Gravitational Waves

For Prelims: India’s Giant Metrewave Radio Telescope, **Gravitational Waves**, Pulsars

For Mains: Gravitational Waves

Why in News?

Recently, an international team of astronomers announced scientific evidence confirming the presence of **gravitational waves** using pulsar observations.

- **India’s Giant Metrewave Radio Telescope (GMRT)** was among the **world’s six large telescopes** that played a vital role in providing this evidence.

What are the Key Findings?

- They reported the first direct evidence for the relentless vibrations of space-time caused by **ultra-low frequency gravitational waves.**
- They also **set new limits on the strength and frequency of these waves,** which are consistent with theoretical predictions.
- They are also tantalisingly close to the discovery of **nanohertz gravitational waves,** which would open up new possibilities for studying galaxy evolution, cosmology, and fundamental physics.

How Does GMRT Detect Gravitational Waves?

- GMRT detects gravitational waves by using **pulsars-the only accessible celestial clocks for humans**, which are **rapidly rotating neutron stars.**
- Pulsars emit regular pulses of radio waves that can be used to **measure their rotation periods and distances with high precision.**
- By observing **Pulsar timing arrays (PTAs)** distributed across the sky, GMRT can look for **tiny variations in their pulse arrival times** caused by **gravitational waves** passing through the **Earth-pulsar line of sight.** This technique is known as **pulsar timing.**
- GMRT is a crucial player in the PTA experiment, as it provides unique data at low radio frequencies and high sensitivity.

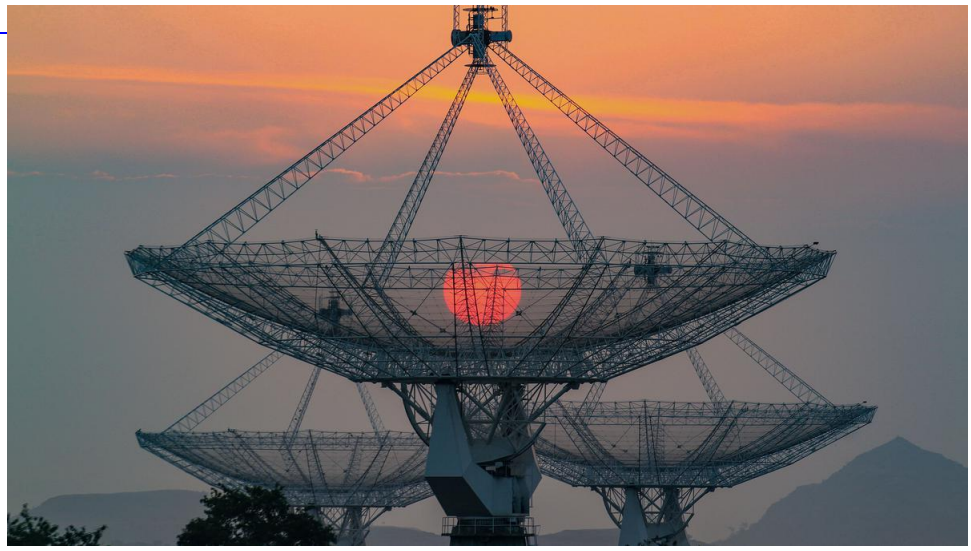
Note:

- PTAs are international collaborations of radio telescopes that observe hundreds of pulsars over many years to search for gravitational waves in the nanohertz band.
- **GMRT is part of the Indian Pulsar Timing Array (InPTA)**, which is a collaboration of **Indian and Japanese researchers** that uses GMRT data along with other telescopes.

What is GMRT?

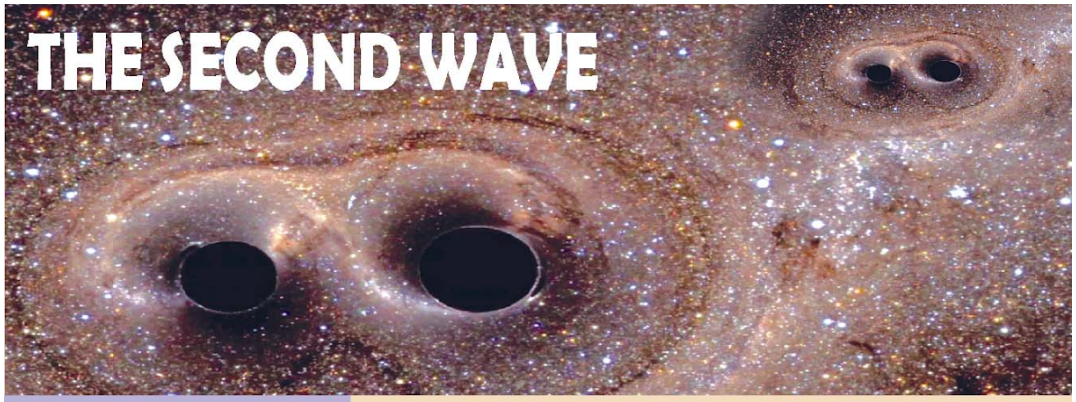
- GMRT is a **low-frequency radio telescope** consisting of an array of 30 fully steerable parabolic radio telescopes of 45-meter diameter.
- It is located near **Narayangaon, Pune** in India, and operated by the **National Centre for Radio Astrophysics (NCRA)**, a part of the **Tata Institute of Fundamental Research**, Mumbai.
- It is one of the **largest and most sensitive radio telescope** array in the world at low frequencies.
- GMRT has recently undergone significant upgrades in its receivers and electronics, which have improved its sensitivity and bandwidth. It is now known as the **upgraded GMRT (uGMRT).**

//



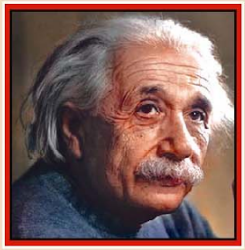
What are Gravitational Waves?

- **About:**
  - Gravitational waves are **ripples in space-time caused by violent and energetic processes in the Universe.**
  - **Albert Einstein** predicted their existence in his **general theory of Relativity in 1916.**
- **Production of Gravitational Waves**
  - **Cataclysmic Events:** The strongest gravitational waves originate from **colliding** black holes**,** supernovae**, and colliding neutron stars.**
  - **Neutron Star Rotation**: Gravitational waves can also be produced by the **rotation of non-perfectly spherical neutron stars** and possibly remnants of gravitational radiation from the **Big Bang.**
- **Features and Detection**
  - Gravitational waves are challenging to detect due to their **weak interaction with matter.**
    - Gravitational waves were first detected in 2015 using an experiment involving Laser Interferometer Gravitational Observatory (LIGO) **detectors.**
  - Sensitive instruments like interferometers, such as the LIGO, are developed to detect gravitational waves by measuring tiny disturbances in space-time.



EINSTEIN'S THEORY

Einstein predicted the existence of the waves in his theory of relativity a century ago, and scientists have been able to detect them with an instrument known as the Laser Interferometer Gravitational-Wave Observatory, or LIGO



GRAVITATIONAL WAVES

Black holes form in the final stage of most massive stars' evolution. The space bodies are so dense that neither light nor matter can escape them.

Sometimes the holes couple, orbiting in a 'dance' around each other as they lose energy in the form of gravitational waves, ultimately merging into a single black hole

Those gravitational waves allow scientists to detect when the black holes merge

THE FIRST DETECTION

The first detection of waves– in September 2015 –was announced in February 2016, in a landmark discovery for physics and astronomy after decades of efforts

THE NEW WAVE

Researchers announced they had found the waves a second time in December 2015, produced by the collision of two black holes some 1.4 billion years ago.

SIZE OF BLACKHOLE

It is very significant that these black holes were much less massive than those in the first detection. It is a promising start to mapping the populations of black holes in our universe.

WHAT IS LIGO? The Laser Interferometer Gravitational-Wave Observatory (LIGO) consists of two identical detectors 3,000 km apart – one in Livingston, Louisiana and the other in Hanford, Washington

UPSC Civil Services Examination, Previous Year Question (PYQ)

Prelims

Q. Recently, scientists observed the merger of giant 'blackholes' billions of light-years away from the Earth. What is the significance of this observation? (2019)

(a) 'Higgs boson particles' were detected.
(b) 'Gravitational waves' were detected.
(c) Possibility of intergalactic space travel through 'wormhole' was confirmed.
(d) It enabled the scientists to understand 'singularity'

Ans: (b)

Q. What is the purpose of 'evolved Laser Interferometer Space Antenna (eLISA)' project? (2017)

(a) To detect neutrinos
(b) To detect gravitational waves
(c) To detect the effectiveness of missile defence system
(d) To study the effect of solar flares on our communication systems

Ans: (b)

- “evolved Laser Interferometer Space Antenna (eLISA)” is a project to measure gravitational waves in the frequency range of 0.1mHz to 100mHz.
- The project consists of 3 spacecrafts which will fly in a triangular path around the earth. The arm length of each edge of this imaginary triangle will be about 50 million km.
- Inside these spacecrafts will be placed free falling cubes with 46 mm side. If these free falling cubes are hit by gravitational waves, then the change in the distance between these cubes will be accurately measured by Laser interferometer.
- **Therefore, option (b) is the correct answer**

Source: TH