Embargoed till 00.00 UTC (05:30 AM,IST), 29 June, 2023

Popular Version

Hint for relentless humming of universe by low frequency gravitational waves

An International team of astronomers from India, Japan and Europe has published the results from monitoring pulsars, nature's best clocks, using six of the World's most sensitive radio telescopes, including India's largest telescope uGMRT. These results provide a hint of evidence for the relentless vibrations of the fabric of the universe, caused by ultra-low frequency gravitational waves. Such waves are expected to originate from a large number of dancing monster black hole pairs, crores of times heavier than our Sun. The team's results are a crucial milestone in opening a new, astrophysically-rich window in the gravitational wave spectrum.

Such dancing monster Black Hole pairs, expected to lurk in the centers of colliding galaxies, create ripples in the fabric of our cosmos, and astronomers call them nano-hertz gravitational waves as their wavelengths can be many lakhs of crores of kilometers. The relentless cacophony of gravitational waves from a large number of supermassive black hole pairs create a persistent humming of our universe. The team, consisting of members of European Pulsar Timing Array (EPTA) and Indian Pulsar Timing Array (InPTA) consortia, published their results in two papers in the Astronomy and Astrophysics journal and their results hint at the presence of such gravitational waves in their data set.

These light-year-scale ripples can only be detected by synthesizing a galactic-scale gravitational-wave detector using pulsars-the only accessible celestial clocks for the humans. Pulsars are a type of rapidly rotating neutron stars that are essentially embers of dead stars, present in our galaxy. Fortunately, a pulsar is a cosmic lighthouse as it emits radio beams that flashes by the Earth regularly just like a lighthouse near a harbor.

Astronomers monitor these pulsars using the best radio telescopes of the world including India's premiere radio telescope, the uGMRT, situated near Pune. In recent years, uGMRT has made significant contributions in precisely recording the little flashes of pulsar's radio beams so that we can use pulsars as celestial clocks.

"According to Einstein, gravitational waves change the arrival times of these radio flashes and thereby affect the measured ticks of our cosmic clocks. These changes are so tiny that astronomers need sensitive telescopes like the uGMRT and a collection of radio pulsars to separate these changes from other disturbances. The slow variation of this signal has meant that it takes decades to look for these elusive nano-hertz gravitational waves" explains Prof. Bhal Chandra Joshi of NCRA-TIFR, Pune who founded the InPTA collaboration during the last decade.

Scientists of the EPTA in collaboration with the Indo-Japanese colleagues of the InPTA have reported detailed results of analysing pulsar data collected over 25 years with six of the world's largest radio telescopes. This includes more than three years of very sensitive data collected using the unique low radio frequency range and the flexibility of India's largest radio telescope - the uGMRT. The analysis of this unique data set has revealed that the measured rate of ticking of these cosmic clocks has characteristic irregularities, common across the twenty-five pulsars that have been monitored. This is consistent with the effect produced by gravitational waves at ultra-low frequency (waves that oscillate with periods between one and ten years).

Prof Yashwant Gupta, Centre Director at NCRA-TIFR which runs the uGMRT, commented "It is fantastic to see our unique uGMRT data being used for the ongoing international efforts on gravitational wave astronomy. Carrying out high precision timing of pulsars for such a purpose was one of the crucial science targets of the major upgrade of the GMRT that we carried out during 2013-2019, and I am extremely pleased to see it producing fruit within the first few years. The wideband receiver systems that we designed and built for the upgraded GMRT are the ones that have enabled the high quality data from the lower radio frequencies that the GMRT is contributing to the international collaboration".

Not surprisingly, nano-hertz frequency gravitational waves carry information about some of the best-kept secrets of the Universe. The cosmic population of black hole pairs with masses that are ten-to-hundred crores times more than the mass of our Sun are expected to be formed when their parent galaxies merge and such a population emits gravitational waves at these frequencies. Further, various other phenomena that may have taken place when the Universe was in its infancy, just a few seconds old, also produce these waves at these astronomically long wavelengths. According to Prof. A. Gopakumar, TIFR, Mumbai, and Chair of the InPTA consortium, "The results presented today mark the beginning of a new journey into the Universe to unveil some of these mysteries. More importantly, this is the first time that an Indian telescope's data is used for hunting gravitational waves".

To detect these gravitational-wave signals, astronomers in a "Pulsar Timing Array" (PTA) collaboration exploit many ultra stable pulsar clocks, distributed across our Milky Way galaxy, to create a "galactic-scale gravitational-wave detector". Measurements of the exact arrival times of the pulsars, which have been going on for decades, are being compared with each other to study the influence of gravitational waves. As radio signals travel through space and time, the presence of gravitational waves affects their path in a characteristic way: some pulses will arrive a little (less than a millionth of a second) later, some a little earlier.

This gigantic galactic-size GW detector synthesised by incorporating 25 meticulously chosen pulsars in our Milky Way Galaxy makes it possible to access the variations in the pulse arrival times created by gravitational waves with a frequency of oscillation 10 billion times slower than those first observed in 2015 by the two ground-based LIGO detectors in the United States of America. "Interestingly, kilometer-sized LIGO sees flashing gravitational wave signals that last for seconds. In contrast, our galaxy-sized PTA is beginning to sense a permanent vibration of the fabric of our universe or in other words a gravitational wave background at nano-hertz frequencies. The resulting new window to the universe is expected to get wider with new telescopes like the Square Kilometre Array (SKA) in the near future where India is expected to play a decisive role", says Prof. A. Gopakumar.

The current results are based on a coordinated observing campaign using the five largest radio telescopes in Europe: the 100-m Effelsberg radio telescope in Germany, the Lovell Telescope of the Jodrell Bank Observatory in the United Kingdom, the Nancay Radio Telescope in France, the Sardinia Radio Telescope in Italy and the Westerbork Synthesis Radio Telescope in the Netherlands. To complement this data set, observations with the upgraded Giant Metrewave Radio Telescope in India were included in the analysis. Once a month, the European telescopes are additionally added together to give an extra boost to the sensitivity.

"Our collaboration between colleagues across Europe, India and Japan not only shows that an international effort is successful and very rewarding scientifically, but we hope to also serve as a role model for the global IPTA efforts", says Prof. Michael Kramer, Director - Max-Planck-Institut für Radioastronomie, Bonn, Germany who along with Prof. Bhal Chandra Joshi is instrumental in creating close collaborations between the European and Indian PTAs.

The analysis of the European and Indian Pulsar Timing Array (EPTA+InPTA) data which is presented today has revealed the presence of a common signal across the pulsars in the array which is broadly in agreement with being due to gravitational waves. "The signal is persistent throughout the many years of monitoring of these pulsars, as if these cosmic clocks are pitching and rolling in the waves of space-time. This emerging evidence is in line with what astrophysicists expect", says Prof.

Keitaro Takahashi, Kumamoto University, Japan who leads Japanese efforts with his Indian and European colleagues.

The EPTA+InPTA results are complemented by the coordinated publications made by other PTAs across the world, namely the Australian (PPTA), Chinese (CPTA) and North-American (NANOGrav) pulsar timing array collaborations. This same evidence for gravitational waves is seen by NANOGrav and consistent with results reported by the CPTA and PPTA.

“The results reported by the EPTA+InPTA collaboration are tantalizingly close to the discovery of nano-hertz gravitational waves and are the culmination of many years of efforts by many scientists including early career researchers and undergraduate students. We are grateful to the NSM computing facilities at IIT Hyderabad and IIT Roorkee, along with the computing infrastructure of NCRA, Pune and TIFR, Mumbai which helped to unveil these results’’, states Prof. Shantanu Desai of IIT, Hyderabad.

Importantly, work is already in progress where scientists from the four collaborations – EPTA, InPTA, PPTA and NANOGrav – are combining their data sets under the auspices of the International Pulsar Timing Array (IPTA) to create an array consisting of over 100 pulsars that may allow them to reach this goal in the near future. This combined IPTA data set is expected to be more sensitive and scientists are excited about the constraints they can place on the GWB along with understanding various other phenomena that may have taken place when the Universe was in its infancy, just a few seconds old, which can also produce gravitational waves at these astronomically long wavelengths.

“This is really exciting!”, says Dr. Pratik Tarafdar of The Institute of Mathematical Sciences, Chennai, who feels that “we are within a whisker of achieving such dynamic range where one can finally listen to the bass sections in this cosmic gravitational-wave-symphony."

In the subsequent years, the IPTA consortium expects to find gravitational waves from individual pairs of monster black holes like the one suspected to lurk in a very active galaxy called OJ 287. Such discoveries will enhance astrophysical information that can be extracted from PTA observations, similar to the iconic neutron star merger GW170817, observed by LIGO and many telescopes in the electromagnetic spectrum during 2017. “Along with the upcoming Square Kilometre Array, this pancontinental collaboration is expected to fully complement the discoveries from future space-based and ground-based gravitational wave observatories including LIGO-India”, believes Prof. Bhal Chandra Joshi.

The InPTA experiment involves researchers from NCRA (Pune), TIFR (Mumbai), IIT (Roorkee), IISER (Bhopal), IIT (Hyderabad), IMSc (Chennai) and RRI (Bengaluru) along with their colleagues from Kumamoto University, Japan.

Technical Press Release

Tuning in for the relentless humming of our universe

Indian and Japanese astronomers, which form the Indian Pulsar Timing Array (InPTA) collaboration (https://inpta.iitr.ac.in/), have been using the premiere low frequency Indian radio telescope, the upgraded Giant Metrewave Radio Telescope (uGMRT), located 80 km from Pune, to make precise measurements of tiny effects on signals from about 20 milli-second pulsars,nature’s best clocks, for the last 5 years in the quest of these gravitational waves. Recently, they combined their data with similar high-precision higher frequency data obtained using 5 large radio telescopes in Germany, France, United Kingdom and Italy over the last 24 years to carry out one of the most sensitive searches for these waves.

The results of this search by the InPTA and European Pulsar Timing Array collaboration (EPTA), published on June 29, 2023, reveal evidence of an emerging signal similar to nano-Hertz Gravitational Waves. Results consistent with this search have also been published simultaneously by three other international pulsar timing array (PTA) experiments.

It is highly likely that the combination of the data from all these experiments, including unique low frequency data contributed by the InPTA, under the auspices of International Pulsar Timing Array (IPTA) later next year may lead to an unambiguous discovery of these elusive gravitational waves with light-year wavelengths.

Gravitational waves, predicted by Einstein almost a century back, shrink and stretch the space and time around us. This ripple in space-time is imperceptible to us, but can alter the tick-tock of a clock by a very small amount in Einstein's theory. PTA experiments like the InPTA attempt to measure such changes in celestial clocks called radio pulsars. These are faint radio sources, which emit clock like radio pulses with a regularity comparable to the best terrestrial atomic clocks.

GWs passing near the earth can shorten or lengthen by a very tiny amount the observed period of these millisecond period pulsars. A sensitive telescope like the uGMRT can be used to count the number of pulses received every second making it possible to measure these periods to a fraction of a billionth of a second. The InPTA along with its international partners in Australia, Europe and North America has been precisely doing this for the last decade or more.

Now all clocks have imperfections. So, how do astronomers separate the noise of these clocks from GWs? These GWs are emitted by massive black hole binaries or pairs with a period of about decade or frequency of nano-Hertz, which corresponds to the time each black hole of the pair takes to go around its partner. While the GWs from a single pair is too

weak, GWs from many such pairs combine to form a much stronger "hum" or background. This "music" of black holes is not only very characteristic in its "sound", it leaves different imprints on pairs of pulsar clocks being used to "listen" to it. While the sound is similarly loud on two pulsars separated by a small angle in the sky, its similarity or "correlation" is different as the angle between two pulsars changes. Astronomers use these peculiarities of the GWs signal to differentiate the "black hole hum" from other types of "noise" which a single pulsar clock may show. Amongst these noises are imperfections caused by propagation of radio waves in the medium between us and the pulsar clock. It turns out that these are best measured at radio frequencies near 400 MHz, where the uGMRT is currently the world's most sensitive radio telescope.
The InPTA astronomers have used this unique feature of the uGMRT, apart from its sub-array and seamless wideband frequency coverage capabilities to provide precise characterization of this noise to our European colleague in the InPTA-EPTA data combination.

The InPTA-EPTA collaboration has used this combined data to distinguish the propagation and other noise from the GWs signal. In the recently published papers, these experiments have hinted at a gradual emergence of GWs signal with the expected two peculiar characteristics mentioned above - the spectrum and the spatial correlation. While the "smoking gun" evidence is still emerging, the results impact our understanding of how the galaxies evolved in our universe and of the cosmic strings and dark matter. With the ongoing effort to combine the InPTA-EPTA data with the North American Nano-Hertz Gravitational Wave (NANOGrav), the Parkes Pulsar Timing Array (PPTA) and MeerTime Pulsar Timing Array (MPTA) data, the IPTA hopes to open this new window to the Universe in the next year or so.

Contacts:

Keitaro Takahashi: Kumamoto University, Japan
(keitaro@kumamoto-u.ac.jp)

P Arumugam: 8979890366, arumugam@ph.iitr.ac.in., IIT Roorkee
Bhal Chandra Joshi: 9422315542, bcj@ncra.tifr.res.in, DAE, NCRA-TIFR, Pune/IIT Roorkee
Yashwant Gupta: ygupta@ncra.tifr.res.in NCRA-TIFR, Pune
A. Gopakumar: TIFR, Mumbai, 09869039269, gopu.tifr@gmail.com
Manjari Bagchi: IMSc, Chennai; 96771 46926
Shantanu Desai: IIT Hyderabad 9619127162 shantanud@phy.iith.ac.in
T. Prabu: 944 857 3994, prabu@rri.res.in, RRI, Bengaluru,
Mayuresh Surnis: IISER Bhopal, msurnis@iiserb.ac.in 7666183077
Yogesh Maan: ymaan@ncra.tifr.res.in NCRA–TIFR, Pune