# Gamma Rays: From Neutron Stars, Supernovas, or "Beebees"?

Shortly after 2 July 1967 the scientists and engineers at Los Alamos, New Mexico must have been shocked to see that an intense burst of gamma rays had been recorded by several Vela satellites, which were designed to monitor the Nuclear Test Ban Treaty. The bursts of radiation were characteristic of nuclear debris, so one might have guessed that a hydrogen bomb had been set off in space. The data from such events have only recently been made available to scientists without security clearances, and when a graph of the first event was released, a small section had been excised with a razor blade. Subsequent examinations of the first event and others like it have shown that they did not come from any object in the solar system, so the identification of the gamma ray bursts has become a scientific rather than a political problem. Seven other experiments in space, including those on Apollo 16, have confirmed the gamma ray bursts, and the question of their origin appears to be the greatest puzzle astronomers have confronted in the last year.

The Vela gamma ray bursts are so rare that it seems unlikely they would have been discovered with an ordinary scientific satellite. But the Vela satellite system is designed for surveillance of all directions at all times. About five events per year have been detected. The start of each event is signaled by a short pulse of gamma rays, from 0.1 to 4 seconds long, and it is usually followed by one or more succeeding pulses. But the whole burst is usually over within a minute.

Although the events are called gamma ray bursts, the characteristics of the radiation are quite different from the phenomena usually studied in the new field called gamma ray astronomy. Whereas most gamma ray astronomers study radiation with an energy of 50 million electron volts (Mev), most of the energy in the newly discovered bursts occurs between 0.1 and 1.2 Mev, and at the lower end of the energy range there is no clear distinction between gamma rays and x-rays. The bursts are so intense that there is little question whether the signal is just a fluctuation in the intensity of background noise—a problem that often arises in the analysis of discrete sources of high energy gamma rays.

Each of the 23 events catalogued so far by the team of Ray Klebesadel, Ian Strong, and Roy Olson at the Los Alamos Scientific Laboratory triggered a response from scintillation counters in at least two satellites in the Vela system. (Of four satellites in a circular orbit with a 120,000-km radius, three are usually active.) Because of the finite speed of light, the burst of gamma rays reaches the different satellites at slightly different times (0.8 second elapses as gamma rays cross the orbit diameter), and the direction of the bursts can be delimited from the arrival times. When a burst is detected by three satellites, the arrival times are sufficient to establish that the burst came from one of two small areas in the sky (the ambiguity arises because events on one side of the orbital plane cannot be distinguished from those on the other). However, additional data from other satellites have made it possible to establish a unique direction for three of the events (Fig. 1).

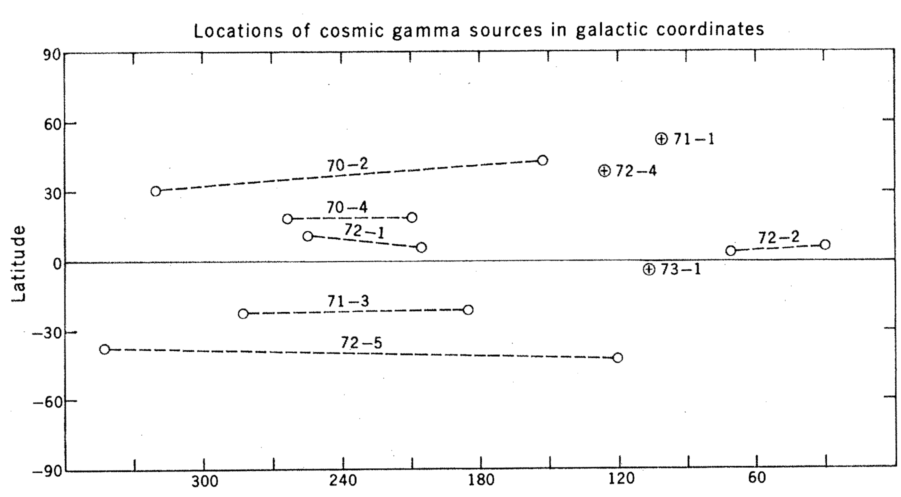


Fig. 1. The locations of sources of gamma ray bursts detected by Vela satellites. Sources within our galaxy might be concentrated about the line at 0° latitude. For six gamma ray bursts, the position of the source is ambiguous, and may be at one of two locations connected by a dotted line. For three others, a unique location has been determined.

An experiment with the IMP-6 satellite, by T. Cline and U. Desai at Goddard Space Flight Center, Greenbelt, Maryland, confirmed the photon nature of the events and measured the range of energies of the gamma rays. The x-ray detectors on the OSO-7 satellite observed one of the events, thus removing the ambiguity about its position, and the gamma ray bursts have also been detected by the instrumentation of the x-ray satellite Uhuru and the geophysical satellite OGO-5.

In spite of the ambiguity about the locations of most of the bursts, it is clear that they do not come from the earth, the sun, or the planets, and, with one possible exception, the directions do not correspond to any of the closest stars. About 5 years ago S. A. Colgate suggested that supernovas might be the source of sharp gamma ray pulses, but so far no supernovas have been found that started at the time of a burst. Supernovas do not seem to occur in our galaxy often enough to account for the bursts, and the question whether the sources are outside the galaxy or not is far from settled. Strong thinks that the distribution in Fig. 1 is evidence that the sources are inside the galaxy, because they are concentrated in the hemisphere away from the galactic center and there seem to be slightly fewer at high latitudes. If the sources were no more than a few hundred parsecs away (1 parsec is 3.3 light years), such a distribution would be expected, he argues, because the sun is on the inside of a spiral arm of the galaxy, and the galaxy is a relatively thin disk. But more gamma ray events are needed to get a good idea of the distribution, and it is possible that the sources lie isotropically distributed in other galaxies, which would put their distances at $10^6$ parsecs or more.

The well-known astronomical objects

## By Jupiter!

As Pioneer 10 rounded Jupiter last week, it sent back spectacular photos of the massive red planet and confirmed that in many ways Jupiter hardly seems like a planet at all. By checking the surface of Jupiter in darkness as well as daylight, Pioneer verified that Jupiter radiates 2.5 times as much heat as it absorbs from the sun. Pioneer also found helium, in addition to hydrogen, in Jupiter's atmosphere, showing constituents similar to the sun. The biggest surprise was that the magnetic field of Jupiter is shaped like an enormously distended disk, except near the planet where it is more rounded like the earth's field. When all the measurements from Pioneer are analyzed, scientists should be able to determine how much the field is tilted, and whether it is centered on the middle of the planet. A greatly displaced field could be evidence that Jupiter is at least partially solid. Pioneer hasn't been able to probe deep enough below the clouds to determine whether Jupiter has a liquid or solid surface—or any surface at all. But a very important achievement was the imaging of the planet for the first time in slanting light. The picture shows the Red Spot and the shadow of Jupiter's moon, Io, in more detail than ever seen before. Two pictures with even better resolution will be released later, showing the Red Spot and the crescent view of the planet as Pioneer was departing.—W.D.M.

were not expected to produce the type of gamma ray bursts that have been observed. Even though the early supernova theory of Colgate predicted gamma ray bursts, they were more energetic, shorter in duration, and single rather than multiple bursts. Perhaps a good measure of the excitement astronomers feel about this newly discovered phenomenon is the number of theories that have been proposed since the discovery was announced on 1 June 1973. No fewer than six seriously elaborated theories have been proposed so far: a modified theory for sources in extragalactic supernovas, four theories for sources in various sorts of stars in the galaxy, and one far-out but plausible idea that the gamma rays might come from the breakup of relativistic "beebees" within the solar system. The large number of theories is even more surprising because the possibilities are greatly constrained by the energy of the gamma rays, the shortness of the bursts, and the observation that multiple bursts frequently occur.

A gamma ray burst could be generated during a supernova event as the shock wave in an expanding star broke through the surface. Colgate, who is at the New Mexico Institute of Mining and Technology, Socorro, proposes that type II supernovas which occur in massive stars with hydrogen envelopes might be more likely to produce the observed gamma ray bursts than the type I supernovas of older, more compact stars that he considered in his early theory. Because the photons are emitted from a larger surface layer which is expanding at relativistic speed, the gamma ray pulse would be about 0.5-second long. Colgate's theory has somewhat more difficulty explaining why the supernovas have not been seen and how successive pulses are generated. He argues that only a small fraction of type II supernovas will be energetic enough to emit gamma rays in a pulse sharp enough to be detected by the Vela spacecraft, so it is not surprising that these few supernovas are not spotted. A second pulse of gamma rays would come out of the star later than the first, according to Colgate, if it arose from the formation of deuterium at a layer fairly deep within the star.

By contrast Martin Harwit and E. E. Salpeter have proposed that the gamma ray bursts originate inside the galaxy, and are caused by comets passing close by neutron stars and falling onto them. For a neutron star, just as for the sun, the chances for very close passage are good, and a comet can break into several pieces. On second passage these pieces could be captured—presumably because their density had decreased—and multiple gamma ray bursts would result. The gamma rays would be produced by a shock front set up as the material from the comet ran into itself as it was being funneled onto the surface of the neutron star, and the shortness of the bursts would be consistent with the orbital period and high velocity expected for material falling onto a compact object like a neutron star. The efficiency with which gamma rays can be produced by this method is not well known, and more comets than are found in the solar system would be needed to produce gamma ray bursts at the rate observed, but not an exorbitantly large number more.

Not just comets, but any sort of matter might produce radiation by falling onto a neutron star. A theory proposed by Donald Lamb, Fred Lamb, and David Pines, at the University of Illinois, Urbana, suggests that the unexplained gamma ray bursts are produced in binary star systems where, for instance, an old neutron star might be circling a normal star in a very tight orbit. If the normal star flared, and ejected about the same amount of matter as the sun does during large flares, Lamb and his associates think that gamma bursts could be produced with the energy and duration observed.

The explanation is quite similar to the explanation widely accepted for a common phenomenon in x-ray astronomy. In fact, the Illinois scientists say they were led to their theory by noting that a reasonable estimate of the total power emitted by the sources of gamma ray bursts coincides well with the total power of x-ray sources. The x-ray sources known in binary systems are thought to be relatively young, however, and are not plentiful enough to account for the number of gamma bursts observed. But older neutron stars in binary systems should be much more abundant.

Another theory for gamma ray bursts that originate within the galaxy, proposed by Floyd Stecker and Kenneth Frost at Goddard Space Flight Center, is that giant stellar flares in white dwarf stars produce the bursts. Noting that the energy and time structure of solar x-ray bursts are quite similar to those of the gamma ray bursts, Stecker and Frost see the x-ray bursts from the sun as a clue to what may be happening on a much larger scale. To be consistent with the observations, the giant flares would have to have $10^6$ and perhaps $10^{10}$ times as much energy as a strong solar flare. Since energy is stored in the magnetic fields of a star, Stecker and Frost propose that white dwarfs, which have intense magnetic fields with values as high as $10^7$ gauss, are the source.

In exchange for the requirement of very large energies, a theory by Ken Brecher and Phillip Morrison at the Massachusetts Institute of Technology, Cambridge, proposes that modest but directional stellar flares produce the gamma ray bursts. The price they pay for the lower total energy in each flare, however, is that the flares must be much more frequent than in the previous theory. Brecher and Morrison propose that directed beams of electrons stream out of the sun, hit optical photons, and convert them to gamma

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*Speaking of Science*

# Breeder Program: Bethe Panel Calls for Reorientation

The soundness of technical decisions made by the Atomic Energy Commission in its breeder reactor program have long been a subject of internal debate within the nuclear power community. Those who disagreed with Milton Shaw, director of the breeder project until his resignation in June 1973, frequently if privately complained of the lack of high level review of what is still the United States' largest energy research and development effort. A new report, the first independent assessment of the program commissioned by the AEC in many years, gives substance to those dissenting views and proposes a major reorientation of the program's goal and procedures while reaffirming the importance of the breeder as a future energy source.

The report recommends, among other things, redesign of the two major facilities in the breeder program—the Fast Flux Test Facility (FFTF) now under construction in Hanford, Washington, and the demonstration breeder reactor to be built in Oak Ridge, Tennessee. It calls for an accelerated research program on advanced nuclear fuels and for a change in the management policies affecting the conduct of the research. The report appears to have had sufficient impact on the AEC to cause some last minute changes in the agency's proposed budget for next year (fiscal year 1975), which is now in preparation.

The report is the work of a panel headed by Hans Bethe of Cornell, a well-respected nuclear physicist.* It originated in one of a series of workshops on major energy options which were financed by the AEC to assist AEC chairman Dixy Lee Ray in preparing an expanded energy research and development plan for President Nixon. The Bethe panel considered long-range energy sources and, on the basis of a possible shortage of uranium within 20 years, concluded that advanced nuclear power reactors of either the fission or the fusion type were urgently needed. They reendorsed the liquid metal–cooled fast breeder reactor (LMFBR) as the most logical first choice, but criticized the limited progress to date and the present directions of the program.

The planned demonstration reactor, for example, will be neither an economically competitive source of electricity nor an effective breeder with its present design and intended fuel. The major advantage of breeder reactors is that they produce more fuel than they consume, thus, in theory, freeing the nuclear power industry from its present dependence on high grade uranium reserves and breeding enough new fuel to supply additional reactors as needed. A measure of breeding effectiveness is the doubling time, the period required to double a reactor's initial inventory of fissionable material; doubling times of 10 years or less have generally been considered necessary to meet a demand for electricity that now doubles every 9 years. In contrast, the panel estimates a doubling time of between 30 and 60 years for the demonstration plant. A reactor of such low performance, they conclude, is not a useful breeder at all.

One source of trouble, according to the report, is that the goals of the breeder program have been somewhat confused. One objective, an economically competitive reactor, the panel thought could best be left to industry. A second and truly national objective is to develop a reactor with high breeding capability and low fuel requirements. It is this second goal, the panel suggests, which has been lost sight of in recent years and which they recommend as the focus of the AEC's redirected efforts.

The panel goes on to point out that the uranium oxide fuels currently being developed will probably not yield satisfactory doubling times even when pushed to their theoretical limit. Oxide fuels turn out to capture more low energy neutrons than originally expected, and the steel alloys used to clad all nuclear fuels swell under heavy neutron irradiation, thus requiring that unproductive space be

* Other members of the Bethe panel were Walter Zinn, one of the pioneer nuclear reactor designers (now retired); Chauncy Starr, head of the utility industry's Electric Power Research Institute; Milton Levenson, also of the institute; and Sol Buchsbaum, Bell Laboratories. The complete series of workshop reports—covering fossil fuels, short- and long-range nuclear options, and institutional problems—together with a lengthy overview article and other material is available as the *Report of the Cornell Workshops on the Major Issues of a National Energy Research and Development Program* and can be obtained from the Laboratory of Plasma Studies, Cornell University, Ithaca, New York 14850.

rays. Because the gamma rays would be oriented in only one direction, the energy needed to trigger a Vela satellite would be much less than if they were spreading out equally in all directions.

Clearly the most novel theory of gamma bursts has come from Jonathan Grindlay, at the Center for Astrophysics, Cambridge, Massachusetts, who proposes that a rain of small iron pellets generated by pulsars falls on the solar system, and that the pellets are broken up by sunlight to produce gamma rays. If little iron grains about 1 mm in diameter were traveling toward the solar system at relativistic speeds, they would perhaps break into several blobs or melt into droplets at a distance 30 times the orbit of Pluto. As sunlight grew more intense, the material would break up further into individual atoms, and as they ionized, cascades of x-rays would be produced. At about the mean orbital diameter of Pluto most atoms would radiate, and because of their relativistic speeds the radiation would be shifted by the Doppler effect into gamma rays emitted in a small cone. If the cone, which Grindlay expects to have a diameter comparable to three times the moon's orbit, were pointed at the earth, the Vela satellites would be triggered. Grindlay points out that a simple test of this theory would be to see if any distant satellite, such as the Pioneer satellites to Jupiter, also detected a gamma burst.

Other possible explanations for the unique gamma ray bursts have also been discussed. Reuven Ramaty, at Goddard, has proposed that the source may be an extragalactic neutron star, and one jocular individual has even proposed the "catastrophe theory," namely that the bursts do indeed come from nuclear weapons, perhaps as other civilizations detonate themselves. The puzzle is not yet solved, and the data are coming in so slowly that astronomers may be vexed for a good while to come.—WILLIAM D. METZ

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left within the breeder core to accommodate the swelling. Both effects raise the doubling times that can be achieved. Fuel in the form of uranium carbide or perhaps uranium nitride, although these forms have not been well studied, has a higher potential, and the panel recommends a major new effort to develop them and to find improved cladding alloys. So urgent is the need for irradiation experiments with these advanced fuels, the panel believes, that they suggest the AEC attempt to borrow space in French and British breeder reactors until the FFTF is complete. (The AEC says it has contacted the British and the French, but with a comfortable lead on the U.S. program they showed no interest in helping us catch up.)

To facilitate the research program, the panel recommends dedicating the FFTF to testing advanced fuels and suggests design changes to make it a more flexible test reactor. The demonstration reactor, on the other hand, should be frankly oriented toward commercial feasibility by giving industrial contractors a relatively free hand in its design, even at the risk of delaying its construction a year or two. By uncoupling the FFTF and the demonstration plant the panel hopes to more closely approach both the commercial goal and the national goal.

The panel report implicitly criticizes past management policies within the breeder program and calls for the AEC to tell its laboratories and contractors what to do, but not how to do it. The new director of the breeder program, T. A. Nemzek, told *Science* that he is in full agreement with such a policy and that he favors encouraging initiative in and delegating more authority to the field. "We are making decisions here that should be made elsewhere." The intended changes may thus presage an end to the long and often bitter conflict within the nuclear community over the management of the reactor program and a new measure of independence for the AEC's national laboratories.

Nemzek also agrees with the need to put more emphasis on the development of advanced fuels, although he is more optimistic about the potential for oxide fuels than is the Bethe panel. In any case, he intends to rapidly expand ongoing work on improved cladding and has inserted new money for work on carbide fuels into next year's budget. Nemzek does not believe that the breeder program needs to be greatly reoriented, however, and he defends the present approach of starting with a conservatively designed demonstration plant and gradually upgrading its fuel. Nonetheless, a review (which Nemzek describes as thorough) of the demonstration plant design is under way with industrial participation.

The urgency of the breeder program depends strongly on how much uranium is available, and the remarkable fact is that neither the AEC nor anyone else has more than questionable estimates of available reserves. The Bethe panel raises a number of questions about the uranium supply situation, including: How much intermediate grade ore (extractable at $10 to $30 a pound) is there? Is it feasible to mine low-grade ores, considering the large environmental impact this would have? Should import of uranium be permitted? In view of the priority of the breeder program, the Bethe panel believes it important to get better answers to these questions than are available now.

As far as fusion is concerned, the panel cautioned against overoptimism and recommended a deliberate approach. A decision to build a large-scale test reactor of the magnetic confinement type should only be made, the panel suggests, after considerable experience with smaller machines, and not as early as next year. In laser fusion, the panel recommended more basic work with small lasers on the interactions of laser beams with plasmas. They also suggested exploring the possibilities of electron beam fusion, since efficient, high energy electron beams already exist.

The sweeping nature of the Bethe panel's recommendations and their sharp enumeration of technical oversights within the breeder project suggest the need for more frequent independent assessments of the AEC's major programs. In the early years of the agency's existence, prominent university and industrial scientists regularly undertook such reviews. In the 1960's, however, the agency tended to seek its own counsel and became more defensive in its role as a promoter of nuclear power. The Bethe panel's report and the agency's reaction to it may indicate that a return to earlier practices has begun. Bethe himself believes "the academic community should return to an active advisory role." And Nemzek told *Science* he thinks it is a healthy trend and is looking for means to assure more overseeing of all facets of his program.

—ALLEN L. HAMMOND