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

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Many thanks for the excellent report, Dragos.

First, we would like to direct you to the long General Comments to the overlapping comments of the Reviewers where most of the questions is answered.

However your particular questions we will take into account in resubmission.

Yes, indeed, mirror modes seem to be the rare case where an effect like this can, in principle, become realised. Not only for electronds but under modified conditions also for ions (which we didn't dare to include here but what could be easily done by reformulation and might even be better in application to ion mirror modes while electrons possibly apply better to electron mirrors which, interstingly enough, have also been

observed at too large amplitudes scattered over the ion mirror modes —- it would be interesting to check conditions, where only electron and no ion mirrors develop, i.e. conditions of isotropic ions and anisotropic electrons). Ture, the bouncing is the key ingredient by reducing the parallel speed which is needed for resonance with the waves. It is clear that one needs electrostatic waves, alle electromagnetic have perpendicular electric fields and thus are not suited for attractive potentials. But the key observation is that one needs to do the calculation for two electrons, in order to get pairs.

The other problem is locking. We gave the main arguments in the General Response why locking occurs: it is, as you correctly noticed, a question of stability. We have explicated the reason in the General Response. Briefly: locking at $Z = s_m$ for the pair occurs for two reasons: first their we have $U \approx c_s \approx 0$ thus only $u \neq 0$ in the jitter motion (which, rightly as you say, is irregular). Returning into bouncing requires that $mu^2 > \Phi$, i.e. the energy in the jitter must exceed the trapping potential. If this happens then the mirror force can katapult the pair out of resonace and let it return into bounce. If not the pair will, at least for some time, be locked. Thus there will be a number of pairs which decay, another number which is stable for some time. However, sinde the particles have no identity always new pairs will form and others decay, so one will have s fluctuating population of pairs present all time. This is the main point.

The other reason for being locked is that the ion sound does not participate in bouncing. Thus once the three particles (2 electrons plus ion sound) interact and a sufficiently large trapping potential evolves, the ion sound wave does not easily allow the pair to return into bounce becasue this would require turning the waves around. But all of this is a question of stability analysis. Some pairs will decay, some will as pairs return to bounce (those with large u) and some will be stably loked. It is not that U vanishes completely but that $U = c_s$ becomes close to the mirror point (just before $U = 0$) where the pairing occurs. This means that the pair is locked to the slow ion sound (nearly zero velocity), negligible with respect to the thermal speed in the perpendicular motion.

The question on the diamagnetic effect is intriguing. We were probalby overoptimistic.

In any magnetised plasma there is a global diamagnetic effect slightly reducing the magnetisation. But this effect (Landau diamagnetism in a homogeneous plasma) is not remarkable because it is global distributed over the entire domain and in weakly inhomogeneous plasmas also not remarkable. Our expectation was that the restriction of the motion to a current shell by locking would concentrate the diamagnetic effec locally. This might be, as I said, too opitimistic. So the heuristic section on the magnetisation is not relevant. Since it is very hard to make the relevant calculation in the inhomogeneous case (surface current plus its stresses produced by an unknown distribution of pairs), the heuristic estimate of the factor α is probably too large, possibly way too large.

The realistic idea is probably that the large addition perpendicular temperature anisotropy introduced by the generation of locked pairs at the quasilinear saturation level, which is in pressure balance with the heated population, destroys the quasilinear stability and drives the instability towards larger magnetic depletion. There are two possibities. Either this causes additional heating and new quasilinear saturation at higher depletion while by erasing the pair additional anisotropy also destroying the pairs (new pairs may form on the hotter plasma background such that this process could in principle continue), or colder (at perpendicular speeds below trapping/reflection/bounce) neutral plasma is attracted (sucked in) along the magnetic field and contributes by hsear number to enhanced pressure to come up for pressure balance.

These are two realistic possibilities, both causing deeper mirrors and both based on pair formation. This is most interesting in both (for electrons and ions as well) cases which would be open to experimental investigation: identification of the sucked in flow and the pair populations.

Thanks also for the minor comments.

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