Two-decade measurement of cosmic ray solar diurnal anisotropy with GRAPES-3

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(On behalf of the GRAPES-3 collaboration)

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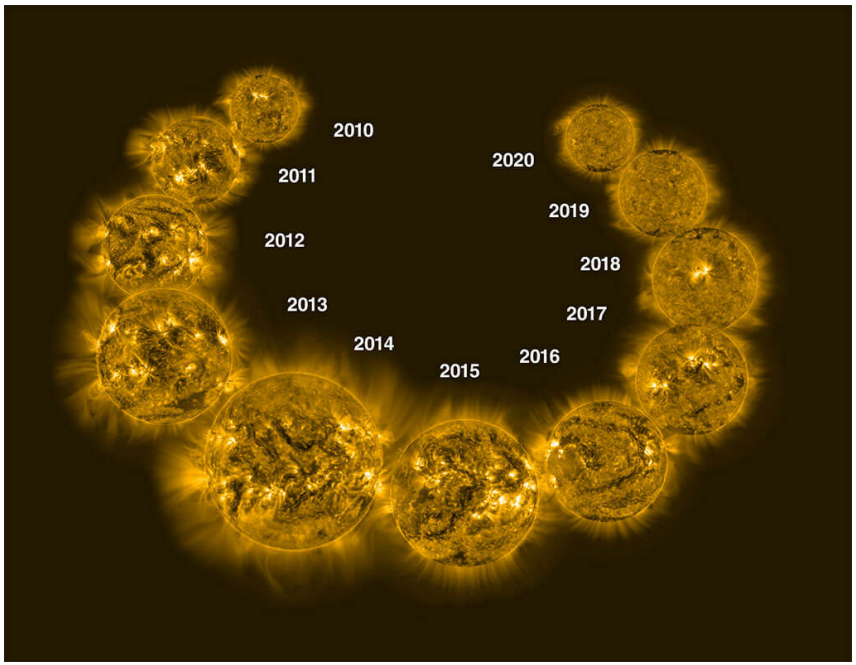
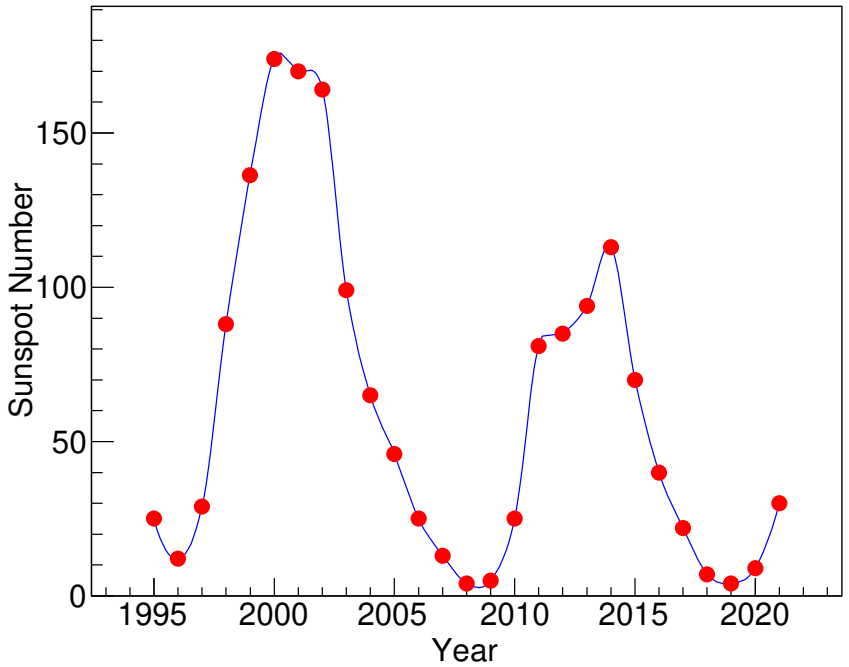
Outline

Motivation

- The Sun's magnetic field undergoes a 11 year cycle.
- The modulation effects of cosmic rays have been extensively investigated to understand the solar terrestrial environment.





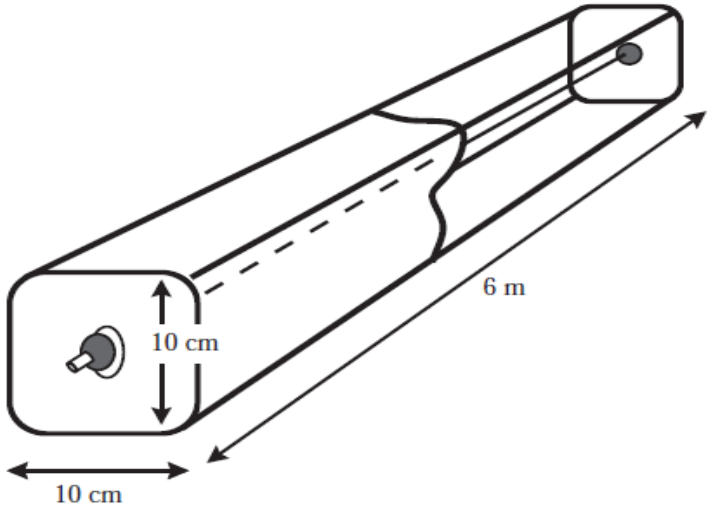
Evolution of Sun in extreme UV light by PROBA2 spacecraft (ref:https://spaceplace.nasa.gov/solar-cycles/en/)

GRAPES-3 Experiment

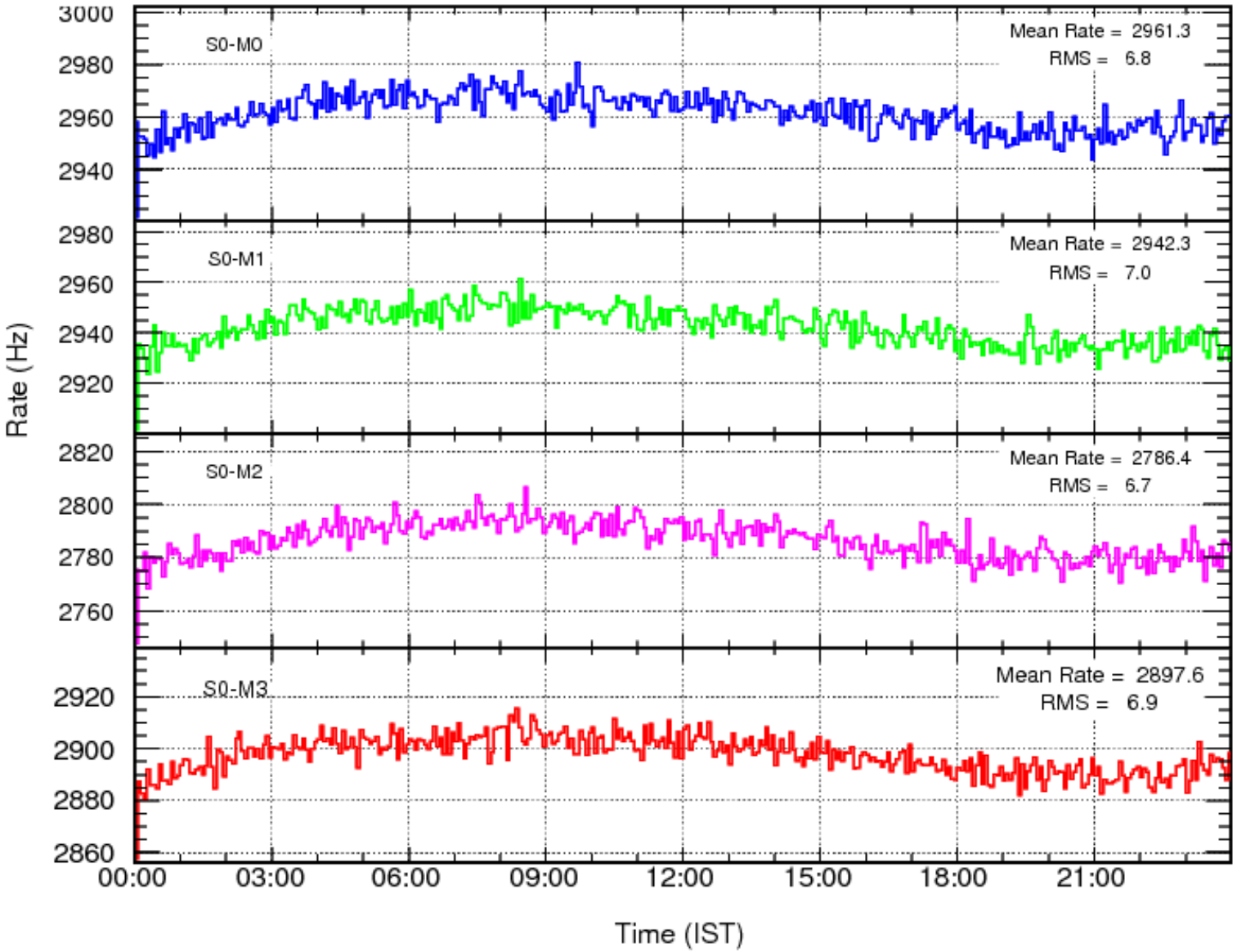
- Located at Ooty, India (11.4° N, 76.7° E and 2.2 km above msl).
- 400 plastic scintillation detectors (1 m^2 each) spread over 25,000 m^2.
- Tracking muon telescope (560 m^2).

Tracking Muon Telescope

- Proportional counter (PRC) is the basic element
- Total = 3712 PRCs
- 4 super-modules (140 m^2 each) = 560 m^2.
- 2.4 m thick concrete absorber, E_μ = Sec(θ) GeV
- Sky coverage = 2.3 sr



Muon Telescope Module Data

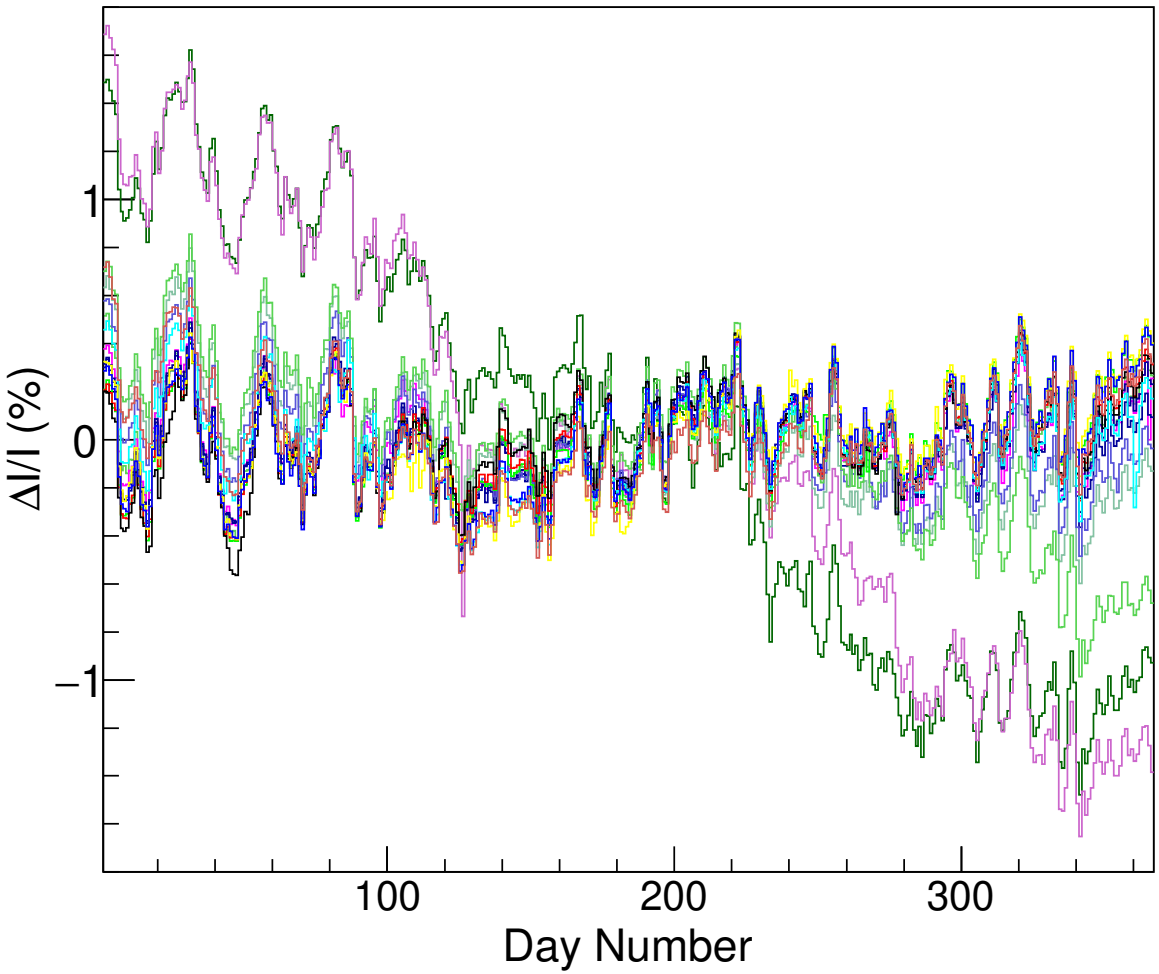


Data Handling

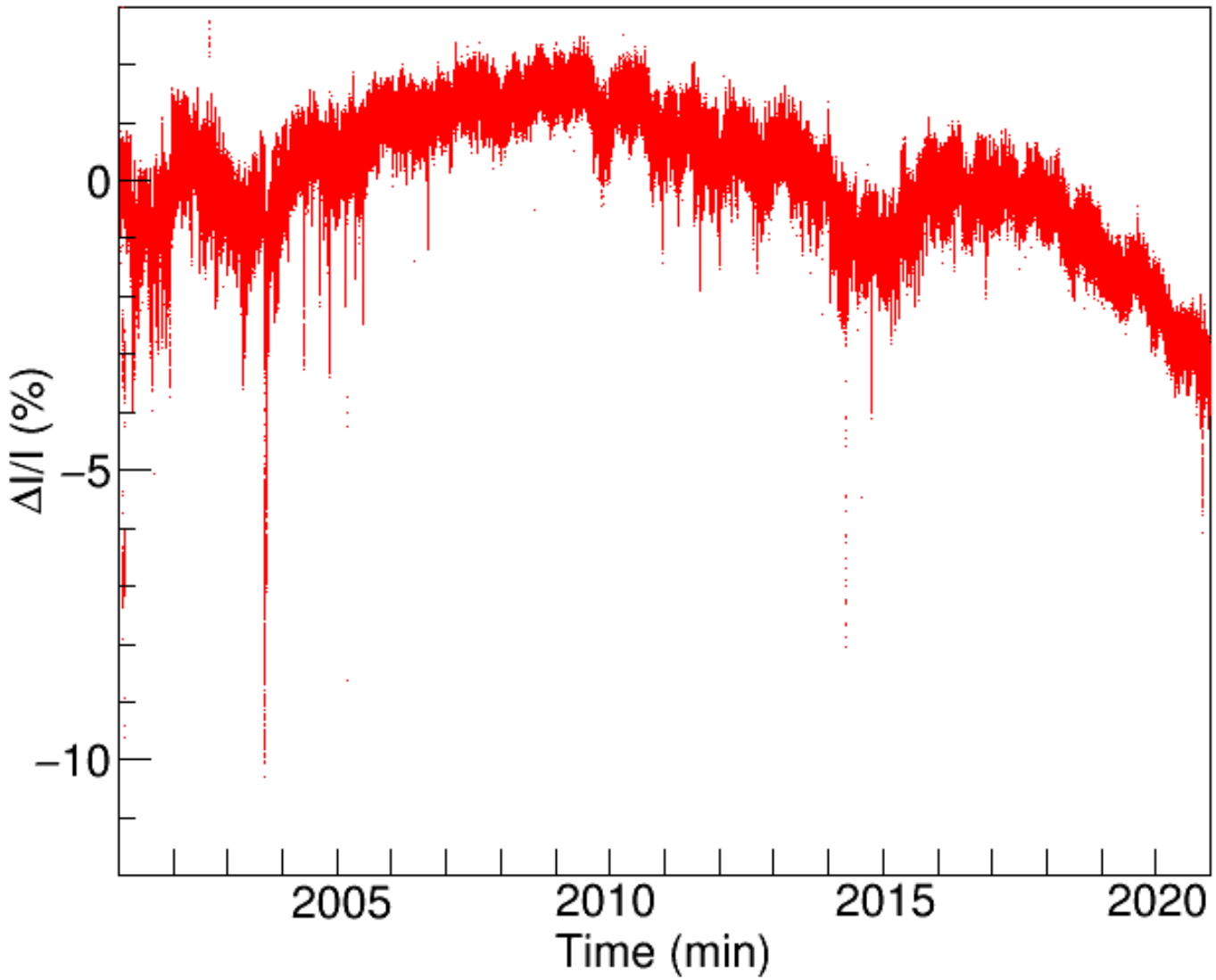
- GRAPES-3 muon telescope is continuously recording data from past two decades.
- Sudden power failure or the instrument problems can cause the abnormality in the data.
  - Single bin drop
  - Single day module rate
  - Long-term module rate
- Such data periods need to be identified and corrected (if possible) before using it for any physics analysis.

Long-term Module problem Handling (2008)

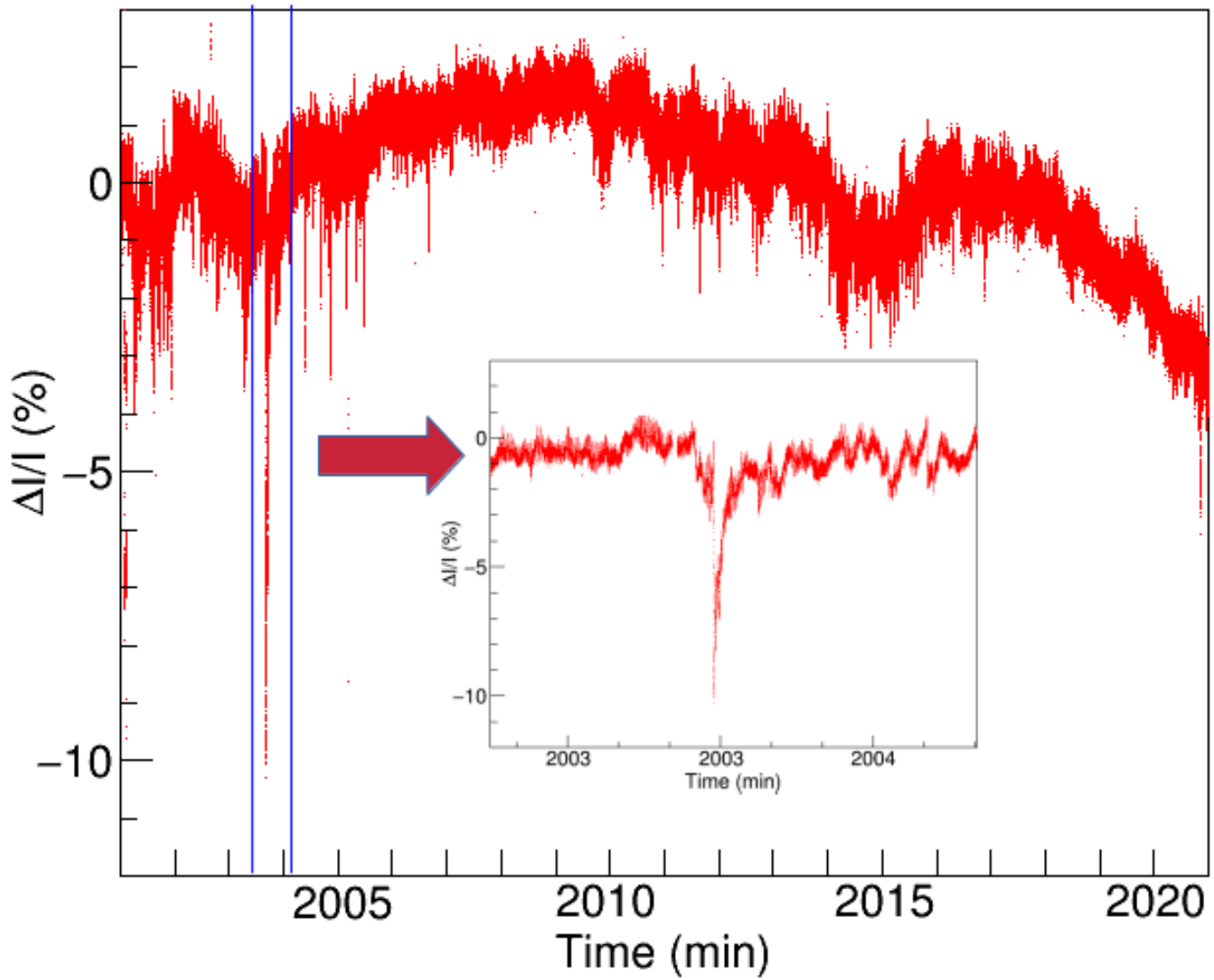
The normalized module rates are averaged over one day.



Final Muon Rate (2001-2021)



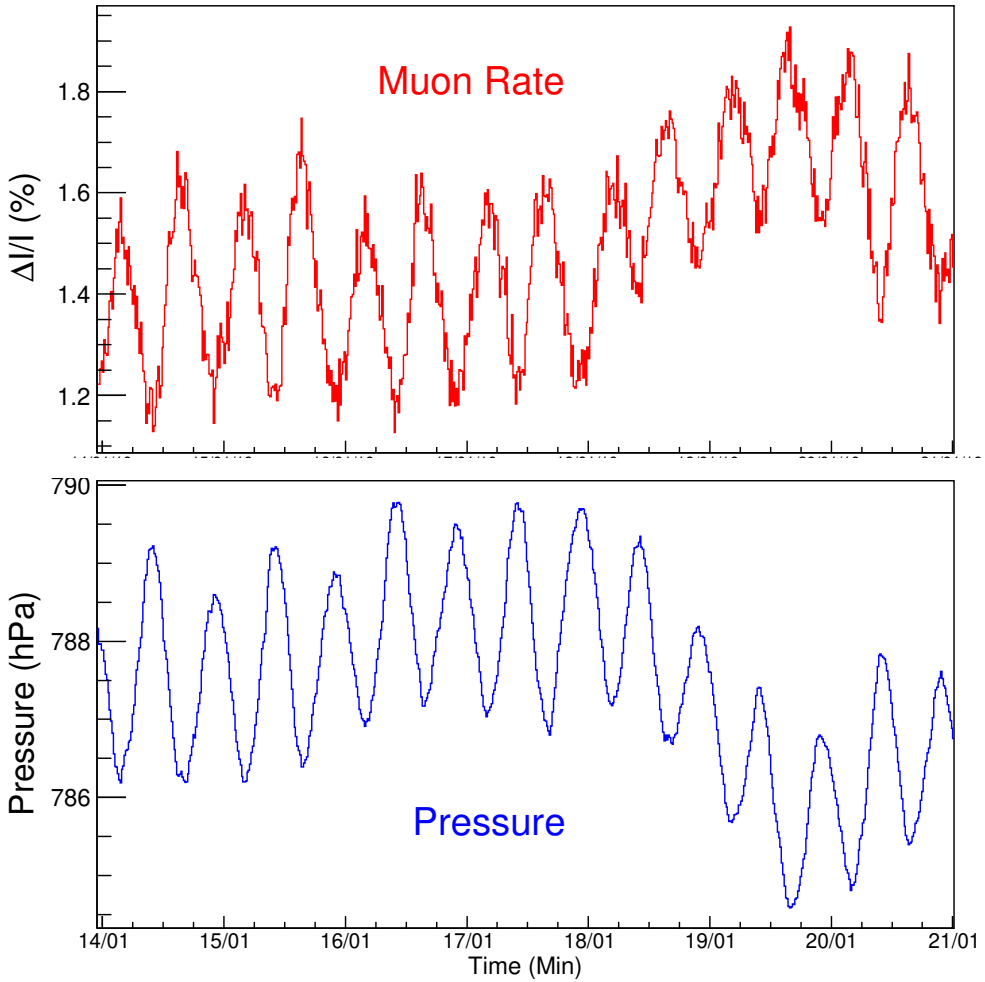
Final Muon Rate (2001-2021)



T. Nonaka et al., Physical Review D 74, (2006) 052003

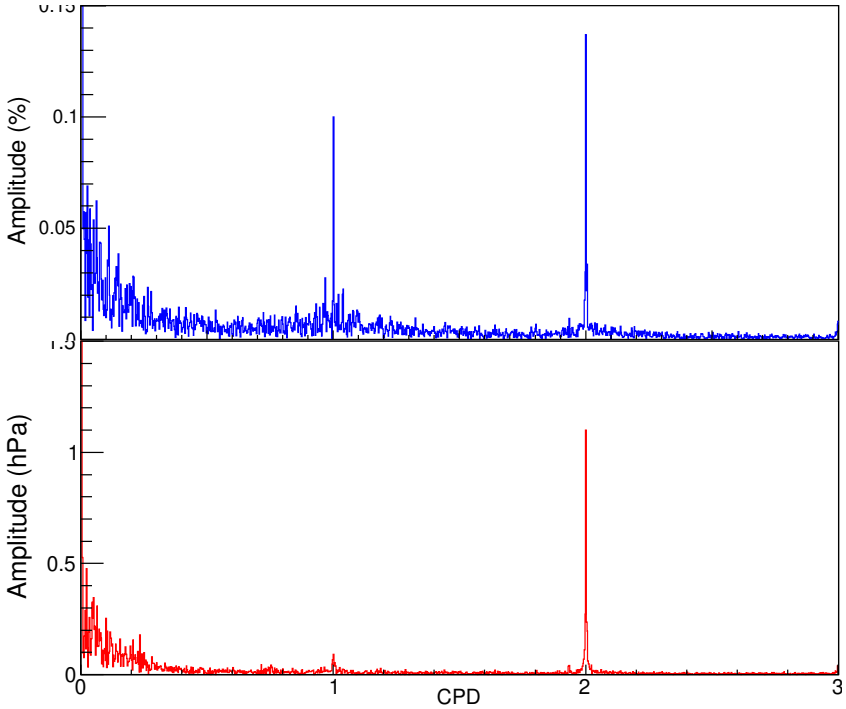
Atmospheric Pressure Effect

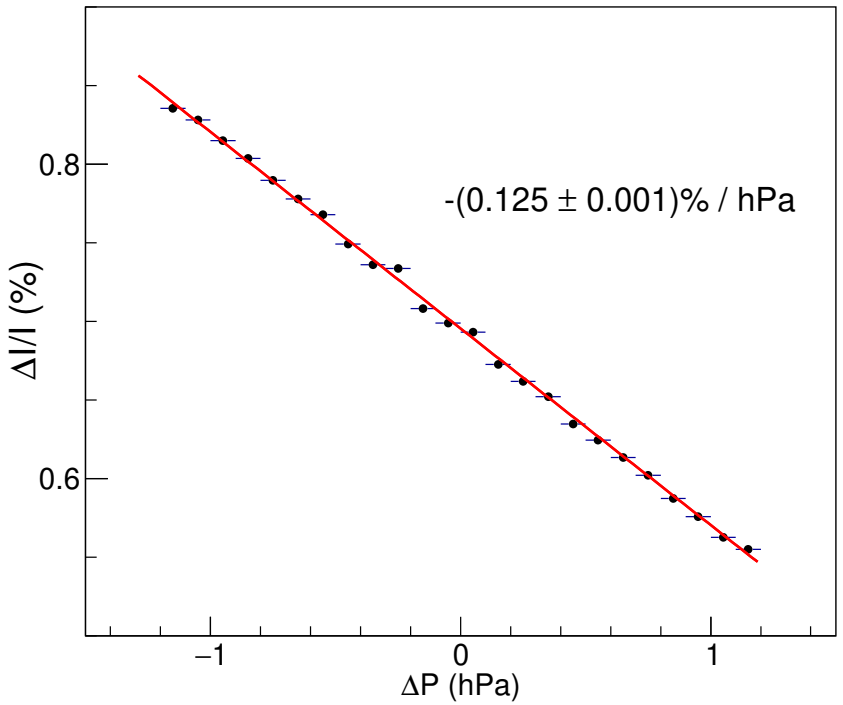
Muon rate shows the anti-correlation with atmospheric pressure.



Atmospheric Pressure Coefficient (Year-2020)

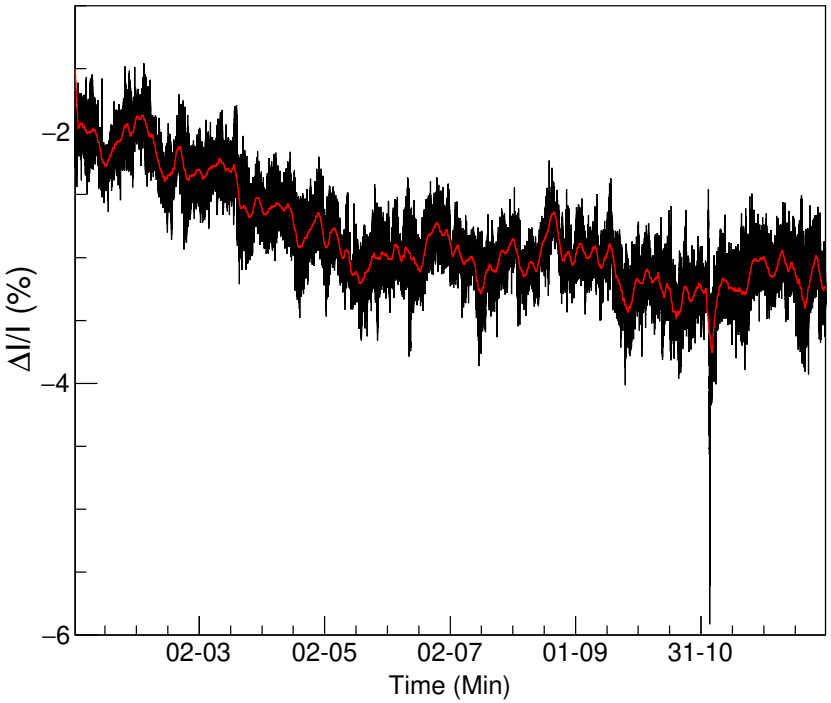
A fast Fourier transform technique is used to obatin the pressure coefficients.

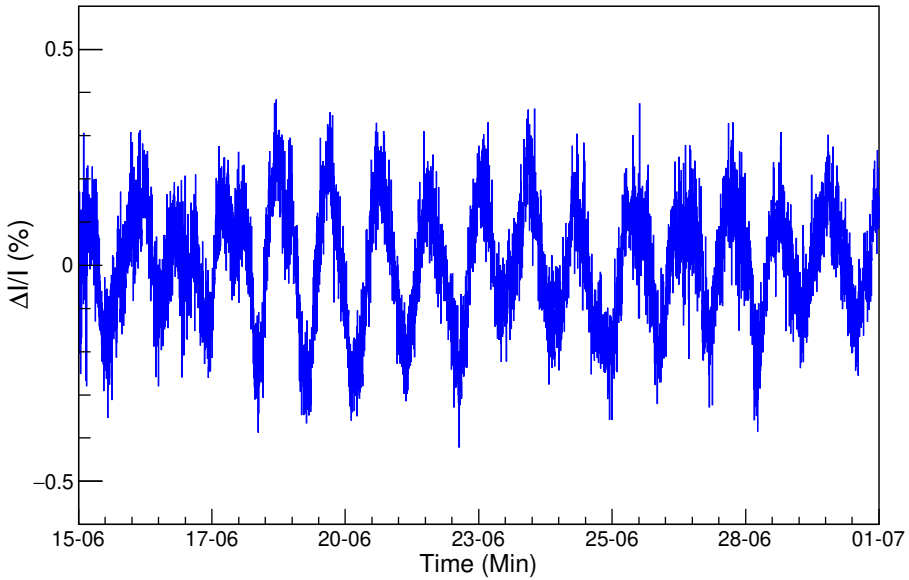




Data Filtering (Year-2021)

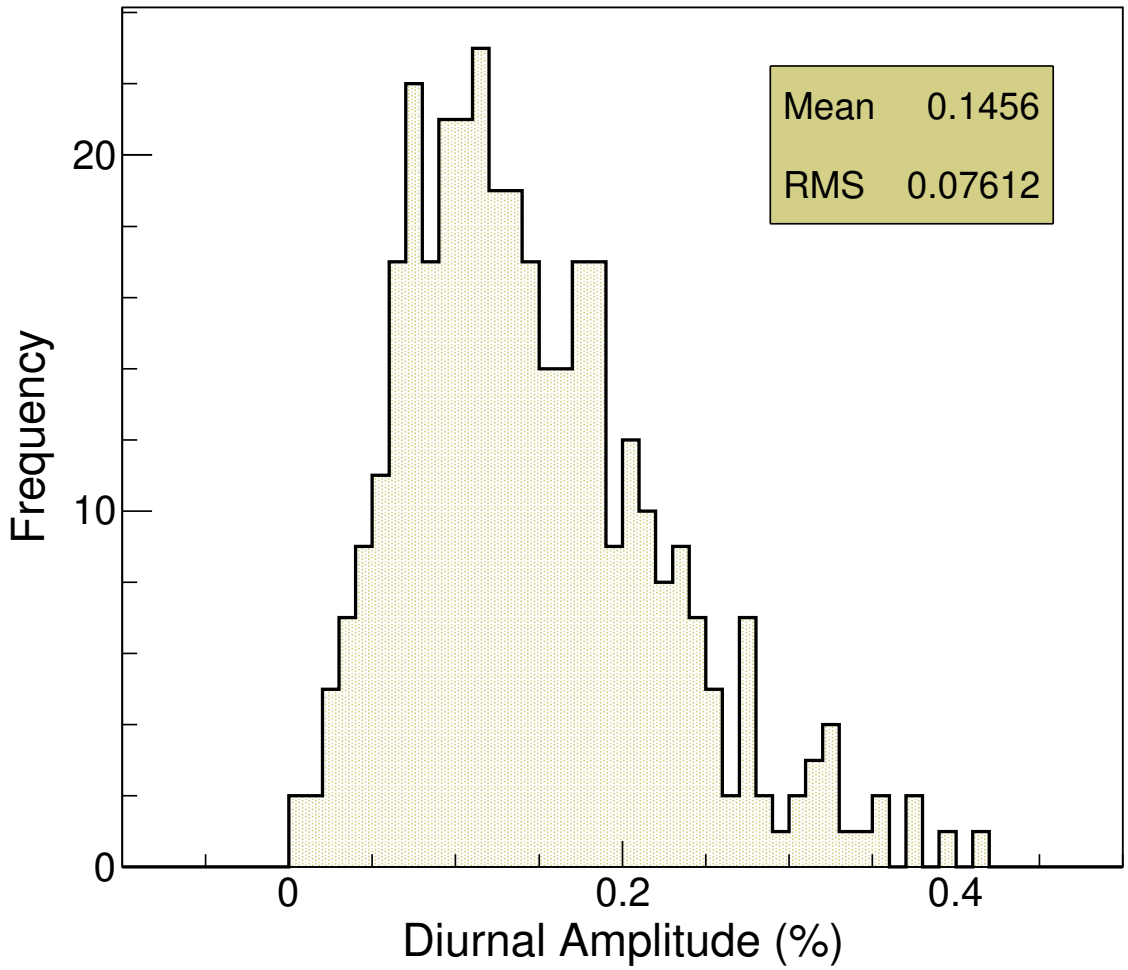
A three-day running average is used to filter out the slow variations.



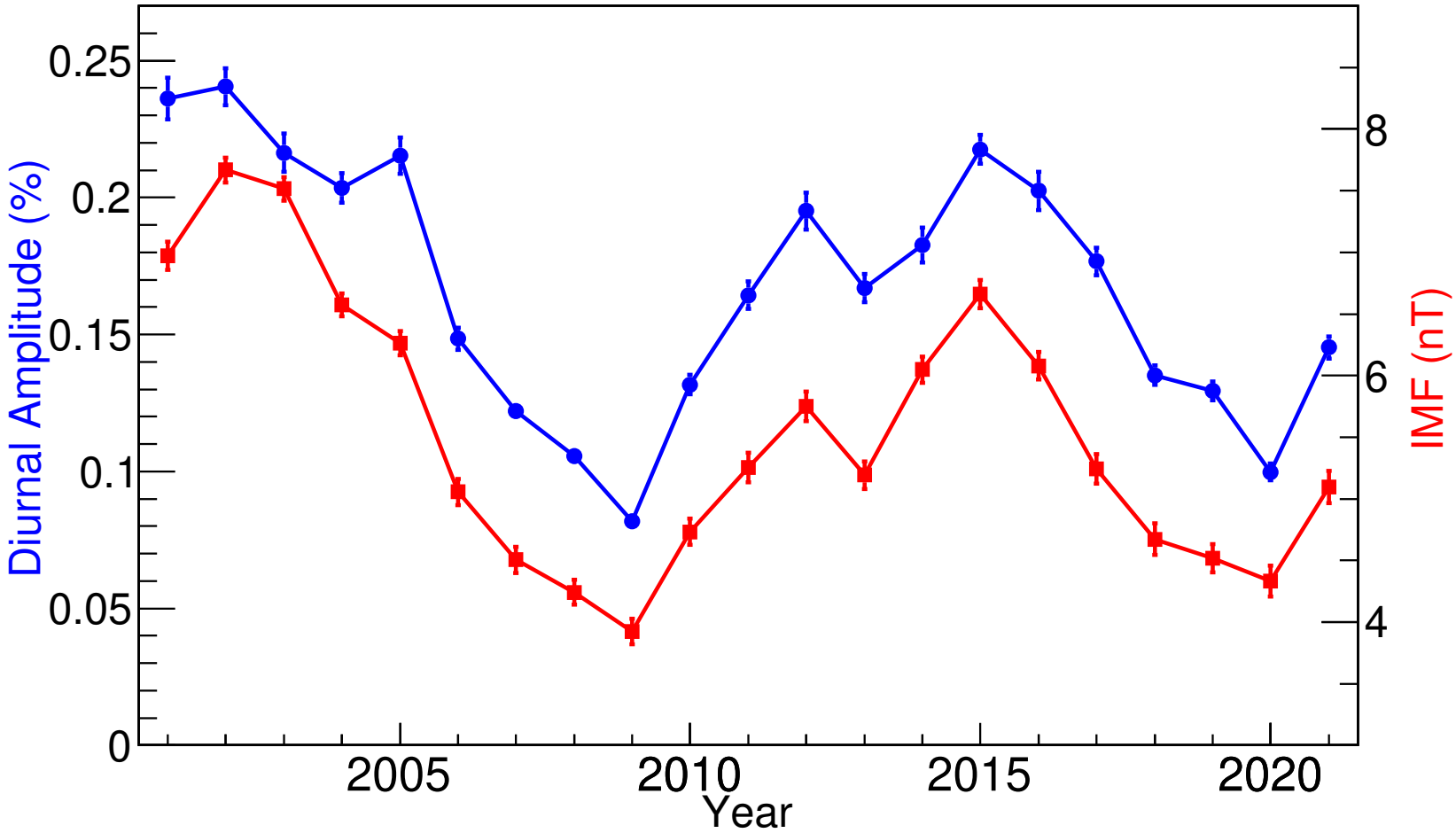


Yearly DA Distribution (Year-2021)

Fourier series technique is used to obtained the daily diurnal amplitudes.

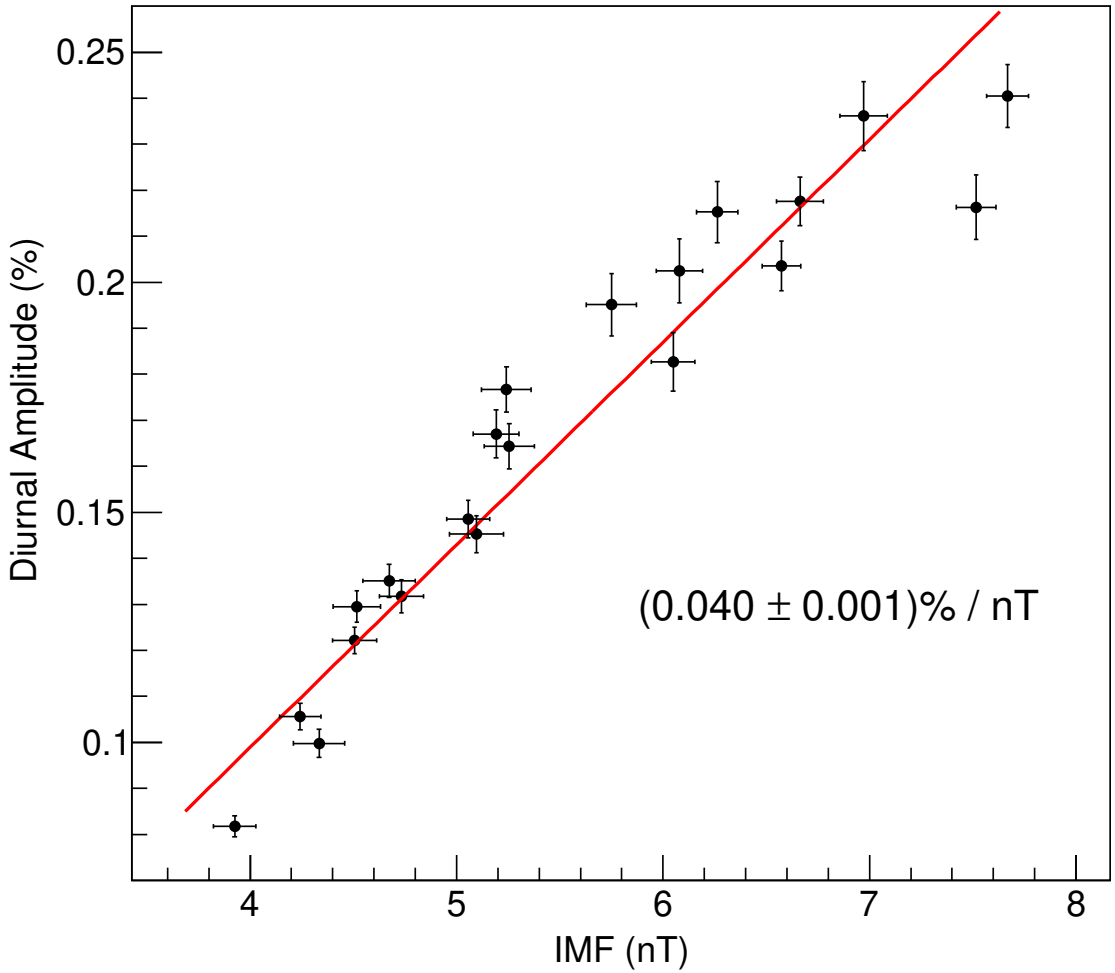


Yearly variation of DA Amplitude and IMF

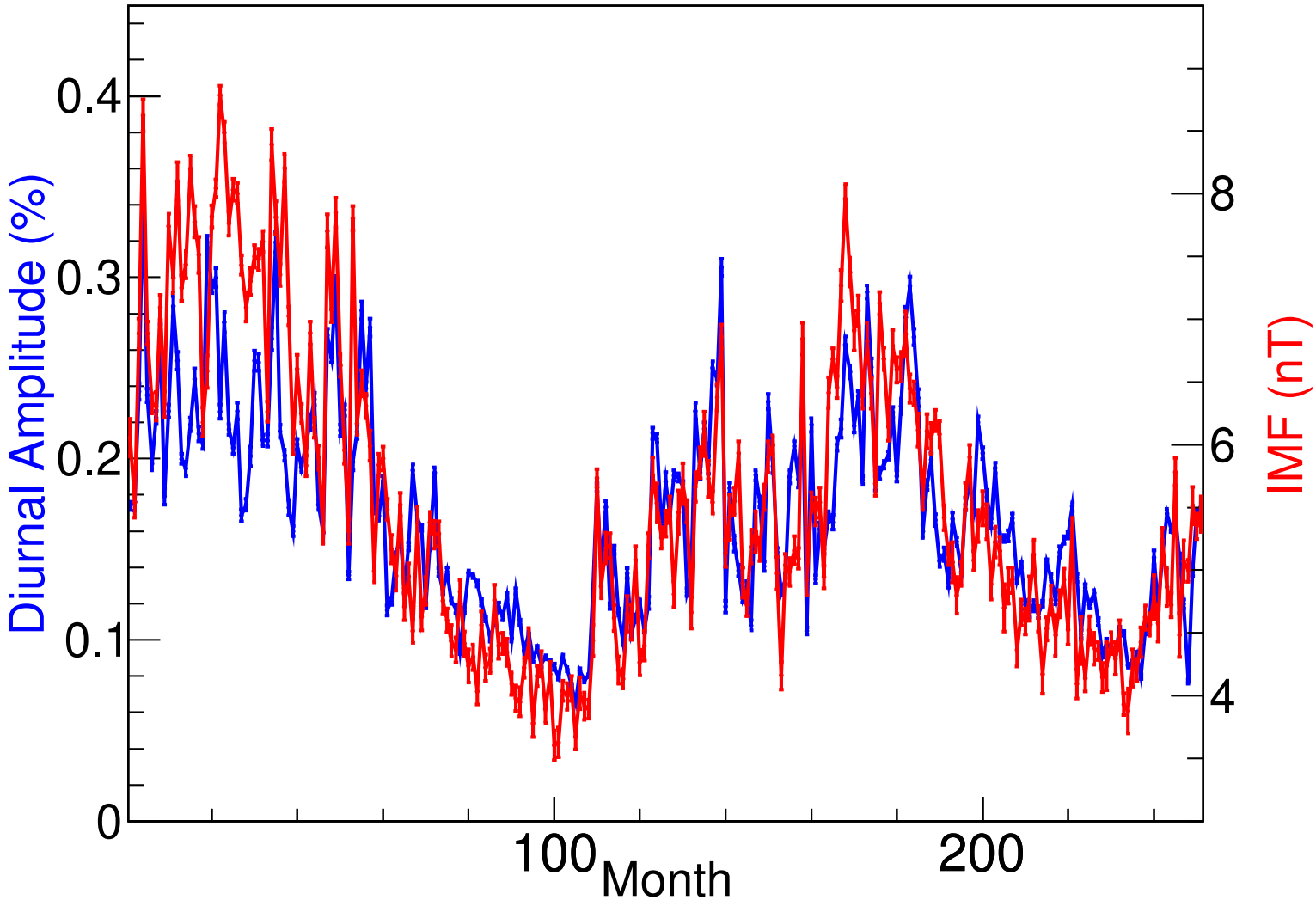


Yearly Relationship between DA Amplitude and IMF

Correlation Coefficient = 0.95 ± 0.07

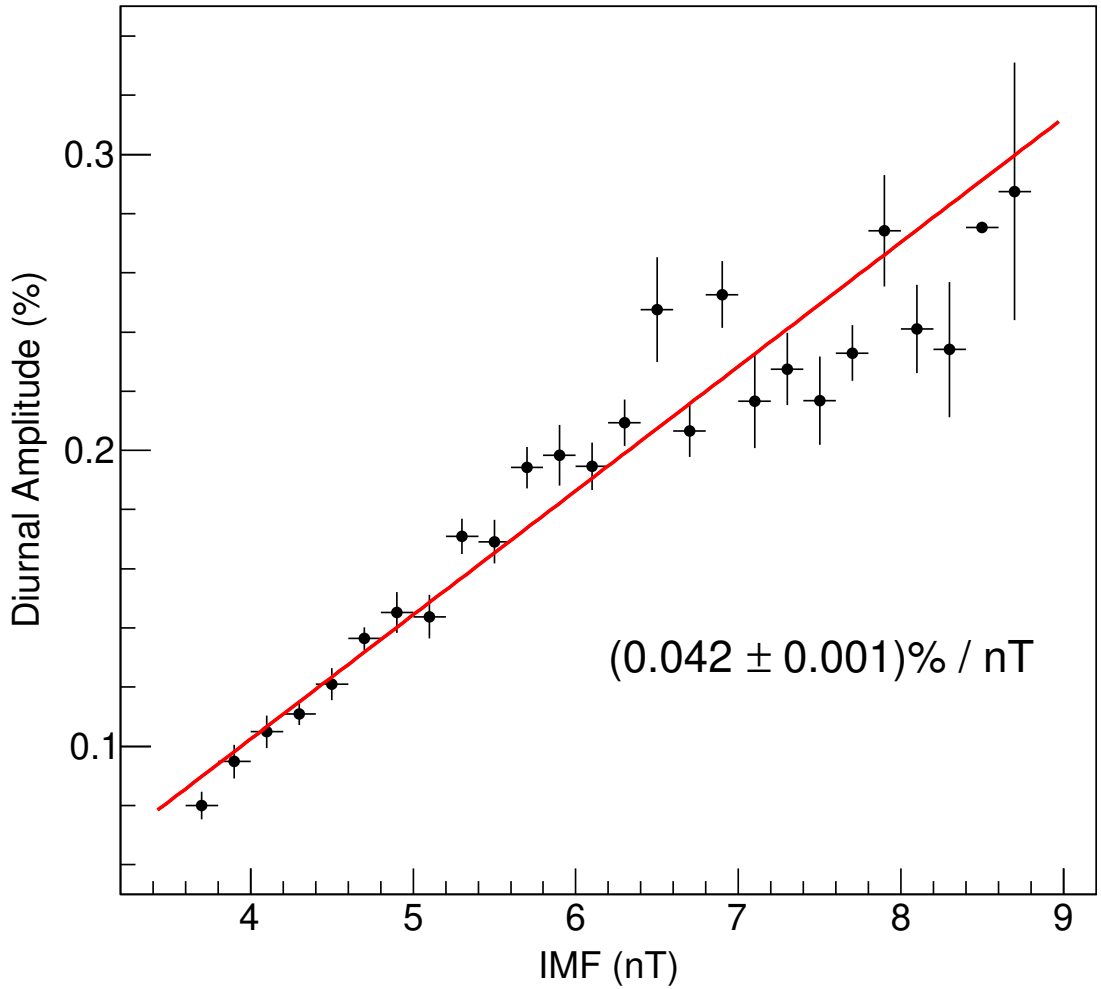


Monthly variation of DA Amplitude and IMF



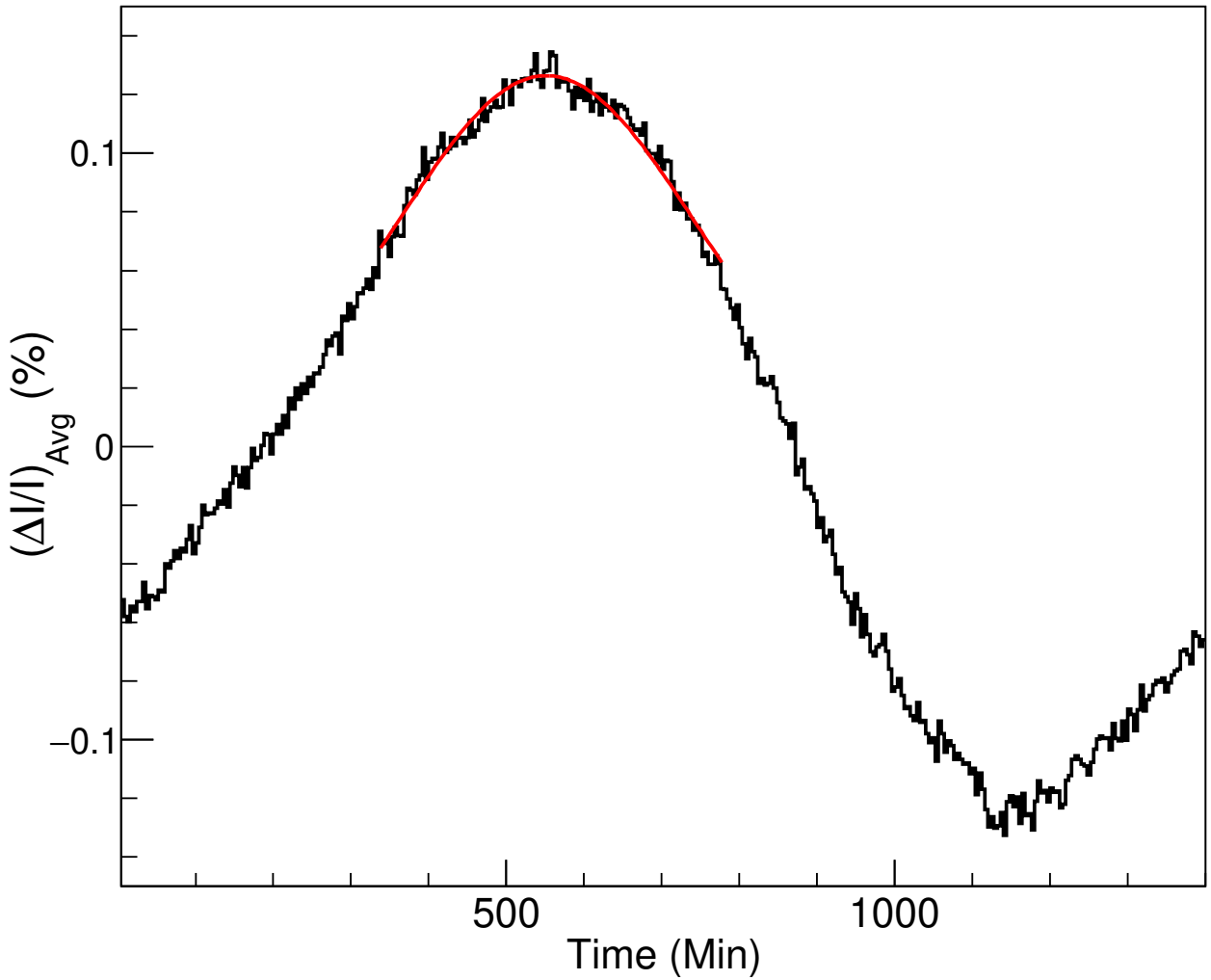
Monthly Relationship between DA Amplitude and IMF

Correlation Coefficient = 0.85 ± 0.03

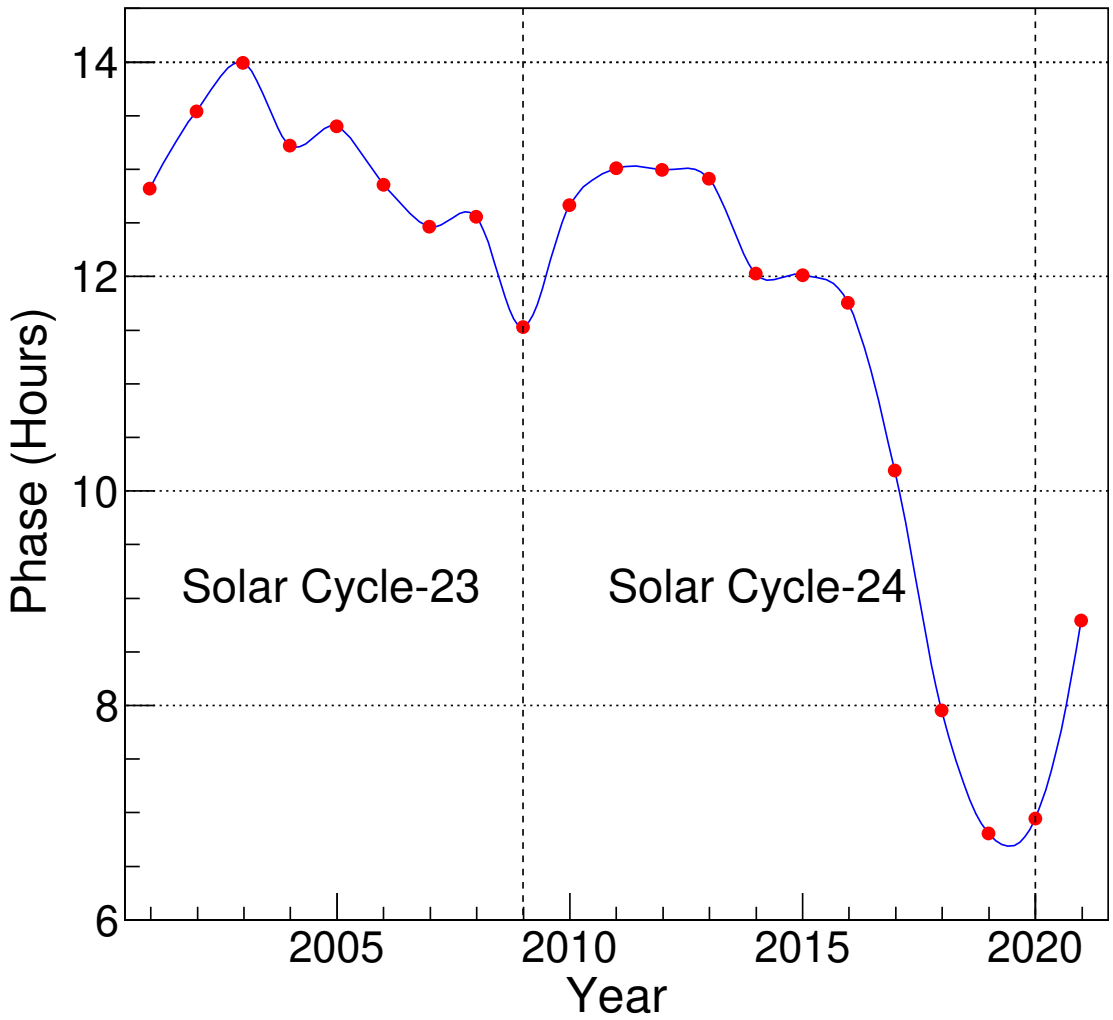


Yearly Phase Determination (Year-2021)

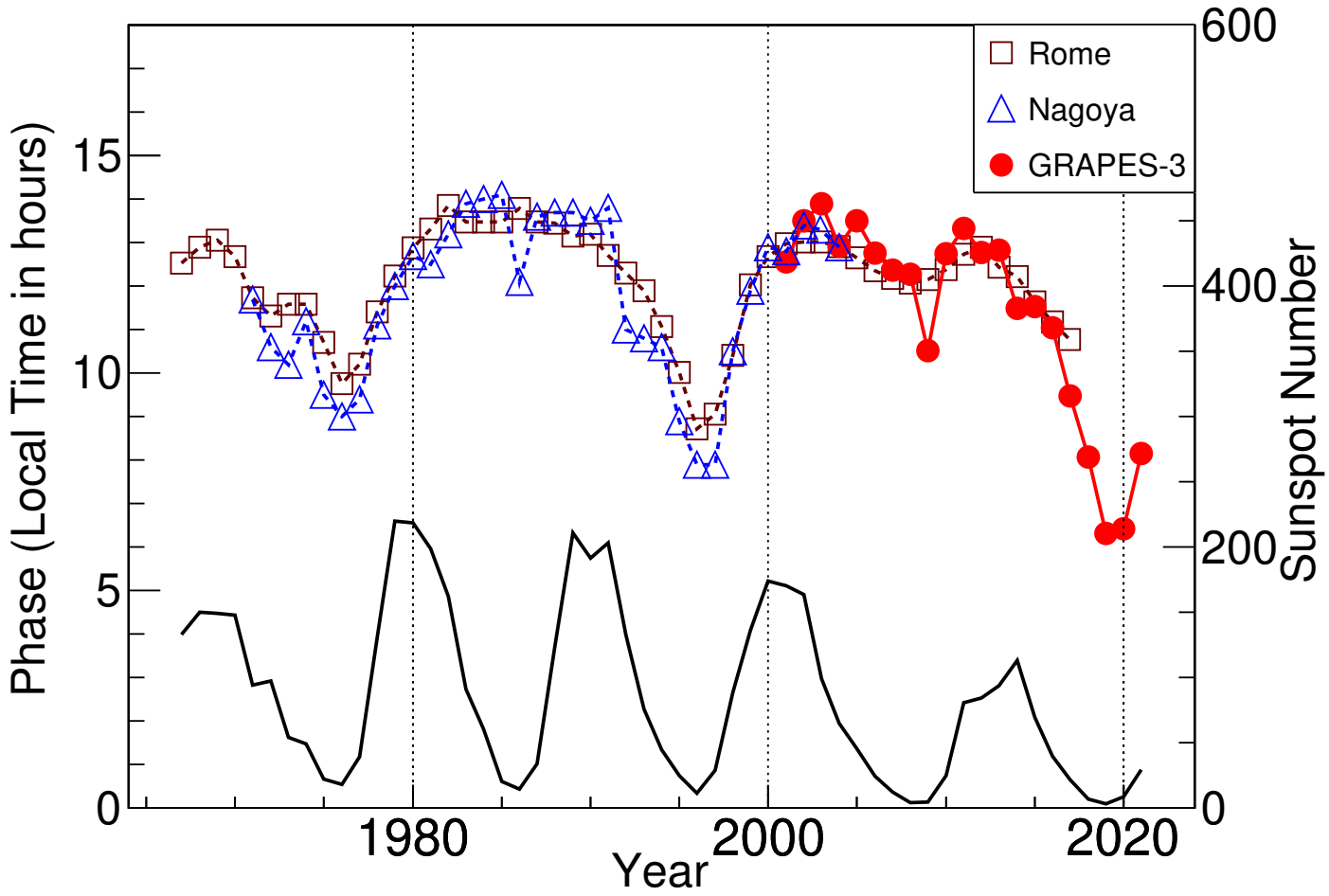
The filtered data is folded modulo 24 h for each year.



Yearly Phase Variation



Yearly Phase Variation



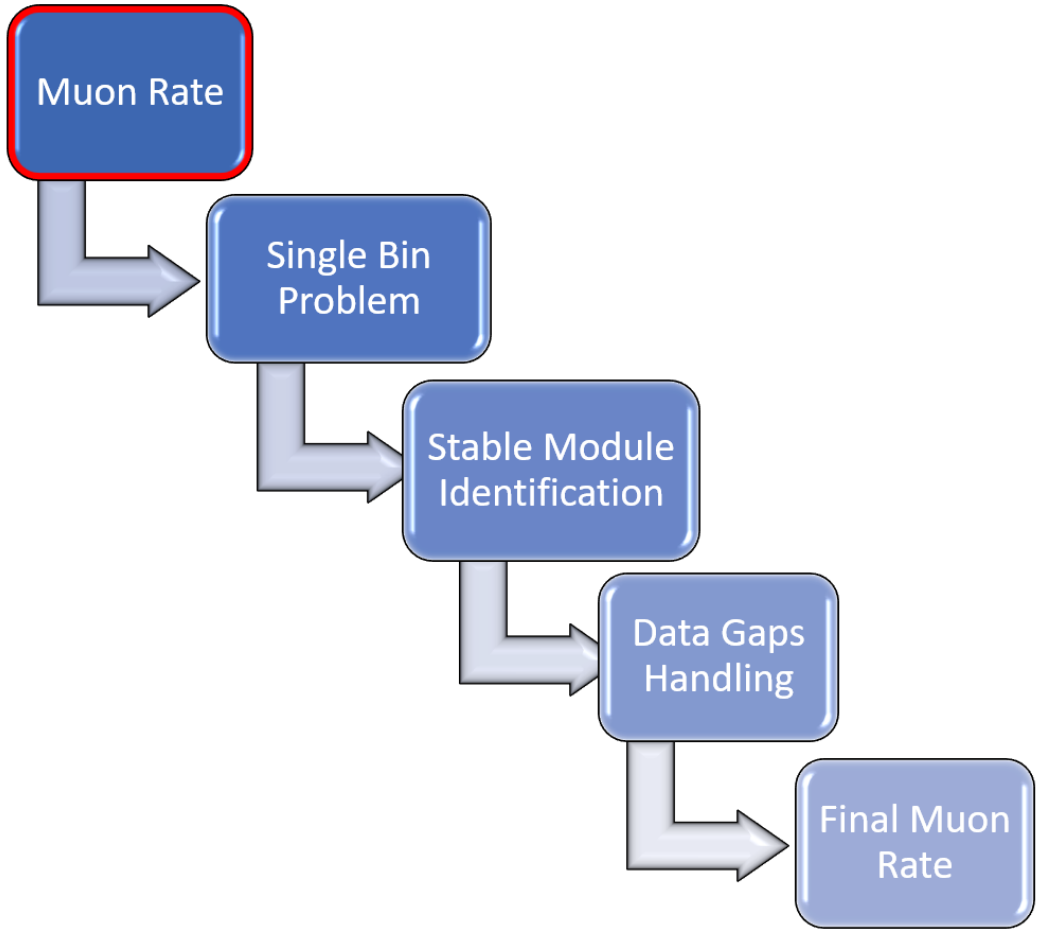
Rome Data: E.H. Park et al., J. Astron. Space Sci. 35(4), 219-225 (2018)

Summary

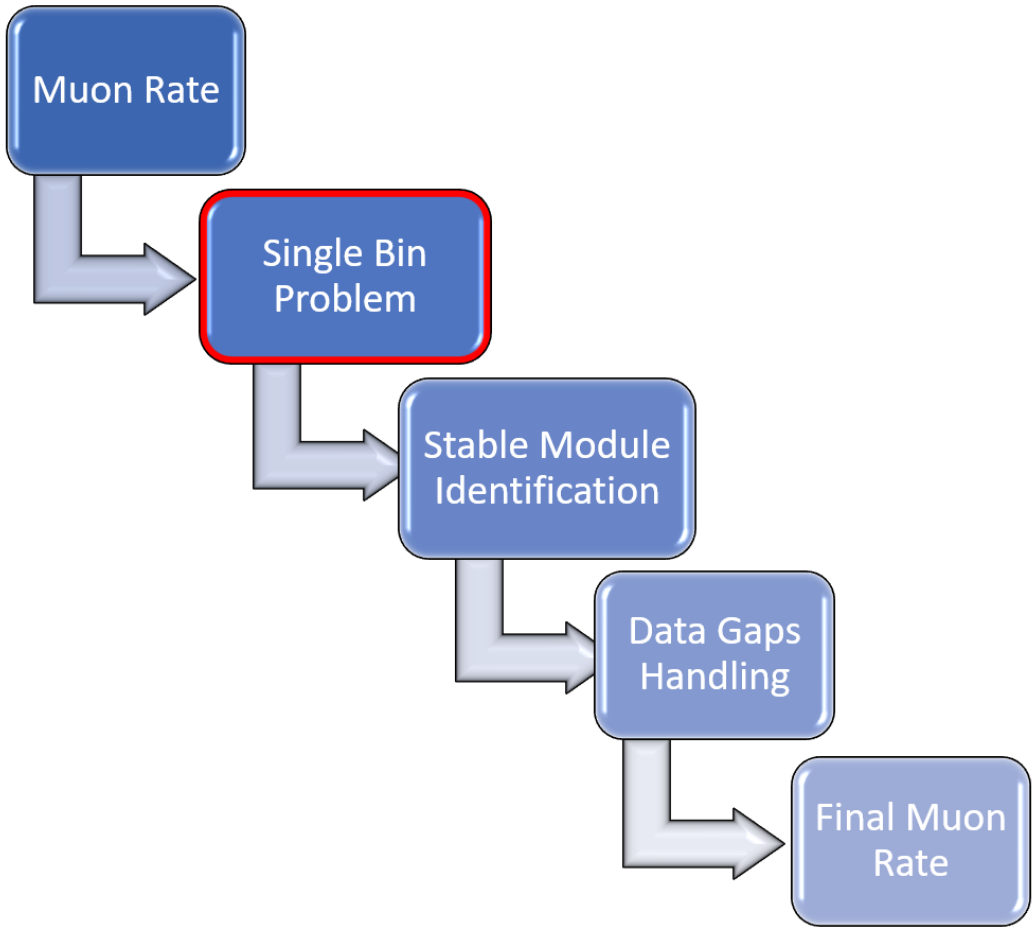
- A continuous data stream of G3MT for 21 years (2001-2021) is prepared after taking care of the intermittent and long-term problems.
- The pressure corrections are applied using the pressure coefficient obtained from the min solar activity period (2020) data.
- A strong correlation is observed between solar diurnal anisotropy (SDA) and the interplanetary magnetic field (IMF) on yearly and monthly time scales; hence it can be used as a good proxy for the IMF.
- The phase of the SDA shows a prominent 22 Y periodicity corresponding to the time shift towards the earlier hours for minimum solar activity periods.


THANKS

Flow of Data Handling



Flow of Data Handling



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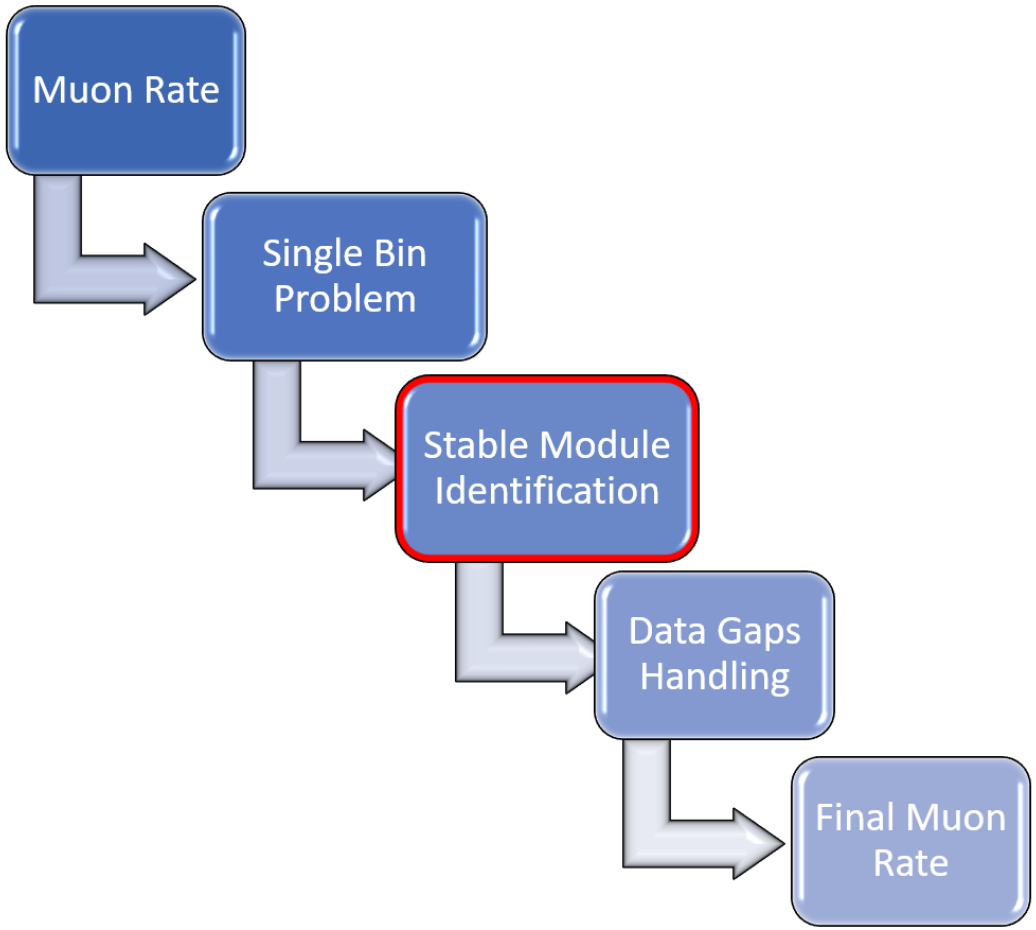


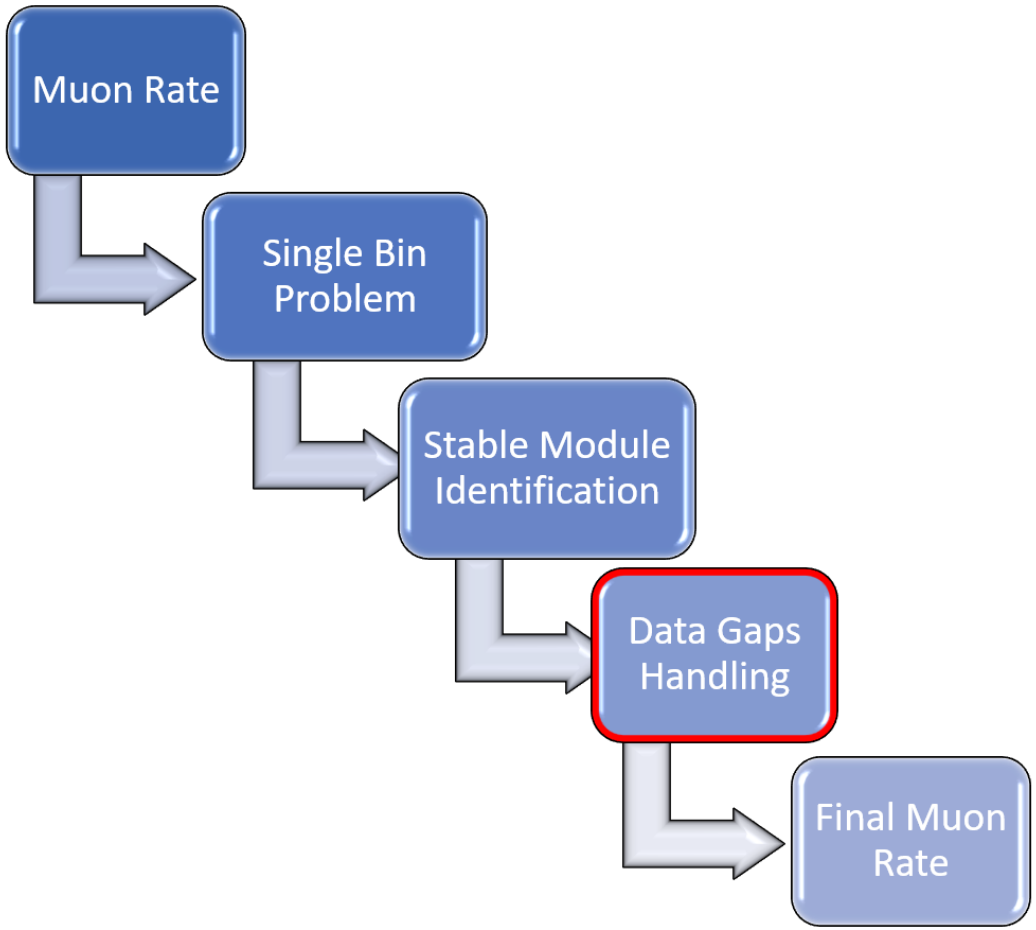
Single Day Module Problem Handling

- The lowest RMS module (RMS > 0) is considered as a most stable module of the day.
- After identification of the stable module, the ratios of other modules with stable module are calculated

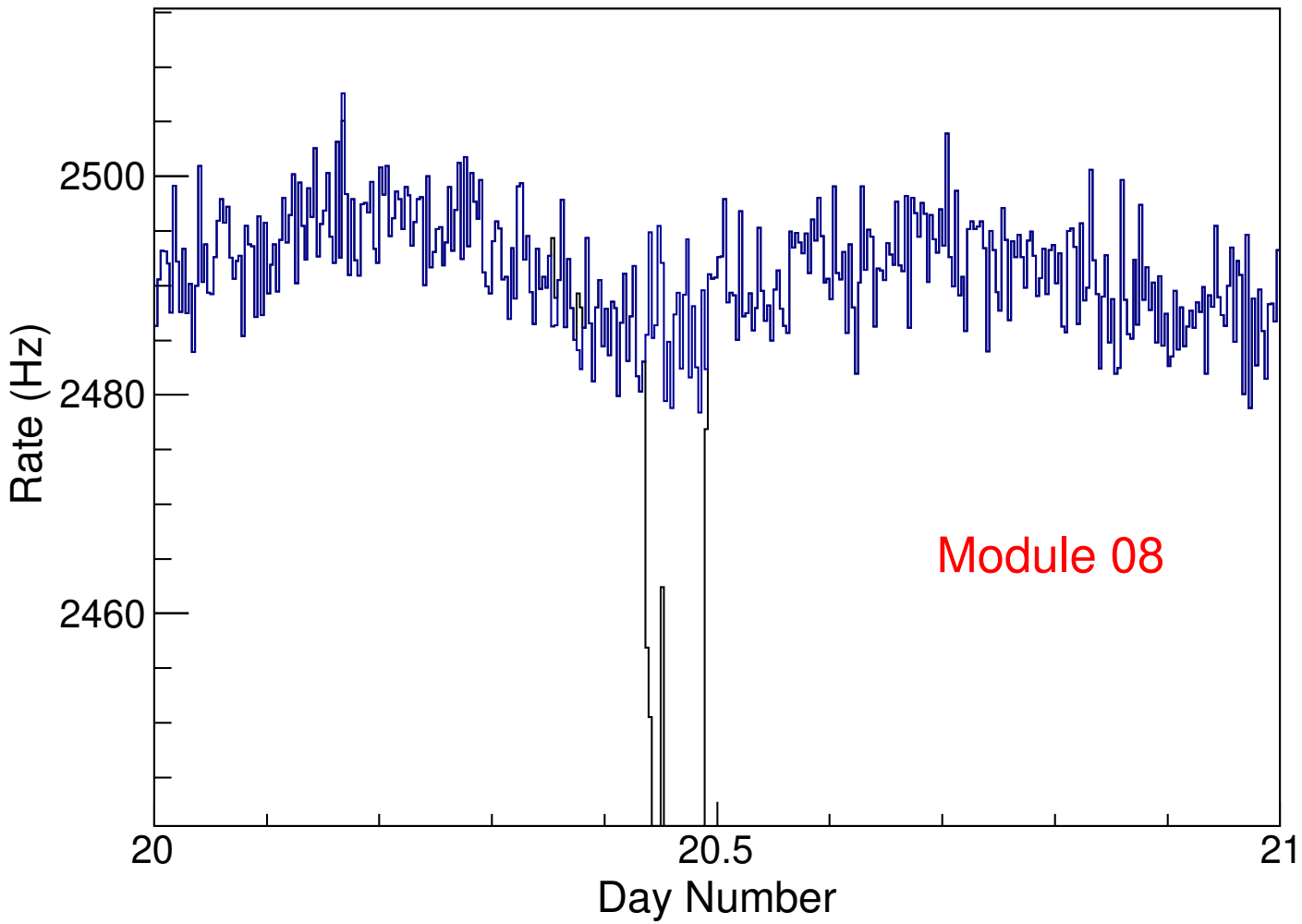
$$\text{Ratio}_{K-Module} = \frac{K-ModuleMean}{StableModuleMean}$$

- Now these ratios are used to fill the missing data of all other modules by using the stable module data.

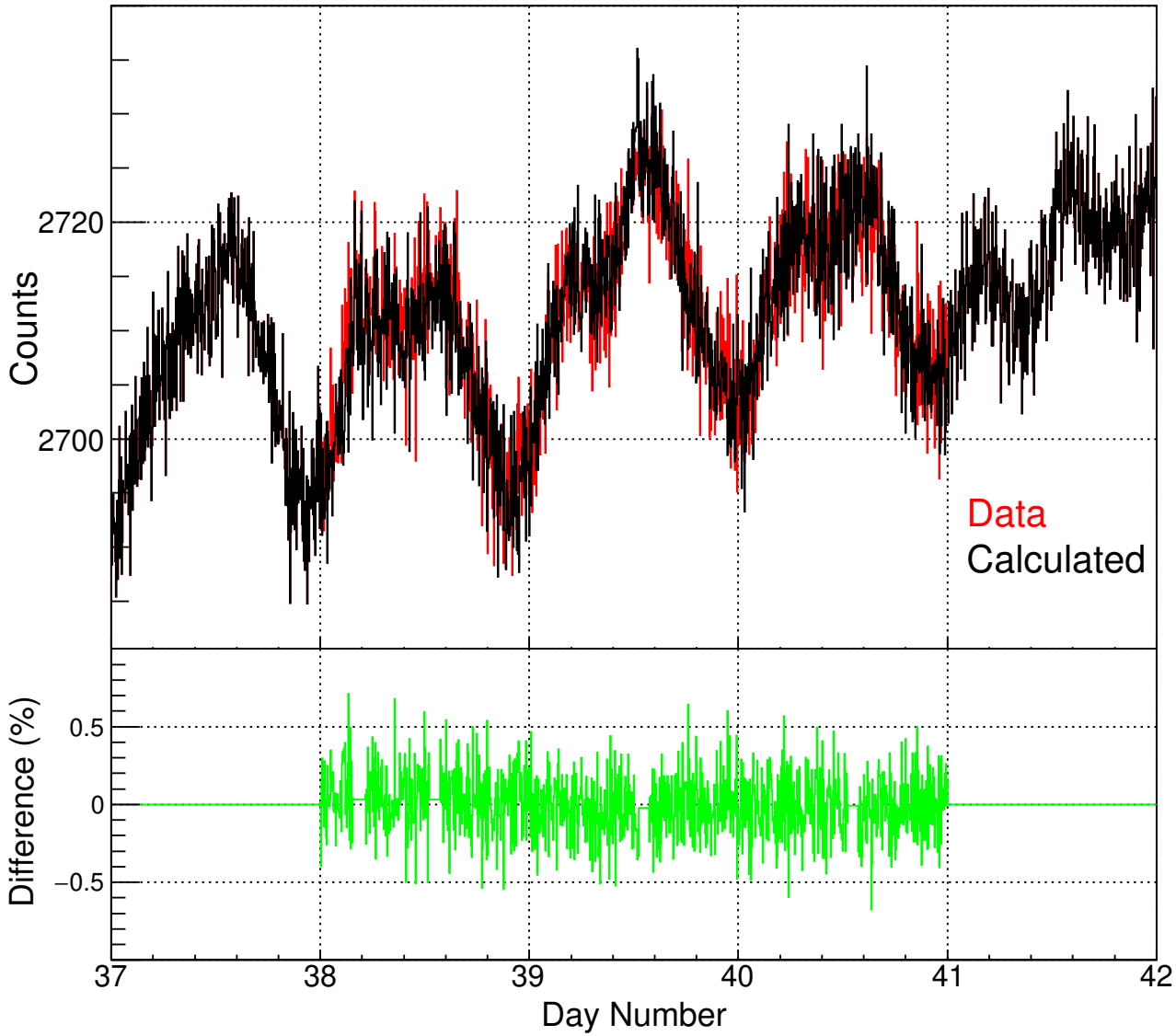
Flow of Data Handling



Single Day Module Problem Handling



Module Rates Comparison



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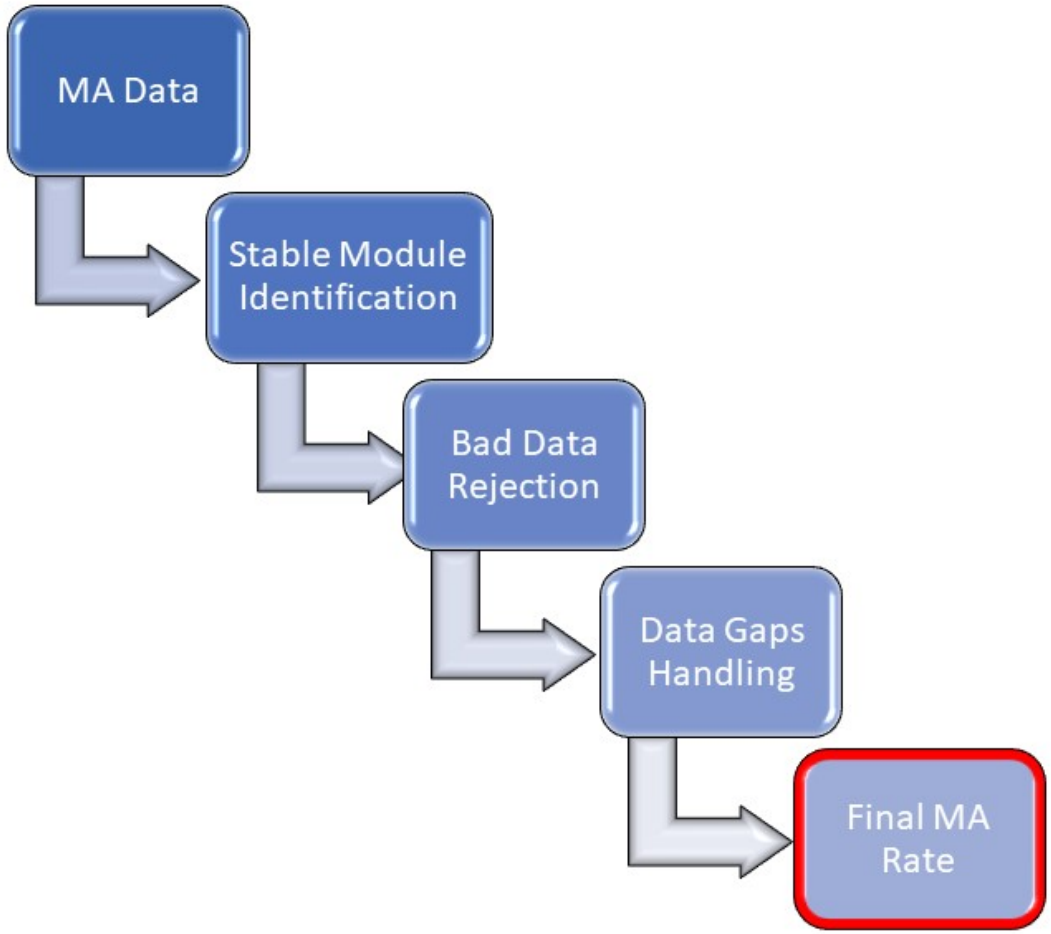
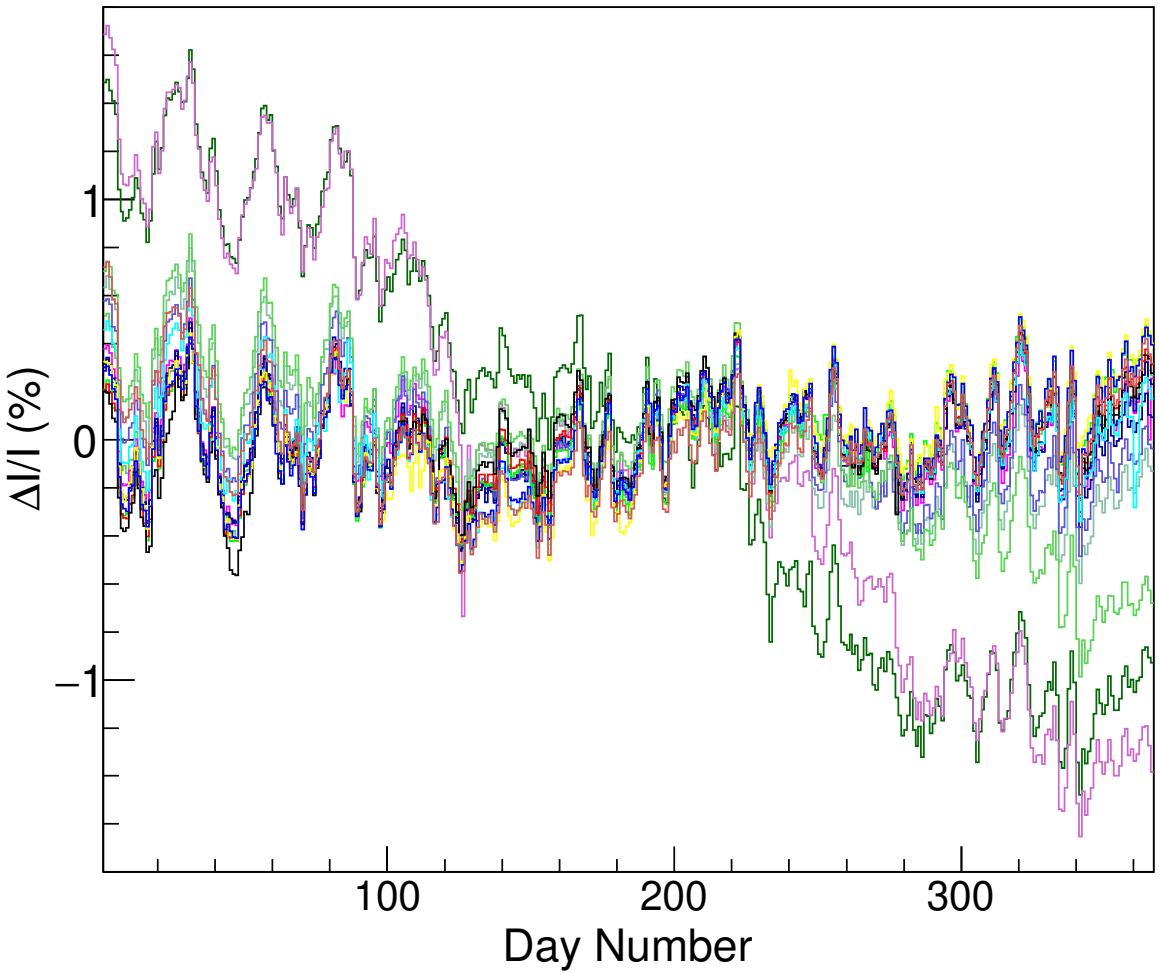
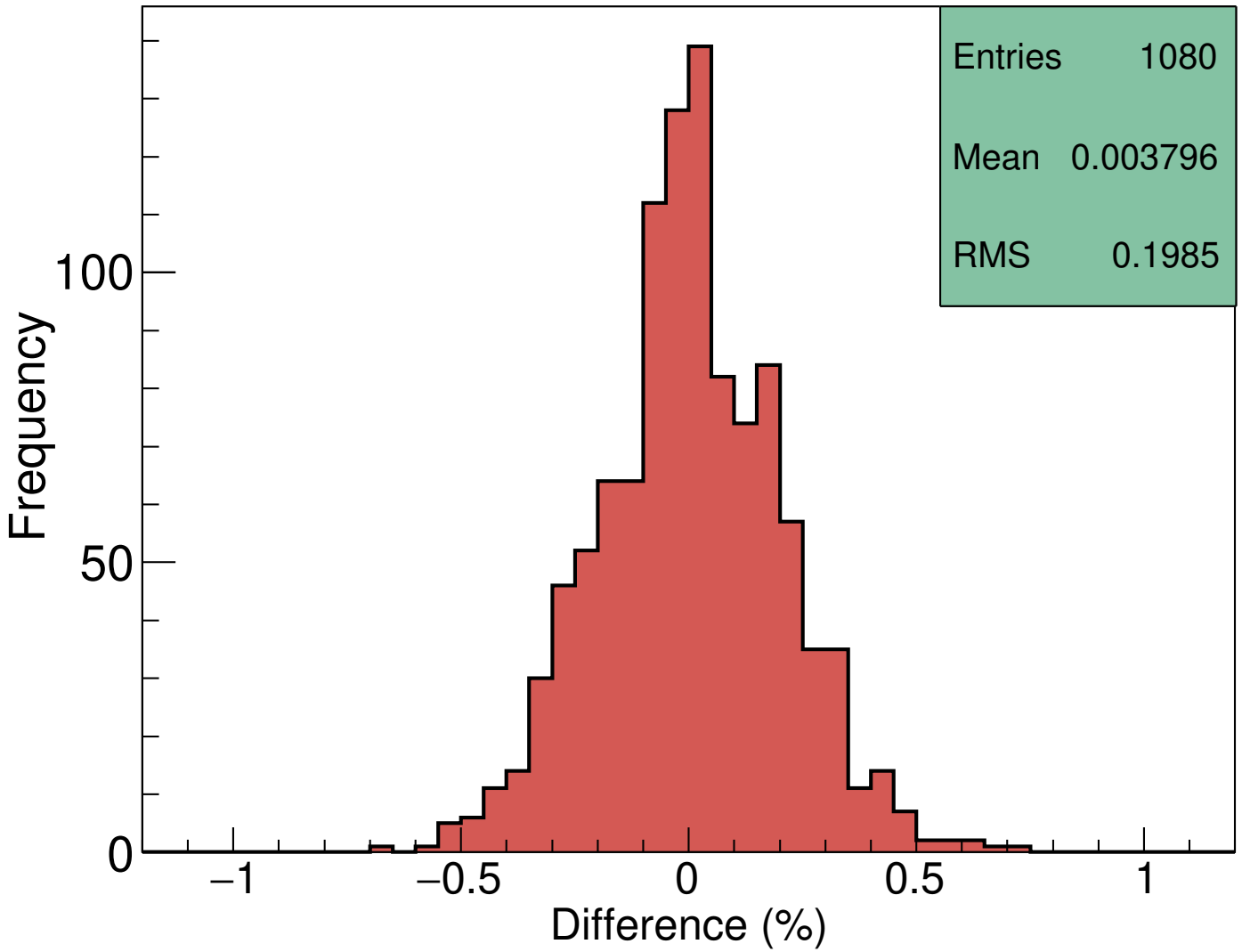


Long-term Module problem Handling (2008)

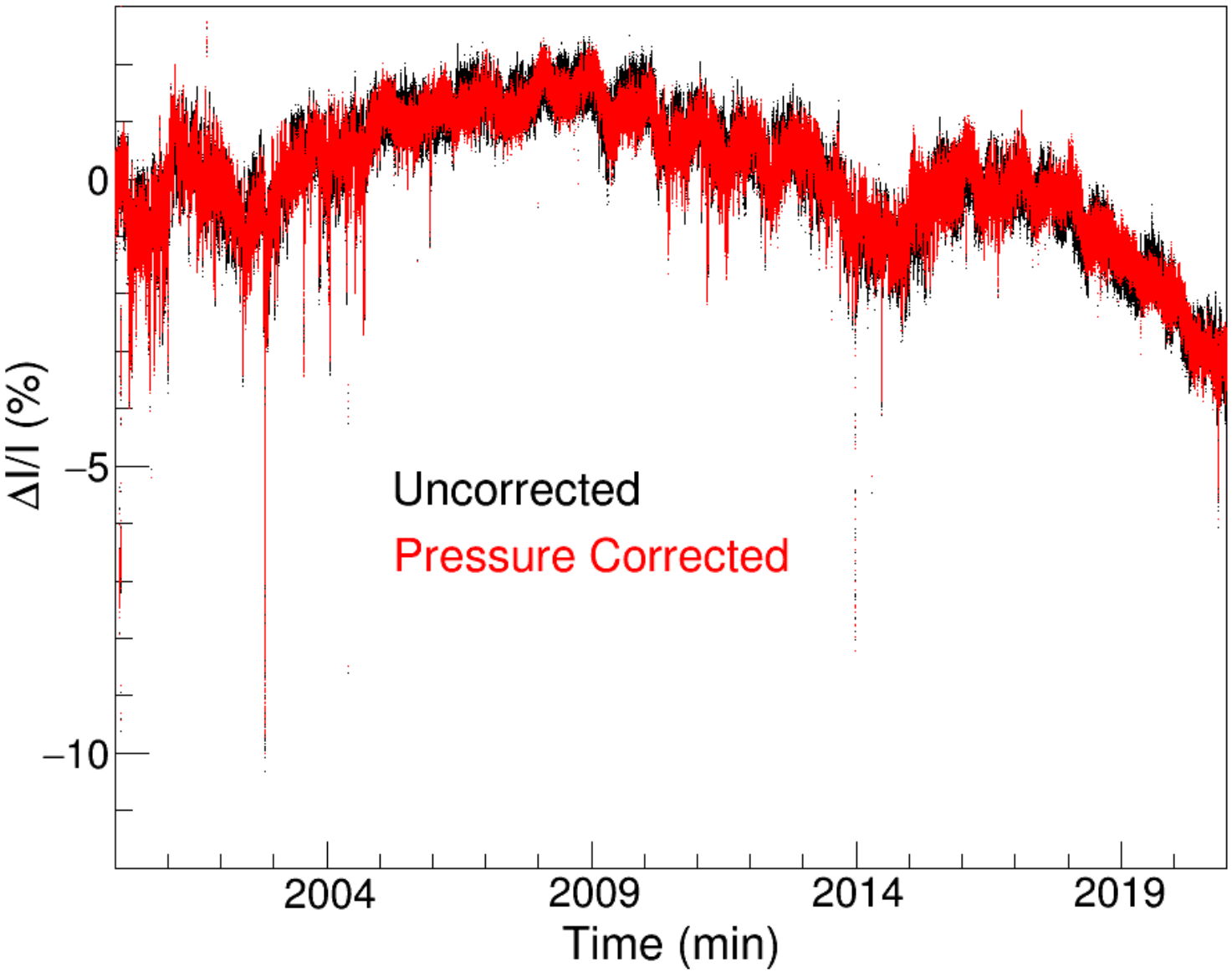
The normalized module rates are averaged over one day.



Data Gaps Handling



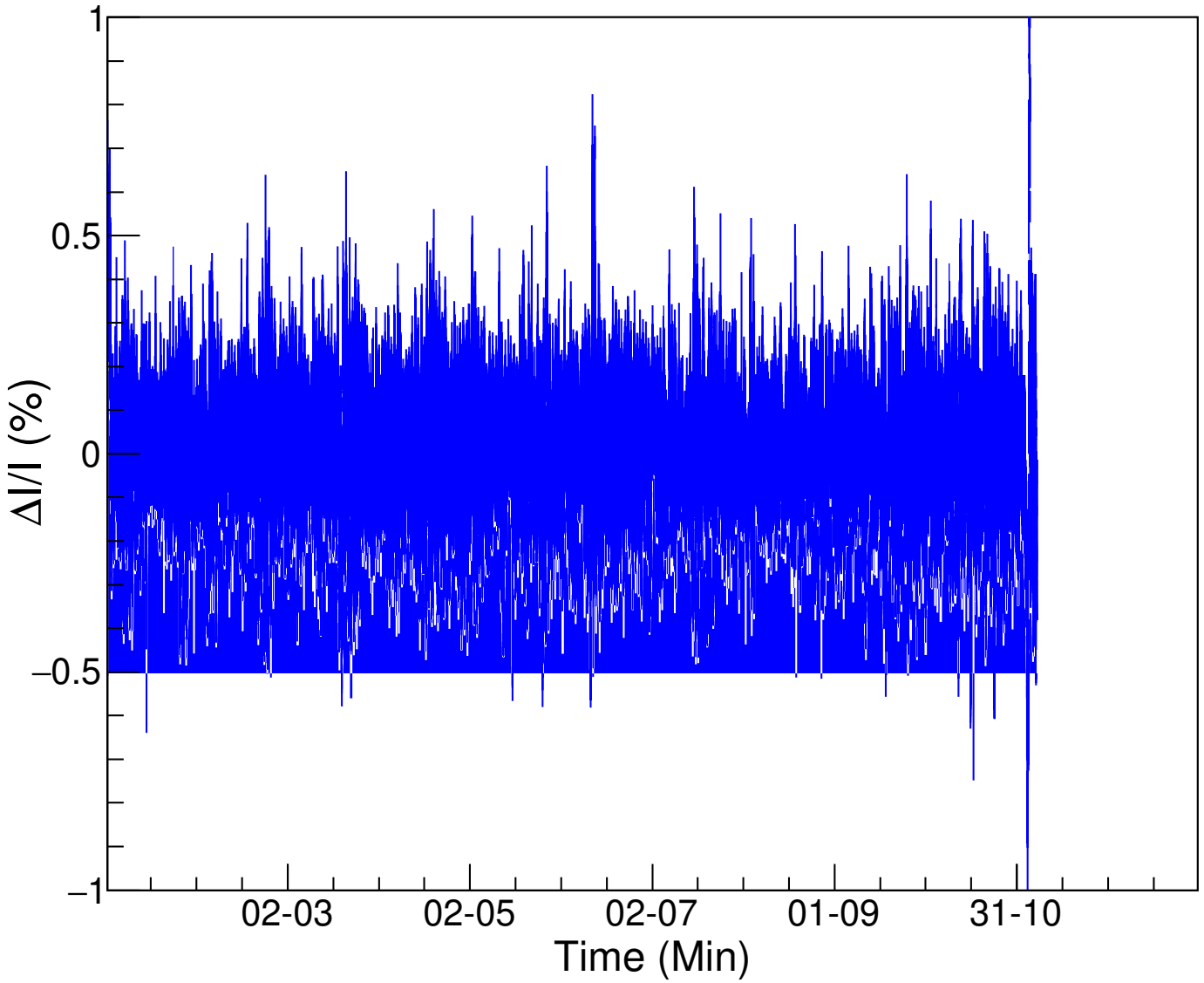
Atmospheric Pressure Correction (2001-2021)



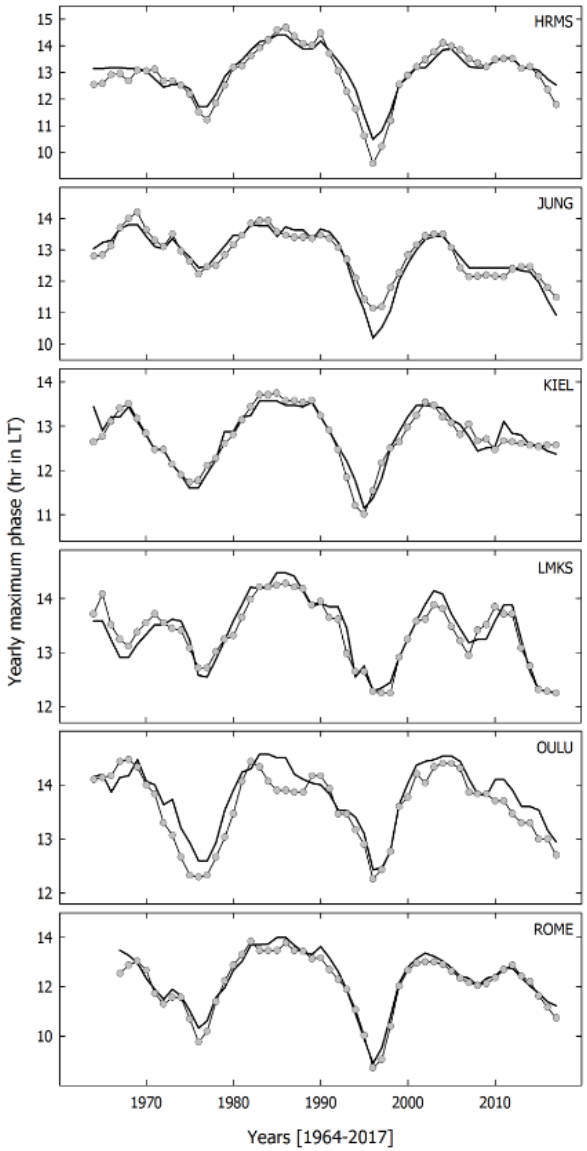
Solar Diurnal Anisotropy

- The modulation effects of cosmic rays have been extensively investigated to understand the solar terrestrial environment.
- Ground based detectors record the diurnal variations every day as their acceptance cone sweeps through the direction containing the spatial anisotropy.
- The solar diurnal anisotropy (SDA) variation of cosmic ray intensity shows significant day-to-day variation reflecting the continuously changing conditions in the interstellar space.
- The quantitative study of SDA amplitude and phase can better understand daily solar modulations and their relationship with other solar parameters.

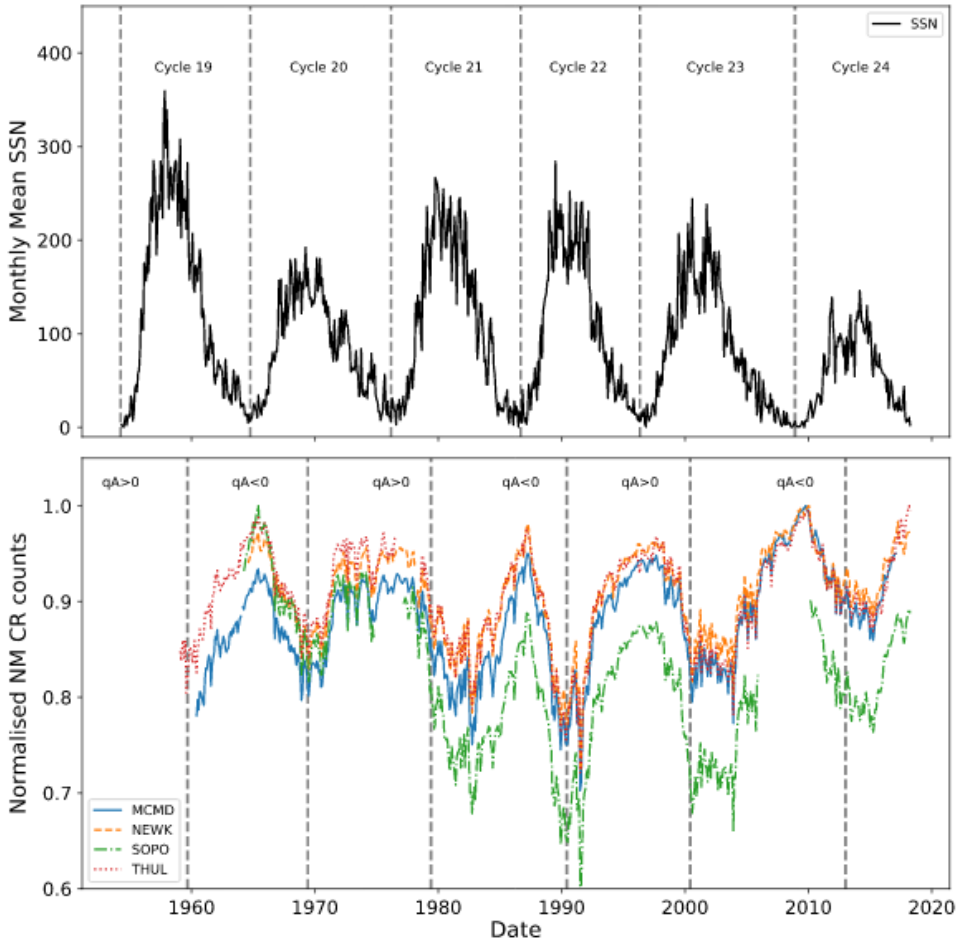
Data Filtering (Year-2021)



NM Phase Variations



Motivation



Ref: E. Ross et al., Solar Physics 294, 8 (2019)