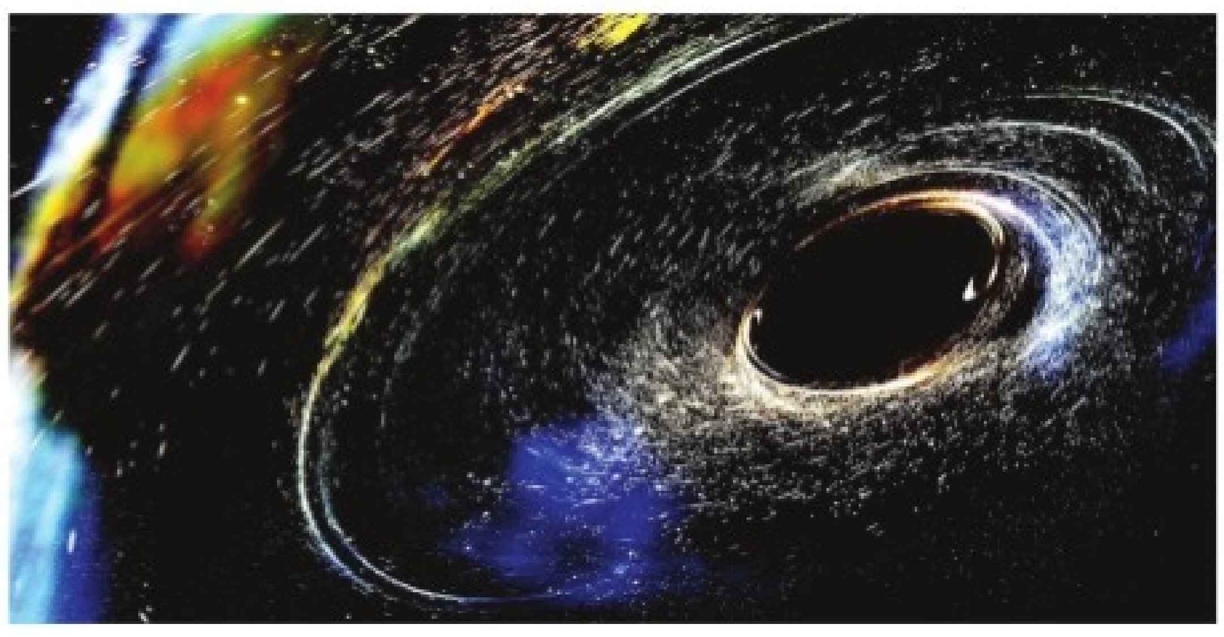
Keeping the noise down

The last mile in subduing disturbances is the most difficult to navigate when studying gravitational-waves



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The quest for gravitational-waves, which arise from events far in deep space, calls for detecting the feeblest of signals that we encounter. And we need such quiet to make them out that noise control is the first challenge to overcome.

Gravitational-waves are detected by the effect they have on the dimensions of space. The most sensitive arrangement to detect gravitational-waves, to date, hence uses interference of light when the length of a path of light, past which the gravitational-wave passes, is altered. The innate "grainy" nature of the light source, however, limits sensitivity, as it could mask the variation of intensity caused by a gravitational-wave. Using a more powerful beam would overcome this effect, but it would increase the miniscule jitter that light imposes on mirrors, which are part of the apparatus. Controlling this disturbance, known as Quantum Radiation Pressure Noise, would hence be critical.

Jonathan Cripe, Nancy Aggarwal, Robert Lanza, Adam Libson, Robinjeet Singh, Paula Heu, David Follman, Garrett D Cole, Nergis Mavalvala and Thomas Corbitt, from Louisiana State University, MIT, the University of Vienna and Crystalline Mirror Solutions, an optics firm in Santa Barbara and Vienna, report in the journal, *Nature*, that they have created a device to measure, and perhaps lead to ways to mitigate this last mentioned effect.

The gravitational-wave is an effect that is predicted by Einstein's General Theory of Relativity, which reinterprets the nature of gravity. Starting from the observation that the acceleration due to gravity is indistinguishable from any other acceleration, Einstein takes the help of the equivalence of mass and energy to connect the nature of mass with energy in space, and thence the force of gravity with curvature that a mass induces in the fabric of space. While it has been verified that the presence of a mass does bend the path of a beam of light, as if space is curved, a consequence of the theory is that accelerated masses should lose energy by radiation of gravity waves, just like acceleration of electric charges leads to electromagnetic waves.

Like electromagnetic waves create electric and magnetic fields where they pass, a gravitational-wave would cause spatial shrinking and stretching when it passes. The Laser Interferometer Gravitational-wave Observatory, or LIGO, consists of a pair of four kilometre-long channels, at right angles, through which a laser beam is split and then recombined. In case a gravitational-wave was to pass over the LIGO, there would be differential changes in the dimensions of the two arms. Even very minute changes would show up as interference of the two halves of the split beam of light, when they combine.

The trouble is that there so many causes of minute changes in dimensions, with attendant interference of light, even when there is no gravitational-wave. For example, tremors in the earth, perhaps even traffic or heavy footfall, could trigger an interference pattern. To take care of this disturbance, the tubes of the Ligo are very securely housed and then, there are two LIGO arrangements, one at Louisiana and the other at Washington, 3,002 kms apart, and an event is counted only if it occurs in both the LIGOs at once. But a more persistent cause of disturbance is that the laser source of the light is itself not continuous, but staccato, the manner of individual atoms in the laser material, which de-excite and emit photons.

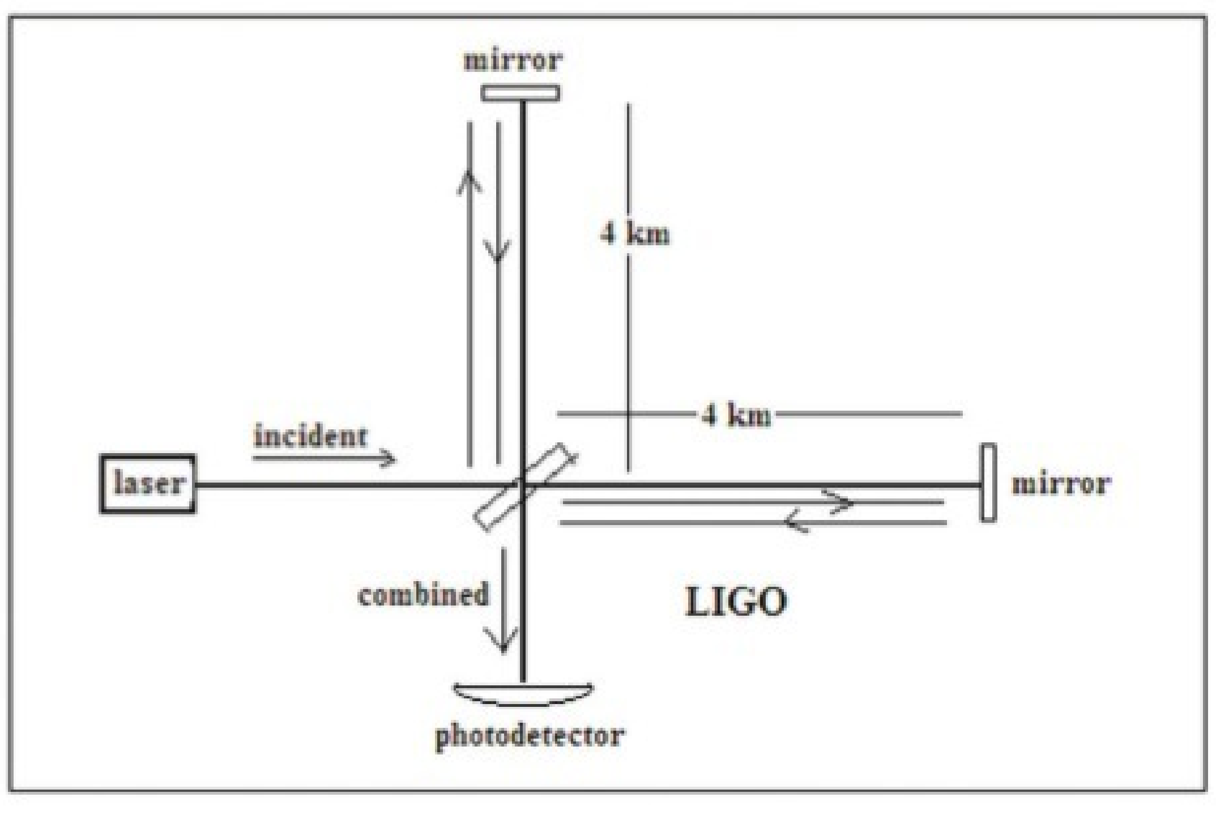
We are all aware that when we toss a coin, in the long run, the number of heads and tails will be about the same. But in the short run, of just a few tries, there can be series of more head or more tails. It is the same with the laser. While the light output, on the average, is uniform, with a low power beam, where there are fewer atomic transitions, the emission of photons over a short period of time is not uniform. This non-uniformity, in the LIGO, could be mistaken for a gravitational-wave.

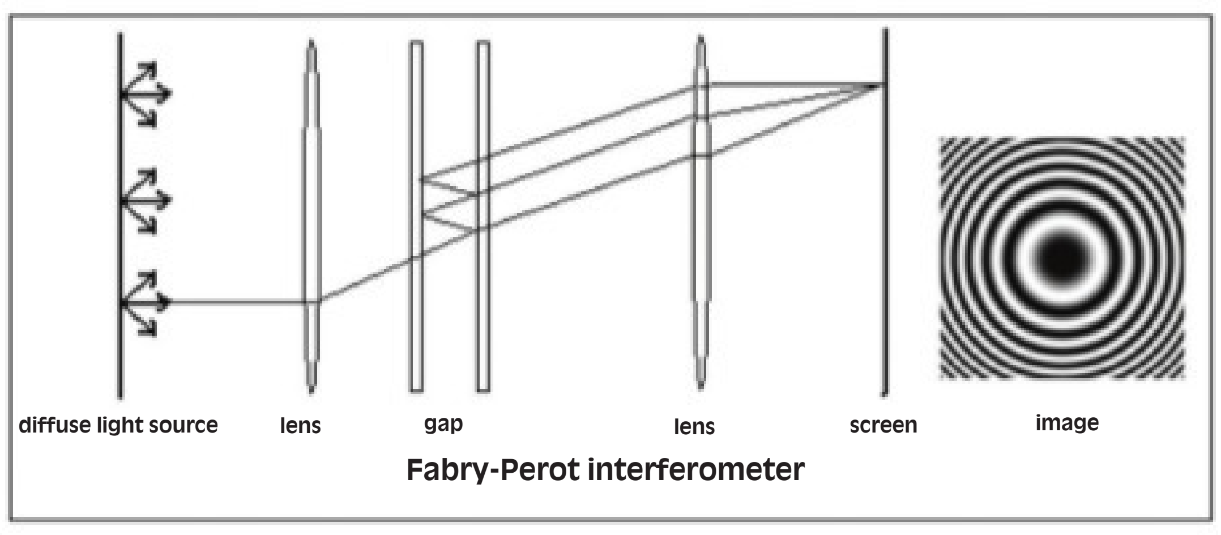
One way of dealing with this problem is to use a more powerful laser beam, where there are billions of atom transitions every second. The LIGO actually uses a 100 kW beam, which is quite powerful. But there is a limit to this recourse, as light has momentum, albeit very low. A powerful beam would hence materially impact the mirror off which the laser beam needs to be reflected. This effect on the mirrors of the Ligo, which arises from the particle nature of light, is a very feeble but definite source of uncertainty in the intensity variations in the interference pattern.

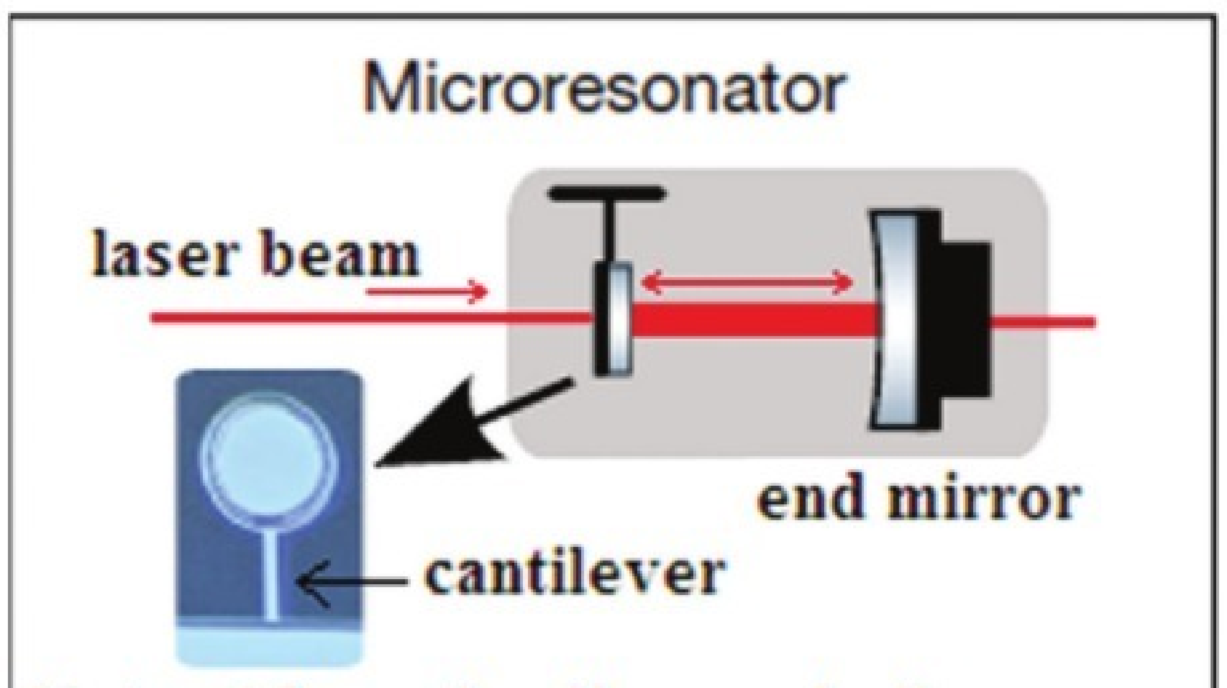
As this effect, the QRPN mentioned earlier, is so feeble, there has been no way to study this feature in the laboratory. This is because real-life apparatus are subject to mechanical disturbances that create noise, which is much more energetic than the subtle effect that we wish to study. The group writing in the journal describes a device and a method that deals with these limitations.

The device that they have created is miniature interferometer, not, four kms long, but of the order of one cm, with components that are measured in microns. The heart of the device is what is called a Fabry-Pérot cavity. The Fabry-Pérot arrangement is a pair of closely placed, parallel, partially transparent mirrors. When light of a single colour is admitted, at certain angles, the gap between the mirrors would be a whole number of wavelengths of light and reflected wavelets would reinforce or annihilate each other. An interference pattern is thus created and the pattern is a sensitive measure of space between the mirrors.

In the device now developed, one side of the Fabry-Pérot cavity is a curved mirror, while the other side is 70 micron reflector mounted on 55 micron lever, an elastic cantilever. The light entering and exiting the cavity is measured by photodetectors, which also control the intensity and phase of the light beam.







Extract from the diagram in the paper

Just like the interference pattern of an optical, parallel mirror, the Fabry-Pérot interferometer can display the dimensions of the interferometer gap, the rise and fall of reflected intensity in the cantilever device represents the interplay of the mechanical vibration of the reflector mirror and the effect of the light pressure. The design minimises the disturbances due to changes of temperature and does not call for cooling to low temperatures before the jitter caused by light pressure can be observed.

The paper finds that their system shows QRPN affects at the frequencies from two kH to 100kH, a range that corresponds to frequencies of interest in gravitational-wave research. The system could thus serve as a platform to try out ways to reduce quantum noise, and improve the sensitivity of gravitational-wave detectors.

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Unwelcome visitors

Here's why dangerous asteroids heading to Earth are so hard to detect

The meteor trail 200 kms away from Chelyabinsk in 2013

JONTI HORNER

Earth is often in the firing line of fragments of asteroids and comets, most of which burn up tens of kilometres above our heads. But occasionally, something larger gets through.

That's what happened off Russia's east coast on December 18 last year. A giant explosion occurred above the Bering Sea when an asteroid some ten metres across detonated with an explosive energy ten times greater than the bomb dropped on Hiroshima.

So why didn't we see this asteroid coming? And why are we only hearing about its explosive arrival now?

Nobody saw it

Had the December explosion occurred near a city — as happened at Chelyabinsk in February 2013 — we would have heard all about it at the time. But because it happened in a remote part of the world, it went unremarked for more than three months, until details were unveiled at the 50th Lunar and Planetary Science Conference this week, based on NASA's collection of fireball data.

So where did this asteroid come from?

At risk from space debris

The Solar System is littered with material left over from the formation of the planets. Most of it is locked up in stable reservoirs — the Asteroid belt, the Edgeworth-Kuiper belt and the Oort cloud — far from Earth.

Those reservoirs continually leak objects into interplanetary space, injecting fresh debris into orbits that cross those of the planets. The inner Solar System is awash with debris, ranging from tiny flecks of dust to comets and asteroids many kilometres in diameter.

The vast majority of the debris that collides with Earth is utterly harmless, but our planet still bears the scars of collisions with much larger bodies. The largest, most devastating impacts (like that which helped to kill the dinosaurs 65 million years ago) are the rarest. But smaller, more frequent collisions also pose a marked risk.

In 1908, in Tunguska, Siberia, a vast explosion levelled more than 2,000 square kilometres of forest. Due to the remote location, no deaths were recorded. Had the impact happened just two hours later, the city of St Petersburg could have been destroyed.

In 2013, it was a 10,000-tonne asteroid that detonated above the Russian city of Chelyabinsk. More than 1,500 people were injured and around 7,000 buildings were damaged, but amazingly nobody was killed.

We're still trying to work out how often events like this happen. Our information on the frequency of the larger impacts is pretty limited, so estimates can vary dramatically. Typically, people argue that Tunguska-sized impacts happen every few hundred years, but that's just based on a sample of one event. The truth is, we don't really know.

What can we do about it?

Over the past couple of decades, a concerted effort has been made to search for potentially hazardous objects that pose a threat before they hit Earth. The result is the identification of thousands of near-Earth asteroids upwards of a few metres across.

Once found, the orbits of those objects can be determined, and their paths predicted into the future, to see whether an impact is possible or even likely. The longer we can observe a given object, the better that prediction becomes.

But as we saw with Chelyabinsk in 2013, and again in December, we're not there yet. While the catalogue of potentially hazardous objects continues to grow, many still remain undetected, waiting to catch us by surprise.

If we discover a collision is pending in the coming days, we can work out where and when the collision will happen. That happened for the first time in 2008 when astronomers discovered the tiny asteroid 2008 TC3, 19 hours before it hit Earth's atmosphere over northern Sudan. For impacts predicted with a longer lead time, it will be possible to work out whether the object is truly dangerous, or would merely produce a spectacular but harmless fireball (like 2008 TC3).

For any objects that truly pose a threat, the race will be on to deflect them — to turn a hit into a miss.

Searching the skies

Before we can quantify the threat an object poses, we first need to know that the object is there. But finding asteroids is hard. Surveys scour the skies, looking for faint star-like points moving against the background stars. A bigger asteroid will reflect more sunlight, and therefore appear brighter in the sky — at a given distance from Earth. As a result, the smaller the object, the closer it must be to Earth before we can spot it.

Objects, the size of the Chelyabinsk and Bering Sea events (about 20 and 10 metres IN diameter, respectively) are tiny. They can only be spotted when passing very close to our planet. The vast majority of the time they are simply undetectable. As a result, having impacts like these come out of the blue is really the norm, rather than the exception.

The Chelyabinsk impact is a great example. Moving on its orbit around the Sun, it approached us in the daylight sky — totally hidden in the Sun's glare. For larger objects, which impact much less frequently but would do far more damage, it is fair to expect we would receive some warning.

Why not move the asteroid?

While we need to keep searching for threatening objects, there is another way we could protect ourselves. Missions such as Hayabusa, Hayabusa 2 and OSIRIS-REx have demonstrated the ability to travel to near-Earth asteroids, land on their surfaces, and move things around. From there, it is just a short hop to being able to deflect them — to change a potential collision into a near-miss.

Interestingly, ideas of asteroid deflection dovetail nicely with the possibility of asteroid mining. The technology needed to extract material from an asteroid and send it back to Earth could equally be used to alter the orbit of that asteroid, moving it away from a potential collision with our planet.

We're not quite there yet, but for the first time in our history, we have the potential to truly control our own destiny.

The writer is professor of astrophysics, University of Southern Queensland, Australia. This article first appeared on www.theconversation.com

PLUS POINTS

Wiping bad memories

Giving patients a dose of anaesthetic could help them recover from past trauma or even cure phobias, a new study has suggested. If people are asked to recall painful memories shortly before being knocked out by the drug propofol, scientists found those memories were noticeably weaker the next day. Anything from a fear of spiders to post-traumatic stress disorder could potentially be relieved if researchers can work out how to harness this effect in patients.

Scientists used to assume that once a memory had formed in someone's mind, it was virtually impossible to target and eliminate. Experiments in rodents gradually revealed this was not the case, but the procedures being used — such as injecting substances into rats' brains — were not suitable for humans. Firing electric shocks through the heads of people with severe depression turned out to be an effective way to erase bad memories, but this too was not ideal.

"Electroconvulsive therapy is a very invasive treatment, so if you're thinking long-term of how to selectively target emotional memories that produce problems, and we can do something simpler — that would be better," Bryan Strange of the Polytechnic University of Madrid told *The Independent*.

As people undergoing such treatments are also given anaesthetic drugs, Strange and his team wondered if these were playing a role in the selective memory loss.

When sedated in hospitals, he noted that patients show some amnesia for the period before their procedure, although this memory loss does not extend to their wider lives.

To test the idea, the team began by asking 50 participants to watch slideshows telling emotional stories, including a boy involved in a car accident and an attack on a young woman. After a week had passed, they were shown parts of the slideshow to jog their memories, before being injected with propofol.

Half of the subjects were then asked to recall the story 24 hours later, as well as a story that had not been "reactivated" in their minds prior to sedation.

The researchers found that those participants could not remember the reactivated as well as the non-reactivated story. "What was interesting about the effects of propofol was that it was very selective for the emotional component of the story," said Strange, noting it was the moments of violence or injury that proved harder to recall.

If unpleasant memories can be isolated, potentially using virtual reality, he said phobias that can be traced to specific events — such as crashing a car — could also be isolated and dealt with. "It's certainly worth a try," said Strange. Ravi Das, who is undertaking similar research at University College London but was not involved in the current study, said the paper was an interesting development in a growing area of research. "We know the unhelpful memory process is a core part of things like PTSD and also addictive disorders as well," he said.

However, with no treatments that directly weaken memories ready to use in patients just yet, he said this goal was still a "blue sky aim". Besides propofol, Das noted that other drugs, including ketamine, were being considered in the development of such treatments.

The new findings were published in the journal *Science Advances*.

The independent