ICARE instruments and data sets

Robert ECOFFET, CNES

They made it possible
Michel LABRUNEE, Sébastien BARDE, Françoise BEZERRA,
Guy ROLLAND, Eric LORFEVRE, CNES
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 MANGERET, 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)

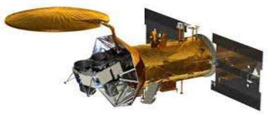
Short description of the instruments

ICARE and ICARE-NG

High-E charged particle detectors

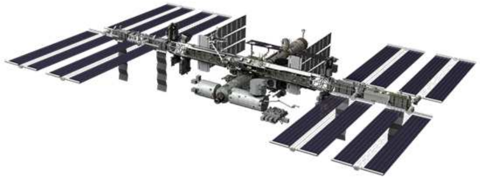
JASON-3, 1336 km, 66°

JASON-2, 1336 km, 66°

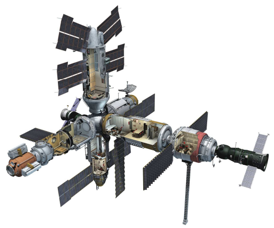


SAC-D, 657 km, 98°

SAC-C, 705 km, 98°



ISS, 400 km, 51.6°



MIR, 400 km, 51.6°

Electron and proton measurements
(Si diodes single / coincidence)

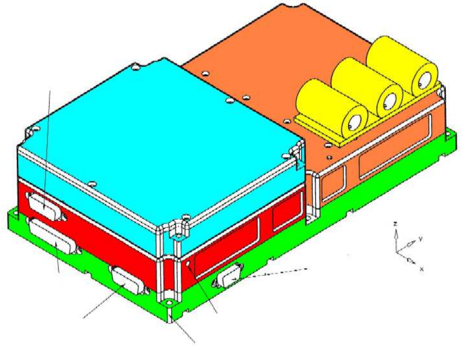
Angle of visibility 30° (half cone)

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



ICARE

ICARE-NG

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

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

CNES

Mission decision and funding

Instrument & technology board definition

Instrument development and qualification (with EREMS company)

Instrument operations and interface with satellite ground segment

Level 0 (TM) and level 1 (counts, channels) data

Spacecraft data (attitude, operations,…)

ONERA

Detector design

Response functions and calibrations

Instrument programming requirements

In-flight calibration

Level 2 data (flux, energy)

SW activity indices

Models (incl. of course other data sources)

Radiation belts science

TRAD : dosimeters
IES : dosimeters
AIRBUS, TAS, CNES : test components

Technology board

ONERA

IPSAT visualization tool
Radiation belts indices

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

TRAD

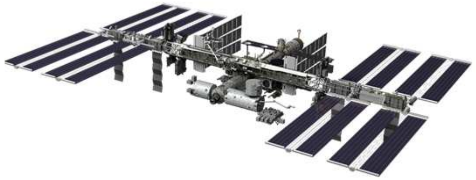
OMERE engineering tool

http://www.trad.fr/en/download/

SODAD

Active micro-debris detector

SAC-D, 657 km, 98°



ISS, 400 km, 51.6°

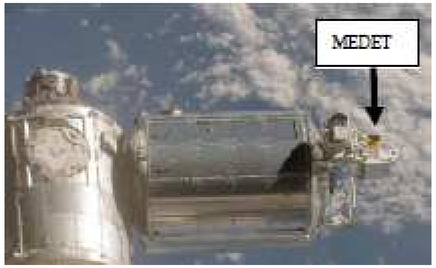
Active detector
- 2 inches diameter p-type silicon wafer

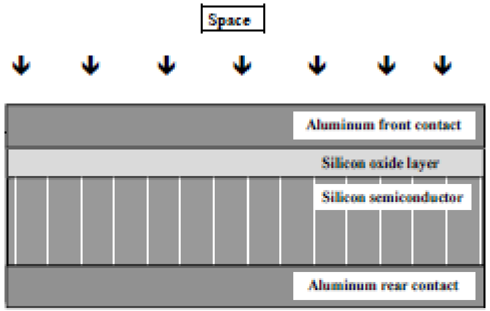
Principle
- wafer used as a capacitor, when debris strikes, capacitor discharges and current is measured

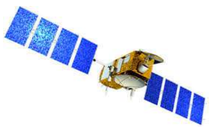
Flown on EuTEF/MEDET payload on COLUMBUS module of ISS

Flown on SAC-D on 3 satellite faces

SAC-D spacecraft interface
- ICARE/NG Radiation Monitor







JASON-3, 1336 km, 66°

AMBER

"Active Monitor Box of Electrostatic Risk"

Low-E charged particle detector

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

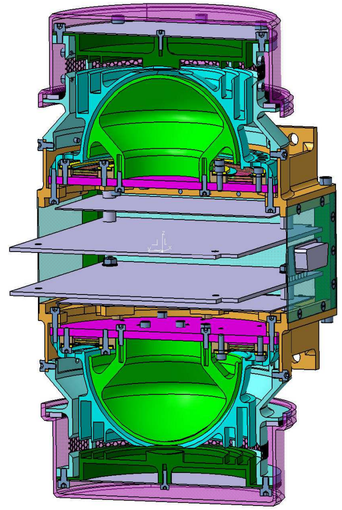
Angle of visibility 175° /12°

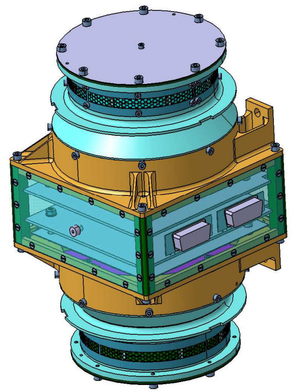
Flux
-from some pA/cm² to some nA/cm².

Energy
- from 10eV up to 30keV

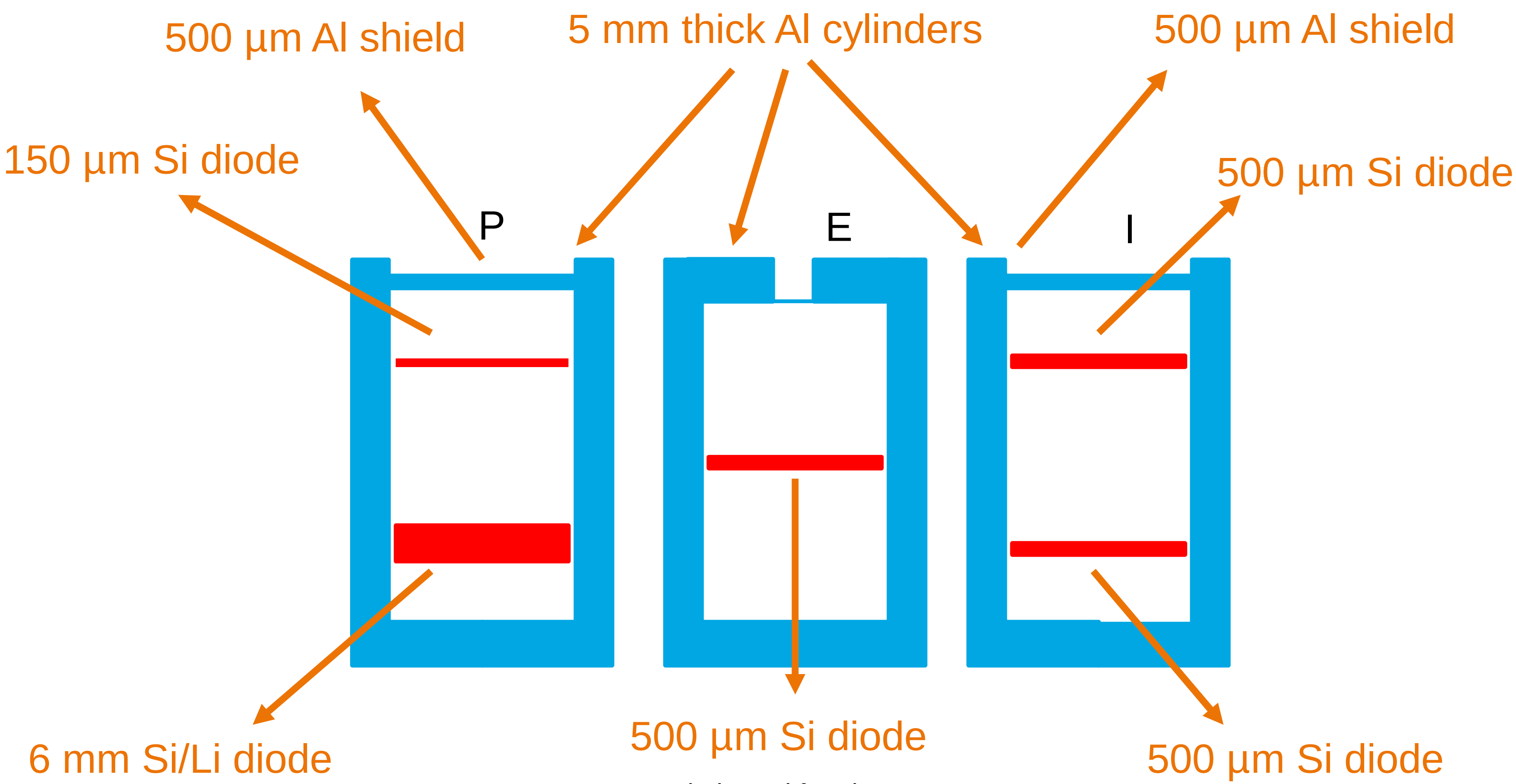
Sampling rate
- one measurement every 500ms

Spacecraft interface
- ICARE/NG Radiation Monitor





ICARE detectors



(adapted from)

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

D. Falguère, D. Boscher, T. Nuns, S. Duzellier, S. Bourdarie, R. Ecoffet, S. Barde, J. Cueto, C. Alonzo, and C. Hoffman

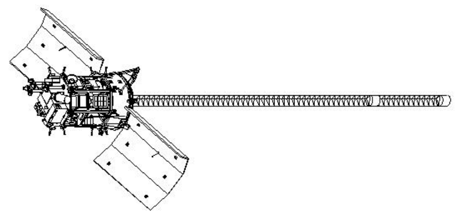
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 6, DECEMBER 2002

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

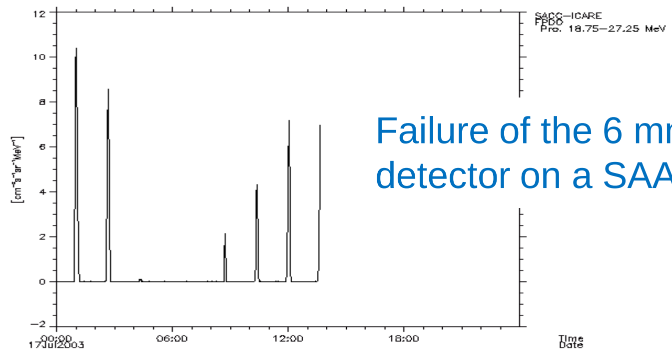
Electrons		Protons	Alpha	
Differential (MeV)	Integral (MeV)	Differential (MeV)	Differential (MeV)	Integral (MeV)
0.19-0.25	>0.9	9.65-11.35	54.5-75.5	>100
0.23-0.29	>1.5	*12.5-18.5*		
0.29-0.35	>1.7	*18.75-27.25*		
0.33-0.39	>2.0	*27-40*		
0.39-0.45		39.5-40.5		
0.45-0.51		35-50		
0.53-0.59		37-55		
0.59-0.65		39-59		
0.64-0.76		41-63		
0.76-0.88		46-75		
1.08-1.36		49-85		
1.24-1.60		53-110		
1.28-1.72		61-140		
1.72-2.20		75-180		
2.19-2.67		85-240		
2.67-3.15		110-380		
3.15-3.63				
3.63-4.11				



SAC-C, 705 km, 98°

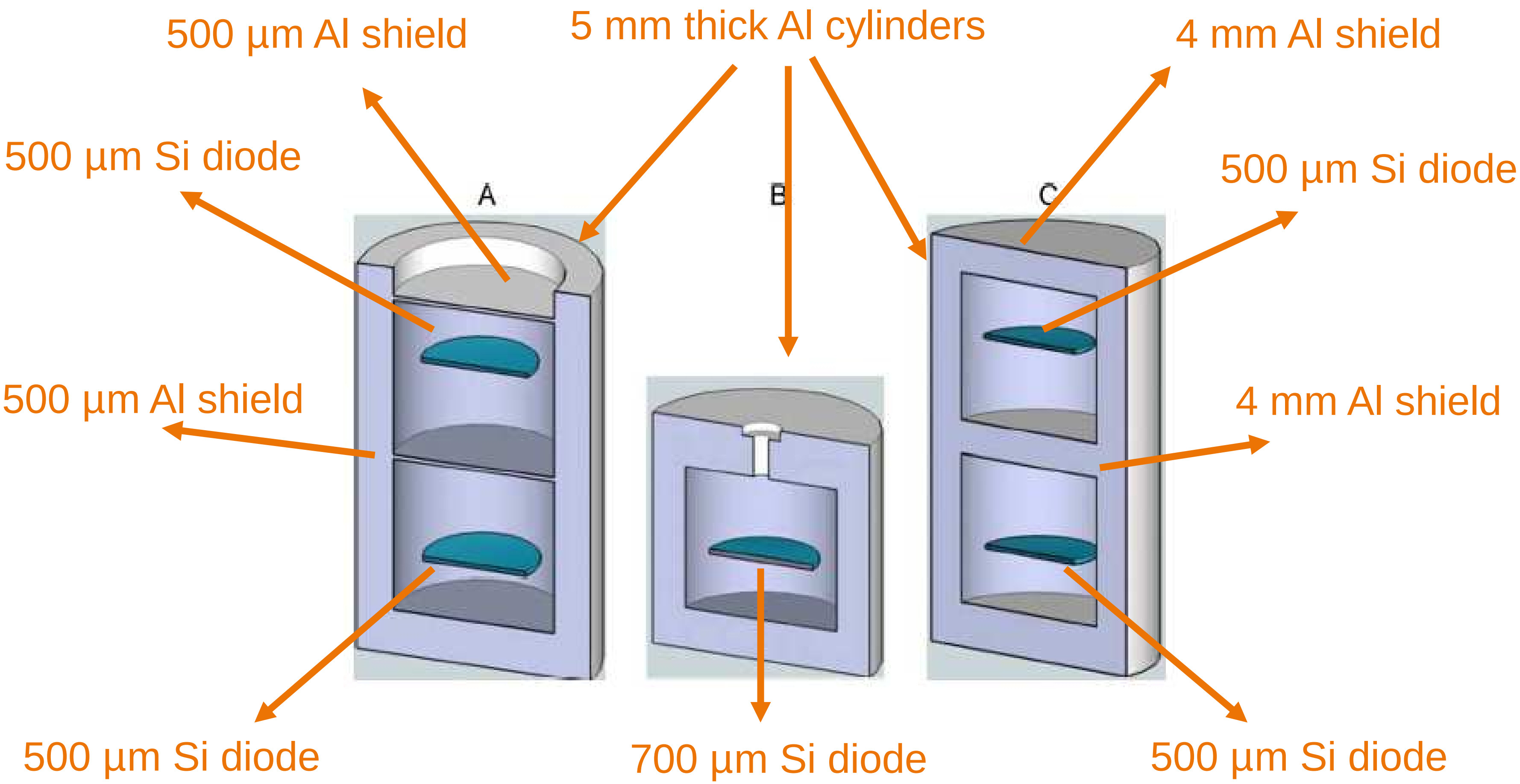
Dec 2000-April 2012

Dec 2000-July 2003



Failure of the 6 mm detector on a SAA pass

ICARE-NG detectors



In Flight Measurements of Radiation Environment on Board the French Satellite JASON-2

Daniel Boscher, Sebastien A. Bourdarie, Didier Falguère, Didier Lazaro, Philippe Bourdoux, Thomas Baldran, Guy Rolland, Eric Lorfèvre, and Robert Ecoffet

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 3, JUNE 2011

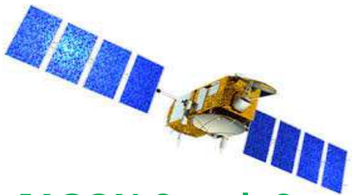
ICARE-NG spectrometer energy channels

•On JASON, ICARE-NG looks through the satellite wall

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

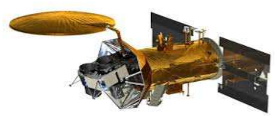
- Elementary level 1 data is particle count per channel over 16s integration periods

Electrons		Protons	
Integral (MeV)	Differential (MeV)	Integral (MeV)	Differential (MeV)
>1.6	3.6	>64	27.5
>1.67		>69	86
>1.74		>76	89
>1.81		>80	91
>1.88		>83	93
>1.95		>87	95
>2.02		>93	98
>2.09		>94	104
>2.6		>97	105
		>104	112
		>108	114
		>113	120
		>115	126
		>119	132
		>127	142
		>138	155
		>163	
		>186	
		>222	
		>292	



JASON-2 and -3
1336 km, 66°

Electrons		Protons	
Integral (MeV)	Integral (MeV)	Integral (MeV)	Differential (MeV)
> 0.249	> 1.093	> 54	12.9
> 0.270	> 1.135	> 56	18.6
> 0.299	> 1.192	> 60	31
> 0.320	> 1.226	> 65	47.3
> 0.342	> 1.300	> 66	61
> 0.363	> 1.359	> 70	63
> 0.384	> 1.508	> 73	64
> 0.413	> 1.657	> 75	65
> 0.455	> 1.823	> 80	67
> 0.505	> 1.974	> 81	69
> 0.554	> 2.106	> 85	74
> 0.604	> 2.254	> 90	75
> 0.653	> 2.404	> 100	80
> 0.703	> 2.567	> 105	81
> 0.752	> 2.680	> 115	85
> 0.802	> 2.770	> 130	90
> 0.870	> 2.850	> 160	100
> 0.895	> 2.930	> 190	115
> 0.930	> 3.010		
> 0.986	> 3.090		
> 0.994	> 3.170		
> 1.078	> 3.250		

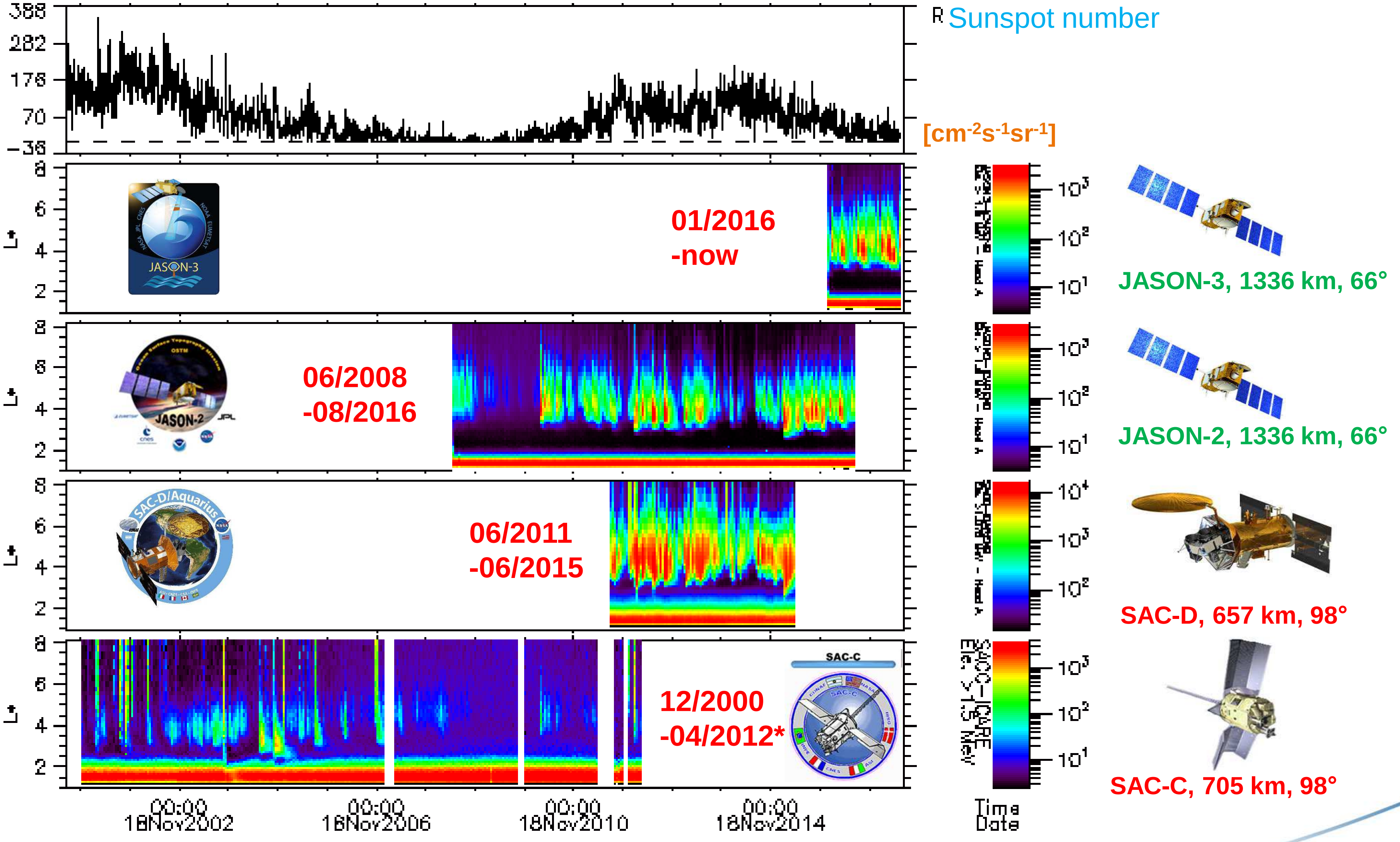


SAC-D
657 km, 98°

ICARE missions

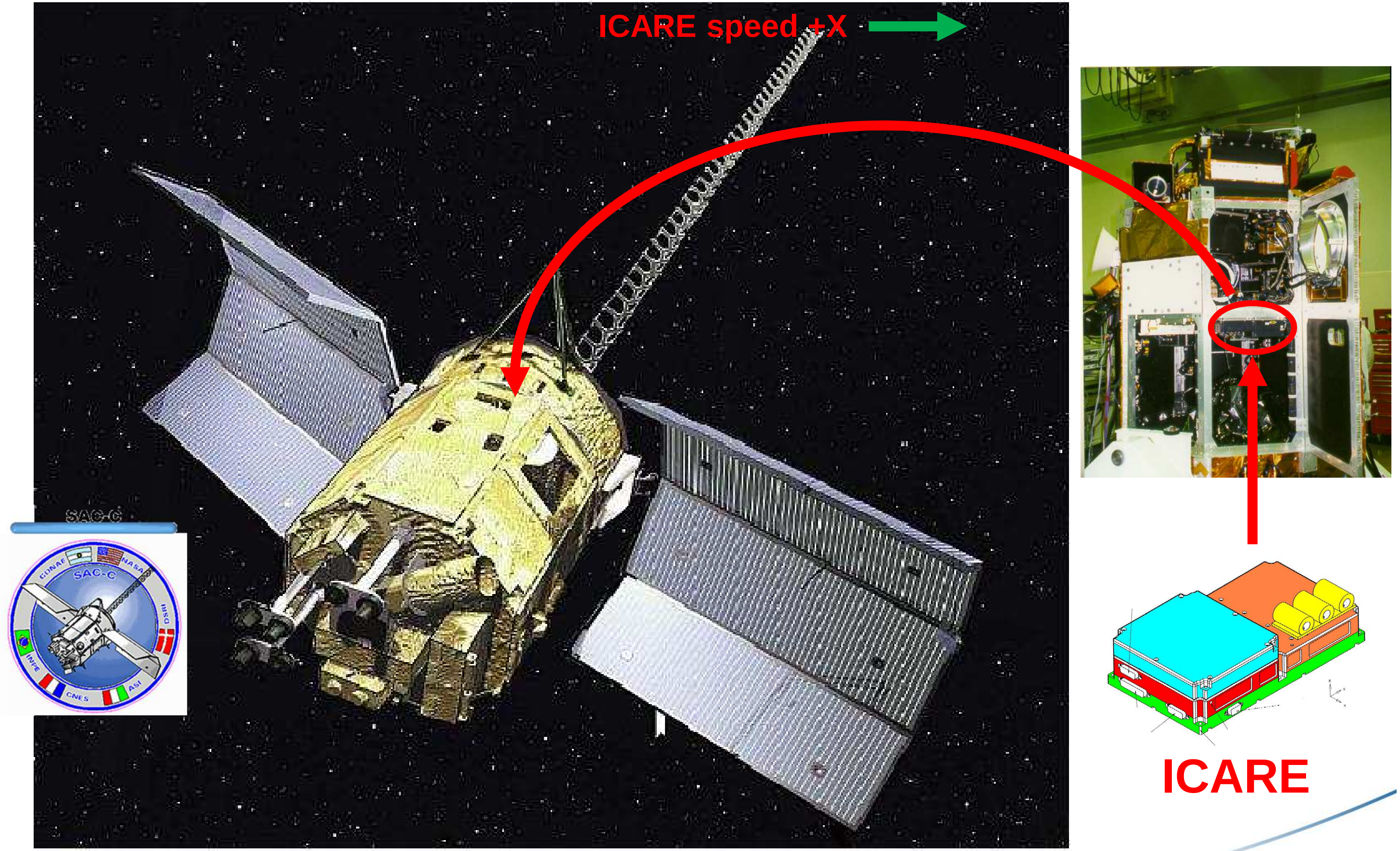
Mission timelines

~ >1.5 MeV e- integral channels

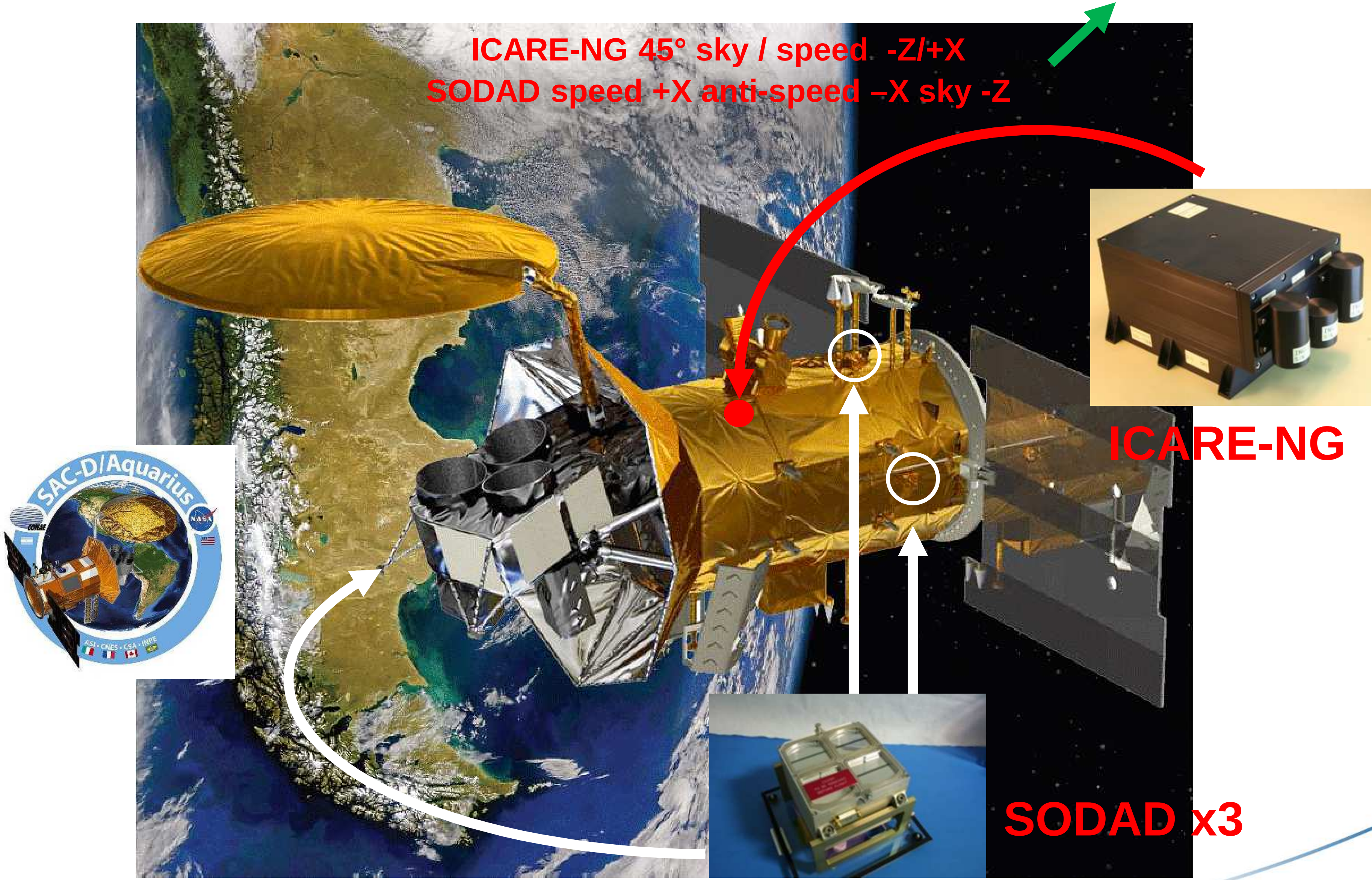


* Some channels 12/2000-07/2003, see previous slides

Instrument accommodation on SAC-C (ICARE mission)



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



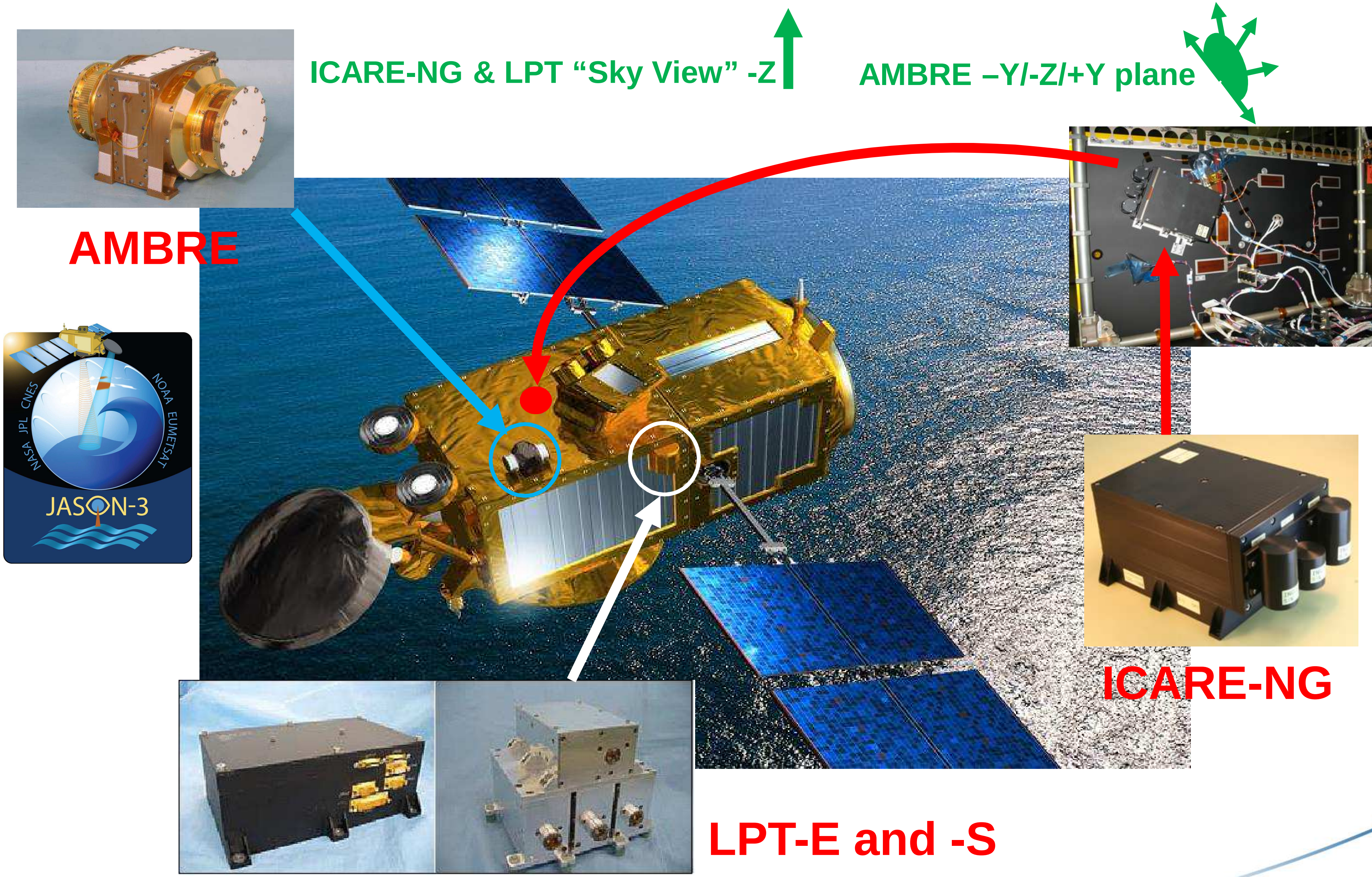
cnes

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

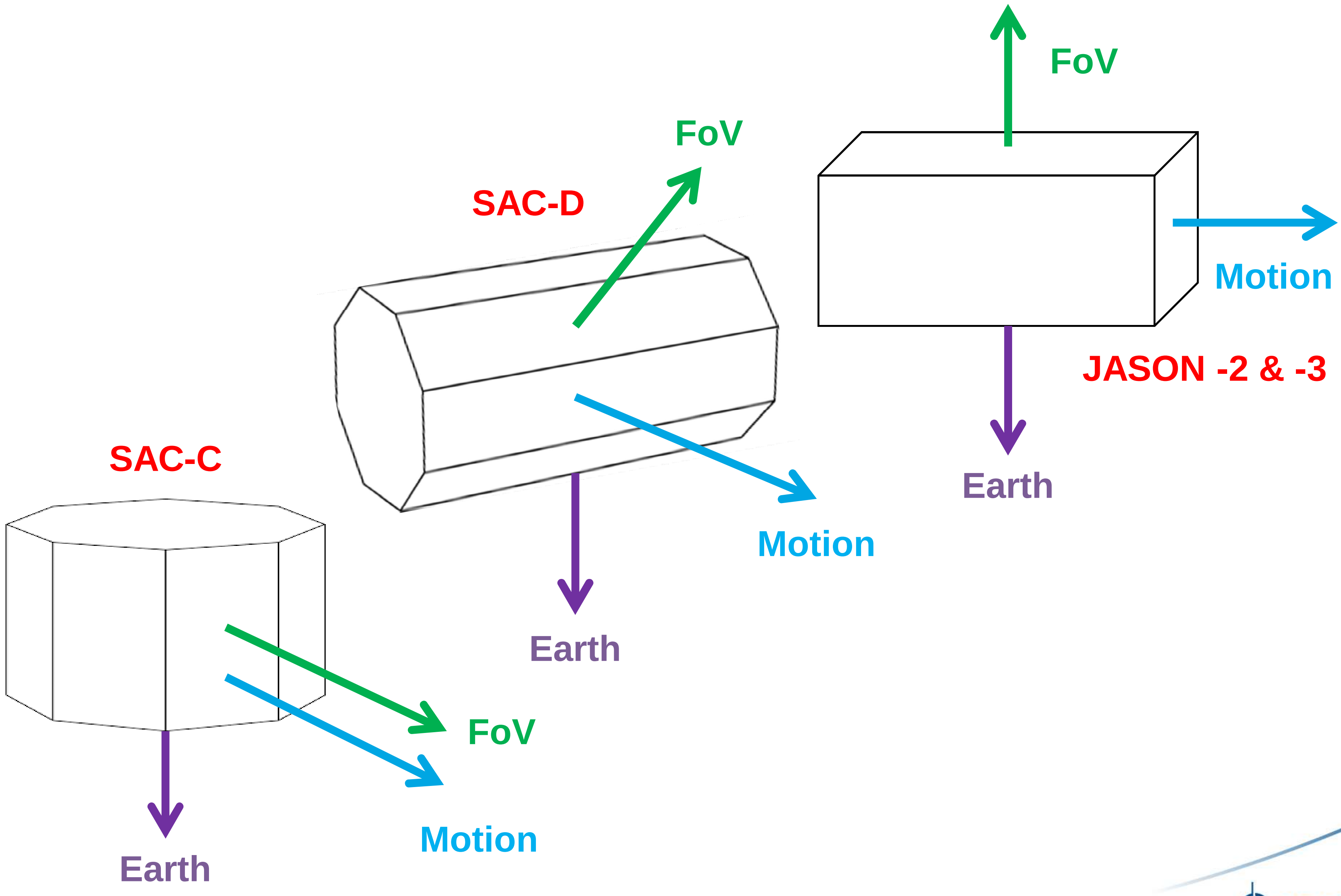
ICARE-NG & LPT "Sky View" -Z

LPT-E and -S

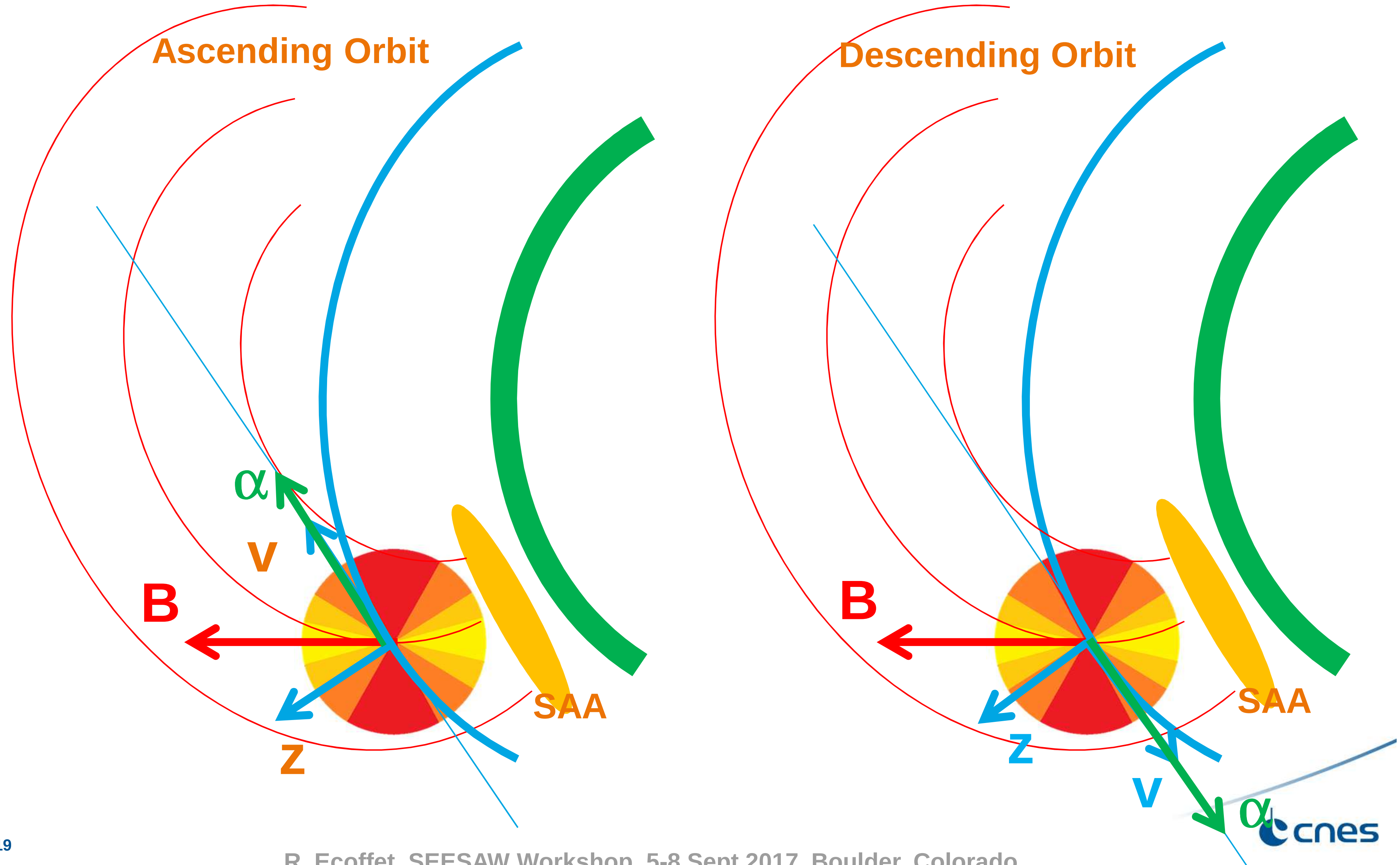
Instrument accommodation on JASON-3 (CARMEN-3 mission)



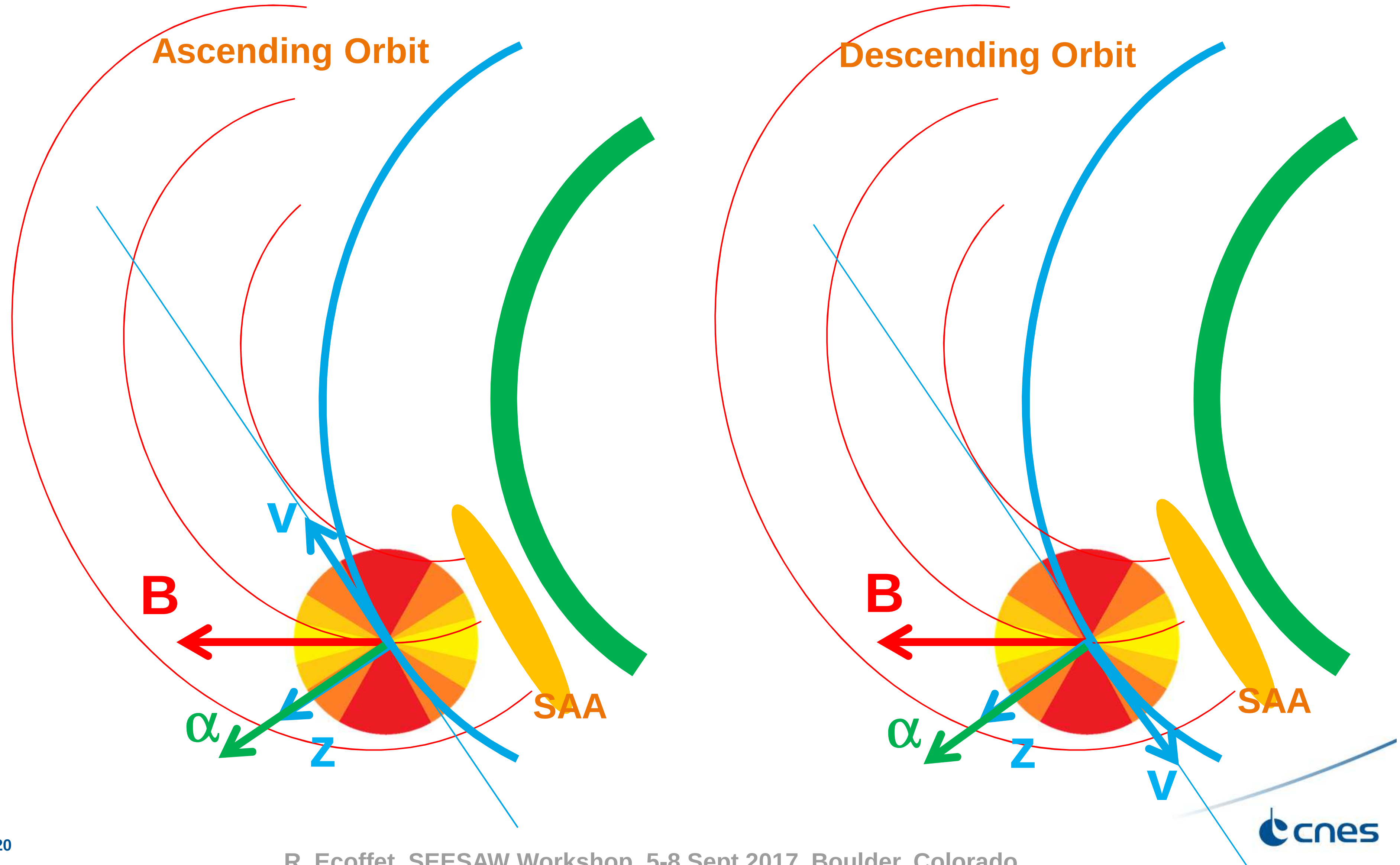
Line of view of the instruments



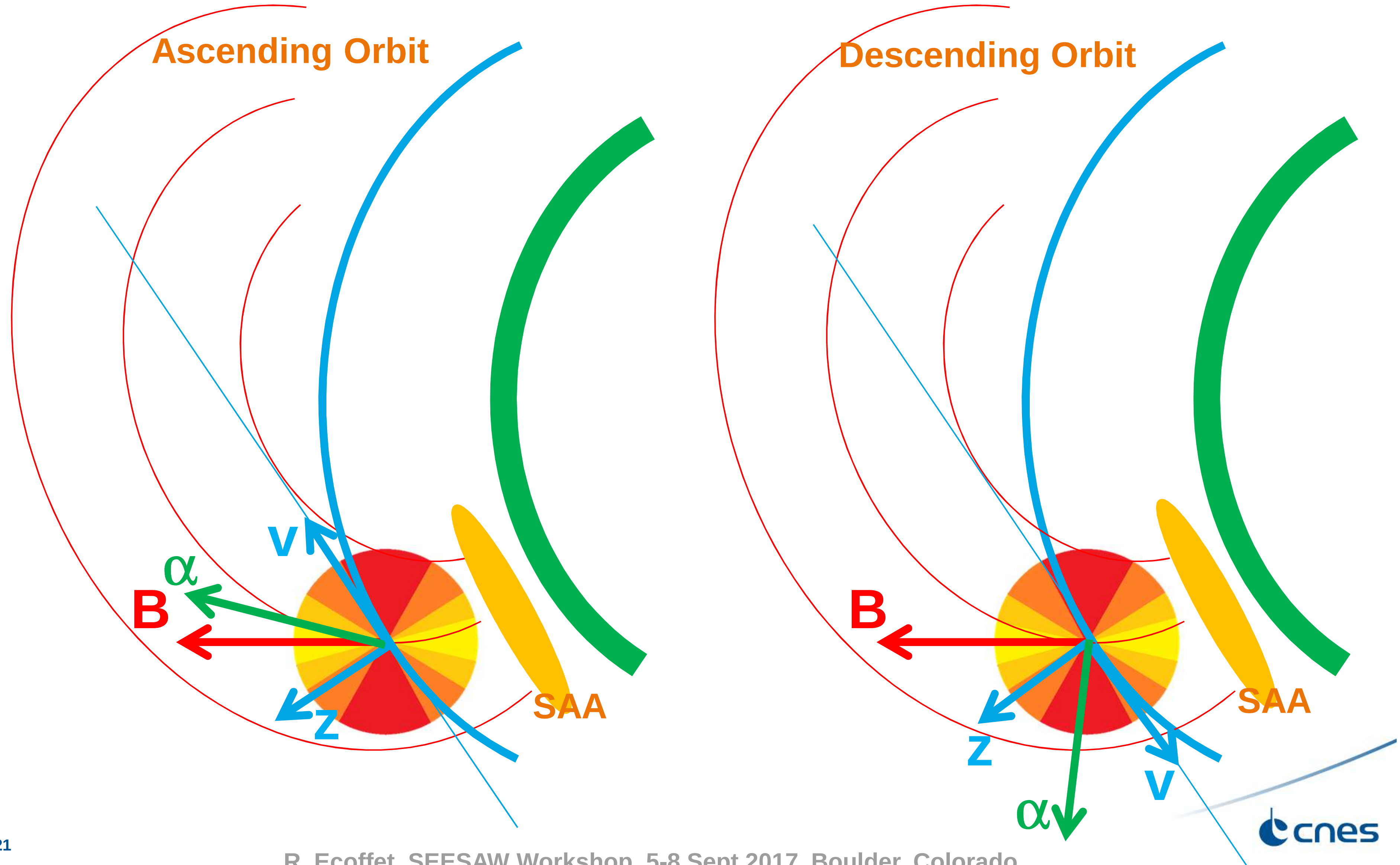
Line of view of ICARE / SAC-C



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



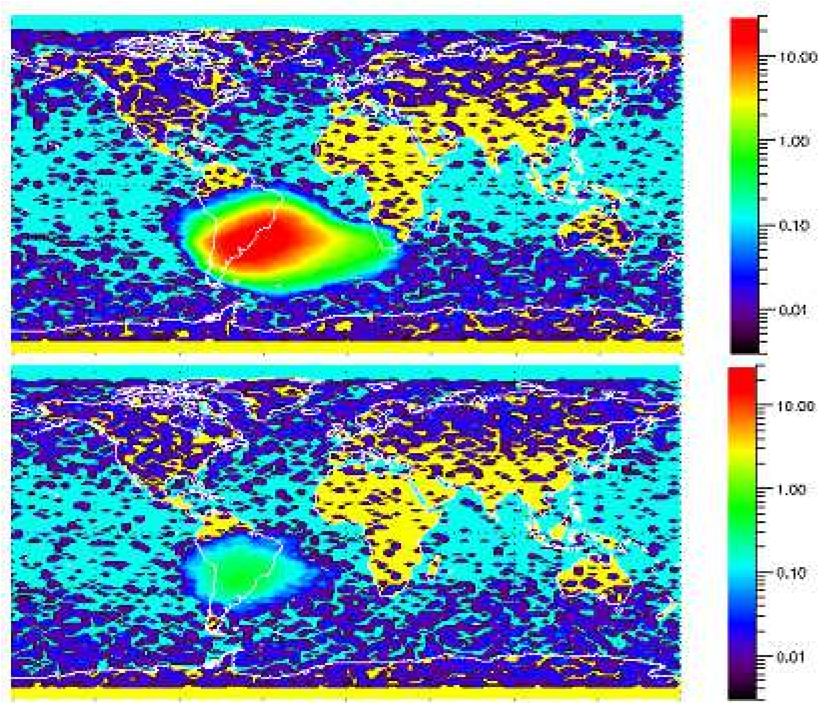
Line of view of ICARE-NG / SAC-D



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



Descending orbits

Ascending orbits

29 MeV protons

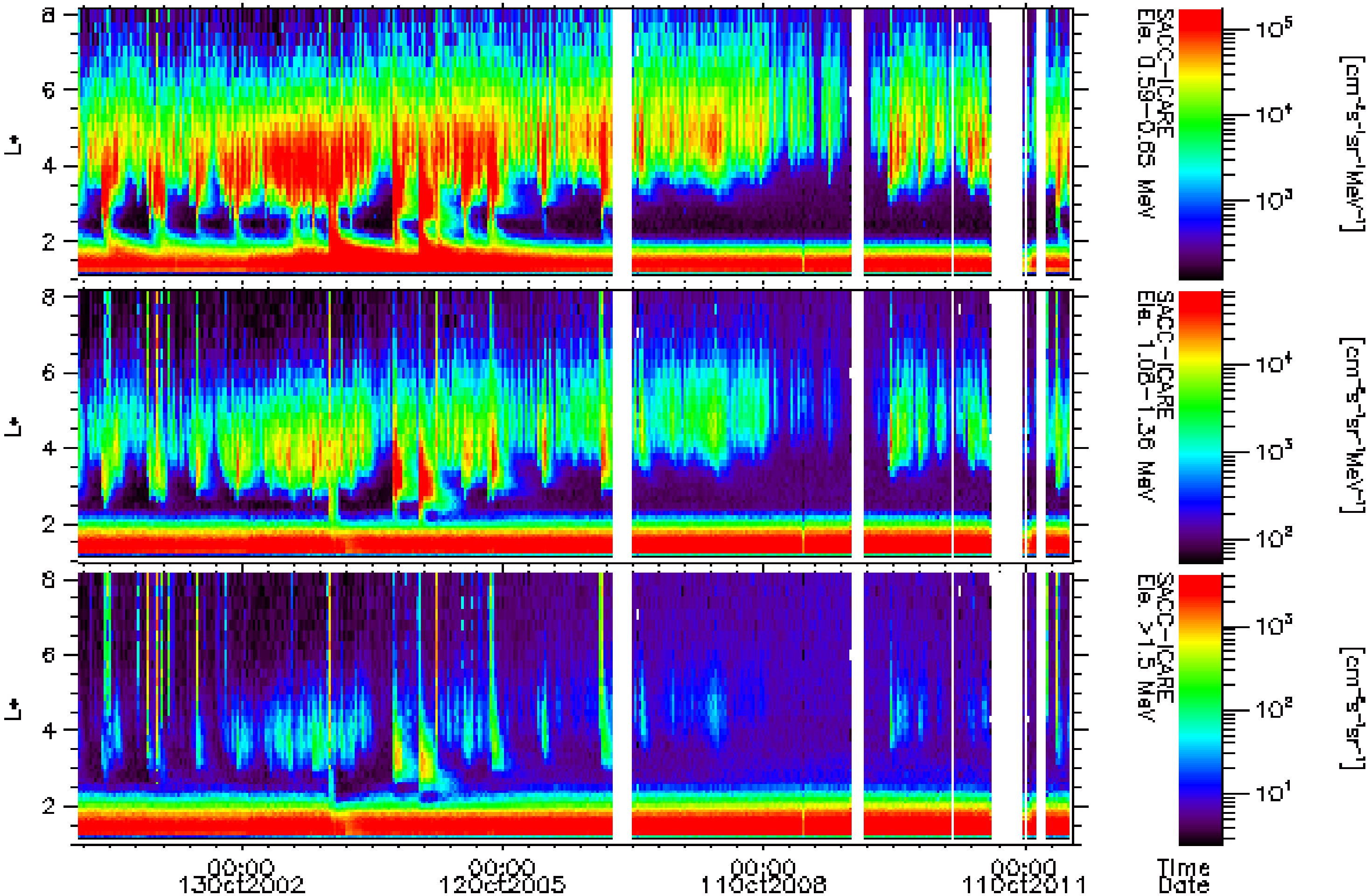
In-Flight Measurements of Radiation Environment on Board the Argentinean Satellite SAC-D

D. Boscher, T. Cayton, V. Maget, S. Bourdarie, D. Lazaro, T. Baldran, P. Bourdoux, E. Lorfèvre, G. Rolland, and R. Ecoffet

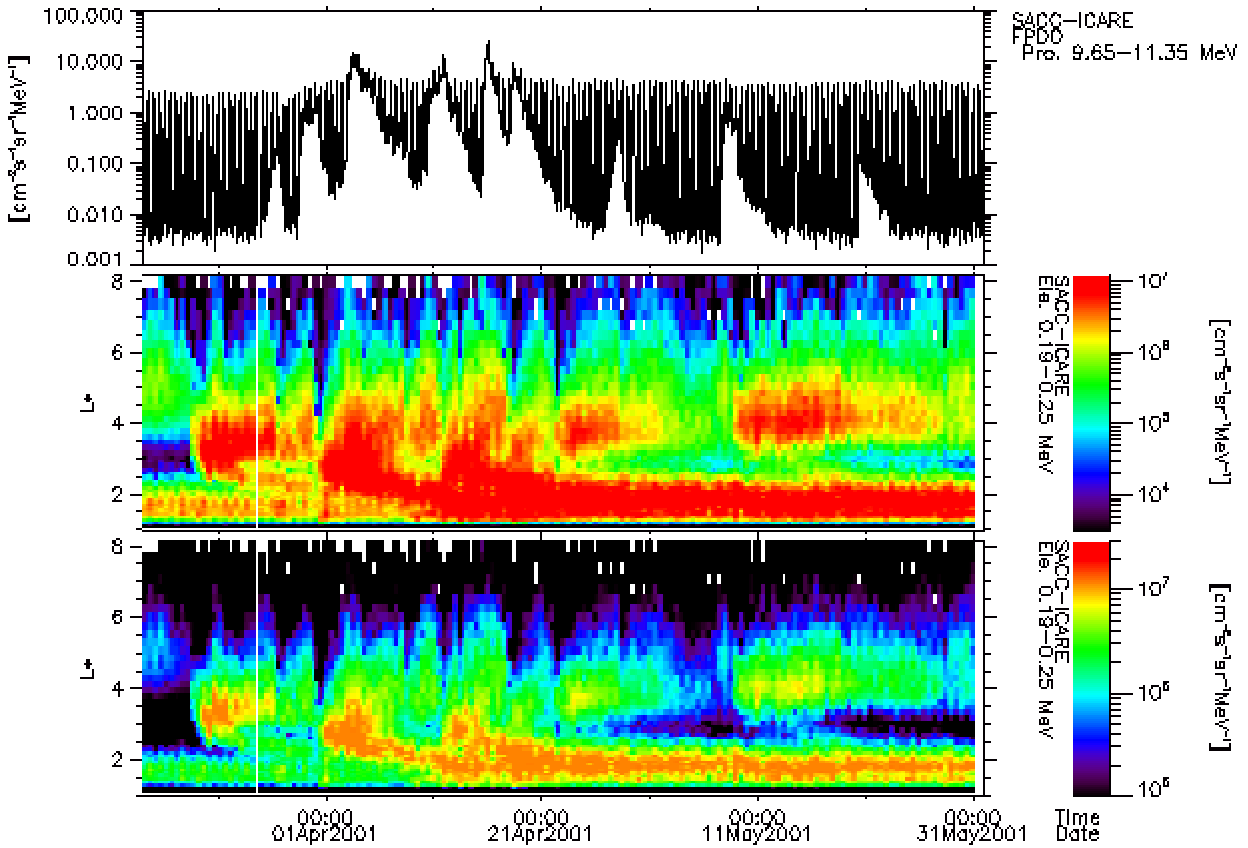
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 6, DECEMBER 2014

A few examples of observations

SAC-C overview

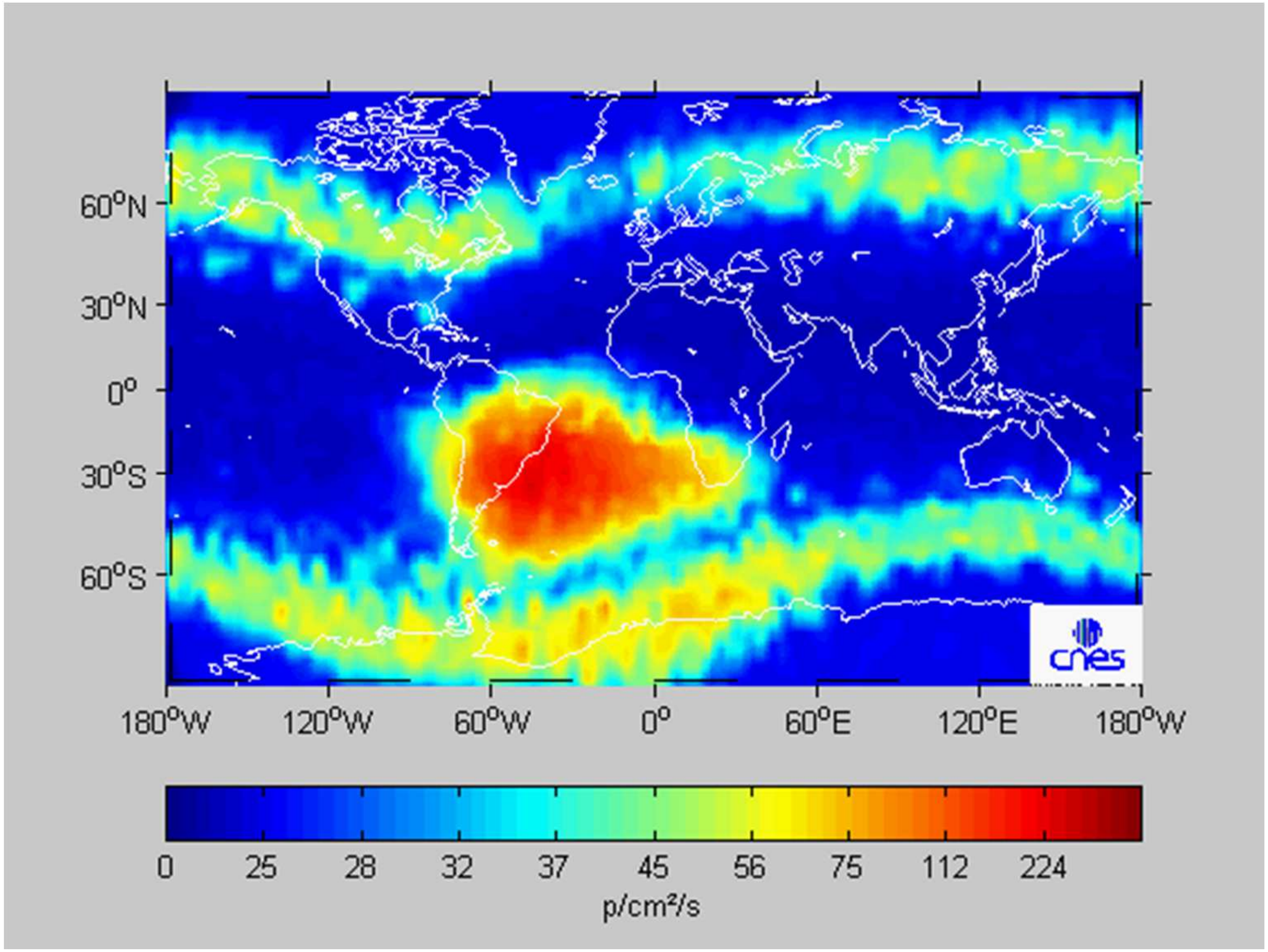


Magnetic storms and particle events
15 March – 30 May 2001, SAC-C



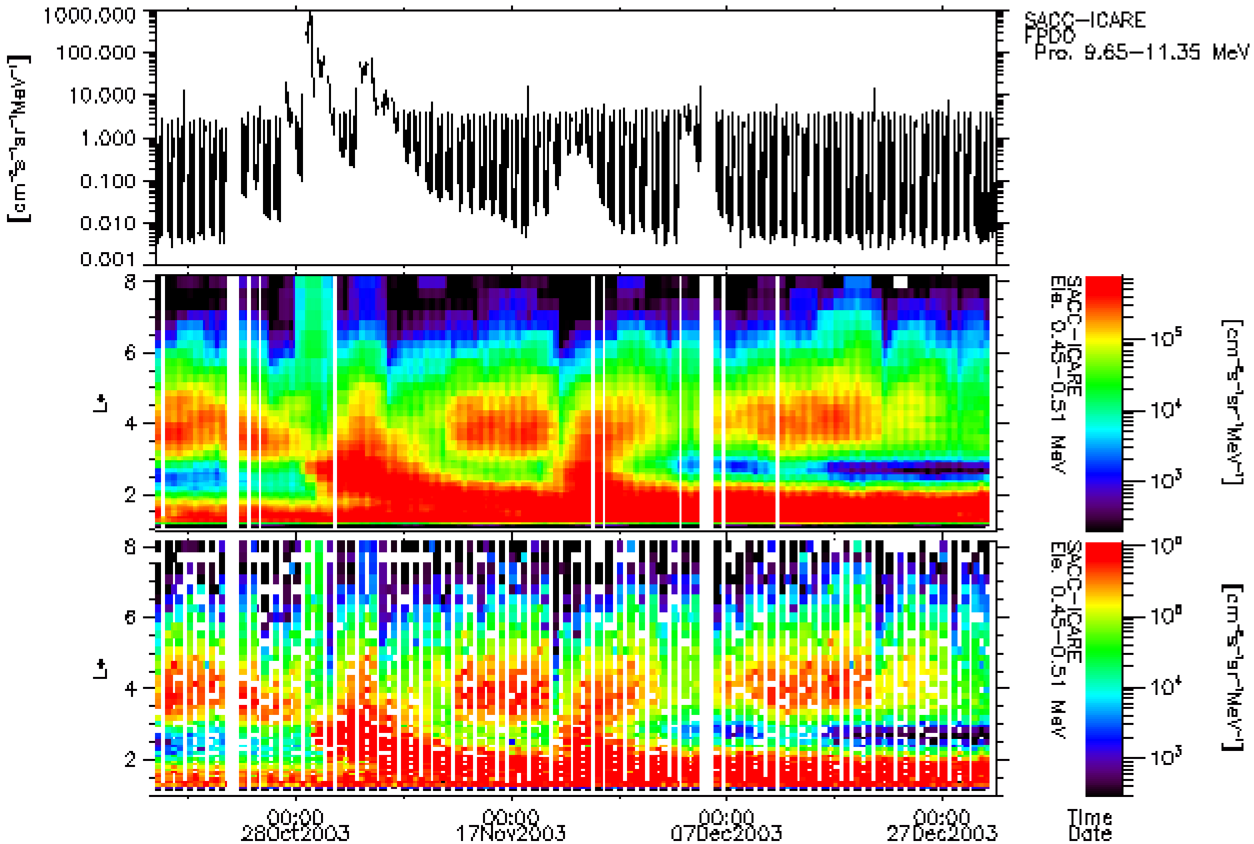
Same e- channel, different color scales to enhance contrast in high flux zones

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



Total count ("rapid counter") on "E" head

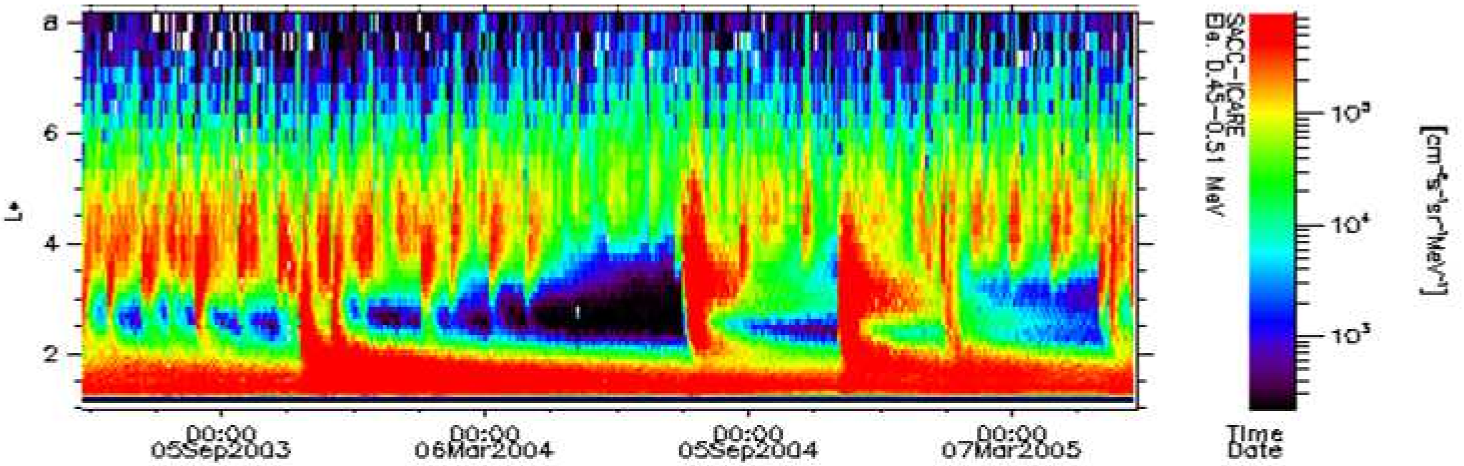
Magnetic storms and particle events
15 Oct. 2003 – 31 Dec. 2003, SAC-C



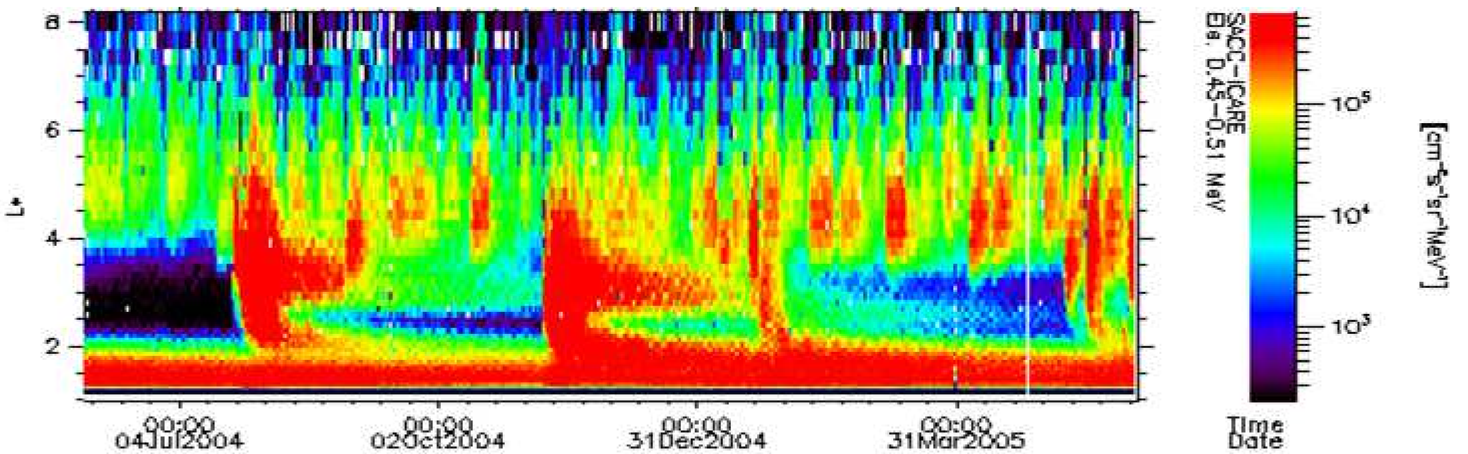
With or without smoothing (horizontal & vertical) : for a certain period the satellite power system had an issue and ICARE was cycled 50% of the time

cnes

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

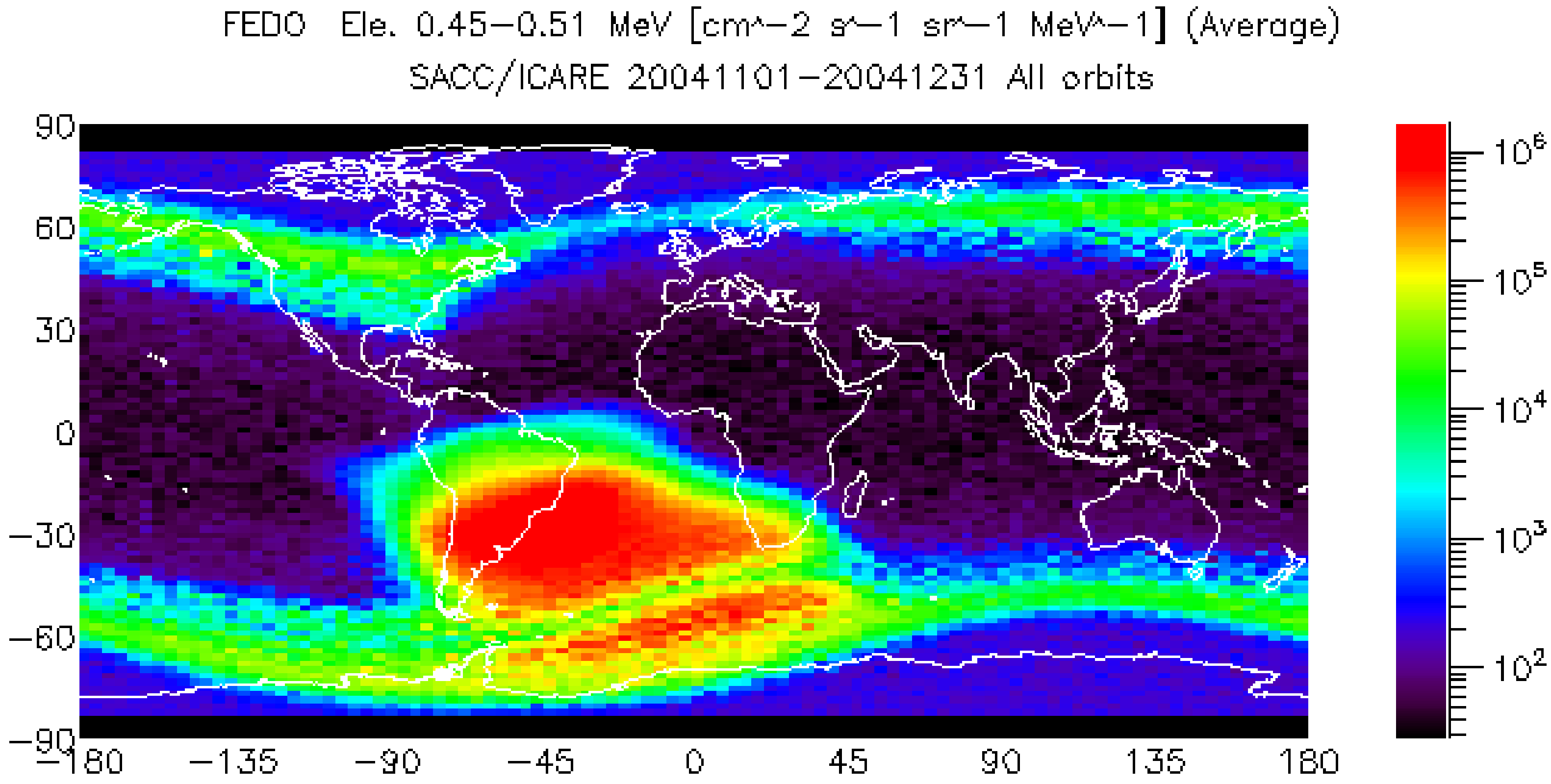


Period 1st June 2003 – 1st June 2005, SAC-C



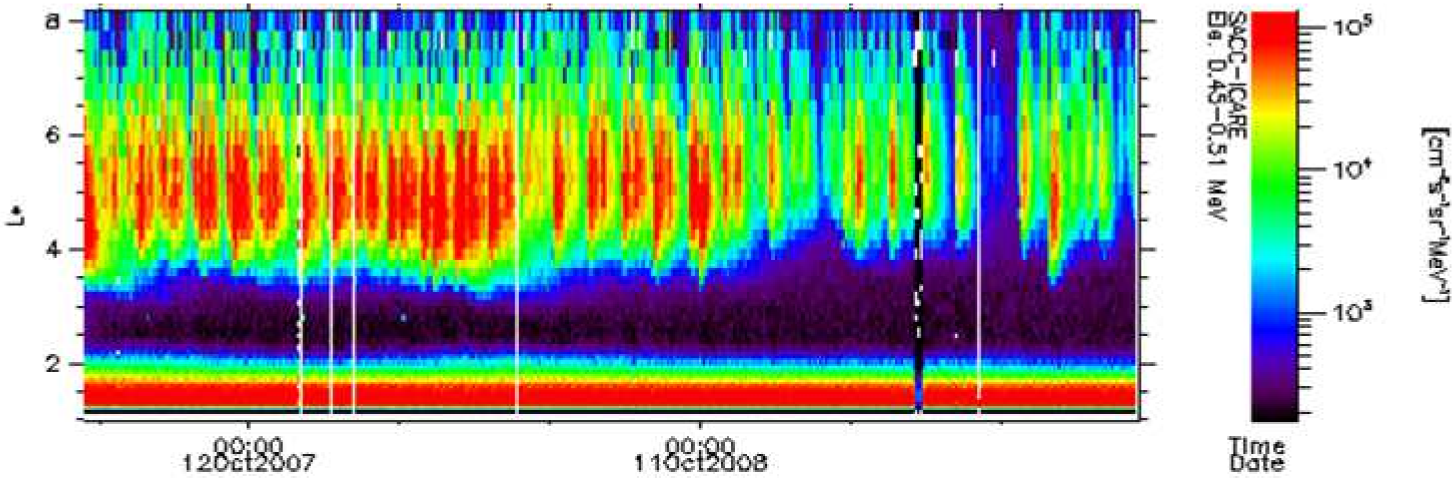
Period 1st June 2004 – 1st June 2005, SAC-C

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

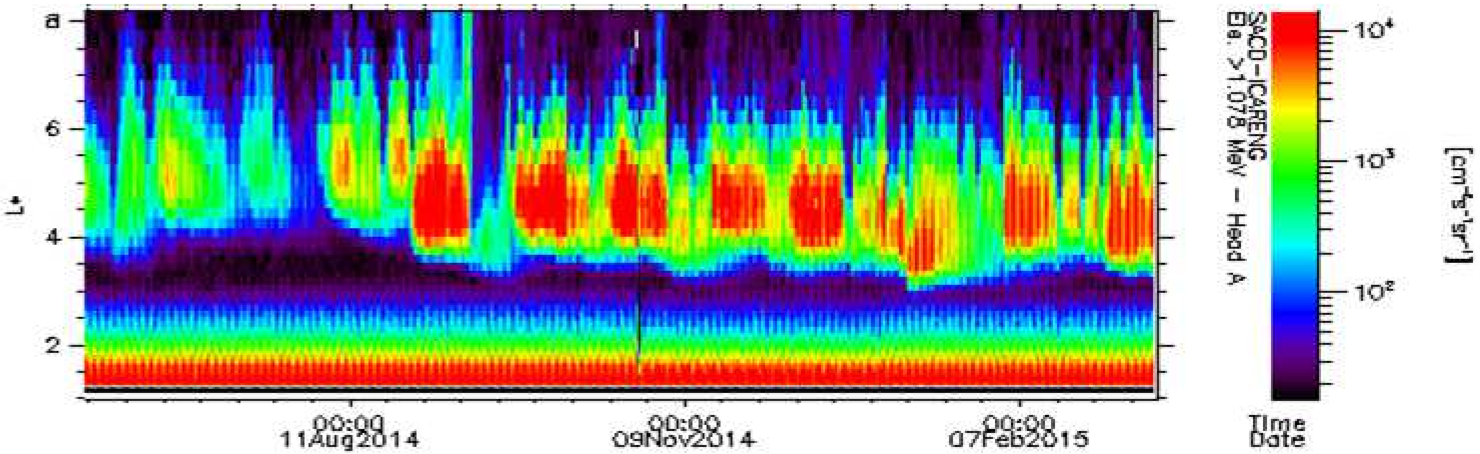


Period 1st Nov. 2004 – 31 Dec. 2004, SAC-C

Coronal holes : 28-day modulation of the outer belt

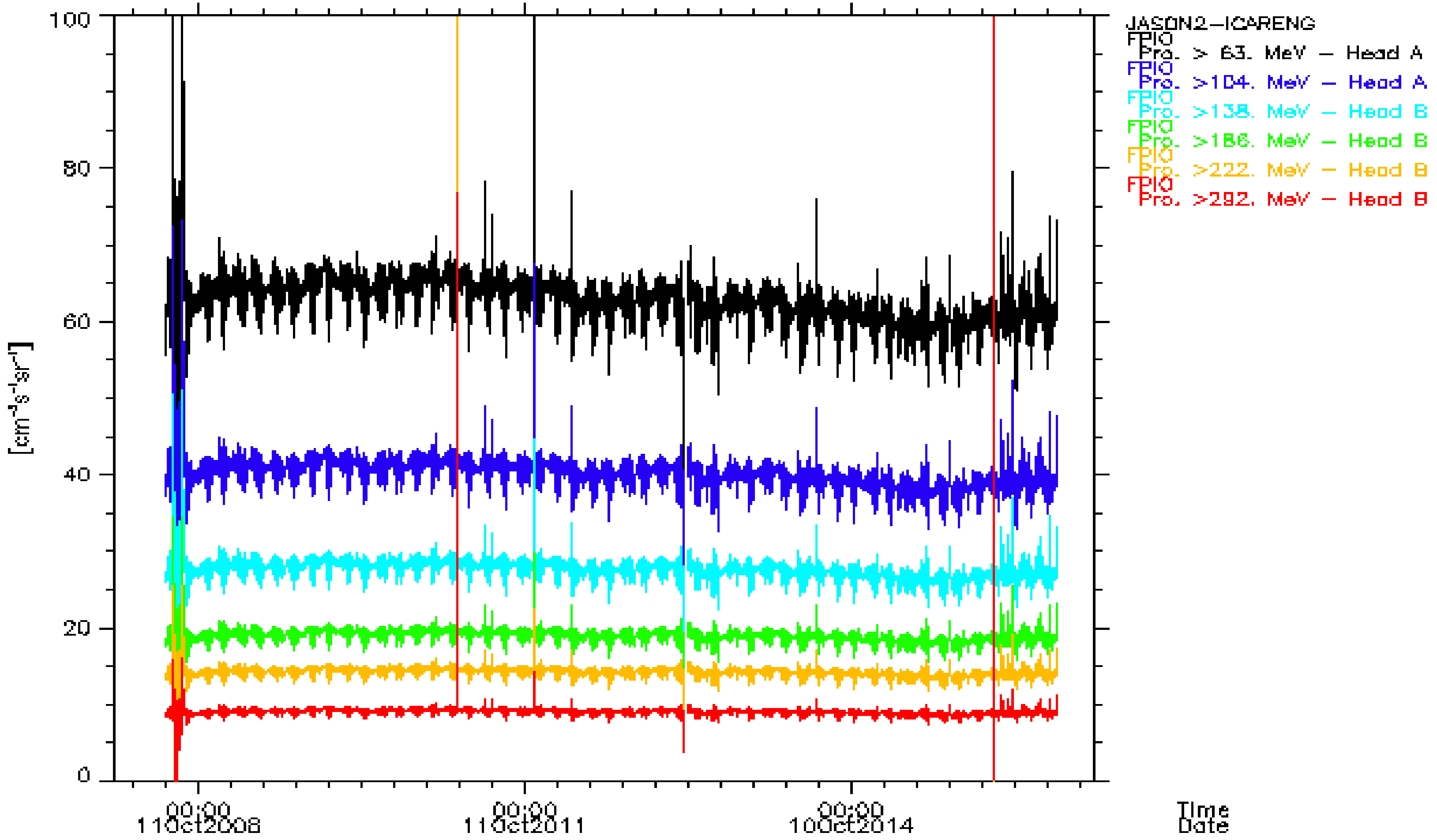


Period 1st June 2007 – 30 Sept. 2009, SAC-C



Period 1st June 2014 – 15 March 2015, SAC-D

High energy proton belt is fairly stable (Jason orbit)



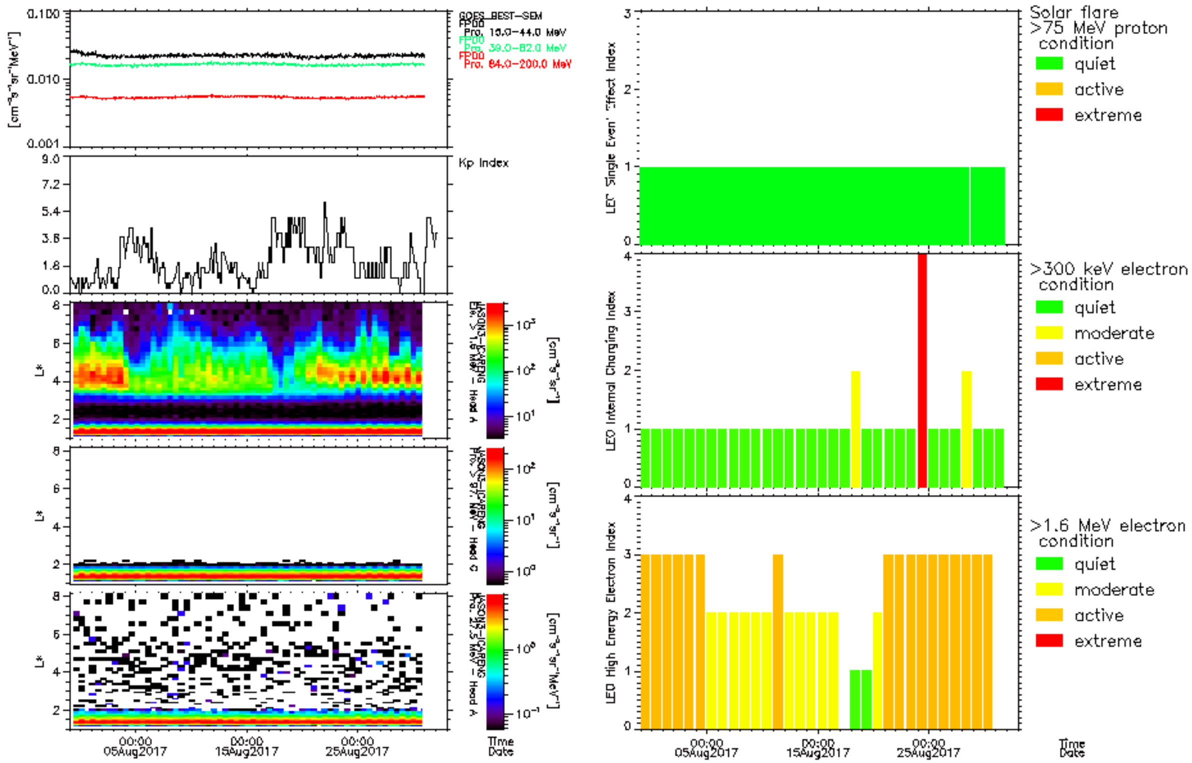
Use of the data by ONERA

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

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