The science of cosmology is at the threshold of a revolution: beliefs which have been held sacrosanct for almost eight decades are close to being shattered and a whole new paradigm for understanding the universe is emerging. Ever since 1920s, when Edwin Hubble observed that the universe was expanding, astronomers and cosmologists have believed that the expansion is slowing down as the pull of gravity exerts restraint on the expansion. Now, due to some extraordinary results in the last one year from exploding stars known as supernovae, cosmologists are being forced reconsider this belief in a decelerating universe and instead consider a universe which is accelerating at a quickening pace. “These new results are certainly the most significant event in astronomy in a long time”, says Prof. Jeff Willick of the Stanford University.

The expansion of the universe has played an important role in the development of our understanding of the cosmos. Expansion is important because Einstein’s general theory of relativity (the theory that we currently believe is the best we have for describing the nature of space and time) tells us that it is intimately linked with the geometry of the universe and ultimately with the nature and amount of matter in the universe. At the beginning of the century, most astronomers favored a static unchanging universe. In fact, though Einstein’s theory predicted a dynamic universe, he himself was not convinced of the accuracy of his theory. After all, since the force of gravity was attractive, a universe governed by gravity alone should ultimately collapse under its own force. This led him to add a term to his equations, a sort of “anti-gravity” force (called a cosmological constant) which was repulsive. This term could stabilize the universe which could now stay the same size as time passes. This view of a static universe received a blow with the observations of Edwin Hubble in 1929, which showed that the galaxies were flying apart.

The attractive force of gravity counterbalances the outward expansion of the universe. This gravity is the collective effect of the matter in the universe in the form of galaxies, and the stars, planets, humans, computers, etc. In short, any matter in the universe exerts a gravitational pull. The balance between the outward expansion and the slowing down by gravity has a profound effect on the nature of the universe and its future. The geometry of the universe, i.e. its overall structure depends crucially on the result of this contest between the two impulses. If the force of gravity were more overpowering than the outward expansion, the universe will be closed and gravity will eventually win resulting in a “big crunch” in the distant future. On the contrary, if the expansion was to win the battle, the universe would be open and the universe would continue to expand indefinitely. If the two were balance exactly, then the universe will be “flat”. Till recently, the cosmological models favored a flat universe.

It all started with the work of Edwin Hubble in the twenties. These observations played a central role in shaping the new view of the universe as it were. According to his observations, not only were galaxies flying apart from each other, but the further they are, the faster they were receding. The tool to measure the receding velocities of the galaxies is the redshift. The waves of light emitted by a galaxy moving away from us are stretched towards the red part of the spectrum. This effect is similar to the changing pitch of a passing siren or train whistle. However, in the context of the expanding universe, a more instructive way to look at the redshift of the receding galaxies is that the expansion of the universe stretches the waves of light emitted by the galaxy. In this way of looking at things, the farther the galaxy, the more time it takes for light to travel to us and the more stretched the waves of light are towards the red part of the spectrum. Thus, the astronomer has to is to look at the spectrum of the light emitted by any object and find out by how much any wavelength has been stretched. This way the velocity of the cosmological object can be determined.

Measuring the velocity of the galaxy is only one part of the story: the other, more difficult part is to estimate the distance to the galaxy. To do this, we use the simple fact that the farther the object, the less bright it appears to us. However, even to use this principle, we need to know how bright the object is intrinsically. This is where the problems start since we do not know enough about distant galaxies. In Hubble's time, it was assumed that all the galaxies had the same intrinsic brightness. Thus, if a galaxy appeared a fourth as bright as another one, it was twice as far away from us. Even then, astronomers realized that this simplifying assumption was wrong since galaxies differed in their properties and hence their brightness. . Matters are further complicated by the fact that some galaxies are so far away that the light that we receive from them has taken million, and in some cases, billions of years to travel to us. Thus, we are observing these far off galaxies not as they are today, but what they were when they were significantly younger. These effects makes measurement of cosmic distances one of the most challenging tasks for astronomers even today.

What the astronomers need are sources of light whose intrinsic brightness is known. Then, using these sources as beacons or standard sources (or candles as astronomers call them) they can compare the brightness of other objects to get an idea of the distance to them. Unfortunately, there are not too many of these standard sources that we know of. About a decade ago, some astronomers realized that one of the most spectacular objects in the universe, a type Ia supernovae, could be used as standard sources.

A supernova is a small star, which explodes at the end of its life. This explosion is not an ordinary one: In a matter of a few days, the star gives out more energy than an entire galaxy (which typically has a hundred billion stars!). The source of this energy is a runaway thermonuclear reaction, which blows the star apart. One kind of supernova is a Type Ia supernova. This occurs in a double star system in which one of the stars is a very dense and heavy star known as a white dwarf. The white dwarf sucks in matter from the companion star and this triggers the runaway thermonuclear explosion. These supernovae vary in their brightness but by studying several of them in the last few years, the astronomers realized that they were could be used as standard sources for distance measurement. In a typical galaxy, there is on an average one supernova explosion in 300 years. Thus if we monitor thousands of galaxies continuously, we could see many such cosmic explosions in one year.

This is precisely what two groups of astronomers have done. One set of astronomers, called the “High-Z Team” has been using a telescope in Chile to monitor supernovae while the other group, called the “Supernova Cosmology Project” has been using telescopes in Hawaii. The idea is to use large electronic detectors on some of the biggest telescopes. A large part of the sky is imaged at regular intervals and using digital light detectors any changes are spotted. If the two images of the same part of the sky show any differences, that is a spot of light shows up which was not there in the earlier image, then the astronomers know that they could have seen a supernova event. Once this is confirmed, the giant telescopes like the Keck telescope in Hawaii and even the Hubble Space telescope are used to take detailed images of the event and confirm if the image is actually of a supernova. These images then give us the redshift of the supernova and its brightness.

Using these techniques, the two teams have studied about 70 supernovae in the last decade or so. These supernovae exploded some 5 to 7 billion years ago, when the universe was only half as old as it is now. The result of this study of supernovae has surprised the whole community of scientists. The supernovae appear to be much fainter than expected! Though the difference is not much (the most distant supernovae being only 25% dimmer than expected) it is still large enough for cosmologists to rethink their favorite models of the universe.

How does this one result have such a profound influence on our view of the universe? And what is the cause of this discrepancy between theory and observation? When the astronomers have ruled out all other sources for the discrepancy in the observations and the theoretical expectations, then only one cause remains: that the universe expanded more slowly in the past than at present. If this was indeed the case, then the most distant supernovae will have a smaller redshift than anticipated. This is because the universe would have been expanding more slowly in the past when the light was emitted from these supernovae (these explosions took place some 4 billion years ago and we are just now receiving the light from them). Thus light traveling at that time was travelling in a universe which was expanding more slowly then today. Or looked at another way, the universe is accelerating rather than decelerating as was thought before.

This new evidence of an accelerating universe has a deep impact on the history and the future of the universe. A universe that has normal matter only cannot possibly accelerate since gravity is always attractive. The fact that the universe is accelerating and not decelerating implies that there is not enough matter to provide the gravitational force, which is needed to slow the expansion. A low matter density in the universe as mentioned above implies naively that the universe is open. However, the currently fashionable and successful models of the universe do not favor this. These models, called the inflationary models are very successful in explaining a host of observations. The inflationary models favor a universe, which is flat, i.e. one in which the gravitational attraction is exactly balanced by the outward expansion. So what is the solution? The low matter density implied by the supernovae is in contradiction with the predictions of the inflationary models.

Surprisingly, the solution lies in invoking what Einstein had called “his worst blunder”; the cosmological constant. This “anti-gravity” force is responsible for counteracting against the force of gravity. If the amount of this force were large enough, it would provide just the right amount of expansion to account for the observations of the supernovae. Apart from the supernova observations, there are other observations, which need to be also taken into account for a consistent theory or model of our universe. Among these are the estimates for the age of the universe, the observations of the cosmic microwave background radiation (remnant of the radiation from the Big Bang which has been detected and measured by the scientists using the Cosmic Microwave Background Explorer satellite) and the formation of galaxies in our universe.

Combining all these measurements about our universe is not an easy task. There are several competing theories and models but the consensus among astronomers seems to be zeroing in on a universe, which has both matter and the cosmological constant and is flat. However, as Prof. Shri Kulkarni of Caltech warns, “Though the supernovae data is suggesting some evidence for a cosmological constant, the “yardstick itself (i.e. the supernova)-- its nature and potential evolution of the progenitor -- is yet to be understood and we need more efforts in that direction before accepting a great result”. Nevertheless, most astronomers are now coming around to believe that the matter in galaxies, stars etc. contributes about 30% of the energy needed to make the universe flat while the other 70% is contributed by the cosmological constant or the anti-gravity force.

How certain are the cosmologists about the correctness of this model? Prof. Willick is of the opinion that “ this data is pointing to something radically new about our universe, and perhaps about physics itself”. In the coming years, several new experiments are expected to improve our knowledge about the cosmos tremendously. Among these are the new infrared detectors, the Next Generation Space Telescope and improved measurements of the cosmic microwave background radiation through new satellites. These will allow the astronomers to test their predictions to a much greater accuracy and precision. “Today we are in a transitional stage of our understanding “, adds Prof. Willick. Moreover, who knows, one might find that the universe has many more surprises in store than we imagine for us. After all, " there are more things on heaven and earth, Horatio, than are dreamt in your philosophy”. Prof. Kulkarni sums up the situation aptly when he says that “Great Results Need Great Proof and to which I will add Great Understanding”. However, one thing is certain: the old accepted paradigm of a flat universe filled only with normal matter is dead.