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A Physical Model of Electron Radiation Belts of Saturn

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Abstract

Enrolling on the Cassini age, ONERA have been developed a physical Salammbô model for the radiation belts of Saturn, including several physical processes governing the kronian magnetosphere. Results have been compared with Cassini 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 of the high energy electrons with dense environment (atmosphere…); interaction with neutral particles ejected from Enceladus (model of neutral cloud from Cassidy & Johnson model [3] [4]); interaction with natural satellites of Saturn (moons are comparable to absorbent objects [5] [6]); interaction with the dust of the rings system. Concerning this last but not the least interaction, a model of the Saturn rings system, based on the literature, has been built with different sub-rings, different thickness, different size of particles, etc [7] [8]. Physical processes generated by these interactions, are energy degradations, absorptions and pitch angle diffusions of the electrons.

The last physical process correspond to the transport of the high energy particles from the boundary condition of the model (L = 6 Rs) to the planet and is called radial diffusion [2].

An example of the importance of each physical process is shown on Figure 1 for 380 keV electrons with an equatorial pitch angle of 80°. This figure represents the 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] [9]). Moving away from the planet, local absorption due to the satellites (Figure 1. (2)) Epimetheus and Janus makes also an absence in the electron flux (L ~ 2.5 Rs). Beyond L = 2.5 Rs, the most important physical process is the radial diffusion (Figure 1. (1)). Moreover, influence of the interaction of the electron radiation belts with neutral cloud particles (Figure1. (4a) and (4b)) is too weak to have an significant effect (see also [2]).

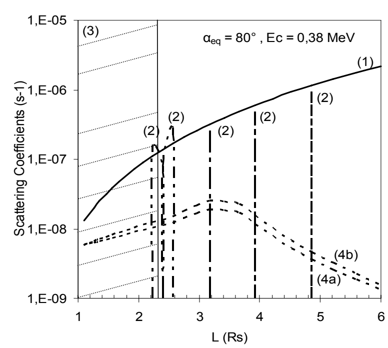

Figure 1. Evolution of diffusion coefficients for electrons of 0.38 MeV and near the equator (α_{eq} =

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)

No interaction with atmosphere appears in this figure. In fact, interaction with atmosphere occurs near the planet but there is no electron flux due to the main rings absorption for these L values.

3. Analysis of data and comparisons with Salammbô

A first radiation belt model of Saturn has been developed with the main physical processes described before. In order to have a complete model, a boundary condition has to be integrated in Salammbô.

In a first time, Voyager 2 data have been used to construct this boundary condition at L = 6 Rs. However, the quality of these data could be argued (only few information on the calibration of the particle detector) and the data correspond to only one flyby and may not be representative to the mean electrons flux at L= 6 Rs.

Unlike Voyager 2, Cassini probe has the advantage of being an orbiter which greatly increases the statistical data. So, Cassini data have been the subject of a detailed analysis in order to build a new boundary condition at L = 6 Rs. This new boundary condition leads to new results for the kronian radiation belts model.

Figure 2 compares the results of Salammbô (red curve) with electrons fluxes measured by Cassini (black curve) for the E1 orbit (2005/03/09) and for three channels (C4,C5 and C6). The panel on the top of the figure represents L values encounter by the probe.

Figure 2 shows that there is a global coherence between Salammbô electron fluxes and Cassini electron measurements . However, Salammbô fluxes are too high compared to measurements and some differences could be observed. How could we explain these differences?

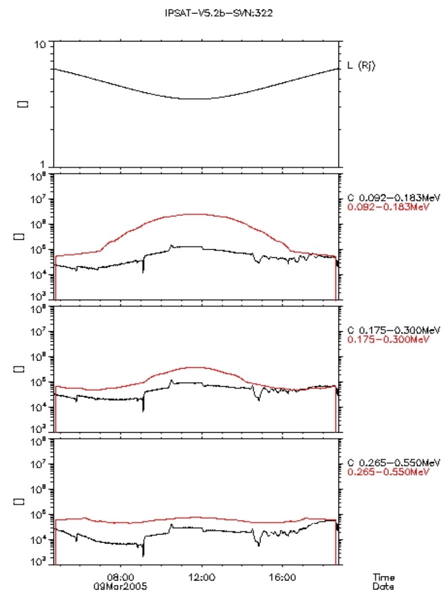

Figure 2. Comparison of Salammbô fluxes (red curve) with electrons fluxes measured by Cassini (black curve) for three energy channels: 0.092-0.183 MeV (C4), 0.175-0.300 MeV (C5), 0.0265-0.550 MeV (C6). The curve on the top represents L values encounter by the probe (L < 6 Rs).

4. Discussion and Conclusion

It is essential to say that Salammbô, in the Saturn case, is a static radiation belts model and can not reproduce the electron dynamic due to the solar wind. However, several hypothesis have been envisaged to improve the model.

First, the detailed analysis of Cassini data shows that Enceladus causes a very localized effect around it. But it seems that this effect can not create such differences. Indeed, Salammbô 3D is a drift averaged model which not take into account an effect so localized in longitude.

Secondly, waves have been detected in the magnetosphere between 4.8 and 8 Rs [10] and it is well known that waves interact with high energy electron which can modify the electron distribution in the radiation belts. Before integrating this physical process into Salammbô, it is important to study the waves influence on the radiation belts electrons in the kronian magnetosphere. This physical process could explain the divergences between Salammbô and in-situ data.

The electrons radiation belts model and studies about these two hypothesis will be presented in more details.

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