Results from the ICARE-NG detectors onboard SAC-D, JASON 2 and JASON 3 satellites

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retour sur innovation

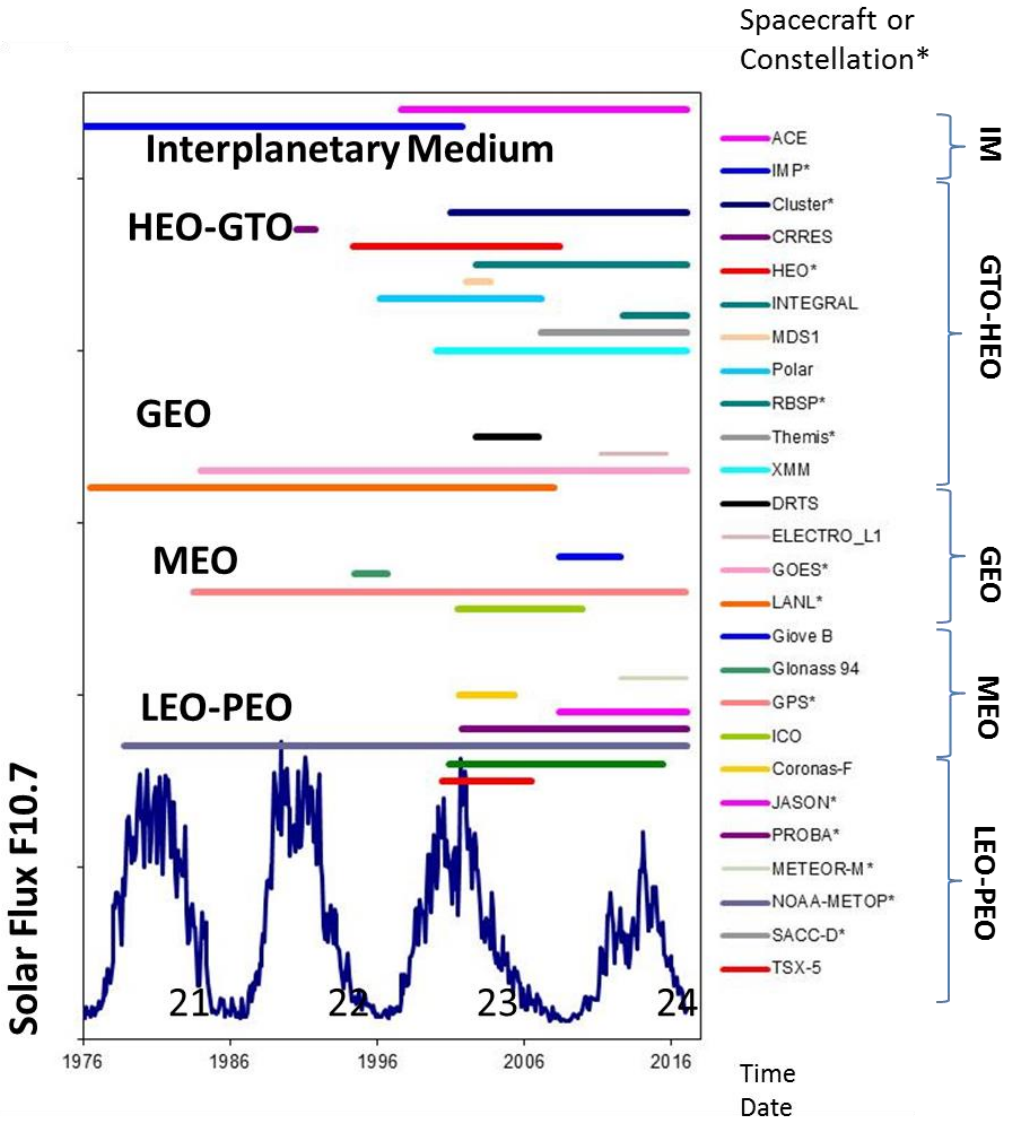
Overview

- IPODE database
- Introduction to the ICARE instruments family
- ICARE monitor (SAC-C results)
- ICARE-NG monitor (SAC-D, JASON2 and 3 results)
- Conclusions

IPODE (Ionising Particle Onera DatabasE)

- more than 100 spacecraft/detector
- electron, proton and alpha particles
- Main orbits covered
- More than 3 solar cycles
- ~1 keV to few MeV for electrons
- ~1keV to few 100 MeV for protons
- Permanent update

- *Operational support from CNES*
- *Multiannual CNES R&D contracts*



Introduction to the ICARE monitors family

In the context of Space Weather and/or Climatology:

Only few “operational” measurements are available (i.e. long term, same detector):

- *NOAA-POES satellites*
- *GPS satellites*
- *GOES and LANL-GEO satellites*

LEO are good opportunities to obtain a global view of the outer belt (average, extreme events), and to seek the conditions of creation of proton second belts

→ Need for long term measurements

Opportunity with CNES:

- Develop a radiation monitor for the SAC-C mission (CONAE)
- Devoted to:
  - the observation of high energy electron spectrum
  - The observation of proton second belts

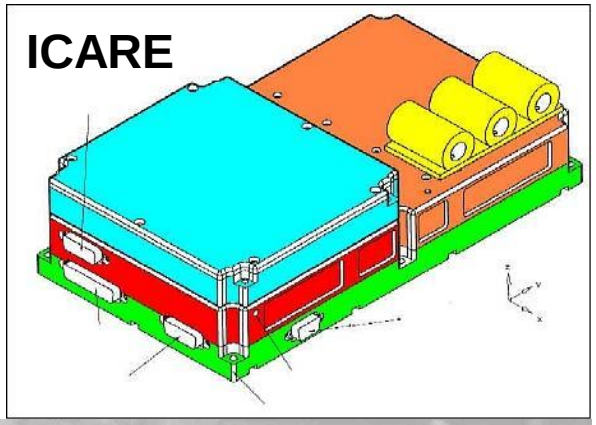
Not a science class instrument but a radiation monitor easy to embark

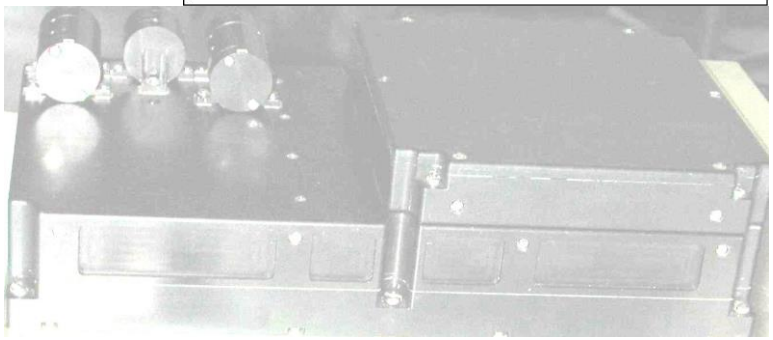
The ICARE detector family / satellites (evolution)

On-board missions:

- **MIR** (SPICA)
- **SAC-C** (20 nov. 2000, 705km, 98°)

Dimensions: 116 x 202 x 90 mm
Weight: 2 kg
Power: 2.5 W (Peak 2.8W)





3 heads of detection:

- **Electrons** - 200 keV – 3.5 MeV
- **Protons** - 10 – 30 MeV
- **Alpha ions** - about 70 MeV

http://craterre.onecert.fr/radiation_monitors/ICARE.html

ICARE onboard SAC-C

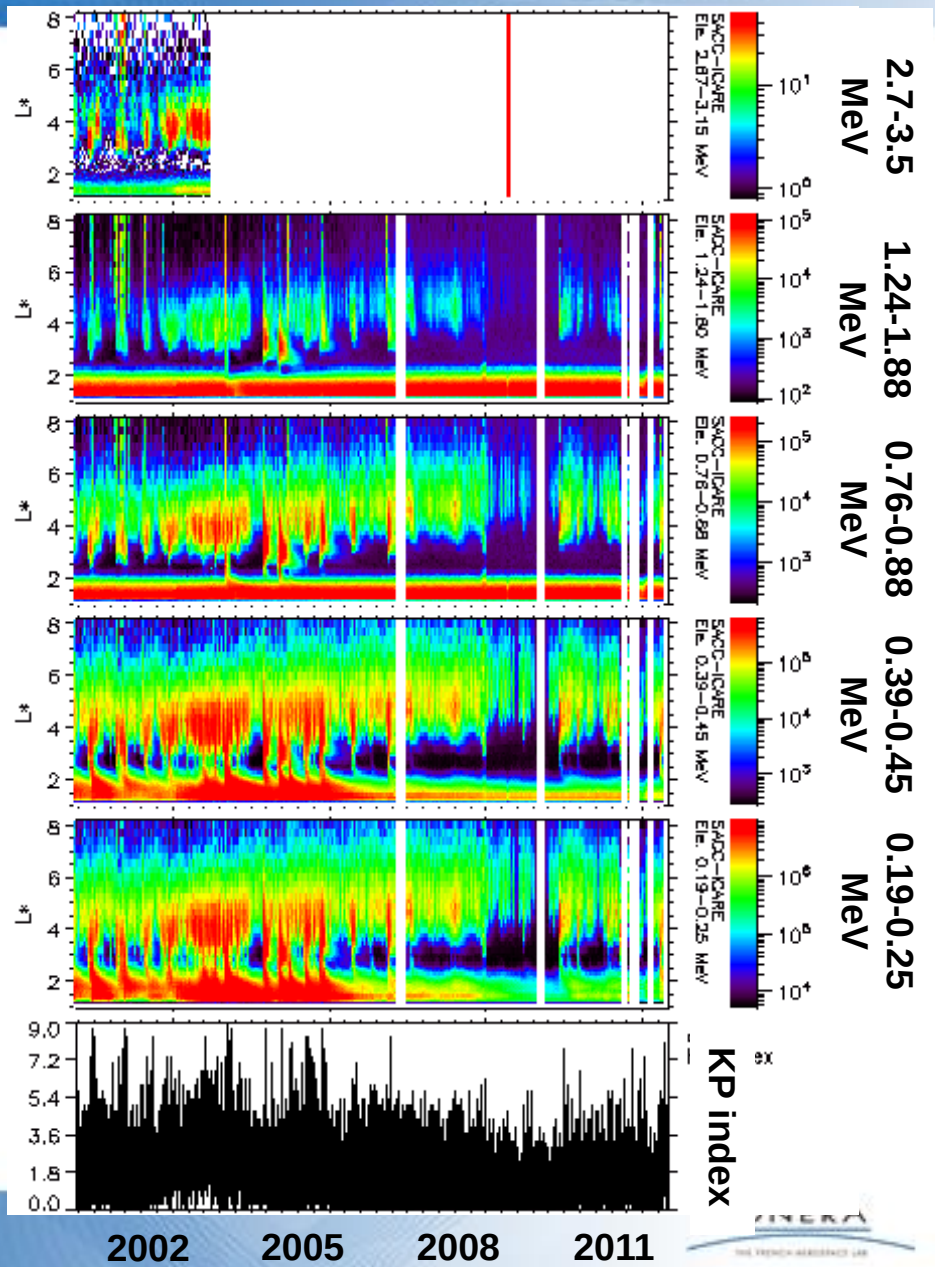
Electron results

Lesson learned

- *Continuous spectrum* from 200keV to 4MeV (possibility to obtain good averages-worst cases)
- *Magnetic storms of July and Nov 2004*
- *Nearly one solar cycle* (from Dec 2000 to March 2012)

Limitations

- *Proton contamination*
- *One diode out of order after 2.5 years* (6mm) → spectrum limited to 200keV-1.6MeV
- *64s time resolution*



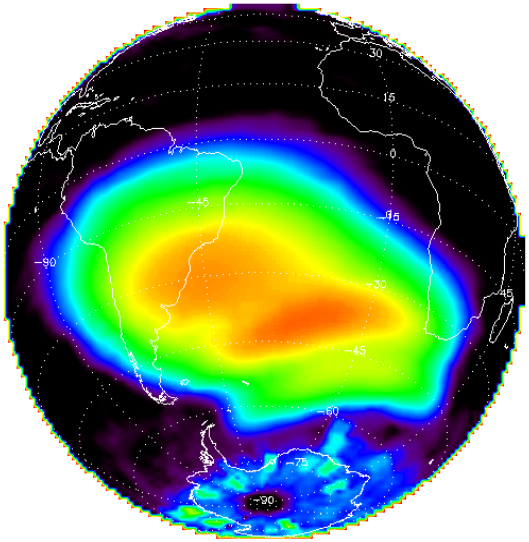
ICARE onboard SAC-C

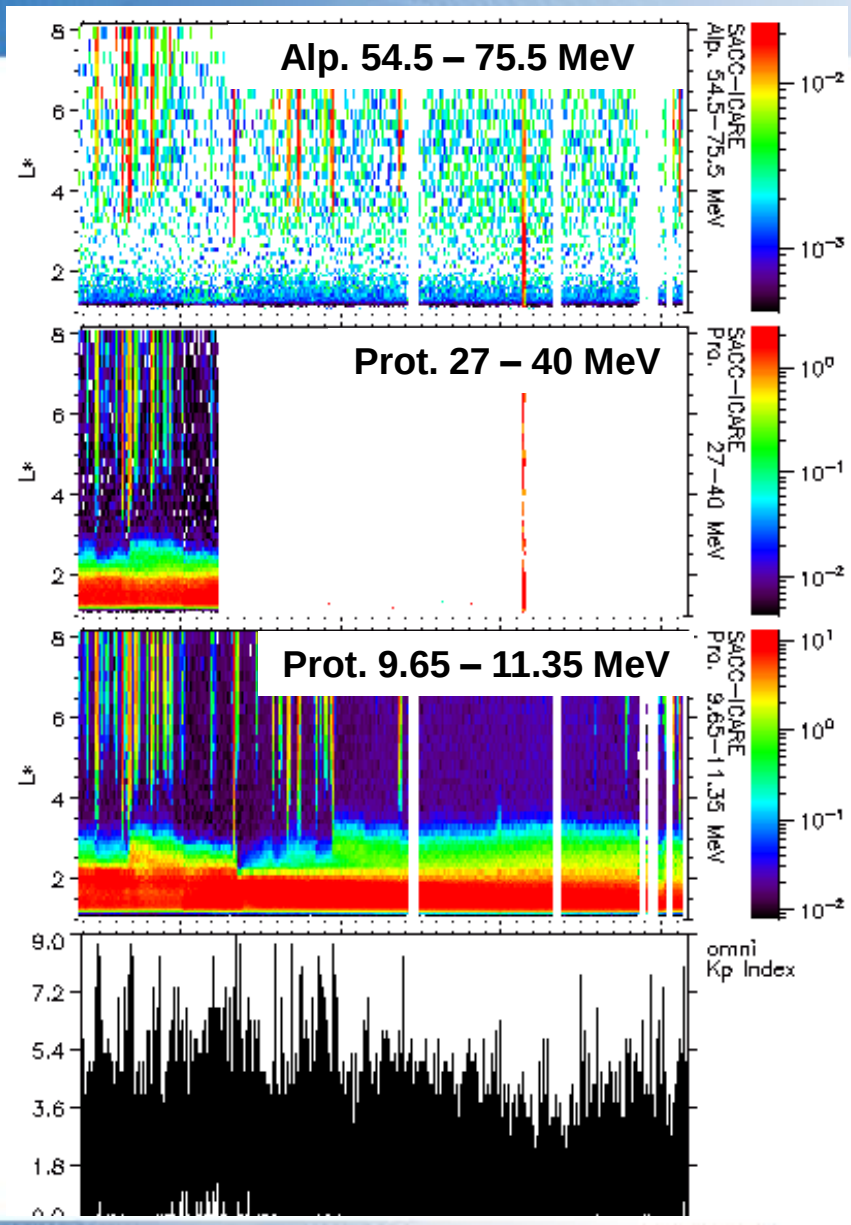
Proton and Ions results

Lesson learned:

The 10 MeV proton channel clearly observes creation as well as disappearance of second belt. ***Even third belt discovery***

December 2001





Limitations:

- *One diode out of order after 2.5 years* (6mm)
- *Proton spectrum limited*

Conclusions

References:

Falguère, D., D. Boscher, T. Nuns, S. Duzellier, S. Bourdarie, R. Ecoffet, S. Barde, J. Cueto, C. Alonzo, C. Hoffman, *In-Flight observations of the radiation environment and its effects on devices in the SAC-C polar orbit*, IEEE Trans. Nuc. Sci., 49(6): 2782-2787, December 2002.

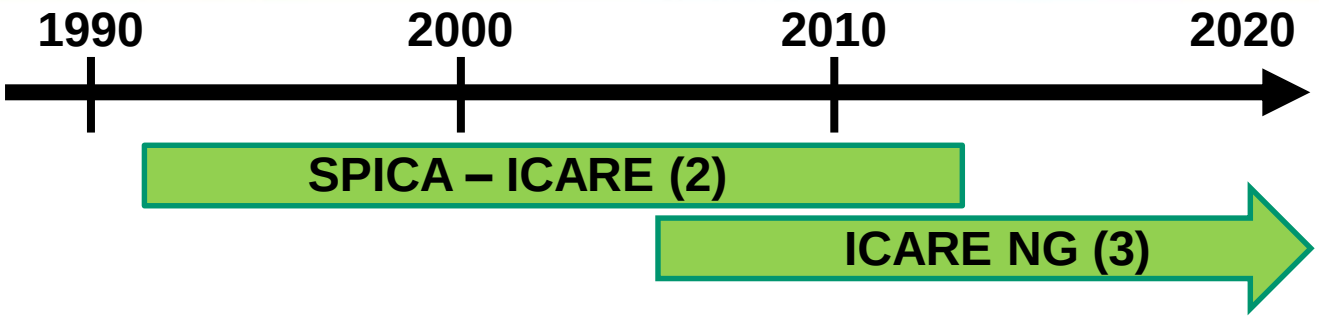
Benck, S., L. Mazzino, M. Cyamukungu, J. Cabrera, V. Pierrard, *Low altitude energetic electron lifetimes after enhanced magnetic activity as deduced from SAC-C and DEMETER data*, Ann. Geophys., vol. 28, pp. 849-859, March 2010.

Maget, V., S. Bourdarie, and G. Rolland, *Characterizing Solar Energetic Particles Access to any Earth-Space Location*, IEEE Transactions on Nuclear Science, 60(4), 2404–2410, doi:10.1109/TNS.2012.2233756, 2013.

→ **Improvements consecutively conducted on the ICARE monitor:**

- *Electrons* : same 200keV-4MeV spectrum but without 6mm thick diode
- *Protons*: 10MeV but also other channels to observe the spectrum in second belts
- *16s time resolution*

The ICARE detector family / satellites (evolution)



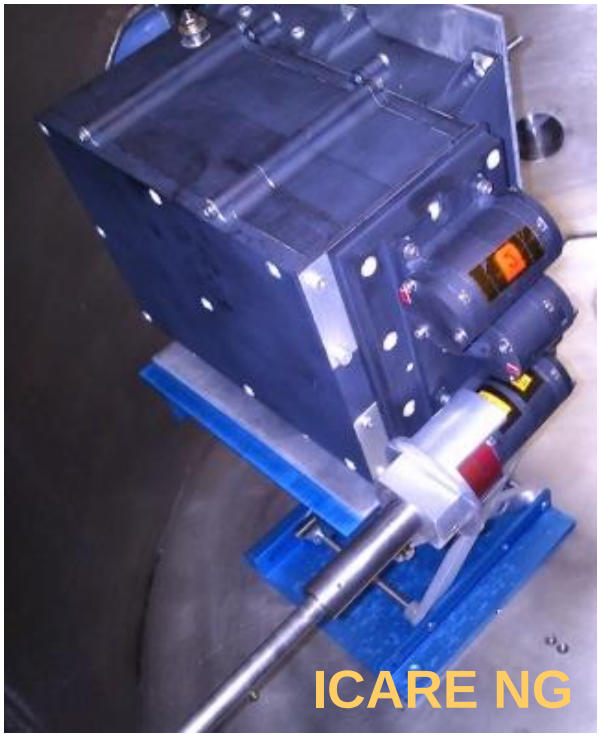
On-board missions:

- **JASON 2** (20 June 2008, 1330 km, 66°)
- **SAC-D** (10 June 2011 – 7 June 2015, 715 km, 98°)
- **JASON 3** (17 January 2016, 1330 km, 66°)

Dimensions: 197 x 118 x 96 mm
Weight: 2.4 kg
Power: 4 W (Peak 6 W)

3 heads of detection but 5 configurations:

- **Electrons**: 200 keV – 3.5 MeV
- **Protons**: 10 – 200 MeV



ICARE-NG onboard JASON 2

Electrons results

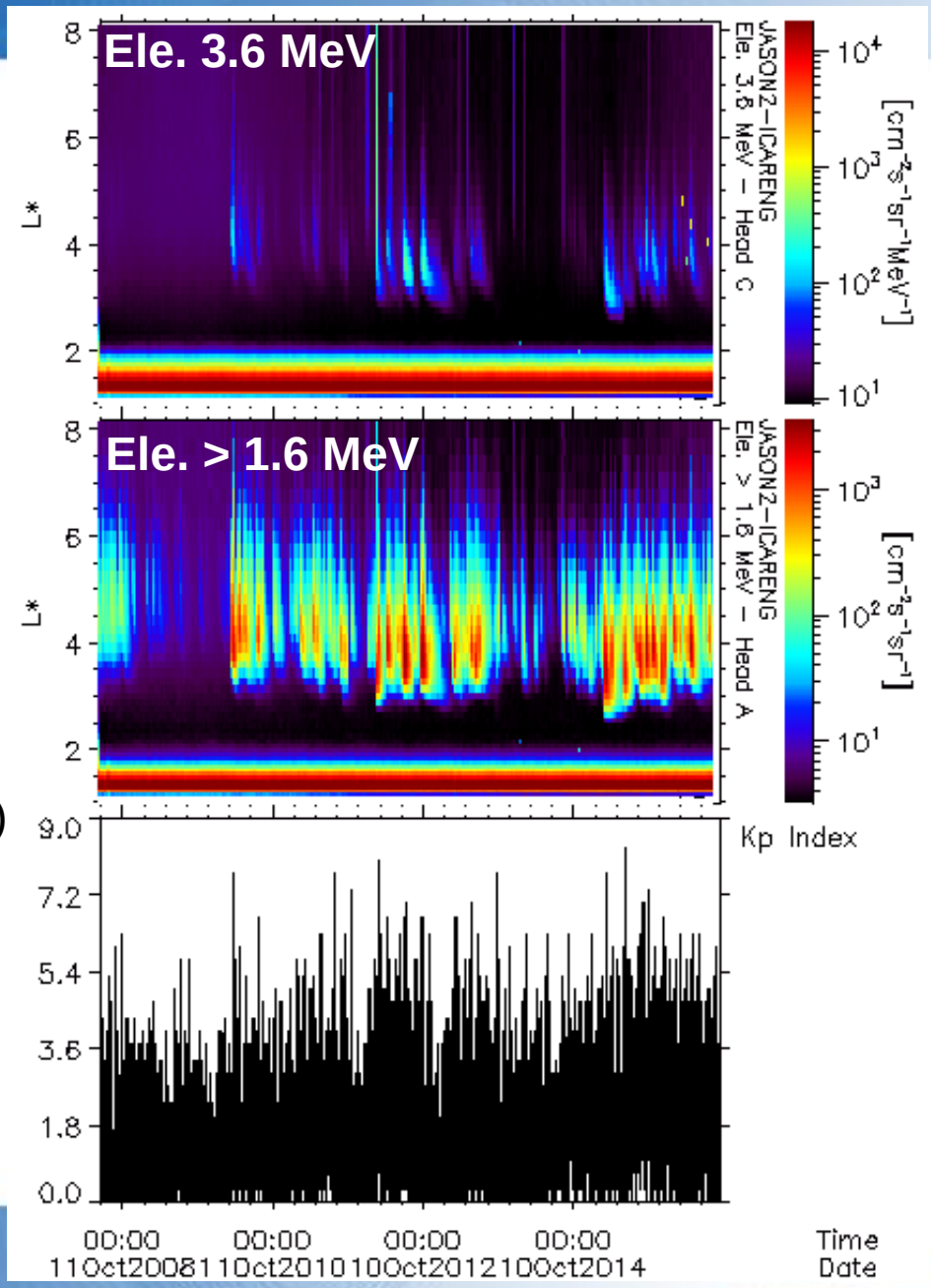
ICARE-NG was switched on 22 June 2008

Lesson learned:

- Good measurements along this new orbit
- Less contamination
- Spectrum 1.6-3.6MeV
- Improved data unfolding using SVD-based deconvolution (down to 825 keV)

Limitations:

Monitor inside the satellite → low energy electrons are not observable

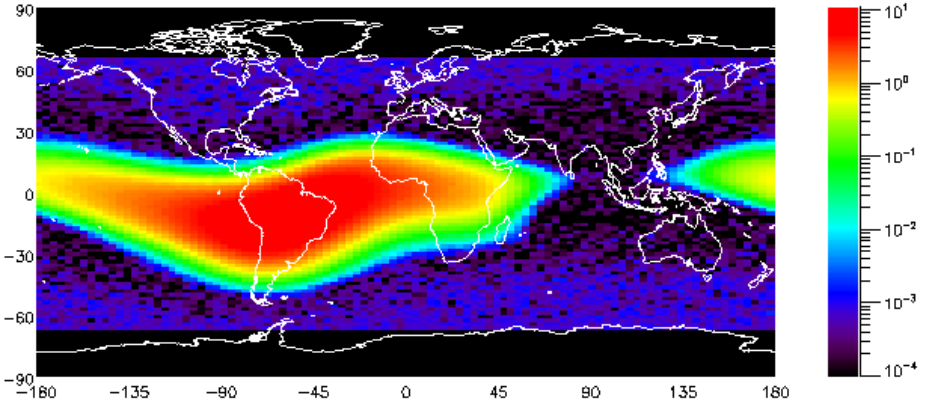


ICARE-NG onboard JASON 2

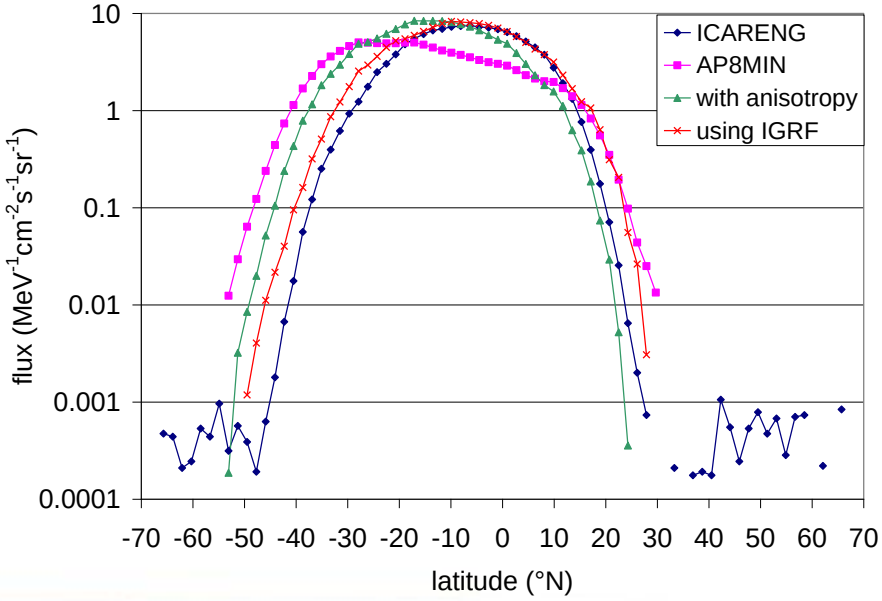
Protons results

Lesson learned:

- Opportunity to observe the SAA at 1330km altitude
- Study of the solar cycle influence at this altitude
- Study of the influence of the satellite shielding and the anisotropy
- Spectrum: 67 – 292 MeV
- Improved data unfolding using SVD-based deconvolution (40 – 500 MeV)



Protons 88MeV August-November 2008



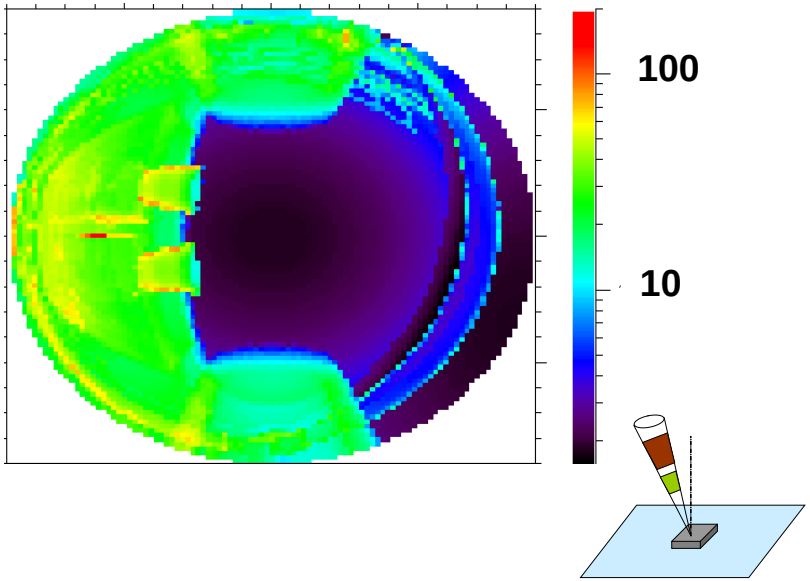
Limitations:

Monitor inside the satellite → difficult to observe second belts

ICARE-NG onboard JASON 2

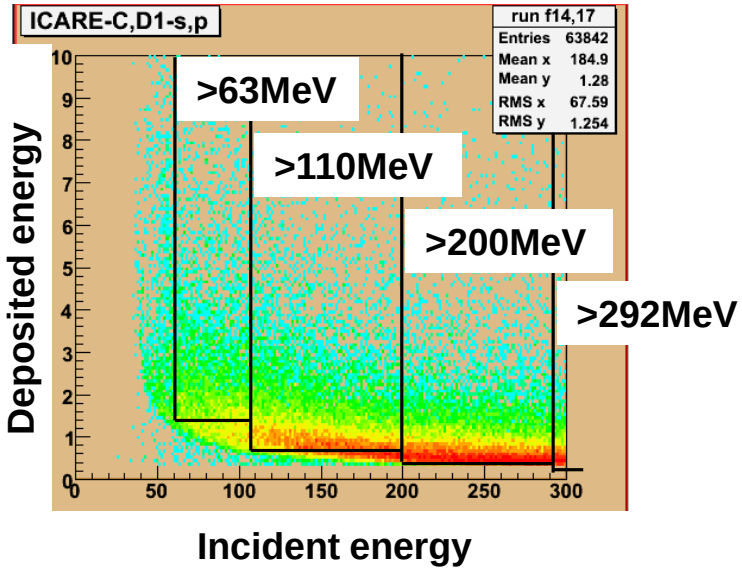
Focus on the data analysis

Integration "on" JASON 2



Fish-eye view of the sectoring analysis of the B head: equivalent Al thickness (mm)

Refined modeling of ICARE-NG sensitivity

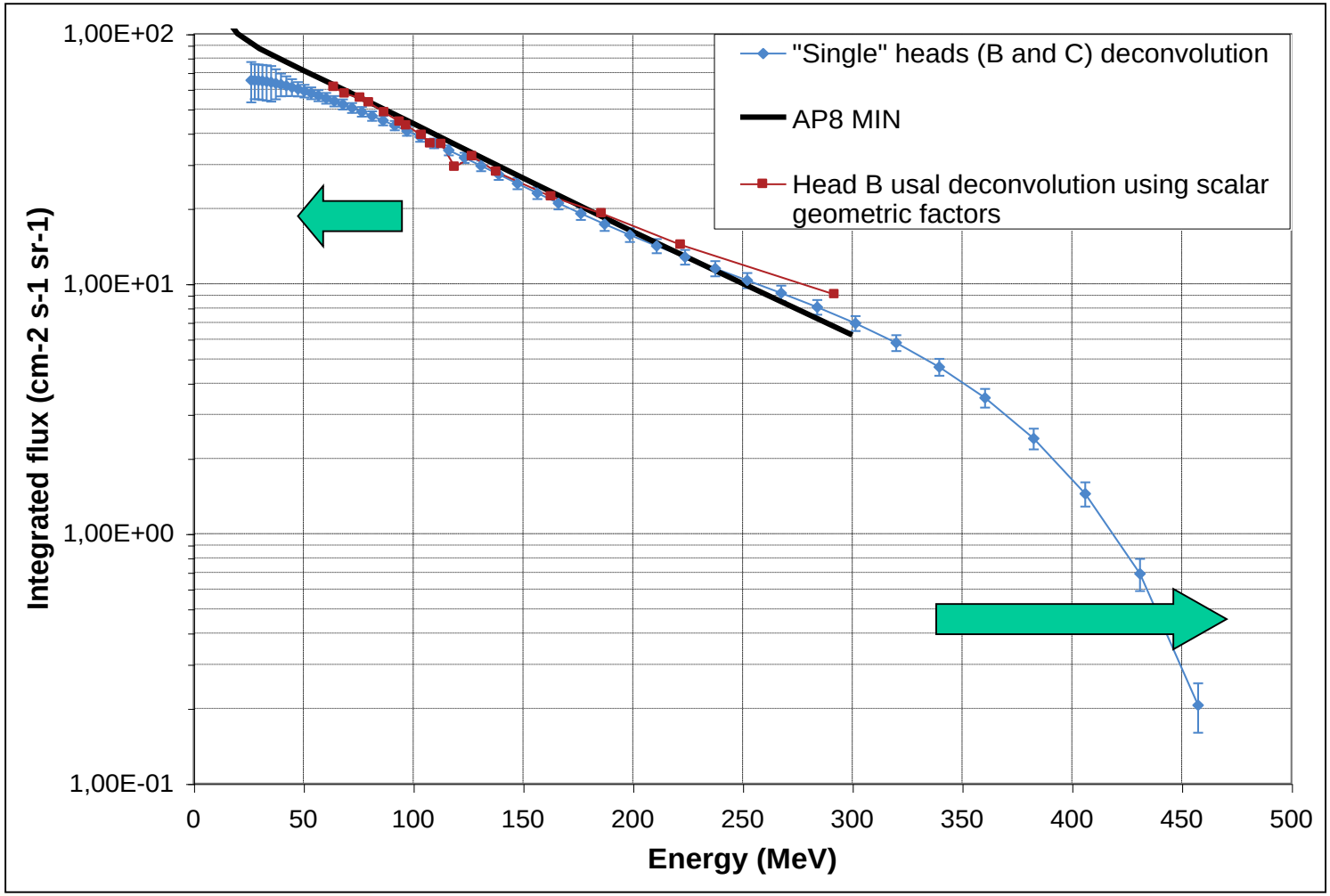


GEANT 4 calculations of the response matrix for all head's configurations (30 000 000 particles launched)

"Hand-made" unfolding:

- 10 electron channels (1.6 MeV to 3.6 MeV)
- 42 proton channels (63 MeV to 292 MeV)

Improvements using global deconvolution using SVD inversion:



References

Boscher, D., S.A. Bourdarie, D. Falguere, D. Lazaro, P. Bourdoux, T. Baldran, G. Rolland, E. Lorfevre, R. Ecoffet, *In Flight Measurements of Radiation Environment on Board the French Satellite JASON-2*, IEEE Trans. Nuc. Sci., vol.58-3, pp. 916-922, 2011, doi: 10.1109/TNS.2011.2106513, 2011.

Maget V., S. Bourdarie, D. Lazaro, D. Boscher, G. Rolland, R. Ecoffet, and E. Lorfevre, *Unfolding JASON-2/ICARE-NG High-Energy Particles Measurements Using a Singular Value Decomposition Approach*, IEEE Transactions on Nuclear Science, vol. Early Access Online, 2014.

Boscher, D., A. Sicard-Piet, D. Lazaro, T. Cayton, and G. Rolland, *A New Proton Model for Low Altitude High Energy Specification*, IEEE Transactions on Nuclear Science, 61(6), 3401–3407, doi:10.1109/TNS.2014.2365214, 2014.

ICARE-NG onboard SAC - D

Electrons results

Reminder:

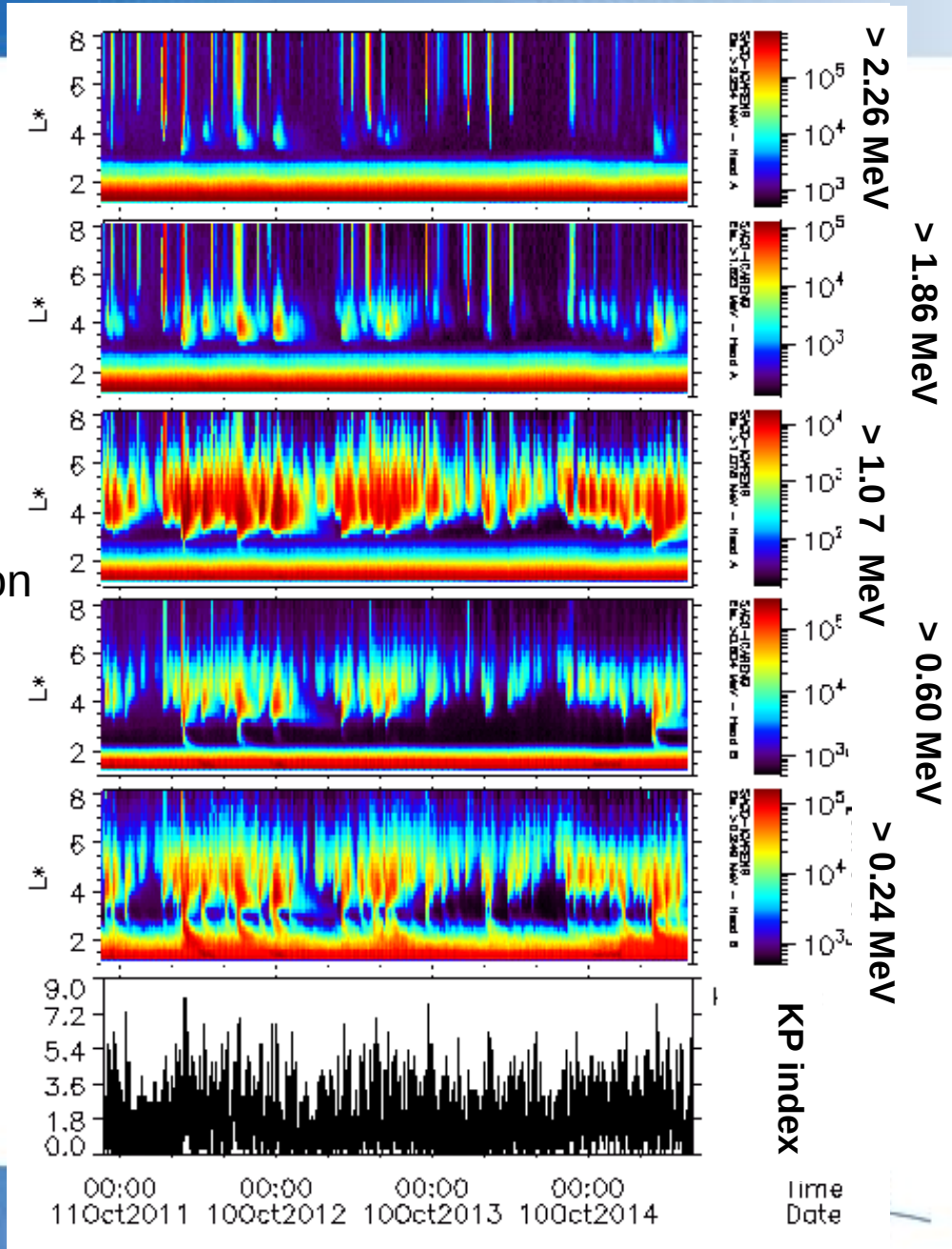
- SSO satellite 715km altitude
- Launched 10 June 2011
- ICARE-NG switched on 30 Aug. 2011

Lesson learned:

- 250keV-3.3MeV, but careful with proton contamination
- Good comparison with SAC-C

Limitations:

Early end of life (2015) due to satellite power system failure



ICARE onboard SAC - D

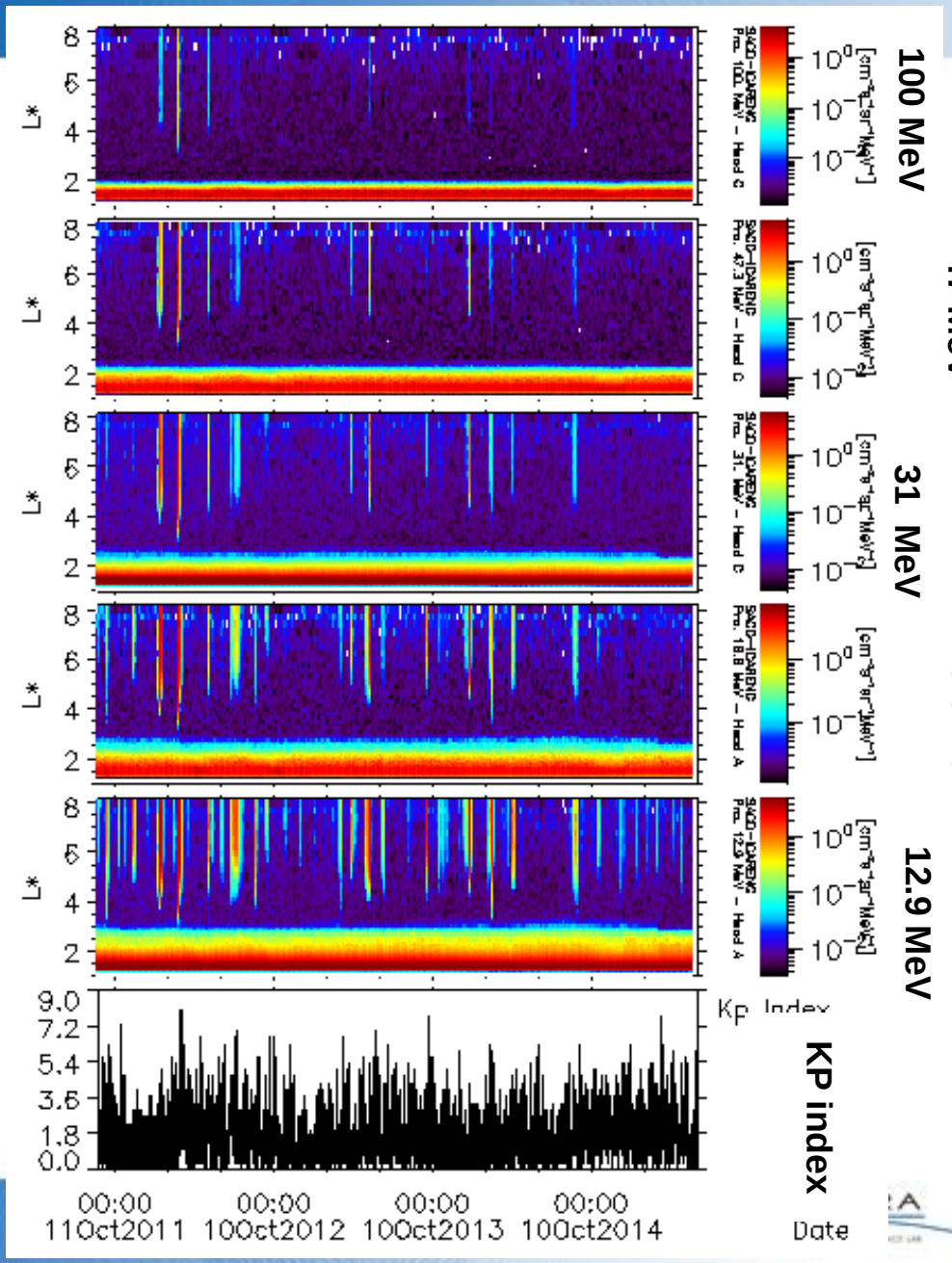
Protons results

Lesson learned:

- Spectrum 12.8 MeV – 190 MeV
- Extended to a few MeV up to 500 MeV using SVD-based unfolding
- Good comparison with SAC-C

Limitations:

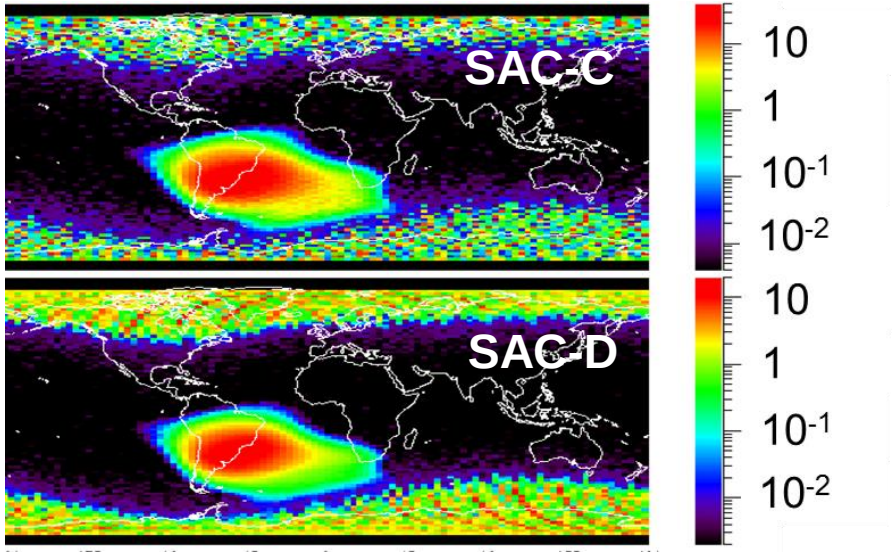
Early end of life (2015) due to satellite power system failure



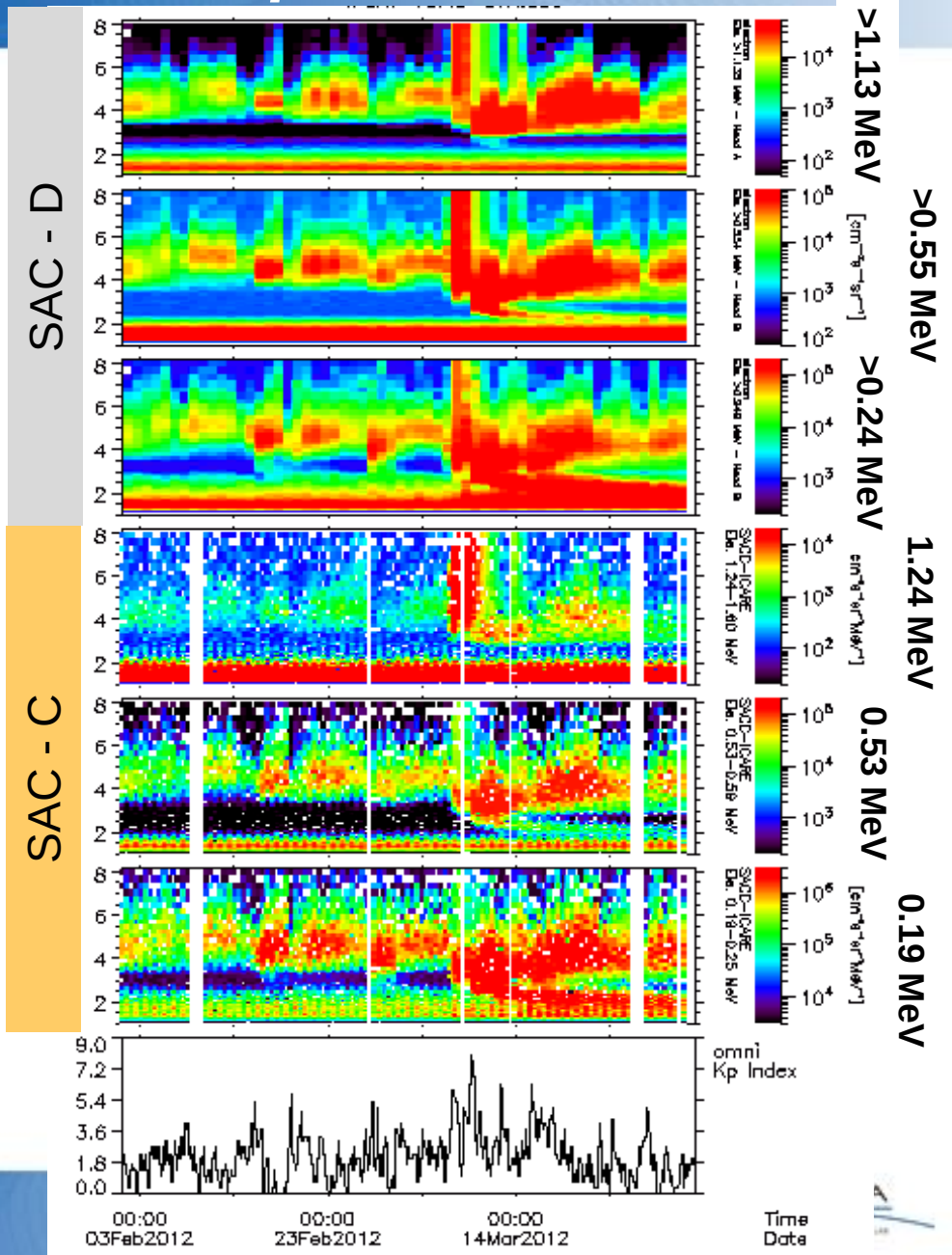
ICARE-NG onboard SAC - D

Comparison with SAC - C

Protons~10MeV Feb-Apr 2012



Flux in MeV-1 cm-2 s-1 sr-1



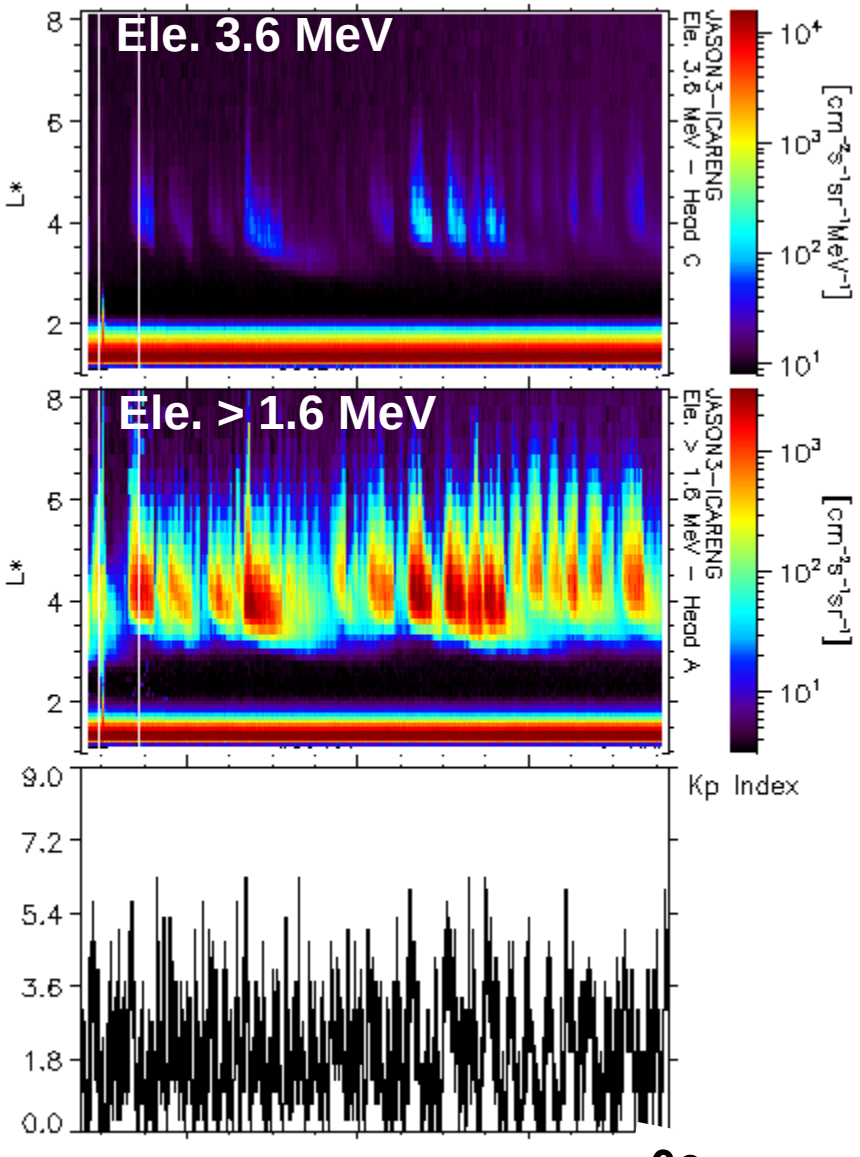
Conclusion

Reference

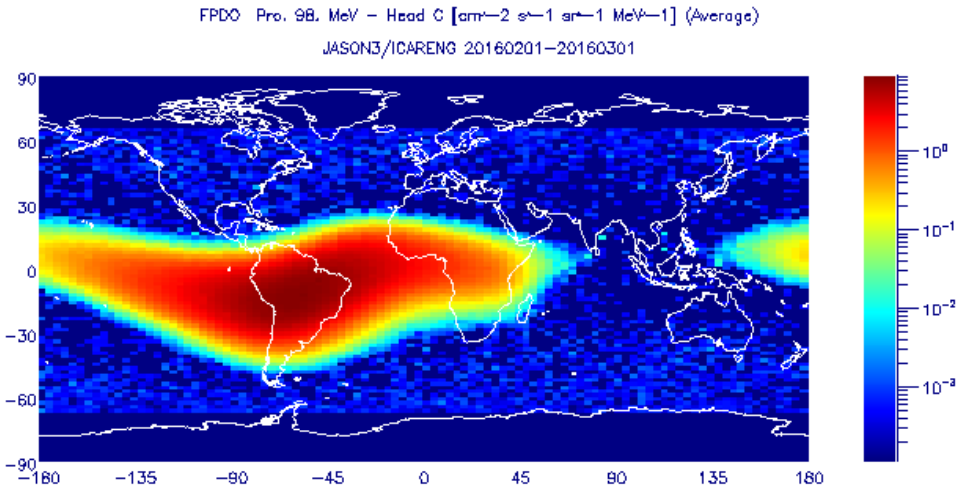
Boscher, D., T. Cayton, V. Maget, S. Bourdarie, D. Lazaro, T. Baldran, P. Bourdoux, E. Lorfèvre, G. Rolland, R. Ecoffet, *In flight measurements of radiation environment on board the Argentinean satellite SAC-D*, submitted to IEEE Trans. Nucl. Sci., 2014

ICARE-NG onboard JASON3

First year results



100 MeV protons (Feb. 2016)



06/03/2017

Good practice developed

Near real-time processing of the ICARE / ICARE-NG data

Files Exchange Server

Binary raw data
-Carmen Telemetry
Ancillary data
-House keeping
-Predicted/Restituted orbit
-Quaternions
-Telecommand

Every 1.5 hour

Dedicated Tools managed by crontab

DFAXlib
(Binary data decoding)

+

IRBEM* Library
(magnetic coordinates, orbit propagator,…)

+

Data Analysis
(saturation, contamination,…)

Output data
PRBEM/CDF**
Format standard

IPODE@ONERA

* International Radiation Belt Environment Modelling Library (PRBEM - COSPAR)

** Panel on radiation Belt Environment Modelling (COSPAR)

General conclusions

- *Global knowledge* of the whole configuration / implantation of the detector on board its host (3D shielding by the satellite, response function of each head,…)
- More than one solar cycle of ICARE / ICARE-NG measurements
- Overlapping of measurements
- Even used for science purposes
- Of prime importance for specification models: OPAL, GREEN models

Satellite name	Launch date	Power on date	Power off date	Sat. end of life
SAC-C	21/11/2000	09/12/2000	30/04/2012	15/08/2013
SAC-D	10/06/2011	30/08/2011	08/06/2015	08/06/2015
JASON 2	20/06/2008	22/06/2008	31/08/2016	…
JASON 3	17/01/2016	19/01/2016	…	…