Statistical Assessment of Mercury's Northern Plasma Sheet Horn with MESSENGER Data

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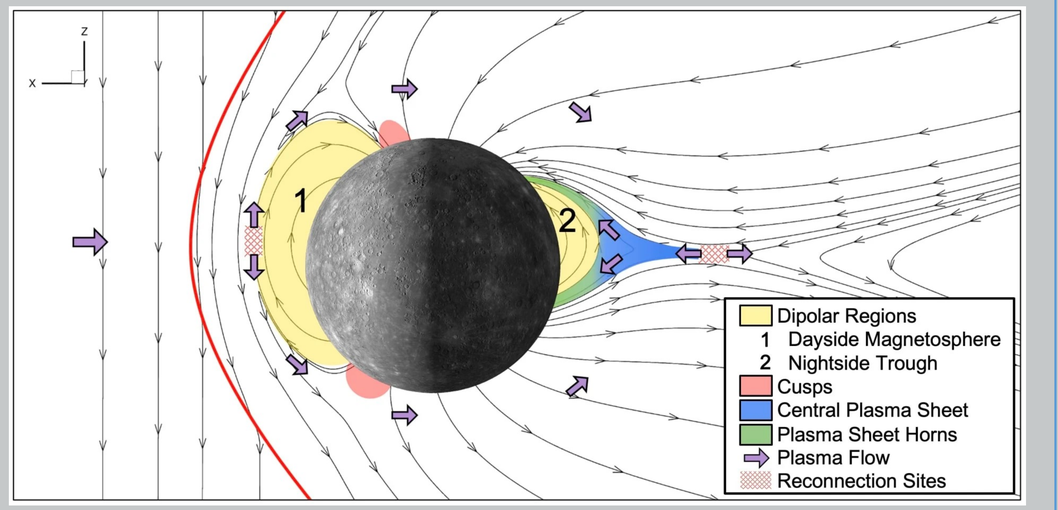
1. Abstract

Mercury's magnetosphere is the most like Earth's of any in the solar system, dominated by the Dungey cycle in its dynamic response to solar wind forcing. We have identified, and describe in detail for the first time, Mercury's northern plasma sheet horn (in green at right) – a Dungey cycle feature key to plasma precipitation. We found three possible geometries for potential horn observation by MESSENGER, and describe a case study here in detail. Estimates of proton precipitation flux are performed, which show precipitation levels on the same order of magnitude as the estimated proton precipitation flux in the dayside cusp, despite the higher average energy of the protons in the horn. Potential paths for future study of the horns are discussed, including opportunities for statistical analysis across the MESSENGER mission.



2. Sample Orbit

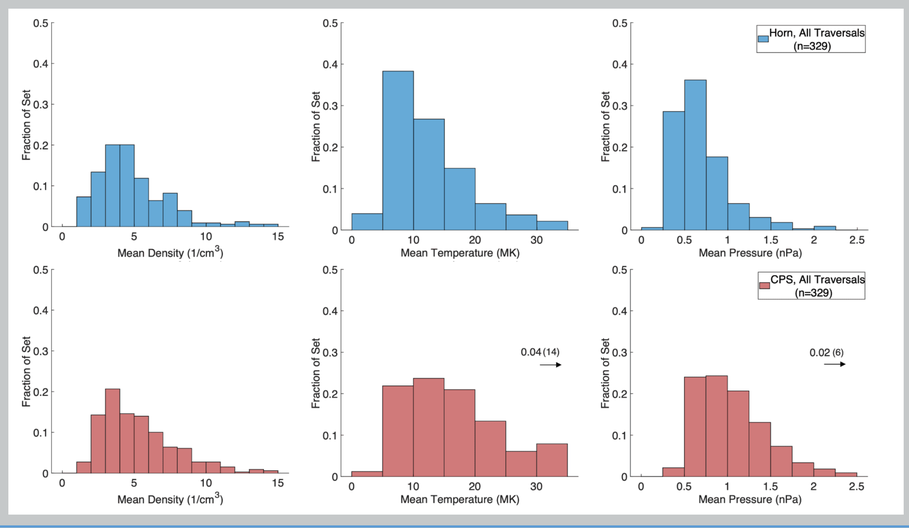
The below figure displays a traversal of the northern plasma sheet horn and central plasma sheet at Mercury. On the right are time-series panels showing the energy spectrogram, colored according to proton flux in $(cm^2\ s\ sr\ keV)^{-1}$; pitch angle histogram; density in particles per cubic centimeter and average proton temperature; plasma beta; elevation angle of B; and the MSO X and Z components of the magnetic field and its magnitude. Vertical lines show crossings between regions labeled across the top: the sheath, dayside magnetosphere, cusp, northern lobe, northern horn, nightside dipolar trough, central plasma sheet, and southern lobe. On the left, MESSENGER's orbit is projected into the MSO XZ and XY planes with color-coded horn and CPS and the (Winslow et al. 2013) model magnetopause boundary (light blue).

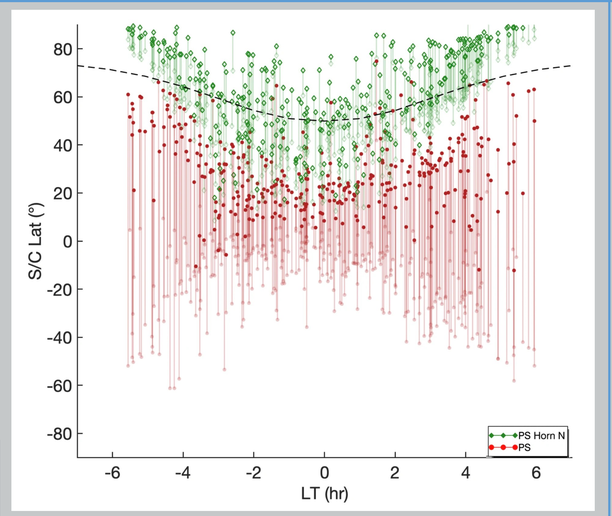
The region on the nightside labeled as the dipolar trough can be easily identified as such by its location in space (see left); smooth, dipolar magnetic field; and the presence of high-energy ring current-like ions also present in the dayside closed field region.

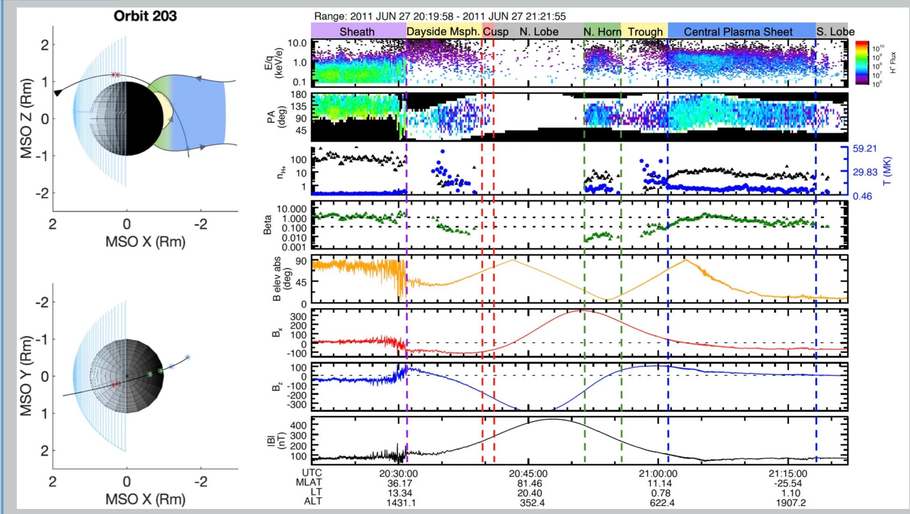
3. Statistical Survey Results

Figure at right shows the observed boundaries for the plasma sheet horn (green) and central plasma sheet (red) in a survey of over 300 events observed by the MESSENGER spacecraft. Far away from midnight, the horn is thinner and less variable than near the noon-midnight plane. The horn also begins at a lower latitude on average near midnight, which is consistent with the model open-closed field line boundary at the surface (dashed line). Thinning of the central plasma sheet toward midnight is consistent with previous results from (Poh et al., 2017), (Dewey et al., 2021), and others.

Below, analysis of plasma data in the two regions across the survey shows that the plasma is slightly less dense, at a slightly lower temperature, and at a slightly lower pressure in the horn than in the CPS, on average.







4. Conclusions and Next Steps

At this time, we have developed four primary conclusions from our work:

1. Mercury's northern plasma sheet horn is well developed, and was observed by MESSENGER in at least hundreds of orbits
2. Precipitation in the northern horn (not shown) is on the order of 4e7 per cm^2 per s - the same order of magnitude as in the northern dayside cusp.
3. A survey of over 300 horn observations has enabled new insights into the location of the open-closed field line boundary at altitude.
4. Within our survey, the density, temperature, and pressure of ions in the horn are slightly lower on average than in the central plasma sheet.

Using this data set, we plan to conduct a number of investigations into the horn and central plasma sheet, including:

1. Coincident measurements of the horn by FIPS, MAG, and other instruments acting as in-situ sensors;
2. Seasonality signals in the average density, temperature, and pressure;
3. Connections between the horn traced northern latitude – an estimate of a footpoint of the open-closed field line boundary – and conditions elsewhere in the magnetosphere; and
4. Correlations with other nightside features, including dipolarizations and loading/unloading events in the southern lobe.

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