Four hundredth anniversary of Kepler's supernova

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The explosion of a star produces a spectacular astronomical phenomenon – a supernova. For some time the exploding star becomes as bright as the whole galaxy in which it is embedded. In our own galaxy, the Milky Way, a supernova, if such an event were to occur, might be visible even in broad daylight. As the announcement for the Supernova conference in June 2004 at Padua (connected with the anniversary of Kepler's supernova) said: Supernovae, which are nowadays believed to be the end-point in the evolution of massive stars and stars of low mass in close binary systems, have played a key role in the evolution and development of astrophysics. We discuss at first Tycho's supernova which elicited considerable interest when it was seen in 1572. Later we discuss Kepler's supernova and Galileo's reactions to its appearance. Some general aspects of supernovae are discussed at the end.

Tycho's supernova

The appearance of a supernova is best expressed in the words of one of the most famous observers of the past, Tycho Brahe[1]: 'Last year (1572), in the month of November, on the 11th day of the month, in the evening, after sunset, when I was contemplating the stars in a clear sky, I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining almost directly above my head; and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky, even the smallest, to say nothing of a star so conspicuous and bright as this. I was so astonished of this sight that I was not ashamed to doubt the trustworthiness of my own eyes. But when I observed that others, on having the place pointed out to them, could see that there was really a star there, I had no further doubts. A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world'. Tycho found it at about as brilliant as Jupiter, and it became soon equal to Venus. For about two weeks the star could be seen in daylight. At the end of November it began to fade and change colour, from bright white over yellow and orange to faint reddish light, finally fading away from visibility in March, 1574, having been visible to the naked eye for about 16 months.

To quote Tycho Brahe again: '. . . all philosophers agree . . . that the heavens and the celestial bodies in the heavens are without increase or dimunition and that they undergo no alteration either in number or in light . . . or in any other aspect.. . . I tried to determine whether it had a parallax and if so how great a one. . . . Therefore (not finding any parallax), we shall find it necessary to place this star not below the moon but far above. . . . It is among the fixed stars. Hence it is not some peculiar kind of comet . . .'. He published a small book, *De Stella Nova* (1573), thereby coining the term nova for a 'new' star.

This new star was such a great surprise for Tycho Brahe since it violated a canon of the Western thought that the skies were immutable and thus did not allow for any new astronomical phenomenon. According to the Greeks, the heavens were perfect and complete and celestial visitors like comets, meteors, etc. were thought of as phenomena connected with terrestrial atmosphere. As Hurd and Kipling[1] state, 'Brahe's observation was a direct challenge to the Aristotelian concept that the universe was confined by a sphere containing an unalterable number of stars'. According to James Jeans[2], 'Tycho . . . dealt a shattering blow to the Aristotelian cosmology'. Thus, it did take some courage on part of Tyco Brahe in 1572 to publicize the supernova in Cassiopeia which eventually came to be associated with his name.

Compare this with Chinese reports of a similar event in AD 1054 (culled from at least four accounts at different times in the Sung-shih [*Annals of the Sung Dynasty*][3]: 'On the 1st year of the Chi-ho reign period, 5th month, chi-chou (day) [July 4, 1054], a guest star appeared approximately several inches to the south-east of Tian-kuan [Aldebaran]. After a year and more it gradually vanished. . . . Yang Wei-te said, 'I humbly observe that a guest star has appeared. . . . If one carefully examines the prognostications concerning the emperor, the interpretation is. . . . Earlier, the guest star appeared in the morning . . . and was visible in the daytime, like Venus. It had pointed rays in the four directions and its colour was reddish-white. Altogether it was visible in daytime for 23 days'. Chinese termed such new stars as guest stars! There are conflicting reports on whether this event was seen and recorded in Europe[4a]. There are no definite recordings of this event in India[5].

The major difference between western and eastern reports is the lack of the surprise element in latter accounts. It is because the Chinese did not have reservations which characterized the western world. Keeping track of new astronomical phenomenon and its subsequent recording was a necessary part of forecasting catastrophes for the emperor and thus the empire. The profusion of references also points to the excellent record keeping reflecting the historical sense of the civilization. Their purely astrological enterprise has left us with wealth of astronomical archival data!

One has to note that the new star of 1572 appeared almost three decades after the death of Nicolaus Copernicus at the age of 70. Since the heliocentric theory of Copernicus refuted the earlier geocentric models of Aristotle and Ptolemy, it was not acceptable to the Catholic church. Further, a few years before the death of Copernicus, Martin Luther had ridiculed the heliocentric ideas. Thus the theory was anathema to the entire religious community! However, the foreword for the book written by a disciple of Copernicus imp-

lied that this was just a theory and thus it was not taken very seriously. In a poem by John Donne, Copernicus seeks entry to hell saying : 'I have turned the whole frame of the world, and am thereby almost a new Creator?'. The entry was rejected with the reply that the invention was nothing new and it did not upset the scheme of heavens in any major way!

Tycho Brahe was also not a believer in the Copernican theory and had his own compromise model for the solar system. In the Tychonian system, the earth is in the centre of the universe, the sun revolves around the earth and the other planets revolve around the sun. It can be shown through a geometric argument that the motions of the planets and the sun relative to the earth in the Tychonian system are equivalent to the motions in the Copernican system. While his sighting of the new star of 1572 had proved that the heavens were not immutable as the Greeks thought, it also signaled that something was wrong with their overall thinking. Thirty two years later there was a further blow to Aristotle!

Kepler's supernova

While a conjunction of Jupiter and Mars in Sagittarius had been predicted for 8 October 1604, it did not happen till a day later when a very bright new star was also seen near the place of the conjunction. Johannes Kepler, 34 years old at that time, first saw it on 17 October, and started a systematic study of the phenomenon. Initially as bright as Mars, the object brightened up and surpassed Jupiter in brilliance within a few days (According to Baade in the 20th century, the peak brightness was perhaps close to magnitude –2.25) and became invisible in twilight of November. At its reappearance in January 1605, it was still brighter than Antares and remained visible until March, 1606. He also wrote a book on the phenomenon in which he felt that all causes have to be looked into carefully before declaring that it is a new creation. He also wondered whether it could be the result of some random concatenation of atoms in the heavens. According to Clark and Stephenson[3], Kepler did not observe this in as detailed a manner as Tycho Brahe and the literature on this new star is rather scattered.

Galileo had been shown the star of 1572 when he was a child. According to Stillman Drake[6] Galileo, a professor at Padua at that time, had shown very little interest in astronomy with no record of his having made astronomical observations before 1604. He however had confessed seven years earlier in a personal letter to Kepler that he believed in the heliocentric theory of Copernicus. Galileo observed the new star for the first time on 28 October 1604. At that time he said that it was no disgrace for the university mathematician to have missed the first appearance of the star, as though he was obliged to keep watch every night of his life to see whether a new star might appear! He gave three public lectures probably in November, of which only a fragment and some notes have survived. The lectures were attended by a large audience. He took occasion to rebuke his hearers for thronging to hear about an ephemeral novelty, while for the much more wonderful and important truths about the permanent stars and facts of nature they had but deaf ears! He used the parallax concept to demonstrate that the new star was much further than the moon, at least as far as the other fixed stars. However the star slowly diminished in its brightness which suggested to Galileo that it might be moving away from the earth. He expected to find a parallatic shift because of earth's movement, but did not find it. Drake believes that Galileo therefore simply lost faith in the Copernican theory between 1605 and 1610, the year of his monumental discoveries with the telescope. According to both Shararat[7] and Drake, a pamphlet purportedly authored by Galileo had favourable references to Copernicus in its first version which disappeared later! According to Shararat, 'his suggestion was that the phenomenon was caused by condensed vapours far out in space, vapours which may have had their origin on or near earth'.

Tycho's new star had created interest but not much commotion because of the prejudices of Aristotelian scholars. However, observation of a second new star in 1604 within a short time was to ring alarm bells! The appearance of these two supernovae within a relatively short time and which could be seen by all the populace was catalytic in bringing down the Greek ideas of the Cosmos[6,4b]. The detailed and scholarly work of scientists like Copernicus, Galileo and Kepler regarding the solar system would have been too unapproachable for the common man to have had much effect. If the new star of 1604 had arrived four years earlier, it probably could have saved Guardino Bruno who was burnt alive by the Inquisition for his supposedly heretic theories of astronomy!

Supernovae as end points of stellar evolution

These guest stars remained as just novelties for a long time. Galileo's exasperated statement about that of 1604—'Why new stars ? I know nothing about old stars also!'—indicated political correctness as well as the state of astronomical knowledge. At that time nobody knew what made even ordinary stars shine. About 175 years later, a comet hunter called Messier located a strange object in the Taurus constellation which became known as the Crab nebula. Even when the telescopes improved it became difficult to resolve this object and hence it remained mysterious.

However, in the 1920s it was identified as the remnant of the guest star of 1054 AD. And it was a decade later (1934) and just after the discovery of neutrons that astronomers Walter Baade and Fritz Zwicky (who also coined the word supernova) wrote: 'With all reservation, we are of the opinion, that a supernova represents the transition from a regular star to a neutron star, in other words, a star consisting mainly of neutrons'. They reasoned that if a normal star could be made to implode until it was very dense—its material would transform into a 'gas' of neutrons. The gravity would be so intense that not only would the size of the star be reduced, but also some (about ten) per cent of the original mass would be converted into explosive energy which would radiate out into space. If the mass of the core of the shrunken star was about the same as that of the Sun (one solar mass), and ten per cent of it were converted into energy would be just what was needed to produce the incredible brightness of the supernovae. In the course of a supernova explosion, the dying star releases more energy within few seconds, than during its entire lifetime. For months, it shines brightly, outshining the billions of stars within its galaxy.

While stars can create elements only up to iron during fusion, the heavier elements are actually created inside stars and in the violent collapses before a super-

nova. The supernova remnants, as they move through space and blend into the interstellar medium, are responsible for distributing these heavy elements. Further, knowledge about many astrophysical processes has come from studies of the Crab Supernova, which is termed the Rosetta Stone of modern astrophysics (There is Crab and then there is everything else!) and which houses the most famous neutron star – the Crab pulsar – which rotates 30 times in a second. As for the other supernovae, the supernova of 1006 (in Lupus), probably the brightest in history, is expected to be a source of Cosmic rays. Faint radio objects (3C10 and 3C358) are seen today at the positions of both Tycho's and Kepler's supernovae respectively.

The last two decades have brought in further understanding of astrophysical processes from exciting work on supernovae. SN 1987A, which appeared in February of 1987 in the nearby LMC galaxy (the first extragalactic supernova had been seen in another nearby galaxy Andromeda in 1885), confirmed a host of predictions including formation of various isotopes and emission of neutrinos. The observation in the last few years that the distant supernovae are more distant than expected has brought in the concept of an accelerating Universe. To cap it all, the phenomena of Gamma Ray Bursts which represent the most intense emission of energy in the universe have also been connected with supernovae.

Frequency of supernovae

According to Clark and Stephenson[3], the unambiguous historical supernovae are only six – in the years 185, 1006, 1054, 1181, 1572, 1604 – in the last 2000 years which were visible to the naked eye in our galaxy. However, like the supernova of 1680 (which resulted in the strongest radio source Cassiopeia A and which was probably seen by Flamsteed, the first Astronomer Royal of England) many may not have been clear to the naked eye. The modern calculations give about one supernova per galaxy in about 30 years. Stars in our galaxy which are due to go out with a bang in the future include the red giants Betelgeuse and Antares.

While some supernovae in the past have been responsible for the life on earth, it is interesting to ask what would be the possible effects of a nearby supernova on this planet. The nearest recorded supernova is the Crab nebula at a distance of 2 kiloparsec (6600 light years). However the prolific gamma ray emitter Geminga pulsar discovered a decade ago is only about 100 parsec away. Its age is estimated to be about 340,0000 years by which time the *Homo erectus* who was already on the scene should have seen a very luminous object. According to Ellis and Schramm[8] a supernova has to be at a distance of ~ 10 parsec which would destroy the ozone layer for hundreds of years letting in the potentially lethal solar ultraviolet rays. The probability for such an occurrence is one in a few hundred million years.

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