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THE GOODARD PROGRAM OF GAMMA RAY TRANSIENT ASTRONOMY

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The Goddard Program of Gamma Ray Transient Astronomy*

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Abstract. The Goddard program of gamma ray burst studies is briefly reviewed. The past results, present status and future expectations are outlined regarding our endeavors using experiments on balloons, IMP-6 and -7, OGO-3, ISEE-1 and -3, Helios-2, Solar Maximum Mission, the Einstein Observatory, Solar Polar and the Gamma Ray Observatory, and with the interplanetary gamma ray burst networks, to which some of these spacecraft sensors contribute. Additional emphasis is given to the recent discovery of a new type of gamma ray transient, detected on 1979 March 5.

1. Introduction

Gamma ray burst observations, after seven years of necessary delay since their discovery (Klebesadel et al., 1973), have proceeded from accidental detection to detailed phenomenology. We at Goddard have been fortunate to have been involved in certain of the various high-resolution spectral, temporal and directional studies, outlined herein, that are finally contributing to a clearer picture of gamma ray transients. Gamma ray bursts now appear to form at least one if not several of a variety of possible transient classes, some if not most of which may be linked to neutron star processes because of their spectral qualities. An extragalactic origin for at least one of these is definitely indicated, however, which is clearly distinct in its many unusual features. We believe that these results indicate the need for a great deal of future study. Some of the possible directions to future progress in this discipline are outlined.

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2. Brief Historical Picture

The Goddard program began in 1972 with the initiation of a balloon flight project to search for celestial low-energy γ-ray transients then assumed to be expected from distant supernovae (Colgate, 1968) and thought to be possible from galactic pulsars, black holes and/or sources of x-ray variability. We were also then attempting to search through our existing solar flare monitor records from OGO-1, -3 and -5 and IMP-6 to find any increases of non-solar origin that could be compared with data simultaneously collected with other spacecraft. These solar flare monitors were instrumented for transients of tens of seconds to several minutes duration, and, except for IMP-6, were not continuously monitored at all energy thresholds. Also, magnetospheric variations of all characters were encountered in the Earth orbits of these satellites. The unpromising result was that very few candidate transient events were found. As this program was being outlined at the Lecce Conference on Supernovae and Supernova Remnants (Cline and Desai, 1973a), we heard of the Los Alamos discovery of gamma ray bursts (Klebesadel et al., 1973). (In retrospect, given the present status of the 1979 March 5 event, supernova remnants were not the wrong place to begin!) We soon found that several of the Vela events of 1971-2 were among our candidate list and several more were also concealed in the OGO/IMP data as well. Thus, our reports, confirming the validity of the Vela events and making the first spectral measurements of gamma-ray bursts, were circumstantially possible immediately (Cline and Desai, 1973b; Cline et al., 1973). Unfortunately, there was no overlap on the OGO-1 -3, -5 or IMP-6 coverage throughout the 1964 to 1972 time period. However, one of the events in our candidate list that we had notified W. Wheaton and M. Ulmer about, that was also in the Vela list, was found in the OSO-7 data. Because of the directionality of the OSO-7 telescope, this provided the first confirmation of a Vela-derived event direction (a fairly significant result at the time, given the nature of the triangulation scheme then employed using data from the Earth-orbiting Vela spacecraft) and it also extended the range of the spectral observations to the region from 20 to 100 keV (Wheaton et al., 1973).

The IMP-7 satellite had been also instrumented with a much earlier designed but slightly improved solar flare monitor, basically similar to the IMP-6 sensor. Within a few months this experiment produced additional spectral data on a number of events, all of which involved coarse energy resolution and time averaging so slow that only all-event averages were obtained (Cline and Desai, 1975a). The intriguing result, nevertheless, was that the event-average spectra were all mutually similar and similar to the one high statistical accuracy event spectrum obtained with Apollo-16 (Metzger et al., 1974; Trombka et al., 1974). As we can now infer, there is considerable second-order variability with time and there do eixst nuclear and annihilation lines in gamma-ray transient spectra (Mazets et al.; Teegarden and Cline; in these proceedings). The need for a second-generation study of the correlation of spectral similarity or variability with extent of line contribution is now indicated. The OGO/IMP solar flare instrumentation provided neither the time structure information on the millisecond to second scale, useful for gamma ray bursts, nor additional directional results. However, the IMP-7 results in the 1973-1975 period were of sufficient sensitivity to extend the range of the size spectrum; this provided evidence that the Vela turn-over was instrumental, and that the -1.5 index power law, expected from an undefinitely extended source volume, was not yet violated (Cline and Desai, 1975).

Our 1973 data, like all other observations of that time period, were accidentally obtained in the course of making other studies. However, the similarity of these phenomena to those contemplated in our initial transient program naturally prompted us to devote our full attention here. We presented an outline to NASA, attended and supported by W. D. Evans of LASL, indicating the scientific value of gamma ray burst studies and indicating the nonavailability of space opportunities; we suggested that proposals for small experiments be considered for interplanetary spacecraft of entirely differing scientific objectives and that alterations, for transient detection, of other experiments under development at the time be entertained. The modification of the GSFC cosmic ray experiment on Helios-2, GSFC-instrumented modifications of the Max Planck cosmic ray experiments on ISEE-1 and -3, LASL-instrumented changes of the UC-Berkeley experiment on ISEE-3, and changes in the UCSD experiment on HEAO-1 were eventually undertaken; also, LASL placed an experiment on Pioneer Venus Orbiter.

The 1974 balloon flight of a large scintillator, planned earlier as a search for transient activity in the all-sky gamma ray flux, was undertaken. It showed variability, but indicated no events clearly identifiable as Vela-type bursts. The upper limit to the small-event size spectrum was also entirely consistent with an extrapolation of the -1.5 index power law portion of the Vela size spectrum. The following year we conducted the simultaneous exposure of two balloon-borne instruments, separated by several hundred miles in order to avoid strictly local effects of possible magnetospheric origin. To our knowledge, this was the only attempted and/or successful dual balloon flight of that kind; its results were too meager, and required too much good fortune to justify continuing the same program. A wide variety of fluctuations were observed, but showed only an effect of temporally associated variations, and indicated none that were actually simultaneous in time and outside statistically expected background fluctuations. Again, the small-event size spectrum upper limit was not inconsistent with a -1.5 index power law extrapolation (Cline et al., 1975b). A recent study with a more sensitive detector (Fishman et al., 1978) is the first suggestion of a small-event turn-over in the size spectrum. The need for continuing this kind of study is evident in terms of the possibility that a low-latitude or southern hemisphere exposure may provide a galactic plane anisotropy of small events.

3. Helios-2 Observations

At the time of the discovery of gamma-ray bursts, it was apparent that the opportunities were limited for obtaining high-resolution source positions by the triangulation technique with interplanetary probes. These could provide the very long base lines needed for great directional accuracy, but all journeying to the outer planets employ on-board power sources which generate intense gamma-ray backgrounds. The only then available benign platform was the solar orbiter Helios-2. It could be modified to include a small piggy-back instrument, added to the NASA/Goddard cosmic-ray detector, provided the weight was ≈ 1 kg. An instrument capable of detecting and of measuring the profiles of the known variety of bursts was accordingly created. Launched on 15 January 1976 into an orbit of 0.29 AU perihelion and 1 AU aphelion, it has worked for over 4 years. This instrument was the first to operate in space that was designed specifically to study cosmic gamma-ray bursts. It is also the first burst detector put into interplanetary space for the purpose of obtaining high-resolution burst source locations by use of its long baseline for time-of-flight source triangulation. It is the only sensor yet flown that can detect events at a detector-to-Earth distance of ≈ 2 AU; in fact, one event, in July 1977, was recorded at a distance of 1.98 AU.

The Helios-2 sensor is a 3.8-cm by 1.9-cm CsI crystal with a command-adjustable threshold usually set at ≈ 100 keV. Three commandable trigger modes are used in order to accommodate widely varying intensity risetimes, integrating for ≈ 4, 31.25 and 250 milliseconds. These are adjusted in flight at levels that are as sensitive as are commensurate with tolerable background rates. (To date, only the 1979 March 5 event triggered the 4ms mode.) An occurrence of any trigger at a time defined as 'T_0' causes the count rates to be stored in three memories on ≈ 4, 31 and 250 ms time scales following T_0 and to be held in three circulating memories prior to T_0.

In this manner, precursor information is made available, providing continuous time histories throughout each event. As a result, time histories of 128 seconds duration with 0.25 second resolution, 16 seconds with 31-ms resolution, and 2 seconds with 4-ms resolution are provided, nested about the trigger time. Although the high-resolution temporal definition is obtained for only a portion of a long event, in practice fast time fluctuations within that time window can be identified and compared with the profiles from other instruments to obtain accurate time differences. The Helios-2 event trigger time initializes the gamma-ray burst time history. The trigger time on the spacecraft is determined by knowing the ground-received time and subtracting the down-link photon travel time as determined from sun-centered orbit calculations. The accuracy of this process varies from a few milliseconds to several tens of milliseconds depending on whether the spacecraft, at the time of the event, was transmitting data or storing it for later transmission. The accuracy of the Helios-2 gamma ray burst timing process has been checked and calibrated often both with artificial (ground-commanded) triggers and by using the event profile roll modulation; in addition, the 5 March 1979 event itself provided the first naturally occurring 1-millisecond calibration point for mutual consistency.

The first six events were on 28 January, 22 March, 7 April and 19 April 1976, and on 10 March and 8 July 1977. Time profile comparisons with the Vela system are not capable of the accuracy obtained with linear profile sensors, since the Vela temporal profiles are obtained on a time base that expands geometrically from 16ms to 16 seconds. This limitation generally resulted in ~ 100-ms overall comparison accuracy, when taking into account all effects. The Helios-2 time history for the 1977 July event was obtained at nearly 2 AU from the Earth, behind the Sun, and was read out later at a time when low bit-rate telemetry was being used; its accuracy is therefore less than the others.

The 28 January 1976 gamma-ray burst, the first confirmed Helios-2 event, was also observed with the X-ray sky survey instrument on the Ariel-5 satellite, as well as with Vela-5A and -6A. This circumstance made possible a significant reduction in the size of the source region, giving the first 'small' source field, ~ 1 sq. degree (Cline et al., 1979a). This area contains neither any steady x-ray source as scanned by HEAO-A nor any previously catalogued "interesting" objects: x-ray, radio or infrared sources, x-ray transients, quasars, seyferts, globular clusters, flare stars, pulsars, white dwarfs or high energy gamma-ray sources. The source rings of some of the other events were limited by the detection or absence of detection, when it would have been possible, with OSO-8 and SAS-3 to above- or below- horizon positions. The resulting source fields, shown in Figure 1, are also all inconsistent with the directions of all known celestial x-ray objects, x-ray bursters and high-energy gamma-ray source regions. It was concluded that gamma-ray burst source objects therefore form a distinct class from all lower energy x-ray or higher energy γ-ray emitters (Cline et al., 1979b).

Another result of the observations of these events was that the intensities and temporal profiles agreed over distances of up to 0.7 AU, taking into account the projected width, $R \cos(90-\theta)$, of the wavefront. This observation ruled out nearby, solar system origin models and the relativistic dust grain model which predicted narrow (≈ 0.01-AU in extent) focussed beams of gamma rays originating within the distant solar system (Grindlay and Fazio, 1974). Also, the source regions, as shown in Figure 1, are not concentrated at low galactic latitude, consistent with earlier indications of the absence of an apparent galactic source distribution (Strong and Klebesadel, 1974).

One curious result, however, was that the relatively small source position of the 76 January 28 event was consistent with that of a 20-minute gamma-ray transient on 10 June 1974, which exhibited line structure at 0.41, 1.79, 2.22 and 5.95 MeV (Jacobson et al., 1978). The instrument field of view for that observation is over 20° wide, so that the association of the gamma-ray line transient with the gamma-ray burst could be entirely accidental. However in retrospect (now that we know that gamma ray bursts also exhibit nuclear and annihilation lines with the same redshift as in the balloon transient), this accident was, in a sense, prophetic. It is reasonable to assume that most classes of gamma-ray transients are physically related both in terms of the necessary requirements of pair production in the electromagnetically dense source regions and in terms of the ≈ 20 per cent redshift, given a neutron star origin process.

Several other events observed with Helios-2, also detected in 1977 with the Prognoz-6 satellite, provided additional source location arcs (Estulin et al., 1979), which resulted in positions of slightly improved quality to the 1976-7 Helios-Vela source fields. Again, no candidate source objects were within these areas. Other 1976-1977 Helios-2 events were also detected with earth-orbiters including the Solrad and HEAO satellites (unpublished). The late 1978-1979 Helios-2 events were all observed with the other spacecraft participating in the interplanetary gamma ray burst network; these are discussed in the following sections.

4. The 1979 March 5 Transient

The interplanetary gamma ray burst sensor network was completed when Helios-2, launched in January 1976, and Pioneer Venus Orbiter, launched in May 1978, were accompanied in space by the launches of ISEE-3 and of Venera-11 and -12 in August 1978. Following the detection of a number of typical gamma ray bursts throughout the autumn and winter of 1978-9, an unusual event was observed on March 5. In our ISEE-3 readouts, it immediately appeared to be so unusual that we at Goddard wondered whether it might be an instrumental effect, until its detection was soon confirmed with other spacecraft. Some of the early timing data were not inconsistent with the possibility of an unusually short solar flare transient, but correct timing determinations soon proved this incorrect. By late April, it was appreciated that a uniquely uncommon event had been observed and that its source direction was consistent with the supernova remnant N49 in the LMC, although several more months of effort were required before we were all ready to submit for publication the description of the burst (Cline et al., 1980) and of its direction (Evans et al., 1980). In our descriptive paper we claimed that this event was so atypical that it could not be classified as a gamma ray burst, and the source location, in another galaxy, was so unexpected that this result in itself was either suspect or else indicated that an entirely new and inexplicable phenomenon had been observed.

The overall picture of the March 5 transient time history is shown in Figure 2, illustrating the initial high-intensity spike and the subsequent low-intensity oscillations. Figure 3 shows the details of the rise to intensity maximum within one millisecond, the extent and shape of the initial pulse, and the first 22 8-second oscillations arranged vertically to exhibit the pulse structure in the decay mode (Cline et al., 1980a). The data illustrated in these figures are from Goddard experiments on ISEE-3 and Helios-2; the ISEE-3 scintillator, similar to that on Helios-2 is one of three Goddard sensors on that spacecraft (Cline et al., 1978). This event was also observed with at least eleven other detectors, including the LASL instruments on Pioneer Venus Orbiter, ISEE-3 and the Vela system (Evans et al., 1979), the French-Soviet experiments on Venera-11 and -12 (Barat et al., 1979), all of which are involved in the interplanetary network, two separate sensors on Venera-11 and -12 (Mazets et al., 1979), SAS-3 (G. Clark, pri. comm.) and HEAO-B (M. Weisskoph, pri. comm.). There is no known conflict of measurement between any of these.

The unusual properties of the time history of this event are listed as follows. First, the maximum intensity is > several $\times 10^{-3}$ erg cm^{-2}sec^{-1}, an unsure and probably minimum value due both to the unknown fluxes below the $\geq$ 50 keV thresholds and to the problems of pulse pile-up effects at these energies. The intensity above about 100 keV is thus at least one order of magnitude greater than that of any gamma-ray burst observed during the ten years of essentially continuous monitoring with the Vela system (Klebesadel, pri. comm.). Second, the rise time is short compared with the 1-millisecond temporal resolution capabilities of the ISEE-C instrument: a two order of magnitude increase in less than one millisecond implies a time constant of less than 200 microseconds. This is about 100 times shorter a characteristic time than previously measured bursts exhibited, or can be limited to, due to the lack of fast timing circuitry before 1976. Third, the high-intensity portion is exceptionally brief; with a ≈ 120-millisecond width, it is shorter than over 95 percent of all earlier events detected, although similar in extent to two or three low-intensity events. This initial pulse shape is regular and smooth, with little modulation, unlike typical gamma ray bursts which are generally highly structured.

The maximum flux occurs ≈ 20 ms after the <1 msec onset. After ≈ 120 ms there is an abrupt transition to a decay portion of ≈ 35 ms time constant. This fast decay from high intensity is followed by a long, regularly pulsing decay at a much lower intensity. It is not known whether gamma ray bursts in general or the special class of low intensity, narrow events also have this property since, relative to their maximum intensity, such a low level post-burst decay feature is below detectability. This long duration decay phase contains a monotonic average-intensity decay with a time constant of about 50 seconds superimposed with a regular pulsing character of 8 seconds period. This 8-second feature maintains its compound shape for over 20 cycles; this clear periodicity has never been suggested in any other gamma ray transient. The great intensity, fast rise time, narrow and featureless initial spike, and the regular > 22-interval 8-second oscillation with its compound pulse shape all argue against its classification as a typical gamma-ray burst (Cline et al., 1980).

The spectral features of this event are also of great interest. Unfortunately the Goddard high-resolution germanium gamma-ray spectrometer on ISEE-3 (Teegarden and Cline, 1980; these Proceedings) was not usable for the March 5 event; however, the results of the Leningrad group with Venera-11 and -12 (Mazets et al., 1979; also these Proceedings) provide a remarkable spectrum with a much steeper than typical continuum and a ≈ 420-keV line. The continuum spectrum in itself is another atypical feature of this event, unlike the usual hard spectrum with its 150-keV exponential characteristic in the 100-400 keV region (Cline and Desai, 1975). The 420-keV line is an important feature of this event, but as Mazets' other events (these Proceedings) indicate, and as the ISEE-3 high resolution spectrometer results show (Teegarden and Cline, these Proceedings), this line is now recognized as not only not atypical but more likely an expected component in most gamma ray transients. Another unique contribution of the Leningrad group is the detection of three additional small transients, observed with Venera-11 and -12, following the March 5 event by ≈0.6, 29 and 50 days delay. The intensities were ≈ 3, 1 and 0.5 percent that of the peak March 5 intensity, respectively (Golenetskii et al., 1979). A very rough inverse proportionality is evident in that the greater the relative delay from one event to the next the smaller the relative intensity. The intensity profiles of these are generally wider than that of the initial March 5 spike, but, at up to 1 second wide, they are more similar to it than to typical, Vela-type gamma-ray bursts. The directions as deduced from Venera-11 and -12 data alone are consistent with that of the March 5 event. Only one of these bursts was observed with only Helios-2 in the gamma ray network; however, given their sequential and temporal connection to the March 5 event, and given that the initial March 6 event error box of several square degrees is consistent with that for the March 5 event, the supposition of their common source seems assured. This result is another curious property of the March 5 event: no gamma-ray bursts prior to 1979 have ever been shown to originate from a common source, although one more series of three events in early 1979 was also found to be consistent with having a single source direction (Mazets et al., 1979).

The source direction of the March 5 transient is that of N49, a well-known supernova remnant in the Large Magellanic Cloud (Evans et al., 1980). This source identification is the first successful application of the high directional resolution obtainable with the interplanetary gamma ray burst network (see Figure 4). The distance to N49 is 55 kpc, over two orders of magnitude greater than the distance of typical gamma ray bursts assumed from their isotopic source distribution and from considerations of photon self absorption in the high density region near the source (Cavallo and Rees, 1975; Schmidt, 1978). Also, the March 5 transient is, by at least a factor of 10, the most intense event observed; thus, the absolute source intensity would be $> 10^5$ as great as what was expected, i.e., between several x 10^{44} and 10^{45} erg sec^{-1} at peak intensity. The presence of a clearly identifiable source candidate object within several tens of seconds of arc from the source field center, unlike the case for typical gamma-ray bursts, and the requirement of an intrinsic source intensity that is a great factor higher than previously assumed possible are two more unique properties of this event, in addition to the descriptive features that are amply atypical in themselves. Although one possible approach is to dismiss the N49 location as a (highly unlikely) coincidence, our position has been and is to suggest that all these features mutually reinforce the need for a unique interpretation with N49 as source (Cline, 1980).

Clearly, if the interplanetary network had not created in time to detect this once-per-decade event, a lower resolution source field of perhaps several square degrees (such as from the Leningrad sensors on the Veneras or from the Vela network) would not have provided the link to N49. Given that the spectrum contains a feature that can be identified as an annihilation line with the redshift appropriate for a neutron star, as do also several typical gamma ray bursts (Mazets et al.; Teegarden and Cline; these Proceedings) the distinction is that this event can be associated with a supernova remnant, rather than an isolated neutron star. The density of bare neutron stars has been estimated to be considerable (Ostriker et al., 1970) and these objects may ultimately therefore be found to relate to typical gamma ray bursts. If N49, within the LMC, is the source of the March 5 event, why is there not an event distribution containing even brighter, similar transients from closer objects within our galaxy and extending to include hundreds more that would be above detectable thresholds within the last few years? (Even if the event originated from a relatively nearby object, one would expect that the size spectrum would contain more than the three "fast" Vela events catalogued in the last decade (Klebesadel, pri. comm.) that are of < 0.3 second duration). Both these anomalies can be made to fit the construct that a supernova remnant can produce a transient of the March 5 class approximately once, or rarely, if ever, during its lifetime. Then the rate of occurrence of these events is the same as the rate of occurrence of supernova, and the detection of only one in ten years from our galaxy and its satellites is entirely self consistent. This assumption can be verified with the large-area MSFC sensor to be flown on the Gamma Ray Observatory, which is of adequate sensitivity to detect similar short-duration events from the Virgo supercluster (Fishman et al., these Proceedings).

One conceivable explanation within this framework is to assume that after sufficient time has elapsed for the condensed object to catch up to its remnant shell, which cannot have slowed down sufficiently for this to occur until it is 'relatively' old (N49 is perhaps > 10^4 years; Mathewson and Clarke, 1975), then the density of matter becomes adequate to permit gradual accretion to significant proportions for an internal transition in the neutron star to be ultimately required. Consistent with this suggestion is the amount of mass-energy in the March 5 event at N49, given reasonable assumptions as to the conversion efficiency factor, the density of matter in the shell and the matter accumulation time (R. Mushotzky and P. Meszaros, pri. comm). Another consistent feature is that the time constant for dissipation of internal, gravitational energy in a neutron star of 1.4 $M_\odot$ is between 80 and 200 milliseconds (Thorne, 1969; Detweiler, 1975). entirely consistent with the intense portion of the March 5 event. Details of these and other speculations need specific attention before any model for the source process can be considered to be an explanation, but their consistency aids the hypothesis of a distinction between typical gamma ray bursts from presumed nearby sources and transients from distant supernova remnants.

Considering the physical properties of the observable surface of the emission, rather than the parent emission process within, recent calculations by Ramaty and coworkers (previewed in these Proceedings) indicate that the self-absorption in the incredibly high photon density near the source is not only consistent with the inferred intrinsic intensity but in fact both requires the presence of an annihilation line and fits the observed shapes of the red-shifted line component and the high-intensity continuum radiation. Given these results, and a release from the supposition that the source intensity cannot fit the 55 kpc distance to N49, we are no longer constrained to consider the N49 source identification as unlikely, at the least. In fact, several other correlations can be inferred. For example, the iron gamma ray line observed in the 1978 November 19 gamma ray burst (Teegarden and Cline, 1980) could not have been detected in the March 5 event since the photon atmosphere above the neutron star in this case is too thick. This result gives hints of what the phenomenology of gamma ray spectroscopy in gamma ray transients may promise, considering the variety of recent data outlined at this meeting and recalling the anomalous slow event of 10 June 1974 (Jacobson et al., 1978).

5. High Directional Resolution Studies

Several gamma-ray bursts that have been detected with the interplanetary gamma-ray burst network, in addition to the unusual March 5 transient, have source directions that are being currently determined to high precision. It is outside the scope of this paper, regarding the Goddard program, to report on the findings of the network consortium; these results are being published by the combined GSFC, LASL, CERS and SRI authorships. It is expected that some of the initial reports will be in print approximately in parallel with these Proceedings, including a source field for the 1979 March 5 transient of area less than 3 percent that originally defined, and, it is hoped, the definitive studies of the 19 and 24 November 1978, 13 January, 14 April and 25 May 1979 events. At the time of writing, none of the high-precision (≤ 5-arc minute) source fields have yet been associated with candidate (point) source objects. In fact, the first gamma-ray burst source region to be accurately located, that of 19 November 1978, has recently been optically scrutinized, as has that of the N49 region (Fishman et al., these Proceedings). They report that no objects other than main-sequence and therefore uninteresting stars have been found in the November 19 field, and that the stars in the March 5 field are also at the distance of the LMC. It is also the case that our computerized searches through catalogs of the source locations of x-ray transients, pulsars, supernova remnants, or other possible candidates have produced no success, as yet, for the 1978-9 events of typical burst character.

The Einstein Observatory (HEAO-B) is presently in orbit, functioning as the first high-sensitivity, high-resolution focussing x-ray telescope in history; this observatory is programmable to study sources of interest to arc-second resolution, and has the sensitivity to observe sources many orders of magnitude weaker than previously discernible. A guest investigator program exists to accommodate research projects of a variety of purposes, in complete analogy to those of traditional, ground-based astronomical observations. Our consortium proposal to survey the source regions of accurately located gamma ray bursts was recently accepted. The consortium members are presently determining the maximum number of high-precision source fields for scheduling in that program before the orbit lifetime of the HEAO-B spacecraft is terminated by re-entry. In addition, a reinvestigation of the N49 remnant structure is planned. An observation of this object was routinely carried out within one month of the March 5 transient (Helfand and Long, 1979; also, see Figure 4). It is planned to observe this region at least once more so as to investigate the possibility of any measureable effect of the blast wave on the shell structure, or to investigate whether some other clue in this mystery may be detectable.

The gamma ray burst network, it is hoped, will ultimately provide several tens of accurately triangulated source fields, as well as many time histories, spectra and related measurables. At the time of writing, the Goddard sensors include a small ISEE-1 solid-state (Cd-Te) array, a Goddard-MPI-Maryland ISEE-3 scintillator sensor (also, see Teegarden's paper on these Proceedings for the ISEE-3 Goddard high-resolution germanium γ-ray spectrometer report), and the Helios-2 solar orbiter scintillator sensor. Recently, the Solar Maximum Mission spacecraft was successfully launched. This satellite includes another Goddard gamma-ray burst sensor, but with continuous, high-temporal resolution gamma-ray transient sensitivity; it will therefore augment the interplanetary network with another near-Earth vertex. (In addition, if a burst source is near the sun's direction, a high temporal resolution spectroscopic study of the burst will be made in the collimated, memory-store, "solar flare" mode of operation. This occurrence may not be unlikely: an OSO experiment (Wheaton et al., 1973) and the HEAO-A γ-ray experiment (F. Knight and J. Matteson, pri. comm.) each detected one event within their collimated field of view). The continuous, high time resolution background monitoring may also make possible a search for more transient γ-ray anomalies, such as the 20-minute effect observed with a balloon flight in 1974 (Jacobson et al., 1978).

The next planned interplanetary network of gamma ray burst sensors designed to explore both cosmic transients and solar variations is the International Solar

Polar Mission. The Goddard/U. of California sensor on the NASA spacecraft and the Toulouse/Max-Planck sensor on the ESA spacecraft will be placed several astronomical units of distance apart, above and below the ecliptic plane, so as to triangulate burst source directions and study solar flare x-ray directivities and anisotropies in detail. Another, near-Earth sensor will be needed to complete the system; depending on the chronology, the Gamma Ray Observatory (GRO) or other spacecraft may fill this role. The expected resolution is slightly superior to the best that the present network can provide: a 3-AU x 2-AU x 2-AU triangle with 5 millisecond temporal resolution would improve on the existing network by up to a factor of ten in direction resolution. In addition, if GRO is simultaneously functional, then the additional advantage occurs of providing source positions for transients that are studied with high spectroscopic resolution by GRO.

6. High Spectroscopic Resolution Studies

At the present time, the 420-keV feature in the March 1979 transient (Mazets, these Proceedings), the similar feature and the nuclear iron line in the November 1979 burst (Teegarden and Cline, these Proceedings) and the family of lines with similar redshifts in the slow transient of June 10, 1974 (Jacobson et al., 1978) indicate that these three distinctly different kinds of gamma ray transients may each originate in neutron star processes. The possibilities for continued observation of the spectral details of gamma ray transients are still promising, despite the malfunction of the high resolution ISEE-3 burst spectrometer. The Venera-11 and -12 sensors (E. Mazets, Leningrad, principal investigator) are still functioning, and both the SMM flare experiment (K. Frost, Goddard, principal investigator) and the HEAO-C gamma ray spectrometer (A. Jacobson, JPL, principal investigator) have been recently launched. In addition, a large area, high resolution gamma ray spectrometer has been selected for the Gamma Ray Observatory. This experiment will be a collaborative effort between the University of California at San Diego (L. Peterson, principal investigator), JPL, Goddard, CESR-Toulouse, CEN-Saclay and Bell Laboratories/Sandia Corporation. Although it also is a collimated telescope, like the HEAO-C and SMM sensors, its sensitivity and resolution, coupled with a large memory for high counting rate capabilities, give it truly second-generation experiment status for study of the gamma ray transients that happen to have source direction in its comparatively wide field of view. The uncollimated large area experiment on the same spacecraft (J. Fishman, MSFC, principal investigator) will provide both coarse directional resolution for all-sky viewing and additional counting rate capability to complement the UCSD spectrometer, as well as additional medium resolution spectral capabilities and extended, small event sensitivity (see Fishman, these Proceedings). The total complement of all these experiments should provide continuing and improved gamma ray transient measurements and, of course, may yield additional unexpected results as well. However, like so many of the experiments of the early 1970's, except for the MSFC instrumentation, none of the HEAO, SMM or GRO experiments were designed with gamma ray transient studies in mind as the central objectives. The sum total of new results presented by the attendees at this Conference surely indicate that directional and spectral gamma ray transient studies are maturing to the point where definitive studies will soon be justified. Perhaps, after not too many years, we may meet again with specific research programs having the systematic, high-resolution spectroscopic study of gamma ray transients as the primary scientific goal.

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References

Barat, S., Chambon, G., Hurley, K., Niel, M., Vedrenne, G., Estulin, I. V., Kurt, V. G., and Zenchenko, V. M. 1979, Astron. Astrophys. 79, L24.

Cavallo, G., Rees, M. J. 1978, Mon. Not. R. Astron. Soc. 183, 359.

Cline, T. L., and Desai, U. D. 1973a, (Proceedings of the International Conference on Supernova, Leece, Italy) "Supernovae and Supernova Remnants", Astrophys. and Space Sci. Library 45, Leidel Publ.

Cline, T. L., and Desai, U. D. 1973b, Proceedings of the 13th International Conference on Cosmic Rays, Denver, Colorado, 1, 80.

Cline, T. L., Desai, U. D., Klebesadel, R. W. and Strong, I. B. 1973, Ap. J. (Letters) 185, L1.

Cline, T. L., and Desai, U. D. 1975a, Ap. J. (Letters) 196, L43.

Cline, T. L., and Desai, U. D. 1975b, (Proceedings of the COSPAR Conference, Varna, Bulgaria) Astrophys. and Space Sci. 42, 17.

Cline, T. L., Desai, U. D., Schmidt, W. K. H., and Teegarden, B. J. 1977, Nature 266, 694.

Cline, T. L., Gloeckler, G., Hovestadt, D., and Teegarden, B. J. 1978, IEEE Trans., GE-16, 173.

Cline, T. L., Desai, U. D., Pizzichini, G., Spizzichino, A., Trainor, J., Klebesadel, R., Ricketts, M., and Helmken, H. 1979a, Ap. J. (Letters) 229, L47.

Cline, T. L., Desai, U. D., Pizzichini, G., Spizzichino, A., Trainor, J. H., Klebesadel, R. W., and Helmken, H. 1979b, Ap. J. (Letters) 232, L1.

Cline, T. L. 1980, accepted for publication in Comments on Astrophysics; also, NASA Tech. Mem 805 (1979).

Cline, T. L., Desai, U. D., Pizzichini, G., Teegarden, B. J., Evans, W. D., Klebesadel, R. W., Laros, J. G., Hurley, K., Niel, M., Vedrenne, G., Estulin, I. V., Kuznetsov, A. V., Zenchenko, V. M., Hovestadt, D., and Clocekler, G. 1980, to be published in Ap. J. (Letters); also NASA Tech. Mem. 80570 (1979).

Colgate, S. A. 1968, Canadian J. Phys. 46, 5476.

Datweiler, S. L. 1975, Ap. J. 197, 203.

Estulin, I. V., Cline, T. L., Vedrenne, G., Kuznetsov, A. V., Mersov, G. A., Niel, M., Novak, B. L., and Hurley, K. 1979, Astron. Zhurnal-Pis'ma, 5, No. 11.

Evans, W. D., Klebesadel, R. W., Laros, J. G., Cline, T. L., Desai, U. D., Teegarden, B., Pizzichini, G., Margon, B., Hurley, K., Niel, M., Vedrenne, G., Estulin, I. V., and Mazets, E. P. 1979, Proceedings of the 16th International Conference on Cosmic Rays, Kyoto, Japan, Paper # OG 5-6.

Evans, W. D., Klebesadel, R. W., Laros, J. G., Cline, T. L., Desai, U. D., Pizzichini, G., Teegarden, B. J., Hurley, K. Niel, M., Vedrenne, G., Estulin, I. V., Kuznetsov, A. V., Zenchenko, V. M. 1980, to be publ. in Ap. J. (Letters).

Fishman, G. J., Meegan, C. A., Watts, J. W., Jr., and Derrickson, J. H. 1978, Ap. J. (Letters) 223, L13.

Fishman, G. J. 1980; these Proceedings.

Golenetskii, S. V., Mazets, E. P., Il'inskii, V. N., and Gur'yan, Yu. A., to be published in Pis'ma v. Astron. Zhurnal.

Helfand, D. J. and Long, K. S. 1979, Nature 282, 589.

Jacobson, A. S., Ling, J. C., Mahoney, W. A., and Willett, J. B. 1978, Gamma Ray Spectroscopy in Astrophysics, ed. T. L. Cline and R. Ramaty, NASA Tech. Mem. 79619, (1978), 228.

Klebesadel, R. W., Strong, I. B. and Olson, R. A. 1973, Ap. J. (Letters) 182, L85.

Klebesadel, R. W., and Strong, I. B. 1976, Ap. Space Sci. 42, 1.

Mathewson, D. S., and Clarke, J. M. 1975, Ap. J. 179, 89.

Mazets, E. P., Golenetskii, S. V., Il'inskii, V. N., Aptekar, R. L., and Guryan, Yu. A. 1979, Nature 282, 587.

Mazets, E. P. 1980; these Proceedings

Metzger, A. E., Parker, R. H., Gilman, D., Peterson, L. E., and Trombka, J. I. 1974, Ap. J. (Letters) 194, L19.

Ostriker, J. P., Rees, M. J., and Silk, J. 1970, Astrophys. Lett. 6, 179.

Schmidt, W. K. H. 1978, Nature 271, 525.

Strong, I. B. and Klebesadel, R. W. 1975, Nature 251, 396.

Teegarden, B. J. and Cline, T. L. 1980, to be published in Ap. J. (Letters); NASA Tech. Mem 80575 (1979).

Teegarden, B. J. 1980; these Proceedings.

Thorne, K. S. 1969, Ap. J. 158, 1.

Trombka, J. I., Eller, E. L., Schmadebeck, R. L., Adler, I., Metzger, A. E., Gilman, D., Gorenstein, P., and Bjorkholm, P. 1974, Ap. J. (Letters) 194, L27.

Wheaton, W. A., Ulmer, M. P., Baity, W. A., Datlowe, D. W., Elcan, M. J., Peterson, L. E., Klebesadel, R. W., Strong, I. B., Cline, T. L., and Desai, U. D. 1973, Ap. J. (Letters) 185, L57.

Figure 1 - The source fields of the six early Helios-2 gamma-ray bursts, shown in a galactic coordinate, equal solid angle representation. In spite of the proximity of several of these bands to the galactic plane, there is no consistency with the directions of any other x-ray or gamma-ray source objects, or with the positions of known supernova remnants or pulsars.

Figure 2 - The time history of the 1979 March 5 transient as observed with the GSFC-MPI-UM sensor on the ISEE-3 space probe. Following the extremely high-intensity spike of very brief duration, there are regularly periodic features of compound structure that occur every 8 seconds with monotonically decreasing intensity.

Figure 3a - The onset of the high intensity portion of the 1979 March 5 transient. A time constant of less than 0.2 millisecond is inferred from the increase of two orders of magnitude from near background to essentially full intensity within a resolution time of 1 millisecond. (In this instrument the time to accumulate 64 photons is recorded to 1 msec accuracy; the first several readings are in fact 1-msec and 2-msec accumulations). This $\lesssim$ 1 msec full rise in the onset shape is seen with each of several independently instrumented sensors on ISEE-3.

Figure 3b - Details of the high intensity portion of the 1979 March 5 transient, as observed with the Helios-2 sensor. A maximum slightly above the initial rise is observed about 20 msec after onset. The intensity decay following maximum is roughly monotonic, but appears to have an initial $\approx$ 100 msec interval obeying a $\approx$ 150 msec exponential time constant, followed by a steeper slope of $\approx$ 35 msec time constant.

Figure 3c - The first 22 cycles of the March 5 event, plotted on an 8.00-second per period basis, with the event onset chosen as zero of time, folded with an increasing number of cycles per plot. The initially larger peak appears statistically consistent with a position at constant phase to within 1 second, yielding an average period of 8.00 ±0.05 seconds. A varying, initially smaller interpulse appears to remain in phase with the intense onset spike.

Figure 4 - The source field error box for the 1979 March 5 transient as determined by the nine-spacecraft interplanetary gamma-ray burst network (Evans et al., 1980), plotted on the x-ray surface brightness contour map of the N49 and (N49) region, as observed with the HEAO-B high-resolution imager (Helfand and Long, 1979). The contour levels correspond to 0.025, 0.1, 0.2, 0.4 and 0.62 counts $((1'\mathrm{x}1')\mathrm{s})^{-1}$. No x-ray point source has been resolved. The change in x-ray intensity from shortly before to several days after March 5 event was $<2\mathrm{x}10^{-12}$ erg cm^{-2}sec^{-1}, and the point source upper limit is also $\sim 2\mathrm{x}10^{-12}$ erg cm^{-2}sec^{-1}, or $\approx 10^{-9}$ that of the transient itself, independent of distance (Helfand and Long, 1979). The implied luminosity at 55 kpc is $<4\mathrm{x}10^{45}$ erg sec^{-1}, two orders of magnitude below that of a typical pulsating binary x-ray source.

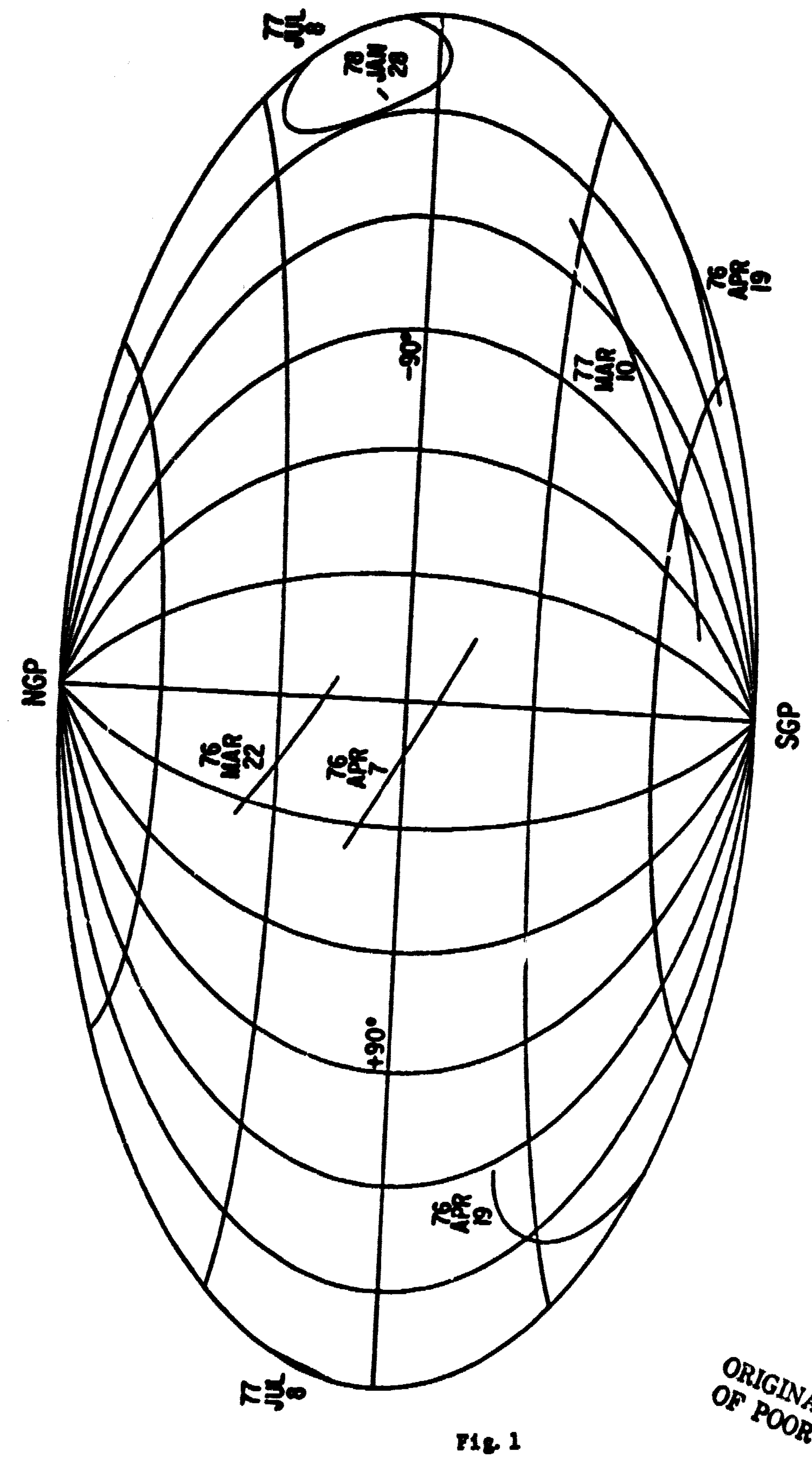
NGP
SGP
-90°
+90°
77 JUL 8
78 JAN 28
76 APR 19
77 MAR 10
76 MAR 22
76 APR 7
76 APR 19
77 JUL 8

Fig. 1

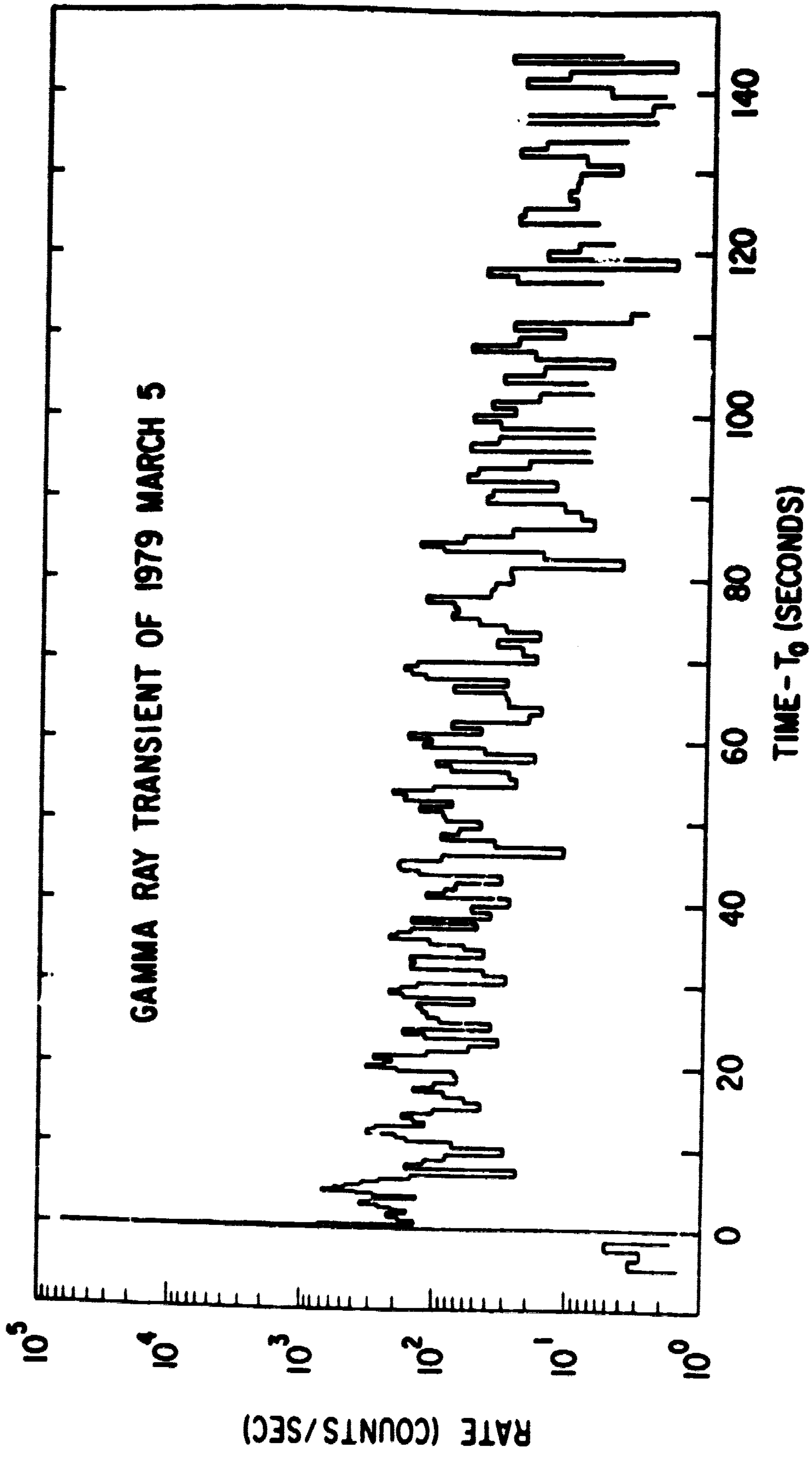
GAMMA RAY TRANSIENT OF 1979 MARCH 5
RATE (COUNTS/SEC)
10^0
10^1
10^2
10^3
10^4
10^5
TIME - T_0 (SECONDS)
0
20
40
60
80
100
120
140

Fig. 2

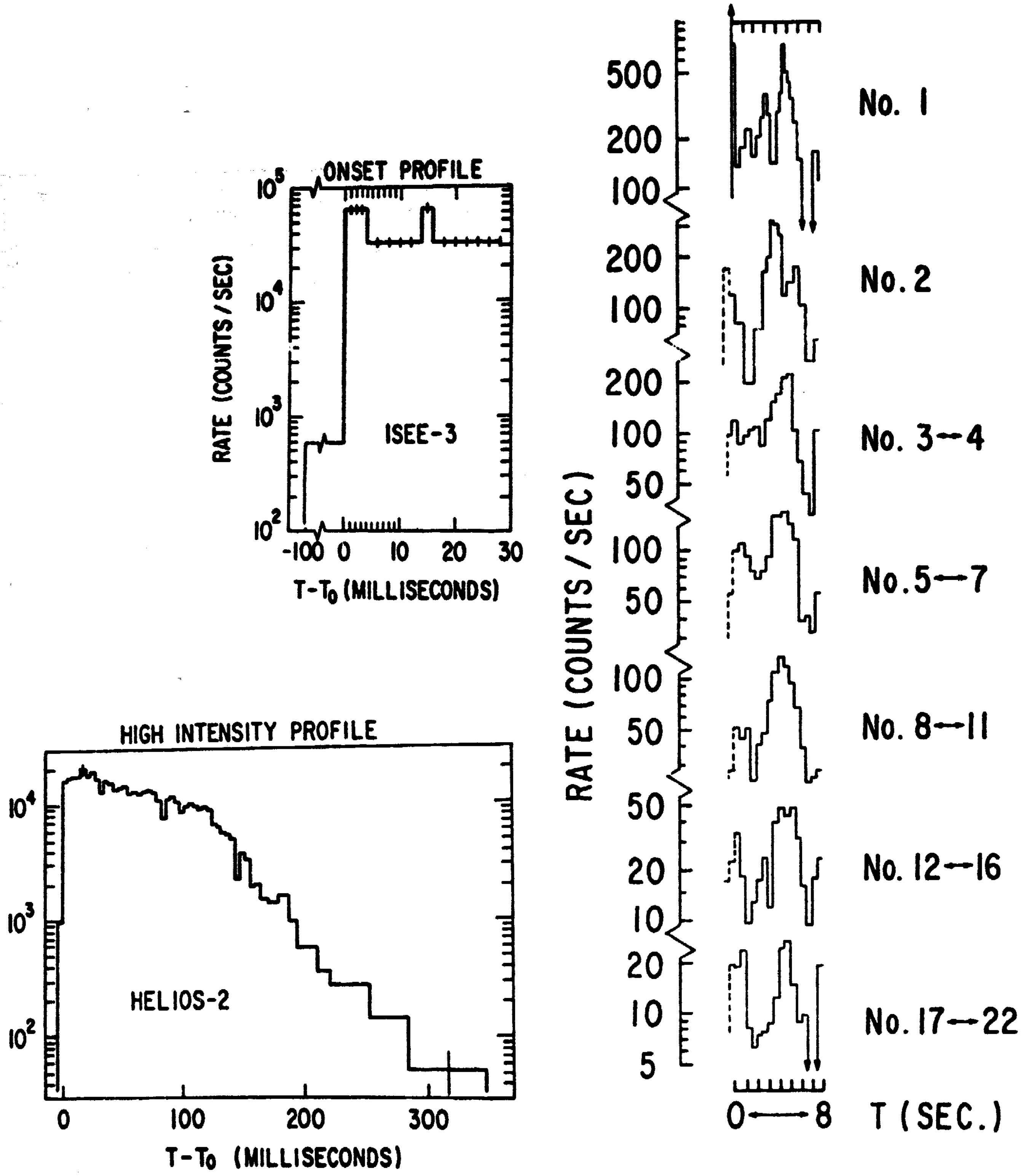
ONSET PROFILE
RATE (COUNTS / SEC)
10^5
10^4
10^3
10^2
ISEE-3
-100
0
10
20
30
T-T₀ (MILLISECONDS)
HIGH INTENSITY PROFILE
10^4
10^3
10^2
HELIOS-2
0
100
200
300
T-T₀ (MILLISECONDS)
RATE (COUNTS / SEC)
500
200
100
200
100
200
100
50
100
50
100
50
50
20
10
20
10
5
No. 1
No. 2
No. 3→4
No. 5→7
No. 8→11
No. 12→16
No. 17→22
0←→8
T (SEC.)

Fig. 3

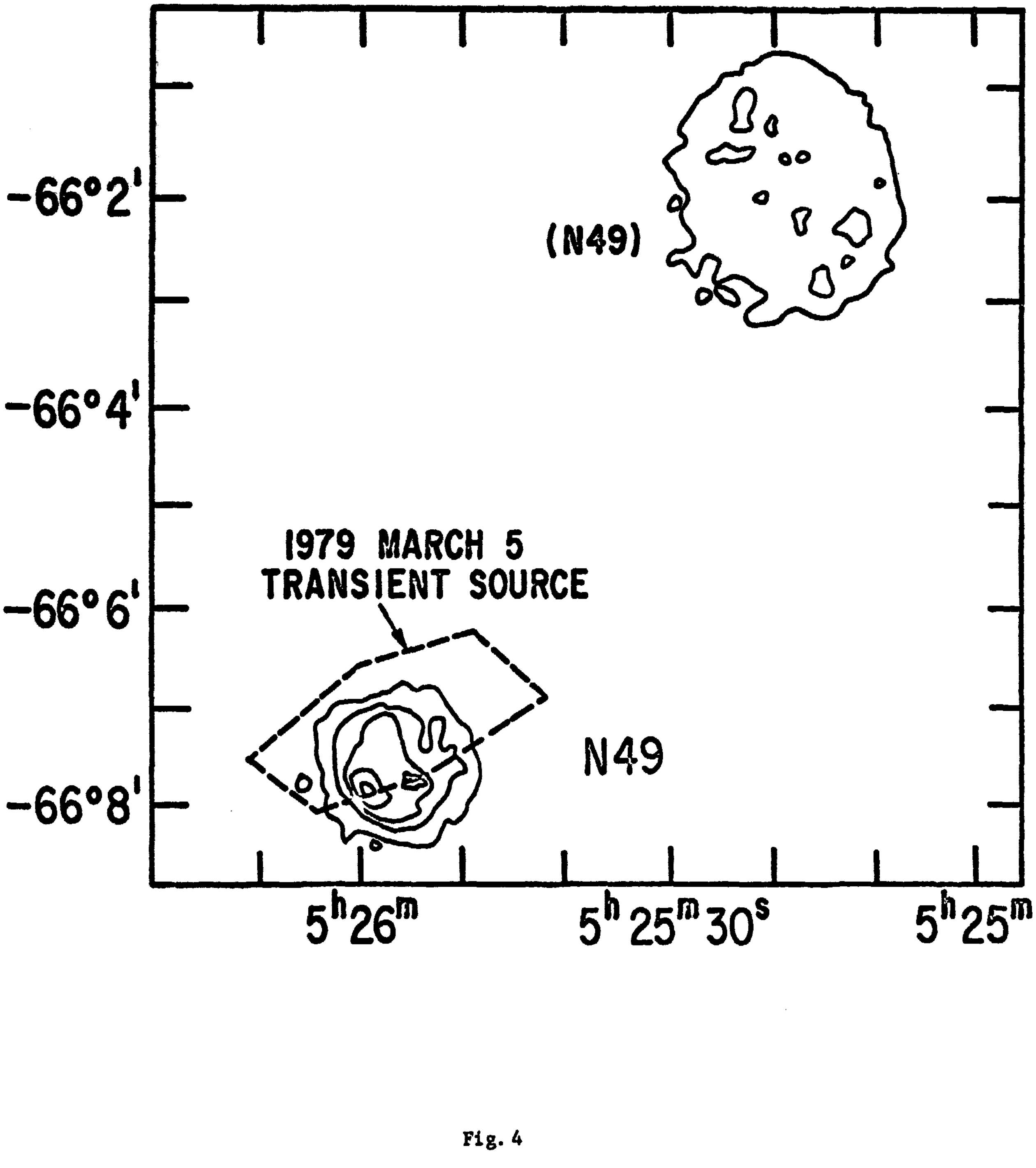
-66°2'
-66°4'
-66°6'
-66°8'
(N49)
1979 MARCH 5
TRANSIENT SOURCE
N49
5^h26^m
$5^h25^m30^s$
5^h25^m

Fig. 4

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16. Abstract

The Goddard program of gamma ray burst studies is briefly reviewed. The past results, present status and future expectations are outlined regarding our endeavors using experiments on balloons, IMP-6 and -7, OGO-3, ISEE-1 and -3, Helios-2, Solar Maximum Mission, the Einstein Observatory, Solar Polar and the Gamma Ray Observatory, and with the interplanetary gamma ray burst netowrks, to which some of these speacecraft sensors contribute. Additional emphasis is given to the recent discovery of a new type of gamma ray transient, detected on 1979 March 5.

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