Scientists glean new insights into convection in planets and stars

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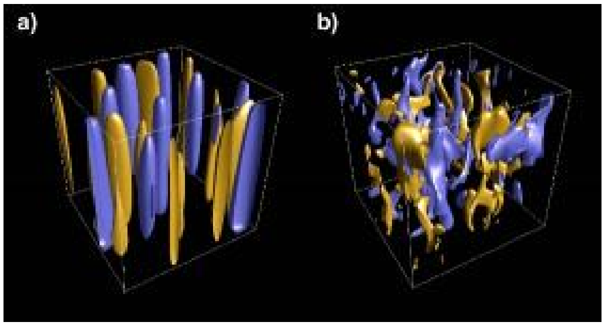

This image illustrates the two ways in which convecting fluid will generally behave; "a" represents rapidly rotating convection, and "b" represents chaotic, non-rotating convection. In the journal Nature, Eric King, Jonathan Aurnou and colleagues report on when a convecting fluid goes from "a" to "b" and on the implications of their surprising findings.

(PhysOrg.com) -- A new study by UCLA planetary scientists and their colleagues in Germany overturns a longstanding scientific tenet and provides new insights into how convection controls much of what we observe in planets and stars.

The research, federally funded by the National Science Foundation, unifies results from an extensive array of previous experiments. It appears in the Jan. 15 edition of the journal *Nature*.

"The Nature paper allows us new and meaningful predictions for where we should observe different behaviors throughout the universe wherever there are rotating convection systems, and that means planets and stars," said study co-author Jonathan Aurnou, a UCLA associate professor of planetary physics. "This allows us to make predictions for almost any body where we can measure the rotation rate and heat coming out. For me, that's exciting."

Convection describes the transfer of heat, or thermal energy, from one location to another through the movement of fluids such as liquids, gases and slow-flowing solids. As an example, when a bowl of water is heated on a stove, the heated portion of the water becomes buoyant and rises through the surrounding cooler water, while the cooler water drops down to be heated, creating a convection current.

On a larger scale, convection is an important process in the Earth's core, its atmosphere and its oceans, as well as the cores and atmospheres of other planets; it controls features such as the strength and structure of magnetic fields, atmospheric jets and heat flux patterns, according to lead study author Eric King, a UCLA graduate student in Earth and space sciences who works in Aurnou's lab.

It is known that convection is affected by planetary rotation, and for decades, scientists have believed that the influence of rotation on convection depends on the competition between two global-scale forces: the Coriolis force, which is the force that arises in all rotating systems, and the non-rotational buoyancy force. In the Nature paper, King, Aurnou and their colleagues dispute this, presenting results from laboratory and numerical experiments demonstrating that transitions between rotationally dominated and non-rotating convection behavior are determined instead by the relative thicknesses of fluids' thermal (non-rotating) and the Ekman (rotating) boundary layers.

There are two very different ways in which convecting fluids will generally behave. One is known as chaotic turbulence, which can be seen when a fluid is not rotating, as in the example of a boiling pot of water. The other is when a fluid is rapidly rotating, during which convection becomes well-organized. In the image above (to see image, visit www.newsroom.ucla.edu/portal/u … ection-in-78488.aspx), figure "a" represents the movement of fluid in rapidly rotating convection, while "b" represents the non-rotating convection.

"Scientists have been arguing for decades that rotation should dominate all the convection, all the fluid dynamics on stars and planets, but nobody has systematically measured when this domination by the rotational Coriolis effects occur," Aurnou said. "When do the Coriolis effects take over? How does convection occur on a rotating body, such as a planet or star? All of these bodies are rotating; how does the rotation affect the convection?

"We actually went out and quantitatively measured when rotation controls the system," he said. "We are asking, what is controlling the convection and how do you apply that to planets and stars?"

To obtain such measurements, King, with help from Aurnou and Jerome Noir, a research associate in Aurnou's laboratory, designed and constructed a 10-foot-tall state-of-the-science device called the Rotating Magneto-Convection device, or RoMag, which allows for the study of complex interactions among planetary convection ingredients.

The RoMag, a cylinder that sits on a spinning pedestal with a computer that collects data in a rotating frame, is the only device of its kind in the world. Scientists can drive and control thermal convection in the device's tank by applying heat from below and can learn how efficiently heat is transferred by convection.

"In building this device, we had to become electricians, plumbers, engineers, materials scientists," King said.

"Eric [King] showed up to an empty lab more than four years ago," Aurnou said. "When Eric first visited our laboratory, I asked whether he does experimental work. He said, 'No, but I'm pretty good with my stereo.' I said, 'We can work with that.' Eric is not an engineer but is very good in the lab."

In the Nature paper, King, Aurnou and colleagues report how rapidly a fluid needs to rotate and what controls the transition when it goes from well-organized rotational convection ("a") to chaotic turbulence ("b"). The findings were surprising.

While scientists can predict how strong the Coriolis and buoyancy forces should each be in a rotating convective system, they have also thought that based on their predictions, they could say whether "a" or "b" should occur.

"We have shown that is not right," King said. "And I think we have figured out what is right."

What is right, he explained, is that fluids' boundary layers, not the strength of the Coriolis and buoyancy forces, control the rotating convection system. A boundary layer is a sliver-thin layer of fluid between the bulk of the fluid and the boundary.

"If you take a cup of coffee and spin it, the fluid in the middle isn't moving, but at the very edge, right against the wall, it has to move," King said. "As I rotate the cup, a thin piece of the fluid is rotating with the coffee cup. Until that thin layer of fluid can communicate its rotation to the rest of the coffee, the interior is not going to rotate. If you have a piece of dirt in coffee and try to rotate it away from you, it won't work unless it is right against the wall; that is why. The boundary layer controls whether the rest of the fluid knows it should be rotating. The boundary layer is the layer of fluid that communicates the boundary physics to the interior fluid far from the boundaries."

This layer is, surprisingly, the key to the transition from "a" to "b".

"We're showing there is a boundary layer called an Ekman layer that is a thin, rotating boundary layer of fluid that lets the rest of the fluid know that it is in a rotating container," King said. "We have shown that in 'a' there is an Ekman layer. When we go to 'b', the Ekman layer is becoming partially destroyed, and therefore rotation can no longer be effectively communicated to the rest of the fluid. This becomes important with planets and stars.

"We have shown that it's much easier to get the chaotic convection ('b') than was previously thought," he said. "Scientists had incorrectly assumed that planets and stars, because they are so big and rotate so fast, must be dominated by the effects of rotation. They thought the fluid dynamics in the Earth's core, for example, must be completely dominated by the effects of rotation. We are showing that we have to rethink that."

"We have shown that the standard assumption, that 'b' is irrelevant for planetary and stellar bodies, is incorrect," Aurnou said. "We can now predict, based on our laboratory measurements and computer simulations, when a planetary and stellar body should be in one regime versus the other regime."

Aurnou and King believe the Earth's core is not far from the transition between well-organized rotational convection and chaotic turbulence.

"We don't know what the physical processes in the Earth's core are," Aurnou said. "Our findings allow us, given an estimate of the amount of heat coming from the core, to make a much better determination of where the dynamics exist. It looks like the Earth's core is not far from the transition, while everyone thought we are firmly and deeply in 'a'. That's what our findings suggest, and that is a big change. We will continue to study this question."

So far, the experiments have been conducted in water. King plans to rebuild RoMag so that the device can accommodate liquid metal. Planetary cores are predominantly composed of molten iron and often have strong magnetic fields. The scientists' research should give further insight into planetary cores, including the Earth's.

For the research reported in Nature, King and Aurnou used both experimental laboratory studies and numerical models. In addition to Noir, they worked with Stephan Stellmach of the University of California, Santa Cruz, who was formerly based in Germany, and with Ulrich Hansen in Germany.

Provided by UCLA

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