AstroTalk: Behind the news headlines of January 2013

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A giant blast wave that hit the Earth…

You may have heard of the so-called 'gamma-ray bursts', cosmic explosions that are thought to be the most violent outbursts in the Universe. Some scientists say that their intensity places them second only to the Big Bang, the cataclysmic event that formed the beginning of the Universe as we know it. Now imagine what would happen if one of those gamma-ray bursts occurred relatively nearby, in our Milly Way galaxy, and what its consequences would be for us here on Earth… Well, it appears that this scenario actually happened in the 8th Century AD, now almost 1240 years ago.

In 2012, Japanese scientists announced the detection of high levels of the radioactive isotopes carbon-14 (^{14}C) and beryllium-10 (^{10}Be) in cedar-tree rings formed in the year 775 AD, suggesting that a burst of radiation struck the Earth then or in the previous year. These radioactive atomic elements form when cosmic rays (radiation from space) collide with nitrogen atoms in the Earth's upper atmosphere. The atomic nucleus of ^{14}C contains 6 protons and 8 neutrons, as opposed to the most common naturally occurring carbon isotope, ^{12}C, which contains 6 protons and 6 neutrons in its nucleus, and is not radioactive. In nature, ^{14}C contributes only 1 part in a trillion (0.0000000001%) to the ensemble of carbon species; through so-called β (beta) decay (emission of electrons or positrons from atomic nuclei), ^{14}C will eventually form ^{14}N, one of two stable, non-radioactive forms of nitrogen. This radioactive decay reaction takes about 5,730 years, a period referred to as the half-life of ^{14}C, because on this timescale roughly half of the population of radioactive nuclei will have decayed to stable nitrogen-14 atoms. Similarly, ^{10}Be nuclei have 4 protons and 6 neutrons, while stable ^{8}Be has only 4 neutrons. ^{10}Be decays to ^{10}B (boron-10) through β decay with a half-life time of 1.39 million years.

Earlier research had ruled out the nearby explosion of a massive star (a so-called 'supernova'), because nothing that may have resembled such an event was recorded in observations at the time and no supernova remnant has been found. The research team, as well as some of their competitors in the USA, also considered whether a 'solar flare', an energetic outburst of radiation from the surface of the Sun, could have been responsible, but these outbursts are probably not powerful enough to cause the observed high levels of ^{14}C. Large solar flares are likely accompanied by ejections of material from the Sun's corona, i.e., the Sun's hot outer atmosphere extending millions of kilometers into space, leading to beautiful displays of the northern and southern lights (aurorae), but again no historical records suggest that these took place.

Following this announcement, researchers pointed to an entry in the Anglo–Saxon Chronicle that describes a 'red crucifix' seen after sunset and suggested that this might point to a supernova. But, they stated, this dates from 776, which would have been too late to account for the carbon-14 data. I found this quite intriguing, so I decided to look this up. The Anglo–Saxon Chronicle has been made available online by the Online Medieval and Classical Library (http://omacl.org/Anglo/). This manuscript was originally compiled on the orders of King Alfred the Great in approximately AD 890, and subsequently maintained and added to by generations of anonymous scribes until the middle of the 12th Century AD. The original language is Anglo–Saxon (Old English), but later entries are essentially Middle English. This is what the relevant entry says:

> A.D. 774. This year the Northumbrians banished their king, Alred, from York at Easter-tide; and chose Ethelred, the son of Mull, for their lord, who reigned four winters. **This year also appeared in the heavens a red crucifix, after sunset**; the Mercians and the men of Kent fought at Otford; and wonderful serpents were seen in the land of the South-Saxons.

Note that the entry is actually for the year 774 AD, and not for AD 776 as stated by the Japanese research team! I have added the boldface to highlight the astronomical event. The geographic elements in this entry refer to places in what is presently the United Kingdom; 'Easter-tide' is an old-fashioned reference to the time of Easter.

However, this piece of historical evidence still does not explain why no supernova remnant has been detected, because the debris from such an event would still be visible in telescopes today. So, now German researchers have offered another explanation: a massive explosion that took place within the Milky Way. One of the authors of the paper, Professor Ralph Neuhäuser, from the Institute of Astrophysics at the University of Jena, said: "We looked in the spectra of short gamma-ray bursts to estimate whether this would be consistent with the production rate of carbon-14 and beryllium-10 that we observed – and [we found] that it is fully consistent."

These enormous emissions of energy occur when black holes, neutron stars, or white dwarfs collide – the galactic mergers take just seconds, but they send out a powerful wave of radiation. In fact, gamma-ray bursts, intense flashes of gamma rays lasting from milliseconds to minutes, are the most energetic events known in the Universe. Although they were first detected in 1967 by the US Vela 3 and 4 satellites as part of their classified missions to monitor compliance of the Soviet Union with the Nuclear Test Ban Treaty, it took until the 1991 launch of the Compton Gamma-Ray Observatory before their extragalactic nature was confirmed. This was achieved by observations with the Burst and Transient Source Explorer (BATSE) gamma-ray detector, which showed that the distribution of gamma-ray bursts is not concentrated in the Galactic plane or the Galactic Centre, but they are found anywhere in the sky. However, some scientists continued to support an origin in the outer halo of our Milky Way until the first reliable distances had been measured.

Although gamma-ray bursts and their observable features are extremely diverse and complex, they can be roughly divided into broadly overlapping 'long–soft' and ‘short–hard’ classes, where the terms ‘soft’ and ‘hard’ refer to their spectra; soft and hard represent low-energy and highly energetic gamma rays, respectively. The boundary between the long and short classes is usually set at 2 seconds. The former last, on average, 30 seconds from peak brightness until the end of their ‘afterglow’. They are mostly associated with supernova explosions in actively star-forming galaxies, which hence suggests that they are linked to massive progenitor stars. The majority of gamma-ray bursts detected to date are of the long–soft variety; because of their long afterglows – compared to enhanced peak intensities lasting for several hundred milliseconds and much fainter afterglows for the short–hard bursts, which may be related to collisions and mergers of neutron stars or white dwarfs (both are end stages of stars, the difference being found in their different original masses) – they have also been studied most extensively.

When these events happen, some energy is released in the form of gamma rays, the most energetic part of the electromagnetic spectrum (which includes visible light). Prof. Neuhäuser said, “Gamma-ray bursts are very, very explosive and energetic events, and so we considered from the energy what would be the distance given the energy observed.” The short bursts are seen in other galaxies many times each year but – in contrast to long duration bursts – without any corresponding visible light.

If this is the explanation for the AD 774–775 radiation burst, then the merging stars could not be closer than some 3,000 lightyears, or it would have led to the extinction of some terrestrial life. Based on the ^{14}C measurements, Prof. Neuhäuser’s team believes that the gamma-ray burst originated in a system between 3,000 and 12,000 lightyears from the Sun, and that is inside of our Milky Way galaxy! Although the event sounds dramatic, our medieval ancestors might not have noticed much. If the gamma-ray burst happened at this distance, the radiation would have been absorbed by our atmosphere, only leaving a trace in the isotopes that eventually found their way into our trees and the Antarctic ice. The researchers do not think that it even emitted any visible light. If they are right, then this would explain why no records exist of a supernova or auroral display. Other work suggests that some visible light may be emitted during short gamma-ray bursts that could be seen in a relatively nearby event. This might only be seen for a few days and could be missed easily, but nonetheless it may be worthwhile for historians to look again through contemporary texts.

Astronomers could also look for the merged object, a 1200 year-old black hole or neutron star, 3,000–12,000 lightyears from the Sun but without the characteristic gas and dust of a supernova remnant. Prof. Neuhäuser comments, “If the gamma-ray burst had been much closer to the Earth, it would have caused significant harm to the biosphere.” Observations of deep space suggest that gamma ray-bursts are rare. In the last 3,000 years, the maximum age of trees alive today, only one such event appears to have taken place. Prof. Neuhäuser said it was unlikely that the Earth would see another one soon, but if we did, this time it could make more of an impact. If such a cosmic explosion happened at the same distance as the 8th Century event, it could knock out our satellites. Wherever a gamma-ray burst occurs, any planets in the vicinity suffer. Further away, but still at a distance of just a few hundred lightyears, the radiation from a gamma-ray burst would destroy the protective ozone in the upper atmosphere, allowing ultraviolet radiation to kill terrestrial plant life, and animals would starve. Only sea life would remain unharmed. However, this, said Prof. Neuhäuser, was "extremely unlikely". It is estimated that such nearby bursts can be expected only every 300 million years.

Observing gamma-ray bursts

Detectable for only a few seconds but possessing enormous energy, gamma-ray bursts are difficult to capture because their energy does not penetrate the Earth's atmosphere. However, thanks to a telescope in space that orbits the Earth, astrophysicists are filling in the unknowns surrounding these bursts and uncovering new questions. The Fermi Gamma-Ray Space Telescope launched on 11 June 2008. As part of its mission, the telescope records any gamma-ray bursts within its viewing area.

"Fermi is lucky to measure the highest energy portion of the gamma-ray burst emission, which last for hundreds to thousands of seconds – maybe 20 minutes," said Péter Mészáros, Professor at Pennsylvania State University (USA). Most gamma-ray bursts occur when stars that are more than 25 times larger than our Sun come to the end of their lives. When the internal nuclear reaction in these stars ends, the star collapses in on itself and forms a black hole. The outer envelope of the star is ejected, forming a supernova. "The black hole is rotating rapidly and as it is swallowing the matter from the star, the rotation ejects a jet of material through the supernova envelope," said Mészáros.

This jet causes the gamma-ray burst, which briefly becomes the brightest thing in the sky. However, unlike supernovas that radiate in all directions, gamma-ray bursts radiate in a very narrow area, and Fermi sees only jets ejecting in its direction. We actually miss about 500 gamma-ray bursts for every one we detect. The Fermi telescope has enabled scientists to look at the very fast – near the speed of light – jets producing the gamma-ray emission. While researchers are still modifying scientific theories on the nature of these bursts, thanks to Fermi, they now have actual measurements to add to the theoretical debate.

"Fermi has done much better in measuring how close to the speed of light the jet gets," said Mészáros. "But we still don't know if it is 99.9995% of the speed of light or 99.99995% of the speed of light." Gamma-ray bursts occur in many places in the universe, but because they are a product of aging stars they may be able to shed some light on the beginnings of the universe. The bursts are visible at the longest distance from earth and therefore at the earliest time in the universe. "We think we can detect them at the infancy of the universe," said Mészáros. This is exciting, because their study would potentially allow us to understand the earliest stages of the evolution of the Universe as a whole!

Figures (in no particular order):

Figure 1: Artist's impression of a gamma-ray burst. (*Credit: NASA/D. Berry.*)

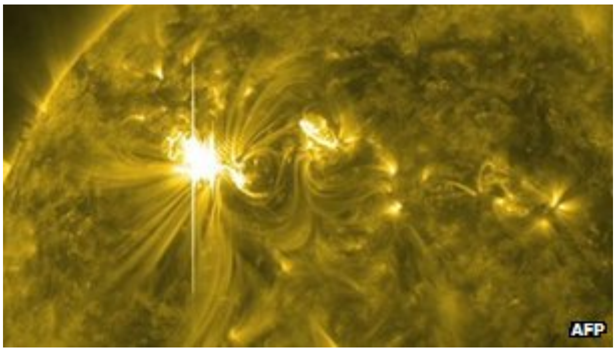

Figure 2: Solar flare. (Credit: AFP.)

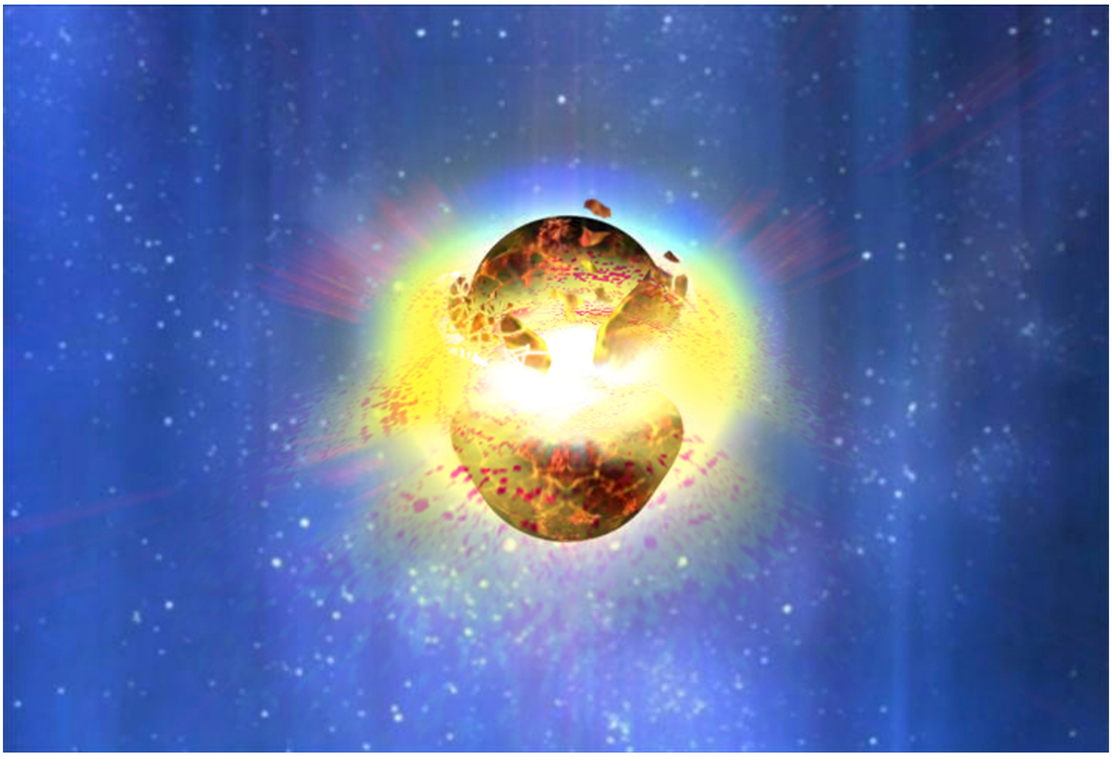

Figure 3: Artist's impression of the merger of two neutron stars. Short-duration gamma-ray bursts are thought to be caused by the merger of some combination of white dwarfs, neutron stars or black holes. Theory suggests that they are short-lived, because there is little dust and gas to fuel an 'afterglow'. (*Credit: Part of an image from NASA/Dana Berry.*)

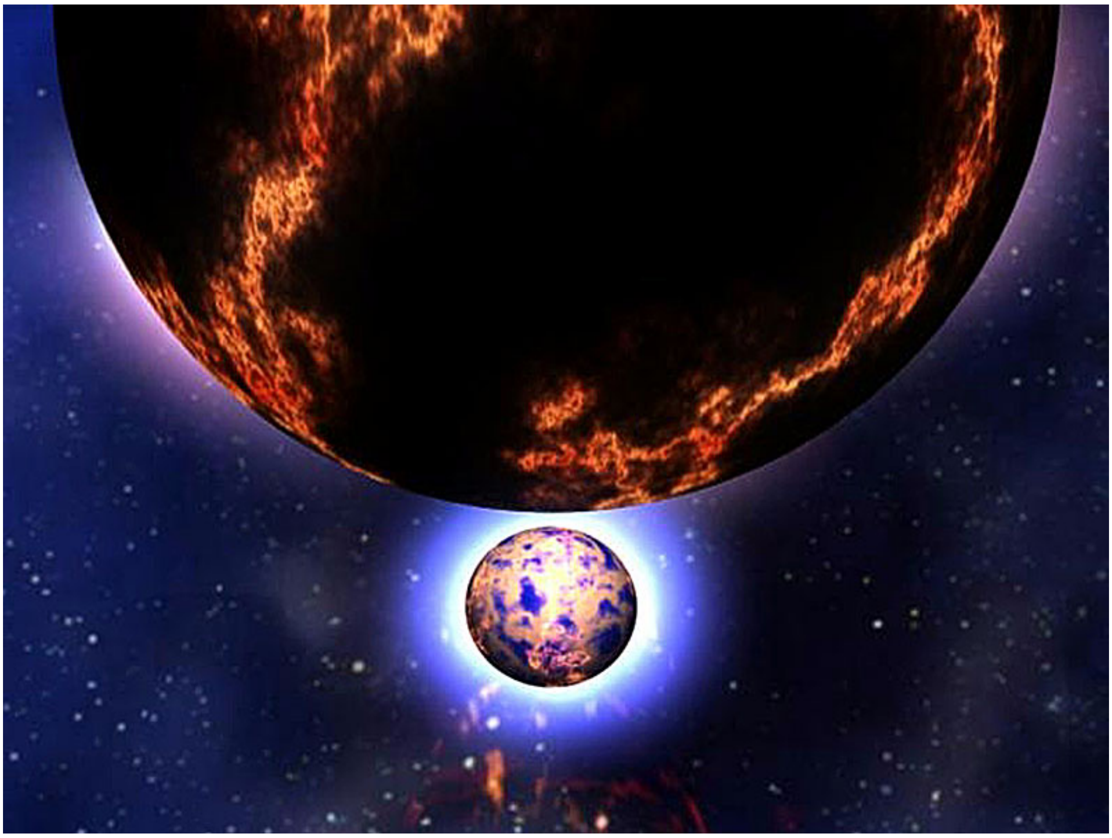

Figure 4: Artist's impression of a neutron-star merger, leading to a gamma-ray burst. (*Credit: NASA/Dana Berry.*)

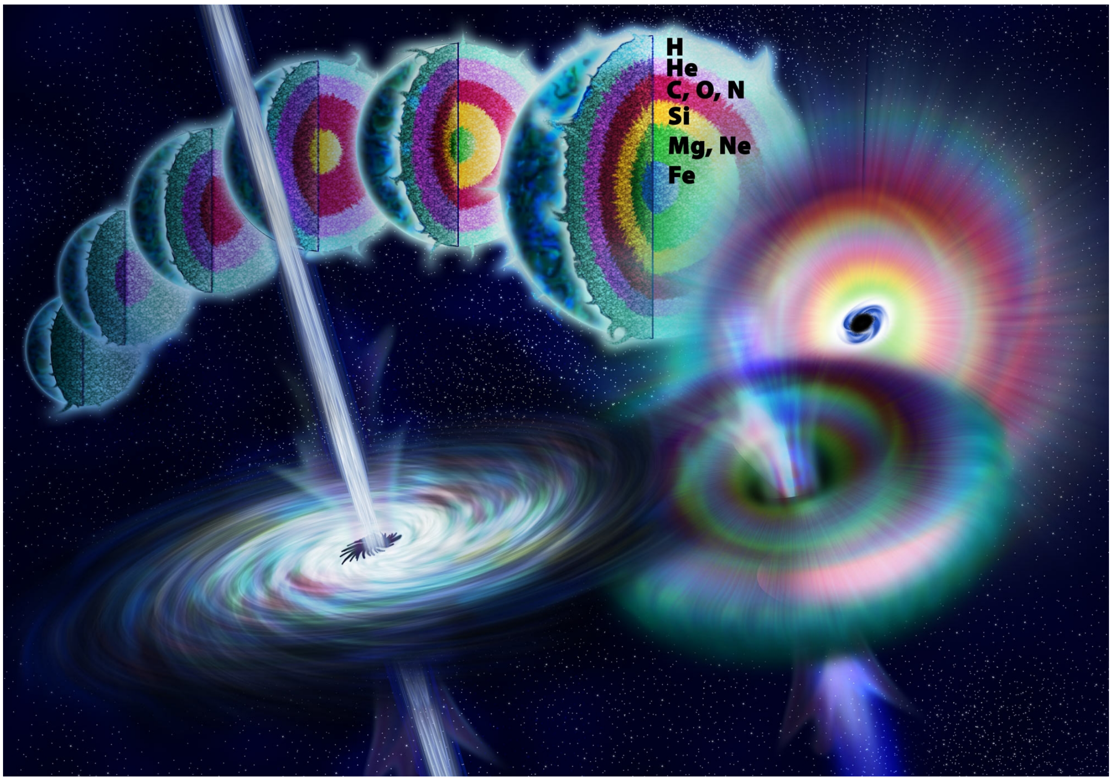

Figure 5: Drawing of a massive star collapsing to form a black hole. Energy released as jets along the axis of rotation forms a gamma-ray burst that lasts from a few milliseconds to minutes. Such an event within several thousand light years of Earth could disrupt the biosphere by wiping out

half of the ozone layer, creating nitrogen dioxide and potentially cause a mass extinction. (*Credit: National Science Foundation/Nicolle Rager Fuller.*)