Effects of Hot Protons on the Pitch-Angle Scattering of Ring Current Protons by EMIC Waves

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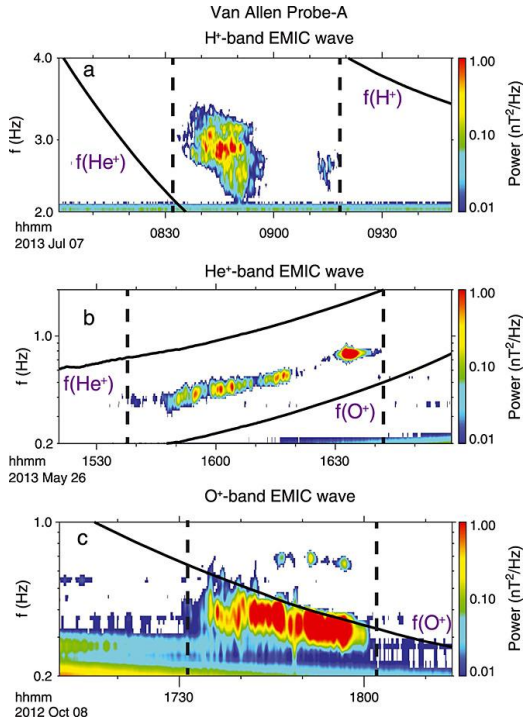
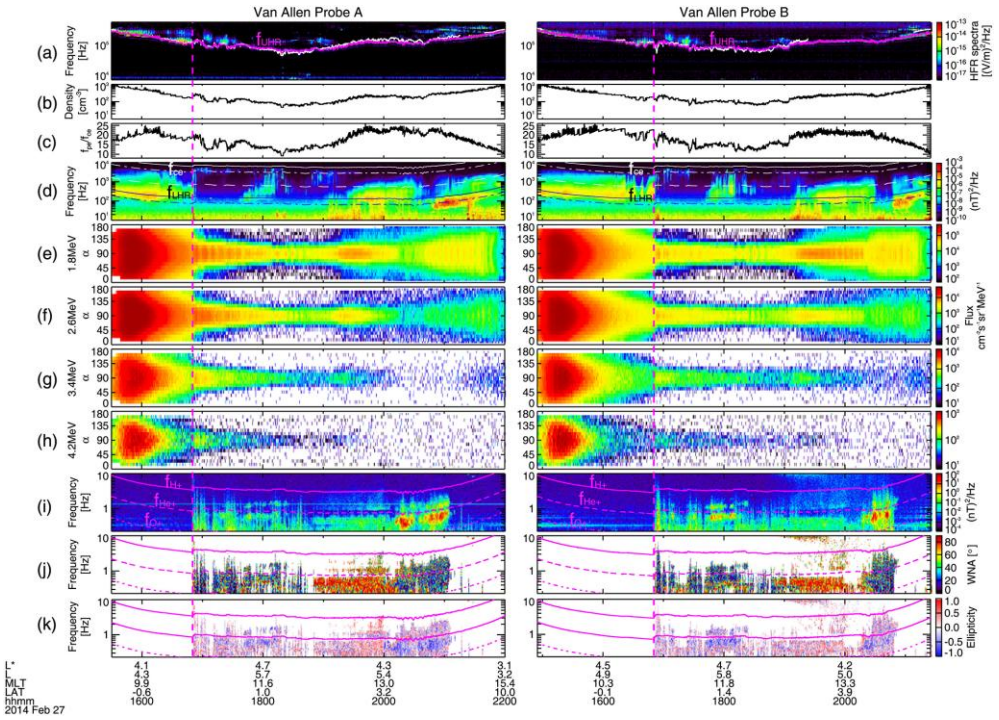
Introduction

1. EMIC wave characteristics



- In three distinct frequency bands (H^+, He^+, and O^+)
- Frequency range ~0.1 - 5 Hz
- Predominately L-mode

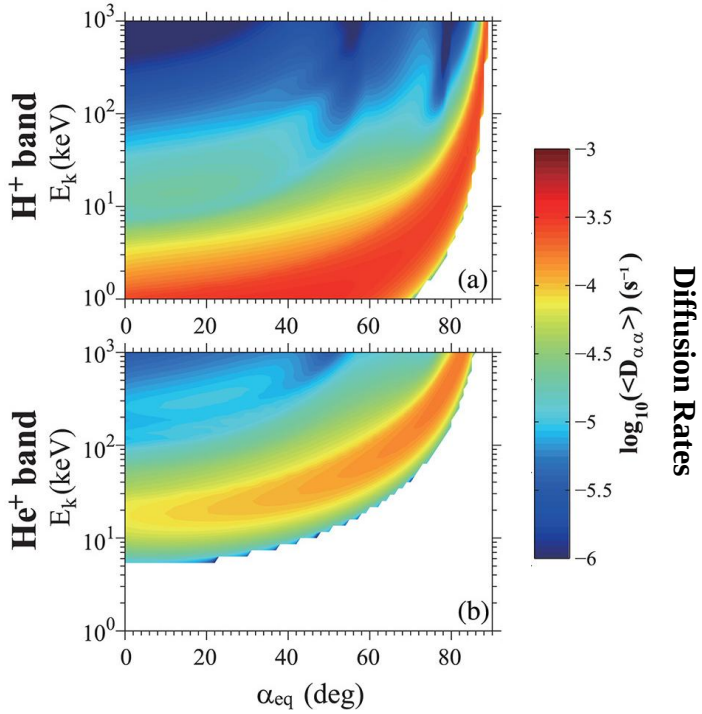
2. Interaction with electrons



(Zhang et al., 2016, JGR)

- Can effectively precipitate ~MeV electrons in radiation belts

3. Interaction with protons

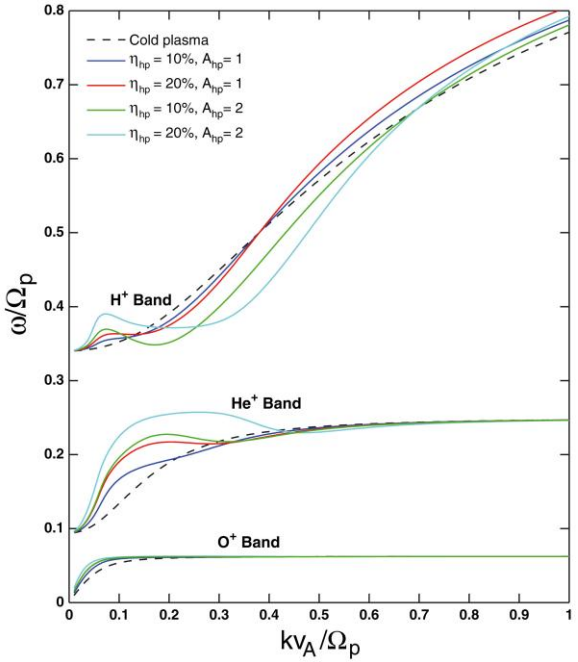


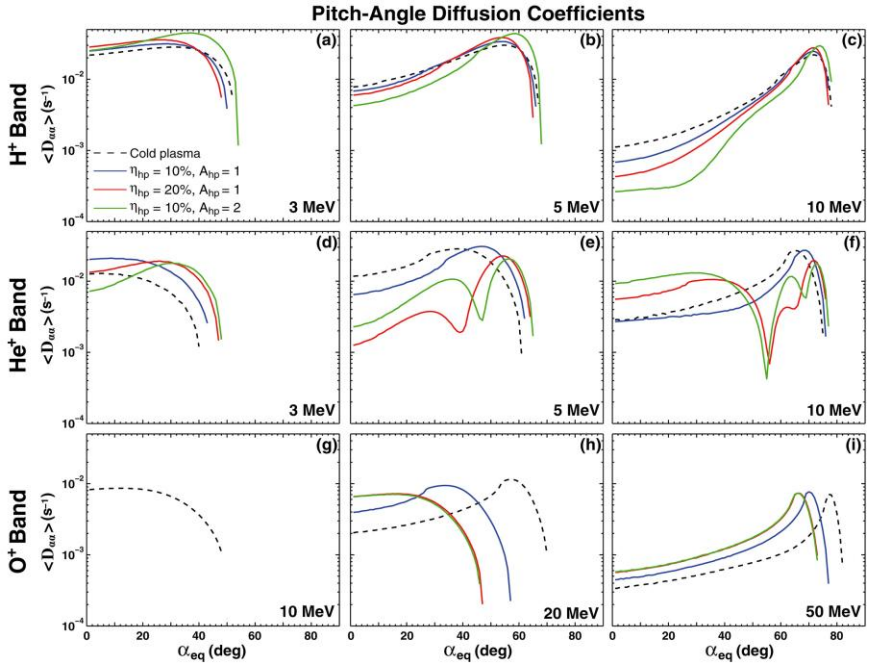
(Cao et al., 2016, JGR)

- Can also scatter ring current protons below tens of keV.

Introduction

4. Hot plasma effects on the cyclotron-resonant pitch-angle scattering rates of radiation belt electrons due to EMIC waves (Ni et al., 2017, GRL)





- Inclusion of hot protons can modify the dispersion relation for each of the three (H+, He+, and O+) wave bands.
- The hot plasma modification is more pronounced with increasing hot proton abundance or temperature anisotropy.

Hot plasma effects

- H+ band: weaken the pitch angle scattering efficiency of >5 MeV electrons.
- He+ band: result in a large difference up to an order of magnitude of scattering of >3 MeV electron.
- O+ band: cause a strong increase of the electron minimum resonant energy.

Method

Setting hot plasma parameters (η_{hp} and A_{hp})

↓

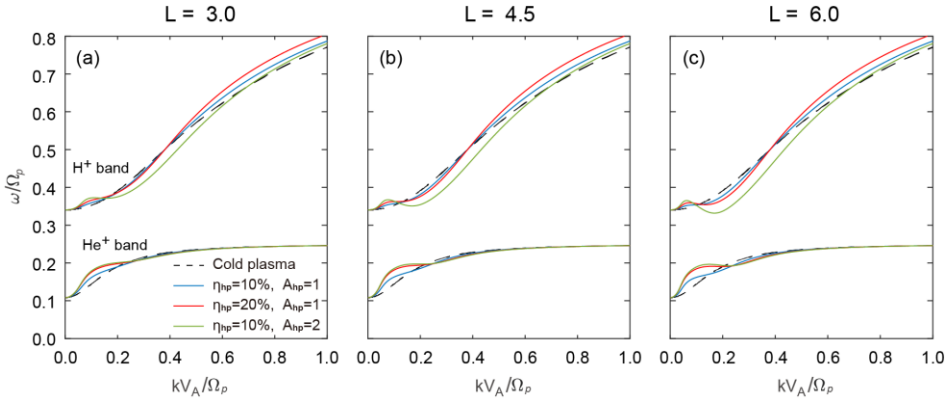
hot plasma dispersion relation of EMIC waves

↓ resonance condition

pitch angle diffusion coefficients $D_{\alpha\alpha}$

Results

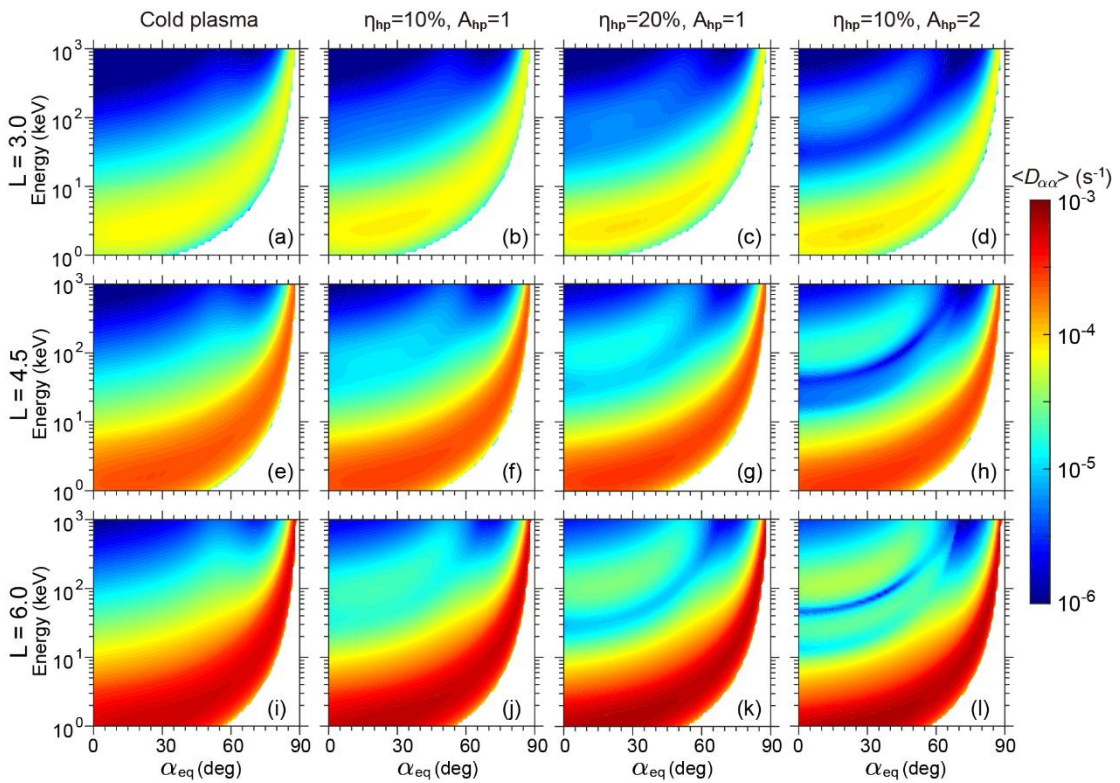
1. dispersion relation



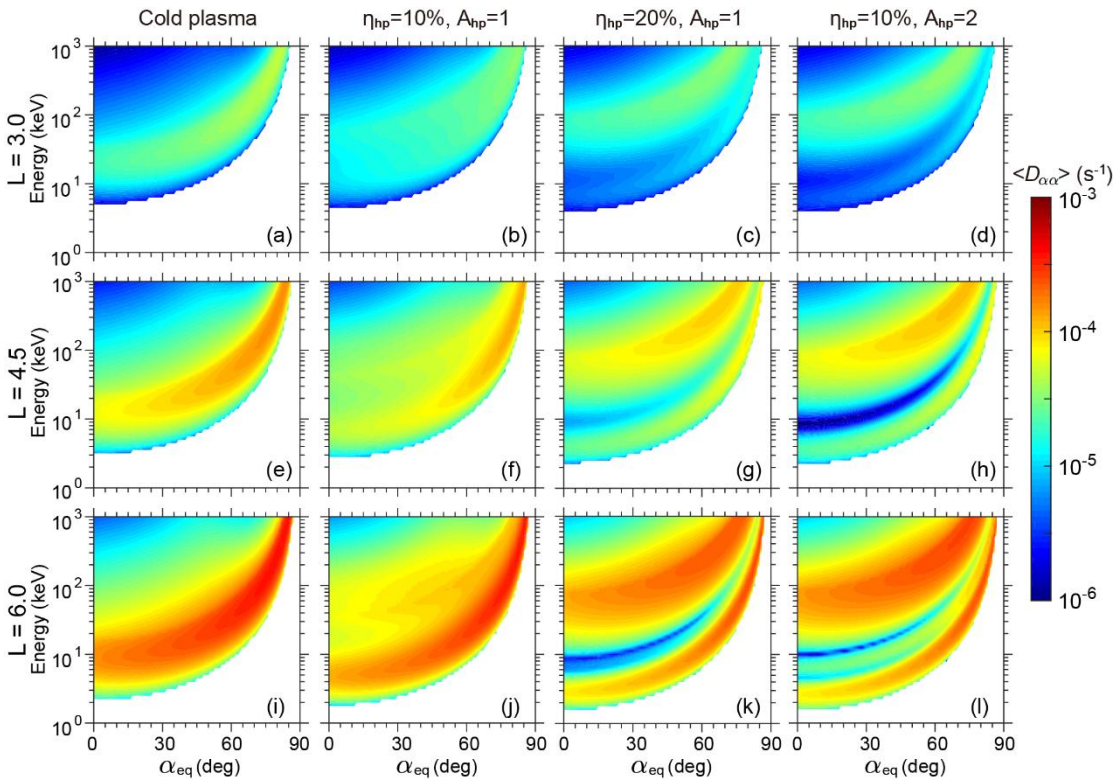
- Inclusion of hot protons significantly modify the dispersion relation of EMIC waves.
- Obvious discrepancies occur at almost all wave numbers for H^+ band, while only at small wave numbers for He^+ band.
- Such discrepancies become more pronounced as η_{hp}, A_{hp} or L-shell increases.

Results

2. Diffusion rates induced by H+ band EMIC waves



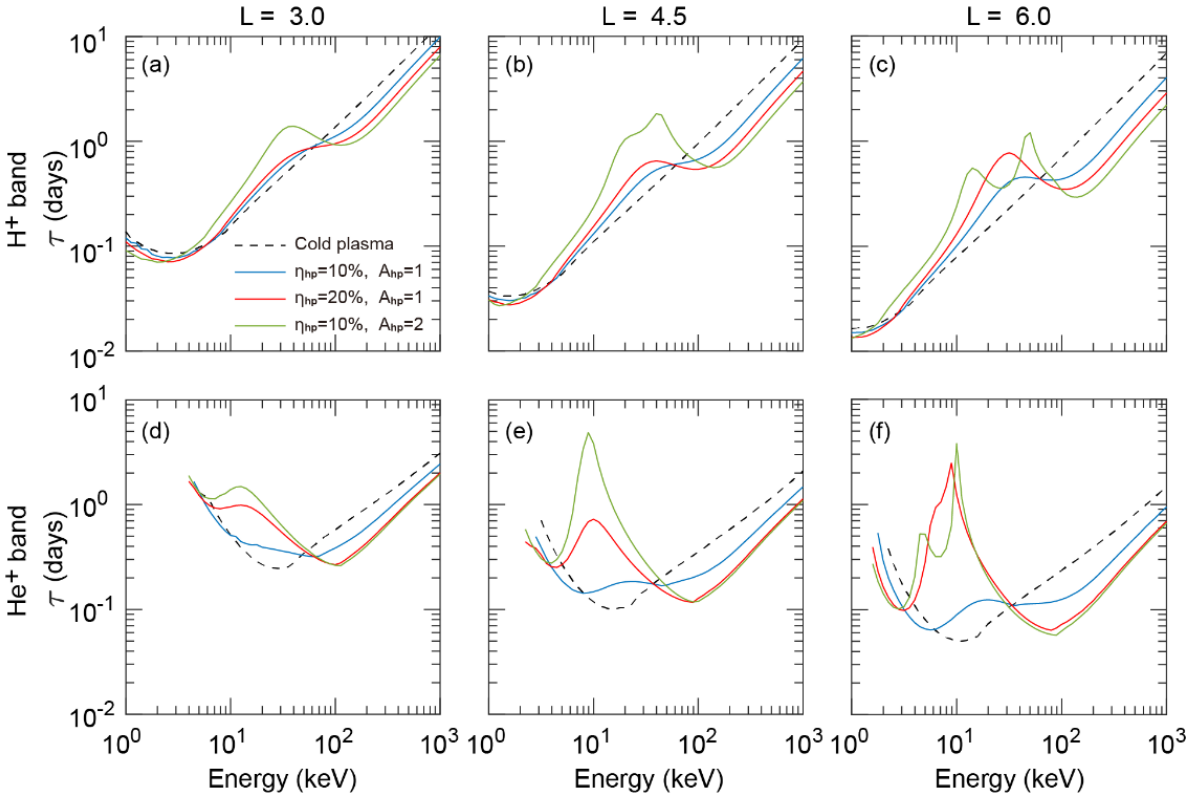
3. Diffusion rates induced by He+ band EMIC waves



- The modification of EMIC wave dispersion relations by hot protons can subsequently result in obvious changes in the bounce-averaged pitch angle diffusion coefficients of protons.
- Significant decrease of diffusion coefficients for H^+ band and He^+ band is found in proton energy ranges of ~ 10− 60 keV and 4 - 30 keV, above which the diffusion coefficients increase at low pitch angles and decrease at relatively high pitch angles.
- At a fixed *L*-shell, the corresponding differences in diffusion coefficients between the cold and hot plasma approaches become greater with increasing η_{hp} and A_{hp}.

Results

4. Proton loss timescales



- For H^+ band (He^+ band) EMIC waves, the cold plasma approximation leads to a pronounced underestimate of the loss timescales of ~ 5 - 60 keV (~ 4 – 40 keV) protons and an overestimate of the loss timescales of > ~ 60 keV (> ~ 40 keV) protons.
- The changes in proton loss timescales are generally smaller than a factor of ~ 5 for H^+ band but can be larger than an order of magnitude for He^+ band, showing a strong dependence on η_{hp}, A_{hp} and L-shell.

Summary

Hot plasma effects can

- significantly **modify the dispersion relation** of both H^+ and He^+ band EMIC waves. The discrepancies become **more pronounced** as hot proton concentration η_{hp}, temperature anisotropy A_{hp} or L-shell increases.
- result in **obvious changes** in the pitch angle diffusion coefficients of protons.
- strongly influence the EMIC wave induced loss of ring current protons. For H^+ band (He^+ band) EMIC waves, the cold plasma approximation leads to **a pronounced underestimate of the loss timescales of tens of keV protons** and **an overestimate of the loss timescales of protons at higher energies**.

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