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**PRESS RELEASE**

# Quantum Transport: Bosons and Fermions Obey a Universal Law

**Through a rigorous mathematical analysis of current fluctuations around their average value, a new study published in Physical Review Letters reveals an unexpected connection between the behavior of two fundamentally different types of particles.**

Trieste, 23 May 2025

The world around us is made of two fundamentally different kinds of particles: fermions and bosons. Fermions are solitary by nature — if they were cars on a busy road, each one would be forced to respect the space in front and avoid others. Bosons, on the other hand, are far more sociable. They like to group together. In the world of bosonic quantum vehicles, traffic jams simply don't exist — these cars actually want to overlap.

Yet, according to new research published in Physical Review Letters, there is a hidden connection between these two kinds of particles — one that becomes visible when studying the fluctuations of their flow around its average. Remarkably, these fluctuations follow the same universal law for both types of particles. This surprising universality, demonstrated through a rigorous mathematical approach, provides a powerful new tool for understanding quantum transport. Even more surprisingly, the same law also governs seemingly unrelated natural phenomena, such as the growth of crystal surfaces or the spread of wildfires.

This research is the result of a collaboration between Professor Andrea Gambassi of the Statistical Physics group at SISSA and colleagues and doctoral students from the Technical Universities of Vienna and Munich.

**Advanced Mathematical Tools to Describe Fundamental Particles**

Imagine quantum particles moving along a one-way street, hopping from one spot to the next — but only when nudged by an external “environment,” like an energy reservoir that makes the motion possible. This kind of motion is known as dissipative transport, and it's not just theoretical: it can actually be observed in experiments involving ultracold atoms or special quantum materials.

“In our study,” explain first authors Yuri Minoguchi and Julian Huber, “we analyzed the long-time behavior of bosons and, in particular, how their flow — the number of particles passing through in a given time — fluctuates. To do this, we combined numerical simulations with advanced mathematical tools from theoretical physics. That’s when we stumbled upon something truly surprising.”

**Bosons like Fermions**

“We discovered that this process follows the same universal laws that describe the growth of irregular surfaces — a class of phenomena known as the KPZ universality class, named after physicists Mehran Kardar, Giorgio Parisi, and Yi-Cheng Zhang, who first studied it 40 years ago” authors explain: “What makes this result so striking is that fermions, which behave very differently from bosons, also follow the same law. Even though fermions avoid each other, and bosons like to bunch up, their large-scale behavior under dissipative transport is governed by the same rules. That’s scientifically very significant.”

**But Differences Still Exist…**

When we zoom in on the details, the differences become clear again. By analyzing the full statistics of the fluctuations — not just the average flow, but how it varies over time — bosons and fermions reveal distinct behaviors. Using a visual analogy, fermionic transport resembles a kind of erosion, where a surface is worn down; bosonic transport, instead, looks like growth, with the surface expanding over time.

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“Even with these differences,” the researchers note, “this analogy allows us to unify different phenomena under a single framework. It shows us that deep down, the physical world is governed by universal laws that connect systems which appear to have nothing in common. Understanding these connections helps us grasp how particle transport works in quantum systems — and that’s a conceptually powerful result.”

**Beyond Theory: Practical Implications for Lab Research**

The significance of this research goes beyond pure theory. It was in fact inspired by the interest of Peter Rabl and Louis Garbe in quantum cascade lasers (QCLs) — devices in quantum optics where electrons "descend" a potential ladder, emitting coherent laser light. But what happens if the electrons are replaced by bosons? “To answer that,” the authors explain, “we first needed to understand how bosons behave under dissipative transport. That led us to develop and analyze the statistical physics models described in this work, combining the different areas of expertise of the team.”

The results, they conclude, are not only conceptually interesting, but also relevant for experimental physicists. They offer new insight into experiments involving cold atoms or long-lived quasi-particles in nanophotonic lattices, where the very phenomena described in the paper can be realized and studied in the lab.

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**IMAGE**
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