The Universe's Hum and an opportunity to explore

Indian Express, July 6th, 2023.

The first detection of gravitational waves was announced on February 11th, 2016. These had been predicted, almost exactly a century ago by Einstein as a natural consequence of his theory of gravity- the Theory of General Relativity. General Relativity implies that under certain circumstances, space itself would be stretched and compressed resulting in the production of gravitational waves-much like throwing a stone in a placid pool of water. Detection and study of gravitational waves has since opened a new window into our universe at the largest scales. Now astronomers from several collaborations have announced detection of ultra-low frequency gravitational waves which could expand this window to explore hitherto unexplored regions of the universe.

Since the first detection of gravitational waves by LIGO (Laser Interferometry Gravitational-wave Observatory) dozens of detections of short, high frequency gravitational wave bursts have been observed by detectors at LIGO as well as in Italy and Japan. These high-frequency waves are thought to be a result of collisions of black holes with masses of the same order as our Sun, as well as of neutron stars. Black holes and neutron stars are stellar remnants of stars which have exhausted their nuclear fuel.

LIGO, as the name suggests is based on the principle of interference. A laser beam is split into two, each of which is sent down a pair of arms, each several kilometers long which are oriented perpendicular to each other. The beams are reflected back and then made to interfere. If there has been no disturbance, the beams cancel each other out exactly. However, occasionally when a gravitational wave passes through the interferometer arms, it would stretch and compress the arms by an incredibly small amount- a million trillion times smaller than the proton. This will result in the beams not cancelling each other. The signal, after some clever data-analysis to rule out other possibilities like seismic tremors, is then taken as a gravitational wave detection.

The detections at LIGO and other detectors have all been of high frequency waves- typically a few kilohertz. The sensitivity is determined by the length of the arms of the detector- the lower the frequency of the waves, the longer the arms which are required to detect them. This is one of the motivations for LISA, the planned space based detector by the European Space Agency. This detector would have arms which would be several million kilometers long. For the nanohertz (a billionth of a hertz) waves which have now been reported, one would have needed a galaxy sized detector- clearly not something which can be built.

The scientists instead decided to use Nature itself and used our Milky Way as the detector in an ingenious manner. The basic idea is to use radio pulses from objects called millisecond pulsars to detect the elusive waves. Millisecond pulsars are rapidly spinning neutron stars which beam radio waves in regular pulses. These pulses arrive on earth with extremely regularity. If an ultra-low frequency gravitational wave distorts the intervening space between a pulsar and us, it can change the arrival time of these pulses.

This of course is the theory. What is required is painstaking data collection of many millisecond pulsars over years. For this, five multinational teams have been collecting data for over two decades on pulsar timings. These are the North American Nanohertz Observatory for Gravitational Waves, The European Pulsar Timing Array (PTA), Indo-Japanese PTA, Parkes PTA from Australia and the Chinese PTA. Each of these groups is a collaboration of several scientists from many institutions.

The Indo-Japan PTA has researchers from the National Center for Radio Astrophysics (NCRA), Raman Research Institute and several other institutes. The facility used to collect the data was the upgraded Giant Meter wave Radio Telescope (μGMRT) at Narayangaon near Pune. This array of 30 radio antennas, each with a diameter of 45 meters separated by a maximum distance of 25 kilometers is amongst the most advanced radio telescopes in the world for low frequency observations. Data from a particular class of millisecond pulsars was collected for over a decade to detect the effect of gravitational waves.

The detection is a tour de force since even without the gravitational waves, there are several factors which might cause the pulsar timings to vary. All of these need to be individually accounted and compensated for. The only way that such a tiny signal can be gleaned from the background is by doing a statistical analysis of dozens of pulsars over many years. This is one of the reasons why none of the collaborations are yet claiming a fool-proof discovery- what in scientific jargon is 5-sigma level where the chance of it being a random event is one part in 3.5 million. Nonetheless, no one doubts that as more data is collected and analysed, the 5-sigma gold standard would be achieved.

The origin of these nanohertz waves is not yet determined, though the most likely scenario is of supermassive black holes orbiting each other. These gargantuan objects, each with a mass millions of times of our Sun, are typically found at the center of galaxies. When galaxies collide or merge, these could pair off and produce the waves which are detected. Although such mergers and collisions may seem unlikely, given the vast scale of the universe and the 13 billion years since galaxies first formed, there could be many such events. The combined effect of these mergers is to produce the constant background of these disturbances of spacetime. There are other possibilities too which are being considered including exotic objects like cosmic strings and even inflation- an event at the very beginning of the universe which resulted in an exponential increase in its size.

Whatever the ultimate origin of what is being called the "hum" of the universe by the press, it is clear that these nanohertz waves would, in future, allow us to explore the earliest universe. As to whether the "hum" is the primordial "*aum*" as one commentator in the press seemed to think, we can only wait and watch. Or hear.