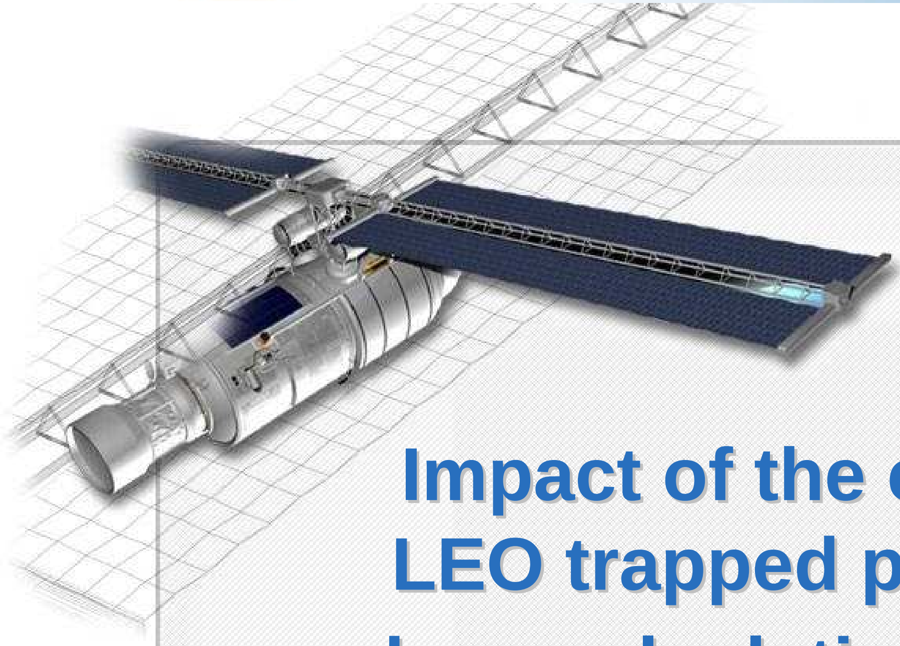


Impact of the consideration of the LEO trapped proton anisotropy on dose calculation at component level

P. Pourrouquet, A. Varotsou and R. Fonta, TRAD
D. Boscher, ONERA/DESP
R. Ecoffet, CNES

Context

- Trapped proton fluxes at Low Earth Orbit (LEO) are anisotropic due to the interaction with the Earth's atmosphere. A steep pitch-angle distribution is observed related to the atmospheric loss cone.
- At LEO the dose is deposited mainly by trapped protons
- The proton anisotropy is not currently taken into account in the radiation hardness process at industrial level. This would make the process long and complicated.
- Along the orbit the satellite changes orientation w.r.t. to the magnetic field => probable attenuation of the anisotropy effect

Objective

- Quantify the impact of taking into account the trapped proton anisotropy on the deposited dose calculation, by considering a realistic satellite 3D radiation model

Outline

- Description of activities
  - Anisotropic flux calculation
  - Satellite attitude definition
  - Anisotropic flux inside the satellite
  - TID calculation at component level
- Results
- Conclusions

Description of activities

1. Definition of anisotropic flux w.r.t. the magnetic field
2. Definition of the satellite orientation w.r.t. the magnetic field
3. Use the above to define the anisotropic flux at component level inside the satellite
4. Calculation of deposited dose using Sector Analysis for both isotropic and anisotropic fluxes
5. Comparison between results

1- Anisotropic flux calculation

- Badhwar & Konradi [1990] model

$$j = K\,\xi\,e^{-\beta\xi} \qquad \text{where} \qquad \xi = \frac{\sin\alpha}{\sqrt{B}} - \frac{\sin\alpha_L}{\sqrt{B}}$$

$$J = 4\pi \int_{\alpha_L}^{\pi/2} j \sin\alpha\, d\alpha = 4\pi K \int_{\alpha_L}^{\pi/2} \xi e^{-\beta\xi} \sin\alpha\, d\alpha$$

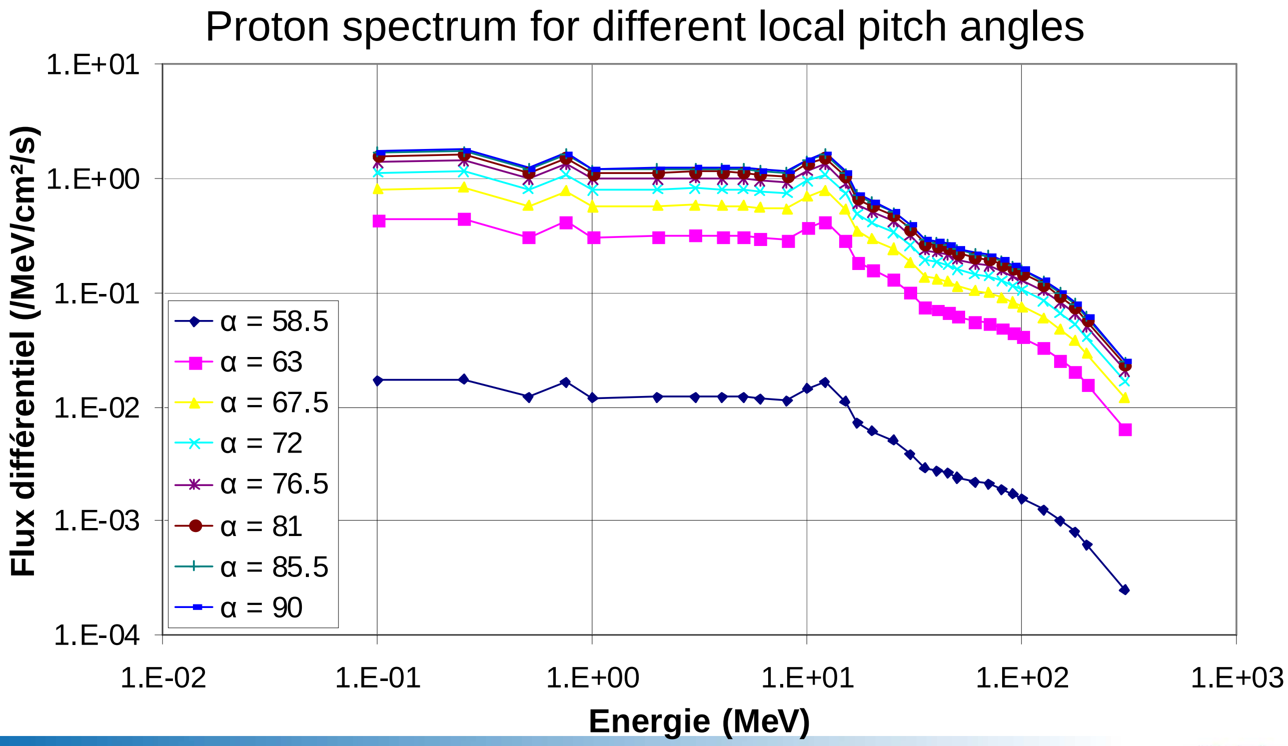
- Using values from Siegl [2009]

$$\sin\alpha_L = \sqrt{\frac{B}{Bo}}\sin\left(\frac{\pi}{180}\frac{1}{-0.032392+0.039836L}\right)$$

$$\beta[\sqrt{G}] = \frac{1}{0.13164 - 8.8674Ln(L)}$$

1- Anisotropic flux calculation

- Remarks:
  - Anisotropy different at each point of the orbit
  - Local pitch angle α_L, > 90° for high L values: orbit points are excluded
  - Anisotropy at a specific point of the orbit is independent of the energy



Altitude :

660 km

Latitude :

-34.39°

Longitude :

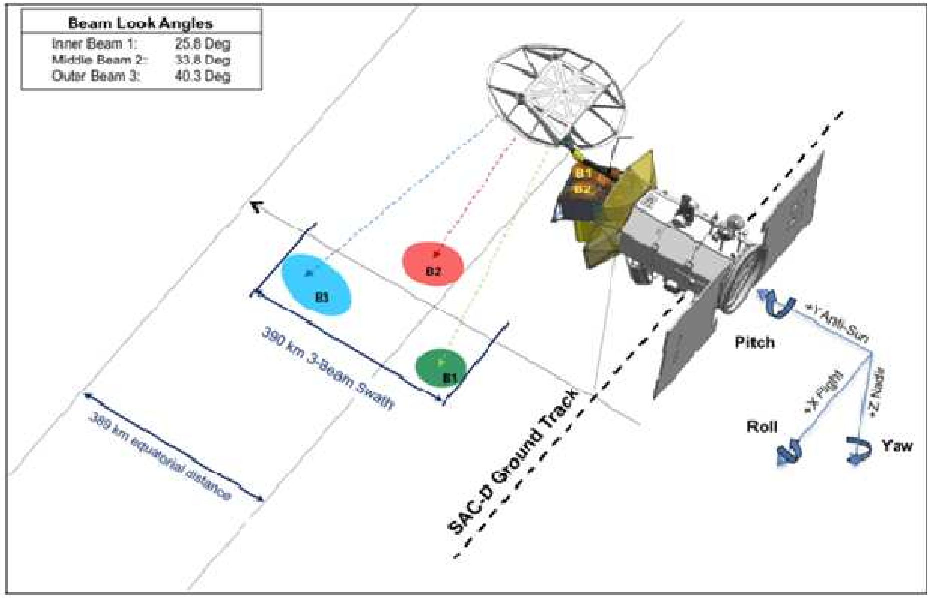
-39.06°

L :

1.544

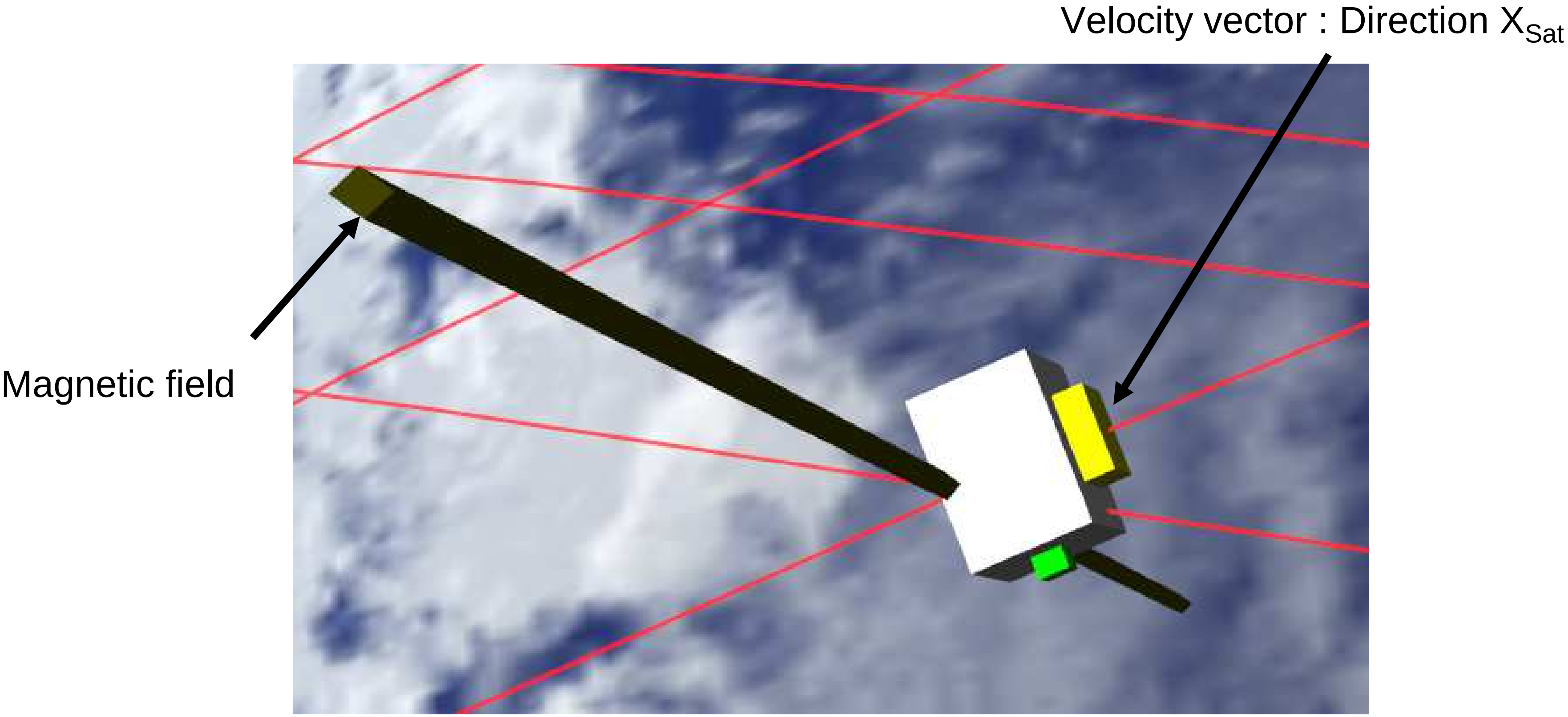
2- Satellite attitude definition

- Use of quaternions
  - Missing/bad data for the first part of the studied mission (SACD)
- Use of SACD mission characteristics
  - Direction Z_{sat} : oriented towards the center of the Earth
  - Direction X_{sat} : oriented following the satellite velocity vector
  - Direction Y_{sat} : from orthogonal satellite coordinate system



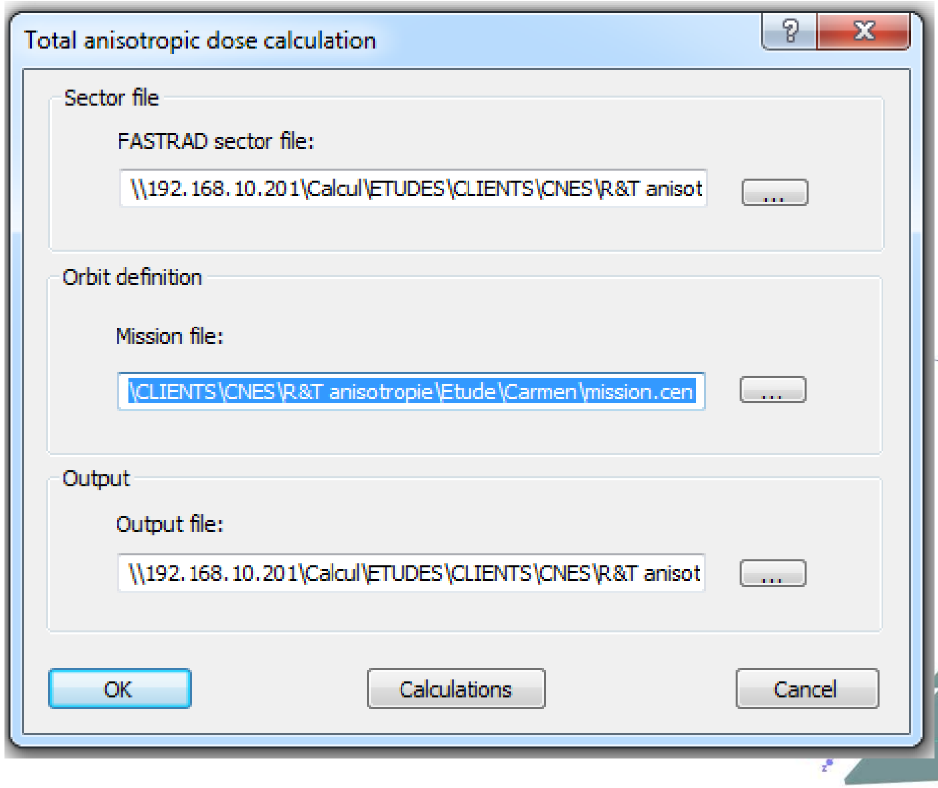
3- Anisotropic flux inside the satellite

- Use of all information described before
- Development of a special algorithm in OMERE to estimate the satellite orientation w.r.t. to the magnetic field at each point of the mission



4- TID calculation at component level

- Sum of flux for each direction inside the satellite for the whole mission
- Calculation (Sector Analysis) of deposited dose by isotropic and anisotropic flux, considering the shielding brought by a satellite platform, an equipment (ICARE-NG) and component packages



Total anisotropic dose calculation

Sector file

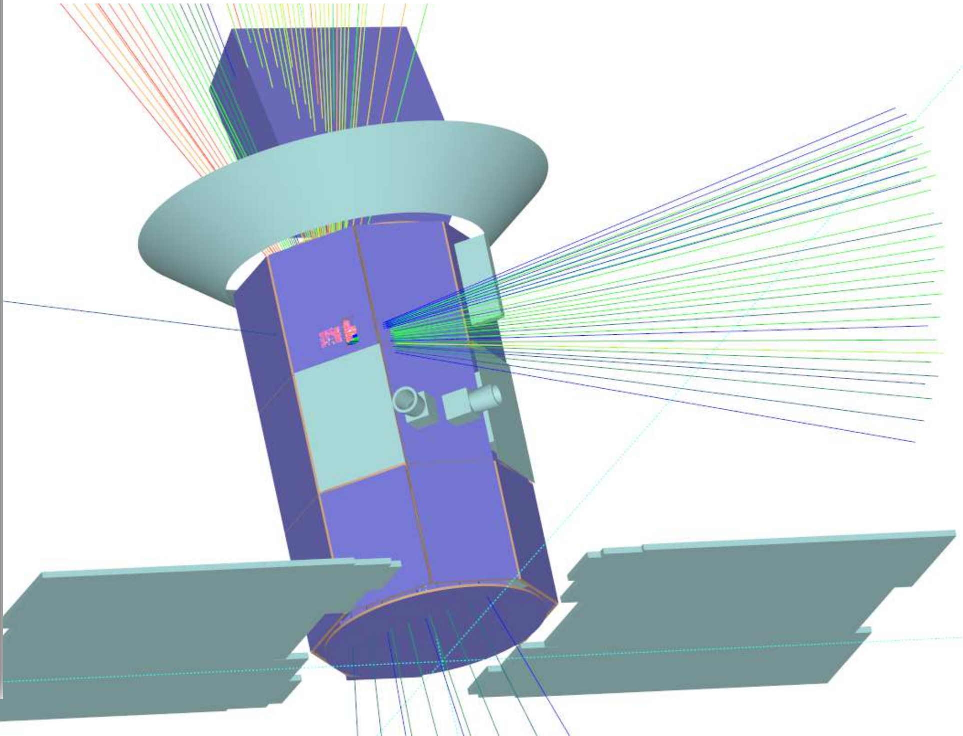
FASTRAD sector file: \\192.168.10.201\Calcul\ETUDES\CLIENTS\CNES\R&T anisot

Orbit definition

Mission file: \CLIENTS\CNES\R&T anisotropie\Etude\Carmen\mission.cen

Output

Output file: \\192.168.10.201\Calcul\ETUDES\CLIENTS\CNES\R&T anisot



5- Results

- Estimated dose on the outside of the satellite for 2 LEO missions – validation of the calculation algorithm
  - Isotropic flux gives identical result to anisotropic flux

Mission	**Flux Isotrope** Dose totale Protons piégés	**Flux Anisotrope** Dose totale Protons piégés	Différence Anisotrope/Isotrope
	rad	rad	%
SAC-D	1.61E+05	1.61E+05	0
Jason 2	3.96E+06	3.96E+06	0

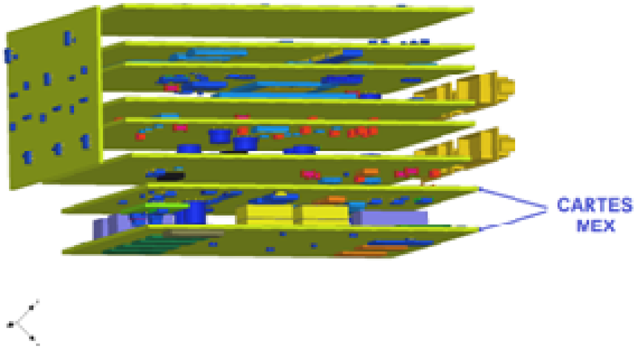
5- Results

- Dose in 4 simple particle detector models in Aluminum:
  - ”A” cylinder: lateral thickness 4mm, top thickness 500µm and bottom thickness 5mm
  - ”C” cylinder: lateral thickness 4mm, top thickness 4mm and bottom thickness 5mm
  - ”2mm” cylinder: all thicknesses 2mm
  - ”20mm” cylinder: all thicknesses 20mm

Mission	**Cylinder**	**Isotropic Flux** Total Dose Trapped protons	**Anisotropic Flux** Total Dose Trapped protons	Difference Anisotropic/Isotropic
		rad	rad	%
SAC-D	A	1.27E+03	1.29E+03	1.6%
	C	8.88E+02	8.76E+02	-1.3%
	2mm	1.04E+03	1.03E+03	-1.0%
	20mm	4.38E+02	4.26E+02	-2.8%

5- Results

- Dose inside the SACD platform for the whole mission.
  - Study on multiple components of the CARMEN experience inside the ICARE-NG equipment



Composant	**Flux Isotrope** Dose totale Protons piégés	**Flux Anisotrope** Dose totale Protons piégés	Différence Anisotrope/Isotrope
	rad	rad	%
RADFET1	456	433	-5.1
RADFET2	458	437	-4.7
Z52 - MAX892	528	520	-1.5
Z75 - MAX892	525	503	-4.2
IRFC360 - T8	365	353	-3.0

- Comparison with in-flight measurements

Composant	**Mesure en vol** Dose totale	**Flux Isotrope** Dose totale	**Flux Anisotrope** Dose totale	Différence Anisotrope/Mesure
	rad	rad	rad	%
RADFET1	555	561	538	-3.1
RADFET2	555	563	542	-2.4

Conclusions

- Consideration of the trapped proton anisotropy does not have an impact on multiple components studied
    - Using the Badhwar & Konradi [1990] model
    - Using a realistic satellite and equipment radiation model
    - Considering the whole SACD mission

- Possible perspectives :
    - Study the impact on the mission’s dose rate. For that, the satellite attitude needs to be known during the mission (quaternions or worst-case).

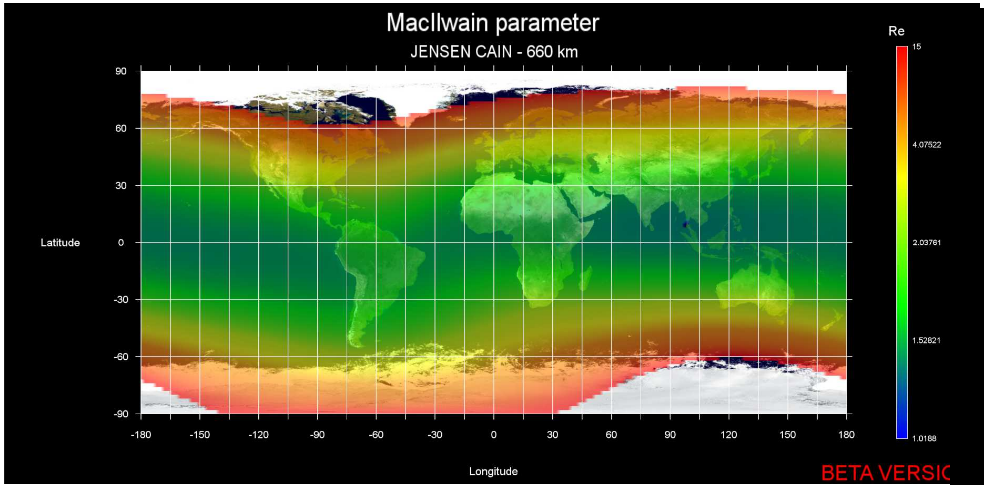
5- Results

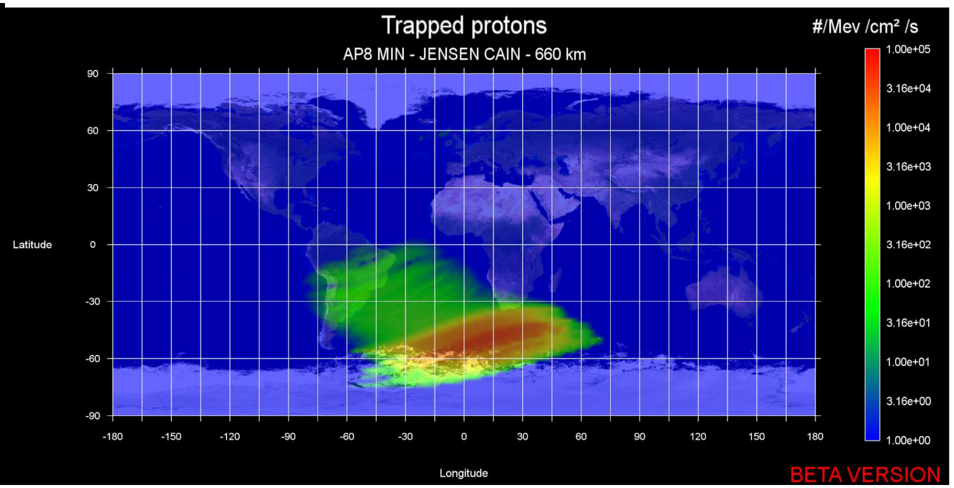
- Dose à l’extérieur : étude du modèle d’anisotropie de Badhwar & Konradi pour les missions SAC-D & JASON-2

Mission	**Flux Isotrope** Dose totale Protons piégés	**Flux Anisotrope** Dose totale Protons piégés	Différence Anisotrope/Isotrope
	rad	rad	%
SAC-D	1.70E+05	1.61E+05	-4.9
Jason 2	4.23E+06	3.96E+06	-6.3

- Perte de flux due à une limite du modèle : α_L supérieur à 90° pour de grands L

  => surtout vrai pour les faibles énergies (inférieures à 2 MeV)





5- Results

- To counteract this effect, we decided to remove from the isotropic flux all the data corresponding to α_L above 90°.

Mission	**Flux Isotrope** Dose totale Protons piégés	**Flux Anisotrope** Dose totale Protons piégés	Différence Anisotrope/Isotrope
	rad	rad	%
SAC-D	1.61E+05	1.61E+05	0
Jason 2	3.96E+06	3.96E+06	0

- Isotropic flux is now identical to anisotropic flux

Planches additionnelles (1)

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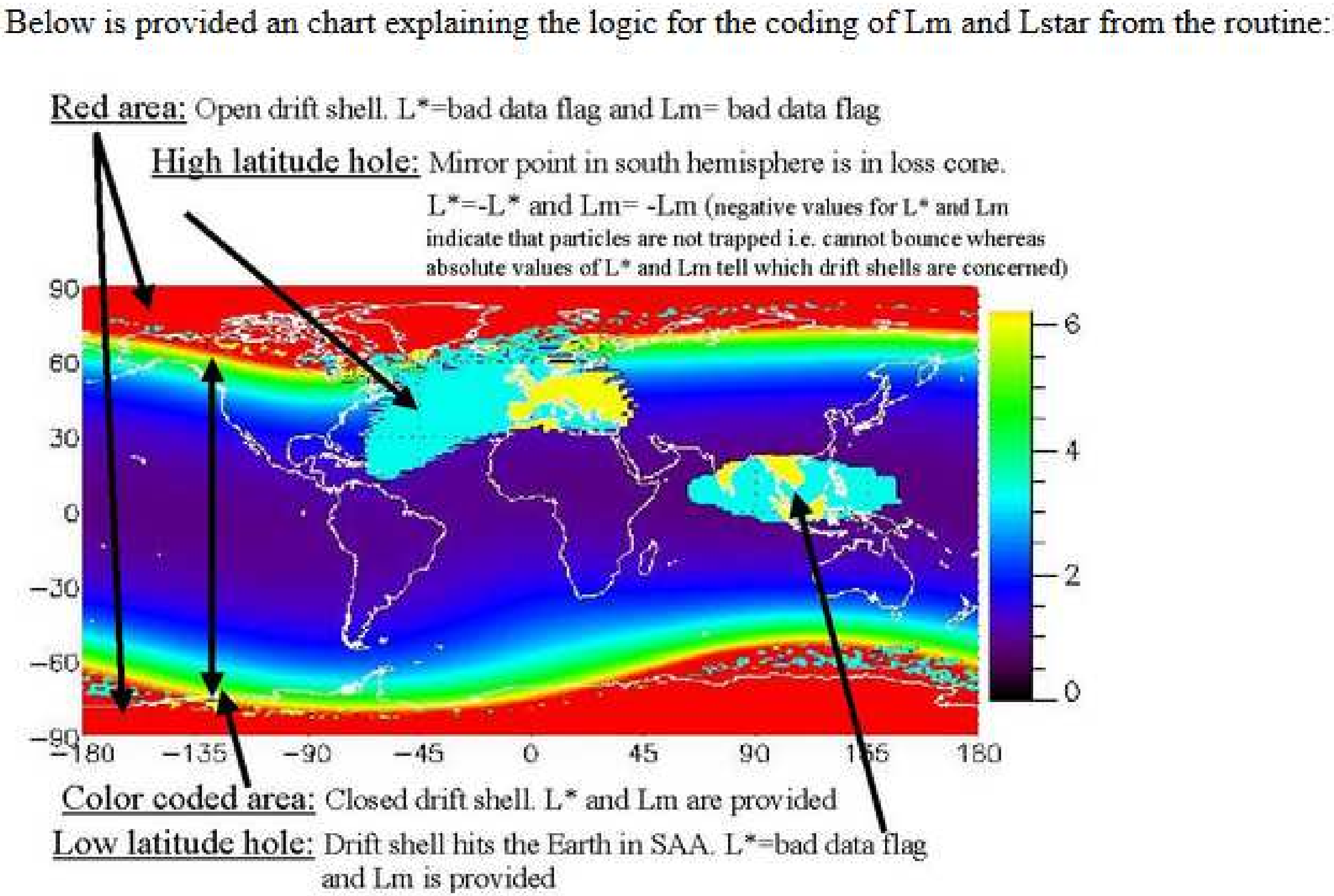

Below is provided an chart explaining the logic for the coding of Lm and Lstar from the routine:

Red area: Open drift shell. L*=bad data flag and Lm= bad data flag

High latitude hole: Mirror point in south hemisphere is in loss cone. L*=-L* and Lm= -Lm (negative values for L* and Lm indicate that particles are not trapped i.e. cannot bounce whereas absolute values of L* and Lm tell which drift shells are concerned)

Color coded area: Closed drift shell. L* and Lm are provided

Low latitude hole: Drift shell hits the Earth in SAA. L*=bad data flag and Lm is provided

Planches additionnelles (2)

Cartographie L > 4 pour l'altitude de SAC-D (660 km)