The Kinetic Evolution of the Electron Strahl in the Inner Heliosphere

Seong-Yeop Jeong[1], Daniel Verscharen[1,2], Christian Vocks[3], Joel B. Abraham[1], Christopher J. Owen[1], Robert T. Wicks[4], Andrew N. Fazakerley[1], David Stansby[1], Laura bercic[1], Georgios Nicolaou[5], Jeffersson A. Agudelo Rueda[1] and Mayur Bakrania[1]

[1]Mullard Space Science Laboratory, University College London, Dorking, RH5 6NT, UK; s.jeong.17@ucl.ac.uk
[2]Space Science Center, University of New Hampshire, Durham, NH 03824, USA
[3]Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, D-14482 Potsdam, Germany
[4]Northumbria University, Newcastle, UK
[5]Southwest Research Institute, San Antonio, TX 78238, USA

1. Kinetic Transport Equation

$$\frac{\partial f}{\partial t}+[U+\cos\theta v_\parallel]\frac{\partial f}{\partial r}-[U+\cos\theta v_\parallel]\left\{\frac{1}{\cos\theta}\frac{\partial U}{\partial r}+\frac{\partial \ln\cos\theta}{\partial r}v_\parallel\right\}\frac{\partial f}{\partial v_\parallel}+\cos\theta\frac{q}{m}E\frac{\partial f}{\partial v_\parallel}$$
$$+\frac{v_\perp}{2}\frac{\partial \ln B_z}{\partial r}\left\{[U+\cos\theta v_\parallel]\frac{\partial f}{\partial v_\perp}-\cos\theta v_\perp\frac{\partial f}{\partial v_\parallel}\right\}=\left(\frac{\partial f}{\partial t}\right)_{exp}+\left(\frac{\partial f}{\partial t}\right)_{col}$$

Where

$$\left(\frac{\partial f}{\partial t}\right)_{exp}=-[U+\cos\theta v_\parallel]\frac{\partial}{\partial r}\left[\ln\left(\frac{B_z}{\cos\theta}r^2\right)\right]f \quad and \quad \cos\theta=\frac{B_r}{\sqrt{B_r^2+B_\phi^2}}$$

❖ ***Fokker-Planck Operator***

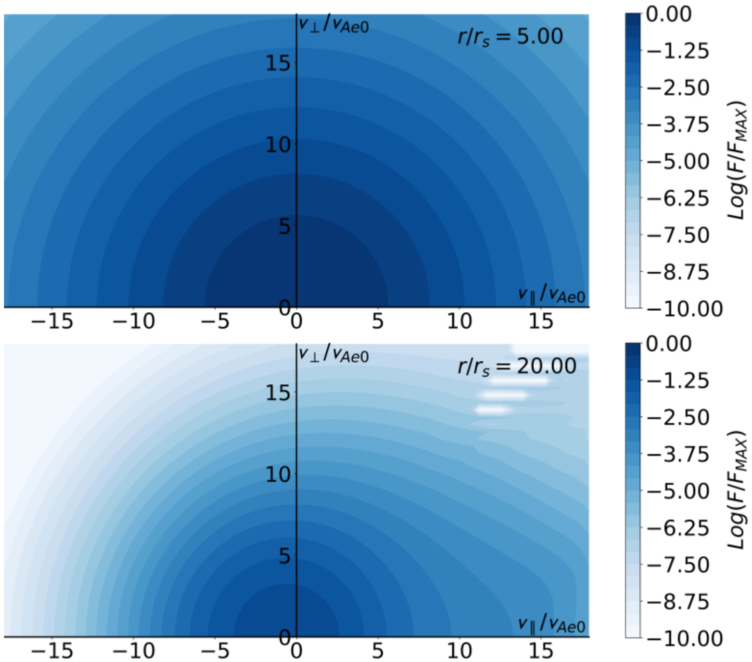
$$\left(\frac{\partial f}{\partial t}\right)_{col}=\sum_b \Gamma_b\left\{4\pi\frac{m}{m_b}f_b f+\frac{\partial H}{\partial v_\perp}\frac{\partial f}{\partial v_\perp}+\frac{\partial H}{\partial v_\parallel}\frac{\partial f}{\partial v_\parallel}+\frac{1}{2}\left(\frac{\partial^2 G}{\partial v_\perp^2}\frac{\partial^2 f}{\partial v_\perp^2}+\frac{\partial^2 G}{\partial v_\parallel^2}\frac{\partial^2 f}{\partial v_\parallel^2}+2\frac{\partial^2 G}{\partial v_\perp\partial v_\parallel}\frac{\partial^2 f}{\partial v_\perp\partial v_\parallel}+\frac{1}{v_\perp^2}\frac{\partial G}{\partial v_\perp}\frac{\partial f}{\partial v_\perp}\right)\right\}$$

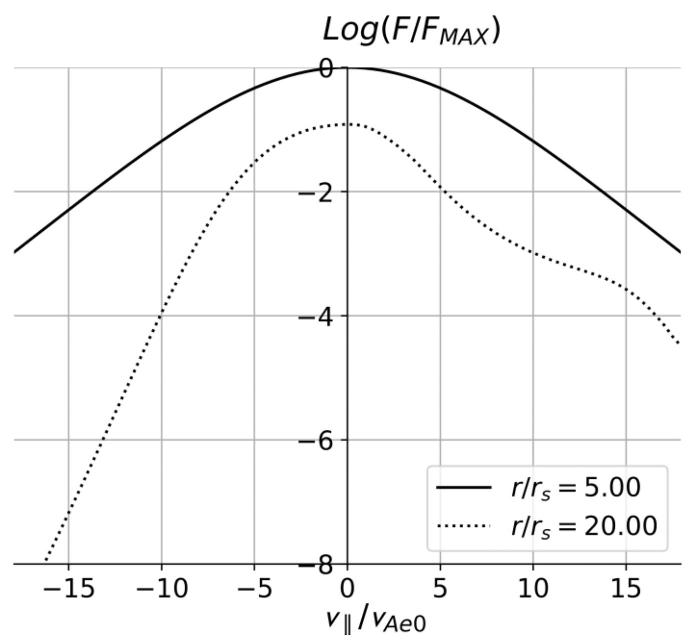
Where

$$G(\mathrm{v})\equiv\int f_b(v')|\mathrm{v}-v'|\,d^3v', \qquad H(v)\equiv\frac{m_b-m}{m_b}\int f_b(v')\,|v-v'|^{-1}d^3v' \quad and \quad \Gamma_b=4\pi\left(\frac{ZZ_bq^2}{m}\right)^2\ln\Lambda_b$$

(Ljepojevic et al. 1990; Rosenbluth et al. 1957)

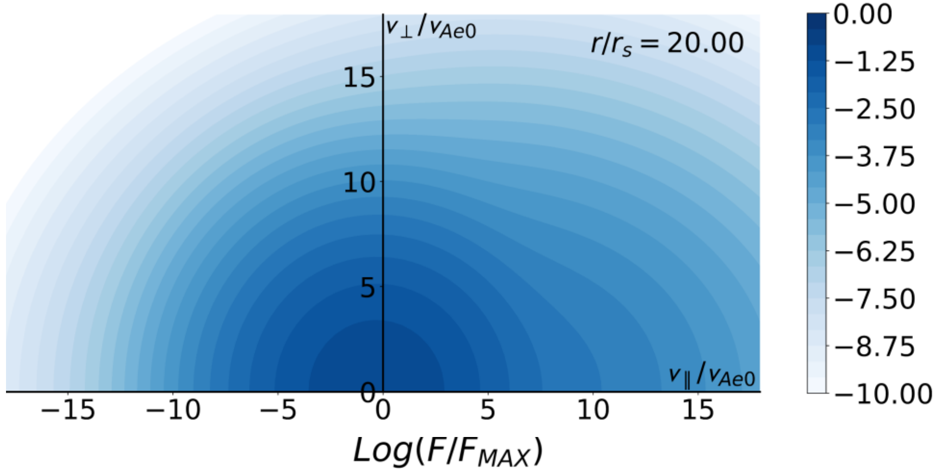
2. Numerical Results for the Kinetic Evolution of an Electron VDF

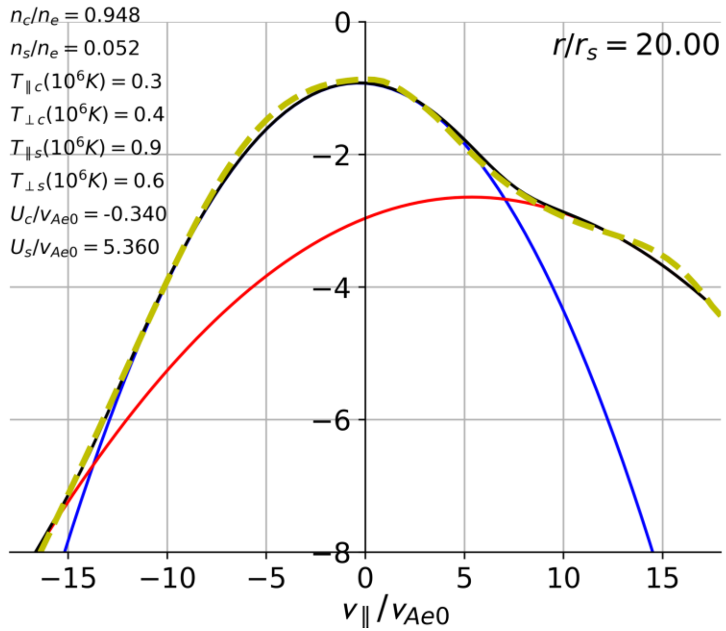


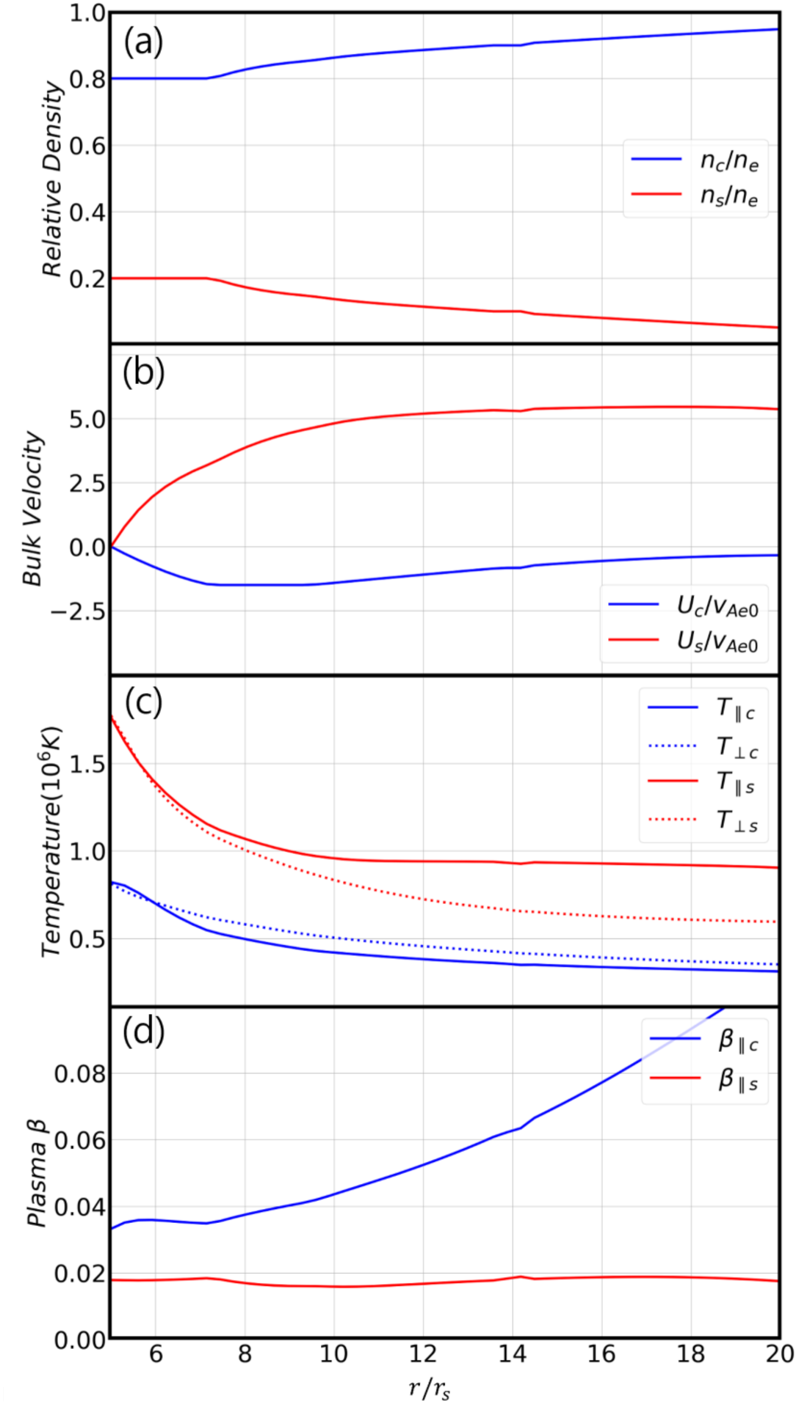


We solve the kinetic transport equation, given in Section 1. In this section, our numerical solution shows the radial evolution of an electron VDF through the spherical expansion of the solar wind from 5 solar radii to 20 solar radii.

3. Fitting

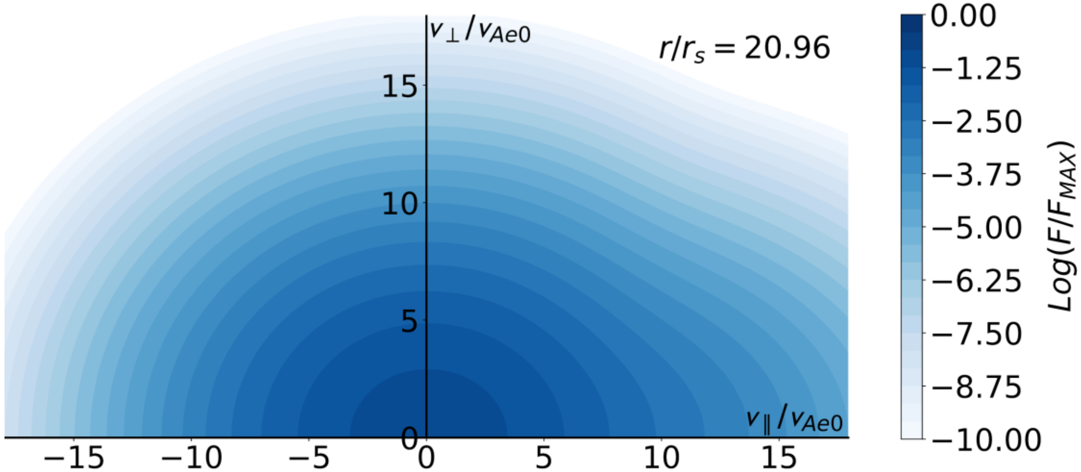


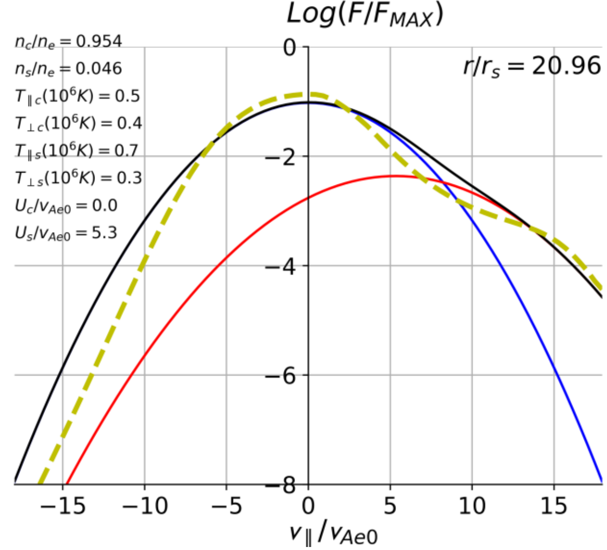




We apply the fitting scheme to our numerical solution. We fit our electron VDF with the Maxwellian core and strahl. The above figures show the fitted electron VDF at 20 solar radii. The four plots at the right side show the fitted parameters of electron core and strahl.

4. Comparison with PSP measurements

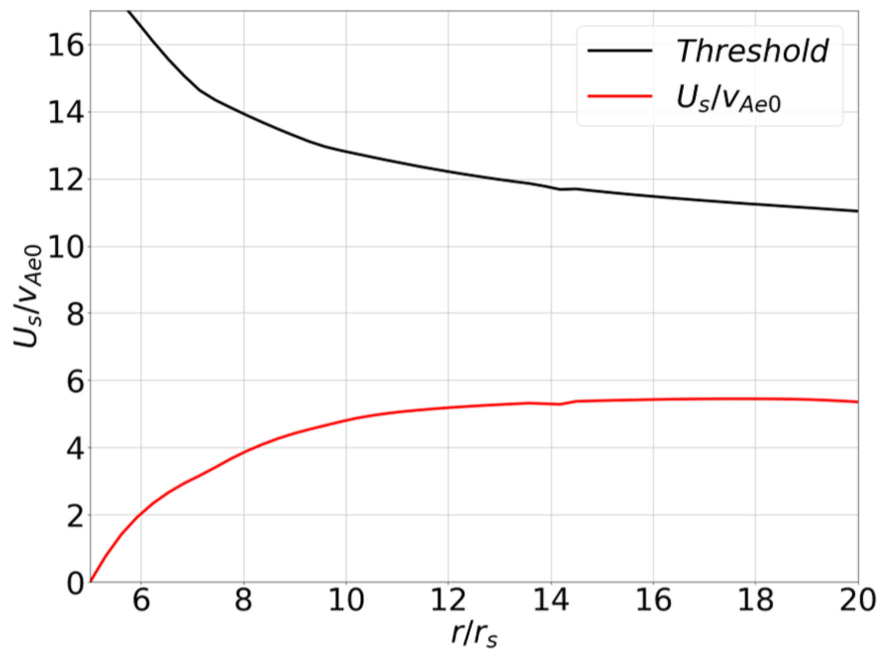




We compare the fitted parameters from numerical solutions with the fitted parameters from the electron VDF measured by PSP. The above figures show the fitted electron VDF (black line) measured by PSP at 20.96 solar radii on 27/09/2020 at 20:24:18 during encounter 6.

5. Oblique Fast-Magnetosonic/Whistler (FM/W) Instability

We investigate the scattering of electron strahl through the oblique FM/W instability by using the fitted parameters from our numerical solution. The above figure shows the comparison of the strahl bulk velocity (red line) with the threshold for the oblique FM/W instability (black line). In our interesting region, the electron strahl is not scattered because the strahl bulk velocity is lower than the threshold.



- Threshold for the strahl scattering

$$U_s \gtrsim 3 v_{\parallel th,c}$$

where

$$v_{\parallel th,c} = \sqrt{\frac{2 k_B T_{\parallel c}}{m_e}}$$