Braiding magnetic fields

Study of the buildup of magnetic helicity in the solar atmosphere with 3D numerical simulations

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In Short

- Magnetic helicity describes the helical structure of the magnetic field. Twisting and braiding of the magnetic field increases the magnetic helicity. The interplanetary space inherits the helical structures from the solar magnetic field to some extent. To properly analyze the helicity in the solar wind, one must know how the solar magnetic field builds up magnetic helicity and how much is then transported into the heliosphere.
- The aim of the project is to analyze the buildup of magnetic helicity in the solar magnetic field. The movement for the braiding and twisting is provided by the motion of the plasma on the solar surface, leading to an increase in magnetic helicity in the structures above the solar surface.
- We use observationally driven numerical simulations to study the buildup of magnetic helicity. We use direct observations of the magnetic field and plasma motions on the surface of the Sun as an input into our simulations. We use different types of simulations with different velocity fields to analyze the importance of each component of the plasma motions on the surface of the Sun.

Magnetic helicity is a measure of the twisting and knotting of the magnetic field. It plays a role in how a turbulent plasma, like in the solar wind, evolves [1].

The solar wind and coronal mass ejections carry magnetic helicity away from the Sun into the heliosphere. The interplanetary magnetic field then inherits some of the helical structures from the solar magnetic field. Plasma turbulence then plays a role in transporting and distributing magnetic helicity over the different scales. To get an accurate picture of the helicity in the solar wind, one has to know how helicity is generated in the solar magnetic field. Regions with strong magnetic fields on the Sun are called active regions. They show arcades of loops filled with plasma emitting radiation in extreme ultraviolet light. The conductivity in these loops is high and the plasma is there linked to the magnetic field and the loops can be used as tracer of the magnetic field.

The movements on the surface of the Sun now braid and twist the magnetic field lines, which in turn builds up the magnetic helicity in such structures. Over time, this leads to more and more helicity being built up until it is ejected from the Sun. On the surface of the Sun, we find different components of the velocity field. One component describes large-scale flows with a low amplitude. The other component describes a small-scale velocity field with higher amplitude, which is caused by convective motions below the surface. Hot material rises within one granule, flows to the edge of the granule while cooling down. On the edges, the plasma sinks down again to be reheated below the surface. The computing project aims to understand how the movements on the surface of the Sun build up magnetic helicity. For this purpose, we conduct observationally driven numerical 3D simulations with the Pencil Code[3]. The Pencil Code is designed for weakly compressible magneto-hydrodynamic flows. Its modularity allows the code to be adapted to a multitude of problems in for example solar and stellar physics, cosmology and dynamo theory. Observationally driven simulations use observational data as a basis to drive the simulations in a self consistent way. We use the velocity field and magnetic field data from observations as an input for our simulations. The velocity field prescribes the motion of the plasma, which in turn drags the magnetic field around, leading to twisting and braiding. The use of observational data means that any match between the output of the simulation and real observations is intrinsic instead of just a random match. The method is detailed in Bourdin (2020)[4]. Simulations with the Pencil Code have been used in the past to study magnetic helicity[5,6].

The project will contain two types of simulations. The first type are the full magneto-hydrodynamic simulations and will solve the full set of the differential equations of magneto-hydrodynamics. We run two simulations so that we can use different velocity fields to drive the simulation from the bottom. The first one uses the full velocity field with both components. The second one uses only the large-scale velocities. This allows us to compare the effect of the different components on the generated magnetic

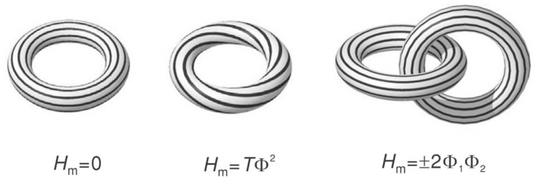

Figure 1: *Magnetic helicity of field lines in torus configuration: untwisted on the left, twisted by T turns in the middle, and two intersecting but untwisted tori on the right. Φ is the total magnetic flux. Figure from Wiegelmann and Sakurai (2021)[2].*

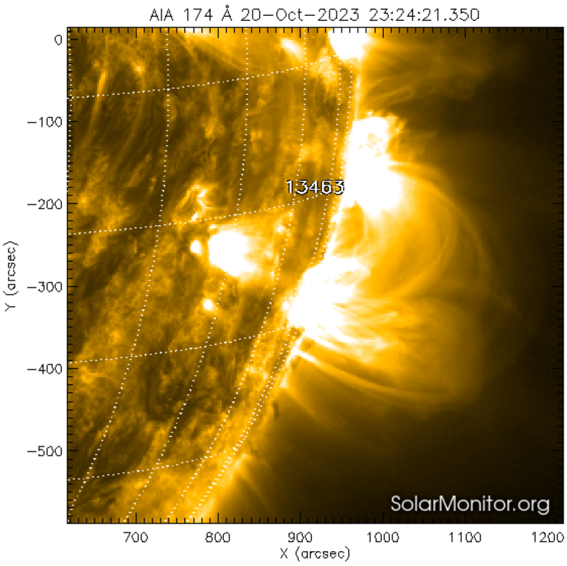

Figure 2: *Coronal loops seen in extreme ultraviolet light on the edge of the Sun. The bright regions are hot and show strong emission. Loops can reach several thousand kilometers above the surface. Movement at the surface of the Sun can braid and twist the magnetic field within the loops, leading to an increased magnetic helicity. Image supplied courtesy of SolarMonitor.org.*

helicity.

The second type of simulation will use a different method called ambipolar diffusion. Here, only the induction equation, describing the change of the magnetic field over time, will be solved. We directly prescribe the changes in the magnetic field due to the motions in the photosphere to drive this type of simulation, as the velocity field cannot be used as a direct input. These types of simulations are computationally less expensive, thus allowing for a larger number of simulations to be run. We will use different combinations of the components of the velocity field and also different diffusion parameters in our simulation. These simulations will complement the two full magneto-hydrodynamic simulations, allowing a direct comparison between both methods.

WWW

`https://www.tu-braunschweig.de/theophys`

More Information

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