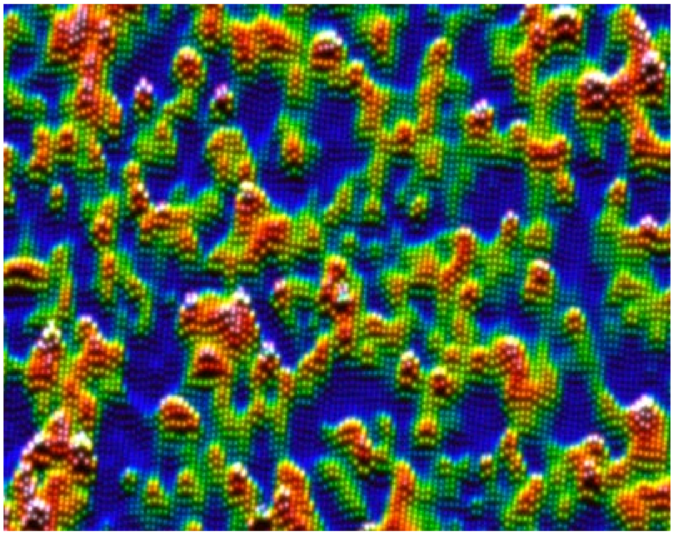
Fractal patterns spotted in the quantum realm

Feb 9, 2010   7 comments



Quantum repetition Fractal patterns enter the quantum world

From thunderous mountain landscapes viewed from above to the erratic trajectories of Brownian motion, fractal patterns exist at many scales in nature. Physicists believe that fractals also exist in the quantum world, and now a group of researchers in the US has shown that this is indeed the case. This image shows the fractal pattern that results when the waves associated with electrons start to interfere with each other.

A fractal is a geometric entity whose basic patterns are repeated at ever decreasing sizes. For example, a river system is an approximate fractal pattern as the channels branch off into progressively narrower tributaries moving upstream; at each confluence the pattern is a smaller version of the previous branching.

A sudden transition

Ali Yazdani at Princeton University in the US and his colleagues have revealed that these patterns also exist at the scale of individual atoms in a solid. And the key to this effect is a sudden transition where a material changes from a metal to an insulator. At this transition, the waves associated with individual electrons go from being extended across the whole system to being localized at lattice sites.

At this metal–insulator transition the electron waves become squashed together. They begin to affect each other in a complicated network of constructive and destructive interference, which results in a fractal pattern. Yazdani and his team were able to observe this effect using a scanning tunnelling microscope (STM), which provided the atomic scale resolution.

We do this stuff every day, but once we managed to get the experiment to work with this material, we were confronted with

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The material used was the ferromagnetic semiconductor gallium arsenide doped with up to 5% manganese, chosen because the researchers are interested in efficient ways of turning a semiconductor into a magnet. Indeed, doping gallium arsenide in this way has become a popular approach in the burgeoning field of spintronics – electronics that exploits the spin of particles as well as their charge. Spintronics has the potential to boost the speed of computing and electronics.

what look like random patterns

Ali Yazdani, Princeton University

Serendipitous discovery

Talking about his research, Yazdani admits that observing these fractals was not the primary aim of this research. "We do this stuff every day, but once we managed to get the experiment to work with this material, we were confronted with what look like random patterns," he says. His group went on to develop the theory and realized that the electrons they were observing were on the brink of localization.

Yazdani and his team intend to develop their research by comparing the collective versus individual behaviour of electrons in their system and how this influences the spatial patterns. The bigger picture of this research is to connect these patterns with theories of magnetism to advance both fundamental research and the development of spintronics applications.

This research is published in *Science*.

About the author

James Dacey is a reporter for *physicsworld.com*

7 comments

Add your comments on this article

1 **kasuha**
Feb 9, 2010 2:58 PM
Prague, Czech Republic

The image indeed resembles fractal landscapes but it looks like it's going to smooth out both on zooming in and out which is not usual fractal property - so I think it should be called chaos rather than fractal.

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2 **quantumgravity666**
Feb 13, 2010 10:36 AM
New Delhi

Quote:

> *Originally posted by* ***kasuha***
> The image indeed resembles fractal landscapes but it looks like it's going to smooth out both on zooming in and out which is not usual fractal property - so I think it should be called chaos rather than fractal.

a very valid point that you brought up regarding resolution and how either zoomnig in or out would sharpen the image. but don't you think that chaos (sensitive dependence on initial conditions) can be extant even when the substance does show fractal geometry at a quantum scale.

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3 **jjeherrera**
Feb 9, 2010 4:49 PM
Ciudad Universitaria, Mexico

However they claim to be able to measure the fractal dimensions. Interesting paper!

Reply to this comment   Offensive? Unsuitable? Notify Editor

4 **Jarek Duda**
Feb 10, 2010 3:31 PM

Great pictures, but Brownian motion or rather standard random walk on crystalic lattice with defects doesn't have such localization properties...
For such case much better is Maximal Entropy Random Walk in which we take paths as the fundamental entities - so if there is no point to emphasize any of them, the best is to assume uniform probability distribution among all possible paths. This random walk has strong localization properties (in analog to Anderson localization) and it's stationary probability density is kind of similar to these fractal shapes:
demonstrations.wolfr…
prl.aps.org…e160602
It's resemblence to behavior known from quantum mechanics is even clearer if we take Boltzman distribution among paths instead (arxiv.org…0910.2724)

Edited by Jarek Duda on Feb 10, 2010 3:37 PM.

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5 **T.Roc**

Maximal Entropy Random Walk

Feb 14, 2010 12:43 AM
Santiago, Chile

This is an important achievement. The reply above is also very interesting. There is a thread on Anderson localization at Sapo's Joint here: saposjoint.net…viewtopic.php

I also started one for the paper linked above on Maximal Entropy Random Walk, here: saposjoint.net…viewtopic.php

Maybe you can comment on that paper?

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6 **gianni.tee**
Feb 12, 2010 11:21 PM
*, Serbia

Fractals and phase transitions

The picture does not look like a fractal, but it could be the case of statistical self similarity at the critical state. I guess it is the universal theme of phase transitions.

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7 **Jarek Duda**
Feb 22, 2010 3:30 PM

Quantum states of lattice with defects

Quantum mechanics says that free electrons on lattice with defects should finally obtain quantum ground state for this lattice (exactly the same equations and so pictures as for MERW from my previous comment).

So it also says that while achieving this ground state, electrons should deexcitate from higher quantum states of such lattice ... so we should observe photons produced while such deexcitations, shouldn't we?

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