Time Variability of Cosmic Rays Flux

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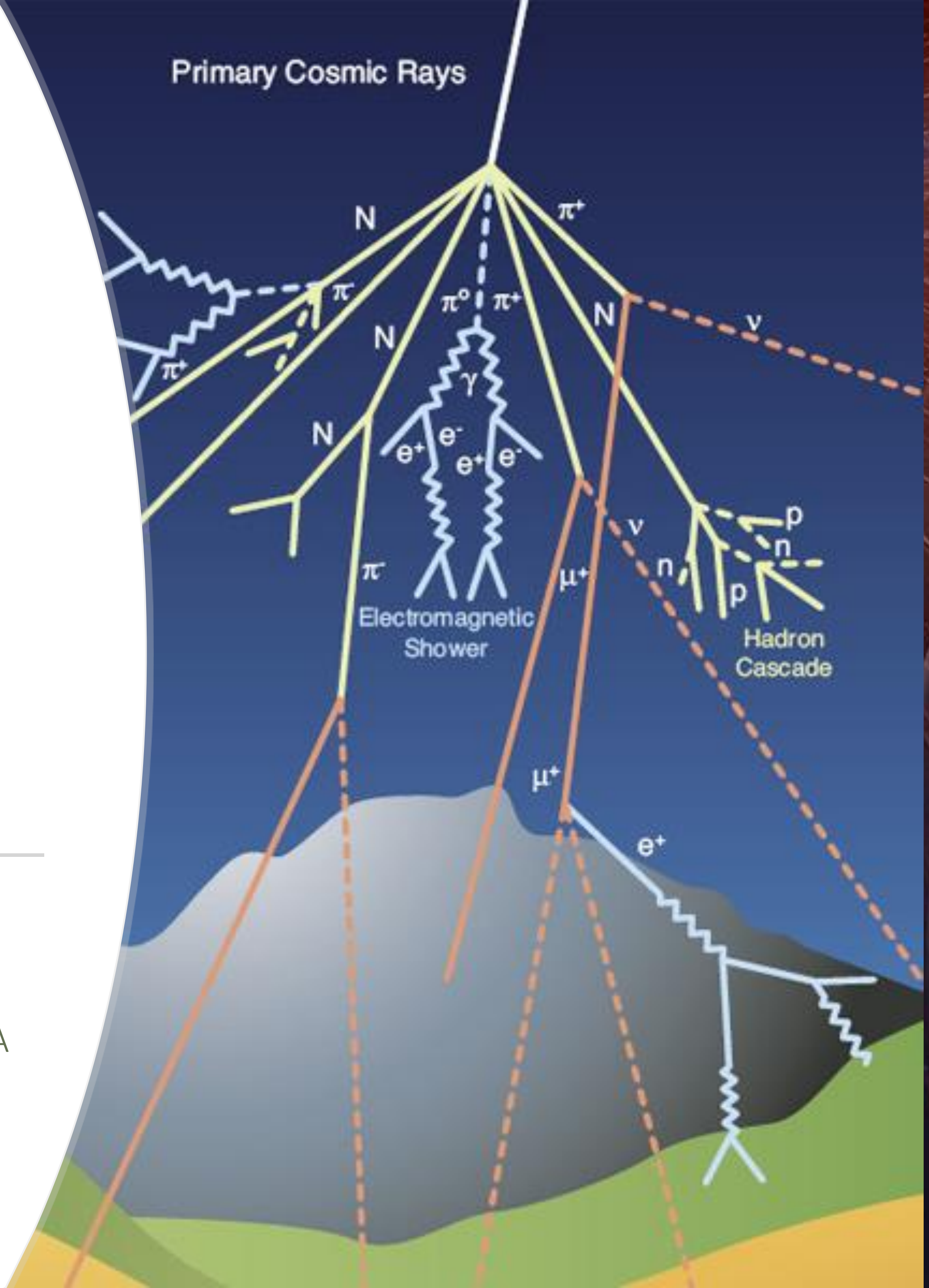
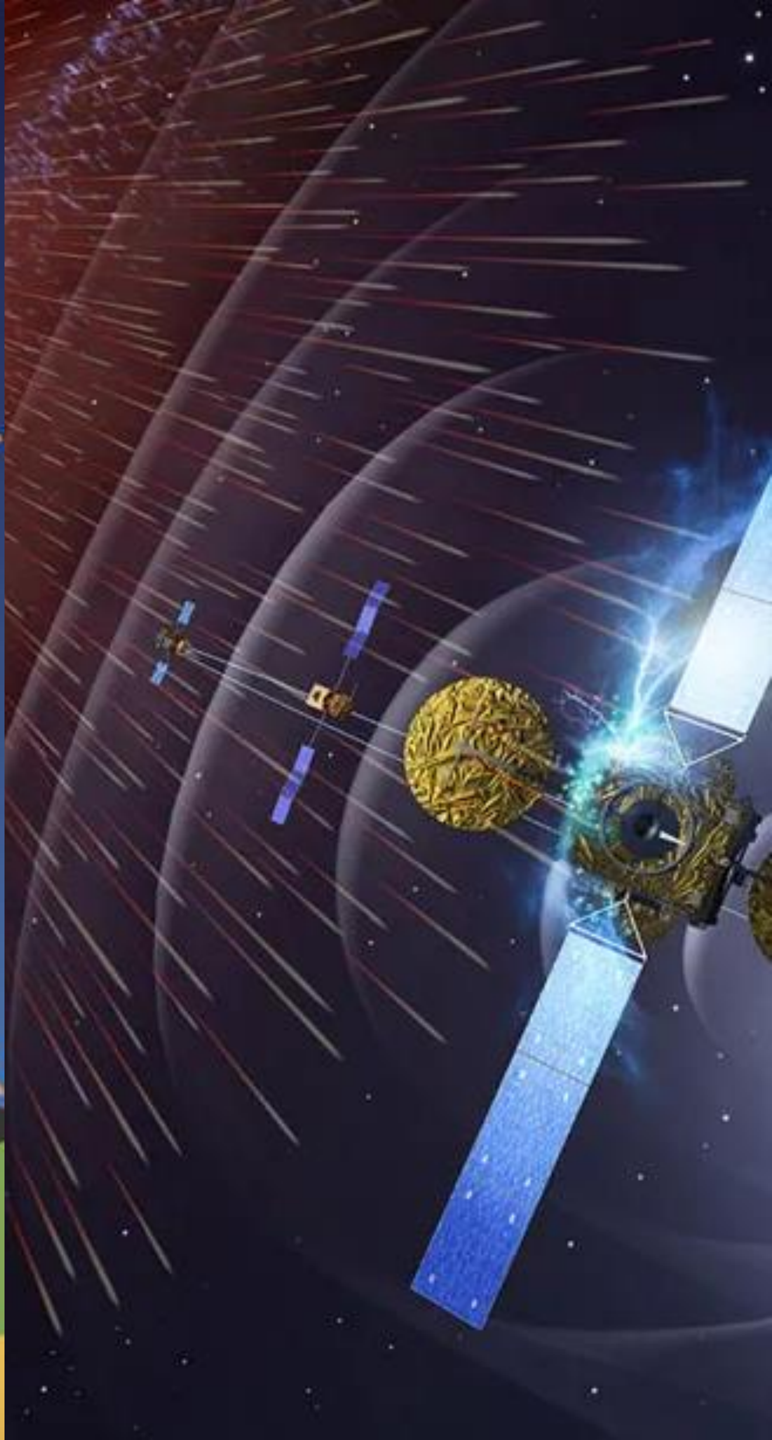
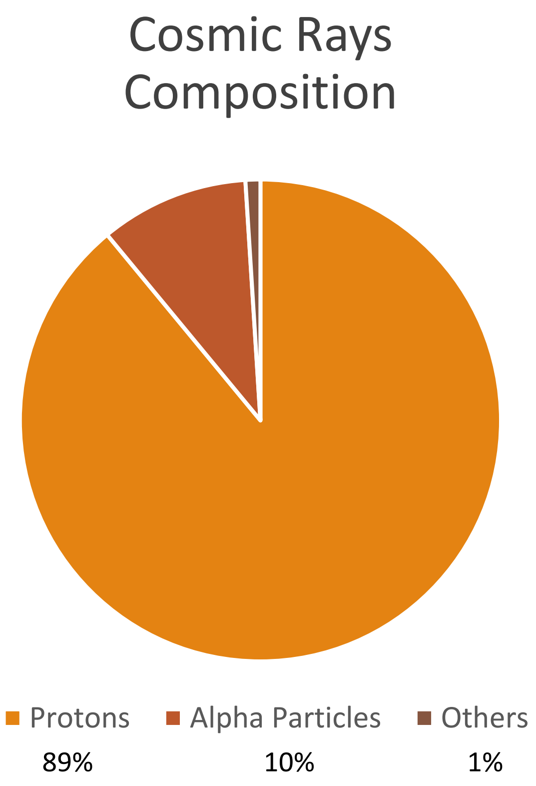




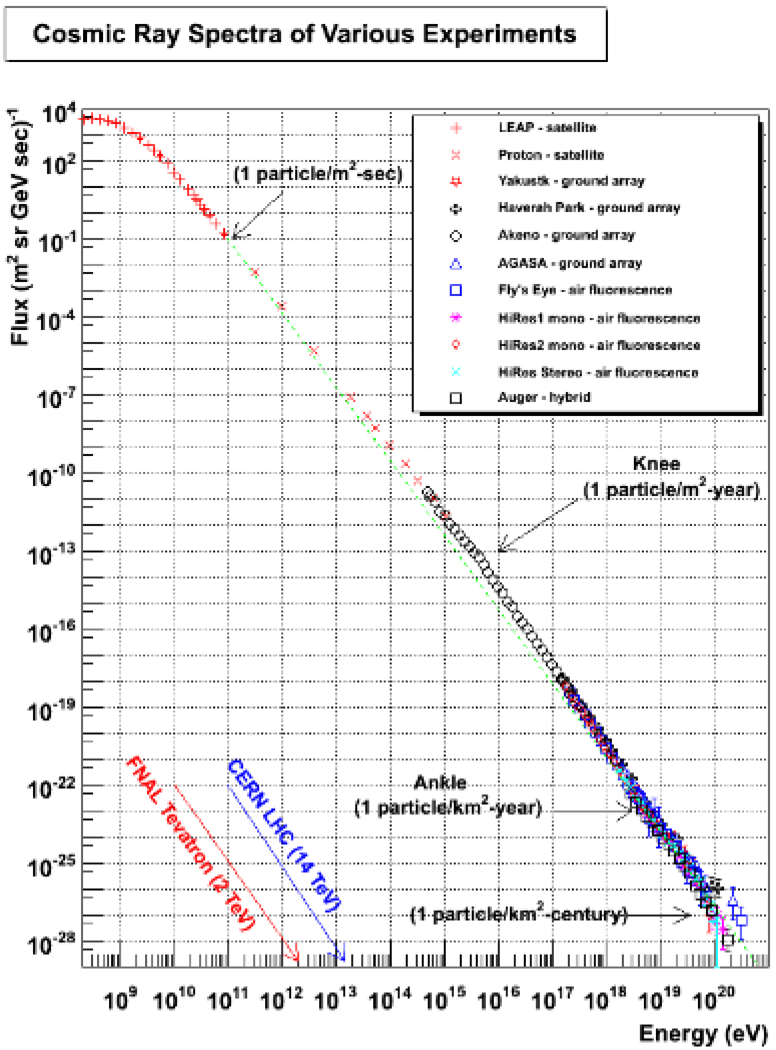
What are Cosmic Rays?

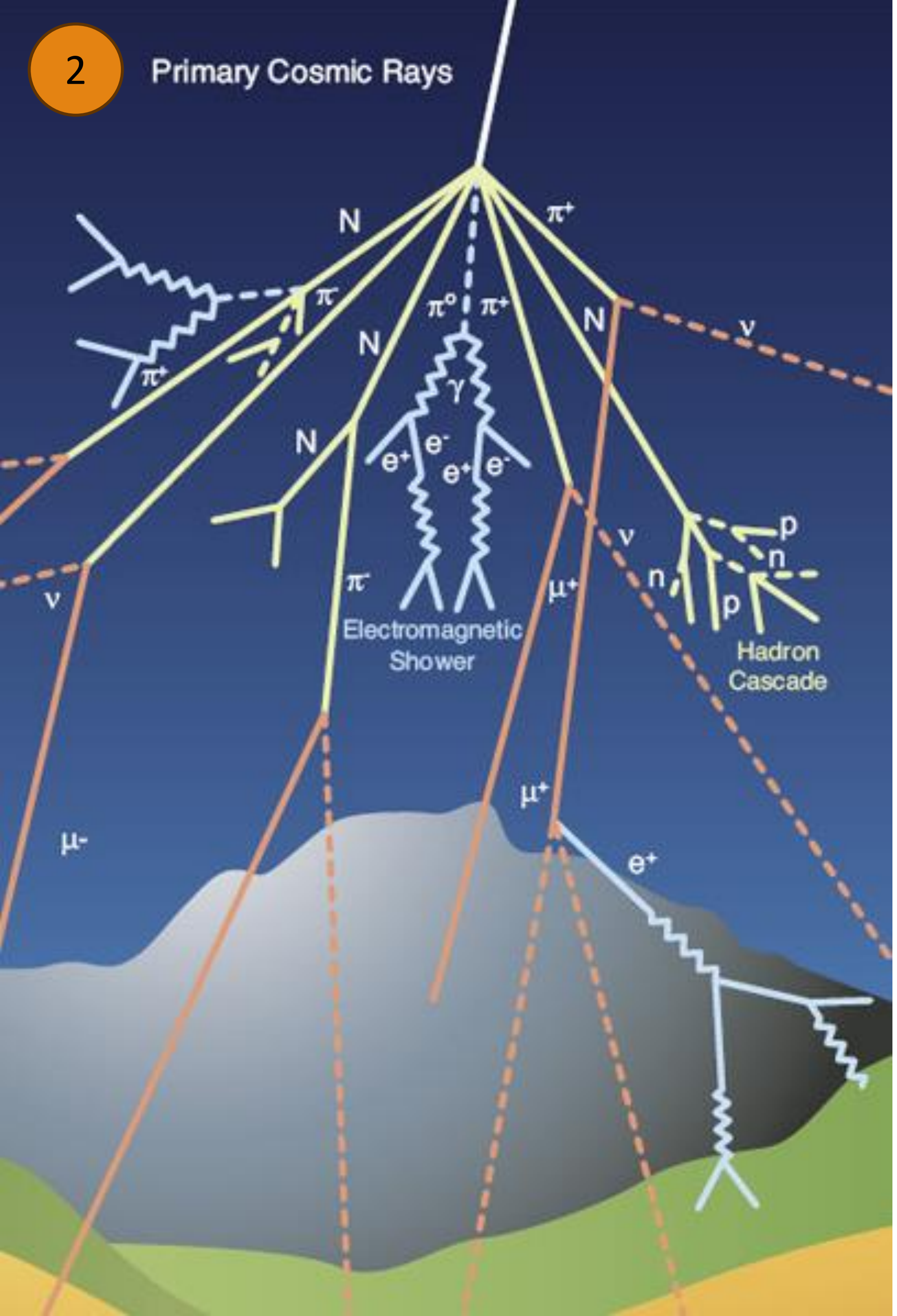


Energetic elementary particles and nuclei with lifetimes of order 10^6 years or longer.

Energies ranging from a few MeV to as much as 10^8 TeV.

Particles are accelerated by various astrophysical sources (Sun, supernovae, etc.) becoming primary cosmic rays.





Cosmic Rays hitting the Earth

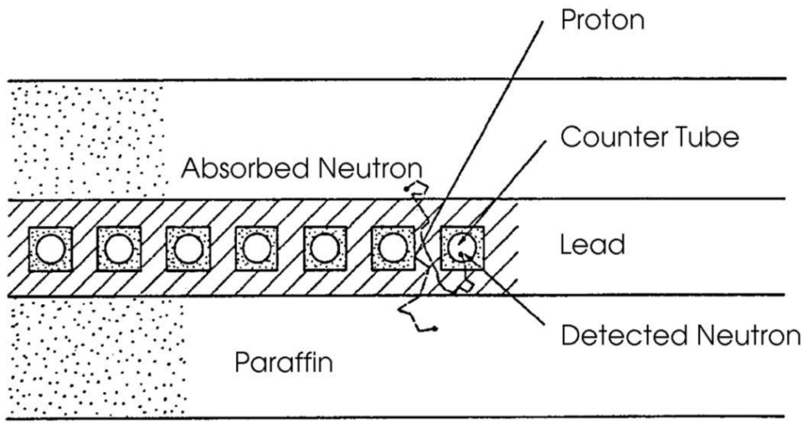
Cosmic rays with energies below a few hundred MeV/nucleon are absorbed in the atmosphere due to ionization.

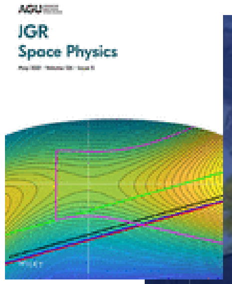
Higher energy particles generate nuclear-electromagnetic cascades, of secondary cosmic rays such as pions, muons and neutrons.

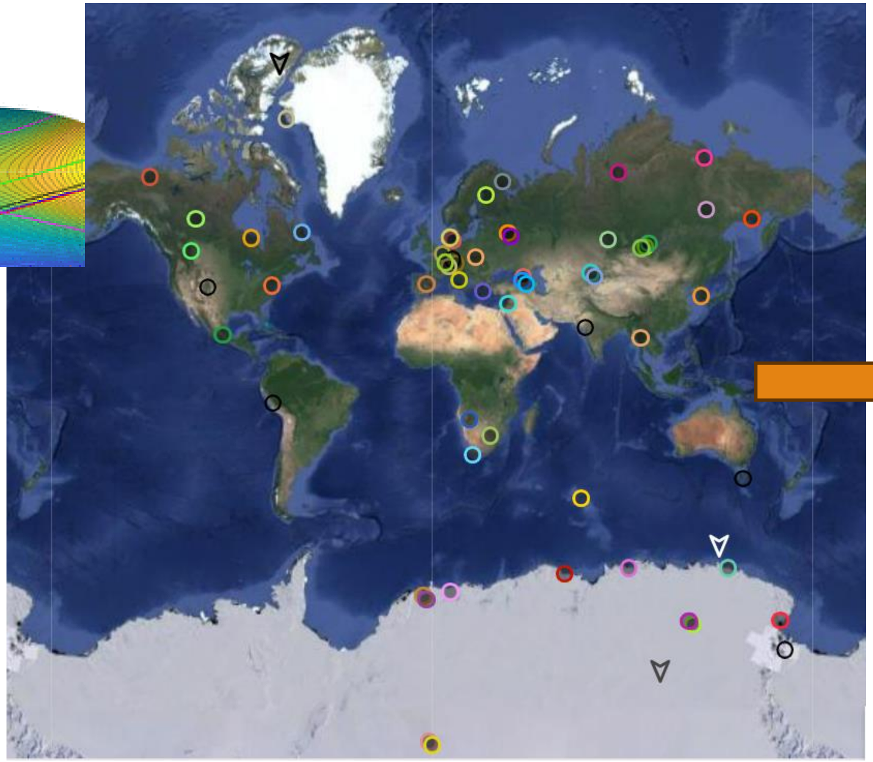
By measuring the neutron flux, we can effectively gauge high-energy cosmic rays (R > 1 GV), a task often beyond the capabilities of most space-based detectors, primarily due to their limited surface area.

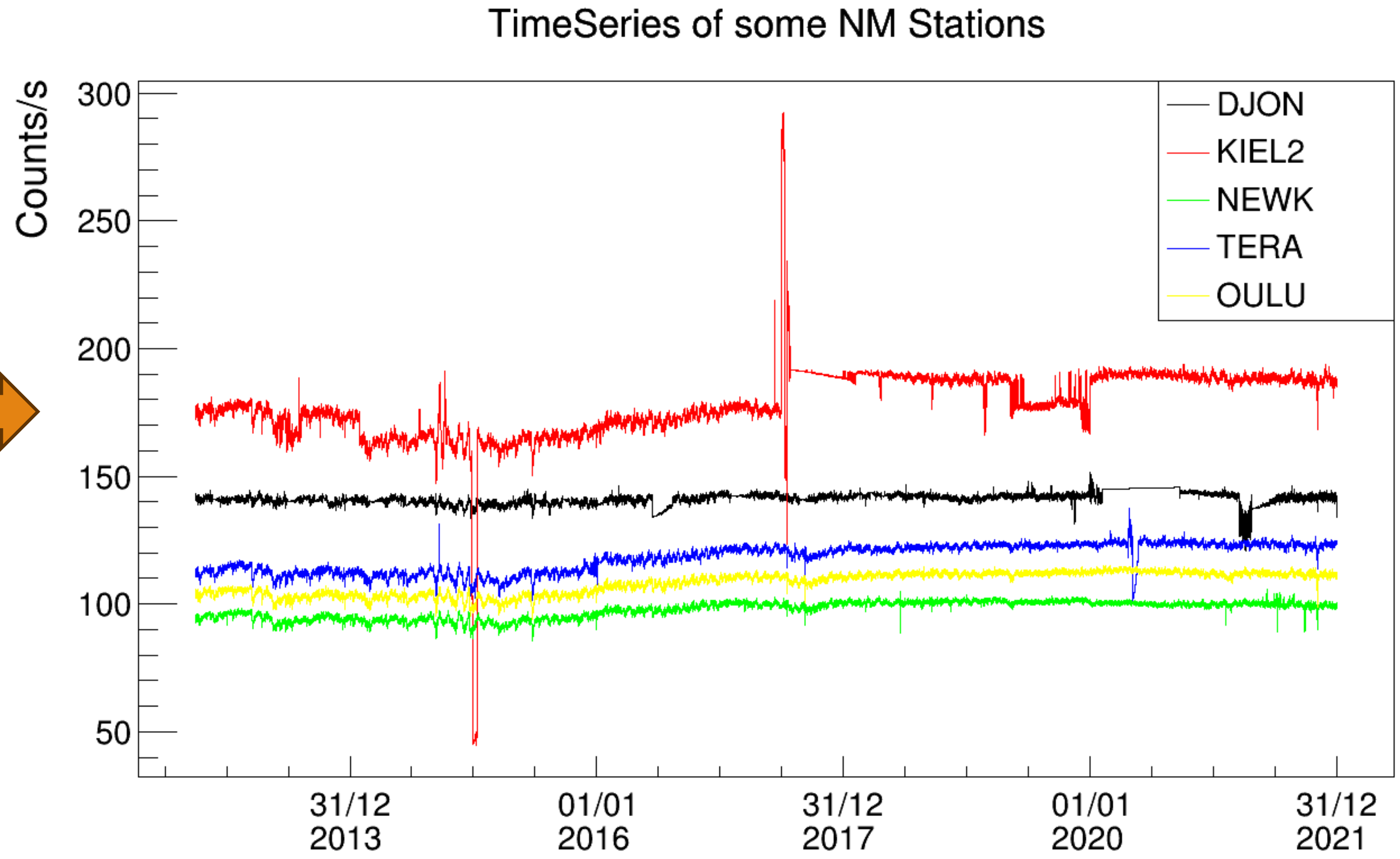
3

NMDB stations









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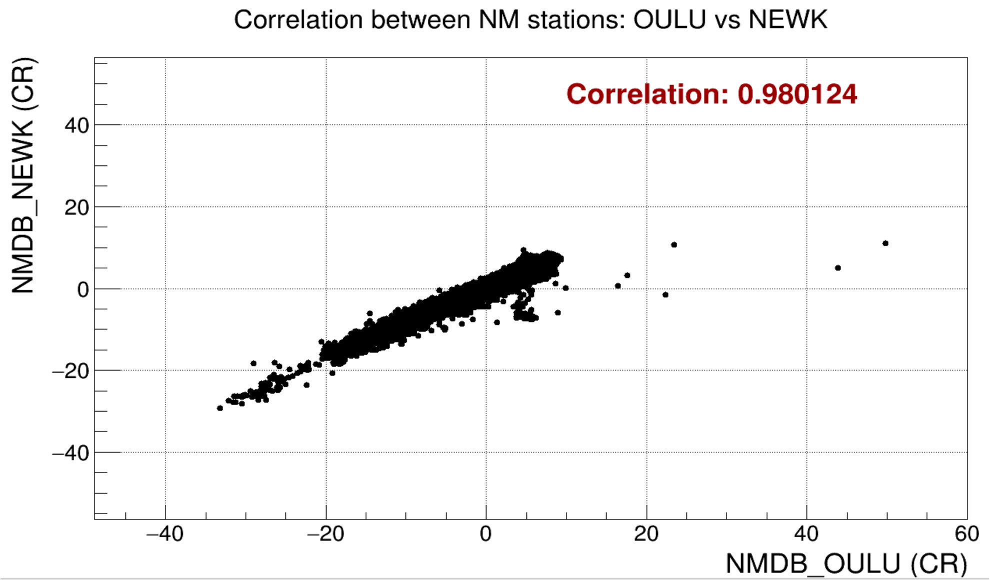
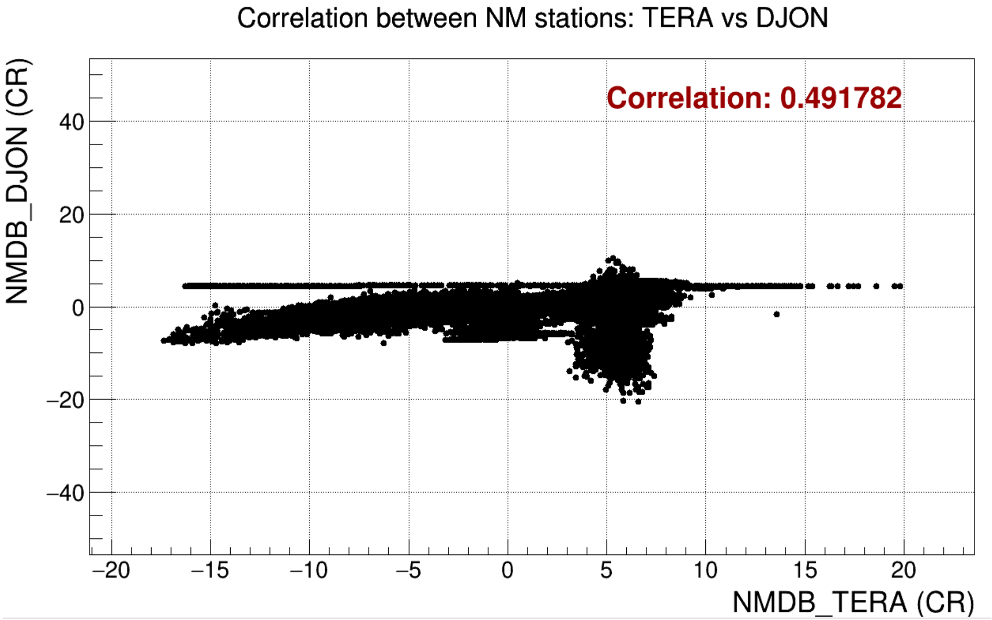
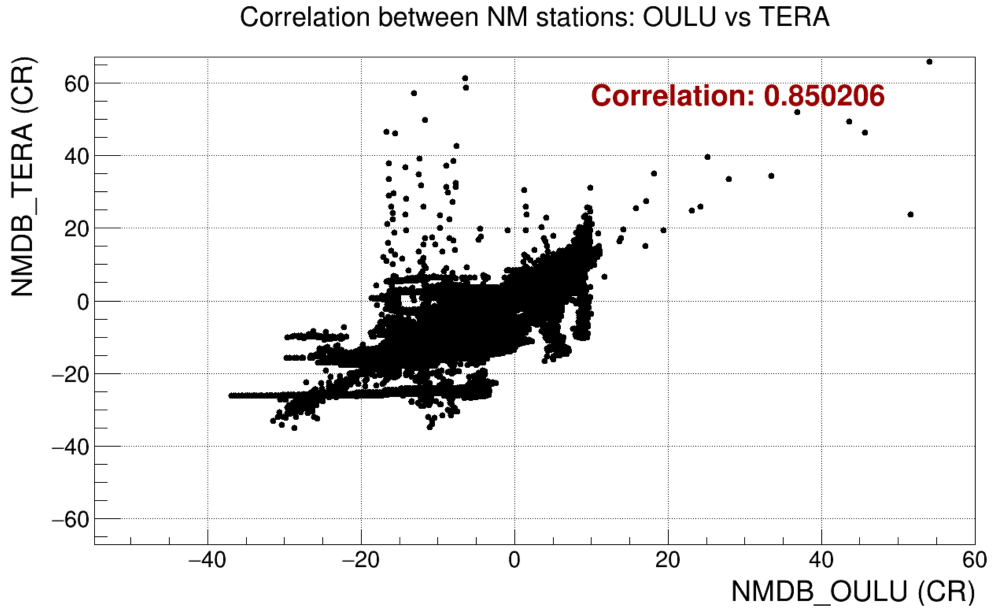
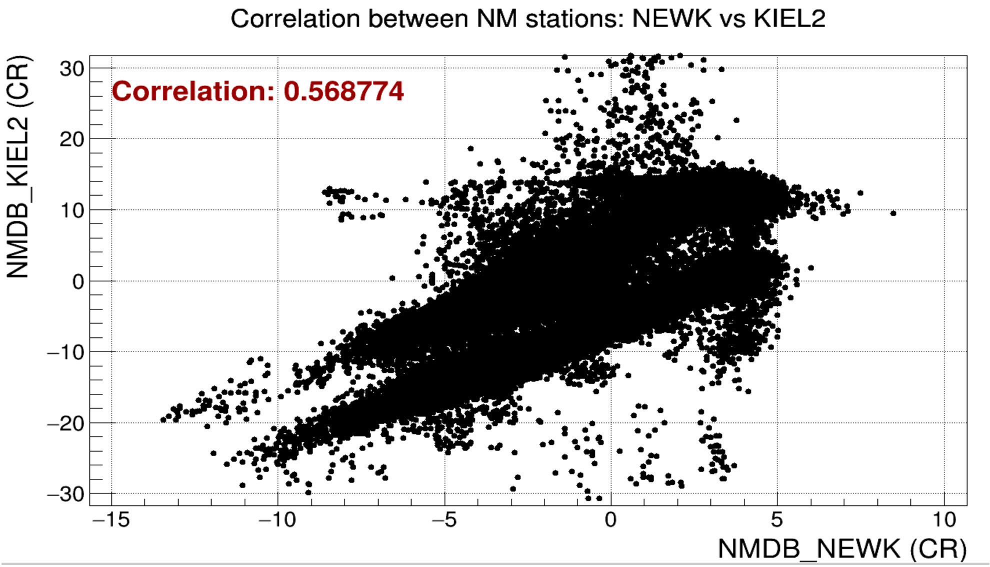
Correlation between NM stations







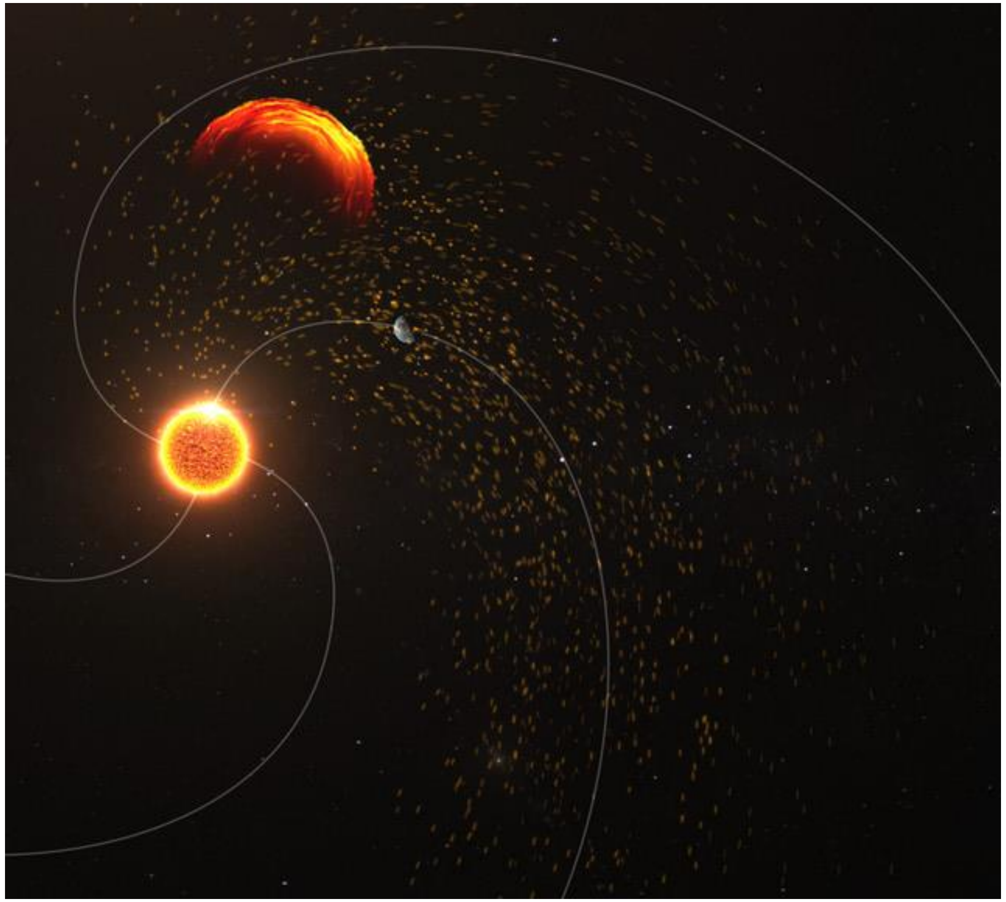


SEPs (Solar Energetic Particles)

SEPs are acelerated charged particles, mainly protons,emitted by the Sun.

These particles are acelerated either during solar flares or during Coronal Mass Ejections (CMEs)

Very high energy SEPs (> 500 MeV) can penetrate through the Earth's magnetic field which are detected at ground level (GLE)



Procedure in Data Analysis

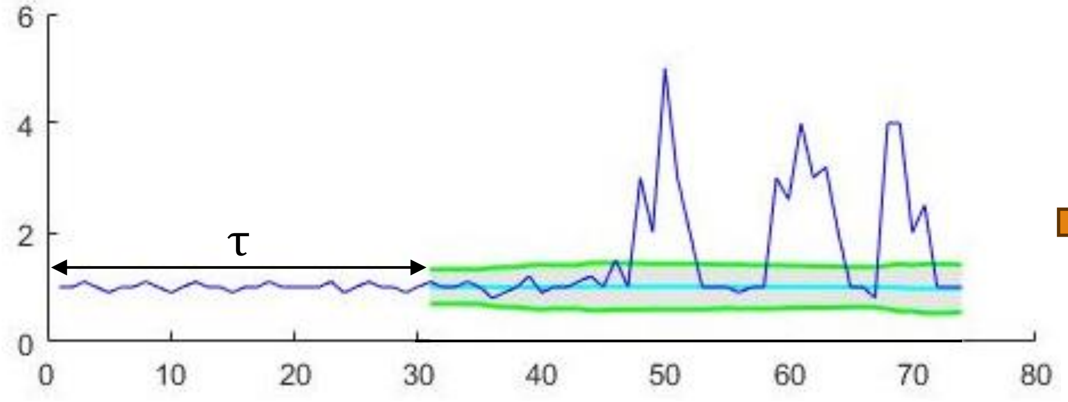
Methods used in Data Analysis:

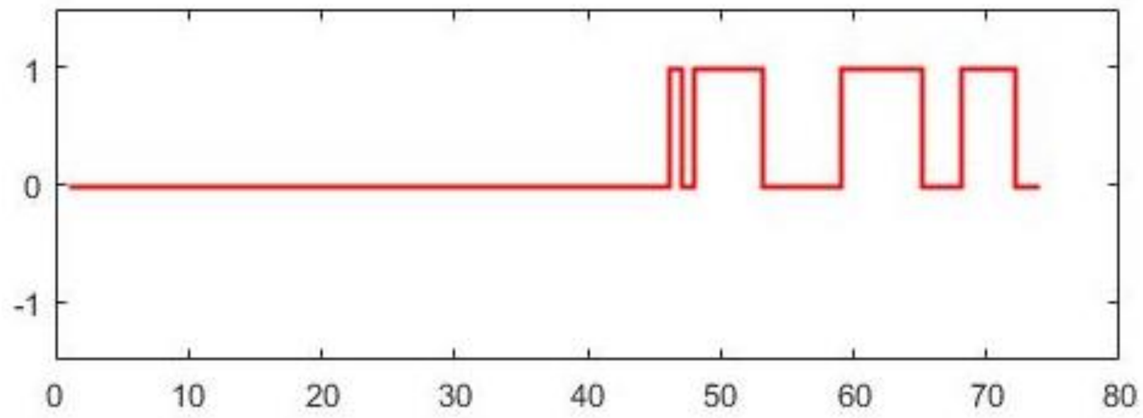
Search for SEPs in neutron monitor data from different stations.	→	Z-Score Peak Detection Algorithm
Correlation of neutron flux data from different stations.	→	Scatter Plot
Determine the periodicities in neutron flux.	→	Fourier Transform Wavelet Transform
Correlation of the 11 years solar activity cycle in the number of sunspots (SSN) and neutron flux.		

Z-Score Peak Detection Algorithm

Peak Detection Inputs:

- **Lag** (how many previous points to consider)
- **Threshold** (how much deviated from the rest to be considered part of a peak)
- **Influence** (how much relative weight do peak points have)



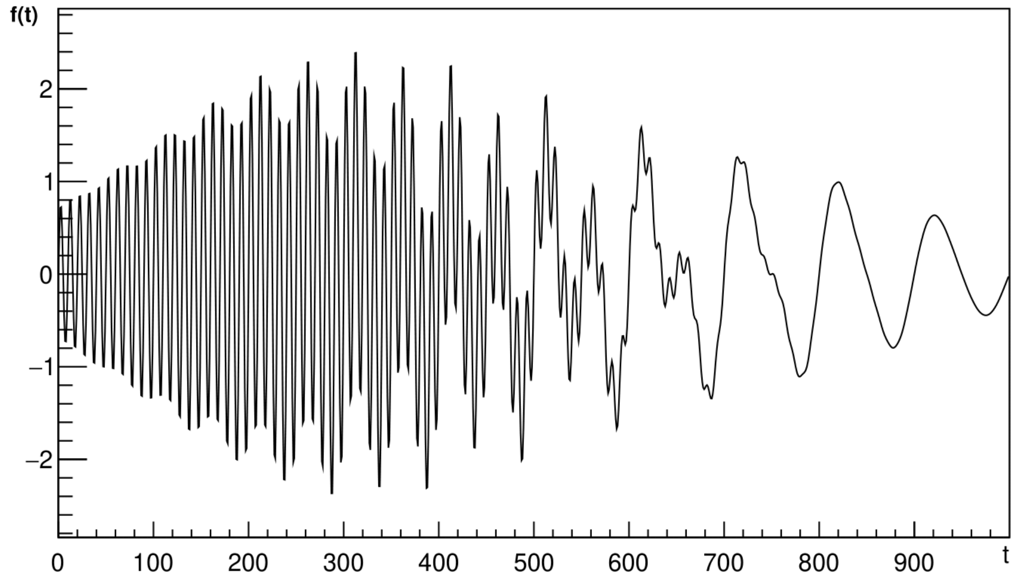


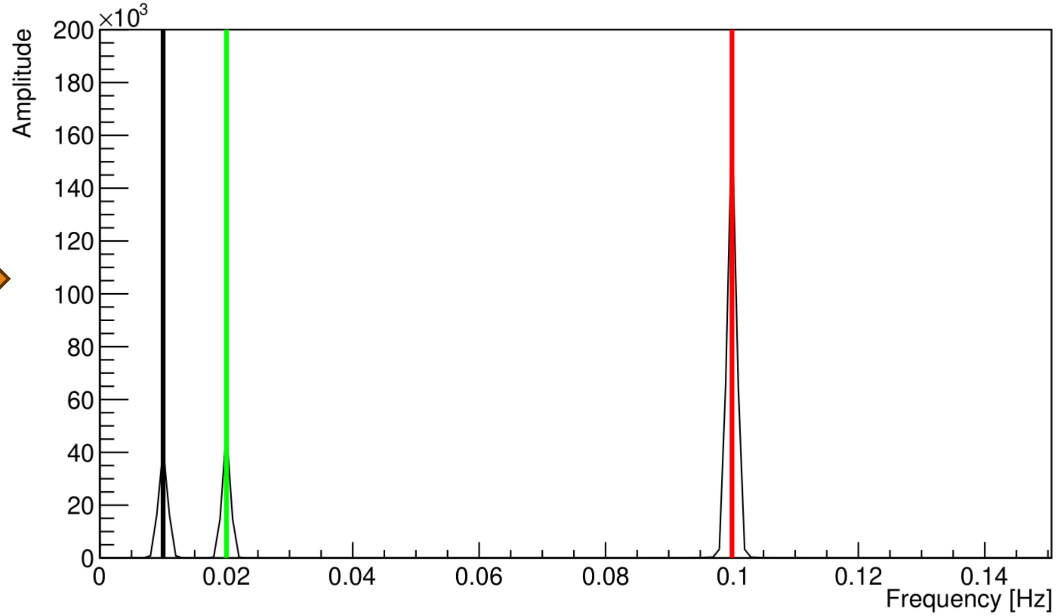
$$x_i - \mu > \Gamma \cdot \sigma \quad \rightarrow \quad x_i \text{ is part of a peak}$$

Γ : Threshold (nr. of s.d.) μ : Moving average (in window of length τ) σ : Standard deviation (of data in window of length τ)

Fourier Transform

$$\mathscr{F}[f(t)](\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-i\omega t}\, dt$$





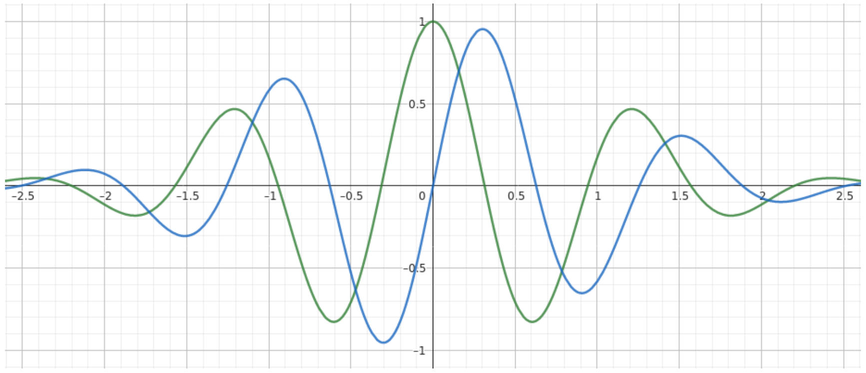
When do the periodicities start or end?

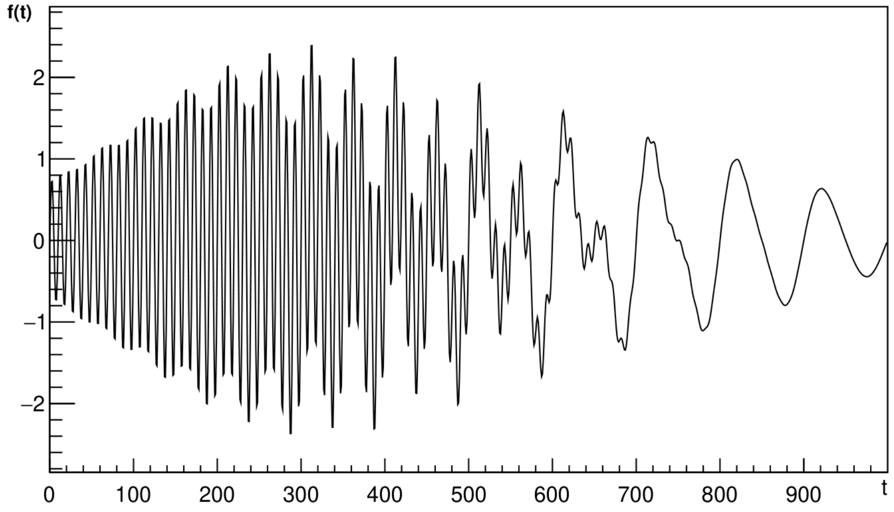
Wavelet Transform

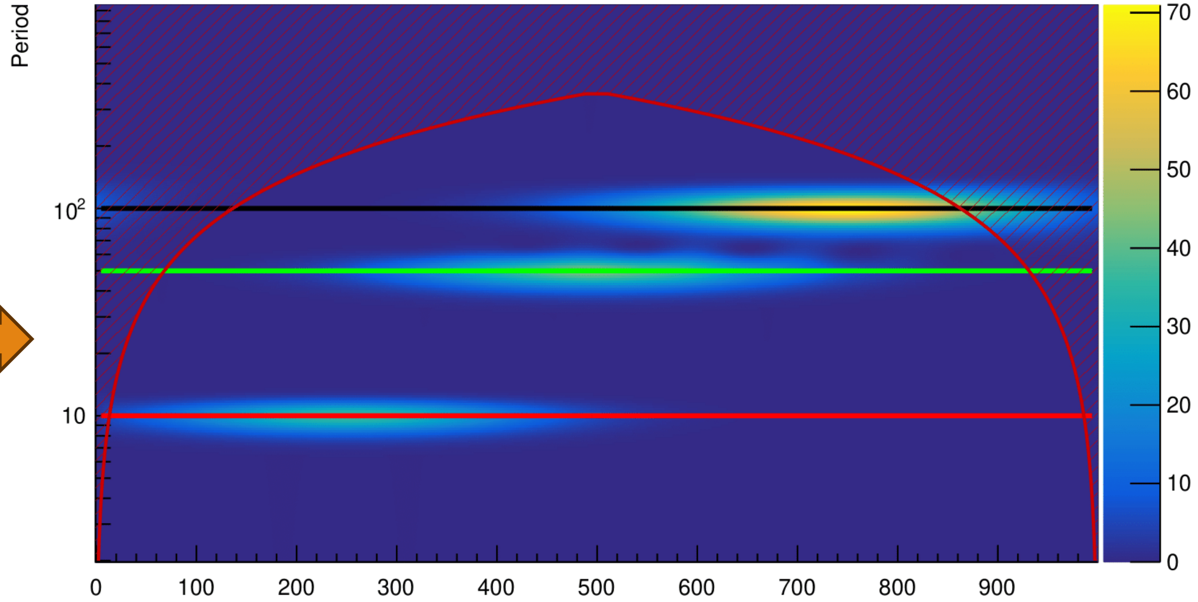
$$W_{t_0}(s) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} f(t)\, \psi^* \left(\frac{t-t_0}{s}\right)\, dt$$

$$\psi(\eta) = \pi^{-\frac{1}{4}} e^{i\omega_0 \eta} e^{-\frac{\eta^2}{2}}, \quad \eta = \frac{t-t_0}{s}$$

Morlet Wavelet

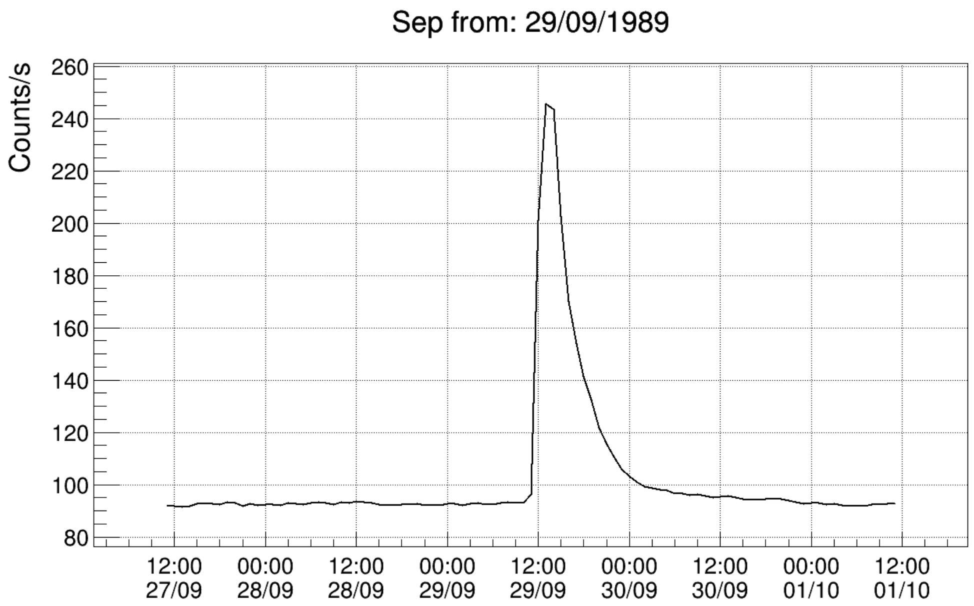


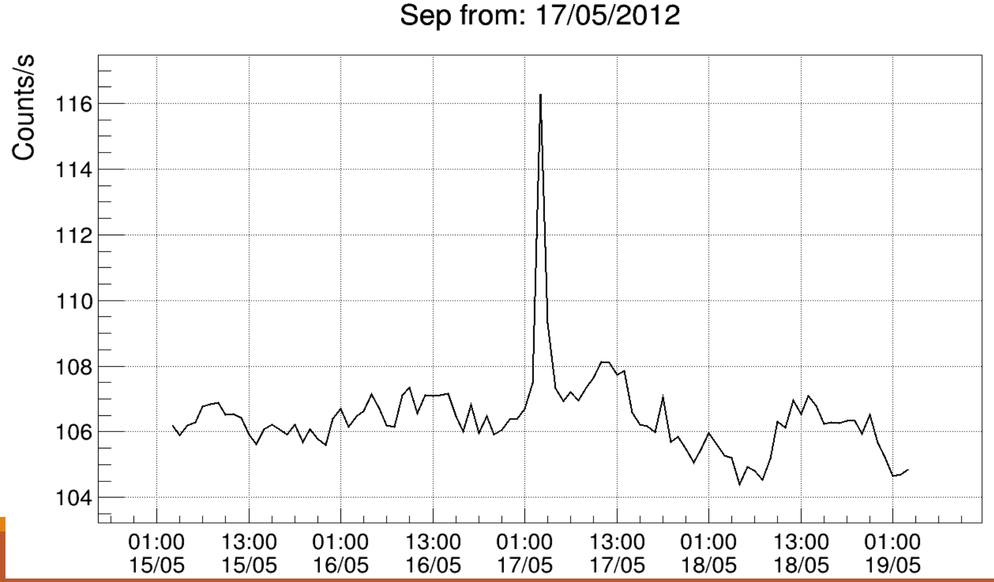




Data Analysis

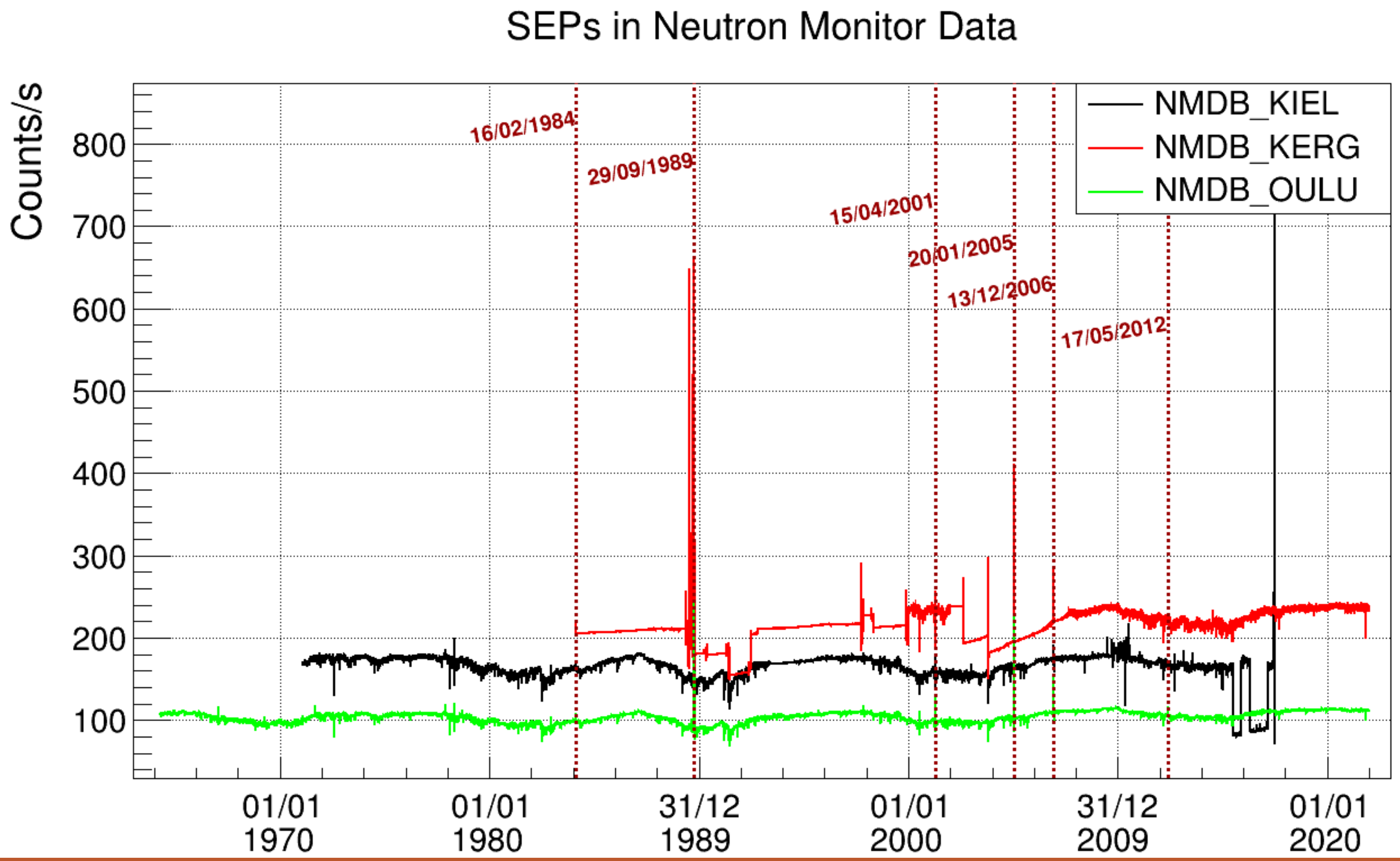
SEPs in Neutron Monitor Data



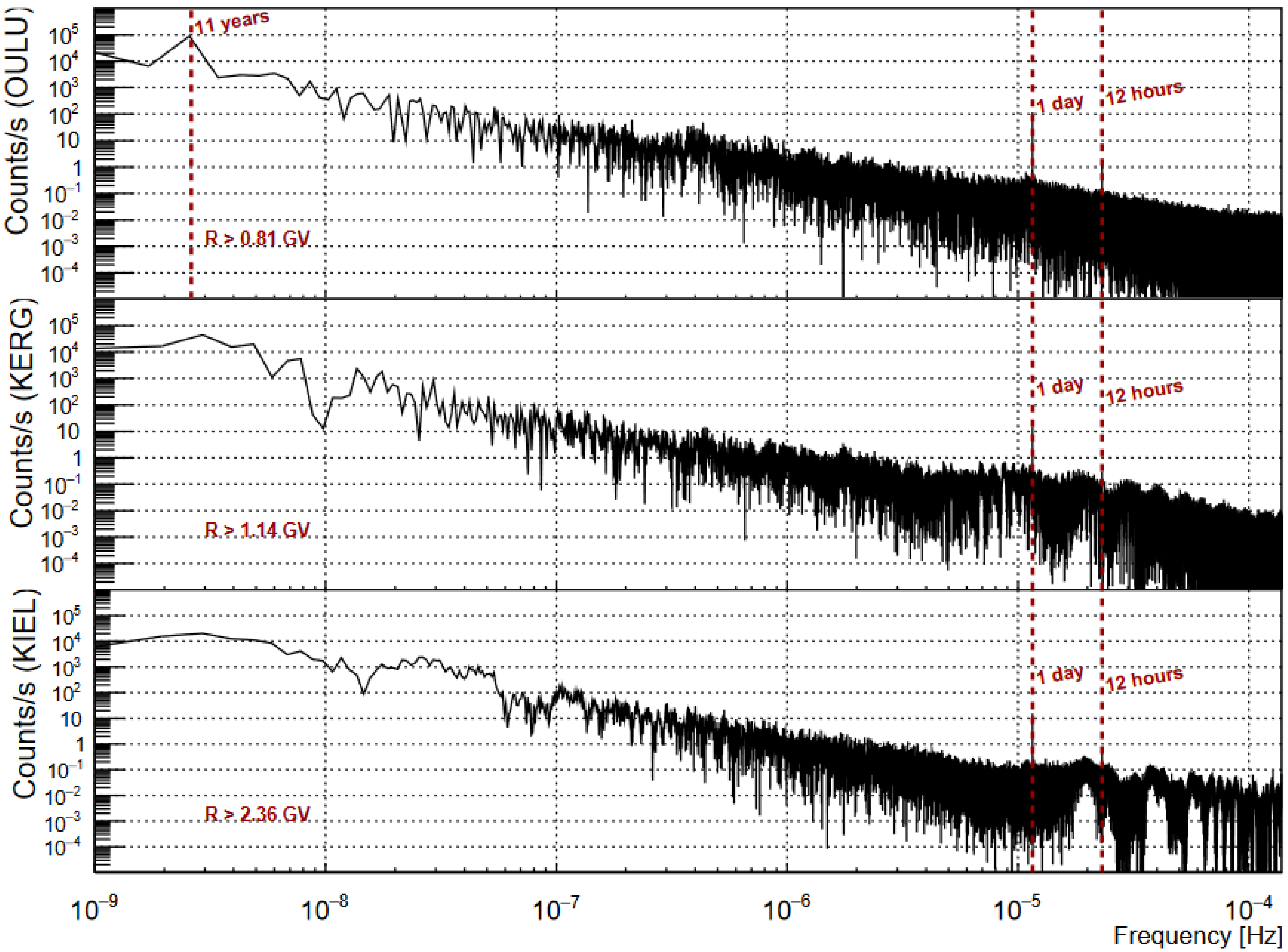


Neutron Monitor Stations considered:

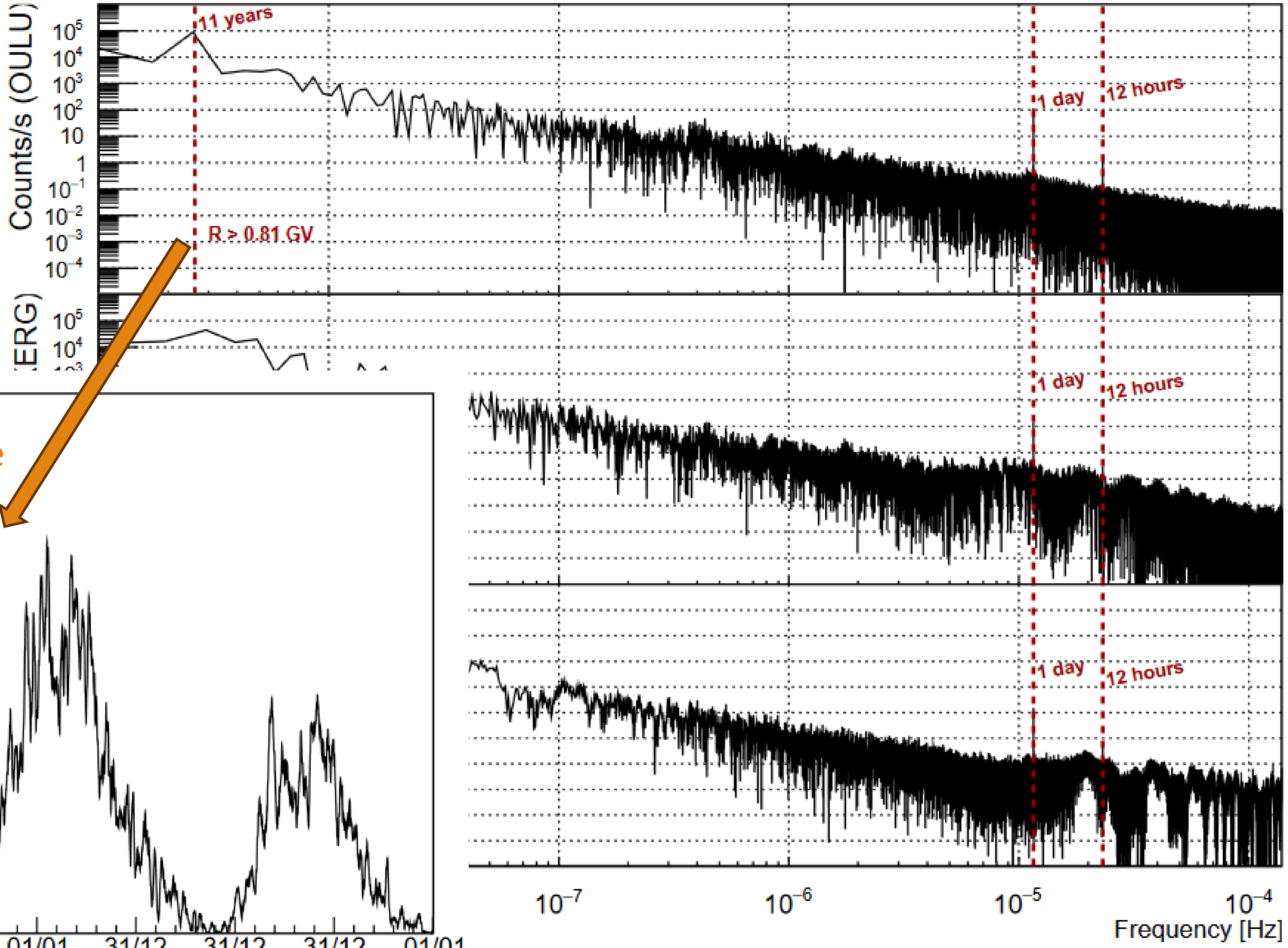
- AATB
- KERG
- MOSC
- SOPB
- DRBS
- KIEL
- OULU
- TERA

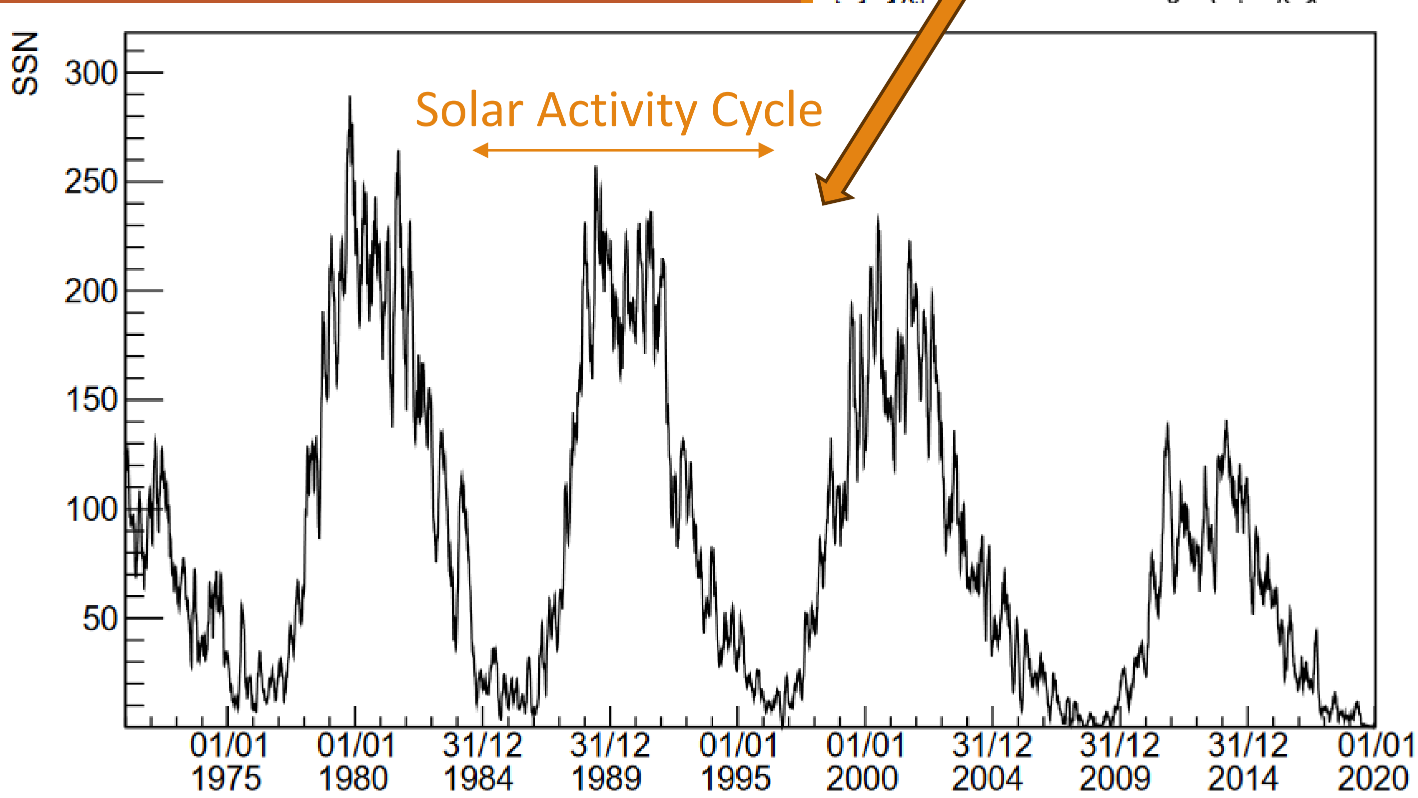


Periodicities in Neutron Flux



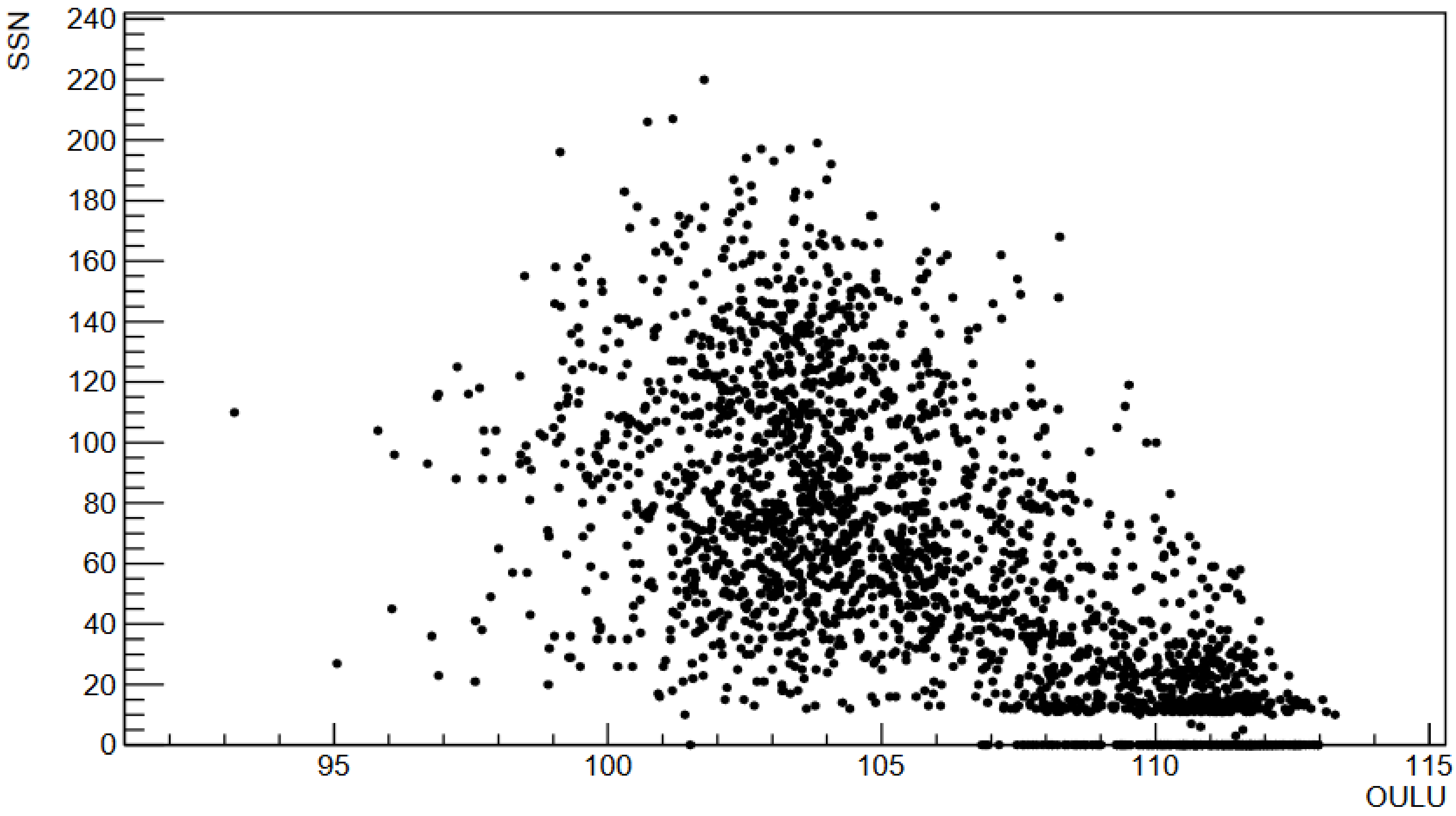
Periodicities in Neutron Flux





Correlation between Neutron Flux and SSN

Sunspot Number (SSN) vs. Neutron Flux (OULU) Scatter Plot

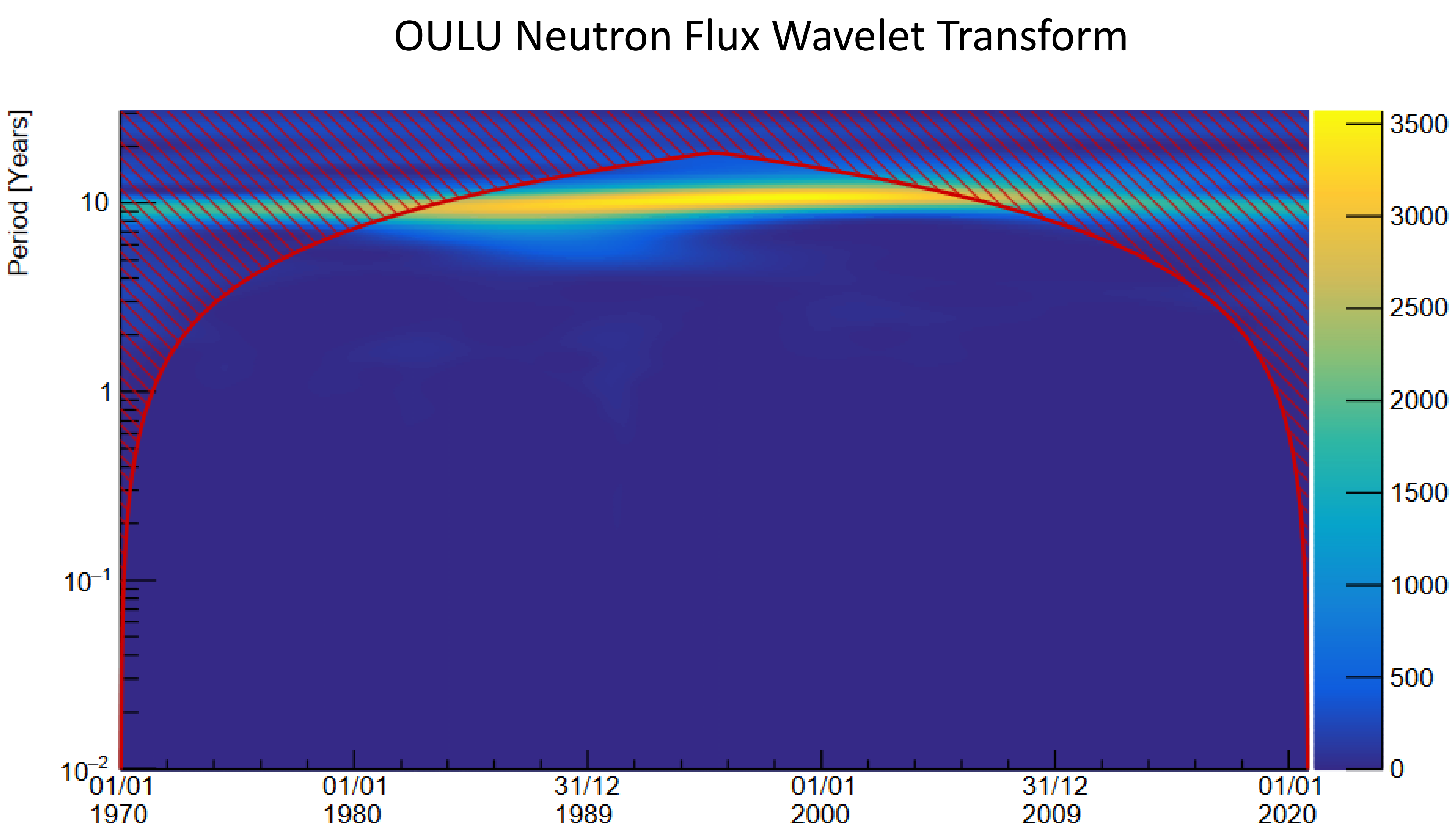


Correlation = - 0.674 → Significant Anti-Correlation

Neutron Flux Wavelet Transform

11 years periodicity is present throughout the signal

Although faint, we can see something happened around 1990



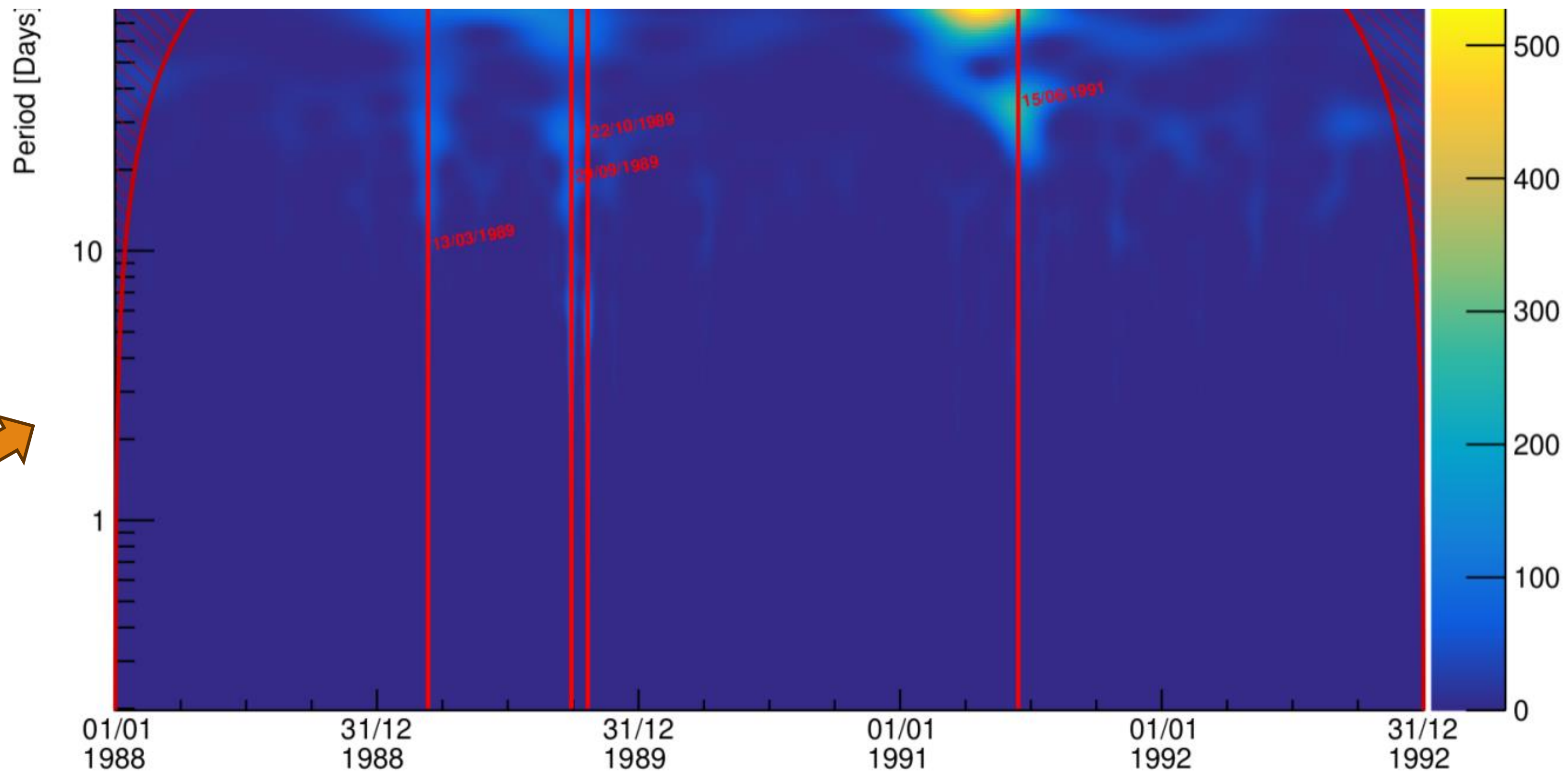
Could there be other periodicities hidden in the Periodogram?

Neutron Flux Wavelet Transform

11 years periodicity is present throughout the signal

Although faint, we can see something happened around 1990

OULU Neutron Flux Wavelet Transform



Conclusions

The work conducted met the proposed objectives:

- Study the periodicity of cosmic rays by studying neutron flux
- Study SEP ocurrences over time
- Develop and utilize algorithms to process and analyze data
- Learn new methods of processing and analyzing data

With this in mind, during our research we also did some analysis than was not presented here

Additionaly, we think some topics should get some more analysis that we would like to do in a future project

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