Geophysics using the Hubble Space Telescope
or
Using the garbage of the HST

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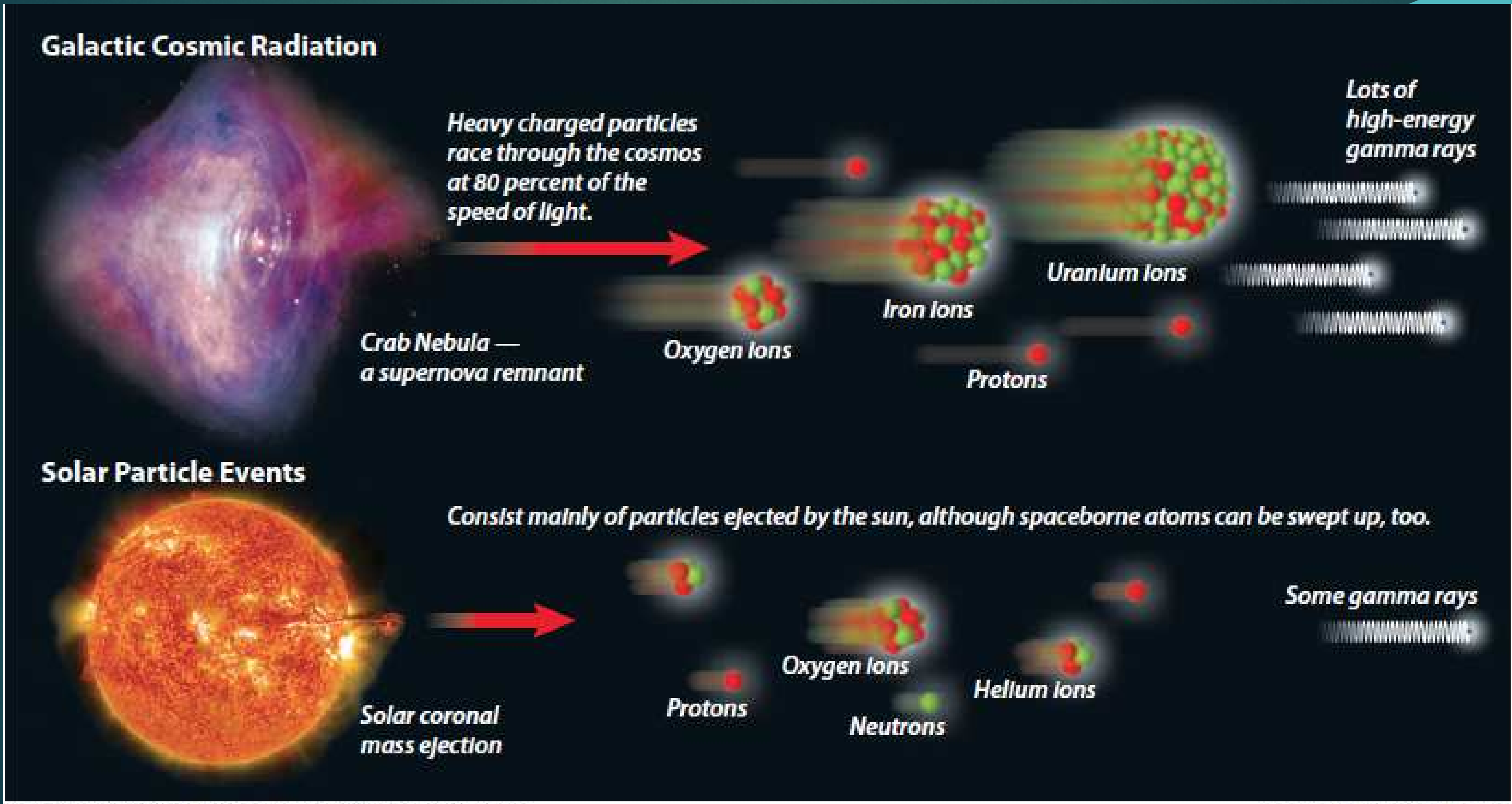
Cosmic rays = Galactic cosmic particles + Solar Energetic Particles

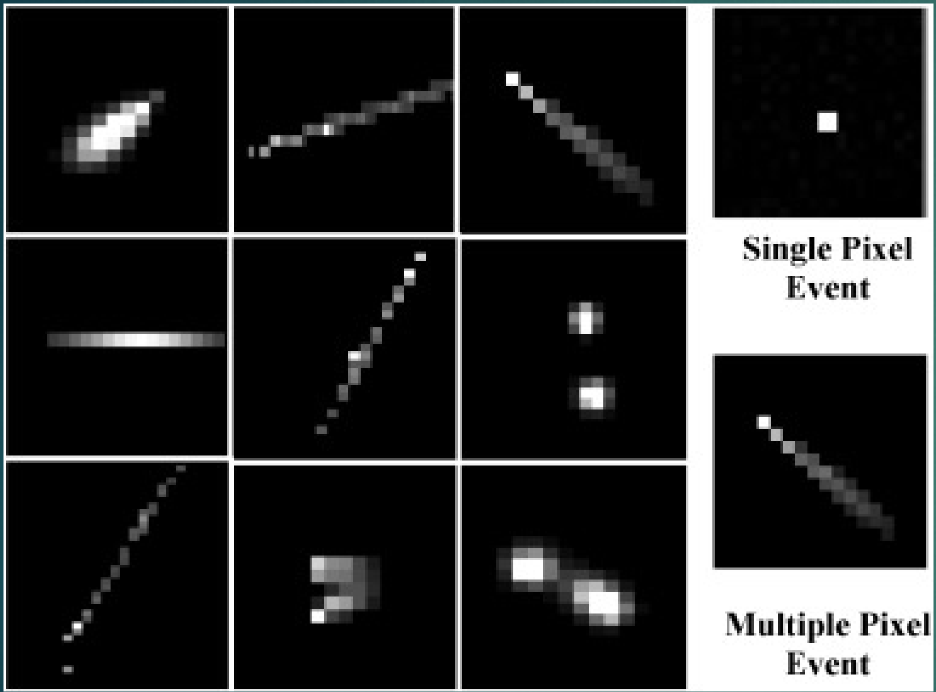


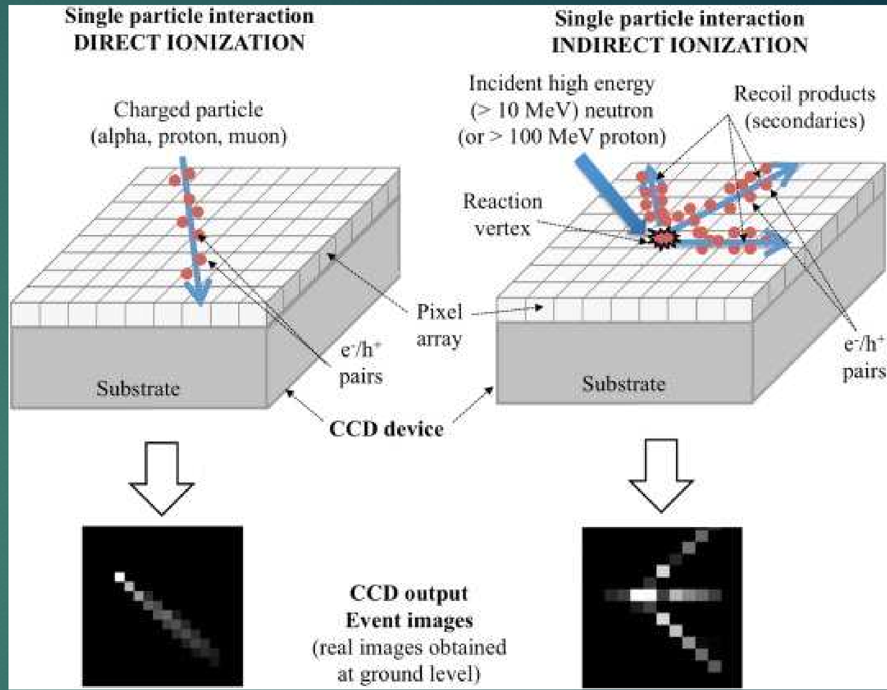
Sources: NASA SOHO solar observatory, NASA Hubble and Chandra images

Graphic by John Bretschneider

Cosmic rays in astronomical images

Taken from Saoud et al. (2016)





Direct ionization is achieved through Coulomb interactions between a charged particle and atoms of the device. The charged particle strips electrons of atoms as it passes through the device thereby causing ionizations. Heavy ions, low energy protons and muons directly ionize matter.

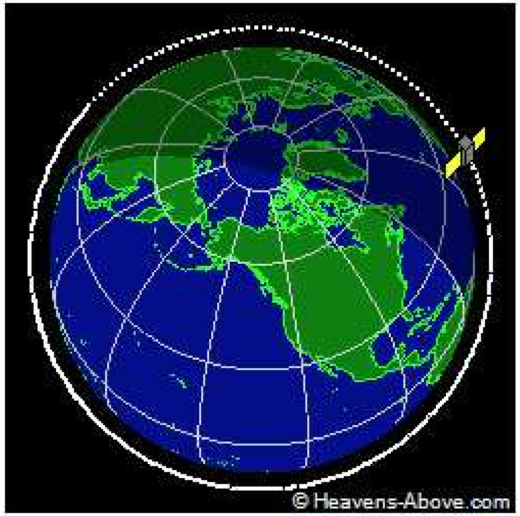
Indirect ionization is of concern for atmospheric neutrons and high-energy protons (>100 MeV) that are able to ionize by collision with the target nuclei. Neutrons ionize indirectly, they do not interact via the Coulomb force, and so they can travel through several centimeters of material without interacting with other particles and can remain undetected with CCD.

Cosmic rays in HST images

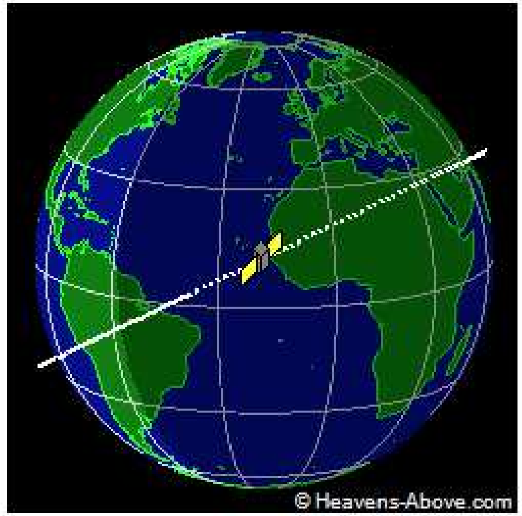
HST orbit

Regime	Low Earth
Semi-major axis	6,919 km
Eccentricity	0.000283
Perigee	539 km
Apogee	543 km
Inclination	28.47°
Period	95.47 minutes
Mean motion	15.08 rev/day
Velocity	7.59 km/s

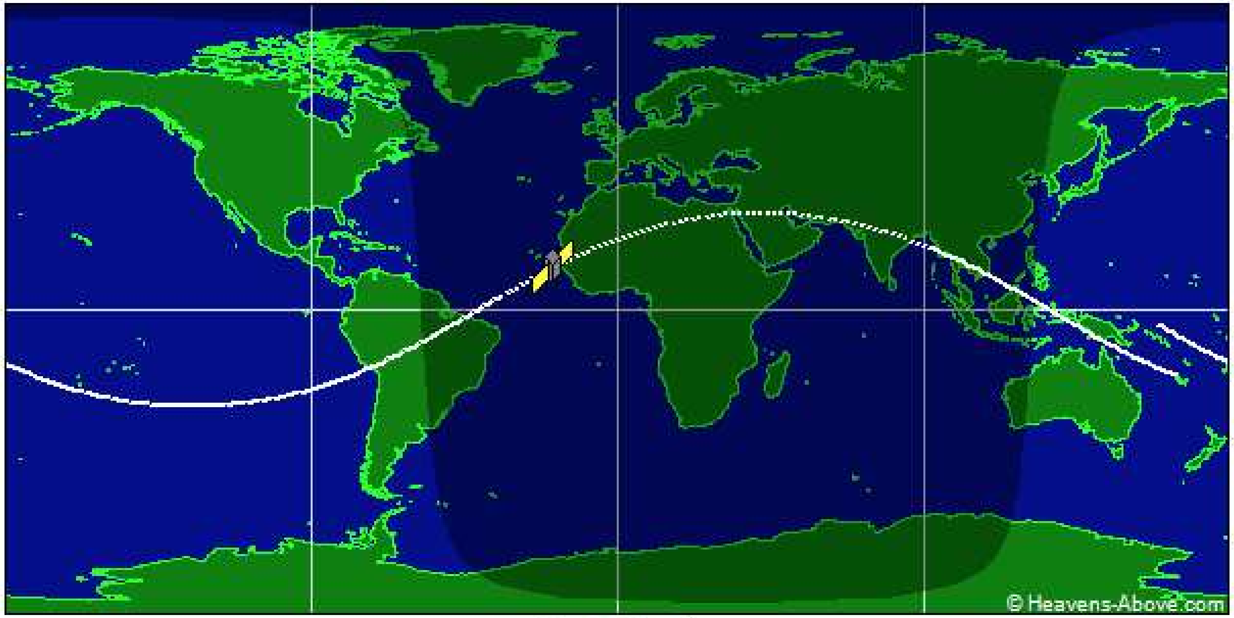
A unique CR detector at 500km above the surface in operation for 25yr (2 solar cycles).



View from above orbital plane

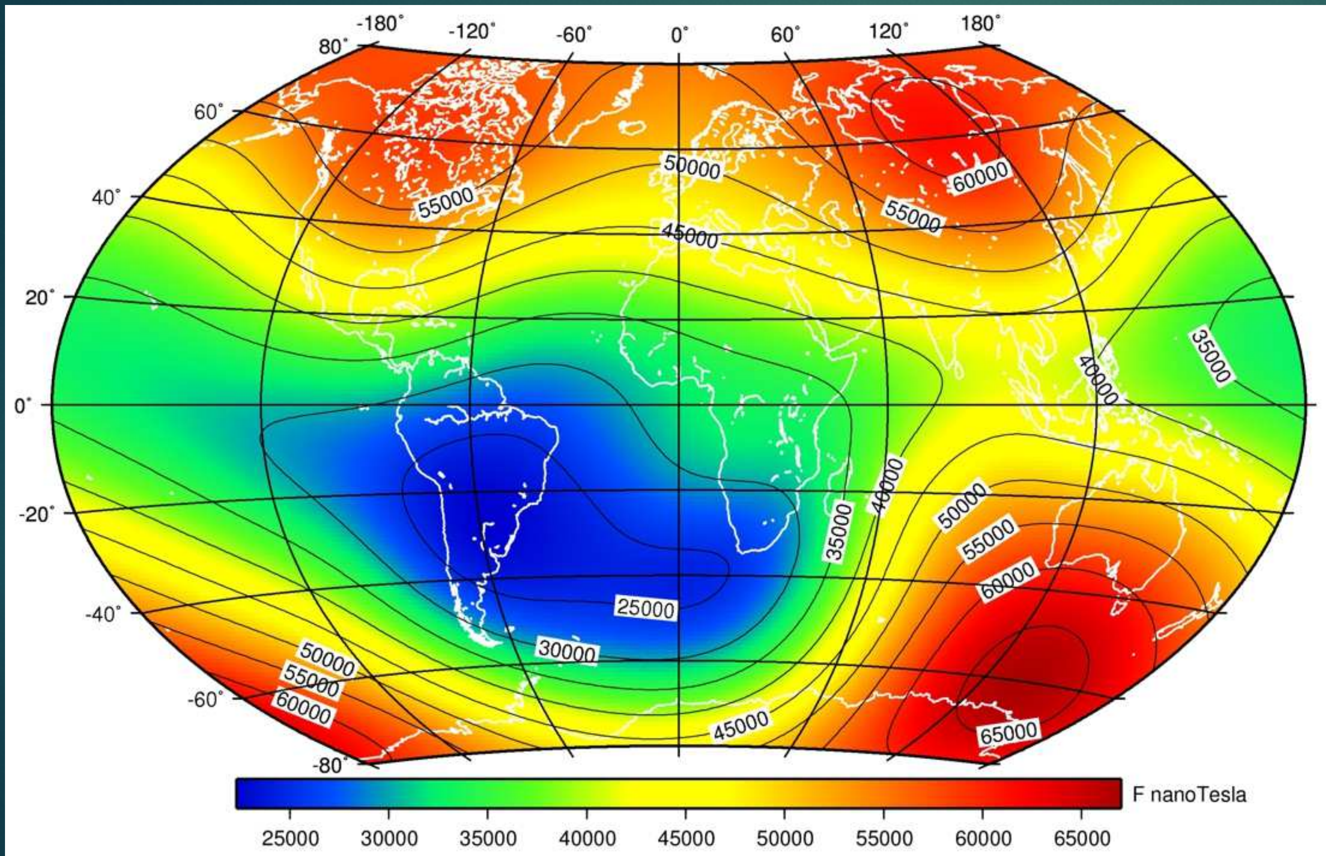


View from above satellite

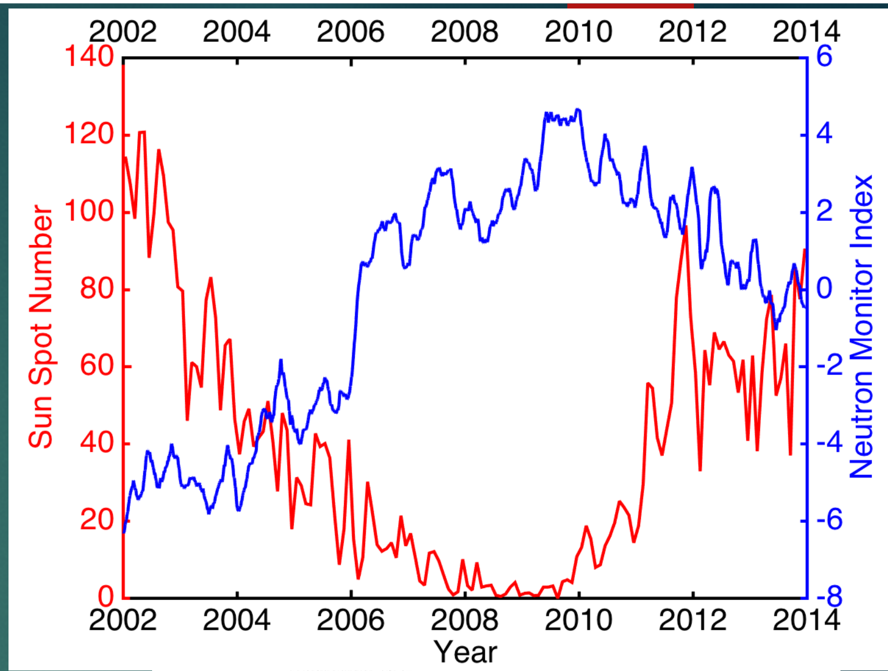


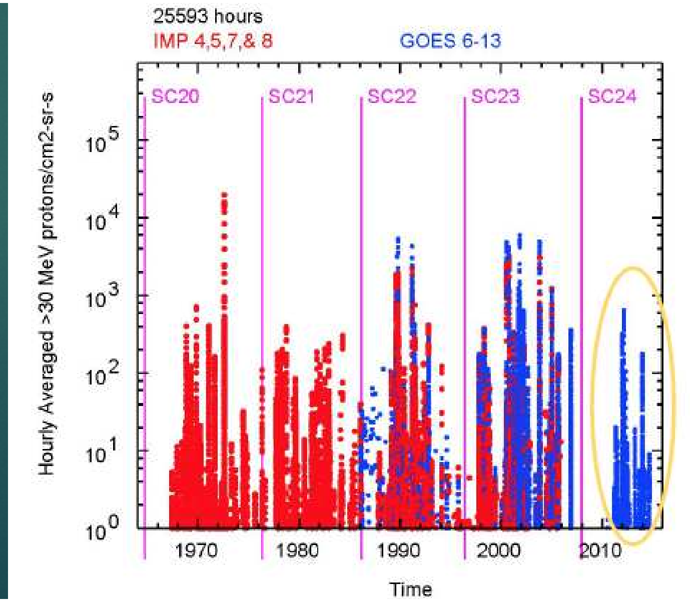
Ground track

A variable environment in space and time



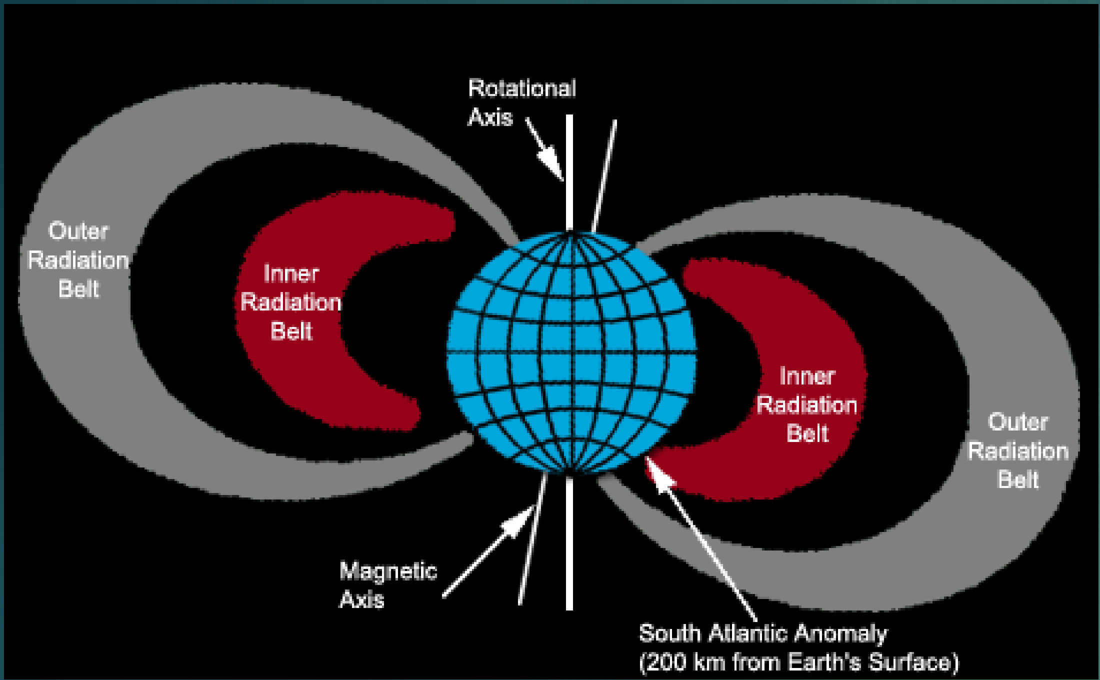
World Magnetic Model (WMM)
by British Geological Survey (2015)

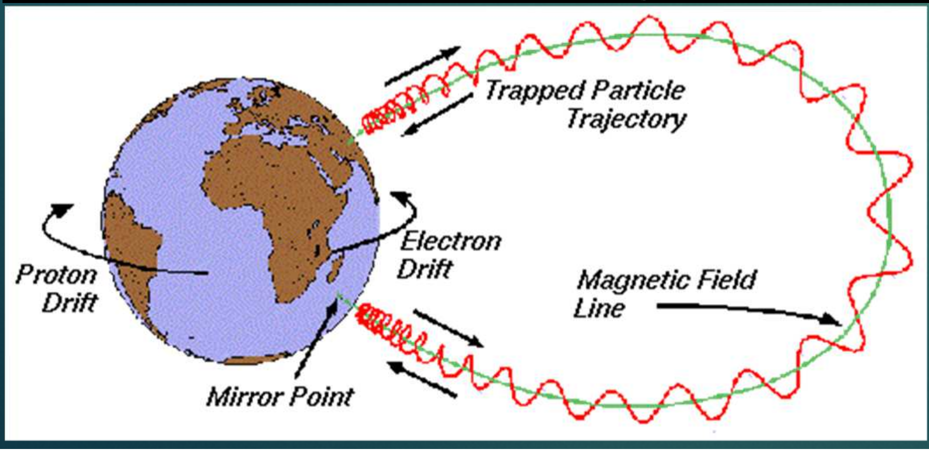




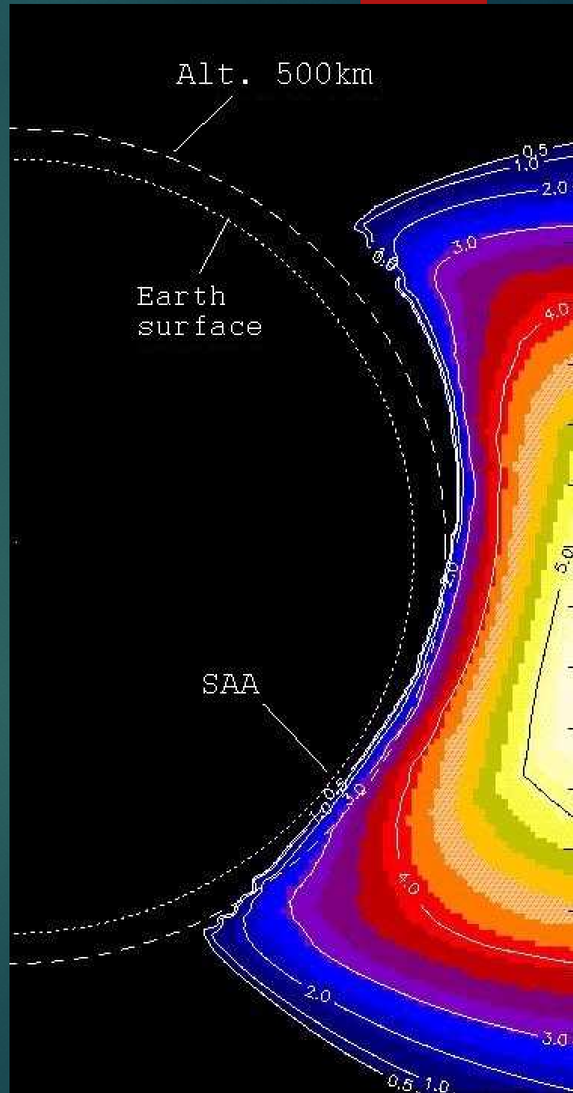
SEP events detected by GOES (Tylka, 2015)

Van Allen radiation belts & SAMA

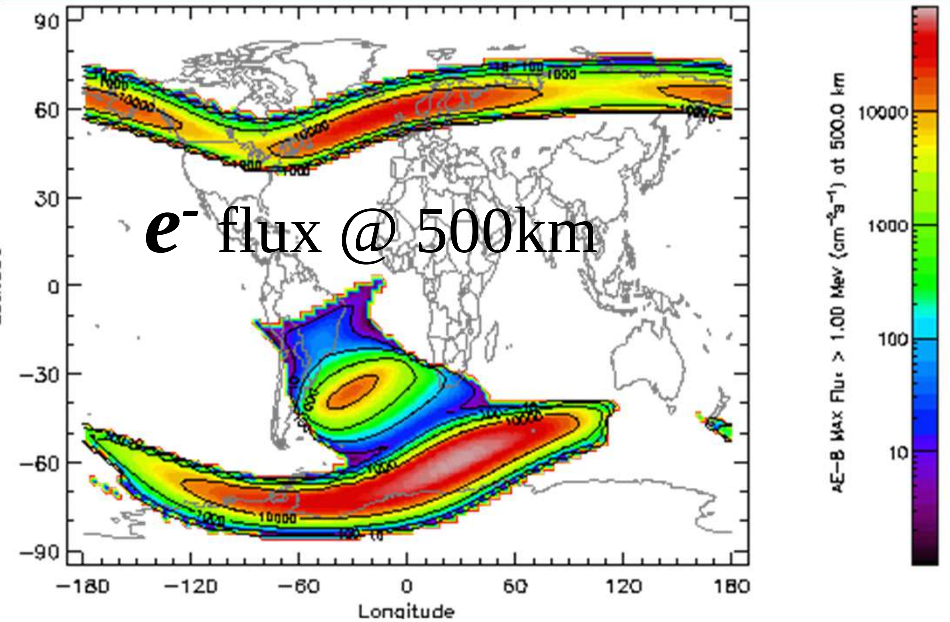


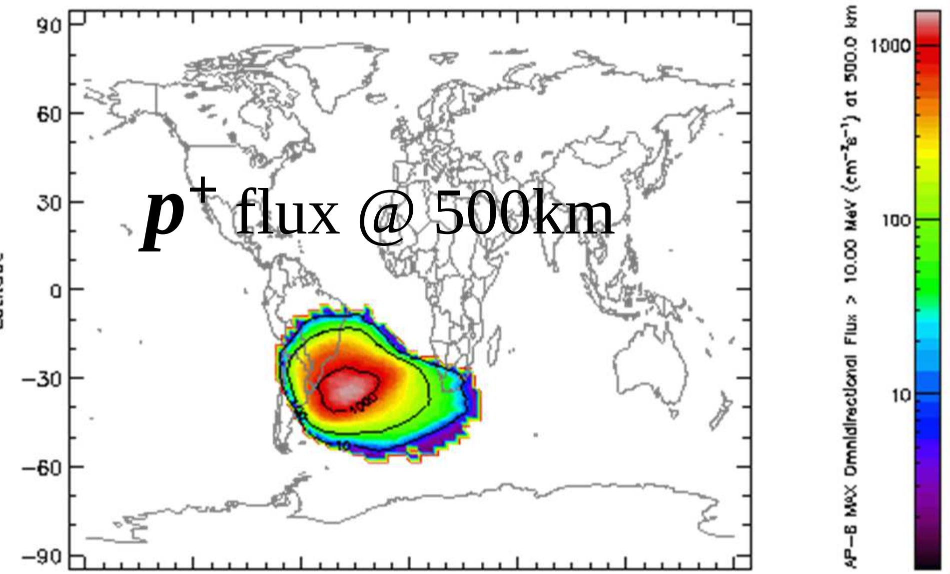


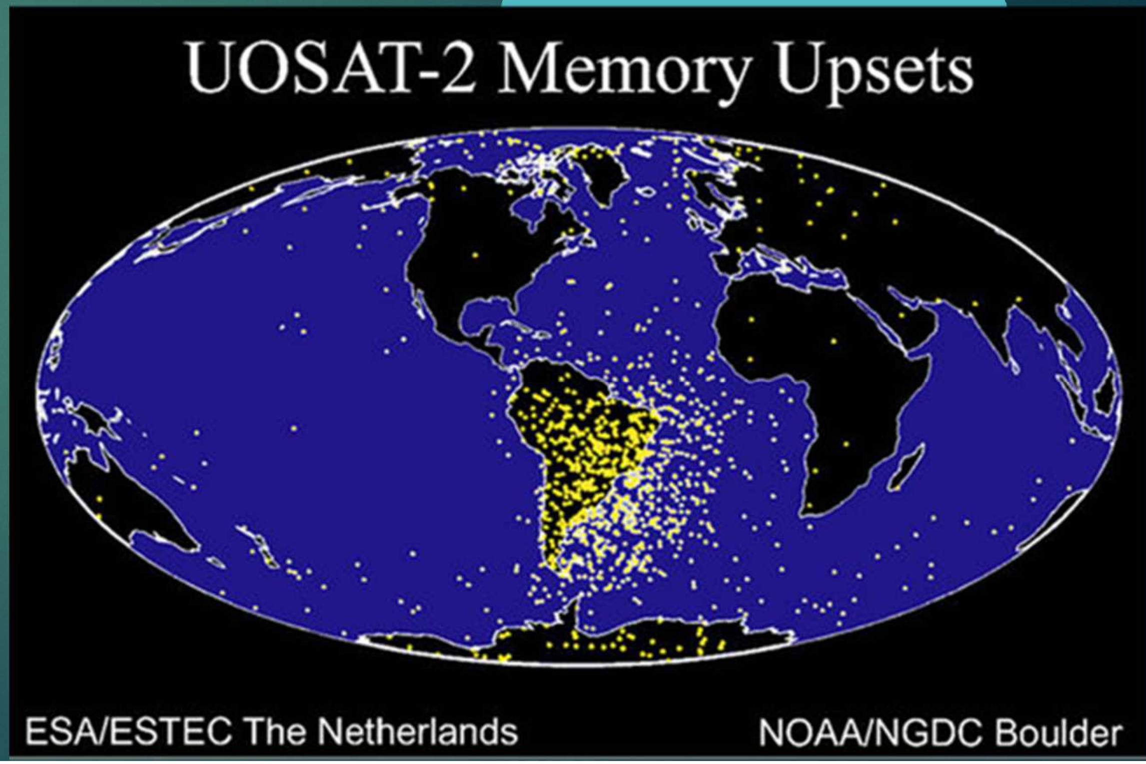
The proton raddiation belt comes to a distance of 500 km above the surface in the SAMA region; just the orbital distance of HST.



Consequences of Energetic particles at 500km





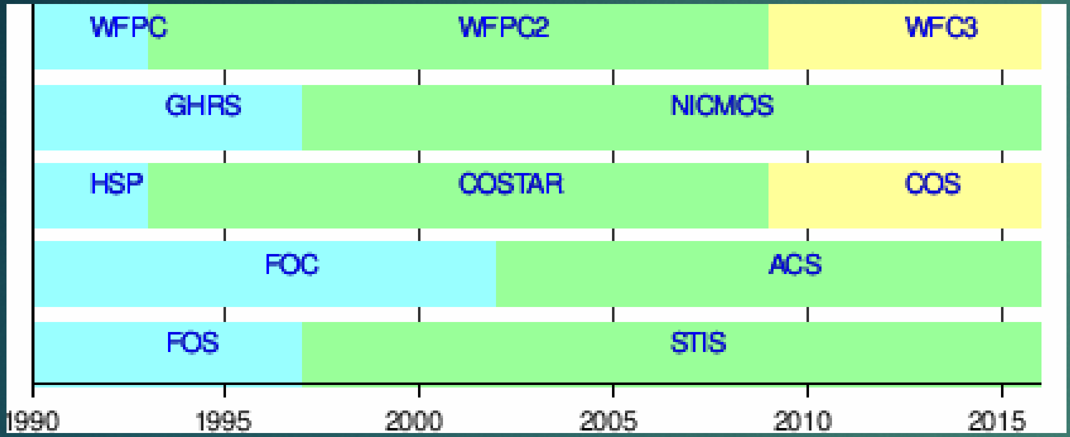


Project: Geophysics using Hubble Space Telescope

- We propose to use the entire data set of DARK images taken by the HST during its >25 yr of operations to monitor the "Cosmic Rays" (CR) flux as a function of:
  - Time
  - Location of the spacecraft
- The proposal was approved by the STScI for the Hubble Space Telescope Cycle 24 Archival run (06/2016).
- We got ~130.000 dark frames from 5 different instruments (7 detectors).
  - ~ 15 TB of data
  - ~15000 hr of observation during ~ 22yr

Instruments

Years of operation for each instrument



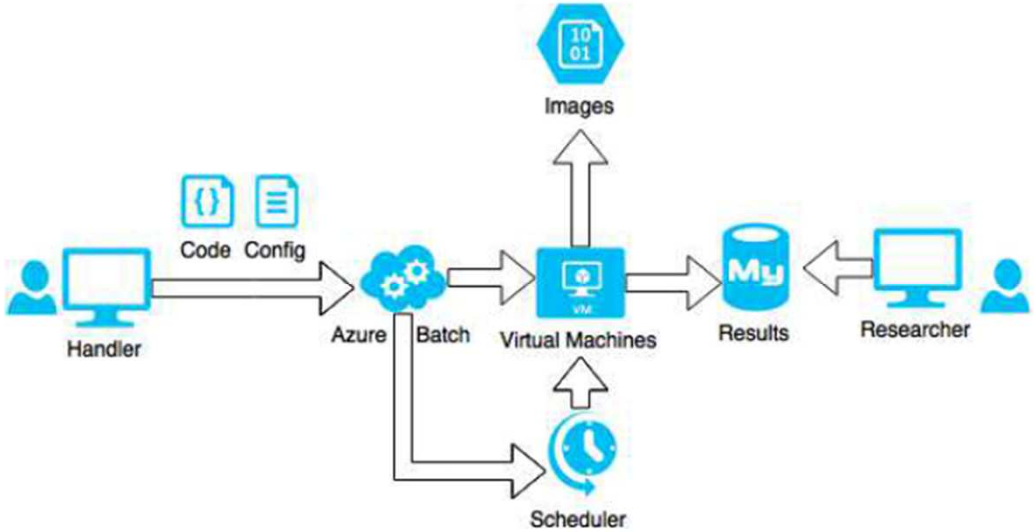
Instrument	Detector	Number	Type	# pixels x	# pixels y	size pixel μm)	size pixel μm)	Area (mm^2)
WFPC2		4	CCD	800	800	15	15	144
STIS		1	CCD	1024	1024	21	21	462
NICMOS		3	HgCdTe	256	256	40	40	105
ACS	HRC	1	CCD	1024	1024	21	21	462
ACS	WFC	2	CCD	4096	2048	15	15	1887
WFC3	UV	2	CCD	4096	2051	15	15	1890
WFC3	IR	1	HgCdTe	1014	1014	18	18	333

Dark images

A **dark frame** is an image captured with the sensor in the dark, with the shutter on and for a long exposure time. A significant amount of charge can accumulate in the CCD pixels due to thermal excitation. Astronomers overcome the problem of dark charge by cooling the CCDs. Nevertheless, there are pixels (or group of pixels) with values with large dispersion compared to the rest: hot and cold pixels. All cold pixels and some hot ones are caused by physical defects. They do not change in position with time (almost). Pixels with high values that change from frame to frame are cosmic rays impacts.

Processing pipeline

Image processing is performed on virtual machines from the Microsoft Azure cloud platform using a developed Python application.



For the CR detection, we use a python version of L.A. Cosmic algorithm (van Dokkum, 2001; cosmic.py - Tewes, 2010).

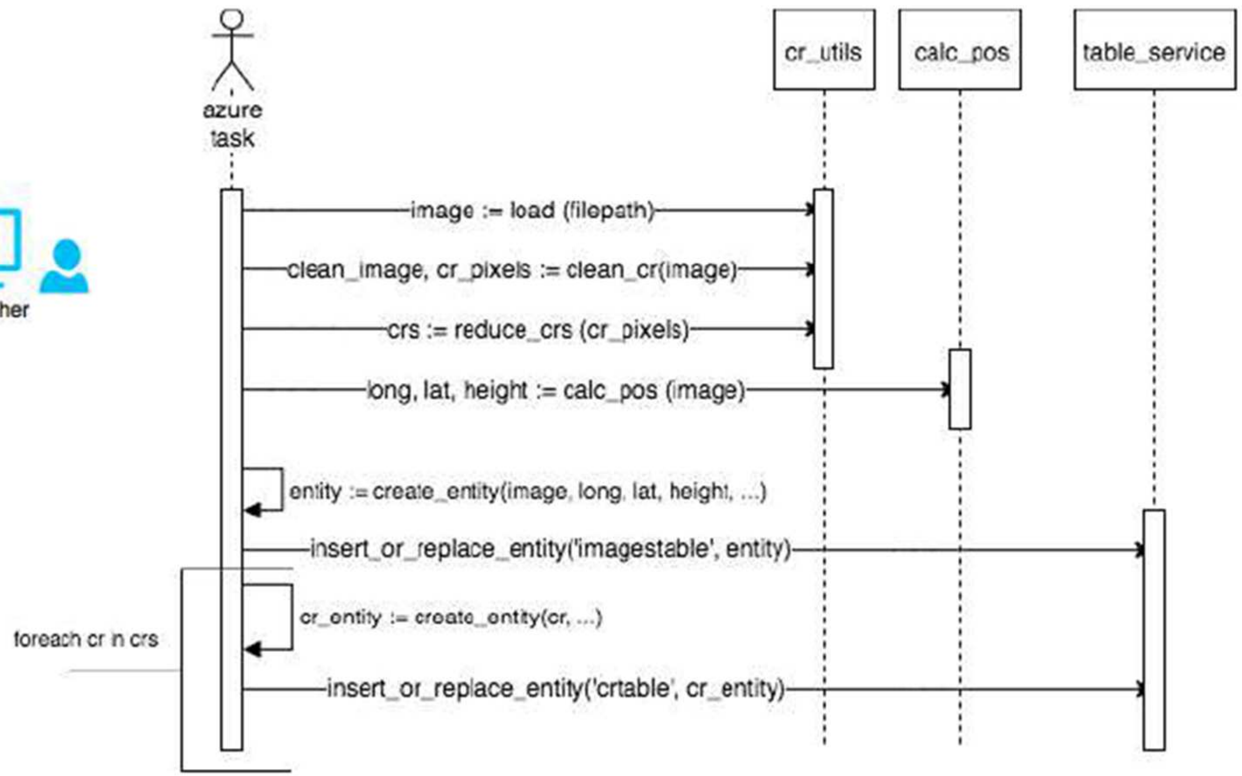
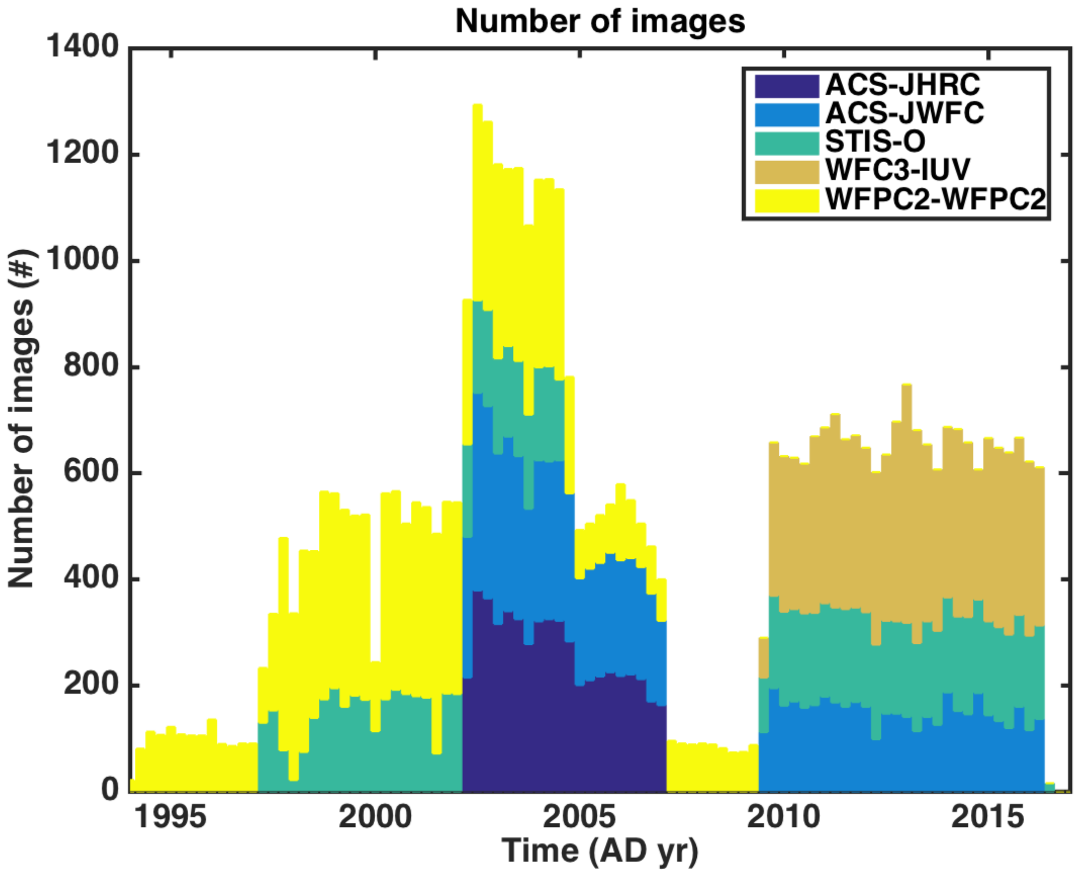
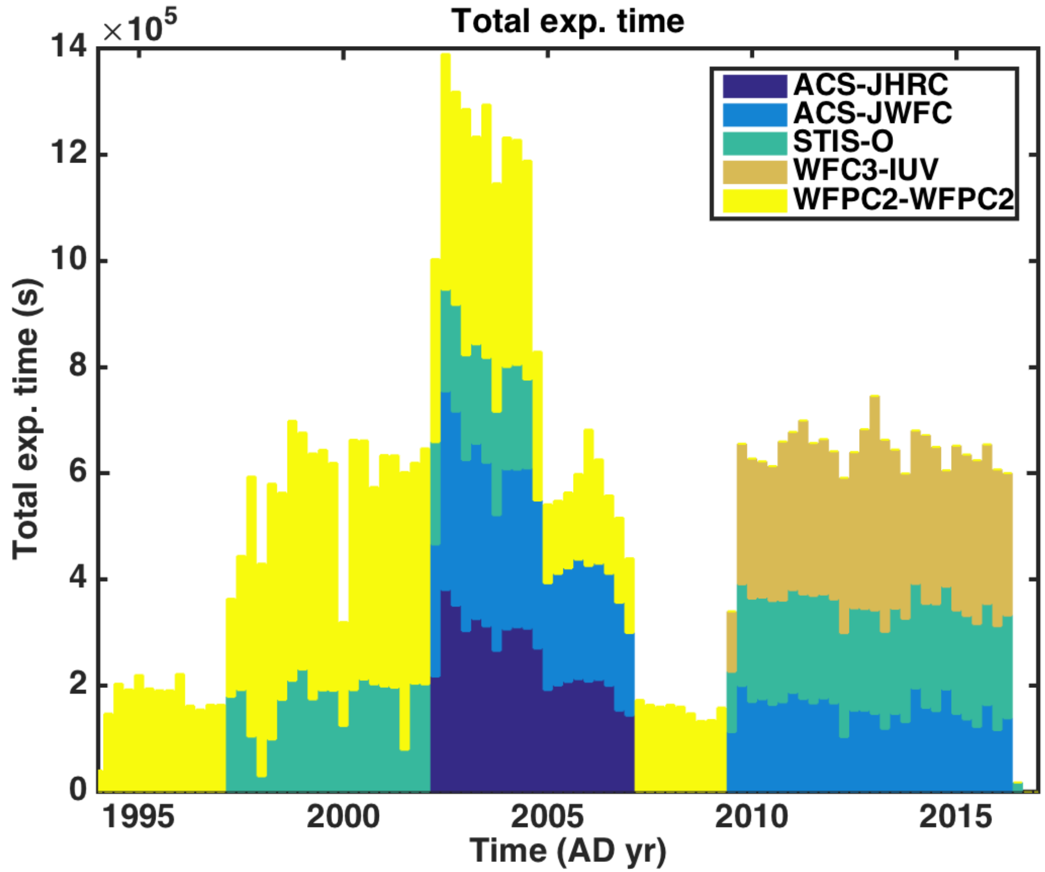


Fig. 3. Sequence diagram for the application executed on Azure

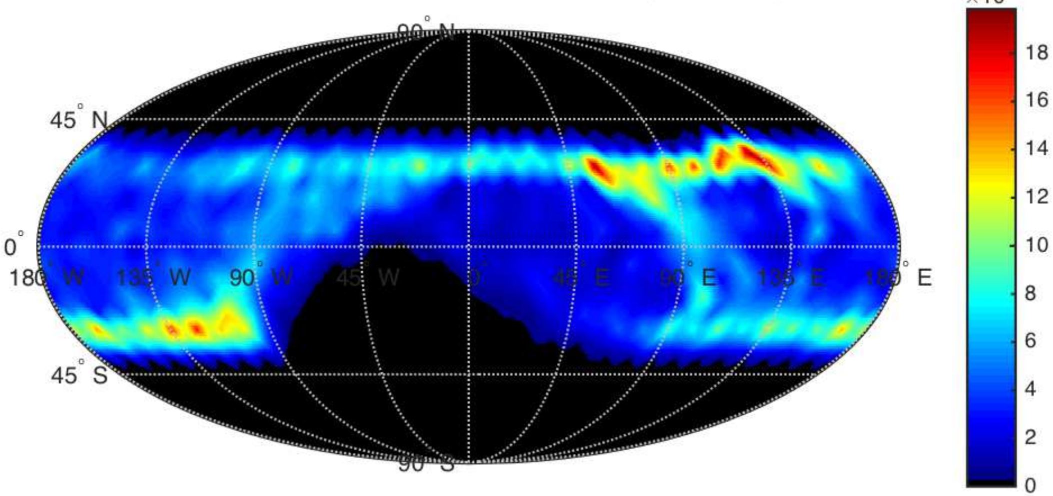
Time coverage of CCD instruments



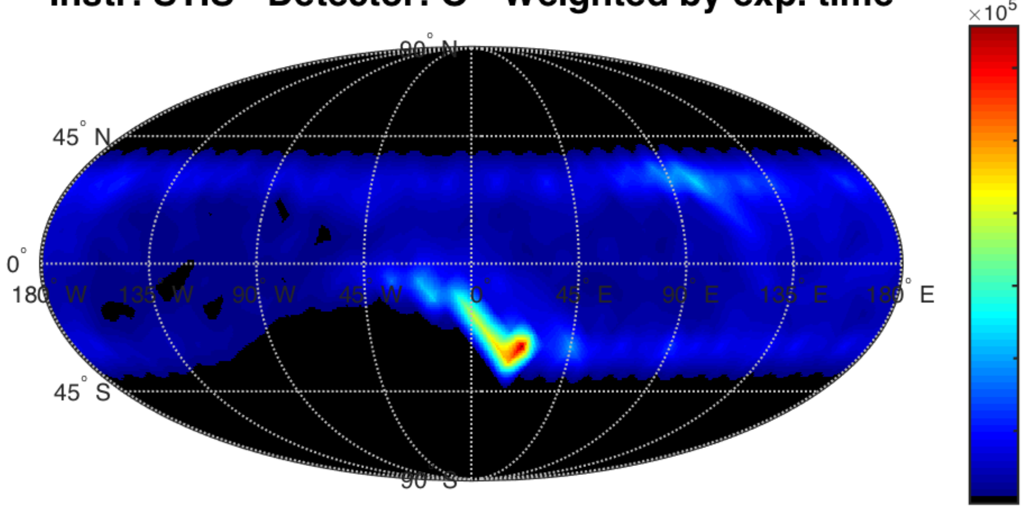


Geographic coverage

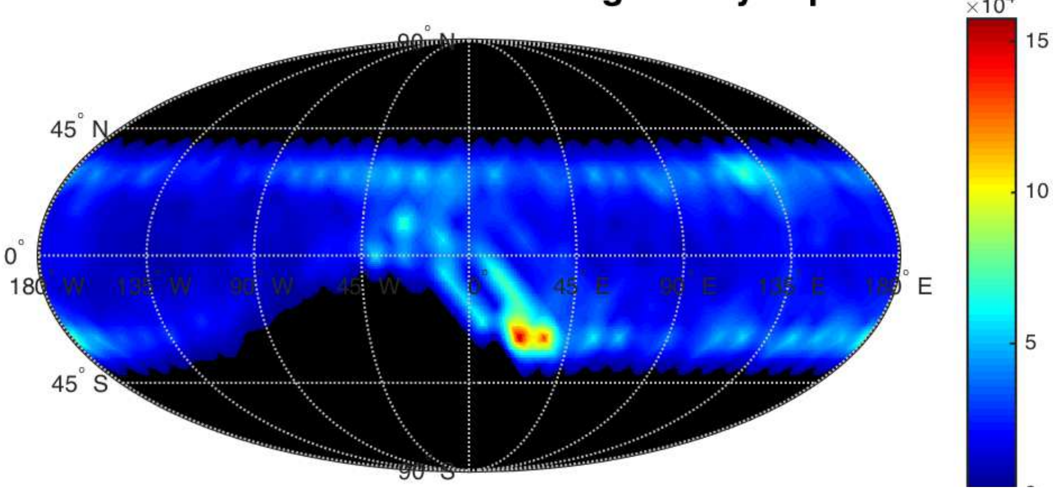
Instr: WFPC2 - Detector: WFPC2 - Weighted by exp. time



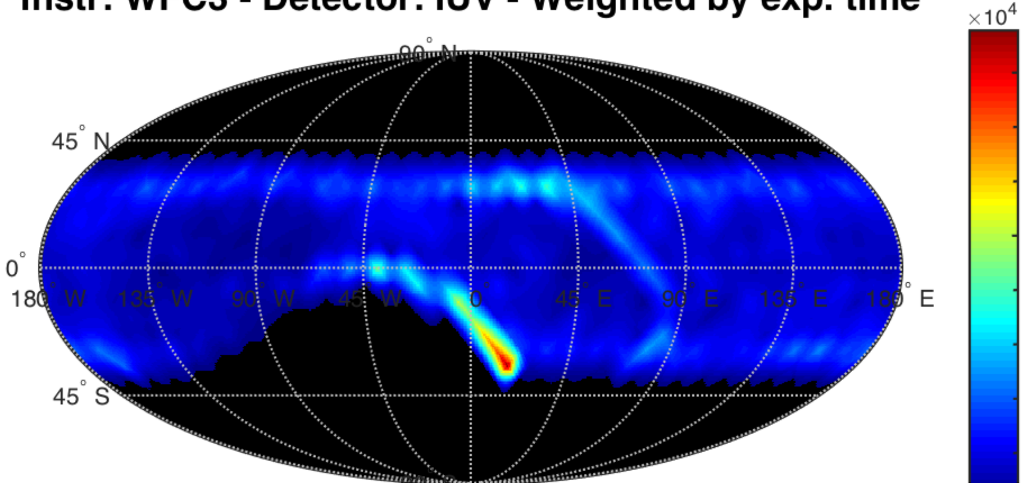
Instr: STIS - Detector: O - Weighted by exp. time



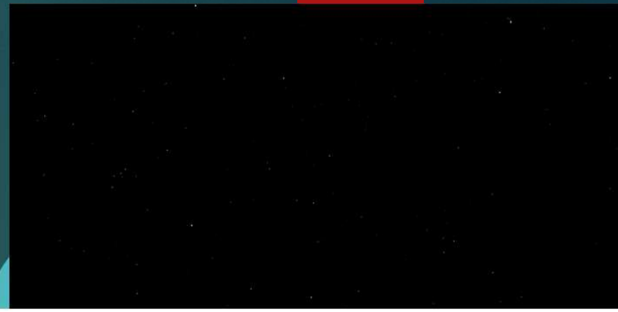
Instr: ACS - Detector: JWFC - Weighted by exp. time

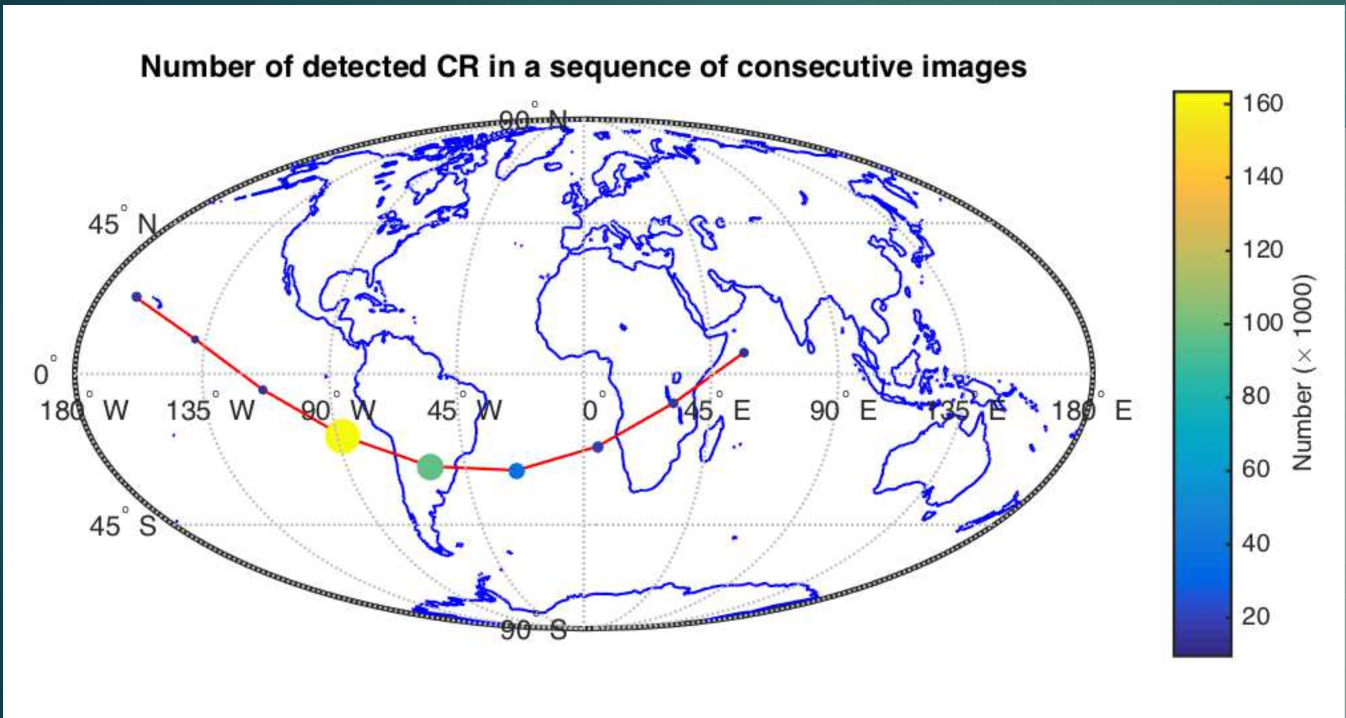


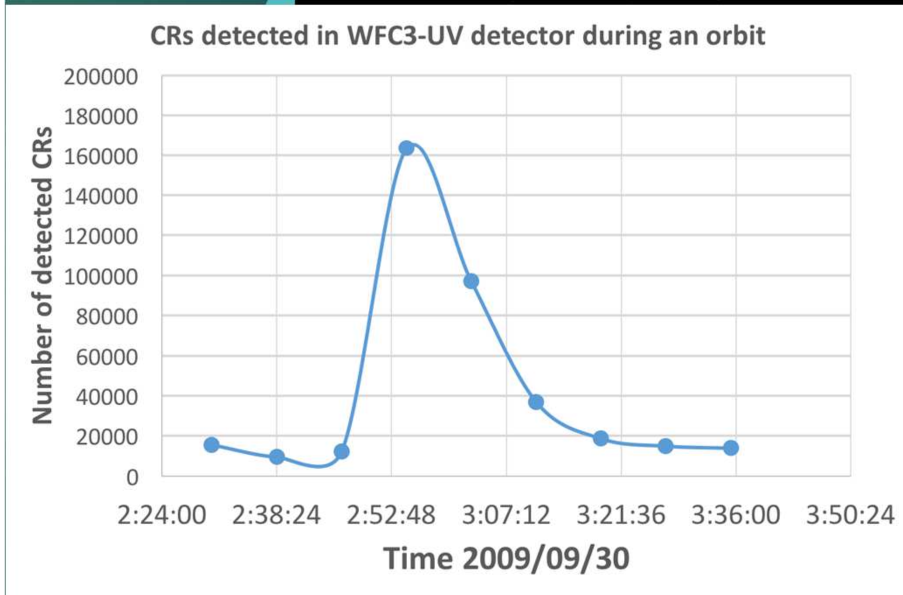
Instr: WFC3 - Detector: IUV - Weighted by exp. time



A sharp increase in the #CRs while crossing the SAMA

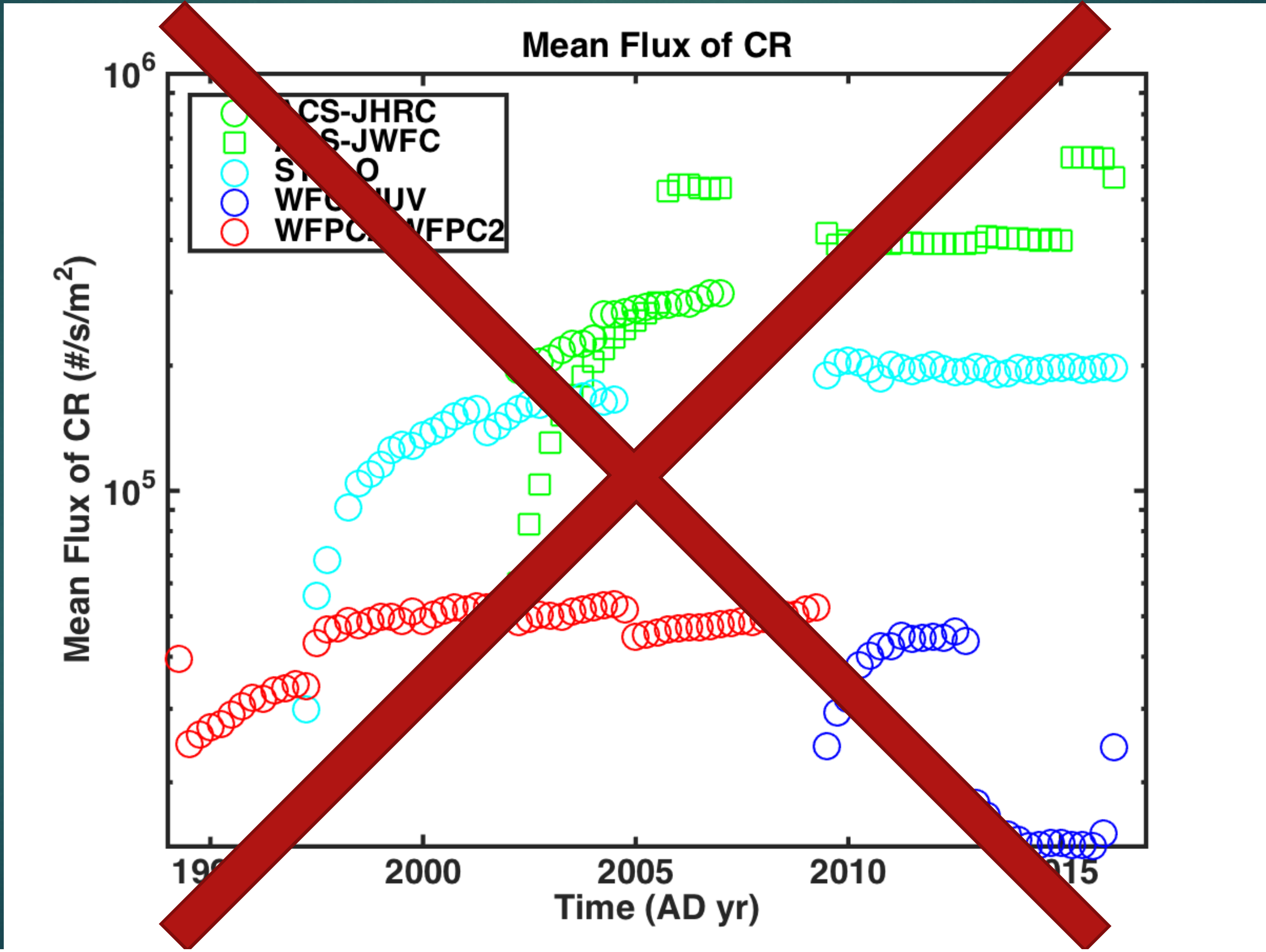






The dots mark the HST position at the start of the 360s exposure. The color and size of the dots are proportional to the number of detected CRs.

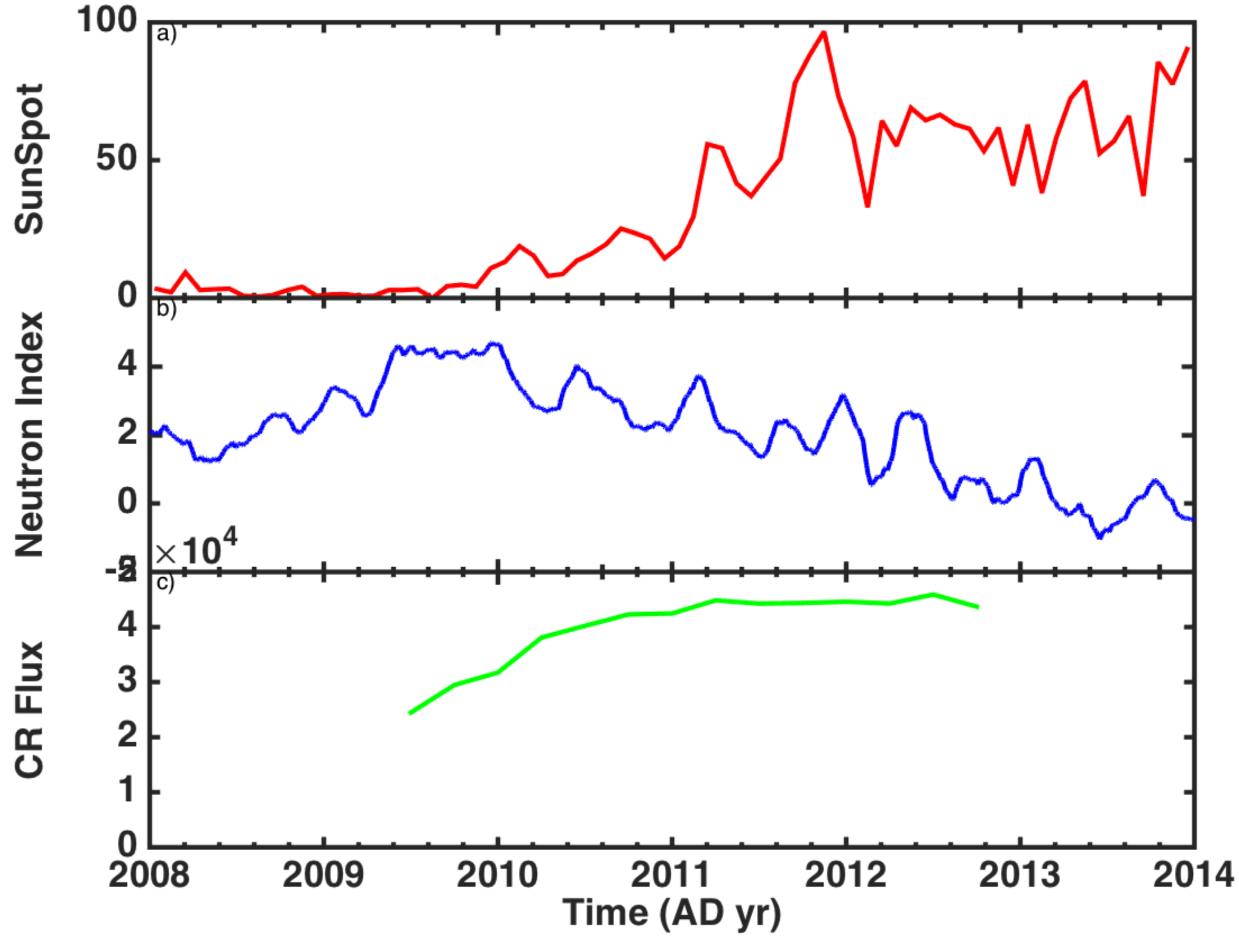
Time evolution of the CR flux



A possible correlation

Neutron Monitor Index @ surface

CR flux from images of WFC3 - UV



Preliminary conclusions

- We have access to ~130.000 dark frames from 5 different instruments, corresponding to 15000 hr of observation along ~ 22yr
- Large increment of the CR flux for a factor > 10 was detected during passages in the SAMA region.
- **VERY PRELIMINARY:** The CR flux @ 500 km correlates with solar activity, but has opposite correlation with the CR flux on the surface, measured by the neutron stations.

Future works

- Compare CR detection algorithms
- Include IR detectors in the analysis
- Include new instruments (WFPC1, FOC, FOS, …)
- Correlate fluxes with:
  - Solar activity
  - CR detector on the surface (e.g. muon detectors)
- Extend the analysis to the complete HST data sets: 100k hr and over 1M images.

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