Kinetic theory and simulation of electron-strahl scattering in the solar wind

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We investigate the scattering of strahl electrons by microinstabilities as a mechanism for creating the electron halo in the solar wind. We develop a mathematical framework for the description of electron-driven microinstabilities and discuss the associated physical mechanisms. We find that an instability of the oblique fast-magnetosonic/whistler (FM/W) mode is the best candidate for a microinstability that scatters strahl electrons into the halo. We derive approximate analytic expressions for the FM/W instability threshold in two different $\beta_c$ regimes, where $\beta_c$ is the ratio of the core electrons' thermal pressure to the magnetic pressure, and confirm the accuracy of these thresholds through comparison with numerical solutions to the hot-plasma dispersion relation. We find that the strahl-driven oblique FM/W instability creates copious FM/W waves under low-$\beta_c$ conditions when $U_{0s}>3w_c$, where $U_{0s}$ is the strahl speed and $w_c$ is the thermal speed of the core electrons. These waves have a frequency of about half the local electron gyrofrequency. We also derive an analytic expression for the oblique FM/W instability for $\beta_c\sim1$. The comparison of our theoretical results with data from the Wind spacecraft confirms the relevance of the oblique FM/W instability for the solar wind. In addition, we find a good agreement between our theoretical results and numerical solutions to the quasilinear diffusion equation. We make predictions for the electron strahl close to the Sun, which will be tested by measurements from Parker Solar Probe and Solar Orbiter.