"Black Holes and Time Warps: Einstein's outrageous legacy", by Kip S. Thorne, Papermac (1994), Rs. 330/-.

Soon after Albert Einstein formulated his theory of general relativity in 1915, Prof. A.S. Eddington, the most famous astronomer of his time was asked whether it was true that only three people in the world understood the theory of general relativity. Not known for his modesty, Eddington promptly shot back, " Who is the third?" The story, apocryphal as it may be, reflected the awe inspiring intellectual achievement that the theory of general theory of relativity was in its early years. Widely acknowledged as one of the most beautiful and elegant theory in physics, it is a crowning achievement of the human intellect.

Einstein 's motivation to extend the special theory of relativity,(which he had formulated in 1905) was to include the effects of gravitation and physics as seen by accelerated observers. The special theory of relativity was only applicable to observers at rest or in uniform motion. <u>Remarkably, in this quest, he had no observations to guide him but had to rely primarily on the criteria of elegance and simplicity. The key to general relativity was the principle of equivalence: an idea that the laws of physics are the same for an observer in uniform motion or at rest (technically speaking, an observer in an inertial frame) as they are for an observer who is falling freely in a gravitational field. The demands of a natural incorporation of the special theory of relativity in this framework and the principle of equivalence gave rise to this theory of gravity.</u>

The novel aspect of the general theory was the idea that gravity is a "curved spacetime "phenomenon. That space and time, which were independent entities in pre-Einsteinian physics, were actually intimately connected into a single entity had already been proposed in the special theory of relativity. However, the spacetime of special relativity was "flat" (or Minkowskian). The notion of a spacetime which had curvature was an extremely radical departure. The curved spacetime produces effects which are identical to those produced by the gravitational field of a body. This was a revolutionary idea which led to a theory which was fundamentally different from the theory of gravity proposed by Isaac Newton in 1687, though the successful results of Newtonian theory were reproduced by the Einstein theory. According to this viewpoint, the curvature of spacetime made possible to look at the gravitational field with no reference to the sources producing the field. The motion of material bodies in the gravitational filed was thus explained by their motion in a spacetime which itself was non-flat. <u>This spacetime is referred to technically as a "four dimensional Riemannian geometry".</u>

General theory of relativity had an enormous influence on scientific thought in its earlier years. The whole perspective with which we viewed the universe underwent a radical change. Sadly, despite its earlier successes, the theory of relativity became cut off from the mainstream of physics, which was now almost exclusively focused on solving the problems of microscopic domain. With the advent of quantum mechanics, the other revolutionary theory of the early twentieth century, most scientists were engaged in understanding the microscopic domain. Apart from intellectual curiosity, there was also the question of experimental verification. Quantum mechanics as applied to atoms and molecules was amenable to experimental tests which could verify or falsify the theory. General relativity on the other hand, had little observational contact apart from cosmology and some classical tests. Cosmological observations could have had a direct impact on general theory but the state of observations in cosmology was pathetic. Consequently, general relativity was relegated to the background and became a formalistic , stagnant subject, primarily of interest to mathematicians..

Things began to change in the 1950's. With the development of new technologies in the war, there were tremendous advances in experiments. <u>Radar echo experiments from Venus, the gravitational red shift measurement of Pound and Rebka, the discovery of the quasar were some of the events which led to a renewed interest in</u>

the theory. On the theoretical side there had been significant advances in the preceding years. Many scientists including Robert Oppenhiemer, Lev Landau, Snyder, Roger Penrose, Robert Dicke, S. Chandrasekhar and John Wheeler had done path breaking work in understanding the general theory and applying it to objects in the universe. Thus began the “renaissance of general relativity” as this period has been referred to by the noted relativist Clifford Will. The fifties and the sixties proved to be extremely productive years for what was thought to be a stagnant field. So much so that in the seventies, general relativity was back on the centerstage of physics. The legacy of Albert Einstein’s general theory of relativity was now occupying some of the world’s most brilliant minds. It is the history of this legacy that Kip Thorne has introduced us to now in his “Black Holes and Time Warps: Einstein’s outrageous legacy”.

One of the best known relativist and astrophysicist, Thorne is eminently suited to do the job. Apart from some seminal contributions in the field, he has also authored (with Charles Misner and John Wheeler) the best known text book “Gravitation”. This book, referred to as “MTW “or simply “the black phone book” is a daunting tome of over a thousand pages from which a generation of physicists have learnt the subject. But “Black Holes and Time Warps” is far from being awe inspiring. It is a brilliant, easy to read and yet comprehensive overview of the whole field.

“Of all the conceptions of the human mind, from unicorns to gargoyles to the hydrogen bomb, the most fantastic, perhaps is the black hole: a hole in space with a definite edge into which anything can fall and out of which nothing can escape; a hole with a gravitational force so strong that even light is caught and held in its grip; a hole that curves space and warps time. “Thus begins the book’s prologue which is in the form of a science fiction story. This is apt since, “.black holes seem more at home in the realms of science fiction and ancient myth than in the real universe”. In this we are introduced to the amazing properties of black holes through the eyes of the captain of a spaceship sent out to explore black holes by some future civilisation. Complete with all the trappings of a “Star Trek” episode and hints of Kubrick’s “2001” (there is actually a computer called DAWN, which has a peculiar property that it is not permitted to give a warning if a human being is making a mistake! This is to ensure that human life does not lose its richness which comes with making mistakes!), the prologue gives us a fascinating preview of what is in the book.

The book begins with a couple of chapters devoted to describing the revolution brought about by Einstein by his theory of relativity. The Newtonian conception of space and time as absolute entities were replaced by a worldview where space and time depend on the observer. Einstein followed this triumph by another intellectual *tour de force:* the general theory of relativity. This was a marriage of the theory of relativity and gravitation. Given that the ideas of relativity are not at all common-sensical, Thorne has done a marvellous job of making them accessible to the non specialist reader. The mathematics is kept at a minimum and accurate analogies are used to give us a flavour of the physical ideas behind these otherwise highly mathematical theories.

In 1915, Einstein received a paper from Karl Schwarzschild, a distinguished astrophysicist. Schwarzschild, then serving in the German army on the Russian front, had worked out the predictions that the new theory of gravitation made about stars. His calculation was elegant and though only valid under a set of assumptions, his result (now known as the Schwarzschild geometry) has had an enormous influence in our understanding of the universe. Schwarzschild essentially considered a perfectly spherical, non-spinning star and calculated the properties of spacetime around it as a function of the mass of the star. One of the remarkable results obtained by Schwarzschild was that if the star was massive enough, not only space around it will be curved but time would also behave differently. The time flows more slowly near the star’s surface than far away! An what’s more, in the extreme case, time would come to a stand still if the mass of the star was larger than a critical mass! This conclusion of Schwarzschild, though based on the application of general

relativity to stars, was the same as had been conjectured by the English natural philosopher John Michell and Pierre Simon Laplace in the end of the eighteenth century. But, as luck would have it, Schwarzschild's arguments failed to convince Einstein and other ruling deities of cosmology like Eddington, who were not comfortable with the extreme results which the theory predicted. Predictably, the whole idea of a black hole, as this extreme object came to be known subsequently, died a premature death, like its progenitor Schwarzschild, who was killed in the war.
The story now moves to India in 1928, where a bright young student, Subramanyam Chandrasekhar is trying to grapple with the evolution of a kind of star known as a white dwarf. The life history of a star was not very well understood at that time. The accepted "folklore" had it that at any point in a star's life there is an inexorable fight going on between the force of gravity which tries to shrink the star and internal pressure which pushes out. Now since the star is giving out radiation (heat and light) the internal pressure decreases and gravity will shrink the star further. The burning question was how does this gradual shrinking end? Eddington's answer to this question led to several paradoxes and this did not satisfy Chandrasekhar. So he worked out a theory which led to the famous Chandrasekhar limit , the maximum mass that a star can have as a white dwarf. The episode of Eddington's hostility to this young Ph.D. student is now well known and is very well recounted in Thorne's book which also explains the physics of white dwarfs in an excellent way.
The next few chapters of the book are devoted to two other kinds of stellar corpses, namely neutron stars and black holes. The idea of neutron stars, stars which are slightly more massive than our Sun, but only about 100-1000 km in radius, was proposed by Zwicky in the 30's but was not taken very seriously. Subsequent work was done by Landau, Oppenheimer and Tolman and it is finally now accepted that not only do neutron stars exist but are also responsible for pulsars, objects in the sky which emit radio pulses with and eerie regularity. Thorne explains the physics of neutron stars, and the exciting tale of the genesis of the idea in an masterful way. Here history is woven in with physics, sociology of science finds place with personal insights into the temperaments of various scientists. For instance, one of the key actors in the tale is Robert Oppenheimer, who later headed the Manhattan project to build the first atomic bomb. Oppenheimer was a meticulous physicist, but much less innovative than others. The reason, as I.I. Rabi (another great scientist and a close friend of Oppenheimer) speculates, lay in Oppenheimer's interest in Hinduism. As Rabi says, " ..Oppenheimer was overeducated in those fields which lie outside the scientific tradition, such as is his interest in religion, in Hindu religion in particular, which resulted in a feeling for the mystery of the universe that surrounded him almost like a fog. He saw physics clearly, but at the border he tended to feel that there was much more of the mysterious than there actually was". Or an excellent discussion on the application of Thomas Kuhn's concept of paradigm to general relativity.
The whole field of black hole physics, which was revived in the sixties is covered in a few chapters. This introduction to the subject, which arguably is one of the most perplexing and fascinating in physics, is certainly the best one I have read. The subject is a highly mathematical one but Thorne brings it to life with the help of excellent analogies and diagrams, bringing to fore the same talent as was evident in his textbook. Classical black holes, their observational evidence in the form of X-ray sources like Cygnus X-1 and singularities in general relativity are very well summarised in these few chapters. He also devotes a chapter to gravitational radiation, which is supposed to be emitted by matter. Though several efforts have been going on since the sixties for their detection, we have not yet directly detected any gravitational radiation. But it is a tribute to the solid foundations on which general relativity is built that scientists continue the search for it. In fact, two new multinational collaborations LIGO (Laser Interferometer gravitational Observatory) in the US and VIRGO in Europe are in advanced stages of completion. These experiments hope to catch a glimpse of the wrinkle in spacetime produced for

instance when there is a collision of two black holes. Of course, the fact there is gravitational radiation has been indirectly confirmed by Hulse and Taylor in their Nobel Prize winning work on binary pulsars.

In 1975, Stephen Hawking shocked the world by showing that black holes, contrary to what was believed, actually emit radiation. This was a result of quantum effects in the neighbourhood of a black hole., This discovery (which was actually done somewhat earlier by Zeldovich) led to a whole new hitherto unexplored field of black hole physics with quantum mechanics. Thorne relates the history of the work leading upto and consequent to this result. Here once again, he weaves a narrative that interlocks history with physics with personal observations. He comments on the differing styles of work of various scientists and how they are shaped by the socio-political milieu. This is most evident is the contrast between the Russian scientists and their Western counterparts. While people like Zeldovich and Landau could collect some of the best minds in the Soviet Union and thus form a school whose energies were focused on a few problems , no such school formed in the West. Even John Wheeler, who probably produced the maximum number of students who are working in the field, could not form a Wheeler school. Thorne argues that the crucial difference lay in the different ways in which academia functions in the Soviet Union and the West. Having spent a lot of time collaborating with the Soviets, he is certainly very well informed and his observations are very thought provoking.

The last few chapters of the book are more speculative and in fact based on work which is very recent. This includes topics like wormholes and the possibility of time travel with wormholes. Even here Thorne is very categorical in pointing out which part is well established and what is still just speculation. Of course, since he is one of the key players in the wormhole game, he has his biases which he points out candidly.

Einstein’s theory is now about eight decades old and still stands out as one of humanity’s greatest intellectual achievement. As Hawking points out in his foreword to the book, “The theory of black holes was developed before there was any indication from observations that they actually existed. I do not know of any other example in science where such a great extrapolation was successfully made solely on the basis of thought. It shows the remarkable power and depth of Einstein’s theory”. Kip Thorne has written an excellent book. It has a wonderful glossary and an extensive bibliography to help readers to follow up. It is extremely reader friendly and accessible, comprehensive and balanced. This is certainly one of the best popular science books to come out in a long time. One just hopes that it enjoys the success of “ A Brief History of Time” which was certainly a mediocre book when compared to this one.