# 1st Semester report

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

## Introduction

The existence of active longitudes (ALs) has been a long-debated topic within the field of solar physics. In recent times, interest has risen considerably towards this phenomenon, as more evidence is gathering that would inspire the development of a more complex solar dynamo model that accounts for ALs.

In essence, what we mean by ALs is that the Sun generates phenomena (such as sunspot groups, flares or faculae) with a longitude dependence. That is, the longitude distribution of e.g. the sunspot groups throughout a solar cycle (SC) is not described by a uniform distribution in the longitudinal direction, but by a distribution that has peaks at certain longitude intervals. One main reason that such a distribution is difficult to be shown, is the differential rotation of the Sun; longitudes are not easy to identify, as each latitude revolves at a slightly different angular velocity due to the differential rotation. Another reason is that this non-uniform longitudinal distribution, just like the latitudinal butterfly diagram, appears to be time-dependent; the longitude(s) at which the distribution's peak(s) can be found at a given moment of time varies throughout the solar cycle.

My work so far is concerned with demonstrating a new way to show the existence of these ALs, as well as looking for patterns in the time-dependence of the aforementioned distribution's peaks.

## Description of research work carried out in current semester

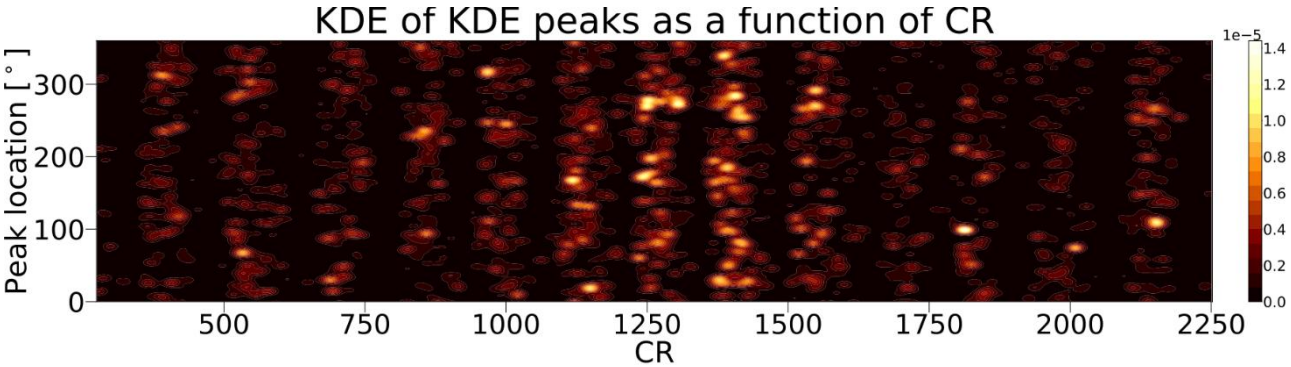
My thesis aims to provide support and further evidence towards the existence of ALs by utilising long-term sunspot and solar flare datasets. The datasets in use include sunspot group data covering close to 150 years, compiled from multiple ground-based observatories (see Mandal et.al. 2020), as well as the SOON (Solar Observing Optical Network) and GOES (Geostationary Operational Environmental Satellite) flare catalogues.

Kernel density estimation (KDE, see Rosenblatt 1956; Parzen 1962) was employed to search for longitudinal coherence of sunspot groups and flares in synoptic maps. Furthermore, I have also searched for large-scale structures by applying a 2D KDE to the peaks of the 1D KDEs (longitude as a function of Carrington rotation (CR)). Finally, in order to test the reliability of our approach, I have generated artificial solar cycles by simulating sunspots with randomised properties, most notably assigning longitudes from a uniform distribution.

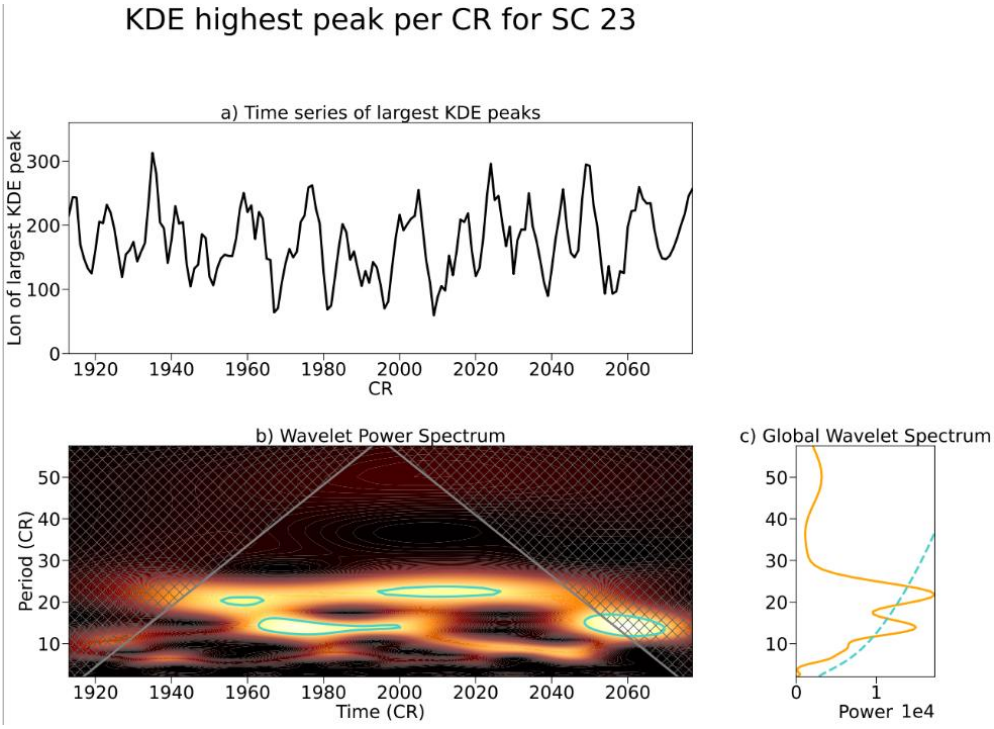
Distinguishable features were identified in the 2D KDEs, showing that during certain epochs of the solar cycle, a specific longitude range may exhibit heightened activity, which may later switch off entirely, and a new one would appear ~180° away, consistent with the AL's flip-flop effect.

An artificial dataset for control was also constructed, as part of the effort to validate the existence of ALs, in which the longitudes of sunspots were randomised, allowing a direct comparison with the observational data.

Although the randomised datasets also exhibited “AL”s in their 2D KDEs, these differed notably from the observed patterns: inactive longitudes were less pronounced, and active patches appeared shorter-lived and more numerous.
I have also identified an indicator parameter for a qualitative comparison: the number of KDE peaks (in the 1D KDE) per number of CRs in a given solar cycle. This indicator showed a markedly different distribution between the randomised and observed datasets, and was further confirmed by a Cucconi test (see Marozzi 2009) p value of 0.0177.
In conclusion, the observational data showed significantly different structures than what we would expect if there was no time-dependence in the longitudinal distribution of sunspots. Further, the time-dependent characteristics were also investigated, using wavelet-analysis. One recurring idea in previous works on ALs is that the centres of these clusters are about 180° from one-another, something that my previous work also shows. The longitudinal positions of these clusters, more specifically, the largest amplitude (KDE amplitude) cluster identified in a CR was used as input for the wavelet analysis to find patterns in them. Similarly, the longitude differences of the 2 largest peaks was also used as input. Periods were found in these input datasets falling within the period ranges of the Quasi Biennial Oscillations (QSOs) that have been studied extensively in other solar phenomena (see Chowdhury2009, Kudela2010).
Separating the periodicities found in real and the previously used artificial data has been inconclusive, though much time was spent on finding a valid metric and method.




2D KDE of the investigated sunspot group dataset covering about a period of 150 years, expressed in CRs. Certain longitudes are preferred in different parts of solar cycles. The colorbar shows the value of the probability density function, resulting from the KDE.




The upper panel shows the dataseries constructed from the longitudes of KDE peak, corresponding to the locations of the largest AL of a CR. The lower panels are the wavelet and global wavelet power spectrums, showing what periodicities are present in the signal (top panel). The significant periods are all within the 0.8-4 year periodicity range of the QSOs.

# 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 Autumn Semester 2025/2026

Physics of the solar atmosphere – completed with a grade 5
Solar System plasma physics – completed with a grade 5
Both courses were 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

Special note
Please note that I was off sick the month of January due to illness.