

Supplementary Information for
**Direct Evidence for Cross-scale Energy Transfer in
Mars's Space**

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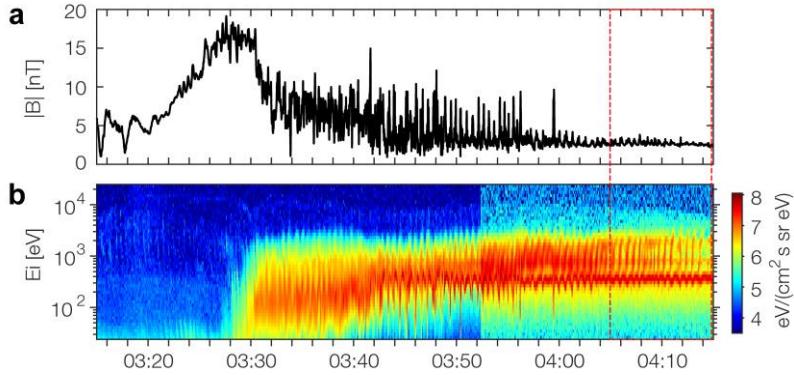
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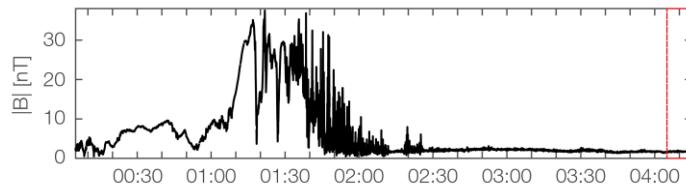
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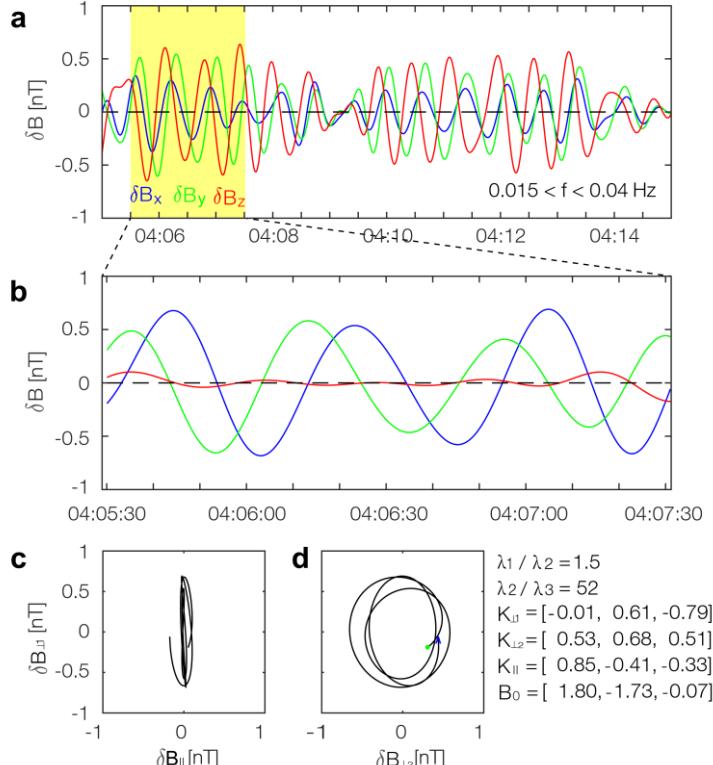
37 **Supplementary Fig. 1. MAVEN crossing a quasi-parallel bow shock.** **a** Magnetic
 38 field strength. **b** Ion differential energy flux. Approximately 35 minutes prior to the
 39 interval of interval (marked by red dashed box), MAVEN's passage across the bow
 40 shock into the solar wind detected a broad shock transition region characterized by
 41 intense magnetic field fluctuation—a signature indicative of a quasi-parallel bow
 42 shock.

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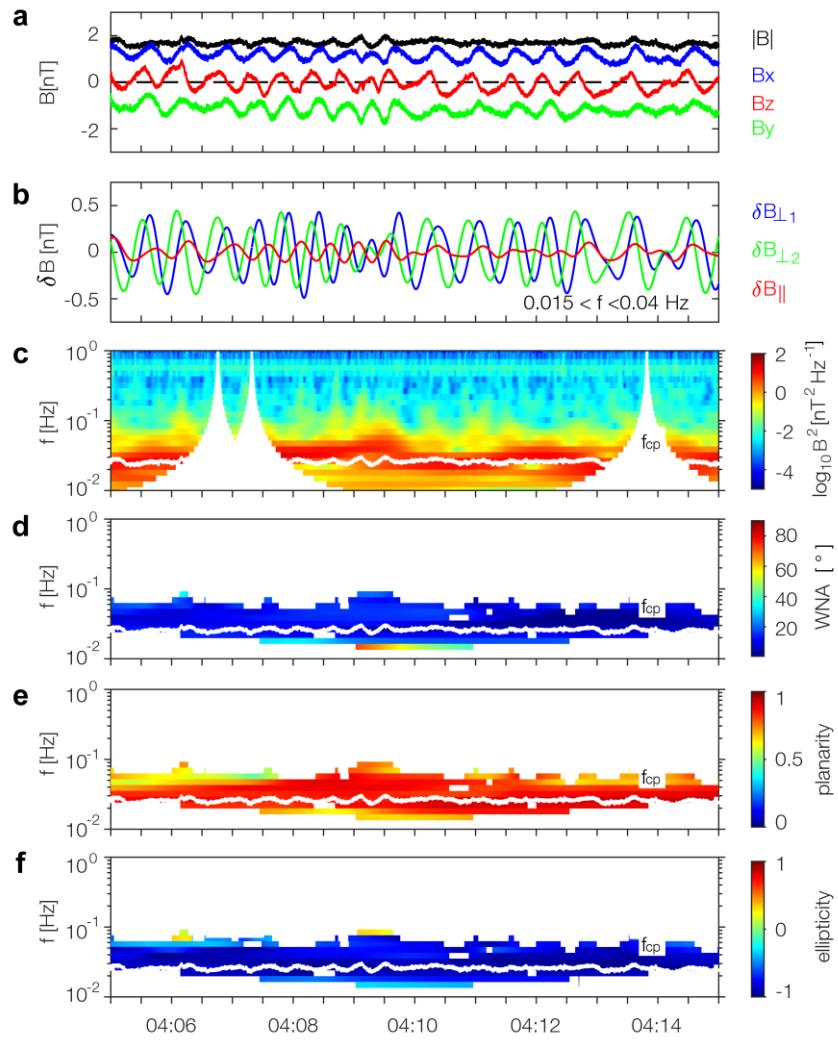
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45 **Supplementary Fig. 2. Tianwen-1 crossing a quasi-parallel bow shock.**
 46 Approximately 150 minutes prior to the interval of interval (marked by red dashed
 47 box), **Tianwen-1**'s passage across the bow shock into the solar wind detected a broad
 48 shock transition region characterized by intense magnetic field fluctuation—a
 signature indicative of a quasi-parallel bow shock.



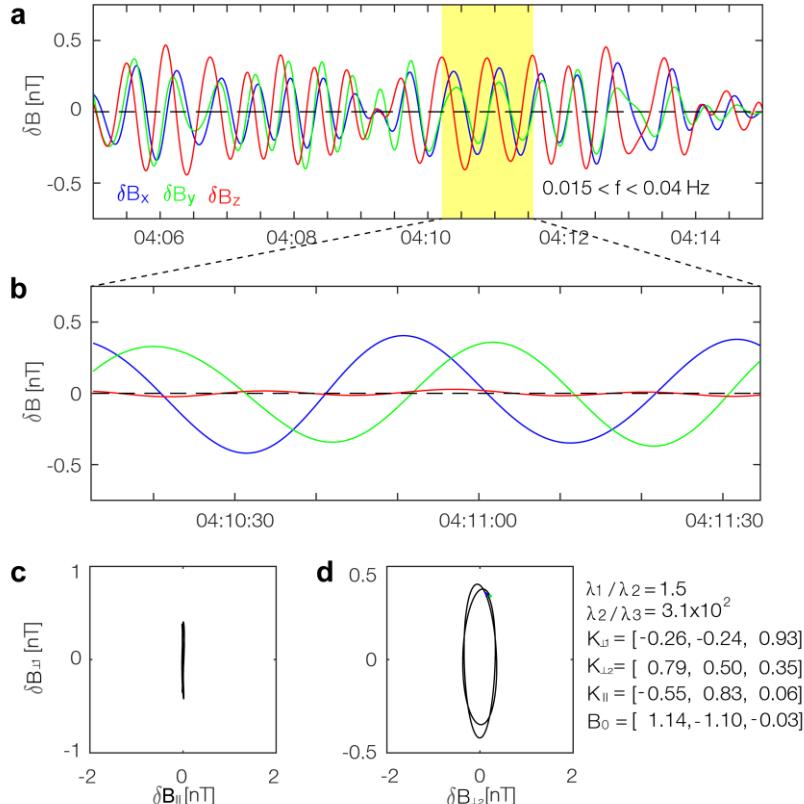
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50 **Supplementary Fig. 3. Minimum variation analysis (MVA) on low-frequency**
 51 **waves observed by MAVEN.** **a** Waveform $\delta\mathbf{B}$ of the low-frequency wave obtained
 52 by a band-pass filtering between 0.015–0.04 Hz during the interval of interest
 53 (04:05:00–04:15:00 UT). **b** A Zoom-in view of this waveform $\delta\mathbf{B}$ between
 54 04:05:30.044 and 04:07:30.060 UT. Vector quantities in panels **a–b** are shown in the
 55 Mars solar orbital (MSO) coordinates. **c–d** Hodograph of $\delta B_{\parallel} - \delta B_{\perp 1}$ (**c**) and $\delta B_{\perp 2} -$
 56 $\delta B_{\perp 1}$ (**d**) obtained from MVA on this waveform $\delta\mathbf{B}$ between 04:05:30.044 and
 57 04:07:30.060 UT. K_{\parallel} , the minimum variation direction, represents the wave
 58 propagating direction in MSO coordinate. Both $K_{\perp 1}$ and $K_{\perp 2}$ are perpendicular K_{\parallel} ,
 59 completing the right-hand coordinate system. Therefore, the waveform $(\delta B_{\perp 1}, \delta B_{\perp 2},$
 60 $\delta B_{\parallel})$ in the $(K_{\perp 1}, K_{\perp 2}, K_{\parallel})$ coordinate can be transformed from that in MSO
 61 coordinate. The ratio of intermediate to minimum eigenvalue is 52, large enough to
 62 ensure the reliability of the MVA result. The green dot in panel **d** represents start point,
 63 while the blue arrow in panel **d** denotes end point. Hodograph of $\delta B_{\perp 2} - \delta B_{\perp 1}$
 64 exhibit a left-handed polarization characteristic.



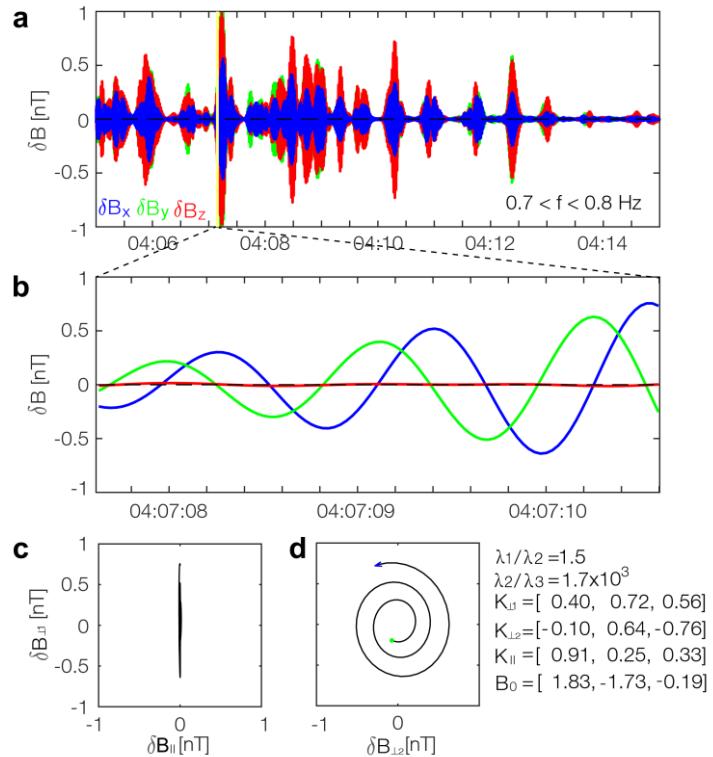
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66 **Supplementary Fig. 4. Polarization analysis of low-frequency waves observed by**
 67 **Tianwen-1 spacecraft.** **a–f** Polarization analysis of low-frequency waves, including
 68 magnetic field B_x , B_y and B_z components (**a**), waveform δB_x , δB_y and δB_z
 69 components obtained by a band-pass filtering between 0.015 and 0.04 Hz (**b**), power
 70 spectral density of magnetic field (**c**), wave normal angle (**d**), planarity (**e**), and
 71 ellipticity (**f**). The white lines in panels **c–f** denotes proton cyclotron frequency (f_{cp}).
 72 This polarization analysis is obtained by conducting the well-established singular
 73 value decomposition (SVD) method of the magnetic fields.



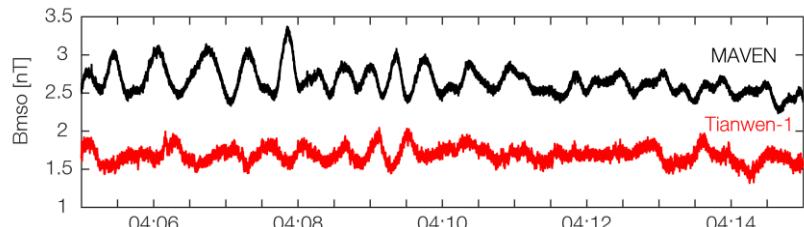
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75 **Supplementary Fig. 5. Minimum variation analysis (MVA) on low-frequency**
 76 **waves observed by Tianwen-1 spacecraft.** **a** Waveform $\delta\mathbf{B}$ of the low-frequency
 77 wave obtained by a band-pass filtering between 0.015–0.04 Hz during the interval of
 78 interest (04:05:00–04:15:00 UT). **b** A Zoom-in view of this waveform $\delta\mathbf{B}$ between
 79 04:10:12.572 and 04:11:34.572 UT. Vector quantities in panels **a–b** are shown in the
 80 Mars solar orbital (MSO) coordinates. **c–d** Hodograph of $\delta B_{\parallel} - \delta B_{\perp 1}$ (**c**) and $\delta B_{\perp 2} -$
 81 $\delta B_{\perp 1}$ (**d**) obtained from MVA on this waveform $\delta\mathbf{B}$ between 04:10:12.572 and
 82 04:11:34.572 UT. K_{\parallel} , the minimum variation direction, represents the wave
 83 propagating direction in MSO coordinate. Both $K_{\perp 1}$ and $K_{\perp 2}$ are perpendicular K_{\parallel} ,
 84 completing the right-hand coordinate system. Therefore, the waveform $(\delta B_{\perp 1}, \delta B_{\perp 2},$
 85 $\delta B_{\parallel})$ in the $(K_{\perp 1}, K_{\perp 2}, K_{\parallel})$ coordinate can be transformed from that in MSO
 86 coordinate. The ratio of intermediate to minimum eigenvalue is 310, large enough to
 87 ensure the reliability of the MVA result. The green dot in panel **d** represents start point,
 88 while the blue arrow in panel **d** denotes end point. Hodograph of $\delta B_{\perp 2} - \delta B_{\perp 1}$
 89 exhibit a left-handed polarization characteristic.



90

91 **Supplementary Fig. 6. Minimum variation analysis (MVA) on whistler-mode**
 92 **waves observed by MAVEN.** **a** Waveform $\delta\mathbf{B}$ of the low-frequency wave obtained
 93 by a band-pass filtering between 0.7–0.8 Hz during the interval of interest (04:05:00–
 94 04:15:00 UT). **b** A Zoom-in view of this waveform $\delta\mathbf{B}$ between 04:07:07.624 and
 95 04:07:10.606 UT. Vector quantities in panels **a–b** are shown in the Mars solar orbital
 96 (MSO) coordinates. **c–d** Hodograph of $\delta B_{\parallel} - \delta B_{\perp 1}$ (**c**) and $\delta B_{\perp 2} - \delta B_{\perp 1}$ (**d**) obtained
 97 from MVA on this waveform $\delta\mathbf{B}$ between 04:07:07.624 and 04:07:10.606 UT. K_{\parallel} , the
 98 minimum variation direction, represents the wave propagating direction in MSO
 99 coordinate. Both $K_{\perp 1}$ and $K_{\perp 2}$ are perpendicular K_{\parallel} , completing the right-hand
 100 coordinate system. Therefore, the waveform $(\delta B_{\perp 1}, \delta B_{\perp 2}, \delta B_{\parallel})$ in the $(K_{\perp 1}, K_{\perp 2}, K_{\parallel})$
 101 coordinate can be transformed from that in MSO coordinate. The ratio of intermediate
 102 to minimum eigenvalue is 1700, large enough to ensure the reliability of the MVA
 103 result. The green dot in panel **d** represents start point, while the blue arrow in panel **d**
 104 denotes end point. Hodograph of $\delta B_{\perp 2} - \delta B_{\perp 1}$ exhibit a left-handed polarization
 105 characteristic.



106
107 **Supplementary Fig. 7. Comparison between oscillation amplitude of low-**
108 **frequency waves detected by MAVEN and Tianwen-1.** The black and red curve
109 represents oscillation amplitude of low-frequency waves detected by MAVEN and
110 Tianwen-1, respectively. They are band-passed magnetic strength between 0.015 Hz
111 and 0.04 Hz.