Dear Dr. Foster,

Thank you very much for your comments. Here is our response.

lines 255-258: Two techniques for calculating the normal vector of the shock (n) are described. How well do these two techniques agree with each other?

The Finnish data base gives the coordinates of the normal vector to shocks as calculated from the magnetic field data and velocities using the mixed mode method of Abraham-Shrauner and Yun [1976]. When there is data gap in the velocity components, the normal is calculated using magnetic field coplanarity [Colburn and Sonett, 1966]. Abraham-Shrauner [1972] suggested the "mixed mode method as an alternative to other methods when the accuracy of the magnetic field used in the calculations is uncertain". She noted that, for example, if the magnetic field is exactly normal or tangential to the shock front, magnetic coplanarity fails to give an expression for the shock normal. Our list of interplanetary shocks contains events for which the determination of the values of the magnetic field ahead and behind the shock was not very complicated (no strong oscillations), so we always use magnetic field coplanarity to calculate the shock orientations. We found that the sense of our shock orientations (spiral or orthospiral) agrees well with the shock parameters in the Finnish database.

For the fast mode propagation velocities, it would be good to describe the theoretical parametric dependence of the fast mode velocity (e.g. its dependence on radial distance). How well do the observed pulse velocities agree with theory for the Feb 2014 event (e.g. lines 310-312) and others?

The exact value of the fast mode wave speed in the magnetosphere depends on the direction of its propagation. For propagation perpendicular to B, the phase velocity V_F is $(V_A^2+C_S^2)$, where V_A is Alfven velocity and C_S is the sound velocity.

The Alfven velocity is given by $\mathbf{V}_A=\mathbf{B}/(\mu_0\rho)^{-1/2}$. To calculate V_A we used the Carpenter and Anderson density profile obtained from a least squares linear fit to 25 ISEE dayside saturated plasmasphere profiles [J. Geophys. Res., 97, A2, 1097-1109, 1992].

Figure 1a shows their reference density profile given by $n_e = 10^{(-0.3145L+3.9043)}$ for L increments of 0.5. Figure 1b and Figure 1c show the values of the magnetic field obtained from a CCMC run for the Tsyganenko geomagnetic field model for the solar wind conditions on February 27, 2014 and the corresponding Alfven velocity, respectively. Then we set the plasmapause at L = 6 and took the density n_e as 4 cm^{-3} beyond this distance to obtain the corresponding Alfven velocity presented in Figure 1d. The values for the Alfven velocity at the locations of Van Allen Probes A (L=5.1) and B (L=5.5) are about 284 km/s whereas at the GOES location it is 1240 km/s. Because the temperature is very low, the fast mode velocity is the same as the Alfven velocity in the plasmasphere [Takahashi et al., J. Geophys. Res. 115, 2010] and is only ~100 km/s greater in the outer magnetosphere. These model values for the fast mode velocities are in good agreement with the values obtained in our paper.

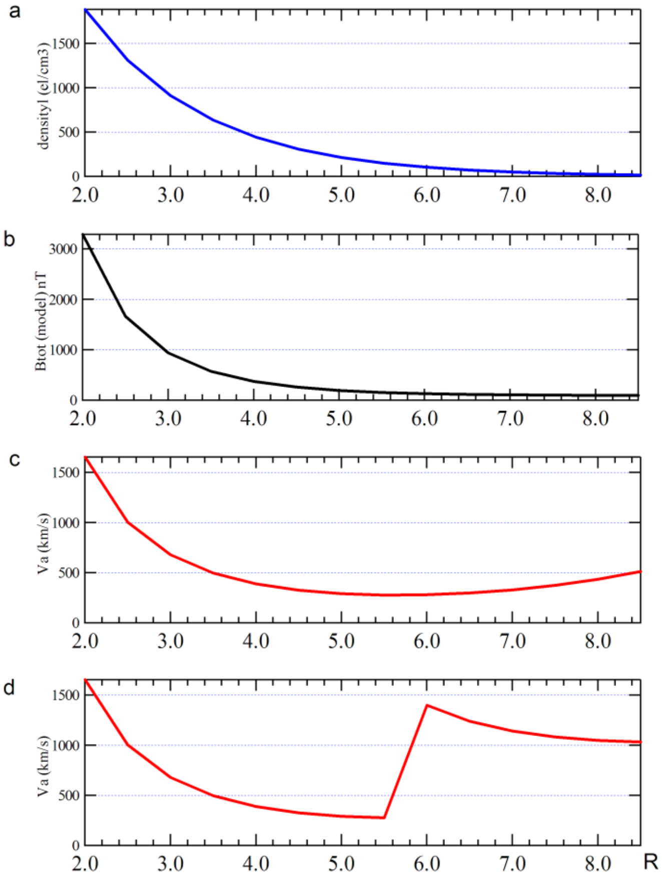

Figure 1. Radial profiles: (a) reference density profile given by $n_e = 10^{(-0.3145L+3.9043)}$ for L increments of 0.5, (b) values of the magnetic field obtained from a CCMC run for the Tsyganenko geomagnetic field model, corresponding Alfven velocities (c) without and (d) with a plasmapause.

In the Introduction (lines 89-100), the resonant acceleration of trapped particles is discussed briefly. This paper presents observations and calculations of the propagation speed of the shock-induced pulse, the strength and variation of Ey, and the associated plasma drift velocities Vx and Vy. A useful addition to the paper would be to present some detail on how those parameters have important effects on plasma acceleration in interactions involving the initial fast-mode pulse or with subsequent ULF oscillations. For example, the studies of Wygant et al [1994] using CRRES data, Foster et al. [2015] using Van Allen Probes data, and others have shown that within the magnetosphere, the tailward propagation of the strong shock-induced electric field impulse can result in the extremely fast acceleration of high energy, ultra-relativistic electrons deep within Earth's Van Allen radiation belts. The strong electric field associated with the shock- induced fast mode pulse is of about 1-min duration and accelerates radiation belt electrons for the length of time they are exposed to it.

We added new Figures 7, 10, 11, 12, made some calculations, rewrote the section of statistical study and the conclusions to improve our paper.

Thank you again for your help.

Regards,

Galina Korotova.

Dear Referee2,

Thank you very much for your corrections and suggestions. We took your commemts seriously and it took some time to prepare our reply. Here is our reply.

The major one concerns the fact that it is quite difficult to find what is really new in this study. Of course the results are very interesting but they not provide perspectives or insights of what they could offer to inner magnetosphere scientists. First, the authors should highlight the main results in the abstract section. Then, at the end of the introduction section, it is not clear also what is the main purpose of this study and what it is new. Finally in the conclusion section, it is still not evident to find what is new compared to previous studies. The authors should try to improve this.

We have now highlighted the main results in the abstract and in the introduction discussing the purpose of the paper . We rewrote the conclusion of the paper.

In this idea, I would like also to recommend the authors to analyze and discuss maybe a little bit more on the implications of their work regarding three directions:

Using the multi-events analysis and their conclusions, is there a way to deduce from solar wind precursors, what will be the response of the magnetosphere : could we be able to estimate / anticipate the induced electric fields characteristics (directions, amplitudes, periods, ...) that could be of interest regarding space weather (intensity, plasma heating, time lag...) ?

We added a new Figure 10 and showed that the periods of the pulsations initiated by IP shocks increase with radius. We believe that most pulsations in the dayside magnetosphere at L < 6 are produced by field-line resonances.

Regarding space weather we added three additional Figures 11, 12 and 13 and a new paragraph in the statistical study section to describe the response of the magnetosphere to IP shocks**.** In particular we have a much more extensive discussion of electric field direction, amplitudes and period.

Electron perpendicular temperatures observed by HOPE were available for 30 events. 13 events showed an increase of temperature, 6 events showed a decrease of temperature and 11 events did not show any change. Proton perpendicular temperatures were available for 40 events. 24 events showed a decrease of T, 12 events showed an increase of T and 12 events did not show any change. We did not find any consistent pattern for behavior of electron and proton temperatures after impact of IP shocks.

Based on this analysis (both the February 27th 2014 and the multicase study), some interesting perspectives / analysis could be made between the analyzed characteristics of the electrisc fields induced and the response of the radiation belts during these disturbed time especially regarding: dropouts at low energy induced by convection electric field (E < 100 keV) and radial transport trough typical radial diffusion for all energies?

Here we are studying the immediate response to IP shocks. Studies of diffusion would require determining ULF wave amplitudes, the extent of wave fields, and simulations which are beyond the scope of this paper.

We added a paragraph to the paper:
Understanding and predicting such responses is important for reducing the risks associated with space exploration. We found that 55 events showed an electron enhancement at energies of 32-54 keV measured by MagEIS at all local time and three of them were accompanied by intensity decreases at higher energies. Five events showed a decrease of the 32-54 keV energy electrons observed in the nightside magnetosphere.

What is the impact of the plasmasphere in the dayside sector and in the nightside sector on induced electric fields at such times as the plasmasphere is no more circular (and conversely)?

The figure below presents the magnitude of Vx flow velocities as a function of plasmaspheric density obtained from electric potential on the Van Allen Probes. Consistent with expectations, the velocities induced by IP shocks can attain greater values in regions of low magnetosphere densities and are invariably small for regions where densities exceed 260 cm-3.

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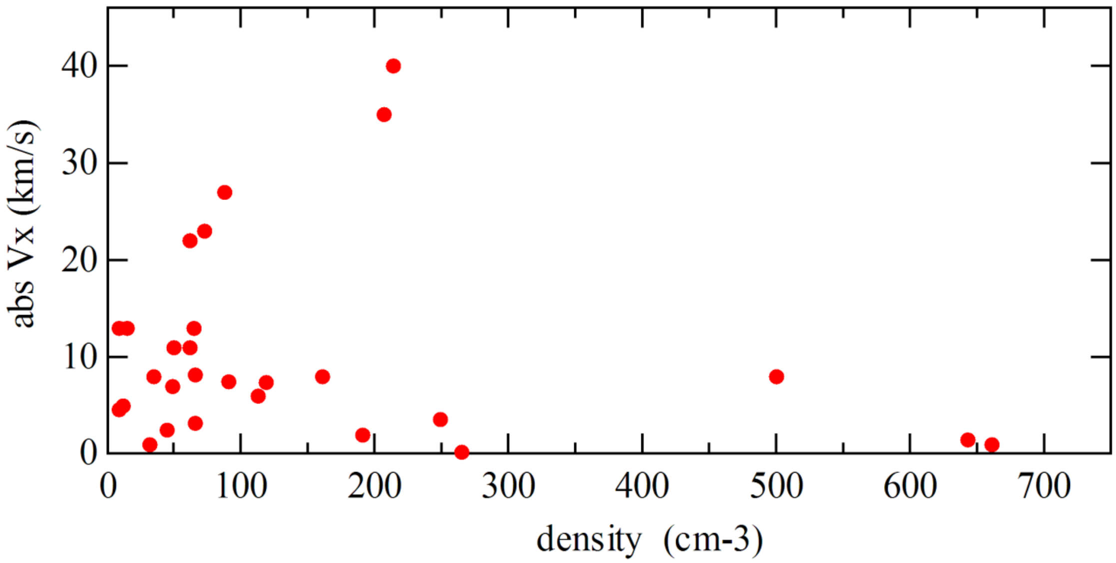

Amplitudes of shock induced Vx flow velocities as a function of plasmaspheric density obtained from electric potential on the Van Allen Probes.

We corrected minor errors.

Thank you again for your help.

G. Korotova

Dear Referee 3,

Thank you very much for your comments and suggestions.

Here is our reply.

Instead of GSE coordinates, a field-aligned coordinate system might be able to show in a more clear way the radial and azimuthal directions of propagation as well as the direction of the electric field with respect to the magnetosphere. For example, in Figure 6 the azimuthal components are discussed but Ey GSE is plotted.

We used GSE coordinates because the magnetic field data were already available in these coordinates. Our results suffice to show clearly a pattern for the radial and azimuthal directions of propagation as well as the direction of the electric field in GSE coordinates. We replaced "azimuthal" with Ey.

It is mentioned that "In the solar wind Cluster 2 observed the shock earlier then and Cluster 1, respectively, that is the shock moved dawnward". Was this supposed to mean "earlier than Cluster 1"? If yes, in Figure 2, C2 appears to be located dawnward of C1, so the shock should be moving duskward. Please clarify.

Yes. We believe that the shock moved dawnward across the magnetosphere. The reason for this is that we have used both Wind and Cluster observations to make numerous coplanarity calculations of the normal to the IP shock for a wide variety of observed upstream and downstream input parameters. After a useful online discussion with Prof. Owen we chose a very typical normal that pointed in the (x, y, z) direction [-0.8, -0.4, -0.3]. From this, we conclude that the shock propagated dawnward and antisunward and struck the duskside magnetopause first, precisely consistent with the picture that we drew in the paper. We avoided discussing the nz component as we get very mixed results for sense of this component depending on the input parameters chosen.

The referee is correct. From timing considerations and the Cluster observations, it appears that the shock should propagate duskward from C2 to C1. However, we are examining 3s time resolution observations from Cluster, the two spacecraft are very close together, and the times corresponding to the observations differ for the two spacecraft. The apparent lag from C2 to C1 is an artifact of the times when 3s observations are available. When we use C1 and C3, located further apart, the lag time is most definitely consistent with dawnward and antisunward shock propagation.

It is written that "In the outer magnetosphere the propagation velocity for the disturbance was about 1348 km/s between Goes 13 and 15 but only about 390 km/s between Van Allen Probes B and A". These are greatly inconsistent, and this discrepancy is not discussed in the paper. To my understanding, this can only be reconciled if a different propagation direction is assumed for the red arrows of Figure 2, which might also re-quire a reconsideration of the shock front propagation. A possible orientation could be an arrow that originates from the pre-noon region (e.g. 0900 LT) and points towards the Earth, which is different from the results of the paper. Please discuss.

Please, read our reply to Dr, Foster (lines 25-47).

These model values for the fast mode velocities are in good agreement with the values obtained in our paper.

Please discuss in greater detail the methodology used in order to determine spiral and orthospiral orientations of the shock normal, and the expected errors in these estimates.

The Finnish IP shock data base gives the coordinates of the normal vector to shocks as calculated from the magnetic field data and velocities using the mixed mode method of Abraham-Shrauner and Yun [1976]. When there is data gap in the velocity components, the normal is calculated using magnetic field coplanarity [Colburn and Sonett, 1966]. Abraham-Shrauner [1972] suggested the "mixed mode method as an alternative to other methods when the accuracy of the magnetic field used in the calculations is uncertain". She noted that, for example, if the magnetic field is exactly normal or tangential to the shock front, magnetic coplanarity fails to give an expression for the shock normal. Our list of interplanetary shocks contains events for which the determination of the values of the magnetic field ahead and behind the shock was not very complicated (no strong oscillations). We also removed some events with IMF radial orientation, so we can always use magnetic field coplanarity to calculate the shock orientations. Though our calculations sometimes give different values for the normal vectors and depends on the choice of intervals chosen for the calculation, we repeatedly obtain the same sense of normal orientation for all the calculations and pairs of upstream and downstream values: dawnward or duskward for each of our calculations. We also found that the sense of our shock orientations (spiral or orthospiral) agrees well with the shock parameters in the Finnish database.

The association of the four groups with ongoing processes could be further discussed. E.g., Pi pulsations and substorms are not mentioned at all in the paper

We added a paragraph and a new Figure 11 in the paper.

The ULF electric field pulsations of Pc and Pi types produced by IP shocks are observed at all local times and in the range of periods from several tens of seconds to several minutes. We believe that the magnetic field as well the electric field pulsations initiated by IP shocks are generated by a wide variety of mechanisms including plasma instabilities, transient reconnection, pressure pulses, and often correspond to field line resonances. Their characteristic features are determined to large extent by local time. In the dayside magnetosphere typical pulsations are of the Pc5 type. Sometimes they last for more than twenty wave cycles without noticeable damping which could be explained by a continuous input of the solar wind energy into the magnetosphere. In the nightside magnetosphere during substorms, the generation of Pi2 pulsations is more common. They exhibit an irregular form, last 3-5 wave cycles, and often exhibit damping. Figure 10 presents periods of the pulsations (measured for the first wave cycle of oscillations) as a function of radius and shows that periods increase with increasing radius. A simple explanation for this behavior of pulsation frequencies with radial distance can be given in terms of standing Alfvén waves along resonant field lines (Sugiura and Wilson, 1964). The length of the field lines, the magnetic field strength, and the plasma density distribution determine the Alfvén velocity, and the periods of the pulsations. This plot indicates that most electric field pulsations of the Pc5 type in the dayside magnetosphere at $L < 6$ are produced by field line resonances.

We added some information on shocks and substorms.

Discontinuities in the solar wind plasma such as shocks have often been considered as possible triggers for the release of energy stored within the magnetotail in the form of magnetospheric substorms. Most previous studies of shocks leading to substorms have relied on ground magnetometer observations. Recently it has been shown that the use of global auroral images to identify substorm onsets has some advantages over many other alternative substorm onset signatures, such as low-latitude Pi2 pulsations, auroral kilometric radiation (AKR), and dispersionless particle injections and magnetic field dipolarization at geosynchronous orbits [e.g., Liou et al., 2003]. To identify substorms triggered by shocks in our study we considered negative magnetic bays by examining the westward auroral electrojet AL index at the times when SSC were determined from low-latitude ground magnetograms.. As a quantitative definition for the substorm bay does not exist we used the criteria of Liou et el. [2003] that there should be a sharp decrease in AL of at least 100 nT occurring within a 20 min window starting at the SSC. We found that shocks triggered a substorm in the magnetosphere in 17 of the 30 examined events. Further study whether these negative magnetic bays are unique identifiers of substorms is beyond the scope of the paper**.**

Thank you again for your help with improving the paper.

Regards,

Galina Korotova.