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LOCALIZATION, TIME HISTORIES, AND ENERGY SPECTRA OF A NEW TYPE OF RECURRENT HIGH-ENERGY TRANSIENT SOURCE

J.-L. ATTEIA, M. BOER, K. HURLEY, M. NIEL, AND G. VEDRENNE
Centre d'Etude Spatiale des Rayonnements (CNRS-UPS), Toulouse
E. E. FENIMORE, R. W. KLEBESADEL, AND J. G. LAROS
Los Alamos National Laboratory
A. V. KUZNETSOV, R. A. SUNYAEV, AND O. V. TEREKHOV
Institute for Space Research, Moscow
AND
C. KOUVELIOTOU, T. CLINE, B. DENNIS, U. DESAI, AND L. ORWIG
NASA/Goddard Space Flight Center
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ABSTRACT

We report the detection of a recurrent high-energy transient source which is neither a classical X-ray nor a gamma-ray burster, but whose properties are intermediate between the two. The energy spectra of 12 recurrent events are found to be soft, characterized by kT's of 34–56 keV. The time histories are short ($\leq$ 128 ms) with rise and fall times as fast as ~ 10 ms. The source location is a 0.12 deg^2 region about 10° from the Galactic center.

Subject headings: gamma rays: burst — X-rays: bursts

I. INTRODUCTION

Among the characteristics of the "classical" gamma-ray bursters are a hard energy spectrum, often with a very high energy tail extending to 10's of MeV (e.g., Matz *et al.* 1985), an isotropic spatial distribution (e.g., Atteia *et al.* 1987*a*), and a lack of evidence for recurring bursts from a single source (Schaefer and Cline 1985; Atteia *et al.* 1987*a*). This is in marked contrast to the X-ray bursters, which have soft spectra, a spatial distribution concentrated in the Galactic bulge, and a tendency to repeat (Lewin and Joss 1981). In this *Letter* we report the detection of a recurrent burst source whose energy spectra are harder than those of X-ray bursters, but softer than those of gamma-bursters; whose time histories resemble those of a short gamma burst, rather than those of an X-ray burst; but whose repetitive behavior is unlike that of any gamma-ray burst source, and somewhat resembles that of X-ray bursters. In addition, the location of this object, near the direction of the Galactic center, hints at a possible relation to X-ray burst sources. The companion *Letter* (Laros *et al.* 1987) documents the activity of this source, which we call the *S*oft *G*amma *R*epeater 1806 – 20, over a 7 yr period.

A single burst from the source was first observed on 1979 January 7 by instruments in the interplanetary network (Laros *et al.* 1986) and by the KONUS experiment (Mazets *et al.* 1981). The source was subsequently detected again as four short events in the data of the Franco-Soviet Signe experiment aboard the *Prognoz 9* (*P9*) spacecraft (Boer *et al.* 1986), all of which were confirmed in the data of the *International Cometary Explorer* (*ICE*) gamma-ray burst detector (Laros *et al.* 1987), and one of which was also found in the data from the *Solar Maximum Mission* (*SMM*: Kouveliotou *et al.* 1986). Subsequent comparison of the *ICE*, *P9*, *Pioneer Venus Orbiter* (*PVO*), *SMM*, and *Venera 13* and *14* Signe (*V13, V14*) event lists revealed that a total of 13 events had been simultaneously detected by a Franco-Soviet experiment and at least one other instrument (Table 1). Given the individual experiment event rates, 0.04 random *ICE/P9* coincidences would have been expected.

The 178 cm^2 NaI scintillation counters aboard *P9* (Boer *et al.* 1986) were, at the time of launch, the largest dedicated gamma-burst detectors yet put into orbit and had extended low-energy spectral coverage. These factors possibly played an important role in the detection of the repetition of this source.

II. TIME HISTORIES

Figure 1 displays the raw count rate data for the 12 *P9* events, with the highest time resolution available (1/64 s). The energy ranges indicated are simply those defined by lower and upper level discriminators; the available spectral information (§ III and Fig. 2) indicates that it is unlikely that any photons were in fact recorded above ~ 200 keV in most cases. Dead-time corrections have not been applied but would increase the maximum count rates of the most intense events by only about 30% (Kuznetsov *et al.* 1987).

A striking feature of all events is their brevity: the FWHM ranges from < 16 ms to ~ 128 ms. To further characterize the time histories, we have fitted simple exponential functions to the leading and trailing edges of the time histories, to obtain the *e*-folding rise and fall times, as was done for the

TABLE 1

PROPERTIES OF SGR 1806 − 20

Date	Spacecraft Observing	Rise Time (ms)	Fall Time (ms)	Duration (FWHM, ms)	kT (keV) for OTTB Fit	Fluence > 30 keV 10^{-7} ergs cm^{-2} for OTTB Fit	Peak Flux > 30 keV 10^{-5} ergs cm^{-2} s^{-1}
1979 Jan 7	*P7, ICE, K11*	< 18[a]	175[a]	200[a]	35[b]	12 [b]	0.62[b]
1983 Mar 20[c]	*V13, ICE*	...	...	...	...	...	...
1983 Jul 18	*P9, ICE*	11	15	< 16	40	5.8	1.8
1983 Aug 20	*P9, ICE*	18	29	32	40[d]	9.3	1.2
1983 Aug 29	*P9, ICE, SMM*[e]	30	64	48	54	8.8	0.91
1983 Nov 1	*P9, ICE*	145	120	100	38	6.0	0.71
1983 Nov 10	*P9, ICE*	12	126	64	40	25.0	2.3
1983 Nov 13	*P9, ICE*	14	< 7	< 16	56	8.5	4.3
1983 Nov 14	*P9, ICE*	38	47	16	44	6.3	1.4
1983 Nov 15	*P9, ICE*	29	37	64	34	8.5	0.99
1983 Nov 16	*P9, ICE*	65	65	128	41	43.0	3.7
1983 Nov 18	*P9, ICE*	40	144	128	37	36.0	2.3
1983 Nov 19	*P9, ICE*	15	34	64	36	18.0	2.4
1983 Dec 22	*P9, ICE*	9	12	< 16	36	7.6	2.0

[a] From data of Mazets *et al.* 1981.
[b] From *Prognoz 7* data.
[c] No *V13* time history or spectral data available due to telemetry noise.
[d] Assumed for purposes of fluence calculation; event was detected in only one spectral channel.
[e] Kouveliotou *et al.* 1987.

hard, nonrepeating gamma-bursters by Barat *et al.* (1984). The results are summarized in Table 1. Given the count rate statistics, these fits, while generally satisfactory, are not unique, and in some cases, only upper limits are obtained. Although these repeating events tend to have slightly faster rise and decay times than the "classical" gamma-bursters, the times are not significantly faster.

III. ENERGY SPECTRA, FLUENCES, AND PEAK FLUXES

The energy spectra of the 12 events were measured in ≤ 4 *P9* energy channels with 0.5 s resolution, allowing simple spectral fits to be obtained. Figure 2 shows the deconvolved (photon) spectra for the four most intense events measured by *P9* and, for comparison, the spectrum of the 1979 January 7 event, as measured by *Prognoz 7* (see also Laros *et al.* 1986). Energy spectra for the other events will be found in Kuznetsov *et al.* (1987).

All spectra may be fitted by an optically thin thermal bremsstrahlung (OTTB) function, with the Gaunt factor included ($\chi^2/df = 0.07$–1.55, $kT = 34$–56 keV). For the four intense events of Figure 2, which had the best statistics, two other functions were tested. First, a redshifted blackbody spectrum from the surface of a 1.3 $M_{\odot}$, 16 km radius object ($\chi^2/df = 2$–10, $kT \approx 17$ keV) and second, a power-law spectrum ($\chi^2/df = 0.7$–29, spectral index ≈ -3.6).

Table 1 summarizes the results of the OTTB fits. For those events where confidence intervals can be established (i.e., those detected in three or four channels), the 90% confidence intervals for the temperatures are large enough to be consistent with a single kT of about 42 keV. The fitting procedure, and particularly the form of the OTTB function (i.e., with or without the Gaunt factor), can change this value by ~ 10 keV (e.g., Kuznetsov *et al.* 1987). The fluences and peak fluxes have been extrapolated to a common energy range (> 30 keV). The peak fluxes cannot be measured directly, since the time resolution of the spectral memory is considerably longer than that of the time history memory. However, they may be estimated by assuming that the spectral shape does not change throughout the event, and scaling it to the highest count rate in the time histories. See Kuznetsov *et al.* (1987) for a more complete discussion of fluence and flux estimates. Both the fluences and peak fluxes vary over a dynamic range of 6 or 7 to 1 for the 12 events.

IV. LOCALIZATION

The 13 1983 events in Table 1 have been localized using the directional response of the *ICE* detector, and arrival time analysis. (The 1979 January 7 localization is explained in Laros *et al.* 1986; for more details on the *ICE* detector and data, see Laros *et al.* 1987.) Two additional events which were detected over interplanetary baselines on 1983 November 16 by *PVO*, *ICE*, and *SMM*, and by *PVO* and *ICE* (but not by *P9*) have similarly been localized. The *ICE* detector response relative to *P9* limits the arrival direction to an annulus of half-width 4° centered on the ecliptic plane, while arrival time analysis results in annuli whose half-widths range from 0°.03 to 13°, and which intersect the 8° wide *ICE* band to define one or two error boxes. A total of 21 error boxes is obtained, and they cover ~ 3200 deg^2. Their intersections are consistent with a single source position. The probability that these error boxes, if randomly distributed, overlap at *any* number of locations may be estimated at about 0.05.

The final error box which contains the true source region with 99.74% (3 σ equivalent) probability is obtained by combining the annuli via a least-squares method, similar to that

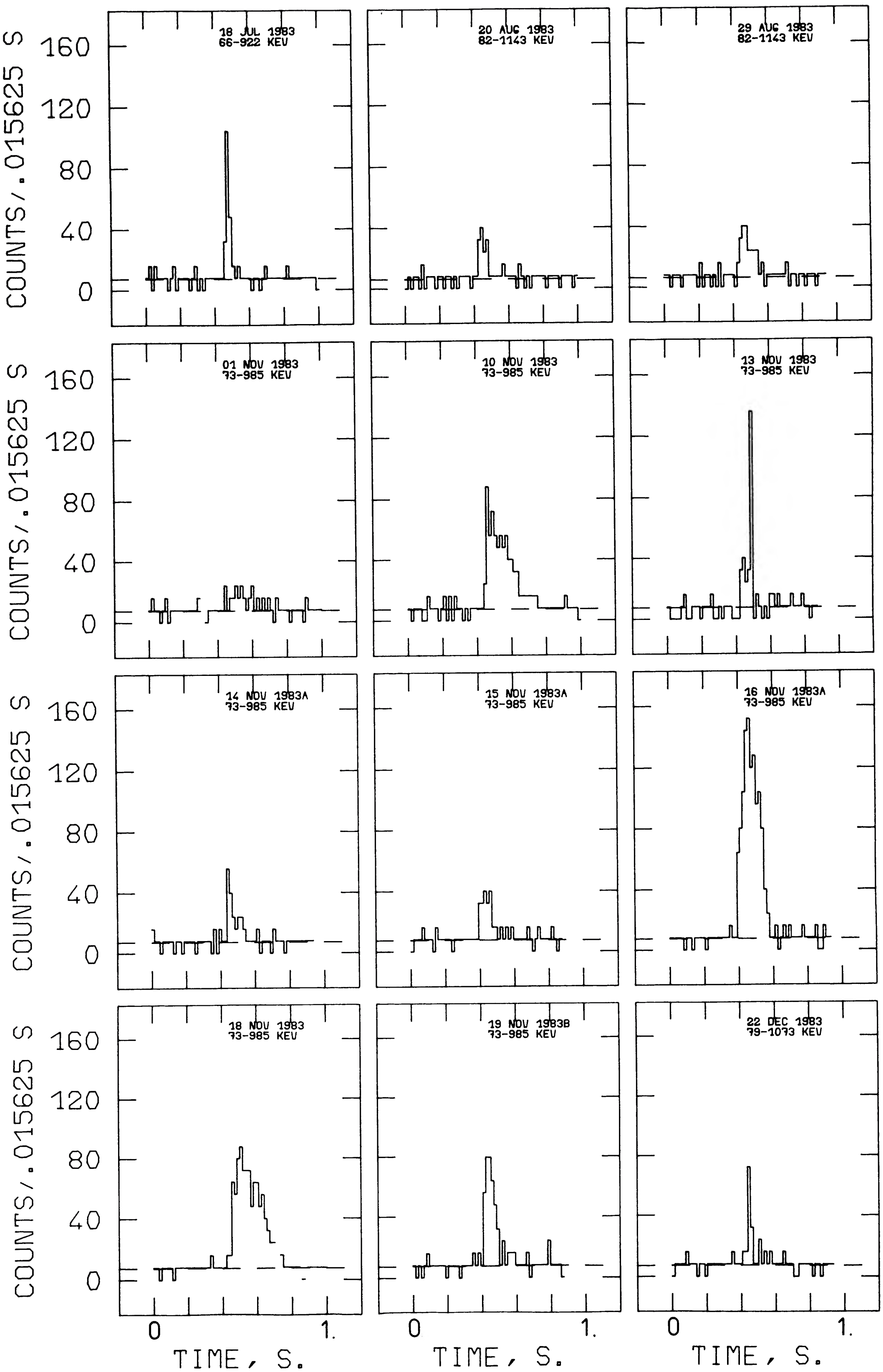

FIG. 1.—The raw time history data for the 12 repeating events detected by the *P9* Signe experiment

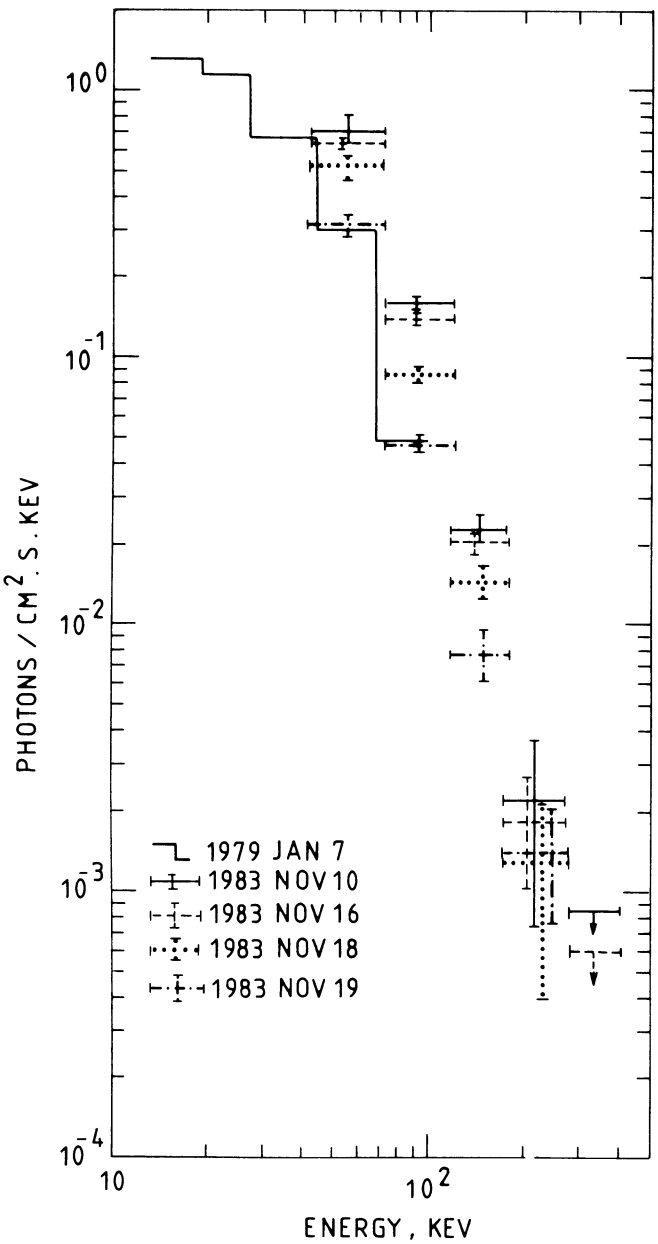

FIG. 2.—Deconvolved (photon) spectra of the four most intense events detected by *P9*. For comparison, the initial 1979 January 7 event, detected by *Prognoz 7*, is shown. The January 7 and November 10 spectra are 0.5 s integrations; all others are over 1 s. One sigma upper limits are shown for the 270–407 keV range; they are identical for the November 16, 18, and 19 events.

described in Cline *et al.* (1984). It is an ellipse with major axis 2°06, minor axis 0°074, centered at $\alpha_{1950} = 18^h05^m38^s$, $\delta_{1950} = -20°26'40''$, having a surface area of 430 arcmin^2 (Fig. 3). (For comparison, the 2 σ and 4 σ ellipses have major and minor axes 1°5, 0°05 and 2°6, 0°09.) The probability that the error boxes overlap over a *common* region this size is vanishingly small.

The center of this error box is about 10° from the Galactic center (almost all of this distance is in Galactic longitude). Catalog searches have revealed no steady or transient X-ray or gamma-ray sources in it. It is, however, in a densely populated region containing stars of up to 7th mag. A search of the *Einstein* and *EXOSAT* archives has turned up one *Einstein* observation which covers about one-half of the box. No X-ray source was found in it.

V. DISCUSSION

Paczyński (1987) has suggested that repeating gamma-bursters may be distant, gravitationally microlensed sources. Babul, Paczyński, and Spergel (1987) have shown that a single tightly beamed, microlensed source can produce apparently dissimilar time histories. In these models, the sources are at cosmological distances, and the energy released is $\sim 10^{51}$ ergs s^{-1}.

If, on the other hand, the source is in our Galaxy, it may be located at a distance of $\sim$ 8.5 kpc. This is suggested not only by the apparent location (see also Kouveliotou *et al.* 1987), but also by the fact that the recurrent behavior at least superficially resembles that of some X-ray bursters, which are distributed in the Galactic bulge. As an example, the radiating surface area required by a 17 keV blackbody at this distance to produce the peak flux of the intense November 16 event would be about 15% of the surface of a 16 km radius neutron star. However the total luminosity over this fraction of the surface would be about 1500 times the Eddington limit, and therefore this source would have to be about 1500 times more luminous than X-ray bursters.

Mazets *et al.* (1982) and Golenetskii, Ilyinskii, and Mazets (1984) have discussed the unusual 1979 March 5 source as a prototype for a particular class of short bursters, which would be located at relatively small distances ($\sim$ 100 pc), and have soft energy spectra. Two of the sources in the class were repeaters (1979 March 5 and 1979 March 24). Thus SGR 1806 − 20 is similar to them in these two general respects; it is different, however, in that both the number of recurrences and/or the range of fluences (> 100 and $\sim$ 30:1, respectively, for the *ICE* events—see Laros *et al.* 1987) far exceed that of either of these two sources, assuming that observations of the latter were not limited by selection effects. If the highest peak flux of SGR 1806 − 20 is associated with the Eddington luminosity of a 1.3 $M_\odot$ neutron star, the source distance would be $\sim$ 175 pc.

Finally, following Fenimore *et al.* (1982), we may estimate the characteristic dimension of the source from the shortest observed rise time ($\sim$ 10 ms), assume that the emission is OTTB from a source whose temperature is $\sim$ 50 keV and whose optical depth $\tau \sim 1$ and determine the distance to the source. The result is $\sim$ 6 pc.

Whatever the source distance may be, we conclude that these data strengthen the evidence for the existence of a class of soft, repeating bursters, with characteristics intermediate between those of the X-ray and gamma-ray bursters. The number of such sources is not easy to estimate reliably, since most spacecraft instruments flown to date have not had the combination of high sensitivity to soft spectra and good sky

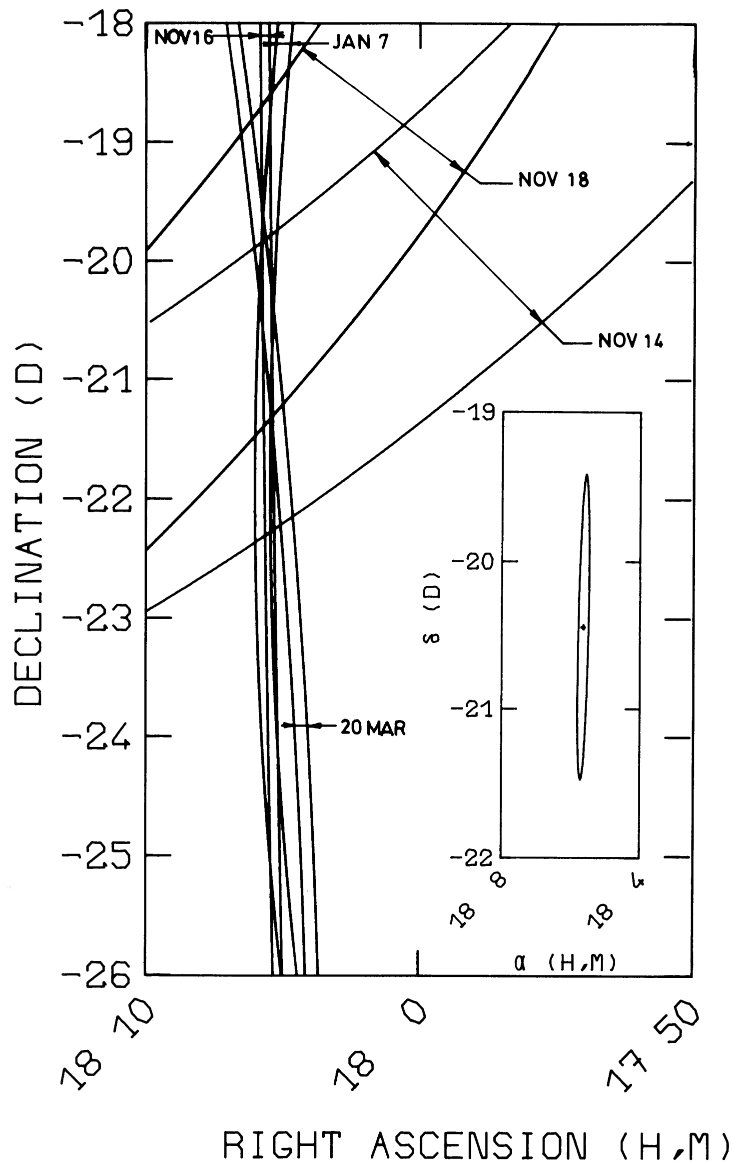

FIG. 3.—Source location annuli for five well-localized events: 1979 January 7, 1983 March 20, 1983 November 16, 1983 November 14, and 1983 November 18. Other annuli are displayed in Atteia *et al.* (1987*b*) (*inset*). The final 3 σ error ellipse taking all localizations into account.

coverage over a long period of time to establish a complete survey. Based on the fact that *ICE* was sensitive to 15% of the sky and detected this source leads to a number of the order of 7, if their distribution is isotropic. Some support for this may be found in the fact that several other examples of possible soft repeaters have been identified in the *P9* data base (Atteia *et al.* 1987*c*). They remain, however, unconfirmed by other spacecraft at this time.

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J.-L. Atteia, M. Boer, K. Hurley, M. Niel, and G. Vedrenne: Centre d'Etude Spatiale des Rayonnements (CNRS-UPS), B.P. 4346, 31029 Toulouse, Cedex, France

T. Cline: NASA/Goddard Space Flight Center, Code 661, Greenbelt, MD 20771

B. Dennis, U. Desai, C. Kouveliotou, and L. Orwig: NASA/Goddard Space Flight Center, Code 682, Greenbelt, MD 20771

E. E. Fenimore, R. W. Klebesadel, and J. G. Laros: Los Alamos National Laboratory, P.O. Box 1663, Mail Stop 436, Los Alamos, NM 87545

A. Kuznetsov, R. Sunyaev, and O. Terekhov: Institute for Space Research (I.K.I.), Profsoyouznaya 88, 117810 Moscow, U.S.S.R.