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Quasi periodicities in CMEs using Lomb-Scargle periodogram method for Solar Cycles 23-24

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Abstract
We present here a study of quasi-periodicity in CME occurrence rate and CME mass rate during solar cycles 23-4 from January 1996 to December 2019. We have utilized Lomb-Scargle (L-S) periodogram method to determine the periodicity. We have used data from the Coordinated Data Analysis Workshops (CDAW) catalog on board SOHO. Our analysis revealed that most detected periods fall within the category of very long-term periodicities. The longest identified period, 10.76 years, aligns with the duration of the solar cycle, while the 5.42-year period represents approximately half of a full cycle. Notably, many of these long-term periods emerged from the investigation of halo CME periodicity. Annual-scale periods of 349, 368, and 431 days were observed exclusively in the total CME occurrence rate during solar cycle 23. Rieger-type periodicities were detected only in the total CME occurrences across both solar cycles 23 and 24. Quasi-biennial periods were also found, but solely in relation to total CME occurrences and CME mass rates. Additionally, short-term periods of 45 and 60 days were identified in the total CME occurrence rate during cycle 23, and in the halo CME mass rate when analyzing both cycles 23 and 24 together.

Keywords: Coronal mass ejections, solar cycle, periodicity, rieger type periodicity

Introduction
The periodicity in different solar activity features is resembled from few days to number of years. The most well-known periodicity is solar cycle (SC) of 11 year, also known as Schwabe cycle. Periodicities ranging from 27 days to 11 years are referred to as "midrange" or intermediate (Bai, 2003) [3]. After Rieger *et al*. (1984) [38] identified a 154-day periodicity in high-energy solar flares, numerous studies began investigating midrange periodicities across various solar parameters. During Solar Cycle 21, multiple findings reported periodicities around 155 days, known as Riéger-type periodicities, in data related to solar flares. Subsequent analyses uncovered additional midrange periods including 78, 84, 127, 83, 64, 129, 230, 295, 330, and 392 days across different phases of several solar cycles (Bai and Sturrock, 1991, 1993; Ozguc and Atac, 1994; Lou *et al*., 2003; Ataç, Özgüç, and Rybak, 2006; Chowdhury and Ray, 2006; Chowdhury, Khan, and Ray, 2009; Mendoza and Velasco-Herrera, 2011; Kilcik *et al*., 2018; Oloketuyi, Liu, and Zhao, 2019) [4, 5, 32, 26, 2, 9, 8, 27, 20, 31].
The periodicity is determined for various solar activity features in the past research articles. For instance, Midrange periodicities are determined in the radio observations (Das and Chatterjee, 1996; Das and Nag, 1999, 1998; Zieba *et al*., 2001) [10, 12, 11, 39]. A 1.3-year periodicity has been detected at the base of the solar convection zone (Howe *et al*., 2000, 2007) [16, 17], and also observed in time series of sunspot area (SSA) and sunspot number (SSN) (Krivova and Solanki, 2002) [22].
Coronal mass ejections (CMEs) represent one of the most significant expressions of solar magnetic activity (N. Gopalswamy, 2016; G Michalek *et al*., 2022) [14, 28]. They influence the interplanetary environment and space weather by generating heliospheric disturbances, shock waves, and accelerating energetic particles (N Gopalswamy, 2022) [15]. CMEs are crucial for understanding the dynamics of heliospheric disturbances, shock formation, and particle acceleration (S. Feng *et al*., 2013) [13].

In addition, CMEs can trigger geomagnetic storms and can be generating factor for Solar Energetic Particle (SEP) events, posing hazards to spacecraft systems and human spaceflight (SW Kahler, 1982; GE Brueckner *et al*., 1998; DV Reames, 1999; J. Zhang *et al*., 2007) [18, 6, 36, 40]. Their interaction with the solar wind can lead to the development of complex magnetic configurations, such as magnetic clouds, which contribute to sustained space weather effects (TH Zurbuchen & IG Richardson, 2006) [41].

To determine the periodicity in the occurrence rate and mass rate of CMEs can play a crucial role to forecast the space weather and to have the idea about the solar magnetic activity. We therefore present here the study of periodicity in CMEs during solar cycles 23-24. Section 2 contains the observations and methodology. Analysis and results are presented in section 3. Section 4 illustrates the discussion and conclusion.

Observations and Methodology

We used the SOHO/LASCO CME catalog of CDAW Data Center NASA. The website of the CME catalog is https://cdaw.gsfc.nasa.gov. We have covered the data from January, 1996 to December, 2019 spanning two solar cycles 23 and 24. The total number of CME events taken in this wide data range is 30127.

We have used Lomb-Scargle (L-S) periodogram (Lomb, 1976; Scargle, 1982) [25], method for the determination of periodicity in CMEs. The Lomb-Scargle periodogram is a widely used method for detecting and measuring periodicity in unevenly sampled time-series data. It efficiently calculates a power spectrum estimator similar to a Fourier transform, making it a straightforward tool for identifying oscillation periods in irregular datasets. Although Lomb-Scargle periodogram technique is motivated by Fourier analysis,the Lomb-Scargle method can also be interpreted as a least-squares fitting approach. Rooted in Bayesian probability theory, it has been shown in some cases to closely align with phase-folding methods based on data binning (Swingler, 1989) [24]. Consequently, the Lomb-Scargle periodogram is considered a valuable technique for analyzing periodic signals in non-uniformly spaced data within the field of solar physics.

Analysis and Results

We have taken total CMEs occurred in solar cycles 23 and 24. We have calculated the periodicity for halo CMEs also. The detailed analysis and results are described in following sub-sections.

Periodicity in Total CMEs Occurrence Rate

We have used L-S periodogram technique to determine the periodicity in occurrence rate of CMEs for solar cycle 23. The obtained periodogram is shown in Figure 1. Red dotted line is representing 99% confidence level and green dotted line is showing the 95% confidence level. This power spectrum shows that several periods are obtained for CME occurrence rate but there are few periods of them corresponding to which peak is sharp and above the 95 or 99% confidence level. We have omitted very short periods less than 10 days because of the possibility of data gap of these equivalent days. We have therefore extracted all the L-S periodograms for the physically prominent periods which are statistically significant also and are above the 95% and 99% confidence level.

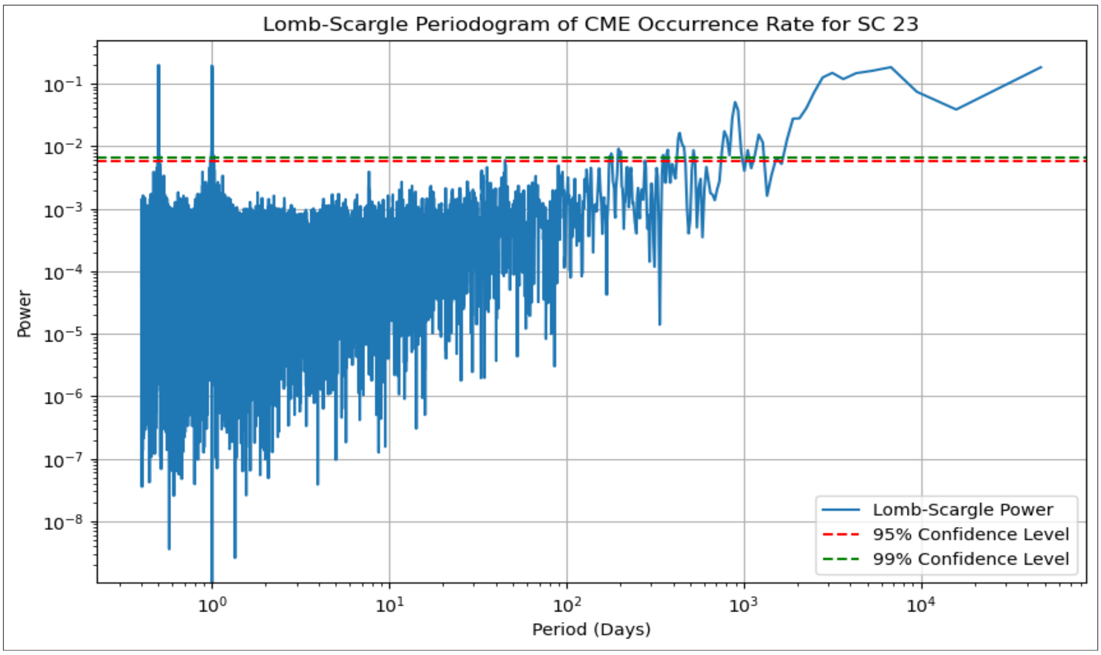

Fig 1: Lomb-Scargle (L-S) periodogram of CME occurrence rate for solar cycle 23.

Thus we have extracted the periods for CME occurrence rate for cycle 23 as shown in Figure 2. Most prominent period corresponding to which we got the maximum power is the period of 891 days. Another very long term periods of 1041 (2.85 year) and 1207 (3.31 year) days were also found above the 99% confidence level. The periods which were found above the 95% level but below the 99% confidence level are 45 and 277 days. We observed two Rieger type periodicities of 178 and 195 days. The annual periods of 349, 368 and 431 days were also observed. Quasi-Biennial periods of 518 and 776 days were observed for the cycle 23 in this study of CME occurrence rate.

We analyzed the periodicities in CME occurrence rate for solar cycle 24 using L-S periodogram (Figure 3). We got four prominent periods above 99% confidence level and these periods are 183, 537, 1142 and 1605 days in increasing order of power spectrum, *viz* physically most prominent period is 1605 days. We categorized the quasi-periods of 1142 and 1605 days as very long term periods.

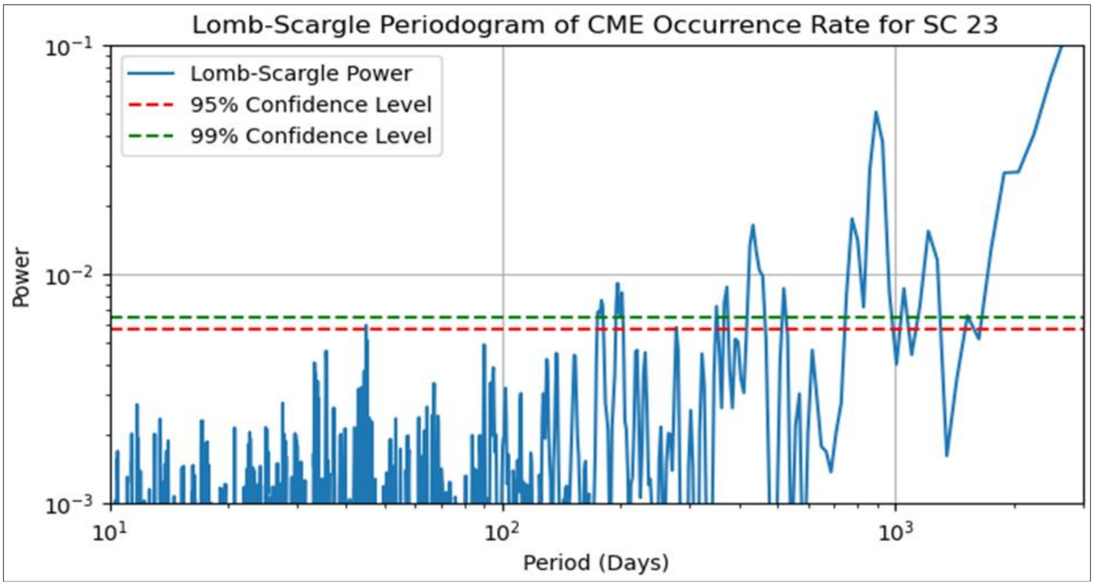

Fig 2: L-S periodogram of CME occurrence rate extracted for prominent periods for solar cycle 23.

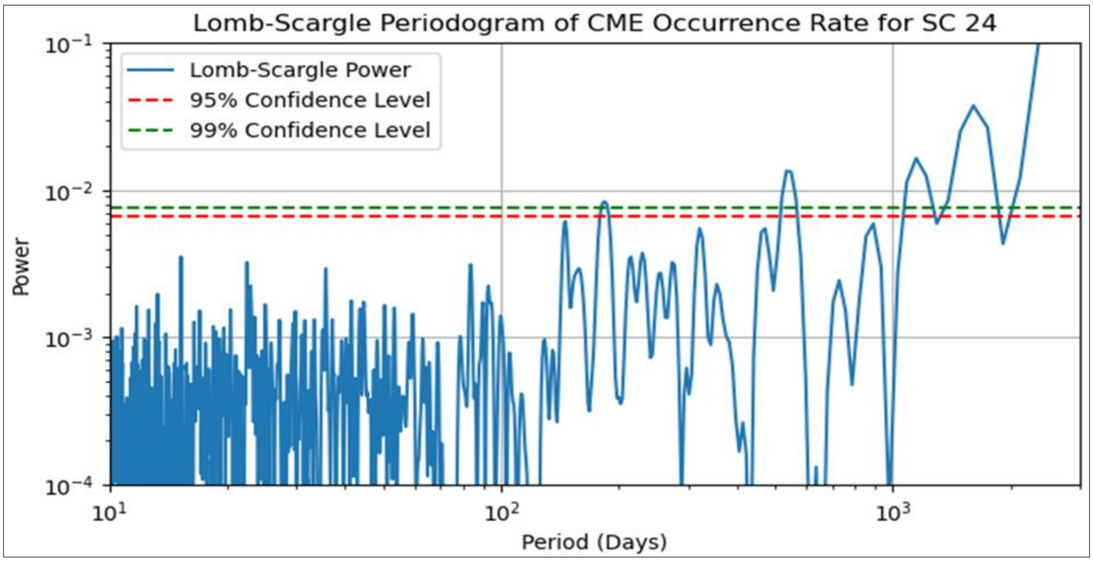

Fig 3: L-S periodogram of CME occurrence rate for solar cycle 24.

Periodicity in Total CMEs Mass Rate

Figure 4 shows the L-S periodogram of CME mass rate for solar cycle 23. We observed mid-term periodicities of 219 and 323 days, which are characterized as intermediate periods. Two very long periods of 922 (2.5 year) and 1259 (3.45 year) days were also detected in our study of CME mass rate.

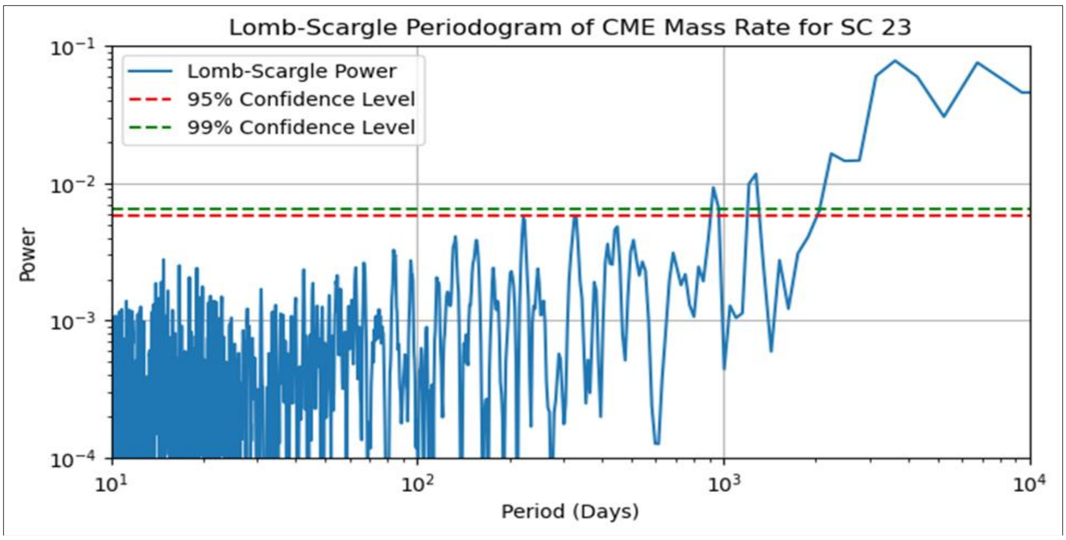

Fig 4: L-S periodogram of CME mass rate for solar cycle 23.

The same periodogram of CME mass rate was made for cycle 24 also (Figure 5) and found that quasi Biennial period of 634 days (1.74 year) and two very long periods of 1142 (3.13 year) and 1590 (4.36 year) days are the most prominent periods which fall above the confidence level of 99%.

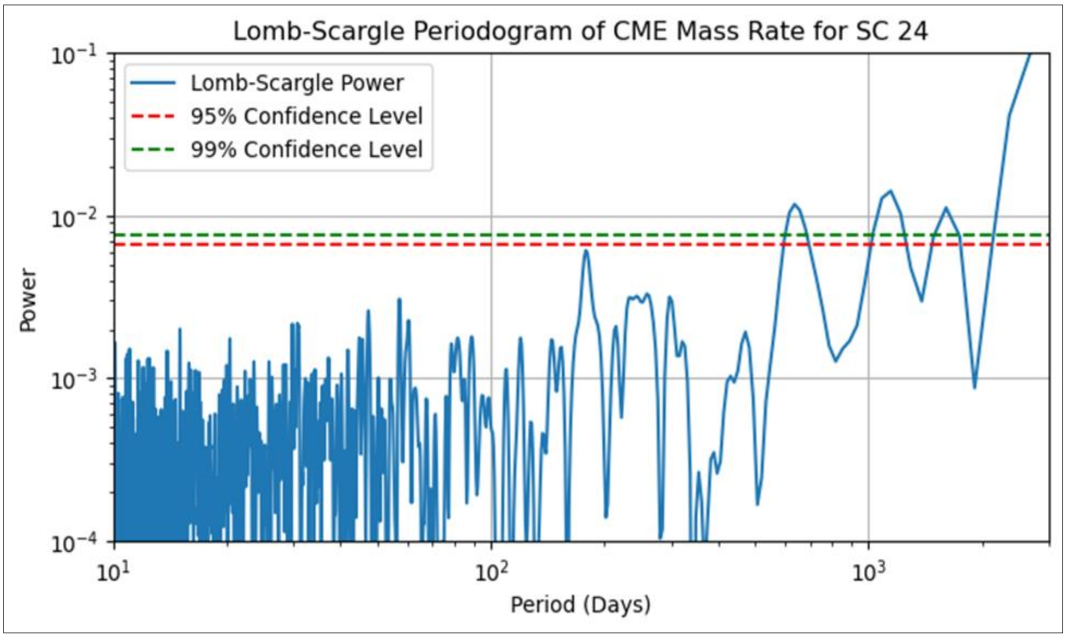

Fig 5: L-S periodogram of CME mass rate for solar cycle 24

Periodicity in Halo CMEs occurrence rate and mass rate

We determined the periodicity of halo CMEs occurrence rate for solar cycle 23 (Figure 6) and found four prominent periods which are statistically significant. Two periods which were detected below 99% confidence level and above the 95% confidence level are 202 and 272 days. Two more significant periods were observed which fall again in the category of very long term periods and these periods were 1231 (3.37 year) and 1980 (5.42 year) days. The same periodicity was calculated for solar cycle 24 also but we didn't get any period which was statistically significant, all the periods were below the 95% confidence level. So we analyzed the periodicities in halo CME occurrence for both solar cycles 23 and 24, and found that only one period of 1161 (3.18 year) days is statistically significant above the confidence level 99%. Halo CME mass rate was analyzed to find the periodicity separately in cycle 23 and 24, but no period was found above the confidence level of 95%. We then took the solar cycle 23 and 24 together to find this periodicity and found two periods of 60 and 3922 (10.76 year) days.

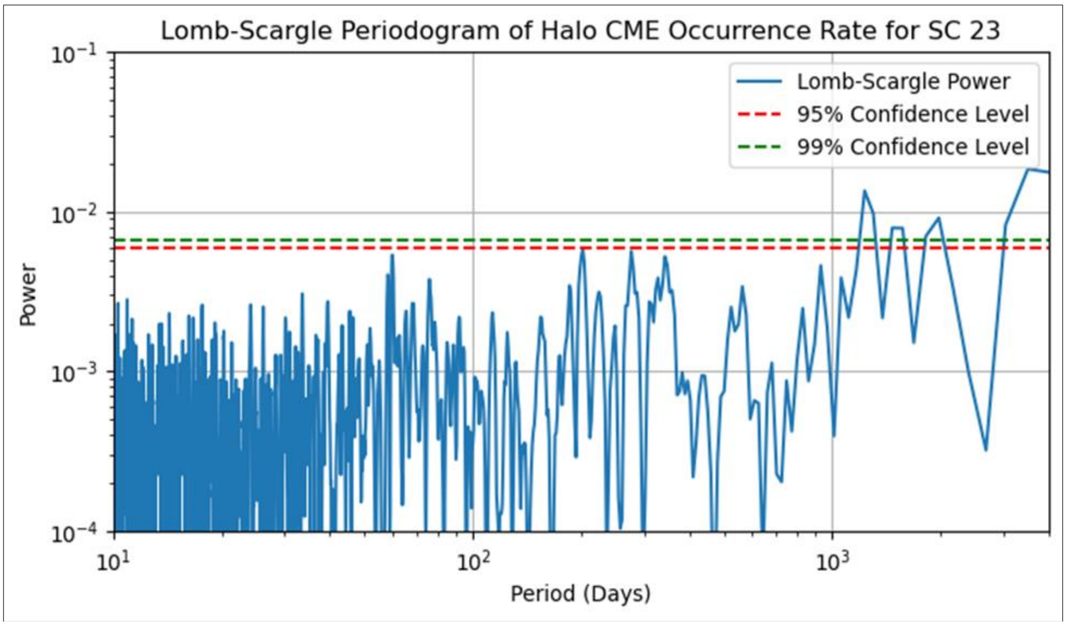

Fig 6: L-S periodogram of halo CME occurrence rate for solar cycle 23.

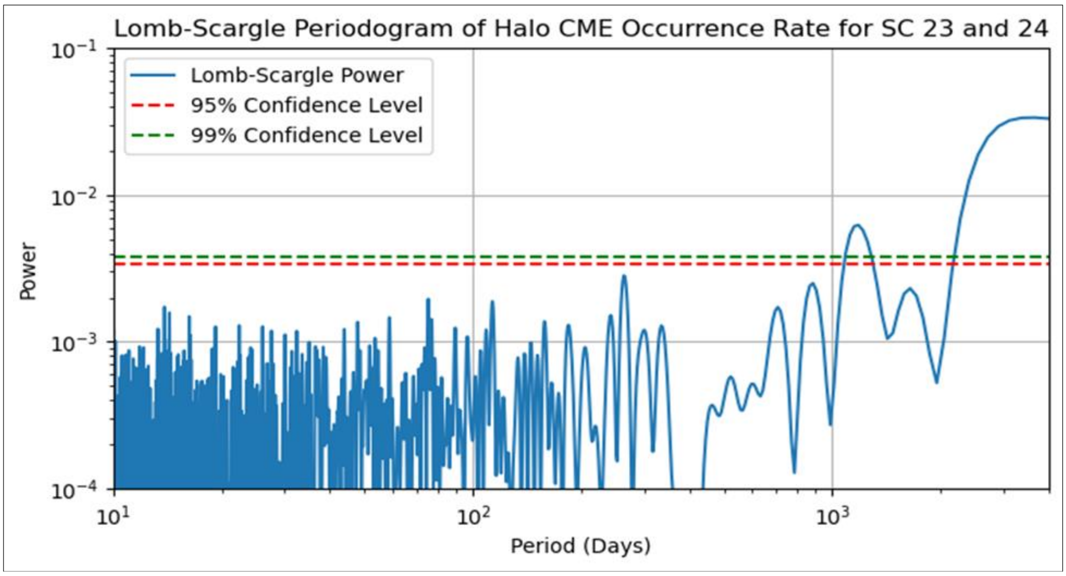

Fig 7: L-S periodogram of halo CME occurrence rate for solar cycles 23 and 24 combined.

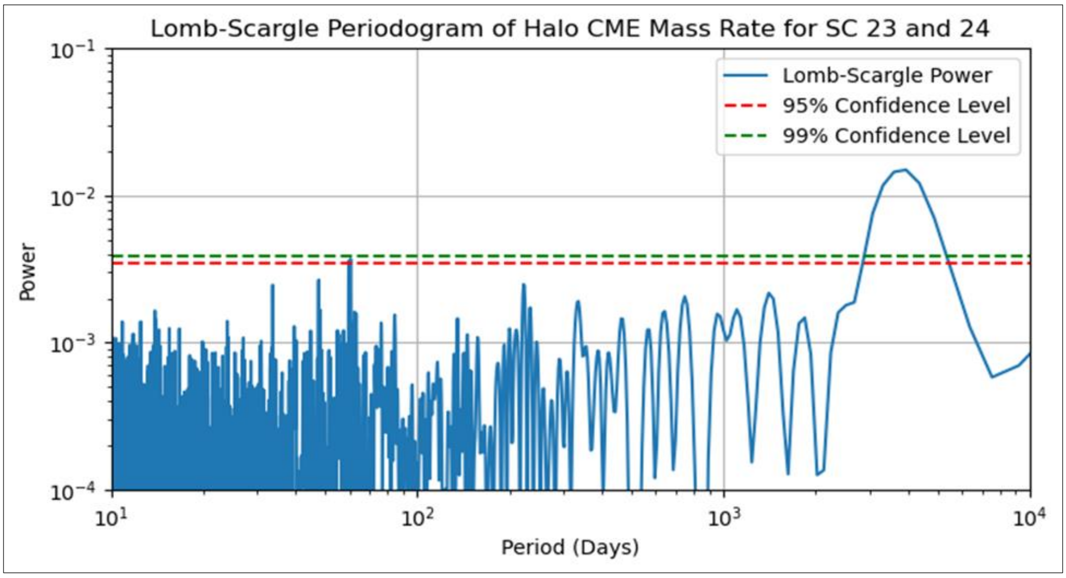

Fig 8: L-S periodogram of halo CME mass rate for solar cycles 23 and 24 combined.

Discussion and Conclusion

We had taken solar cycles 23 and 24 into consideration to determine quasi-periodicities in CMEs occurrence and mass rate and found the different range of quasi-periodicities. The different ranges of these quasi-periodicities are tabulated in Table 1.

Table 1: Different range of quasi-periodicities for CME occurrence and mass rate.

Time series data	37-98 days$	100-199 days$$	200-330 days#	≈ 365 days (≈1 year)##	~ 500 to 900 days (~1.5 to 2.5 year)@	> 900 days (> 2.5 years)@@
CME Occurrence SC23	45	178, 195	277	349, 368, 431	518, 776, 891	1041, 1207
CME Occurrence SC24		183			537	1142, 1605
CME Mass rate SC23			219, 323			922, 1259
CME Mass rate SC24					634	1142, 1590
Halo CME Occurrence SC23			202, 272			1231, 1980
Halo CME Occurrence SC 23 & 24					-	1161
Halo CME Mass SC23 & 24	60	-	-	-	-	3922

$ Other short term periods, $$ Rieger and Rieger type periods, # intermediate periods, ## annual period, @ quasi-biennial periods, @@ very long term periods

From Table 1 it is evident that most of the periods belong to very long term periodicity. The highest period is corresponding to the period of solar cycle and is of 10.76 years. The period of 5.42 year is half of the solar cycle duration. We found in our study that the most of the very long periods are found during the investigation of halo CMEs periodicity. The annual periods of 349, 368 and 431 days were obtained only for the total CME occurrence rate during solar cycle 23. Rieger type periodicities were observed for total CME occurrences only during both solar cycles 23 and 24. Quasi-Biennial periods were also obtained for total CME occurrences and mass rates only. Other short term periods of 45 and 60 days were found for total CME occurrence rate during cycle 23 and halo CME mass rate during both cycles 23 and 24 combined.

Most of the periods obtained in our study are also exhibited in other studies also. For instance, Aroori *et al*., 2021 [1] found the periodicities of 44 and 66 days for the solar radio emissions at different wavelengths. Choudhary *et al*. (2014) [7] examined the periodicity of soft X-ray (SXR) flares and identified a dominant period of 180 days during solar cycle 23 and 150 days during cycle 24. Intermediate periods of 202, 219, 272, 277 and 323 days are also supported by previous studies also ((Lean and Brueckner, 1989; Pap *et al*., 1990; Oliver *et al*., 1992; Lou *et al*., 2003) [24, 35, 30, 26]. Similarly other results like quasi-Biennial periods and very long term periods are supported by previous studies (Nayar *et al*., 2002; Özgüc *et al*., 2002; Knaack *et al*., 2004; Lara *et al*., 2008; Katsavrias *et al*., 2012; Aroori *et al*., 2021) [29, 33, 21, 23, 19, 1].

The magnetic polarity changes in 22 year and we found here a quasi-period of 10.76 years which is half of the magnetic polarity cycle. We can say that halo CMEs are also show the periodic behavior like magnetic activity in the solar atmosphere. The abundant occurrence of very long term periods in halo CMEs shows that the strong magnetic flux emergences can be the reason for the production of halo CMEs, because longer period means change in the relative parameter is slow and longest periodicity occurs for magnetic polarity of Sun.

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References

1. Aroori M, Vemareddy P, Chowdhury P, Yellaiah G. Solar Physics. 2021;296(3):43.
2. Ataç T, Özgüç A. Solar Physics. 2006;233:139.
3. Bai T. Astrophysical Journal. 2003;591:406.
4. Bai T, Sturrock PA. Nature. 1991;350:141-3.
5. Bai T, Sturrock PA. Astrophysical Journal. 1993;409:476.
6. Brueckner GE, Delaboudiniere JP, Howard RA, *et al*. Geophysical Research Letters. 1998;25:3019.
7. Choudhary DP, Lawrence JK, Norris M, Cadavid AC. Solar Physics. 2014;289(2):649-56.
8. Chowdhury P, Khan M, Ray PC. Monthly Notices of the Royal Astronomical Society. 2009;392:1159.
9. Chowdhury P, Ray PC. Monthly Notices of the Royal Astronomical Society. 2006;373:1577.
10. Das TK, Chatterjee TN. Monthly Notices of the Royal Astronomical Society. 1996;278:6.
11. Das TK, Nag TK. Solar Physics. 1998;179(2):431.
12. Das TK, Nag TK. Monthly notices of the royal astronomical society. 1999;303:221.
13. Feng S, Wu DJ, Chao JK. Astrophysical Journal. 2013;774:141.
14. Gopalswamy N. Geoscience Letters. 2016;3:8.
15. Gopalswamy N. Atmosphere. 2022;13:1781.
16. Howe R, Dalsgaard CJ, Hill F, *et al*. Science. 2000;287(5462):2456.
17. Howe R, Dalsgaard CJ, Hill F, *et al*. Advances in Space Research. 2007;40:915.
18. Kahler SW. Journal of Geophysical Research. 1982;87:3439.
19. Katsavrias C, Papadema PP, Moussas X. Solar Physics. 2012;280(2):623.
20. Kilcik A, Yurchyshyn V, Donmez B, *et al*. Solar Physics. 2018;293:63.
21. Knaack R, Stenflo JO, Berdyugina SV. Astronomy and Astrophysics. 2004;418:L17.
22. Krivova NA, Solanki SK. Astronomy and Astrophysics. 2002;394:701.
23. Lara A, Borgazzi A, Mendes O Jr, Rosa R, Domingues MO. Solar Physics. 2008;248:155.
24. Lean J, Brueckner GE. Astrophysical Journal. 1989;337:568.
25. Lomb NR. Astrophysics and Space Science. 1976;39:447-62.
26. Lou YQ, Wang YM, Fan Z, Wang S, Wang JX. Monthly Notices of the Royal Astronomical Society. 2003;345(3):809-18.
27. Mendoza B, Herrera VVM. Solar Physics. 2011;271(1):169-82.
28. Michalek G, Gopalswamy N, Yashiro S. Astrophysical Journal Letters. 2022;927:L16.
29. Nayar SP, Radhika VN, Revathy K, Ramadas V. Solar Physics. 2002;208(2):359.
30. Oliver R, Carbonell M, Ballester JL. Solar Physics. 1992;137(1):141-153.
31. Oloketuyi J, Liu Y, Zhao M. Astrophysical Journal. 2019;874(1):20.
32. Özgüç A, Ataç T. Solar Physics. 1994;150(1):339-346.
33. Özgüç A, Ataç T, Rybák J. In: Wilson A, editor. ESA Special Publication. 2002;2:709.
34. Özgüç A, Ataç T, Rybák J. Solar Physics. 2004;223(1):287-304.
35. Pap J, Tobiska WK, Bouwer SD. Solar Physics. 1990;129(1):165-189.
36. Reames DV. Space Science Reviews. 1999;90:413.
37. Scargle JD. Astrophysical Journal. 1982;263:835-853.
38. Rieger E, Kanbach G, Reppin C, Share GH, Forrest DJ, Chupp EL. Nature. 1984;312:623.
39. Zięba S, Masłowski J, Michalec A, Kułak A. Astronomy and Astrophysics. 2001;377(1):297-311.
40. Zhang J, Richardson IG, Webb DF, *et al*. Journal of Geophysical Research: Space Physics. 2007;112:A12103.
41. Zurbuchen TH, Richardson IG. Space Science Reviews. 2006;123:31.