Spatial Distribution of Plasma Density in Earth's Radiation Belts Using Van Allen Probes Observations

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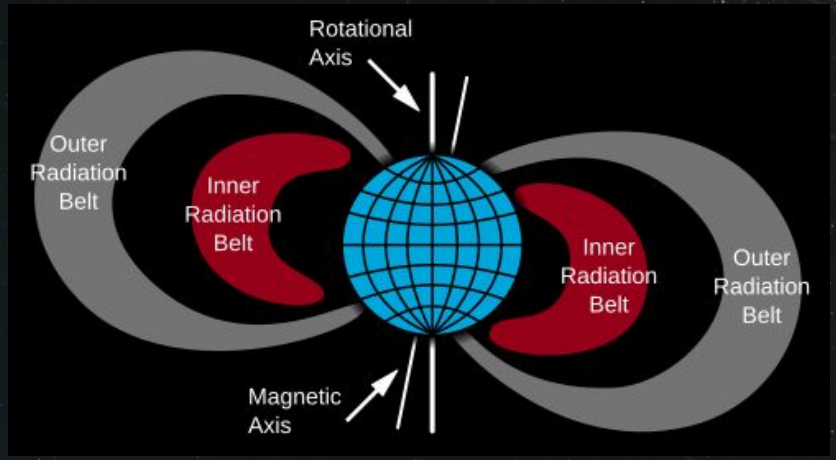
NASA | Van Allen Probes | University of Iowa

Earth's Radiation Belts

- Impact satellite operations
- Radiation risk for astronauts
- Key driver of space weather
- Electron acceleration & loss processes



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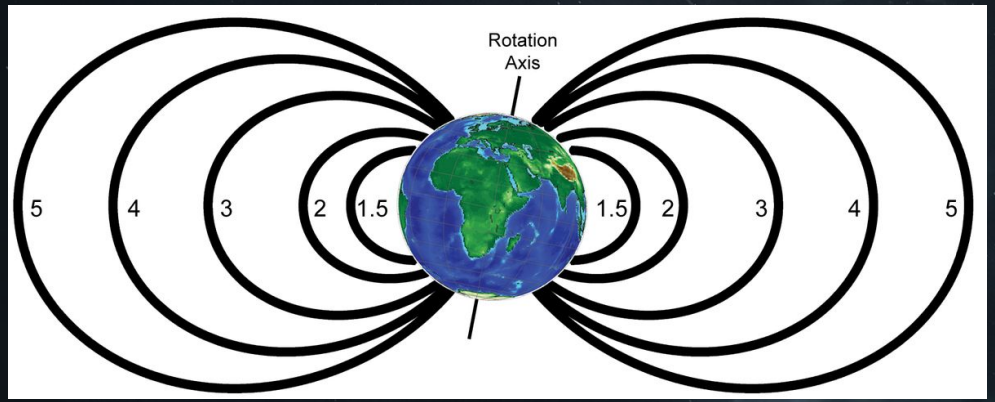
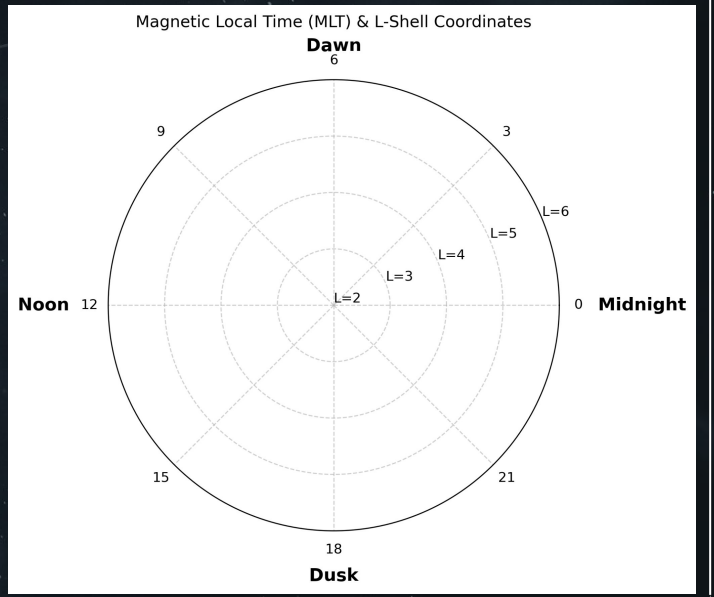
Magnetosphere Coords (L-shells and MLT)



Golden, Wikimedia Commons

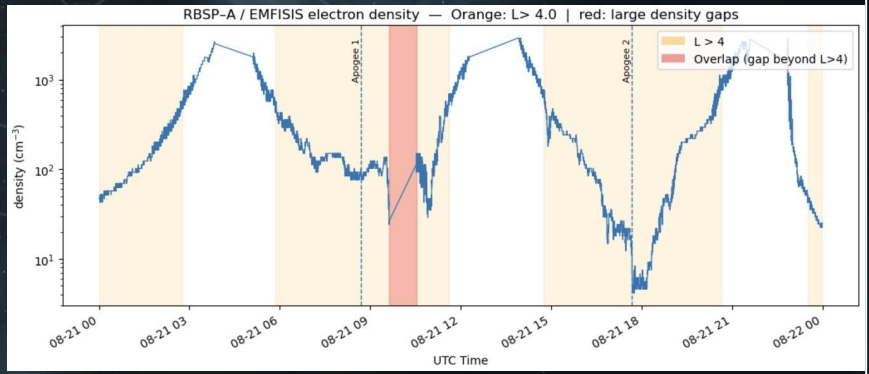
L-shells



Magnetic Local Time (MLT)

What's the Challenge?

- Wave-particle interactions control electrons
- Strongly dependent on plasma density
- Low-density regions at high L-shells
  - Poorly understood environments
- Density controls wave propagation and growth
- Determines electron acceleration & loss



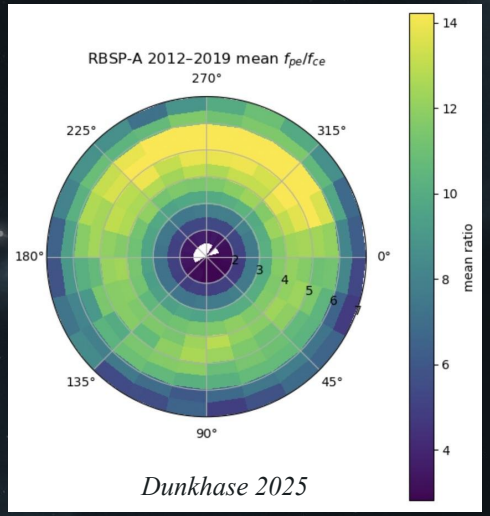
Dunkhase 2025

Research Goal

- Map plasma density structure
- Focus: Outer belt and L-shells
- Compare geomagnetic activity

Data Sources:

- Van Allen Probes (RBSP-A)
- EMFISIS instrument
- World Data Center for AE Index, Kyoto (geomagnetic activity)
- Time range: 2012–2019



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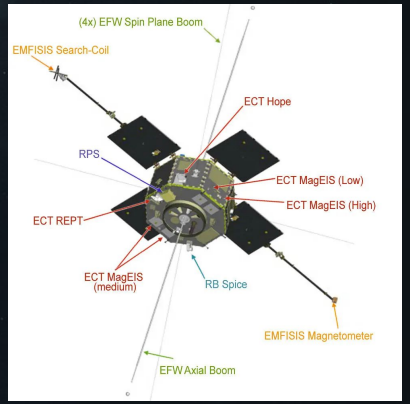

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Methods

- Map to L-shell & MLT & bin data
- Separate by AE activity

Key Parameters:

- Electron Plasma Frequency (w_pe)
- Electron Cyclotron Frequency (w_ce)
- Density Proxy: w_pe/w_ce

$$\omega_{pe} \approx 56400\sqrt{n_e} \ \text{[kHz]}$$

$$\omega_{ce} = \frac{eB}{m_e} \approx 176B \ \text{[kHz]}$$

$$\frac{\omega_{pe}}{\omega_{ce}} \approx \frac{310.71\sqrt{n_e}}{B}$$

$$\frac{\omega_{pe}}{\omega_{ce}} \propto \frac{\sqrt{n_e}}{B}$$

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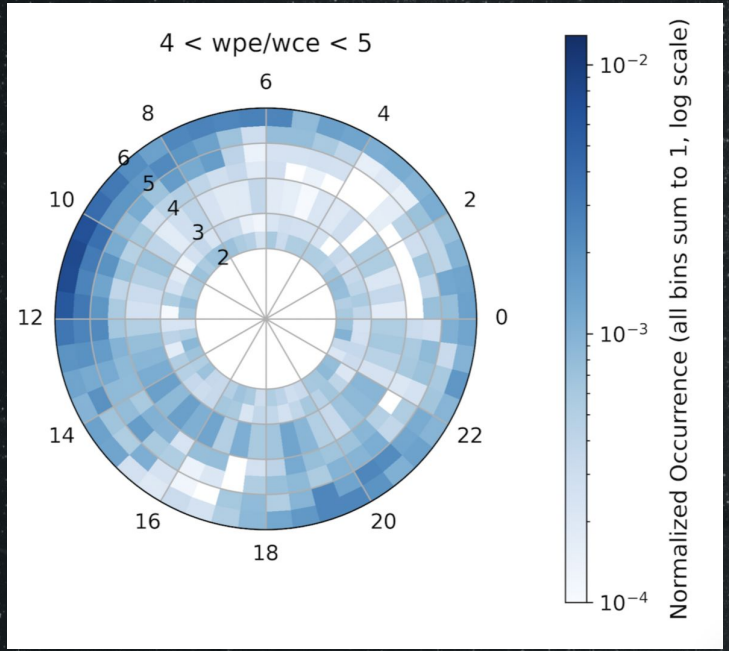
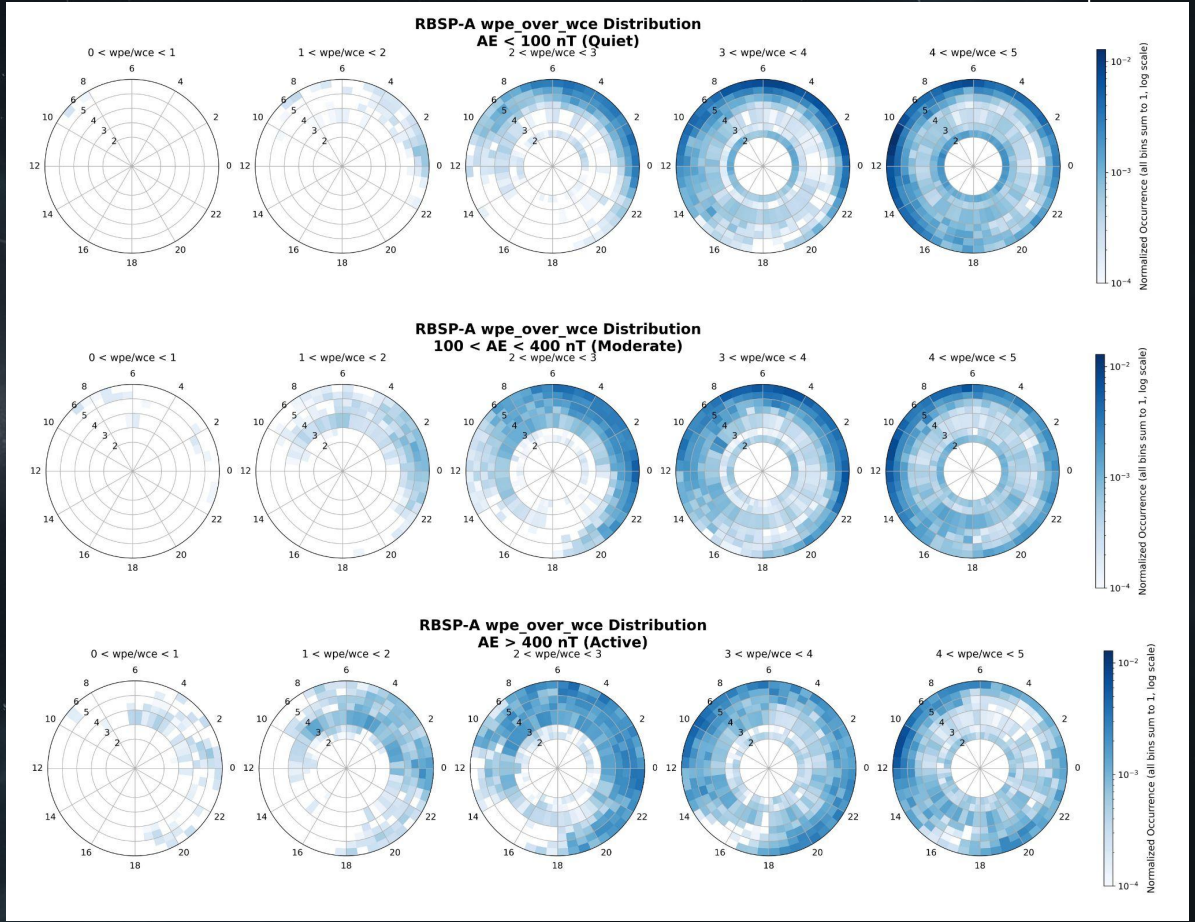


$$\frac{\omega_{pe}}{\omega_{ce}} \propto \frac{\sqrt{n_e}}{B}$$

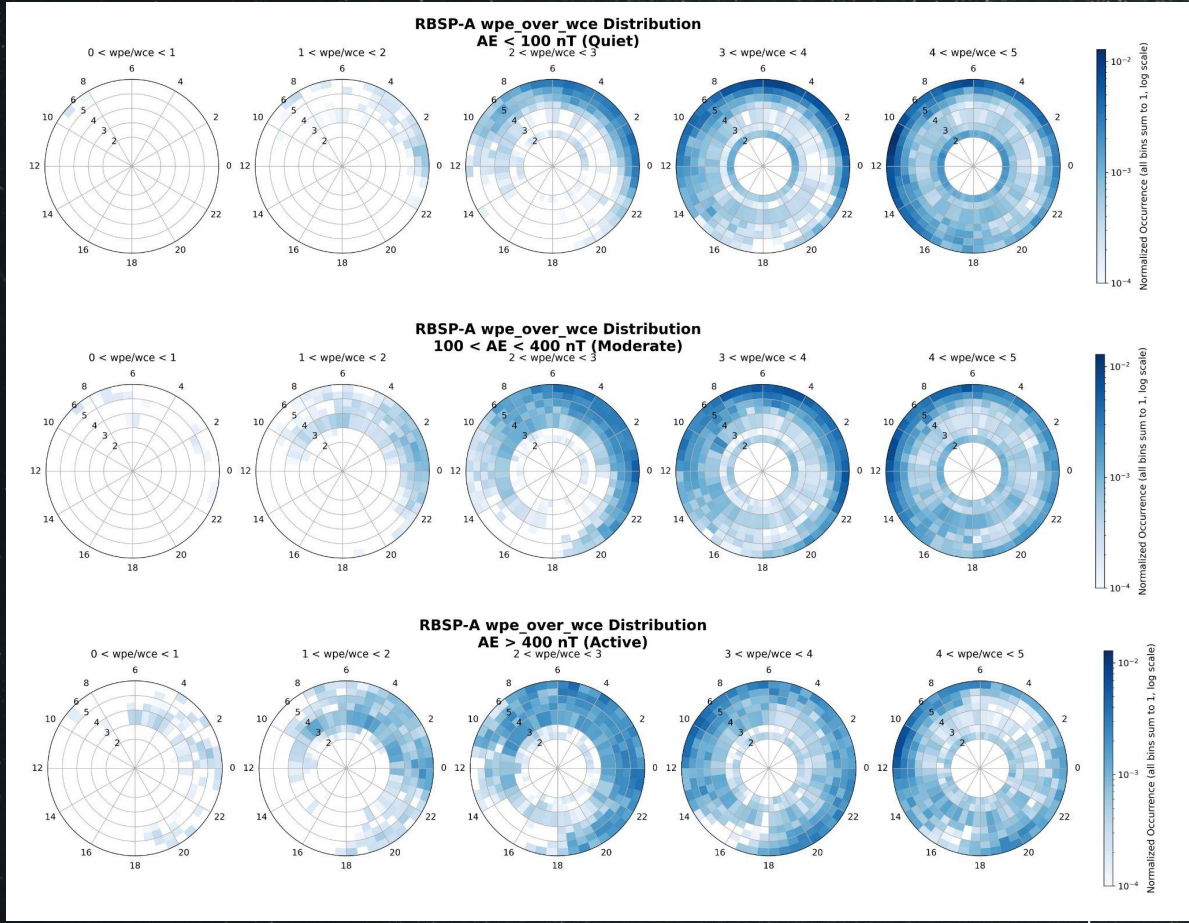
Results

- Plasma density varies with L-shell
- Very low density is rare but physically important
- Moderate-high density dominates
- Clear spatial structure (L & MLT)
- Activity increases variability



What This Means

- Density not uniform across outer belt
- Low density → enables interaction with relativistic electrons
- Higher density closer to Earth
- Activity redistributes plasma



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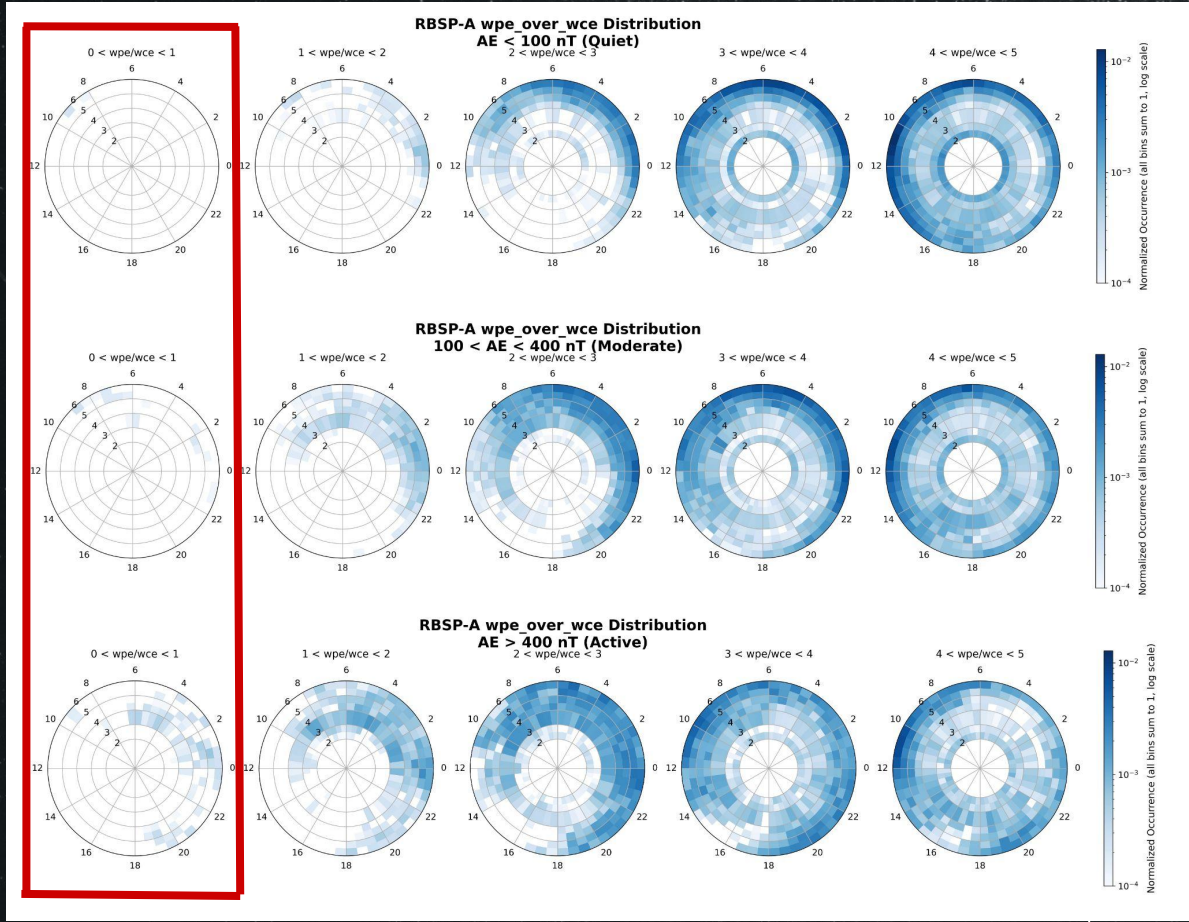

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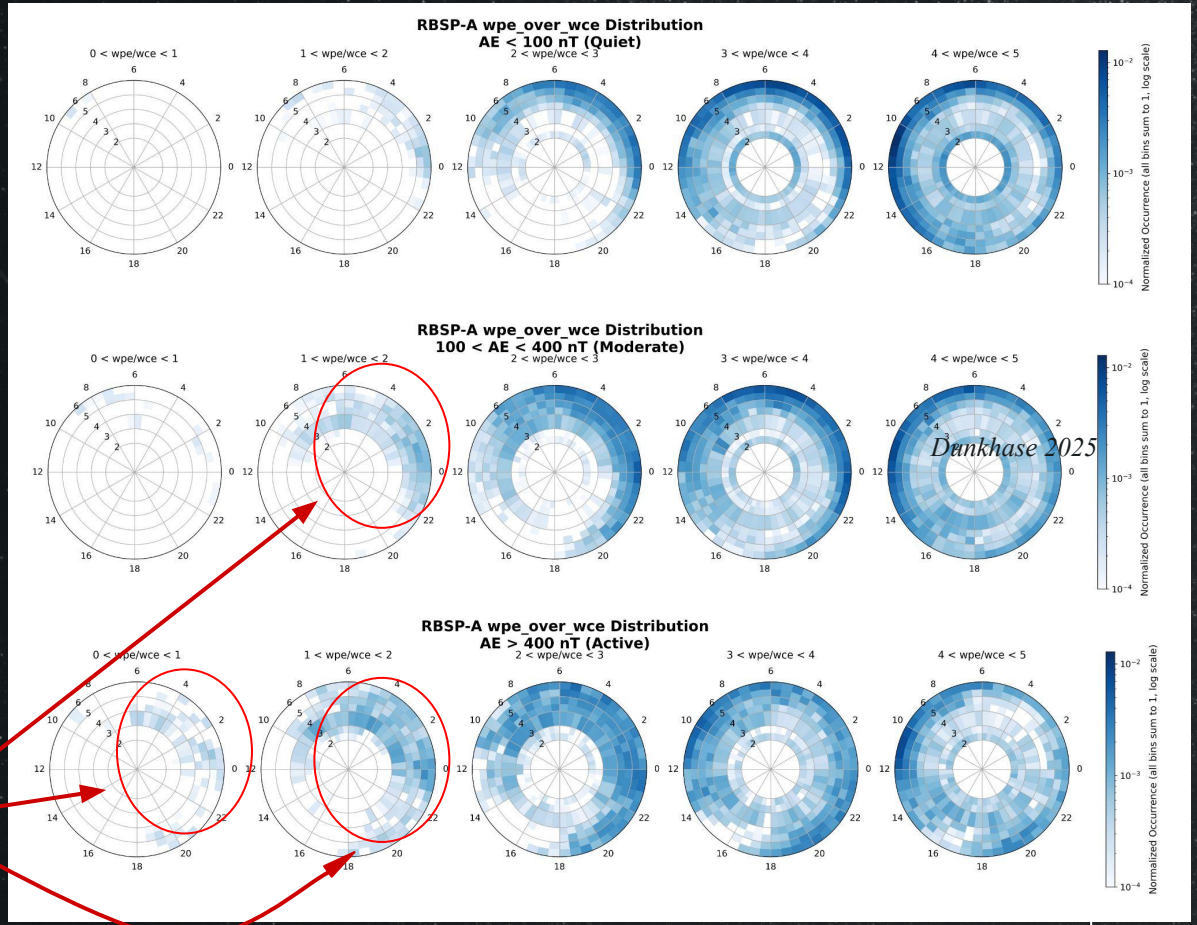
Enhanced low-density occurrence (midnight to dawn, high AE) → Dawn side linked to chorus waves & pulsating aurora



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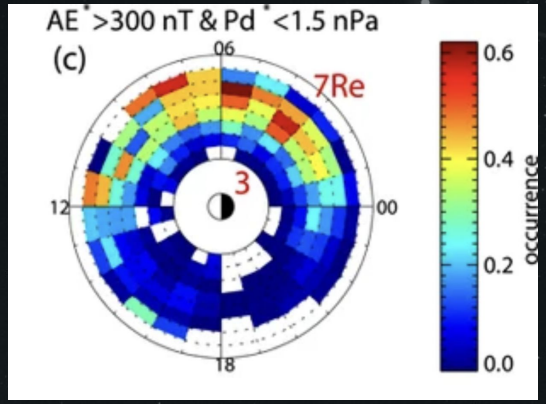

The chorus waves occurrence rate distribution in the L-MLT (Ma et al., 2002)

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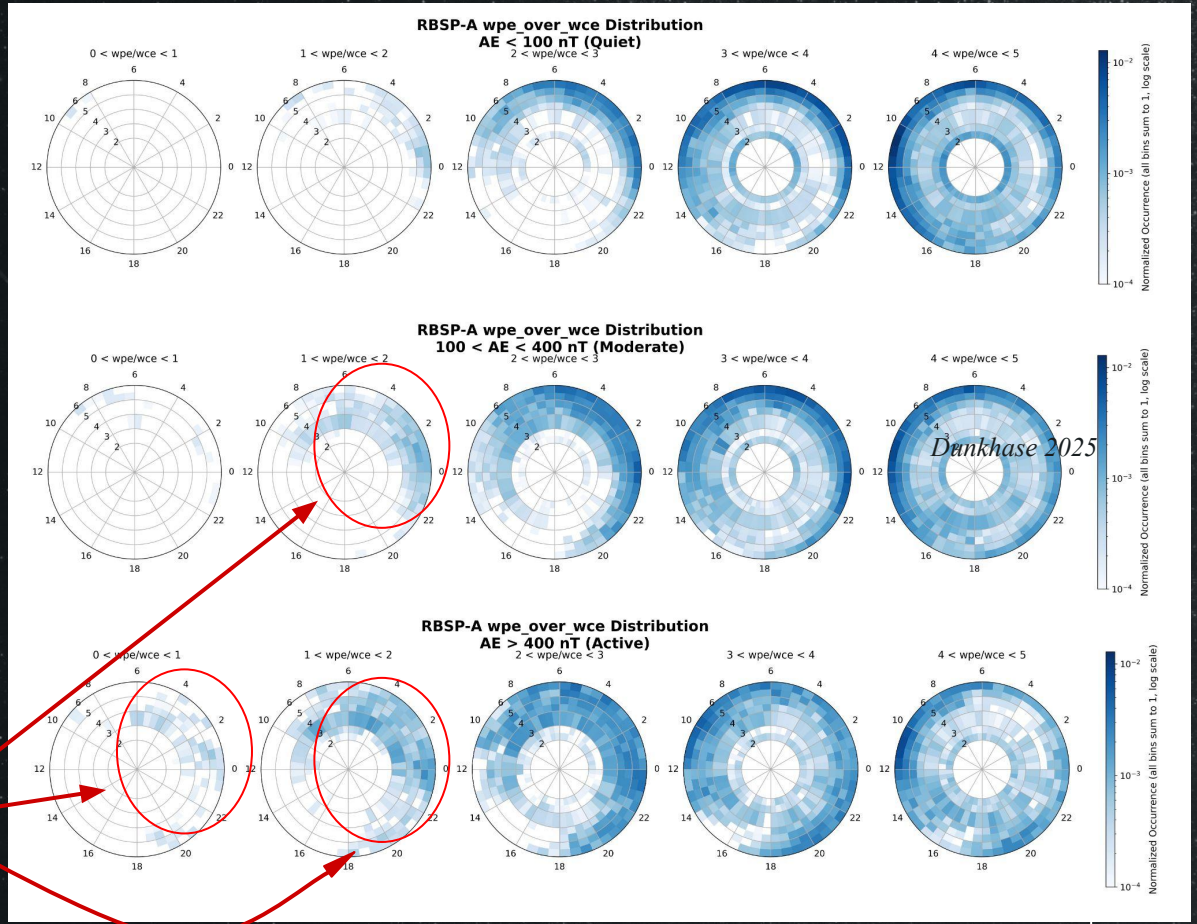

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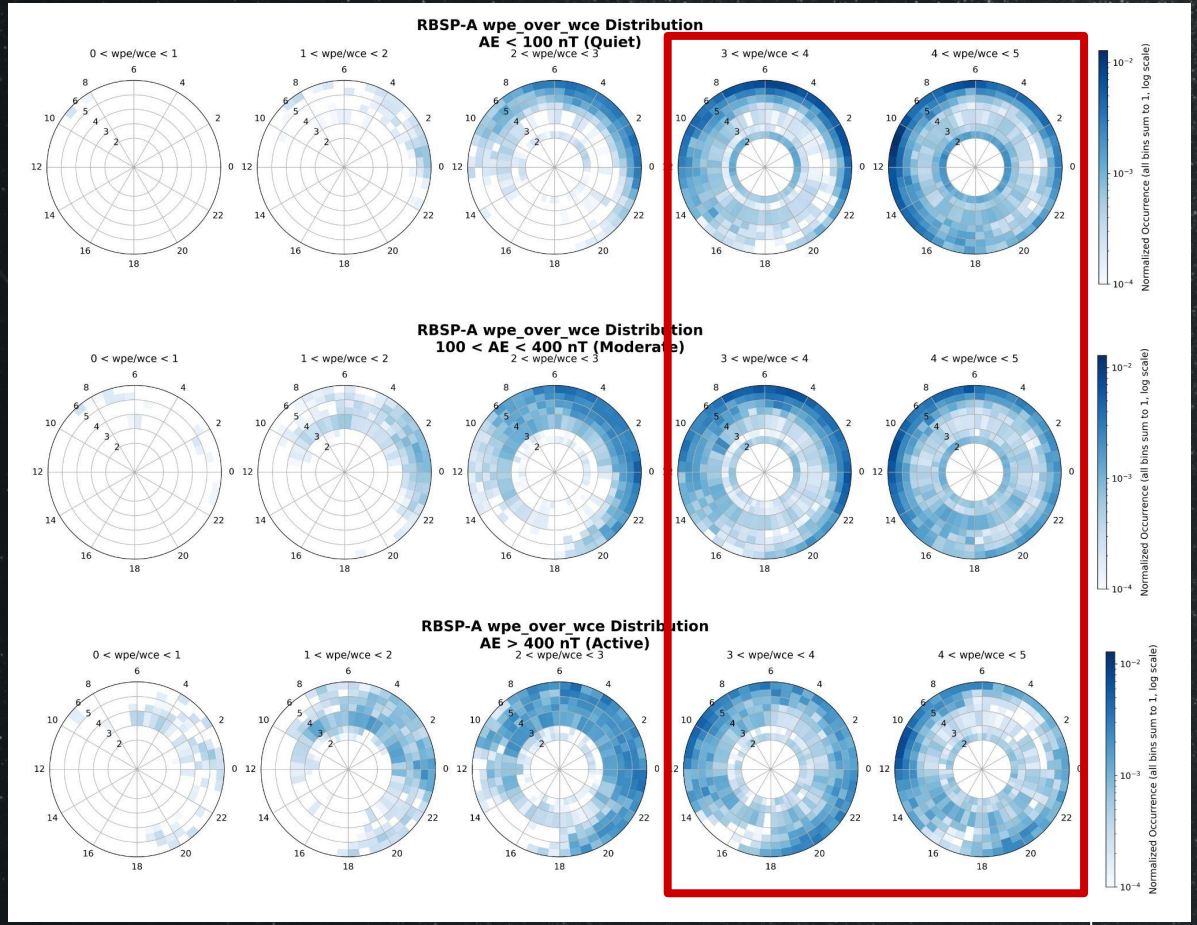

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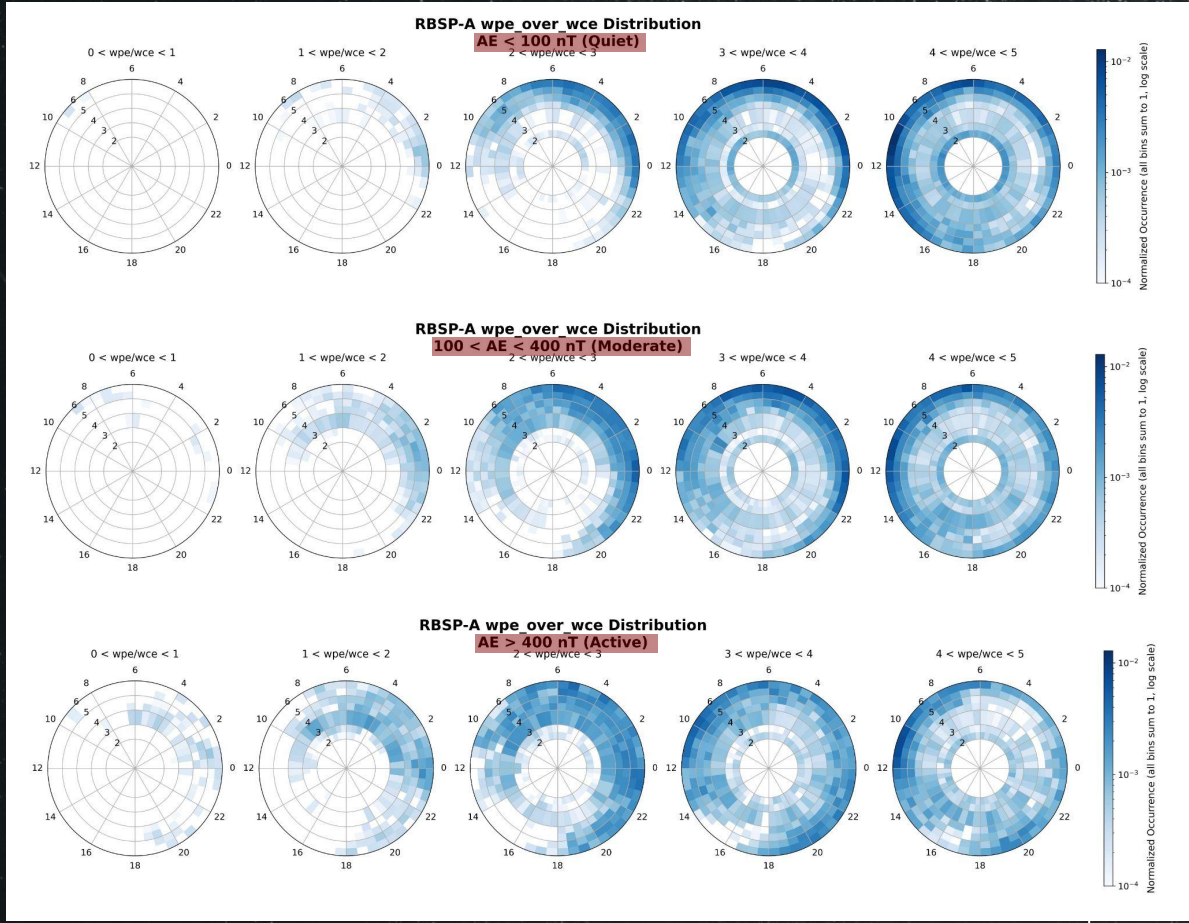

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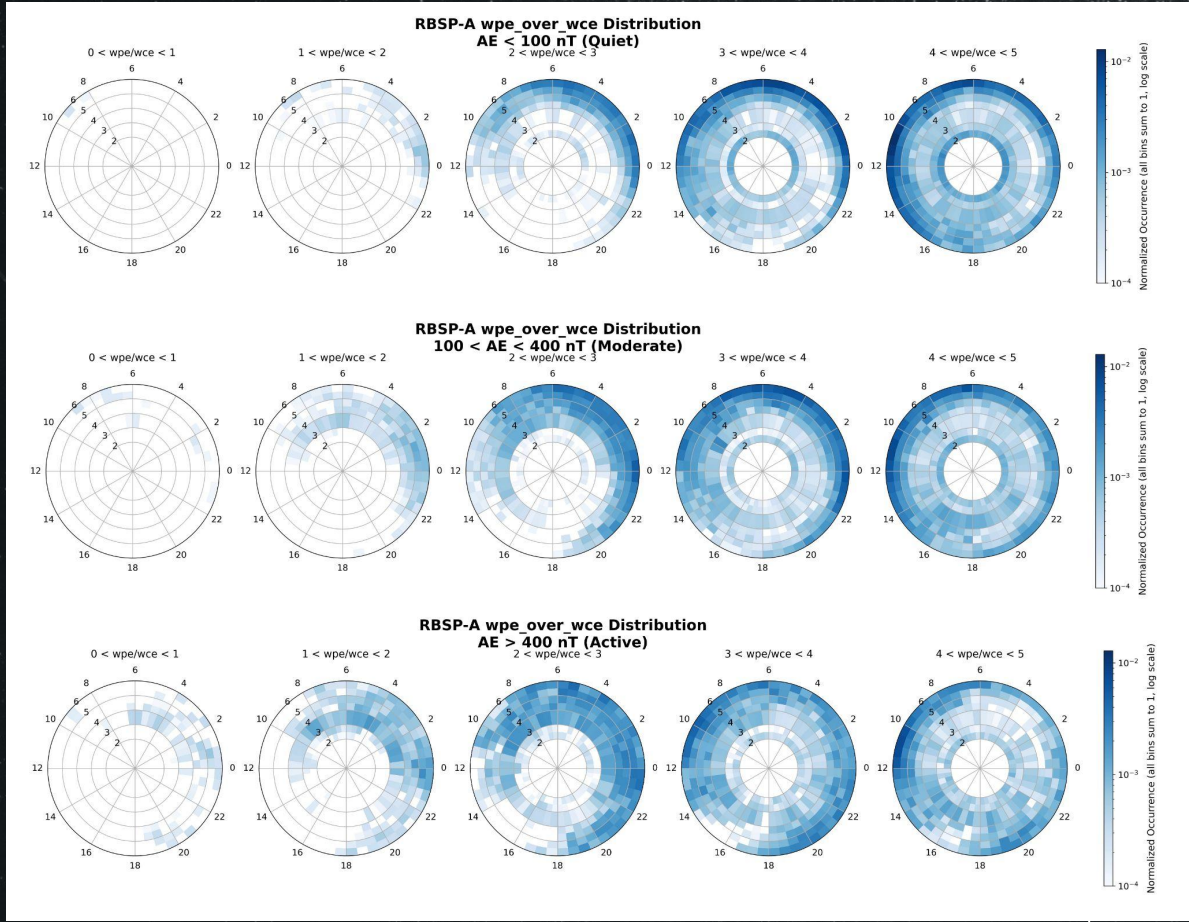
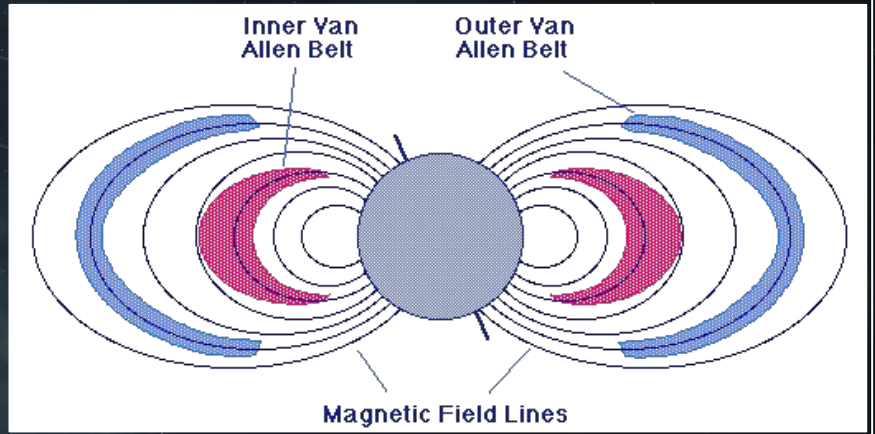


Conclusions

Takeaway: Plasma density shows structure that changes with geomagnetic activity

- Density varies with L-shell & MLT
- Low density is rare but critical for relativistic electrons
- Activity increases variability
- Outer belt has diverse environments
- Impacts wave–particle interactions



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Acknowledgments

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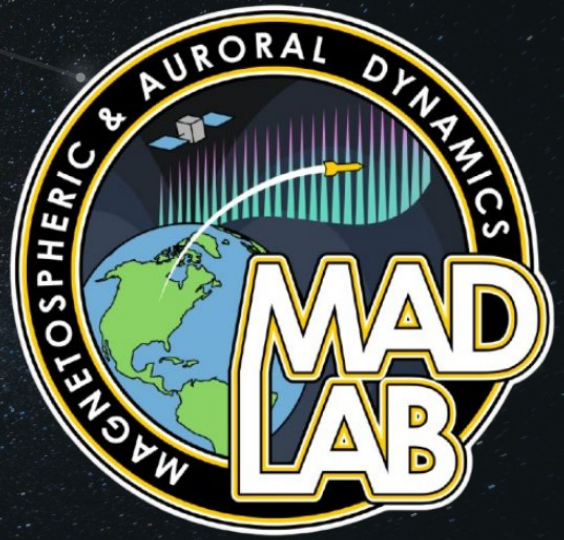
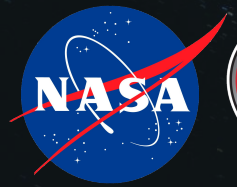
- The Magnetospheric & Auroral Dynamics Lab





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