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GAMMA RAY TRANSIENTS

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1. PROLOGUE

History has had its periods of magnificent excess, when vast amounts of human effort were devoted to cultural projects that transcended the necessities of survival and commerce. Obvious examples begin with the construction of the great pyramids. Much later, Europe's cathedrals were the ultimate commitment of society's surplus energy to expressions of the spirit. The explorations of the remote regions of the Earth followed in time as luxuries of civilization that were also adventurous investments. During the last century, technologies of all kinds were obsessively undertaken, with results that have transformed life. Most recently, and for a brief moment fitting onto this logarithmically shrinking temporal series, were the years of the intense involvement of our segment of society in the exploration of space. This endeavor is generally thought of as having things in common with each of those earlier enterprises; it might even be considered as an evolutionary culmination of their entire trend.

The primary motivations for the American space effort during its first few years were the immediate and compelling issues of national image and defense. The civilian space agency was the most visible response to the Sputnik challenge, but not the country's principal space program, becoming second or third, depending on the bookkeeping, behind both the defense space development and the surveillance budgets. The desire to fulfill its mission of promoting the national image ensured that NASA emphasize manned exploration—rather than focusing only on remote sensing with automated instrumentation—in order to enlist and maintain the enthusiastic support of the public. As the technologies proved themselves with the early successes,

and as the race to the Moon was won, practical enterprises such as navigation, communication, and weather monitoring grew in scope. The large-scale lunar and deep space activities have given way to the shuttle and, more recently, to the space station, near-earth projects intended to prepare for the systematic future growth into space.

My point is that scientific research was never a necessary ingredient in any of this. Appealing close-up photos of the distant objects of the solar system notwithstanding, pure research for its own sake was, as always, a luxury of which the typical spectator, or voter, was almost completely unaware. I like to think that Frank McDonald was more responsible than any other one person for the way that science, in fact, did figure into the space arena.

2. INTRODUCTION

The diversity of the accounts that might attempt to describe Frank McDonald's influence on the course of space science would be considerable, no doubt scattering throughout a diagram in argument space of at least four dimensions. My opinions are therefore entirely my own. In the early days there were, of course, a number of creative individuals who were deeply committed to scientific excellence as the first priority. These were the people who promoted space science as a valuable function for Goddard as a federal center, or who sought to constructively influence NASA program creation, or who administered research empires, or who also valued the maintenance of scientific activities as a support service to NASA, citing solar protons as health hazards in space, for example. McDonald is one individual who seemed to combine all of these career objectives simultaneously, even while pursuing personal research of considerable merit and coaching apprentices and thesis students and teaching on the side.

Entirely in Frank's own style, as well, was the generation of new research capabilities. Nurtured within his lab, these groups worked in areas generally outside his own specialty of cosmic radiation although potentially related with some interdisciplinary values. Following various growth rates, and either transplanted elsewhere or remaining, these have come to range from mature

individual scientists sharing support facilities to competitive laboratory empires. A creation of this nature is a complex, simultaneously insurance-buying, sphere of influence-extending, and yet selfless, risk-taking, and entirely existential act. On a comparatively minor scale, even McDonald's work-a-day ideas and advice could result in significant career opportunities or alterations. One such episode in the early 1970's made possible a unique development in astrophysics, in my opinion, and is what I wish to use as illustration here.

3. HISTORY

The discovery of cosmic gamma ray bursts was published after more than a dozen brief and inexplicable increases of the 100 keV count rate in cislunar space had been observed in the course of a nuclear test-band monitoring program [Klebesadal, Strong, and Olson, 1973]. This serendipitous space age discovery was made, not with NASA or European scientific instrumentation, but with systems designed at the Los Alamos Laboratory for the detection of nuclear explosions beyond the atmosphere. Its release was quite conservatively delayed until after several years of confidence building through the consistent accumulation of data. Analysis of the onset times of each rate increase at the widely separated orbiting instruments, not exactly in coincidence, could geometrically define event propagation planes. The pattern of the source directions found in this manner was consistent with isotropy and bore no relation to the locations of the Earth, Moon, or Sun. The gamma ray counting rates were similar to those from solar flares, obviously indicating much greater total emission, at least billions of times greater, if indeed coming from outer space. Since the events were not found to be from supernovae, the only mechanisms then suggested as sources of observable cosmic gamma ray transients [Colgate, 1968], and since their discovery predated that of X-ray bursts, gamma ray bursts were a real surprise.

New life was thus injected both into gamma ray astrophysics and into the astronomy of transients. Despite an earlier prediction that exotic forms of cosmic information might be transmitted in nuclear gamma rays [Morrison, 1985], this energy region had continued to be disappointing. Compared with the X-ray band, that has been more than generous in its rewards in astronomy,

the 0.1 to 10 MeV region then seemed to require such elaborate instrumentation for equivalent signal strengths as to be almost hopelessly impractical. Yet, here was an unexpected phenomenon with counting rates practically off scale, found with very small and relatively crude detectors, and having energy releases certain to be enormous, even though the sources were as yet unidentified. Further, the curiosity value of this discovery was enhanced by the fact that these observations (in this very wavelength region hitherto encompassing little more than a static form of neutral cosmic ray background) were characterized by almost immeasurably rapid time scales. The excitement of the moment, while prompting many imaginative ideas and speculations, left experimenters unable to immediately conduct new observations in response, given that the detection rate was far too low for a rocket or balloon flight to have any chance of being aloft during an event and that spacecraft experiments took years to get into the mission schedules and to get done.

At that time I had just started a low energy gamma ray astronomy effort at Goddard. The primary objective, coincidentally enough in retrospect, was gamma ray transients, then thought to be possibly observable as signatures of distant supernovae [Colgate, 1968]. I was building a balloon payload for this purpose, as well as searching through and comparing existing spacecraft data records for evidence of transient gamma ray behavior. Only weeks before the release to the public of the discovery of bursts by Los Alamos, several anomalous counting rate increases had been found in my IMP-eye solar flare hard X-ray data. These were detected outside the Earth's environment and were also apparently of non-solar origin. We could find independent evidence for only one of them in other spacecraft records. That was, however, not very firm evidence, being a single time coincidence in the list of hundreds of fluctuations that had been accumulated by an OSO-7 instrument in near-earth orbit. When the Los Alamos list was published, our IMP-eye bursts, all of which appeared on that list, both gave immediate confirmation to the gamma ray burst phenomenon and included the first burst energy spectrum, demonstrating its distinctly non-X-ray nature [Cline et al., 1973].

With the single OSO-IMP event, a more extended spectrum was obtained, together with the first approximate source direction confirmation [Wheaton et al., 1973]. The latter was also of particular interest at that time, due to the uncertainties inherent in Los Alamos' technique of finding the burst

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wavefront vector using the relative Vela satellite burst 'trigger' timings. This single OSO source field, although quite large, was typical of the existing pattern, having an anomalous direction at high galactic latitude, far from the brightest X-ray emitters, that, of course, enhanced the source mystery and provided even more confirmation that an entirely prime scientific phenomenon was ripe for exploration.

With Frank McDonald's appreciation of this opportunity and with his administrative and moral support, I was able to believe that I had some chance of demonstrating the urgency of the situation to NASA Headquarters. I well remember promoting—in the company of other interested persons, including George Pieper, Les Meredith, and Doyle Evans—the opportunities that then existed, which, if ignored or unnecessarily postponed, could be left wide open to other space groups or missed entirely. John Naugle, to his great credit, endorsed the two propositions that physics and astronomy instruments then under construction not be excluded from the opportunity for modifications to include gamma ray burst observational capabilities, if appropriate and at low cost, and that competitive proposals for new experiments, even on space missions not necessarily devoted to astronomy, be considered for possible gamma ray burst instruments, when appropriate and at minimal cost. This action made possible the American participation in the gamma ray burst interplanetary network. In retrospect, it probably enabled all the domestic spaceborne gamma ray burst studies to be carried out in the entire one and a half decades before Gamma Ray Observatory, with the exception of Solar Maximum Mission. The situation otherwise would not have been a multivertex network capable of high accuracy 'triangulation,' but a single long baseline from several near-earth instruments to the various Franco-Soviet instruments on the Veneras.

The experiences of those days began a commitment that continues to the present. While developing new ways to research this puzzle, our previously scoped gamma ray transient studies were redirected towards gamma ray bursts. The inconclusive results of our first balloon-borne experiment prompted us to put up in the following year two balloon instruments simultaneously, with a distance separation of several midwestern states. This search for smaller sized and hopefully more frequently occurring events incorporated the obvious requirement that independent detections would be needed to establish an

ephemeral effect as real. The results [Cline et al., 1976] were like those that plague even present-day high sensitivity balloon searches [e.g., Meegan, Fishman, and Wilson, 1985], namely, a lack of detection of the weak bursts that should seem to be required from a reasonably extended size distribution.

4. OBSERVATIONS

Helios-2 was the first gamma ray burst instrument launched; its initial results, in 1976, seemed to deepen the mystery. The great distance of this solar orbiter, of up to two astronomical units, made possible the determination of considerably more definitive source location loci. The comparison of its measurements with those from the near-earth Vela system provided source fields in the form of ring segments as narrow as a minute of arc, although up to tens of degrees in length. Sources were not, of course, identifiable with such observations, but candidate sources could be unambiguously eliminated by the lack of positional agreement. All the burst observations showed a clear and complete lack of agreement with the locations of all obvious candidate sources such as the well-known X-ray objects [Cline et al., 1979]. This problem of source identification (at least for the 'classical' types of >100 keV character, as discussed below) continues in some form to the present.

The first interplanetary burst network was completed in 1978 with the launches of Pioneer Venus Orbiter and Veneras-11 and -12. A variety of instruments on these spacecraft, flown to and beyond the planet Venus, provided the necessary third vertex in the 'triangulation' array, complementing those near the Earth and Helios-2 in its solar orbit. Later, the Veneras were to outdistance Venus, giving a multiply determined array. Also, the several burst detectors piggybacked on the third International Sun Earth Explorer (ISEE) supplied considerable improvement in the accuracy of the near-earth data useful for this network. With its initial results, this progression of gamma ray burst source directions determined with ever-increasing accuracy (that turned out not to be consistent with the positions of known objects) reached its conclusion. Source fields were derived with sizes from tens of arc-seconds to arc-minutes in dimension, yielding precise 'error boxes' sufficiently small to establish source identification, if reasonable agreement were to be found, but (with the particular exception noted below) finding fields that were either entirely empty

or empty of other than random stellar foreground objects [Laros et al., 1981, illustrated in Figure 1; Cline et al., 1981; Barat et al., 1984a, b; and Cline et al., 1984]: Clearly, not only were the gamma ray burst sources extremely elusive, but any of their companions that may exist in binary associations as well.

One totally unexpected discovery made possible by these results was that of an archived optical transient [Schaefer, 1983], precisely within the November
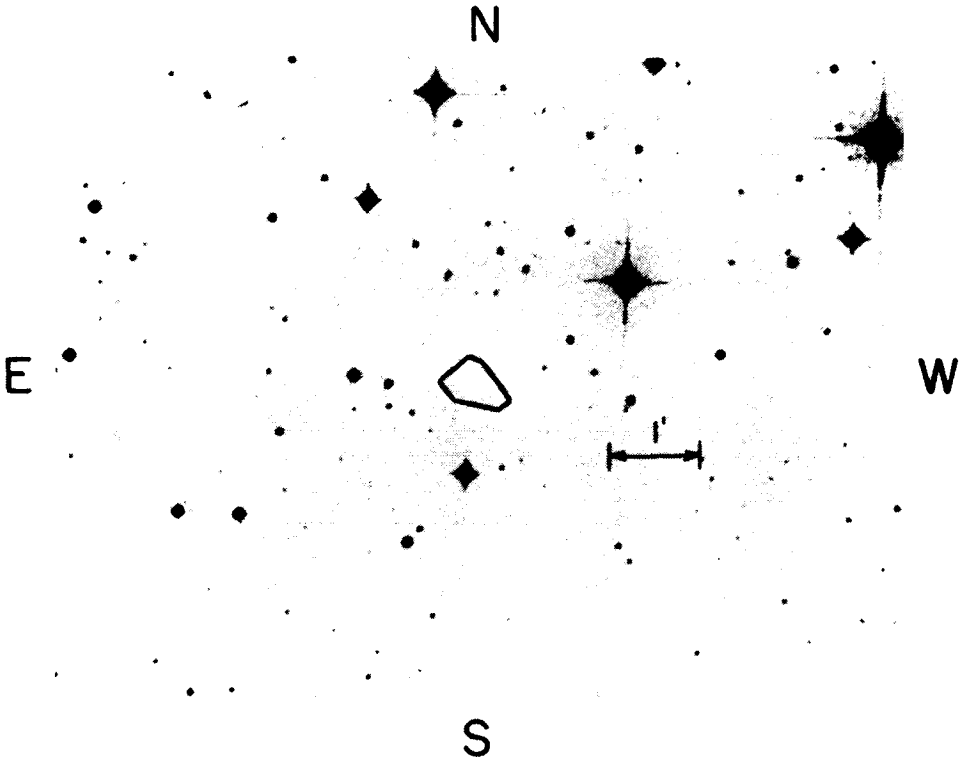

Figure 1. One of the initial gamma ray burst source fields determined with the interplanetary network [Laros et al., 1981], typical in its absence of apparent optical counterparts. These also have no X-ray counterparts.

19, 1978 burst source field [Cline et al., 1984]. Figure 2 shows comparison photos. The flash, found in a search through hundreds of stored prints, has somewhat of a 'supernova' appearance, but in fact lasted less than several minutes. Taken in the year 1928, it was fortuitously in one of a series of several exposures (providing 'before' and 'after' shots for comparison) photographed the same night. Both an analysis of the character of the transient's image in the emulsion and the fact of a rounded shape (compared with the elliptical star images made by motion of the camera) are consistent with a brief duration relative to the 45-minute exposure. Since this discovery, two more archived optical transient effects have been found in other network burst source fields [Schaefer et al., 1984]. These also have decades of separation between the time of the optical flashes, in the early to mid-1900's, and the gamma ray bursts, in 1978 and 1979. Since the celestial positions of the optical transients are known to several seconds of arc, it has been possible to examine those fields to present-day optical limits. The results are that only extremely faint source candidates of inconclusive and possibly time-varying character can be marginally inferred [Pedersen et al., 1983; Schaefer, Seitzer, and Bradt, 1983]. Of course, source proper motion over the decades between optical and gamma ray transients may be a problem in the utility of the archived positions.

Optical transient observations obtained in real time, however, might make possible comparative studies that could be useful for 'instantaneous' gamma ray burst source positions. At present, two new kinds of ground-level instruments are being built in the hopes of exploiting this effect. One will survey and map the sky in optical transient effects [Ricker et al., 1983]. Another will use directional information from the first to reorient a telescope mirror, thus determining a transient's position as it occurs with the maximum precision obtainable, viewing it within its calibrating, neighboring stellar field [Teegarden et al., 1983]. Both these are being installed at Kitt Peak Observatory for operation in the near future.

Another unique course of events prompted by network gamma ray burst observations centers on the March 5, 1979 gamma ray transient. That occurrence provided a picture that still appears, as it did at the time, to be that of a once-in-a-lifetime event. This burst differed in its properties in such detail that I was convinced that it was not 'another' gamma ray burst, but a separate class of event in itself [Cline, 1980]. That claim, made when high resolution burst
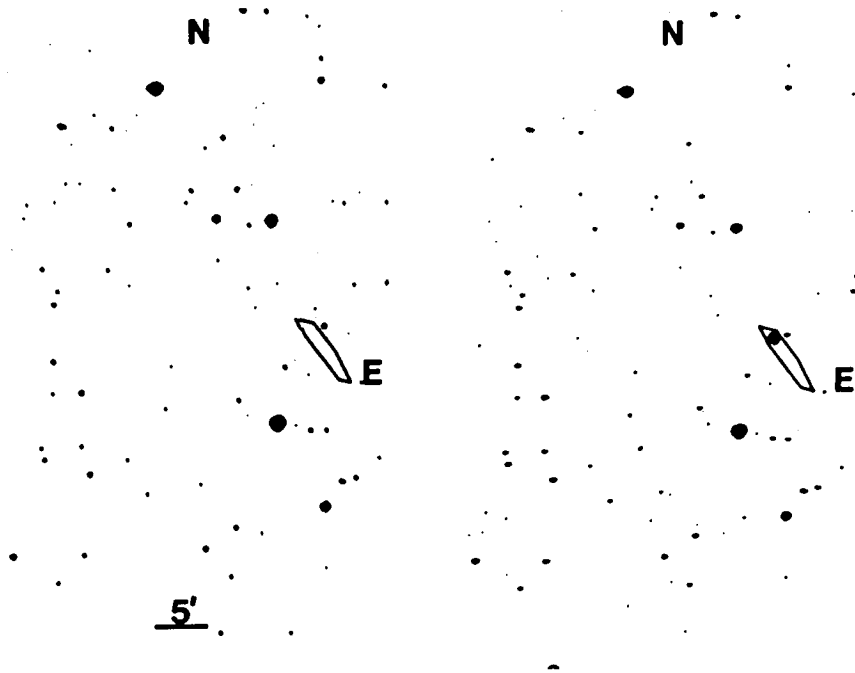
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Figure 2. Two 1928 archival plates, including the one with the first optical transient [Schaefer, 1983] found within a gamma ray burst source field [Cline et al., 1984], which is also plotted.

instrumentation had been in operation for three years' time, still appears as a reasonable approximation. No event monitored in the seven years since has come close to duplicating it. The Leningrad group concentrated on the 8-second periodicity as a central feature and found that the continuum spectrum was softer than usual [Mazets et al., 1979a]. It also later discovered the series of small events that appeared to trickle out in sequel fashion [Mazets et al., 1979b]. Instruments on ISEE-3, Helios-2, and Pioneer-Venus Orbiter had the resolution to observe the <0.2 msec risetime of this transient [shown in Figure 3; Cline et al., 1980], which remains particular only to this event of the many hundreds logged. The initial measurement of the source direction [Evans et
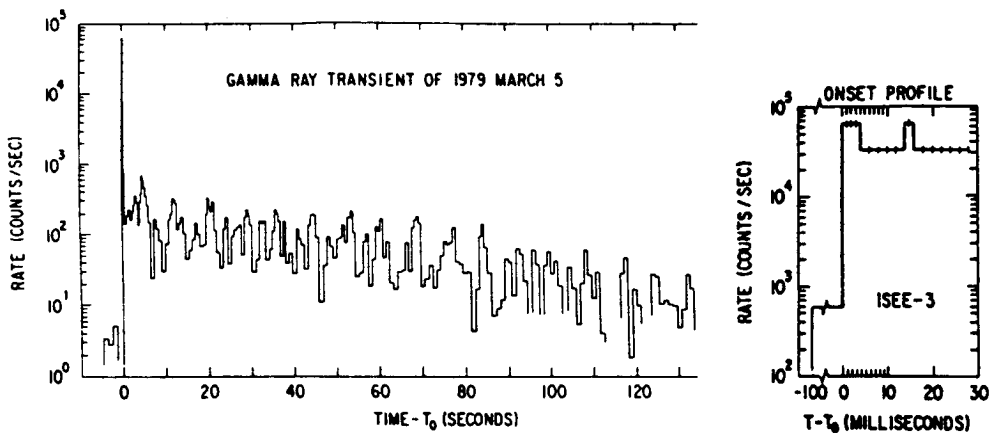
Figure 3. The time history of the March 5, 1979 event [Cline et al., 1980]. On the left is the overall picture, illustrating the intense, 150-msec wide peak and the periodic declining afterglow. On the right is the detail of the unique onset, with its < 0.2 msec rise time constant.

al., 1980] provided the spectacular but controversially interpreted result of a precise, two-arc-minute fit onto the position of N49, a supernova remnant in the Large Magellanic Cloud (LMC) at a distance of 55 kpc, about 5 times the distance from us of the galactic center. A complete analysis using all available measurement capability refined it to a sliver-shaped field only seconds of arc from the center of N49 [Figure 4; Cline et al., 1982]. This remains as the most precise measurement in gamma ray astronomy.

The photon spectrum of the March 5 event, like some others, contained a 400 keV increase [Mazets et al., 1979a]. This experimental feature was barely capable of independent confirmation, using the ISEE-3 high resolution gamma ray spectrometer, only in the case of another event [Teegarden and Cline, 1980]. Its existence remains as a controversial issue, given the lack of confirmation with the SMM spectrometer [Nolan et al., 1983, 1984] in a large number of more recent Venera events. Soon after the March 5 event, its various features, including the line, were fit to models consistent with the N49 distance [Ramaty et al., 1980; Liang, 1981]. One possible explanation for the energy
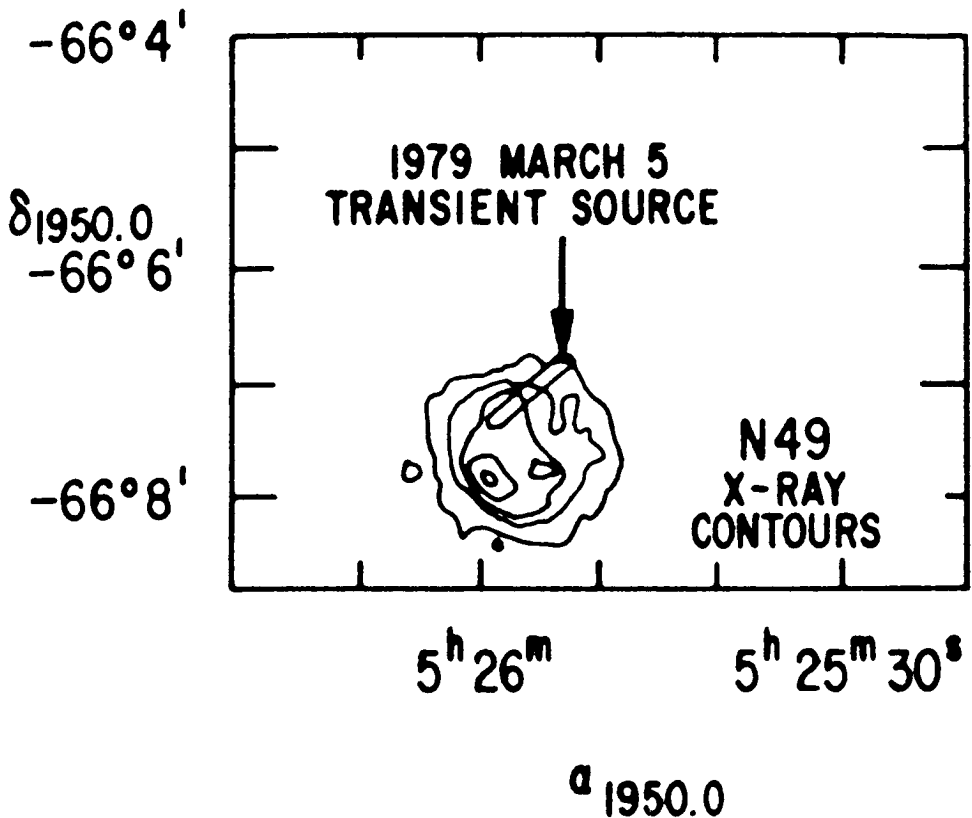
Figure 4. The precise source position of the March 5, 1979 event [Cline et al., 1982], plotted on the contours of the N49 supernova remnant, as measured with the Einstein X-ray telescope [Helfand and Long, 1979].

mechanism used the gravitational storage mode of a neutron star [Ramaty, Lingenfelter, and Bussard, 1981]. This source controversy also persists, with a very recent contention that the distance of N49 may be outside that physically possible by a factor of about 5 unless some gamma ray beaming exists [Liang, 1986]. Such a requirement does not seem a strong constraint, given the rarity of the sole detection.

5. PHENOMENOLOGY

The intent of this note is not to review the field of gamma ray transients, quite the contrary. My purposes in what remains—acknowledging the encouragement of Frank McDonald in the creation of the network—are to tie these examples of the early contributions that the network made to astrophysics together with certain very recent developments (that it also made possible) and to provide a new viewpoint regarding the observations. This recent view [Cline, 1986] appears to be compatible with all the facts and to provide the possible resolution of certain current inconsistencies. It also continues to favor an N49 source for the March 5, 1979 event, the identification, as outlined above, that I have always supported.

The subject of gamma ray bursts has been reviewed in detail in three conferences and workshops in recent years, with published proceedings edited by Lingenfelter, Hudson, and Worrall [1982], Woosley [1983], and Liang and Petrosian [1984]. These reviews virtually exhausted the material then available and are highly recommended. In spite of all the attention to the details of the experimental results, however, very little that is definitive has been produced by theoretical burst studies. This is not entirely the 'fault' of the theoreticians, since (with the exception of the March 5 event) there is no identified candidate source object to provide a source distance, nor is there a source pattern anisotropy to calibrate a scale for the source distances within the galactic disk.

There is another shortcoming inherent in interpretations of continuum burst spectra. I base it on a combination of misfortunes: (1) gamma ray spectra are 'obliging', which means that the observed pulse height distributions cannot be unambiguously converted into energy spectra; (2) burst time histories, from early measurements to the present, are seen to fluctuate dramatically, perhaps beyond the limits of instrumental resolution—and energy spectra are of necessity measured with considerably coarser time-resolution than are time histories—so it is clear that their inferences may be in considerable error [e.g., Norris et al., 1986]; and (3) even minimizing these limitations, observed burst spectra generally happen to be quite amenable to a wide variety of presumably specific fits. Thus, a 'fault' of the model makers may instead be excessive zeal, permitting overconfident interpretations of the experimental details. In

fact, with so little that can be truly pinned down about gamma ray bursts, the range of source ideas seems to have stopped converging but instead now provides some *deja vu* with its variety. One recent cosmological origin model combines the latitude that modern physics and superstrings can give to the imagination with gravitational focusing [Paczynski, 1986].

One gamma ray burst observational puzzle has centered for years on the inconsistency of an observed cutoff in the size spectrum with the fact of an isotropic source distribution, as one sample illustrates in Figure 5. (A plot of the integral number of events 'N(S)' seen with magnitude greater than size 'S' would obey a power law of index -1.5 if the sources are randomly distributed throughout an indefinitely extended three-dimensional region of space; it would taper to an index nearer -1.0 for a population of events coming from a two-dimensional source volume like the galactic disk, in which case an anisotropy could be observed.) A great deal of attention has been devoted to resolving this problem. Approaches range from the adoption of a galactic halo source region [Jennings, 1985], which would be clearly consistent both with isotropy and with a size spectrum cutoff, to the selection of a redefinition of 'size' (using peak, rather than total, intensity) that can be adjusted so as to provide a spectrum with no cutoff problem [Higdon and Lingenfelter, 1986]. Also, it has been popular to simply attribute instrumental inadequacies and miscalibrations as responsible for any observed cutoffs so as to dismiss the problem. The latter permits the view that burst sources are very near by, even compared with the thickness of the galactic disk, a view that always had the intrinsic appeal of minimizing energy considerations. The earliest models required a nearby source from photon density considerations [Schmidt, 1978], although their unconfirmed spectral 1 MeV cutoff is another question.

I have been concerned for some time, however, that the size cutoff problem is more involved than is given credit, with its generally unnoticed connections to two other issues. First, the occurrence of groups of typically small events had been observed on at least two occasions [Mazets et al., 1979b, 1981]. Each presents a cluster in time from 'repeater' sources, i.e., each series has its own mutually consistent source directions. One concern was therefore that if the instruments in use are able to observe small events, identifying them in isolated groups or patterns, and if these are also gamma ray bursts, then those same detectors could not be exhibiting the instrumental insensitivity that appears
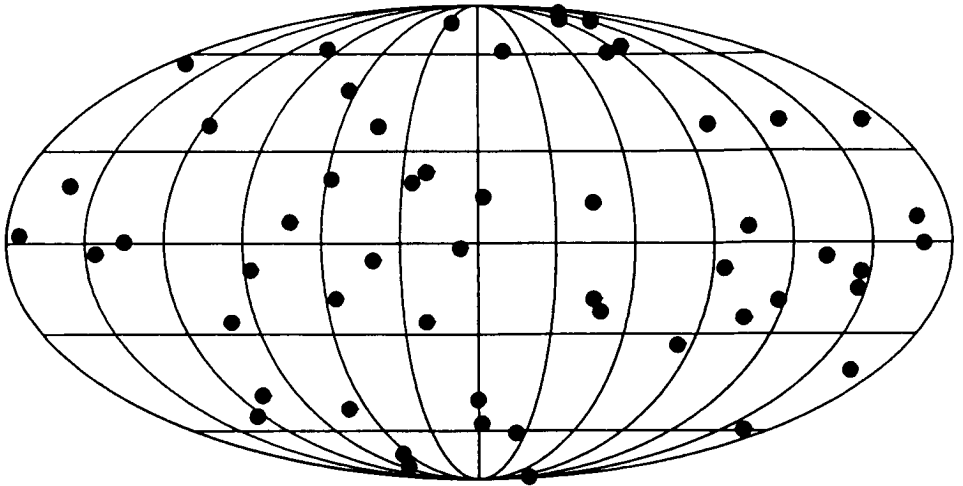
Figure 5. One source distribution pattern of gamma ray bursts [Atteia et al., 1986], seen to be consistent with isotropy. Different instruments produce their individual catalogs; this one was recently compiled with observations from the interplanetary network.

to exist regarding the creation of a cutoff in the size spectrum of the more intense events. The small events should also be observed in greater numbers, in random directions and at random times like the larger bursts, quite clearly not occurring only in specific directions and in groups. One possible resolution to this seemingly trivial inconsistency is discussed below.

The second concern was that the March 5, 1979 event and its properties may be misunderstood, i.e., underestimated in its relevance, in two ways:

(1)   The event surely has too precise a positional agreement with the supernova remnant N49 to have that possible identification ignored by writing it off as 'accident'. In spite of the great mathematical unlikelihood of its chance coincidence, a variety of workers in this field have, since its discovery, preferred to work on that event as an unusually bright gamma ray burst considering it to be from a source

possibly closer than most [e.g., Helfand and Long, 1979]. I have felt that this outlook would needlessly waste a singular opportunity to investigate what may be a far more instructive lesson in physics.

(2) The March 5 event was too anomalous in its properties, with its < 200 microsecond onset time constant and its clear periodicity, to be defined as 'another' gamma ray burst. Both of these properties remain as anomalous as ever, with the accumulation of hundreds of additional events for comparison [e.g., Hurley, et al., 1987]. The opposing view is that an economy of assumptions argues against considering the event to be in a distinct class. However, to identify that event as a typical gamma ray burst and interpret its periodicity as confirming a neutron star origin concept for gamma ray bursts always seemed to me surely distasteful if the phenomenon of its periodicity sets it apart from all other gamma ray bursts. That approach has also seemed to me particularly unaesthetic if its source identification with a supernova remnant (an object necessarily associated with a neutron star) is simultaneously dismissed.

Thus, the issue of the gamma ray burst size spectrum was not separable either from the problems of understanding the distance of the most interesting event or from the issue of the number of event classes.

Two other distinctive features of the March 5, 1979 event pertain to the scenario to be suggested. First, as alluded to earlier, it appears to have a considerably softer spectrum than most gamma ray bursts. A large proportion of bursts intense enough to permit accurate differential spectra are characterized in the 150 keV region [Cline and Desai, 1975] with recently found extensions to many tens of MeV [Matz et al., 1985]. The March 5 event, like its associated sequel series and like the other spring 1979 series, is characterized instead in the 30 keV region.

Second, the fact that this intense event can be associated with several other events is both unique and relevant. All hard or 'classical' bursts appear to be isolated in source direction. Low-intensity events followed (and perhaps other similar events may have preceded) the March 5 event. These events were found from 1979 to at least the early 1980's with independently determined

source directions that overlap onto a common field of one or two square degrees [Mazets et al., 1981] implying a common source. That field includes the arc-minute source field of the March 5 event, implying in turn that both it and this series originated from the same source. The positional evidence for that identification is a factor of about 3600 weaker than the positional connection of the March 5 event to N49 (!) but no analogous reasons exist to contest it. The small events have similar maximum intensities but their time histories vary considerably. One flat 'square wave' of 3.5-second duration has no trace of the compound 8-second periodicity so clear in the March 5 event, providing an incidental piece to the puzzle.

6. CONCLUSIONS

A recent discovery is that a third series has been found. This one has a source direction in the galactic bulge at several degrees from the galactic center (close enough to support the assumption that its origin is likely to be at that distance) and consistent with the source direction of an event of four years' earlier observation [Laros et al., 1986]. Some of the generally small and brief events were found buried in 1983 Prognoz-9 data [Hurley, et al., 1987], and were confirmed as well as augmented with a greater profusion of single-spacecraft candidate events in ISEE-3 data [Laros, et al., 1987]; some were also confirmed in SMM data [Kouveliotou, et al., 1987]. The spectrum of the January event is somewhat similar to the spectra of the other two repeater series. All three have spectral characters in the 30 keV region, well above that of X-ray bursts and equally well below the several hundred keV character of the hard gamma ray bursts. As mentioned above, this further distinguishes them from the hard bursts, none of which have yet been found to repeat. The parameter of time history also provides at least a statistically distinguishing feature: the hard bursts can have temporal durations over a very wide range, from the fractional seconds to at least one minute, as well as varying from simple to complex in temporal structure, whereas the soft events are generally brief and simple.

Thus, a new classification of events (occasionally suggested over the years to account for earlier indications of distinctions based on one or another of these three parameters) now appears to be more evident than before. It seems

that this consideration also resolves several features of the size spectrum issue discussed in previous pages. The repeating, soft bursts and the hard, or 'classical' bursts differ considerably in their source and emission properties. Thus, detector effects clearly could provide for a relative sensitivity to one class and a relative insensitivity to the other, producing the 'cutoff' in the classical gamma ray burst size spectrum but having an entirely differing bias for the repeater populations—yet unknown, since their size spectra are entirely uninvestigated. Further, all the small-event repeating series appear to fit this class of events, with characters intermediate in energy at around 30 keV and with basically single-spiked time histories. The March 5 event process itself must relate to the production of that class. Since these intermediate-energy and hard classes of gamma ray transients have so little in common, the fact that the periodicity of the March 5 event may imply its neutron star origin does not necessarily reflect on the origins of 'classical' gamma ray bursts—although it is certainly most likely that all kinds of transients from X-ray bursts to gamma ray bursts do have neutron star origins. The emission processes responsible for these event classes, however, may be surely as distinct as they appear to be.

What I suggest, in concluding, is the possibility of a fourth characteristic that may distinguish these two event classes, namely, source direction pattern. Gamma ray bursts of the hard, nonrepeating, and common variety may have an isotropic source pattern, but the source directions of the three series of soft repeating events can be interpreted to show a glimmer of an emerging pattern. Based on the 'statistics of three counts', of course, it is nevertheless interesting to note that the three repeaters have sources consistent with the galactic plane, the galactic bulge near the center, and N49 in the nearby (by galactic dimensions) LMC.

All this defends the N49 identification with a plausibility picture, based on the occurrence of repeating event origins in high density (galactic or LMC) regions. It is consistent with resolving the several inconsistencies in gamma ray burst phenomonology outlined earlier. As illustrated in Figure 6, this contention makes for a comparison of the familiar source pattern seen in visible starlight, in X-ray binaries [Wood et al., 1984], and in the infrared. Also, the intensities of the galactic bulge events may be assumed to be somewhat greater than those of the sequels from the March 5 source, since they have
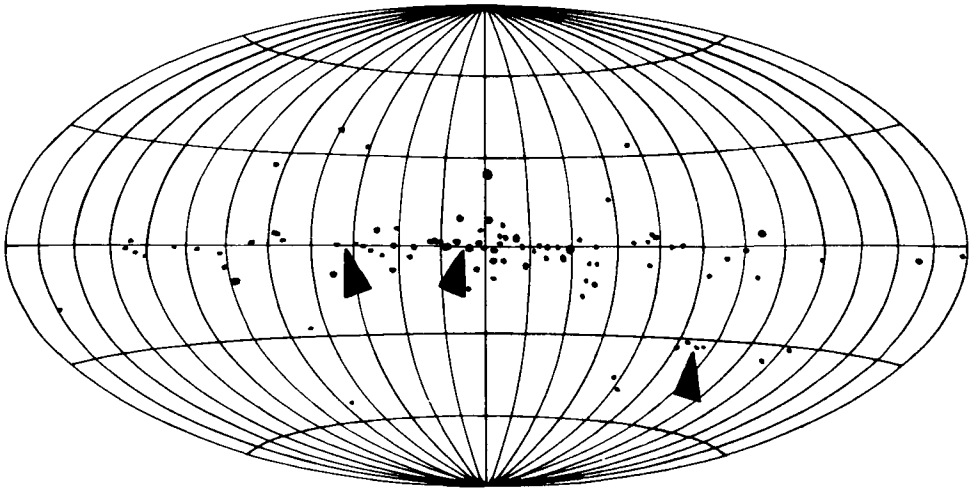
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Figure 6. The sources of the three known intermediate-energy, repeating gamma ray transient series. It is too soon to have a statistically meaningful pattern; the three locations available are, like the X-ray binaries, consistent with high density regions in the disk and LMC.

been observed with less sensitive instrumentation. (That is, the only detector capable of detecting the March 5 sequels was not in use for the recent bulge event discovery, whereas some of the instruments observing the recent series had also been up during those years.) That inference is consistent with the fact of the galactic center to LMC distance ratio. The March 5 event itself is, as before, the exception. Perhaps further analyses will provide new enlightenment. In the meantime, the viewpoint suggested may provide a clue towards the understanding of the nature of the singular March 5 event and of gamma ray transients in general.

7. EPILOGUE

Questions form the natural termination of a science essay, rather than a list of accomplishments. The questions-to-answers ratio in the situation regarding gamma ray bursts is larger than that which is typical for a subdiscipline

now over 12 years old. 'Enigmatic' is still one of the adjectives often used and 'puzzle' a frequent noun. Given the continued nonavailability of reliable long duration balloons, it is a fact that all variations of gamma ray transients can be investigated only with spacecraft, although the optical transient connection may someday permit sea level studies to be made. The Gamma Ray Observatory will contain the only 'next-generation' instrument planned to be put in orbit for some time, although several instruments similar to those used in the past decade will continue to see service on nondomestic programs. No plans exist for a spacecraft high resolution gamma ray burst spectrometer that might, for example, separate red-shifted annihilation lines from those expected from a 'grasar', i.e., a gamma ray annihilation line laser [Ramaty, McKinley, and Jones, 1982]. Such are the unanswered fantasies that studies of gamma ray transients can promote. Valuable and hopefully definitive information should surely be forthcoming from GRO. Perhaps the continued scrutiny of existing data will produce additional surprises. Frank McDonald has said, "Are gamma ray bursts a transient phenomenon?" Was the exploration of space, as we knew it in the decades past, with its opportunities for highly individualized creativity, flowering within the massive and seemingly impersonal team projects, a transient phenomenon? One thing is clear: the heyday of space science was both Camelot, as those in Greenbelt happily knew it, and wild frontier, as those who launched their own science payloads in balloon gondolas, rockets, and satellites are privileged to remember. As such, like the physics era of 'string and sealing-wax', it cannot be repeated.

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