Low-frequency waves in the Martian magnetosphere and their response to upstream solar wind driving conditions by Ruhunusiri+[2015]

Reiko Nomura (ISAS/JAXA)
Dec. 24, 2015 火星勉強会拡大版

Citation: Ruhunusiri, S., J. S. Halekas, J. E. P. Connerney, J. R. Espley, J. P. McFadden, D. E. Larson, D. L. Mitchell, C. Mazelle, and B. M. Jakosky (2015), Low-frequency waves in the Martian magnetosphere and their response to upstream solar wind driving conditions, Geophys. Res. Lett., 42, 8917–8924, doi:10.1002/2015GL064968.

1. introduction

What has been done in this study.	the characterization of four modes (Alfven, Fast, Mirror mode, and slow waves) for low frequency (LF, with highest power near and below the local gyrofrequency) plasma waves by the transport ratios in the Martian magnetosphere.
Why LF waves are interesting?	Because the simultaneous existence of the induced magnetosphere and the extended exosphere at Mars presents us a unique environment to study LF plasma waves in the solar system.
Why LF waves are important?	Because they transfer the momentum and energy, and are also the indirect way to infer the underlying physics (e.g., the temperature anisotropy) operating in the Martian magnetosphere.
What's new!	Previous studies: either the magnetic field or electron and ion density measurement only for the characterization of LF waves. This study: both particle and field measurements are applied.

2. Low-Frequency Identification

- Two techniques are used for identifying four wave modes in general.
  - Dispersion relations (× two spacecraft are necessary to find a wavelength)
  - **The transport ratios** which are correlation coefficients or ratios between the magnetic field fluctuations and particle moment fluctuations [*Gary*, 1993, *Song+*, 1994, and *Denton+*, 1995] ← in this study
- The method of *Song+* [1994] can distinguish four wave modes by only four transport ratios: transverse ratio T_R, compressional ratio C_R, phase ratio P_R, and Doppler ratio D_R (↓Table 1).

Table 1. Value Ranges for the Transport Ratios for Identification of the LF Wave Modes in a High Beta Plasma Based on *Song et al.* [1994][a]

Wave Mode	$T_R = \frac{(\delta \mathbf{B} \cdot \delta \mathbf{B} - \delta B_{\parallel}^2)}{\delta B_{\parallel}^2}$	$C_R = \frac{\delta N_i^2}{N_{i0}^2} / \frac{\delta \mathbf{B} \cdot \delta \mathbf{B}}{B_0^2}$	$P_R = \frac{\delta N_i}{N_{i0}} / \frac{\delta B_{\parallel}}{B_0}$	$D_R = \frac{\delta \mathbf{V}_i \cdot \delta \mathbf{V}_i}{V_{i0}^2} / \frac{\delta \mathbf{B} \cdot \delta \mathbf{B}}{B_0^2}$
Alfvén and quasi-parallel slow	> 1	< 1	–	–
Quasi-parallel fast	> 1	> 1	–	–
Quasi-perpendicular fast	< 1	–	> 0	–
Quasi-perpendicular slow	< 1	–	< 0	> 1
Mirror	< 1	–	< 0	< 1

[a]Here $\delta B_{\parallel}$ is the fluctuating component of the magnetic field parallel to the ambient magnetic field.

The computation of the transport ratio requires fluctuating components of Fourier components of the ion density δNi, ion velocity δVi, magnetic field δB, and mean values of the ion density Vi0, and the magnetic field B0.

3. Method

- Instruments (res.)
  - SWIA (4s)
  - STATIC (4s)
  - MAG (averaged 4s)
- LF wave target
  - The frequency<0.13Hz
- The terminology
  - ✓ **Alfven waves**: both Alfven and quasi-parallel slow waves
  - ✓ **Fast waves**: both the quasi-parallel and quasi-perpendicular types.
  - ✓ **Slow wavea**: quasi-perpendicular type.

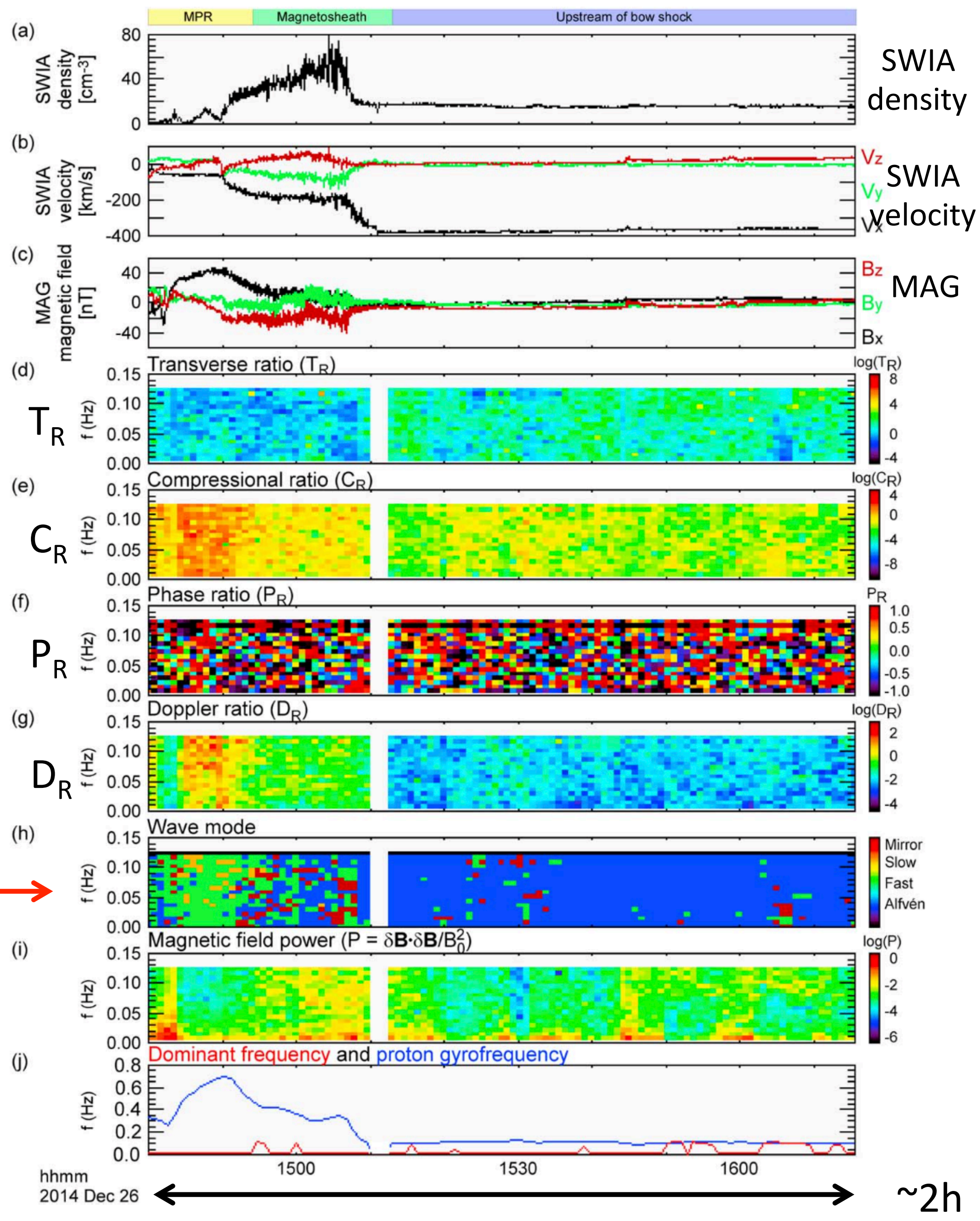
MAVEN

Transport ratios

Wave modes identified by the transport ratios

For the determination of dominant waves

MAVEN MAG



4. Caveats inside the magnetic pileup boundary (MPB)

- Instrument limitation
  - SWIA inside of the MPB
    - Incomplete the phase-space coverage and the multi-ion composition because SWIA measures the energy range of >25eV and SWIA show low count rates. → removed from in this study
    - → Comparison of SWIA and STATIC (with wider phase-space coverage from 0.1 to 30keV) transport ratios shows good quantitative and qualitative agreement.
- Method limitation
  - The *Song+*[1994] was developed to identify waves in a high beta plasma.
    - The downstream of the MPB, magnetic field draping leads to low plasma betas.
    - No definitive conclusions in this paper regarding the nature of waves downstream of MPB.

The transport ratios

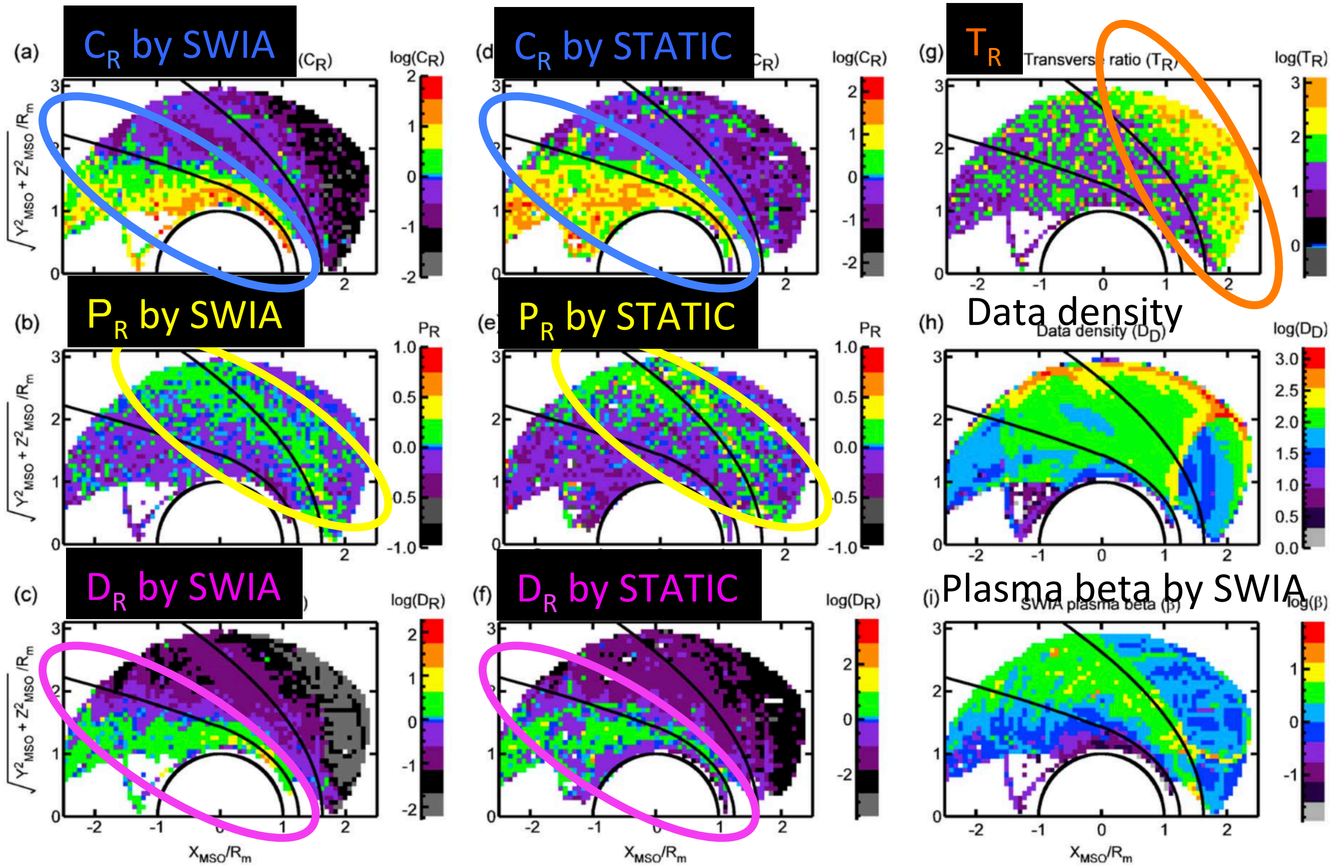
The transport ratio	interpretation
The transverse ratio T_R	$T_R>1$ means that the waves are mainly transverse.
The compressional ratio C_R	The relative fluctuation strengths of the ion density to the magnetic field.
The phase ratio P_R	The phase difference between the ion density fluctuations and the magnetic field fluctuations parallel to the ambient magnetic field.
The Doppler ratio D_R	The relative fluctuations of the ion velocity and the magnetic field.

5. Observations

Orbit maps of the four transport ratio corresponding to the dominant wave modes

Conditions
for statistical study

- MSO coordinate
- The averaged transport ratio with a spatial grid of 250km×250km ($0.06R_M \times 0.06R_M$)
- For 7 Oct. 2014-28 Apr. 2015 (> 700 MAVEN orbits)
- > the data density of 10



Interpretations…

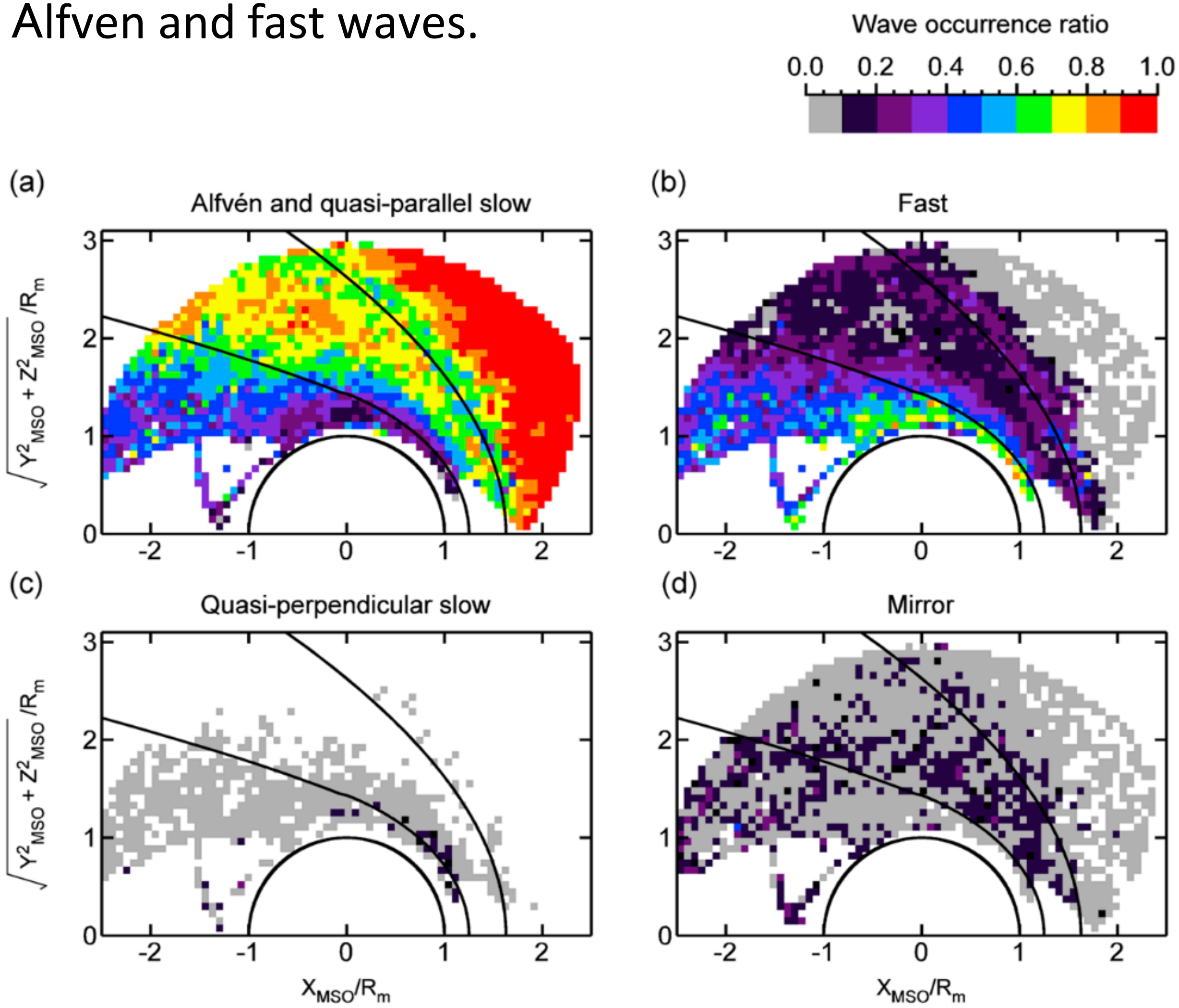
- T_R: LF waves are more transverse in the upstream region than in the magnetosphere.
- C_R: the upstream is dominated by magnetic field fluctuations
  ↔ downstream of the MPB is dominated by ion density fluctuations
- P_R the parallel magnetic field fluctuations tend to be in phase in the ion density fluctuations upstream
  ↔ out of phase in downstream
- D_R: in the upstream region the magnetic field fluctuations exceed the ion velocity fluctuations
  ↔ opposite characteristic in the downstream of MPB.

5. Observations

The wave occurrence ratios for the four LF wave modes

- The dominant wave modes in the Martian magnetosphere and in the upstream region are Alfven and fast waves.

- **Alfven waves**: the highest occurrence in both the upstream region and in the magnetosheath
- **Fast waves**: higher occurrence with going toward the MPB and at bow shocks
- **Mirror mode waves**: very low occurrence
- **Slow waves**: the lowest occurrence in the four modes

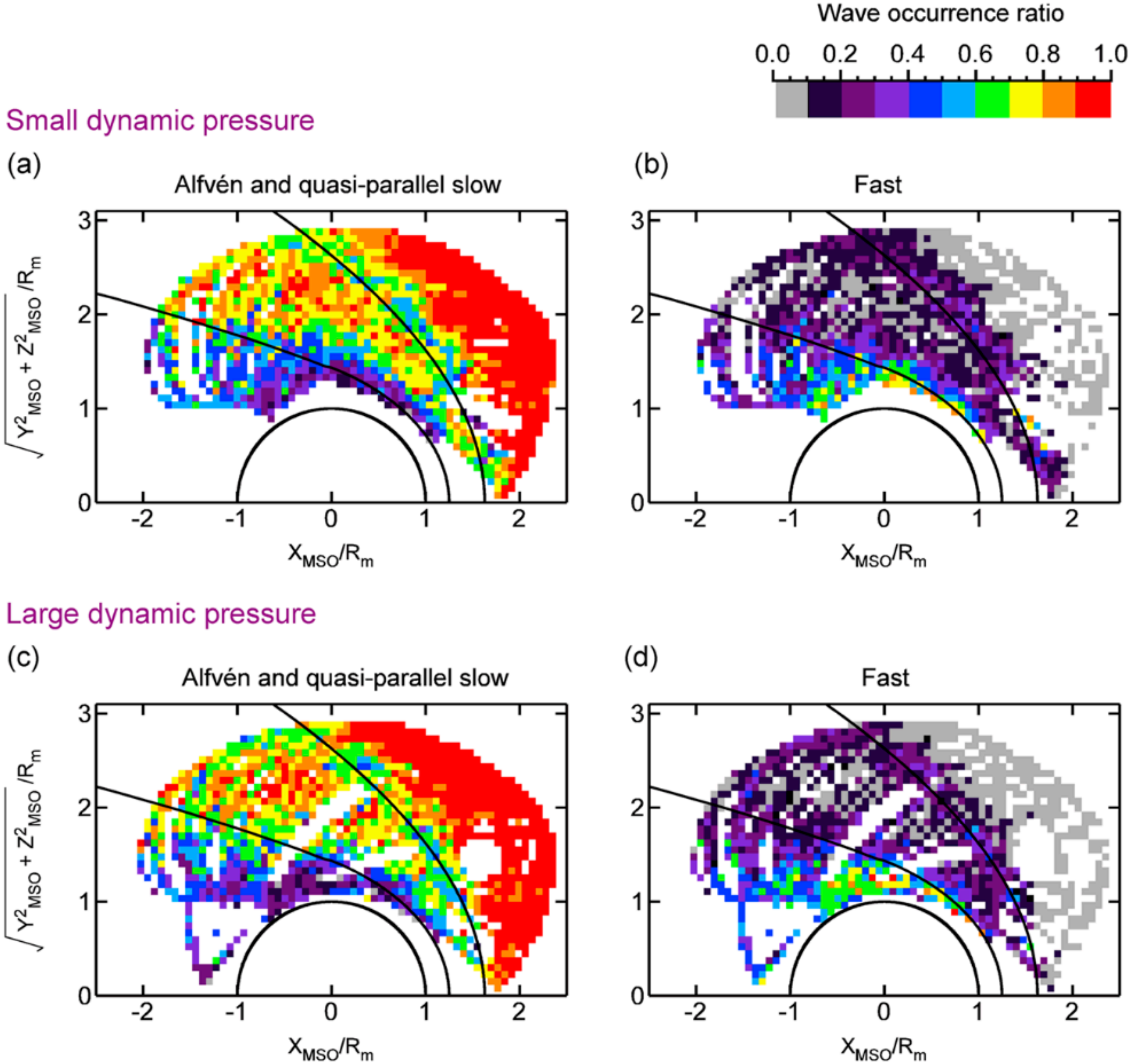


5. Observations

Alfven and fast wave occurrence ratio variability in response to the solar wind dynamic pressure variations

when the dynamic pressure is high

- **Alfven waves**:
  higher occurrence rate
- **Fast waves**:
  pushed farther inward



6. Discussion, Summary, and Conclusions

- The LF waves at were investigated by the transport ratios calculated from the MAVEN SWIA, STATIC, and MAG measurements.
- The *Song+*[1994] technique for the transport ration has been applied for a statistical investigation.

wave	characteristic
Alfven waves	the upstream Alfven waves penetrate all the way toward the MPB and possibly even deeper.
Fast waves	the high occurrence ratio near the upstream side and downstream of the MPB. ←by the KH instability?
Alfven/fast waves near the bow shock	due to bow shock phenomena such as reflection of ions and leakage of magnetosheath plasma into the upstream region? ← necessary to investigate the response to upstream conditions such as the interplanetary magnetic field direction.
Mirror mode waves	a relatively high occurrence in the dayside magnetosheath but lower occurrence than Alfven/fast waves.
Slow waves	the lowest occurrence in the four wave modes. Higher occurrence rate in the magnetosheath near the MPB and highest near the subsolar point.