Characteristic Signatures of Radial or Local Acceleration of Electron inside Earth Radiation Belt

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Abstract

Radiation belt science has several enigmatic issues among which is yet unexplained electron acceleration in the million electron Volt (MeV) energy range. An extensive data set of Relativistic Electron-Proton Tele-scope (REPT) on board the Radiation Belt Storm Probe (RBSP) is studied for the 28 June, 2013 electron acceleration event. Phase space density is first determined for 2.30 MeV particles from measured integral flux and then calculated for the appropriate energy that conserves the first adiabatic invariant. It is shown that the time dependent radial profile of phase space density supports the local acceleration mechanism.

Key words: Electron Acceleration; Phase Space Density; Local Peak

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INTRODUCTION

Both experimental and theoretical studies have been carried out to study the earth's radiation environment; however, progress in the radiation belt particle measurement advanced tremendously after the launch of the Van Allen Probes mission (RBSP) (Mauk et al., 2013; Baker et al., 2013). In this regard major studies have done calculation of electron phase space density (PSD) using adiabatic coordinates (Chen et al., 2007a, 2007b; Tu et al., 2009; Turneret et al. 2012; Morely et al., 2013; Baker et al., 2014). Radial diffusion - a radical process for radial transport lowers down the gradients, transportation of plasma from high phase space density to the low. In this study of phase space density identification of peaks or gradients is a major setback as the in-situ satellite measurements do not come in terms with the adiabatic invariants. Phase space density is characterized by physically tenor-based measurements than by flux because of the constraints of Liouville's theorem. Also its calculations in terms of adiabatic invariants have been mostly based on dynamic geomagnetic storm intervals (Selesnick et al., 1997a, 1997b, 1998, 2000). Studies (Hilmer et al., 2000; McAdams et al., 2001; Reeves et al., 2013; Boyd et al., 2014) have also reported measurements which clearly distinguish between two types of acceleration including the ones where authors used NASA's Van Allen Radiation Belt Storm Probes.

MATERIALS AND METHODS

REPT consists of a stack of high-performance silicon solid-state detectors in a telescope configuration, a collimation aperture, and a thick case surrounding the detector stack to prevent the sensors from penetrating radiations (Baker et al., 2012). This instrument is pointed perpendicular to the spin axis of the spacecraft and measures high-energy electrons up to 20 MeV with excellent sensitivity and also measures magnetospheric and solar protons to energies well above E=100 MeV. The sublime task for the REPT design is to measure electron intensities in the range 10^{-2}–10^{6} particles/cm^2 s sr MeV and energy spectra ratio up to 25 % (Baker et al., 2012).

We follow the basic method outlined in (Chen et al., 2005) to calculate the phase space density. Let us write the equation for

$$f_{ch} = \{ jch / < p^2c^2 > [1.66\ EXP\ -10\ ]\} * 200.3 \qquad (1)$$

where j is the particle flux in 1/cm^{2}sr s keV and the numerical factor is given by

$$< p^2 c^2 > = ½\ [k_{min}(k_{min} + 2\ m_o c^2) + k_{max}(k_{max} + 2\ m_o c^2) \qquad (2)$$

Where the K_{min} and K_{max} are the lower and upper limit of energy channel in MeV, respectively, and $m_o c^2$ is the rest energy of an electron.
"L*" is defined as the radial distance to the equatorial location where an electron crosses if all external magnetic fields were slowly turned off leaving only an internal dipole field (Roederer, 1970), which is related to third adiabatic
invariant given as

$$L^* = 2\,\pi\,\mu\,/\,\emptyset\,R_E \qquad (3)$$

where "μ" is the earth's magnetic dipole moment, R_E is the radius of earth and Ø is the magnetic flux enclosed in the particle drift. The calculation was done with the Tsyganeko field model.

RESULTS

Figure 1 manifests a relativistic electron acceleration event which took place on June 28, 2013. The panels show the Kp index, the disturbance storm time index, the interplanetary magnetic field north-south component and solar wind speed. The interplanetary magnetic field (IMF B_y) feeds on more strongly southward after first 3 hours in genesis of day then fall down slightly after one hour. IMF B_z declines below zero values after 9UT enables reconnection with the earth's magnetic field to transfer energy to magnetosphere.

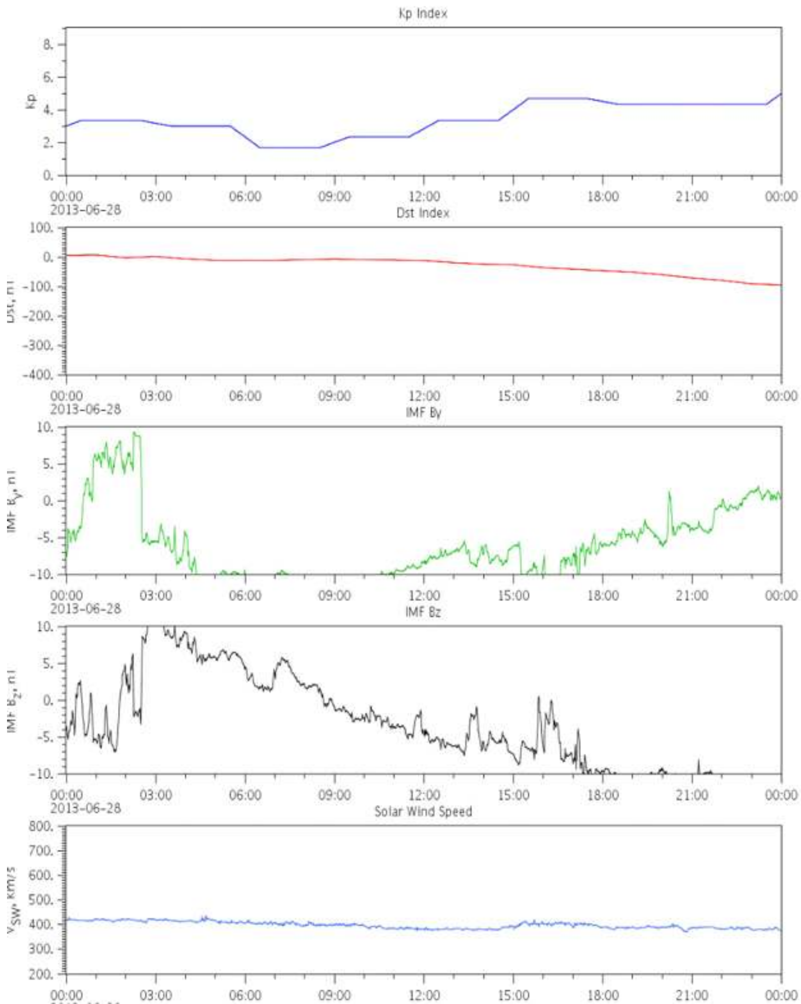

Figure 1: Graph shows Kp index, the disturbance storm time index, the interplanetary magnetic field north-south component and solar wind speed on 28 June 2013

The REPT instrument electron flux near all pitch angles are shown in figure 2. Flux intensities are color coded based on the color bar at the right vertical column side. The measurements show a very weak flux increase at the beginning of the event and pitch angle annihilated as the event progresses. The most appearance of electrons over the entire range of pitch angles are in boundary of 30 to 150 degrees except between time duration of 08 to 10 UT, as seen in the three panels. Our choice of first adiabatic invariance μ is determined by the electron instrument energy range.

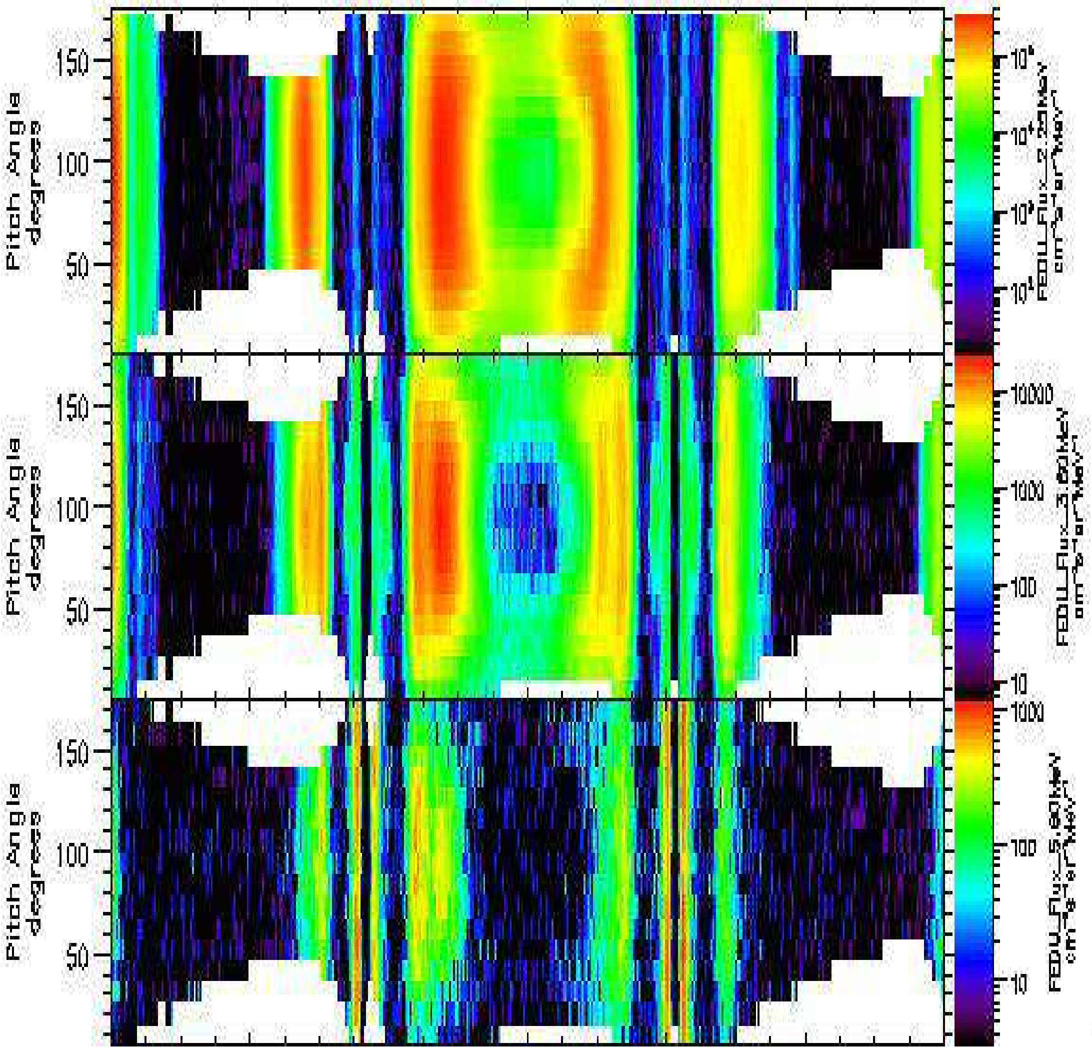

Figure 2: FEDU spectrograms by pitch angle at sample energies

Figure 3 shows the flux of 2.30 MeV electron fluxes as a function of L shell and time. From the flux measurements, it is clear that there was a increase in the relativistic electron flux between L = 4.0 to 5.0 (We calculate μ and choose a value of μ= 1414 MeV/G). The observed value of electron energy flux is converted to PSD as function of the first adiabatic invariant using equation (1) at equatorially mirroring particle (2nd adiabatic invariance is zero). The results of L* calculation for the space craft corresponding to μ= 1414 MeV/G are also shown in figure 4.

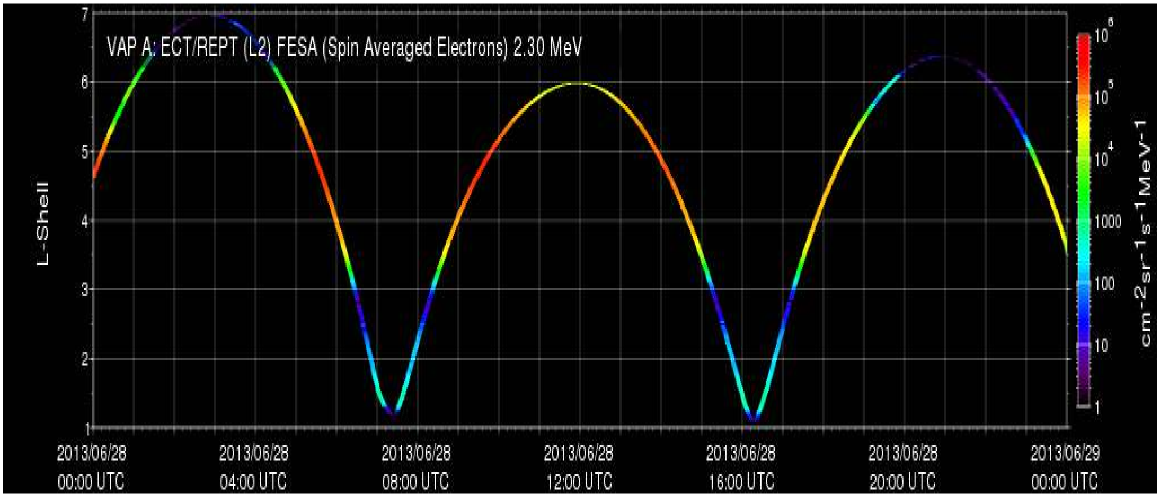

Figure 3: FESA for 2.30 MeV energy channel

The minimum to maximum range of phase space density is plotted in order to look for the characteristics signatures of either radial or local acceleration. The plotted PSD values between time of 08:00 UT 11:00 UT against L* are shown in figure 4. At the onset, there is smooth continuation of the gradients. From 08:43UT, the radiation belt experiences a swift up lift increase in phase space density that goes along for more than an hour till 10:20UT.The analysis identified the development of peaks in electron phase space density, which is a compelling evidence for local electron acceleration.

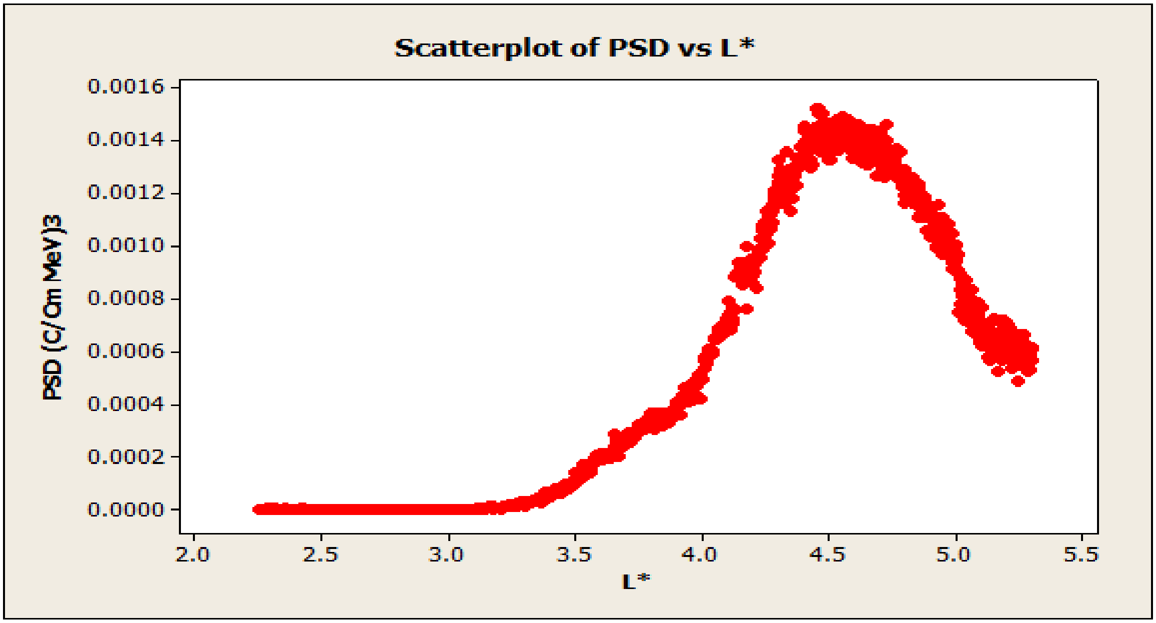

Figure 4: Graph between PSD verses L*

DISCUSSION

The strength of the pitch angle scattering appears to be most intense near the position in L of the maximum of the relativistic electron flux. Our calculated values of phase space density in adiabatic invariance space confirmed that the same characteristic signature of local acceleration was observed in the June 2013 storm that was reported by previous studies of this type especially by Reeves et al., on (OCT: 2012). The time evolution of PSD (L*) show quick formation of the peak and then spreads out. The above results can be expanded to look at the EMFISIS data to observe chorus waves.

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