Relativistic Electron Precipitation Detections with CALET on the International Space Station

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for the CALET collaboration

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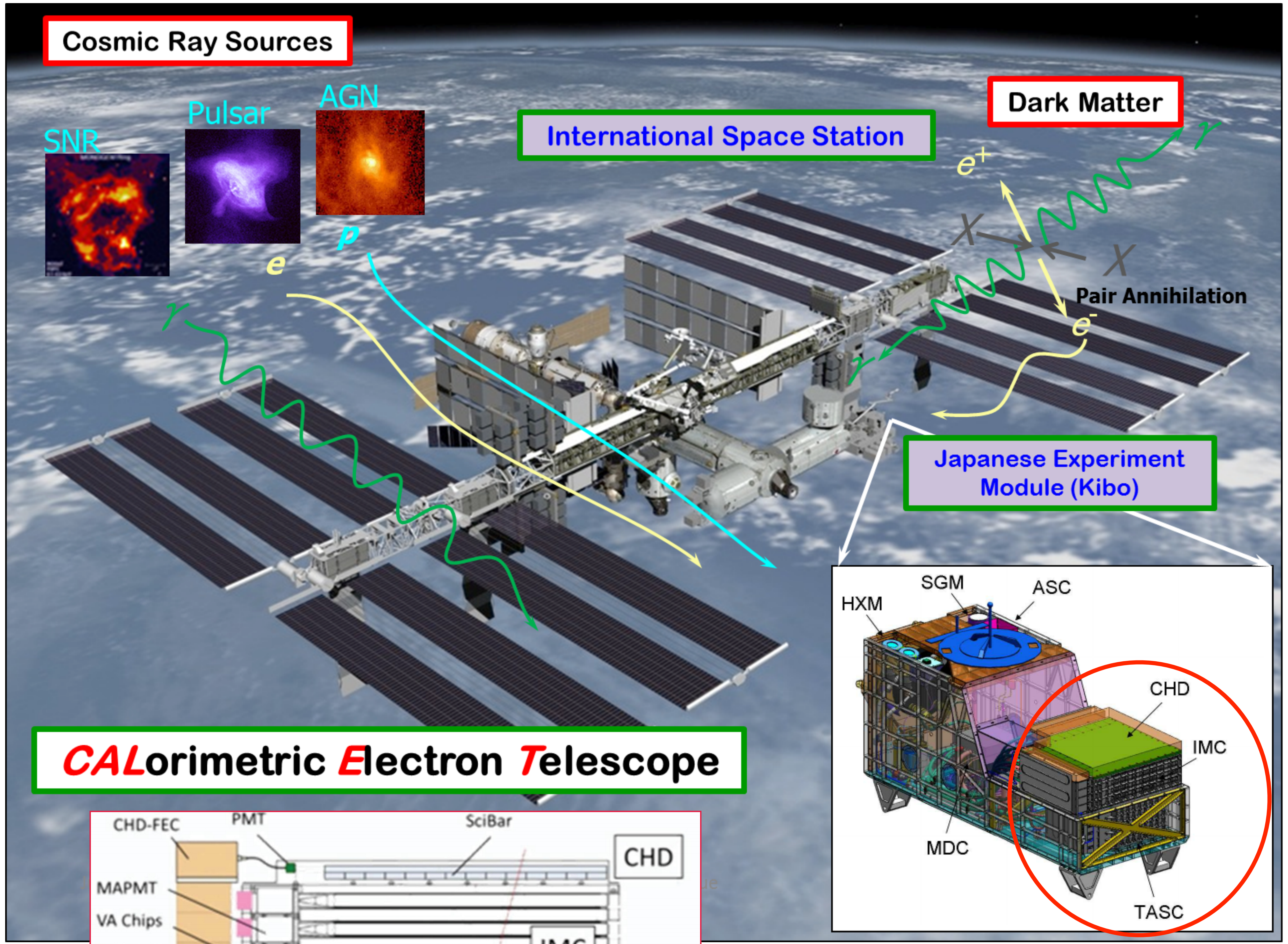
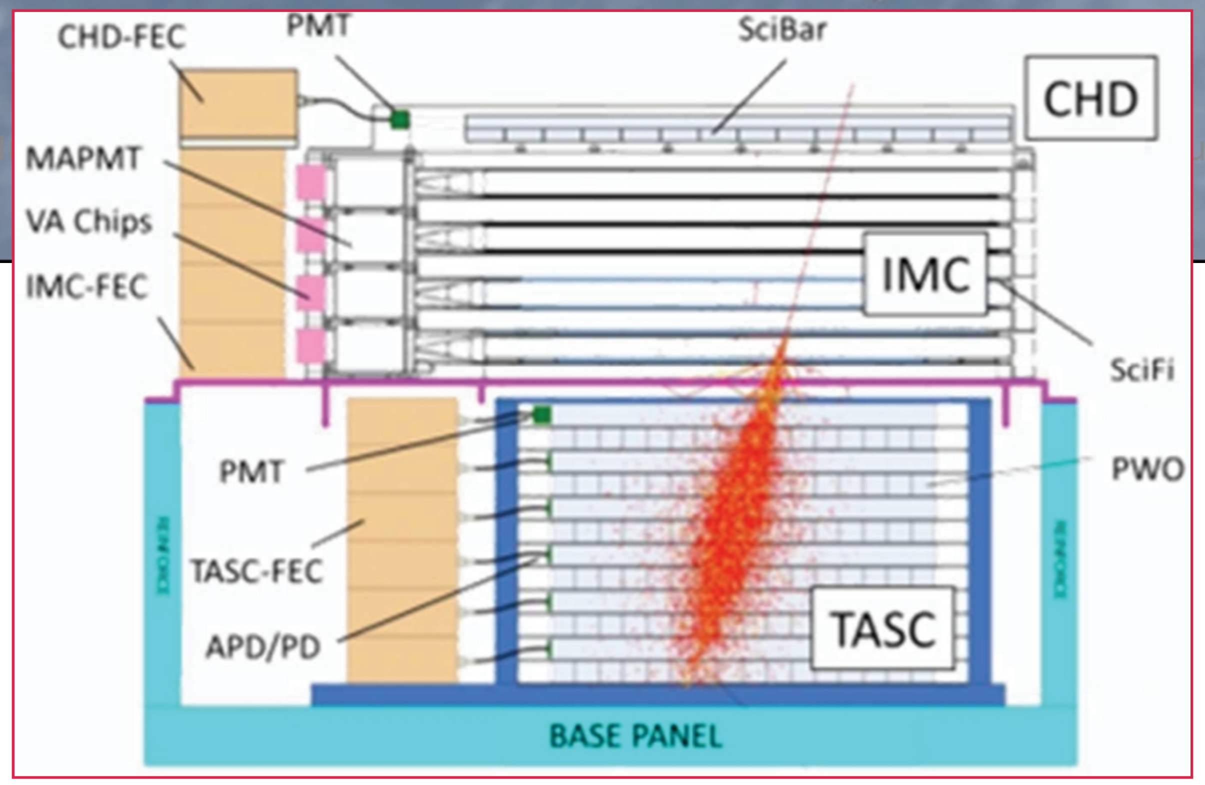
The CALET experiment on the ISS



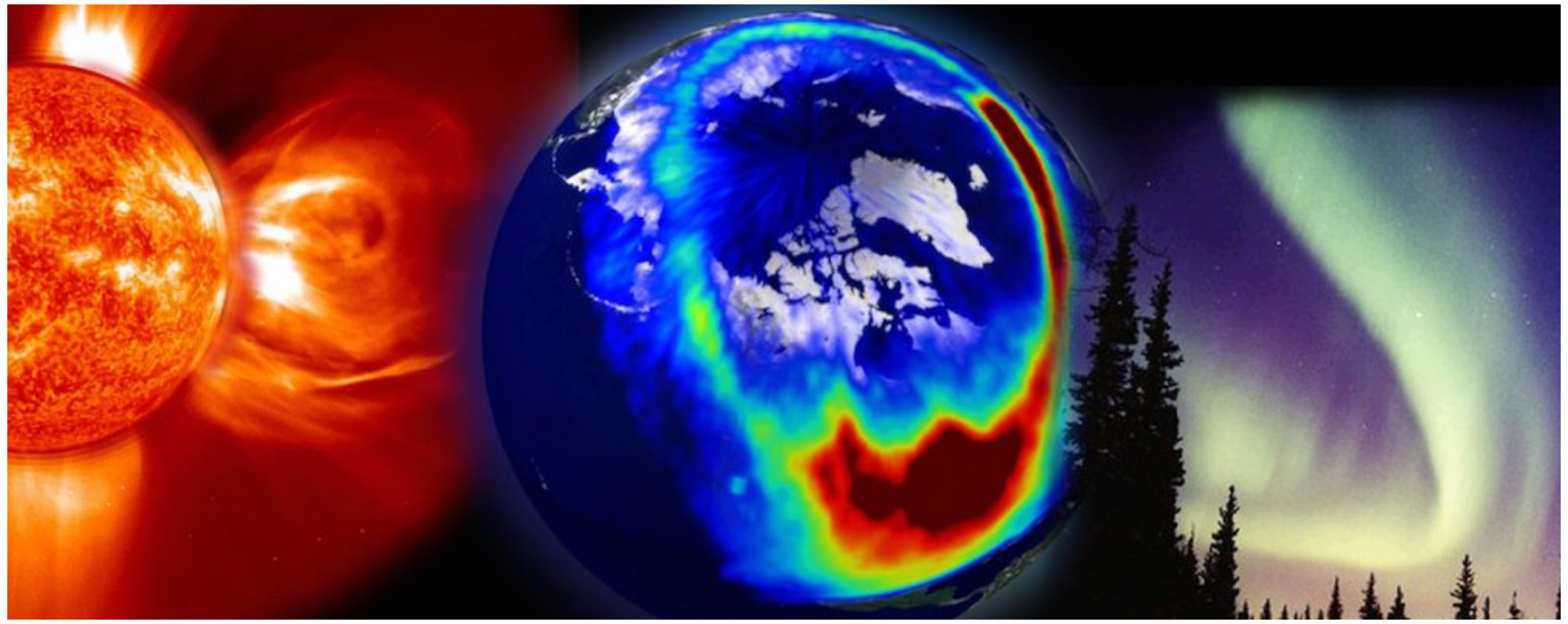


- The CALorimetric Electron Telescope (CALET) project is a Japan-led international mission in collaboration with Italy and USA, installed on the ISS in Aug 2015

- Large-area high-performance instrument primarily intended to investigate nearby cosmic-ray accelerators and search for dark matter by precisely measuring
  - ☑ all-electron and gamma-ray spectra in a wide energy range from 1 GeV to 20 TeV.
  - ☑ energy spectra of protons, heliums, and heavier nuclei up to 1 PeV/particle, and the ultra-heavy ($Z > 28$) nuclei composition above 600 MeV/n.

- It is composed by three sub-detector systems:
  - a two-layered hodoscope of plastic scintillators (**CHD**) providing charge measurements (Z=1 to ~40)
  - a finely-segmented sampling calorimeter (**IMC**) used to determine the incoming-particle trajectory
  - a homogeneous calorimeter (**TASC**) with a 27 radiation-length thickness, which completely absorbs the electron shower energy in the TeV energy range and separate electrons from the overwhelming flux of protons.

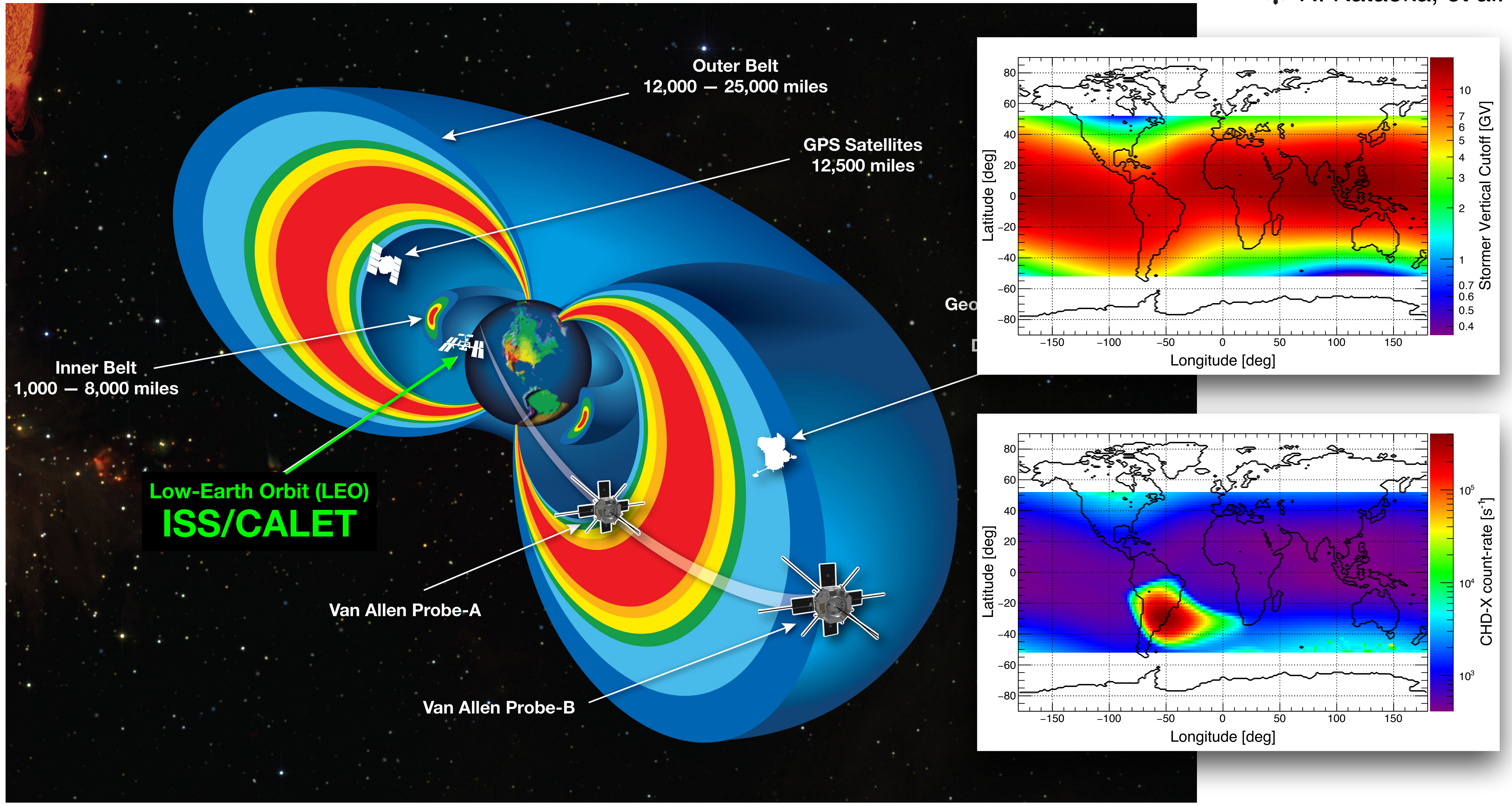
The CALET experiment on the ISS

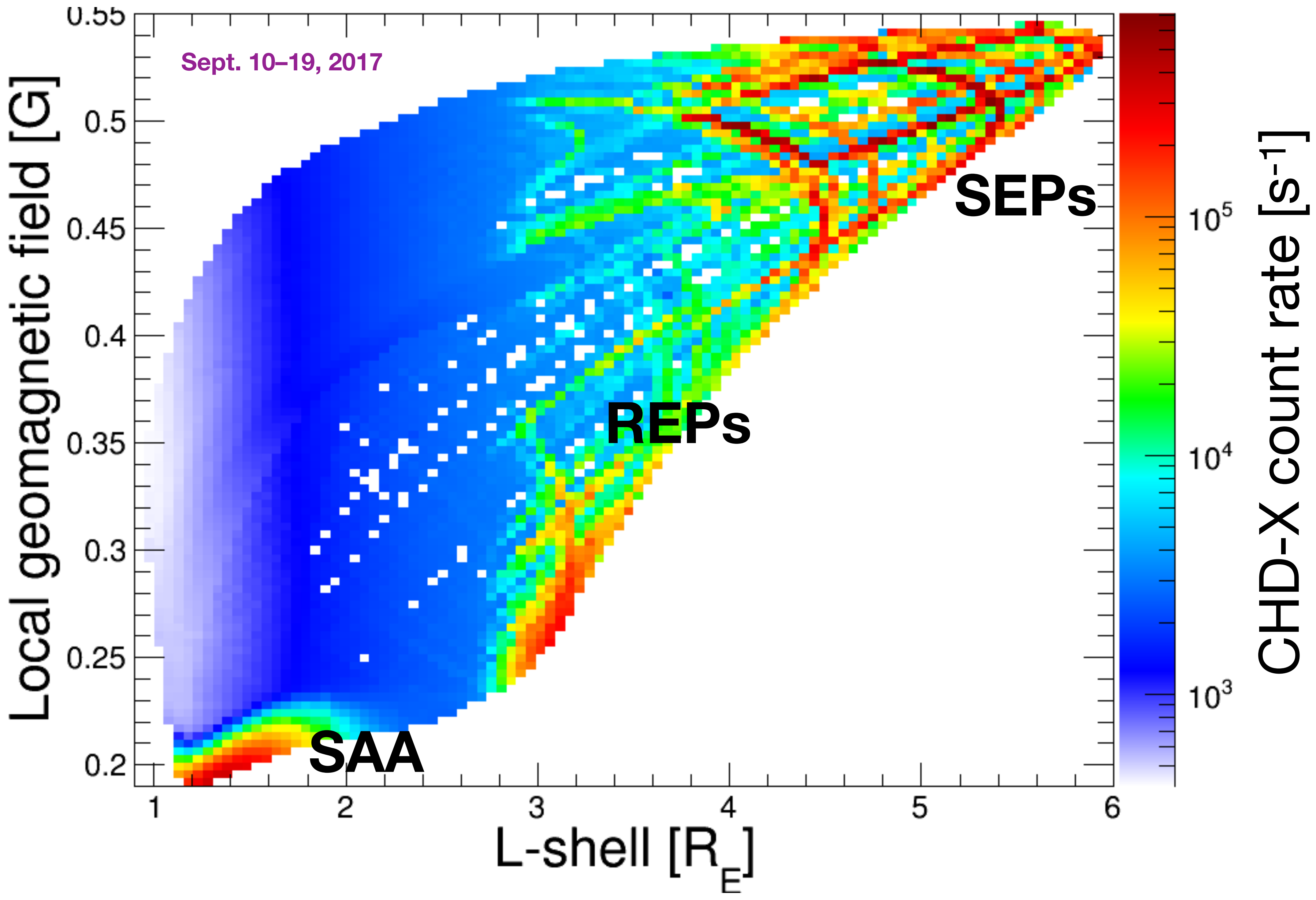


CALET is also able to provide a continuous monitoring of the space weather phenomena affecting the near-Earth environment, including

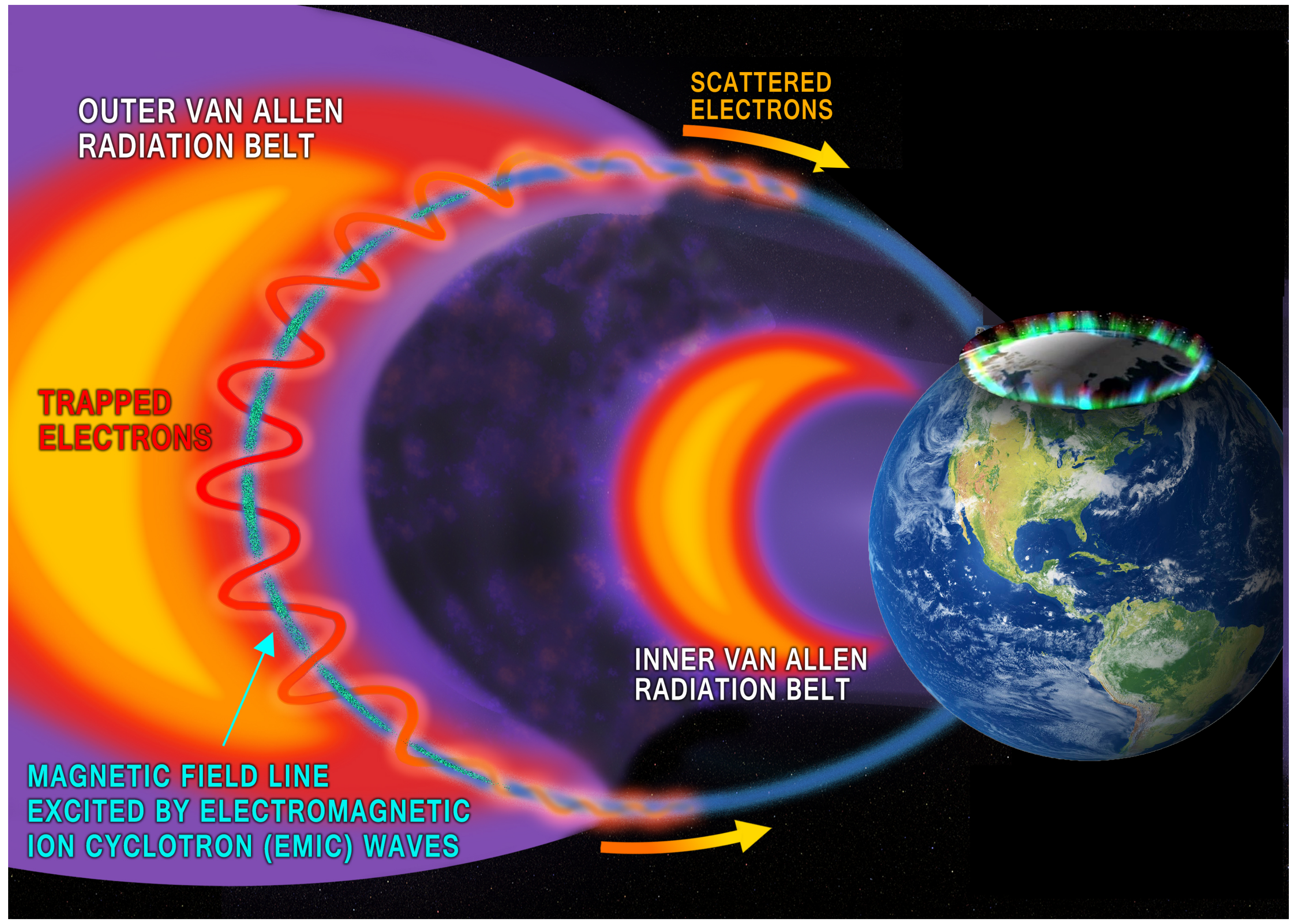
- ☑ solar energetic particles (SEPs) at high geomagnetic latitudes
- ☑ inner-belt protons in the South-Atlantic anomaly (SAA) region
- ☑ relativistic electron precipitation (REP) events near the inner boundary of the outer radiation belt

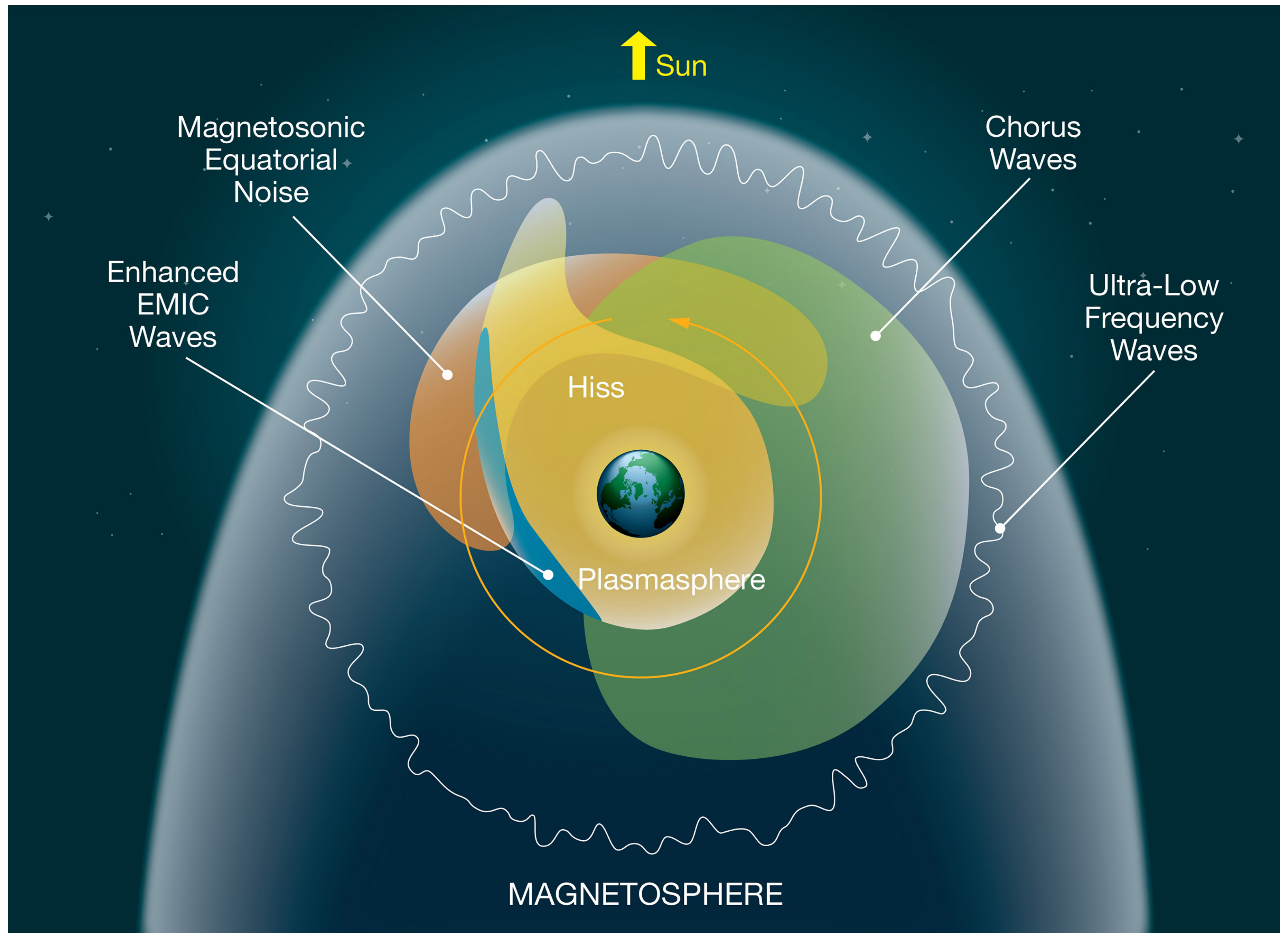
✻ A. Bruno, et al. 2019, PoS ICRC2019, 1063, https://doi.org/10.22323/1. 358.1063
✻ R. Kataoka, et al. 2016, Geophys. Res. Lett., 43, 4119, https://doi.org/10.1002/2016GL068930
✻ H. Ueno et al.,2020, Space Weather, 18, https://doi.org/10.1029/2019SW002280
✻ R. Kataoka, et al. 2020, J. Geophys. Res. Space Physics, 125, e2020JA027875, https://doi.org/ 10.1029/2020JA027875



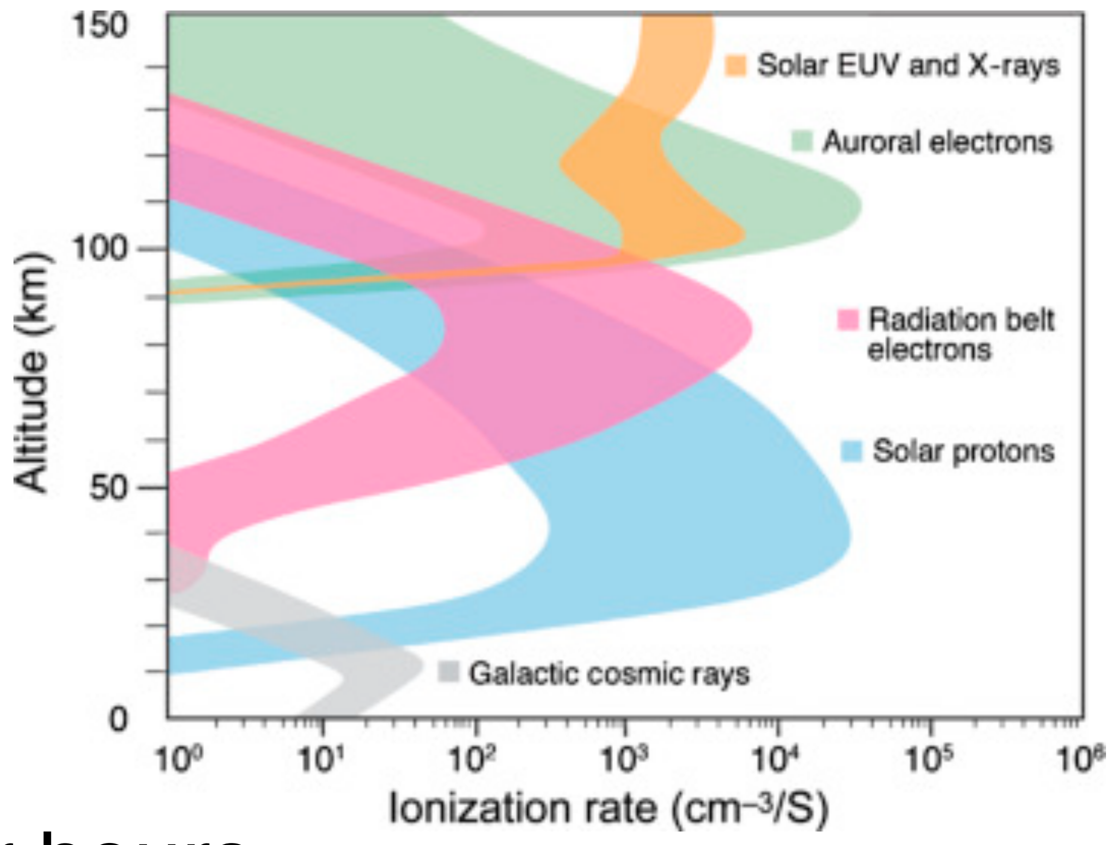


Relativistic Electron Precipitation



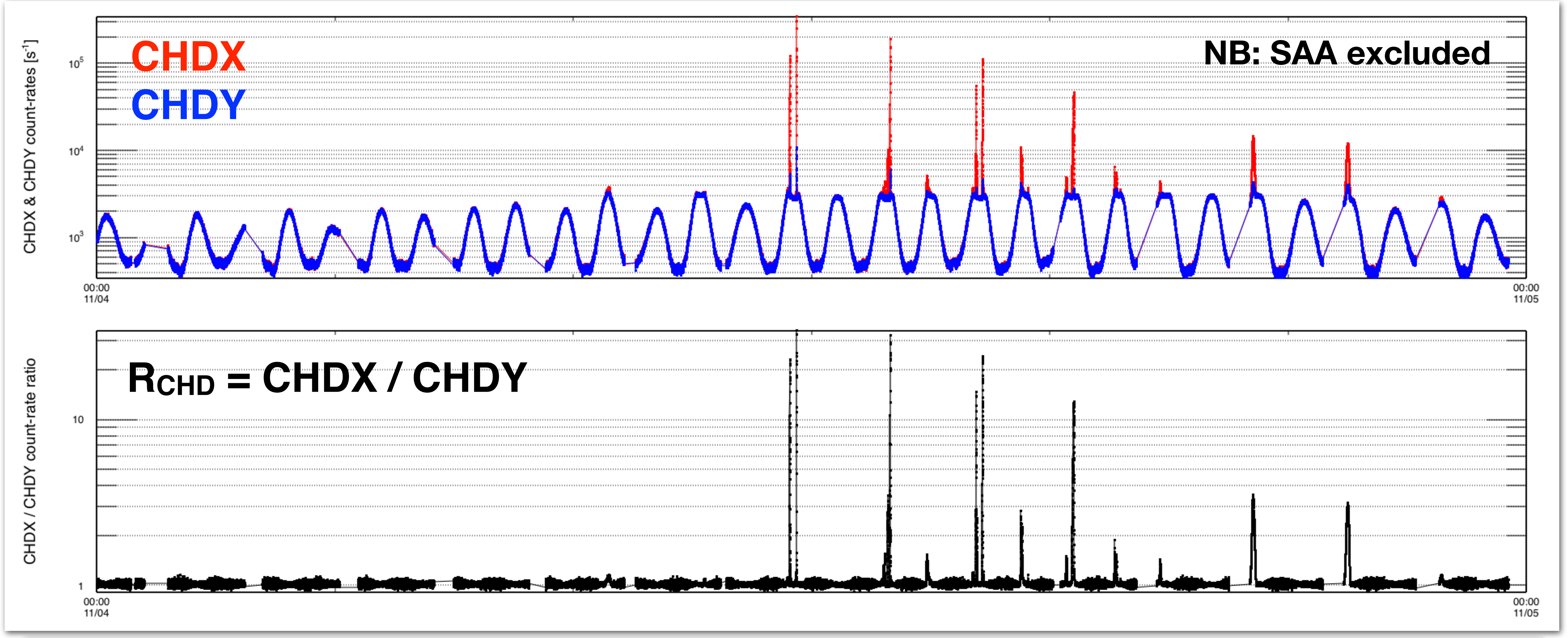


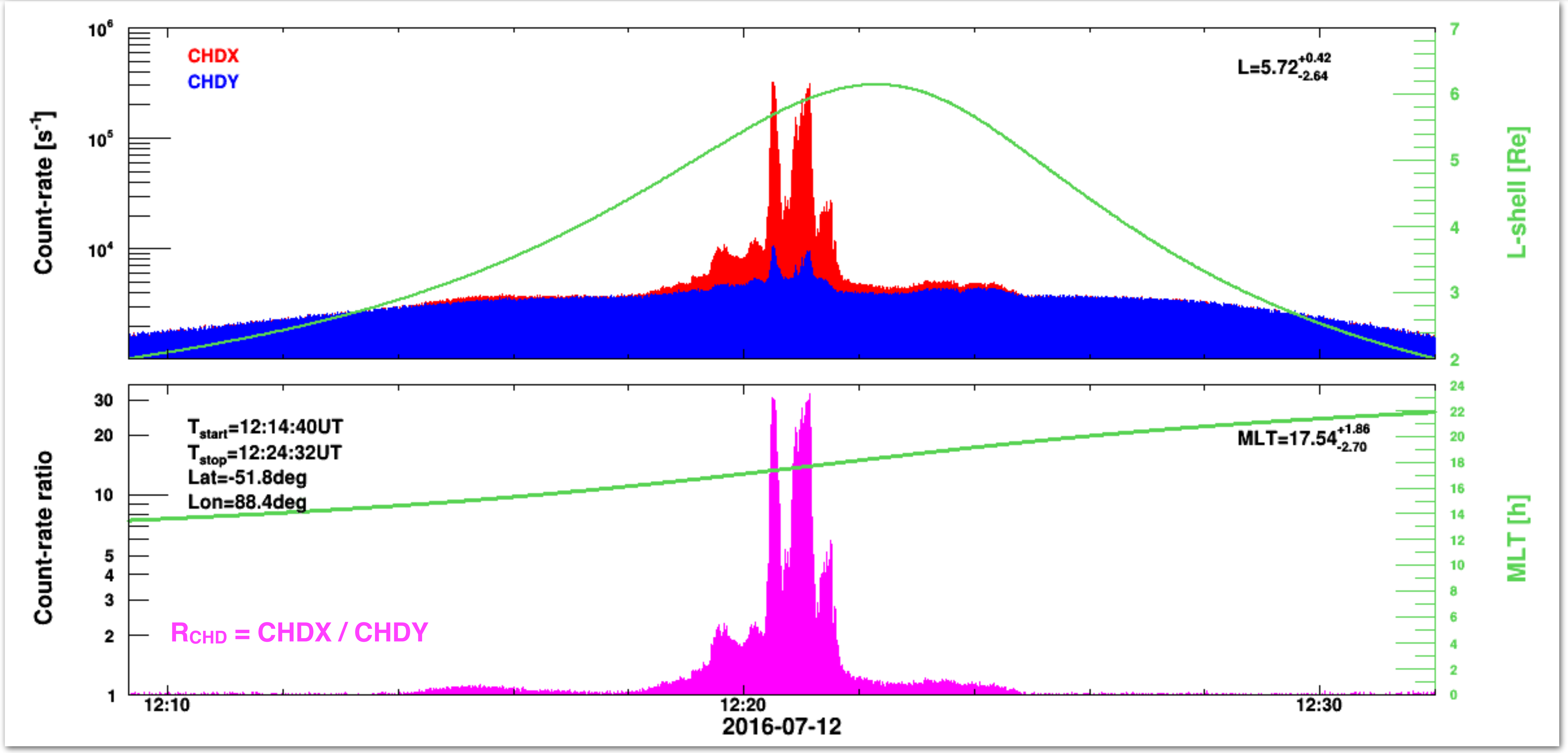
- REP is a Space Weather phenomenon in which energetic electrons penetrate into the upper or middle atmosphere, strongly influencing the electrodynamics and chemical structure



- Common phenomenon near the high-latitude boundary of the outer radiation belt
- Limited to few degree bands, sometime persisting for hours
- Globally, REP events occur mostly during the declining phase of the solar cycle, typically in association with high-speed streams and under active geomagnetic conditions
- They can be driven by different types of magnetospheric waves, including:
  - ☑ Plasmaspheric HISS,
  - ☑ Whistler mode chorus,
  - ☑ EMIC waves
- Other possible mechanisms include field-line curvature scattering and loss through the magnetopause

REP event identification with CALET



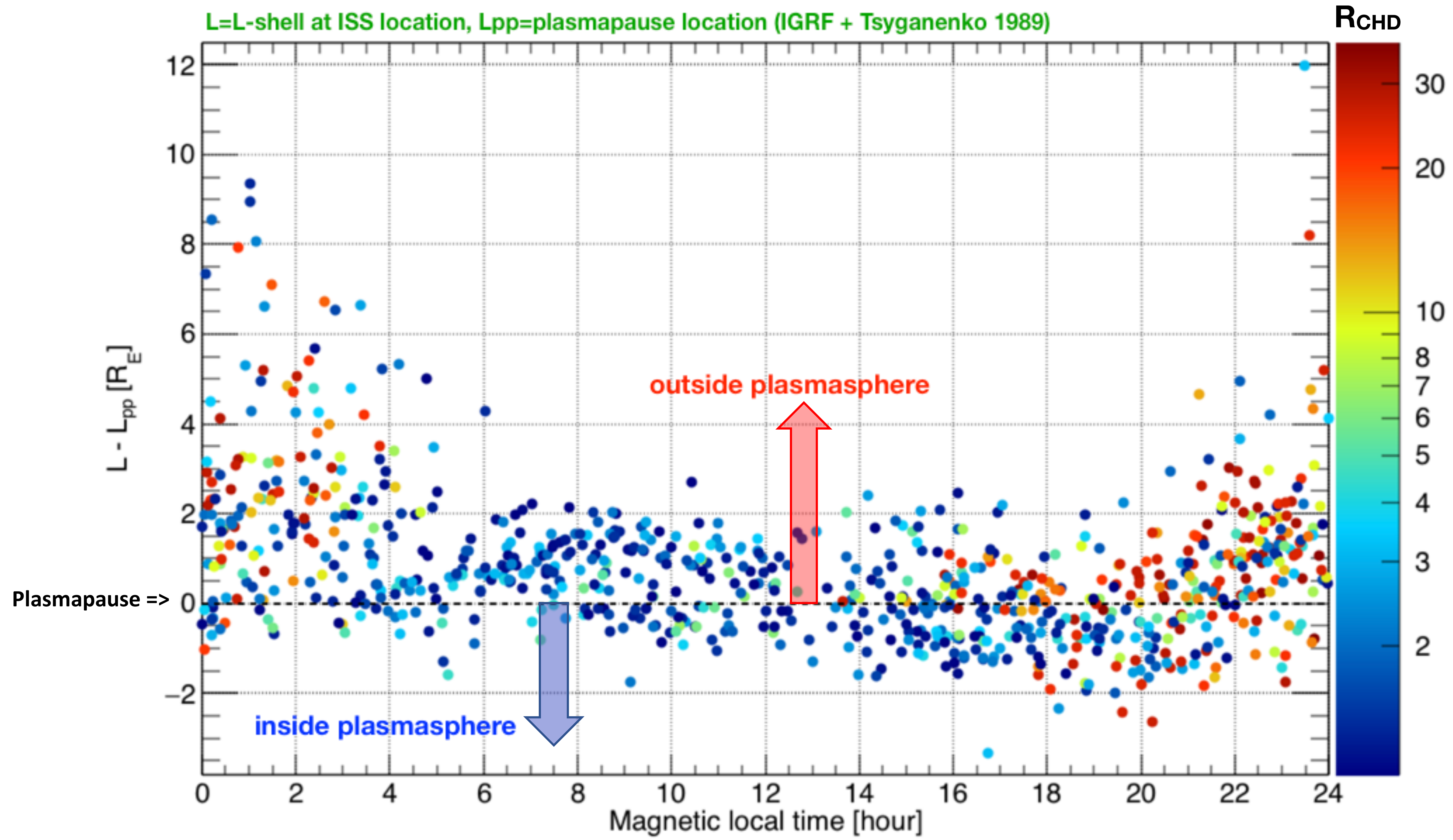


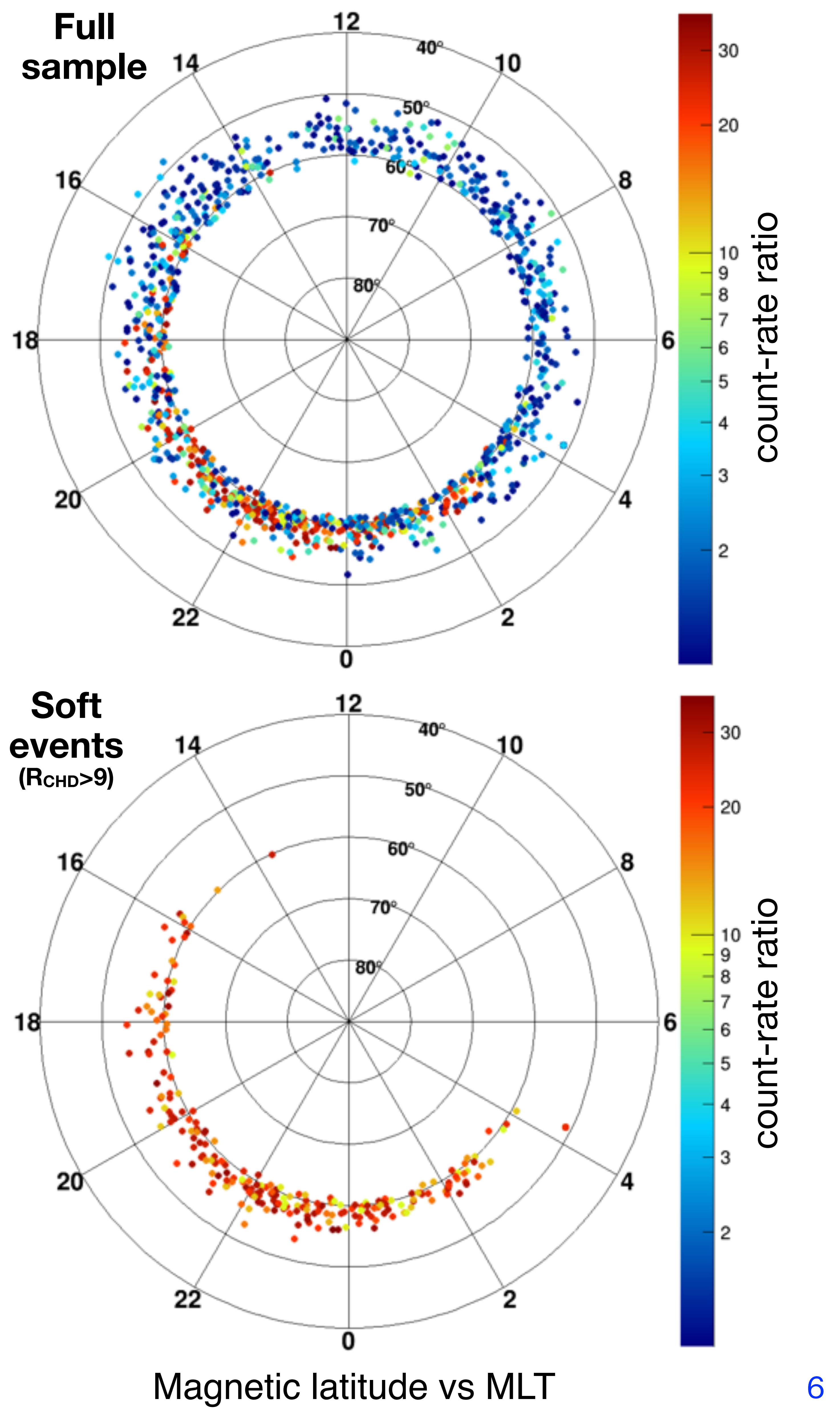
- For this analysis we used the count-rate measurements from the two CHD layers
  - ☑ CHDX, electron threshold ~1.5 MeV
  - ☑ CHDY, electron threshold ~3.4 MeV
- ~ 20-min observational intervals at highest magnetic latitudes (outer-belt boundary)
- REP selection:

$$R_{xy} = CHDX/CHDY > 1 + 3\sigma_R$$

- The count-rate ratio provides an estimate of the spectral hardness
- SAA region ($B<0.25$ G, $L<2.6$ R_E) and SEP event intervals excluded

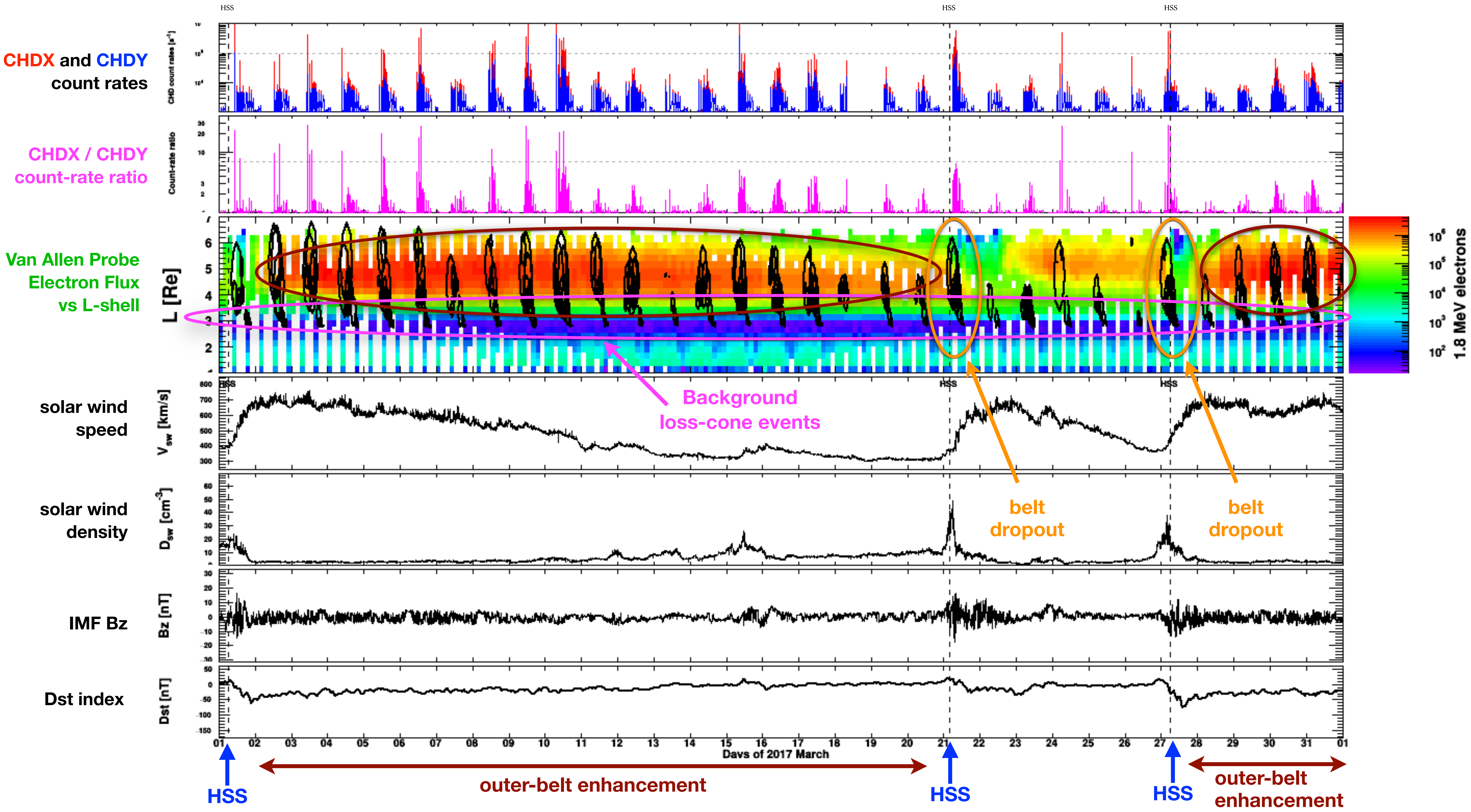
REP spatial distribution





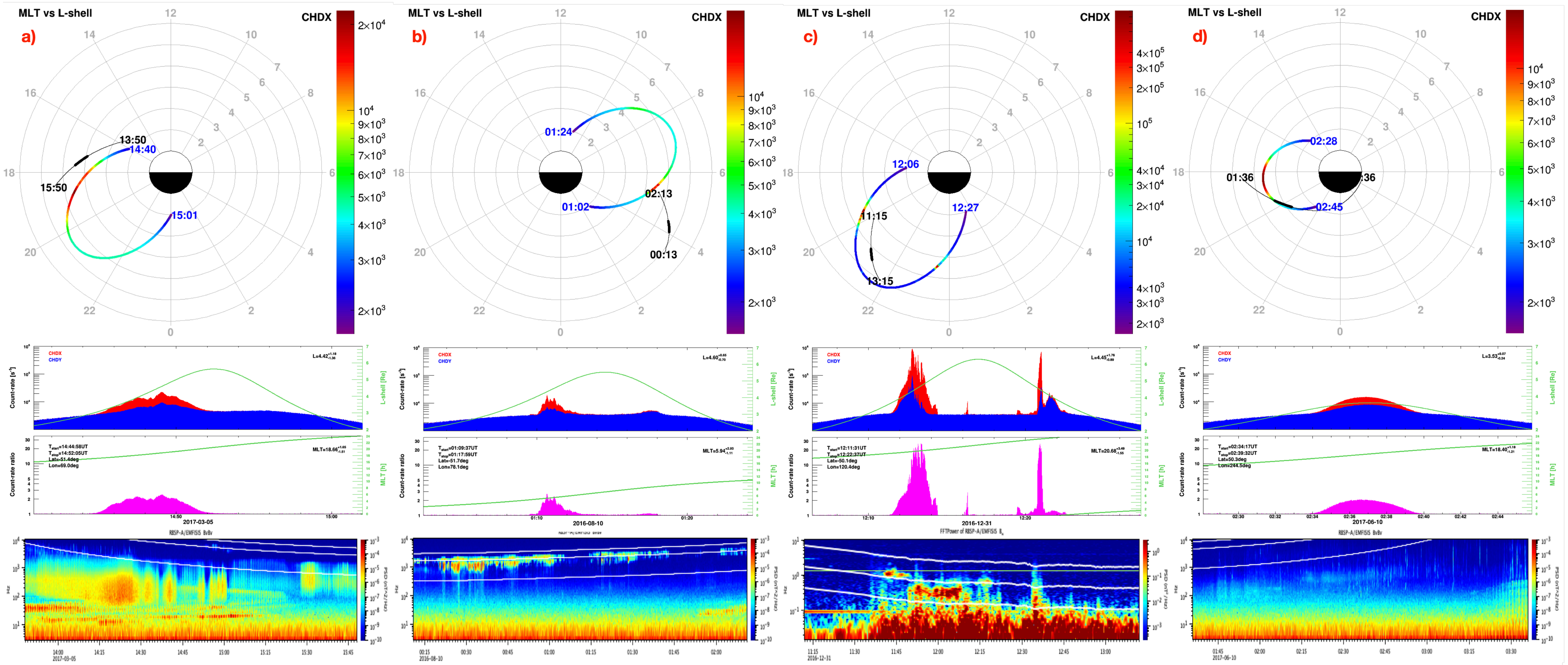
REP events are found to concentrate around the plasmapause. On average, the distribution corresponding to high CHDX/CHDY count-rate ratio (red) is located outside the plasmasphere

CALET REP observations and contextual data



To have a clearer view of the detected REP events, we compared CALET observations (top two panels) to outer-radiation belt electron measurements (third panel) and other contextual data, including interplanetary and geomagnetic parameters (last four panels). This figure shows the different observations as a function of time, during a sample month (March 2017). In particular, the third panel shows the 1.8 eV electron flux measured by the Van Allen Probes vs L-shell, with the black ovals marking the corresponding CALET REP detections. We can essentially subdivide the CALET REP sample into three categories. The first corresponds to events recorded during periods of enhanced outer-belt electron intensities (dark-red ovals). The second comprises events detected during intervals of outer-belt depletions (orange ovals), typically following the arrival of solar-wind structures. The third category includes ordinary loss-cone electrons, commonly observed at relatively low latitudes around *L*~3 R_E (magenta oval). This precipitation is not necessarily linked to local scattering mechanisms, and constitutes a background component to REP events.

Wave drivers



We took advantage of the plasma wave measurements of the Van Allen Probes in the equatorial plane to investigate the drivers of the MeV electron precipitation observed by CALET. A coordinated study is in progress based on the analysis of conjunction intervals during the time period in which both missions were operative (October 2015 – June 2019). Four sample events are reported here. The MLT vs L dial plots in the the top panels display the trajectory of the ISS during the selected REP interval (~20-min), with the color code indicating the CHDX count rate; for comparison, the black curve denotes the trajectory of one of the Probes during the 2-hour interval around CALET detection, marked by the thick segment. The middle panels display the CALET count-rates and count-rate ratios. Finally, the bottom panels show the magnetic field measurements made by the Probes during the 2-hour interval around CALET detection. Such results suggest, for the first three events, an association with three different wave drivers, namely plasmaspheric Hiss waves (a), whistler-mode chorus waves (b) and electromagnetic ion cyclotron (EMIC) waves (c), respectively. On the other hand, the fourth event (d) is a typical loss-cone event commonly observed at relatively low drift shells, apparently not linked to any particular wave activity.

Summary and future work

The CALET experiment on the ISS is able to provide a continuous monitoring of space-weather phenomena affecting the near-Earth environment, including relativistic electron precipitation. Its observations in LEO can be used to complement those of the Van Allen Probes in the highly-eccentric orbit.

We are carrying out a coordinated study between the two missions to identify the wave populations generated near the magnetic equator which are potentially responsible for the electron precipitation directly observed by CALET.

In addition, taking advantage of the large recorded data sample, we plan to perform a statistical investigation of REP occurrence vs solar-wind/geomagnetic drivers, in order to sort REP events by wave-driver and precipitation type (temporal profiles, spectral hardness, etc.), enabling a more complete picture of the global precipitation origin and rates.