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NASA GRANT NAG5-720
16 April 1987 - 15 November 1987

THE GAMMA-RAY SPECTROMETER EXPERIMENT ON THE SOLAR MAXIMUM MISSION SATELLITE

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Prepared by:

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Prepared for:

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GREENBELT, MARYLAND 20771

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SMM GRS - Semi-Annual Status Report

Period 1987, April 16 - 1987 November 15

SUMMARY

In this report we summarize the major activities of the *SMM* GRS team members at UNH and NRL and the work of Guest Investigators since the last *Semi-Annual Report* through 1987 November 15. In addition, we provide an updated list of published papers and invited papers or contributed papers presented at scientific meetings.

May 15, 1988

Introduction

The reporting requirements for the subject grant require an activity report at the end of the grant year. At about the same time this report was due, we were requested to provide nearly identical material for the Operating Satellite Review at NASA Headquarters in late January 1988. Therefore, for the record, we are formally submitting a draft of that report in satisfaction of this reporting requirements.

TO: Joe Gurman
SMM Project Scientist
Goddard Space Flight Center

CC: J.D. Bohlin
Chief, Solar and Heliospheric Physics Branch

FROM: E.L. Chupp
Principal Investigator – SMM Gamma-Ray Spectrometer

DATE: January 22, 1988

SUBJECT: Material for Operations Review

Enclosed is a set of transparencies and accompanying descriptive paragraphs which highlight only some of the major recent discoveries and accomplishments made with the SMM Gamma-Ray Experiment since the last review in January 1987. We understand that this material will be used to support the forthcoming operating satellites review at NASA Headquarters. For the current review we emphasize the two SMM accomplishments that have been highlighted in Physics News of 1987, described in Physics Today, January 1988. These are the discovery of ^{56}Co γ rays from SN1987A and the discovery of the 154 day periodicity of flares in 1984, both made by the SMM GRS.

The specific topics covered are:

1. News release on SMM GRS SN1987A observations presented at the January 1988 meeting of the American Astronomical Society in Austin, Texas (4 illustrations).

2. The first evidence for the 154 day periodicity of flares from the SMM GRS (2 illustrations).

3. The γ-ray spectrum of a large flare and the inferred isotopic abundance ratios (2 illustrations).

4. The time distribution of γ-ray bursts and solar flares seen by SMM GRS (1 illustration).

5. Strongly scattered 2.22 MeV photons during the extended phase of the 1982 June 3 flare suggests a new acceleration mechanism (1 illustration).

Work on the analysis of data from the SMM GRS is being carried out by co-investigators from:

The Institute for Extraterrestrial Physics
Max Planck Institute for Pysics and Astrophysics
8046 Garching, Federal Republic of Germany
Contract 010K017ZA/WS/WRK 0275:4

The E.O. Hulburt Center of Space Research
The Naval Research Laboratory
Washington, DC 20375
NASA Contract S.14513-D

Department of Physics
The Unversity of New Hamphsire
Durham, NH 03824
NASA Grant NAG5-720

The material for this brief report was provided by Dr. G. H. Share – Naval Research Laboratory for the non-solar results, and Drs. W. T. Vestrand D. J. Forrest and E. L. Chupp – University of New Hampshire for the solar flare results.

Distribution List

D. Bohlin
G. Share
D. Forrest
T. Vestrand
G. Vincent
G. Wiseman
P. Pashby
G. Kanbach
E. Rieger
C. Reppin

FOR RELEASE: January 13, 1988

SOLAR MAXIMUM MISSION SATELLITE DETECTS GAMMA-RAY LINE EMISSION FROM SUPERNOVA IN THE LMC AND ALSO PROVIDES DIRECT CONSTRAINTS ON NEUTRINO LIFETIMES

Today, work has been reported to the 171st American Astronomical Society meeting at Austin, Texas by a team of US and German scientists, who have detected gamma-ray emission from the bright, nearby supernova SN1987A, which occurred on February 23 of 1987 in the Large Magellanic Cloud. The team also presented significant constraints on supernova neutrino lifetimes.

One report described the detection of gamma rays from radioactive cobalt in the debris of the supernova and was presented by Drs. Gerald Share, Steven Matz, and Mark Leising of the Naval Research Laboratory in Washington D.C., Professor Edward Chupp and Dr. Thomas Vestrand of the University of New Hampshire, Durham, New Hampshire, and Dr. Claus Reppin of the Max Planck Institute for Extraterrestrial Physics in the Federal Republic of Germany. A paper detailing these measurements was submitted for publication in the British journal *Nature*, earlier this month.

The measurement was made with the gamma-ray spectrometer (GRS) on NASA's Solar Maximum Mission *SMM* satellite, which was launched in 1980. The spectrometer was designed and built by the University of New Hampshire and West German scientists, under the direction of Professor Chupp, the Principal Investigator. The analysis which revealed the radioactive cobalt was performed at the Naval Research Laboratory in collaboration with the scientists at the University of New Hampshire.

It is now well established that in SN1987A the core of a star, ten to twenty times more massive than the Sun, collapsed to form a neutron star or a black hole. The high temperatures and pressures produced in the explosion cause nuclei to fuse, making heavier elements from lighter ones. Some of the nuclei created by this process are unstable, or radioactive, and they decay into other elements, giving off energy in the process, some of which is in the form of gamma rays.

The detection of gamma rays from radioactive cobalt confirms that supernovae are the principal birthplaces of elements found in the universe, such as iron. These elements are created from the fusion of lighter elements during the explosion of the star. The force of the explosion expels these heavy elements along with the lighter elements, such as carbon, which were synthesized in the star at earlier times. The elements are dispersed in space and ultimately are recycled to form new stars and planetary systems, such as our own.

'These cataclysmic deaths of stars have planted the seeds for the birth of life on Earth,' says Dr. Share of the Naval Research Laboratory (NRL).

The detection of gamma rays from the supernova was complicated by the fact that the direction to the Large Magellanic Cloud is at right angles to the viewing direction of the gamma-ray spectrometer. Only about a third of the gamma rays from the supernova are able to make their way through the spacecraft and reach the detector. The design of the satellite prevents the detector from being pointed directly at the supernova. However, it can be pointed to within about 50 degrees of the supernova, for short periods of time, as shown in Figure 1., to enable more of the gamma rays to reach the detector.

The scientists also devised a way to use the disk of the Earth to prove that the gamma rays came from the direction of the supernova. They did this by separately accumulating data when the supernova was visible and when it was blocked by the Earth. The gamma rays only appeared when the supernova was visible.

The gamma-ray lines, emitted during the decay of radioactive cobalt to stable iron, first appeared in August of 1987, about the same time as energetic X-rays were observed by the Japanese Ginga satellite and Soviet and West German experiments on the Soviet MIR space station.

The most intense gamma-ray line at 847 keV expected from the decay of cobalt was detected. This is revealed in the top portion of Figure 2. which shows the measured intensities of this radiation from the direction of the supernova since 1981. The last two points covering the period from August to October of 1987 are significantly higher than the rest. The second most intense line at 1238 keV exhibited a marginal increase at the same time. (See lower portion of Figure 2.)

The detection of the lines is illustrated in the spectrum accumulated over the same time period and plotted in the top of Figure 3. The lines are not apparent in a spectrum accumulated over a similar period two years earlier which is shown at the bottom of the figure.

The early appearance of the gamma radiation and the ratio of the intensities of these two lines suggest that the cobalt may have been directly exposed to us, in contrast to what is expected if the cobalt were embedded in a massive cloud. Figure 4. is an artist's conception of three different scenarios for the distribution of the radioactive cobalt in the supernova. From left to right: the cobalt is concentrated at the center of the expanding envelope, the cobalt is symmetrically mixed into the envelope, and the cobalt is distributed in blobs and jets expelled during the explosion. The *SMM* observations suggest that a small fraction (one to two percent) of the radioactive cobalt may have been able to move toward the outer edge of the envelope, directly exposing the radioactivity to us.

Preliminary measurements from *SMM* which cover the period from the middle of November to the middle of December, suggest that the massive envelope covering the remaining radioactive cobalt may be clearing. If so, this will allow detailed studies of the radioactivity by the SMM gamma-ray spectrometer and by balloon-borne instruments to be launched by NASA in the coming months.

....

The *SMM* team also made a significant discovery pertaining to our understanding of elementary particles, using the fact that no gamma-ray burst was observed coincident with the supernova neutrino flash. Professor Chupp and Dr. Vestrand of the University of New Hampshire reported, on behalf of their colleagues, that this result allows a strong constraint to be placed on the lifetime of massive neutrinos, if they are produced in the stellar collapse. This additional *SMM* observation improves upon earlier indirect estimates of massive neutrino lifetimes by more than a factor of 100, as has recently been pointed out by Drs. Kolb and Turner of the Fermi National Accelerator Laboratory.

Some astronomers and physicists also believe that supernova events could give rise to a burst of gamma rays from the interaction of particles that are accelerated by the shock wave which is believed to initiate the optical outburst. Also, some astronomers believe that a rotating neutron star may have been formed in the collapse of the original star. If so, the rapidly spinning star, with a strong magnetic field, could generate high-energy particles called cosmic rays. These in turn may produce gamma rays with energies above 10 million electron volts in the outer part of the supernova remnant.

Professor Chupp also reported that continuing efforts are in progress to study these other sources of supernova gamma rays.

For More Information Contact:
At the University of New Hampshire:
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At the Naval Research Laboratory:
Dr. Gerald H. Share (202-767-3027)

VIEW-GRAPH NARRATIVES
(Headquarters Operating Satellites Review, Jan. 1988)

T-1 SMM GRS, – AN OVERVIEW OF 1987 ACCOMPLISHMENTS AND 1984 REVISITED

- Detection of ^{56}Co radioactive decay γ-ray lines from SN1987A (See IAU Circular 4510 – 87/12/11 and press release to 171st meeting of AAS at Austin, Texas.)
- Further analysis of the 154 day periodicity of flares discovered in 1984 from GRS data has stimulated further studies into its possible cause. (See Physics News in 1987 in Physics Today – January 1988.)
- The detailed analysis of the γ-ray spectra in the large flare on April 27, 1981 has lead to conflicting information on solar abundances.
- Over a period of 8 years the SMM GRS has observed both solar flares and cosmic γ-ray bursts with no instrument degradation.
- The down scattered photons from the original 2.223 MeV photospheric photons observed on 1982 June 3 have been studied in detail leading to evidence for a new acceleration mechanism.

T-2 ARTIST'S CONCEPTION OF NASA'S SMM SATELLITE SUPERIMPOSED ON A PHOTOGRAPH OF THE SUPERNOVA

Artists's conception of NASA's Solar Maximum Mission satellite in orbit (derived from a NASA document EP-205) superimposed on a photograph of the supernova (over-exposed star) in the Large Magellanic Cloud (Photograph courtesy of National Optical Astronomy Observatories and the National Science Foundation). Composite produced by Mr. Tom Phillips of the Naval Research Laboratory.

This material was presented to the American Astronomical Society meeting in Austin, Texas on January 13, 1988 by Dr. Gerald Share of the Naval Research Laboratory, Washington, D.C. and co-authors at NRL, the University of New Hampshire, and Max Planck Institut in West Germany.

T-3 SMM GRS DETECTION OF SN1987A COLBALT GAMMA-RAY LINES

^{56}Co gamma-ray line intensities from the direction of the Supernova in the Large Magellanic Cloud recorded by the Gamma-Ray Spectrometer on NASA's Solar Maximum Mission satellite since 1981. Intensity of the 847 keV line was significantly above background from August through October 1987; the increase in intensity of the 1238 keV line was less significant.

This material was presented to the American Astronomical Society meeting in Austin, Texas on January 13, 1988 by Drs. Gerald Share, Steven Matz, and Mark Leising of the Naval Research Laboratory, Washington, D.C., Prof. Edward Chupp and Dr. Tom Vestrand of the University of New Hampshire, and Dr. Claus Reppin of the Max Planck Institute in West Germany.

T-4 SMM GRS GAMMA-RAY SPECTRUM ACCUMULATED FROM SN1987A

Gamma-ray spectrum (top) accumulated from the direction of the supernova in the Large Magellanic Cloud from August to October 1987 and an equivalent spectrum (bottom) accumulated before the supernova in 1985. For purposes of comparison, the solid curve shows the expected shape of the two lines from radioactive cobalt produced in the supernova, superimposed on a residual background continuum. Measurements were made with the Gamma-Ray Spectrometer on board NASA's Solar Maximum Mission satellite.

This material was presented to the American Astronomical Society meeting in Austin, Texas on January 13, 1988 by Drs. Gerald Share, Steven Matz, and Mark Leising of the Naval Research Laboratory, Washington, D.C., Prof. Edward Chupp and Dr. Tom Vestrand of the University of New Hampshire, and Dr. Claus Reppin of the Max Planck Institute in West Germany.

T-5 DISTRIBUTION OF RADIOACTIVE COBALT WITHIN THE ENVELOPE OF THE SUPERNOVA

Artist's conception of three different scenarios for the distribution of radioactive cobalt within the massive envelope of the supernova. From left to right: the cobalt is concentrated at the center of the expanding envelope, and the cobalt is distributed in blobs and jets expelled during the explosion. (Artwork created by Mr. Tom Phillips of the Naval Research Laboratory.)

This material was presented to the American Astronomical Society meeting in Austin, Texas on January 13, 1988 by Drs. Gerald Share, Steven Matz, and Mark Leising of the Naval Research Laboratory, Washington, D.C., Prof. Edward Chupp and Dr. Tom Vestrand of the University of New Hampshire, and Dr. Claus Reppin of the Max Planck Institute in West Germany.

T-6 POWER SPECTRUM OF EVENTS DERIVED FROM SMM OBSERVATIONS

The power spectrum of events derived from the observed SMM GRS flare frequency. This is the basic discovery of the 154 day periodicity in flare occurrence. Analysis reported in 1987 suggests that a basic period may be 51 days. See enclosed recent Physics Today article – January 1988.

T-7 SMM GRS PHASE PLOT FOR EVENTS AT A PERIOD OF 154 DAYS

The phase plot for the SMM GRS events at a period of 154 days. Note the fact that about 1/3 of the events above 300 keV occur in a pulsed manner.

T-8 SMM GRS SOLAR FLARE GAMMA-RAY SPECTRUM

Elemental abundance studies using nuclear γ-ray line analysis has long been an objective of gamma-ray astronomy. The SMM GRS has used this technique to determine the elemental abundance at the site where γ-ray are produced in solar flares.

The figure shows a measured γ-ray energy loss spectrum from a large limb flare along with two smooth fitted curves representing γ-ray emission model. The lower curve represents a power-law electron bremsstrahlung from primary accelerated electrons, and the upper curve, in good agreement with the observation, represents the sum of this electron bremsstrahlung plus a complex nuclear γ-ray spectrum. The nuclear γ-ray spectrum is used to determine the elemental abundances in the target region where the γ-rays are produced.

T-9 SMM GRS GAMMA-RAY AND PHOTOSPHERIC ELEMENTAL ABUNDANCES

The figure shows the derived γ-ray abundances (closed circles) compared with our best estimate of the solar photospheric or local galactic (open boxes). It is clear that the two observations are not consistent.

T-10 SOLAR AND COSMIC EVENTS OBSERVED BY SMM GRS SINCE 1980

The figure shows the rate of GRS cosmic burst and solar flare event detected from the SMM launch in February 1980 through the thrid quarter of 1987. The uniform destribution of cosmic bursts (open circles) can be compared to the bunching up of solar flares (open diamonds) in 1980-1983.

T-11 SMM GRS OBSERVATION OF COMPTON CONTINUUM FOR 2.223 MEV PHOTONS

The gamma-ray spectrum below the 2.22 MeV line for the extended phase of the 1982 June 3 flare shows a very strong Compton tail. This requires an extremely hard proton spectrum for production of the neutrons which give the γ-ray line.

The particle spectrum responsible for producing the neutrons must be at least as hard as the $s = 1.7$ power law spectrum measured by McDonald for interplanetary particles associated with this flare. This analysis supports the idea proposed by Ramaty, Murphy, and Dermer, and Forrest *et al.* that the extended phase of June 3 is an example of a new acceleration component.

T-1 SMM GRS, – AN OVERVIEW OF 1987 ACCOMPLISHMENTS AND 1984 REVISITED

- Detection of ^{56}Co radioactive decay γ-ray lines from SN1987A (See IAU Circular 4510 – 87/12/11 and press release to 171st meeting of AAS at Austin, Texas.)
- Further analysis of the 154 day periodicity of flares discovered in 1984 from GRS data has stimulated further studies into its possible cause. (See Physics News in 1987 in Physics Today – January 1988.)
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- The down scattered photons from the original 2.223 MeV photospheric photons observed on 1982 June 3 have been studied in detail leading to evidence for a new acceleration mechanism.

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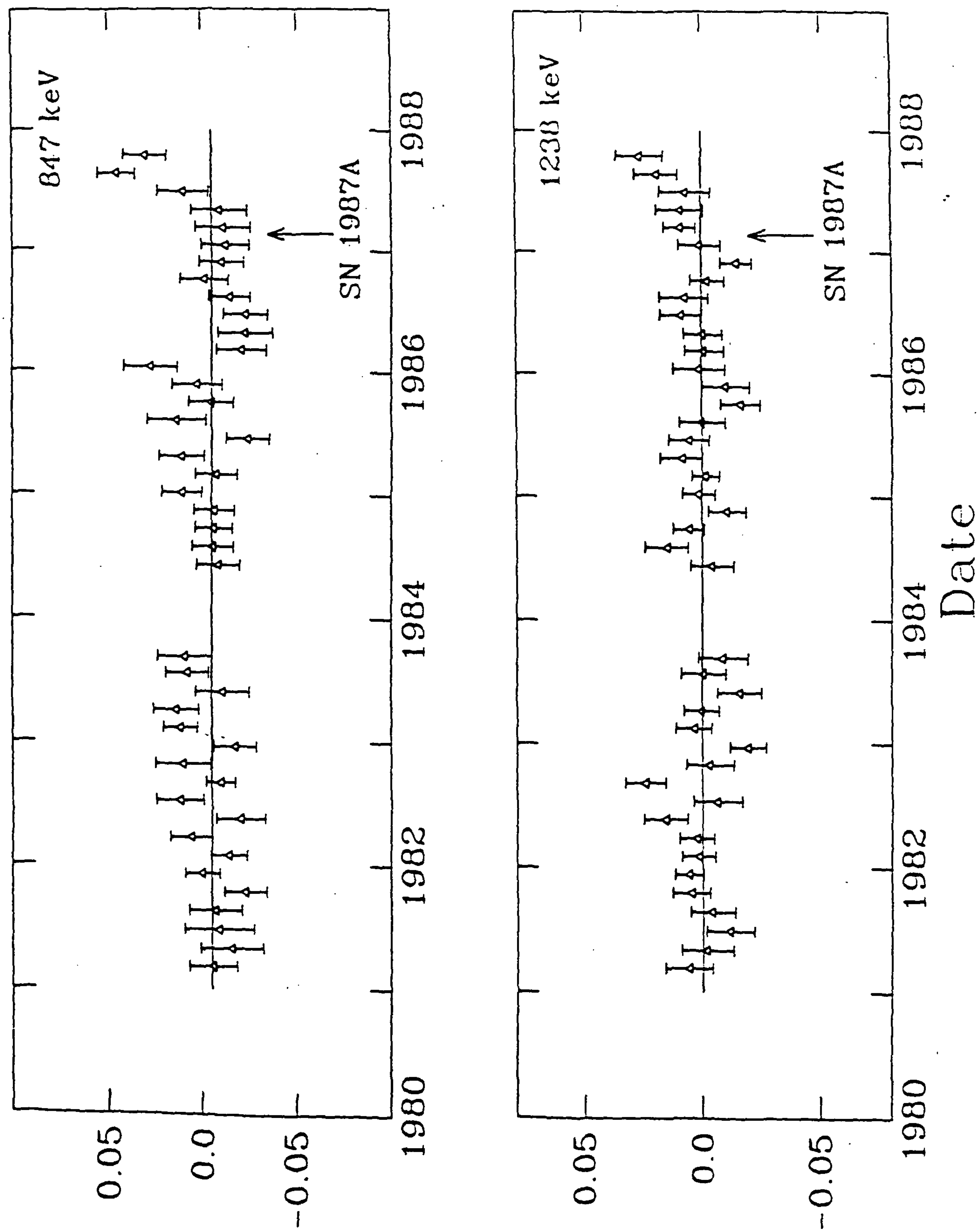
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SN 1987A
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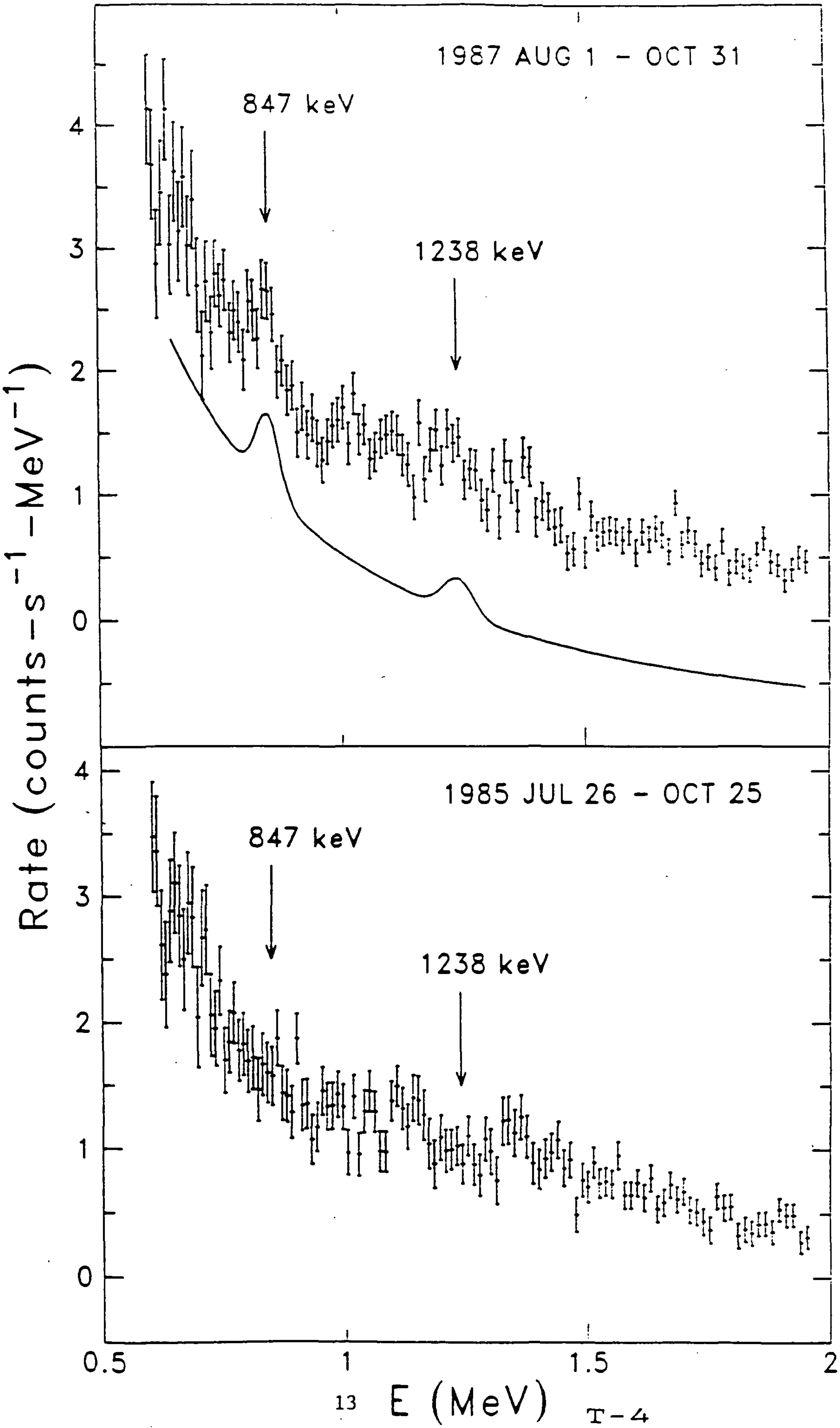
1984
1986
1988
Date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847 keV
1238 keV
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847 keV
1238 keV
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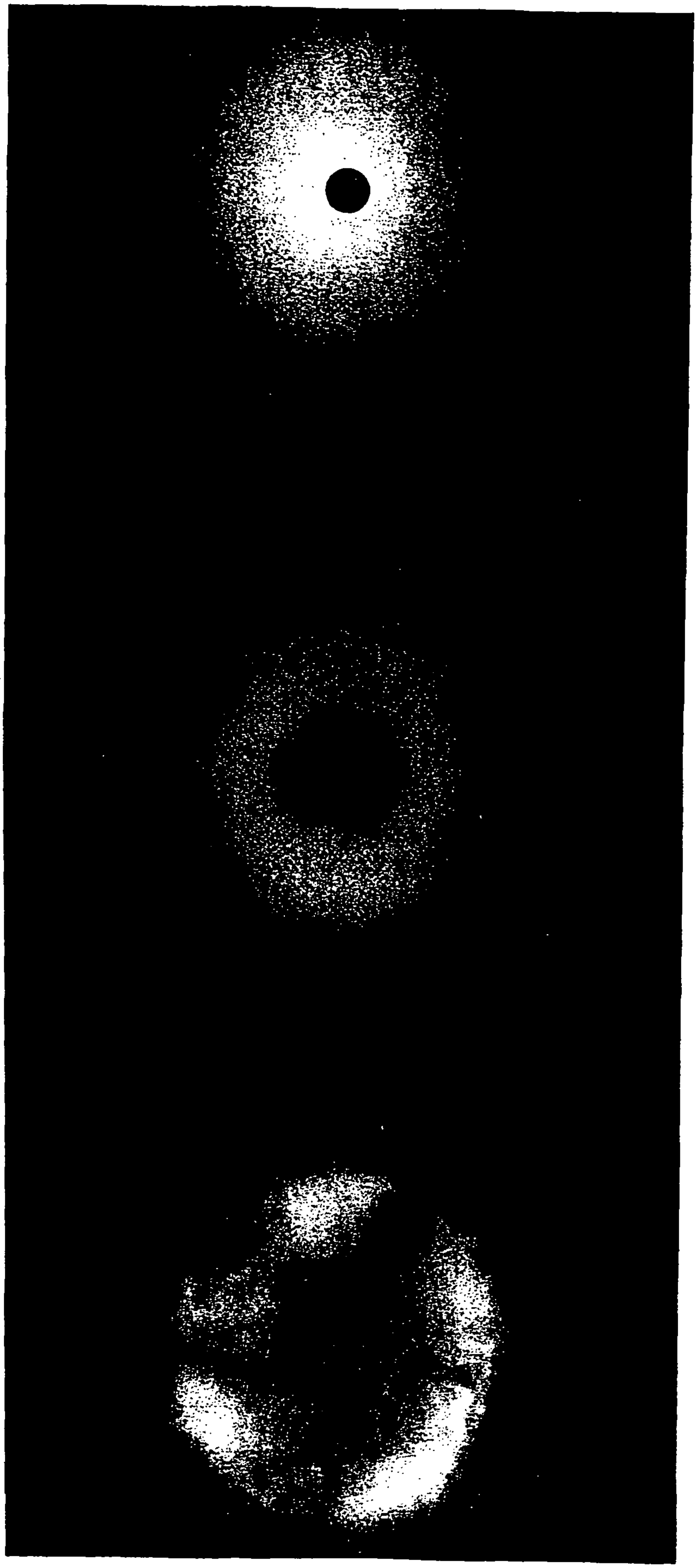
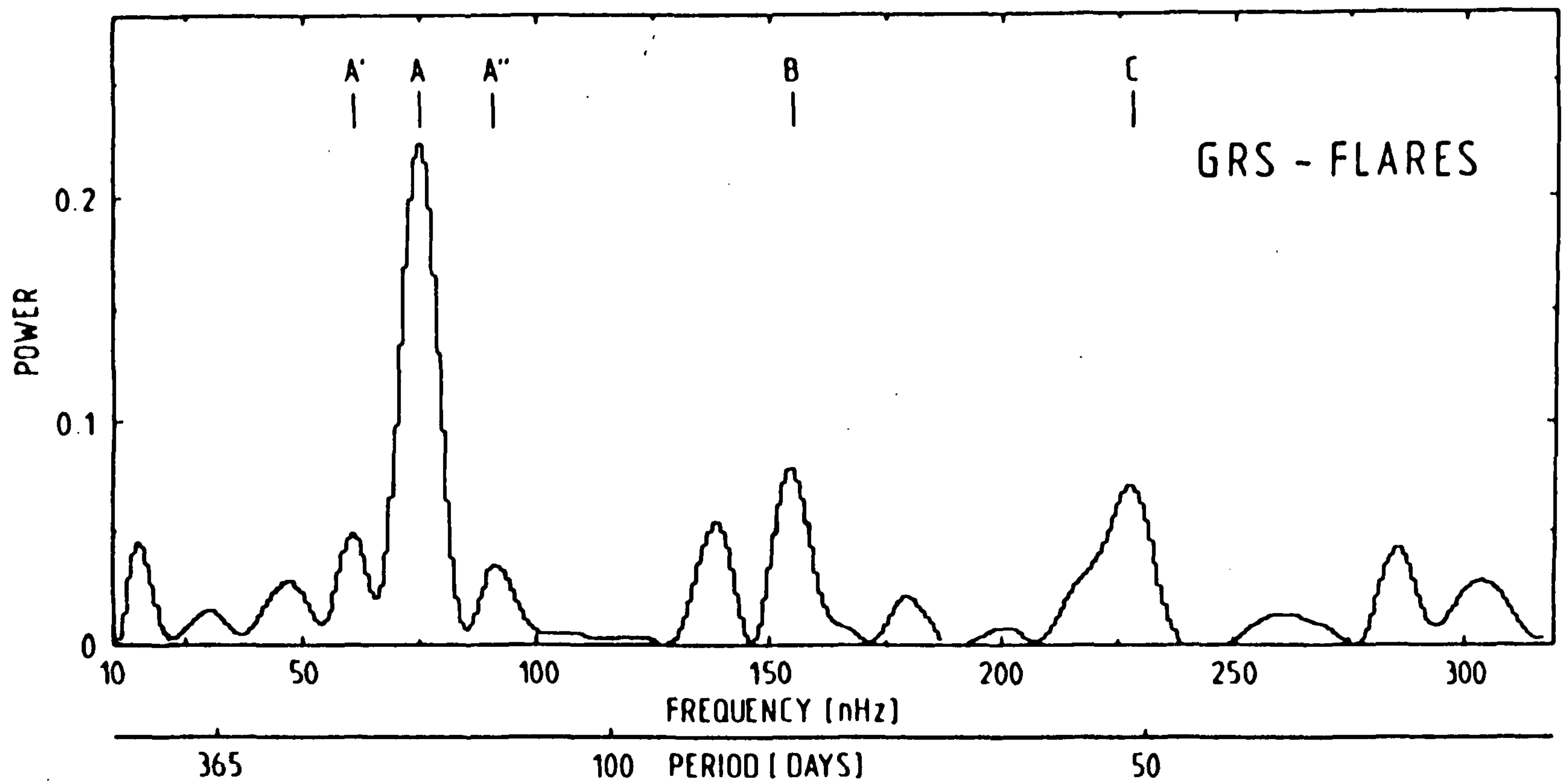
2
3
4
0.5
1
1.5
2

T-4

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A
A''
B
C
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0.1
0
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100
150
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300
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100
PERIOD (DAYS)
50

T-6

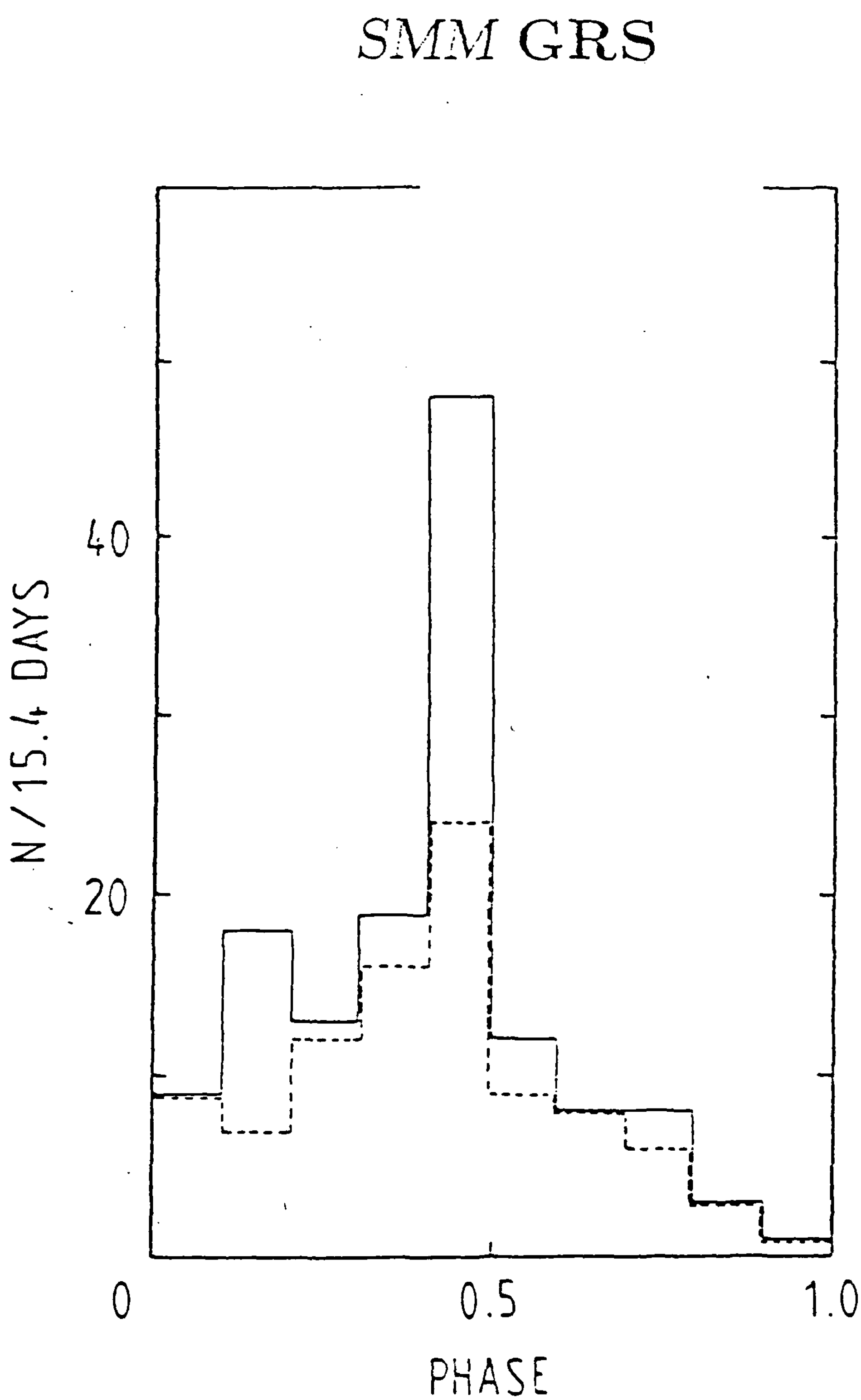

Figure. 8

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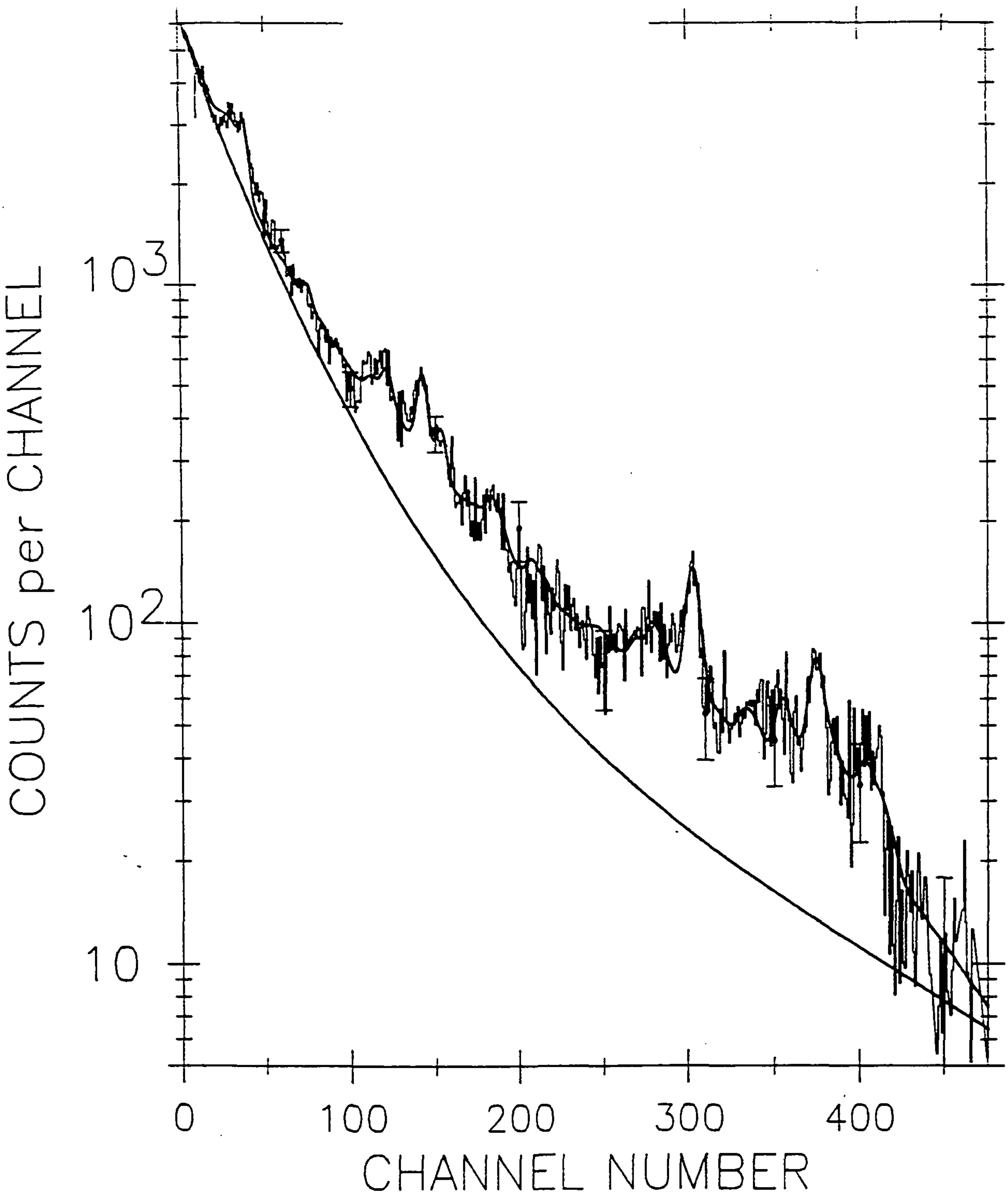
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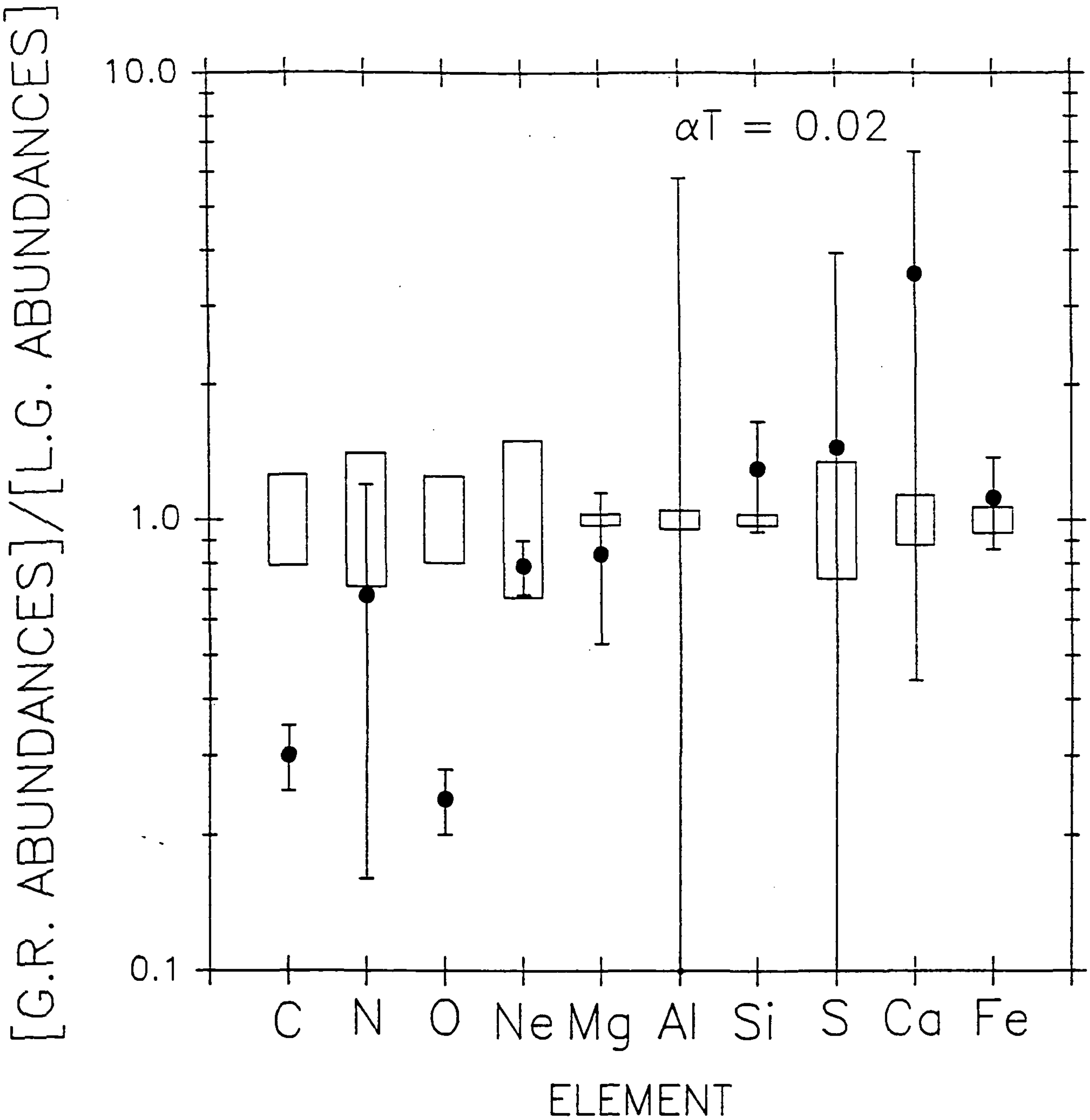
CHANNEL NUMBER

T-8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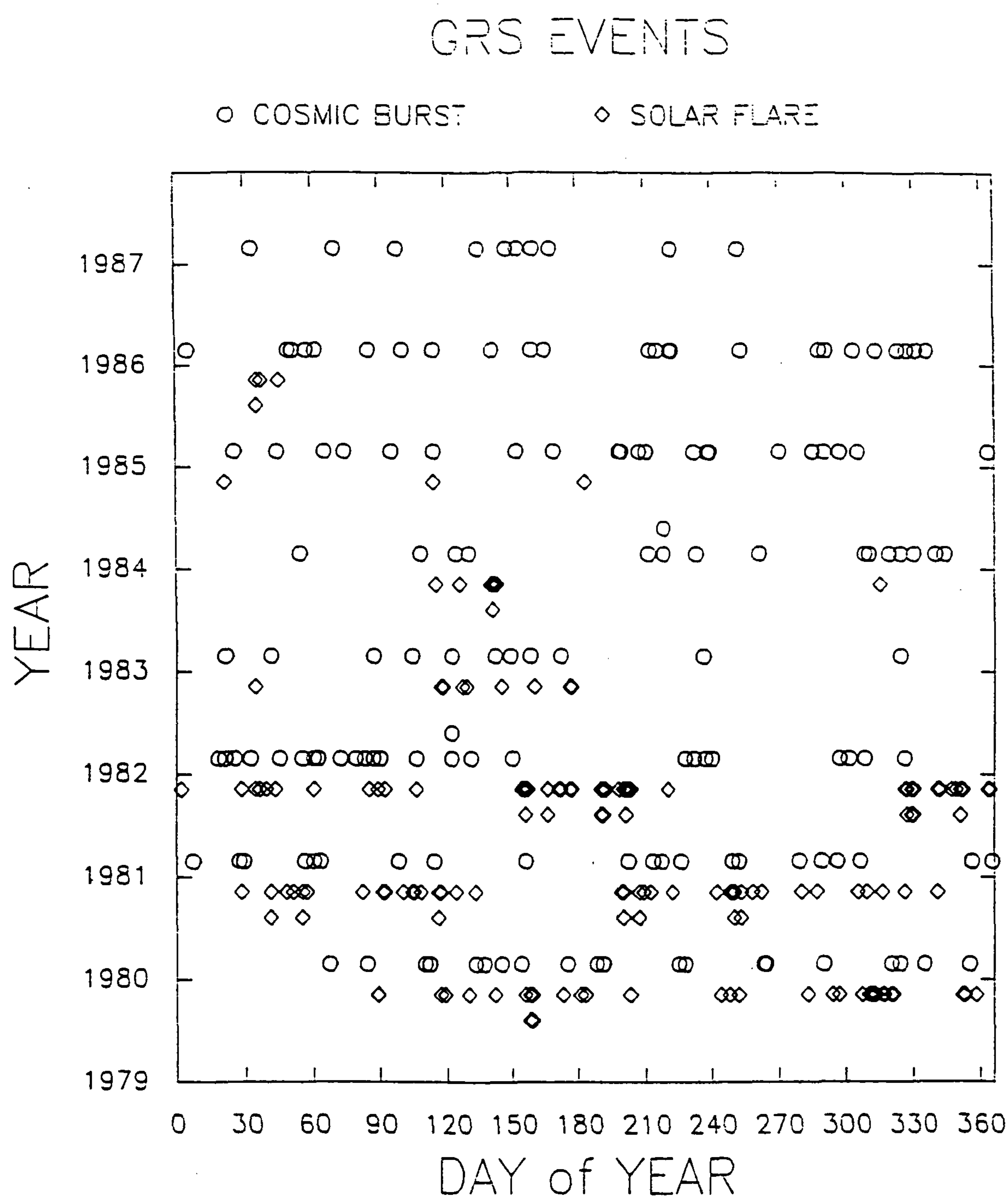
T-9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1981
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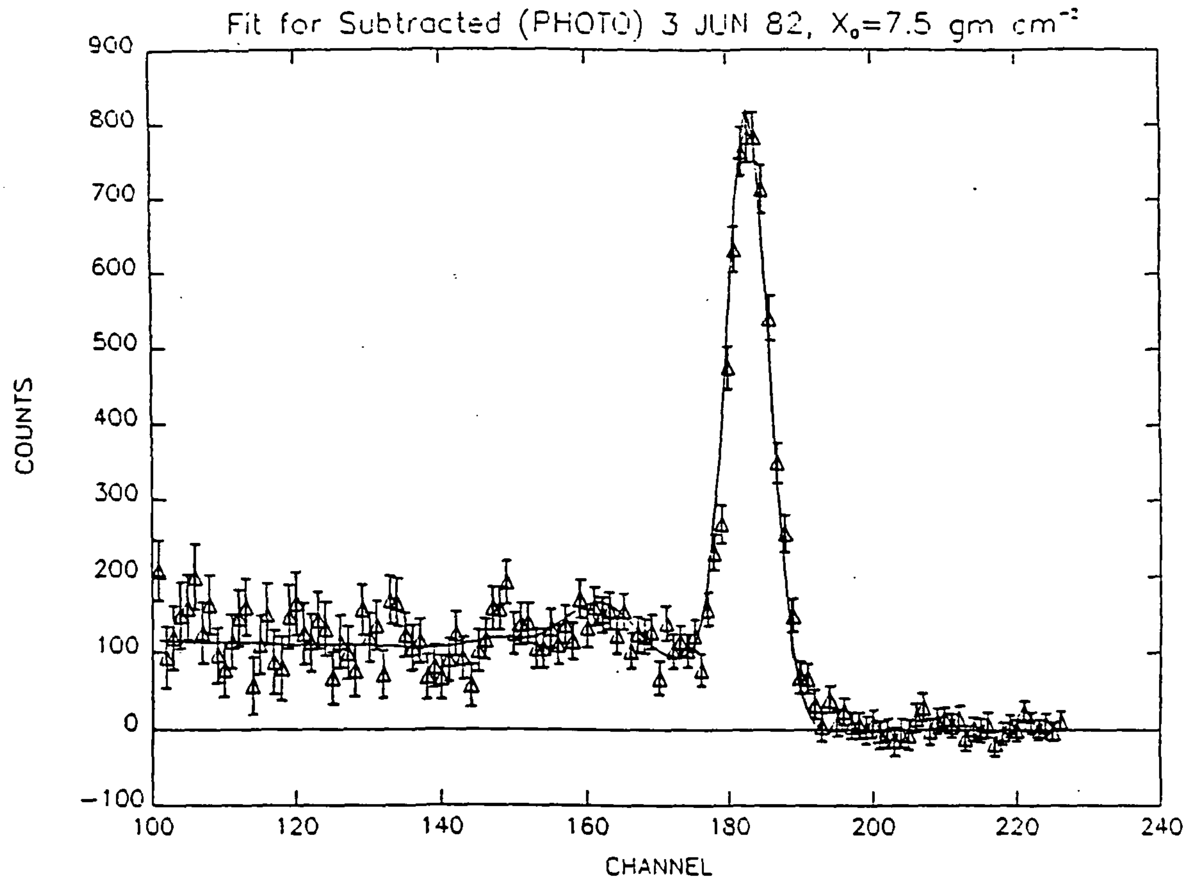
DAY of YEAR

T-10



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100
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140
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180
200
220
240

T-11

SUMMARY LIST OF SMM PUBLICATIONS 1986 thru 1987

1986

Publications

"Rapid Acceleration of Energetic Particles in the 1982 February 8 Solar Flare," S. R. Kane, E. L. Chupp, D. J. Forrest, G. H. Share, E. Rieger, Ap. J.(Letters), 300, L95 (1986).

"Spectral Evolution of Pulse Structures in Gamma-Ray Bursts," J. P. Norris, G. H. Share, D. C. Messina, T. L. Cline, U. D. Desai, B. R. Dennis, E. L. Chupp. Ap. J. 301, 213 (1986).

"Gammastrahlen von der Sonne", E. Rieger, Sterne und Weltraum 25, 576 (1986).

"Very Energetic Gamma-Rays from the 3 June 1982 Solar Flare," D. Forrest, W. T. Vestrand, E. Chupp, E. Rieger, J. Cooper, G. H. Share. Adv. Space Res., Vol. 6, No. 6, 115 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

"Evidence for Solar Flare Directivity from the Gamma-Ray Spectrometer aboard the SMM Satellite", W. T. Vestrand, D. J. Forrest, E. L. Chupp, E. Rieger, G. Share. Adv. Space Res., Vol. 6, No. 6 125-126 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

"SMM Observation of a Cosmic Gamma-Ray Burst from 20 Kev to 100 MeV," G. H. Share, S. M. Matz, D. C. Messina, F. L. Nolan, E. L. Chupp, D. J. Forrest, J. F. Cooper. Adv. Space Res. Vol. 6, No. 4, 15-18 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

"Observations of Galactic Gamma-Radiation with the SMM Spectrometer," G. H. Share, R. L. Kinzer, D. C. Messina, W. R. Purcell, E. L. Chupp, D. J. Forrest, E. Rieger. Adv. Space Res. Vol. 6, No. 4, 145-148 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30- July 11, 1986).

"Measurement of Gamma-Ray Line Intensities from the Earth's Atmosphere," J. R. Letaw, G. H. Share, R. L. Kinzer, R. Silberberg, E. L. Chupp, D. J. Forrest, E. Rieger. Adv. Space Res. Vol. 6, No. 4, 133-137 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

"Spectral Evolution in Gamma-Ray Bursts," J. P. Norris, C. Kouveliotou, G. H. Share, D. C. Messina, S. M. Matz, B. R. Dennis, U. D. Desai, T. L. Cline, E. L. Chupp. Adv. Space Res. Vol. 6, No. 4, 19-22 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

"A Search for Evidence of Energetic Protons Immediately Prior to the Impulsive Phase of Solar Flares," G. M. Simnett, G. H. Share, D. C. Messina, E. L. Chupp, D. J. Forrest, E. Rieger. Adv. Space Res. Vol. 6, No. 6, 105-108 (1986), (Also presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986).

Contributed Papers at Meetings

"Solar Flare Nuclear-Gamma-Rays and Interplanetary Proton Events," E. W. Cliver, D. J. Forrest, R. E. McGuire, T. T. Von Rosenvinge. Presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986.

"Measurement of Gamma-Ray Line Intensities from Earth's Atmosphere," J. R. Letaw, G. H. Share, R. L. Kinzer, R. Silberberg, C. H. Tsao, E. L. Chupp, D. J. Forrest, E. Rieger. Presented at XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986.

"Properties of Flares and Sites Using the 154 Day Period," J. Narayanaswamy, D. J. Forrest, E. L. Chupp. Presented at the XXVI Plenary Meeting of COSPAR, Toulouse, France, June 30-July 11, 1986.

1987

Publications

"High-Energy Particle Production in Solar Flares (SEP, Gamma-Ray and Neutron Emissions)," E. L. Chupp. Physica Scripta (vol. 35, May 1987).

"Solar Neutron Emissivity During the Large Flare on 1982 June 3," E. L. Chupp, H. Debrunner, E. Flückiger, D. J. Forrest, F. Golliez, G. Kanbach, W. T. Vestrand, J. Cooper, G. Share, Ap.J., 318, 913 (1987).

"SMM Detection of Diffuse Galactic 0.511 MeV Positron Annihilation Radiation," G. H. Share, R. L. Kinzer, D. C. Messina, W. R. Purcell, E. L. Chupp, D. J. Forrest, C. Reppin. Paper in preparation for Astrophysical Journal (1988).

"SMM Detection of Diffuse Galactic 0.511 MeV Postitron Annihilation Radiation," G. H. Share, R. L. Kinzer, D. C. Messina, W. R. Purcell, E. L. Chupp, D. J. Forrest, C. Reppin. 20th International Cosmic Ray Conference Papers, 1, 56 (1987).

"A Search for Gamma-Ray Lines from Recent Supernovae," S. M. Matz, G. H. Share, R. L. Kinzer, E. L. Chupp, D. J. Forrest, C. Reppin. 20th International Cosmic Ray Conference Papers, 1, 168.

"Mercury 2000: Stereoscopic Observations of Gamma Ray Flares," J. F. Cooper, A. E. Metzger, E. L. Chupp. 20th International Cosmic Ray Conference Papers, 4, 395 (1987).

"Simulations of Stereoscopic Solar Flare Observations," W. T. Vestrand, A. Ghosh. 20th International Cosmic Ray Conference Papers, 3, 57 (1987).

"Correlative Study of Solar Gamma-Ray Events and Energetic Particle Events," B. Klecker, D. J. Forrest, E. Rieger, E. L. Chupp, D. Hovestadt, G. Kanbach, C. Reppin, G. H. Share. 20th International Cosmic Ray Conference Papers, 3, 69 (1987).

"Gamma-Ray Emission from a Solar Flare Observed also as a Ground Level Event," E. Rieger, G. Bazilevskaya, D. J. Forrest, E. L. Chupp, G. Kanbach, C. Reppin, G. H. Share. 20th International Cosmic Ray Conference Papers, 3, 65 (1987).

"Solar Flare Nuclear Gamma-Rays and Interplanetary Proton Events," E. W. Cliver, D. J. Forrest, R. E. McGuire, T. T. von Rosenvinge, D. V. Reames, H. V. Cane, S. R. Kane. 20th International Cosmic Ray Conference Papers, 3, 61 (1987).

"The Directivity of High-Energy Emission from Solar Flares: *Solar Maximum Mission* Observations," W. T. Vestrand, D. J. Forrest, E. L. Chupp. Ap. J., 322, 1010 (1987).

Invited Papers at Meetings

"High Energy Particle Production in solar Flares (SEP, Gamma-Ray and Neutron Emissions)," E. L. Chupp. Physica Scripta

"Satellite Observation of Atmospheric Nuclear Gamma Radiation," J. R. Letaw, G. H. Share, R. L. Kinzer, R. Silberberg, E. L. Chupp, D. J. Forrest, E. Rieger. Submitted to Journal of Geophysical Research, Sept. (1988).

Contibuted Papers at Meetings

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