VOYAGER ULTRAVIOLET SPECTROMETER GUEST OBSERVER AND DATA ANALYSIS HANDBOOK

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VERSION 1.1
Mar 25, 1992

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1.0 Introduction

The Voyager Ultraviolet Spectrometers (UVS) are nearly identical instruments, sensitive over the wavelength range 500 to 1700 Å and operating on board the Voyager 1 and 2 spacecraft in the outer solar system. Although designed primarily to observe extreme and far ultraviolet (EUV and FUV) emission from the atmospheres of the outer planets and several of their satellites, these instruments have proven exceptionally effective at conducting a wide variety of exploratory astronomical observations at wavelengths below 1200 Å. Numerous observations of stellar and non-stellar astrophysical targets have been conducted since shortly after launch in 1977.

At present the UVS instruments on both spacecraft are operating normally and are conducting observations of astrophysical targets as well as observations of the interstellar wind and the sun. The Voyager spacecraft are part of the Voyager Interstellar Mission (VIM) which, after Oct. 1 1991 will be under the direction of the NASA division of Space Plasma Physics. Spacecraft operations, including UVS sequencing are conducted by the Voyager Project at the Jet Propulsion Laboratory at Pasadena California. A UVS Guest Observer Program is overseen by the NASA Astrophysics Division (Code EZ) under the direction of the program scientist, Dr. Ronald Oliversen at the Goddard Spaceflight Center in Greenbelt, MD. Operational support of the UVS observing program is provided by the Voyager Data Analysis Center at the Lunar and Planetary Laboratory at the University of Arizona in Tucson, AZ. The Voyager Data Analysis Center also maintains archives of UVS astronomical data and supports the analysis of Voyager Guest Observer and Archive data.

This Handbook is intended to familiarize Guest Observers and Archive Guest Investigators with the UVS instruments, their operations and characteristics, and to provide a helpful introduction to some of the techniques and software used in the analysis of the UVS data.

2.0 UVS Observations: An Overview

2.1 Instrumentation

The Voyager UVS instruments are compact, Wadsworth mounted, objective grating spectrometers covering the wavelength range 500 to 1700 Å (See Fig. 2.1). Collimation of incoming UV radiation is accomplished with a series of 13 precession mechanical baffles, or aperture plates, which define a primary instrumental field-of-view (FOV) of 0.10° x 0.87° (FWHM). A single normal incidence reflection from a concave diffraction grating then focuses the dispersed image onto an array detector. The grating is a platinum coated replica, ruled at 540 lines/mm, blazed at 800Å and having a radius of curvature of 400.1 mm. Dispersion in the image plane is 93 Å /mm. In addition to the primary FOV, each UVS has a small 20° off-axis port which allows direct viewing of the sun, at decreased detector gain.

The open, photon counting detector consists of a dual microchannel plate (MCP) and a 128-element linear self-scanned readout array. For wavelengths shortward of 1250 Å, the quantum efficiency of the MCP is that of the bare glass, ~10%. Longward of 1250Å, the quantum efficiency is enhanced by the use of a semi-transparent CuI photocathode deposited on a MgF_2 substrate. The MCP is normally operated at a gain of $\sim 10^6$ and its output is proximity focused onto a linear array of aluminum anodes. Each of the 128 anodes (126 active plus two dead, trailing channels) is accessed every 320 μs and its output charge passed to a charge sensitive amplifier. Amplifier output for each channel is digitally converted to a 16-bit word and summed in internal shift register memory. Memory registers are read out by the spacecraft flight data system at various defined rates, and transmitted back to earth as log-compressed 10-bit words. For the astronomical observations discussed here, the two prime data rates currently in use produce one complete spectrum every 3.84 s or every 240 s. The UVS instruments are solar blind, have no moving parts, and have operated continuously since launch in 1977. With the singular exception of a decrease in the Voyager 1 MCP gain, due to excessive radiation-induced counts during passage through the inner Jovian magnetosphere, both instruments have remained photometrically stable at a better than 3% level since 1977. Detailed descriptions of the Voyager instruments are contained in Broadfoot et al. (1977). In-flight performance of the UVS from launch through the 1979 Jupiter encounters is reviewed in Broadfoot et al. (1981).

As objective grating spectrometers, (a table of channel vs. wavelength is given in Appendix A) the instruments have differing spectral resolutions for point source and diffuse sources. For stellar (point) sources spectral resolution is ~18 Å, while for diffuse (filled field) sources it is ~30Å. Instrumental sensitivity is optimized for the 800 to 1200 Å region. Typical limiting sensitivities at 1050 Å for stellar continua are 5×10^{-13} ergs cm^{-2} s^{-1} Å^{-1} for Voyager 2 and 1×10^{-12} ergs cm^{-2} s^{-1} Å^{-1} for Voyager 1. On-axis integration times necessary to achieve these limits are ~1 day. As a practical matter, however, there is often a need to observe adjacent sky background for a comparable period of time. For diffuse emission, limits of 100 photons cm^{-2} s^{-1} Å^{-1} str^{-1} and 6000 photons cm^{-2} s^{-1} str^{-1}, for continuum and line emission, respectively, in the 500 to 1200 Å band have been achieved, using Voyager 2 (Holberg 1986). Very long integration times, measured in days, are a normal mode of observing with the UVS. The instruments have low backgrounds, 2.5×10^{-3} counts s^{-1} $channel^{-1}$, which primarily results from gamma rays from the spacecraft radioisotope thermoelectric generators (RTG) and scattering interplanetary H I Lyman series and He I 584 Å emission lines. A summary of instrumental parameters is contained in Table 2.1

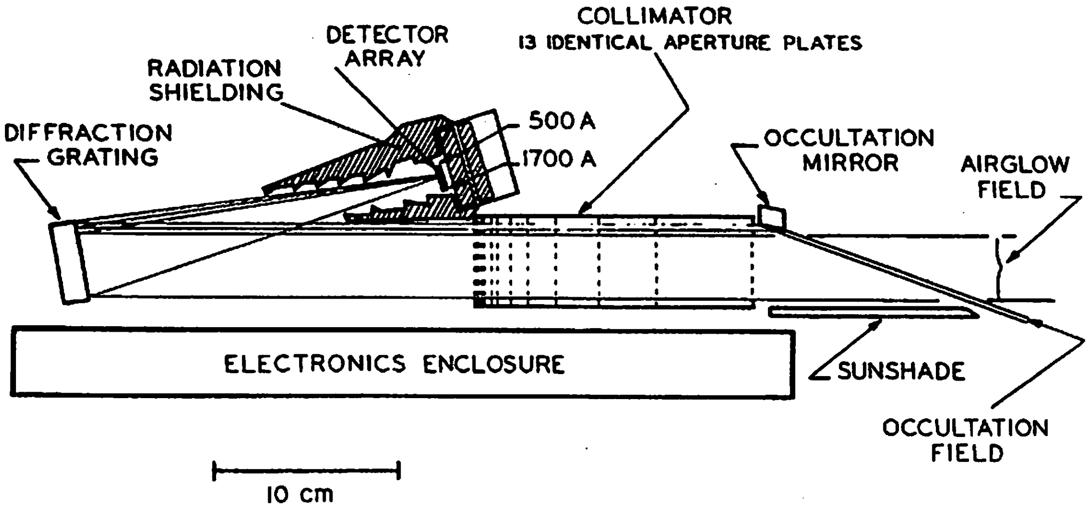


Fig. 2.1. A diagram of the optical layout of the UVS. Light enters the primary aperture ('Airglow Field') and passes through a set of 13 mechanical baffles which restricts the primary field of view to a FWHM of 0.1° in the dispersion direction. The concave grating disperses wavelengths and images the fields on the detector array. A 20° off-axis aperture ('Occultation Field') is used for viewing the sun.

TABLE 2.1

Voyager Ultraviolet spectrometers

Optical Configuration

Wadsworth Mount Objective Grating
21 cm^2 Platinum replica Grating, Blazed at 800Å
Mechanical Collimation: 0.°10 x 0.°87 Field of View

Photon Counting Detector

128 Channel Microchannel Plate, Bare for $\lambda < 1250$Å
CuI on MgF_2 Filter for $\lambda > 1250$Å
Self-Scanned Aluminum Anode Array
Integration Times of 3.84 to 240 Seconds
Dark counts 2.5 x 10^{-3} counts s^{-1} $channel^{-1}$

Performance

Spectral Range (Å): $525 < \lambda < 1650$
Resolution: ~ 18Å (9.26Å/channel)
Limiting Flux: 0.2-0.5x10^{-22} ergs cm^{-2} sec^{-1} $Å^{-1}$ at 1000Å
Stability: <2% Change in 3 Years
Absolute Calibration: ~10-15%

2.2 The Voyager Spacecraft

We briefly describe here those relevant aspects of the Voyager Spacecraft which influence UVS data and observations. The drawing of the spacecraft shown in Fig. 2.2 illustrates many of the features described in the following sections. Two excellent sources of additional general information on the spacecraft are: the Science and Mission Systems Handbook (JPL publication, PD 618-128) and the Voyager Neptune Travel Guide (JPL Pub 89-24).

Voyager 1 was launched on 1 Sept. 1977 and encountered Jupiter and Saturn in 1979 and 1980, respectively. It is now leaving the solar system at a rate of ~3.5 AU/yr. along a trajectory inclined +35° to the ecliptic in the general direction of the constellation Hercules. Voyager 2, launched on 20 Aug. 1977, encountered all four of the Jovian planets. The final encounter with Neptune in 1989 placed Voyager 2 on a trajectory inclined -48° to the ecliptic and departing the solar system ~ 2.7 AU/yr toward the constellation Sagittarius. In Voyager project documentation the Voyager 1 and 2 spacecraft are variously referred to as V1 and V2, S/C A and S/C B, S/C 31 and S/C 32, and JST and JSX, respectively.

2.2.1 Spacecraft Subsystems

Each spacecraft is powered by three Radioisotope Thermoelectric Generators (RTG's) which together contain 24 kg of ^{238}Pu and currently produce ~360 watts of power. Gamma rays from the RTG's, which are located on a boom opposite the science boom containing the UVS, constitute the primary source of instrumental dark counts for the UVS. RTG output is declining at approximately 7 watts/yr and shortly after the year 2000 there will be insufficient power to operate the UVS.

Data from the UVS is read out and formatted by the Flight Data System (FDS) and transmitted over the spacecrafts 3.7 m high gain antenna. Two down-link frequencies are used; X band at 3.2 cm and S band at 13 cm. Although, numerous data rates have been used throughout the mission, they fall into two main categories, "high rate" and "cruise". High rate data is transmitted at X band and received using NASA 70 m antennae at the NASA Deep Space Network (DSN) antennas in Spain, California, and Australia. Low rate data or 'cruise' data is transmitted at S band and is received at 34 m antennas at the same locations. UVS data rates in the both high rate and cruise configuration are listed in Table 3.1.1. In general, lower rate cruise data corresponds to longer UVS integration times per spectrum. The current UV5a mode is actually a cruise mode, but yields UVS data at the nominal high rate integration time: of 3.84s per spectrum. The UV5a data format, which was conceived by Mike Urban at JPL, uses the 600 bits/s of down link signal margin to transmit high rate UVS data frames.

The attitude of the spacecraft and the articulation of the scan platform are controlled by the Attitude and Articulation Control System (AACS) (Fig. 2.3). Except when maneuvering under gyro control, the spacecraft is three-axis stabilized in a fixed orientation through a combination of a two-axis sun sensor for pitch and yaw control and a star tracker for roll reference. Bias commands ("sun sensor biases") are periodically issued to the sun sensor, which is electronically offset the solar reference point in pitch and yaw so that the high gain antenna axis remains pointed at the earth, as seen from Voyager. The net effect of tracking the earth with the high gain antenna is that the UVS field of view will

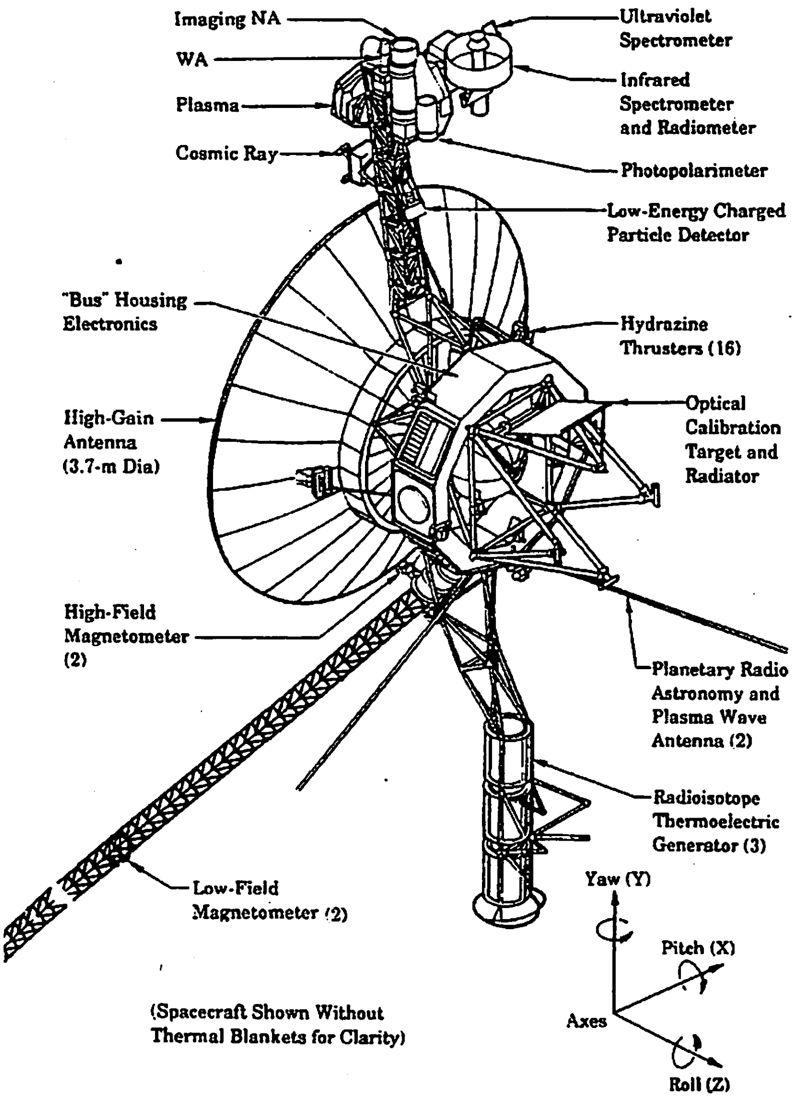


Fig. 2.2 A drawing of the Voyager spacecraft indicating the location of various components. The location of the UVS, on the scan platform at the end of the science boom, is shown at the upper right. Note the orientation of the principal body-fixed axes of the spacecraft shown at the lower right.

slowly drift with respect to the celestial frame. The motion of the spacecraft about its three principal axes is actively controlled with the use of small hydrazine thrusters. These thrusters are activated in a computer controlled feed back-loop which uses error signals from the sun sensor and star tracker. The amplitudes of the allowed angular excursions about each axis ("deadbands") are adjustable. Normally these deadbands are set to 0.05° amplitude in pitch, yaw and roll when transmitting high rate data. Typical limit cycle periods are 12 to 30 min. This limit cycle motion causes an apparent motion of any source in both the dispersion and cross-dispersion directions with respect to the UVS slit. Resolving this motion into dispersion and cross-dispersion components and locating the source with

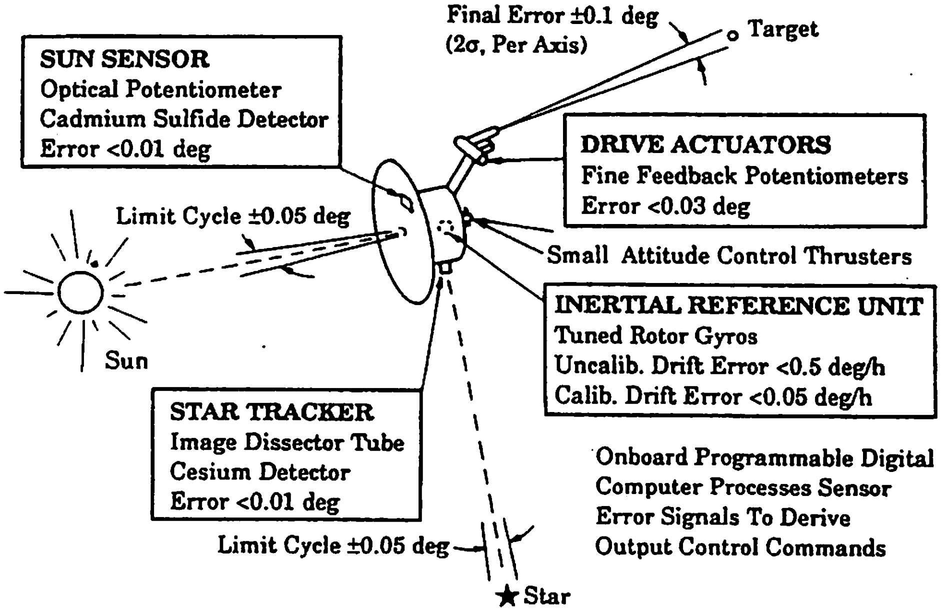


Fig. 2.3 A cartoon illustrating elements of the spacecraft attitude control system. The sun sensor controls the pitch and yaw axes of the spacecraft while the star tracker maintains the roll orientation. Scan platform pointing is achieved by drive actuators on the azimuth and elevation axes. When required for maneuvers, spacecraft orientation can be switched from celestial reference to inertial, or gyroscopic reference.

respect to the center of the slit is the principle task in the reduction of UVS stellar data. The scan platform coordinate system is a body-fixed spherical coordinate system composed of an orthogonal Elevation (EL) and Azimuthal (AZ) grid. The EL = 0° pole is off set 7° from the negative roll axis of the spacecraft, which is also coincident with the axis of the high gain antenna. Thus, low EL angles lie in the earth-sun hemisphere while EL > 90° angles are in the anti-sun hemisphere. The AZ = 0° direction is along the + yaw axis which is parallel to the science boom. A unique relation between AZ/EL and RA/DEC requires that the orientation of the spacecraft be specified. When the spacecraft is on celestial reference, i.e. when it is not being maneuvered under gyro reference, the orientation can be described by a pair of sun sensor bias angles which give the pitch and yaw offsets of the roll axis from the sun and the particular star being used by the star tracker for roll reference. Since the spacecraft's position with respect to the sun and the earth is known to great accuracy the orientation can be uniquely determined from knowledge of the date and the roll star. The program SKYMAP (4.1) can be used to determine the relationship between the AZ/EL and RA/DEC coordinate systems for both spacecraft at any point during the mission.

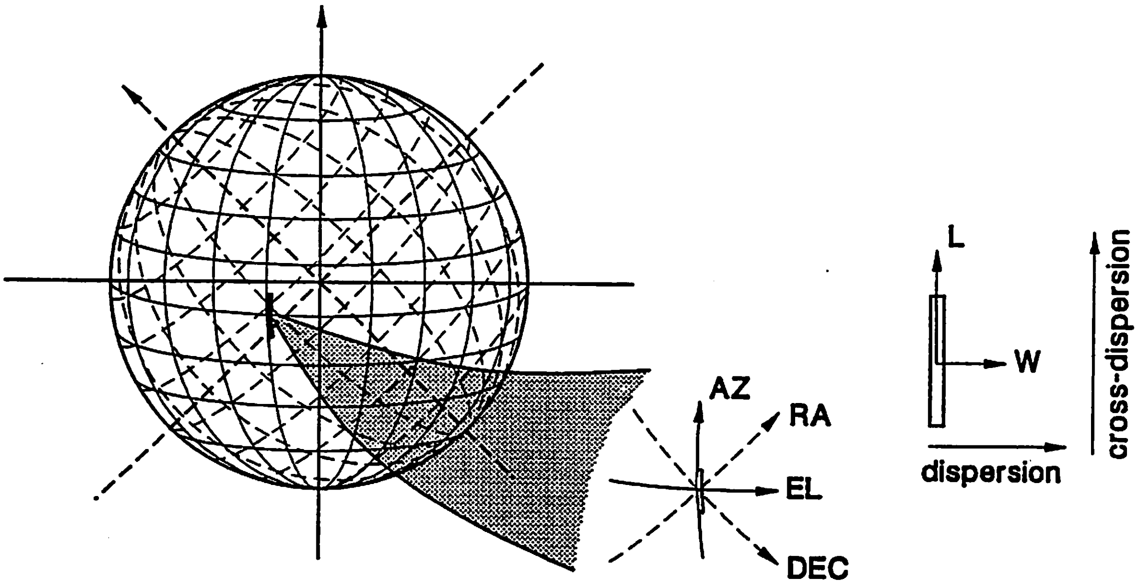
It is possible to point the scan platform in virtually any direction, however, for any given roll star certain regions of the sky will be obscured by spacecraft structure, as seen from the UVS on the science boom. In Fig 2.5 we show the portions of the sky obscured and the locations of the sun for both Voyager 1 and 2 during mid-1992. Current roll stars for Voyager 1 and 2 are Rigel Kentarus and Canopus, respectively. Voyager 1 will remain on Rigel Kentarus for the foreseeable future, however, it is planned to roll Voyager 2 to Vega in mid-1992.

The UVS can be targeted by driving the scan platform to predetermined actuator angles. These acutator angles are the AZ and EL of the scan platform as defined by read-out potentiometers on the output shafts of the scan platform axes. They may differ subtly from the idealized AZ/EL coordinates used by SKYMAP by up to 0.5°

2.2.2 Coordinate Systems

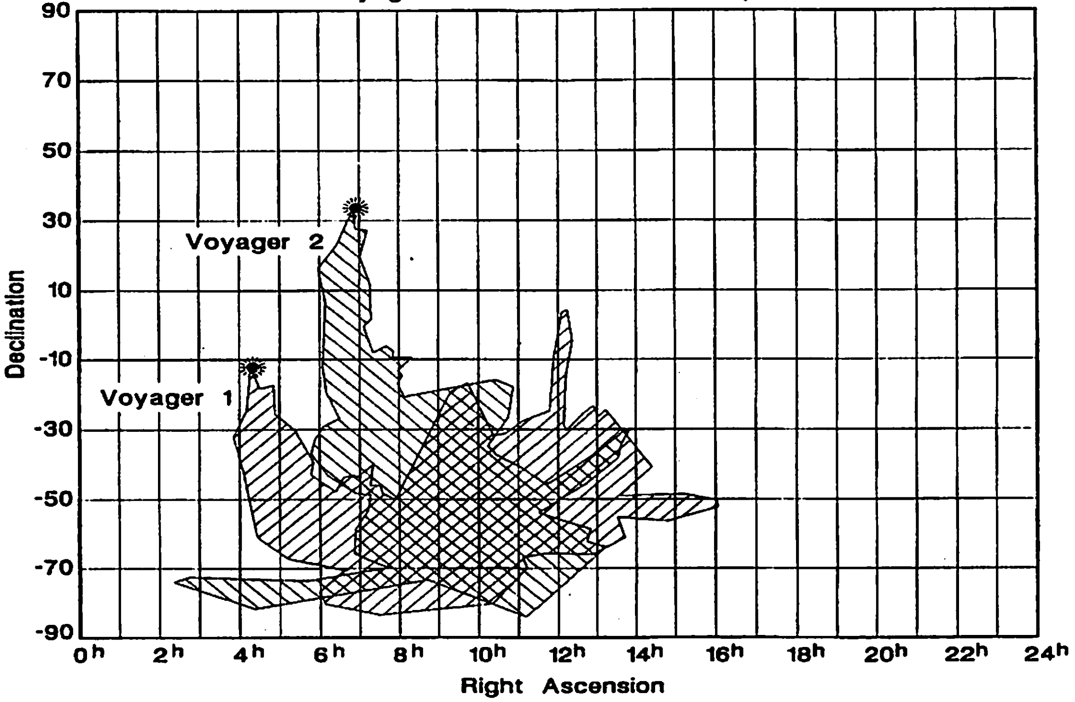
The Voyager UVS employs three primary coordinate systems, the celestial coordinates right ascension (RA) and declination (Dec) for epoch 1950.0, the scan platform coordinates azimuth (AZ) and elevation (EL), and the instrumental coordinates length (L) and width (W). The relationships between these three systems are illustrated in Figure 2.4.

Fig. 2.4



VOYAGER 1 AND 2 OBSCURATION ZONES 1992.5

Voyager 2 Roll Reference Canopus



VOYAGER 1 AND 2 OBSCURATION ZONES 1992.5

Voyager 2 Roll Reference Vega

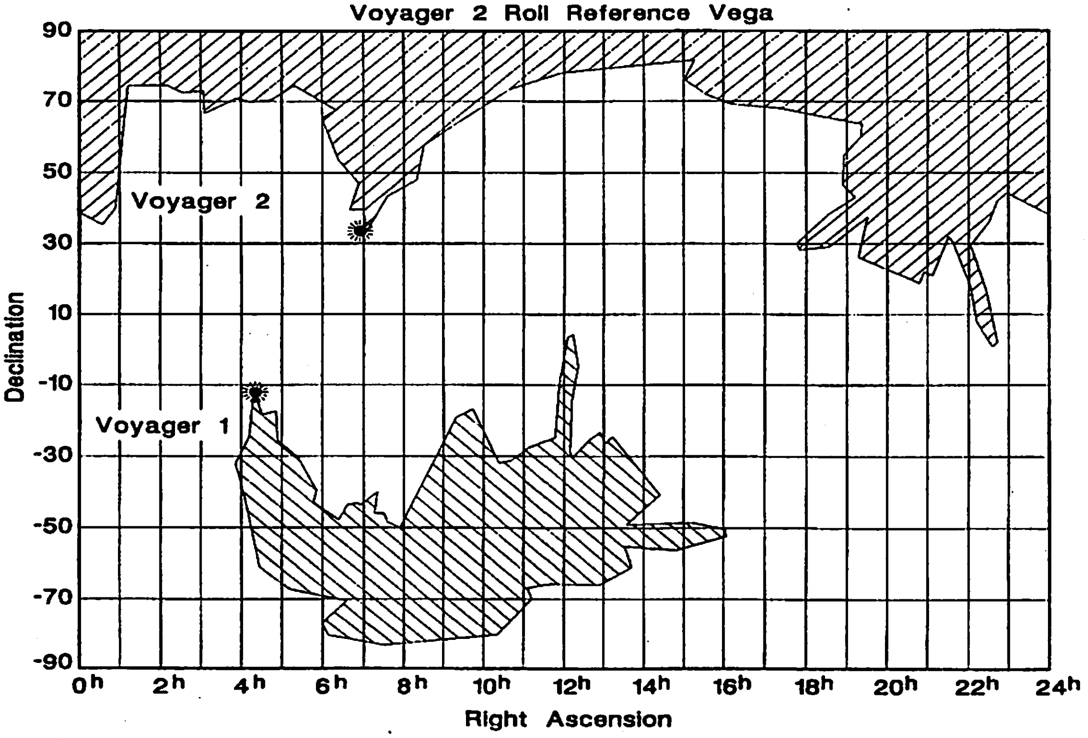


Fig. 2.4 Zones of the celestial sphere which are obscured by spacecraft structure for Voyager 1 and 2. Also shown is the apparent location of the sun as seen from each spacecraft. The epoch of each plot is 1992.5. The top plot reflects the current obscuration zones for each spacecraft. The bottom plot illustrates the result of the planned change of the Voyager 2 roll reference star from Canopus to Vega in mid-1992.

3.0 UVS Data and Reduction Procedures

In this section we describe some of the general features of UVS data and the basic stages of data reduction and analysis. Individual programs which perform data analysis and reduction functions are described in detail in subsequent sections.

3.1 Data Reduction

3.1.1 Data Rates and Compression

Over the years a number of UVS data rates have been employed. In each, except the current CR-5T cruise mode, a complete 126 channel UVS spectrum is recorded during a base integration time. In Table 3.1.1 we list past and present UVS data modes and the corresponding base integration times.

TABLE 3.1.1

UVS Data Rates and Modes

Mode	Mode No.	Integration time (s)	Dates
OC1	1	0.32	1977-1989
GS-3	2	3.84	1977-present
CR-1	3	12.00	1977-78
CR-2	4	48.00	1977-78
CR-4	6	192.00	1979-83
CR-5	7	576.00	1983-90
CR-6	8	720.00	1977-78
CR-5T	9	240.00	1990-present
UV5a	10	3.84	1990-present

A brief word of explanation concerning the above data rates is warranted. Although the Voyager spacecraft have employed a number of data rates over the years UVS data rates fall into two primary categories; Cruise (CR modes) and General Science (GS modes and UV5a). Low data rate Cruise modes are the result of employing a combination the spacecraft's low gain antenna and 34 m DSN ground stations. High data rate General Science data modes use the spacecraft's high gain antenna and 70 m DSN ground stations. High data rates require a narrow limit cycle dead band in order to point the high gain antenna accurately at the earth. In a Cruise mode configuration limit cycle dead bands are normally expanded.

When UVS data files are extracted from the data archive it is often advantageous to "compress" or time average the spectra, particularly at high data rates. This time averaging produces a more compact file of spectra, each having a longer integration time. This is done by time averaging each *n* spectra to produce a series of spectra, having an integration time *n* times the base integration time, but a count rate defined by base integration time. For example, the base integration time of GS-3 data is 3.84 s. A compression of 3:1 will yield a series of spectra each with an integration time of 11.52 s but a count rate having units of counts per 3.84 s. In compressing spectra, header information such as pointing is also averaged, however the Spacecraft Event Time (SCET) in the header corresponds to the SCET of the first of the *n* spectra being averaged. In most circumstances compression of high rate data results in no significant loss of spatial information as long as the compression does not exceed 3:1 or 4:1. In the on-line archive files, GS-3 data has been compressed 3:1 so that each spectrum has an integration time of 11.52s.

3.1.2 Pointing Corrections

The time averaged position of the center of the UVS slit in celestial and scan platform coordinates is recorded in the header of each UVS spectrum. The celestial coordinates (RA and DEC) are computed directly from spacecraft engineering data which includes encoded azimuth and elevation of the scan platform, the sun sensor bias angles, and the attitude control system error signals in pitch, yaw and roll. The remaining information necessary to determine UVS pointing is the time and roll reference star. Often, however, it is necessary or advantageous to correct this pointing information. There are several reasons why such corrections may be necessary. Due to an ambiguous high order bit in the readout engineering words which specify the scan platform AZ and EL, the UVS pointing may *appear* to be in error by exactly one revolution (7.488°) of the fine potentiometer for either AZ or EL (or both). These apparent errors are easily recognized by checking header coordinates against SKYMAP or VOYLOG. Errors of a more subtle nature are due to readout noise in, the scan platform AZ and EL, the sun sensor bias angles and the AACS error signals. The effect of this pointing "noise" is to induce small stochastic changes in the computed RA and DEC of individual spectra. This can result in a degradation of spatial resolution when binning spectra on the sky.

Most of these errors can be easily corrected through use of the Program FIXPT (Sec 5.2) which allows the user to fix the AZ, EL and sun sensor bias angles to their commanded values and re-computes the pointing information in the header of each spectrum. Application of FIXPT is a standard processing step applied to all Guest Observer (GO) data. A further refinement in pointing correction, which allows smoothing of the pitch, yaw and roll error signals with a low pass filter, is also available but this is a time-consuming interactive procedure which is normally not used except for data sets which require the best available pointing information, such as light curves.

3.1.3 FPN

Raw Voyager spectra contain no correction for inherent channel-to-channel variations. The standard means of correcting such variations is to apply a simple flat field vector called a "Fixed Pattern Noise" or "FPN" correction. Because of the high stability of the Voyager instruments these FPN corrections are represented by unique time invariant spectra. (see Fig. 3.1.1). For Voyager 1 and 2 the appropriate FPN corrections are:

TABLE 3.1.2

FPN Corrections

Voyager 1 (pre-1979)......	FPN 47
Voyager 1 (post-1979)....	FPN 51
Voyager 2 (all)................	FPN 76

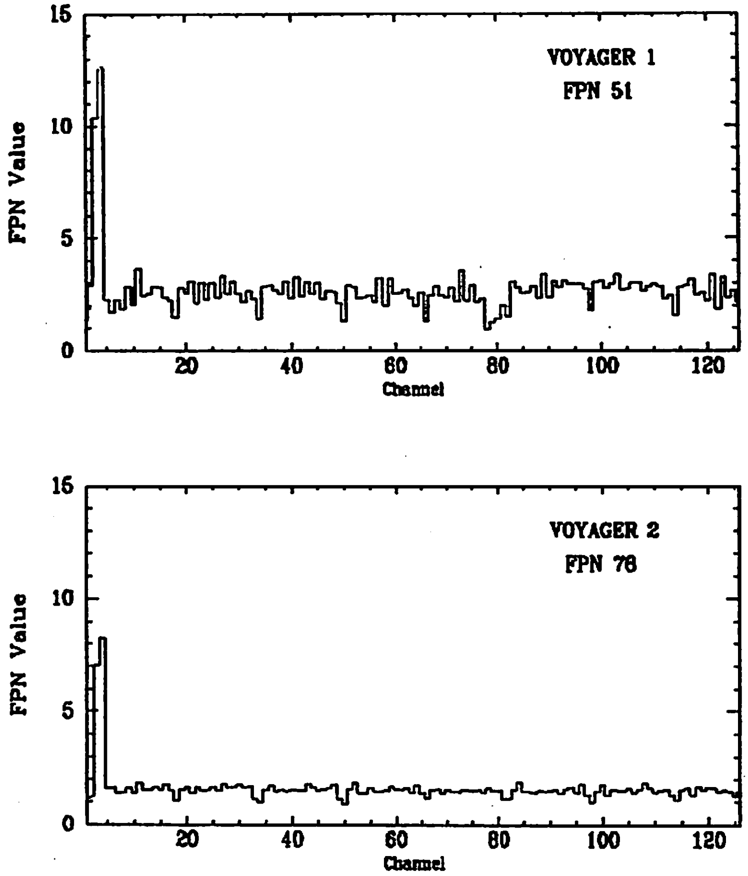


Fig 3.1.1 The flat fielding or FPN correction for Voyagers 1 and 2.

The need for the two Voyager 1 FPN corrections arises from the 30% loss of sensitivity which occurred during the passage through the intense Jovian radiation belts. This resulted in a counting induced reduction in the detector gain, which in turn altered the pulse height distribution of each channel. FPN 51, which applies to Voyager 1 spectra obtained following March 1979, was subsequently derived from a careful comparison of pre- and post- Jupiter data for various objects.

There are several aspects of the FPN spectra which should be noted. First, FPN is a multiplicative correction and for historical reasons was not defined as having an average of unity. The instrumental calibration incorporates the average value of the FPN. Within Voyager-specific IRAF routines discussed here the correct FPN is automatically applied to the reduced or displayed spectra. Second, channels 3 and 4 on both spacecraft have very large FPN corrections, i.e. the are insensitive. Consequently relatively large over or under shoots are possible in these channels. If excessive values are noted it is advisable to set these channels to the values of their neighbors.

3.1.4 Dark Counts

The UVS have no dark slides for the determination of instrumental dark counts. A practical solution to this problem is to point the UVS at a photometric calibration target located in the solar shadow of the spacecraft and integrate for extended periods of time. These "Dark Cal Plate" observations have occurred at approximately 2 yr. intervals on both spacecraft. They last from a week to 12 days and result in 300,000 s to 800,000 s of integration time. During these observations the only detectable photon signal is a small residual Lyman alpha feature due to a reflection of the nearly isotropic interplanetary Lyman alpha line from the shadowed dark calibration plate. Typical dark plate spectra for both spacecraft are shown in Fig. 3.1.4. The primary agent responsible for UVS dark counts is gamma radiation from the RTG's discussed in 2.1. The RTG's effectively constitute a point source, as seen by the UVS located on the science boom opposite the RTG boom. When the orientation of the scan platform changes relative to the RTG's then the intervening surface mass density of the other instruments on the scan platform effectively cast 'shadows' on the UVS modulating the dark count rate. The spectral shape of the underlying dark count spectrum, however, remains invariant to a high degree.

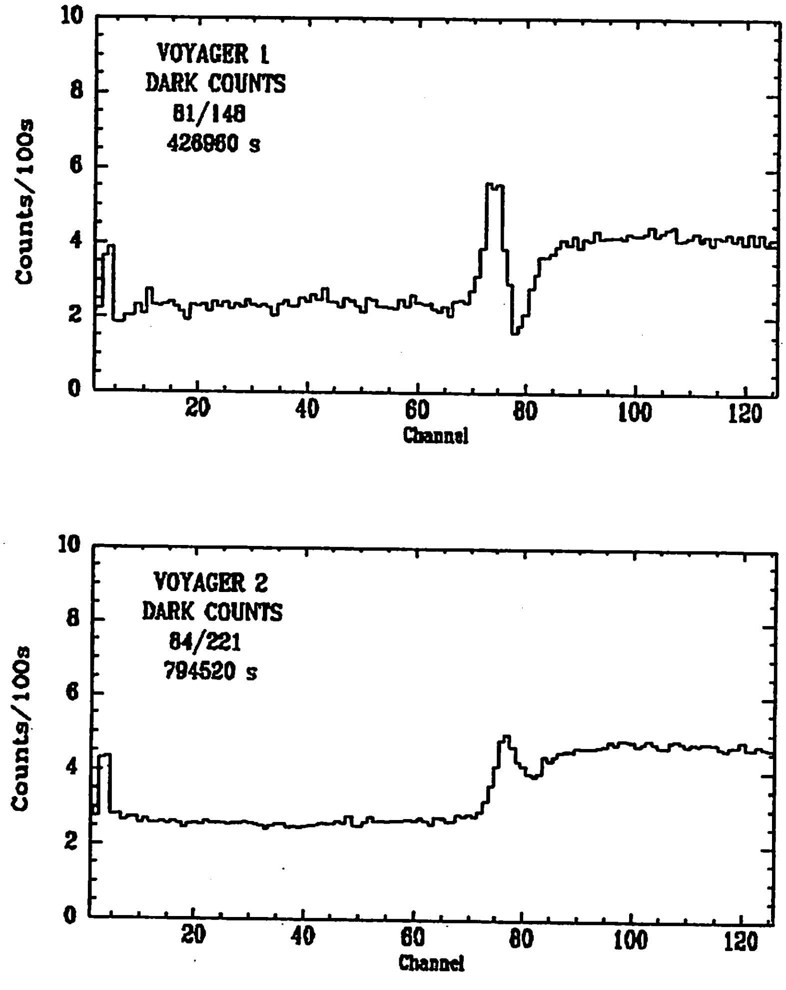


Fig 3.1.4 Representative UVS dark count spectra for Voyager 1 and 2. These spectra were acquired while the UVS was pointed at a photometric calibration target in the solar shadow of the spacecraft. The instrumental counts are primarily from the RTG's. A small residual Lyman alpha signal (near channel 75) is due to reflected sky background is the only photon component present.

The simple shape seen in Fig 3.1.4 is produced by Compton electrons induced by gamma rays interacting with the UVS detector shielding and housing. The plateau seen longward of 1300 Å in both instruments is believed due to Cherenkov radiation in the MgF_2 substrate of the filter photocathode covering the long wave-length channels. In addition to the RTG's, cosmic rays also are responsible for some of the dark counts. During the most recent solar maximum the dark cal plate spectral intensity was observed to increase by 50%. This is believed to be the result of anomalous cosmic rays who's intensity is modulated by the interplanetary magnetic field. Solar particles are believed to contribute very little to the dark cal plate counts. With the exception of several very strong solar flares in 1977 and 1978, when the spacecraft were near 1 AU, no influence of solar events has been observed. Dark counts can be removed from UVS spectra in two ways. The simplest and most direct approach is to subtract sky background accumulated adjacent (in time and space) to the target. This effectively removes the dark count component as well as the intrinsic sky background component. Often, however, this is not a practical alternative if sufficient local source-free sky background is not available or if one is attempting to observe a diffuse source such as the sky background where, by definition, no unrelated sky background is available. In such cases an effective alternative is to construct a synthetic sky background from known source-free observations of sufficient duration. This task is accomplished using BKGND.

3.1.5 Sky Background Subtraction

The UVS slits are relatively large and there-fore sensitive to sky background emission. Fortunately, in the far UV the sky is generally quite dark and diffuse starlight is seldom a serious problem. However, bright emission lines arising from the interplanetary medium (IPM) are a ubiquitous component of UVS data. In Fig. 3.1.5 we show the major components of this emission; H I Lyman alpha, beta and gamma and He I 584 Å. These lines are the result of strong solar chromospheric emission lines scattering from neutral H and He which are entering the solar system from the local interstellar medium. The physics of this "interstellar wind" is complex and leads to a diffuse line emission which is inhomogeneous in both space and time. Even at the great distances of Voyager, the IPM responds to active regions of the solar chromosphere as the sun rotates. This means that the sky brightness as seen by the UVS can change noticeably on the time scale of days. As with instrumental dark counts, there are two standard means of removing sky background; direct subtraction of adjacent sky background, if available, and construction of a synthetic sky background spectrum. For the latter case, where insufficient local sky background is available, the program BKGND (6.2) allows the user to determine the appropriate level of dark counts and IPM emission lines from an appropriate template sky background spectrum.

3.1.6 Descattering

The Voyager UVS gratings are replicas of ruled gratings and generally exhibit more scattering than modern holographic gratings. A highly effective means of correcting for grating scattered light is to "descatter" a spectrum. Descattering is accomplished through the use of a matrix operator which corrects for scattering with in the instrument. Briefly, the instrumental response to scattering from a line or continuum source is

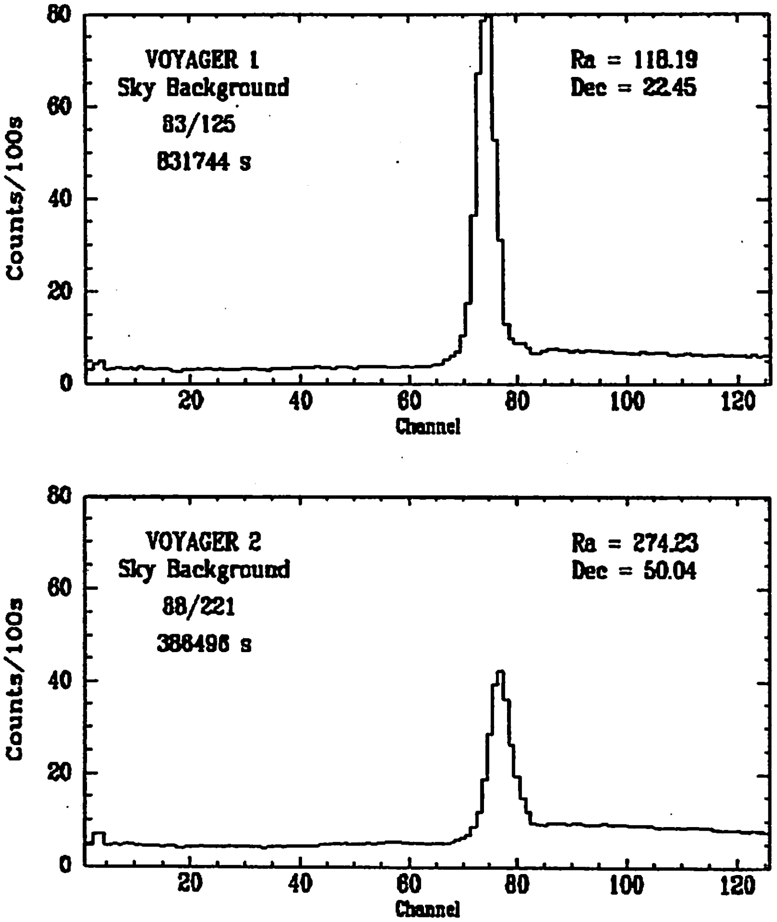


Fig 3.1.5 Representative sky background spectra for Voyager 1 and 2. These spectra are composed of a dark count component (see 3.1.4) and emission lines from the interplanetary medium.

modeled by a 126x126 element matrix which describes the count rate response of the instrument at channel j to the observed signal at channel i. This scattering matrix is completely empirical, having been determined from scattering measurements of 50 individual emission lines covering the entire band pass of the flight instruments. Scattered light is removed from Voyager spectra in a self-consistent manner through the use of a "descattering" matrix. The descattering matrix is essentially a discrete differential operator which globally corrects the spectrum for scattering but leaves a strong channel-to-channel variation in the resulting spectrum. A "1-2-1" smooth following descattering will eliminate the latter effect. In Fig. 3.1.6 we demonstrate the results of descattering a stellar spectrum. Descattering is a linear operation with respect to UVS spectra.Dark counts should be subtracted from UVS spectra prior to descattering as the descattering algorithm assumes that only photon events are present in the spectrum. Table 3.1.6 gives both the scattering (forward going) and descattering (backward) matrices for Voyagers 1 and 2. It is also important to note that descattering will also correct for the second order response of the grating. Therefore, if the spectrum to be descattered contains artifacts, such as anomalously high or low counts in channels 3 or 4, a corresponding "correction" will occur with descattering at channels corresponding to 2λ.

TABLE 3.1.6

UVS Descattering Matrices

	forward	backward (descatter)
Voyager 1	22	21
Voyager 2	34	35

3.1.7 Calibration

The determination of the absolute calibration of the UVS instruments is discussed in Holberg et al. (1983) and Holberg et al. (1991). Stored calibration files are used to convert fully reduced count rate spectra into absolute units. Some programs, such as SPBIN, apply the calibration automatically when outputting final results. In other programs, such as VOY, where this step is performed by the user it is always assumed that the calibration is being applied to *fully reduced count rate spectra having units of counts per second.* The sensitivity curves for Voyagers 1 and 2 are shown in Fig. 3.1.7 for a continuum point source in absolute units of photons cm^{-2} s^{-1} $Å^{-1}$. Conversions to alternate intensity units such as ergs cm^{-2} s^{-1} $Å^{-1}$ and ergs cm^{-2} s^{-1} Hz^{-1} are possible. For diffuse, filled field sources, an effective solid angle of 1.65×10^{-5} steradians is used for both spacecraft.

3.2 POINT SOURCE EXTRACTION

The primary data reduction activity associated with UVS stellar data is the extraction of representative stellar spectra from the normal, time-ordered sequences in which spectra are obtained. This is most frequently done by sorting the spectra into a spatially-ordered sequence, locating spectra obtained near the center of the UVS FOV, and summing the results into a representative spectrum which is corrected for off-axis effects. In this section we will discuss this process. The data reduction software associated with this process, SPBIN, is discussed in section 5.

3.2.1 Field of View

The UVS is an objective grating spectrometer. Due to inherently low reflectiveness of optical materials at wavelengths much below 1100Å, it lacks the collimating fore-optics normally associated with most astronomical spectrometers. Instead, a mechanical collimator is employed to restrict the FOV. A set of 13 identical mechanical baffles, having a net transmission of 33%, defines a slit-like FOV of 0.1° by 0.87°. Vignetting of the incoming beam by the baffle assembly produces a symmetrical gausssian-like response across the FOV in the dispersion direction. The relative responses of the Voyager 1 and 2 primary FOV are shown in Fig. 3.2.1. Precise measurements of the relative responses for both spacecraft have been measured by rastering a star across the FOV. The principal task of UVS data reduction is frequently to locate the position of the star with respect to the on-axis position. For a bright star this is usually possible to achieve this with an accuracy of greater than 0.01° in the W or dispersion direction. In very precise work, where careful attention is paid to the limit cycle, precisions of 0.001° have been achieved.

Since the UVS has no moving parts, the slit response is highly stable. In Fig. 3.2.1 we

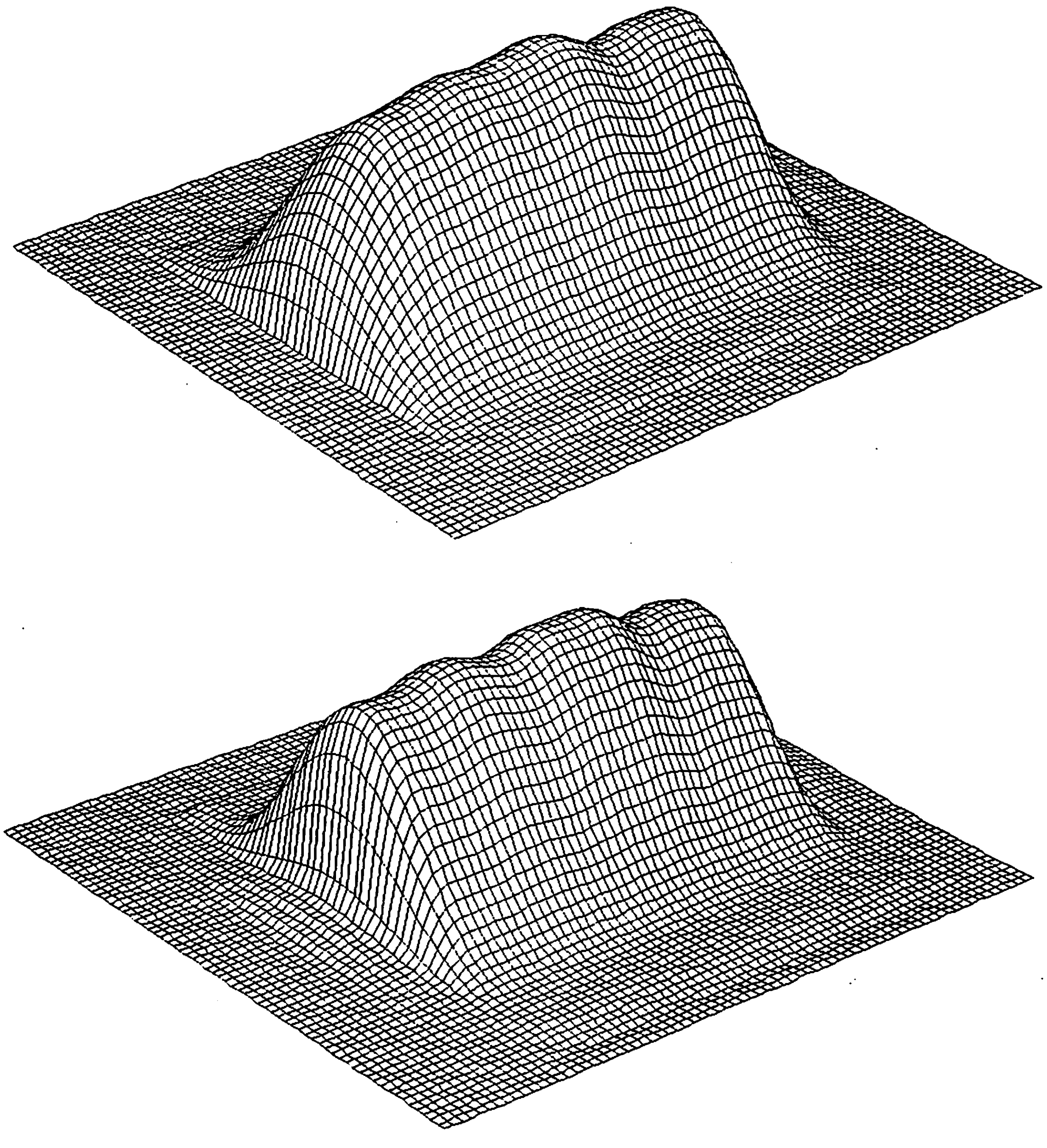


Fig 3.2.1 Relative response maps for the Voyager 1 and 2 Fields of View. The long dimension in the cross-dispersion or L dimension. The narrow dimension is the dispersion or W dimension. The "bumps" along the longitudinal axis defining the slit center are due to a repeller grid in front of the detector.

show the measured slit response functions for Voyagers 1 and 2 in both the dispersion (W) and cross-dispersion (L) dimensions. In the L dimension, along the length of the slit there are small variations at the 3% level due to a repeller grid in front of the detector. In general, limit cycle motion serves to average out this effect. At wavelengths longward of 1350Å where a filter photocathode covers the detector, there is a slight 10% asymmetry in the W response on either side of the center of the FOV.

4.0 VOYLOG

VOYLOG is an interactive program which allows access to a log of Voyager 1 and 2 cruise science observations from launch to the present; The periods of planetary encounter are not currently covered. VOYLOG enables the user to search the database for particular observations, types of observations, and or combinations of spacecraft parameters. It contains UVS-specific information abstracted from the spacecraft Sequence of Events (SOE), and is intended to largely replace voluminous paper records which comprise the SOE.

VOYLOG is a stand alone program which can be invoked by typing 'VOYLOG' Output files can be created and printed. Output from VOYLOG currently has a two column format containing the following items:

Left Column

Item	Explanation
Spacecraft:	Voyager 1 or 2
Object:	Name of target observed
SCET:	SpaceCraft Event Time - UT at the spacecraft (YR/DAY/HR:MN:SEC)
Target RA:	1950 decimal Right Ascension of target (see Note 1)
Target DEC:	1950 decimal Declination of target (see Note 1)
Data Mode:	Spacecraft Data Mode (see Note 2)
Comments:	Miscellaneous information on the observation

Right Column

Item	Explanation
Program:	Guest Observer Program ID (if relevant)
Class:	Object Class
Duration:	Time between adjacent VOYLOG entries (DAY/HR:MN) see Note 3
SOE AZ:	Scan Platform Actuator Azimuth (see Note 4)
SOE EL:	Scan Platform Actuator Elevation (see Note 4)
Dead Band:	Amplitude of the Spacecraft Limit Cycle

NOTES:

1. This usually corresponds to the targeted celestial coordinates. Actual instrumental pointing may differ slightly and must be determined from the data.

2. Data Mode: Any "GS" or "UV" data mode corresponds to 3.84 seconds per spectrum (high rate). "CR" modes correspond to low rate data. CR-5 = 576 seconds per spectrum CR-5T = 240 seconds per (compressed) spectrum.

3. Duration is the clock time between any consecutive entries in VOYLOG. For example, it might be the length of time in a particular data mode. It DOES NOT correspond to the amount of data recorded on the ground. The amount of actual data and its quality can only be assessed from the data records themselves.

4. These are the actuator angles to which the scan platform was driven. They should correspond closely to the read out actuator angles in the spectral headers in the data records. SKYMAP uses an idealized (linear) definition of AZ-EL which will differ from SOE AZ-EL by up to 0.5 deg.

```
VOYLOG>                     SAMPLE OUTPUT
--------------------------------------------------------------------------
Spacecraft      : Voyager 1            Program      : VA12GP
Object          : HD 120324            Class        : B2IV
SCET            : 90/110/17:21:24      Duration     : 000/01:54
Target RA       : 206.650              SOE AZ       : 343.877
Target DEC      : -42.225              SOE EL       : 107.623
Data Mode       : GS-6                 Dead Bands   : .05/.10/.25
Comments        : Mu Cen
--------------------------------------------------------------------------
Spacecraft      : Voyager 1            Program      : VA12GP
Object          : HD 120324            Class        : B2IV
SCET            : 90/110/19:15:48      Duration     : 002/14:14
Target RA       : 206.650              SOE AZ       : 343.877
Target DEC      : -42.225              SOE EL       : 107.623
Data Mode       : CR-5                 Dead Bands   : .05/.10/.25
Comments        : Mu Cen
--------------------------------------------------------------------------
Spacecraft      : Voyager 1            Program      : VA12GP
Object          : HD 217675            Class        : B5III
SCET            : 90/113/10:05:27      Duration     : 000/06:55
Target RA       : 344.904              SOE AZ       : 178.994
Target DEC      : 42.057               SOE EL       : 99.307
Data Mode       : CR-5                 Dead Bands   : .05/.10/.25
Comments        :
--------------------------------------------------------------------------
Spacecraft      : Voyager 1            Program      : VA12GP
Object          : HD 217675            Class        : B5III
SCET            : 90/113/17:00:36      Duration     : 000/01:30
Target RA       : 344.904              SOE AZ       : 178.994
Target DEC      : 42.057               SOE EL       : 99.307
Data Mode       : GS-6                 Dead Bands   : .05/.10/.25
Comments        :
--------------------------------------------------------------------------
```

Spacecraft	: Voyager 1	Program	: VA12GP
Object	: HD 217675	Class	: B5III
SCET	: 90/113/18:31:00	Duration	: 001/14:44
Target RA	: 344.904	SOE AZ	: 178.994
Target DEC	: 42.057	SOE EL	: 99.307
Data Mode	: CR-5	Dead Bands	: .05/.10/.25
Comments	:		

4.0.1 NEW VOYLOG FEATURES (3/23/92)

I. REMOTE DATA EXTRACTION

It is now possible to remotely access Voyager archive data files using VOYLOG. The data available is compressed cruise data (3:1 for high rate data and 1:1 for low data rates). Currently available data extends form launch to mid-1990 on both spacecraft. Extracted data can be specified by identifying the desired periods using VOYLOG search parameters and then typing "extract". It requires up to 2 hrs. to extract a file, which is then placed in the argus anonymous directory. You are notified via return E-mail when the file is ready and have up to 24 hrs to ftp the file. Currently these data are not pointing corrected, however, we plan to simultaneously issue a file of bias angle corrections with each data file so that users can make their own pointing corrections. Current restrictions include a file size limit of 60 Mbytes (~15 million spectra), a 24 hr. residence time, and no remote access to proprietary data (VA and VB program ID's)

II. INDICATION OF AVAILABLE DATA

VOYLOG now contains an indication of the actual amount of available data and the type (data mode) of spectra for most observations. This should give a better indication than the Duration entry in VOYLOG which merely indicated the clock time between events in VOYLOG. The available data is reported under the entry DATA in VOYLOG.

III. OBJECT ALIASES

VOYLOG can now deal with most common aliases for the object of astronomical targets. For example, all observations of Delta Sco can be found by using either "Del Sco", "BD-22 4068", "HD 143275, "SAO 184014", or "HR 5953"

4.0.2 A QUICK GUIDE TO USING VOYLOG (11/26/91)

I. LOGGING IN AND OUT

1. Telnet to argus: telnet argus.lpl.arizona.edu (128.196.88.9)
2. At the login prompt type: voylog (this gets you into the program)
3. Create a LOGFILE? answer y or n
4. E-mail Return address:

   SPAN format: username@span_node.span i.e. (holberg@looney.span)

   Internet format: username@hostname (full hostname is recommended)

5. Logout: bye (your logfile is returned via Email if you answered 'y' to 3.)
6. All commands and search fields are case insensitive.

II. SEARCHING

1. After search fields are set up as you would like, type: run
2. Current status of search fields type: status
3. Reset all search parameters type: reset
4. Spacecraft toggle: Example: v1 - toggles v1 off and on
5. Object Search:

   Example: object 'Alp Vir' (will return all observations of Alpha Virginis)

   Examples: Vega, 'HD 120324', 'BD +28 4211', 'HR 1099', 'Cygnus Loop'

   Rules: object fields containing a blank should be enclosed in ' ' partial names are valid i.e. "Bet" will turn up all observations of objects containing the string "bet" in the object name

   Aliases: voylog is currently equipped to handle many common aliases. It is still a good idea to search on RA and Dec when in doubt.

6. RA and Dec Search:

   Example: RA 344 345
   Dec 42 43
   (this 1x1 window will turn up all observations of HD 217675 and its alias Omi And)

   Coordinates: epoch is 1950.0 in decimal and Sexagesimal notation.

7. AZ/EL Search:

   Example: AZ 349 351
   EL 109 111
   (this 2x2 window will turn up observations of the spacecraft's target plate)

8. Date Search:

   Example: date 81/300/00:00 81/306/21:00

   Format: truncated year/day of year/hh:mm:ss

9. Object Class:

   Examples: B8IV, A0V, B0.5Ia, sdB, DA, PNN, GCL

10. Program ID:

    Examples: VA08HS, VB07RH

    (currently data with program ID's cannot be extracted remotely)

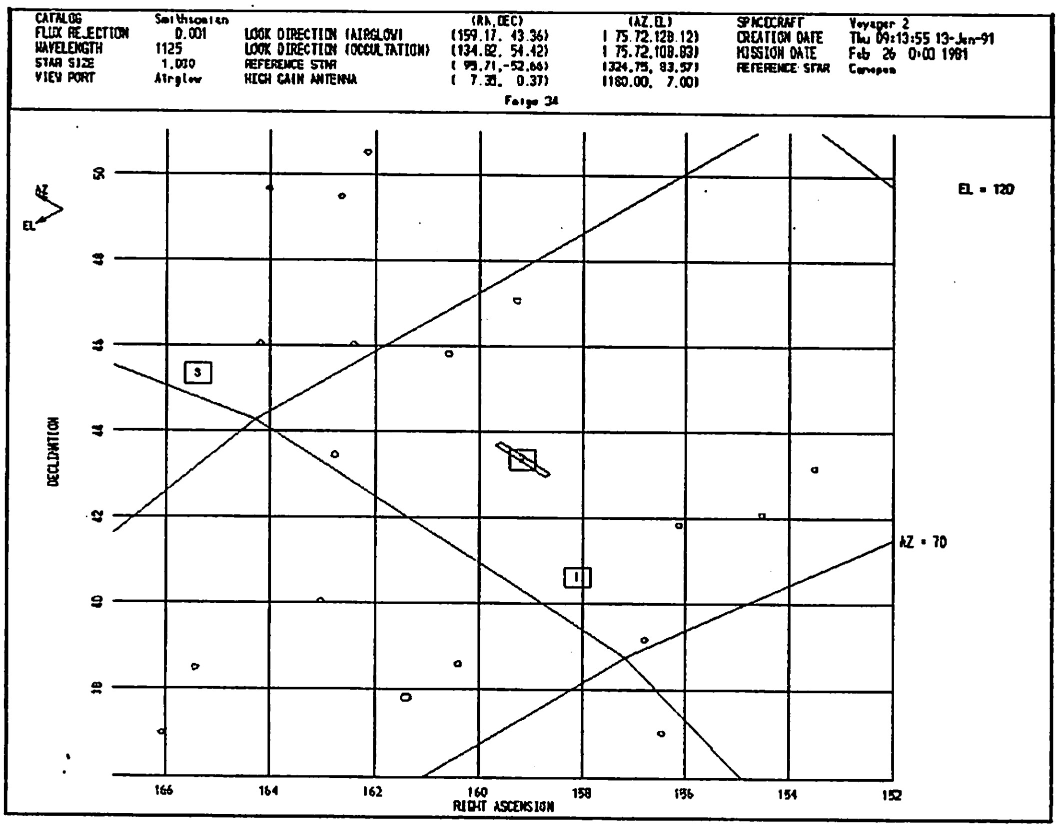
III. DATA EXTRACTION:

1. To extract data using the current search parameters type: extract Currently all VA and VB program IDs are locked to remote extraction. 2. Data logs: voylog now will list the archive data blocks corresponding to voylog entries. This should help in deciding the quantity and type of data available in the archives for each observation. This data can then be extracted.

IV. MISCELLANEOUS

1. Verbose will produce an abbreviated voylog listing reporting only changes in scan plat form position.
2. Help: help - will list the full help file to the screen. help cmd - help screen for each command

4.1 SKYMAP



```
CATALOG         Smithsonian                                     (RA,DEC)           (AZ,EL)          SPACECRAFT       Voyager 2
FLUX REJECTION    0.001    LOOK DIRECTION (AIRGLOW)        (159.17, 43.36)     ( 75.72,128.12)   CREATION DATE    Thu 09:13:55 13-Jan-91
WAVELENGTH       1125      LOOK DIRECTION (OCCULTATION)    (134.82, 54.42)     ( 75.72,108.83)   MISSION DATE     Feb 26 0:00 1981
STAR SIZE         1.000    REFERENCE STAR                  ( 95.71,-52.66)     (324.75, 83.57)   REFERENCE STAR   Canopus
VIEW PORT        Airglow   HIGH GAIN ANTENNA               (  7.38,  0.37)     (180.00,  7.00)
                                                              Feige 34
```

Fig 4.1 A SKYMAP plot of the field near Feige 34. The UVS slit is projected onto the sky and an AZ/EL grid has been overlayed. The stars are displayed with respect to their relative brightness at 1125Å. The boxes represent prior UVS Targets.

SKYMAP can be used to portray the sky as seen by Voyager at a series of selected wavelengths. It is useful both in planning observations and enhancing the understanding of the data analysis process. The minimum information needed to specify a SKYMAP plot is 1) the spacecraft, 2) the time, and 3) the look direction. An example of a SKYMAP plot is shown in Figure 4.1. The sky, at an effective wavelength of 1125Å, is displaced in Mercator projection in RA and Dec. The UVS FOV is shown centered on the target (Feige 34). Other UVS targets in the field are shown as numbered boxes and UV-bright field stars are shown as circles of whose diameters indicate the 1125Å magnitudes of the stars. The header at the top of Figure 4.1 contains information on the look direction of both the airglow port and the occultation port in RA and Dec and AZ/EL, the spacecraft, the observation date and roll reference star. Obscuration of either or both ports will be indicated if it occurs.

4.1.1 SKYMAP FEATURES

Look direction can be specified in either RA/DEC or AZ/EL depending on whether the mode is set to 1 or 2, respectively. This feature can be used to estimate the speed and direction of the drift of the UVS FOV with respect to the sky by targeting to the object at time τ1 in RA/DEC and noting the corresponding AZ/EL and then targeting this AZ/EL in mode 2 at time τ2. This feature can also be sued to determine such things as the RA/DEC of a sky background position which has been specified as a delta AZ or delta EL.

Look ports can be switched by setting the changeport parameter to ‘yes’. For example, if SKYMAP is first run for a position to which the airglow port is targeted it is possible to examine the corresponding part of the sky being viewed by the occultation port by setting changeport to ‘yes’. The occultation port is offset in EL from the airglow port by -19.5°.

4.1.2 Catalogs:

Currently the Yale Bright Star Catalogue and the Smithsonian Bright Star Catalogue are available. Also available is a catalogue of previous Voyager observations. When invoked the symbols Δ and ∇ indicate the locations of previous Voyager 1 and 2 observations.

4.2 TSPLOT

TSPLOT allows the viewing of a data file as a time-ordered sequence. In this capacity, it often provides an excellent ‘map’ outlining the contents of a data file, such as, periods of bad data or bad pointing and serves as a record of spacecraft limit cycle motion. In all but one mode, TSPLOT is a passive program which does not alter the data file.

EXAMPLE:

Figure 4.2 shows a 1 hr. segment of a Voyager 1 data file from an observation of HR 1679. In the upper panel the observed intensity in channels 40 to 65 (approximately 900 to 1130 Å) is plotted as a function of time, or location within the file. The modulation of the signal is a result of the motion of the star within the UVS FOV; the peak signal corresponds to the star crossing the center of the FOV. This motion is plotted in the two lower panels. In the bottom panel the component of motion in the dispersion direction is recorded. The abscissa represents relative angular displacement in the EL-W coordinate, where EL is the fixed scan platform elevation. W is the computed displacement, in degrees, of the FOV due to spacecraft limit cycle motion in the EL dimension. The arrow at the left indicates the direction of increasing EL and corresponds to the EL arrow in SPBIN and SKYMAP. In this plot the peak-to-peak amplitude of the W motion is ~0.2 deg and the period is approximately 30 min. The EL-W scale is shown at the right while scan platform EL is shown on the left hand scale.

Motion in the cross-dispersion dimension is shown in the middle panel. Again this is relative motion with respect to the fixed azimuth of the scan platform. The L coordinate is along the length of the slit and computed from the expression ΔAZsin(EL). As with the EL motion, the amplitude is given on the right and the absolute azimuth scale is on the left. Limit cycle motions in the dispersion and cross-dispersion dimensions often correlate.

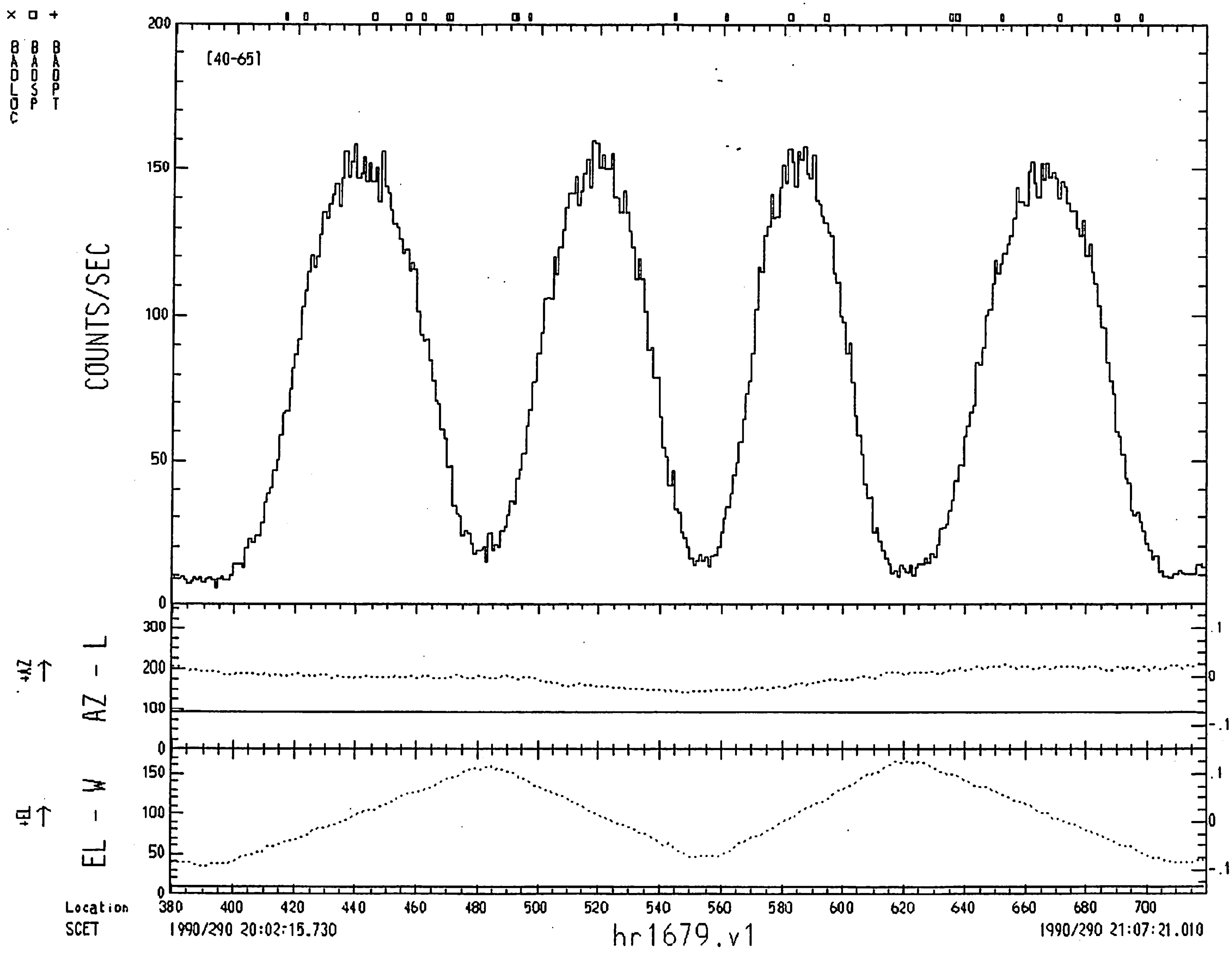
4.2.1 ABOUT USING TSPLOT

- It is a good idea to first plot a sample of TSPLOT output to the screen (device=stdgraph) before committing to a long plot on a laser printer or a Versatec raster plotter.

4.2.2 TSPLOT FEATURES

- TSPLOT can plot any set of channel ranges on panels 1,2 or 3, although, panel 3 can plot AZ and EL and the corresponding scan platform motions.
- TSPLOT can output ASCII files containing file location, SCET, counts and pointing information
- Specific locations or ranges of locations can have their spectral quality or pointing flags changed through the use of with the cursor in TSPLOT. This is very useful for marking unwanted spectra or segments of a file for exclusion in subsequent data processing phases.
- File locations corresponding to bad spectra (❑), bad pointing (+) or bad locations (x) are indicated along the top of the plot.

Figure 4.2


× BADLOC
□ BADSP
+ BADPT
COUNTS/SEC
[40-65]
200
150
100
50
0
AZ - L
↑ +AZ
300
200
100
0
.1
0
-.1
EL - W
↑ +EL
150
100
50
0
.1
0
-.1
Location
SCET
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
1990/290 20:02:15.730
hr1679.v1
1990/290 21:07:21.010

4.3 SPBIN

SPBIN is the primary tool for the extraction of stellar spectra from Voyager data. It sorts spectra into user defined spatial bins and permits the extraction of spectra which have been corrected for off-axis effects, instrumental scattering, sky background and photometric calibration. SPBIN has two stages. The first stage creates a set of spatial bins in the FOV coordinates L and W and displays the observed intensity in a defined spectral region as a function of these bin coordinates. The intensity vs W can be matched to a template representing the normalized response of the FOV as a function of W. This allows the location of the on-axis spectra to be defined. The second stage uses location of the on-axis point and a specified window in L and W to accumulate a single representative spectrum which has been corrected for off-axis effects. The subsequent data reduction stages of descattering and photometric calibration are accomplished by single key strokes.

4.3.1 STAGE 1 - LOCATING THE STAR

The header of each Voyager data spectrum contains several types of pointing information. In addition to the scan platform AZ and EL and the corresponding RA and Dec, these include the spacecraft AACS error signals for displacements in pitch, yaw and roll, and the resulting components of limit cycle motion in the FOV coordinates L and W. Also recorded is a 2x2 matrix which is used to transform relative displacements in L and W into relative displacements in RA and Dec. AZ and EL and the error signals about the principal axes are fundamental values determined from the spacecraft engineering data; all other pointing data are computed from these quantities and a knowledge of the spacecraft orientation in inertial space. The relations between these various quantities are illustrated in Figure 2.4.

In the initial stage of SPBIN the observed intensity, in a selected range of channels, is displayed vs 'delta W', where 'delta W' is the relative displacement in the W coordinate with respect to a user specified RA and Dec. An example of such a display is seen in the example in Fig 4.3. If a point source is obviously present in the data it will produce a local maxima in the intensity distribution. The shape of this intensity distribution can be directly compared with a smooth normalized intensity distribution whose center and height are controlled with the cursor (the dotted curve). The goal of matching the observed intensity distribution to the template distribution is simply to define the location, in delta W space, of the on-axis point. Once the on-axis point has been located spectra can be accumulated, corrected for off-axis effects and extracted. The expected intensity distribution, or template, defines the instrumental response to a star passing through the UVS FOV in the dispersion direction. The particular shape is well defined and observed to be constant for each spacecraft. This shape is due to vignetting of the stellar beam by the mechanical baffels which define the FOV. The full-width-half-maximum response for each spacecraft is 0.10°. In the region of the bare microchannel plate ($\lambda < 1281$ Å), its shape is invariant and highly symmetric. There is a 5 to 10% asymmetry in the shape in the longer wave length channels, presumably caused by the shift of the wavelength of the incident photons as a function of off-axis angle with respect to the strong sensitivity gradient in this part of the detector. The template curves in SPBIN have been obtained directly from fits to the observed instrumental response to bright stars.

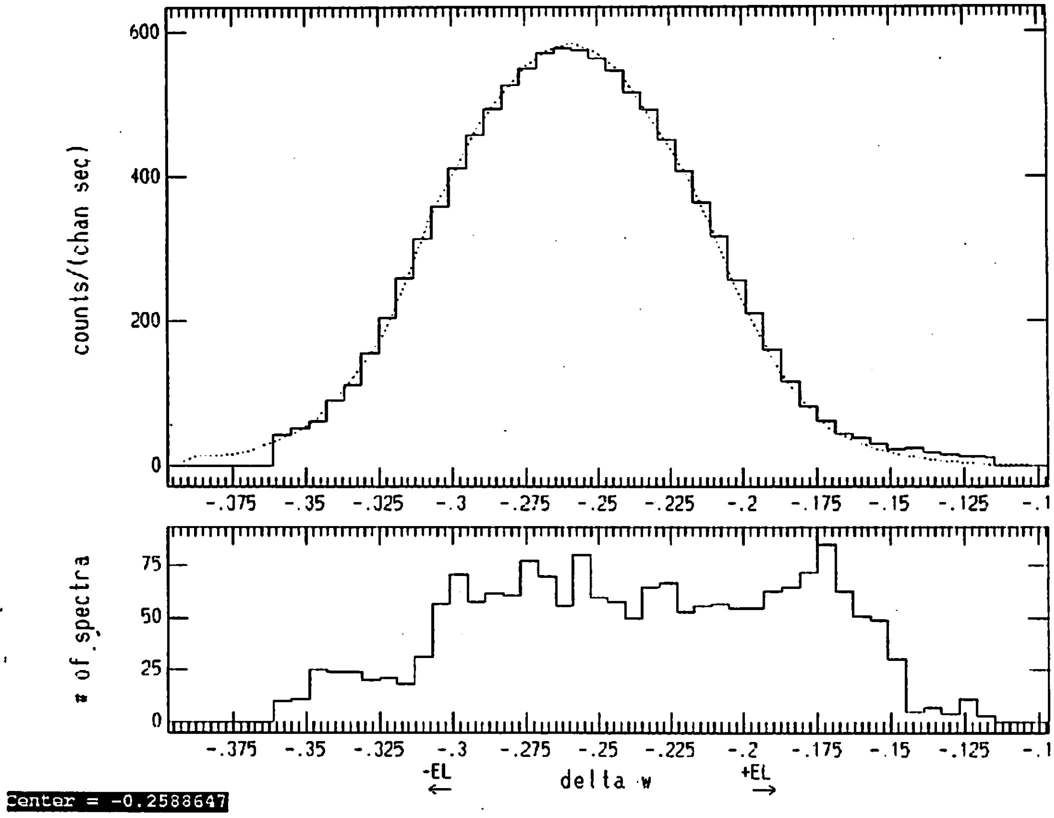
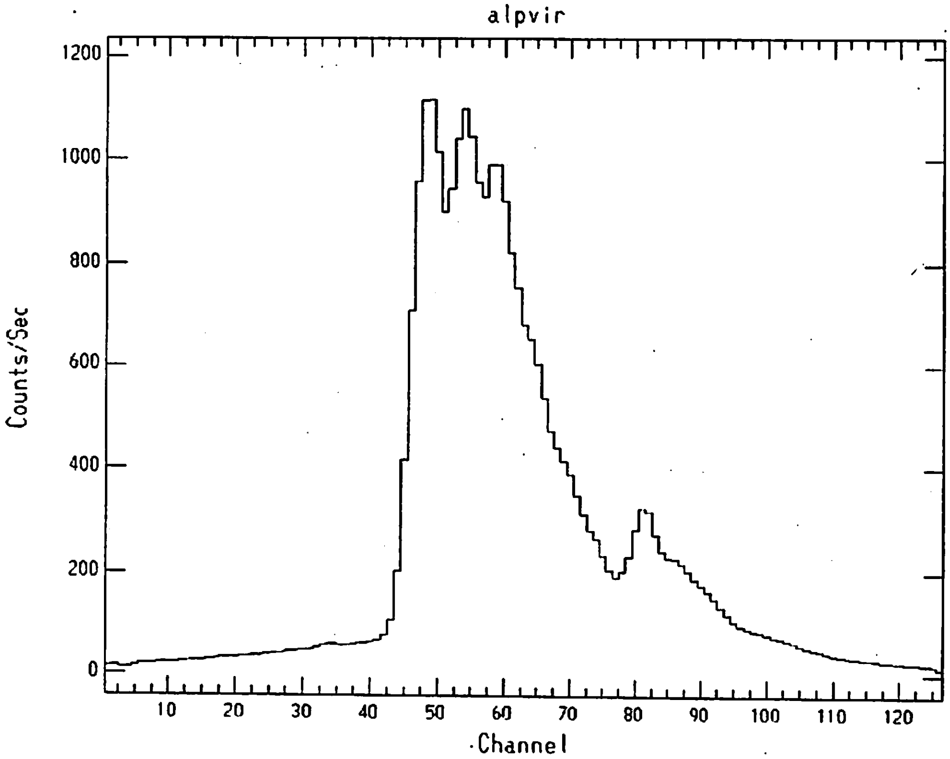


Figure 4.3

Figure 4.3 shows the first stage of SPBIN for a Voyager 1 observation of alpha Vir. Here the limit cycle motion extends several tenths of a degree in W and the intensity in channels 40-65 (900 to 1130 A) is seen to strongly peak near delta W = -0.26°. The star is observed to be well centered in the FOV and the limit cycle motion carries it well into the wings of the FOV response. The dotted curve has been placed with the cursor so that its peak intensity and centroid closely match the observed intensity distribution. Note that the width of the expected intensity distribution is invariant. The on-axis point for this particular data set is thus specified in delta W. It should be pointed out that the origin of the delta W scale in SPBIN is defined with respect to the absolute RA and Dec given to SPBIN by the user. The sizes and locations of the bins within the array can be controlled by fixing a maximum and minimum range in delta W over which the binning should occur. SPBIN employs a fixed number of 50 bins.

Figure 4.3.1



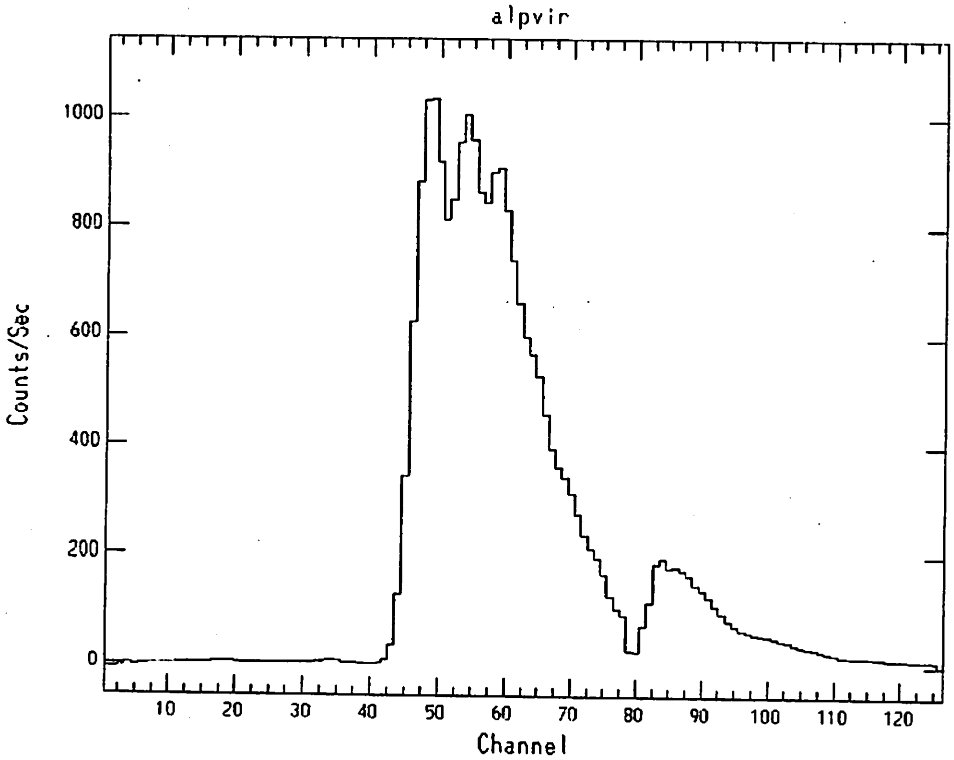


Figure 4.3.2

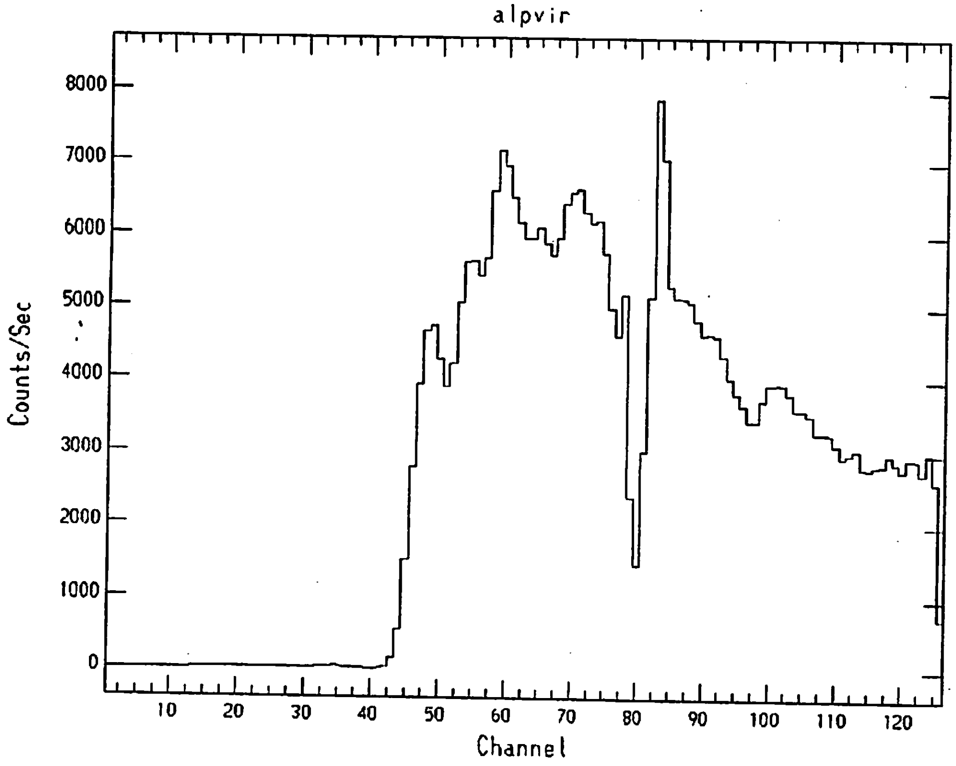
4.3.2 USEFULL ADVICE IN USING STAGE 1

In stage 1, binning will fail if the given RA and Dec are not in close proximity to the values contained in the spectral headers of the data set. Check your coordinates in SP-BIN with those in the data set for consistency.

The observed intensity distribution may not match expected point source response curve if any of the following conditions occur:

1. There is more than one UV bright star in the FOV.
2. The limit cycle motion fails to bring the star near the center of the FOV.
3. The stellar source is variable on a time scale comparable to the length of the data set. If you expect this to be the case, bin over shorter time periods.
4. The star has "moved" with respect on-axis location in delta W. This can occur when data files of several days in duration are binned. This is caused by a slight shifting of the AZ/EL grid with respect to the RA/Dec frame due to spacecraft orbital motion. This motion is nominally taken into account in the computing the pointing information in the spectral header, however, small drifts can occur causing an apparent broadening of the observed response curve. Again, bin over shorter time periods.
5. The source is faint and you have neglected to subtract sky background.

Figure 4.3.3



4.3.3 STAGE 2, ACCUMULATING SPECTRA

After the star has been located with respect to the center of the FOV, spectra can be accumulated, corrected for off-axis effects and displayed. This can be done by simply hitting the ‘n’ key. The result for the alpha Vir data set is given in Fig4.3.1 which shows a accumulated spectrum for alpha Vir.

Before accumulation is done, however, it is advisable to check several parameters. The ‘binwidth’ parameter should be set to the value of Δ W over which you wish to accumulate spectra. Setting binwidth to wide introduces increased off-axis correction effects, setting it to narrow reduces the number of spectra binned and hence the over all signal-to-noise. A value of binwidth=0.035° is often a good compromise. For a point source ‘shift’ must be set to ‘yes’. This invokes the correction algorithm for off-axis spectra. If your data is from a diffuse source, ‘shift’ should be set to ‘no’. Finally, before accumulating spectra it is always wise to display the observed intensity along the slit by hitting the ‘l’ key. One can use the cursor and ‘j’ and ‘k’ keys to restrict the L range of spectra being binned.

After spectra have been binned and accumulated the remaining data reduction steps are quite simple. The accumulated spectra can be descattered (3.1.6) by hitting the ‘s’ key. (See Fig 4.3.2). Absolute calibration (see 3.1.7) by hitting the ‘c’ key (See Fig 4.3.3). The final step is to write the output to a file, this is accomplished by hitting the ‘n’ key. Once a spectrum is written in stage 2, SPBIN is exited. Writing out a spectrum can be done at any point in stage 2, if the calibration has been applied, the results are written into a 2-location file with location 1 being the extracted spectrum in units of photons cm^{-2}s^{-1}Å^{-1} and location 2 corresponding to the relative statistical errors.

The SPBIN parameters used to reduce the alpha Vir data in this sample are given in Table 4.3.

TABLE 4.3

SPBIN Parameter List for Previous Example

input = “alpvir” List of Voyager UVS input data files

output = “alpvir.out” List of IRAF final spectra images

Ly_files = “alpvir.lya” List of Lyman background files

(locranges = “1-1881”) List of location ranges to use

(chranges = “43-65”) List of channel ranges to use

(ra = 200.637) Right Ascension of object (+-DD:MM:SS)

(dec = -10.901) Declination of object (+-DD:MM:SS)

(pointing = no) Include bad pointing locations

(spectra = no) Include bad spectra locations

(interactive = yes) Run task interactively

(genlog = no) Generate a logfile of parameters used

(divisor = 1.732) Divisor used to compute percentage errors

(background = no) Subtraction background during solution

```
(rtgscale = INDEF) Scale to apply to RTG background
(Lyscale = INDEF) Scale to apply to Lyman background
(directory = “voyager$db/”) Logical template directory
(rtgfname = “rtg”) RTG filename in ‘directory’
(fpnfname = “fpn”) FPN filename in ‘directory’
(calfname = “cal”) Calibration filename in ‘directory’
(matfname = “m35”) Scattering matrix filename in ‘directory’
(slitfunc = “slit_func”) Slit function filename in ‘directory’
(windw = no) Window delta W during aspect solution
(mindw = -0.05) Minimum delta W window position
(maxdw = 0.1) Maximum delta W window position
(windl = no) Window delta L during aspect solution
(mindl = -5.) Minimum delta L window position
(maxdl = 5.) Maximum delta L window position
(center = -0.25886470079422) Center of fitted slit function
(height = 585.12890625) Height of fitted slit function
(dlmin = 0.16174870729446) Minimum delta L value determined
(dlmax = 0.69322288036347) Maximum delta L value determined
(binwidth = 0.035) Sum spectra within center +/- binwidth
(shift = yes) Shift off-axis spectra for final spectrum
(coords = “”) graphics cursor input
(device = “stdgraph”) graphics device for plots
(mode = “ql”)
```

4.4 ASCII OUTPUT: ASCIIOUT

ASCIIOUT enable one to write out the results of a reduced Voyager spectrum in a standard ASCII output format. ASCIIOUT assumes a standard calibrated spectrum as input and outputs the contents of each channel in the following format for a point (or a diffuse) source.

Column 1: CHAN - channel number n
Column 2: w(Å) - central wavelength L_n
Column 3: Ph/Å - photons cm^{-2} s^{-1} $Å^{-1}$ ($ster^{-1}$)
Column 4: Erg/Å - ergs cm^{-2} s^{-1} $Å^{-1}$ ($ster^{-1}$)
Column 5: CNTS/S - counts s^{-1}
Column 6: UNC - Relative Statistical Uncertainty
Column 7: Flag - Data Flags {0=good, 1=unreliable}

The user can either set data flags for a set of channel ranges or zero out a set of channel ranges. For example, channels 3 and 4 or both spacecraft are very insensitive and are frequently zeroed out. The header contains the following information:

1) Input file name
2) A comment line
3) An indication as to a point or diffuse source spectrum
4) Spacecraft ID (V1 or V2)
5) Spacecraft Event Time of data (YR/DDD/HH:MM:SS.SSS)
6) Data Mode
7) # of Spectra accumulated
8) Duration in seconds.

A partial example of an example of ASCIIOUT file is contained below.

```
ASCIIOUT IN_FILE: xi_per.v2.out Comments: xi_per voy 1 - point source
V2:1980/178/15:00:00.000 DMODE=GS3 #SPECTRA=1731 DUR(S)=6647.050
```

CHAN	w(Å)	Ph/Å	erg/Å	CNTS/S	UNC	FLAG
1	518.08	-1.5493E-1	-5.940E-12	-6.7332E-2	5.0615E-2	0
2	527.34	-1.0946E-1	-4.123E-12	-4.8017E-2	5.3709E-2	0
3	536.60	0.0000E0	0.0000E0	0.0000E0	0.0000E0	1
4	545.86	0.0000E0	0.0000E0	0.0000E0	0.0000E0	1
5	555.12	-3.5520E-2	-1.271E-12	-1.5211E-2	6.1741E-2	0
6	564.38	3.6887E-2	1.2983E-12	1.5631E-2	5.9904E-2	0
7	573.64	7.3014E-2	2.5284E-12	3.0487E-2	5.2852E-2	0
8	582.90	5.1931E-2	1.7697E-12	2.1420E-2	5.3890E-2	0
9	592.16	3.3879E-2	1.1365E-12	1.3810E-2	5.8926E-2	0
10	601.42	2.8294E-2	9.3454E-13	1.1304E-2	5.4800E-2	0
11	610.68	5.0295E-2	1.6360E-12	1.9593E-2	6.3931E-2	0
12	619.94	6.4201E-2	2.0572E-12	2.4346E-2	5.5931E-2	0
13	629.20	8.4731E-2	2.6750E-12	3.0899E-2	5.5670E-2	0
14	638.46	6.7641E-2	2.1045E-12	2.3822E-2	5.9409E-2	0
15	647.72	6.0518E-2	1.8560E-12	2.0774E-2	5.6107E-2	0

4.5 BACKGROUND SUBTRACTION: BKGND

There are two primary sources of background in Voyager spectra, a relatively featureless dark count spectrum and a diffuse emission line spectrum. The origins of these two components are discussed in 3.1.4 and 3.1.5, respectively. The most straight forward means of removing both sources of background is to use observations of adjacent source-free regions of the sky near the target and directly subtract these from your data. Often such background is not readily available and other means of estimating the background components must be employed. This is the task of BKGND.

BKGND uses a source-free sky background spectrum as a spectral template to decompose the target spectrum into its background components. BKGND then uses those components to form a 'synthetic' background which can be removed from the data. Successful use of BKGND relies on several conditions. First, the template spectrum must contain no sources; files of such template spectra exist for both spacecraft. Second, the template spectrum should possess sufficient integration time to be compatible with the S/N requirements of the observations in question. Third, BKGND assumes that some region of the target spectrum contains no direct (non-scattered) photon signal. For example, this is almost universally the case for all sources in the 500 to 900 Å range of the Lyman continuum but would not be the case for the handful of known EUV sources such as HZ 43 or G191 B2B.

The use of BKGND is illustrated by the example of the input parameter list in Table 4.5. The source file, 'src_files', contains the data you wish to background subtract and the locations to be used within this file are specified by the parameter 'srcloc'. These locations can be the entire file, however, they should be those most representative of the sky background. For example, if a bright star is being background subtracted, it is best to use location ranges where the star is furthest off-axis. This can be determined from an examination of the TSPLOT records.

The location of the template background spectrum is specified by the parameters 'bkg_files' and 'bkgloc'. This can be part of the source file, but usually it is a file specifically constructed from other observations of known source-free regions of the sky, often of long duration. The template spectrum must originate from the same spacecraft as the source spectrum. Two channel ranges must be set for the proper operation of BKGND. These are specified by the parameters 'rtgchans' and 'Lychans'. The parameter 'rtgchans' refers to the range of channels in the spectrum defined as containing no intrinsic photon events. This serves as a measure of the dark count level in both the source and template spectra. For example, if the observation consists of a star which is not an EUV source (which is nearly always the case), then channels in the region of the Lyman continuum ($\lambda < 900$ Å) should contain only a non-photon dark counts and a pseudo-continuum of scattered photons from the FUV ($\lambda > 900$ Å) continuum, if any. The reason for this is, of course, is that the opacity of the interstellar medium shortward of the Lyman limit is so large for most sources that no intrinsic emission from the source is expected. There does exist a ubiquitous He I 584 Å emission line from the interplanetary medium (see 3.1.5) which is centered on channels 4 and 6 in Voyagers 1 and 2, respectively. Choosing 'rtgchans' to lie between this line and 900 Å is standard procedure; 'rtgchans' = 15-35 is nearly always a good choice for both spacecraft.

The second set of channel ranges which must be set is 'Lychans', which defines the peak of the Lyman alpha sky background emission in the spectrum. It is assumed here that the origin of this line in both the source and template spectrum is resonant scattering of solar Lyman alpha in the interplanetary medium. In Voyagers 1 and 2 the Lyman alpha line is observed to peak in channels 74 and 76, respectively. Selecting several channels, or just one channel, to define the Lyman alpha intensity is common. If the source is relatively faint and the Lyman alpha background clearly stands out then it is safe to assume that relatively little intrinsic stellar continuum is contained within the Lyman alpha channel ranges. If, on the other hand the star is relatively bright and the Lyman alpha region is observed to be in 'absorption' then care must be taken to minimize the amount of stellar continuum being subtracted along with the sky background. This can be done by selecting just a single channel to define 'Lychans' and seeking a range of locations in your source file where the source is observed to be most off axis. It is important to remember to set three remaining parameters before running BKGND. The parameters 'rtgscale' and 'Lyscale' should both be set to 'INDEF', if you wish to have them determined by BKGND. If numerical values are set for these parameters then the synthetic background spectrum will have these values. The parameter 'matfname' should be set to be compatible with the descattering matrices for the spacecraft being used; 'm21' and 'm35', respectively.

The output of BKGND is a one-location file(s) specified by the parameter 'Lyfiles' which contains the synthetic background spectrum to be subtracted. This is the background file name which is used in SPBIN under the same parameter name 'Ly_files'. Associated with the synthetic background file are the two scale parameters 'rtgscale' and 'Lyscale' which are determined by BKGND and are also used in SPBIN. If a synthetic background spectrum is being used these parameters should initially be set to 'INDEF' in SPBIN. They can subsequently be modified in SPBIN. BKGND will also plot the results of the spectral decomposition of the source spectrum. Three count rate spectral components are shown, the dark count spectrum, the interplanetary emission spectrum and the residual source spectrum. If you want to look specifically at the interplanetary emission component with, say VPLOT, be aware it that contains no flat field correction.The use of BKGND is illustrated by the example of the input parameter list

TABLE 4.5

Example of a BKGND parameter list

```
src_files = “hd206165.v1” List of source count-rate spectrum files
srcloc = “5161-17940” List of source location ranges to use
bkg_files = “skybak.90” List of source-free sky background files
bkgloc = “43-43” List of background location ranges to use
Ly_files = “hd206165.v1.lya” List of output Lyman background files
(usebkgnd = yes) Use source-free syk background files
(genlog = no) Generate a logfile of parameters used
(pointing = no) Include bad pointing locations
(spectra = no) Include bad spectra locations
(scale = 1.) [sec] Background scale factor
(rtgchans = “15-40”) List of RTG channel ranges to use
(rtgscale = 3.8928859233856) RTG particle scale factor
(Lychans = “75-77”) List of Lyman channel ranges to use
(Lyscale = 0.0058966181240976) Lyman scale factor
(interactive = yes) Run task interactively
(directory = “voyager$db/”) Logical template directory
(rtgfname = “rtg”) Filename of RTG spectra in ‘directory’
(fpnfname = “fpn”) Filename of FPN spectra in ‘directory’
(matfname = “m21”) Filename of Scattering Matrix in ‘directory’
(xlabel = “Channel”) x-axis label
(ylabel = “Counts/interval”) y-axis label
(coords = “”) graphics cursor input
(device = “stdgraph”) graphics device for plots
(mode = “ql”)
```

APPENDIX A UVS DISPERSION RELATIONS

The UVS instruments have similar dispersions of 9.26 Å per channel. The relation between channel number and wavelength is:

$$\lambda(\text{Å}) = \lambda_0 + 9.26\ \text{n}. \quad (1a)$$

Where is the central wavelength of channel number n in angstroms and

(Voyager 1) $\lambda_0 = 530.20$ Å,
(Voyager 2) $\lambda_0 = 508.82$ Å.

TABLE 1A

Central Wavelength Vs Channnel Number

Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)	Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)	Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)
1.	539.46	518.08	26.	770.96	749.58	51.	1002.46	981.08
2.	548.72	527.34	27.	780.22	758.84	52.	1011.72	990.34
3.	557.98	536.60	28.	789.48	768.10	53.	1020.98	999.60
4.	567.24	545.86	29.	798.74	777.36	54.	1030.24	1008.86
5.	576.50	555.12	30.	808.00	786.62	55.	1039.50	1018.12
6.	585.76	564.38	31.	817.26	795.88	56.	1048.76	1027.38
7.	595.02	573.64	32.	826.52	805.14	57.	1058.02	1036.64
8.	604.28	582.90	33.	835.78	814.40	58.	1067.28	1045.90
9.	613.54	592.16	34.	845.04	823.66	59.	1076.54	1055.16
10.	622.80	601.42	35.	854.30	832.92	60.	1085.80	1064.42
11.	632.06	610.68	36.	863.56	842.18	61.	1095.06	1073.68
12.	641.32	619.94	37.	872.82	851.44	62.	1104.32	1082.94
13.	650.58	629.20	38.	882.08	860.70	63.	1113.58	1092.20
14.	659.84	638.46	39.	891.34	869.96	64.	1122.84	1101.46
15.	669.10	647.72	40.	900.60	879.22	65.	1132.10	1110.72
16.	678.36	656.98	41.	909.86	888.48	66.	1141.36	1119.98
17.	687.62	666.24	42.	919.12	897.74	67.	1150.62	1129.24
18.	696.88	675.50	43.	928.38	907.00	68.	1159.88	1138.50
19.	706.14	684.76	44.	937.64	916.26	69.	1169.14	1147.76
20.	715.40	694.02	45.	946.90	925.52	70.	1178.40	1157.02
21.	724.66	703.28	46.	956.16	934.78	71.	1187.66	1166.28
22.	733.92	712.54	47.	965.42	944.04	72.	1196.92	1175.54
23.	743.18	721.80	48.	974.68	953.30	73.	1206.18	1184.80
24.	752.44	731.06	49.	983.94	962.56	74.	1215.44	1194.06
25.	761.70	740.32	50.	993.20	971.82	75.	1224.70	1203.32

Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)	Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)	Channel Number	Voyager 1 λ(Å)	Voyager 2 λ(Å)
76.	1233.96	1212.58	101.	1465.46	1444.08	126.	1696.96	1675.58
77.	1243.22	1221.84	102.	1474.72	1453.34			
78.	1252.48	1231.10	103.	1483.98	1462.60			
79.	1261.74	1240.36	104.	1493.24	1471.86			
80.	1271.00	1249.62	105.	1502.50	1481.12			
81.	1280.26	1258.88	106.	1511.76	1490.38			
82.	1289.52	1268.14	107.	1521.02	1499.64			
83.	1298.78	1277.40	108.	1530.28	1508.90			
84.	1308.04	1286.66	109.	1539.54	1518.16			
85.	1317.30	1295.92	110.	1548.80	1527.42			
86.	1326.56	1305.18	111.	1558.06	1536.68			
87.	1335.82	1314.44	112.	1567.32	1545.94			
88.	1345.08	1323.70	113.	1576.58	1555.20			
89.	1354.34	1332.96	114.	1585.84	1564.46			
90.	1363.60	1342.22	115.	1595.10	1573.72			
91.	1372.86	1351.48	116.	1604.36	1582.98			
92.	1382.12	1360.74	117.	1613.62	1592.24			
93.	1391.38	1370.00	118.	1622.88	1601.50			
94.	1400.64	1379.26	119.	1632.14	1610.76			
95.	1409.90	1388.52	120.	1641.40	1620.02			
96.	1419.16	1397.78	121.	1650.66	1629.28			
97.	1428.42	1407.04	122.	1659.92	1638.54			
98.	1437.68	1416.30	123.	1669.18	1647.80			
99.	1446.94	1425.56	124.	1678.44	1657.06			
100.	1456.20	1434.82	125.	1687.70	1666.32			