1987ApJ...320L.111L

THE ASTROPHYSICAL JOURNAL, **320**:L111–L115, 1987 September 15

# A NEW TYPE OF REPETITIVE BEHAVIOR IN A HIGH-ENERGY TRANSIENT

J. G. LAROS, E. E. FENIMORE, AND R. W. KLEBESADEL
Los Alamos National Laboratory
J.-L. ATTEIA, M. BOER, K. HURLEY, M. NIEL, AND G. VEDRENNE
CESR, Toulouse, France
S. R. KANE
Space Sciences Laboratory, UC Berkeley
C. KOUVELIOTOU,[1] T. L. CLINE, B. R. DENNIS, U. D. DESAI, AND L. E. ORWIG
NASA/Goddard Space Flight Center
AND
A. V. KUZNETSOV, R. A. SUNYAEV, AND O. V. TEREKHOV
Institute for Space Research, Moscow
*Received 1987 April 14; accepted 1987 June 15*

## ABSTRACT

The source of GB 790107, an event originally classified as a γ-ray burst, has been seen to repeat approximately 100 times during the time interval from 1978 August 13 to 1986 June 27. Most of the repetitions occurred in late 1983. Two *Letters* present the initial observations of this new type of repetitive behavior in a high-energy burster. The emphasis of this *Letter*, which uses primarily 5–100 keV data from the UCB/Los Alamos experiment on the *International Cometary Explorer* spacecraft, is on arguments for the reality and correct interpretation of the observed phenomenon, and on the properties of the source that are revealed by noting the intensities and occurrence times of the repetitions. We find that the outbursts occur in clusters having time scales ranging approximately from an hour to a month. There is little evidence for any other pattern to the repetitions. The separation between events can range from seconds to years, with little correlation between separation and event intensity. The observed range in intensity, limited by the instrumental threshold, is greater than a factor of 30. The spectra of events are similar to one another and can be described (nonuniquely) as ~ 35 keV thermal bremsstrahlung with evidence for a low-energy deficiency. The companion *Letter* emphasizes time histories, localizations, and additional spectral information on this enigmatic high-energy burster.

*Subject heading:* gamma rays: bursts

## I. INTRODUCTION

GB 790107 was first cataloged as a gamma-ray burst (GRB) by Mazets *et al.* (1981). Subsequently, because of its short duration, it was included in a study (Mazets *et al.* 1982) suggesting that short events, most (but not all) of which seemed to have abnormally soft spectra, might belong to a distinct class. Among these short events were the repeaters GB 790305b (the "March 5 event") and GB 790324. This early work was augmented by Laros *et al.* (1986) who, in a paper presenting new observations of GB 790107, concluded that most short events were probably normal GRBs, but that a few short events, by virtue of their soft spectra, might indeed be members of a new class. The probable "charter members" of this class were the 1979 March repeaters plus GB 790107 and GB 790930. As that paper was going to press, our attention was drawn to 1983 and 1984 *Prognoz 9* (*P9*) observations of nine events that were short and bunched in time into four discrete groups. Four of the nine events were confirmed (Laros 1986; Hurley 1986) by the UCB/Los Alamos experiment on the *International Cometary Explorer* (*ICE*). The *ICE* data showed that these events were spectrally very similar to GB 790107, and that they all (including GB 790107) originated from the same ~ 15% of the sky. Amazingly, further independent examination of *ICE* data quickly revealed an episode of intense burster activity, unlike anything previously observed from a high-energy source. This activity is briefly mentioned in a *Note added in proof* to the Laros *et al.* (1986) paper. In this *Letter* we will describe this activity, discussing intensity and time-of-occurrence information covering a 7 yr span of *ICE* data. We will present arguments for its reality and association with the GB 790107 source, which we shall call SGR 1806 − 20 (soft gamma repeater, followed by its location). As part of these arguments we will present a moderately precise location derived from *ICE*, *Solar Maximum Mission* (*SMM*), *Pioneer Venus Orbiter* (*PVO*), and *Venera 13* (*V13*) Signe data, and will relate it to the published (Laros *et al.* 1986) GB 790107 location. Time histories and spectral data on specific events, plus a detailed description of the location information, may be found in the companion *Letter* (Atteia *et al.* 1987).

## II. INSTRUMENTATION AND DATA REDUCTION

The UCB/Los Alamos Solar Spectrometer/GRB instrument (Anderson *et al.* 1978) was designed to continuously

---

[1] On leave from the University of Athens.

view the Sun. On the spinning *ICE* spacecraft this was accomplished by pointing the spin axis at the north ecliptic pole, and collimating the instrument to a 10° (FWHM) band coincident with the ecliptic plane. Thus, any source (not just the Sun) within $\leq 10°$ of the ecliptic plane is continuously monitored by this instrument. Conversely, sources in the remaining ~ 85% of the sky are never in the detector field of view; but the collimator has the desirable effect of enhancing our sensitivity by reducing the background count rates. Above ~ 100 keV, the collimators become transparent in order to provide greater sky coverage for "normal" GRBs with their much harder spectra. The *ICE* sensors are a 22 $cm^2$ NaI scintillator ordinarily covering the 25–2000 keV range (dependent on the exact detector gain at a given time) and a 1.2 $cm^2$ proportional counter covering 5–14 keV. The data are telemetered both in real time and, for the > 300 keV data, in a high time resolution memory-readout mode. For real-time data the time resolution in 18 spectral channels is usually 0.5 s, but depends on the telemetry bit rate.

*ICE* real-time temporal coverage through the end of 1983 was high and fairly uniform. Data outages were typically only a few tens of hours per week, and memory-readouts caused the loss of only minutes per day. Solar activity sometimes raised the > 25 keV background to levels where our sensitivity to short cosmic events was significantly reduced, but prolonged periods of such intense activity were rare. We estimate the effective temporal coverage from 1978 August through 1983 December to be approximately 75% ± 25%, with the indicated variation representing extremes in the weekly averages. In 1984 January, when the Cometary Mission began, coverage dropped rather abruptly to $\leq 20\%$. Also, in April of that year a bit-rate reduction caused a factor of 2 degradation in our time resolution, with an accompanying decrease in sensitivity to short events. Overall, the probability per unit time of detecting a short event in 1984–1986 was about a factor of 5 lower than 1978–1983.

Data reduction consisted of a search of the *ICE* real-time data for additional SGR activity, based on the nearly identical *ICE* signatures of GB 790107 and the four events detected by *P9* in 1983. Approximately 2/3 of the signal appeared in the 25–40 keV lowest energy scintillator channel (SC1), with most of the remaining counts falling in the 40–72 keV channel (SC2). Some events produced counts in the 5–14 keV proportional counter (PC) channels and in the 72–104 keV scintillator channel, but never more that a few percent of the total response. Consequently, our search used SC1 as the "trigger" channel (except during a few times when the detector gain was higher than normal) with SC2 and the other channels used for verification. Specifically, our event criteria were (1) a response in SC1 having less than a $10^{-7}$ chance probability; (2) $\leq 10^{-2}$ chance probability in SC2; (3) most of the signal in SC1; (4) reasonable counting rates in the other six PC and SC channels available in the Los Alamos data stream; (5) no adjacent glitches or data dropouts; (6) net flux evident in either 1 or 2 adjacent 0.5 s accumulations; and (7) no activity or glitches in the Los Alamos Plasma Electron Analyzer Experiment (also on *ICE*) when such data were available. Together, these criteria effectively remove spurious signals caused by statistical fluctuations, data errors, magnetospheric phenomena, and known types of event such as normal GRBs, solar flares, or X-ray bursts.

Figure 1*a*, which shows the number of events vs. time at 0.5 month time resolution, is excellent confirmation that we have succeeded in eliminating false events. The fact that there are time periods longer than a year with no activity implies a false event rate of $\lesssim 1$ per year. Thus, $\gtrsim 95\%$ of the 111 candidate bursts reported here are almost certainly real, cosmic bursts that do not represent an already recognized form of activity. As further evidence of the reality of the events, 18 of them (the "solid" events of Fig. 1) have been verified by *PVO*, *P9*, *SMM*, and/or *V13*. This is in agreement with the number of expected confirmations, taking into account the sensitivities, sky coverages, and live times of the various experiments on these spacecraft. Actually, first estimates seemed to indicate the *P9*, with sensitivity and time-coverage factors of approximately 0.5 relative to *ICE*, should have detected more than 20 of the *ICE* events (instead of 12). However, *P9*'s memory-readout system generated 3.2 hr of dead-time immediately following each event trigger. The clustering of the events (see Fig. 1) approximately doubles the effect of this dead-time, relative to the case of randomly arriving bursts. Thus, a total of 12 detections by *P9* is very close to the expected number.

## III. RESULTS

We have established that, between 1978 August 13 and 1986 June 27, the UCB/Los Alamos experiment on *ICE* observed 111 candidate cosmic events which were not GRBs, solar events, or X-ray bursts. Based on the body of evidence presented below, we propose that the vast majority—i.e., at least 90%—of these events are due to a single source, SGR 1806 − 20. We have already seen in Figure 1*a* that the events are clustered at a few discrete times. Thus, it is unlikely that there are more that a few different sources giving rise to the events. All of these sources must be in the same ~ 15% of the sky, near the ecliptic plane. Furthermore, all of the 18 confirmed events in 1983 March, July, August, November, and December have approximate arrival time localizations that are consistent with one another and with the GB 790107 location. (See the companion *Letter* for the full localization information, but in a somewhat different context.) The *SMM* data also contain marginally significant spikes at the predicted arrival times, based on the GB 790107 location, for two additional *ICE* events. Therefore, it seems most probable that the 1983–1984 activity is from a single source identical to, or certainly within a few degrees of, the GB 790107 source. It is likely that the same is true for six events in 1980 and 1981.

The strong link between events in the 1979 and 1983 time frames is provided by five bursts that were observed by interplanetary spacecraft. First, GB 790107 was localized to an 8° by 0°.024 strip (Laros *et al.* 1986) using time of arrival analysis and instrumental response arguments. On 1983 November 16, two intense outbursts only 1 s apart were observed by *PVO*, *ICE*, and *SMM* (Laros 1986; Kouveliotou *et al.* 1986). A third event was observed 14 minutes earlier by

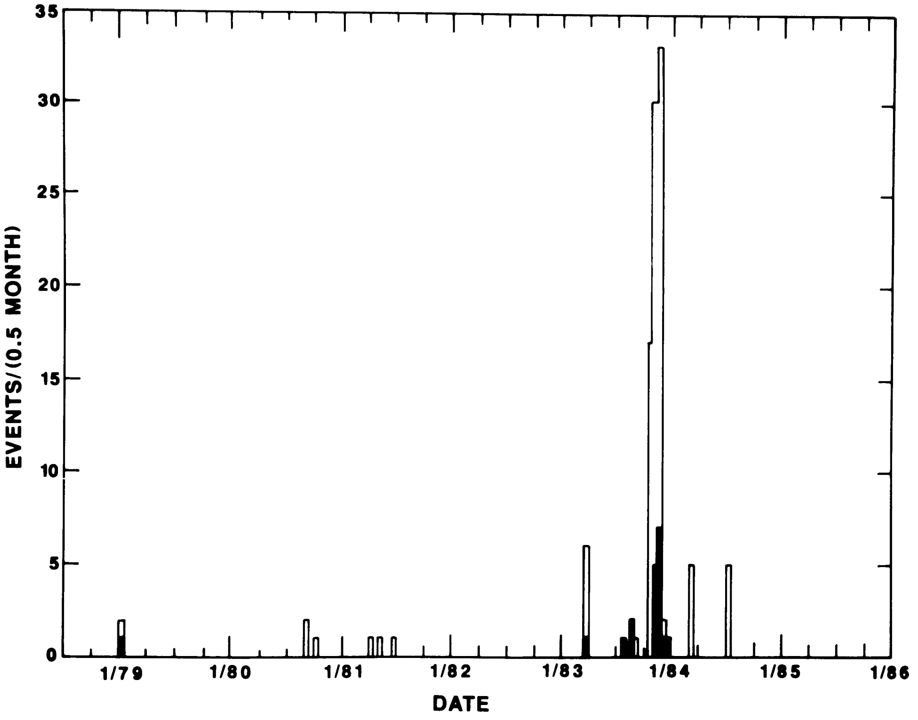

FIG. 1*a*

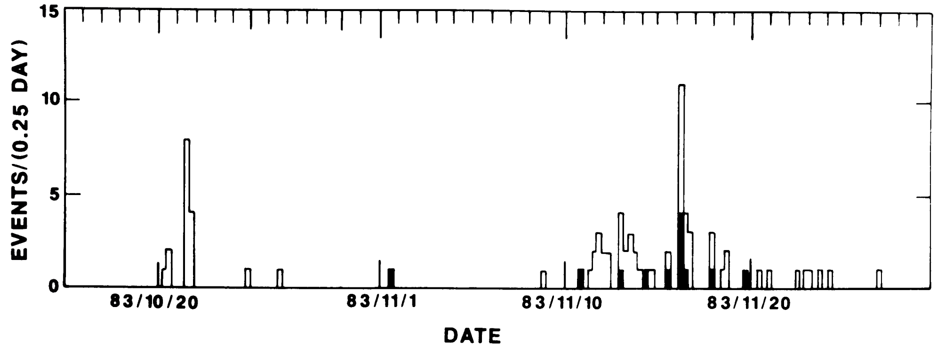

FIG. 1.—*ICE* event occurrence vs. time. The filled-in part of each histogram in the subset of events also observed by other spacecraft. In (*a*) we show 8 yr of data at 0.5 month time resolution; (*b*) presents 1.5 months of data at 0.25 day resolution. The temporal coverage is about 75% in 1978–1983, and about 20% thereafter.

*PVO* and *ICE*. These November 16 events are certainly from a single source, which can be localized to an 8° by 0°.03 strip by the same methods used for GB 790107. Similarly, an event observed on 1983 March 20 by *V13* and *ICE* can be localized to an 8° by 0°.106 strip. The three narrow strips (January 7, March 20, and November 16) have a common intersection near $(\alpha, \delta)_{1950} = (18^h06^m, -20°)$. For random strips, the chance probability of such an intersection is practically zero. Actually, the strips are neither randomly located nor randomly oriented, for the following reasons:

1. The *ICE* coverage limits the strip locations to ~ 15% of the sky.
2. One pair of strips must always intersect if there are two burst sources (and three strips).
3. Given our geometry, with observing platforms near the ecliptic, time-of-arrival analysis produces strips that are nearly parallel in the vicinity of the ecliptic plane.

Under these conditions, the chance probability of two or more sources reduces approximately to the probability that a 0°.024 interval of ecliptic longitude overlaps a randomly chosen 0°.03 interval, or $1.5 \times 10^{-4}$.

Other, much more speculative links between the events may exist. One is an approximate 2.4 yr interval between the active periods that occurred near 1979 January, 1981 June, and 1983 November. Another is a possible 4 month period most easily seen (or imagined) in the 1983–1984 time frame, but also compatible with the 1979–1981 events. The lack of observed events in mid-1986 argues against a 2.4 yr time interval, but

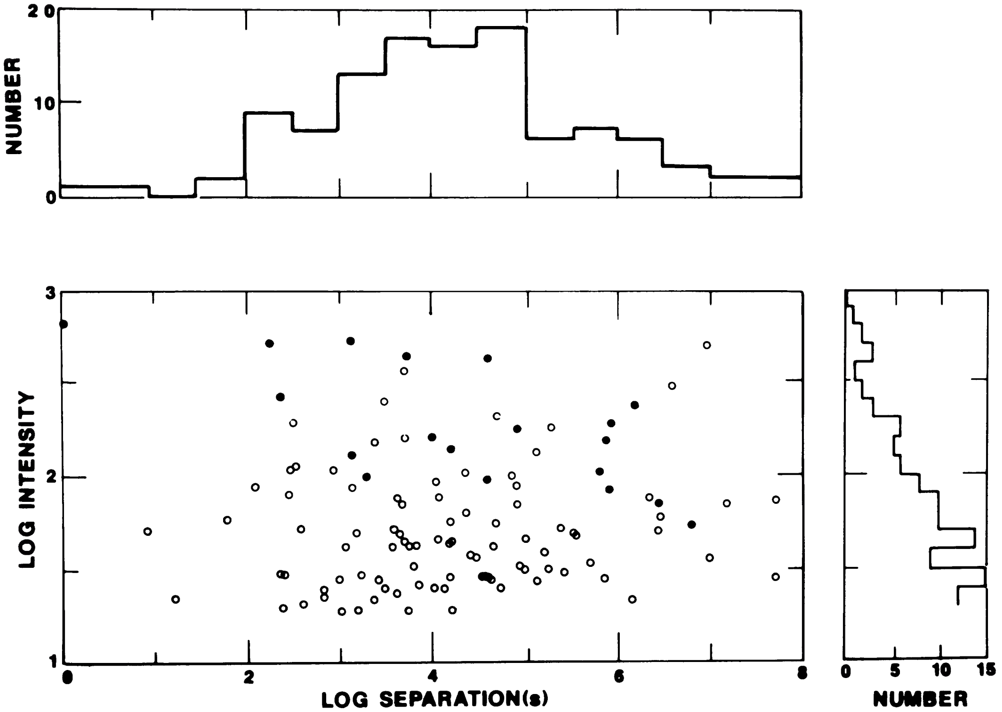

FIG. 2.—Statistical properties of the 111 observed *ICE* events. The central part of the figure (*circles*, with the circles filled in for multiply observed events) displays the 25–40 keV intensity of each event vs. the time to the next event. This display has also been integrated both in vertical columns to give the distribution of separations (*top*) and in horizontal rows to give the intensity distribution or luminosity function (*right*).

the *ICE* real-time coverage in 1986 was less than about 20%. The discovery of more events must precede further comment on the likelihood of a 4 month period.

In any case, our assumptions that all 111 of the observed *ICE* events are real and from the same source might not be rigorously true. Thus, the distributions that we will present could contain the equivalent of a small noise component. Also, other distortions probably have been introduced by the lack of complete temporal coverage and nonuniformity in the coverage. In view of these possible distortions, which are difficult to correct due to the sporadic nature of the source, the analyses presented below will not be unjustifiably quantitative.

Figure 1*b*, which is similar to Figure 1*a* but covers only the 6 weeks centered on the 1983 November active period at 0.25 day time resolution, shows that clusters, identified in the *P9* data and in Figure 1*a*, persist on shorter time scales. In fact, eight of the 12 events on October 21 and 10 of the 18 events on November 16 occurred in time periods of 1 hr. Figure 2 is a particular compilation of event arrival time and intensity information. The central part of the figure shows event intensity $I$ versus the time interval $\Delta T$ to the next event, with each event represented as a circle. Filled circles are confirmed events. This plot reveals the remarkable nature of the repetitions. There is little or no correlation between $I$ and $\Delta T$, except possibly for the very weakest events. At intensities below $\log I = 1.4$, 12 of 15 events are associated with intervals shorter than the median interval of 1400 s. The most intense events apparently have no preferred $\Delta T$, and are followed by intervals ranging from 1 s to $> 1$ yr. A type II X-ray burster similar to the Rapid Burster, which SGR 1806 − 20 might be thought to resemble, should show a much higher degree of correlation. The $I$ versus $\Delta T$ plot has also been binned in logarithmic intervals of both $I$ and $\Delta T$ to yield the distribution of intervals (*top*) and the intensity distribution or luminosity function (*right*). The $\Delta T$-distribution shows an expected sharp drop at $\Delta T \approx 10^5$ s, given the tendency of the events to occur in clusters as seen in Figure 1. The luminosity function can be fitted by a power law ($dN/dL \sim L^{-\alpha}$) with index $\alpha = 2$ at intensities above $\log L = 1.7$; at lower intensities the function flattens, approaching $\alpha = 1$. Because of the similar spectra and time histories of the SGR 1806 − 20 repetitions (in contrast to the diversity of normal GRBs) the instrument threshold is rather sharply defined and has a large effect only on the lowest luminosity bin in Figure 2. Variations in detector background affected the threshold only a small fraction of the time. Therefore, the flattening does not appear to be an instrumental effect. Exponentials yield poor fits to the luminosity function. Neither the $\Delta T$-distribution nor the luminosity function (nor the repetition pattern) resemble those of either type I or type II X-ray bursters (Lewin and Joss 1983).

Preliminary spectral fits using 5–200 keV *ICE* data gave results similar to those published on GB 790107 (Laros *et al.* 1986). Power laws are definitely ruled out; acceptable fits can be obtained from thermal bremsstrahlung with temperatures between 25 and 40 keV, except at low energies where there are indications of fewer than expected counts.

## IV. SUMMARY AND CONCLUSIONS

The high-energy burster SGR 1806 − 20 (GB 790107) has been observed to repeat, on the order of 100 times, between 1978 August 13 and 1986 June 27. Most of the repetitions are in the latter part of 1983. All are clustered on time scales of hours to months. Although only 18 of the 111 observed *ICE* events are confirmed, it is doubtful that more than a few of them are spurious or due to other sources. Simple analyses have shown the repetitive behavior to be remarkable, with very little correlation between burst intensity and interval between bursts. The tremendous range in intervals, with seconds to years (but usually $< 10^5$ s) separating the bursts of comparable intensity, is also amazing. The range in the intensities of the repetitions spans at least a factor of 30. The luminosity function can be approximated by a power law that flattens at low luminosities. The question of what future activity to expect from this source is obviously an important one. Unfortunately, the only patterns in the long-term behavior that could be described as predictive of more events in the near future are extremely speculative. On the pessimistic side, if the intense 1983–1984 activity has depleted the system, the source could be quiet for several years.

The Los Alamos authors thank R. Robinson and D. Salazar for greatly expediting the processing of nearly the entire 7 yr Los Alamos *ICE* data base. J. Gosling kindly examined *ICE* Plasma Analyzer Experiment data at the times of the SGR outbursts. R. I. Epstein and J. P. Norris provided helpful comments. This work was supported by the US Department of Energy and by NASA under contract A47981B, grant NAG 5-376, and grant NSG 5-066 at the Catholic University of America. On the French side, this work was supported by the Centre Nationale d'Etudes Spatiales.

## REFERENCES

Anderson, K. A., *et al.* 1978, *IEEE Trans. Geosci. Electron.*, **GE-16**, 157.
Atteia, J.-L., *et al.* 1987, *Ap. J. (Letters)*, **320**, L105.
Hurley, K. 1986, talk delivered at Los Alamos Workshop on "Gamma-Ray Stars," Taos, NM.
Kouveliotou, C., *et al.* 1986, talk delivered at the Toulouse COSPAR meeting.
Laros, J. G. 1986, talk delivered at the Los Alamos Workshop on "Gamma-Ray Stars," Taos, NM.
Laros, J. G., *et al.* 1986, *Nature*, **322**, 152.
Lewin, W. H. G., and Joss, P. C. 1983, in *Accretion Driven Stellar X-Ray Sources*, ed. W. H. G. Lewin and E. P. J. van den Heuvel (Cambridge: Cambridge University Press), p. 41.
Mazets, E. P., Golenetskii, S. V., Guryan, Yu. A., and Ilyinski, V. N. 1982, *Ap. Space Sci.*, **84**, 173.
Mazets, E. P., *et al.* 1981, *Ap. Space Sci.*, **80**, 3.

J.-L. Atteia, M. Boer, K. Hurley, M. Niel, and G. Vedrenne: CESR, Toulouse, France

T. L. Cline, B. R. Dennis, U. D. Desai, C. Kouveliotou, and L. E. Orwig: NASA/Goddard Space Flight Center, Greenbelt, MD 20771

E. E. Fenimore, R. W. Klebesadel, and J. G. Laros: Los Alamos National Laboratory, Los Alamos, NM 87545

S. R. Kane: Space Sciences Laboratory, University of California, Berkeley, CA 94720

A. V. Kuznetsov, R. A. Sunyaev, and O. V. Terekhov: Institute for Space Research, Moscow, U.S.S.R.