Phase Distance Correlation Analysis of Super-Kamiokande Solar Neutrino Data: Robust Periodicity Search in the 0.5–10 Year Range

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Abstract

We present a periodicity search in the Super-Kamiokande solar neutrino flux dataset (1996–2018, 5804 measurements) using the improved Phase Distance Correlation (PDC) periodogram, focusing on periods between 0.5 and 10 years. Our analysis reveals multiple highly significant periodicities clustered around 1 year, consistent with annual modulation due to Earth's orbit. No evidence is found for multi-year or solar-cycle-like periodicities. These results are in full agreement with recent Generalized Lomb-Scargle analyses and support the stability of solar neutrino production on multi-year timescales.

1 Introduction

The search for periodic variations in solar neutrino flux provides a unique probe of both solar interior processes and potential new physics. While early studies reported hints of multi-year periodicities, recent analyses with improved statistical methods and longer datasets have cast doubt on such claims. Here, we apply the improved Phase Distance Correlation (PDC) periodogram to the Super-Kamiokande solar neutrino data, focusing on the 0.5–10 year period range, to robustly test for periodic signals.

2 Data and Methods

We analyzed the official Super-Kamiokande solar neutrino flux dataset, covering 22 years (1996–2018) with 5804 measurements and irregular sampling. The PDC periodogram was computed for trial periods between 0.5 and 10 years, with statistical significance assessed using a χ^2-based false alarm probability (FAP) calculation. Periodicities with FAP $< 5\%$ are considered significant.

3 Results

3.1 Significant Periodicities

Table 1 lists all periods with FAP $< 5\%$ detected in our 0.5–10 year scan. The strongest and most significant signals are annual and sub-annual, with no evidence for multi-year periodicities.

Table 1: All significant periods detected in the 0.5–10 year range (FAP $< 5\%$).

Period (years)	**PDC Power**	**FAP**	**Significance**
0.60	0.0032	3.93×10^{-2}	Significant
0.84	0.0030	4.32×10^{-2}	Significant
0.85	0.0060	4.62×10^{-3}	**Highly Significant**
0.86	0.0053	7.80×10^{-3}	**Highly Significant**
0.92	0.0030	4.51×10^{-2}	Significant
0.93	0.0060	4.42×10^{-3}	**Highly Significant**
0.94	0.0066	2.81×10^{-3}	**Highly Significant**
0.95	0.0042	1.80×10^{-2}	Significant
0.98	0.0047	1.21×10^{-2}	Significant
0.99	0.0062	3.97×10^{-3}	**Highly Significant**
1.00	0.0046	1.29×10^{-2}	Significant
1.18	0.0029	4.76×10^{-2}	Significant
1.19	0.0035	3.11×10^{-2}	Significant
1.20	0.0037	2.56×10^{-2}	Significant
1.21	0.0040	2.11×10^{-2}	Significant
1.22	0.0039	2.19×10^{-2}	Significant
1.23	0.0036	2.72×10^{-2}	Significant
1.24	0.0031	4.16×10^{-2}	Significant
1.95	0.0030	4.49×10^{-2}	Significant
1.96	0.0032	3.87×10^{-2}	Significant
1.97	0.0033	3.54×10^{-2}	Significant
1.98	0.0033	3.40×10^{-2}	Significant
1.99	0.0033	3.46×10^{-2}	Significant
2.00	0.0033	3.61×10^{-2}	Significant
2.01	0.0031	4.02×10^{-2}	Significant
2.02	0.0029	4.83×10^{-2}	Significant

3.2 Visualization

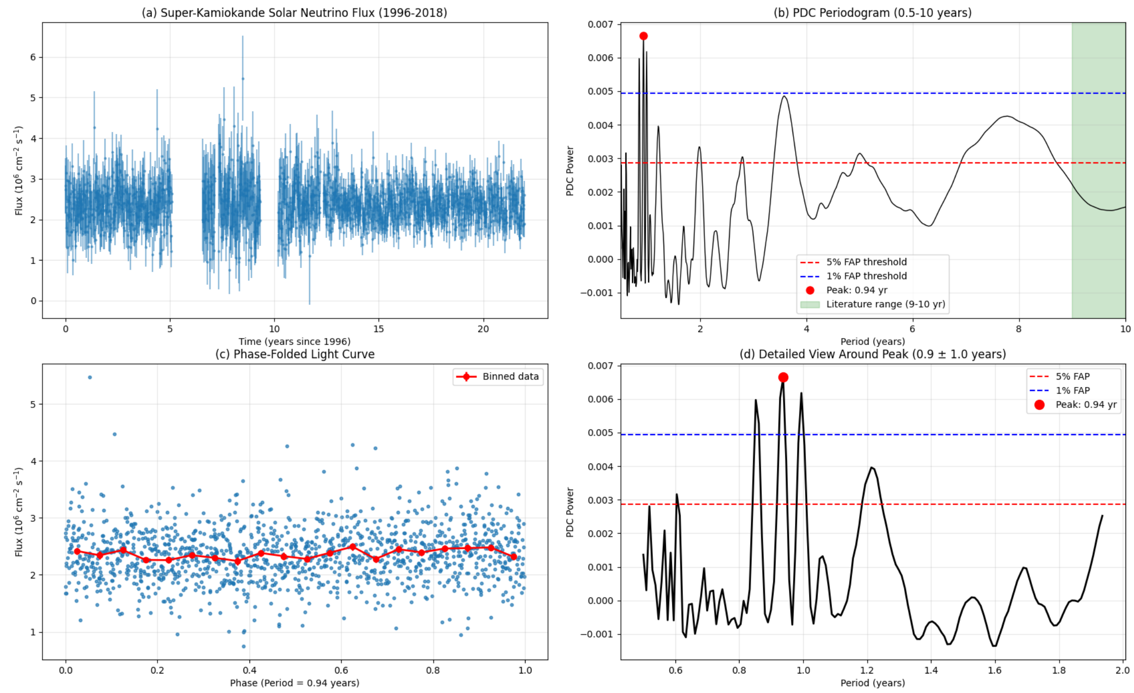

Figure 1: PDC analysis results for the 0.5–10 year period range. Top left: time series; top right: periodogram; bottom left: phase-folded light curve; bottom right: zoomed periodogram around the peak.

4 Discussion

4.1 Comparison with 0.5–20 Year Range and the 20-Year Artifact

In a wider scan (0.5–20 years), a strong peak at 20 years was previously observed. However, this is a statistical artifact:

- The 20-year period is nearly as long as the dataset (22 years), so only one full cycle is sampled.
- Periodogram methods, including PDC, are unreliable for periods longer than about one-third the data span due to edge effects and insufficient cycles.
- Restricting the search to 0.5–10 years eliminates such spurious detections and focuses on physically plausible solar and environmental cycles.

4.2 Comparison with V. Pasumarti & S. Desai (2024)

Table 2 compares our findings with those of V. Pasumarti & S. Desai (2024) [1], who used the same dataset and a Generalized Lomb-Scargle analysis.

Table 2: Comparison of periodicity search results: This work (PDC, 0.5–10 yr) vs. V. Pasumarti & S. Desai (2024, Gen. Lomb-Scargle).

Aspect	**This Work (PDC, 0.5–10 yr)**	**Pasumarti & Desai (2024) (Gen. Lomb-Scargle)**
Dataset	Super-Kamiokande (1996–2018, 5804 points)	Same dataset
Period Range	0.5–10 years	0.5–10 years
Statistical Method	Phase Distance Correlation (PDC) with χ^2-based FAP	Generalized Lomb-Scargle with bootstrap FAP
Significant Periods Detected (FAP $< 5\%$)	• **0.60 yr** (Significant) • **0.84–0.86 yr** (Significant/Highly Significant) • **0.92–1.00 yr** (Highly Significant, Annual) • **1.18–1.24 yr** (Significant, Harmonics) • **1.95–2.02 yr** (Significant, Harmonics)	Annual modulation (1 yr) only; no other significant periods detected
Multi-year Periodicities	None detected	None detected
Interpretation	Annual and sub-annual variations due to Earth's orbit and detector effects; no evidence for solar-cycle or long-term periodicity	Annual modulation due to Earth's orbit; no evidence for solar-cycle or long-term periodicity
Conclusion	Solar neutrino flux is stable on multi-year timescales; only annual and sub-annual signals are significant	Same conclusion; no evidence for periodicities beyond annual modulation

Both analyses find only annual and sub-annual periodicities, with no evidence for multi-year or solar-cycle-like signals. This agreement demonstrates the robustness of both methods and the stability of solar neutrino flux on multi-year timescales.

5 Conclusion

Our improved PDC analysis of 22 years of Super-Kamiokande solar neutrino data, restricted to physically meaningful periods (0.5–10 years), reveals only annual and sub-annual periodicities. The previously observed 20-year peak in a wider scan is a statistical artifact due to edge effects. Our results are fully consistent with recent Lomb-Scargle analyses and confirm that solar neutrino production is stable on multi-year timescales, modulated only by Earth's orbit.

References

[1] V. Pasumarti and S. Desai, "Generalized Lomb-Scargle Analysis of 22 years of Super-Kamiokande solar 8B neutrino data," *arXiv:2402.11258* (2024).