SIR P. T. SARVAJANIK COLLEGE OF SCIENCE
DEPARTMENT OF PHYSICS

SPECTRUM

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COSMOLOGY

The Origin and Evolution of the Universe

Editorial

How did the Universe start? How did the universe evolve into a structure that is observed today? Whether it is Stationary, Shrinking or Expanding? – These profound questions have puzzled the human race since time immemorial. The field of science which tries to provide answers to such questions including those regarding the distribution and interrelation of all the galaxies, cluster of galaxies is known as Cosmology. Theoretical astrophysicist David N. Spergel has described cosmology as a "historical science" because "when we look out in space, we look back in time" due to the finite nature of the speed of light.

The Nobel Prize in Physics 2019 has created a buzz in the field of Cosmology as it was awarded "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos" with one half to James Peebles "for theoretical discoveries in physical cosmology", the other half jointly to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star." To share the excitement created by the Nobel Prize it gives me immense pleasure to put forward this special issue of SPECTRUM dedicated to the field of Cosmology.

The Issue comprises of articles across the Spectrum spreading from "Light" to the "Nobel Prize in Physics 2019" which includes an article on the life sketch of one of the greatest women scientist, **"Vera Rubin"**.

We are grateful to Dr. Pruthul Desai for contributing an article to this issue of SPECTRUM which forms a series of articles since the inception of this magazine. I hope that the readers would enjoy reading it.

Dr. Pruthul Desai, in the article, *It's a Wiggly Wiggly Universe*, writes about the Nobel Prize in Physics for 2019 which was shared between Peebles, who received half of it and Michel Mayor and Didier Queloz, receiving remaining half. Dr. Desai discussed the enormous contribution made by P J E Peebles in the development and understanding of cosmology beginning from, just after the Big Bang to the present time. Peebles is a versatile personality, having contribution in the fields, such as Cold Dark Matter, Structure Formation and Cosmological Constant and Dark Energy. He also explained the importance of the works of Mayor and Quiloz and significance of exo-planets.

Another article, written by our faculty, Dr. Nisha Patel, is about the life and work of Vera Rubin, an American Astronomer. She is well-known for her pioneering work on galaxy rotation rate. *An admired role model and a passionate champion of female scientists* - writes "Nature" for her contribution as a scientist. Her passion for her work is reflected in her quote:*I would prefer to stay up and watch the stars than sleep.*Carnegie Institution President, Mr. Matthew Scott, called her a *National Treasure*. A mother of four children and a rigorous scientist Vera was able to balance between the two, as she writes in the preface of her book; *I succeeded in my two goals – to have a family and to be an astronomer*. She further added, *having a family and a career was very hard, but it's doable*. Her most inspiring quote is: *Each one of you can change the world, for you are made of star stuff and you are connected to the universe.*

The article on "Light" written by one of the student member of the Physics Club, Mr. Krupamaya mentions some of the historical facts, beliefs and properties of light. He also talks about the how the light is emitted by its source and has tried to relate it with Maxwell's equations, his effort is worth appreciable.

The article on "A Neutron Star", written by another student, Mr. Viraj Kalsariya, narrates in detail the evolutionary phase of the neutron star. It goes on to explain its birth, its properties and its future in a lucid manner. The budding astronomers would definitely like to read it.

The report of the activities carried out during this quarter of the year is also presented in brief. We are indeed happy to see not only increased participation of our students in the various activities but also winning prizes in them and thus bringing glory to the college.

Prof. Viresh Thakkar
Editor

Contents

1. It's a Wiggly Wiggly Universe

Dr. Pruthul Desai

During last fifty years, modern cosmology has evolved into a science of precision and tool to discover new physics. Owing to the seminal work of P J E Peebles we have a unified model capable of describing the evolution of the universe from fraction of a second of its birth to its present epoch. As a result, our understanding of the universe has significantly changed and with that the view of our own place in the universe. Peeblees' ground breaking work on cold dark matter, structure formation, his monumental interpretation of the cosmological constant as dark energy, all of which combined together fetched him one half of the Nobel Prize in Physics- 2019, is presented. The remarkable discovery of "Exoplanets" by Michel Mayor and Didier Queloz which fetched the duo the Nobel prize and its implications on our own place in the universe is briefly discussed.

1.1 Introduction

The Nobel Prize in Physics-2019 has been awarded "*for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos.*" with one half to James Peebles "*for theoretical discoveries in physical cosmology*" and the other half jointly to Michel Mayor and Didier Queloz "*for the discovery of an exoplanet orbiting a solar-type star.*"

Suffice it to say, cosmology wouldn't be where it is today without the efforts of Jim Peebles. Peebles had made seminal contributions in developing theoretical framework of cosmology through detailed modelling and computer simulations which paints a picture about evolution of the universe from its earliest epoch to the present era and into the distant future.

Looking back over his career spanning half a century, Peebles, who is the Albert Einstein Professor Emeritus of Science at Princeton University, said he had never set out with a grand plan. "I could think of one or two things to do in cosmology. I just did them and kept going," he said. "The prizes and awards, they are charming, much appreciated, but that's not part of your plans. You should enter science because you are fascinated by it."

Since time immemorial, humans have been fascinated by the starry sky and have speculated whether there are worlds like our own somewhere else in the universe. The discovery of exoplanets rotating around a star like our Sun has thrown light on some of the physical processes responsible for the birth of planets and reshaped understanding of *our* place in the universe. We hope to that we may eventually find an answer to the eternal question of whether other lifeforms are out there in the cosmos or not.

1.2 Physical Cosmology

1.2.1 Origin of Modern Cosmology

Cosmology is a branch of astronomy concerned with the studies of the origin and evolution of the universe, from the Big Bang to today and on into the future. It is the scientific study of the origin, evolution, and eventual fate of the universe. Physical cosmology is the scientific study of the universe's origin, its large-scale structures and dynamics, and its ultimate fate, as well as the laws of science that govern these areas. Due to our inherent inability to experiment with it, its origin and evolution have always been prone to wild speculation. Peebles has contributed immensely to several essential pieces in this puzzle. The current picture of cosmic evolution is depicted in the fig.(1). The first known speculation about an evolving - non static - universe in

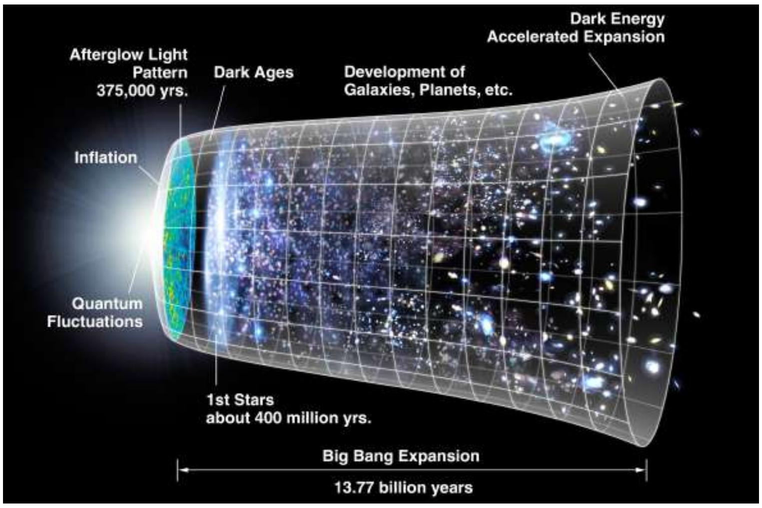

Figure 1: Cosmic evolution.
(Source: https://en.wikipedia.org/wiki/Big_Bang)

print, was perhaps, made by the American writer Edgar Allan Poe [1]. Poe in his prose poem *Eureka* promulgates the idea that the Universe had a beginning and he goes on to suggest that it started out as a "primordial particle", which then exploded.

In 1917, Einstein realised that solutions of equations of General Relativity can be applied to study the large scale structure or space-time geometry of the universe. Since the universe appeared to be unchanging at a large scale, he sought to find solution that describes the static universe i.e whose spatial geometry is not changing with time. However, the static universe is not the solution to the original Einstein's equations of general relativity (nor of Newtonian physics either) because the universe will collapse under the attractive gravitational force [2].

To avoid this scenario he artificially introduced a fudge factor - popularly known as the cosmological constant - as an additional term to his field equations which would provide a repulsive force to counterbalance gravity thus giving rise to a static universe. Later on when Einstein got finally convinced that the universe is expanding, he pronounced it as the "*greatest blunder of his life*."

The Russian mathematician and cosmologist Alexander Friedman developed the first dynamical models of the universe by exactly solving Einstein's field equation using assumptions of homogeneity and isotropy of space; often called the "cosmological principle." Roughly speaking, homogeneity requires that at a given moment of cosmic time every spatial point "looks the same," and isotropy holds if there are no geometrically preferred spatial directions. Friedman goes on to show that the solution, which is referred to as Friedmann-Lamaître universe, give rise to three possible types of geometry viz. the universe can be open (positive curvature), closed (negative curvature) or flat (zero curvature) depending upon the energy of the universe being greater than, less than or equal to the critical energy density respectively [3, 4]. The critical density is defined as an average density of matter and energy in the universe that would keep it balanced between two extreme fates: eternal expansion and collapse.

Friedman realised that an open expanding universe must have a "beginning" which corresponds to a point with no spatial extension called "singularity". Friedman wrote: "The time since the creation of the world is the time which has passed from the moment at which space was a point to the present state". For the first time, the notion of the origin of the universe was derived not from a philosophical doctrine but from a fundamental theory of physics.

In 1927, an important step was taken by the Belgian Catholic priest and astronomer Georges Lamaître, who perspicaciously interpreted the observations of the redshifts of galaxies as due to the expansion of the universe [5]. A more general acceptance that the universe was indeed expanding, came with the observations by the American astronomer Edwin Hubble in 1929[6]. In 1931, he argued that if the universe was expanding at current epoch, then in the past, it should have originated as an extremely small 'primeval atom'[7].

Hubble's observation which is known as the *Hubble law* expresses the linear relationship between recessional velocity of a galaxy with its distance from us. The Hubble law is just what one would expect for a homogeneous expanding universe, as in the Big Bang theory. In other words, no galaxy occupies a special place in this universe.

1.2.2 The birth of Physical Cosmology

In the late 1940s, the Russian-American physicist George Gamow put forward a crude model of a hot Big Bang [8]. According to Gamow, the early universe was a hot and dense inferno of interacting nuclear particles such as protons and neutrons. The interactions resulted in the formation of the chemical elements. The structures should not begin to form until the density of radiation was roughly equal to the density of matter, and found that this should happen at temperature of few thousand degrees. In 1948, Alpher and Herman suggested that the present universe should have a temperature around 5 K [9]. Not many physicists at the time thought that the resulting radiation would be possible to observe, Andrei Doroshkevich and Igor Novikov being a few exceptions.

A fundamentally different theory named the Steady State theory of the universe was introduced by Fred Hoyle, Hermann Bondi and Thomas Gold in 1948. The theory jettisoned the idea of big bang and postulated that the universe had existed in an eternity of time and would continue existing eternally. Moreover, the theory came up with the idea that the average density of matter in the universe remained the same despite its continual expansion. To explain this, it was suggested that a tiny amount of matter was created throughout the universe in such a manner that the average density remained same even if the universe expanded. Importantly, the Steady State theory avoided the thorny question of the beginning of the universe. Therefore, starting from 1948 to the early 1960s the Steady State theory was a possible alternative to the evolutionary models of the universe such as the Big Bang theory.

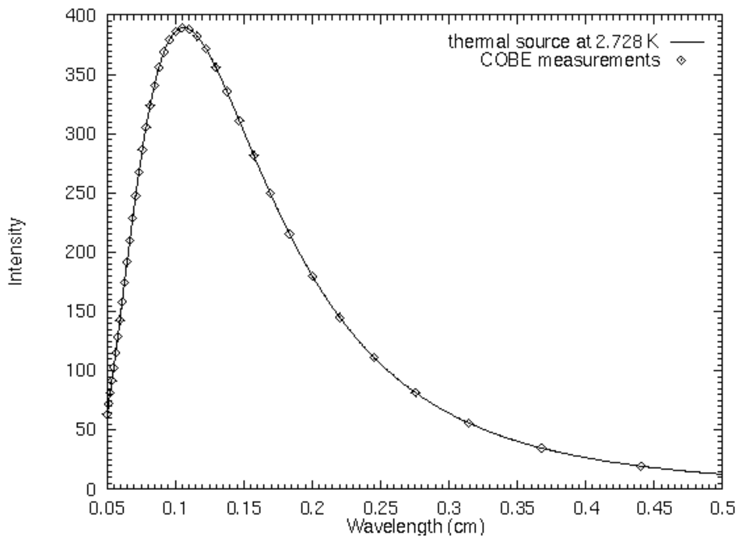

Figure 2: Cosmic Microwave Background Radiation.
(Source: https://www.astronomynotes.com/cosmolgy/s5.htm)

In 1964, Robert Dicke from Princeton University, got interested in hot big bang cosmology. Unaware of the 1940s work of Alpher, Gamow and Herman, he suggested there ought to be a “cold” leftover radiation from the “hot” early universe, of a few degrees Kelvin temperature. He asked his students Roll and Wilkinson to build a ‘Dicke radiometer’ to look for this radiation. And he asked Peebles to ‘think of the theoretical consequences’. Thus began Peebles’ path to glory.

In 1965, Arno Penzias and Robert Wilson working at Bell labs accidently discovered a signal received by horn antenna of their radio telescope which was coming from all directions. Penzias and Wilson were completely clueless about the origin of this puzzling buzz of microwaves. When Dicke heard about it, his face fell. “Boys, we’ve been scooped!" he explained to his Princeton collaborators. A companion paper by Dicke and his collaborators [10] was published in *The Astrophysical Journal Letters* along with the research paper by Penzias and Wilson [11]. While Penzias and Wilson described their discovery, Dicke and his collaborators provided the interpretation of the results of Penzias and Wilson by calling it the Cosmic Microwave Background (CMB) radiation - a relic of the Big Bang.

The serendipitous discovery of the ubiquitous Cosmic Microwave Background radiation fig.(2) by Arno Penzias and Robert Wilson in 1965, tilted the balance in favour of the Big Bang theory. According to the Big Bang theory, in the early universe which was extremely hot, light (or photon) was coupled to matter such as protons, neutrons and electrons - a hot baryon-photon plasma. But as the universe expanded it cooled and when its temperature was nearly 3000 K the energetically depleted photon could no longer ionise atoms and electrons. As a result electrons combined with protons to form atoms in a process known as *recombination*, and photons were set free. This mechanism, during which an interaction can no longer maintain the equilibrium between various particles because of cosmic expansion, is called *decoupling*.

As the universe expanded, the wavelength of the photons are stretched out, lowering their energy. These photons which left nearly 13 billion years ago are observed today as an all pervading “background radiation” in the form of very weak microwaves. The existence of a background radiation which is soaking the cosmos thus follows naturally from the Big Bang theory and had in fact been predicted by Alpher and Herman as early as 1948. On the other hand, the new phenomenon could be accommodated by the steady state theory only by means of the arbitrary and highly artificial hypotheses.

The formation of light nuclei enables us to look back in time to when CMB was formed. This epoch lasted only 100,000 years, a minuscule fraction of the 13.8 billion years - the life span of the universe. Cosmologists think of this epoch as a fictitious surface, a 100,000 light year - “thick” shell known as the “last scattering surface” in the four dimensional space-time continuum. The last scattering surface surrounds us and represents the shell from which all the photons we now see as the CMB set off on their nearly 14 billion year journey [12].

Immediately after the discovery of CMB the entire spectrum of the relic radiation was measured and was found to match well with the Planck's distribution. This implies that the universe was in the thermal equilibrium when the radiation was released, which was at a temperature approximately 3000 K. Today it is near 3 K. In their landmark 1965 paper [10], Peebles and coworkers refined their earlier calculations on Helium abundance and based on the recently observed temperature of the CMB, the authors discussed a constraint on the amount of baryonic matter (i.e. matter consisting of nucleons that can participate in the formation of elements) in the universe. This is one of the pillars of the Big Bang model. The authors also noted that the actual amount of visible matter in the universe is much less than that needed to account for the expansion rate of the universe and even suggested that the large quantity of exotic matter is necessary to fill this gap. Peebles started a concerted effort to simulate galaxy formation and suggested that the correlation function as a valuable toll in cosmology.

Soon extra efforts were put to search for any variation in temperature distribution of CMB or anisotropy in the CMB. It was believed that anisotropies must exist to account for the observed structures like myriad stars, galaxies, galaxy clusters etc. In 1967, the first groundbreaking study was carried out by Sachs and Wolfe - called Sachs-Wolfe effect, which was evident at the large scales. At the small scales, anisotropy was interpreted by Peebles and his student J T Yu [13] to occur because of initial matter density fluctuations and propagating acoustic waves in the hot baryon-photon primordial soup.

The Russian cosmologists Sunyaev and Zeldovich [14] explained the physics behind the acoustic waves and the peaks occurring in the power spectrum of CMB and their periodic nature. Peebles and Yu [13] worked out the power spectra of density fluctuations for different cosmological parameters. The power spectrum for a flat universe produced by Peebles and Yu is shown in the fig.(3).

1.2.3 Dark Matter

In the 1970s astronomer Vera Rubin had observed something peculiar about the rotational speeds of stars in distant galaxies. Starting with a study of Andromeda galaxy, M31, Rubin established that the rotational speed of stars in the outer spiral didn't die off with the distance from the galactic centre, as would be expected if the stars in the galaxy followed the same behaviour as the planets in our solar system. In other words, the stars along the spiral arms seem to be virtually rotating at the same rate as the stars near the galactic centre, as if, Neptune was keeping pace with Mercury in a race around the Sun. A graph for the variation of the radial

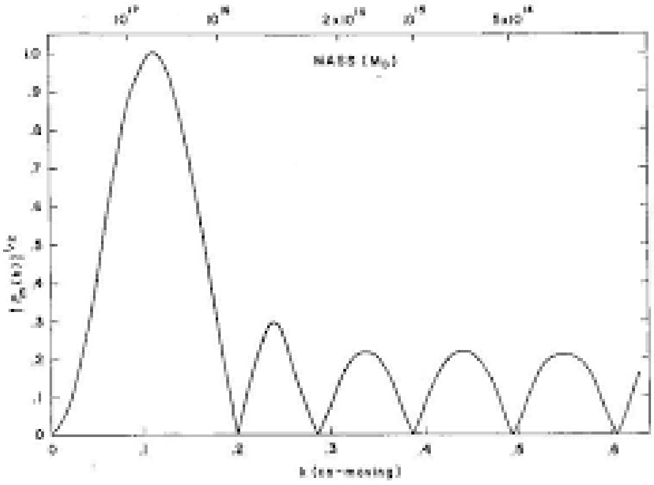

Figure 3: Power spectrum for a flat universe obtained by Peebles and Yu
(Source:
https://www.nobelprize.org/uploads/2019/10/advanced-physicsprize2019-2.pdf)

velocity with distance from the centre of the galaxy for the Andromeda galaxy, M31, obtained by Rubin is shown in the fig.(4). Along with her collaborator, Kent Ford, Rubin extended her study to other spiral galaxies and found that the failure to falloff was ubiquitous: no galaxy behaves like a supersized solar system.

What are these curves trying to tell us? The first interpretation is that if all the matter is contained in the visible boundary of the galaxy, then the laws of gravity, whether of Newton or Einstein, fails. The velocity curves of stars of different galaxies could not be accounted for solely by luminous matter in conjunction with Newtonian gravity. Some astronomers, including Rubin herself, thought that we needed to tweak the laws of physics to get things right. But others, including Peebles, figured out that there was more to a galaxy than meets the eye. The constant velocity of rotation out to such large distances means that the galaxy possesses invisible matter beyond its visible boundary.

To explain Rubin's unexpected observations, Ostriker and Peebles used computer simulations to recreate that effect. "There are reasons," read the opening sentence of their paper[15], "increasing in number and quality, to believe that the masses of ordinary galaxies may have been underestimated by a factor of 10 or more." They showed that individual galaxies and groups or clusters of galaxies are embedded in enormous distributions of cold, weakly interacting dark matter. These dark matter "halos" provide the scaffolding for all luminous structures in the universe. In early 1930s, while studying the motion of galaxies in the Coma cluster, Swiss Astrophysicist Fritz Zwicky, at Caltech, was led to conclude the existence of *Dunkle Matarie*, the German phrase for dark matter, to account for the missing mass which must be responsible for the observed large velocities of the outer galaxies. But the idea remained in oblivion for nearly four decades till Ostriker and Peebles revived it again. What could be the composition

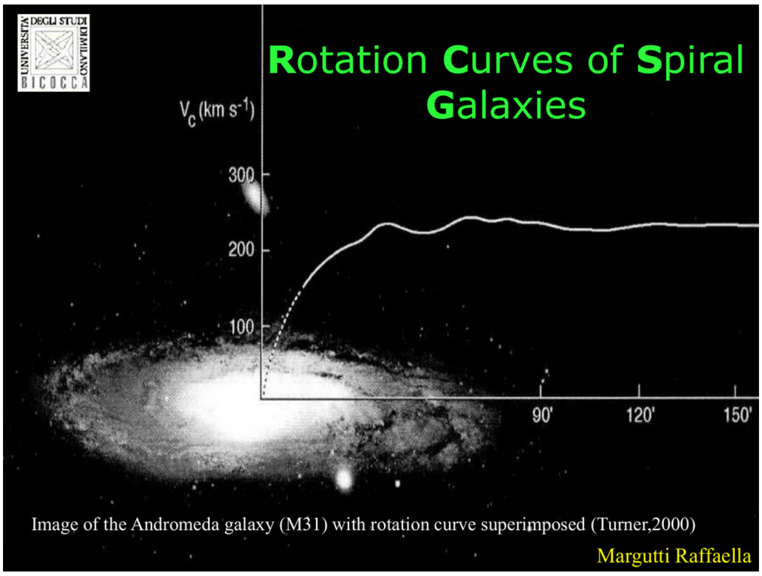

Figure 4: Variation of radial velocity with distance from the centre of the galaxy (Source: https://darkmatterdarkenergy.com/2016/12/)

of dark matter? The early candidates were massive neutrinos which were believed to form hot dark matter (hot means relativistic at the time of decoupling). However, neutrinos led to the top-down approach to the galaxy formation meaning that the largest super clusters were formed first, followed by clusters and galaxies. This top-down scenario does not match the experimental observations and thus ruled out neutrinos as dark matter.

In early 1980s, cosmology was in crisis. If observed baryonic density alone is considered in the calculation of temperature anisotropy for a universe which is open and with density less than the critical density, the theoretical predictions exceeded the limits set by experimental observations. On the other hand, if the density of ordinary baryonic matter had been at the critical value, the galaxies we have observed could never have formed. In addition, in order for the amount of light elements to be correctly predicted by the theory, the amount of ordinary matter that exists could not exceed that already found.

Once again Peebles comes to the rescue of the Big Bang theory by proposing the existence of "cold dark matter." In his landmark paper [17], Peebles calls "Cold Dark Matter" (CMD) - a new form of matter that does not interact with light (and hence does not interact with anything else except through gravity). According to Peebles, the CMB indicates that any type of matter coupled to the radiation must have been very smooth, much too smooth to provide seeds for structure formation. Cold dark matter decouples from the baryonic matter and radiation early, leaving a minimal imprint on the CMB. After recombination, however, the cold dark matter perturbations generate perturbations in the baryonic matter sufficiently large to seed structure formation. Peebles predicted a temperature anisotropy given by

$$\frac{\delta T}{T} = 5 \times 10^{-6} \tag{1}$$

These predictions were verified by the Cosmic Background Explorer (COBE) satellite some years later[16].

1.2.4 Large Scale Structure Formation

Although the isotropic microwave background indicates that the universe in the *past* was extraordinarily homogeneous, we know that the universe *today* is not exactly homogeneous: we observe galaxies, clusters and superclusters on large scales. At such large scales we see a "cosmic web", a pattern which extends end-to-end of the universe in which galaxies are intersperced in the background of gigantic voids. How did *that* happen? The answer to this perplexing question was provided by Peebles and his coworkers. According to Peebles[17], the answer lies in the minute variations in temperature of the CMB across the universe, small wiggles, no bigger than 1 part in 100000. Peebles ingeniously connected these wiggles in temperature of CMB to the very small primordial inhomogeneities in the "photon-baryon plasma" which existed just a fraction short of the decoulpling of photons from it.

Eventually these little nuggets would grow to become galaxies, and some galaxies agglomerated to form clusters of galaxies. The accumulation of mass locally, left empty regions elsewhere and these empty regions expanded into voids in the fabric of cosmos. Peblees' revolutionary idea was vindicated nearly four decades later when the results from the Planck satellite just how accurate the theoretical predictions were.

1.2.5 Dark Energy

In early 1980s, more and more measurements pointed towards the existence of flat universe, i.e. a universe in which the energy density equals the critical density. In other words,from the observed current value we can conclude that the universe must have been extremely fine-tuned to criticality in the past. The theory of inflation - a rapid expansion phase of the universe at its earliest epoch, was developed independently by Kazanas; Guth; and Starobinsky to account for the flat universe. The name inflation comes from the fact that the universe expansion had to be enormous, incredibly big during an extremely small instant of time (of the order of 10^{-33}

seconds). In this infinitesimal fraction of a second the universe expanded from the size of a peanut to that of the present Milky Way (in volume, an increase of at least 75 orders of magnitude). Though the inflation correctly predicted the critical density, the inferred matter density (including the dark matter) accounted for only one third of the critical value.

In 1984, Peebles [18] reintroduced the dreaded "cosmological constant " (λ), that Einstein posited and then disowned. Peebles saw the constant as a way to rescue the structure of the universe from itself. Re-adding Einstein's constant could provide the missing energy and negative pressure which is responsible for the accelerated expansion of the universe. As the universe continues to expand over time, the negative pressure associated with the cosmological constant (the form of dark energy) increasingly dominates over opposing gravitational forces, and the expansion of the universe accelerates. Thus Peebles improved on his earlier model of cold dark matter to include the contribution of the 'λ, the latest incarnation in our understanding of the cosmos and is referred to as the λCDM-model. The idea was triumphantly confirmed in 1998, when astronomers Saul Perlmutter, Brian Schmidt and Adam Reiss discovered the accelerated expansion of the universe [19, 20].

The power spectrum of CMB obtained by the Planck satellite is shown in the fig.(5).

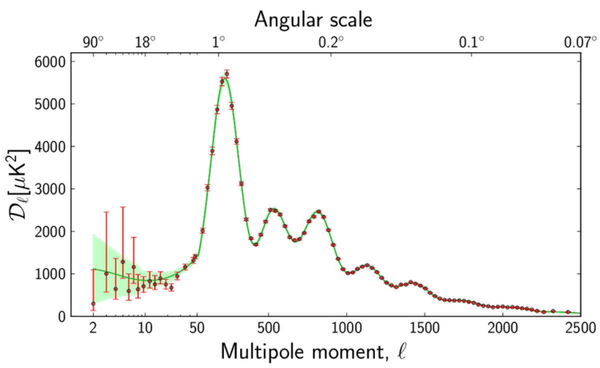

Figure 5: Temperature anisotropies in CMB measured by the Planck satellite
(Source:
https://www.nobelprize.org/uploads/2019/10/advanced-physicsprize2019-2.pdf)

The first peak in the spectrum was interpreted by Peebles as an evidence that the universe is geometrically flat, i.e. two parallel line will never meet. The second peak shows that ordinary matter is just 5 % of the matter and energy in the universe. The third peak shows that 26 % of the universe consists of dark matter. From these three peaks, it is possible to conclude that if 31% [5%+26%] of the universe is composed of matter, then 69% must be dark energy in order to fulfil the requirement for a flat universe.

Thus all the stars, planets and galaxies that we can be seen today make up just 4 percent of the universe. The other 96 percent is made of stuff astronomers can't see, detect or even comprehend. From our current understanding, the distribution of mass and energy is given in the fig.(6). The light which soaks us can be 'seen' with prying eyes of our satellites COBE,

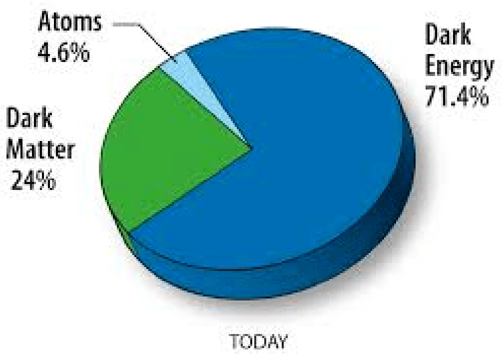

Figure 6: The composition of the universe.
(Source: https://wmap.gsfc.nasa.gov/universe/uni_matter.html)

WMAP and PLANCK, which have transformed it into images, each time more and more clear and sharper. Putting all the pieces of the jigsaw puzzle together resulted in the λCDM-model and remains the best bet for explaining the accelerated expansion of the universe.

An octogenarian today, Peebles still continues to work on the cosmic quandaries such as composition of dark matter and dark energy.

1.3 Exoplanets exist!

1.3.1 The Discovery of Exoplanet

Exoplanets are planets orbiting a Sun-like star outside our solar system. Although their existence was speculated long back, conclusive evidence was elusive till Michel Mayor and Didier Queloz irrefutably observed its existence in 1995. They announced their sensational discovery at an astronomy conference in Florence, Italy, on 6 October 1995. The landmark discovery showed conclusively that the Sun isn't the only star to host a family of planets and triggered large number of dedicated missions - both ground-based and space-based - to detect exoplanets. As a result, today, the discovery of exoplanets is so commonplace that announcements rarely even break into the news, and it's only a matter of time before we find an Earth-like twin.

The exoplanet discovered by Mayor and Queloz, named 51 Pegasi b, moves rapidly around its star, 51 Pegasi, which is 50 light years from the Earth. It takes four days to complete its orbit, which means that its path is close to the star – only eight million kilometres from it. The star heats the planet to more than 1,000 °C. Things are considerably calmer on Earth, which has a year-long orbit around the Sun at a distance of 150 million kilometres.

The newly discovered planet also turned out to be surprisingly large – a gaseous ball that is comparable to the solar system's biggest gas giant, Jupiter. Compared to the Earth, Jupiter's volume is 1,300 times greater and it weighs 300 times as much. According to previous ideas about how planetary systems are formed,the Jupiter-sized planets should have been created far from their host stars, and consequently take a long time to orbit them. The Jupiter takes almost 12 years to complete one circuit of the Sun, so 51 Pegasi b's short orbital period was a complete surprise to exoplanet hunters.

Why was the Nobel Prize awarded to the discovery? It is not so much for the new physics that this discovery brought about but rather for an improvement in the experimental techniques to detect exoplanets. Also it has the bearing on our world view of Man's place in the universe.

1.3.2 Radial Velocity Method

The Radial Velocity Method [21] is one of the most common techniques used for detecting exoplanets and was proposed by Otto Struve more than 50 years ago. The method is based on the measurement of the stellar radial velocities. Since the Doppler shifts in the frequency of light received are extremely small in such cases, it took more than half a century to develop detectors sensitive enough to measure it. A schematic of the Radial Velocity method which uses the principle of the Doppler effect is shown in fig.(7). If plane of the orbit is parallel to the sky (inclination angle i = 0) or for an observer on the Earth it is "face-on", then no Doppler shift occurs. If it is "edge-on" then the planetary mass can be detected from the Doppler shifts. In general, because the inclination angle is not known, only $M_{planet} \times sin(i)$ can be determined, setting a lower limit to the mass of the planet.

For an "edge-on" configuration, as shown in fig.(7), the light received from the star will be blue shifted when the star is approaching earth in its orbit around the centre of mass of star and its companion planet system and will be redshifted when it moves away. In the non-relativistic limit the radial velocity can be determined from the Doppler formula as:

$$\frac{\triangle\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{res}}{\lambda_{res}} = \frac{V_{RV}}{c} \tag{2}$$

where $\triangle\lambda$ is the shift in wavelength, c is the speed of light, λ_{obs} and λ_{res} are the observed and rest frame wavelengths.

For a given star, the wavelength shift will depend on the mass of the companion planet and its

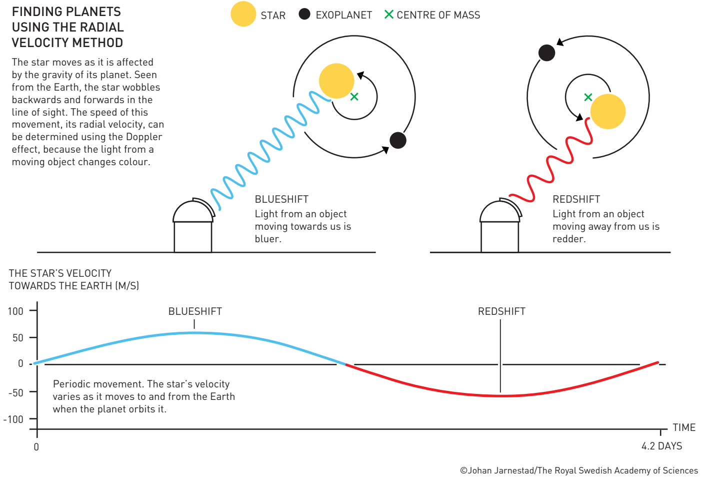

Figure 7: Radial velocity technique
(Source: https://twitter.com/nobelprize/status/1181550417588768768)

distance from the centre of mass. Greater the mass of the planet, more will be the shift. Also, closer the planet, more will be the shift. For example, for the Jupiter orbiting the Sun at 5 AU distance will cause the Sun to move at a speed of 12 m/s which is equivalent to a wavelength shift of 10^{-14} m (10^{-5}nm)in the visible spectral range. Similarly, the Doppler wobble of the Sun caused by the Earth orbiting at 1 AU distance is merely 10 cm/s, making the detection of Earth-like planets a formidable task even with the current technology.

The pair developed a fibre-fed echelle spectrograph ELODIE to hunt for exoplanets. This discovery was made possible by the one-of-a-kind Elodie instrument installed on the famous telescope measuring 193 cm in diameter. Designed by the Observatoire de Marseille (OHP), and Observatoire de Genève, Elodie was later built by teams from the OHP to measure the radial velocity of stars, in other words their speed in relation to the Earth. ELODIE could detect changes in a star's radial velocity of 13 m/s fig.(8) which helped Queloz and Mayor detected a Jupiter like planet companion of a star named 51 Pegasi. Today, it is just one of the several methods that astronomers use to find exoplanets and study their atmospheres and potential exomoons. The Nobel prize winning work was published in November 1995 issue of *Nature* [22]. Queloz said the sheer numbers of planets made it hard to believe that ours was the only one to host life. "We may find out that life is extremely rare. We know life is special, but we may not acknowledge how special or rare it is," he said. "It's not impossible that in the next 20 to 30 years there will be new kinds of equipment that would be able to answer this question. Whether they will find something is open."

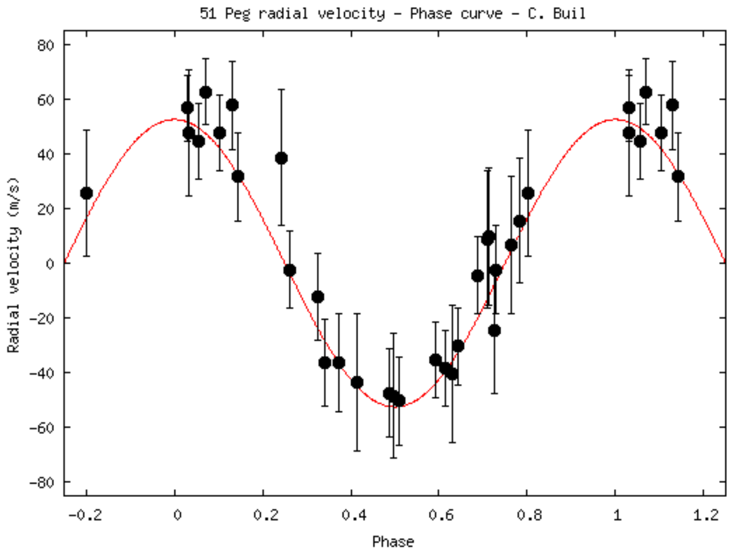

Figure 8: Radial velocity phase curve of 51 Pegasi observed by Mayor and Queloz (Source: http://www.thespectrumofriemannium.com/2019/10/13/log236-exoplanets/)

"From the seeds of cosmic structure, generated almost fourteen billion years ago, to the building blocks of planets and even life, the work of Peebles, Mayor and Queloz tackles some of the most profound questions that humanity has ever pondered: where do we come from? Where are we going? Is there life elsewhere in the universe?" says Günther Hasinger, ESA Director of Science.

Queloz and Mayor collaborated on further searches for extrasolar planets. Beginning in 1998, they used the CORALIE spectrograph at La Silla Observatory in Chile to search for planets around 1,647 nearby stars. The CORALIE project has found more than 100 extrasolar planet candidates.

Learning about these strange and varied worlds beyond our solar system has transformed our understanding of how planets are formed and given new focus to the question of whether there could be alien life out somewhere.

1.4 Conclusion

It is indisputable that the theories postulated by Peebles fit the currently-available observational data with an astonishing precision, but there are also many other observations that await a full theoretical explanation. Nevertheless, these open questions in no way diminish the theoretical contribution of Peebles over 20 years.

Peebles is credited with developing the theoretical tools that allowed scientists to perform a cosmic inventory of what the universe is made from, showing that ordinary matter makes up just 5% of its known contents, with the rest being dark matter and dark energy. In other words, adding up our knowledge of the universe, we must confess that over 95% of it is, as of today, "*terra incognita*." It means a lot is to be discovered - a scientific feast in waiting!

We can only hope that further exploration of exoplanets will solve the Fermi paradox and may give us the answer to our eternal question: Are we truly ALONE in this universe?

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2. Vera Rubin: Who Brought Dark Matter Into Light
Dr. Nisha Patel

"**Devise your own paths**"... words of enduring wisdom by Vera Rubin; a female scientist who engraved her path in the field dominated by men, a mentor, a protagonist and a boundary-breaker fuelled by a true love for science and the stars,... a trailblazer in true sense! Even if you never heard of Vera Rubin before, you certainly would have heard of the dark matter. American astronomer Vera Rubin changed the way we think of the universe by showing that galaxies primarily comprise of the dark matter and thus brought to life an entirely new field of study named observational cosmology.

2.1 An inquisitive child

Rubin was born on 23th July, 1928 to the family of Jewish immigrant parents who had always invigorated Rubin's scientific interests. Her parents, Pesach Kobchefski and Rose Applebaum met at Bell telephone Company while working and got married. They had two children, Vera and her elder sister Ruth. Her mother coaxed the librarian of the local library to allow Rubin checkout on science books from the "12 and over" section, though she was under age . Rubin had showed strong liking for astronomy at very young age. With the help of her father Vera had built a telescope which she was using to take photograph of motion of stars. Nevertheless, it was Rubin's eternal curiosity that drove her. Vera and her sister Ruth shared a room, with Vera's bed against a window with a clear view of the north sky. According to Vera, it was always more interesting to her to watch the stars than to sleep. Rubin was transfixed by stars and galaxies. Her parents were very supportive to her except one thing that they never like her to stay up all night.

2.2 A strenuous start

During her school days, Vera's teachers were not so encouraging. Her teachers used to ignore girls in the class. She hardly knew any astronomer at that time In spite of all this she was clear about what she wanted to do in her life. Luckily, she met one female astronomer,Maria Mitchell who was the first female professional astronomer in the United States. Meeting Maria changed the course of Vera's life. Though, Maria did not have college education, she was appointed as professor at Vassar College in New York. During 1865 to 1888, she worked at Vassar and later served as the director of Vassar College Observatory. Following her footprints, Vera applied to Vassar. Her application was accepted with scholarship. When she informed her school teacher about that, he just advised her to stay away from science. Undeterred, Vera continued and graduated from Vassar as the lone astronomy major in her class.

Figure 1: Vera Rubin was the only woman to graduate in astronomy at Vassar College in 1948 (Source: https://www.aip.org/remembering-vera-rubin)

2.3 Personal life and back to the field

In the 1947, Rubin spent summer in Washington DC, working at the Naval Research Laboratory where she was introduced to Robert (Bob) Rubin by her parents. At the time, Robert was training to be an officer in the US Navy and studying chemistry at Cornell University.

The two married in 1948. She was 19 and he was 21. Although Vera got admission to the graduate programme at Harvard University which had a reputed astronomy department, she chose to join her husband at Cornell, instead.

In 1950, Rubin completed her master's thesis just before giving birth to her first child. She was supposed to present her research work at meeting of the American Astronomical Society (AAS). Her adviser told Vera that it made more sense for him to give the talk, as he was already a member of AAS and she would be a new mother, but Rubin insisted she would do it and she gave a talk at meeting of the AAS just after birth of her first child.

Theoretical physicist and cosmologist George Gamow who is known for his contributions to developing the Big Bang theory, among other foundational work, heard about Rubin's AAS talk and began asking her questions. One of the questions, "Is there a scale length in the distribution of galaxies?" so intrigued Vera that she decided to work on it for her Ph. D. thesis. Gamow happily served as her thesis advisor.

Vera not only pursued a prolific scientific career but, also championed the causes of other women in science. She was a Pioneering astrophysicist at a time when hardly any women worked in the field of astronomy. She was prevented from joining a doctorate program in Astronomy at Princeton on the basis of her gender. However, she did not give up and finally earned her Ph. D. from Georgetown University. She became albeit unintentionally, a crusader for the promotion of women's participation in science.

In the year 1964, during a conference, influential astronomer Allan Sandage, who had published the first good estimate of the Hubble constant in the year 1958, asked Rubin if she was interested to be an observer at the Palomar Mountain at the Carnegie Institute's 200-inch telescope. Rubin readily accepted and started observing distant galaxies from the same place where, in 1933, astronomer Fritz Zwicky had made startling discovery of the mysterious type of matter which he named as the "*dunkle Materie*" or "dark matter". He noticed that the galaxies in the Coma Cluster were moving too quickly... so quickly that they should have broken apart. Judging by the mass of their visible matter, they should not have had the gravitational pull to hold together. He concluded that the cluster must be more massive than it appeared, and that most of this mass must come from matter that could not be seen. He presented this avant-garde idea to the Swiss Physical Society, but it did not catch on.

Rubin was the first woman to gain official approval to use the Palomar Observatory in Southern California in 1964 at that time, she had to claim use of a bathroom since, no facilities existed for women within the building. For many years, the observatory was a researcher's man cave. Rubin was one of the first women to gain access to it. But when she join they observatory, she was informed that there was no women's restroom in that building. She went to her research room, she cut up paper into a skirt image and stuck it on the little person image on the door of the bathroom. "There you go; now you have a ladies' room" Vera said. That type of pluckiest person Vera Rubin was !!!

2.4 The rotation curves and dark matter

In 1965, after a brief stint as a professor at Georgetown, Rubin began her work at the Department of Terrestrial Magnetism, Carnegie Institute in Washington D.C. where, she met astronomer Kent Ford and his spectacular spectrometer, which was more sensitive than any other at the time. Thus began one of the most enduring and fruitful partnership ever in science.

Rubin and Ford made their observations at Lowell Observatory and Kitt Peak National Observatory. On a typical clear night, they pointed the telescope at galaxy M31, commonly known as Andromeda. They closely observed the spectra of stars in the Galaxy to determine their velocities. They expected to see it rotates like the solar system does.

The surprises came very quickly... In our solar system, planets closest to the centre are the fastest-moving, as they are most affected by the gravitational pull of the Sun. Mercury, the closest, moves about 1.6 times as rapidly as Earth, whereas Neptune, the farthest, moves at less than 0.2 times Earth's speed. The expectation was that galaxies behaved the same way. But they ended up with most astonished result. The rotation curves were flat, explicating that objects closer to the centre of Andromeda were moving at the same speed as objects closer to the outskirts. They concentrated on the odd behaviour of galaxies. Soon there were 20, then 40, then 60 rotation curves, and they were all flat. The failure in falloff was ubiquitous. But what did the flat rotation curves mean? The popularly accepted answer is that the way the galaxies in Andromeda move is influenced by dark matter. If a galaxy is formed in the centre of a disk of invisible dark matter, the gravitational pull of the dark matter will affect how quickly each of its parts moves, flattening the rotation curves.

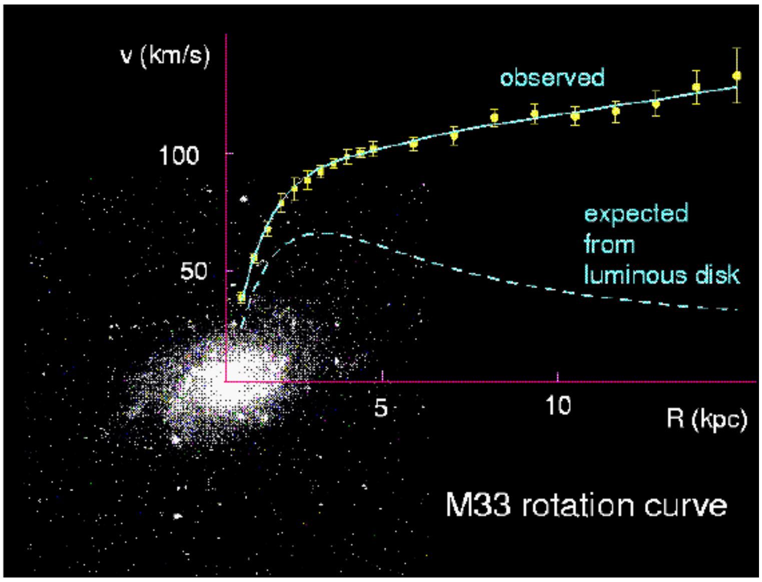

Figure 2: The observed Rotation Curve of galaxy M33
(Source: https://physics.stackexchange.com/questions/517123/non-flat-galaxy-rotation-curves)

Dark matter was proposed as a concept by Fritz Zwicky in 1933, who also noticed discrepancies in the amount of mass that astronomers could see and the physical quantity that should actually exist, but few paid attention to their work, and their research was considered little more than a cosmological oddity. It was Rubin who realized that if a halo of dark matter adorned each galaxy, matter would spread throughout the galaxy instead of concentrating in the centre and the force of gravity and orbital velocity would be similar in all parts.

Rubin was agnostic about the idea of dark matter and wrote that she would be delighted if the explanation actually came in the form of a new understanding of how gravity works on the cosmic scale. she said "One needs to keep an open mind in seeking solutions."

A few years after the discovery of dark matter by Rubin, physicists such as Jeremiah Ostriker and James Peebles provided the theoretical framework to support her work and the mysterious substance settled into its celebrated place in science. In 2013, the planck satellite measured the dark matter content of the universe by observing microwave background radiation, the radiation left over from the Big Bang that fills the entire Universe. The result showed that dark matter was grouped first and later the common matter was added, forming the agglomerates of galaxies.

In 2016, the Dark Energy Survey, led by Fermilab (Fermi National Accelerator Laboratory) of the United States, published a map with 26 million galaxies that presents the heterogeneous distribution of dark matter in a band billions of light years wide. The objective of the analysis is to seek explanations for the expansion of the Universe. Either it will expand continuously or there will be enough matter to slow it down. When we look into space, we see a lot of matter, but the Universe acts as if there were more than what is experimentally observable, something with a greater gravitational influence than might be expected.

2.5 ... and a culmination without recognition

Vera Rubin persisted with her research and mentorship until her death in 2016. She transformed modern physics and astronomy with her observations showing that galaxies and stars are immersed in the gravitational grip of vast clouds of dark matter, died on Christmas day, 2016 in Princeton at the age of 88. The call from Sweden would never come for Vera Rubin.

Her work in astronomy ushered in a revolution in how we saw the Universe, most of the Universe, Rubin discovered, is invisible to us, yet this material has had a profound effect on literally everything.

2.6 The scientific legacy:

After credited with the serendipitous discovery of dark matter, Rubin continued her work, receiving recognition for her contributions in various ways.

1. From 1972 to 1977 she served as associate editor of the Astronomical Journal.

2. From 1977 to 1982 she served as associate editor of Astrophysical Journal Letters.
3. In 1993, she received the National Medal of Science from President Bill Clinton.
4. In 1994 she received the Dickson Prize in Science from Carnegie-Mellon University.
5. In 1994 she received the Henry Norris Russell Lectureship from the American Astronomical Society.
6. In 1996 she became the second woman to receive the Gold Medal of the Royal Astronomical Society in London (168 years after the first, Caroline Herschel in 1828).
7. In 1996 President Clinton nominated her to provide input to Congress as a member of the National Science Board for a term of six years.
8. In 1997 she and a few other members of the National Science board were invited to visit the McMurdo research station at the South Pole.
9. In 2004, the National Academy of Sciences awarded Rubin the James Craig Watson Medal for "her seminal observations of dark matter in galaxies... and for generous mentoring of young astronomers, men and women."
10. She is memorialized in the solar system by Ridge in the Gale crater on Mars and the asteroid, 5726 Rubin.

2.7 Quotes by Vera Rubin

1. "I became an astronomer because I could not imagine living on Earth and not trying to understand how the Universe works."
2. "Fight injustice and discrimination in all its guises... You do better."
3. "Having a family and a career was very hard, but it's do-able."
4. "Each one of you can change the world, for you are made of star stuff, and you are connected to the universe."
5. I live and work with three basic assumptions.
   (a) "There is no problem in science that can be solved by a man that cannot be solved by a woman."
   (b) "Worldwide, half of all brains are in women."
   (c) "We all need permission to do science, but for reasons that are deeply ingrained in history, this permission is more often given to men than to women."

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3. A NEUTRON STAR

Mr. Viraj Kalsariya

3.1 Discovery

On November 28, 1967 JOCELYN BELL, an Astronomy student from Cambridge (England) was investigating Quasar - the powerful dynamos of light and are some of the brightest celestial objects. She was examining radio waves data from the most sensitive telescope of its sort. When she analyzed them, mysterious pulse grabbed her attention. It seemed like very regular pulse but it was not coming from quasars. It was due to a new cosmological phenomenon. In February, 1968 JOCELYN BELL and ANTONY HEWISH published the discovery of a super dense highly magnetized celestial body: A NEUTRON STAR

3.2 Birth of a neutron star

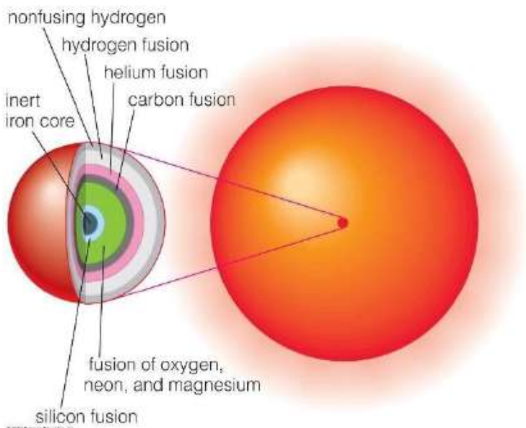

Figure 1: Fusion Reaction in Core of the Massive Star
(Source: Credit: 2015 Pearson Education, Inc.)

The life of a star is dominated by two forces being in balance, its own gravity and the radiation pressure of its fusion reaction. In the core of stars, Hydrogen nuclei are fused to form Helium. Eventually, Hydrogen nuclei in the core are exhausted. If a star is massive enough, Helium fused to form Carbon. The core of these massive stars becomes layered like onions. As heavier and heavier nuclei build at the center, Carbon nuclei fuse to from Neon, which then leads to Oxygen, which further leads to Silicon and it goes all the way to Iron. Since Iron is not able to produce sufficient energy to maintain its structure, the fusion stops.

When fusion stops, the radiation starts dropping rapidly and gravity and radiation are off-balanced. When its core mass exceeds about 1.4 solar masse to 3.2 solar masse, a catastrophic

Figure 2: Super Nova Explosion
(Source: Credit: Earth-chronicles.com)

collapse takes place. The velocity of the outer part of the core reaches up to 70,000 km/s as it collapses towards the center of the star. And now, only the fundamental forces inside an atom are left to fight the gravitational collapse. The quantum mechanical repulsion of electron is overcome. Electrons fuse with protons to produce neutrons, packed as densely as atomic nucleus. The outer layers of the Star are catapulted into space in a violent supernova explosion. The star shoots most of its innards into space, seeding the galaxy with heavy elements and this event gives birth to “A Neutron Star”.

3.3 What is a neutron star

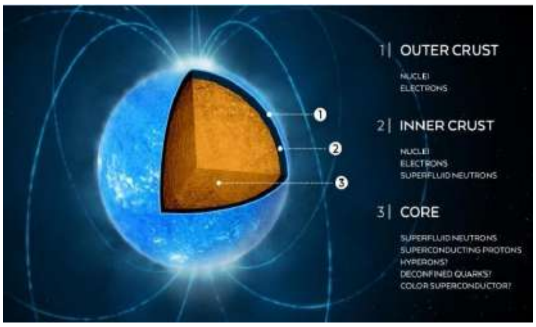

Figure 3: Inside the Neutron Star
(Source: Credit: inspirehep.net)

The crust is extremely hard and most likely made of an iron atom nuclei lattice with a sea of electron flowing through it. The closer we get to the core the more neutrons and the fewer protons we see (in the inner crust) until there is just an incredibly dense soup of indistinguishable neutrons (in outer core). The core of the neutron stars are very, very weird. We are not sure what their properties are, but our closest guess is super-fluid neutron degenerate matter or some kind of ultra-dense quark matter called quark-gluon plasma. This doesn’t make any sense in traditional way and can only exist in such an ultra extreme environment.

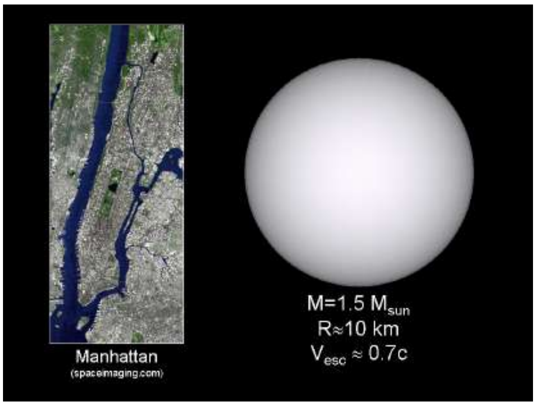

Figure 4: Comparing Neutron Star with Earth
(Source: Credit: Astronomy.ohio-state.edu)

Think of a compact ball inside of which protons and electrons fuse into neutrons and form a frictionless liquid called super-fluid, surround by a crust. This material is incredibly dense, equivalent to the mass of a fully-loaded container ship squeezed into a human hair or 1 cubic centimeter of neutron star contains the same mass as an iron cube 700 meter across. That's roughly 1 billion tons, as massive as Mount Everest, in a space having the size of a sugar cube. Deeper in the crust, the neutron super-fluid forms different phases that physicist call "nuclear pasta" as it's squeezed from lasagna to spaghetti-like shapes and its gravity is so effective that if you were to drop an object from 1 meter over the surface, it would hit the star in one microsecond and accelerate up to 7.2 Gm/h. The surface is super flat, with irregularities of 5 mm maximum, with super thin (10 cm) atmosphere of hot plasma. The surface temperature is about 1 MK (temperature of the surface of the Sun is about 5800 K).

"To achieve this density [of a Neutron Star] at home, just cram a herd of 50 million Elephants into the volume of a Thimble."

–Neil deGrasse Tyson.

The massive pre-cursors to neutron stars often spin. When they collapse, stars that are typically millions of kilometers wide, compress down to neutron stars that are only about 25 kilometers across. But the original star's angular momentum is preserved. That's the reason why neutron star spins much more rapidly than its parent. The fastest moving neutron star found till date is PULSAR, 18000 light years away in the constellation of Sagittarius which scientist cataloged as PSR J1748-244ad. At its equator spinning at approximately 24% of the speed of light, or over 252 Gm/h or rotates a little over 700 times a second. This is so fast that the star has a rather strange shape. We call these objects pulsars because they emit a strong radio signal.

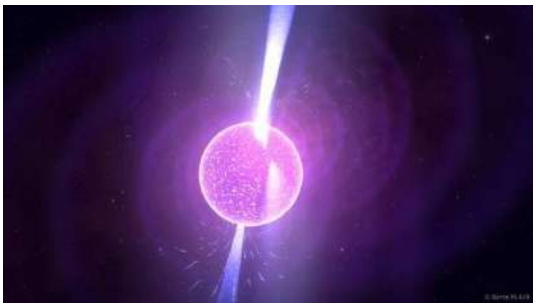

Figure 5: Pulsars
(Source: Credit: Kevin M. Gil)

Neutron stars also have the strongest magnetic field of any known object. The magnetic field of the neutron star is roughly 8 Trillion times stronger than the Magnetic field of Earth. So strong that atoms are affected when they are under its influence.

This magnetic concentration forms vortexes that radiate beams from the magnetic poles. Since the poles aren't always aligned with the rotational axis of the star, the beams spin like lighthouse beacons, which appear to blink when viewed from the Earth. We call them PULSARS. The detection of one of these tantalizing flashing signals by an astrophysicist Jocelyn bell in 1967 was in fact, the way we indirectly discovered neutron stars in the first place.

3.4 Death of neutron star

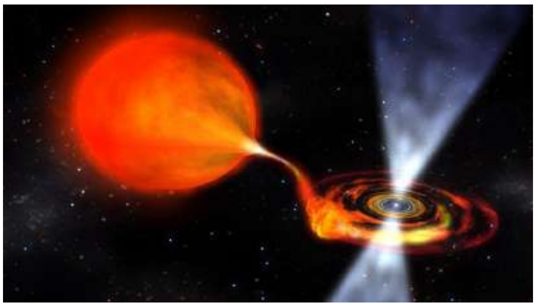

Figure 6: A fast-spin neutron star feeding off the matter from the red giant companion
(Source: Credit: ESA)

An aging neutron star's furious rotation slows over a period of billions of years as it radiates away its energy in the form of electromagnetic waves and gravity waves. But not all the neutron stars disappear so quietly. For example, we've observed binary systems where a neutron star coorbits another star; a neutron star can feed on a lighter companion, gorging on its more loosely bound atmosphere before eventually collapsing cataclysmically into a black hole. While many stars exist as binary systems, only a small percentage of those end up as neutron-star binaries,

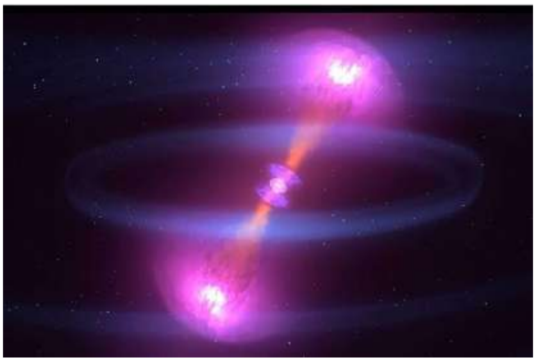

Figure 7: The Collision of Two Neutron Stars
(Source: Credit: NASA's Goddard Space Flight Center/ CI Lab)

Where two neutron stars circle each other in waltz doomed to end as a merger. When they finally collide, they send gravity waves through space-time, just like ripples produced when a stone is thrown into a calm lake. Einstein's General Theory of Relativity predicted this phenomenon over 100 years ago, but it wasn't directly verified until 2017 when Gravitational-wave observatories LIGO and VIRGO observed a neutron star collision. Other telescopes picked up a burst of gamma rays and flash of light, and later X-rays and radio signals, all from the same impact. That became the most studied event in the history of Astronomy. It yielded a treasure trove of data that's helped pin down the Speed of Gravity, bolster important theories in Astrophysics and provide evidence for the origin of heavy elements like Gold and Platinum. Neutron stars haven't given up all their secrets yet. LIGO and VIRGO are being upgraded to detect more collisions. That will help us learn what else the Spectacular demise of these dense, pulsating, spinning magnets can tell us about the Universe.

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4. Light

Mr. Krupamaya Panda

4.1 Introduction

Very first thing that links our consciousness to the rest of the universe is “light”. In a more scientific way, light is an electromagnetic wave, ranging from gamma rays to radio waves in our physical world[1].

In Physics, the word ’light’ is usually used for visible electromagnetic waves. Since, our eyes were evolved in such a manner that we can see only electromagnetic waves ranging from 330 nm to 770 nm of wavelength and rest of the wavelengths are beyond our sensations. But because of technological revolution now we are able to observe whole electromagnetic spectrum[1].

4.2 Structure

As famous physicist Richard P. Feynman once said, “there is a difference between knowing name of something and knowing something”[2]. What we discussed till now is our knowing something’s name. Before 6 months from now, I had watched a web series about Albert Einstein’s life named ‘Genius’[3]. What I am going to describe here is part of one of its episodes. The video shows, how might have Einstein imagined about light. From a layman’s viewpoint, what would it look like? Here’s the answer with little modification, such a person only observes a homogeneous radiance coming from a torch or a lamp or from the Sun. Nothing special to do.

If you ask a 10th grade student studying ray-optics what would light look like, he would answer that its a ray or huge number of straight glowing lines moving at a speed of 299,792,458 m/s from a source. Let us go a little further and ask high a school student, he would say that light is a transverse wave oscillating at right angles to its direction of propagation, moving with a phase velocity v and travelling at speed 299,792,458 m/s. That is not where we stop. Let us go for a more accurate description of light. We know that Maxwell's equations state that light is made up of oscillating electric field and magnetic field. So if we imagine beyond a transverse wave, we would notice electric field and magnetic field oscillating with respect to each other at right angles and propagating through the space with the speed 299,792,458 m/s. That is a correct way of imagining light if you are a Physics student. Later on we would also see that light sometimes behaves as a particle, which shows dependency of light's nature on its dimensions[4].

4.3 Origin

From Maxwell's revolutionary ideas, we know that, time varying electric field gives rise to space varying magnetic field and vice-versa. So, if we can have one, we can have the other[5].

The simplest form of the source of an electromagnetic wave can be referred to as an oscillating electric dipole. An electric dipole consists of a positive and a negative charge separated by a finite distance. Now if any of them or both try to have a harmonic motion relative to the other, then it gives rise to electromagnetic waves. According to Quantum theory, the electric dipole moment of the dipole (atom) is the source of light[6].

As per our current understanding of Physics, the most common and interesting source of light or electromagnetic waves is a Hydrogen atom. A Hydrogen atom is made up of a proton-electron binary system. From Bohr's model, we also know about the origin of atomic spectra, which says that in Hydrogen atom, if we can disturb electron's orbit or it's position relative to proton we can actually create electromagnetic wave or a photon[6].

This phenomenon can be described as follows: Let us first assume that a Hydrogen atom is in its ground state. Now somehow we try to disturb this system (usually discharging electricity through a glass tube filled with hydrogen gas). By doing so, what we do is that we try to change electron's orbit or its position relative to the nucleus, say putting it in excited state. Now it would try to come back to its ground state and during that if we try to observe this situation from electron's point of view what we would observe is that the electric field around it is changing with respect to position. Since you are watching from electron's point of view, your position is changing relative to proton, so gradient of Electric field also changes.[10] From Maxwell's equations, we have, curl of vector E equals to the rate of change of magnetic field with respect to time. So, here with change in position relative to proton is equivalent to curl of electric field vector, thus a time varying magnetic field will arise at right angles to the electric field due to electromagnetic induction. If such an external disturbance continues a series of oscillating electric and magnetic fields would be observed. Such series of oscillating fields will behave like wave trains propagating in every direction from source (atom) at a speed of 299,458,789 m/s[5].

"In the beginning, God said, the four dimensional diversions of an anti-symmetric second rank tensor equals zero and there was light."

- Michio Kaku

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5. Report of activities during this quarter


An interactive talk was arranged on 24th September, 2019 on "Interdependence of Science and Technology" in collaboration with SCET, Surat. Dr. C. M. Nautiyal, a multi-dimensional personality, such as Consultant (INSA), Scientist in-charge of Radio-carbon lab, Science Writer and Science Communication Trainer served as the resource person. The students enjoyed it and there was a long lasting interaction between the students and the expert. Dr. Mehul Pandya, a


Senior Scientist at ISRO and an active member of one of the most successful space programs of ISRO, MOM (Mars Orbiter Mission), was invited to deliver a talk on 17th December, 2019 by the Physics Club. The title of the talk was "Story of Rocket" in which he discussed basics of Rocket Science and India's Space Missions. The students got an opportunity to have an understanding of the basic concepts of rocket science and the difficulties that the scientists face while designing any project related to it. They had active interaction with the expert even after the presentation. Dr. Kathan Shukla from IIM, Ahmedabad was invited to have interaction with


the students of the college on 21st December, 2019. He shared his experience with the students and also explained the importance of management as a career and also its significance in the daily life. Our college has purchased a telescope for sky gazing activity and we frequently

arrange for the same. This year, the amateur astronomers had a golden opportunity to witness a annular solar eclipse which happened on 26th December, 2019. However, in Surat, we had opportunity to observe partial solar eclipse. We had mounted the telescope on the terrace of the Biology Department and for almost four hours from starting till the end of the eclipse, the students, faculties and the invitees took the advantage of observing the eclipse through the telescope and solar baader astro solar safety film. It turned out to be a memorable experience for all. This year, we introduced a new activity for the students of Physics Club. The students

were given some selected papers from various peer reviewed journal, which they had to study, understand and then discuss with the members of the club on 30th December, 2019. The following students gave presentation on different papers:

1. Krupamaya Panda
2. Shruti Tiwari
3. Ishant Sabhaya

NEW JOINEE TO OUR DEPARTMENT

Mr. Kileen Mahajan

Mr. Kileen Mahajan has 31+ years of experience in teaching Electronics and Physics at B.Sc. level and has also taught at postgraduate courses in M.Sc. and MCA. He has 28 years of experience in product designing for industry and has designed many indigenous machines for the first time in India. His designs are being used in Indian Railways, X-ray machine manufacturing, Electronics industry and ISRO. His area of interest is focused on (but not limited to) CNC machines, AI, Robotics and Embedded Systems. He is a voracious reader and his other areas of interest include Motivational Training, Counselling, Rain Water Harvesting, Waste Management and 3D Printing.

Mr. Bhupeshkumar J. Lad

Mr. Bhupeshkumar J. Lad has 25+ years of experience in teaching Electronics and Physics at B.Sc. level and has also taught at postgraduate courses in M.Sc. He has 17 years of experience in Programme officer in NSS Unit of VNSGU a scheme run by Central Govt of India and other Schemes such as SBSI and UBA run by MHRD. Paper poster presentation on Crystal Growth and its Properties of Ba+ dopped KDP. 11th Feb,2018.

An occasion for lifetime: *On December 26, 2019, a partial solar eclipse was visible from Surat. We arranged our telescope to see this rare spectacle. Large number of students, faculty members and common public remained present on this momentous occasion. The Chairman of Sarvajanik Education Society, Mr. Kamlesh Yagnik, accompanied by his family members, also dropped in.*