Correlation between precipitation and acceleration of relativistic electrons by whistler mode chorus waves

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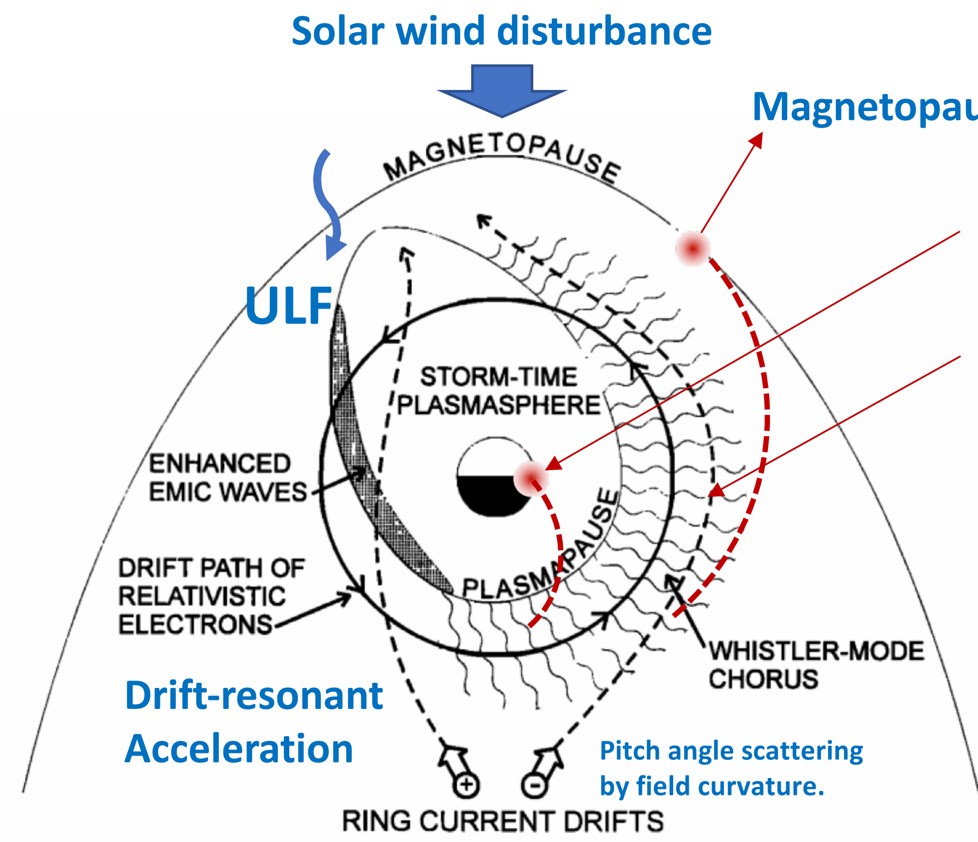
Causes of electron acceleration and loss



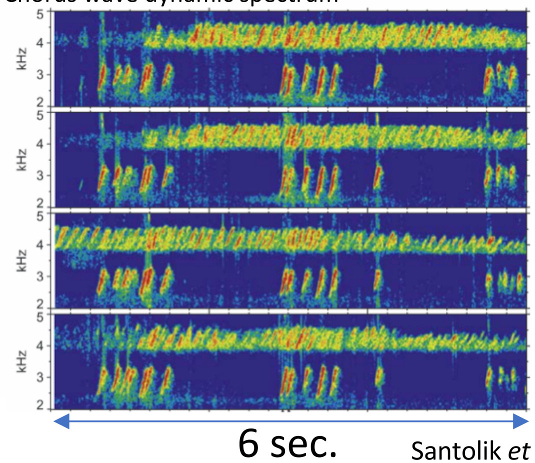
Summers et al. (1998), JGR

Precipitation Loss

- Whistlers, EMIC

Resonant Acceleration

Chorus wave dynamic spectrum



Santolik *et al.* (2003), JGR

S.Saito, Y. Miyoshi, and S. Kurita, “*Correlation between precipitation and acceleration of relativistic electrons by whistler mode chorus waves: GEMSIS-RBW simulations*”, Chapman Conference on Particle Dynamics in the Earth’s Radiation Belts, Cascais, Portugal, 4-9 March 2018.

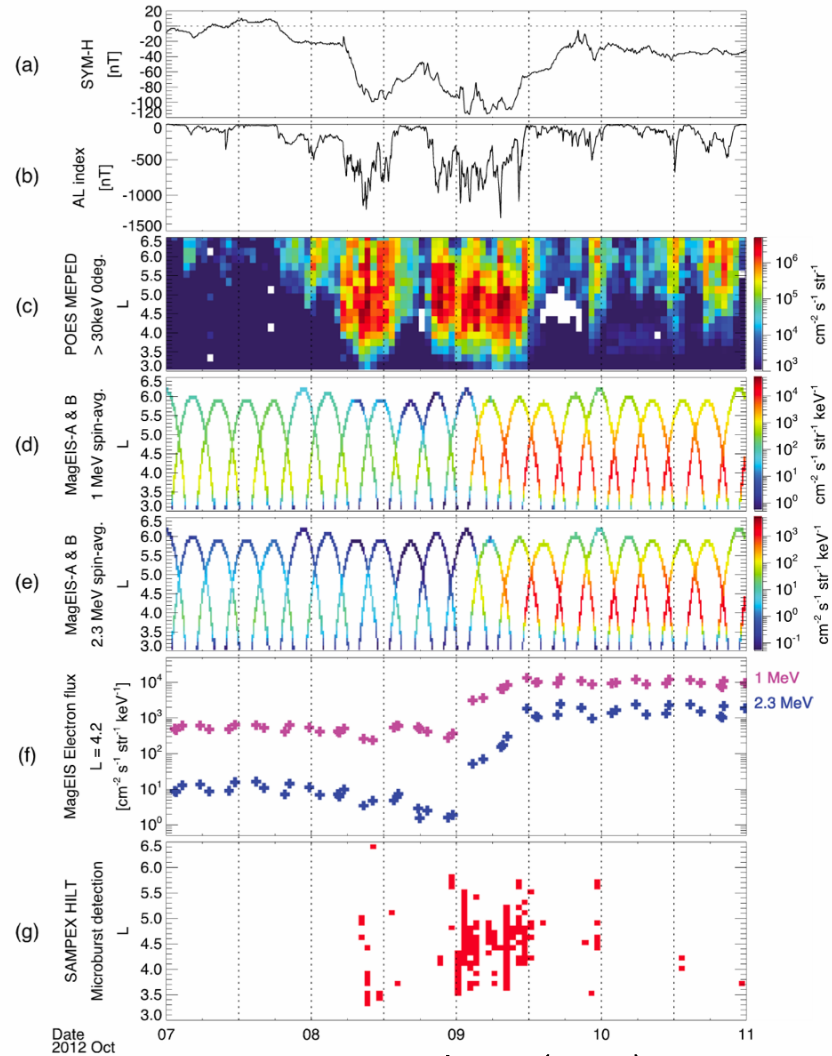
Observation

- Two-steps magnetic storms

- Precipitation of tens keV electrons
  - Enhancement of whistler-mode chorus waves (Thorne et al. Nature 2013)

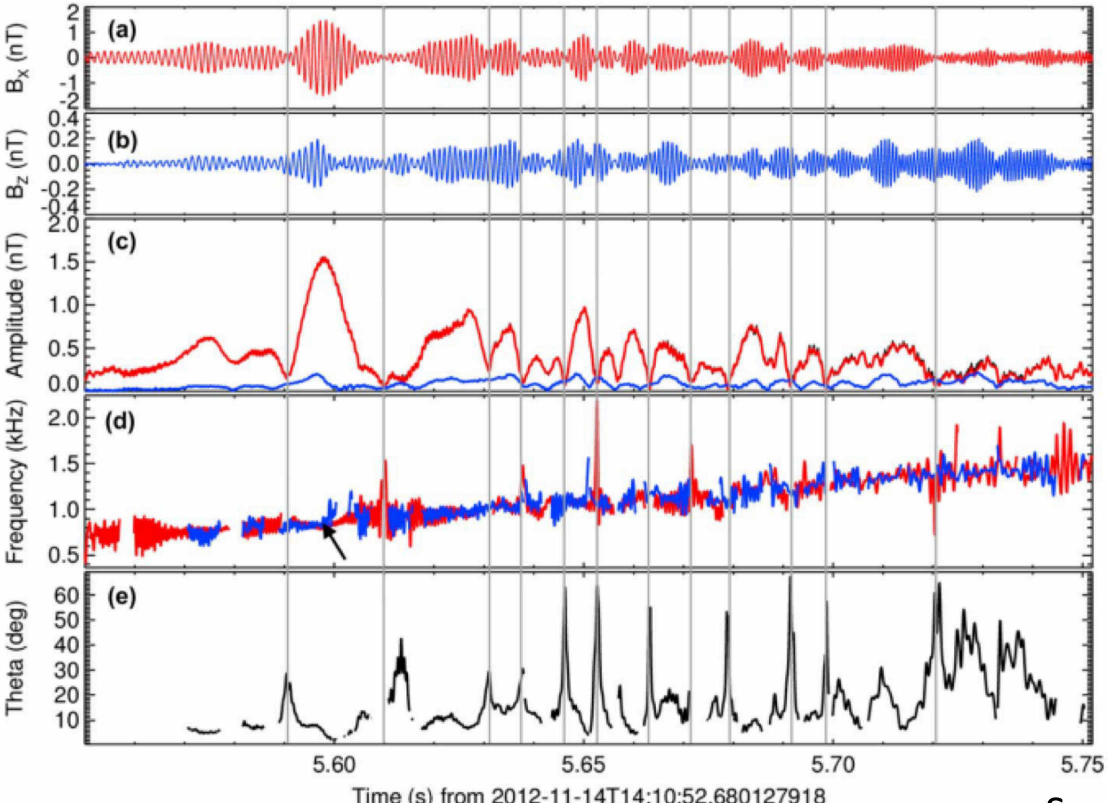
- The former storm has no flux enhancement in MeV, whereas the later one has large flux enhancement.
  - **The former storm >>> Few microbursts**
  - **The later storm >>> Active microbursts**

- **Not all whistler chorus waves show rapid flux enhancement and precipitation of relativistic electrons.**



Kurita *et al.* GRL (2016)

Fine structure of chorus wave packets



Amplitude modulation

Raising Tone

Signature of incoherence(?)

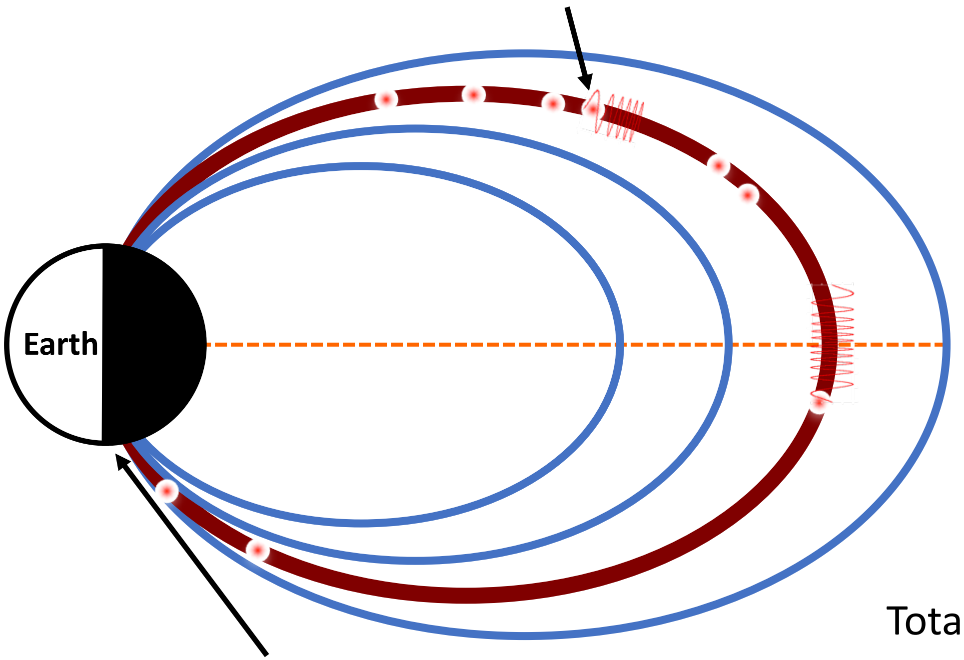
Santolik *et al.* 2014, GRL

What we study

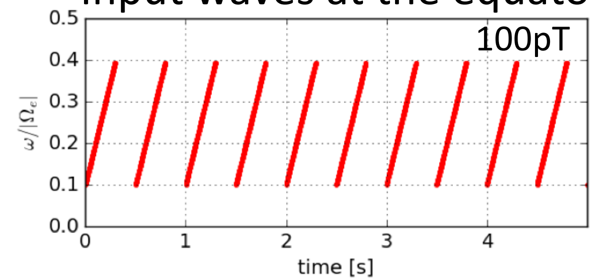
- Wave property dependence on relativistic electron flux enhancement
  - Magnetic latitude whistlers can propagate
  - Coherent/incoherent whistlers

Wave-particle interaction model: RBW Model

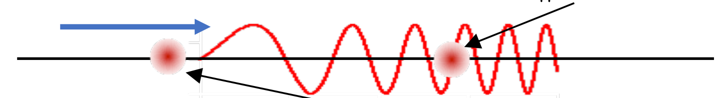
Acceleration (including nonlinear process)



Atmospheric precipitation by pitch angle scattering



Non-Adiabatic change $\Delta p'_{\|}, \Delta p'_{\perp}$



Adiabatic change $\Delta p_{\|}, \Delta p_{\perp}$

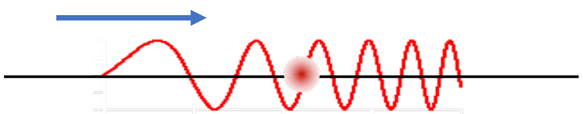
Total momentum change in dt:

$$\Delta P_{\|} = \Delta p_{\|} + \Delta p'_{\|}$$

$$\Delta P_{\perp} = \Delta p_{\perp} + \Delta p'_{\perp}$$

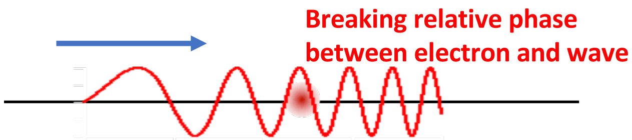
A simple model for a chorus property

- Assume interactions with <u>coherent waves</u>.



The phase trapping can take place in the wave fields.

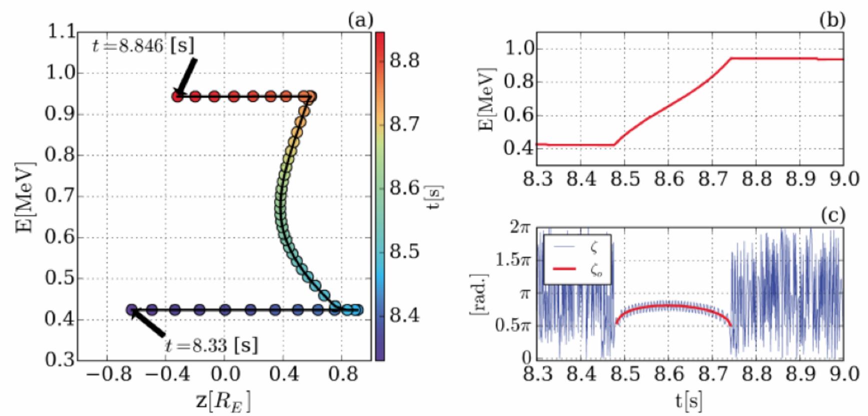
- Assume interactions with <u>incoherent waves</u>. (Phase Angle Breaking)



Quasi-linear-like scattering takes place in the wave fields.

Phase trapping: One of fast acceleration processes by whistler chorus waves.
Albert 2002, Omura *et al.* 2007
(Relativistic Turning Acc.)

<u>Demonstration of the nonlinear acceleration by RBW model.</u>



Saito *et al.* 2016, JGR

Simulation Parameters

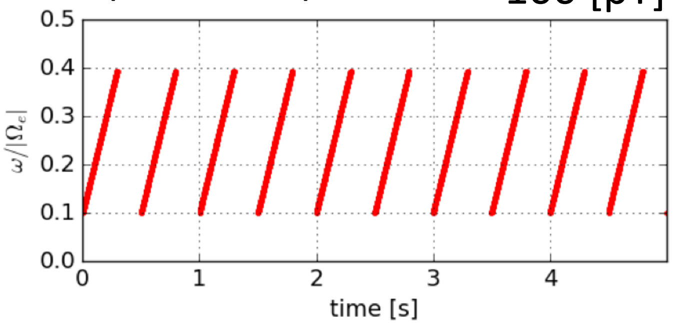
- **Maximum magnetic latitude**
  - 10 [deg.] (confined around the equator)
  - 50 [deg.] (propagate to high magnetic latitudes)

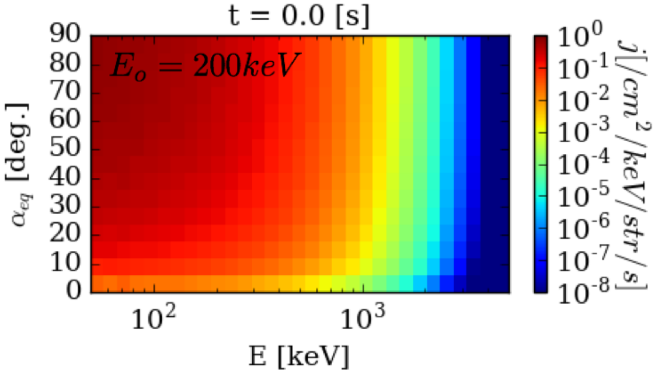
- **Wave coherency**
  - On (assuming coherent waves)
  - Off (assuming incoherent waves: Phase breaking every 1ms)

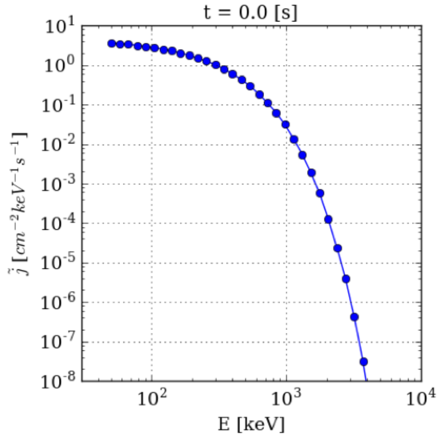
- **Physical conditions**
  - Assuming the dipole field model
  - L = 5
  - f_p/f_c = 4 at the equator (~10 cm^{-3})
  - Constant density along the field line
  - Parallel propagating whistlers satisfying the cold plasma dispersion relation

Wave model and initial flux distribution

Input wave spectrum 100 [pT]



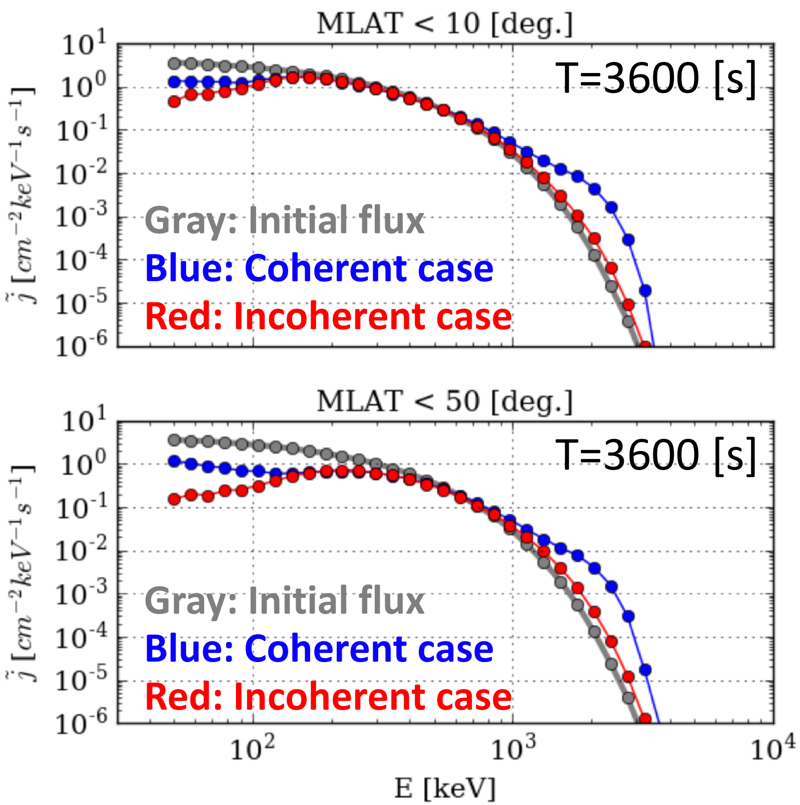




Element lasting time: 400 [ms]
Emission frequency: 2 [Hz]
Frequency sweep rate: 1 [rad/s^2]
Wave amplitude: 100 [pT]

$$j(E, \alpha_{eq}, t = 0) = \exp\left(-\frac{E}{E_o}\right) \sin \alpha_{eq}$$

Flux distribution in energy



Coherent case:

- About **50-times** larger flux @ 2MeV

Incoherent case:

- About **5-times** larger flux @ 2MeV

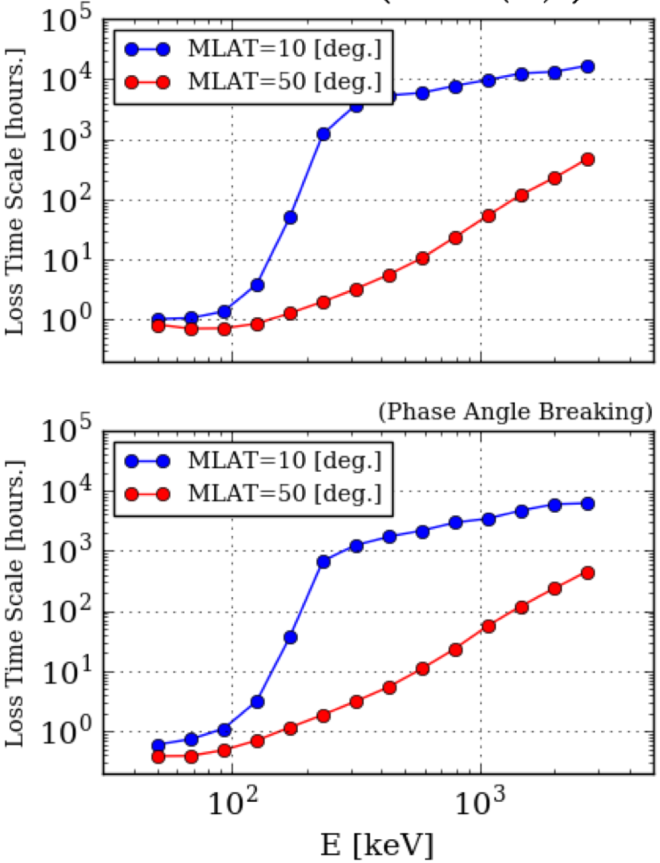
Nonlinear scattering leads to more efficient flux enhancement.

Maximum magnetic latitude does not strongly depend on flux enhancement of relativistic electrons.

S.Saito, Y. Miyoshi, and S. Kurita, "*Correlation between precipitation and acceleration of relativistic electrons by whistler mode chorus waves: GEMSIS-RBW simulations*", Chapman Conference on Particle Dynamics in the Earth's Radiation Belts, Cascais, Portugal, 4-9 March 2018.

Precipitation loss time scale

$$\tau_{loss}(E) = t\left(\ln \frac{N(E,t)}{N_o(E)}\right)^{-1}$$



MLAT dependence:

- Chorus waves propagating at higher MLATs can precipitate high energy electrons more rapidly.

In order to precipitate relativistic electrons rapidly, chorus waves should propagate to high MLATs.

→ **Consistent with suggestion by Horne and Thorne (GRL, 2003)**

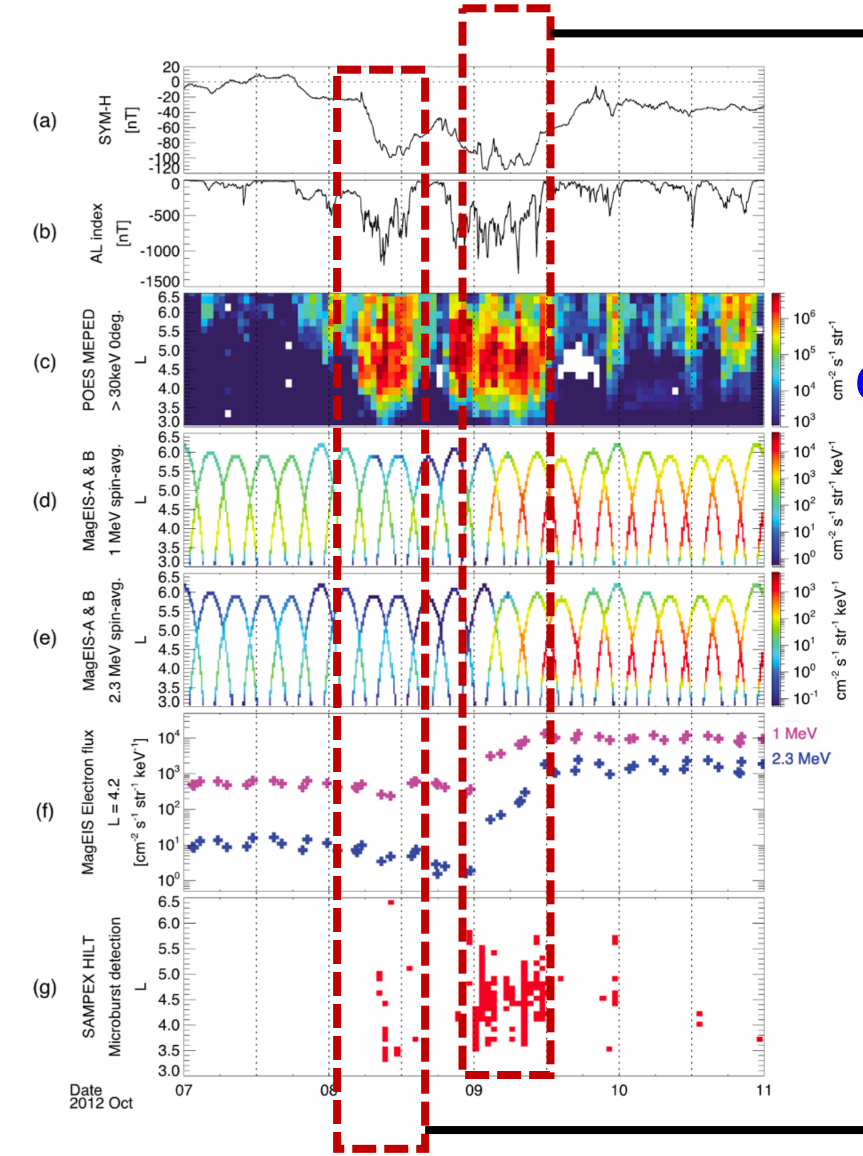
Include "Phase Angle Breaking":

- Almost same results as that without the breaking.

Nonlinear phase trapping does not influence on the precipitation loss.

Summary of Simulation results

MLAT / Coherency	< 10 [deg.]	< 50 [deg.]
Coherent waves	MeV Acc: **Yes** MeV Loss: **No**	MeV Acc: **Yes** MeV Loss: **Yes**
Incoherent waves	MeV Acc: **Weak** MeV Loss: **No**	MeV Acc: **Weak** MeV Loss: **Yes**



Microbursts

+

Fast flux enhancement in MeV

Coherent whistlers propagating at high MLATs.

Few Microbursts

+

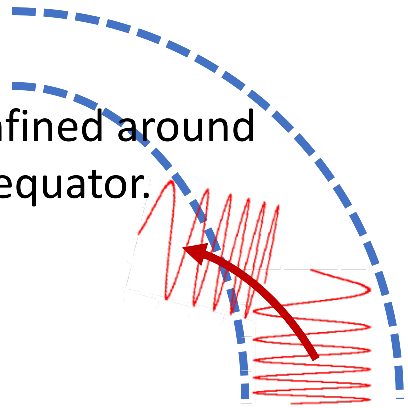
Low flux enhancement in MeV

Incoherent whistlers around the equator.

Kurita et al. GRL 2016

Duct formation?

No Duct formation

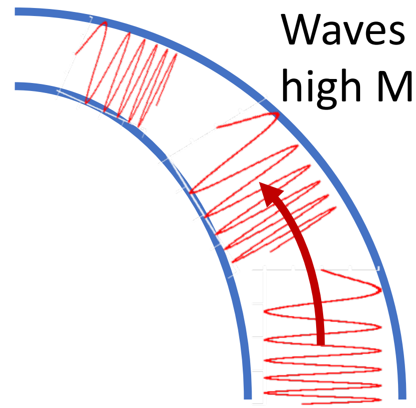


Waves are confined around the magnetic equator.

Generation of "**Incoherent**" whistler chorus element

(High probability of Intermittent nature in elements)

Duct formation



Waves propagate at high MLATs.

Generation of "**Coherent**" whistler chorus element

(Low probability of Intermittent nature in elements)

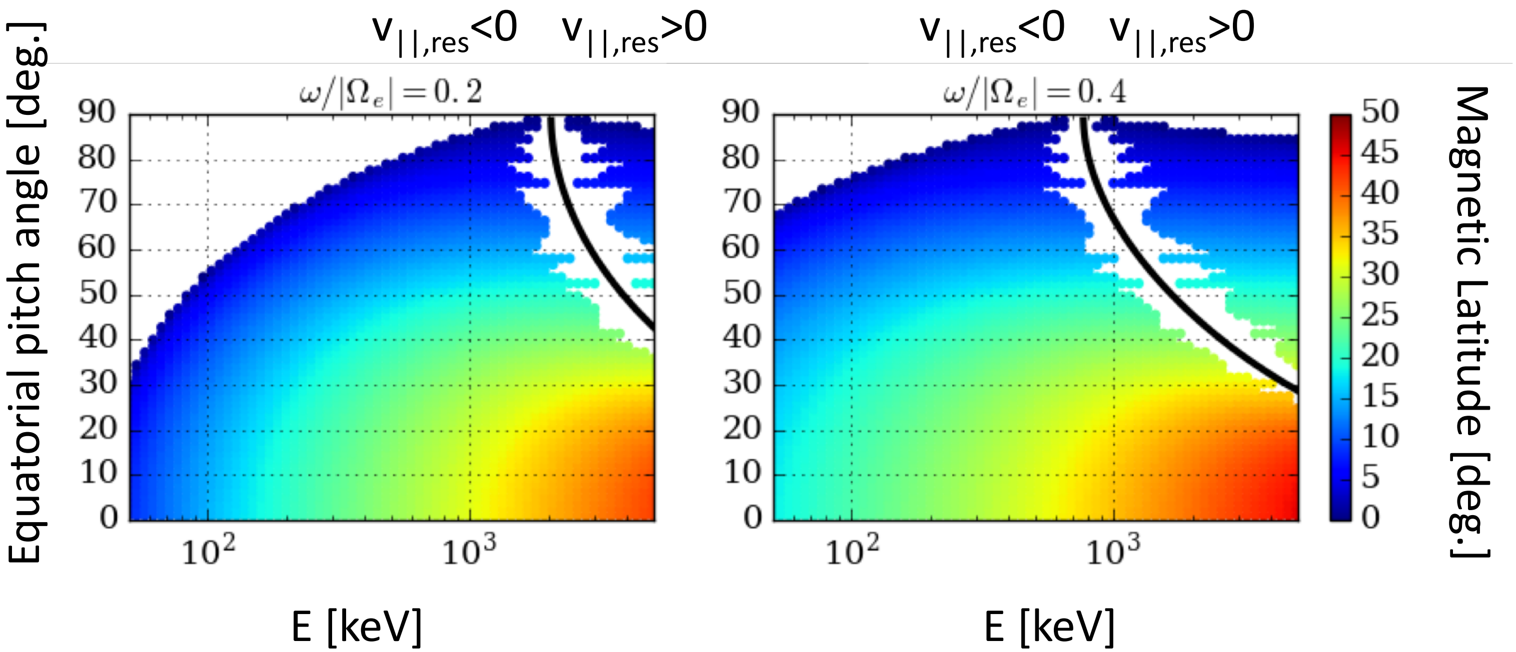
Correlation between duct formation and coherent element generation?

Conclusion and Suggestion

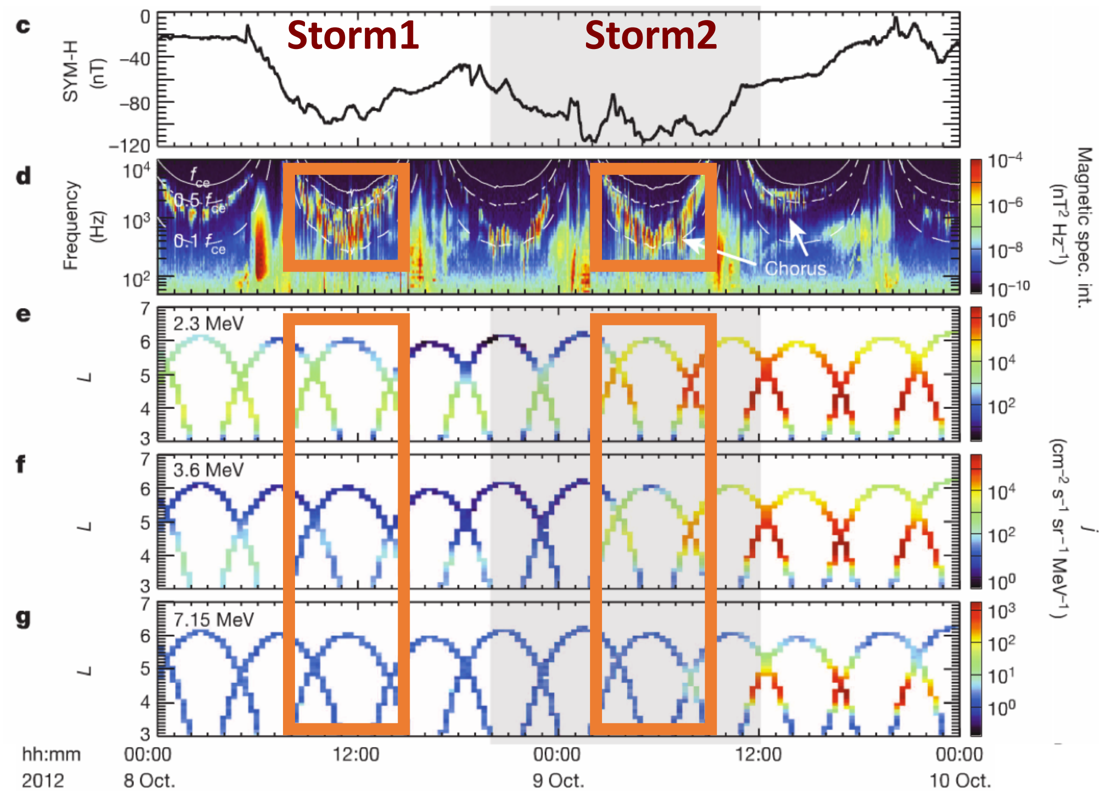
- MeV flux enhancement
  - No dependence of MLAT (>10deg.)
  - Coherency influences on efficiency of flux enhancement.
- MeV electron precipitation
  - Strong dependence of MLAT
  - No dependence on coherency
- If relativistic electron microbursts are a proxy of efficient MeV flux enhancement, only coherent whistlers can propagate to high magnetic latitudes.
  - Suggesting relationship between duct formation and coherent whistler chorus generation?

Backup Slides

Resonance condition

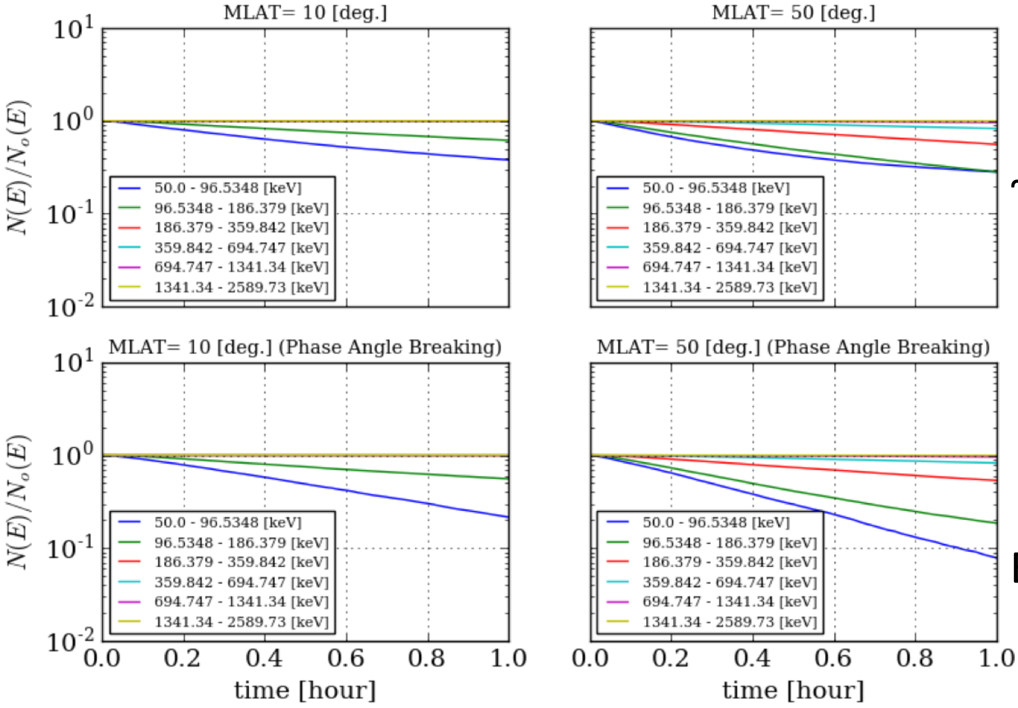


Chorus waves in the magnetic storms



Thorne *et al.* (2013) Nature, 504, 411–414, doi:10.1038/nature12889

Time history of the number of trapped electrons.



Exclude Phase Angle Breaking

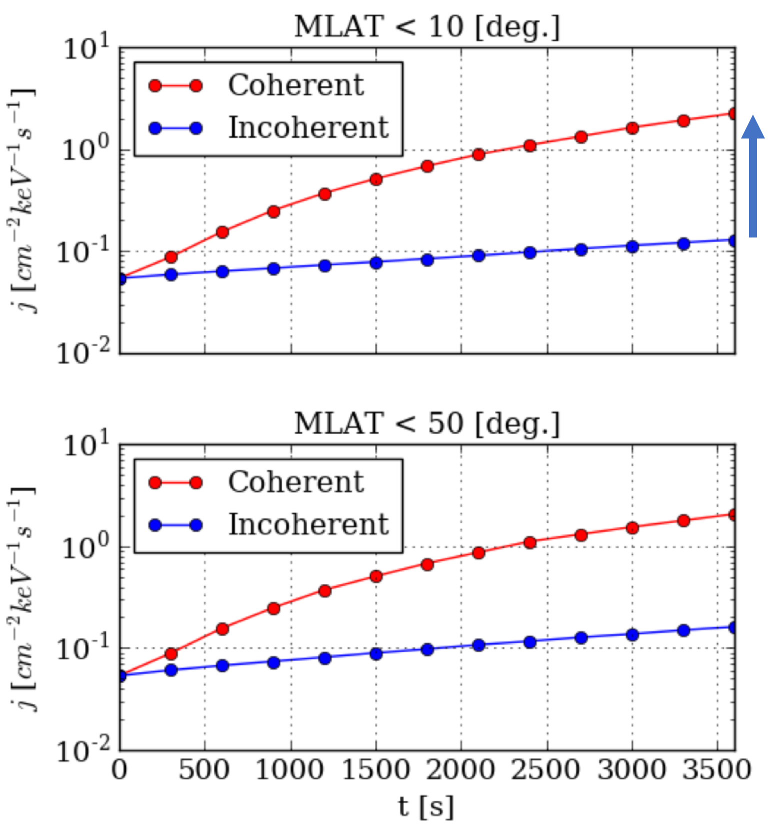
~ Almost exponential decay

Include Phase Angle Breaking

Exponential decay

Exponential decay: $\frac{N(E,t)}{N_o(E)} \overset{\text{def}}{=} \exp \frac{t}{\tau_{loss}(E)}$ ➡ Decay time scale: $\tau_{loss}(E) = t \left(\ln \frac{N(E,t)}{N_o(E)} \right)^{-1}$

>2MeV flux variation in time



>10 times faster enhancement

Coherent whistlers show more efficient flux enhancement.
→ Nonlinear phase trapping
(Albert 2002, Omura *et al.* 2007)

Magnetic latitude at which whistlers can reach is not a strong function of >2MeV flux enhancement.