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ULF waves in the foreshock formed by the radial IMF: their effect on solar wind sheath-like deflection

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Abstract

Particle reflection at the bow shock provides a source of free energy to drive local instabilities and turbulence within the foreshock. A variety of low-frequency fluctuations (up to 16 mHz) results from the interactions of back-streaming ions with the incoming solar wind flow.

We report observations of low-frequency magnetosonic waves observed during intervals of a radial interplanetary magnetic field in the foreshock.

A case study of simultaneous dual THEMIS spacecraft observations of asymmetrical fluctuations in V_y (Fig 1.) is complemented by a statistical study of similar solar wind deflections in the foreshock.

Our moment calculations do not include the reflected particles as well as heavier ions, revealed the modulation of a solar wind core and deflection of the solar wind in the foreshock.

We conclude that large asymmetrical V_y velocity component fluctuations are typical for the foreshock formed by the radial IMF. The asymmetry of fluctuations changes the mean direction of the incoming solar wind flow within the foreshock leading to preconditioning prior to its encounter with the bow shock.

Ex. 1: Case study of simultaneous observations

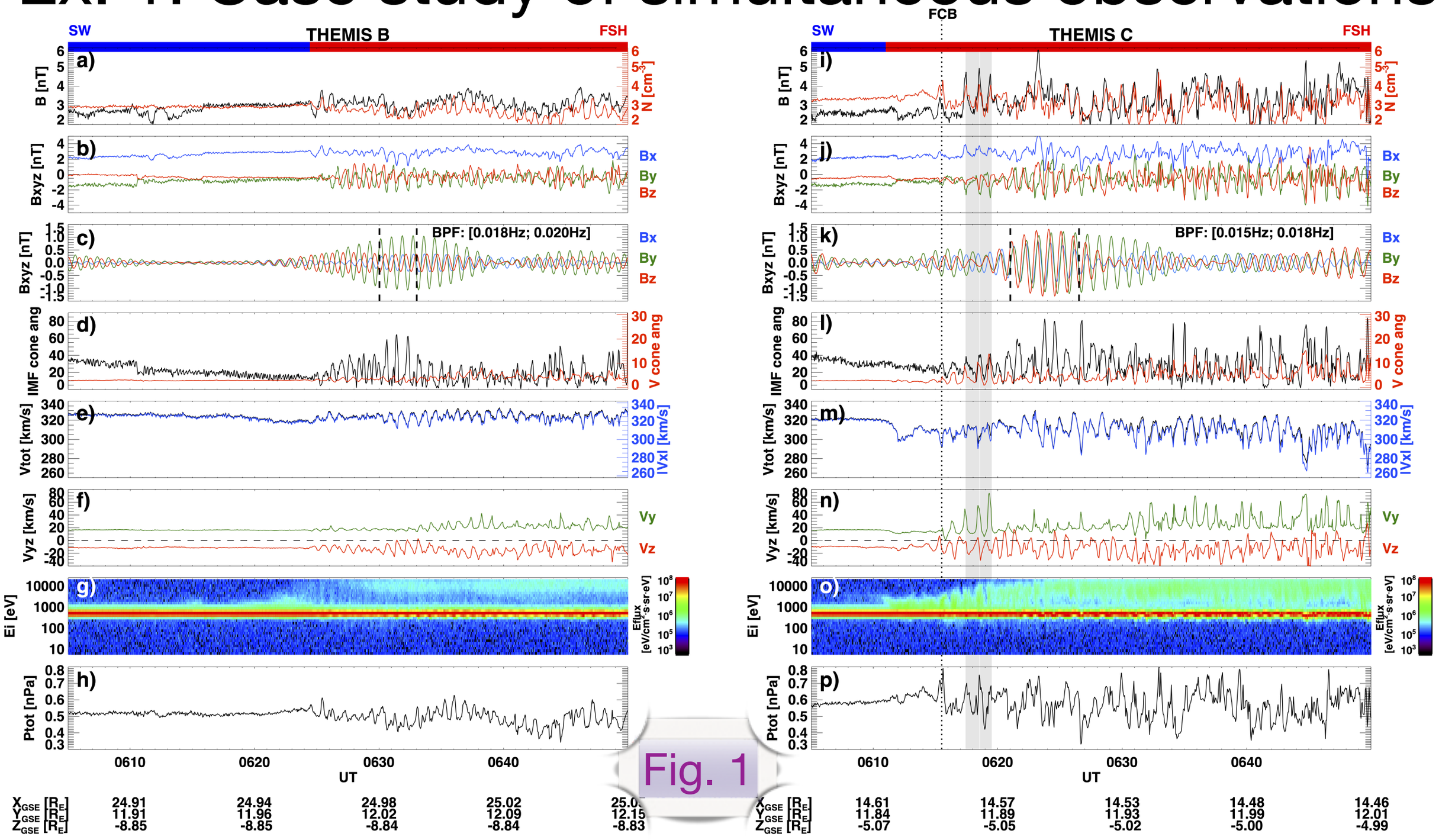

Fig. 1

THEMIS B, C observations of: **(a,j)** magnetic field magnitude (*black*) and density (*red*); **(b,j)** GSE magnetic field components; **(c,k)** GSE magnetic field components processed by band-pass filter; **(d,l)** IMF (*black*) and solar wind flux (*red*) cone angles; **(e,m)** the solar wind total velocity (*black*) and VX (*blue*); **(f,n)** VY (*green*) and VZ (*red*) velocity components; **(g,o)** ion energy spectra from the ESA instrument; **(h,p)** total pressure.
The *vertical shaded area* marks two observed cavitons.

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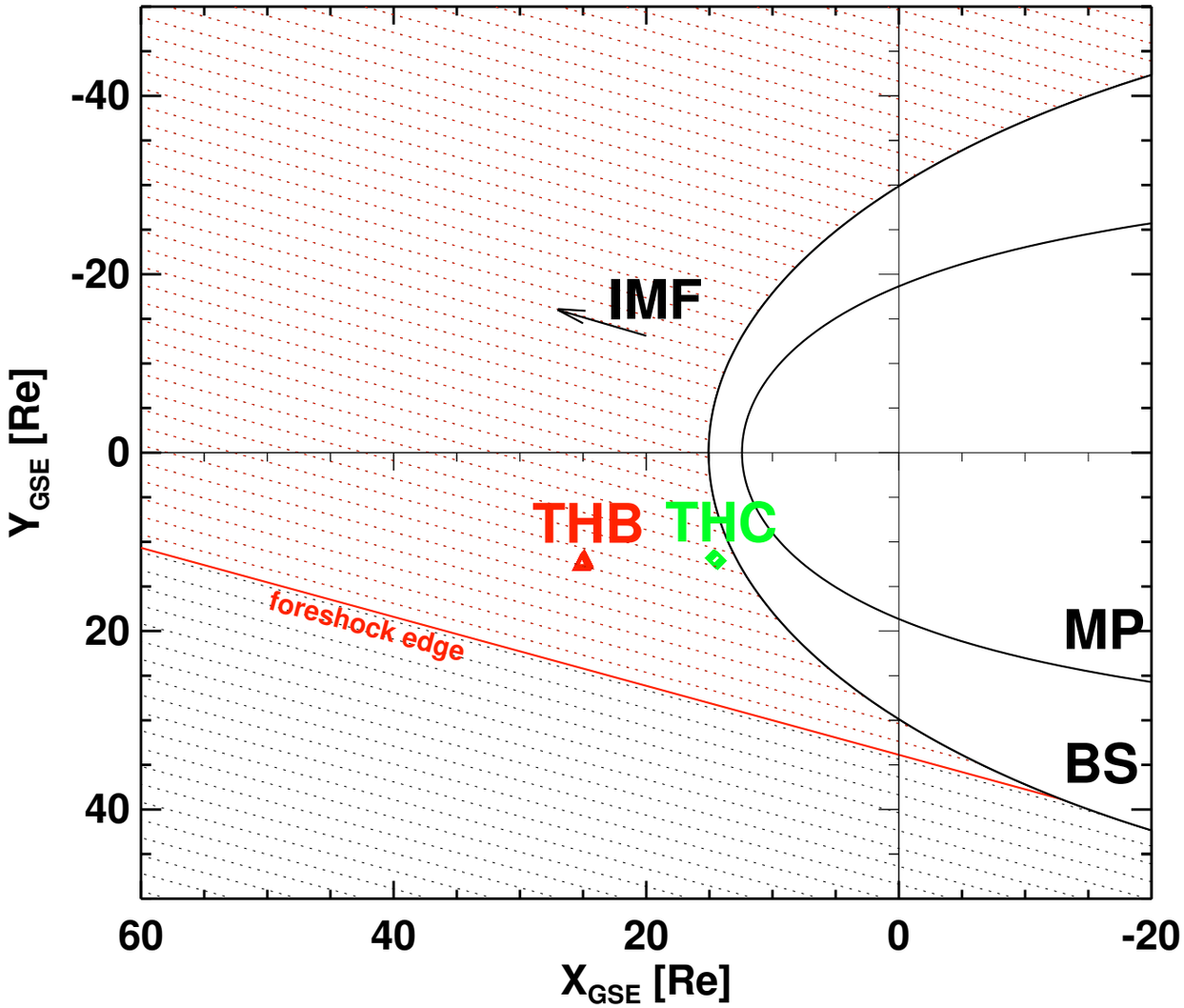

Fig. 2

THEMIS B (▲) and C (◇) locations projected into the X -Y plane at 0610 - 0700 UT on July 7, 2008. Parabolas indicate modeled position of bow shock [*Jerab et al., 2005*] and magnetopause [*Shue et al., 1997*]. The red line shows estimated foreshock edge.

- THB & THC are located upstream from the BSH with positive Y_{GSE} coordinate; THB being further upstream (~10 Re from the BSH) (Fig. 2)
- at both locations large quasi-sinusoidal waves in B and plasma (*Fig. 1 b,j*)
- fluctuations are observed for small cone angles (<45) (*Fig. 1 d,l*)
- THC: more intense fluctuations
- B and N correlate at THC; mostly correlate at THB (*Fig. 1 a,i*)

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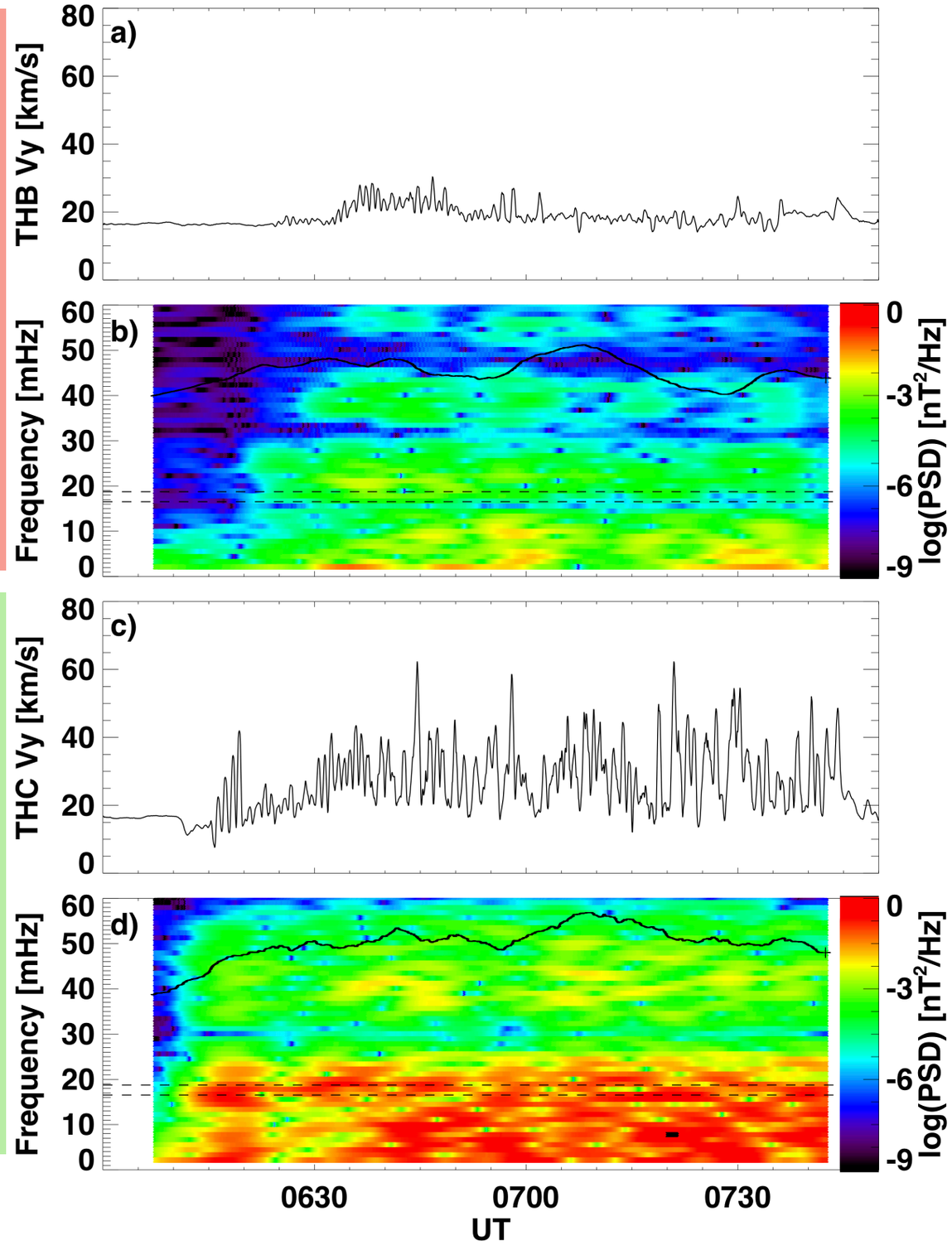
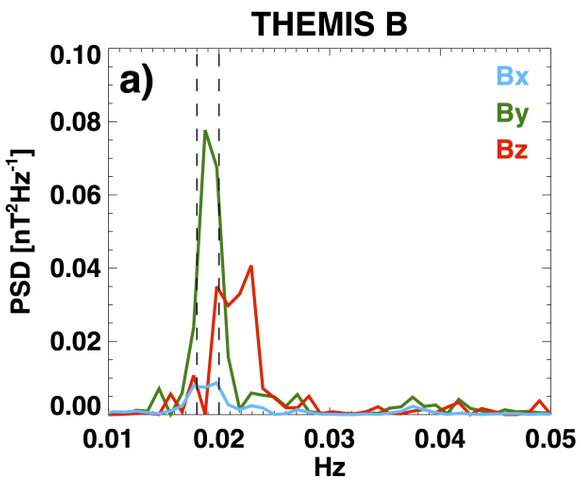
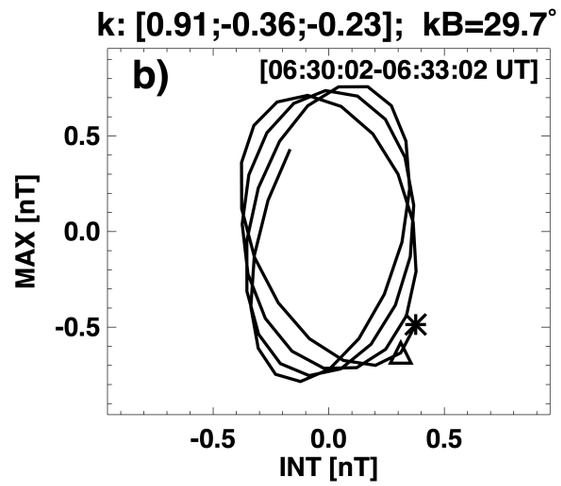
Ex. 1: Case study of simultaneous observations

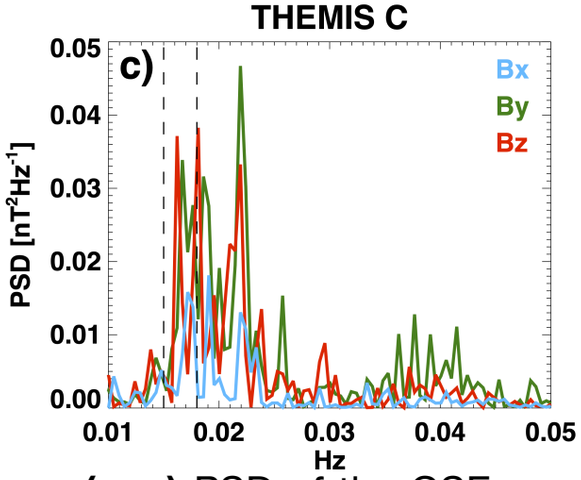
THB

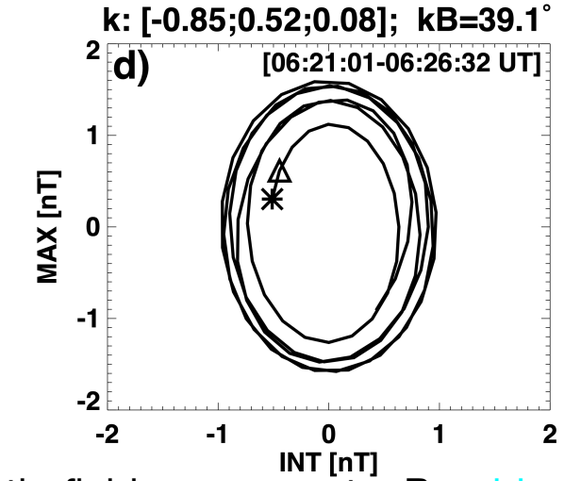
THC











(a, c) PSD of the GSE magnetic field components: B_X - blue, B_Y - green, B_Z - red. Vertical dashed lines correspond to the frequencies of a band-pass filter: 0.018 - 0.02 Hz for THEMIS B and 0.015 - 0.018 Hz for THEMIS C (see *Fig. 1 c,k*);

(b, d) Hodograms of filtered and converted magnetic field into MVA coordinates. Asterisks/triangles indicate the beginning/ end of first vectors.

- nearly circularly right-handed polarized waves
- kinetic fast magnetosonic waves

- V_Y fluctuates with frequency ~ 0. 02 Hz at THB (0630-0700 UT); more disturbed fluctuations of V_Y at THC, variety of waves are observed

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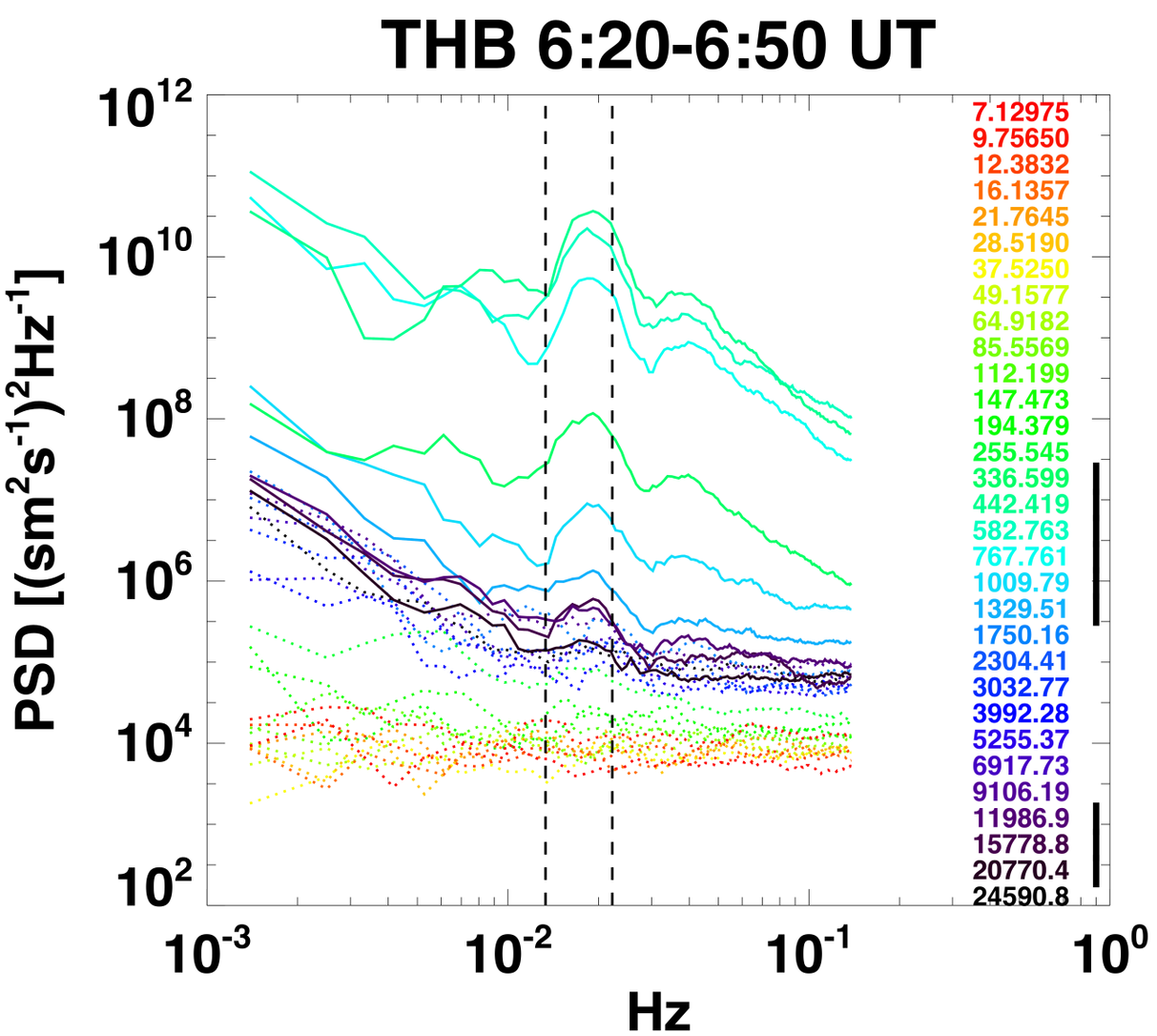
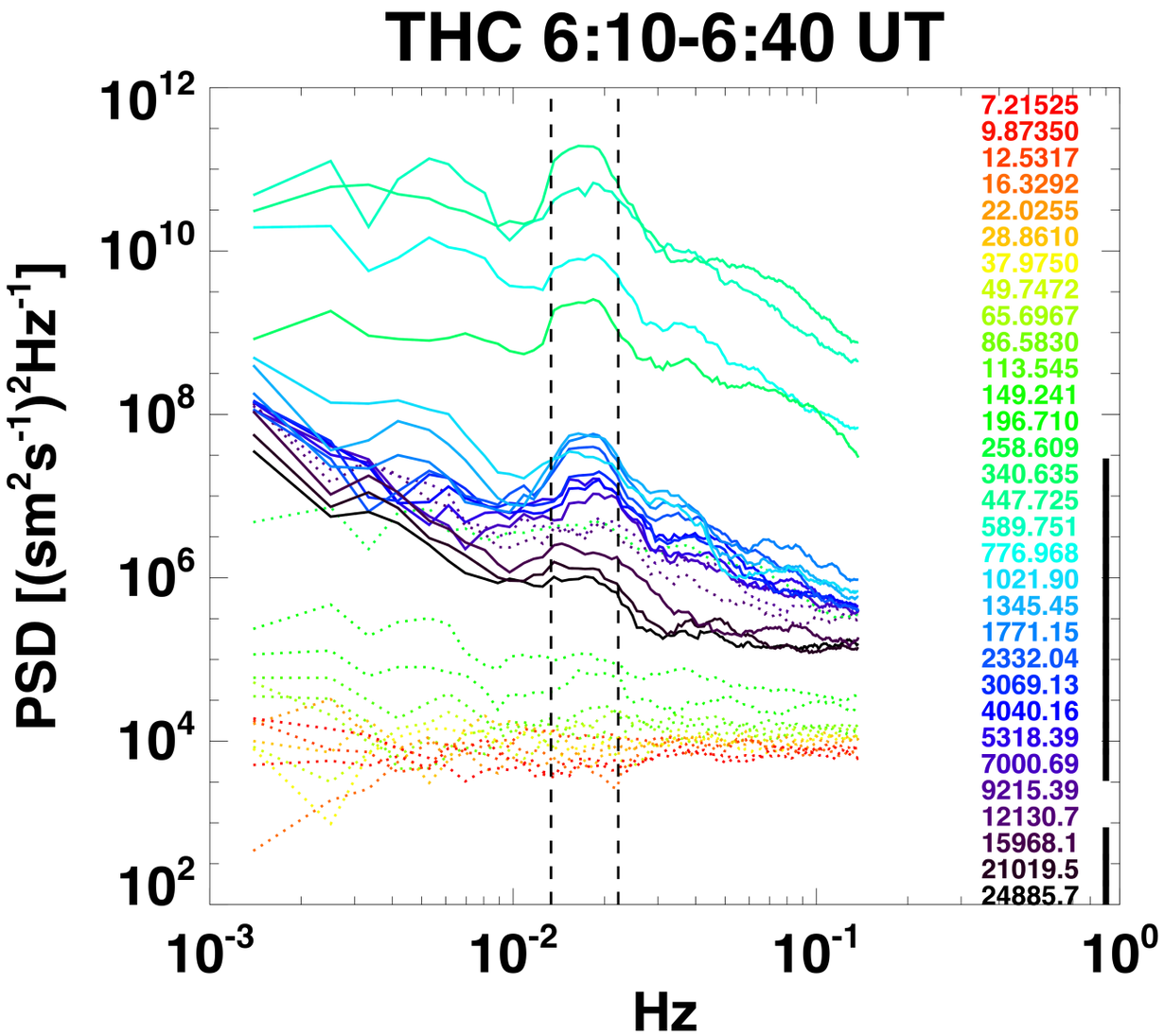
Ex. 1: Case study of simultaneous observations



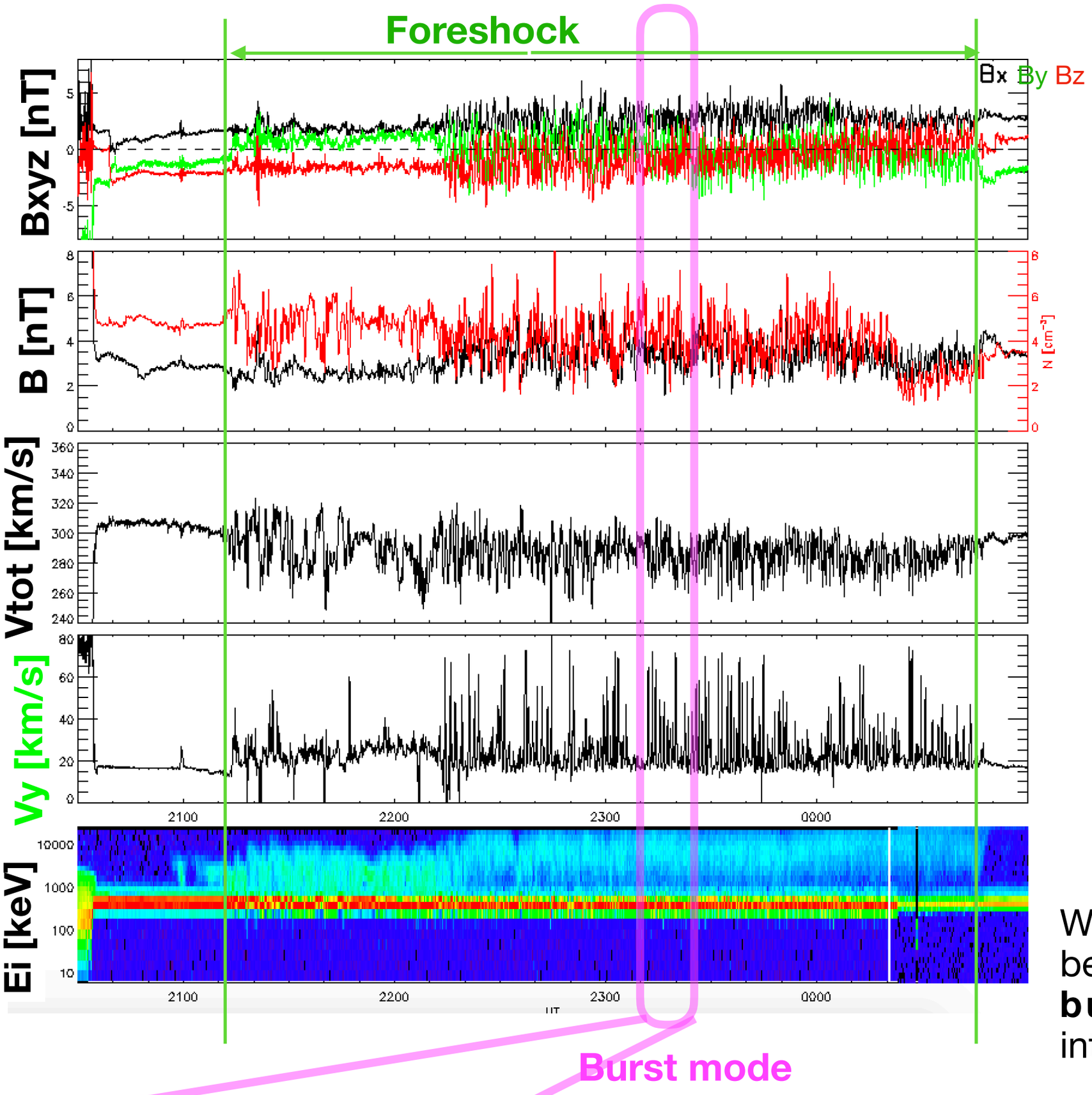
PSD of THEMIS B ion energy flux variations calculated on 0620-0650 UT interval



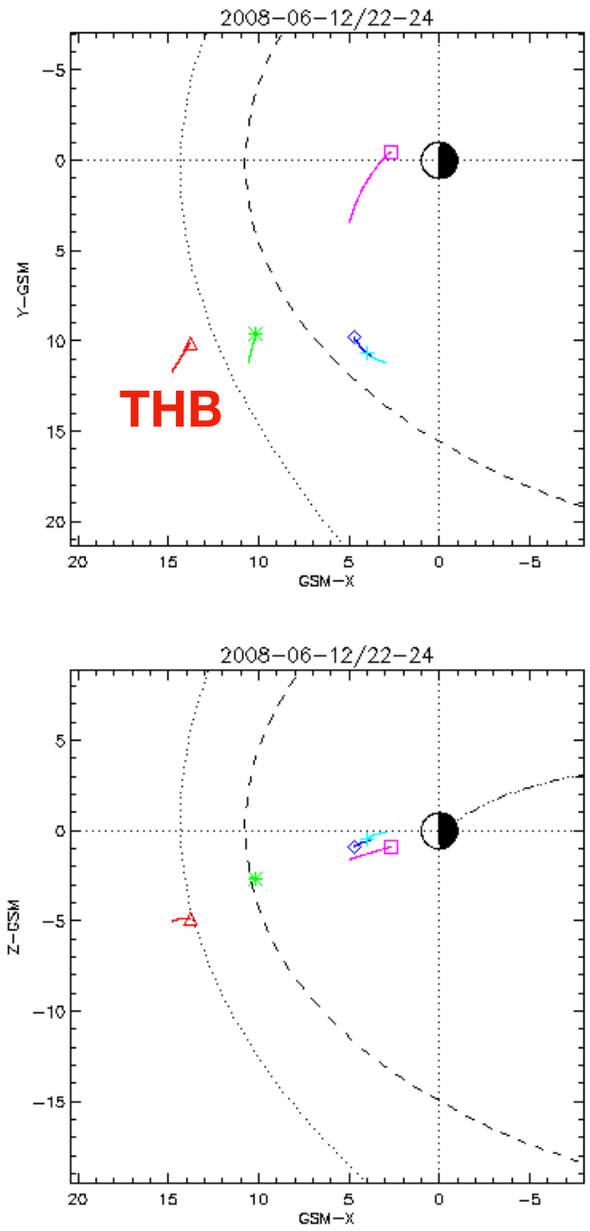
PSD of THEMIS C ion energy flux variations calculated on 0610-0640 UT interval

- ion fluxes from the solar core energy range (~ 330 - 590 eV) are modulated together with reflected hot ions (> 12 keV) with the similar frequency

Ex. 2: THEMIS B observations in the FSH

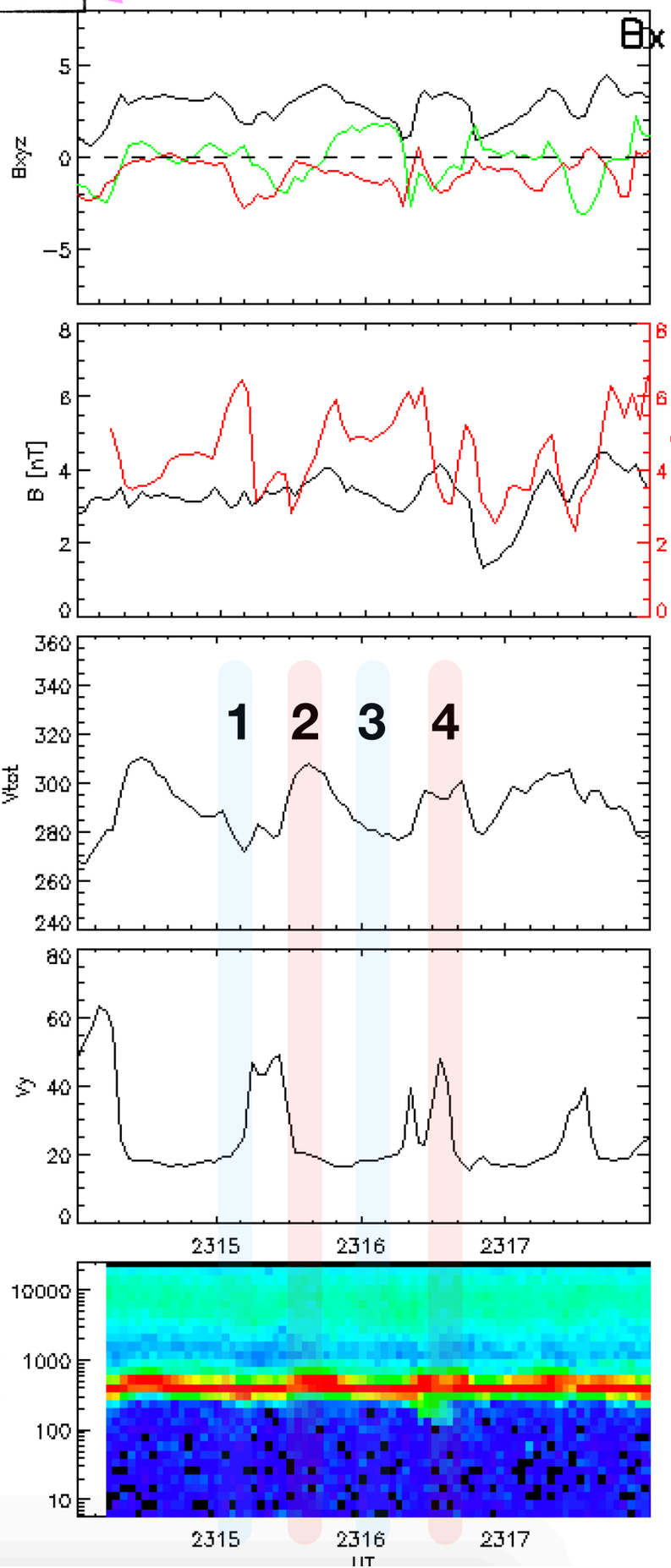


THEMIS B 2008-07-12



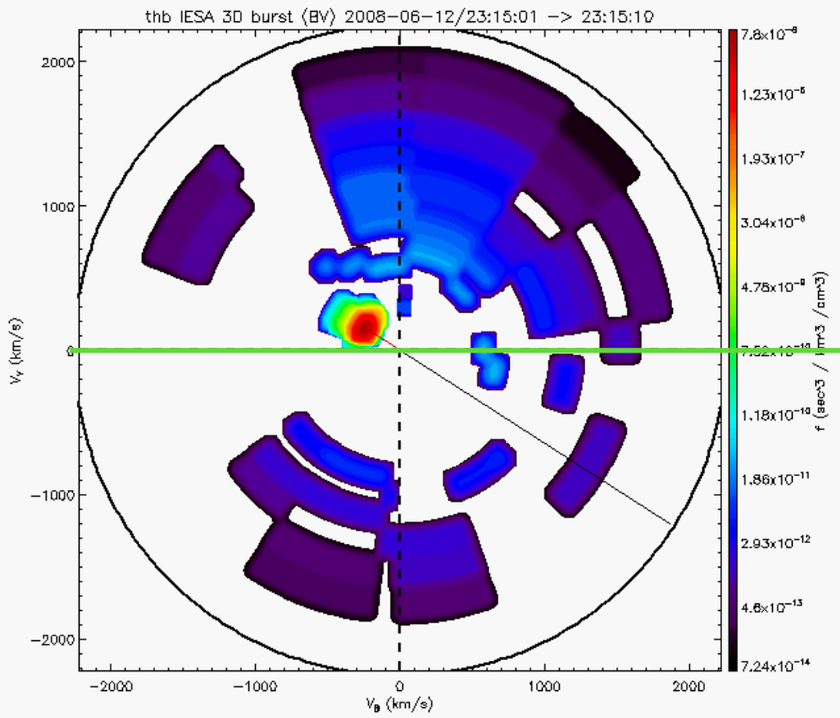
We selected these observations because of available data in the **burst mode** (see extended interval on the next page).

THEMIS B: burst mode

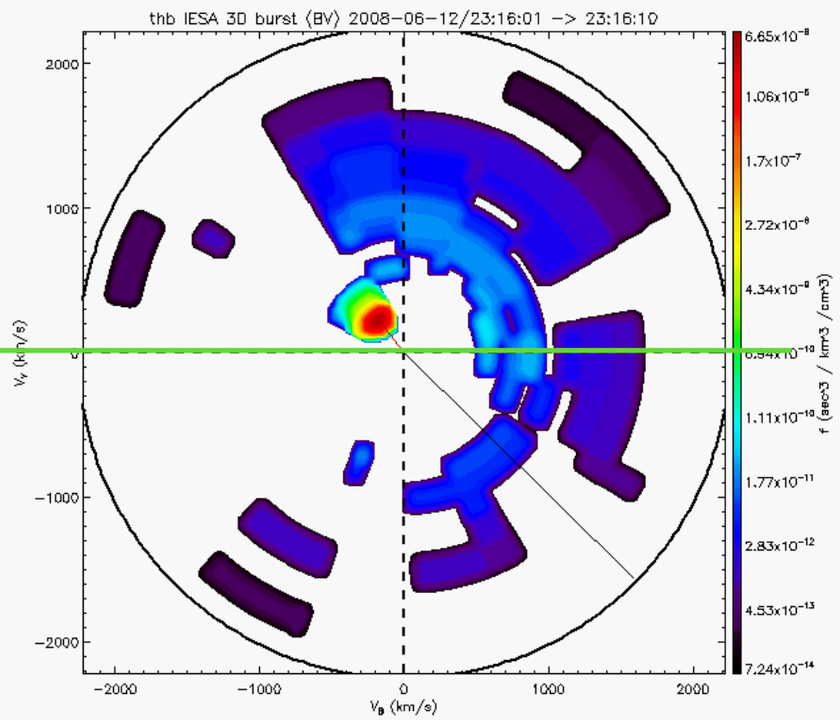


For intervals 1-4 we plot VDs using TDAS software on a 10 s window:

1

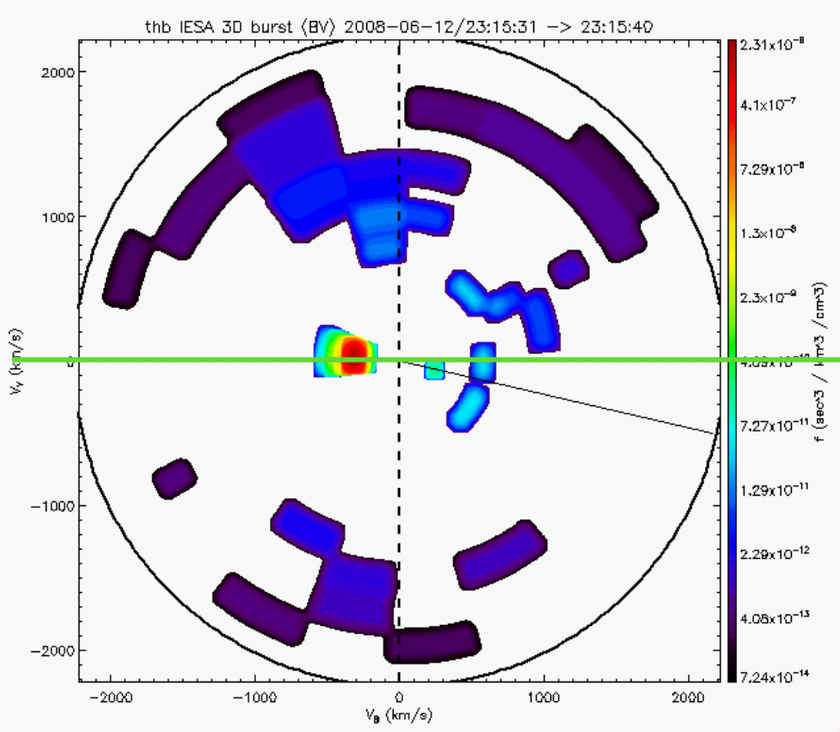


3



Rotation BV: The x axis is parallel to B field; the bulk velocity defines the x-y plane.

2



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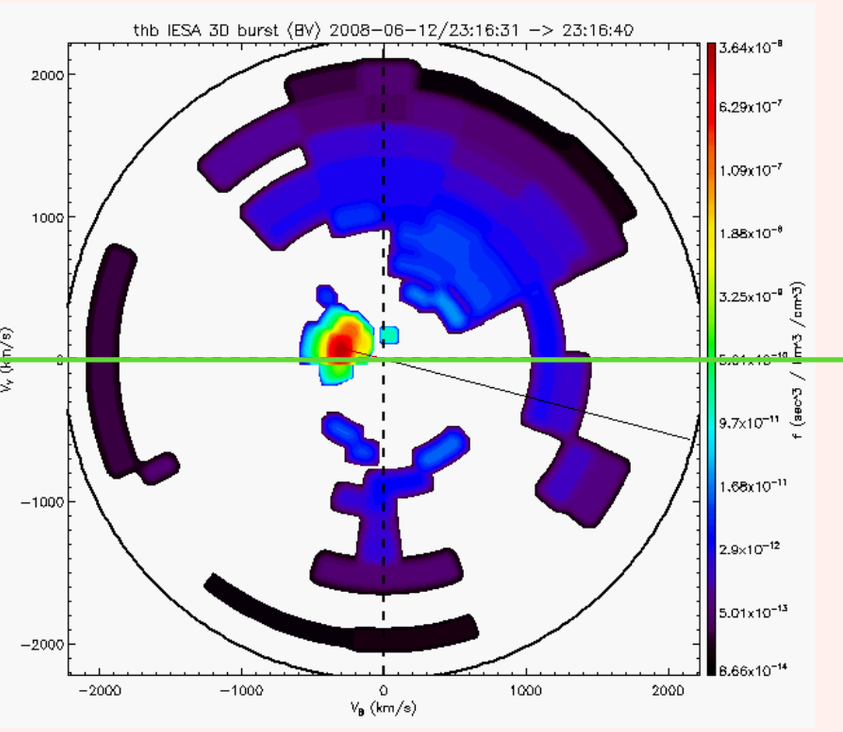
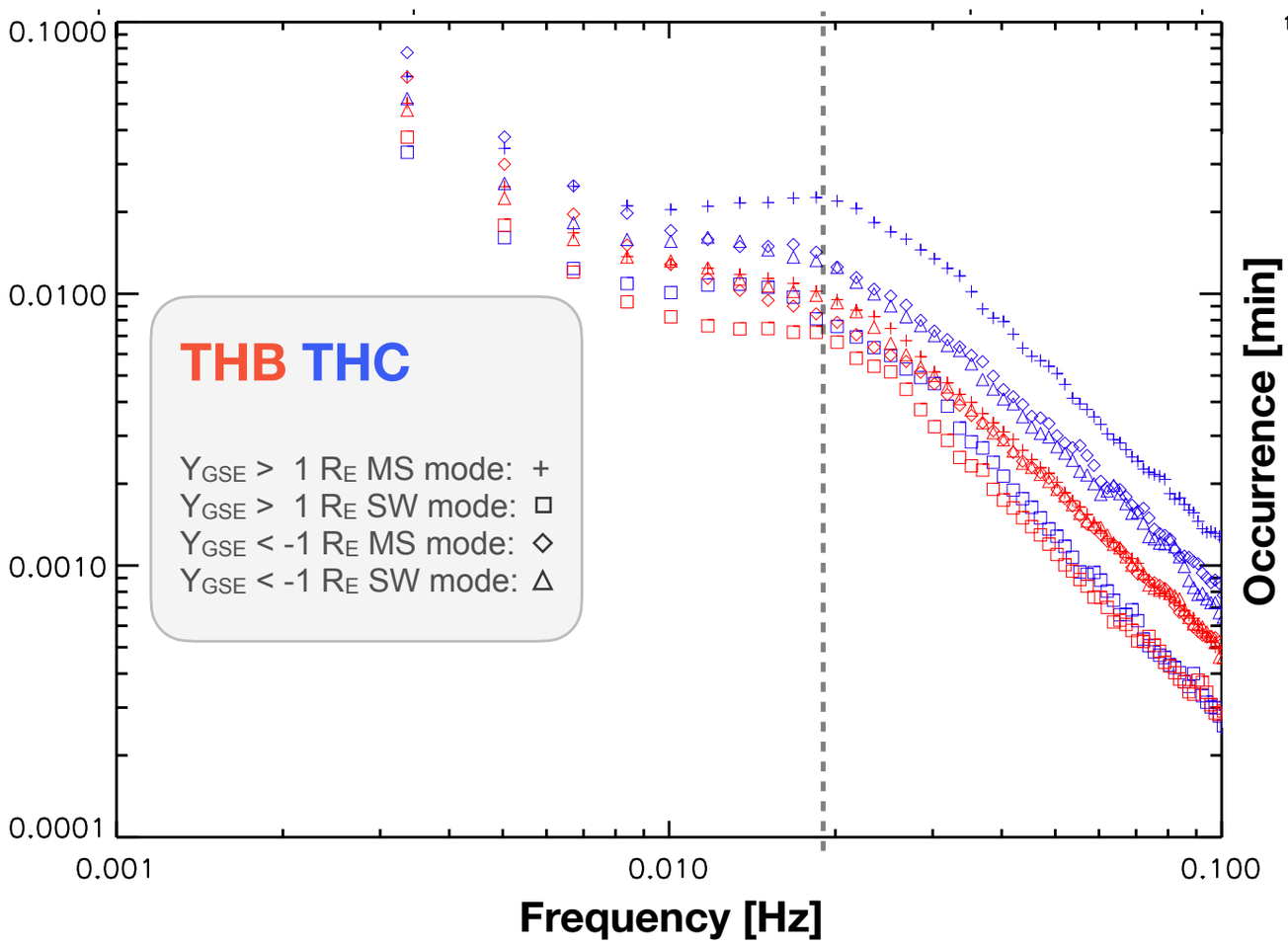
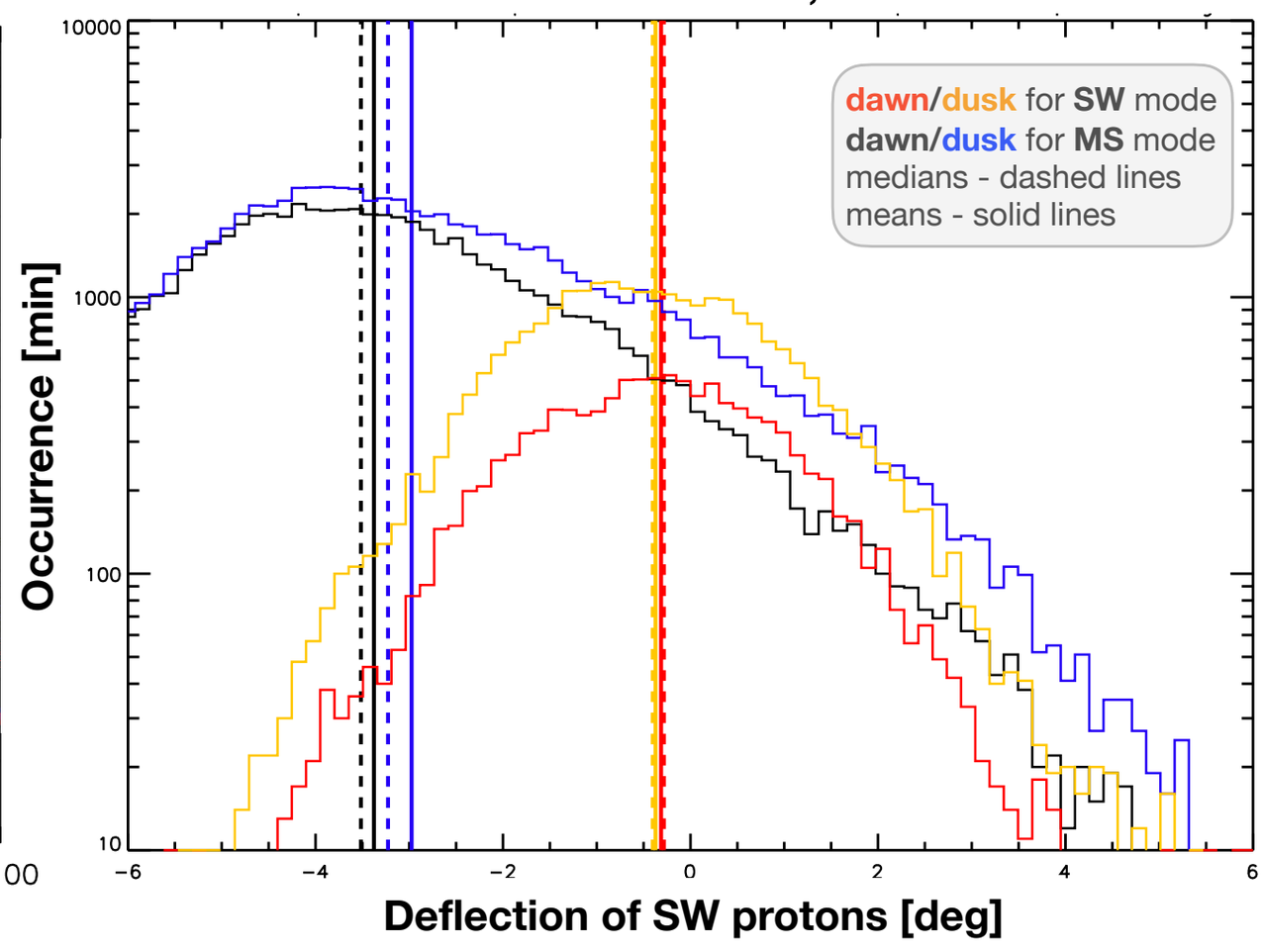


- SW core fluctuates together with reflected hot ions

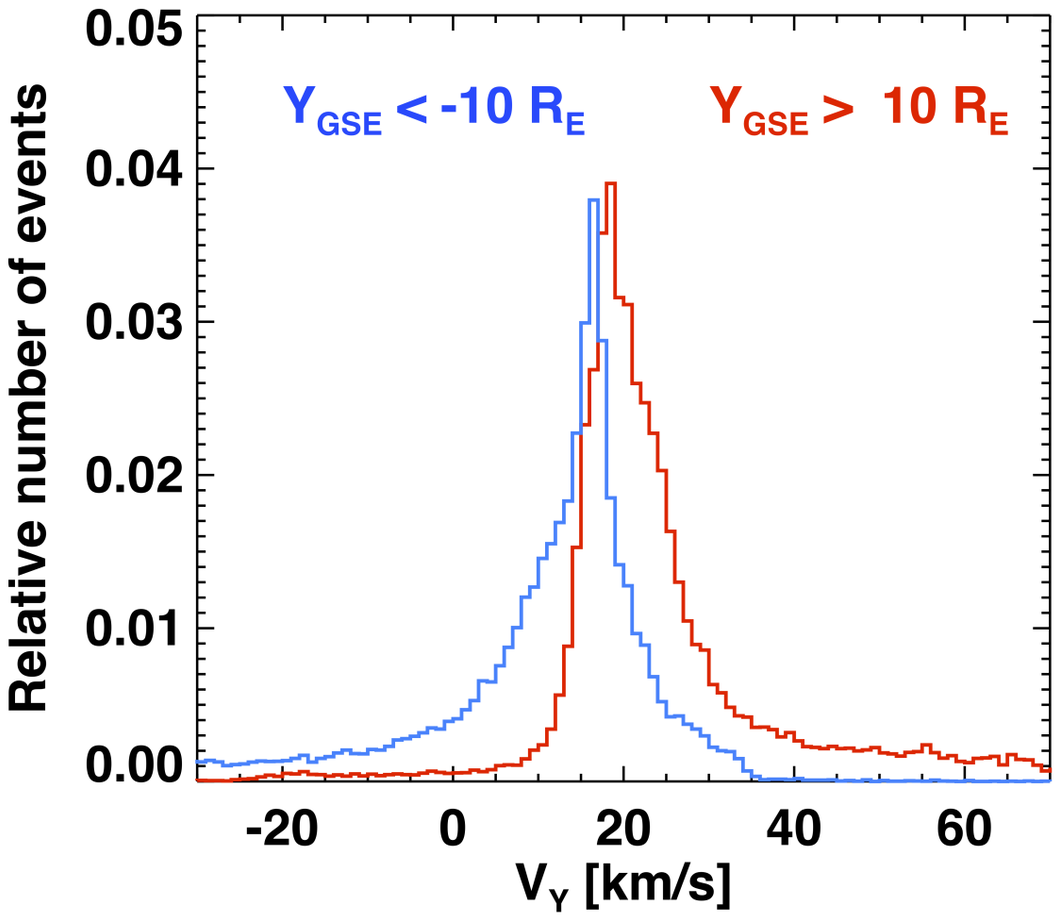
Statistical results from ESA THEMIS data

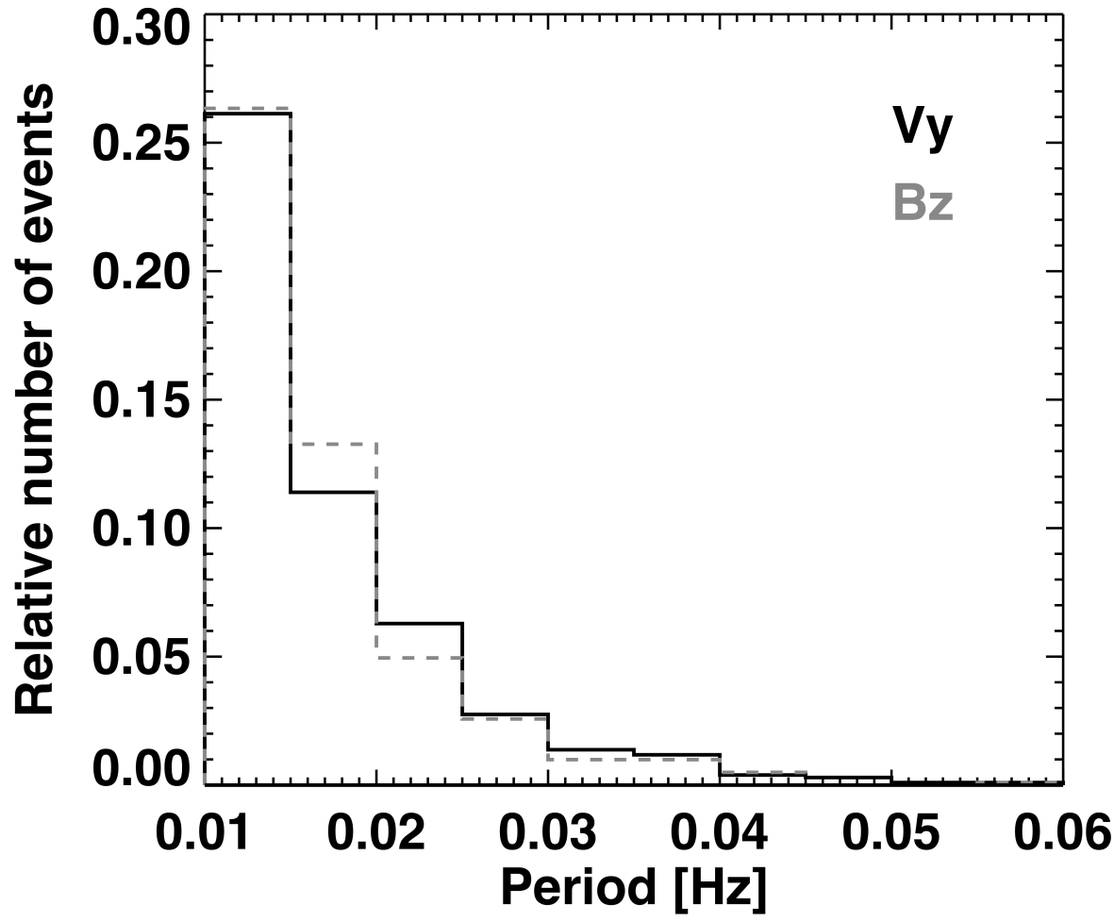




- We used **THB** and **THC** data for **2007-early 2019 years** (ARTEMIS data are excluded near the lunar wake of close to the lunar dayside);
- THEMIS data are divided according to the “mode” of measurement: **magnetospheric (MS)**, and the **solar wind (SW)**;
- **Left plot:** PSD calculated on 10 min intervals; peak of B tot fluctuations is at ~ 50 s for the THC in MS mode, as these data where taken closer to the BS, where more intense fluctuations are observed;
- **Right plot:** more pronounced SW deflection in data from MS mode; in this mode data are taken from region closest to BS;

Statistical results from MOM THEMIS data





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- THEMIS observations in the FSH during radial IMF for October 2007 - January 2010 period;
- **Left plot:** a histogram of the V_Y component in the FSH; distributions are skewed duskward in the dusk foreshock and dawnward in the dawn foreshock;
- **Right plot:** a histogram of V_Y and B_Z periods of variations in the FSH.

Conclusions

From several cases of THEMIS foreshock observations during radial IMF:

- V_Y fluctuations were skewed toward the positive (duskward) values and observed at the dusk FSH side;
- Fluctuation period of 60s and can be observed in plasma velocity, density, the magnetic field strength and components;
- Minimum variance analysis of waves in the first case study revealed a right-handed polarization in the spacecraft frame of reference at both locations; they can be fast magnetosonic waves;
- modulation was visible both in the distribution core and in fluxes of suprathermal reflected ions.

From our statistical study:

- More intense fluctuations of magnetic field in regions closer to the BS with frequency ~50 s
- More pronounced SW deflections in data from MS mode; we observe a spatial dependence of SW deflections in the FSH;
- Large asymmetrical V_Y velocity component fluctuations are typical for the FSH formed by the radial IMF.
- The asymmetry of fluctuations changes the mean direction of the incoming solar wind flow within the FSH leading to preconditioning prior to its encounter with the BS.