Creation of model of quasi-trapped proton fluxes below Earth's radiation belt

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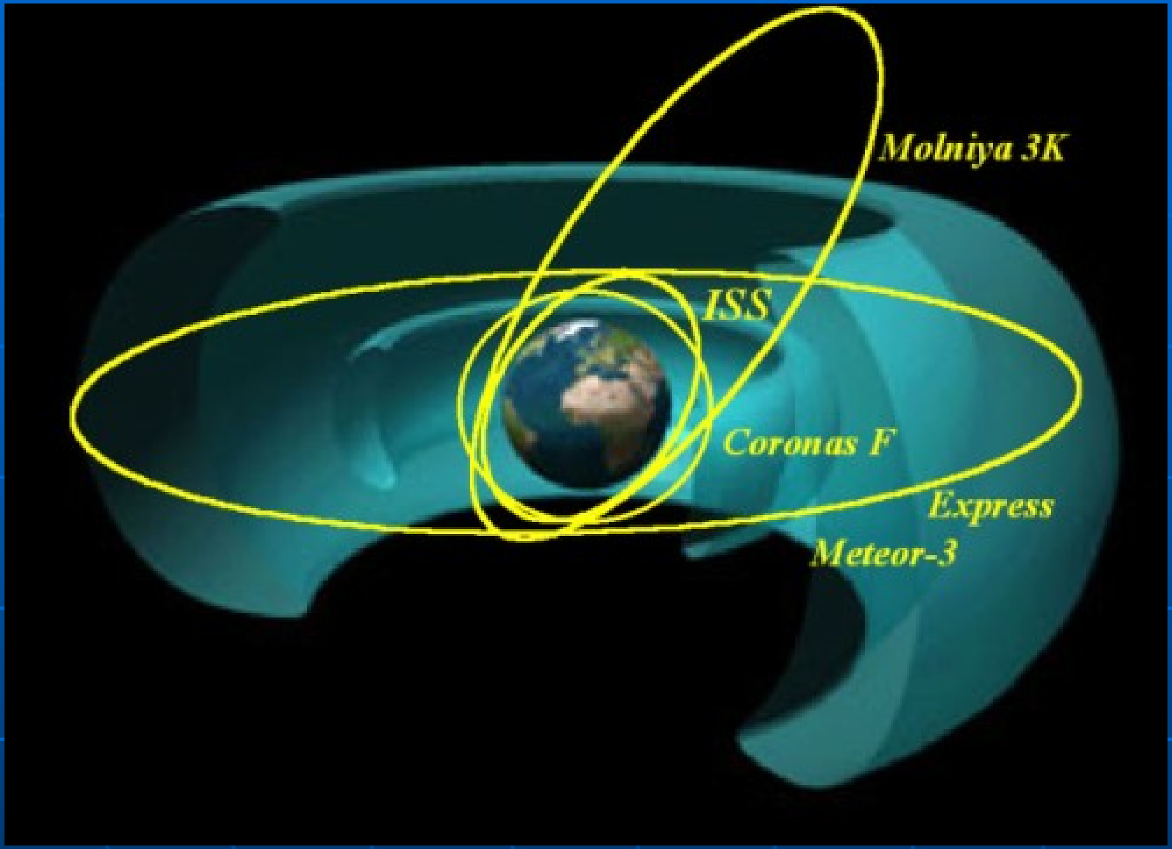
Earth’s radiation belts



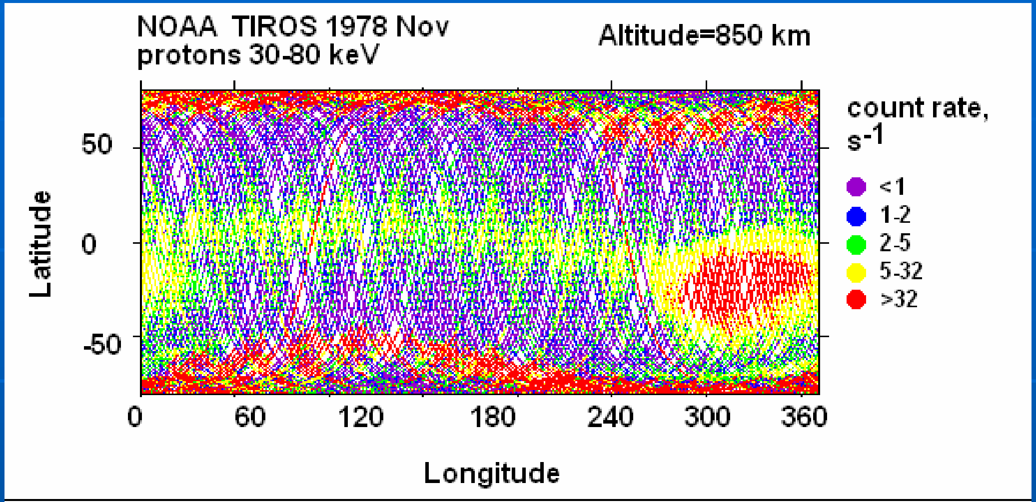
As we know there are regions of intense charged particles fluxes near the Earth. The maxima of these belts lies at very high altitudes from the Earth.
L=2.2=7680 km,
L=4.0=19200 km.

Figure shows the orbits of some space satellites and ISS in comparison to Earth’s dimensions and radiation belts dimensions are given for example

Discovering

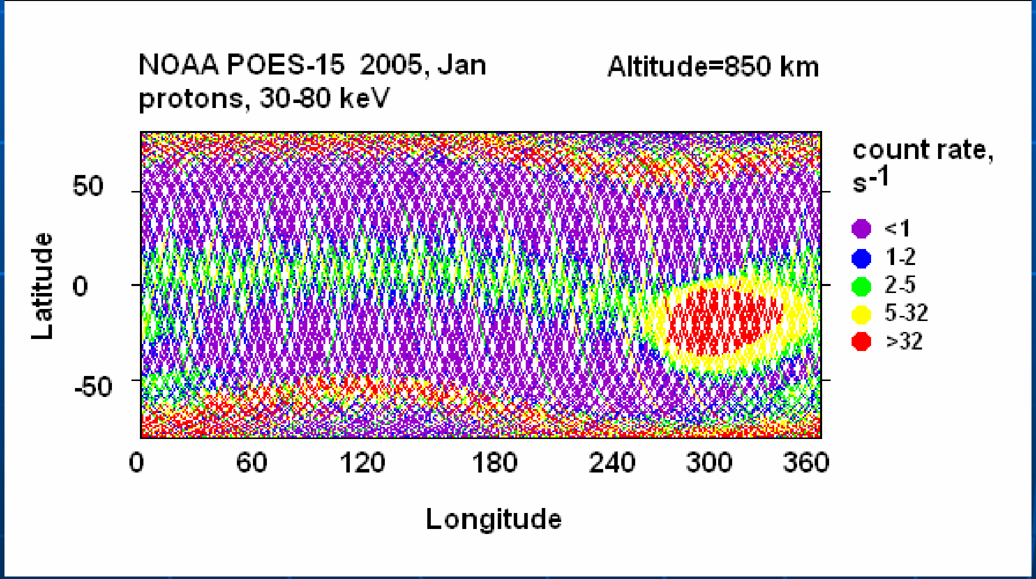
In 1972 Moritz J. published that he discovered the low-energy (about 10 keV – 10 MeV as we know now) proton flux enhancements near equator at altitudes up to 1000 km (L<1.15). This protons can not live a lot of time at this altitude. So there had to be the source – radiation belt and ring current as we know now. The illustrations are below.

Proton fluxes at 850 km altitude



NOAA TIROS-N, 1978,

Ep=30-80 keV

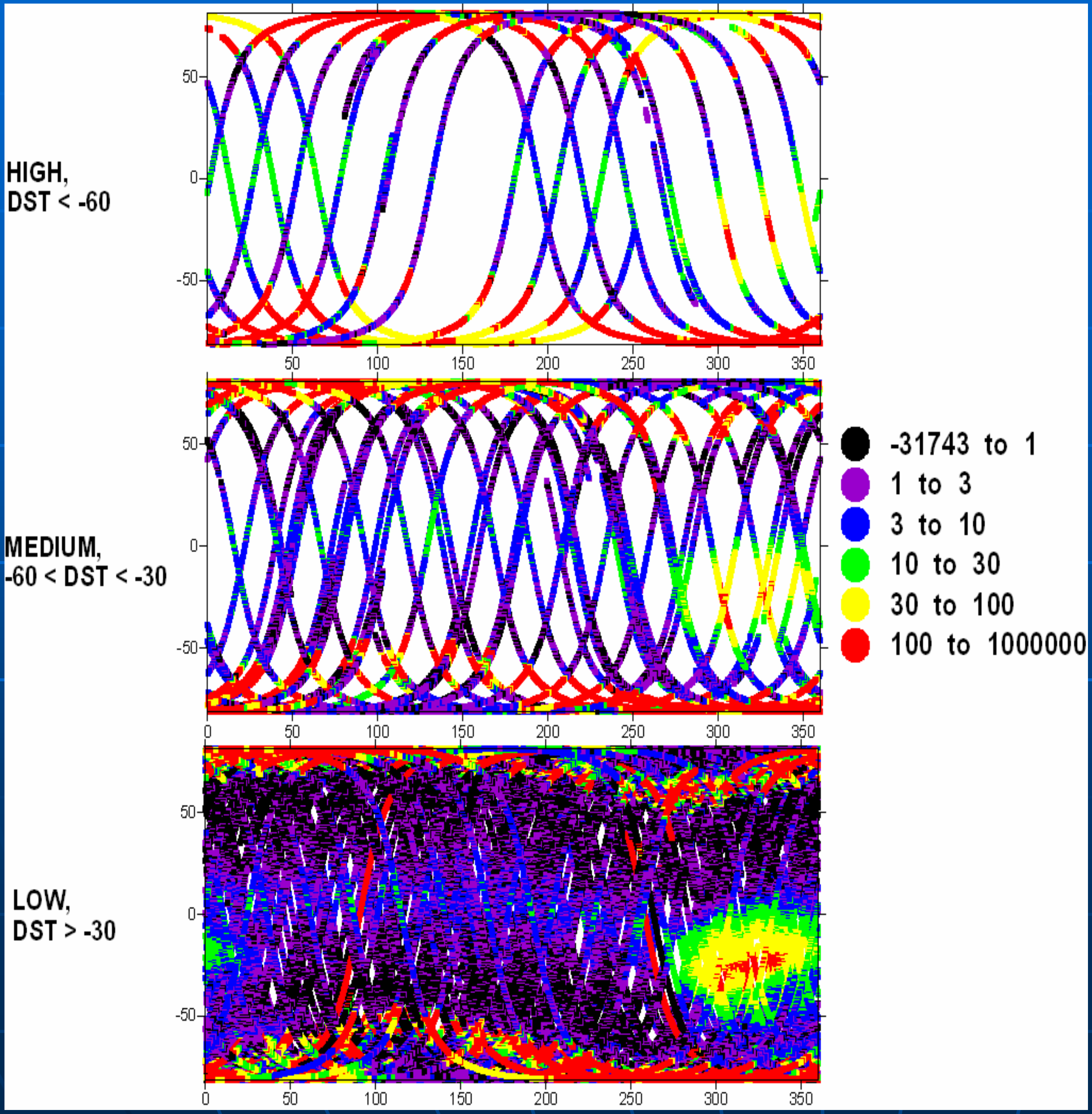


NOAA POES-17, 2005,

Ep=30-80 keV

This band of proton flux enhancements is observed for the long time. Here are the maps of protons for 1978 and 2005 years.

Dynamics of proton fluxes below radiation belts



The 30-80 keV proton flux depends on geomagnetic activity. The higher activity (Dst) the higher flux.

This figure allows us to say that there is correlation of near-equatorial proton fluxes and radiation belt and ring current.

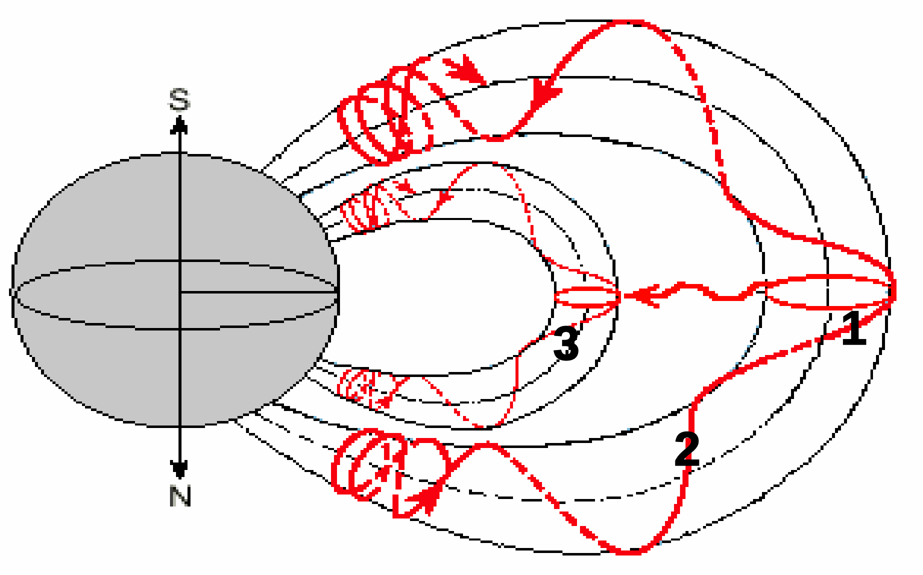
The other name of this formation is Storm-Time Equatorial Belt (STEB), Søraas et al.

But we can see it at very weak activity (Dst > -30)!

The main feature

- The low-energy near-equatorial protons is instrument for investigation of radiation belt and ring current dynamics as it was shown by Moritz and Søraas.

Double charge-exchange mechanism



1. The energetic protons of outer radiation belt interacts with neutral protons of exosphere (upper part of atmosphere) producing the flux of energetic (*) neutrals:

$p^* + H \rightarrow H^* + p$

2. The energetic neutrals freely moves in the Earth’s magnetic field. The neutral can collide with atomic Oxygen in the dense part of atmosphere in reaction:

$H^* + O \rightarrow p^* + O^-$

3. The produced proton can become trapped in the magnetic field in near-equatorial region. The pitch-angle distribution of radiation belt protons have maximum at 90° and produce peak of flux at equator. The protons with pitch-angles in the cone of loss disappears in the atmosphere.

Problems to solve

- The features of proton flux distribution was not accurately described before, there was lack of data.
- The well-known model of radiation belts (NASA AP8) does not take this protons into account. Probably because of low dose produced by this protons. Probably this phenomenon was not discovered when the AP8 was developed.
- There is not no empirical model of that proton fluxes.

Results of work

- 1. The large database of proton flux enhancements observed by several space experiments onboard space satellites and space stations from 1978 to 2005

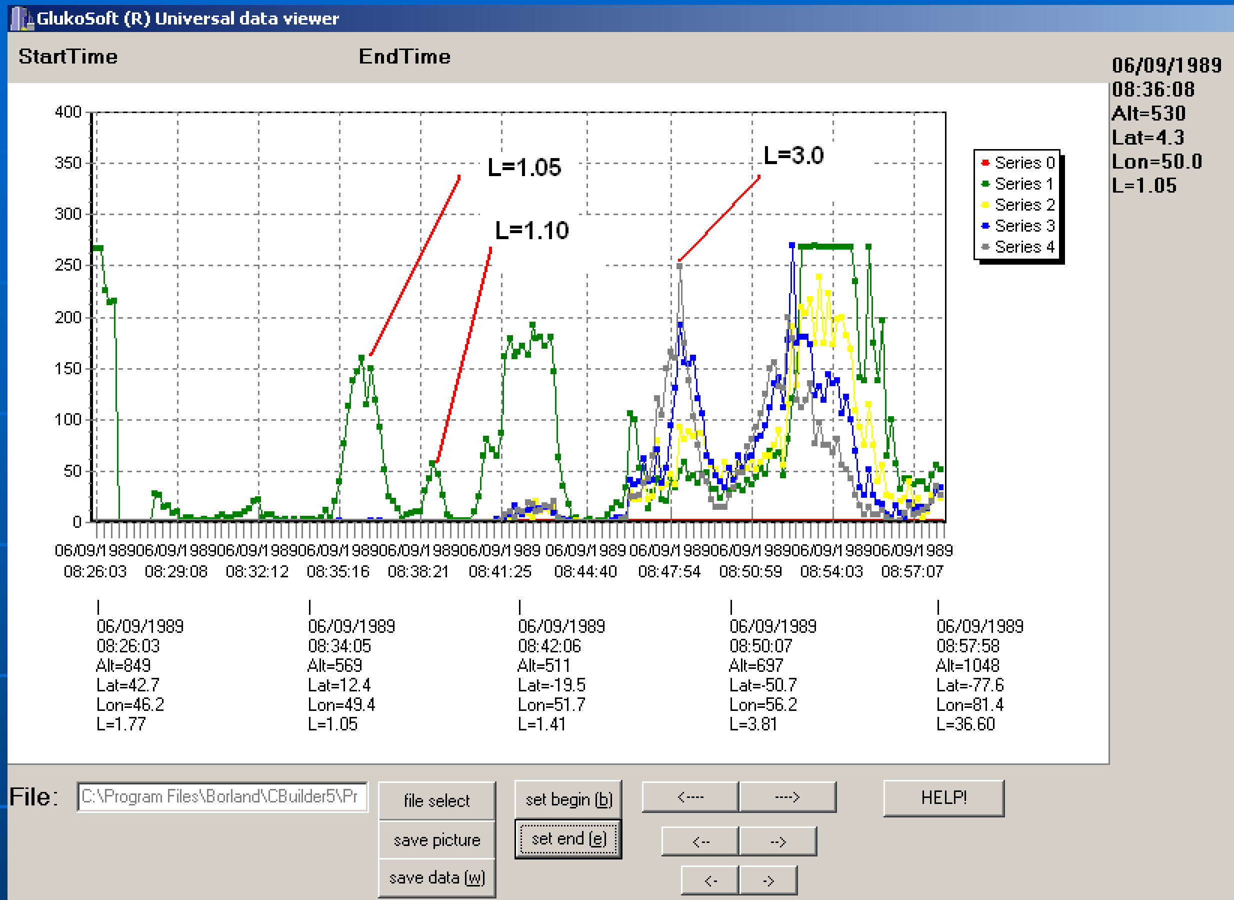
Experiments

Space apparatus	Year	Altitude, km	Inclina-tion	Energy of protons
NOAA TIROS-N	1978	850	98.9°	Ep=0,03-2,5 MeV
Active (Intercosmos-24)	1989-1992	500-2500	81.3°	Ep=55-550 keV
MIR (Sprut-V)	1991	400	51.6°	Ep=0,1-8,0 MeV
Coronas-I	1994	500	83°	Ep>1 MeV
SAMPEX	1992-1998	520-670	82º	Ep>770 keV
MIR (Sprut-VI)	1999	350	51.6°	Ep=0,3-5,0 MeV
NOAA POES-17	2005	850	98.9°	Ep=0,03-2,5 MeV
Univesitetsky-Tatyana	2005	920-980	83°	Ep>2 MeV

Results of work

- 2. The program Universal Data Viewer for viewing and analysis of experimental data

The Universal Data Viewer

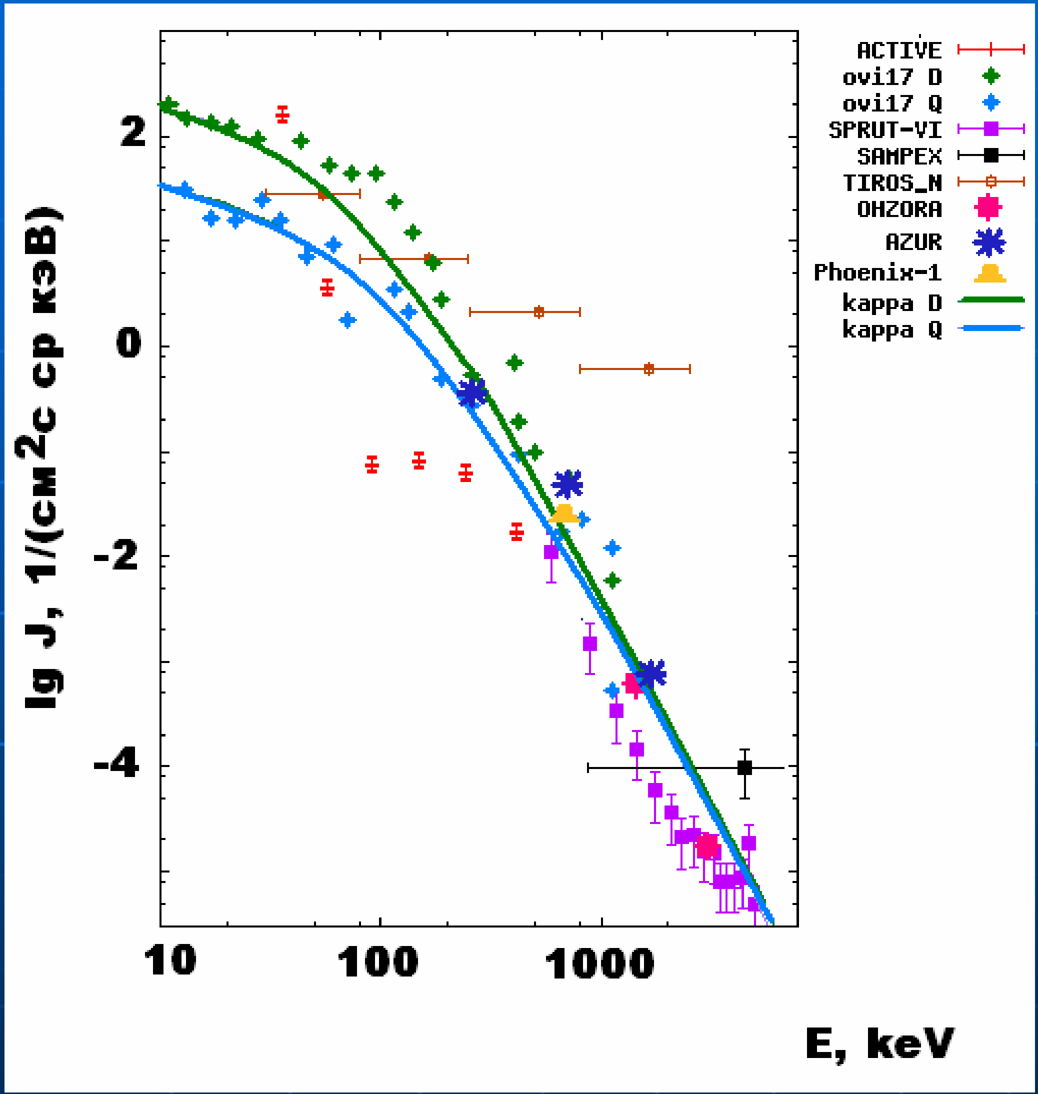


This program was created for visualization of satellite experimental data. It can draw the particle flux dependence from time. The program allows to adopt it to show almost any text data files using (changing) small and simple configuration file

Results of work

- 3. According to data of ~10 satellites the shape of energy spectrum was defined. The simple kappa-function approximate the spectrum in whole energy range.

Energy spectrum



$$f(E) = A\left(1 + \frac{E}{kE_0}\right)^{-k-1}$$

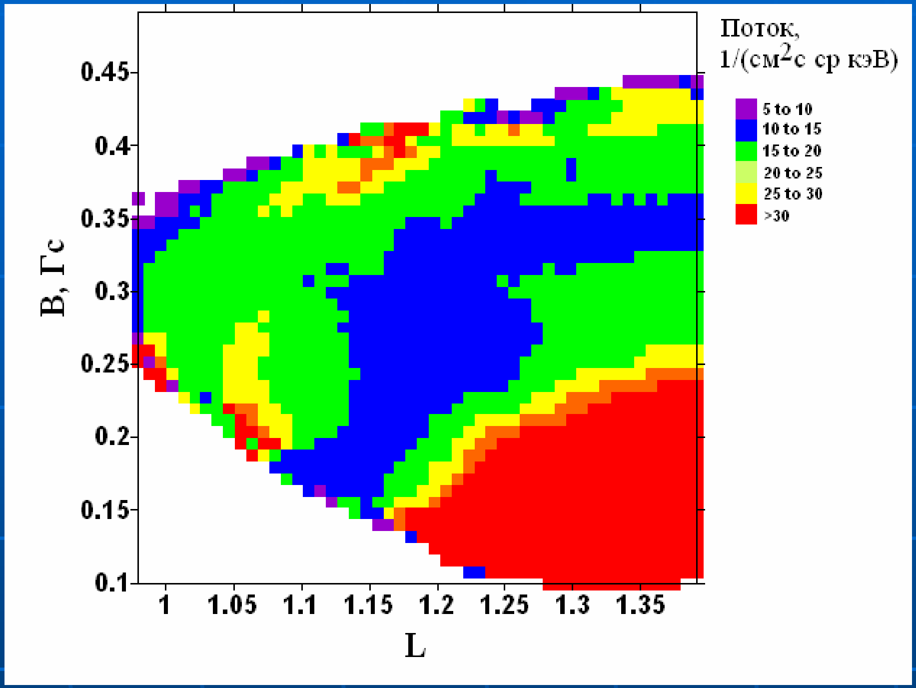
Here we can see the average energy spectrum and approximation of all experimental spectra for high (green) and low (blue) geomagnetic activity. The kappa function approximate this spectrum better than power-law, exponential or Maxwell functions

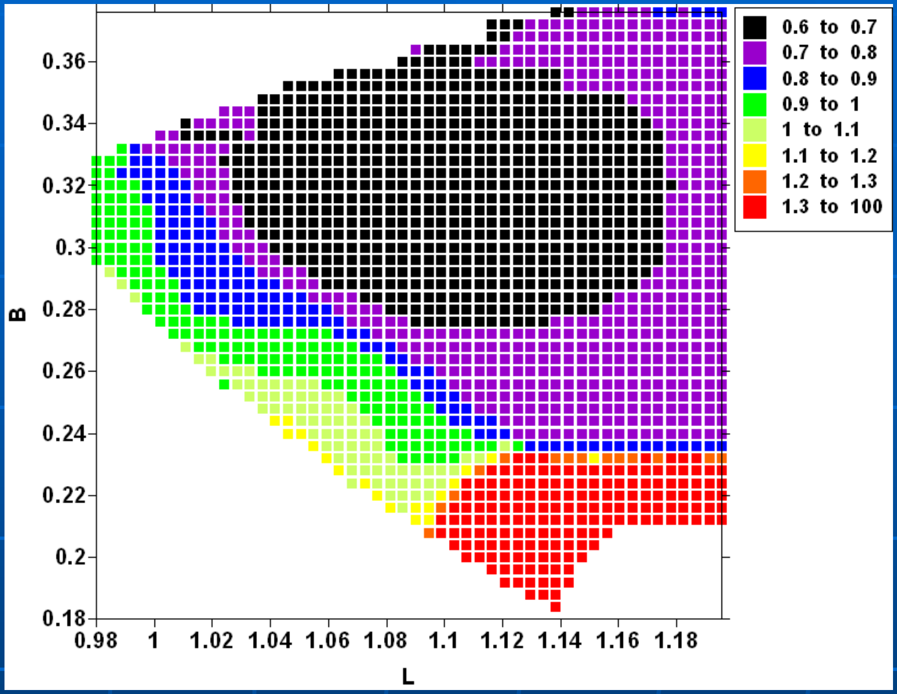
The kappa-like spectra of protons are observed at outer boundary of rad. belts due to interaction of instabilities of several types and mixing of several populations of protons with different temperatures, *Antonova, Kovtyukh.*

Results of work

- 4. The LB-distribution of proton fluxes was found

LB-distribution





The protons flux dependence on L,B according the ACTIVE (left) and SAMPEX (right) satellites. The proton flux enhancements are observed at L<1.15 in the left part of figures. The right bottom part is the inner part of radiation belt.

Results of work

- 5. Using the energy spectrum approximation and the LB-distribution the model of proton fluxes was created. The model is freely available via Internet:

  http://cosrad.sinp.msu.ru/cgi-bin/model/main.pl

LEP model input characteristics

$0.98\ R_e < L < 1.15\ R_e$

0.1 Gs < B < 0.5 Gs

~200 km < Altitude < ~1300 km

10 keV < E < 10 MeV

geomagnetic activity level (high or low)

http://cosrad.sinp.msu.ru/cgi-bin/model/main.pl

Web-interface of LEP model

http://cosrad.sinp.../main.pl?lep=true

LEP Model

Orbit

IGRF field

AP8AE8 model

LEP model

Calculate:
Low-energy near-equatorial protons (LEP)
Average energy spectrum

Results:
LEP Model flux file
LEP flux picture | rainbow color | log scale | 0.100
Average spectrum file
Average spectrum picture

Total (AP8/AE8+LEP)

http://cosrad.sinp.msu.ru/cgi-bin/model/main.pl

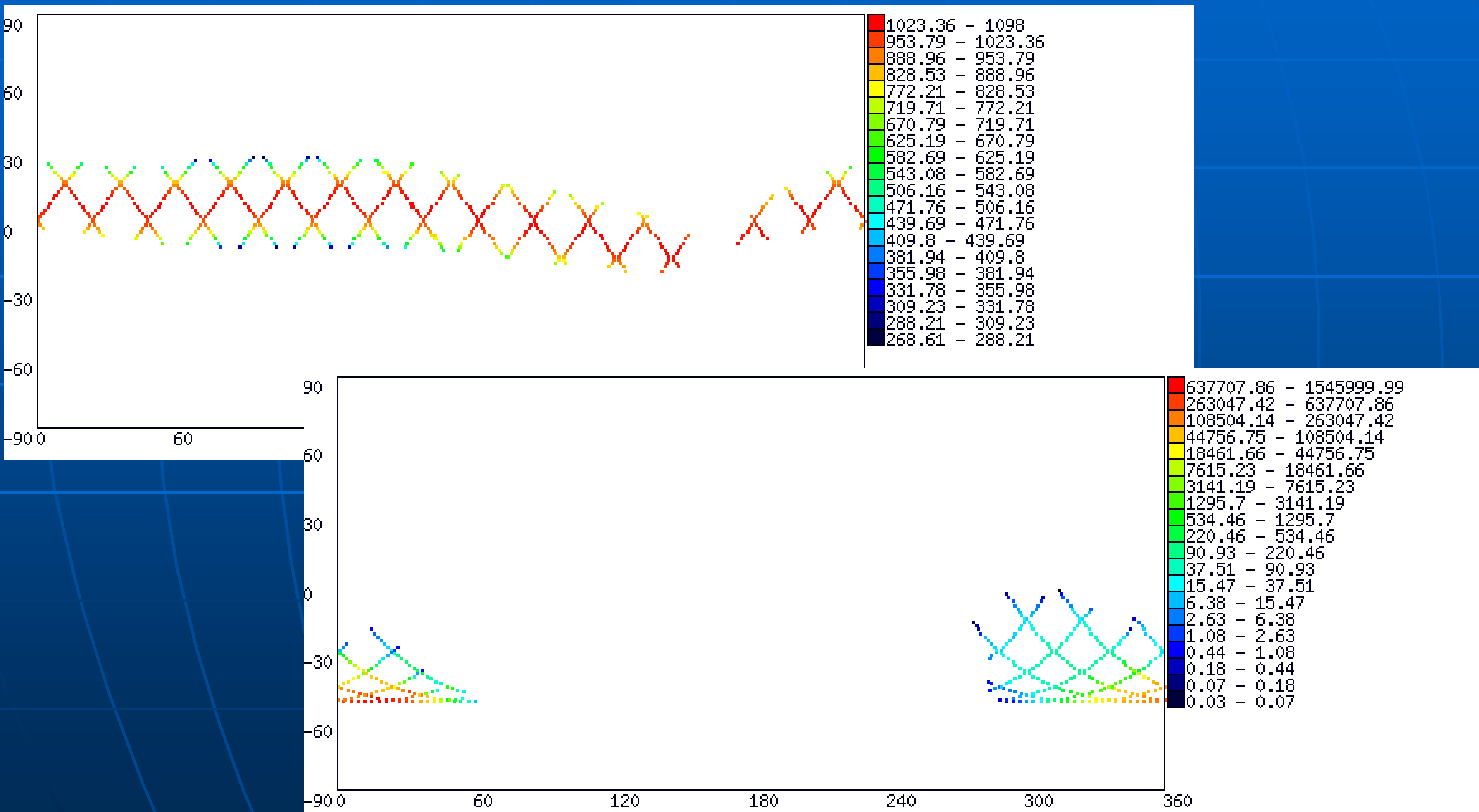
Work scheme of LEP model

- The generation of satellite orbit using start coordinates, inclination, apogee, perigee
- The calculation of magnetic field B/B0 and L using the IGRF model
- The calculation of near-equatorial proton fluxes using the energy, L, B/B0, level of geomagnetic activity (high, low)
- The calculation of protons according AP8 model (optionally)
- The drawing of maps and spectra for comparison

http://cosrad.sinp.msu.ru/cgi-bin/model/main.pl

Results of modelling

Altitude 500 km, 2005 year, Ep>100 keV, AP8MAX + LEP



http://cosrad.sinp.msu.ru/cgi-bin/model/main.pl

Conclusion

- The large database of proton flux enhancements was created
- The program for visualization of satellite experimental data was created.
- The features of proton flux distribution was defined and described
- The empirical model was created. The model is freely available via Internet. The model allows to predict proton fluxes with energies $10\ \text{keV} < E < 10\ \text{MeV}$ for high and low level of geomagnetic activity

Thank you for attention!