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Interactive comment on "Observational support for the electron mirror mode: AMPTE-IRM and Equator-S measurements in the magnetosheath" *by* Rudolf A. Treumann and Wolfgang Baumjohann

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1. For a minor comment, please state the spec (sampling rate, dynamic range...) of the instruments that the authors used in the study.

We start with the simplest question. Magnetic observations on Eq-S were at 128 Hz sampling rate. This allowed Baumjohann et al 1999 (paper to which we refer as a basis for this investigation) to marginally (concerning sampling) resolve oscillations in the magnetic field in time at the bottom of the ion mirror modes under the conditions of a $\sim$30 nT main field at frequency $\sim$0.1 electron cyclotron frequency (the dynamic range of the magnetometer was sufficient at 0.1 nT). It did not allow resolution of whistlers

at higher frequencies above say 0.3 cyclotron. Observations of whistlers in this range have been ubiquitous when using wave-electric field instrumentation on other spacecraft (see the references for the basic papers) on which the presence of whistlers have been reasonably claimed. Since no magnetic wave observations were available for those waves, the Baumjohann 1999 paper was important to show their magnetic component thus confirming lion roars to be whistlers seen in the electric wave and the fluctuating magnetic fields. There also were the arguments given for the nature of such waves as whistlers, and even a weak resonant anisotropy in the electrons could be theoretically inferred.

2. The authors explained in Lines 52-57, that the lion roars are in the whistler mode branch and mostly parallel propagation, but I cannot find the characteristic from the panels.

From the above it is clear that higher frequency than those in Baumjohann 1999 could not be directly seen in the magnetic recordings of any, in particular not the Eq-S spacecraft. In the figure shown here, which is at the highest Eq-S time resolution (sic 128 Hz), the higher frequency > 0.3 electron cyclotron frequency whisters cannot be resolved in time. However, where the instrument could in the average detect their presence, it should observe a broadening of the magnetic trace. Inspecting the magnetic trace this is exactly what is seen and this is seen in relation to the much lower frequency magnetic oscillations overlaid on the ion mirror trace. Evidence for such higher frequency temporarily unresolved waves is therefore given in these observations. More can, however not be done.

3. Since the pressure balance between the magnetic field and the ions are important for the mirror mode structures, the plot of the ion beta (and also electron beta for the electron mirror mode?) will be important.

The reason for why not more can be done from Eq-S observations alone is that no plasma or particle measurements were available due to failure of the plasma instrument, as has been explicitly said in the text of the original submission and was learly noted in Baumjohann 1999. Thus the demand of the AR#2 (which is identical to the demand of AR#1) could not be satisfied even if we wanted. In additn, time resolution of the plasma isntrument would have been a mere $\sim$3 s spin which would marginally sufficed to show pressure balance with ion mirrors but would have been illusionary with electron mirrors.

4. In Figure 1, it looks the lion roars and another bursty spectra (electron mirror wave?) do not appear simultaneously.

Fig 1 is AMPTE IRM data. Here the plasma instrument had spin resolution $\sim$4s which is sufficient to demonstrate plasma-magnetic anticorrelation as seen in the new Fig 2 where 3 cases have been shaded. This should suffice though could be done statistically better. We consider this superficial for our purposes as it has been done in many other papers already and is well known for the ion mode. For the same reason, it would be illusionary to try to demonstrate pressure balance between electron and ion mirror modes. Thus the demand of the AR#2 (as also that of AR#1) can principally not be satisfied based on the available data.

5. The authors only showed the dynamic spectra or waveforms of the magnetic field, but my question is how did the authors identify the mirror, electron mirror and lion roars?

For the identification of ion mirrors see the above comments and papers by Lucek et al 1998a,b from Eq-S to which we refer. Concerning the distinction of We refer to the theoretical distinction between both mdoes as given from the linear calculation of Noreen. As we have said in the paper, the mirror modes are convected across the spacecraft. Hence (contrary to whistlers whose frequency is not affected by the perpendicular transport as they propagate parallel to the magnetic field and there is no Doppler shift) the frequency of the ion and electron mirror modes is low, roughly 0. Therefore their temporal scales map their spatial extension (Taylor's hypothesis!).We

thus can compare their temporal lengths. This shows that those magnetic oscilaltions on the flanks which we identify as electron mirrors are roughly 10 times shorter than those of the ion mirror modes in Eq-S. This corresponds almost exactly to the different ranges in the linear claculations of Noreen et al 2017. This is stong support for the electron mirror modes.

In addition, the amplitudes of the electron mirror modes (as we identify them) is much smaller than that of the ion mirror mode but much larger than those of the whistlers (lion roars) in agreement with Noreen's predictions of a factor 10 difference.

Now, this last prediction is based on a quasilinear calculation, and AR#1 has complained that the saturation amplitudes are way to large when compared with the quasilinear saturation level. This is true. But the relation between the levels is precisely what is observed.

This leads to the question, why the absolute amplitudes are so large, another factor of 10 larger than the quasilinear saturation, and this for both modes, the ion mode as well.

The answer is that quasilinear theory does not apply to the mirror modes! Mirror modes are in the weakly turbulent plasma state, where quasilinear saturation is erased by mode-mode and wave-particle interactions. The problem is that such a theory hs not yet been developed for mirror modes simply because the interacting modes have not been identified yet. We therefore propose that one of the modes participating in weak turbulence is just the electron mirror which hterefore should, in contrast to Noreen et al, not be treated quaislinearly but included into a weakly turbulent theory. Other modes can be found in electromagnetic ion-cyclotron modes and also drift-modes excited on the plasma and field gradinet in the mirror modes which may grow on the boundaries of the mirror modes and inhibit quasilinear saturation.

However, this also allows us to identify one caveat: ioncyclotron or drift waves as a possibility to replace those modes which we call electron mirrors. This can be decided only on the basis of spacecraft data of higher plasma and field resolution.

Finally: there is a grave mnisunderstanding in the role of anisotropies in mirror modes and whistlers. These anisotropies have nothing in common with each other. Whistlers (lion roars) life from resonsnt particle anisotropies (trapped resonant electrons, a minor component of electrons), while mirrors are driven by macro-anisotropies: the temperature anisotropies of the bulk plasma. Thus evolution of whistlers on the account of resonant particles has nothing in common with the evolution of mirror modes on the expense of the temperature anisotropy. Any argument based on putting them equal is simply wrong.

6. We do not comment on the problem of the higher frequencies seen in the wave spectra of AMPTE IRM. This has been sufficiently explained already in the first version of the paper and is a little more elaborated included in the revised version.

Nevertheless, thanks to the AR#2 for forcing us to write such an extended response.

Needless to say that we have included some of these comments (in less extended form) into the revision. plus two figures which may help understanding our reasoning. We also hope that this paper will ingnite further research in the physics of mirror modes, in particular its kinetic turbulent state.

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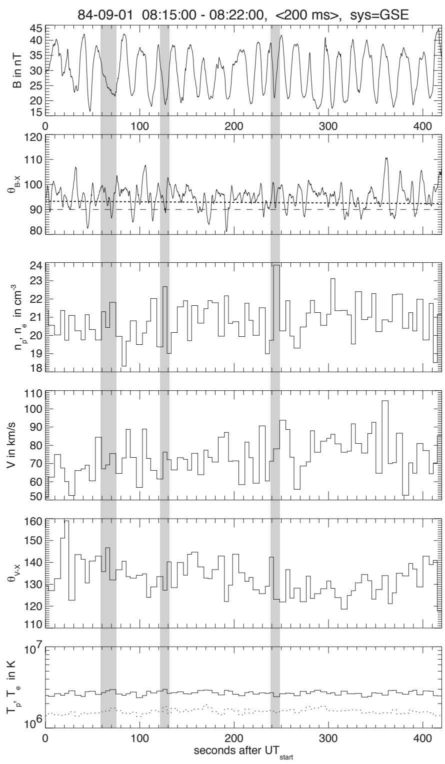

Fig. 1. AMPTE IRM plasma and field data 6 min at available resolution showing the anticorrelation between B and NT. Three cases are shaded.

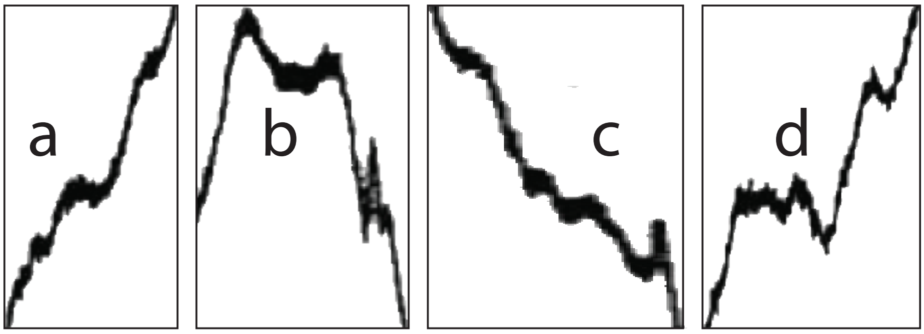

Fig. 2. Zoom into the magnetic trace of Eq-S showing evidence for superposition of high frequency waves related to those events we call electron mirror modes