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GRAVITATIONAL WAVES, BLACK HOLES, AND HEAVY ELEMENTS

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There has been a new opening for the vast knowledge in understanding the objects and processes in the universe recently, such as gravitational waves that we read about but never saw its existence, merger of black holes that we were not aware of, the heavy elements that we see on the Earth but do not quite know how they were created. It appears that all these three items are related to each other. The knowledge is certainly interesting and filling the gaps we need to know for advances. The scope has been recognized by Nobel prizes in Physics in 2017 and 2020.

What are gravitational waves?

A charged particle when accelerates or decelerates emits electromagnetic waves which travels at the speed of the light. One common example of it is the x-ray machines in medical facilities. Electrons traveling from cathode to anode under a voltage difference hit on a target slab and decelerate causing emission of x-rays which is used for diagnostics and therapy of a patient. Similarly when a mass is accelerating or decelerating, it produces gravitational waves which travels at the speed of the light. It was first predicted by Albert Einstein.

Just as the water ripples, gravitational waves distort all matter momentarily as they pass through them. If they pass through the Earth, everything including everyone on Earth will expand and contract back by less than the width of an atom. These distortions are minute. Gravitational waves are long and very weak and are the reasons for not being able to be detected. Explosion of a giant

star can produce gravitational waves that are strong enough to be detected.

LIGO detector for gravitational waves

The idea that minute expansion in a very short time could be detected through laser interferometry was around among scientists before and in early 1960s. Around 1960, LIGO (Laser Interference Gravitational-wave Observatory) set-up was initiated in the US under the leadership of Rainer Weiss. In the set-up, a laser beam is split into two evenly divided beams by a splitter. These two beams travel through the two arms set in L shaped but of equal length of about 2.5 miles or 4 km as seen in Figure 1. Each arm has two mirrors at the two ends that form a resonant optical cavity. The mirrors force the laser beams to bounce back and forth hundreds of times covering a distance of more than 1000 km before the beams recombine to destructive interference. So with no disturbances, the two beams cancel out each other and the photodetector will show darkness.

If a burst of gravitational waves passes through area, one beam will be slightly longer than the other by the distortion of the land and register a signal even for a split-second difference of recombination of the beams. However the first detection of gravitational waves had to wait until September 2015. The reason was that many engineering and science upgrades were needed to catch the signal. In the optical cavities, 11 kg mirrors were replaced with 40 kg ones to minimize thermal noise and were suspended from an intricate pendulum system to isolate mechanical vibrations.



Another vibration isolation system was installed to continuously counteract any vibration from seismic and any other ambient activities.



Figure 1: LIGO detector at Hanford for detection of gravitational waves

To determine the direction of the source of waves, first two LIGO detectors were built, one in Hanford, Washington State and the other one in Livingston, Louisiana, with a distance of about 1865 miles (3000 km) apart. To reduce the uncertainty of direction, another detector was built later by VIRGO in Pisa, Italy. These facilities are in a long distance apart so that there would be a slight difference in the time when each would sense the passing of the waves. This delay enabled researchers to calculate very approximately where on the sky the gravitational waves came from or the collision had occurred.

Merging of black holes or neutron stars - a kilonova event

When a star loses all its hydrogen in nuclear fusion to form elements, mainly helium, it collapses and expands. If the mass of the star is large, it can end up to collapsing and going through supernova explosion and then collapsing the materials to form a dense core of a neutron star or a black hole. If the core is massive, it may form a black hole, which has a very strong gravitational pull that matter even light can not escape. A less massive core will form a neutron star. Its gravitational pull of a neutron star is strong enough to crush protons together with electrons to

form neutrons. A neutron star is small, typically with diameters of about 12 miles but is very dense such that a neutron star's mass may be about the same as that of the sun or somewhat higher. Using the general theory of relativity, Roger Penrose extended and completed the work of Einstein to show that formation of a black hole is a singularity where space and time merge and shared the 2020 Nobel prize in Physics for his work.

Two black holes or neutron stars can merge in a cataclysmic event known as kilonova that produces enormous amount of energy and part of the mass is converted to strong gravitational waves. The merger takes place in a short amount of time, from seconds to about a minute. The merger of two neutron stars, detected on August 14, 2019, was about a minute compared to 1-2 seconds for two black holes.

LIGO detector is sensitive to gravitational radiation in the 20-2000 Hz range which are created by the mergers of some combination of black holes and neutron stars. In 2015, gravitational waves, created by merger of two black holes, were detected for the first time. During 2015 - 2019, LIGO detectors detected 4 black hole mergers and one neutron stars merger. In one merger of the two black holes, one 25 times the mass of our Sun and the other 31 times the mass of our star, produced a new spinning black hole with 53 times the mass of the Sun. This means that about three solar masses were converted into gravitational-wave energy during the coalescence. In 2020 the LIGO and Virgo Collaborations detected the gravitational waves released from the heaviest kilonova ever documented where a 65-solar-mass black hole and an 85-solar-mass black hole merged into a gigantic 142-solar-mass black hole, sometime called as the monster black hole. Physics Nobel prize in 2017

went to 3 members, Rainer Weiss, Barry C. Barish, and Kip S. Thorne, of the LIGO projects that detected gravitational waves from mergers.

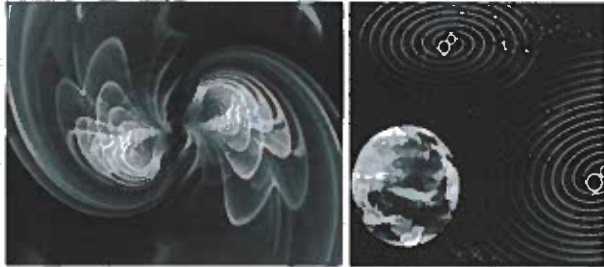


Figure 2. L: A computer simulation of gravitational waves radiating from two merging black holes. R: Gravitational waves emitted by mergers.

Creation of heavy elements

It has been found that heavy, such as heavier than Zn in the periodic table, element are produced by rapid process, called the r-process, during supernova explosions. However, there is lack of understanding of the r-process. Heavy elements are also created inside the star through neutron captures but in a very slow process called s-process.

During the discovery of merger of two neutron stars on Aug. 17, 2020, LIGO and Virgo detectors detected a gravitational-wave signal possessing an extraordinary amount of electromagnetic

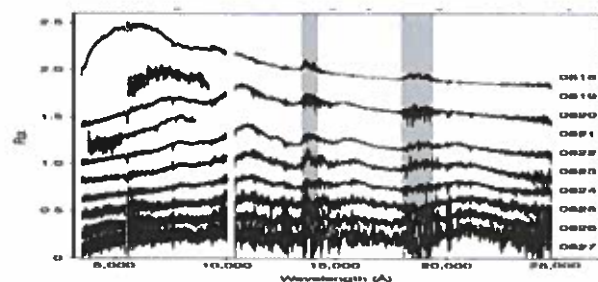


Figure 3: Time variation of kilonova spectra from August 18 (top curve) to 27 (lowest curve) in 2017 shows the peak emission in the optical wavelength range (5000 Å) shifting to NIR 2.5 μm (Pian et al 2017). The spectra correspond to emission of lanthanides.

energy, something like a billion times the energy of the luminosity of the Milky Way. The electromagnetic energy corresponded to emissions by heavy elements, called the lanthanides (Figure 3).

Lanthanides are the 15 elements in row of elements with atomic numbers from 57 (La - lanthanum) to 71 (Lu - lutetium) in the periodic table, the row above the last one in Figure 4. The chart below shows the periodic table of elements from the NIST (National Institute of Standards and Technology).

Figure 4: Periodic table of elements

It may be noted that the periodic table lists 118 elements. The yellow boxes contain the heavy elements that have been artificially produced in the laboratory. They are not found on the Earth. However, some of them have been detected in the astrophysical spectra indicating these elements form naturally.

Detection of lanthanides has revealed that kilonova event of mergers of neutron stars or black holes is another way of having the r-process for creation of heavy elements. J. Johnson (Science 2019) of OSU has created a version of the periodic table, Figure 5, that shows the origin of the elements that we know.

This version of the table includes all seven processes for the creation of all elements in the periodic table where colors in each element box indicate the process of creation of the element: 1) Big



bang fusion (black), 2) cosmic ray fission (purple), 3) exploding massive stars (turquoise), 4) exploding white dwarfs (light blue), 5) exploding neutron stars (orange), 6) dying low-mass stars (yellow), 7) Very radioactive isotopes. Although this version of the periodic table is becoming popular, there is another version produced by another team using theoretical model which has some disagreement with this present version. More accurate version will come with more observations and more accurate calculations. These recent developments will

increase our knowledge considerably in the near future.

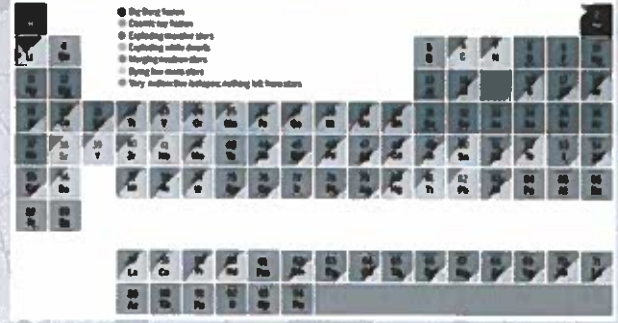


Figure 5. A version of the Periodic table showing origin of creation of elements (Johnson 2019)



নাগরিক বিজ্ঞান

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ইউনিভার্সিটি অফ টেক্সাস অ্যাট অস্টিন
যুক্তরাষ্ট্র

করোনার সুবাদে ইদানিং অণুজীব বিজ্ঞান বলে একটা বিষয়ের ওপর জাতির চোখ পড়েছে।

অসম্ভব ছোট ছোট কিছু বস্তু আমাদের সমস্ত পরিবেশ ছেয়ে আছে- ভাতের প্লেট থেকে সাগর মহাসাগর পর্যন্ত। এমনিতে এদের সাথে আমাদের সখ্যতাই থাকে। কিন্তু অসাবধানে আমরা যদি তাদের পাতা সংসারে হাত দেই- তাহলে বিপদ। নতুন করোনাভাইরাস এতদিন বনেবাদাড়ে বাদুড় আর বনরুইয়ের পেটে ছিল, তাতে সমস্যা ছিল না। সমস্যাটা বীধল যখন একদল অতি বুদ্ধিমান মানুষ মনে করল- বনরুইগুলো ধরে ধরে এদের গায়ের আঁশগুলো ছ্যাঁচা দরকার। সেই গুঁড়ো দিয়ে ওষুধ বানানো যাবে। এরকম বনের জীবকে নিয়ে টানাহ্যাঁচড়া ব্ল্যাকমার্কেট করলে ভাইরাসের ছল গায়ে বিধবেই।

যত জায়গায় অণুজীব সংক্রান্ত যতরকম বিপদ ঘটে, সবকিছুর পেছনেই আমাদের কোন না কোন বেআক্কেলেপনা থাকে।

দক্ষিণ আমেরিকায় হাইতি বলে একটা দেশ আছে। আজ থেকে বছর দশেক আগে সেখানে ভয়াবহ এক কলেরা প্রাদুর্ভাব হয়। কলেরা জানেন তো? এই রোগে ধরলে শরীরের যাবতীয় পানি স্রোতের মত সামনে পেছনে দিয়ে বেরিয়ে আসে- কেউ যেন দেহের ফ্লাশ টেনে দিয়েছে।

আমাদের দেশে এটা নিতান্তই পরিচিত ব্যাপারে, বছরে বার দু'য়েক করে কলেরার ধাক্কা আসে। কিন্তু হাইতিতে বিগত এক শতকে এই জিনিস এই প্রথম- রীতিমত চোখের পলকে এসে সে হাইতির দু'লাখ মানুষকে শুইয়ে দিল, আরো দশলাখকে শরণার্থী বানিয়ে ছাড়ল।

তো এই মহাবিপদটার সূত্রপাত কোথায়? এখন বিজ্ঞানীরা এর উত্তর জানেন।

দু'হাজার চারের দিকে হাইতিতে জাতিসংঘের শান্তিরক্ষী বাহিনীর জমায়েত শুরু হয়। উদ্দেশ্য ছিল দেশটার রাজনৈতিক দাঙ্গাহাঙ্গামা সামলানো। এদের মধ্যে নেপালী একটা গ্রুপ পেটে কলেরার জীবাণু নিয়ে গিয়েছিল, আর তাদের ক্যাম্প থেকেই নর্দমার পাইপ লিক হয়ে কলেরা বাবাজী নদীতে গিয়ে পড়েছে। আর যাবে কোথায়, সেই নদীর পানি ব্যবহারের সূত্র ধরে মহামারীর আগুন ছড়িয়ে গেল।

এসব দুর্ঘটনার নীতিকথা হল, প্রকৃতির সাথে সমঝে চলার একটা ব্যাপার আছে। বিশেষ করে প্রকৃতির এই অদেখা বাসিন্দাদের সাথে। এদের সাথে বেমক্কা ঠোকাঠুকি লাগলে প্রলয় ঘটে যেতে পারে। সেই ঠোকাঠুকিটা যাতে না লাগে, এজন্য আসলে জানতে হবে এদের জীবনধারা ঠিক কেমন। এরা কোথায় থাকে না থাকে, কী খায়, কীভাবে