John Baez Jul 25, 2012 (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.

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

+28 **7**

36 comments

Akira Bergman Jul 25, 2012 (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 Jul 25, 2012
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. Jul 25, 2012
Had gravitational shock wave colisions not been studied before?

John Baez Jul 25, 2012 (edited) *+1*
+Thomas R. - This paper is not about gravitational shock waves; it's about gravitational singularities caused by colliding shock waves in a fluid.

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 shock 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 even though it's continuous. That's sufficiently subtle that I can see why it's new.

John Baez Jul 25, 2012 (edited)
+Sergey Ten - It's a shock wave with a discontinous 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 Jul 25, 2012
+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 Jul 25, 2012
Thanks, +John Baez! What would cause a gravitational shock wave?

Greg Kuperberg Jul 25, 2012
Andy Fell is the UC Davis science reporter. He's not one of the researchers.

Stephen Villano Jul 25, 2012
+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 Jul 25, 2012
+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.

Stephen Villano Jul 25, 2012
+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 Jul 25, 2012
+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 Jul 25, 2012 ***+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 Jul 25, 2012
+Greg Kuperberg - whoops! I'll fix that. Now things make more sense.

Akira Bergman Jul 25, 2012
Thanks +John Baez, my misinterpretation was due to my fixations.

John Baez Jul 25, 2012
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.

John Baez Jul 25, 2012 ***+1***
+Jane Shevtsov wrote: "What would cause a gravitational shock wave?"

Good question! I'd never thought about that - my work in quantum gravity was very abstract, I wasn't one of those folks who spends their time studying lots of solutions of Einstein's equations (the equations of general relativity) and their properties. So I just did what anyone would do - Google "gravitational shock wave". And then I did what not anyone would do - read the paper that showed up on top.

It mentioned that a gravitational shock wave would be caused by a "beam of null matter". That's relativity-speak for a beam of photons or some other sort of massless particle travelling at the speed of light; I include the jargon just so you can wow your friends. In something like plain English:

A homogeneous cylindrical beam of light with completely sharp edges, most notably a completely flat front edge, will create a discontinuity in the geometry of spacetime propagating outwards in all directions at the speed of light: a **gravitational shock wave**.

Of course this situation is idealized, but the paper mentioned that this is situation is *approximated* by the ultra-fast jets of matter that may be shot out by the collapsing stars that cause gamma-ray bursts.

There may be lots of other extreme situations that could, in theory, cause gravitational shock waves.

http://arxiv.org/abs/gr-qc/0303105

John Baez Jul 25, 2012
+Akira Bergman wrote: "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."

This is your own personal theory, not an established fact or even a widely studied theory. I urge everyone to clearly distinguish between these things when making statements about science; it's very confusing not to do so.

Akira Bergman Jul 25, 2012 (edited)
+John Baez , I agree that the statement on entanglement is a speculation, but it was only meant to be a clarification on the first one. But the point is taken. More discipline is necessary when it comes to science.

Stephen Villano Jul 25, 2012
+John Baez , "A homogeneous cylindrical beam of light with completely sharp edges, most notably a completely flat front edge, will create a discontinuity in the geometry of spacetime..."

So, a collimated laser with a flat front should also generate a gravitational shock wave. ;)
Seriously though, relativistic jets are matter with mass, largely, not massless photons. The jets tend to be collimated due to intense on steroids magnetic fields from the star, from my understanding of current knowledge of relativistic jets.

I'll also ask, how does the photon cylindrical beam interact with gravity/space-time/mass/whatever to cause a gravitational shockwave? Or any OTHER gravitational effect? I'm missing something here, as a massless particle/wave interacting with gravity.
Photons, from my understanding, only bend due to bending of space-time caused by gravity, I'm aware of no other interaction of significance.
Indeed, if we found a coupling between the electromagnetic and gravitation, we'd be quite grandly unified!

Akira Bergman Jul 25, 2012 (edited)
+Stephen Villano ,a mirror box filled with light has mass due to light.

John Baez Jul 26, 2012 (edited)
+Stephen Villano wrote: "So, a collimated laser with a flat front should also generate a gravitational shock wave. ;)"

Right, exactly - this is no joke. A gravitational shock wave is not necessarily a big thing that's easy to notice! Maybe you're imagining some sort of Hollywood movie disaster with buildings collapsing. But one can have arbitrarily weak shock waves in general relativity; there could be hundreds going through your body right now and you wouldn't necessarily notice.

But again: as I said, we should only expect a shock wave in the mathematical sense of an actual *discontinuity* in the metric in limit where we pretend the laser beam has a completely flat front. In reality it never does, and if you look close enough you start needing quantum optics to accurately treat what's going.

"Seriously though, relativistic jets are matter with mass, largely, not massless photons."

Right, but as the paper notes, the effect of very rapidly moving matter on the gravitational field can be conveniently approximated by the effect of matter moving at the speed of light. The reason is that their energy-momentum tensors are very similar.

"I'll also ask, how does the photon cylindrical beam interact with gravity/space-time/mass/whatever to cause a gravitational shockwave? Or any OTHER gravitational effect?"

Anything with energy or momentum affects the geometry of spacetime (also known as "the gravitational field"). This includes light.

Indeed, if you believe the Sun gravity affects light (which it does, as in the bending of starlight), you'd darn well *better* believe that the light affects the Sun in return. The light has momentum, which changes as the Sun bends its path, so conservation of momentum would be violated if the light didn't create a gravitational field that pulled on the Sun!

Einstein's equations for gravity, together with Maxwell's equations for electromagnetism, say exactly how this works.

Stephen Villano Jul 26, 2012
+John Baez , after I posted that, I recalled there is pretty much a never when one could see a purely flat photon front.
However, a normally curved front can meet a gravitationally curved front that cancels the curvatures. However, flat is relative, as at some scales, the lack of true flatness is moot overall (after all, if the front is curved over tens of kilometers by a small amount and it's only a hundred kilometers wide, the effect is essentially null.

No, I'm not thinking buildings flying apart. I'm thinking of interactions that are measurable by such minute things as radio telescopes. Or, in a lab, spectral shifts of gravitationally influenced photons. We should have long been able to observe irregularities in laser experiments that would prove this paper.

To be honest, if I had the money, I'd pay it out in large amounts to attempt to find proof. If we don't find it, we'd find new phenomena that would lead to better understanding of physics overall.
For, in science, the greatest discoveries weren't eureka moments, they were the moments of, "Huh, THAT was interesting..."

However, even IF the paper proves incorrect, it WOULD simplify modeling of highly energetic events. Just as Prandtl–Glauert singularity math, which there is not real singularity, is still used to simplify supersonic flows.
Because, while there IS no ideal gas, the notion is useful in modeling and understanding.

Stephen Villano Jul 26, 2012
+John Baez , what is the current threshold of detection of mass change in a Bose-Einstein condensate?
A bit OT, but, slightly germane to the concepts involved.
After all, M=E/C^2.
The change would be small, the question is if we can detect that with our current technology.

John Baez Jul 26, 2012 **+2**
+Stephen Villano wrote: "We should have long been able to observe irregularities in laser experiments that would prove this paper."

Actually, a quick back-of-the-envelope calculation shows that gravitational effects produced by a laser in the laboratory are not something we'd be able to detect with current equipment. They're much, *much* too weak.

Why do people, mainly men it seems, feel the urge to *make stuff up* when talking about subjects they haven't studied? I've never understood this. I make guesses, but then I say "I don't know much about this, but I would guess...." And when I'm talking to someone who has studied a subject, I ask them questions about it, not tell them my guesses as if they were facts.

John Baez Jul 26, 2012
Quick back-of-the-envelope calculation: take the energy in a laser beam, divide by the speed of light squared to get a mass, then multiply by G to get the gravitational effect. Tiny, tiny, tiny, tiny! - you don't even need to do the calculation to start laughing. You might as well look for the gravitational effect of swimming protozoan.

John Baez Jul 26, 2012 (edited) **+1**
Okay, this is silly, but now I want to check my work. The National Ignition Facility is really heavy-duty: they've got a 192-beam, 1.8-megajoule laser system that blasts a 10-meter-diameter target. Now convert that energy into mass by dividing by the speed of light squared. I get 2 × 10^(-11) kilograms.

I read here a homework exercise where they ask you to estimate the mass of a paramecium:

http://umdberg.pbworks.com/w/page/45918100/Propelling%20a%20Paramecium%3A%202%20--%20Estimations

They approximate a paramecium by a sphere 1/4 millimeter in diameter. That seems really big to me, but that gives a volume of about 7 × 10^(-11) cubic meters, or a mass, assuming a density similar to that of water, of about 7 × 10^(-8) kilograms.

So, I'm getting that the gravitational effect of the laser beams at the National Ignition Facility is roughly .00025 times the gravitational effect of this (admittedly surprisingly large) paramecium.

This is very *very* rough, but I could be off by 4 or 5 orders of magnitude and the point would remain: we're not going to be detecting gravitational effects from laser beams in the next few decades.

Stephen Villano Jul 26, 2012 *+1*
Actually, it comes down to two factors. Sensitivity of the equipment. Energy involved in the experiment.
For the latter, one need only go to the national ignition experiment.
For the former, one needs to invent new technology that IS sensitive enough.
I HAVE studied the subject. Very long ago. The technology has changed over the decades and I've not bothered to keep up, as I developed a dislike in the field I was in, that of nuclear arms.
Hence, I'm not acquainted with our current leading edge sensor sensitivities.
And hence, my questions above.

I'm not trying to debate science, but find a detection threshold for this. If it doesn't actually occur, it is still highly valuable in simplification of modeling.
Indeed, this discussion gave me some interesting notions on stellar and galactic jets and Rayleigh instability in a highly magnetized field. I might give that series of notions to an undergraduate to consider for a thesis.

As for the gravitational effect of a protozoan being laughable, one can consider the laughable notion of measuring the mass of an electron and its "size". Then, consider the much later non-laughable electron microscope.
Lousy comparison, true, but it's late.
If one gives a "laughable" standard to detect, there IS a non-zero potential that someone will find a way to detect it. As laughable as it is to us right now.
Or more simply put, my mother related how laughable it was to think of a man on the moon, it was a reference to pure insanity. She and I watched Armstrong walk on the moon when I was a child.
I've watched things I laughed about as impossible in my own fields come into being by ingenuity and leveraging of technology.
I'm not talking about some impossible technological leap, but potentially one that leverages other known factors to make the current "impossible" become measurable.
As in the difference between a refracting telescope vs a reflecting one. Same technological problem, different and more effective solution.

Hence, my questions here.
Ignorance can ONLY be corrected by education. Dismissal simply ignores that fact and perpetuates ignorance.
While time constraints ARE of a valid concern, one should never dismiss questions by dismissal, but out of expression of time constraints.
Lest we perpetuate ignorance.
And as the ignorant rule, eventually erase our science budgets,

which would be a disaster for all.
If you had other discussions that elaborated on the subject at hand overall, I'd highly recommend posting links to them to save precious time.

Oh, thanks for the paramecium mass information. Off the cuff, the mass would be barely detectable with an apparatus outside of the orbit of Jupiter, with single photon emitters/detectors, detected with Scotty's tricorder. ;)
Now, can you give evidence that the difference in signal is equal or higher than that of the mass of a paramecium? Or is it at what level lower?
What is the current threshold of detection of our current leading edge detectors?
In short, what is the problem in proving or disproving the work?
Once we define a problem, we can THEN work to resolve it and define the laws of our universe much finer!
I'm not trying to anger you. I'm simply trying to model reality, just as everyone else is.

John Baez Jul 26, 2012 **+3**
My point was simply that you asserted, confidently, "We should have long been able to observe irregularities in laser experiments that would prove this paper," without having done a mental check on whether you really knew this. If you didn't know it, you could have added a phrase like "I would think..." or "Isn't it true that... ?"

I really enjoy talking to people whose statements I can rely on: when they say something, they have really strong evidence for it, and when they're less sure, they indicate that. Most of the people I work with are like that, and most of the people who comment on my blog are like that. It's really enjoyable.

I've heard that mathematicians are, more than anyone else, happy to admit their ignorance. I don't know if that's true. (See, I'm doing it!) But it's a quality I admire.

Perhaps it's too much to expect people to distinguish between what they know and what they're guessing in what's more or less an online chat room. I was probably put into an irritable state of mind by Akira's equally confident-sounding claim "I understand that space-time is a construct that comes out of the quantum interactions in QM" - which is again something that nobody could possibly know at this point in history.

(If "understand" meant "believe", then that remark would be okay: it would mean it's his personal belief, not some fact he understands.)

Akira Bergman Jul 26, 2012 (edited)
You were nitpicking and rude, with me anyway.

Your irritable teachers' ego is in conflict with your aspirations of being a planet saver and a web educator.

John Baez Jul 26, 2012
Sorry, I get irritable and easily get rude when discussing quantum gravity and related aspects of fundamental physics. I spent decades studying them and carefully shade my sentences with qualifiers indicating the extent to which facts are known - through experiment, mathematical proof, plausible argument, etc.. It shocks me how many people seem happy to state their unproved personal guesses in the same language with which I'd state a

personal guesses in the same language with which I'd state a proven fact. But why does this *irritate* me? I guess it's because I eventually gave up working on quantum gravity because it was too hard to know if anyone was making real progress. I saw lots of very smart people spinning their wheels in elegant ways and decided I didn't want to spend the rest of my life like that. I switched to subjects where the truth was easier to discern. If it were as easy as some people seem to think, we'd have figured everything out by now!

So, you can imagine me as a tired old mountain climber, descending after failing to reach the peak, meeting some young and peppy fellows who plan to *jump* to the top.

Stephen Villano Jul 26, 2012
Just remember, some of those young and preppy fellows planning to jump to the top end up like the rest, stumbling and never reaching the top. However, they invent neat new detection techniques and experimental technologies that help the next generation in their attempted jump.
In short, each failure in developing further theory is simply more pavement on the road along which scientific knowledge travels. It makes the road a bit less bumpy for the new generation to travel in their study.

Akira Bergman Jul 26, 2012
+John Baez admission of weakness is a good quality. It looks even better on the high achievers, who tend to be a bit highly strung, specially on the subjects they care about.

I will try and be more careful on these big topics.

Colin Gopaul Jul 26, 2012 (edited)
+John Baez Great job as always. Keep it up. Maybe its time for some music posts (not that its always to my taste). So strange you have not posted anything new today. Don't be too hard on yourself, you are an excellent teacher and even popularize(r) (along the lines of Physics Today) to have such a readership from so diverse and far-apart people. This was a nice paper I'd ordinarily not be aware of, nor able to grasp much of it without this post. The same can be said of so many others.

Thomas R. Jul 27, 2012
I know +John Baez since ages and have a tendency to "go far out on a limb" (shall be the engl. version of "sich weit aus dem Fenster lehnen") with expressing more or less clear mixtures of ideas and impressions, but found never that he were "irritable and easily get rude" - despite having lots of occasions to do so.

John Baez Jul 27, 2012
Thanks, everyone! I'm feeling better today, and when people wake up in the USA I'll post a link to something I wrote about Platonic solids, full of pretty pictures. Topics related to quantum gravity apparently have the power to get me upset, but the beauty of geometry calms me down. :-)

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