Science AMA Series: We are the LIGO Scientific Collaboration, and we are back with our 3rd detection of Gravitational Waves. Ask us anything!

LIGO-Collaboration [1] and r/Science AMAs[1]

[1]Affiliation not available

April 17, 2023

Abstract

Hello Reddit, we will be answering questions starting at 1 PM EST. We have a large team of scientists from many different timezones, so we will continue answering questions throughout the week. Keep the questions coming! About this Discovery: On January 4, 2017 the LIGO twin detectors detected gravitational waves for the third time. The gravitational waves detected this time came from the merger of 2 intermediate mass black holes about 3 billion lightyears away! This is the furthest detection yet, and it confirms the existence of stellar-mass black holes. The black holes were about 32 solar masses and 19 solar masses which merged to form a black hole of about 49 solar masses. This means that 2 suns worth of energy was dispersed in all directions as gravitational waves (think of dropping a stone in water)! More info can be found here Simulations and graphics: Simulation of this detections merger Animation of the merger with gravitational wave representation The board of answering scientists: Martin Hendry Bernard F Whiting Brynley Pearlstone Kenneth Strain Varun Bhalerao Andrew Matas Avneet Singh Sean McWilliams Aaron Zimmerman Hunter Gabbard Rob Coyne Daniel Williams Tyson Littenberg Carl-Johan Haster Giles Hammond Jennifer Wright Sean Levey Andrew Spencer The LIGO Laboratory is funded by the NSF, and operated by Caltech and MIT, which conceived and built the Observatory. The NSF led in financial support for the Advanced LIGO project with funding organizations in Germany (MPG), the U.K. (STFC) and Australia (ARC) making significant commitments to the project. More than 1,000 scientists from around the world participate in the effort through the LIGO Scientific Collaboration, which includes the GEO Collaboration. LIGO partners with the Virgo Collaboration, which is supported by Centre National de la Recherche Scientifique (CNRS), Istituto Nazionale di Fisica Nucleare (INFN) and Nikhef, as well as Virgo's host institution, the European Gravitational Observatory, a consortium that includes 280 additional scientists throughout Europe. Additional partners are listed at: http://ligo.org/partners.php.

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LIGO-COLLABORATION R/SCIENCE

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More info can be found here

Simulations and graphics:

Simulation of this detections merger

Animation of the merger with gravitational wave representation

The board of answering scientists:

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Sean Levey
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WRITE A REVIEW

CORRESPONDENCE:

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What is the significance of knowing that gravitational waves are real? Does everything emit these waves or is it only special cases? Can your instruments get more accurate and precise or are they about as accurate as can be?

FuseInHD

Having detected gravitational waves is significant for many reasons: it affirms that our current understanding of gravity (General Relativity) works well up to the limits that we've tested it; it gives us insight into exotic phenomena like the merging of black holes; and importantly, it provides us a whole new way of observing the universe! With three solid detections under our belt, we can safely say that we've opened a new window into observational astronomy that will answer all sorts of questions (some of which we probably haven't even thought to ask yet).

As for what can emit gravitational waves? Anything that has mass (or energy) which accelerates in the correct way can produce gravitational waves. But not just any acceleration will do! If the acceleration has spherical symmetry (imagine a ball that just gets bigger and smaller) or cylindrical symmetry (imagine that same ball spinning around on its axis) then it will not produce gravitational waves. Stars, for example, don't emit GWs as they expand and contract, nor when they're simply rotating. But if you throw in an asymmetry (a "bump" on the surface, or a second star in orbit around the first) then you can produce gravitational waves!

This is true even of very small objects! Waving your hand back and forth satisfies all these requirements (your hand has mass and the act of waving is a type of asymmetric acceleration), so ostensibly this should produce gravitational waves too! But even though gravity seems like a powerful force (it keeps us on the surface of the Earth, after all) in truth the force of gravity is quite weak. And gravitational waves are weaker still!

In order to produce gravitational waves that are detectable, you need far more mass and energy than you can get from waving your hand. In order for LIGO to be able to detect gravitational waves, they have to be generated by objects with mass comparable to our sun or larger! The two black holes that merged during the GW170104 event each had masses 20 to 30 times greater than our sun, and the gravitational waves were still tiny! So tiny, in fact, that their effect on our detectors was to change their length (4 kilometers) by barely a couple ATTOmeters -- a thousand times less than the diameter of an atomic nucleus. It's amazing that we can build a device sensitive enough to measure changes in length that small!

With that said, we have plans to make our detectors even more sensitive. Right now we're in our second observing run. When we're finished with this run late this summer, we'll shut down for a little while to make improvements. We'll repeat this process until we get to "design sensitivity" - which should be a factor of 2-3 more sensitive than we are now.

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

What is the significance of knowing that gravitational waves are real? Does everything emit these waves or is it only special cases? Can your instruments get more accurate and precise or are they about as accurate as can be?

FuseInHD

(Another one of our scientists also answered this question, so here's more input!)

Hi /u/FuseInHD,

What is the significance of knowing that gravitational waves are real?

It expands the volume of stuff in the universe that we can observe with telescopes. Objects that don't emit any or much radiation in the electromagnetic spectrum, ie. black holes, neutron star binaries, could emit gravitational waves that tell us how they are spinning and what mass they are.

Does everything emit these waves or is it only special cases?

Short answer: no not everything emits them. Long answer: To emit gravitational waves an object needs three things: to have mass, to be accelerating, to not have spherical symmetry. To clarify that last point, a uniform sphere rotating about its axis fulfils the first two conditions but not the third.

Can your instruments get more accurate and precise or are they about as accurate as can be?

Our instruments can definitely get more precise, some of this involves investigating things in the detector environment that cause us to lose sensitivity in the instrument periodically (ie. intermittent faults in the electronics, light from the main laser beam hitting things inside the system that you don't want it to hit and bouncing back into the main beam). These effects are worked on between observation 'runs' and on maintenance day once a week.

We also have a list of near-term, longer-term and far-term plans for detector upgrades which are developed by either the LIGO laboratories at Caltech and MIT or at other LIGO Scientific Collaboration institutions all over the world. A large part of these involve new materials or technology innovations and so it takes many scientists (and time) to get these to the point where they can be added to the detectors.

In terms of improving accuracy, adding more detectors to our network: the Virgo detector, Italy the KAGRA detector, Japan the LIGOIndia detector, India will allow us to improve the accuracy of our calculation of the gravitational wave source position on the sky, so we will know more accurately where a wave is coming from when we see it. The first two are currently being worked on and should join us soon and the third is planned but has not started construction.

[PhD student, experimental interferometry]

Curious: what is the wavelength of gravitational waves? Big like radio or small like ultraviolet?

greenthumble

Hi /u/greenthumble, Light, as a wave can be of any wavelength. We classify them, as you rightly suggest into groups, radio with long wavelength, visible light in thew middle, and gamma rays on the short side. However, gravitational waves aren't light, they're an entirely different phemnomenon - stretches and squeezes in the spacetime metric that can alter the length of a metre. They, like light, cover a spectrum. Gravitational waves with longer wavelengths (lower frequencies) have been about, we think, since the big bang. Events at a 10-6 hertz correspond to really heavy objects like supermassive black holes in the centre of galaxies, and as we move up the frequency scale, we think about lighter things, a pair of black holes, a pair of neutron stars, and faster moving lighter things too. I hope that this has answered your question!

Is the LIGO just running all the time, collecting data? How much power does it use? Is it expensive to run and maintain?

How much data does the LIGO create and how do you seperate signal from noise?

Thanks!

maceireann

During observation runs we try to have the detectors collecting data 24 hours a day. However many things can cause the detectors to go down, such as earthquakes, power glitches and even wind. There are people on site 24/7 to keep an eye on the detectors and to fix them when they go wrong. There are also regularly scheduled times when the detectors are taken offline to preform maintainance and commisioning tasks.

While running the detectors, we collect a vast amount of data, currently as I am writiing this the Livingston detector is collecting 53 MB/s (so over 100 MB/s for the two LIGO detectors). As well as the gravitational wave data we also monitor every subsystem of the detector as well as the buildings and local enviroments.

Running the interferometer uses a significant amount of power to maintain the low pressure in the 4km vacuum enclosures and to run the lasers and the computing facilities. Infact after labour cost, electricity usage is the largest operating cost.

Signals can be separated from the background noise by looking for those signals that show up in both detectors within a few miliseconds of each other (the time is takes a gravitational wave to travel between the two detetors in Louisiana and Washington state). These signals can be further extracted from the noise by comparing them to templates of what black hole collisions look like.

For more information on how we collect and analyse data see a previouse answer: https://www.reddit.com/r/science/comments/6fekz5/science_ama_series_we_are_the_ligo_scientific/dihugyo/

LIGO Science Fellow/UoGlasgow Research Student

Hi, I've done a little over 6000 classifications in Gravity Spy. :) What kind of sources do false positive chirps usually come from? Do you get false positives that hit both detectors at about the right timing?

crazyjkass

Hi /u/crazyjkass, Thanks for your work on GravitySpy, it really does a lot to help us on our searches!

Our detector is very sensitive, and reacts to an awful lot. When the mirrors move relative to each other, we get some signal in the strain channel. Our code then runs over that code with what's called a matches template search, looking for compact binary coalescences - 2 black holes, 2 neutron stars, or one BH and one NS, falling in ands spiralling around each other. Each mass pairing gives a unique signal, and so a unique template. When the data and the template have a low mismatch, then it looks like a signal. However, as you know, not all signal are true signals. These false positive chirps are caused by any number of disturbance to the interferometer. Noise sources might be a truck going down a nearby bumpy road, a refrigerator running where it should be quiet, or 100 LEDs flashing in unison. but none of these look like chirps.

The chirpiest noise that I can think of is something we call a "blip glitch" - they're pretty short, and like a chirp, they have a rising edge, so could have low mismatch. These blips have a wide variety of morphologies, so can look like any number of events.

Unfortunately, we don't know what causes these blips. It's an infamous problem in the detector characteristics team. That's why we need people like you to help sort them out for us! Computers need a lot of training to tell the different between a blip and a chirp, but humans are better at that kind of task. Fortunately, blip glitches are short, and don't happen all that often - so the chances of getting them in both detectors at once are pretty low. It's not impossible though.

I hope that's answered your question,

Continuous waves data analysis, Research student at University of Glasgow

One thing that was said while at college is that gravity is one of the least understood forces that act upon us, and that there is a enormous gap of knowledge compared to, let's say, magnetism and electricity. We feel it and predict what could happen, but what it actually is is unknown. It's much like biology where we can see what happens and kinda predict and manipulate some reactions, but we mostly have no idea on what's going on.

Does that applies to gravity? How LIGO helps to understand the nature of it? Pushing to science fiction a little, do you think we could even manipulate gravity even without understanding it clearly, much like we do with biological processes?

tigerjerusalem

Hi /u/tigerjerusalem,

Yes, in many ways gravity is the least understood of the forces we know about in nature. For example, Newton's constant G determines the overall strength of gravity, and it has not been measured very accurately compared to the constants associated with the other forces. This is because gravity is so much weaker than the other forces, and building an experiment to accurately measure the strength of gravity is very challenging.

We do have a great theory for how classical gravity works: Einstein's theory of General Relativity. But because gravity is so much weaker than, say, the electromagnetic force, it's also hard for us to verify all of the predictions from this theory. We send and receive electromagnetic waves like light and radio all the time, but it takes the incredible efforts of the LIGO and Virgo collaborations to detect gravitational waves from the most intense sources in the whole universe. So while we have a theory of gravity, our efforts to test it are way behind compared to other forces.

The situation is even worse if we are talking about understanding gravity at the smallest scales. For this we need a theory of quantum gravity. There is no agreed upon theory of quantum gravity, while we've understood the quantum theory of the other forces for decades.

Now, as for harnessing gravity, this is tough, and again it's because gravity is so weak. It takes a lot of mass to make much gravity. Also, the only way to do really cool things with gravity (like antigravity or faster than light travel) requires "exotic" forms of matter. These may be impossible to realize in the lab in quantities that allow us to do anything.

how fast do gravitational waves travel?

MarkC0410

Indeed, as others have mentioned, gravitational waves travel at the speed of light!

But it's less that "gravitational waves travel at the same speed as light" and it's more that "there is a maximum speed for any interaction in nature." Gravitational waves, light (or other theoretical massless particles) all travel at this maximum speed. This "speed limit" crops up all over physics! (And it is intimately related to the concept of "spacetime" in our modern theory of gravity: General Relativity.)

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Is LIGO currently sensitive enough to detect a binary neutron star inspiral? What about just the rotation of a single neutron star? How significant of a discovery would detection of either phenomenon be?

shiruken

LIGO is certainly sensitive enough to detect a binary neutron star inspiral, IF the inspiral happens close enough to us!

There are two major things that contribute to LIGO's sensitivity to a given type of event: how massive the objects are, and how far away from us the event occurs. More massive objects (like the 20 and 30 solar mass black holes that merged during GW170104) can be detected when they are much further away (up to a few billion light years). Since neutron stars are less massive, they need to be closer to us in order for LIGO to be able to detect them. Currently, LIGO should be sensitive to binary neutron star mergers out to a few hundred million light years. The fact that we haven't seen any (yet!) doesn't mean that LIGO isn't sensitive to them, it just means there haven't been any "nearby" mergers during the (relatively brief) time that LIGO has been observing.

For singular spinning neutron stars the story is a bit different. We expect the gravitational waves from single neutron stars to be much weaker than those from binary mergers. As a result, we only have a real shot at detecting these sources if they're here in our own galaxy. But the way we search for single neutron stars is also different. For binary mergers, we're looking for short (loud) "chirps" of gravitational waves. Single neutron stars will emit with an almost constant "hum." Where as the "chirp" is over and done with, the "hum" is always there, so the longer we listen for it the better chance we have of detecting it.

In either case, we have a great deal to learn from detecting gravitational waves from neutron stars. Any observation of a neutron star merger or a single neutron star will help us answer questions about the details of their structure and composition (still relatively open questions). Binary mergers of neutron stars are thought to be the cause of certain gamma-ray bursts (which are ultra-relativistic and highly energetic explosions). Detecting one with LIGO at the same time as an electromagnetic telescope or satellite will answer a lot of essential questions about how these events occur and what causes them! This so-called "multimessenger astronomy" is the next big frontier in observing our universe, and events involving neutron stars are our best shot at getting there!

No matter how you slice it, a LIGO detection involving a neutron star would be an enormous discovery!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

How can you determine the distance from just the waves? Is it the intensity? And how accurate are these readings?

TransToucanSam

Hi, /u/TransToucanSam, and thanks for the question.

In order to know this answer, you need a little background on the search algorithms and source parameters.

The kind of search we use to find these binary-black hole signals (and any binary merger) is called a matched template search. We pick 2 black hole masses, some starting conditions (like spin parameters, which way the merger is facing etc) at simulate the binary merger, and what signal we would see at Earth. Then, we take that simulated signal (the template) and compare it to the data we have. We move that template along in time for the whole observation, at each time, measuring the match, how much the template matches the data we see. If there's a match, woohoo! We move that template, and the candidate signal forward for consideration, and continue the search, with another set of parameters.

Here's the thing though: for each unique pair of black hole masses that you pick, you will get a unique signal template out of it. No 2 mass pairs have the same template. So the best matching template gives you the source mass, and that's a unique thing. If the event was close by, it would be loud, and if it was far away it would be quieter, so by scaling the amplitude up and down to best fit the observed signal, we can get some idea of the distance.

Unfortunately, that’s not the full story. This amplitude is also affected by which way the merger was facing. You can think about it as 2 BHs spiralling around on a disk, and it really matters whether we saw it edge on, or face on. So unfortunately, it is tricky to pin down well how far away these events came from, and that’s why the errors on these values are so large.

However, if we can constrain the event to a signle host galaxy, we can do way better, and get loads of cool science out of it. But for a binary black hole, that's a pretty far out ask to be honest.

I hope that answers that question!

BP, continuous gravitational wave data analysis, research student, University of Glasgow

About this discovery, how can you tell where the waves came from?

Also, how this will affect the current understanding of black holes and their stability?

Finally, why is Daniel Williams's name in caps? Is he a yeller?

cebrito

Hi /u/cebrito,

About this discovery, how can you tell where the waves came from?

It basically works a bit like your ears determining where a sound comes from. Imagine you heard a weak sound, you know there is a sound, but you don't exactly know where the sound is coming from. But imagine a few of you heard the same sound at the same time, then all of you combine the information together, you would then have a better idea of where the sound is actually from.

In the case where we try to tell where the source of a gravitational wave signal is, we gather the information about the arrival time of the signal at various detectors together, and then we can localise the source to a certain area. This is done by comparing the arrival time of the signals at the detectors as we know that gravitational waves travel at the speed of light. The size of the error on the sky position of the source depends on how sensitive the detectors are and in which region on the sky the source is.

At the moment, we only have two detectors we are using for observations just now (the third one, Virgo, is still undergoing sensitivity improvements and will come online in the coming months) which means that the error on our estimated sky position for the source of the waves is still very large.

The plus side of this is that as we add more detectors we shrink this error and so will know more accurately where the signals come from once additional detectors (a currently-being-developed detector in Japan, KAGRA, and a planned detector in India, LIGOIndia) are switched on.

Also, how this will affect the current understanding of black holes and their stability?

The only information the gravitational wave signal gives us about black holes is there masses and their spins. This discovery gives only limited information about the spins of the merging black holes but this merger has similar masses to our first discovery, GW150914. We cannot really use GW discoveries to estimate how long-lived the black hole is. The one limit we can set on age is we can use the amplitude of the signal to estimate how far away the black hole is, and this will limit how long ago the merger happened.

Since this merger is similar in mass to GW150914 we can use these two discoveries and any future ones we make of a similar mass to narrow down how these binaries were formed. There are several competing astronomy theories of how this happens but we don't currently have enough information to rule all but one out.

Finally, why is Daniel Williams's name in caps? Is he a yeller? He is a yeller, but only when trying to make important points about python/astronomy.

[PhD student, experimental interferometry]

EDIT: Reviewed with colleague

Thanks for doing this AMA! I have a question about the animation of the black hole coalescence and gravitational wave generation: Are the gravitational waves only emitted in a single plane or are they emitted in all directions?

shiruken

Hi /u/shiruken,

The gravitational waves are emitted in all directions when black holes coalesce. For the purposes of visualization, we usually have to represent only the waves in a single plane (for example, the strength of the waves in the plane is usually represented by the height of the ripples visualized). Just for fun, I'll also say that though the waves are emitted in all directions, they are not emitted equally in all directions. The waves emitted perpendicular to the plane the holes orbit in are stronger than the waves emitted along the plane.

Greetings from mother Russia!

1) Why only black holes? Where are grav waves from collision of neutron stars?

2) What do you think about eLISA? Will it work someday?

tolik89

Greetings! Glad you could join us. One of the things I love about science is how easily it bridges time zones and international boundaries. (Though it can make teleconferences hard to schedule, sometimes! Same with AMAs, I suspect.) Let me take a crack at your questions:

(1) Part of the reason we've seen black hole mergers but no neutron star mergers is just how unexpectedly massive these black holes were. Until our first detection (GW150914) all of the "stellar mass" black holes (meaning the ones that are comparable to the mass of a typical star) were between roughly 5 and 15 times more massive than our sun. The black holes we have detected with LIGO have been as massive as 35 solar masses prior to merging, and over 60 solar masses after! These are by far the most massive stellar black holes with known mass ever observed! As a result, we can detect them at much farther distances, and it turns out these events are much more common than many of us expected. As far as neutron stars are concerned, we're still roughly on track with our expectations going into observation with LIGO. Had we been lucky, we might've detected one by now, but while our sensitivity is good, it's still at the lower end of what you'd expect to detect neutron star mergers. If we get through our current observing run and the next one, and we still haven't seen any neutron stars, then it might be time to start adjusting our expectations. (But I'm still hopeful that we're on pace.)

(2) I love eLISA! And I'm very confident that it'll work once it gets airborne (spaceborne, I guess). They had a successful start to their pathfinding mission somewhat recently, and things are looking good for the future. The great thing about LISA is that it'll sample a different (but related) portion of the gravitational wave "spectrum" (meaning it will be sensitive to different phenomena than ground-based interferometers). As a result, we'll get to observe gravitational waves from all sorts of astronomical events that we wouldn't be able to detect with LIGO. It's just like how we have telescopes for different portions of the electromagnetic spectrum. To use an analogy, LIGO will be like the high-frequency X- and gamma-ray telescopes, LISA will be like the optical telescopes, and pulsar timing arrays (another exciting frontier of gravitational wave astronomy) will be like low-frequency radio telescopes. (Though the definition of "high" and "low" frequency are very different between electromagnetic and gravitational waves.)

Thanks for your questions!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

I visited your location in Livingston Parish, Louisiana many years ago. From what I understand, particularly "quiet" areas were chosen as LIGO sites due to the nature of measuring these gravitational waves. Does the recent suburban and economic growth of the area affect LIGO's accuracy at this particular site? If so how will you proceed in choosing future locations?

The_Whitest_Walker

The LIGO Livingston site was orginally choosen in part due to the isolation and the availability of land.

It is also true that the population of Baton Rogue and surrounding areas has grown greatly over the last few years.

One concern would be if traffic through Livingston and on the interstate I-12 increased noticably.

For now I don't belive it is a major concern. Current location problems that we are sensitive to are freight trains passing though Livingston and logging in the area.

[LLO Science Fellow]

Hello and thank you so much for being here to speak with us!

What is the greatest distance the LIGO can detect gravitational waves at? Are you expecting to find even further out black holes or other anomalies?

Can you explain, for us non-physicists, how the detectors work? These discoveries are absolutely fascinating.

Thank you again, your time is appreciated.

FillsYourNiche

Glad to be here!

The distance that LIGO can detect sources depends on the source itself: if the objects involved are more massive, we can detect them farther away. For some approximate numbers, at our current sensitivity we can detect binary black hole mergers like GW170104 and GW150914 out to a few billion light years. We are currently sensitive to less massive events, like binary neutron star mergers, out to a few hundred million light years. But we plan to gradually improve our sensitivity over the next few years, and hope to see a factor of 2-3 improvement in these numbers by the time we reach "design sensitivity."

As for how the detectors work, the gist is as follows:

In simple terms, the practical effect of gravitational waves moving through an object (in this case, our detector) is to cause it to alternate between being "stretched" and "squished" by a small amount. If you imagine putting two rulers together in the shape of an "L" and pass a gravitational wave through them, one ruler will shrink a little while the other will stretch, then vice versa, and so on. If you could measure the difference in lengths of those rulers, you'd be measuring the strength of the gravitational wave that caused the change!

In practice that's exactly what we do: each LIGO detector (and indeed, other gravitational wave detectors like GEO, Virgo, KAGRA, etc) is functionally a pair of rulers set in an "L"-shape. Except instead of rulers, we use lasers. Those lasers travel down each arm of the "L", bounce off of massive mirrors that can be affected by gravitational waves, then recombine. If there are no gravitational waves, then the recombined laser light perfectly cancels out and we see nothing in our detector. But when a gravitational wave passes by, one arm stretches and the other arm shrinks, which causes the laser to recombine slightly differently. Instead of seeing nothing, we see a little bit of light! The light oscillates back and forth between "some light" and "no light" and by doing very careful data analysis we can connect those changes in light to the gravitational wave that passed through.

It requires a lot of work, because a lot of other things can affect the output of our detector too. Earthquakes, electrical interference, even trucks driving down the road! Only after we meticulously filter out all of that additional "noise" do we ever claim that a signal is from a gravitational wave. It's an impressive feat, because gravitational waves are exceptionally weak. The effective change in length of one of the "arms" in our detector (each of which is 4 kilometers long) is substantially smaller than the width of an atomic nucleus! (That's somewhat of a simplification, but it gives you an idea of how sensitive LIGO is!)

So in a way, we've build the world's most accurate rulers to detect some of the universes weakest signals!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Hello from an aspiring Physicist!

One of the big excitements of the gravitational wave detection as I understand it, is the possibility of seeing the universe through a different lens. How can we use gravitational waves to see the universe in this different way, as opposed to electromagnetism and what is the future for astronomy and gravitational waves?

Thank you so much for this AMA!

Saintscratch

Hello! Always happy to see a fellow physicist on these threads!

The way I like to think about it is by way of an analogy our own senses. We can see, smell, touch, and so on. Any individual sense can tell us something about an object we're perceiving, but we don't get the whole picture. If I look at an apple, I can tell what color it is, but I can't readily tell how it tastes. If I hear a car speeding down the road, I might have a sense of how fast it's going and what kind of engine it has, but I probably won't know what make and model it is unless I look at it. (Though some car enthusiasts might beg to differ.)

In that way, electromagnetic astronomy (that is, astronomy using light) is like using our eyes (literally, in some cases). We use it to see what's happening in the universe. But there are a lot of things that we can't see. What's happening inside of a star, for example? We can infer what's going on by looking at what's happening on the surface (in fact, that's part of how we know as much as we do about the interior of our sun), but we can't see it directly. Each new way of observing our universe that we develop is like adding another observational "sense".

Imagine, for example, that you're watching "The Empire Strikes Back" for the first time, but you're doing it with the sound turned off. (For those out there who haven't seen it, I encourage you to do this experiment yourself!) Our heroes have made their way to a city in the clouds, and our young protagonist is having a show down with the villainous man in black. (You might know that his name is "Darth Vader" -- but only if you're good at lip reading!) With the battle over, the man in black has backed our hero into a corner, and they are now having a conversation. Suddenly, our hero gets a look of shock and horror on his face. Clearly, the man in black just told him something important! But what was it? We don't know! The man in black is wearing a mask, and we can't see his face to read his lips!

For those of you who have seen the film, think of how much information we're missing out on by not being able to hear the dialogue in that scene.

So gravitational waves, in this analogy, are very much like our ears. We use them to "listen" to the universe, giving us access to information that our "eyes" cannot see on their own. For example, gravitational waves pass through even very massive objects almost effortlessly, so they can travel from the interior of objects (or events) almost unperturbed. Plus, they're not necessarily coupled to the emission of light. On their own, this immediately helps us by giving us access to events that we can "hear" but cannot "see." (The merging of two black holes, for example, doesn't produce enough light for us to see it! Same with so-called "dark matter".) But the real gains will come when we can use our "eyes" and "ears" together to get a bigger picture of cosmic events than we'd get from only using one of them.

This "multi-messenger astronomy" is the real future of astronomical observation. Using light, gravitational waves, neutrinos and more to develop a more and more complete understanding of the events we're observing. Gravitational waves are the next big step in that pursuit, and are set to revolutionize what we know about some of the universe's most exotic and exciting phenomena!

After all, it's thanks to them that we know that Darth Vader told Luke all about midichlorians, right?

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Hey guys!

Thanks for the AMA!

Main Question: Gravitational Waves, General Relativity, Teleportation and Time Travel. (How) do these ideas inter-connect, and could there ever be any real-world applications between them?

Extra Question: As both of the LIGO's detectors are on the same tectonic plate, how do you rule out vibrations from with the Earth itself?

HerbziKal

Hi /u/HerbziKal,

Main Question: Gravitational Waves, General Relativity, Teleportation and Time Travel. (How) do these ideas inter-connect, and could there ever be any real-world applications between them?

Well the first two are pretty strongly connected. The theory for gravitational waves comes out of the theory of general relativity. You can start with Einstein's equations for GR and end up with a wave equation that describes a time varying perturbation (ripple) on top of the curvature of space-time that we get for an object that has mass, in general relativity. The real world application between these two is that gravitational wave observations can tell us if gravity follows general relativity in systems with different masses and with higher gravitational fields than most things we can see on earth or with conventional telescopes.

Teleportation is sadly not possible in current theoretical physics, unless you can think of something like entanglement. This is when two identical particles are from the same source and what we do to one of them affects the other particle without us directly interacting with it. Although its not the proper teleportation we see in eg. Star Trek. It is not really connected to gravitational waves in any way and I can't really see how it could be...unfortunately.

Time travel is sort of connected to gravitational wave astronomy, in that the signals we have seen are from mergers that have happened billions of years ago and the signal has taken those years to reach us at earth. This is the same for all telescopes: when you see something out in the universe, you are looking back in time as both light and gravitational signals travel at a finite speed (around 30 000 000 metres per second).

I also can't see any real world applications between the time travel, teleportation and gravitational waves. Although the great thing about science is that every so often we do an experiment or discover some new equation that completely turns on its head some of our trusted theories and uncovers things we previusly thought were impossible.

Extra Question: As both of the LIGO's detectors are on the same tectonic plate, how do you rule out vibrations from with the Earth itself?

LIGO uses data from other monitoring systems: eg weather stations, earthquake monitors, lightning strike monitors to cross-check its data. But there are also active seismic isolation systems that both detectors sit on and these rely on knowledge of the frequency and size of seismic waves to counteract their effect on the detector using complex electronic and mechanical control systems.

[PhD student, experimental interferometry]

What are the long term goals for the LIGO project? Will an expansion of this kind of technology eventually enable us to map out the space around us via some sort of gravity spectrum instead of the electromagnetic spectrum?

LurkBot9000

Hi /u/LurkBot9000,

The long term goal of the LIGO project is to keep observing gravitational waves, while improving existing detectors and building new ones. The current LIGO detectors are not yet as sensitive as they've been designed to be. Instead, the strategy is to improve and upgrade the detectors, then let them run for a while to try to see things, and repeat that cycle every year or two until we hit the design goal. On top of this, the Virgo gravitational wave detector is turning on in Europe, the KAGRA detector is being built in Japan, and there are plans for a LIGO detector in India.

As we continue to improve the detectors and increase their number, we will see events like merging black holes more frequently and pinpoint them in space more precisely. As you say, this will allow us to explore the universe in gravitational waves, but only in a narrow range of frequencies. To get the full gravitational spectrum, we need to go even further and build gravitational wave detectors in space (look up the LISA mission for instance) or by exploit natural clocks that exist in our galaxy and can be used to detect waves (take a look at pulsar timing arrays). Over time, scientists can map out gravitational waves over many frequencies, just like seeing the universe in radio, infrared, and optical light.

Hi and thanks for doing this AMA.

I was wondering if there were other sorts of phenomena could be observed with these detectors. Merging black holes obviously create a huge gravitational distortion, but what else could we potentially discover as the technology improves?

ScurvyRobot

Hi /u/ScurvyRobot,

There are a number of phenomena that LIGO and VIRGO, the sister detector are currently searching for that aren't just a pair of black holes smashing together.

But first, you have to understand that gravitational waves are emitted by any mass that experiences an acceleration. This is easy to see for a pair of plack holes, they're falls inwards each other (accelerating inwards) AND being whipped around in an orbit (circular acceleration). But the waves that are emitted are pretty weak. So to have a chance of being detected we'd like it to be heavy (like black holes) or close!

The obvious next source to look for is similar - a pair of neutron stars falling in and inspiralling into each other, or a black hole and a neutron star falling together. Neutron stars are about 2 solar masses, so lighter than the black holes we've seen before, but we expect them to be pretty common in our galaxy - which is close! In fact, one of the measurements that the LIGO machines use on site is how far away LIGO could see a pair of neutron stars falling into each other. It's been pretty consistently above 50MPc (more than 150 million light years away!) - much larger than our galaxy.

This is really exciting because neutron stars are these exotic stars, and we don't really know what makes them tick. They are remnants of dead stars, the cores of supernovae, and are made up of the same stuff as the core of an atom. We don't know how that matter works in bulk, but we think it's pretty dense. Neutron stars are usually observed as pulsars - which is just basically looking at the star's northern and southern lights, so it's tricky to get information about their innards. But a direct observation of 2 such stars crashing could be pretty illuminating.

Another source we're on the look out for are supernovae - when a star is old and dies, often it starts burning through its less efficient fuel, but this is unsustainable. The pressure from the internals can't match the gravity of the star's mass, and it falls in on itself, imploding and exploding. The core is compressed into a remnant - often a neutron star, sometimes a black hole, and the rest is thrown off of the star. If the material thrown off wasn't spherically symmetrical, it delivers a big kick and a juicy gravitational wave. This is nice because we can see stars - we're surrounded by them. If a star in our galaxy goes supernova, we can see is with our eyes, and it's close enough that we can see it with our detectors too. This could put some really nice constraints on supernova models, about the last seconds of a star's life, and on the formation of the remnants.

One more source is again about these neutron stars. We see that pulsars are rotating (it's the pulse part of pulsar). If the centre of mass was slightly off of the rotational axis, this could deliver gravitational waves. But instead of being loud and short like the other examples, these might last for a very long time - thousands of years. We can use a trick from regular astronomy here and listen for a pulsar's periodic signal for longer and longer to try and build up signal.

I like to use the analogy of a bucket in the rain. In torrential downpour (loud signal) you can fill your bucket to1 litre (get a detection) quickly. If you have only a little drizzle (weak signals) we would want to leave our bucket out in the rain longer (observe a source for a long time) to fill it up (detect a quiet source).

Again, with this kind of source under our belt, we could learn a lot about neutron stars - we can only see the pulsars that are pointing at us, so having a method that doesn't rely on light is super handy!

And finally, the old faithful answer for scientists: we don't know. We are open to all kind of out there things like cosmic strings, and different theories of gravity other than GR, exotic dense objects, and unmodelled things that pass through - that's some really exciting stuff!

I hope that's answered your question!

Does the detection of gravitational waves by LIGO make it easier for the BICEP2 crew to detect gravitational waves from inflation? As I understand it, the wave types from both phenomenon are different for a variety of reasons. However, does LIGOs detection help in this search?

ZombieHitchens2012

Hi /u/ZombieHitchens2012,

Great question, and you are exactly right: experiments like BICEP/Keck, ACT, SPT and more look for the imprints of gravitational waves on the Cosmic Microwave Background, which is light from the earliest moments of the Universe than can reach us. "Inflation," which is the idea that the Universe expanded explosively in its first moments, would produce the gravitational waves these telescopes look for. Those waves are very different than the ones LIGO can detect. For one thing, they have gigantically large wavelengths, and cannot be detected by LIGO.

So there's no immediate connection between these different kinds of gravitational waves, and LIGO's successes don't help those other efforts directly. I think to see any impact, we have to take a step back. The direct detection of gravitational waves raises excitement about gravitational waves and about astronomy overall. I hope that this excitement translates into funding decisions, which do have a strong impact on whether big experiments like BICEP/Keck can succeed or even be attempted.

If I recall correctly from the first detection announcement, the displacement caused by the passing gravitational wave is miniscule. What kind of resolutions do LIGO and VIRGO have? What are the limitations on increasing that resolution to detect smaller events?

shiruken

You're absolutely right, /u/shiruken! In fact, minuscule is probably an understatement. The fractional change in length of our detector for the GW170104 event was 5E-22! Which means our 4-kilometer arms were displaced by roughly 2 attometers, over a thousand times smaller than the size of an atomic nucleus! My favorite analogy is that measuring these gravitational waves is like measuring the distance to the nearest star (other than our sun) to the precision of a width of a human hair. It's almost unfathomable!

These sensitivity limits are set by a number of factors inherent to the detectors and where they're built. Being built on the ground, they're sensitive to seismic noise (earthquakes as well as regular vibrations in the ground, even those e.g. caused by trucks driving past the observatories). We use high-powered lasers, which have their own sources of noise related to the behavior of light due to quantum mechanics. Heat builds up on the mirrors we use to reflect the light, which causes small variations in our detector. And there are dozens of other things as well! By gradually improving each of these subsystems (better seismic isolation, optimizing laser throughput, improving optical coatings on our mirrors, etc) we can push our sensitivity to better and better limits. This allows us to detect events like GW170104 and GW150914 out to further and further distances. But it should also allow us to detect events involving smaller and smaller objects (like neutron stars).

There are some tough limits to work around. For example, there is a trade off between two different sources of quantum noise from our lasers. The general understanding is that when you improve one noise source, you make the other worse. However you can do some really creative tricks (in this case, a process called "optical squeezing") that let you work around these limitations to improve sensitivity. We have dozens (nay, hundreds) of extremely talented scientists working very hard to constantly implement improvements like this into our detectors, while others are hard at work designing new ones!

Ultimately though, when you're talking about the types of events that LIGO (and by extension Virgo, KAGRA, etc) will be sensitive to there is also a fundamental limit set by the dynamics of the event itself. All detectors are only sensitive to a certain range of frequencies (for LIGO that range is very roughly 10 Hertz to 2000 Hertz, Virgo is similar). That means we are only sensitive to events that emit gravitational waves at those frequencies, which is directly related to how fast objects are orbiting/rotating. For LIGO and Virgo, this means we can only detect the mergers of "stellar mass" compact objects (meaning "small" objects like neutron stars, and black holes with masses up to several tens of times the mass of our sun). Larger objects will orbit (or rotate) too slowly, and the gravitational waves they emit will be outside of the frequency range of our detectors. Thus to detect objects like white dwarf binaries, or supermassive black holes, you will need different detectors (like the space based LISA, or pulsar timing arrays).

Though there are a lot of other phenomena that we expect to be able to emit gravitational waves in the LIGO sensitivity band beyond just neutron star or black hole mergers. Single neutron stars in our galaxy, supernovae, gamma-ray bursts and other exotic phenomena could all possibly emit gravitational waves at the right frequencies. Here's hoping they're strong enough for us to detect!

I hope this answered your question!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Congrats on the third detection!

*Do you guys use open source software? *If so what language? *Is there a link with more info?

I have a degree in Physics and currently work in the private sector. Would be an awesome opportunity to be able to contribute!

bobbywjamc

Great question, /u/bobbywjamc! Yes, a large portion of our software is publicly available. As is some of our data! The hub for all of this is the "LIGO Open Science Center" (https://losc.ligo.org). There you can find tutorials, links to our software packages, tools for analyzing gravitational wave data yourself, and links to all sorts of ongoing projects. We encourage anyone interested in gravitational waves and data analysis to take a look and play around. LOSC > Software will get you to a good starting point.

Most of the software is written in Python or various iterations of C, though there is also quite a bit of matlab too, depending on which working group developed the code. There are several example scripts available on the LOSC, as well as links to the major python libraries and entire LSCsoft software repositories.

One of the fun projects folks can do themselves using data available on the LOSC is to use matched filtering algorithms to find the events we've detected yourself in real data! (Including this third one!) Those interested can go to the LOSC > Tutorials section to get started.

Gravity Spy (https://www.zooniverse.org/projects/zooniverse/gravity-spy) is another way people can contribute by looking through real LIGO data and helping to classify noise "glitches" that often crop up in the detectors. This isn't quite the technical endeavor you asked about /u/bobbywjamc, but other folks who want to get involved but might not have the programming background can still help contribute!

Always glad to see interest in the technical side of things!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

How many more do you expect to see in 2017

xumx

It's hard to say with absolute certainty. With three solid detections under our belt in a bit under a year of total observing time we've reasonably narrowed down the rate at which these events occur. But we'll need to detect a few more before we have a precise measure. Our current observing run is wrapping up at the end of this summer. Given what we know so far about binary black hole merger rates, it would be reasonable to expect anywhere between "none" to "a couple" other events between now and the end of the year.

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Thank you everyone for the AMA.

What are some challenges in increasing the sensitivity factor of detectors? What research and efforts are being carried out in this area?

Gskran

Hi /u/Gskran one challenge just now is that to increase sensitivity of the detectors we need to scale up the power of the primary laser.

This is to reduce something called 'quantum shot noise' which is basically unwanted signal caused by the fact that at some moments there are more photons (particles whch light is made up of) in the detector than at others.

The problem with this 'scaling up', is that light exerts a force on objects. The more light power we have in the detector, the more it pushes on our detectors mirrors. If this happens too much, the electronic and mechanical systems controlling the detector can no longer hold it in its operating range and so will no longer be sensitive to graviational waves until these control systems are improved or the laser power is turned down. This effect is called parametric instability (in case you want to do soem further reading about it).

More long term research is being carried out for a major upgrade to Advanced LIGO. This involves running the main detector mirrors at cryogenic temperatures. Basically another type of noise we encounter when trying to measure gravitational waves is one called 'thermal noise' and is caused by molecules in the detector materials jiggling around because they have heat energy.

There is an effort to change the material the detector mirrors are made of to silicon, which will give us lower thermal noise than the currently used silica (glass, very similar to window glass but more pure). This only gives us better performance if it is run at very low temperatures (20 degrees above absolute zero I think). There are investigations ongoing into the physics of silicon mirrors, what materials we need to make the mirror surface reflective, and also the different laser frequency we need to use with these new materials (because silicon is not transparent to the laser frequency we currently use).

[PhD student, experimental interferometry]

Hello,

That's really nice to see you here!

Let's start:

- How much data u collect per second? If it's not constant tell me min / max / avg.
- How much time do you need to process data you collected?
- What kind of technology (stream analytics etc.) you use?
- Is it better to fight a hundredth horses of the size of a duck or one duck size of a horse?

vuvkid

Hey, thanks for your questions! I'll try to touch on each of them:

1) LIGO's base sampling rate is 16,384 Hz. Though in practice this is often re-sampled depending on the needs of a given search.

2) The time it takes to process the data depends on the type of search we're running. We have several "low latency" data analysis tools that process the data almost in real time. They're constantly running, looking for loud events in the data. Other tools work on the timescales of hours. But the "final" analyses presented in published papers are done over many different timescales, with cross-checks and refinement being done over weeks and months after the initial event.

3) To be glib, we probably have more analysis tools than we do data analysis! (Hyperbole, yes, but sometimes it feels that way.) The primary tools for these types of events (i.e. binary mergers) are "matched filtering" algorithms that look for specific families of signals in our data. But we have several other tools as well: "excess power" algorithms that just look for signals that are "louder" than you'd expect from the noise, Bayesian estimation tools to reconstruct signals and do parameter estimation,

and dozens of specialized software packages each optimized for different needs.

4) I'm pretty sure the correct answer here is a hundred duck-sized horses: ducks can be nasty and I'm terrified by the prospect of fighting one the size of a horse. With that said, a horse-sized duck is pretty massive! Maybe if we fought close enough to the detectors, LIGO could see some gravitational waves from it!

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Hey guys, do you have any advice for somebody who wants to get into the Interferometry field? This stuff is fascinating to me and I'd love to be a part of it

MuxedoXenosaga

It depends at what level you are looking to get involved, and what experience you have.

There is certainly a lot of active research in the area of laser interferomety, focussed on making the detectors more sensitive.

Working on interferemetry for gravitational wave detection involves understanding of the lasers that produce the input light for the interometers, the suspended mirrors that form the interferometer, and electornic feedback control systems that control the detector. So ideally if you have a physics education (or are currently working on one) and have any experience or knowledge of lasers and optics that would a good staring point. It is a fascinating research area to work in.

Many reseach groups within the LIGO collaboration have experimental interferometry research groups that may be offering summer student placements and graduate research oppertunities.

[Graduate Student working on Interferometry for future Gravitational Wave Detectors]

What do you envision being the greatest impact on the daily life of an average non-scientific person like myself due to this discovery? I find these types of news articles fascinating, but I don't know enough to figure out how the discoveries could be practically applied.

jgstate1

Hi /u/jgstate1 I think if you just consider the discoveries we make with LIGO it is hard to see the benefit of the discovery of, say, a binary black hole merger, it is something that on first glance won't seem to affect the life of the average person.

However, if you consider the technology that has been developed to make these detectors sensitive enough to see things like mergers, there will be an affect on more 'practical' technologies that can be used in industry.

For instance in order to isolate the mirrors used in the detectors from vibrations in the ground caused by earthquakes, people walking, wind, trains nearby,etc. many new isolation systems have been developed. Some of these sense how the ground is moving and can be adapted and used to find objects below the earth's surface or ocean beds. This could be of use in oil and gas industries, ie. might help us look for hard to find oil wells.

The materials of the mirrors themselves have also been closely investigated, as have the laser technology we use, and these could be applied in the photonics industry and in manufacturing.

For most large science collaborations like our own, there are also many more sociological benefits, ie. working with a large number of scientists from completely different countries improves cooperation across political borders.

One final point is that with new discoveries in astronomy, we find out more about how the universe itself works. I think this benefits society as whole as I think it increases our engagement with the world around us. So this would maybe be what I consider the most important point.

[PhD student, experimental interferometry]

I heard you guys find a signal about once every month or month and a half. Why are you only at 3 events now?

PastelFlamingo150

The problem is that our detectors are not turned on and tuned to be sensitive at all times. In a given "science run", where we try our best to maximise the time the detectors are sensitive, the detectors might only reach peak sensitivity around 60% of that time. When it gets windy, or bad weather strikes, or bad traffic passes nearby, or a strong earthquake happens somewhere on Earth, then the detectors can fall out of their highly sensitive state. At that point, it might take minutes to hours for them to become sensitive again.

When one of the detectors falls out of this sensitive state, or undergoes planned maintenance, we cannot sense gravitational waves (or, more correctly, we cannot tell if a signal in the other detector - which might still be online - is truly a gravitational wave or just a nearby truck passing or bird flying overhead with the same signal properties!). The amount of time in which both observatories are highly sensitive is only a fraction of the total time we spend in a science run. That means that, even though we've been running the detectors for longer than 3 months, we've not seen more than 3 detections.

-SL, postdoc in gravitational wave interferometry, Institute for Gravitational Research, University of Glasgow, UK

How far can this technology go if there was no limit in funding? Could perhaps arrays of thousands of detectors create a 2d image of gravitational radiation in the same way as we have images of electromagnetic radiation?

AsterJ

Now there's a juicy question. If we also assume there are enough trained scientists to build, commission and operate an infinite number of detectors* then indeed having many, many more detectors around the world would help a lot with determining the point in the sky from where a gravitational wave came. That would let us point conventional telescopes at that part of the sky to see if any light was emitted alongside the gravitational wave, which would let us learn even more.

However, there are diminishing returns to adding more detectors with the same sensitivity as the existing ones. It's much better to build a few, huge, extremely sensitive detectors around the planet. Indeed, the long term goal of our field is to build "ultimate" facilities in Europe and the US which would be capable of not only seeing gravitational waves at cosmological distances (i.e. sources at high redshifts), but also potentially the gravitational wave background - the gravitational wave "noise" produced by smaller sources that can't be individually resolved. It would be absolutely mind-boggling to me if we were able to build detectors capable of measuring gravitational waves so precisely, that we were limited by the noise from too many sources!

I should add that there is some interesting work from theorists in our field that suggests there is an ultimate limit to the sensitivity we are able to achieve. We are already limited by the quantum nature of light in the existing detectors (arising from Heisenberg's Uncertainty Principle, i.e. that one cannot measure two different observables, such as the position and momentum of a mirror, simultaneously), so efforts are under way to develop new techniques to reduce quantum noise. However, some theory suggests that there might be an ultimate, universal limit to these techniques, that no amount of money could overcome. But we're a long way from that sensitivity - there's still plenty of money to be spent improving the existing detectors!

*There are barely enough to run the ones we have!

-SL, postdoc in gravitational wave interferometry, Institute for Gravitational Research, University of Glasgow, UK

Thanks for the AMA!

I saw an interview which unfortunately I can't remember the link of, were they talked about how it has been surprising the lack of detection of neutron star mergers by LIGO. Two questions:

1- Is this lack of neutron star mergers really a concern? What's the word on science street about it?

2- Speaking of sensitivity, the interview mentioned that signals from neutron star mergers should be plentiful with a detector 2 or 4 times as sensible as LIGO. But given how LIGO is already ridiculously sensible, what engineering steps could be possibly taken for the next generation of detectors? Built them in space? Even better noise-reduction algorithms? Moar struts? (KSP joke for those in the known) Something super sci-fi?

Thanks!

Oscuraga

Hey /u/Oscuraga, thanks for the questions! As a neutron star enthusiast myself, I'm certainly keen to find out where all these neutron star mergers are hiding!

(1) I wouldn't say the lack of neutron star mergers is a "concern" yet. Prior to turning LIGO back on in 2015 the estimates for just how often we'd see binary neutron star mergers varied greatly. There were estimates anywhere from "once every few years" at peak sensitivity all the way up to "hundreds per year." Most people expected reality to fall somewhere in the middle, and a lack of detection up until now at our current sensitivity is consistent with that. Even if that's a little surprising, it's nothing to be concerned about quite yet! But if we get to the end of our third observing run (we are currently in our second) and we have still not seen any neutron-star mergers, that's when we our expectations will start to be in tension with our observations.

(2) Right now we're sensitive to binary neutron star mergers out to a few hundred million light years. There is a detailed plan to improve that by a factor of 2-3 on our way to "design sensitivity" over the course of the next few years. In between observing runs (and during regular maintenance) our exceptionally talented instrumentalists work hard on integrating new technologies into the detectors, eliminating sources of spurious noise, and a host of other things to improve sensitivity. Beyond the current generation of ground based detectors (which includes LIGO, Virgo, GEO, KAGRA as well as other planned detectors such as LIGO-India) there are also plans to build a detector in space. The LISA project was recently successful in their "pathfinding" mission (while we're making video game jokes, no, this one did not go to Andromeda). They are on track for eventually building a detector in space (though it will be different to different types of objects than the ground-based interferometers). There are also projects underway to use very precise measurements of pulsars to measure the effects of gravitational waves using so-called "pulsar timing arrays." So there are a lot of paths to improve our ability to detect gravitational waves!

But of course, all of that is moot, because the solution is always more struts, right?

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

What is the distance a gravitational wave can travel? With an expanding universe, and the sheer amount of objects that could cause these waves it seems like we would be getting them more frequently.

Cor-Kel

Ostensibly gravitational waves can travel indefinitely. The problem is that the further away from the source the gravitational wave gets, the weaker it becomes. To be precise, the part of the gravitational wave that we are sensitive to (its amplitude) is inversely proportional to the distance from the source. This sets a limit on how close a source needs to be in order for its gravitational waves to be strong enough to detect when they get to us, and it helps explains why we don't detect them more frequently.

(Note that the fact that we're sensitive to gravitational wave amplitude is in contrast to how we detect light. We detect light based on its flux, or brightness, not its amplitude. So while our ability to detect gravitational waves falls off as the inverse of distance, our ability to detect light falls off as the inverse of distance squared. Just an interesting little tid-bit related to your question!)

~RC, post-doc, gravitational wave and gamma-ray astronomer at Texas Tech University

Thanks for doing this AMA!

Do you think when the James Webb telescope is launched it will be able to benefit your research? If so do you think you will be able to get any time on it?

duckman42

In principle, yes! James Webb, along with other telescopes such as Hubble, look at the electromagnetic spectrum, i.e. light. Gravitational waves are not light, but we know that some predicted sources of gravitational waves may emit light as well. We have set up a system of automated alerts which quickly assess whether a candidate gravitational wave is significant, and if it is, it sends an email to astronomers running telescopes all around the world. If they can slew their telescopes to the part of the sky we predict the gravitational wave came from, they might be able to catch a glimpse of the light that was emitted alongside the gravitational wave. We call this process "EM follow-up".

James Webb could in theory be used for EM follow-up. However, space-based telescopes are extremely expensive to run - so I am sure James Webb will have a busy schedule to study particular objects in the sky and will not take time to look for EM counterparts to gravitational waves. There's always the chance that James Webb or Hubble happens to be looking at the same part of the sky that a gravitational wave comes from, though, in which case it might see something!

One last remark to make is that the three detections we've made so far have been from black holes. Unfortunately, it seems that black holes don't emit EM radiation when they emit gravitational waves, so EM follow-up has not proven fruitful. However, EM partners will keep looking, and there's always the chance we see a new source (such as neutron star binaries) from which we think there's a better chance of EM emission. That would allow us to test whether gravitational waves really travel at the speed of light!

-SL, postdoc in gravitational wave interferometry, Institute for Gravitational Research, University of Glasgow, UK

You guys are awesome! This whole opperations is unfathumable!

Love you all.

My question: Do gravitational waves exhibit a doppler shift?

tip-top-honky-konk

Hello, /u/tip-top-honky-konk

The answer to your question is - yes! My own research is based about continuous gravitational waves from rotating neutron stars. These, we think, are always emitting, and emit quasi-monochromatically - which means almost at a fixed frequency. However, when we search for them, we have to modulate the frequency of the signal to account for the Doppler shift of:

The observatory rotating with the Earth (1 day period) The Earth going around the sun (1 year period)

For shorter signals, these Doppler shift terms aren't really all that relevant, as the time scales are so short. But they certainly have to be taken account of for longer signals.

I hope that has answered your question!

BP, continuous gravitational waves, Research student, University of Glasgow