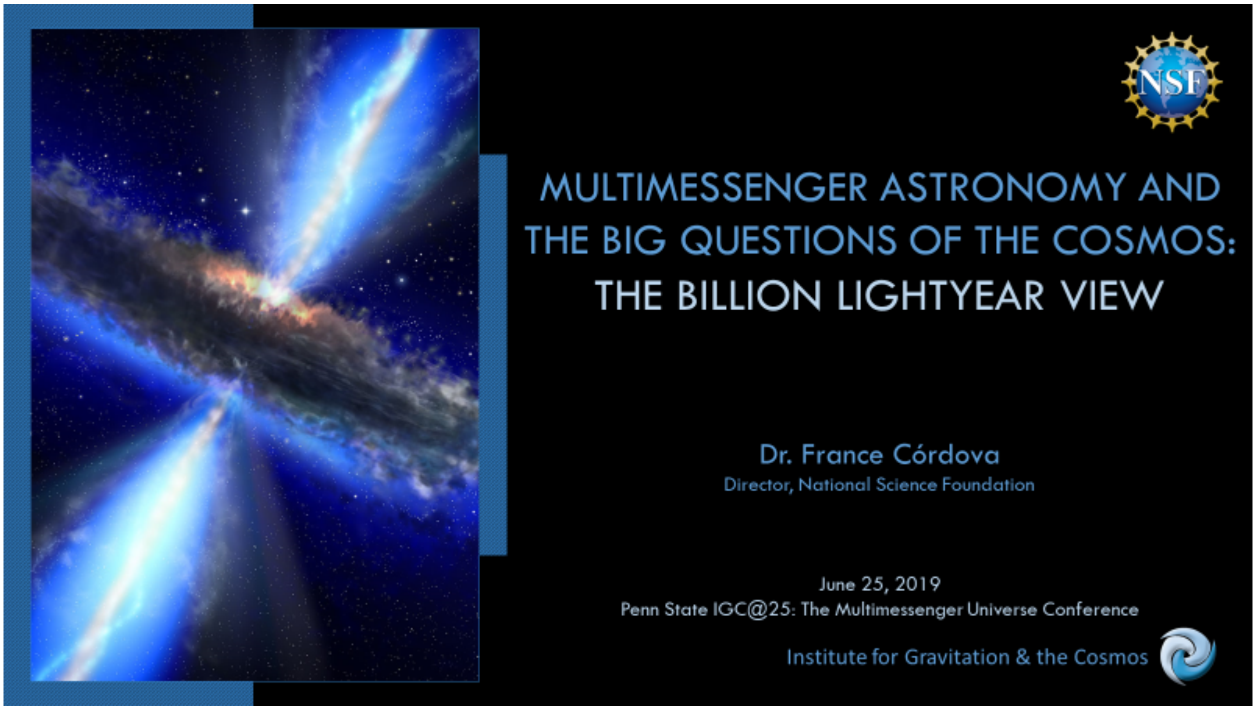


Today marks an important milestone in the lifetime of this vital institution — a coming-of-age for the IGC and the start of what promises to be an even more impactful 25 years of service to our field. I was proud to support the establishment of the IGC during my tenure here as Professor and Chair of the Astronomy and Astrophysics Department, and it is a joy to be a part of this anniversary celebration.

We are … Penn State!

Today also marks a special homecoming for me. I treasure the experience I had here at Penn State and the many wonderful friendships I made. I am delighted to see some of those friends here tonight. This campus brings back fond memories of my children's early days, which were happily spent here. In fact, my son made his television debut at only two years old rocking on the Nittany Lion Shrine!

Making the Climb

As with most endeavors, including public speaking, there is a hierarchy of difficulty. Take rock-climbing for example: I'd classify talking with colleagues around the lunch table a Class 3 experience — Class 3 is like walking on a gently sloping mountain trail. The chances of falling are minimal. Whereas, the discussion following an astrophysics seminar is closer to a Class 4 experience — like scrambling up rocks, with only a little exposure.

THEN we get into Class 5 — the serious stuff where you need ropes and hardware to protect yourself in case of falling. There is lots of exposure in Class 5, which is reflected in a decimal system. 5.3 is your basic scientific lecture: you know your stuff, but if you do something silly, you can get bruised. So, you do your homework, and you rely on your experience to pull you along.

Higher decimals reflect more technical difficulty: a 5.5 climb is demanding — hard to do for a novice, but exciting and only minimal risk of falling if you are experienced. In the world of public-speaking, it is a serious talk, perhaps defending your PhD thesis. By the time you get to class 5.10, well that used to be the hardest of climbs, only done by the pioneers of rock-climbing. When I did my first 5.10 climb, I felt exhilaration — equivalent to proposing a new theory or a new, exciting discovery. You could fall hard, and every limb is tested. “Is this the end of my career?” you worry.

I would put commencement talks in the 5.10 category, too. Are my jokes landing? Why aren’t I getting the same laughs as Ellen DeGeneres or the same “OMG — that’s amazing” as Steve Jobs? I’ve given a couple of these at Penn State in the past few years. I guess commencement speeches really do die faster than 1 over r-squared, because the news about how I did definitely didn’t make it to our conference organizers! Today, they’ve pushed me into 5.12 territory: a banquet speech! Don’t they realize that folks have been listening to speeches ALL DAY and need to unwind? Has anyone estimated how many glasses of wine have been drunk over dinner already? Does anyone really want to hear me go through NSF’s Ten Big Ideas for Investment right now? Really?

I promise not to go there. I will not share with you NSF’s *TEN* Big Ideas. Since it’s evening, how about if I focus on only *ONE*? I picked this one because it’s the subject of your conference: Multi-Messenger Astrophysics, which we call Windows on the Universe. And, truth be told, for the scientists making giant leaps in this territory 5.12-plus skill is required.

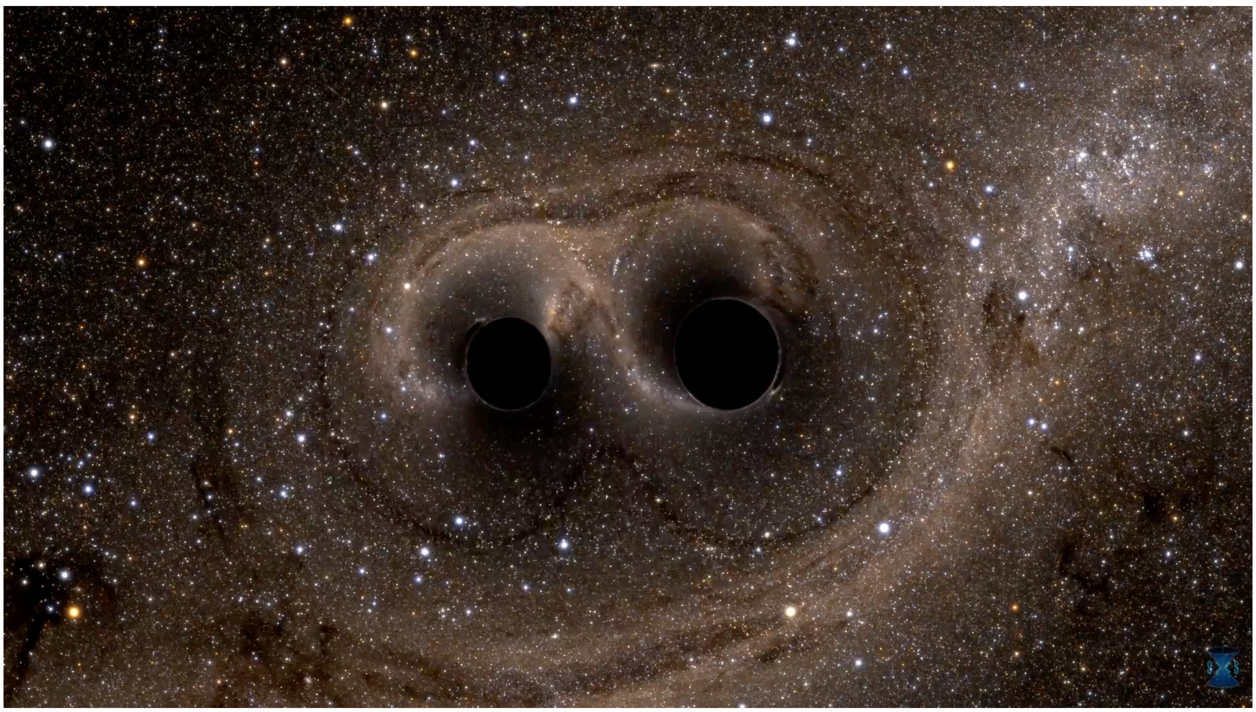
Windows on the Universe

For decades, our agency has invested in theoretical research into the workings of the cosmos and built the observational infrastructure needed to test those theories. The universe echoes with “messengers” carrying information over billions of light years. As we are all aware, photons are messengers, as are cosmic rays and neutrinos. Four years ago, NSF’s LIGO allowed us to add another messenger — gravitational waves.

Our Windows on the Universe Big Idea capitalizes on this era of multi-messenger astrophysics. When we announced it, even we could not have anticipated how soon we’d see new, groundbreaking discoveries.

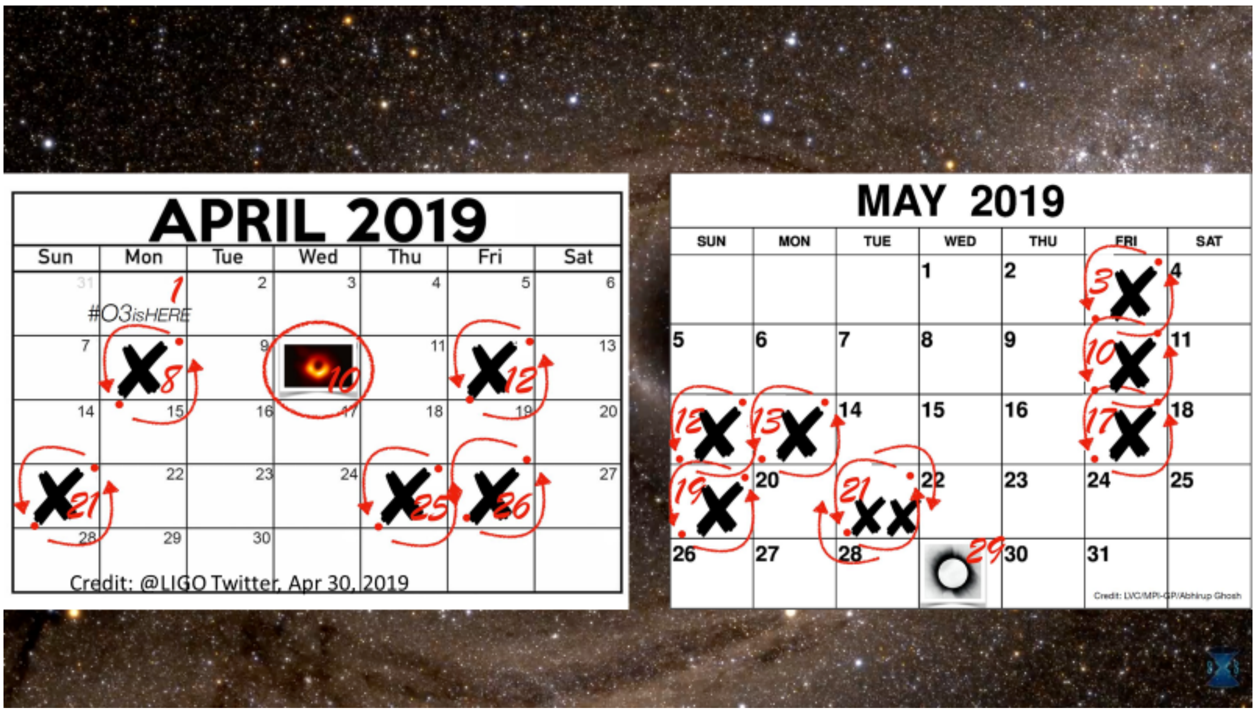
The detection of two neutron stars colliding in 2017, which involved photons and – thanks to NSF’s LIGO – gravitational waves, marked the first observation of cosmic phenomena through two messengers.

And then, just last year, NSF's IceCube Neutrino Observatory in Antarctica detected a high-energy neutrino. Ground and space-based telescopes were able to use that information to rapidly pivot to the source of the neutrino where they saw light from the same source: a flaring blazar. This was the first evidence of an astrophysical source of high-energy cosmic rays.



This is a simulation of the type of black hole merger that produces the gravitational waves LIGO is looking for. In 2015, LIGO underwent a major upgrade, known as Advanced LIGO, and just three and a half months into Advanced LIGO's first run, it detected its first black hole merger, 1.3 billion light years away. In 2017, Advanced LIGO made another new discovery: a merger of two neutron stars.

Since then, the sensitivity of LIGO's detectors has increased the volume of space that can be surveyed by a factor of 4. The updated LIGO-Virgo detector network relaunched on April 1 of this year.



And wow! We already have more than a dozen potential detections in the past two and a half months, including 6 or 7 potential black hole mergers, two potential neutron star mergers, and, possibly, the first detection of a neutron star colliding with a black hole.

And Fridays are great for finding gravitational waves, but apparently they take Saturdays off.

We are at the beginning of a new age of astrophysics, and phenomena that some thought we would never be able to detect are now being observed on a weekly basis.

And we continue to see new breakthroughs from the researchers and instruments we support across the range of astronomical messengers. The Event Horizon Telescope, which gave us our first-ever image of a black hole, is expected to play an active role in multi-messenger astronomy in the future. NSF supported the Event Horizon Telescope effort for almost two decades, and we were thrilled to share the stage with its collaborators when they came together to deliver this image to the world.

Behind this breakthrough was an enormous engineering achievement. There were countless technical challenges involved in linking a heterogenous group of telescopes into one enormous virtual dish. For over a decade, astronomers, engineers and computer scientists traveled telescope by telescope, installing the atomic clocks, data recorders and other hardware necessary for the task. In some cases, specialized equipment was required. At the South Pole, a new receiver had to be built to detect the radiation they needed and extra precautions made to ensure all the equipment would work in the cold and harsh environment of the Antarctic. Once each facility was functional, they had to be tested and re-tested, site by site, ensuring researchers could seize the finite window of observation available to them. Over many years and multiple trips, new bridges of international cooperation were built.

For EHT to be carried out by a single nation, it would have been extremely costly, even with our vast global network of ground-based telescopes. Instead, we chose to invest in our global partnerships, which enabled access to telescopes around the world. Ultimately, a team comprised of 60 institutes working in more than 20 nations contributed to this breakthrough. Perhaps heralding a new era of global cooperation — one that is led by science.

Multi-messenger astronomy is truly a global undertaking. To realize the full potential of multi-messenger astrophysics, collaboration with our interagency and international partners is vital. That was true of the LIGO and IceCube discoveries, and it was true of the Event Horizon Telescope project to image a black hole. And thanks to the NSF's sustained investments like these, we are poised to lead this burgeoning field for the foreseeable future.

NSF is uniquely positioned to build bridges between academia, government departments and institutions, industry, and other sectors. As the astronomy and astrophysics community builds bigger and more sensitive telescopes, we will need better and more efficient ways to manage them and process the data they produce.

Vera Rubin

Yesterday, I participated in a memorial symposium for Dr. Vera Rubin. She laid the groundwork for so much of the important work we're doing in astronomy and astrophysics today. It was a joy to meet her in the course of my own career, and even be featured alongside her on a publication celebrating women astronomers, a compliment I treasure to this day.

The Large Synoptic Survey Telescope (LSST)

The legacy of her research and the discoveries it opened up have played a central role in the development of state-of-the-art facilities like the Large Synoptic Survey Telescope, currently under construction on Cerro Pachon in Chile. LSST promises to deliver a wider and deeper view of the Universe — advancing observations from static images to a 10-year movie of the sky. The facility is an 8.4 meter-class wide-field optical telescope designed to carry out surveys of nearly half the sky. When completed, it will produce a comprehensive data set enabling hundreds of fundamental studies in astrophysics. LSST has the potential to advance every field of astronomical study from the inner Solar System to the large-scale structure of the Universe.

LSST is a great example of how the future of astronomy will require not just cutting-edge scientific research, but also cutting-edge administration and collaboration to support research. Private partners were integral in the early stages of LSST, investing in its design and development prior to NSF's construction award. Today, the facility is a collaboration between NSF and the Department of Energy. This is another in the many innovative partnerships NSF is undertaking across sectors. These are efforts that are at the core of our continuing growth into a more agile and responsive agency.

Future astronomical research facilities must be designed, built, and operated with the multi-messenger universe in mind. That will require cross-cutting partnerships and interdisciplinary teamwork, not just within the research community, but across academic institutions, across federal agencies and departments that support research, and even across governments.

The grand goals embodied by the LSST also come with grand challenges. One of those challenges will be processing an inflow of data as vast and complex as the universe itself — about 20 terabytes of raw data per night, cataloging more than 18 billion objects over its first year alone. It's no wonder that more than half its operational costs are dedicated to data management.

The multi-messenger universe will also multiply the volume of data required to understand it. The connections between data will be another layer of complexity in assembling a complete picture from these disparate messengers. We have already made progress with data processing and information management at many of our largest and most productive facilities—including facilities like the National Radio Astronomy Observatory, as well as Hubble, Chandra, and others. But looking forward, we know that data mining and novel approaches to exploring large data sets can lead to extraordinary discoveries. The future of multi-messenger astronomy will rely on our ability to marshal computational resources and artificial intelligence to efficiently transform data into information.

The multi-messenger universe has so much to teach us, not just about the universe, but about the ways in which we explore it.

I recently gave one of those 5.10 talks I mentioned: a commencement speech at Caltech. It was great to be “home” to speak to the next generation about the lessons I have learned. One of those lessons was the value of interdisciplinary work.

At NSF, we call it convergence, and it has changed the way we work. We actively invite researchers to think outside their disciplinary or methodological boxes about how to approach big challenges. Multi-messenger astronomy is a great example of this concept in action. Answers to big challenges can be found by widening our circle of computational, theoretical, and experimental partnerships.

We’re seeing it across the scientific community. We’re even seeing it across NSF’s Ten Big Ideas. A discussion about the Windows on the

Universe naturally touches on the Big Ideas of Harnessing the Data Revolution and Mid-Scale Infrastructure.

A passion I share with IGC is broadening participation of women and underrepresented minorities in science. This resulted in our INCLUDES enabling Big Idea: an initiative to enhance our scientific leadership and productivity by including talent from all backgrounds in STEM education, careers, and communities. This is just as important to our research capabilities as new observational facilities or computational methods. Just as multi-messenger astrophysics enhances our understanding by widening our perspective, the science community will be stronger when it can draw on a diversity of backgrounds.

The Billion Lightyear View

It's been very exciting to be an astronomer over the past several decades. I did my early research in x-ray astronomy, which was a new window at the time. And to be able to have a bird's eye view as director of NSF as the discoveries from the IceCube Neutrino Observatory and LIGO were released was a special privilege.

When you get to the top of a 5.12 climb, it's a great feeling to be able to look out over the landscape around you. Sometimes you can see for miles. You can often see new peaks to climb. Science is the same: each discovery opens up a new view with new challenges to set your sights on.

I'm very excited to see what the future of multi-messenger astronomy holds. You are scaling the Big Questions of the universe, with a view of billions of lightyears.

Thank you!