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Precise Source Location of the Anomalous 1979 March 5 Gamma Ray Transient

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GAMMA RAY TRANSIENT

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ABSTRACT

Refinements in the source direction analysis of the observations of the unusual 1979 March 5 gamma-ray transient are presented. The final results from the interplanetary gamma-ray burst network produce a 0.1 arc-min² error box. It is nested inside the initially determined 2 arc-min² source region of Evans et al. (1980) that identified the supernova remnant N49 in the Large Magellanic Cloud as a possible source. This smaller source location is within both the optical and X-ray contours of N49 although not positioned at either contour center.

I. INTRODUCTION

The gamma-ray transient of 1979 March 5 is one of the most singular astrophysical phenomena detected during the last two decades of observations made with space-borne instruments. Its phenomenology (including a record intensity of 2×10^{-3} erg cm⁻² sec⁻¹, a $\lesssim 200$ microsec risetime, and a regular 8-second oscillating decay) appears to be unlike that of the "classical" gamma-ray bursts (Cline et al. 1980a) that have been observed for some years (Klebesadel et al. 1973). It does, however, have a ≈ 400 -keV spectral feature (Mazets et al. 1979a) as do some classical bursts (Mazets et al. 1979b; Teegarden and Cline, 1980). Neutron-star origins for both phenomena can be therefore inferred, invoking a ≈ 25 percent gravitational redshift from the 511-keV annihilation line energy. Its source location, although compatible with that of the supernova remnant N49 in the Large Magellanic Cloud (Evans et al. 1979a; 1980) has not been generally recognized as an actual source object identification, due to the concern that the distance of 55 kpc renders source modelling difficult. However, the existence of at least one modelling exercise (Ramaty et al. 1980a, 1980b) invoking N49 as source and providing good fits to the observations dilutes that objection. A recent extension of that model yields an independent source luminosity, derived from first principles, of $\sim 10^{44}$ ergs sec⁻¹, entirely consistent with this event at the source distance of the LMC (Liang 1981).

The fact that this gamma ray event, possibly the only one of its kind clearly identified in over a decade of monitoring, is presently generating a variety of observational and theoretical studies prompts a thorough reanalysis of the available data in order to produce the most precise source location possible. In a review of the data from seven spacecraft, using the final ephemeris corrections, we have determined that a precise error box can be defined that is both inside N49 and off its center. We believe that the

accuracy of this source location reinforces the examination of N49 as a possible source identification and may provide new information regarding unusual neutron star phenomena.

II. INSTRUMENTATION

The 1979 March 5 event was observed with all of the spacecraft that form the interplanetary gamma-ray burst network¹ and with three of the four Vela satellites that discovered (Klebesadel et al. 1973) the gamma-ray burst phenomenon. In addition, near-Earth timing redundancy has been attained with a detection using the HEAO-2 (Einstein Observatory), which provided a fortuitous observation of the intense portion of the transient with its Monitor Proportional Counter (MPC). This instrument is nominally sensitive to X-rays in the bandwidth from 1.1 to 22 keV, but it can be also sensitive to higher energy photons if they are present in sufficient intensities to produce measureable numbers of secondaries. The unusual intensity and spectrum of the March 5 event permitted its chance detection with the MPC, providing another accurate onset measurement (Weisskopf et al. 1980).

III. DATA ANALYSIS

The initial directional analyses of the 1979 March 5 event (Evans et al. 1980; Vedrenne et al. 1979) showed that the various spacecraft timing observations were mutually consistent to within better than 100 msec. Using real-time spacecraft commands that induce artificial, timed gamma-ray burst triggers, absolute timing calibrations for Helios-2, ISEE-3 and PVO had been

¹The network spacecraft are the interplanetary probes Helios-2, Pioneer Venus Orbiter (PVO), International Sun-Earth Explorer-3 (ISEE-3), Venera-11 and -12, and the Earth orbiter Prognoz-7. Their use in the initial study of the 1979 March 5 event (Cline et al. 1980a; Evans et al. 1980) and in positional studies of 'classical' gamma ray bursts (Laros et al. 1981; Cline et al. 1981) has been described. For detailed instrument descriptions, see also Barat et al. 1981, Cline et al. 1979a and Klebesadel et al. 1980.

verified to within the same measure of accuracy. In our reanalysis, all considered sources of error available for study have been examined: clock drifts, receiving station clock accuracies, spacecraft location accuracies, information processing time delays, and 'downlink' light travel times; we have also completely reviewed the data processing techniques and the assumptions involved. For example, the spacecraft locations and heliocentric downlink times, independently of the mission orbit tapes, were derived for Helios-2 and for PVO from the master spacecraft ephemeris data logs. All possible inaccuracies in the analyses of the data from the various spacecraft (that can be uncovered in a reasonable length of time) have been considered. The error analysis is developed with a self-consistency procedure, as follows.

At the time of this event the network sensors were located in four widely spaced vertices composed of Helios-2, PVO, the closely travelling pair Venera-11 and -12 and the near Earth group ISEE-3, Prognoz-7 and HEAO-2. This situation yields four accurate non-independent determinations of the source position. The times that ISEE-3, Prognoz-7 and HEAO-2 provide for wavefronts through a reference point at the Earth's center are consistent with the 1 to 3 msec instrument integration times and onset time counting rate fluctuations. They thereby provide a composite Earth-center onset time of accuracy $\approx \pm 2.5$ msec. Similarly, using determinations that incorporate either one of the two Venera spaceprobes, reference times found using the other Venera give 8-msec discrepancies, indicating the amount of their relative timing error. The total, absolute Venera timing error, like that for PVO or Helios-2, cannot be determined. A value of ± 20 ms for the Venera system provides an error box that overlaps the Helios-2/PVO/Earth location center (see Figure 1); this value is reasonable, given the 8-msec lower limit. A value of ± 40 ms for Helios-2 provides a box correspondingly overlapping the Venera/PVO/Earth center; this is twice as large as the Venera error but is appropriate, given

that there is no two-spacecraft internal check here and that, e.g., the ground station errors for Helios-2 were found to be in the ≈ 10 msec region. A value of ± 5 ms is used for PV0, based on a detailed calibration process and entirely consistent with the assumption that a space/time determination for a spacecraft in orbit about Venus would be expected to be in considerably less error than that for an interplanetary trajectory. These values provide a mutually consistent derivation, as illustrated in Figure 1, and appear to be reasonable in terms of all residual uncertainties.

Finally, the correction was made for the relative displacements of the spacecraft during the elapsed times between wavefront detection. A fully relativistic treatment has been published (Bisnovaty-Kogan et al. 1981). The first-order, Newtonian term (entirely equivalent to the classical aberration correction) was treated in two independent ways: one is that made by applying an aberration correction to a strictly geocentric determination; the other is made by using sun-centered spacecraft locations, each taken at the moment of event detection, and sun-centered times (obtained by determining the differences between geocentered downlink times and those calculated for a clock at the sun). These agreed exactly, giving a ≈ 20.5 arc-second correction. The final 1950.0-epoch source determinations are illustrated in Figure 1. Only the positions of the error bands that are the most restrictive are shown; these are common to, or nested within, the larger error bands.

IV. RESULTS

The source location field derived here is shown in Figure 2, plotted with X-ray contours (Helfand and Long 1979) of the N49 supernova remnant in the Large Magellanic Cloud. The size of this error box is 5 percent that of the initial 2 arc-min^2 determination (Evans et al. 1980), for which conservative timing and positional errors had been incorporated; this position is

inside that initial error box and is consistent with an independent data subset source field (Vedrenne et al. 1979). It is also within the X-ray contour of N49, but is displaced from the X-ray center of the remnant in the narrowest (i.e., most accurately determined) dimension by 15 to 55 arc seconds. Given the line-of-sight uncertainty, it could be located at the surface of the remnant. This proper displacement would imply a > 400 to 1400 km/sec velocity, if a motion from the center to the remnant edge is inferred, assuming $< 10,000$ years for the time interval since the occurrence of the supernova. This velocity is higher than typical although not outside the (poorly known) range of snr neutron star velocities, depending on the (also ill defined) remnant age estimate. Given the high density of supernova remnants in the LMC and the proximity of the "(N49)" companion remnant, and a possibility of a high density of neutron stars of other origins (Ostriker et al. 1970), there may be reason to speculate that the burst source is not necessarily the same neutron star as that derived from the N49 parent object. In any event, the off-center location of the source field is not necessarily evidence that the N49 field overlap is a chance coincidence.

V. DISCUSSION

The identification of N49 as a possible source of the 1979 March 5 transient was established by Evans et al. (1980) with the ~ 50 percent overlap of a ~ 2 arc-min² error box on a ~ 2 arc min² snr contour. Since the location of the much smaller source field derived here is entirely inside the remnant, the probability of chance association has been reduced by roughly a factor of two. Nevertheless, the fact that this 0.1 arc-min² source region does not fall outside N49 avoids destroying that identification. We maintain that it is fruitful to consider the possibility of N49 as the event source, despite the temptation to prefer a chance foreground object as source in order to

avoid the energy density considerations inherent in an LMC identification. This possibility is clearly suggestive, because of the small likelihood* of a chance X-ray source association, because of the absence of additional candidate source objects in the neighborhood of this field other than stars found to be at distances consistent with that of the LMC (Fishman et al. 1981), and because of the presence of a 420 keV feature in this event (Mazets et al. 1979a) implying a possible neutron star origin, given the general associations between supernova remnants, high energy phenomena and neutron stars.

With no other transient events unambiguously identified over the last 10 years of monitoring as in the same class, the question of observational rarity must be considered, for either source preference: N49, or a chance foreground object. An extragalactic origin is consistent with the assumption that such events could have a visible rate similar to that of supernovae. Thus, one detection in 10 years of an event originating either in the LMC or in the distant regions of our galaxy can be reasonable. However, taking into account the present instrumental characteristics, the observation of a continuous size spectrum or 'luminosity function' of similar events would be more likely for the case of a nearby object at -33° galactic latitude as source for the March 5 event (Cline et al. 1980b).

Since the time of an initial review of the properties of this spectacular transient (Cline 1980) there have been other, continuing studies of its various features (Golenetskii et al. 1979; Mazets et al. 1979c; Barat et al. 1979, Terrell et al. 1980; Fenimore et al. 1981). These have not resolved the N49 source energy dilemma. However, a theoretical treatment, calculated on the basis of pair production and synchrotron cooling (Ramaty

*A note regarding the a posteriori statistics of the N49 identification argues for a $\approx 10^{-3}$ value (Fellen 1981), rather than the earlier 10^{-4} to 10^{-6} value (Evans et al. 1980; Cline 1980).

et al. 1980a), fits the spectral data quite well and is consistent with the LMC source distance. The generating mechanism of the event is not addressed in the spectral fit, but one novel possibility (Ramaty et al. 1980b) is consistent with a neutron star vibration model. A recent extension of that spectral treatment to include inverse comptonization actually provides an independent derivation of the source luminosity at $\approx 10^{44}$ erg sec⁻¹ (Liang 1981), providing a strong argument for the N49 identification.

The singular feature of this transient is the fact of an association with any known source. 'Classical' gamma ray bursts not only do not originate from known X-ray objects (Cline et al. 1979b) but have been found to originate in essentially optical empty fields (Laros et al. 1981; Cline et al. 1981). There are, however, both possible radio source associations (Hjellming and Ewald 1981) and a possible optical transient association (Schaefer, 1981) for the 1978 November 19 burst. Either one may yet become the missing link to an identifiable source object. At present, all data on 'classical' bursts are consistent with nonvisible neutron stars having no visible companion stars or associated remnants in contrast to the 1979 March 5 event. One prospect exists for investigating the possibility that the event originated in the LMC; if so, sufficiently large detectors should be able to discern events anisotropically arriving from the Virgo supercluster region. The Gamma Ray Observatory will carry an instrument with this capability (Fishman 1980).

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FIGURE CAPTIONS

Figure 1. The three-spacecraft source fields, maintaining the Earth-to-PVO band and indicating the centers and edges of the Helios/PVO/Earth, Venera-11/PVO/Earth and Venera-12/PVO/Earth locations. The size of each of the three error boxes is such that overlap exists with the centers of the others. The resultant common source location can be defined as using the outer and inner bands as upper and lower limits. The median source location is ~ 0.09 arc-min² in size; as such, it is the most precisely determined gamma ray source error box in existence.

Figure 2. The 1979 March 5 transient source location plotted with X-ray contours (Helfand and Long 1979) of the N49 supernova remnant. The box is not consistent with a location at the remnant center but has a displacement of at least 4pc. It is similarly displaced from the optical contour center; the radio contour definition (HPBW) of ~ 2 arc min. (Milne et al. 1980) does not permit a similarly precise comparison.

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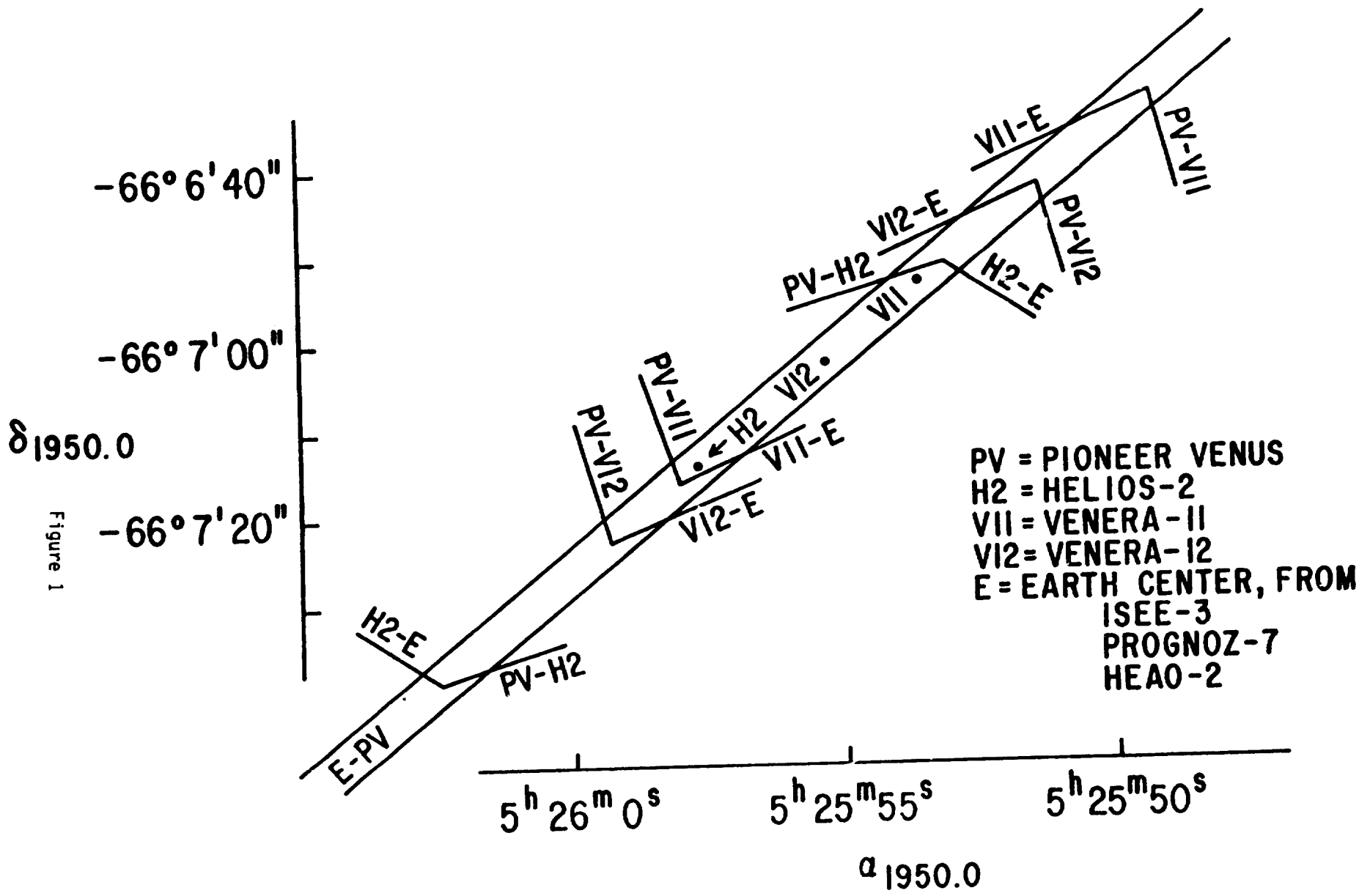
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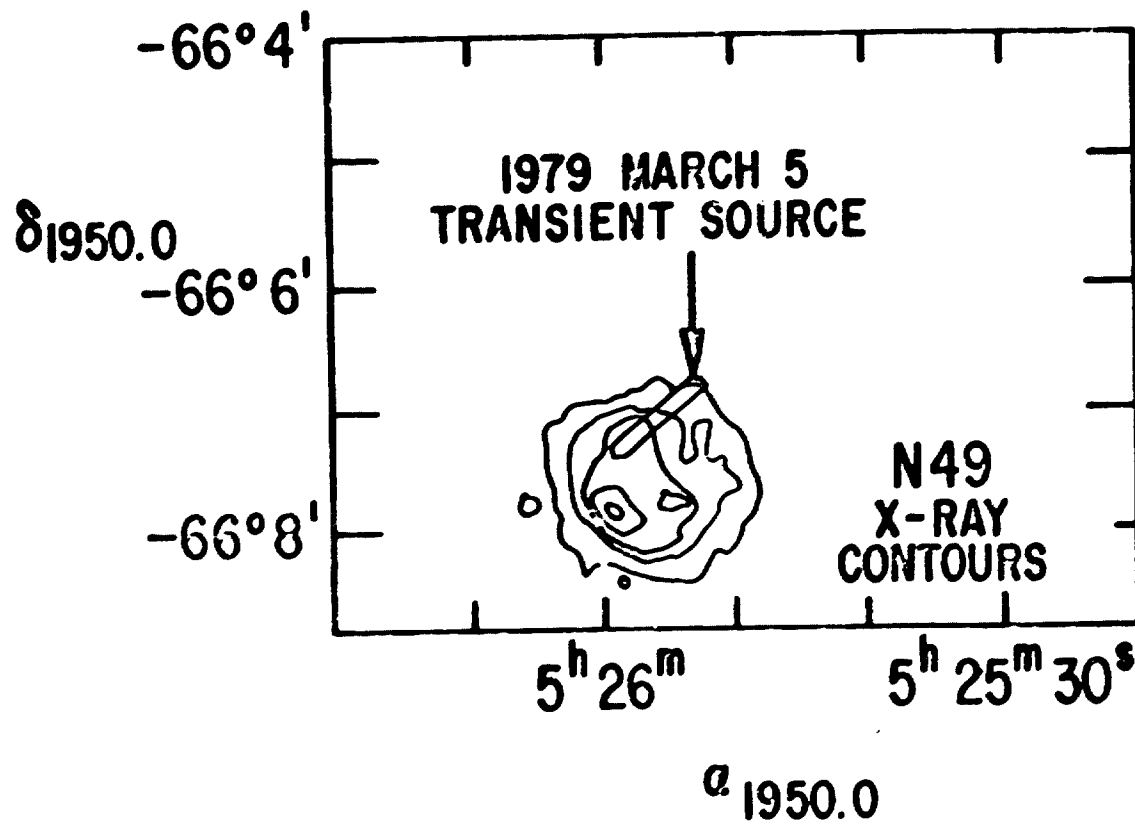


Figure 2