Impact of Interplanetary Coronal Mass Ejections and High Speed Streams on the dynamic variations of the electron population in the outer Van Allen belt

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Introduction

The outer Van Allen radiation belt is an environment with intense variability, where acceleration mechanisms drive seed electrons to relativistic and ultra – relativistic energies. This procedure strongly depends on the interplanetary driver of the geomagnetic disturbance. Various theories of how electrons accelerate exist, yet all of them have as basic condition the violation of one or more adiabatic invariants. These theories can be divided into two major categories: 1) inward radial diffusion and 2) in situ acceleration.

In this study, we examine **46 events** from the Van Allen Probes era (2012 – 2018), which we categorize according to the interplanetary driver of the geomagnetic disturbance. We study 16 events caused by **Interplanetary Coronal Mass Ejections (ICMEs)** and 30 events caused by **High Speed Streams (HSSs)** following Stream Interaction Regions (SIRs).

To that end we calculate the electron phase space density (PSD) for three values of the first adiabatic invariant *μ*, corresponding to the different electrons' energies, while examining the PSD behavior for three distinct values of the second adiabatic invariant *K*. We perform a Superposed Epoch Analysis (SEA), in order to compare the Solar Wind parameters and the PSD (time & radial profiles) of the two drivers.

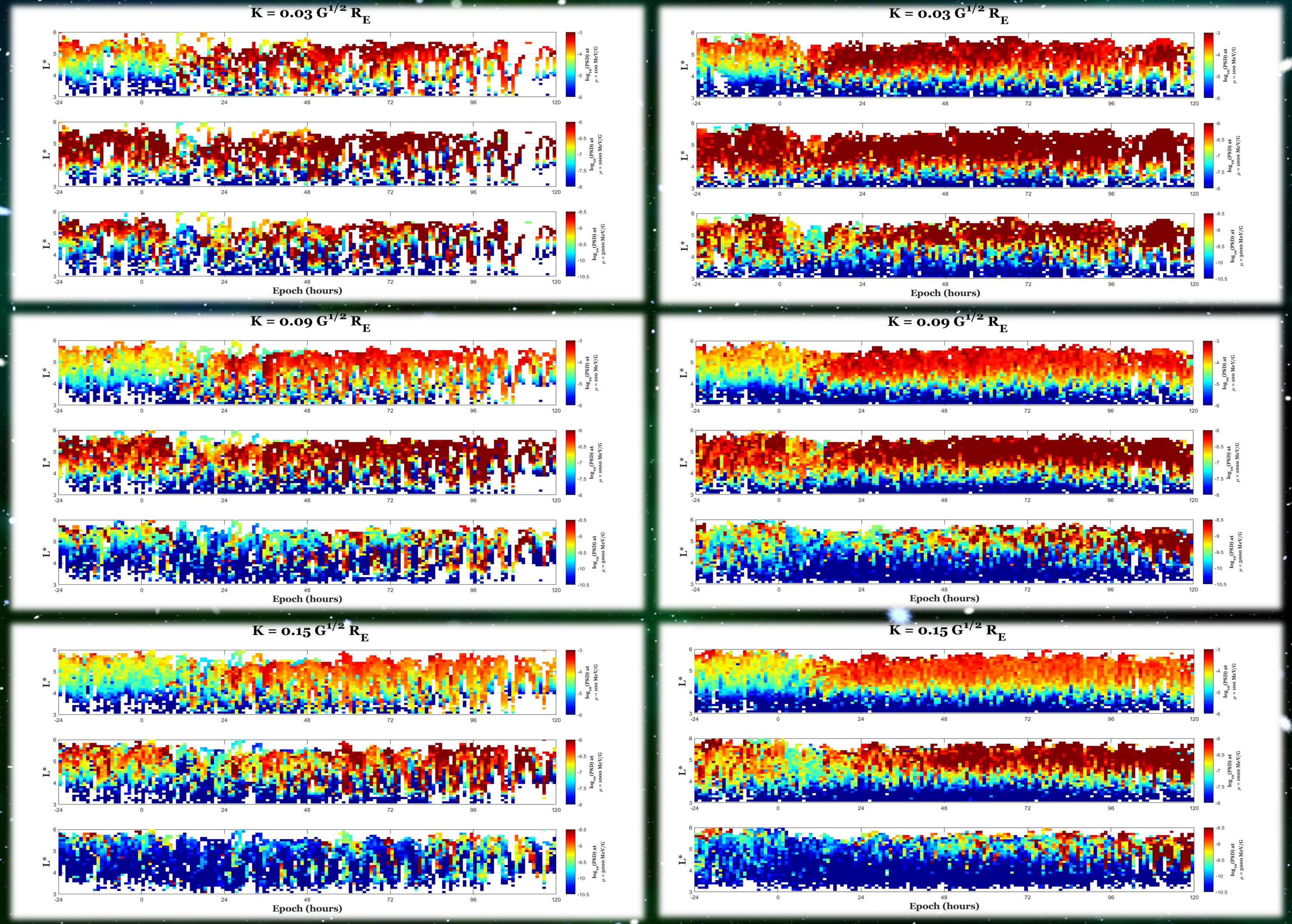

Figure I: Time profiles for electron PSD for different *μ* and *K* values

Electron PSD for:

Seed electrons: $\mu = 100$ [MeV/G], E = 100 – 600 [keV]

Relativistic electrons: $\mu = 1000$ [MeV/G], E = 1-3 [MeV]

Ultra – Relativistic electrons: $\mu = 5000$ [MeV/G], E = 3 – 8 [MeV]

for *K* values: 0.03, 0.09 and 0.15 $G^{1/2}R_E$

Abstract:

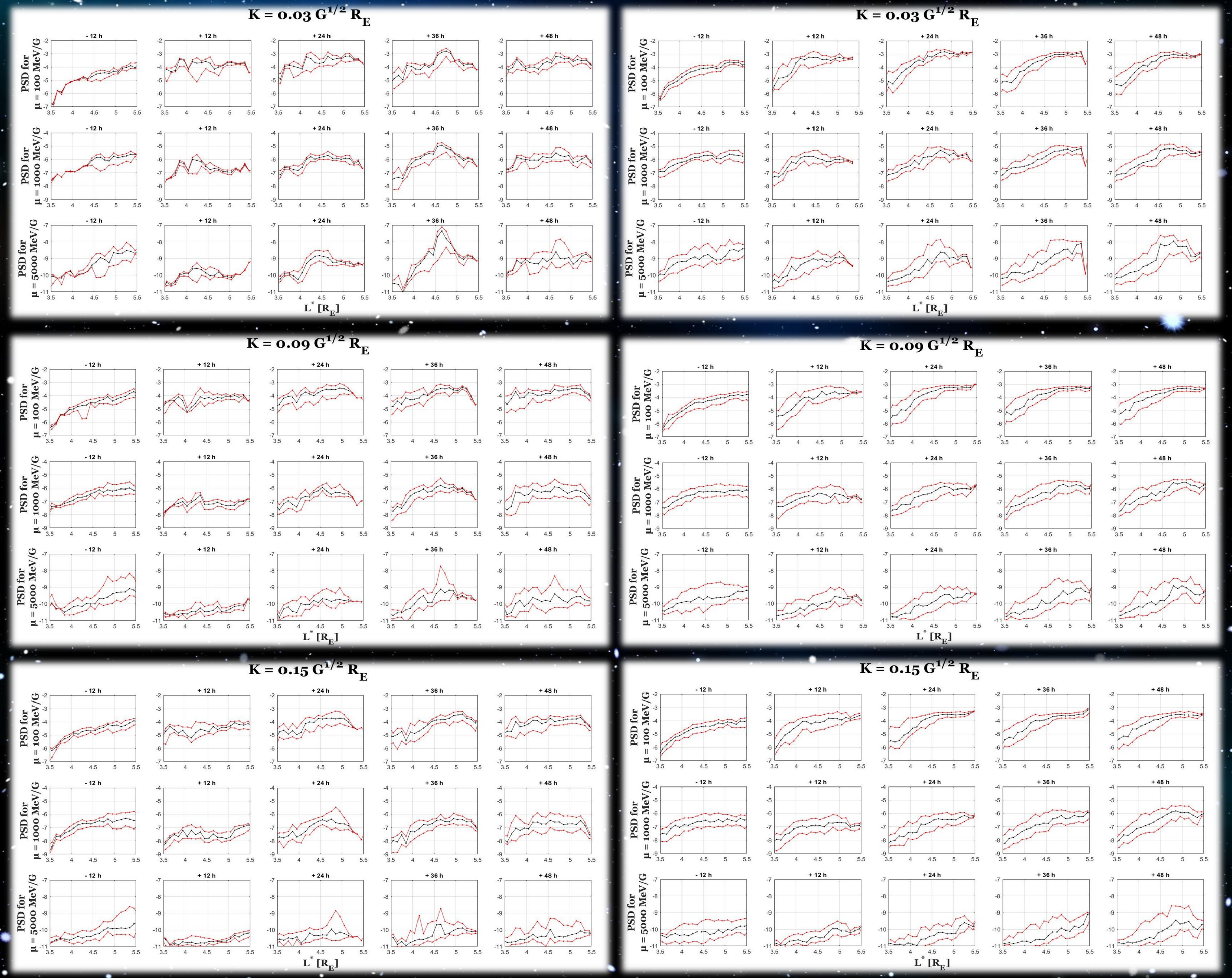

Figure II: Radial profiles for electron PSD for different *μ* and *K* values

Event selection and Superposed Epoch Analysis

The events need to emerge after at least **12 hours of quiet-time** average solar wind conditions, meaning:

$V_{SW} < 400$ [km/s]
$P_{SW} < 3$ [nPa]
SYM-H > -20 [nT]
AL > -300 [nT]
-5 [nT] < B_z < 5 [nT]

The selected events are chosen in order to have a single driver, spanning the maximum/declining phase of Solar Cycle 24. In the SEA for ICME events, the key time t_0 is defined as the time of the **arrival of the shock**, while for the SIR events, the time is defined by the **maximum solar wind pressure**.

Adiabatic invariants' values:
μ = 100, 1000, 5000 [MeV/G]
K = 0.03, 0.09, 0.15 [$G^{1/2}$ R_E]
$3 \le L^* \le 6$

Magnetospheric parameters

(L_{MP} [R_E])

Solar Wind parameters

(P_{SW} [nPa], V_{SW} [km/s], Bz [nT], IMF [nT], Ey [mV/m])

Geomagnetic indices

(Dst [nT], AL [nT])

Figure III. Differences between ICMEs and SIRs for solar wind and magnetospheric parameters, and geomagnetic indices, from NASA's OMNIWeb Service. The black line is defined as the median value, the red lines represent the quantiles, with the upper red line corresponding to 75% of the events, and the lower to the 25% of the events.

The most distinguishable differences are that the ICMEs are characterized by more intense magnetopause compression, higher values for the solar wind's pressure and more intense magnetic storms and substorms, while the SIRs by higher values for the solar wind's velocity and shorter time period for all parameters to recover.

The different structures of the ICME are visible. The sheath region appears right after the shock and lasts up until 18h. It is characterized by high values of solar wind pressure, due to its high density. The magnetic cloud affects the magnetosphere after 18h.

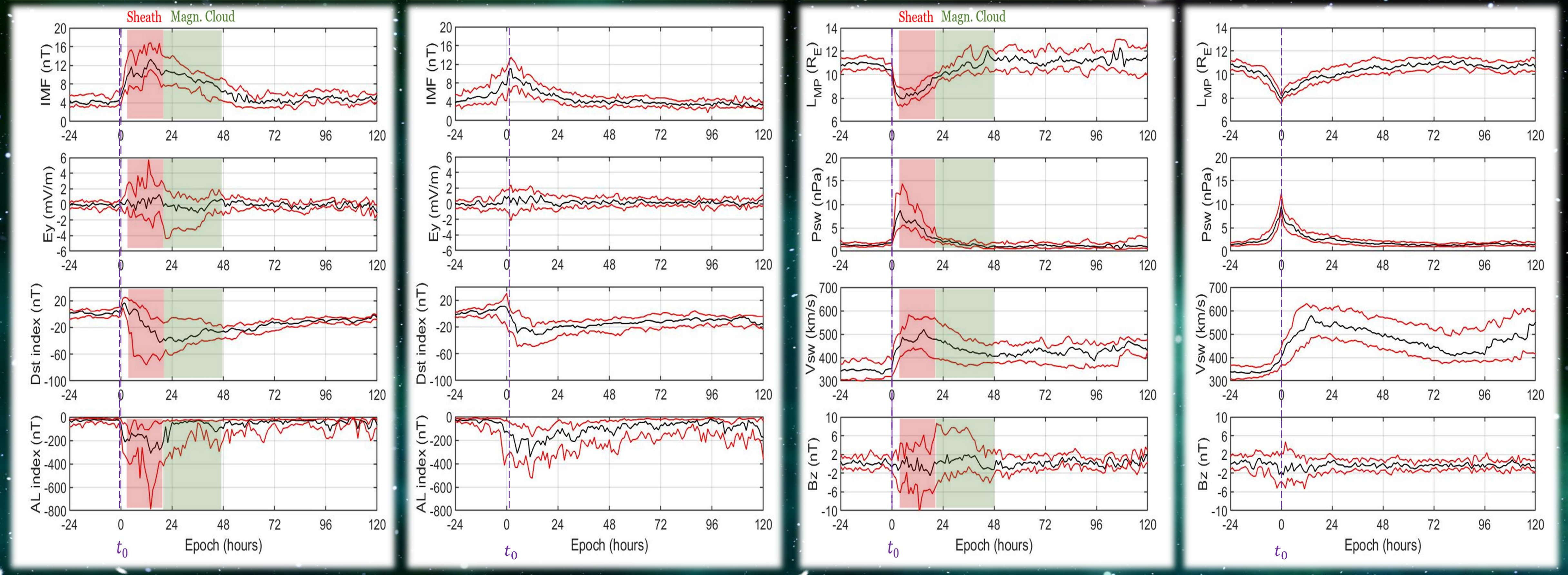

Figure III: Parameters and Indices

Conclusions

- Comparing the <u>solar wind parameters</u>, SIRs have more stable dynamic, while ICMEs have greater variability. ICMEs have a major impact on the geomagnetic field, as the Dst and AL indices reach lower values, while the phases of the magnetic storms are easily observable. The recovery phase of the magnetic storms during SIRs lasts a shorter period of time.
- Comparing the <u>time profiles</u> we conclude that ICMEs are characterized by strong magnetopause shadowing during the first 12h, for all values of the first and second adiabatic invariant. It is noteworthy that during SIRs the increase in the ultra-relativistic electron PSD is more significant, rendering the outer Van Allen belt more dangerous.
- Comparing the <u>radial profiles</u>, the two drivers affect the outer radiation belt differently. During ICMEs, electrons are enhanced via local acceleration, while, during SIRs, the mechanism of radial diffusion is preferred.
- During <u>ICMEs</u>, peaks appear around 24h and are strongly visible at 36h, for all electrons. This leads to the conclusion that electrons are enhanced via local acceleration. Combining this observation with the substorm activity, we note that the AL index is intense during the first 24h, so the waves (chorus) appear in the next few hours. Furthermore, the solar wind is fast during the first 24h, so we believe that, during the wave - particle interactions, ULF waves do not participate.
- During <u>SIRs</u>, at +24h we observe a small peak of the PSD at L^*=4.7 which indicates the local acceleration of electrons. Moreover, at +36h and +48h the electrons are accelerated through radial diffusion, affecting the ultra-relativistic electron population too. The acceleration in these time periods is justified due to the increased pressure and high speed of the solar wind, which are observed mainly in the first 24h after the zero epoch time.