Gravitational Waves

November 23, 2018

[Manifest Pedagogy]

The new observations and inferences on the phenomena that occur in the universe always make one curious. So, is true with UPSC. The questions on Einstein' theory of relativity, Higgs Boson and space-time have proved it time and again. Hence, studying these observations holistically will help one to handle any type of surprise questions.

In news

Question on validity of LIGO detections

In syllabus

Awareness in the fields of Space

Static dimensions

1. Gravitational waves
2. Electromagnetic Spectrum

Current dimensions

1. LIGO Experiment
2. VIRGO
3. IndIGO, the Indian Initiative in Gravitational-wave Observations

Content

What are Gravitational Waves?

Gravitational waves are 'ripples' in the fabric of space-time caused by some of the most violent and energetic processes in the Universe.

Albert Einstein predicted the existence of gravitational waves in 1916 in his general theory of relativity. Einstein’s mathematics showed that massive accelerating objects (such as neutron stars or black holes orbiting each other) would disrupt space-time in such a way that ‘waves’ of distorted space would radiate from the source (like the movement of waves away from a stone thrown into a pond). Furthermore, these ripples would travel at the speed of light through the Universe, carrying with them information about their cataclysmic origins, as well as invaluable clues to the nature of gravity itself.

The strongest gravitational waves are produced by catastrophic events such as

- Colliding black holes
- The collapse of stellar cores (supernovae)
- Coalescing neutron stars or white dwarf stars
- The slightly wobbly rotation of neutron stars that are not perfect spheres
- Possibly the remnants of gravitational radiation created by the birth of the Universe

Two-dimensional illustration of how mass in the Universe distorts space-time.

Why to detect Gravitational waves?

Historically, scientists have relied almost exclusively on electromagnetic radiation (visible light, X-rays, radio waves, microwaves, etc.) to study objects and phenomena in the Universe (some are trying to use subatomic particles, called neutrinos, as well). Each of these sources of information provides scientists with a different but complementary view of the Universe.

- Though gravitational waves were predicted to exist in 1916, actual proof of their existence wouldn’t arrive until 1974. In that year, two astronomers working at the Arecibo Radio Observatory in Puerto Rico discovered a binary pulsar—two extremely dense and heavy stars in orbit around each other.
- In 1993, astrophysicists Russell Hulse and Joseph Taylor received the Nobel Prize in Physics for their 1974 discovery of a binary pair of neutron stars 21,000 light years from Earth. Seven years later, after tracking the radio emissions of one star in the pair over a period of years, Taylor and two other colleagues noted that the time it takes for the two stars to orbit each other was decreasing exactly in a way that general relativity predicted if the two stars were radiating gravitational waves. Analyses of other binary neutron star systems confirmed this effect firmly concluding that gravitational waves were not just theoretical.
- Since then, many astronomers have studied the timing of pulsar radio-emissions and found similar effects, further confirming the existence of gravitational waves. But these confirmations had always come indirectly or mathematically and not through actual ‘physical’ contact.

All of this changed on September 14, 2015, when LIGO physically sensed the distortions in space-time caused by passing gravitational waves generated by two colliding black holes nearly 1.3 billion light years away.

Artist’s Impression of a Binary Pulsar

Laser Interferometer Gravitational-wave Observatory (LIGO)

- LIGO is the world’s largest gravitational wave observatory and a marvel of engineering. Comprising two enormous laser interferometers located thousands of kms apart, LIGO exploits the physical properties of light and of space itself to detect and understand the origins of gravitational waves.
- LIGO (and other detectors like it) is unlike any other observatory on Earth. More than an observatory, LIGO is a remarkable physics experiment on the scale and complexity of some of the world’s giant particle accelerators and nuclear physics laboratories. Though its mission is to detect gravitational waves from some of the most violent and energetic processes in the Universe, the data collects may have far-reaching effects on many areas of physics including gravitation, relativity, astrophysics, cosmology, particle physics, and nuclear physics.
- It is capable of measuring a distance on the order of 10^{-19}meters required inventing and refining innovative technology. Most of LIGO’s most impressive technology

resides in its

- Seismic isolation systems (which remove unwanted vibrations)
- Vacuum systems (to make sure the laser light is kept pure)
- Optics components (to preserve laser light and laser power)
- Computing infrastructure (to handle the mindboggling amount of data that LIGO collects).

The processes that generate gravitational waves can be extremely violent and destructive, by the time the waves reach Earth they are billions of times smaller. In fact, by the time gravitational waves from LIGO’s first detection reached us, the amount of space-time wobbling they generated was thousands of times smaller than the nucleus of an atom! Such inconceivably small measurements are what LIGO was designed to make.

VIRGO

Virgo is a giant laser interferometer designed to detect gravitational waves.

Virgo has been designed and built by a collaboration of

- The French Centre National de la Recherche Scientifique (CNRS)
- The Italian Istituto Nazionale di Fisica Nucleare (INFN)

It is now operated and improved in Cascina, a small town near Pisa on the site of the European Gravitational Observatory (EGO), by an international collaboration of scientists from France, Italy, the Netherlands, Poland, and Hungary.

LIGO and VIRGO announce the detection of a black hole binary merger from June 8, 2017.

Question on validity of detections

LIGO’s feat was among the most electrifying announcements in recent years. Since detecting this binary black hole (BBH) merger, the LIGO Scientific Collaboration (LSC) has made six such observations. Five of these were mergers of black holes in very different locations in space and with very different characteristics such as mass, and one was the merger of a pair of so-called neutron stars (binary neutron stars).

Such mergers had been modelled theoretically even before the detection. The measurement was made easier because the team had templates for the type of signals to expect. The last few detections have been done in conjunction with another detector, Virgo. After the first discovery, the LSC made public its data. Analysing this, in 2017 a group of scientists questioned the validity of the first detection.

IndIGO: the Indian Initiative in Gravitational-wave Observations

- IndIGO, is an initiative to set up advanced experimental facilities, with appropriate theoretical and computational support, for a multi-institutional Indian national project in gravitational-wave astronomy.
- Since 2009, the IndIGO Consortium has been involved in constructing the Indian road-map for Gravitational Wave Astronomy and a phased strategy towards Indian participation in realizing the crucial gravitational-wave observatory in the Asia-Pacific region.
- The current major IndIGO plans on gravitational-wave astronomy relate to the LIGO-India project. LIGO-India is a planned advanced gravitational-wave detector to be located in India, to be built and operated in collaboration with the LIGO USA and its international partners Australia, Germany and the UK.
- The project recently received the in-principle approval from the Indian government.

Test yourself: Mould your thoughts

What are gravitational waves? Explain the observations of LIGO. How LIGO detections have created ripples in scientist fraternity?