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A Physical Model of Electron Radiation Belts of Saturn

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Abstract

Enrolling on the Cassini age, a physical Salammbô model for the radiation belts of Saturn have been developed including several physical processes governing the kronian magnetosphere. Results have been compared with Cassini MIMI LEMMS data.

1. Introduction

For two decades, ONERA proposes studies about radiation belts of the magnetized planets. First, in the 90's, the development of a physical model, named Salammbô, carried out a model of the radiation belts of the Earth. Then, for few years, analysis of the magnetosphere of Jupiter and in-situ data (Pioneer, Voyager, Galileo) allow to build a physical model of the radiation belts of Jupiter [1].

Enrolling on the Cassini age, this study now allows to develop an electron radiation belts model for Saturn environment, based on the jovian model. Indeed, like Jupiter, Saturn has rings, moons, and is similar to Jupiter in many respects (composition, rocky nucleus, etc). Furthermore, Saturn is also comparable to the Earth: magnitudes of the magnetic fields are the same and thus, dynamics of magnetospheres are similar.

2. Salammbô, a physical model of radiation belts

Salammbô is a three dimensions physical model based on the resolution of the Fokker Planck diffusion equation [2]. Diffusion coefficients related to several physical processes, have to be integrated to the equation.

In this kronian electron model, coefficients are linked up to different interactions: interaction between high energy electrons and dense environment (atmosphere…); interaction between energetic electrons and neutral particles ejected from Enceladus (model of neutral cloud from Cassidy & Johnson model [3] [4]); interaction between energetic electrons and natural satellites of Saturn (moons are comparable to absorbent objects [5] [6]); interaction between high energy electrons and dust rings [7][8]; wave - particle interaction. Concerning the last interaction, data are from RPWS instrument [9] from 1 Hz to about 12000 Hz. Physical processes generated by these interaction are energy and pitch angle diffusions.

Radial diffusion process correspond to the transport of the high energy particles from the boundary condition of the model (L = 6 Rs) to the planet [2].

An example of the importance of each physical process is shown on Figure 1 for 1 MeV electrons with an equatorial pitch angle of 80°. This figure represents coefficients of each physical process (s^{-1}) versus L values. Close to the planet (L < 2.33 Rs), absorption due to main rings (Figure 1. (3)) is the most important physical process in such a way that it makes a totally absence of electrons flux (see also [2] [10]). Beyond L = 2.5 Rs, the most important physical processes are radial diffusion (Figure 1. (1)) and local absorption due to satellites (Figure 1. (2)). Coefficients due to the neutral cloud and coefficients due to wave particle interaction also appear on this figure (respectively Figure 1.(4) and Figure 1. (5)).

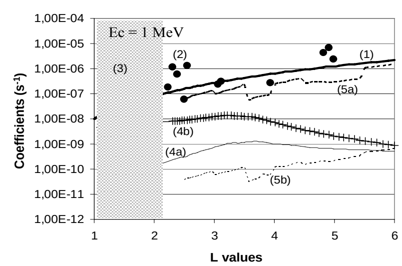

Figure 1. Evolution of diffusion coefficients for electrons of 1 MeV and near the equator (α_{eq} = 80°): (1) radial diffusion (transport) (2) interaction with naturals satellites (absorption) (3) interaction with the main rings (absorption) (4) interaction with neutral particles ((4a) pitch angle diffusion, (4b) energy degradations) (5) wave particle interaction ((5a) pitch angle diffusion, (5b) energy diffusion) 4. Tables

3. Analysis of data and comparisons with Salammbô

Physical processes have been computed and an isotropic boundary condition to the model has been built. The boundary condition, based on Cassini measurements at L = 6 at the equator, models an electron injection from the magnetotail into the inner radiation belts.

Results have been compared to Cassini MIMI LEMMS data to validate the Salammbô model: we compute a Cassini mean flux (logarithmic mean) to compare it with flux resulting from our mean model Salammbô.

Figure 2 presents comparisons between Salammbô fluxes (red solid line) and Cassini mean fluxes (black solid line) for high energy electrons (E3 channel: 600 < E < 4950 keV) and low energy electrons (C1 channel: 27 < E < 48 keV).

Figure 2 shows that there is a global coherence between Salammbô electron fluxes and Cassini electron measurements although results are better for high energies.

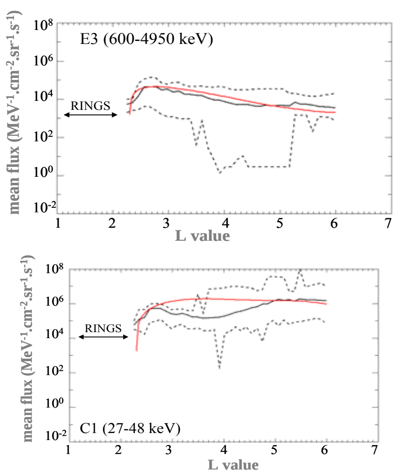

Figure 2. Comparisons between Salammbô fluxes (red solid lines) and Cassini mean fluxes (black solid lines) for E3 (600 < E < 4950 keV) and C1 (27 < E < 48 keV) channels. Dotted lines are minimum and maximum Cassini measurements.

4. Discussion and Conclusion

We present a new version of Salammbô focused on Saturn's electrons radiation belts, including radial diffusion and interactions of electrons with Kronian moons, rings, waves, and neutrals particles. Importance of each physical process has been compared. Results suggest that interaction of electrons with neutral particles is not a major physical process for high energy electron but can have an importance for the low energy electrons (E < ~50 keV) and that wave particle interaction can have a real influence on fluxes.

Several hypothesis have been envisaged to explain differences observed between Cassini mean flux and Salammbô flux at low energies, notably interaction of energetic electrons with neutral particles. We think that we are not able to recreate depletions with Salammbô 3D model because neutrals are modelled all along the drift and it is not the case: they are localised around Enceladus. A fourth dimension, which would be the Magnetic Local Time, would permit to model the neutral cloud around Enceladus and so a 4D model can maybe recreate on Salammbô fluxes depletions observed on measurements. It is important to add that doubts exist on Cassini data and it can be also a dependence on MLT or pitch angle we do not consider on our model.

In addition, Salammbô kronian model has been compared to an empirical radiation belts model named SATRAD [10] and to a recent work by Mauk et al. [11]. Comparisons of Salammbô with in situ data and empirical model confirm that Salammbô is a good mean model for Saturn electrons radiation belts for energies from about hundred keV to a few MeV.

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