Cone or flask? The shape that detects confinement

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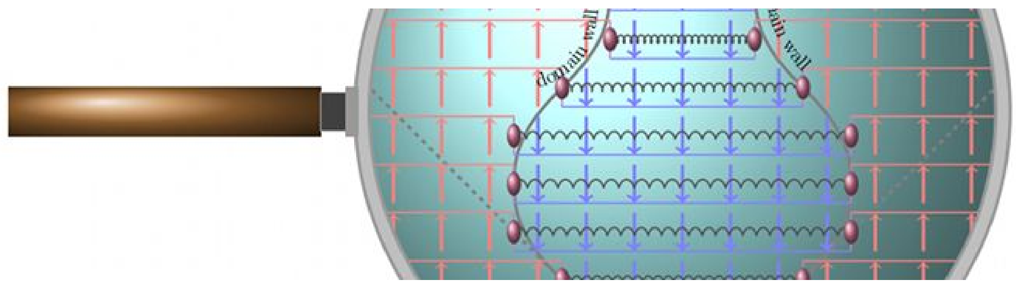

Credit: International School of Advanced Studies (SISSA)

In physics, confinement of particles is such an important phenomenon that the Clay Mathematics Institute has even pledged an award of a million dollars to anyone who can give a convincing and exhaustive scientific explanation from a mathematical point of view. For example, the quarks are confined in pairs or threes by the strong interaction- the force which holds the nuclei of the atoms together- making up neutrons and protons. A recent study at SISSA adds a new chapter to what we know about confinement. Using a relatively simple method, it has been shown how to determine whether, in a system with ferromagnetic characteristics, the emerging "particles" are subject to confinement. The study was published in *Nature Physics*.

Strong interaction is one of the four fundamental forces of physics, the most intense of which is the one that holds together the nucleus of an atom. "We can say that this force is the reason we exist, since without it none of the elements that make us up would exist," jokes Pasquale Calabrese, Theoretical Physicist at the International School for Advanced Studies (SISSA) in Trieste, who coordinated the new study. This strong interaction causes quarks to remain "confined" so that it is impossible to observe them isolated under normal conditions in nature. "It is as if these fundamental particles were joined by springs: the more you pull them apart, the more they try to get closer to each other," says Calabrese. "In fact, this phenomenon does not only exist for elementary particles, as in the example of quarks, but also in models of statistical physics and condensed matter, which were the subject of the study we conducted in collaboration with the University of Budapest."

In their research, Calabrese and colleagues, including SISSA researcher Mario Collura, formulated a prediction for the behavior of a ferromagnetic system driven away from its thermodynamic equilibrium. "Up to now these systems had been investigated in an equilibrium state, but we did not know what would happen if we move away from it", says the scientist.

The system studied by Calabrese is a "spin chain" in a ferromagnetic state. The "spin" is like a microscopic magnet and can be represented by an arrow. When the spins in a material are aligned (that is, the arrows all point in the same direction) the material is in a ferromagnetic state, or, a macroscopic magnet.

Stains that spread, cones and flasks

"For simplicity, we can imagine the system in equilibrium as a large number of arrows all pointing in the same direction. When this is perturbed, by applying a magnetic field, for example, some arrows will turn. In this case we say that 'particles' are created," says Calabrese. "In a normal system with no confinement, these areas with reversed arrows tend to expand spatially in an indefinite way, a bit like a red wine stain on a paper towel. The graph that shows this spatial expansion in time is a cone, technically called a 'light cone.'"

If the particles in the system are confined, however, then things are different. "Actually, what we call particles in this case are the walls that delimit the areas with reversed arrows, the edges of the 'stains.' The more they turn away, the more they are attracted to each other. This means the stain will not expand as it would in the normal system, but rather, after a certain time, start contracting." The graph in this case is no longer a cone. "It looks more like a flask, which widens at first and then narrows again."

"If in the system, whether virtual or real, the graph that represents 'correlations' (the arrows in the same direction) takes on a flask-shaped form rather than a cone, then we know that the particles are confined. This makes it easy to verify the presence of confinement," says Calabrese.

Calabrese and colleagues' study is completely theoretical, making it almost an exception for a journal that normally publishes experimental or theoretical/experimental research." This leads us to think that the model we proposed was deemed promising for research in this field, including experimental studies. In many cases it is difficult to detect confinement. In this way, for these materials, it is much simpler. We are working hard to ensure that this phenomenon can be observed experimentally in the near future."

More information: Marton Kormos et al. Real-time confinement following a quantum quench to a non-integrable model, *Nature Physics* (2016). DOI: 10.1038/NPHYS3934

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