John Baez 9:26 PM (edited) - Public

In 2011 Moritz Reintjes and Blake Temple were studying Einstein's theory of gravity, and they found that it allows for a new kind of singularity. +Jane Shevtsov asked me to explain this, and she posts a lot of good stuff here, so I'll give it a try. (This is not a free service I offer to everyone!)

A 'singularity' is a place where the solutions of some equations become infinite. One kind you've heard of is a 'black hole'. As you approach the singularity in the middle of a black hole, general relativity says the curvature of spacetime - or if that sounds too mysterious, the gravitational field - becomes infinite. Right *at* the singularity it would *be* infinite, but we usually say general relativity breaks down under such extreme conditions. Needless to say, nobody has gone into a black hole, checked what's really happening, and reported back. But people can study singularities using math, and that's what these guys are doing.

Another kind of singularity is the 'big bang'. As you go back in time towards the big bang, general relativity says the curvature of spacetime becomes infinite... but in a very different way than for a black hole.

Reintjes and Temple showed that according to general relativity, a new kind of singularity can happen when 'shock waves' in a fluid collide.

What's a 'shock wave'? If you've ever heard a sonic boom you've experienced one. It's a pulse in a fluid where its density, pressure and velocity take a sudden jump. In fact it's a kind of singularity in its own right. If you take the equations for a compressible fluid with zero viscosity and solve them, you often get shock waves - and the derivatives of the density, pressure and velocity are infinite in these solutions.

Now in general relativity, the density of matter affects the gravitational field. So you might think a shock wave would cause a singularity in the gravitational field, too. But no, basically not.

But Reintjes and Temple go a step further: they look at solutions of general relativity where a spherically symmetric shock wave comes crashing in to a single point. When crashes in, they get a singularity in the gravitational field at that point. But it's not as dramatic as a black hole; in fact life goes on as usual after the collision occurs! So it's a singularity of a new kind.

In reality, of course, the viscosity of a fluid is never exactly zero. Nothing is ever exactly spherically symmetric, either. These assumptions were made to make the math a bit easier. However, in the conclusions of their paper, they claim that interesting effects should still happen. But don't hope for this to be tested in the lab. You might at best see it in the middle of a supernova, or something like that. So I'd say this result is of 'merely theoretical interest'... but being a theorist, that means I think it's interesting.

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Finally, for the mathematicians out there, I should say that this singularity is very mild. The metric is Lipschitz continuous, but you can't find coordinates in which it has Lipschitz continuous first derivatives! In simple terms, this is like a 'wrinkle' in spacetime. This is a very mild singularity compared to a black hole. For mathematicians, it's as subtle and delicious as a good bottle of Château Lafite Rothschild. Not that I've ever tried one of *those*. I'm just groping for a good image here...

For details, try the actual paper:

• Moritz Reintjes and Blake Temple, Points of general relativistic shock wave Interaction are "regularity singularities" where spacetime is not locally flat, http://arxiv.org/abs/1105.0798

Also by the way, the press release speaks of "the biggest shockwave of all, created from the Big Bang when the universe burst into existence". That sounds like baloney to me - the big bang is a singularity but I don't think it created a shock wave. I could be wrong, but I bet it's just the journalist getting a bit carried away.

UC Davis News & Information :: A wrinkle in space-time »

Mathematicians at UC Davis have come up with a new way to crinkle up the fabric of space-time -- at least in theory. "We show that space-time cannot be locally flat at a point where two shock

+18 **3**

16 comments

Akira Bergman 5:45 AM (edited)
GR assumes an aether in the form of "a compressible fluid with zero viscosity", while SR refutes it. A bit like the dichotomy between SM and QM in this respect, although not too sure about this one.

Sergey Ten 6:53 AM
So this singularity should kind of invalidate velocity and energy of whatever stumble into it? Also it should be ideal shockwave, with discontinuous density, or realistic, with high density jump? If it should be discontinuous from the start it's not quite mind-boggling - garbage in, garbage out.

Thomas R. 9:15 AM
Had gravitational shock wave colisions not been studied before?

John Baez 12:09 PM (edited) ***+1***
+Thomas R. - I don't know the state of the art in this subject, though it's reviewed to some extent in the paper's introduction. I imagine head-on collisions of gravitational plane waves had been studied in immense detail, because they're easier. The waves studied here are spherically symmetric, with the waves colliding at the center. I imagine someone must have studied these too, but this is a heavily mathematical paper: it shows not merely that the metric fails to be smooth at the point of collision, but that you can't find *any* coordinates for which it has Lipschitz continuous first derivatives, even though it's continuous. That's sufficiently subtle that I can see why it's new.

John Baez 12:14 PM (edited)

+Sergey Ten - It's a shock wave with a discontinuous density, velocity and pressure. Such shocks arise quite generically in solutions of the equations for a compressible fluid with zero viscosity. I'd hazard a guess that nonzero viscosity might be enough to make the solutions continuous... but then you're dealing with the Navier-Stokes equations and nobody has even proved they have solutions except for short times... so it might be hard to prove anything!

The authors argue that while with viscosity you won't get *discontinuous* densities and thus probably won't get non-Lipschitz-continuous derivatives in the metric on spacetime, if the viscosity is small the metric will still have _very rapidly changing_ derivatives. In other words, while their assumptions are an idealized limiting case of a physically realistic situation, they should still give some clue about what more realistic situations are like.

Nothing in the paper I read is particularly shocking; while it looks like very good work, the fact that +Jane Shevtsov saw a news release about it is mainly a credit to U. C. Davis' press department. It's not often that you see press releases about someone proving a function is Lipschitz continuous but lacks Lipschitz continuous first derivatives. :-)

John Baez 11:58 AM
+Akira Bergman wrote: "GR assumes an aether in the form of "a compressible fluid with zero viscosity", while SR refutes it."

That doesn't make sense to me. First of all, GR subsumes all the insights of SR. Second of all, if you're talking about actual fluids instead of "aether", SR prohibits *incompressible* fluids.

Jane Shevtsov 12:23 PM
Thanks, +John Baez! What would cause a gravitational shock wave?

Greg Kuperberg 12:41 PM
Andy Fell is the UC Davis science reporter. He's not one of the researchers.

Stephen Villano 2:24 PM
+Jane Shevtsov , I can think of a few things, all of which are involving redistribution of large masses.
Neutron stars colliding, a stellar core and a neutron star colliding, black hole coalescing are excellent examples that would trigger gravitational shockwaves, as huge masses are trying to find their common center quite rapidly.
+John Baez , do you think there might be an observation able to be made from Sag A*? One would think that region would be rife with collisions that could trigger the effects described and potentially may be observable by radio telescopes.

Akira Bergman 5:58 PM
+John Baez why then use the liquid analogy to explain the gravity shock waves? Why is there no other analogy? I have seen the liquid analogy many times in the explanation of the black hole horizon, like "space-time falls in so fast that even light can not escape".

I need to reread the theory no doubt, but I find it a bit hard to accept that something that does not exist should have curvature. Quantum foam theories indicate substance to it

Quantum foam theories indicate substance to it.

Stephen Villano 8:21 PM
+Akira Bergman , it isn't liquid, but fluid. Fluids can include gases, as all tend to behave much alike when flowing.
A solid won't flow, but a fluid will flow.
In the case of a black hole, it's easier to explain the concept in the terms of a drain than to try to explain matter and energy falling in in three dimensions and include curving of space-time as the cause.

Actually, quantum foam is simply quanta changing at the smallest levels of space-time. It's not some boiling liquid.

Akira Bergman 9:05 PM
+Stephen Villano, I understand that space-time is a construct that comes out of the quantum interactions in QM. Hence the entanglement concept; all quanta are related and from this relationship space-time comes out.

Obviously, a similar situation exists in relativity, the difference being that instead of quanta we use continuous distributions of mass and differential calculus in a 4-manifold.

John Baez 9:15 PM *+1*
+Akira Bergman wrote: "why then use the liquid analogy to explain the gravity shock waves?"

I wasn't. I wasn't using any analogy and I wasn't talking about gravitational shock waves. I was talking about how a spherically symmetric inwards-moving shock wave in a fluid - a gas or liquid - can cause a singularity in the gravitational field when it collides with itself at the central point. I think if you reread my post with this in mind, it will make more sense.

John Baez 9:17 PM
+Greg Kuperberg - whoops! I'll fix that. Now things make more sense.

Akira Bergman 9:17 PM
Thanks +John Baez, my misinterpretation was due to my fixations.

John Baez 9:30 PM
I've edited my post to make it clear right from the start that I'm talking about a shock wave in a fluid, not in the gravitational field itself.