Long-period oscillations control the sun's differential rotation: Study

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Three-dimensional visualization of the high-latitude oscillations in the sun. Snapshot of streamlines of the long-period high-latitude oscillations in the convection zone. The red and blue colors denote the prograde (same as rotation) and retrograde (opposite to rotation) zonal flows, respectively. Credit: MPS / Y. Bekki

The sun's differential rotation pattern has puzzled scientists for decades: While the poles rotate with a period of approximately 34 days, mid-latitudes rotate faster and the equatorial region requires only approximately 24 days for a full rotation.

In addition, advances in helioseismology (i.e., probing the solar interior with the help of solar acoustic waves) have established that this rotational profile is nearly constant throughout the entire convection zone. This layer of the sun stretches from a depth of approximately 200,000 kilometers to the visible solar surface and is home to violent upheavals of hot plasma which play a crucial role in driving solar magnetism and activity.

While theoretical models have long postulated a slight temperature difference between solar poles and equator to maintain the sun's rotational pattern, it has proven notoriously difficult to measure. After all, observations have to "look through" the background of the sun's deep interior, which measures up to a million degrees in temperature. However, as researchers from the Max Planck Institute for Solar System Research (MPS) show, it is now possible to determine the temperature difference from the observations of the long-period oscillations of the sun.

The work is published in the journal *Science Advances*.

In their analysis of observational data obtained by the Helioseismic and Magnetic Imager (HMI) onboard NASA's Solar Dynamics Observatory from 2017 to 2021, the scientists turned to global solar oscillations with long periods that can be discerned as swirling motions at the solar surface. Scientists from MPS reported their discovery of these inertial oscillations three years ago. Among these observed modes, the high-latitude modes with velocities of up to 70 km per hour proved to be especially influential.

To study the nonlinear nature of these high-latitude oscillations, the team conducted a set of three-dimensional numerical simulations. In their simulations, the high-latitude oscillations carry heat from the solar poles to the equator, which limits the temperature difference between the sun's poles and the equator to less than seven degrees.

"This very small temperature difference between the poles and the equator controls the angular momentum balance in the sun and thus is an important feedback mechanism for the sun's global dynamics," says MPS Director Prof. Dr. Laurent Gizon.

In their simulations, the researchers for the first time described the crucial processes in a fully three-dimensional model. Former endeavors had been limited to two-dimensional approaches that assumed the symmetry about the sun's rotation axis.

"Matching the nonlinear simulations to the observations allowed us to understand the physics of the long-period oscillations and their role in controlling the sun's differential rotation," says MPS postdoc and the lead author of the study Dr. Yuto Bekki.

The solar high-latitude oscillations are driven by a temperature gradient in a similar way to extratropical cyclones on the Earth. The physics is similar, though the details are different: "In the sun, the solar pole is about seven degrees hotter than equator and this is enough to drive flows of about 70 kilometers per hour over a large fraction of the sun. The process is somewhat similar to the driving of cyclones," says MPS scientist Dr. Robert Cameron.

Probing the physics of the sun's deep interior is difficult. This study is important as it shows that the long-period oscillations of the sun are not only useful probes of the solar interior, but that they play an active role in the way the sun works. Future work will be aimed at better understanding the role of these oscillations and their diagnostic potential.

More information: Yuto Bekki et al, The Sun's differential rotation is controlled by high-latitude baroclinically unstable inertial modes, *Science Advances* (2024). DOI: 10.1126/sciadv.adk5643

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