The Electric Field of the Sun and Solar Wind

C. Fred Driscoll, UCSD Physics

Q : How can a Solar Photon Flux of $\Gamma_{\varepsilon\gamma} \sim 60.\,\mathrm{MW/m^2}$
possibly create a Solar Wind with $\Gamma_{KE} \sim 60.\,\mathrm{W/m^2}$?

A : With Electric Fields (at surface)

Gravi-Thermo-Electric $eE_G \sim +1.4\,\mathrm{eV/Mm}$ <- - - Eddington, Rosseland (1924)
and Photo-Electric $eE_\gamma \sim +4.6\,\mathrm{eV/Mm}$ from average $\sigma_{\gamma e} \sim 3\mathrm{x}10^{-24}\ \mathrm{m^2}$
thereby dominating gravity $m_p g \sim -2.8\,\mathrm{eV/Mm}$ modeled here
and "levitating" Protons to keV energies.

Note : Photon-electron cross-section $\sigma_{\gamma e}$ varies broadly;
collisions heat the plasma, maintaining a "self-consistent drive";
additional theory is needed.
: "Runaway" protons escape H0 background, requiring a kinetic analysis.
: The un-neutralized charge Q is *exceedingly* small (~ 10^{-36}),
making a true Poisson solution difficult.
: The "global spherical" model identifies the energetics; but structures on
the mega-meter scale are probably dominant.

But : ~~MHD~~ These processes are precluded by the assumptions of MHD.

Stellar Hydro Eqns: mass $m_p\ m_e$ charge $e^-\ p^+$ photons γ

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

2 $\nabla \bullet \Gamma_{\varepsilon\gamma}(r) = \frac{d}{dt}\varepsilon(r)$ Energy Generation

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

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

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

4a+b $[(n_e + n_p)T]' - \frac{\Gamma_{\varepsilon\gamma}}{c\, l_\gamma} + n_p m_p \Psi' = 0$ Hydro Force

$l_\gamma \equiv 1 / n_e \sigma_{\gamma e}$

Photon Drive of Solar Wind : γ ⇝ { p+, e-, H*, $H^{(-)}$ }

$$\Gamma_{\varepsilon\gamma} \sim 60.\,\mathrm{MW/m^2}\ \rho^{-2}$$

Hydro Equil :

$$\frac{\Gamma_{\varepsilon\gamma}}{2c}\sigma_{\gamma e} + \frac{m_p}{2}\Psi' + e\Phi' = 0$$

Gravito-Thermo-Electric

Photo-Electric

$$\sigma(H^*) \sim \pi a_0^2 = 0.6\,\mathrm{x}10^{-20}\,\mathrm{m^2}$$

$$\sigma(H^- bf) \sim 0.5\,\mathrm{x}10^{-20}\,\mathrm{m^2}$$

$$\sigma(H^{(-)} ff) \sim 0.5\,\mathrm{x}10^{-20}\,\mathrm{m^2}$$

$$\sigma_{\gamma e} \sim 3.4\,\mathrm{x}10^{-24} = \text{Modeled here}$$

$$\sigma_T = 0.7\,\mathrm{x}10^{-28}\,\mathrm{m^2}$$

Runaway p+ :

$$\frac{d}{dr}\mathcal{E}_p = -m_p\Psi' - e\Phi'$$

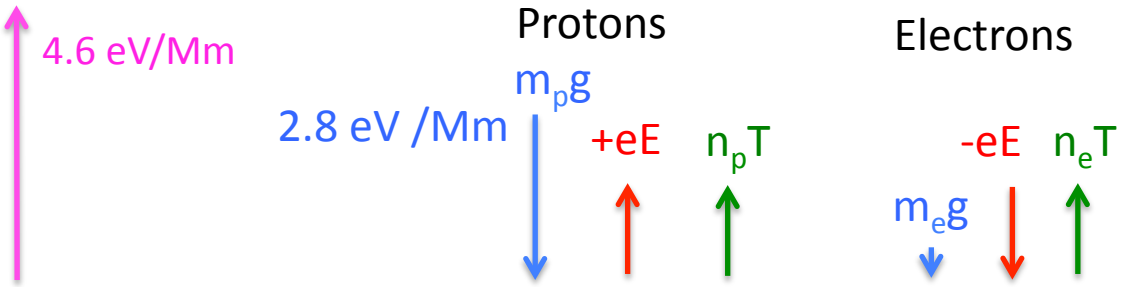
$$\mathcal{E}_{p+}(\rho) \sim \mathcal{E}_0 + (1.3\mathrm{keV})\left[1 - 1/\rho\right]/R_s$$

$$v_p(\rho) \sim (500.\mathrm{km/s})\left[1 - 1/\rho\right]$$

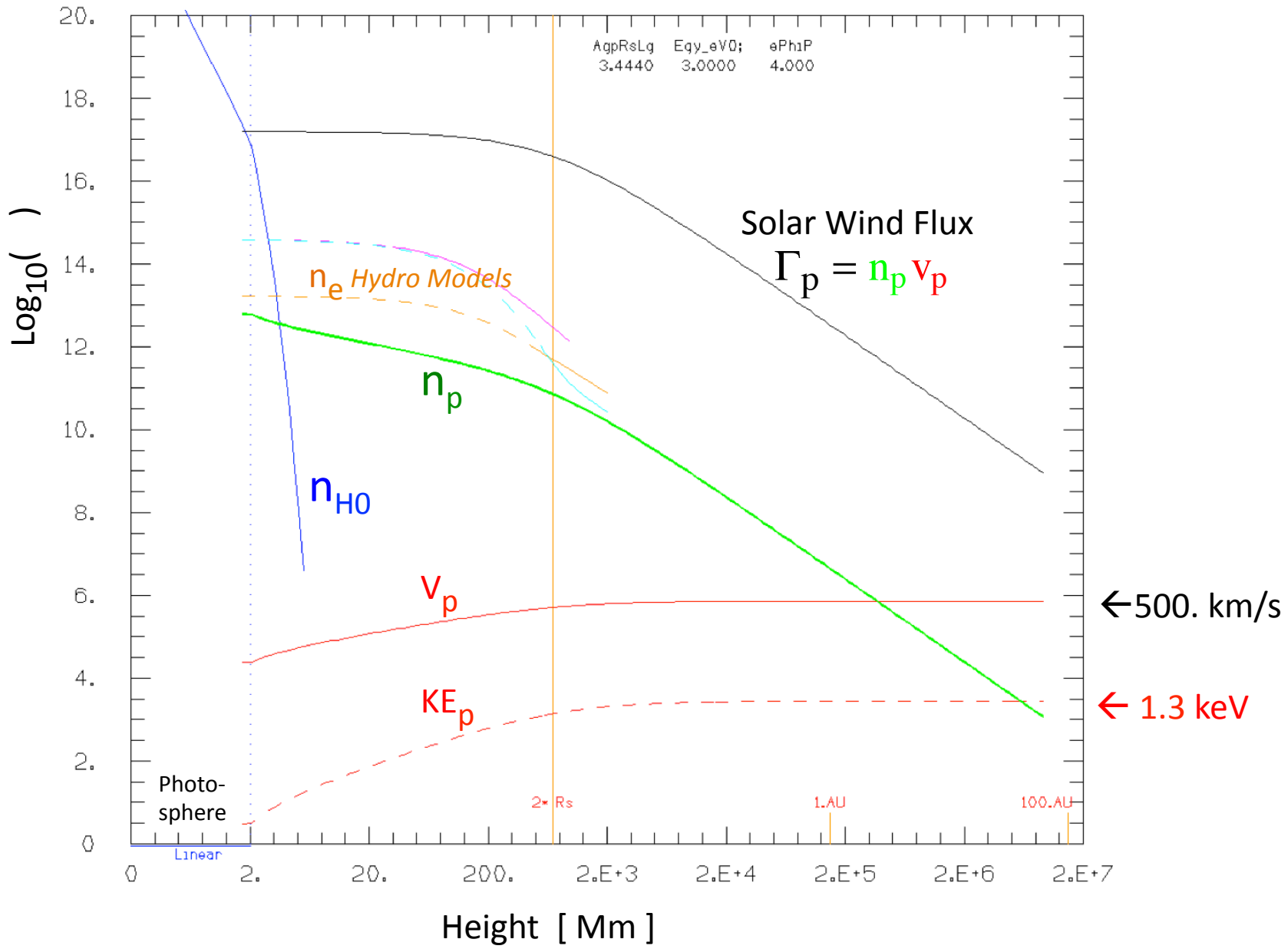
$$n_p(\rho) \sim 3\mathrm{x}10^{11}\ \rho^{-2}\ \mathrm{m^{-3}}$$

$$\Gamma_p(\rho) \sim 1.6\mathrm{x}10^{17}\ \rho^{-2}\ \mathrm{s^{-1}m^{-2}}$$

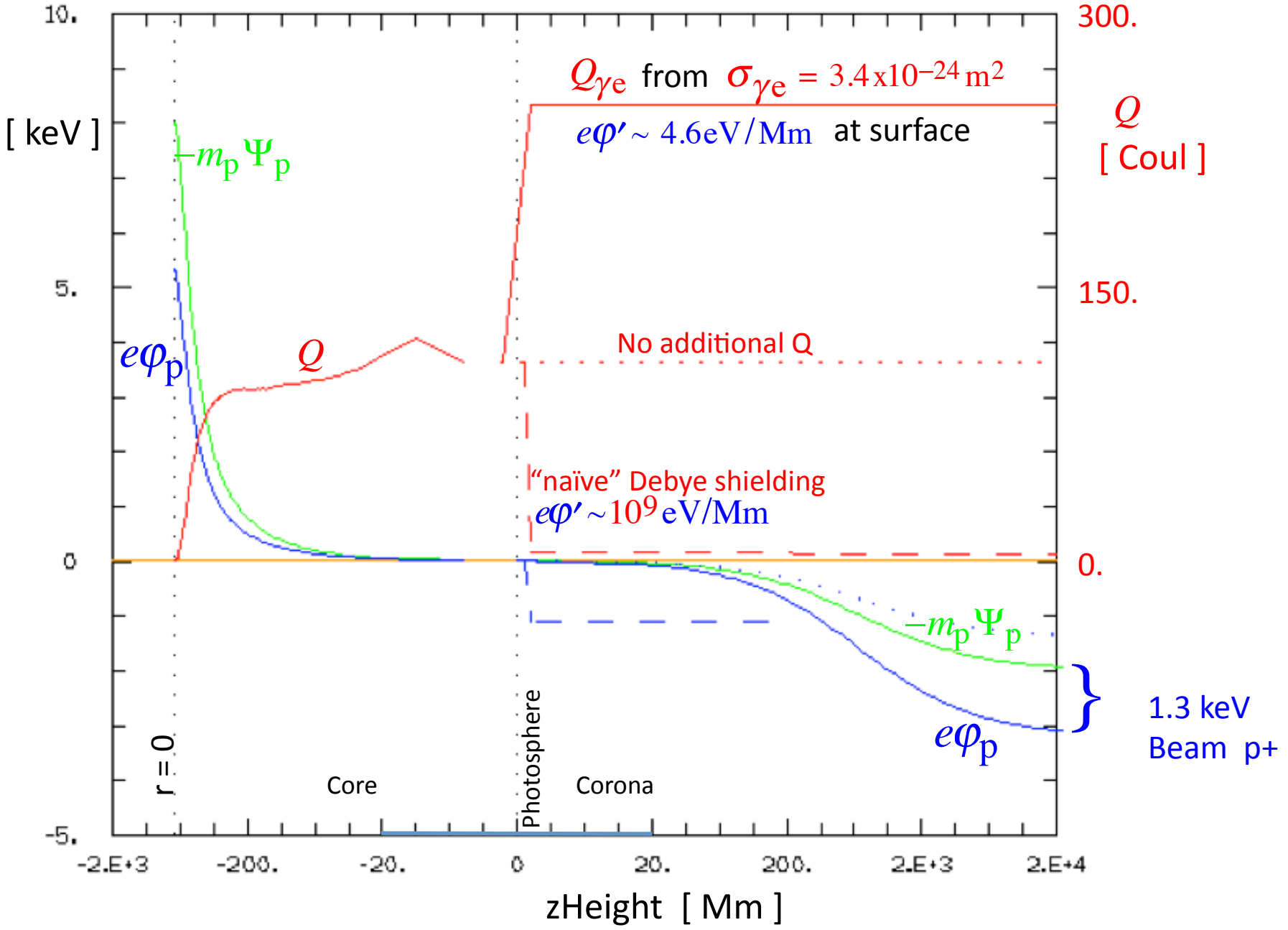
$$\Gamma_{KE}(p^+) \sim 60.\ \mathrm{W/m^2}\ \rho^{-2}$$



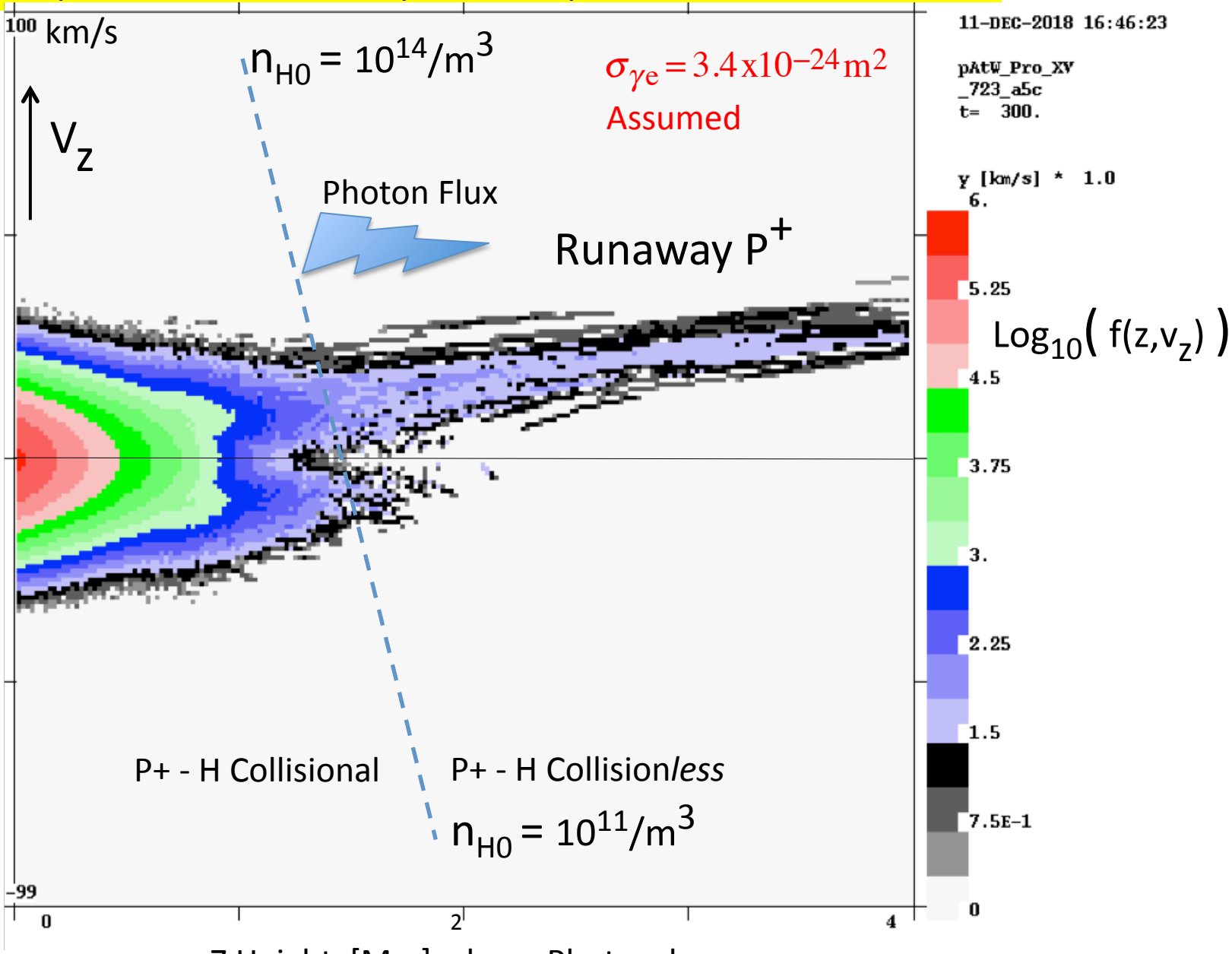
Photon-Driven Solar Wind p+ Flux, Density, Velocity, Energy
assuming average $\sigma_{\gamma e} = 3.4 \times 10^{-24}\ m^2$



Q, φ, Ψ from (a) Photon-driven charge separation, giving 1.3keV Solar Wind;
(b) No additional charge; (c) "naïve" Debye shielding, giving 10^9 eV/Mm



"1-d PIC Sim" : Collisional e-p+ Source, Photon Force, H^0 Drag, e- p+ Kinetics, Poisson Eqn => e- p+ Beam



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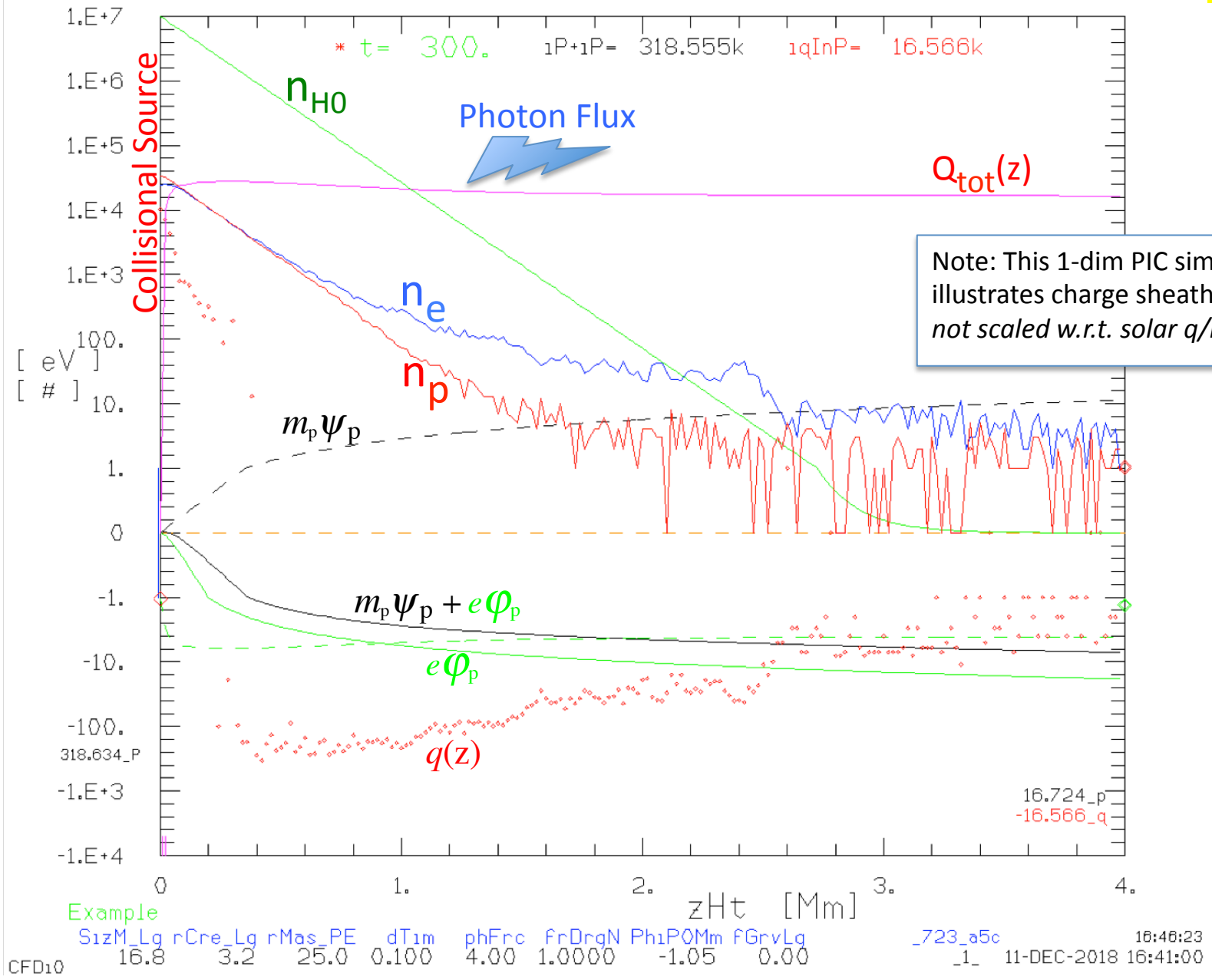
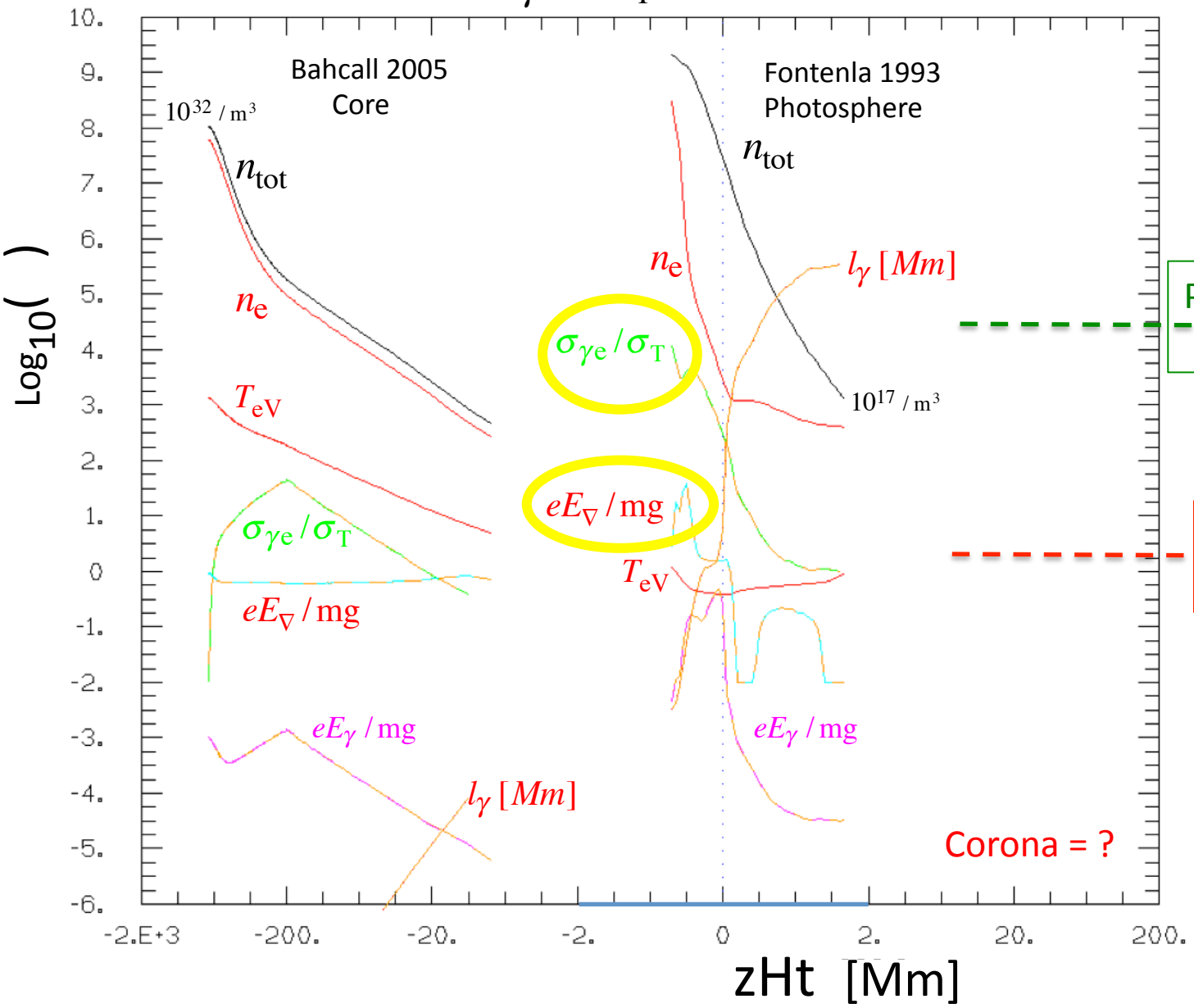


Note: This 1-dim PIC simulation illustrates charge sheath formation; but is *not scaled w.r.t. solar q/m or density.*

Standard Hydro Models *Ignore* Q,φ,E in Core & Photosphere;
but exhibit regions of $\sigma_{\gamma e} >> \sigma_T$ and photon-driven proton "levitation"



Photon Drive Model
$\sigma_{\gamma e}/\sigma_T$ ~ $10^{4.5}$

Protons Levitated
if eE_∇ / mg > 1

Traditional Hydro Corona Models (no Wind)

Cranmer / Kohl 1999
Strachan / Kohl 1993
Badalyn /Livshitz 1985
Van de Hulst 1950

Models K-Corona polarized Brightness pB
coming from Photons scattering off *free, isolated* electrons .

Assumes $\sigma_{\gamma e} = \sigma_T = 0.6 \times 10^{-28}\ m^2$

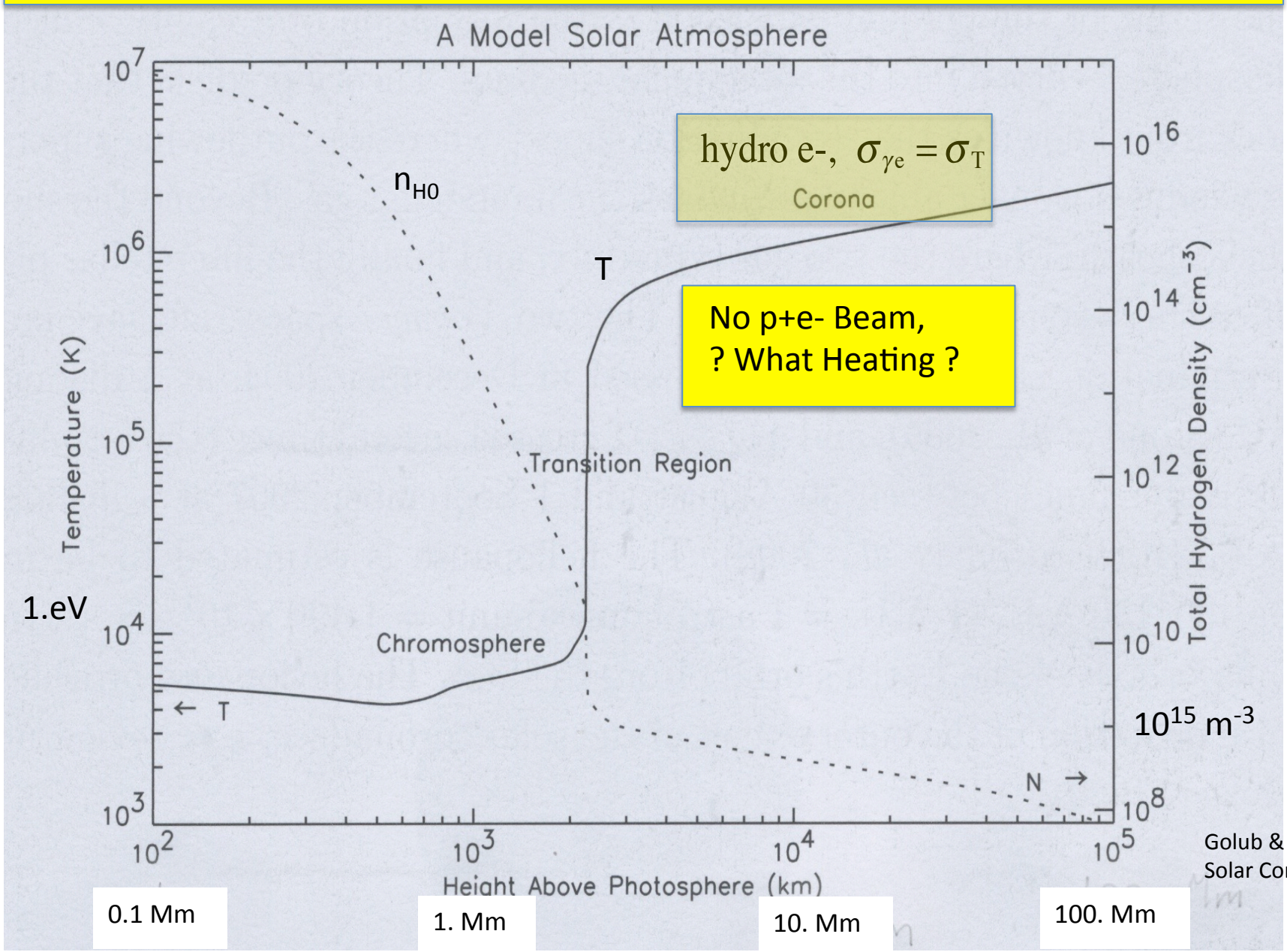
Measured light scattering pB ,
de-convoluted along the line-of-sight

gives $n_e(\rho) = n_p(\rho) = 10^{11.9}\rho^{-2.57} + 10^{14.6}\rho^{-10.5}\ [m^{-3}]$

Assuming Hydrostatic Equilibrium : $[(n_e + n_p)T]' + \Psi' = 0$

determines the required $T \sim 120.eV$

MHD Models : Coronal Heating and Solar Wind Energetics remain elusive



Golub & Pasachoff, Solar Corona

Abstract #361117

The Electric Fields of the Sun and Solar Wind

Charles Fred Driscoll, University of California San Diego, La Jolla, CA, United States

Abstract Text:

A simple model of solar electric fields explains the (quiet sun) solar wind energetics and coronal heating, invoking only gravitational settling and photon scattering. In the (collisional) solar interior, gravity necessarily generates a radial electric field eE~ -½ m_p g ; protons are 50% levitated, with eE(R_s)~ 1.4eV/Mm from displaced charge Q(R_s)~ -75.Coul. In the (weakly collisional) outer photosphere/corona, electron scattering of the photon flux Γ_E gives eE = (Γ_E/c) σ_{ye}. An (averge) eE~ (4.eV/Mm)(r/R_s)$^{-2}$ from photon-electron cross-section σ_{ye} ~ 3x10^{-24}m^2 will generate the observed solar wind: protons are accelerated out of the 2.keV gravity well and up to 1.3keV kinetic energy within several R_s, with total particle energy flux ~10^{-6} Γ_E. Here, the proton acceleration kinetics is that of plasma "runaways," where the faster particles are less collisional and thereby gain more energy, generating "kappa-distributions." Similar beam generation in plasma sheaths is endemic to laboratory plasmas. The cross-section σ_{ye} (per free electron) for the correlated $e^-/p^+/H^0/H^-$ beam-plasma is difficult to predict theoretically; but the requistite σ_{ye} is less than 10$^{-3}\sigma(H^-)$.

With this photon cross-section, the coherent proton/electron "flow-sheath" *is* the glowing K-Corona, obviating the T~100eV hydrostatic model (Van deHulst, 1950). Filamentation (~1.Mm)^2 of the flow will arise from the convection and recombination ("roiling") dynamics of surface granulations, with local electric fields generating strong currents and local magnetic fields. Statistical charge fluctuations, current filamentation, and neutral gas drag on the distant proton /electron flows will produce the pervasive *fluctuating* magnetic fields observed by spacecraft. This kinetic-electric model obviates the MHD chimeras[1] of "frozen-in" but rotating dipolized magnetic monopole spirals, and non-energy-conserving "constant temperature" flow generation (Parker 1958).

1. http://TheMhdMuddle.ucsd.edu

Plain-Language Summary:
The Sun emits copious energy in the form of light; and it also emits about one millionth as much energy in a persistent "solar wind" stream of electrons and protons. The physical mechanism by which the solar wind is generated (and the solar corona is heated) has been a long-standing mystery. Here, it is shown that the protons are accelerated by weak electric fields, which arise naturally due to outward "thermo-electric" forces on the electrons. Essentially, the wind consists of "runaway" particles, emerging out of the collisional fluid of the solar surface into the nearly collisonless corona plasma.

Prior analysis has focused on magnetic fields, which are readily observed from afar, but which are inherently dissipative. In contrast, electric fields are harder to detect and harder to quantify theoretically; but even the weak field of three flashlight batteries every thousand kilometers is sufficient to launch solar protons outward. Similar electric fields in solar surface granulations will produce large currents and localized magnetic fields; and charge fluctuations in the solar wind will produce the fluctuating magnetic fields detected by many satellites. Here, substantial theory challenges remain, to quantify the statistics of fluctuating plasmas, currents, and fields.

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cfd_agu@sdphl0.ucsd.edu

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First Presenting Author

Presenting Author

Charles Fred Driscoll

Primary Email: cfd_agu@sdphl0.ucsd.edu

Affiliation(s):

University of California San Diego
La Jolla CA 92093 (United States)