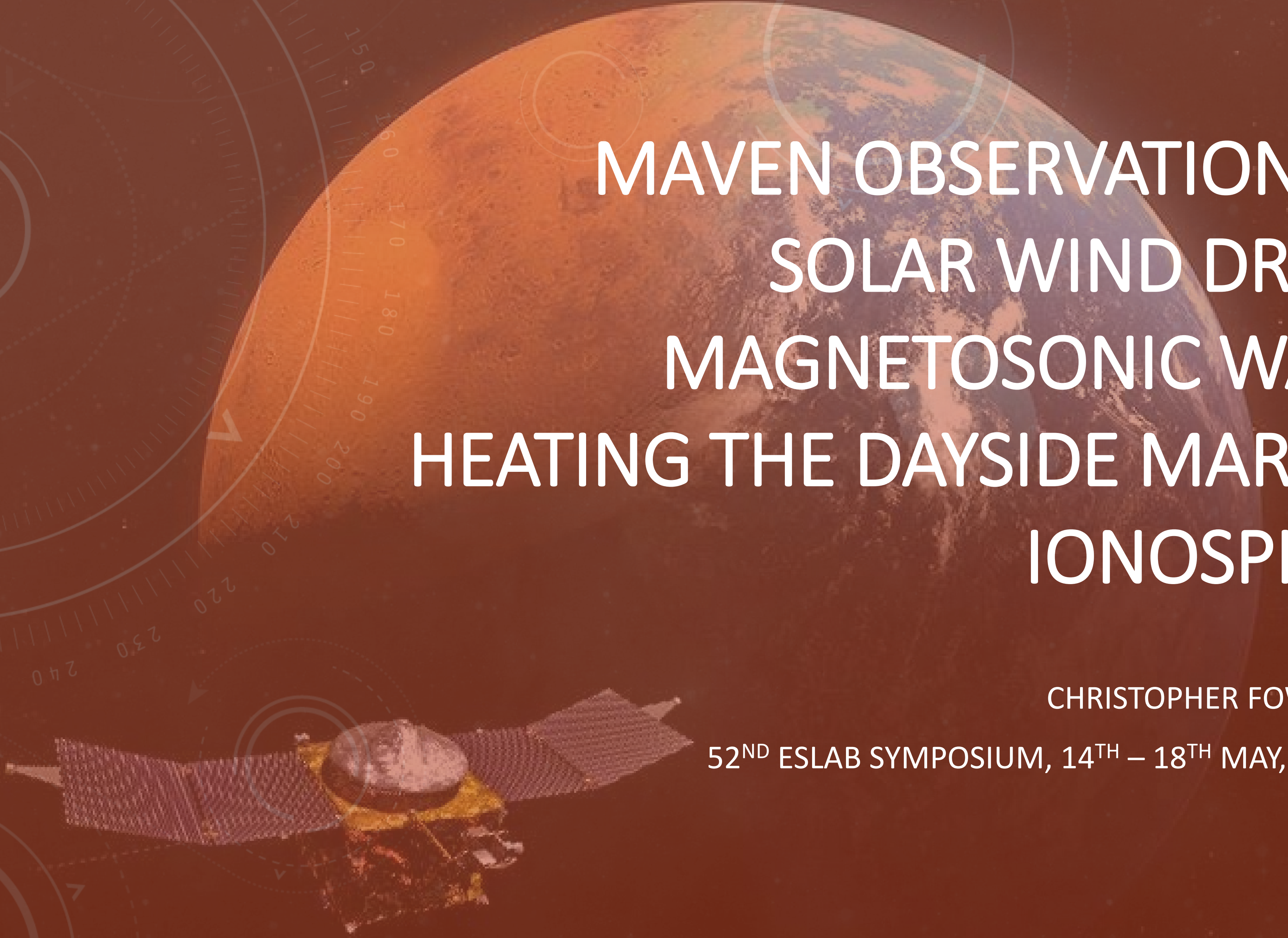

MAVEN OBSERVATIONS OF SOLAR WIND DRIVEN MAGNETOSONIC WAVES HEATING THE DAYSIDE MARTIAN IONOSPHERE

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52ND ESLAB SYMPOSIUM, 14TH – 18TH MAY, 2018.

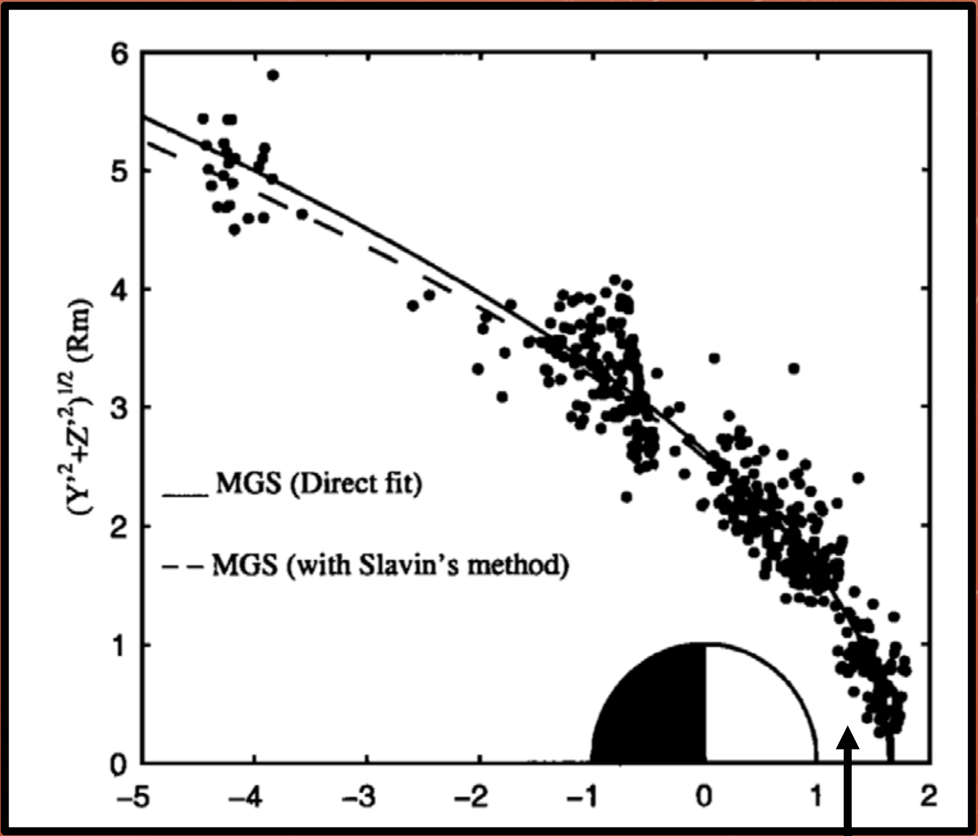
INTRODUCTION

- Important energy sources for planetary atmospheres:
    - Solar radiation.
    - Solar wind (~10^6 times less energy than SR).

- Waves generated at ~proton gyro-length scale at planetary bow shock.

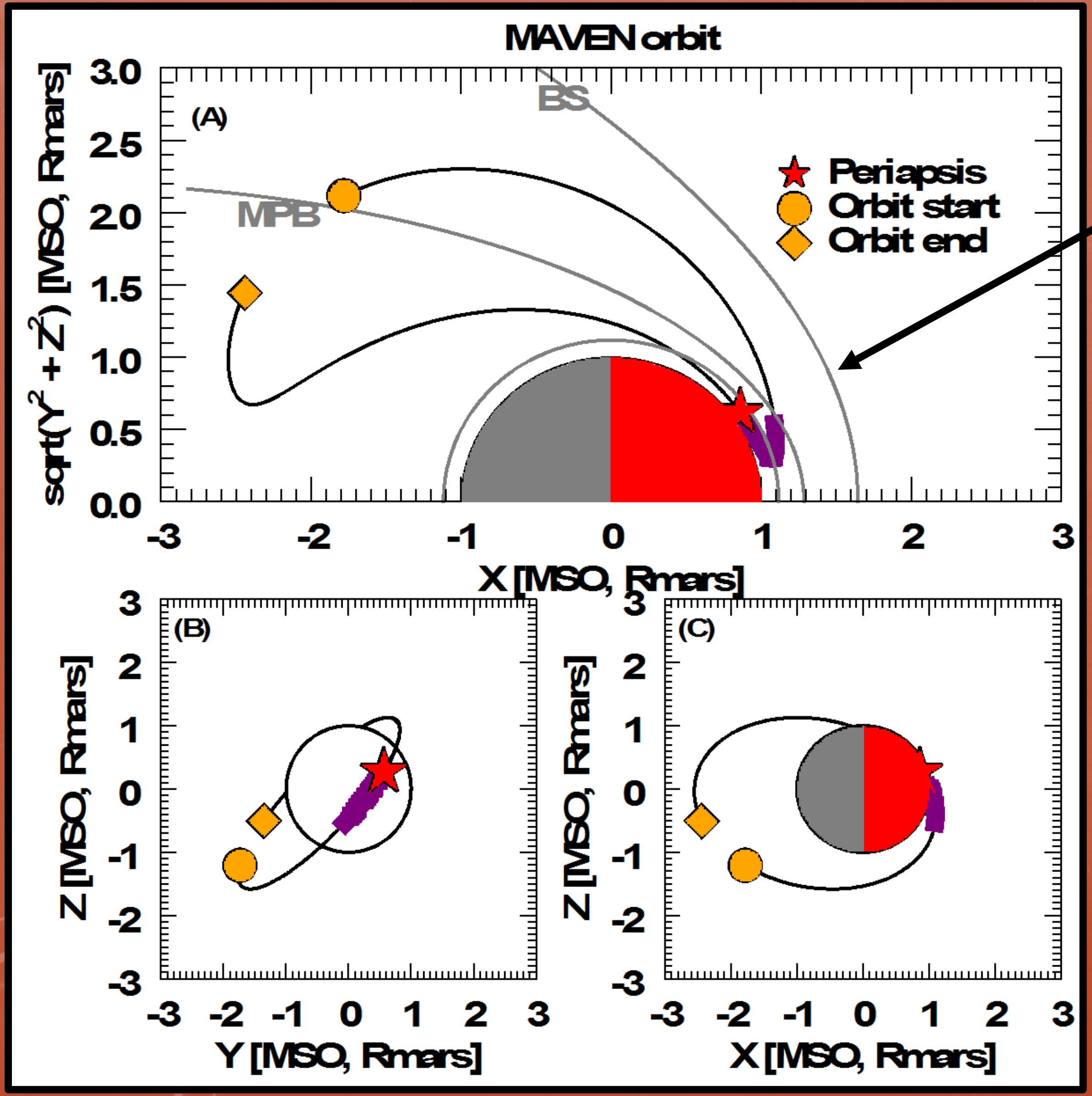
- Does the small scale size of the induced Martian magnetosphere allow for “direct” energy transfer from the solar wind to the ionosphere?

Vignes et al., 2000.



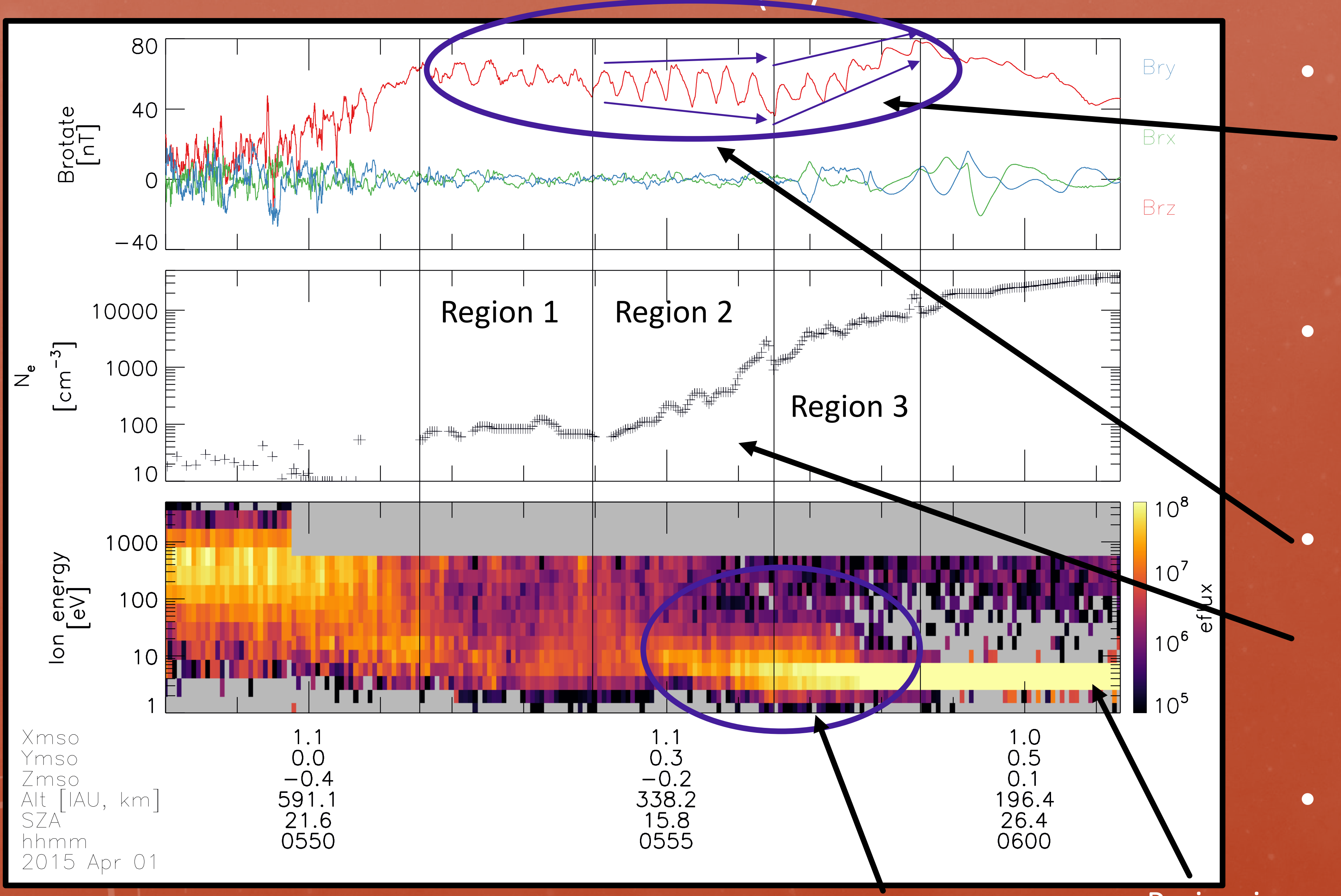
Solar wind proton gyro radius typically ~1500 km (0.5 R_{mars}).

MAVEN ORBIT TRAJECTORY



- Empirical bow shock and magnetic pileup boundaries (Vignes et al., 2000).
- MAVEN inbound segment passes through inner magnetosheath and into the ~sub-solar ionosphere.
- The following figures show ~15 minutes of plasma data (spanning the purple line here).

MAVEN OBSERVATIONS: (1): MAGNETOSONIC (MS) WAVES



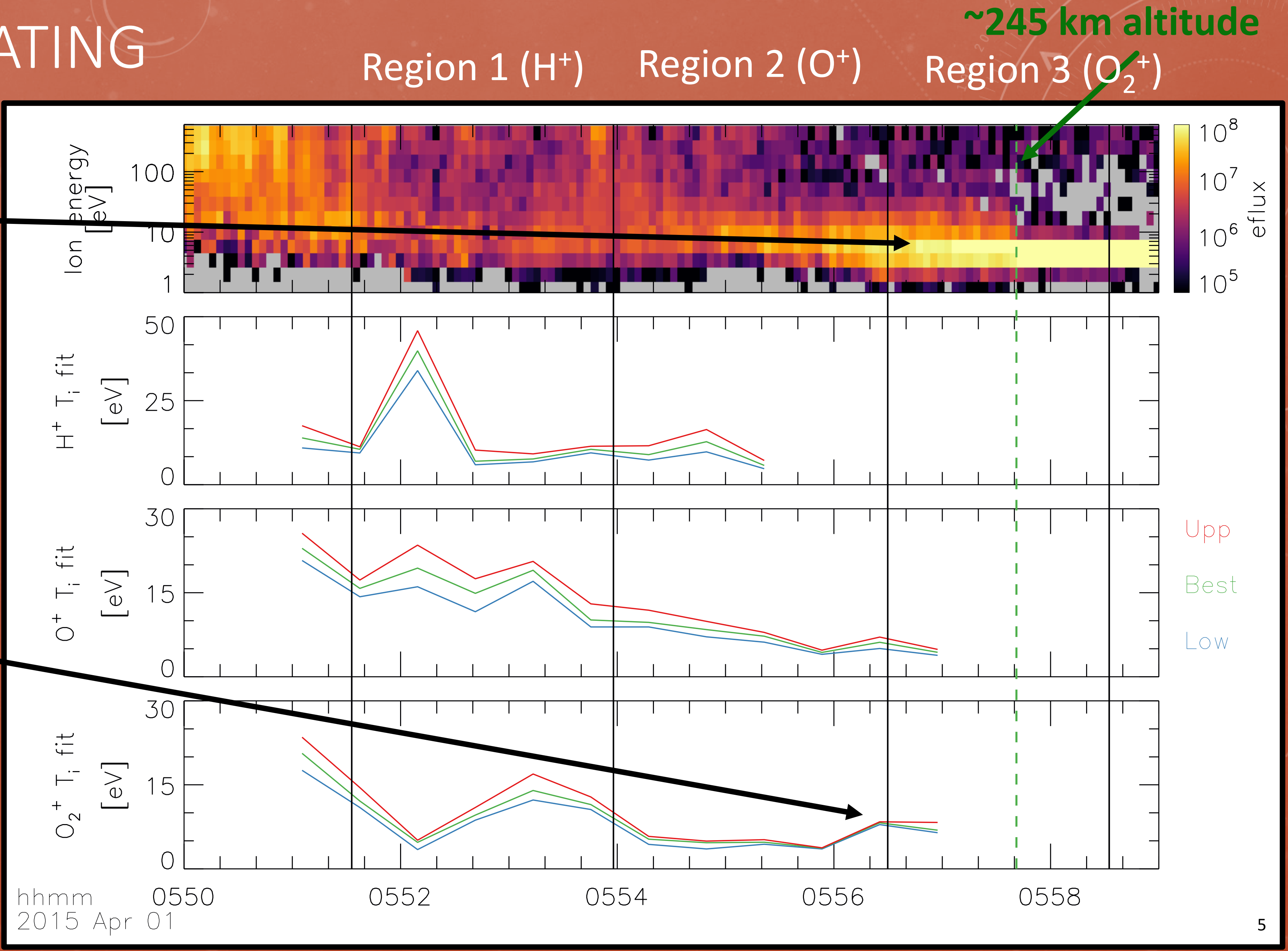
Heated ions close to periapsis

Periapsis

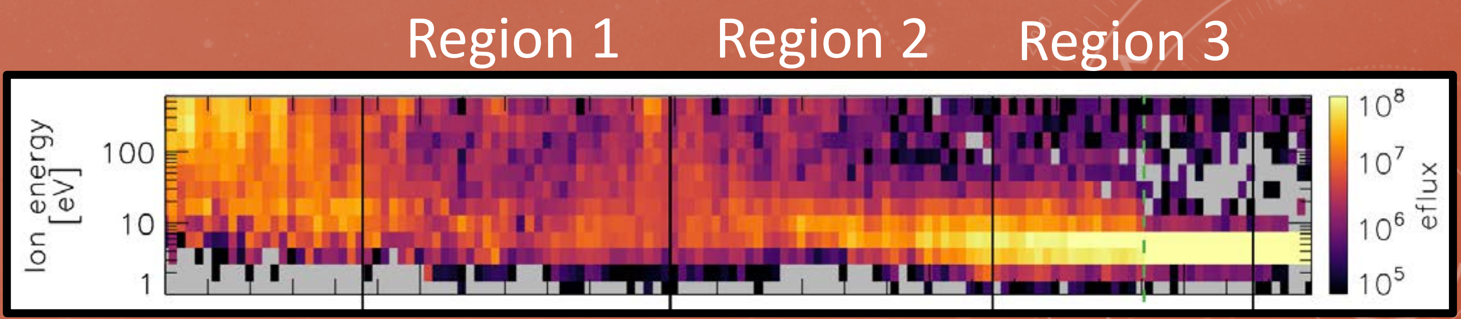
- 20-25 nT waves in parallel **B**, at ~0.035 Hz.
- **B** aligned in ~Z MSO direction.
- Region 2: wave amplitudes increase as density increases.
- Wavelengths are 100's of km (large).

(2A): ION HEATING

- Significant wave damping and ion heating observed in Region 3.
- O_2^+ is dominant ion in Region 3.
- T_i of ~5 eV observed.



(2B): ION HEATING

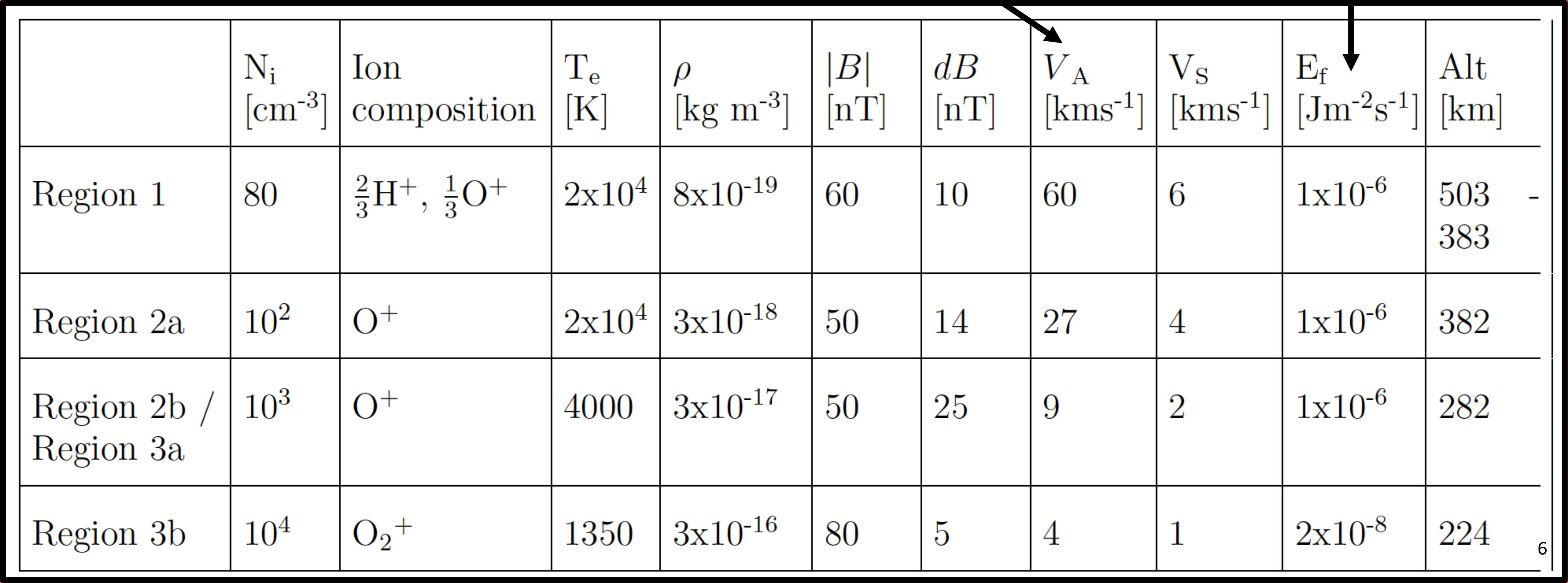


- Wave damping occurs primarily in Region 3 (O_2^+ dominated ionosphere).

$E_f \propto V_A \langle dB^2 \rangle$

Alfven velocity is ~ group velocity

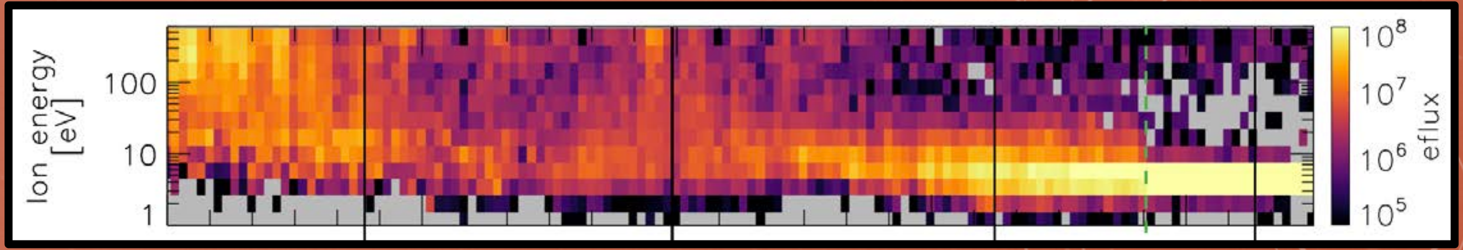
Wave damping occurs in Region 3.



	N_i [cm^{-3}]	Ion composition	T_e [K]	ρ [kg m^{-3}]	$\|B\|$ [nT]	dB [nT]	V_A [kms^{-1}]	V_S [kms^{-1}]	E_f [$Jm^{-2}s^{-1}$]	Alt [km]
Region 1	80	$\frac{2}{3}H^+$, $\frac{1}{3}O^+$	$2x10^4$	$8x10^{-19}$	60	10	60	6	$1x10^{-6}$	503 - 383
Region 2a	10^2	O^+	$2x10^4$	$3x10^{-18}$	50	14	27	4	$1x10^{-6}$	382
Region 2b / Region 3a	10^3	O^+	4000	$3x10^{-17}$	50	25	9	2	$1x10^{-6}$	282
Region 3b	10^4	O_2^+	1350	$3x10^{-16}$	80	5	4	1	$2x10^{-8}$	224

(2C): ION HEATING

Region 1 (H^+) Region 2 (O^+) Region 3 (O_2^+)



- **Ion heating rates:**
  - **0.03 to 0.2 eV s^{-1} per ion.**
  - **Escape energy in ~10 – 70 s!**

- Why does this heating occur?

  - Adiabatic vs non adiabatic motion:

    - O^+ gyro period just above wave frequency.
    - O_2^+ gyro period just below wave frequency.

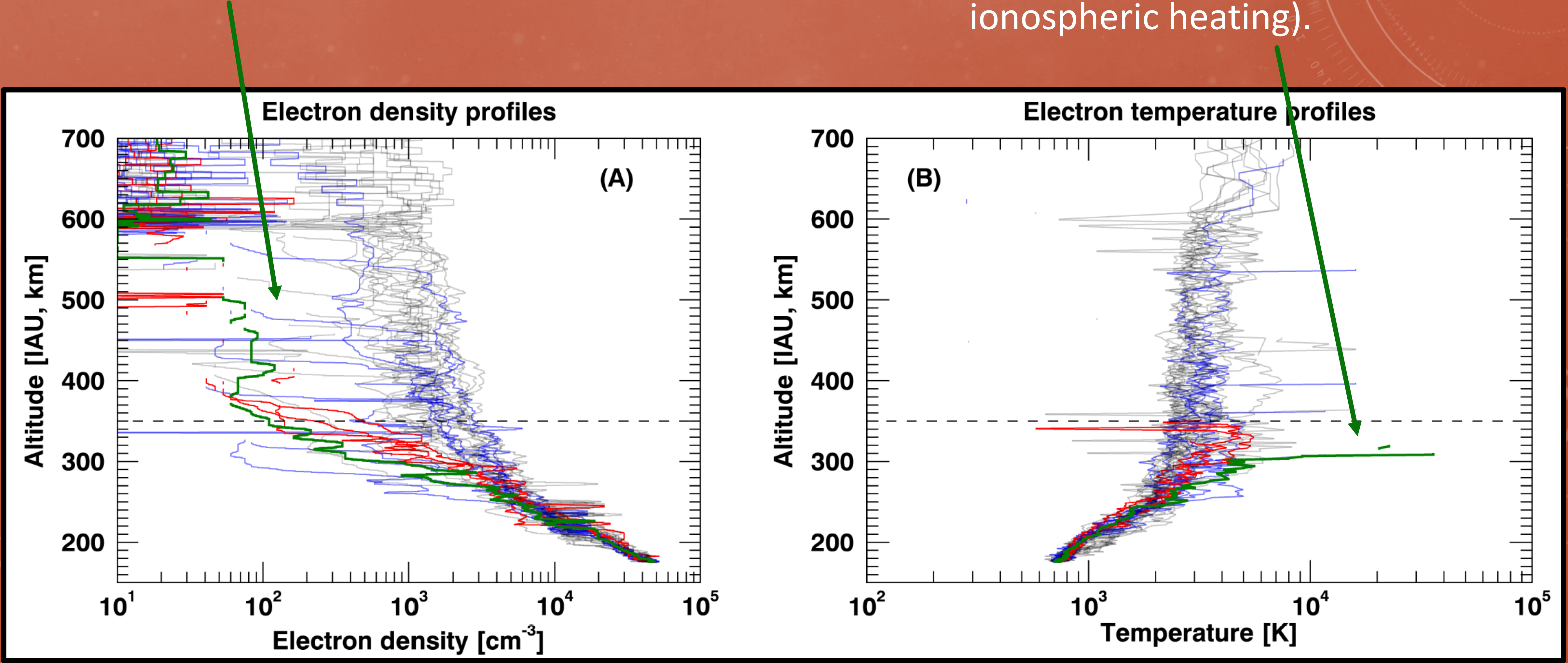
    - Leads to ion energization perpendicular to local **B** (observed by STATIC).

  - Heating efficiency likely a function of: ion composition, mass, density, **|B|**, wave frequency.

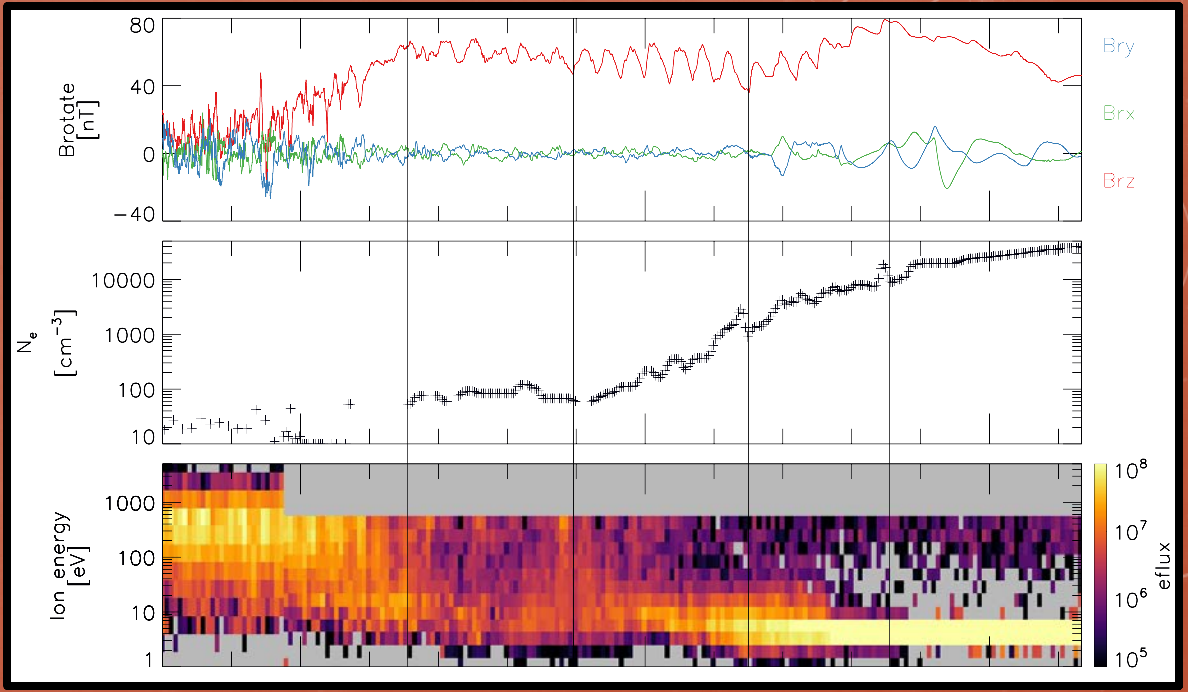
ARE THESE WAVES AND HEATING IMPORTANT AT MARS?

- Upper ionosphere > 250 km is severely depleted during this and similar events.

- Electron temperature enhanced during this event (suggests ionospheric heating).



CONCLUSIONS



- Effects of magnetosonic wave fronts “crashing” into the Martian ionosphere:
  - Plasma density and temperature variations of ~20-100% in amplitude.
  - Whistler waves generated at compressional wave fronts.
  - Wave damping in dense, O_2^+ dominated ionosphere leads to significant ion heating.
- Observed event severely erodes the dayside ionosphere.
  - Implications for long term evolution of Martian climate, and those at other unmagnetized bodies.

This study: Fowler et al., 2018, MAVEN observations of magnetosonic waves heating the dayside Martian ionosphere, JGR Space Physics.

Accompanying manuscript in preparation: Collinson et al., 2018, Ringing the ionosphere of Mars: Ionospheric compression, energization, and escape resulting from the impact of ultra-low frequency magnetosonic waves generated upstream of Mars, JGR Space Physics.

BACKUP SLIDES

WAVE DISPERSION RELATION FOR MS WAVE:

$$\omega^2 = K^2 \frac{{V_\mathrm{S}}^2 + {V_\mathrm{A}}^2}{1 + \frac{{V_\mathrm{A}}^2}{c^2}}$$

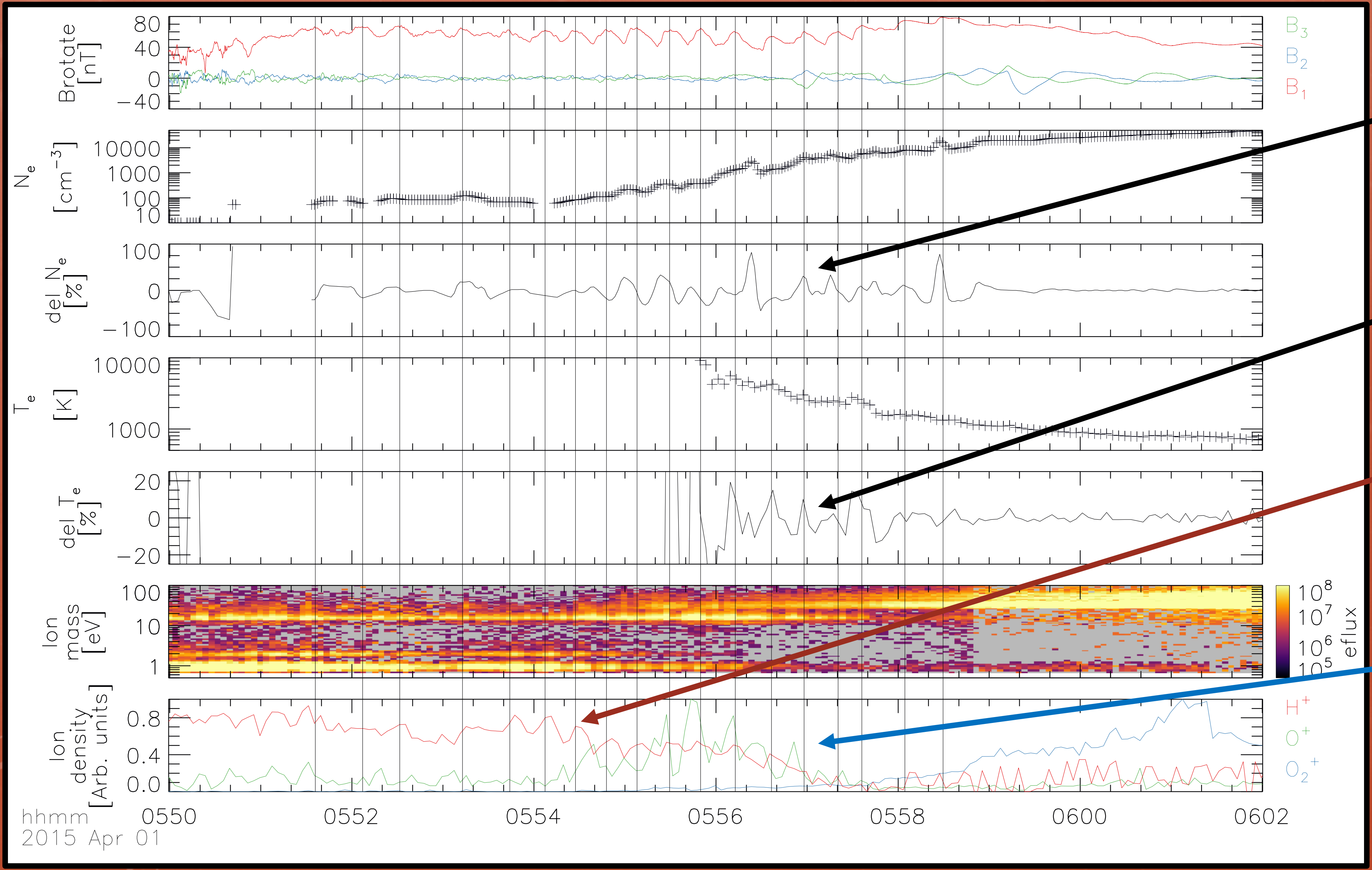
$$\sum_i n_\mathrm{i} m_\mathrm{i}$$

$$V_\mathrm{S} \text{ is defined as } \sqrt{\frac{\gamma k_\mathrm{b} T_\mathrm{e}}{m_\mathrm{i}}};\ V_\mathrm{A} \text{ as } \sqrt{\frac{B}{\mu_0 \rho}}$$

ENERGY DENSITY OF A MS WAVE:

- Energy density (Ed) == pressure.
- Ed = $<(B0 + B1.\cos(wt))^2> / 2u - B0^2/2u$
  - $B0^2 + 2B1B0.\cos(wt) + B1^2.\cos^2(wt) - B0^2$
  - → Ed ~ $B1^2 / 4u$

(2A): IONOSPHERIC DENSITY VARIATIONS



- Variations in Ne show no obvious correlation with MS waves.
- Variations in Te show correlation with MS waves.
- Light ion (H^+) density variations correlate with MS waves.
- Heavier ions (O^+, O_2^+) do not correlate well with MS waves.

(2B): IONOSPHERIC DENSITY VARIATIONS

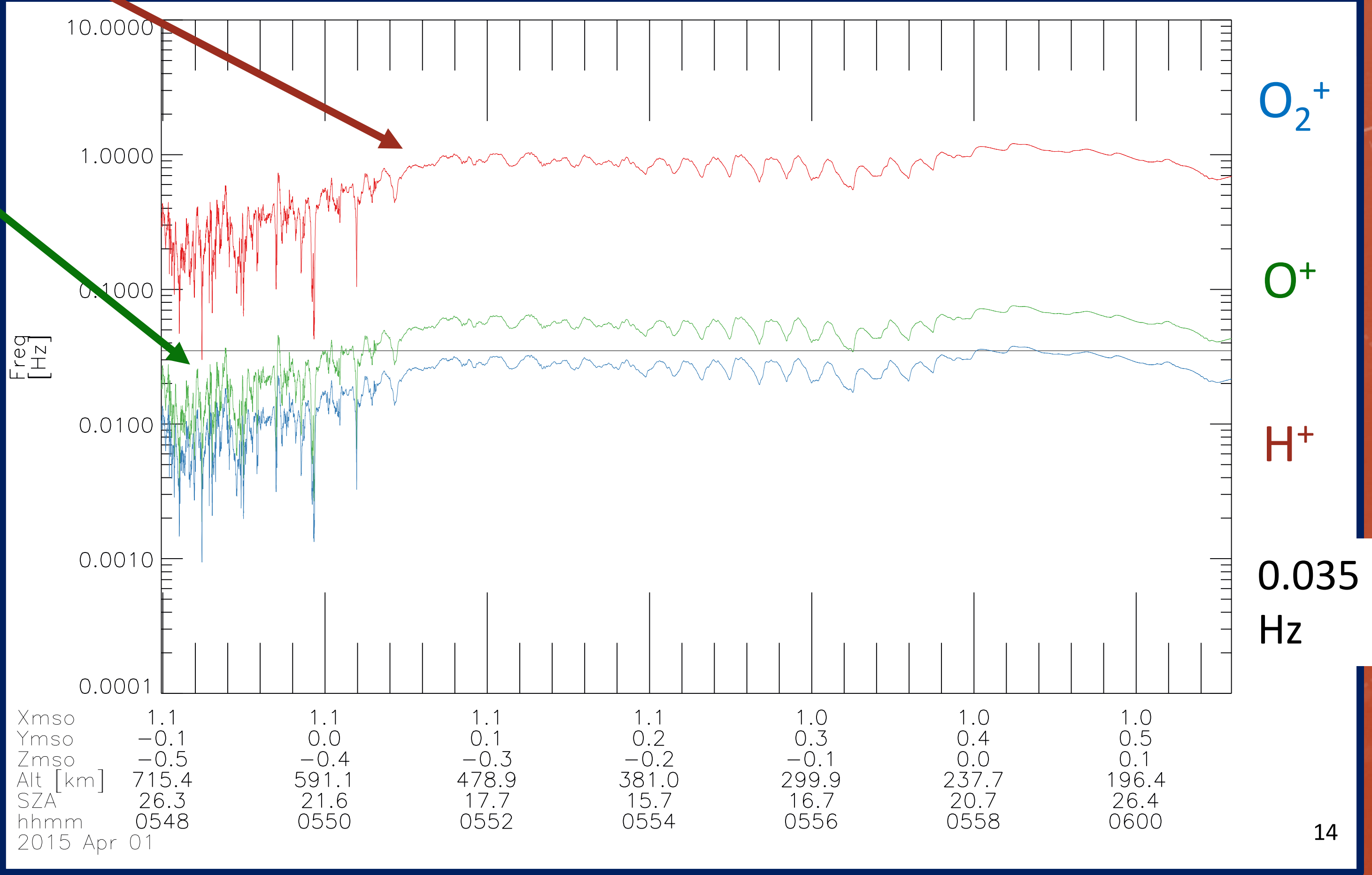
- When protons dominate the ion composition (higher altitudes):

  - H^+ gyro period ~ 15 x 0.035 Hz => Protons expected to respond to changes in **B**, as observed.
  - Suprathermal electron densities also correlate with **B** (see next slide).

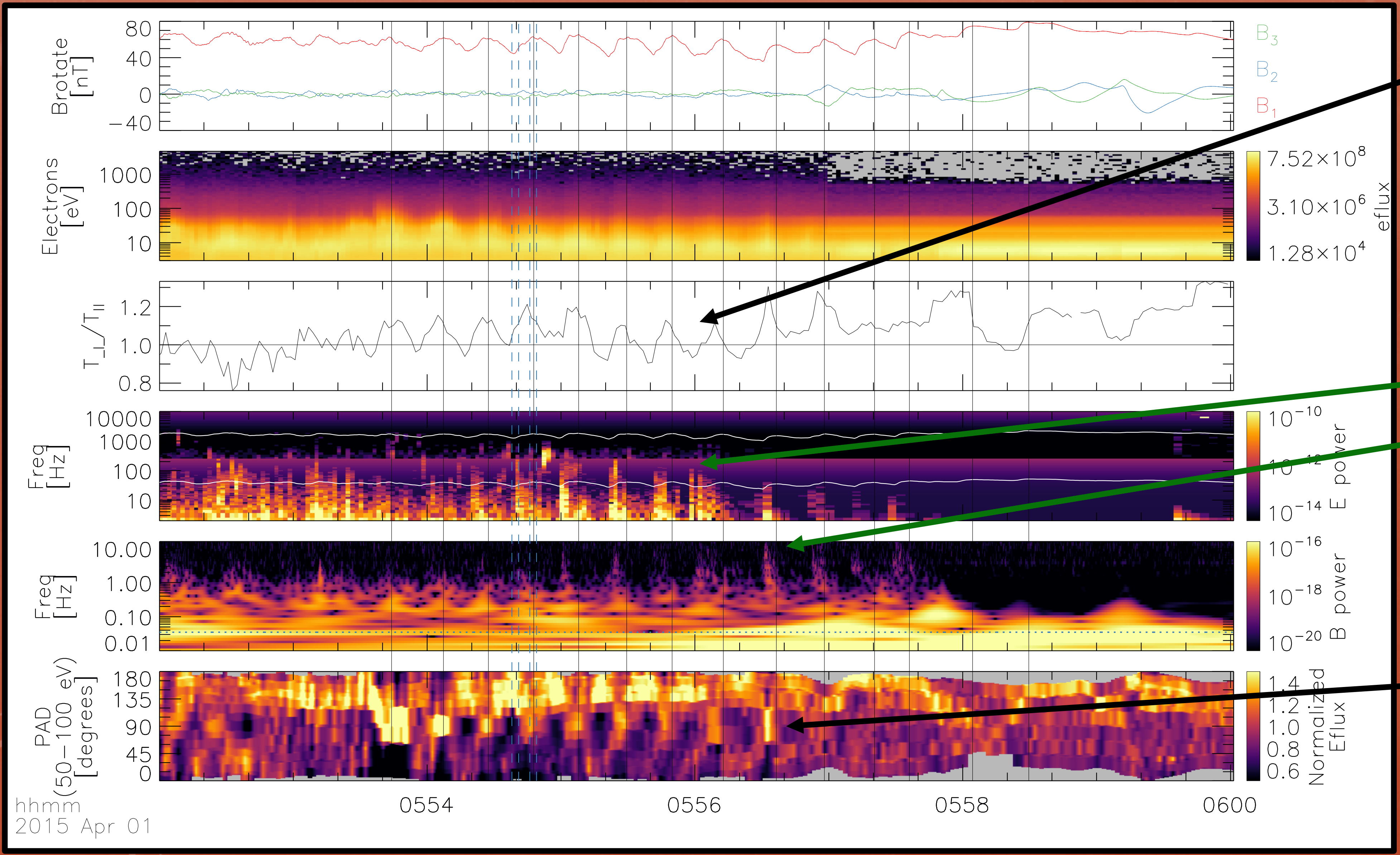
- When heavier ions dominate the ion composition (lower altitudes):

  - Gyro periods are very close to 0.035 Hz => ions not expected to respond to changes in **B**.

  - To maintain charge neutrality, ionospheric electron density also follows ion density variations.



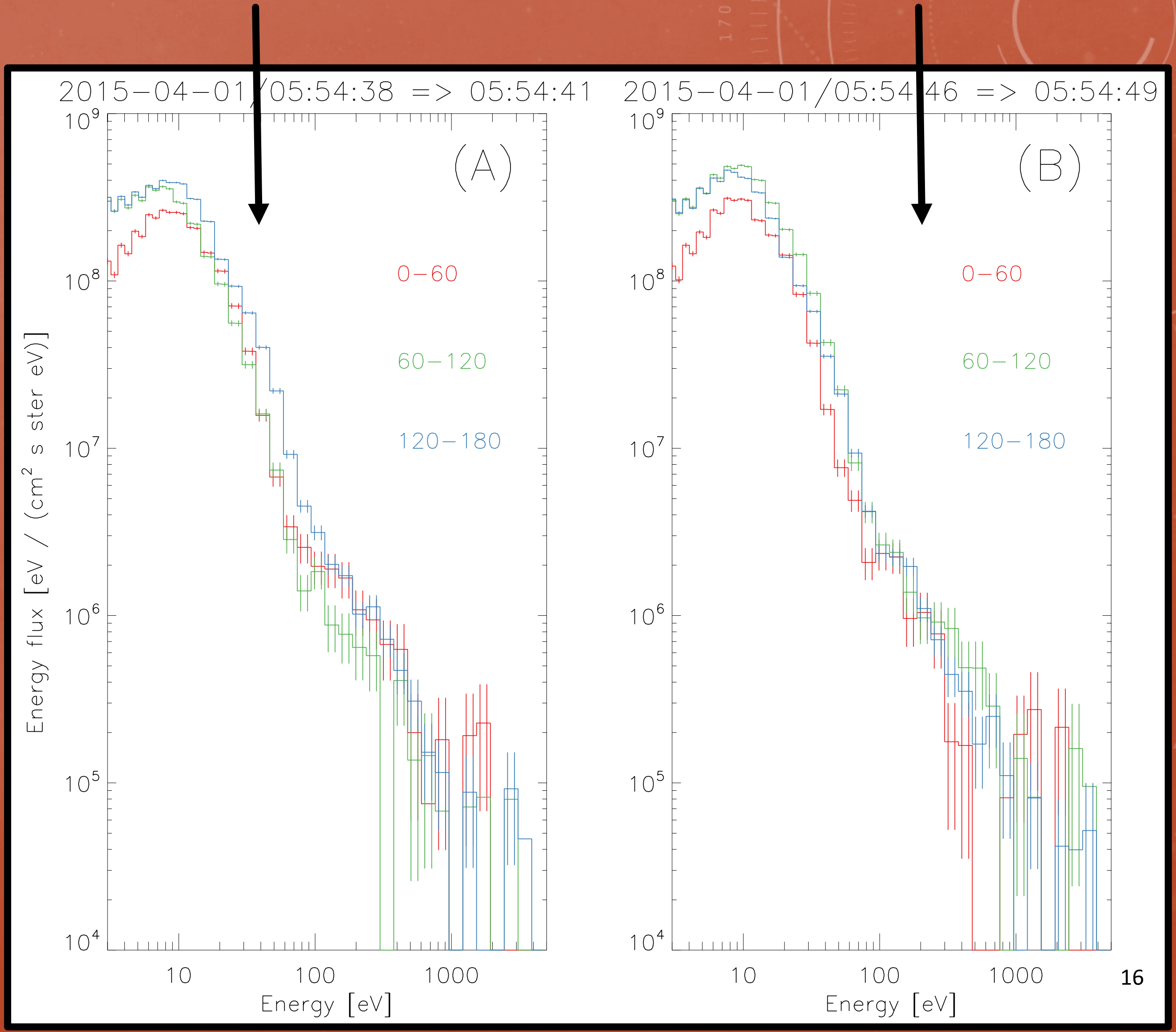
(3A): WHISTLER WAVE GENERATION



- Suprathermal temperature anisotropy observed coincident with MS wave peaks.
- Whistler waves also observed coincident with MS wave peaks.
- Suprathermal electrons become less field aligned during times of B compression.

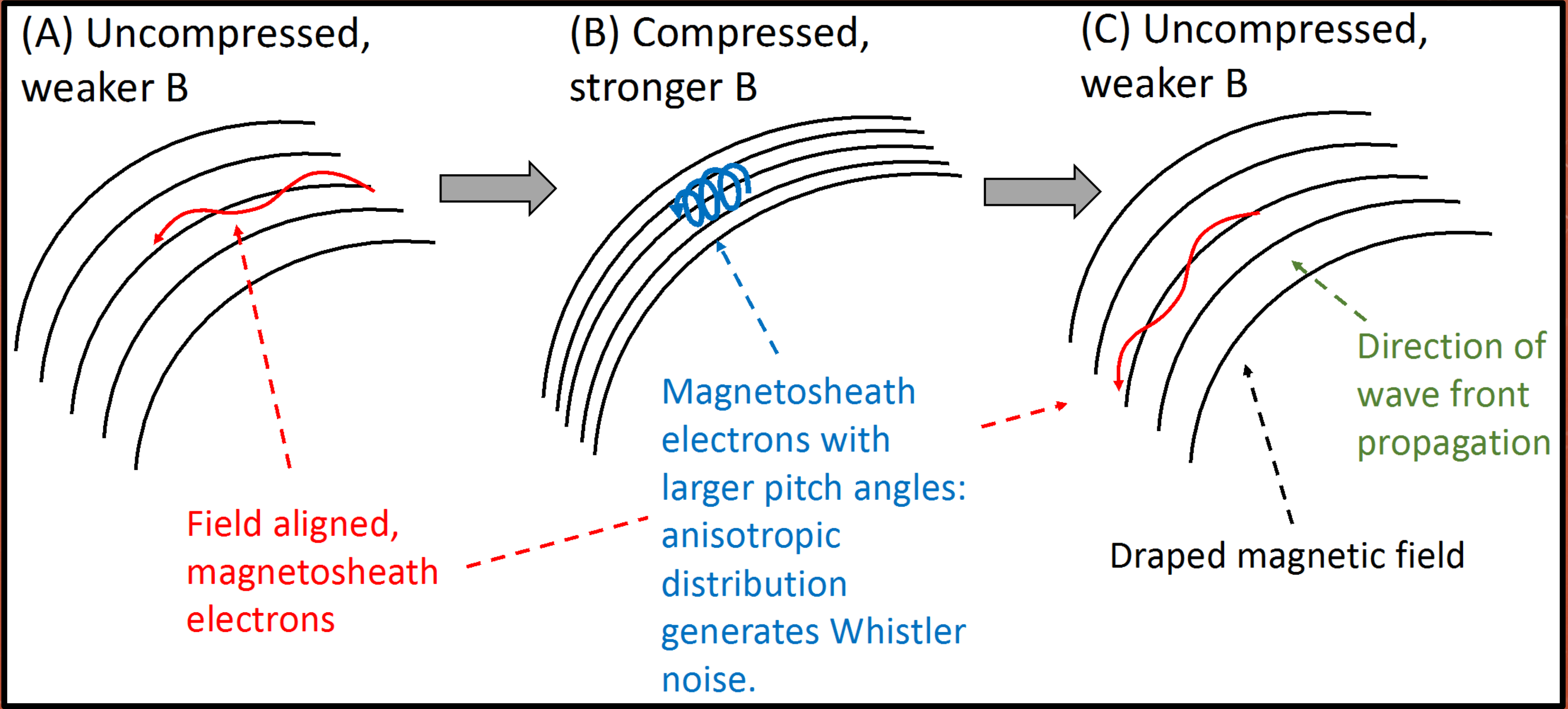
(3B): WHISTLER WAVE GENERATION

- Electron gyro frequency >> 0.035 Hz.
    - During magnetic compression, electron PAD becomes less field aligned to conserve magnetic invariant.
    - Change in PAD leads to temperature anisotropy perpendicular to local **B**.
    - Population is then unstable to generation of Whistler noise (e.g. Kennel and Petschek, 1966).
- Exact Whistler generation mechanism unclear – electrons >~ 1 KeV should generate the observed Whistlers; these make up < 0.1% of the population density though (slow growth rate).


Magnetic trough

Magnetic compression

WHISTLERS (BACKUP)



(A) Uncompressed, weaker B

(B) Compressed, stronger B

(C) Uncompressed, weaker B

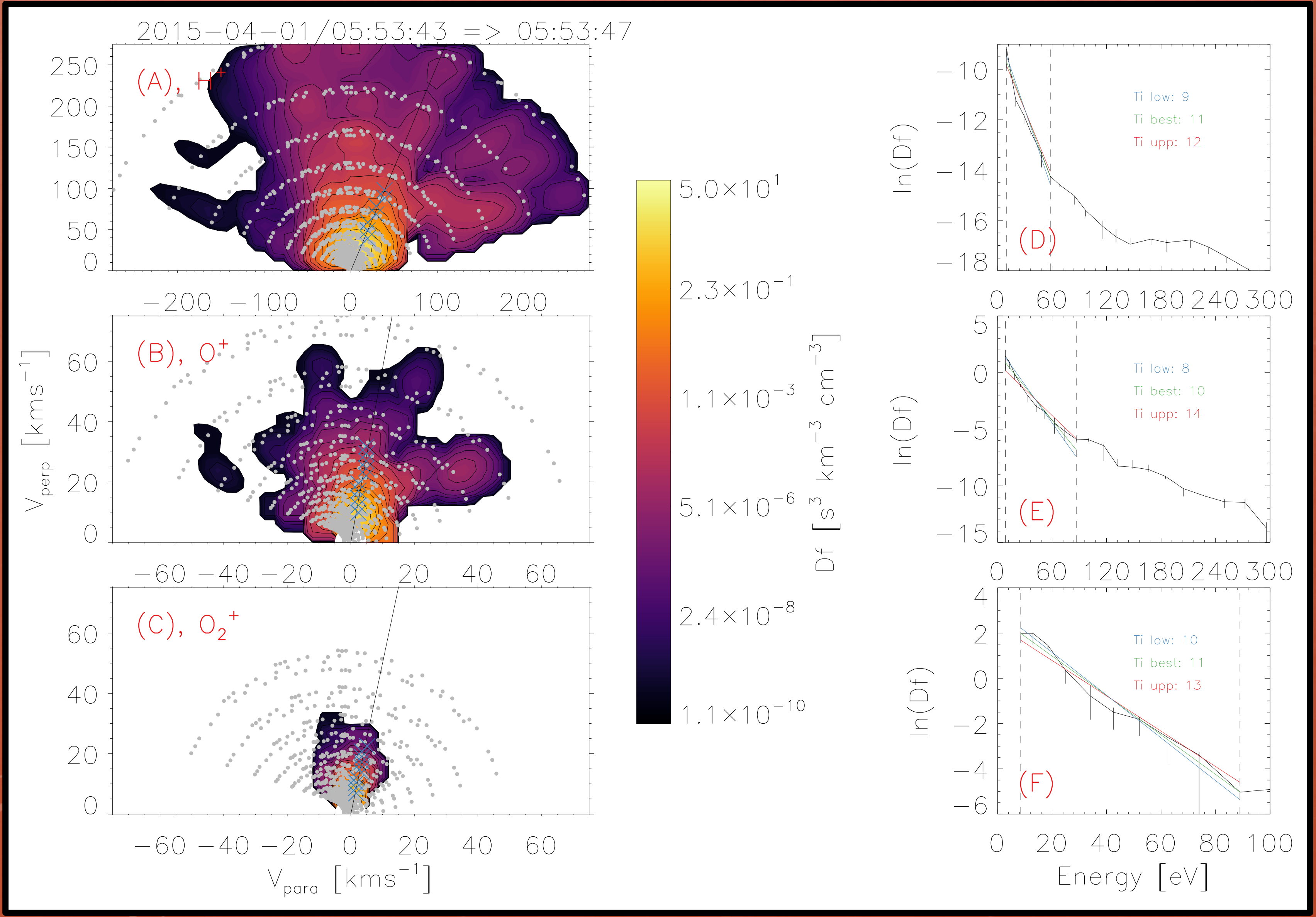
Field aligned, magnetosheath electrons

Magnetosheath electrons with larger pitch angles: anisotropic distribution generates Whistler noise.

Direction of wave front propagation

Draped magnetic field

(4A): ION HEATING – ION VELOCITY DISTRIBUTIONS



- Obtain estimates of T_i by fitting to ridge of conic distribution.
- Conics show energization perpendicular to local **B**.