A new global "charge-electric" model builds on standard fluid models for the solar Core (Bahcall 2005) and Photosphere (Averett 2015). The plasma fluid equilibrium equations require a DC electric field balancing gravity on protons in the Core (Pannekoek 1924), arising from a distributed charge of $77 \cdot C$.

Here, we include the additional electric field required to balance the outward photon drag on electrons in the plasma Sheath, which is hard to calculate. Fortunately, a novel "virial" relation between gravitational and electric energies limits the total electric potential to $e\Phi(0) = 10. \text{keV}$, from a total charge of $+460. \text{C}$. This upper limit appears to be the global stable state for the Sun.

The surface potential is then $\Phi(R_s) = 6. \text{kV}$, and the electric force is 3x stronger than gravity on a proton. This electric potential can accelerate a proton to a kinetic energy of $4. \text{keV}$, when not dissipated by gas, dust, or electro-magnetic turbulence.

1) The Ulysses proton data shows a 15-year "hard limit" of $4. \text{keV}$ (880. km/s), over all directions above and below the ecliptic, during low sunspot activity (McComas 2000).

2) Two analyses of the PSP electron VDF data for $15 < r/R_s < 80$ obtain electric potentials in close agreement with $\Phi = 6. \text{keV} (r/R_s)^{-1}$, possibly due to "reverse runaway" electrons (Berčič 2021, Halekas 2022).

The electric model can explain many puzzling surface effects, including the fluctuating magnetic fields from surface currents. The electric field 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.

"Ohm's Balance" can be rather complicated for multiple species, and "reverse runaways" are probably endemic to systems "made inhomogeneous by gravity, rotation, and radiation" (Scudder 2019).
Surface Convection Cells, \( A \sim (1.\text{Mm})^2 \), \( \tau \sim 5.\text{min.} \) \# \sim 10^7

"Lightning Jets" appear as Filamentary Spicules

Levitated and Flowing Prominences

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

\[- eE = 3\{ m_p \} g \rightarrow \text{accelerate } P^+ \]
\[- e = 1\{ P^+ + 2H^0 \} g \rightarrow \text{neutrally bouyant } \]

\( \lambda = 656.\mu \text{m} \)

\[ \text{Lang 1995} \]

Brandt 1970

? Initiation points for Jets ?

Pereira "Quantifying Spicules" 2012

NASA / SDO 2010 "What is a Solar Prominence?"
Equilibrium Stellar Fluid Eqns: mass charge photons

\[ m_p \Psi' \approx 2.8 \, eV \, / \, Mm \quad @ \, R_s \]

Gravity

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

Electric Potential

\[ \Gamma_{e\gamma} \sim 65 \cdot MW \, / \, m^2 \quad @ \, R_s \]

Fusion Energy Flux

\[ \Gamma_{e\gamma} \approx 1.4 \, eV \, / \, Mm \]

Thermal Energy Diffusion

\[ \sigma_{\gamma e} \equiv \frac{1}{l_{\gamma e} n_e} \]

\[ \frac{\Gamma_{e\gamma}}{c} \sigma_{\gamma e} = eE(r) \]

Photo-Electron Drag: \( \gamma/e \) - cross-section is 

\[ 1 < \sigma_{\gamma e} < 10^8 \quad \times 10^{-28} \, m^2 \]

large for correlated e-/p+

\[ \sim \text{like Target Normal Sheath Acceleration} \]

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

1b \[ \nabla^2 \Phi(r) = - k_1 e \, (n_p - n_e) \]

\[ \nabla \cdot \Gamma_e(r) = \frac{d}{dt} \epsilon(r) \]

2 \[ -(4aT^3) \, T'(r) \, l_\gamma = \frac{4}{c} \Gamma_e \]

\[ 3 \quad [n_p T]^' + n_p m_p \Psi' + (+e)n_p \Phi' = 0 \]

Proton Fluid Momentum

\[ 4a \quad \frac{\Gamma_{e\gamma}}{c l_{\gamma e}} + n_m \Psi' + (-e)n_e \Phi' = 0 \]

Electron Fluid Momentum

\[ 4b \quad [(2n)T]^' - \frac{\Gamma_{e\gamma}}{c l_{\gamma e}} + n_m \Psi' = 0 \]

Total Fluid Momentum

\[ 4a + 4b \quad \frac{\Gamma_{e\gamma}}{c l_{\gamma e} n_e} + m_p \Psi' = 0 \]

Electric Field

Gravito-Electric

A. Pannekoek

in high-density collisional regime

S. Rosseland (1924)

A.E. Eddington

-1/2 \[ m_p \, g(r) \approx eE(r) \]

@ \( R_s \)}
The Total Solar Charge is set by a Virial Limit, and the Maximum Proton Energy follows as 4. keV

( Pannekoek / Rosseland /Eddington ) \textbf{Gravito-Electric Charge} \quad Q_G
( Target Normal Sheath Acceleration ) \textbf{Photo-Electric Charge} \quad Q_\gamma = Q_G \times 5

\[ \Phi(0) = -\Psi_G(0) \]

\[ \Gamma = 65. \text{MW/m}^2 \]

\[ e\Phi^{(1)} \text{ is required to contain electrons, giving } eE = \frac{1}{2} m_p g \text{ from } Q_G = 77. \text{C} \]

\[ \Phi - \Psi \text{ Energetics} \]

\[ \Delta \mathcal{E}_{\text{pw}} = \Phi - -\Psi = 4. \text{keV} \]

\[ 6 \times Q_G = 460. \text{Coul} \]

\[ Q_\gamma \]

\[ \text{The Photon Flux } \Gamma \text{ drags electrons out of the Sheath, leaving positive charge } Q_\gamma. \]

\[ \text{The total charge build-up is limited to } 6 \times Q_G \text{ by the "Virial Limit" } \Phi(0) \leq -\Psi_G(0) \]

\[ \text{This leaves } \Delta \mathcal{E}_{\text{pw}} = 4. \text{keV available to accelerate protons off the surface.} \]
**Ohm's Balance:**

0) **Earth Wires**

1) **Sun Core**
   Gravito-Electric (Pannekoek)  
   \( Q \sim +77 \text{C} \)

2) **Plasma Sheath, Photo-Electron Push Out**  
   \( Q \sim +460 \text{C} \)

**Wires:** An external battery creates an electric field which drives electron flow \( J_e \). The moving electrons collide with stationary ions, creating time-fluctuating reverse fields \( <E_{\text{coll}}>_t \) which are the resistivity \( \rho \).

**Gravity** confines protons, but has negligible effect on electrons. After \( \sim 10^{20} \) electrons leave, the resulting electric field \( E_G \) contains the \( \sim 10^{57} \) other electrons. \( eE_G = ½ m_p g \), independent of Temperature.

**Photo-Electron:** The outward flux of EM energy \( \Gamma_e \) pushes strongly on electrons, but not on protons. This increases the total displaced electron charge to \( 460 \text{C} \), giving \( e(E_G + E_r) = 3 * m_p g \). Prominences of 1/3 ionized hydrogen may be "neutrally levitated" for long times.

**Jets** of protons broadly neutralized by electrons can penetrate the resistive hydrogen atmosphere, due to "avalanche breakdown", as with Earth lightning.

These Jets may propagate coherently to large radii; or they be dispersed by turbulent surface currents, or by gas and dust, especially in the ecliptic plane of the planets.

Electrons which are moving rapidly relative to the protons are essentially "photo-transparent", with small \( \sigma_{\gamma e} \). They may continue accelerating towards the Sun, with decreasing cross-section to photons, plasma, and gas.
The energization of Proton Beams out of the Solar Sheath is similar to the "Target-Normal Sheath Acceleration in the laboratory.

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

The DC "pondermoive" force $\vec{F}_{\gamma e^-}$ results from the AC EM field $\gamma$ coupling to the AC $e^-$ response. The heavy $p^+$ respond weakly and feel negligible force $\vec{F}_{\gamma p^+} \approx 0$.

(1) Solar Sheath

$\rho_{pe} \sim 10^{24}$/m$^3$

$\gamma \sim 10^{7.8}$ W/m$^2$

$\nu \sim 1$ eV

$E_{pb} \sim 10^{3.6}$ eV

$\vec{F}_{\gamma e^-}$

$E_{pb}$

$p^+$

(2) Laser - Target Sheath Accel

$\rho_{pe} \sim 10^{30}$

$\gamma \sim 10^{15}$ W/m$^2$

$E_{pb} \sim 10^8$ eV

$\vec{F}_{\gamma e^-}$

$E_{pb}$

$p^+$
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 $T \approx 1350\,\text{eV} = 1.6 \times 10^7\,\text{Kelvin}$. Fusion energy diffuses out to $R_{\text{sun}}$ as a Photons 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 ~2 Mm thick (yellow) covers the interior plasma. Here, the description must change from a collisional fluid to collision-less particles.

The Charge increases to $460\,\text{C}$ at $R_s$, giving $eE = -3\,\text{m}_p\text{g}$. Lightning Proton Jets form in pinched avalanche breakdown of Photospheric resistivity, and accelerate to 4 keV unless slowed by neutrals, dust, or turbulent fields.

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

The Jets appear as Spicules; the Corona is diffuse Jets, inflowing neutrals, and downward runaway electrons.
How much Solar Charge, at what Radii?
"Show us the Energy, Ulysses"
ranges, it almost cancels out the electric potential even at larger
distances, and overtakes the extrapolated electric potential in
magnitude at a comparatively large heliocentric radius of
\( \sim 9R_S \). For the slower speed ranges, on the other hand, the
gravitational potential does not overtake the extrapolated
electric potential in magnitude until a heliocentric radius of

Figure 6.
Radial evolution of the local electric potential with respect to in
finity \( (f_c) \), as determined from SPAN-Electron measurements of the sunward cutoff in the
EVDF, binned by asymptotic solar wind speed \( (v_{ASY}) \) in nine ranges, as indicated. Colored lines represent median values for each radius
– speed bin, and error bars represent upper and lower quartiles. The two dashed curves show approximate power law extrapolations for low and high asymptotic speeds.

Figure 7.
Radial evolution of the sum of the electric potential
(same as Figure 6) and the gravitational potential per charge for protons, with respect to in
finity, binned by asymptotic solar wind speed \( (v_{ASY}) \) , same ranges as Figure 6. Colored lines represent median values for each radius
– speed bin, and error bars represent upper and
lower quartiles. The two dashed curves show the same power law extrapolations as Figure 6, with the addition of the gravitational potential, with diamonds indicating
the maxima in the total potential.


Geometric Maxwell-Lorentz: Discrete $e^-$, $p^+$

$$\{\hat{E}, \hat{B}\} = \{E, B\} / e \sim [l^{-2}]$$

$$\nabla \cdot \hat{E}(x) = 4\pi \sum_{j=1}^{N} s_j \delta(x - x_j)$$

$$\nabla \cdot \hat{B}(x) = 0$$

Fluidize: $N \to N / \varepsilon$\hspace{1cm} Constant: $\varepsilon \to 0$

$$\{\hat{E}, \hat{B}\} \to \{\hat{E}, \hat{B}\} / \varepsilon$$

$$e \to \varepsilon e$$

$$m \to \varepsilon m$$

$$T \to \varepsilon T$$

$$r_e \to \varepsilon r_e \to 0$$

$$\rho_d \to \varepsilon \rho_d \to 0$$

MHD: $Q = 0$\hspace{1cm} $E = 0$\hspace{1cm} $\nabla \cdot J = 0$

Fundamental Constants

- $e^2 = 1.44 \text{ eV} \cdot \text{nm}$
- $hc = 1240. \text{ eV} \cdot \text{nm}$
- $Gm_p^2 / e^2 = 0.81 \times 10^{-36}$

Plasma Parameters:

- Size scale $r_e, n$\hspace{1cm} Size scale $\beta \equiv \nu / c$
- Rate scale $b \equiv e^2 / T = r_e \beta^{-2} \to 0$
- $\nu_c = n \nu b^2 = n r_e \beta^{-3} \ln \Lambda \to 0$
- $\rho_a = \frac{m_e \nu_c}{e^2} = n \beta^{-3} \ln \Lambda / c \to 0$
- $g \equiv \frac{1}{n \lambda_D^3} = \left[ nr_e^3 \beta^{-6} (4\pi)^3 \right]^{1/2} \to 0$

Prototypes

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