Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-86-AC4, 2019

Annales Geophysicae Discussions
Open Access

Interactive comment on "Mirror mode physics: Amplitude limit" *by* Rudolf A. Treumann and Wolfgang Baumjohann

Rudolf A. Treumann and Wolfgang Baumjohann

treumannr@gmail.com

Received and published: 8 September 2019

Thanks very much for the important comments.

We would like to direct you to the General Response we made were the overlapping questions of all 4 Reviewers have been discussed.

Here just some specific responses to your points which are all very reasonable.

1. 2. We believe that in the General Response we have given arguments to this point. It is a question of the stability of pairing (which is implicit in your criticism) which we did not attack at this point just staying with a simple argument. In principle, if no pairing would exist the two electrons would simply continue their bounce motion after having reached their common mirror point $Z = s_m$ being reflected by the mirror force. At s_m

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they have as a pair zero parallel speed, just the small jitter velocity. Hence if the energy in the jitter is less than the trapping potential the pair will be stable and cannot return into bounce because no force acts on it to drive it back. This is the stability problem said in a few words. Thus for some stable pairs there is the possiblity to become locked at the mirror point, others will return to bouncing, maybe after some rest, maybe immmediately, some will dissolve. However, always new pairs will form such that in the average there will be a stable pair component present. This is the same in BCS of superconductivity where the pairs come and go but in the average exist as a population. However, the proof of this point requires solving the stability problem which we did not do yet as it is not just an easy task. Locking itself is very interesting, and we believe that mirror modes are a rare case where this kind of physics is at least imaginable and possible as kind of a very rare macro-quantum state in high temperature plasma physics where such effects are not expected normally.

Concerning the ion sound spectrum: there is a broad spectrum of ion sound for instance in the magnetosheath (the place where most mirror modes have been observed) as background noise. Any pair will always find a group of waves with that it can resonate. We have taken this into account by integrating over the whole k spectrum of ion sound waves in the potential expression. So this is not a big problem in fact. In looking at obervations (cf. Rodriguez and Gurnett 1975 or ours Treumann and Baumjohann 2018 on the electron mirror mode) the ion sound spectrum is indeed about constantly there and is sufficiently broadband to affect some part of the bouncing electron (or also ion) distribution (the latter we did not consider, however the equations are formally the same with exception of different speeds and inertial effects).

The question on the jitter motion we have not attacked. We assumed that $u \ll V$. However, the range u determines the range of k which is in resonance. Again, when u becomes large this range may not exist, and the pair will dissolve rapidly because the potential will decay. These are of course all questions which cannot be answered easily nor calculated easily. Our assumption is that u is sufficiently small. As in all

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those theories there is always some uncertainty in the assumptions.

3. Don't put too much weight on the susceptibility. This whole part is highly speculative. However to explain what we suggested:

Of course, any plasma containing gyrating charges has some diamagnetism which is however very weak and distributed over the entire volume such that it is not remarkable (the famous incoherent Landau diamagnetisms per particle which is just one third of the Bohr magneton).

Our argument is that the pair current is restricted to a shell of some comparably narrow width Δr because all pairs have the same orbital speed v_e (the gyration phase plays no role because at both bounce and mirror frequencies it is unimportant). Our term coherent is meant in just this restricted sense.

The concentration of pairs in this shell implies a surface current whose magnetic effect should locally become measurable. Still the effect might be weak and probalby is, because the fraction of pairs α is probably much less than estimated on the assumption that its yield would be 50% of the mirror mode. The idea is rather that this probably as well small diamagnetism might start inflow of plasma from the surrounding such that the quasilinear threshold can be overcome. The final state is then not determined in the way we proposed but differently by how much plasma of low perpendicular energy flows in from outside.

Actually, at this point in application to mirror modes, one should turn to include ions as our theory would directly apply only to electrons and thus to the electron mirror mode. The equations however also hold for ions though at different time scale. We did not dare to apply them to ions but this is possible (and demanded even by one of the reviewers). Similar effects may be expected. With ions definitely the magnetisation would be completely unimportant as only electrons play a role in the magnetisation susceptibiity.

The physics would then not go the way on calculation of the magnetic susceptibility but on the inclusion of the additional large perpendicular anisotropy provided by the pairs (both electrons and ions) which restarts the mirror instability at the quasilinear level to continue growing and exceeding the quasilinear limit. This causes an uncompensated pressure deficiency in the mirror mode which needs to be compensated by sucking in low perpendicular energy particles (quasi-neutral ions and electrons) along the field from the outside. It seems that this would be a more realistic mechanism.

We shall rewrite this part of the paper in this spirit in order to prevent misunderstanding and over-valueing the magnetisation. Though thermodynamically this would be much more interesting and important as a physical effect and was reason for our excitement, it is probably unrealistic. On the state of the physics of our days there are very little effects left which can cause real basic physics excitation.

The pure fact of the realistic possiblity of pairing (singlet states) in mirror modes in high temperature plasma should be sufficient but should not lead to exaggerations in expectations.

Once more many thanks for your comments which we hope have been clarified by the above responses at least to our own satisfaction.

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