Ubiquity of Kelvin-Helmholtz waves at Earth's magnetopause

Shiva Kavosi , Joachim Raeder
University of New Hampshire, Durham, NH,USA

Abstract

- Magnetic reconnection is believed to be the dominant process by which solar wind plasma enters the magnetosphere. However, for periods of northward interplanetary magnetic field (IMF) reconnection is less likely at the dayside magnetopause, and Kelvin-Helmholtz waves (KHWs) may be important agents for plasma entry and for the excitation of ultra-low-frequency (ULF) waves. The relative importance of KHWs is controversial because no statistical data on their occurrence frequency exist. Here we survey 7 years of in situ data from the NASA THEMIS (Time History of Events and Macro scale Interactions during Substorms) mission and find that KHWs occur at the magnetopause ~19% of the time. The rate increases with solar wind speed, Alfven Mach number and number density, but is mostly independent of IMF magnitude.

- KHW occurs at the magnetopause ,regardless of the solar wind (SW) and IMF conditions and can significantly alter the magnetopause and thus change the energy levels of our planet's radiation belts. The K-H waves can stimulate magnetospheric ultra-low frequency waves, which transfer energy from large-scale motions to alter the behavior of charged particles on tiny scales. KHWs may thus be more important for plasma transport across the magnetopause than previously thought, and frequently drive magnetospheric ULF waves.

Event Selection

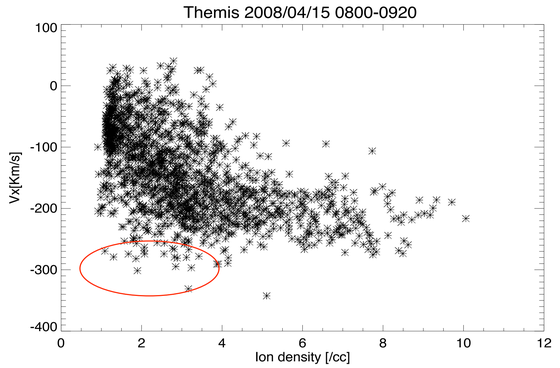

Figure 2. Scatter plot of the velocity component, Vx, tangential to the nominal magnetopause versus ion density. Here the −x direction is defined to be along the ion velocity (in GSM) and is roughly along the −M direction (anti-sunward) in LMN coordinates. The plot confirms that this event is developed rolled up vortices because fraction of the low-density magnetospheric plasmas flows faster than the magnetosheath plasma.

Detailed analysis of the event On 15 April 2008 Themis C observed quasi periodic fluctuations at dusk flank magnetopause during the interval 8:00-9:00. The solar wind had a flow speed 375 km/s and density =5 n/cc and IMF (-1.5,1,2.5) nT. Also there was no pressure pulse soon before the event. Themis C was located at (-6.8,18,-1.0) and was moving anti sunward direction during this interval. Figure 1 shows Quasi-periodic fluctuations of the bulk plasma and magnetic field parameters during the interval 0800-0900. Note that red vertical dashed lines demonstrate the density and VM (velocity in M direction) jumps from the magnetospheric to magneto- sheath which shows transient point from magnetosphere-to-magnetosheath. We expected to see total pressure minimized at the center of the vortices, while it is maximized at the edge of the edge of vortices. Each of the magnetosphere-to-magnetosheath transitions, (red dash line) characterized by a large and rapid density increase, coincides approximately with a maximum in the total pressure. We have also seen each red dash line passes through the bipolar BN and maxima in Btot (<10 nT). Moreover these fluctuations in magnetic field are continues . All these signatures confirm that Themis C observed rolled-up KH vortices. We record such events as KHI in our data set.

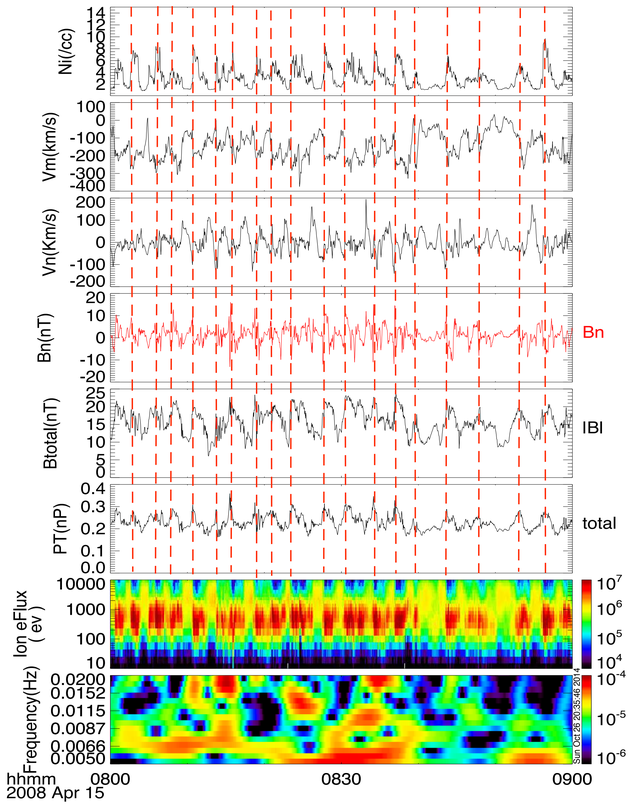

Figure 1. Time series of data in GSM taken by the Themis C on 15 Apr 2008. From top to bottom: (a) Ion density, (b) M component of the velocity (in the Earth's rest frame) VM, (c) N components of the velocity VN, (d) N component of magnetic field BN (e) Magnetic field magnitude Btotal, (f) total (magnetic plus ion) pressure, (g) Ion energy flux expectrogram plot in time versus energy versus eFlux , and (h) wavelet spectra of the total pressure .

Results

- **a)** Figure 3 (a) shows occurrence percentage of KHW (orange bins) and the corresponding number of 5-minute intervals (gray bins) as a function of solar wind speed. The latter is shown to assess the statistical significance of the data. As expected, the occurrence frequency increases with solar wind speed.
- **b)** The KHW dependence on solar wind density is weak. At low densities there is a positive correlation, which tapers out for densities larger than 10/cc.
- **c)** There is also a positive correlation with the solar wind Alfven Mach number, which also tapers out at high (>12) Mach numbers
- **d)** The IMF magnitude appears only to have an effect for unusual high values (>16 nT).

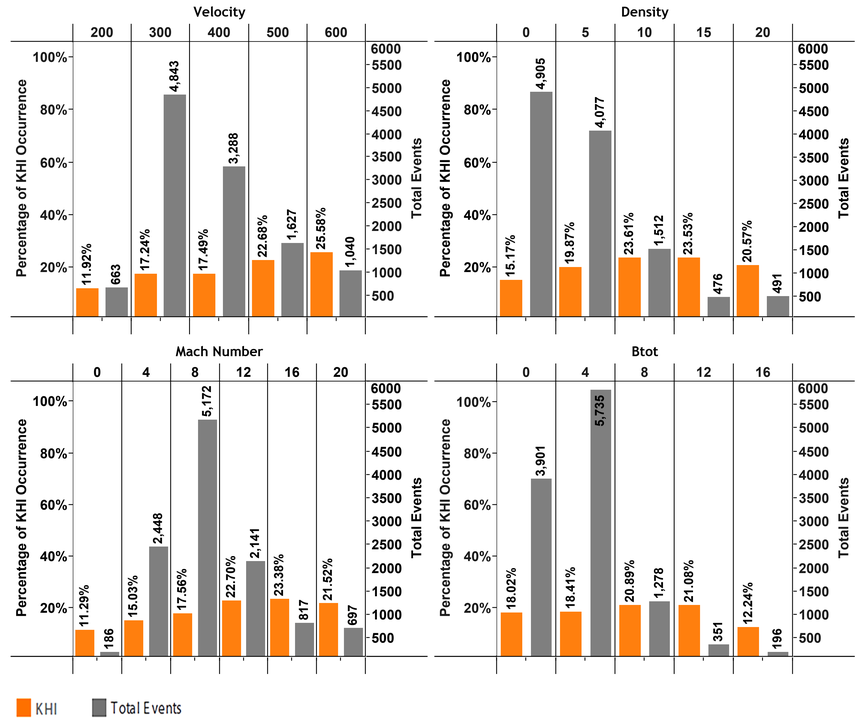

Figure 3: **Occurrence rate of KHW as a function of solar wind plasma parameters**. Orange bins show the relative KHW occurrence rate, and gray bins show the number of five-minute KHW intervals in that bin. See text for details.

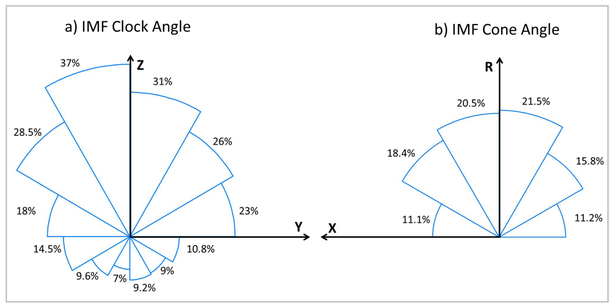

Figure 4. KHW occurrence rate as a function of IMF clock angle (atan(By/Bz) and cone angle (acos(Bx/|B|)). X points towards the sun, Y points duskward, Z points north, and R=(Y2+Z2)1/2. KHW occurrence maximizes for northward IMF, but is still significant during southward IMF (a). The IMF is more effective generating KHW when it is oriented perpendicular to the sun-Earth line (b).

Figure 4. shows the KHW occurrence rate as a function of IMF clock angle and of IMF cone angle. As a function of clock angle, the occurrence rate is ~35% for near northward IMF, near 20% if the IMF lies in the equatorial plane, and about 15% for southward IMF. The fact that KHW occurs during southward IMF at a significant rate is unexpected; because it is generally thought that magnetic reconnection would dominate during Such conditions and prevent KHW growth .

Summary

- Seven years of THEMIS data yield more than 1000 hours of magnetopause observations.
- Kelvin-Helmholtz (KH) waves produced by flow shear had been observed at the magnetopause previously, but were thought to be rare.
- THEMIS finds that KH waves occur 19% of the time. More often when the Interplanetary Magnetic Field (IMF) is northward (~40%), but also significant when the IMF is southward (~10%). This occurrence rate is much higher than expected.
- KH waves are also found when they are least expected, during slow solar wind (~270 km/s).
- The KHW occurrence rate increases with SW speed and SW Alfven Mach number and SW number density but is mostly independent of IMF magnitude. The occurrence rate increases with IMF cone angle and maximizes at zero IMF clock angle.
- The high KH occurrence frequency has significant implications for plasma entry into the magnetosphere, and for the excitation of ULF waves, which in turn energize the radiation belts.

References

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