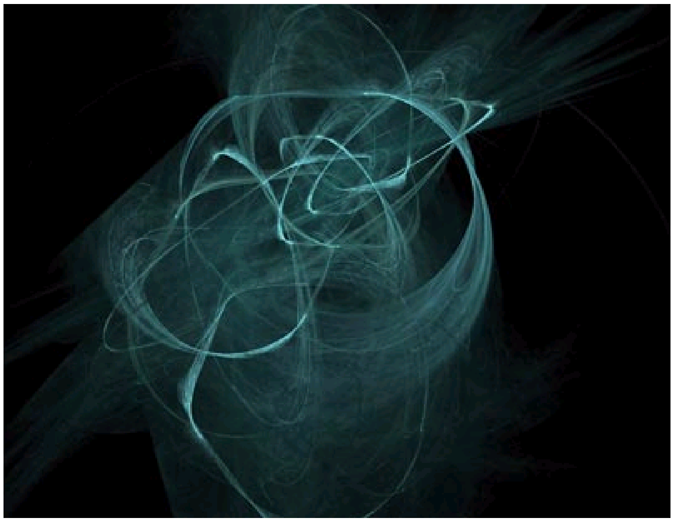
Fractals boost superconductivity

Aug 13, 2010 15 comments



A fractal flame rendered with the program Apophysis

Fractal patterns are ubiquitous in nature from the shape of a galaxy to the structure of a snowflake. They may also lie behind the mysterious phenomenon of high-temperature superconductivity, according to a group of physicists in Europe who have observed the characteristic scale-invariant patterns in the structure of a superconducting copper oxide, using a new kind of X-ray microscopy.

High-temperature superconductivity was discovered in a class of ceramic compounds known as cuprates, which consist of layers of copper oxide sandwiched between other elements, by IBM researchers Georg Bednorz and Alex Müller in 1986. Since the discovery, scientists have identified cuprates that remain superconducting at temperatures as high as 135 K, but the mechanism behind the phenomenon remains a mystery. Unlike conventional superconductors, such as elemental mercury or lead, high-temperature superconductors do not appear to create the pairs of electrons needed for zero-resistance conductivity via vibrations of the crystal lattice.

Could be in the oxygen stripes

Some theoretical physicists have suggested that high-temperature superconductivity may be linked to the distribution of oxygen ions in the layers between the copper oxide. They say it might be the formation of some of these ions into rows, or "stripes", that is responsible for cuprates' remarkable conduction properties.

To investigate these claims, a team including Antonio Bianconi at the University of Rome "La Sapienza" exposed a sample of the superconductor lanthanum copper oxide to X-rays generated at the European Synchrotron Radiation Facility in France. By using advanced X-ray optics, the researchers were able to focus the powerful beam down to a spot one-millionth of a metre across and perform X-ray diffraction analysis over this tiny area. Scanning the beam across the sample and obtaining a scattering pattern for each square micron of the sample, Bianconi and colleagues obtained an extremely detailed picture of the superconductor's structure, with high scattering intensity corresponding to greater structural order.

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What they found was that this intensity followed a power-law distribution, in other words that the superconductor was made up of a small number of very high-ordered regions and larger numbers of disordered regions. This, they say, is the hallmark of a scale-free distribution, which is typical of a fractal pattern – with the oxygen stripes forming a similar structure on all scales up to 400 µm.

Fractal scales with temperature

In addition, the researchers found that this fractal distribution increases the temperature up to which the lanthanum copper oxide remains superconducting. They altered the transition temperature of the sample by heat treatment and then recorded its X-ray diffraction image. Carrying out this process at five different transition temperatures, they found that the higher this temperature the more closely the intensity pattern resembled a power law.

To try and explain this correlation, Bianconi suggests that the fractal distribution of oxygen ions makes the ordered and disordered regions of the superconductor very highly interconnected, which maximizes the interference between the wavefunctions of the superconducting condensates of these two regions. This, he says, increases the stability of the quantum coherence that is responsible for superconductivity, rendering the superconducting state robust at higher temperatures.

Nigel Hussey of the University of Bristol describes the research as a "beautiful example of self-organization and complexity in a transition metal oxide" but is not convinced that the current result sheds further light on the cause of high-temperature superconductivity. "Crystalline order does not cause superconductivity, but it can improve it," he says. "Likewise, disorder can weaken it."

This research is described in *Nature*.

About the author

Edwin Cartlidge is a science writer based in Rome

15 comments

Comments on this article are now closed.

1 **davilla**
Aug 13, 2010 7:00 PM

This work is really opening a window for me to understand the relation between complexity and the maximum critical temperature.

I want to remark that reading popular books I have noticed that Onnes experimentally and Bardeen teoretically found low temperature superconductivity in perfect metals, On the contrary chemical research since the 1930 has found that the critical temperature is increasing in more complex and multicomponent intermetallics near a lattice instability, and in the complex transition metal oxydes or even more complex pnictides.

The search of high Tc by synthesis of more perfect metals always failed.
I was pleased to see here, that for the first time, such a complexity is finally becoming object of quantitative physics.
More complex more beatiful.

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2 **bob77**
Aug 13, 2010 7:50 PM

the experimental findings of this work are very interesting. I was wondering however of which could be the origin of this fractal distributions. Could be the understanding of the origin of these fractals be the answer to the long standing question of why cuprates are the most wonderful high temperature superconductors known?

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3 **Ragtime**
Aug 13, 2010 8:19 PM
Prague, Czech Republic

Quote:

> *Originally posted by* ***bob77***
> which could be the origin of this fractal distributions

In my model high Tc superconductivity arises, when electrons are getting compressed in such a way, their mutual forces are compensating mutually at short distances. The motion of every electron is affected by repulsive forces of neighboring electrons from many direction at the same moment - as the result electrons are moving freely through the resulting electron fluid in high-speed waves.

During compression of electrons fluid the nested fractal density fluctuations of particles may be formed.

Such fluctuations can be observed during nested condensation of supercritical fluid, too and they can be modeled with computer particle simulations. A nice examples of fractal videos can be observed here and at R. Prozorov's web site:

www.cmpgroup.ameslab…index.html
www.fys.uio.no…

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4 **davilla**
Aug 14, 2010 6:14 PM

shape resonance?

I feel that this complexity is like a macroscopic signature of quantum fluctuations, how it is possible? The shape resonance invoked by Bianconi could be the quantum trick? I would like to collect opinions on this subject.

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5 **sergeimoscow**
Aug 15, 2010 11:23 AM

Fractals in cuprates

Very interesting result to have fractal distribution of dopants in cuprates. The misfit strain on the
verge of
crystal melting due to defects could be the origin of fractal
distribution. An idea that oxygens image electronic critical
fluctuations is impressive, though
oxygen mass might be filtering caracteristic electron fluctuating time.
Sergei M.

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6 **Ragtime**
Aug 16, 2010 12:52 AM
Prague, Czech Republic

Quote:

> *Originally posted by **davilla***
> I feel that this complexity is like a macroscopic signature of quantum fluctuations, how it is possible?

I explained it already: QM operates in nested Hilbert space in the same way, like nested fluctuations of heavily compressed / cooled particles, which are repulsing at distance.

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7 **davilla**
Aug 16, 2010 9:32 AM

looking for more details and deeper physics

Very interesting,
I feel that the power law in mobiler oxygen ordering indicates also material instabiltiy derived by quantum fluctuations near a critical natural misft between layers in these heterostructrues at atomic limit,

Quote:

> *Originally posted by **Ragtime***
> Quote:
>
> > *Originally posted by **davilla***
> > I feel that this complexity is like a macroscopic signature of quantum fluctuations, how it is possible?
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8 **davilla**
Aug 16, 2010 9:34 AM

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Quote:

> *Originally posted by **Ragtime***
> Quote:
>
> > *Originally posted by **davilla***
> > I feel that this complexity is like a macroscopic signature of quantum fluctuations, how it is possible?
>
> I explained it already: QM operates in nested Hilbert space in the same way, like nested fluctuations of heavily compressed / cooled particles, which are repulsing at distance.

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9 **davilla**

fractals near natural misfit between layers

Aug 16, 2010 9:43 AM

I agree with Segei, there should be something unique here.
The case of La_2CuO_4 is a real going beck to the origins of HTS in 1986. It is the simplest cuprate perovkite, the added mobile oxygens convert a fist layer a Mott insulator (CuO_2 plane) to a superconductor and the second layer a large gap insulator (Lanthanum oxide) into a ionic conductor.
Now the Bianconi-Aeppli group sees that in the ionic conductor plane the frozen oxygen pattern at low temperature shows a scale free pattern of striped domains.

Clearly there should be in the game between the two layers
the key role of the natural misfit between the two type of layers called also "superlattice misfit strain"

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10 **Ragtime**
Aug 16, 2010 11:13 AM
Prague, Czech Republic

Quote:

> *Originally posted by **davilla***
> .. power law in mobile oxygen ordering indicates also material instability derived by quantum fluctuations near a critical natural misfit between layers in these heterostructrues at atomic limit

It could explain low-temperature photoelectric effect (cryogenic electron emission phenomenon), which follows power law too.

iopscience.iop.org…

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11 **julesruis**
Aug 16, 2010 8:05 PM

www.fractal.org

For more information about fractals, see wwww.fractal.org and more spicific:
www.fractal.org/Mandelbulb.pdf and www.fractal.org/Fratalary/Fractalary.htm

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12 **felicim**
Aug 17, 2010 10:48 AM

Very interesting indeed. It would be interesting to know if similar power-law distributions can be observed in other high-Tc superconductors.

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13 **bil79**
Aug 17, 2010 11:47 AM

Quote:

> *Originally posted by **davilla***
> I agree with Segei, there should be something unique here.
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this work is interesting because it underlines the importance of the distribution of oxygen interstitials between the layers. It is striking that the distribution of oxygen atoms, characterized by domain sizes that go up to 400um,can have such a strong influence on the electronic properties of the material.

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14 **ruben_s**
Aug 21, 2010 6:22 PM

Very nice experimental work. I hope it will urge theoreticians to find a comprehensive picture of high temperature superconductivity. It is intriguing that the scale-invariant distribution of the ions relates to the critical temperature: maybe someday exploiting this property we will be able to build superconductors at room temperature...who knows!

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15 **gianni.tee**
Aug 21, 2010 7:49 PM
*, Serbia

Percolation

This must be the case of percolation at critical threshold. If superconductivity exists only in the critical state, the opposing influences such as periodic potentials in the material, are in balance. That allows the superconductivity. I wonder though, if the correlation length is not defined meaningfully in the critical state, does it mean that the scale at which we give explanation of this particular superconductivity can be macroscopic?

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