THE ASTROPHYSICAL JOURNAL, 422:L71–L74, 1994 February 20

RAPID SEARCHES FOR COUNTERPARTS OF GRB 930131

BRADLEY E. SCHAEFER,[1,2,3] SCOTT D. BARTHELMY,[1,2,3] DAVID M. PALMER,[1,4,5] THOMAS L. CLINE,[1] KEVIN C. HURLEY,[6] MICHAEL SOMMER,[7] MICHEL BOER,[7,8] MICHEL NIEL,[8] GERALD J. FISHMAN,[9] CHRYSSA KOUVELIOTOU,[2,9] CHARLES A. MEEGAN,[9] M. J. COE,[10] BRUCE G. ELMEGREEN,[11] BERNARD J. MCNAMARA,[12] THOMAS HARRISON,[12] ALAN OWENS,[13] NEYLE SOLLEE,[14,15] JOHN STULL,[15,16] MICHAEL PALERMITI,[15,17] RICHARD SCHWARTZ,[15,18] JACK BROOKS,[15,19] ROLAND VANDERSPEK,[20], GEORGE R. RICKER,[20] HANS A. KRIMM,[20] WOLFGANG WENZEL,[21] JOCHEN GREINER,[7] RENE HUDEC,[22] MIROSLAV NOVAK,[22] JIRI BOROVICKA,[22] MIROSLAV PREDOTA,[23] CHARLES D. BAILYN,[3,24] LORRAINE O. HANLON,[25] K. BENNETT,[25] TITUS A. TH. SPOELSTRA,[26] ALAIN SMETTE,[27] HOLGER PEDERSEN,[28] RALPH FLORENTIN,[28] CHRISTIAN POLLAS,[29] HELMUT STEINLE,[7] K.-J. SCHRAMM,[30] K. V. K. IYENGAR,[31] AND T. P. PRABHU[31]

Received 1993 April 12; accepted 1993 December 2

ABSTRACT

A fading counterpart to a gamma-ray burst (GRB) would appear as a point source inside a GRB error region soon after the burst which dims on a timescale from minutes to days. The favorable circumstances of the burst GRB 930131 allowed for an international campaign to search for fading counterparts starting 6.8 hr after the burst. We report observations from many optical sites, two radio telescopes, and archival *ROSAT* data, including deep Schmidt exposures 35, 44, and 64 hr after the burst. No fading counterparts were detected with our observations.

Subject heading: gamma rays: bursts

1. INTRODUCTION

Optical, radio, and ultraviolet flashes are expected during the gamma-ray event by many different mechanisms (Liang 1985; Hartmann, Woosley, & Arons 1988; Rappaport & Joss 1985). Numerous searches have been made for GRB flashes with archival plates, patrol photographs, and photoelectric monitors (Pedersen et al. 1984, and see reviews in Schaefer 1986 and Hudec 1992). Several strong candidates for flashes from GRBs have been found in archival photographs (Hudec 1993, but See Greiner 1992), although the relationship of the flash to the later gamma-ray event is not known.

Quiescent counterparts are expected in many wavelengths in many models, although the details vary greatly with the model. The only error boxes sufficiently small for deep searches are those produced by burst timing with spacecraft in the Interplanetary Network (IPN). Unfortunately, deep searches in the radio (Schaefer et al. 1989), infrared (Schaefer et al. 1987), optical (Schaefer 1992), extreme ultraviolet (Owens et al. 1993), and X-ray (Boer et al. 1988) have not turned up any convincing counterparts.

Fading counterparts to GRBs would temporarily appear bright in some energy range soon after a burst, but dim with time. Many mechanisms have been proposed that can produce these transient sources, including recombination of ionized material near the burster, pair production followed by annihilation in a shell near the burster, decay of unstable nuclei created by the gamma radiation in a medium surrounding the burster, and the heating of a neutron star or a stellar companion star which then radiates away its extra energy (Jennings 1983; Rappaport & Joss 1985; Eichler & Cheng 1989; Fencl,

[1] NASA/Goddard Space Flight Center, Code 661, Greenbelt, MD 20771.
[2] Universities Space Research Association.
[3] Visiting Astronomer, Cerro Tololo Inter-American Observatory and Kitt Peak National Observatory, operated by AURA, Inc., under contract with the National Science Foundation.
[4] Guest Observer at the Very Large Array, a part of the National Radio Astronomy Observatory which is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.
[5] National Research Council-GSFC Research Associate.
[6] Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 94720.
[7] Max-Planck-Institute for Extraterrestrial Physics, D-8046 Garching, Germany.
[8] Centre d'Etude Spatiale des Rayonnements (CNRS/UPS), F-31029 Toulouse, France.
[9] NASA/Marshall Space Flight Center, ES-62, Huntsville, AL 35812.
[10] Physics Department, The University of Southampton, Southampton SO9 5NH, UK.
[11] IBM Corporation, Watson Research Center, P.O. Box 218, Yorktown Heights, NY 10598.
[12] New Mexico State University, Dept. of Astronomy, Box 4500, Las Cruces, NM 88003
[13] University of Leicester, University Road, Leicester LE1 7RH, UK.
[14] P.O. Box 211, Crestone CO 81131.
[15] Santa Barbara Astronomy Group.
[16] Alfred University, 26 North Main Street, Alfred, NY 14802.
[17] Palermiti Observatory, 16222 133rd Drive North, Jupiter, FL 33478.
[18] 1530 Miramar Lane, Santa Barbara, CA 93108.
[19] 1337 Highland Road, Santa Ynez, CA 93460.
[20] Massachusetts Institute of Technology, 37-527, Cambridge, MA 02139.
[21] Sonneberg Observatory, Sternwartestrasse 32, D-O-6400 Sonneberg, Germany.
[22] Astronomical Institute, 251 65 Ondrejov, Czech Republic.
[23] Meteorological Station Churanov, Churanov, Czech Republic.
[24] Yale University, Department of Astronomy, P.O. Box 6666, New Haven, CT 06511.
[25] Astrophysics Division, ESA-ESTEC, Keplerlaan 1, NL-2200 AG Noordwijk, The Netherlands.
[26] NFRA, Radio Observatory, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands.
[27] European Southern Observatory, Casilla 567, La Serena, Chile.
[28] Copenhagen University Observatory, Oster Voldgade 3, DK 1350, Copenhagen K, Denmark.
[29] Observatoire de la Cote d' Azur, CERGA, Observatoire du Calern, F-06460 Saint Vallier de Thiey, France.
[30] Hamburger Sternwarte, Gojenbergsweg 112, W-2050 Hamburg 80, Germany.
[31] Indian Institute of Astrophysics, Bangalore 560034, India.

Boyd, & Hartmann 1992; Band & Hartmann 1992). The predicted timescales for fading vary considerably, but typical durations are from minutes to days. Given the scientific importance of detecting GRB counterparts, we have organized a network of observers willing to look into GRB boxes soon after the burst. The first multiwavelength observing campaign was carried out in response to a burst which occurred on 1992 May 1 (Hurley et al. 1993). At that time, weather and communications problems limited the response to about 12 days after the event. In this *Letter*, we report on a larger, considerably faster campaign to find a fading counterpart.

2. BURST POSITION

On 1993 January 31 at 18:57:11.71 UT, the BATSE detectors on the *Compton Gamma Ray Observatory* detected a gamma-ray burst which had the highest peak flux of any burst ever detected by BATSE. This burst has been designated GRB 930131 and it was inside the fields of view (FOV) of COMPTEL and EGRET. The BATSE and COMPTEL Instrument Teams were able to measure a preliminary position within 6 hr (Ryan, Kippen, & Varendorff 1993) and to notify observers throughout the world. Preliminary positions were also produced by the BATSE, EGRET, and IPN teams (Cline et al. 1993; Sommer et al. 1993). The preliminary positions were subsequently improved, with the final BATSE, COMPTEL, EGRET, and IPN results appearing in Kouveliotou et al. (1994), Ryan et al. (1994), Sommer et al. (1994), and this *Letter*, respectively. There is good agreement between these independent measures (see Fig. 1).

GRB 930131 was detected with both the *GRO* and *Ulysses* spacecraft. (The Gamma Ray Spectrometer on the Mars *Observer* spacecraft was in a standby mode at the time of the burst.) With two spacecraft, the IPN can only produce an annulus on the sky on which the burster must lie. Fortunately, the great distance between *Ulysses* and *GRO* (roughly 2105 lt-seconds or 4.22 AU), the large collecting area and high time resolution of BATSE, and the sharp structures in the light curve of GRB 930131 have allowed for a remarkably thin annulus. Currently, the annulus total width is 43″ (90% confidence), although further analysis will significantly reduce the systematic uncertainties and yield an annulus as much as a factor of 5 narrower. The center of the annulus is at a right ascension of $10^{h}45^{m}37^{s}.9$ and a declination of −14°33′47″, with a radius of 22°.254. All positions in this *Letter* are in J2000 coordinates.

The EGRET, BATSE, COMPTEL, and IPN burst positions are displayed in the left-hand panel of Figure 1. The middle panel shows the combined EGRET/COMPTEL/BATSE probability along the arc, with the most likely declination of −10°.15. The right-hand panel shows the FOVs of those observations from Table 1 that intersected the IPN arc.

3. OBSERVATIONS

Many groups responded with rapid response counterpart searches for GRB 930131. Table 1 is a detailed journal of observations. The fastest response was 14 hr at Blue Mesa Observatory, although Ondrejov has patrol plates from 6.8 hr after the burst. We obtained deep Schmidt images 35, 44, and 64 hr after the burst that cover the entire IPN arc. In all, we collected images from 39 separate times ranging from 6.8 hr to 24 days after the burst. Several of our counterpart searches were based on preliminary positions and did not overlap with the final error region.

Despite the length of the annulus, it was not possible to request a *ROSAT* Target of Opportunity (as was done for the 1992 May 1 event [Hurley et al. 1993]) because of the satellite's Sun-angle constraint. However, archival soft X-ray and extreme ultraviolet (EUV) data from the *ROSAT* All-Sky Survey (2 yr before the gamma-ray burst) were examined for a possible quiescent counterpart. The data analyzed were collected for 7 days in 1990 July and 4 days around 1990 December 20 for the EUV wide-field camera, and for 2 days around 1990 December 20 for the X-ray Telescope of *ROSAT*. The

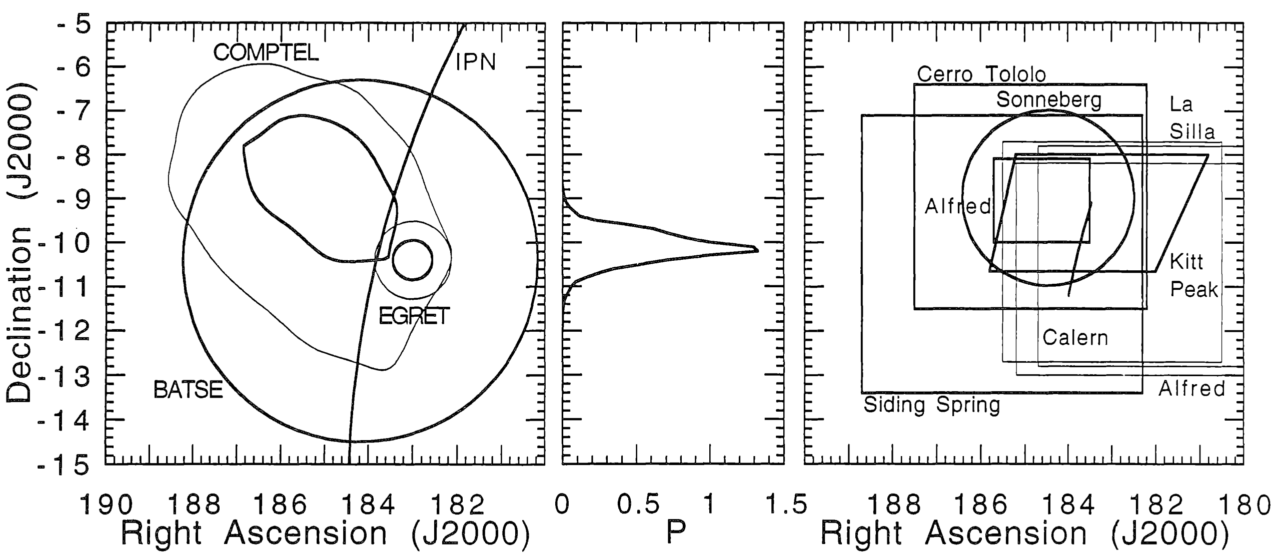

FIG. 1.—Position and coverage of GRB 930131. The left-hand panel shows the 1 and 2 σ uncertainty regions (*thick and thin curves*, respectively) from EGRET (Sommer et al. 1994), COMPTEL (Ryan et al. 1994), BATSE (Kouveliotou et al. 1994), and the IPN (this *Letter*). The regions nicely overlap at a declination of roughly −10°. The middle panel shows the combined probability density (in units of deg^{-1}) from EGRET/COMPTEL/BATSE as a function of declination along the arc. The most likely declination is −10°.45, with a 68% probability of lying between declinations of −10°.45 and −9°.75, and with a 99% probability of lying between declinations of −11°.2 and −9°.1. The right-hand panel shows the FOVs of the observations from Table 1 that cover the IPN arc. The 99% probability section of the IPN arc are plotted as a thick curve. The observations are labelled by the observing site, with the images taken within five days of the burst indicated with thick lines.

TABLE 1

RAPID RESPONSE OBSERVATIONS OF GRB 930131

ΔT (d)	Observer	Site	D (cm)	$m_{\rm lim}$	Total FOV	Declination Coverage of IPN Arc	Detector
0.28	MN	Andrejov, Czech	0.9	7.0	180° diameter	−20° to 0°	FOMAPAN 100
0.58	BJM	Blue Mesa, NM	61	19.0	0°75 × 0°75	[a]	*V* CCD grids
1.28	JB	Ondrejov, Czech	0.9	6.0	180° diameter	−20° to 0°	FOMAPAN 100
1.34	MP	Churanov, Czech	0.9	7.5	180° diameter	−20° to 0°	ORWO NP 27
1.46	BES	Cerro Tololo, Chile	91	20.5	5°25 × 5°25	−11.5° to −6.4°	Unfiltered IIa-O
1.58	DMP	Very Large Array, NM	[b]	[b]	1°0 diameter	[a]	20 cm wavelength
1.64	BGE	Kitt Peak, AZ	91	21.0	40′ diameter	[a]	*B* CCD grids
1.66[c]	RV	Kitt Peak AZ	1.7	7–8[d]	15° × 20°	−16° to 0°	Unfiltered CCD
1.85	MJC	Siding Spring, Australia	124	23	6°25 × 6°25	−13°06 to −7°71	WG305 and 4415
2.08	KVKI	Kavalur, India	102	21	3′4 × 2′3	[a]	*BVRI* CCD
2.19	TPP	Kavalur, India	230	21	4′ × 6′	[a]	*R* and Hα CCD
2.41	TW[e]	Sonneberg, Germany	40	15.0	4°0 diameter[f]	−10°9 to −7°6	Unfiltered ZU21
2.58	BJM	Blue Mesa, NM	61	19.0	0°75 × 0°75	[a]	*V* CCD grids
2.65	BGE	Kitt Peak, AZ	91	21.0	4°0 × 2°6	−10°6 to −8°0	*R* CCD grids
3.34	MP	Churanov, Czech	0.9	7.5	180° diameter	−20° to 0°	ORWO NP 27
3.41	TW[e]	Sonneberg, Germany	40	15.0	4°0 diameter[f]	−10°9 to −7°6	Unfiltered ZU21
4.59	JS	Alfred, NY	6.0	13.0	2°2 × 1°9	−10°0 to −8°9	Unfiltered ST-6 CCD
4.78	NS	Crestone, CO	12.5	14.0	1°2 × 1°0	[a]	Unfiltered ST-6 CCD
6.57	TATS	Westerbork, Netherlands	[g]	[g]	0°33 × 0°04	[a]	6 cm wavelength
7.37	HS	Calar Alto, Spain	220	20	3′ × 5′	[a]	*R* CCD
12.7	NS	Crestone,CO	62	19.5	12′ × 10′	[a]	Unfiltered ST-6 CCD
13.4	MP	Jupiter, FL	22	19.0	14′ × 17′	[a]	Unfiltered ST-6 CCD
16.7	AS	La Silla, Chile	100	19	5° × 5°	−12°5 to −7°7	RG630 and IIIa Fse
17.3	CP	Calern, France	90	19	5° × 5°	−12°8 to −7°8	RG610 and Tech. Pan
17.7	JS	Alfred, NY	6.0	12.3	5°6 × 4°8	−13°0 to −8°2	Unfiltered ST-6 CCD
18.3	RF	Brorfelde, Denmark	45	20	0°5 × 1°0	[a]	*R* CCD
20.3	CP	Calern, France	90	19	5° × 5°	−12°8 to −7°8	RG610 and Tech. Pan
20.3	HP	La Palma, Spain	256	20	1°2 × 0°05	[a]	Unfiltered CCD grids
22.3	CP	Calern, France	90	19	5° × 5°	−12°8 to −7°8	GG385 and IIIaJ
24.4	CDB	Cerro Tololo, Chile	91	19.0	0°22 × 1°9	[a]	*V* and *R* CCD grids

[a] The observation did not cover the IPN arc.
[b] The observations (in the BnA array) reached a limit of roughly 0.2 mJy for a 3 σ detection.
[c] The ETC session UT starting times (and exposure times) are Feb 2 10:50 (0.66 hr), Feb 3 8:38 (1.84 hr), Feb 5 11:22 (0.71 hr), Feb 17 10:43 (0.36 hr), Feb 22 3:20 (1.15 hr), Feb 23 11:57 (0.05 hr), Feb 25 8:11 (0.76 hr), Feb 26 12:17 (0.17 hr), and Feb 27 10:18 (0.94 hr).
[d] The quoted limiting magnitude range is for the detection of an optical flash of 1 s duration.
[e] Thomas Weber.
[f] This plate had a total FOV of 100 deg^2, but was blink compared with earlier images only over a region as indicated (see also Wenzel & Greiner 1993).
[g] Frequency = 4874 MHz, bandwidth = 80 MHz, and limiting sensitivity = 0.12 mJy.

average 3 σ flux limits for a constant EUV source along the IPN arc are 0.0063 and 0.00859 counts per second in the S1 (90–140 eV) and S2 (110–200 eV) filters, respectively. For an intrinsic source spectrum shaped as a blackbody with a temperature of 10^6 K and no Galactic absorption, these limits correspond to 2.2×10^{-11} ergs cm^{-2} s^{-1} for the S1 filter and 2.9×10^{-11} ergs cm^{-2} s^{-1} for the S2 filter. In addition, the *ROSAT* EUV data were examined for any short duration bursts with the program described in Owens et al. (1993). The threshold for this search was the 1 σ probability level, where the probability level for random fluctuations was calculated with a correction for the number of trials in the images examined. For the soft X-ray data from *ROSAT*, the 3 σ upper flux limits for a point source in the 0.1–2.4 keV range along the triangulation arc are 0.009 counts per second at a declination of −8°3 and 0.012 counts per second at a declination of −11°5, with the gradient being due to the difference in exposure times. For a 10^6 K blackbody and no Galactic absorption, this corresponds to 4×10^{-14} ergs cm^{-2} s^{-1} and 5×10^{-14} ergs cm^{-2} s^{-1}, respectively.

4. RESULTS

The primary result of our rapid response campaign for GRB 930131 was that no GRB counterpart was identified. The time delays and magnitude limits are presented in Table 1. In addition, no archival EUV or X-ray counterpart was detected with *ROSAT*.

Five optical variable sources were discovered with our images, all of which are outside the final combined error region and thus cannot have any connection with GRB 930131. However, we did find a nonstellar $V \approx 23$ image at $12^h14^m46^s.1$ and −9°56′45″ (23″3 from the IPN arc center line) on the rapid response plate from Siding Spring which did not appear on a comparison plate. The discovery of faint variable stars is to be expected in our study. Hawkins (1983) demonstrates that roughly 0.1% of all stars brighter than $B = 21$ are variable with an amplitude greater than 0.3 mag. For the study of the Kitt Peak images, roughly 2000 stars were viewed in a total area covering 1.37 deg^2. Thus, we expected to find roughly two variable stars unrelated to the gamma-ray burst source from the Kitt Peak images, and this is how many we found. The Siding Spring plate was compared with a similar plate taken on 1993 March 5 over an area within 6′ of the IPN arc. The comparison plate was not quite as deep, but nevertheless showed 7834 objects in the region examined. There are 19 sources which appear on the rapid response plate that should have, but did not, appear on the comparison plate. This implies a fraction of 0.2% of the sources brighter than roughly 23 mag will have "disappeared" on some other plate. The total area of the final GRB error box is 3.05% of the entire region examined, so that of the approximately 239 sources in the box, the expected number of fading counterpart candidates is roughly 0.5 for the Siding Spring image.

In the *ROSAT* X-Ray Telescope data, there are two X-ray sources located about 7′ and 0.′3 (with a positional uncertainty of 0.′5) from the center of the IPN annulus. The two sources are consistent in position with HD 106225 (a $V = 8.3$ mag K star) and HR 4657 (a $V = 6.11$ mag F5 V star), respectively. Tentatively, we identified both *ROSAT* sources as coronally active stars probably not responsible for GRB 930131.

The *ROSAT* All-Sky Survey did reveal an EUV source whose image is consistent with the instrumental point spread function. The source was detected at the 2.7 σ confidence level with the S1 filter, 3.5 σ with the S2 filter, and 4.3 σ in the composite image. Many independent positions across the image were examined, so the overall probability that some fluctuations will appear at this brightness or brighter is 0.8%. The flux of this source is 0.0035 and 0.010 counts per second in the S1 and S2 filters, respectively. There are of order 1000 EUV sources detected by *ROSAT* as bright as or brighter than this source. The position of this source is right ascension $12^h12^m21^s.7$ and declination $-8°3'51''$ with an error circle 2.′5 in radius at the 90% confidence level. This position is consistent with the IPN annulus but is not consistent with the position along the annulus as determined by EGRET or COMPTEL. The probability that a *ROSAT* source at least as bright as seen should have a position consistent with the IPN annulus is of order 2%.

The two brightest sources in the GRB error box are stars ($V = 6.11$ for HR 4657 and $R = 12.5$ for an anonymous star). No extended source appears in the IPN arc to the limit of the Palomar plates.

5. RAPID RESPONSE CAMPAIGNS

For COMPTEL, BATSE, EGRET, and the IPN, their final positions shifted from the preliminary positions for a variety of reasons. A trade-off between accuracy and delay is a fundamental characterstic of GRB positions. Therefore, some searches might end up imaging the sky away from the burster. This is a regrettable but unavoidable aspect of the need for fast reaction.

The large size of the preliminary error boxes requires the utilization of telescopes with large FOVs. The use of large image mosaics is time-consuming and cannot reach faint limits. In addition, large FOVs provide insurance against shifts in the burst position. The typical size of preliminary GRO error region ranges from 2° to 10° in radius, so only telescopes with comparable FOVs should be used for rapid response.

Communication difficulties resulted in significant delays for acquiring data. Our experience suggests that burst notifications should be sent by as many channels as possible, with alternatives for each, including day/night FAX, phone, and e-mail. Interested observers should send their names, phone numbers, e-mail addresses, locations, FOVs, limiting magnitudes, and availability to each provider of burst positions or coordinators.

We thank James M. Ryan, R. Marc Kippen, and the COMPTEL Team for their rapid determination and dissemination. We acknowledge funding from JPL Contract 958056 for *Ulysses* operations and NASA NAGS 1560 for the IPN work. The *Ulysses* GRB detector was constructed in France with support of the Centre National d'Etudes Spatiale. We would like to thank the staff of the UK Schmidt at the Anglo Australian Observatory for taking the films and the COSMOS Unit at the Royal Observatory Edinburgh for measuring them. Observations by B. G. E. were made with the Burrell Schmidt of the Warner and Swasey Observatory, Case Western Reserve University; B. G. E. would like to thank Alex Wong from Williams College and Meredith MacKenzie from Swarthmore College for help with the observations. The ETC observations are supported by NASA grant NAGW-2089. L. O. H. wishes to acknowledge an ESA fellowship. M. B. acknowledges the kind hospitality of the Max-Planck-Institut für Extraterrestrische Physik, through the CNRS/MPG exchange agreement.

REFERENCES

Band, D. L., & Hartmann, D. H. 1992, in Gamma-Ray Bursts, ed. W. S. Paciesas & G. J. Fishman (New York: AIP), 342
Boer, M., et al. 1988, A&A, 202, 117
Cline, T. L., et al. 1993, IAU Circ., No. 5703
Eichler, D., & Cheng, A. F. 1989, ApJ, 336, 360
Fencl, H. S., Boyd, R. N., & Hartmann, D. H. 1992, in Gamma-Ray Bursts, ed. W. S. Paciesas & G. J. Fishman (New York: AIP), 267
Greiner, J. 1992, A&A, 264, 121
Hartmann, D., Woosley, S. E., & Arons, J. 1988, ApJ, 332, 777
Hawkins, M. R. S. 1983, MNRAS, 202, 571
Hudec, R. 1992, in Gamma-Ray Bursts, ed. W. S. Paciesas & G. J. Fishman (New York: AIP), 323
———. 1993, A&AS, 97, 49
Hurley, K., et al. 1993, in Proc. INTEGRAL Workshop, Les Diablerets Switzerland, in press
Jennings, M. C. 1983, ApJ, 273, 309
Kouveliotou, C., et al. 1994, ApJ, 422, L59
Liang, E. P. 1985, Nature, 313, 202
Owens, A., Page, C. G., Sembay, S., & Schaefer, B. E. 1993, MNRAS, 260, L25
Owens, A., Sembay, S., Sims, M., Wells, A., & Schaefer, B. E. 1993, in Compton Gamma-Ray Observatory, ed. M. Friedlander, N. Gehrels, & D. J. Macomb (New York: AIP), 798
Pedersen, H., et al. 1984, Nature, 312, 46
Rappaport, S. A., & Joss, P. C. 1985, Nature, 314, 242
Ryan, J., Kippen, M., & Varendorff, M. 1993, IAU Circ., No. 5702
Ryan, J., et al. 1994, ApJ, 422, L67
Schaefer, B. E. 1986, in Gamma-Ray Bursts, ed. E. P. Liang & V. Petrosian (New York: AIP), 47
———. 1992, in Gamma-Ray Bursts, ed. C. Ho, R. I. Epstein, & E. E. Fenimore (Cambridge: Cambridge Univ. Press), 107
Schaefer, B. E., et al. 1987, ApJ, 313, 226
Schaefer, B. E., et al. 1989, ApJ, 340, 455
Sommer, M., et al. 1994, IAU Cir., No. 5707
Sommer, M., et al. 1994, ApJ, 422, L63
Wenzel, W., & Greiner, J. 1993, IAU Circ., No. 5708