Who will see a nearby supernova?

The detection in 1987 of a supernova in the Large Magellanic Cloud has lead to an estimate of the maximum rate of galactic supernovae so unrestrictive that the best response must be to run neutrino detectors for decades on end.

ALTHOUGH the supernova found in the Large Magellanic Cloud in February 1987 has kept many astronomers on their toes, it has not been much of a public spectacle. Even those of us lucky enough to be in the Southern Hemisphere have not been able to point to a new star shining in the sky. Indeed, even those with access to telescopes have had to use the most refined instrumentation to glean scraps of information from the supernova.

This is a far cry what it must have seemed like in China in 1054, when the star whose principal remnant is the Crab nebula blew up. Later, Tycho Brahe and Kepler each had the good luck to record supernova explosions in the Galaxy, which amounts to three visible galactic supernovae in a millennium. So can one work by the rule that there is one visible supernova every 300 years or so? The chances are probably greater than that, for the Crab explosion spotted by the Chinese appears not to have been recorded elsewhere in the world, even though it is said to have been bright enough to be visible by day. The rate of one explosion every 300 years, implying a (human) lifetime-chance of one in five, is probably a lower limit.

Now there is also what seems to be an upper limit, derived from the observation of the neutrinos accompanying the explosion of the Large Magellanic Cloud supernova (known as 1987a). Two years ago, it was reckoned to be something of a marvel that two special-purposes neutrino-detectors, one in the United States and one in Japan, had been functioning at the time and were able to record the small flux of neutrinos from the Large Magellanic Cloud at the time of the explosion.

The Irvine–Michigan–Brookhaven collaboration, which has for nearly a decade been operating a neutrino detector 600 metres underground in an Ohio salt-mine, has used just over two years' worth of data to fix an limit for the recurrence rate of galactic supernovae (S.T.Dye *et al. Phys. Rev. Lett.* **62**, 2069; 1989). The limit is that the galactic supernova rate must be less than 1.5 a year.

As these things go, the neutrino detector is a simple affair. Its purpose was originally to detect the decay of protons (still a live issue in high-energy physics although the lifetime of the proton is clearly greater than the least it might have been). There is a huge tank of water (8,000 tonnes of it) in which energetic neutrinos, by interaction with electrons or protons, yield relativistic electrons or positrons which, by travelling faster than the velocity of light in water, yield pulses of Čerenkov radiation (light) that can be recorded by more than 2,000 sensitive photomultipliers.

Crudely, the greater the energy of the electrons into which the neutrino is converted, the more photomultiplier tubes will record signals, so it is possible to select events whose energy exceeds some threshold by requiring that the number of tubes which fire should exceed some number. (Some device of this kind is in any case needed to filter away random discharges of the photomultipliers.)

In reality, the operation of this deep-mine detector is plainly something of a well-regulated nightmare. Despite the great depth, the equipment records 2.7 cosmic-ray muons every second (which must be identified and discarded from the records by using the directional properties of the photomultipliers to show that these particles begin life outside the water tank). Cosmic-ray neutrino interactions within the water-tank are luckily less frequent, at roughly two a day.

Supernova 1987a blessed the neutrino-detector on 23 February 1987 with eight neutrino events in a time-span of 6 seconds. The similar Japanese experiment, Kamiokande-II, yielded 11 neutrino events at exactly the same time (within the one second uncertainty of the time measurement). Since those measurements, there can have been no doubt in reasonable people's minds that even very distant supernovae (the Large Magellanic Cloud is 50,000 parsec away) deliver neutrinos at the surface of the Earth.

So why not use the same records to search for signals from other supernovae? This is what the Irvine–Michigan–Brookhaven collaboration has now done. Briefly, they have found no other, but in the process they have been able to fix a limit on the presumed rate of supernova occurrence within the Galaxy.

The argument is both interesting and important. Galactic supernova should produce much stronger signals than 1987a. Roughly half the stars in the Galaxy are within 10,000 parsec of the Sun, which is also the distance of the galactic centre. So, in principle, searching the existing record for past galactic supernovae simply involves hunting for clutches of neutrino events in the Ohio records.

The practical difficulty, of course, is hunting for bunches of putative neutrino events spanning a few seconds in records which, between them, span more than 700 days. The task has been slightly complicated by the need, at the Ohio detector, to deal with the two groups of records from before July 1984 and after May 1986 (when the sensitivity of the instrument had been improved).

By themselves, the separate records give modestly disappointing lower limits for the rate of galactic supernova explosions — there must be fewer than one every two years or so. Putting them both together gives the result that there are likely (with 90 per cent confidence) to be fewer than one every 1.5 years. The inference is relatively robust. The important provisos are that the likelihood of supernovae outside the 10,000 parsecs in which the first version of the Ohio equipment could detect explosions with reasonable efficiency is representative of the more distant parts of the Galaxy, and that the effect of the supernova is the collapse of a massive star either into a neutron star or a black hole.

Inevitably, the limit now obtained, based as it is on just two years of observation, is not much of a constraint on the theoreticians. Dye *et al.* point out that most estimates of the galactic rate of supernovae explosions, based on arguments from the pulsar population or the presumed rate of nucleosynthesis or even from direct observation of the supernova rate in other galaxies, give estimates of one every 10 years at the maximum. Wrily, the Irvine–Michigan–Brookhaven collaboration points out that it would take 70 years of observation with its detector to put a 90 per cent confidence limit on an estimate that the rate of supernova explosion is less than one every 30 years.

Quite what that means for the chance that some people now alive will see a supernova with the naked eye is therefore, for a long time to come, an open question. Some say that only three-quarters of the Galaxy is visible from the region of the Sun, but supernovae appear to be concentrated in regions of star-formation, where obscuring gas and dust will be common, so that the chances of seeing them will be even smaller. So Dye *et al.* are right to say that the best strategy for detecting supernovae will be to "build, maintain and operate for decades" detectors capable of surveying the whole Galaxy.

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