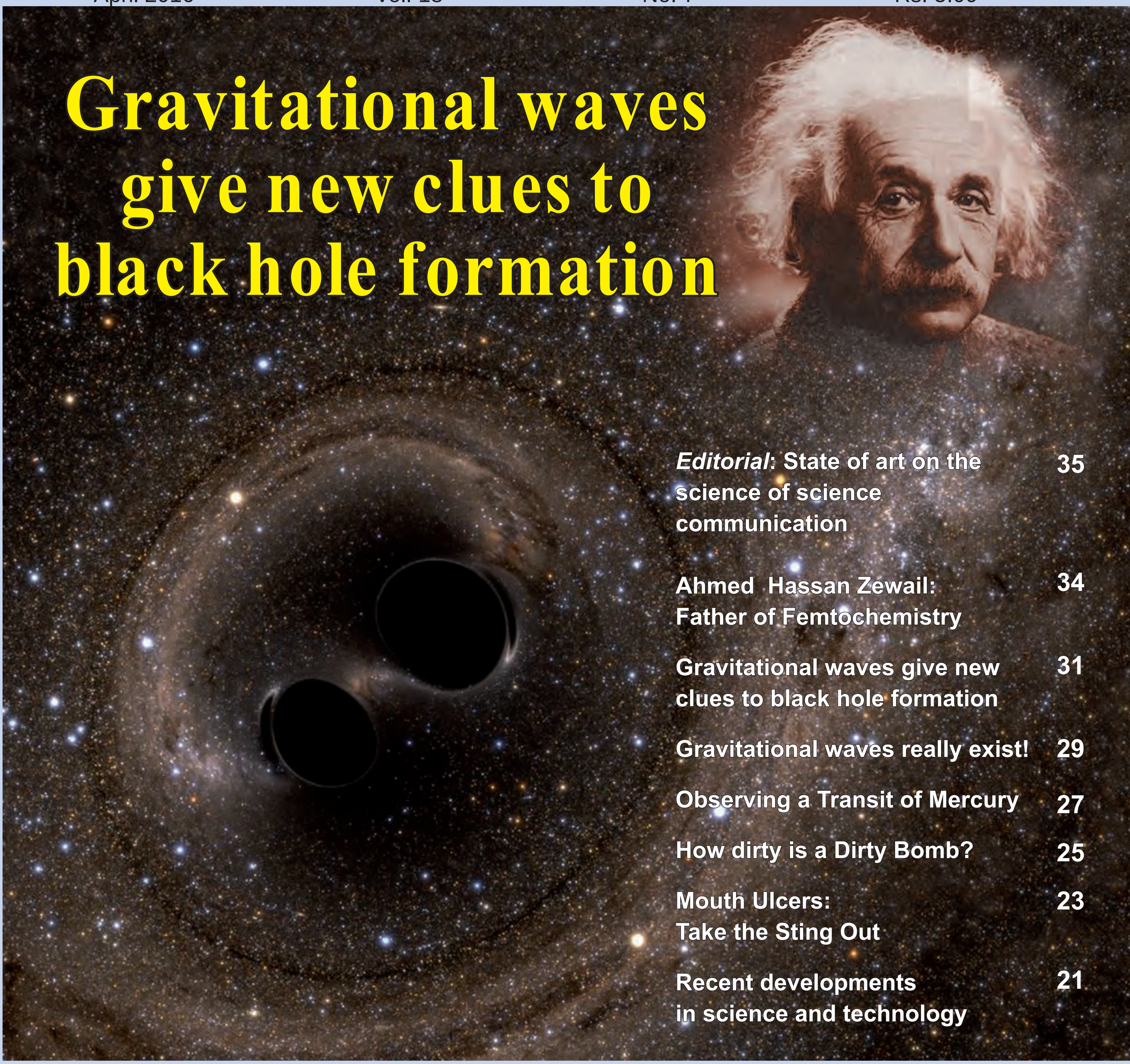
R.N. 70269/98
ISSN : 0972-169X

Postal Registration No.: DL-SW-1/4082/15-17
Date of posting: 26-27 of advance month
Date of publication: 24 of advance month

Vigyan Prasar

DREAM 2047

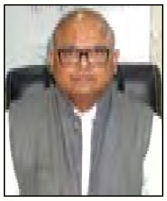
April 2016 Vol. 18 No. 7 Rs. 5.00



Gravitational waves give new clues to black hole formation

... think scientifically, act scientifically... think scientifically, act scientifically... think scientifically, act...

State of art on the science of science communication



Dr. R. Gopichandran

The National Academies of Sciences, Engineering, and Medicine that met in Washington DC last month[1] deliberated on the forms and functions of science communication. They raised 14 important questions pertaining to three important strands of science communication. It is refreshing to note they are included as part of a research agenda. Refreshing because it creates a window of opportunity for fellows like me to inform recalcitrant minds that science communication is as scientific a pursuit as tinkering with hard and soft tools/techniques/models and that it calls for a logical framework to pursue it as an inclusive engagement process. I call this state of the art also because it is probably amongst the most recent and recognises several interfaces of science communication with real quality-of-life implications. The parameters implicit in the framework can be suitably superimposed on locations and related challenges across political, social and cultural contexts.

Please look at the 14 questions carefully. I compliment the academies for this timely deliberation. It is timely because opportunities for science communication are growing significantly. Communicators can use these 14 questions to strengthen the logical frameworks of their interventions. Public policies that invite communities to understand the implications of developments in science and technology because of their influence on quality of life provide templates for communication-based engagement. India's robust development-oriented approaches establish a real-life connect with even such aspects as waste management, sanitation and health. Will it not be wise to also see if the spread and depth of circumstances that transform learning to action are aligned with the stated goals of reducing externalities? Some of the focal points of such enabling circumstances include the architecture and ease of implementing regulations, support through incentives/disincentives and institutional mechanisms that deliver information in a timely manner. The latter should also build capacities to engage in well informed collective action. It is high time these three aspects receive their due attention by communicators. They need to "also" go beyond top-down deficit-model based supply of information on basics of science and technology. "Also", because we cannot defocus from basics and that alone cannot be the whole programme.

I invite responses from such communicators/managers of communication programmes who believe science communication is not 'scientific' enough and science communicators are not scientists. Please look up the 14 questions from the cited reference and try to justify the stand that science communicators are not scientists. I invoke a call for rational thinking that science communication dynamics is as robust a field of science as hard/soft tools/techniques/models. The ability to use, devise and apply logical frameworks calls for a synthesis of qualitative and quantitative attributes of content, timeliness, tools of communication, interpretation of biases and the ability to develop scenarios about engagement that can be successful or otherwise.

I once again congratulate the Academies in the stated reference for their deliberations. I reinforce my submission about the urgent need to respect science communicators as scientists with a call that science communication should not be trivialized as cosmetic. In fact science communication is probably a platform for convergence for policies, programmes and their impacts. Please also look up the 2030 Agenda for Sustainable Development. The 17 goals and 169 targets are excellent platforms for engagement. Is it possible to even remotely argue these are "too scientific" for science communication/ communicators? Another classic reference in this context is also presented for your reference[2]. This also means we need to go beyond an overemphasis on beliefs and related branding. Studies on beliefs as thrusts for science communication should be truly incisive to respect cultural and developmental priorities of communities they interpret. It is important to also propose ways and means of overcoming challenges and not stop at some self perpetuating inferences that could be speculations at best.

References secured on 14 March 2016.

1. 2016 The National Academies of Sciences, Engineering, Medicine Committee on the Science of Science Communication: A Research Agenda Meeting #2 February 24-25, 2016 Keck Center, Room 201 500 5th Street NW Washington, DC 20001 http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_170866.pdf
2. 2014 Communicating Science to the Public; Opportunities and Challenges for the Asia Pacific Region Springer http://www.springer.com/in/book/9789401790963

Email: r.gopichandran@vigyanprasar.gov.in

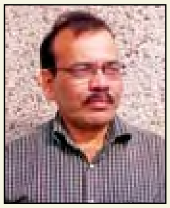
Editor : R Gopichandran
Associate editor : Rintu Nath
Production : Manish Mohan Gore and Pradeep Kumar
Expert member : Biman Basu
Address for correspondence : Vigyan Prasar, C-24, Qutab Institutional Area, New Delhi-110 016
Tel : 011-26967532; Fax : 0120-2404437
e-mail : info@vigyanprasar.gov.in
website : http://www.vigyanprasar.gov.in

Vigyan Prasar is not responsible for the statements/opinions expressed and photographs used by the authors in their articles/write-ups published in "*Dream 2047*"

Articles, excerpts from articles published in "*Dream 2047*" may be freely reproduced with due acknowledgement/credit, provided periodicals in which they are reproduced are distributed free.

Published and Printed by Manish Mohan Gore on behalf of Vigyan Prasar, C-24, Qutab Institutional Area, New Delhi - 110 016 and Printed at Aravali Printers & Publishers Pvt. Ltd., W-30, Okhla Industrial Area, Phase-II, New Delhi-110 020 Phone: 011-26388830-32.

Ahmed Hassan Zewail Father of Femtochemistry



Dr. Subodh Mahanti
E-mail: subodhmahanti@gmail.com

"As a boy it was clear that my inclinations were toward the physical sciences. Mathematics, mechanics, and chemistry were among the fields that gave me a special satisfaction. Social sciences were not attractive because in those days much emphasis was placed on memorization of subjects, name and the like, and for reasons unknown (to me), my mind kept asking 'how' and 'why'. This characteristic has persisted from the beginning of my life. In my teens, I recall feeling a thrill when I solved a difficult problem in mechanics for instance, considering all of the tricky operational forces of a car going uphill or downhill. Even though chemistry required some mathematization, I was intrigued by the 'mathematics of chemistry'."

Ahmed H. Zewail (www.zewail.caltech.edu/biography/Autobiography.pdf)

"Ahmed Zewail is being awarded the Nobel Prize in Chemistry because he was the first to conduct experiments that clearly show the decisive moments in the life of a molecule – the breaking and formation of chemical bonds. He has been able to see the reality behind Arrhenius theory. It is of great importance to be able in detail to understand and predict the progress of a chemical reaction. Femtochemistry has found applications in all branches of chemistry, but also in in adjoining fields…Femtochemistry has radically changed the way we look at chemical reactions. A hundred years of mist surrounding the transition state has cleared."

Professor Bengt Norden, in his Presentation Speech for the 1999 Nobel Prize in Chemistry

Antonio Machado (1875-1939), the Spanish poet, wrote: "Wanderer, your footsteps are the road, and nothing more; wanderer, there is no road, the road is made by walking." This is a profound truth. However, very few dare to walk uncharted terrains and create new road, the majority feel comfortable on walking a well-trodden road. Ahmed Zewail is one of those few with the necessary courage and conviction to dare to create new road. He created a new field of chemistry called femtochemistry. He was awarded the 1999 Nobel Prize in Chemistry "for his studies of the transition states of chemical reactions using femtosecond spectroscopy." He is the first Egyptian to receive a Nobel Prize in science. He became the third Egyptian to receive a Nobel Prize; the other two were: Anwar Al-Sadat, a former President of Egypt (1978, Peace), and Naguib Mahfouz (1998, Literature).

Ahmed Zewail is regarded as the Father of Femtochemistry – the study of chemical reactions across femtoseconds. This has been possible by using a rapid ultrafast laser technique, consisting of ultrashort laser flashes. Femtochemistry allows scientists to study the most elementary motions of atoms during chemical change, namely breaking, making and transforming chemical bonds that take place at very short time-scales of few femtoseconds. These are indeed very short time-scales as 1 femtosecond is equal

Ahmed H. Zewail

to 10^{-15} second or 0.000 000 000 000 0001 second, which is to a second as a second is to 32 million years! At such short time-scale the distance travelled is very small and chemical and biological processes appear 'frozen' in time.

To understand what we mean by femtochemistry, it will be better if we quote its founder, Zewail. In his Nobel Lecture, Zewail said: "Observation of the very act that brings about chemistry – is the wellspring of the field of femtochemistry, which is the study of molecular motions in the hitherto unobserved ephemeral transition states of physical, chemical and biological changes." Further, in one of his papers titled, "Femtochemistry – Past, Present and Future", Zewail wrote: "Actual atomic motions involved in chemical reactions had never been observed in real time despite the rich history of chemistry of over two millennia.

Chemical bonds break, form, or geometrically change with awesome rapidity. Whether in isolation or in any other phase, this ultrafast transformation is a dynamic process involving the mechanical motion of electrons and atomic nuclei. The speed of atomic motion is ~ 1 km/second and hence, to record atomic-scale dynamics over a distance of an angstrom, the average time required is ~100 femtoseconds (fs). The very act of such atomic motions as reactions unfold and pass through their transition states is the focus of the field of femtochemistry. With fs time resolution we can "freeze" structures far from equilibrium and prior to their vibrational and rotational motions, or reactivity."

The Nobel Foundation's Press Release announcing the 1999 Nobel Prize in Chemistry to Ahmed H. Zewail noted: "Femtochemistry has fundamentally changed our view of chemical reactions. From a phenomenon described in relatively vague metaphors as 'activation' and 'transition scale' we can now see the movements of individual atoms as we imagine them. They are no longer invisible. Here lies the reason why the femtochemistry research initiated by this year's Nobel Laureate has led to explosive development. With the world's fastest camera available, only the imagination sets bounds for new problems to tackle."

Antonio Machado, the Spanish poet

Zewail's pioneering contributions brought about a revolution in chemistry and related scientific fields. With the emergence of femtochemistry we can now explain why certain chemical reactions take place and not others and the effect of temperature on the speed and yield of reactions. It has wide range of applications, ranging from the functioning of catalysts and design of molecular electronic components to the mechanisms of important life processes and the production of future medicines. The femtochemistry technique developed by Zewail may be described as the world's fastest camera. Before femtochemistry came into being, the actual atomic motions involved in chemical reactions could not be investigated in real time because these processes take place with awesome rapidity.

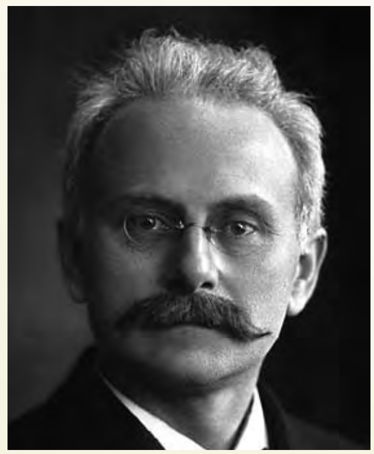
Ahmed Hassan Zewail was born on 26 February 1946 at Damanhur, the "city of light", only 60 km away from Alexandria, "the home of ancient learning". He spent his childhood in Disuq (also spelt as Desouk), a small town in the delta of the Nile. Recalling his early childhood, Zewail wrote: "The dawn of my memory begins with my days, at Disuq's preparatory school. I am the only son in a family of three sisters and two loving parents. My father was liked and respected by city community – he was helpful, cheerful and very much enjoyed his life. He worked for the government

Anwar Al Sadat, the Egyptian President

and also had his own business. My mother, a good-natured, contented person, devoted all her life to her children, and, in particular, to me. She was central to my "walks of life" with her kindness, total devotion and and native intelligence." Besides his parents, Zewail was greatly influenced by one of his uncles: "Uncle Rizk was special in my boyhood years and I learned much from him – an appreciation for critical analyses, an enjoyment of music and intermingling with the masses and intellectuals alike."

After completing his school education, Zewail joined Alexandria University. He graduated with a degree of Bachelor of Science with the highest honours (Distinction with First Class Honour). After his graduation, he was appointed as a demonstrator ('Moeid') at Alexandria University. He had to undertake classes for undergraduate students. The appointment also allowed him to carry out research work toward a Master's degree and then a PhD. He completed the required research work for his Master's degree in about eight months. The topic of his research work was to study the effects of solvents on the spectra of certain molecules. Based on his research work he published several research papers. He did not remain at Alexandria University to work for his PhD degree, though his appointment was a tenured position and after his completion of his PhD degree he was to get a faculty position. Encouraged by one of his teachers, Professor El Zaby, he decided to go to the United States. He got offers from a number of US universities, but finally he decided to work in the Laboratory for Research on the Structure of Matter (LRSM) at the University of Pennsylvania. His research adviser was Robin Hochstrasser. Recalling his days of PhD work at the Pennsylvania University, Zewail wrote: "I was working almost 'day and night', and doing several projects at the same time. The Stark effect of simple molecules; the Zeeman effect of solids like NO_2- and benzene; the optical detection of magnetic resonance (ODMR); double resonance techniques, etc. Now, thinking about it, I cannot imagine doing all this again, but of course then I was 'young and innocent'".

After completing his PhD, Zewail went to the University of California, Berkeley to work as a Post-Doctoral Fellow, where he worked with Charles B. Harris. In 1976, Zewail left Berkeley to join the California Institute of Technology (Caltech) as a faculty member.

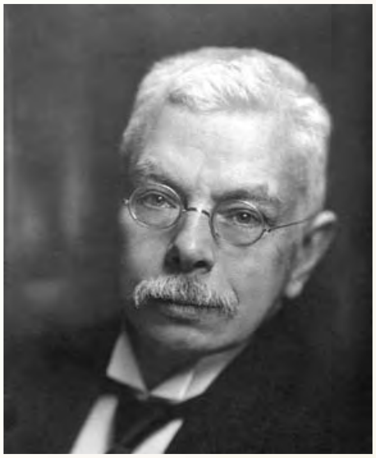


Johannes Stark

Zewail developed a deep interest in music in his childhood and continued to nurture this interest. In his autobiographical write-up written for the Nobel Foundation, Zewail wrote: "Culturally, my interests were focused – reading, music, some sports and playing backgammon. The great singer Um Kulthum (actually named Kawkab Elsherq – a superstar of the East) had major influence on appreciation of music. On the first Thursday of each month we listened to Um Kulthum's concert – "waslats" (three songs) – for more than three hours. During all my study years in Egypt, the music of this unique figure gave me special happiness and her voice was often in the background while I was studying mathematics, chemistry…etc. After three decades I still have same feeling and passion for her music. In America, the only music I have been able to appreciate on this level is classical, and some jazz and still is my real joy."

Zwail has published over 600 research papers and has edited a number of books including *Adavances in Laser Spectroscopy* (SPIE, Belingham, 1977), *Advances in Laser Spectroscopy* (Springer-

Verlag, Berlin-Heidelberg, 1978); *Photochemistry and Photobiology,* Vols. 1-2 (Harwood Academic, London, 1983); *Physical Biology: From Atom to Medicine* (Imperial College Press, London, 2009). He has also written two biographical works namely, *Voyage through Time: Walks of Life to the Nobel Prize* (American University of Cairo Press, Cairo, 2002) and *Age of Science* (Shoruk House for Publishing and Distribution, 2005). The *Age of Science,* originally written in Arabic, discusses about the relationships between Islam and Science in the Age of Science but this is also an autobiography of Zewail.



Peter Zeeman

Zewail has received innumerable prizes including the Nobel Prize in recognition of his significant work. It is not simply possible to list all the prizes received by Zewail. Some of the important prizes that he received are: *Buck-Whitney Medal* of the American Chemical Society (1985); *Harrison Howe Award* of the American Chemical Society (1989); *King Faisal International Prize* in Science (1989); *Carl Zeiss International Award,* Germany (1992); *Wolf Prize* in Chemistry of the Wolf Foundation, Israel (1993); *Earle K. Plyler Prize* of the American Physical Society (1993), Medal of the Royal Netherlands Academy of Arts and Sciences, Holland (1993); *Herbert P. Broida Prize* of the American Physical Society (1995); *Leonardo Da Vinci Award* of Excellence, France (1995); *College de France Medal*, France (1995); *Peter Debye Award* of the American Chemical Society (1996); *National Academy of Sciences Award*, Chemical Sciences, USA (1996); *Peking University Medal*, Beijing, China (1996); the *First E. B. Wilson Award* of the American Chemical Society (1997); *Linus Pauling Medal Award* (1997); *William H. Nicholas Medal Award* (1997); Richard C. Tolman Medal Award (1998); *Paul Karrer Gold Medal*, University of Zurich, Switzerland (1998); *E. O. Lawrence Award*, US Government (1998); *Roentgen Prize* (100th Anniversary of the Discovery of X-rays), Germany (1999); *Grand Collar of the Nile,* the Highest State Honour conferred by the Egyptian President (1999); the *Priestley Medal* from the American Chemical Society (2011); and *Davy Medal* from the Royal Society of London (2011).

On 27 April 2009, US President Baraka Obama appointed Zewail to the President's Council of Advisors on Science and Technology. In January 2010, Ahmed Zewail along with Elias Zerhouni and Bruce Alberts became the first US envoys to Islam. They visited Muslim majority countries in North Africa to Southeast Asia.

The achievements of Zewail are truly significant and revolutionary. How could he achieve so much? Zewail in his autobiographical work, *Voyage Through Time: Walks of Life to the Nobel Prize*, wrote: "I don't know all the reasons for these achievements, but I know that I love what I do and I have never wanted to rest on my laurels." In his Commencement Address at the California Institute of Technology (10 June 2011), Zewail said: "When I came to the United States in 1969, I was not dreaming of a Nobel Prize, nor was I dreaming a Bill Gates fortune. Armed with excellent education I received in Egypt, I was simply on a quest for knowledge and a PhD degree from a reputable institution in the United States."

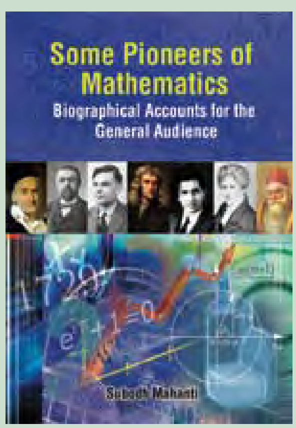
In 1982, Zewail became a natural citizen of the USA. Currently Zewail is the Linus Chair Professor of Chemistry, Professor of Physics and Director of the Physical Biology Centre for the Ultrafast Science and Technology at the California Institute of Technology.

Zewail's message for the young people is: "Always be guided by the light of knowledge and wisdom to shape your future, the future of your country, and the future of the world."

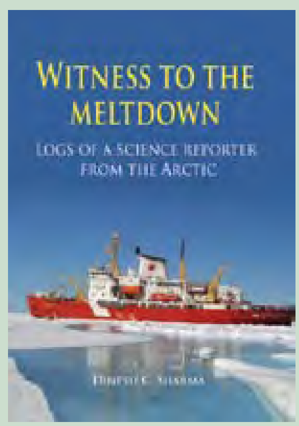
(*The article is a popular representation of the important points on the life and work of Ahmed Hassan Zewail available in the existing literature. The idea is to inspire the younger generation to know more about Ahmed Hassan Zewail. The author is grateful to those whose works have contributed to writing this article.*)

Dr. Subodh Mahanti worked in Vigyan Prasar (1994-2014) and co-ordinated several science popularisation projects. He has written extensively. He writes both in Hindi and English.

Recent Publications of Vigyan Prasar



Some Pioneers of Mathematics
Biographical Accounts for the General Audience
Author: Subodh Mahanti
ISBN: 978-81-7480-264-4
Price: ₹200



Witness to the Meltdown
Logs of A Science Reporter from the Arctic
Author: Dinesh C Sharma
ISBN: 978-81-7480-266-8
Price: ₹200

Story of the Sky
Author: Samar Bagchi
ISBN: 978-81-7480-272-9
Price: ₹50

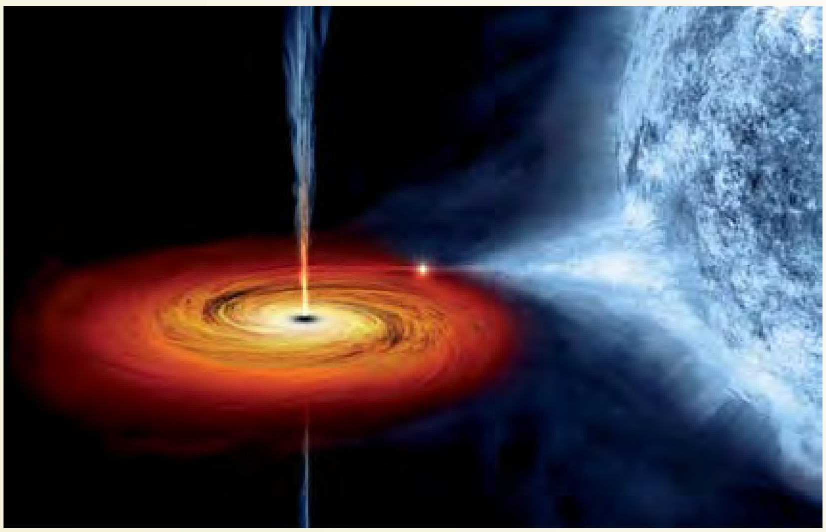
Gravitational waves give new clues to black hole formation

Biman Basu
E-mail: bimanbasu@gmail.com

Ever since the news broke of the first direct detection of gravitational waves by the Advanced Laser Interferometer Gravitational-wave Observatory, or LIGO, a lot has been written about the historic discovery, but few have pointed to the mystery of the masses of the two black holes, located 1.3 billion light-years away, the merger of which is believed to have created the ripples in space-time detected by LIGO. According to the scientists, this is the first black-hole merger that scientists have observed. The violent event radiated more energy in a short time – in the form of gravitational waves – "than all the stars in the observable Universe emitted as light in the same amount of time".

Gravitational waves were predicted by Albert Einstein more than 100 years ago in his general theory of relativity. In 1916, Einstein had predicted that rapid movement of massive objects would create ripples in the fabric of space-time that would propagate at the speed of light throughout the universe. He also predicted that ripples caused by the motion of large masses like binary neutron stars or black holes should be large enough for us to detect them across light years on Earth. Scientists have been trying to detect the elusive ripples for several decades including an attempt in the 1960s by American physicist Joseph Weber to detect them directly using a huge aluminium cylinder. But none succeeded till LIGO first detected them on 14 September last year.

Indirect evidence of gravitational waves was, however, found as far back as 1974 when American physicists Russell Hulse and Joseph Taylor observed the motion of a pulsar orbiting another star. Pulsars are extremely dense, rapidly rotating neutron stars that emit regular radio pulses. The timing of these pulses is so precise that they can be used to measure the pulsar's position and motion with extreme accuracy. What the two physicists found was that the orbit of the pulsar decayed over time as energy radiated away from the system as gravitational waves.



An artist's drawing a black hole named Cygnus X-1. It formed when a large star caved in. This black hole pulls matter from blue star beside it. (Credits: NASA/CXC/M. Weiss)

The rate of this energy decay matched the predictions of general relativity, confirming the existence of gravitational waves, although it was indirect evidence. For this discovery Hulse and Taylor were jointly awarded the Nobel Prize in Physics in 1993.

According to the LIGO scientists, in the present case, merger of two black holes with masses 36 and 29 times that of the mass of the Sun (as obtained through computer simulations) gave rise to the gravitational waves that were detected by the LIGO instruments. Here the masses of the black holes appear rather unusual because stellar black holes formed by the collapse of massive stars usually come with 10-15 solar masses, although supermassive black holes with millions of solar masses residing at the centre of our galaxy and many others are also known. But black holes with 30-35 solar masses were unknown, No one had ever detected so heavy "stellar mass" black holes, and they are hard to fit into current theory.

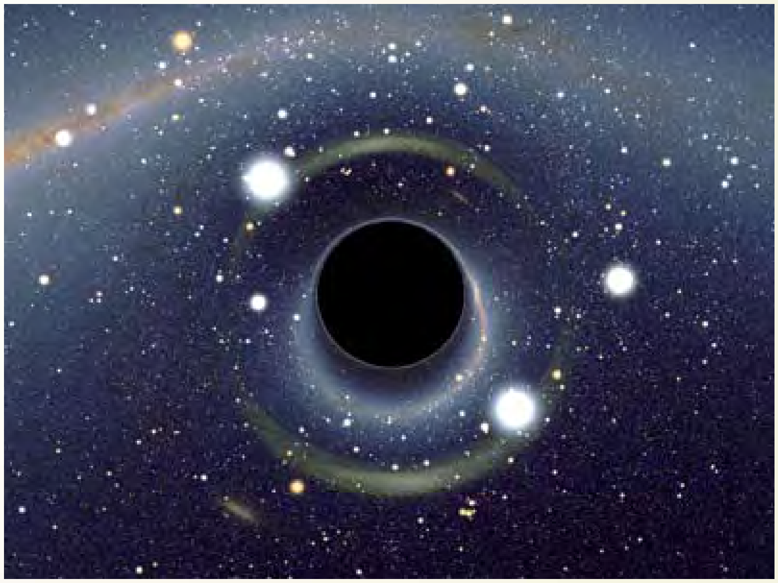
It is well known that a black hole is formed when a massive star with a mass larger than 20 solar masses burns out and collapses at the end of its life. When a very massive star exhausts its nuclear fuel it explodes as a supernova. The outer parts of the star are expelled violently into space, while the core completely collapses under its own weight. If the core remaining after the supernova is very massive (more than 2.5 times the mass of the Sun), no known repulsive force inside a star can push back hard enough to prevent gravity from completely collapsing the core into a black hole.

Since black holes do not emit light or any electromagnetic radiation they cannot be detected by optical or radio telescopes and their presence can only be inferred from their gravitational effect on nearby stars and detection of the high-energy radiation emitted by swirling matter falling into them. Astrophysicists have spotted stellar-mass black holes in our galaxy mainly by searching for systems in which a black hole devours a companion star, emitting high-energy radiation. By observing the motion of the companion star and the gas streaming into the black hole, they have deduced that the heaviest of them has a mass about 15 times as much as the Sun. Then how do 30-35 solar mass black holes form?

According to astrophysicists, a star big enough to produce a 30-stellar-mass black hole would have to be very unusual. That is because according to theory any massive star that contains elements heavier than helium will lose mass as it burns out. Ions of oxygen, calcium, and iron will be blown out into space by the star's hot atmosphere thus making the star keep losing mass.

Radiation-driven mass loss is a key process in the evolution of massive stars. According to Jeffrey McClintock, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, "If you start with a 40-solar-mass star, by the time of collapse it's down to 10 solar masses".

Physicists have come up with two possibilities to account for the 30-35 solar mass black holes. One is that the original stars formed very early, when the universe was just a couple of billion years old and contained only hydrogen and helium. (Heavier elements were formed later in supernova explosions.) But it is also known that massive stars burn out faster – in a few million years – and it is difficult to explain how black holes formed out of them could have survived for billions of years before spiralling together. The other possibility is, the stars were probably born more recently, in dwarf galaxies like the Large Magellanic Cloud that are lower in heavy elements than the Milky Way is.



Simulated view of a black hole (centre) in front of the Large Magellanic Cloud. Note the gravitational lensing effect, which produces two enlarged but highly distorted views of the Cloud. Across the top, the Milky Way disk appears distorted into an arc. (Credit: Wikimedia)

An interesting twist to the formation of twin black holes in the present case came up following detection of a gamma-ray burst by the Fermi Gamma-ray Space Telescope just 0.4 second after the signal was received by LIGO. According to researchers of the Harvard-Smithsonian Center for Astrophysics (CfA), this may indicate that the two black holes might have been formed from a single, massive star whose death generated the gamma-ray burst. "It's the cosmic equivalent of a pregnant woman carrying twins inside her belly," says Harvard astrophysicist Avi Loeb.

The explanation offered is simple: Normally, when a massive star reaches the end of its life, its core collapses into a single black hole. But, the researchers say, if the star was massive enough and spinning very fast, its core might stretch into a dumbbell shape and fragment into two clumps, each forming its own black hole. If true, this may be yet another way black holes could form from massive stars.

Researchers believe that in the next 2 or 3 years, LIGO could spot dozens of black hole mergers, the analysis of which could probably "reveal which formation scenario happened more often, throwing new light on black hole formation".

At present three detectors – two units of LIGO in the US and VIRGO of the European Gravitational Observatory in Italy – are being used for detection of gravitational waves. Looking farther ahead, LIGO researchers hope to greatly improve their ability to pinpoint sources in the sky by adding a fourth detector to the LIGO-Virgo network, in India. To be known as LIGO-India, the facility will be a collaborative project between the LIGO Laboratory and the Indian Initiative in Gravitational-wave Observations (IndIGO) to create a world-class gravitational-wave detector in India. The LIGO Laboratory, in collaboration with the US National Science Foundation and Advanced LIGO partners from the UK, Germany and Australia, has offered to provide all of the designs and hardware for one of the three planned Advanced LIGO detectors to be installed, commissioned, and operated by Indian scientists in a facility to be built in India. The Indian government has in principle approved an expenditure of 146 million US dollars for the proposed project.

In addition to throwing up questions about the formation of black holes, the detection of gravitational waves has also opened up an entirely new field of astronomy – gravitational-wave astronomy – in which scientists will listen to the waves to learn more about the objects that can produce them, including black holes, neutron stars and supernovae. Till now we could learn about the universe only using electromagnetic signals, namely visible light, radio waves, microwaves, X-rays, gamma rays, etc. Now astronomers will be able to study the universe through gravitational waves, which may reveal new, hitherto unknown objects and violent processes going on there. Gravitational-wave astronomy will also allow astronomers to look further back in time and deeper inside the most extreme objects in the universe including black holes.

Biman Basu is a former editor of the popular science monthly Science Reporter, published by CSIR, He is a winner of the 1994 'NCSTC National Award for Science Popularisation'. He is the author of more than 45 popular science books.

VP website

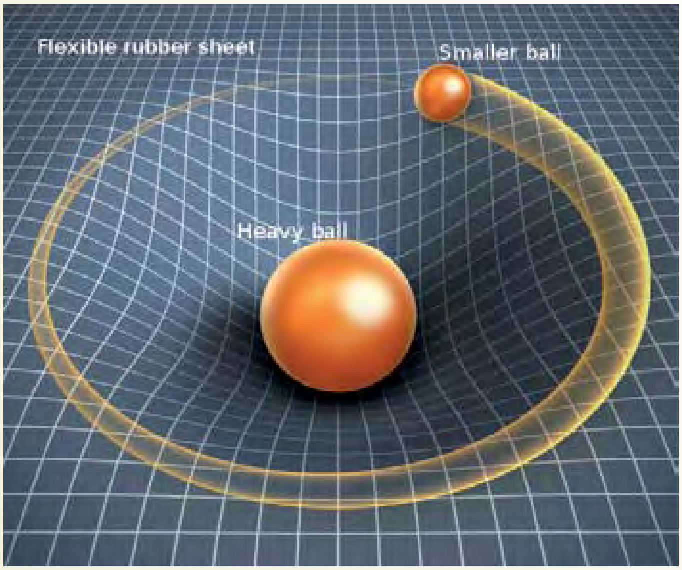
Join Vigyan Prasar digital library to read online publications. You may also join the discussion forum to ask science and technology related questions and also answer fellow participants' queries. We also have streaming science videos, science radio serials, online science quiz, hand-on activities, and many more features and programmes related to science and technology. Log-on to www.vigyanprasar.gov.in

Gravitational waves really exist!

Ashwin Kumar K
E-mail: iamashwin99@gmail.com

Gravitational waves are the last prediction of Einstein's general theory of relativity, which was formulated over 100 years ago. Scientists at LIGO (The Laser Interferometer Gravitational-wave Observatory) in the US have now successfully verified its existence. Let's look at what gravitational waves are, how they are formed and why this is a milestone discovery.

In general theory of relativity, Einstein showed us that the force of gravity is an illusion. Instead, mass warps the fabric of 4-D space-time, leading to what we see as motion under gravity. Now it turns out that general relativity makes predictions far beyond gravity. There is the deflection of light that we see as gravitational lensing. There is the slowing of time in gravitational field. There is the dragging of space-time by spinning masses (If you don't know what they are, don't worry it won't hinder the process of understanding gravitational waves). Einstein was astounding, because every one of these predictions from his beautiful work has been physically tested and verified. However, there was one last, incredible prediction that had never been directly observed (until now that is) and that was gravitational waves. The idea of gravity not as a force, but as warped space-time, is often depicted in analogy as a flexible rubber sheet being depressed by a heavy ball. Drop a heavy ball onto a stretched rubber sheet and a dip forms. When another smaller ball is brought near it, it would be dragged toward the bigger ball because of the curvature in the rubber sheet formed by the big ball. This according to general relativity is gravitational pull when the rubber sheet is the fabric of space-time, the big ball is the source of gravitation (say the Sun) and the smaller ball may be a planet. This analogy is quite good. But, for understanding gravitational waves we could develop a different analogy which will help us understand better.



Artists depiction of how mass warps the fabric of 4-D space

Consider a pond, a reservoir of calm water without any waves. Now if you put a very light object, say a paper boat, the water will be slightly depressed by the paper boat, just like the flexible rubber sheet being depressed by a heavy ball as we saw earlier. Now if you drag your fingers across the water, you generate a water wave. It is the same deal with gravitational waves. Accelerate a mass through space-time in the right way, and you produce gravitational ripples – an outflowing fluctuation of expanding and contracting space-time. Physicists sometimes call these gravitational waves "ripples in space-time", where space-time includes time as well as the three spatial dimensions we are used to. Now you may like to know what sort of movement produces gravitational waves. In general terms, gravitational waves are radiated by massive objects whose motion involves acceleration, provided that the motion is not perfectly cylindrically symmetric, like a spinning disk or sphere. Cylindrical symmetry means that we can rotate about the long axis and the system will remain same. Spherical symmetry is shown by a radially expanding or contracting sphere.

Imagine a spinning dumbbell. If the dumbbell spins like a wheel on an axle, it will not radiate gravitational waves; if it tumbles end over end, as in the case of two planets orbiting each other, it will radiate gravitational waves. The heavier the dumbbell and the faster it tumbles, the stronger would be the gravitational radiation it gives off, like in the case of neutron stars or black holes orbiting each other rapidly.

Water waves generated while dragging the finger across water surface

Now the speed of waves in our pond is determined by the physical properties of water like its density and its stiffness. Gravitational waves propagate at the speed of light. Just as the water waves die down as they go farther, the power of gravitational waves also die down inversely as a function of distance.

How do gravitational waves look like? Unlike ripples in the pond which are up-down, transverse waves, gravitational waves propagate longitudinally as a fluctuation of compressed and

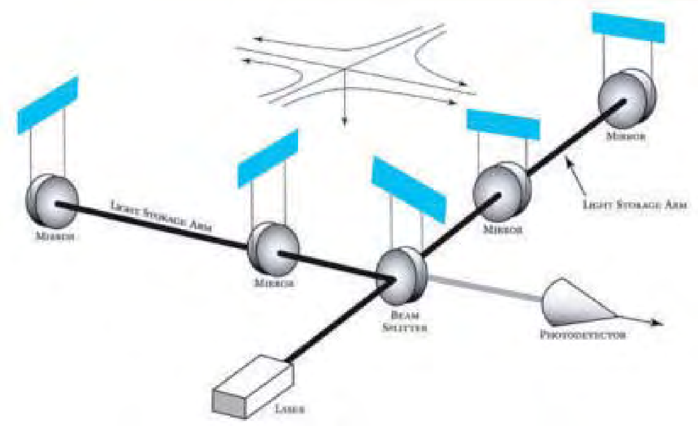


Diagram of a basic interferometer design. (Image: LIGO)

stretched space. So if a gravitational wave passes through, you will become shorter and flatter then longer and thinner. But the amount of compression and stretching would be miniscule. According to calculations, the most powerful gravitational wave passing through you would change your height by less than one-thousandth the diameter of a proton!

That is why detecting gravitational waves is a very difficult task. And it is no wonder that they remained the only major prediction of general relativity without a direct measurement. It is difficult business; so much so that an indirect measurement of gravitational waves involving pulsars by Russell A. Hulse and Joseph H. Taylor, Jr led to the 1993 Nobel Prize in Physics! But direct detection of gravitational waves can lead to a whole new level of understanding of black holes, neutron stars (pulsars), and the like.

How do you detect a change in length at the order of 10^{-18} metre? The team at LIGO found a solution. They built a detector (based on interferometry) that could do the job. The detector can be thought of as a 'gravitational wave radio', picking up waves that are in the set frequency.

The experimental setup goes something like this: Shoot a laser beam. Split it in two, and then send the twin beams at right angles down four-kilometre-long vacuum tubes. Bounce them off mirrors back and forth 400 times before bringing the beams back together. Now, if we get the length of those paths just right, we can make the peaks of one of those light waves line up with the valleys of the other, causing them to completely cancel out because of destructive interference. However, if there is a disturbance say because of a passing gravitational wave, then it will shrink one of those paths and lengthen the other, and then *vice versa*, ultimately resulting in a slight time delay in the arrival of one of the beams and causing an interference pattern.

It appears quite simple, but there is a catch – anything can cause such tiny changes in path lengths – extremely weak seismic activity, or even a car driving kilometres away. These ubiquitous terrestrial signals are regarded as noise. The good news is, a gravitational wave has a very distinct pattern, first contracting one arm while stretching the other, and then oscillating over time, rather than a static pattern as in case of a noise. But to be extra sure, it is better to detectors at multiple sites. And there are two LIGO sites – one in Washington, and one in Louisiana in the US. India is also going to have a LIGO set-up to increase the number of detectors globally.

Aerial view of the LIGO detector in Hanford, WA. (Image: LIGO)

Interestingly, between 2002 and 2010 when the LIGO was first run, it found no gravitational waves. That was partly because of the fact that violent events that give rise to these waves happen very rarely (about once every 10,000 years in a given galaxy), and also LIGO still had bare minimum sensitivity. After seeing nothing for a long time, LIGO was shut down so it could level up to advanced LIGO, which is 10 times more sensitive and could scan through 1000 times more volume of the universe! So the advanced LIGO had more chances of detection. And fairly enough, the team announced that they had detected a gravitational wave on 14 September last year. According to the announcement made on 11 February this year, the ripples were caused by two orbiting black holes when they collided and merged about 1.3 billion light years away. The LIGO team is very sure of the detection as they have taken nearly 5 months to verify that they have the real deal! Also they routinely inject false signals into the system to verify if their confirmation system is working properly.

What does this discovery mean to you and me? Probably nothing! But to scientists studying the universe it means a lot! Gravitational waves carry information on the motions of objects in the universe. Scientists feel that this is a milestone similar to the discovery of the telescope that helped us look at the universe far away from our hospitable Earth. Gravitational waves have a frequency – a number of stretches and contractions per second – that matches the rate at which black holes orbit each other just before they merge. So, just by measuring the characteristics of a gravitational wave we can tell the orbital rate of collapsing black holes several billions light years away, far beyond what we can do now. Of course, scientists at LIGO had studied black hole merger with computer simulations before they finally detected one. The physics that went into the creation of a gravitational wave is encoded in the wave itself. To extract this information, gravitational wave detectors will act very much like radios – just as radios extract the music that is encoded in the radio waves they receive. Now that we know that these waves are detectable, it opens up an entirely new window for observing the universe. It marks a new era of astronomy!

The author Ashwin Kumar K is a 12th grade student and a science enthusiast.

Observing a Transit of Mercury


Sudhindra Nath Biswas*
Dr. Utpal Mukhopadhyay**
E-mail: nath.sudhin@gmail.com
utpalsbv@gmail.com

We are all familiar with eclipses of the Sun. A transit is a less frequent and not so familiar phenomenon as an eclipse, but it is an interesting celestial event involving the Sun and one of the inferior planets – Mercury or Venus – whose orbits lie between the Sun and the orbit of the Earth. When an inferior planet, during its orbital motion, passes in front of the Sun and appears from Earth as a tiny black dot moving over the solar disc, it is called a transit of the corresponding planet. French astronomer Pierre Gassendi (1592-1655) recorded the first ever transit when he observed the transit of Mercury on 7 November 1631. A telescope was used for the first time on the Indian soil by English astronomer Jeremy Shakerley when he observed the transit of Mercury from Surat (21°10′ 13″ N, 72°45′52″ E) on 24 October 1651. Keeping in view the transit of the Mercury, scheduled to occur on 9 May 2016, let us have a look at the event in detail.

Pierre Gassendi

Four contacts of a transit

There are four stages in the transit of an inferior planet, known as 'contacts'. The moment at which the tiny dot-like disc of the transiting planet first touches the solar disc from outside is taken as 'first contact' (Fig.1a). Thus the transit of the planet begins with the first contact. After a few minutes, when the tiny black dot of the transiting planet is seen (by projecting the image of the Sun on a screen) to be completely inside the solar disc, but still touching the outer rim, the moment marks the second contact (Fig.1b). The duration between the first and contact is defined as the 'ingress' of the transit. The tiny black dot of the planet is then seen to continuously move towards the other end of the solar disc until the planet touches the outer rim of the Sun once again internally, marking the third contact (Fig.1d). Finally, the tiny dot of the planet is seen to touch the solar disc from outside as it moves away from the Sun, which is known as the fourth contact. The transit ends immediately after the fourth contact. The time interval between the third and fourth contacts is designated as the egress of the transit. After the termination of the egress, the planet disappears into the glare of sunlight. Thus the total period of a transit executed by an inferior planet is the time interval between the first and the fourth 'contacts' of the planet with the Sun.

Path of Mercury Transit 2016

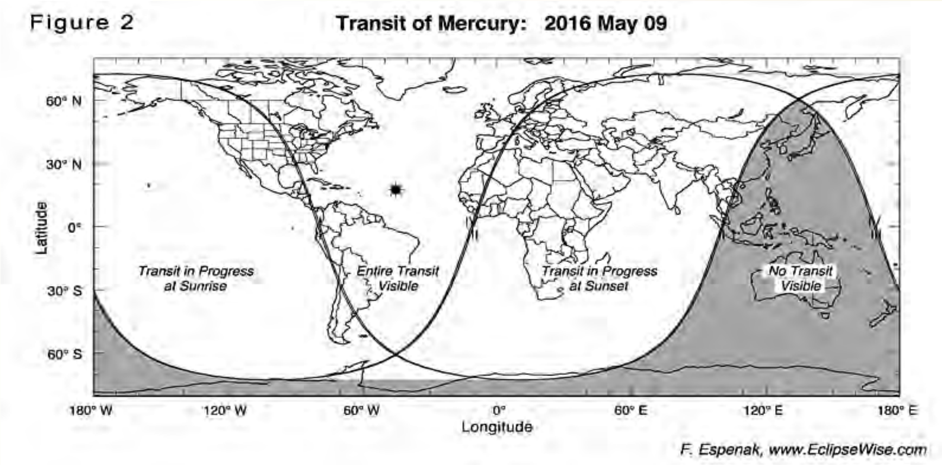
A transit of longest duration occurs at a time when an inferior planet traverses along the largest chord, i.e., the diameter of the solar disc. Such transit is known as the 'central transit'. The ingress and egress duration of the same transit of a planet are almost equal, but such duration becomes longer as the planet transits along the smaller chords of the solar disc. These phenomena are revealed from the catalogue of transits of inferior planets prepared by Fred Espenak in 2003, which has been referred hereafter as the *Catalogue of Transits 2003*. This catalogue contains the timings of 94 transits of Mercury for the period of 700 years from 1601 to 2003 AD. Due to certain celestial configuration, the transit of Mercury on 9 May, 2016, will be of 7 h 30 m duration, 16 h 42 m to 00 h 12 m IST on the next day.

Frequency of transits of Mercury

The plane on which the elliptical orbit of the Earth lies is known as the ecliptic plane**.** The apparent path of the Sun on the celestial sphere is defined as the ecliptic. The orbital plane of an inferior planet intersects the ecliptic plane along a line known as the line of nodes**.** The two end points of the nodal line are called nodes. In order to display a transit, the planet

Table 1: Contact times in UT (= IST – 5h 30m) of some transits with extreme values, including forthcoming transits of Mercury. (UT – Universal Time; IST – Indian Standard Time)

Planet	Date	Contact times				Total duration h : m
		First h: m	Second h: m	Third h: m	Fourth h: m	
Mercury	04.11.1664	15:53	15:54	21:10	21:11	5:18
	05.05.1707	19:33	19:37	03:27	03:30	7:57
	15.11.1999	21:15	21:30	21:52	22:07	0:52
	09.05.2016	11:12	11:15	18:39	18:42	7:30
	11.11.2019	12:35	12:37	18:02	18:04	5:29



has to pass through any of the nodes. The Earth crosses the nodal line of Mercury in early November and again in early May. Accordingly, the planet can be observed from Earth to execute a transit either in November (known as November transit) or in May (known as May transit). During a November transit, the orbital velocity of Mercury near its perihelion (nearest to the Sun) is 58.98 km/s and the angular diameters of the Sun and Mercury appear from the Earth as 1,937 and 10 arc seconds respectively, so that the size of the latter appears to be 1/194 of the former. The orbital velocity of Mercury near its aphelion (farthest from the Sun) is 38.86 km/s during the May transit. At that time the apparent diameter of Mercury is about 12 arc sec; that is, 1/158 of the diameter of the Sun, which is 1,902 arc sec.

Out of 94 transits of Mercury listed in the *Catalogue of Transits 2003*, there are 63 November transits and only 31 May transits. An analysis of the transit dates of Mercury from the *Catalogue of Transits 2003* reveals the component intervals between two successive transits to be 3.5, 6, 7, 9.5, and 13 years. The combination of the component intervals yields a cycle of 46 years for a particular type of transit punctuated by another cycle of 33 years after every 3 or 4 cycles of 46 years. The component intervals beginning with a November transit terminate with either November or May transit, whereas those starting with a May transit end only with a November transit. The November transits may recur after an interval of 6, 7, 13, 33 or 46 years, but May transits recur only after 13 or 33 years. The Earth crosses the nodal line of Mercury in early November from the side of its ascending node and again in early May from the side of descending node. Accordingly, the planet can be observed from the Earth to execute a transit either in November as November transit or in May as May transit.

Visibility of Mercury

The average orbital distance of Mercury from the Sun is much smaller than that of the Earth. So, the maximum elongation of Mercury – the angular displacement from the Sun – is quite small, about 28°. Due to its small angle of elongation, Mercury can be observed only for a period of 24-50 days, either in the Eastern sky before sunrise or in the Western sky after sunset, for a maximum duration of about 100 minutes on a particular day. However, the occurrence of a total solar eclipse and a transit of Mercury are the two celestial events when Mercury can be observed high up in the sky along with the Sun. During a total solar eclipse, when the Moon completely blocks the solar disc, the sky becomes totally dark for a few minutes when some bright stars and the inferior planets become visible close to the eclipsed Sun. But at the time of a transit, an inferior planet blocks a tiny part of the bright solar disc and becomes visible as a moving dark spot.

Table 2. Timings of sunrise and sunset in six major cities of India on 9 May 2016 (IST)

Name of the city	Sunrise h m	Sunset h m
Kolkata (22°34′N, 88°24′E)	04 : 57	18 : 08
Chennai (13°04′N, 80°24′E)	05 : 44	18 : 25
Bengaluru (12°58′N,77°38′E)	05 : 55	18 : 36
New Delhi (28°38′N,77°12′E)	05 : 33	19 : 01
Mumbai (18°55′N, 72°12′E)	06 : 06	19 : 03
Guwahati (26°11′ N, 91°44′ E)	04 : 39	17 : 59

Viewing of Mercury transit 2016

The transit of the Mercury on 9 May 2016 will be of about 7 h 30 m duration, beginning at 16 h 42 m IST (11 h 12 m UT). During this period the transit will be visible from all over the globe except Antarctica, Australia and Far East of Asia. The total duration of the transit, from beginning to end, will be visible only from the Western parts of Europe and Africa, North Polar Circle along with the Eastern parts of North and South America. Only the last part of the transit will be visible from the Western parts of North and South America in the morning, while in the Eastern part of Africa, Europe and Western part of Asia (including the Indian sub-continent) the transit will begin in the afternoon. In India, the Sun will set before the greatest transit occurs at 20 h 27 m IST.

The observation of a total solar eclipse or a transit of an inferior planet is a lifetime experience because such celestial events are very rare. Only about 13 or 14 transits of Mercury occur per century. But one needs to be extremely careful while observing any solar phenomenon because looking at the Sun directly or through the telescope can cause permanent damage to eyesight. So, for the safety of the eyes, never look at the Sun directly. The safest way to observe a solar eclipse or a planetary transit is by projecting the Sun's image on a screen fitted in front of the eyepiece of the telescope.

Mr. Sudhindra Nath Biswas, a retired school teacher who received National Teacher Award from the President of India. He is actively engaged in astronomy popularization programme for more than forty years.

Dr. Utpal Mukhopadhyay obtained Doctorate degree in cosmology by working on Lambda-dark energy. He is a popular science writer and science populariser.

How dirty is a Dirty Bomb?

M.S.S. Murthy
E-mail: mssmurthyb104@gmail.com

Recently newspapers reported that from the hospitals and laboratories of the Iraqi and Syrian areas seized by the ISIS forces, the jihadist groups have stolen radioactive materials. Mosul University, the second largest academic institution in Iraq, has been under the control of ISIS since June 2014. Fears are expressed that the jihadists could build "Dirty bombs" from these stolen materials. According to a media report the Iraqi Government has appealed to the United Nations for international help to "stave off the threat". Similarly, the Australian foreign minister recently acknowledged that the NATO countries are concerned about the situation.

A dirty bomb is device that combines conventional explosives such as dynamite or TNT with a radioactive material that may disperse when the device explodes. For this reason it is also called a "radiological dispersal device". The dispersed radioactive material that emits nuclear radiations like alpha particles, beta particles and gamma rays, constitute the 'dirty' part of the bomb. However, a dirty bomb is not a nuclear weapon.

What makes the security authorities so concerned about the dirty bomb? Radioactive materials like cobalt-60, strontium-90, iodine-131, caesium-137, iridium-192, polonium-210, plutonium-238, radium-226, americium-241, californium-251 are extensively used all over the world in hospitals, in agriculture, in industry and in research laboratories for diagnosis and treatment of diseases like cancer and sterilising medical products, for plant breeding and irradiating potatoes and onions to prevent sprouting while storage, for non-destructive testing of welds and casts, and for a range of experimental works. Though all countries have strict regulations dealing with the production, use and final disposal of radioactive materials, some of them are still lost or stolen each year. Though majority of them are recovered, even if a small percentage falls into the wrong hands it will be a cause for concern. In present situation all the radioactive sources in use in the territories seized by the jihadists come under their control.

Test explosion of a dirty bomb in Israel and a drone monitoring the area for radioactive dispersal (Source: Haaretz)

How does a dirty bomb work?

Any type of radioactive material can be used to spike an explosive device. The explosion tears the radioactive material into fine particles. The buoyancy of the air that has been heated in the explosion may carry the particles tens of metres above the explosion site. From there the radioactivity quickly spreads far and wide, facilitated by the blowing winds. As the plume cools, the particles settle down on whatever they intercept – buildings, people, vegetation, water bodies and so on. The dispersion decreases as one moves away from the point of detonation.

People may be exposed to the radiation emitted by these particles, either from outside the body, or from inside when they breathe the air or eat/drink food contaminated with these particles. The harmful effects of radiation on people depend upon a number of parameters like the type of radiation, amount of radiation absorbed by the body, whether the exposure is internal or external, and duration of the exposure.

For evaluating the consequences of a dirty bomb the BBC programme *Horizon* considered a hypothetical case in which 4.5 kg of Semetx (a plastic explosive) mixed with just about 20 grams of caesium-137 powder exploding in London's Trafalgar Square. For a wind speed of about 5 m/sec it is estimated that people living 3 km away from ground zero will receive a radiation dose of one millisievert (mSv) in one year. This is about half the natural background radiation (2mSv) received by everybody even without the explosion of a dirty bomb.

As one moves closer to the epicentre of the explosion, the radiation level would increase, becoming 6 times the background radiation level at 1 km, and as high as 80 times at 200 metres. These levels, however, are far too low to result in radiation sickness and fatality in the population. The lethal dose for humans (50 percent of the exposed people dying within 30 days) is estimated to be about 5,000 mSv. Hence if there is any causality following the detonation of a dirty bomb, it is caused by the initial blast of the conventional explosive and not due to radiation. However, the main concern for people close to the epicentre would be a slight increase in the risk of cancer over their lifetime (assuming that they live in that contaminated area for a year, the cancer risk would increase by less than one percent of the natural cancer risk at 200 metres and by less than 0.1 percent at 1 km distance) and an even smaller increase in the risk of genetic defects among the children born to the exposed persons. These are over and above the spontaneous risks.

Israeli newspaper *Haaretz* reported on 8 June 2015 that the country's defence forces test detonated, over a period of four years a series of 20 dirty bombs in the southern desert to study some of the parameters that affect the dispersal of radioactive materials and the resulting radiation levels. The devices were constructed using of explosive material ranging from 250 gram to 25 kg, laced with technicium-99 – a radioactive isotope used for medical imaging. Tiny drones equipped with suitable instruments were deployed to measure the radiation levels and blast force.

Close calls

Though a dirty bomb has never been used in a conflict situation, there have been several close calls. The first one occurred in November 1995 when the Chechnyan rebels disclosed that they had buried a caesium-137 source wrapped with an explosive at a park in Moscow. The police recovered it before it was activated. Again, in December 1998 Russian security forces discovered a container filled with radioactive material attached to an explosive mine near a railway line in the Chechnyan capital.

On 8 May 2002, US citizen Jose Padilla was arrested on suspension that he was planning a dirty bomb attack. In 2007, Indian-born Dhirren Barot from Northern England pleaded guilty of planning dirty bomb attacks in the UK and the US. On 30 November 2007 the on-line edition of *The Independent* reported the arrest of two Hungarians and one Ukrainian for possessing 481 gm of highly enriched, weapon-grade uranium powder. Though 20 to 25 kg of enriched uranium are required to build a nuclear weapon, small amounts are enough for a dirty bomb. The fact that the material was in an easily dispersible form was of special concern to the security authorities.

More recently in July 2014, ISIS militants seized 50 kg of unenriched uranium from Mosul University in Iraq. Though it is not enough for producing a nuclear weapon, it is good enough for a dirty bomb.

Post explosion

But how do we know that a dirty bomb has been exploded? Since we cannot see, smell or hear radiation, there are no obvious signs of its presence. Only special instruments like radiation detectors can confirm the presence of radioactivity. In some instances such instruments are installed on fire engines, since they are the first ones that arrive at the scene of explosion. Once the presence of radiation is established, experts trained in radiation emergencies will move in.

Under favourable weather conditions, it takes only a few minutes for the radioactivity to spread over a wide area. Hence, nothing can be done to stop it. All the above estimates of radiation levels are based on the assumption that no clean-up operation takes place after explosion. Hence assessing the level of radioactive contamination and decontaminating the area in the immediate aftermath of the explosion will be of prime importance in reducing the health impact of a dirty bomb.

The emergency response team will first segregate the seriously injured persons, check the level of contamination and arrange for immediate medical help. Simultaneously they may conduct land and aerial survey to assess the level of contamination and prepare for decontamination procedures. Radioactive particles get embedded in building materials and become difficult to remove them. Washing, scrubbing, removing top soil are some of the decontamination procedures. Highly contaminated buildings may have to be abandoned or pulled down. These procedures are potentially expensive and also generate a lot of waste materials which have to be treated as radioactive waste.

India's preparedness

All these operations require special training, sensitive radiation monitoring instruments, special clothing and respirators for the protection of the emergency response personnel themselves. The Crisis Management Group of the Department of Atomic Energy has developed a network of 18 emergency response centres across the country and also trained various public functionaries like customs officials, police, fire brigade, paramilitary forces to handle such situations. All these centres are linked to a nodal emergency response centre located at the Bhabha Atomic Research Centre in Mumbai.

Dos and Don'ts

Experts advise people not to panic but to remain indoors and close all the doors and windows to prevent the entry of the radioactive particles. If outdoor at the time of the blast, one should reach home as soon as possible, change clothes, take a shower and remain indoors until further instructions.

People's fear of radiation is not always logical, even when the associated health hazards are minimal. Many people consider radiation exposure freighting, because it cannot be seen or felt and hence constitutes an unknown danger. Hence, more than the health effects of radiation, dealing with the public fear may prove to be a greater challenge in the event of detonation of a dirty bomb, which in fact is the main goal of the perpetrators. For the same reason the device is also known as the "mass disruptive weapon". If more people are informed about such events, more will be better equipped to face the situation. Hence, the scientific fraternity and the media need to educate the public about the true nature of such events to help mitigate the psychological trauma and the economic loss.

M.S.S. Murthy, B-104, Terrace Garden Apartments, 2nd Main Road, BSK IIIrd Stage, Bengaluru-85.

Mouth Ulcers
Take the Sting Out

Dr. Yatish Agarwal
E-mail: dryatish@yahoo.com

The Greeks call them 'aphthous ulcers', the Americans 'canker sores', the Dutch 'sprouts' and, in North India, people give them the name of '*chhalas*'!

Believe me, ulcers in the mouth do not spare anybody. Some 1 in 5 people at some stage in their life suffer their wrath. Down the ages, they have affected kings and queens, nobles and commoners exhibiting no major love or concession for age, and defying geographic boundaries with impunity. Women are affected a little more often than men.

In spite of making their presence felt for centuries, they continue to hide their secrets pretty well. Till now, nobody knows for sure what causes them. But they are easy to identify.

Recognising them

Mouth ulcers are painful round or oval sores that form in the mouth, most often on the inside of the cheeks or lips. They're usually white, red, yellow or grey in colour and are inflammed (red and swollen) around the edge.

Mostly, they erupt suddenly, and in the beginning, may be accompanied by general symptoms like mild fever and malaise. They are shallow, have a flat and fairly even border, and the immediate surrounding area is red. Often they appear as white spots due to a false membrane covering them. They may occur singly or in multiple numbers anywhere in the oral cavity—on inner side of the lips and cheeks, or on the undersurface of the tongue.

Mouth ulcers are usually harmless. They can make things uncomfortable, especially when you eat, drink or brush your teeth. Mealtime can particularly be painful. Salty foods produce a sting, and spices and hot food are best shunned.

The good bit is these ulcers mostly heal by themselves. They usually disappear without treatment in 10-14 days. Mouthwashes and lozenges may ease the pain, and may help the ulcers to heal more quickly. But they may recur from time to time.

Types of aphthous ulcers

Minor aphthous ulcers

Eighty per cent mouth ulcers are of minor nature. They are small, round, or oval, and are less than 10 mm across. They look pale yellow, but the area around them may look swollen and red. Only one ulcer may develop, but up to five may appear at the same time. Each ulcer lasts 7-10 days, and then goes without leaving a scar. They are not usually very painful.

Major aphthous ulcers

They occur in about 10 per cent cases. They tend to be 10 mm or larger across. Usually only one or two appear at a time. Each ulcer lasts from two weeks to several months, but will heal leaving a scar. They can be very painful and eating may become difficult.

Herpetiform ulcers

Herpetiform ulcers occur in about 1 in 10 cases. These are tiny pinhead-sized ulcers, about 1-2 mm across. Multiple ulcers occur at the same time, but some may join together and form irregular shapes. Each ulcer lasts one week to two months. Despite the name, they have nothing to do with herpes or the herpes virus.

Causes of mouth ulcers

Nobody knows for definite what causes mouth ulcers. They are not contagious, and you cannot "catch" them from anybody. They are not caused by any bacteria or virus. In most cases, these ulcers develop in people who are healthy without any apparent reason.

They may, however, in some cases, be related to one or the other factor or disease. These include:

Injury

Several kinds of trivial injuries such as badly fitting dentures, or a graze from a harsh toothbrush can produce mouth ulcers.

Hormones and ulcers

Changes in the levels of sex hormones may precipitate mouth ulcers in women. Some women find that mouth ulcers occur just before their period. In some women, the ulcers only develop after the menopause.

Smoking and ulcers

Some ex-smokers find they develop ulcers only after stopping smoking.

Iron, vitamins and ulcers

A lack of iron or a lack of certain vitamins, such as vitamin B12 and folic acid may be a factor in some cases.

Food allergy and ulcers

Rarely, mouth ulcers may be caused due to a food allergy.

Genetic factors and ulcers

Mouth ulcers tend to run in some families. A genetic factor may, therefore, play a part in some cases.

Stress and ulcers

Stress or anxiety can be a potent trigger of aphthous mouth ulcers in some people. Ulcers are common among students during the exam days. Stress is also a contributory factor when these ulcers develop following a bout of fever.

Medications and ulcers

Some medications can cause mouth ulcers. Medicines that can cause mouth ulcers include anti-inflammatory medicines like ibuprofen and the anti-amoebic pills metronidazole. Oral nicotine replacement therapy can also be a culprit.

Ulcers of a different kind

People with Crohn's disease, celiac disease, HIV infection, and Behçet's disease are liable to develop mouth ulcers. However, these ulcers are not of the aphthous kind.

Red flags

You should inform your doctor if you have any of the following symptoms in addition to the mouth ulcers:

- Skin or genital ulcers
- Joint pains and inflammation.
- If severe mouth ulcers develop after taking a medicine.
- If the ulcer gets worse or lasts for longer than three weeks, or if you develop ulcers repeatedly. This is especially important if you are a smoker.
- If you notice increased pain or redness, or feel unwell with a high temperature (fever), it may indicate that a mouth ulcer has become secondarily infected with germs (bacteria). This may need treatment with antibiotics.
- Cancer of the mouth can sometimes start as an unusual mouth ulcer that does not heal. You should see a doctor or dentist if you have a mouth ulcer that has lasted for more than three weeks without sign of healing, or is different in any way. Your GP or dentist may refer you urgently to the outpatient clinic to see an ear nose and throat (ENT) specialist or an oral surgeon. A small tissue biopsy of the ulcer may be taken in clinic and examined, to exclude cancer.

Treatments for aphthous ulcers

Though mysterious in nature, the treatment of aphthous ulcers is fairly simple. The aim is to ease the pain, and to help them to heal as quickly as possible. There is no treatment that prevents aphthous mouth ulcers from recurring.

General measures

Avoiding spicy foods, acidic fruit drinks, and very salty foods (such as crisps) which can make the pain and stinging worse.

Using a straw to drink, to avoid the liquids touching ulcers in the front of the mouth. However, do not drink hot drinks with a straw, as you may burn your throat.

Using a very soft toothbrush. See a dentist if you have badly fitting dentures.

If you suspect a medication is causing the ulcers, then a change may be possible.

Warm saline rinses

This might offer good relief. Add half-a-teaspoon of common salt to a glass of lukewarm water, and rinse your mouth. Repeat this every few hours. It may be painful and the solution may sting, but the result is worth it. Such bland mouth rinses also help keep the ulcers clean.

Try chlorhexidine mouthwash

It may reduce the pain and also help ulcers to heal more quickly. It also helps to prevent ulcers from becoming infected. Use chlorhexidine mouthwash twice a day. It may stain teeth brown if you use it regularly. However, the stain is not usually permanent, and can be reduced by avoiding drinks that contain tannin such as tea, coffee, or red wine, and by brushing teeth before use. Rinse your mouth well after you brush your teeth, as some ingredients in toothpaste can inactivate chlorhexidine.

Consider special lozenges

Steroid lozenges may also reduce the pain, and may help ulcers to heal more quickly. By using your tongue you can keep a lozenge in contact with an ulcer until the lozenge dissolves. A steroid lozenge works best the sooner it is started once an ulcer erupts. If used early, it may 'nip it in the bud' and prevent an ulcer from fully erupting. The usual dose is one lozenge, four times a day, until the ulcer goes. In children, use for no more than five days at a time.

Do not try antibiotics

Do not take any antibiotics. They provide no relief and may add to your misery.

Use analgesics

Take any simple over-the-counter analgesic, if the pain becomes intolerable. Simple paracetamol may be the best.

Take vitamin pills

Doctors often prescribe multivitamin capsules and pills to tide over aphthous ulcers. Nutritional deficiencies can be a cause of mouth ulcers.

Soothing solutions

Use boroglycerine to cover the ulcers. You could use cotton-buds for making this application. Pure *desi ghee* or butter oil works equally well. This provides excellent temporary relief.

Save yourself from flare-ups. The intake of some eatables such as nuts, chocolates and citrus fruits is known to flare up ulcers. Therefore, just stay off these eatables until the ulcers disappear.

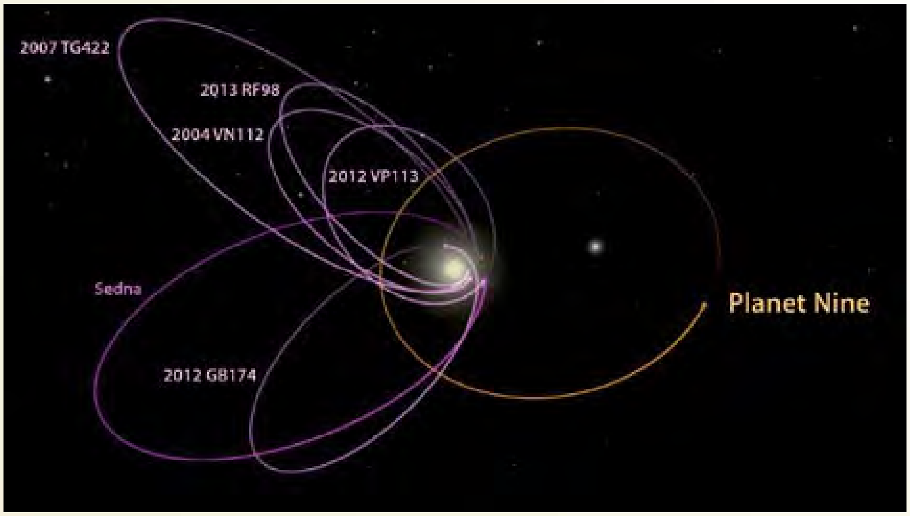
Prof Yatish Agarwal is a physician and teacher at New Delhi's Safdarjung Hospital. He has authored 47 popular health-books.

Recent Developments in Science and Technology

Biman Basu E-mail: bimanbasu@gmail.com

Ninth planet of the solar system?

Ever since Pluto, the ninth planet of the solar system, was relegated to the status of a dwarf planet, the solar system was left with only eight planets. But recent work by a team of researchers at the California Institute of Technology (Caltech) point to the existence in the outer solar system of an object that could be a real ninth planet. Nicknamed 'Planet Nine', with a mass almost 10 times the mass of the Earth, the new planet orbits the Sun about 20 times farther away, in a highly eccentric orbit.



Orbit of ninth planet

Interestingly, the scientists are yet to see the planet; their discovery is based entirely on observation of a few objects beyond the Kuiper Belt and computer simulations. The Kuiper Belt is a field of icy objects and debris beyond Neptune that extends outward from Neptune's orbit, about 4.5 billion kilometres from the Sun, to a bit less than twice Neptune's orbit – about nine billion kilometres.

The story begins around 2003, when Michael E. Brown, a professor of planetary astronomy at Caltech and his colleagues spotted an icy world more than 2,250 kilometres across at a distance of 13 billion kilometres that remained well outside the Kuiper Belt even at the closest point in its orbit. Before the discovery, astronomers believed that beyond the Kuiper Belt lay mostly empty space. No one could convincingly explain how the object, which Brown named Sedna, got there, and the hope was that the discovery of more Sedna-like worlds would provide clearer clues. In January 2005, Brown discovered another Pluto-size object, now known as Eris (dia. 2,236 km), in the Kuiper Belt. Since then half a dozen small bodies have been discovered in distant elliptical orbits beyond the Kuiper Belt. Surprisingly, according to Brown and his Caltech colleague Konstantin Batygin, the orbits of all six loop outward in the same quadrant of the solar system and are tilted at about the same angle. The odds of that happening by chance are about 1 in 14,000. According to them, "A ninth planet could be gravitationally herding them into these orbits" (Astronomical Journal). According to the scientists, the potential ninth planet, at its closest, would be about 32 billion kilometres away; at its farthest, it could be 160 billion kilometres away. One trip around the Sun would take 10,000 to 20,000 years.

Since then, astronomers have been looking for the elusive object but found nothing, deepening the mystery. The riddle was finally solved through computer simulations. When Batygin, a theorist, tried placing a planet among the half a dozen objects discovered beyond the Kuiper Belt using computer simulations, he found it scattered some Kuiper Belt objects, but the orbits were not sufficiently eccentric. Then he examined what would happen if a ninth planet were looping outward in the opposite direction. That, he said, gave "a beautiful match to the real data". The computer simulations showed that the planet swept up the Kuiper Belt objects and placed them temporarily in the elliptical orbits, as seen at present.

According to the scientists, another strange result that came out of the simulations was that a few Kuiper Belt objects were supposed to have been knocked into orbits perpendicular to those of the planets. And indeed, as many as five of the objects had been found in perpendicular orbits. "They're exactly where we predicted them to be. Now we can go and find the new planet and make the solar system have nine planets once again," Brown said. "There have only been two true planets discovered since ancient times, and this would be a third. It's a pretty substantial chunk of our solar system that's still out there to be found, which is pretty exciting," he added.

The brightest supernova in the universe

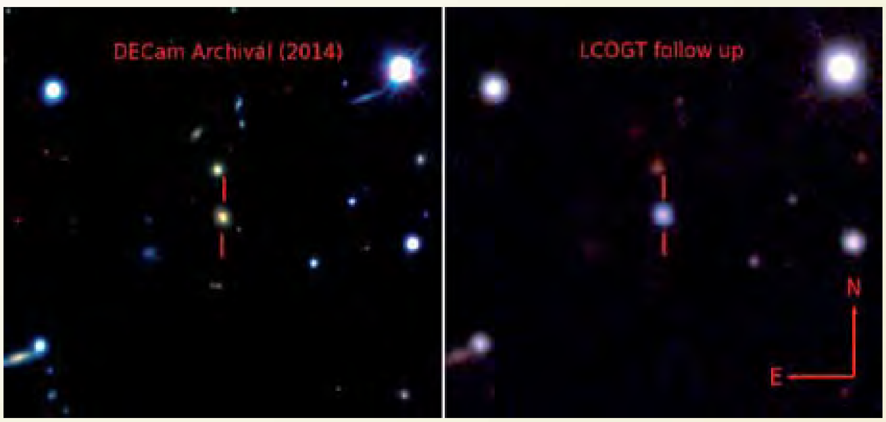
A supernova is the last stage of a massive dying star that explodes, scattering loads of its stellar remnants out into the surrounding space. Depending on the type of supernova, different heavy elements, such as gold and other precious metals, are forged in these powerful explosions and spread throughout the cosmos, seeding other stars and their planets. Heavy elements like gold, mercury, iron, etc., exist on Earth because our Sun was born out of a gas cloud carrying stuff thrown out by a nearby supernova.

A supernova usually attains a brightness a few million times that of the original star and typically lasts for several weeks, often becoming visible in daytime sky, before fading away. But a recently discovered supernova in a galaxy 3.8 billion light-years away breaks all records; it was as bright as 570 billion Suns. According to astronomers, it was the most

Brightest supernova

violently explosive supernova so far detected in the history of the universe.

The new supernova belongs to a rare new class of superluminous supernovae – sometimes dubbed ‘hypernovae’. The new discovery was spotted in June last year by a system of eight small 14-centimetre telescopes at two sites in Chile and Hawaii, collectively known as the All Sky Automated Survey for SuperNovae (ASAS-SN) that can scan the entire sky every 2 to 3 days. At its peak, ASAS-SN-15lh, as the new supernova has been dubbed, “was twice as luminous as any previously seen, thousands of times brighter than a normal supernova, and outshone our entire Milky Way galaxy by 50 times”.



Supernova galaxy

The actual brightness of any celestial object can be determined only if its distance is known. This is because if an apparently dim object was close by, it must be fairly weak. But if it was far away, then the dim-looking object must actually be quite powerful. By studying the red shift in the spectrum of the supernova using the 10-metre South African Large Telescope, the scientists found that the supernova was some 3.8 billion light years away. So, this object was really, really bright!

After examining the bright, slowly fading afterglow of ASASSN-15lh in the months following its discovery, astronomers have gleaned a few basic clues about the origin of the event. For example, the observations have revealed that ASASSN-15lh bears certain features consistent with hydrogen-poor (Type I) superluminous supernovae, which are one of the two main types of these explosions. ASASSN-15lh has also shown a rate of fall in temperature and expansion in radius similar to some previously discovered Type I superluminous supernova. However, the observations showed that ASASSN-15lh is not just brighter, but also hotter, than most Type I supernovae.

Scientists are still looking for the mechanism of the enormous power of the explosion that led to the brightest supernova. One hypothesis is that the event is somehow connected to highly magnetised, rapidly spinning neutron stars called magnetars, which are the leftover, hyper-compressed cores of massive, exploded stars.

Hydrogen is the most abundant element in the universe – stars, including our Sun, are made almost entirely out of it, with a little helium and traces of heavier chemicals. It is the most basic atom, made up of a single proton and electron, and it has served as an important model for scientists studying physics at smaller scales. The hydrogen system is very important to fundamental physics, and “has paved the way to applied models in the early staged of quantum mechanics”. Hydrogen found on Earth is normally a gas at room temperature, but recently researchers have succeeded in producing hydrogen into a totally different, previously unknown state known as “phase V” by putting it under extremely high pressure with diamond anvils.

Hydrogen is relatively rare in Earth’s atmosphere; but it is found abundantly in the gas giants like Jupiter and Saturn which hold enormous amounts of hydrogen under extreme pressures and temperatures. It is known that hydrogen can be liquefied at an extremely low temperature (-252.87oC) and is routinely used as cryogenic rocket fuel. At extremely high temperatures like those found in the outermost region of the Sun’s atmosphere (corona) hydrogen atom’s electrons are stripped from the protons, forming an ionised gas known as plasma. But till recently, not much was known about what happens to hydrogen under extremely high pressures, although theorists had predicted as early as 1935 that, under extreme pressures but at mild temperatures, hydrogen should actually form a solid – one where the covalent bonds holding hydrogen molecules together break apart and the atoms’ electrons roam free, turning the gas into a shiny, greyish, metallic solid. It was predicted that this state would emerge if molecular hydrogen was put under 25 billion pascals, or 25 gigapascals, of pressure – equivalent to 3.25 million times that of Earth’s atmosphere – “an unfathomable pressure not technically

Hydrogen-diamonds

feasible in laboratories at that time".

The breakthrough was achieved at the University of Edinburgh in Scotland by a team led by Eugene Gregoryanz. They put a small amount of hydrogen between two diamond anvils, and raised the pressure to 384 gigapascals. By comparison, Earth's atmosphere is 100 kilopascals. The researchers found that, when the pressure hit the 325-gigapascal mark, the hydrogen became a solid, "with the atoms forming layers that alternated between orderly and jumbled arrangements" with electrons beginning to behave like those of a metal. This is the first time anyone has seen this form of hydrogen at close to room temperature (about 27°C), the scientists said (*Nature*, 2016; 529 (7584): 63 DOI: 10.1038/nature16164). The team says that the newly found phase is only the beginning of the molecular separation and that still higher pressures are needed to create the pure atomic and metallic state predicted by theory.

Speaking about the breakthrough, Gregoryanz said: "The past 30 years of the high-pressure research saw numerous claims of the creation of metallic hydrogen in the laboratory, but all these claims were later disproved. Our study presents the first experimental evidence that hydrogen could behave as predicted, although at much higher pressures than previously thought. The finding will help to advance the fundamental and planetary sciences."

The first flower blooms in space

For the first time ever, a flower has bloomed in the zero gravity of space, US astronaut Scott Kelly announced from the International Space Station (ISS) in January. The orange-coloured zinnia – a plant related to the sunflower – appears very similar to those grown on Earth, except for the curled edges of the petals, which could be due to the zero-gravity conditions. The flowers were grown in the Vegetable Production System (VEGGIE) on board the ISS. Last year in July, the same facility was used to grow red lettuce which the astronauts had consumed on board (Dream 2047, September 2015).

Zinnias on space station become first flowers to bloom in space

According to NASA, zinnia flowers were chosen because they could help scientists understand how plants flower and grow in the microgravity environment of space. VEGGIE project manager Trent Smith says, "The zinnia plant is very different from lettuce. It is more sensitive to environmental parameters and light characteristics. It has a longer growth duration between 60 and 80 days. Thus, it is a more difficult plant to grow, and allowing it to flower, along with the longer growth duration, makes it a good precursor to a tomato plant."

The experiment to grow the first-ever flowering crop on the orbiting laboratory was designed primarily to learn how to grow fresh produce in orbit for NASA's journey to Mars. The experiment was activated in November 2015. Illumination was provided by red, green, and blue LED lights 10 hours a day to stimulate growth of the plants. VEGGIE also has a variable lighting system that allows it to adapt to specific growth stages and life cycles of plants.

The blooming of the zinnia plants in zero gravity was, however, not without problems that at one stage threatened to destroy all the plants. In December last year, the plants were not looking good; the leaves and buds were covered in mould because of a leak in the plant container. To make the matter worse, an unplanned spacewalk delayed fixing the problem in the space garden and by end of December the plants were dying. Astronaut Kelly had to act quickly to remove mouldy leaves and dry the plant chamber. Within a month, the plants were on the rebound and some buds had sprouted, producing the first flowers to bloom in space. According to NASA, "The unexpected turns experienced during this VEGGIE run have actually offered bountiful opportunities for new learning and better understanding of one of the critical components to future journeys to Mars". The zinnia experiment shows that plants can indeed endure long-duration missions in isolated, confined and extreme environments – environments that are artificial and deprived of nature. Lessons learned from the zinnia study will be used to help with the next flowering plant experiment in 2017, this one with an edible outcome – tomatoes!

Dream 2047

Articles invited

Vigyan Prasar invites original popular science articles for publication in its monthly science magazine *Dream 2047*. At present the magazine has 50,000 subscribers. The article may be limited to 3,000 words and can be written in English or Hindi. Regular coloumns on i) Health ii) Recent developments in science and technology are also welcome. Honorarium, as per Vigyan Prasar norm, is paid to the author(s) if the article is accepted for publication. For details please log-on to www.vigyanprasar.gov.in or e-mail to dream@vigyanprasar.gov.in