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Modelling the Earth's Radiation Belts with Applications to Jupiter and Saturn

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Abstract

There has been a revolution in our understanding of how the Earth's radiation belts are formed over the past few years[1], and what causes large variations in electron flux. There is now clear evidence that variations in the flux of relativistic electrons in the outer belt cannot be explained by radial diffusion alone, and that some other local acceleration and loss mechanisms must be operating[2]. Cyclotron resonant electron acceleration by whistler mode waves is a leading acceleration mechanism[3], but there are also other types of wave-particle interactions which can contribute to radiation belt variations.

Here we show how wave-particle interactions, including whistler mode waves, magnetosonic waves and electromagnetic ion cyclotron waves, can contribute to radiation belt variations. We discuss how these wave-particle interactions can be included into global radiation belt models, and present results from a new global radiation belt model developed at the British Antarctic Survey. The model includes radial diffusion and wave-particle interactions due to plasmaspheric hiss and whistler mode chorus. The model includes the effects of geomagnetic activity on wave power and plasma density which are known to affect electron loss and acceleration rates. The frequency spectrum of each wave mode has been carefully modelled using CRRES satellite data and pitch angle and energy diffusion rates calculated for different magnetic local times and different L shells. The effects of plasmaspheric plumes on wave-particle interactions are included in the model without the need for an explicit plasmapause model. We show that when the model is run with radial diffusion and plasmaspheric hiss the model can reproduce electron losses observed by CRRES very well. When the model is run to simulate geomagnetic storms observed without including chorus waves we find that the electron flux at MeV energies is too small compared to CRRES observations. We find that electron acceleration due to chorus waves is essential for reproducing the variations in the flux of MeV electrons during geomagnetic storms.

We consider the magnetospheres of Jupiter and Saturn and note that whistler mode waves are observed at both planets. We show that cyclotron resonant wave acceleration also operates at Jupiter[4], outside of the orbit of the moon Io, and may provide an important contribution to the formation of Jupiter's radiation belt. We also suggest that cyclotron resonant acceleration provides a missing link in the production of synchrotron radiation from the planet. We also show that cyclotron resonant acceleration maybe effective at Saturn at locations above the geomagnetic equator.

References

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