Topology of high latitude magnetosphere during large magnetic storms and the main mechanisms of relativistic electron acceleration

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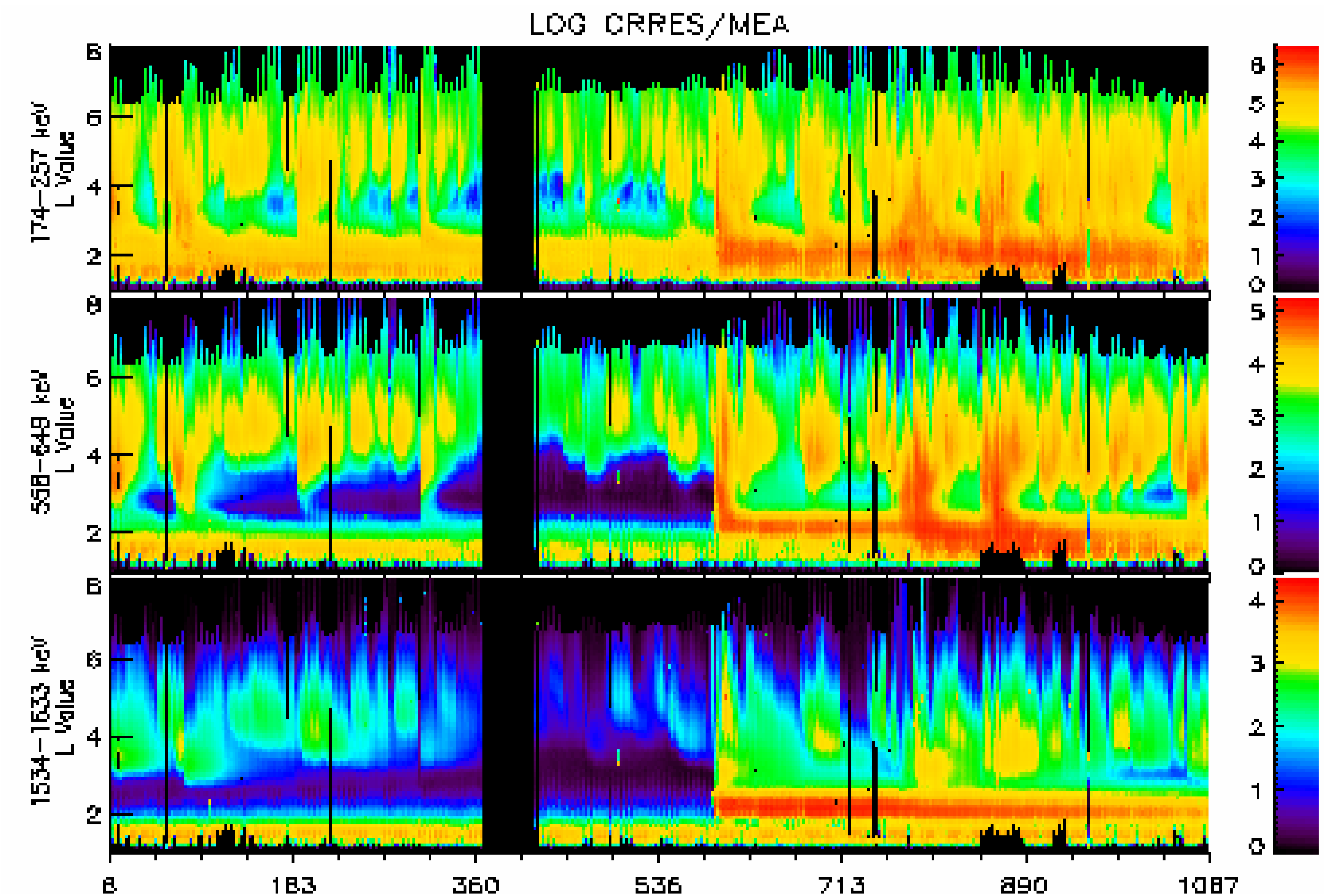
- Problem of acceleration of relativistic electrons in the magnetosphere of the Earth.
- Inner magnetosphere source of relativistic electrons.
- Relativistic electrons and magnetospheric substorms.
- Role of regular and turbulent mechanisms of relativistic electron acceleration.
- Magnetospheric topology and magnetic storms.

Position of the source of acceleration of relativistic electrons inside the magnetosphere

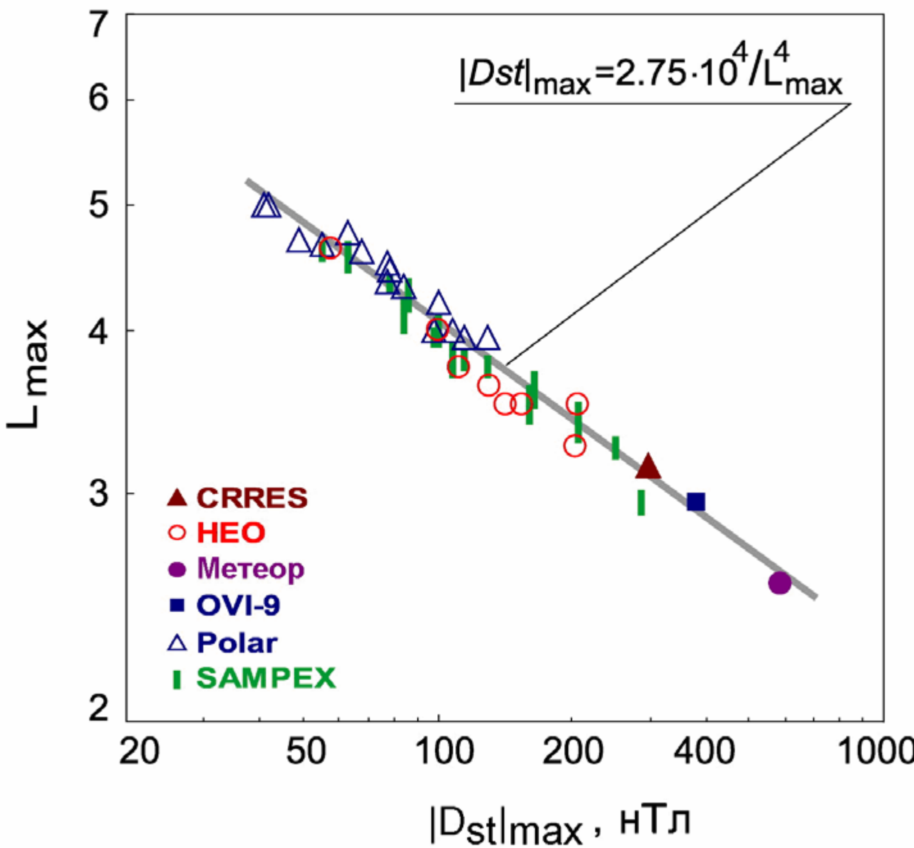


July 1990 Orbit Number **Oct 1991**

Li and Temerin, Space Sci. Rev. 2001

Relativistic electrons as a rule appear during recovery phase of magnetic storm. The localization of the place of there appearance is connected with the maximum value of Dst variation by relation of Tverskaya (1986), Tverskaya et al. (2003).

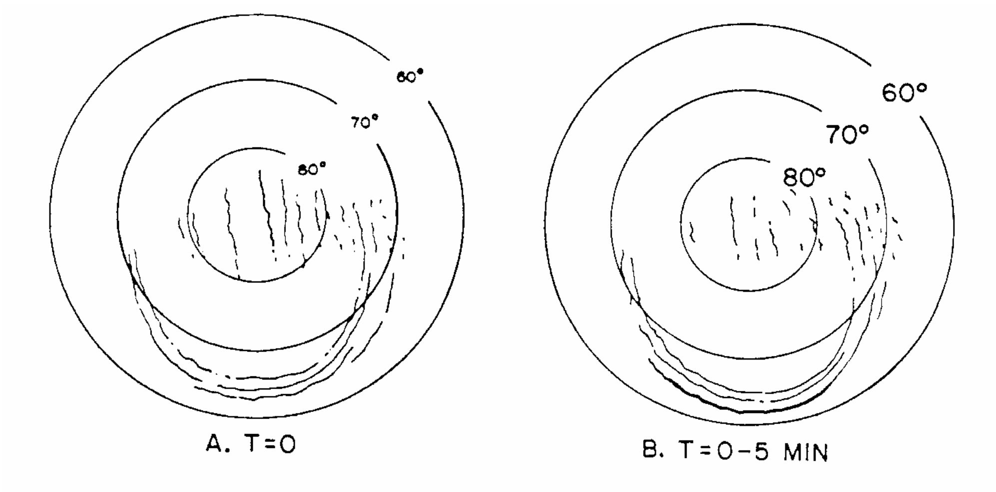
Sometimes it is possible to observe the increase of relativistic electrons at low L without increase at geostationary satellites (Tverskaya et al., 2005).



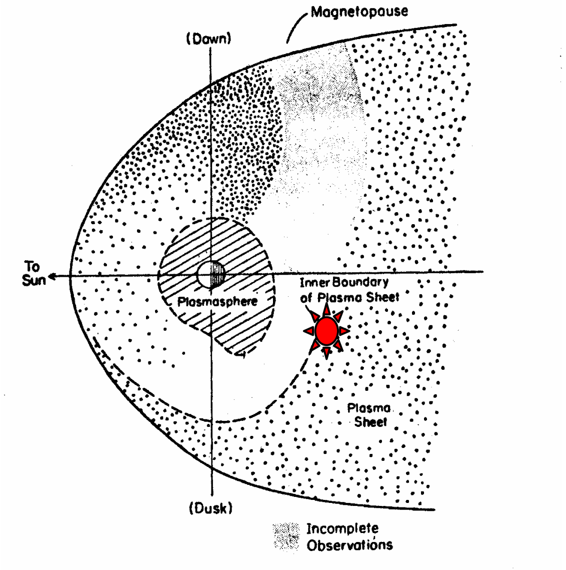
Appearance of relativistic electrons is deeply connect with **magnetospheric substorms** at the time of magnetic storms. Substorms produce the “seed” population of electrons with energies ~100-200 keV which later is accelerated till MeV energies. Strong substorms can accelerate electrons till relativistic energies (Ingraham et al., 2001). However ordinary substorms can not be considered as powerful souse of relativistic electrons. High and long lasting substorm activity on a storm recovery phase and high velocity of the solar wind are the necessary condition of the highest electron output.

Substorm as the inner magnetosphere phenomena

Akasofu (1964) effect – first auroral arc brightening on the equatorial boundary of the auroral oval



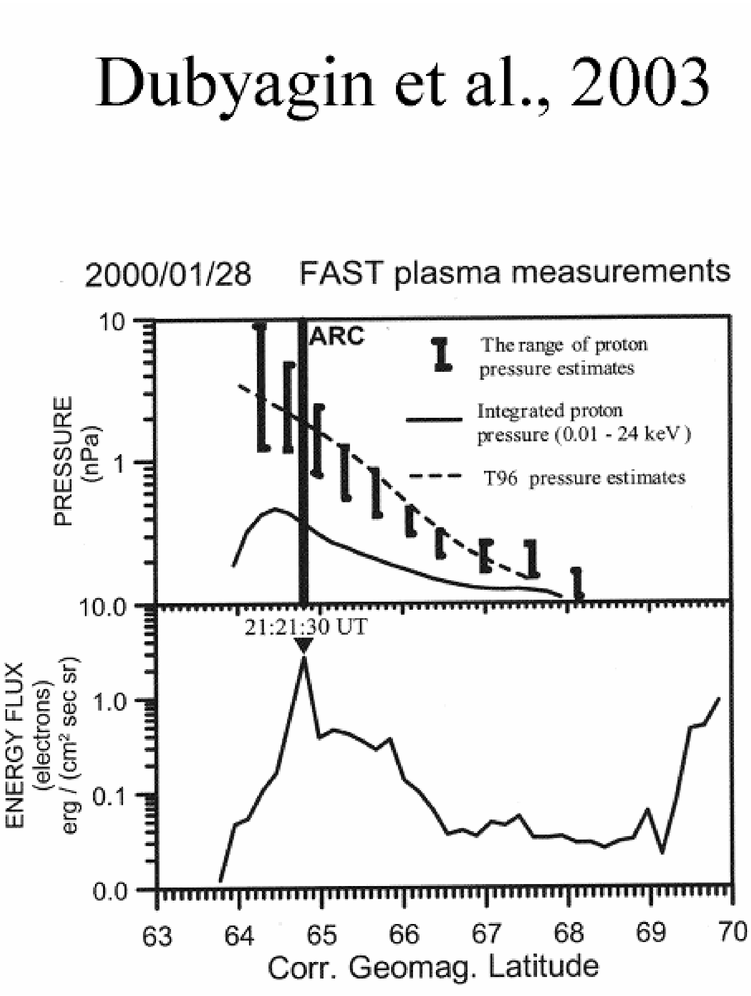
Akasofu (1964)

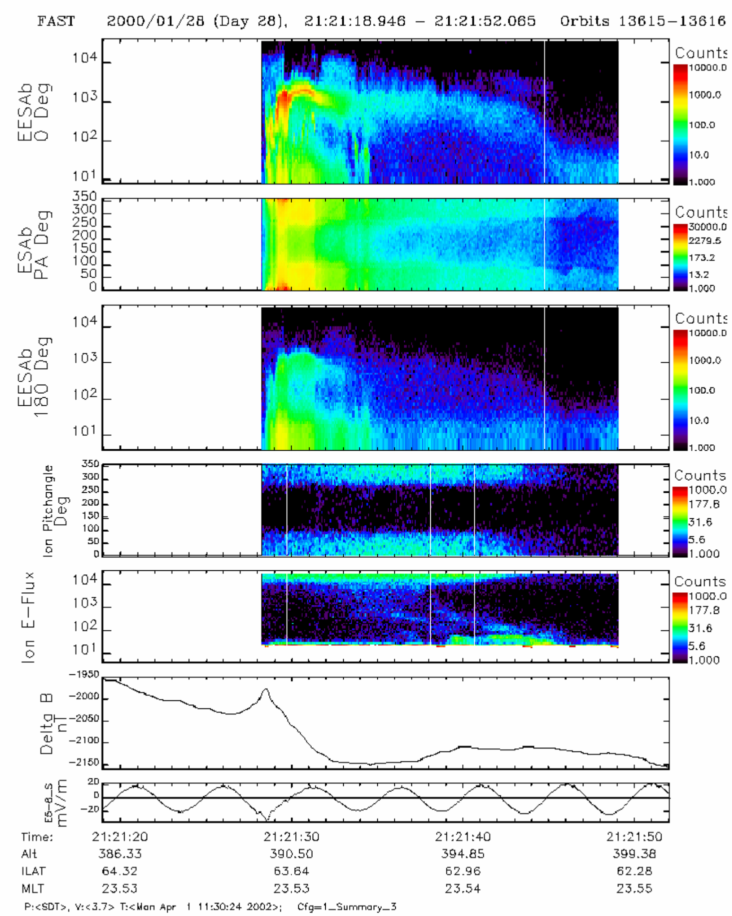


Vasyliunas, 1968

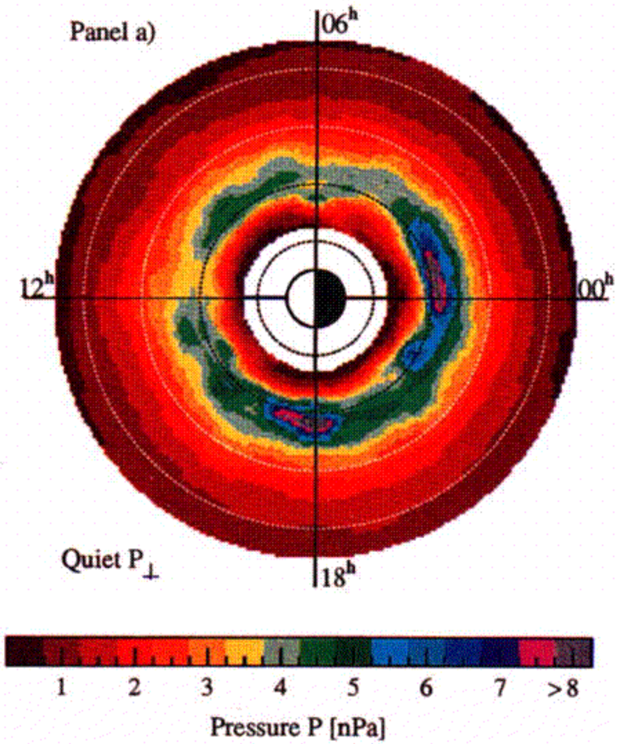
Inner magnetospheric location of substorm onset can be clear even at the end of 60-th. Investigations of dispersionless injections near the geostationary orbit demonstrated the action of acceleration mechanisms inside the magnetosphere. We have now multiple supports of these early findings (see revives of Akasofu, Ohtani, Meng and Liou, Lui, *Space Science Reviews*, **113**, 2004).

Most clear support of the concept of the inner magnetosphere substorm onset was obtained by Dubyagin et al. (2003) using data of fast measurements. Results of particle observations coincide with the predictions of substorm theory developed by Antonova (2002), Stepanova et al. (2002).

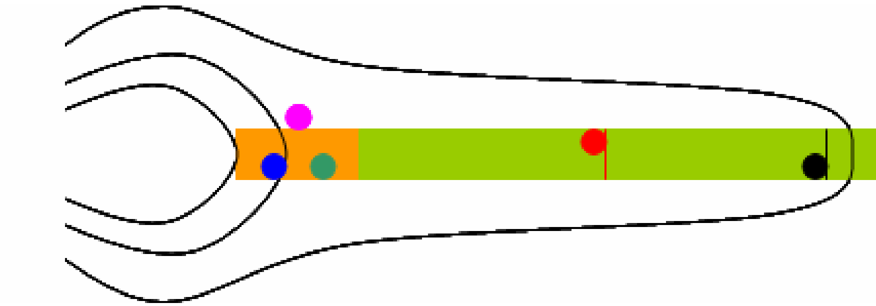


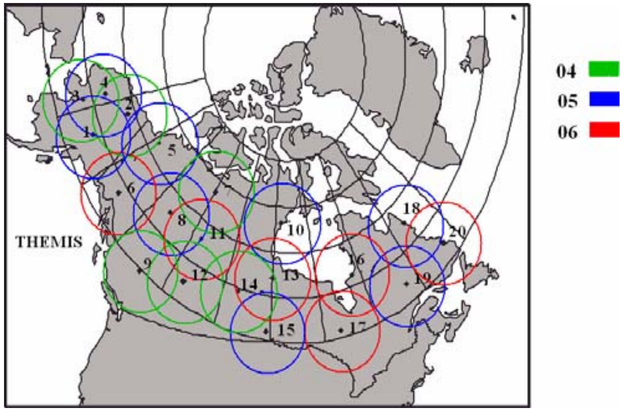


Global picture of plasma pressure distribution also shows the existence of particle acceleration region near the geostationary orbit.



DeMichelis et al. (1998)





Realization of Themis (launched 15 February 2007, Kennedy SC, Cape Canaveral , ~06h AST) program will clarify the situation.

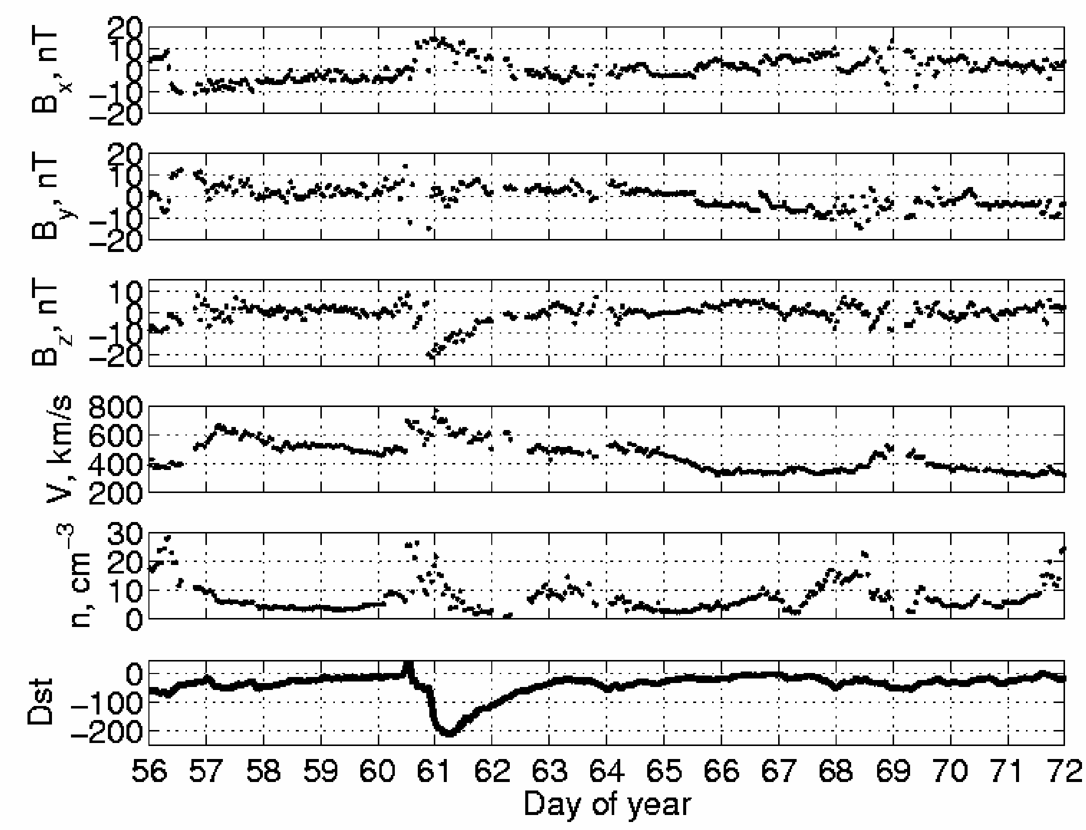
Two main approaches of the solution of the problem of acceleration of relativistic electrons:

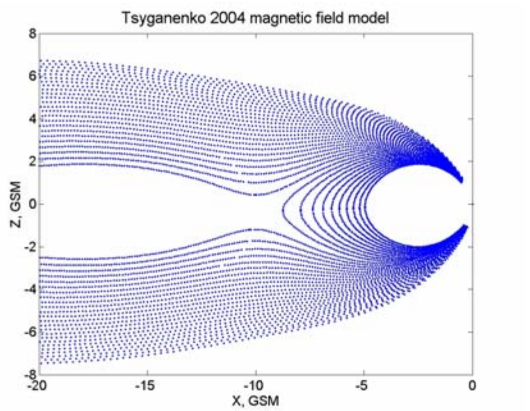
Stochastic acceleration by fluctuating electric fields.

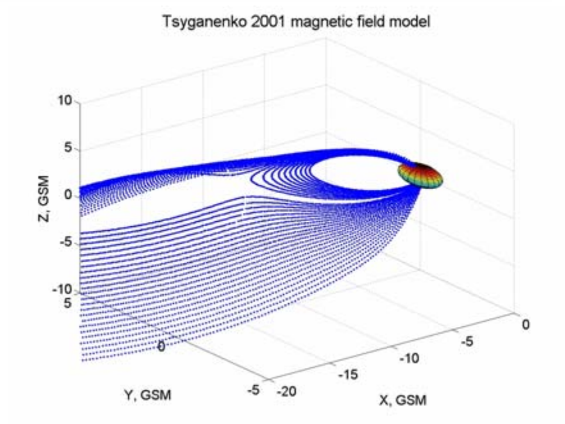
Injection of seed" population in the region of depressed magnetic field inside the magnetosphere and regular betatron acceleration due to magnetic field increase during storm time recovery phase.

Stochastic mechanisms of acceleration are most popular now. Interactions with ULF (Fujimoto and Nishida, 1990; Liu et al., 1999; Hudson et al., 1999; Elkington et al., 1999; Liu et al., 1999$ Summers and Ma, 2000; Dmitriev et al., 2001; Bahareva and Dmitriev, 2002; Kozyreva et al., 2007 ets.) and whisther mode waves (Horne and Thorne, 1998; Summers et al., 1998, 2002, 2004; Summers and Ma, 2000; Horne et al., 2005; Varotsou et al., 2005; Demihov et al., 2006; Summers et al., 2007; Thorne et al., 2007 ets.), AKR ets. are analyzed. However the **effectiveness of stochastic mechanisms can be clarified only excluding action of regular mechanism**.

Results of the restore of magnetic configuration during great magnetic storm 1-5 March 1982 using Tsyganenko-2004 model







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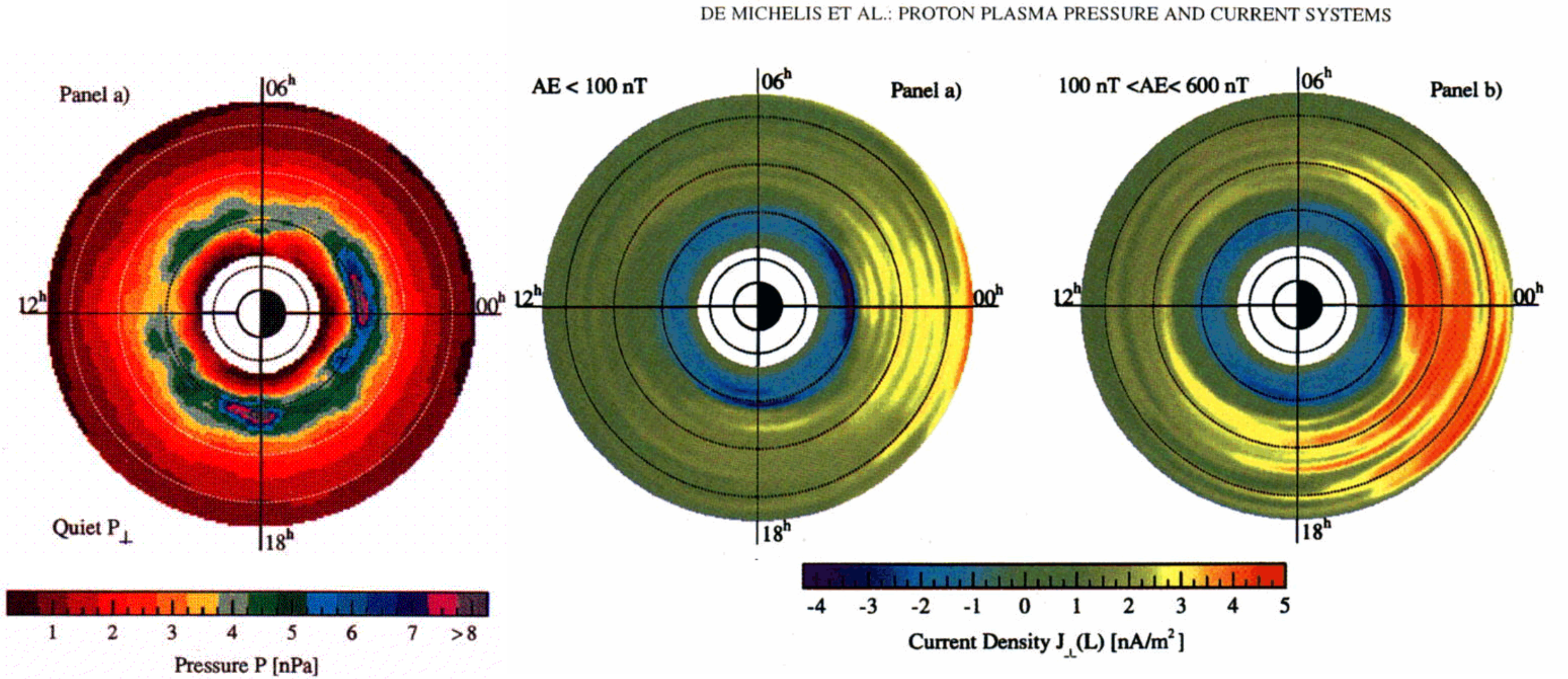
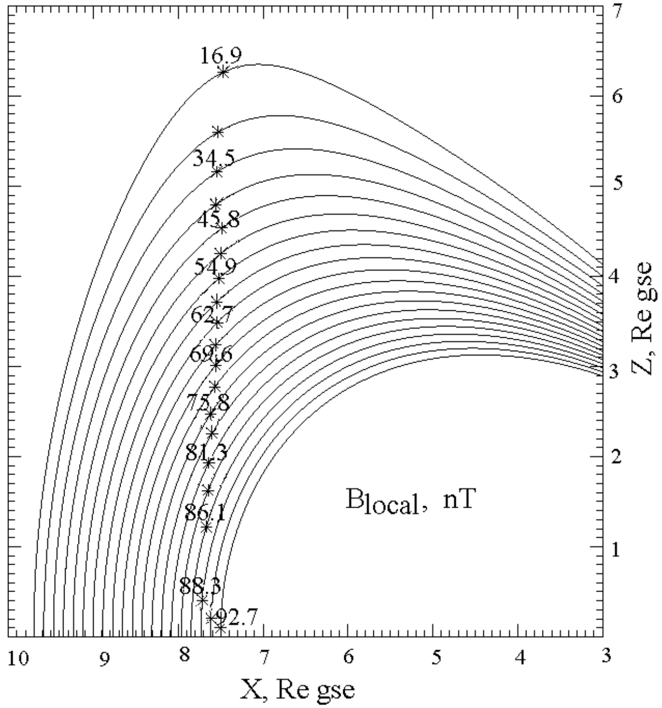
Existing magnetic field models unfortunately can not give the proper magnetic field description during great geomagnetic storms as not all current systems are taken into account.



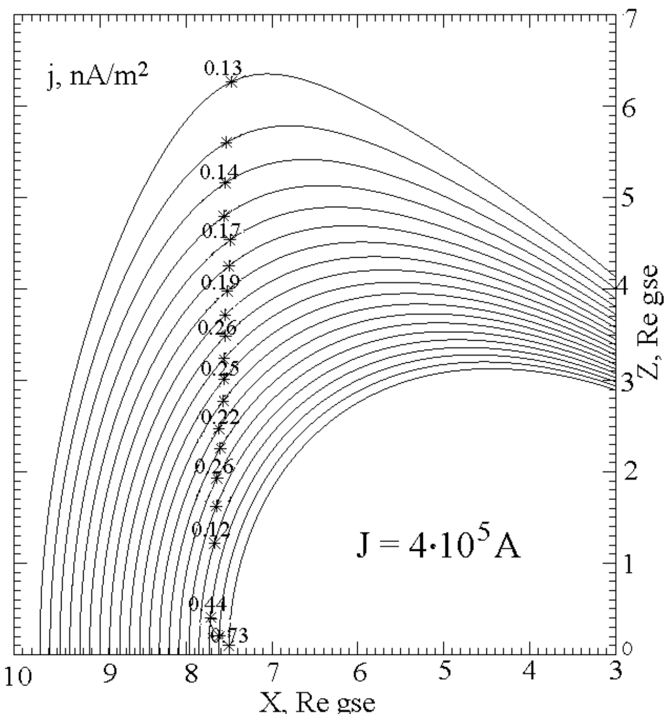
The condition of magnetostatic equilibrium when plasma pressure is near to isotropic has the form:

$$[\mathbf{jB}] = \nabla p$$

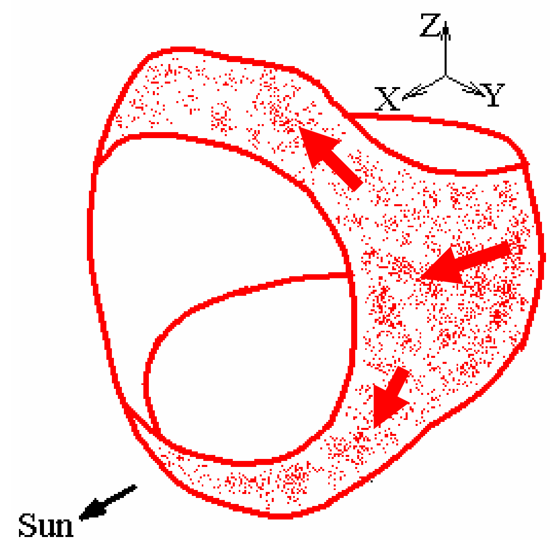
It is possible to determine current density using measure plasma pressure gradient and magnetic field as was done by DeMichelis et al. (1998). Obtained picture does not take into account the daytime magnetic field configuration.



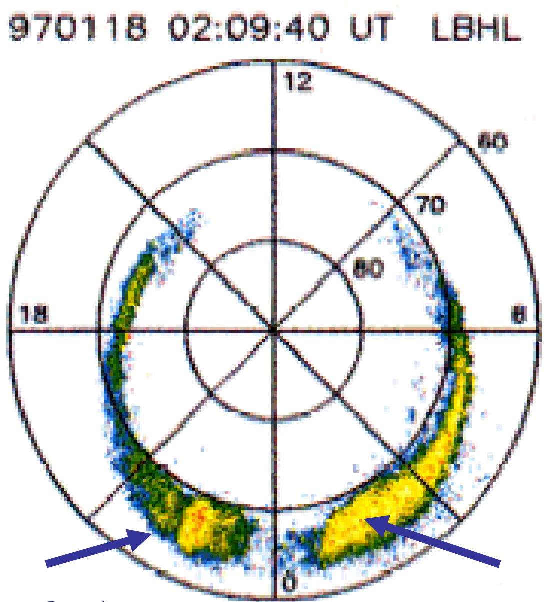
Results of the calculation of current densities on dayside auroral field lines leads to values comparable with nighttime current densities at the same geocentric distances. Integral current between 7.5 and 9.7 R_E constitute ~10^5-10^6 A.



Considerable part of nighttime transverse current can be closed inside the magnetosphere. Ordinary ring current (RC) has a high latitude continuation CRC. Most part of auroral oval is the result of CRC region mapping on ionospheric altitudes.



Chua et al. (1998)



5.0 erg/cm^{2}s^{-1}

6.7 erg/cm^{2}s^{-1}

1.5 erg/cm^{2}s^{-1}

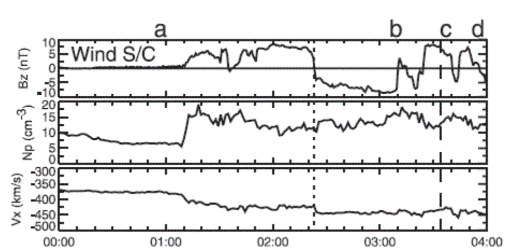
Maximal energy flux if field-aligned potential drop = 0 (Antonova, 1979)

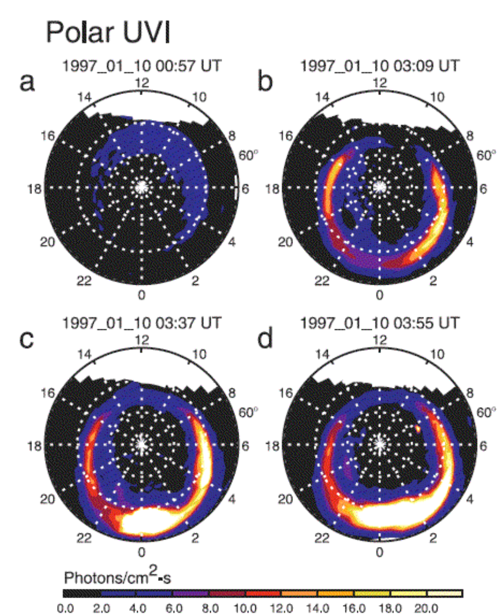
$$\varepsilon^{*} = n_e^{0} T_e^{3/2} 2^{1/2} / \left(\pi m_e\right)^{1/2} = 0.6\,\mathrm{erg/cm^2 s}$$

$$\text{if } n = 1\,\mathrm{cm^{-3}},\ T_e = 0.5\,\mathrm{keV}$$

$$\varepsilon = 0.5\varepsilon^{*}\left[1 + \left(1 + e\delta\Phi / T_e\right)^2\right]$$

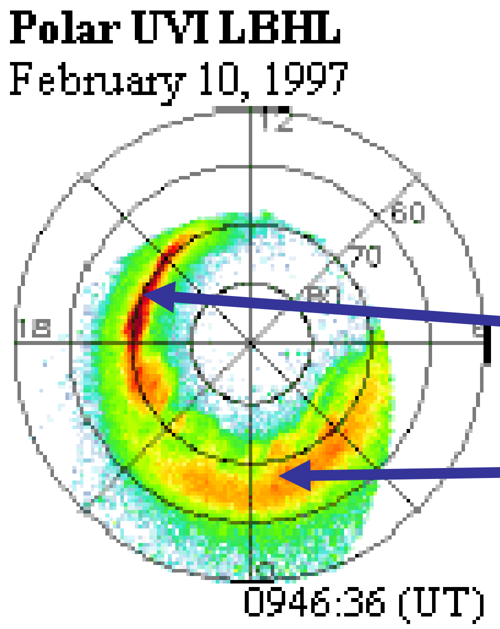
Shue et al., GRL (2002)



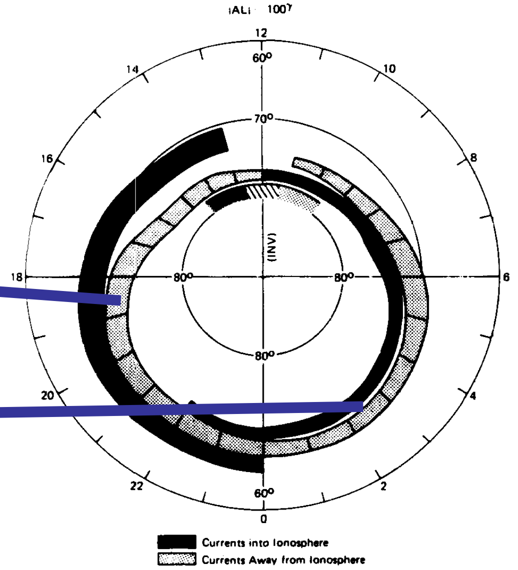


Picture of upward field-aligned currents can be observed using data of auroral oval observations.

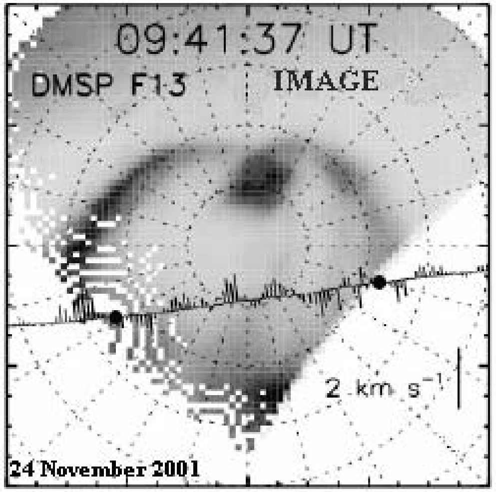
Quite time UVI images show upward field-aligned current distribution



Iijima and Potemra (1996)



Sometimes it is possible to observe cusp as separate entity (Milan et al., 2006)



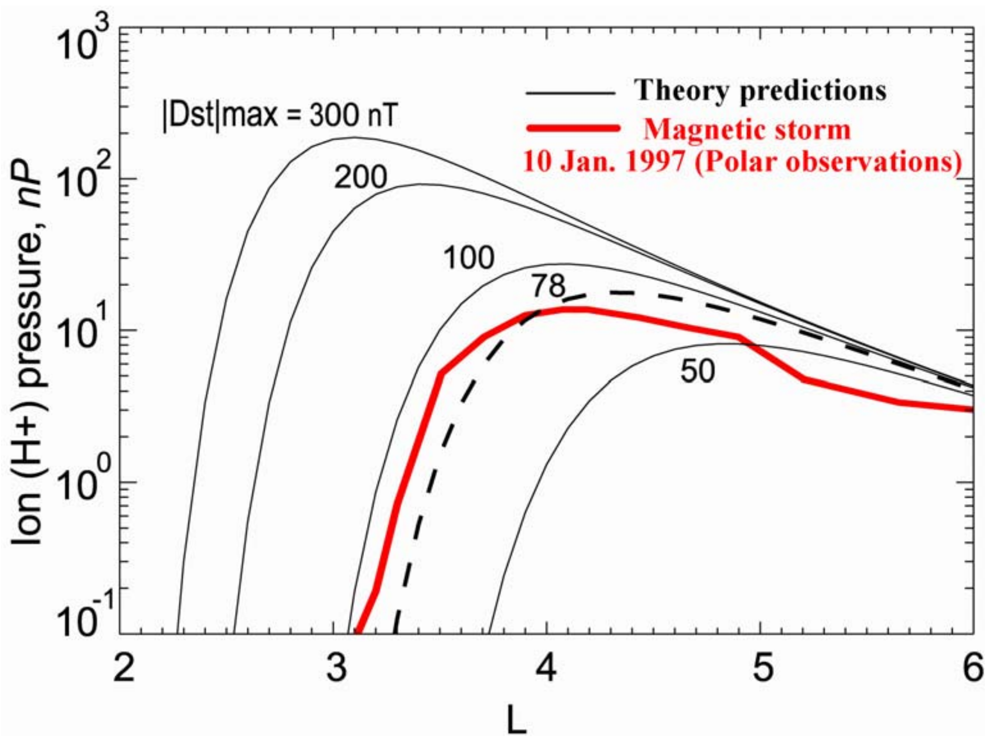
The dependence $\left| D_{st} \right|_{\max} = 2.75 \cdot 10^{4} L_{\max}^{-4}$ nTl

obtains the theoretical explanation (see Tverskoy, 1997) including the value of coefficient (Antonova, 2005) in azimuthally symmetric case:

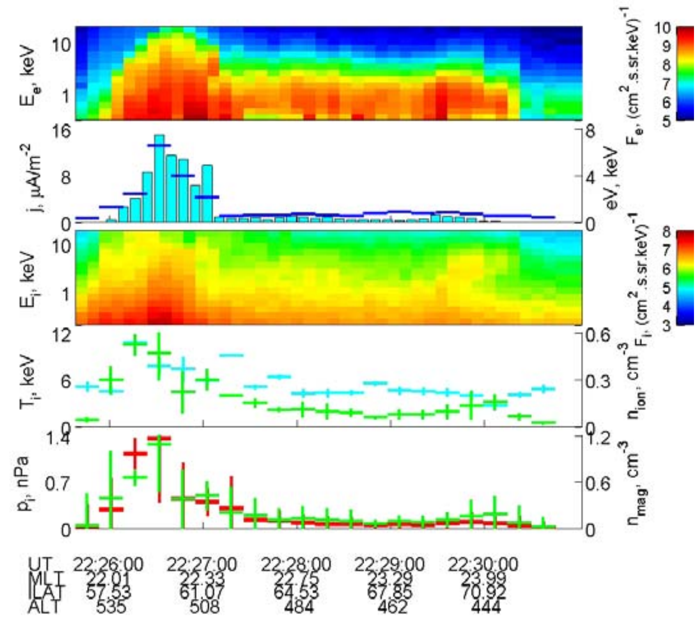
$$\left| D_{st}^{*crit} \right| = \frac{27}{70} \frac{\mu_0}{B_{eq}} p_{ex} L_{ex}^{7} L_{in}^{-4} = \frac{27}{140} \frac{B_{lobe}^{2}}{B_{eq}} L_{ex}^{7} L_{in}^{-4} \text{ nTl}$$

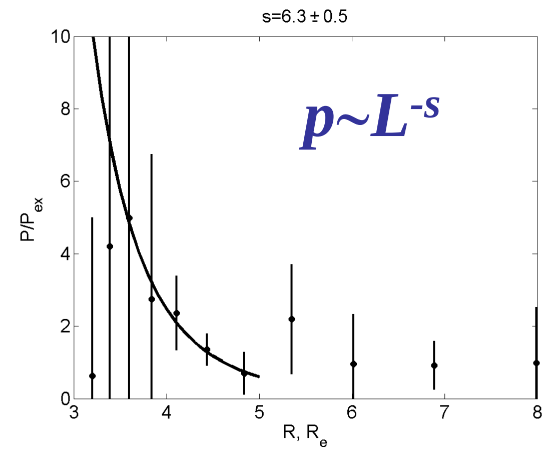
It was taken into account that upper limit of the inner magnetospheric particle feeling is determined by the stability of the distribution of the plasma pressure. This limit exists in spite of the action of different acceleration and transport mechanisms of plasma particles.

Comparison of theory predictions with the results of experimental observations



Tverskaya et al. (2005)

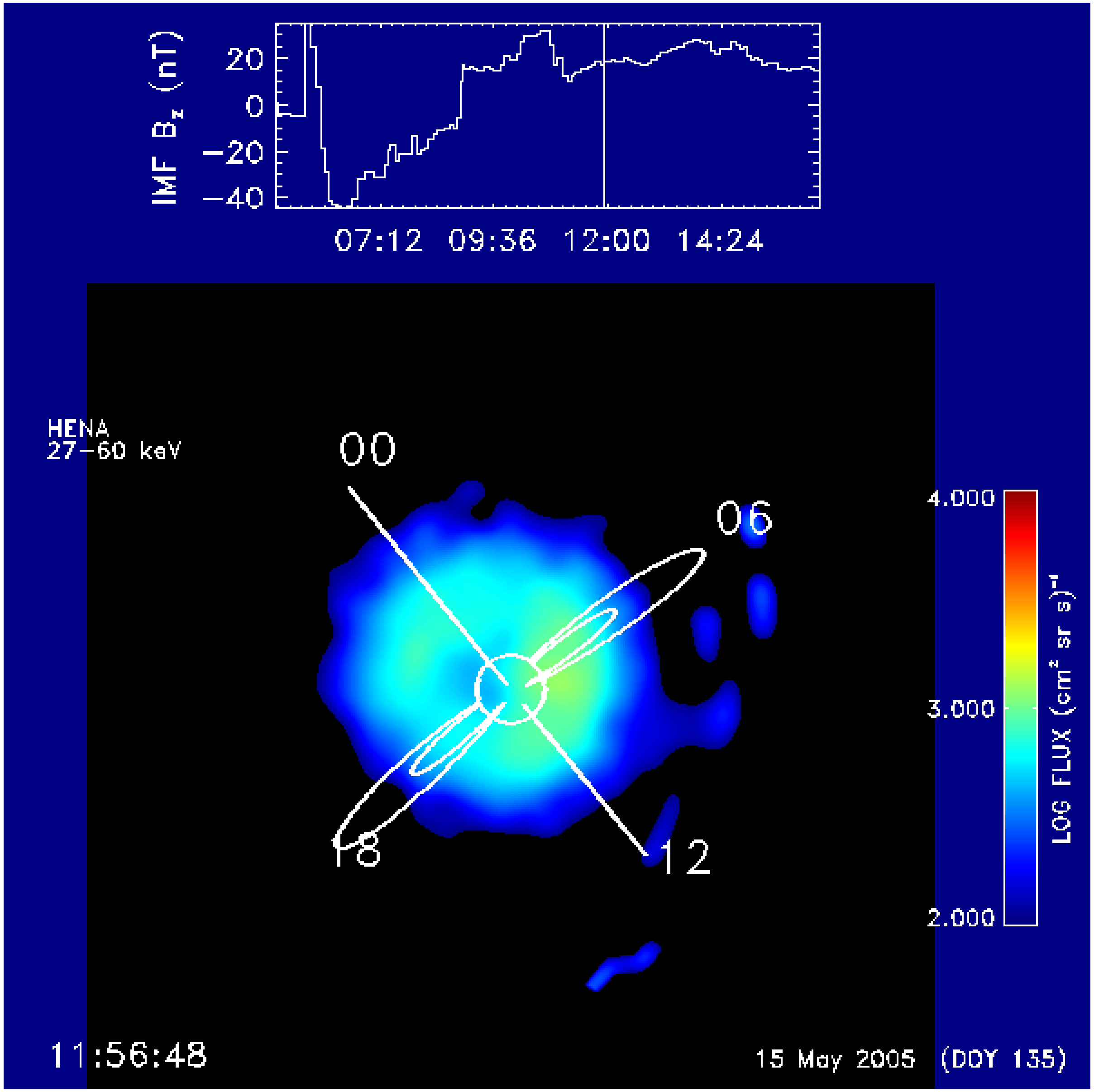




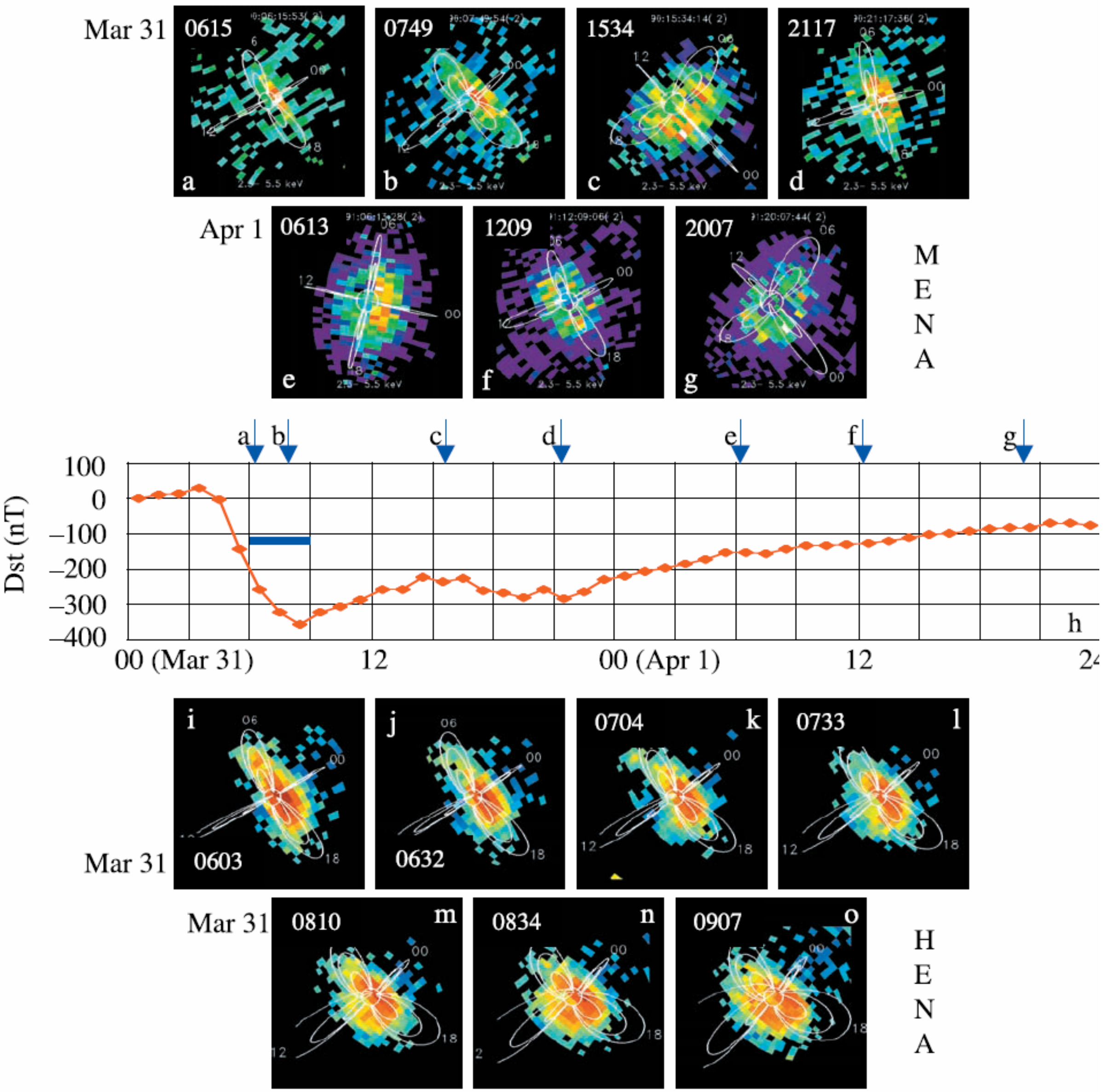
Antonova and Stepanova (2005)

However symmetric ring current does not produce great magnetic field distortion and plasma parameter β<1. An order of magnitude larger with β>1 magnetic field distortions are connected with asymmetric ring current

Ring current Dynamics for the magnetic storm 15 May, 2005



Brandt and Mitchell, 2006



Skoug et al., 2003

Magnetic storm 31 March 2001

$(D_{st})_{min}$ = -350nT

At the geostationary orbit $B_z \sim 0$, B~300 nT

The restore of magnetic field during storm recovery phase can produce considerable betatron acceleration.

Conclusions:

•The solution of the problem of acceleration of relativistic electrons requires proper models of magnetic field taking into account the distribution of plasma pressure inside the magnetosphere.

•Substorm expansion phase onset begins on the quasidipole magnetic field lines and has the inner magnetospheric nature.

•Dayside part of inner magnetosphere transverse currents flow at high latitudes. Such currents are closed inside the magnetosphere by nighttime transverse currents and constitute the high latitude continuation of ordinary ring current.

•The development of asymmetric ring current produce magnetic field distortion with $\beta > 1$. Ring current symmetrization leads to restore of magnetic configuration and particle acceleration.

•Regular and stochastic acceleration mechanisms can produce definite contribution in the acceleration of relativistic electrons. The contribution of stochastic mechanisms can be obtained only after extraction of the contribution of regular mechanisms.

Thank you for your attention