Review report on "Short Large-Amplitude Magnetic Structures (SLAMS) at Mercury observed by MESSENGER" by T. Karlsson, F. Plaschke, A.N. Glass, and J.M. Raines.

This work is a valuable investigation of SLAMS at Mercury. The authors surveyed 4 years of MESSENGER data finding 429 events identified as SLAMS in the near-Mercury environment for later categorization into 4 types according to specific characteristics of the events. This is already an important achievement as previous studies of SLAMS in Mercury have a case-by-case approach. Statistics on duration, location, and magnetic field are presented in this work, then authors move to explore possible dependencies of SLAMS, particularly in terms of the geometry of the shock and their relation to this structure. Though some questions arise in the first part of the manuscript which would benefit from some clarifications, the second part is in need of more discussion.

The authors explore the full near-Mercury environment and found SLAMS-like signatures, including both quasi-parallel and perpendicular upstream regions. There is a problem from the beginning, as the authors do not confine the search to the foreshock region where ULF waves exist and can evolve into SLAMS. When considering the quasi-perpendicular region the authors found events that resemble SLAMS' features but is hard to think they truly are such structures as there is no source for them there. The are two main concerns about this that the authors do not succeed to explain/sustain and even contradict themselves (see my comments on Sec. 3.2.5 and on lines 305-313 of the Discussion):

- SLAMS-like events are found in regions with large θ_{Bn}, which is unexpected as such structures are native to the quasi-parallel region upstream of the shock.
- SLAMS-like events are found in regions magnetically unconnected to the bow shock, despite such structures are related to the foreshock.

It is well written with a logical order in the presentation of results and discussion. Being a statistical analysis it gives good information on these structures and potentially will allow to establish comparison of such structures at Mercury and other planetary environment. However, as said before some of the physical interpretation needs stronger arguments/reasons, and so the reviewer asks for major revisions before the manuscript could be in shape for publication.

MAJOR COMMENTS

Lines 5-6: The author mentioned studying cases of SLAMS isolated from ULF waves which differ substantially from the definition of SLAMS as steepened waves. ¿What is the SLAMS formation mechanism in that case?

Lines 15, 20: The foreshock is, by definition, the region magnetically connected to the shock as it is the region where SW incident particles are reflected by the shock meaning that is the quasi-parallel region upstream of the shock. But here it says it can be connected to the quasi-perpendicular portion which is not true.

Line 50: What does it mean cyclic behavior of SLAMS?

Sec. 2.3 Does the Tao model work only for quiet solar wind conditions? Is this the best model to use when lacking plasma measurements? Could ENLIL work best for this purpose?

Line 120: Though the enhanced particle flux and waves are a good sign of being in the foreshock region, the magnetic field depression around 11:10 UT is not consistent. We would expect strong perturbations of the field but not such a decrease. Even more, the field magnitude goes well below the ambient solar wind or even the values for the foreshock at around 10:45 UT. One even could argue that this structure resembles a Hot Flow Anomaly.
i) What is behaving the ion velocity?
ii) What is the authors' physical interpretation of such low B-field?
iii) How far from the bow shock is the SLAMS located?
iv) Is the event here presented the most typical one in the catalog? Is it representative of the other 428 cases?

Sec. 3.1 The zoom-in of the event (Figure 1h-j) shows a nice analogy with SLAMS observed at Earth as the authors pointed out (shape, compression, polarization, and frequency). But the region where these structures are seems to be more complex than just a foreshock region (Figure 1 a-d). I would suggest including a more "typical" (Earth-like) case and keeping this complex event with more discussion on the plasma surrounding the SLAMS.

Line 147-149: Could the authors check for the solar wind velocity or dynamic pressure of all the cases, particularly those within the sheath? To have an idea whether they were observed during periods of fast/dense solar wind or even during the passage of some solar transient so that the bow shock location could be moved closer to the planet. Perhaps this would also give information on SLAMS and solar wind dependency.
i) How many SLAMS are downstream of the modeled bow shock?
ii) There are two clear outliers in the sample, around x~2.2R_M and rho~4.3R_M. Do they have any particular signature or difference from the rest?

Sec. 3.2.1 a) Are the types of SLAMS somewhat related to the distance they were observed? Can they be identified as clusters in Figure 2.
b) The “higher frequency” category seems to be just very compressive waves that satisfy the only B-field criteria. In that sense, there is a reasonable doubt that the 40 structures in this category are SLAMS. Do the authors check if they are embedded in the foreshock region (ion spectra) in the visual inspection? What is the angle θ_{Bn} for those events?

Sec. 3.2.2 a) Are the 11 whistler precursors observations the only ones in the whole dataset? Or just 11 cases were labeled as such? b) Are the 11 cases within the “sharp” SLAMS category? c) I suggest including an event positively identified as a SLAMS instead of the shocklet presented in this section for continuity of the main topic which is SLAMS.

Sec. 3.2.3 From Figure 3 it is clear that isolated/sharp structures will have shorter/larger duration than any other category, possibly infringing some biased in the statistics. On the other hand, the duration reported by Schwartz et al. (1992) corresponds to SLAMS of the wave field or sharp category. In order to have a better comparison with their terrestrial counterparts, it would be good to include the statistics for each category.

Sec. 3.2.4 The solar wind around Mercury is characterized by a low Alfvénic mach number, typically 4-6 but it can be much lower.
a) In Figure 6 the B_o for SW periods peaks at 20 nT, which is far from expected. Is this discrepancy only due to the errors in Tao’s model? What else could be responsible for it?
b) From Figure 6 it is true that as a global trend, the SLAMS will still be more prone to appear during very low M_A, which can be satisfied for a faster/denser solar wind or a low B-field. The authors focus on the second case, but no discussion on the first case is mentioned possibly because V and N are model derived. The manuscript will benefit from more discussion on how to overcome the FPI limitations and also the pros and cons of using Tao’s model.
c) Romanelli et al., 2021 showed that the occurrence of ULF waves increases for low B-field for heliocentric distances between 0.31 and 0.47 AU, which is associated with a larger reflection of SW protons as the heliocentric distance increases. The reflected particles work as the source of such waves. This will actually also explain why in the present study SLAMS defined as the result of the non-linear evolution of ULF waves, are observed for low B_o values.
d) A reference to the SW M_A should be included. See e.g. Romanelli et al. (2021) and references therein.

Sec . 3.2.5
a) How many events are downstream of the nominal bow shock in Figure 1? Is it a similar number to the groups 0 and 2 in Table 2?
b) Line 235: How was calculated the angle? Indeed this is a surprising result as SLAMS would be related to the foreshock (quasi-parallel) region where the ULF waves exist.
c) If a SLAMS is connected to the shock, that means the structure is upstream of the quasi-parallel shock. Then, according to Table 2, those are 363 events and so 66 events are in the quasi-perpendicular portion of the shock. But when calculating θ_{Bn}, Figure 9, the probability of SLAMS in the q-perpendicular region is not much lower than for the q-parallel region. These two results contradict each other.
d) One could argue that those found in the quasi-perpendicular region where not originated there but rather in the quasi-parallel region and later traveled to the other region. Actually, the authors make this point for the “isolated” SLAMS category, which sounds reasonable and could also explain -at least in part- why in Figure 9 the θ_{Bn} is so broad.
e) Line 244-249: the middle panel of Figure 11 includes only the connected events, while the other panels include connected and not connected which prevents the reader from a direct comparison. The authors should show all panels for only the connected events. See my comment on lines 256-257.
f) Line 250: This result again sustains the fact that the probability of SLAMS in the foreshock region (connected to the shock, Table 2) is higher, but opposite to what is shown in Figure 7. This review has no other but to ask again for a response to such a dichotomy.

Line 256-257: The authors note the SLAMS they studied -similar to Earth- “are found on field lines connecting to the bow shock”. Therefore SLAMS are foreshock structures and so they are 363 of such SLAMS which should have θ_{Bn} angles typical for the quasi-parallel region upstream of the shock. The problem explained in my comments on Sec. 3.2.5 prevails here.

Lines 267-274: What are the θ_{Bn} angles of the 6 isolated events? Are they in the “connected to the shock” group? This reviewer thinks the connectivity to the shock would be more important to check before the type of structures, as it will be warranted that the structures are in the foreshock. Could the authors check for the 363 events connected to the bow shock how many structures are for each category? Is the isolated category still there?

Lines 284-286: How this ratio will give information on the wave growth rate? Please explain.

Lines 287-295: One can argue that because of the weak bow shock at Mercury, in terms of its M_A, the reflection of particles is less effective than at Earth. This would mean that waves possibly need more time to develop from the resonance of incident and backstreaming particles. The number of wave periods for a “geometrically equivalent” distance, and hence growth rate, would be lower at Mercury than at Earth.
On the other hand, authors could find some references to the typical ULF waves frequency at Earth and Mercury, calculate the ratio and on the other hand calculate the number of wave periods separately for each planet. This way they could avoid “rough estimates” and have more realistic numbers.

Lines 297-301: In the cited works, indeed it is shown that some characteristics typical of a foreshock region can be found for angles θ_{Bn} larger than 45°; however it is very clear that the distribution of parameters peaks for 15-40° (see Glass et al., 2023). Events beyond θ_{Bn}=50° are scarce and do not representative of the whole sample. This scenario differs widely from what is presented here in Figure 9 and cannot be compared. What is more, Blanco-Cano et al., 2009 reported ULF waves far from the nose of the shock for a radial IMF configuration and for low cone angle, θ_{BV}, that is still well within the foreshock; but do not report foreshock-like parameters/particles/waves for large θ_{Bn}. In brief, the explanation for the unexpected behavior of θ_{Bn} in Figure 9 is reasonably arguable.

Lines 301-304: The authors could estimate the size of the SLAMS along the spacecraft trajectory, either using a proxy (case by case) or an average of the V_{sw}. Normalized to R_m would give a better idea of how extended are the structures in order to help sustain this alternative explanation.
Actually, one can take the 1.2s with an average V_{SW}~460 km/s (Diego et al. 2020 and references therein), we found the extension to be 0.22R_M. This reviewer finds it hard to think that a SLAMS with a cross-section of (at least) 0.02 R_M located in the quasi-parallel region could be extended into the quasi-perpendicular shock. At most, one could think that if this SLAM is located at the edge of the foreshock then the statement is true; but according to the statistical results in Figure 9, there would be a very large number of SLAMS with this configuration.

Lines 305-313: In lines 286-293 and after some rough estimations on the wave growth rate in Mercury and Earth foreshocks, the authors conclude that “the non-linear development of SLAMS should be comparable between Earth and Mercury”. Such result go against the new interpretation presented now in the discussion section.

Line 338-339: As mentioned before this conclusion is reasonably arguable and should be adapted after a detailed revision of all the reviewer comments.

MINOR COMMENTS
Lines 25: the → then
Line 111: Should said “Example” as only one case is presented.
Line 133: “higher frequency oscillations **IN** the middle”
Line 142: “… has ~~has…~~”
Line 177: “SLAMS 170” possibly a typo?
Line 180: “gyro radius” → gyrofrequency
Line 200: On → One
Line 227: 0.5;R_M → 0.5R_M
Figure 6: The unit for B_o is missing in the label for the horizontal axis.

References:

1. Romanelli, N., DiBraccio, G.A. Occurrence rate of ultra-low frequency waves in the foreshock of Mercury increases with heliocentric distance. (2021) Nat. Commun. 12, 6748. https://doi.org/10.1038/s41467-021-26344-2
2. Zhang, H., Zong, Q., Connor, H. et al. (2022) Dayside Transient Phenomena and Their Impact on the Magnetosphere and Ionosphere. Space Sci Rev 218, 40. https://doi.org/10.1007/s11214-021-00865-0
3. Diego, P., Piersanti, M., Laurenza, M., & Villante, U. (2020). Properties of solar wind structures at Mercury's orbit. Journal of Geophysical Research: Space Physics, 125, e2020JA028281. https://doi.org/10.1029/2020JA028281