2nd Semester report

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Ph.D. Thesis title: Exploring Spatial and Temporal Patterns Across Solar Cycles Focusing on Active Longitudes

Introduction

Active longitudes (ALs) are proposed behavioural patterns on the Sun in which certain manifestations of solar activity preferentially occur at specific longitudes. These preferred longitudes are not fixed but evolve over time, typically on timescales of several Carrington rotations (CRs). Despite decades of investigation, the existence of ALs remains a topic of debate, largely because their origin, evolution, and physical significance are still not fully understood. In this work, we sought to provide further evidence for the existence of ALs by analysing long-term datasets of sunspot groups and solar flares. To assess whether the observed patterns could arise by chance, we also constructed artificial control datasets in which sunspot longitudes were randomised while preserving the overall characteristics of the solar cycle. Kernel density estimation (KDE) was applied to identify longitudinal concentrations of sunspot groups and flares on synoptic maps. To investigate the temporal evolution of these structures, a two-dimensional KDE was further applied to the peaks of the one-dimensional KDE distributions, allowing us to track preferred longitudes as a function of Carrington rotation. In addition, artificial solar cycles were generated by simulating sunspot populations with randomised properties, most importantly assigning longitudes from a uniform distribution. The analysis revealed distinct and persistent features in the observational data. During certain phases of the solar cycle, enhanced activity was concentrated within a limited longitude range, which could subsequently disappear and re-emerge approximately 180° away, consistent with the previously reported flip-flop behaviour of ALs. Although similar structures occasionally appeared in the randomised datasets, their characteristics differed markedly from the observations. Inactive longitude regions were less pronounced, while active regions were generally shorter-lived and more numerous. Furthermore, we identified a quantitative indicator based on the number of KDE peaks per Carrington rotation within a solar cycle. This parameter exhibited significantly different distributions in the observational and randomised datasets, with a Cucconi test yielding a p-value of 0.0177, providing statistical evidence that the observed AL patterns are unlikely to result solely from random fluctuations.

Description of research work carried out in current semester

During the second semester, my research focused on further investigating the nature and behaviour of ALs on the Sun. Building on the results obtained in the previous semester and published in Csaszar et al. 2026 A&A, I extended the analysis by incorporating geomagnetic activity data, specifically the aa-index, to explore potential connections between solar ALs

and long-term variations in geomagnetic activity. Preliminary analyses revealed similarities between the wavelet power spectra of the aa-index and the AL time series, suggesting possible links between persistent solar activity patterns and the terrestrial geomagnetic response. This work is ongoing and forms part of a second publication currently in preparation.
A second major aspect of the semester involved exploring alternative methods to demonstrate the existence of ALs. While previous analyses were based primarily on two-dimensional representations of solar activity, this semester I investigated a three-dimensional approach aimed at revealing the spatial and temporal clustering of activity in a more comprehensive manner. Although a statistically significant result has not yet been achieved, the analysis has identified promising structures, and work is continuing to develop more robust techniques for quantifying and visualising the observed clustering. In addition, considerable effort was devoted to reproducing and validating previous results, ensuring the robustness and reliability of the analysis methods and datasets used throughout the project. This process also provided an opportunity to further refine the data-processing pipeline and improve the reproducibility of the research workflow.
Overall, the work carried out during this semester has expanded the investigation of ALs into new areas, including their possible connection to geomagnetic activity and the development of novel methodologies for characterising their long-term evolution and spatial organisation. These studies provide the foundation for the next phase of the project and the preparation of future publications.

Publications:

Exploring spatial and temporal patterns across solar cycles:
Focusing on active longitudes, **K. Császár**, M. B. Korsós, Sz. Soós, and R. Erdélyi – accepted for publishing in A&A
Exploring spatial and temporal patterns across solar cycles:
Active longitude oscillations, **K. Császár**, M. B. Korsós, Sz. Soós, and R. Erdélyi – In preparation, to be sent for publishing in A&A

Studies in Spring Semester 2025/2026

Radioastronomy 2 – completed with a grade 5
Course was taken at ELTE

Conferences in current semester

I have not attended any conferences in any form in the semester.
Regular attendee of the astronomy department's "astro pizza" seminar series.
Regular attendee of the Solar group weekly Friday meetings

Teaching activity in current semester

I was teaching the "Csillagászati észlelési gyakorlatok 1" practical course to the bachelor's students in the astronomy specialization of the physics and earth sciences BSc programmes.