Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-7-AC1, 2019

Annales Geophysicae Discussions
Open Access

Interactive comment on "Low frequency magnetic variations at high-β Earth bow shocks" *by* Anatoli A. Petrukovich et al.

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Received and published: 8 May 2019

Reply to Referee 1

We are grateful to the Referee for attention and inspiring us to make a deeper insight in plasma physics.

Comment

The previous version of the paper did not reach any substantial conclusions. This version of the paper does not reach any substantial conclusions either. It seems that the authors do not realize that simple description of observations is not physics. It is necessary to extract new knowledge from these observations. I inclined to reject the paper. Yet, I would like to give one more chance. Please make sure to show

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Discussion paper

how this study advances our understanding of shock physics beyond just presenting figures and stating that "Magnetic field and ion density jumps are smeared to a couple tens of seconds". Claiming that "High-β (β > 10) shocks are relatively rare and largely unexplored class of Earth bow shock" is inappropriate for Conclusions. What new physics is found ?

Reply

Perhaps, the referee is not satisfied with the style of Conclusions section. We are aware of three papers addressing specifically high-beta shocks (Formisano et al, 1975, Winterhalter et al, 1988, Farris et al, 1992). Our new quantitative results are actually fully listed in subsection 3.4.

1. First of all, the study systematically addresses the issue of finding high-beta shock examples and proving their beta values. The overall number of potential candidates is estimated. Statistics of Cluster multipoint shock events with small separation is assembled.

2. With 22 Cluster examples, a typical appearance of oblique high-beta shock was well identified, including ramp structure and general properties of variations.

3. Polarization, typical frequency, in some cases, the spatial scale of dominating magnetic variations was determined. Two distinct variants of wave structure were found, with dominating 0.5 Hz and 2 Hz waves. (Note, that the only wave property reported before was “very high amplitude”).

4. Comparison with the previous results shows distinct difference of observed variations from that previously reported in low beta shocks, in particular, it is not consistent with fast magnetosonic or Alfven waves. There is some consistency with Weibel mode.

What was really not done, is some “ultimate identification of wavemode”, requiring reliable wave vector determination. It, of course, remains one of our primary goals in the following studies. Perhaps this was meant by the Referee as absence of new physics. We, however, can not expect that all problems of high-beta shocks will be solved in the first paper. Hundreds of papers were written on more ordinary shocks, and still many things are not clear. We make the conclusions more specific and also enhance interpretations (though more speculative at this stage) in Discussion.

Changes in the text

(In Discussion):

... A shock example #3 with very low upstream magnetic field about 1 nT exhibits very variable direction of magnetic field both upstream and downstream, complicating definition of shock magnetic geometry. This issue might be of a special interest, since at some (very small) value of magnetic field, it's direction should become unimportant for the shock structure. Then, there will be no difference between perpendicular and parallel shocks and the shock spatial scale, as well as ion escape upstream, should be defined with some nonmagnetic parameters. Our study suggests preliminarily, that transition to 'non-magnetic' case may occur as in Example #3, at β of several tens. Thus, one of the main topics for the future studies is to observe in greater detail the dependence of the shock scales for the events with the extreme large β....

...An alternative wave mode candidate, frequently suggested for high-β plasma, is Weibel instability. With no seed magnetic field, the Weibel mode has only imaginary frequency. The latter means that the magnetic field clamps are growing faster than propagate. For finite magnetic field **?** suggested, that Weibel mode grows as a mix of two opposite circular polarizations, attains some small real part of frequency and is fundamentally similar to drift mirror mode. Thus, in some features (linear polarization, chaotic phase) it is consistent with observations.

(In conclusions): High-β ($\beta > 10$) shocks are relatively rare and largely unexplored class of Earth bow shock. Formation of high-β interplanetary plasmas is mostly related with dense slow solar wind and very low magnetic field up to 1–2 nT. Due to spatial variability of low IMF, it is more difficult to determine shock geometry for higher β (in

OMNI) cases. However, at some (large) β shock structure should become independent from magnetic field direction. This is an interesting direction of future studies.

In oblique and quasi-perpendicular shocks, the main magnetic field and ion density jumps are smeared to several hundred km. Dominating magnetic variations have amplitudes much larger than the background field, frequencies 0.2–0.5 Hz, sometimes, $\sim$2 Hz. Polarization is mostly irregular and close to linear. The spatial scales range from several tens to couple hundred km. These properties are definitely different from that for fast magnetosonic or Alfvén modes earlier reported for other shock types. In some features the variations may be consistent with the Weibel instability, but observations with more closely spaced spacecraft are necessary to conclude more definitely on the wave mode.

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