Signal Characteristics in Two-Martian-Year Broadband Seismic and Magnetometer Data Recorded on the Martian Surface with InSight

InSight任務在火星表面紀錄兩個火星年的寬頻地震儀和磁力儀訊號特徵

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Introduction and Objectives

- InSight had operated two Martian years since its landing at Elysium Planitia on November 26, 2018 (Fig. 1).

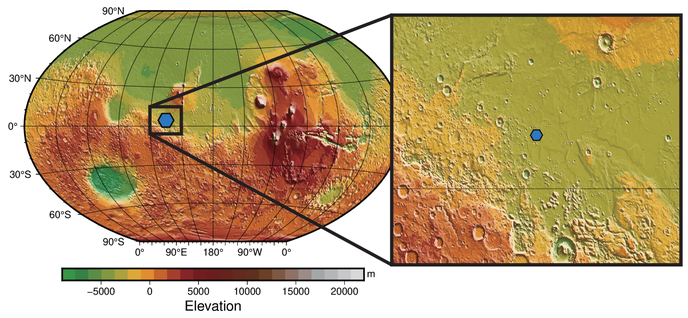

Fig. 1. InSight landing site (4.5°N, 135.9°E) on a topographic map. The topographic map uses data from the Mars Orbiter Laser Altimeter.

- One day and one year on Mars are different from Earth.
  1 sol (solar day) on Mars: ~24 hrs 40 mins (~8.9×10^4 sec)
  1 Martian year: ~668 sols (~6×10^7 sec)
- Sol #0 was the landing date of InSight, and InSight had operated about two-Martian-years (Fig. 2).

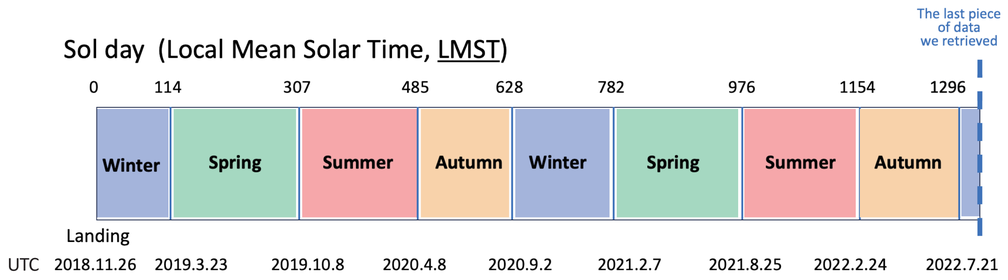

Fig. 2. The seasons within InSight mission since sol #0 (UTC 2018.11.26).

★1 Validating diurnal trends in the seismic data

Previous studies (e.g. *Lognonné et al.,* 2020 and *Ceylan et al.*, 2021) have indicated seismic data changing over the Martian day. In this summer project, first, I would like to verify these specific daily signal patterns in the data we collected from open source (doi: 10.18715/-SEIS.INSIGHT.XB_2016).

★2 Investigating the seasonal variations in both seismic and magnetic data

Additionally, we would like to explore the seismic and magnetic changes over two Martian years and identify the signal characteristics in seasonal trends.

Daily Change of Seismic Signals

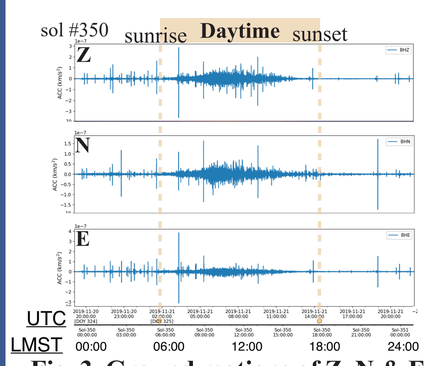

Fig. 3. Ground motions of Z, N & E components following rotation from raw U, V & W recorded by SEIS of InSight.

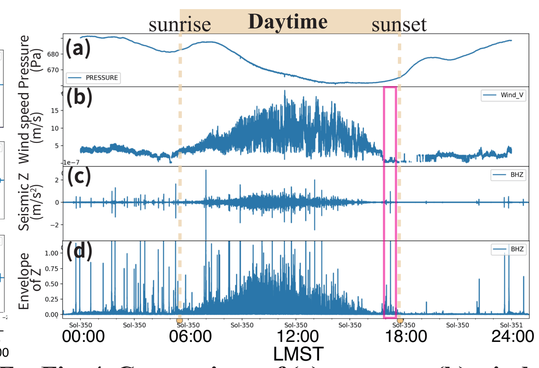

Fig. 4. Comparison of (a) pressure, (b) wind speed, (c) seismic recordings Z, and (d) envelope of Z on sol #350.

- In general, we note that the signals are stronger in daytime (Fig. 3), but quieter in early morning and night which are consistent with findings from previous studies.
- The correlation between wind speed and noise-level of seismic data can be recognized when we plot the envelope of seismic data (Fig. 4).
- The marsquakes can be detected easier while the wind is weak (see pink box in Fig. 4; *Ceylan et al.*, 2021).
- The energy for each of these vibrations is notably higher in the horizontal components compared to the verticals (Fig. 5).
- 4 Hz and 6–7 Hz signals are the lander resonances excited by wind which are clearly seen in all 3 components (Fig. 5; e.g. *Ceylan et al.*, 2021 & *Driel et al.*, 2021).
- The multiple superimposed resonant modes are seen in horizontal obviously (Fig. 5a and 5b; e.g. *Charalambous et al.*, 2021).

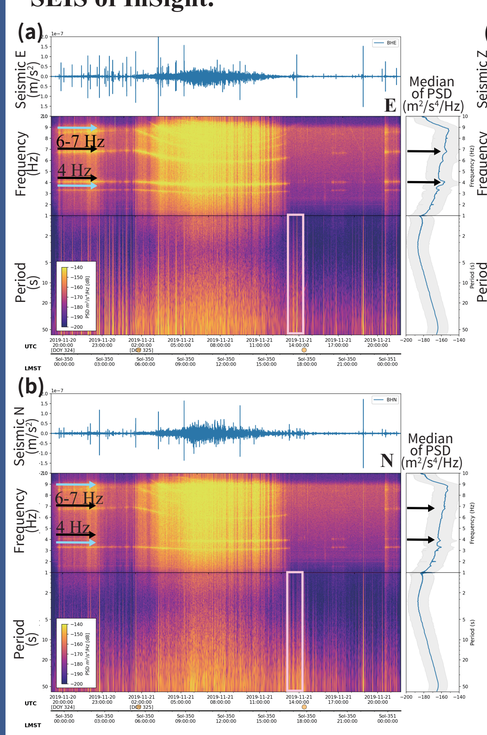

Fig. 5. The power spectral densities (PSD) for (a) E, (b) N and (c) Z components on sol #350. In each (a), (b) and (c), the color-coded panel is the spectrogram. The upper panel is the time series of ground motion, and the right pannel is the median of PSD. Black arrows indicate 4 and 6–7 Hz modes, respectively. Light blue arrows are the multiple superimposed resonant modes. Pink box is the signal-example of marsquakes.

Observations of Magnetic Fields

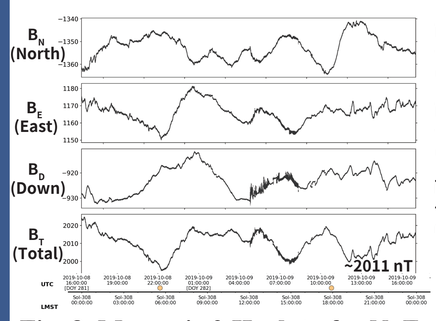

Fig. 8. Magnetic 2 Hz data for N, E and D components measured by IFG of InSight on sol # 308.

- The total magnetic strength (B_T) is calculated by N, E & D components measuring at InSight on Martian surface (Fig. 8).

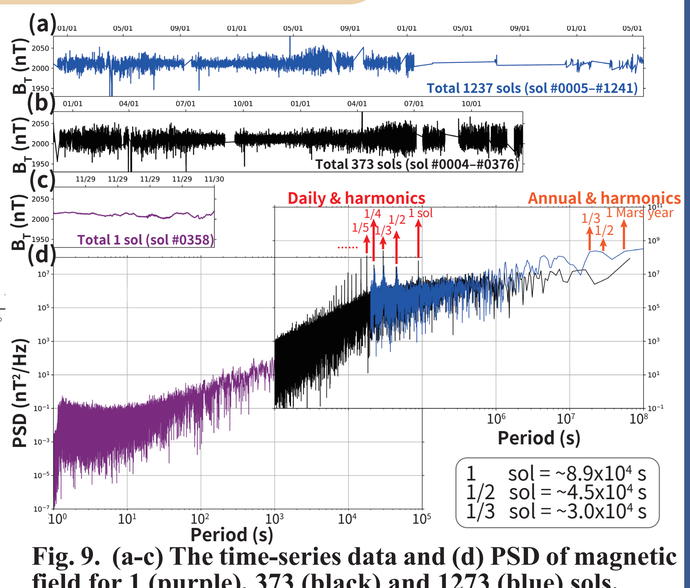

Fig. 9. (a-c) The time-series data and (d) PSD of magnetic field for 1 (purple), 373 (black) and 1273 (blue) sols.

- The peaks at 1 sol, 1/2 sol, 1/3 sol, etc. are the daily and its harmonics (Fig. 9b & d).
- Despite the data gaps, total 1237 sols magnetic data shows spectral signature at 1 Martian year, 1/2 year, 1/3 year, etc. These are the annual variation and its harmonics in the magnetic field (Fig. 9a & d).

Magnetic Field Strength on Mars: Summer vs. Autumn

- Brighter colors indicate higher power spectral density in the spectrogram (Fig. 10).
- During autumn, the daily and harmonic peaks at periods of ~10^3–10^5 sec exhibit higher energy compared to summer (red dash boxes in Fig. 10).

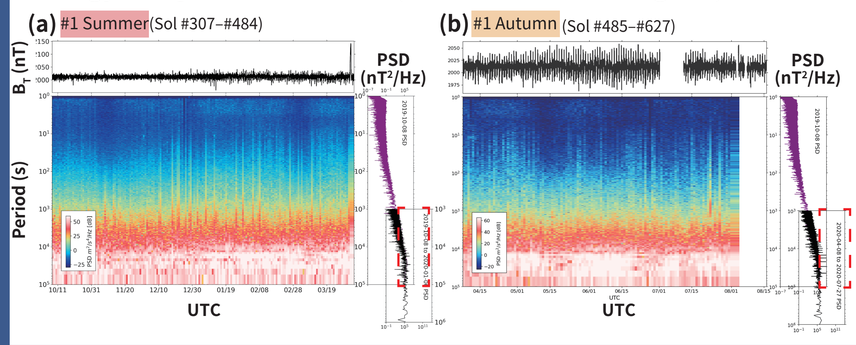

Fig. 10. Spectrograms of PSD in (a) summer and (b) autumn. Color-filled areas represent the strength of PSD. Upper and right panels show B_T in time and period domains, respectively.

Seasonal Variations of Wind Speed and Seismic Noise

- Similar to the daily changes, we observed the 4 and 6–7 Hz modes shifting to lower frequencies when noise levels were higher over two Martian years (see black dash lines in Fig. 6).
- The noise level of SEIS in autumn and winter is relatively higher (~ -150 dB) than in summer and spring (~ -160 dB, Fig. 6).
- The higher noise level in autumn and winter is associated with stronger wind (Fig. 6 and 7).

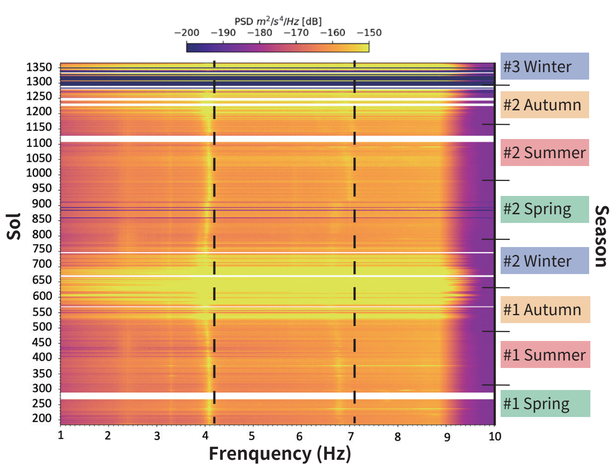

Fig. 6. The color-coded daily median of PSD from 1–10 Hz in two Martian years (sol #185 to #1366). Right y-axis corresponds to different seasons on northern hemisphere of Mars.

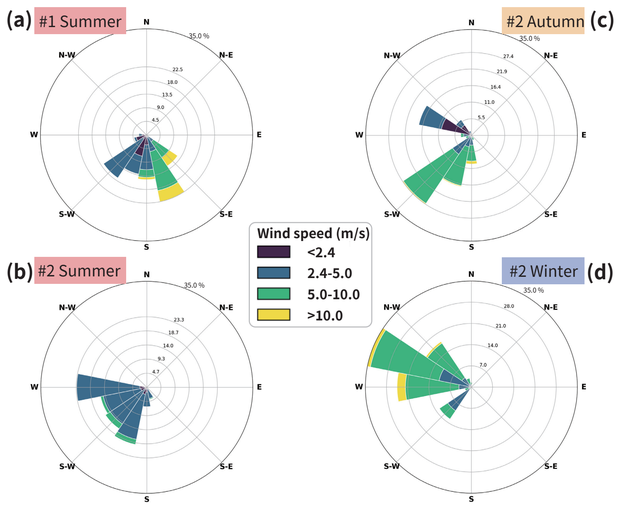

Fig. 7. The wind roses for wind speed and direction in (a & b) summer, (c) autumn and (d) winter. Different colors are wind speeds recorded by TWINS of InSight. The circles represent the percentage of time that the wind blew from a particular direction.

Seasonal Characteristics in Total Magnetic Strength

- From spectral signature between 0–1 sol (Fig. 11), the majority of peaks are strongest during autumn (especially at 1/6 sol), with exception of peak at 1 sol.
- Most prominent peaks during spring are weaker than other seasons (Fig. 11).
- In contrast, the majority of peaks within the 1–10 sols during spring are stronger than in autumn and summer (Fig. 12).
- These observations are obtained for the first time (Fig.11 & 12), so we currently lack explanations for each of the peaks.

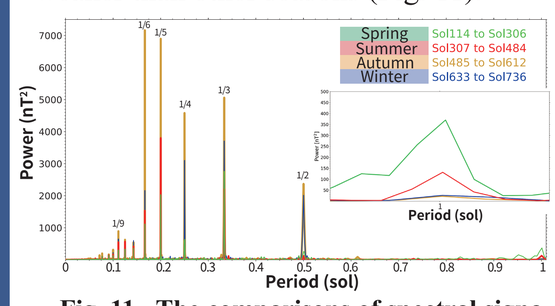

Fig. 11. The comparisons of spectral signatures between 0–1 sol across four seasons.

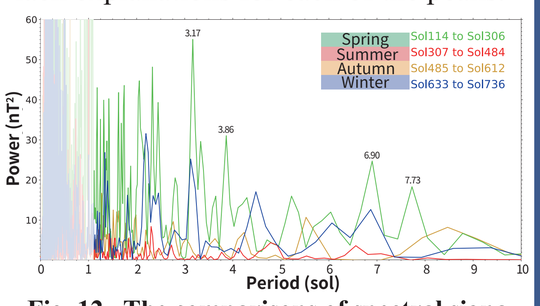

Fig. 12. The comparisons of spectral signatures between 1–10 sols across four seasons.

Key Points

- Despite the wind and thermal shield covering the seismic sensors, 4 and 6–7 Hz modes remain distinctly visible in noise background, and their strength increase with higher wind speeds. These modes shift to lower frequencies in higher noise levels over two Martian years.
- In summer and spring, seismic signals are weaker by ~10 dB than in autumn and winter. These differences match the changing wind speeds across four seasons.
- The primary signals observed in the power spectral density of the magnetic data collected at the Martian surface over a total of 1237 Martian days are the daily period, annual variations, and their harmonics.
- Spectral peaks occurring in less than 1 sol are most pronounced during autumn and weaker in spring. However, for peaks spanning from 1 to 10 sols, spring shows stronger signals compared to autumn.

References & Acknowledgements

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Other InSight data used in this study are from Planetary Data System Geoscience node. https://pds-geosciences.wustl.edu/missions/insight/

Data and Software Data from the article 'High frequency seismic events on Mars observed by InSight. https://zenodo.org/record/4383084

NASA IRIS PDS PyGMT ObsPy A Python Framework for Seismology IPGP DLR JPL Jet Propulsion Laboratory California Institute of Technology