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Interactive comment on "The mirror mode: A superconducting space plasma analogue" *by* Rudolf A. Treumann and Wolfgang Baumjohann

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We thank the referee for his encouraging report.

It is indeed surprising though satisfactory to find that a similarity exists between quantum and classical effects. This should not be exaggerated, because it is (so far) just a similarity and does not mean that the mirror mode is a macroscopic quantum effect.

We would like to highlight at this place some points (which in the manuscript have not been discussed as they are more general than the mere mirror instability).

The analogue circumvents stepping up the ladder from linear to fully nonlinear theory of the mirror mode which in purely classical thinking is rather difficult if not impossible. The reference to quantum methods enables to directly go to the final thermodynamic

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equilibrium state even though the result describes just the saturated state of the mirror mode but does not illuminate how and in which way this state is reached. (Trying to do this in classical thermodynamics, i.e. without reference to a “wave function”, turned out to run into unsurmountable difficulties, which explains why so far no steady state other than quasilinear has been investigated for mirror modes.) This is the same as in superconductivity which is based on stationary quantum theory while not beeing an evolution theory in time. It just distinguished two phases: the normal (resistive) and the abnormal (superconducting) phases, which works because of the pairing of electrons and bose-einstein condensation of these pairs in the lowest energy state where they become superfluid and escape resistance.

This kind of pairing is clearly absent in a plasma with temperatures by far exceeding any pair binding energies. However, there is a similar kind of “pairing” viz. trapping of large numbers of particles when magnetic bottles form by chance and thermal anisotropy allows the number of trapped particles to grow. Those particles can be considered as forming one large quasiparticle. But in contrast to superconductivity there is no change in mass because the ratio of charge to mass remains constant and spins play no role for two reasons: the plasma is classical and, in addition, the average spin averaged over all directions of the large number of trapped particles is zero plus possibly one which plays no role (recall that pairs have twice the mass and twice the charge, but in their pairing interaction the doubling of mass in the spin interaction term does not drop out but causes their bosonic nature). The trapped particles therefore are statistically all bosons, behave like bosons and allow the description by one common wave function.

The untrapped particle population are the particles of high energy respectively those with large parallel velocity. They escape trapping.

This we did in the mean field mean wave function approach where the ratio (according to the above discussion) $N_m q/N_m m = q/m$ is the same as for one particle. One can take this as justification of proof for the validity of our approach.

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It would be interesting to investigate the superfluid behaviour of this trapped population. It will give rise to three types of waves: ion-acoustic waves (purely electrostatic), Alfven waves (purely electromagnetic), electromagnetic ion-cyclotron waves (no linear dispersion). Hence the former if sufficiently short wavelength play the role of phonons in superfluidity, i.e. not acting like a viscosity/resistance, the latter are like rotons. Hence, near criticality the trapped particles behave like a spuerfluid.

This behaviour should be taken into account in any more precise theory. This means that one should refer to the Bose distribution with finite mass and temperature anisotropy and variable ratio of trapped to ambient plasma density, consider Alfven waves (liner dispersion) as photons and ion-cyclotron waves as rotons. Then one would be in the position to develop a more precise thermodynamic theory of the mirror modes.

In summary, this is an interesting concept.

Once more many thanks to the reviewer.

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