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# Investigating the role of crustal magnetic fields on Mars' ionospheric dynamics with MARSIS-Mars Express

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*Image: Mars Global Surveyor*

# Background: Martian Magnetosphere

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- 'Hybrid' magnetosphere: a combination of induced and intrinsic origin.
  - Induced component:
    Result of the direct interaction of the solar wind IMF with the ionosphere. (~10-20 nT at the ionopause)
  - Intrinsic component:
    Remnant crustal magnetic field mainly in the southern hemisphere. (Up to 1500 nT)

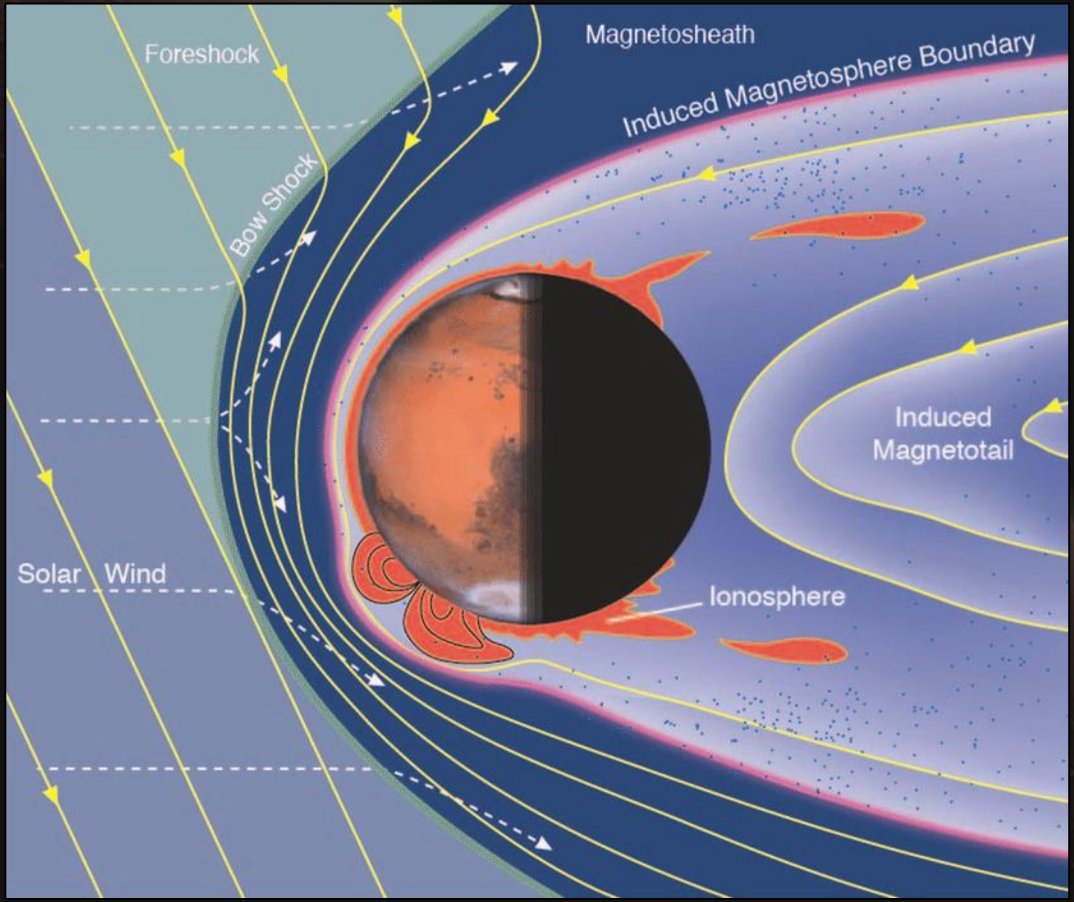


*Diagram of the solar wind interaction with Mars from D.A. Brain et al., (2015).*

# Background: Dayside Martian Ionosphere

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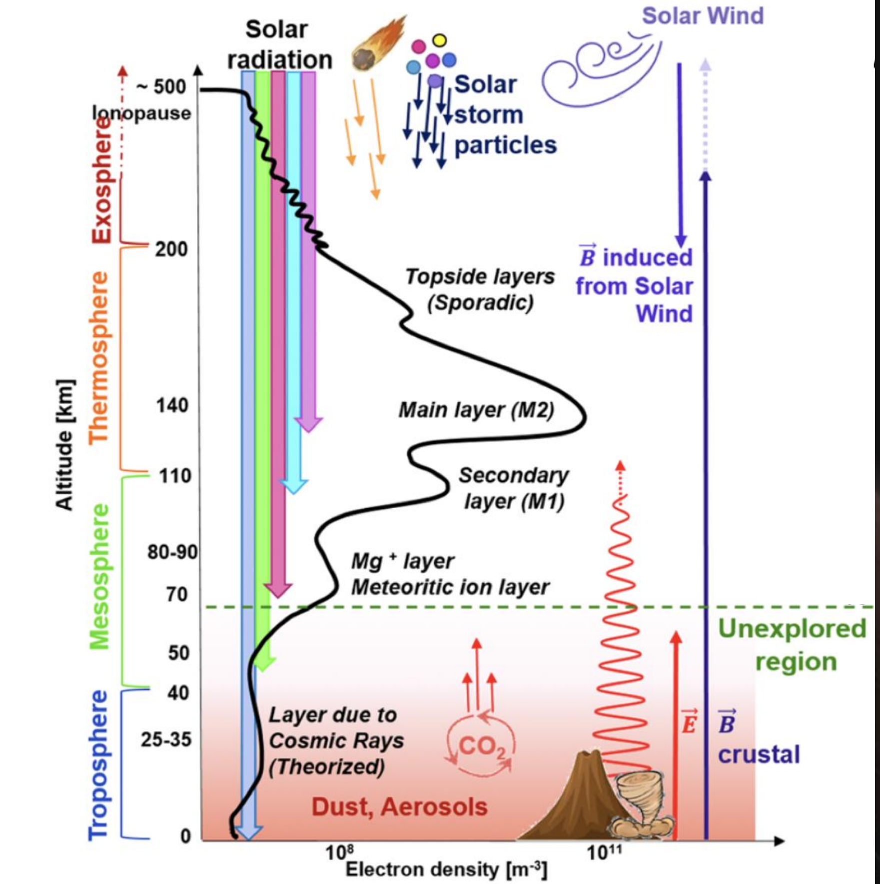
- Electron density of main ionospheric layer peaks at ~140 km altitude.
- Secondary layer produced by soft X-Rays.
- Solar wind IMF penetrating the ionosphere magnetises and compresses the ionosphere.
- The effects of the crustal magnetic field on ionospheric dynamics are yet to be fully understood.




*Typical dayside ionospheric profile at Mars from Sanchez-Cano et al., (2021).*

# Objectives

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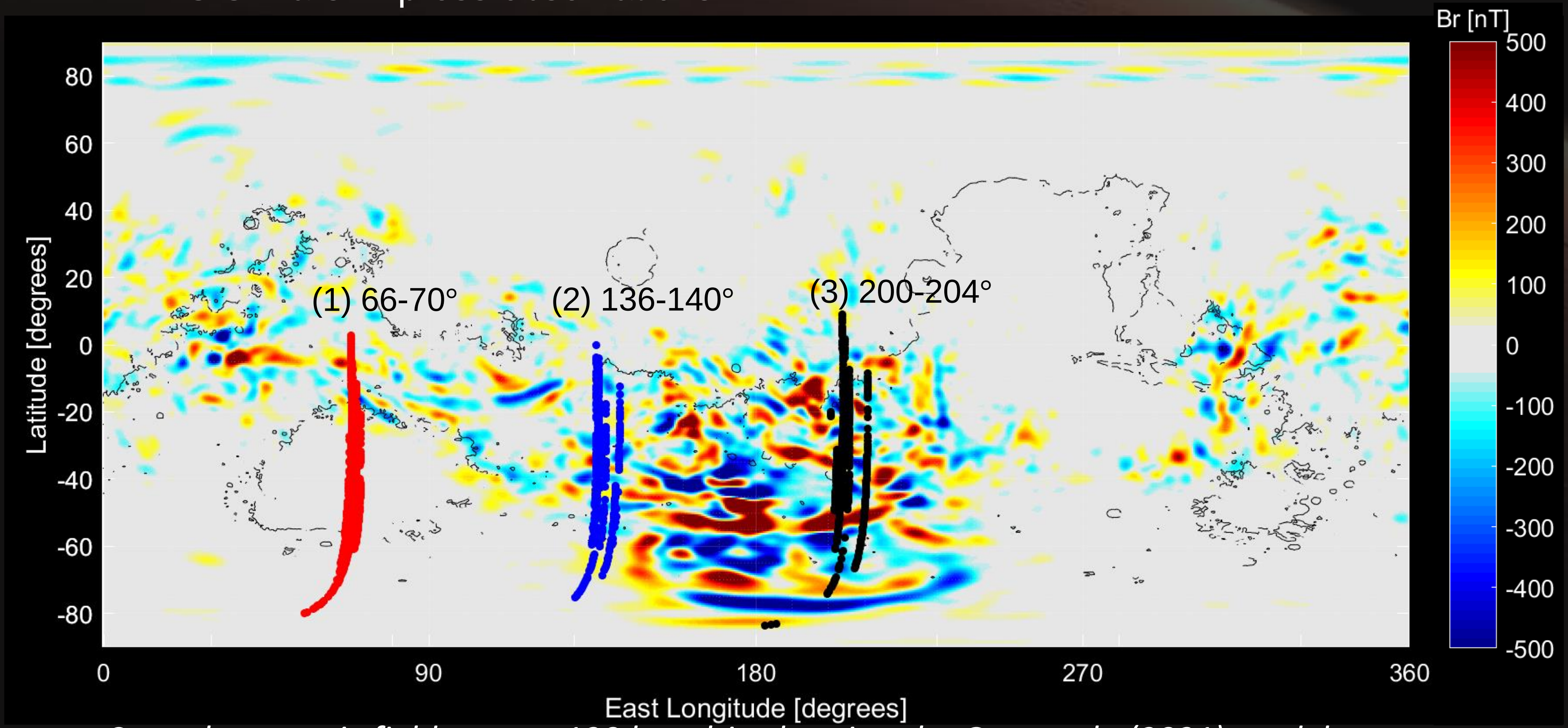
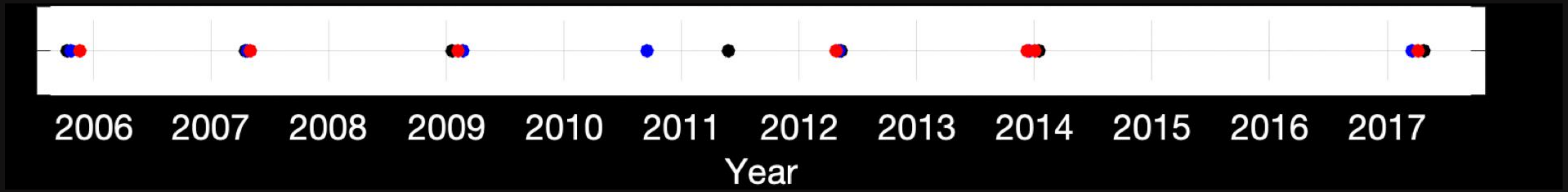
Investigate the dynamics of Mars' ionosphere over the crustal magnetic field using MARSIS-Mars Express observations.




*Crustal magnetic field map at 120 km altitude using the Gao et al., (2021) model, based on MGS and MAVEN data.*




- Temporal variation:
  - Solar cycle and seasons.
- Spatial variation:
  - Regions over the crustal magnetic field.
- Focused on 21 orbits (2005-2017) across three longitude intervals.
- Ionogram selection criteria: altitude < 650 km
- 1295 ionograms scaled.

# Principles of ionospheric sounding by MARSIS

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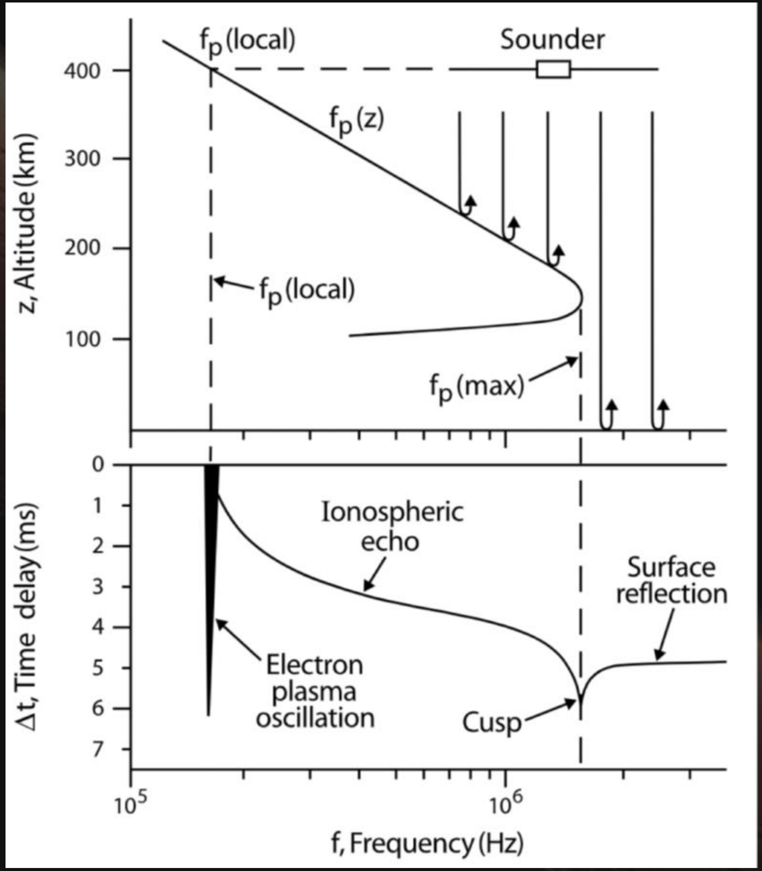
- AIS (Active Ionospheric Sounding) mode.
  - Transmitted frequency sweeps through 160 quasi-logarithmically values between 0.1-5.4 MHz.
  - Sweep repeated every 7.54 s.
  - Each transmitted pulse lasts 91.4 µs.
  - Echo intensities measured between 0 to 7.31ms at 80 equally spaced time intervals.
- Reflection: $f$, radar frequency equals the, $f_p$, plasma frequency ($f_p \propto \sqrt{\text{electron density}}$)




*Top panel: Electron plasma frequency profile.*
*Bottom panel: Corresponding ionogram.*
*Diagram from Gurnett et al., (2008).*

# Method:
# Electron Density Profiles

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- Requires inversion of the ionospheric trace using Abel's equation:

$$z(f_p) = \frac{c}{\pi} \int_{\alpha 0}^{\frac{\pi}{2}} \Delta t\left(f_p\, sin\alpha\right)\, d\alpha$$

$\Delta t$ = time delay

$f_p$ = plasma frequency

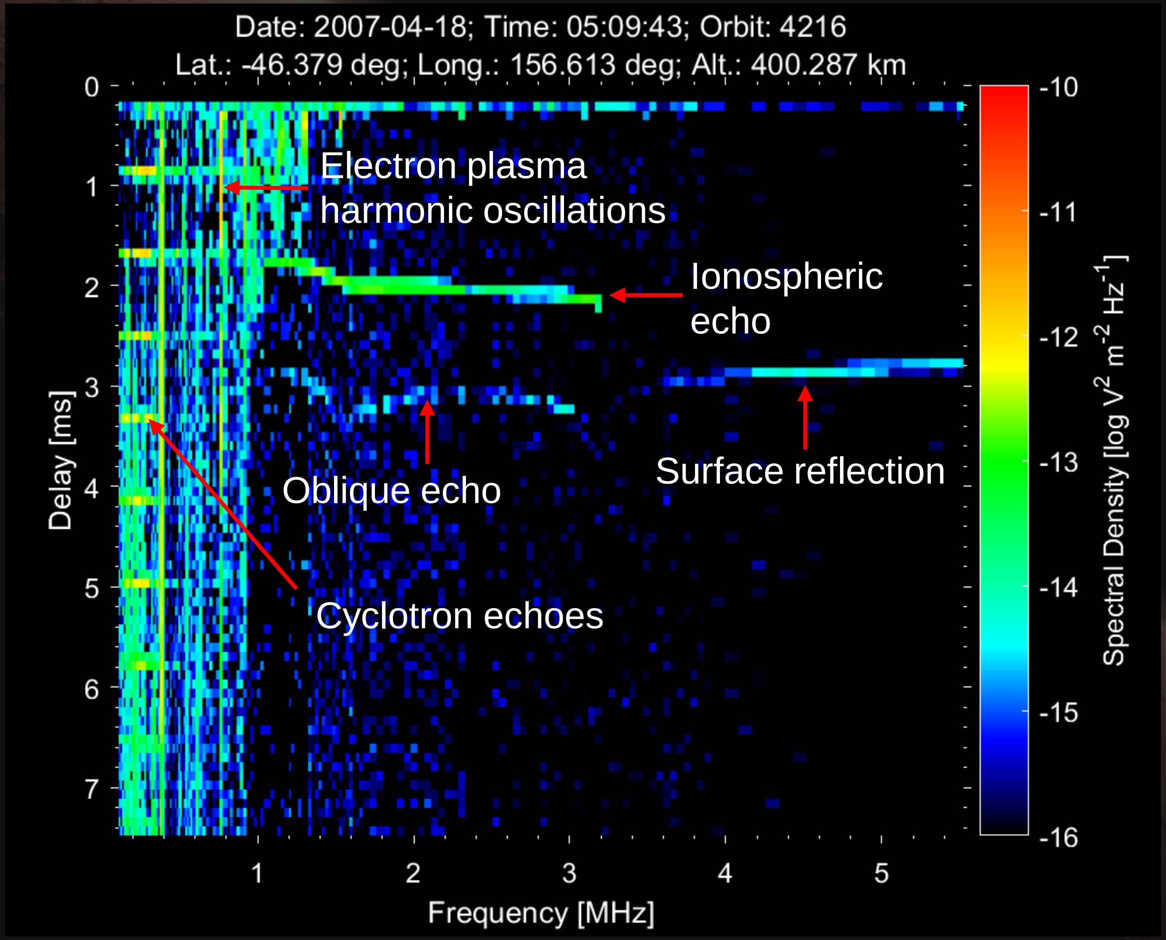
$f_w$ = radar frequency

$z_{sc}$ = spacecraft altitude

$c$ = speed of light

$sin\alpha = \frac{f_w}{f_p}$

$sin\alpha_o = \frac{f_p(z_{sc})}{f_p}$




*Example of ionogram produced using MAISDAT.*

# Method:
# Electron Density Profiles

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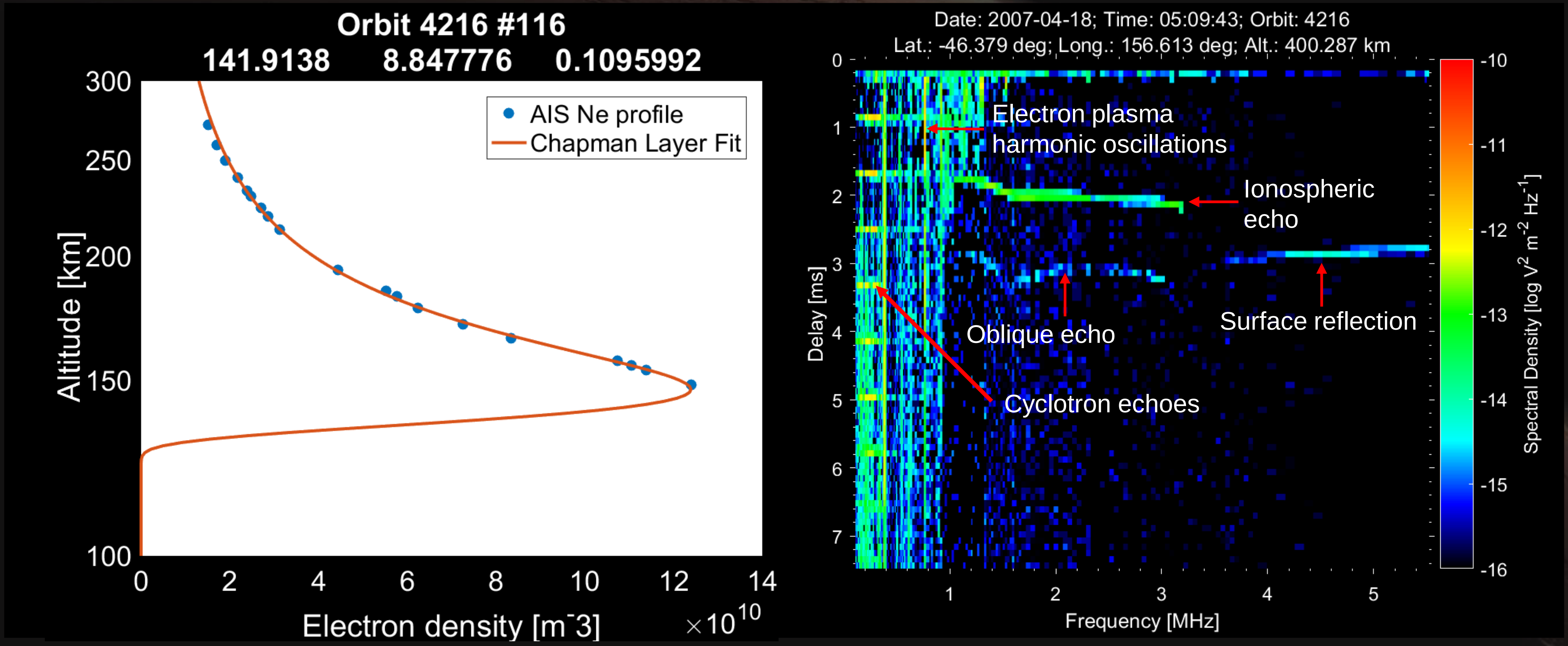


*Electron density profile (left), corresponding to the ionogram (right), fitted with an $\alpha$ −Chapman layer.*

# Method:
# Electron Density Profiles

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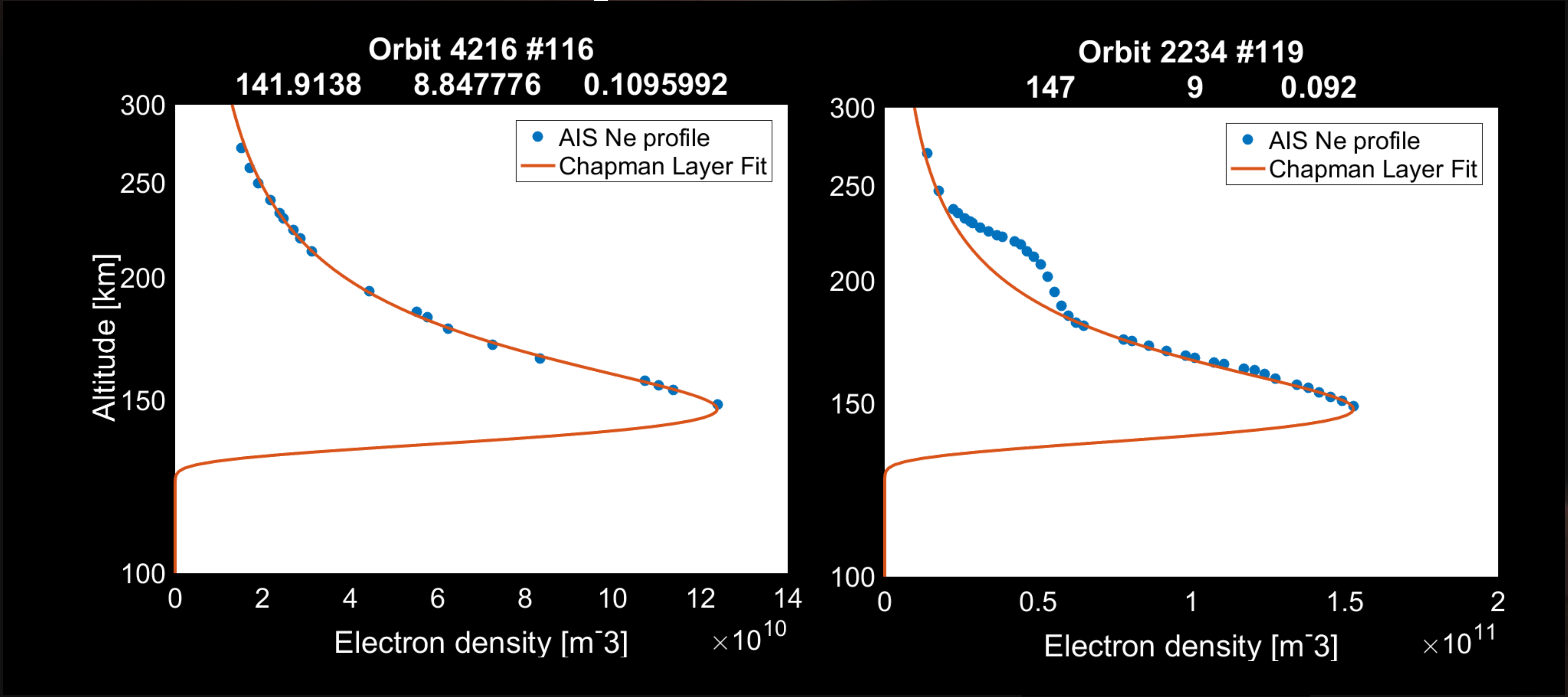


*Example electron density profiles fitted with $\alpha$ –Chapman layers.*

# Results

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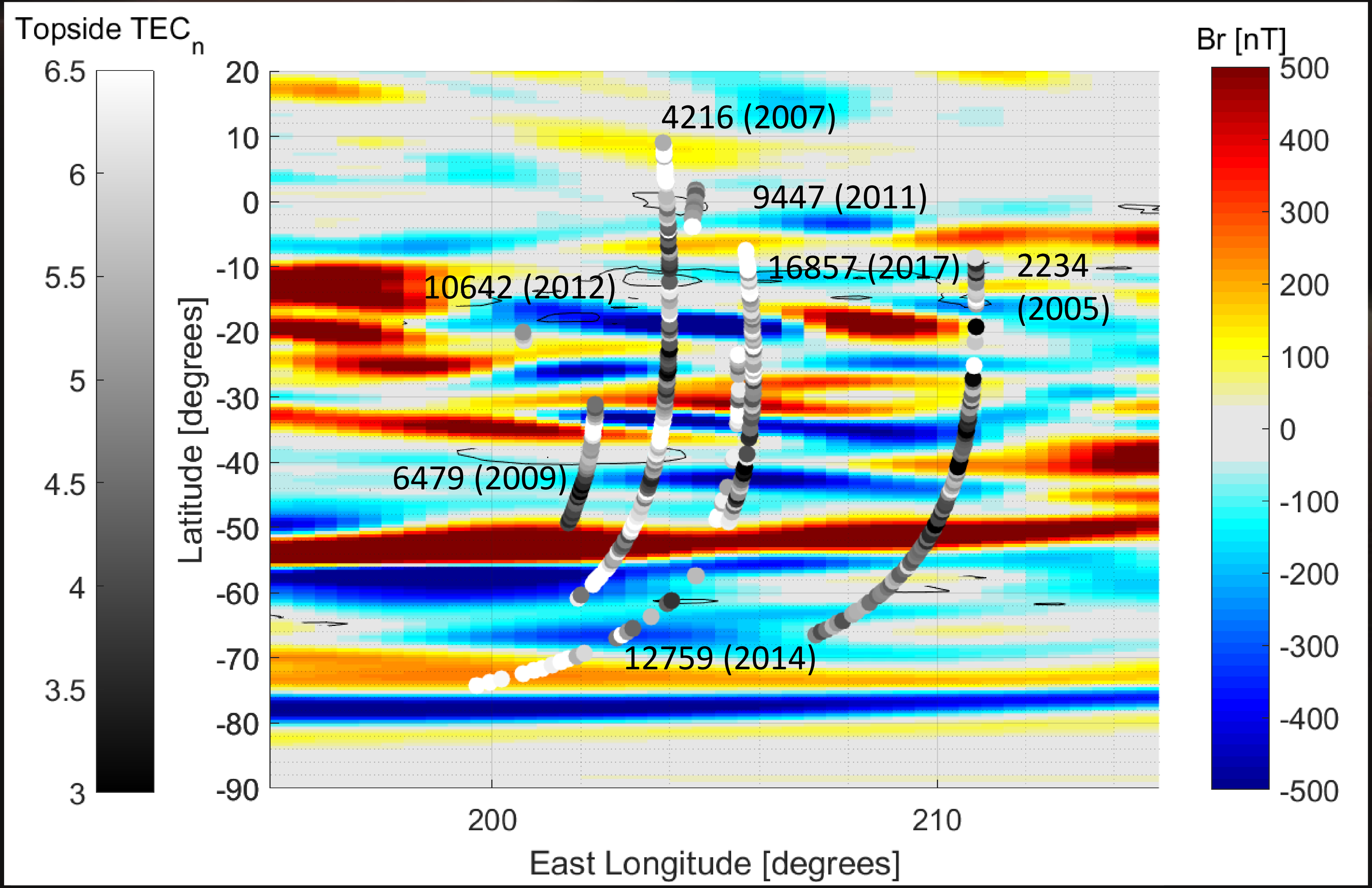
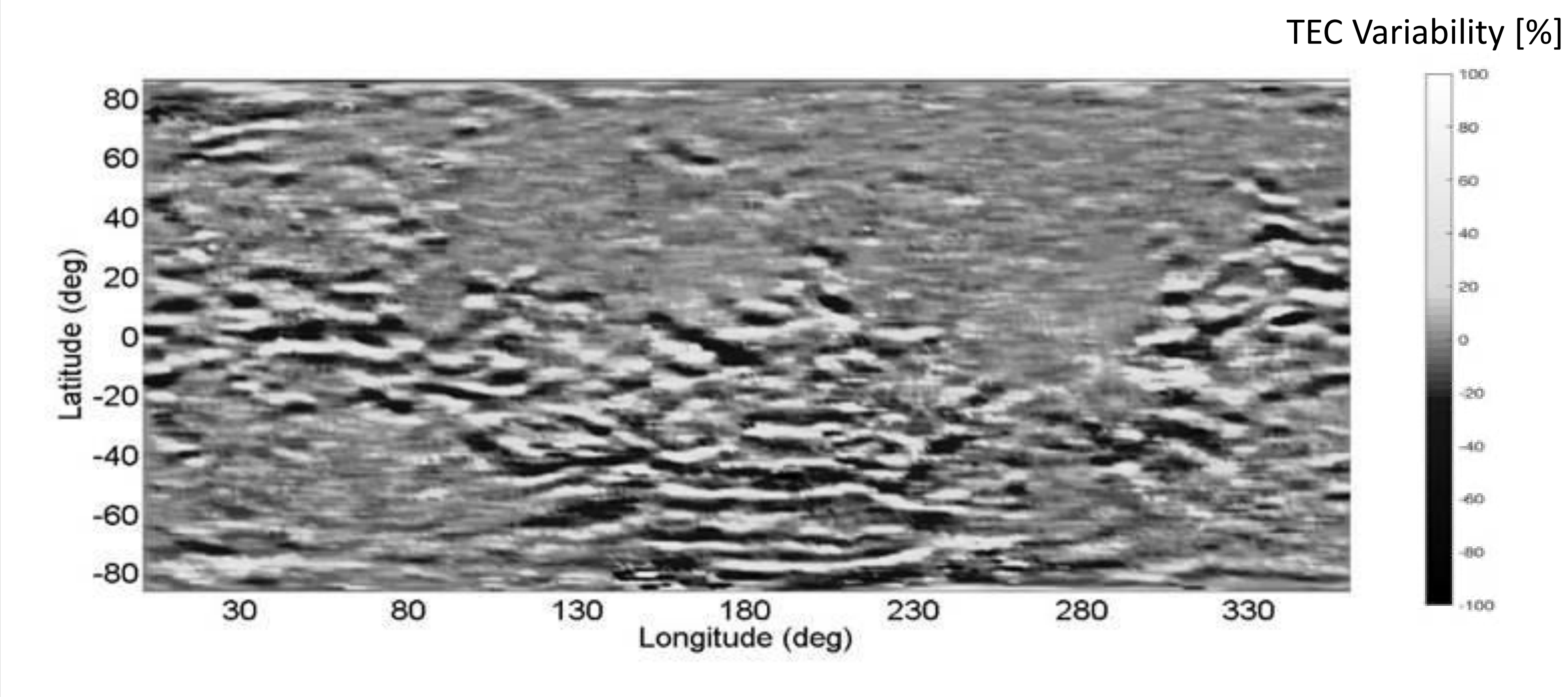



*Gao et al., (2021) crustal magnetic field model map at 120 km altitude overplotted with $TEC_n$, the topside total electron content of normalised electron density profiles. Labelled are corresponding orbit numbers and years.*

Variability in $\mathrm{TEC_n}$ over the crustal magnetic fields is consistent for orbits between 2005 to 2017.

# Comparison:




Adapted from Cartacci et al., (2013).
TEC variability is highest over the crustal magnetic field region with strong, quasi-vertical field lines.

# Results

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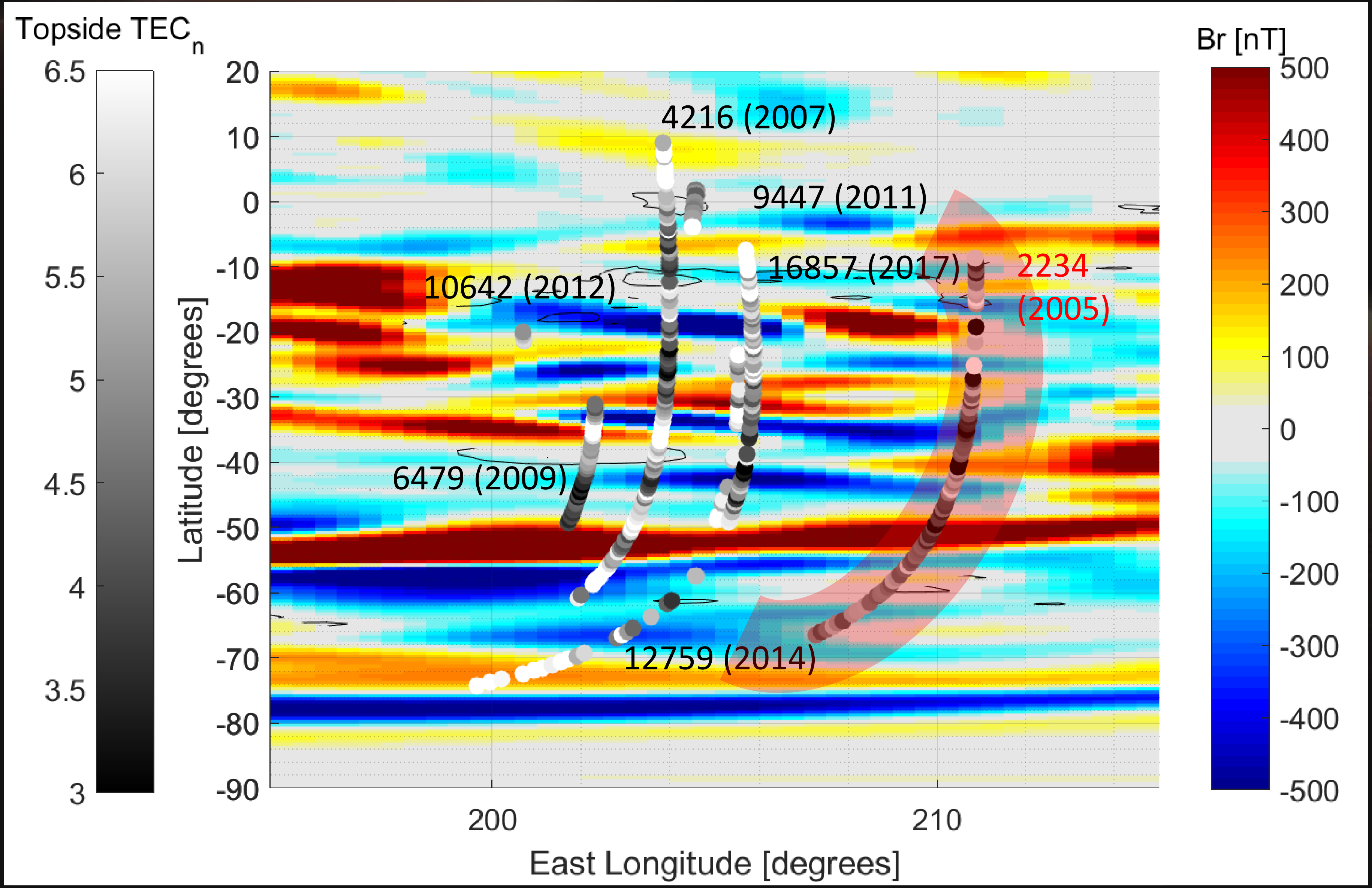


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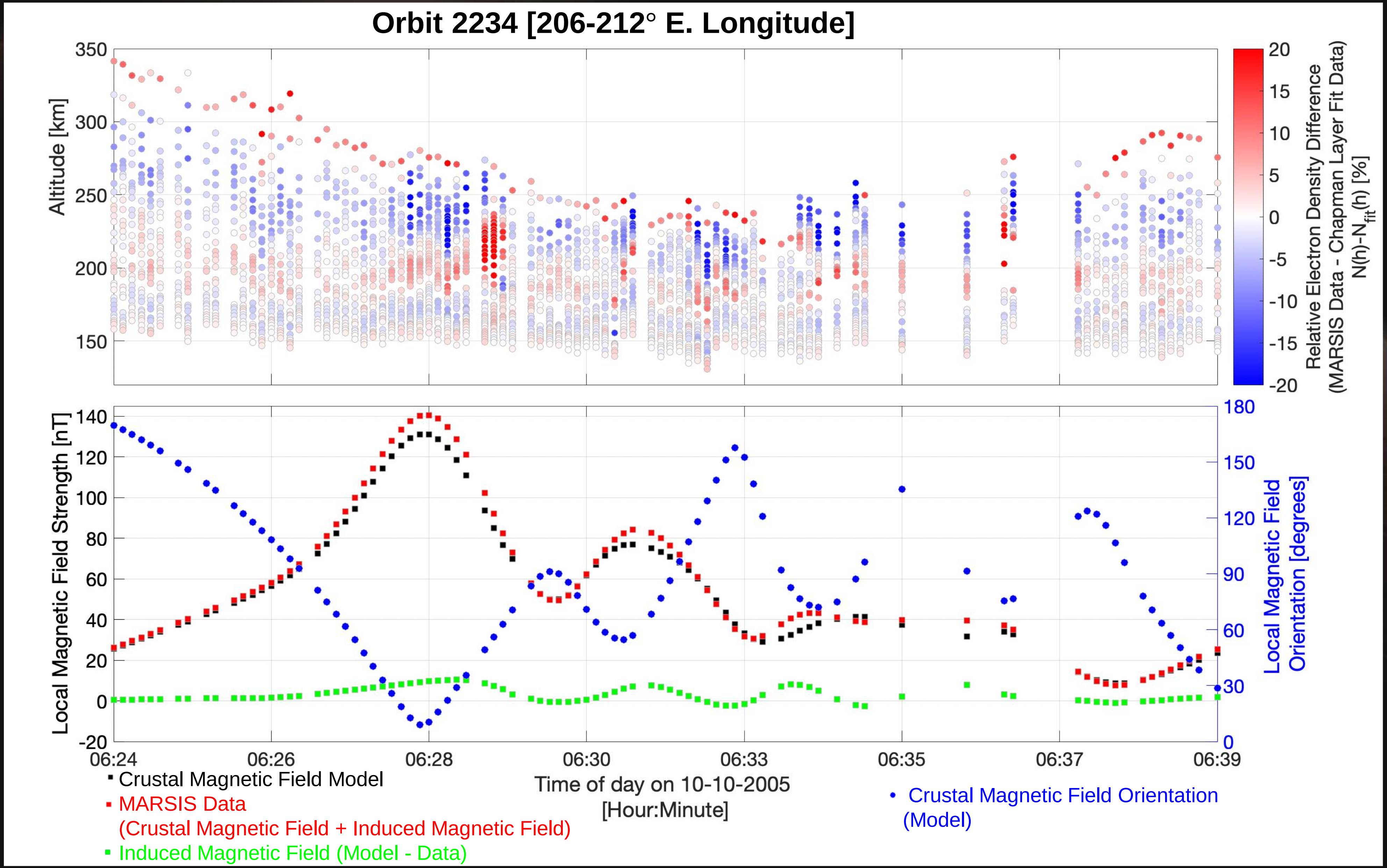
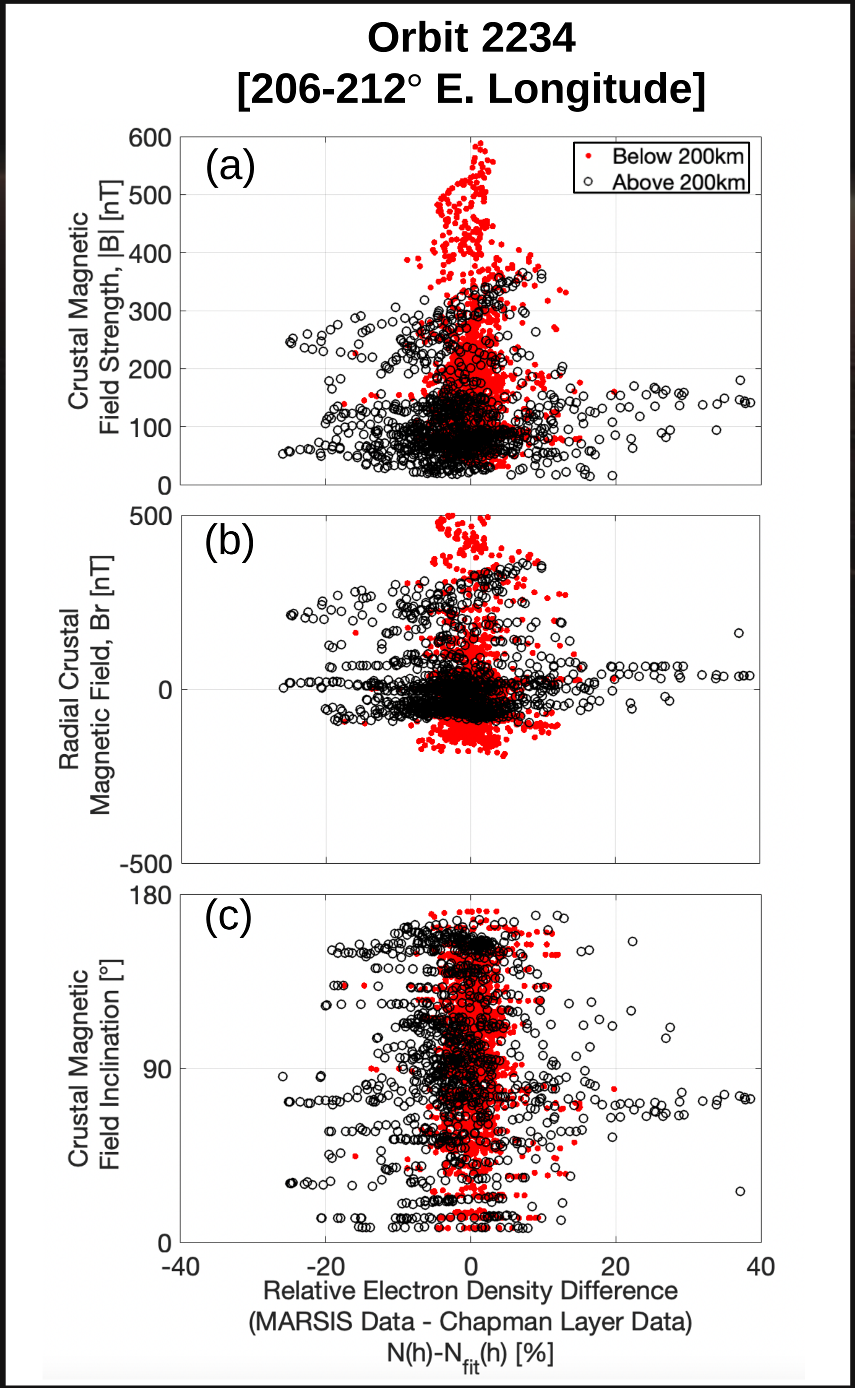



***Top panel:*** *Relative electron density difference between MARSIS data from Orbit 2234 and a Chapman layer.*

***Bottom panel:*** *Local magnetic field strength and orientation from the crustal magnetic field model and MARSIS data.*

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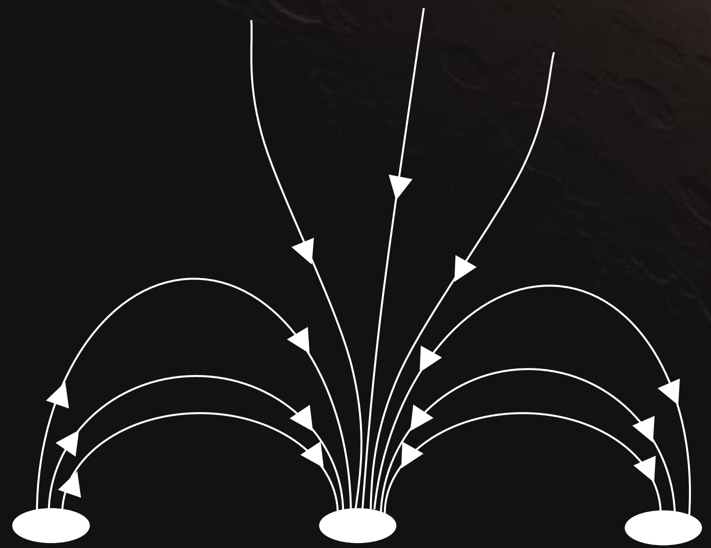
# Results

*Modelled total (a) and radial (b) crustal magnetic field strength and its inclination (c) plotted as a function of the relative electron density difference.*

Largest relative electron density difference for crustal magnetic field with:

- |B| between 100-200 nT
- Br close to zero.
- Inclination ~90 degrees.



# Conclusions

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- 1295 ionograms from 2005-2017 have been inverted to electron density profiles.
- Focused on 3 regions: on the edge of, over and without main crustal magnetic fields.
- Preliminary work shows relation between the crustal magnetic field orientation and the electron density profiles.

# Future Work

- Analyse in further detail the electron density profile variabilities of each orbit.
- Investigate how the time varying solar wind-crustal magnetic field interaction affects the ionospheric dynamics.