Reply R1

1. I find the observations far from convincing. There is no confirmatory plasma data showing that the plasma pressure is out of phase with the magnetic pressure.

We have explicitly said, already in the original submission, that there were no plasma data in Eq-S. This had been mentioned already in Baumjohann et al 1999, and before in Lucek et al. 1998a,b to which we refer. In particular Lucek et al. have given unambiguous proof, using other arguments and observations, that the large amplitude magnetic oscillations were (ion-) mirror modes. In fact, of the sequence used in Lucek, the 1999 paper by Baumjohann took a short exerpt at high resolution (128 Hz) to demonstrate the observation of lion roars at the bottom of the mirror troughs where the whistlers could marginally be resolved as oscillations in the magnetic field. The magnetic time resolution would, however, not be sufficient to resolve the higher frequency whistlers. All earlier observations of lion roars (see the literature) were not based on magnetic but on wave observations like in our figure 1.

What concerns AMPTE IRM, there is no need anymore to prove pressure balance. AMPTE IRM had a large record of ion mirror modes in confirmed pressure balance. The 6 min sequence shown in Fig 1 is long enough as belonging to the family of mirrors. In order to show what the reviewer demands, we nevertheless added a new figure showing plasma and magnetic data from AMPTE IRM over 6 min where the anti-correlation between ion mirror modes and plasma (density, temperature) is obvious. Three cases are indicated by shading. We dare to overload the paper with more of this.

We have also given the time resolutions. The reviewer might realize that the time resolution of 4 s spin for AMPTE IRM inhibits a clearer one-to-one anti-correlation. It could be done better statistically but for our purposes it suffices to show that there is anti-correlation. Nature was so unkind not to align the spin with the magnetic field in the mirrors such that there are only single cases which at the available spin resolution of the plasma data exhibit the anti-correlation.

What concerns Eq-S, the mirror waves shown are a high resolution 128 Hz exerpt from the full lower resolution sequences in Lucek et al. where it was shown that these are mirror modes even though no plasma data were available. Would they have been available, they could at 3 s time resolution be used marginally for demonstrating pressure balance in the ion mirror modes, but there would have been no chance to demonstrate the pressure balance in the electron mirrors. Thus the demand of the referee could anyway not have been satisfied and is in fact malevolent. All the relevant references which have published thes numbers, in order to satisfy the reviewer, have been added. We are sorry, but we do not have better examples from those measurements in this time resolution in particular as those data have not survived or are not anymore readable from old tapes.

2. The authors have also not addressed why the electron anisotropy would not be absorbed by the electromagnetic whistler mode “lion roars” instead of by the electron mirror mode instability. Thus from a theoretical point of view, electron mirror modes would not be expected.

We are surprised! The text of the review suggests that the reviewer is not a beginner but firm in both observation and theory. However, he still is subject to the typical misunderstanding of the role of anisotropy.

In fact, the anisotropy driving any mirror modes is a fluid-macroscopic anisotropy. That which excites whistlers is the anisotropy of a small group of higher energy resonant trapped particles. The reviewer should consult Kennel and Petschek 1966 where this was quite clearly expressed. But the reviewer is excused because this misunderstanding is widely spread.

Whistlers live on the anisotropy of the energetic resonant particles (radiation belt electrons, for instance). Depletion of this anisotropy does by no means affect any possible macroscopic temperature anisotropy which drives mirror modes. For the depletion of the latter the temperature of the bulk must be changed, which the resonant particles are unable to do. They are just a few and don't do nothing on the macroscopic anisotropy.

The large 50% ion mirror amplitudes prove that depletion of anisotropy does not happen for the ion mirror mode anyway.

Lion roars are as well unable to do anything on the anisotropy which drives the electron mirror mode. Thus any quasilinear calculation misses the real effect which nobody has so far treated properly in theory. Noreen's calculation (or our own earlier 1997 quasilinear treatment of the fluid ion-mirror mode) does not say anything in this respect. It just proves that quasilinear theory does not apply to any of the observed mirror modes because all observations demonstrate that the amplitudes exceed the quasilinear level by far. This, however, is no argument against their (or earlier) linear calculations which can be used and give reasonable results.

Concerning the references, we have included the suggestions (and a bunch of others more). Thanks for alerting us.

Needless to say that we have introduced a substantial number of explanations in the text (all in blue), added two figures: fig 2 showing the anticorrelation magnetic-plasma in AMPTE IRM, fig 4 a blow up of some regions where indications of high-frequency whistlers (lion roars) are evident from the Eq-S magnetic field trace noting that these cannot be resolved by the 128 Hz magnetic resolution which just marginally sufficed to resolve the lowest whistler frequencies at the bottom of the ion-mirror modes in Baumjohann et al 1999. The wave observations of AMPTE IRM show clear indiations of the presence of all those whistlers.

Finally, we changed the title of the paper in order to accommodate the doubts of this reviewer, since our observations and discussion is reasonable but is no direct observational proof. Some other possibilities still exist which me mention in the paper. One would be electromagnetic ion-cyclotron waves (ion whistlers) in weak kinetic turbulence which could be mistaken as electron mirrors though we argue against that possibility. We have indicated this caveat in the text. The other are short wavelength drift modes which we cannot exclude but also cannot identify. Any proper weak kinetic turbulence of ion mirror modes should identify and account for those short wavelength eletromagnetic drift waves and ion-whistlers excited in the plasma and magnetic pressure gradients inside mirror modes. These waves grow on timescales much faster than the quasilinear mirror saturation scale such that quasilinear depletion does not come into effect and the mirror mode can reach the observed large amplitudes.

Reply AR#2

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 ~30 nT main field at frequency ~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 whistlers 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 clearly 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 addition, time resolution of the plasma isntrument would have been a mere ~3 s spin which would marginally suffice 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 ~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 refer to the theoretical distinction between both mod,es 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 amplitude 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 in the mirror modes.

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 has 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 therefore should, in contrast to Noreen et al, not be treated quasilinearly but included into a weakly turbulent theory. Other candidates can be found in electromagnetic ion-cyclotron modes and also drift-modes excited on the plasma and field gradients 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: ion-cyclotron or drift waves as a possibility to replace those modes which we call electron mirrors. This question 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) live from resonant particle anisotropies (trapped resonant electrons, a minor component of electron population), 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 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.