Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-6-SC1, 2019

Annales
Geophysicae
Discussions

Interactive comment on "Comments on "Cavitons and spontaneous hot flow anomalies in a hybrid-Vlasov global magnetospheric simulation" by Blanco-Cano et al. (2018)" *by* Gábor Facskó

Xochitl Blanco-Cano

xbc@geofisica.unam.mx

Received and published: 4 February 2019

Below we describe the main characteristics of hot flow anomalies and spontaneous hot flow anomalies. We also address specific points mentioned in the comment by Facskó (2019), and include information that supports the identification of SHFAs in our article Blanco-Cano et al., 2018 "Cavitons and spontaneous hot flow anomalies in a hybrid-Vlasov global magnetospheric simulation".

Hot flow anomalies (HFAs) are structures of hot tenuous plasma which form when a solar wind discontinuity (current sheet/tangential discontinuity) interacts with a planetary bow shock [Thomsen et al., 1993; Schwartz, 1995; Lucek et al., 2004]. Particles, reflected from the bow shock, can be swept toward the interplanetary current sheet where they become trapped and heated when the motional electric fields have the appropriate orientation. HFAs are characterized by a hot core of deflected plasma with bulk velocities much slower than those of the solar wind, in addition the magnetic field magnitude and density decrease inside them. The edges of HFAs show strong compression regions with enhanced density and magnetic field magnitude. Due to expansión, it is posible that shocks are observed at one or both edges of HFAs. (Lucek et al., 2004, Schwartz et al., 2018).

Spontaneous hot flow anomalies (SHFA) share several of the characteristics of HFAs, the plasma in their cores is hot with decrements in magnetic field magnitude and density. In addition, the solar wind flow inside them is decelerated and deflected.The edges of SHFA show compression, with enhanced magnetic filed magnitude and density (Zhang et al., 2013).

Although these two type of foreshock transients share various properties, SHFAs and HFAs are different structures because the former are not associated with solar wind current sheet interaction with the bow shock, while HFAs are. The proposed formation mechanism for SHFAs includes multiple ion reflection between foreshock cavitons and the bow shock (Omidi et al. 2013) as cavitons approach the shock and ion trapping by the cavitons. To our knowledge, no shock formation has been reported at the edges of SHFA.

Below we address specific points related to our paper.

Density values on Figure 3 are displayed in a logarithmic scale and decrements in n_p do not show so well. Areas shaded in grey, yellow and blue satisfy the caviton criteria $n_p < 0.8 n_{psw}$ and $B < 0.8 B_{sw}$. Only the structures where $\beta > 10$ are identified as SHFAs. These structures satisfy $T > 4X10^6 K$, which is in agreement with the temperatures reported in the literature for SHFAs (Zhang et al., 2013, Chu et al., 2017). The same applies to Figure 7 with SHFAs observed only at cuts 1 and 3 very near the bow shock. Figure 9 shows clear drops in B and N satifying the criteria for cavitons, and this structure is identified as a caviton: "Figure 9 shows a time series from a virtual spacecraft positioned at $x = 0R_E$, z =-$35R_E$ around the time when a caviton, marked by the green area on the plot, crosses this location." We are not aware of any requirement for shocks associated with the shoulders of SHFAs - HFAs yes, but not SHFAs. As stated in Zhang et al., 2013, SHFAs show that the low density and magnetic field strength core is bounded by compression regions on both edges. For HFA the situation can be different with over-pressure causing HFA expansion, and the possibility of shocks being driven at one or both edges (Lucek et al., 2004, Schwartz et al., 2018).

Concerning VDFs: The Lucek et al., 2004 and Zhang et al. (2010) figures are both for HFAs, not for SHFAs. The Zhang et al. (2010) figure is from within the quasi-parallel shock region, and is very similar to what we show in panels c, h and n of Figure 6, with the solar wind beam and backstreaming ions which have been thermalized. Zhang et al. (2013) show distributions inside a proto-SHFA which are less thermalized than the ones we show in Figure 6. In relation to the shoulders at the edges of SHFA: Our model limits the shoulders associated with SHFAs and cavitons due to the used total variation diminishing flux limiters (a common tool for maintaining stability in advective numerical methods). Hybrid-PIC models do not use flux limiters, so can indeed have stronger peaks and shoulders. Hybrid-Vlasov models on the other hand have realistic dipole moments and noise-free tenuous plasma description throughout the foreshock region.

Our model lacks the turbulent magnetic fields within SHFAs as we do not attempt to model grid-scale field oscillations.

The fact that shoulders growth is limited in our model, does not affect the study of their dynamics and evolution as they cross the bow shock. The lack of the turbulence inside the SHFA does not limit the main goals of the study.

Velocity decrements occur in most of our identified SHFAs. More analysis of spacecraft data are needed to understand in a better way decrements and deviations of velocity inside SHFA. As stated in Parks et al., 2013, a solar wind beam with steady velocity and constant temperature can be observed inside HFAs. The decrement in velocity is due to the appearence of backstreaming particles that move in the oposite direction to the solar wind and can reduce the mean velocity as computed via moments. This second population also can contribute to increments in temperature via moment calculation.

References

Chu C., H. Zhang, D. Sibeck et al., Ann. Geophys., 35, 443-451, 2017.

Lucek, E. A., Horbury, T. S., Balogh, A., Dandouras, I., and RèMe, H.: Cluster observations of hot flow anomalies, Journal of Geophysical Research (Space Physics), 109, A06207, https://doi.org/10.1029/2003JA010016, 2004. Omidi, N., Zhang, H., Sibeck, D., and Turner, D.: Spontaneous hot flow anomalies at quasi-parallel shocks: 2. Hybrid simulations, Journal of Geophysical Research (Space Physics), 118, 173–180, https://doi.org/10.1029/2012JA018099, 2013.

Parks G. K., E., Lee, N. Lin et al 2013 ApJL 771 L39, 2013.

Thomsen, M. F., V. A. Thomas, D. Winske, J. T. Gosling, M. H. Farris, and C. T. Russell, Observational test of hot flow anomaly formation by the interaction of a magnetic discontinuity with the bow shock, J. Geophys. Res., 98(A9), 15319–15330, doi:10.1029/93JA00792, 1993.

Schwartz S. J., Hot flow anomalies near Earth Bow shock, Adv. Space Res., 15 (8/9), 1995

Schwartz S. J., Avanov, L., Turner, D., Zhang, H., Gingell, I., Eastwood, J. P., et al., Ion kinetics in a hot flow anomaly: MMS observations. Geophysical Research Letters. 45, 11,520–11,529. https://doi.org/10.1029/2018GL080189, 2018.

Zhang, H., Sibeck, D. G., Zong, Q.-G., Gary, S. P., McFadden, J. P., Larson, D., Glassmeier, K.-H., and Angelopoulos, V.: Time History of Events and Macroscale Interactions during Substorms observations of a series of hot flow anomaly events, Journal of Geophysical Research (Space Physics), 115, A12235, https://doi.org/10.1029/2009JA015180, 2010.

Zhang, H., Sibeck, D. G., Zong, Q.-G., Omidi, N., Turner, D., and Clausen, L. B. N.: Spontaneous hot flow anomalies at quasi-parallel shocks: 1. Observations, Journal of Geophysical Research (Space Physics), 118, 3357–3363, https://doi.org/10.1002/jgra.50376, 2013.

Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-6, 2019.