The inner secrets of planets and stars

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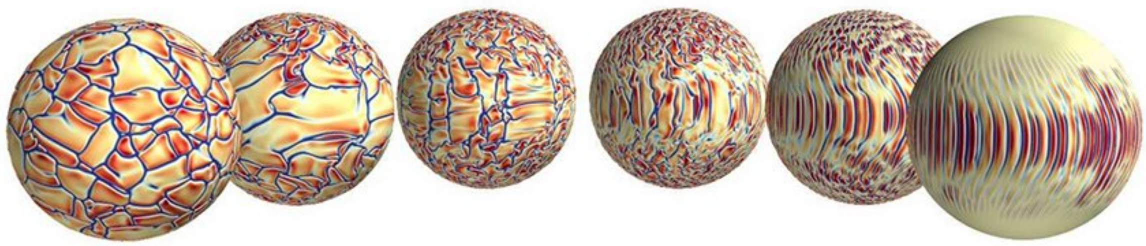

A 3-D rendering shows simulated solar convection realized at different rotation rates. Regions of upflow and downflow are rendered in red and blue, respectively. As rotational influence increases from left (non-rotating) to right (rapidly rotating), convective patterns become increasingly more organized and elongated. Understanding the sun's location along this spectrum represents a major step toward understanding how it sustains a magnetic field. Credit: Nick Featherstone and Bradley Hindman, University of Colorado Boulder

After a five-year, 1.74 billion-mile journey, NASA's Juno spacecraft entered Jupiter's orbit in July 2016, to begin its mission to collect data on the structure, atmosphere, and magnetic and gravitational fields of the mysterious planet.

For UCLA Geophysicist Jonathan Aurnou, the timing could not have been much better.

Just as Juno reached its destination, Aurnou and his colleagues from the Computational Infrastructure for Geodynamics (CIG) had begun carrying out massive 3-D simulations at the Argonne Leadership Computing Facility (ALCF), a U.S. Department of Energy (DOE) Office of Science User Facility, to model and predict the turbulent interior processes that produce Jupiter's intense magnetic field.

While the timing of the two research efforts was coincidental, it presents an opportunity to compare the most detailed Jupiter observations ever captured with the highest-resolution Jupiter simulations ever performed.

Aurnou, who leads the CIG's Geodynamo Working Group, hopes that the advanced models they are creating with the Mira supercomputer will complement the NASA probe's findings to reveal a full understanding of the Jupiter's internal dynamics.

"Even with Juno, we're not going to be able to get a great physical sampling of the turbulence occurring in Jupiter's deep interior," he said. "Only a supercomputer can help get us under that lid."

Aurnou and his collaborators are also using Mira to study the magnetic fields on Earth and the sun at an unprecedented level of detail.

Dynamic dynamos

Magnetic fields are generated deep in the cores of planets and stars by a process known as dynamo action. This occurs when the rotating, convective motion of electrically conducting fluids (e.g., liquid metal in planets and plasma in stars) converts kinetic energy into magnetic energy. A better understanding of the dynamo process will provide new insights into the birth and evolution of the solar system, and shed light on planetary systems being discovered around other stars.

Modeling the internal dynamics of Jupiter, Earth and the sun all bring unique challenges, but the three vastly different astrophysical bodies do share one thing in common—simulating their dynamo processes requires a massive amount of computing power.

With their project at the ALCF, Aurnou's CIG team set out to develop and demonstrate high-resolution 3-D dynamo models at the largest scale possible.

Stellar research

When the project began in 2015, the team's primary focus was the sun. Understanding the solar dynamo is key to predicting solar flares, coronal mass ejections and other drivers of space weather, which can impact the performance and reliability of space-borne and ground-based technological systems, such as satellite-based communications.

With access to Mira, the team has performed some of the highest-resolution and most turbulent simulations of solar convection. In a paper published in *Astrophysical Journal Letters*, they used the simulations to place upper bounds on the typical flow speed in the solar convection zone—a key parameter to understanding how the sun generates its magnetic field and transports heat from its deep interior.

According to University of Colorado Boulder researcher Nick Featherstone, who is leading the project's solar dynamo effort, the team's findings have been driven by their model's ability to efficiently simulate both rotation and the Sun's spherical shape, which are extremely computationally demanding to incorporate together in a high-resolution model.

"To study the deep convection zone, you need the sphere," Featherstone said. "And to get it right, it needs to be rotating."

Understanding Earth at its core

Magnetic fields in terrestrial planets like Earth are generated by the physical properties of their liquid metal cores. However, due to limited computing power, previous Earth dynamo models have been forced to simulate fluids with electrical conductivities that far exceed that of actual liquid metals.

To overcome this issue, the CIG team is building a high-resolution model that is capable of simulating the metallic properties of Earth's molten iron core. Their ongoing geodynamo simulations are already showing that flows and coupled magnetic structures develop on both small and large scales, revealing new processes that do not appear at lower resolutions.

"If you can't simulate a realistic metal, you're going to have trouble simulating turbulence accurately," Aurnou said. "Nobody could afford to do this computationally, until now. So, a big driver for us is to open the door to the community and provide a concrete example of what is possible with today's fastest supercomputers."

Jupiter ascending

In Jupiter's case, the team's ultimate goal is to create a coupled model that accounts for both its dynamo region and its powerful atmospheric winds, known as jets. This involves developing a "deep atmosphere" model in which Jupiter's jet region extends all the way through the planet and connects to the dynamo region.

So far, the researchers have made significant progress with the atmospheric model, enabling the highest-resolution giant-planet simulations yet achieved. The researchers will use the Jupiter simulations to predict surface vortices, zonal jet flows and thermal emissions in detail and compare those to observational data from the Juno mission.

Ultimately, the team plans to make their results publicly available to the broader research community.

"You can almost think of our computational efforts like a space mission," Aurnou said. "Just like the Juno spacecraft, Mira is a unique and special device. When we get datasets from these amazing scientific tools, we want to make them openly available and put them out to the whole community to look at in different ways."

More information: Nicholas A. Featherstone et al. THE EMERGENCE OF SOLAR SUPERGRANULATION AS A NATURAL CONSEQUENCE OF ROTATIONALLY CONSTRAINED INTERIOR CONVECTION, *The Astrophysical Journal* (2016). DOI: 10.3847/2041-8205/830/1/L15

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