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GAMMA RAY BURSTS: A REVIEW OF RECENT HIGH-PRECISION MEASUREMENTS

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INTRODUCTION

Observations of gamma ray bursts have proceeded quite recently from accidental detection and circumstantial survey to detailed study with dedicated instruments. It is a pleasure to report here on the variety of recent measurements and discoveries that contribute to a much richer picture of gamma ray transients than was available even months ago. Many of these measurements are genuinely high precision in character: precise in spatial, in temporal, and in spectral definition. They include perhaps seven or eight entirely unanticipated discoveries and developments, as well as certain other improvements in the studies of the properties of gamma ray bursts. The results all have in common consistency with neutron stars as the origin objects for gamma ray transients. However, a variety of origin mechanisms may be required in order to account for the diversity of observed transient characters, perhaps as dissimilar mutually as they are dissimilar in turn to the X-ray burst classes. The scope of this review gives me the opportunity to outline these results, but with treatments that, in my opinion, must be more brief than deserved. The rich overall potential of this new field of gamma ray <u>transients</u> reminds us that in astrophysics, as in other domains, information flow is maximized when change takes place.

EARLY DEVELOPMENTS IN GAMMA RAY TRANSIENTS

The historical development of gamma ray transient studies--from the discovery of gamma ray bursts[1] until the period of recent development, beginning in late 1978--has been thoroughly reviewed[2] and will not be treated in detail here. It is sufficient to list the general properties of gamma ray bursts, as accumulated at that time, as follows:

Intensity:	~ 10^{-5} to 10^{-3} erg cm^{-2} per event;
Occurrence Rate:	~ 10/year, totalling ~ 100 prior to 1979;
Typical Energy:	> 100 keV as usual detection threshold;
Energy Spectra:	~ -1 index photon power law at < 100 keV and ~ -2.5 at > 400 keV;
Time Scale:	~ 0.1 to 30 second durations;
Time Structure:	aperiodic, with fractional sec. variations;
Sources:	No candidate source objects definable;
Source Directions:	Poorly defined but isotropic in pattern;
Source Associations:	No known X-ray emitters with consistent identifications; and
Size Spectrum:	Power law of - 1.5 index for > 3 10^{-5} erg cm^{-2} with upper limits claimed below extrapolation of that rate for > 10^{-7} erg cm^{-2}.

The observational phenomenology of several years ago centered on the great energy flux of gamma ray bursts, on the rarity of event occurrence and on the lack of correlations to celestial effects observed in other spectral regions--in the radio, visible, or even lower energy X-ray or higher energy gamma ray domains. The most restrictive source location inferences of the late 1970s came from the paucity of small-event observations using large balloon-borne detectors. As reviewed by Hurley[2], a variety of searches for weak events (that should occur at rates of several per day, given an extension of the -1.5 index power law evidenced in the satellite observations of strong events) yielded upper limits rather than the detection of a population of small events. These results imply a source region distribution of finite extent, presumably a galactic one. If so, reasonable galactic distance scale could be inferred to provide an absolute source strength calibration[3,4,5]. Although these results, consistent with ~ 100 to 200 pc source distances, agree with the interstellar model that was expected, it is fair to note that they are based on an absence of small event observation, rather than on the presence of, e.g., an observed galactic disk anisotropy. This observation may not be possible until the extended flight, in the southern hemisphere or in space, of a somewhat more sensitive detector system, such as will be onboard the Gamma Ray Observatory[6].

Two early developments that occurred before the recent period of high-resolution gamma ray burst observations were the detections of other kinds of transient phenomena in the same energy domain. These discoveries were made using high-resolution gamma ray spectrometers incorporating intrinsic germanium sensors. They are significant in that they both point to neutron stars as their sources, while pre-dating the observations of gamma ray burst spectral features which point to their neutron star source compatibility. First, a weak and narrow 400 keV line feature was observed for some hours in a 1976 study with a balloon-borne spectrometer, having a source direction consistent with that of the Crab nebula[7]. This effect was not observed with a similar balloon exposure on another occasion[8] and is thereby consistent with a transient effect; also, its detection has not been repeated since. At face value, however, the inference can be made of the existence of a positron-electron line redshifted from 511 keV by an amount consistent with the surface gravity of a neutron star (that itself could be the prime object within the Crab nebula). The < 3 keV width of the 400 keV line has been invoked as evidence for a process of gamma ray amplification stimulated by annihilation radiation[9]. This is an extremely novel and speculative inference, one of several that has been prompted by gamma ray transient studies, as we shall see.

Another discovery in high-resolution gamma ray spectroscopy suggests a more firm justification for neutron star origins for gamma ray transients. In this case, a long-lasting intensity increase (observed for 20 minutes both with a spectrometer and with an associated instrument) was found to possess four spectral features or lines consistent with no discernable continuum radiation[8]. Although one line is exactly at the neutron capture, deuteron formation energy of 2.18 to 2.26 MeV, the other three are at energies (0.41, 1.79 and 5.95 MeV) for which there are no obvious candidate isotopes. These three, however, are consistent with mutually similar redshifts of ~ 25 percent from the annihilation, the neutron capture and the 7.64 MeV ^{56}Fe lines. The realization of this fact prompted an explanation invoking a bimodal source process with episodic accretion onto a neutron star, proving both for a variety of processes at the surface and for the observability of deuteron formation in a region in the accretion disk and the atmosphere of a companion star[10]. The explanation may also appear speculative, but the observations of several lines with similar, ~ 25 percent redshift requirements does strengthen the implication of some kind of neutron star origin process. The fact that no observations of other long-lived (~ 20-minute) transients have been made makes this slow 1974 June 10 balloon event, by default, perhaps as observationally anomalous as is the unusually 1979 March 5 event, to be outlined later. In any case, its extremely unusual duration (relative to the 0.1 to 30 second bursts) shows that gamma ray transients may have a wide variety of characters and/or that instrument selection effects may have operated in the past so as to permit the observation of limited population samples.

RECENT SPECTRAL OBSERVATIONS

During 1978, the first instruments flown for the purpose of gamma ray burst spectroscopy were launched on the Soviet Venus-encounter probes Venera-11 and -12 and on the interplanetary International Sun-Earth Explorer-3 (ISEE-3). The Veneras each carried scintillation gamma ray spectrometers providing spectral coverage with a moderate energy resolution sensitive up to ~ 1 MeV, and ISEE-3 carried a germanium spectrometer with a high-resolution capability sensitive to higher energies. The discovery that each made[11,12] was the existence of a ≈ 420 keV line feature present in some gamma ray burst spectra although not in all. ISEE-3 observed the line in one of two late-1978 events before instrument failure. The Veneras observed it in the same event and in several others in 1978-1979. At a FWHM of 50 to 100 keV, the feature is much wider than the ISEE-3 instrument resolution; in the Venera scintillation data its evidence in only one event might not be convincing. However, the existence of an increase at this particular energy, present in several burst events within a population that exhibit some diversity of spectral continuum shapes (given its observation in one event with two instruments of such widely differing natures) provides much more convincing proof. Further, its existence in the anomalous 1979 March 5 event[13], to be discussed below, as well as the link to other gamma ray transient phenomena, mentioned earlier, now confirm the ~ 400 keV line as a central feature in all known forms of gamma ray transients. There is probably a good·reason for this, namely, that gamma ray bursts can be characterized by the presence of annihilation radiation, distorted by the self-absorption process and the other interactions with its medium, primarily composed of electron-positron pairs generating and generated by the same radiation, contained within the intense gravitational and magnetic field environment of neutron stars. This view has been developed[14] particularly for the 1979 March 5 event. In the case of the more 'classical' gamma ray bursts, the picture is complicated by nuclear gamma ray lines signifying the existence of processes other than those related to pair production and annihilation. The 1978 November 19 burst (Figure 1) was also found, with ISEE-3[12], to contain a ~ 700 to 740 keV feature (Figure 2) and a hard extension of its > 1 MeV spectrum, compatible with a similarly redshifted first-excited iron 847 keV line and with the required but unresolved composite presence of the other lines in the iron series[15]. The Venera instruments provided evidence for the ~ 400 keV feature in several other bursts (Figure 3) during 1979[16] but were relatively insensitive in the energy region of the iron series, providing no additional evidence for those lines. No other omnidirectional or transient spectrometer has yet been flown to confirm or extend these observations.

The most recent discovery in gamma ray burst spectral studies is that of low energy (up to 65 keV) features that are entirely consistent with identification as cyclotron resonance phenomena[16]. These features (Figure 4) were uncovered only in the Venera-11 and -12 observations (due, unfortunately, to a lack of differential resolution below 100 keV in other gamma ray burst sensors then in operation). Thus, unlike the 400 keV line, they are unconfirmed with other instruments; and, like the 400 keV line, their existence in only one burst spectrum would be relatively unconvincing. However, the facts that their strengths vary from event to event and within a given event as a function of time, provide greater confidence in their existence. Perhaps due to instrumental selection effects, such that these low-energy features can be observed better in the weaker bursts, whereas the ~ 400 keV line can be observed only in the stronger, or perhaps due to an actual source effect, only one gamma ray burst was found to contain both phenomena. Also, only one burst contains an apparent emission line, while the absorption effect is seen in a large number of cases. The interpretation as cyclotron absorption and emission features adds greatly to the neutron star origin model for gamma ray bursts, since the ~ 50 keV value fits the expected energy due to the assumed ~ 5×10^{12} gauss magnetic field associated with neutron stars. The variety of these features adds greatly to the potential of transient phenomena as a laboratory for the study of basic processes taking place within extremely intense fields.

A more recent complicating development is the detection with the Solar Maximum Mission (SMM) of a transient event arriving on 1980 April 19 from a sun-ward direction and having a spectrum apparently containing a time-varying cyclotron resonance feature[17]. If this event is cosmic in origin, there are two independent coincidences: one between its time of detection and that of a microwave event of assumed solar origin, and the other its agreement in timing delay from the Sun's atmosphere between detections at a spacecraft orbiting Venus[18] and at those near the Earth[19]. (The use of absolute intensity comparisons at these locations, due to differing instrument characteristics, has not yet resolved this uncertainty.) If the event is solar, as would appear probable, the cyclotron resonance phenomenon description cannot be used; thus, given the presence of the same features in cosmic bursts, one concludes that the cyclotron resonance interpretation is not necessarily the only possible one.

Table 1

Evolution of Evidence for Neutron Star Origins of Gamma Ray Transient Phenomena

Event Date	Transient Type	Observed Features	Interpretation	Reference
1976 May 10-11	Several hour balloon-borne	Narrow 400-keV line, Crab nebula	0.511-MeV red-shifted	7
1974 June 11	20-minute in 30° f.o.v.	0.41, 1.79, 2.23 5.95-MeV lines	0.511, 2.23, 7.64-MeV red-shifted	8
Bursts 1978-80	'Classical' gamma ray	~ 400 to ~ 450-keV line feature	0.511-MeV red-shifted	11
1978 Nov. 19	'Classical' gamma ray	420-keV and 700-keV lines	0.511, 0.847-MeV red-shifted	12
1979 March 5	Anomalous Transient	~ 400-keV line on soft spectrum	0.511-MeV red-shifted	13
Bursts 1978-80	Smaller 'Classical'	25 to 65 keV features	Cyclotron Resonances	16

DIRECTIONAL MEASUREMENTS

High precision directional studies of gamma ray bursts became possible with the completion of the interplanetary burst network, also in 1978. This remarkable development is, in a sense, the largest baseline telescope in history, timing wavefronts over up to 1000 light-seconds in extent with a few milliseconds of relative and absolute timing accuracy. Its formation has made possible the definition of gamma ray transient source fields to a precision of from several seconds of arc to minutes of arc, depending on chance spacecraft separations at the detection times. The network is formed of a solar orbiter (Helios-2), two space probes (Veneras-11 and -12), a planetary mission (Pioneer Venus Orbiter), an interplanetary spacecraft at the Sun-Earth Lagrangian point (ISEE-3) and earth satellites (Prognoz-7 and other contributors, such as the HEAO-2 or the SMM). The first two discoveries of this network were the position of the precise source field determination[20] of the 1979 March 5 event at the location of N49, a supernova remnant in the LMC (Figure 5), and the description of that event as a new phenomenon entirely unlike all other 'classical' gamma ray bursts[21]. These topics will be treated separately, below. Source fields of several gamma ray burst events of the typical or 'classical' variety have, using the network, recently been localized with comparable accuracy; those of 1979 April 6[22], 1978 November 19[23], November 24[24], 1979 January 13[25] and April 18[25]. All of these had in common the result that (despite the small source fields of size down to and below 1 arc-min^2) there are no candidate source objects—although for differing reasons. In some cases, the source box is sufficiently close to the galactic disk that many objects are contained so that optical source confusion is totally unavoidable; in other cases, the box is either entirely empty of optically visible objects (Figure 6) or empty down to better than the 18th magnitude (Figure 7). None of these source fields contains any 'candidate' source objects such as supernova remnants or X-ray emitters of any type, including known pulsars or neutron stars. This result leaves room for the conclusion that if nearby neutron stars are assumed to be the sources of all gamma ray bursts, both these stars and their possible companions, if any, are fairly weak optically, and must be less luminous than main sequence M stars. Also, if the 1979 March 5 event is interpreted to be a 'classical' event with only unusual features, its source is not N49 but an undetected neutron star exactly positioned in the line of sight (all optical objects in the vicinity of the source field being, like N49, at the distance of the LMC[26]). A similarity between the 1979 April 6 and March 5 events was examined[22] but found to be inconclusive.

An exciting possibility has recently presented itself in a VLA study[27] of one high-precision source region. Several weak radio sources are found to have a Sco X-1 like pattern and to be positioned in possible association (Figure 8) with the 1978 November 19 source field, the first one to be accurately determined[23] that could be observable at the northern hemisphere VLA location. Although the likelihood for random radio source association is not small, two of these sources are highly polarized, and are the only polarized sources in a very large scan area centered on this burst source. None of the various radio sources is coincident with any optical image down to about the 22nd magnitude. The region bracketed by the two polarized sources, separated by 10 arc minutes, contains the burst field, as well as two other non-polarized radio sources and a weak, marginally identifiable X-ray source uncovered in a guest investigation search with the HEAO-2 (Einstein Observatory) High Resolution Imager of this burst source location[23]. An association between any two or all three of the gamma ray burst, X-ray source and radio source categories may be accidental; further searches in other gamma ray burst source fields will be necessary to establish a pattern. At the time of writing, only two or three more exist that have declinations permitting their observation with the VLA. Although more of this category are expected, the interplanetary network has not functioned since early 1980 and the total number of such source fields may remain small for some time. However, the detection of time variability or proper motion in one or several may make possible extremely accurate (sub arc-second) radio positions that may be the missing link between the ~ arc min^2 gamma ray fields and actual source object identification.

THE 1979 MARCH 5 EVENT

The 1979 March 5 event has been mentioned earlier in regards to its ~ 400-keV spectral feature[13], its precise source location at the position of the N49 supernova remnant[20] and its phenomenological description as distinct from the 'classical' gamma ray bursts[21]. I have always personally maintained that this event is of a unique classification and that its identification with N49 is not accidental[28,29]. Thus, the assumptions that it is a well-defined gamma ray burst and that its origin direction at N49 is a coincidence amount to ignoring new physics that would be potential in the investigation of the data at face value. The initial reactions to the observations were to point out quite correctly that this burst would not be visible from N49, at a 55 kpc distance at the Large Magellanic Cloud, assuming it to be from a steady state Eddington-limited accretion[13] and that a variety of considerations of the burst data and of the X-ray data from the N49 remnant place severe requirements on any model[30], such as to generate pessimism regarding N49 as source. During these 2 years, however, although no experimental or theoretical 'proof' of N49 as source has been found, a rich variety of theoretical investigations of the N49 source requirements[14,31,32,33,34] has emerged. My opinion is that if a model can be devised that is compatible with all the observations, with the N49 source distance and with a production process that is entirely different from whatever would be the source model for 'classical' gamma ray bursts, this is a genuine discovery. In fact, the calculations are not only consistent with the LMC source distance[14,31,32] but, with a recent development, derive the value of that distance as a necessary result[33]. In addition, a one-photon annihilation 1.022-MeV line, redshifted appropriately, is predicted[34]. These calculations are reviewed in another presentation in this Symposium[32], and I will not outline them here. At present, it may be too early to guarantee they are exactly correct.

The data regarding the March 5 event are listed in Table 2 and the time history is illustrated in Figures 9, 10 and 11. The fact that it contains the first periodic feature found in bursts, at an 8 second period, helped the neutron star origin hypothesis[23], although it has not yet been theoretically investigated whether this is a rotational, precessional or radial oscillation period. The rise time of less than 0.2 millisecond and the non-random form of the temporal history are totally unique for gamma ray bursts[21], suggestive of a differing origin process. Thus, linking this event to a neutron star process because of the 400-keV line feature (Figure 13) does not address the problem of the origin of 'classical' gamma ray bursts.

Since there are no other identifiable events of similar shape and intensity in 10 years of monitoring, the question of the rarity of this event must be addressed for any source model. Consistent with an origin at N49 is 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 in the LMC is reasonable and about as probable as an event in our own galaxy. Another feature of the March 5 event is the series of extremely weak events that trail it by days to weeks[11], having source directions poorly defined but entirely consistent with its source direction. (Only one other such series has been detected[11], but with a source direction in the galactic plane consistent with a location in the disk at a distance of up to half that to the LMC. Was there an undetected primary March-5 like event for this series, anisotropically emitted?)

The most recent discovery to be included in this review is that of the high-precision March 5 event source field, derived from the final analysis of the results from the interplanetary network[35] (Figure 13). The off-center location is of course compatible with a position at the surface of the remnant (since the line of sight component is unknown). This would imply a ~ 1000 km/sec velocity over 10,000 years assuming the central neutron star is the parent object, catching up to its own shell due to some unaccounted for, high momentum. Given the density of supernova remnants in the LMC, perhaps the burst source object is not the N49 parent object.

CONCLUDING REMARKS

I have attempted to present this collection of exciting results with the conservative approach of maximum caution: perhaps a galactic disk distribution of 'classical' gamma ray bursts will not soon be found; perhaps repeated observations of a narrow 400-keV line from the Crab nebula, or of a slow transient containing only lines but no continuum will not soon be made;

perhaps there are other explanations for the kinks in the low-energy spectra of bursts; perhaps radio source associations will not soon link burst sources to identifiable objects; perhaps the March 5 event did not originate at N49! The optimistic view--that these data must surely represent only the surface of a rich new lode of astrophysical information--prevails, however, overcoming any pessimism regarding the observational results, inconclusive as they may yet appear. The first stage of theorizing of gamma ray transients, following the gamma ray burst discovery involved, as you will recall, a sky-is-the-limit array of speculations[36]. The present stage is somewhat more specific with speculations and considerations regarding such diverse ideas as an annihilation radiation gas, gravitational radiation, cyclotron resonances, e^+/e^- single-photon annihilation, verification of the general equivalence principle[37], amplification stimulated by annihilation radiation, and other considerations of electron-photon interactions and nuclear gamma ray production in the super-intense fields of neutron stars. Yet the actual, confirmed distances to, and intensities of, transient sources are still unknown. Surely in the near future we will be even more enlightened and entertained with the third stage.

Table 2

List of the Observed Properties of

the 1979 March 5 Event[11,20,21,30,31]

Initial Intensity Peak

Discernable by factor $>10^4$ above all omnidirectional backgrounds

Peak flux $> 2 \times 10^{-3}$ erg cm^{-2} sec^{-1}; > 10 x largest 'classical' event

Onset time constant of less than 200 microseconds

Duration ≈ 120 milliseconds of initial, high intensity portion

Decay time constant ≈ 35 milliseconds, for $\gtrsim$ 300 millisecond portion

Spectrum more intense < 100 keV relative to 'classical' events

Spectral line feature at ≈ 420 keV

Direction localized to within N49 snr, ~ 40 arc seconds from center

Flux equivalent to $\gtrsim 5 \times 10^{44}$ erg sec^{-1} if omnidirectionally emitted from N49

Transient to steady state X-ray flux ratio $> 10^9$, independent of source distance

Subsequent, Oscillating Intensity Decay

Oscillation period of 8.00 ± 0.05 seconds

Periodically repeating profile of compound, pulse/interpulse structure

Average decay time constant ≈ 50 seconds

Spectrally featureless; steeper > 100 keV than in initial peak

Flux of decay portion $< 2 \times 10^{-5}$ erg cm^{-2} sec^{-1}, $< 10^{-2}$ that of peak

Total output equivalent $\gtrsim 4 \times 10^{44}$ erg, if omnidirectional emitted from N49

Delayed Bursts

Three weak events following initial event by ≈ 0.60, 29.37 and 50.11 days

Direction of one localized to ≈ $6^o \times 0.4^o$ error box containing March 5 source

Peak fluxes ≈ 3, 1, and 0.5 percent that of March 5 event, respectively

Intensity profiles roughly 1 second, 0.1 and 0.2 second FWHM, respectively

Spectrally similar to keV March 5 event < 100 keV, not resolvable > 100 keV

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FIGURE CAPTIONS

Figure 1. Two time histories of the 1978 November 19 gamma ray burst (of the more than twelve made on various spacecraft) showing the random temporal structure in this rapidly varying, intense event.

Figure 2. Energy spectra of the 1978 November 4 and November 19 bursts measured with the ISEE-3 high-resolution (intrinsic germanium) gamma ray spectrometer. Evidence for a ~ 420-keV feature is much stronger in the November 19 event, which also exhibits evidence for another line at ~ 700 keV[12]. These are interpreted as the annihilation and first-excited nuclear iron lines, similarly redshifted from 511 and 847 keV. The insert shows the second spectrum on a linear count rate scale.

Figure 3. Selected energy spectra of bursts observed by the Leningrad group with Venera-11 and Venera-12 using scintillation counter spectrometers[11,16] (courtesy, E. P. Mazets). Evidence exists in these bursts (1978 September 18, November 19, 1979, January 16 and April 18) for ~ 420 keV features; many other bursts show little or nothing in the way of departure from smooth continuum spectra.

Figure 4. A sample of energy spectra of events observed by the Leningrad group (courtesy, E. P. Mazets), selected to illustrate the diversity of low energy features[16]. These bursts (1979 March 7, March 29, May 26, June 22 and November 1) show an apparent absorption feature, evolution in time, an emission feature, both low and high energy features, and, again, evolution in time, respectively.

Figure 5. The initial 1979 March 5 source determination[20], illustrating compatability with the supernova remnant N49 located at a distance of ~ 55 kpc in the Large Magellanic Cloud.

Figure 6. The source field of the 1979 April 6 burst (courtesy, J. G. Laros) as determined with the interplanetary network[22]. There are no optical objects within the error box to a limiting magnitude of ~ 22.5.

Figure 7. The source field of the 1978 November 19 burst as determined with the interplanetary network[23]. Only very weak point sources at ~ 18th magnitude are included; as in the 1979 April 6 event, there is no coincidence with known X-ray sources.

Figure 8. The source field of the 1978 November 19 event[23], showing the presence of nonpolarized and polarized radio sources found with the VLA[27] in a study of this region. The polarized sources are the only such found in the square degree vicinity of the error box. A very weak X-ray source, found with the Einstein Observatory in a guest investigation of this region[23] is shown; no association of radio source with gamma ray source can be assumed until corroborative evidence is found, such as an intensity change or a proper motion. No optical sources are found at the positions of the radio sources.

Figure 9. The overall time history of the unique 1979 March 5 event, as observed with ISEE-3[21], one of many instruments to detect this intense event. The initial high-intensity portion is observed as a more than four orders-of-magnitude increase. The decay portion, tracked until the instrument memory was filled, has about a one-minute time constant.

Figure 10. The high intensity position of the 1979 March 5 event on expanded time scales[21], so as to illustrate its ~ 150-millisecond width and its rise to maximum intensity in less than one millisecond; the onset measurement implies a time constant of intensity increase of less than 0.2 milliseconds. No other gamma ray transient has been observed to have a rise time shorter than several milliseconds, although a small fraction of catalogued events do consist of single intensity increases of similar durations. The initial peak is the most intense (non-solar) X-ray/gamma ray transient ever observed.

Figure 11. The first 22 cycles of the 1979 March 5 event, plotted on an 8.00-second per period basis, with the event onset chosen as zero of time, folded with an increasing number of cycles per plot[21]. The features are entirely stable in phase although varying somewhat in amplitude. No other gamma ray transient has shown clear evidence for periodicity in time.

Figure 12. The spectrum of the 1979 March 5 event intensity peak[13]. Also shown is the calculated form of the spectrum derived from considerations of synchrotron cooling and annihilation of electron-positron pairs in the intense magnetic and gravitational fields of a neutron star[14]. Both the line and continuum shapes appear to demonstrate a remarkably good fit.

Figure 13. The precise source position of the 1979 March 5 transient derived from the final analysis of the observations made with the interplanetary network[31], plotted on the X-ray surface brightness contour map of the N49 and (N49) region, as observed with the Einstein Observatory[30].

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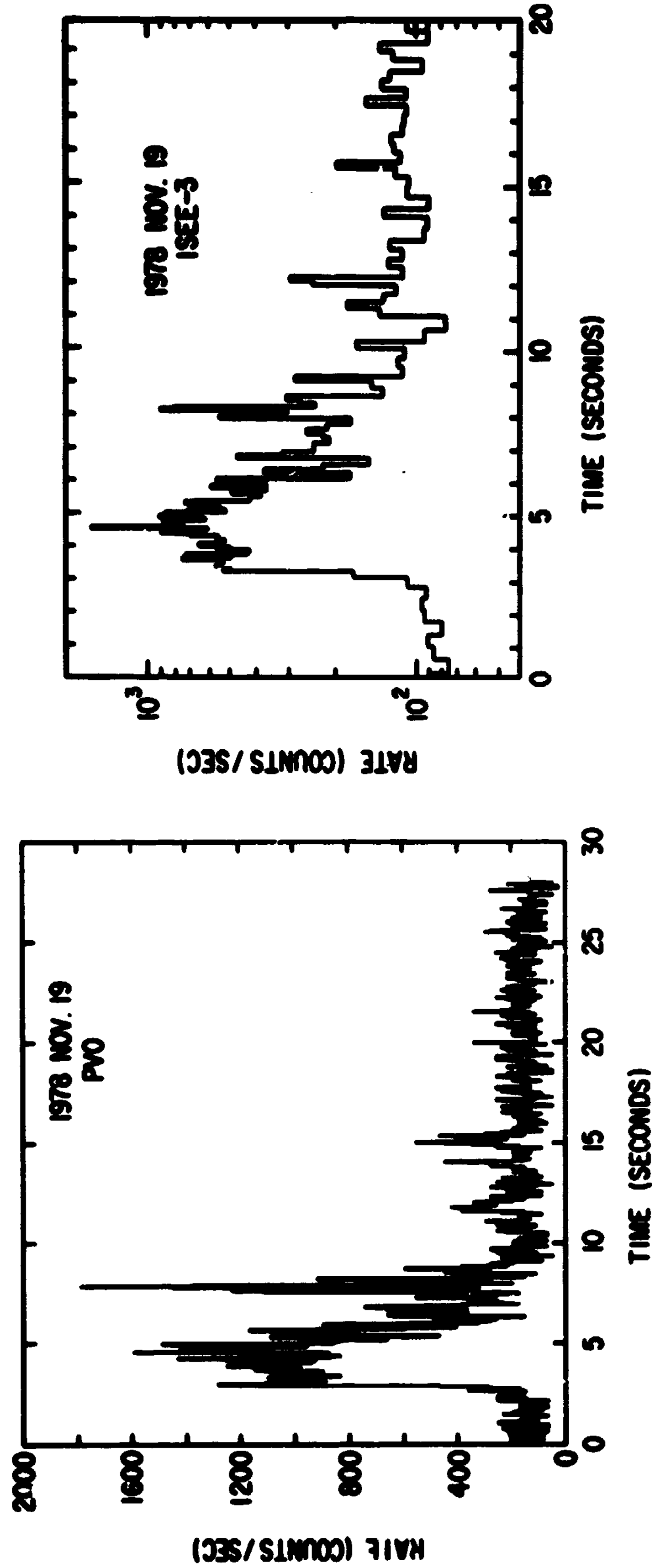
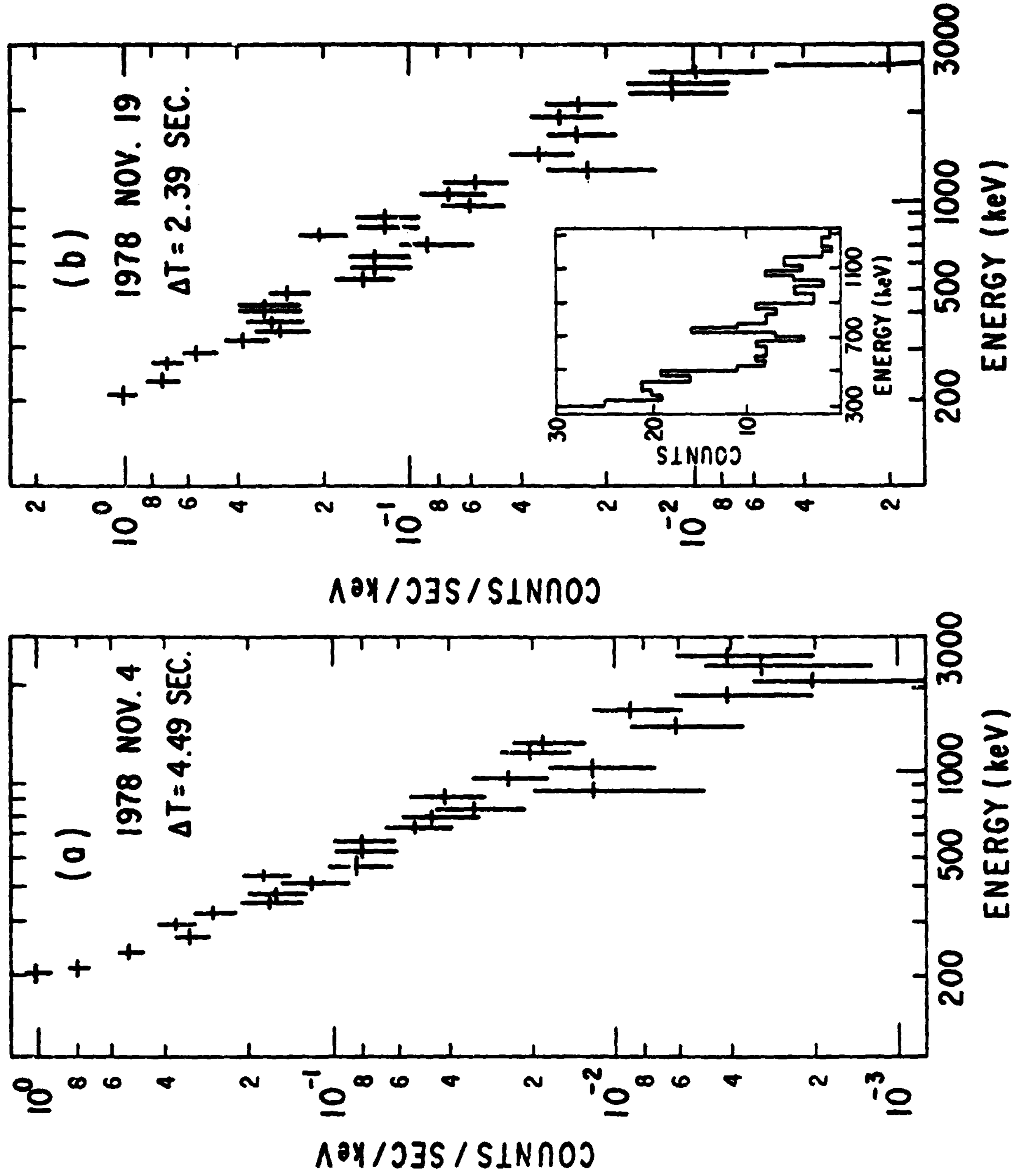


1978 NOV. 19
ISEE-3
RATE (COUNTS/SEC)
TIME (SECONDS)
1978 NOV. 19
PVO
RATE (COUNTS/SEC)
TIME (SECONDS)

Figure 1



(a)
1978 NOV. 4
ΔT = 4.49 SEC.
(b)
1978 NOV. 19
ΔT = 2.39 SEC.
COUNTS / SEC / keV
ENERGY (keV)
COUNTS
ENERGY (keV)

Figure 2

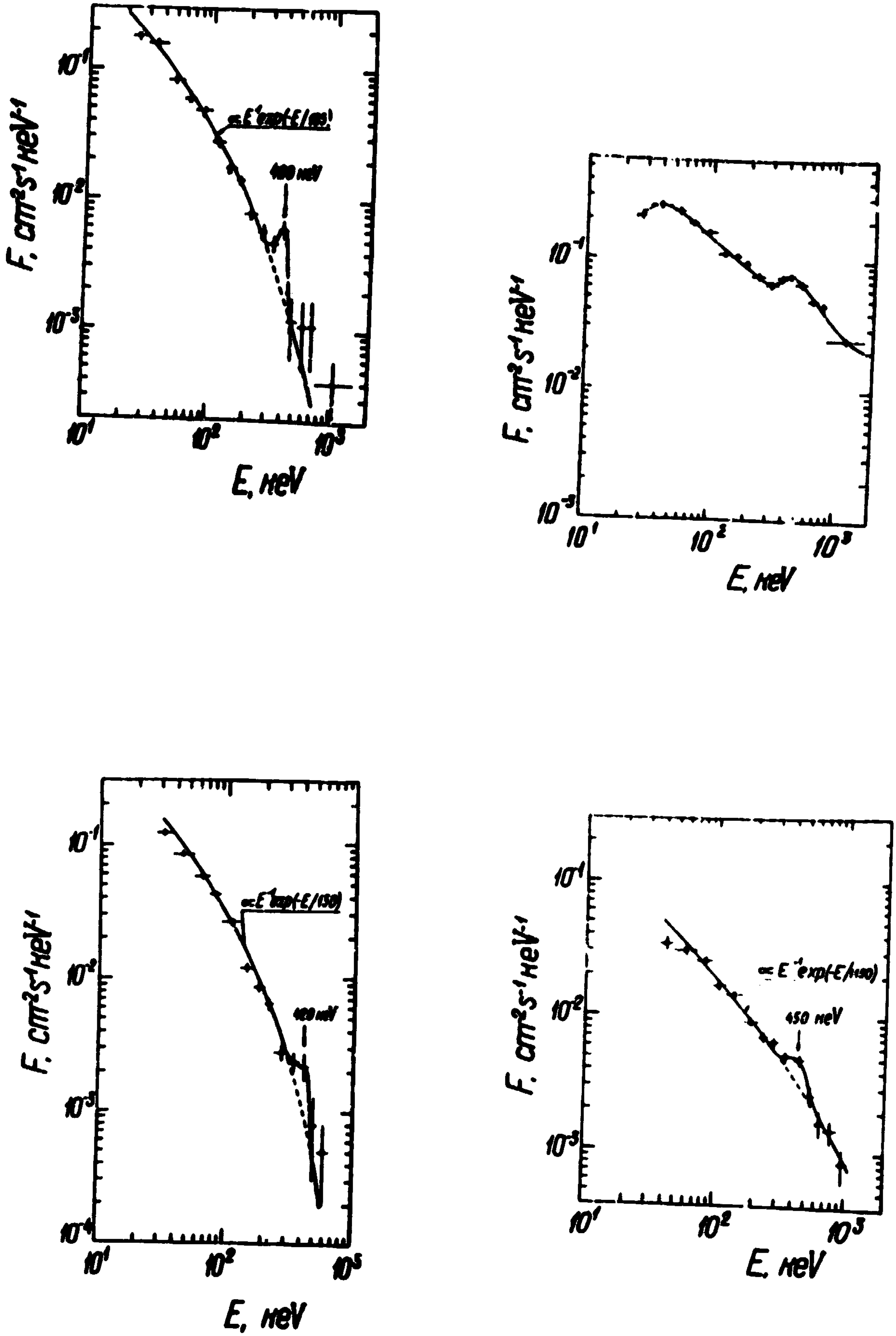


Figure 3

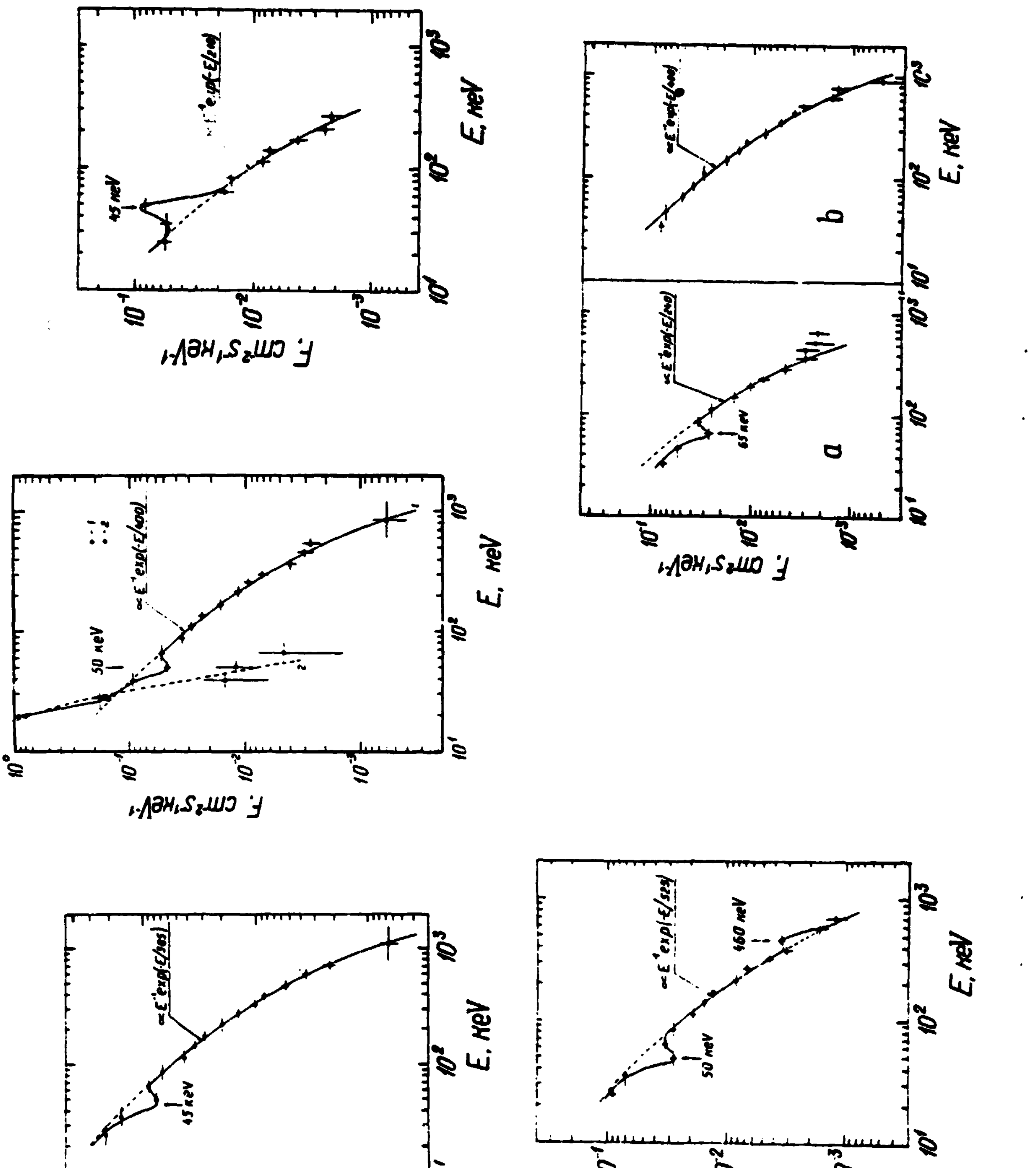


Figure 4

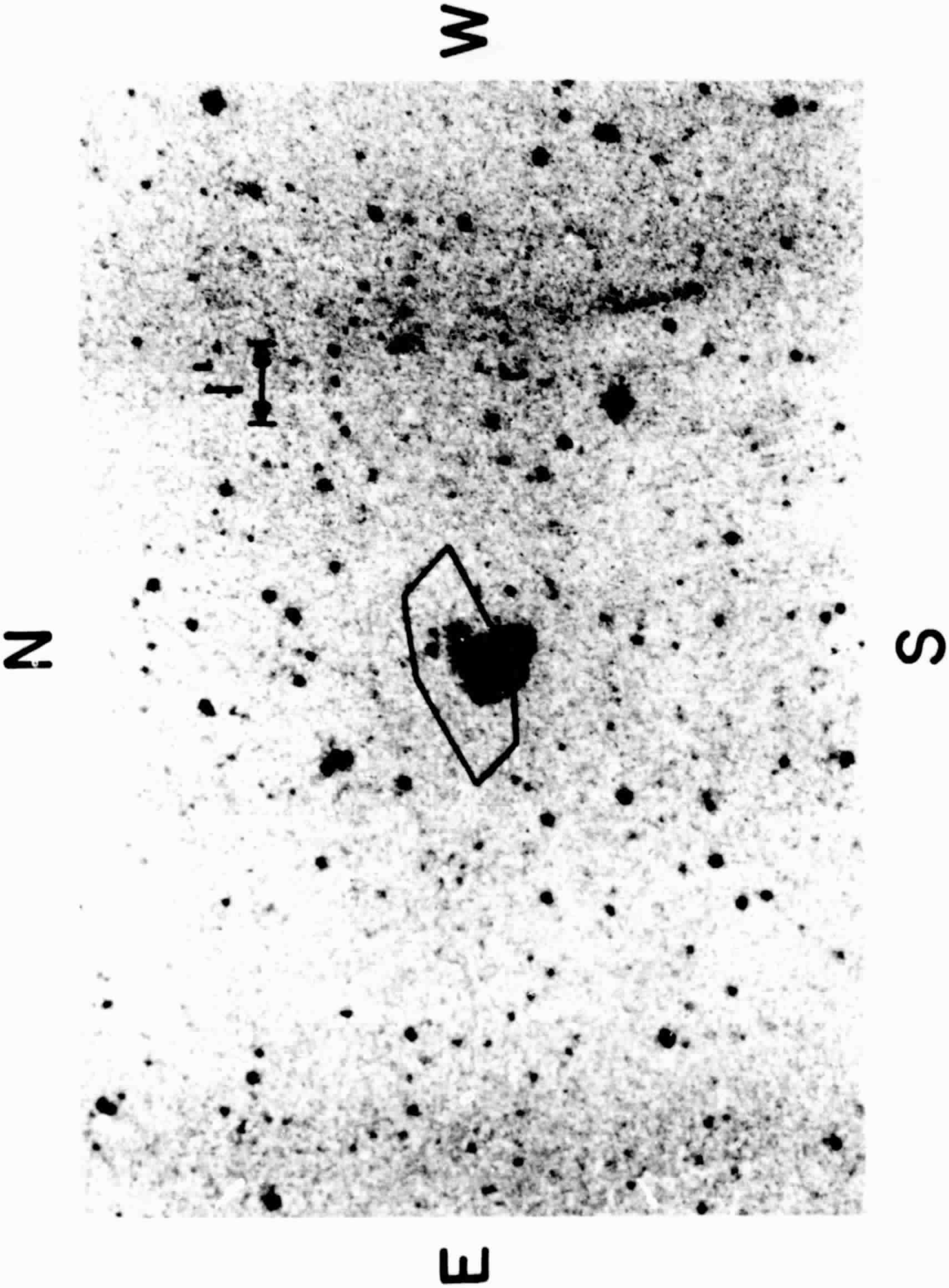


Figure 5

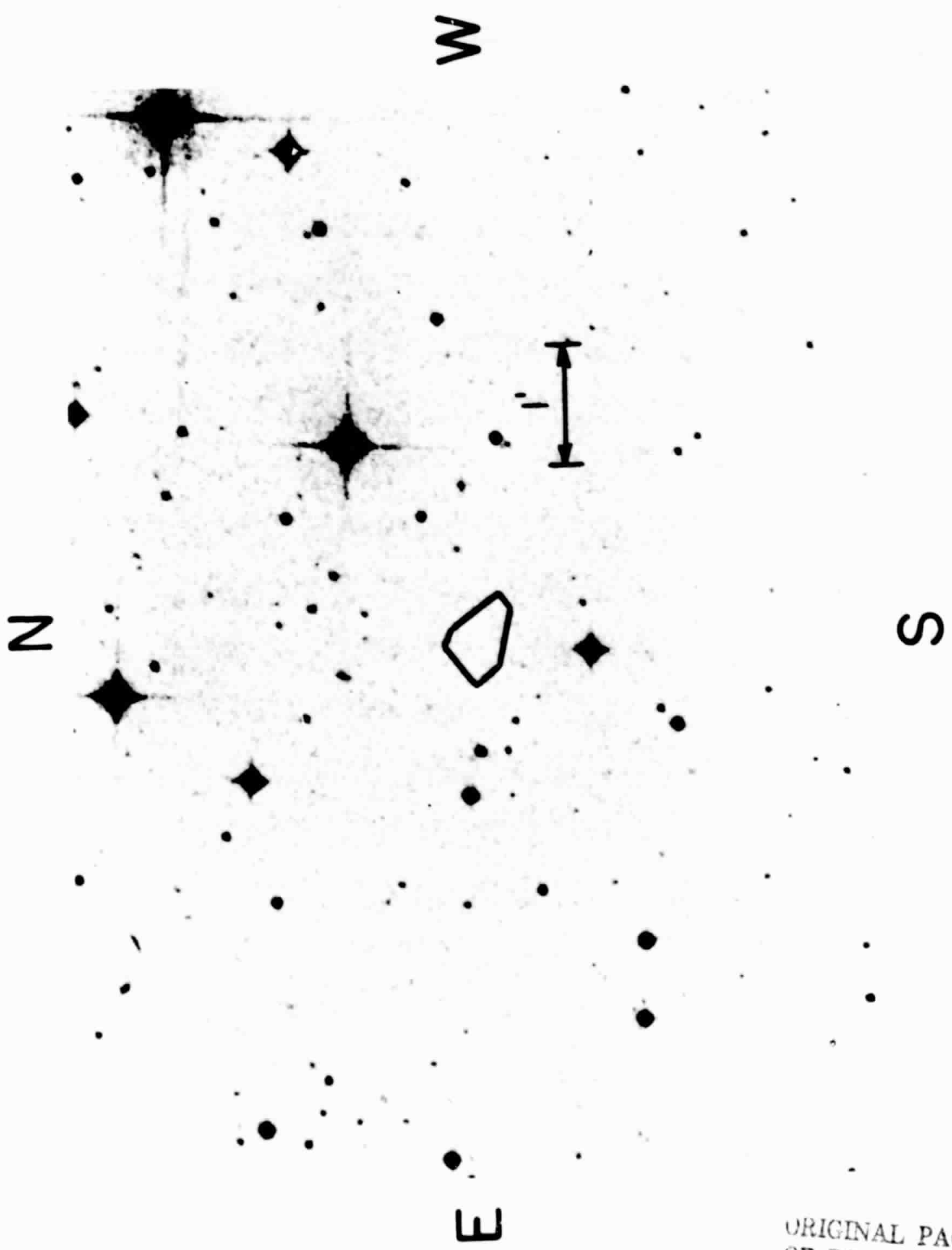


Figure 6

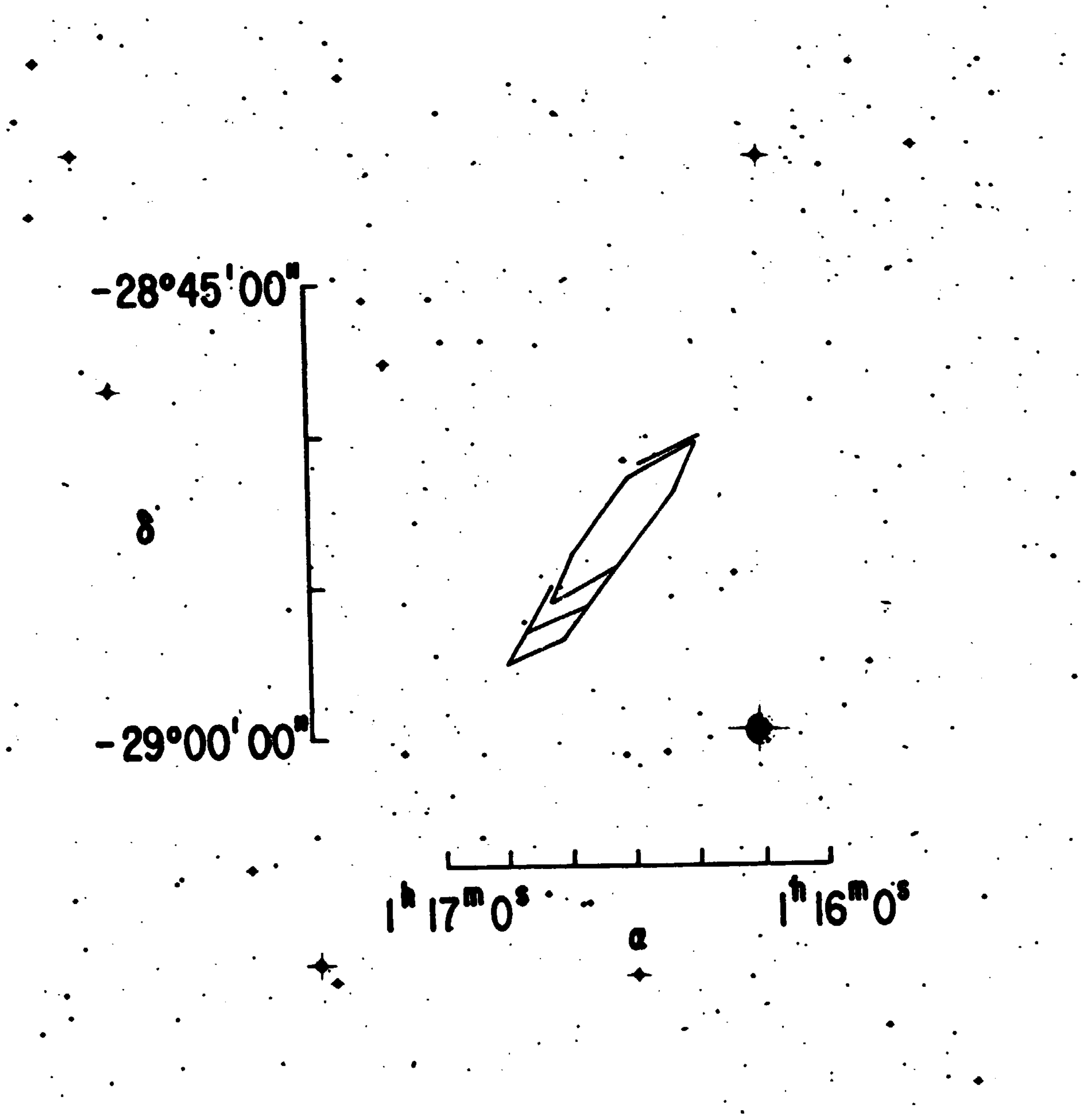


Figure 7

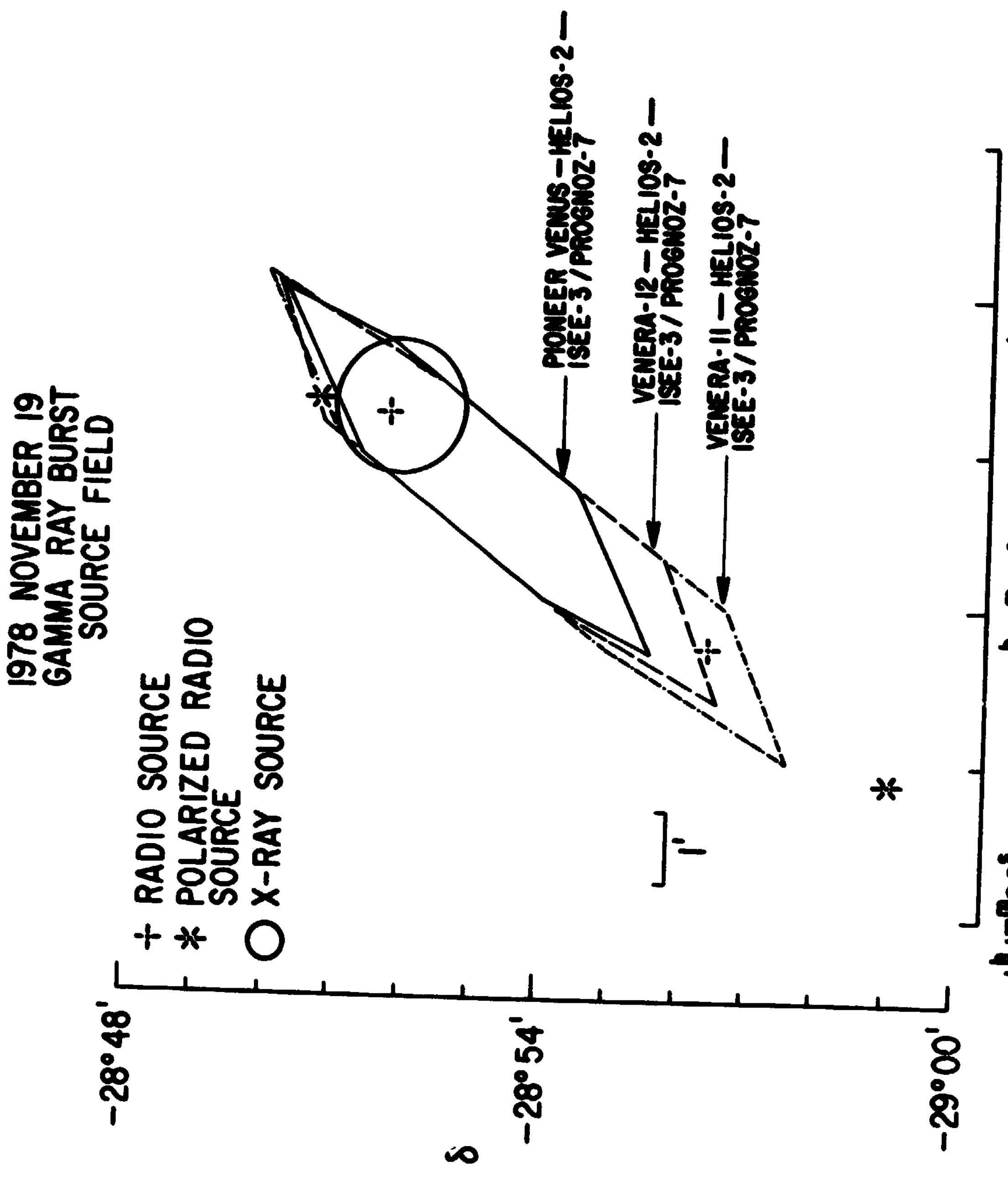

1978 NOVEMBER 19
GAMMA RAY BURST
SOURCE FIELD
RADIO SOURCE
POLARIZED RADIO SOURCE
X-RAY SOURCE
1'
PIONEER VENUS — HELIOS-2 — ISEE-3 / PROGNOZ-7
VENERA-12 — HELIOS-2 — ISEE-3 / PROGNOZ-7
VENERA-11 — HELIOS-2 — ISEE-3 / PROGNOZ-7
-28°48'
-28°54'
-29°00'
δ
1h17m00s
1h16m40s
1h16m20s
α

Figure 8

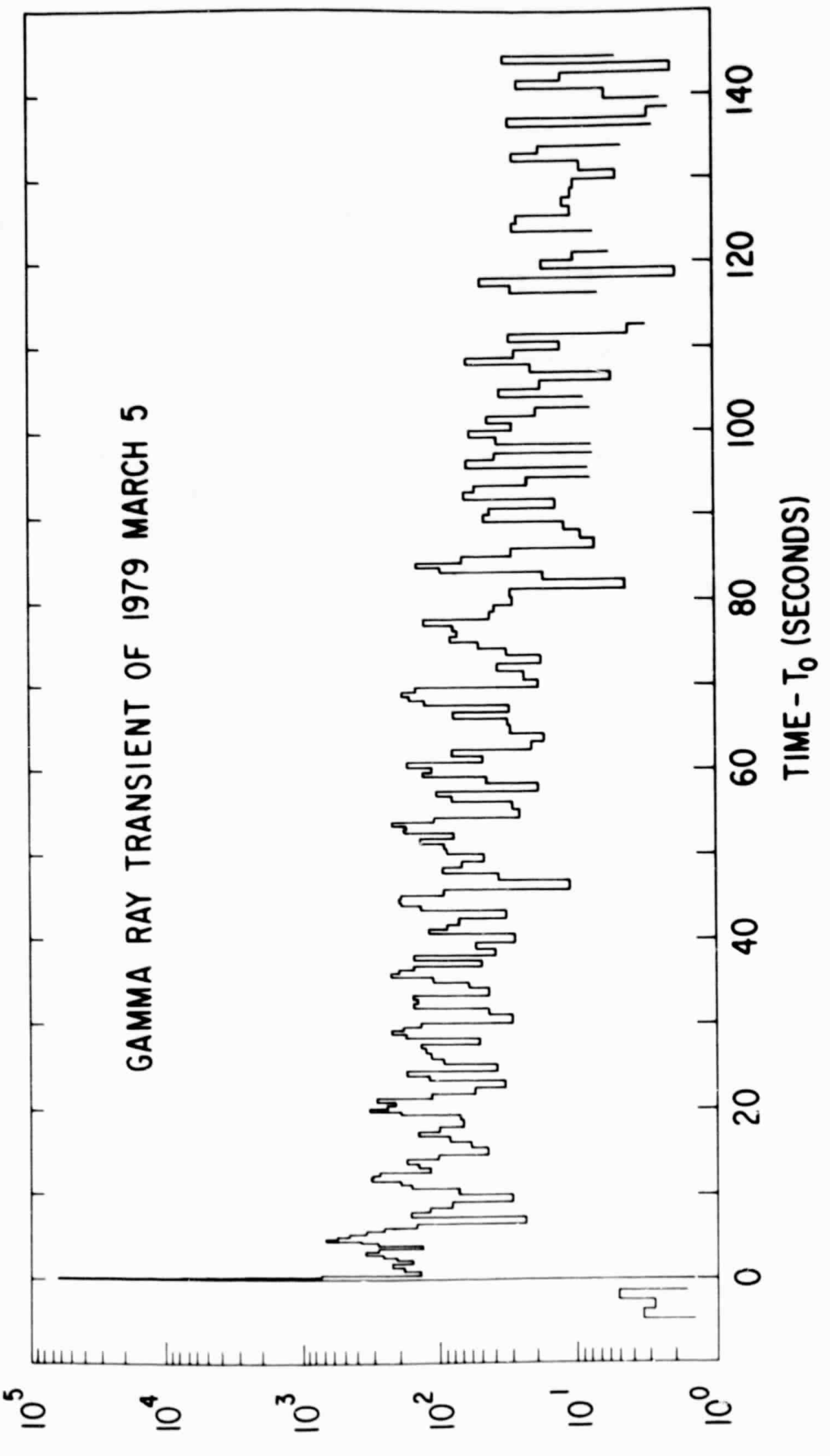
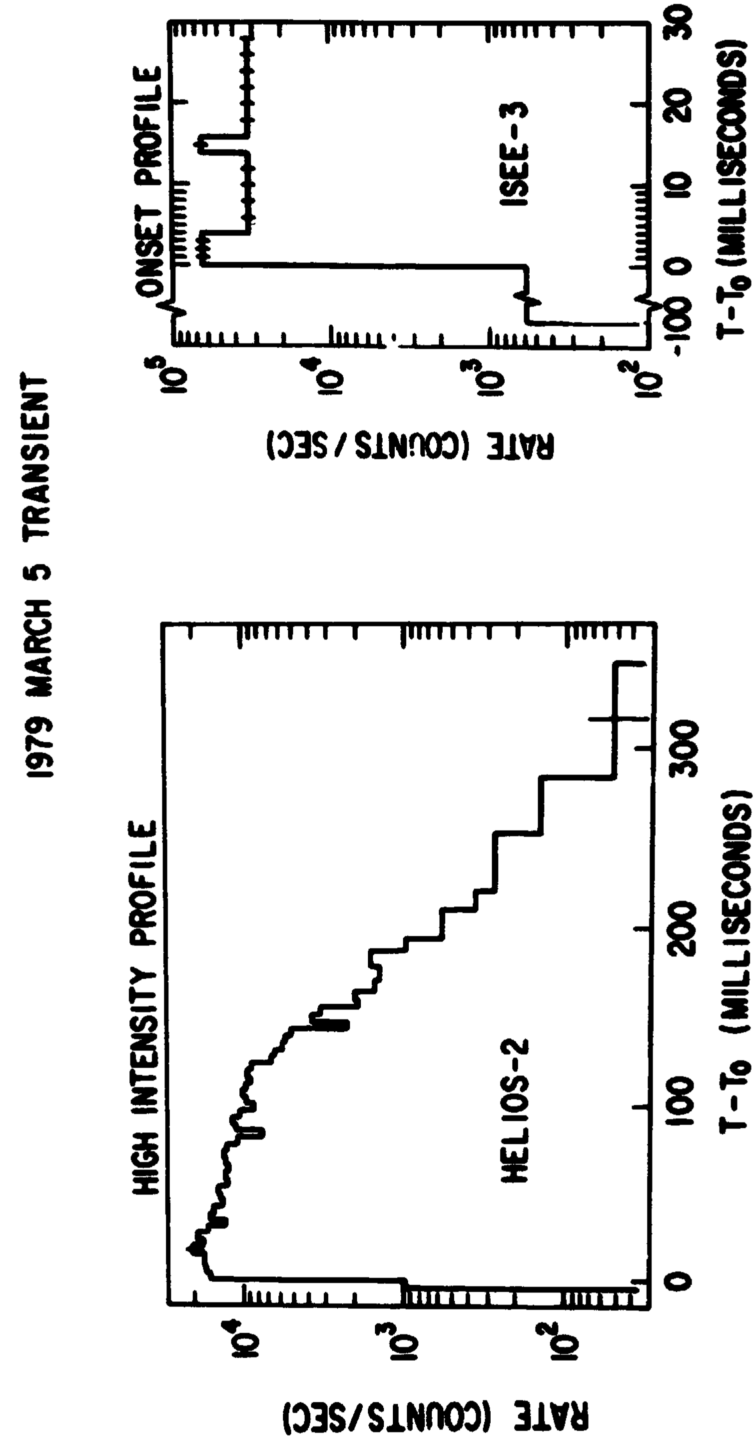

GAMMA RAY TRANSIENT OF 1979 MARCH 5
TIME - T_0 (SECONDS)
RATE (COUNTS/SEC)
0
20
40
60
80
100
120
140
10^0
10^1
10^2
10^3
10^4
10^5

Figure 9



1979 MARCH 5 TRANSIENT
HIGH INTENSITY PROFILE
HELIOS-2
RATE (COUNTS/SEC)
T-T0 (MILLISECONDS)
0
100
200
300
ONSET PROFILE
ISEE-3
RATE (COUNTS / SEC)
T-T0 (MILLISECONDS)
-100
0
10
20
30

Figure 10

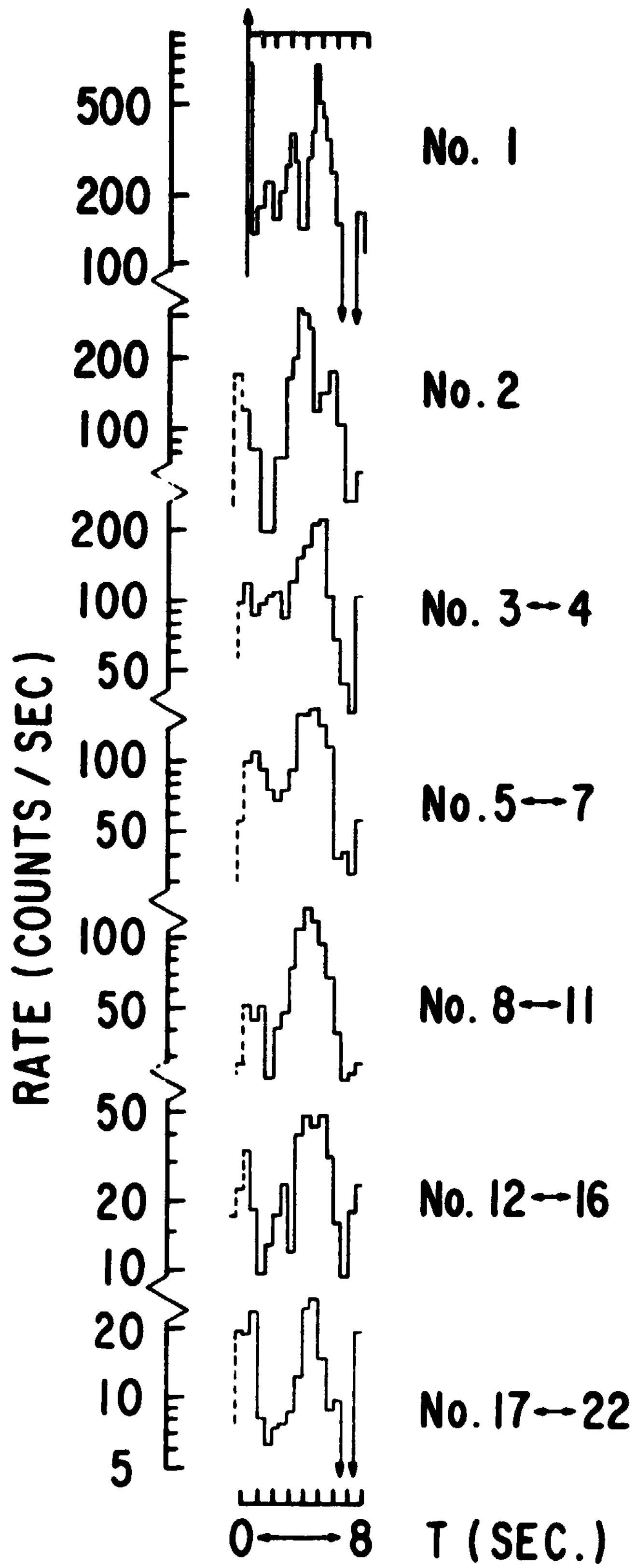
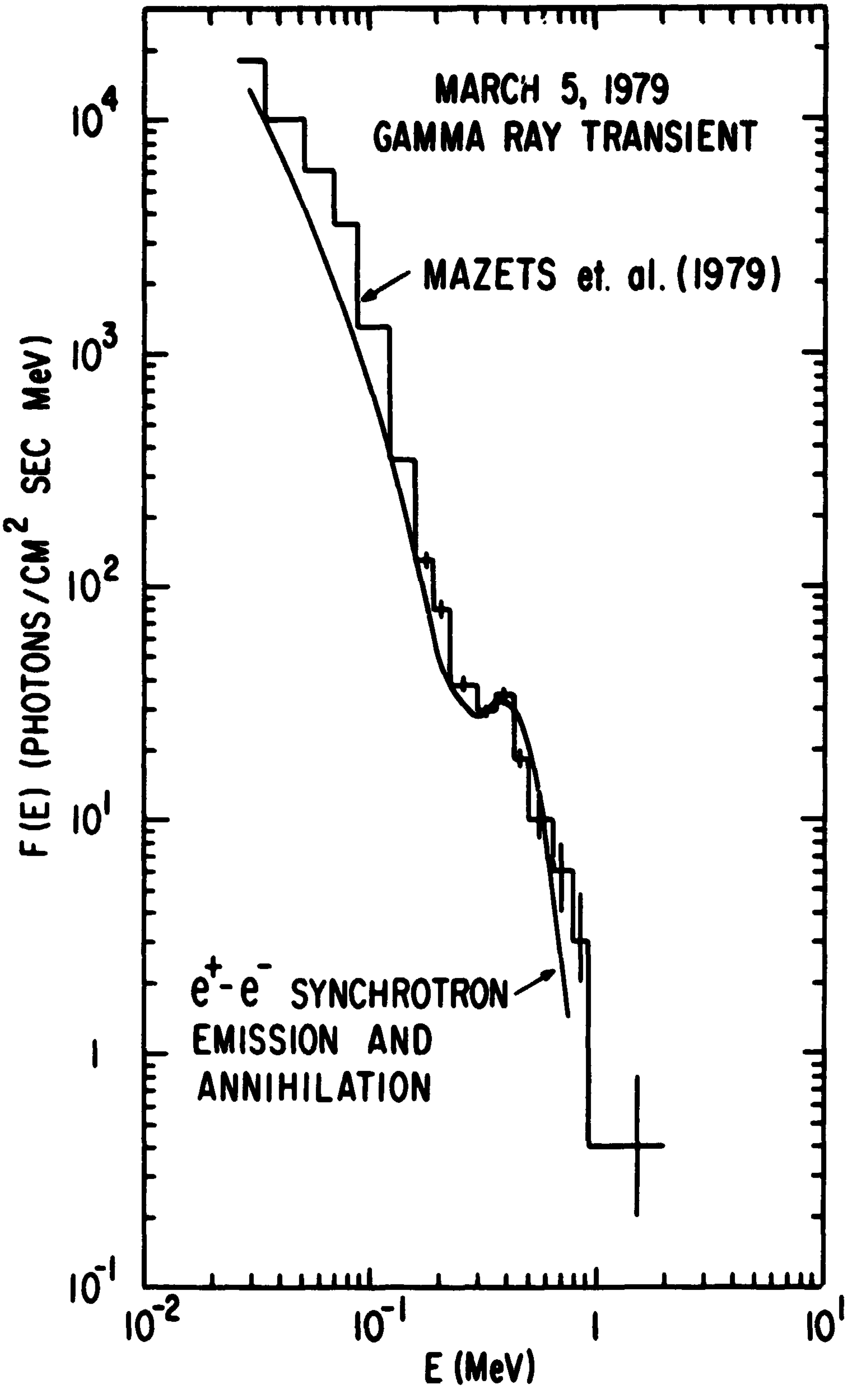
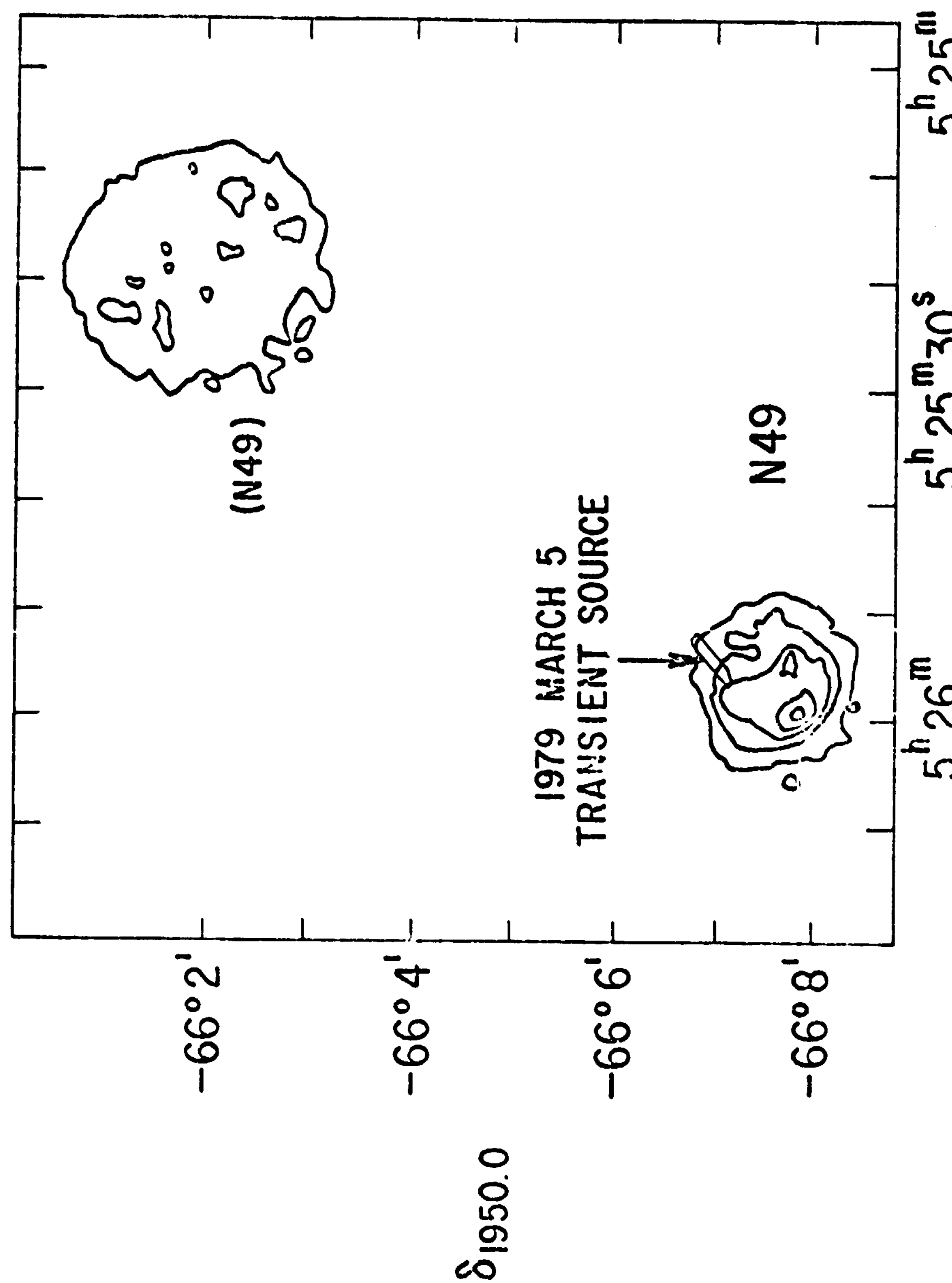

RATE (COUNTS / SEC)
500
200
100
200
100
200
100
50
100
50
100
50
50
20
10
20
10
5
No. 1
No. 2
No. 3→4
No. 5→7
No. 8→11
No. 12→16
No. 17→22
0→8
T (SEC.)

Figure 11



MARCH 5, 1979
GAMMA RAY TRANSIENT
MAZETS et. al. (1979)
e^+-e^- SYNCHROTRON
EMISSION AND
ANNIHILATION
F(E) (PHOTONS/CM^2 SEC MeV)
E (MeV)
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-1}
1
10^1

Figure 12



1979 MARCH 5
TRANSIENT SOURCE
N49
(N49)
5h25m
5h25m30s
5h26m
α1950.0
−66°2'
−66°4'
−66°6'
−66°8'
δ1950.0

Figure 13