Statistical study of the IMF flow-aligned component impact on the current sheet structure in Martian magnetotail

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Outline

- Introduction
- Motivation
- Our Work
  - Method
  - Case study
  - Statistical study
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- Question & Answer.
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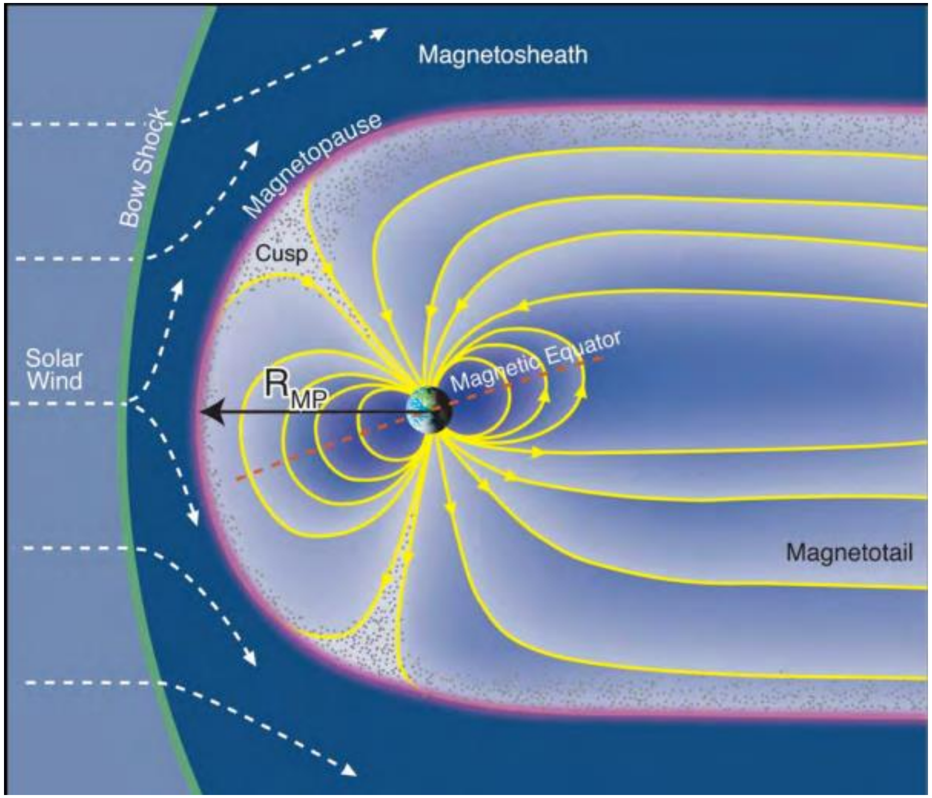
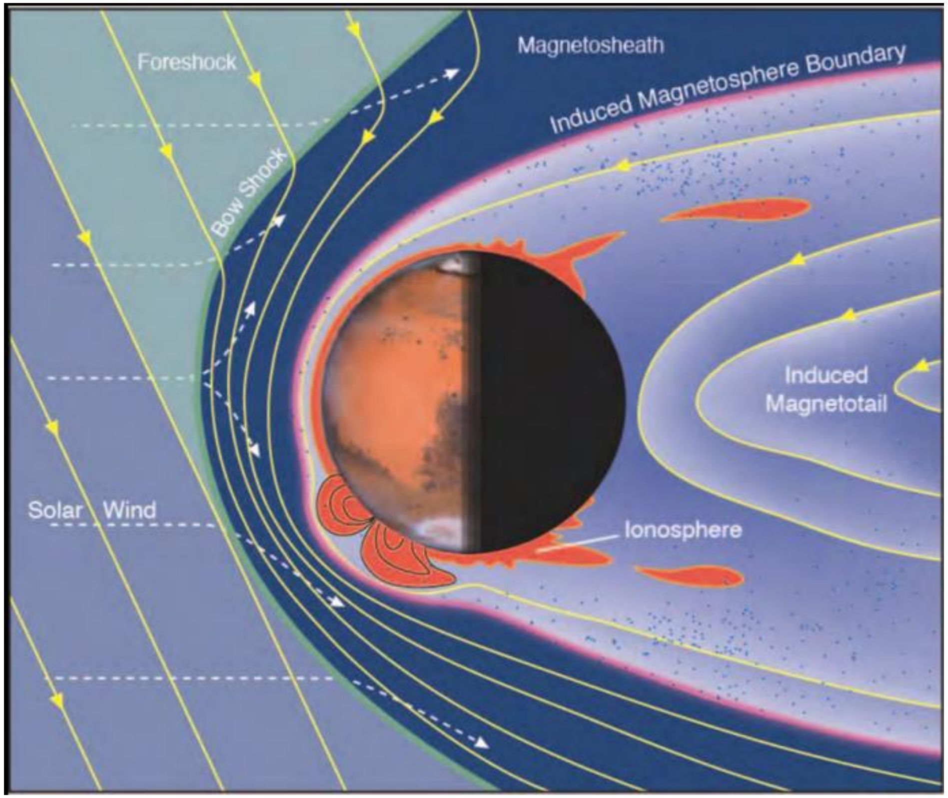
Introduction



Bagenal et al., (2015)



Brain et al., (2015)

Introduction

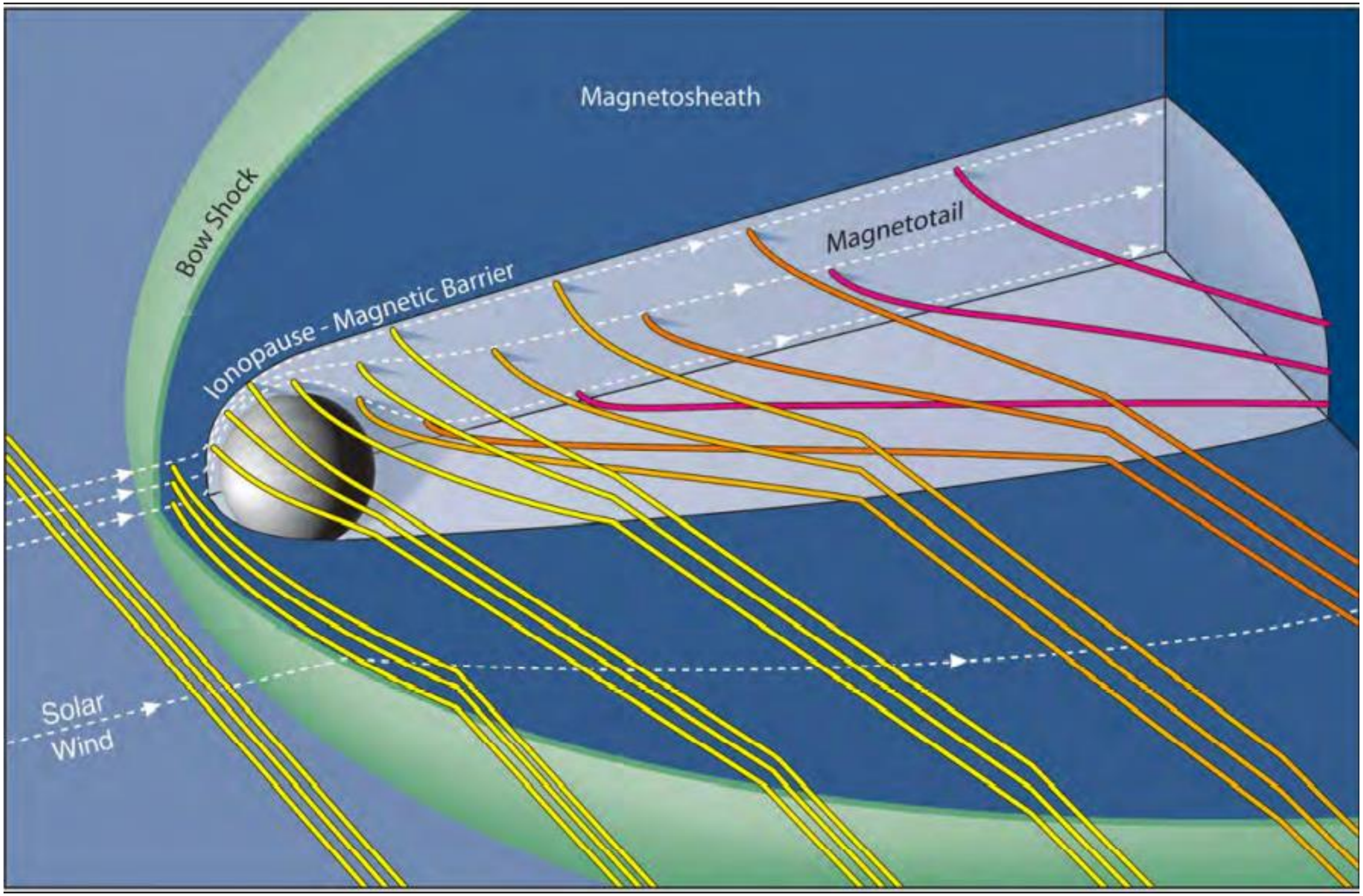
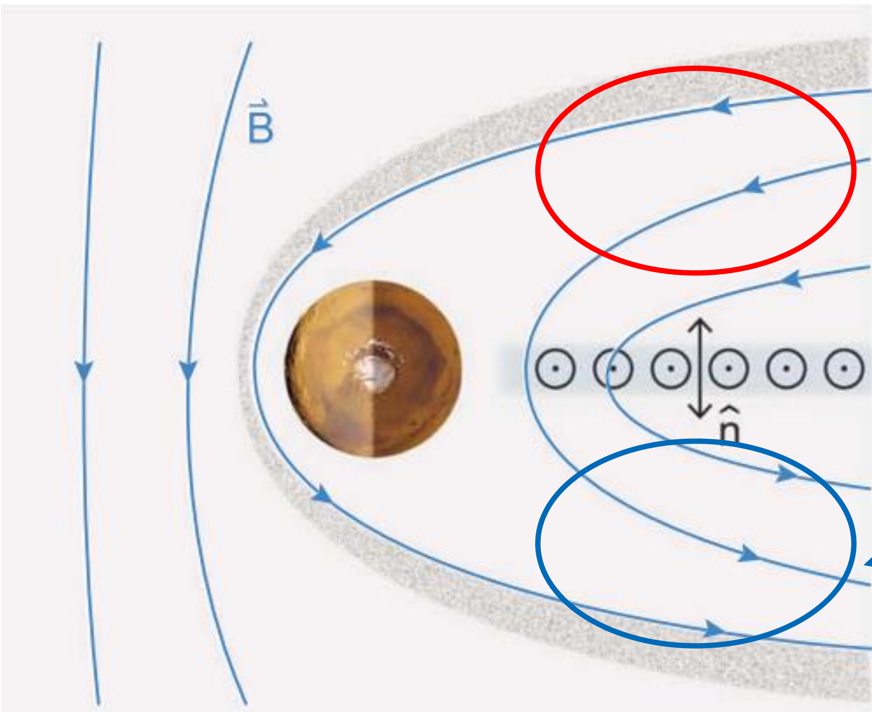
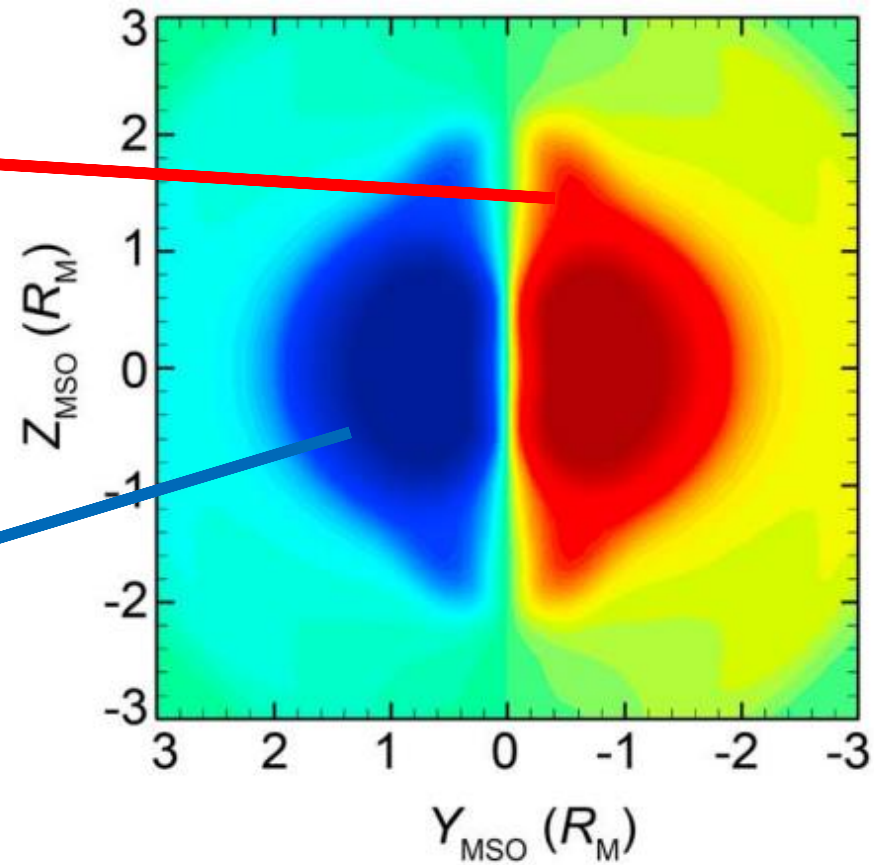


Image Credit: CU Boulder LASP

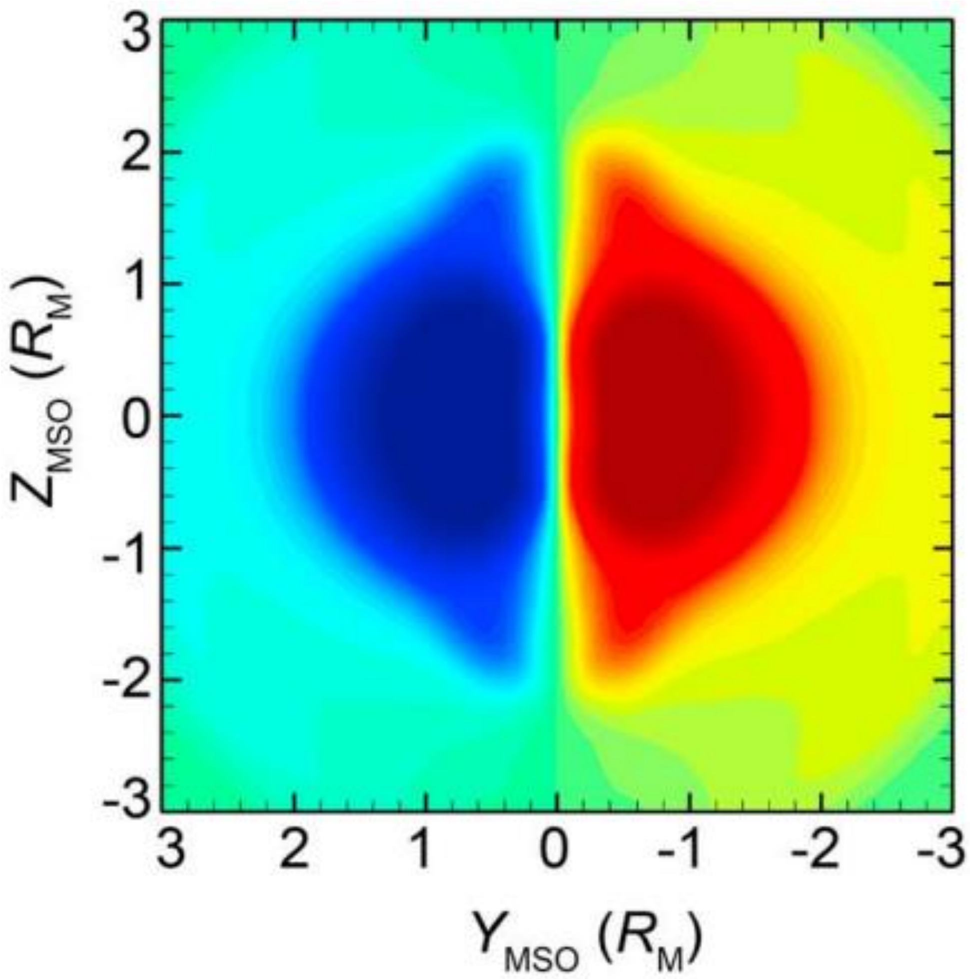
Introduction





DiBraccio et al.,(2017)

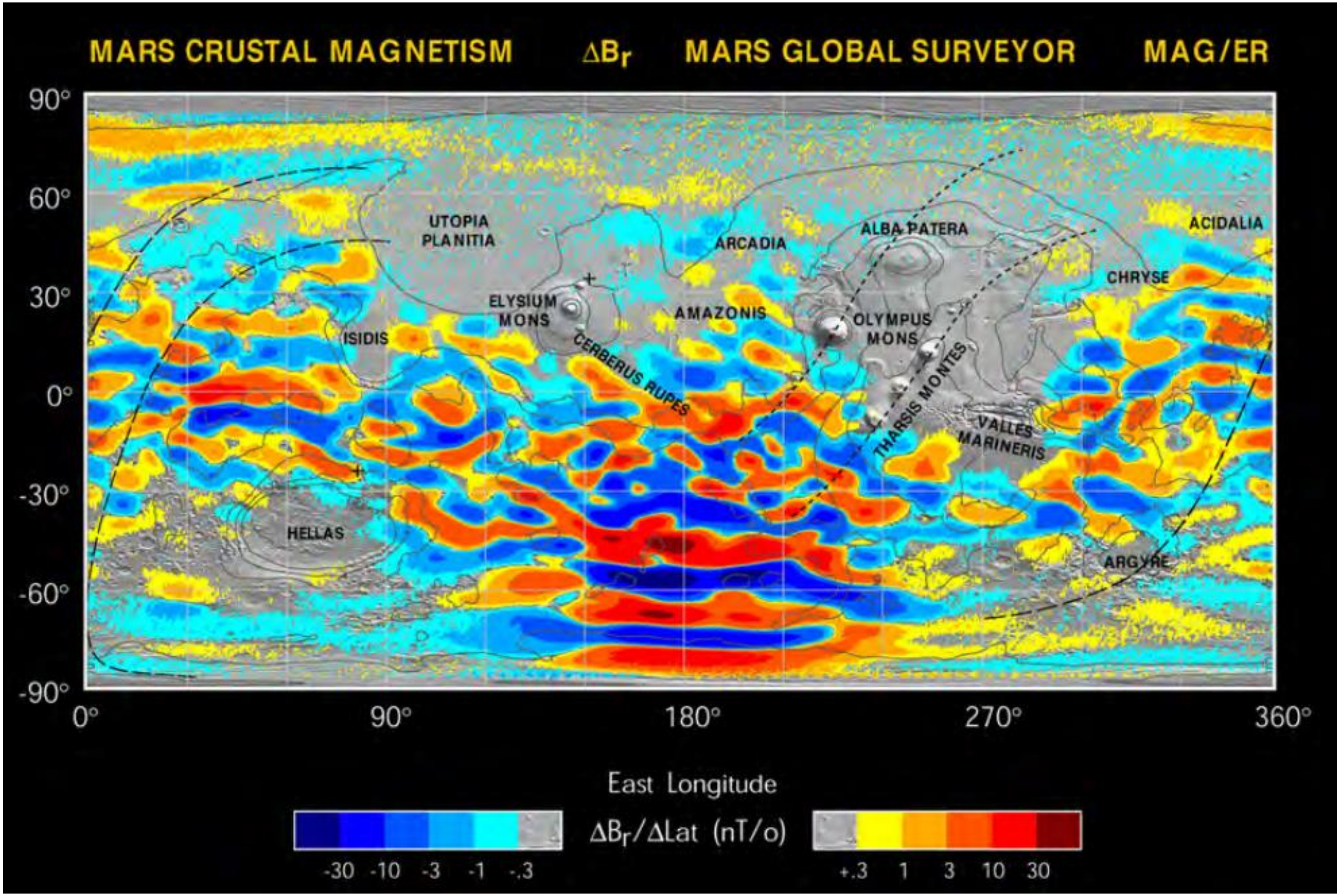
Introduction



DiBraccio et al., (2018)

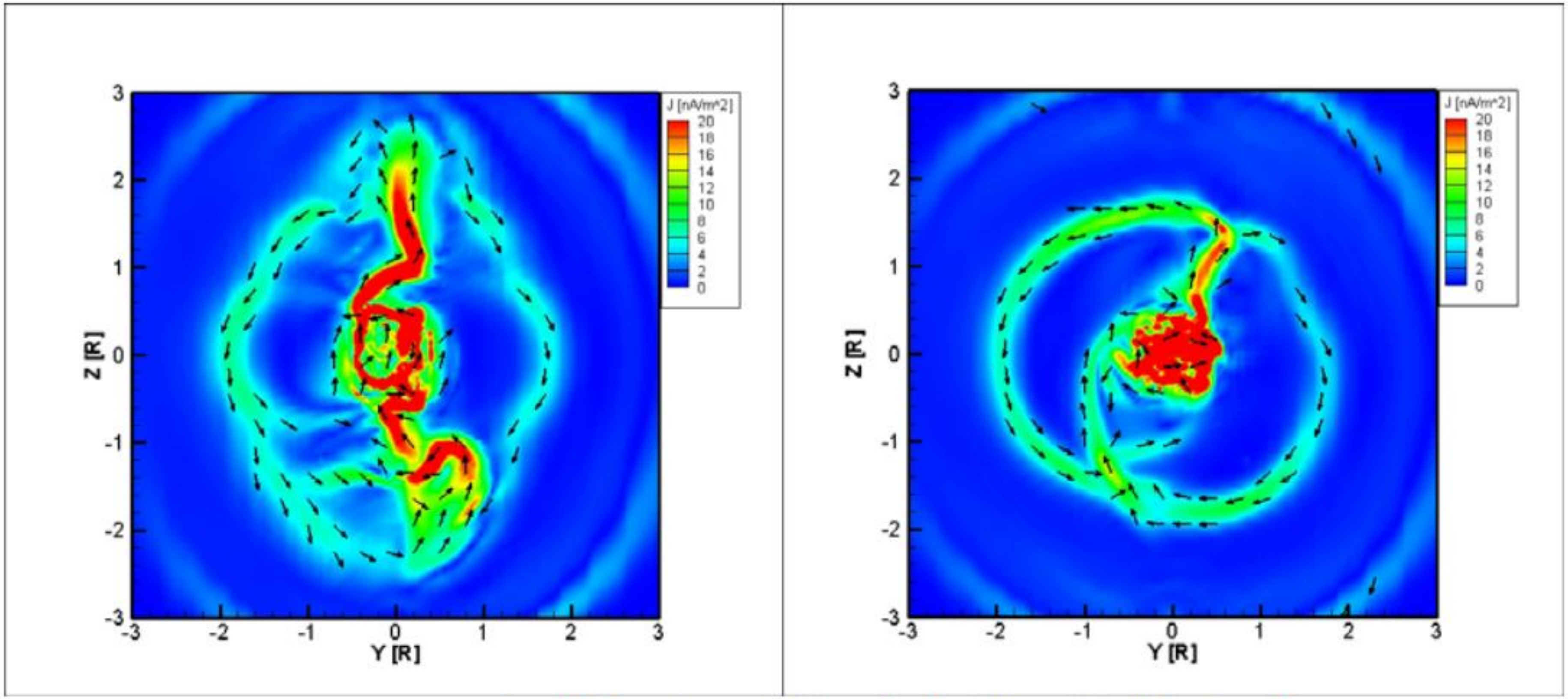
1. Mars' magnetic tail, called the "magnetotail," is the region of the Martian magnetosphere that extends behind the planet.
2. The magnetotail consists of two magnetic lobes:
   - One directed towards Mars
   - One directed away from Mars

Introduction



Connerney et al., PNAS, 2005

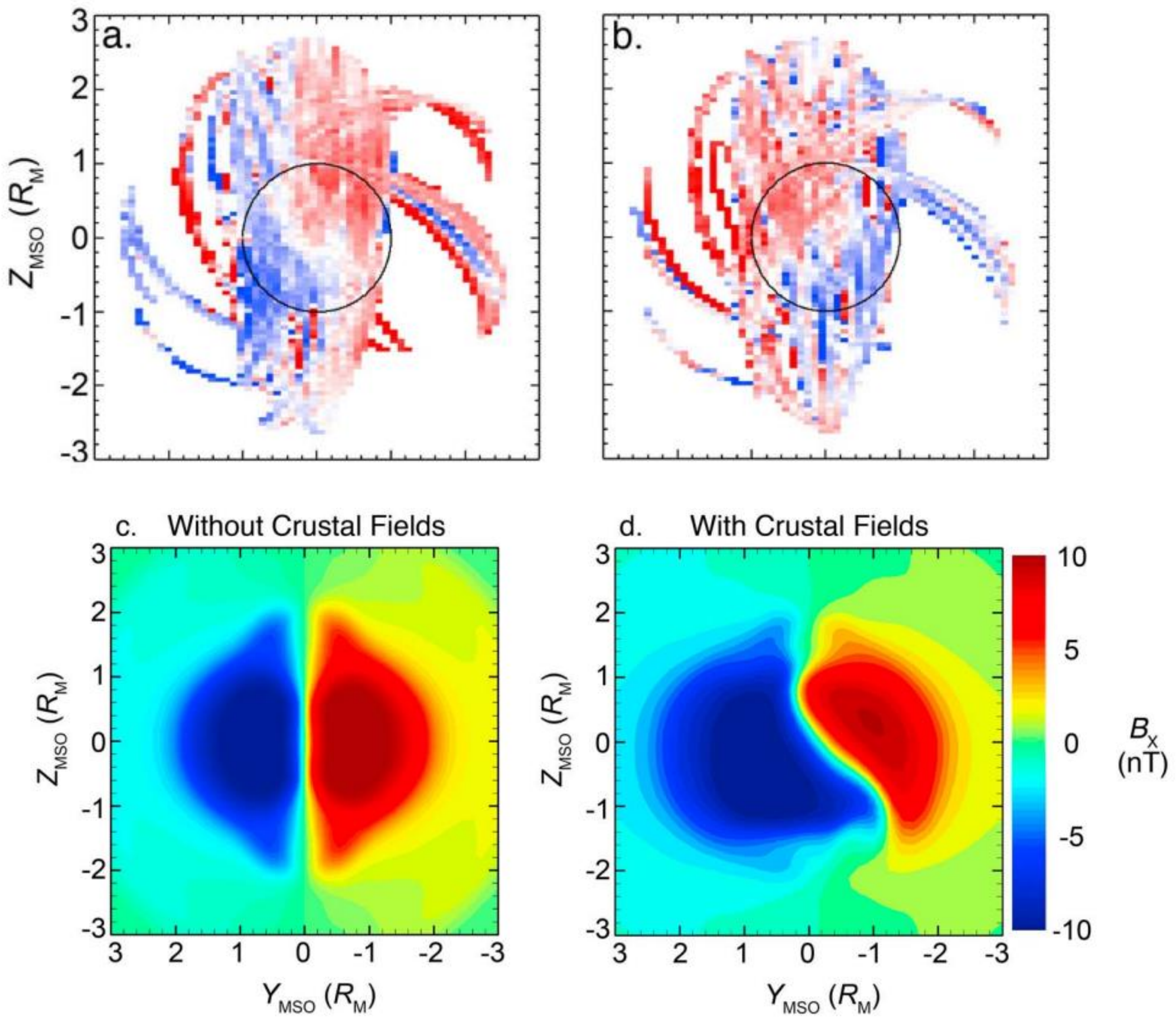
Introduction



Slice of the current density vector at X=-1.1 R_M. Left: without crustal fields. Right: with crustal fields.

Image Credit: Yuanzheng Wen

Introduction



DiBraccio et al., (2018)

Introduction

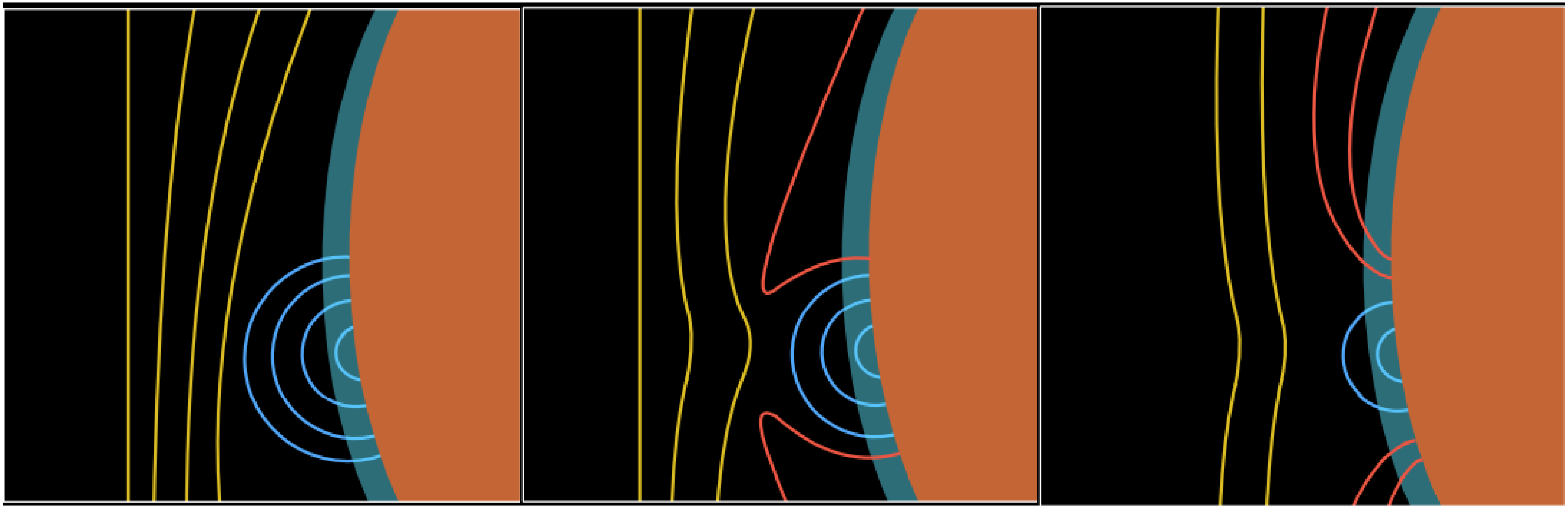


Image Credit: Tristan Weber/University of Colorado

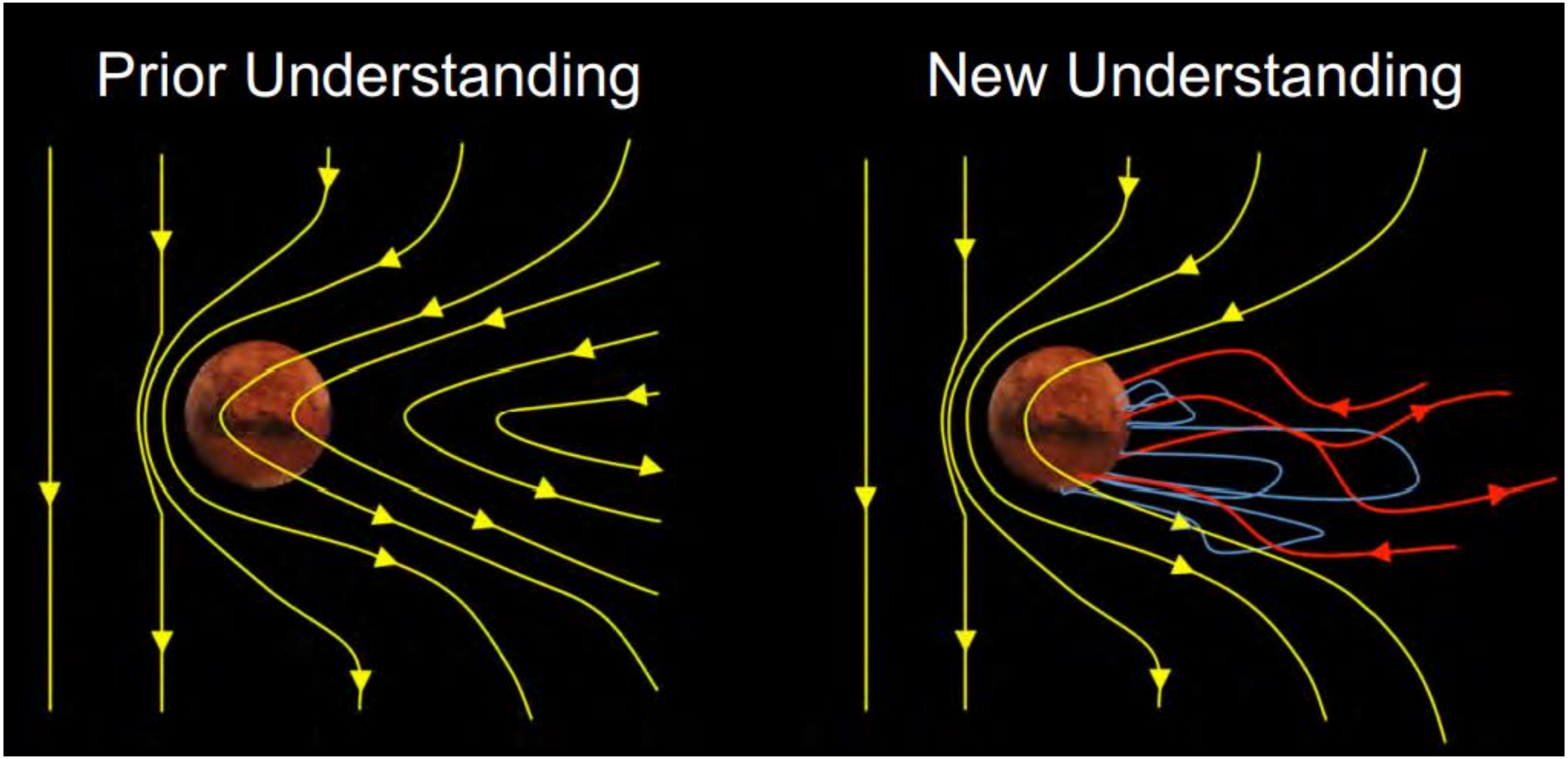
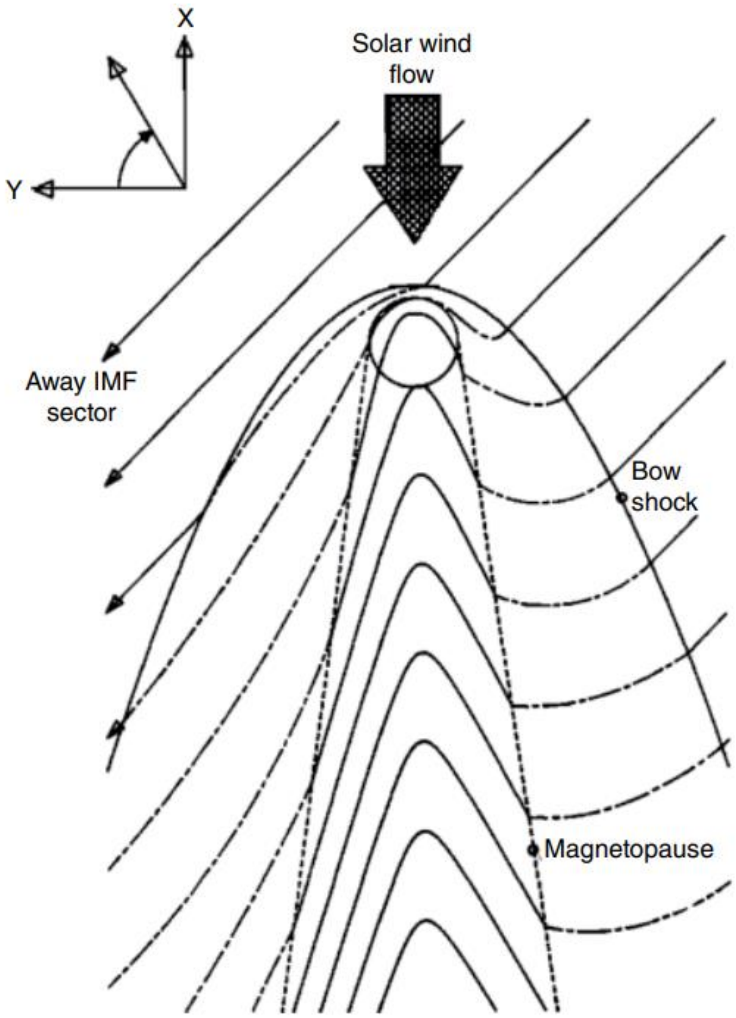
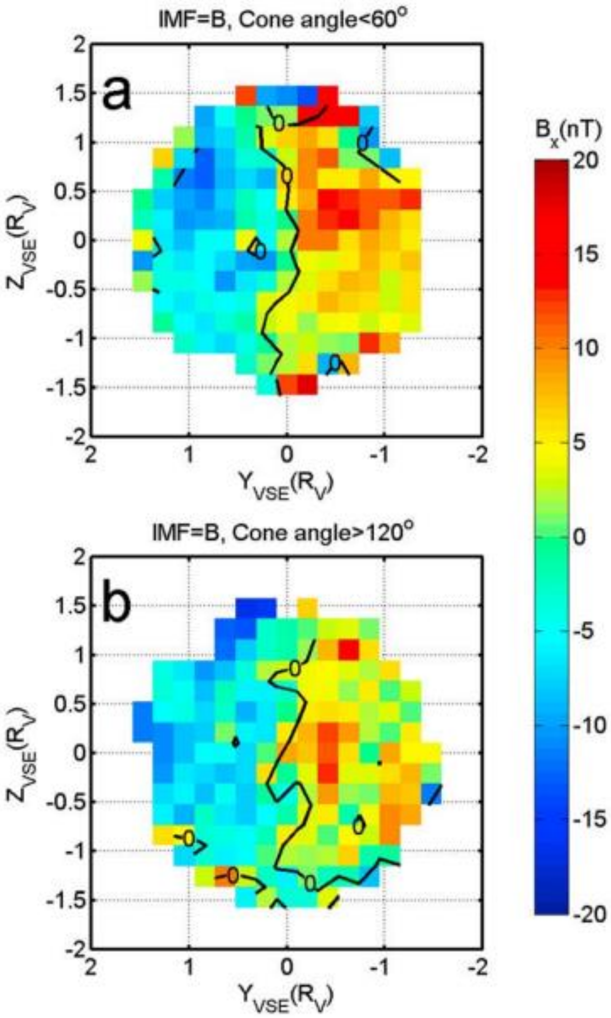


Image Credit: NASA/GSFC

Motivation

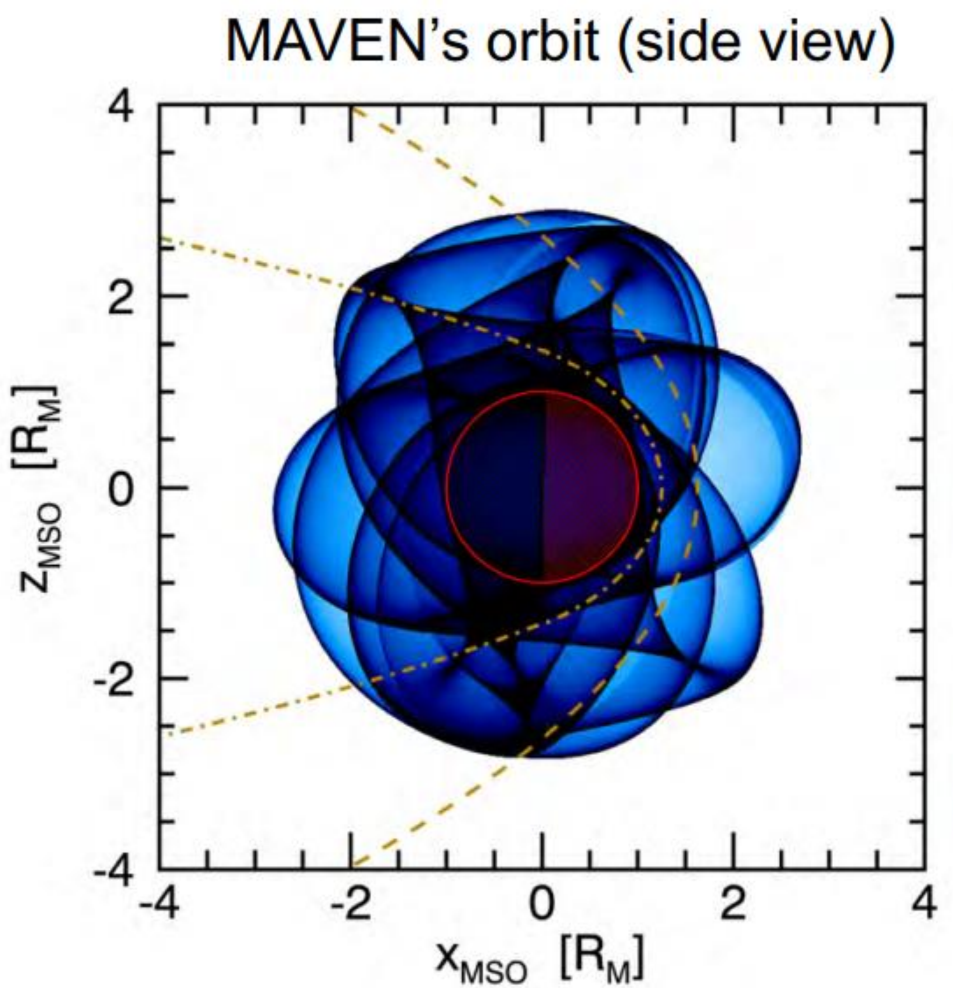


McComas et al., (1986)



Rong et al., (2016)

Our work



Gruesbeck et al., (2018)

1. MAVEN's orbit precesses about Mars to sample different regions of the Martian atmosphere and magnetosphere.
2. Observations of solar wind enable monitoring of upstream parameters and solar activity
3. In order to determine how the magnetotail responds to changes in solar wind and IMF, we look for orbits where MAVEN measures the upstream solar wind and the magnetotail

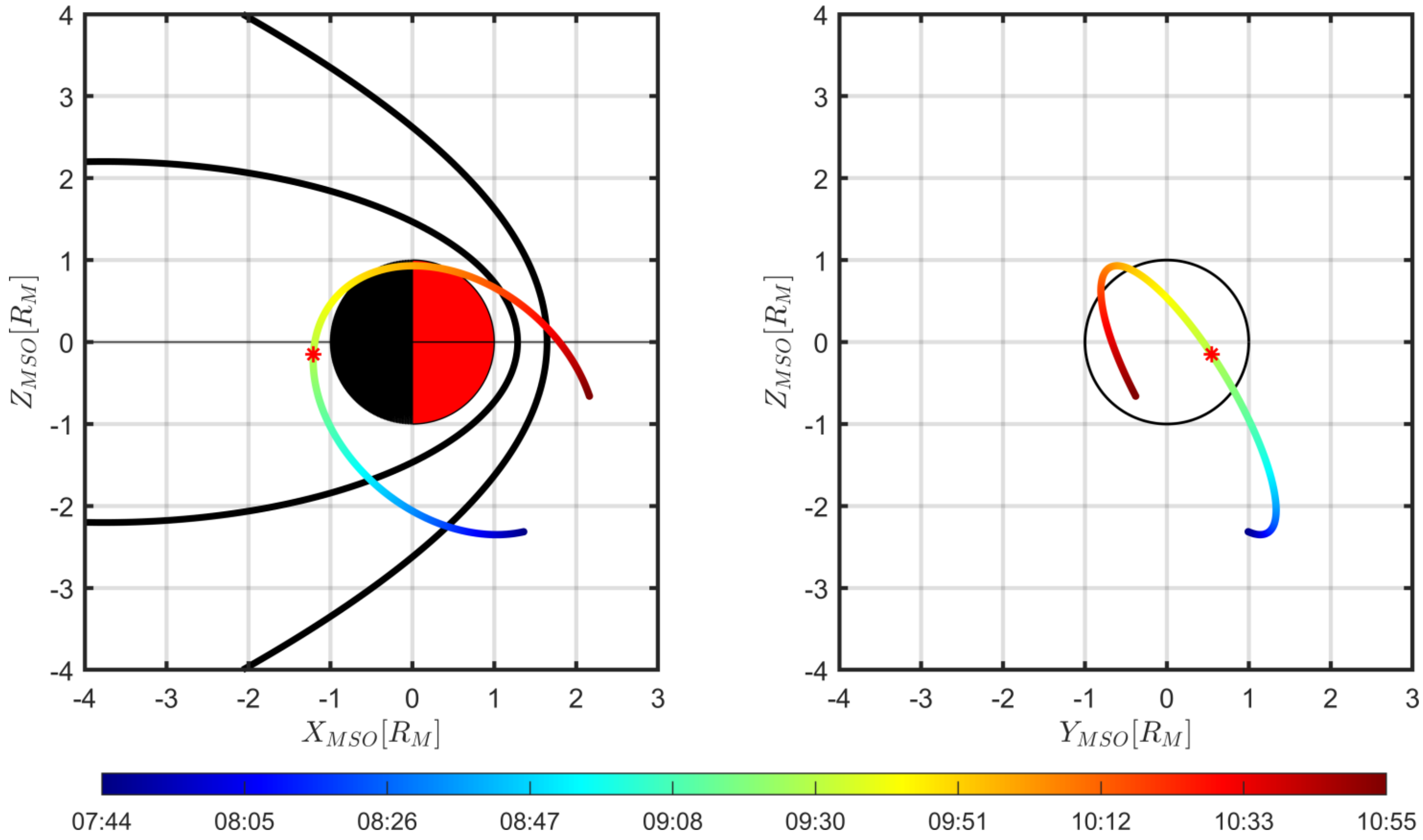
Our work

Selected MAVEN crossing of Martian magnetosphere under steady IMF conditions

- Selected MAVEN magnetospheric crossings from Oct 2014-Feb 2020 based on magnetic field data from MAG and ion energy spectrogram from SWIA. (7684 crossings)
- B1 (B2) averaged IMF 30 min before (after) bow shock inbound (outbound) crossings.
- Steady IMF criteria: 1. Angele between B1 and B2 less than 30° 2. $\frac{2||\mathbf{B}_1|-|\mathbf{B}_2||}{|\mathbf{B}_1|+|\mathbf{B}_2|} < 0.2$ (Rong et al., 2014, 2016)
- Selected MAVEN crossings of Martian magnetosphere under steady IMF conditions. (1445 crossings)

Our work

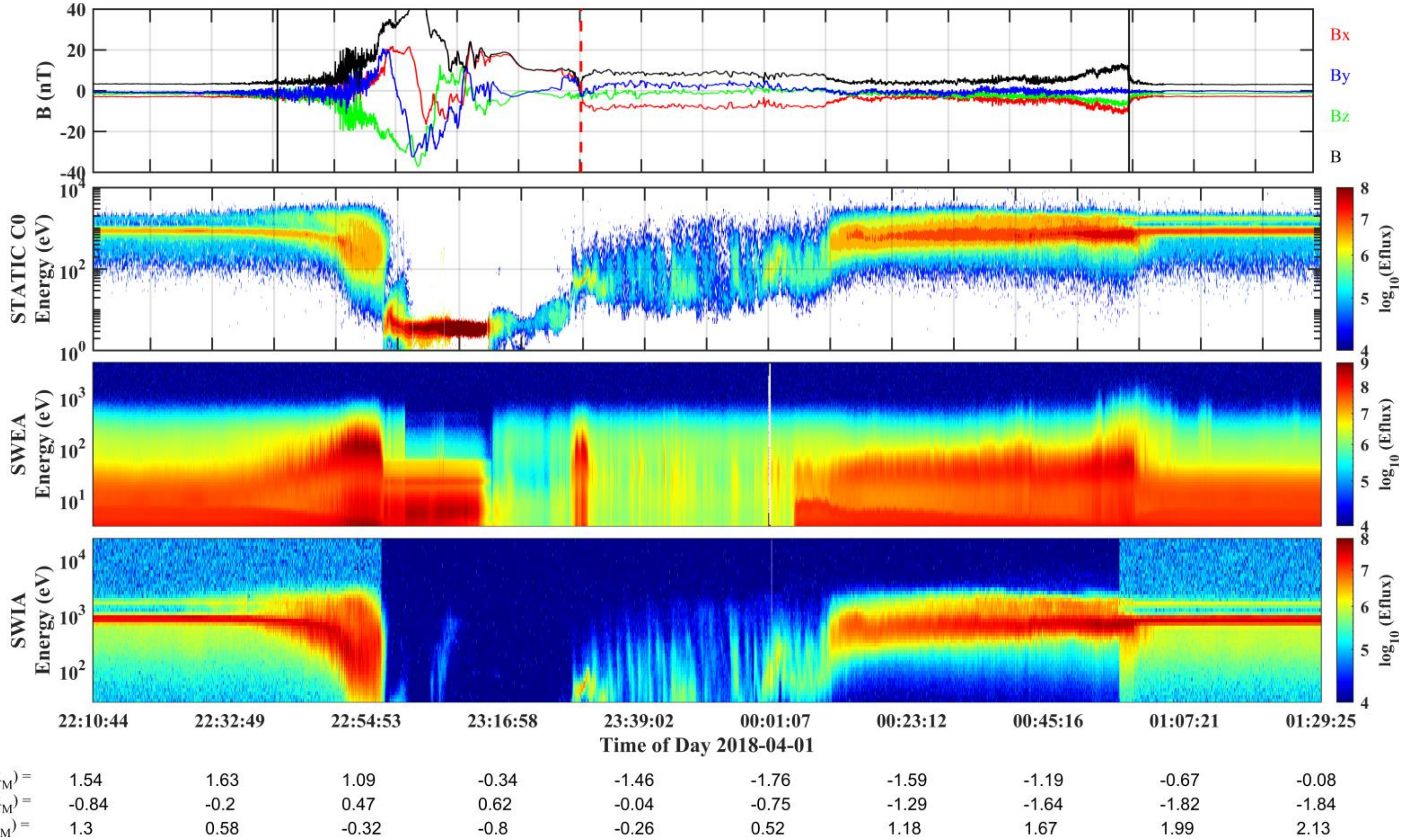
Selected MAVEN crossing of Martian magnetosphere under steady IMF conditions



Example of MAVEN magnetospheric crossing on 2014-12-22

Our work

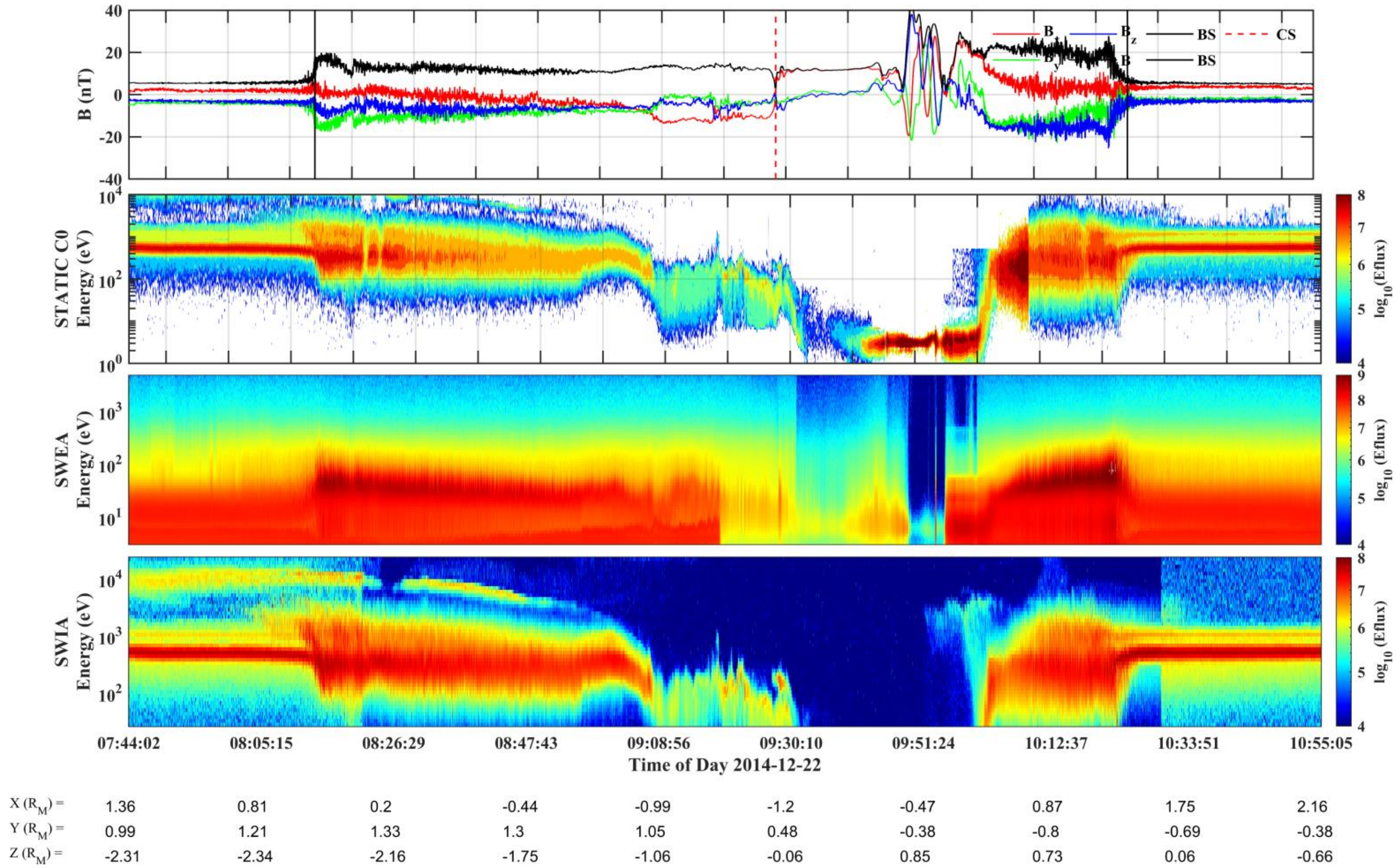
Selected good current sheet crossing cases



Examples of good current sheet crossing cases.
CS crossing is identified by change of Bx sign and enhancement of ion, electron flux.

Our work

Selected good current sheet crossing cases



Examples of good current sheet crossing cases.
CS crossing is identified by change of Bx sign and enhancement of ion, electron flux.

Our work

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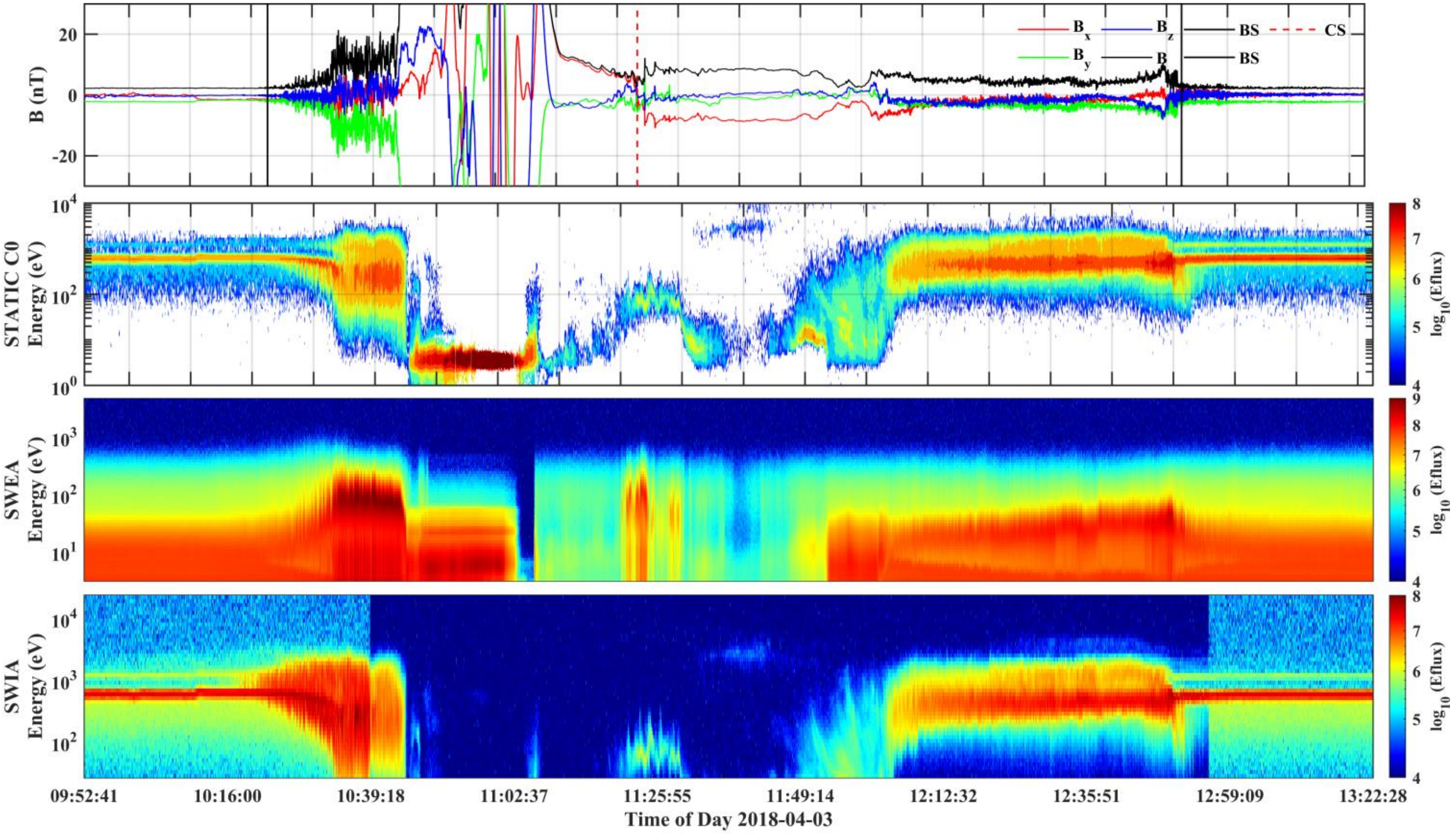
Selected good current sheet crossing cases



X (R_M) =	1.4	1.62	1.26	-0.14	-1.42	-1.79	-1.64	-1.22	-0.66	-0.03
Y (R_M) =	-1.05	-0.42	0.32	0.66	0.06	-0.68	-1.25	-1.62	-1.81	-1.82
Z (R_M) =	1.47	0.77	-0.17	-0.8	-0.31	0.5	1.2	1.71	2.03	2.14

Examples of good current sheet crossing cases.
CS crossing is identified by change of Bx sign and enhancement of ion, electron flux.

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Applied Minimum Variance Analysis (MVA) [Sonnerup and Scheible, 1998]

- $\sigma^2 = \frac{1}{M}\sum_{m=1}^{M} \left|\left(\boldsymbol{B}^{(m)} - \langle \boldsymbol{B} \rangle\right) \cdot \hat{\boldsymbol{n}}\right|^2$

- $\sum_{v=1}^{3} M_{\mu v}^{B} n_v = \lambda n_\mu$

- Set up local Cartesian coordinates $\{\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3\}$ for a current sheet. $\mathbf{x}_1$, $\mathbf{x}_2$, and $\mathbf{x}_3$ are orthogonal eigenvectors ($\mathbf{x}_3 = \mathbf{x}_1 \times \mathbf{x}_2$) of the magnetic variance matrix $M_{\mu v} = \langle B_\mu B_v \rangle - \langle B_\mu \rangle \langle B_v \rangle$

- The corresponding eigenvalues of $\mathbf{x}_1$, $\mathbf{x}_2$, and $\mathbf{x}_3$ are $\lambda_1, \lambda_2, \lambda_3$.

- The eigenvectors $\mathbf{x}_1$, $\mathbf{x}_2$, and $\mathbf{x}_3$ written as $\hat{\mathbf{L}}, \widehat{\mathbf{M}}, \widehat{\mathbf{N}}$ represent the directions of maximum, intermediate and the minimum variance of the magnetic field.

- $\widehat{\mathbf{N}}$ is seen as the normal of the current sheet. Both $\widehat{\mathbf{N}}$ and $\widehat{-\mathbf{N}}$ are valid current sheet normal in terms of MVA.

Research Experience and Projects

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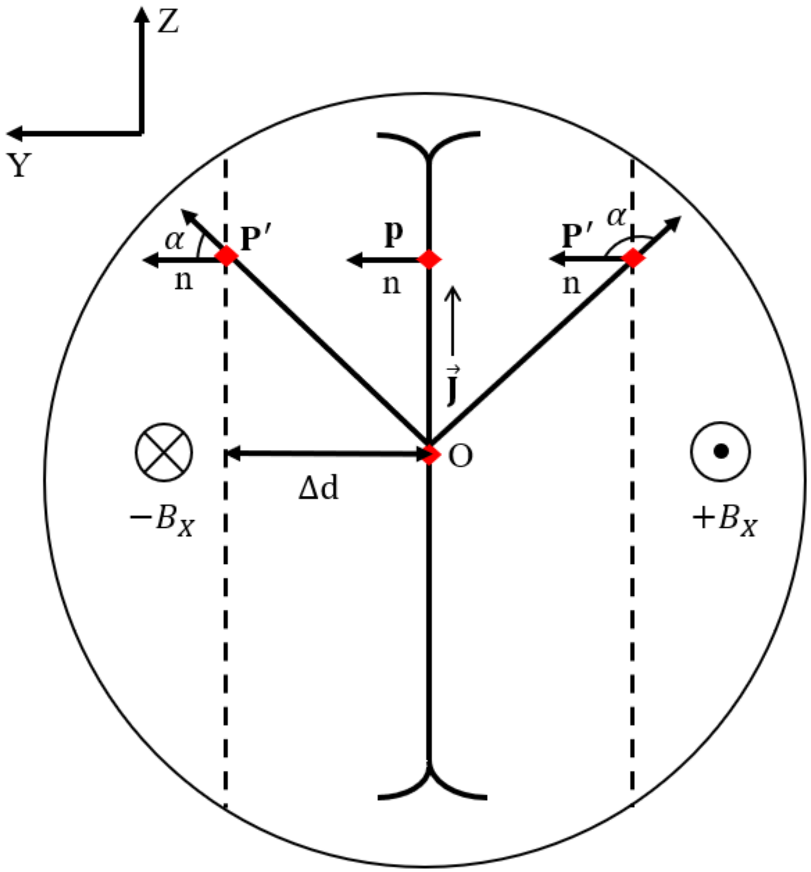
Calculated current sheet shift distance



$$\hat{\mathbf{n}} = \mathrm{sgn}(-\Delta B_X)\,\mathrm{sgn}\left(\hat{\mathbf{v}}_t \cdot \hat{\mathbf{N}}\right)\hat{\mathbf{N}}$$

$$\text{Shfit Distance: } \Delta d = \left|\overrightarrow{OP'}\right| \cos\alpha$$

$$Radius: R = \sqrt{\left|\overrightarrow{OP'}\right|^2 - \Delta d^2}$$

$$Angular\ \text{uncertainty}:$$

$$|\Delta\varphi_{ij}| = |\Delta\varphi_{ji}| = \sqrt{\frac{\lambda_3(\lambda_i + \lambda_j - \lambda_3)}{(N-1)(\lambda_i - \lambda_j)^2}}$$

Image Credit: Yuanzheng Wen

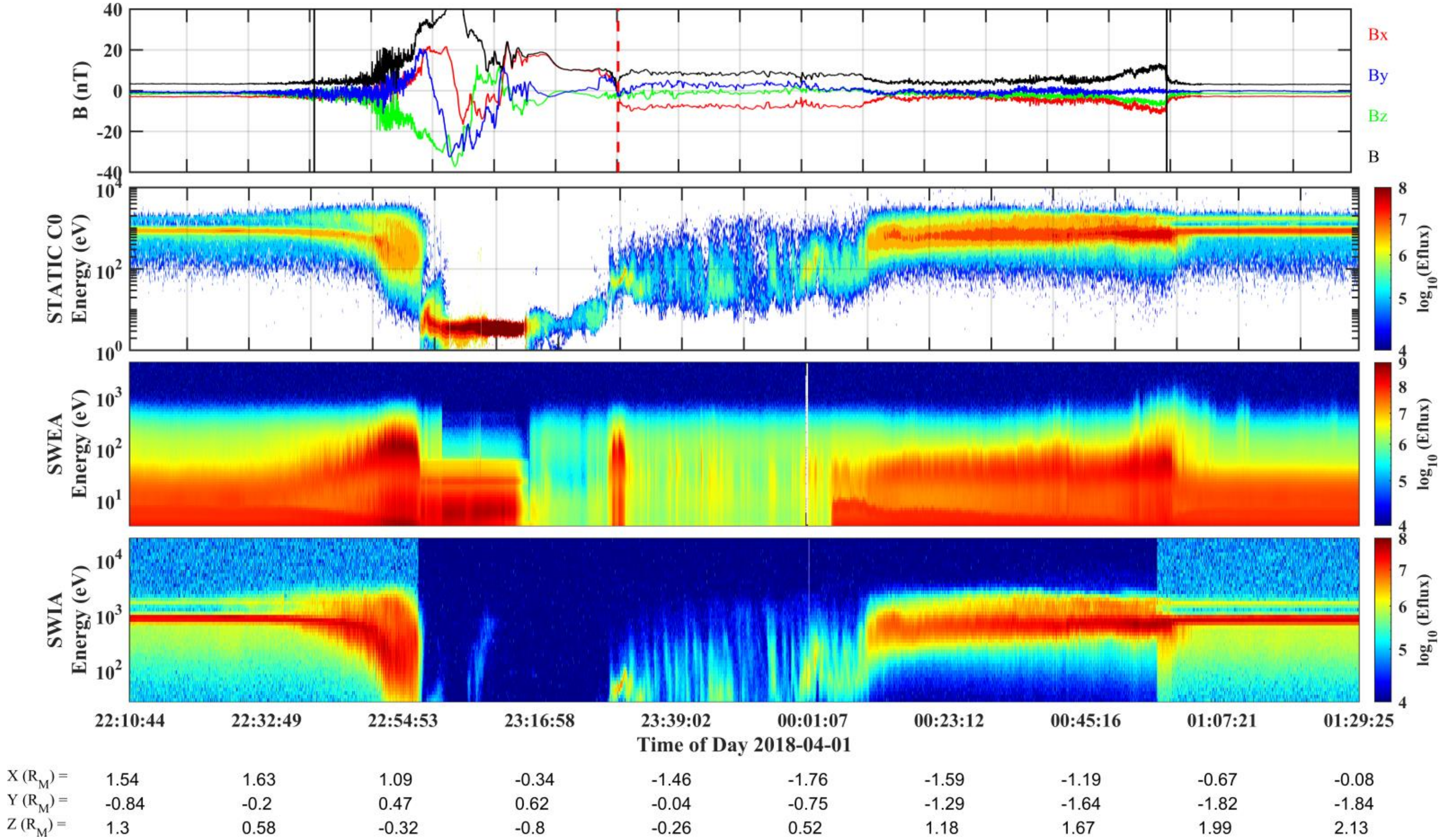
Research Experience and Projects

Case selection criteria

- MAVEN should be located in the Martian magnetotail region, with region confinement $-3R_M < X < -0.5R_M$, $\rho = \sqrt{Y^2 + Z^2} < 1.3R_M$.
- Evident flapping event of the CS should not occur during the crossing, the CS crossing should only occur one time during the magnetotail crossing.
- Steady IMF criteria: 1. Angele between B1 and B2 less than 30° 2. $\frac{2||\mathbf{B}_1|-|\mathbf{B}_2||}{|\mathbf{B}_1|+|\mathbf{B}_2|} < 0.2$ (Rong et al., 2014, 2016)
- No large fluctuations should occur in the upstream IMF.
- To avoid the potential influence of the crustal magnetic fields, the CS crossing should be above at least 400 km when MAVEN is flying above the strongest crustal magnetic field regions.

Research Experience and Projects

Selected good current sheet crossing cases



Examples of good current sheet crossing cases.
CS crossing is identified by change of Bx sign and enhancement of ion, electron flux.

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The Parameters Regarding Martian Magnetotail Current Sheet Crossing

Time	Location[a] (R_M)	IMF[b]	Cone Angle[b]	$\hat{n}$	λ_2/λ_3	Δd^c
2014/12/29 15:32:44	(-1.07, 0.74, -0.16)	(2.43, -0.56, -0.66)	20°	(0.48 0.79 -0.35)	3.93	0.73∈ [0.72, 0.74]
2015/09/03 21:52:51	(-1.19, -0.42, -0.38)	(-3.10, 6.52, 0.19)	115°	(-0.11 0.73 -0.68)	10.81	-0.05∈ [-0.08, -0.02]
2018/02/19 00:47:08	(-0.68, -1.12, -0.20)	(-1.94, -0.63, 1.24)	145°	(0.12 0.18 0.98)	3.95	-0.40∈ [-0.50, -0.29]
2014/12/22 09:28:21	(-1.21, 0.55, -0.15)	(2.77, -3.24, -3.20)	59°	(-0.03 0.97 -0.24)	11.91	0.57∈ [0.56, 0.57]
2015/08/31 20:01:48	(-1.17, -0.49, -0.34)	(0.47, 4.43, -0.98)	84°	(0.22 -0.47 -0.85)	10.28	0.53∈ [0.52, 0.55]
2015/09/29 09:09:28	(-1.55, 0.14, -0.41)	(0.23, 2.19, -0.06)	84°	(-0.01 0.40 -0.92)	11.59	0.43∈ [0.430, 0.432]
2018/04/03 11:23:17	(-1.33, 0.15, -0.4)	(-0.19, -2.13, -0.06)	95°	(-0.23 -0.37 -0.90)	8.17	-0.43∈ [-0.43, -0.43]
2014/12/04 06:00:12	(-1.47, 0.05, -0.25)	(-0.58, 3.47, -1.56)	99°	(0.18 0.45 -0.88)	1.64	0.25∈ [0.23, 0.25]
2017/07/09 19:53:59	(-1.32, 1.08, -1.52)	(-3.10, 6.52, 0.19)	103°	(-0.29 -0.93 0.23)	4.47	-0.68∈ [-0.85, -0.43]
2014/12/05 09:40:14	(-1.30, -0.10, 0.13)	(-3.84, 2.98, -0.87)	141°	(0.23 0.97 -0.09)	5.33	-0.11∈ [-0.12, -0.10]
2016/02/02 11:02:04	(-1.00, -0.82, -0.31)	(-4.73, 0.61, 1.73)	159°	(0.33 0.85 0.42)	5.40	-0.87∈ [-0.88, -0.87]
2016/03/05 03:56:42	(-1.20, -0.12, 0.48)	(-1.34, -0.29, -0.59)	154°	(-0.73 0.1 -0.68)	9.31	-0.49∈ [-0.50, -0.49]
2018/03/14 12:41:51	(-1.17, -0.40, -0.39)	(-2.04, 1.41, 0.53)	144°	(0.17 0.91 -0.37)	10.71	-0.22∈ [-0.25, -0.20]
2016/08/15 20:30:25	(-1.10, -0.12, 0.37)	(3.28, 0.70, 1.31)	24°	(-0.35 -0.67 0.65)	15.52	0.34∈ [0.34,0.35]

Research Experience and Projects

Correlations between CS shifted distance and IMF cone angle

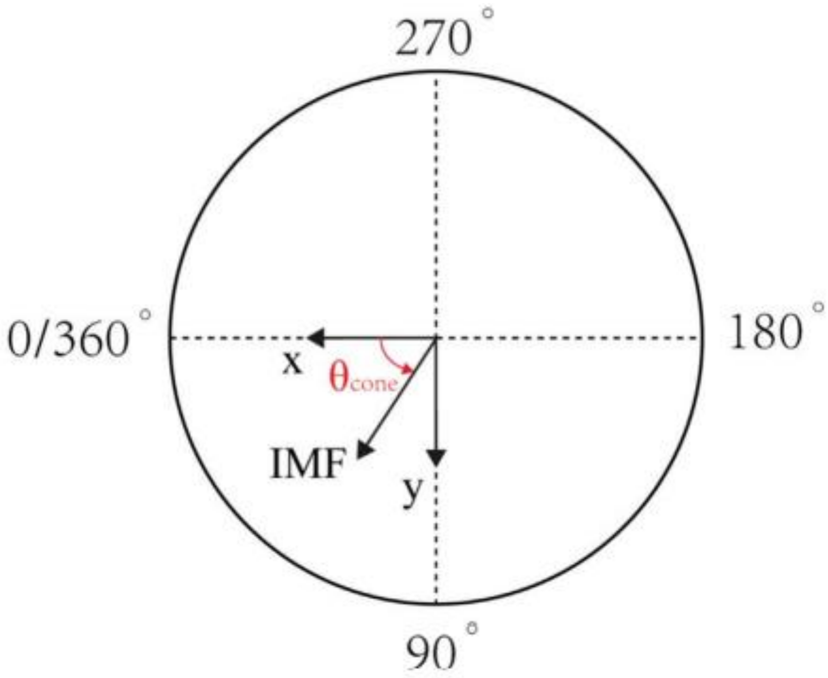
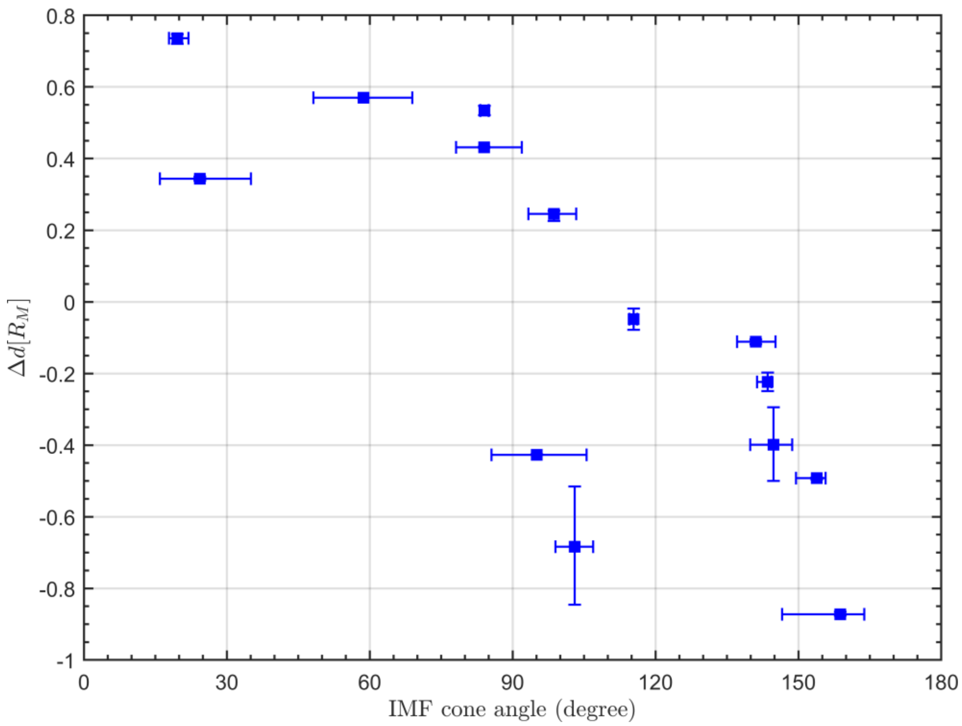


Diagram illustrating the IMF cone angle
Liu et al., (2021)



CS shifted distance as a function of the IMF cone angle

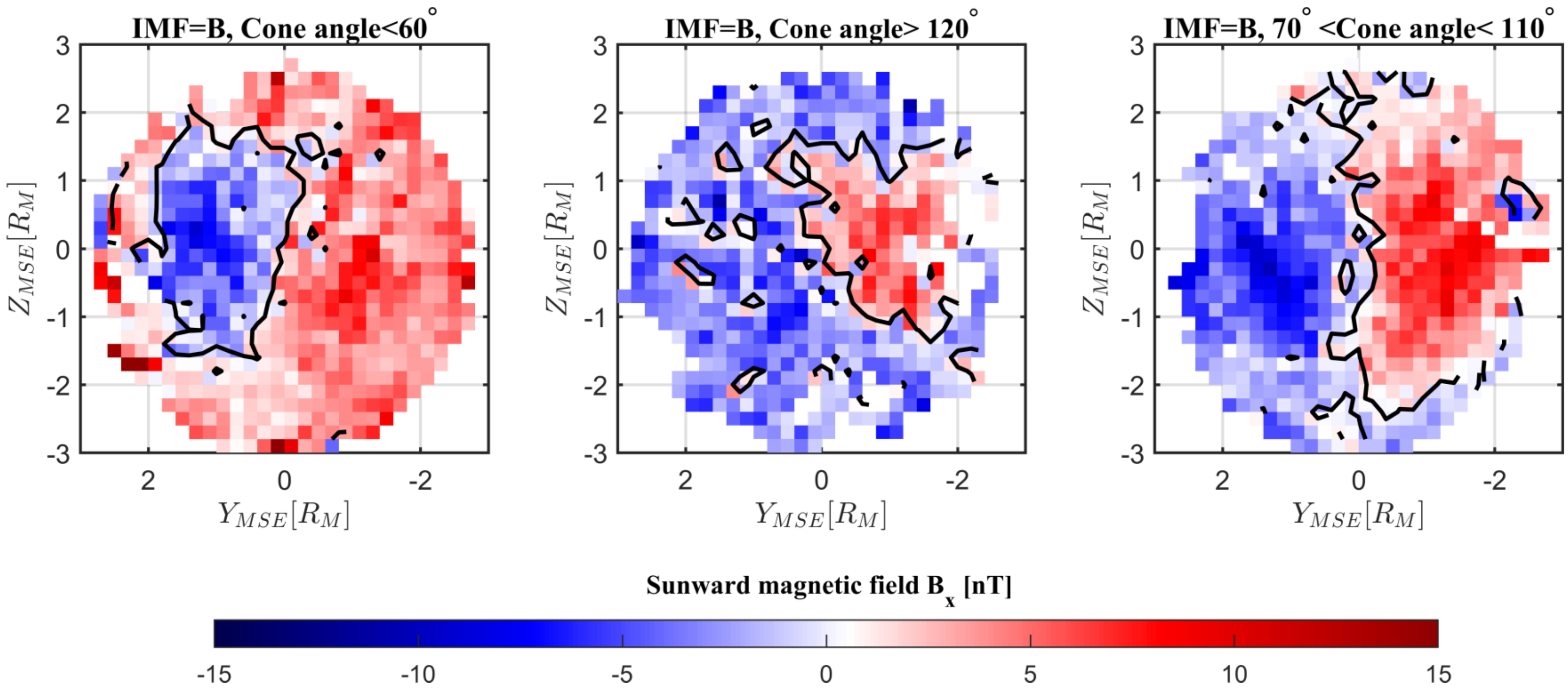
Research Experience and Projects

Statics of the current sheet structures of the Martian magnetotail

- Statistics is carried out in Mars-Solar-Electric (MSE) coordinates.
- X axis: X in MSO coordinates. Z axis: $\mathbf{E} = -\mathbf{v}_{SW} \times \mathbf{B}$. Y axis: X × Z. Z_{MSE} axis is basically contained in the current sheet plane which is nominally located at Y_{MSE} ~ 0.
- Selected orbits meet the steady IMF requirements (1445 crossings)
- Set up the MSE coordinates using upstream IMF ($\mathbf{B} = (\mathbf{B}_1 + \mathbf{B}_2)/2$), region confinement ($-3R_M < X_{MSE} < -0.5R_M$)
- Transformed the magnetic field data into MSE coordinates
- IMF cone angle $< 60^\circ$ (500 crossings), IMF cone angle $> 120^\circ$(260 crossings), 70° <IMF cone angle $< 110^\circ$ (439 crossings)
- Computed the contours of B_X=0 to present the average configurations of the current sheet structures in the magnetotail.

Research Experience and Projects

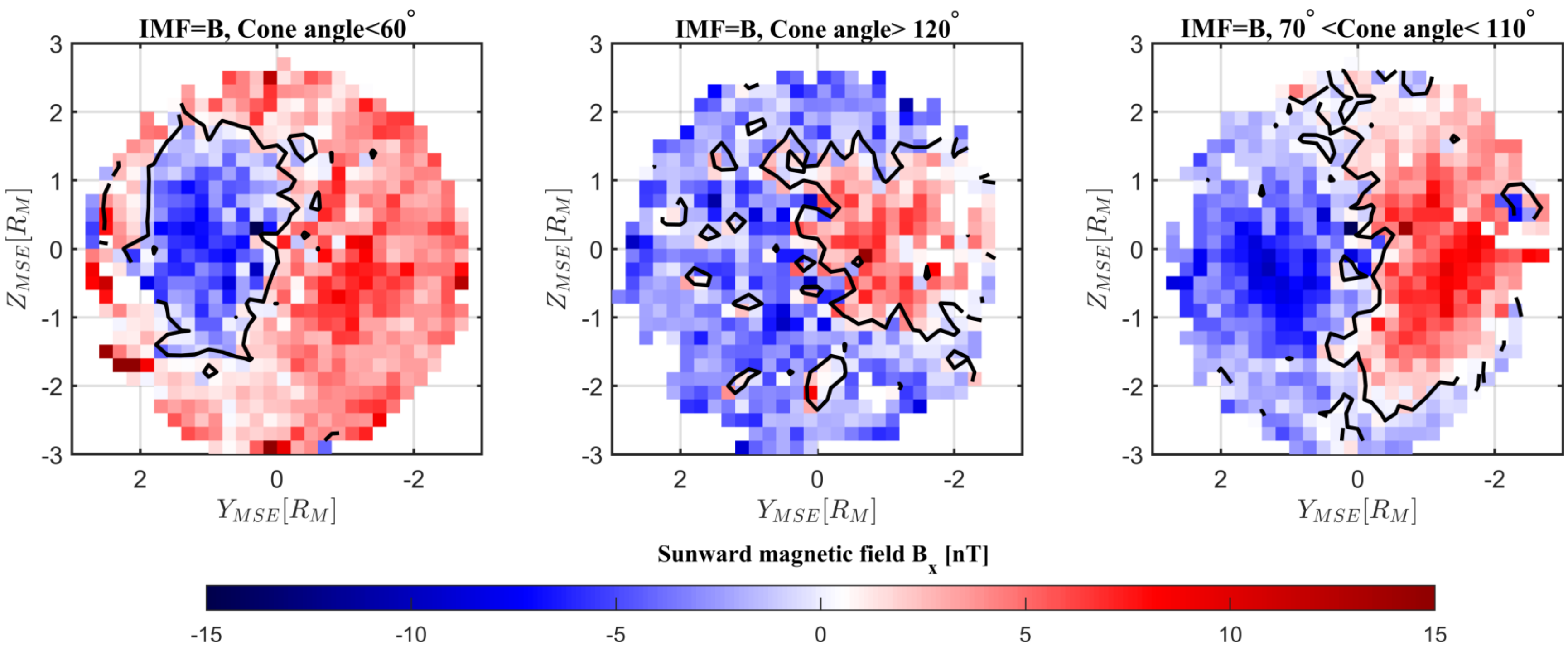
Statics of the current sheet structures of Martian magnetotail



Average configurations of current sheet structures under different IMF cone angles.
(with strong crustal fields omitted)

Research Experience and Projects

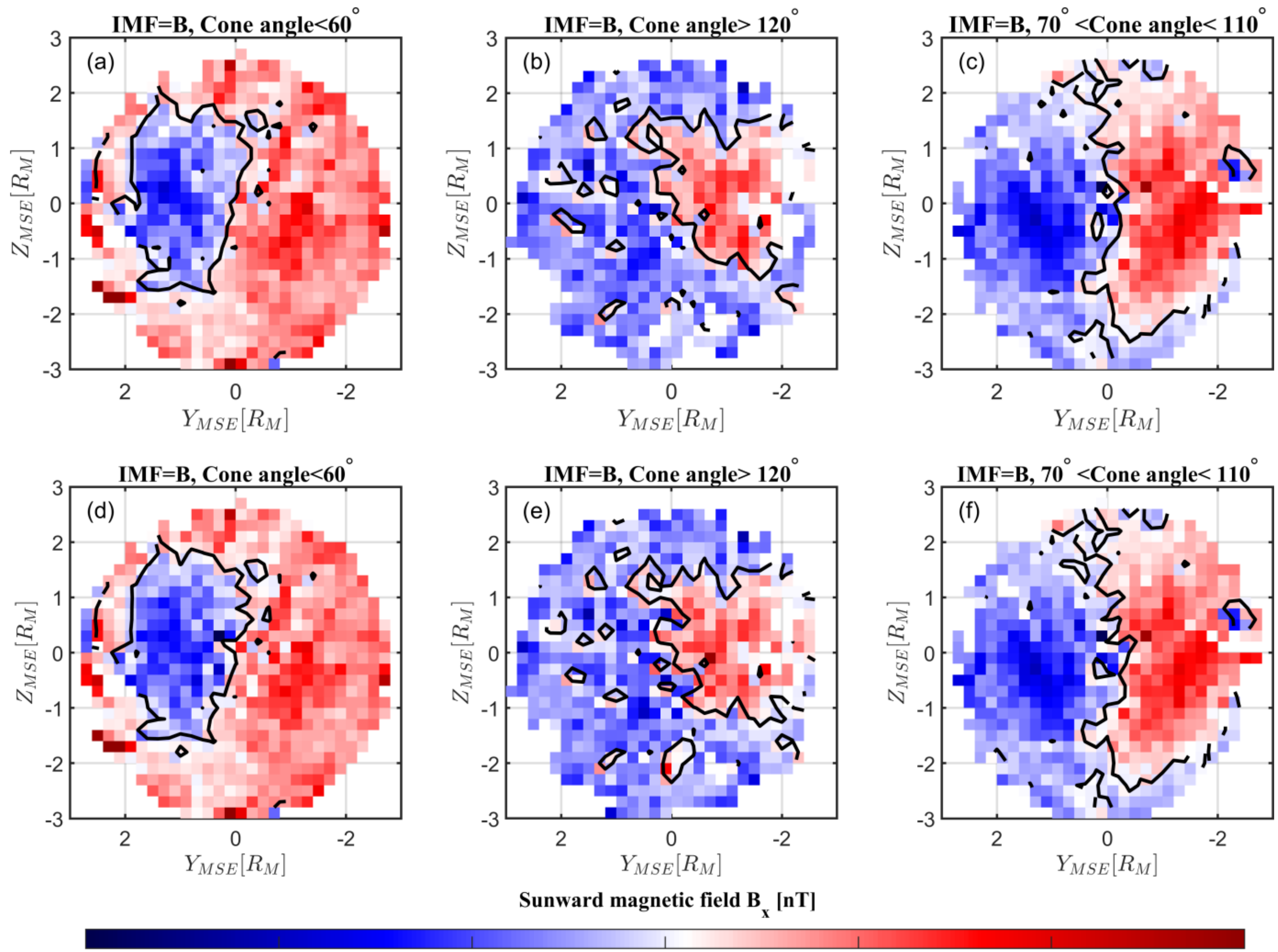
Statics of the current sheet structures of Martian magnetotail



Average configurations of current sheet structures under different IMF cone angles.
(with strong crustal fields)

Research Experience and Projects

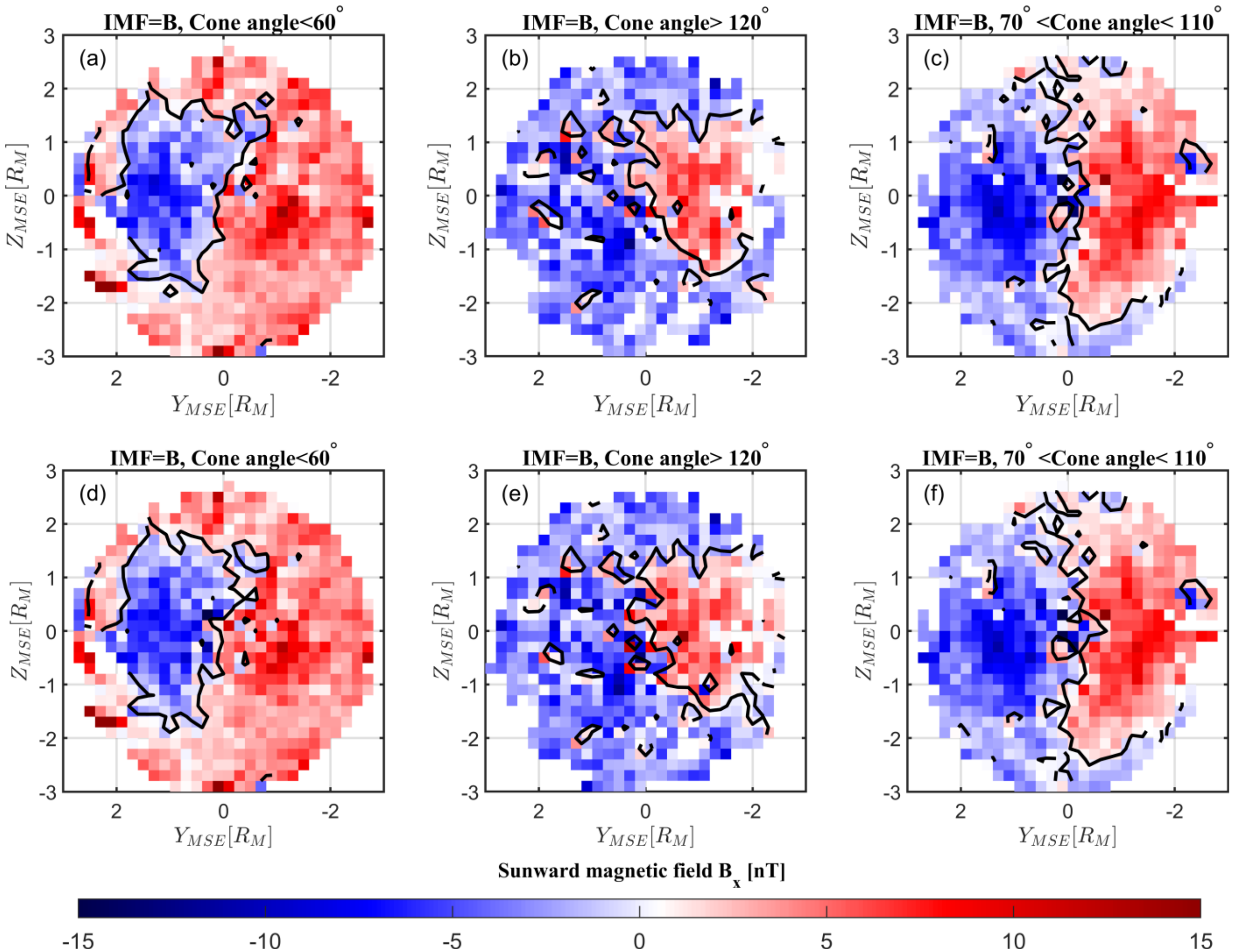
Statics of the current sheet structures of Martian magnetotail



Average configurations of current sheet structures under different IMF cone angles
$(-3R_M < X_{MSE} < -0.5R_M)$

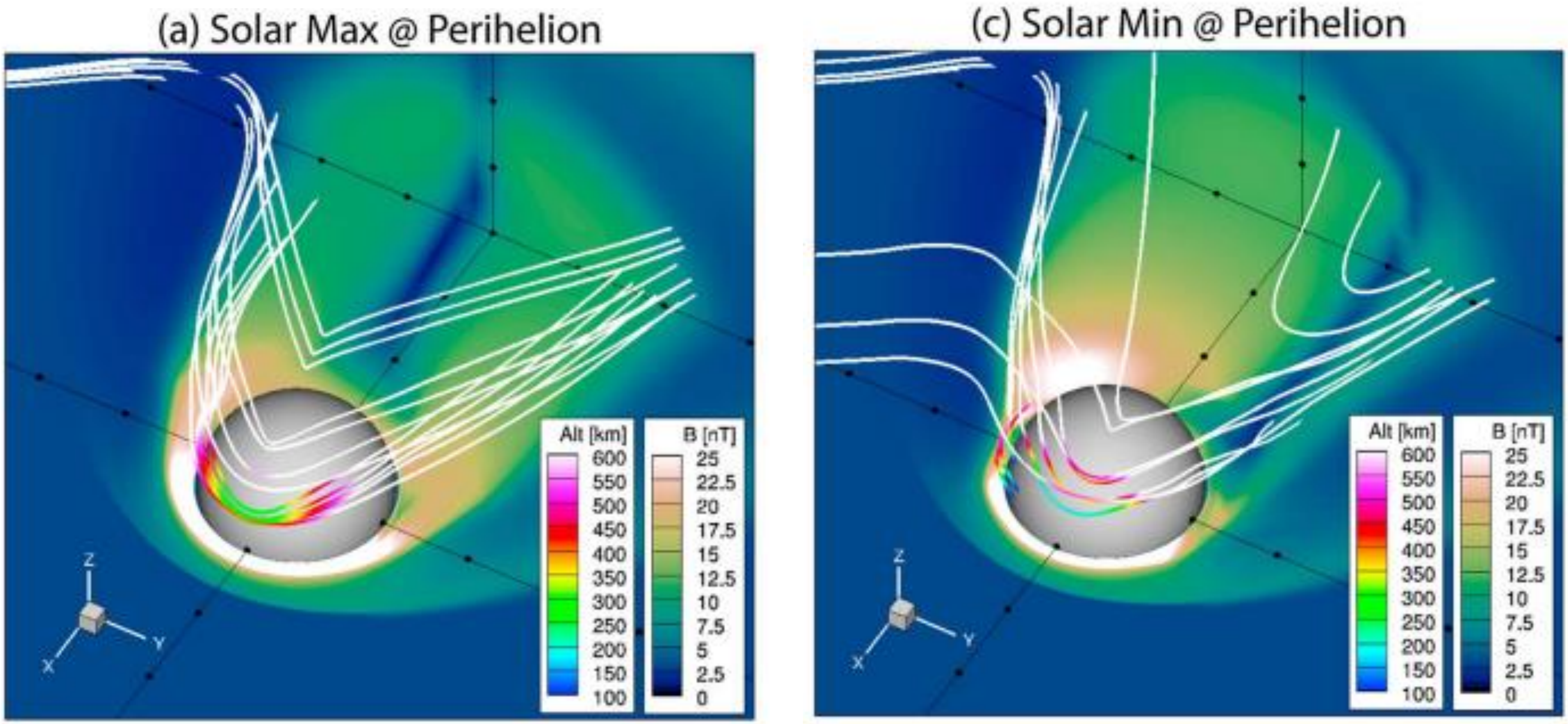
Research Experience and Projects

Statics of the current sheet structures of Martian magnetotail



Average configurations of current sheet structures under different IMF cone angles
$(-1.5R_M < X_{MSE} < -0.5R_M)$

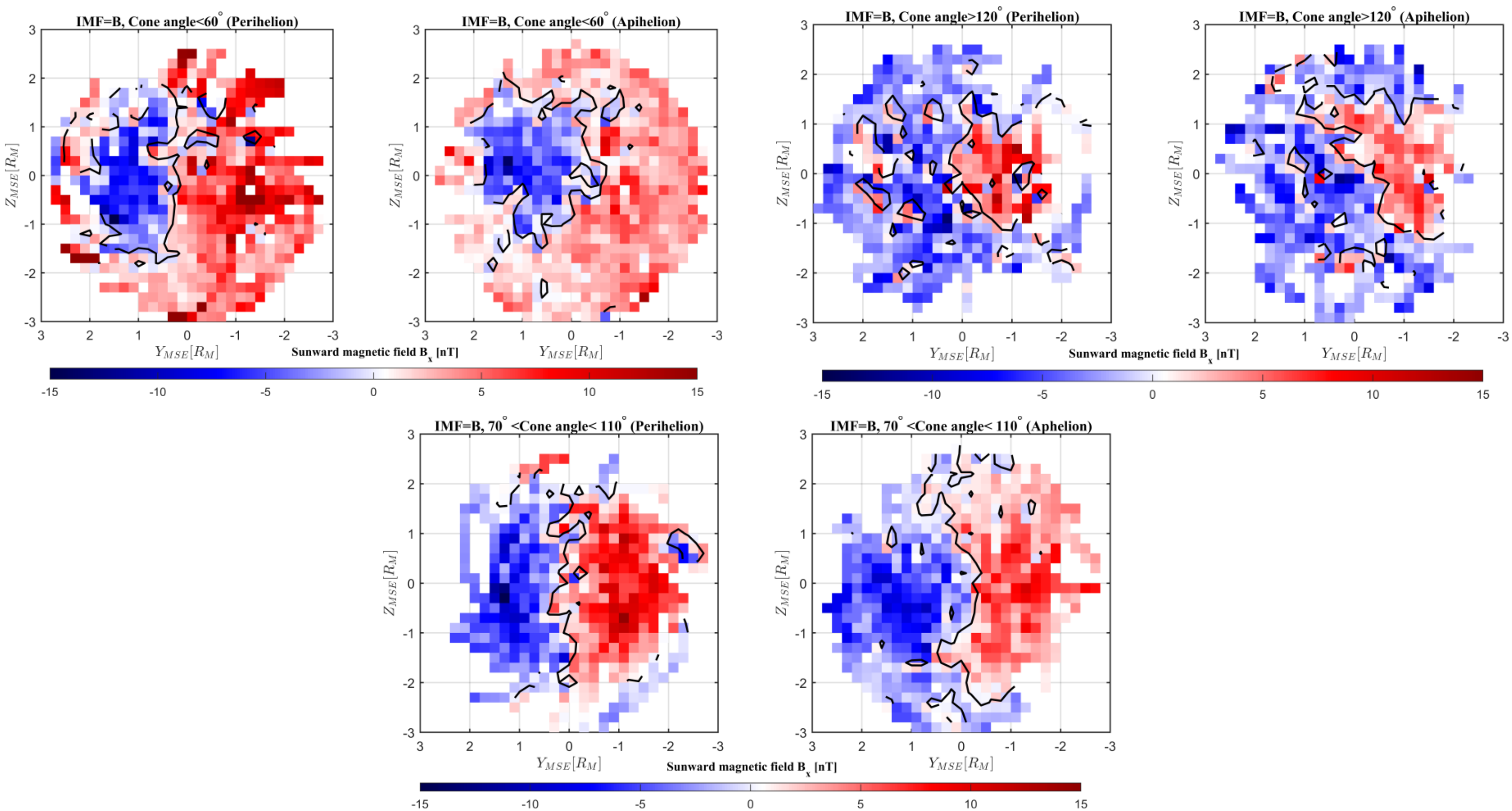
Research Experience and Projects



Liemohn et al., (2017)

Research Experience and Projects

Statics of the current sheet structures of Martian magnetotail



Average configurations of current sheet structures under different IMF cone angles.
(With different Solar EUV intensity comparisons)

Research Experience and Projects

Conclusions

- There is a systematic Y (i.e., dawn-dusk) asymmetry in the location of the Martian magnetotail current sheet in the modified MSE coordinates.
- The shifted distance of the current sheet is sensitive to the IMF cone angle.
- The asymmetry is controlled by the flow-aligned component of IMF, shifting to the dawn (-Y) during the tailward IMF conditions and to the dusk (+Y) during the sunward IMF conditions.
- The shift found in this study is dominated by the IMF orientation, with influences from the crustal magnetic fields and solar EUV intensity.

Future work

- Analyze ionospheric effects on the current sheet shift.
- Quantitively analyzed the solar EUV intensity effects on CS shift and compare with simulation work (Liemohn et al., 2017)
- TBD

Research Experience and Projects

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Confidential manuscript submitted to *JGR: Space Physics*

Statistical investigations of the flow-aligned component of IMF impact on current sheet structure in the Martian magnetotail: MAVEN observations

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Q & A

Thanks for your attention! Any question?

Acknowledgements to all my supervisors and collaborators