The Rhythm of the Universe:
A review of universal story told by Avijit

Biplab Pal

[I just received the book " Alo Hate Chaliyache Andharer Yatri" by Avijit Roy. ***Avijit told us most authentic story of Astrophysics.*** *I was reading his books and thinking of adding my own perception of the subject. So I decided to write this lengthy review which is just not the review but has some more literature that will enhance the appreciation of the readers.*

The book has seven chapters. For chapter 1-3, I have formed my own perception for a long time since I was a student of physics. In the review of chapter 3, I have given my own way to understand Einstein's curvature in GTR. For chapter4,5 and 6, I am quite dependant on various books and websites to absorb latest and greatest discoveries in Astrophysics except for the subject of Chandrashekhar limit on which I worked as a student and therefore, I have my own realization. Finally, again on chapter 7 that describes how modern physics influenced the mythical doctrine of religion, I have tried to provide my insight into the subject]

"*Death is an essential element in the progress of science, since it takes care of conservative scientists of a previous generation reluctant to let go of an old, fallacious theory and embrace a new and accurate one*"
-Theory of Big Bang, Simon Singh

Do we need to read popular physics?

In my childhood, I used to read a lot of popular science book. Samarjit Kar, Dipankar Home, Jayanta Bishnu Narlikar and Surjendu Bikash KarMahapatra were my favorite writers. But when I was a student of physics, I used to hate reading popular science book. My friend, Prof Sougato Bose, who is a Professor of Quantum Physics in London University, always forced me to read latest and greatest of popular physics—Emperor's new mind, Road to reality (Roger Penrose), First three minutes (Stephen Wienberg) to name a few. We were vertically split in our physics ideology in our batch. In first category, Sougato, Anupam (Dr Anupam Majumdar, scientist in Astrophysics in international center for theoretical physics in Italy), Sonali (Dr Sonali Tammhankar, scientist in Princeton University), Nilima (Professor Nilima Nigam, Professor of mathematics in McGill University, Canada) held the view that physics is for searching supreme beauty of the universe—to answer the questions of eternal quest of the mankind. So strong was their conviction that Anupam used to carry a copy of "Brief History of Time" with him all the time referring it as his Bible. He was such a passionate lover of the quest of the universe that in his final year, he swallowed sleeping pills all because he was having difficulty in understanding differential geometry—essential craft of mathematics for understanding modern theories in general theories of relativity! Me and Ashish (Dr Ashish Bharadwaraj, a scientist and a great atheist in Bell Labs, NJ) were of the opinion that essence of Physics is in its application to improve the quality of life. For us, atheism was quite normal choice (and thinking about God is a natural stupidity) and we never thought that Physics will be so useful to break the religious belief system of the common people.

However, after twelve years of hostel life with some of the best brilliant minds in India, when I returned to social life, I came across with so many people with strong belief in God and supernaturalism, I have changed my opinion. Popular physics does have very important role to play in our society to shape and mould the opinion of the common people. Avijit's book 'Alo Hate Chaliyache Andharer Yatri " is one of the greatest attempts in Bengali literature to educate our minds with the quest of natural questions—who we are? What is this universe around us? What are those stars? Will they live for ever? How are they born? How this Universe was created? Will it die one day?

Chapter1: Story of Newton and Chapter 2: Story of Kepler:

Ever since prehistoric time, mankind is asking these questions. Greeks are the first to document these questions and came up with a model of cosmos—earth centric Universe. More popularly known as Ptolemy's model which has governed the thinking of the authors of Bible and Koran. And thus the thinking of thousands of followers of Christianity and Islam till Copernicus corrected it—earth revolves around sun. Quite naturally Church's reaction was hostile- Bruno was burnt to death, Galileo was sent to prison. We all know this but in Avijit's book you will find quite informative history of Bruno and Galileo. We learn that Bruno was the strongest of atheist of all the times who didn't change his belief in science in favor of Church before a looming death sentence. This is in sharp contrast with Galileo who was a God fearing Christian and changed his statement fearing death. Avijit narrated the history in great details.

Newton's story: First chapter of the book started with Newton, Sir Isaac Newton. We all know the popular story of apple hitting in his head in his grandmother's farmhouse of Canterbury and the myth that ignited his invention of laws of gravitation—laws that changed the understanding of the universe for ever. However, the real story is told in the book.

Philosophiae Naturalis Principia: I would like to speak a few words of my own perception of the book. Long time back, I was going through an 18th century translation of Principia (a book by Newton where he documented his laws of motion and Gravitation. For knowing more about Principia, read the Appendix of Alo Hate

Chaliyache Andharer Yatri) in our IIT-Kharagpur library. There is not a single algebra in the book as the analysis has been done in Euclidian geometry. I observed that he has used the Planetary orbital a lot in his drawing and based on Kepler's law of Planetary motion ---in the same time interval, a planet sweeps same area all the time, Newton found proportionality in the areas of different triangle that he can draw using his latest discoveries of real analysis (calculus). It is easy to come into conclusion of Gravitation—especially if you have already discovered the laws of motion and thus for the first time, defined what we know as 'Force' and 'Momentum'. In true sense, inverse square law of Gravitation was discovered by Keplar in his second law. Human civilization needed a Newton who could have defined the force and created the language of real analysis to transform the laws of planetary motion into the laws of Gravitation.

Chapter3: Einstein and General Theory of Relativity

However laws of Gravitation are not enough to understand the behavior of the universe and stars. One needs to understand basics of quantum thermodynamics and general theory of relativity to understand the nature of evolution of our universe.
So in third chapter, author explains what is this theory of relativity—special and general that propounded by greatest physicist of last century, Albert Einstein. Special theory is explained very nicely, a layman also would understand. For General theory, author provided a popular imagination of curvature.

Freely Falling Objects: Best way to understand GTR is by understanding freely falling object around us. Newton's laws of Gravitation tell us that two bodies attract each other in straight line—we call it a freely falling body. When somebody jumps from the roof without any forward motion, we all know, we fall straight into the ground. Earth is pulled by Sun in straight line.

What is this straight line? Shortest path between two points! Is it?

Euclidian Geometry: Of course it is. If somebody wants to measure the shortest distance between USA and India, one has to dig a straight tunnel between USA and India. This is a simple conclusion that has been proved by the Greek, Indians long time back. Common sense.

But does this shortest path solve any problem for the Airlines who want to fly from USA to India? Absolutely not, because we can not bore a hole through Earth's core. So what is the shortest path then knowing that we have to find a shortest path on the surface of a sphere? Can Euclidian shortest path help?

Understanding Riemannian geometry: Here enters Riemannian geometry, geometry of curved surface. This geometry is defined a by a term called metric –which is synonymous with distance between two points evaluated through a new branch of mathematics called Tensors. So what is the difference?

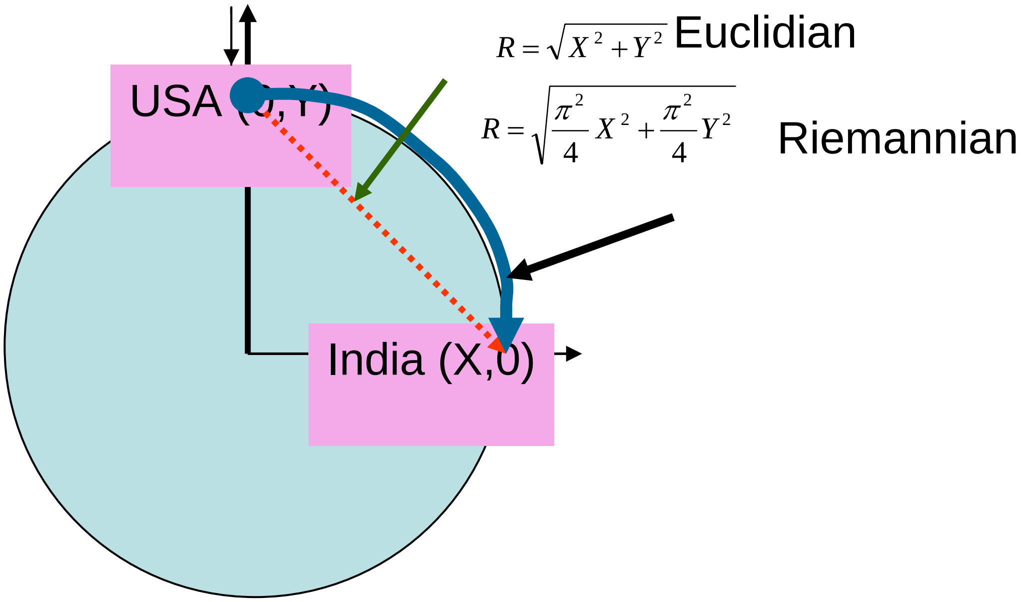
Well, as per Euclid, if a point has a co-ordinate X,Y, its distance from origin (0,0), is

$$R = \sqrt{X^2 + Y^2}$$

But in Rimenian's Geometry, the shortest distance from the origin is presented in a generalized form:

$$R = \sqrt{a.X^2 + bY^2 + cXY}$$

Euclidian Geometry is a special case of Rimenian Geometry with a=1,b=1 and c=0. These parameters a,b,c are also the measure of curvature. With this knowledge, we can easily solve the shortest path problem of the Airlines. Look at the picture below.



General Theory of Relativity : But what is its relationship with Einstein's GTR? Simple. Newton said (also we observe) two bodies attract and approach towards each other in straight line or shortest path between them. A ball in USA and a ball in India will attract each other along Euclidian line as shown in red line in the above picture. Based on his experience in special theory of relativity which he found based on the fact that velocity of light is constant and nobody can move faster than light, Einstein came to conclusion that two bodies indeed move to each other in shortest possible path but not in Euclidian Geometry but in Riemannian Geometry in four dimension.

He concluded that in the absence of any mass nearby, any object will move in Euclidian shortest pathway. However, instead of two space co-ordinates X,Y as shown above, you have to think the space in terms of X (Length), Y (Width), Z(Height) and SQRT(-1)*ct (c is velocity of light, t is time). But basic fact remains same. Shortest path:

$$R = \sqrt{X^2 + Y^2 + Z^2 - c^2 t^2}$$

This is his special theory of relativity. So what he says, that in free space the ball in USA will move in Euclidian line as long as there is no ball in India (assume there is nothing in the Universe except these two balls we are discussing about).

However, in the presence of any object (in this case the ball in India), this shortest path or the path of the body (ball in USA) that has been attracted in the gravitation field, will follow Riemenian shortest path:

$$R = \sqrt{aX^2 + bY^2 + cZ^2 - fc^2 t^2 + dXY + eXZ + gYZ.........}$$

Who determines these a,b,c..? The mass of the object that is attracting. This is all about GTR. Mass of the attracting object determines the curvature co-efficient a,b,c..etc. a=1,b=1..means there is no curvature, no mass attracting the body.

Finally, how this curvature looks like:? However in practicality due to spherical symmetry in Gravitation, space co-ordinates are spherical $(,r,\theta,\varphi\ )$ and actual metric in presence of mass looks like

$$dS^2 = (1 - \frac{R_G}{R})dt^2 + \frac{dr^2}{1 - \frac{R_G}{R}} + r^2(d\theta^2 + \sin^2\theta d\varphi^2)$$

So the curvature constant a=(1-Rg/R)! with Rg=2M, in cosmological unit where c=1, G=1. This means if there is no mass, Rg=0 and metric (read as shortest path) will be Euclidian as we have seen before. We also find more mass means more curvature as (1-Rg/R) term will deviate more from 1!

How this idea has been verified and influenced the idea of the Universe? Please read the book to know more about its history, verification and impact.

Chapter4: Big Bang and Expanding Universe:

The next chapter was on Expanding universe as a natural outcome of Einstein's GTR. Though author started with Chandrashekhar limit to emphasize the role of quantum statistics in cosmology.

Discovery of Expanding Universe: When Einstein began to apply his theory to the structure of the universe, he was dismayed to find that it predicted either an expanding or contracting universe--something entirely incompatible with the prevailing notion of a static universe. In what he would later call "the greatest blunder of my life," Einstein added a term called the cosmological constant to his equations that would make his calculations consistent with a static universe.

Einstein admitted his mistake in 1929 when Edwin Hubble showed that distant galaxies were, indeed, receding from the earth, and the further away they were, the faster they were moving. That discovery changed cosmology.

Doppler Effect and red shift: The familiar sound of a train whistle as it recedes into the distance is a consequence of the Doppler Effect. As the train moves away from the listener, the crests of the sound waves are stretched out or shifted, resulting in a lower pitch. The faster the train recedes, the more stretched out the waves become. The same holds true for any wave-emitting object--whether they are sound waves, light waves, or radio waves. Conversely, the wavelengths of objects that are moving toward us are shorter than those emitted by an object at rest.

The standard candles in the sky! Atoms emit or absorb light in characteristic wavelengths: hydrogen, helium, and all the other atomic elements have their own spectrum signatures. In the early part of this century, Vesto Slipher was studying the spectra of light emitted from nearby galaxies. He noticed that the light coming from many galaxies was shifted toward the red, or longer wavelength, end of the spectrum. The simplest interpretation of this "red shift" was that the galaxies were moving away from us.

Hubble's model: Hubble, who had been the first to establish that the universe included many other galaxies outside of our own, noticed something else: the galaxies were receding from us at a velocity proportional to their distance. The more distant the galaxy, the greater its red shift, and therefore the higher the velocity, a relation known as Hubble's Law.

The velocity **v** could be determined by multiplying the distance **R** by **H**, the Hubble constant, given by the slope of the line in the above graph, in units of kilometers per second per million light years. The Hubble constant describes the universe's rate of expansion.

Actually in simple form: Velocity of the Galaxies is proportional to the distance of the galaxies from us.

The apparent linearity of Hubble's Law implies that the universe is uniformly expanding. What does that actually mean?

For one thing, it means that no matter which galaxy we happen to be in, virtually all of the other galaxies are moving away from us (the exceptions are at the local level: gravitational attraction pulls neighboring galaxies, such as Andromeda and the Milky Way, closer together). In other words, it's not as though we here on earth are at the center of the universe and everything else is receding from us. The universe has no "edge" as such.

It also means that the galaxies are not moving away through space, they are moving away with space, as space itself expands. Think of a loaf of unbaked raisin bread you've set in a warm place to rise. The raisins are like galaxies or clusters of galaxies, and the dough, space. As the dough rises, the raisins move farther apart, but they've moved with the dough, not through the dough.

Riddle of accuracy of Hubble constant and the age of the universe: Determining the Hubble Constant is something of a Holy Grail for cosmologists, because it holds the key to the age of the universe. Imagine running a film of cosmic expansion backwards to the Big Bang—in other words, a contracting universe instead of an expanding universe. Because the Hubble Constant is a measure of how much space is expanding in units of distance per second, it's possible to estimate how long it would take, rolling the movie backwards, for the most distant galaxies to collide with each other and finally collapse in the Big Bang.

Unfortunately, it's not so easy to determine the Hubble Constant. While cosmologists have mastered the trick of determining a galaxy's red shift, and therefore its velocity, determining the distance to far-off objects is quite another matter. We don't have any yardsticks that long.

Instead, cosmologists use standard candles, bright beacons that serve as reference points. One kind of standard candle are the Cepheid variables (the North Star is one), so called because they blink at a rate that is precisely related to their brightness. Because the brightness of individual stars is proportional to their distance from us, cosmologists compare nearby Cepheids (to which we know the precise distance) to those farther away. A Cepheid that is four times fainter than a nearby Cepheid is estimated to be twice as far away. Cosmologists use an entire ladder of distance indicators that are calibrated using the lower (nearest) rungs.

Until just recently, most estimates of the Hubble Constant have hovered around 50, which implies that the universe is about 20 billion years old. However, this provides only an upper limit to the age of the universe, and is based on the present rate of expansion, as observed by the recession of distant galaxies. It's likely that this rate was greater in earlier epochs of cosmic evolution. As galaxies tugged at each other through their gravitation, the expansion slowed down.

The Hubble Telescope was designed, in part, to find Cepheid variables and other standard candles even farther away than those detectable by ground-based telescopes. Cosmologists hoped that these objects, not influenced by the gravitational pull of the Milky Way, would yield more accurate information about the expansion of the universe.

One team using the Hubble Telescope found a number of Cepheids in the Virgo cluster, which allowed them to estimate the distance to the far-off Coma cluster.

The team estimated the Hubble Constant to be 80, which would make the universe eight to twelve billion years old. Separate, ground-based observations of another galaxy within Virgo yield an even higher value of 87.

Other groups using another kind of standard candle called supernovae --massive stars that have collapsed and exploded--come up with lower Hubble Constants, either 73 or 50.

On the other hand, astronomers who study the chemistry and life cycles of stars are quite certain that the oldest stars in the Milky Way are about 14 billion years old. Clearly, cosmologists are facing a paradox: you can't have stars that are older than the universe!

All of the galaxies studied are only in the region of 50 million light years from Earth, too close to get a more truly "global" value for the Hubble Constant. Studies are now underway at several observatories worldwide, and with the Hubble Telescope, to probe much further out and find red shifts corresponding to times when the universe was one fourth or less than its present size.

Clearly the pressure is on to find a correct value for the Hubble Constant. Cosmologists hope that better instrumentation, earth-bound and space-born, will provide the means to do so.

Chandra and his limit:

In the beginning of this chapter, author takes us to wonderful world of quantum statistics and how it made difference with Chandrashekhar limit. Readers get a thorough history of Edington versus Chandra dispute over this most important discovery that for the first time made it clear that Astrophysics need to account for relativistic quantum mechanics for understanding of the universe. Author outlines the history and the discovery but did provide much physics with it. So I think I should add my two cents in explaining how Fermi-Dirac statistics made a difference in concluding Chandrashekhar limit that proved that stars with mass greater than 1.4 times that of sun explode into Super Nova – or massive explosion and then contracted into neutron stars.

Chandra the man : Though Chandrashekhar is known for his limit, most of us forget his more important contribution in stellar structure—he was a true genius of fluid and plasma dynamics. Born on 19th October,1910. Chandrashekhar was the first to develop the theory of stellar structure and evolution and subsequently he was awarded the prestigious Nobel Prize for Stellar research along with Albert William Fowler in 1983.

He came to IIT-Kharagpur in 1968 and delivered a week long lecture on Fluid Dynamics and not on his limit!

White Dwarfs: A white dwarf is a star with very high temperatures but very low luminosity. These stars are about the size of the earth but have the mass of the sun. They form at the end of the life cycle of low to medium mass stars.

All stars have most of their mass contained in their core in which most of the atoms (hydrogen and helium) go through fusion. Fusion is complete when all nuclei have fused to form carbon nuclei. At this stage the atmosphere of the star collapses back onto the core. (See White Dwarves , by Yunfei Huang) As fusion occurs the density of the core increases rapidly with the nucleons being pushed closer and closer together. The electrons which are part of the fusing atoms don't take part in the reactions and remain to form plasma around the growing core.

Like many of his contemporaries Chandrashekhar applied Einstein's Theory of Special Relativity and Pauli's Exclusion Principle to derive an upper limit for the size of a white dwarf. According to the Exclusion principle two similar electrons cannot both occur in the same quantum state. It is somewhat like entering into a movie hall and filling up the seats one by one. Question is how far this filling process will continue? Answer lies in the temperature and density of the electron gas.

What is temperature basically? It is nothing but an indication of average kinetic energy (energy with which they are moving to and fro).

Application of Fermi-Dirac statistics: On the other hand density of the electron gas determines what will be the highest kinetic energy of the electron assuming that all the electrons are filling up movie hall one by one without keeping any row open. This highest energy is known as Fermi level and corresponding temperature (Fermi energy / Boltzman constant) is known as Fermi temperature. This is entirely dependant on density of the electron gas. And what determines this density in a star? Mass of the star because density in a star is determined by self-gravitating force. Meaning inner core is attracting outer core and centrifugal force of outer core is holding it back.

Magic of Fermi Temperature: How many electrons are free to participate is determined by the ratio of stellar temperature to the Fermi temperature. Larger the Fermi temperature (or the density of the start) there is more probability to find a lot more electron with very high kinetic energy . It is easy to imagine that in heavy stars in which Fermi temperature is high, available electrons have higher kinetic energy to escape the gravitational force of the core. And therefore they will not collapse into the core. This is the core of Chandrashekhar limit that Chandra thought about while he was traveling to Cambridge in 1930. By then he already worked on couple of small topics in statistical thermodynamics based on his training work in Indian cultivation science in Jadavpur. In Calcutta, for a brief period he worked under his uncle, Sir C.V.Raman who won Nobel Prize in 1930. In appendix, readers will find a glorious history of Raman Effect by Sir CV Raman and his student KS Krishnan.

The limit: If the star has mass under a certain value, 1.44 times the mass of the sun, it will finally exist as a white dwarf. If the mass is more than this value, another reaction will occur where the electrons will fuse with the protons to form more neutrons and the star will eventually die out as a neutron star. The largest stars die out as Black Holes

This chapter also provided a detail history of experimental verification on expanding universe. The most important proof among them is microwave background radiation.

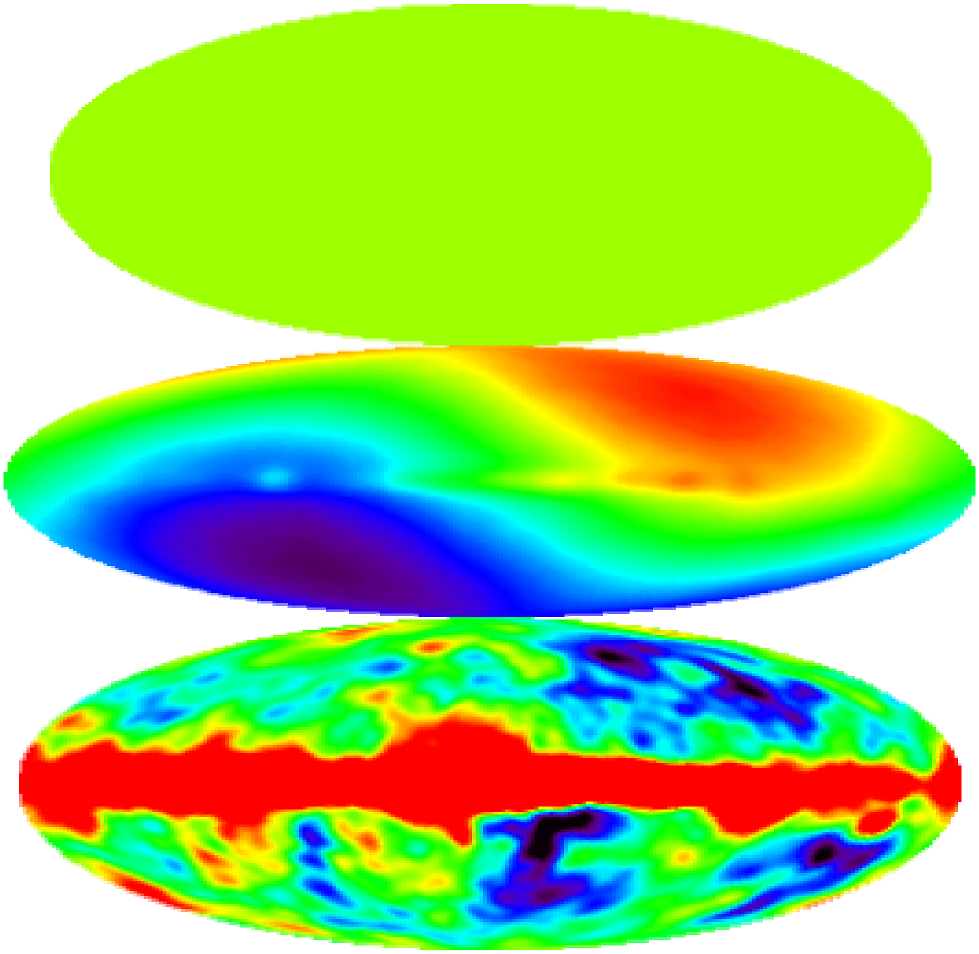
Tests of the Big Bang: The CMB

The Big Bang theory predicts that the early universe was a very hot place and that as it expands, the gas within it cools. Thus the universe should be filled with radiation that is literally the remnant heat left over from the Big Bang, called the “cosmic microwave background radiation”, or CMB.

Discovery of the Cosmic Microwave Background

The existence of the CMB radiation was first predicted by George Gamow in 1948, and by Ralph Alpher and Robert Herman in 1950. It was first observed inadvertently in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey. The radiation was acting as a source of excess noise in a radio receiver they were building. Coincidentally, researchers at nearby Princeton University, led by Robert Dicke and including Dave Wilkinson of the WMAP science team, were devising an experiment to find the CMB. When they heard about the Bell Labs result they immediately realized that the CMB had been found. The result was a pair of papers in the Physical Review: one by Penzias and Wilson detailing the observations, and one by Dicke, Peebles, Roll, and Wilkinson giving the cosmological interpretation. Penzias and Wilson shared the 1978 Nobel Prize in physics for their discovery.

Today, the CMB radiation is very cold, only 2.725° above absolute zero, thus this radiation shines primarily in the microwave portion of the electromagnetic spectrum, and is invisible to the naked eye. However, it fills the universe and can be detected everywhere we look. In fact, if we could see microwaves, the entire sky would glow with a brightness that was astonishingly uniform in every direction. The picture in the following page shows a false color depiction of the temperature (brightness) of the CMB over the full sky (projected onto an oval, similar to a map of the Earth). The temperature is uniform to better than one part in a thousand! This uniformity is one compelling reason to interpret the radiation as remnant heat from the Big Bang; it would be very difficult to imagine a local source of radiation that was this uniform. In fact, many scientists have tried to devise alternative explanations for the source of this radiation but none have succeeded.



Source [NASA]

Figure [NASA] CMB: This figure, produced by the COBE science team, shows three false color images of the sky as seen at microwave frequencies. The orientation of the maps are such that the plane of the Milky Way runs horizontally across the center of each image. The top figure shows the temperature of the microwave sky in a scale in which blue is 0 Kelvin (absolute zero) and red is 4 Kelvin. Note that the temperature appears completely uniform on this scale. The actual temperature of the cosmic microwave background is 2.725 Kelvin. The middle image is the same map displayed in a scale such that blue corresponds to 2.721 Kelvin and red is 2.729 Kelvin. The "yin-yang" pattern is the dipole anisotropy that results from the motion of the Sun relative to the rest frame of the cosmic microwave background. The bottom figure shows the microwave sky after the dipole anisotropy has been subtracted from the map. This removal eliminates most of the fluctuations in the map: the ones that remain are thirty times smaller. On this map, the hot regions, shown in red, are 0.0002 Kelvin hotter than the cold regions, shown in blue.

Why study the Cosmic Microwave Background?

Since light travels at a finite speed, astronomers observing distant objects are looking into the past. Most of the stars that are visible to the naked eye in the night sky are 10 to 100 light years away. Thus, we see them as they were 10 to 100 years ago. We observe Andromeda, the nearest big galaxy, as it was three million years ago. Astronomers observing distant galaxies with the Hubble Space Telescope can see them as they were only a few billion years after the Big Bang. (Most cosmologists believe that the universe is between 12 and 14 billion years old.)

The CMB radiation was emitted only a few hundred thousand years after the Big Bang, long before stars or galaxies ever existed. Thus, by studying the detailed physical properties of the radiation, we can learn about conditions in the universe on very large scales, since the radiation we see today has traveled over such a large distance, and at very early times.

The Origin of the Cosmic Microwave Background

The expansion indicates the universe was smaller, denser and hotter in the distant past. When the visible universe was half its present size, the density of matter was eight times higher and the cosmic microwave background was twice as hot. When the visible universe was one hundredth of its present size, the cosmic microwave background was a hundred times hotter (273 degrees above absolute zero or 32 degrees Fahrenheit, the temperature at which water freezes to form ice on the Earth's surface). In addition to this cosmic microwave background radiation, the early universe was filled with hot hydrogen gas with a density of about 1000 atoms per cubic centimeter. When the visible universe was only one hundred millionth its present size, its temperature was 273 million degrees above absolute zero and the density of matter was comparable to the density of air at the Earth's surface. At these high temperatures, the hydrogen was completely ionized into free protons and electrons.

Since the universe was so very hot through most of its early history, there were no atoms in the early universe, only free electrons and nuclei. (Nuclei are made of neutrons and protons). The cosmic microwave background photons easily scatter off of electrons. Thus, photons wandered through the early universe, just as optical light wanders through a dense fog. This process of multiple scattering produces what is called a “thermal” or “blackbody” spectrum of photons. According to the Big Bang theory, the frequency spectrum of the CMB should have this blackbody form. This was indeed measured with tremendous accuracy by the FIRAS experiment on NASA's COBE satellite.

This figure shows the prediction of the Big Bang theory for the energy spectrum of the cosmic microwave background radiation compared to the observed energy spectrum. The FIRAS experiment measured the spectrum at 34 equally spaced points along the blackbody curve. The error bars on the data points are so small that they can not be seen under the predicted curve in the figure! There is no alternative theory yet proposed that predicts this energy spectrum. The accurate measurement of its shape was another important test of the Big Bang theory.

“Surface of Last Scattering”

Eventually, the universe cooled sufficiently that protons and electrons could combine to form neutral hydrogen. This was thought to occur roughly 400,000 years after the Big Bang when the universe was about one eleven hundredth its present size. Cosmic microwave background photons interact very weakly with neutral hydrogen.

The behavior of CMB photons moving through the early universe is analogous to the propagation of optical light through the Earth's atmosphere. Water droplets in a cloud are very effective at scattering light, while optical light moves freely through clear air. Thus, on a cloudy day, we can look through the air out towards the clouds, but can not see through the opaque clouds. Cosmologists studying the cosmic microwave background radiation can look through much of the universe back to when it was opaque: a view back to 400,000 years after the Big Bang. This “wall of light“ is called the surface of last scattering since it was the last time most of the CMB photons directly scattered off of matter. When we make maps of the temperature of the CMB, we are mapping this surface of last scattering.

As shown above, one of the most striking features about the cosmic microwave background is its uniformity. Only with very sensitive instruments, such as COBE and WMAP, can cosmologists detect fluctuations in the cosmic microwave background temperature. By studying these fluctuations, cosmologists can learn about the origin of galaxies and large scale structures of galaxies and they can measure the basic parameters of the Big Bang theory.

Readers will find this chapter an amazing reading.

Chapter 5: Future of the Universe and dark matter

In the next chapter (5^{TH}) , Avijit took us to the riddle of dark matter and energy. And the future of the universe. In the previous chapter we have learned the beginning through Big Bang but this chapter discusses what the end of the Universe is if there is any. In order to understand the evolution and future of the universe, we need to understand dark matters – still a sacred secret in Cosmology. This is "stuff" which cannot be seen directly -- so what makes us think that it exists at all? Its presence is inferred indirectly from the motions of astronomical objects, specifically stellar, galactic, and galaxy cluster/super cluster observations. It is also required in order to enable gravity to amplify the small fluctuations in the Cosmic Microwave Background enough to form the large-scale structures that we see in the universe today.

Dark matters: For each of the stellar, galactic, and galaxy cluster/super cluster observations the basic principle is that if we measure velocities in some region, then there has to be enough mass there for gravity to stop all the objects flying apart. When such velocity measurements are done on large scales, it turns out that the amount of inferred mass is much more than can be explained by the luminous stuff. Hence we infer that there is dark matter in the Universe.

What do scientists look for when they search for dark matter? We cannot see or touch it: its existence is implied. Possibilities for dark matter range from tiny subatomic particles weighing 100,000 times less than an electron to black holes with masses millions of times that of the sun . The two main categories that scientists consider as possible candidates for dark matter have been dubbed MACHOs (Massive Astrophysical Compact Halo Objects), and WIMPs (Weakly Interacting Massive Particles). Although these acronyms are amusing, they can help you remember which is which. MACHOs are the big, strong dark matter objects ranging in size from small stars to super massive black holes. MACHOs are made of 'ordinary' matter, which is called *baryonic* matter. WIMPs, on the other hand, are the little weak subatomic dark matter candidates, which are thought to be made of stuff other than ordinary matter, called *non-baryonic* matter.

Astronomers search for MACHOs while particle physicists look for WIMPs: Astronomers and particle physicists disagree about what they think dark matter is. Walter Stockwell, of the dark matter team at the Center for Particle Astrophysics at U.C. Berkeley, describes this difference. "The nature of what we find to be the dark matter will have a great effect on particle physics and astronomy. The controversy starts when people made theories of what this matter could be--and the first split is between ordinary baryonic matter and non-baryonic matter" . Since MACHOs are too far away and WIMPs are too small to be seen, astronomers and particle physicists have devised ways of trying to infer their existence.

MACHOs: Massive Compact Halo Objects are non-luminous objects that make up the halos around galaxies. Machos are thought to be primarily brown dwarf stars and black holes. Like many astronomical objects, their existence had been predicted by theory long before there was any proof. The existence of brown dwarfs was predicted by theories that describe star formation. Black holes were predicted by Albert Einstein's General Theory of Relativity from the singularity of GTR equation. See appendix A.

Brown Dwarfs: Brown dwarfs are made out of hydrogen--the same as our sun but they are typically much smaller. Stars like our sun form when a mass of hydrogen collapses under its own gravity and the intense pressure initiates a nuclear reaction, emitting light and energy. Brown dwarfs are different from normal stars. Because of their relatively low mass, brown dwarfs do not have enough gravity to ignite when they form. Thus, a brown dwarf is not a "real" star; it is an accumulation of hydrogen gas held together by gravity. Brown dwarfs give off some heat and a small amount of light

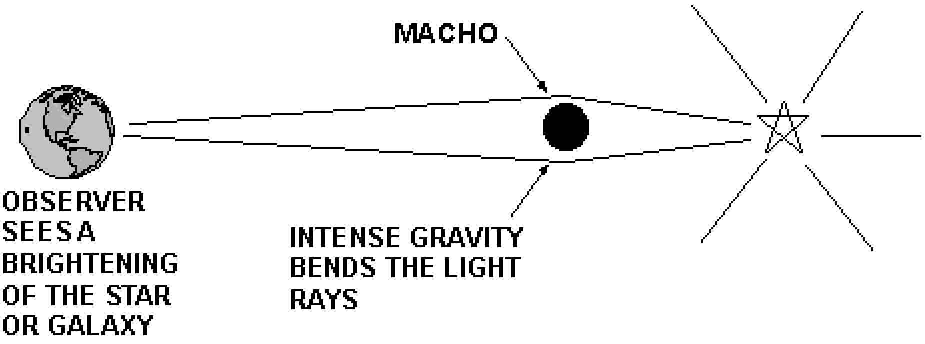
Black Holes: (see appendix A) Black holes, unlike brown dwarfs, have an overabundance of matter. All that matter "collapses" under its own enormous gravity into a relatively small area. The black hole is so dense that anything that comes too close to it, even light, cannot escape the pull of its gravitational field. Stars at safe distance will circle around the black hole, much like the motion of the planets around the sun. Black holes emit no light; they are truly black. And possible last stable phase of the star-a neutron star.

Can we detect MACHOs?

Astronomers are faced with quite a challenge with detecting MACHOs. They must detect, over astronomical distances, things that give off little or no light. But the task is becoming easier as astronomers create more refined telescopes and techniques for detecting MACHOs.

Searching with Hubble: With the repair of the Hubble Space Telescope, astronomers can detect brown dwarfs in the halos of our own and nearby galaxies. Images produced by the Hubble Telescope, however, do not reveal the large numbers of brown dwarfs that astronomers hoped to find. "We expected [the Hubble images] to be covered wall to wall by faint, red stars," reported Francesco Paresce of the Johns Hopkins University Space Telescope Science Institute in the *Chronicle of Higher Education*. Research results are disappointing--calculations based on the Hubble research estimate that brown dwarfs constitute only 6% of galactic halo matter.

Gravitational Lensing. Astronomers use a technique called *gravitational lensing* in the search for dark matter halo objects. Gravitational lensing occurs when a brown dwarf or a black hole passes between a light source, such as a star or a galaxy, and an observer on the Earth. The object focuses the light rays, causing the light source to brighten. Astronomers diligently search photographs of the night sky for the telltale brightening that indicates the presence of a MACHO.
Wouldn't a MACHO block the light? How can dark matter act like a lens? The answer is gravity. Albert Einstein proved in 1919 that gravity bends light rays (see the appendix of the book). He predicted that a star, which was positioned behind the sun, would be visible during a total eclipse. Einstein was right--the gravity of the sun bent the light rays coming from the star and made it appear next to the sun.



Gravitational Lensing--how MACHOs focus light

Not only can astronomers detect MACHOs with the gravitational lens technique, but they can also calculate the mass of the MACHO by determining distances and the duration of the lens effect. Although gravitational lensing has been known since Einstein's demonstration, astronomers have only begun to use the technique to look for MACHOs in the past two or three years.

Gravitational Lensing projects include the MACHO project (America and Australia), the EROS project (France), and the OGLE project (America and Poland). Preliminary data from these projects suggest the existence of lens objects with masses between that of Jupiter and the sun.

Circling Stars: Another way to detect a black hole is to notice the gravitational effect that it has on objects around it. When astronomers see stars circling around something, but cannot see what that something is, they suspect a black hole. And by observing the circling objects, the astronomers can conclude that, indeed, a black hole does exist.

In January of 1995, a team of American and Japanese scientists announced "compelling evidence" for the existence of a massive black hole at the American Astronomical Society meeting . Led by Dr. Makoto Miyosi of the Mizusawa Astrogeodynamics Observatory and Dr. James Moran of the Harvard-Smithsonian Center for Astrophysics, this group calculated the rotational velocity from the Doppler shifts of circling stars to determine the mass of the black hole. This black hole has a mass equivalent to 36 million of our suns . While this finding and others like it are encouraging, MACHO researchers have not turned up enough brown dwarfs and black holes to account for the missing mass. Thus, most scientists concede that dark matter is a combination of baryonic MACHOs and non-baryonic WIMPs.

WIMPs:

In their efforts to find the missing 90% of the universe, particle physicists theorize the existence of tiny non-baryonic particles that are different from what we call "ordinary" matter. Smaller than atoms, Weakly Interactive Massive Particles (for details, please see the Book. More information on WIMP can be found on the appendix of the book) are thought to have mass, but usually interact with baryonic matter gravitationally--they pass right through ordinary matter. Since each WIMP has only a small amount of mass, there needs to be a large number of them to make up the bulk of the missing matter. That means that millions of WIMPs are passing through ordinary matter--the Earth and you and me--every few seconds. Although some people claim that WIMPs were proposed only because they provide a "quick fix" to the missing matter problem, most physicists believe that WIMPs do exist. According to Walter Stockwell, astronomers also concede that at least some of the missing matter must be WIMPs. "I think the MACHO groups themselves would tell you that they can't say MACHOs make up the dark matter". The problem with searching for WIMPs is that they rarely interact with ordinary matter and radiation, which makes them difficult to detect.

Detecting WIMPs: All hope of proving WIMPs exist rest on the theory that, on occasion, a WIMP will interact with ordinary matter. Because WIMPs can pass through ordinary matter, a rare WIMP interaction can take place inside a solid object. The trick to detecting a WIMP is to witness one of these interactions. Dr. Bernard Sadoulet and Walter Stockwell at the Center for Particle Astrophysics hope to do just that. Their project involves cooling a large crystal to almost absolute zero, which restricts the motions of its atoms. The energy created by a WIMP interaction with an atom in the crystal will then register on their instruments as heat. Because their research is still in progress, there are no results available.

A similar WIMP detection project is under way in Antarctica. The AMANDA project (Antarctica Muon and Neutrino Detector Array) is a collaboration of the University of Chicago, Princeton University, and AT&T, which is partially funded by the National Science Foundation. AMANDA scientists are placing detection instruments deep within the Antarctic ice. Instead of using a crystal, like the Berkeley team, the AMANDA group is using the Antarctic ice sheet itself as a WIMP detector.

Dark Matter and the future of the Universe

The search for dark matter is about more than explaining discrepancies in galactic mass calculations. The missing matter problem has people questioning the validity of current theories about how the universe formed, and how it will ultimately end.

Clumping: One of the problems with the Big Bang theory is its failure to explain how stars and galaxies could form in a young universe that was evenly distributed in all directions. What started the clumping? In a smooth universe, every particle would have the same gravitational effect on every other particle; the universe would remain the same. But something supplied the initial gravity to allow galaxies to form. Physicists suggest dark matter WIMPs as the solution. Since WIMPs only affect baryon matter gravitationally, physicists say this dark matter could be the "seed" of galactic formation. "We don't have a completely successful model of galaxy formation," explains Walter Stockwell, "but the most successful models to date seem to need plenty of non-baryonic dark matter".

Closed, Open and Flat: There are three current scenarios that predict the future of the universe . If the universe is *closed*, gravity will catch up with the expansion and the universe will eventually be pulled back into a single point. This model suggests an endless series on Big Bangs and "Big Crunches." An *open* universe has more bang than gravity--it will keep expanding forever. And the *flat* universe has exactly enough mass to gravitationally stop the universe from expanding, but not enough to pull itself back in. A flat universe is said to have a *critical density* of 1 (for details, see the book).

What does the expansion of the universe have to do with the missing mass? The more mass, the more gravity. Whether the universe is closed, open, or flat depends on how much mass there is. This is where dark matter comes into the picture. Without dark matter, critical density lies somewhere between 0.1 and 0.01, and we live in an open universe. If there is a whole lot of dark matter, we could live in a closed universe. Just the right amount of dark matter, and we live in a flat universe. The amount of dark matter that exists determines the fate of the universe (for details see the book)

Many Theories. Scientists are tossing theories back and forth. Some are skeptical of WIMPs; particle physicists say MACHOs will never account for 90% of the universe. Some, like H.C. Arp, G. Burbage, F. Hoyle, and J.V. Narlikan claim that discrepancies like the dark matter problem discredits the Big Bang theory. In *Nature* they proclaim, "We do not believe that it is possible to advance science profitably when the gap between theoretical speculation becomes too wide, as we feel it has . . . over the past two decades. The time has surely come to open doors, not to seek to close them by attaching words like 'standard' and 'mature' to theories that, judged from their continuing non-performance, are inadequate" . Others say there is no missing mass. In his book, *What Matters: No Expanding Universe No Big Bang*, J.L. Riley claims that galactic red shift is just the effect of light turning into matter as it ages, and not the universe expanding.

But most scientists like Walter Stockwell have faith in the Big Bang. "The theorists will come up with all sorts of reasons why this or that can or cannot be and change their minds every other year," he says. "We experimentalists will trudge ahead with our experiments. The Big Bang theory will outlive any of this stuff. It works very well as the overall framework to explain how the universe is today"
.

Now the missing mass problem is threatening humankind's place in the universe again. If non-baryonic dark matter does exist, then our world and the people in it will be removed even farther from the center. Dr. Sadoulet tells the *New York Times*, "It will be the ultimate Copernican revolution. Not only are we not at the center of the universe as we know it, but we aren't even made up of the same stuff as most of the universe. We are just this small excess, an insignificant phenomenon, and the universe is something completely different".

A dark matter discovery could possibly affect our view of our place in the universe. If scientists prove that non-baryonic matter does exist, it would mean that our world and the people in it are made of something which comprises an insignificant portion of the physical universe. A discovery of this nature, however, probably will not affect our day-to-day process of living. "It's hard for me to imagine people getting bothered by the fact that most of the universe is something other than baryonic. How many people even know what baryonic means?" comments Walter Stockwell, "Most of the universe is something other than human. If their philosophy already accepts that humans are not the center of the universe, then saying protons and neutrons aren't the center of the universe doesn't seem like much of a stretch to me" . Perhaps the only thing a dark matter discovery will give us is some perspective.

Accelerating Universe:

In 1998 a 10-year study of the spectacular astronomical events known as supernovae took an astonishing turn.

The History: Several years earlier the international Supernova Cosmology Project, based at the Department of Energy's Lawrence Berkeley National Laboratory, had developed a way to find many of these bright exploding stars, once thought to occur too randomly for systematic search. By 1998 the Supernova Cosmology Project and another team using the same method, the High-Z Supernova Search Team based at the Mount Stromlo and Siding Spring Observatories in Australia, had recorded several dozen supernovae, including some so distant that their light had started toward Earth when the universe was only a fraction of its present age.

Their goal was to measure changes in the expansion rate of the universe, which in turn would yield clues to the origin, structure, and fate of the cosmos. Like everyone else, the researchers assumed that expansion had been slowing under the gravitational attraction of matter since shortly after the Big Bang, and that this deceleration rate could be used to determine the average density of matter in the universe.

The last thing the two teams expected to find was that the expansion of the universe is not slowing at all. Instead, it is accelerating.

Word soon spread beyond the scientific community; "the accelerating universe" made front-page news around the world and touched the imaginations of people everywhere. But with the discovery came a host of new questions, and the challenge of finding new ways to answer them.

What’s the difference with Hubble’s model? In 1929, when Edwin Hubble announced that the universe is expanding, he opened a door to unexpected discovery as we have seen in the chapter four of the book. The knowledge that expansion is accelerating opens the way to new advances, many of them unpredictable.

The Supernova Cosmology Project collaborators and their colleagues in the High-Z Supernova Search team, whose results agree on the acceleration, use instruments more powerful and sensitive than anything Hubble dreamed of, including giant telescopes on the ground, the Space Telescope named for Hubble himself, charge-coupled devices instead of photographic plates, and supercomputers. Yet the basic strategy is much the same — to measure cosmic expansion by comparing the distances of far-off objects with their red shifts. A star's distance can be estimated from its brightness as seen on Earth, if its total emitted light is known — the farther away it is, the dimmer it appears. Accurate estimates of total emitted light are possible for only a few kinds of astronomical objects; these "standard candles," like an ordinary candle seen across a dark room, reveal their distance by their apparent brightness.

The Supernova Cosmology Project uses type Ia supernovae as standard candles — exploding stars as bright as entire galaxies that can be seen across billions of light years. These thermonuclear cataclysms emit most of their energy in a few weeks, and during that time each gives off nearly the same amount of light. The challenge is to catch them before they reach their brightest emission, then follows them until they fade.

In a typical galaxy, type supernovae occur only two or three times in a thousand years; a decade ago, astronomers thought they were too rare and unpredictable to waste valuable telescope time searching for them. Then the Supernova Cosmology Project demonstrated that if a moonless patch of sky filled with tens of thousands of galaxies is photographed digitally and then photographed again three weeks later, over a dozen bright spots will appear on the second set of images that were not on the first — a batch of supernova candidates whose identity can be quickly confirmed with follow-up observations.

Using these methods, the Supernova Cosmology Project showed that a few nights on the world's best telescopes can guarantee a bevy of "supernovae on demand."

The red-shift of astronomical objects is measured by comparing characteristic spectral lines of elements in them with spectral lines of the same elements measured in the laboratory. The higher the red-shift, the more distant the object that emitted the light (More red-shift means more velocity actually. As per Hubble’s model, more velocity means larger distance from us)

The farthest red-shifted galaxies discussed by Edwin Hubble in 1929 were about 6,000,000 light-years away; the light of such "close" galaxies was emitted recently, and the expansion of the universe since then has been relatively small.

Light from the most distant galaxies has traveled billions of years, giving a snapshot of the universe at a fraction of its present age. If expansion were now slowing under the influence of gravity, as astronomers expected before 1998, supernovae in distant galaxies should appear brighter and closer than their high red-shifts might otherwise suggest.

This is very easy to understand from our day to day experience. Suppose you are seeing off a relative from your house who came with bike. He starts his bike with horn. He then continues to accelerate (typically, he should be getting 20km/hour in 50m, 40km/hour in 100m..Likewise). You will observe that his pitch (frequency) of his horn is continuously fading to larger extent. Since Hubble predicted that closer Galaxies will have less velocity compared to distant Galaxies, we should expect that red-shift produced from distant Galaxies will be a lot higher.

The distant supernovae found so far tell a different story. At high red shifts, the most distant supernovae are dimmer than they would be if the universe were slowing under the influence of gravity; they must be located farther away than would be expected for a given red-shift — larger-than-expected distances that can only be explained if the expansion rate of the universe is accelerating.

New Geometry? What do these observations imply about the geometry of the universe? What if that geometry is not Euclidean, or "flat," but "curved" instead? If the universe were open, with negative curvature — and if observations of supernovae were subject to some systematic distortion, such as a novel form of intergalactic dust that absorbs their light — distant supernovae might appear deceptively fainter, mimicking acceleration. To determine the curvature of the universe and to detect possible distortions are among the goals of the Supernova Cosmology Project.

Negative Curvature? : While it may be too soon to rule out a negatively curved universe, there is independent evidence against it. For example, measurements of the cosmic microwave background radiation hint that the universe is probably flat — its energy density equal to the critical energy density.

By far the most successful explanation for the flatness of the universe, which is otherwise extremely unlikely, is the theory known as inflation.

Dark Energy: If the universe is flat and expanding ever faster, some invisible, unidentified energy must be offsetting gravity. In the beginning, when matter was close together and the universe was dense, gravitational attraction was much stronger. Now that matter is far apart and the density of the universe is low, this mysterious energy is pushing space itself outward at an accelerating rate. Its nature is unknown.

Was Einstein right? One proposal goes by the name of "the cosmological constant." In 1917 Albert Einstein, who assumed the universe was static, added an arbitrary term to the general theory of relativity to make sure his equations described it that way. When it became clear that the universe really is expanding, Einstein abandoned the cosmological term, later calling it his biggest blunder.

The cosmological constant has repeatedly been dismissed by physicists, only to return. If to Einstein it was only a mathematical term, today it is identified with the energy of the vacuum itself, a consequence of quantum theory.

Yet if it is confirmed to operate in our universe, the cosmological constant will present theorists with a formidable problem, which can be phrased as a simple question: why is it so small? Any attempt to calculate the cosmological constant from quantum theory gives an answer more than *50 orders of magnitude* larger than what is observed. Other candidates for the mysterious energy component of the universe, called "dark" energy, have been proposed as well, some rather exotic.

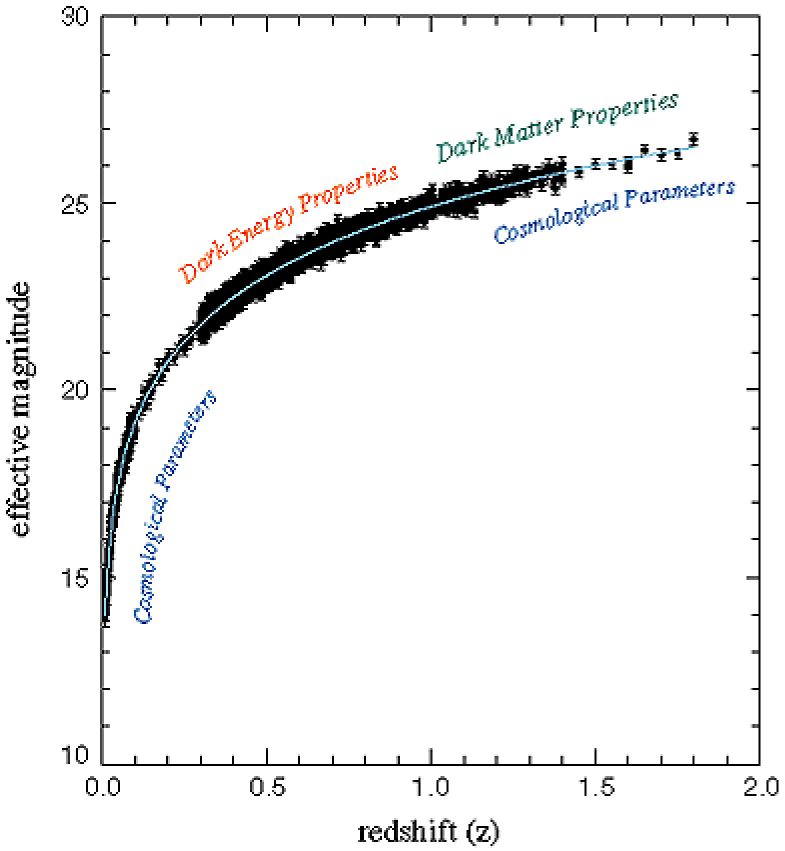
Different kinds of mechanisms driving accelerating expansion would produce different observable consequences, but only if much more data of much higher quality can be gathered, some from farther back in time. Better observations of more supernovae over a wider range of red shifts must be plotted before the question of what is causing expansion to accelerate can be answered with confidence.

CCD imaging and beyond: Charge-coupled devices (CCDs), now commonly found in still cameras and video recorders, convert light images to electronic data that can be immediately processed by computer. Because CCDs are far more sensitive than photographic emulsions, they revolutionized astronomy in the 1970s. This is one invention that started in Astrophysics and now overwhelmed and revolutionized

To detect short-wavelength blue light, astronomical CCDs must be carefully thinned and back-illuminated, so that electrons generated on the back of the chip can reach wiring on the front. Their sensitivity to longer wavelengths is poor, a major drawback to good measurement of high red-shifts.

The Supernova Cosmology Project, drawing on experience with silicon detectors developed at Berkeley Lab for high-energy physics — detectors which can sort a few events of interest from a particle accelerator's storm of radiation, such as those used to identify top quark decays at Fermilab's Tevatron — devised a rugged CCD that mimics the electrical properties of a thin, blue-sensitive chip while extending sensitivity into the infrared.

Moreover, the new CCD is designed so that many chips can be placed side-by-side in large-format mosaics for astronomical imaging; the chip is already in preliminary use at Lick Observatory.



Of the dozens of type supernovae discovered in over a decade of ground-based observation, most have red-shifts (or Z) much less than 1.0. A single year of satellite observation could find thousands of supernovae at red-shifts up to 1.5 and beyond, yielding critical data on the mass density, vacuum energy density, curvature of the universe, and the mysterious "dark energy."

The ideal place for a supernova telescope would be far from atmospheric distortion and cloudy nights; the telescope should always point away from the sun's glare and the moon's glow. The ideal place for a supernova telescope is aboard a satellite.

SNAP: These considerations have led to a proposal for a satellite called SNAP, a SuperNova/Acceleration Probe, to orbit a 1.8-meter reflecting telescope fitted with a billion-pixel CCD camera, the largest astronomical CCD imager ever constructed. By repeatedly imaging just one or two large patches of sky, SNAP could gather 2,000 type Ia supernovae in a single year, 20 times the number from a decade of ground-based search. Because of enhanced sensitivity to infrared light above the atmosphere, many of these new supernovae would be at distances and red-shifts far greater than any yet found.

SNAP's optics would serve a simple set of instruments: a CCD with 10 times the area of the Sloan Digital Sky Survey camera and more efficient at all wavelengths than any current astronomical camera, plus a spectrometer system to record accurate and consistent spectra, from the near ultraviolet to the near infrared, for every supernova it captures.

With this proposed satellite, effects of dust and elemental composition on the brightness and red-shift of very distant supernovae will be resolved. SNAP would also shed new light on galactic clusters, gamma-ray busters, forms of cold dark matter, comets in our own solar system, and many other astronomical phenomena. The essential purpose of the SNAP proposal, however, is to address the most fundamental cosmological questions that the readers will be asking after going through the book.: will the universe last forever? Is the universe infinite in extent?

However there is alternative theory to explain the expanding universe as well. The most popular among them is slowing down of light velocity which otherwise we have learned to be constant.

Slowing down of light velocity? If light were traveling faster originally, then a slowdown would make distant objects appear fainter. The reason these supernovae would appear fainter is that light was traveling faster when it left them. This would make these objects appear farther away than they really are. This would also mean that the light spent less time in transit, so that there would be less time for space to expand, and thus the red shift would be reduced. Since light was traveling faster through the initial distance (ID) than through the final distance (FD), the contribution to the red-shift would be proportionally larger from FD than from ID. Both effects would mean that distant objects would tend to be much dimmer, and apparently farther away, than one would expect based on their red-shift according to Hubble's law.

This explanation does not assume that the red shift itself is caused by a slowdown in the speed of light, although that is another interesting possibility. We are assuming that when light slows down, its apparent frequency is unchanged. However, other assumptions can also be considered.

THEORY OF EVERYTHING: STRING THEORY: CHAPTER 6

Why String Theory?

Relativistic quantum field theory has worked very well to describe the observed behaviors and properties of elementary particles. But the theory itself only works well when gravity is so weak that it can be neglected. Particle theory only works when we pretend gravity doesn't exist.

General relativity has yielded a wealth of insight into the Universe, the orbits of planets, the evolution of stars and galaxies, the Big Bang and recently observed black holes and gravitational lenses. However, the theory itself only works when we pretend that the

Universe is purely classical and that quantum mechanics is not needed in our description of Nature.

String theory is believed to close this gap.

Originally, string theory was proposed as an explanation for the observed relationship between mass and spin for certain particles called hadrons, which include the proton and neutron. Things didn't work out, though, and Quantum Chromodynamics eventually proved a better theory for hadrons. But particles in string theory arise as excitations of the string, and included in the excitations of a string in string theory is a particle with zero mass and two units of spin.

If there were a good quantum theory of gravity, then the particle that would carry the gravitational force would have zero mass and two units of spin**.** This has been known by theoretical physicists for a long time. This theorized particle is called the **graviton**. This led early string theorists to propose that string theory be applied not as a theory of hadronic particles, but as a theory of **quantum gravity**, the unfulfilled fantasy of theoretical physics in the particle and gravity communities for decades.

But it wasn't enough that there be a graviton predicted by string theory. One can add a graviton to quantum field theory by hand, but the calculations that are supposed to describe Nature become useless. This is because, as illustrated in the diagram above, particle interactions occur at a single point of space-time, at zero distance between the interacting particles. For gravitons, the mathematics behaves so badly at zero distance that the answers just don't make sense. In string theory, the strings collide over a small but finite distance, and the answers do make sense.

This doesn't mean that string theory is not without its deficiencies. But the zero distance behavior is such that we can combine quantum mechanics and gravity**,** and we can talk sensibly about a string excitation that carries the gravitational force. This was a very great hurdle that was overcome for late 20th century physics, which is why so many young people are willing to learn the grueling complex and abstract mathematics that is necessary to study a quantum theory of interacting strings.

What is this String?

Think of a guitar string that has been tuned by stretching the string under tension across the guitar. Depending on how the string is plucked and how much tension is in the string, different musical notes will be created by the string. These musical notes could be said to be **excitation modes** of that guitar string under tension.
In a similar manner, in string theory, the elementary particles we observe in particle

accelerators could be thought of as the "musical notes" or excitation modes of elementary strings.

In string theory, as in guitar playing, the string must be stretched under tension in order to become excited. However, the strings in string theory are floating in space-time, they aren't tied down to a guitar. Nonetheless, they have tension. The string tension in string theory is denoted by the quantity 1/(2 p a'), where a' is pronounced "alpha prime" and is equal to the square of the string length scale.

If string theory is to be a theory of quantum gravity, then the average size of a string should be somewhere near the length scale of quantum gravity, called the **Planck length**, which is about 10^{-33} centimeters, or about a millionth of a billionth of a billionth of a billionth of a centimeter. Unfortunately, this means that strings are way too small to see by current or expected particle physics technology (or financing!!) and so string theorists must devise more clever methods to test the theory than just looking for little strings in particle experiments.

String theories are classified according to whether or not the strings are required to be closed loops, and whether or not the particle spectrum includes Fermions. In order to include fermions in string theory, there must be a special kind of symmetry called **super symmetry**, which means for every boson (particle that transmits a force) there is a corresponding Fermion (particle that makes up matter). So super symmetry relates the particles that transmit forces to the particles that make up matter. Supersymmetric partners to currently known particles have not been observed in particle experiments, but theorists believe this is because supersymmetric particles are too massive to be detected at current accelerators. Particle accelerators could be on the verge of finding evidence for high energy supersymmetry in the next decade. Evidence for supersymmetry at high energy would be compelling evidence that string theory was a good mathematical model for Nature at the smallest distance scales.

The History: Contribution of Prof Ashok Sen

Kaluza-Klein Theory (1921): Electromagnetism can be derived from gravity in a unified theory if there are four space dimensions instead of three, and the fourth is curled into a tiny circle. Kaluza and Klein made this discovery independently of each other.

String theory is born (1970): Three particle theorists independently realize that the dual theories developed in 1968 to describe the particle spectrum also describe the quantum mechanics of oscillating strings. This marks the official birth of string theory.

Super Symmetry (1971) Supersymmetry is invented in two contexts at once: in ordinary particle field theory and as a consequence of introducing fermions into string theory. It holds the promise of resolving many problems in particle theory, but requires equal numbers of fermions and bosons, so it cannot be an exact symmetry of Nature.

Graviton (1974): String theory using closed strings fails to describe hadronic physics because the spin 2 excitation has zero mass. Oops, that makes it an ideal candidate for the missing theory of quantum gravity!! This marks the advent of string theory as a proposed unified theory of all four observed forces in Nature.

SuperGravity (1976): Supersymmetry is added to gravity, making supergravity. This progress is especially important to string theory, where gravity can't be separated from the spectrum of excitations.

Super String (1980): String theory plus supersymmetry yields an excitation spectrum that has equal numbers of fermions and bosons, showing that string theory can be made totally supersymmetric. The resulting objects are called superstrings.

The Big Year (1984): This was the year for string theory! Deadly anomalies that threatened to make the theory senseless were discovered to cancel each other when the underlying symmetries in the theory belong two special groups. Finally string theory is accepted by the mainstream physics community as an actual candidate theory uniting quantum mechanics, particle physics and gravity. 1991-

Duality Revolution (1995): Interesting work on stringy black holes in higher dimensions leads to a revolution in understanding how different versions of string theory are related through duality transformations. This unlocks a surge of progress towards a deeper nonperturbative picture of string theory.

Black Hole Entropy (1996): Using Einstein relativity and Hawking radiation, there were hints in the past that black holes have thermodynamic properties that need to be understood microscopically. A microscopic origin for black hole thermodynamics is finally achieved in string theory. String theory sheds amazing light on the entire perplexing subject of black hole quantum mechanics.

TIFR (Tata Institute of Fundamental Research), Mumbai has a proud history of developing String theory for last two decades under the leadership of Prof Ashok Sen—the undisputedly greatest living Indian Astrophysicist and theoretician (till he left TIFR). Here is an introduction to their contribution in String theory from TIFR website:

“Significant breakthroughs have been made in the sub-area of string theory and mathematical physics. Noncritical string theory in d dimensions has been reinterpreted as (d+1)-dimensional critical string theory with the Liouville mode providing the extra dimension. Recent ideas of holographic renormalization group were anticipated in the context of noncritical strings and their connection with gravitational equations in one higher dimension. Important results in 2-dimensional string theory have been (i) the discovery of new physical states, perturbations by which deform the background geometry, (ii) a topological formulation given by a twisted supersymmetric coset model and (iii) the development of a nonperturbative formulation and the discovery of an associated infinite dimensional symmetry. New critical exponents, associated with the transition from a smooth to a polymer phase of random surfaces, have been discovered. A black hole solution to the classical equations of 2-dimensional string theory has been found. The low-energy s-wave absorption cross-section for a minimally coupled massless scalar by a spherically symmetric black hole has been shown to be given, independent of the number of dimensions, by the horizon area. D-brane based microscopic models of string theory black holes have been developed and this has led to a calculation of the absorption and Hawking decay rate of a slightly nonextremal black hole agreeing exactly with the semiclassical result. BPS saturated classical solutions representing planar 3-string junctions have been discovered. An M theory dual to K3 compactification of type IIB string theory to six dimensions has been obtained, providing a new string duality. The operator product expansion has been geometrized yielding a generalized projective structure on a compact Riemann surface”

Different types of String: M theory and second String revolution

There are several ways theorists can build string theories. Start with the elementary ingredient: a wiggling tiny string. Next decide: should it be an open string or a closed string? Then ask: will I settle for only bosons (particles that transmit forces) or will I ask for Fermions, too (particles that make up matter)? (Remember that in string theory, a particle is like a note played on the string.)

If the answer to the last question is "Bosons only, please!" then one gets bosonic string theory. If the answer is "No, I demand that matter exist!" then we wind up needing supersymmetry, which means an equal matching between bosons (particles that transmit forces) and fermions (particles that make up matter). A supersymmetric string theory is called a superstring theory. There are five kinds of superstring theories, shown in the table below.

The final question for making a string theory should be: can I do quantum mechanics sensibly? For bosonic strings, this question is only answered in the affirmative if the space-time dimensions number **26**. For superstrings we can whittle it down to **10**. How we get down to the four space-time dimensions we observe in our world is another story.

If we ask how to get from ten space-time dimensions to four space-time dimensions, then the number of string theories grows, because there are so many possible ways to make six dimensions much much smaller than the other four in string theory. This process of compactification of unwanted spacetime dimensions yields interesting physics on its own.

But the number of string theories has also been shrinking in recent years, because string theorists are discovering that what they thought were completely different theories were in fact different ways of looking at the same theory!

This period in string history has been given the name **the second string revolution**.

Second String Revolution: And now the biggest rush in string research is to collapse the theories into one theory, which some people want to call **M theory**, for it is the Mother of all theories. For details, see the book.

Another surprising revelation was that superstring theories are not just theories of one-dimensional objects. There are higher dimensional objects in string theory with dimensions from zero (points) to nine, called p-branes. In terms of branes, what we usually call a membrane would be a two-brane, a string is called a one-brane and a point is called a zero-brane.

What makes a p-brane? A p-brane is a spacetime object that is a solution to the Einstein equation in the low energy limit of superstring theory, with the energy density of the nongravitational fields confined to some p-dimensional subspace of the nine space dimensions in the theory. (Remember, superstring theory lives in ten space-time dimensions, which means one time dimension plus nine space dimensions.) For example, in a solution with electric charge, if the energy density in the electromagnetic field was distributed along a line in space-time, this one-dimensional line would be considered a p-brane with p=1.

A special class of p-branes in string theory are called D branes. Roughly speaking, a D brane is a p-brane where the ends of open strings are localized on the brane. A D brane is like a collective excitation of strings.

These objects took a long time to be discovered in string theory, because they are buried deep in the mathematics of T-duality. D branes are important in understanding black holes in string theory, especially in counting the quantum states that lead to black hole entropy, which was a very big accomplishment for string theory.

How many dimension?

Before string theory won the full attention of the theoretical physics community, the most popular unified theory was an eleven dimensional theory of supergravity, which is supersymmetry combined with gravity. The eleven-dimensional spacetime was to be compactified on a small 7-dimensional sphere, for example, leaving four spacetime dimensions visible to observer’s at large distances.

This theory didn't work as a unified theory of particle physics, because it doesn't have a sensible quantum limit as a point particle theory. But this eleven dimensional theory would not die. It eventually came back to life in the strong coupling limit of superstring theory in ten dimensions.

How could a superstring theory with ten space-time dimensions turn into a supergravity theory with eleven spacetime dimensions? We've already learned that duality relations between superstring theories relate very different theories, equate large distance with small distance, and exchange strong coupling with weak coupling. So there must be some duality relation that can explain how a superstring theory that requires ten spacetime dimensions for quantum consistency can really be a theory in eleven space-time dimensions after all.

Since we know that all string theories are related, and we suspect that they are but different limits of some more fundamental theory, then perhaps that more fundamental theory exists in eleven space-time dimensions? These questions bring us to the topic of M theory.

The theory currently known as M

Technically speaking, **M theory** is the unknown eleven-dimensional theory whose low energy limit is the supergravity theory in eleven dimensions discussed above. However, many people have taken to also using **M theory** to label the unknown theory believed to be the fundamental theory from which the known superstring theories emerge as special limits.

We still don't know the fundamental M theory, but a lot has been learned about the eleven-dimensional M theory and how it relates to superstrings in ten spacetime dimensions.

In M theory, there are also extended objects, but they are called **M branes** rather than D branes. One class of the M branes in this theory has two space dimensions, and this is called an **M2 brane**.

Now consider M theory with the tenth space dimension compactified into a circle of radius R. If one of the two space dimensions that make up the M2 brane is wound around that circle, then we can equate the resulting object with the fundamental string (one-brane) of type IIA superstring theory. The type IIA theory appears to be a ten dimensional theory in the normal perturbative limit, but reveals an extra space dimension, and equivalence to M theory, in the limit of very strong coupling..

We still don't know what the fundamental theory behind string theory is, but judging from all of these relationships, it must be a very interesting and rich theory, one where distance scales, coupling strengths and even the number of dimensions in space-time are not fixed concepts but fluid entities that shift with our point of view.

Chapter7: Universe and God: In search of final truth

By seventeenth century, science was beginning to discredit mythology of religious cosmos. Newton became almost obsessed with the desire to purge Christianity of its mythical doctrine. He was convinced that irrational dogmas of the Tritiny and the incarnation were the result of conspiracy, forgery and chicanery. While working on his book Principia, Newton also started working on a bizarre treatise entitled “The philosophical origin of gentile theology’ where he argued that Noah revealed a rational religion of monotheism free of mythology and in principle the religion is in harmony with natural laws.

The fact that religion has to comply with the objective method of science was first stated by Francis Bacon in his book “Advancement of learning.” This royal physician of King James I insisted that even the most sacred doctrine of the religion should be subjected to rigorous scrutiny of empirical science. There was no taker for his philosophy in those days, but today we have reached a critical phase in civilization where Hindues, Muslims, Christians and Buddhists are proclaiming that their scripture already contained modern discoveries and therefore their faith is in conformance with modern science. Or in other words, all the religious gurus accepted the demand placed by Bacon in 1605, but are unwilling to accept the fact that subjective method of religion can no way reach the same truth revealed in theoretical physics.

Avijit is fighting with a lot of such metaphysical religious people in our website www.mukto-mona.com. In this chapter, he has methodically listed all such approaches so far made to prove the existence of God and their futile attempt to conform to the theories of physics in the name of 'Intelligent Design' theory. So Avijit is carrying the rational sword from Newton who started the war against mythical doctrine in religion.

I will add an interesting story. During 1984, Jayanta Bishnu Narlikar (an Astrophysicist in TIFR who was student of Fred Hoyle who coined the term 'Big Bang') made steady state theory of universe very popular in India. Since Upanishad says Universe is eternal and has no beginning and end, every Hindu theologist jumped into it as if Upanishad has been testified through steady state theory. After Big Bang received more popularity over steady state and idea of singular point was coined, I found the same set of Hindu theologists are claiming that the singularity point of BigBang is the 'Non-dual Bramhan'! So whether the Universe is expanding or accelerating or dying, it does matter. Everything is in Veda!

Reality is, discovery in Astrophysics in last century has dumped God as a supreme creator. But still surprisingly, we find more people are interested in religion than before. Why is such anomaly?

Last century was also a century of technological innovation as well that has bestowed mankind with wealth. With wealth and comfortable standard of living, human being has turned more materialistic than ever. This materialism has created self destructive individualism which has failed to imbibe an enduring objective in human life. So, people are turning more towards religion to get an enduring objective in life which otherwise they were lacking in materialist world.

Having a set of secular ethics is no substitute for religion. Never.

However this century will belong to Biology and Genetics. With more discoveries in Nucleotides in our DNA and its correlation with human behavior and evolution, we will learn about objective of human being as imposed by nature. I am sure, this century will give birth to a new religion based on new discoveries of Biology, which I love to call "Bio-Objectivism" .

Bio-Objectivism will end the days of mystical religions – Christianity, Hinduism, Islam and Buddhism. For ever.

'Selfish Genes' by Richard Dockins is beginning of this sagacious religion: Bo-Objectivism.

Conclusion:

There are some conceptual mistakes in the book. Authors write ‘Microwave background radiation has 3K temperature means, the radiation will heat the water up by 3K’. Not really. There is no correlation. Also he describes diffraction as phenomena that we observe when traveling light get obstructed by small pinhole. Quite narrow definition indeed. Anytime light get obstructed by solid object of any shape (larger than wavelength of light), we observe diffraction of varying magnitude. There are few insignificant errata of this nature which I believe we will not see in the next edition.

Over all, I must say that every Bengali who has some questions about the universe, must read “Alo Hate Chaliyache Andharer Yatri’ to find light in their thinking pathway.

APPENDIX:A

General Theory of Relativity and Black Holes

Try to jump so high that you fly right off of the Earth into outer space. What happens? Why don't you get very far? You are essentially trapped on Earth, unless you can find a rocket that can travel at **escape velocity** away from the Earth.

The escape velocity can be calculated in Newtonian gravity by using energy conservation of an object of mass m in the gravitational field of a planet of mass M and radius R in D space dimensions (take D=4 in this case:

$$v_{ESCAPE} = \sqrt{\frac{GM}{R^{D-2}}}$$

The escape velocity for the surface of the Earth is about 11 km/sec. Notice that's only 37 millionths of the speed of light. Under what conditions would the escape velocity from the surface of some planet or star be equal to the speed of light?

$$for, v_{ESCAPE} = c ::: R_c = \sqrt{\frac{2GM}{c^2}}$$

For a planet the mass of the Earth, this distance is only about a centimeter. So if the Earth were less than a centimeter in diameter, the escape velocity at the surface would be greater than the speed of light.

But thanks to Einstein we learned that when any velocity in a gravitating system approaches the speed of light, the Newtonian theory of gravity has to be put aside for the relativistically invariance theory of Einstein. The relativistic formulation of gravity in General Relativity starts with the Einstein equation relating the curvature of the spacetime geometry to the energy of the matter and radiation in the spacetime

$$R_{\mu\nu} - \frac{1}{2} g R_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$

The solution to the Einstein equations for the space-time around a planet or star of mass M is called the Schwarzschild metric

$$dS^2 = (1 - \frac{R_G}{R})dt^2 + \frac{dr^2}{1 - \frac{R_G}{R}} + r^2(d\theta^2 + \sin^2\theta d\varphi^2)$$

Like a,b,c..etc.curvature parameters that we have discussed in Rimenian curvature, in spherical coordinates, curvature for time,r, θ, φ are respectively (1-R/R_G), 1/(1-R/R_G) etc.for above metric.

(This is for d=4 spacetime dimensions. Can you guess from the Newtonian limit for D space dimensions what the Schwarzschild metric looks like for d spacetime dimensions) In units where Newton's constant and the speed of light are both set to unity, the gravitational radius R_G can be written

$$G_N = C = 1 ::: R_G = 2M$$

Note that an assumption has been made that we are outside the gravitating body in question. If we're outside the body, and the radial size R of the body satisfies $R>R_G$, then we don't need to know about what happens at coordinate $r=R_G$ because this metric doesn't apply to $r<R$.

If $R<R_G$, we have to face the problem of what happens when $r=R_G$. The metric looks singular there, but actually the spacetime is smooth, so that an observer falling into the body's gravitational pull from $r>R_G$ to $r<R_G$ won't feel anything special.

But the problem is: such an observer will never, under any circumstances, not even with the most powerful rocket in the world, ever be able to cross back to $r>R_G$.

In this case, this gravitating body is called a black hole, and at the coordinate value $r=R_G$, there exists something called a black hole **event horizon**. The event horizon is the relativistic geometric expression of the escape velocity becoming equal to the speed of light. Once anything, even light, crosses the event horizon, it can never escape back out to $r>R_G$ again.

Black holes can be created by the **gravitational collapse** of large stars that are at least twice as massive as our Sun. Normally, stars balance the gravitational force with the pressure from the nuclear fusion reactions inside. When a star gets old and burns up all of its hydrogen into helium and then turns the helium into heavier elements like iron and nickel, it can have three fates. The first two fates occur for stars less than about twice the mass of our Sun (and one of them will be our Sun's eventual fate). These two fates both depend on the Fermi gas as we have seen in the previous chapter- two fermions cannot be in the same quantum state at the same time. This means that the two stable destinies for a collapsing star will be:

1. a white dwarf supported by the Fermionic repulsion pressure of the electrons in the heavy atoms in the core
2. a neutron star supported by the Fermionic repulsion pressure of the neutrons in the nuclei of the heavy atoms in the core

If the mass of the collapsing star is too large, bigger than twice the mass of our Sun, the Fermionic repulsion pressure of either the electrons or the neutrons is not strong enough to prevent the ultimate gravitational collapse into a **black hole**.

The estimated age of the Universe is several times the lifespan of an average star. This means there must have been a lot of stars bigger than twice the mass of our Sun that have burned their hydrogen and collapsed since the Universe began. Our Universe ought to contain many black holes, if the model that astrophysicists use to describe their formation is correct. Black holes created by the collapse of individual stars should only be about 2 to 100 times as massive as our Sun.

Another way that black holes can be created is the gravitational collapse of the center of a large cluster of stars. These types of black holes can be very much more massive than our Sun. There may be one of them in the center of every galaxy, including our galaxy, the Milky Way. The black hole shown above sits in the middle of the galaxy called NGC 7052, surrounded by a bright cloud of dust 3,700 light-years in diameter. The mass of this black hole is about **300 million times the mass of our Sun**.