

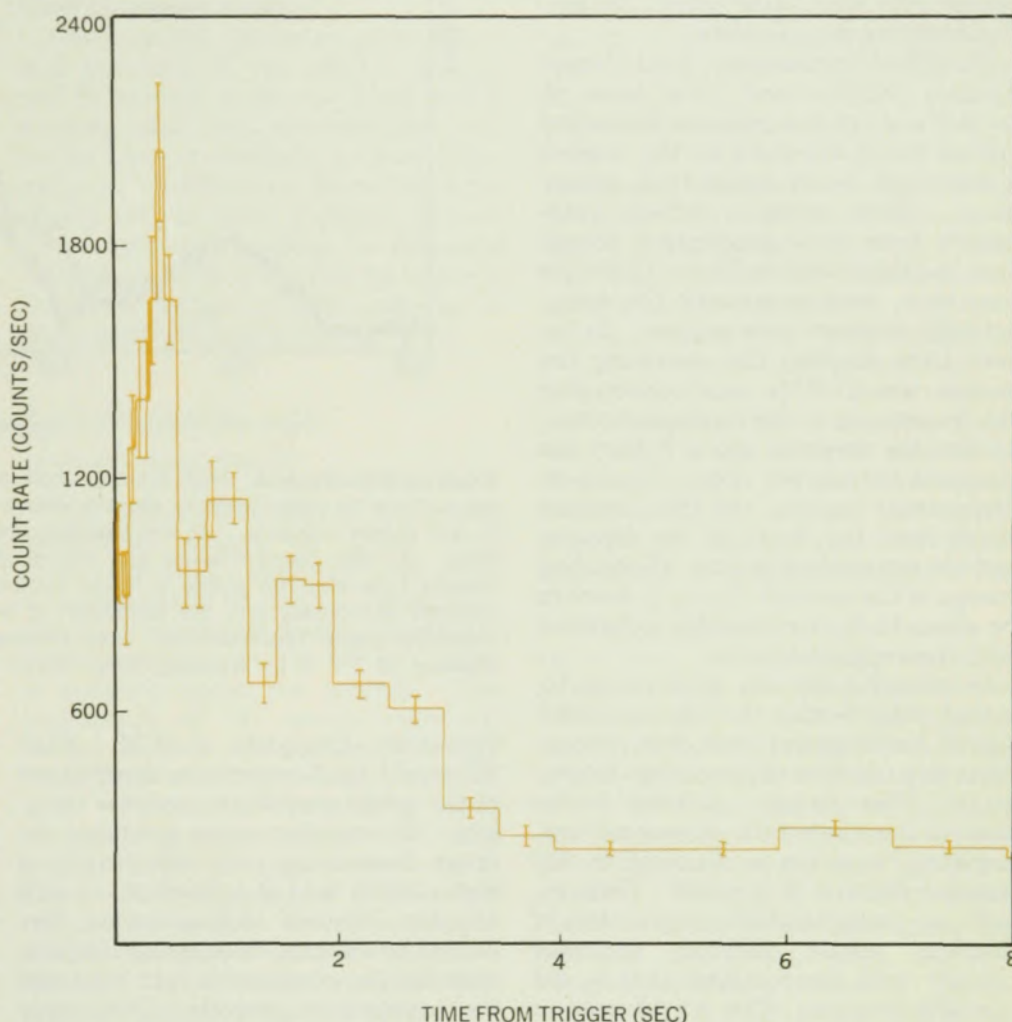
search & discovery

Many models proposed to explain cosmic gamma-ray bursts

The various wavelength regimes of observational astronomy seem to generate their maximum excitement when rapid time-varying phenomena are first observed. For example, radioastronomy gave us pulsars; x-ray astronomy has its flares and pulsating sources. Now it is the turn of gamma-ray astronomy. Ray Klebesadel, Ian Strong and Roy Olson (Los Alamos) recently reported¹ finding 16 short bursts of cosmic gamma radiation in three-years-worth of data from the Vela satellite program.

These observations were quickly confirmed by Thomas Cline and Upendra Desai (Goddard Space Flight Center), who reported their work with OGO and IMP satellites at the 13th International Cosmic Ray Conference held last August at the University of Denver. In October Cline, Desai, Klebesadel and Strong published² details on the energy spectra of some of the bursts, and the same four authors together with William Wheaton, Mel Ulmer, William Baity, Dayton Datlowe, Michael Elcan and Laurence Peterson (University of California, San Diego) published³ data on direction and spectral variability of one burst, obtained from OSO-7. And 40 papers on all aspects of the bursts, including several more observations by European and other US groups, were presented at the Conference on Transient Cosmic Gamma- and X-Ray Sources at Los Alamos in September.

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Cosmic gamma-ray burst, 14 May 1972. This event, shown here in data from the Vela satellite program, was also observed by IMP-6 and OSO-7 spacecraft. Note the multiple peaks near the onset of the burst. (From Ian B. Strong, Los Alamos Scientific Laboratory.)

Electron-hole droplets in germanium and silicon

When a new state of a well-known substance is found, enthusiasm spreads as theorists try to predict its properties and experimenters to verify its existence. This excitement has certainly followed the discovery of a condensed metallic phase in germanium and silicon. The apparent confirmation of conducting electron-hole "droplets" (about 1 micron in size) at temperatures of a few Kelvin is particularly good news for many-body theory because germanium and silicon are probably the best studied of all semiconductors and offer clean, simple systems for testing ideas.

The first reported hint of this conducting phase was J. R. Haynes's (Bell Labs) 1966 discovery¹ of a new lumines-

cence line from silicon subjected to low temperatures and powerful optical excitation. He interpreted the radiation as the decay of biexcitons—neutral molecules consisting of two electron-hole pairs—in analogy with the then well-known decay of one exciton, at higher energies. A few years later V. M. Asnin and A. A. Rogachev (Ioffe Institute, Leningrad) found² a sharp increase in the photoconductivity of germanium as they increased optical pumping power. L. V. Keldysh (Lebedev Institute, Moscow) then proposed³ that the phenomenon producing the jump in conductivity was the transition from a neutral excitonic gas to a metallic liquid. Subsequently the phenomenon

has been studied by several groups in the Soviet Union, most notably that of Ya. Pokrovskii and K. I. Svistanova⁴ (Institute of Radio Engineering and Electronics).

This metallic phase must be more stable than a molecular condensate of excitons under the same conditions. Calculations of the energy of the metallic state in the multivalley semiconductor have been done by William F. Brinkman and T. Maurice Rice (Bell Labs) and by M. Combescot and Philippe Nozières⁵ (Grenoble). P. Vashista, P. Battacharya and K. S. Singwi (Northwestern University) have pointed out⁶ that the correlations in the motions of electrons with holes in the condensed

are to improve this excitation method to make a greater quantity of the condensed phase so that parameters of interest to theorists can be more conveniently studied. And, he notes, if the droplet phenomenon is eventually of technological importance, electrical excitation will be advantageous.

—*Marian S. Rothenberg*

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Fifty-two nations join in Geodynamics Project

The birth of the plate tectonics model of the earth has provided impetus for the Geodynamics Project, an international program under the auspices of the International Council of Scientific Unions. Fifty-two nations are participating in the project, which is planned for the period 1971-79 with the first three years to serve as a planning period.

US participation in the program will be guided by the Geodynamics Committee of the NAS, which has prepared a report with the help of hundreds of scientists and scores of institutions. Federal funding of \$50 million to come primarily from NSF and the US Geological Survey will serve to promote five major objectives:

- ▶ to develop further the basic model of plate tectonics,
- ▶ to test and demonstrate its ability to

explain and predict phenomena,

▶ to determine the degree to which it can be extended, its limitations in scale, in time and in the phenomena it will explain,

▶ to investigate whether apparently unrelated geodynamic phenomena are independent or are in some way related to the model, and

▶ to examine the implications of the findings with regard to basic and applied research.

Geodynamics, the study of the forces and processes in the earth's interior, will be studied under the international program with particular attention paid to the basic mechanism of earth deformations. Information from the study should help to solve economic and societal problems relating to the solid earth by providing answers for issues of interest to federal agencies and mining and petroleum industries.

Cosmic gamma rays

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The stored recordings of data from gamma-ray sensors on board Vela, OGO and IMP satellites, and from x-ray telescopes on OSO-7, contain evidence of occasional bursts of photons in the energy range 150-250 keV, most of duration about ten seconds. The appearance of the events correlates neither in time nor position with any other known astrophysical phenomenon. Theoretical speculation runs through a gamut of models including shock waves in supernovae, stellar flares, collapsing neutron stars, comet capture by neutron stars, and many others. Interest in these bursts, as in the other transient astronomical observations, derives from the clues they could give to an understanding of the mechanism of the highest-energy processes in astrophysics—those associated with the final cataclysmic stages in stellar evolution.

Observations. About 20 gamma-ray bursts have now been identified in searches of records going back to 1967 data, giving an estimated rate of about four events per year over the whole sky. Coincidences among independent satellite observations serve to distinguish "good" data from noise and instrumental effects—only those events seen by two or more satellites simultaneously have been counted. This is all "archaeological" data, as Cline pointed out to *PHYSICS TODAY*. He believes that most of the old data are in now, and only occasional reports of new events are to be expected from currently orbiting satellite instrumentation.

The Vela series of satellites monitors the limited nuclear test-ban treaty of 1963; their sensitivity to short-term photon flashes in the gamma region

would, for example, detect bombs detonated behind the moon. Stirling Colgate (New Mexico Institute of Mining and Technology), a Los Alamos consultant, realized that this system would also be sensitive to gamma bursts that he and others believed would be released by supernovae. However, searches of early Vela data near the times of appearance of supernovae met with no success. Later Vela satellites, those numbered 5A, 5B, 6A and 6B, possess improved instrumentation, which allows short-time-scale phenomena to be more easily dug out of the old records, and much more accurate (± 0.016 sec) event timing. These four spacecraft (in orbit simultaneously) successfully detected 16 events in the period July 1969 to July 1972 that satisfied the criterion of simultaneous observation.

Vela detectors are omnidirectional, but comparison of the arrival times of a burst of photons at each satellite gives enough angular resolution to rule out the sun as the source of most of the observed bursts. There is no energy resolution in Vela data; the energy window for the detectors is 0.2-1.0 MeV (Vela 5) and 0.3-1.5 MeV (Vela 6).

News of these gamma-ray bursts set off a flurry of excitement in other groups holding similar data. At the NASA Goddard Space Flight Center, Cline and Desai were able to find one of the Vela events in their 1969 data from OGO-3 and had already independently extracted six more from the 1971-72 period in data from the IMP-6 satellite. These IMP-6 data provided direct evidence that the signals are produced by gamma rays and not charged particles or neutrons. Detectors on board OGO-3 and IMP-6 are omnidirectional, like the ones on the Vela satellites, but IMP-6 gives energy spectra not available from Vela.

The most complete observation available to date is of a burst that occurred 14 May 1972 (see figure). This one, as well as being observed by three Vela satellites and the IMP-6, fell within the scan path of the x-ray telescopes on board OSO-7. With these instruments (narrow-angle cosmic x-ray telescope and wide-angle solar x-ray telescope operated by the University of California, San Diego) unambiguous determination of the direction of the burst and time-dependent energy spectra were available for the first time.

Five of the events were seen by Uhuru, American Science and Engineering's x-ray satellite, and reported at the Los Alamos meeting by David Koch. Uhuru's collimators, effective in the 2-20 keV range, did not screen out the higher-energy gamma radiation, which produced Compton elec-

trons in the counter. Thus the detectors responded isotropically.

Properties. The bursts show integrated photon fluxes ranging from 10^{-5} erg/cm² to about 5×10^{-4} erg/cm², with a maximum flux intensity up to around 4×10^{-4} erg/cm² sec. Each event consists of a rapid flux increase—attaining its peak in less than 1/10 sec—followed by a slower decay over a period of several seconds. Multiple peaks often occur in the first tenth of a second or so, and the peak width at half height is usually around 1 or 2 sec for the whole event. The energy spectra fit a power law with an intensity going as $1/E$ approximately in the range 10 keV–100 keV, and, between 100 keV and 1 MeV, all six events seen by IMP-6 are consistent with exponential spectra.

Many attempts have been made to correlate these gamma-ray bursts in time and space with other astronomical events and objects. First, because of the Colgate prediction, the Los Alamos group working with Vela data compared the gamma-burst occurrences with supernova observations. There was no correlation; in fact the result was rather an anticorrelation in the sense that no gamma-ray burst accompanied the largest supernova in the period, NGC 5253.

Cline and Desai reported at the Denver conference that they had searched for time correlations with galactic radio-noise spikes, with rapid atmospheric fluorescence increases, with the Cygnus X-3 radio flare, and even with Joseph Weber's published times for gravitational radiation events, with no success.

The direction from which the gamma-ray bursts come gives no clue to their origin either. The event with the best position coordinates, that of 14 May 1972 observed by OSO-7, was not near any known x-ray source, supernova or flare star. None of the Vela events correlated with the positions of known supernovae. The arrival directions appear to be isotropic, although the statistics are as yet too low to be significant. As Klaus Pinkau (Max Planck Institute, Munich) cautiously said when summarizing the known facts for the Denver conference, the data "are consistent with isotropy." Certainly terrestrial and solar-system origins have been ruled out.

Conjectures. As might be expected, theoretical astronomers have had a field day trying to explain these observations, with no general agreement yet. Many theoretical models were aired at the Los Alamos conference; Colgate's view of the explanations put forward so far is that "most of them have an equal probability of being correct." His own model involves supernovae, but the Type II kind found to occur in the rela-

tively young stars of the spiral arms of galaxies rather than Type I supernovae of the older stars on which his earlier predictions had been modeled. He thinks the bursts originate when a shock wave rises to the surface of the star.

One problem with any "supernova" explanation is the lack of correlation with optical observations. The difficulty can be avoided by postulating that the supernovae in question radiate relatively weakly in the visible wavelengths, a theory first put forward by Philip Morrison (MIT); such events are known to observers as "theoretician's supernovae." Colgate acknowledges the variable time structure to be a much more difficult obstacle. Strong suggested that, as half-a-dozen bursts detected by Vela were extremely brief (all much less than 0.5 sec), these might be the best candidates for supernovae.

Reuven Ramaty (Goddard) and Jeffrey Cohen (University of Pennsylvania), and, independently, Remo Ruffini (Princeton), suggest that in a gamma burst we are seeing a "quiet" collapse of a white-dwarf star to become a neutron star without a supernova stage. At Los Alamos, Ramaty suggested that the very hot neutron star cools by radiating as a black body, and the roughly ten-second gamma bursts represent an integration of the black-body radiation during the fast cooling process. If the neutron star "bounces," (collapses, expands and collapses again) this model could account for the multiple-spike structure often observed near the onset of a burst.

Floyd Stecker and Kenneth Frost (Goddard) believe⁴ that the gamma bursts show many of the same properties as do solar x-ray bursts, and therefore suggest that we are seeing evidence of stellar "superflares" from certain high-magnetic-field stars. The high field could have the effect of changing the ratio of x-ray to optical emission, so explaining the lack of correlation with known objects. Obvious candidates for such stars, Stecker told us, are white dwarfs, which are very faint anyway. Not everyone agrees with the premise that gamma bursts and solar x-ray bursts are similar; the energy spectra seem to be somewhat different.

A stellar flare model is also the choice of Philip Morrison and Kenneth Brecher (MIT), but rather than following Stecker and Frost's analogy with solar flares they prefer an approach from fundamentals.

Martin Harwit and Edwin Salpeter (Cornell) reported at the Los Alamos meeting on their model of gamma-burst emission by comet capture. Suppose, they say, that comets are about ten times more abundant around

other stars than they are in the solar system. Suppose further that a comet survives the supernova stage in a star's evolution if it happens to be in a distant part of its orbit at the time. Then occasionally a comet may suffer an orbit perturbation that brings it within a few hundred kilometers of a neutron star. The comet may not be captured straight away; it may swing out again, being broken up into fragments as it goes. The debris would then rain down upon the star the next time the comet comes round, the pieces all reaching the surface within a few seconds producing x rays and gamma rays upon impact. The structures seen in many of the gamma bursts could be the result of individual comet fragments impacting separately.

This comet-and-neutron-star model is one of a more general class of accretion models that have been considered by David Pines and Donald and Fred Lamb (University of Illinois), which Donald Lamb presented at the Los Alamos conference.

These are only a few of the many conjectures currently being discussed. Theoretical astronomers have never been at a loss to invent models when a new kind of data comes along (remember the first pulsars?), and with gamma-ray bursts they appear to have cataclysmic events that provide them with plenty of scope. —JTS

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Canadian role confirmed for 144-inch telescope

The implementation of a joint project to build a 144-inch reflecting telescope on Mauna Kea, Hawaii is closer with the confirmation of Canadian participation by the Canadian government. Also involved in the program is the Centre National de la Recherche Scientifique, which is awaiting French government approval, and the University of Hawaii, which will provide the site, access roads and support facilities.

The site, which is 13 800 feet above sea level, is expected to afford 2800 hours per year of clear viewing. The telescope, which has a primary mirror made out of Cervit, will join an 88-inch reflecting telescope that the University of Hawaii already maintains on the site. □