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Solar Particle Event Detection with the LUMINA Optical Fiber Dosimeter aboard the International Space Station

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Context – Space Weather, an Unpredictable Hazard

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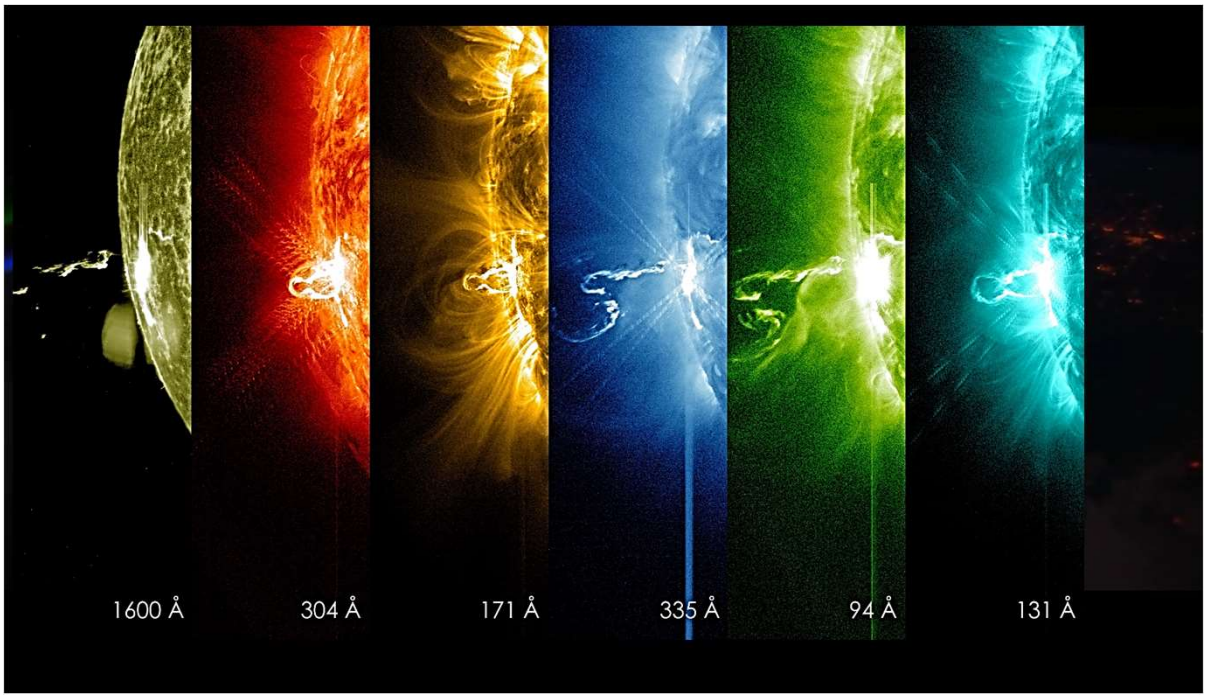


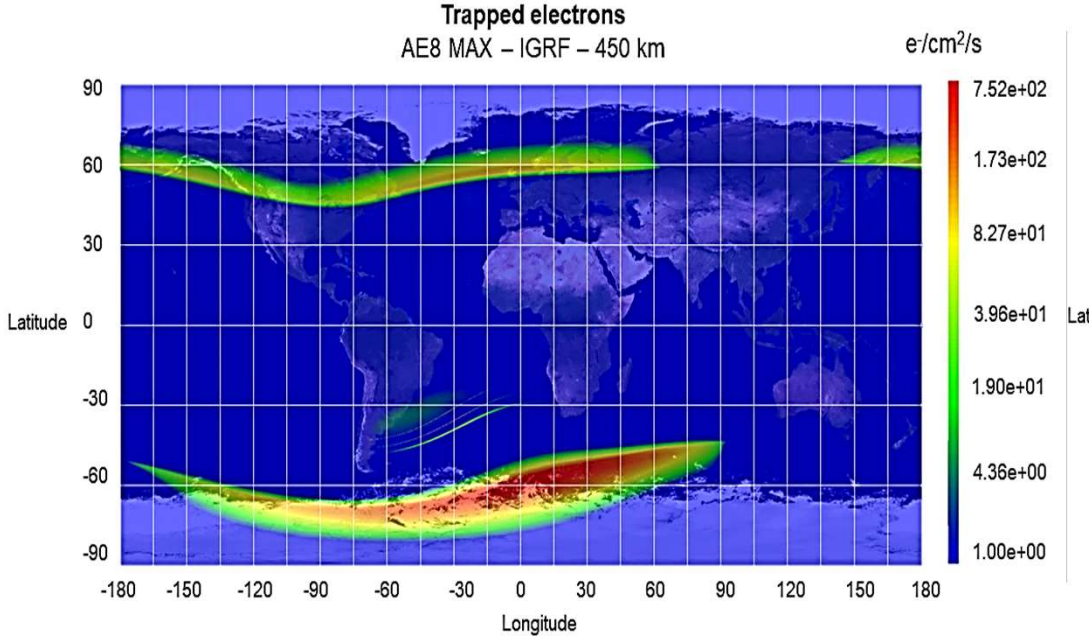
X-class solar flare (SF) the On Feb. 24, 2014. NASA's Solar Dynamics Observatory captured images of the first moments of this event. © NASA/SDO.

- **Solar Particle Events (SPEs)**
  - Stochastic and violent events.
  - Can release large amounts of energy and matter.
  - Their frequency and intensity are related to the solar cycle.
  - Mainly two waves of particles (precursor and impulsive stages).

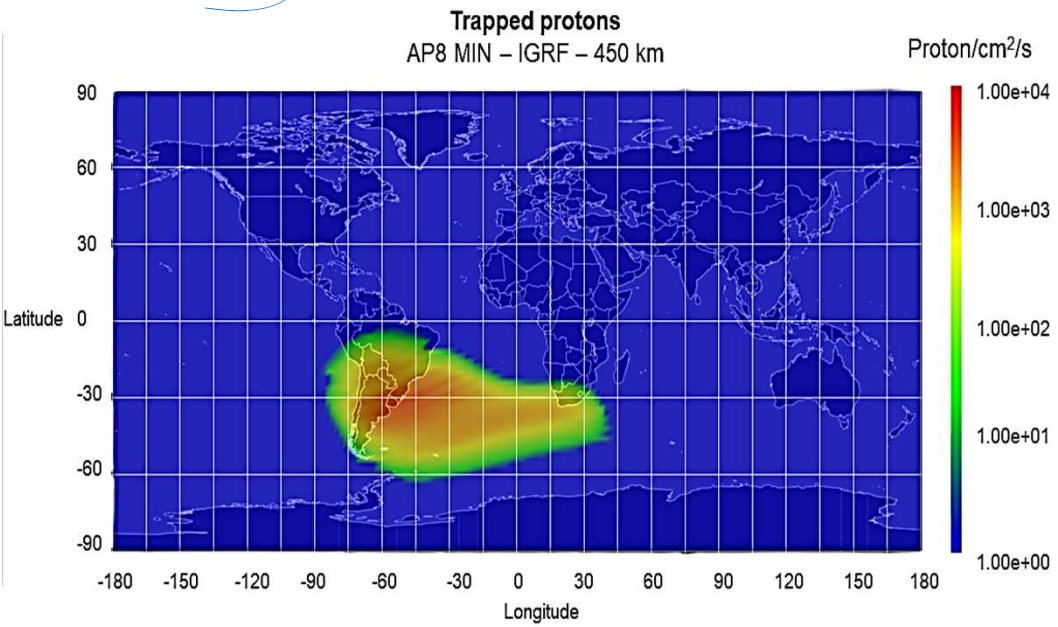
- Ionizing radiations jeopardize in different ways the integrity of living beings.
  - This issue is primordial for future long-term missions.

A robust dosimeter, providing real time measurements of the dose rate levels can help anticipating the solar events with appropriate reactions.

Context –The ISS faces distinct type of particles : Electrons, Protons from Van Allen radiation Belts and some heavy ions from Galactic Cosmic Rays.



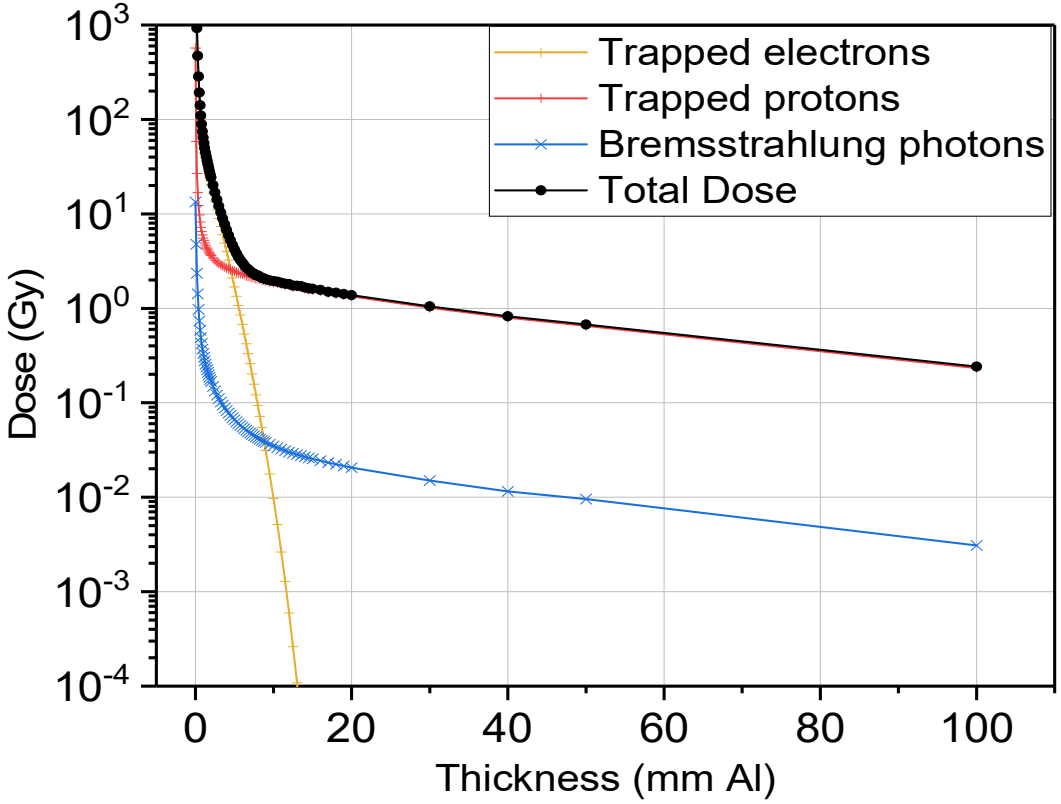
➢ **High Energy Electrons mainly populate the High latitudes**



➢ **An abundance of Protons in the SAA at 450 km**

Even if The ISS is well protected thanks to the Earth's magnetic fields, It is important to consider the different effects of radiations in the LUMINA Context.

Context – Considering the ISS shield, the main contributor to the dose are the high energy protons.



Contribution on Total Ionizing Dose inside the ISS :

- **Low Energy Protons and Electrons**
  - **Attenuated by the ISS's ten centimeters Aluminum.**
- **Trapped Electrons > 4 MeV**
  - **Minor Contribution by Bremsstrahlung effects.**
- **Trapped Protons > 100 MeV**
  - **Major Contribution by direct deposition or secondary particle generations.**

The SAA makes a very significant contribution to the total ionizing dose.

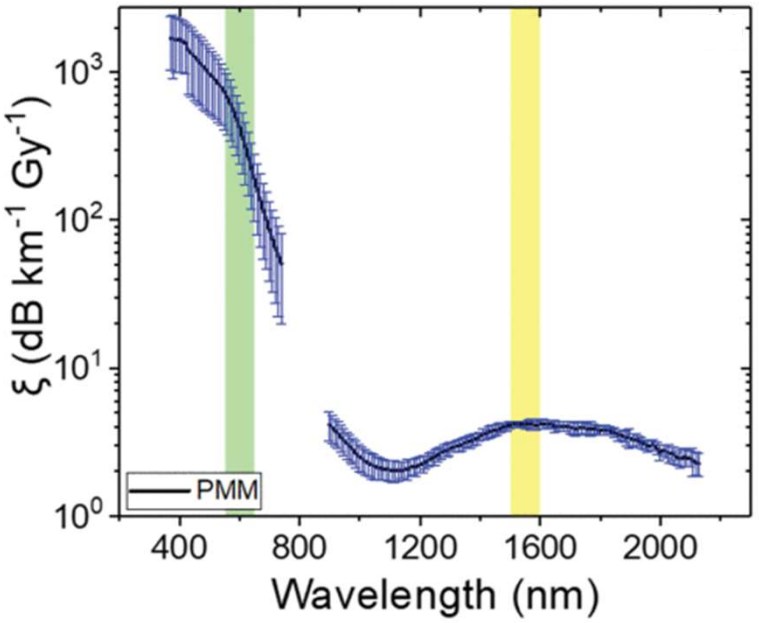
However, electrons are not to be neglected as they are abundant in the polar regions where protons are rather absent.

Conception – Protected by the spacecraft, astronauts are subjected to a very low dose rate environment.

P-doped optical fiber radiation sensitivities

Some Features are required for a good dosimeter :

- Ability to detect few hundreds of µGy(SiO_2)/day
- Insensitivity to dose rate
- Insensitivity to nature particle
- Insensitivity to small variations of temperature
- Absence of recovery



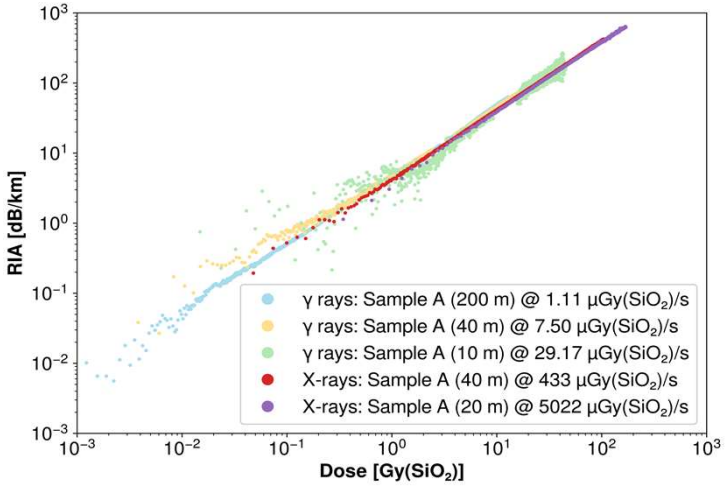
The Radiation Sensitive phosphosilicate optical fibers have all of these characteristics and we are interested into two particular wavelengths : 638 nm and 1535 nm for Radiation Induced Attenuation (RIA) based dosimetry.

Conception – 1535 nm and 638 nm present the good features for RIA-Dosimetry in such environment.

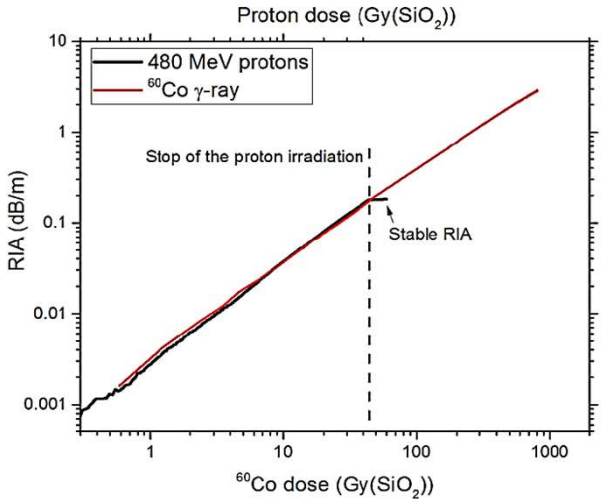
ξ = 4 dB km^{-1} Gy^{-1} **λ = 1535nm** ξ = 140 dB km^{-1} Gy^{-1} **λ = 638nm**

Compatibility with interrogation tools (source & detectors)

- "Linear" RIA increase with dose (up to 500 Gy) and dose rate.
- Absence of recovery and possibility to reset



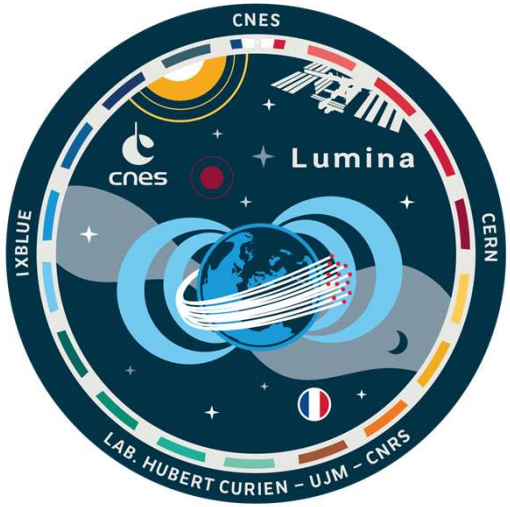
A. Meyer *et al.*, TNS, 2022



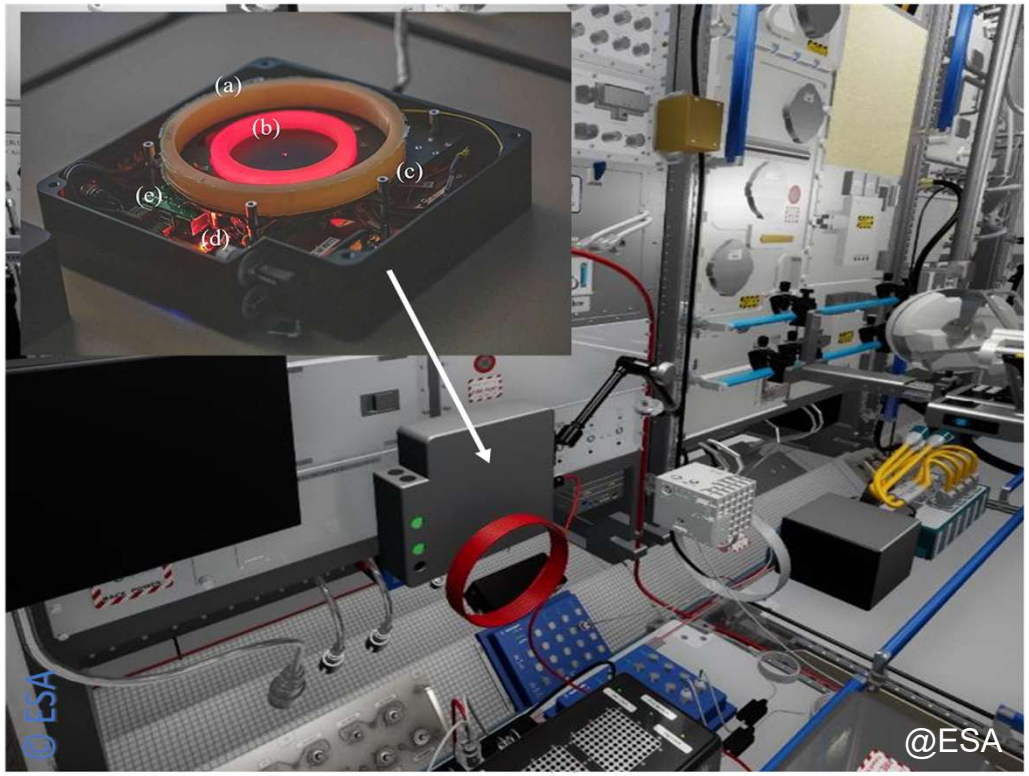
Diego Di Francesca *et al.*, JLT 2019

Optical Fiber based RIA dosimetry is possible to measure the low RIA levels (low induced losses) associated with the ISS radiation.

LUMINA project: an optical fiber dosimeter in the ISS Colombus Module.



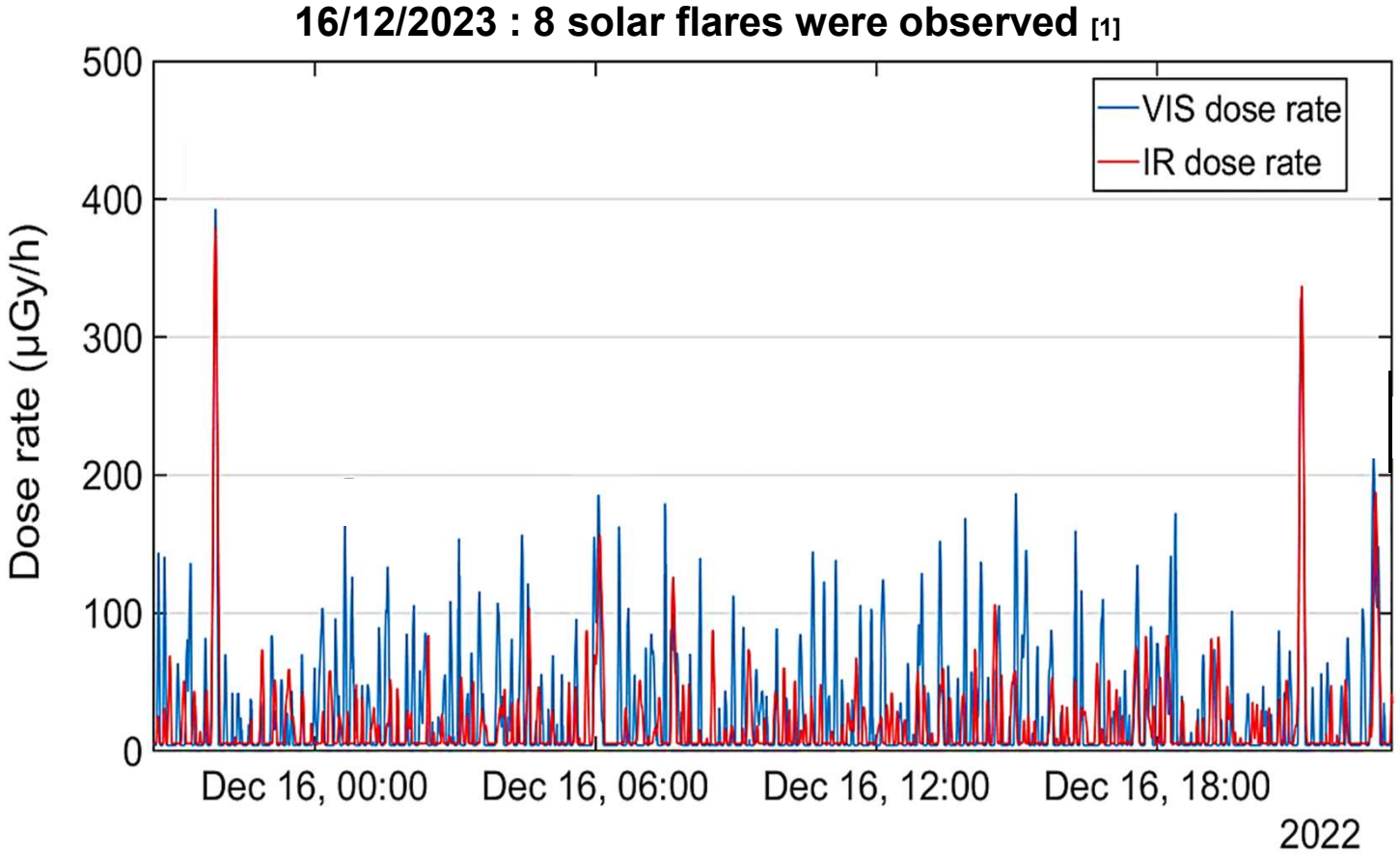
LUMINA dosimeter has been installed in August 2021. Since that time, new astronauts continued to work and the dosimeter still collects data.



(a) Fiber coil working (1535 nm)
(b) Fiber coil working (638 nm)
(c) Opto-electronic boards
(d) Interface board
(e) Raspberry Pi

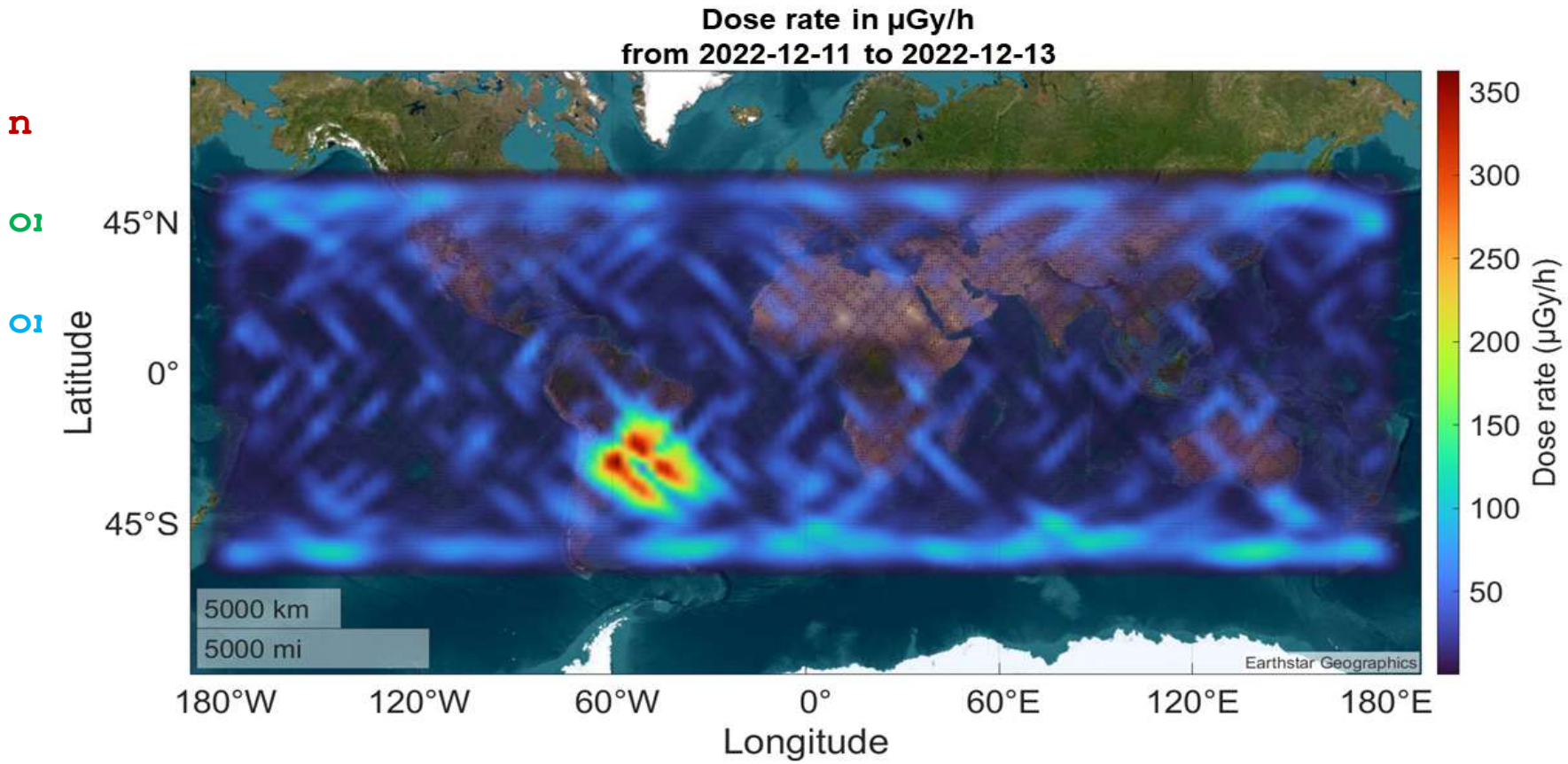
Results – Dose rate calculations enable us to identify the zones crossed by the ISS.

- Potential consequences of SPE on the dose rates measured by LUMINA.
- During SAA passages, VIS and IR sensors give a relative close dose rate.
- Outside the SAA, the VIS appears more sensitive to dose rate variations.

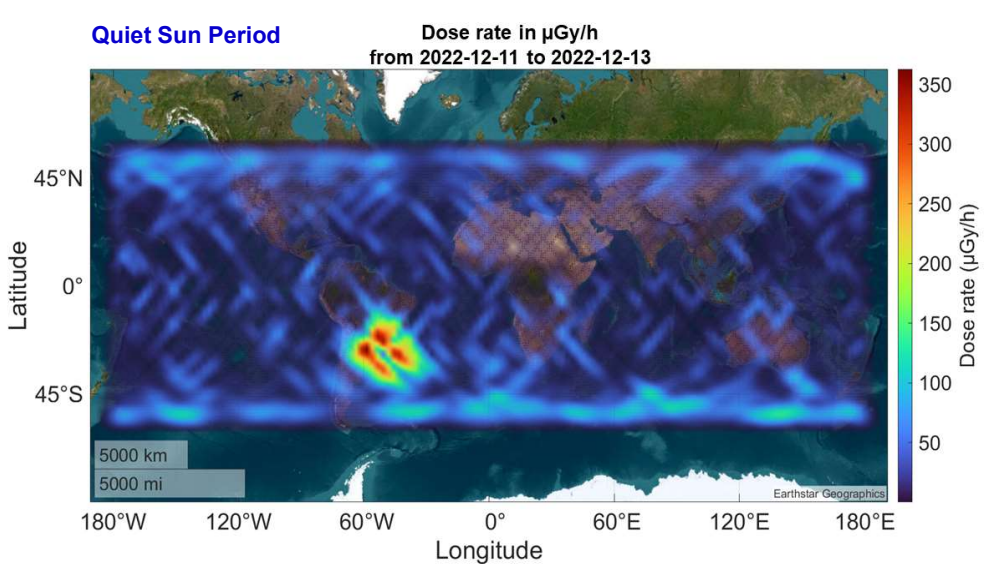


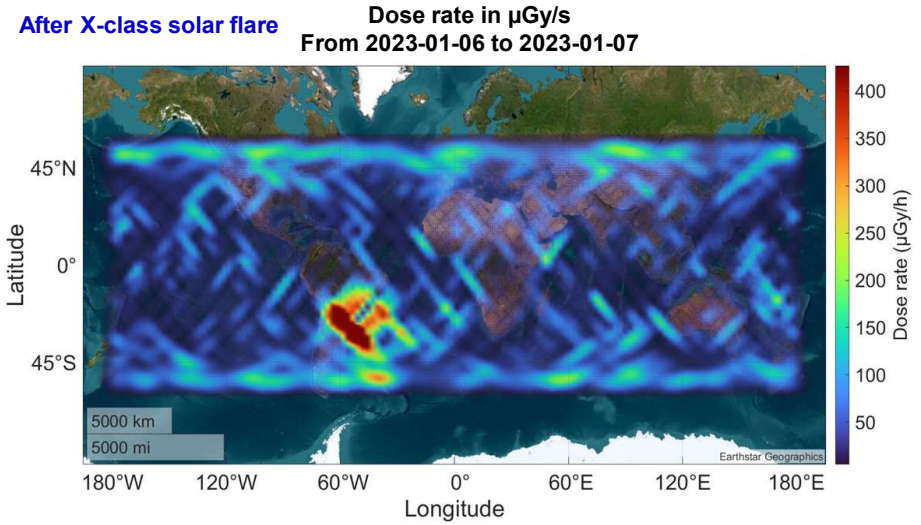
[1] : https://www.spaceweatherlive.com

Results – Combining the calculated dose rate peaks and ISS ephemeris for dose rate mapping creation.

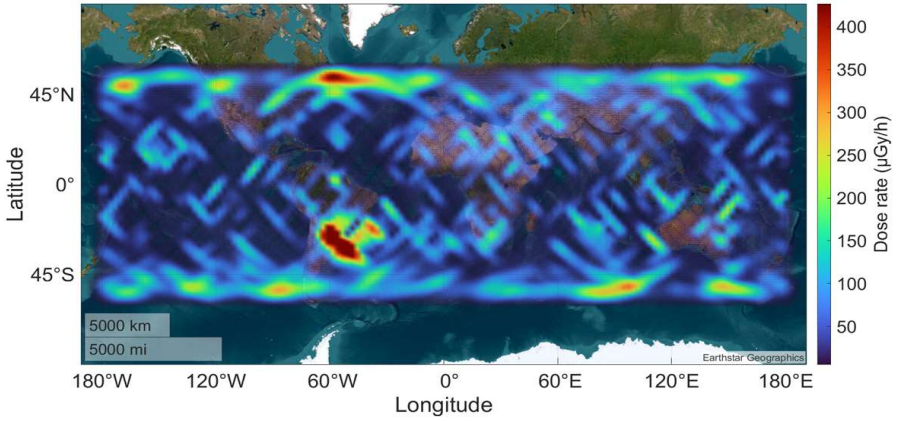


Results – Consequences of Solar Particle Event can be clearly identified in the “Pole areas”





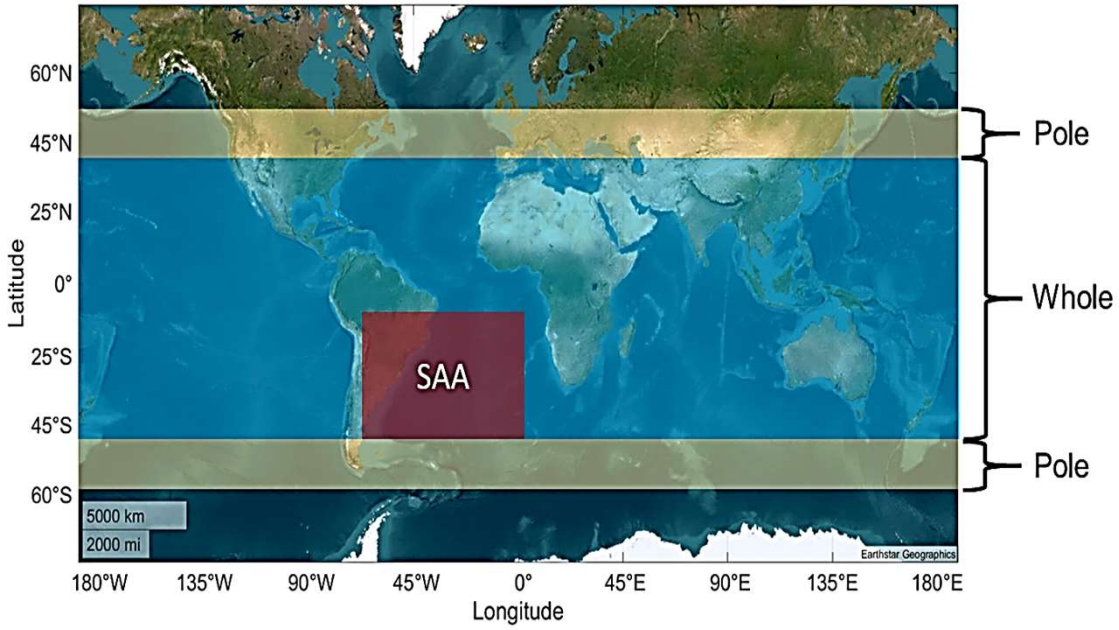
IR CHANNEL



VIS CHANNEL

Potential consequences of SPE on the dose rates measured by LUMINA : increase of dose rate in the region where Latitude > 45°S and Latitude < 45°S

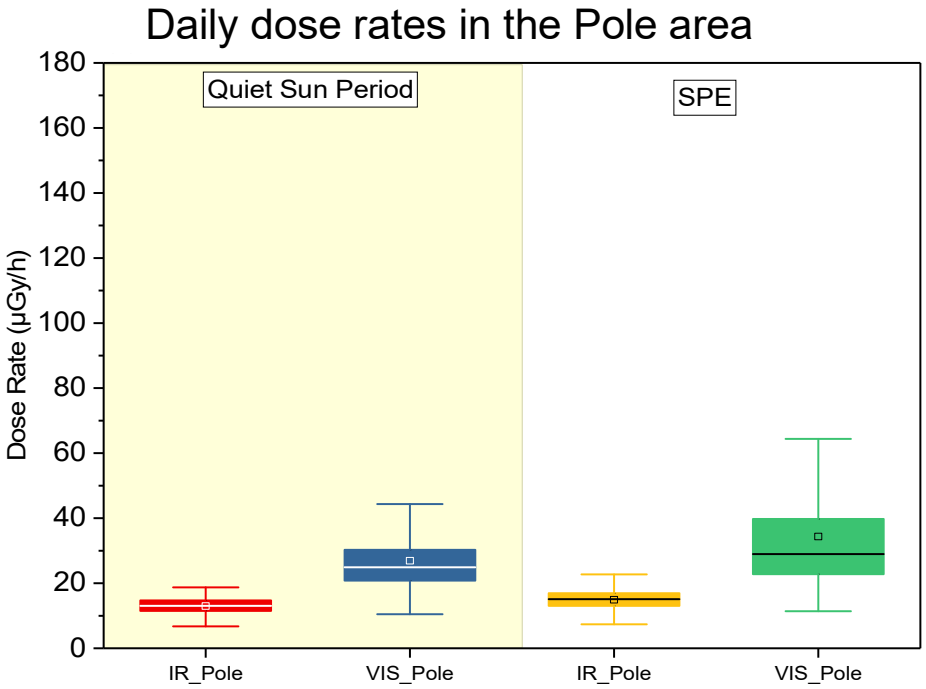
Methods for Solar Flares Consequence Detection

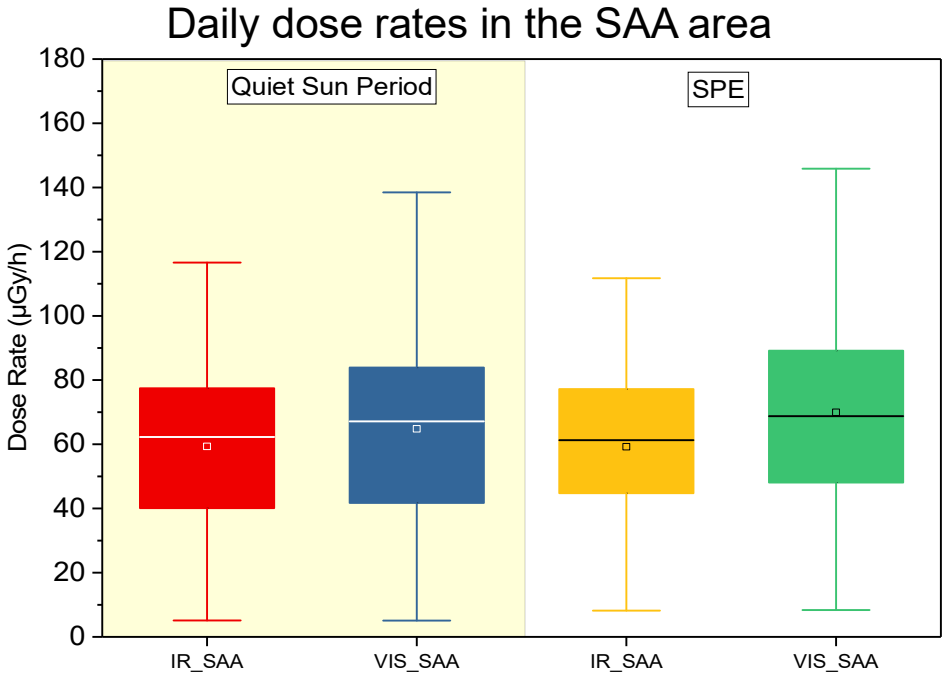


- Dose rate calculations over a period.
- Combining with latitude, longitude, altitude and time.
- Definition of three zones of interest :
  - The ‘’Pole’’
  - The Whole
  - The SAA
- Studying the evolution of dose rate in these regions during the mission. **Comparing dose rates** during High Solar activity and during Quiet Period.

First, concerning the ‘’ Whole ‘’ part, no significant change was noticeable.

Results & Statistics – The ”pole” region remains the place where the consequences of SPEs are the easiest to detect (699 analyzed days which 220 days with at least one Solar Flare)





- An increase of dose rate is not obvious for IR channel, but it is the case for the more radiation sensitive VIS channel (30 times more sensitive to the IR).
- The « pole » areas remain the place where the consequences of the SPEs are the easiest to detect.

Conclusions : Lumina was pushed to its detection limit capacities and provide some interesting results.

- ❑ Promising results in very challenging conditions: The ISS is well designed to protect its occupants from most of ionizing dangers.
  - Vis channel remains the best channel to detect SPE consequences into pole areas.
  - Impossible to distinguish the solar flare intensity classes (M, X-class).
- ❑ Particle dynamics in the poles and SAA remain complex, and a SF does not systematically increase the measured dose rate.
- ❑ The altitude of the ISS is constantly changing.
- ❑ Less shielded position (outside the module) for a larger RIA.
  - But new environmental constraints (temperature, void…)

Thank you for your attention!

Any questions?

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