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MESSENGER observations of large-amplitude Kelvin-Helmholtz waves at Mercury's magnetopause

Torbjörn Sundberg (1), Scott A. Boardsen (1,2), James A. Slavin (1), Brian J. Anderson (3), Haje Korth (3), Thomas H. Zurbuchen (4), Jim M. Raines (4), and Sean C. Solomon (5)
(1) Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; (2) Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, MD 21228, USA; (3) Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; (4) Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109, USA; (5) Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA (torbjorn.sundberg@nasa.gov).

1. Introduction

The Kelvin-Helmholtz (KH) instability is a driving process for planetary magnetospheres. The instability is triggered by the velocity shear at the magnetopause, which can lead to wave growth along the flanks of the magnetosphere, and eventually, rolled-up vortices that transfer solar wind plasma and energy into the magnetospheric system. The instability is known to be active at Earth during periods of northward interplanetary magnetic field (IMF) [5]. Analysis of Magnetometer data from MESSENGER's flybys of Mercury showed clear evidence for rolled-up Kelvin-Helmholtz vortices on the flanks of the planet's magnetosphere [4,8]. We here present additional evidence from MESSENGER orbital observations on how the Kelvin-Helmholtz instability serves to drive Mercury's magnetosphere when the IMF is strongly northward. In particular, the observations reported here show for the first time that the KH instability can transfer substantial amounts of magnetosheath plasma into the magnetosphere even at Mercury's post-noon magnetopause.

2. MESSENGER Observations

On 15 May 2011, MESSENGER's periapsis was located on the post-noon side of the planet, inside the dayside magnetosphere, at approximately 14:50 magnetic local time. As the spacecraft approached the equatorial plane from the north, the Magnetometer [1] observed a series of non-linear waves in the magnetic field, shown in Figure 1. The field components are given in Mercury solar orbital coordinates (MSO), where X_{MSO} is directed from the center of the planet toward the Sun, Z_{MSO} is normal to Mercury's orbital plane (positive toward north), and Y_{MSO} completes the orthogonal, right-handed system, positive toward dusk.

The fluctuations were primarily present as an oscillation in the B_x component and as saw-tooth-shaped waves in B_y. This pattern is considered a typical signature of KH waves [8]. No oscillations were recorded after the magnetopause exit at ~09:31:20 UTC, and the magnetic field remained strongly northward throughout the magnetosheath. After the bow shock crossing, MESSENGER also recorded a strong, steady northward IMF in the solar wind for more than an hour after the vortex encounters.

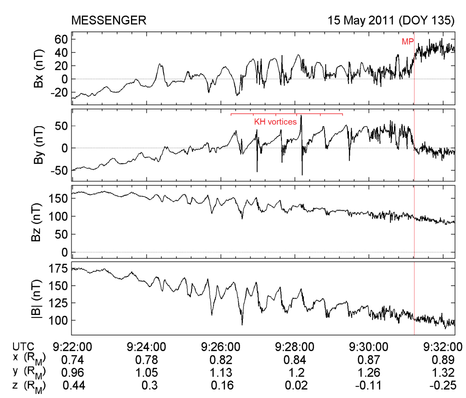

Figure 1: Overview of MESSENGER Magnetometer measurements on 15 May 2011. The panels show the magnetic field components and magnitude versus time and position, given in units of Mercury radius R_M. A vertical red line marks the magnetopause (MP).

The Fast Imaging Plasma Spectrometer (FIPS) measurements [3] for this event are displayed in Figure 2. The plasma measurements also showed clear periodic signatures of dense magnetosheath plasma at each wave encounter. This behavior is strong evidence for a train of KH vortices traversed by the spacecraft on the inside of the magnetopause, filled with magnetosheath plasma and twisting the magnetic field lines as they roll-up.

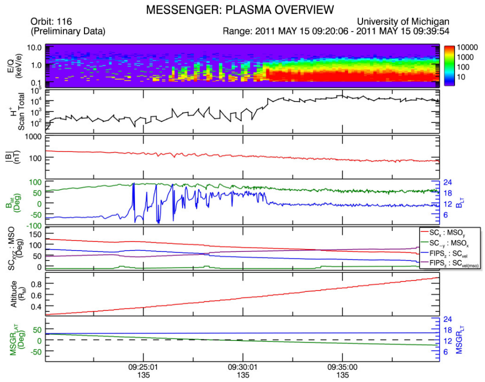

Figure 2: FIPS plasma measurements for 15 May 2011. Top to bottom are relative phase space density (arb. units) of H^+ versus energy per charge (E/Q), total H^+ relative phase space density (arb. units), the magnetic field properties, the FIPS and spacecraft pointing angles, and the spacecraft position.

3. Discussion

The IMF observations suggest that the solar wind was extremely stable and held favorable conditions for the KH instability for the duration of the event. The saw-tooth pattern observed in the B_y component of the magnetic field is a clear signature of non-linear KH waves, which, together with the repeated pattern of the particle observations, show that magnetosheath plasma was being merged into the magnetosphere by KH waves that were already fully developed in the post-noon sector of the magnetopause. This observation implies high KH growth rates at the sub-solar magnetopause. In comparison, most KH observations at Earth have reported non-linear waves only tailward of the dawn-dusk meridian. The observations reported here indicate that there is a substantial plasma transport connected with Kelvin-Helmholtz waves at Mercury and may provide an explanation for the thick dayside boundary layer detected inside Mercury’s magnetopause [2,6,7].

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