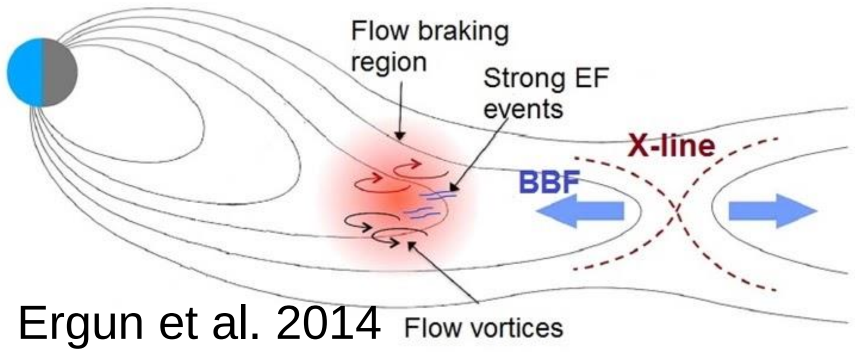
Comparison of ion pressure variations derived from Cluster/CODIF and the combined Cluster/CODIF&RAPID data during prolonged dipolarizations in the near Earth magnetotail

Andrey Malykhin[1] , Elena Grigorenko[1,2,3], Elena Kronberg[4,5], and Patrick Daly[4]

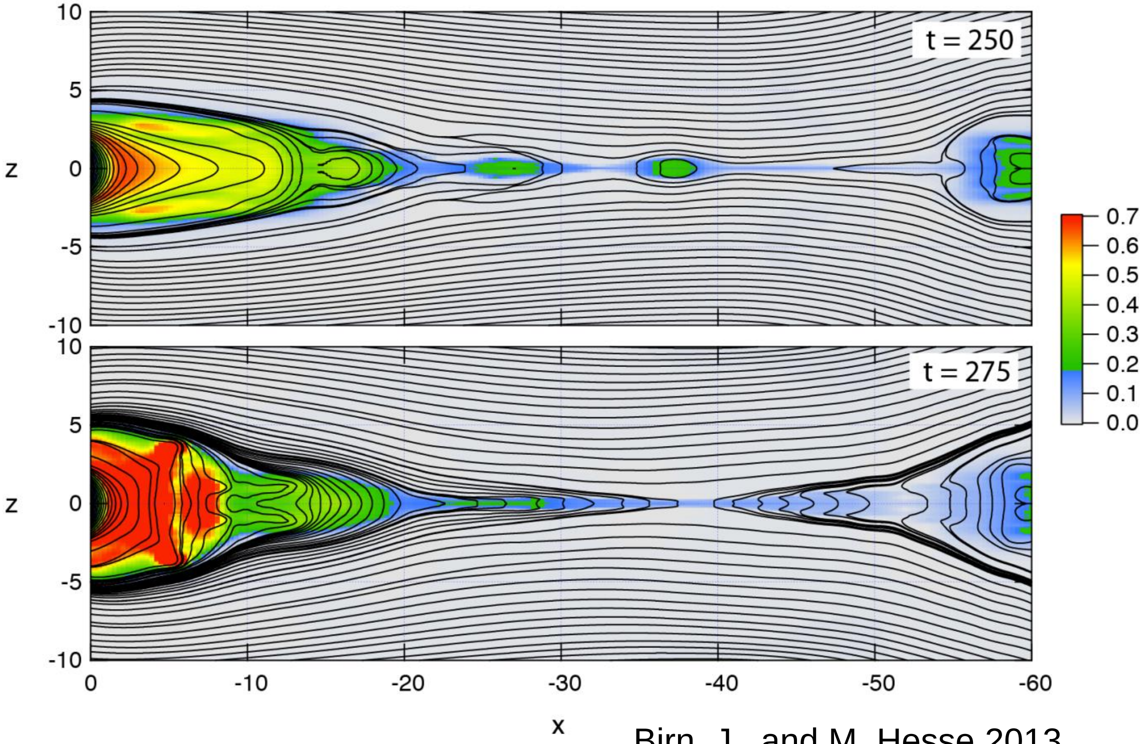
(anmaurdreg@gmail.com)

1 Space Research Institute (RAS), Plasma physics, Moscow, Russian Federation
2 St. Petersburg State University, Saint Petersburg, Russia
3 Department of Space Physics, Moscow Institute of Physics and Technology, Moscow, Russia
4 Max Planck Institute for Solar System Research, Göttingen, Germany
5 Ludwig Maximilian University of Munich, Munich, Germany

Introduction



Ergun et al. 2014



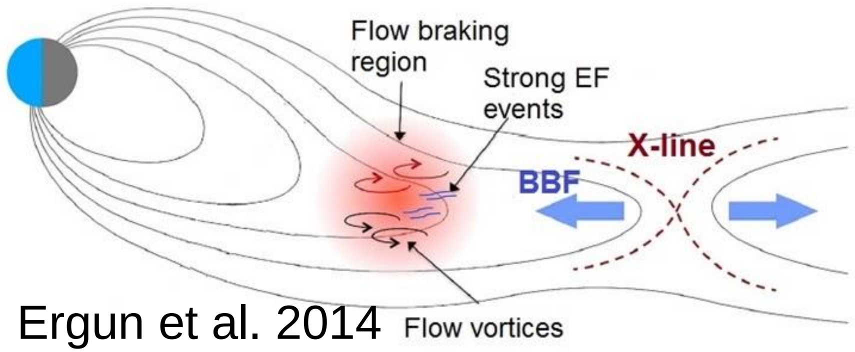
Birn, J., and M. Hesse 2013

The process of dipolarization of the magnetic field plays an important role in the dynamics of geomagnetic tail. This phenomenon manifests in the change of the configuration of the field lines from elongated to more dipole-like, which is followed by a rapid increase in the northward magnetic field component (B_Z). Dipolarization can be divided into two classes:

(1) single dipolarization fronts (DFs) that propagate toward the Earth with fast plasma flows (Angelopoulos et al., 1992; Nakamura et al., 2002; Runov et al., 2009)

(2) so-called “secondary” dipolarizations observed in the plasma sheet of the near-Earth tail as a result of the accumulation of magnetic flux due to the arrival and deceleration of fast plasma flows with multiple DFs (Nakamura et al., 2009).

Introduction



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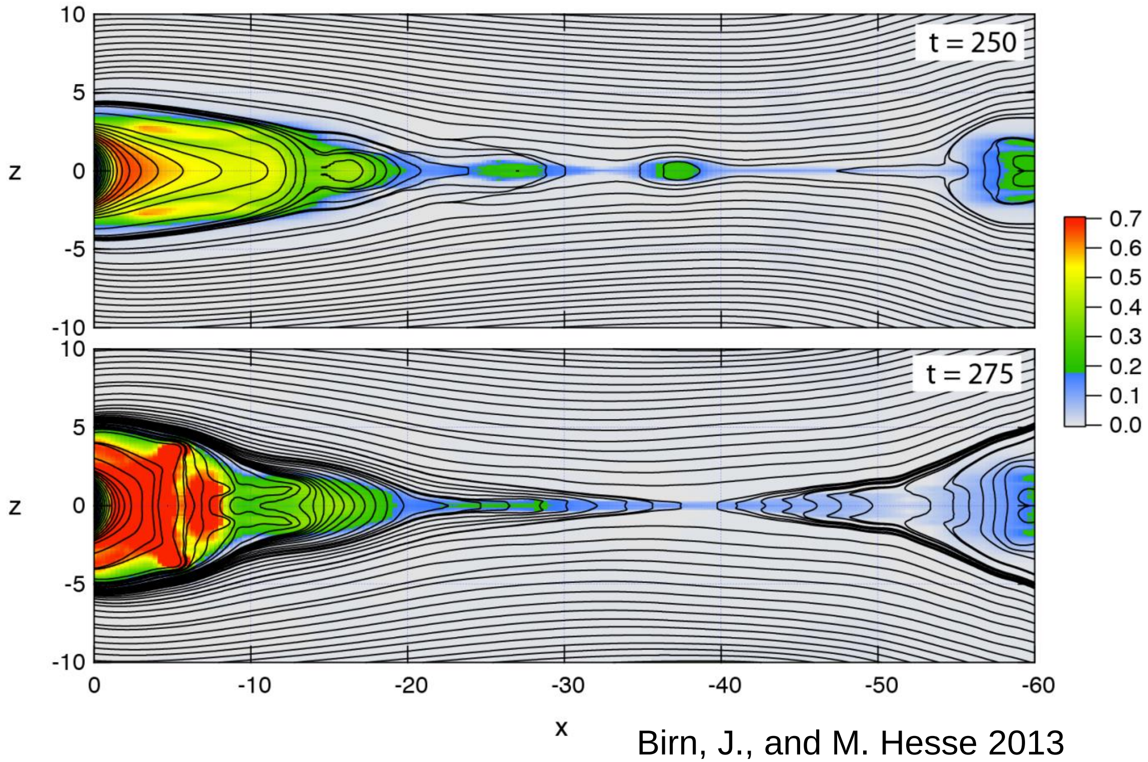


Birn, J., and M. Hesse 2013

DFs play the significant role in the acceleration of the local plasma population (Luo et al., 2014). It was shown that of light (H^+) and heavy (O^+) ions are effectively accelerated due to nonadiabatic interaction with a propagating isolated DF [Delcourt et al., 1994; Nosé et al., 2000; Artemyev et al. 2012, Ukhorskiy et al. 2013, Greco et al. 2014, 2015, Zhukova et al. 2018; Grigorenko et al., 2017; Malykhin et al., 2018, 2019].

Grigorenko et al. 2016 discussed the problem of the reliable determination of the proton temperature in the hot PS during secondary dipolarizations. It was shown that the energy corresponding to the maximum proton flux during such periods approaches 30–40 keV, that makes it impossible to calculate correctly the temperature and pressure of plasma populations by using only Cluster/CIS experiment data.

Problem

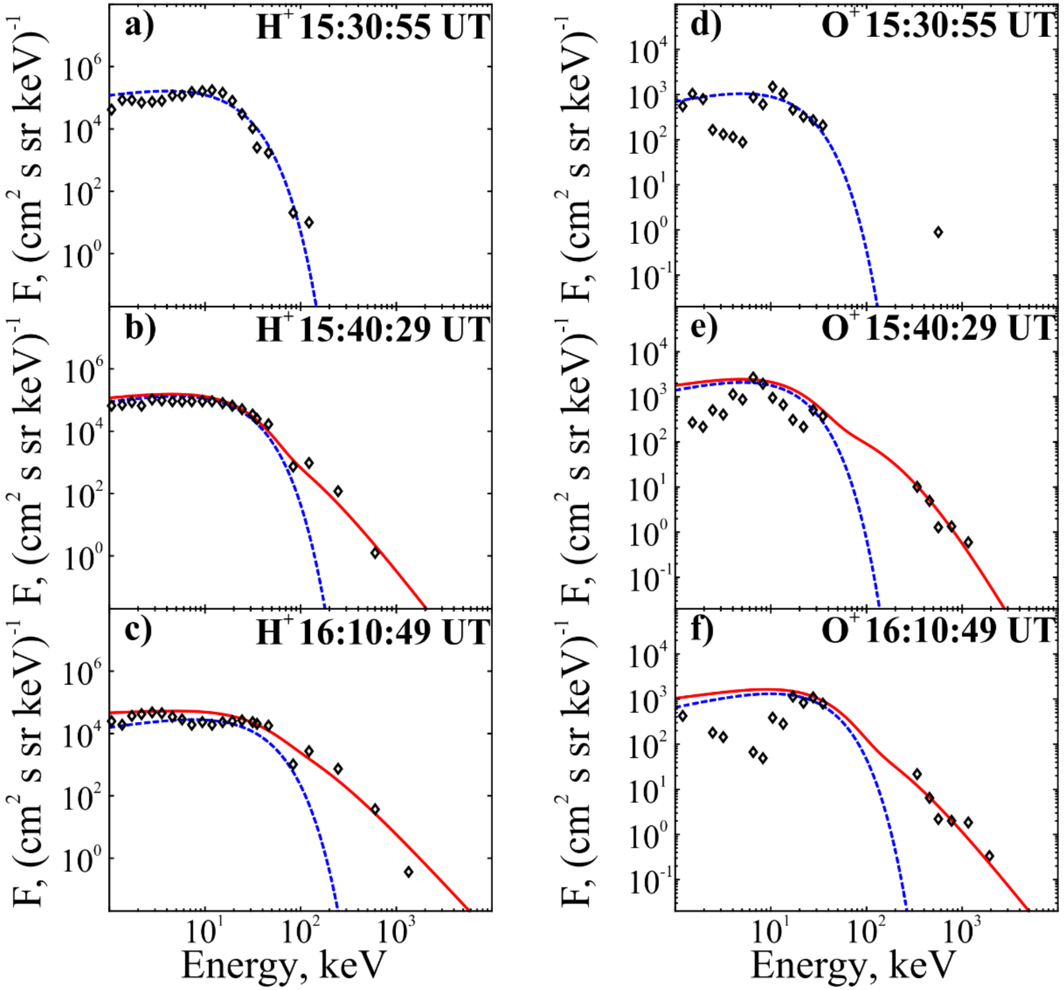
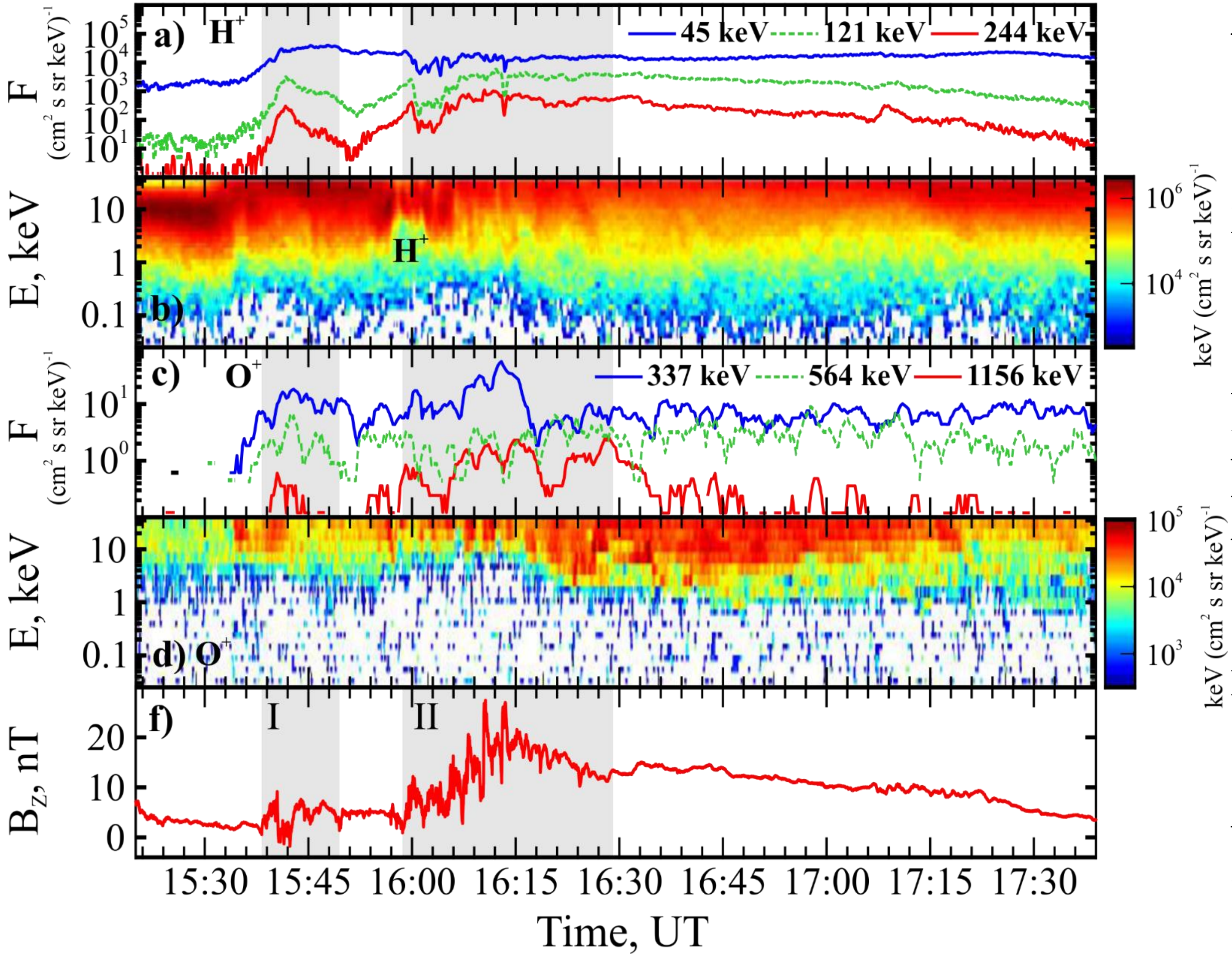


Figure 1. Energy spectra of H^+ and O^+ ions measured before dipolarisation event (a, d); during the growth phase of dipolarization (b, e) and in the flux pile up region (c, f). The blue line shows Maxwellian type distribution, and the red line shows the combined Maxwellian and kappa distributions.

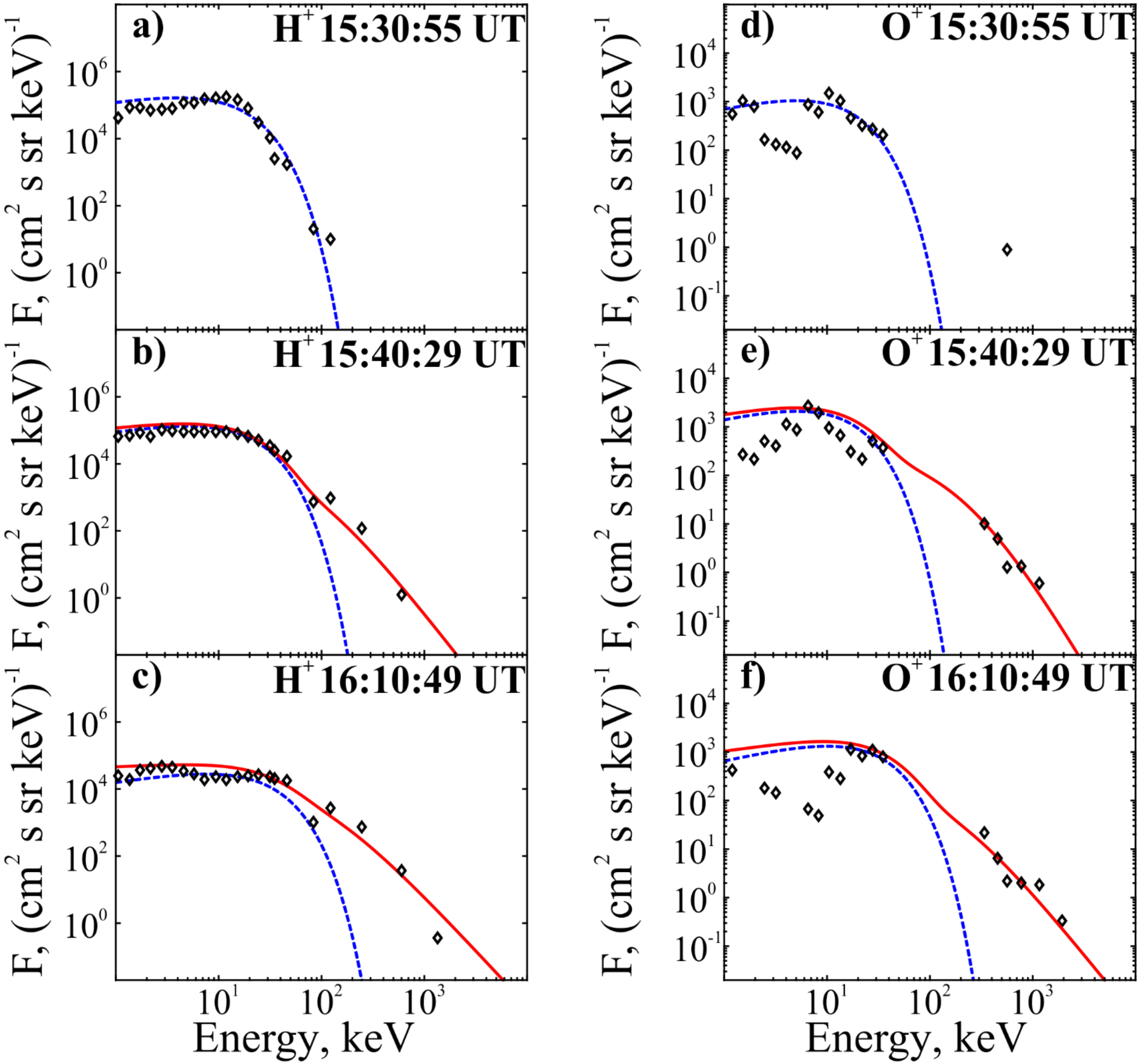
In this presentation, we would like to present an analysis of the dynamics of thermal (up to 40 keV) and suprathermal (~45 keV– 1.3 MeV) H^+ and O^+ ion fluxes and their pressure variations observed by Cluster satellites in 11 dipolarization events in the PS of the near-Earth magnetotail ($X \leq -19$ RE).

We show that the calculation of the ion-component pressure in the low-energy range (up to 40 keV) during dipolarization gives significantly lower values than the pressure determined in the energy range up to ~1.3 MeV with the technique described by Kronberg et al. (2013). The error is particularly significant in the calculation of the pressure of heavy ions (O^+).

An example of the observation of dipolarization in the near-Earth tail by Cluster satellites on September 24, 2003, at 15:20–17:39 UT (Cluster at [–16.4, 4.2, 2.4] R_E)



A few minutes before dipolarization onset, RAPID recorded the beginning of enhancement of the energetic H^+ and O^+ ion fluxes. The E–T proton spectrogram shows the flux increase up to the upper energy threshold of the detector (~40 keV, panel a). An increased flux of heavy ions (O^+) was also observed close to the upper energy threshold of CODIF (panel c). This means that CODIF does not register the entire velocity distribution function of H^+ and O^+ ions. And thus their **moments cannot be calculated correctly.**

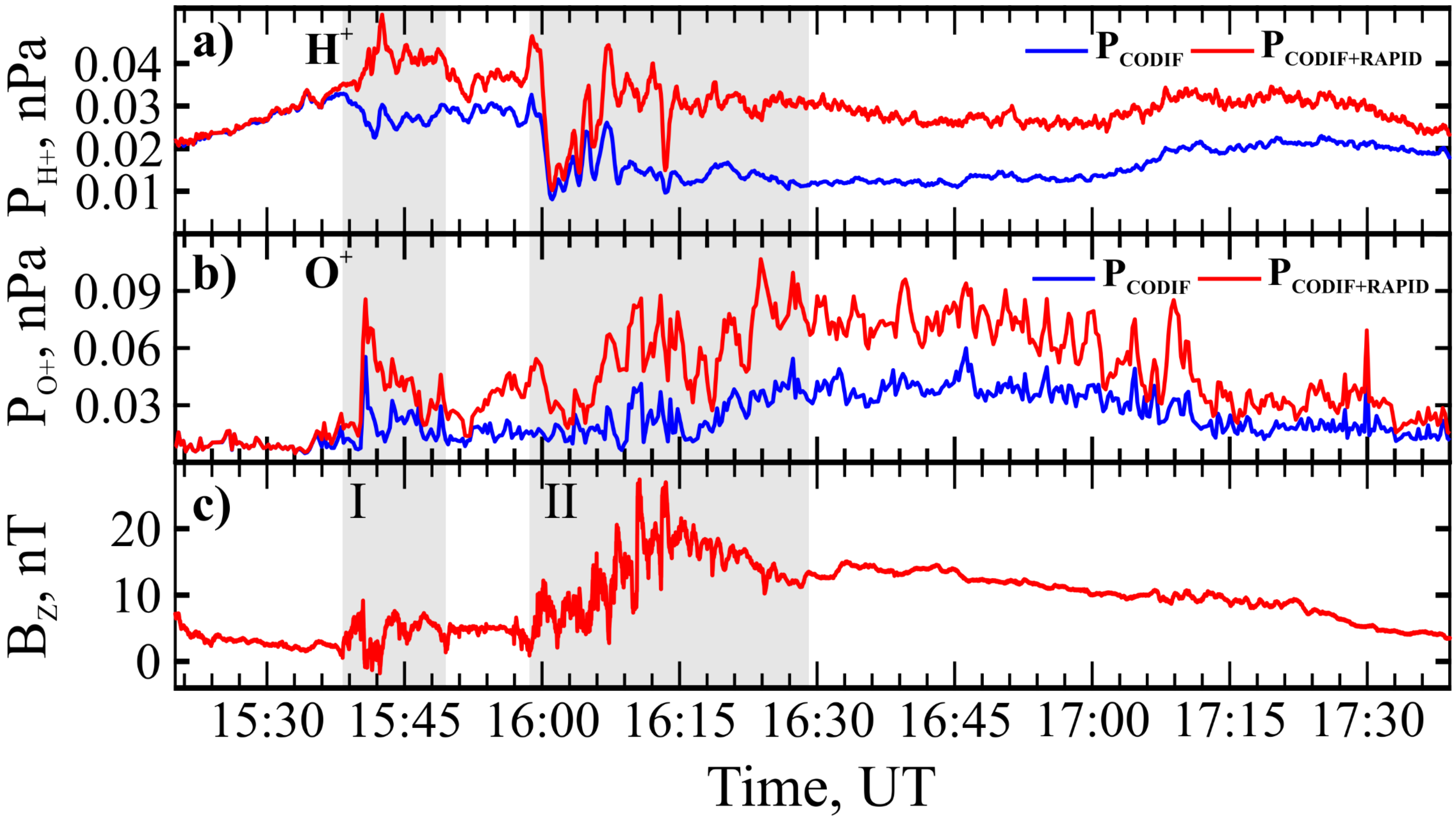


The energy distributions of the fluxes of both ion components before depolarization (at 15:30:55 UT) can be described by the Maxwell function:

$$J_M(E) = J_1\left(\frac{2\pi}{\sqrt{(\pi E_0)^3}}\right)\sqrt{E}\exp\left(-\frac{E-E_0}{E_0}\right)$$

After the onset of depolarization a power-law high-energy tail appears in the distribution. The J(E) spectrum in the energy range up to 1.3 MeV was approximated by the sum of the Maxwellian ($J_M(E)$) and kappa distributions (J_2):

$$J_D(E) = J_M(E) + J_2\left(1+\frac{E}{\kappa E_{0\varkappa}}\right)^{(-\varkappa-1)}$$



Before the onset of dipolarization I, the pressure value according to CODIF (shown by the gray line) coincided with the pressure calculated from the CODIF and RAPID data (shown by the black line).

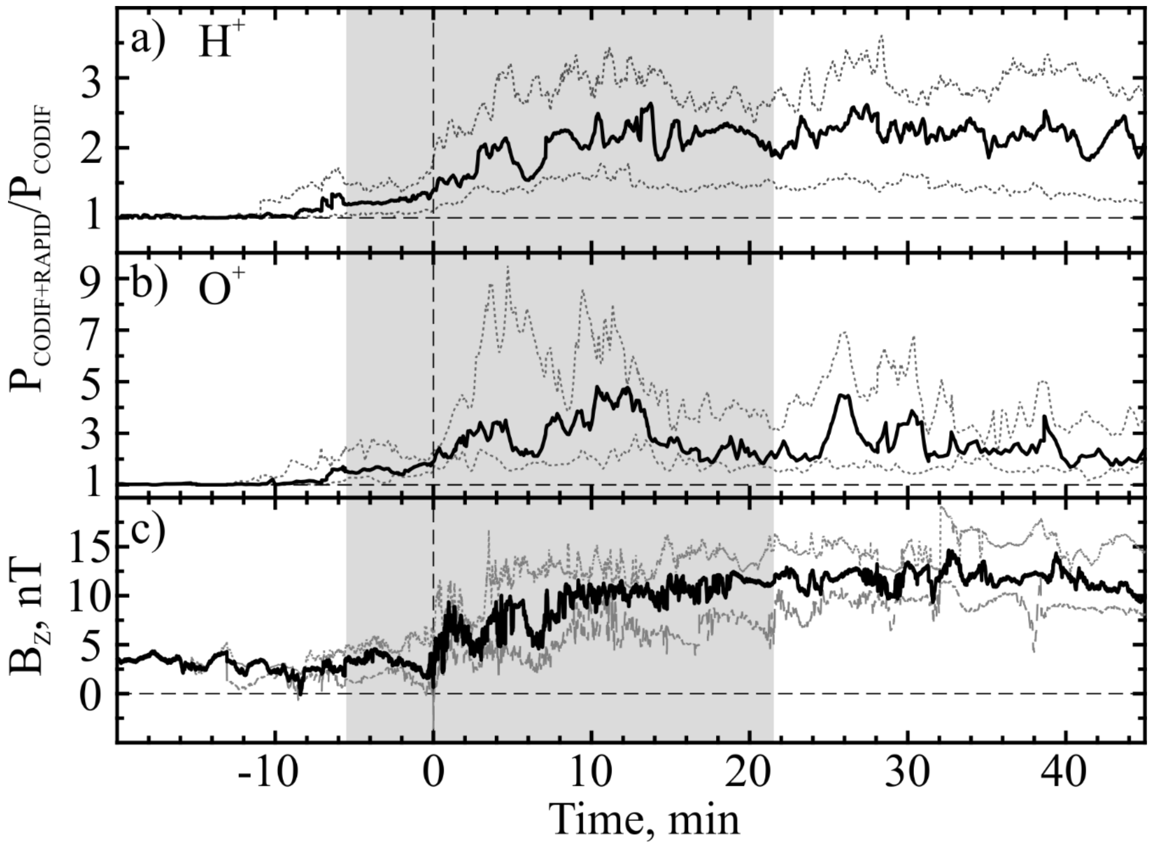
However, a discrepancy in the values of these pressures begins to occur a few minutes before the onset, reaching its maximum during dipolarization.

Specifically, the H+ ion pressure calculated with allowance for the energetic population **($P_{CODIF+RAPID}$) during dipolarization was nearly three times higher than the pressure calculated without the energetic population (P_{CODIF})**. A similar result was obtained (Kronberg et al., 2017) in the analysis of the contribution of an energetic ion population to the total plasma pressure in the tail PS during a magnetic storm.

For oxygen, a difference in pressure $P_{CODIF+RAPID}/P_{CODIF}$ ~ 8 was observed.

STATISTICAL ANALYSIS OF PRESSURE VARIATIONS

In order to study statistically the contribution of suprathermal ion population in ion pressure during dipolarization we study 11 dipolarization events in the near geomagnetic tail observed by Cluster satellites at distances from the Earth X ≤ –19 RE. [Malykhin et al. 2020 - DOI: 10.1134/S0016793220010090]



Superposed epoch analysis shows that the difference in the pressure calculated with and without the energetic ion population (an increase in the $P_{CODIF+RAPID}/P_{CODIF}$ value) begins several minutes before the onset of dipolarization. The $P_{CODIF+RAPID}/P_{CODIF}$ value reaches its maximum (~2.5 for H^+ ions and ~5 for O^+ ions) for both ion components by the end of the dipolarization growth phase. The $P_{CODIF+RAPID}/P_{CODIF}$ value for heavy ions increases faster than for light ions. After the B_Z magnetic field component reached its maximum level, the $P_{CODIF+RAPID}/P_{CODIF}$ value calculated for H+ ions remains nearly constant (~2) for a rather long time (tens of minutes). For O^+ ions, this value also remains quite high for tens of minutes after the end of the dipolarization growth phase; however, it undergoes significant variations associated with the variations in the fluxes of energetic O^+ ions observed by RAPID.

CONCLUSIONS

We analyzed the dynamics of fluxes of thermal (up to 40 keV) and suprathermal (~45 keV– 1.3 MeV) H^+ and O^+ ions and the pressure variations of these ion components observed by Cluster satellites in 11 dipolarization events in the PS of the near-Earth magnetotail ($X \leq -19$ RE). The following was found:

—During dipolarization, the energy of H^+ and O^+ ions corresponding to the maximum flux approached or exceeded the upper energy threshold of the CODIF thermal plasma mass spectrometers (~40 keV), which lead to the underestimation of the thermal pressure of these ion populations.

—The difference in ion pressures calculated without the high-energy population (up to 40 keV) and with it (in the energy range up to ~1.3 MeV) begins to occur several minutes before the onset of dipolarization and reaches its maximum by the end of the dipolarization growth phase.

—The most significant error associated with underestimation of pressure is observed for heavy ions: the median value of the $P_{CODIF+RAPID}/P_{CODIF}$ ratio reaches ~5 by the end of the dipolarization growth phase.

—The error associated with underestimation of pressure for H^+ ions is smaller than that for heavy ions: the median value of the $P_{CODIF+RAPID}/P_{CODIF}$ ratio reaches ~2.5 by the end of the dipolarization growth phase;

—The difference of pressures calculated with and without energetic populations of H^+ and O^+ ions remains significant (~2) for tens of minutes after the end of the dipolarization growth phase.