Direct Modulation of Electron Precipitation by ULF waves

A. W. Degeling[1], I. J. Rae[2], C. E. J. Watt[3], Q. Q. Shi[1] and R. Rankin[4]

1. *Institute of Space Sciences, Shandong University, Weihai, P. R. China*
2. *Mullard Space Science Laboratory, University College London, U.K.*
3. *Department of Meteorology, University of Reading, Reading, U.K.*
4. *Department of Physics, University of Alberta, Edmonton, Canada.*

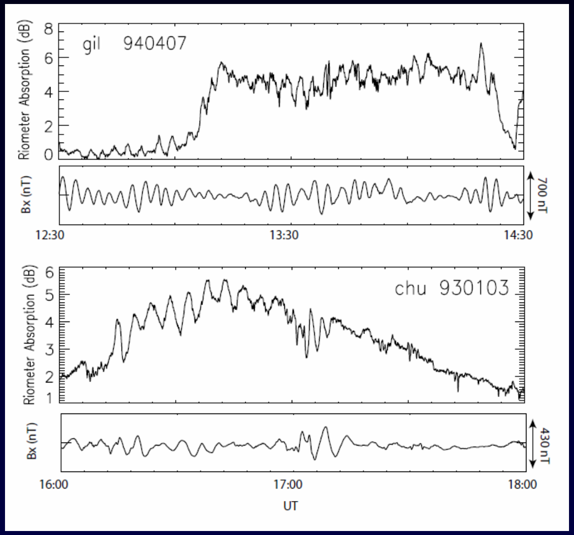
Observed Correlations in Pc5 ULF Waves and Modulated Electron Precipitation

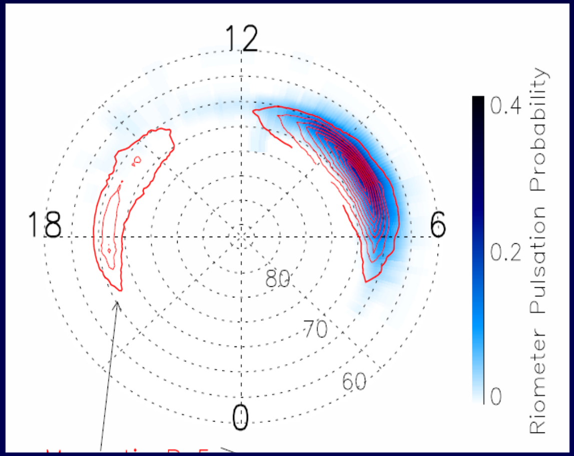
E.g.: Spanswick et al., JGR 2005:

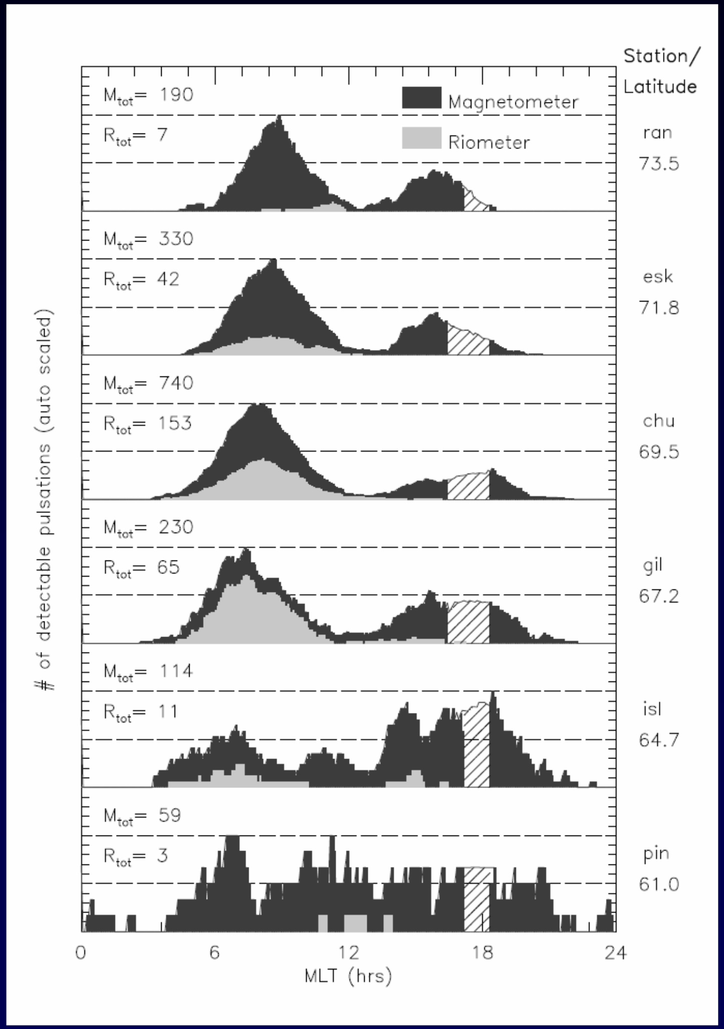
- (Riometer obs: 30+ keV e$^-$ precipitation).
- Clear preference for morning sector.
- General explanation:
  ULF waves modulate the growth rate of Whistler mode Chorus emissions:
  ⇒ Affects pitch angle scattering rate.
  ⇒ modulates precipitation.

BUT: Can ULF waves directly modulate electron precipitation?

- Recent work by Rae et al., JGR 2018 (poster, this meeting) indicates this possibility.





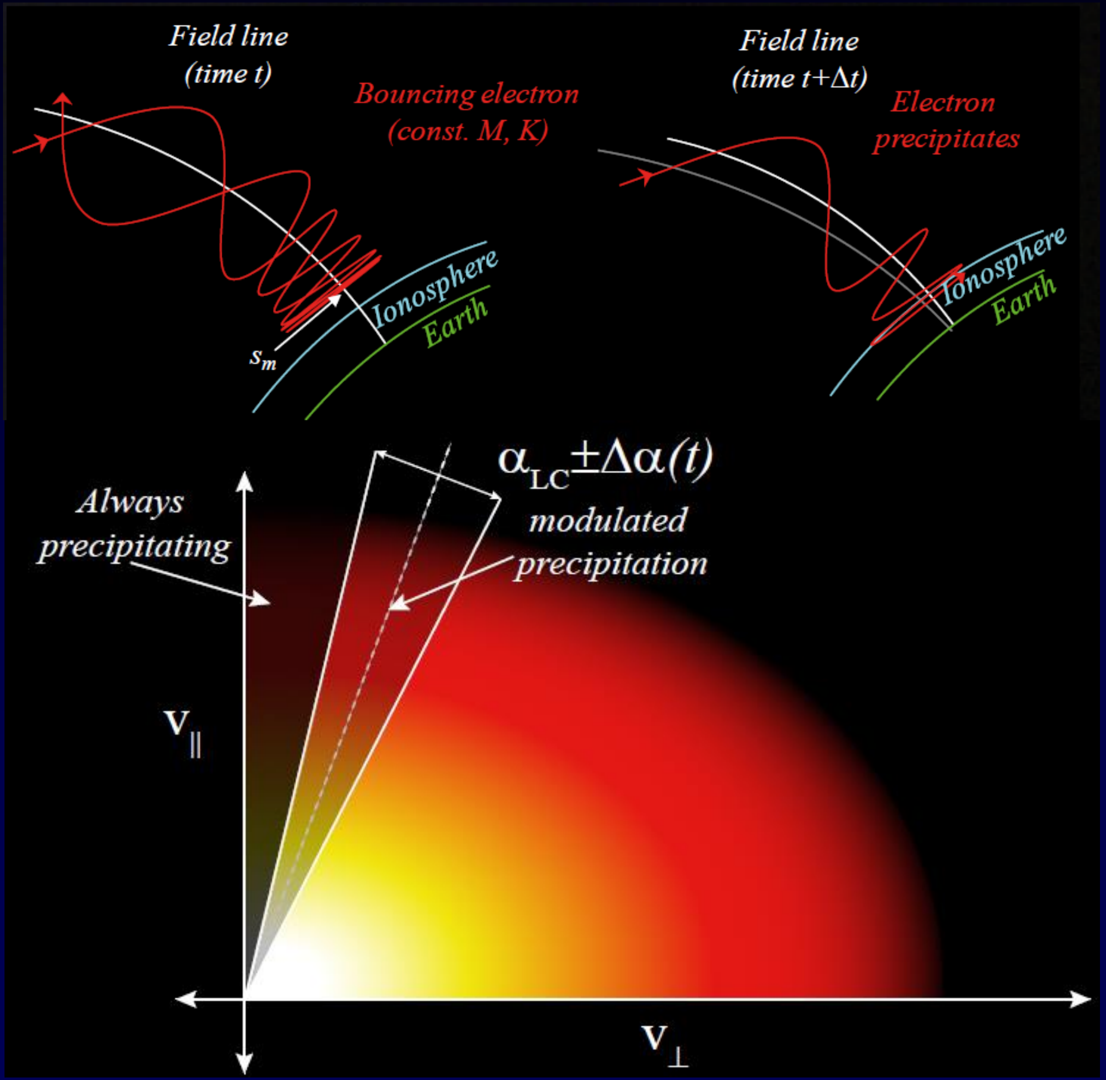


Modulated Precipitation directly by ULF waves?

- Hypothesis: ULF waves directly affect the precipitation of W>30 keV electrons (observed by riometers):
  - Equatorial pitch angle for loss cone:

$$\alpha_{LC} = \cos^{-1}\left(\left(1-\frac{B_{eq}}{B_{ion}}\right)^{1/2}\right)$$

  - B_{eq} is affected by ULF waves, particularly at high L-shell.
  - Simple picture: Modulation in α_{LC} => modulation in precipitation.



How to investigate this...?

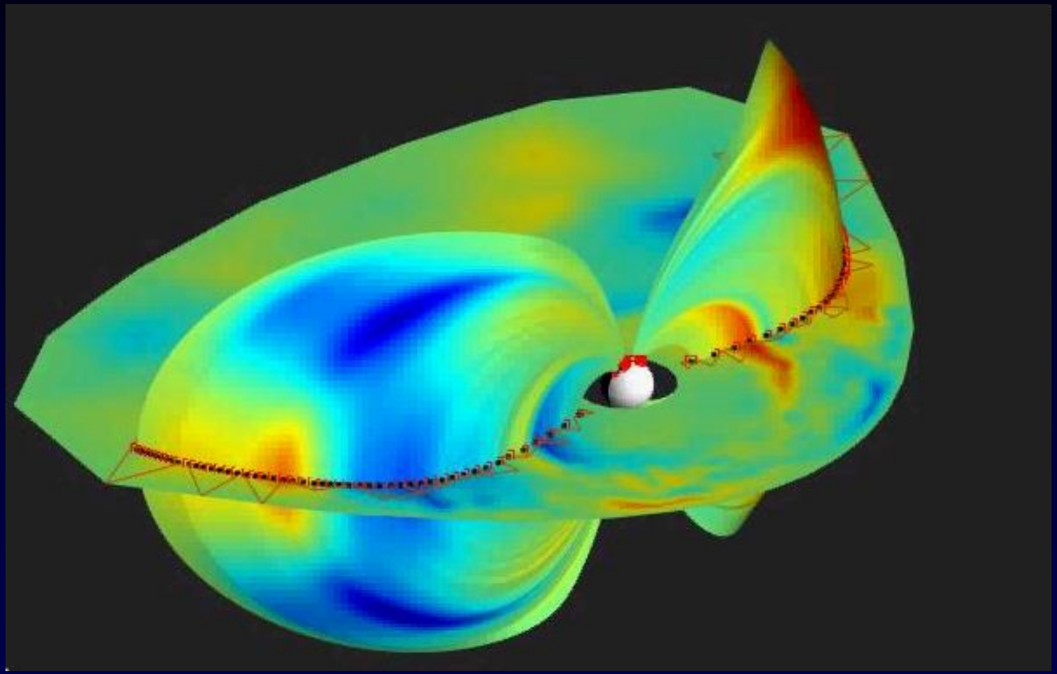
- Assume an initial distribution $f(\propto, W)$ for electrons.
- Perturb magnetic field using model ULF waves (Degeling et al., JGR 2018)
- Initial stab based on the simple picture:
  - To find total precipitating flux detected by riometers, calculate:

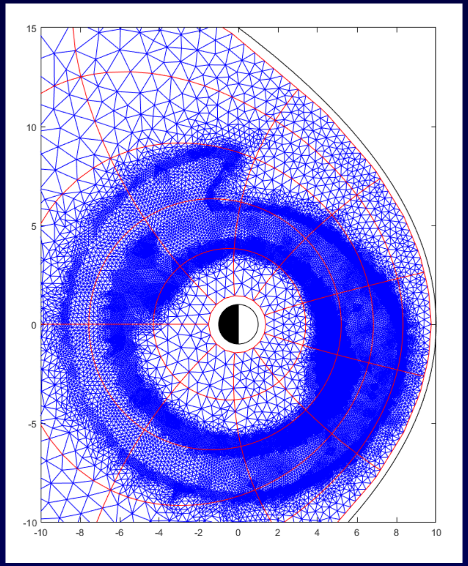
$$\int_{W_0}^{\infty}\int_{0}^{\alpha_{LC}} f(\propto, W) W dW d\alpha$$

- Include transport effects using Backward Liouville Test Kinetic (BLTK) method:
  - Bounce-average model to calculate trajectories with constant M, K.
  - Account for losses along drift path when mirror pt lies within ionosphere.

3D ULF wave model

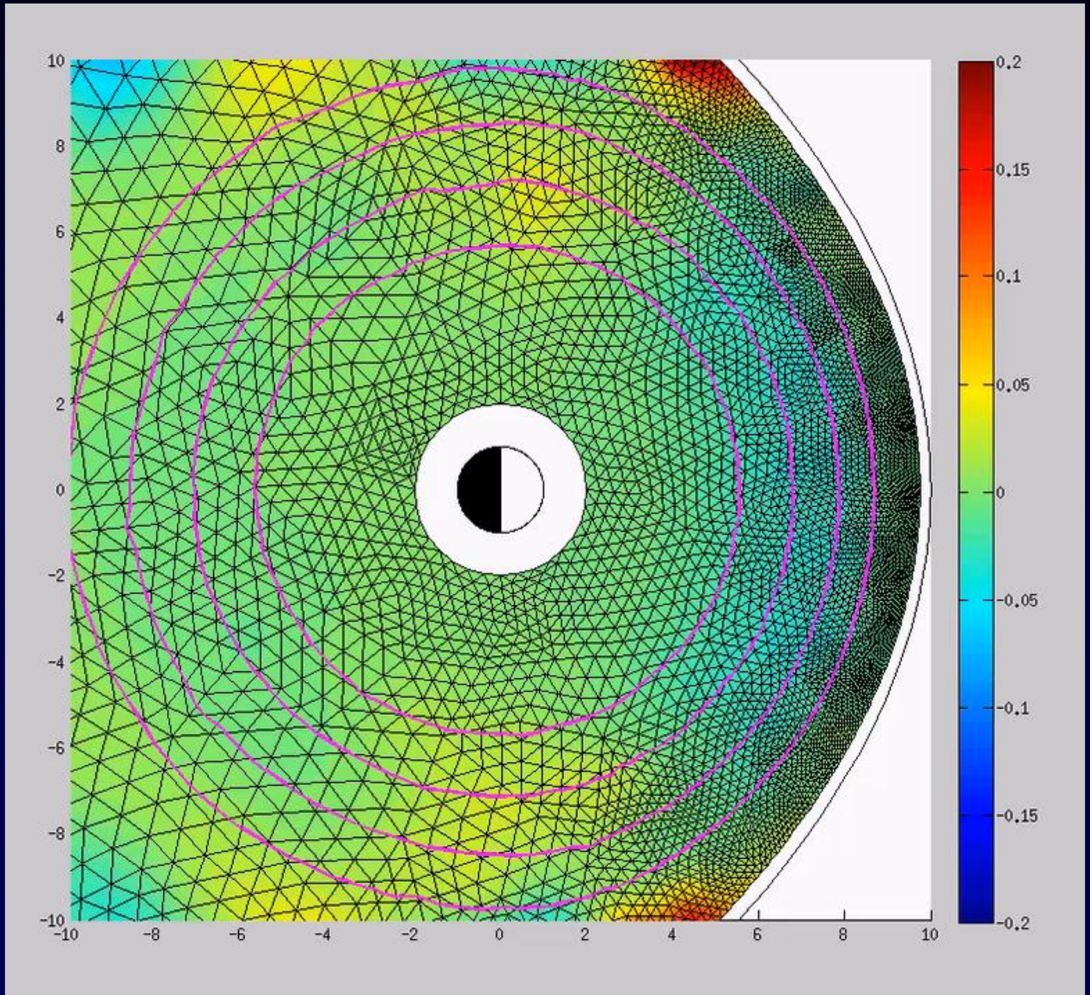
- Background magnetic field:
  - Stern vacuum field used (Stern, JGR 1985)
- Spectral method for γ direction:
  - 3D PDE => N (~10) coupled 2D PDEs in (α, β, t)
  - High σ_p ionospheric B.C. => Nodes in E.





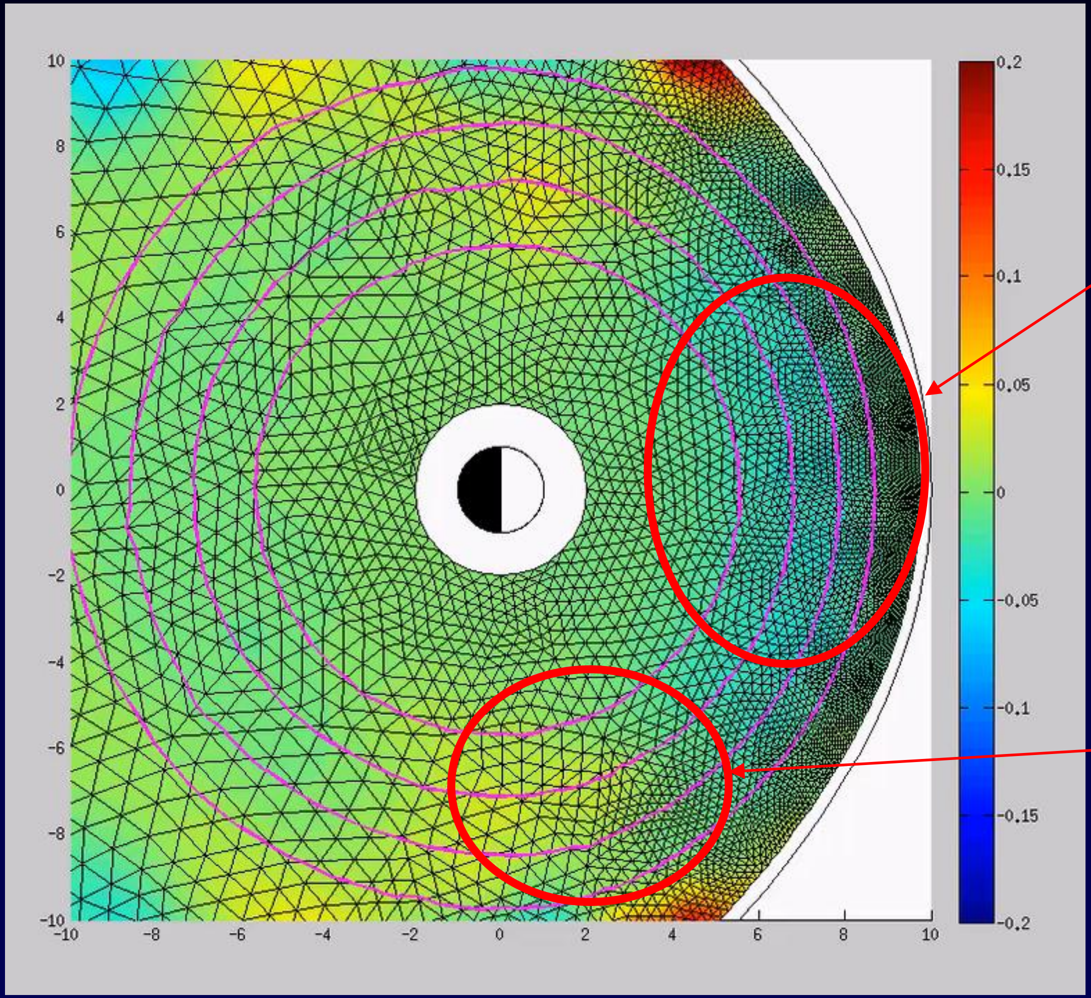
- Coupled 2D PDEs solved using FEM.
  - Refined mesh based on SAW resonant surfaces.
  - Simple radial density profile used for this study.
  - Waves launched along magnetopause boundary using a symmetric profile about 12 MLT.

Spatial Structure of $\Delta\alpha_{LC} / \alpha_{LC}$ due to ULF MHD Fast mode waves

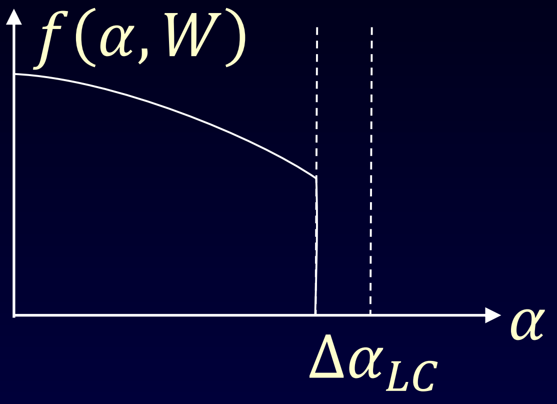


- This example: Continuously driven 3 mHz magnetopause perturbations launch MHD fast modes into the dayside magnetosphere.
- If the loss cone is rapidly refilled on ULF wave timescales by an isotropic parent distribution (…) then the precipitating flux modulation would also look like this.

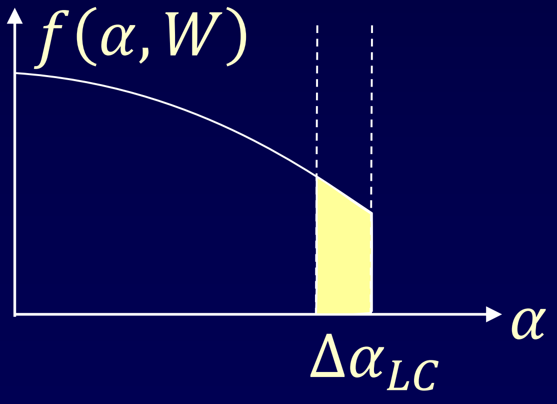
Spatial Structure of $\Delta\alpha_{LC}/\alpha_{LC}$ due to ULF MHD Fast mode waves



Loss cone flux already depleted

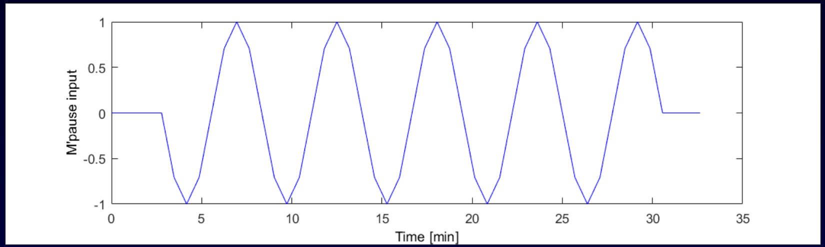


Modulated precipitation occurs here

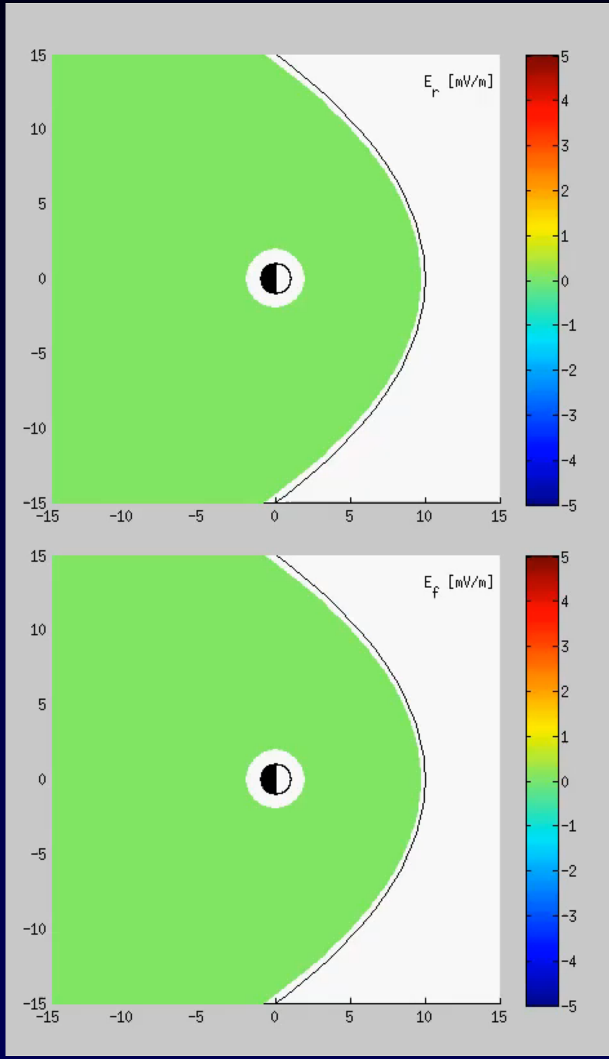


Including Drift Effects Using Bounce-Average Model

- Run ULF wave model with a short duration wave 3 mHz packet input:



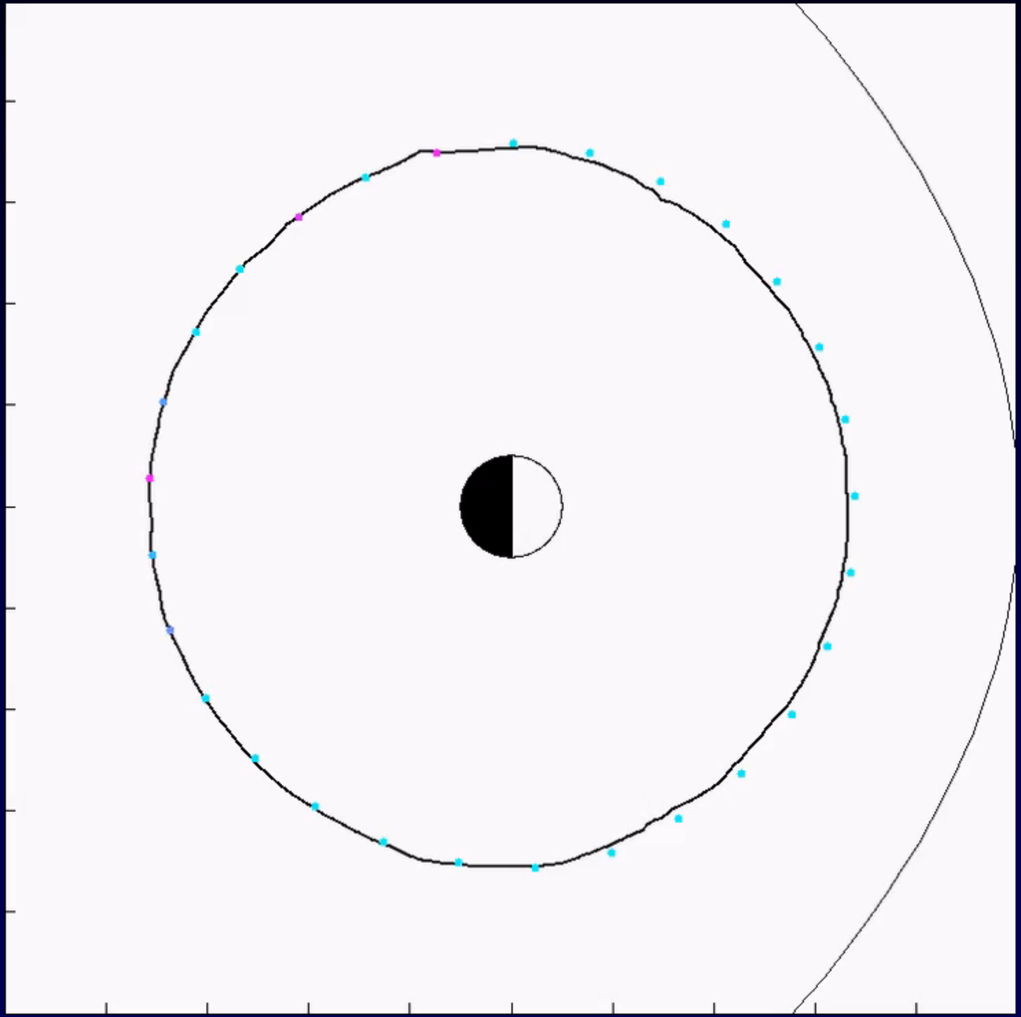
- Calculate 1st order field line displacements from E-field outputs.
- Calculate B(s) and bounce-average quadrature quantities for a set of (M,K) coordinates on ULF wave model 2D mesh.
- Calculate "Backward Liouville Test Kinetic" trajectories, interpolating drift velocities onto e^- positions.



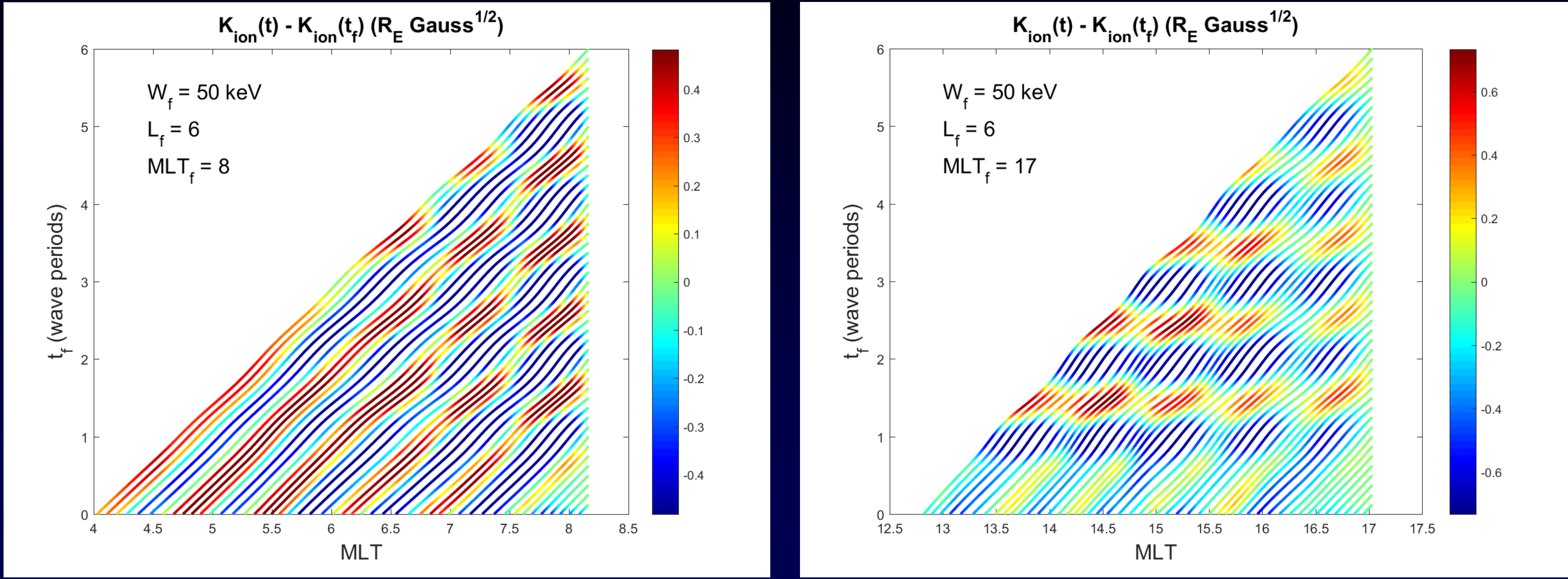
BLTK Trajectories

Backward Liouville Test Kinetic method including ionospheric loss:

- At $t = t_f$ ("measurement time"):
  - Choose final values for (L,MLT,W)
  - Set $K = K_{ion}(L,MLT,t_f)$
- Integrate back to t = 0 (where PSD is given)
- *If* $K_{ion}(t)>K_{ion}(t_f)$ *along entire trajectory:* Map PSD to final t_f
- *Otherwise:* Set PSD = 0
- Scan values of t_f.



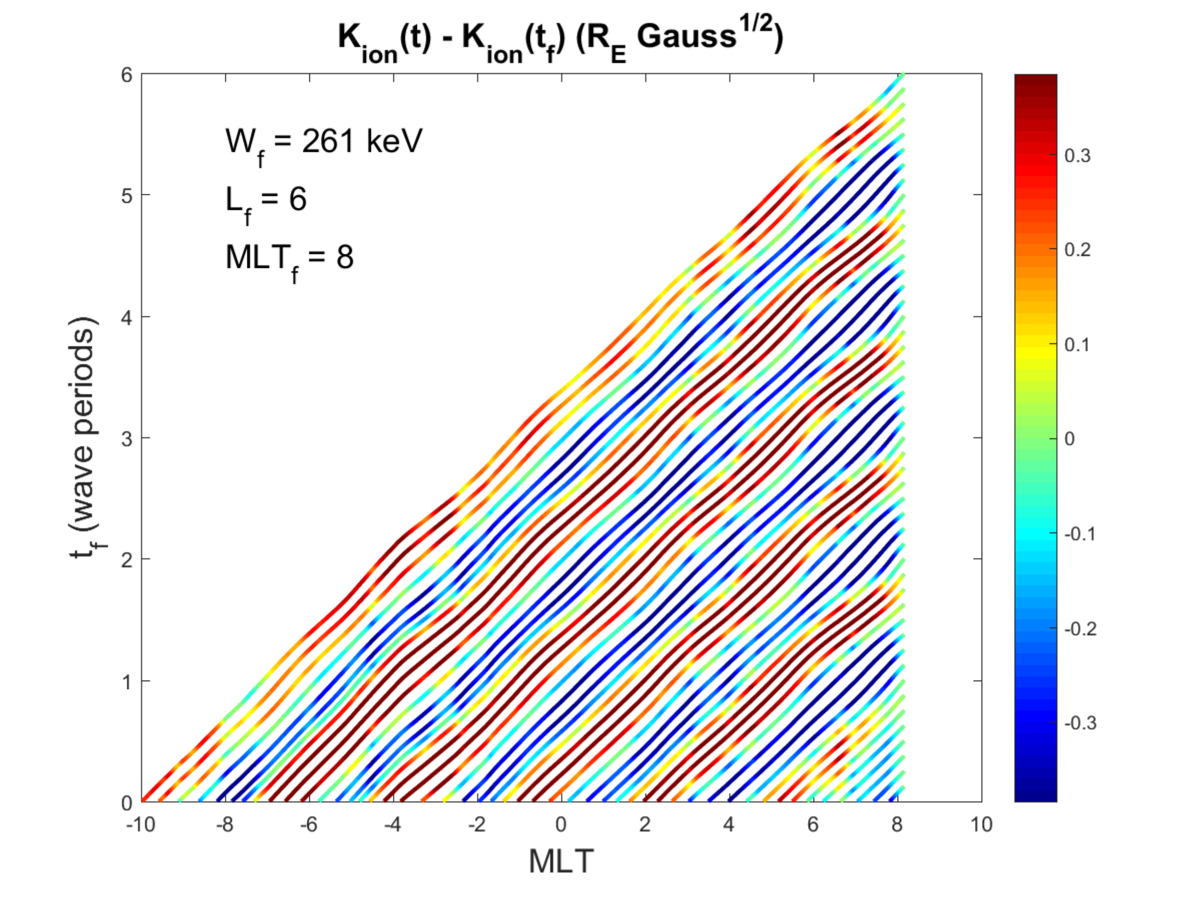
Accounting for previous precipitation along a trajectory:



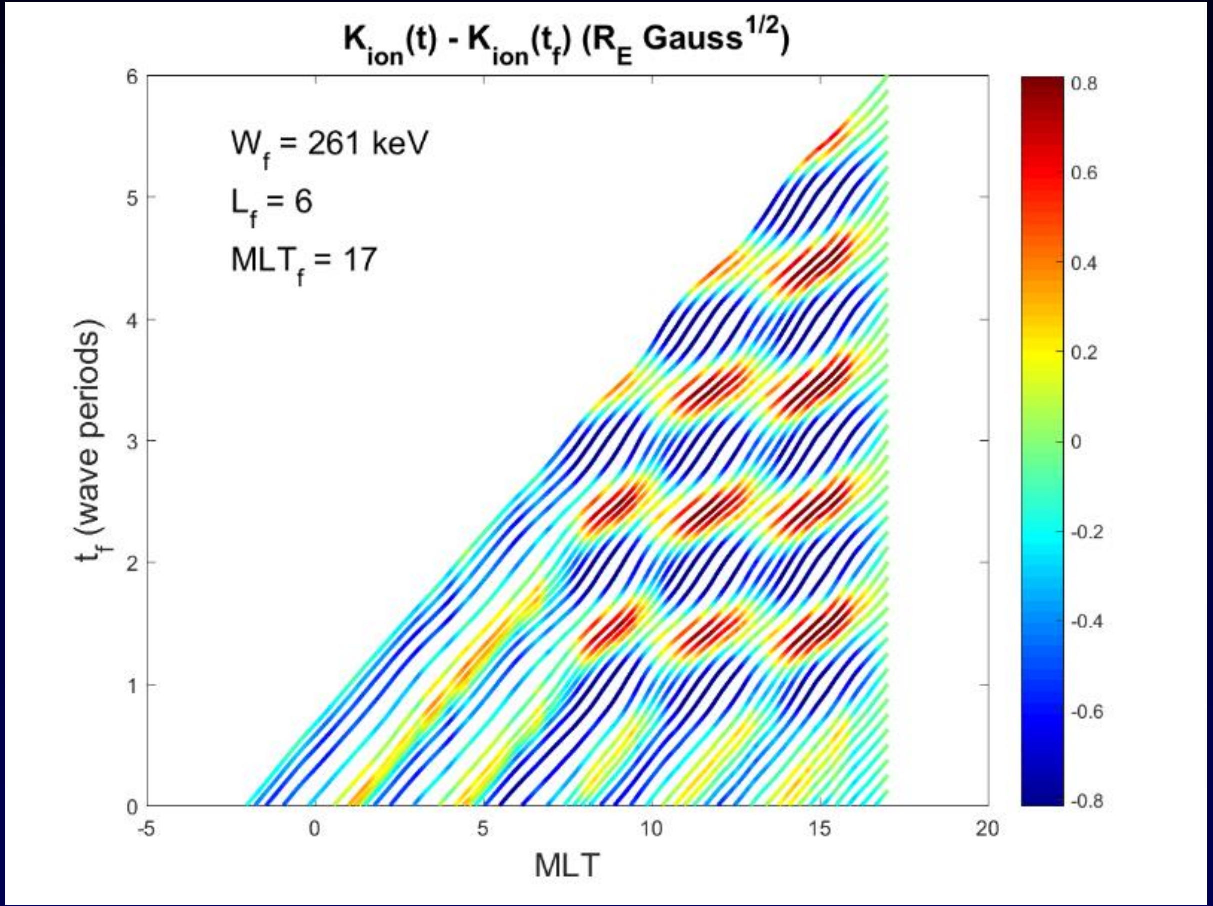
Morning

Evening

Accounting for previous precipitation along a trajectory:

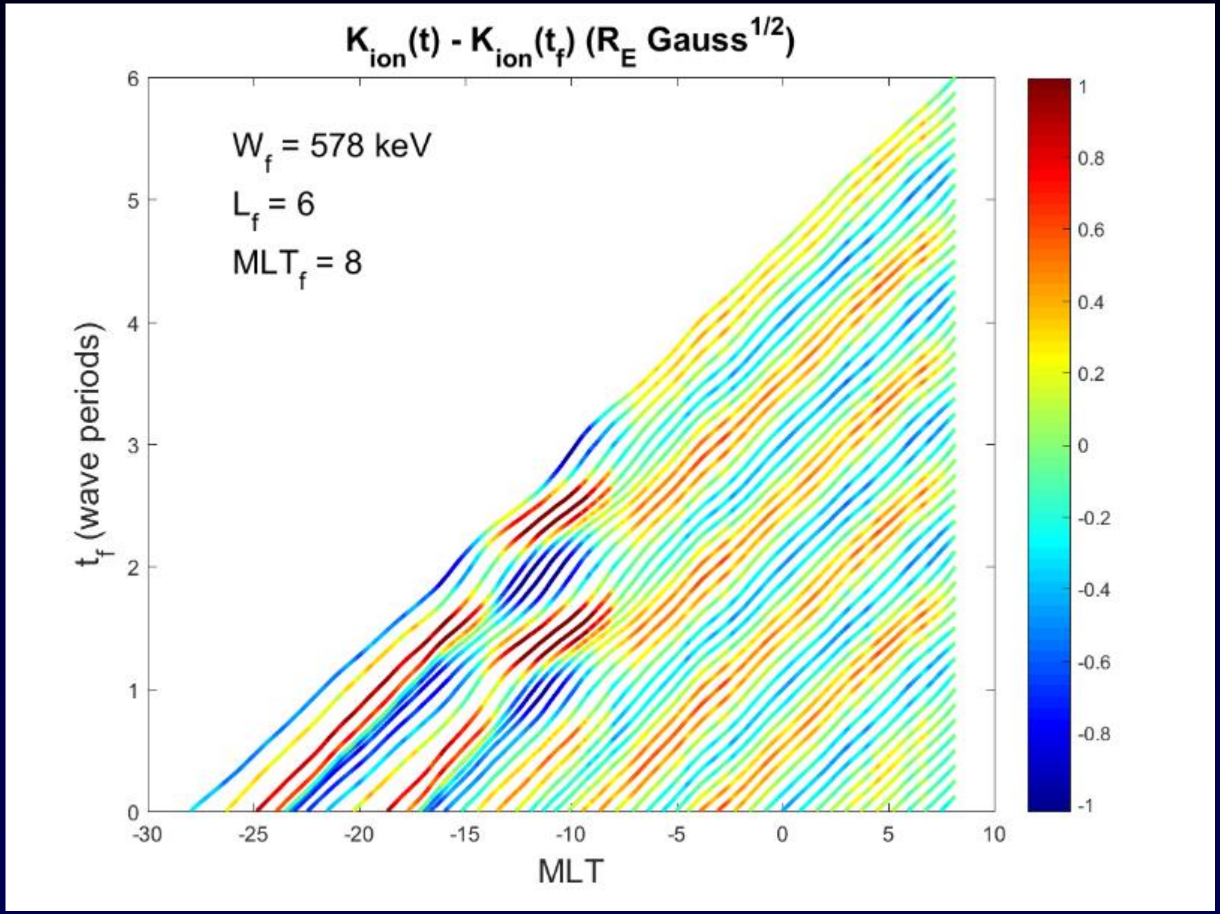


Morning

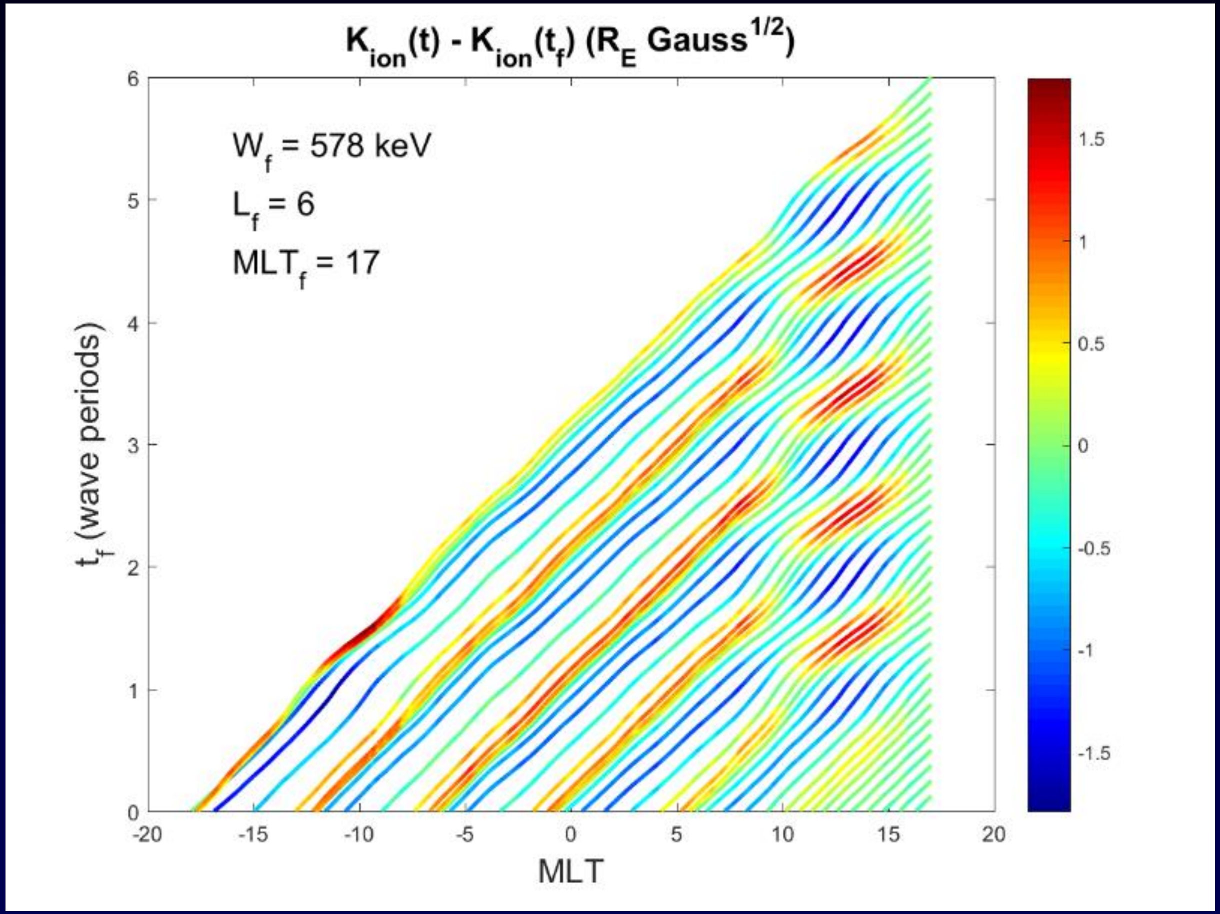


Evening

Accounting for previous precipitation along a trajectory:

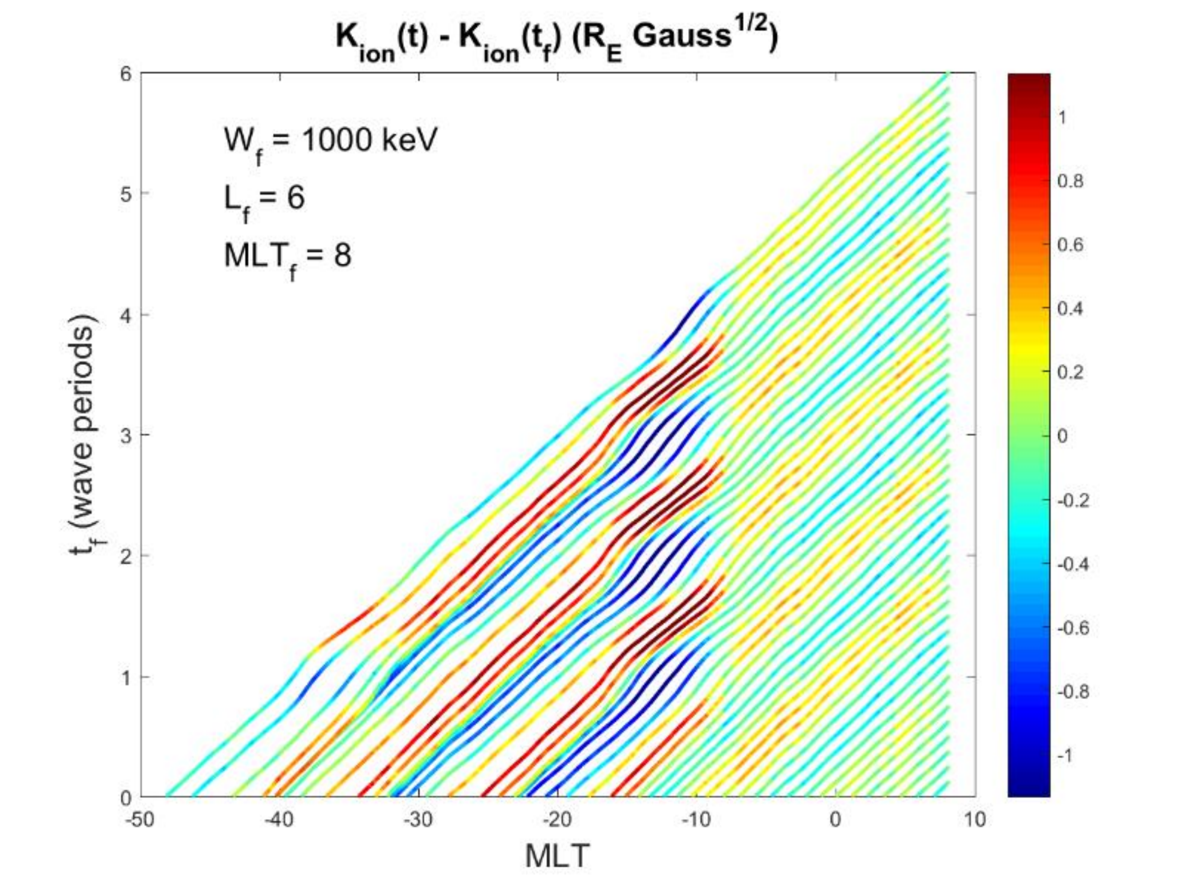


Morning

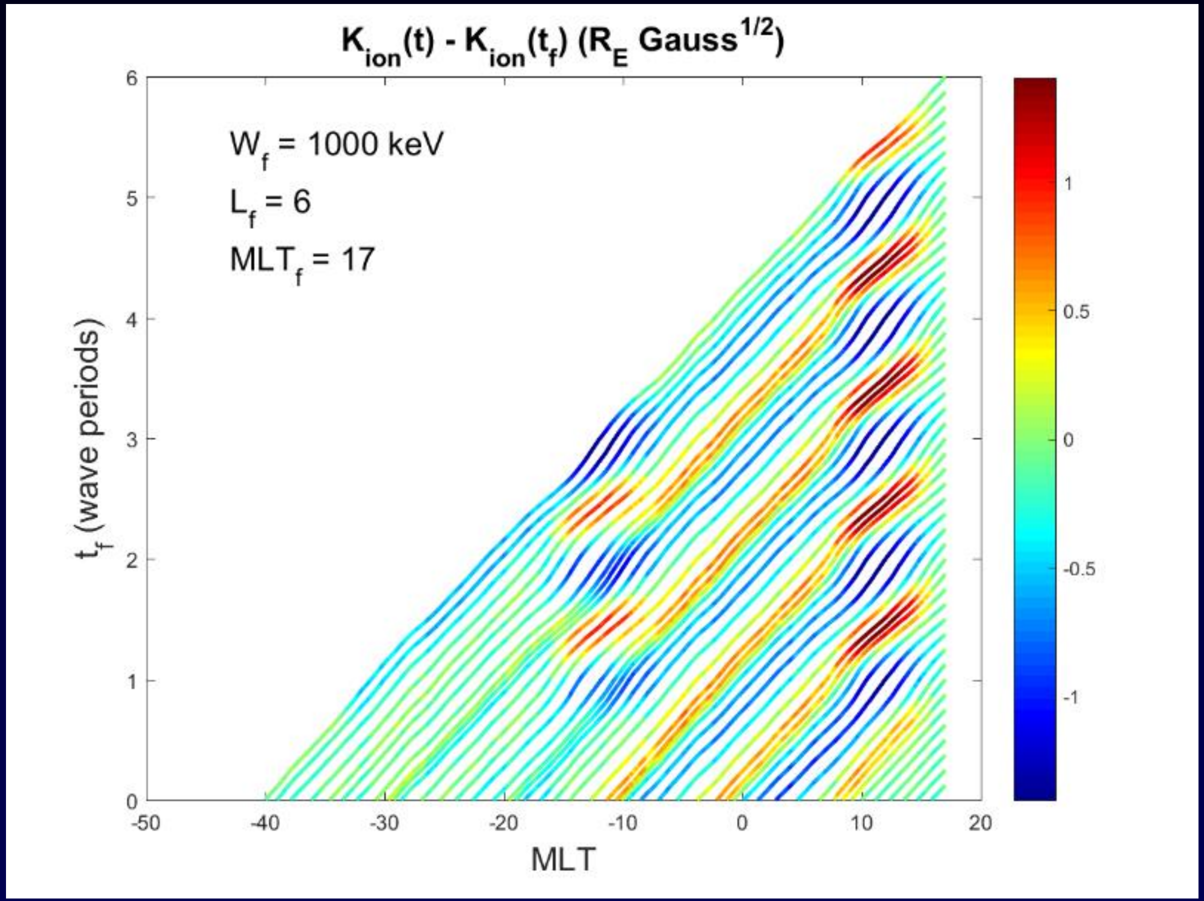


Evening

Accounting for previous precipitation along a trajectory:



Morning



Evening

Future directions

In order to more rigorously make predictions / comparisons against observations, we need to:

- Include timescales for pitch-angle scattering:
  - re-filling rate of loss cone
  - validity of adiabatic invariants
- Account for factors controlling ULF wave power distribution in the dayside magnetosphere e.g. plasma density profile.