

Science AMA: We are the first people to observe neutron stars colliding that the LIGO team detected, we're the Swope Discovery Team, ask us anything about supernovas, astrophysics, and, of course, neutron star collisions, AMA!

SwopeTeam ¹ and r/Science AMAs¹

¹Affiliation not available

April 17, 2023

Abstract

Hi Reddit! EDIT: And that's all for us from the Swope Team! Thank you for the great questions. Sorry we couldn't answer every one of them. And thank you for the reddit gold, even if it wasn't made in a neutron star-neutron star collision. We are Ben Shappee, Maria Drout, Tony Piro, Josh Simon, Ryan Foley, Dave Coulter, and Charlie Kilpatrick, a group of astronomers from the Carnegie Observatories and UC Santa Cruz who were the first people ever to see light from two neutron stars colliding. We call ourselves the Swope Discovery Team because we used a telescope in Chile named after pioneering astronomer Henrietta Swope to find the light from the explosion that happened when the two stars crashed into each other over a hundred million years ago and sent gravitational waves toward Earth. You can read more about our discovery—just announced yesterday—here: <https://carnegiescience.edu/node/2250> Or watch a video of us explaining what gravitational waves and neutron stars even are here: <https://vimeo.com/238283885> We also took the first spectra of light from the event. Like prisms separate sunlight into the colors of the rainbow, spectra separate the light from a star or other object into its component wavelengths. Studying these spectra can help us answer a longstanding astrophysics mystery about the origin of certain heavy elements including gold and platinum. You can watch a video about our spectra here: <https://vimeo.com/238284111> We'll be back at 11 am ET to answer your questions, ask us anything! Dr. Ben Shappee: I just completed a Hubble, Carnegie-Princeton Fellowship at the Carnegie Observatories and am mere weeks into a faculty position at University of Hawaii's Institute for Astronomy. I'm a founding member of the ASAS-SN supernova-hunting project. Dr. Maria Drout: I am currently a NASA Hubble Postdoctoral Fellow at the Carnegie Observatories and I also hold a research associate position at the University of Toronto. I study supernovae and other exotic transients. Dr. Tony Piro: I am a theoretical astrophysicist and the George Ellery Hale Distinguished Scholar in Theoretical Astrophysics at the Carnegie Observatories. I am the P.I. of the Swope Supernova Survey. Dr. Josh Simon: I am a staff scientist at the Carnegie Observatories. I study nearby galaxies, which help me answer questions about dark matter, star formation, and the process of galaxy evolution. Dr. Ryan Foley: I am a a faculty member at UC Santa Cruz. I represented the Swope Team at the LIGO and NSF press conference about the neutron star collision discovery on Monday in Washington, DC. Dr. Charlie Kilpatrick: I am a postdoc at UC Santa Cruz. I specialize in supernovae. Almost Dr. Dave Coulter: I am a second year graduate student at UC Santa Cruz. I am a founding member of the Swope Supernova Survey. EDIT: Here's our team! <https://imgur.com/gallery/8lZyg>

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SWOPETEAM [R/SCIENCE](#)

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How much does space time “wobble” when close (say 1 AU) to a black hole merger? Ignoring other effects, what effect would such wobbling have on structures?

[hvgotcodes](#)

TONY: At about 1 AU from a BH merger, the strain would be about 10^8 (this is the fractional change in length). This means that if you had LIGO about 1 AU from the BH merger (with its 4 kilometer arms), the change in the length of the arms would be about 4 millimeters.

What sort of order of magnitude of energy was released during the collision?

[slartbarg](#)

DAVE: Looking at the kinetic energy budget of the kilonova, we can divide it into two parts: that coming from the blue and that coming from the red. The blue component was less massive (~0.025 times the mass of the Sun), but accelerated to ~ 0.25 the speed of light. The red component was ~0.035 solar masses accelerated to ~ 0.15c. Together that means the energy of the blast was roughly 10^{52} ergs, or about a 10 times more powerful than a supernova. This kinetic energy dwarfs the radiation energy we detected (by ~ 100,000x), which was around 10^{47} ergs.

TONY: During the few tens of seconds of inspiral, 5×10^{52} ergs of energy was released in gravitational wave emission. This is about 50 times the total amount of energy radiated by the Sun during its 10 billion year life.

Hi everyone, thank you for being here and thank you for your work! I am an undergrad studying astronomy and I was curious how a Neutron Star merger is related to similar events like supernovae.

1) Does this event resemble other supernovae in their light curves? Could they be used as "standard candles" in the same way as Type 1a, or do we need more examples to tell?

2) When does the peak optical emission occur relative to the LIGO trigger? Were the optical observations only on the "tail-end" of the kilonova light curve, or did you see it increase before reaching a maximum?

Again, thank you so much for your hard work!

[kashwakbass97](#)

RYAN: Wow, these are really informed questions! Thanks for participating. I spend a lot of my time performing cosmological measurements with Type Ia supernovae, so this would be the intersection of all my research!

[1] The kilonova has roughly the same peak brightness as some supernovae, but it rises and fades *much* faster than any known supernova — even the ones we used to call “fast.” Until we have a bigger sample, we won’t know how standard kilonovae are in light, but we are already using this object as a “standard siren,” where we can determine its distance from the gravitational wave data.

[2] It looks like the bluest light peaked within about a day of the merger. The infrared took another couple of days to reach peak. So we think we got it while it was still rising, but we always would love to have even earlier data!

How much of a delay was there between the gravitational wave "chirp" and the optical signal you

detected? If there was a delay, why does one exist? Shouldn't both phenomenon travel at the speed of light?

What was the process for LIGO/VIRGO informing astronomers of a gravitational wave so telescopes could be retasked?

[shiruken](#)

CHARLIE: Most of the delay came from the fact that LIGO can only localize the gravitational wave signal to a region on the sky of about 30 square degrees. That's about 120 full Moon's worth of area to search. We need much better precision in order to determine the exact galaxy where the optical transient occurred. Between waiting for sunset in Chile and searching every large galaxy we knew about in those 30 square degrees, it took us about 11 hours after the LIGO trigger to find the optical source.

LIGO uses an email alerts system and web forum to distribute information about their gravitational wave alerts. We received an email about this event then immediately went to LIGO's website to download maps of the sky that showed the approximate location of the source. Everything was directly under our control after that point, from planning the sequence of galaxies we would observe to final image processing and analysis. Members of our team created a schedule of galaxies to search, drove the Swope telescope manually, downloaded images, and searched the images by eye. Surprisingly, the level of human intervention was one of the reasons our team was able to discover this object first and maximize its science impact.

What implications does this finding have for understanding the expansion of the universe?

[ExactFunctor](#)

RYAN: We are already using this object as a "standard siren" to measure the expansion rate of the universe (the Hubble constant). Amazingly, this measurement is very similar to the same measurement made through other means (Cepheid variable stars + Type Ia supernovae or the cosmic microwave background + baryon acoustic oscillations). As we build up our statistics with more events, we will really be able to nail this down, and it will be a nice way to independently make this measurement.

Very proud to see someone I have some association with involved in this discovery.

What would you consider to be the biggest impact that the discovery of short gamma Ray bursts are attributed to merging binary stars?

[konzine](#)

TONY: Gamma-ray bursts have been known about since the 1960s when the US sent up satellites to monitor nuclear weapons tests. By the early 1980s, there were probably more theories for the origin of gamma-ray bursts than actual bursts observed. That how excited everyone was about them! Over the following decades, it was realized that they had a cosmological origin, and that there were different classes (long and short). The best bet for the short variety was neutron star mergers, but this was mostly based on their locations (which seemed to be kicked like neutron stars are) and that we basically couldn't think of a better explanation! So to finally have this confirmed is an amazing intellectual achievement, involving thousands of scientists over a period of well over 50 years.

We've been detecting GRBs for 25+ years. How lucky are we that the closest GRB ever happened in an era when both advanced LIGO detectors were online, VIRGO had just started up, and both

INTEGRAL and Fermi were in the right half of the sky!? 1 in 10? 1 in 500?

Also, what would the process have been if the search area wasn't so well constrained and we were searching 100 or 1000 times more sky? Would Swope, or any other telescopes, have found the optical source at all? Or how long would it have taken?

[exohugh](#)

JOSH: I think there was definitely a bit of luck involved in this first detection being so nearby - if I had to bet, I would say that it will be a while before LIGO-Virgo find another neutron star merger closer than 150 million light years. I'd have to think a bit about how to calculate a real probability, though!

The constrained search area from the combined gravitational and gamma-ray signals was essential to us being able to find the optical light so fast and getting to study it so early on. With a larger area, you could still use the same two basic approaches that different teams did this time, either observing individual galaxies that we know are at the right distance, or just imaging the entire region one piece at a time. But that would have taken a lot longer (could easily have been multiple days), and we didn't have much time in this case because the location of the merger was only visible for the first hour and a half of the night.

Hi there doctors! Thanks for doing an AMA.

A colleague of mine recently gave me an article which suggested that "black holes" as we know/observe them might actually be boson stars. While I almost nearly grasp what a boson star actually *is*, how in heavens does one *form*? (Also, supposedly they would appear bright at the core but I'm not sure how that would be observable if the thing has enough gravitational pull to pull in surrounding light?) Hopefully one or more of you will be able to make sense of my question, since I have almost no idea what I'm talking about.

Also, how did each/any of you get interested in astronomy/astrophysics?

Thanks!

[Duke Paul](#)

TONY: Although I've seen talks on boson stars, I honestly can't say I remember a good explanation for why they should exist. How I got into astrophysics (I'm a theorist) was that I studied physics as a undergraduate/graduate student. I was excited by astrophysics because it was an opportunity to use all the different types of physics I was learning (gravity, nuclear reactions, magnetic fields, fluid flows, etc.) on the same problems. Plus, I get to study astrophysical explosions now, and what could be better than that?!

MARIA: I was always interested in science while growing up. For a long time I thought I wanted to be an archaeologist. Sometime in high school I started reading more about astronomy and was fascinated by the big questions. Also, around that time I read a story about an astronomer who was going on an observing run to a big telescope and they stopped to buy some ice cream on the way. The ice cream then exploded when they went up the mountain ... I thought that was so cool! So I decided to study astronomy in college. In retrospect, I had no idea what I was getting into at the time, but I loved it.

Any spectra that possibly hints at any elements formed in the fabled 'island of stability'?

[kraftpulp](#)

JOSH: No, unfortunately as of now we can't say anything about the formation of even heavier

elements than those we already know! There are two things that make identifying individual elements in the spectrum of SSS17a really hard. First, all of the stuff created in the explosion is moving at very high velocities, around 30 percent of the speed of light. Because of the Doppler shift, that means that any emission or absorption lines from that material are very wide, so lots of lines end up getting smeared together in what we see at the telescope. Second, heavy elements like the ones made by neutron star mergers have enormous numbers of possible lines (like millions), and we simply haven't measured the wavelengths of all of those in the laboratory yet.

So, are there clouds of platinum and gold in gaseous form floating around? Or just chunks of metal? Which I guess are asteroids. Never mind.

[identicalBadger](#)

JOSH: The material that we observed early on was very hot—11,000 K about 12 hours after the merger, cooling off to about 2,500 K a few weeks later. But even at that point, the material would still be a gas (really a plasma, since it would be completely ionized). Once it gets to 1,500 K or so, solids can begin to form. Usually that starts with what we call dust grains, which can be large molecules or very small bits of minerals. I don't think anybody has worked out in detail exactly what happens in the aftermath of an event like this, but probably all of the material created spreads out too much (remember, it's moving at 30 percent of the speed of light) to coalesce into big chunks of anything.

Pure gold or platinum asteroids would be a lot cooler, though.

If you had to bet, what would you put chances of the remains of the collision being a neutron star, black hole, etc are?

[sluuuurp](#)

MARIA: Right now, I would say 75 percent black hole. But I would also be happy to be wrong!

The main factors influencing my bet are the radio and X-ray emissions that were observed after a few weeks. They are consistent with the idea that a jet moving a significant fraction of the speed of light was produced in the explosion. And we think you need a black hole for that.

But if that is true, then the black hole formed would be (by far) the lowest-mass black hole that we know about. So it would be incredibly important for understanding the boundary between neutron stars and black holes.

What other never-before-seen astronomical events would you like to tackle next? Would those events have as much importance in our understanding of astronomy as neutron star collisions had on our understanding of the origin of those certain heavy elements?

[Xenoprimatology](#)

RYAN: I would love to witness a Milky Way supernova. The last time one was detected in real time was about 400 years ago. With all of our new instruments, including LIGO, we would learn so much about how stars live and die. I'd even settle for a supernova in Andromeda!

Depending on the kind of supernova and what data we got, we could learn a lot about how elements like iron are produced. In some ways, more-common elements like iron are more important than the heaviest elements. The iron in your blood came from an exploding star!

How are these binary neutron star systems located? Are they pulsars that you constantly monitor or do you constantly look out for such events? Thanks in Advance! Congratulations for the Discovery!

[A-Manual](#)

TONY: This neutron star binary was located in the galaxy NGC 4993, which is about 130 million light years from us. The neutron stars were likely pulsars like you say, but they were too far away to detect the radio pulsations. We see thousands of radio pulsars, but they are within our own galaxy. Some of these pulsars in our galaxy are even in binaries with other neutron stars. We can use their pulsar emission to accurately measure the inspiral due to gravitational wave emission (the discovery of which garnered the Nobel Prize in Physics in 1993). Unfortunately, these will take hundreds of millions of years to coalesce, so we won't see them merge any time soon.

Congratulations on your achievement! I've got many questions, but most are too pedestrian to bother you with.

1/ how common (given the massive number of stars and former stars in the cosmos) do we believe NS-NS mergers are? Is this a phenomenon we can anticipate observing somewhat regularly as our instruments and methods continue to be refined?

2/ after the resulting nova and whatever is going to be ejected gets ejected, what is left behind after a NS-NS merger? Another NS? Something else?

3/ Are NS restricted to certain relatively consistent mass scales, unlike say black holes, which apparently come in many sizes?

Thanks!

[Hrothgar_unbound](#)

TONY: Thanks so much! This has been a whirlwind couple months.

1. We see NS-NS binaries in our own galaxy, so we can estimate roughly how often they should merge from their distribution of separations. This gives a number of roughly a merger in our galaxy every 50,000 years or so. This is very uncertain though because there are only a handful of NS-NS binaries in our galaxy. Another way to estimate this is to use the rate of short gamma-ray bursts (because now we know for sure from this event that short gamma-ray bursts are from NS-NS mergers). This gives roughly the same rate, but the problem is that the gamma-rays are beamed, so this introduces a big uncertainty. The true rate will be found by LIGO/Virgo once we have a larger sample of gravitational wave detections.
2. The short answer is that we don't know what was left over for sure. It depends on the uncertain physics of the very interior of neutron stars. Depending on this, there is a maximum mass a neutron star can support before it collapses to form a black hole. If the combined mass is above this, then a black hole is made, otherwise a massive neutron star results. In principle, LIGO can see the ringing of the merger remnant and tell whether a neutron star or black hole is left. This would be an incredible result, and would really constrain our theories about neutron star interiors. Unfortunately, nothing was detected after the merger in this particular event because LIGO is not sensitive enough yet at these high frequencies. Something to look forward to in the future!
3. Most neutron stars have a mass around 1.4 times the mass of our Sun. This is called the Chandrasekhar mass, and it is set by when the iron core of a massive star collapses, initiating the supernova explosion. The maximum mass of a neutron star is set by its uncertain interior physics.

This is probably between 2.2 to 2.5 times the mass of the Sun, but this is still uncertain. One of the neutron stars in the binary looks to be a few tenths of solar masses larger. This one was probably born first, and then accreted some material from the other star before it died. A similar mass asymmetry is also seen in neutron star binaries in our galaxy.

I understand that when the event occurred, astronomers using the telescopes had to redirect to the mergers. Some astronomers wait months to use telescopes. How are those astronomers reimbursed? How do observatories operate without ticking off a bunch of astronomers?

[blablbliam](#)

JOSH:

Well, I was one of those astronomers. :)

Ryan had also asked me if I would use some of my telescope time to observe the black hole merger that LIGO and Virgo detected three days earlier (GW170814), and I told him no that time. (It's generally up to the astronomer at the telescope to decide how to respond to such requests.) But because a neutron star merger was something completely new and we thought we had a chance at detecting it, I was willing to give up some of my planned observations for this one.

To continue observing the event after the night of discovery, we were fortunate that so many of our colleagues were incredibly generous and understanding with their telescope time. (Some of them were almost as excited about this opportunity as we were!) If this were an Academy Awards speech we would have a very long list of thank yous. Because they knew what the impact of the discovery could be, almost everyone we asked for observations agreed to help. All of the astronomers who provided data or telescope time are included as co-authors on the papers we wrote, and where we can do so we will also give them some of our time in return over the coming months.

MARIA: This is a great question! And the answer varies from observatory to observatory. Some observatories operate on a "queue" schedule, which means that no one is assigned a particular night, but a schedule is made for each night with targets for multiple programs. For those observatories, events like this are (relatively...) simple. The merger will just be given the highest priority for that night, but all the other programs will still get their data on a different night.

However, other observatories (like ours at Las Campanas) are still "traditionally" scheduled: observers are assigned a night months in advance. In cases like that, we just ask very very nicely ;-)

But seriously, it's very rare that anyone is forced to give up their observing time. For this event we emailed all the observers to ask if they would be willing to observe for us during their time. (It actually helped that the merger was only visible for the first hour of the night in Chile, so we weren't asking them to drop everything.) In exchange we both offer to observe targets for them during our own time in the coming weeks/months, and they are also included as co-authors on the paper(s). Most people were very excited and happy to contribute to this. But there were also a few people who politely declined. For those nights, we just tried to make other arrangements.

As a general question, what does this discovery mean for science in say, 50 or 100 years from now? What does it mean for technology in that same timeframe, or even further out? What sort of huge questions will this answer in the generations to come?

[Chef_Lebowski](#)

JOSH: I think it's impossible to predict that right now. In fact, there are very few scientific discoveries

whose implications 50-100 years in the future can be forecast with any accuracy. Look at the development of the laser as an example. How many of the things that we use lasers for today (like detecting gravitational waves!) would any of the inventors have predicted in 1960? It's incredible that LIGO can measure such tiny changes, and maybe that technical achievement will have other applications.

Thank you for doing this ama! I find this whole thing so amazing. I've heard from multiple scientists that in theory, the collision creates many of the heavier elements like gold and platinum. I always thought supernovas created these by fusing their iron core into heavier elements when they finally go supernova. How can a neutron star made of entirely neutrons, create the protons and electrons needed to make these heavy elements?

[zbertoli](#)

DAVE: The answer is in the "r-process" (r for rapid neutron capture). While it is true that neutron stars are made up of mostly neutrons, they also contain protons and electrons, and in fact seed nuclei of iron group elements. When the progenitor system to SSS17a merged, these seed elements were tidally thrown out into space, along with an enormous flux of free neutrons. Because neutrons don't have any electrical charge, they can get close enough to these seed nuclei to be captured. This process is "rapid" because multiple neutrons can be captured before the isotope can decay. In this way, the seed nuclei grow in mass number and also become highly radioactive.

In fact, it's the radioactive decay of these heavy, unstable elements that powers the kilonova by releasing gamma-rays that heat the ejecta mass and make it glow. The byproduct of this decay (i.e. transmutation) are the heavy isotopes we see at the bottom the periodic table.

How fast are the atoms on the surface of pulsars moving if they complete a rotation within one second? Would they ever spin fast enough to rip themselves apart?

[AgentG91](#)

TONY: This is only about 1/5000th of the speed of light. But some neutron stars are spinning up 1000 revolution per second. In this case the surface is actually moving a significant fraction of the speed of light.

Congratulations to the entire team. I am as excited as any member of the astrophysics community, even though my area of research is not astrophysics.

1. If both gravitational waves and GRB were triggered at the same time, why did we observe a 11 second delay in detecting the two events? Is there a mathematical explanation behind this? If I understand correctly, the speed of light changes depending on the medium, however, the speed of the gravitational waves remain *constant* irrespective of the medium in which they traverse.
2. In the previous question, I made an assumption that the gravitational waves travel with a constant speed. However, in the animation posted by NASA, we noticed increase in frequency of the gravitational waves before the collision of the neutron stars (NS). Can you explain in simple words, how does the speed of the gravitational waves change during collision of two NS or two black holes?
3. How precisely can we say if these two events, i.e., creation of GRB and gravitational waves were triggered at the same time?

[dundermifflined](#)

TONY: Thanks so much. We are super excited as well, and especially excited that we get to share this with you now.

The gamma-rays came out about two seconds after the merger. We think this delay is a sum of how long it took to generate the relativistic jet and how long it took that jet to break out of the cloud of debris that was around the merger. Radio waves could be delayed by material between the source and us, but the gamma-rays basically go the speed of light.

Gravitational waves always go the speed of light (as far as we can tell), so it might just be the way the event was animated that gave you the impression of a changing speed.

What is the next "holy grail" discovery that LIGO is predicted to find?

[ScottyMo1](#)

RYAN: There are two remaining "holy grails": a supernova and something completely unexpected.

The other thing we're still waiting for is the merger of a neutron star and a black hole. That would be very exciting, but since we've seen two neutron stars merge and two black holes merge, it's not quite as amazing as the other two.

Why were there two distinct frequencies of light (red and blue)?

[malimacx](#)

TONY: We saw that the emission was bright with blue light for the first couple days and then bright in red light over the next few weeks. We think this is due to material with different compositions. The heaviest elements generated absorb the blue light really well (because they have lots of electronic transitions--think of the orbitals from chemistry class), so this would give the red component. The blue component is still from heavy elements, but not as heavy as the red component.

Now that an NS-NS event has happened, what does the community plan to do different/better for the next one?

Certainly having more than one location get early spectral measurements is one goal.

Also, what instrument will come online in the next 10 years that will add to our understanding of future events?

[jeffh4](#)

JOSH: I don't think any of us have had enough time yet to think about what we should do differently! But like you say, the early observations are key. We would like to find one faster, because even 11 hours after the merger, when we spotted this one, we had already missed the peak of the blue/ultraviolet light. And it would be amazing to get continuous observations for the first 24 hours or so. We could see SSS17a changing in just one hour, so having the full sequence of its behavior starting right after the neutron stars collided would teach us a lot.

In the next month or so, the Zwicky Transient Facility (ZTF), which should be able to find some more neutron star mergers, will start operations at Palomar Observatory. And the next-generation Large Synoptic Survey Telescope, currently under construction in Chile, will completely change the field of

time-domain astronomy when it comes on line in 2020-2021. So there's a lot to look forward to if you like gigantic cosmic explosions!

Do gravitational waves undergo redshift like visible light?

[HAL-Over-9001](#)

TONY: Yes! By combining the distance from the event with this redshift, gravitational waves can be used as cosmological probes to measure the expansion rate of the universe from the Big Bang. People are doing these measurements lots of other ways (like with Type Ia supernovae, which is something Ryan works on), but this will be another important check.

I'm very much an amateur astronomer (really just a hobby like interest in the subject). If I remember correctly neutron stars and black holes are formed in a very similar manner. What ultimately decides if a dying star will end up as a black hole or as a neutron star?

[orbweaver82](#)

CHARLIE: Yes, both neutron stars and black holes are formed from the inert iron cores of massive stars. When the massive star reaches the end of its life, it collapses onto itself and compresses into the densest matter in the universe. Whether that core will eventually form a neutron star or black hole mainly depends on its mass. Higher-mass cores have too much self-gravity and catastrophically collapse down to black holes. The lower-mass cores somehow hold themselves up and form neutron stars. That "somehow" is related to how soft or stiff the neutron star matter really is, which we call the "equation of state."

Personally, I think one of the most-exciting results from the neutron star merger is that LIGO was able to measure the masses of the individual neutron star components. If the merger formed a black hole, which is expected, it would be the lowest-mass black hole about which we know.

I have no idea where to even begin with a question, but freakin awesome, guys!!

[mattmeluke](#)

[Thanks!](#) You are awesome for joining us!

Couple questions - I think these would fall in to the Astro physics category, or theoretical physics rather, I have no idea where that line would be.

What percentage of stars in the night sky no longer exist by the time the light reaches earth?

Do you think forward time travel (time dilation) will be a thing? The faster we go the more time dilation, right? Would this enable a person to leave and come back hundreds of years in the future while Only aging 30 years or so?

Maybe i just watch too much science fiction ☺

[kesnik](#)

JOSH: The percentage of stars that have exploded as supernovae before the light we're currently seeing reaches us is incredibly tiny. Most stars that you can see by eye are within a few thousand light

years of us, so the time it takes their light to get to us is the blink of an eye in the lifetime of a star. Still, since there are about one supernova every 100 years in our galaxy, chances are good that the light from the one that Ryan's waiting for is already on its way to us . . . but don't hold your breath because it could still be hundreds of years before it gets here!

If we can figure out how to travel at relativistic velocities (which I hope we do), the time dilation effects you mention will definitely happen. And I doubt there's any such thing as too much science fiction!

Congrats! Regarding the collision, did you detect anything interesting on the internal structure of the neutron stars?

[animengus](#)

TONY: From the actual light we observed, we don't have constraints on the internal structure of the neutron stars. What we are observing is the radioactive glow of the outflowing ejecta. From the gravitational wave signals, LIGO can, in principle, measure the tidal interactions as the stars merge, but given that LIGO is still not at maximum sensitivity, it does not get super strong constraints on this from this event.

What was the most unexpected find about what your team observed?

[murderedcats](#)

TONY: I would say that there were two unexpected results of our observations. First, the red light we saw coming from the radioactive glow of the heavy elements generated in the ejecta over about three weeks matched what theorists have been predicting in work done over the last decade. It's rare when theorists get something so right! Second, there was bright blue light seen during the first few days. This might be ejecta with a slightly different composition (fewer neutrons), but I would say there is still not a consensus answer for where this component is coming from.

First of all, congratulations on the discovery, guys! Given how rare this is, I'm sure you're all feeling lucky. Or are you guys? Is this a "I couldn't believe we saw this in our lifetime kind of thing", or a "This was going to happen eventually, because this is the nature of our work/telescope/etc."

And a second question, slightly related: are star collisions predictable? Can we plot out when two different stars are heading in each other's way and wait?

[KnightOfTheMind](#)

RYAN: We were lucky, but also prepared. We planned for this kind of event and had several fire drills to get ready. We had an idea what to look for, and we executed a careful strategy.

We discovered the kilonova in our ninth image of the night. But based on our calculations, those first nine images had about a 50 percent chance of finding the kilonova, if one existed at all. So in that sense, it was a coin flip. We would have been lucky if it was in our first image or in our 50th, but the ninth was right about what we would have expected.

The luck is that it wasn't cloudy, that the object was well positioned for our observatory, and that LIGO and Virgo did the hard work of giving us a small region of the sky to search.

Wow, this is really cool! I've always had a bit of a soft spot for space stuff, so it's great to be able to talk

to people who are doing it. Here are my questions:

1. Why didn't any telescopes in Africa see it? Johannesburg, South Africa is 5 hours ahead of Santiago, Chile, which means telescopes there would have still had 5 hours warning. Why did the visibility window have to drift to Chile before anyone could pick it up?
2. I assume you guys don't just sit around the Swope telescope every day waiting to hear about LIGO Chirps. What were you supposed to be doing that night?
3. You guys also were using a big Magellan telescope that night. Was the fact that Swope is small a contributor to why it found the event first? I'm thinking of like a nimble mini Cooper from the Italian Job swerving in and out of galaxies while a lumbering tank takes too long to move around. Is that how it actually is?

Thanks a lot!

[luhbron_james](#)

JOSH:

Good questions!

1. I think working toward getting a detection in five hours instead of 11 hours is one of the things both LIGO and astronomers will be thinking about after this event. As to why it wasn't discovered in South Africa, for one thing there just aren't as many telescopes there as in Chile. But there are some, and at least one, run by the MASTER team, did start a search. However, the LIGO-Virgo team updated their analysis of exactly where on the sky the gravitational waves were coming from about five hours after the initial detection, which was a bit late for telescopes in Africa to respond.
2. The main project on the Swope is measuring the brightness of supernovae, both ones that have just been discovered and older ones in which the team members are interested.
3. Small and nimble can definitely be a winning strategy in some cases, but I don't think that was the main factor here. Rather, the key was that Charlie was set up to download, process, and examine the Swope images pretty much in real time. That meant he could compare each image to a previous image of the same galaxy within a few minutes of when it was taken. At Magellan we didn't have the person-power for that—just taking each image and moving on to the next galaxy without losing any time was as much as I could handle!

I had a lot of fun yesterday reading the news coverage, but one thing I didn't see much about is the spectra. Does anything about the spectra tell you it's two neutron stars colliding vs. a neutron star and a black hole? Was there anything about the spectra that surprised you? Thanks.

[Superconducting_Girl](#)

MARIA: First off, the spectra are awesome! I've stared at a lot of supernova spectra over the years and these are unlike anything I had seen before. I was surprised at how quickly they changed. Over 3 days the spectrum of the explosion completely changed its appearance: it going from very blue to very red and developed a broad feature or bump in the near infrared. We even saw the spectrum notably change in 1 hour on the first night of observations. That was shocking to me. You can see the spectra from Ben's paper in this Figure: <https://imgur.com/a/PD5mQ>

The spectrum does tell you that there was at least one neutron star involved in the merger. The bump in the spectrum in the near infrared is a signature of heavy elements that were made in the explosion. So far we haven't used the spectra to try to distinguish if it was a merger of two neutron stars or a

neutron star and a black hole. The main constraints on that have come from (a) the masses that LIGO measures from the gravitational wave signal and (b) our estimates of how much mass was thrown out in the explosion.

In principle, the merger type would make the spectrum look different, though. We think there were two components to this explosion: a blue component that is only visible for a few days and a red component visible for weeks. The relative contribution of those will be different for a neutron star neutron star merger versus a neutron star-black hole merger.

Hi, thanks so much for doing this and answering all of our questions. This is super exciting even for those of us less technical.

How rare is an event like this?

[Lushkies](#)

DAVE: If we assume a merger rate comparable with binary population synthesis (i.e. simulations that "realistically" evolve populations of stars), we think there could be ~ 25 events like this every million years in a Milky Way-like galaxy. If we assume that SSS17a is typical (it produced ~ 0.06 times the mass of the Sun in heavy elements), and we multiply SSS17a's yield by this rate, it is in rough agreement with the amount of heavy elements we infer in the Galaxy.

Keep up the awesome work! It's an amazing time for gravitational and astrophysics. I took some time out of my classes to watch the press conference yesterday, and it was definitely worthwhile.

I'm a first year graduate student just starting my PhD with the intention of working in theoretical or computational condensed matter. Slightly off-topic, but what's your best advice for someone just beginning grad school?

I spend a lot of my time feeling overwhelmed with the material. I do well on problem sets and feel like I spend all my time on the material, but I never feel familiar with it, the way I did during undergrad. Did you struggle with anything in a similar way during graduate school?

[Help-I-Am-Lost](#)

DAVE: I have some thoughts, which you are welcome to take with a solar mass of salt. For me personally, my best advice (at least what I've been operating on) is to do some real thinking about what it looks like when you have the job you want after your program, and spend most of your effort trying to accomplish that. The ratio of your student life to your professional life will hopefully be very small, so in that sense, coursework and program requirements are fleeting. Do them as well as you can (definitely don't NOT do them), but for what you can't master in the moment, create bookmarks in your head where you can find the answers. From what I've seen in research so far, there aren't so much "answers" as there are degrees of confidence. Quantifying that is a huge skill. The most successful/happiest people I know in the program are essentially emulating independent researchers and faculty. They're going to conferences and colloquia, networking, and focusing on research.

What are some of the scientific theories that this event will shed incite on?

[Midax](#)

TONY: This event solves all at once a bunch of different problems and hypotheses we have had for many decades. This is one of the reasons why this is so exciting (besides the fact that we simply have

never witnessed gravitational waves from merging neutron stars before). (1) We have long thought that neutron star mergers make short gamma-ray bursts, but we could never see the neutron stars to confirm this. With the LIGO gravitational waves and the gamma-ray burst seen two seconds later, now we know for sure. (2) For more than 70 years, we have had theories for where most of the elements in the universe heavier than iron come from (stuff like gold, platinum, uranium, and plutonium). This confirms that they come from neutron star mergers. (3) Theorists have been trying to guess what neutron star mergers look like in optical light for over a decade, and now we know. (And the theorists were actually pretty close!).

Where are you looking for the next collision?

[zabrowskir](#)

CHARLIE: LIGO and Virgo have certain "blind spots" where they're less sensitive to detecting a gravitational wave event, but between all of the interferometers, new events can be detected anywhere on the sky. The only limit on our ability to detect neutron star mergers is the strength of the signal and the maximum distance at which that signal is detectable by LIGO/Virgo. Some estimates suggest we could see neutron star mergers 650 million light years from Earth - so we only have 1200 trillion trillion cubic light years to search!

How can you guys pinpoint the source of gravitational waves so accurately? Is there gravitational "background noise" like there is for EM radiation?

[THE MAGIC OF REALITY](#)

TONY: The location of the gravitational wave source is triangulated from the relative timing and phase of the signal across the different gravitational wave detections (which are in Washington state, Louisiana, and Italy). This is similar to how humans locate things with their hearing. From this, LIGO gave us a region on the sky of about 10 degrees squared, which is much less than previous gravitational wave events (which were hundreds or thousands of degrees squared). This might not sound like a lot, but the moon covers only about 0.2 degrees squared, so it is still a lot of area to cover with a telescope. This is why our discovery of the optical counterpart was so important. We can locate light much more accurately than gravitational waves. This allows LIGO (for example) to measure the inclination of the binary better from the gravitational wave signal because they know from us exactly from how far away the signal is coming.

There is background noise that LIGO has to deal with, but it's mostly terrestrial. Things like earthquakes, cars driving by, logging trucks, ocean waves hitting the shore, and more are all potential noise sources that LIGO has to understand and eliminate so it can focus on gravitational waves.

Hey Fam, way to go!

As someone who only is able to appreciate this from a "whoa that's awesome" perspective, what sort of effects will this type of an observation have on day to day life or the current technologies?

Thank ya kindly

[Adversely Possessed](#)

JOSH:

As Ryan wrote in response to another question, we (and LIGO) are doing this work to improve our

understanding of the universe, not because of immediate practical implications. That said, a lot of fundamental research does end up leading to unforeseen benefits and new technologies. Einstein certainly wasn't thinking about GPS when he was developing general relativity! The measurements that gravitational wave detectors have to be able to make in order to detect anything are so absurdly sensitive that I could easily imagine that related technology will have other applications.

So, is your life going to be any different tomorrow? Probably not, unless you were losing a lot of sleep waiting for the next gravitational wave detection or something! But what will it mean 50 years down the line? Who knows?

Pretty exciting stuff, guys, thank you. I realize you all think of it as "just going to work and doing what I like" and "just doing my job", but hey, it's fun to have a fan.

I'd be curious to know whether any of you could expand a little bit on the areas we can potentially learn more about in the future based on this research, especially as the techniques you used are refined and applied again.

Is there potential to learn more about how black holes and neutron stars "work," at a fundamental level, from examining edge-cases between neutron stars and black holes? For example, once we get a clearer idea of what the maximum mass of a neutron star (or perhaps a pair of them) is, is there potential to infer things we don't now know about their internal structure and composition? Will we potentially be able to examine neutron star binary-collision wreckage to learn something new about how black holes form?

[RaspersProgress](#)

TONY: The nature of the material inside neutron stars remains one of the biggest unsolved problem in physics and astrophysics. This is because the material is so extreme, we cannot do experiments on Earth to investigate it. In the future, as LIGO gets more sensitive, this might be answered. For example, better measurements of the tidal deformation during the merger would be an important constraint on the internal structure of the neutron stars. Also, if the post merger ringing of the remnant could be seen with gravitational waves, this would tell us if a neutron star or black hole formed (this wasn't observed in the case of the August 17th event). If such ringing is seen from many neutron star mergers, we would learn about the maximum mass before a neutron star becomes a black hole, which would be a huge constraint on their internal structure as well.