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ABSTRACT

The precise source regions of three moderately intense gamma ray bursts are derived. These events were observed with the first interplanetary burst sensor network on 1978 November 24 and 1979 November 5 and 16. The optimum locations of the detectors, widely separated throughout the inner solar system, allowed for high-accuracy, over-determined source fields of size 0.7 to 7. arc-min^2. All three locations are at fairly high galactic latitude in regions of low source confusion; none can be identified with a steady source object. A search in archived photographs for transients that can be associated with these source fields, however, produced one of the two optical flash events described in the companion Letter (Schaefer et al., 1984). These provide the first confirmation of the gamma-ray burst/optical transient association discovered by Schaefer (1981).

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INTRODUCTION

The understanding of gamma-ray bursts has been slow to evolve, due in large part to the lack of identifications with known celestial objects. Only the event of 1979 March 5, a transient with characteristics that can be argued to be anomalous (Cline et al., 1980), has a source field consistent with a known celestial object. This is the supernova remnant N49 in the Large Magellanic Cloud (Evans et al., 1980; Cline et al., 1982) which, as a source identification, is nevertheless controversial because of its extragalactic distance. All other high-precision gamma-ray burst source fields are either empty of steady optical objects down to mag 22 (e.g., Laros et al., 1981; Cline et al., 1981; Barat et al., 1983) or can be subject to background object confusion (e.g., Barat et al., 1984). The discovery of an archived optical transient (Schaefer, 1981), positioned within an apparently empty field of several arc min in dimension (Cline et al., 1981), may provide the means to reduce the search area to several arc-seconds in extent. Deep optical searches of this region have thus far produced evidence for source objects that are marginal, ambiguous, and/or variable in time (Pederson et al., 1983; Schaefer et al., 1983).

We report here the accurately defined source fields of three additional gamma-ray burst events detected with the first interplanetary network, the system used for all high-precision directional measurements during 1978-1980. These events may be the last that can be derived in such an optimum, over-determined manner (i.e., with four or more spacecraft at mutually great separations--see Figure 1) until the late 1980s. The three bursts vary in character but are all moderately intense--permitting their detailed study with the interplanetary network. The common feature resulting from the source 'triangulations' is that of a precisely determined source field. All three are removed from the galactic disk and therefore in regions of relatively low stellar density. Searches for associated phenomena that can point to possible celestial source identifications are thus facilitated with these events. Two of the source fields are near to the celestial equator and are thus amenable to scrutiny using ground-based telescopes in both the northern and southern hemispheres. The first and only known optical association with any of these regions is an optical flash archived since 1901, and recently uncovered, as described in the companion Letter (Schaefer et al., 1984). That paper reports on both this and another optical flash (photographed in 1944) that appear to provide the first confirmation of the flash/burst association discovered by Schaefer (1981). The original association linked a 1928 flash to the source area (Cline et al., 1981) of the 1978 November 19 burst. The 1901 optical transient location is within the 1979 November 5 burst source region reported here with a $\lesssim$ two standard-deviation error. This fit is entirely similar to the fit of the initially discovered 1928 transient-1978 gamma-ray burst source association when analyzed in a similar manner.

INSTRUMENTATION

The observations described here were made with various instruments participating in the first interplanetary spacecraft network of gamma-ray burst sensors. This array was composed of both satellites and spaceprobes. The near-Earth spacecraft included the same Vela satellites that discovered the gamma ray burst phenomenon over a decade ago (Klebesadel et al., 1973), the Earth Satellite Prognoz-7 and the ISEE-3 probe. That vehicle orbited the primary Sun-Earth Lagrangian point when making the observations described nere; it is now in a comet-encounter trajectory. The distant space probes were the Pioneer-Venus Orbiter, Veneras-11 and -12 in transit towards or away from Venus, and Helios-2 in solar orbit. A considerable number of other events are yet to be described in print by this consortium; these were observed either with fewer spacecraft and/or with less precision. Full descriptions of the instruments have been published (see, e.g., Anderson et al., 1978; Barat et al., 1981; Cline et al., 1979; Evans et al., 1979; Klebesadel et al., 1980) and need no elaboration here. The Venera-11 and -12 and Prognoz-7 instruments are Franco-Soviet collaborations on Soviet spacecraft. The Goddard Helios-2 instrument was added on to a Goddard experiment on the German Helios spacecraft and both the Los Alamos and the Goddard ISEE-3 experiments were add-on modifications to other experiments on the NASA International Sun-Earth Explorer. The Pioneer-Venus Orbiter instrument is a Los Alamos experiment on that NASA vehicle, and Los Alamos instruments on the Vela spacecraft array are independently supported, presently by the Department of Energy.

DATA ANALYSIS

The data analysis techniques used to derive the gamma ray burst source fields are a continuation of those methods described in earlier studies, such as for the 1979 March 5 event (Evans et al., 1980; Cline et al., 1982), the 1979 April 6 event (Laros et al., 1981), the 1978 November 19 event (Cline et al., 1981) and the 1979 June 13 event (Barat et al., 1983). Analyses of those events have demonstrated that the various residual errors in timing accuracy are correctly estimated. The heliocentric timing technique, which is entirely equivalent to an aberration correction, has also been developed. In this paper, we extend those methods with a new technique that derives a single, composite error field from four or more spacecraft observations. Our previous derivations reported the most accurate, mutually-dependent three-spacecraft error fields (e.g., Evans et al., 1980 and Cline et al., 1981). The new method has the advantage that it makes use of all of the available directional information, weighting each measurement appropriately to yield one final result. It can be outlined as follows. Comparison of the wavefront arrival times at each of any two spacecraft defines a ring-shaped celestial source region locus. The accuracy of this comparison is a function of how well the time histories from the different detection instruments can be compared. (Figure 2 illustrates the variability in time-history determination for these events.) Any point in celestial coordinates is separated from each ring or annulus by some distance that is related to the probability of its likelihood as source. For N spacecraft there are N(N-1)/2 annular loci that can mutually intersect in up to N(N-1)(N-2)/3 source "triangulations". For example, five spacecraft can produce 20 "triangulations". When the time history alignment adjustments and readjustments are made (often with laborious reanalyses of data) such as to permit half of the intersections (one on each ring) to cluster, then the event is considered by the experimenters to be localized. For redundant, > 3-spacecraft situations, all the data producing these several overlapping 'triangulations' are now taken into account by defining a goodness-of-fit value for each point in space. Given that the separation of that point from each of the source rings is associated with some error related to the mutual data comparison from that pair of observations, the normalized rms summation of these errors constitutes the likelihood value of that point as source. The normalization results from the fact that 3 spacecraft can define one source field uniquely. Contours of regions of source likelihood then result from plots of these grids of individual fit values.

RESULTS

The gamma-ray burst source fields are shown in Figure 3. The sizes of these source regions vary from 0.7 to over 7 arc-min^2, small enough to easily permit detailed study, particularly since they are all in regions of very low stellar image density. As yet, there is no evidence for association with any candidate steady source object. Computerized searches through catalogs of positions of compact objects including supernova remnants, pulsars, neutron stars and white dwarfs did not yield any positive results. This situation is similar to all the past burst event analyses, other than that of 1979 March 5. An optical transient, similar to that discovered by Schaefer (1981), in the 1978 November 19 burst source field was, however, also found in the 1975 November 5 burst source field developed here. The evidence for the existence of this optical event is discussed in a companion Letter (Schaefer et al., 1984). This is one of two optical transients that provide the first confirmation of the gamma-ray burst/optical transient association. The great advantage of the detection of an archived optical event is its aid in reducing the source location field by another order of magnitude or more, assuming no proper motion. Deep optical scrutiny of the first of these three tiny ($\approx$ 0.04 arc-min^2) source regions has, thus far, produced only marginal and/or ambiguous results (Pederson et al., 1983; Schaefer et al., 1983).

This letter and a companion paper outlining the 1979 January 13 event analysis (Barat et al., 1984) complete the published descriptions of all the most accurately definable source fields from the first network that are overdetermined, i.e., all those that can be determined with a wide, interplanetary scatter of ≥ 4 spacecraft. Descriptions of certain other well-defined burst source regions are in press (Laros et al., 1984). These events occurred after the Venera spacecraft separated at a great distance from Venus (and from the Earth), providing a third long baseline, required after the demise of Helios-2. Future high-precision gamma ray burst source location observations from interplanetary spacecraft will also include some events from the second network, making use of observations from Veneras-13 and -14 during a several-month period with adequately long baselines following their Venus encounters in 1982-1983. The ICE (formerly called ISEE-3) spacecraft in its 1984-1985 comet-encounter trajectory may make possible an additional long-baseline network of limited lifespan. Finally, networks later in the decade will incorporate the International Solar Polar Mission and possibly other planetary missions. It is yet entirely possible that some source pattern or identification will emerge from their results and from the optical transient studies they promote.

REFERENCES

Anderson, K. A., et al. 1978, IEEE Trans., GE-16, 157.

Barat, C., et al., 1984 (Ap. J., in press).

Barat et al., (submitted to Ap. J. Letters).

Cline, T., et al., 1979, Ap. J. (Letters) 229, L47.

Cline, T., et al., 1980, Ap. J. (Letters), 237, L1.

Cline, T., et al., 1981, Ap. J. (Letters), 246, L133.

Cline, T., et al., 1982, Ap. J. (Letters), 255, L45.

Evans, W. D., et al., 1980, Ap. J. (Letters), 237, L7.

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

Klebesadel, R., Evans, W., Glore, J., Spalding, R., and Wymer, F., 1980, IEEE Trans. GE-18, 1.

Laros, J. G., et al., 1981, Ap. J. (Letters), 245, L63.

Laros, J. G., et al., 1984, submitted to Ap. J.

Pederson, H., Motch, C., Tarenghi, M., Danzinger, J., Pizzichini, G., and Lewin, W. H. G., 1983, Ap. J. (Letters) 270, L43.

Schaefer, B. E., 1981, Nature, 294, 722.

Schaefer, B. E., Seitzer, P., Bradt, H. V., 1983, Ap. J. (Letters), 270, L49.

Schaefer, B., et al., 1984, submitted to Ap. J. (Letters).

FIGURE CAPTIONS

Figure 1. Instrument geometry for the three burst events projected on the ecliptic plane: the 1979 November arrays (+ and x) constitute optimum detector situations with overdeterminations (> 3 spacecraft) having mutual separations all with long baselines. The 1978

November array is more typical, with a fractional-AU scatter (indicated with dots). The Earth-orbiters Prognoz-7 and Vela 5 and the position of the Sun give the 1-AU scale. The ecliptic latitudes of the 3 gamma-ray burst directional vectors are 15 to 22 degrees. This fact, combined with the near-ecliptic plane locations of the instruments, limits the source field accuracies more in declination than in right ascension.

Figures 2a, b, and c. Sample time histories of the bursts. (a), the 1979 November 16 event is statistically well defined; it is unusual with a quiet gap of nearly 1-minute duration separating two intense features. (b), the November 24 event consists of broader, less well-defined features. (c), the November 5 event is fairly weak but typical, with randomly and rapidly fluctuating features. The accuracies of time history comparison vary, with typical values in the 50-120 msec range.

Figures 3a, b, and c. The contours of source region likelihood: the dashed areas are meant to represent 99 percent confidence limits, and the inner areas, 90 percent confidence. The error field of the best resolved event is about 0.7 arc-min^2 in size. The source of the optical transient of Schaefer (1984) is located less than 1 arc-minute from the axis of one burst source field, but is not entirely inside the inner area. This is taken to be statistically reasonable and is not regarded as meaningful evidence for source proper motion. A reanalysis, with this method, of the 1978 November 19 burst event gives the location of the first archived optical flash (Schaefer, 1981) also to be on the edge of the inner, ~ 90 percent-confident, area.

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ADDRESSES

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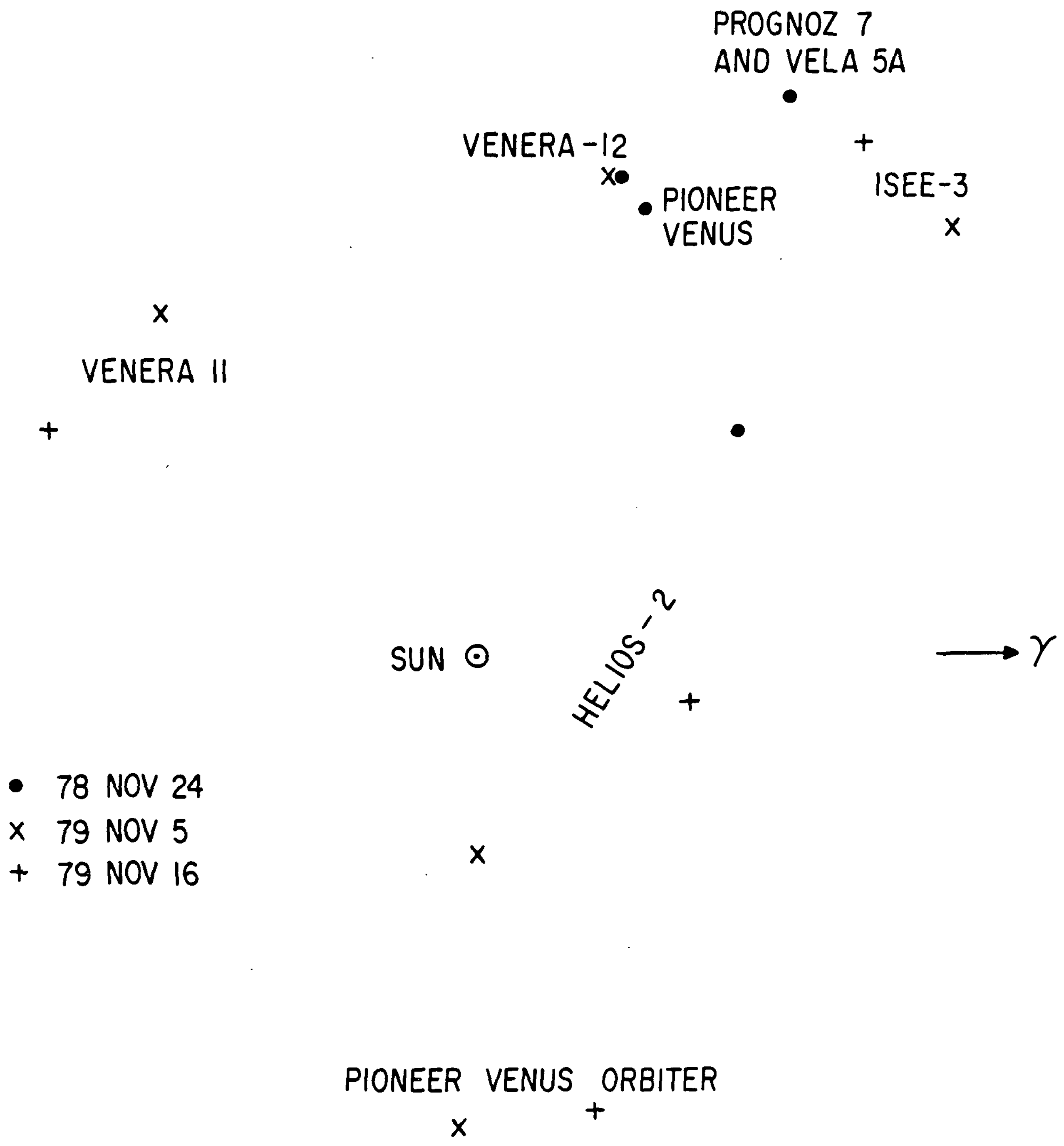
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AND VELA 5A
VENERA-12
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VENUS
ISEE-3
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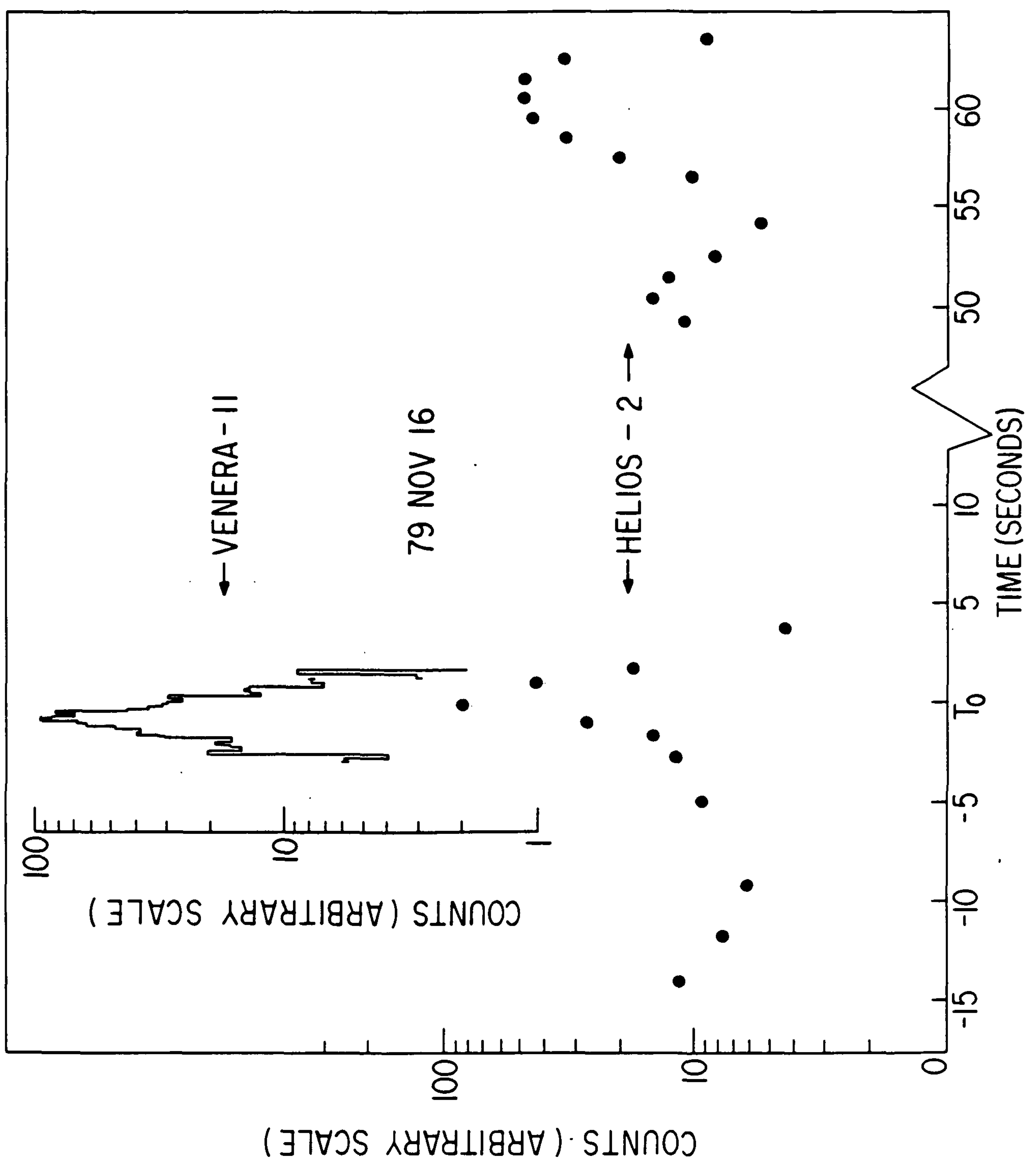
• 78 NOV 24
x 79 NOV 5
+ 79 NOV 16
PIONEER VENUS ORBITER

Fig.1



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←HELIOS - 2 →
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Fig.2A

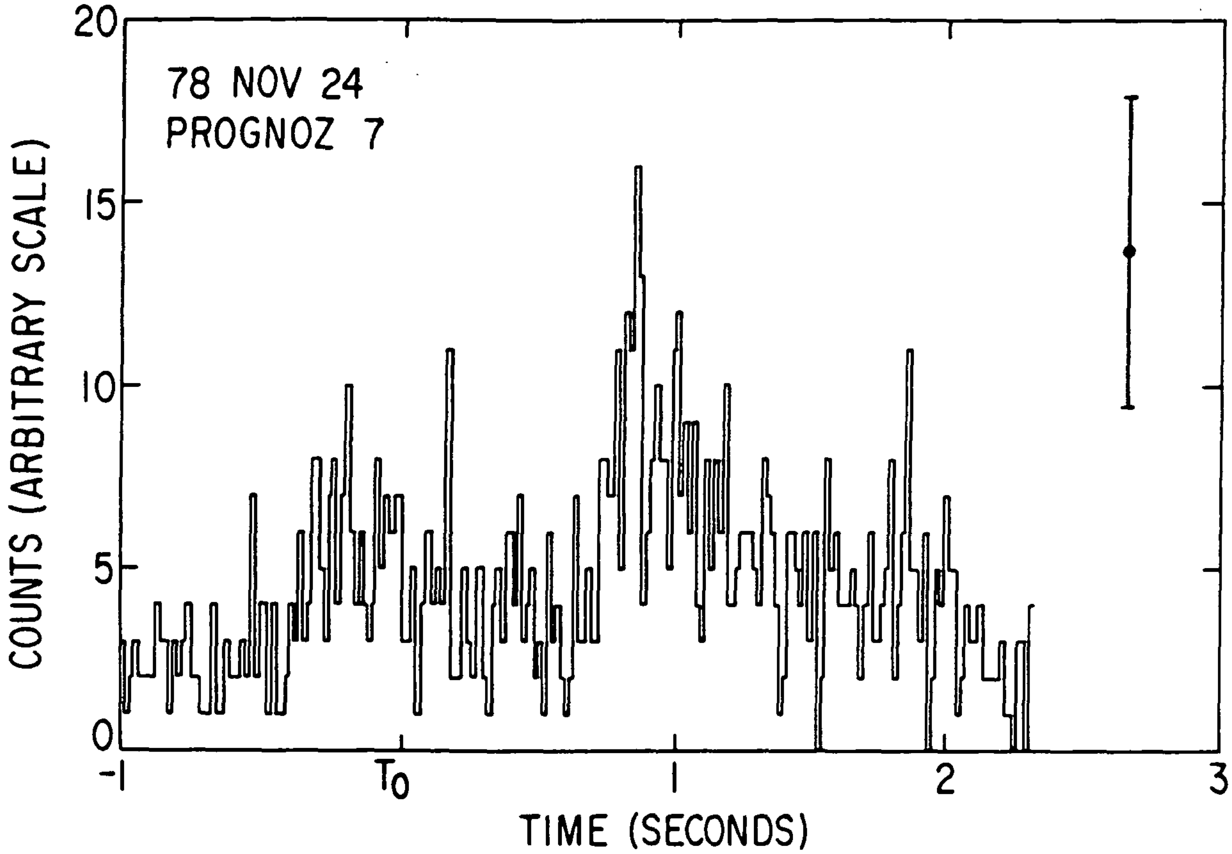

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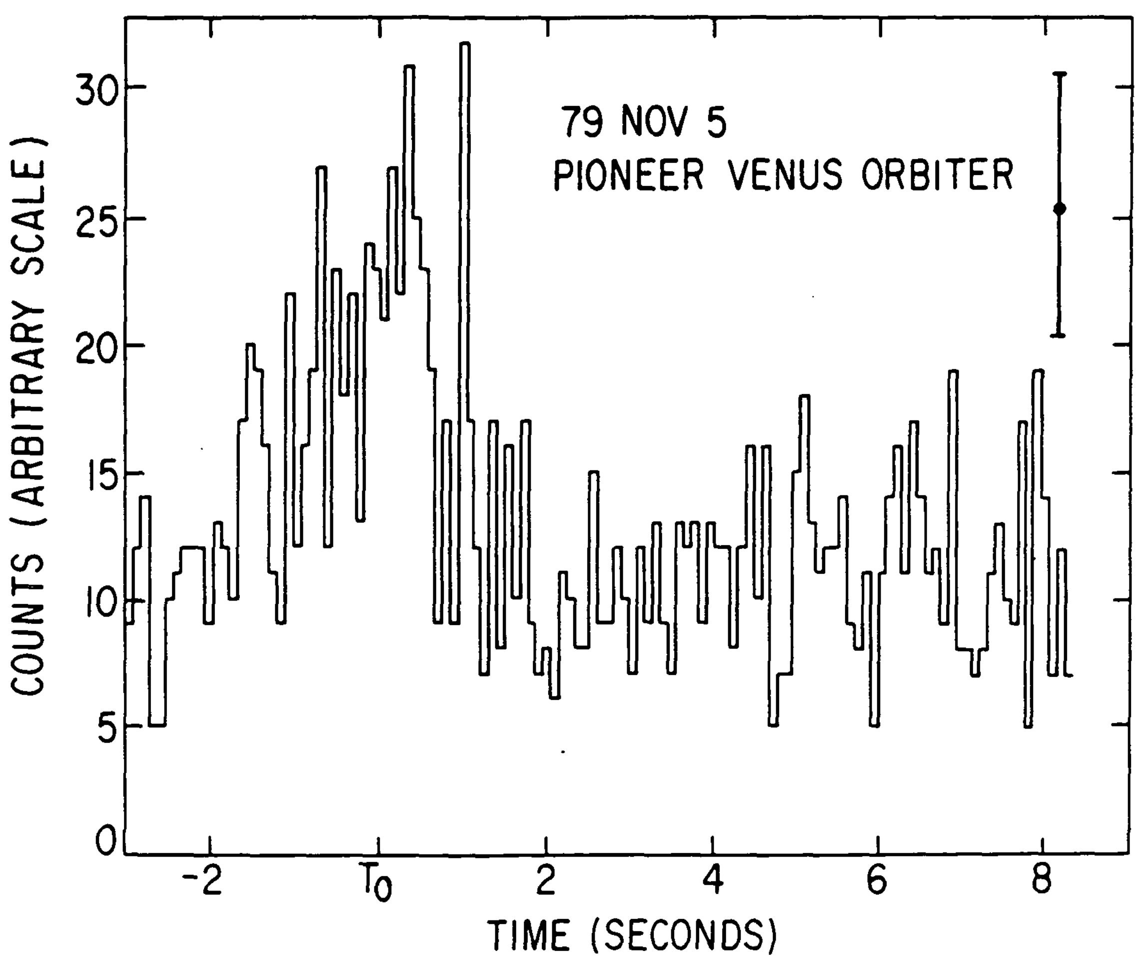
Fig.2B



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COUNTS (ARBITRARY SCALE)
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Fig.2C

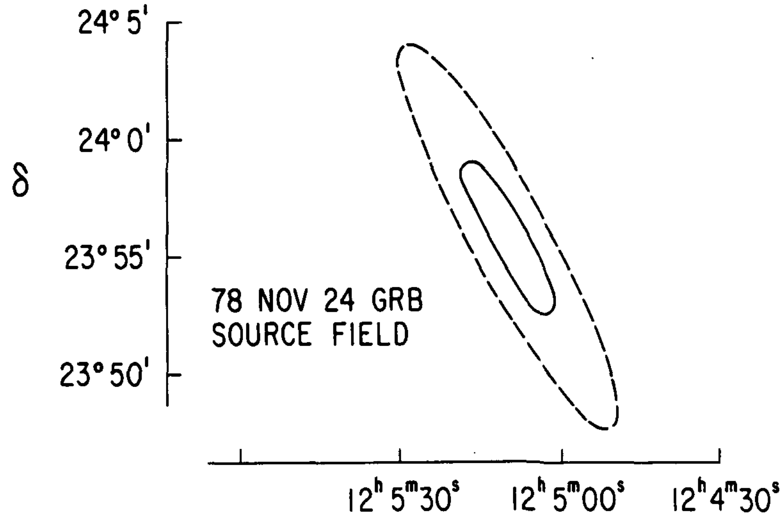

Fig.3A

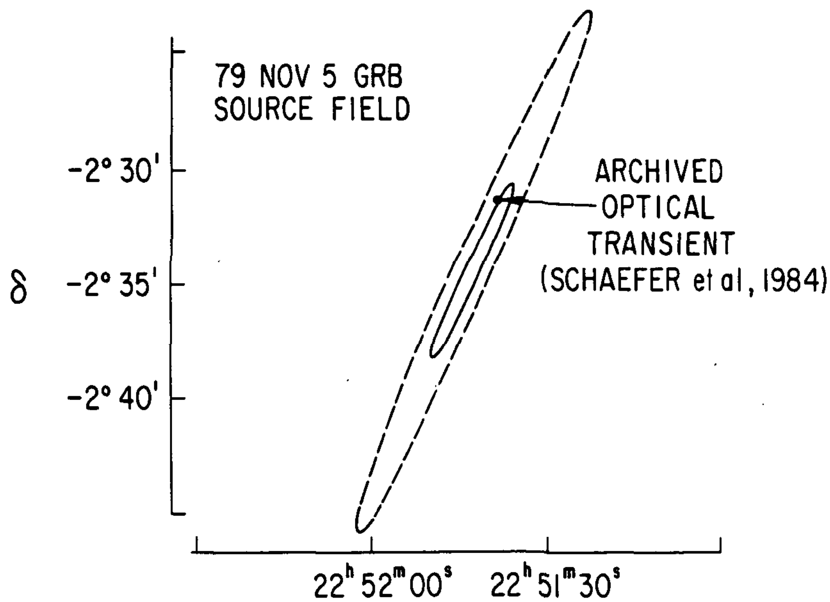

Fig.3B

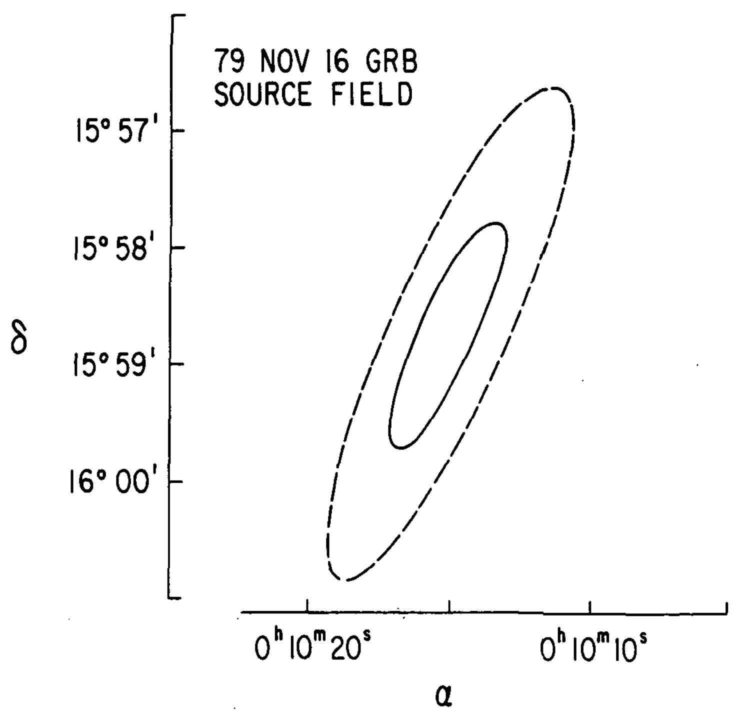

Fig.3C

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16. Abstract

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