The magnetic fields and behaviour of the sun have long fascinated astrophysicists. Sunspot observations, theoretical models and computer simulations can provide important insights into solar behaviour, says Professor Axel Brandenburg, who works on developing an accurate model of the solar dynamo.

Cycles of the Sun

The cosmos has been a source of study for some of history's most celebrated scientists, including Galileo, Copernicus and Newton, whose observations and analysis of celestial objects underpin much of today's astrophysics research. The availability of accurate observational data has allowed scientists to develop evidence-based theories on the physical behaviour of the Earth, the Sun and the planets, work which is very much still in progress. While this is a vast, technically demanding field which offers numerous challenges for scientific exploration, researchers do have some common findings on which to build. “We know that magnetic fields operate in many objects of interest to astrophysics, including at the bottom of the Sun, the Earth and accretion discs. Over recent years there has been a lot of focus on the magnetic field of the Sun. This is not an irregular magnetic field; rather there is some systematic order, in that it shows a regular 11-year cycle,” explains Professor Axel Brandenburg. Based at the Nordic Institute for Theoretical Physics (NORDITA) in Stockholm, Professor Brandenburg’s research group is involved in a number of projects in cutting-edge areas of astrophysics, including galactic magnetism, black hole magnetospheres and the solar dynamo. Existing data on this final area, the physical process that generates the Sun’s magnetic field, presents a complex picture, and demands correspondingly advanced scientific expertise. “The remarkable thing about the Sun is that its magnetic field shows an order on a much larger scale than you would expect in comparison to the size of the turbulent motions. This is despite the fact that its fluid motions are quite chaotic – in fact turbulent, with quite low length scales,” continues Professor Brandenburg.

“At the Greenwich laboratory they have been recording detailed positions of each sunspot since the late nineteenth century, while we also have other sources from around the world,” he says. “The Sun rotates, so in analysing sunspots we have identified an equation and map them by their latitude. We know that sunspots behave cyclically, and that they emerge at higher latitudes at the beginning of a cycle – around 30º on either side of the Sun. Then, as the cycle becomes stronger the sunspots emerge predominantly at lower latitudes. It’s not that each sunspot moves, but new spots tend to emerge at lower latitudes – that’s what we call a dynamo wave. We believe the underlying mechanism for this is a large-scale magnetic field that propagates during this gradual 11-year period, from mid-latitudes to lower latitudes, and that sunspots emerge as a local manifestation of the larger-scale magnetic field beneath the surface. The Sun’s magnetic field is highly turbulent, so if you limit the number of field lines it would be a chaotic bundle.”

Theoretical development is crucial to the search for an improved understanding of these kinds of processes, and indeed this is an area that has attracted much research attention, along with efforts to improve computer simulations of astrophysics. The turbulent time-scales in the Sun are measured in minutes near the surface and significantly longer at the bottom of the convection zone, an aspect of solar behaviour that the alpha-omega dynamo theory seeks to explain. The alpha-omega dynamo theory tries to explain the behaviour of a turbulent system – the Sun – and to calculate the behaviours of the mean magnetic field and the mean velocity field by taking into account correlations between small-scale fluctuations in velocity. Turbulent diffusion is a very simple example of such an effect, it can be illustrated by the simple process of creaming in coffee, although in magnetic or velocity fields the effects are of course felt on a much larger scale. From that time on, the term ‘generating the Sun’ has been used in the scientific community, including not just dissipative effects, but also generative effects. One of them is called the Alpha effect, which is responsible for generating the Sun’s large-scale magnetic field, including the 11-year cycle, says Professor Brandenburg. The project uses complex-based memory. This is so-called because it is fundamental to all of us who can develop a physical understanding in terms of the underlying, simple equations, but also to then use those equations to predict future development, like the way the solar cycle will behave over the next few years.”

At a glance

Full Project Title
Astrophysical Dynamos

Project Funding
€2.22 Million

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Project Objectives
This work complements large-scale numerical simulations with numerically guided analytical approaches. An ultimate goal is to have a physically consistent model of the solar dynamo.

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Axel Brandenburg received his PhD at the University of XYZ, in 1990. After two postdocs at Nordita and at the National Centre for Atmospheric Research in Boulder/ Colorado for work in 1996 as Professor of Applied Mathematics to the University of Newcastle upon Tyne. In 2008 he became Professor of Astrophysics at Nordita.