THEORETICAL STUDY OF THE SOLAR MAGNETIC CYCLE AND ITS IRREGULARITIES:

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Sunspots are the seats of large-scale strong magnetic field on the surface of the Sun. The number of sunspots on the face of the Sun is observed to vary cyclically with an average period of about 11 years. However the solar cycle is not regular. The strength of the sunspot cycle as well as its period varies cycle to cycle in an irregular manner. One puzzling aspect of this 11-year sunspot cycle is the Maunder minimum in 17th century when sunspots disappeared almost for 70 years. Indirect studies suggest that there were several other such events in the past.

During my PhD period I was particularly involved to understand the origin and the evolution of Sun's large-scale magnetic field, the solar cycle and particularly their irregular features using *kinematic mean-field dynamo models*. In these studies, I have applied a *flux transport dynamo model* in which the velocity field (the meridional circulation and the differential rotation) is prescribed. In this dynamo model, the toroidal field is generated by the strong differential rotation in the convection zone and the poloidal field is generated near the solar surface from the decay of the sunspots (so-called the Babcock-Leighton mechanism). The turbulent diffusion and the meridional circulation are the two important flux transport agents in this model which communicate these two spatially segregated source regions of the magnetic field.

First, I have explored several important aspects of this dynamo model. Particularly, I have studied the turbulent pumping of the magnetic flux in the dynamo model and its implication in the solar cycle prediction. Turbulent pumping is an efficient mechanism of transporting the poloidal magnetic field from the surface layer of the poloidal field to the generating layer of the toroidal field. We have shown that by including the pumping in the dynamo model, reduces the memory of the solar cycle and hence it affects the prediction of the solar cycle. Then we have studied the confinement of the tachocline problem. We employ a flux transport dynamo model coupled with the simple feedback formula of the fast tachocline model which basically relates the thickness of the tachocline to the Maxwell stress. We find that this nonlinear coupling not only produces a stable solar-like dynamo solution but also a significant latitudinal variation in the tachocline thickness which is in agreement with the observations. Next, we have studied the effect of the feedback of the dynamo generated magnetic field on the meridional circulation. We have seen that the dynamo generated magnetic field has profound effect on the velocity field and therefore on the dynamo.

After studying above few aspects of flux transport dynamo model, we use this model to reproduce several important irregular features of the solar cycle. We have modelled cycle to cycle variation of the solar cycle strength and the period using variable meridional circulation. We have also modelled the Waldmeier effect which is the inverse correlation between the rise time and the strength of the solar cycle. Next, we have shown that, if the poloidal field at the end of a cycle falls to a very low value due to the strong fluctuations in its generation process, then this can produce a Maunder minimum or a Maunder-like grand minimum. We have shown another possibility of producing the Maunder minimum:

if the meridional circulation falls to a very low value, then this also can produce a Maunder minimum. We have also explored the effect of the combined fluctuations in producing the Maunder-like event.

We know that the Maunder minimum mentioned above was not unique. From the study of cosmogenic isotopes ^{14}C in old tree rings and ^{10}Be in polar ice, it is found that there have been several grand minima in the past. Analyses of these isotopes indicate that there have been about 27 grand minima in the last 11,400 years. We address the question how grand minima are produced and specifically calculate the frequency of occurrence of grand minima from a theoretical model. With reasonable guidance from the observational data of last 28 solar cycles, we show that a flux transport dynamo model is able to reproduce the observed result of the frequency of grand minima reasonably well.

The full thesis can be downloaded from
`http://www.nordita.org/~bbkarak/karak_thesis.pdf`

Publications resulted from thesis

7. **Karak, B. B.** & Petrovay, K. 2013, *On the compatibility of a flux transport dynamo with a fast tachocline scenario*, **Solar Physics, 282,** 321.

6. **Karak, B. B.** & Nandy, D. 2012, *Turbulent Pumping of Magnetic Flux Reduces Solar Cycle Memory and thus Impacts Predictability of the Sun's Activity*, **The Astrophysical Journal Letters, 761,** L13.

5. Choudhuri, A. R. & **Karak, B. B.** 2012, *The origin of grand minima in the sunspot cycle*, **Physical Review Letters, 109,** 171103.

4. **Karak, B. B.** & Choudhuri, A. R. 2012, *Quenching of Meridional Circulation in Flux Transport Dynamo Models*, **Solar Physics, 278,** 137.

3. **Karak, B. B.** & Choudhuri, A. R. 2011, *The Waldmeier effect and the flux transport solar dynamo*, **Monthly Notices of the Royal Astronomical Society, 410**, 1503.

2. **Karak, B. B.** 2010, *Importance of Meridional Circulation in Flux Transport Dynamo: Possibility of Maunder-like Grand Minimum*, **The Astrophysical Journal, 724**, 1021.

1. Choudhuri, A. R. & **Karak, B. B.** 2009, *A possible explanation of the Maunder minimum from a flux transport dynamo model*, **Research in Astronomy and Astrophysics (Letters), 9**, 953.