

TEDx Talk – Final

In this age of Internet start-ups, we have come to expect the rapid development of ideas into products with an early payoff (or failure). But some efforts, especially scientific research, need to play the 'long game', sometimes lasting decades.

To make these 'very long' games a success requires the willingness, the capacity to pursue research that we don't know will work, and may take a long time to know if it will. It requires not just the dedication of researchers, but also steady support from backers and, sometimes, a bit of luck. LIGO, which made the first detection of gravitational waves ever just last year is one such effort

For millennia, we have used light to observe the cosmos. Historically, observatories were built by coming up with a design, then finding someone very rich to pay for it before the researchers passed away.

[LICK observatory]

In the 19th century, the richest man in California was convinced to build the largest telescope of its age as his tomb, instead of a building a massive pyramid in the middle of San Francisco. Now, most large telescopes are funded by governments. These are subject to the whims of election cycles and public opinion, but typically don't make you bury someone under them

Forty to fifty years ago, astronomers had built telescopes that covered the spectrum of electromagnetic radiation, from X-rays to visible light to infrared to radio waves. They had made some great discoveries with these telescopes. But they were also finding that most of the matter in the universe would never be seen in those telescopes.

[Black Hole slide]

The long-theorized black holes appeared to actually exist. Predicted as the final state for very massive stars, these black holes undergo a gravitational collapse so extreme, that even light itself can never, ever, escape (hence the name). There appeared to be huge black holes with the mass of a million suns at the center of galaxies.

Even more disturbing, astronomers were finding that four-fifths of the matter in the universe was not the normal atoms and such that make up stars (and us). This 'dark matter' could only be found indirectly, by how its gravitational pull worked on the stars that could be seen.

[GW spiral slide]

There was a possibility. Einstein had predicted that there was gravitational radiation. Generated when massive objects accelerate, such as a pair of black holes tightly orbiting each other, these gravitational waves propagate away at the speed of light, going through everything.

[GW propagate slide]

As the waves pass, they squeeze space-time in one direction while stretching it in another. But even the most powerful sources of gravitational waves would leave only the faintest ripple when they got to our Earth. These ghostly ripples would squeeze things by only 1/10,000 the size of a proton over a few kilometers. Seemed impossible to detect.

[RAI Weiss slide]

Rai Weiss at MIT and others thought a new instrument, the laser interferometer, could do the trick. Rai Weiss spent a summer calculating how to do this (after assigning it as a problem set to his students). He found that you would need a very large L-shaped interferometer, with arms several kilometers long. It would need to be enclosed in one of the largest vacuum systems ever built.

Getting funding for this 'crazy idea' was hard at first. Administrators at the National Science Foundation (NSF) were intrigued, but started off with modest grants.

[Early interferometer slide]

They had to demonstrate that the key technologies needed to build such a thing were possible. They brought in industrialists to help these 'desktop scientists' with planning how to build such a large facility.

At the end of the 80s, plans for the laser interferometers were getting serious. All the basic technologies had been demonstrated. But to carry this out would

require a hundred million dollars, dwarfing the existing budget for astronomy. How was this to happen?

[LIGO slide]

Some luck helped. The site locations, whittled down from a list of candidates, ended up in the districts of some key congressmen and senators, who became advocates for this proposed Laser Interferometer Gravitational-Wave Observatory, LIGO for short. Laws were passed to give the NSF a separate pot of money for such major projects. The initial funding was eventually approved.

But the early 90s were a tough time in science - funding for other large projects was being slashed. The Superconducting Super Collider (SSC) in Texas was even cancelled. The nascent LIGO effort did get some benefit from this. It picked up several managers experienced at large science projects. It also got some surplus furniture.

Such long-term projects need to be broken down into stages. The challenge of each stage is to prove that the project can meet the goals set for that stage. This builds confidence in the backers (and the scientists) that it just might succeed.

[SRD slide]

The next big hurdle for LIGO was to prove they could build a small network of interferometers and operate them jointly, around the clock, for a couple years. LIGO did just this, and also demonstrated that they had met performance targets somewhat boldly predicted ten years before.

[Einstein@Home slide]

LIGO also engaged the public. Einstein@Home was created, which allowed hundreds of thousands of ordinary people to use the idle time on their computers to help search for signals from wobbly pulsars. It also had a cool screensaver. This allowed them to share in the joy and excitement of discovering something never seen before.

But LIGO wasn't as lucky as hoped. In all that time there were no surprise discoveries of gravitational waves from sources that were a lot closer than astronomers thought they were.

[Advanced LIGO slide]

But funding had been secured for the next stage - Advanced LIGO. Here, all the innards - lasers, optics, isolation systems, electronics were replaced with designs capable of detecting the weaker gravitational waves actually expected. The initial mirrors had been hung from simple wires. The new mirrors were suspended in four separate levels, the last on fine by very strong silica glass fibers.

This was all to ensure that the mirrors were isolated so well from external vibrations that they could pick up the one vibration they could never be shielded from – the squeezing of space-time by gravitational waves. In a sense, these were the quietest rooms ever created in which to hear the faintest pin drop imaginable.

[Control Room slide]

By last year, LIGO had all this installed and had gotten the interferometers tuned up and running stably. And that is luck came back in. Because just as they were beginning the search in earnest, the scientists got the surprise of our lifetimes.

[Discovery slide]

An absolutely perfect signal had arrived at the two observatories. It was almost too good. Most had expected it would be a subtle signal that would take a lot of computer processing to find, and that after many weeks. But this was so strong one could see it easily in the data.

When analyzed in detail, it was from a binary black hole merger. This was a pair of black holes, each 30 times more massive than the sun, that had completed their death spiral 1.3 billion years ago. That collision converted three suns worth of energy into gravitational waves alone, with no light produced.

The worst thing for some – they couldn't tell anyone yet about this great achievement. They first had to rule out all other possible causes. Remember, they would be claiming to detect something that no one else could, from a source that no other telescope could ever see.

[Black hole set slide]

LIGO's discoveries (there were three such last year) greatly increased the number of known black holes, and these much larger than ever seen before. It may also start to resolve the mystery of that 'dark matter' I spoke about. Physicists have

searched for over twenty years to find some unknown, exotic particles to make up this dark matter, but have found none. After the LIGO discovery, some now propose that instead, the 'dark matter' is from unseen black holes created just after the big bang.

[GW network slide]

Because gravitational waves go through everything, you can't focus them as in a telescope. You can only triangulate the source location based on timing. The required network of gravitational-wave observatories for this new field will expand. A third one in Italy will join in the next year. The Japanese are building one inside a mountain. And next decade, another observatory should be operating in India.

[LISA slide]

Another very long-term effort is also underway. The LISA project plans a laser interferometer in space. It would be able to detect gravitational waves from much fainter, but much closer objects, some in our own galaxy. Just this past March, they demonstrated the critical technologies from a satellite launched out beyond the Earth. This research, already active for 20 years, and with satellites a mere one million kilometers apart, is a long game indeed.