Superfuids may merge via corkscrew mechanism

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Scientists at the Florida State University-headquartered National High Magnetic Field Laboratory have made a discovery in fluid dynamics that is truly worth uncorking a bottle of fine wine.

Wei Guo, an associate professor of mechanical engineering at the

FAMU-FSU College of Engineering, and MagLab graduate research assistant Toshiaki Kanai published a new study in the journal *Physical Review Letters* that sheds light on how quantum fluids—also called superfluids –merge. It turns out they use a corkscrew mechanism.

At the atomic level, these fluids obey an entirely different set of rules that arise at ultra-low, or cryogenic , temperatures. In this case, that temperature hovers around -273 degrees Celsius (about -460 degrees Fahrenheit), far colder than anywhere on Earth. Such an environment can be reached only with great effort in special laboratories.

In other words, quantum fluids, also called superfluids, are really bizarre. They're also of great interest to scientists in part because they exist in the cosmos—in neutron stars and, possibly, in dark matter .

"Neutron stars, essentially, are big, rotating superfluid drops, and those drops can merge together," said Guo, a trained physicist who oversees the MagLab's Cryogenics Research Group . "So we asked the question: What happens when rotating superfluid drops merge together? How does the rotation get transferred from one to another?"

The answer they got, based on numerical simulations, came as quite a surprise. The results showed the rotation of these fluids bore little resemblance to classical fluid dynamics. However, it can be appreciated by anyone who enjoys the occasional goblet of gewürztraminer: The mechanism was a corkscrew.

The superfluid they modeled was a Bose-Einstein condensate. BECs are an entirely different state of matter than air, liquid, solid or plasma, formed by cooling a very low-density gas to nearly absolute zero, the lowest possible temperature. In this frigid state the atoms, sucked of almost all their energy, essentially act as one. They have zero viscosity; a BEC flows without dissipating any energy.

In our classical world, when a spinning raindrop falls into a still body of water, the raindrop's rotational motion and angular momentum are transferred to the water it plops into through spinning structures we know as eddies.

But when Kanai created a model to see what happens in the quantum world when a spinning drop of BEC merges with a static one, there was no sign of eddies or vortices. Yet there was a transfer of motion.

"The vortices remained in the spinning drop—but they didn't get transferred to the top," Guo explained. "But somehow rotational motion and angular momentum did get transferred to the other region. So we felt that there must be some different mechanism playing that role. A strange structure appeared at the interface of the two drops—strange because it does not appear in conventional, viscous fluids."

That strange structure: a corkscrew.

"The structure serves pretty much like a corkscrew," exerting a torque, Guo explained. "It generates the rotational motion in the top, static one, and then slows down the rotation of the bottom one. In this way, the rotation is transferred from the bottom to the top."

The results were doubly exciting, said Kanai, who seemed a bit dazed to already be a lead author on a publication while still a graduate student in physics at Florida State.

"After we observed the corkscrew structure the first time, we had so many questions," he said. "What causes this structure? How does the structure affect the dynamics? So the discovery itself was very interesting; but after that, understanding the discovery was also very exciting."

Guo said their work may shed light on other areas of research—dark matter and neutron stars on the cosmological level and, on the quantum level, the development of BEC-based technologies like sensors or quantum computers, an emerging field called atomtronics.

"This may provide astrophysicists some information about what kind of structures they should look at when they observe the sky," Guo said.

So next time you uncork a bottle of vino and admire its viscosity as it swirls around your glass, raise a toast to torque, to bizarre, inviscid Bose-Einstein condensates and to the never-ending wonders of science.

More information: Toshiaki Kanai et al. Torque and Angular-Momentum Transfer in Merging Rotating Bose-Einstein Condensates, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.105302

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