Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/7600--15-9639

Volume 3.
NRL SSD Research Achievements: 1980–1990

Jill Dahlburg
George Doschek
Christoph Englert
Lynn Hutting
W. Neil Johnson
Mark Linton
Sarah McDonald
Jeff Morrill
Dennis Socker

Space Science Division

October 30, 2015

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
30-10-2015	Memorandum Report	1980 – 1990

4. TITLE AND SUBTITLE

Volume 3. NRL SSD Research Achievements: 1980–1990

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Jill Dahlburg, George Doschek, Christoph Englert, Lynn Hutting, W. Neil Johnson, Mark Linton, Sarah McDonald, Jeff Morrill, and Dennis Socker

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/7600--15-9639

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

10. SPONSOR / MONITOR'S ACRONYM(S)

NRL

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In the 1980s several different types of space research missions included Naval Research Laboratory (NRL) Space Science Division (SSD) space experiments. This summary provides a technical overview of some of the major NRL SSD research achievements during this decade, 1980-1990.

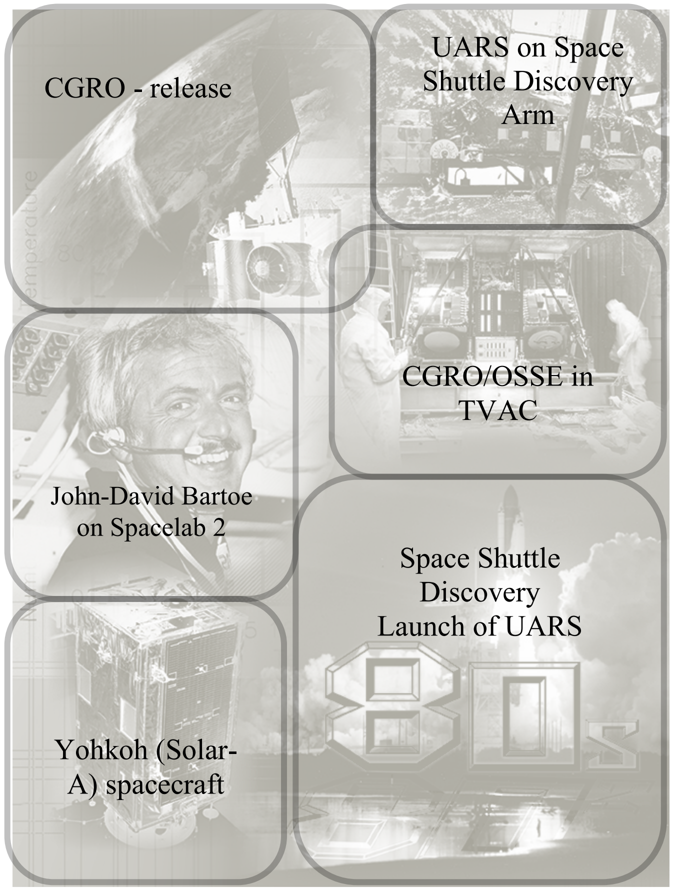
15. SUBJECT TERMS

Space Science History

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Jill Dahlburg
Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	50	**19b. TELEPHONE NUMBER** *(include area code)* (202) 767-6343

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18


Temperature
80s



In the 1980's several different types of space research missions included Naval Research Laboratory (NRL) Space Science Division (SSD) space experiments. SSD scientists centrally participated in the NASA concept of manned science in space through the Spacelab program carried out on the Space Shuttle. On the Shuttle Spacelab flight, SSD scientists flew a high-resolution ultraviolet (UV) spectrometer HRTS (High Resolution Telescope Spectrograph) primarily to study the lower solar transition region, or the temperature region of the solar atmosphere between about 20,000K and 200,000K. They also flew a UV solar radiometer, SUSIM (Solar Ultraviolet Specral Irradiance Monitor), which was flown on several Shuttle flights as well as on the Upper Atmosphere Research Satellite (UARS), with the goal of understanding changes in the Earth's upper atmosphere so that informed policy decisions could be made regarding the human role in climate change. On the Japanese-led solar mission, *Yohkoh*, SSD scientists participated as part of an international collaboration with UK scientists in an X-ray spectroscopy experiment BCS (Bragg Crystal Spectrometer) to study the high-temperature component of solar flares. In astrophysics, there was the launch of a major NASA high energy observatory, the Compton Gamma Ray Observatory (CGRO), on which SSD scientists flew the Oriented Scintillation Spectrometer Experiment (OSSE) to investigate high energy astrophysical topics ranging from distant supernova remnants and matter-anti-matter annihilation to the non-thermal component of solar flares that occur much nearer home.

PREFACE

We offer these summaries of Naval Research Laboratory (NRL) Space Science Division (SSD) research achievements to provide a technical overview of NRL space science accomplishments from the beginning of the Division in 1952 through the first decade of the 21st century.

These summaries are presented in five Volumes:

Volume 1. NRL SSD Research Achievements: 1960-1970
Volume 2. NRL SSD Research Achievements: 1970-1980
Volume 3. NRL SSD Research Achievements: 1980-1990
Volume 4. NRL SSD Research Achievements: 1990-2000
Volume 5. NRL SSD Research Achievements: 2000-2010

The importance of space science basic research in support of naval needs was robustly championed by Homer Newell, the Division's second Superintendent, who noted to the US Congress in 1957, "A strong basic research program is essential to continuing vitality of applied R&D in missiles or any other military or peacetime applications. New facts, new ideas, new techniques, new materials, new instruments, all come from the basic research effort..." As the dozens of summaries in these five Volumes tremendously attest, extraordinary ranges of research and results have been achieved.

To document significant SSD historical accomplishments, Drs. George Doschek and Jill Dahlburg requested current and former SSD researchers to contribute technical achievement summaries to these Volumes on the basis of their personal memories about the scientific activities in which they were involved. The contributions received were then loosely organized by decade into these five featured Volumes, after being edited for clarity by George Doschek, Tanisha Lucas, and Jill Dahlburg.

George Doschek would like to express his gratitude to all the researchers who have contributed to these summaries, and particularly to those with whom he has personally worked. The SSD has and is currently continuing to provide substantive and significant contributions to the developments of experimental space science since its origins after World War II, and it has been a privilege to be part of this effort. These Volumes convey stories about curiosity, hopes, and aspirations of scientists fascinated by exploration of the Universe with instrumentation placed beyond the Earth's atmosphere.

Tanisha Lucas wishes to acknowledge that she has benefited from the advice, assistance, and all of the contributions that our researchers put into these documents. She wishes to express her gratitude to the NRL SSD researchers for their remarkable scientific contributions, her appreciation for the advice on content and organization for this book provided by Dr. Jill Dahlburg, and her many thanks to Dr. George Doschek for closely working with her in compiling and arranging these Volumes.

Jill Dahlburg acknowledges with pleasure and gratitude the request from Dr. John Montgomery, NRL Director of Research, that these Volumes be developed. They present a unique account of exceptional contributions from the NRL SSD broad-spectrum research, development and experimentation program to study the atmospheres of the Sun and the Earth, the physics and properties of high-energy space environments, and solar activity and its effects on the Earth's atmosphere, and to transition these capabilities to operational use.

Finally, George, Tanisha and Jill would together like to thank Ms. Kathryn Grouss who worked with us to prepare these Volumes during 2014, for her exceptional cooperation, professionalism, assistance and advice, and to Dr. Angelina Callahan, NRL Associate Historian, for her many beneficial insights and suggestions, and her unswerving encouragement.

George Doschek, *NRL SSD Historian*
Tanisha Lucas, *NRL SSD Research Achievements Managing Editor*
Jill Dahlburg, *NRL SSD Superintendent*

Manuscript approved December 22, 2014.

Table of Contents

Overview of the NRL Space Science Division 1980's Decade

At the US Naval Research Laboratory (NRL), the story of space research formally began in 1952, with the creation of the NRL Atmospheres and Astrophysics (A&A) Division under the direction of Dr. John Hagen, and a Division charter to perform research and development in the field of space science. The Division's second Superintendent, Homer Newell (1956-1958), continued A&A's seminal space research both at NRL and then later at the National Aeronautics and Space Administration (NASA). Following Dr. Newell's departure to NASA in 1958, Herbert Friedman assumed leadership of NRL space science as the third A&A Division Superintendent (1958-1982). Dr. Friedman oversaw the renaming of the Division from A&A to Space Science, in 1968, and in 1982 he transitioned the Division to the leadership of Dr. Herbert Gursky, who served as SSD's fourth Superintendent from 1982-2006. Jill Dahlburg, the fifth and current SSD Superintendent, was appointed to the position in 2007 following her service as Acting SSD Superintendent from May 2006. The scope of the NRL Space Science Division encompasses theoretical, experimental and numerical research of geophysics science and technology, solar and heliospheric physics, and the high-energy space environment, and the conception, design, fabrication, integration, test, operation and experimentation with forefront space instrumentation, for the purpose of enabling Navy/ Marine Corps and wider DoD robust access to space assets.

In the 1980's, NRL Space Science Division (SSD) researchers led and participated in a very broad range of manned and unmanned space missions.

In the area of geophysics science and technology, a forefront SSD-led ultraviolet (UV) solar radiometer SUSIM (Solar Ultraviolet Spectral Irradiance Monitor) was flown on several Shuttle flights as well as on NASA's Upper Atmosphere Research Satellite (UARS); see Essay 80's.1 (and also 80's.7) for an overview of SUSIM, which has as goal understanding changes in the Earth's upper atmosphere so that informed policy decisions could be made regarding the human role in climate change. The decade also saw the initiation of Synthetic Scene Generation Model (SSGM) development and support activity for the Missile Defense Agency, as summarized in Essay 80's.4.

High energy space environment research was significantly furthered in the 1980's, with the launch of a major NASA high energy observatory, the Compton Gamma Ray Observatory (CGRO). The 17-ton CGRO -- one of NASA's Great Observatories along with the Hubble Space Telescope, the Chandra X-ray Observatory, and the Spitzer Space Telescope -- included SSD's OSSE (Oriented Scintillation Spectrometer Experiment). Essay 80's.2 describes highlights of OSSE's spectacular observational results of phenomena ranging from distant supernova remnants and matter-anti-matter annihilation to the non-thermal component of solar flares that occur much nearer home.

In NRL SSD 1980's solar and heliospheric physics research, Division researchers participated with both science and hardware in the Japanese solar spacecraft mission, *Yohkoh*, primarily through an international collaboration with UK scientists in an X-ray spectroscopy experiment, BCS (Bragg Crystal Spectrometer). Essay 80's.3 describes BCS-enabled studies of the high temperature component of solar flares, from which much was learned about multi-million degree upflowing plasmas produced by chromospheric evaporation and the temperatures of flares as a function of X-ray class. The vibrant *Yohkoh* collaboration served in addition as the basis for the SSD collaboration on the next Japanese solar mission, *Hinode* (see Chapter 2000's.4, about the Extreme-ultraviolet Imaging Spectrometer on *Hinode*). Another important 1980's solar research activity was SSD's contribution to the gamma ray experiment on NASA's SMM (Solar Maximum Mission), as described in Essay 80's.5. A productive solar theory activity to interpret the wealth of new solar data being obtained from SSD experiments was also grown during this decade. Essay 80's.6 discusses this activity's numerical simulations of the solar atmosphere in the quiet Sun, in solar flares, and in coronal mass ejections, and how this scientific research led to many advances in understanding and capabilities, including the Wang-Sheeley-Arge model. Finally, Essay 80's.7 describes a wealth of world-leading research performed through SSD's participation in the NASA Spacelab program, centrally Spacelab 2, with SUSIM and also HRTS (High Resolution Telescope Spectrograph, HRTS) that focused on the temperature region of the solar atmosphere between about 20,000K and 200,000K, which is termed the lower solar transition region.

80's.1: The Solar Ultraviolet Spectral Irradiance Monitor (SUSIM): 1977-2005

Contributed by Jeff S. Morrill, Linton Floyd *(retired from NRL)*, **and Lynn Hutting**

1.0 Introduction

As part of the study of solar irradiance variability and its impact on the terrestrial environment, NASA sponsored the two Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) instruments. The SUSIM program was conducted by the Solar Physics Branch in the Space Science Division (SSD) at NRL from 1977 through 2005. Both instruments measured the absolute irradiance of the solar ultraviolet (UV) light in the wavelength range 115 to 410 nm. The SUSIM/ATLAS (ATmospheric Laboratory for Applications and Science) instrument flew repeatedly on the Space Shuttle which allowed pre- and post-flight calibrations. The SUSIM/UARS instrument flew aboard the Upper Atmosphere Research Satellite (UARS) and utilized four onboard calibration lamps, multiple detectors, two spectrometers, and many filters and gratings in order to maintain calibration over the 14 year mission. Using the knowledge gained from the SUSIM/ATLAS instrument, improvements in system performance were realized for the SUSIM/UARS instrument. These improvements allowed SUSIM/UARS to make high quality solar UV irradiance observations from October 11, 1991 through August 1, 2005, through an entire solar cycle. The SUSIM/UARS instrument was still functional at the time UARS was decommissioned.

The follow-on NASA solar irradiance mission, Solar Radiation and Climate Experiment (SORCE), was launched in early 2003. Two of the instruments that are part of this mission measured solar UV irradiance during most of the final two years of the SUSIM/UARS mission. Recent comparisons of results from SUSIM with UV results from SORCE showed significant differences. Comparison of SUSIM observations at solar minimum and solar maximum with similar observations from other space based instruments and predictions of proxy-based models have shown comparable results. The discrepancies between the SORCE observations and those of SUSIM and other instruments or models indicate the potential need for the reevaluation of the SORCE instrumental calibration and a review is currently taking place under NASA direction. The analysis of these discrepancies is an example of the ongoing usage of the SUSIM/UARS observations and the current value of these observations to the scientific community.

2.0 Scientific Motivation Behind the SUSIM Program

There are three general areas of scientific interest which benefit from measurements of the solar UV irradiance spectrum:

(1) Solar Physics: What are the mechanisms responsible for the workings of and changes in the spectrum of the Sun, our nearest star?

(2) Earth's Upper Atmosphere: What changes result from the absorption of UV radiation in the stratosphere, mesosphere, and thermosphere?

(3) Earth's Climate: What changes in the Sun's output produce changes in tropospheric temperatures?

The observations made by the SUSIM program addressed these three important science questions and are discussed below.

2.1 *Solar Physics*

The relative variability of the Sun's radiation at UV wavelengths is far greater than the relative variability in the Sun's total solar irradiance (TSI) integrated over all wavelengths. The UV light measured by SUSIM originates in the upper photosphere, chromosphere, and corona of the Sun. Generally, longer wavelengths radiate from deeper in the solar atmosphere. Strong absorption lines (such as Mg II or Ca II) are exceptions to this rule, with these features originating at much higher altitudes than the surrounding spectrum. Various ground based indices of solar activity, such as sunspot number, fluxes at various radio frequencies (F10.7 cm), and the total area and location of solar active regions, have been shown to correlate with variations in the UV spectrum. Measurements of the solar UV spectrum have improved our understanding of the dynamic processes at the various altitudes in the solar atmosphere and their connection to other solar indices and events.

2.2 *Earth's Upper Atmosphere*

Solar UV radiation is primarily responsible for both creation and destruction of ozone in the Earth's stratosphere and mesosphere. Ozone is the molecular form of oxygen which shields the Earth's surface from solar UV-B (290-320 nm) radiation by absorption. This process causes the temperature in the stratosphere to be higher than in the upper troposphere. Stratospheric ozone densities are known to vary with the 11-year solar cycle, and solar variability over the solar cycle causes expansion and contraction of the outward extension of the Earth's atmosphere into space. Scientists have used SUSIM data along with constituent, dynamical, and other radiation measurements made by UARS instruments to better model the processes occurring in the Earth's upper atmosphere, particularly involving the creation and destruction of ozone.

2.3 *Earth's Climate*

The connection between the variability of solar UV radiation and changes in climate remain uncertain. Recent measurements of the Sun's total irradiance show that it varied by about 0.1% during the 11-year solar cycle and SUSIM observations have shown that about 60% of that variability occurs in the UV [Kirvova et al., 2006; Morrill et al., 2011]. Initially, computational models indicated that this level of variation is insufficient to significantly modulate the climate. However, more recent models have begun to include subtle feedback mechanisms (e.g. enhanced cloud formation) which could magnify the impact of small variations so that changes in the upper atmosphere induced by solar UV light could similarly affect climate. Since the SUSIM solar UV spectral irradiance observations have spanned more than an 11-year solar cycle, this data set will play an extremely important role in determining the impact of solar variability on climate change.

3.0 The SUSIM INSTRUMENT

3.1 *SUSIM ATLAS*

The first SUSIM instrument was designed and fabricated at NRL by a group of SSD Staff Scientists lead by Guenter Brueckner (PI) and included John Bartoe, Dianne Prinz, and Michael VanHoosier and other NRL Staff and contract personnel as part of a NASA sponsored program. SUSIM first flew on the Space Shuttle as part of the OSS-1 Mission, in 1982 [VanHoosier, et al., 1988]. That instrument was reflown on Spacelab-2 in August 1985, ATLAS-1 in March 1992, ATLAS-2 in April 1993, and ATLAS-3 Missions in November 1994. Calibrations, updates, and refurbishment were performed after each flight. These post flight activities resolved problems, overcame operational limitations in calibration or flight operations, and implemented improvements discovered during the previous Space Shuttle mission. The launch of a sister instrument on the

Upper Atmospheric Research Satellite in September 1991 made some of the improvements to the ATLAS instrument possible when spare flight hardware from the SUSIM/UARS instrument became available for SUSIM/ATLAS. Most of the changes were made specifically to decrease uncertainty in the absolute irradiance of the data. In the following paragraphs, the instrument that flew on ATLAS-3 is described.

NRL's SUSIM instrument has two identical double-dispersion scanning spectrometers, seven detectors, entrance and exit slits, filters, and gratings enclosed within a case. Doors sealed the case when not making measurements to prevent external contamination from entering the optical area. All materials were specially chosen to minimize any contamination to the optical elements. The SUSIM/ATLAS instrument is shown in Figure 80s.1.1. SUSIM covers the wavelength range 110-410 nm with 0.15 and 5.0 nm resolution.

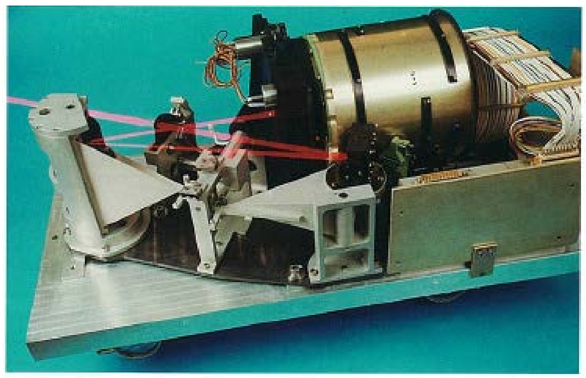


Figure 80s.1.1 – The NRL/SSD SUSIM/ATLAS instrument shown without its external case. The red laser beam shows the path on which the Sun's rays travel (credit: NRL).

The SUSIM experiment overcame the difficulty of making high accuracy measurements in the ultraviolet by using contamination control techniques to minimize changes. Remaining changes were tracked with an on board deuterium lamp (D_2). Only one of the two spectrometers was used for solar measurements. The sensitometric changes of both spectrometers were monitored with the D_2 lamp to make calibration and characterization measurements of all the optical elements. The solar spectrometer was compared to the calibration spectrometer to fully determine its solar UV induced sensitometric changes. During the course of the numerous spaceflight missions, several major improvements were made prior to the final flight of SUSIM ATLAS on the ATLAS-3 Space Shuttle Mission. The improvements in accuracy provided by these modifications provided significant increases in quality in the resulting solar irradiance measurements made during the ATLAS-3 Mission. The OSS-1 pallet that held SUSIM on the Space Shuttle is shown in Figure 80s.1.2. The work by Cebula et al. [1996] and Woods et al. [1996] present results from the ATLAS missions.

Figure 80s.1.2 – The OSS-1 pallet in the Space Shuttle payload bay collecting irradiance data (credit: NASA).

3.2 *SUSIM UARS*

The original design of the SUSIM instrument was modified to include the addition of a second spectrometer, filters, and calibration lamps. During the mission this allowed numerous calibrations to be performed so that the well-known sensitivity degradation of solar instruments could be accurately determined. For the SUSIM/UARS experiment, measurements of each of the four D_2 lamps took place on monthly, quarterly, semi-annual, and annual cadences. All four lamps began operations simultaneously with the on-orbit solar observations. The SUSIM/UARS instrument is shown in Figure 80s.1.3. The SUSIM/UARS team included Guenter Brueckner* (PI, 1991-1998), Dianne Prinz* (Optical Design; PI, 1998-2002), John Cook* (PI, 2002-2005), John Bartoe* (CoI), Michael VanHoosier* (Prog. Sci., 1991-1993), Judith Lean* (Proj. Sci., 1988-1993), James Parker* (Proj. Man.), Linton Floyd** (Ops. Man.; Proj. Sci., 1993-2005), Reinhardt Wing** (SUSIM I&T Rep.), Kenneth Edlow** (Sr. Soft. Eng.), Eric Norgren ** (Soft. Eng.), G. Cooke** (Soft. Eng.), Eric Harder** (Soft. Eng.), Benjamin Au* (Elect. Eng.), David Sohl* (Test Eng.), Donald Conroy* (Mech. Eng.), Edward Shepler* (Mech. Eng.), Donald Kruelski** (Elect. Sys. Eng.), Lynn Herring** (Hutting) (Ops. Asst.), Robert Priddy** (Mech. Tech.), Scott Shipley** (Elect. Tech.), Nancy Linder* (Programmer), Paul Reiser** (Inst. Cal.), Patrick Crane** (Inst. Cal.)[* NRL/SSD Staff; ** NRL/Contractor].

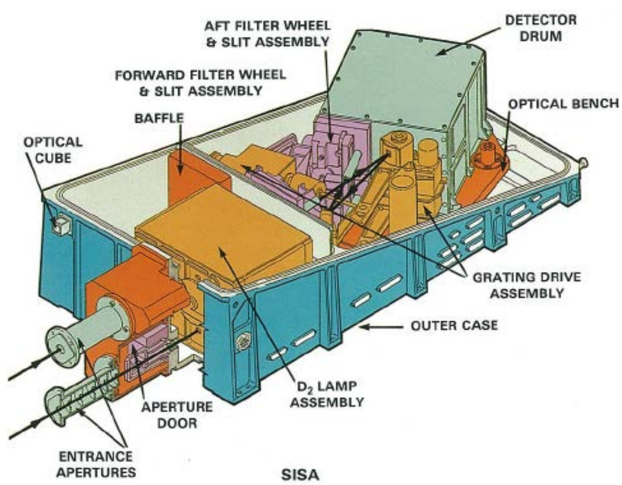


Figure 80s.1.3 – The NRL/SSD SUSIM/UARS instrument shown with the case lid off, comprises two double-dispersion spectrometers with a common scanning mechanism inside a hermetically sealed case that provides much of the contamination protection (credit: NRL).

The SUSIM/UARS instrument had the added advantage of a long duration flight with a robust calibration capability. Original plans for periodic cross-calibrations from SUSIM/ATLAS underflights were dropped when NASA canceled the ATLAS program after ATLAS-3. Because the onboard calibration of the UARS instrument was working so well, no attempts to calibrate the UARS instrument using the SUSIM/ATLAS observations were attempted. An artist's version of UARS is shown in Figure 80s.1.4 and results of the SUSIM UARS mission are presented in the work by Brueckner et al. [1993, 1996].

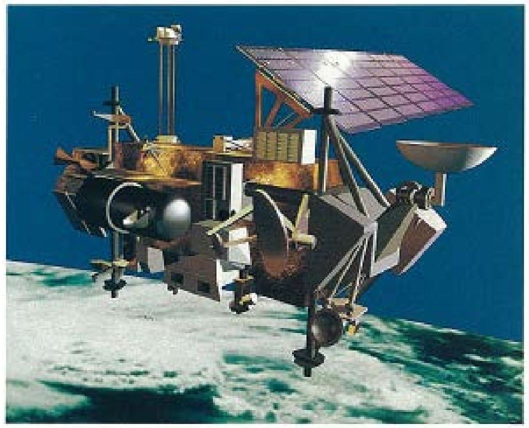


Figure 80s.1.4 - The SUSIM flight on the UARS mission was launched on STS 48 in September 1991 and operated at 600 km above the Earth in an orbit inclined 57 degrees to the Equator. This orbit permitted UARS to provide essentially global coverage of the stratosphere and mesosphere. Ten UARS experiments provided the most comprehensive data sets on energy inputs, wind, and chemical composition ever gathered at that time. Taken together, this data sets provided the first simultaneous, comprehensive global coverage of these closely coupled atmospheric properties (credit: NASA).

3.3 *UV Intensity Calibration*

Calibration was an extremely important and arduous task for the SUSIM team largely because detected UV light can degrade the responsivity of an instrument by an uncertain amount during the course of the measurement. The ground-based calibration of both SUSIM UV instruments, along with many others, was carried out using the Synchrotron Ultraviolet Radiation Facility (SURF) light source at the National Institutes of Standards and Technology (NIST). SUSIM/ATLAS was calibrated both before and after each flight with the three flights having occurred approximately yearly. Consequently, the SUSIM/ATLAS-3 results are an extremely high quality measure of the absolute solar UV intensity. SUSIM/UARS was also calibrated before flight and carried four deuterium lamps which were used to maintain instrument calibration during the 14-year mission. Calibration procedures and results are presented in Andrews and Van Hoosier [1996] and Woods et al. [1996].

4.0 Scientific Contributions Made by the SUSIM Program

4.1 *Solar Measurements*

For centuries, the number of sunspots has been observed to vary on an 11-year cycle. Measurements during the last two solar cycles have shown that sunspot numbers and the magnitude of solar UV light are roughly correlated. Because solar UV radiation is absorbed by the Earth's atmosphere, this radiation can only be accurately measured from orbit. To observe the Sun in the UV over an entire 11-year solar cycle requires a satellite-based instrument.

The two SUSIM instruments made measurements over the 115-410 nm wavelength range for short periods from the Space Shuttle and for more than a solar cycle from UARS. Through careful and accurate calibrations made before and after the Shuttle flights and before and during the UARS mission, the calibration of these instruments was maintained at an absolute accuracy of 6% and a relative accuracy of 2%. While the SUSIM/ATLAS observations were for the brief duration associated with a Space Shuttle mission, the pre- and post-flight calibration made these observations of extremely high quality. These two instruments have provided a wide range of data products which are still in use by the scientific community [Floyd et al. 2003, Crane et al., 2004;

Krivova et al., 2006; Lumpe et al. 2007; Morrill et al., 2011]. Papers and presentations made with SUSIM data continue at present (2013).

4.2 *Daily Solar Irradiance Spectra*

The final version of SUSIM solar UV irradiance data extends from 12 October 1991 through 1 August 2005. An example of the solar spectrum measured by SUSIM is shown in Figure 80s.1.5. Solar UV spectral irradiances are available on 4460 days which represents nearly 90% of the days during this period. Improvements to this final version were made in gain and temperature corrections, solar pointing corrections, lamp characterization, reference channel responsivities, and working channel responsivities, especially at wavelengths above 260 nm [Floyd et al., 2003]. The final 2-year portion of this data set is currently being compared to other recent data sets to ensure the continuation of an accurate solar spectral irradiance time series [Morrill et al., 2014].

4.3 *Composite, Model, and Solar Minimum Irradiance Spectra*

Measurements from the SUSIM/ATLAS instrument have been included in a set of widely used solar reference spectra. Two solar irradiance composite reference spectra, corresponding to different levels of solar activity for 29 March 1992 and 11 November 1994 during the ATLAS missions were presented by Thuillier et al. [2004]. These spectra span a wavelength range of 0.1 to 2400 nm and are based on the combined measurements of several instruments, including SUSIM/ATLAS, during the time period of the NASA-sponsored ATLAS-1 and ATLAS-3 missions, respectively.

A solar spectral irradiance model has been generated based on fits between the Mg II index (see below) and the SUSIM irradiance observed at 1.1 and 0.15 nm resolution [Morrill et al., 2011]. This model is currently being used to estimate the UV irradiance and TSI for the past century.

A solar minimum spectrum has been estimated based on SUSIM data at 1.1 nm and 0.15 nm resolutions. Part of this study shows an expected decrease in the UV spectrum below the observed average spectra for the last several solar minima [Morrill et al., 2010 & 2011].

4.4 *SUSIM UARS Mg II Index*

The Mg II Index has been shown to be a useful proxy for solar UV irradiance. This index is formed as the intensity ratio of the strong Mg II emission lines at 280 nm to the intensity of the nearby wings. These strong emission lines lie at the core of a deep absorption feature in the solar spectrum so this index is also referred to as the Mg II core-to-wing ratio. The wings of this ratio are formed in the solar photosphere while the emission lines are produced at higher altitudes in the chromosphere. The behavior of the irradiance of these lines over time has been found to be a convenient proxy for changes in chromospheric and upper photospheric UV flux over a wide range of UV wavelengths. Generally described, the Mg II index is the ratio of the irradiance at the core of the Mg II feature (containing the variable emission lines) to that of its relatively less variable wings. Because the Mg II index is an irradiance ratio of spectral features from nearby wavelengths, variations and degradation in instrumental response tends to cancel. As a result, the Mg II index is relatively insensitive to such instrumental effects. The UARS/SUSIM Mg II index was the first near-real-time (daily) MgII index. This index covers the full 14-year period of the UARS Mission and is included in the work by Viereck et al [2004]. A study examining the relationship between SUSIM UV irradiance and the MgII index and other indices was done by Floyd et al. [2005].

4.5 *SUSIM UARS Thermospheric Molecular Oxygen Density Profiles*

SUSIM/UARS also observed occultations of the Sun by the Earth's atmosphere. From measurements of the amount of UV light of selected wavelengths that penetrate the atmosphere as a function of tangent altitude, densities of molecular oxygen in the thermosphere and ozone in the mesosphere and stratosphere were recovered. A sophisticated algorithm has been developed to deconvolve both the changing altitude along a given line of sight and the range of lines of sight that are a consequence of the finite size of the Sun. Ozone occultation measurements were made between 255 and 321 nm from 1991 through 1999. Molecular oxygen measurements were performed between 144 and 171 nm from 1991 to 1999 and from 2003 to 2005. A description of the data and analysis for molecular oxygen appears in Lumpe et al. [2007].

4.6 *Comparisons of UV Irradiances: SUSIM vs. Other Measured and Modeled Values*

An example of a recent use of the SUSIM irradiance observations involves the comparison of this data set with observations from the NASA follow-on solar irradiance mission, SORCE. The SUSIM mission on UARS started in 1991 and ended in 2005 while the SORCE mission started in 2003 and has continued until 2012 with limited data collection during the last year. Calibration efforts by the SORCE team have proceeded without a detailed comparison with SUSIM observations. The initial SORCE results show a significant decrease in UV irradiance during the most recent declining solar cycle and this decrease was much greater than had been observed during other recent solar cycles.

The first reporting of these results [Harder et al., 2009] did not cause significant concern in the irradiance community given the unusually weak nature of the most recent solar cycle. However, more recent results from SORCE [Haigh et al., 2010] indicate that the decrease in UV irradiance reported by SORCE is greater than the decrease shown by the SUSIM observations by a factor of ~ 10 near 310 nm [Morrill et al., 2014]. Work by Deland and Cebula [2012] and Lean and Deland [2012] have also shown similar differences using data from the SBUV (Solar Backscatter UV) instrument and model results from the NRL Solar Spectral Irradiance (NRLSSI) model, respectively. All these efforts [Deland and Cebula, 2012; Lean and Deland, 2012; Morrill et al., 2014] show evidence for the potential need to reevaluate the degradation correction in the SORCE calibration. Given the concerns about the SORCE spectral irradiance data and the fact that this data set has been used for numerous atmospheric chemistry studies [e.g. Haigh et al., 2010 and references therein], the validity of the conclusions of these atmospheric chemistry studies could be in question. Further calibration efforts have been proposed which will combine the SUSIM and SBUV data to generate a high quality long term SSI dataset, comparable to the TSI data time series, for use by the atmospheric modeling community.

5.0 Conclusions

SUSIM was a NASA sponsored program at NRL that spanned nearly 3 decades and provided significant data to the scientific community. NRL/SSD contributed the design, fabrication, calibration, and testing of two significant space flight instruments and a long term data analysis activity. These instruments flew onboard the Space Shuttle and a major satellite mission dedicated to atmospheric research, UARS. These activities helped establish another aspect of NRL as a world leader in solar spectroscopy. Even after the end of the SUSIM program at NRL in 2005, data analysis efforts in the irradiance community and data application in the atmospheric research community continue to utilize the results of the SUSIM program.

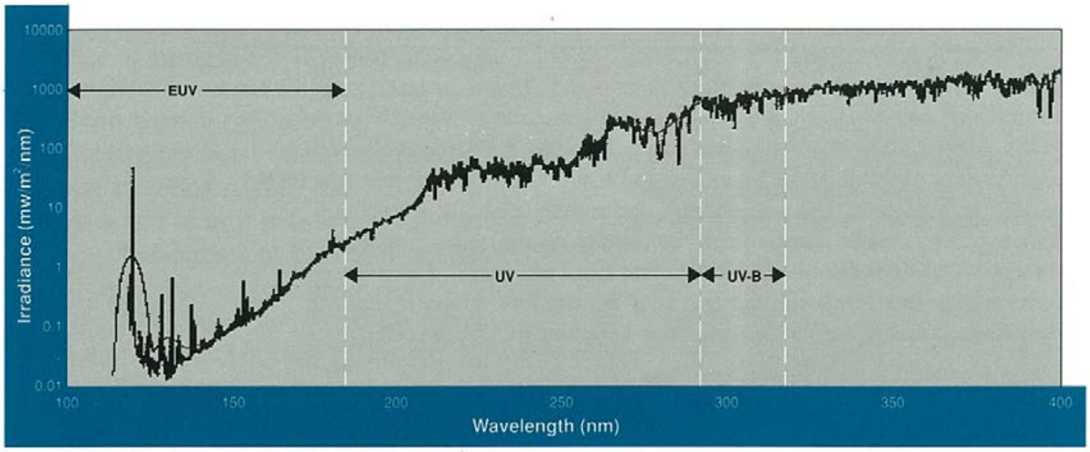


Figure 80s.1.5 – Example of the solar ultraviolet spectrum measured by SUSIM. The ultraviolet radiation (UV) at wavelengths below 180 nm is absorbed high in the atmosphere primarily by atomic and molecular oxygen. At longer wavelengths, between 180 and 290 nm, UV is absorbed by either O_2 or O_3; weak O_3 absorption between 290 and 320 nm permits biologically damaging UV-B to reach the surface. As O_3 is depleted, the UV-B at the surface increases rapidly, causing higher incidences of skin cancer and other harmful effects on the biosphere (credit: NRL).

References: 80's.1: The Solar Ultraviolet Spectral Irradiance Monitor (SUSIM): 1977-2005

M. Andrews and M. VanHoosier, Calibration of Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) on ATLAS-2, *Metrologia* **32**, 629, 1996.

G. Brueckner, L Floyd, P. Lund, D. Prinz, and M. VanHoosier, Solar Ultraviolet Spectral Irradiance Observations for the UARS/SUSIM Experiment, *Metrologia* **32**, 661-665, 1996.

R. Cebula, G. Thuillier, M. VanHoosier, E. Hilsenrath, M. Here, G. Brueckner, and P. Simon, Observation of the solar irradiance in the 200-360 nm interval during the ATLAS-1 Mission: A comparison among three sets of measurements - SSBUV SOLSPEC, and SUSIM, *Geophys. Res. Lett.*, **23**, 2289-2292, 1996.

P. Crane, L. Floyd, J. Cook, L. Herring, E. Avrett, and D. Prinz, Center to Limb Behavior of Solar Active Regions at Ultraviolet Wavelengths, *Astronomy and Astrophysics*, **419**, 735, 2004.

M. Deland and R Cebula, Solar UV variations during the decline of cycle 23, *J. Atmos. Sol. Terr. Phys.,* **77**, 225, 2012.

L. Floyd, J. Cook, L. Herring, and P. Crane, SUSIM'S 11-Year Observational Record of the Solar UV Irradiance, *Adv. Space Res*., **31**, 2111, 2003.

L. Floyd, J. Newmark, J. Cook, L. Herring, and D. McMullin, Solar EUV and UV Spectral Irradiances, and Solar Indices, *J. Atmos. Sol. Terr. Phys*., **67**, 3, 2005.

J. Haigh, A. Winning, R. Toumi, J. Harder, An influence of solar spectral variations on radiative forcing of climate, *Nature*, **467**, 696, 2010.

J. Harder, J. Fontenla, P. Pilewski, E. Richard, T. Woods, Trends in solar spectral irradiance variability in the visible and infrared, *Geophys. Res. Lett*., **36**, L07801, 2009.

N. Krivova, S. Solanki, and L. Floyd, Reconstruction of solar UV irradiance in cycle 23, *Astronomy and Astrophysics*, **452**, 631, 2006.

J. Lean and M. Deland, How does the Sun's spectrum vary, *Am. Metro. Soc.*, **25**, 2555, 2012.

J. Lumpe, L. Floyd, L. Herring, S. Gibson, B. Lewis, Measurements of thermospheric molecular oxygen from the Solar Ultraviolet Spectral Irradaince Monitor, *J. Geophys. Res.*, **112**, D16308, 2007.

J. Morrill, L. Floyd, D. McMullin, M. Snow, R. Viereck, Comparing estimates of the Mg II index at solar minimum from 1961 through 1981 with the observed Mg II index from 1978 to present, In: Cranmer, S., Hoeksema, J., Kohl, J. (eds.) SOHO-23: Understanding a Peculiar Solar Minimum, *ASP Conf. Ser.*, **428**, 315, 2010.

J. Morrill, L. Floyd, D. McMullin, The solar ultraviolet spectrum estimated using the Mg II index and Ca II K disk activity, *Sol. Phys.*, **269**, 253, 2011.

J. Morrill, L. Floyd, D. McMullin, Comparison of solar UV spectral irradiance from SUSIM and SORCE, *Sol. Phys.* **289**, 3641, 2014 (doi: 10.1007/s11207-014-0535-5).

G. Thuillier, L. Floyd, T. Woods, R. Cebula, E. Hilsenrath, M. Herse, D. Labs, Solar irradiance reference spectra for two solar active levels, *Adv. Sp. Res.*, **34**, 256, 2004.

M. VanHoosier, J.-D. Bartoe, G. Brueckner, D. Prinz, Absolute Solar Spectral Irradiance 120nm-400nm (Results from the Solar Ultraviolet Spectral Irradiance Monitor-SUSIM-Experiment on board Spacelab 2), *Astrophys. Lett. Comm.*, **27**, 163, 1988.

T. Woods, D. Prinz, G. Rottman, J. London, P. Crane, R. Cebula, E. Hilsenrath, G Brueckner, M. Andrews, O. White, M. VanHoosier, L. Floyd, L. Herring, B. Knapp, C. Pankratz, and P. A. Reiser, Validation of the UARS solar ultraviolet irradiance: Comparison with the ATLAS 1 and 2 measurements, *J. Geophys. Res.*, **101**, 9541, 1996.

R. Viereck, L. Floyd, P. Crane, T. Woods, B. Knapp, G. Rottman, M. Weber, L. Puga, M. DeLand, A Composite Mg II Index Spanning from 1978 to 2003, *Space Weather*, **2**, S10005, doi:10.1029/2004SW000084, 2004.

80's.2: Oriented Scintillation Spectrometer Experiment (OSSE) on the Compton Gamma Ray Observatory: 1977-2000

Contributed by W. Neil Johnson

1.0 Introduction

The *Compton Gamma Ray Observatory* (*CGRO*) mission began in 1977 as a NASA Announcement of Opportunity for a Principal Investigator (PI)-class mission to be launched in 1983. Space Science Division's Oriented Scintillation Spectrometer Experiment (OSSE) was selected from 25 proposals along with four other instruments for the mission. As a major new mission for NASA, Congressional approval was required and not actually received until 1982 when construction began in earnest. In this period a descope of the original instruments was required due to available mission resources as well as funding. OSSE successfully defended its science mission and implementation plan to become one of the four instruments to be flown: Energetic Gamma Ray Experiment Telescope (EGRET), the Imaging Compton Telescope (COMPTEL), the Oriented Scintillation Spectroscopy Experiment (OSSE), and the Burst and Transient Source Experiment (BATSE). These four instruments covered an unprecedented six decades of the electromagnetic spectrum, from 30 keV to 30 GeV. After launch, the Observatory was named in honor of Dr. Arthur Holly Compton, who won the Nobel Prize in physics for work on scattering of high-energy photons by electrons - a process which was central to the gamma-ray detection techniques of all four instruments.

The mission was working toward a 1988 launch on NASA's Space Shuttle when the Challenger accident occurred. The recovery of Space Shuttle operations delayed the launch of *CGRO* until April 5, 1991 aboard the Space Shuttle Atlantis (Figure 80s.2.1). One result of the delay was the inclusion of *CGRO* into NASA's Great Observatory series of missions with three other primary missions: the *Hubble Space Telescope* (1990 launch), the *Chandra X-ray Observatory* (1999 launch), and the *Spitzer Space Telescope* (2003 launch). This change from a PI-class mission to an Observatory-class mission extended the mission life well beyond the original one-year duration, and it ultimately operated successfully for over nine years. At 17 tons, *CGRO* was the heaviest astrophysical payload ever flown. It was safely de-orbited and re-entered the Earth's atmosphere on June 4, 2000.

Figure 80s.2.1 - Photo of the 17,000 kg Compton Gamma Ray Observatory as seen on release from the Space Shuttle Atlantis in April 1991. OSSE is the upper-most instrument in the photo, COMPTEL is the central cylindrical instrument and EGRET is the bottom-most instrument. The BATSE instrument is distributed on the four corners of the observatory (credit: NASA).

2.0 The OSSE Instrument

The OSSE instrument was developed and operated by a collaboration of scientists and engineers from NRL's Space Science Division, Northwestern University, and the Royal Aircraft Establishment in England. SSD's James D. Kurfess was the Principal Investigator. Ball Aerospace Systems Division was the principal contractor for the construction of the instrument. W. Neil Johnson was the Project Scientist. Other key members of the development team were NRL/SSD researchers Mark S. Strickman (Data Analysis), Robert L. Kinzer (Detectors), Jack Daily and Byron Leas (Flight Software), Rob Cameron (Integration and Test), and J. Eric Grove (Mission Operations).

The OSSE consisted of four NaI scintillation detectors, sensitive to energies from 50 keV to 10 MeV (Figure 80s.2.2). Each of these detectors was individually pointed, allowing observations of a gamma-ray source to be alternated with observations of nearby background regions. This technique for accurate subtraction of background contamination was key to achieving high sensitivity measurements in this gamma ray band. Figure 80s.2.3 shows the four detector systems mounted in their independent orientation controls during preparation for thermal vacuum testing at Ball Aerospace Systems Division.

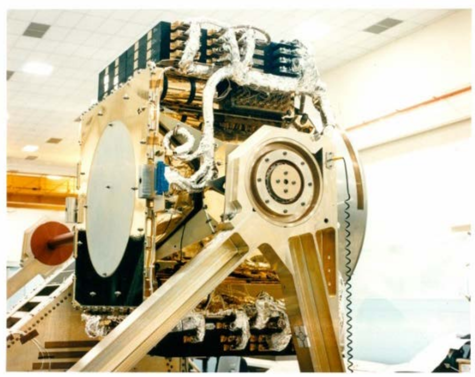


Figure 80s.2.2 - One of the 4 identical 350 kg OSSE detector systems mounted on its rotation axis. Each system consisted of a 13" diameter x 7" thick NaI / CsI phoswich scintillation detector surrounded by a 3" thick NaI anticoincidence shield and collimated to a 3.8 degree x 11.4 degree aperture field of view by a tungsten grid collimator (credit: NRL).

3.0 Science with OSSE

The OSSE produced significant results on a variety of astrophysical topics: including the energy spectrum of nuclear lines in solar flares, the radioactive decay of nuclei in supernova remnants, the signature of matter-antimatter (electron-positron) annihilation in the Galactic center region, and the characteristics of high energy radiation from black holes of all sizes – from galactic, few solar mass black holes to those massive (> 10^6 solar masses) black holes in the core of active galactic nuclei. Some of the key scientific results:

- **Positron Annihilation Radiation in the Center of our Galaxy**: The detection of 511 keV positron annihilation radiation from the Galactic Center was first detected in 1970 but it wasn't until the OSSE observations that its extent and characteristics were understood. While OSSE was not an imaging instrument, through a series of observations, it was possible to measure the extent of this diffuse radiation and to create a map of its intensity. OSSE showed that the emission was largely confined to the central Galactic bulge with a smaller component from the Galactic disk. The bulge distribution is thought to be from radioactive decays (^{56}Co and ^{44}Sc) from Type Ia supernovae. The disk component is consistent with the distribution and decay of

^{26}Al seen in the disk from massive-star nucleosynthesis. The spectral shape of the 511 keV annihilation radiation also provides information about the medium in which the annihilations are occurring. In low density, neutral media positronium will form and can decay into a three photon continuum instead of two 511 keV line photons. OSSE measured this ratio of positronium to annihilation line to be 0.93 which is consistent with annihilation in warm, neutral H or H_2 environment with density ~10^{14} cm^{-3}.

- **The Nature of gamma-ray Emission from Active Galactic Nuclei**: The *CGRO* mission showed for the first time that there are clearly two classes of gamma-□-ray-emitting Active Galactic Nuclei (AGN) in the sky: these are the jet-dominated blazars, with apparent non-thermal jet emissions often peaking in the *CGRO* EGRET band, and the more ordinary radio-quiet Seyferts, with emissions more closely related to the accretion disk presumably energizing the nuclear black hole. The higher energy EGRET instrument (gamma rays > 30MeV) identified 66 blazar type AGNs during the mission while detecting no Seyfert AGNs. On the other hand, OSSE detected over 20 Seyfert AGN. The analyses of these objects showed that the observed emission above 50 keV is well described by thermal Comptonization spectra with characteristic temperatures ~ 100 keV. The overall spectra from Type 1 Seyferts was seen to be softer than that from the Type 2 Seyferts.

- **Galactic Black Hole Binaries:** Observations above 50 keV with OSSE demonstrated that in the gamma-ray band there exist two spectral states that appear to be the extensions of the X-ray low (hard) and high (soft) states. The former state cuts off with e-folding energy of ~ 100 keV and has its peak luminosity near this energy; thus suggesting that substantial corrections needed to be made to the historical estimates of the bolometric luminosity of black holes in this "low" state. In contrast, OSSE showed that, in the X-ray high (soft) state, the luminosity peaks in the soft X-rays and the spectrum extends with an unbroken power law, even up to energies above 500 keV. The breaking gamma-ray spectrum can be modeled by Comptonization of soft photons from the accretion disk in a hot thermal plasma. The unbroken spectrum is harder to understand but could arise from bulk-motion Comptonization in an accretion flow that is approaching the Eddington limit.

- **Solar Flares:** Nuclear gamma-ray spectroscopy of solar flares as performed by OSSE provides information about the composition, angular distribution and energy spectrum of flare-accelerated ions, the physical conditions of the flaring magnetic loop, and the composition of the ambient medium. The large flares in June 1991 were studied in detail with OSSE. Gamma-ray line ratios showed that the ambient composition at the flare site was consistent with that of the corona when averaged over the flare but varied as the flare progressed. The composition of the accelerated ions was shown to be consistent with that seen in impulsive events in interplanetary space and to have an alpha/proton ratio greater than 0.1. The energy contained in the accelerated ions was shown to be comparable to that of the accelerated electrons. Comparisons of the neutron capture and de-excitation lines provided constraints on the photospheric ^{3}He/H ratio.

- **Supernovae and Novae:** One of OSSE's high priority objectives was to detect and study the radioactivity produced in nearby supernovae and novae. However, due to the infrequency of these events, few opportunities were available. SN 1987A, a Type II (core collapse) supernova, was observed 1600 days after its explosion. However, OSSE was able to measure the late time ^{57}Co line and inferred an initial ^{57}Ni mass that was in line with nucleosynthesis considerations, but a factor of 3 less than that suggested by ultraviolet, optical and infrared light output from the event. This discrepancy was resolved by delayed recombination from earlier decays and the OSSE estimate held. Observations of SN 1993J, also a core collapse SN, resulted in detection of hard x-ray emission which was interpreted as thermal emission at T ~ 10^9 K from the forward-shocked circumstellar matter.

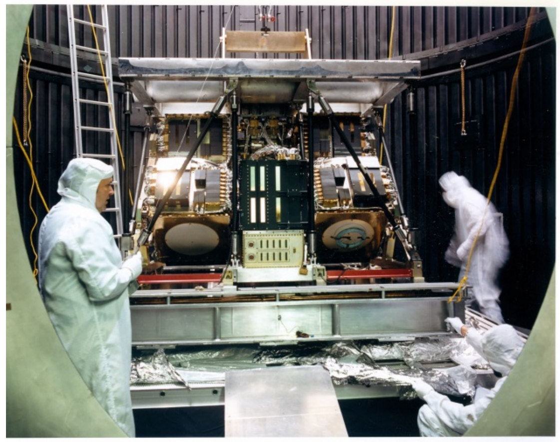


Figure 80s.2.3 – NRL's 1800 kg OSSE instrument in the thermal vacuum chamber at Ball Aerospace Systems Division. The exterior thermal shield was removed for the test. The front two detectors are looking downward, while the two rear detectors are directed upward (credit: NRL).

References: 80s.2: Oriented Scintillation Spectrometer Experiment (OSSE) on the *Compton Gamma Ray Observatory*: 1977-2000

Kurfess, J. D., D. L. Bertsch, et al., "Overview of the Compton Observatory Instruments", in: Dermer C. D., Kurfess J. D., & Strickman M. S. (eds.), Proceedings of the Fourth Compton Symposium, (New York: AIP), pp. 509-523, (1997).

Kurfess, J. D., W. N. Johnson, et al., "Oriented Scintillation Spectrometer Experiment Observations of Co-57 in SN-1987A." Astrophysical Journal 399(2): L137-L140, (1992).

Johnson, W. N., R. L. Kinzer, et al., "The Oriented Scintillation Spectrometer Experiment - Instrument Description." Astrophysical Journal Supplement Series 86(2): 693-712, (1993).

McNaron Brown, K., W. N. Johnson, et al., "OSSE Observations of Blazars." Astrophysical Journal 451(2): 575-584, (1995).

Johnson, W. N., K. McNaron Brown, et al., "Long-term monitoring of NGC 4151 by OSSE." Astrophysical Journal 482(1): 173-177, (1997).

Purcell, W. R., L.-X. Cheng, et al., "OSSE Mapping of Galactic 511 keV Positron Annihilation Line Emission", Astrophysical Journal, 491(2), 725, (1997).

Murphy, R. J., G. H. Share, et al., "Accelerated particle composition and energetics and ambient abundances from gamma-ray spectroscopy of the 1991 June 4 solar flare." Astrophysical Journal 490(2): 883-900, (1997).

Grove, J. E., W. N. Johnson, et al., "Gamma-ray spectral states of galactic black hole candidates." Astrophysical Journal 500(2): 899-908, (1998).

Zdziarski, A. A., J. Poutanen, W. N. Johnson, "Observations of Seyfert galaxies by OSSE and parameters of their X-ray/gamma-ray sources." Astrophysical Journal 542(2): 703-709, (2000).

Kinzer, R. L., P. A. Milne, et al., "Positron Annihilation Radiation from the Inner Galaxy." Astrophysical Journal 559(1): 282-295, (2001).

80's.3: The Bragg Crystal Spectrometer (BCS) Experiment on the Japanese Yohkoh (Solar-A) Spacecraft

Contributed by George A. Doschek

1.0 Background

The history of the BCS X-ray spectrometer experiment is one of the anomalies of space science. After the highly successful Japanese *Hinotori* solar physics mission, the Japanese decided (~1984) to expand their solar physics program to include foreign partners, as their X-ray astronomy program had done. Before the name Solar-A was given to the first of a series of "expanded" solar missions; it was referred to as the High Energy Solar Physics (HESP) mission. To design this major mission, they convened an international working group to discuss the science and spacecraft. Don Michels from NRL was a member of this working group. A three-axis stabilized spacecraft was chosen. After this decision, four instruments were selected for flight.

In early 1985 Professor Yasuo Tanaka of the Institute of Space and Astronautical Science (ISAS) sent Dr. David Bohlin, the NASA solar physics program officer, a telex outlining the proposed HESP program and asking for NASA participation in the program. Around the same time Dr. S. M. Krimigis, Chair of the National Academy of Science Committee on Solar and Space Physics (CSSP) sent to members of the CSSP a draft resolution endorsing the HESP mission and suggesting that about 5% of the Explorer budget might be directed towards "Science of Opportunity" possibilities such as HESP. The CSSP did endorse the mission and NASA decided to participate. NASA funded a grazing incidence Soft X-ray Telescope (SXT) with Loren Acton from Lockheed's Palo Alto Research Laboratory as Principal Investigator. A Hard X-ray imaging Telescope (HXT) and an assortment of high energy broadband detectors (Wide Band Spectrometer, WBS) were built by Japanese scientists. The BCS initiative was entirely independent of the formal Japan/US HESP activity. In 1984 NRL's Dr. George Doschek (at that time Head of the NRL/SSD Solar Terrestrial Relationships Branch (STRB)) wrote a letter to the Japanese proposing participation of his group in HESP. Doschek and his group proposed flying Bragg crystal spectrometers to record the spectral lines of highly ionized iron and perhaps other elements that are emitted during solar flares. Independently, United Kingdom (UK) scientists proposed similar instrumentation to the Japanese. Ultimately, after the discussions described below had occurred, the Japanese accepted the BCS for Solar-A with Professor Len Culhane from University College London Mullard Space Science Laboratory (UCL-MSSL) as the Principal Investigator outside of Japan. There were Japanese Principal Investigators for all instruments on Solar-A. The Japanese BCS Principal Investigator was Professor Eijiro Hiei from the National Astronomical Observatory of Japan (NAOJ). Dr. Tetsuya Watanabe from NAOJ was assigned the task of assuring that the Solar-A BCS science goals were met and interfacing the UK and NRL groups with all the Japanese Solar-A participants involved in integrating the BCS into the Solar-A spacecraft and setting up data operations and analysis in Japan. The detailed design of the BCS was conceived by NRL scientists (Dr. George Doschek, NRL Principal Investigator, with Drs. Uri Feldman, Charles Brown, and John Mariska), UK UCL-MSSL scientists such as Prof. Culhane, and NAOJ scientists, particularly Dr. Watanabe. All the Solar-A instruments are described in detail in a special issue of Solar Physics, Volume 136.

Before accepting the BCS on Solar-A with the international collaboration described above, there was an extensive back-and-forth discussion with the Japanese concerning the scientific rationale for flying another BCS experiment considering the fairly large number of times Bragg spectrometers had already been flown, and several visits by Japanese scientists to NRL to discuss the science and technical aspects of the experiment occurred. The scientists involved at this stage at NRL were Doschek, Feldman, and Brown. They wanted to fly flat scanning crystal spectrometers, but the

Japanese engineers were worried about the tiny angular momentum generated by the scanning and seriously resisted this idea. In September 1985 Doschek wrote a letter to HESP Japanese Program Manager Prof. Yoshiaki Ogawara describing the science that might be done with a Bragg spectrometer. A question about the sensitivity of the proposed BCS relative to previous instruments came up and in July 1986 Doschek provided a satisfactory answer to Ogawara. More questions about the BCS were answered by Doschek in a letter to Dr. Tetsuya Watanabe in September 1986, who became the Japanese BCS Project Scientist. A prominent non-NRL scientist, Dr. Richard Canfield of the University of Hawaii, wrote letters to the Japanese strongly supporting the Bragg for HESP. NRL's Dr. Herbert Gursky, then Superintendent of the SSD, wrote a letter in September 1986 to the prominent Japanese X-ray astronomer and friend Professor Minoru Oda of ISAS and stated that should the BCS be accepted for HESP "…I will do everything in my power to assure its success and the ultimate success of HESP as a science mission."

As an aside, communications with the Japanese should be mentioned. At that time there was no e-mail. Doschek talked with Japanese scientists by telephone, calling them from his home at around 10:00 PM to allow for the time difference between NRL and Japan (13-14 hours). Other forms of communication were telex and letters. E-mail became possible about the time the project actually started. Without e-mail, building BCS would have been considerably more difficult.

As these events were unfolding, it was necessary for NRL scientists to solve three problems: (1) Who would fund the BCS? NRL would not have sufficient funds to build the entire BCS, (2) The Japanese were hesitant about having the BCS led by NRL. How would this be handled? And, (3) What should be done about the angular momentum generated by scanning flat spectrometers? All these problems got resolved when Dr. Loren Acton, then at Lockheed, called Doschek and proposed a collaboration between NRL and UCL-MSSL, led by Professor Culhane. Instead of flying flat crystal spectrometers, Acton proposed switching to bent crystal spectrometers that have no moving parts (as was flown on the NASA *Solar Maximum Mission* (*SMM*)) (see Figure 80s.3.1), thus solving the angular momentum problem and finding another funding partner for NRL. Doschek enthusiastically agreed and got in contact with Culhane, who he knew well, and it was decided to propose the BCS as an NRL/UCL-MSSL consortium to the Japanese, with the consortium led by UCL-MSSL. Management of the project was decided at an American Astronomical Society Solar Physics Division meeting in Ames, Iowa, after Acton, Culhane, and Doschek took a brief automobile ride in a cornfield. Eventually the Rutherford Appleton Laboratory (RAL) in the UK, led by Dr. James Lang, was added to the consortium.

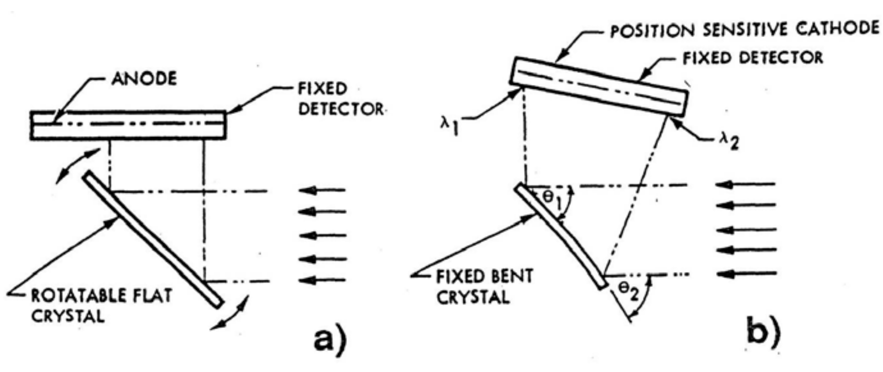


Figure 80s.3.1 – The diffracted X-ray wavelength depends on the angle, theta. To observe more than one wavelength with a flat crystal spectrometer, the crystal must be rotated to change theta as shown in (a). In a bent crystal spectrometer a range of wavelengths is simultaneously diffracted between the two angles shown in (b) above (credit: Figure 1 in Culhane et al. 1991, courtesy Solar Physics).

Discussions between Doschek and Culhane lead to a BCS proposal (dated May 1986) that was prepared at NRL and sent to the Japanese. This was before the Ames, Iowa meeting where it was agreed that UCL-MSSL would lead the project. The proposal was only 13 pages long with two additional figures. This was the only BCS proposal that NRL had to prepare throughout the mission. To alleviate Japanese concerns, the Principal Investigator of the proposal was first selected to be Dr. Richard Deslattes of the National Institute of Standards and Technology (NIST), an outstanding crystallographer who had grown the *P78-1* crystals, tested and calibrated the *SMM* crystals, and who would provide the BCS crystals.

With the above management issues solved, and all scientific and technical issues understood, the Japanese accepted the BCS for HESP. Doschek received a telex in December 1986 from Dr. Watanabe stating that the BCS was accepted for flight on HESP. Unfortunately, one of the outstanding Japanese solar physicists and expert in X-ray spectroscopy, Dr. Katsuo Tanaka (NAOJ), had been diagnosed with cancer and had only a few years to live, and he chose not to work on the BCS project. His early passing was a serious loss to the international solar physics community.

As mentioned, the Japanese appointed Professor Eijiro Hiei of NAOJ as the formal Japanese BCS PI. He was a first class solar physicist but with no space hardware experience. He left the BCS decisions involving Japan support entirely in the hands of Dr. Watanabe. In summary, there were three BCS PIs: the formal Japanese PI (Hiei), the overall instrument PI (Culhane), and the NRL PI (Doschek). A formal agreement was established between Japan and UCL-MSSL for the BCS, and UCL-MSSL and NRL established a Memorandum of Understanding containing the deliverables that NRL would provide for the BCS. This agreement was signed by Dr. Timothy Coffey, then NRL Director of Research.

At NRL the chief hardware scientist was Brown. Doschek and Feldman dealt with science issues. Later as the program got under way, Dr. John Mariska became an important contributor to data handling and processing, and in developing analysis tools. Technical support within SSD for BCS came from Mr. Donald Woods (mechanical) and James Ward (engineering drawings). The crystals and their mounts were contracted out to Dr. Deslattes at NIST.

2.0 The Solar-A Spacecraft

Solar-A was launched on 30 August 1991 from the Kagoshima Space Center into a nearly circular orbit of about 600 km altitude and 90 minute period by a Japanese M-3S-II rocket and was renamed *Yohkoh* (Sunbeam in Japanese). The spacecraft and instrumentation operated successfully for more than 10 years, covering one half of a complete 22-year solar cycle. The 3-axis stabilized spacecraft was approximately 100x100x200 cm and weighed about 400 kg. Operations ended on 14 December 2001 and the spacecraft entered the Earth's atmosphere on 12 September 2005. An overview of the mission is given by Ogawara et al. (1991).

3.0 The BCS Spectrometers

After considerable discussion and debate, four wavelength ranges were chosen that covered important X-ray transitions of Fe, Ca, and S. The four bent crystals were housed in two spectrometer boxes, mounted on opposite sides of a center panel in the *Yohkoh* spacecraft. The crystals were all Ge and covered the wavelength ranges: 1.7636 – 1.8044 Å (Fe XXVI resonance lines and associated satellite lines); 1.8298 – 1.8942 Å (Fe XXV lines and associated satellite lines); 3.1631 – 3.1912 Å (Ca XIX lines and associated satellite lines); and 5.0160 – 5.1143 Å (S XV lines and associated satellite lines). The crystals were grown, mounted on substrates, and calibrated at NIST by Richard Deslattes with Brown participating in the calibration and handling the interfaces at NRL. The Ge single crystals were huge, up to 4 x 18 cm in size, and of long radius of curvature, providing high spectral resolution and high sensitivity over the narrow spectral ranges selected.

The spectrometer structures were built by NRL with Brown designing and procuring them. Brown also procured and mounted two aluminized Kapton entrance filters to keep solar heat off the crystals. NRL also supplied two Fe 55 sources to perform in orbit detector calibrations, thermisters, shipping containers, instrument alignment devices, and an instrument mounting cube to facilitate ground testing. The two detectors and associated electronics were built by UCL-MSSL, who was also in charge of overall program management. RAL supplied the detector high voltage supplies and ground support equipment and were responsible for end-to-end X-ray calibration. A detailed description of the instrument is given by Culhane et al. (1991). A photo of one BCS spectrometer box is shown in Figure 80s.3.2. The NRL hardware and science contributions were funded entirely by NRL.

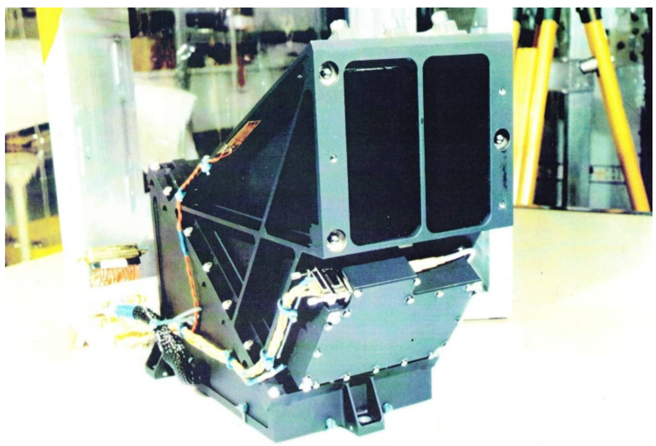


Figure 80s.3.2 – One of the BCS spectrometers. The large holes are the entrance apertures for two crystals attached to the top of the box. The detector and electronic box are in the bottom part of the box (credit: UCL-MSSL).

4.0 Science Results and Impact

The most important results from BCS involving NRL scientists are:

1 - The peak temperature of the soft X-ray flare does not exceed about 23 MK. This was suggested from *P78-1* data (Doschek & Feldman 1987), but it was not extensively investigated. Although there is a superhot component that reaches temperatures of about 40 MK, the emission measure in this component is far less than in the main thermal component. This is still unexplained by theory, and stellar flares can be much hotter. Using BCS *Yohkoh* spectra, the statistical distribution of flare temperatures could be investigated much more thoroughly than with the Solar Flare X-ray Spectrometer (SOLFLEX) on *P78-1*. Using BCS data, the average temperature of flares was determined as a function of Geostationary Operational Environmental Satellite (GOES) X-ray class (Feldman et al. 1995. See Figure 80s.3.3). The peak temperatures were determined from X-ray satellite line to resonance line ratios in spectra of Fe emission lines. *Yohkoh* BCS spectra of Fe XXV and its satellite lines are shown in Figure 80s.3.3 for a typical flare. BCS confirmed the peak temperatures of the thermal X-ray flare found from SOLFLEX and gave the distribution as a function of emission measure/intensity. During the solar minimum phase that *Yohkoh* observed, it was possible to investigate the temperature of very faint flares, i.e., A-class flares. In more active solar phases, these are normally swamped in the GOES data by stronger events. With BCS it was found that the average temperature of A2-A9 flares is about 5 MK, with emission measures varying between 2 x 10^{46} and 1 x 10^{48} cm^{-3} (Feldman, Doschek, & Behring 1996). Finally, the distribution of solar flare intensities was compared with available stellar data by Feldman, Laming, & Doschek (1995) (Figure 80s.3.3).

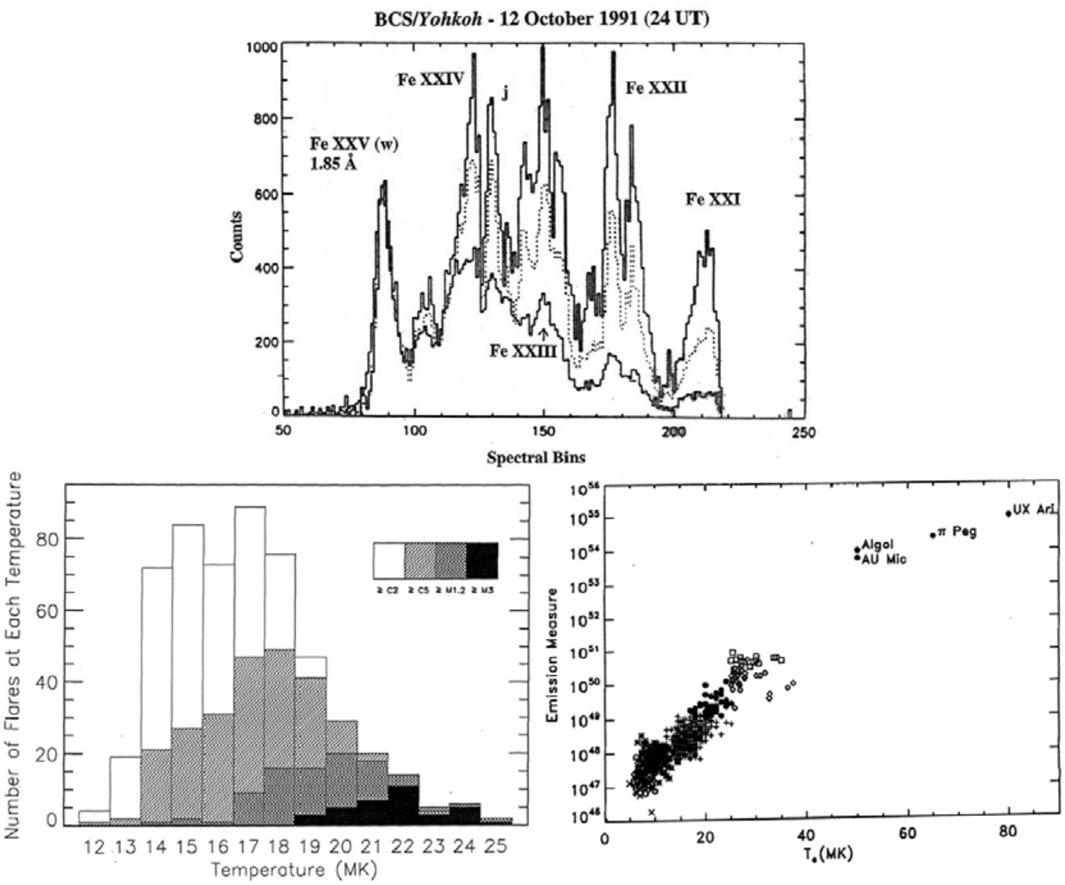


Figure 80s.3.3 – Top: Fe XXV spectra and associated satellite lines from a flare observed by Yohkoh. The three spectra are normalized to the brightness of the Fe XXV resonance line (w) and show the cooling of the flare, i.e., the satellite line intensities increase relative to the resonance line as the flare cools (credit: Figure 6 in Doschek 2006, Advances in Space Research). Bottom left: The peak temperature of flares as a function of X-ray class (Figure 3 in Feldman, Doschek, Mariska, and Brown 1995, reproduced by permission of the AAS). Bottom right: The emission measures of solar flares plotted as a function of temperature compared with flares observed on certain active stars (Figure 2 in Feldman, Laming, and Doschek 1995, reproduced by permission of the AAS).

2 - Large outflows from the chromosphere during the impulsive phase of flares with speeds of 400 – 800 km/s were correlated within a few seconds with hard X-ray bursts observed with the Hard X-ray Telescope on *Yohkoh* or a hard X-ray detector on the Compton Gamma Ray Observatory (CGRO; Bentley et al. 1994. See Figure 80s.3.4; and Essay 80s.2 for a discussion about CGRO). This is the chromospheric response to high energy non-thermal electrons which impact the chromosphere. These electrons are presumably accelerated near sites where magnetic reconnection is occurring.

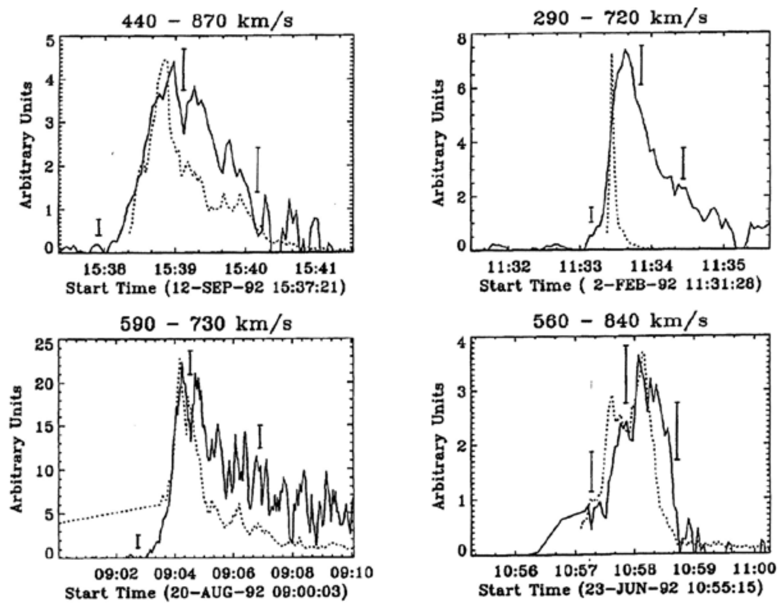


Figure 80s.3.4 – Ca XIX resonance line blueshifted emission intensity in the indicated-line-of-sight speed ranges and HXT hard X-ray intensity in the 23-33 keV channel. Solid curve: average blueshifted Ca XIX intensity. Dotted curve: hard X-ray intensity. The light curves are normalized relative to each other. The vertical bars are 1 σ standard deviations, assuming Poisson statistics (Figure 2 in Bentley et al. 1994, reproduced by permission of the AAS).

3 – With the high sensitivity and simultaneous wavelength coverage of BCS, it was possible to investigate Doppler shifts and non-thermal motions much earlier in a flare than was possible with SOLFLEX and other earlier flown spectrometers. It was possible to investigate correlations of the flare impulsive phase dynamics with quantities such as the peak intensity and flare rise times, etc. The results of this work did not totally support either the electron-beam driven flare model or the thermal flare model (Mariska, Doschek, & Bentley 1993; Mariska 1994). For most flares, the line profiles appeared first near their rest wavelengths rather than blueshifted as expected from evaporation theory (Doschek & Warren 2005). This was later better described by a "thread" model of flare flux tubes in which evaporation occurs sequentially in the threads rather than simultaneously in the entire flux tube (Warren & Doschek 2005). The observations are then consistent with at least the thermal evaporation model.

4 – BCS data were combined with data from SXT in an attempt to connect evaporation with the SXT X-ray flare images (e.g., Doschek, Strong, & Tsuneta 1995). This work was only partially successful because BCS had only one dimension of partial spatial resolution and the flares observed were structurally complicated. Some success was had in relating the BCS plasma diagnostics to the loop tops and loop footpoints by observing flares occulted by the solar limb and comparing them to non-occulted flares (Mariska, Sakao, & Bentley 1996). All of these efforts were at the limits of what BCS could be expected to deliver.

5 – Finally, more recently BCS data were used to detect wave motions in flares (Mariska 2006). Average oscillation periods of 5.5 minutes were derived along with decay times of 5 minutes and amplitudes of 17 km/s and inferred displacements of 1070 km. For some flares, intensity fluctuations strongly indicate that the waves are standing slow-mode waves.

References: 80's.3 The Bragg Crystal Spectrometer (BCS) Experiment on the Japanese *Yohkoh* (Solar-A) Spacecraft

Bentley, R. D., Doschek, G. A., Simnett, G. M., Rilee, M. L., Mariska, J. T., Culhane, J. L., Kosugi, T., & Watanabe, T. 1994, The correlation of solar flare hard X-ray bursts with Doppler blueshifted soft X-ray flare emission, Astrophys. J., 421, L55

Culhane, J. L. et al. 1991, Sol. Phys., 136, 89

Doschek, G. A. 2006, Advances in Space Research, 38, 1482

Doschek, G. A., & Feldman, U. 1987, Astrophys. J., 313, 883

Doschek, G. A., Strong, K. T., & Tsuneta, S. 1995, Astrophys. J., 440, 370

Doschek, G. A., & Warren, H. P. 2005, Astrophys. J., 629, 1150

Feldman, U., Doschek, G. A., & Behring, W. E. 1996, Astrophys. J., 461, 465

Feldman, U., Doschek, G. A., Mariska, J. T., & Brown, C. M. 1995, Relationships between Temperature and Emission Measure in Solar Flares Determined from Highly Ionized Iron Spectra and from Broadband X-Ray Detectors, Astrophys. J., 450, 441

Feldman, U., Laming, J. M., & Doschek, G. A. 1995, The Correlation of Solar Flare Temperature and Emission Measure Extrapolated to the Case of Stellar Flares, Astrophys. J., 451, L79

Mariska, J. T. 1994, Astrophys. J., 434, 756

Mariska, J. T. 2006, Astrophys. J., 639, 484

Mariska, J. T., Doschek, G. A., & Bentley, R. D. 1993, Astrophys. J., 419, 418

Mariska, J. T., Sakao, T., & Bentley, R. D. 1996, Astrophys. J., 459, 815

Ogawara, Y., Takano, T., Kato, T., Kosugi, T., Tsuneta, S., Watanabe, T., Kondo, I., & Uchida, Y. 1991, Sol. Phys., 136, 1

Warren, H. P., & Doschek, G. A. 2005, Astrophys. J., 618, L157

80's.4: Two Decades of Operational Support to Missile Defense: Backgrounds Data Center and the Synthetic Scene Generation Model

Contributed by Sarah E. McDonald and Jules M. Goldspiel *(formerly of NRL)*

1.0 Introduction

From the late 1980's through 2012, the Space Science Division (SSD) provided scientific, technical and managerial support to the Missile Defense Agency (MDA), which has its origins as the Strategic Defense Initiative Organization (SDIO) launched by President Reagan in 1983. Under President Clinton, the SDIO was reorganized and renamed the Ballistic Missile Defense Organization (BMDO). High-fidelity background and environmental phenomenology as they relate to clutter suppression, target detection, discrimination, and tracking are of interest to MDA systems engineers and for adding necessary detail to lower fidelity simulations. NRL recognized the need for high-fidelity modeling of the battlespace environment. In 1987, the NRL SSD was given the responsibility by SDIO to provide the Research & Development elements within SDIO with observable phenomenology information, including scene generation capabilities. Dr. Herbert Gursky, then Superintendent of the Space Science Division, established the Office of Strategic Phenomena to meet the SDIO requirements, and Dr. Harry Heckathorn stepped up to lead the effort.

2.0 Synthetic Scene Generation Model (SSGM)

Development of SSGM, then named the Strategic Scene Generation Model, began in 1987 and was led by Mr. Bruce Wilcoxen. The program was most recently led by Dr. Jules Goldspiel of NRL/SSD. The first version of the SSGM software was released in 1990. With graphical tools to construct and visualize targets and missile defense scenarios, SSGM allows users to simulate a battlespace environment in which ballistic and cruise missiles are detected, acquired, tracked and engaged against natural backgrounds. To provide these capabilities, SSGM integrated high-fidelity physics-based models and databases developed by Army, Air Force and Navy research facilities into a common software framework. By integrating standard DoD models, SSGM provided a traceable standard for generating complex electro-optical (including limited Lidar) and radio frequency signature information. This signature information was produced in the form of radiance images, spectra and radar cross-section data. For electro-optical signatures, SSGM covers the ultraviolet, visible and infrared wavelength ranges, although some components are restricted to only the Infrared bands.

SSGM is a physics-based code. To produce a time-based sequence of radiance scenes, SSGM does not simply interpolate between a set of existing satellite images or pre-calculated data models. In SSGM, the radiance and spectral signatures of every frame of each simulation are calculated based on the illumination sources (Sun, Earth, Moon), object temperatures (ambient, aero-heated, engine heated), material properties, orientations, and atmospheric effects (absorption, emission, scattering) that are relevant to the waveband specified by the user. SSGM does not have inherent restrictions on the duration of a scenario or the time interval between radiance scenes. This allows SSGM to be used by analysts interested in all phases of threat flights, from launch to intercept (or impact) where scenarios may be minutes or hours long, as well as analysts interested in the last few milliseconds before intercept.

For many years SSGM served as MDA's benchmark software for assessing the ability of various electro-optical sensors and advanced surveillance and interceptor concepts to perform their intended mission. The SSGM software suite continued to be actively developed through 2001 at which time MDA began an effort to produce a replacement software model that could build on the success of SSGM. While the replacement code was being designed and developed, SSGM was minimally supported and the program was frequently "cancelled". With focused modifications and improvements, NRL kept SSGM viable through 2011 despite the age of the code and the funding restrictions because later efforts to produce replacement codes have not yet succeeded in matching SSGM's capabilities (although the radar capability could not be maintained in SSGM through the later years of the program). The most recent release of SSGM in late 2010 represents an update to the thirteenth major release of the software package. As of early 2012, SSGM was still the only MDA software program able to provide full physics-based simulation coverage of the full battlespace environment in ultraviolet (UV) through IR wavebands. Accordingly, SSGM is still used by Government, Federally Funded Research and Development Centers (FFRDC) and Industry organizations to assist with the design, simulation, and testing of sensor and system performance. SSGM is also used to perform research and development analyses, to support system acquisition, and to provide a common phenomenology basis for various studies associated with missile defense.

3.0 Backgrounds Data Center and Virtual Data Center

The **Backgrounds Data Center** (BDC), led by Dr. William Snyder, was established in 1989 within the Office of Strategic Phenomena (Code 7604) as one of the three SDIO phenomenology data centers. The BDC became the designated archive for backgrounds data collected by the SDIO, and subsequently the BMDO, programs, and provided expertise on the integrated high-fidelity phenomenology for critical missile defense engagement regimes for Theater Air and Missile Defense (TAMD) and National Missile Defense (NMD). The BDC played a key role in supporting the Midcourse Space Experiment (MSX), which launched in April 1996 and was the first demonstration of space technology to identify and track ballistic missiles during the midcourse flight phase. The BDC served as the primary data distribution center for MSX data during the first year of its mission. Other BDC holdings included data from the Infrared Background Signature Survey (IBSS), Ultra-Violet Plume Instrument (UVPI), Ultra-Violet Limb Imaging Experiment (UVLIM), and the Far Ultra-Violet Camera (FUVCAM) sensors.

The purpose of the BDC was to store, catalog and distribute classified and unclassified data to the user community and to assist them with analysis. On-site facilities for data analysis were established and consisted of workstations running the VMS (Virtual Memory System) and Unix operation systems with access to software packages such as Interactive Data Language (IDL), Image Reduction and Analysis Facility (IRAF) and Khoros. The BDC team also developed innovative tools making use of leading edge technology to connect remote users to the unclassified datasets held at NRL. Initially, tools such as the Science Catalog Information Exchange System (SCIES) provided access to the BDC's catalog system via an Ethernet connection to a VT100 interface. By 1996, the catalog access fully transitioned to the World Wide Web via the BDC website. At the end of 1997, the MSX data holdings were transitioned to the other Data Centers. The BDC briefly lived on as the Backgrounds Center of Expertise, but was dismantled in 1998.

In 1996, Dr. Bryan Dorland, then at SSD, developed the concept for a **Virtual Data Center**, to connect the terabytes of data holdings of the BMDO Data Centers via a secure classified intranet. A prototype system was developed in 1996-1997, which demonstrated that users could browse select holdings of the three data centers, download datasets and run SSGM through a web browser. In the following years, Dr. Sarah McDonald of NRL/SSD led the software development for the operational VDC. This technology was transitioned in 1999 to the Joint National Test Facility, now the Missile Defense Integration and Operations Center, and is still in operations today.

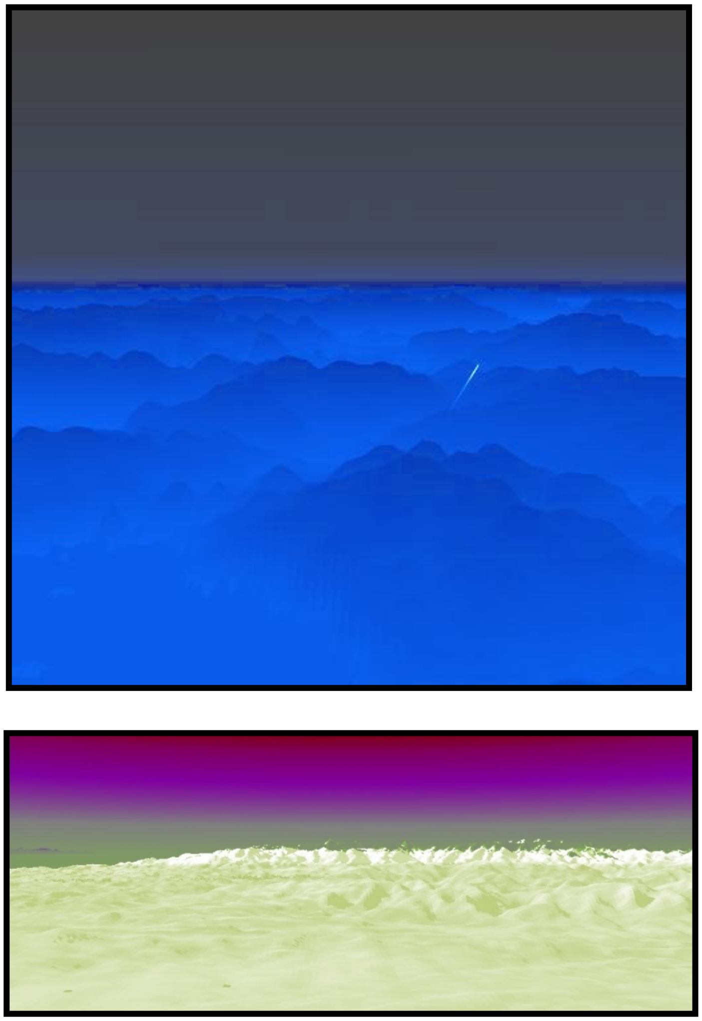


Figure 80s.4.1 – Synthetic Scene Generation Model (SSGM) generated scenes: (top) boosting missile above a cloud deck as seen by a long-wavelength infrared sensor, (bottom) terrain and clouds as seen by a mid-wavelength infrared sensor. (credit: NRL)

References: 80s.4: Two Decades of Operational Support to the Missile Defense Community: The Backgrounds Data Center and Synthetic Scene Generation Model

Heckathorn, H. and D.C. Anding. Overview of the Strategic Scene Generation Model (SSGM), in SSGM Papers Presented at the Meeting of the IRIS Specialty Group on Targets, Backgrounds and Discrimination, Naval Postgraduate School, 1990.

McDonald, S.E., B.N. Dorland, and H.M. Heckathorn (2000), The BMDO Virtual Data Center, *2000 NRL Review*, 2000.

Snyder, W.A., H. Gursky, H.M. Heckathorn, R.L. Lucke, B.N. Dorland, R.A. Kessel, S.L. Berg, and E.G. Dombrowski, The Backgrounds Data Center, *SPIE*, Vol. 2282 Ultraviolet Technology V, 1994.

Wieland, F., H. Heckathorn, A. Szabo, and J. Haynes, Object-Oriented Design of a Scene Generation Simulation, Proc. 27th Annual Simulation Symposium (IEEE), 1994.

80's.5: The NASA *Solar Maximum Mission*

Gerald H. Share *(retired from NRL)*

1.0 Introduction

Following its successful series of Orbiting Solar Observatories in which NRL played a significant role (see Essay 60s.2), in the early 1970's, NASA embarked on developing a comprehensive mission to study the Sun during the peak of its 21st activity cycle. The planners envisioned a satellite known as the Solar Maximum Mission (SMM) that contained a suite of instruments including a gamma-ray spectrometer. The foundations for this experiment came from both theoretical studies that showed how such a spectrometer could measure elemental abundances in the chromosphere and provide information on electrons and ions accelerated to energies up to hundreds of MeV, and from detection of nuclear lines in two flares that occurred in August 1969 with a simple spectrometer designed by the University of New Hampshire.

NRL was in an excellent position to provide the gamma-ray spectrometer for SMM based on its development of compact hard-ray detectors, called Phoswich's, that incorporated two different types of alkali halide crystals. Drs. James Kurfess and Neil Johnson led the balloon-borne effort using this technology in the Space Science Division and also took the lead in writing the proposal. The proposal was well received by the peer review panel, but ultimately NASA selected a competing instrument design submitted by the University of New Hampshire under Principal Investigator Professor Edward Chupp. Because of the high ranking of the NRL proposal, NASA set up a collaborative effort between the SSD Gamma-ray Astrophysics Branch and the University of New Hampshire. Although NRL did not have a direct role in the hardware development phase of the Gamma Ray Spectrometer (GRS) its scientists served in an advisory capacity and Dr. Robert Kinzer developed Monte Carlo simulations of the instrument's response to gamma radiation. Drs. Kinzer, Mark Strickman, and Gerald Share also began development of software to provide a microfilm archive of instrumental parameters and critical rates, spectroscopic analyses, long-duration background studies, and automatic searches for astrophysical transients and solar flares.

2.0 The Solar Maximum Mission

SMM was launched on a Thor Delta rocket on February 14, 1980. Eight instruments were housed in the Multi-Mission Spacecraft designed to be serviced by the Shuttle. Problems developed with three instruments within the first weeks after launch and shortly thereafter the spacecraft gyros began to fail. With failure of the third gyro, nine months after launch, only the three non-imaging instruments, including the GRS could continue normal observations. Plans began to service SMM, to repair the gyros and repair one of the instruments. In April 1984 the Shuttle Challenger successfully captured SMM (see Figure 80s.5.1) and made the necessary repairs. On April 24, just after SMM once again began operations, the Sun erupted with the largest flare of Cycle 21. The GRS made observations for close to ten years covering the fall of Cycle 21 and rising phase of Cycle 22. During that time period it cataloged close to 190 flares with emission above 300 keV and made many discoveries. Scientists from the University of New Hampshire, Max Planck Institute, and NRL whose work contributed directly to these discoveries include Drs. Edward Chupp, Dave Forrest, James Ryan, Thomas Vestrand from the University of New Hamshire, Eric Rieger from Max Planck Institute, and Ronald Murphy and Gerald Share from NRL/SSD. The instrument's spectral resolution and effective area has provided an excellent database that surprisingly is still being analyzed using new theoretical and analysis tools.

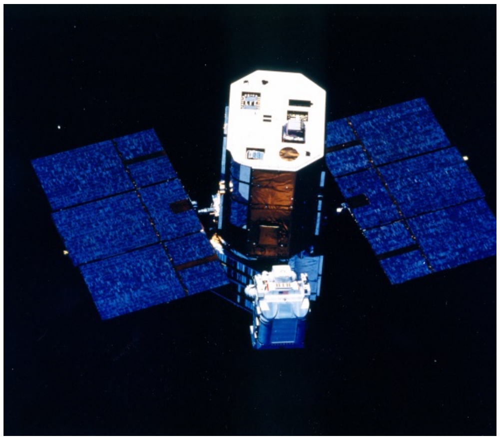


Figure 80s.5.1 - Photo taken from the Shuttle Challenger of an astronaut attempting to capture the SMM satellite during the repair mission in April 1984 (credit: NASA).

3.0 SMM Solar Physics Discoveries

Listed below are some of the key solar discoveries of the SMM spectrometer that Space Science Division scientists led or contributed to:

1. The first direct observation of solar-flare produced neutrons on 1980 June 21. Subsequent detections were made in at least two other flares.
2. Discovery of a 154-day periodicity in the occurrence of hard X-ray flares. This was based on observations in the late phase of solar cycle 21 and has been confirmed by other flare observations. It appears to be related to a fundamental period of 25.5 days.
3. Measurements of the time histories of hard X-ray and gamma-ray emissions in solar flares, especially the one on 1982 February 8, that have shown that tens of MeV ions and/or electrons can be accelerated within a second of hundreds of keV electrons.
4. Discovery of pion-decay gamma-ray emission from the interaction of hundreds of MeV flare-accelerated protons deep in the solar atmosphere through spectral measurement of >10 MeV gamma-rays and 511-keV postitron annihilation radiation.
5. Strong evidence that the angular distribution of flare-accelerated electrons is not isotropic from statistical studies of the flare locations and energy spectra.
6. Discovery that the fluxes of >300 keV electrons and >5 MeV protons accelerated in flares are well correlated.
7. Evidence that the delay in the interaction rate of ions is dependent on loop length.
8. Detailed spectroscopic studies of 19 gamma-ray line flares that revealed flare-to-flare variability in the ambient chromospheric composition and hardness of the accelerated ion spectrum, best fit by a power-law function (see Figure 80s.5.2). A study of these same flares revealed that the accelerated alpha-particle/proton ratio exceeded the nominal 10% that had previously been assumed.

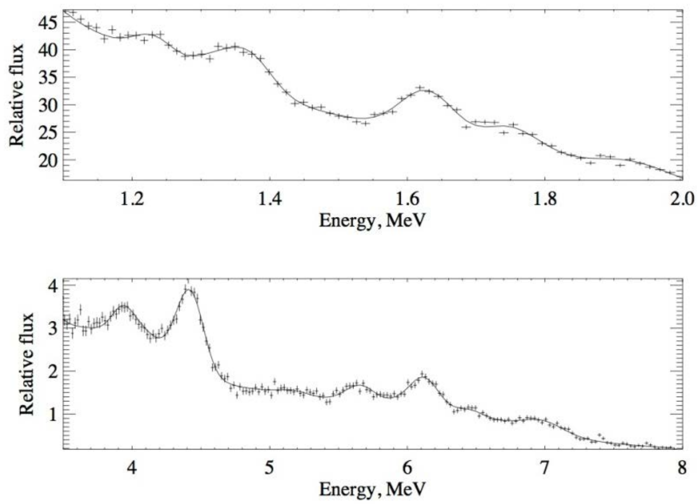


Figure 80s.5.2- Summed gamma-ray spectrum from 19 flares observed by SMM revealing nuclear lines from Fe, Mg, Ne, Si, C, and O (credit: NRL).

9. Using the 9-year SMM data base stringent limits were placed on the quiescent 2.2 MeV neutron capture line emission. This study showed that the flux of >1 MeV ions from small flares or continuous acceleration is 4 orders of magnitude too small to account for coronal heating.

4.0 SMM Astrophysical Discoveries

During the early phases of the SMM Mission the NRL scientists focused their activities in studying cosmic gamma-ray bursts and in the development of tools that enabled a detailed understanding of the gamma-ray background and its variability. These tools were developed in the expectation that the gamma-ray spectrometer with its large field of view of the sky might become a powerful instrument for studying various cosmic sources (NRL/SSD Post-doctoral Fellows Stephen Matz and Mark Leising and NRL Visiting Research Scientist Michael Harris played important roles in some of these studies). This expectation was brought to fruition as shown by the list of astrophysical discoveries below:

1. SMM spectra of gamma-ray bursts revealed for the first time that high-energy (greater than 1 MeV) emission is a common and energetically important feature. In fact the spectrum of the burst on 1984 August 5 extended up to 100 MeV, the highest energy recorded until the launch the Compton Gamma Ray Observatory in 1991. The spectrometer also placed constraining limits on the presence of emission lines in the spectra of bursts; such features were reported earlier and had been given as evidence for a Galactic origin of the bursts.

2. With its broad aperture, the SMM spectrometer revealed the presence of a constant source of 1.81-MeV line emission emanating from a region consistent with the center of the Milky Way Galaxy. The line originates from the decay of ^{26}Al that has a half-life of 720,000 years and is produced by nucleosynthesis in novae, supernovae, and massive stars. This high-significance multi-year observation confirmed the 5-sigma discovery of the line by a high-resolution germanium spectrometer on the NASA *High Energy Astronomy Observatory* (*HEAO-1*) in 1979-80.

3. The SMM spectrometer also detected a strong 511-keV line source of positron-electron annihilation during annual transits of the Galactic Center through its aperture. The line was first discovered by Dr. Neil Johnson of NRL/SSD using balloon observations made in the

1960's and 70's. It was originally believed to come from a variable localized source. However, the SMM observations showed that the emission was constant in time and consistent with an extended Galactic source. The line can originate from positrons produced from supernovae, novae, Wolf-Rayet stars, giant stars, and other sources.

4. About nine months after the Type II supernova (1987A) explosion in the Large Magellanic Cloud galaxy, the SMM spectrometer recorded gamma-ray lines from the decay of freshly synthesized ^{56}Co. This unambiguously proved that Fe and other heavy elements are produced by nucleosynthesis in supernovae. The early detection of the gamma rays also indicated that the explosion was highly asymmetric. The SMM gamma-ray spectrum remains the best ever to be observed from a supernova and revealed the presence of 7 lines from the decay of ^{56}Co (see Figure 80s.5.3).

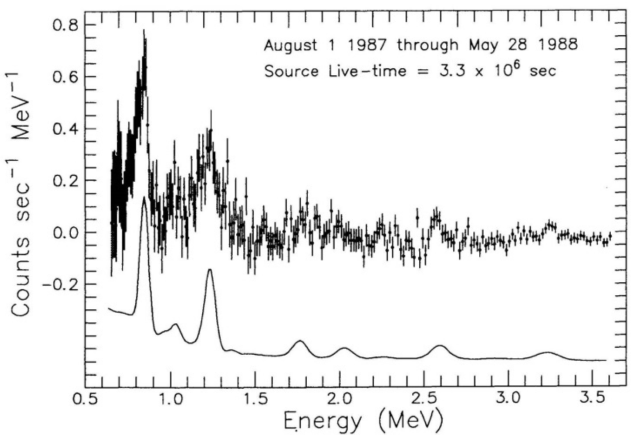


Figure 80s.5.3 - Gamma-ray spectrum of the 1987A supernova in the Large Magellanic Cloud measured by SMM revealing line from the decay of ^{56}Co (credit: Astrophysical Journal. See Leising et al reference).

5. The spectrometer also set stringent upper limits on fluxes in various lines expected from astrophysical sources including nucleosynthetic lines from Type Ia supernovae, novae, and neutron stars, from cosmic-ray interactions with the Galactic interstellar medium, and extragalactic sources.

6. The long exposure time of the spectrometer also enabled the search for a variety of nuclear line transients that had been reported in the literature, none of which were substantiated. It also made the first high significance measurement of the spectrum from the Galactic Center region from 0.3 to 9 MeV and obtained the best measurement to date of the positronium fraction, that providing information on the location where the Galactic annihilation line is produced (see Figure 80s.5.4).

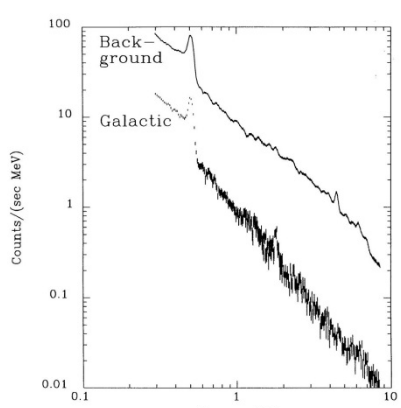


Figure 80s.5.4 - Gamma-ray spectrum of the Galactic Center region measured by SMM including the 511 and 1809 keV lines from radioactive decays (Astrophysical Journal, see Harris et al. reference).

5.0 Another SMM Discovery

Early in the SMM Mission Dr. Eric Rieger at the Max Planck Institute in Garching, Germany identified what appeared to be bursts of annihilation radiation at 511 keV in the SMM data. Automatic burst search routines at NRL cataloged the times of these bursts. With the assistance of Dr. Keith Marlow it was determined that these bursts began just after the launch of Cosmos 1176 on 1980 April 29 and stopped before that mission ended. Cosmos 1176 was the first of a new series of nuclear-powered satellites developed by the Soviet Union to monitor the U.S. Fleet using high-powered radar systems. Cosmos 954 was an earlier version of this system that re-entered the atmosphere in 1978 with its nuclear reactor.

The 511 keV transients were determined to be due to the passage of SMM through short-lived magnetically trapped belts of positrons from pair production of gamma-rays emitted from the reactor. As a result it was possible for the spectrometer to detect the presence of a reactor in orbit that was thousands of km away. There were two other classes of events that were detected by SMM. The second class-of-events was observed in the particle shield and came from electrons also in temporary radiation belts. These were observed at different times than the 511-keV events due to the different precession directions of electron and positron belts. The third class exhibited a continuum from 300 keV to about 7 MeV and had relatively symmetric rise and fall times, with typical durations of a few minutes. These events were due to detection of gamma rays from the reactors when the Cosmos satellites were within 400 km of SMM. This work was published in a special issue of Science Magazine and additional material is in NRL Reports. This is an excellent example of how instruments designed for civilian applications can be of use to the Navy.

6.0 SMM Recognition

In recognition of the contributions that the NRL and University of New Hampshire analyses of SMM data made to the field of high-energy astrophysics, the American Astronomical Society awarded the 1992 Rossi Prize to Dr. Gerald Share of NRL/SSD.

References: 80s.5: The NASA *Solar Maximum Mission*

Chupp, E. L., et al. "Solar Neutron Emissivity During the Large Flare on 1982 June 3" (1987). ApJ, vol. 318 p. 913-925.

Forrest, D. J., Chupp, E. L., et al. (1980). "The Gamma-ray Spectrometer for the Solar Maximum Mission." Solar Physics, vol. 65, p. 15-23.

Harris, M.J., Share, G. H., Leising, M. D., et al. (1990), "Measurement of the 0.3-8.5 MeV Galactic Gamma-ray spectrum from the Galactic Center Direction", ApJ, vol. 362, p. 135-146.

Leising, M. D. and Share, G. H. (1990). "The Gamma-Ray Light Curves of SN 1987A", ApJ, vol. 357, p. 638-648.

Share, G. H. and Murphy, R. J. (1995). "Gamma-Ray Measurements of Flare-to-Flare Variations in Ambient Solar Abundances", ApJ, vol. 452, p. 933-943.

Share, G. H., Kinzer, R. L., et al. (1985), "Detection Of Galactic Al-26 Gamma Radiation by the SMM Spectrometer", ApJ, vol 292, p. L61-L65.

Share, G. H., Kinzer, R. L., et al. (1988). "SMM Detection of Diffuse Galactic 511 KeV Annihilation Radiation", ApJ, vol 326, p. 717-732.

Share, G. H., Kurfess, J. D., et al. (1989). "Geomagnetic Origin for Transient Particle Events from Nuclear Reactor--Powered Satellites", Science, vol. 244, Issue 4903, p. 444-448

Share, G. H., Kouveliotou, C., and Schwartz, R. (1999). "Cosmic Studies" in "The Many Faces of the Sun", ed. Strong et al., Springer-Verlag, New York, p. 507-532.

Vestrand, W. T., Share, G. H., et al. (1999). "The Solar Maximum Mission Atlas Of Gamma-Ray Flares", ApJ Supp, vol 120, p. 409-467.

80's.6: Solar Physics Modeling

Contributed by Mark G. Linton and George A. Doschek

1.0 Introduction

The goal of the solar physics modeling effort at NRL has been to understand the physics of solar and heliospheric activity. A focused activity in this area was developed during the 1980s and 1990s under NASA's Solar Theory Program, with joint support from NRL, and continues as a vibrant albeit much broader effort today. NRL research in this area includes a focus on magnetic loop hydrodynamics and magnetic reconnection, and uses these studies to understand and model the initiation of coronal mass ejections (CMEs) and flares, the primary solar/heliospheric drivers of space weather. Researchers model phenomena that are of central importance to the Sun-Earth connection, and investigate processes that are fundamental to all space and astrophysical plasmas. The objectives include gaining a theoretical understanding with sufficient depth that we can interpret the spectacular observations obtained by many decades of heliophysics observations, among them: *Yohkoh*, the *Solar and Heliospheric Observatory* (*SOHO*), the *Transition Region and Coronal Explorer* (*TRACE*), the *Solar Terrestrial Relations Observatory* (*STEREO*), *Hinode* and the *Solar Dynamics Observatory* (*SDO*); to use this research to better understand the sources of space environmental effects with emphasis on areas that can significantly impact civilian and military space and communications assets; and, to prepare for and help define the next generation of NASA solar/heliospheric missions. Below, we briefly highlight a few of the many phenomena on which the NRL solar modeling effort has focused on during this time: plasma behavior in active region magnetic flux tubes, prominence dynamics, magnetic reconnection, and CME initiation.

2.0 Background

2.1 *Origin*

A core of the solar theory activity at NRL began in the NRL SSD Code 7670 Solar Terrestrial Relationships Branch around 1980 after a chance phone call between the 7670 Branch Head and Elaine Oran of the NRL Laboratory for Computational Physics & Fluid Dynamics (LCP&FD). The NRL Director of Research wanted to achieve some physical understanding of the immense amount of solar data from space experiments being collected in the Solar Physics (7660) and Solar Terrestrial Relationships (7670) Branches of the NRL Space Science Division. About at the same time, NASA began its Solar Theory Program, to which the SSD submitted a successful proposal. The proposal was joint between SSD and LCP&FD personnel and had as goal to develop a 1D plasma hydrodynamics (HD) model for plasma confined to magnetic flux tubes (loops) using the LCP Flux Corrected Transport algorithm as the basis for numerical modeling. The LCP&FD Chief Scientist, Jay Boris, was strongly supportive of this joint effort and, along with Elaine Oran, participated in the initial development. The formal Principal Investigator of the NASA proposal was the Code 7670 Branch Head, George Doschek, and the lead individual in the SSD who worked closely with LCP&FD in guiding them regarding solar physics and who participated in the numerical development was John Mariska, who was the key SSD individual in making the NRL theory program a huge success in its beginning phase. Other early SSD participants in the program who did significant work were George Doschek (SSD), Chung-Chieh Cheng (SSD), and a later hire, Judy Karpen (SSD). In NRL LCP&FD, Jay Boris, Elaine Oran, David Book, Russell Dahlburg, and Rick DeVore were the participants.

A 1D solar magnetic flux tube model was developed and the first "debut" announcement of NRL results was a series of oral presentations given at the 1981 January Solar Physics Division meeting at Taos, New Mexico. Plasma HD numerical simulations were relatively new in solar physics at the time but NRL's activity was not alone and several theoretical groups developed in the field. One benchmarking activity among different groups using 1D numerical simulations was carried out as a product of the NASA Solar Maximum Mission Workshop (Kopp et al. 1986).

The 1D 2-fluid model still exists as an NRL on-line theoretical product. It contains a moveable transition region grid, a high energy particle hard X-ray code addition (obtained by John Mariska working with Gordon Emslie and James Miller at Marshall Space Flight Center and the University of Alabama), the ability to simulate loop tapering at loop footpoints, and a conductive flux algorithm that is an improvement over simple Spitzer conductivity. Some non-ionization equilibrium capability is also present in the code. Heat can be put into the loop at any location. Many papers resulted from applications of the 1D model to a variety of solar problems, including multi-million degree heated plasma in flaring flux tubes and "coronal bullets," now known as jets (Karpen et al. 1982, 1984).

Spiro Antiochos arrived to the NRL SSD in the mid-1980s and became the SSD Head of a section within Code 7670, the Solar Theory Section. He greatly expanded the theoretical effort by coordinating with LCP&FD the SSD work in the development of highly sophisticated 2D, 2.5D, and fully 3D numerical codes that included the self-consistent magnetohydrodynamical (MHD) evolution of the plasma and magnetic field. James Klimchuk also arrived to NRL SSD and added substantially to the productivity of this effort, forming a bridge between data and theory in the group's activities. Spiro Antiochos and his NRL co-workers developed models of transition region loops, prominences, and coronal mass ejections. In particular he developed the coronal mass ejection breakout model (see discussion in Section 5). Spiro won the prestigious Hale Prize of the Solar Physics Division of the American Astronomical Society in 2005, as well as the NRL top science award, the E. O. Hulburt Annual Science Award, in 2006. The current NRL coordinator of this activity is Mark Linton, Head of SSD's Heliophysics Theory and Modeling Section in the currently combined Codes 7660 and 7670 Branches, the Solar & Heliospheric Physics Branch (7680) that is under the direction of Dr. Dennis Socker.

2.2 *An Unexpected Huge Bonus*

Quite by accident, Neil Sheeley, Jr., then a Section Head in Code 7670, happened to be at the Taos NM Solar Physics Division meeting at the same time that Jay Boris was there. They discussed a paper about flux transport and meridional flow, given by Lockheed researchers Ted Tarbell and Alan Title on the previous day. Jay Boris suggested that there was no need to speculate on how fast magnetic flux might spread out from its sources because it could be simulated and the results could be compared with observations. So on returning to NRL, Jay Boris wrote a Fortran code and Neil Sheeley extracted the sources of magnetic flux from Kitt Peak magnetograms. After preliminary work, Jay Boris turned his part of the project over to Rick DeVore, who was an NRL contractor (later employee of NRL LCP&FD) and Princeton graduate student looking for a thesis project. Over the next few years, Sheeley and DeVore succeeded in simulating the transport of flux on the Sun and determining the effective diffusion rate. The comparison with observations worked best if the diffusion were assisted by a small poleward meridional flow. Among the results were two NRL Alan Berman Publication Award papers, a Princeton PhD thesis and a University of Colorado Donald E. Billings Award in Astrophysics (DeVore).

At about the same time as the modeling work began; Yi-Ming Wang joined NRL SSD. Yi-Ming hit the ground running and supplemented the flux-transport code with a potential field program to extend the field into the corona. Then by comparing the coronal field derived from solar observations with in situ measurements of solar wind speed, Wang and Sheeley found an empirical relation between the coronal expansion factor and the asymptotic wind speed in the heliosphere. If the coronal field flared out substantially, the wind speed would be low, but if the field flared out much less as it went through the corona, the wind speed at Earth would be much higher. The model was used to deduce the windspeed at the Voyager spacecraft located in the outer end of the heliosphere and at the Ulysses spacecraft as it moved over the Sun's poles.

The model's success was appreciated by the NOAA/Space Environment Center, where an Air Force officer spent a year working with Neil to compare forecasts made with the Wang and Sheeley model with those that were routinely done by NOAA. Then, Sheeley and Wang provided the software to Nick Arge, a post-doc at NOAA employed by funding from the ONR contract research program that Neil had managed, and Nick made the model part of the NOAA and Air Force Weather Agency (AFWA) forecasting operations. It is now known as the Wang-Sheeley-Arge model. Eventually, Neil Sheeley also won both the E. O. Hulburt award and the Hale Prize.

3.0 Coronal Loop Evolution and Solar Prominence Formation

Much can be learned about the solar corona from one dimensional coronal magnetic loop modeling. As noted, a significant part of the early work in the solar modeling effort at NRL focused on this method of probing the solar atmosphere, and the work has proved rich enough that it continues to this day. The early work on the quiet Sun focused on the response of the solar atmosphere to temporal variations and spatial asymmetry in the heating rate of plasma in a closed flux tube, loop tapering, and non-ionization equilibrium effects (e.g., Mariska et al. 1982; Mariska & Boris 1983). The 1D model was applied to flaring loops and the impulsive response of the chromosphere was computed as well as X-ray spectroscopic evaporation signatures produced by the dynamics (e.g., Cheng et al. 1983; Doschek et al. 1983). The dynamical response of the atmosphere to high energy particle deposition in the chromosphere was also investigated (e.g., Mariska, Emslie, & Peng 1989).

SSD theorist James Klimchuk made significant advances in understanding the mystery of how coronal magnetic fields are heated to millions of degrees when the photosphere below them is only 6000 degrees. Using both spectroscopic methods (Klimchuk & Cargill 2001) and loop models (Klimchuk et al. 2008), Jim developed methods for studying coronal loop heating, and theorized that localized reconnection events or "nanoflares" can be used to explain heated loop observations.

These loop models were then used to study the cooler side of the coronal plasma, namely prominences. Solar prominences are spectacular phenomena consisting of $\sim 10^{16}$ g of dense hydrogen-alpha-emitting material which appears to float high up in the tenuous X-ray corona. The prominence mass must be supported against gravity by the coronal magnetic field, so it is inferred that field lines must have a "dipped" geometry in the corona where material can cool and condense and then remain in a stable configuration. NRL theorists Spiro Antiochos (SSD), Jim Klimchuk, Russell Dahlburg (LCP&FD), and Judy Karpen (SSD) developed a model that accounts for this cooling and condensation of plasma into dipped flux tubes. They proposed a simple and appealing mechanism for the origin of prominence plasma, based only on the assumption that the heating in a prominence flux tube is concentrated near the chromosphere, on scales of $\sim 10^9$ cm (Antiochos & Klimchuk 1991; Dahlburg et al. 1998; Antiochos et al. 1999). Interestingly, *TRACE* observations independently find the same heating profile for many X-ray loops. They demonstrated with detailed one dimensional adaptive mesh refinement simulations (solving the full energy equation) that this "thermal non-equilibrium" mechanism produces, in general, a dynamic cycle of condensation formation, flow, and freefall (Antiochos et al. 2000), explaining both the formation of the prominence mass and the recently observed counter-streaming flows. Furthermore, they found that the process works almost as well in loops that are flat or moderately arched, which implies that field line dips are not even necessary to explain prominences whose mass is in constant motion (Karpen et al. 2001, Karpen & Antiochos 2008).

At the time, however, it proved difficult to demonstrate a process that would produce field-line dips in the first place (e.g. Klimchuk 1990; Dahlburg et al. 1991). A severe constraint on any mechanism for forming dips is that, since prominences/filaments are very common on the Sun, their magnetic structure must be straightforward to obtain. The group then proposed (Antiochos et al. 1994) and verified with simulations (DeVore & Antiochos 2000) a natural process for the formation of dips (Antiochos et al. 2000). The model assumes a fully three dimensional (3D), bipolar region with a large footpoint shear on the field. In agreement with observations, the shear is concentrated near the photospheric neutral line. As shown in Figure 80s.6.1 the low-lying flux is strongly sheared whereas the overlying flux is sheared weakly or not at all. Consequently, the low-lying flux tries to expand outward while the overlying flux exerts a restraining force. In 3D the sheared field lines are restrained preferentially near their midpoints, where the overlying field is strongest and, hence, field-line dips form there (see Figure 80s.6.1). The resulting structure also exhibits the distinctive S-curve associated with filaments, which produces the observed polarity inversion in the field component transverse to the prominence axis (Antiochos et al. 1994). DeVore et al. (2005) later showed how interacting sheared arcades can build up long prominence structures along a neutral line.

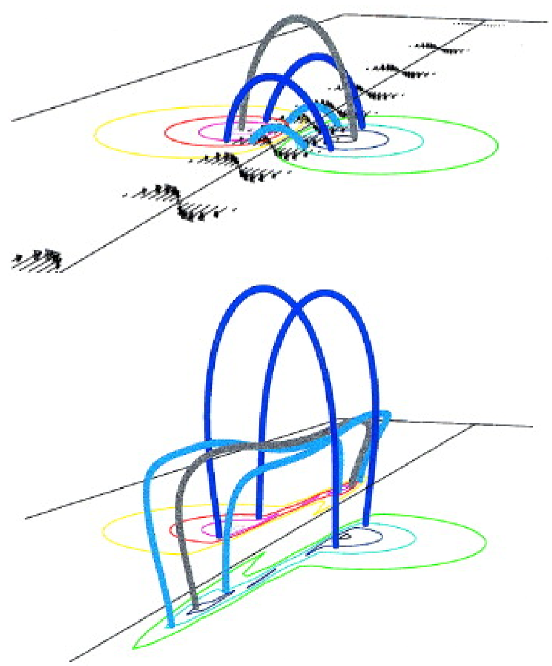


Figure 80s.6.1 - Perspective views of the initial conditions (top panel) and final results for modest footpoint displacements (bottom panel) of the prominence model are shown, from DeVore and Antiochos (2000). Color contours on the bottom surface denote lines of constant B_z, while the thick loops denote selected magnetic field lines. The black arrows in the left panels show the direction and relative magnitudes of the imposed footpoint displacements (credit: Astrophysical Journal 539, 954, 2000, reproduced by permission of the AAS).

4.0 Magnetic Reconnection

Three-dimensional magnetic reconnection is of fundamental importance to the understanding of solar activity and space weather. Its nature is such that increased complexity leads to increased activity and energy release, as evidenced, for example, by the high flare activity of delta-spots. Due to its complexity, however, 3D reconnection is a difficult and challenging problem to study in its full generality. Consequently, when the group first tackled this problem, they elected to focus on the reconnection of magnetic flux tubes, the basic building blocks of the magnetic field in the Sun-

Earth environment. From sunspots to coronal loops, from interplanetary magnetic clouds to flux transfer events in the magnetosphere, flux tubes appear throughout the Sun-Earth environment. Due to the complexity inherent in 3D flux tube reconnection, most early investigations were restricted to the study of the collision of flux tubes with their axes either parallel or anti-parallel. An early numerical experiment of this nature was carried out by NRL's Russell Dahlburg and Spiro Antiochos (Dahlburg & Antiochos 1995). They simulated the collision of straight tubes in parallel and anti-parallel collisions, finding that in some cases the tubes did not reconnect, in others they merged into one tube, and in still others they annihilated each other.

Subsequently, our efforts delved into the complexities of nonparallel flux tube reconnection. In a novel numerical experiment, Dahlburg, Antiochos, & Norton (1997) simulated an orthogonal flux-tube reconnection event which resulted in the two tubes tunneling through each other. Then in 2001, NRL's Mark Linton (SSD), with Dahlburg and Antiochos, carried out the first comprehensive study of straight flux tube collisions at all angles, and found a rich array of interactions: the colliding flux tubes exhibit four distinct classes of interaction, depending upon the interaction angle and the relative sign of twist: bounce, slingshot, tunnel, and merge (Linton, Dahlburg & Antiochos 2001). For the bounce, there is very little interaction or energy release. The merge and slingshot are more classical reconnection scenarios, similar to what had been seen in two dimensional reconnection (island merging, and X-point reconnection, respectively). The tunnel reconnection, which confirmed the earlier findings of Dahlburg and Antiochos, is fundamentally three dimensional in nature, as it is not even possible in 2D reconnection. An example of a pair of colliding tubes which first tunnels and then merges is shown in Figure 80s.6.2. As shown analytically by Linton & Antiochos (2002), it is a phenomenon which minimizes magnetic energy while conserving magnetic helicity, which describes how complex or knotted a magnetic field configuration is.

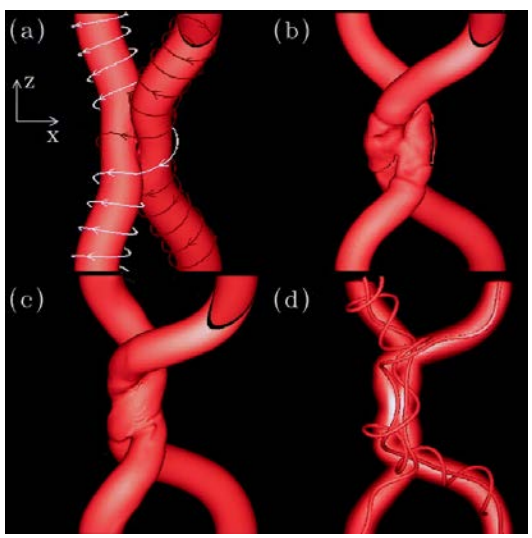


Figure 80s.6.2 - Results from simulations of the collision and reconnection of a pair of magnetic flux ropes, from Linton et al. 2001. The tubes first reconnection in a tunnel interaction (panels a and b), where the fields passing through each other to reform as flux ropes on the other side. The tubes then are pulled back in towards each other, and merge in the center into a single flux rope (panels c and d). In these panels, the red isosurfaces show the magnetic field a 1/3 of the maximum value, the fieldlines in panel a show a pair of representative fieldlines just after reconnection. Panel d shows a line of sight integration of magnetic field strength superimposed with several fieldlines (credit: Astrophysical Journal 553,905, 2001, reproduced by permission of the AAS).

Later, this work was extended to 3-D reconnection that occurs in the current sheets created by solar eruptions, which is generally accepted to be the source of coronal flares. Motivated by the research of SSD researchers Neil Sheeley, Harry Warren, and Yi-Ming Wang (Sheeley et al. 2004), which found novel downflowing features in coronal observations, Mark Linton and colleagues studied how reconnection in coronal current sheets could create similar down-flowing magnetic features. They studied how reconnected magnetic fields in a coronal current sheet are created by localized interaction regions in an initially uniform current sheet (Linton & Longcope 2006). They then studied how such newly created flux tubes will interact with the low coronal fields below them (Linton, Longcope & DeVore, 2009). This work revealed that the high downward velocities of the reconnected fields are rapidly decelerated as the fields hit arcade-like magnetic loops in the low corona, in agreement with the observations of Sheeley et al. (2004). The predicted deceleration at the arcade loops closely matches the observed behavior of down-flowing reconnected fields seen by *TRACE* and *Yohkoh*, indicating that this model provides fundamental physical insight into key aspects of observed flare dynamics. This work has proven to be critically important for interpreting observations of coronal reconnection and down-flows.

5.0 Coronal Mass Ejections

One of the most challenging, important problems in solar/heliospheric physics is understanding the processes responsible for giant magnetic disruptions such as CMEs and eruptive flares. The exponential growth of space-based technologies has made operations increasingly vulnerable to the variable radiation, plasma, and magnetic field emissions from the Sun. Geoeffective CMEs can create a broad variety of space weather disturbances at Earth and in near-Earth space, ranging from solar energetic particles at satellite orbits, to neutral and charged particle density enhancements in the upper atmosphere, and to geomagnetically induced electric currents on the ground. Consequently, CMEs are a core interest in solar activity forecasting. These major events also provide a unique opportunity to study, in revealing detail, MHD instability and non-equilibrium -- processes that are at the heart of space physics and plasma astrophysics.

In the late 1990s, Antiochos (1998) proposed an idea to solve this long-standing energy problem. He, Klimchuk and DeVore (Antiochos et al. 1999) showed that the key is to remove the unsheared overlying flux while keeping it closed at all times. This is impossible for a bipolar flux system like the field of Figure 80s.6.1, but in a multipolar flux system, magnetic reconnection can do precisely this trick. Figure 80s.6.3 shows the essential physics of their model. The magnetic topology consists of four distinct flux systems. Strongly sheared field lines are emerging at the equatorial neutral line and pushing outward. These field lines, which correspond to dipped prominence field, are being held down by the overlying, unsheared field lines. Reconnection at the X-point between these two flux systems then removes the overlying field, allowing the sheared field to “break out”. This process runs away, and the CME eruption occurs. The CME flux rope is formed, via reconnection, during the eruption. Here the sheared, erupting field starts to pinch off below the CME, creating a thin current sheet which becomes tearing mode unstable and reconnects, as in the magnetotail plasmoid creation mechanism. This creates, in two dimensions, a disconnected flux rope at the center of the erupting shear field. This continues through the rest of the simulation until most of the erupting field has reconnected and the CME consists primarily of a twisted flux rope. This evolution is shown in Figure 80s.6.3. This “breakout” model explains how large eruptive flares usually are associated with the appearance of active region (AR) magnetic fields in certain unusual configurations: the so-called delta-spot active regions, in which two or more sunspot umbrae of opposite polarity form within the same penumbra. Simple bipolar regions, on the other hand, are usually inactive. The key point is that the magnetic complexity of, at least, a delta-spot is needed in order to have in 3D a four flux system that is equivalent to the topology of Figure 80s.6.3 (Antiochos 1998).

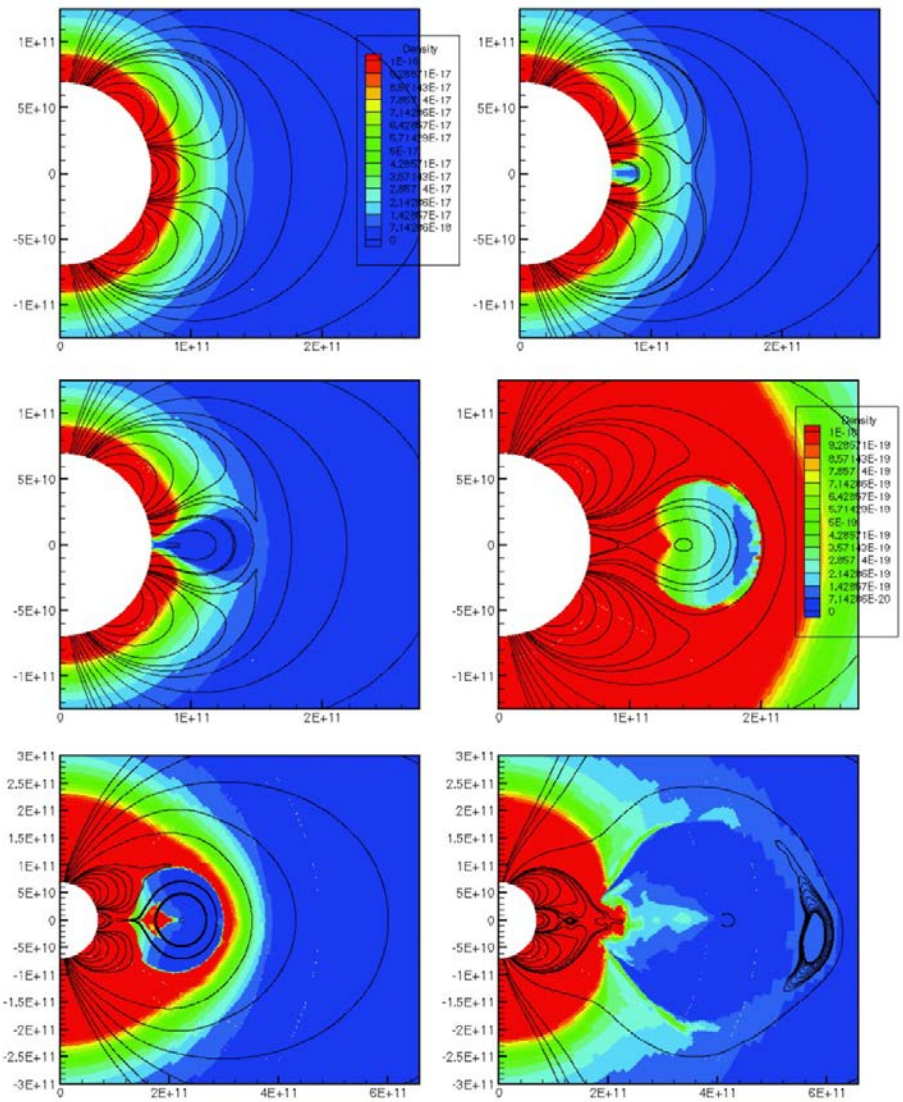


Figure 80s.6.3 - Snapshots of magnetic field (fieldlines) and mass density (color scale) evolution during a simulation of a breakout CME, from MacNeice et al., 2004. The central dipole of the initial quadrupolar configuration is sheared so that the central dipole rises up and reconnects through the overlying X-point. This removes overlying field, allowing the dipole to pinch off to form a disconnected CME flux rope, which then erupts (credit: Astrophysical Journal 614, 102, 2004, reproduced by permission of the AAS).

References: 80's.6 Solar Physics Modeling

Antiochos & Klimchuk "A Model for the Formation of Solar Prominences," ApJ 378, 372 (1991).

Antiochos, Dahlburg & Klimchuk " The Magnetic Field of Solar Prominences," ApJ 420, 41 (1994).

Antiochos "The Magnetic Topology of Solar Eruptions," ApJ 502, L181-L184 (1998).

Antiochos, DeVore & Klimchuk "A Model for Solar Coronal Mass Ejections," ApJ 510, 485 (1999).

Antiochos, MacNeice, Spicer & Klimchuk "The Dynamic Formation of Prominence Condensations," ApJ 512, 985 (1999).

Antiochos et al. “The Thermal Nonequilibrium of Prominences,” ApJ 536 494 (2000).
Cheng, C.-C., Oran, E. S., Doschek, G. A., Boris, J. P., & Mariska, J. T. “Numerical Simulations of Loops Heated to Solar Flare Temperatures. I. Gasdynamics,” ApJ 265, 1090 (1983).
Dahlburg, Anticohos & Zhang “Dynamics of Solar Coronal Magnetic Fields,” ApJ 383, 420 (1991).
Dahlburg & Antiochos “Reconnection of Antiparallel Magnetic Flux Tubes,” JGR 100, 16991 (1995).
Dahlburg, Antiochos, & Norton “Magnetic Flux Tube Tunneling,” Phys Rev E 56, 2094 (1997).
Dahlburg, Antiochos & Klimchuk “Prominence Formation by Localized Heating,” ApJ 495, 485 (1998).
DeVore & Antiochos “Dynamical Formation and Stability of Helical Prominence Magnetic Fields,” ApJ 539, 954 (2000).
DeVore & Antiochos “Homologous Confined Filament Eruptions via Magnetic Breakout,” ApJ 680, 740 (2008).
DeVore, Antiochos & Aulanier “Solar Prominence Interactions,” ApJ 629, 122 (2005).
Doschek, G. A., Cheng, C.-C., Oran, E. S., Boris, J. P., & Mariska, J. T. “Numerical Simulations of Loops Heated to Solar Flare Temperatures. II. X-ray and UV Spectroscopy,” ApJ, 265, 1103.
Karpen, Antiochos, Hohensee, Klimchuk & MacNeice “Are Magnetic Dips Necessary for Prominence Formation?” ApJ 553, 85 (2001).
Karpen & Antiochos “Condensation Formation by Impulsive Heating in Prominences,” ApJ 676, 658 (2008).
Karpen, Oran, Mariska, Boris & Brueckner “The Dynamics of Accelerating Coronal Bullets,” ApJ 261, 375 (1982).
Karpen, Oran & Boris “Detailed Studies of the Dynamics and Energetics of Coronal Bullets,” ApJ 287, 396 (1984).
Klimchuk “Shear Induced Inflation of Coronal Magnetic Fields,” ApJ 354, 745 (1990).
Klimchuk & Cargill “Spectroscopic Diagnostics of Nanoflare-heated Loops,” ApJ 553, 440 (2001).
Klimchuk, Patsourakos & Cargill “Highly Efficient Modeling of Dynamic Coronal Loops,” ApJ 682, 1351 (2008).
Kopp, R. A., Fisher, G. H., MacNeice, P., McWhirter, R. W. P., & Peres, G. 1986, “Energetic Phenonmena ofn the Sun“, Proceedings of the Solar Maximum Mission Flare Workshop, NASA Conference Publication 2439, chapter 7.
Linton, Dahlburg & Antiochos “Reconnection of Twisted Flux Tubes as a Function of Contact Angle,” ApJ 553, 703 (2001).
Linton & Antiochos “Theoretical Energy Analysis of Reconnecting Twisted Magnetic Flux Tubes,” ApJ 581, 703 (2002).
Linton & Longcope “A Model for Patchy Reconnection in Three Dimensions,” ApJ 642, 1177 (2006).
Linton, Longcope & DeVore “Patchy Reconnection in a Y-type Current Sheet,” Earth Planets and Space, 61, 573 (2009).
Lynch, Antiochos, DeVore et al. “Topological Evolution of Fast Magnetic Breakout CME in Three Dimensions,” ApJ 683, 1192 (2008).
MacNeice, Antiochos, Phillips, Spicer, DeVore & Olson “A Numerical Study of the Breakout Model for Coronal Mass Ejection Initiation,” ApJ 614, 1028 (2004).
Mariska, J. T., & Boris, J. P. “Dynamics and Spectroscopy of Asymmetrically Heated Coronal Loops,” ApJ, 267 409 (1983).
Mariska, J. T., Doschek, G. A., Boris, J. P., Oran, E. S., & Young, Jr., T. R. “Solar Transition Region Response to Variations in the Heating Rate,” ApJ 255 783 (1982).
Mariska, J. T., Emslie, A. G., & Li, Peng “Numerical Simulations of Impulsively Heated Solar Flares,” ApJ 341, 1067 (1989).
Sheeley, Warren & Wang “The Origin of Postflare Loops,” ApJ 626, 1224 (2004).

80’s.7: NRL Instruments on Spacelab-2

Contributed by Dennis G. Socker and George Doschek

1.0 Spacelab-2 and the NRL Space Science Division Spacelab-2 Contributions

The Spacelab-2 mission was flown aboard Space Shuttle Challenger from July 29 to August 6, 1985. It was the third in a series of twenty-two flights for a configurable, modular, reusable, and Space Shuttle compatible laboratory that enabled astronauts to conduct space experiments in Earth orbit during the post-Apollo and pre-International Space Station era from 1983 to 1998. Spacelab was developed under an international Memorandum of Understanding signed in 1973 by the National Aeronautics and Space Administration (NASA) and the European Space Research Organization (ESRO). The primary Spacelab-2 mission objective was verification of several Spacelab systems to be flown for the first time. The secondary mission objective was demonstration of Spacelab’s capability to support an ambitious and complex science payload consisting of fourteen multidisciplinary solar, astrophysics, and space physics experiments on a single mission.
Onboard Shuttle Challenger for the mission was Dr. John-David Bartoe, the NRL Solar Physics Branch Solar Spectroscopy section head. Serving as one of two payload specialists, Dr. Bartoe was a member of the third set of otherwise career science personnel that would temporarily apply their particular discipline expertise to the objectives of a given Spacelab mission. Dr. Dianne K. Prinz, also a member of the Solar Physics Branch, was one of two alternate Payload Specialists for the mission who performed as mission communicator for the onboard Payload Specialists.

The Spacelab-2 solar payload was comprised of four experiments of which two, the High Resolution Telescope and Spectrograph (HRTS) and the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM), were conceived, developed, and operated under the leadership of Principal Investigator Dr. Guenter E. Brueckner, the Solar Physics Branch Head. The HRTS (Bartoe & Brueckner 1975) consisted of a 30 cm aperture Gregorian telescope and double dispersion tandem Wadsworth spectrograph focal plane instrument invented by Dr. Brueckner. The spectrograph operated at ultraviolet wavelengths and was designed to investigate the dynamics of the lower solar transition region. The lower transition region is the part of the solar atmosphere between the chromosphere and the corona with plasma temperatures in the 20,000 - 200,000 K range and which radiates strong ultraviolet emission lines. The SSD Solar Physics Branch flew HRTS many times on rockets (see the essay 90’s.4 by Korendyke in the 1990s chapter). The HRTS was capable of higher ultraviolet spectral science information throughput efficiency observations of the solar transition region than any other solar telescope-spectrograph system of the period. The SUSIM (VanHoosier et al. 1981; and, also see this Volume's Essay 80’s.1), was a dual dispersion scanning spectrophotometer capable of performing the highest precision absolute measurement of the variable solar ultraviolet irradiance at earth in the 115 - 410Å region of the spectrum that causes significant variations in the Earth’s ionosphere and thermosphere.

The velocity field data for the solar transition region and lower corona collected by HRTS on Spacelab-2 contributed significantly not only to our knowledge of the transition region but also to our scientific understanding of the origins of the solar wind. The Spacelab-2 SUSIM science result is significant in the context of a larger multi-mission SUSIM measurement set obtained on five shuttle missions starting in 1982, including Spacelab-2; and a second SUSIM flown on the *Upper Atmosphere Research Satellite* (*UARS*) from 1991 to 2005 that together covered a full twenty-two year solar variability cycle (see the essay by Morrill et al. in this chapter, 80s.1). The SUSIM measurement set improved absolute and relative, eleven year solar ultraviolet (115-440 nm) spectro-radiometric measurement precision by an order or magnitude from the ~30% level available immediately before the period to the 0.3-3% level.

The Spacelab concept grew out of the contemporaneous Space Shuttle and Space Station program development in the 1960s when a modular approach (see references: Experiment Module Concepts Study) to satisfying science and technology experiment requirements for the Station identified in the Candidate Experiment Program for Manned Space Stations (see references: Candidate Experiment Program for Manned Space Stations) was adapted to accommodate the case where only the Shuttle became operational. By 1973, several cycles of the Shuttle Orbital Applications Requirements (SOAR) studies resulted in the Shuttle Sortie Missions concept, one of which was a sortie habitable laboratory and exposed pallets in a cargo bay configuration. Of these, the so called Nondeployed Solar Payload (see references: Shuttle Orbital Applications and Requirements), was eventually realized as part of the Spacelab-2 mission flown aboard the Space Shuttle Challenger.

The European Space Agency (ESA), formed by the merger of the European Space Research Organization (ESRO) and the European Launch development Organization in 1975, developed Spacelab, a configurable, modular, reusable, and United States of America Space Transportation System (STS) compatible laboratory that enabled astronauts to conduct space experiments from Earth orbit. Spacelab components ultimately flew on twenty-two space shuttle missions starting with Spacelab-1 in 1983 and ending with Neurolab in 1998. Flown as the primary payload aboard Space Shuttle Challenger's eighth flight (STS-51F), Spacelab-2 included solar physics, atmospheric physics, plasma physics, high energy astrophysics, infrared astronomy, technology research, and life science experiments. Spacelab-2 was the first of the Spacelab missions to employ a pallets-only configuration, wherein the crew operated the experiments from the Shuttle aft flight deck. It was also the first mission for the ESA pallet mounted precision Instrument Pointing System (IPS), to which a four experiment Sun pointed solar payload package was attached (Figure 80s.7.1). The gimbaled IPS provided precision solar pointing for the two large solar telescopes, HRTS and the shorter Solar Optical Universal Polarimeter (SOUP), independent of the angle between the Shuttle cargo bay normal and the solar vector.

Figure 80s.7.1 – The Spacelab-2 IPS with its four solar instruments sun pointed from the payload bay of Shuttle Challenger. HRTS, the longest instrument, is in the first Cartesian quadrant (upper right) and SUSIM is in the fourth quadrant (lower right) (credit: NASA).

As the final Spacelab verification flight, the main STS-51F mission objectives included performance verification of the Spacelab systems. Spacelab-2 was the IPS qualifying mission and thus a very significant fraction of available mission resources were dedicated to the in-flight adjustment and evaluation of the IPS control algorithm pointing characteristics rather than to the Sun pointed experiments for science data collection. The IPS, hard mounted to a Spacelab pallet, was required to stabilize pointing of its three axes gimbal with up to a 7000kg load in the presence of crew activity and the Shuttle reaction control system's six vernier engine thruster firings. In the absence of an instrument level HRTS image motion compensation (IMC) system, good image quality from the HRTS, with its 0.5 arcsecond spatial resolution, required better than 1 micro-radian solar pointing stability from the IPS. This represented a challenging systems engineering problem for the mission. Accordingly NASA planned follow-on solar missions for the IPS and the solar payload designated Sunlab-1 (manifested as STS 71-O, Sept 1987, on Columbia), Sunlab-2 (1989), Sunlab-3 (1990). Based on Spacelab-2 precision pointing results, the HRTS project was funded for development of a retrofitted IMC system during the Sunlab-1 preparation period after Spacelab-2.

Collectively the four solar experiments on the IPS conducted both global and high resolution observations of the solar atmosphere. The Spacelab-2 HRTS operated in the 119nm-168nm spectral interval. The stigmatic spectrograph entrance slit, located at the 45mm diameter solar disk real image formed by the telescope, could be rastered across the telescopic image one raster step per spectrograph photographic film (Schumann-type) camera exposure to generate data for post flight reconstruction of 0.005nm bandpass monochromatic output images of fine scale structures in the solar transition region, chromosphere, and low corona in the light of emission lines arising from various ions. Velocity fields, among other things, could be produced from these images. A very small section of a HRTS spectrum is shown in Figure 80s.7.2. This spectrum shows obvious Doppler shifts due to motions in the highly dynamic transition region. The SUSIM was a precisely calibrated scanning spectrophotometer that analyzed the wavelength dependent solar irradiance at Earth with spectral resolutions of 0.15nm and 5nm in the 120-400nm spectral interval with an absolute radiometric accuracy of ≤ 3%. The SUSIM was used to determine long and short-term variation of the total ultraviolet flux emitted by the Sun that modulates the energy balance and chemical composition in the earth's upper atmosphere.

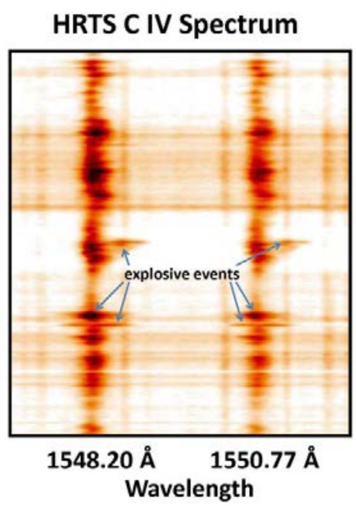


Figure 80s.7.2 – A sample of the HRTS spectrum centered on the C IV doublet near 1550 Å. C IV is formed in the lower transition region near 100,000 K. Outflows from a few km/s to around 100 km/s occur regularly in the transition region and some are called explosive events. They may be due to magnetic reconnection in the transition region (credit: NRL).

As mentioned, prior to the Spacelab-2 mission HRTS had been developed as a sounding rocket payload where it had flown four times from the White Sands Missile Range. The Spacelab-2 SUSIM had been developed explicitly for Space Shuttle/Spacelab. It had one previous flight aboard STS-3 (1982) as part of the Office of Space Science-1 payload, a precursor to the Spacelab missions, where it was hard mounted to an orbital flight test pallet.

Based on its Spacelab-2 performance, the HRTS was funded for another Spacelab mission to be called Sunlab, which was eventually cancelled as a result of the Challenger accident. It was then funded for a Phase A concept definition study for the *Orbiting Solar Observatory* (*OSL*), a NASA facility-class mission that was subsequently cancelled in 1991 due to budget issues. The OSL thematic concept was adopted by the Japanese solar physics community and morphed into the present Solar-B/*Hinode* mission (see the essay 2000s.4 in the 2000s chapter). The corporate knowledge of solar ultraviolet (UV) rastering slit spectrograph imaging technology from HRTS and multi-layer optics technology developed by the SSD contributed to the objectives and design of NRL's contribution to the *Hinode* Extreme-Ultraviolet Imaging Spectrometer (EIS). SUSIM was subsequently funded for three *Atmospheric Laboratory Applications and Science* (*ATLAS*) missions, and, a second SUSIM for *UARS*.

The major technical achievement of the HRTS is high information throughput efficiency. The quantity of the solar science information contained in the dispersed ultraviolet entrance slit images mapped onto the focal plane of a spectrometer is limited by the optical aberrations introduced by the geometrical arrangement of the gratings. These aberrations, especially astigmatism, degrade the image quality of the solar spectral line profiles bearing the science information and constrain a spectrometer's spectral, spatial, and temporal resolution as well as the reconstructed rastered slit solar imagery. Wadsworth (1896) discovered that a collimated polychromatic beam incident on a single spherical grating is dispersed such that the single diffracted wavelength imaged at the focal point located on the grating normal is stigmatic while the images formed off the normal, at all other wavelengths, exhibit astigmatism. Brueckner conceived of a two concave grating system configured such that each of the dispersed and collimated monochromatic beams from a first spherical grating (G1), illuminated by a polychromatic slit source located at the focal point on the G1 grating normal, illuminate a second and relatively large spherical grating (G2) at which each monochromatic beam locally satisfies the Wadsworth condition again. Stigmatic slit images along both the full length of the slit and over a very extended wavelength range, 49nm on Spacelab-2, are simultaneously formed on the final focal plane detector.

The major SUSIM technical achievement is precise and long term solar ultraviolet measurement. This was accomplished by inclusion within the instrument of a deuterium calibration lamp and by a two independent channel design wherein only one of the channels is subjected to degrading solar ultraviolet radiation for extended periods of time and the other is kept pristine by only infrequent solar ultraviolet exposure. SUSIM was flown on five Space Shuttle missions: the NASA Office of Space Science-1 (OSS-1) Spacelab pallet (1982), Spacelab-2 (1985), and three *ATLAS* missions (1992, 1993, 1994) all on Spacelab pallets. A second SUSIM was flown on *UARS* from September 1991 to June 2005. (See the Morrill essay in this chapter 80s.1). The SUSIM Spacelab-2 is unique since it is the only measurement set in the nearly decade long interval, 1982-1991, of the total twenty-two year long record of SUSIM solar ultraviolet spectral irradiance measurements. Ultimately the UV solar irradiance data collected by SUSIM, including Spacelab-2 SUSIM, reduced the then existing ~30% absolute 11 year solar ultraviolet (115-440 nm) spectro-radiometric measurement discrepancies by an order of magnitude to the 0.3-3% level.

2.0 Summary Remarks

The Spacelab-2 HRTS and SUSIM greatly advanced the instrumental state of the art in high information throughput solar spectroscopy and precision solar ultraviolet irradiance measurement in the solar space research era following the *Skylab* and the Apollo Telescope Mount (1973-1979). The results from Spacelab-2 and the series of HRTS rocket flights demonstrated the power of imaging spectroscopy for understanding the physical conditions in the solar atmosphere. This pioneering effort led to the development of three imaging spectrometers on the *Solar & Heliospheric Observatory* (*SOHO*), the EIS instrument on *Hinode*, and the recently NASA launched *Interface Region Imaging Spectrograph*. The SUSIM instrument was subsequently launched on *UARS* and irradiance instruments continue to be developed such as the EUV Variability Experiment flown on the NASA *Solar Dynamics Observatory*. If the Challenger accident had not occurred, it is highly likely that these instruments would have flown on additional Spacelab missions during this period.

John-David Bartoe returned to work in NRL/SSD after Spacelab-2, having contributed to the demonstration of the ability of scientists trained in the astronaut program to fly on the Shuttle and successfully operate scientific instruments in their disciplines. John-David received something similar to a hero's welcome upon his return to NRL. A party was held and congratulations were given to the SSD Spacelab-2 team for an outstanding achievement (see Figure 80s.7.3). John-David illustrated the can-do and courageous attitude of SSD space scientists in all their research efforts by a remark that an SSD scientist remembers John-David making after the terrible Challenger accident. Asked if he would now fly again on the Shuttle if given an opportunity, John-David said, "In a minute".

Figure 80s.7.3 – John-David Bartoe and Dianne Prinz at the NRL celebratory party after Spacelab-2 (credit: NRL).

References: 80s.7: NRL Instruments on Spacelab-2

Candidate Experiment Program for Manned Space Stations, NASA Office of Manned Space Flight, September 15, 1969.

Experiment Module Concepts Study, Final Report, George C. Marshall Space flight Center, October 1970.

John-David F. Bartoe and Guenter E. Brueckner, JOSA, Vol. 65, Issue 1, pp. 13-21 (1975), New stigmatic, coma-free, concave-grating spectrograph.

M. E. VanHoosier, J.-D. F. Bartoe, G. E. Brueckner, D. K. Prinz, and J. W. Cook, Solar Physics 74 (1981) 521-530, A High Precision Solar Ultraviolet Spectral Irradiance Monitor for the Wavelength Region 120-400 nm.

NASA Historical Data Books (SP-4012), 1999, Volume V: NASA Launch Systems, Space Transportation, Human Spaceflight, and Space Science, 1979-1988, page 399.

Shuttle Orbital Applications and Requirements, Supplemental Study, (Payload/Orbiter Interface Trade Tasks), SOAR-IIS, Final Report, Marshall Space Flight Center, MSFC-DRL 299/DR No. MA-04, September 1973.

A1. List of Terms and Acronyms

80s.Decade

- HRTS - High Resolution Telescope Spectrograph
- SUSIM - Solar Ultraviolet Spectral Irradiance Monitor
- UARS - Upper Atmosphere Research Satellite
- CGRO - Compton Gamma Ray Observatory
- OSSE - Oriented Scintillation Spectrometer Experiment
- BCS - Bragg Crystal Spectrometer
- SSGM - Synthetic Scene Generation Model
- SDIO - Strategic Defense Initiative Organization
- MDA - Missile Defense Agency
- SMM - Solar Maximum Mission
- CMEs – Coronal Mass Ejections
- MHD – Magnetohydrodynamic

80s.1

- SUSIM - Solar Ultraviolet Spectral Irradiance Monitor
- UV – Ultraviolet
- ATLAS - ATmospheric Laboratory for Applications and Science
- UARS - Upper Atmosphere Research Satellite
- SORCE - Solar Radiation and Climate Experiment
- TSI - Total Solar Irradiance
- SURF - Synchrotron Ultraviolet Radiation Facility
- NIST - The National Institute for Standards and Technology
- SBUV - Solar Backscatter Ultraviolet
- NRLSSI – NRL Solar Spectral Irradiance

80s.2

- CGRO - Compton Gamma Ray Observatory
- PI - Principal Investigator
- OSSE - Oriented Scintillation Spectrometer Experiment
- EGRET - Energetic Gamma Ray Experiment Telescope
- COMTEL - Imaging Compton Telescope
- BATSE - Burst and Transient Source Experiment
- AGN - Active Galactic Nuclei
- γ-ray – Gamma Ray

80s.3

- BCS - Bragg Crystal Spectrometer
- HESP - High Energy Solar Physics
- CSSP - Committee on Solar and Space Physics
- SXT - Soft X-ray Telescope
- HXT - Hard X-ray imaging Telescope
- WBS - Wide Band Spectrometer
- STRB - Solar Terrestrial Relationships Branch
- SMM - Solar Maximum Mission
- MSSL – Mullard Space Science Laboratory
- RAL - Rutherford Appleton Laboratory
- NIST – National Institute of Standards and Technology
- SOLFLEX – Solar Flare X-rays
- GOES – Geostationary Orbiting Environmental Satellites

80s.4

- MDA - Missile Defense Agency
- SDIO - Strategic Defense Initiative Organization
- BMDO - Ballistic Missile Defense Organization
- SSGM - Synthetic Scene Generation Model
- UV - Ultraviolet
- FFRDC - Federally Funded Research and Development Centers
- BDC – Backgrounds Data Center
- TAMD - Theater Air and Missile Defense
- NMD - National Missile Defense
- MSX - Midcourse Space Experiment
- IBSS – Infrared Background Signature Survey
- UVPI – Ultra-Violet Plume Instrument
- UVLIM – Ultra-Violet Limb Imaging Experiment
- FUVCAM – Far Ultra-Violet Camera
- VMS – Virtual Memory System
- IDL – Interactive Data Language
- IRAF – Image Reduction and Analysis Facility
- SCIES - Science Catalog Information Exchange System
- VDC – Virtual Data Center

80s.5

- SMM - Solar Maximum Mission
- GRS - Gamma Ray Spectrometer

80s.6

- CMEs - coronal mass ejections
- SOHO – Solar & Heliospheric Observatory
- TRACE – Transition Region and Coronal Explorer
- STEREO – Solar Terrestrial Relations Observatory
- LCP&FD - Laboratory for Computational Physics & Fluid Dynamics
- MHD – Magnetohydrodynamic
- NOAA – National Oceanic and Atmospheric Administration
- AR - Active region

80s.7

- ESRO - European Space Research Organization
- HRTS - High Resolution Telescope and Spectrograph
- SUSIM - Solar Ultraviolet Spectral Irradiance Monitor
- UARS - Upper Atmosphere Research Satellite
- SOAR - Shuttle Orbital Applications Requirements
- ESA - European Space Agency
- STS - Space Transportation System
- IPS - Instrument Pointing System
- SOUP - Solar Optical Universal Polarimeter
- IMC - image motion compensation
- OSL - Orbiting Solar Observatory
- UV - Ultraviolet
- EIS - Extreme-Ultraviolet Imaging Spectrometer
- ATLAS - Atmospheric Laboratory Applications and Science
- OSS-1 - Office of Space Science-1
- SOHO - Solar & Heliospheric Observatory