Storm-time near-earth magnetotail dynamics examined using 30 kev proton isotropic boundaries

Natalia Ganushkina (1, 2),
Stepan Dubyagin (2), Michael Liemohn (1)

(1) University of Michigan, Ann Arbor MI, USA
(2) Finnish Meteorological Institute, Helsinki, Finland

The research leading to these results was partly funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302 PROGRESS

The Magnetosphere: New Tools, New Thinking, New Results,
November 12-17, 2017, Puerto Varas, Chile

Magnetotail dynamics and low altitude measurements

Determining the **geometry of the Earth's magnetospheric magnetic field** under various solar wind and IMF conditions is crucial for obtaining connections between ionospheric and auroral features and magnetospheric phenomena.

Knowing the configuration of the magnetic field lines is directly related to the understanding of the **magnetic mapping** in different conditions and between different regions of the near-Earth space.

The only way to determine the magnetic field configuration in the entire magnetosphere is to use **an existing model** .

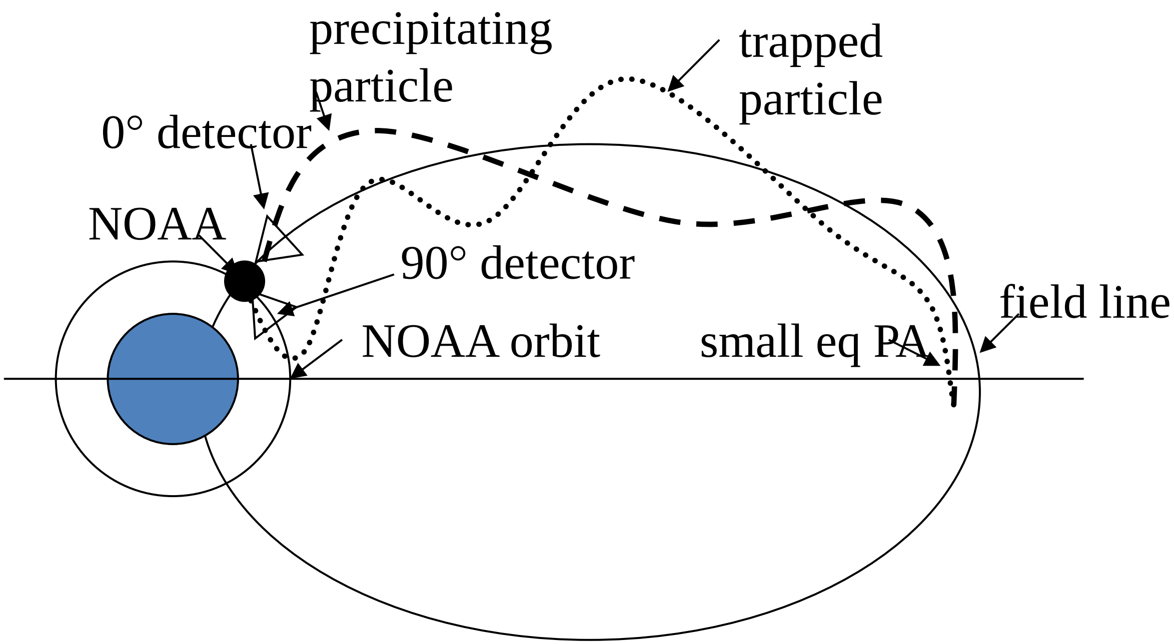
Models need to be validated. There are not so many satellites in the magnetosphere which measure the magnetic field.

At the same time, there exist **continuous measurements on NOAA satellites**, which can provide, though indirectly, valuable information about the dynamics of the magnetospheric magnetic field, in the magnetotail, in particular.

NOAA POES Instrumentation and data

The NOAA POES spacecraft is on **nearly circular Sun-synchronous polar orbit** at an **altitude of about 800 km** with orbital **period about 102 minutes**, which produces 14.1 orbits per day.

SEM-2 contains **MEPED** which measures (with a **time resolution of 2 s)** the flux of the energetic **protons** and electrons from two perpendicular directions in P1 (30–80 keV), P2 (80–240 keV), P3 (240–800 keV).

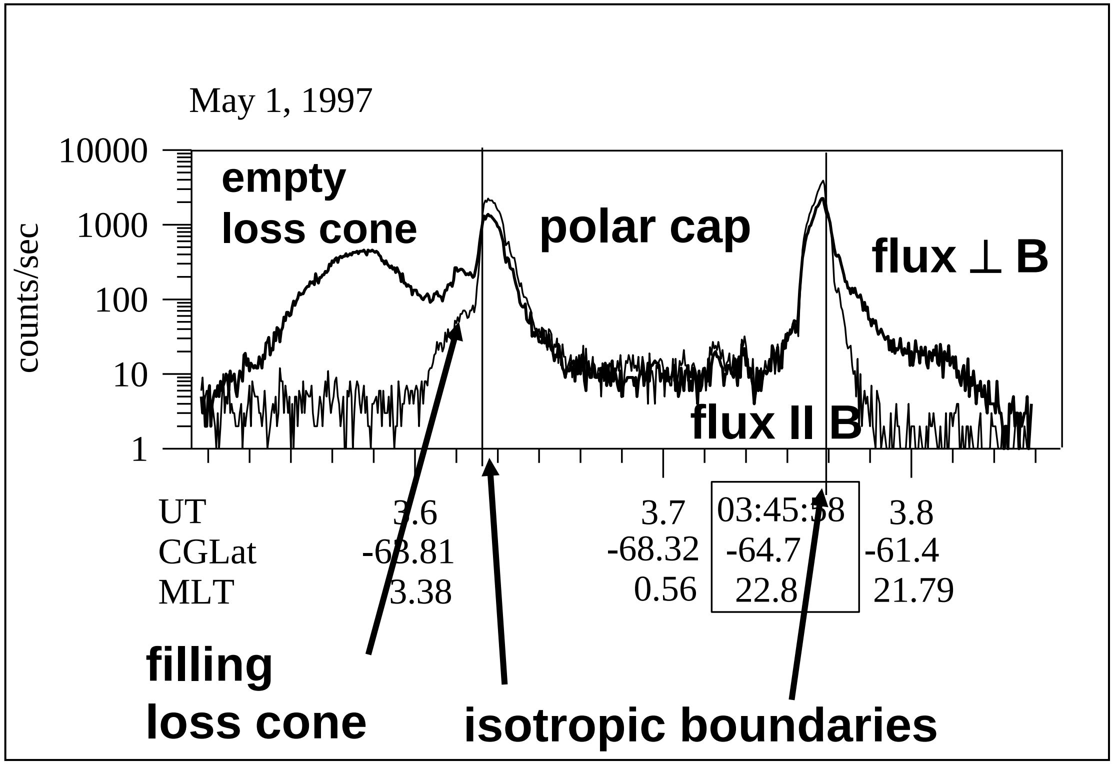


Detectors in the MEPED:

(1) radially outward measures **precipitating particles** in the central part of the loss cone

(2) perpendicular direction measures **locally trapped** particles outside the loss cone.

Properties of isotropic boundaries at low altitudes



lat < 60 deg:
- anisotropic PA distr.;
- max flux ⊥ B;
- locally mirroring
- with 90 deg PA.

lat > 60 deg:
- isotropization;
- flux ⊥ B ≈ flux || B;
- precipitation.

Isotropic boundary (IB) latitude depends on species, E, MLT, activity.

The nightside IB is interpreted as a boundary between the adiabatic and stochastic particle motion in the tail current sheet and is used to determine the degree of magnetic field stretching in the magnetotail

- IBs observed at all MLTs;
- For same species and energy IB lat higher around noon than at midnight;
- The higher the energy, the lower the IB latitude;
- Signature of boundary between regions of adiabatic and chaotic particle motion.

Formation mechanisms of isotropic boundaries

Mechanism of **pitch-angle scattering** (presence of IBs indicates that):
Where: in the magnetotail
Results in: violation of the first adiabatic invariant and scattering ions into a loss-cone
When: during their bouncing motion between two hemispheres
[*Sergeev et al.*, 1983, 1993; *Ganushkina et al.*, 2005].

The mostly debated mechanisms of the pitch-angle scattering responsible for the IB formation on the nightside:
1). field-line-curvature (FLC) scattering [e.g., *Sergeev et al.*, 1983, 1993]

2). scattering by electro-magnetic ion cyclotron (EMIC) waves [e.g., *Kennel and Petschek*, 1966; *Erlandson and Ukhorskiy*, 2001; *Liang et al.*, 2014 , *Sergeev et al*., 2015]

Field-line curvature (FLC) mechanism

For the idealized magnetotail-like configuration, the condition for the loss-cone filling by the FLC-scattering is

$$\kappa = \frac{R_c}{\rho} \le 8,$$

where $R_c = \frac{B_z}{(\partial B / \partial z)}$ is the magnetic field line curvature radius and

$\rho = \frac{\sqrt{2mE}}{qB} \sin\alpha$ is the particle gyroradius in the center of the current sheet

If in some region of magnetotail, the gyration radius of a particle becomes comparable with the field line curvature, a particle is exposed to **pitch angle scattering.**

IB allows to probe the magnetotail configuration remotely (e.g. *Segreev et al*., 1996).

However, recent studies showed that wave-particle interaction cannot be neglected entirely (*Dubyagin et al*., 2013; *Liang et al*., 2014; *Sergeev et al*., 2015)

Storm events and data for them

Date/Time	min(SYM-H)
2011-05-27/16:00:00 2011-05-31/00:00:00	-94
2011-08-05/18:00:00 2011-08-08/00:00:00	-126
2012-04-23/03:00:00 2012-04-26/00:00:00	-125
2012-06-16/20:00:00 2012-06-20/00:00:00	-69
2012-07-14/18:00:00 2012-07-18/00:00:00	-123
2012-09-30/11:00:00 2012-10-03/00:00:00	-138
2012-10-08/00:00:00 2012-10-11/00:00:00	-116
2013-05-31/16:00:00 2013-06-03/00:00:00	-137
2013-06-27/14:00:00 2013-07-01/00:00:00	-111

Data from NOAA-15, 16, 17, 18, 19, METOP-01, 02 in the altitude-adjusted corrected geomagnetic (AACGM) coordinates.

Magnetic field data from the flux gate magnetometer onboard three innermost probes of THEMIS with 1 minute averaging

Storms selected for concurrent observations **at low-altitudes and in the equatorial magnetosphere**: THEMIS on the nightside.

IBs within 21–03 MLT, the region where the magnetic field models are expected to be the most accurate.

The proton MEPED detector is subject to **degradation** resulting in the low energy threshold increase [*Asikainen et al.*, 2012; *Sandanger et al.*, 2015]. 90 deg flux is scaled to the 0 deg telescope energy range following the *Dubyagin et al.* [2013] algorithm.

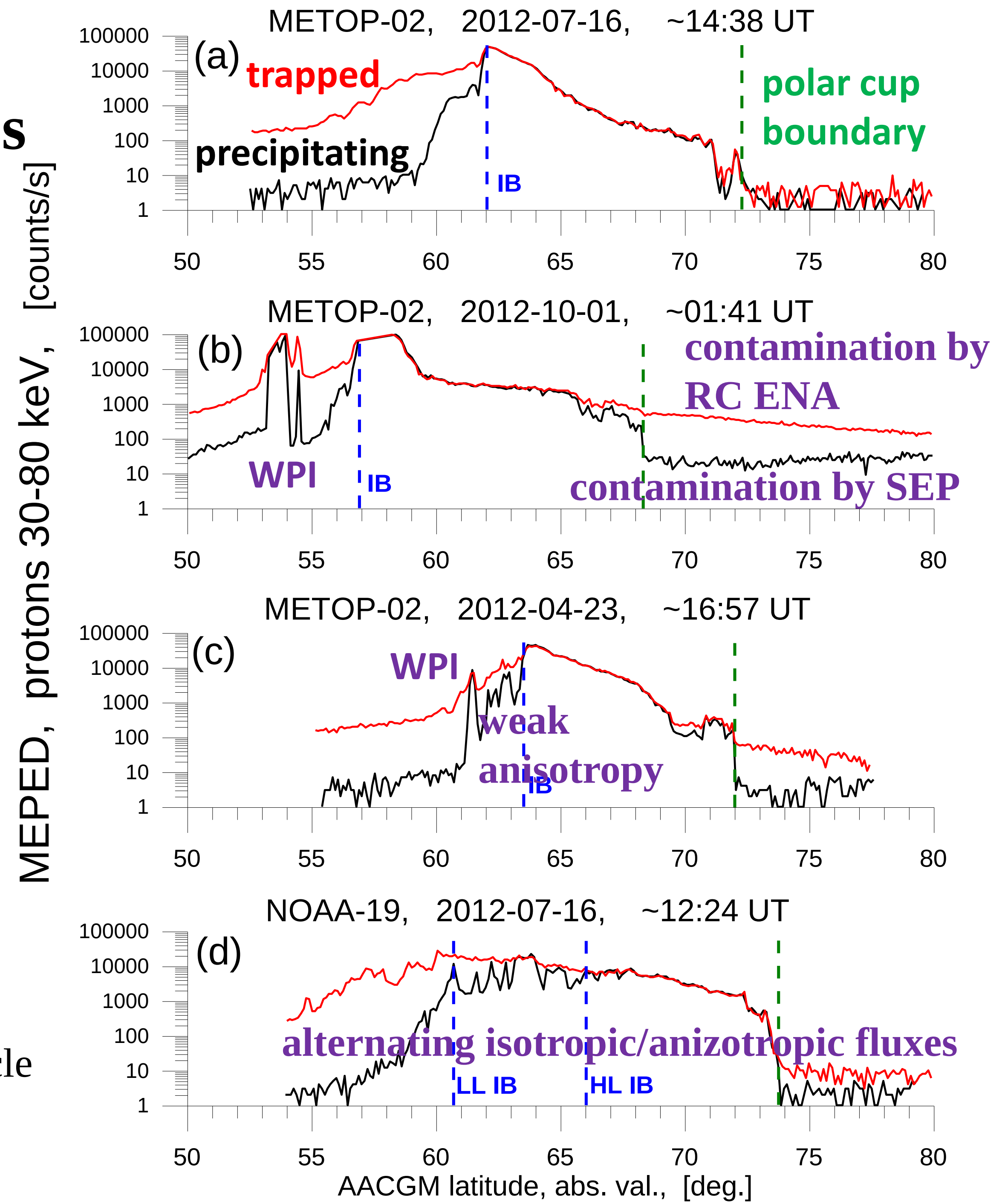
MEPED proton flux latitudinal profiles

Unambiguously defined IB

Localized region of the isotropic precipitations due to WPI

Weak anisotropy, < 1 order of magnitude difference

Alternating isotropic/anizotropic Fluxes: difficult to explain whether using FLC-scattering or wave-particle interaction



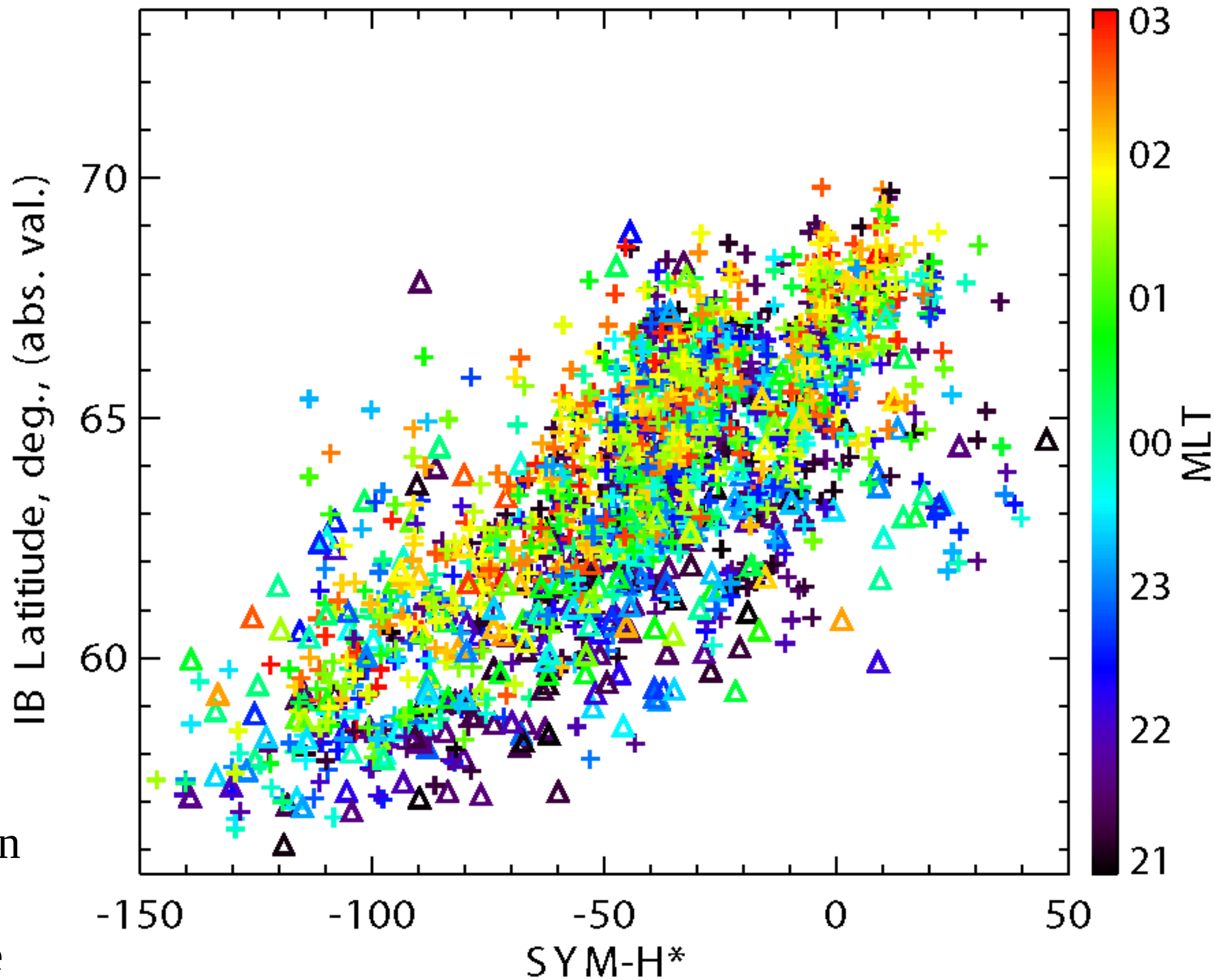
IB latitude dependent on Dst (SYM-H)

Strong IB latitude dependence on SYM-H index has been previously reported (*Soraas et al*., 2002; *Lvova et al*., 2005; *Ganushkina et al*., 2005; *Asikainen et al*., 2010)

Triangles:
storm main phases
Crosses:
storm recovery phases

IBs move equatorward with SYM-H decrease.

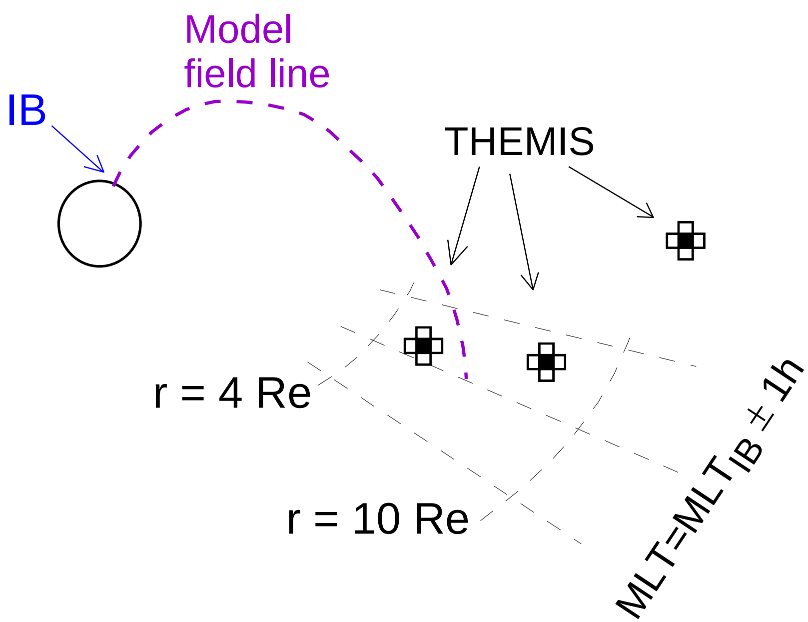
The most equatorial IBs are at 21–24 MLT sector (blue) during main phase (triangles):
(1) interaction with EMIC waves and anomalous IB dispersions;
(2) midnight-dusk is the location where the intense and thin tail current sheet comes close to the Earth during the main phase



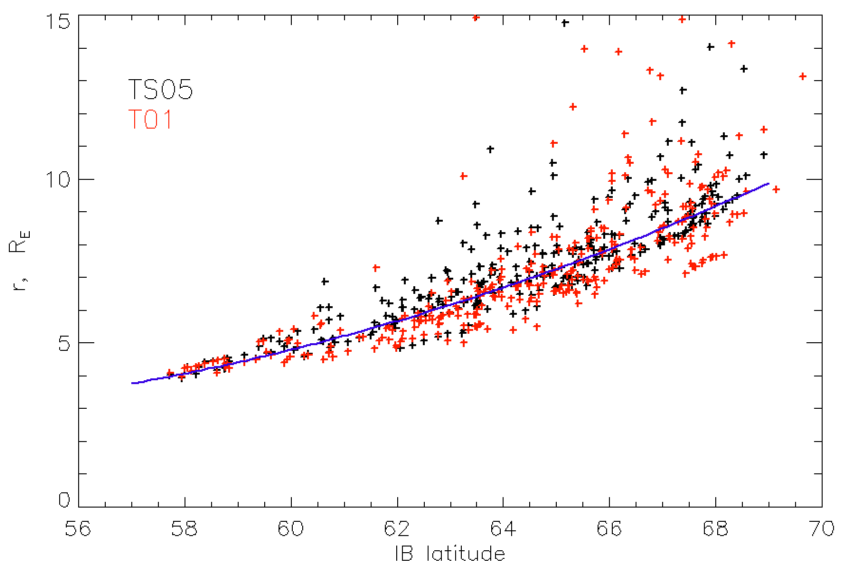
To determine K - parameter

$$\frac{R_C}{\rho} \approx \frac{B_Z}{dBx/dZ} \cdot \frac{eB_Z}{mV} = \frac{eB_Z^2}{mV\,dBx/dZ}$$

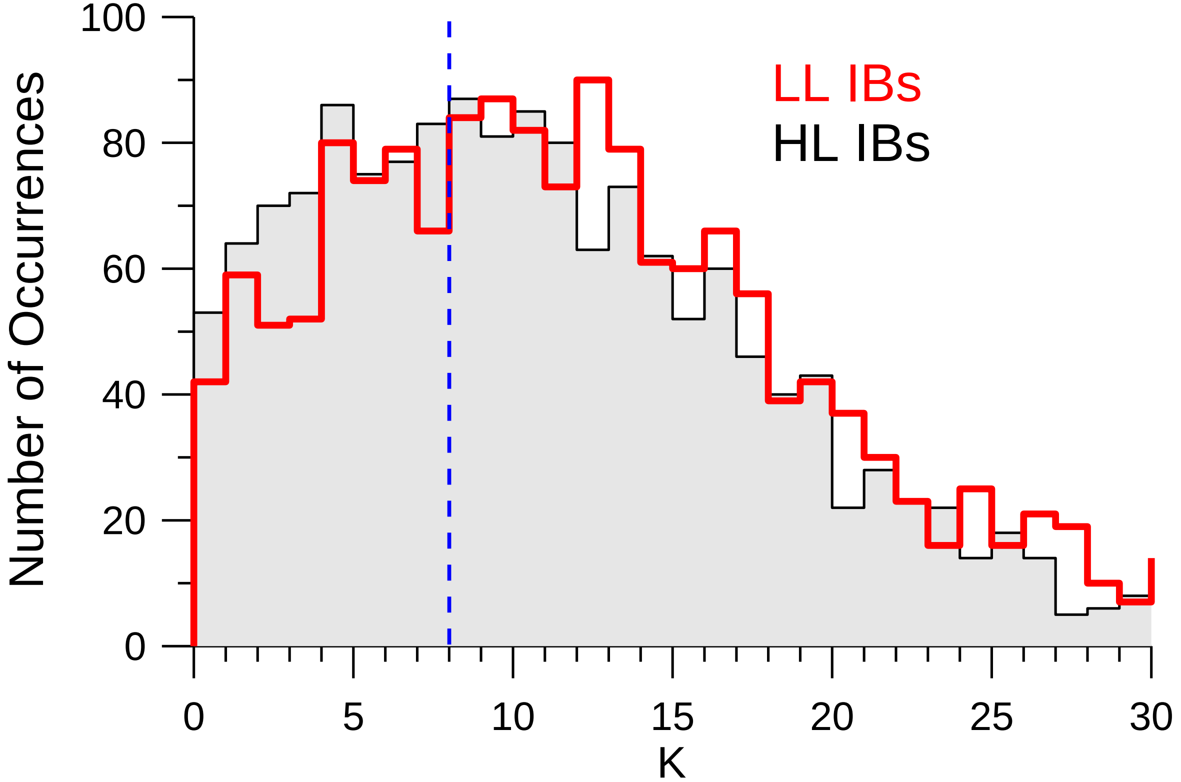
To control the model accuracy:
comparison with in situ magnetic field measurements (THEMIS),
near expected IB equatorial projection (r=4-10Re,
same MLT (plus/minus 1 hour)
as observed IB).



Observed IBs projected onto equatorial plane using T01 and TS05 models: between 4 and 10 Re



K-parameter for observed IB field lines by TS05



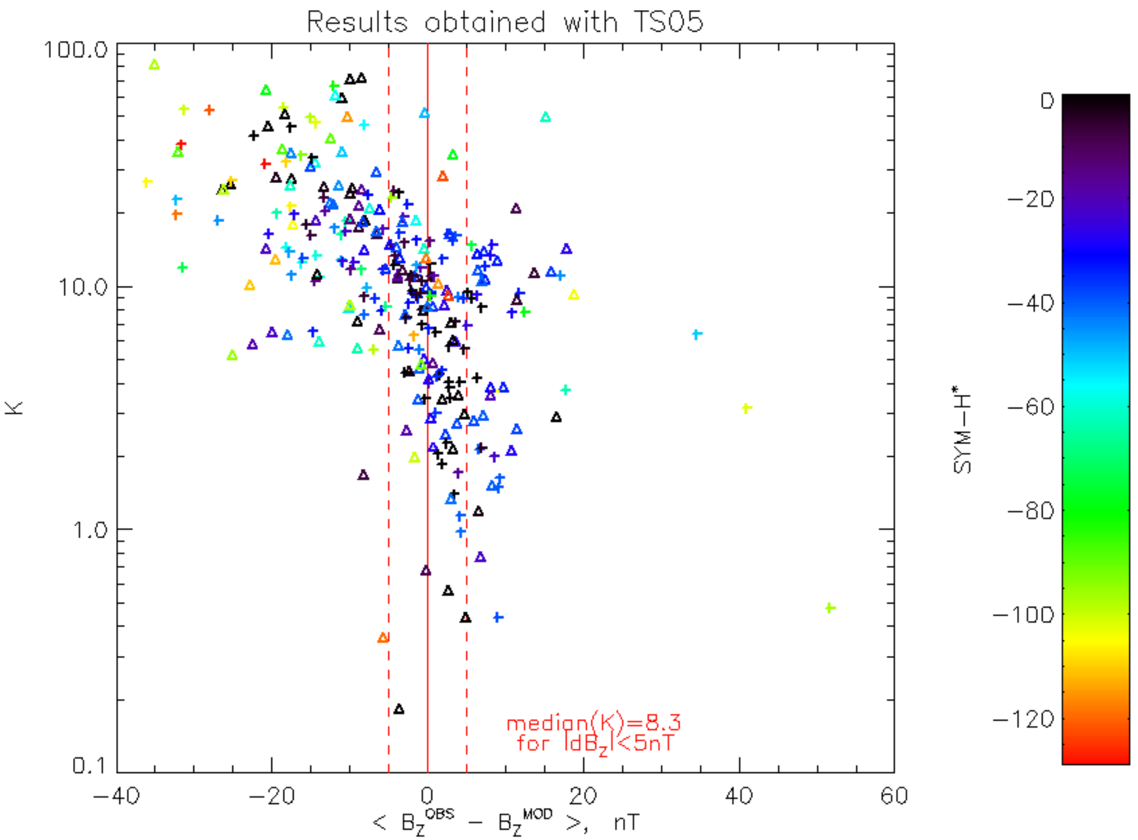
Although distributions are very broad, they are centered at K=8-13.

80% events with estimated K < 13, in agreement with the FLC-scattering mechanism

Remaining 20%: as an occurrence rate for IBs formed by wave-particle interaction in the region of high K-values. Close to the occurrence rate of the anomalous IB dispersion during storm time [*Dubyagin et al.*, 2013] and quiet periods [*Sergeev et al.*, 2015a]; also close to the occurrence rate of the EMIC waves in the inner magnetosphere [*Usanova et al.*, 2012].

K - parameter and model quality

TS05 deviation from real configuration can be large especially during storms. To evaluate model accuracy: compare the magnetic field measurements at THEMIS with modeled.
Bz ~ const across a current sheet. Therefore, $\Delta Bz = < Bz^{obs} - Bz^{mod} >$ is an indicator of the model quality.



model understretched

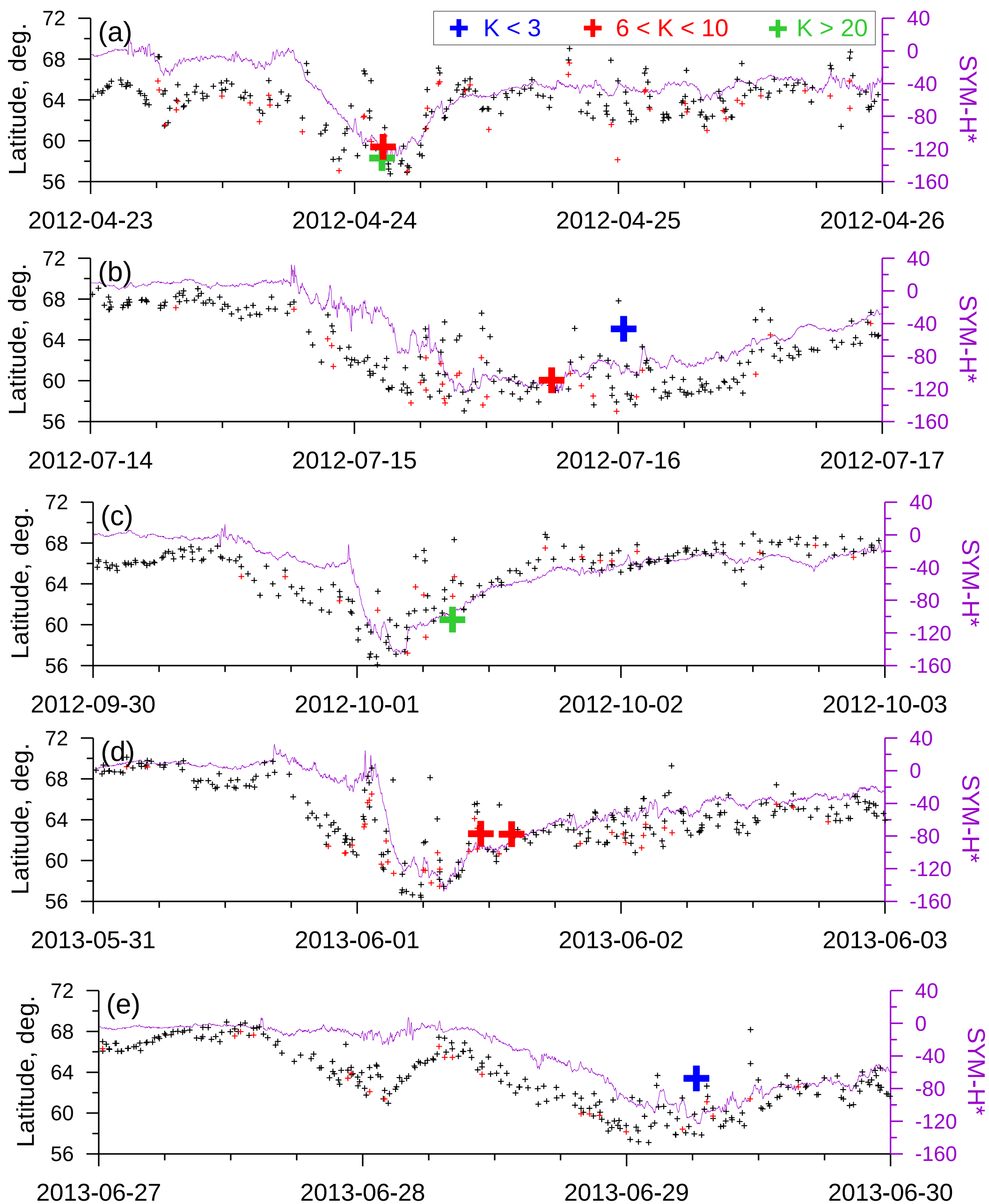
model overstretched

ΔBz <0: model Bz > real Bz; model overestimates K-parameter; model is understretched; equatorial projections of IB are closer to Earth than real.
ΔBz >0: opposite
model underestimates K-parameter for such events.

The clouds of points have a negative slope.

For the events when the TS05 is in a good agreement with magnetic field measurements, the K-distribution, though broad, peaks at K=8.

IB and K – parameter during specific storms



IB latitudes follow the variations of SYM-H closely except for transient periods (IB latitude up and down)

K ≈ 8 (red crosses):
typically found during periods of stable IB location.

K < 3 or K > 20 (green and blue crosses):
during the periods when location of IB underwent fast variations.

Conclusions

1. The latitude of the energetic proton isotropic boundary undergoes dramatic variations and can be as low as at 55 degrees during storm times;

2. No indications were found that the mechanism of the pitch-angle scattering near midnight is systematically different from that during non-storm conditions.

3. The dominant mechanism of isotropic boundary formation is the pitch-angle scattering owning to the curvature of the field lines in the magnetotail current sheet.

4. The upper estimation for the occurrence rate of the isotropic boundaries formed by wave-particle interaction mechanism is about 20%. NOTE: only at 21–03 MLT sector

5. The isotopic boundaries formed by the wave-particle interaction process can be encountered more frequently in the 18–21 MLT sector especially during the main phase.