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

C. Fred Driscoll, UCSD Physics NNP.ucsd.edu/Solar

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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 balanceing gravity on protons in the Core (Pannekoek 1924), arising from a distributed charge of 77.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 $e\Phi(0) = 10$.keV, from a total charge of +460.C.

This upper limit appears to be the global *stable state* for the Sun.

The surface potential is then $\Phi(R_s) = 6.kV$, 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.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 (McComas 2000).

2) Two analyses of the **PSP** electron VDF data for 15 < r/Rs < 80 obtain electric potentials in close agreement with $\Phi = 6.\text{keV} (r/R_s)^{-1}$, 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, $A \sim (1.Mm)^2$, $\tau \sim 5.min$. $\# \sim 10^7$



Brandt 1970 ? Initiation points for Jets ?



Lang 1995

λ = 656.µm





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. "



Equlibrium Stellar Fluid Eqns: mass charge photons $m_p m_e e^- p^+ \gamma$ $\nabla^2 \Psi(r) = G m_p n_p(r)$ 1a $m_p \Psi' \approx 2.8 \, eV \,/\, Mm \quad @R_s$ Gravity $\nabla^2 \Phi(r) = -k_1 e \left(n_p - n_e \right)$ **Electric Potential** $Gm_p^2 \sim 10^{-36} k_1 e^2$!! 1b2 $\nabla \cdot \Gamma_{\varepsilon}(r) = \frac{d}{dt} \varepsilon(r)$ 3 $-(4aT^3)T'(r)l_{\gamma} = \frac{4}{c}\Gamma_{\varepsilon}$ Fusion Energy Flux $\Gamma_{\epsilon\gamma} \sim 65.MW / m^2 @R_s$ Thermal Energy Diffusion $4a \quad [n_pT]' + n_p m_p \Psi' + (+e)n_p \Phi' = 0$ Thermo- $4b \quad [n_eT]' - \frac{\Gamma_{e\gamma}}{c \ l_{\gamma e}} + n_e m_e \Psi' + (-e)n_e \Phi' = 0$ Proton Fluid Momentum **Electron Fluid Momentum** $4a+4b \quad [(2n)T]' - \frac{\Gamma_{\epsilon\gamma}}{c \, l_{\gamma e}} + n m_p \Psi' = 0$ Total Fluid Momentum $4a-4b \qquad \qquad \frac{\Gamma_{\varepsilon\gamma}}{c\,l_{\gamma e}n_e} + m_p \Psi' + (2e)\Phi' = 0 \qquad \text{Electric Field}$ $-\frac{1}{2}m_p g(r) \approx eE(r)$ $@R_s \approx 1.4 \text{ eV} / Mm$ Gravito-Electric
in high-density S. Rosseland (1)
Collisional regime
A.E. EddingtonS. Rosseland (1924) Photo-Electron Drag: γ/e- cross-section is $\frac{1}{\varepsilon\gamma}\sigma_{\gamma e} = eE(r)$ $\sigma_{\gamma e} \equiv \frac{1}{l_{\gamma e} n_{e}}$ large for correlated e-/p+ $(1 < \sigma_{\gamma e} < 10^8) \times 10^{-28} \text{ m}^2$ ~ like Target Normal Sheath Acceleration





Wires : An *external* battery creates an electric field E_{ext} which drives electron flow J_e. The moving electrons collide with stationary lons, creating time-fluctuating reverse fields $< E_{coll} >_t$ which are the resistivity ρ .

Gravity confines protons, but has negligible effect on electrons. After ~10^20 electrons leave, the resulting electric field E_G contains the ~10^57 other electrons. $eE_G = \frac{1}{2} m_p g$, independent of Temperature.

Photo-Electron : The outward flux of EM energy $\Gamma_{e\gamma}$ pushes strongly 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.

Jets of protons broadly neutralilzed by electrons can penetrate the resistive hydrogen atmosphere, due to "avalanch 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 $\sigma_{\gamma\rm e}$. They may continue accelerating towards the Sun, with decreasing cross-section to photons, plasma, and gas.

Photo – Electron Drag 🗖

Displaced e- Charge Electric Field Proton Beam Acceleration



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 $F\gamma e^{-1}$ results from the AC EM field γ coupling to the AC e^{-1} response. The heavy p+ respond weakly and feel negible force $F\gamma p^{+} \approx 0$.

EM Opaque to Transparent; Collisional Fluid to Kinetics









"Show us the Electric Energy, PSP"



Geometric Maxwell-Lorentz : Discrete e⁻, p⁺

p2

 $\omega_{\rm p}^2 \equiv 4\pi n e^2 / m = n r_{\rm e} 4\pi c^2$

Fluidize : $N \rightarrow N/\varepsilon$ Constant : $\hat{B} \rightarrow \{\hat{E}, \hat{B}\} / \varepsilon \quad \{E, B\}$ $e \rightarrow \varepsilon e \qquad Q, \ \mathcal{E}$ $m \rightarrow \varepsilon m \qquad M, \ \nabla$ $T \rightarrow \varepsilon T \qquad nT$ $r_{e} \rightarrow \varepsilon r_{e} \rightarrow 0$ $\gamma \rightarrow \varepsilon \Omega \rightarrow 0$ $V_{A}^{2} \equiv \frac{B^{2}}{4\pi n m_{p}} = \frac{r_{e} \hat{B}^{2} \beta^{-2}}{n \ 4\pi m_{p}}$ MHD: Q = 0E = 0 $\nabla \cdot J = 0$

p⁺ Prototypes
$$t \mid c \mid m \mid m_{e}$$

Fundamental Constants
 $e^{2} = 1.44 \text{ eV} \cdot \text{nm}$ $r_{e} \equiv \frac{e^{2}}{m_{e}c^{2}} = 2.82 \text{ x} 10^{-15} \text{ m}$
 $hc = 1240. \text{ eV} \cdot \text{nm}$ $\tilde{\lambda}_{c} \equiv \frac{hc}{m_{e}c^{2}} = 386.\text{ x} 10^{-15} \text{ m}$
 $\frac{Gm_{p}^{2}}{e^{2}} = 0.81 \text{ x} 10^{-36}$ $r_{e} / \tilde{\lambda}_{c} = 1/137.$
 $a_{0} = \tilde{\lambda}_{c}^{2} / r_{e}$ Bohr radius
 $\hat{\mu}_{B} = \tilde{\lambda}_{c} / 2$ Bohr mageton
ma Parameters : Size scale r_{e} , n
Rate scale $\beta \equiv \overline{v} / c$ $\bar{v}^{2} \equiv T / m_{e}$

$$\begin{split} \omega_{\rm p}^{2} &\equiv 4\pi ne^{2} / m = nr_{\rm e} \, 4\pi c^{2} \\ \lambda_{\rm D}^{-2} &\equiv 4\pi ne^{2} / T = nr_{\rm e} \beta^{-2} \, 4\pi \\ \lambda_{\rm D}^{-2} &\equiv 4\pi ne^{2} / T = nr_{\rm e} \beta^{-2} \, 4\pi \\ \|\beta_{\rm p}^{-1}\| &\equiv \frac{B^{2}}{8\pi nT} = \frac{r_{\rm e} \, \hat{B}^{2} \, \beta^{-2}}{n \, 8\pi} \\ V_{\rm A}^{2} &\equiv \frac{B^{2}}{4\pi nm_{\rm p}} = \frac{r_{\rm e} \, \hat{B}^{2} \, c^{2} \, m_{\rm e}}{n \, 4\pi m_{\rm p}} \end{split} \qquad b &\equiv e^{2} / T = r_{\rm e} \, \beta^{-2} \rightarrow 0 \\ v_{\rm c} &= n \, \overline{v} \, b^{2} \, ln\Lambda = nr_{\rm e}^{2} \, \beta^{-3} \, ln\Lambda \rightarrow 0 \\ \rho_{\rm d} &= \frac{m_{\rm e} \, V_{\rm c}}{e^{2} \, n} = r_{\rm e} \beta^{-3} \, ln\Lambda / c \rightarrow 0 \\ g &\equiv \frac{1}{n \lambda_{\rm D}^{3}} = [nr_{\rm e}^{3} \beta^{-6} (4\pi)^{3}]^{1/2} \rightarrow 0 \end{split}$$

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