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Invited review paper; COSPAR XXIV, Ottawa, Canada, 1982 May 19.

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ABSTRACT

The first interplanetary gamma-ray burst spacecraft network is making possible the precise determination of gamma-ray burst source locations. This network is an international cooperation involving the Helios-2, Pioneer Venus, Venera-11, Venera-12, ISEE-3 and Prognoz-7 spacecraft. The celestial regions that have been defined, with one exception, have no correlations either to known x-ray emitters or to steady optical counterparts, to ~ 22nd mag. The event of 1979 March 5 has a very small source field located within the contour of the supernova remnant N49 in the LMC; the possibility of this measurement as a source identification, the 55 kpc distance of N49 as opposed to the nearby source distances assumed for typical bursts, and the very different characteristics of this event, however, are three arguments for its separate classification. The recent identification of an archived, 50-year old, optical transient within the high-precision source field of a typical burst [1] suggests both that events may repeat and that sources may be localized with even greater accuracy optically.

This review outlines the precise source location data being produced by the first and the second spacecraft networks, the possibilities of additional networks and of related studies in other disciplines, and the prospects both for real-time optical transient observations and for the definition of gamma-ray burst sources by optical transient astronomy.

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INTRODUCTION

The advances made recently in the field of gamma-ray transient astronomy indicate a diverse phenomenology with the potential of furthering our understanding of high radiation density and high field density processes in astrophysics. The interpretations of the observations are not at all certain at this time, however. As the previous reviewer points out [2], there are disagreements regarding the consistent treatment of the continuum spectra, the identification of the low-energy features as neutron-star cyclotron resonance phenomena and even the question of the very existence of these features. The essentially isotropic source distribution and the ill-defined, and possibly inconsistent, event size spectrum continue to provide the argument for sources to be nearby, but without a defined distance scale.

The weight of the observational phenomena is generally assumed to point to neutron-star origins for gamma-ray bursts. Even this conclusion can be considered to be reached with a somewhat shaky logic: the clear periodicity in the anomalous 1979 March 5 event is usually taken as evidence that bursts come from rapidly rotating objects - yet the March 5 event may have an origin in an entirely separate process or kind of object from the typical gamma-ray bursts - which, in fact, do not exhibit clear periodicities. Also, the detection of 420-keV features both in the March 5 event and in a few typical bursts argues for source commonality and for a common interpretation invoking a 20-percent redshift of the 511-keV annihilation line, an effect appropriate to the surface gravitational effect for a typical neutron star. Yet, the initial evidence for 20-percent gamma-ray line redshifts comes from the "Jacobson" transient [3,4], in which there were three identifiable lines that could provide this internally consistent interpretation. It is by no means clear what relation, if any, the Jacobson transient has either to typical bursts or to the March 5 event. In one or both of the two latter cases the GRASAR (gamma ray amplification by stimulated annihilation radiation) model [5] may be a valid competitor for the redshift interpretation in explaining the 420-keV features. This model can agree with the data only in the absence of a strong redshift. We are left, therefore, with possibly circumstantial evidence, based mostly on association, that, like x-ray bursts, the typical gamma-ray bursts, the March 5 event and the Jacobson transient may each have a neutron-star origin mechanism. The various mechanism models must surely differ in kind as well as in degree, invoking such things as an internal transition for the March 5 event and one or more external effects for the slower transients. Details of the data and of the various theoretical treatments that gamma-ray burst observations and the March 5 event have generated can be found in the proceedings of a recent conference on gamma-ray transients [6].

In summary, measurements of the spectral and temporal features of bursts are probably needed in much greater quantity and with far greater precision for real progress to be made in the understanding of transients by means of interpreting their data features alone. The direct identification of burst source objects, however, through their astronomical study in the gamma-ray, the optical and possibly other regimes may be required to obtain a solution to the gamma-ray burst mystery. Present and possible future developments in high-precision transient source studies - including those in real-time optical transient astronomy - are outlined here in order to complete these general reviews of gamma-ray burst astronomy.

SOURCE LOCATION CAPABILITIES

First Network. The first interplanetary gamma-ray burst network consists of experiments flown by the Franco-Soviet consortium at CESR in Toulouse and at SRI in Moscow, by Los Alamos National Laboratory and by Goddard Space Flight Center, in the US. This cooperation has produced over 100 source determinations of varying quality [7,8,9]. At least ten percent of these are genuinely high-precision in character, i.e., consisting of error boxes of size up to several square arc minutes, of which a few are in print: those of the anomalous 1979 March 5 event [10,11,12], the 1978 November 19 event [13] and the 1979 April 6 event [14]. To date, the locations of all typical events (not incl. March 5) are found either to be essentially "empty" source fields (regions containing no obvious candidate source objects such as x-ray emitters, pulsars or supernova remnants but containing only very faint optical objects), or, if near the galactic plane, to be regions of optical source confusion (with no obvious candidate source objects). A number of the more precise source locations are currently under scrutiny in various wavelength domains; their publication is in progress and/or awaiting these other studies.

Table 1 is a list of events observed with the first interplanetary gamma-ray burst network having the minimum requirements for long-baseline "triangulation", that is, with at least three spacecraft mutually separated by distances of at least several tens of light seconds. The source precision inherent in these observations is an error field of size from less than one square arc minute to several hundreds of square arc minutes. The precision attainable for a specific event depends on the time scale of its briefest identifiable feature, the intensity-dependent counting rate statistics, the data encoding schemes in use at the event time, the spaceprobe tracking accuracies and even the ecliptic plane, spacecraft spin axes and detector orientations relative to the burst wavefront. For the best typical events, the variables can combine so as to provide a field definition of less than one square arc minute [14]; in the case of the atypically fast-rising 1979 March 5 event, the limit of about 0.1 square arc minute was achieved [12]. The general result is that of a spectrum of error box sizes distributed over the several orders of magnitude of possible precision; thus, only perhaps one third of the source error boxes that will result from the analysis of these 33 or more events can be of optimum size for use in companion optical studies. The data process involved here is an iterative one; it can consume time in an obviously regenerative manner. Given a stored or "triggered" event in the known data records from one or more spacecraft, the search is prompted for any evidence of the same burst that might be ultimately found in the circumstantial data records of all kinds from other spacecraft. The measurements uncovered in this process, although not of the temporal resolution of the dedicated or stored time histories, often provide useful redundancy, uniqueness or improved locational precision in the source determination. The effort involved is thus warranted, despite the time delays. As of the time of writing, this data analysis process with the first is still continuing. Also, it is still the case that no coincidences of source location with a candidate source object have yet been identified for any event, other than for the anomalous event of 1979 March 5.

1978 Sep 14 60132	1979 Mar 05 57125	1979 May 14 64262.
1978 Sep 18 71368	1979 Mar 07 80327	1979 Jun 13 50755.
1978 Sep 21 14158	1979 Mar 13 62636	1979 Jun 22 02670.
1978 Nov 04 58667	1979 Mar 25 49488	1979 Jul 31 39274.
1978 Nov 15 76044	1979 Mar 29 80512	1979 Oct 14 40286.
1978 Nov 19 34021	1979 Mar 31 76172	1979 Nov 01 64512.
1979 Nov 21 05736	1979 Apr 06 42447	1979 Nov 05 48862.
1979 Nov 24 14130	1979 Apr 12 79346	1979 Nov 15 82420.
1979 Jan 01 00605	1979 Apr 18 27661	1979 Nov 16 51399.
1979 Jan 13 27360	1979 Apr 19 57406	1979 Dec 30 33190.
1979 Feb 11 41967	1979 May 02 15527	1980 Jan 05 38220.

Table 1. Known events from the first network having moderate- to high-precision source determination capability; times are given in seconds, UT.

In addition to the 33 events tabulated, over 70 other bursts that have or are capable of having some less precise source-field localization are presently being analyzed [7,8,9]. These include events that have been observed only with near-Earth spacecraft and with one distant spaceprobe or only with two distant spaceprobes: in these cases, the long-baseline "tripod" effect is not available. (A subset of coincident observations made by the Leningrad group on the Venera spacecraft [15] are incorporated in those cases when the spacecraft separation and burst profiles allow for a high-accuracy combined result; the sensors used for these observations observe an independently selected event sample with thresholds for detection somewhat below those of the various network instruments.) The value of any two-spacecraft observations incorporating only one baseline is in the resulting one-dimensional precision of the source region. Although the shape of that region is a thin celestial ring, earth obscuration measurements or low-resolution directional data often permit limiting its extent to one that is generally a (several degree long) annular segment with one narrow (several arc minute) dimension, having a total area of perhaps less than one square degree. The coordinates of these regions are compared with catalogs of the locations of x-ray sources, supernova remnants, pulsars and other candidate source objects by means of computerized searches. To date, no positive correlations have been found. An initial catalog of these events is in press [16].

Second Network. After the end of spacecraft operations for Helios-2, Venera-11 and Venera-12 in early 1980, accurate "triangulation" was not possible for about a twenty-month interval during which Pioneer Venus was the only spacecraft at a great distance from the Earth. Prognoz-7 had also ceased operation in 1979, but Solar Maximum Mission was launched into Earth orbit in early 1980 with two burst-detecting instruments on board. These are mutually complementary by covering the lower energy [17] and higher energy [18] burst and solar flare regions, each with good spectral capability. In late 1981, Venera-13 and Venera-14 were launched into solar system trajectories with instruments similar to their predecessors, making possible a second interplanetary burst network. This new Venera/PVO/ISEE/SMM network is currently producing burst source locations [7,8,9] at a somewhat higher rate than the first network, due to somewhat lower Venera threshold settings. With Helios-2 observations not available, however, the reduced number of spacecraft necessarily means less coverage and fewer opportunities for redundancy, particularly at the times when the Veneras have little mutual separation and/or when they are close to PVO by the planet Venus.

Future Networks. The next interplanetary burst network will be created when the International Solar Polar Mission is launched. This mission originally consisted of two spacecraft, one American and one European, that would gravitationally deflect from the planet Jupiter, coursing several AU out of the ecliptic plane in opposing hemispheres back towards the vicinity of the Sun. Clearly, the burst source definition of this system, assuming the use of any third, near-Earth mission to complete a triangulation network, would be an order of magnitude superior to its predecessors, given the three baselines of up to several AU length each. The burst experiments were from the Goddard and the CESR-Max Planck groups, respectively. Although the American spacecraft is no longer to be built, and no other interplanetary mission is presently under development with an equivalent gamma-ray burst role, one to several missions that, circumstantially or by intent, are effective candidates for this opportunity appear to be currently under consideration. It is thus possible that an interplanetary burst instrument on a spacecraft with a deep-space, ecliptic-plane trajectory will be accomodated, either by groups in the US, Europe or the USSR. If so, given the European ISPM and assuming the simultaneous existence of some near-Earth mission with gamma-ray burst instruments (such as GRO or OPEN), a solar system burst network with excellent source definition capabilities will be created.

PRECISE SOURCE LOCATIONS

The 1979 March 5 Event. Figure 1 illustrates the precise source region produced by the first interplanetary burst network of the very unusual 1979 March 5 gamma-ray transient [12]. Also shown is the N49 supernova remnant as observed in x-rays with the Einstein Observatory [19]. I have always maintained that the facts - that this event has completely atypical properties and that its directional agreement with N49 both has an extremely remote accidental likelihood and is in contrast to the lack of source object identifications for typical bursts - can argue better for its association with an anomalous source, e.g., one at an unexpected distance, than against it [20,21,22,12]. The source identification of N49 [10,11] is not universally accepted because of objections based on the unusual energy requirements from 55 kpc distance (e.g., [19]); however, the fact that these problems can be overcome (e.g., [23,24,25]) keeps this an open question. In either case, there is no known candidate point source object for this event: the N49 supernova remnant region contains no detectable x-ray point source - independent of source distance - with an upper limit many orders of magnitude below its distributed x-ray emission [19]. The properties of this anomalous event were reviewed soon after the observations [21] and more recently [22], after considerable reanalysis and theoretical modelling, supporting both N49 and local origins, had been done. Further elaboration is outside the scope of this paper.

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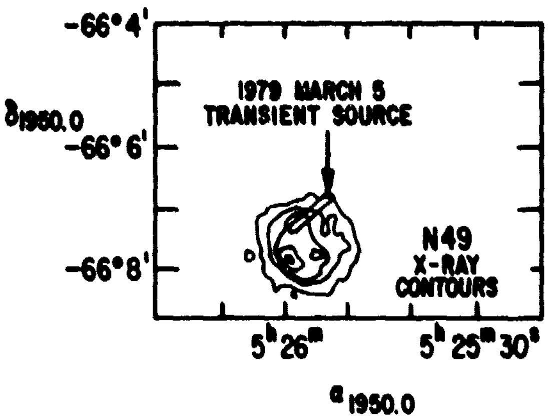

Figure 1. The 1979 March 5 gamma-ray transient source location [12]. Its extent is entirely consistent with that of the LMC supernova remnant N49, although located in an eccentric position. The displacement from the center is at least 15 seconds of arc, corresponding to a 4 parsec distance at 55 kpc.

One of the most unusual features of this event that is also relevant here is its extremely fast rise, providing the most accurate fiducial point for wavefront timing available. Given an increase of over several orders of magnitude in less than one millisecond, equivalent to an exponential risetime constant of less than 200 microseconds [20], the only known competitors in this regard are two events detected in 1979 since the March event, with increases each of a single factor of two in perhaps 5 msec [26]. These are thus slower in onset than the March 5 event by a minimum factor of 25, compared with the ~ 50 msec or 250-times slower rise and fluctuation times of typical events. (This fact is adequate to confuse the issue of event classification by timing features.) The rapid 200-microsecond onset of the March 5 event - besides posing the question as to why typical gamma-ray bursts do not possess it - made possible the limiting definition of gamma-ray transient source localization. Its 0.1 square-arc-minute size, in fact, illustrates the limitations of the first network with regard to spacecraft timing: up to 20 msec. This is about the same as, and is thus adequate for, the burst wavefront definition for typical burst events. All future spacecraft timing systems are expected to be superior in this regard, including the ISPM with its greater tracking challenge, such that the source definition for typical events should be limited only by the fluctuation time used for a wavefront fiducial; this point is discussed below regarding another important event.

Another anomalous feature of the 1979 March 5 event of relevence to these discussions is the association of its approximate source direction with the rough source directions of three weaker transient events that were detected with the Leningrad experiments on Venera-11 and -12 following the March 5 event with delays of 0.6, 29 and 50 days [27]. Given the compatibility of the four source directions and their temporal association to each other and to the March 5 event, it is entirely reasonable to assume that these measurements represent the discovery of the first repeating gamma-ray transient emitter. These three events are several orders of magnitude fainter than the March 5 event and thus may represent only trailing outbursts of immediately available excess energy. If so, there is as yet no direct evidence for the repetition of typical and intense gamma-ray bursts from one source. One other series of events with evidence for a mutual source compatibility has been detected [28]: this is also a series of three weak events, but without the presence of an intense, identifiable "parent" event. One can speculate that if these are interpreted as an outburst series that follows an event similar to that of March 5 but undetected, that initial event must have a strong emission anisotropy, and therefore so may the March 5 event. Assigning all these events to an anomalous class leaves no available evidence for the repetition of gamma-ray bursts of the typical class. This fact is of some importance in the consideration of the possibility of studying known source regions for further transient activity with higher-precision astronomical instruments. A related point relevant to the question of gamma-ray transient source definition regards the possible connection between the the source direction of the first series of repeating events, towards the LMC, and the source direction of the second such series, in the galactic plane at roughly 45 degrees galactic longitude [28]. Both directions are consistent with origin locations in dense galactic regions, one at up to perhaps 20 kpc, or half the distance of the other, at 55 kpc in the LMC. This speculation puts both series into a consistent model - and poses the first conceivable burst direction correlation (inadequate for the term anisotropy) for this subclass of very low-intensity events, in the discs of this galaxy and its neighbor [22].

The 55 kpc distance of N49 in the Large Magellanic Cloud (requiring a factor of ten thousand to one million greater source intensity - if isotropic in emission - than that of a typical burst having an assumed source distance of 0.5 to 50 pc) is the parameter at issue in the central controversy regarding this event. The existence of modelling exercises that not only fit the March 5 spectral and temporal temporal data extremely well [23,24] but also derive the source luminosity fitting the 55 kpc distance [25] point to the value of examining the possibility that N49 in fact is the source. A prime example of the value of examining all such theoretical avenues is the recent creation of the GRASAR model [5] of stimulated annihilation radiation. A great deal of additional study, possibly including the investigation of the implications of gamma-ray coherence, may be required before it will be known whether gamma-ray bursts of any subclass fit this description.

Precise Locations of Typical Gamma Ray Bursts. The source fields of the first two typical gamma-ray bursts studied with the network are shown in in Figures 2 and 3. The field of the 1978 November 19 event [13] is shown using the composite measurements of the near-Earth vehicles as one, Helios-2 as another, and each of the three vehicles then approaching Venus as the third vertex in the three "triangulation" measurements. These are not entirely independent; all rely on a single distant spaceprobe at one vertex, although the other two vertices are redundantly determined. This analysis treatment was conservative in all respects and resul··d in a source field about 2 by 8 minutes of arc in extent.

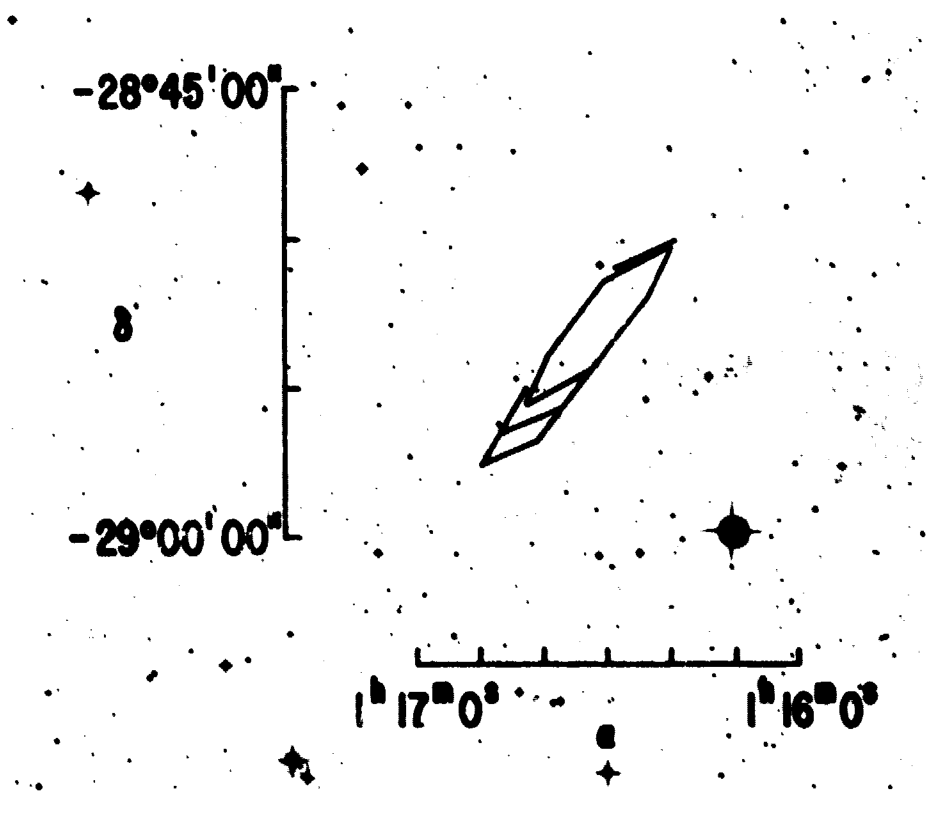

Figure 2. The source field of the 1978 November 19 gamma-ray burst [13]. Only very faint stars are within or adjacent to this region; a computerized search shows no association with catalogued x-ray emitters or other possible objects of interest, such as pulsars or supernova remnants.

The source field of the 1979 April 6 event [14] is shown in Figure 3. Its definition method necessarily differs: at the time of this event, the mutual separation of Venera-11 and -12 was much greater than in the earlier case but data from Helios-2 were missing. Four widely separated vertices were thus available, but with no redundancy at any distant vertex. This source field is less than one square arc minute in size.

Figure 3a. The source region of the 1979 April 6 event, indicating the absence of Palomar- catalogued objects to ~ 22nd. magnitude, direct evidence that both a classical gamma-ray burst source object and its binary companion, if any, are of low intrinsic luminosity [14].

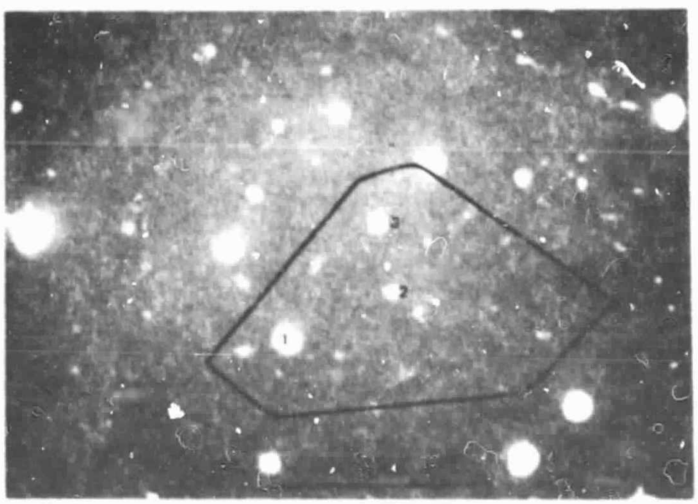

Figure 3b. A recent, more sensitive study of the same region, showing three faint but above noise-level sources within and several more close to the error box: most of these can be assumed, on statistical grounds, to be of extragalactic nature [29]. (Photo courtesy K. Hurley; Figures a and b reversed in east-west sense.)

Each wavefront direction determination necessarily relies on nonredundant or apparently unverifiable single-spacecraft measurements: this is obviously unavoidable if there are fewer than six widely spaced spacecraft in use. Confidence in the results was initially generated by the calibration of clock drifts and by the use of command-induced, artificial gamma-ray burst triggers to fix the zeroes of time of the systems. Nevertheless, in the absence of identified source objects (other than the anomaly of N49), and given the essentially empty optical fields, skepticism or discouragement might have been initially felt to be justifiable.

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The Optical Transient of Schaefer. The very recent discovery of an optical transient within the 1978 November 19 source field [1] clearly provides more than adequate reassurance regarding the accuracy of the 1978 November 19 burst position and/or regarding the spacecraft network method of conducting gamma-ray transient astronomy. This discovery was itself performed in a unique manner. The three published burst source locations [11,13,14] were scrutinized in hundreds of archived photographic plates each, ultimately producing evidence for one bright optical transient, found within the 1978 November 19 field (Figure 4). The photograph had been made in 1928, 50 years before, and was in fact the fourth of six consecutive 45-minute exposures. Analyses of the emulsion produced other substantiating evidence that the duration of the optical event was considerably less than the 45-minute exposure time, possibly a few seconds, entirely comparable to the duration of typical gamma-ray bursts such as the 1978 November 19 event. The limiting magnitude of any steadily emitting object at that location is 23rd; if the burst source is there and within 400 pc, its limiting absolute magnitude is 13th [1] (see Figure 5a). A previous search for real-time optical transient coincidences with a few bursts had set a lower limit to the luminosity ratio L(gr)/L(op) at 800 [28], actually that of the measured value here [1].

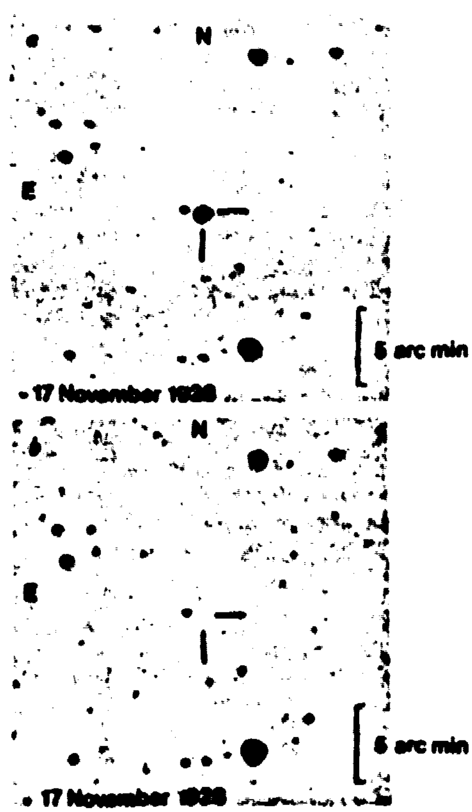


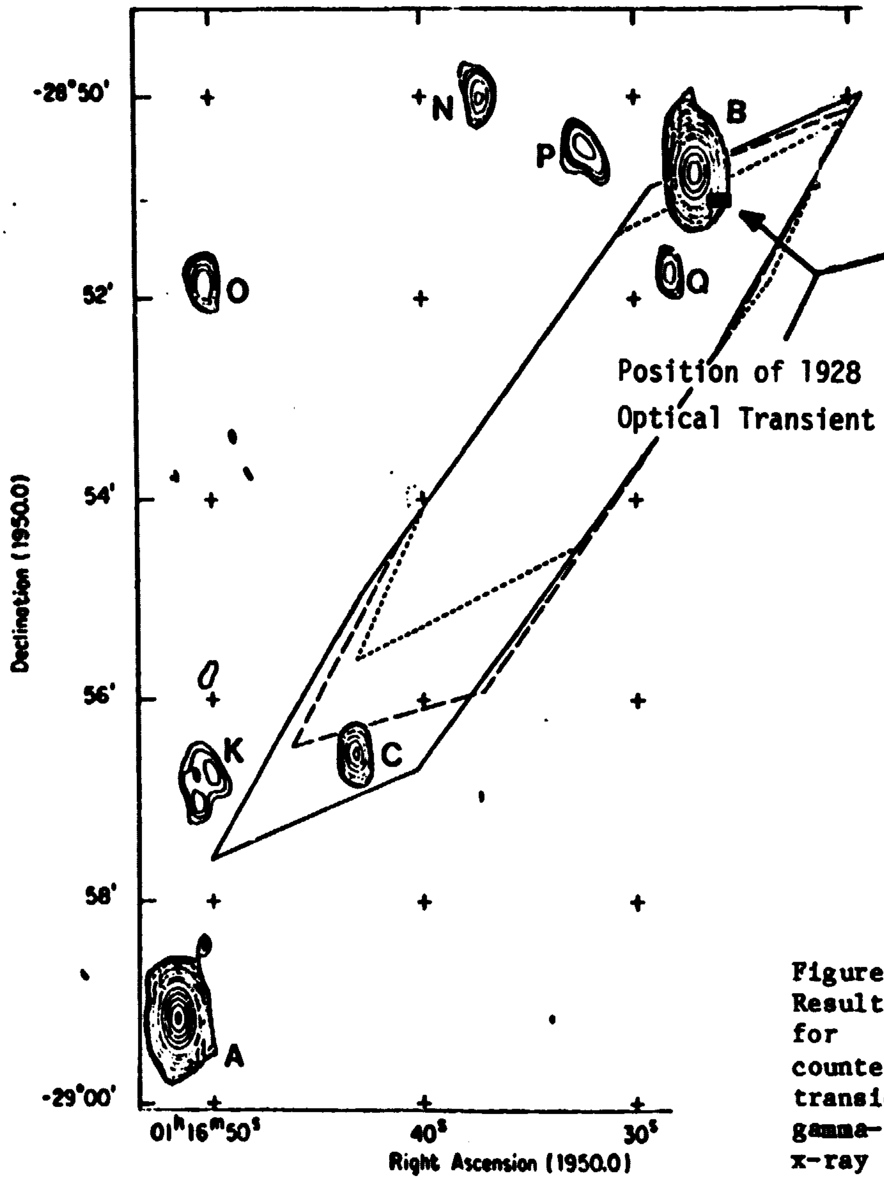
Figure 4. The optical transient found in the 1978 November 19 gamma-ray burst source field [1]. The total visible energy of this 1928 flash was considerable, perhaps one-tenth the total energy in gamma rays in the 1978 burst. The brightness of this flash was between 3rd and 10th magnitude, depending on the time duration assumed (if the 1928 flash had the same duration as the 1978 burst, its intensity was within naked-eye limits).

Given the fact that the total optical viewing time accumulated for the several hundred photographs of the survey represents less than one percent of the 50 years or more elapsed time span, the inferences can be made that detectable optical transients may be commonly emitted by gamma-ray burst source objects, that they may also be emitted at the times of observed gamma-ray bursts, and, if so, that transients detectable in the optical and/or gamma-ray regimes may be observed from the same source region with a repetition time scale somewhere between months and centuries. The great values of this discovery are both in the promise of coordinated gamma-ray burst/optical transient measurement programs that can shed light on the physical processes involved and in the promise of bringing the full power of optical astronomy to bear on the problem of the direct identification of gamma-ray burst source objects. Both of these kinds of investigations are extremely exciting prospects.

One reaction to Schaefer's discovery by this author was to reexamine the circumstances of this source agreement with the burst location (e.g., despite its extremely low random chance likelihood, some believe the N49 position to be coincidental). A reanalysis of the as-published November 19 burst data was carried out using the published centroid of the Schaefer location as a test point [30]. Happily enough, nearly all of the various two-spacecraft timing measurements fit with errors of up to only 10 msec, i.e., about one third the published, conservatively assigned errors of 30 msec. The exceptions that had required the published region to have the dimensions that it does, and to locate the Schaefer point off center, were the near-Earth pair of Prognoz-7 and ISEE-3. They give timing displacements, relative to the Schaefer location, of ~ 30 msec, the value published as appropriate. Thus, redefining the burst source region with a weighting scheme would provide an even better fit to Schaefer's location: the Helios/PVO/Venera-11/Venera-12 observations, from four of the six spacecraft available, would give a maximum-likelihood region more closely centered on the Schaefer location, nested within and one tenth the size of the published region, if one were to contour the probabilities accordingly. This (retropectively analyzed) result provides a gratuitous measure of confidence in the burst/transient association.

INTERDISCIPLINARY STUDIES

Radio Astronomy. The existence of an optical transient recorded within the 1978 November 19 burst source region - the same one and only one that has been radio-surveyed [31] - suggests a review of the radio astronomical measurements in this regard.



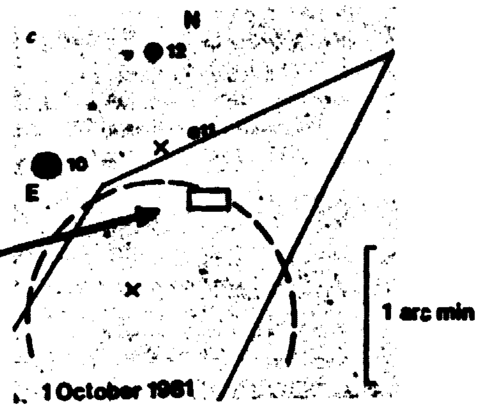


Figure 5a (upper right). Results of a sensitive search for a steady optical counterpart for the 1928 transient [1], showing the gamma-ray (diamond) [13], x-ray (circle) [13], and radio (x's) [31] source positions.

Figure 5b (left). The VLA map at 1465 MHz of the 1978 November 19 burst source field [31], indicating the location of the centroid of the Schaefer transient [1]. Several of the radio sources are located fairly near to its position but none are consistent with it.

One can speculate on the possibility that a source proper motion could link the 50-year separated radio and optical phenomena. The four radio sources nearest the location of the 1928 optical transient are about 20, 45, 70 and 150 seconds of arc from it (Figure 5b). Assuming that the burst source object could have a 10 to 100 pc distance range and that assuming its velocity range could be 100 to 500 km/second, the resulting displacement over the intervening 50-odd years would range from 10 to 500 arc seconds, encompassing the positions of these four sources. Looking at the other way, if one of these for radio sources were to have undergone proper motion from the 1928 Schaefer location, the yearly amount would be 0.4, 0.9, 1.2 or 3. seconds of arc, comparing quite favorably with the results of the above assumptions, which cover a 0.2 to 10 arc second yearly range. A several-year displacement of this magnitude is within the observation limits of the VLA and its study has accordingly been proposed [32]. Clearly, if proper motion were to link these phenomena, such observations could add the radio regime to the optical and gamma-ray, providing additional inputs for the analyses of the physics of gamma ray burst sources. Not only would the study of proper motion be of intrinsic value, but given the sub-arc second resolution and great sensitivity available in radio astronomy, other direct studies, such as of neutron-star magnetospheres, could conceivably be possible.

X-rays. The x-ray astronomy both of the 1978 November 19 burst source and, by association, of burst sources in general, may have some enhanced interest, given the Schaefer source association. The x-ray source found with the Einstein Observatory [13] to be inside the gamma-ray burst source field is also compatible with the Schaefer transient location (Figure 5a). The combined x-ray/optical error box is even smaller, by a factor of ~ 5 or 6, than the gamma ray/optical or gamma ray/x-ray fields, suggesting a likely three-way asociation. Recently, many of the Einstein x-ray source location measurements have been revised in an overall instrument recalibration. This change has resulted in a repositioning of this x-ray source with a new location which is in fact closer to the Schaefer position and with a new error radius which is shorter: at a 42 arc-second distance, and with essentially the same error radius, the association is improved by another factor of 2. Thus, given a three-fold, gamma-ray/x-ray/optical association within an order of magnitude smaller error box than the initial identification, the implications are more worthy of examination [33]. This is the only x-ray source yet found to be consistent with a precisely determined gamma-ray burst source location. Since the 1978 November 19 burst was one of the strongest typical events on record, it may be difficult to continue or improve upon these correlative x-ray studies for some time.

OPTICAL TRANSIENT ASTRONOMY

Optical Transient Monitoring. Several distinct possibilities exist with regard to detecting optical transients from gamma-ray burst sources in real time. One method is that of optically monitoring known gamma-ray burst sources in the hopes of catching a repeat outburst. Surveys using imaging CCD devices are being initiated in spite of the rather pessimistic probabilities of detecting such random and possibly rare occurrences. A second technique employs wide-angle, ground-level optical imaging in conjuction with the data-base comparison, after some period of data collection, with the spacecraft observations of gamma-ray bursts, their Earth-crossing times and their approximate directions. Search programs of both kinds are being attempted in the US and in Europe. In particular, the comparison of optical transient survey data with burst observations collected by the present, second network is also underway [34].

Second-Generation Systems. Future possibilities of burst/transient study may lie in optical systems of vastly improved sensitivity and/or wider field applicability. Larger arrays of CCD imagers are now being considered for this purpose [35]. The presently existing giant Fly's Eye array in Utah is another distinct possibility of great interest. This operational system of over 70 telescopes, using over 800 individual sensors to achieve about 20-square-degree resolution, would be capable of detecting 10th to 14th magnitude optical transients, depending on the transient durations assumed [36], if given the necessary modifications. Either scheme, when operational, could be used in coordination with the surviving network spacecraft or with the next generation of gamma-ray detectors on ISPM, GRO and/or OPEN. A variation on these techniques, but probably without comparable sensitivity, would be the balloon or space flight of combined optical transient and gamma-ray burst instrumentation. The success of any such program, even one with little directional resolution but with only the temporal association of optical events and known bursts, could have the extremely important values of establishing the magnitude of the connection between optical transients and gamma-ray bursts, the luminosity function of the transient emitters, the repetition scales for combined optical/gamma ray effects and, possibly, a repetition scale for single optical effects.

Real-Time Optical Transient Astronomy with a Source-Acquiring Telescope. The direct optical detection and high-resolution photography of optical transient sources may ultimately be accomplished in another way. A Rapidly Moving Telescope has been approved for initial developmental funding at Goddard for the purpose of the real-time study of optical transients [37]. This project was conceived by B. J. Teegarden and is being developed in our Laboratory to be usable in coordination with the CCD imaging system development program at MIT [35]. A two-axis gimballed mirror system (used with an optical telescope of conceivably modest scope), triggered in real time by an optical transient sensed with an intermediate, wide-angle system (such as the CCD imager), will point towards the direction determined with a very fast electronic data processor (also under current development), stabilize its own motion, and (if the time duration of the optical flash persists longer than the 0.9 second these processes require) photograph the transient directly. The star background of course will provide the directional calibration. This project is the first attempt to define a burst source in real time to the degree of accuracy limited by that of optical systems - perhaps better than 1 arc second.

ACKNOWLEDGEMENTS.

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