Semester Report 4

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Ph.D. Thesis title:

"Nonlinearities and Stochastic Perturbations in Dynamo Models"

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- ## Introduction

Synoptic maps of the line-of-sight component of the large scale solar magnetic field have been available on a regular basis since the 1970s. As high resolution observations indicate that this field is mostly concentrated in numerous thin, strong flux tubes that are vertically aligned by buoyancy forces, the true photospheric field is assumed to be radial, and its amplitude on the solar surface, B(θ,φ) can be derived by a de-projection of the line-of sight field. In order to interpret the evolution of the photospheric field on these synoptic maps, surface flux transport (SFT) models were developed in the 1980s. The models described the evolution of the radial component of the magnetic field Br on the solar surface, the equation is the r-component of the MHD induction equation at $r = R_{\Theta}$ under the assumption that the field at the surface is purely vertical, augmented by a source term for Br, and flux removal term, S and D respectively (Jiang, 2014); the source term was included to represent flux emergence in the form of newly appearing bipolar active regions (ARs). After the magnetic fields of decayed active regions are transported to the poles, these contributions gradually change the Sun's polar magnetic field, bringing about the reversal of the polar field and of the soar dipole moment at the middle of activity cycles and build-up a new poloidal field in the late phases of the cycle.

After that a steady improvement on the model were added during 2000s this source decay term introduced to the equation, around 2010, with the increased interest in solar cycle prediction following the abrupt change of the long-term level of solar activity with Cycle 24. As it was realized that the best physical precursor of the amplitude of an upcoming solar cycle was the amplitude of the Sun's polar magnetic field at the start of the cycle (Petrovay, 2010).

- ## Summary of research work carried out in the previous three semesters

The next logical step was the use of SFT models to describe the buildup process of this polar field, in the hope of extending the temporal range of cycle prediction. Any SFT model needs to make assumptions concerning an ill-constrained function, the effective meridional flow profile u(θ), as well as three free parameters: the flow amplitude u_0, the diffusivity η and the decay time scale τ. (Other choices, such as differential rotation or the form of the source, are much better constrained by observations.) The more important an exact quantitative reproduction of the evolving magnetic field is for a given application, the more crucial an appropriate choice of parameters.

In this work we mapped the parameter space of surface flux transport models from the point of view of the spatiotemporal variation of the polar field resulting with a source term representing an average solar cycle, marking the allowed domain compatible with observational constraints. Then we argued that other methods of constraining parameter space are less well suited for applications of SFT to solar cycle prediction. We found that without a significant source term in the SFT equation (τ > 10 yr) the global dipole moment reverses too late in the cycle for all flow profiles and parameters, providing independent supporting evidence for the need of a decay term, even in the case of identical cycles. An allowed domain was found to exist for τ values in the 5–10 yr range for all flow profiles considered. Generally higher values of η (500–700) are preferred, though some solutions with lower η are still allowed. The admitted domain was found to be the most extensive for a simple sinusoidal flow profile with τ ≈ 7 (Fig. 4): in this case, practically the whole upper left half of the u_0–η plane is allowed. Taken by themselves, then, the polar field constraints considered would suggest the use of this simple flow model with the $\eta = u_0$ ratio exceeding about 35.

The sequence of the work during the past 3 semesters was as follows, 1- Solve the integrated toroidal flux equation, where the solution is in the form of the oscillator equation with the parameters of the updated Leighton model, 2- Write a python script which solve the 1D surface flux transportation equation, using FTCS scheme. Then we started using the python code to generate preliminary results, the code was run as follows: 1- run several runs to test the code and modify the bugs in it, and affirming that the Hale Law and Joy's Law were applied 2- Compile the python code for certain values of four parameters to get the values and the changing in the magnetic field and especially the polar field. 3 - After that, the meridional flow profile was changing between (Dikpati, 2006), (van Ballegooijen , Eric , & Cartledge, 1998) and (Lemerle, 2017) profiles, and re-calculate polar field and the source values and plot them with time. As the values of the parameters were changing (Meridional flow velocity, timescale, profile, diffusivity) the new values of the magnetic field were measured in order to plot contour plots between these parameters. after that, several experiments were run, we ran the code for the previous three meridional flow profiles, then using the generated data we plot Butterfly diagram (Figure 2) and contour plots (Figure 3) for different profiles between different parameters (phase dipole moment, reversal of dipole moment, half maximum of dipole moment) which was constrained by the observational values from Wilcox Solar observatory (WSO), Sunspot number (SSN) and axial dipole moment (See table 1, 2).

Cycle number	min.time	WSO at min	WSO max.	WSO max.time	[6]	reversal time	[8]
21	1976.206	-9999	-131.753	1985.79	9.584	1980.708	4.502
22	1986.707	-131.0737	106.417	1993.455	6.748	1990.623	3.916
23	1996.624	97.9358	-65.3589	2004.624	8	2000.708	4.084
24	2008.958	-54.63141	62.82371	2017.958	9	2013.79	4.832

Table 1 WSO data, Column 6 and 8 are the WSO max.time since cycle min and WSO reversal time since cycle min. respectively.

Cycle#	min.time	WSO at min	WSO max.	WSO max.time	[6]	reversal time	[8]
21	1976.206	-9999	4.23	1984.29	8.084	1979.623	3.417
22	1986.707	4	3.96	1992.124	5.417	1989.98	3.273
23	1996.624	1.95	3.1	2003.204	6.58	1999.958	3.334
24	2008.958	1.34	1.93	2017.958	9	2012.708	3.75

Table 2 Dipole moment values, Column 6 and 8 are the p max.time since cycle min and p reversal time since cycle min.

- **Description of research work carried out in the current semester**

During this semester, an enhancements to the python script were added, including two meridional flow profiles from ((Whitbread, 2017), (Wang, 2017)), with the observational constrains taken from (Table 1, 2) and calculating the standard deviation as in (Table 3), the solution for the polar magnetic field with the parameters were plotted (Figure 1) and the admissible areas in the parameter spaces (Figure 3) were selected, several runs for higher resolution plots were made by changing the grid points number and the slowness factor in the code depending on the flow profile (Table 4), some experiments were made regarding code accuracy with a magnetic monopole as an Initial condition was taken, in order to check the magnetic flux conservation, and finally a paper entitled "optimization of the surface flux transport model for the solar polar magnetic field" was wrote and submitted to Astronomy and Astrophysics Journal.

A plausible further extension of this work would admit inter-cycle variations in cycle amplitudes and periods, focusing on how SFT parameter choices influence the interplay of stochastic and nonlinear effects.

Parameter	Mean	Std(σ)
revWSOB	4.33	0.36
revdipmom	3.44	0.18
relWSOB	0.90	0.06
reldipomom	0.84	0.12
hmcycmin	67.5	7.5

Table 3: Observational constraints on the variation of the poloidal field in a typical cycle. Where revWSOB is WSO polar field reversal time from min, revdipmom is the Global dipole moment reversal time from min, relWSOB is the WSO field at cycle min./maximum of WSO field, reldipolmom is the Dipolar moment at cycle min./ maximum of dip.mom. and the hmcycmin is Latitude edge of topknot (half max of WSO field). (Note that 1σ errors are given here, but in our parameter mapping 2σ limits are imposed).

Flow Profile	Nfac	Slowness factor	Latitude0 (degrees)
1	2	4	90
2	1	1	75
3	2	4	89

Table 4: Grid number and slowness factors in addition to the initial latitude for higher resolution runs depending on the flow profile

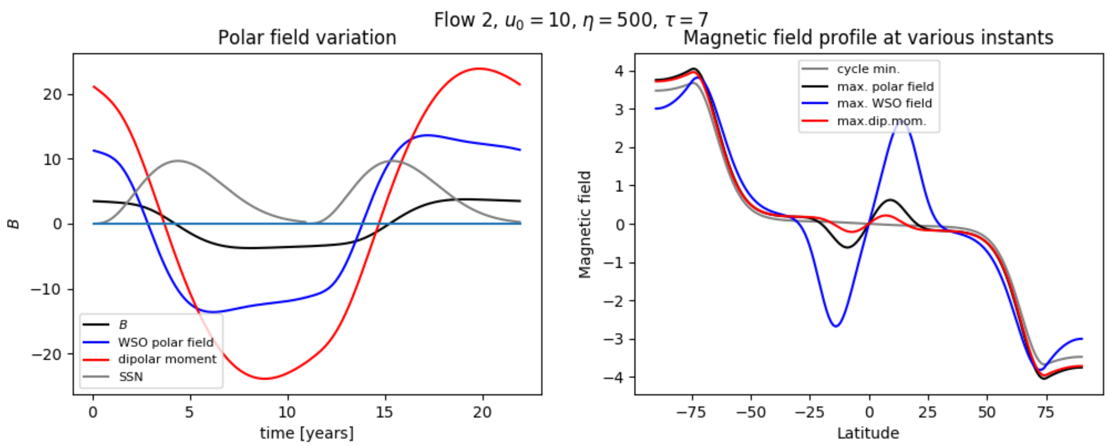

Figure 1: Example of a solution satisfying all observational constraints on the polar magnetic field: temporal variation and latitudinal profiles.

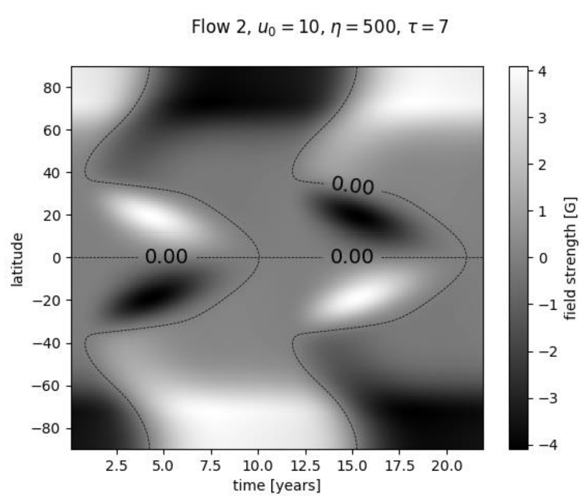

Figure 2: Example of a solution satisfying all observational constraints on the polar magnetic field: butterfly diagram.

Publications

- **Talafha, M. H.,** Al-Wardat, M. A., and Ershaidat, N. M. (2018). A Study of the Abundance of Low-Z Elements in the Sun During its Whole Predicted Life. Astrophysical Bulletin, 73(2), 235-240.
- Suleiman N., Al-wardat M., **Talafha M.,** AL-Ameryeen H., Toth V. (2018). Astronomy education in Jordan. Proceedings of the International Astronomical Union, accepted in October 2018.
- **Mohammed H. Talafha** and Ziad A. Talafha, (2019). Symbols and astrological terms in ancient Arabic inscriptions, Scientific Culture, 5.2, 21-30.
- Petrovay, K. and **Talafha, M. H**. (2019). Optimization of Surface Flux Transport Models for the Solar Polar Magnetic Field. submitted to Astronomy and Astrophysics Journal.

Courses

- FIZ/2/119 - Data mining in astronomy – Dr. László Dobos.

Conference participations during the doctoral studies

- September 4-8, 2017., Budapest, Hungary. The 15th European Solar Physics Meeting.
- November 6, 2017., Budapest, Hungary. Commemorating the 50th anniversary of the discovery of pulsars, Hungarian Academy of science (MTA).
- June 11-16, 2018, Udine, Italy., Advanced topics in MHD.
- August 20-31, 2018., Vienna, Austria, XXX IAU General Assembly, Poster entitled "Astronomy education in Jordan", Nofoz Suleiman, Viktor Toth, Mashhoor Al-wardat**, Mohammed Talafha**.
- September 10 – 13, 2018., Granada, Spain, HINODE -12: The Many Suns, Poster entitled "Optimization of surface flux transport models for the solar polar magnetic field", **Mohammed Talafha** and Kristof Petrovay.
- 5-8 November 2018, Debrecen, Hungary. Neutrino physics school, ATOMKI.
- November 26 - 28, 2018., Dresden, Germany, MHD Days and GdRI Dynamo Meeting, Poster entitled "Optimization of surface flux transport models for the solar polar magnetic field", **Mohammed Talafha** and Kristof Petrovay.
- 4-8, March 2019, Stockholm, Sweden., Solar Helicities in Theory and Observations: Implications for Space Weather and Dynamo Theory, Oral contribution entitled "Optimization of surface flux transport models for the solar polar magnetic field", **Mohammed Talafha** and Kristof Petrovay.
- May 6 – 10, 2019, Hvar, Croatia, 2nd China-Europe Solar Physics Meeting (CESPM 2019), Poster entitled "Optimization of surface flux transport models for the solar polar magnetic field", "Global dipole moment study using optimized surface flux transportation model", **Mohammed Talafha** and Kristof Petrovay.

Conferences in Future

- August 26 - 30, 2019, Göttingen, Germany, Solar Polarization Workshop 9, abstract submitted "Global dipole moment study using optimized surface flux transportation model".
- September 2 - 6, 2019, Tokyo, Japan, Hinode-13 / IPELS 2019 meeting, abstract submitted "Global dipole moment study using optimized surface flux transportation model".

Awards

- ELTE Talent Support scholarship – Budapest, Hungary, Autumn Semester 2018/2019.
- ELTE Talent Support scholarship – Budapest, Hungary, Spring Semester 2018/2019.
- Outstanding student poster award, "Optimization of surface flux transport models for the solar polar magnetic field", 2nd China-Europe Solar Physics Meeting (CESPM 2019), 10 May, 2019, Hvar, Croatia.

- **References**

van Ballegooijen, A., Eric, P., & Cartledge, N. (1998). Magnetic Flux Transport and the Formation of Filament Channels on the Sun. *The Astrophysical Journal, 501*(2), 866-881.

Dikpati, M. D. (2006). Predicting the strength of solar cycle 24 using a flux-transport dynamo-based tool. *Geophysical research letters,*, 33(5).

Jiang, J. H. (2014). Magnetic flux transport at the solar surface. *Space Science Reviews*, 186(1-4), 491-523.

Lemerle, A. C. (2017). A coupled 2× 2D Babcock–Leighton solar dynamo model. II. Reference dynamo solutions. *The Astrophysical Journal*, 834(2), 133.

Petrovay, K. (2010). Solar cycle prediction. *Living Reviews in Solar Physics*, 7(1), 6.

Talafha, M. H.-W. (2018). A Study of the Abundance of Low-Z Elements in the Sun During its Whole Predicted Life. *Astrophysical Bulletin*, 73(2), 235-240.

Wang, W. L. (2017). Buildup of a highly twisted magnetic flux rope during a solar eruption. *Nature communications*, 8(1), 1330.

Whitbread, T. Y.-J. (2017). Parameter optimization for surface flux transport models. *Astronomy & Astrophysics*, 607, A76.

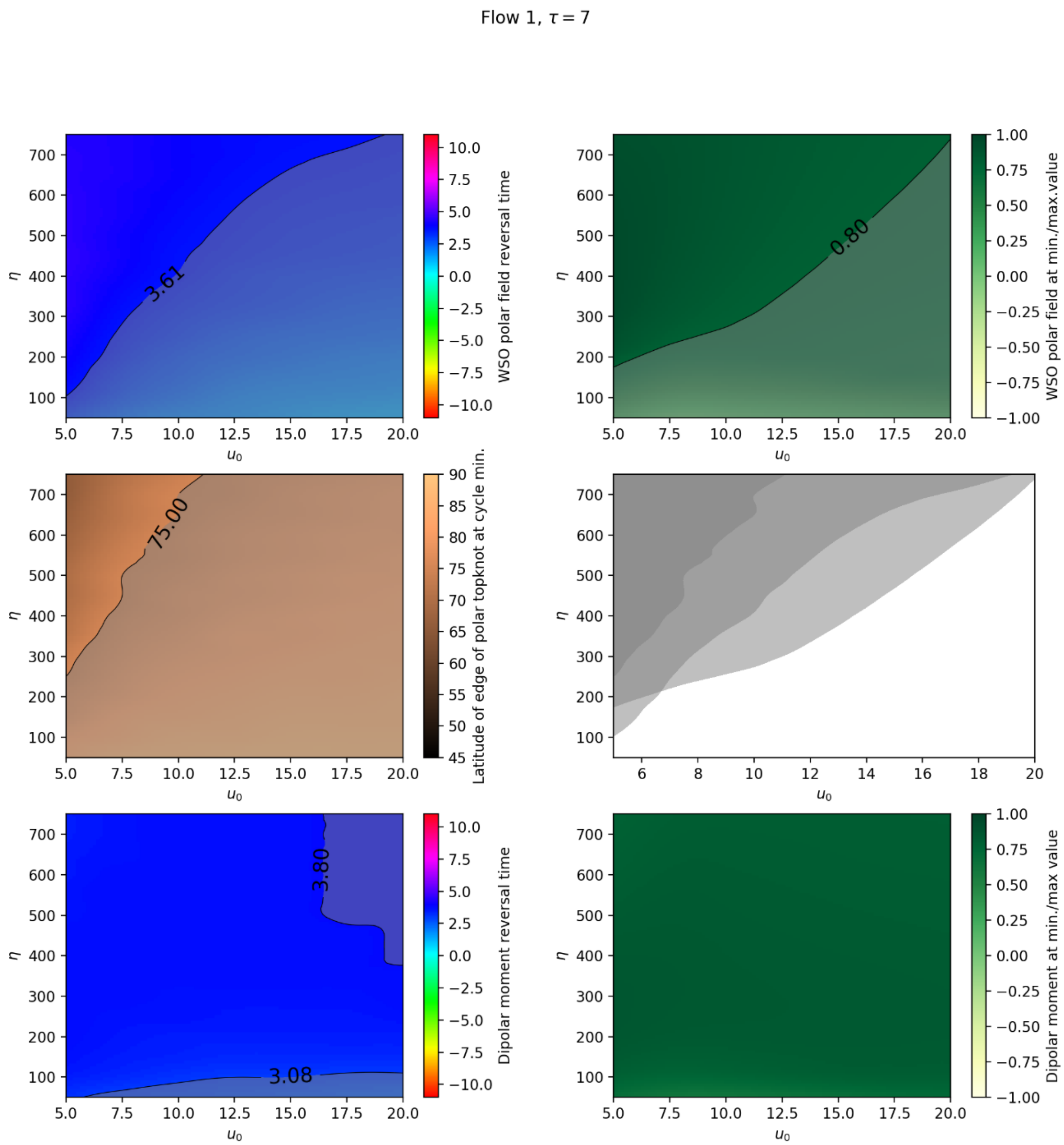

Figure 3 Set of maps of the u_0 -η parameter plane for the case of τ=7, flow type 1. Color coded maps show the distribution of the five merit variables, with the excluded domain masked out (less vivid colors). The domains allowed by the first three merit criteria