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Annual quasiperiodicity in muon rate observed by PolarquEEEst detectors at 79°N

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Abstract. Since 2019, three scintillator-based cosmic ray detectors, readout by SiPM and controlled by low-cost electronics, are installed in the scientific research site in Ny Ålesund (Svalbard) at 79°N, recording muons from secondary cosmic rays. The detectors are part of the EEE Project, a joint project of Centrofermi and INFN, involving almost 100 secondary schools in Italy. After collecting nearly 5 years of data, we were able to analyse the muon rate time series and observe an evident oscillating component with a period of about one year. Applying the Lomb-Scargle periodogram technique, based on sinusoidal fit optimization, we could quantify the annual component, after verifying its independence from environmental and experimental factors.

1. The PolarquEEEst Project and the POLA-R detectors

For several years now, the EEE Project [1] has been bringing science into schools, involving students and teachers in assembling, installing and operating cosmic muon telescopes, based on Multigap Resistive Plate Chambers (MRPC). Today, the EEE Project has 50 MRPC based telescopes, installed in high schools in several cities in Italy. Many other schools participate in data analysis, allowing their students a unique experience of collaborative scientific research.

In 2019, after a successful expedition to northern latitudes [2] with a compact, scintillator-based, muon detector, called POLA-R, the PolarquEEEst Project was launched. In the spirit of EEE, three POLA-R muon detectors were assembled by students and installed in the international research base in Ny Ålesund, Svalbard Archipelago [3]-[4].

Muon measurements at high latitudes are very rare, but it is precisely in these regions that it may be interesting to examine cosmic radiation, where the deflection of the Earth's magnetic field is less efficient.

Figure 1 shows the positions of the three POLA-R detectors, labelled POLA-1, POLA-3 and POLA-4, installed at distances between 700 m and 1100 m each other, in buildings equipped with power and network connections, managed by the Italian CNR. An additional, similar detector, POLA-2, was also positioned in an INFN site at lower latitudes, for reference.

1.1 POLA-R detector description

Initially designed to be installed on a sailing boat, a POLA-R detector is quite compact (0.78x0.56x0.30 m^3), light (less than 50 kg), and has a very low power consumption (13 W). It consists of two planes, each composed of four scintillator tiles (surface 0.3x0.2 m^2), each one equipped with two silicon photomultipliers (SiPM), for a total of 16 channels (Figure 2).

The sensors' system and data acquisition are realised with low-cost commercial components (Raspberry Pi), while the trigger and frontend board were produced inside the collaboration [5]. POLA-R is equipped with several sensors, able to measure temperature in different positions inside and outside the device, atmospheric pressure, humidity, movements and magnetic fields. It is also equipped with GPS for exact positioning and timing, for coincidence studies between different telescopes.

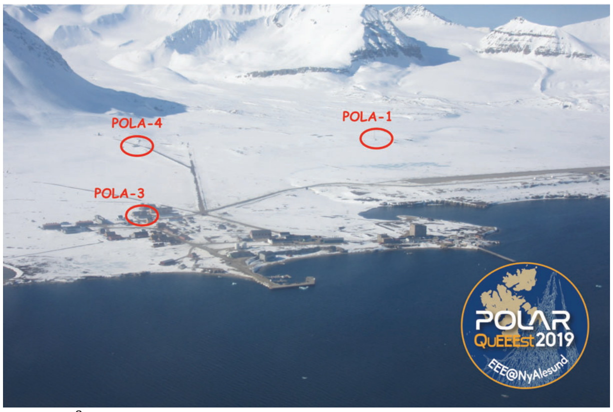

Figure 1. Aerial photo of Ny Ålesund, 79°N in the Svalbard archipelago. The red circles indicate the installation sites of the POLA-R detectors, inside buildings managed by the Italian CNR: POLA-1 in the hutch of the Climate Change Tower, POLA-3 inside the Dirigibile-Italia Base and POLA-4 in the Gruvebadet Laboratory.

1.2 Rate measurements

Data measured by POLA-R are first saved locally, and then sent to the INFN-CNAF computing centre, where the EEE Project's computing infrastructure is being operational for several years. At INFN-CNAF data are calibrated, corrected and stored, together with data recorded by the 50 MRPC telescopes of the EEE Project.

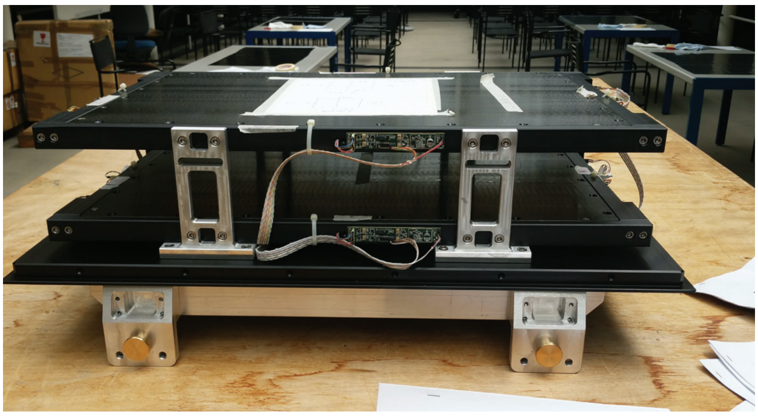

Figure 2. Close-up photo of the two planes of a POLA-R detector, during the assembly phase. Assembly was performed at CERN by high-school students, under the supervision of EEE researchers.

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The muon rate time series is obtained by collecting accepted events in bins of fixed time duration. The plot in Figure 3 shows the rate recorded by the three POLA-R detectors, with a 12 hours binning. The gaps are due to malfunctioning and power interruptions in the research base, that were sometimes difficult to recover, due to the remoteness of the site. The black curve, labelled POLA-A, is the average of the three time series. Statistical errors are evaluated with the standard deviation of the values attributed to the same bin.

2. Quasiperiodicity preliminary analysis

2.1 Mathematical and computational methods: SSA, FFT and Lomb-Scargle periodogram

Even at first glance, the rate shapes shown in Figure 3 suggest the existence of a periodical

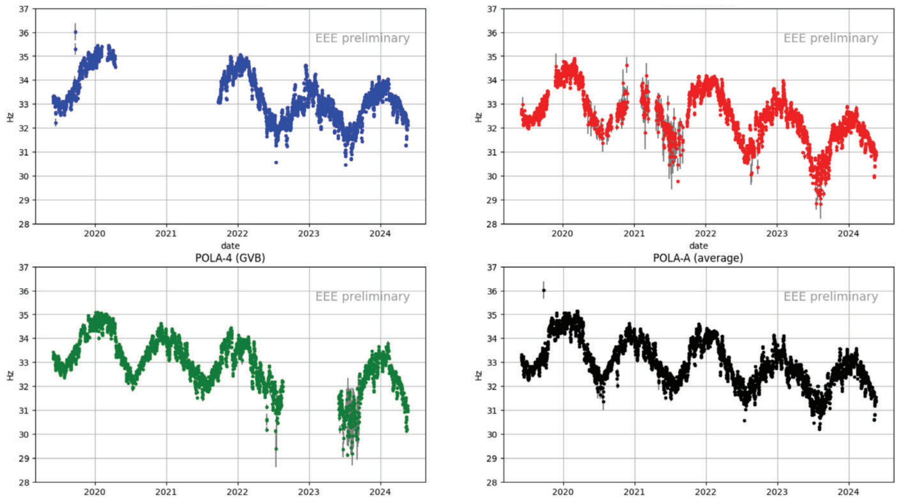

Figure 3. Muon rates recorded by the three POLA-R detectors. The black curve is the average of the three time series.

component. However, the presence of gaps in the datasets means that only short subsets of the time series can guarantee continuous and evenly spaced data.

The most common algorithms for the study of periodic components, like Fast Fourier Transform (FFT) or Singular Spectral Analysis (SSA), despite their efficiency and simplicity, require evenly sampled data, and would therefore have limited application, in our case, undermining the study of annual or longer trends. We therefore focused on the Lomb-Scargle periodogram technique, developed in astronomy for frequency analysis of irregularly spaced data, consisting of least-squares fitting of sinusoidal waves [6]-[7].

The implemented method consents to highlight all the frequencies in the series, to calculate the phase and to build a periodic model. This will allow for further studies on residuals and deviations from the periodic model.

2.2 Quasiperiodicity in muon rates

The resulting Lomb-Scargle periodogram is shown in the Figure 4, where the frequency power is plotted, as a function of the period expressed in days. The highest peak corresponds to the dominant periodicity: POLA-R muon rates have an evident periodic component, with a period between 350 and 370 days, and a maximum occurring between the 1st and the 14th of January,

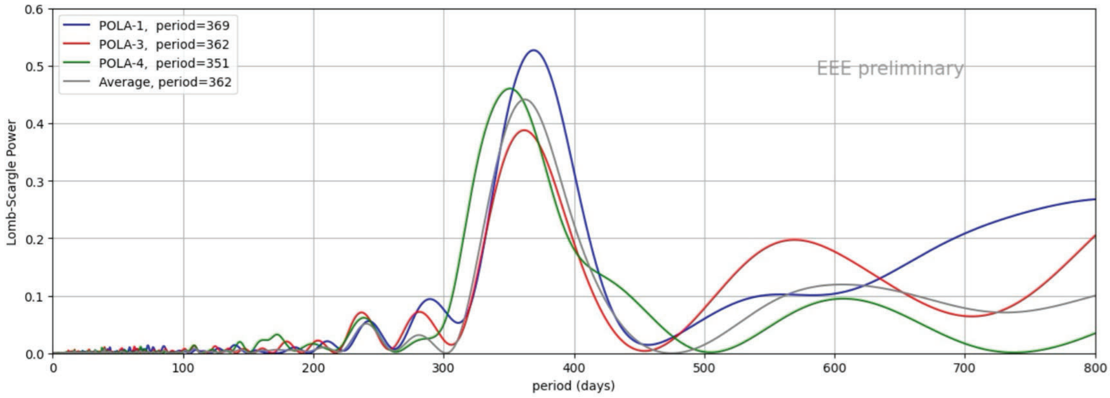

Figure 4. Lomb-Scargle periodogram for the three POLA-R time series and for the average rate.

compatible with an annual quasiperiodicity.

To verify the constancy of the annual periodicity, we computed the Lomb-Scargle periodogram for the average rate on a running time window, and plotted the results in a 2D graph (Figure 5). Periodograms are reported as vertical lines, as a function of the starting day. Colors

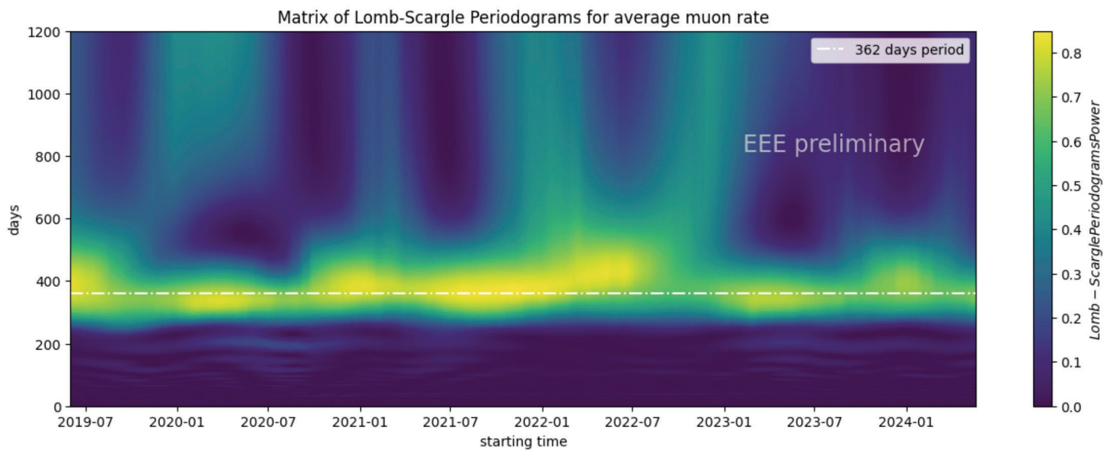

Figure 5. Lomb-Scargle periodograms computed over a running window of 600 days, plotted as a function of the starting time. The dashed line indicates the 362 days periodicity, a visual reference to confirm that the oscillation is stable within the considered time window.

define the frequency power. The plot confirms that the quasiannual periodicity is stable in time.

In Figure 6, the average rate time series is superimposed to the model with basic periodicity and linear trend. The decreasing trend is likely related to the undecennial solar cycle and is the subject of a further analysis. With a different binning and a careful selection of events, studies of possible higher frequencies are also being carried out.

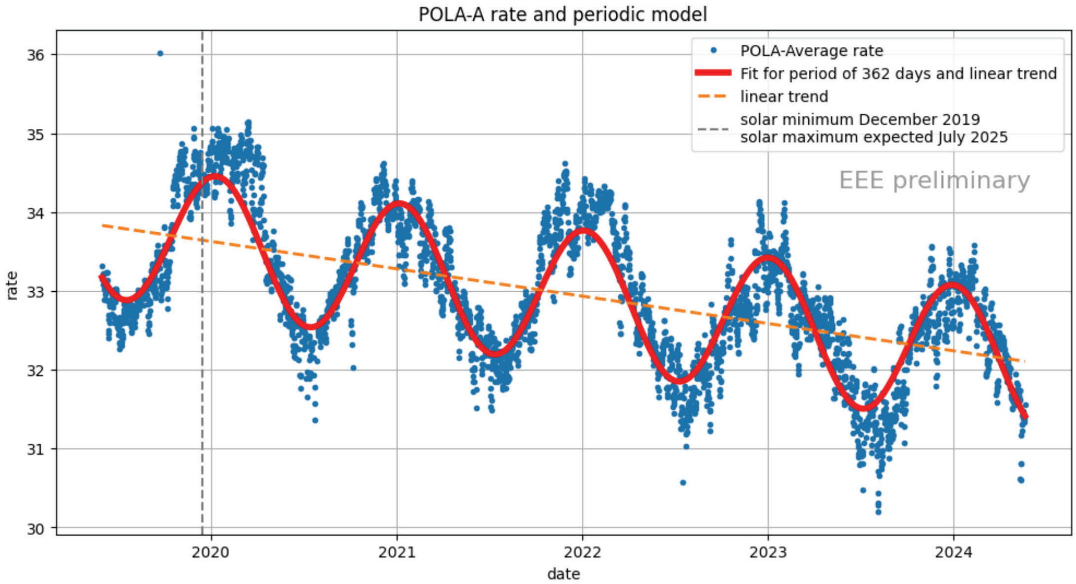

Figure 6. Average rate (in blue) with the first periodicity model on top (red curve). The annual model fits very well with the main oscillations in the muon rate.

Conclusions

The three POLA-R detectors installed in Ny Ålesund since 2019 have recorded five years of data, showing an evident annual quasiperiodicity. Applying the Lomb-Scargle technique we were able to quantify the annual dominant oscillation, to verify its stability in time, to buils models of the periodic components and identify further oscillations.

This study opens doors to several further studies, like the search for higher and lower frequencies. The comparison with other muon detectors and with neutron counters may also shed light on the nature and origin of these oscillations.

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