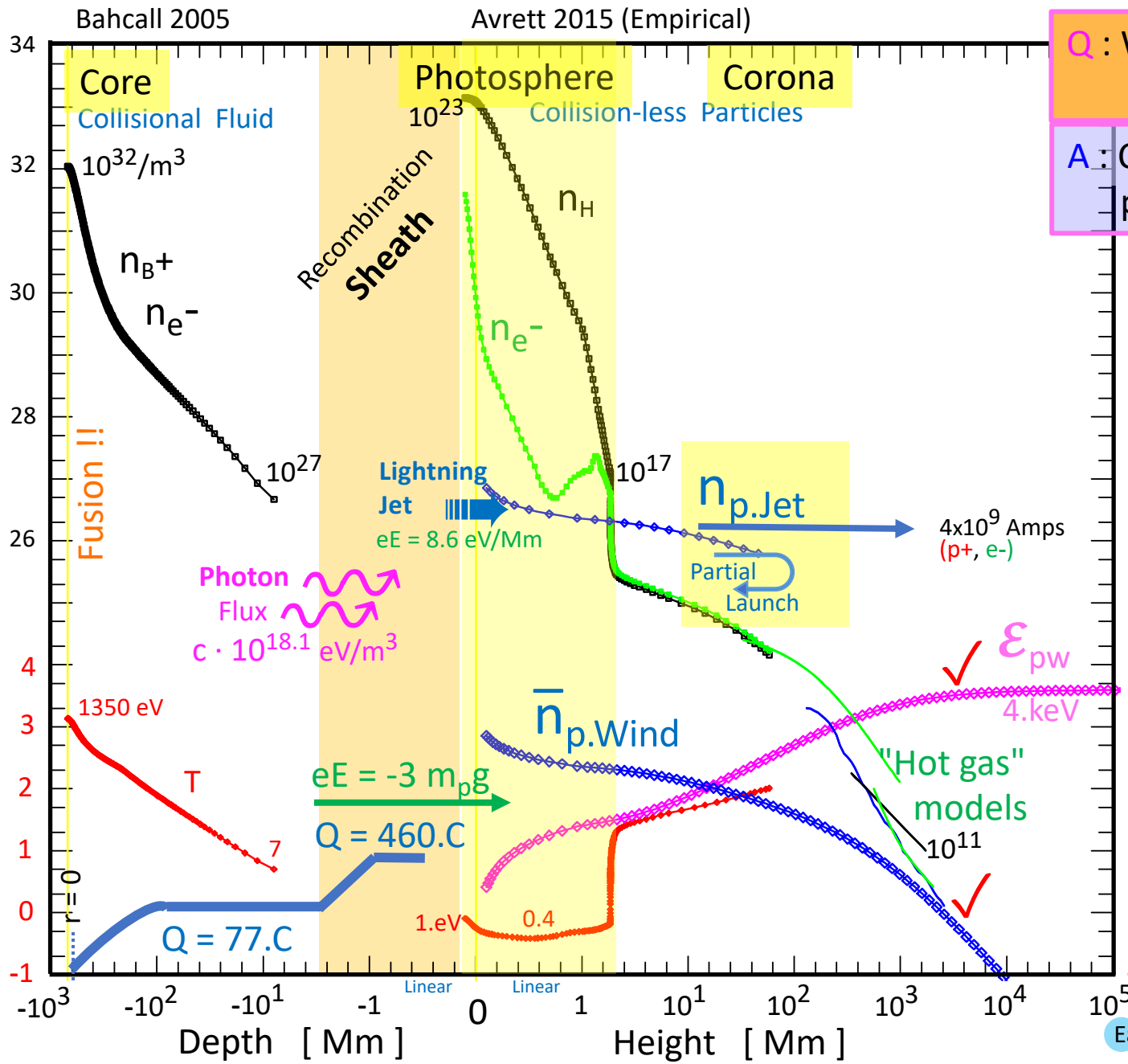
$-eE = 3*\{ m_p \} g \rightarrow$ accelerate P+

$= 1*\{ P^+ + 2H^0 \} g \rightarrow$ **neutrally bouyant**

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 Charge increases to 460.C at R_s , giving eE = -3 m_pg . Lightning Proton Jets form in pinched avalance breakdown of Photospheric resistivity, and accelerate to 4.keV unless slowed by neutrals, dust, or turbulent fields.

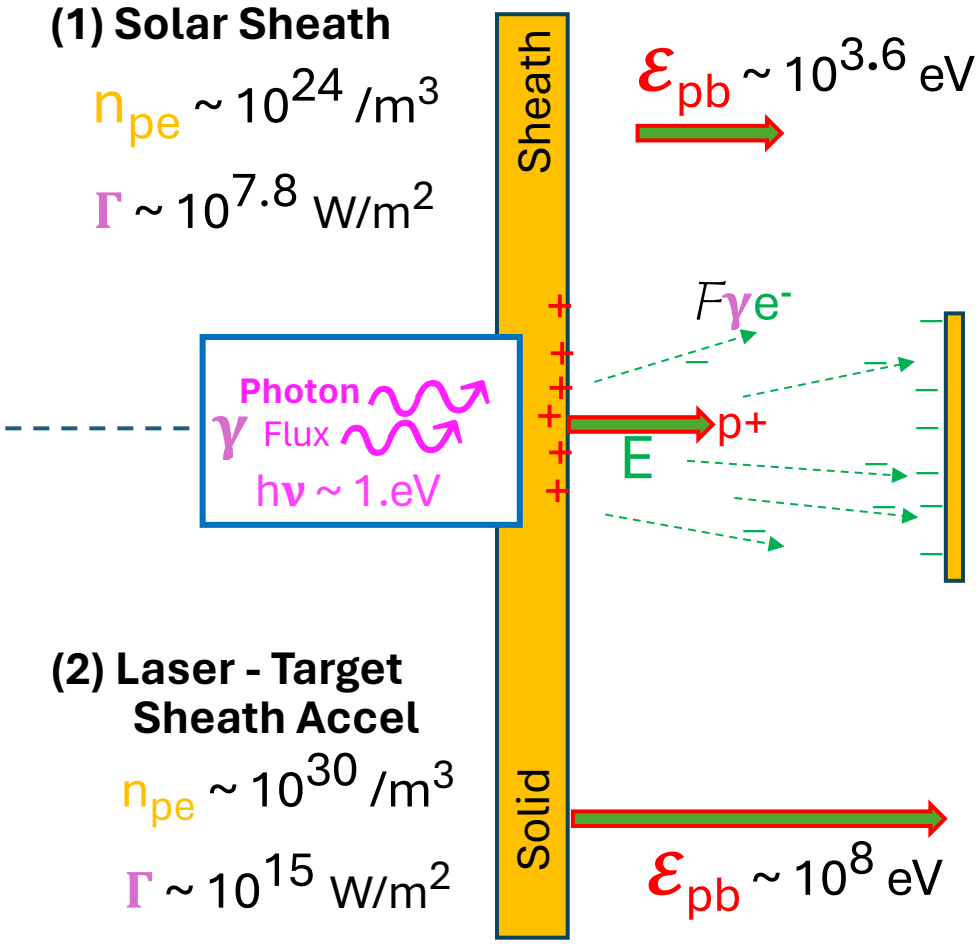
The Jets appear as Spicules; the Corona is diffuse Jets, inflowing neutrals, and downward runaway electrons.

Photo – Electron Drag → Displaced e- Charge
→ Electric Field
→ Proton Beam Acceleration

The acceleration of Proton Beams out of the Solar Sheath is like "Target-Normal Sheath Acceleration" in the lab.

In both cases, the strong electro-magnetic energy flow "drags" and displaces electrons outward; and the resulting electric field accelerates protons to high energy.

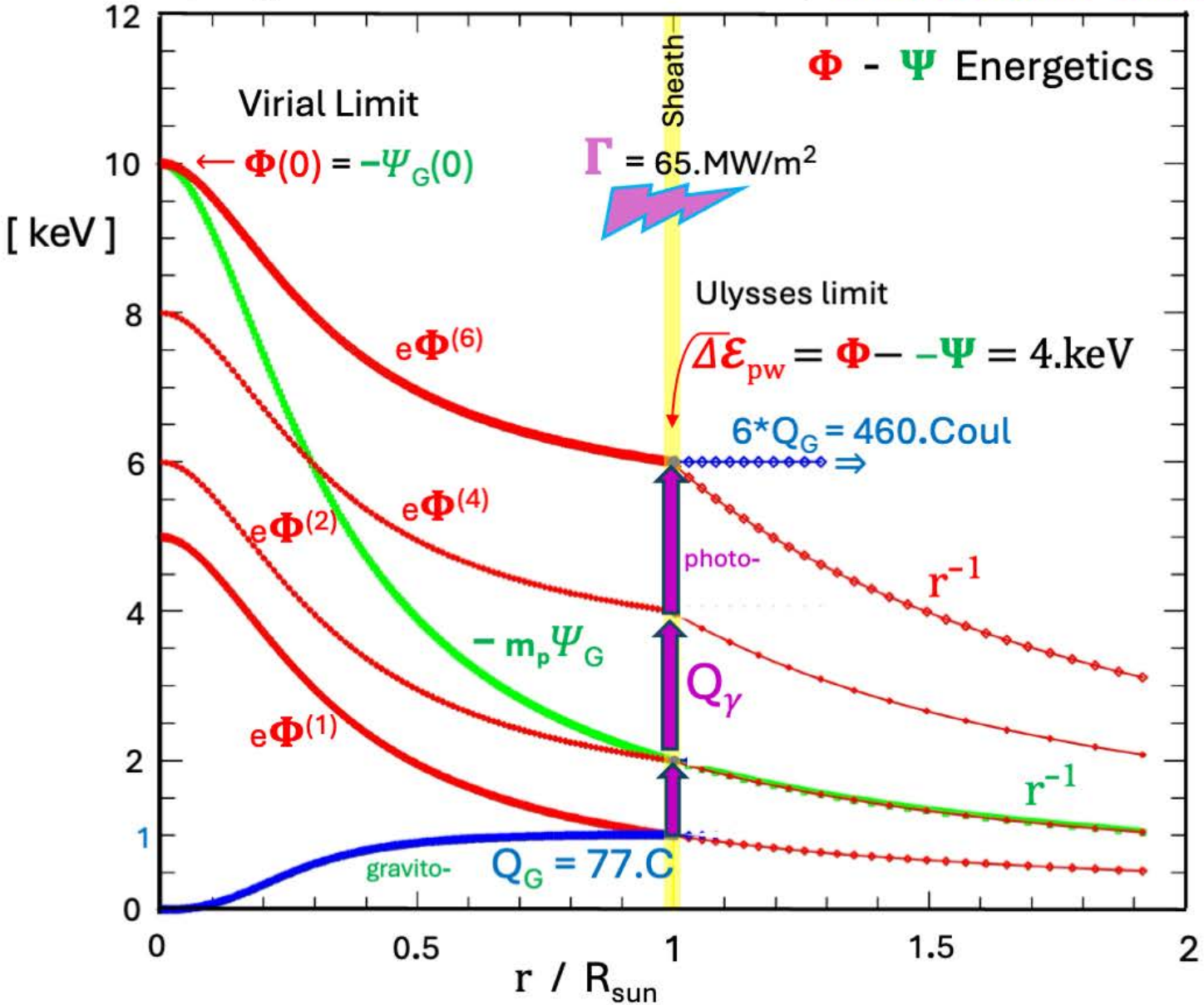
The DC "pondermoive" force $F_{\gamma e^-}$ results from the AC electro-magnetic field γ coupling to the AC e^- response.
(The heavy p+ respond weakly and feel negible force.)



The Total Solar Charge is set by a Virial Limit, and the Maximum Proton Energy follows as 4.keV

(Pannekoek / Rosseland /Eddington) Gravito-Electric Charge Q_G

(Target Normal Sheath Acceleration) Photo-Electric Charge $Q_\gamma = Q_G * 5$



=> Virial Limit Maximum

=> Ulysses Maximum

The "**gravito-electric**" field $e\Phi^{(1)}$ is *required* to contain electrons , giving $eE = ½\, m_p g$ from $Q_G = 77.C$

The **Photon Flux** Γ drags electrons out of the Sheath, leaving positive charge Q_γ .

The total charge build-up is limited to $6*Q_G$ by the "Virial Limit" $\Phi(0) \le -\Psi_G(0)$

This leaves $\Delta\mathcal{E}_{pw} = 4.\text{keV}$ available to accelerate protons off the surface.

Ohm's Balace : Gravity, Electric ; Protons, Electrons

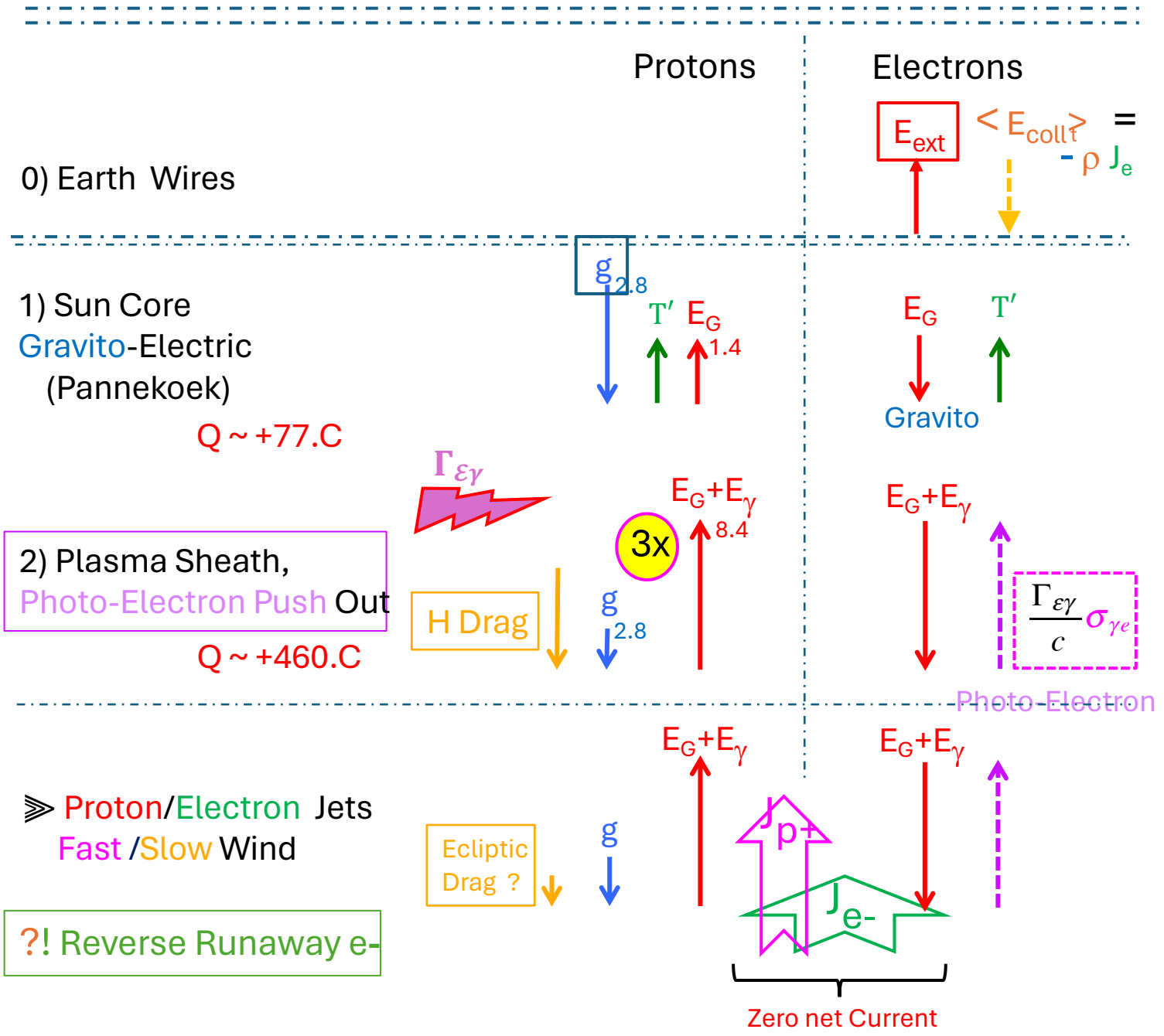
Wires : An *external* battery creates E_{ext} which drives electron flow J_e against time-fluctuating collisional fields $<E_{coll}>_t$ which are the resistivity ρ .

Gravity binds the ~10^{57} protons, but *not* electrons. After ~10^{20} electrons leave, the resulting electric field E_G binds the ~10^{57} other electrons. $eE_G = \frac{1}{2} m_p g$, independent of Temperature.

Photo-Electron : The flux of EM energy $\Gamma_{\varepsilon\gamma}$ pushes on electrons, but not on protons. This increases the total displaced electron charge to 460.C, giving $e(E_G+E_\gamma) = 3 * m_p g$.

Prominences of 1/3 ionized hydrogen may be "neutrally levitated" for long times.

Pinched **Jets** of protons broadly neutralilzed by electrons can form in the resistive hydrogen atmosphere, due to "avalanch breakdown", as with Earth lightning.



Equlibrium Stellar Fluid Eqns:

mass $m_p\ m_e$ charge $e^-\ p^+$ photons γ

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

$$1b \quad \nabla^2\Phi(r) = -k_1\, e\,(n_p - n_e)$$ Electric Potential (charge)

$$2 \quad \nabla \cdot \Gamma_\varepsilon(r) = \frac{d}{dt}\varepsilon(r)$$ Fusion Energy Flux

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

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

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

(Thermo- / Photo- / Electric)

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

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

$$-\tfrac{1}{2} m_p\, g(r) \approx eE(r)$$

$@R_S \approx 1.4\, eV / Mm$

Gravito-Electric in high-density *collisional* regime

A. Pannekoek
S. Rosseland (1924)
A.E. Eddington

$$m_p \Psi' \approx 2.8\, eV / Mm \quad @R_S$$

$$G m_p^2 \sim 10^{-36}\, k_1 e^2 \quad !!$$

$$\Gamma_{\varepsilon\gamma} \sim 65.\, MW / m^2 \quad @R_S$$

$$\sigma_{\gamma e} \equiv \frac{1}{l_{\gamma e}\, n_e}$$

$$\frac{\Gamma_{\varepsilon\gamma}}{c}\sigma_{\gamma e} = eE(r)$$

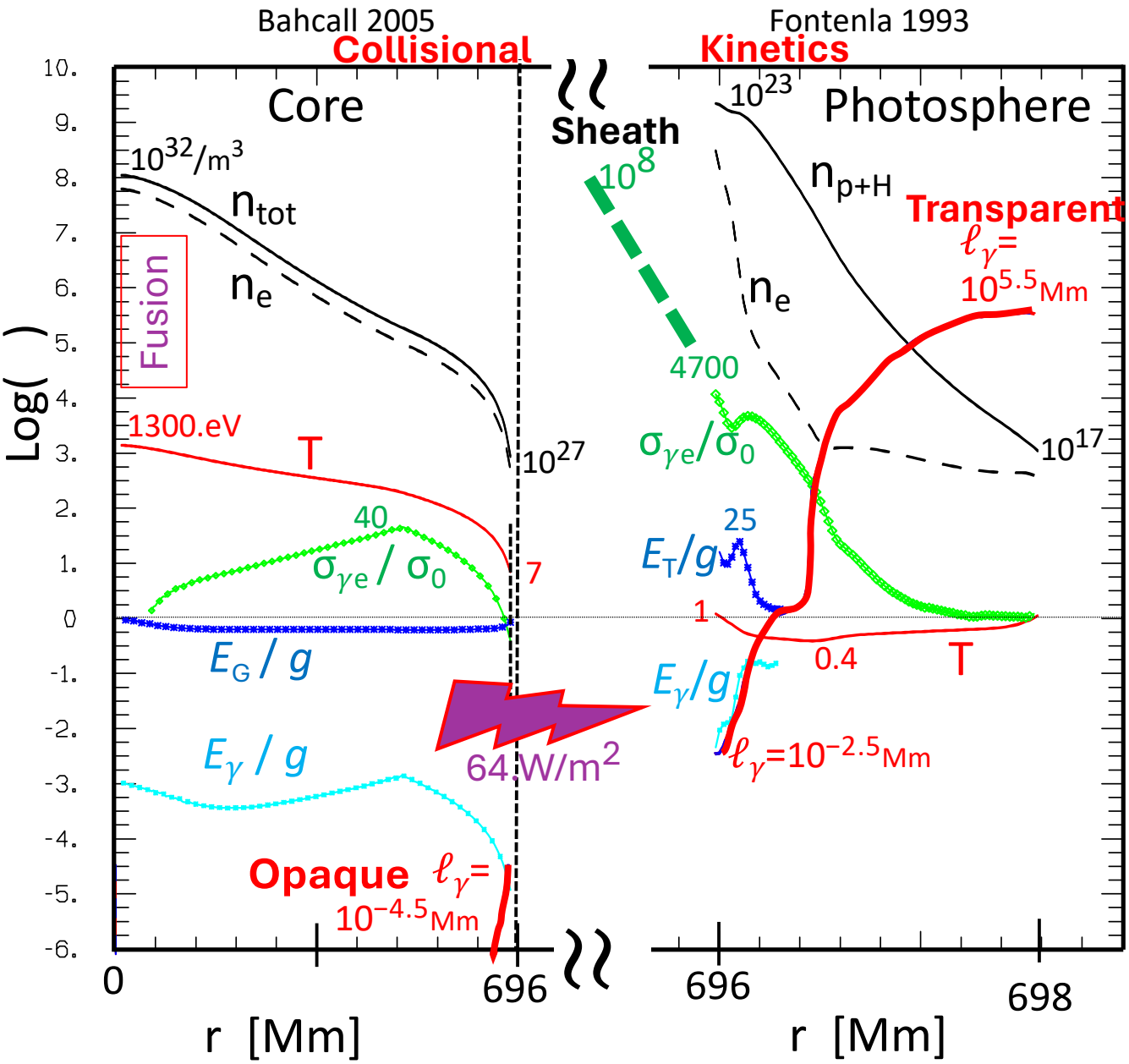
Photo-Electron Drag : γ/e- cross-section is *large* for *correlated* e-/p+

$$(1 < \sigma_{\gamma e} < 10^8)\ \text{x}10^{-28}\ \text{m}^2$$

~ like Target Normal Sheath Acceleration

Photon Pressure on Electrons in the Sheath ; Opaque to Transparent ; Collisional Fluid to Kinetics

The Fusion energy generated in the Core diffuses outward collisionally, until the photon-electron cross-section $\sigma_{\gamma e}$ and electron density $\mathbf{n_e}$ decrease abruptly in the plasma Sheath. There, photons escape kinetically, and electrons are displaced outward, increasing the net positive charge left behind.



Show Us the Energy, Ulysses

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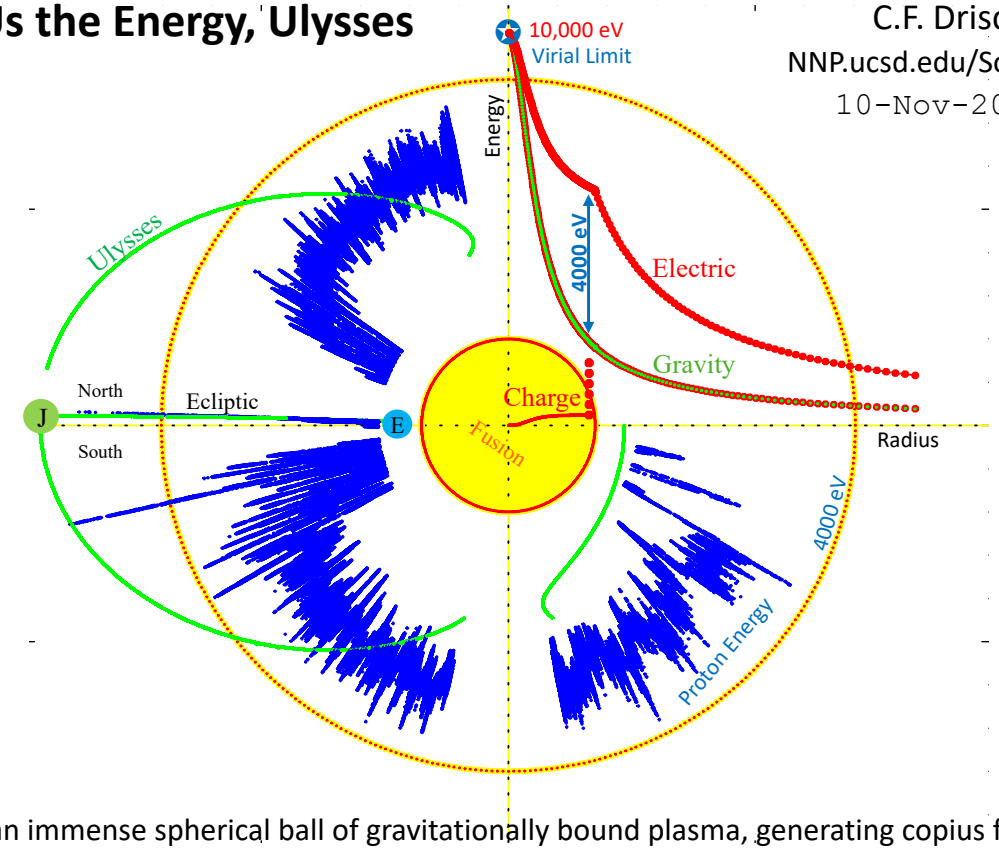
10-Nov-2023



The Sun is an immense spherical ball of gravitationally bound plasma, generating copius 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. One of the NASA/ESA big questions for satellite missions is "What heats the Solar Corona and energizes the Solar Wind ?"

The Ulysses satellite travelled to Jupiter, where a gravity-assist gave it a unique north-south Solar orbit well out of the ecliptic plane of the planets. The largest proton velocities were measured well out of the ecliptic plane. (McComas 2000) Here, a polar plot of 15 years of Solar Wind proton *energies* show a "hard" upper limit of 4000 electron-Volts (orange circle)

Over the past 50 years, Solar Wind models have variously incorporated thermal energy, magnetic turbulence and weak electric fields, always beginning *outside* of the Sun itself.

Professor Charles Driscoll at UCSD has developed a new model which describes the electric fields arising from net charge *inside* the Sun, obtaining quantitative agreement with the Ulysses limit. This has now been published in the Physics of Plasmas. (doi:10.1063/5.0139215)

The electric model posits a net Solar charge displacement of 460.Coulombs, mainly located at the Solar plasma sheath. In simplest terms, this net positive charge occurs because electrons are continuously pushed outward by the enormous outflow of electro-magnetic energy, whereas the protons are not.

Significantly, this displaced charge is uniquely determined by a novel "virial limit", limiting the electric energy to the (accurately known) 10,000.eV gravitational energy at the center of the Sun. This then determines the 4000 eV available to accelerate protons off the Solar surface. The simple model then suggests that dissipation from ecliptic gas, dust, and plasma turbulence cause the intermittent, patchy "slow wind", which impacts the magnetosphere of Earth and displays as the colorful aurora Borealis.

Even given the requisite energy, significant questions remain as to the dynamics, uniformity, and constancy of the proton beam generation. The electric model posits pervasive, persistent "proton lightning jets", analagous to Earth lightning. These appear as the glowing, ever-present "spicules", which densely cover the Solar surface. Moreover, these spatially distributed beams each constitute billions of Amperes, and so can readily create the patchy, fluctuating kilo-Gauss magnetic fields observed on the surface.

Intermittent surface currents can also create the intense surface flashes imaged by the Solar Orbiter satellite, which look distinctly like ground lightning propagation on Earth, in appropriately slow motion. Similarly, the electric model may provide description for the large flowing near-surface "prominences", which remain levitated for hours
.
More importantly, the electric model may provide a basis for modelling extreme "space weather" events such as coronal mass ejections, in terms of large-scale collective potential variations and resultant currents near the Solar surface. This poses substantial challenges and opportunities for future theory and simulations.

How much Solar Charge, at what Radii ?

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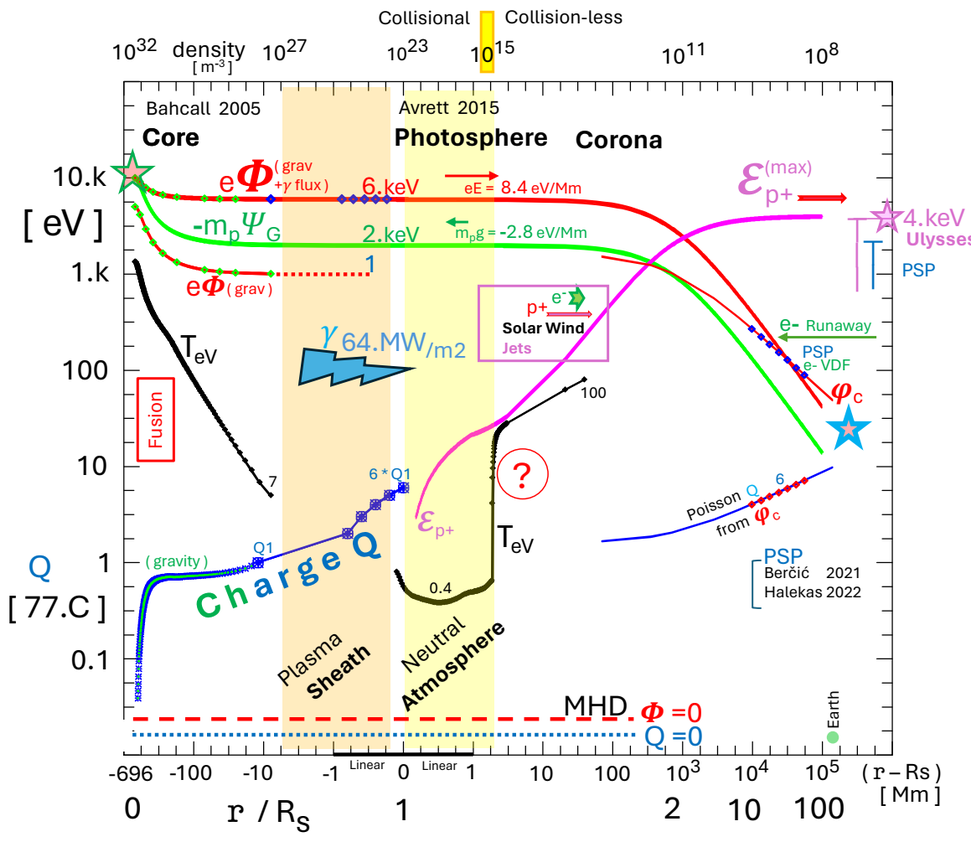
The electric fields and "lightning jets" of the Sun and Solar Wind",
Physics of Plasmas (2023) doi: 10.1063/5.0139215

A new "charge-electric" model of the Sun provides a broad energy basis for the stunning visible surface prominences, and gives quantitative agreement with Solar Wind measurements by the Ulysses and PSP satellites. Moverover, the analysis uncovers a novel "virial" relation between the gravitational energy and the electrostatic energy , which uniquely determines the magnitude of the electric effects.

Most simply, the Sun is a hot plasma ball of protons and electrons, held together by gravity and electric forces, respectively. The electric model is based on two quanitative "standard models" of the Sun, which describe the gravity part well.

--The **Core** model [Bahcall 2005] quantitatively describes the interior mass density and temperature profiles, quantifying the fusion energy release of light and heat. The Core model ends at the (un-modeled) Plasma Sheath, where the plasma transitions from ionized and optically opaque, to a neutral and transparent hydrogen Atmosphere.
--The **Photospheric** model [Avret 2015] is based on an abundance of spectroscopic measurements, and describes a 2.Mm thick radiating Atmosphere at 0.4eV (i.e. 4600 Kelvin), with a sudden transition to a 100.eV **Corona**.



This peculiar temperature jump has led to the long-standing NASA /ESA big mission question of, **"What heats the solar Corona and energizes the Solar Wind ?"** Several generations of "kinetic exospheric" models have attempted to match the observed Solar Wind proton velocities, always starting up in the hot Corona. --In contrast, the new electric model provides a simple answer of **"Electric fields from the net charge *within* the Sun."**

The net solar Charge begins in the dense Core, where a static electric field is *required* to confine the electrons.(Pannekoek 1924) The "few" missing electrons leave a net positive charge of Q_1 = +77.Coulombs (i.e. 0.5×10^{21} e-), quantitatively determined by the known mass profile.

In the Plasma Sheath, additional electrons are "dragged out" by the strong electromagnetic energy flow; but theory estimates of this drag vary widely. Rather, a novel "virial limit" predicts that the central electric energy $e\Phi(0)$ is *limited* to the gravitational energy $m_p\Psi_G(0) = 10.keV$, andthus determining the maximal net charge to be $6 * Q_1 = 460.C$.

This total charge creates an outward electric force of 8.4 eV/Mm on every proton at R_S, which is 3x the inward gravitational force of 2.8 eV/Mm. This energizes proton "Lightning Jets" penetrating the neutral hydrogen Atmosphere, with broad electron neutralization, maintaining the total net charge. These Jets glow as the pervasive (~10^7) "spicules" covering the solar surface. The Jets **heat** the outer Atmosphere and **form** the hot Corona, generating strong magnetic fields from the ~10^9 Amps of proton and electron currents in each Jet.

The proton Jet can accelerate up to an energy of $e\Phi(R_S) - m_p\Psi_G(R_S) = 4.keV$. However, this coherent energy can be dissipated by gas, dust, and electro-magnetic turbulence in the ecliptic plane of the planets; and satellites typically measure proton energies ranging from 0.5 to 2.keV. However, the Ulysses satellite alone travelled north and south of the ecliptic, and 15 years of data shows a "hard limit" of $\mathcal{E}_{p+}^{max} = 4.keV$.

Surprisingly, two recent analyses of the PSP *electron* velocity data have detected a signature of the static electric potential $\varphi_C(r)$, albeit with a puzzling $(r/Rs)^{0.66}$ dependence, suggesting widely distributed charge Q_C from Poisson's equation. However, this is closely consistent with the electric model from interior charge alone.

The charge-electric model provides a broad energy basis for understanding many other puzzling surface effects. Electric potential variations as small as 10.Volts may drive the stunning **surface flashes** recorded by Solar Orbiter, which resemble Earth surface lightning, in slow motion. **Prominences** and **arcs** which persist for hours and days may be 1/3 ionized gas which is "neutrally buoyant", with driven internal currents. **Sunspots** may represent the electric and magnetic interaction of hundreds of Jet currents. More importantly, the occasional energetic "coronal mass eruptions" which adversely impact Earth may involve large-scale interactions of all of these electric and magnetic effects.

June 2004

Show Us the Electric Energy, PSP

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NNP.ucsd.edu /Solar
25-Apr-2024

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, called 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 theory perspective supported by satellite data is now converging on a strikingly simple answer: "The permanent electric field originating below the Corona."

That is, the new electric theory now shows quantitative agreement with satellite data, from both the Parker Solar Probe and the older Ulysses mission.
[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 .

The theory analyzes the solar *surface* effects which are energized by an *underlying* net positive charge. The surface effects include proton jets glowing as the ubiquitous "spicules" before accelerating to form the Solar Wind, local surface currents and magnetic fields, and the visually spectacular levitated arcs and prominences.

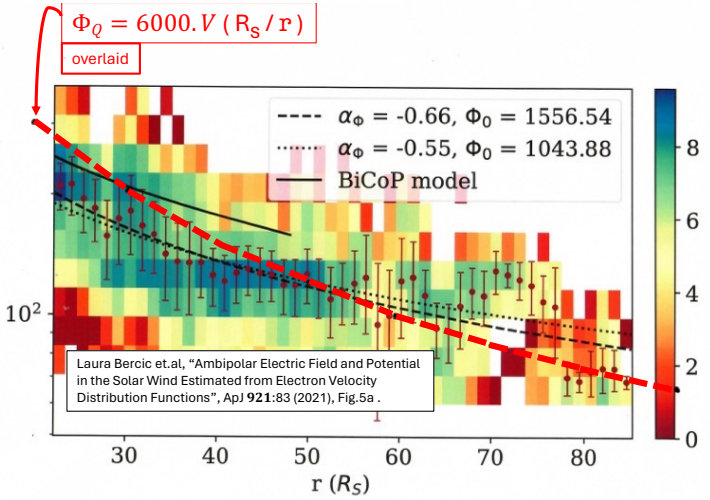
The requisite (miniscule) charge is quantitatively determined by a new "plasma virial limit", giving the maximal electric potential in terms of the well-known gravitational potential, with no adjustable parameters. Quantitatively, the net solar charge gives a potential Φ_Q = 6000.V*(Rs / r) , decreasing with radius; and this accelerates surface protons out of the 2,000 eV gravitational "well", up to a maximum kinetic energy of 4,000 eV.

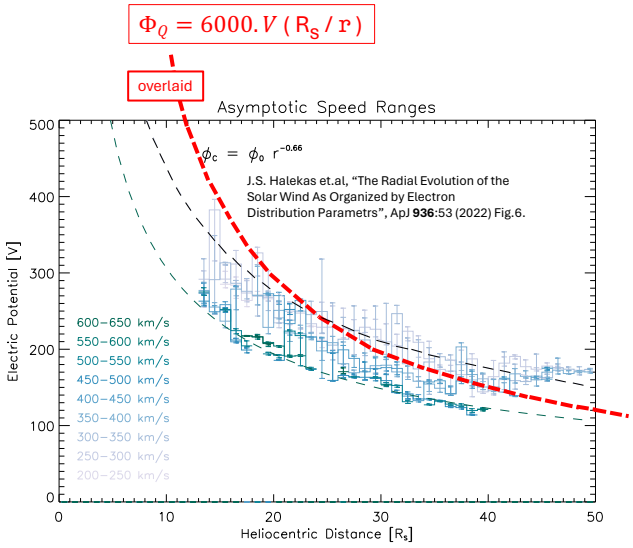
Ulysses This maximal proton acceleration agrees closely with the "hard" upper limit of proton energies measured over the 15 years of Ulysses data. (McComas, 2000) Here, Ulysses provides the *only* measurements of proton energies out of the dusty and turbulent ecliptic plane of the planets, where lower proton velocities are necessarily observed.

PSP Separately, two research teams have published analyses of PSP-measured electron and proton velocities versus distance from the Sun, obtained during PSP's close (but in-ecliptic) encounters. [Bercic 2021, Halekas 2022] They uncovered distinctive non-thermal signatures in the high energy electrons, from which they were able to estimate ambient electric potentials. This included reference to various "exospheric" models, which *start* in the Corona. Surprisingly, the parameter-free electric model for Φ_Q [shown as Red dashed Overlays] agrees broadly with these several inferred potentials, over radii of 15 to 80 *Rsun .

However, the electric field originating in the plasma sheath *below* the Corona energizes surprisingly strong surface effects. This is because the outward electric force on every proton is 3x stronger than the inward gravitational force; and only the thin neutral Hydrogen atmosphere above the plasma sheath mediates the outward flow of energetic particles.

The electric perspective informs the surprising days-long "levitation" of glowing arcs and prominences, and may help in the interpretation of "space weather" which impacts the Earth. More broadly, It also may inform the theory perspective on the birth, stable burning, and unstable collapse of the myriad types of stars.





June 2024