Heliospheric Plasma Sheet (HPS) Impingement onto the Magnetosphere as a Cause of Relativistic Electron Dropouts (REDs) via Coherent EMIC Wave Scattering with Possible Consequences for Climate Change Mechanisms

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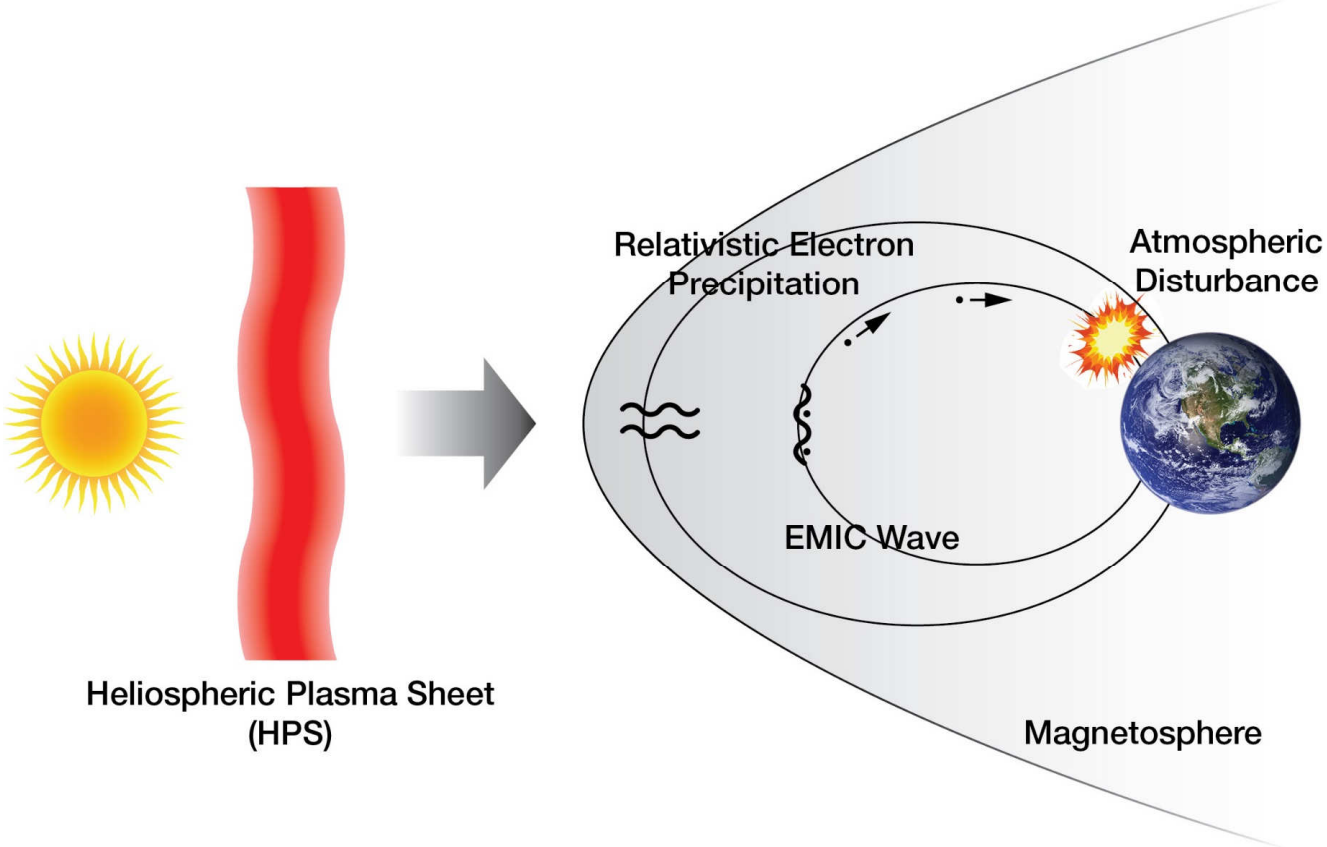
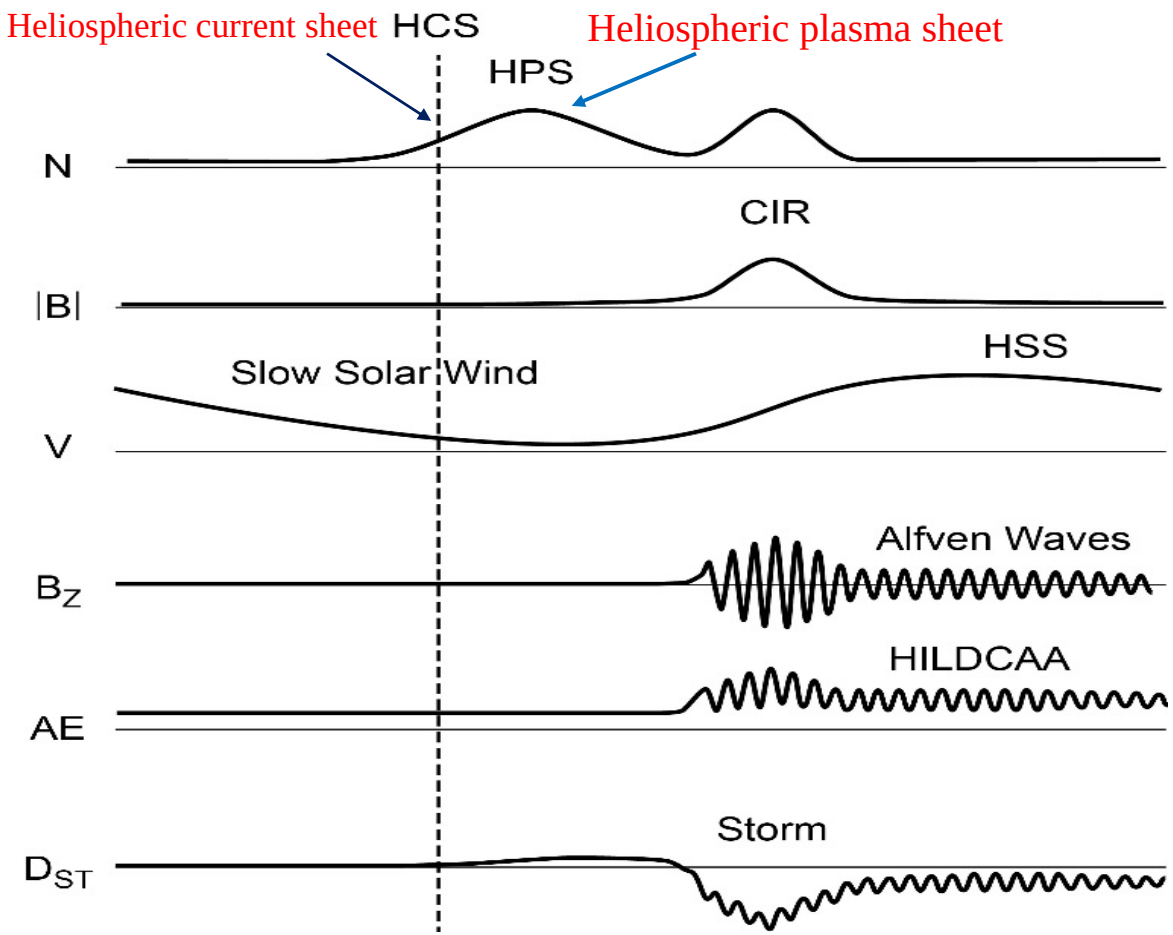

Relativistic Electron
Precipitation
Atmospheric
Disturbance
EMIC Wave
Heliospheric Plasma Sheet
(HPS)
Magnetosphere

Abstract A new scenario is presented for the cause of magnetospheric relativistic electron decreases (REDs) and potential effects in the atmosphere and on climate. High-density solar wind heliospheric plasmasheet (HPS) events impinge onto the magnetosphere, compressing it along with remnant noon-sector outer-zone magnetospheric ~10-100 keV protons. The betatron accelerated protons generate coherent electromagnetic ion cyclotron (EMIC) waves through a temperature anisotropy ($T_{\perp}/T_{\parallel} > 1$) instability. The waves in turn interact with relativistic electrons and cause the rapid loss of these particles to a small region of the atmosphere. A peak total energy deposition of ~3×10^{20} ergs is derived for the precipitating electrons. Maximum energy deposition and creation of electron-ion pairs at 30-50 km and at $<$ 30 km altitude are quantified. We focus the readers' attention on the relevance of this present work to two climate change mechanisms. Wilcox et al. (1973) noted a correlation between solar wind heliospheric current sheet (HCS) crossings and high atmospheric vorticity centers at 300 mb altitude. Tinsley et al. (1994) has constructed a global circuit model which depends on particle precipitation into the atmosphere. Other possible scenarios potentially affecting weather/climate change are also discussed.

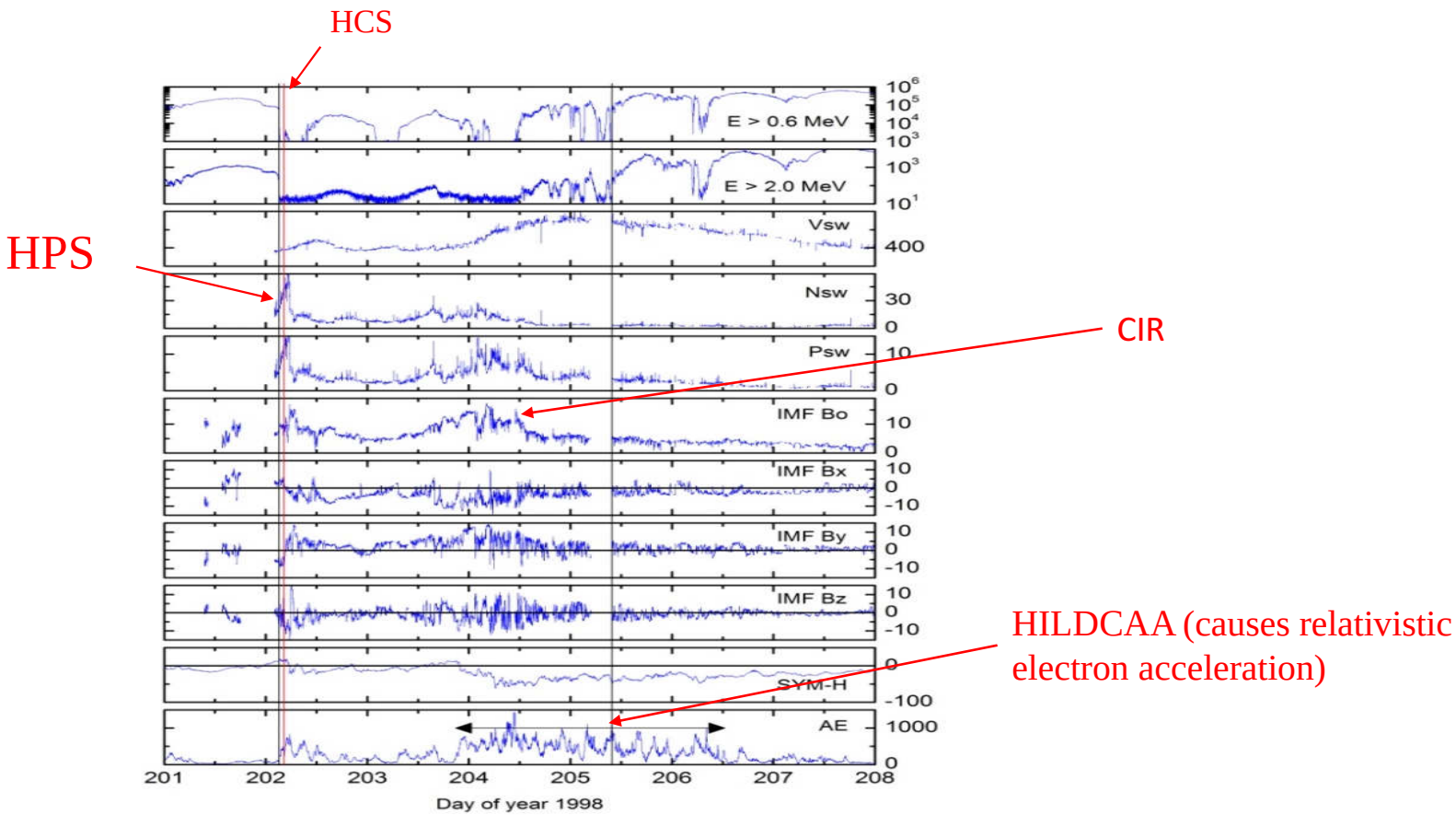
Selection of Low Speed and High Speed Solar Wind Intervals Without Magnetic Storms: 8 Events in SC23

#	Event	Start (DOY UT)	End (DOY UT)	Duration (h)	Peak pressure (nPa)	HCS time (DOY UT)
1	1995_150	150 02:39	150 05:37	3.0	26.6	150 04:44
2	1998_202	202 02:38	202 06:45	4.1	18.6	202 04:27
3	2000_027	027 14:04	027 21:35	7.5	20.3	027 18:03
4	2000_052	052 01:11	052 08:13	7.0	14.8	----
5	2003_258	258 16:32	259 03:16	10.7	8.0	258 20:43
6	2007_056	056 12:00	057 05:32	17.3	12.2	057 03:21
7	2007_243	243 13:43	243 20:52	7.2	5.1	243 21:37
8	2008_058	058 14:07	058 19:48	5.7	9.6	058 17:51



HPS occurs before CIR and HSS

Relativistic Electron Decreases (REDs)



All 8 RED Events Had Associated HPSs

Table 1. Eight HPS Pressure Pulse Events From SC23 That Were Not Followed by Magnetic Storms[a]

Number	Event	Start (DOY UT)	End (DOY UT)	Duration (h)	Peak Pressure (nPa)	HCS Time (DOY UT)
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[a]All eight HPS impacts on the magnetosphere were associated with REDs.

Typical RED decay time ~ 1 hr

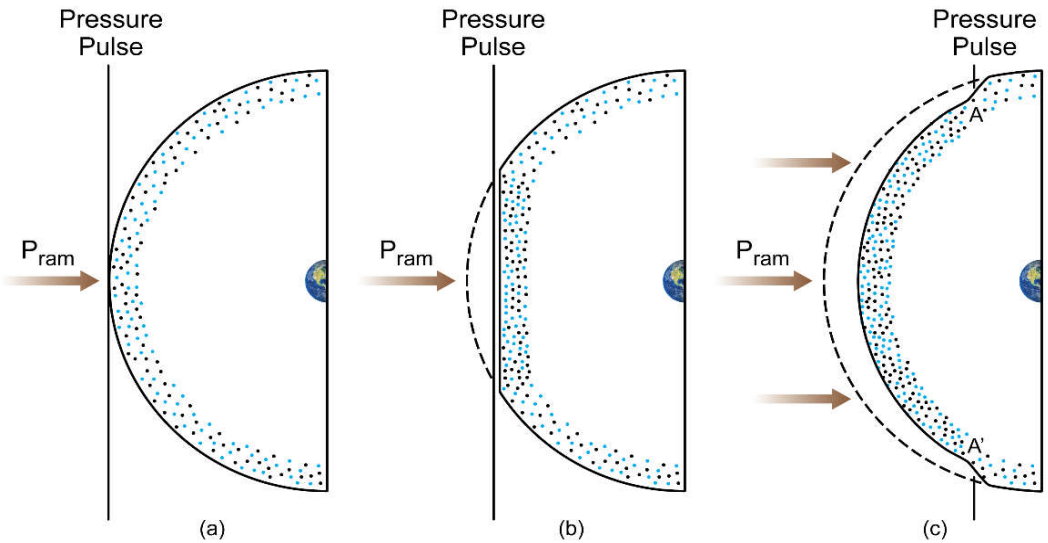
Total Magnetospheric Particle Energy Calculations

A flux decrease of ~10^5 particles cm^{-2} $s^{-1}ster^{-1}$ in the E > 0.6 MeV energy range (~1 MeV electrons) was determined from measurements.

The bounce time of a charged particle is $T_B = L\ R_E\ (3.7 - 1.6 \sin \alpha)\ V_e$ (Baumjohann and Treumann, 2012). Assuming a 2π ster downward flux and a constant flux from L = 6 to 10,

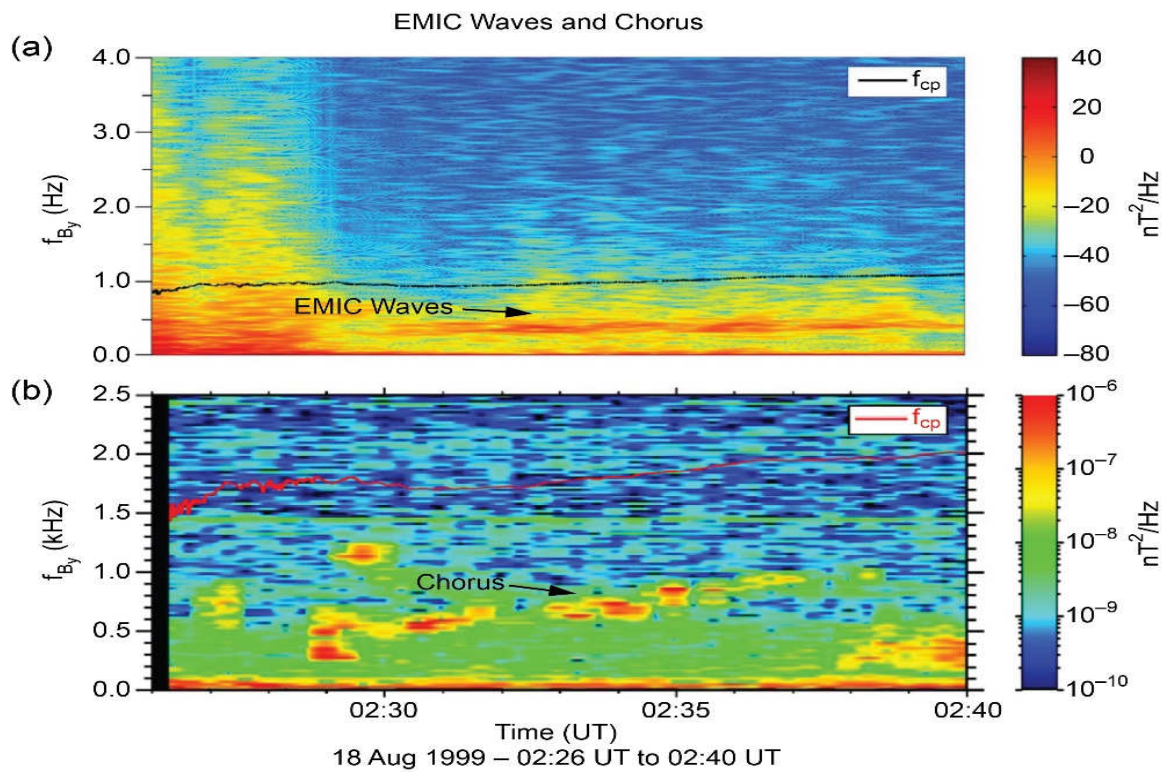
The total energy of ~1 MeV electrons in the magnetosphere from L = 6 to 10 is ~ 3×10^{20} ergs.

The Solar Wind HPS Will Compress the Dayside Magnetosphere



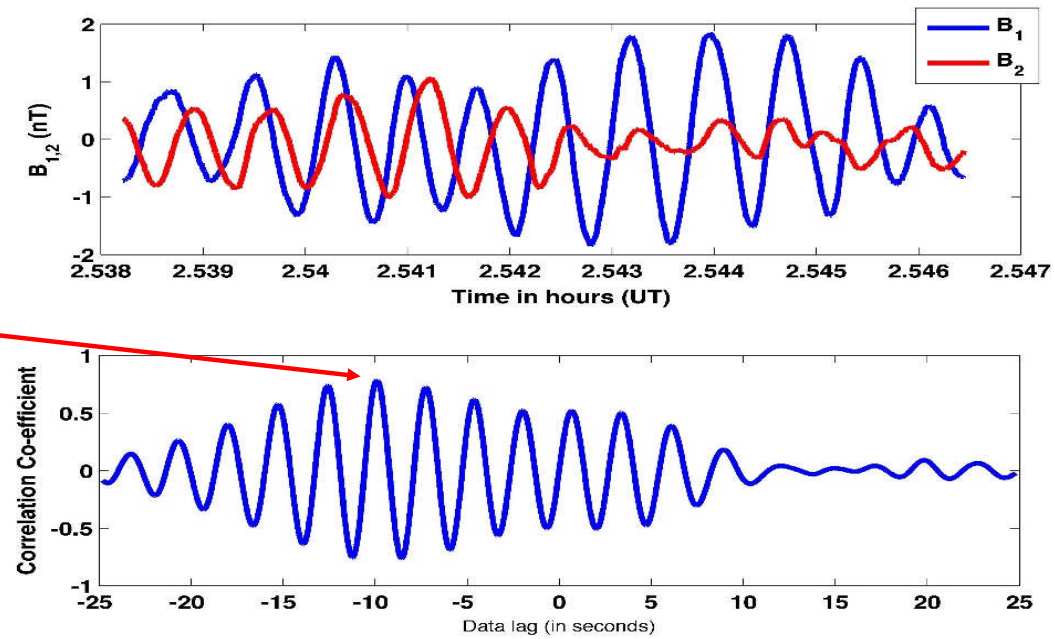
The solar wind pressure pulse will cause the betatron acceleration of preexisting ~10-100 keV electrons and protons in $T_{\perp}$ and thus instability in both particles.

Simultaneous EMIC and Chorus Waves from L = 10 to 7 at ~1300 MLT
Cassini Earth Swing-By



What Do the EMIC Waves Look Like in Detail?

EMIC waves
are **"coherent"**



With coherent waves, the pitch angle transport of resonant particles will be
3 orders of magnitude larger than standard theory.

EMIC Waves Cyclotron Resonant with 0.6 to 0.9 MeV Electrons

Table 3. Electron Anomalous Cyclotron Resonance With Two Cycles of an EMIC Wave of Conservative Amplitude 2.0 nT at a Variety of Different L Shells[a]

Parameters	$L=10$	$L=9$	$L=8$	$L=7$	$L=6$
V_{ph} (* 10^5 m/s)	2.2643	2.1946	2.3163	2.3732	3.499
Ωe (* 10^4 rad/s)	1.077	1.0873	1.2956	1.4756	3.4274
ω (rad/s)	3.107	2.255	2.6	3	3
$V_{\|\|}$ (* 10^8 m/s)	2.8025	2.886	2.9037	2.9057	2.9916
γ	2.8	3.66	3.98	4.019	13.37
$E_{\|\|}$ (MeV)	0.625	0.87	0.954	0.964	3.4
Δt (ms)	4.357	4.11	4.37	4.41	6.32
$\Delta\alpha$ (deg)	31.5	22.6	22.2	22.1	9.5
D (s^{-1})	34.65	18.87	17.08	16.85	2.18
T (ms)	28.9	53	58.5	59.3	457.8

[a]The rows, from top to bottom, are the wave phase velocity, the electron cyclotron frequency at the equator, the parallel speed of the electron along B_0, the parallel kinetic energy of the electron, the time of wave-particle interaction, the amount of particle pitch angle transport, the diffusion coefficient D, and the time for particle pitch angle diffusion T.

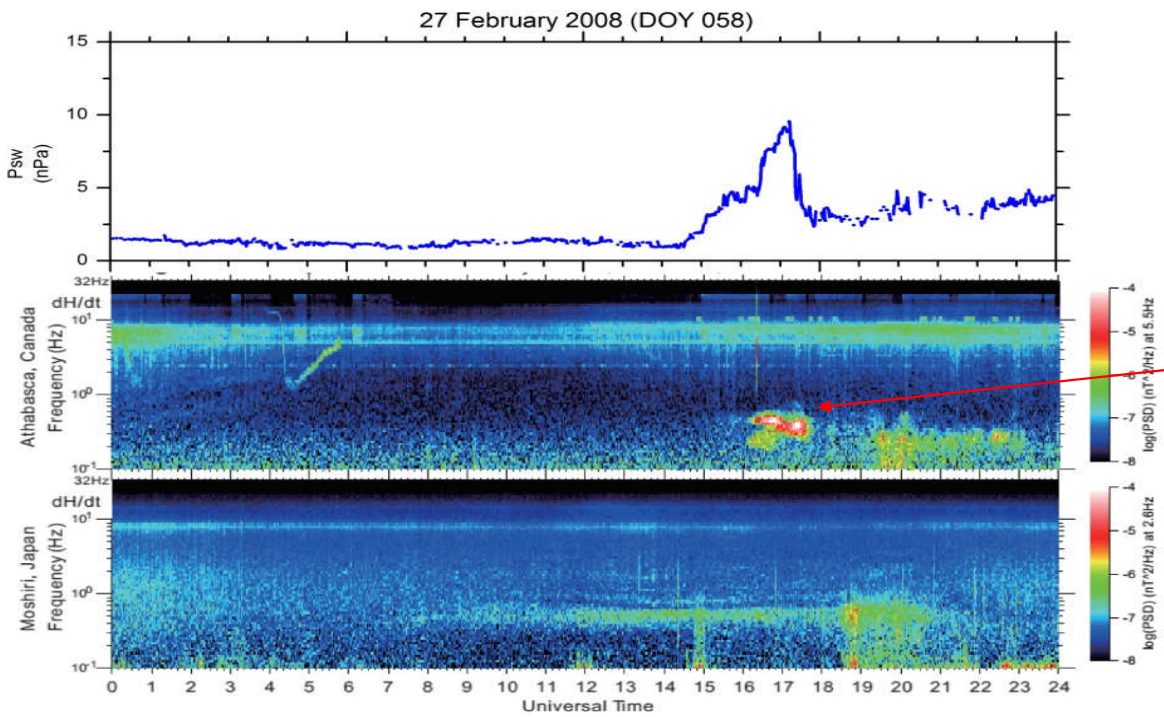
The change $\Delta\alpha$ in particle pitch angle for arbitrary α is obtained as: $\Delta\alpha = \frac{B}{B_0}\Omega\Delta t$

$\Delta\alpha = 23°$; $T = 53$ ms

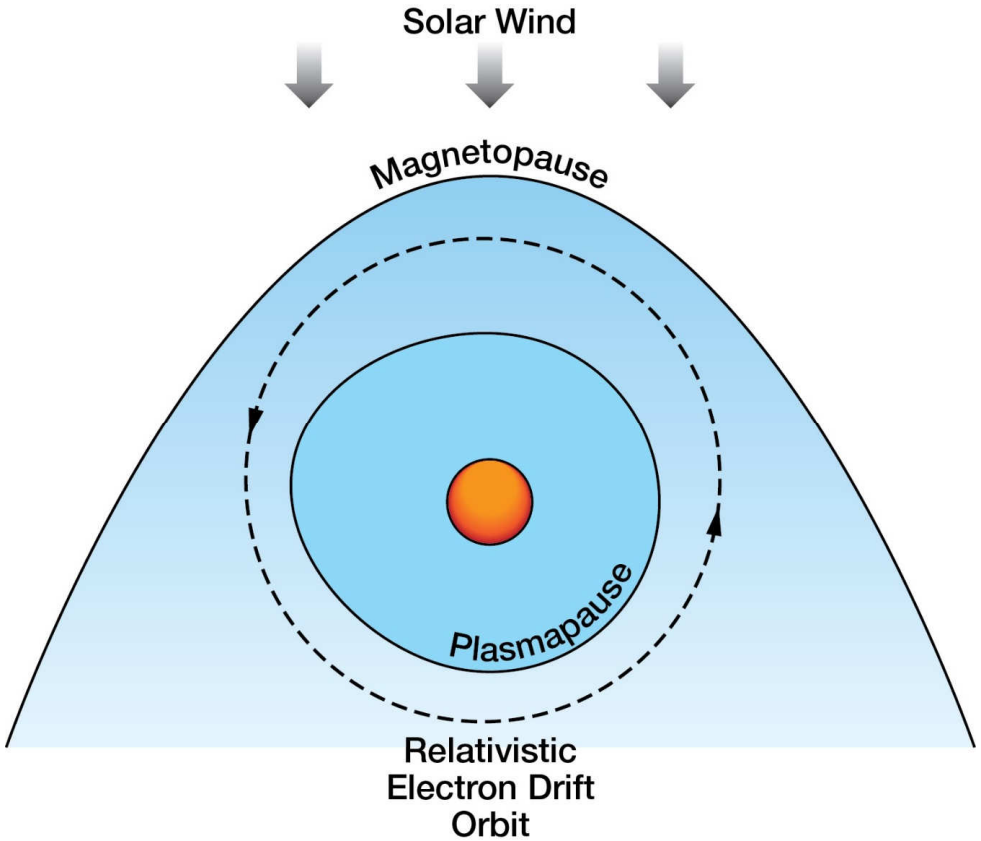
Simultaneous HPS Impingement and Nagoya Univ. ISEE Ground Magnetometer EMIC Waves

Athabasca, Canada
61.7° MLAT, ~09 MLT

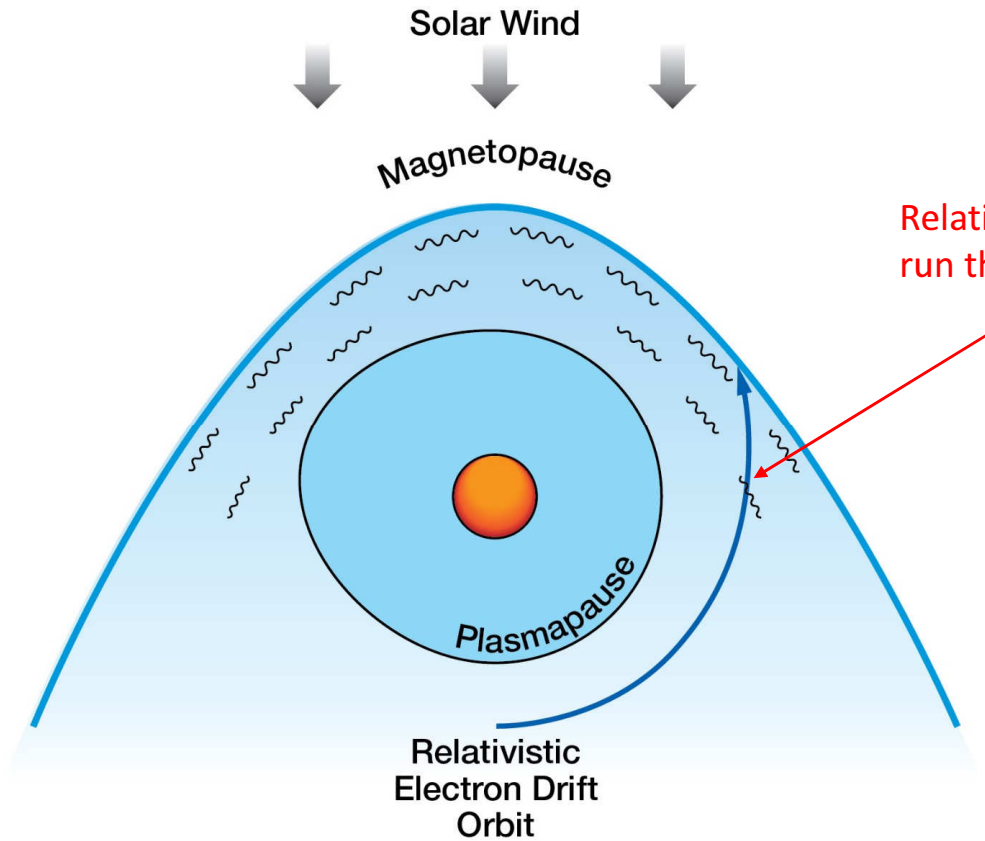
Moshiri, Japan
35° MLAT, ~02 MLT



“Before”

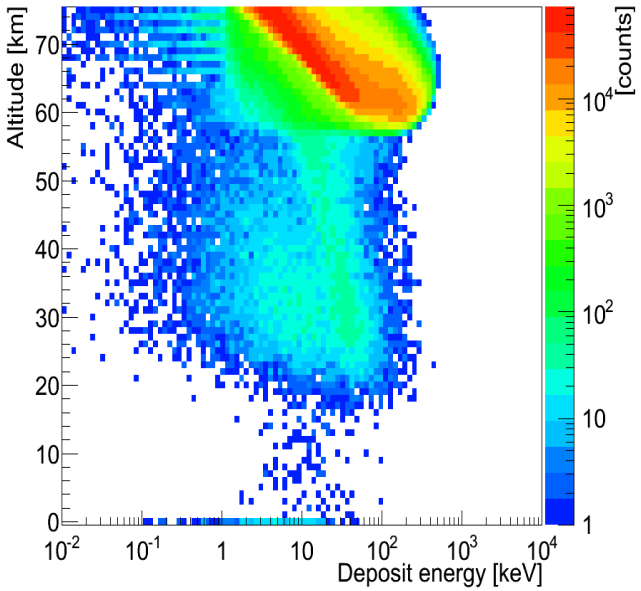

Solar Wind
Magnetopause
Plasmapause
Relativistic
Electron Drift
Orbit

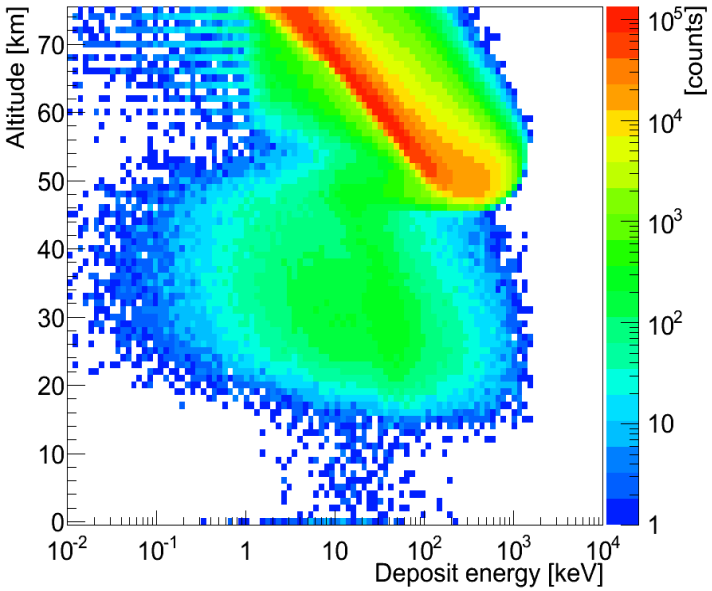
“After”



Relativistic electrons will have to run the EMIC wave gauntlet

The GEANT4 Monte Carlo Code Developed by CERN:
Importance of Precipitation by Relativistic Electrons



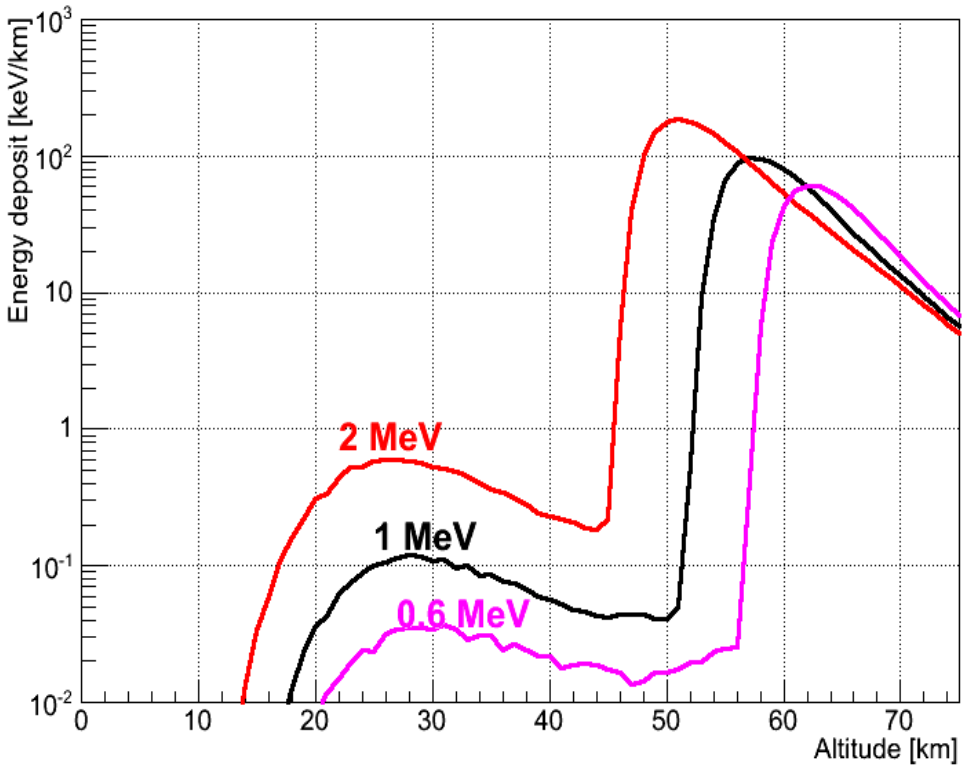


E > 0.6 MeV

E > 2.0 MeV

Vertical magnetic fields assumed in simulations

Energy Depostion as Function of Initial Energy and Altitude



For **E > 0.6 MeV** electrons a maximum of **~4 x 10^{17} ergs** deposited between **50 and 30 km** and **~ 3.0 x 10^{17} ergs** deposited **below 30 km** altitude

For **E > 2.0 MeV** electrons, a maximum of **~1.4 x10^{16} ergs** is deposited between **50 km and 30 km** altitude and a maximum of **~1.8 x 10^{16} ergs** is deposited **below 30 km** altitude.

This energy deposition in a limited region of space is higher than that of Cosmic Rays or Solar Flare particles

HCS crossings and atmospheric winds

- *Wilcox et al.* [1973] have reported a relationship between interplanetary heliospheric current sheet (HCS) crossings and atmospheric winds. They studied the average area of high positive vorticity centers (low pressure troughs) observed during northern hemispheric winters at the ~300 mbar level.

- Our hypothesis is that it is the REDs associated with the HPS crossings and not the HCS crossings that are causing the Wilcox et al. effect.

HCS crossings, interplanetary relativistic electrons and the global electric circuit

- *Tinsley and Deen* [1991] have proposed that an induced change in the current density of the global electric circuit could lead to climate change. The above paper was related to ionization effects from cosmic rays in the middle stratosphere. Later *Tinsley et al.* [1994] suggested that relativistic solar flare electrons could also cause the same effect.

- In the present paper we find no such interplanetary relativistic electrons, but we do show the disappearance (and suggested precipitation) of relativistic magnetospheric electrons. These magnetospheric particles will have higher energy flux deposition than either cosmic rays or solar relativistic electrons.

Can the energy deposited in the mesosphere somewhere between 50 and ~80 km altitude be important? Could the heating be associated with driving planetary or atmospheric gravity waves?

we take a 100 km x 100 km x 5 km volume

+6 K temperature increase if the energy is evenly distributed throughout the volume. Clearly "hot spots" will give substantially higher temperatures and this might be a source to directly drive the atmospheric waves.

NOx Production, ozone depletion: Tropopause Instability?

For the 50 km to 30 km altitude range, there will be 7×10^{27} electron-ion pairs formed and for the < 30 km altitude range there will be 5×10^{27} electron-ion pairs formed.

With a reduction of ozone in the stratosphere, the solar radiation will be absorbed at the tropopause. Could the additional heating lead to instability of this structure?

We have provided a number of scenarios for mechanisms to trigger climate change due to external (solar wind) influences. Further research will indicate which one (if any) is the correct path.

We think this is an interesting topic for young researchers in space physics to pursue.

Thank You For Your Attention