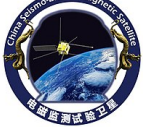

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TIFPA
Trento Institute for Fundamental Physics and Applications

A statistical study of lighting-induced electron precipitation (LEP) events observed by CSES-01

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EGU25 Vienna, 30/04/2025

Lightning-induced Electron Precipitation (LEP)

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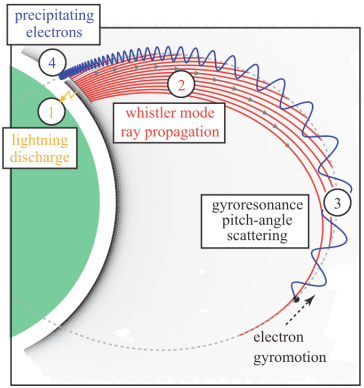


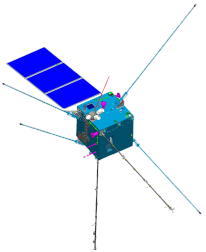
1. small fraction of lightning pulse penetrates magnetosphere and propagates as Whistler mode wave
2. Whistler wave travels with (0.1-0.01)c either obliquely or as duct in plasmasphere
3. at equatorial region (1-10)kHz Whistlers interact with electrons of (100-300)keV in cyclotron resonance and cause pitch angle and energy scattering
4. electrons scatter from trapped orbits to bounce loss cone and precipitate in upper atmosphere

[Inan, U. S., et al. (2010) doi:10.1029/2009JA014775]

- delay from lightning to VLF amplitude change from $<$50 ms to 2 s depend on ducted/non-ducted Whistlers
- ducted Whistler interaction result in poleward particle precipitation, non-ducted interaction more localized

China Seismo Electromagnetic Satellite (CSES-01)

- CSES-01 launched 02/02/2018
- from the Jiuquan Satellite Launch Center in the Gobi Desert (Inner Mongolia)
- sun-synchronous orbit at $\sim$ 500 km altitude
- Inclination 97°
- Period 94 minutes
- Revisit period 5 days
- Mission Life Span $\geq$5 years
- 9 payloads onboard:
  - Search Coil Magnetometer (SCM) for EM wave detection
  - High Energy Particle Package (HEPP-L) for low energy electron



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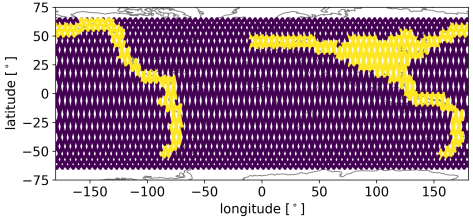
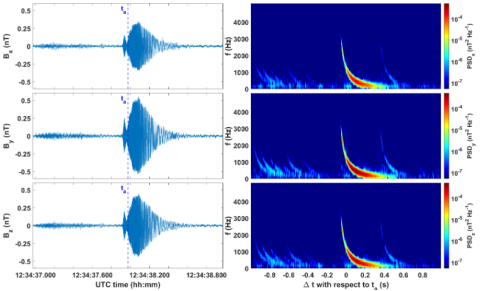
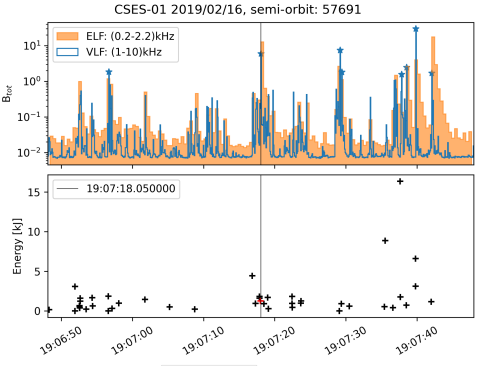


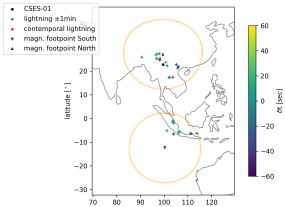
modes: burst / survey

Whistler wave detection & Lightning

Example Whistler wave measured by SCM of CSES-01







- Whistlers seen as sharp peaks in total PSD
- strict time window allows correlation with WWLLN
- Whistler Identification by Spectral Power Estimation and Recognition (WhISPER) algorithm
  [D. Recchiuti et al., Atmosphere 2025, 16(5), 522]

Combination of wave and particle observations

CSES-01 SCM & telescope 0 of HEPP-L

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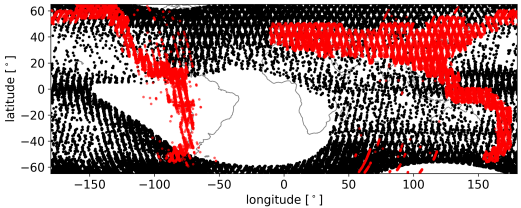
01/2019 - 12/2022:
black: electron bursts (HEPP-L ch 0 100-150 keV)
red: Whistler waves (SCM VLF burst mode)

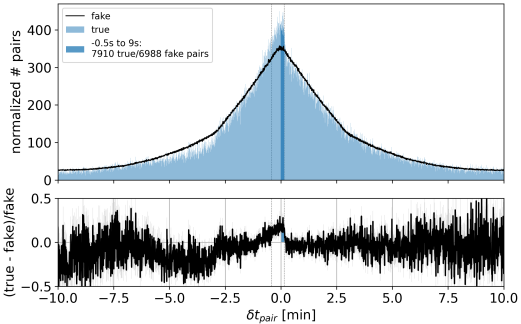


(100-150) keV	tot
PBs	**809,170**
SCM spikes	**68,489**
Partners $0 \leq \delta t \leq 9s$	**7,910**

Search for causative correlation:

- search for SCM peak for every PB in same orbit

$$\delta t_{pair} = t_{PB} - t_{wave} \quad (1)$$

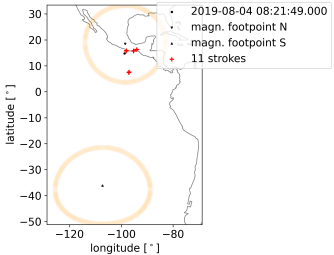


- excess observed between (-25 to 9) seconds
- selection of pairs with wave before PB

Identification of LEP events

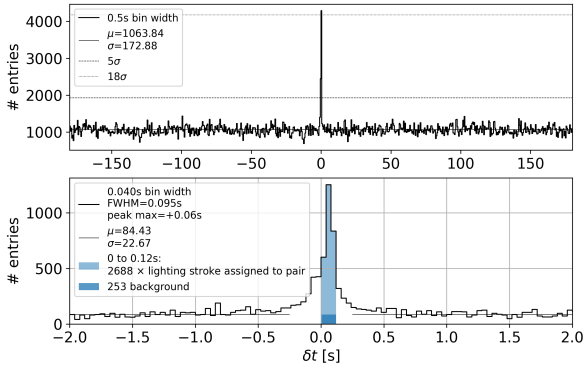
connect wave-particle pairs with WWLLN lightning database

- search for lighting within 15° cone around magnetic footpoints



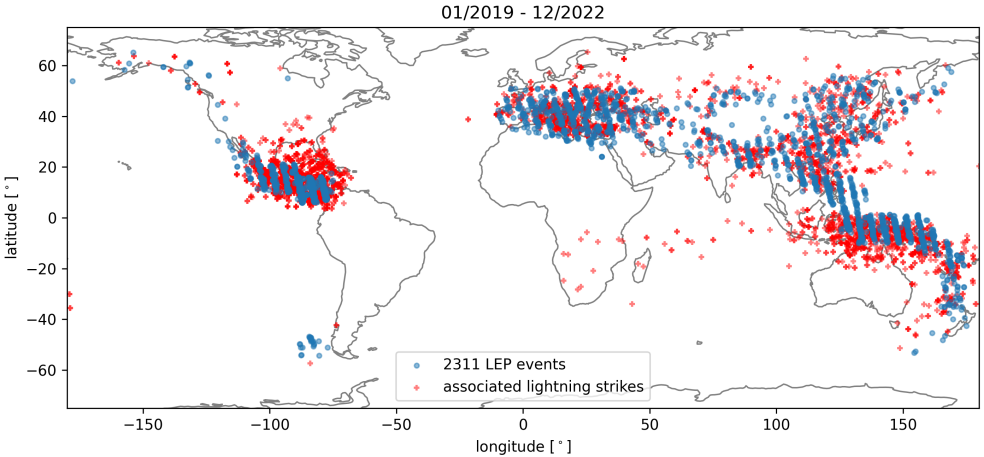
- example with most 11 lighting strikes

$$\delta t = t_{wave} - t_{lightning}$$



- sharp peak at $\sim +60$ ms
- SCM VLF time resolution of 80ms (in burst mode)
- 2,311 LEP events: for 29% of pairs found $\geq$1 lightning strike

Total LEP events



- 212 (8%) events with lighting around the conjugate magnetic footpoint

Seasonality of LEP events

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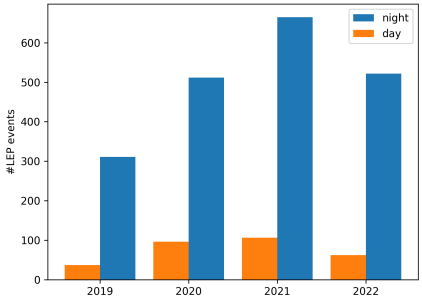

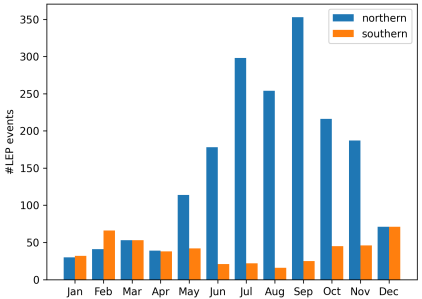

- most LEP events during night-time (transparent ionosphere)
- seasonality consistent with summer periods on southern and northern hemisphere

Deviation between lightning and magnetic foot of particle precipitation

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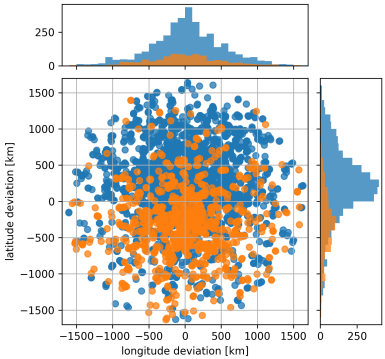

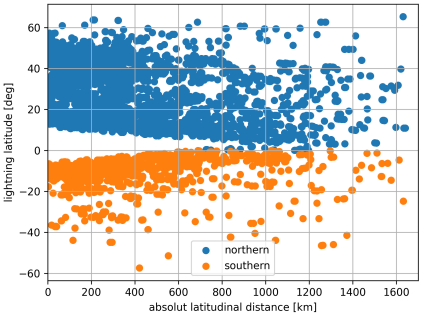

- most LEP events found within distance $< 500\,\mathrm{km}$
- magnetic foot mostly at higher latitudes
- low latitude lightings result in larger distant LEP events

Conclusions & Outlook

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- CSES-01 Search Coil Magnetometer (SCM) data successfully used to identify Whistlers
- CSES-01 HEPP-L data provides low energy electron flux

$\rightarrow$ the combination of both allows the identification of wave-particle interactions

- in 4 years we could identify 2311 lightning-induced electron precipitation events:
  - by strict constrains on causality and timing
  - Whistler $\rightarrow$ electron precipitation correlation proven above background model
  - lighting $\rightarrow$ Whistler causality observed with 18σ significance
  - all with help of WWLLN as ground reference

$\rightarrow$ publication in preparation

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Thank you for the attention!

BACKUP

Number of lightning strikes per LEP & length of particle precipitation

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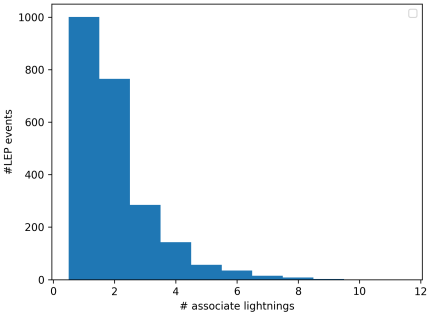

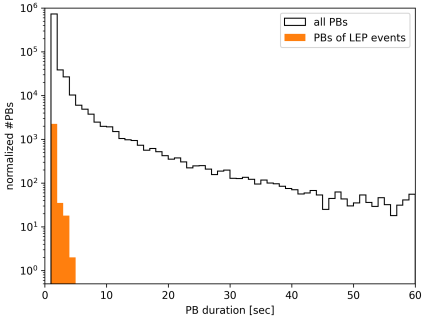

- usually found 1-2 associated lightning strikes
- electron precipitations are short (most 1 second), 4 seconds long