ICARE instruments and data sets

Robert ECOFFET, CNES

They made it possible
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Daniel BOSCHER, Sébastien BOURDARIE, ONERA
Philippe BOURDOUX, Thomas BALDRAN, EREMS
Christian CHATRY, Anna CANALS, Athina VAROTSOU, TRAD
Gérard SARRABAYROUSE, LAAS
Jean-Roch VAILLE, Frédéric SAIGNE, IES - Univ. Montpellier II
Philippe CALVEL, Michel MELOTTE, TAS
Renaud MANGÉRET, Anne SAMARAS, AIRBUS-DS

SEESAW Workshop, 5-8 Sept 2017, Boulder, Colorado
Foreword

Why measure radiation & effects on board a spacecraft?

Science
- Will not be treated here

Engineering: development / improvement of engineering models
- Electron and proton energy spectra with a good resolution
- Dosimeters → useful for integrated measurement

Engineering: verification / improvement of RHA methods
- Dosimeters → feedback on radiation transport techniques
- In-flight component’s behavior → feedback on radiation effects models

Possible interest in spacecraft operations
- Estimation of remaining resource
- Investigation of in-orbit anomalies (local space weather restitution)

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Short description of the instruments
ICARE and ICARE-NG
High-E charged particle detectors

**Electron and proton measurements**
(Si diodes single / coincidence)

**Angle of visibility 30° (half cone)**

**Programmable front end electronics**
- Noise rejection thresholds
- Pre-amp / amp gains
- 8-bit A-to-D converter
- 256 ΔE channels / detector

**On-board functions**
- Channel summation
- Logarithmic compression (mantissa, exponent)
- Warning flags
- Data storage buffer

**Instrument modes**
- Continuous acquisition
- Triggered acquisition

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JASON-3, 1336 km, 66°
JASON-2, 1336 km, 66°
SAC-D, 657 km, 98°
SAC-C, 705 km, 98°
ISS, 400 km, 51.6°
MIR, 400 km, 51.6°

**Technology board**
- Dosimeters
- Test components (drift, SEU, SET, SEL, SEB)

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## How do we work with our partners on the ICARE projects?

<table>
<thead>
<tr>
<th>CNES</th>
<th>ONERA</th>
<th>TRAD</th>
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</thead>
<tbody>
<tr>
<td><strong>Mission decision and funding</strong></td>
<td><strong>Detector design</strong></td>
<td><strong>dosimeters</strong></td>
</tr>
<tr>
<td><strong>Instrument &amp; technology board definition</strong></td>
<td><strong>Response functions and calibrations</strong></td>
<td><strong>IES : dosimeters</strong></td>
</tr>
<tr>
<td><strong>Instrument development and qualification</strong></td>
<td><strong>Instrument programming requirements</strong></td>
<td><strong>AIRBUS, TAS, CNES : test components</strong></td>
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<tr>
<td>(with EREMS company)</td>
<td><strong>In-flight calibration</strong></td>
<td><strong>Technology board</strong></td>
</tr>
<tr>
<td><strong>Instrument operations and interface with satellite ground segment</strong></td>
<td><strong>Level 2 data</strong></td>
<td><strong>OMERE engineering tool</strong></td>
</tr>
<tr>
<td></td>
<td>(flux, energy)</td>
<td><strong>Radiation belts science</strong></td>
</tr>
<tr>
<td><strong>Level 0 (TM) and level 1 (counts, channels) data</strong></td>
<td><strong>SW activity indices</strong></td>
<td></td>
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<tr>
<td><strong>Spacecraft data (attitude, operations,...)</strong></td>
<td><strong>Models (incl. of course other data sources)</strong></td>
<td><strong><a href="http://craterre.onecert.fr/home.html">http://craterre.onecert.fr/home.html</a></strong></td>
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**SODAD**

Active micro-debris detector

**Active detector**
- 2 inches diameter p-type silicon wafer

**Principle**
- wafer used as a capacitor, when debris strikes, capacitor discharges and current is measured

Flown on EuTEF/MEDET payload on COLUMBUS module of ISS

Flown on SAC-D on 3 satellite faces

**SAC-D spacecraft interface**
- ICARE/NG Radiation Monitor

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AMBER

“Active Monitor Box of Electrostatic Risk”
Low-E charged particle detector

Electron and ion measurements
(electrostatic deflexion and multi-channel plate detectors)

Angle of visibility 175° /12°

Flux
-from some pA/cm² to some nA/cm².

Energy
- from 10eV up to 30keV

Sampling rate
- one measurement every 500ms

Spacecraft interface
- ICARE/NG Radiation Monitor
ICARE detectors

500 µm Al shield 5 mm thick Al cylinders 500 µm Al shield

150 µm Si diode

P

E

I

6 mm Si/Li diode 500 µm Si diode 500 µm Si diode

(adapted from)

In-Flight Observations of the Radiation Environment and Its Effects on Devices in the SAC-C Polar Orbit


IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 6, DECEMBER 2002

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ICARE spectrometer energy channels

• On SAC-C, ICARE looked through a window in the satellite wall
  ● Elementary level 1 data is particle count per channel over 64s integration periods

<table>
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<tr>
<th>Electrons</th>
<th>Protons</th>
<th>Alpha</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Differential (MeV)</td>
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<tr>
<td>Differential (MeV)</td>
<td>Integral (MeV)</td>
<td>Differential (MeV)</td>
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<tr>
<td>0.19-0.25</td>
<td>&gt;0.9</td>
<td>9.65-11.35</td>
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<tr>
<td>0.23-0.29</td>
<td>&gt;1.5</td>
<td>12.5-18.5</td>
</tr>
<tr>
<td>0.29-0.35</td>
<td>&gt;1.7</td>
<td>18.75-27.25</td>
</tr>
<tr>
<td>0.33-0.39</td>
<td>&gt;2.0</td>
<td>27-40</td>
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<tr>
<td>0.39-0.45</td>
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<td>39.5-40.5</td>
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<tr>
<td>0.45-0.51</td>
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<td>35-50</td>
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<tr>
<td>0.53-0.59</td>
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<td>37-55</td>
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<tr>
<td>0.59-0.65</td>
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<td>39-59</td>
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<tr>
<td>0.64-0.76</td>
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<td>41-63</td>
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<td>0.76-0.88</td>
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<td>46-75</td>
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<tr>
<td>1.08-1.36</td>
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<td>49-85</td>
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<tr>
<td>1.24-1.60</td>
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<td>53-110</td>
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<td>1.28-1.72</td>
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<td>61-140</td>
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<td>1.72-2.20</td>
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<td>75-180</td>
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<td>2.19-2.67</td>
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<td>2.67-3.15</td>
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<td>110-380</td>
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<tr>
<td>3.15-3.63</td>
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<tr>
<td>3.63-4.11</td>
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SAC-C, 705 km, 98°
Dec 2000-April 2012
Dec 2000-July 2003
Failure of the 6 mm detector on a SAA pass

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ICARE-NG detectors

500 µm Al shield  5 mm thick Al cylinders  4 mm Al shield

500 µm Si diode  500 µm Si diode  500 µm Si diode

500 µm Al shield  4 mm Al shield  4 mm Al shield

500 µm Si diode  700 µm Si diode  500 µm Si diode
ICARE-NG spectrometer energy channels

• On JASON, ICARE-NG looks through the satellite wall
• On SAC-D, ICARE-NG looked through a window in the satellite wall

- Elementary level 1 data is particle count per channel over 16s integration periods

<table>
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<tr>
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<th>Integral (MeV)</th>
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<td>&gt;1.67</td>
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<td>&gt;1.74</td>
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<td>&gt;1.81</td>
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<td>&gt;2.02</td>
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<td>&gt;2.09</td>
<td>94</td>
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<td>&gt;2.6</td>
<td>&gt;104</td>
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<tr>
<td>&gt;104</td>
<td>112</td>
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<td>&gt;108</td>
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<td>&gt;115</td>
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<td>&gt;119</td>
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<td>&gt;127</td>
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<td>&gt;138</td>
<td>155</td>
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<tr>
<td>&gt;163</td>
<td>186</td>
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<tr>
<td>&gt;186</td>
<td>222</td>
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<tr>
<td>&gt;292</td>
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<table>
<thead>
<tr>
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<th>Integral (MeV)</th>
<th>Differential (MeV)</th>
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<tbody>
<tr>
<td><strong>Protons</strong></td>
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<td>&gt;0.249</td>
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<td>&gt;0.270</td>
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<td>&gt;0.299</td>
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<td>&gt;0.320</td>
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<td>&gt;0.342</td>
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<td>&gt;0.363</td>
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<td>&gt;0.384</td>
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<td>&gt;0.413</td>
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<tr>
<td>&gt;0.455</td>
<td>&gt;1.823</td>
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<td>&gt;0.505</td>
<td>&gt;1.974</td>
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<tr>
<td>&gt;0.554</td>
<td>&gt;2.106</td>
<td>&gt;85</td>
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<td>&gt;0.604</td>
<td>&gt;2.254</td>
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<td>&gt;0.653</td>
<td>&gt;2.404</td>
<td>&gt;100</td>
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<td>&gt;0.703</td>
<td>&gt;2.567</td>
<td>&gt;105</td>
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<td>&gt;0.752</td>
<td>&gt;2.680</td>
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<td>&gt;0.802</td>
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<td>&gt;0.895</td>
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<td>&gt;0.930</td>
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<td>&gt;0.994</td>
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<tr>
<td>&gt;1.078</td>
<td>&gt;3.250</td>
<td></td>
</tr>
</tbody>
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ICARE missions
Mission timelines
~ >1.5 MeV e- integral channels

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Instrument accommodation on SAC-C (ICARE mission)
Instrument accommodation on SAC-D (CARMEN-1 mission)

ICARE-NG 45° sky / speed -Z/+X
SODAD speed +X anti-speed -X sky -Z

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Instrument accommodation on JASON-2 (CARMEN-2 mission)

ICARE-NG & LPT “Sky View” -Z

LPT-E and -S

ICARE-NG
Instrument accommodation on JASON-3 (CARMEN-3 mission)

ICARE-NG & LPT “Sky View” -Z

AMBRE –Y/-Z/+Y plane

AMBRE

ICARE-NG

LPT-E and -S

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Line of view of the instruments

SAC-C

SAC-D

JASON -2 & -3

FoV

Motion

Earth
Line of view of ICARE / SAC-C

Ascending Orbit

Descending Orbit

B

SAA

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Line of view of ICARE-NG / JASON-2 & -3

Ascending Orbit

Descending Orbit

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Line of view of ICARE-NG / SAC-D

Ascending Orbit

Descending Orbit

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Consequences of the geometries

On SAC-C and JASON-2 & -3 the orientation of the FoV wrt to the magnetic field is more or less the same for ascending and descending orbits.

On SAC-D the FoV is ~parallel to the field for ascending orbits, and ~perpendicular to the field for descending orbits → flux anisotropy is evidenced.
A few examples of observations
SAC-C overview
Magnetic storms and particle events
15 March – 30 May 2001, SAC-C

Same e- channel, different color scales to enhance contrast in high flux zones

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Magnetic storms and particle events
15 March – 30 May 2001, SAC-C

Total count ("rapid counter") on "E" head
With or without smoothing (horizontal & vertical) : for a certain period the satellite power system had an issue and ICARE was cycled 50% of the time.
High energy electrons, outer belt, slot, and 3rd electron belt

Period 1st June 2003 – 1st June 2005, SAC-C

Period 1st June 2004 – 1st June 2005, SAC-C

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High energy electrons, outer belt, slot, and 3rd electron belt

Coronal holes: 28-day modulation of the outer belt

Period 1st June 2007 – 30 Sept. 2009, SAC-C

Period 1st June 2014 – 15 March 2015, SAC-D
High energy proton belt is fairly stable (Jason orbit)
Use of the data by ONERA

Pipelined into space weather applications (e.g. rad. belt indices)

Compared with specification models (see Sebastien’s talk)

Fed into data assimilation tools + physics-based dynamic model (Salammbô)

Contributes to development of local and global models (see Sebastien’s talk)

Situation Friday Sept. 1st 2017

https://craterre.onecert.fr/home.html

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Conclusions - remarks

A correct interpretation of {flux, energy} data needs
- To know the line of sight of the instrument
- Position and geometry on the host spacecraft
- Spacecraft stabilization and eventually flight dynamics (e.g. yaw steering, etc…)
- Spacecraft attitude data (e.g. quaternions from AOCS system) – best option
- Spacecraft operations (ON/OFF cycling, etc…)
- → Really impacts the “usability” of level 2 data
- → Needed for the reconstruction of omnidirectional fluxes

A strong added value to the interpretation of {flux, energy} data comes from
- A good mechanical model of the instrument and, as far as possible, a representative mechanical model of the spacecraft
- → Good assessment of response functions
- → Eventually, improvement of instrument range / resolution
- The inclusion of dosimeters (TID, DDD) in the instrument
- → Gives integrated values very useful as independent “checksums” to the detectors
- → Pre-requires of course mechanical models