Periodicity in POLA rates

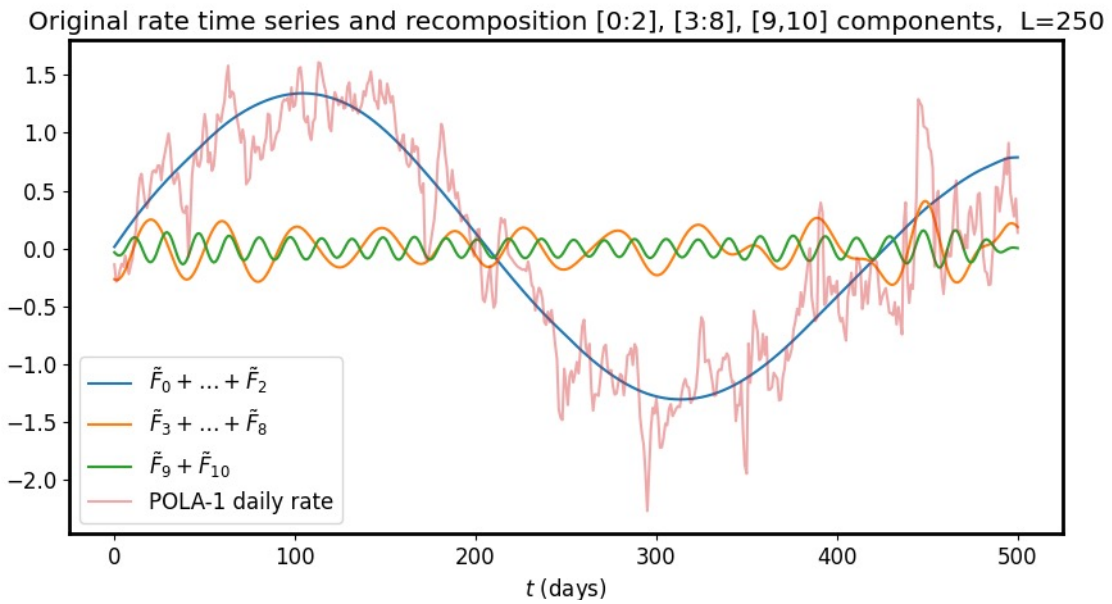
Part II

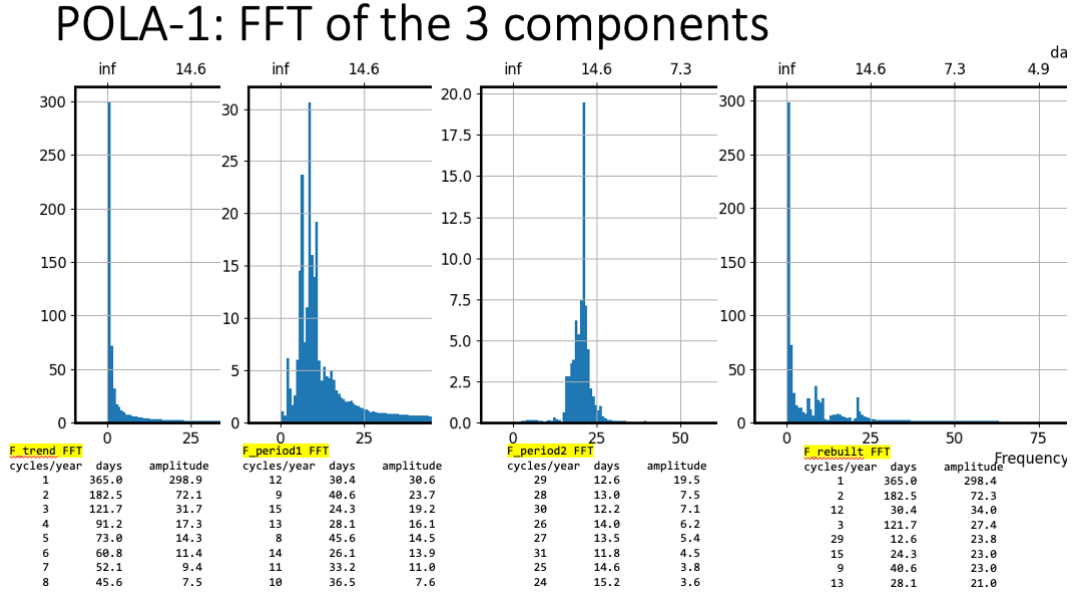
Ombretta Pinazza

November 2023

Periodicity – Part I (presented 4/5/2023)

- Searching periodicity with SSA (Singular Spectrum Analysis) and DFFT
  - Spectral technique able to separate trend, periodicity and noise
- Prerequisite: regularly sampled data
  - Missing data were filled with spline/interpolation





Francesco Nozzoli (presented 8/6/2023)

- Lomb-Scargle periodogram
  - able to detect periodicity for unevenly sampled data
  - able to take into account statistical/experimental errors

Francesco Noferini (presented 3/7/2023)

- New reconstruction for POLA-x rates

Periodicity analysis part II: LSP and new rates

- New reconstruction almost complete
- Error estimated according to FNozzoli
- Eliminating all values marked as bad, plus a few outlyers
- Computing Lomb-Scargle Periodogram (LSP) and identifying peaks
- Applying the same analysis to other time series

- Recent developments:
  - Computing LSP with running windows of 600 days and plotting in 2D
    - to find out if peaks change in time, like for gravitational waves
  - Signal reconstruction, analysis of residuals
    - to identify secondary components and noise

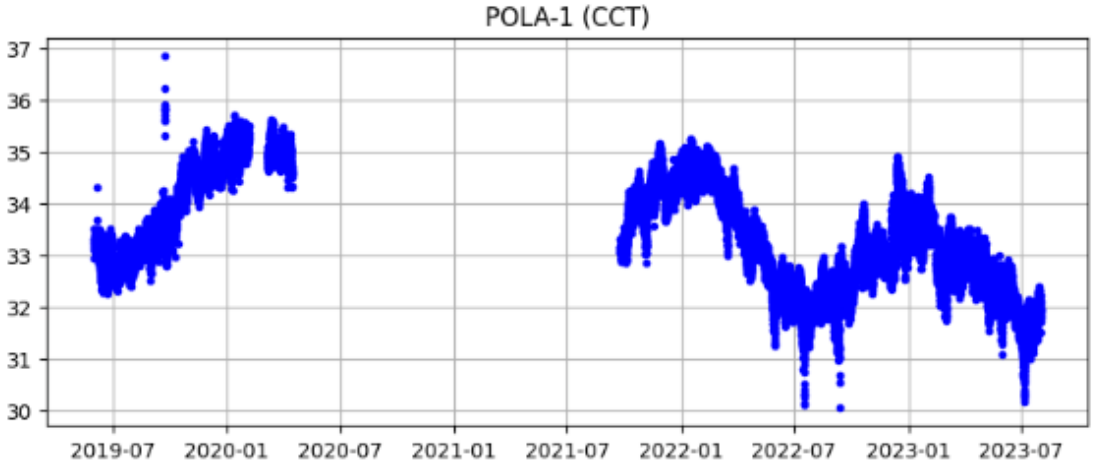
Available time series

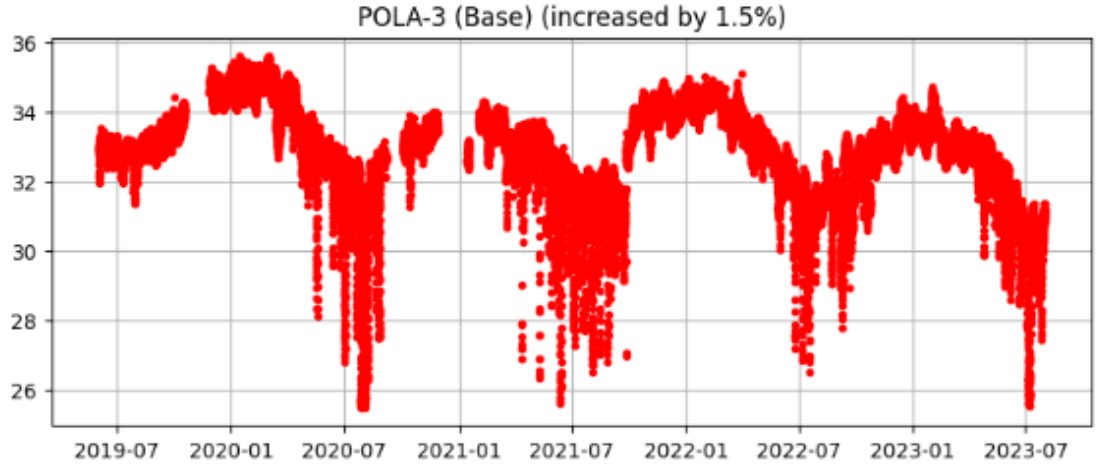
PQ2018=2018-05-01
NYA2019=2019-06-01

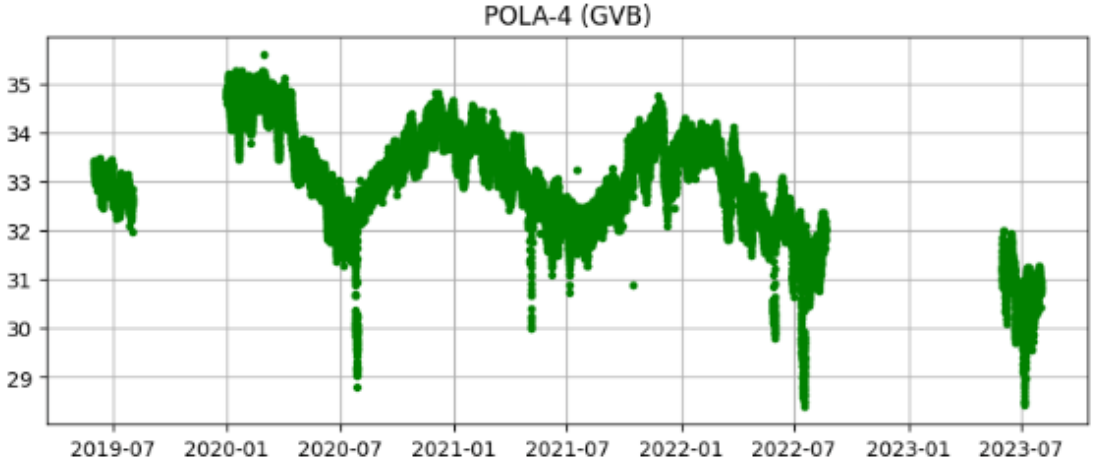
- POLA raw files
  - since PQ2018/NYA2019
- /recon2
  - since PQ2018/NYA2019
  - missing SH values for POLA-4 during 6 months in 2022/2023 →no pressure correction
- /home/eee/analisi/polarRates/
  - New reconstruction, **official rate data**, from PQ2018/NYA2019 to 2023-07-31
- neutron rates from NMDB (corrected for pressure and efficiency)
  - 1min-1h-1d resolution, differential and absolute value
  - OULU available since 1964
- Yang Ba Jin muon telescope (corrected?)
  - Available since 2012
- Kp/Ap/SSN data from NOAA
  - SunSpot Number available since 1932, 1day resolution
- Meteo data at Ny Alesund (CNR, 1 min res)
  - Pressure, temperature, humidity
  - Available from NYA2019 until 2022-12-31
    - with several holes during 2022, trying to fill with temperature datasets (10 min res) from Norwegian Meteorologial Insitute
  - soon I'll request 2023 data

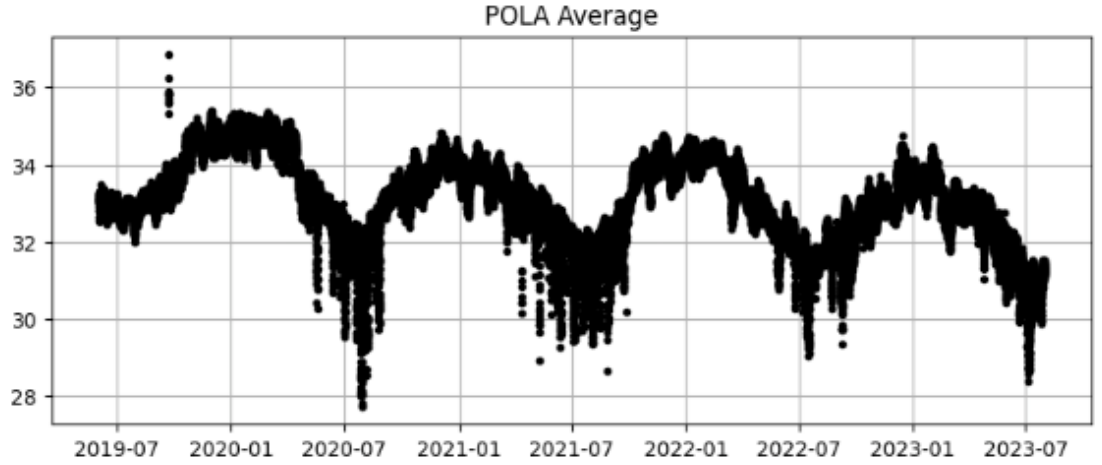
without error bars

New official time series for the POLA rates







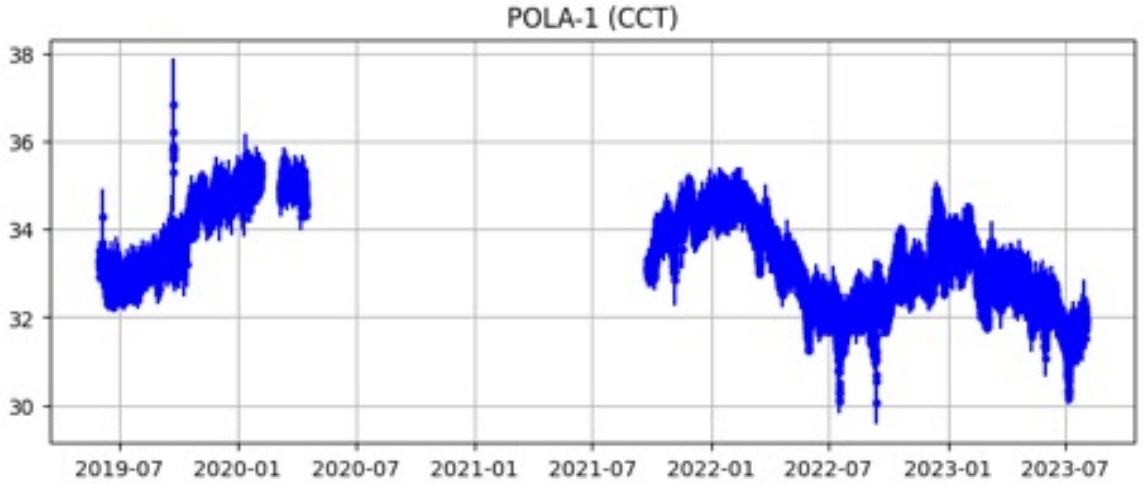


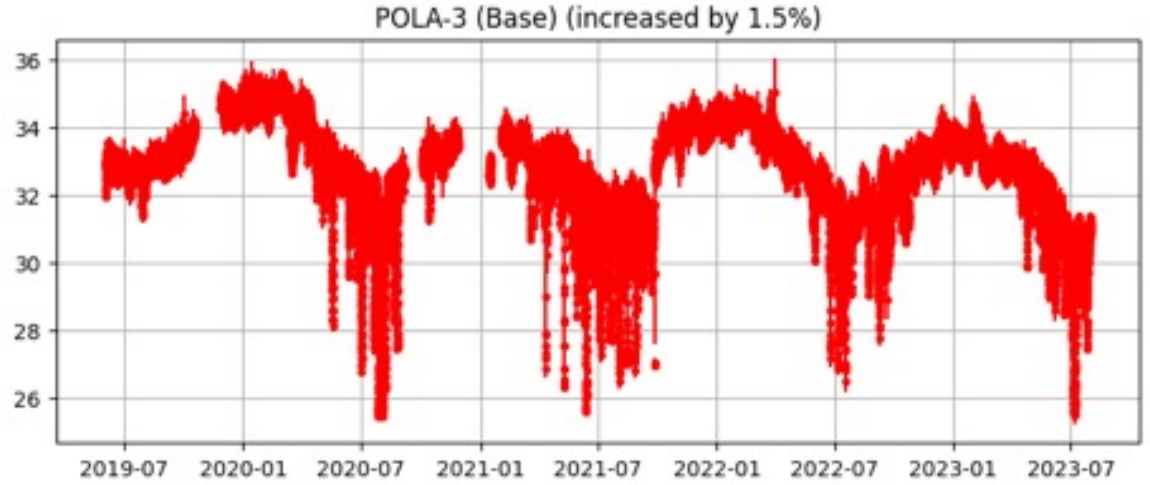
Incertezza statistica/sistematica proposta da FNozzoli

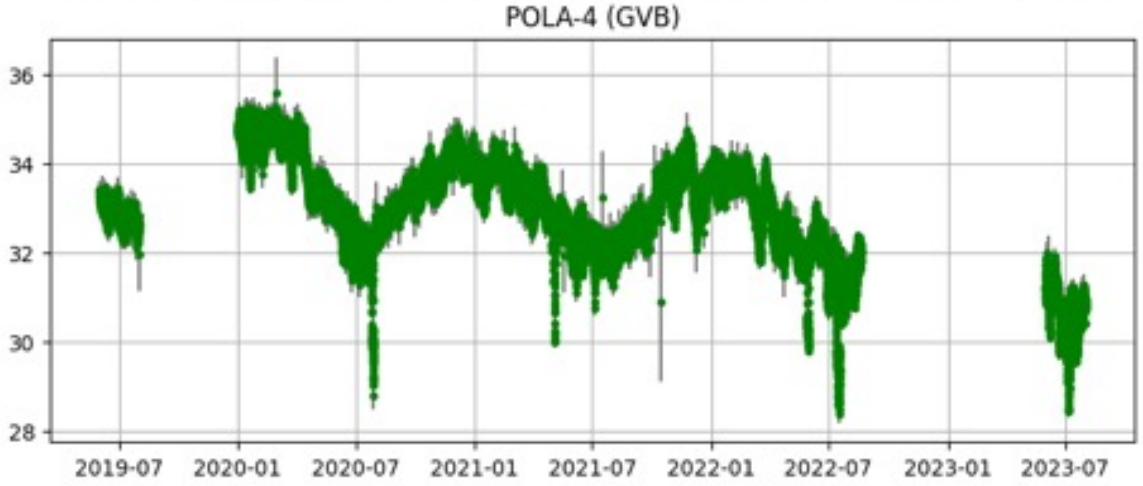
1) Costuire istogramma della differenza **rate[i]-rate[i-1]** (è una sovrastima dell'errore statistico)
2) Definire $\mathbf{err_{stat} = \sigma/\sqrt{2}}$ dal fit gaussiano del bulk
3) Associare al punto $\mathbf{err_{tot}(i) = Max(err_{stat}, Min(|rate[i]-rate[i-1]|,|rate[i]-rate[i+1]|))}$

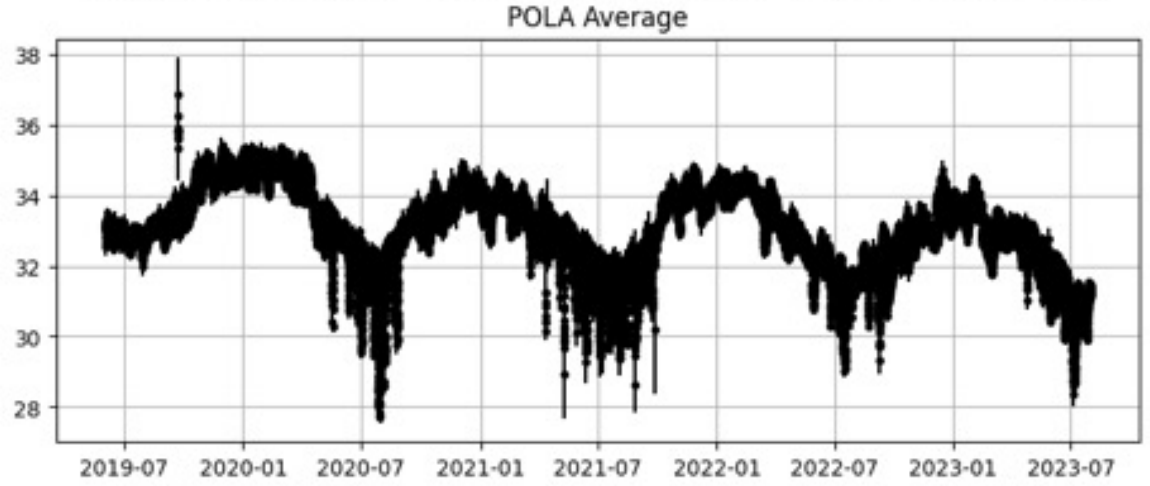
with error bars

New official time series for the POLA rates









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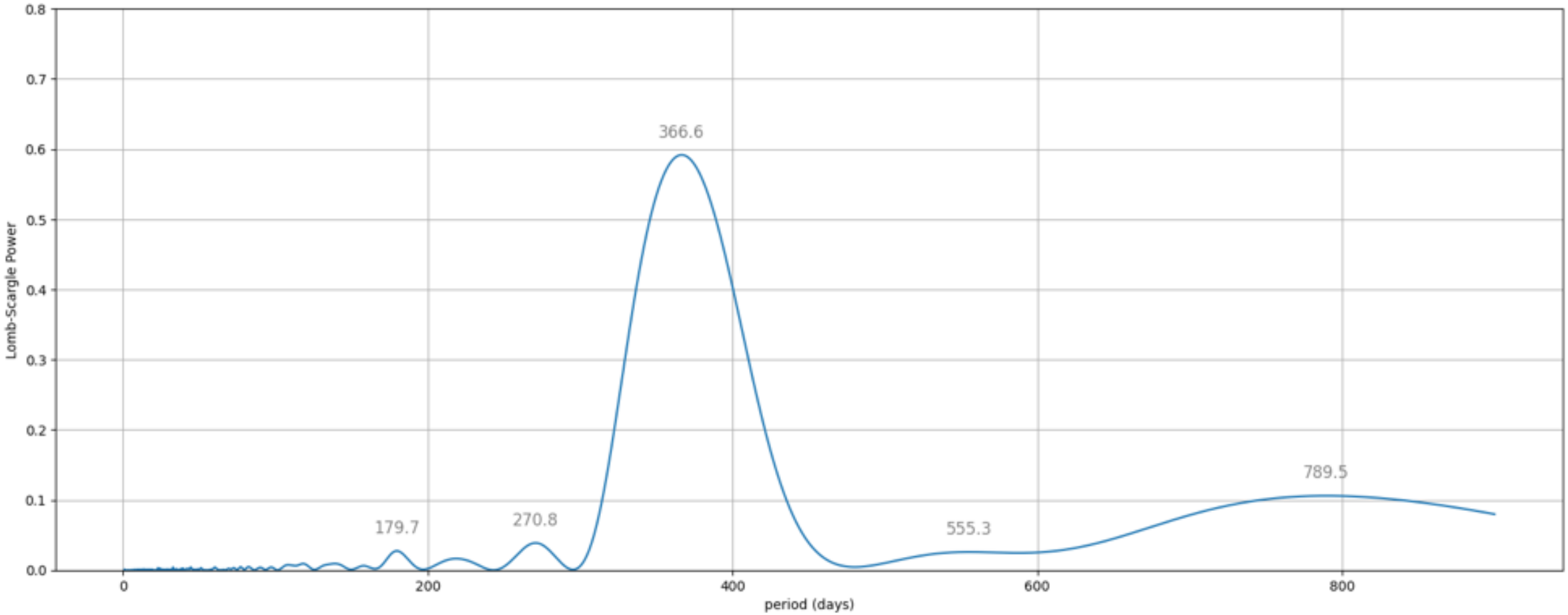
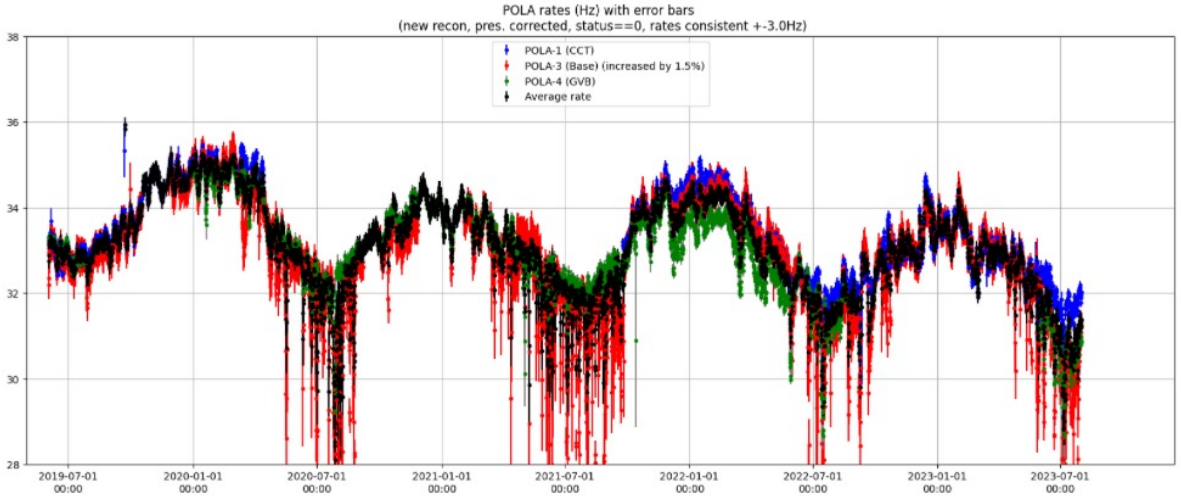
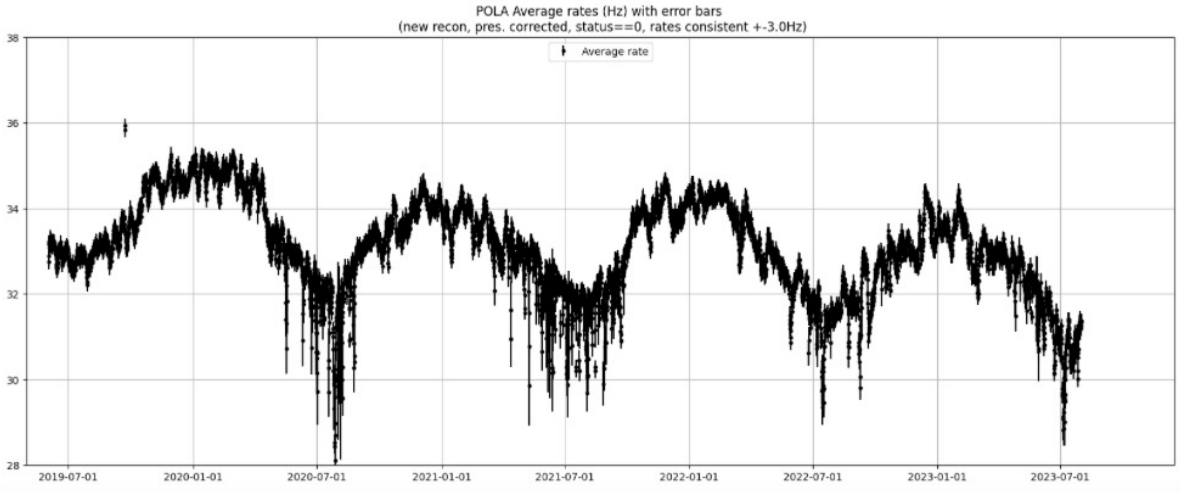
POLA-Average Lomb-Scargle periodogram

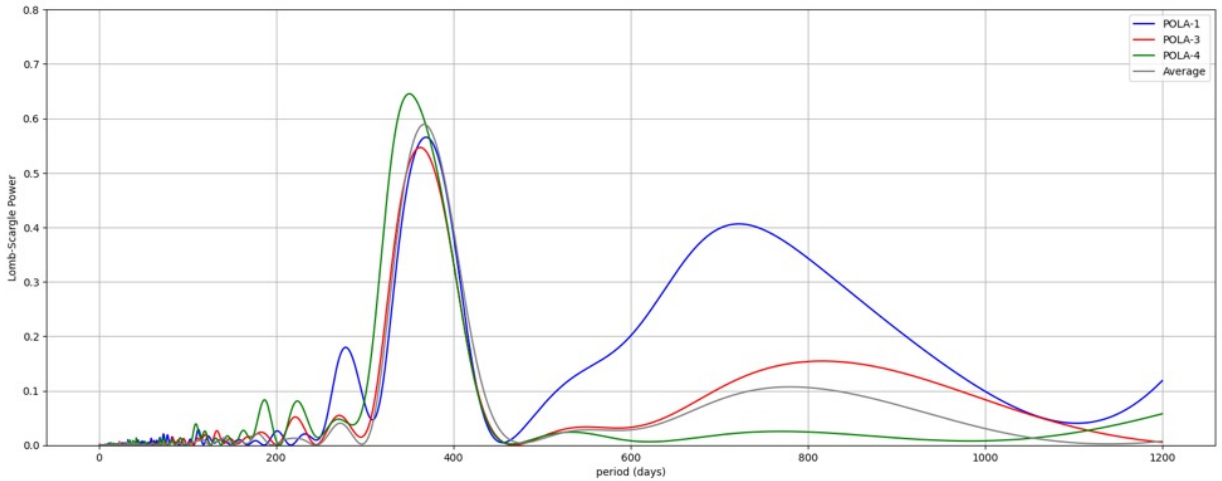


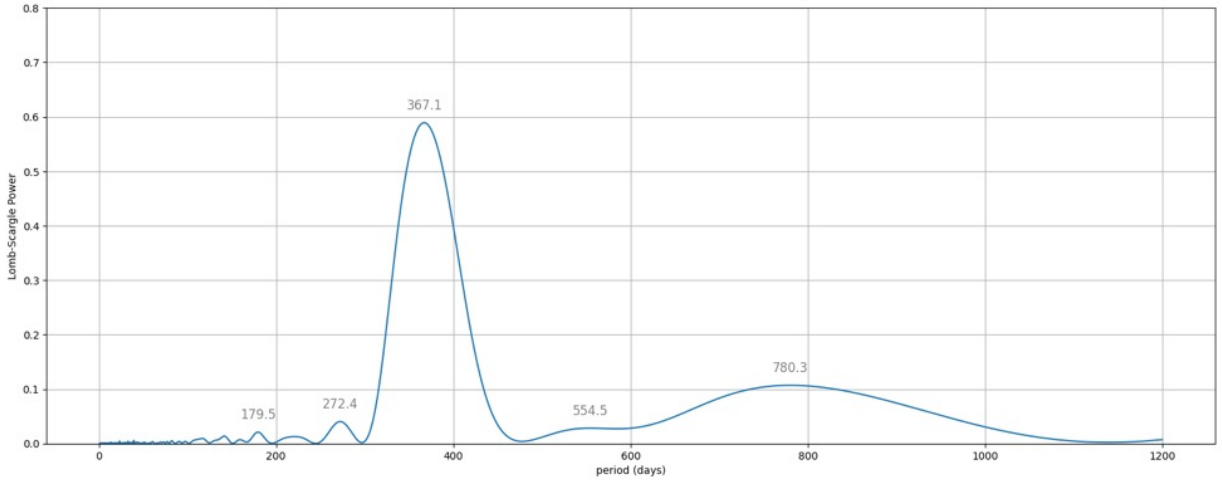
Average of the three POLA

New reconstruction



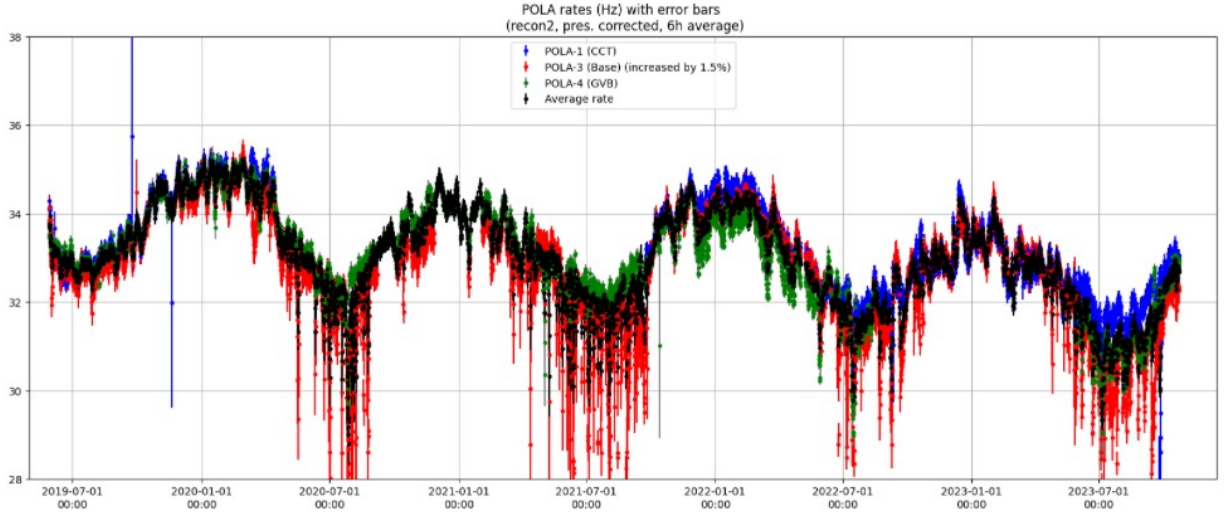


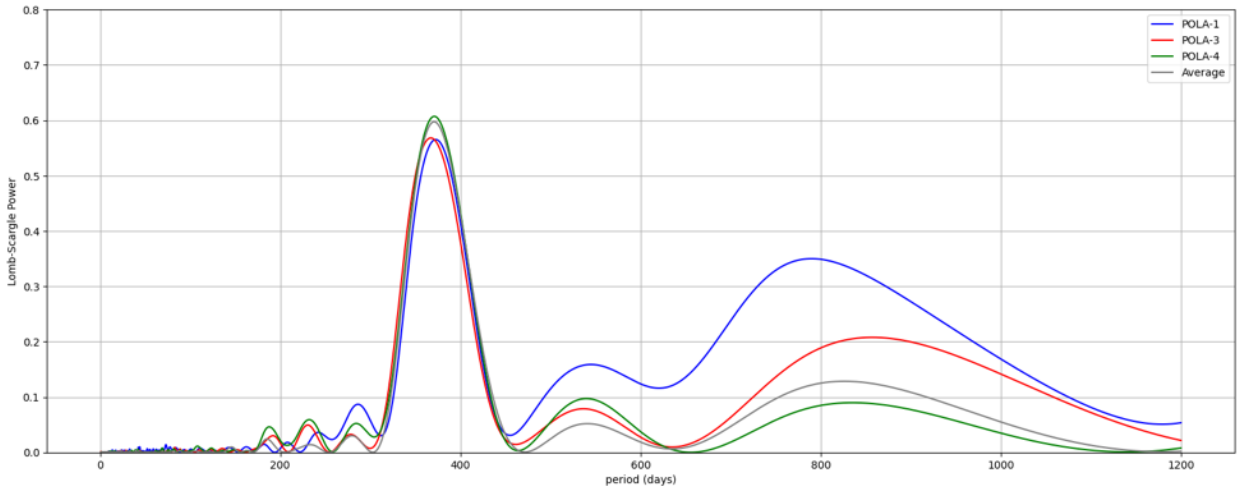


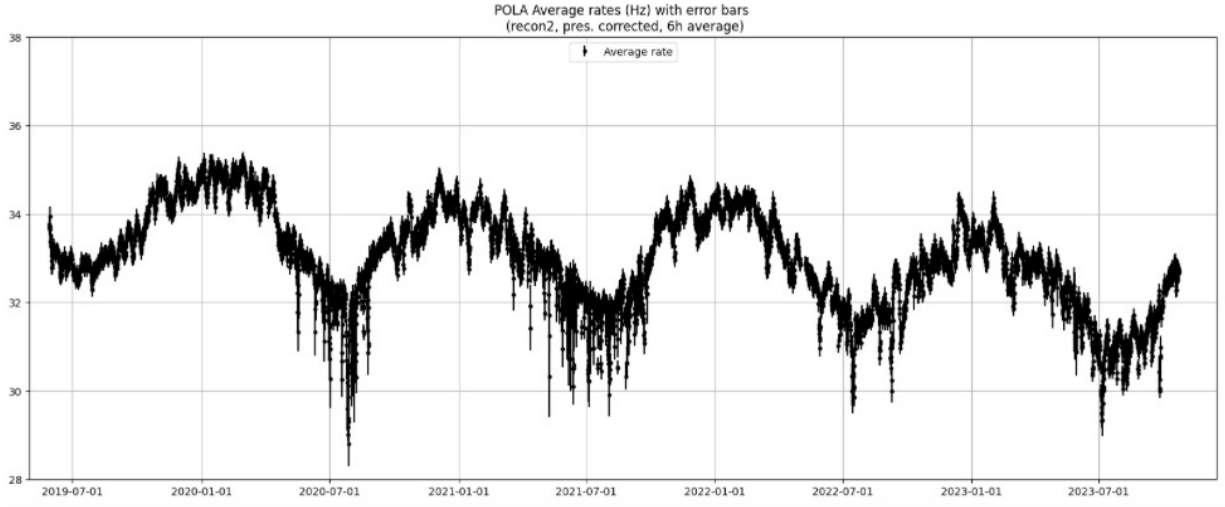


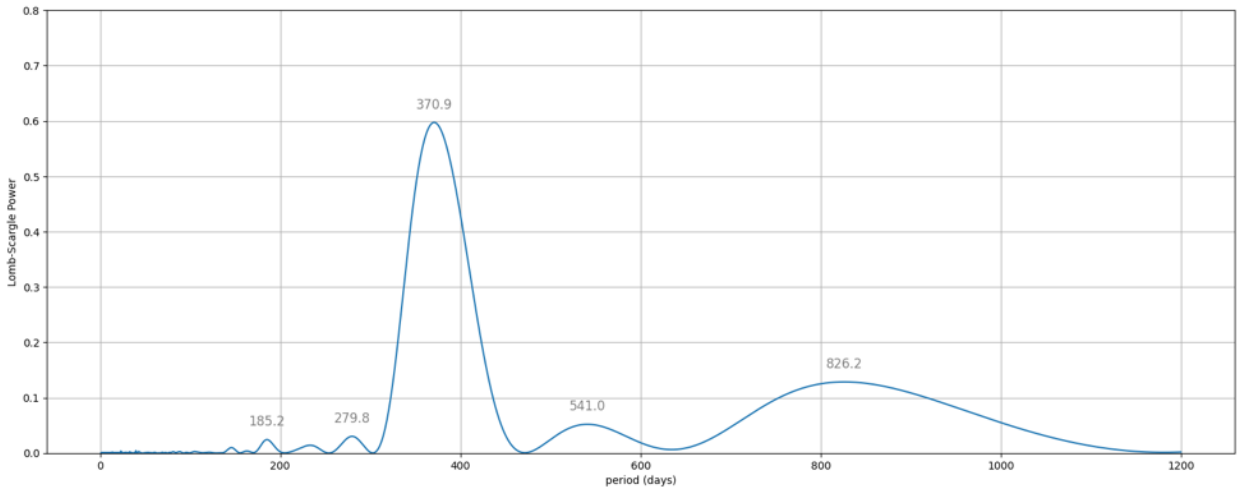
Average of the three POLA

/recon2

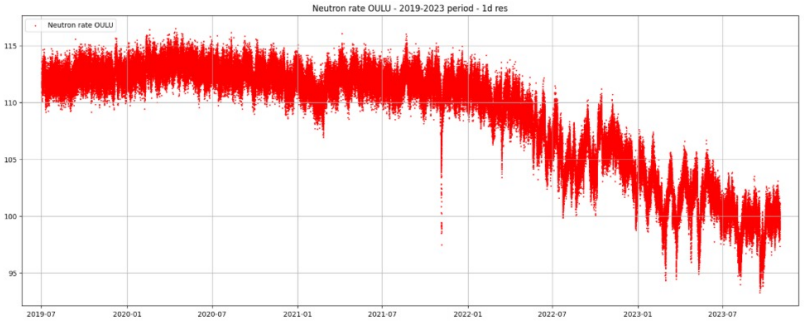


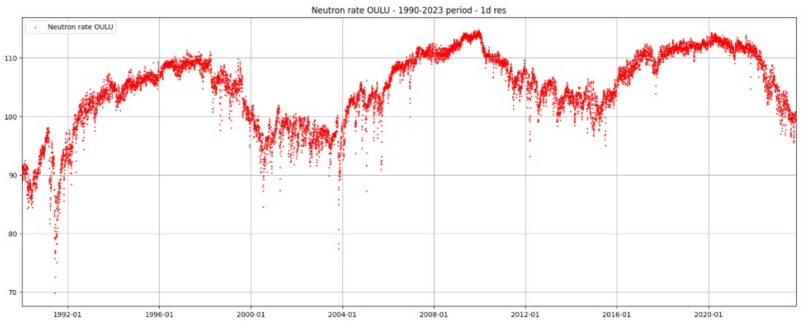


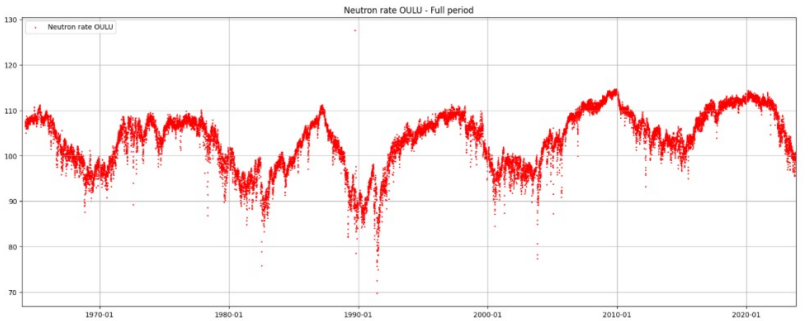


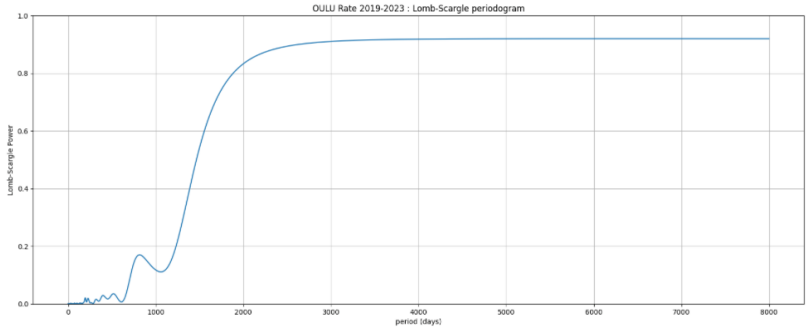


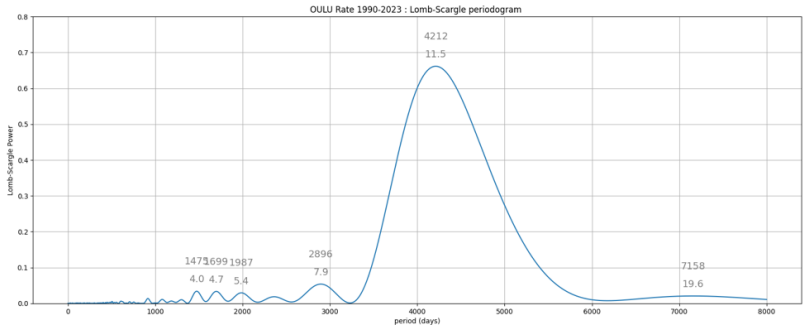
OULU neutron rate (from NMDB)

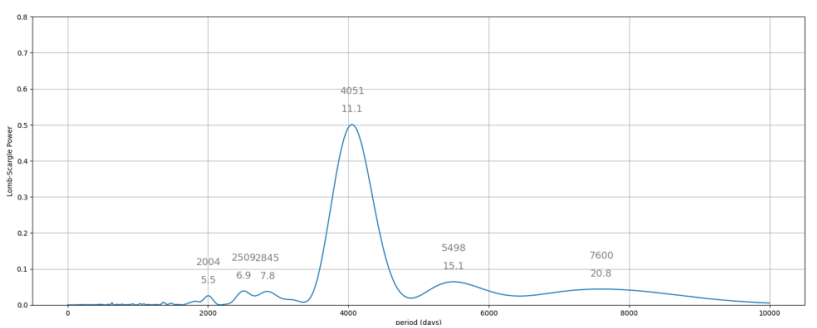


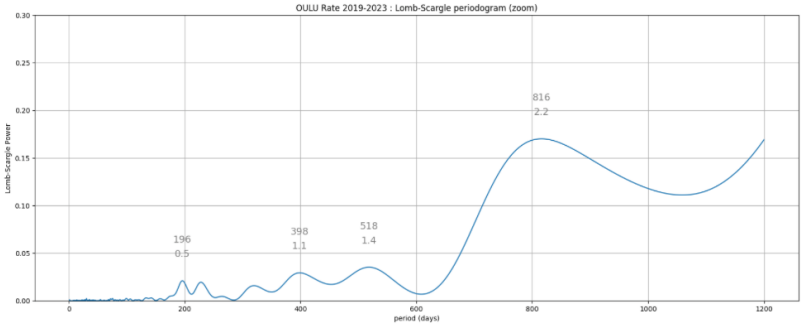


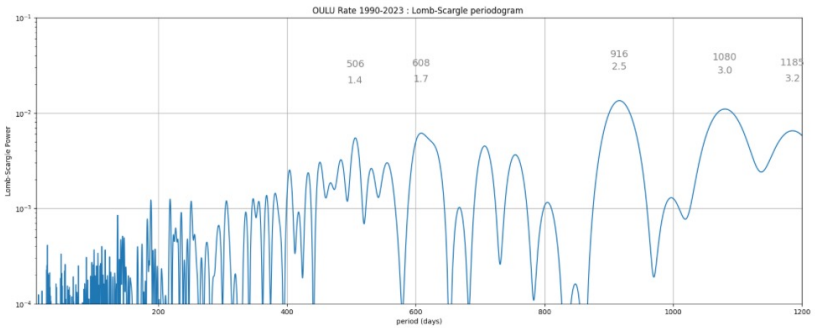












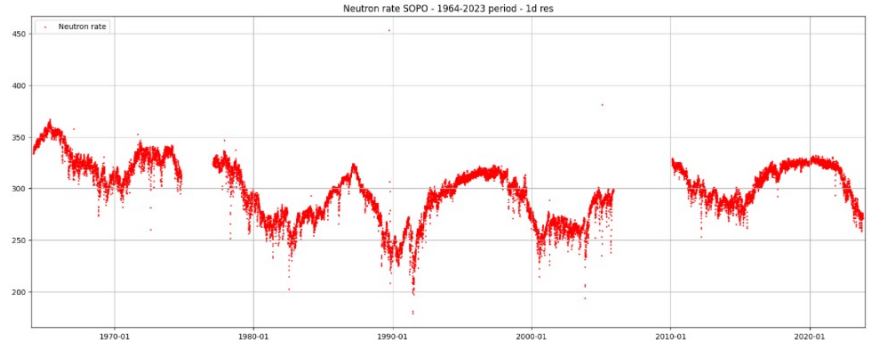
POLA NYA period

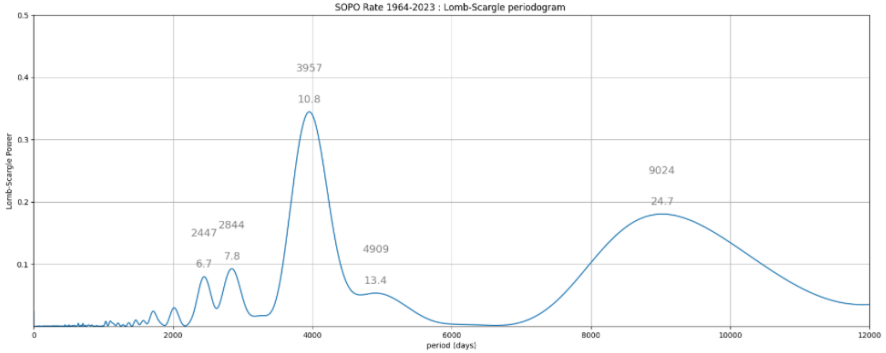
30 years

all available data: 60y

Other neutron monitors

SOPO
Coord: -90,0
South Pole (Cutoff R=0.10, Alt=2820 m)

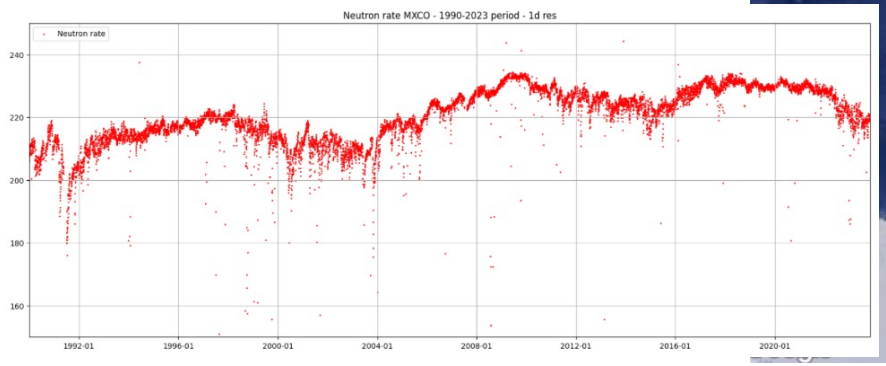


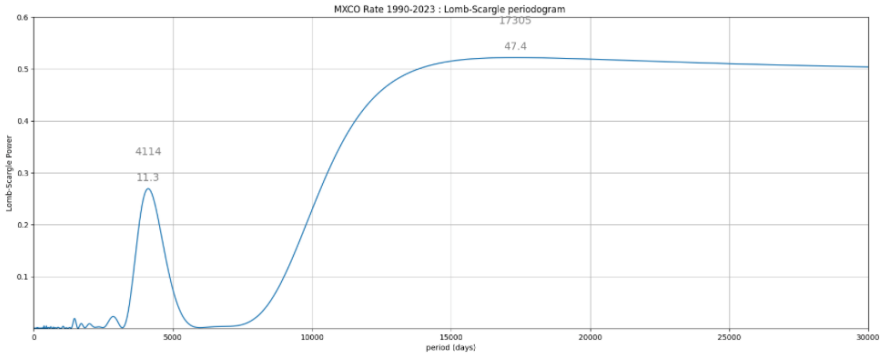


Peaks:

i	index	days	years	power
0	9786	2447	6.7	0.08
1	11371	2844	7.8	0.09
2	15823	3957	10.8	0.34
3	19634	4909	13.4	0.05
4	36093	9024	24.7	0.18

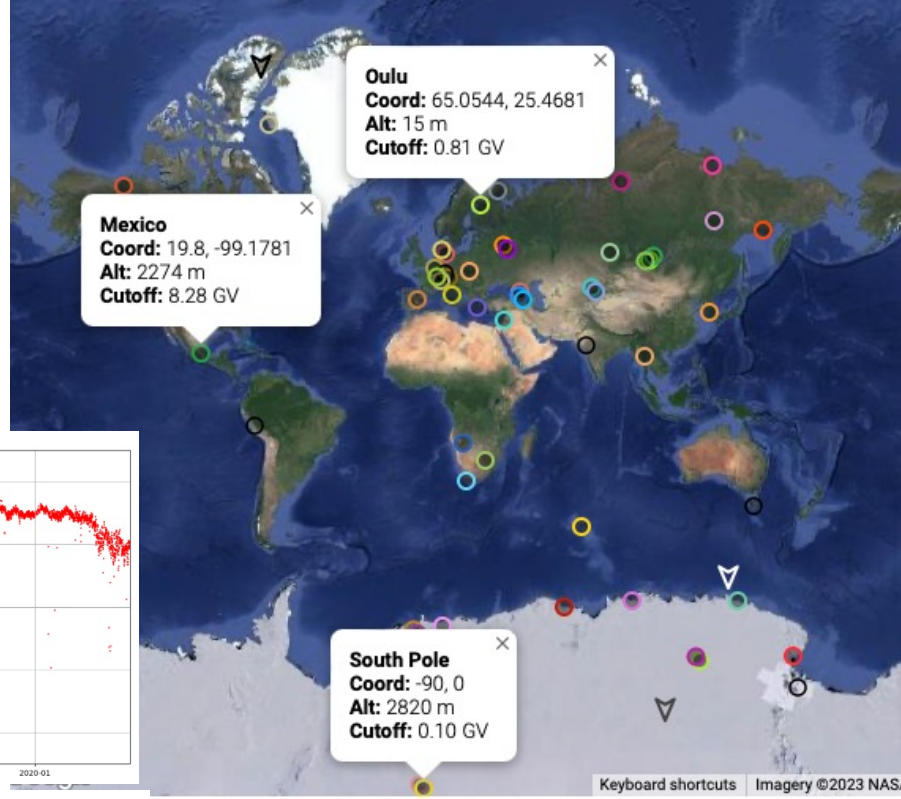
MXCO
Coord:
Mexico (Cutoff R=8.28, Alt=2274 m)



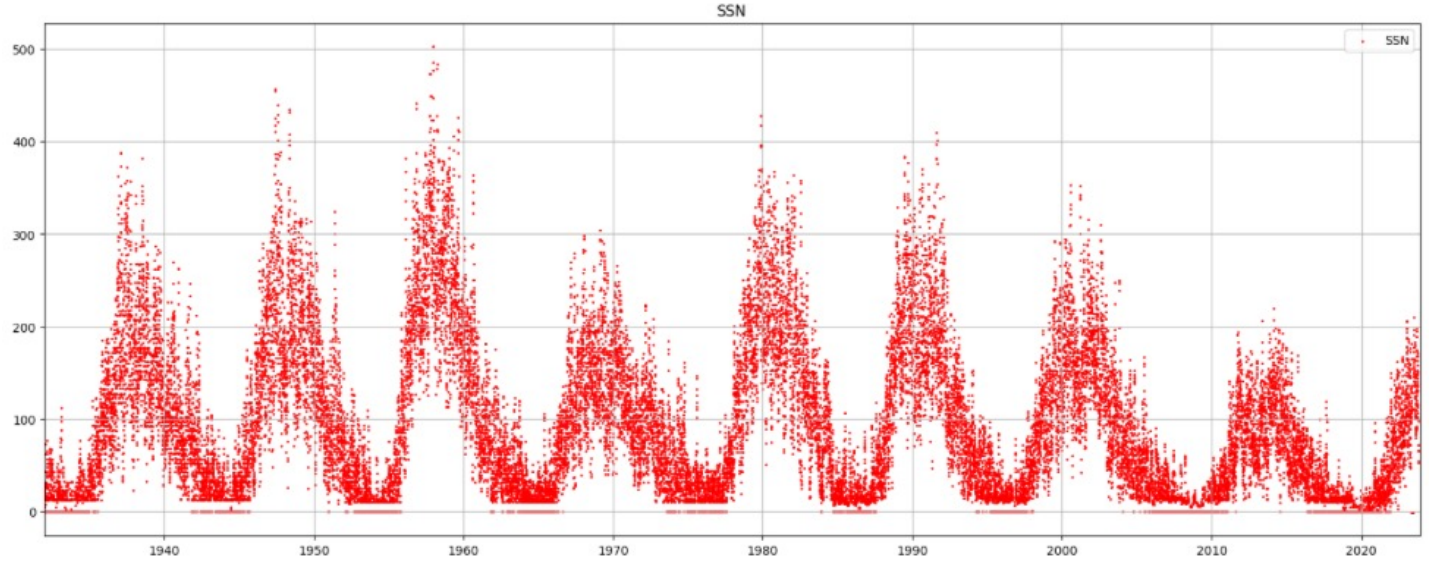


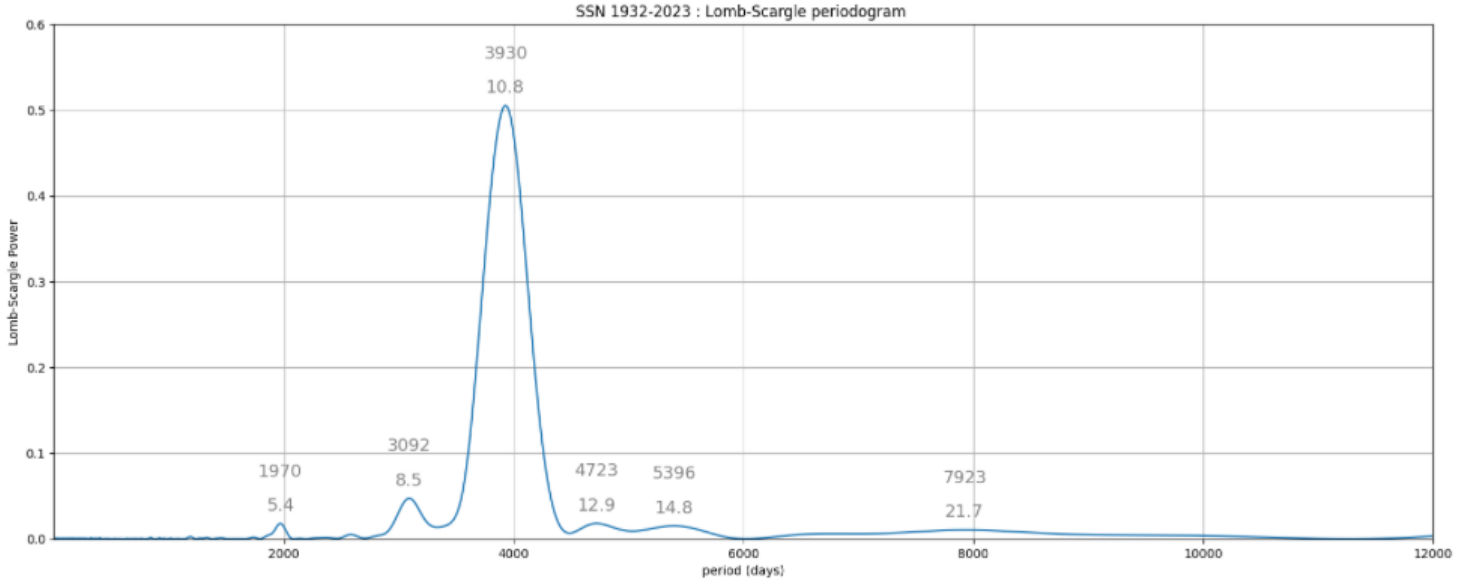
Peaks:

i	index	days	years	power
0	8227	4114	11.3	0.27
1	34609	17305	47.4	0.52



SunSpotNumber (SSN) since 1932

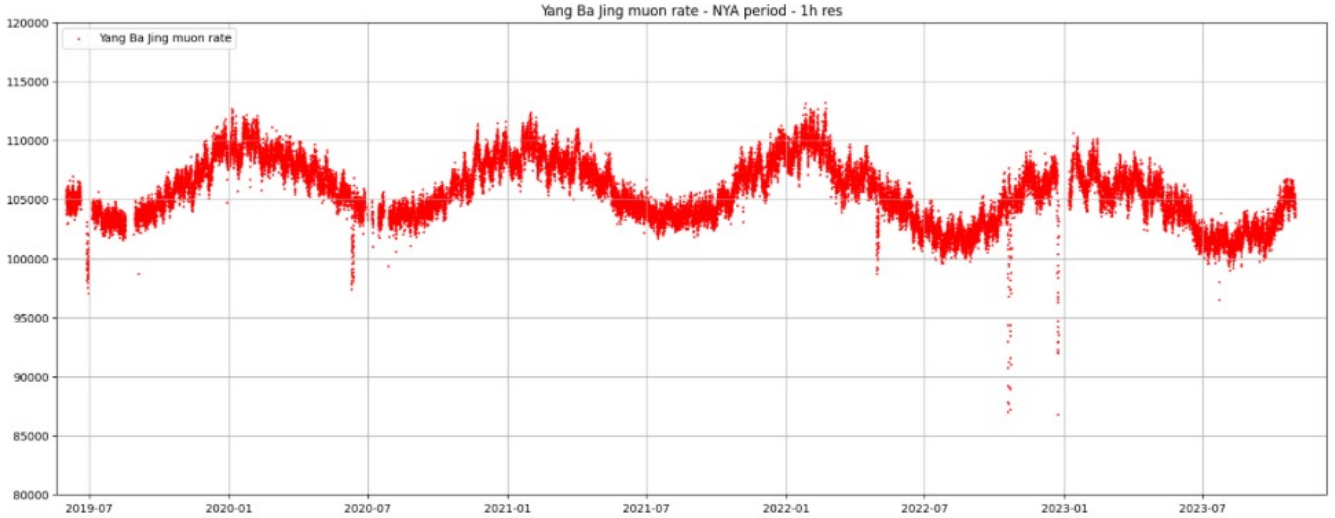


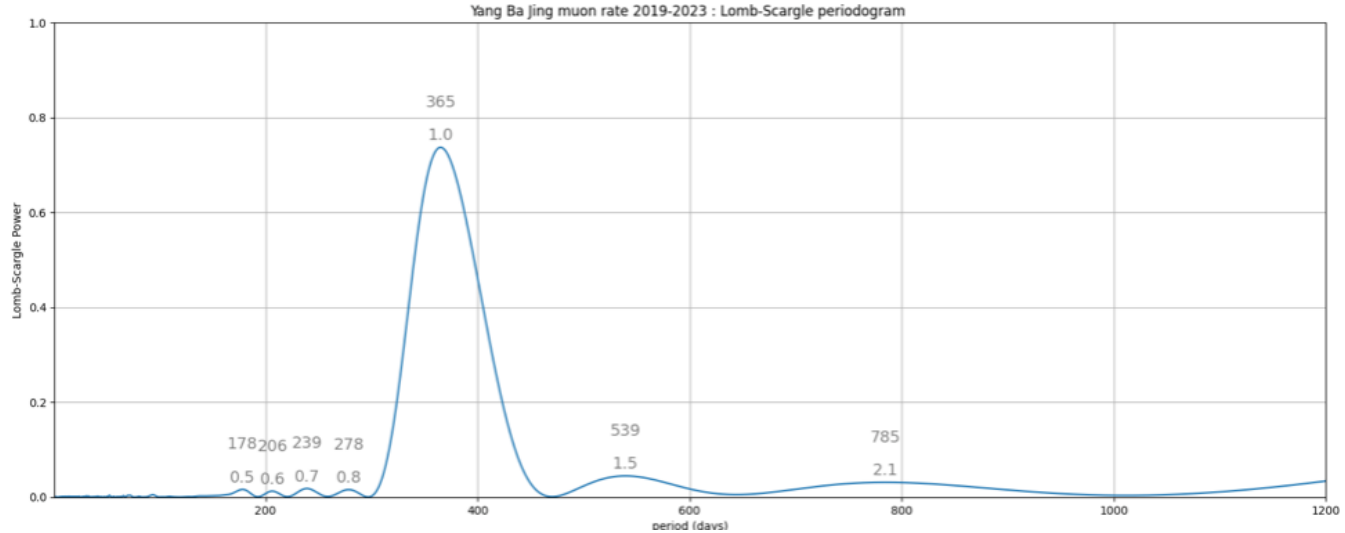


Peaks:

i	index	days	years	power
0	7878	1970	5.4	0.02
1	12366	3092	8.5	0.05
2	15718	3930	10.8	0.51
3	18890	4723	12.9	0.02
4	21582	5396	14.8	0.02
5	31691	7923	21.7	0.01

Yang Ba Jing muon rate (from http://ybjnm.ihep.ac.cn site)



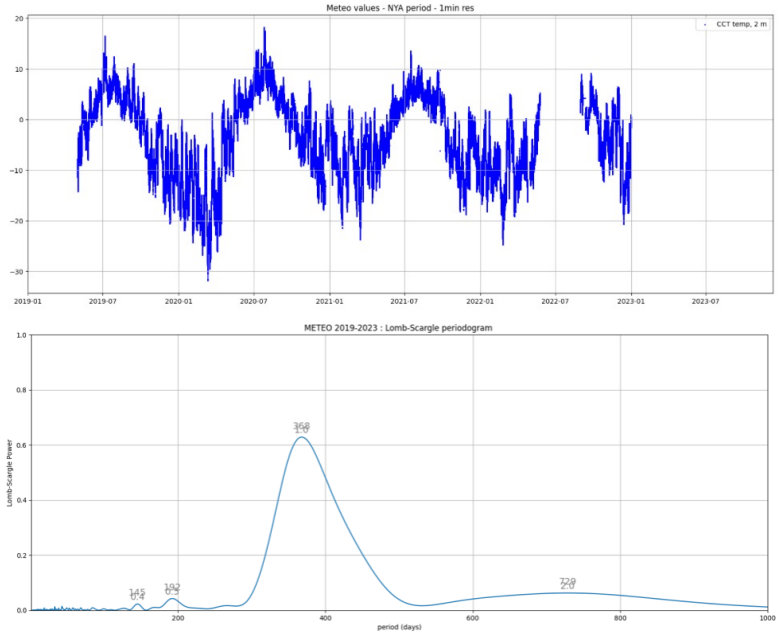


Peaks:

i	index	days	power
0	1775	178	0.02
1	2055	206	0.01
2	2382	239	0.02
3	2777	278	0.02
4	3644	365	0.74
5	5389	539	0.04
6	7842	785	0.03

Meteorological time series (CNR, 2019-2022)

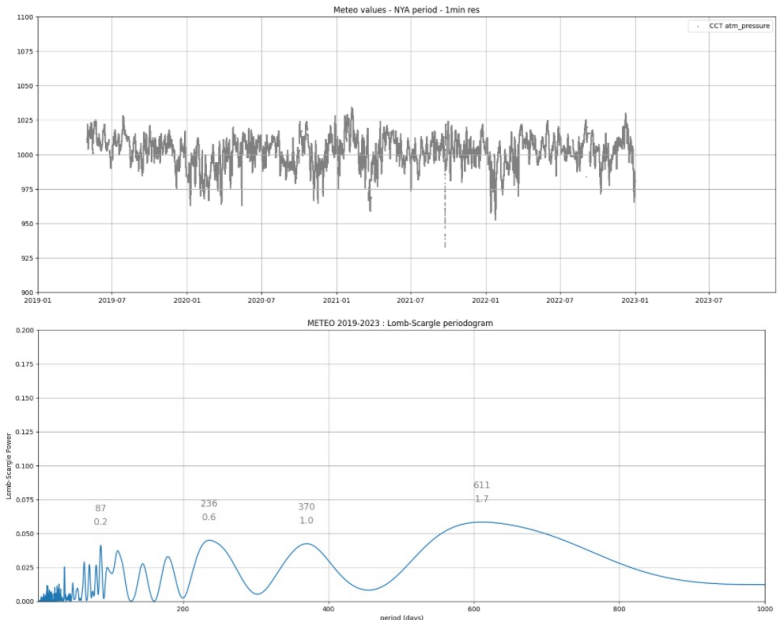
CCT temperature at 2m



Peaks:

i	index	days	power
0	1443	145	0.02
1	1915	192	0.04
2	3672	368	0.63
3	7282	729	0.06

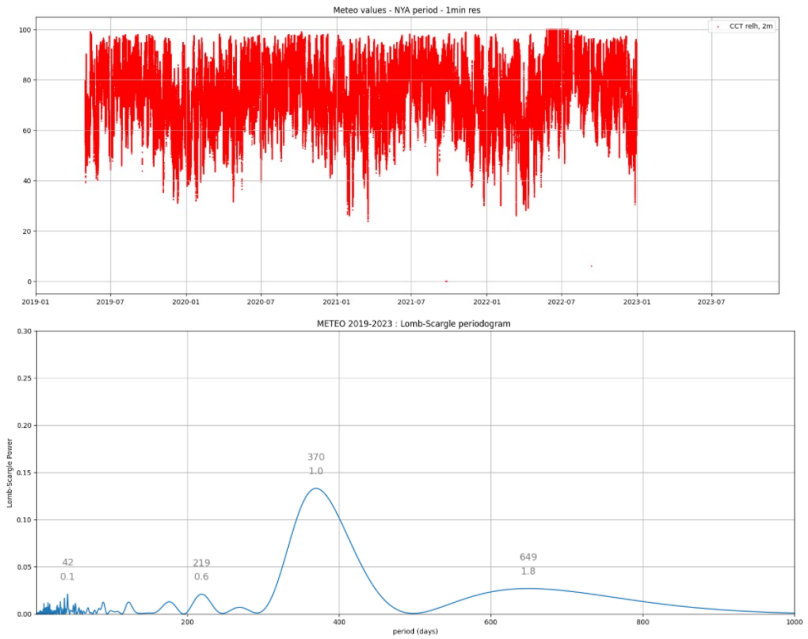
CCT atmospheric pressure



Peaks:

i	index	days	power
0	859	87	0.04
1	2353	236	0.05
2	3693	370	0.04
3	6108	611	0.06

CCT relative humidity at 2m



Peaks:

i	index	days	power
0	413	42	0.02
1	2181	219	0.02
2	3690	370	0.13
3	6489	649	0.03

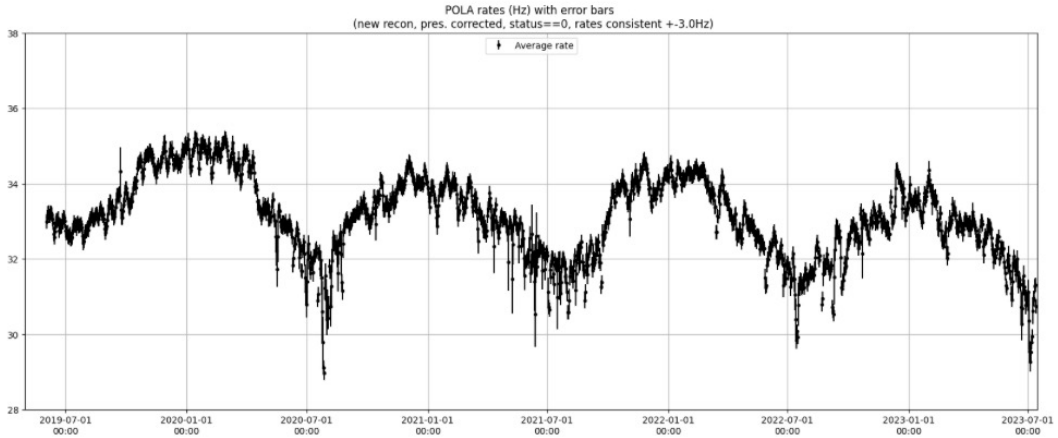
Conclusions

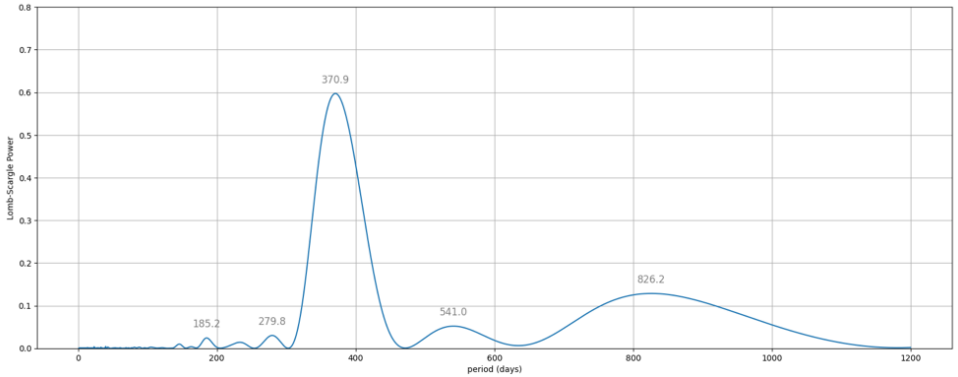
- Lomb-Scargle periodogram is a powerful tool to evaluate periodicities in time series (thank you Francesco!)
- POLA rates show a clear annual periodicity
  - Hidden dependency to temperature/humidity?
  - Same trend is found in YBJ muon rates, but we don't know more
- POLA rates do not show clear periodicities below 1 year
- Neutron datasets do not show any annual trend but a solar cycle dependency (~11 years)
  - POLA rates time series might be too short to be able to show this periodicity

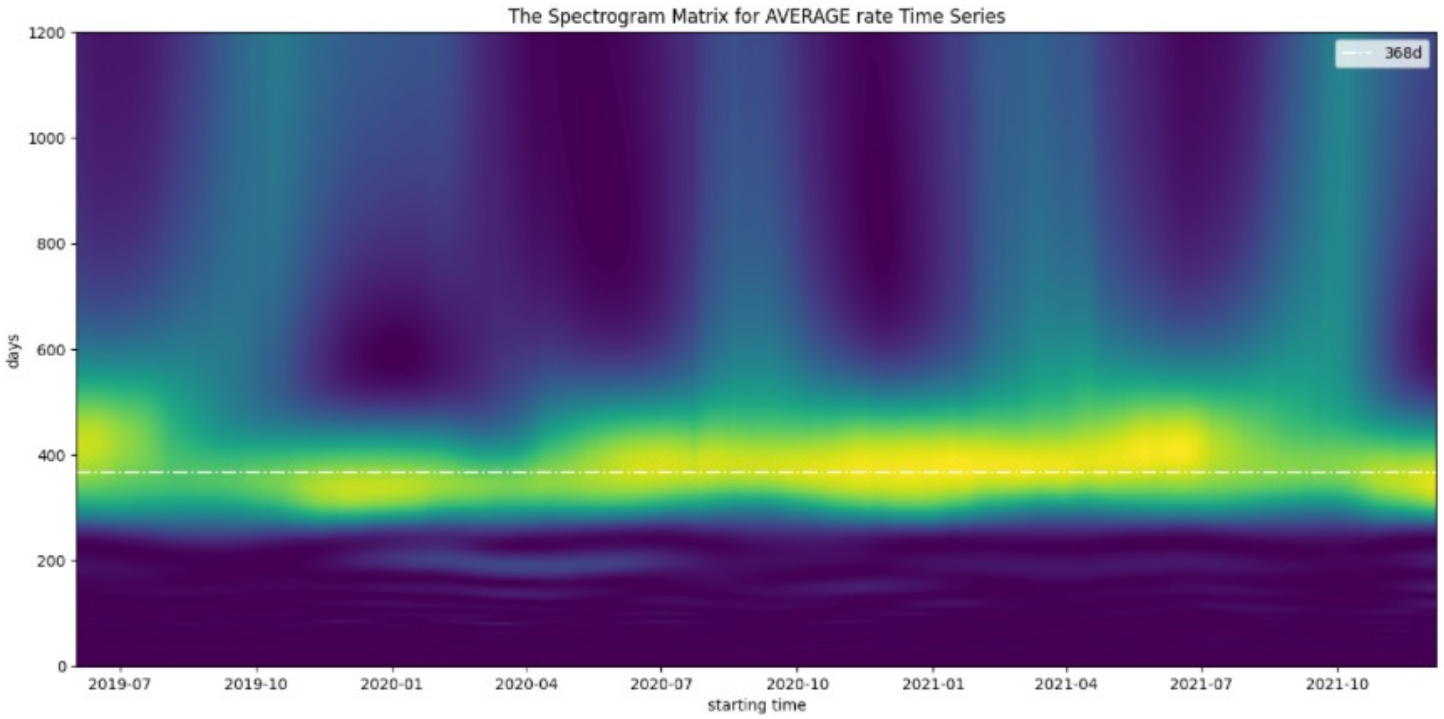
(more slides added →)

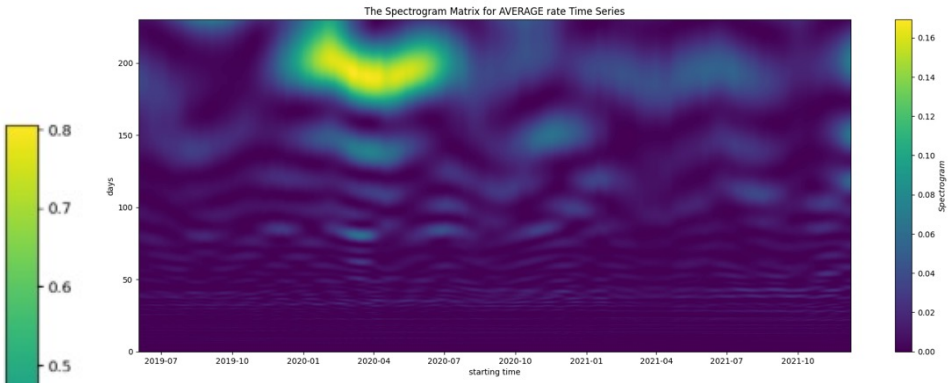
Spectrogram

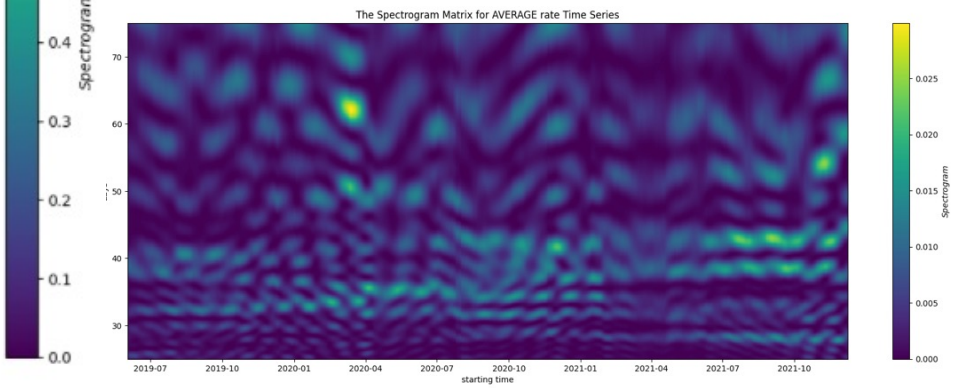
POLA-Average: New reconstruction



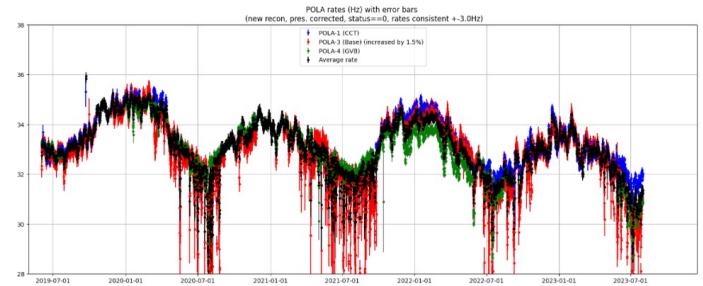


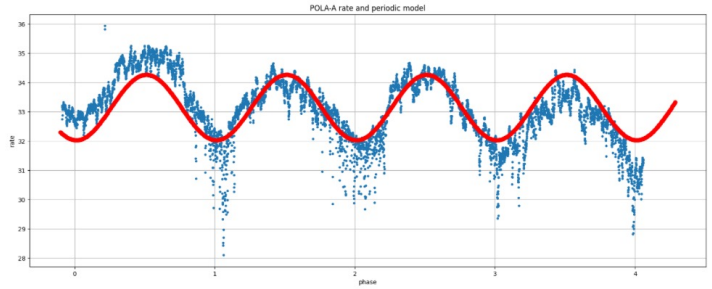


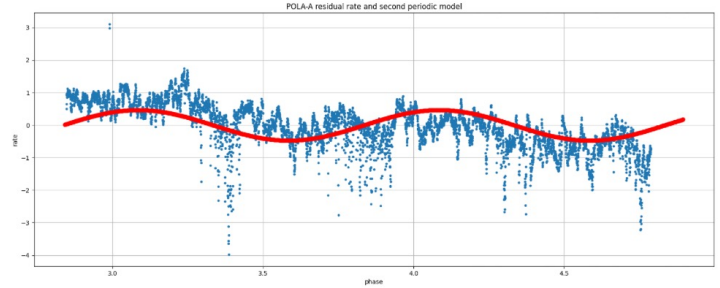


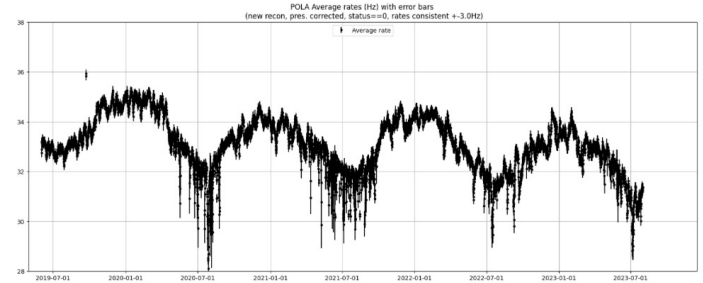


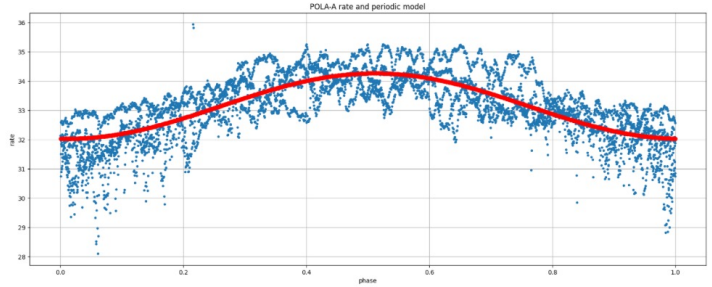
POLA-Average: best fit and residuals

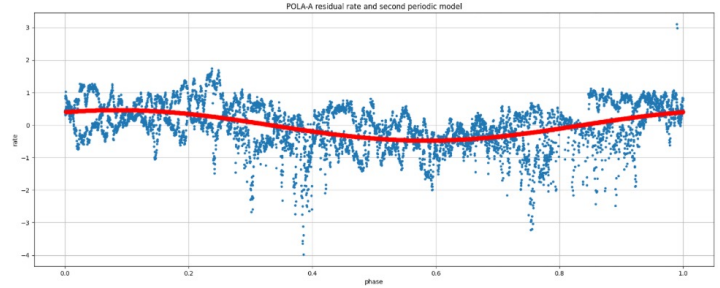


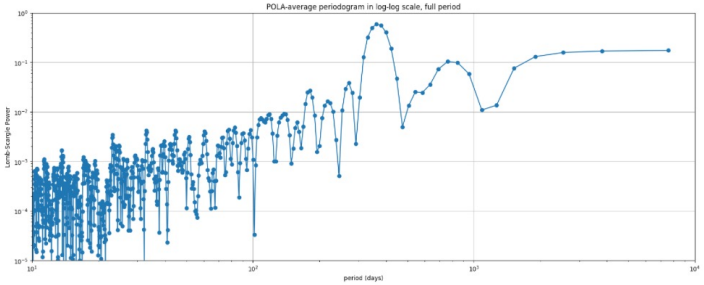


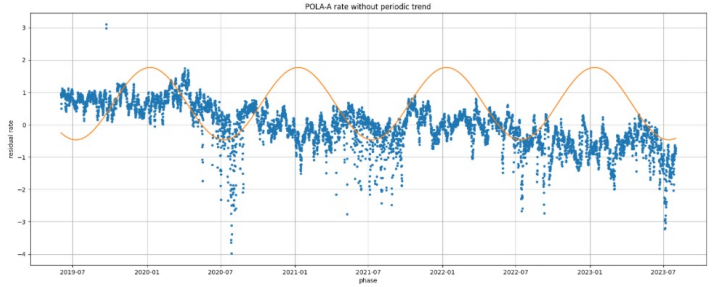


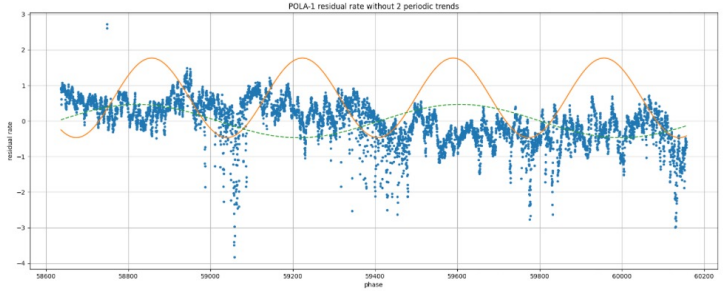


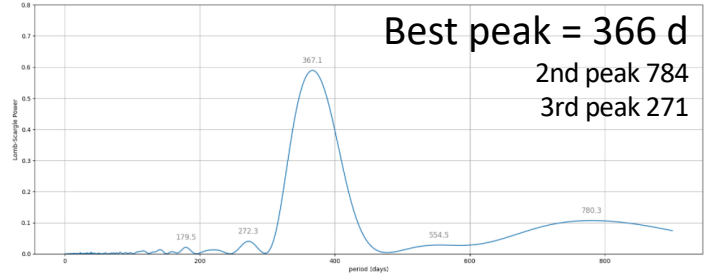


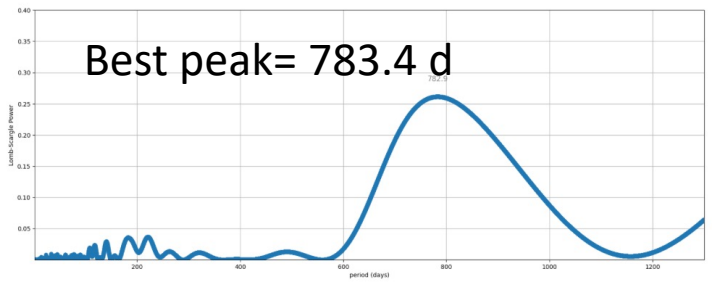


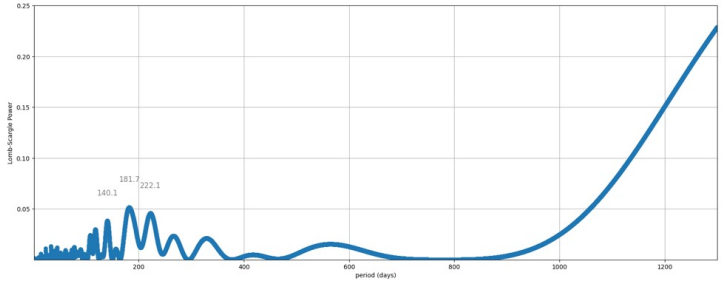




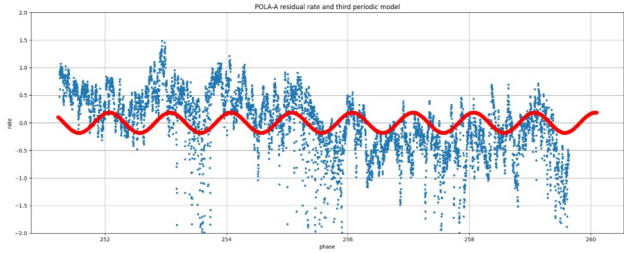


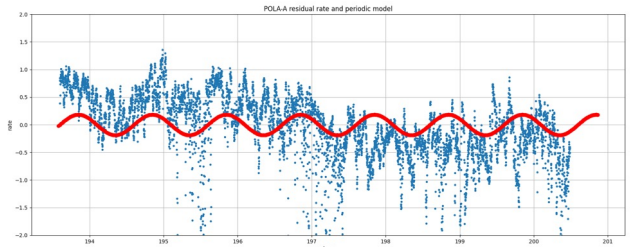


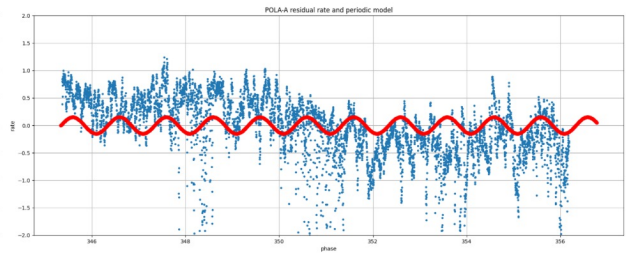


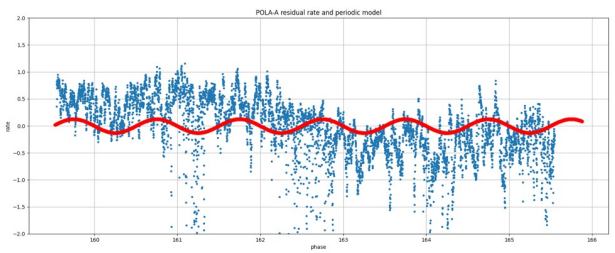


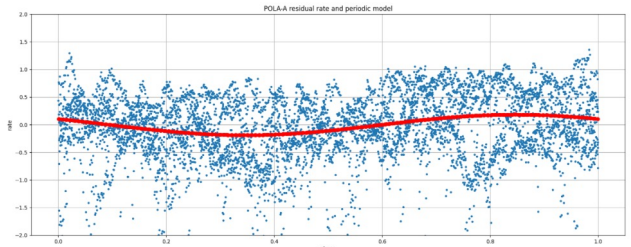
Removing further components: 181.4d, 220.7d, 140d, 253d

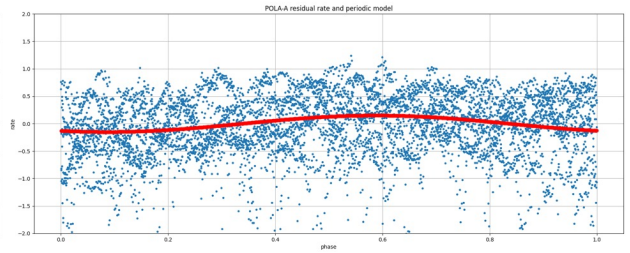


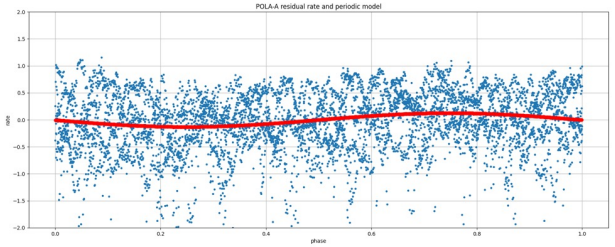


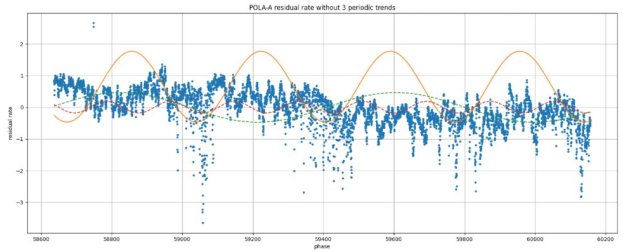


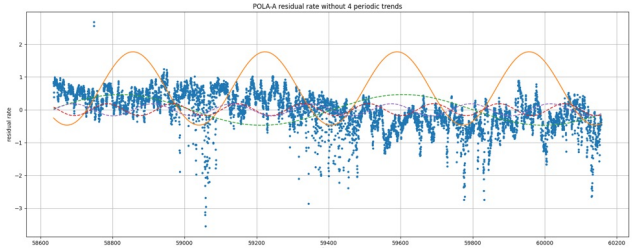


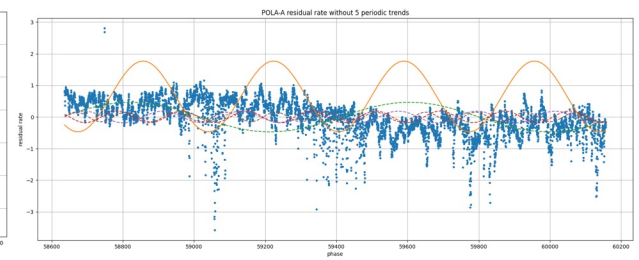


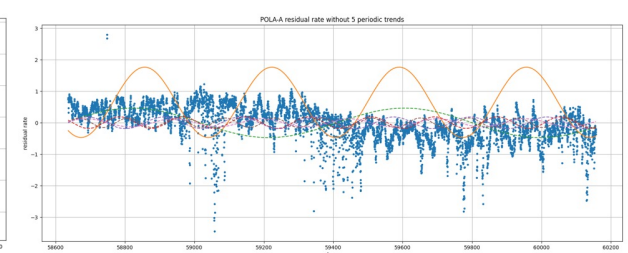


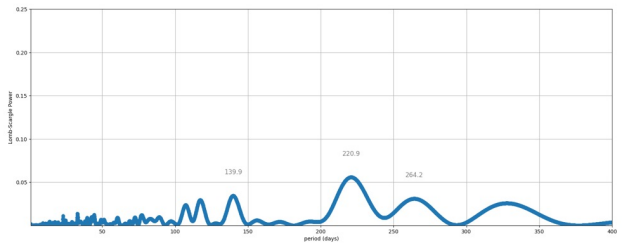


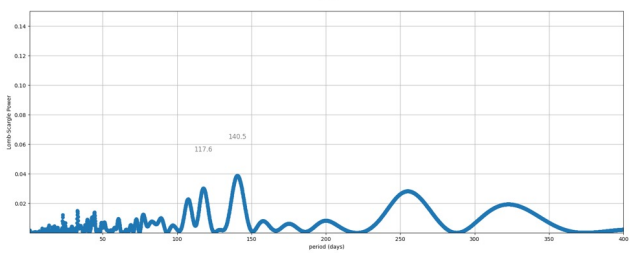


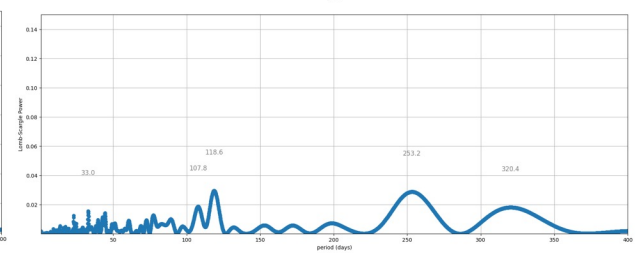


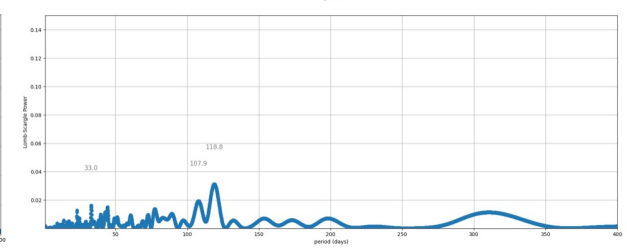




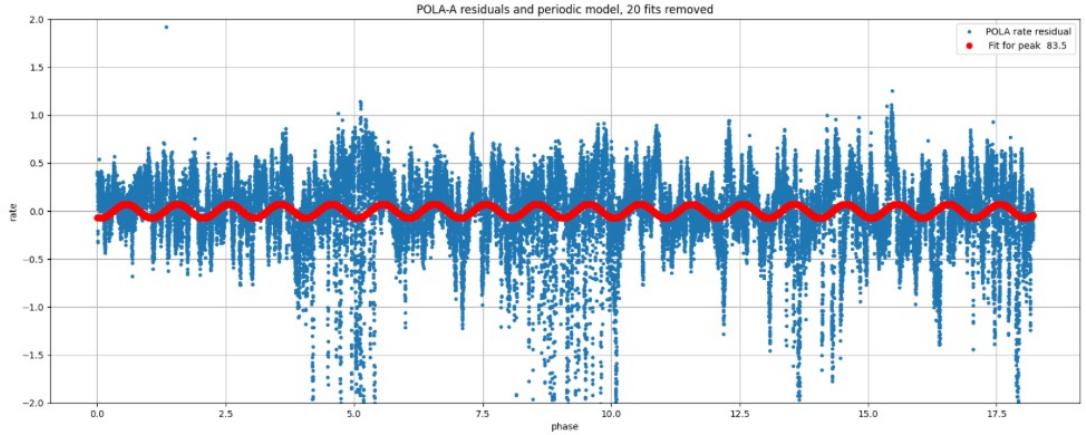


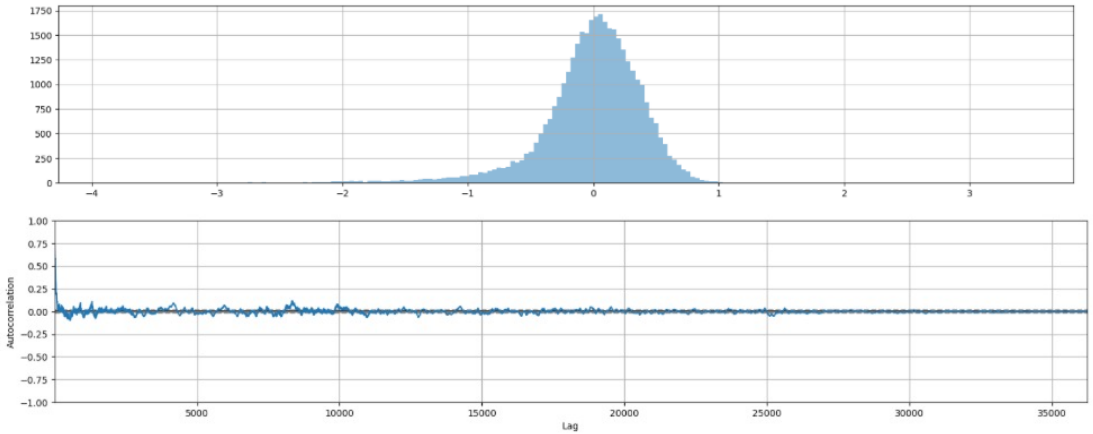


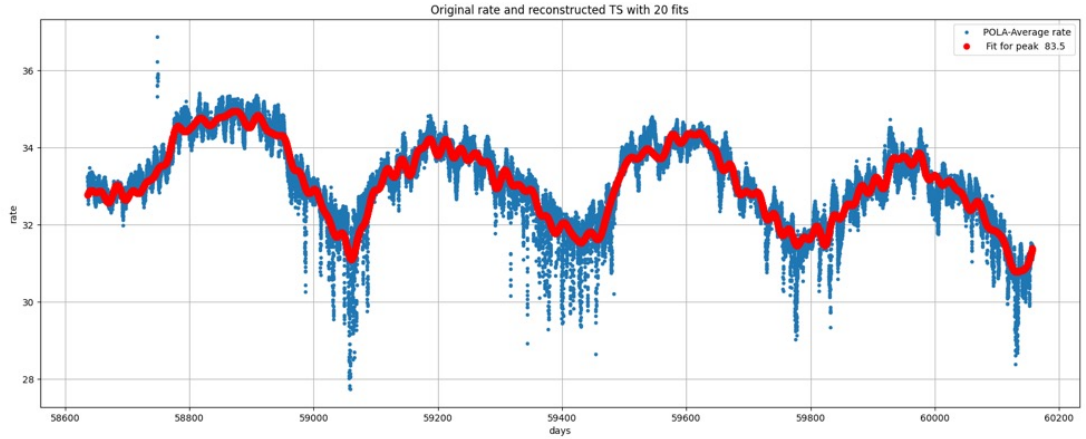


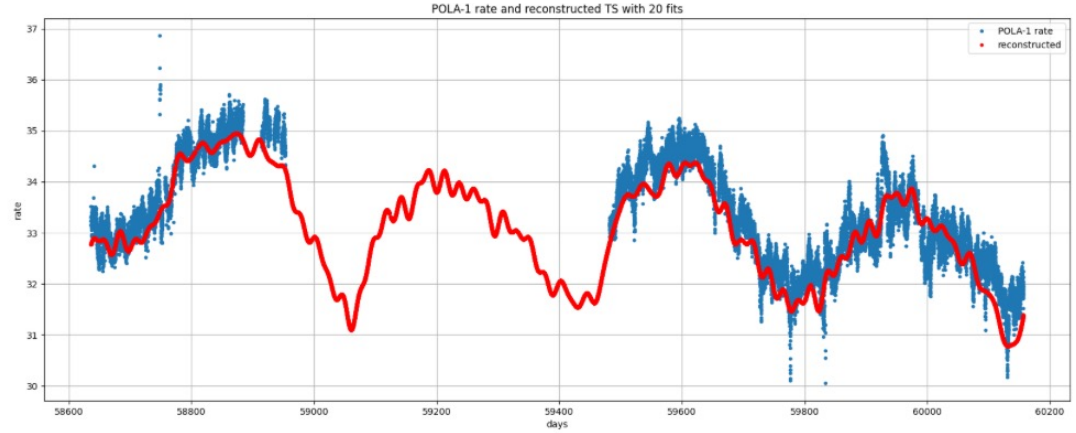


Removed 20 periodic components

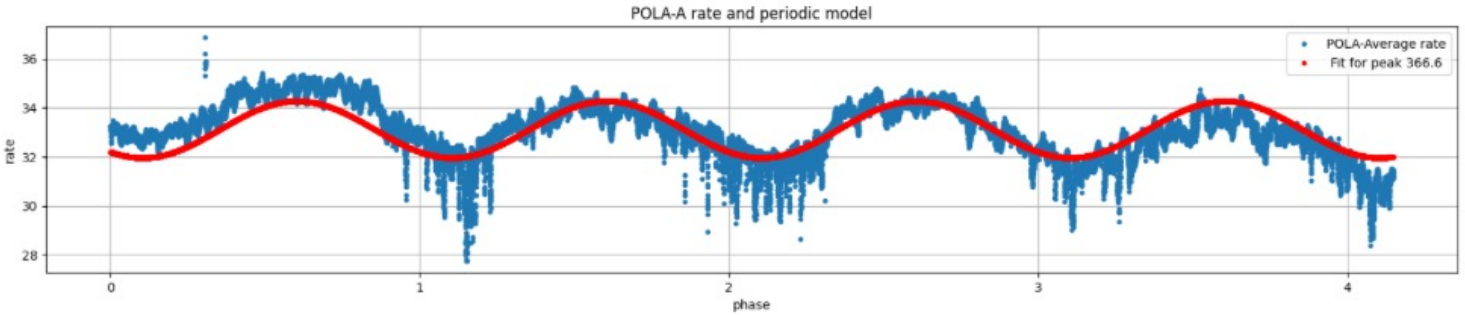


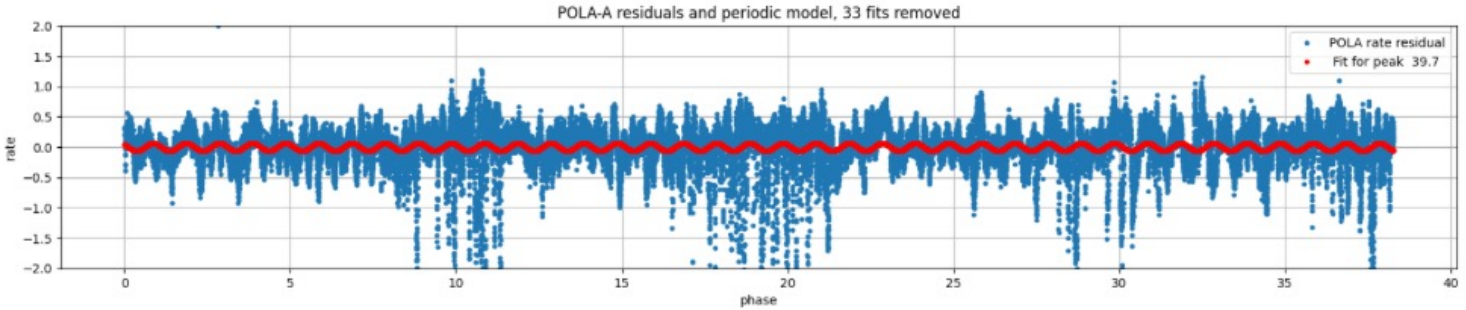


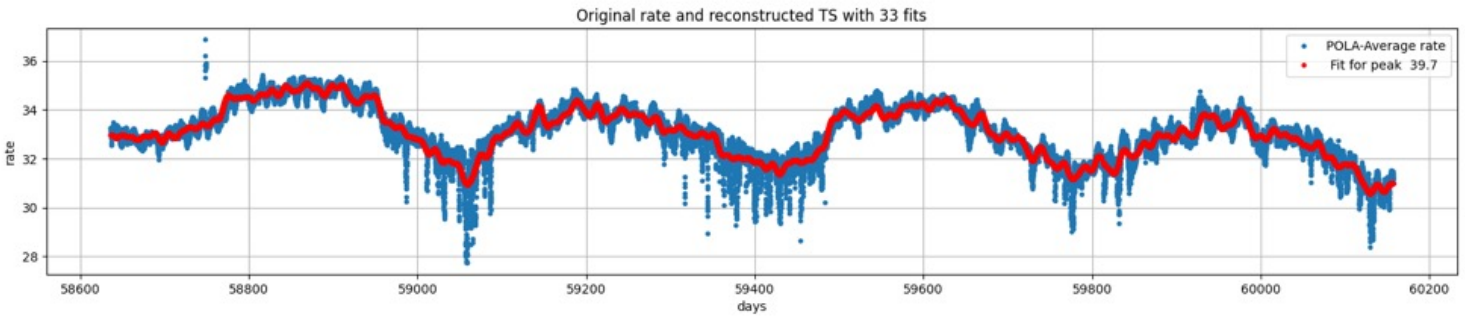


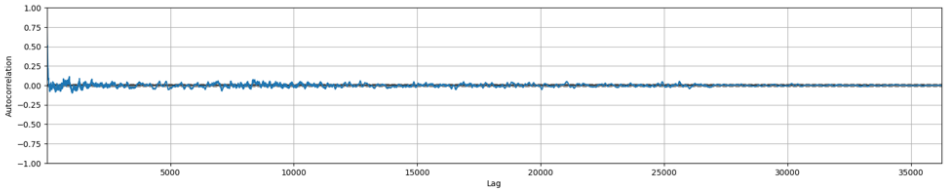


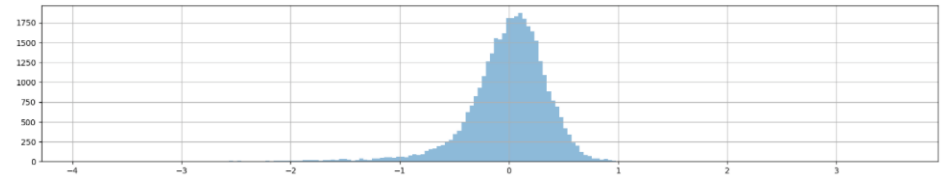
Removed 40 periodic components

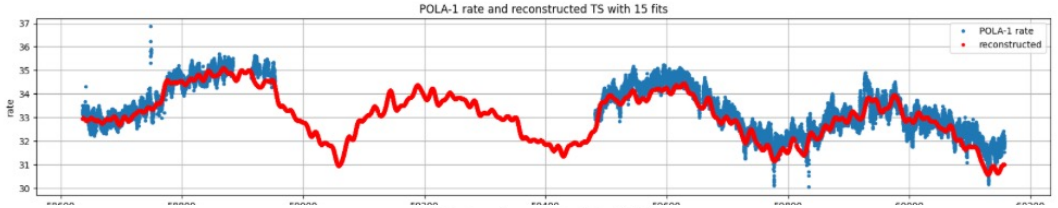


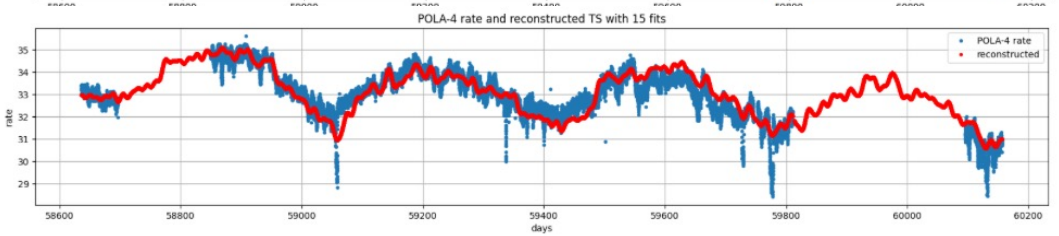












Conclusion /2

- The spectrogram obtained with a time-moving LSP confirms the stability of the 1y periodicity
- Secondary components need further analysis
  - Different time windows and sampling
- The main trend can be represented with 20/40 sinusoidal waves
- Residuals need further analysis to verify their characteristics
  - Ex. Comparing residuals from the 3 POLA

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