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

or... Show us the Energy, Ulysses !!

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Summary :

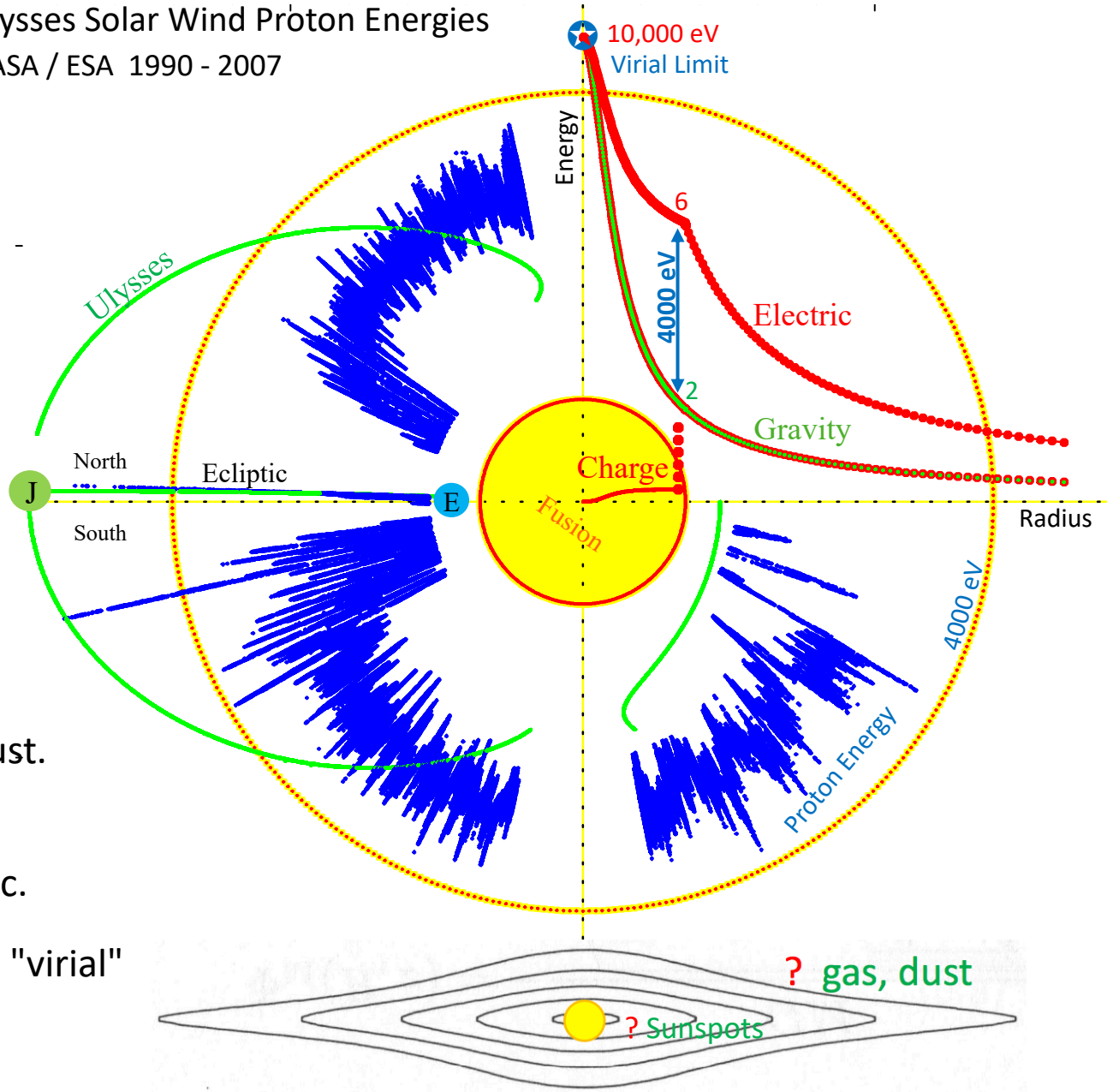
(1) The Sun is charged, by +460. Coulombs, mainly resident in the plasma sheath at Rsun.

(2) The resulting electric potential energy is 6.keV at Rs, whereas the gravitational "well" for protons is 2.keV at Rs.

(3) The 4.keV excess electric energy can accelerate proton Jets to 880.km/s , when not slowed by ecliptic-plane gas & dust.

(4) The Ulysses proton data shows a "hard limit" at 4.keV, over all directions and decades in time, away from the ecliptic.

(5) This 460.C of charge is ***quantitatively determined*** by the "virial" equality of gravity & electric energies (10.keV) at r = 0 .



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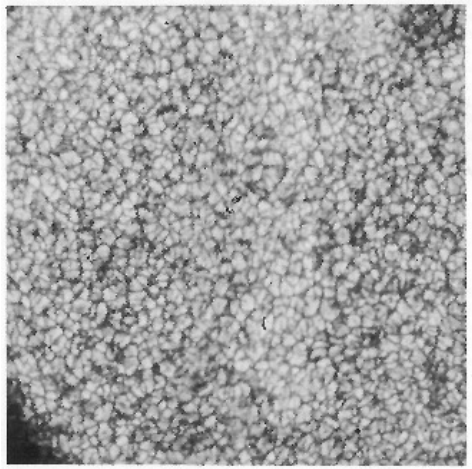
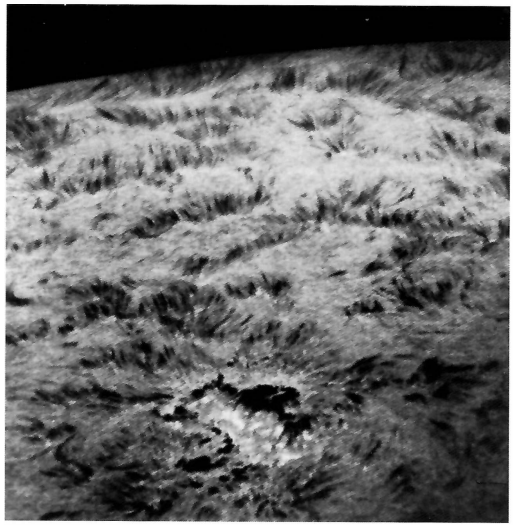
Surface **Convection Cells**,
A ~ $(1.Mm)^2$, τ ~ 5.min. # ~ 10^7

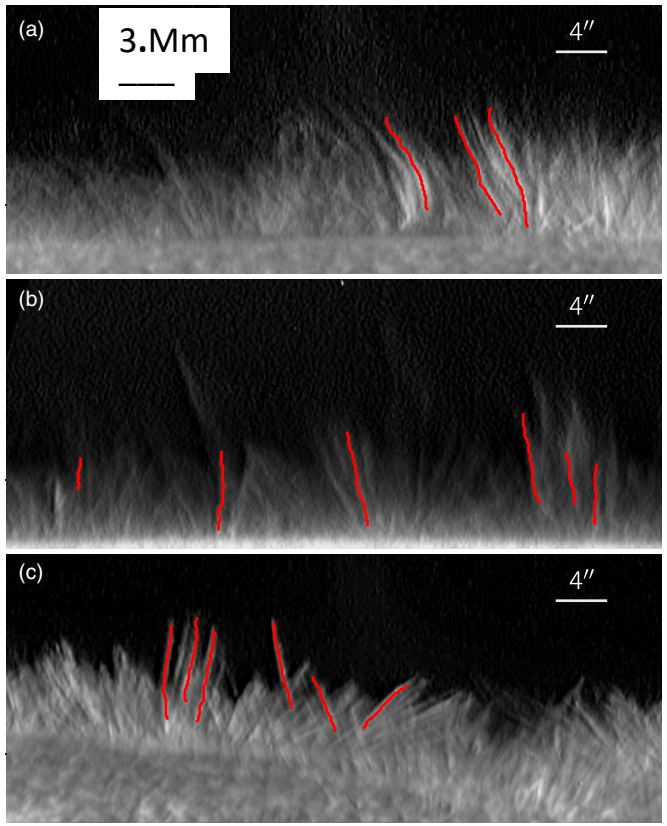


Brandt 1970



Lang 1995

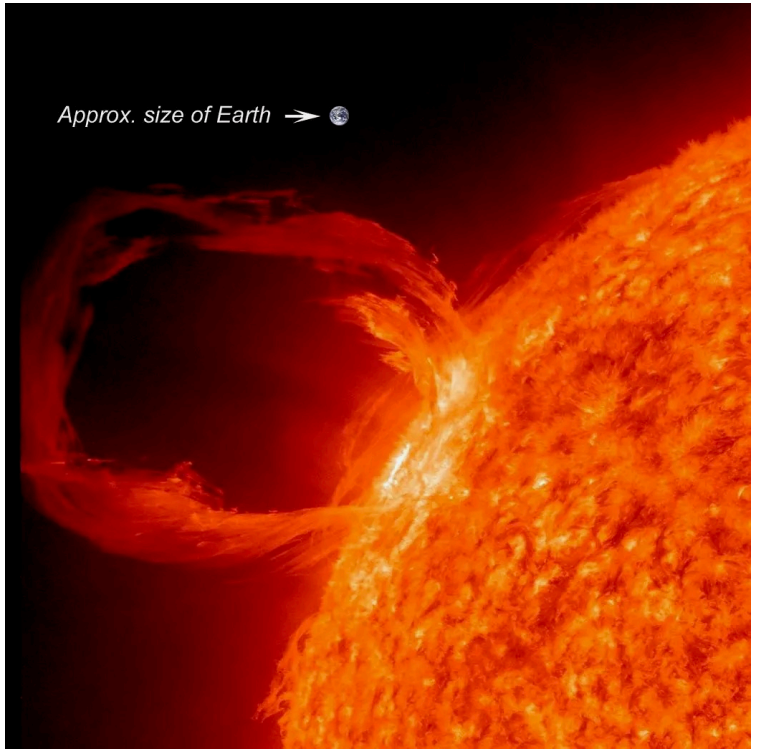
Filamentary **Spicules**,
from energetic Jets, # ~ 10^7



Pereira "Quantifying Spicules" 2012

Spicules are "lightning" proton Jets,
with energy $\mathcal{E} \sim 15.eV$.

Levitated or 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. "

With $eE = -3*m_p g$, a 1/3 ionized H atmosphere
would be neutrally buoyant.

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

$$4a \quad [n_p T]' + n_p m_p \Psi' + (+e) n_p \Phi' = 0$$ Proton Fluid Momentum

$$4b \quad [n_e T]' - \frac{\Gamma_{\varepsilon\gamma}}{c\, l_{\gamma e}} + n_e m_e \Psi' + (-e) n_e \Phi' = 0$$ 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

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

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

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

$(1 < \sigma_{\gamma e} < 10^8)$ x10^{-28} m^2

~ Target Normal Sheath Acceleration

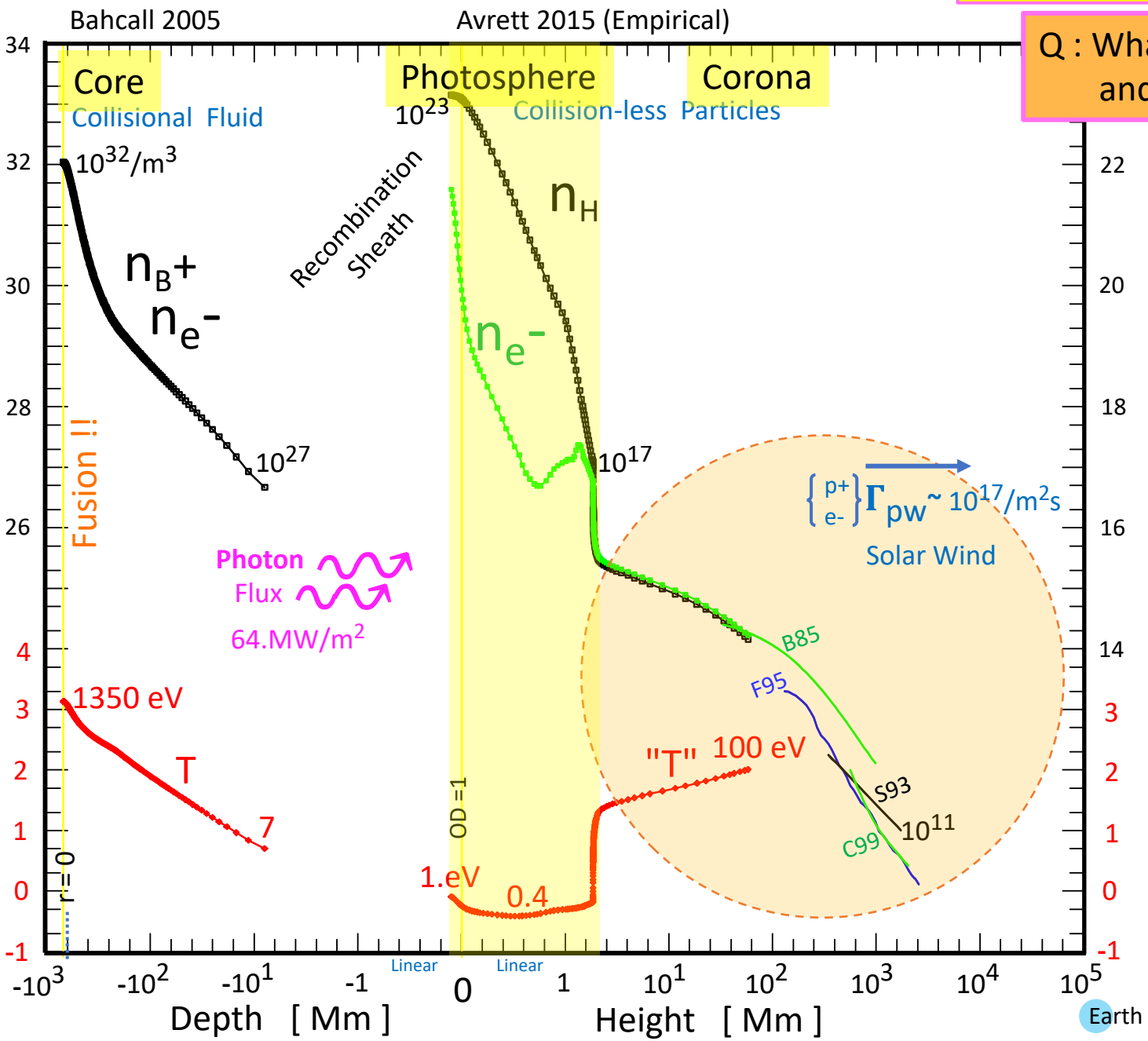
$m_p \Psi' \approx 2.8\, eV / Mm \quad @R_S$

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

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

The Sun, In & Out

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 ~ 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.

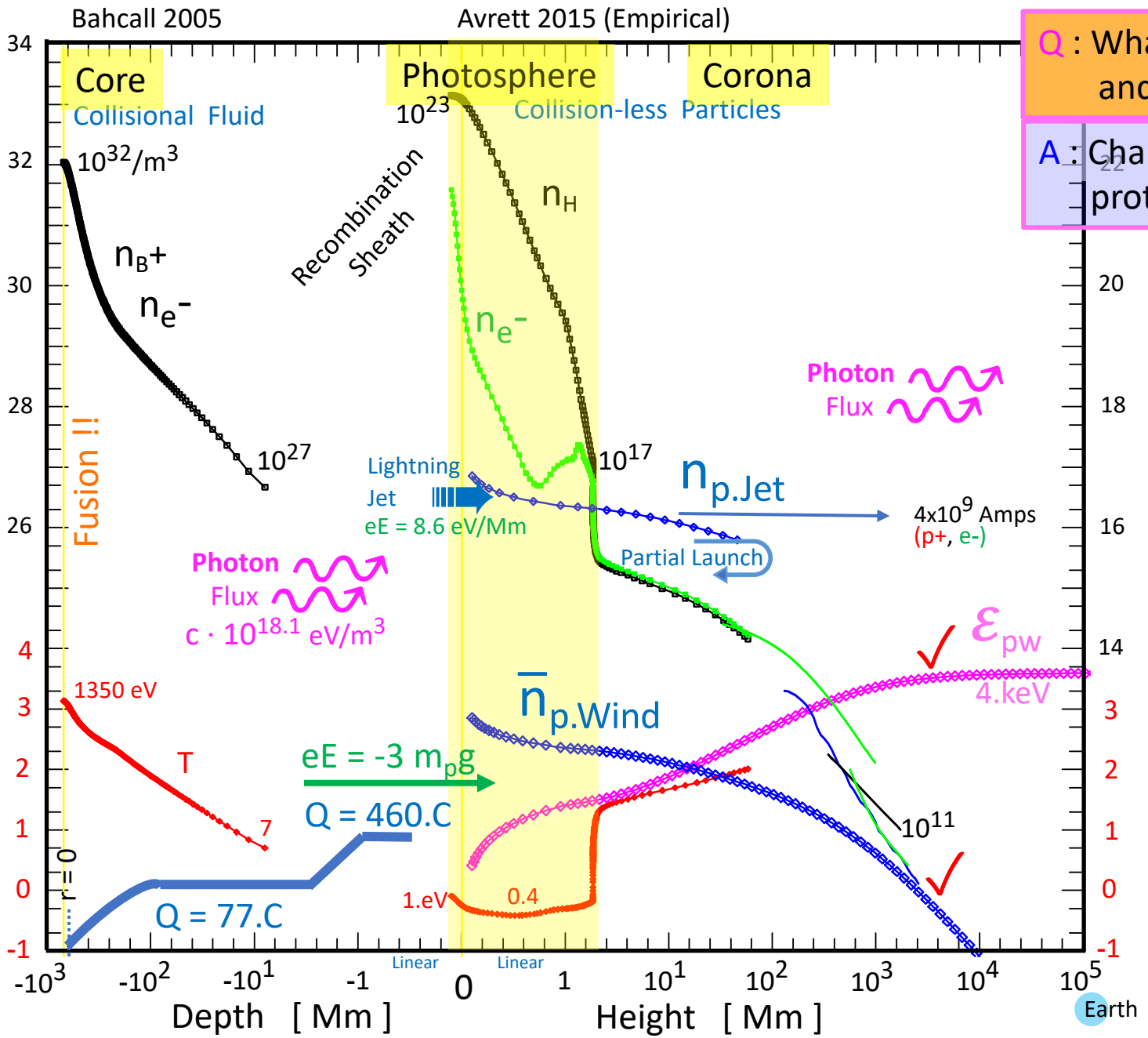
The **Corona** is a very low density, collisionless plasma, with empirical energy of about 100.eV per particle.

The proton/electron Solar **Wind** is an energetic, pervasive, persistent, low-density flux Γ of particles.

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.



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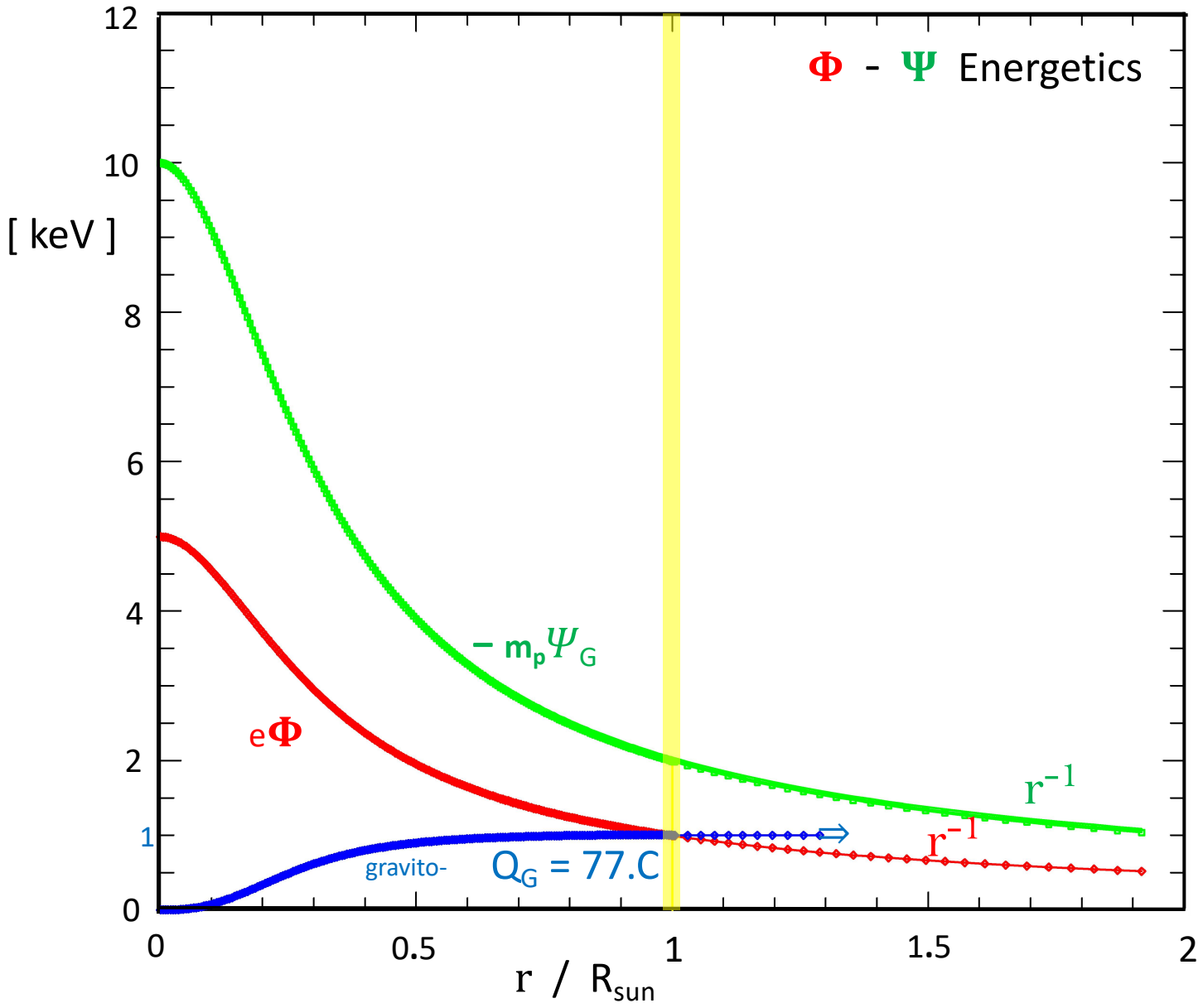
The Charge increases to 460.C at R_s , giving eE = -3 $m_p g$. Lightning Proton Jets form in pinched avalance breakdown of Photospheric resistivity, and accelerate to 4.keV unless slowed by neutrals, dust, or turbulent fields.

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

(Pannekoek / Rosseland /Eddington) Gravito-Electric Charge Q_G => Q_{tot} = 77.C



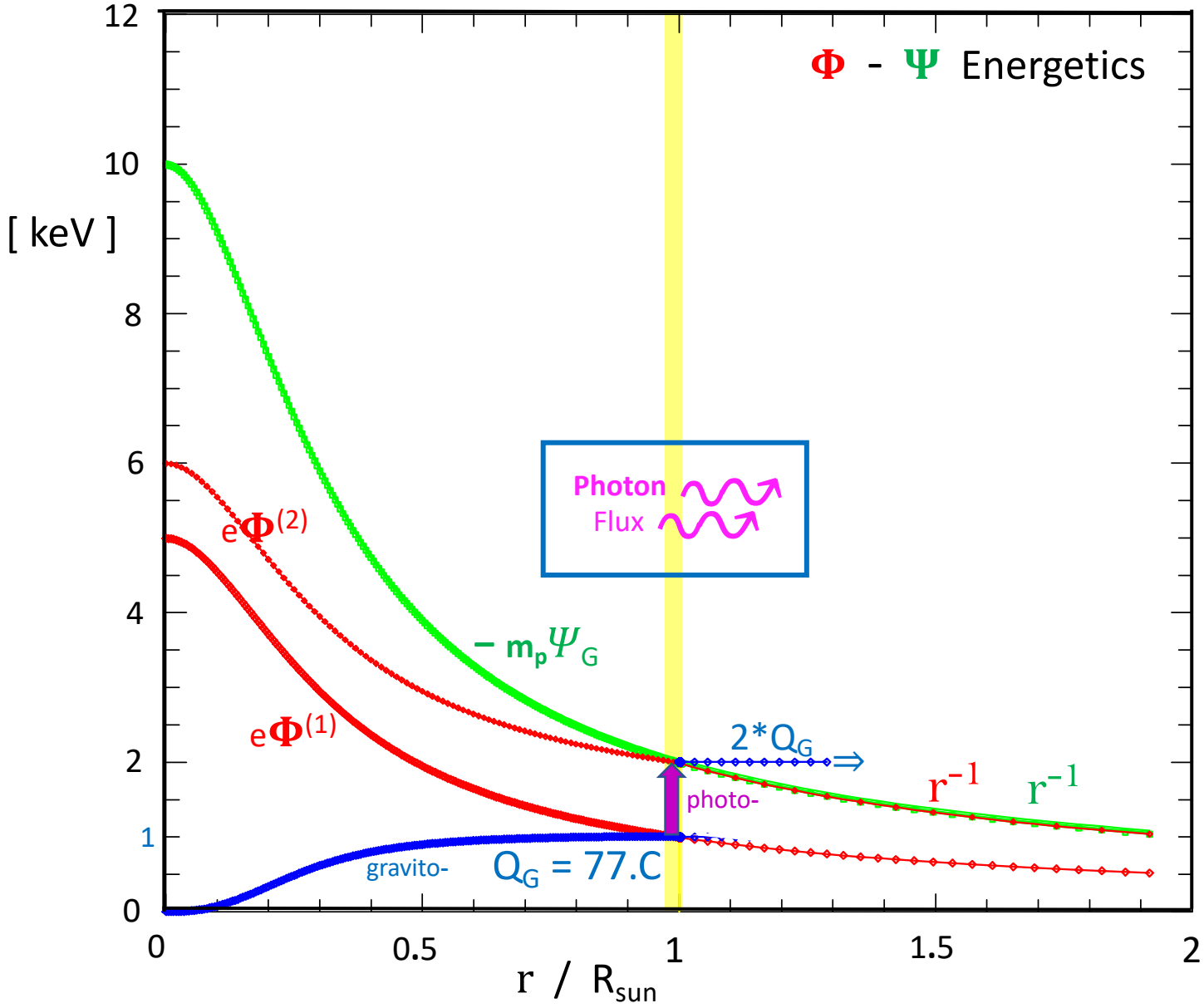
The **Gravito-Electric** field was analyzed 100 years ago by Pannekoek, Rosseland, and Eddington.
The charge displacement and electric field is *required* for two-fluid force-balance of heavy protons and light electrons.

It gives $eE = -½ m_p g$ everywhere in the collisional plasma, so protons are "½ levitated", and electrons are held in. This is unversally accepted, but generally igorned.

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

(Target Normal Sheath Acceleration) Photo-Electric Charge + $Q_\gamma = Q_G * 1 \Rightarrow Q_{tot} = 154.C$

(arbitrary amount)



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- The **Photon Flux** Γ produdes a (pondermotive) **photo-electric** force on electrons. It is called Target Normal Sheath Acceleration when lasers impinge on thin foils, producing proton beams with 1 –> 100 MeV of energy.

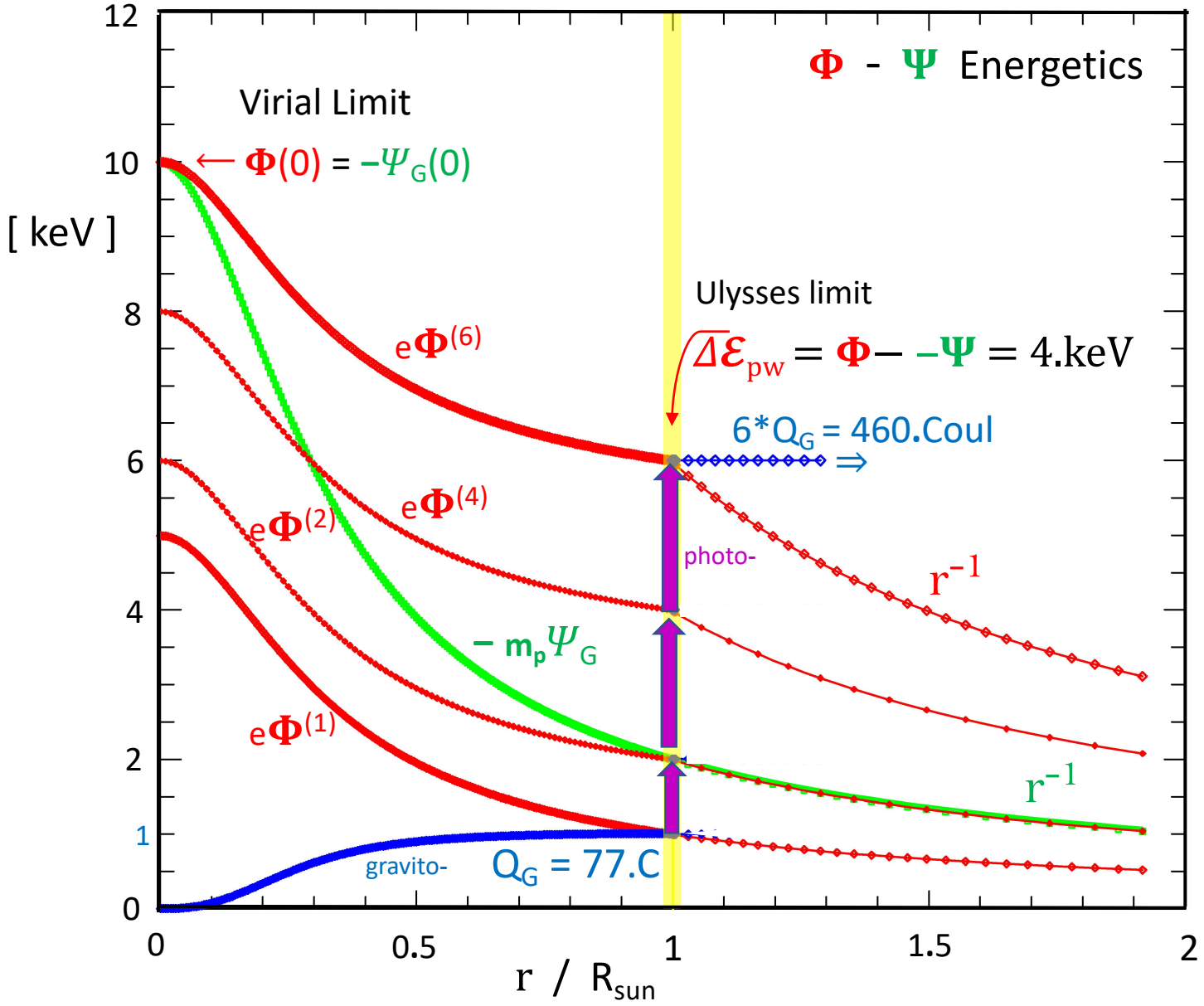
The Total Solar Charge is set by a Virial Limit, and the Maximum Proton Energy follows as 4.keV

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

(Target Normal Sheath Acceleration) Photo-Electric Charge + $Q_\gamma = Q_G * 5$ => Qtot = 460.C

=> Virial Limit Maximum

=> Ulysses Minimum Required



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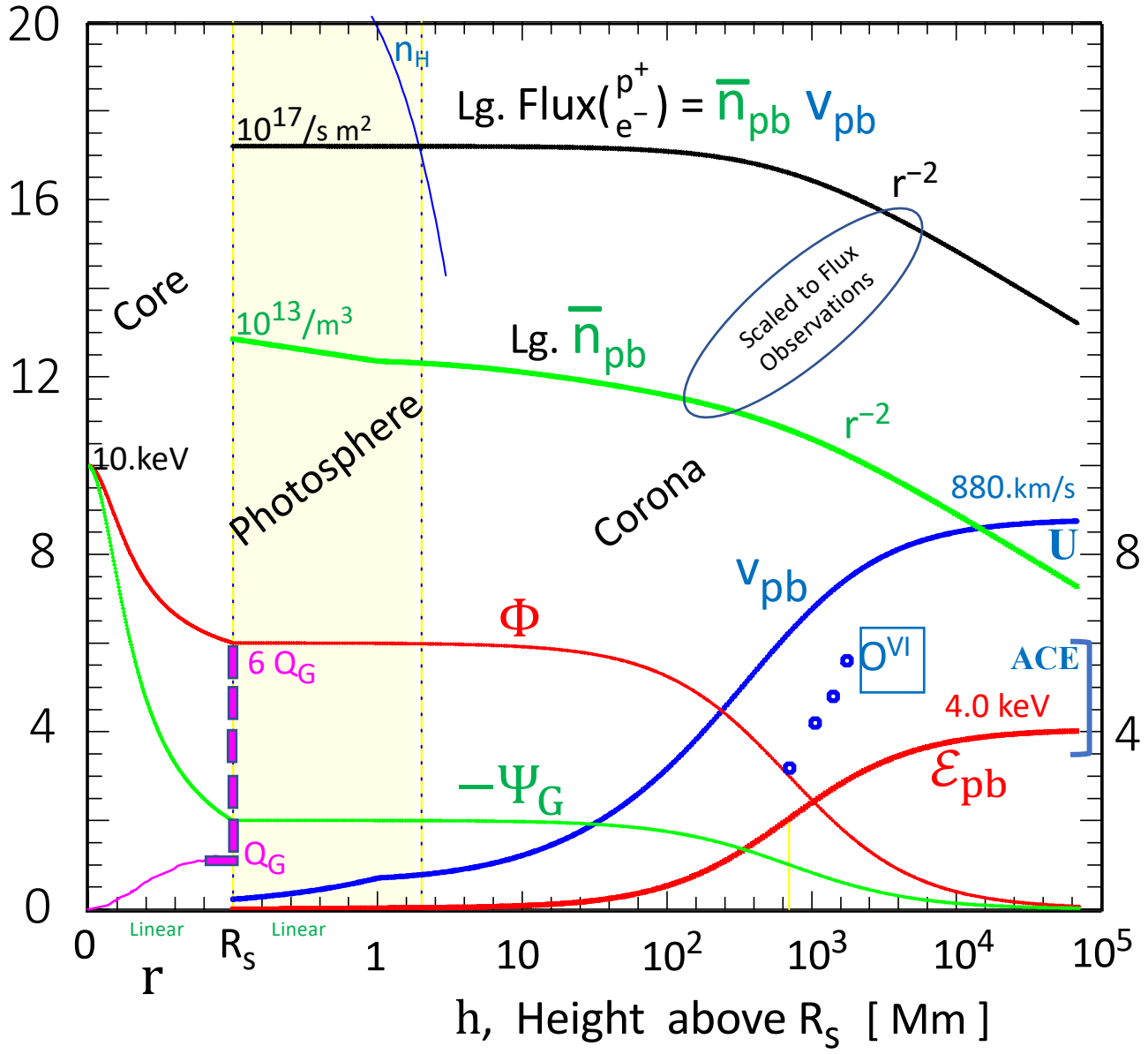
Theoreticaly, the photo-electric field is given by $eE = \Gamma\, \sigma_{e\gamma} / c$, but the cross-sction $\sigma_{e\gamma}$ can range over 1 -> 10^8 times the Thompson cross-section σ_0 .

The charge build-up is limited to $6*Q_G$ by the "Virial" energy relation $\Phi(0) = -\Psi_G(0)$, and this determines the electric energy $\Delta\mathcal{E}_{pw} = 4.\text{keV}$ available to accelerate surface protons.

This 4.keV is the "hard limit" observed by Ulysses .

Proton beam Flux, average density n_{pb}, velocity v_{pb} and energy $\mathcal{E}_{pb}$ versus radius , from "virial" maximum charge $6*Q_G$, giving $\Phi(0) = -\Psi_G(0)$.



The Ulysses-measured maximum proton velocities approach 880.km/s, from an energy of 4.0 keV

The ACE-measured proton velocities in the ecliptic plane range broadly, centered around 350 -500 km/s .

The blue dots are the radial H0 velocities from the self-consistent empirical model A2 of Cranmer 1999.

Ohm's Balance : Protons Electrons

a) Current in Wires

E_{ext} $< E_{coll} > = - \rho J_e$

b) Collis Core Pannekoek Q~+77.C

g 2.8 T′ E_g 1.4

E_G T′

Gravit Thermo

o

c) Sheath, Photo, H Q~+460.C

H Drag g E_G+E_γ 8.6

E_G+E $\frac{\Gamma_{\varepsilon\gamma}}{c}\sigma_{\gamma e}$

γ

Photo

d) Proton Jets Fast /Slow Wind

Ecliptic Drag ? g J_{p+} E_G+E_γ

E_G+E $\frac{\Gamma_{\varepsilon\gamma}}{c}\sigma_{\gamma e}$

γ J_{e-} r^{-2}

Zero net Current

Photo – Electric Beam Acceleration

(1) Solar Sheath

$n_e \sim 10^{24}$ /m^3

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

Photon Flux

hν ~ 1.eV

$\mathcal{E}_{pb} \sim 10^{3.6}$ eV

E

$\mathcal{E}_{pb} \sim 10^{8}$ eV

(2) Target Normal Sheath Accel

$n_e \sim 10^{30}$ /m^3

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