A&A 503, 589–590 (2009)
DOI: 10.1051/0004-6361/20079221e

Astronomy & Astrophysics

Erratum

Drift instabilities in the solar corona within the multi-fluid description

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A&A 481, 853-860 (2008), DOI: 10.1051/0004-6361:20079221

The purpose of this *erratum* is to point out and to correct some unfortunate typographical mistakes, as well as algebraic errors contained in our paper "Drift instabilities in the solar corona within the multi-fluid description" published in A&A 481, 853 (2008). We also want to clarify some important issues with respect to the assumed background state on which the drift-wave instability develops.

The first point is that the nonuniformity of the background density in the corona model considered should be expressed more precisely as

$$n_{0j}(x) = \overline{n}_j\left(1 + \frac{(x - x_0)}{L}\right), \tag{1}$$

whereby the density increases linearly in the coordinate x with respect to some arbitrary reference location x_0, at which the density is assumed to have the constant value $\overline{n}_j$ and not n_{0j}, which is the previous notation that led to some confusion in the subsequent perturbation expansion about the nonuniform equilibrium background state. Therefore, the density as given by Eq. (3) in the original paper should be understood as describing (like in (1)) its dependence on x, starting from position x_0. Because of the above mistake, there is a factor $(1 + (x - x_0)/L)^{-1}$ missing and also a typographical sign error (it should read + rather than −) in the expression for the drift velocity (9) in Mecheri & Marsch (2008). However, the right sign has been used throughout their numerical calculations.

Also, the expression of the drift velocity should not contain the factor $1/\gamma_j$ since we assumed an ideal gas law $p_{0j} = n_{0j}k_BT_{0j} = \rho_{0j}k_BT_{0j}/m_j$ with ρ_{0j} the mass density. Consequently, the acoustic speed C_{sj} is given by $C_{sj}^2 = \partial p_{0j}/\partial\rho_{0j} = k_BT_{0j}/m_j$, and not $\gamma_jk_BT_{0j}/m_j$ as quoted in the original paper. Thus the correct expression of the drift velocity is

$$\boldsymbol{v}_{\rm Dj} = \frac{1}{L}\frac{C_{sj}^2}{\Omega_j}\frac{B_0}{B_{0z}(1 + (x - x_0)/L)}\hat{\boldsymbol{y}}. \tag{2}$$

The second major issue is related to the properties of the assumed background plasma state in the paper by Mecheri & Marsch (2008). If the background electric field $\boldsymbol{E}_0$ is considered to be zero, the equilibrium momentum equation is given by

$$\nabla p_{0j} - q_jn_{0j}(\boldsymbol{v}_{\rm Dj} \times \boldsymbol{B}_0) = 0 \Rightarrow \begin{cases} \boldsymbol{B}_0 \cdot \nabla p_{0j} = 0 \\ \text{and} \\ \boldsymbol{v}_{\rm Dj} = \frac{\boldsymbol{B}_0\times\nabla p_{0j}}{B_0^2 q_j n_{0j}} \end{cases}. \tag{3}$$

Thus in equilibrium the background pressure (and density) gradient must be across $\boldsymbol{B}_0(x, z)$, which has components in both the x- and z-directions. In our original paper, only a pressure gradient in the x-direction was considered. However, consideration of an additional gradient in the z-direction does not change the main equations, (10) to (12), of the paper by Mecheri & Marsch (2008). Moreover, the above system of equations gives

$$\boldsymbol{B}_0 \cdot \nabla p_{0j} = B_{0x}\frac{\partial p_{0j}}{\partial x} + B_{0z}\frac{\partial p_{0j}}{\partial z} \Rightarrow \frac{\partial p_{0j}}{\partial z} = -\frac{B_{0x}}{B_{0z}}\frac{\partial p_{0j}}{\partial x},$$

and then from (3) we have

$$\boldsymbol{v}_{\rm Dj} = \frac{\hat{\boldsymbol{y}}}{B_0^2 q_j n_{0j}}\left(-B_{0x}\frac{\partial p_{0j}}{\partial z} + B_{0z}\frac{\partial p_{0j}}{\partial x}\right) = \frac{\hat{\boldsymbol{y}}}{B_{0z}q_jn_{0j}}\frac{\partial p_{0j}}{\partial x}.$$

Thus, the insertion of the expression for $\partial p_{0j}/\partial z$ into the last equation above leads exactly to the expression of the drift velocity $\boldsymbol{v}_{\rm Dj}$ given in our present Eq. (2).

However, because of the equilibrium diamagnetic current density in the y-direction, $\boldsymbol{j}_0 = \sum_j n_{0j}q_j\boldsymbol{v}_{\rm Dj}$, the background magnetic field must also be perturbed according to Ampère's law. This subtle issue has not been investigated and discussed in the original paper, in which it was assumed (but not mentioned explicitly) that the field perturbation should be negligible due to the low beta of the coronal plasma, where the magnetic pressure dominates the gas pressure. To clarify this point, we now investigate the corresponding equation. For simplicity, we consider that the background plasma has a magnetic field $\boldsymbol{B}_0$ with only one component in the z-direction and a density and pressure gradient in the x-direction. Thus for the curl of $\boldsymbol{B}_0$, Ampère's law gives

$$\nabla \times \boldsymbol{B}_0 = -\frac{{\rm d}B_{0z}}{{\rm d}x}\hat{\boldsymbol{y}} = \mu_0\boldsymbol{j}_0, \tag{4}$$

which by use of (3) can in turn be written as total pressure equilibrium in the form:

$$\frac{\mathrm{d}}{\mathrm{d}x}\left(\sum_j p_{0j} + \frac{B_{0z}^2}{2\mu_0}\right) = 0. \tag{5}$$

Integration of Eq. (5) with respect to the reference position x_0, which has a reference field strength $\bar{B}_{0z}$, leads to

$$B_{0z}(x) = \bar{B}_{0z}\sqrt{1-\beta_\mathrm{p}(x-x_0)/L} \approx \bar{B}_{0z}. \tag{6}$$

It can be clearly seen that, for small plasma beta β_p, the spatial variation of the background magnetic field, induced by the background diamagnetic current density, is very small, and thus $B_{0z}(x) \approx \bar{B}_{0z}$. Due to this additional dependence of $\boldsymbol{B}_0$ on x, the principal question arises whether the neglection of the term $(\boldsymbol{v}_{1j}\cdot\nabla)\boldsymbol{v}_\mathrm{Dj}$ by comparison with the term $(\boldsymbol{k}\cdot\boldsymbol{v}_\mathrm{Dj})\boldsymbol{v}_{1j}$ in the momentum equation is still justified or not. If we insert expression (6), we obtain from (2) the gradient of the drift speed as

$$\frac{\mathrm{d}\boldsymbol{v}_\mathrm{Dj}}{\mathrm{d}x} = -\boldsymbol{v}_\mathrm{Dj}\left(\frac{1-\beta_p(\frac{L+(x-x_0)}{2L})}{L+(x-x_0)}\right) \approx -\frac{\boldsymbol{v}_\mathrm{Dj}}{L+x-x_0}, \tag{7}$$

where we have used $\mathrm{d}B_{0z}/\mathrm{d}x \approx -\beta_\mathrm{p}(\bar{B}_{0z}/2L)$ as obtained from (6). As the β_p is small, we obtain the approximation

$$\begin{aligned}(\boldsymbol{v}_{1j}\cdot\nabla\boldsymbol{v}_\mathrm{Dj})/((\boldsymbol{k}\cdot\boldsymbol{v}_\mathrm{Dj}) \mid \boldsymbol{v}_{1j} \mid) &\approx (L+x-x_0)^{-1}/(2\pi/\lambda)\\ &\lesssim \lambda/(6L)\\ &\approx 10^{-3} \ll 1,\end{aligned} \tag{8}$$

which agrees with the approximations adopted in our paper, in the sense that the wavelength of interest, λ, is much smaller than the non-uniformity length scale L. Indeed the perturbation wavelength λ in our model is close to the ion inertial length, λ_i, i.e., $\lambda \approx \lambda_i \approx 10$ m in typical coronal conditions, and $L = 1$ km. Consequently, the term $(\boldsymbol{v}_{1j}\cdot\nabla)\boldsymbol{v}_\mathrm{Dj}$ can be safely neglected in comparison to the term $(\boldsymbol{k}\cdot\boldsymbol{v}_\mathrm{Dj})\boldsymbol{v}_{1j}$ in the momentum equation.

In conclusion, it turns out that the only difference with the original equations of the paper by Mecheri & Marsch (2008) is the missing term $(1+(x-x_0)/L)^{-1}$ in their expression for the drift velocity. This does not affect the result concerning the local perturbation analysis, since those were calculated at the reference location x_0, where $(1+(x-x_0)/L)^{-1} = 1$. These results were in turn used as initial conditions to solve the ray-tracing equations (as mentioned in Sect. 3.3 of the original paper). However, the results concerning the nonlocal (i.e., ray-tracing) analysis should be recalculated, since $(1+(x-x_0)/L)^{-1}$ is no longer equal to the unity when moving away from the reference location x_0.

The ray-tracing recalculation should also take into account an additional variation of the background pressure (and density) in the z-direction, in order to consistently fulfill the equilibrium conditions (3) mentioned previously. Such a variation may also be represented by a linear profile (similar to the one in the x-direction). In this case the results of the local perturbation analysis will again remain unchanged; however, the extent of the region for which the new ray-tracing calculations are to be performed must be restricted to a smaller region (of $\leq$10 km), thus satisfying that the density is allowed to increase locally by at most a factor $\leq$10 (as mentioned at the end of Sect. 2 of the original paper). Considering this will prevent an increase in the density to unrealistically high coronal values. All this unfortunately was not adequately considered in the original paper.

Acknowledgements. We thank an unknown referee for his considerable efforts in reviewing our original paper with respect to these critical issues, and we appreciate his valuable comments that stimulated and greatly contributed to this *erratum*.

References

Mecheri, R., & Marsch, E. 2008, A&A, 481, 853