2nd Semester Report

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Ph.D. Thesis topic:

“Nonlinearities and Stochastic Perturbations in Dynamo Models”

Thursday, May 29, 2018

Introduction

Nonlinearities and/or stochastic variations in the parameters of solar dynamo models (Cameron & Schüssler, 2016) induce cycle-to-cycle variations in the resulting dynamo-generated magnetic field. The study of stochastically perturbed nonlinear dynamos is therefore a research topic intimately linked with studies of long-term variations of solar activity. Indeed, the 11-year solar cycle is an irregular, quasi-periodic phenomenon, the lengths and amplitudes of individual cycles varying between rather wide limits. Long-term variations are also present, including the Maunder Minimum (Eddy, 1976), a period of very low activity in the late 17^{th} century, and the Modern Maximum, a series of particularly strong solar cycles in the second half of the 20th century. In addition to its theoretical interest, the problem of understanding and predicting such variations has great practical importance, given the increasing vulnerability of human civilization to space weather disturbances.

During my Ph.D. research I will perform a systematic analysis of the effects of different types of (physically well motivated) nonlinearities and stochastic perturbations of the dynamo equations. The objective is to find the signatures in the statistical properties of long term activity variations that correspond to particular types of nonlinearities or perturbations. This might offer observational clues regarding which nonlinear effects or perturbations actually determine the long-term behavior of the solar dynamo.

Description of research work carried out in current semester

In this semester with Prof. Petrovay we started using the python code that we wrote in the previous semester, therefore, I was working on the code and reading in rows so that I can understand both the theory and the experimental work, in this semester I read several papers and some books as listed below.

1- I made a full review for the PDEs, then using Numerical Methods for the Solution of Partial Differential Equations by Luciano Rezzolla (Rezzolla, 2011)
2- The Solar Activity Cycle by André Balogh et.al. (Balogh , et al., 2014) was the best reference to understand the solar cycle in details.
3- The Bipolar Magnetic Regions on The Sun: Global Analysis of the SOHO/MDI Data Set paper by (Kosovichev & Stenflo, 2012). was read
4- Magnetohydrodynamic simulation of the evolution of bipolar magnetic region by (Wu, et al., 1993).
5- A new look at dynamo cycle amplitudes by (Saar & Brandenburg, 2002)
6- Understanding Complex Systems by (Klyatskin, 2015)

This made an essence of the theory and to complete the work we began to run the code as follows:

1- the first thing was to run several runs to test the code and modify the bugs in it, also we use some additional lines in the code so that we can apply the Hale Law and Joy's Law

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, we change the meridional flow profile to (van Ballegooijen , et al., 1998) profile and (Lemerle & Charbonneau, 2017) and re-run the calculation again to get the polar field and the source values and plot them with time.

4- Again, we modified the code again so we can run it for shorter time and using a shell script to automate the runs, we change the values of the parameters (Meridional flow velocity, timescale, profile, diffusivity) and measure the new values of the magnetic field the plotting a contour plots between these parameters.

Educational activities in current semester

In this semester, I studied three subjects in the department, as a review, I took Introduction to Astronomy 2 (2 Credits), the Astrophysical turbulence, dynamos and reconnection II course (6 Credits) and the Linear and non-Linear MHD waves course (6 Credits), also I registered for Guided Research Work (18 Credits).

1- Starting with the induction of astronomy 2 which was a complementary material for the introduction to astronomy 1 which I had taken in the previous semester, in this subject, we started with the brightness and colors of stars and the Color-magnitude diagram, where the general roles and formulas for brightness were taken and how one can measure the distance of a star, then i saw how these stars can be classified according to their color and how is he thermal radiation of a star can tell us much more, after that we moved forward to the second topic which was stellar spectra and how we can study the stars from their spectral lines so that we can know many thing from these lines like the chemical composition and what are the layers consist of, then we studied the Hertzsprung–Russell Diagram (HRD) and how the stars evolve on it and move from one side to another, the next topic was the Binaries, where theses stars were been identified and classified and distinguished between each class and one saw how the orbital motion of these binaries can be.

In the fourth topic, I studied the interstellar medium, how it formed and what are the main components in the interstellar medium, also the nebulae and its classifications and the most important features of each kind of it, and last thing was the main states of hydrogen in the interstellar medium, four states can be found in, the natural hydrogen clouds, the molecular hydrogen clouds including the giant molecular clouds and the

ionized hydrogen zones. in the next topic we studied the sun and its interior, the main properties and the characteristics of it and the layers specifications inside the sun, after that we saw how the sun and sun-like stars evolve on the HRD diagram staring from a cloud of gas and dust to form a protostar then for sufficient mass it continue to a main sequence stars where it stay the longest period on its lifetime and the start die by the red giant phase until it reach white dwarfs phase, and for massive stars they continue to reach either neutron star or a black hole.

Moving forward to the variables star as the next topic, where this kind of stars was identified and classified to eclipsing, rotational, geometrical lensing as geometrical variables and pulsating and eruptive and Cataclismic variables as physical ones, and some examples where studied like Cepheid's, active stars and T Tauri stars were previewed.

In topic 8, the distribution of the stars in the universe had been studied and the methods used to measure the distance for different stars also the different kinds of parallaxes and functions and after that the structure of the galaxy was reviewed briefly, then moving forward to the motion of the stars as the next topic, how we can detect the proper motion of the star, what is the Galactocentric coordinates, and how the galaxy rotates, then the clusters of the stars where studied, the classifications and properties of each class and how one can determine the star clusters distance, and by the end of the lecture an overview about the center of the milky way was introduced.

The next topic was the extragalactic, where we studied the different kinds of galaxies, the origin, the composition and properties of them, then we complete to the dark matter and black holes to study their distinguish features, and finally the last topic was about the structure of the universe,

During the whole semester the Fundamental Astronomy by (Karttunen, et al., 2016) was used as reference book in addition to the lecture slides from Prof. Petrovay (Petrovay, 2018)

2- The second subject in this semester was solar physics were i took it with professor Petrovay, during the semester I attended all the classes, in the beginning, a brief overview of the history of the solar physics starting in 364 B. C. E. the first observations until the current time with the latest satellites orbiting around the sun, then a detailed description of the standard solar model was given, from the ZAMS model of the sun to current time by using the reaction rates of the chemical elements, after that a calibration of the model using the abundance of the helium in the sun as the first parameter and the α_{MLT} as the second one, after that the model was tested using different methods, finally the solar neutrino problem was presented and how with different kinds of detectors had been solved.

The third topic was the helioseismology, where different types of waves occurring in the sun were identified, and how one use these types to predict the morphology of the sun, then a description of the instruments used to measure these waves and there thermotical background was given, at last, the term local helioseismology was explained and how a small events on the surface of the sun can give indications to the overall structure, after

that the different rotations in the sun was reviewed starting with a mathematical description of the rotation by Legendre polynomial and how the plasma of the sun rotates in two different directions, the differential rotation and the meridional flow, for differential rotation , we studied the observations, the origin and some mathematical details of the rotation, then an overall model for these kinds of rotations, in addition to the plasma rotation, one can see these types of the rotation in the tracer rotation (Sunspots, Facula, etc...) were different model were illustrated, in the end of this topic the torsional oscillation was given in details.

The next topic was about the solar telescopes, a full review for the solar telescopes in the past decayed, their locations, specifications, the advantage and disadvantage of each one, and the instruments used in these telescopes, after that we moved forward to topic six which is the polarization and its application, were the stokes parameters was given in mathematical details, after that some devices that depend on the polarization were illustrated, such as Spectrometers, Monochromators, Doppler Imager, ... etc., by the end of this topic the essence of the magnetometry was given.

The next 4 topics were about the structure of the sun starting from the photosphere up to the corona and what are the models seen for these layers, illustrating the activities occurring there and what are the properties for each one, for example, sunspots, facula, prominences ... etc., this part of the course was the most interesting part for me because it is very narrow to my research field especially the sunspot cycle and the magnetic field seen in the photosphere.

Last topic was about the solar cycle, the active regions on the surface of the sun, the structure of the sunspots and their classification and evolution, after that we moved to the flux emergence models and the solar dynamo model in details, last thing was the flux transport model was given.

I used the Sun - an introduction (Michael, 2002) as a reference book for this subject in addition to the lectures slides by Prof. Petrovay (Petrovay, 2018).

3- The last subject was to study the linear and non-linear MHD waves, this subject was a really challenging, since Prof. Robertus von Fay-Siebenburgen was not in the country, so I had to study by myself and send back report for each chapter, it was really a new and exciting way to study, in the beginning of the subject is started to study a description of the sun, the history, the properties all over from the core up to the corona, this chapter was really important cause it refreshes and organize all the information about the sun.

And Since we are studying about the waves we have to see the model, so in chapter 2, a full review was given for the basic equation of Magnetohydrodynamics (MHD) and moving to chapter three to distinguish between (MHD) and Magnetohydrostatic, an excellent representation on the topic was studied.

The most important chapter was number 4, were it talk about the waves, the fundamental modes and the basic equations, sound waves and

magnetically driven waves among other types, in these sections, a full mathematical description was given, by the end of the chapter, the Waves in a nonuniform medium was illustrated for several kinds of magnetic fields and then briefly talk about the waves in the sun.

Chapter 5 was a complement to chapter 4 where it was about the shock waves especially, the Formation of a Hydrodynamic Shock and how the magnetic field effect on it, the Perpendicular Shocks and the Oblique Shocks which have several types like Slow-Mode and Fast-Mode Shocks and switch-Off and Switch-On Shocks.

In chapter 6, Prof. Robertus recommended to study the first 2 section of it, which was about the magnetic reconnection, in the first section it review the history of the magnetic reconnection models and some concepts, although in the second part it talk about the 2D Null points in the reconnection, and finally reading about the Basic Sweet-Parker Model (1958) and Petschek's Model (1964).

Chapter 7 give a full overview of the magnetic instabilities, the linearized Equations and Normal-Mode Method taking as an example the Rayleigh-Taylor Instability.

In this subject I used the book Magnetohydrodynamics of the Sun (Priest, 2014) as a reference book together with online resources especially videos on some YouTube channels

Conferences in current semester

During this semester I attended and will attend several seminars and presentations

1- Every Wednesday there were the Astrophysical lunch in the department, where a discussion for the latest experiments, observations, researches.
2- In Mondays, I attended the GALNUC meeting group where several topics were discussed with other Ph. D. and Pos. Doc. students
3- 10 of June, I'll leave to Udine/Italy to attend a special summer school for Magnetohydrodynamic theory, it will hold by the International Centre for Mechanical Sciences (CISM). In this school 'ADVANCED TOPICS IN MHD' a full review for the MHD theory by scientists from different places (UK, France, Japan, Spain, USA), it will be a good place to invest the time in the summer, and to reorganize the work, I hope that this school will move me forward to the next step of the work.
4- Next September, I'll participate in the HINODE-12 Conference which will hold in Granada in Spain, by a conference paper, I already got a grant from the European Space Agency (ESA) to attend this conference and to participate by an abstract entitled "Optimization of surface flux transport models for the solar polar magnetic field" for a week.

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