Driving of Large Amplitude Compressional ULF waves by an IMF Southward Turning and Solar Wind Pressure Pulses

Lazzeri C.[1], Forsyth C.[1], Samsonov A.[1], Fazakerley A.[1], Archer M.[2], Elsden T.[3]

[1] Mullard Space Science Laboratory, UCL, [2] Imperial College London, [3] University of St. Andrews

Key-points

- We observe narrowband, compressional Ultra Low Frequency (ULF) waves driven by two consecutive solar wind pressure pulses.
- The amplitude and spatial extent of the waves are increased by the second pulse, which is associated with a large and rapid IMF southward turning.
- Observations by Churchill Line ground magnetometer show evidence of Field Line Resonances (FLRs) likely driven by the compressional wave.

I. Solar Wind and Magnetospheric Observations

- Magnetospheric ULF waves have been linked to the generation of Geomagnetically Induced Currents (GICs)[1,2] and the energisation and loss of radiation belt electrons[3,4]. It is crucial for us to understand what drives them.
- On September 26th, 2011, GOES 13 and 15, located at geosynchronous orbit near noon local time, observed large amplitude, compressional (*see III.*) narrowband wave activity.
  The THEMIS spacecraft (A, D, and E), located in the post-noon magnetosphere, showed evidence of multiple crossings.
- Solar wind and IMF data from ARTEMIS **P1** show a large and rapid southward turning (ST) of the Interplanetary Magnetic Field (IMF) accompanied by small dynamic pressure pulses. The SYM-H index showed the recovery phase of a storm.

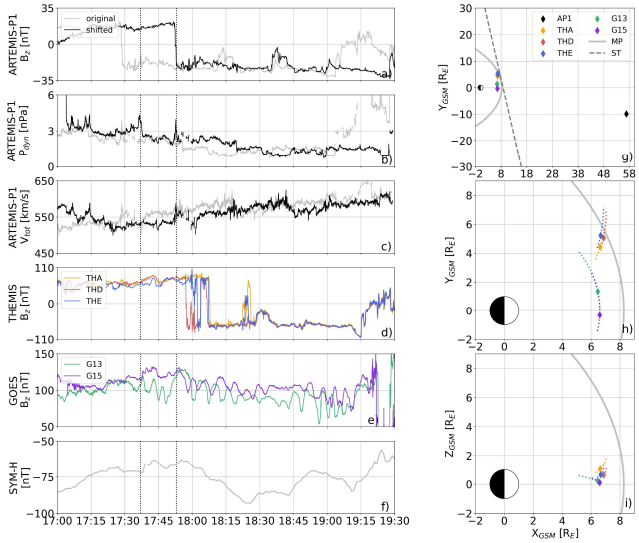

Figure 1. ARTEMIS P1 IMF B_z original (grey) and time-shifted to the magnetopause (black) **(a)** and solar wind dynamic pressure **(b),** B_z component from THEMIS A, D, E **(c)** and GOES 13 and 15 **(d)**, SYM-H index **(e)**, and spacecraft locations **(g,h,i)**.

II. Analysis of Magnetopause Motion

- Field reversals in the Y_{GSM} and Z_{GSM} magnetic field components were detected by the THEMIS spacecraft, indicating magnetopause crossings.
- THEMIS A presents a singular outbound crossing, while D and E present multiple crossings, suggesting the presence of **magnetopause oscillations** at **3.3 mHz**.
- Minimum variance analysis (MVA) on the crossings yields magnetopause normals within 4 to 25 degrees of each other, and average $\hat{n}_{mag}$ = [0.88, 0.42, 0.24], close to radial direction.

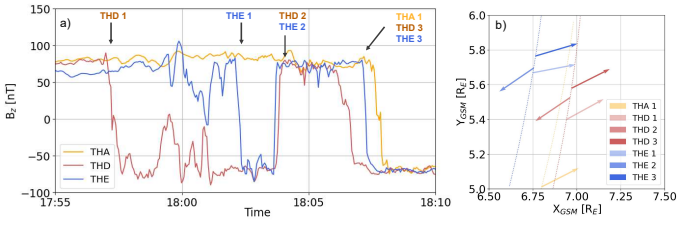

Figure 2. THEMIS A, D, and E B_z components, with arrows indicating changes corresponding to magnetopause crossings **(a)** and GSM XY projections of magnetopause normal vectors obtained by applying MVA on each of the crossings (the dotted lines indicate the THEMIS orbits) **(b)**.

III. Analysis of GOES Oscillations

- The oscillations observed at GOES are mostly **compressional** (i.e. the field-aligned), with a peak frequency of **3.03 mHz (Pc5)**.
- Waves observations at G13 begin at 17:37, and present a large amplitude enhancement at ~17:50, when wave observations also begin at G15.

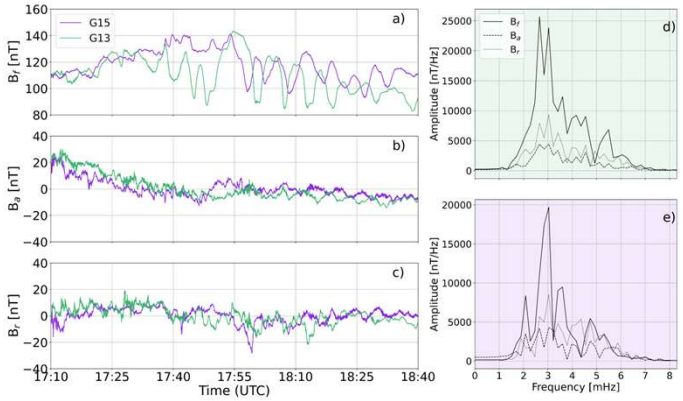

Figure 3. GOES magnetic field data in the field-aligned **(a)**, azimuthal **(b)**, and radial **(c)** component, and the respective Fast Fourier Transform spectra for G13 **(d)** and 15 **(e)**.

- The time of initial wave excitation and that of wave enhancement follow the arrival times of two **consecutive solar wind pressure pulses** at the magnetopause (~25 minutes after observation by ARTEMIS).
- We suggest the following:
  - The *first pulse* excited compressional, **standing fast mode waves** near G13
  - The *second pulse*, associated with the southward turning, led to an **enhancement** of the waves and to an **increase in their spatial extent**.

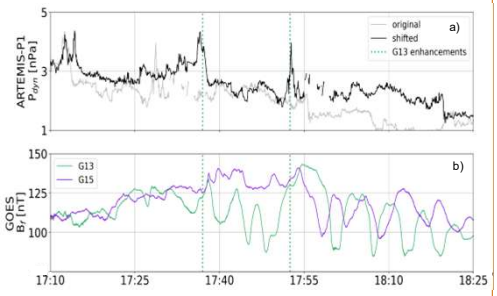

Figure 4. ARTEMIS P1 solar wind dynamic pressure **(a)** and GOES field-aligned B **(b)**. The times of G13 wave enhancements are indicated by dotted lines.

IV. Analysis of Ground Observations

- The Tsyganenko TS04 model[5] mapping suggests the foot-points of the GOES spacecraft were in Eastern Canada, near the Churchill magnetometer line.
- Churchill line magnetometers observed wave power increases at ~17:39 and ~17:53, consistent with the arrival of the solar wind pressure pulses, and analysis of the B_N component revealed similar spectra to that of GOES 13.
- Following the second solar wind pulse, pairs of closest longitudinally aligned stations show signatures of toroidal **Field Line Resonances** (FLRs), likely driven by the standing compressional wave observed at GOES.

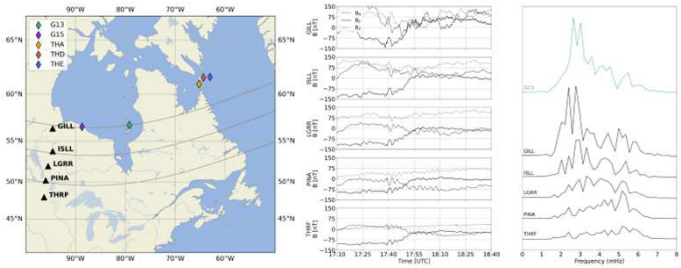

Figure 5. Location of magnetometers stations and spacecraft foot-points **(left),** and ground magnetometer data in NEZ coords **(middle),** FFT of B_N from ground magnetometers and GOES 13 B_r **(right)**.

1. Hartinger et al. (2023), *JGR*
2. Yagova et al. (2021), *Earth Planets Space*
3. Elkington et al. (2003), *JGR*
4. Mann et al. (2012), *Geophysical Monograph Series*
5. Tsyganenko et al. (2005), *JGR*

chiara.lazzeri.22@ucl.ac.uk

Manuscript in preparation