Formation of the "Seed" Population of 1-10 keV Electrons in the Outer Van Allen Radiation Belt by Time Domain Electric Field Bursts

Agapitov, Oleksiy (1,2); Forrest Mozer (1); Anton Artemyev (3); Vladimir Krasnoselskikh (4); and Solene Lejosne (1).

(1) Space Sciences Laboratory, University of California, Berkeley, CA, USA
(2) Taras Shevchenko National University of Kyiv, Astronomy and Space Physics Dept., Kyiv, Ukraine
(3) Space Research Institute, Moscow, Russia
(4) LPC2E, CNRS - University of Orleans, Orleans, France

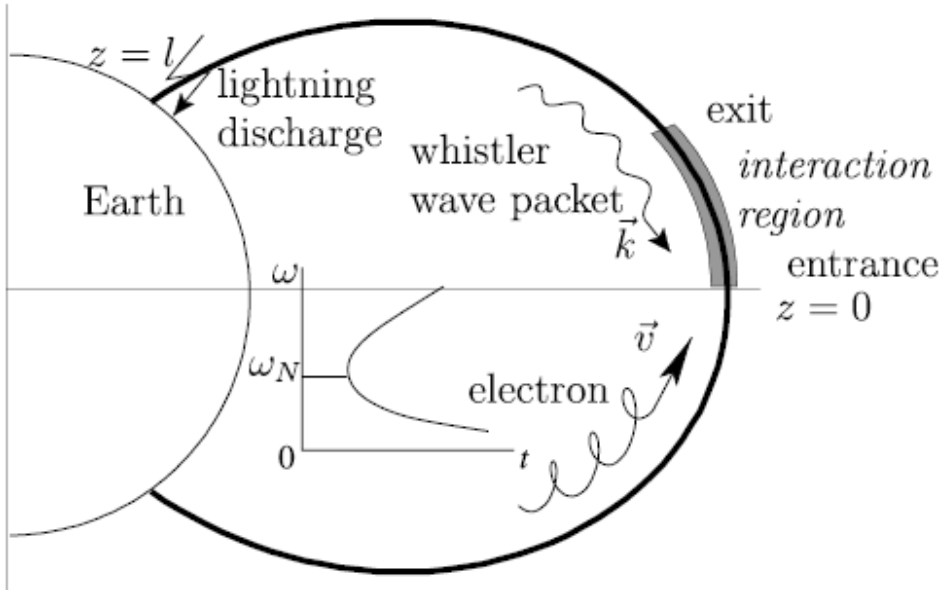
agapitov@ssl.berkeley.edu

November 4, 2014, Portland, OR, LWS meeting

Outline

- **Non-linear wave-particle interaction with whistler waves**
- **Oblique whistlers (OW)**
- **Time Domain Electric Field Bursts (TDS)**
  - TDS properties in the outer radiation belt
  - Model of particles interaction with “electrostatic” TDS
- **Seed population for acceleration by whistler waves from TDS**

Trapping and acceleration by parallel waves

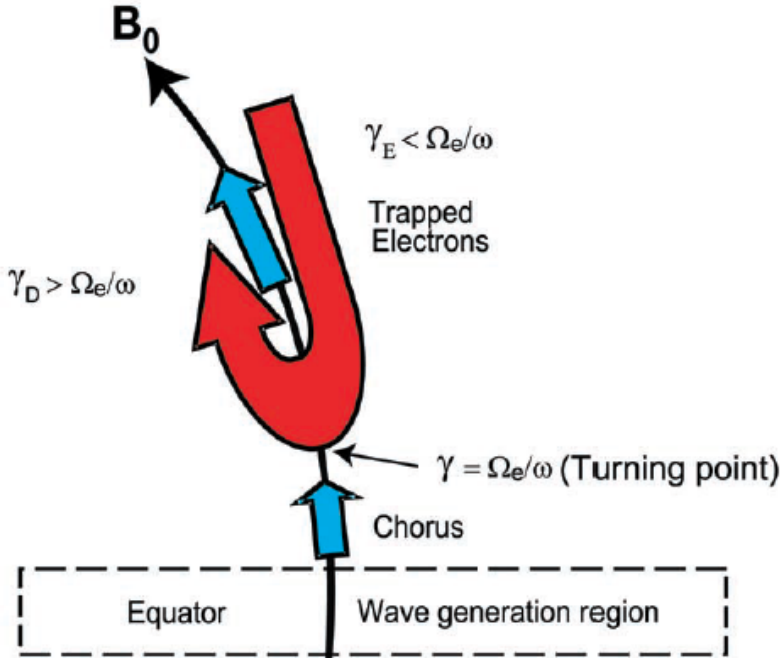


Cyclotron acceleration by whistlers,
V. Y. Trakhtengerts et al. 2003

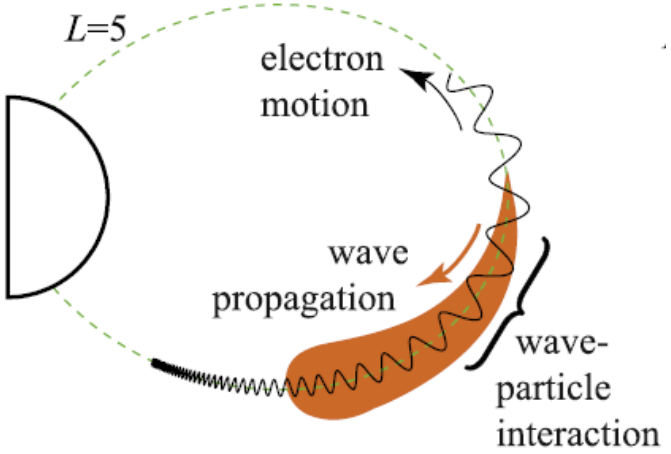
$$\omega - k_{\parallel} v_{\parallel} = n\omega_c/\gamma,$$

Resonant condition

RELATIVISTIC TURNING ACCELERATION



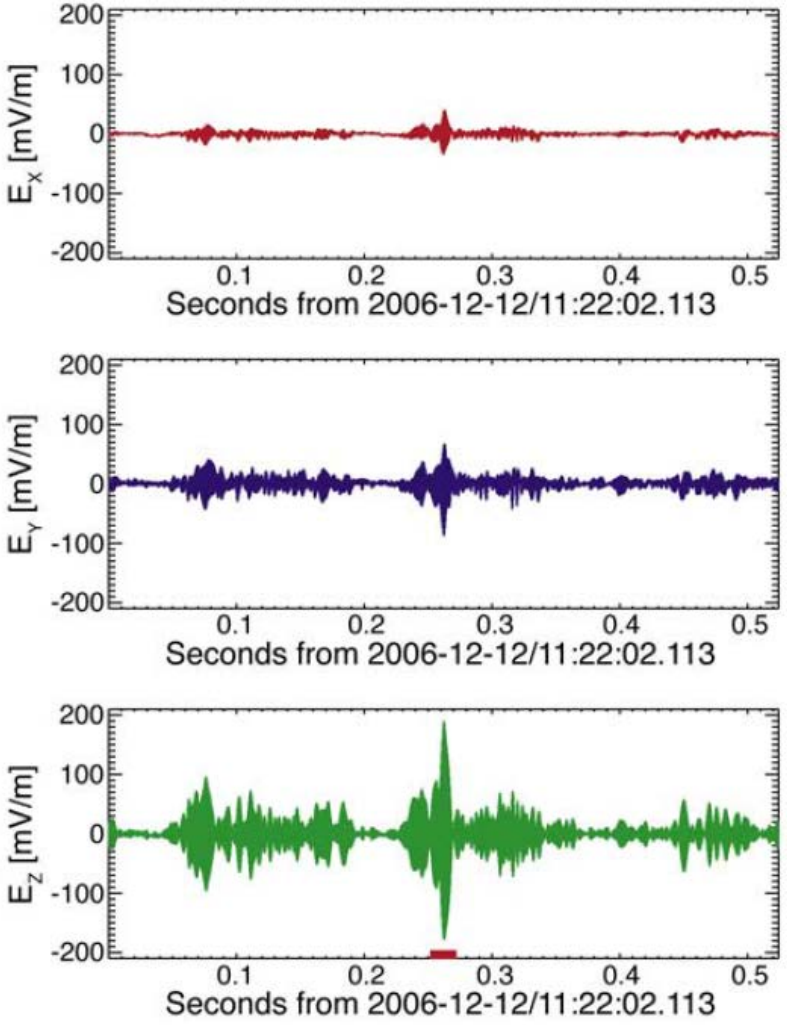
Relativistic turning acceleration….
Y. Omura, et al. 2007

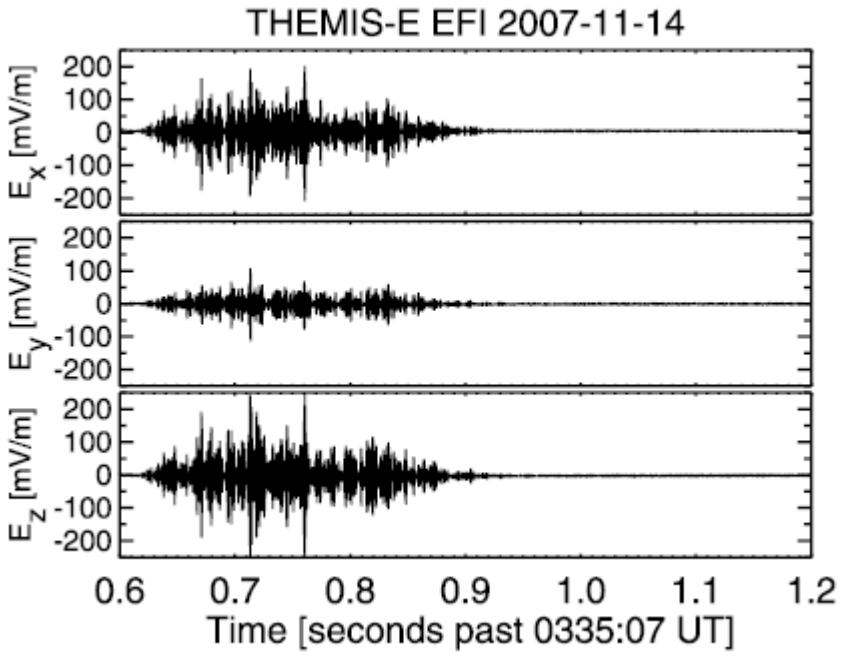


Nonlinear interaction of energetic electrons
with large amplitude chorus
J. Bortnik et al. 2008

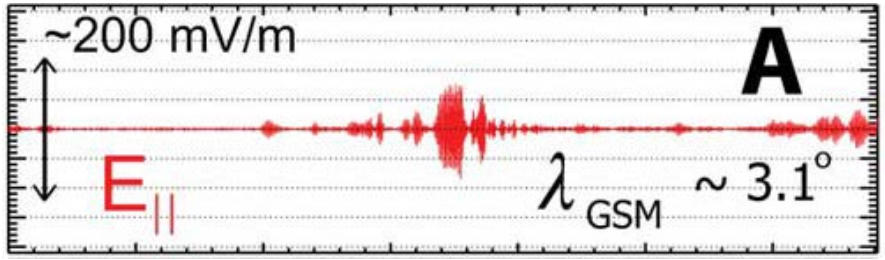
Time Domain Structures

Cattel et al. 2008 GRL



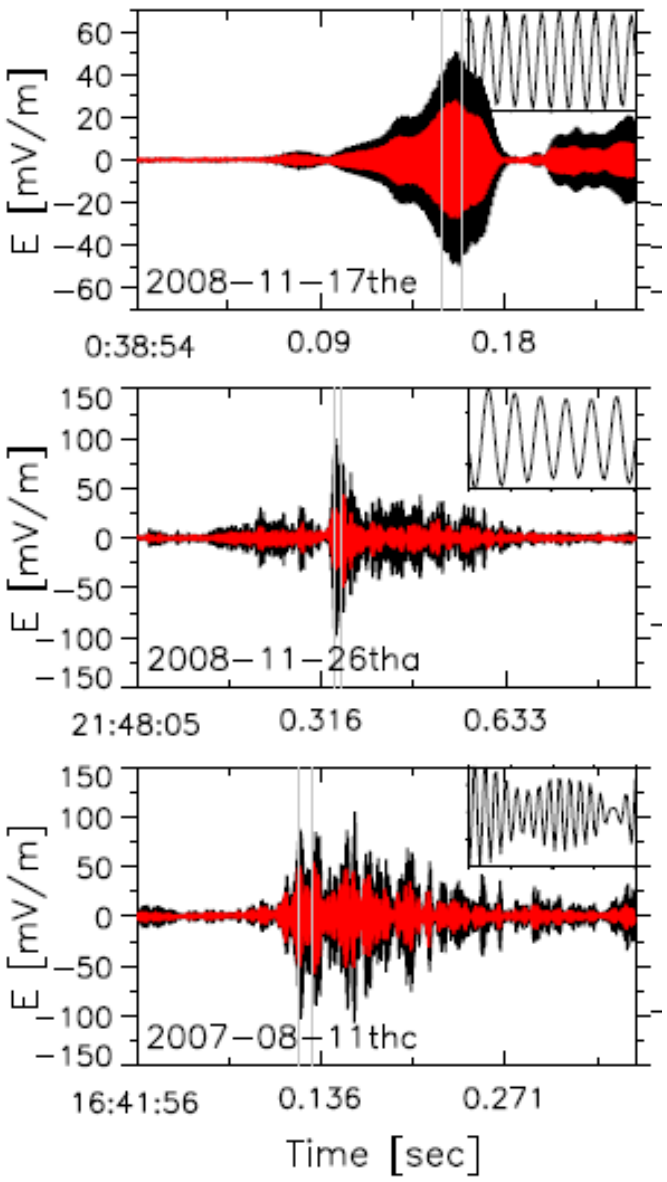


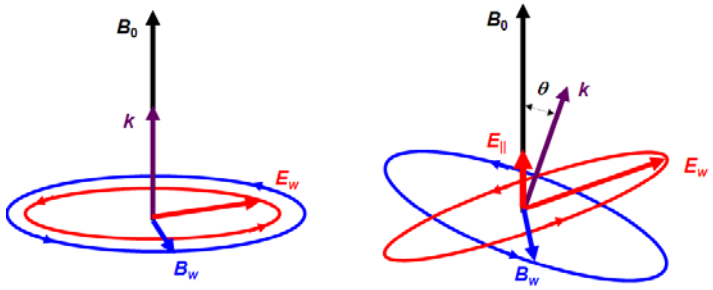
Cully et al. 2008 GRL

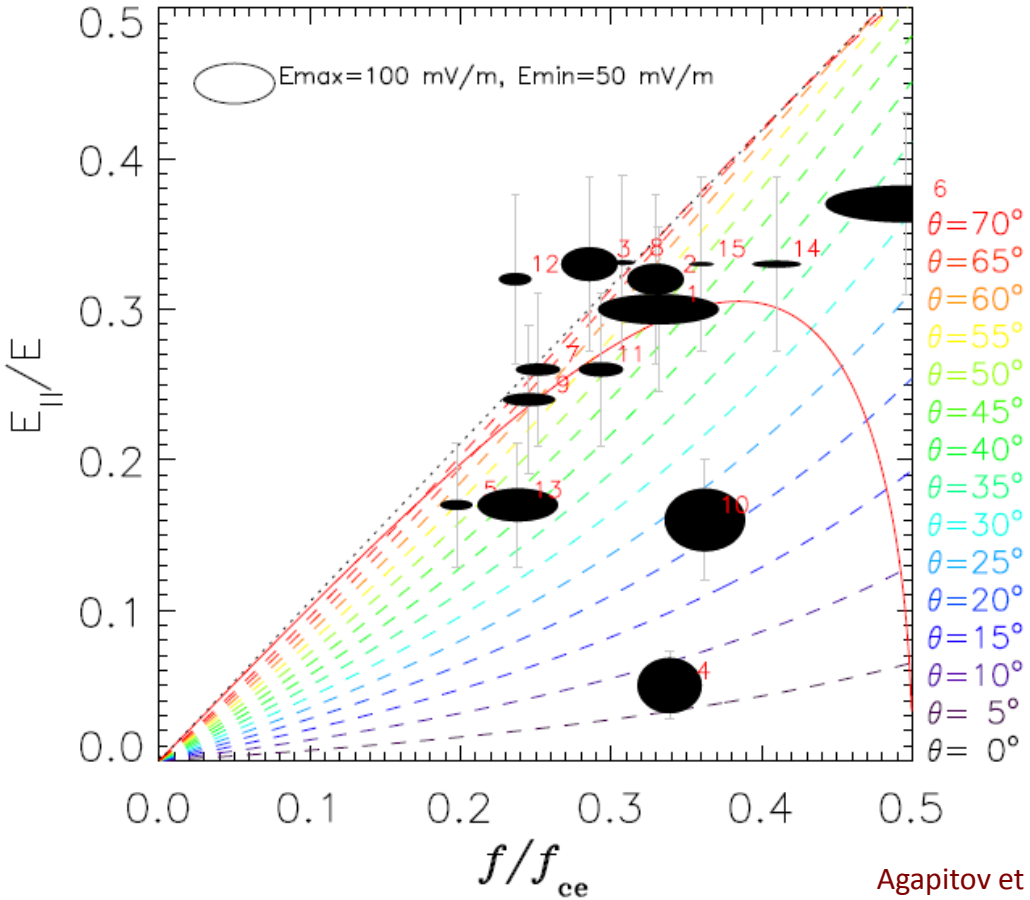


Wilson et al. 2011 GRL

Time Domain Structures



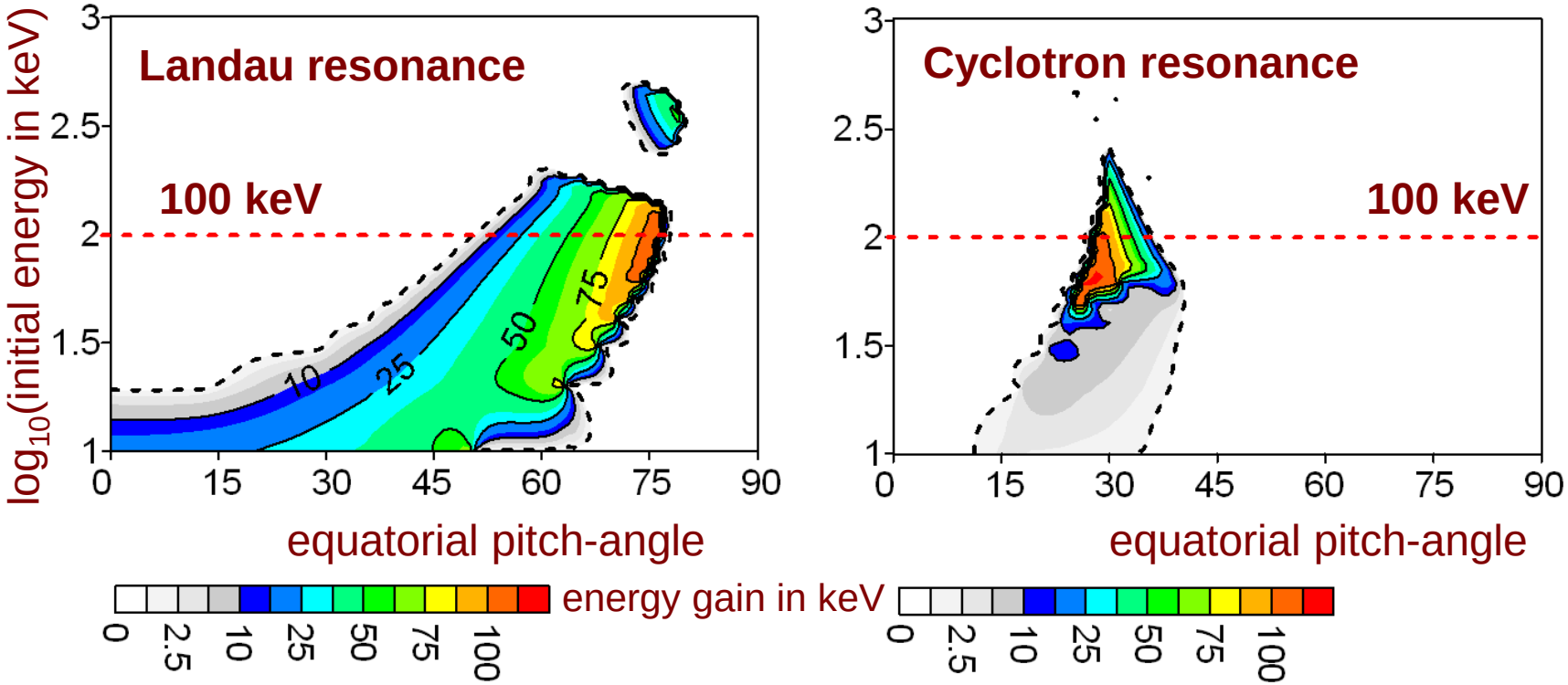




Agapitov et al. JGR2014

Comparison of the energy gains (L=4.5, $E_{0||}$=100 mV/m)

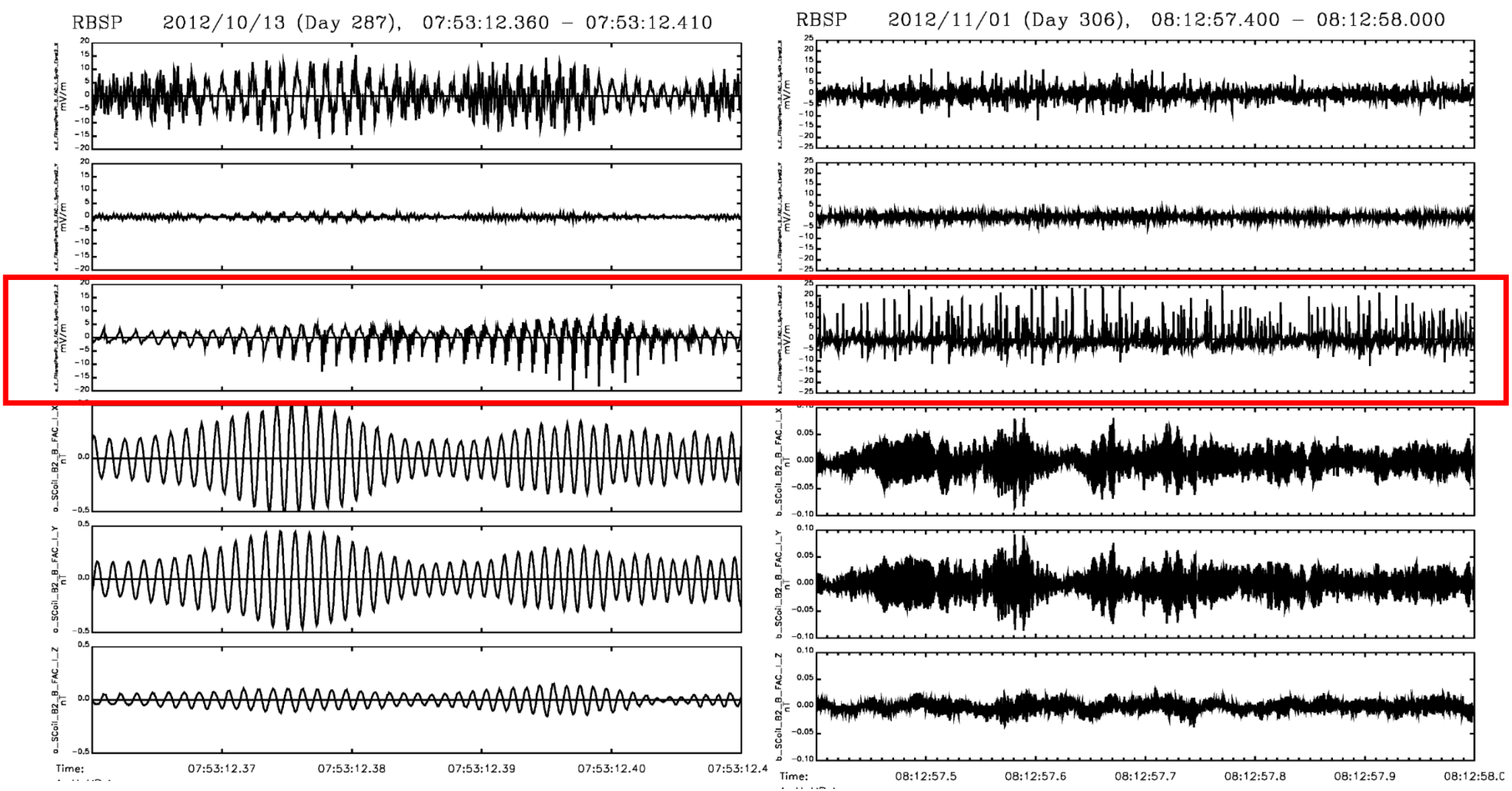
Energy gain for a single trapping (time scale of such trapping is less than 1/4 of bounce period) is shown for two resonances as function of initial energy (vertical axis) and initial equatorial pitch-angle (horizontal axis). **Particles with initial ~100 keV are indicated by horizontal red lines.**



Parallel electric field in oblique whistler waves makes possible wave-particle interaction throuth the Landau resonance that provides

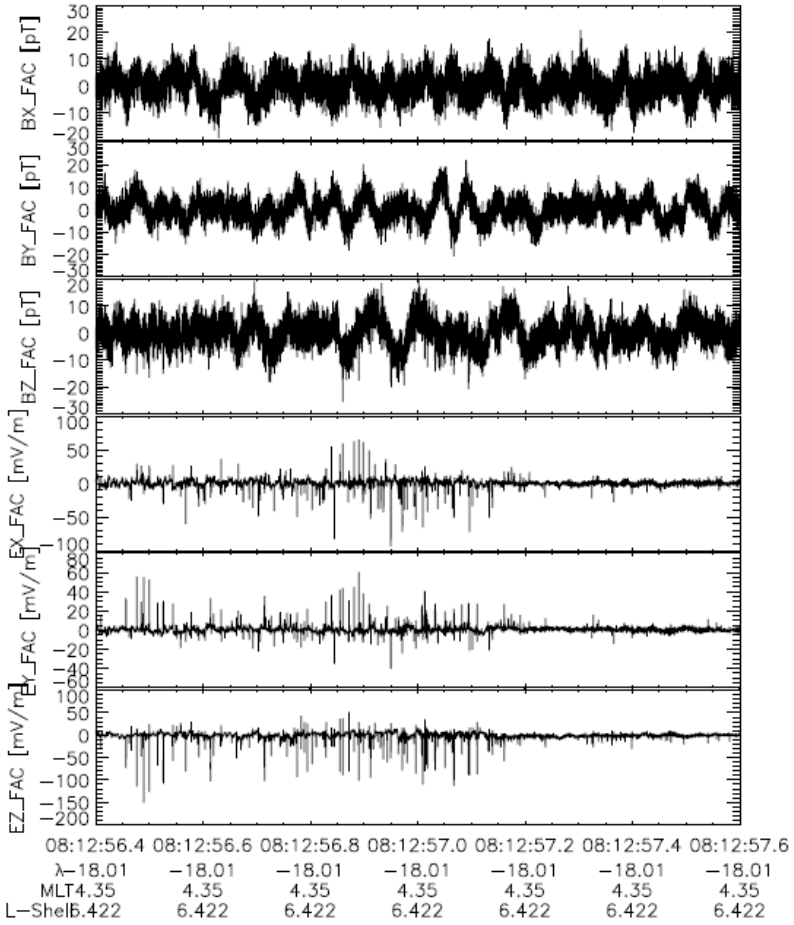
1. Decrease of trapping energy threshold (<10 keV)
2. **Possible non-linear effects for wave field (mainly parallel electric field component)**

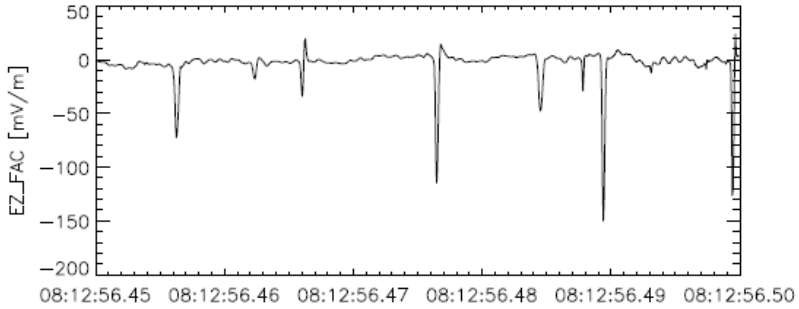
Time Domain Structures

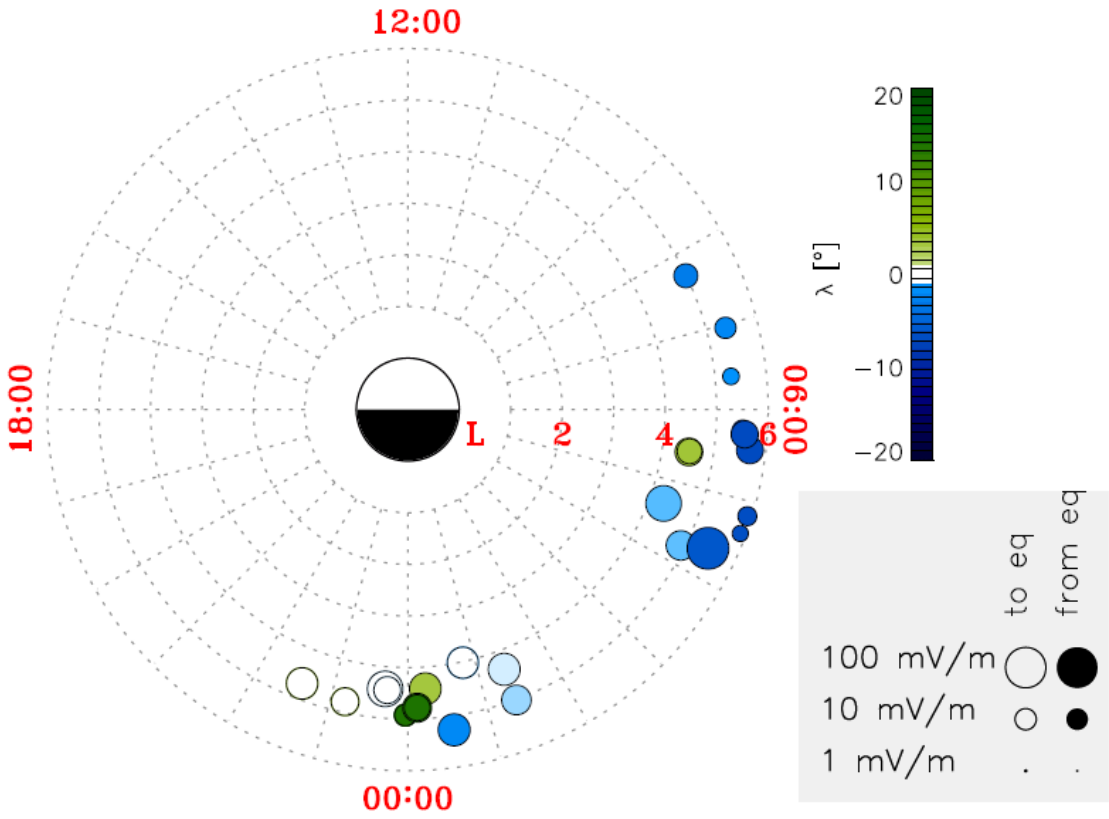


Three components of electric and magnetic field perturbation captures aboard Van Allen probes. The electric field component parallel to the background magnetic field is marked by red

“Electrostatic” Time Domain Structures







Electrostatic double layers can be “positive” or “negative”.

$V_{||}$ ~ 2000-10 000 km/sec

Potential drop ~ 50 eV

The statistics of TDS based on continuous electric and magnetic field spectral measurements is presented by Malaspina et al. [2014]

"Electrostatic" Time Domain Structures

Total net of potential is zero

Electric field model

$$\Phi = \Phi_0 \left(1 - \tanh(\sigma\phi)\right) \exp\left(-\phi^2\right)$$

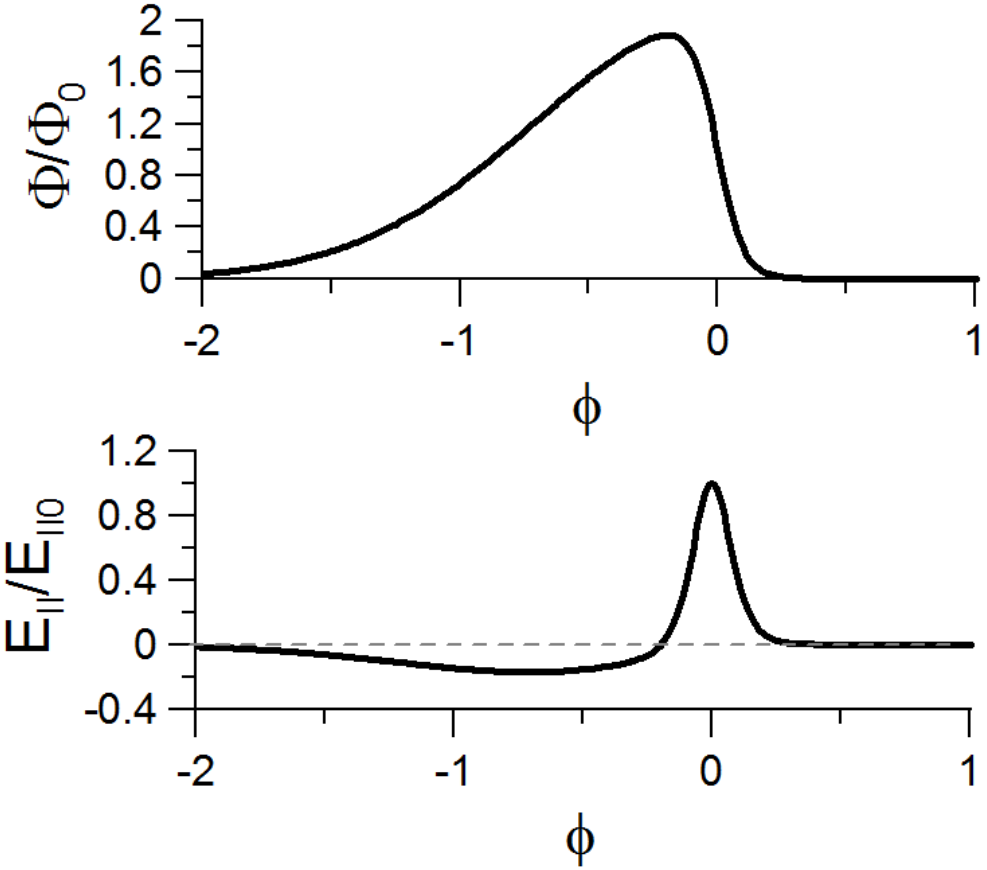
$$E_{\square} = E_{\square 0} \exp\left(-\phi^2\right) f(\phi)$$

$$f(\phi) = \frac{2\phi}{\sigma}\left(1 - \tanh(\sigma\phi)\right) + \frac{1}{\cosh^2(\sigma\phi)}$$

$$E_{\square 0} = \Phi_0 \frac{\sigma}{L}$$

electric field amplitude

phase



$$\phi = \int_0^s \frac{ds'}{L(s')} - \int_0^t \frac{dt'}{T(t')} + \phi_0$$

spatial dispersion

time dispersion

σ regulates the relation between scales of positive and negative electric field ranges

“Electrostatic” Time Domain Structures

Simplified model

$$L(s) = const = L$$

$$T(t) = const = L / v_\phi$$

$$\phi = (s - v_\phi t) / L$$

System parameters

- scale L~1-5 km
- velocity v_ϕ ~ 2000-5000 km/s from the equator
- field amplitude $E_{\parallel 0}$~10 - 100 mV/m
- ratio of scales σ ~ 10 - 100

We assume that localized electric field structures propagates parallel to the background magnetic field. In this case, one can average electron motion over fast gyrorotation, because corresponding magnetic moment μ is conserved! Finely, we get following Hamiltonian for nonrelativistic electrons

$$H = \frac{m_e v_\parallel^2}{2} + \mu B(s) - e\Phi(\phi)$$

(s, $v_\parallel$) are coordinate and velocity along field lines

$B(s)=B_{eq}b(s)$ is dipole magnetic field

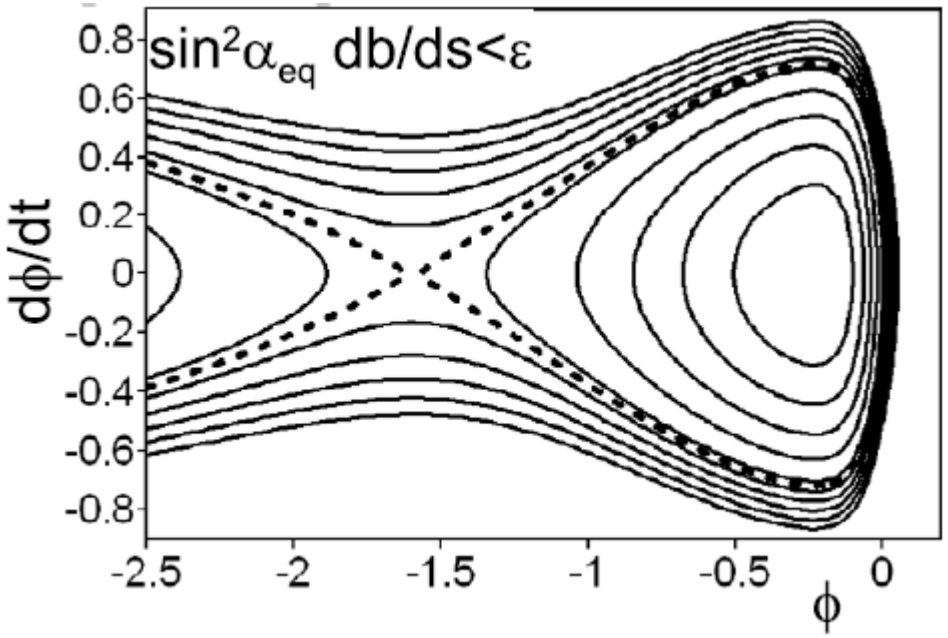
Equations of motion

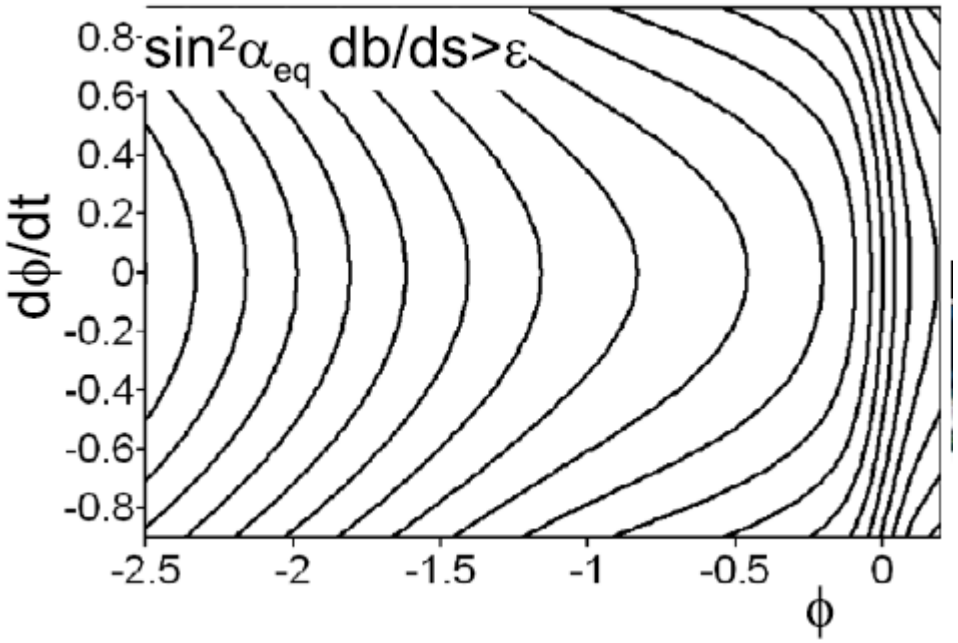
$$\begin{cases} \dot{s} = v_\parallel \\ \dot{v}_\parallel = -\dfrac{v_0^2 \sin^2 \alpha_0}{2R} b'(s/R) + \dfrac{eE_{\parallel 0}}{m_e} \exp\left(-\phi^2\right) f(\phi) \\ \phi = (s - v_\phi t) / L \end{cases}$$

- R is curvature radius of magnetic field lines.
- α_0 is equatorial pitch-angle
- v_0 is the amplitude of initial velocity

"Electrostatic" Time Domain Structures

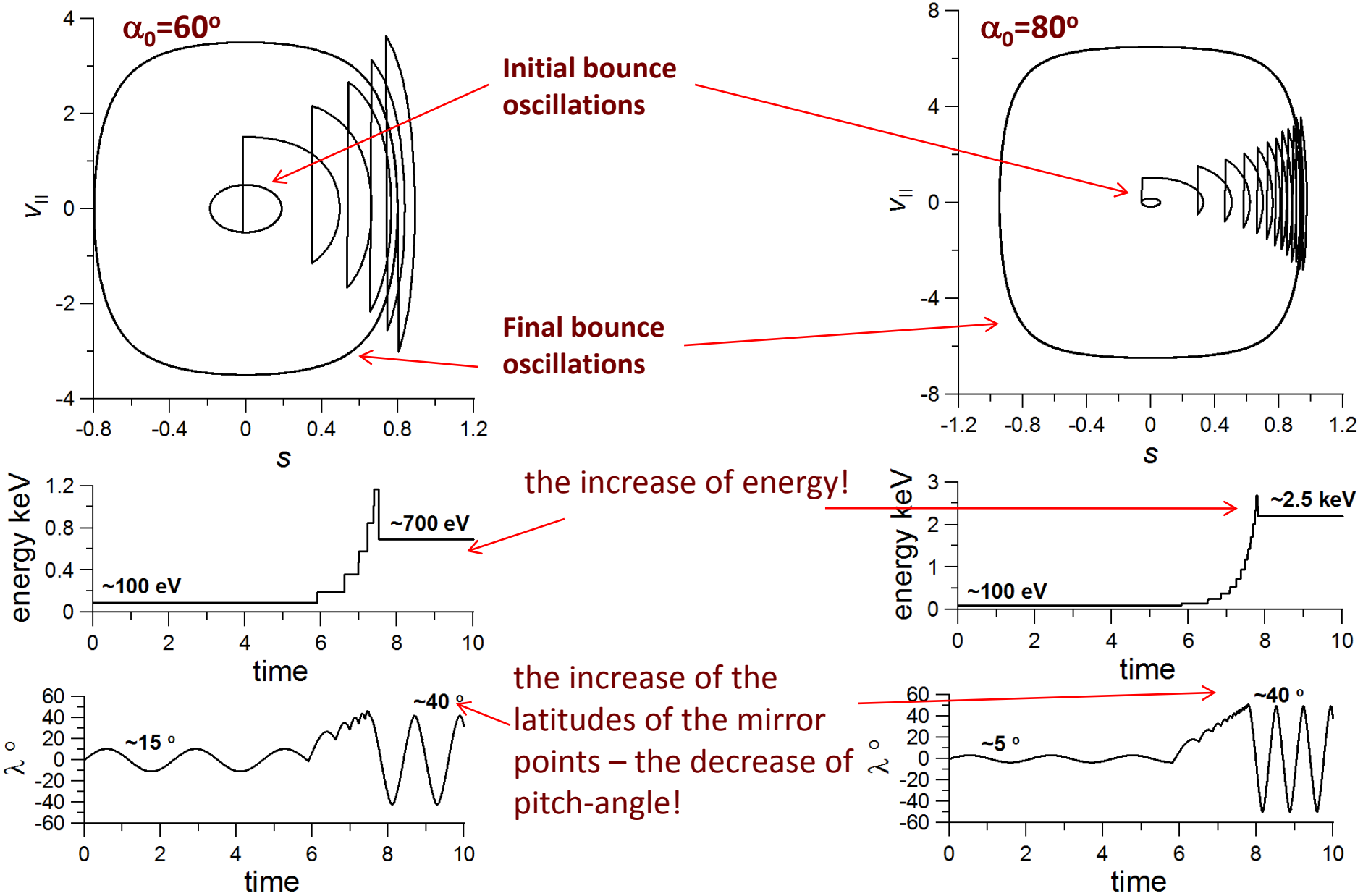
$$H_\phi = \frac{1}{2}\dot{\phi}^2 + \underbrace{\frac{1}{2}\sin^2\alpha_0 b'(s)\phi}_{A} + \underbrace{\frac{1}{2}\varepsilon}_{B}\exp\left(-\phi^2\right)\left(1-\tanh(\sigma\phi)\right)$$



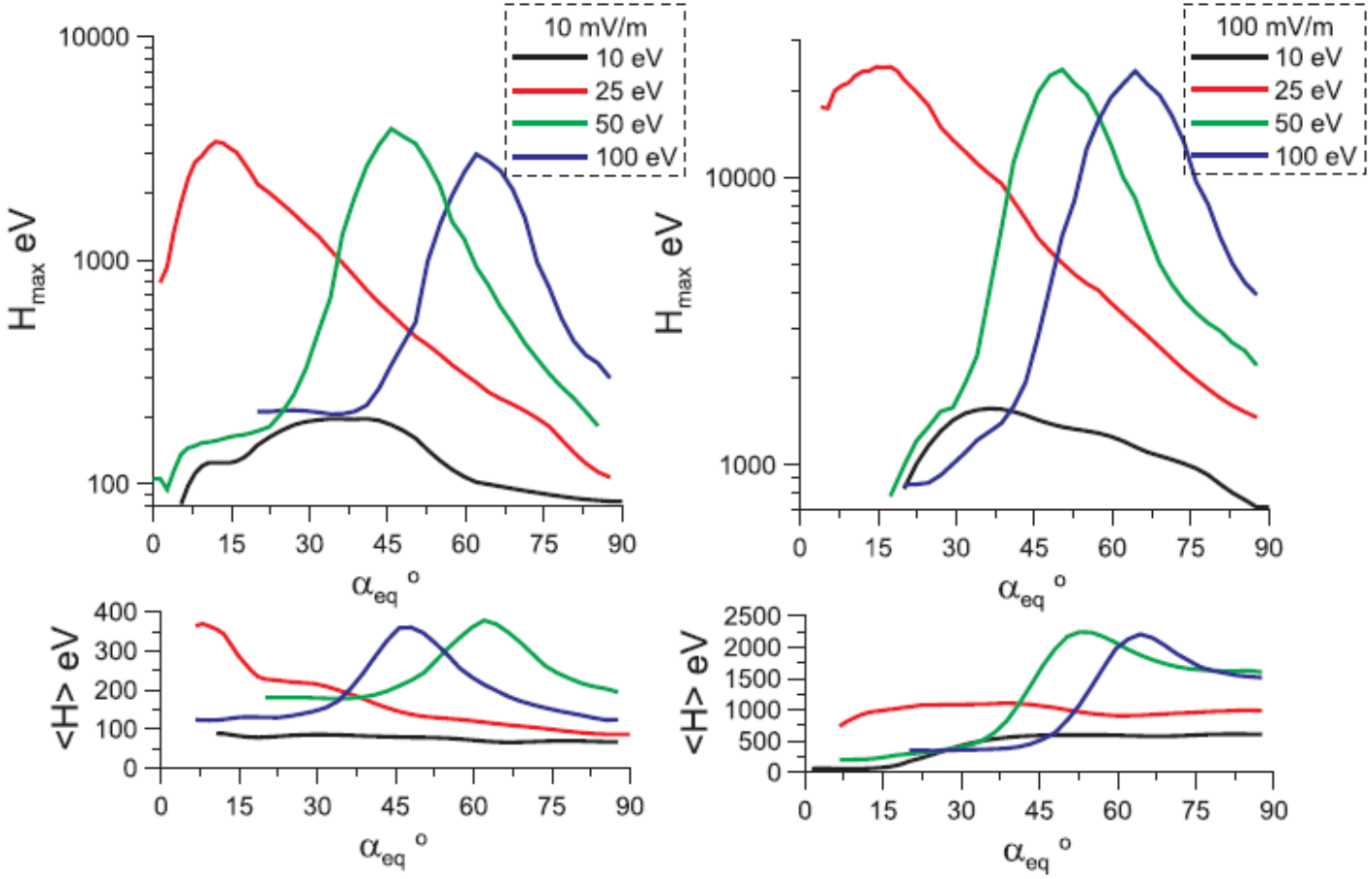


“Electrostatic” Time Domain Structures

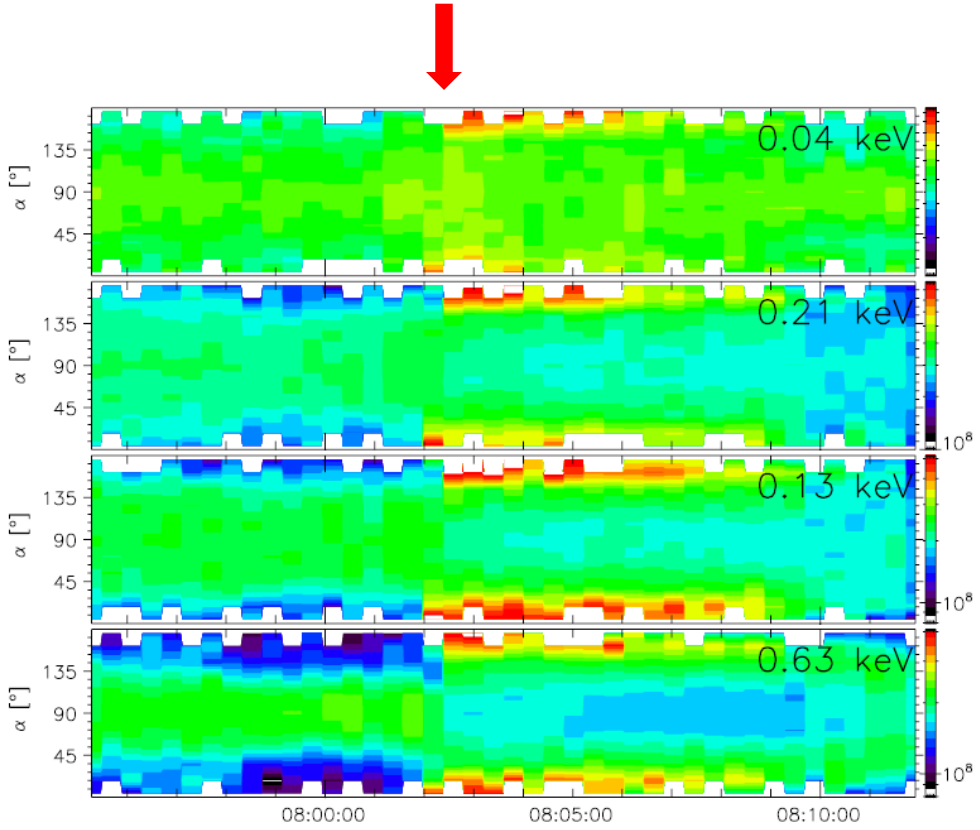
Resonant condition $v_{||}=u_{\phi}$ defines energies for particles which can be trapped (**~100 ev-1 keV**)



“Electrostatic” Time Domain Structures – effects for particles



Energy gain (maximal and average) from a single trapping into electrostatic TDS for 10 mV/m and 100 mV/m DL TDS



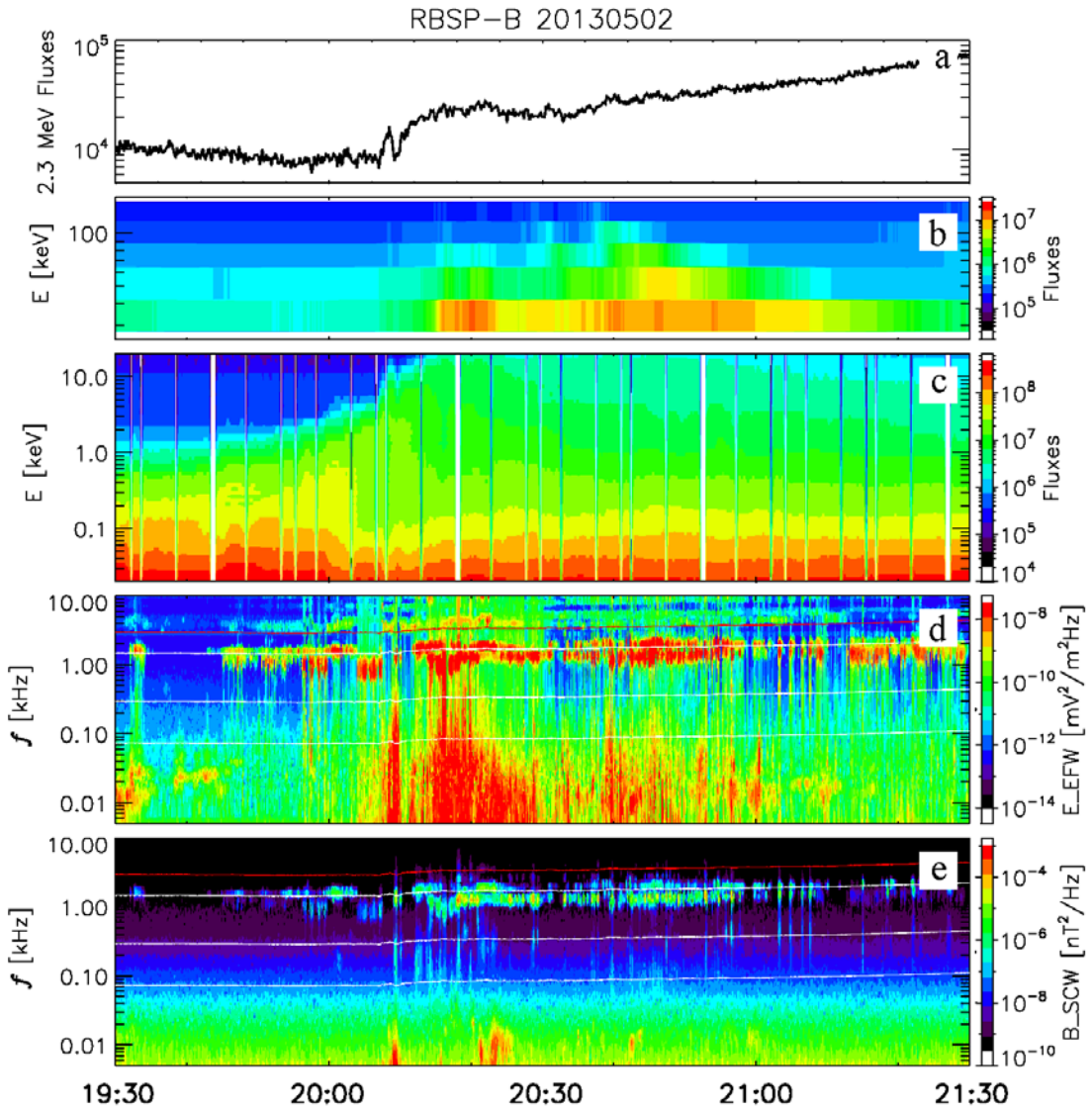
Particles pitch-angle distribution for different energies

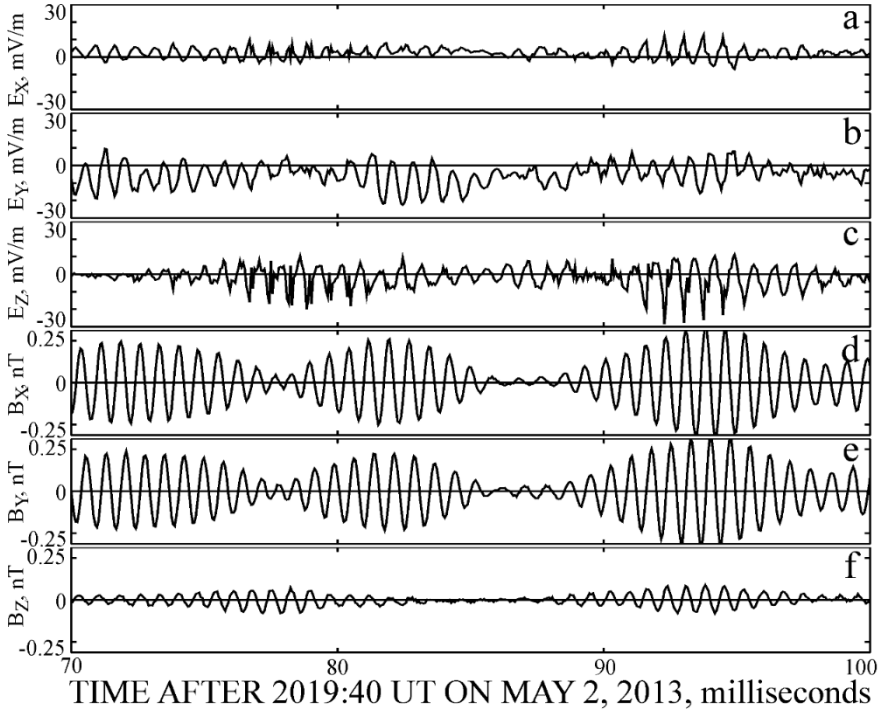
TDS

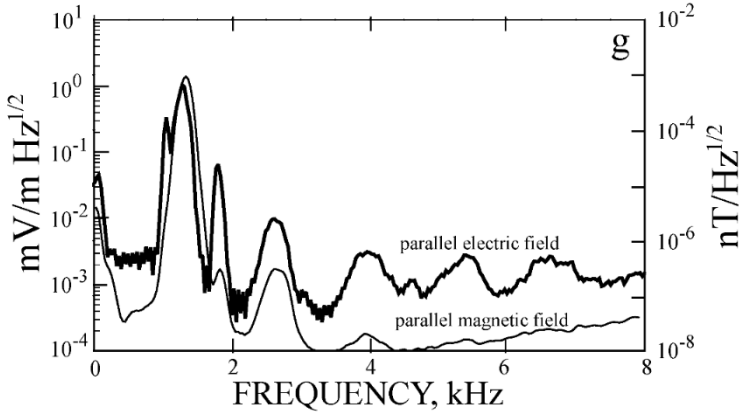
- Regular event that can be observed during ~hour time interval
- Different generation mechanisms -> different properties
- Interaction with low energy particles -> **Large probability of trapping**
- Effective gain of electron energy in single trapping by TDS is ~1-10 keV

Possible effects for the further acceleration

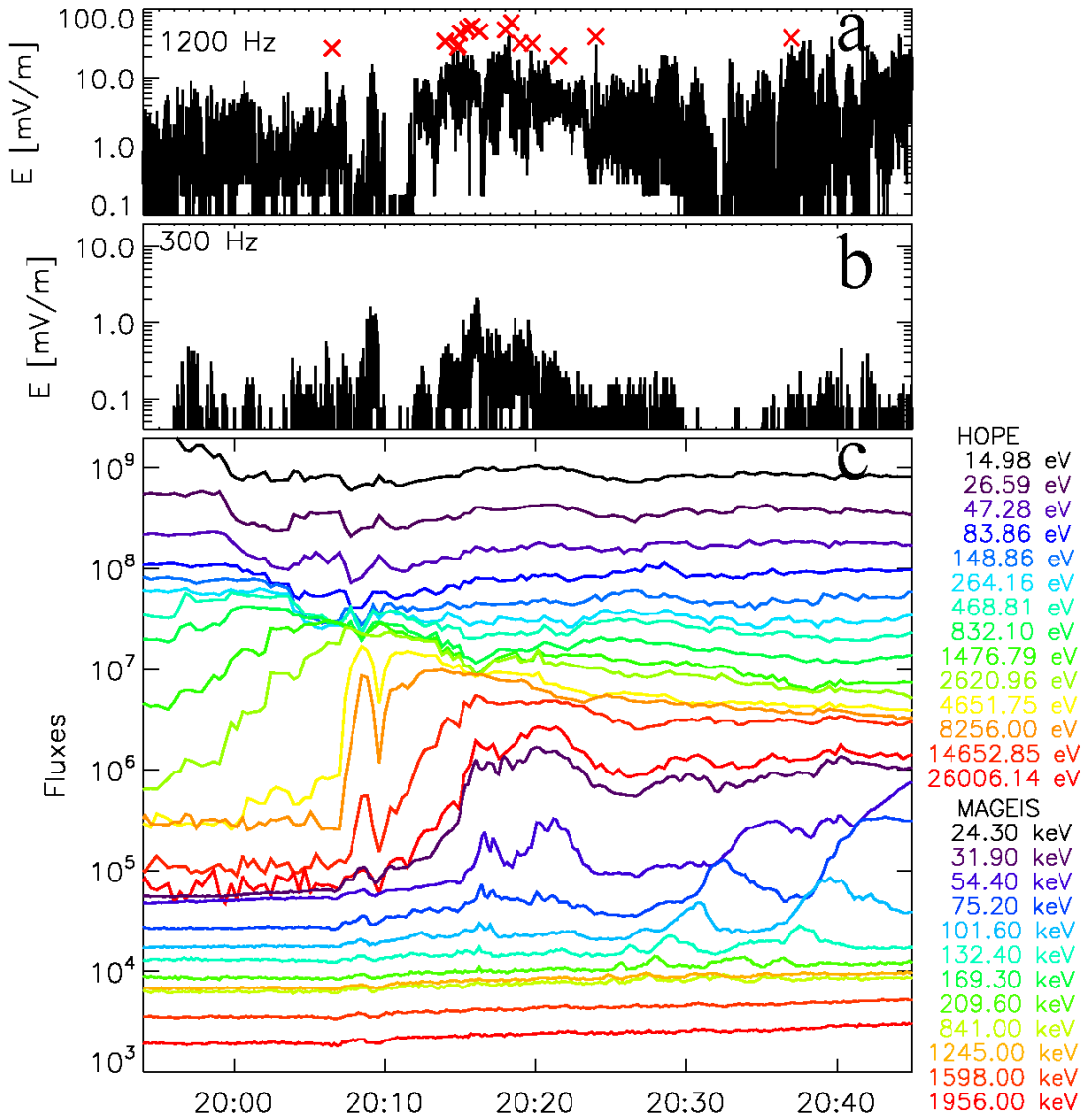
Acceleration event

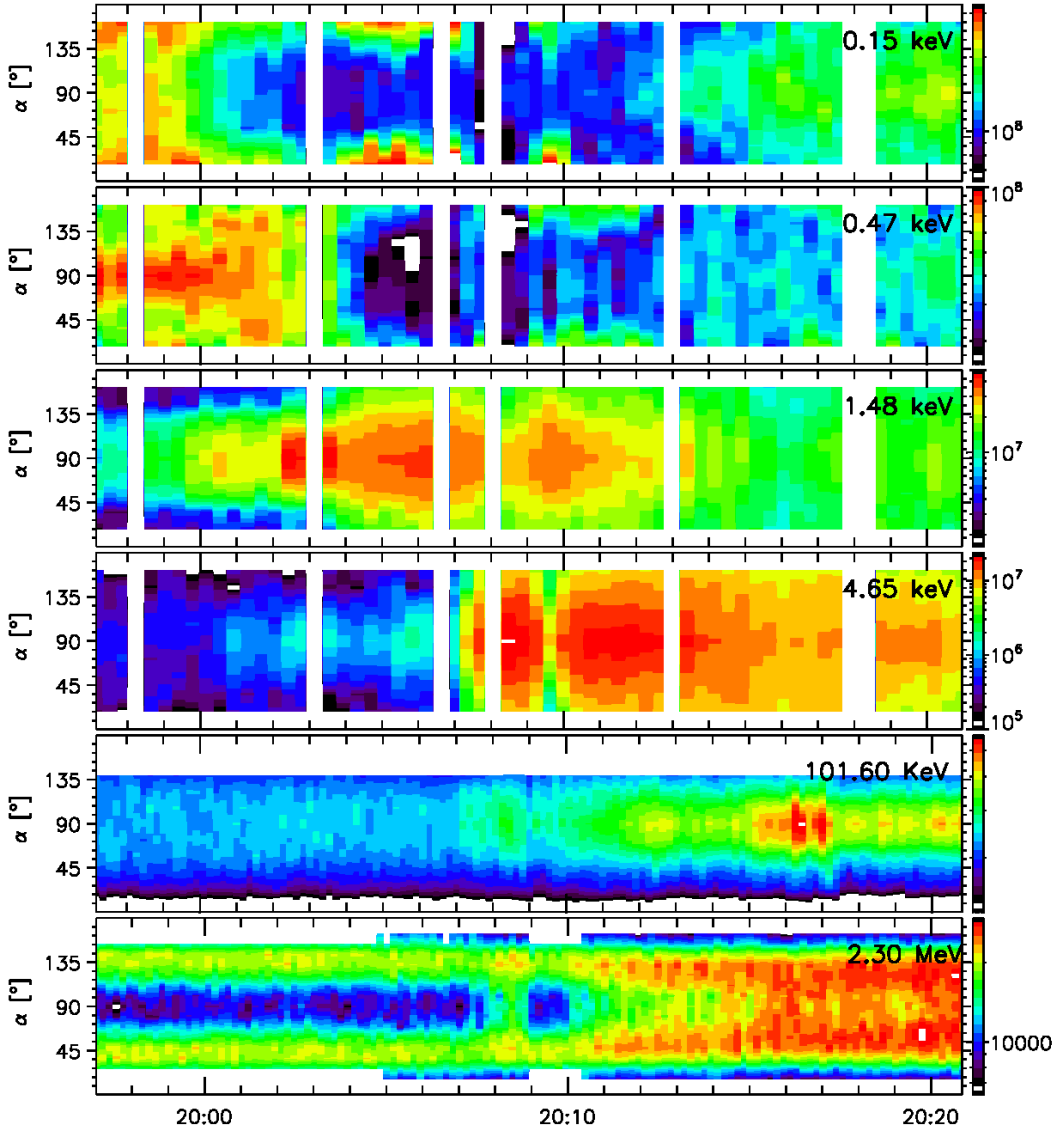




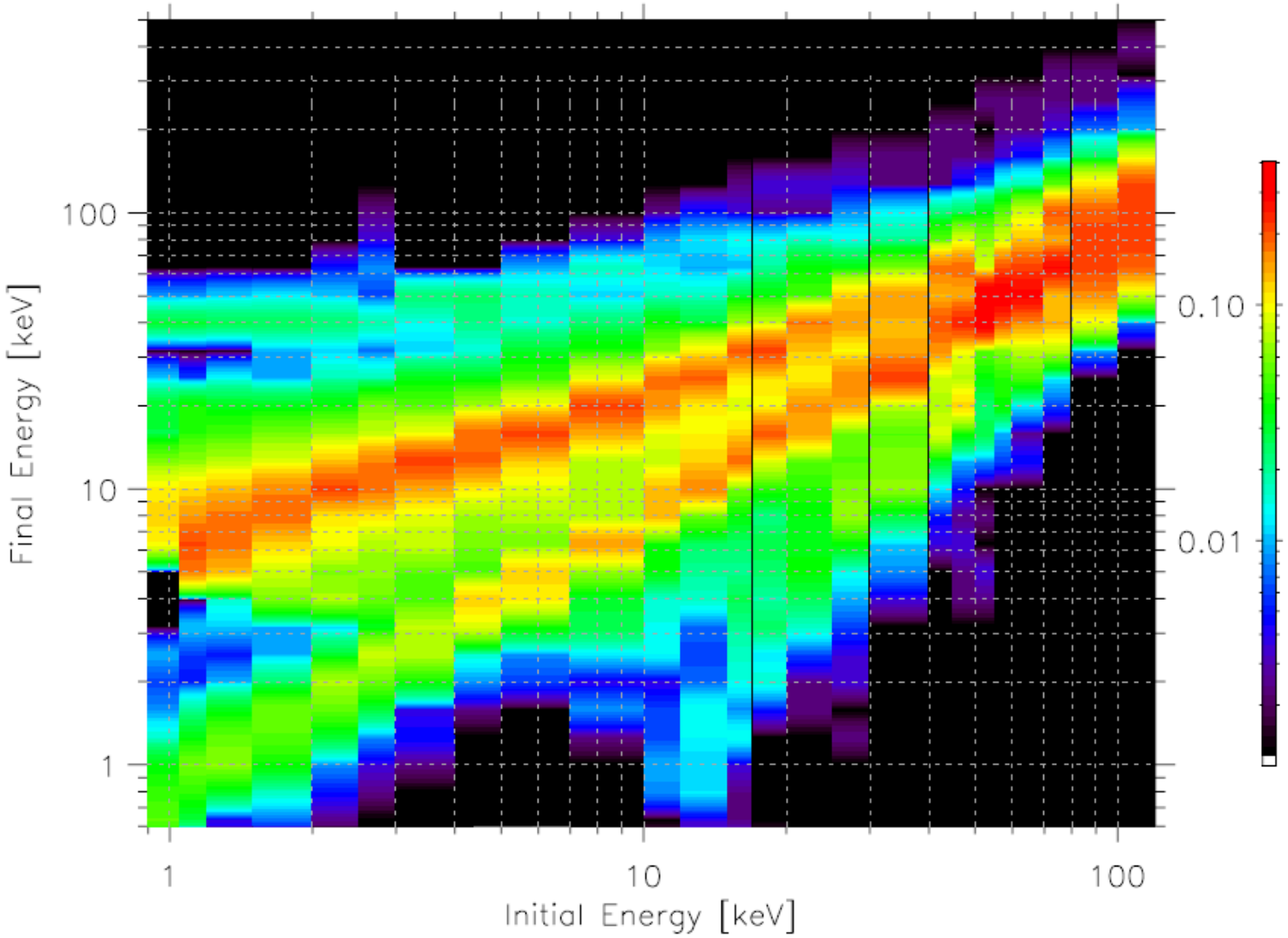


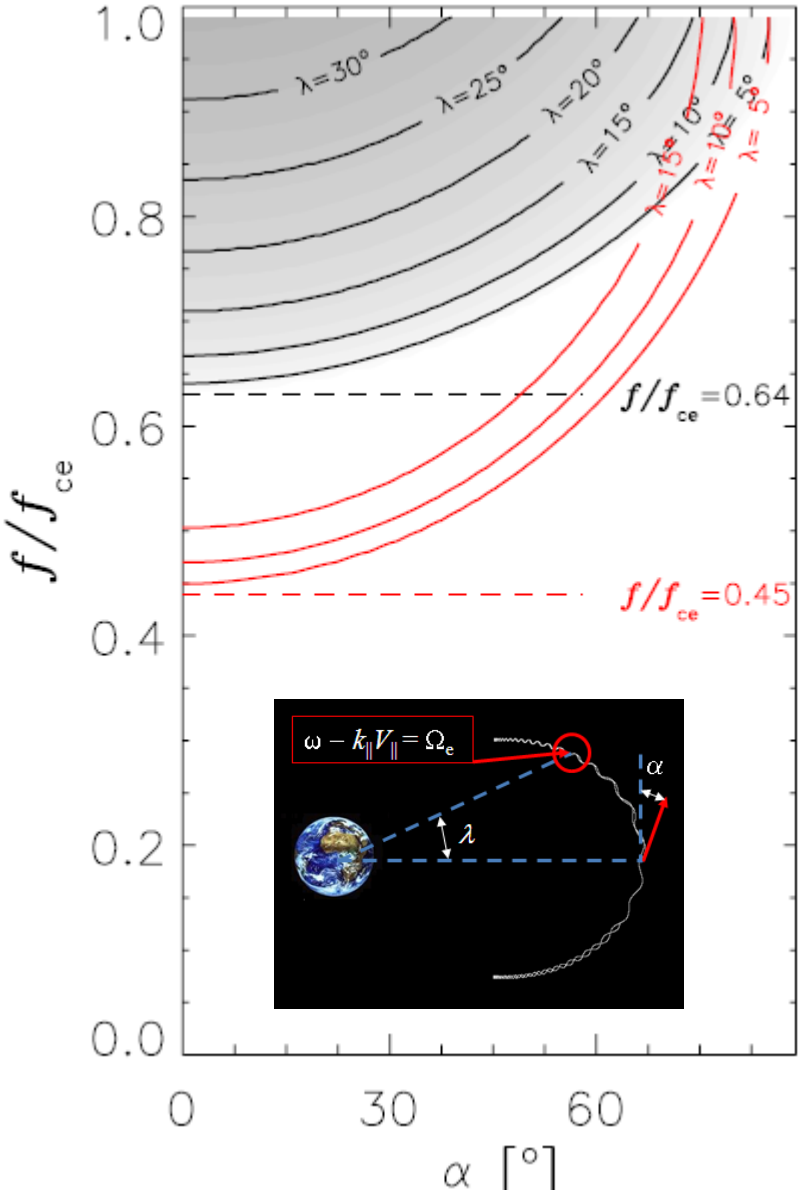
Acceleration event





Time Domain Structures





Conclusions

- **Oblique large amplitude chorus waves provide possibility for non-linear trapping of electrons in the outer radiation belt**
- **In the presence of hot particle population such trapping tends to non-linear effects in wave parallel electric field and can provide development of localized large amplitude electrostatic structures - TDS**
- **In the inhomogeneous magnetic field trapping of low energy electrons into the TDS effective potential increases their parallel energy up to 1-10 keV**
- **Such accelerated particles become the seed population for further acceleration by oblique whistlers through the Landau mechanism or by upper band chorus through the cyclotron acceleration**

A TWO STEP PROCESS:

1. Low energy electrons gain $v_{||}$ in the parallel electric fields in time domain structures, until the resonance condition is satisfied
2. At which point, resonant electrons are accelerated by the perpendicular electric field in the UB chorus whistlers