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[reply to comment on heating of the solar corona by dissipative Alfvén solitons]

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Stasiewicz and Ekeberg Reply: In the preceding Comment [1] on the Letter on heating of the solar corona by alfvénons (dissipative Alfvén solitons), Infeld points out that regions of exponentially varying solutions depicted in Fig. 2 of [2] may not necessarily correspond to soliton solutions. As an example he presents an integrable equation, where it is possible to determine exactly the region of solitons, which is smaller than the region of exponentially varying solutions.

Differential equations (2)–(4) of [2] are more convoluted and do not permit unambiguous determination of the conditions for exact solitonic solutions with an analytical method. In effect, one has to use numerical integration to verify that exponential solutions, which occur in regions where the right-hand side of the dispersion equation

$$(k\lambda_i)^2 = \frac{M^2 - \cos^2\alpha}{M^2\cos^2\alpha} \left(M^2 - \cos^2\alpha - \frac{M^2\sin^2\alpha}{M^2 - \gamma\beta/2} \right) \quad (1)$$

is negative, would fold down and form solitons. Here, $\lambda_i = c/\omega_{pi}$ is the ion inertial length, $M = \omega/kV_A$ is the wave Alfvén Mach number, β is the plasma beta, γ is the polytropic pressure exponent, and α is the propagation angle to the magnetic field.

Figure 1 shows full width at half maximum of solitons, perpendicular to the magnetic field, obtained with numerical integration. White areas correspond to linear modes that include fast/slow magnetosonic ($M+/M-$), acoustic ($S+/S-$), Alfvén ($A+$), and kinetic Alfvén waves ($A-$). It is seen that solitons are found in the whole area of exponential solutions, which differs slightly from that in Fig. 2 of [2], because the previously published picture contains also electron inertia effects not included in the present computations. Equations containing electron inertia were derived in a more general model [3] and should be used for solitons at perpendicular propagation angles, or fast speeds ($M > 1$). The edges of the colored areas represent general transonic boundaries between linear (sinus-like) and nonlinear (solitonic) solutions that include fast and slow alfvénons. The dividing line is the sound speed located at $M_s = (\gamma\beta/2)^{1/2}$. In inhomogeneous media, such as the solar corona or the magnetosphere, obliquely propagating linear waves driven by perpendicular ion flows could cross transonic boundaries and tunnel to regions of solitons. MHD-scale solitons were detected by Cluster satellites in various regions of the magnetosphere and quantitatively modeled either by two fluid, or Hall-MHD equations [3–6].

Typically, the perpendicular size of alfvénons is a few ion inertial lengths, or below unity in blue regions of Fig. 1. The unit length is $\lambda_i \approx 7\text{--}70$ km for a magnetospheric plasma at number density $N \sim 10\text{--}10^3\text{cm}^{-3}$, and only 20 m in the solar corona at number density $N \sim 10^8\text{cm}^{-3}$ (it scales as $\lambda_i \propto N^{-1/2}$). Auroral acceleration structures with perpendicular sizes of 1–100 km can be associated with alfvénons that dissipate by creating localized parallel and perpendicular electric fields. Cor-

FIG. 1 (color online). Perpendicular size of solitons in units of the ion inertial length λ_i for a collisionless plasma at $\beta = 0.01$ and $\gamma = 1.6$. White areas correspond to linear waves.

responding acceleration structures in the solar corona, scaled with λ_i , would have perpendicular widths of some hundreds meters, which is less than the spatial resolution of optical instruments used for solar research. Hence, the alfvénon heating of coronal plasma is expected to produce structures and optical emissions distributed as (multiple) sheaths or curtains along magnetic field lines, with transverse dimension of one instrumental pixel only. At some viewing angles this would give an impression that magnetic field lines tied to hot plasma do not diverge with increasing altitude in the solar corona. Such properties can be seen in images provided by TRACE satellite [7], which supports the hypothesis that heating of the coronal plasma is accomplished by alfvénons [2,8].

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