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FINAL REPORT

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1. INTRODUCTION

The Burst and Transient Source Experiment (BATSE) is one of four instruments on the Compton Observatory which was launched by the space shuttle Atlantis on April 5, 1991. As of the end of November, 1993, BATSE detected more than 830 cosmic gamma-ray bursts and more than 690 solar flares. Pulsed gamma-rays have been detected from at least 16 sources and emission from at least 28 sources (including most of the pulsed sources) has been detected by the Earth occultation technique. The daily BATSE operations tasks represent a substantial level of effort and involve a large team which includes MSFC personnel as well as contractors such as UAH. The effort is naturally divided into several areas: data operations, burst operations, occultation operations, and pulsar operations. UAH personnel have been involved to some extent in all of these as well as contributing to various areas of scientific data analysis.

2. MISSION OPERATIONS

W. Paciesas served as BATSE Mission Operations Software (MOPS) Development Manager, chairing the Level V Configuration Control Board for the MOPS software. Paciesas also supervised distribution of the Individual Burst Data Base (IBDB) files to co-investigators at Goddard Space Flight Center (GSFC) and the University of California, San Diego (UCSD). K. Squier developed software to produce summary reports of Individual Burst Data Base (IBDB) contents for selected triggers. Squier also developed software to modify certain parameters in IBDB files without regenerating the entire IBDB for a particular trigger. An audit trail of changes is maintained as an additional IBDB file. Z. Shariff assisted in BATSE data operations on a regular basis. Shariff, T. Koshut, R. Mallozzi, and J. Brainerd performed burst operations regularly.

Scheduling and Coordination of Daily Data Operations was facilitated by a subcontract with Teledyne-Brown Engineering. W. Henze (TBE) worked with UAH and MSFC operations personnel to develop procedures for implementation of various operations tasks. Henze also produced a data operations manual containing explanations of individual tasks, how to start them, and what to do if something goes wrong.

3. INSTRUMENT CALIBRATION

G. Pendleton worked on improving the channel-to-energy calibration of the large area detectors (LADs) using data from the Crab Nebula. He summarized the results in a conference paper.[1] Pendleton and Paciesas worked with R. Schwartz (GSFC) to study the low-energy response of the BATSE spectroscopy detectors (SDs) using solar flare data, and with B. Schaefer (GSFC) on cross-calibration of BATSE burst data from both LADs and SDs with other GRO instruments. Results of the latter were reported in a conference paper.[2]

Koshut led a study of systematic errors in the location of bursts using the MAXBC datatype.[3]

4. BURST DATA ANALYSIS

Pendleton led studies of continuum spectral characteristics of gamma-ray bursts using low-energy-resolution data (4 channels)[4] and medium-energy-resolution (16 channels).[5] Pendleton collaborated with GRO Guest Investigator (GI) E. Fenimore (Los Alamos Nat. Lab.) and others on the number/intensity distribution of gamma-ray bursts obtained by combining BATSE and PVO data.[6]

Paciesas, Pendleton, Mallozzi and Koshut were part of the collaborative effort to produce the first BATSE catalog of gamma-ray bursts[7] Pendleton was primarily responsible for calculation of burst fluxes and fluences, while Koshut had primary responsibility for calculation of burst durations. The durations were shown to have a bimodal distribution[8] with a minimum around 1–2 s. Koshut led a preliminary study contrasting the properties of short events with short spikes in long events.[9] Pendleton, Koshut and V. Chaganti developed software to be used for production of the second burst catalog, which is in preparation. Chaganti, Koshut and Shariff have been working on the first part of this analysis.

Paciesas coordinated BATSE spectral analysis efforts among UAH, MSFC, GSFC, and UCSD. Paciesas was principal investigator on the successful key project proposal for time-resolved burst spectroscopy in phase 3 of the GRO GI program.[10] Visual searches for spectral features in BATSE bursts were continued as part of this project. No convincing evidence has yet been found for such features;[11] a candidate line found in one burst is probably spurious.[12,13] The lack of line features cannot yet be considered inconsistent with other observations.[14] An automated procedure for exhaustive searches for line features is being implemented.[15] Studies of burst continuum spectra showed differences among bursts as to their temporal evolution.[16-19] The spectroscopy collaboration also produced a catalog of burst spectra.[20]

UAH personnel were involved in various studies of burst sky distributions. Brainerd led a collaboration which found no significant clustering of bursts using a nearest-neighbor analysis.[21] Koshut and Mallozzi worked with other BATSE team members to put limits on heliocentric models for bursts.[22] Pendleton and Paciesas collaborated with J. Hakkila (Mankato St. U.) and others on constraining galactic burst models from BATSE data.[23]

Pendleton, Paciesas and Koshut also collaborated in analysis of recurrent events detected by BATSE from the soft gamma repeater SGR 1900+14.[24]

Brainerd developed a model for burst spectra from sources at comological distances based on Compton scattering in a relatively thick obscuring medium.[25,26]

5. NON-BURST DATA ANALYSIS

Paciesas and Mallozzi worked on occultation analysis of selected sources. Mallozzi searched for low-energy gamma-ray emission from a set of active galactic nuclei (AGNs) detected by EGRET.[27] Paciesas led analysis of temporal and spectral variability of the quasar 3C 273[28] and the transient source Nova Muscae.[29] Paciesas analyzed BATSE data for inclusion in the multi-wavelength study of 3C 273 led by G. Lichti (MPE Garching).[30] Paciesas and Pendleton collaborated with various other BATSE team members on studies of the galactic black-hole candidate GX 339-4, the transient sources GRO J1719-24 and GRS 1009-45, and sources in the galactic center region.[31-33] Paciesas collaborated with the effort led by S. N. Zhang (USRA) to develop a method for producing images from occultation data.[34-36] Paciesas collaborated with J. Greiner (MPE Garching) on analysis of the transient GRS 1915+105[37] and with J. Ling (JPL) on analysis of Cygnus X-1.[38]

M. Stollberg continued analysis of data from the x-ray binary EXO 2030+375 as part of his Ph. D. dissertation.[39] Stollberg also assisted the BATSE team in production pulsar analysis. While performing production analysis, he discovered a new transient pulsar GRO J1008-57.[40] Stollberg and Pendleton collaborated with R. Wilson (MSFC) and others in analysis of this source.[41,42]

Pendleton collaborated with Wilson and others on a study of intensity/torque correlations in Her X-1.[43,44] Paciesas collaborated with B. Rubin (USRA) and others on an investigation of the long-period pulsar 4U 1538-52.[45]

5. OTHER ACTIVITIES

Brainerd and Pendleton served on the local organizing committee for the Gamma-Ray Burst Workshop held in Huntsville on 20–22 October. Stollberg presented a contributed paper at the NATO Advanced Study Institute "Lives of the Neutron Stars" in Kemer, Turkey, during 29 August–11 September. Paciesas, Pendleton and Mallozzi presented contributed papers at the Second Compton Symposium in College Park, MD, during 20–22 September. Paciesas presented an invited talk on "CGRO/BATSE occultation studies of galactic black hole candidates and AGNs" at the workshop on Pairs, Gamma-Rays and Black Holes in Koninki, Poland, during 5–8 October. Stollberg and Paciesas presented contributed papers at the conference on the Evolution of X-Ray Binaries in College Park, MD, during 11–13 October.

Paciesas continued to serve as BATSE representative to the CGRO User's Committee, attending meetings on 26–27 May and 23–24 September. Paciesas reviewed and provided updated BATSE inputs to the CGRO Project Data Management Plan and to the NASA Research Announcement for phase 3 of the GI program.

Meetings of the Burst Spectroscopy Team were held on 24–25 June at MSFC (attended by Paciesas, Pendleton, Brainerd, Koshut and Mallozzi) and on 9–10 September at GSFC (attended by Paciesas and Pendleton).

Copies of selected publications involving UAH personnel as principal author are attached.

REFERENCES

[1] Pendleton, G.N., Paciesas, W.S., Briggs, M.S., Harmon, B.A., Wilson, C.A., Fishman, G.J., Wilson, R.B., and Meegan, C.A. "Channel to Energy Calibration Results for the BATSE Large Area Detectors." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994). [See attachment]

[2] Schaefer, B.E, Teegarden, B., Cline, T., Dingus, B.L., Fishman, G.J., Meegan, C.A., Wilson, R.B., Paciesas, W.S., Pendleton, G.N., Band, D.L., Schneid, E.J., Kwok, P.W., Schönfelder, V., Winckler, C., Hermsen, W., and Kippen, R.M. "Cross Calibration of Burst Spectra with BATSE, EGRET, and COMPTEL for GRB910503." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[3] Koshut, T.M., Paciesas, W.S., Pendleton, G.N., Brock, M.N., Fishman, G.J., Meegan, C.A., and Wilson, R.B. "An Evaluation of BATSE Burst Locations Computed with the MAXBC Datatype." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[4] Pendleton, G.N., Paciesas, W.S., Briggs, M.S., Mallozzi, R.S., Koshut, T.M., Fishman, G.J., Meegan, C.A., Wilson, R.B., Harmon, B.A., and Kouveliotou, C. "The Continuum Spectral Characteristics of Gamma-Ray Bursts Observed by BATSE." *Ap. J.*, in press (1994).

[5] Pendleton, G.N., Paciesas, W.S., Briggs, M.S., Fishman, G.J., Wilson, R.B., Meegan, C.A., and Kouveliotou, C. "Continuum Spectral Characteristics of Bursts Measured with the BATSE Large Area Detectors." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[6] Fenimore, E.E., Epstein, R.I., Ho, C., Klebesadel, R.W., Lacey, C., Laros, J.G., Meier, M., Strohmayer, T., Pendleton, G., Fishman, G., Kouveliotou, C., and Meegan, C. "The intrinsic luminosity of gamma-ray bursts and their host galaxies." *Nature* **366**, 40 (1993).

[7] Fishman, G.J., Meegan, C.A., Wilson, R.B., Brock, M.N., Horack, J.M., Kouveliotou, C., Howard, S., Paciesas, W.S., Briggs, M.S., Pensleton, G.N., Koshut, T.M., Mallozzi, R.S., Stollberg, M., and Lestrade, J.P. "The First BATSE Gamma-Ray Burst Catalog." *Ap. J. Suppl.*, in press (1994).

[8] Kouveliotou, C., Meegan, C.A., Fishman, G.J., Bhat, N.P., Briggs, M.S., Koshut, T.M., Paciesas, W.S., and Pendleton, G.N. "Identification of Two Classes of Gamma-Ray Bursts." *Ap. J.* **413**, L101 (1993).

[9] Koshut, T.M., Pendleton, G.N., Mallozzi, R.S., Paciesas, W.S., and Briggs, M.S. "A Study of Continuum Spectra of Short Duration Gamma-Ray Bursts Observed by BATSE." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[10] Paciesas, W.S., Brainerd, J.J., Briggs, M.S., Pendleton, G.N., band, D.L., Lingenfelter, R., Matteson, J.L., Cline, T., Palmer, D., Teegarden, B.J., Bhat, P.N., Fishman, G.J., Meegan, C.A., Wilson, R.B., Preece, R.D., Kouveliotou, C., and Schaefer, B.E. "Time-Resolved Spectroscopy of Gamma-Ray Bursts." Proposal to NASA in response to NRA 92-OSSA-17 (1993).

[11] Palmer, D.M., Teegarden, B.J., Schaefer, B.E., Cline, T.L., Band, D.L., Ford, L.A., Matteson, J.L., Preece, R.D., Paciesas, W.S., Pendleton, G.N., Briggs, M.S., Fishman, G.J., Meegan, C.A., WIlson, R.B., and Lestrade, J.P. "The Search for Gamma-Ray Burst Spectral Features in the Compton GRO BATSE Data." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[12] Ford, L., Band, D., Matteson, J., Palmer, D., Schaefer, B., Teegarden, B., Preece, R., Briggs, M., Paciesas, W., and Pendleton, G. "A Candidate Absorption Feature from a Gamma Ray Burst Observed by BATSE." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[13] Preece, R.D., Briggs, M., Paciesas, W., Pendleton, G., Ford, L., Band, D., Matteson, J., Palmer, D., Teegarden, B., Schaefer, B., and Brock, M. "Consistency Analysis of a Candidate Line Feature in GRB930506." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[14] Band, D., Ford, L., Matteson, J., Palmer, D., Teegarden, B., Schaefer, B., Briggs, M., Paciesas, W., Pendleton, G., and Preece, R. "Cyclotron Line Search: BATSE-Ginga Consistency." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[15] Schaefer, B.E., Teegarden, B., Palmer, D.M., Cline, T.L., Mitruka, S., Ford, L.A., Band, D.L., Matteson, J.L., Briggs, M.S., Paciesas, W.S., Pendleton, G.N., and Preece,, R.D. "BATSE Cyclotron Line Search Protocol." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[16] Bhat, N.P., Fishman, G.J., Meegan, C.A., Wilson, R.B., Kouveliotou, C., Paciesas, W.S., Pendleton, G.N., and Schaefer, B.E. "Spectral Evolution of a Sub-Class of Gamma

Ray Bursts Observed by BATSE." *Ap. J.*, in press (1994).

[17] Ford, L., Band, D., Matteson, J., Teegarden, B., and Paciesas, W. "Continuum Evolution of Bright Gamma Ray Bursts Observed by BATSE." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[18] Mallozzi, R.S., Pendleton, G.N., Koshut, T.M., Paciesas, W.S., and Briggs, M.S. "The Energy Emission of Gamma-Ray Bursts and Solar Flares." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[19] Preece, R.D., Briggs, M.S., Paciesas, W.S., Pendleton, G.N., Kouveliotou, C., and Brock, M.N. "Spectral Curvature in High-Energy Gamma Ray Bursts Observed by the BATSE Large Area Detectors." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[20] Schaefer, B.E., Teegarden, B.J., Fantasia, S.F., Palmer, D., Cline, T.L., Matteson, J.L., Band, D.L., Ford, L.A., Fishman, G.J., Meegan, C.A., Wilson, R.B., Paciesas, W.S., Pendleton, G.N., Briggs, M.S., and Lestrade, J.P. "BATSE Spectroscopy Catalog of Bright Gamma-Ray Bursts." *Ap. J. Suppl.*, in press (1994).

[21] Horack, J.M., Koshut, T.M., Mallozzi, R.S., Storey, S.D., and Emslie, A.G. "Implications of the BATSE Data for a Heliocentric Origin of Gamma-Ray Bursts." *Ap. J.*, in press (1993).

[22] Brainerd, J.J., Paciesas, W.S., Meegan, C.A., and Fishman, G.J. "The Nearest Neighbors of BATSE Gamma-Ray Bursts: Narrowing the Possibilities." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[23] Hakkila, J., Meegan, C.A., Pendleton, G.N., Fishman, G.J., Wilson, R.B., Paciesas, W.S., Brock, M.N., and Horack, J.M. "Constraints on Galactic Distributions of Gamma_ray Burst Sources from BATSE Observations." *Ap. J.*, in press (1994).

[24] Kouveliotou, C., Fishman, G.J., Meegan, C.A., Paciesas, W.S., Wilson, R.B., van Paradijs, J., Preece, R.D., Briggs, M.S., Pendleton, G.N., Brock, M.N., Koshut, T.M., and Horack, J.M. "Recurrent burst activity from the soft gamma-ray repeater SGR 1900+14." *Nature* **362**, 728 (1993).

[25] Brainerd, J.J. "Producing the Universal Spectrum of Cosmological Gamma-Ray Bursts with the Klein-Nishina Cross Section." *Ap. J.*, in press (1994).

[26] Brainerd, J.J., "The Compton Attenuation Model of Cosmological Gamma-Ray Bursts." In *Gamma-Ray Bursts: Huntsville, AL 1993*, ed. G.J. Fishman, J.J. Brainerd and K. Hurley (New York: Am. Inst. Phys.) in press (1994).

[27] Mallozzi, R.S., Paciesas, W.S., Pendleton, G.N., Briggs, M.S., Harmon, B.A., Wilson, C.A., and Zhang, S.N. "A Search for Extra-Galactic Source Emission using the Earth Occultation Technique." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994). [See attachment]

[28] Paciesas, W.S., Mallozzi, R.S., Pendleton, G.N., Harmon, B.A., Wilson, C.A., Zhang, S.N., and Fishman, G.J. "BATSE Observations of 3C 273." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994). [See attachment]

[29] Paciesas, W.S., Briggs, M.S., Pendleton, G.N., Harmon, B.A., Wilson, C.A., Zhang, S.N., and Fishman, G.J. "BATSE Observations of Nova Muscae 1991." In *The Evolution of X-Ray Binaries*, ed. C. Day and S.S. Holt (New York: Am. Inst. Phys.) in press (1994). [See attachments]

[30] Lichti, G.G., von Montigny, C., Balonek, T., Courvoisier, T.J.-L., Johnson, N., McConnell, M., Paciesas, W., Robson, E.I., Sadun, A., Schalinski, C., Steppe, H., Smith, A.G., Staubert, R., Swanenburg, B.N., Turner, M.J.L., Ulrich, M.-H., and Williams, O.R. "Simultaneous Observations of the Continuum Emission of the Quasar 3C 273 from Radio to Gamma-Ray Energies." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[31] Harmon, B.A., Wilson, C.A., Paciesas, W.S., Pendleton, G.N., Briggs, M.S., Rubin, B.C., Finger, M.H., Fishman, G.J., Brock, M.N., Wilson, R.B., and Meegan, C.A. "Observation of GX 339-4 Hard State Outbursts in 1991 and 1992." *Ap. J.*, in press (1994).

[32] Harmon, B.A., Zhang, S.N., Wilson, C.A., Rubin, B.C., Fishman, G.J., and Paciesas, W.S. "BATSE Observations of Transient Hard X-Ray Sources." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[33] Harmon, B.A., Zhang, S.N., Fishman, G.J., Paciesas, W.S., Rubin, B.C., Meegan, C.A., Wilson, R.B., and Finger, M.H. "BATSE Observations of GX 354-0." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[34] Zhang, S.N., Fishman, G.J., Harmon, B.A., and Paciesas, W.S. "Imaging high-energy astrophysical sources using Earth occultation." *Nature* **366**, 245 (1993).

[35] Zhang, S.N., Fishman, G.J., Harmon, B.A., Paciesas, W.S., Rubin, B.A., Meegan, C.A., Wilson, R.B., and Finger, M.H. "BATSE Images of the Galactic Center Region." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[36] Zhang, S.N., Fishman, G.J., Harmon, B.A., Paciesas, W.S., Meegan, C.A., Wilson, R.B., Finger, M.H., and Rubin, B.C. "A Maskless Gamma-Ray All-Sky Imager: BATSE/CGRO." *IEEE Trans. Nucl. Sci.*, in press (1994).

[37] Greiner, J., Snowden, S., Harmon, B.A., Kouveliotou, C., and Paciesas, W. "ROSAT and BATSE Observations of GRS 1915+105." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[38] Ling, J.C., Wheaton, W.A., Skelton, R.T., Harmon, B.A., Fishman, G.J., and Paciesas, W.S. "BATSE Observations of Cygnus X-1." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[39] Stollberg, M.T., Paciesas, W.S., Finger, M.H., Fishman, G.J., Wilson, R.B., Harmon, B.A., and Wilson, C.A. "Recent Observations of EXO 2030+375 with BATSE." In *The Evolution of X-Ray Binaries*, ed. C. Day and S.S. Holt (New York: Am. Inst. Phys.) in press (1994). [See attachments]

[40] Stollberg, M.T., Finger, M.H., Wilson, R.B., Harmon, B.A., Rubin, B.C., Zhang, N.S., and Fishman, G.J. "GRO J1008-57." I.A.U. Circ. No. 5836 (1993). [See attachment]

[41] Wilson, R.B., Harmon, B.A., Fishman, G.J., Finger, M.H., Stollberg, M.T., Pendleton, G.N., Briggs, M., Prince, T.A., Bildsten, L., Chakrabarty, D., Rubin, B.C., and Zhang, S.N. "BATSE Discovery of a Hard X-Ray Pulsar: GRO J1008-57." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[42] Wilson, R.B., Harmon, B.A., Fishman, G.J., Finger, M.H., Stollberg, M.T., Pendleton, G.J., Briggs, M., Prince, T., Bildsten, L. Chakrabarty, D., Rubin, B.C., and Zhang, S.N. "Discovery of the Hard X-Ray Pulsar GRO J1008-57 by BATSE." In *The Evolution of X-Ray Binaries*, ed. C. Day and S.S. Holt (New York: Am. Inst. Phys.) in press (1994).

[43] Wilson, R.B., Finger, M.H., Pendleton, G.J., Briggs, M., and Bildsten, L. "BATSE Observations of Her X-1: The 35 Day Cycle, Orbit Determination, and Torque Studies." In *The Second Compton Symposium*, ed. C.E. Fichtel, N. Gehrels and J. P. Norris (New York: Am. Inst. Phys.) in press (1994).

[44] Wilson, R.B., Finger, M.H., Pendleton, G.N., Briggs, M., and

Bildsten, L. "Observations of a Correlation between Main-On Intensity and Spin Behavior in Her X-1." In *The Evolution of X-Ray Binaries*, ed. C. Day and S.S. Holt (New York: Am. Inst. Phys.) in press (1994).

[45] Rubin, B.C., Finger, M.H., Wilson, R.B., Fishman, G.J., Meegan, C.A., Paciesas, W.S., Prince, T., Chiu, J., and Chakrabarty, D. "BATSE Observations of 4U 1538-52: A 530 Second Pulsar." In *The Evolution of X-Ray Binaries*, ed. C. Day and S.S. Holt (New York: Am. Inst. Phys.) in press (1994).

ATTACHMENTS

A SEARCH FOR EXTRA-GALACTIC SOURCE EMISSION USING THE EARTH OCCULTATION TECHNIQUE

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ABSTRACT

We use the Earth occultation technique applied to BATSE LAD data to search for emission in the $\sim$ 20-130 keV energy range from active galaxies detected by EGRET. Extrapolating the EGRET power law fits to the photon spectra of these sources to the energy range of BATSE indicates that several of these sources may be visible to BATSE in the absence of changes in the spectral indices with energy. The sensitivity of the occultation technique allows us to put constraints on low energy emission of some of these EGRET sources, giving possible insight into the physical processes occurring in these galaxies.

INTRODUCTION

The Burst and Transient Source Experiment (BATSE) consists of eight independent detector modules mounted on the corners of the Compton Gamma-Ray Observatory (CGRO), and is capable of nearly full-sky observations. This design, explained in detail elsewhere (Fishman et al. 1990, Horack 1991), provides a unique opportunity to observe the gamma-ray sky. Each of the eight detector modules consists of two NaI(Tℓ) scintillation detectors: a Large Area Detector (LAD), optimized for temporal resolution, and a Spectroscopy Detector (SD), optimized for energy resolution.

We use the BATSE CONT datatype from the LADs, which provides 2.048 second resolution in 16 energy channels spanning the range of $\sim$20-1800 keV. The Earth occultation technique, discussed by Harmon et al. (1992), entails fitting rates near each source occultation with a model that assumes a step-like function at the occultation time superimposed on a quadratic background. Additional terms may be added to account for other bright, nearby sources, and energy-dependent atmospheric transmission is included when fitting each occultation step. The occultation technique has the greatest sensitivity below $\sim$ 140 keV; therefore we conduct our search in the 20-130 keV range. Our preliminary search is constrained to the times of observation of several Active Galactic Nuclei (AGN) reported by EGRET (Fichtel et al. 1992); thus the angles between a given source and the LAD normals are not, in general, the optimum angles possible for BATSE.

OBSERVATIONS AND RESULTS

Extrapolation of the power law fits to the photon spectra of 11 sources for which spectral indices and flux measurements were reported (Fictel et al. 1992)

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indicates that five of these may be visible to BATSE, assuming that the spectral indices remain constant with energy. Table 1 indicates these five sources along with the EGRET observation times and GRO viewing period (some sources were observed by EGRET during several time intervals—we have selected the intervals during which EGRET reports observing a high flux). The source 3C273 has been positively observed by BATSE, with reasonable spectral agreement with OSSE (Paciesas et al. 1992). Recent results of BATSE observations of this source are discussed elsewhere (Paciesas et al. 1993).

Table 1. Selected AGN

Source	*Observation period*	*GRO Viewing Period*
CTA102 (2230+114)	23 Jan-06 Feb (1992)	19
PKS0528+134	22 May-30 May (1991)	1
GROJ1635+38 (1633+382)	12 Sept-19 Sept (1991)	9.5
3C279 (1253-055)	16 Jun-28 Jun (1991)	3
3C273 (1226+023)	Omitted	

Occultation steps were measured for each of these sources during the indicated time intervals. The rates from each LAD that observed a given source were combined to yield a count spectrum which was subsequently deconvolved through an appropriate detector response matrix. We use a forward-folding model technique to obtain the best power law fit to the data, with several values assumed for the spectral index. The steepest spectrum for each source corresponds to the approximate slope of the EGRET best-fits. None of the four sources listed in Table 1 showed significant emission above the background observed by BATSE; thus, 3σ upper limits on the flux from each of the four source locations were obtained. CTA102 and PKS0528+134 yielded 3σ upper limit power law fits which lie below the EGRET extrapolation, indicating that the spectra of these sources are less steep in the 20-130 keV energy range during the observation periods shown in Table 1. Figure 1 shows the power laws for several assumed spectral indices. The dotted line indicates the extrapolation of the EGRET spectral functions (Hunter et al. 1993, Kniffen et al. 1993, Mattox et al. 1993, Nolan et al. 1993). Although it is possible that a source yielding 3σ upper limit power laws which are below the EGRET extrapolation could exhibit a spectrum with a slope in the 20-130 keV range identical to that in the EGRET energy range but of lower intensity, the power law fits for which the slopes are less steep in the lower energy band suggest a break in the spectra above 130 keV.

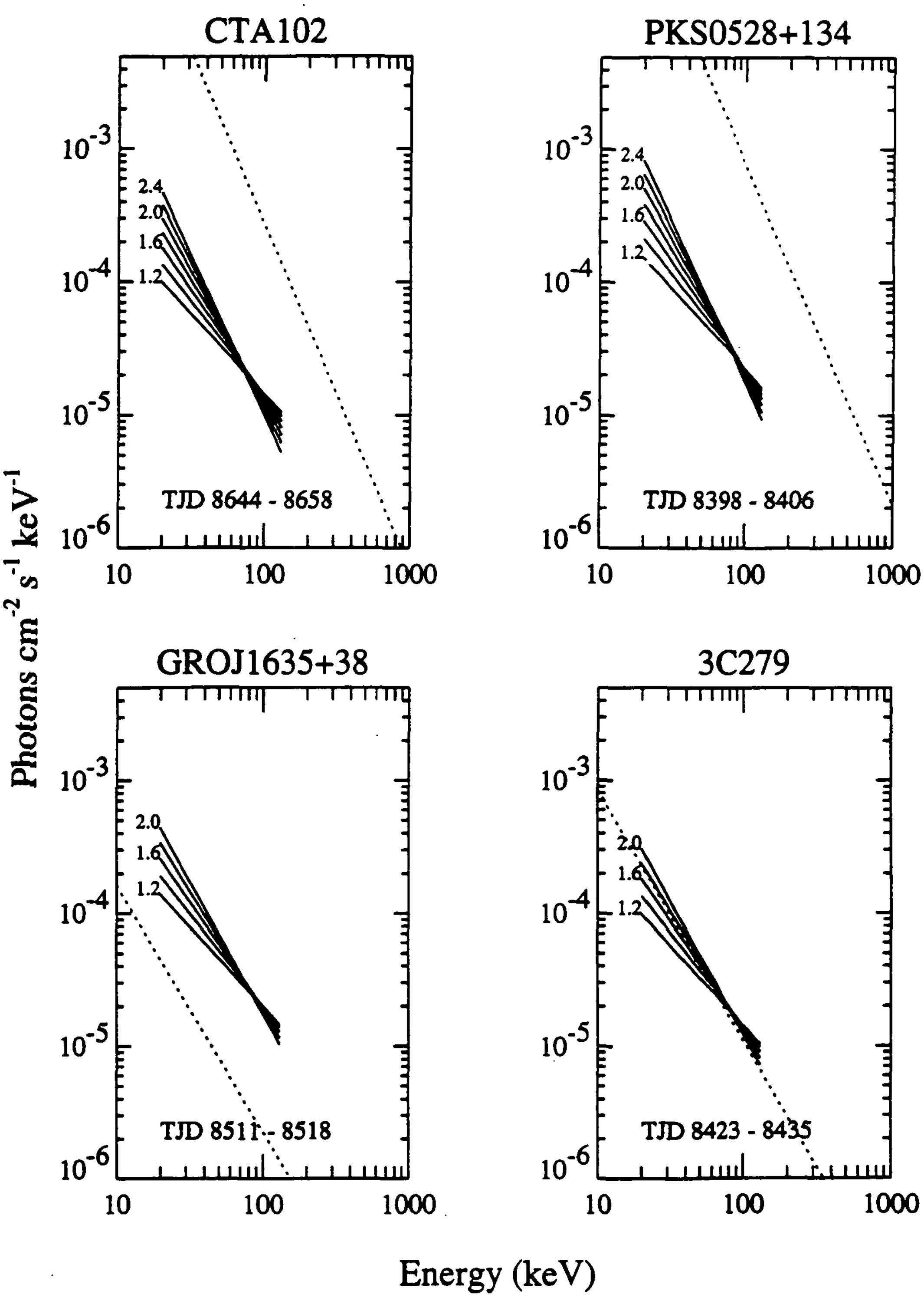

Figure 1. BATSE 3σ Upper Limit Power Law Fits.
The EGRET extrapolation is shown by the dotted line.

Integrating the power law fits to the BATSE data yields 3σ upper limits on the flux from the locations of the four sources listed in Table 1. Table 2 gives these flux estimates for various assumed values of the spectral indices.

Table 2. 3σ Upper Limits on Flux

Source	*Index*	*Flux (mCRAB)*
CTA102 (2230+114)	−2.4	24.5
	−2.2	22.2
	−2.0	20.0
	−1.8	17.9
	−1.6	15.9
	−1.4	14.0
	−1.2	12.1
PKS0528+134	−2.4	43.0
	−2.2	38.1
	−2.0	33.6
	−1.8	29.4
	−1.6	25.5
	−1.4	21.9
	−1.2	18.6
GROJ1635+38 (1633+382)	−2.0	29.2
	−1.8	25.8
	−1.6	22.7
	−1.4	19.8
	−1.2	17.0
3C279 (1253-055)	−2.0	20.3
	−1.8	18.0
	−1.6	16.0
	−1.4	14.0
	−1.2	12.1

CONCLUSIONS

BATSE 3σ upper limit power laws for various assumed spectral indices of CTA102 (2230+114) and PKS0528+134 lie below the extrapolation of the EGRET power law fits during the periods of observation shown in Table 1, indicating that the spectra of these sources must break between ~130 keV and ~100 MeV. The power law fits for GROJ1635+38 (1633+382) lie above the EGRET extrapolation, leaving the spectrum of this source unconstrained in the 20-130 keV band. The 3C279 power laws cluster near the EGRET extrapolation;

those with a flatter slope are in agreement with a possible spectral break at $\lesssim$ 1-10 MeV as suggested by COMPTEL data (Collmar et al. 1992). Since many AGN are known to be highly variable, the spectral shapes indicated by this analysis may not describe the spectra of these sources at other times. An analysis of this type when the geometry of the source locations and the BATSE instrument is more favorable may yield better insight into the spectra of these intriguing sources.

REFERENCES

1. Collmar,W. et al., 1992, Compton Gamma-ray Observatory, eds. M. Friedlander, N. Gehrels, D. Macomb, (New York: AIP), 483.
2. Fichtel, C.E. et al., 1992, Compton Gamma-Ray Observatory, eds. M. Friedlander, N. Gehrels, D. Macomb, (New York: AIP), 461.
3. Fishman, G.J. et al., 1990, Proceedings of the GRO Workshop, 2-39.
4. Harmon, B.A. et al., 1992, The Compton Observatory Science Workshop, eds. C. R. Shrader, N. Gehrels, B. Dennis (NASA CP-3137), 69.
5. Horack, J.M.,1991, Development of the Burst and Transient Source Experiment, NASA-RP 1268.
6. Hunter, S.D. et al., 1993, Ap. J., **402**, 134.
7. Kniffen, D.A. et al., 1993, Ap. J., **411**, 133.
8. Mattox, J.R. et al., 1993, Ap. J., **410**, 609.
9. Nolan, P.L. et al., 1993, Ap. J., **414**, 82.
10. Paciesas, W.S. et al., 1992, Compton Gamma-ray Observatory, eds. M. Friedlander, N. Gehrels, D. Macomb, (New York: AIP), 473.
11. Paciesas, W.S. et al., these proceedings.

BATSE OBSERVATIONS OF 3C273

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ABSTRACT

The quasar 3C273 has been detected by all instruments on CGRO. The emission from this source is monitored continuously by BATSE using Earth occultation. We present results of a preliminary analysis of BATSE data, including light curves of the 3C273 flux covering ~150 days in the interval April–August 1991 and ~350 days in the interval July 1992–April 1993. The source intensity in the energy range 50–300 keV is typically ~0.002 ph cm^{-2} s^{-1}. We find weak evidence for variations of as much as a factor of 3 in the intensity. We derive spectral parameters of 3C273 during the intervals TJD 8422–8435 (15–28 June 1991) and TJD 8532–8546 (3–17 October 1991) for comparison with other CGRO instruments.

1. INTRODUCTION

3C273 is the nearest quasar ($z = 0.16$) and is one of the best-studied extragalactic objects. It is detectable over most of the electromagnetic spectrum (see Courvoisier et al. 1990 for a review), and, prior to the launch of CGRO, it was the only quasar detected in gamma-rays. The first pointed CGRO observation of 3C273 (15–28 June 1991) occurred as part of an international campaign to obtain a simultaneous wideband spectrum of this source (Lichti et al. 1994).

The wide-band spectra of quasars (and AGNs in general) differ significantly from those of stars and most other astrophysical objects. Roughly speaking, the energy flux density (νF_ν) spectrum emitted from quasars is remarkably flat over a wide range, often the entire range from radio to gamma-rays. It is clear, however, that the entire spectrum cannot be explained by a single process. The overall spectrum is a complex combination of many, time-varying, components, some of which are interdependent. For example, the ultraviolet emission in some AGNs may be due to reprocessing of the X-ray flux by the surface layers of the accretion disk (Clavel et al. 1992). Obviously, multi-wavelength study of temporal variability over long timescales is essential to understanding these sources. With its unusual monitoring capabilities, BATSE can contribute much to the study of AGNs by allowing long-term correlation studies between hard X-rays and other wavelengths.

2. OBSERVATIONS

BATSE is capable of nearly continuous monitoring of low-energy gamma-ray sources using Earth occultations (Harmon et al. 1992). Paciesas et al. (1993) reported initial results of observations of 3C273 using this technique. The occultation technique is continually being improved by the BATSE team, leading to improved statistical sensitivity and/or better understanding of systematic errors. We have also developed a technique for image reconstruction using the occultation data (Zhang et al. 1993, 1994). The observations of 3C273 reported here are the results of processing of nearly 450 days of BATSE occultation data using improved algorithms.

The data type used in this investigation consists of 16 energy channels covering the approximate energy range 20–2000 keVwith ~2 s time resolution. BATSE large area detectors facing within 60° of 3C273 were included; each usable occultation rise or set was fit separately

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for each detector and each energy channel using the energy-dependent atmospheric transmission profile of a constant source superimposed on a quadratically varying background. Data within approximately 2 minutes on either side of the occultation were used. Terms for additional sources were included if their occultations occurred during the fit interval and they were known from previous observations to be potentially bright. Occultation steps of 3C273 which occurred within 10 s of a step due to a potentially bright source were eliminated from the analysis.

To derive a long-term light curve, we averaged the count rate spectra from individual steps over each CGRO viewing period (~3–14 days), and deconvolved each average spectrum using conventional forward-folding techniques, assuming a power-law model spectrum with the photon index fixed at −1.7. The fit energy range was 50–300 keV. For technical reasons, we have thus far processed only about 400 days of data in two separate intervals: 144 days near the beginning of the mission (TJD 8368–8511) and 291 days more recently (TJD 8820–9110). We are continuing to process more of the data and will report the results of a longer-term investigation in a future publication.

It can be seen from Figure 1 that BATSE typically detects 3C273 at the 2–3σ significance level in a single two-week CGRO observing period. In some intervals, such as TJD 8960–9000, the fluctuations appear to be larger than expected from statistics alone. Without further study, we cannot rule out systematic effects as being responsible for this behavior; hence, use of these data to study fluctuations on timescales of less than about one month would be premature.

No clear long-term trend is evident in comparing the 1991 data with the 1992/1993 data. The typical source intensity over the entire interval studied is ~0.002 ph cm^{-2} s^{-1}, consistent with the level observed by OSSE (N. Johnson, priv. comm.) in the same energy range during viewing period 3 in June 1991 (TJD 8422–8435). We note that the single BATSE point which covers the latter interval is high relative to the average of the previous BATSE points as well as to the more precise OSSE measurement. This suggests that the high BATSE point may be a statistical fluctuation, but a systematic error of this size cannot be ruled out.

It is also noteworthy that the intensity during the interval TJD 8440–8500 is consistently lower than at other times. We know of no other 3C273 observations during this time to compare with; however, an OSSE measurement during CGRO viewing period 11 in October showed a flux approximately a factor of three lower than the June data (N. Johnson, priv. comm.). The data in Figure 1 suggest that this state of low flux began soon after the June measurements, and persisted at least several months.

To investigate this further, we processed additional data from viewing period 11 to allow a detailed spectral comparison with viewing period 3. We analyzed both data sets using the standard model-dependent forward-folding technique with a power-law model spectrum, allowing both the normalization and spectral index to vary. We found that the spectrum during viewing period 3 (TJD 8422–8435) was adequately fit by a power-law $dN/dE = A_{100}(E/100\,\mathrm{keV})^{\alpha}$, where $A_{100} = (1.8 \pm 0.4) \times 10^{-5}$ ph cm^{-2} s^{-1} keV^{-1} and $\alpha = -1.57 \pm 0.24$ ($\chi^2 = 37.6$ for 40 d.o.f.), whereas for viewing period 11 (TJD 8532–8546) we found $A_{100} = (7.3 \pm 3.6) \times 10^{-6}$ ph cm^{-2} s^{-1} keV^{-1} and $\alpha = -1.40 \pm 0.47$ ($\chi^2 = 42.9$ for 40 d.o.f.). These results provide weak support for the flux decrease between June and October, the latter being a factor of 2.5 ± 1.3 weaker at 100 keV. In both cases, the derived spectral index is consistent with the contemporaneous best-fit OSSE spectrum (N. Johnson, priv. comm.) but the integrated intensity is 50–100% higher. Since the significance of these differences is $\lesssim 1.5\sigma$, it is possible that both represent upward statistical fluctuations. Thus, we cannot be conclusive about systematic errors at this level in our data.

Recently, a technique for producing images using the BATSE occultation data has been

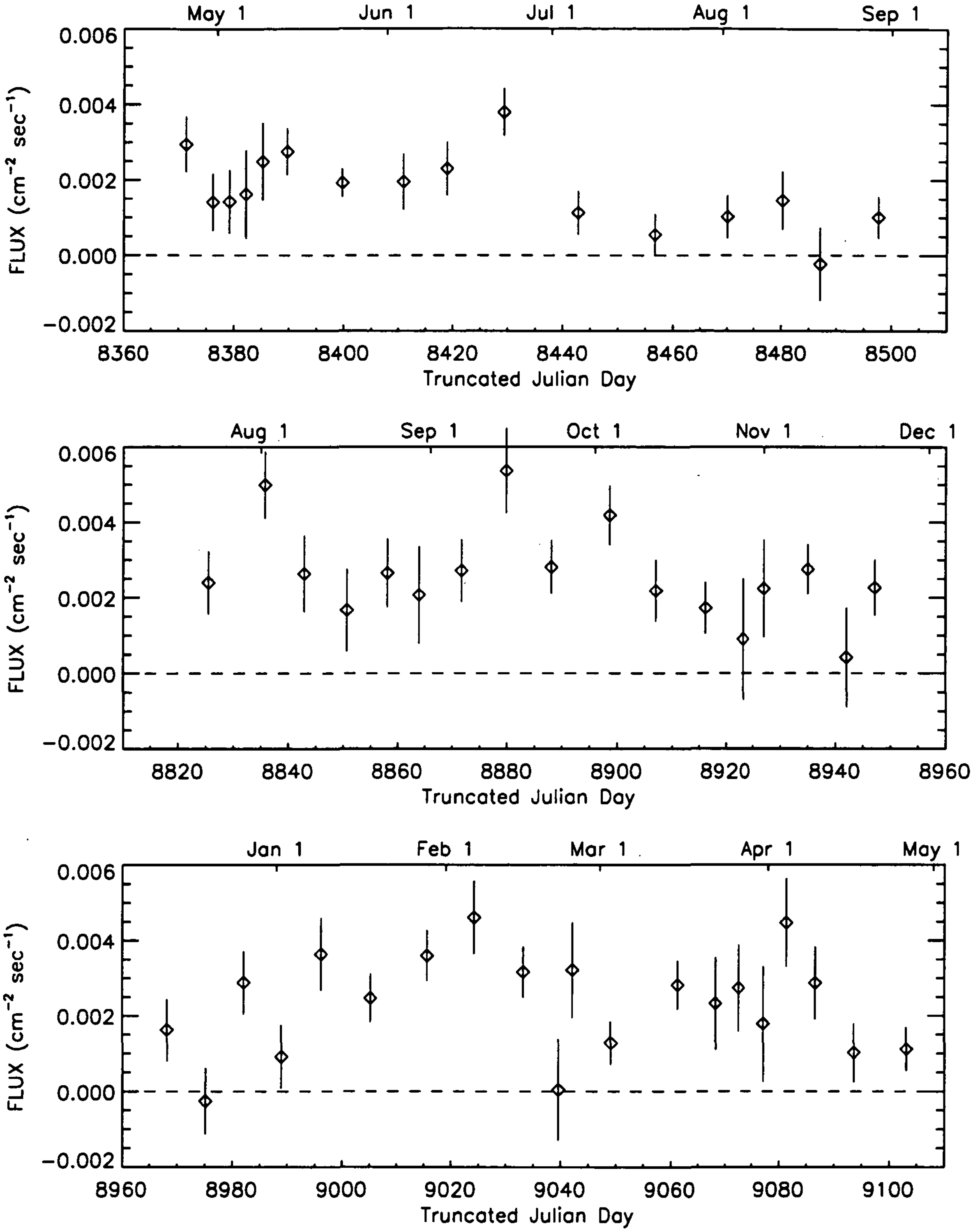

Figure 1: Long-term light curve of 3C273 as monitored by BATSE. The uppermost panel covers the interval from late April to late August 1991. The lower two panels span the interval from mid-June 1992 to late April 1993. Integrations correspond in time to CGRO viewing periods (~3–15 days). The energy range is 50–300 keV.

developed (Zhang et al. 1993, 1994). The technique uses a Radon transform applied to differentiated data (rate as a function of orientation angle and distance to the center of the field-of-view). Images are produced by inversion of the Radon-space data using one of several possible methods (least-squares fitting, maximum entropy method, or algebraic reconstruction). In order to verify that the emission we observed was associated with 3C273, we produced an image of a sky region containing 3C273, shown in Figure 2. It is clear that in this energy range (100–300 keV), only one source, consistent with 3C273, is visible in our data. With our limited angular resolution we cannot rule out the presence of emission from the source GRS 1227+0029 which is 15′ from 3C273 (Bassani et al. 1991); however, this source had a much steeper spectrum than 3C273 and would be unlikely to contribute much above ~50 keV.

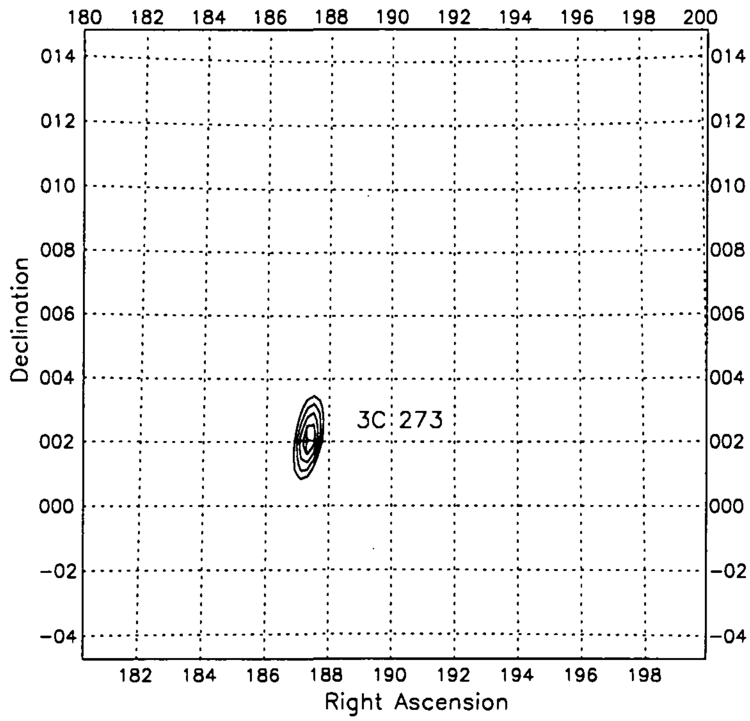

Figure 2: Image of the region near 3C273 during CGRO viewing period 3 (TJD 8422–8435) produced using the Radon transform and maximum-entropy inversion. The energy interval is 100–300 keV. The methodology is described in more detail by Zhang et al. (1993, 1994).

3. SUMMARY

Although the intensity of 3C273 is near our sensitivity limit, it is clear that BATSE can monitor long-term variability of the source. Using our current analysis techniques, the minimum timescale for reliable detection of source variability is about 1–2 months. We continue to investigate the occultation monitoring technique with the goal of improving the statistical precision of the method while controlling systematic errors.

REFERENCES

Clavel, J., et al. 1992, ApJ, **393**, 113.

Courvoisier, T.J.L., et al. 1990, A&A, **234**, 73.

Harmon, B.A., et al. 1992, in *The Compton Observatory Science Workshop*, ed. C. R. Shrader, N. Gehrels & B. Dennis (NASA CP-3137), p. 69.

Hermsen, W., et al. 1993, A&A Suppl. Ser., **97**, 97.

Lichti, G.G., et al. 1994, these proceedings.

Paciesas, W.S., et al. 1993, in *Compton Gamma-Ray Observatory: St. Louis, MO 1992*, ed. M. Friedlander, N. Gehrels & D.J. Macomb (New York: AIP), p. 473
von Montigny, C., et al. 1993, A&A Suppl. Ser., **97**, 101.
Zhang, S.N., et al. 1993, Nature, **366**, 245.
Zhang, S.N., et al. 1994, these proceedings.

BATSE OBSERVATIONS OF NOVA MUSCAE 1991

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ABSTRACT

The *Compton* Burst and Transient Source Experiment (BATSE) detected hard x-ray flux from Nova Muscae 1991 (GS/GRS 1124–68) during an interval of ~100 days beginning ~130 days after the January 1991 main outburst. The light curve during this secondary outburst is roughly symmetric, reaching a maximum around mid-July 1991 at an intensity of ~15% of the peak intensity during the main outburst. The hard x-ray spectrum displays a soft-to-hard evolution during the rise to maximum; the post-maximum spectral evolution is less well determined. We compare our observations with those of the *GRANAT*/SIGMA experiment, which covered the initial outburst well but missed most of the secondary outburst.

1. INTRODUCTION

Nova Muscae 1991 was discovered independently as an x-ray transient (GS/GRS 1124–68) in January 1991 by monitors on *Ginga* (Makino & the *Ginga* team 1991) and *GRANAT* (Lund & Brandt 1991). In low-energy x-rays ($E < 20$ keV), the source reached a maximum intensity of ~8 Crab on 15 January (Kitamoto *et al.* 1992). Subsequently, it decayed almost exponentially with a time constant of ~31 days for ~75 days, at which time a secondary outburst occurred, followed by a further exponential decay with a slightly longer time constant (~37 days). The power density spectrum showed flat low-frequency noise (below ~2 Hz) and variable-frequency quasi-periodic oscillations at higher frequencies (~3–10 Hz) (Tanaka, Makino & Dotani 1991; Grebenev *et al.* 1992). The spectrum was "ultrasoft" at the lowest energies with an apparently power-law tail extending to several hundred keV (Gil'fanov *et al.* 1991). A narrow emission line at 481 ± 22 keV was detected during a 13 hour SIGMA observation on 20–21 January; this was interpreted by Gil'fanov *et al.* as a red-shifted positron annihilation line. The power-law tail diminished in intensity faster than the ultrasoft component during the first few months. Nova Muscae was not detected in high-energy x-rays in April, but was present during SIGMA observations in May and August at ~10% of the January maximum.

An optical nova was detected within the x-ray error circle (Della Valle, Jarvis & West 1991a, 1991b). Subsequent monitoring showed it to decay at a rate similar to the low-energy x-rays. A binary orbital period of 10.42 hours was found, from which a mass function of 3.1 ± 0.4 $M_\odot$ was determined (McClintock, Bailyn & Remillard 1992), making the source a leading black hole candidate.

The BATSE instrument on the Compton Gamma Ray Observatory

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(CGRO) functions as an all-sky monitor by detecting Earth occultations of low-energy gamma-ray sources (Harmon *et al.* 1992). CGRO was launched in April 1991, too late to observe the main outburst of Nova Muscae. Nevertheless, we used the occultation method to search for subsequent emission and found that Nova Muscae was detectable by BATSE during an interval of ~100 days, beginning just before the May 1991 detection by SIGMA.

2. OBSERVATIONS

The BATSE Earth occultation methodology has been described by Harmon *et al.* (1992). We obtained spectra in 16 energy channels spanning the range 20–2000 keV by measuring differences in detector counting rates as Nova Muscae rose above or set below the horizon. We fit the data for each occultation in each energy channel with a model consisting of a source term superimposed on a time-varying background. Potential interference from other sources was handled as follows: A catalog of known bright or potentially bright sources is maintained as part of BATSE mission operations. All such sources whose location was within 60° of the axis of any detector which also saw Nova Muscae were treated as possible interfering sources. If the occultation time of any of the possible interfering sources fell within 10 s of a Nova Muscae occultation step, that step was eliminated from further analysis. Otherwise, terms were included in the fit for all possible interfering sources with an occultation step within the fit region (±110 s around each Nova Muscae occultation step).

We searched for emission from Nova Muscae during the interval 28 April–31 October 1991 (TJD 8374–8560). However, during portions of this time, including the interval prior to 5 May, the source was too far out of the CGRO orbit plane to produce usable occultations. Nevertheless, it was clear from inspection of the initial results that a significant signal was detected from Nova Muscae during much of the time when usable occultations were available. In order to produce a light curve, we summed the individual occultation count rates over 3 day intervals and deconvolved the spectra using conventional forward-folding. For this purpose we assumed a power-law input spectrum with fixed number index $\alpha = -2$.

The upper panel of Figure 1 shows the light curve derived from the BATSE data. The temporal evolution is characterized by a slow, approximately linear rise beginning around 15 May, leading to a single broad, symmetric maximum around 13 July, and a decay below our detection limit around 1 September. For comparison, we show in the same figure the SIGMA observations (Gil'fanov *et al.* 1991). It can be seen from the figure that the maximum flux during our observations was ~15% of the primary maximum. We note that the secondary maximum fell approximately midway between the last two SIGMA observations.

We investigated the evolution of the spectrum during the secondary outburst by summing the data over longer intervals (but never longer than one CGRO viewing period, usually two weeks), and then fitting various models to the resulting count spectra. A single power-law model was found to be an adequate fit in all intervals, although alternative models such as optically thin thermal bremsstrahlung and Sunyaev-Titarchuk Comptonization could not in general be ruled out. In the lower panel of Figure 1 we show the evolution of the power-law index during our observations compared with the SIGMA results. During the secondary outburst, the hardness increases as the intensity rises to a maximum; the trend after the maximum is unclear because of limited statistics. Gil'fanov *et al.* (1991) noted that their data were consistent with a clustering

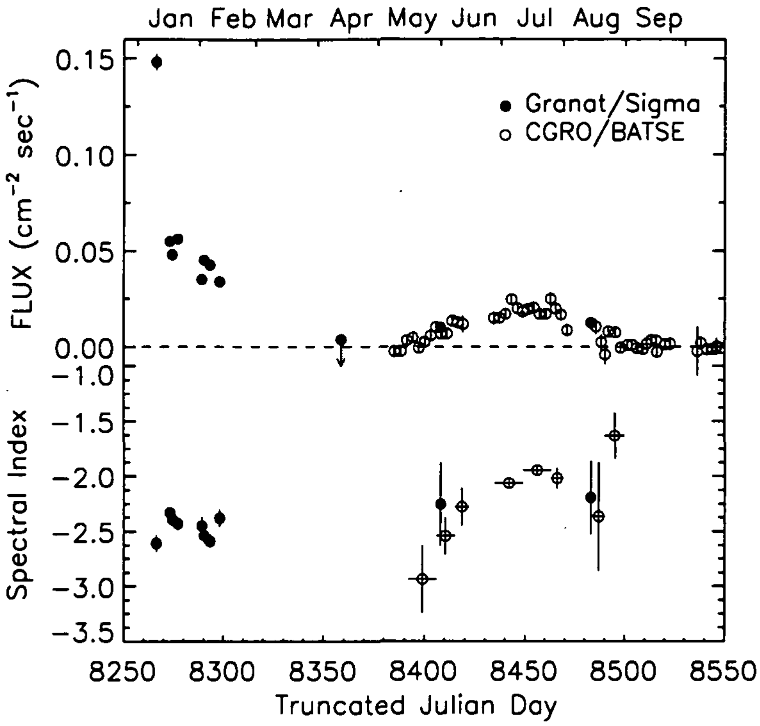

Fig. 1. Intensity and spectral evolution of the entire Nova Muscae outburst, combining both BATSE and SIGMA data, the latter from Gil'fanov *et al.* 1991. The flux is integrated over 35–100 keV.

around an average index $\alpha \approx -2.5$ with no trend throughout the outburst. The BATSE data, however, show a significantly harder spectrum ($\alpha \approx -2$) around the secondary maximum and possibly an even harder spectrum just before the source disappears (although the latter may be subject to systematic errors).

Recently, a technique for producing images using the BATSE occultation data has been developed (Zhang *et al.* 1993). We generated a number of images of the region around Nova Muscae to verify that the latter was in fact the source of any emission detected in our occultation fitting, and that all significant nearby sources had been accounted for. Samples of these are shown in Figure 2, from which one can see that no other source besides Nova Muscae is visible above 55 keV. Below that energy the only other significant source is the recurrent transient pulsar GX 301–2, which was included in our analysis.

3. DISCUSSION

Two main theoretical mechanisms have been proposed to explain the outbursts of black-hole X-ray novae: the disk thermal instability model and the mass transfer instability model (Hameury *et al.* 1990 & refs. therein). Chen, Livio & Gehrels (1993) attempted to explain the entire light curve by a combination of these ideas: a main disk instability outburst is followed by a second outburst (in soft x-rays) due to mass transfer by evaporation of the outer layers of the secondary by x-ray heating. A third outburst also results from mass transfer, this time due to more prolonged heating and expansion of the secondary's convective layer. The second outburst in Nova Muscae was clearly seen in late March in soft x-rays but not in hard x-rays (Kitamoto *et al.* 1992). The hard x-ray secondary maximum which we observed would then correspond in the above scenario to the third outburst. However, if both of the secondary

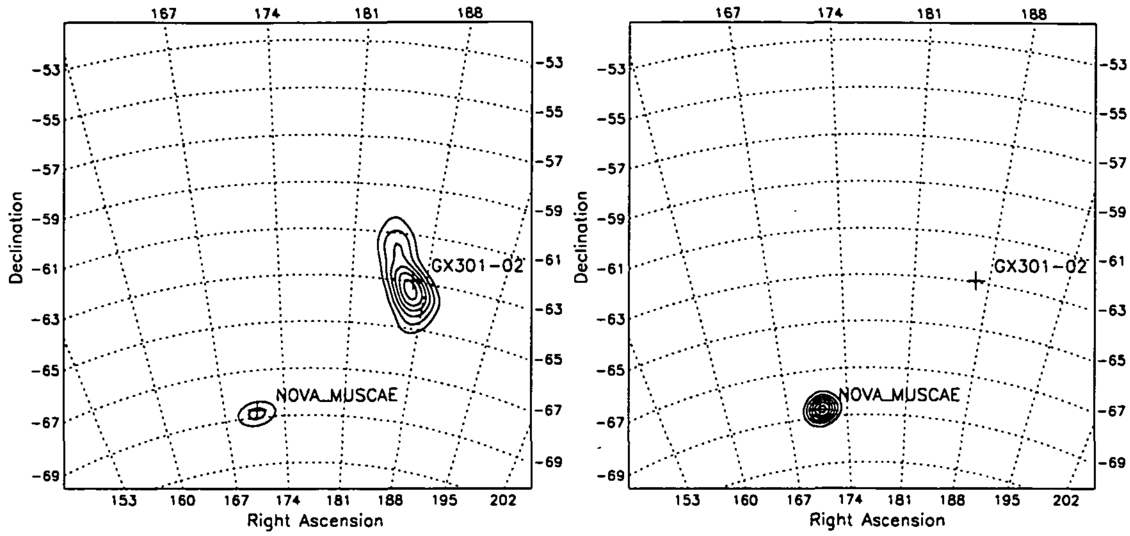

Fig. 2. Images of a region of the sky near Nova Muscae around the time of the secondary maximum (27 June–7 August). The images were produced using the radon transform and maximum-entropy inversion (Zhang *et al.* 1993). The energy intervals are 25–55 keV and 55–110 keV for the left and right panels, respectively.

maxima simply represent episodes of increased mass accretion through the disk, then it is necessary to explain their completely different spectral characteristics. Future models must consider the distinctly different temporal behaviors of the hard power-law and ultrasoft spectral components in black-hole x-ray novae.

REFERENCES

Chen, W., Livio, M., & Gehrels, N., 1993, ApJ, 408, L5
Della Valle, M., Jarvis, B. J., & West, R. 1991a, IAU Circ. No. 5165
Della Valle, M., Jarvis, B. J., & West, R. M. 1991b, Nature, 353, 50
Gil'fanov, M., *et al.* 1991, Sov. Astron. Lett., 17, 437
Grebenev, S., *et al.* 1992, Sov. Astron. Lett., 18, 11
Hameury, J.-M., *et al.* 1990, ApJ, 353, 585
Harmon, B.A., *et al.* 1992, in The Compton Observatory Science Workshop, ed. C. R. Shrader, N. Gehrels & B. Dennis (NASA CP-3137), 69
Kitamoto, S., *et al.* 1992, ApJ, 394, 609
Lund, S., & Brandt, S. 1991, IAU Circ. No. 5161
Makino, F., & the *Ginga* team 1991, IAU Circ. No. 5161
McClintock, J., Bailyn, C., & Remillard, R. 1992, IAU Circ. No. 5499
Tanaka, Y., Makino, F., & Dotani, T. 1991, in Proc. Workshop on Nova Muscae 1991, ed. S. Brandt (Lyngby: Danish Space Research Inst.), 125
Zhang, S. N., Fishman, G. J., Harmon, B. A., & Paciesas, W. S. 1993, Nature, 366, 245

CHANNEL TO ENERGY CALIBRATION RESULTS FOR THE BATSE LARGE AREA DETECTORS

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ABSTRACT

Continuum 16 channel spectra obtained from in flight data are used to identify and correct for nonlinearities in the channel-to-energy conversion algorithm for the BATSE[1] large area detectors. The Crab Nebula spectra obtained by the BATSE earth occultation technique[2] are used to characterize any nonlinearities inherent in the low energy channel bin widths on a detector by detector basis. The bin widths are optimized to remove distortions from observed gamma ray spectra. The recalibrated bin edges are used in an analysis of Crab Pulsar data[3] to verify the improvements in the calibration.

INTRODUCTION

Some nonlinearites in the channel to energy conversion of the medium energy resolution data of the LAD detectors have been quantified and incorporated into the data analysis software. The nonlinearites are due primarily to PHA nonlinearites and, to a lesser extent, intrinsic NaI nonlinearites. Here data from BATSE Large Area Detector (LAD) 3 are used to illustrate the channel to energy nonlinearites and the solution technique.

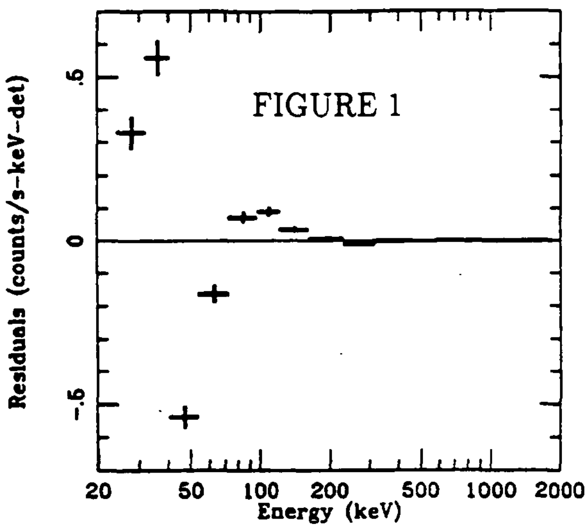
PROCEDURE AND DATA ANALYSIS

Data from pre-launch ground calibrations show hints of channel-to-energy nonlinearites. However the observed count rate is dropping sharply in the energy range effected by the nonlinearites and the input spectrum is a combination of direct flux from local radiation sources and gamma rays scattered in the terrestrial test environment. This input spectrum is not simple enough to model reliably.

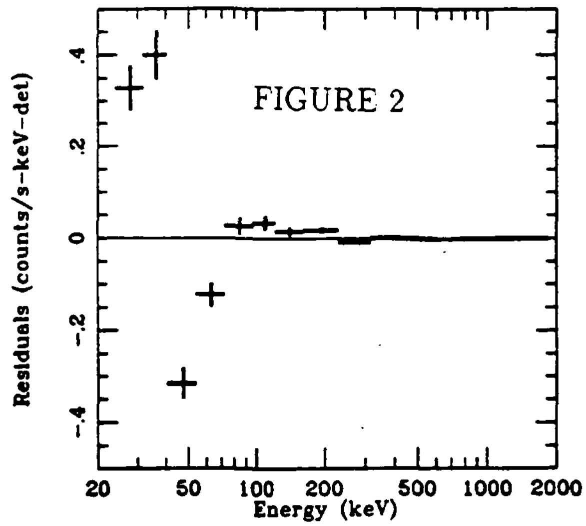
The post-launch spectra obtained from bursts have strong continuum spectra at lower energies. Channel-to-energy nonlinearites are more clearly manifested in this data as structures always present at fixed energies for all spectra observed from an individual detector. Lab measurements of BATSE spare modules indicate that the nonlinearites are present in the low channels of the PHA and are somewhat different for each module.

One way of quantifying the amplitude of the nonlinearites is to study the counts residuals plots of model fits of photon continuum spectra to background subtracted data. Shown in figures 1-3 are fits to CONT data: a medium energy resolution, 16 channel LAD data type. There are two Crab Nebula spectra and one burst spectra shown here for detector 3. The spectra were taken at different detector viewing angles and still the counts residuals patterns are quite similar.

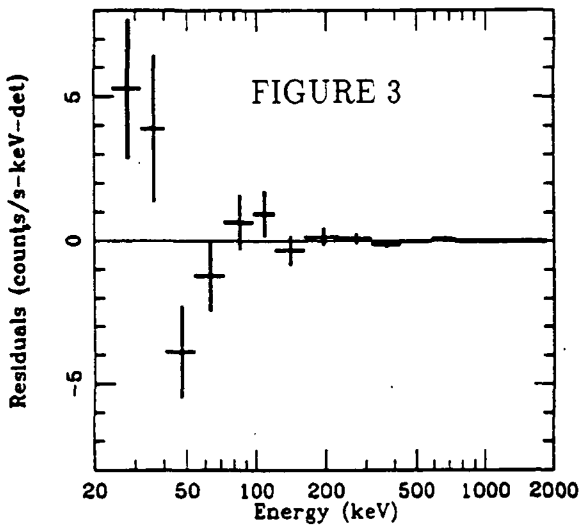
A number of measurements of the continuum spectra of the Crab Nebula flux have been made and they are in overall agreement[4,5].



Residuals of broken powerlaw fit
to Crab nebula data for LAD 3
Aspect angle: 28.1 degrees



Residuals of broken powerlaw fit
to Crab nebula data for LAD 3
Aspect angle: 49.3 degrees



Residuals of broken powerlaw fit
to burst trigger 676 data for LAD 3
Aspect angle: 38.0 degrees

The Crab Nebula spectrum was used as a continuum calibration source for this analysis. Model fits to LAD Crab Nebula data were made by forward folding a broken powerlaw model with fixed spectral parameters and variable amplitude through a detector response matrix[6] (DRM) binned at the original cont data binning. Model counts data were generated and used in combination with the actual data and errors in an algorithm to adjust the bin edges of the data.

The bin relaxation algorithm involved iterating a three step cycle until acceptable bin edges were obtained. The first step was to build a DRM with the current MER binning. For this analysis the DRM's had 16 output channels and 58 input bins. The second step was to model fit the observed counts spectrum with this DRM to get a best fit continuum and a set of model counts per bin. The third step was to take the model and observed counts to calculate new DRM bin edges using the algorithm described below. This three step procedure was repeated until an acceptable fit in chi-square was obtained.

An extensive simulation procedure was used to develop this algorithm. Here model spectra were folded through DRM's of a particular (original) binning to create counts data. These counts data were taken in the simulation as the original observed counts data. Then drms with different binning were made to simulate the systematic bin width errors induced by PHA and NaI nonlinearites. The bin width adjustment procedure was developed and tested using the simulation data until it reliably returned the original matrix bin edges. The essential bin width adjustment was preformed using the statement

new_bin_width=old_bin_width*(observed_counts/model_counts -1)

The total bin width adjustment preformed over the entire procedure was limited to a certain maximum percentage per bin. Also the width adjustment was limited to a small percentage of the significance of the observed data in a particular bin.

Once the new widths were found, the were aligned relative to each other using a gauge iteration procedure. The bin centers were adjusted in sets of adjacent pairs. The bin centers were aligned such that the bins that changed most significantly had their bin centers adjusted most and bins whose widths changed less were shifted less. Then pairs of bin pair centers were adjusted relative to each other and so on until all the bin edges were contiguous. Also the ranges over which recalculated position of the 511 keV centroid, the lowest energy bin edge, and the highest energy bin edge were allowed to drift were restricted.

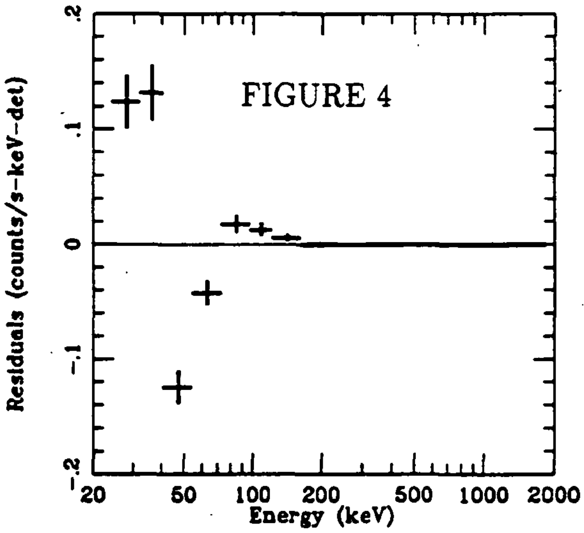
Two sets of occultation data from the Crab Nebula were produced for each detector. There were data sets for two distinct aspect angles to the Crab for each detector. The bin width procedure was run on each data set separately, and when the spectral parameters of Jung, '89 were used, the bin edges relaxed to approximately the same values for an individual detector. Some mapping of the procedures behavior in spectral parameter space was done and it was found that the procedure only worked in a fairly limited range of parameters around the measured Crab spectral parameters.

VERIFICATION

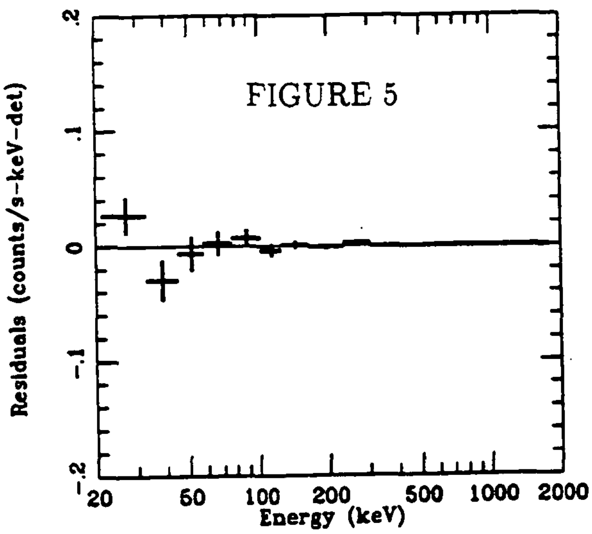
The results were verified by analysing Crab pulse averaged data. This data was not used in the bin edge relaxation procedure so it represents an independent verification of the improvement in the recalibrated bin edges. One interesting feature to note is that a single power law fit to the Crab pulsed spectrum is not satisfactory for the BATSE data. A broken powerlaw is acceptable. This result is true even if a less realistic single powerlaw spectrum is used for the Crab Nebula data in the bin width relaxation algorithm.

The change in slope of the Crab pulsed spectrum with energy is evident from previous measurements reported in the literature[7,8,9]. The spectral indices of single powerlaw fits from previous observations are harder in lower energy ranges and softer in higher energy ranges.

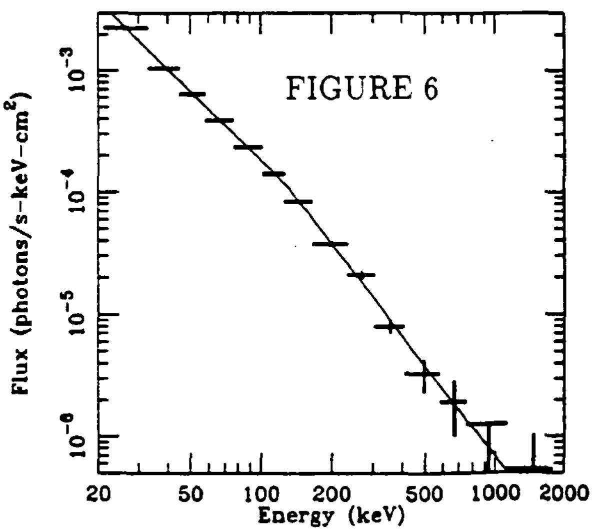
Figures 4 and 5 show before and after residuals plots of fits to the Crab pulsar data with broken power law spectra. The residuals plots of the fits with the new bin edges show considerable improvement over the earlier calibrations.



Residuals of broken powerlaw fit
to Crab pulse averaged data for LAD 3
original bin edges



Residuals of broken powerlaw fit
to Crab pulse averaged data for LAD 3
calibrated bin edges



Broken powerlaw fit
to Crab pulse averaged data for LAD 3
calibrated bin edges

Figure 6 shows the post calibration pulse averaged Crab spectra from LAD 3 for

TJD 8423 to 8436. Delta chi-square analyses show that the spectra from the different detectors are generally in agreement. Pre and post calibration comparisons were made with solar flare spectra and Her-X1 spectra and similar improvements were noted.

REFERENCES

1. Fishman et al, 89, in Proceedings of the GRO Science Workshop, ed. N. Johnson, pp. (2)39-2(50)
2. Harmon et al, 92, in Proceedings of the Compton Gamma-Ray Observatory Conference, ed. M. Friedlander, N. Gehrels, D. Macomb, pp. 314-318
3. Wilson et al, 92, in Proceedings of the Compton Gamma-Ray Observatory Conference, ed. M. Friedlander, N. Gehrels, D. Macomb, pp. 314-318
4. Jung et al., 89 ApJ, 345, 412
5. Strickman, Johnson, & Kurfess, 79, ApJLett. ,230, L15
6. Pendleton et al, 89, in Proceedings of the GRO Science Workshop, ed. N. Johnson, pp. (4)547-4(553)
7. Knight et al, 82, ApJ, 260, 758
8. Mahoney et al, 84, ApJ, 278, 784
9. Kniffen et al, 92, in Proceedings of the Compton Gamma-Ray Observatory Conference, ed. M. Friedlander, N. Gehrels, D. Macomb, pp. 178-187

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GRO J1008-57

M. T. Stollberg, M. H. Finger, R. B. Wilson, B. A. Harmon, B. C. Rubin, N. S. Zhang, and G. J. Fishman report for the Compton Gamma Ray Observatory BATSE team: "Hard x-ray pulsations in the energy range 20-120 keV are being detected from a previously uncatalogued source in the Carina-Vela region. The source location, determined from the observed times of Earth occultation, is centered at R.A. = 10h08m, Decl. = -57.5 deg (equinox 2000.0). The estimated 1-sigma errors are bounded by a box with the following corners: R.A. = 10h09m.5, Decl. = -57 24'; 10h03m.5, -56 24'; 10h07m.0, -57 30'; 10h12m.5, -58 42'. The pulse period on July 19 was 93.587 +/- 0.005 s, corrected to the solar system barycenter. The present outburst was first detected on July 14. The pulsed flux in the range 20-50 keV increased from a detection threshold of about 50 mCrab to about 1.1 Crab (pulsed) on July 18, and this flux has continued to increase slightly since that time. The spectrum of the phase-averaged pulsed flux between E = 20 and 100 keV on July 23-24 has been fitted by an optically thin thermal bremsstrahlung model of the form A/E exp(-E/kT), with A = 0.21 +/- 0.02 photon cmE-2 sE-1 and kT = 18.9 +/- 0.9 keV."

NOVA OPHIUCHI 1993

C. E. Woodward, University of Wyoming; M. A. Greenhouse, National Air and Space Museum; and D. Van Buren, California Institute of Technology, write: "Spectroscopy of N Oph 1993 obtained on June 2.3 UT (62 days after outburst; cf. IAUC 5765) with the Kitt Peak National Observatory 2.1-m telescope (+ CRSP) reveals the following infrared coronal lines (wavelengths listed are observed values, with uncertainty in the last digit given in parentheses): [Ca VIII] 2.322(2)-microns (2P1/2-2P3/2) and [Si VII] 2.470(2)-microns (3P2-3P1). Emission from hydrogen (Brackett-gamma 2.169(1)-microns) and helium (He I 2.060(2)-microns) also were present in the spectra. The observed integrated intensities were (in units of 10E-19 W/cm2): Brackett-gamma, 1.06 +/- 0.01; [Ca VIII], 0.26 +/- 0.05; [Si VII], 0.65 +/- 0.13. The lines were velocity-resolved at about 3600 km/s FWHM. The rapid onset of coronal line emission in N Oph 1993 is similar to that observed in V1500 Cyg and V446 Her. Further spectroscopy is encouraged."

1993 July 27 (5836) Daniel W. E. Green

RECENT OBSERVATIONS OF EXO 2030+375 WITH BATSE

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ABSTRACT

The transient x–ray pulsar EXO 2030+375 has been detected in the Large Area Detectors (LADs) of BATSE during twelve outbursts from February 1992 to July 1993. These data have been fit to a model of the pulsar's rotational phase which assumes an independent torque for each outburst. An intensity history, a pulse period history, a pulsed fraction, and the latest orbit parameters resulting from this fit are presented.

1. INTRODUCTION

EXO 2030+375 has been detected in the BATSE Large Area Detectors (LADs) for twelve consecutive outbursts beginning in February 1992. Each outburst is detected in the first seven of the LADs 16 CONT energy channels (2.048 sec resolution, 20 – 120 keV). The pulse profiles show only slight variations when summed over an entire outburst (typically 10 – 12 days). Details on profiles and spectra have been reported by us previously in Stollberg et al (1993).

This transient has also been seen in Earth occultation data. However, due to its closeness in the sky to Cygnus X–1 and Cygnus X–3, time intervals when the flux from EXO 2030+375 can be extracted are limited. Only one outburst (TJDs 9120 – 9133) was bright enough to be detected by earth occultation at a time when the source flux could be reliably separated from that of the other two sources.

2. OBSERVATIONS

Data from DISCLA channel 1 (20 – 50 keV, 1.024 sec time resolution) were epoch–folded to produce an intensity history for the twelve outbursts seen. Figure 1 shows the intensity history for the twelve outbursts. Each outburst lasts from the day of periastron passage until 10 – 12 days after, with the peak intensity usually occurring five days after periastron passage. The strongest seen by BATSE was the first (February 1992), while the eighth (December 1992) has been the weakest to date.

The gaps between outbursts in Figure 1 have been searched for pulsations from the source: a grid search was performed on the DISCLA channel 1 data over a range of periods ~40 times the variation in period that is seen during a single outburst. The spacing between trial periods was ~3 msec. Figure 2 shows the periods with maximum χ^2 values plotted against the Truncated Julian Day (TJD). Shown are the last four outbursts (February 1993–August 1993). The size of the plotted points is proportional to the significance of the set of tested periods. The random scatter observed between outbursts shows that the source is not detected. The detection limit is $\sim 10^{35}$ ergs-sec^{-1} at 20– 50 keV, based on a 5.3 kpc distance to the pulsar as was reported by Parmar et al (1989).

Our current model for the orbit of EXO 2030+375 assumes an applied torque which is constant throughout the pulsar's orbit but is variable from orbit to orbit. Figure 3 shows the average pulse period derived for each outburst based upon this model. A constant spin–up has been observed since the beginning of the Compton Gamma–Ray Observatory (CGRO) mission.

Using data from the eleventh outburst shown in Figure 1 (TJDs 9120 – 9131), we obtain a pulsed fraction of 0.36 ± 0.05 for the energy range 30 – 70 keV. The value obtained for each subinterval is consistant with this value. This fraction agrees with the fraction obtained from the model of Parmar, White, and Stella (1989), which assumed emission from the poles of the pulsar was a near–pencil beam by the end of EXOSAT's observations of EXO 2030+375 in July 1985.

3. DISCUSSION

For the twelve outbursts seen, the χ^2 per degree of freedom from the current phase model is 3.39 for 20 free parameters. The phase residuals for EXO 2030+375 show a parabolic trend in many of the outbursts once the orbital correction from the current phase model is removed. This indicates that a constant torque applied to the pulsar over an entire orbit is too simple. In the future, we plan to investigate a phase model in which the torque is applied only during each outburst. Nothing further can be concluded about our pulsed fraction until times from other outbursts can be obtained where reliable fluxes for EXO 2030+375 exist.

Finally, the orbital parameters from the latest orbital fit are presented. The errors are an estimate of the total error for each element, adjusted by a factor of $\sim$1.84 to account for the observed scatter in the residuals.

$P_{orb} = 46.03 \pm 0.01$ days
$e = 0.33 \pm 0.03$
$a_x \sin i = 268 \pm 25$ lt–sec
$\omega = 228.2 \pm 5.7$ degrees
$T_{\pi/2} =$ JD 2448781.0 ± 0.3
$T_p =$ JD 2448798.7 ± 0.3

4. REFERENCES

Harmon, B. A., 2nd Compton Symposium, 1993, to be published.

Parmar, A. N., White, N. E., Stella, L., Izzo, C., & Ferri, P. 1989, ApJ, 338, 359

Parmar, A. N., White, N. E., & Stella, L. 1989, ApJ, 338, 373

Stollberg, M. T., Pendleton, G. N., Paciesas, W. S., Finger, M. H., Fishman, G. J., Wilson, R. B., Meegan, C. A., Harmon, B. A., & Wilson, C. A. 1993, in Compton Gamma-Ray Observatory, eds. M. Friedlander, N. Gehrels, & D. J. Macomb (New York: AIP Press) p.371

Wilson, R. B., Harmon, B. A., Fishman, G. J., Paciesas, W. S., & Prince, T. A. IAU Circular, 1992, 5454, 1

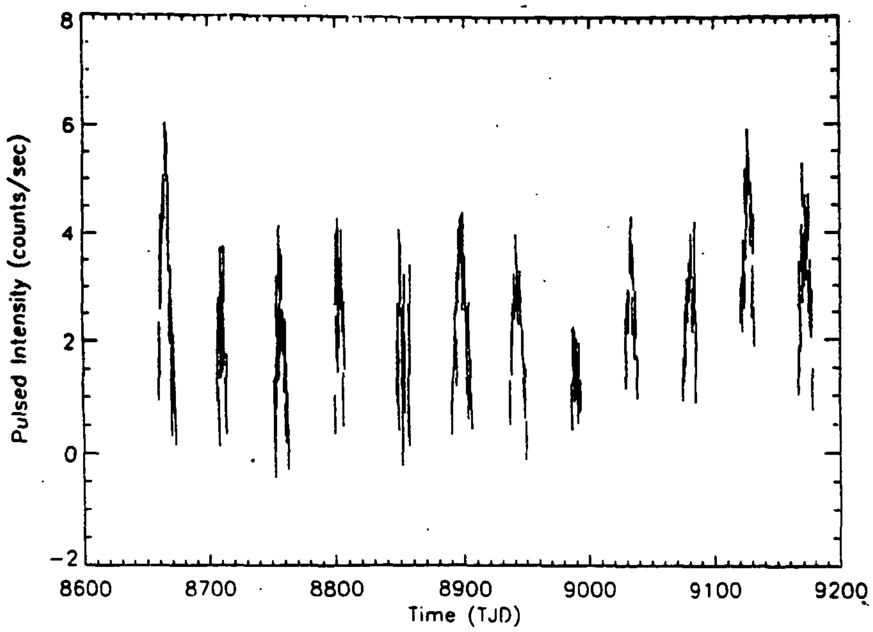

Fig. 1. Intensity history for the twelve outbursts of EXO 2030+375 seen by BATSE from February 1992 to June 1993.

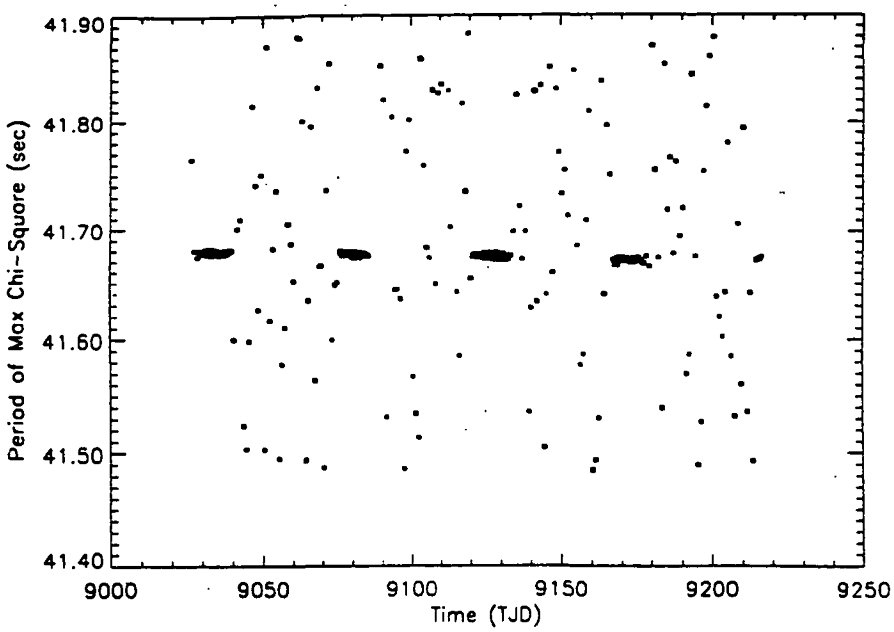

Fig. 2. Epoch folded search for detections of EXO 2030+375 based on the pulsar's pulse period.

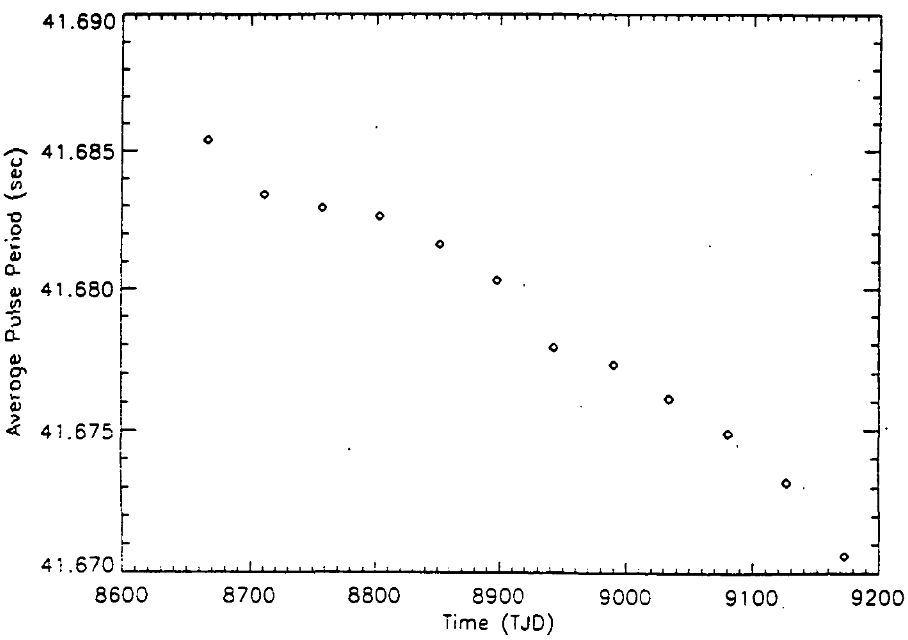

Fig. 3. The average pulse period history of EXO 2030+375 for the twelve outbursts seen by BATSE. A spin-up trend is seen. The errors associated with the pulse periods are smaller than the data points and are not shown.

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15. Supplementary Notes

16. Abstract

Miscellaneous tasks related to the operation of, and analysis of data from, the Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory (CGRO) were performed. The results are summarized and relevant references are included.

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