PLANNING OBSERVATIONS

3.1 Introduction

In completing their proposal forms, proposers must confirm as nearly as possible the technical feasibility of their observations by submitting a separate Technical Justification for each one. This chapter provides calibration information about the EUVE Spectrometer, and guidelines for calculating observation parameters. Section 3.2 contains information on various software and data resources that are made available electronically by the EGO Center to help with Techinical Justification. Section 3.3 is provided to help determine quickly whether a prospective target is observable and merits further calculation to determine the required exposure time. In Sections 3.4, 3.5, and 3.6, the instrument's performance is described in terms of the effective area, spectral resolution, and average background, each a characteristic function of wavelength. These functions represent the most current knowledge of the instrument's performance and operating environment, based on both pre-launch measurements and in-orbit calibration observations.

The functions can be used with model source spectra to calculate instrument count rates and exposure times, generate simulated raw count spectra for proposed targets, and simulate the resolution of instrument spectra. The application of all the instrument characteristics to Technical Justification is discussed and illustrated with example calculations using simulated source spectra and the properties of the Spectrometer.

Section 3.7 provides two variations on a basic formula for calculating signal-to-noise levels for proposed observations once the source and background count rates have been estimated. Integration times for a required signal-to-noise level. can also be calculated from instrument count rates. In addition to the Technical Justification, these quantities are also required to fill out part 2 of the Target Summary Form which must be submitted with each proposal for Spectrometer observations. Technical Justifications for observations with the Scanners or Deep Survey instrument should follow similar lines, using the broadband instrument characteristics in sections 2.3 and A.3.

Sections 3.10, 3.8 and 3.11 present suggestions for planning spectroscopy of diffuse and extended sources, time-critical observations, and multiple sources. Section 3.9 outlines the treatment of proposals for targets of opportunity (TOO). The chapter ends with summary tables of reference constants and useful equations.

It is understood that estimates and simulations are somewhat uncertain. The guidelines of this chapter are intended to encourage well-prepared proposals, which can be considered comparable for the purposes of technical review. Proposers should consult the current UCB/EUVE Call for Observing Proposals, for the specific content requirements. Any necessary clarification of the *Handbook* contents may be obtained by sending mail to:

egoinfo@cea.berkeley.edu

3.2 Electronic Resources for Proposers

As stated in chapter 1, documentation and forms for the UCB/EUVE Call for Observing Proposals, including the forms and instructions for electronic submission, are available from the EGO Center via the CEA/EUVE anonymous *ftp* site, and the *WWW* site. In addition to the text and forms, a number of useful files and software tools are also available to aid applicants in preparing their proposals. You can access the *ftp* site by typing:

```
% ftp ftp.cea.berkeley.edu
```

or

```
% ftp 128.32.154.12
```

or by using the World Wide Web (*WWW*) URL:

http://www.cea.berkeley.edu/

Some of the following information is redundant with section 1.4.1, but different parts of the *ftp* site will be referenced, and some resources are available only through the *WWW*.

3.2.1 Access to *ftp* and *WWW* Online Software

The easiest way to access all electronic resources for proposal preparation is via the *WWW*. All materials specifically regarding this Call for Proposals are available via CEA's *WWW* site at URL:

http://www.cea.berkeley.edu/nra97

The Uniform Resource Locator (URL) for the CEA HomePage is:

http://www.cea.berkeley.edu/

After opening the Home Page, proposers can use mouse selections to access the *ftp* site, print the required materials, save them to disk, or obtain copies of the EGO Center software and instrument reference data. To access the CEA *ftp* site via the CEA *WWW* HomePage, select the item labeled **"FTP Access"**. This will list the top level directory of the CEA/EUVE *ftp* site. Select the directory *nra97* to view the recent Call for Proposals material. Be sure to view the file *README.txt* in this directory to get the most up-to-date instructions on accessing Call for Proposals material.

If necessary, one may obtain Call for Proposals information by sending mail to the *egoinfo* mail address given in section 3.1 above, but this will require additional turn-around time.

3.2.2 Instrument data files

Tabular listings of the Spectrometer effective area, spectral resolution, and background count rates used throughout this chapter are available from the CEA/EUVE *ftp* site. These functions are presented graphically in this chapter, and interpolated values are used in many of the example calculations.

Instrument function files are in the directory */pub/nra97/data*. To obtain data files using *ftp*, log onto the CEA/EUVE *ftp* site as in section 1.4.1, and go to the directory */pub/nra97/data*:

ftp> `cd /pub/nra97/data`

Be sure to view the *README_dat.txt* in this directory. Use the *ftp* command *get* to obtain the information file *README_dat.txt*:

ftp> `bin`

ftp> `get README_dat.txt`

This file contains a directory to the data files. The file names are:

README_dat.txt	Information on data file formats
(sw/mw/lw)_mdf.txt	Minimum detectable flux functions
(sw/mw/lw)_ea1.txt	Effective area in -1st order, for short, medium, and long wavelength channels
(sw/mw/lw)_res.txt	Channel spectral resolutions
(sw/mw/lw)_bgspec.txt	Channel background spectra
(sw/mw)_ea2.txt	Channel effective areas in -2nd order
lw_ea234.txt	-2nd, -3rd, and -4th order effective areas for long wavelength channel
data.tar	A single tar file containing all the above data files.

Then use the *get* command to obtain selected data files, or the entire set of files in tar file format.

3.2.3 IRAF/EUV Software Packages

Some tasks in the IRAF/EUV data reduction software will be helpful to experienced IRAF users for proposal preparation. The simulated instrument spectra used to illustrate the example calculations were produced in IRAF with version 1.4 of the IRAF/EUV software packages, and version 1.8.1 of the reference data. The tasks **mkeuvspec**, for rebinning continuum spectra, and the Spectrometer simulation task **specmod**, were used. The software packages are available in complete form from the CEA/EUVE *ftp* site, in the directory

/pub/software/euv1.7 [1]. It is strongly recommended that users obtain the *README* file and read that first. The */pub/software/euv1.7* directory site includes instructions for installing the packages in your local IRAF environment. The calibration data necessary for running some of the tasks reside in the *ftp* directory */pub/reference/egodata1.14*. A Software User's Guide may be obtained from the */pub/documents* directory.

The IRAF/EUV task **specmod** was used to produce the simulated observation spectra shown in this chapter. **Specmod** takes a list of line fluxes or a one-dimensional spectrum image in photons/cm^2/sec as input, and multiplies each value by the user-supplied integration time, and the instrument effective area. The resulting spectrum is convolved with an instrument point spread function, and rebinned with a bin width (w) chosen by the user.

Note that the input to **specmod** must be in units of photons/cm^2/sec. Model spectra for continuum sources generally have units of photons/cm^2/sec/Å, and must be converted into an IRAF spectral image in photons/cm^2/sec before being input to **specmod**, using the IRAF/EUV task **euvtools.mkeuvspec**. **Mkeuvspec** takes a two-column ASCII file of wavelength and photons/cm^2/sec/Å as input, interpolates and partitions the spectrum according to the output resolution specified by the user, and multiplies each value by the desired output bin width to produce a spectrum in photon flux units for input to **specmod**. It is generally advisable when rebinning input spectra for **specmod** to choose a resolution greater than that required for the simulated spectrum to be produced, by a factor of 2–4.

3.2.4 WWW Utilities

The CEA *WWW* HomePage also contains an Guest Observer HomePage, which provides a number of services, including two routines that may be helpful in writing GO proposals. Select the **"Science"** link, followed by **"The Guest Observer Program"** links, to view the GO HomePage. Following the **"Resources for Proposers and Observers"** and **"Science Tools and Software"** links, followed by link item titled **"Target Visibility"** will lead to a service that creates a plot showing the approximate suitability of a target for viewing over a period of one year, based on target coordinates and instrument/spacecraft pointing constraints. The selection titled **"ISM Server"**[2] calculates the attenuation of a number of sample wavelengths, given the column densities of H I, He I, and He II. These services are only provided via the *WWW*.

3.3 Observability

For an object to be observable with EUVE, its position must be accessible to the chosen instruments for a sufficient period, and its flux must be bright enough after attenuation by the intervening He I/H Icolumn to be detected by the instruments in the requested exposure time. For technical reviews, it is assumed that proposed targets have been tested for suitability of position and minimal observability by the proposer.

[1] This directory is separate from the Call for Proposals directory, *nra97*

[2] based on the description of the ISM absorption in "Interstellar Medium Continuum, Autoionization, and Line Absorption in the Extreme Ultraviolet" by T. Rumph, C.S. Bowyer, and S. Vennes, 1994 AJ (in press)

The Technical Justification of observations does require specific demonstration that each proposed target will produce spectra with the expected count rates and signal-to-noise ratio. Demonstrations may be based on either source and ISM models, or previous observations in the EUV. In cases where the object has already been observed in the EUVE all-sky survey, ROSAT WFC sky survey or with a comparable spectroscopic instrument, proposers can apply these results directly to the Technical Justification.

Any special pointing requests, including requests for dithered observations, should be justified in terms of required S/N. Dithering refers to a strategy of making many pointings near a target, to wash out pseudo-periodic fixed pattern noise in the detectors. At this time, dithering is only applied to sources with a continuum spectrum whose S/N is 10 or more in a single resolution element($\Delta\lambda$). The size of a resolution element is defined in section 3.5. Proposers should request dithering for targets with unknown EUV brightness or spectral distribution, but the EGO Program cannot guarantee this treatment for any proposed source. See section 4.2 for operational details of dithered observations.

In addition, it has been determined that the Deep Survey detector has been damaged near the center. For this reason, observations of EUV objects with instrument count rates greater than 1-3 counts per second in the Deep Survey instrument will be disallowed within .3 degrees of boresight. Higher count rates may be acceptable near the outside of the field of view, but images will be poorly focussed.

3.3.1 Source Position

Observations with EUVE are conducted under some constraints on certain target positions at some times. Pointing directions are limited to no more than 90 degrees from the anti-sun direction. There are also some restrictions on roll angles to prevent excessive heating of the spacecraft in some attitudes. Proposers should be aware that these constraints will impose an upper limit on the total amount of time that any particular target can be observed during the pointed period covered by the current Call for Proposals.

The suitability of a target may be tested for a limited range of roll angles using the **Target Visibility** routine available through the GO Homepage on the *WWW* (see sections 3.2 and 3.2.1). This program plots and lists suitability of a target, on a scale of $0 - 1$ for each day over in a year. A suitability of 0 means the target is not observable, and a value of 1 means that conditions for beginning a continuous observation of the required length are optimal on that day. Suitability is based on anti-sun angle, a range of ± 10 degrees in roll angle, earth occultation of the target, availability of guide stars, and interference from bright objects, like the moon, in the star trackers. Each calendar day corresponds to approximately 25 ksec of nighttime observing.

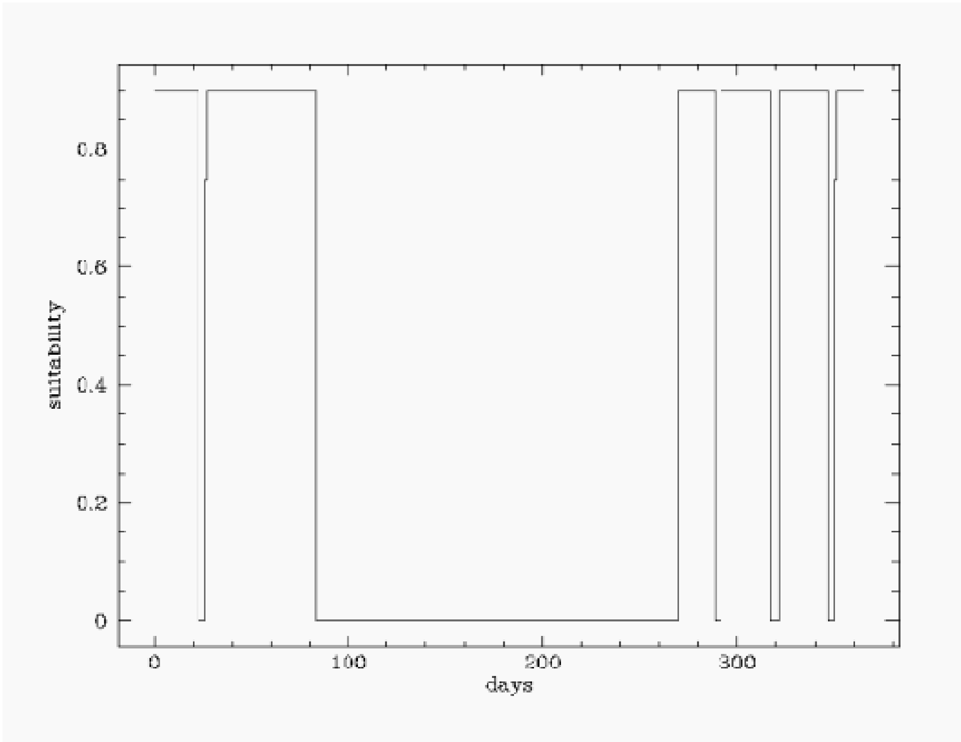
An example of the output of **Target Visibility** for the white dwarf HZ43 is shown in figure 3-1.

Suitability of HZ43

- Right Ascension: 13:16:21.9 (199.0913)
- Declination: +29:05:57.0 (29.0992)
- Exposure: 40000

Suitability 04/01/94 – 04/01/95

The following image is a plot of the suitability values listed below. The suitability is plotted for one year starting with this month. Suitability curves vary from 0 (not suitable) to 1 (best suitability). These results are very coarse with a resolution of 1 day and only sampling roll angles at 10 degree.



Days From 04/01/94 Through 04/01/95

Figure 3-1: Target visibility for example object HZ43 during one year, for roll angles in the range $(-10 - +10)$.

The suitability is about .9 for just under half the days in the year starting on April 6, 1994. For many targets, this program will report a large number of days when the target suitability is above .5, but this does not take into account any requirements for the scheduling of other targets, which may be more constrained. Proposers requesting repeated observations may want to run the visibility routine to confirm that their target(s) will be available for several times the required period. Proposers whose observations are in any way time-critical (e.g. TOO's, periodic events, or coordinated observations) can use the visibility routine to check which parts of the year their target is available.

Note that the existence of days with high suitability does not guarantee that the target will be scheduled on the first, or even any, of these days. The main utility of the program is to identify targets which are mostly unsuitable, or which would be difficult to schedule if other requirements were added, as in programs of coordinated observations. Other physical limitations on pointing and scheduling than those mentioned may further limit target availability. Refer to section 4.3 in chapter 4 for more detail on policies concerning satellite pointing and the handling of anomalies in the observation schedule.

3.3.2 Model Spectra and Predicted Fluxes

In cases where the target flux to the telescope is not available from existing observational data, proposers should use a model spectrum for the target which accounts for both the source flux and interstellar absorption. The Scientific Justification section of such proposals must explain briefly how input fluxes rates for each proposed target were derived, including the type of source flux model and the simulation of absorption by the interstellar HeI/HI column. The assumed hydrogen column density to each source must also be noted on the Target Summary Form. Simulated spectra are not required in the proposals, but proposers are encouraged to present a spectral model for continuum sources if possible, as this can be very helpful for both the Technical Justification, and the technical review process.

Any model spectrum used for Technical Justification must represent the source flux *at the telescope.* This means that both the source physics AND the effect of interstellar medium (ISM) absorption must be accounted for. All instrument characteristics and equations given in this chapter are intended for use with estimates of source flux *after* ISM absorption.

Proposers may wish to use the "ISM server" routine in the GO *WWW* HomePage to calculate the effects of ISM attenuation on their model spectra. Proposers should keep in mind that this routine is based on a particular model of the ISM [18]. It provides estimates of attenuation, but accuracy cannot be guaranteed, and results are highly dependent on the choice of column densities input. The same routine is also available as the IRAF task **euvspec.ism** in the IRAF/EUV software package, version 1.4.

Absorption models and hydrogen column densities can be found in a number of references, such as [18], [15], and [10]. A more complete list of references for column densities to specific targets is included in Appendix C of this *Handbook.* A table of attenuation factors produced by the ISM server for a HeI/HIration of .1 is included in in the directory *nra97/data* of the CEA/EUVE *ftp* site. If a particularly low column density (e.g. $\leq 10^{18}$) is assumed, the proposer must justify the figure on the basis of a previous observation of the same source or one nearby.

Throughout the rest of this chapter, line emission sources and continuum objects are often treated separately. Model spectra for emission sources may consist of a list of fluxes in photons/cm^2/sec. Each line will be treated as a δ-function, and fluxes should represent an integration over the width of the line. Model spectra for continuum sources must be expressed in units of photons/cm^2/sec/Å as a function of wavelength in all Technical Justification materials. Bin sizes must be clearly stated, and the wavelength of each bin will be assumed to be at the center. Sources with lines as wide or wider than a resolution element, or those with both continuum and emission features, should be treated as continuum sources. Spectra representing diffuse or extended sources, such as the moon, clouds, or filaments, may be expressed in photons/cm^2/sec/Å/sr. Note that these units are proportional to, but not equivalent to Rayleighs.

3.3.3 Minimum Detectable Flux

Observability of potential targets in the EUV can be tested at a go/no-go level by comparing model spectra to calculated minimum detectable flux functions. Curves representing the minimum detectable flux (MDF) as a function of wavelength have been made by folding the Spectrometer effective area function together with the expected background rates from diffuse airglow, scattered light, and detector noise at each wavelength. This produces a "bottom line" spectrum which the source flux ($\mathcal{F}$) at the telescope must exceed to be detected at the $3-\sigma$ level within a nominal exposure ($\mathcal{T}$) of 40K seconds.

The MDF function thus represents the calibrated sensitivity of the instrument, in units of photon flux from the source, and can be compared directly to flux measurements or model source spectra in the appropriate units. Model source spectra to be compared to the MDF must include interstellar absorption between the source and the instrument.

Separate MDF functions are included for sources characterized by emission lines and by continuum spectra. Both functions exhibit the wavelength cutoffs of the filter materials in each channel, and the effect of diffuse geocoronal light, which causes the peaks at 304 Å and from 584 to 608 Å, where 304 appears in second order.

At its lowest points, the MDF is determined mostly by the Spectrometer effective areas, intrinsic channel plate noise, and the rate of particle detections. See section 3.6 for a discussion of the count rates associated with these sources of background.

NOTE: SHOWING THAT EXPECTED SOURCE FLUX EXCEEDS THE MDF IS NOT ADEQUATE TECHNICAL JUSTIFICATION for any observation. The MDF functions are provided to help observers quickly assess the viability of targets before embarking on these more complex calculations. Ability to obtain acceptable signal-to-noise levels within a specified integration time must also be demonstrated.

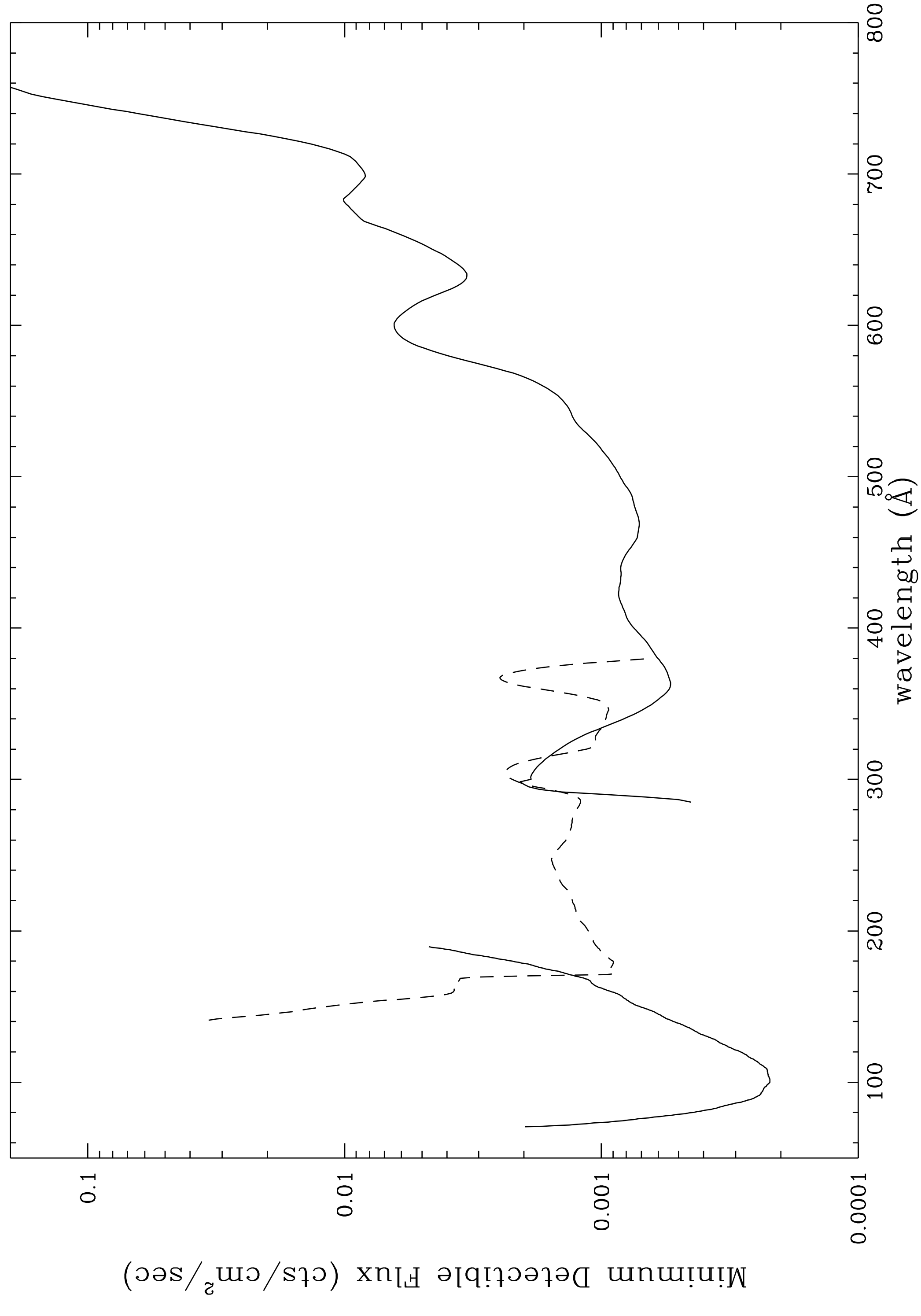


Figure 3–2: Minimum detectable flux for line sources; dashed line is medium wavelength channel.

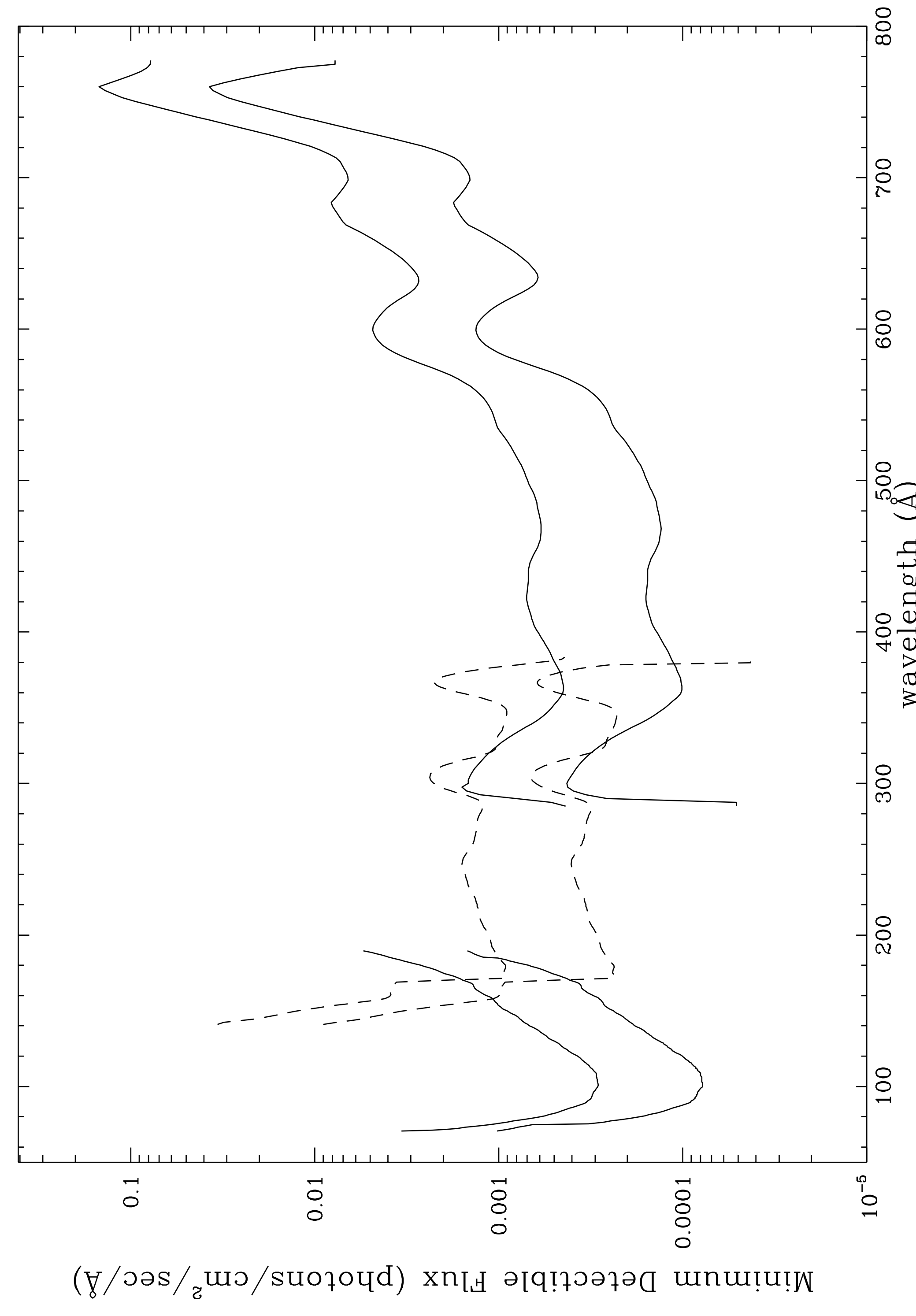


Figure 3−3: Minimum detectable flux for continuum sources.
Upper curve: 1(Å)/bin; lower curve: 10 (Å)/bin.

3.3.3.1 Emission Line Sources

Figure 3-2 shows a graph of the MDF function for line emission in each channel, in photon flux units, appropriate for comparison to a list of integrated line fluxes. Proposers using model spectra in photons/cm^2/sec/Å should use the continuum MDF function in the next section. The plot was made using values from the second column in the tables *sw_mdf.txt, mw_mdf.txt*, and *lw_mdf.txt*, which are available from the *ftp* site as given in section 3.2[3]. The function for the medium wavelength channel is set off as a dashed line to distinguish it from the short and long wavelength ranges.

The nominal exposure of 40K seconds used to produce the MDF was chosen somewhat arbitrarily, so the shape of the function is more important than the levels literally depicted here. If a source's expected flux ($\mathcal{F}$) is marginal or below the MDF function, a 3-σ observation might be achieved with a longer integration. Since σ for Poisson counting statistics is equal to the square root of the time-integrated source signal (S), the signal-to-noise S/σ is proportional to $\sqrt{T}$. This means a 3-σ measurement can be obtained from a flux lower than the MDF by multiplying the observation time by the factor: $\left(\frac{\mathrm{MDF}}{\mathcal{F}}\right)^2$. More detailed formulae for calculating observing times and signal quality are presented in section 3.7. The practical limit on the duration of any single observation will be determined by the Peer Review Panel and scheduling requirements.

Example: Emission source observability An example spectrum for an arbitrary late-type star model is shown in figure 3-4. The model consists of fluxes at a number of wavelengths, in photons/cm^2/sec. Lines have been approximated as δ-functions, with an intrinsic width of $\lambda/\Delta\lambda \simeq 10^3$. The intervening HIcolumn was estimated as 10^{18}/cm^2, and the ratio HeI/HI is 0.1. The spectrum is plotted on the same scale as the MDF function (figure 3-2). Lines observable in 40K seconds can be identified visually by comparing the two plots or by comparing the model fluxes to values interpolated from the files *(sw/mw/lw)_mdf.txt*.

Because of the steepness of the SW MDF, the lines between 70 and 100 Å will not all be observed. The medium and long wavelength spectra could be fairly bright, but the features near the airglow transitions at 304, and 584 Å will fall on top of high backgrounds, which will introduce noise later when the background is subtracted. Comparing the model fluxes with the numerical MDF listing shows that the stronger lines near 256 and 304 Å should be visible, but the line near 584 Å will probably not be observed. Lines longer than 650 Å, while not near any airglow features, will likely fall prey to decreasing effective area and high ISM attenuation.

3.3.3.2 Continuum Sources

The MDF for continuum sources depends much more strongly on how the data are binned during post-processing. Interesting features of some faint sources may be rendered detectable by using wider spectral bins. Figure 3-3 presents the MDF of each Spectrometer

[3] See section 1.4.1 for basic orientation if you have not used *ftp* before.

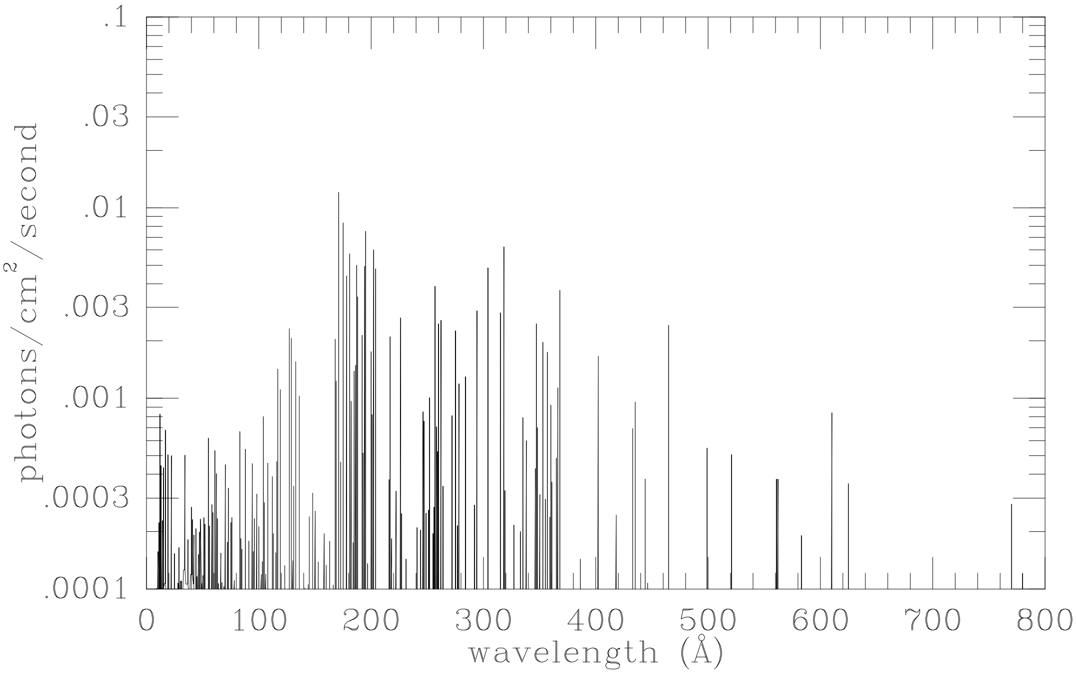


Figure 3-4: Example of a model spectrum for a late-type star, including estimated ISM absorption from HI=10^{18}/cm^2, HeI/HI= 0.1.

channel for two sizes of wavelength bins. Like the MDF for emission sources, this function is based on a 40K second observation, and shows the flux required for a 3-σ measurement. Each of the upper curves corresponds to 1-Å wide bins, and the lower curves to an alternative binning at 10 Å per bin. Again, the medium wavelength channel is set off as a dashed line. Column three of table *(sw/mw/lw)_mdf.txt* gives numerical values for the use of a 1-Å bin.

To scale the MDF for any bin size, divide the 1-Å MDF function by $\sqrt{N}$, where N is the width of the bin in Angstroms. This conversion method produces a relatively conservative (high) MDF for wavelengths not dominated by the background, but is a minimal flux near the airglow features. At 584 Å for example, the ratio of the 1-Å to the 10-Å MDF is about 3.5, much closer to $\sqrt{10}$ than at 400 Å, where the 10 Å binning requires only about the one fifth the flux as the 1-Å binning for a 3-σ measurement.

The bin size should be balanced against the requested integration time such that flux from the target at the telescope exceeds the resulting MDF level while providing sufficient spectral resolution for the proposed science.

Example: continuum source observability A possible model spectrum for G191-B2B is plotted in figure 3-5, in photons/cm^2/sec/Å on a linear scale. The white dwarf model program that produced the spectrum assumed an intervening neutral hydrogen column of 1.76×10^{18}/cm^2 and a ratio of helium to hydrogen of HeI/HI= 0.086. Comparison with the continuum MDF indicates that a 40K second exposure should produce a very bright spectrum with 1-Å bins. Prominent features include a HeIIabsorption feature at 304 Å and the HeIabsorption edge at 504 Å. The first will get lots of interference from diffuse emissions but the 504 edge should still have good S/σ at the 1-Å binning.

There is a more thorough discussion of the spectral resolution in section 3.5, which may be applied to continuum sources to determine the best bin size for a particular measurement.

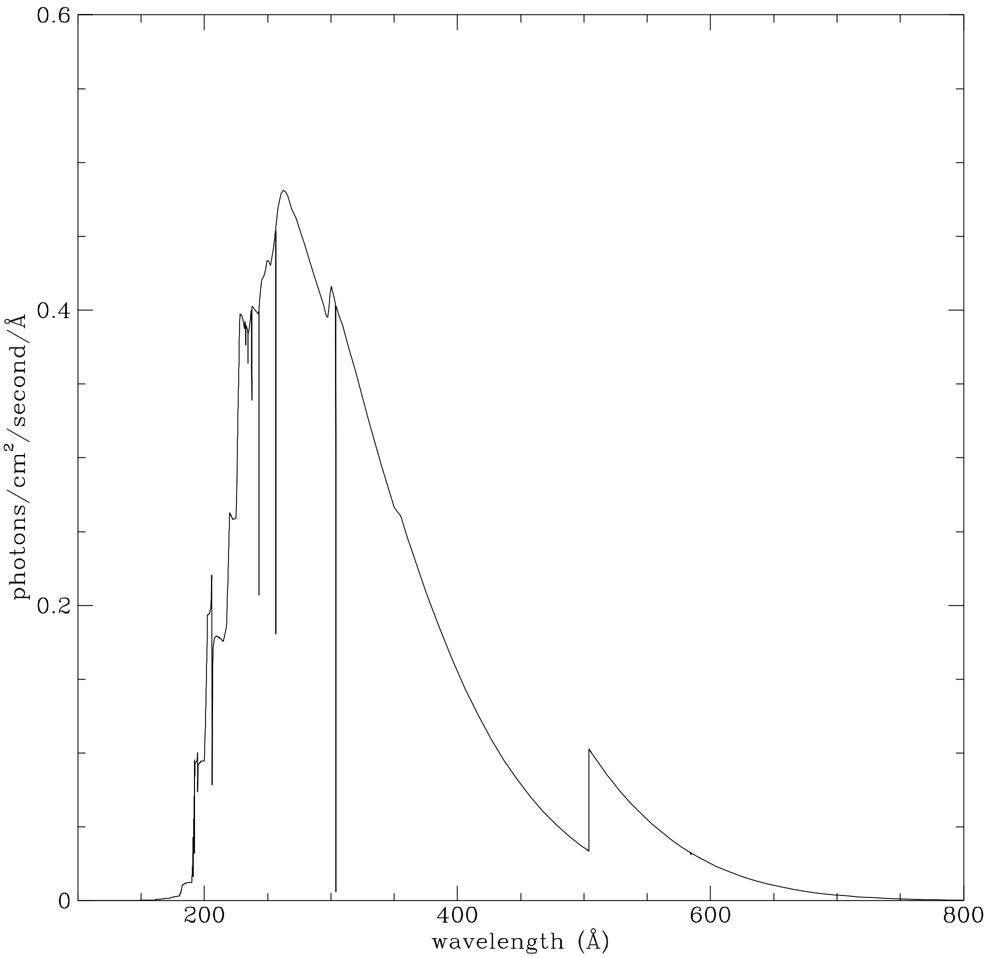


Figure 3-5: Model spectrum for G191-B2B; HI= 1.76×10^{18}, HeI/HI= 0.086. Model contributed by Dr. David Finley

3.4 Effective Area Functions

After establishing that a target object is likely to be detected by the Spectrometer, proposers should estimate the source count rates in the instruments using their model spectrum and the Spectrometer effective area. Once the source count rates and predicted background levels are known, proposers can use them to determine integration times that will meet their scientific requirements.

The effective area of each Spectrometer channel has been measured in both pre-launch and in-orbit calibrations. Functions for first-order (n = −1) effective areas derived from in-orbit calibration data are plotted in figure 3-6. Numerical values are available from the CEA/EUVE *ftp* site in the files *sw_ea1.txt*, *mw_ea1.txt*, and *lw_ea1.txt*. The Spectrometer channel effective area functions pictured in this Handbook and currently available in the *ftp* site are the most current values. Only these effective areas should be used for all proposal calculations under the current UCB/EUVE Call for Observing Proposals.

Expected Spectrometer count rates in each detector from a target object may be obtained by using effective area functions in one of two formulas in sections 3.4.1 or 3.4.2, depending on whether the target is to be considered a line source or a continuum source.

The simplifying assumption that all the light in each bin was from a single wavelength in first order will be sufficient for most cases, but proposals for continuum objects whose intensities peak at short wavelengths may need to address the effect of contamination from higher orders. See section 3.4.3, and the files for higher-order effective areas, *sw_ea2.txt, mw_ea2.txt,* and *lw_ea234.txt* in the directory *nra97/data* of the CEA/EUVE *ftp* site. Diffuse and extended sources are considered in section 3.10.

3.4.1 Count Rates From Emission Line Sources

Spectrometer count rates for narrow emission features can be calculated by multiplying the integrated source flux by the local value of the effective area:

$$\mathrm{S}'_{em} = \mathrm{A}_{eff}(\lambda) \times \mathcal{F}(\lambda) \tag{3-1}$$

where S' is the source count rate in the resolution element centered at λ, in counts/sec, A_{eff} is the effective area in cm^2, and $\mathcal{F}$ is the source flux at the telescope, in photons/cm^2/sec. Raw source counts are simulated by multiplying this instrument count rate by an integration time.

The width of a spectral resolution element, $\Delta\lambda$ is assumed for the bin width in all technical reviews unless another bin width is explicitly stated. See section 3.5 for spectral resolution element sizes.

Because the Spectrometer channel bandpasses overlap, some features may be detected in both the short and medium, or the medium and long wavelength channels. Efficiencies, count rates, and the size of a resolution element will differ (see section 3.5), but the total projected counts can be combined to improve statistics as long as they come from detector areas with comparable background rates.

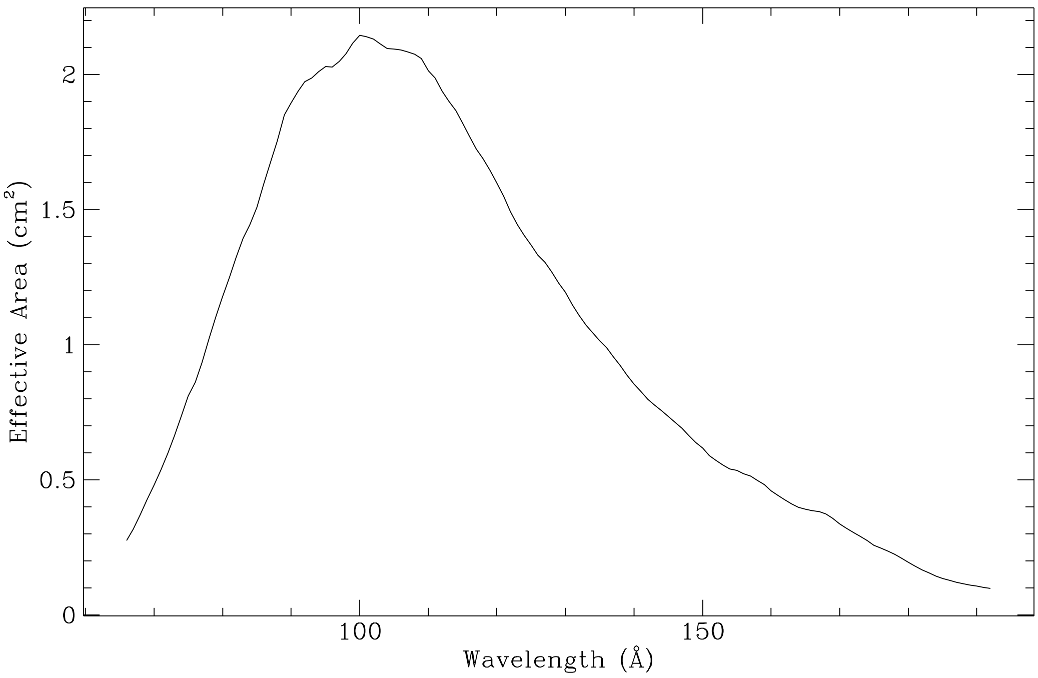


Figure 3-6: a) Spectrometer effective area, short wavelength channel.

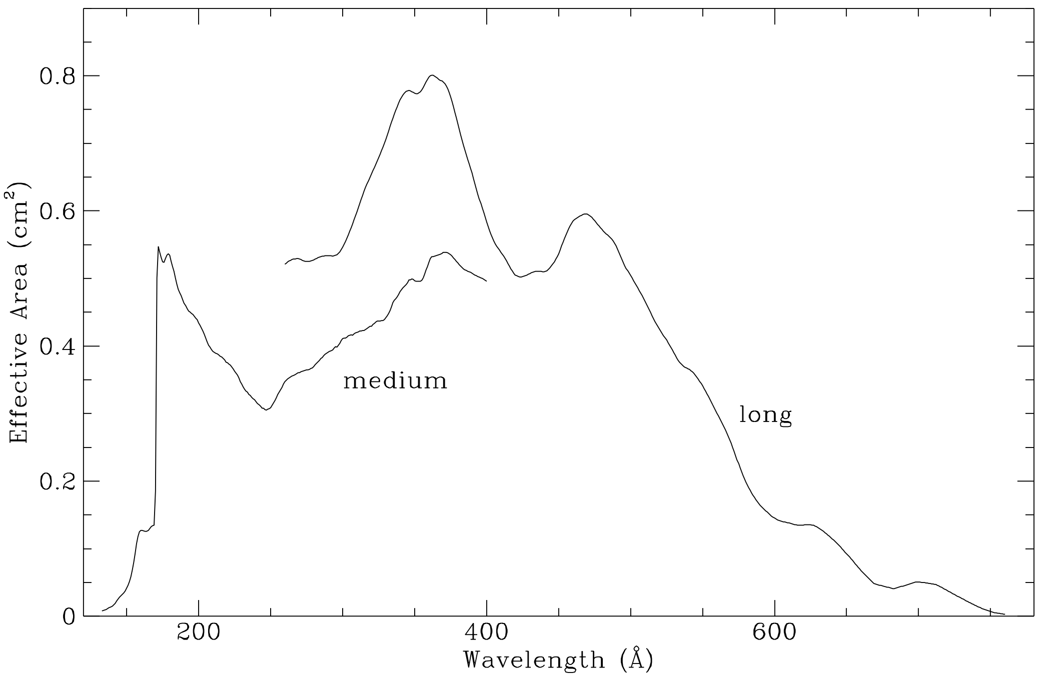


Figure 3-6: b) Spectrometer effective area, medium and long wavelength channels.

Emission/Absorption features in continuum sources

For broad lines or blends, a choice of bin size must be made, and the product of flux and effective area must be integrated over the width of the feature, as for a continuum source. Any object with both continuum of radiation and emission (or absorption) features should also be justified as a continuum source, and model spectra should be in units of photon flux/Å. For such observations, proposers must show that the features can be detected above (in) the continuum with the required S/N ratio.

Example: emission line source count rates Estimate detector count rates in each Spectrometer channel for lines of the late type star model spectrum in section 3.3.3.1. Since the lines are intrinsically narrow, distribution of the counts on the detector is entirely a function of instrument resolution. Multiplying the model source flux by values interpolated from the A_{eff} table using equation 3-1 produces Spectrometer count rates in counts/sec. The IRAF/EUV task **specmod** can also be used with a list of line fluxes as input, to produce instrument count rates for narrow emission features. Table 3-1 lists the projected count rates and widths for several emission features in the short, medium, and long wavelength channels. According to these instrument count rates, a 40 Ks observation would result in about 67 counts from the 104.1 Å line the short channel. The line at 171.06, will be detected in the short channel with 152 counts, and the medium channel with 242 counts. A line at 583.5 Å will have only about 1–2 counts in the long channel, and will be lost in the background from HeI584.33 Å. Those lines that do not have airglow interference will produce good measurements as long as they are well above the noise.

3.4.2 Count Rates From Continuum Sources

Model fluxes for continuum sources should have units of photons/cm^2/sec/Å. To produce instrument count rates from a continuum source spectrum, the A_{eff} function and spectrum must be partitioned with some bin size w, large enough to give adequate count rates. The product of the source spectrum with the A_{eff} function is then summed over some wavelength region of interest. Equation 3-1 becomes the sum:

$$S'_{cont}(\lambda) = \sum_{j=1}^{N} \mathcal{F}(\lambda_j)\, A_{eff}(\lambda_j)\, w \tag{3-2}$$

where $\mathcal{F}$ is the model source flux in photons/cm^2/sec/Å, $A_{eff}(\lambda_j)$ is the effective area function at wavelength λ_j, the center of the jth bin, in cm^2. The region of interest spans bins 1 through N, and w is the bin width in Å. This formula represents a binning which must

Table 3-1: Predicted count rates for a late type star model in the form of a line list

λ (Å)	source flux (photons/cm^2/sec)	instrument count rate (cts/sec) SW	MW	LW
83.0	6.70×10^{-4}	9.35×10^{-4}	-	-
104.1	8.04×10^{-4}	1.68×10^{-3}	-	-
127.0	2.32×10^{-3}	3.03×10^{-3}	-	-
129.0	2.07×10^{-3}	2.54×10^{-3}	-	-
171.06	1.20×10^{-2}	3.83×10^{-3}	6.05×10^{-3}	-
187.2	4.97×10^{-3}	6.00×10^{-4}	2.38×10^{-3}	-
222.0	3.25×10^{-4}	-	1.08×10^{-4}	-
246/247	1.61×10^{-3}	-	4.92×10^{-4}	-
303.8	4.83×10^{-3}	-	2.00×10^{-3}	2.72×10^{-3}
368.0	3.68×10^{-3}	-	1.97×10^{-3}	2.92×10^{-3}
583.4	1.91×10^{-4}	-	-	3.52×10^{-5}
610.0	8.39×10^{-3}	-	-	1.16×10^{-3}

be applied by the observer in reducing the spectrum. In using this formula for planning purposes, proposers must choose a spectral bin width that will demonstrate the viability of the program proposed. A raw source count spectrum is simulated by multiplying by the integration time, $\mathcal{T}$ in the sum.

Example: continuum source count rates A simulated raw count spectrum for the G191-B2B model was obtained using the IRAF/EUV Spectrometer simulation task, **specmod**, in the **euv.euvspec** package.

For this example, we made a target spectrum into an image with .1 Å resolution. **Specmod** was then run on the image with a bin width of .2 Å. The resulting spectra were oversampled with respect to the resolution element size in all channels, so they were reblocked at .5, 1.0, and 2.0 Å to show the best resolution achievable with the Spectrometer. The spectra for the medium and long wavelength channels are shown in figure 3-7 as counts integrated over 40K seconds.

In examining the spectrum, we see that the OIV absorption edge at 298 Å in the medium wavelength and HeIat 504 Å in the long band are easily identified, along with some narrow absorption features. There is a large contribution from geocoronal emission near the oxygen edge, and the absorption line at 304 Å may be lost in subtraction noise.

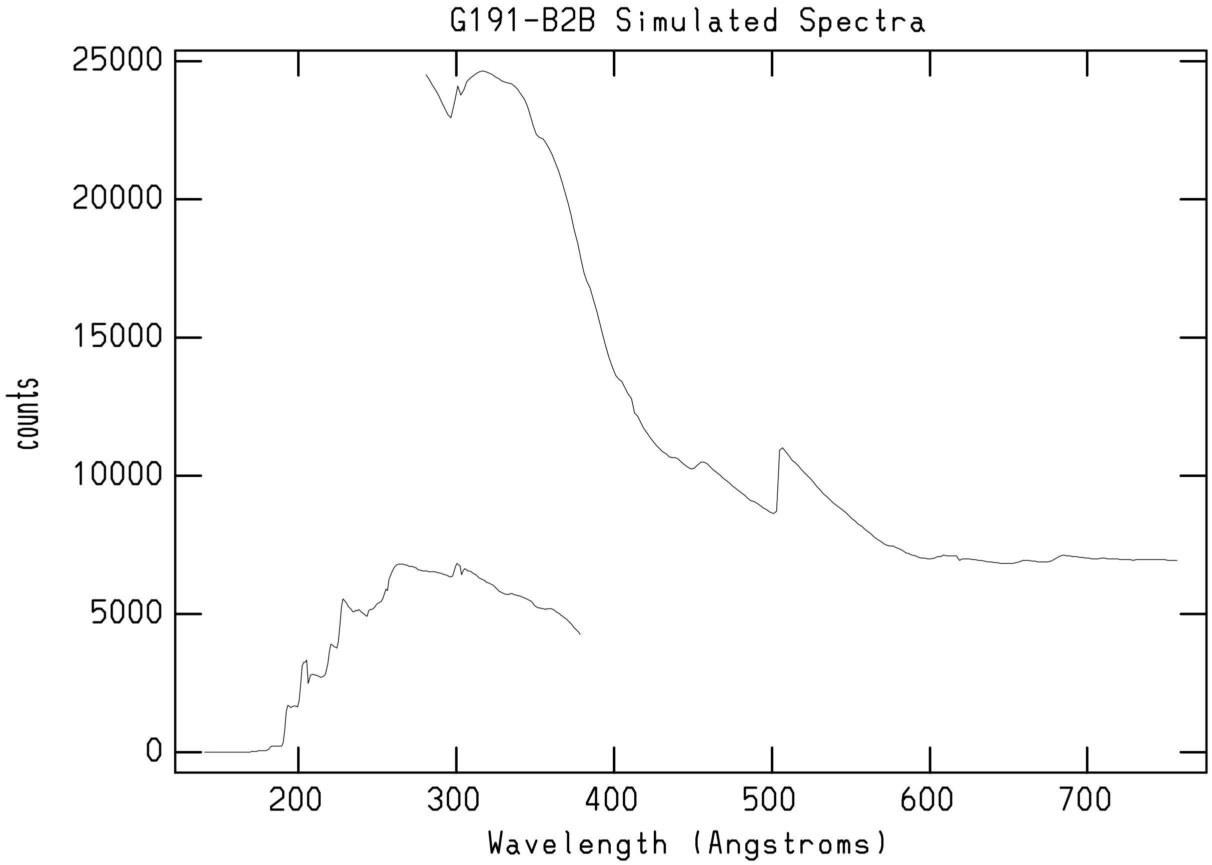


Figure 3-7: Simulated EUVE spectra for G191-B2B in medium and long wavelength channels. Source counts only.

3.4.3 Order Confusion

The EUVE Spectrometer design allows some light from higher ($n \leq -2$) inside orders to be imaged on each detector. Because the instrument is slitless, and each channel spans nearly a factor of three in wavelength, higher orders may be present in any spectra of very bright objects. Overlapping orders will make evaluation of some continuum intensities particularly complex, so it is advisable for observers to give this problem some consideration when writing proposals. Higher order spectra are superimposed on the first order spectra, at the spectral position $\lambda_n = n \times \lambda_1$.

To assist proposers in modeling their source throughputs, the effective areas, in cm^2, of the first few higher orders, as determined from a combination of pre-launch measurements and calibration observations, are shown graphically in figures 3-8, 3-9, and 3-10 below. Tabular versions of the effective areas are available from the CEA/EUVE *ftp* site, from the directory *nra97/data*, as detailed in section 3.2. The files are called *sw_ea2.txt, mw_ea2.txt,* and *lw_ea234.txt*. The absolute errors are estimated at $\leq 15\%$. The graphs and/or tables can be used to estimate the intensity of the higher order throughputs, based on the proposer's model of the source flux at the telescope.

Only -2nd order efficiencies are plotted for the short and medium wavelength channels; estimates of second order effects will be considered sufficient for the purposes of Technical Justification. In the long wavelength channel, -2nd -3rd and -4th orders are shown; proposers should consider carefully which are likely to affect their science program.

Example: Higher order contribution in emission spectrum In the late type star example above, the oxygen line at 610 Å in the long wavelength channel had a low count rate and a total of 2-3 counts in 40K seconds. In addition, the second order flux from the 303.8 Å line will also be imaged nearby. According to figure 3-10 and equation 3-1, this could be as much as:

$$4.83{\times}10^{-3}\,\mathrm{photons/cm^2/sec} \times 0.0335\,\mathrm{cm}^2 \times 40,000\,\mathrm{seconds} \simeq 6-7\,\mathrm{counts}$$

While this quantity may be successfully estimated and subtracted, the noise introduced in the process may render the detection questionable.

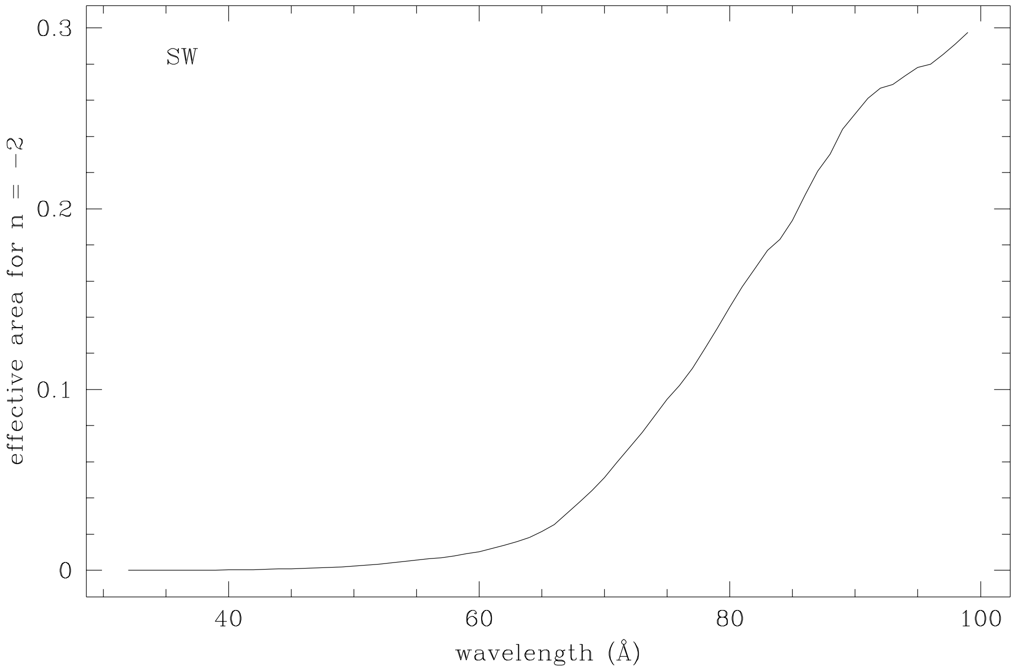


Figure 3-8: Short Wavelength second order effective area, in cm^2. Counts in -2nd order appear at $2 \times \lambda$. Errors $\leq 15\%$.

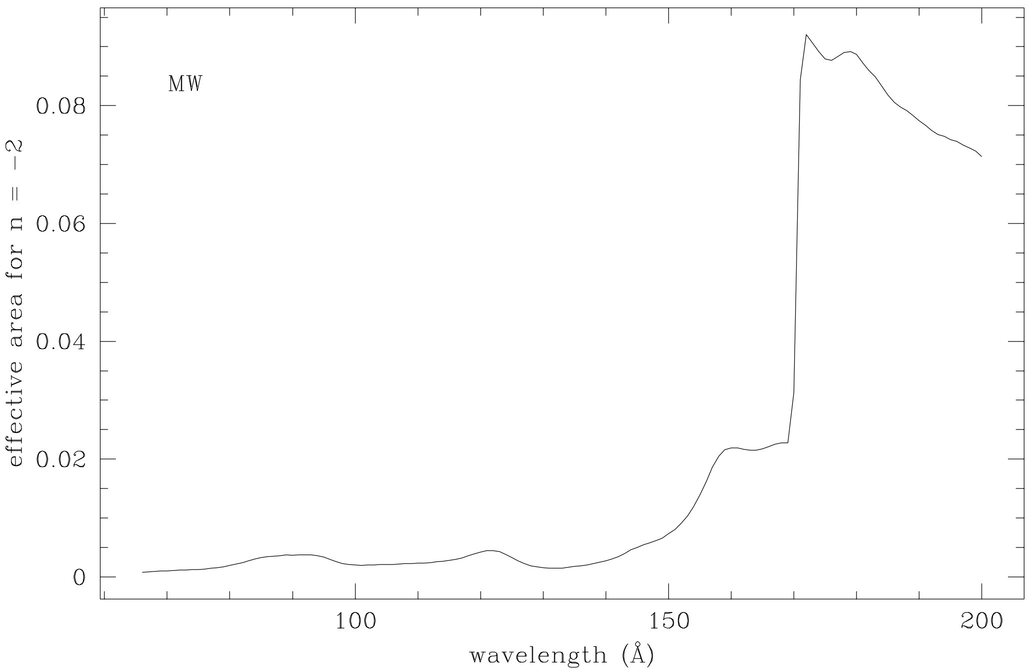


Figure 3-9: Medium Wavelength second order effective area. The spectrum will appear at values of $2 \times \lambda$. Errors $\leq 15\%$.

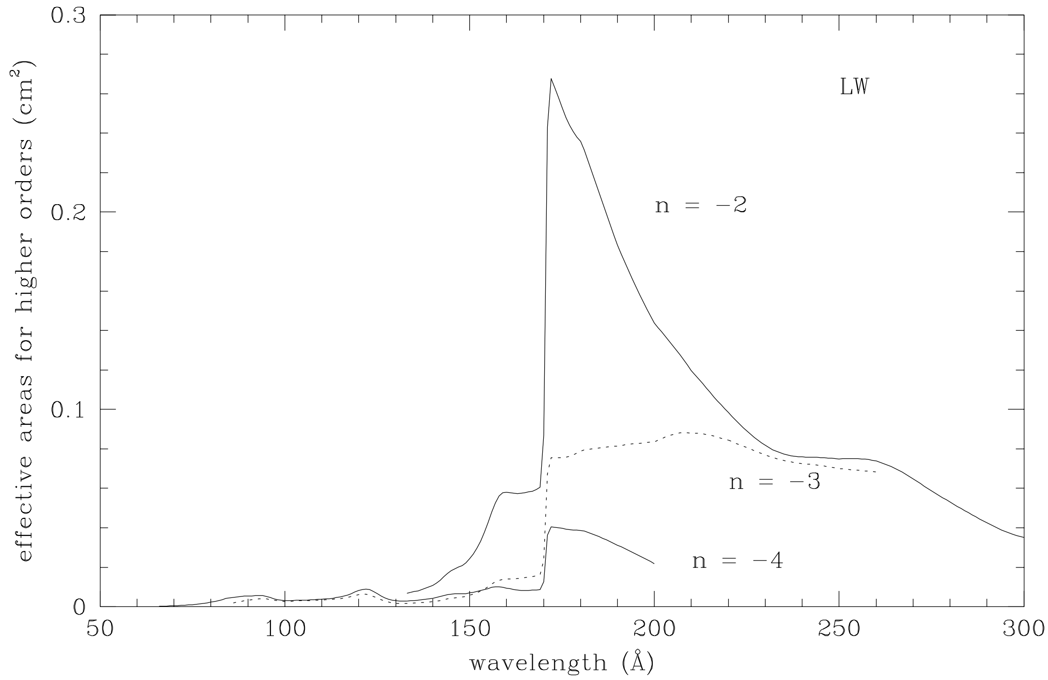


Figure 3-10: Long Wavelength inside order effective areas. Counts in nth order appear at values of $n \times \lambda$. Errors $\leq 15\%$.

3.5 Spectral Resolution

Testing the resolution of the simulated instrument spectra or features may also be desirable for some proposals. Spectral resolution has been measured at a number of wavelengths in each Spectrometer channel during calibrations both before and after launch. Figure 3-11 shows the results of these measurements, plotted as FWHM $\simeq \Delta\lambda$ in Å vs. wavelength for each channel.

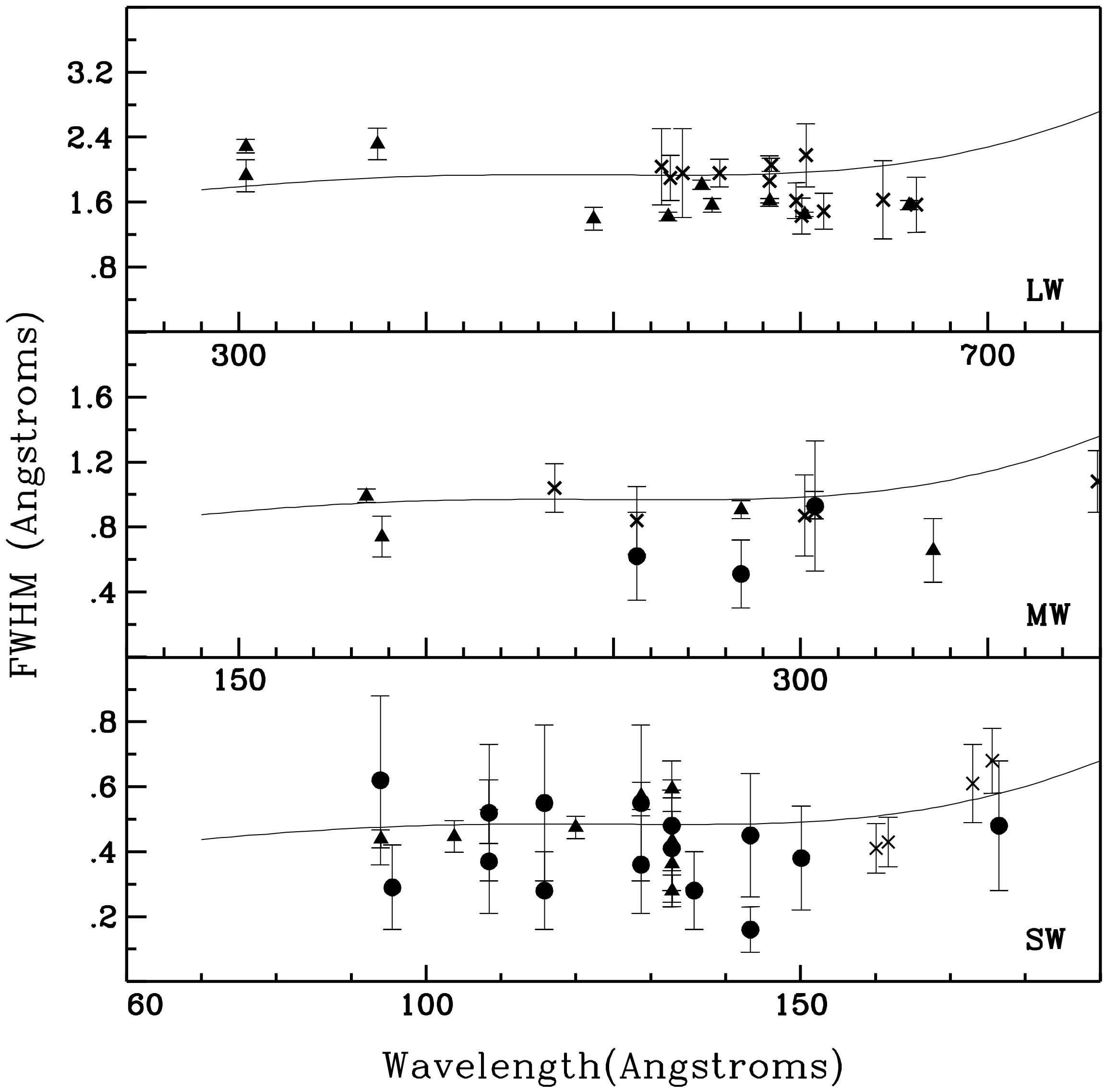


Figure 3-11: EUVE Spectral Resolution. X's: pre-launch measurements. Dots and triangles: measured post-launch. Solid line: theoretical values.

Theoretical curves based on the instrument design are overplotted. The FWHM of each unblended line approximates the size of the local resolution element ($\Delta\lambda$) in Å. Table 3-2 lists the numerical values for some of the points plotted in figure 3-11 In-orbit measurements are labeled with $*$'s. Values of the theoretical resolution function for each channel are available in the *nra97/data* directory of the *ftp* site, in the files *sw_res.txt, mw_res.txt*, and *lw_res.txt*.

Figure 3-11 shows that the size of the resolution element is fairly constant throughout most of the bandpass in each channel. The spectral resolution is expected to degrade toward the long end of each bandpass, due mainly to grating aberrations. For the purpose of Technical Justifications the size of $\Delta\lambda$ may be assumed to be approximately constant in each channel. Because of design symmetries, the width of $\Delta\lambda$ differs from channel to channel by a factor of two:

$$\begin{array}{r} \text{LW:}\ \ \Delta\lambda \simeq 2.0\ \text{Å} \\ \text{MW:}\ \ \Delta\lambda \simeq 1.0\ \text{Å} \\ \text{SW:}\ \ \Delta\lambda \simeq 0.5\ \text{Å} \end{array}$$

These nominal resolution element sizes may be used for most Technical Justification calculations. The effective resolution of any data set will be degraded if the satellite aspect is not accurately known.

Proposers who wish to observe fainter continuum sources may choose to improve the signal-to-noise in their simulated spectra by using a larger bin size during post-processing. This approach is not recommended for line sources unless the total flux is the only quantity of interest, as choosing a greater bin width will adversely affect line width and center. Observations concerned with resolving closely spaced features should be justified directly from the expected count rates, background, and the resolution element size.

Example: Line emission resolution In the late type star example, several pairs of lines are separated by 1 Å or less, but this has a different impact in each Spectrometer channel. For example, a pair of features in the MW range, at 246 and 247 Å, are shown in a simulated spectrum in figure 3-12. Since the two lines are separated by just barely the width of $\Delta\lambda = 1$ Å, their peaks are not separable, even without any background or Poisson noise. By contrast, features separated by 1 Å in the short wavelength channel such as the lines at 187 and 188 Å, are well separated; see figure 3-13.

3.5.1 Imaging Resolution

The Spectrometer's resolution in the imaging direction has also been measured, using many of the same spectral features. Some individual measurements of angular resolution appear in table 3-2, with errors. This information may be useful to any proposers who wish to observe multiple sources.

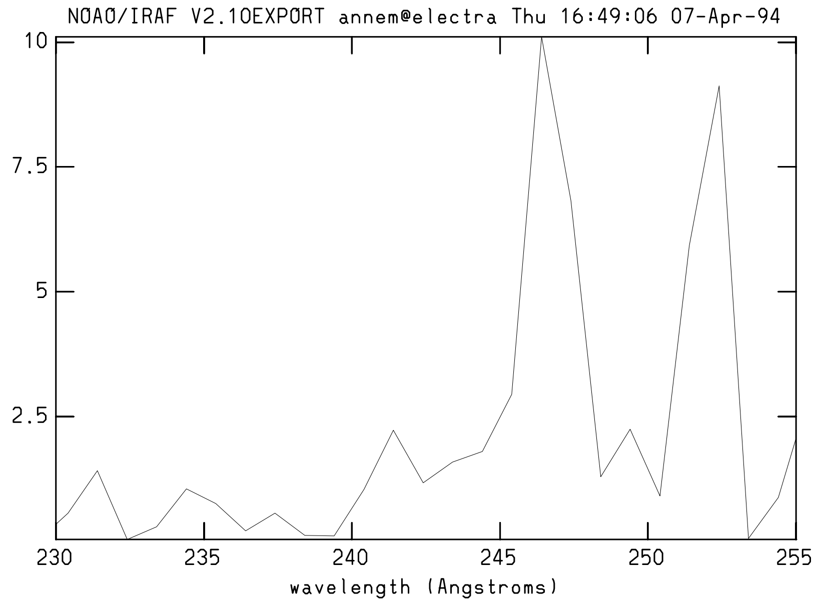


Figure 3-12: Late type star spectrum near 246/247 Å feature. Y-axis is integrated counts.

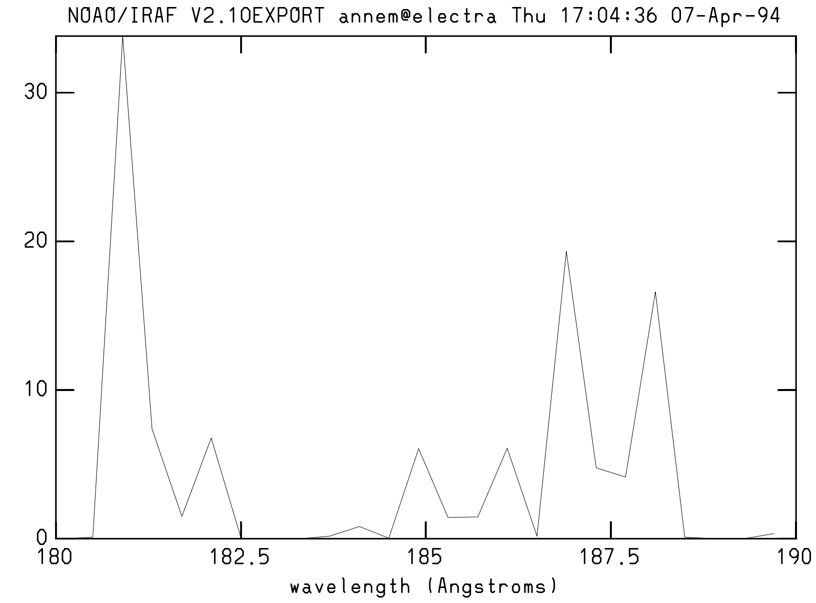


Figure 3-13: Late type star spectrum near 187/188 Å feature. Y-axis is integrated counts.

Table 3-2: Spectral Resolution Measurements. $*$ indicates in-orbit data.

channel	λ	$\Delta\lambda$ (Å)	σ (Å)	$\Delta\Theta_i$(asec)	σ_i(asec)
Short	$*$93.4	0.44	0.028	16.74	2.93
	$*$95.5	0.29	0.13		
	$*$103.8	0.45	0.049	22.60	2.93
	$*$108.4	0.52	0.21	19.67	1.67
	$*$115.8	0.55	0.24		
	$*$120.0	0.47	0.035	19.67	2.09
	$*$128.7	0.57	0.042	12.14	3.35
	$*$132.8	0.59	0.028	26.79	2.93
	$*$132.8	0.36	0.12	31.40	2.93
	$*$132.8	0.43	0.091	38.51	5.86
	$*$132.8	0.40	0.049	23.86	6.70
	$*$143.3	0.45	0.19		
	$*$150.1	0.38	0.16		
	160.1	0.41	0.076		
	161.7	0.43	0.076		
	173.0	0.61	0.12		
	175.6	0.68	0.10		
	$*$176.5	0.48	0.20		
Medium	$*$184.1	0.991	0.042	14.65	1.67
	$*$188.2	0.740	0.12	14.65	4.60
	234.3	1.04	0.15		
	256.3	0.84	0.21		
	$*$284.1	0.51	0.21		
	301.1	0.87	0.25		
	303.8	0.89	0.04		
	$*$303.8	0.935	0.084	19.67	1.67
	$*$335.4	0.656	0.20	23.02	1.67
Long	$*$303.8	2.29	0.084	20.51	1.25
	$*$303.8	1.93	0.20	23.44	0.838
	$*$374.12	2.32	0.20	17.58	1.67
	$*$489.54	1.40	0.14	23.44	0.838
	525.8	2.04	0.47		
	$*$529.3	1.42	0.056	21.35	0.419
	530.5	1.90	0.28		
	537.0	1.96	0.55		
	$*$547.2	1.82	0.056	21.77	0.419
	$*$552.8	1.56	0.084	20.93	0.419
	556.8	1.96	0.17		
	583.4	1.86	0.31		
	$*$583.6	1.62	0.028	23.44	0.419
	584.3	2.06	0.08		
	597.7	1.62	0.22		
	600.6	1.43	0.22		
	$*$602.2	1.45	0.028	22.60	0.419
	602.9	2.18	0.39		
	612.4	1.49	0.22		
	644.1	1.63	0.48		
	$*$658.1	1.56	0.056	22.19	0.419
	661.9	1.57	0.34		

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3.6 Estimated Background Levels

Proposers will need to make estimates of the expected background in the Spectrometer channels in order to determine the exposure times that meet their science criteria. The source signal in any spectral bin has an uncertainty proportional to the square root of the number of source counts, $\sqrt{S}$. The additional sources of background increase the signal error by a factor slightly larger than the square root of the integrated background, $\sqrt{B}$.

This section provides estimates of the average background rate in each of the Spectrometer channels, which can be used to calculate the expected background counts per spectral bin for a given exposure, and in turn for determining expected signal quality and exposure requirements. The various sources of background counts in the Spectrometer detectors and the standard method of background subtraction are described. Then two kinds of estimates are given: a single number of counts/second/Å for each channel, for use over parts of the detectors where the background is fairly flat, and a more detailed background spectrum, also in counts/second/Å, for use over sections of the spectrum and areas where the background rate is changing rapidly. The use of these rates to calculate the average total background counts over a spectrum aperture is discussed, and the results are used in section 3.7 below to determine signal quality.

3.6.1 Sources of Spectrometer background

The background components fall into three main categories:

1. Distributed background: Counts from intrinsic channel plate noise, scattered Lyman α radiation and other light scattered from the optics, and charged particle detections. These are all distributed over the entire detector. The flux level from these sources varies between daytime and nighttime data, and is somewhat dependent on the amount of solar activity [19] and the satellite's magnetic latitude [17].

2. Diffuse emissions from geocoronal helium transitions at 256, 304, and 584 Å fall within the bandpass and are imaged as broad lines in the medium and long wavelength channels, whose width is determined by the collimators' transmission functions. These features are prominent in the estimated background spectra, which are shown below in section 3.6.4.

3. There are several sources of stray light which add to the background in specific areas on the detectors. They are mostly images of geocoronal light which is focussed to some degree by the optics. Most of these leaks have been blocked by baffles. The brightest remaining feature is the bright left edge on the short wavelength detector. It is caused by Lyman α radiation, which is partially focussed by the mirror and reflected from the side of the grating assembly onto the detector. This feature is a fairly constant characteristic of the detectors, and is also included in the background spectra.

3.6.2 Background Subtraction Technique

Background subtraction on EUVE spectral images is usually done by averaging over the imaging direction on part of the detector near the spectrum and subtracting the average from the accumulated counts in each spectral bin. This is advantageous because averaging lowers the background deviation by the ratio of the height (Y, or imaging direction) of the background strip to that of the spectrum. We call this factor n. If spectrum and background regions are chosen so that n is an integer, the deviation of the average background in a bin of arbitrary width in the spectral direction is given by:

$$\sigma_{\overline{\mathrm{B}}} = \sqrt{\sum_{i=1}^{n} \mathrm{B}_i / n^2} \tag{3-3}$$

where $\overline{B}$ represents the averaged background, and B_i denotes the background in bin number i in the *imaging* direction.

The background count rates given throughout this section represent counts/second/Å, averaged over n times the spectrum height, although the bar notation will generally be omitted. When multiplied by bin width (X, or spectral direction) in Å and time in seconds, they give the integrated background counts (B) in a spectral bin. The standard deviation in the background, due to Poisson noise in photon counting detectors is given by $\sigma_{\mathrm{B}} = \sqrt{\mathrm{B}}$. This deviation alone does NOT account for the error introduced by background subtraction; the factor n, which appears below in formulae for calculating signal quality and exposure times in section 3.7, accounts for the error introduced by combining Poisson statistics.

Factor of n for Handbook background estimates.

For the purpose of calculating signal quality, proposers may use the value $n = 10$ to typify the ratio of spectrum height (Y direction) to background height with all background rates given here. No background subtraction technique will be successful on features with low intensities unless the integration time is sufficient to make the feature visible above the the Poisson noise.

3.6.3 Distributed Background

The distributed background in each detector from sources in category 1 above has been monitored continuously since launch.

After one year, the detector pulse height threshold in the short and medium wavelength detectors was lowered to maintain sensitivity as the gain of the detectors decreased with use. The upper pulse height threshold was lowered as well, to decrease the intrinsic detector background in those channels. The thresholds in the long wavelength detector were also lowered slightly.

To obtain estimates of the average background count rates, the per-pixel count rates were averaged over a large area on each detector near the spectrum, multiplied by a spectrum height of approximately 10 pixels, and the result converted to counts/second/Å. We use a script B ($\mathcal{B}$) for the average counts/second/Å. which can be used to estimate the total background associated with a spectral bin of any width on an otherwise "quiet" area of the detector. The values are:

$$\mathcal{B} \simeq 5.4{\times}10^{-4} \text{ counts/second/Å in SW}$$

$$\mathcal{B} \simeq 2.9{\times}10^{-4} \text{ counts/second/Å in MW}$$

$$\mathcal{B} \simeq 1.7{\times}10^{-4} \text{ counts/second/Å in LW}$$

The average distributed background rate is then multiplied by the width of a spectral bin in Å to produce the background count rate per bin:

$$\mathrm{B}' = \mathcal{B} \times w. \tag{3-4}$$

Use the count rate per bin with the expected source count rate to compute integration time from your statistical requirements, using the formulas in section 3.7. To obtain the estimated total background counts per bin, multiply by the spectral bin width and the integration time:

$$\mathrm{B} = \mathcal{B} \times w \times \mathcal{T}. \tag{3-5}$$

Use the total background counts to calculate the S/σ. This method of estimating the background is sufficient for features which are *not* near any detector edge or geocoronal feature, and are affected only by the sources of distributed background mentioned in category 1 in section 3.6.1 above.

Example: Line emission background For a bin width of $w = \Delta\lambda = .5$ Å in the SW detector, and our nominal observing time:

$$\mathrm{B}_{SW} = 5.4{\times}10^{-4} \times .5 \times 40,000 = 11 \text{ counts.}$$

And similarly for the MW and LW channels, with $\Delta\lambda = 1.0$ and 2.0 Å, respectively:

$$\mathrm{B}_{MW} = 2.9{\times}10^{-4} \times 1.0 \times 40,000 = 12 \text{ counts}$$

$$\mathrm{B}_{LW} = 1.7{\times}10^{-4} \times 2.0 \times 40,000 = 14 \text{ counts}$$

These values may be used for narrow emission lines, wherever the average background counts per bin are required, and the feature is well separated from detector edges or geocoronal features.

An inspection of the calibration target spectrum in figure 3-14 gives an idea of the background in proportion to a relatively bright line source. The source is AU Mic, a late-type star with many emission lines. The distributed background has about 10–12 counts in each pixel, with a deviation of about 3–5.

Background subtraction will be more difficult for features near detector edges or the airglow lines, since the background may be greater than the source signal. The appropriate section of the background spectrum presented in the next section should be used in these cases.

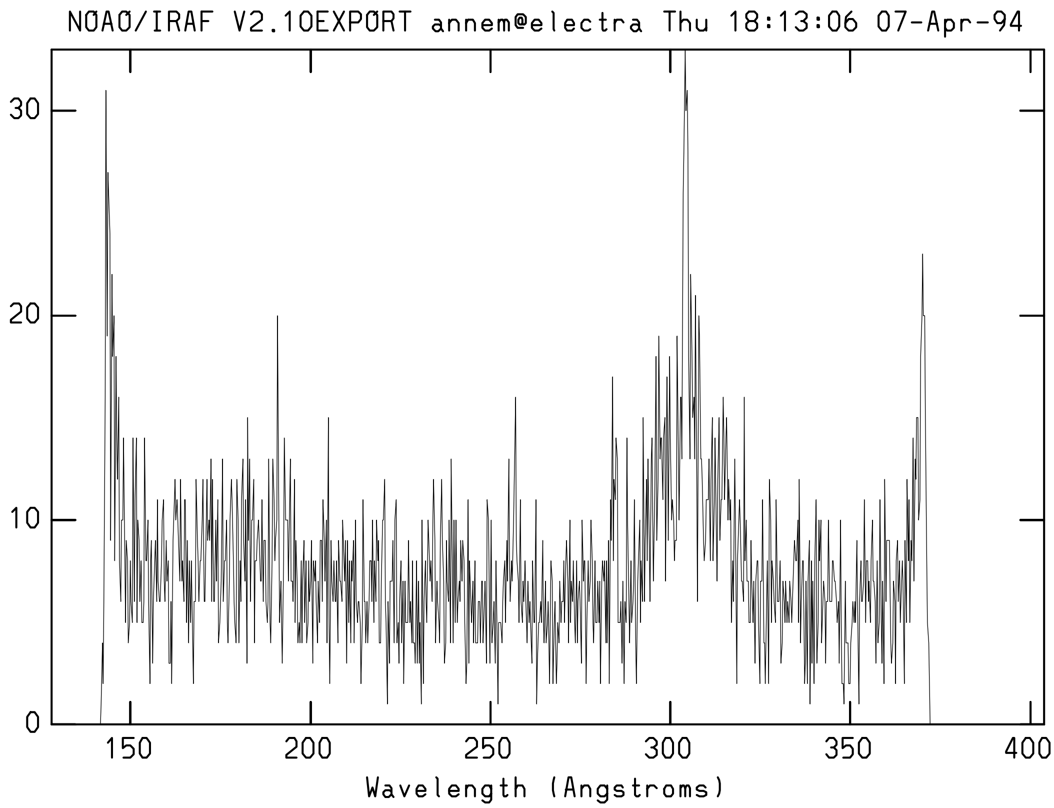

Figure 3-14: Raw spectrum of a late-type star in MW, showing typical background. Y axis scale is accumulated counts per bin.

3.6.4 EUVE Estimated Background Spectra

Spectra which simulate the average background count rate over the entire bandpass were made from composite exposures totaling about 1.5×10^6 seconds, and including many different pointing directions and airglow conditions. First, average count rates were computed over an area ten times the spectrum height (Y) on each detector, to make a one-dimensional spectrum. Since a wide range of airglow count rates was observed during the first seven months of Spectrometer calibration pointings, the airglow features were scaled to slightly above the mean of those observed, to make the background estimate conservative at these wavelengths. Recall that the FWHM of the airglow features is limited to 20 arc minutes by the collimator transmission. Each spectrum was then multiplied by the spectrum height in pixels ($10 \approx 42''$) and fit with a smooth polynomial function.

The resulting curves approximate the average backgrounds summed over the full spectrum height in the imaging direction, in units of counts/second/Å. They can be used to estimate the background counts for continuum source spectra, blended features, or features that fall on detector edges and airglow lines, where background levels are dominated by sources from categories 2 and 3 of section 3.6.1, and may be changing rapidly. The spectra include background from all sources, so the distributed background estimates should not be added. Figures 3-15, 3-16, and 3-17 show the EUVE estimated background spectra in the short, medium and long wavelength bandpasses. The numerical values used to make the plots are available from the CEA/EUVE *ftp* site in the directory *pub/nra97/data*. The filenames are *sw_bgspec.txt, mw_bgspec.txt*, and *lw_bgspec.txt*.

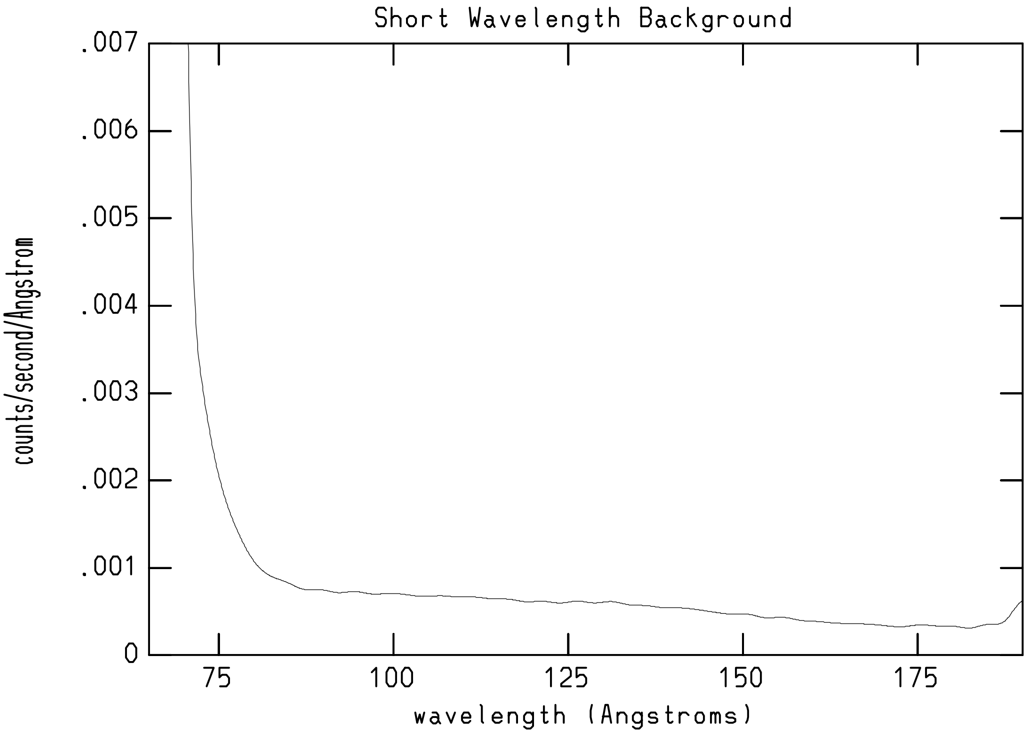

Figure 3-15: Spectrometer background count rate spectrum for SW

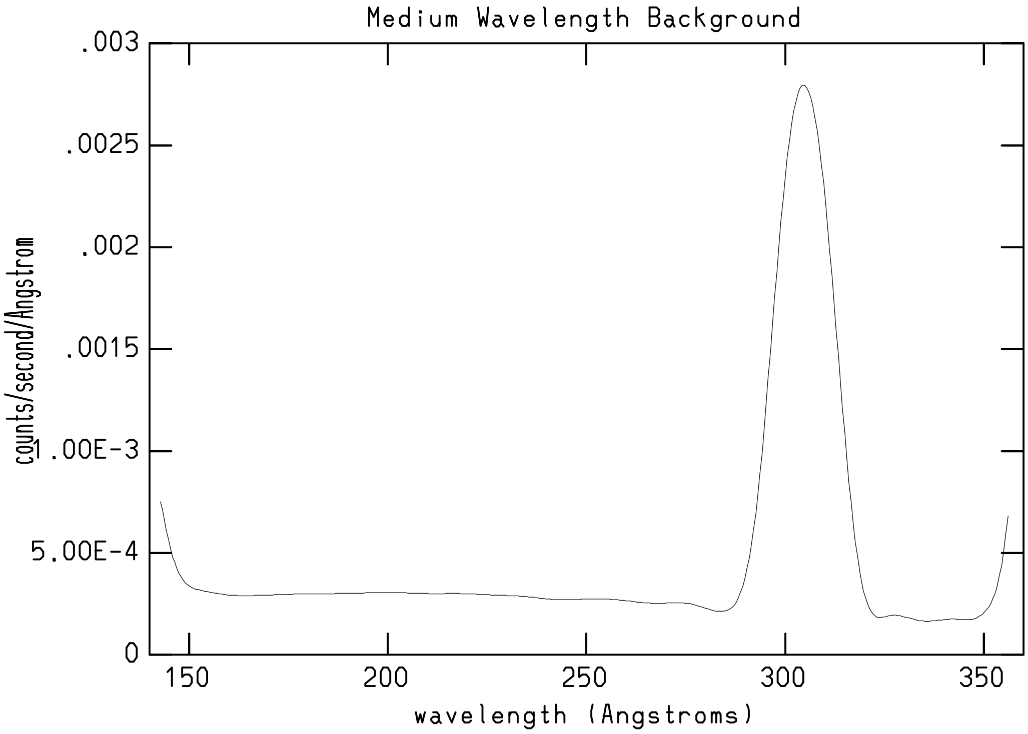

Figure 3-16: Spectrometer background count rate spectrum for MW

A few notes on particular features of the spectra:

- The short wavelength detector has a very bright leading edge, due to Lyman α radiation being scattered by surfaces on the grating holder. Similar reflections have been baffled out of the other channels.
- All the detectors show some rim brightening at a factor of about 1.5 to 3 times the distributed background level, due to distortions in the detector's potential field near the edges.
- The medium wavelength spectrum has a single broad feature from the HeIIline at 304 Å. The same line is also visible at the short end of the long wavelength spectrum, in combination with the rim brightening. Since the half-width of the the collimator response in the long wavelength channel is greater than $(304 - 280)$ Å, the 304 feature is cut off at the short end of the LW spectrum.
- The 304 Å airglow emitted by singly ionized helium can vary by orders of magnitude, depending on the angle of the Spectrometer's boresight with respect to the earth's shadow and the inner ion-trapping region of the earth's magnetic field. The height of the 304 Å features in the background spectra are slightly above-average values, based on rates in the first 7 months' calibration pointings

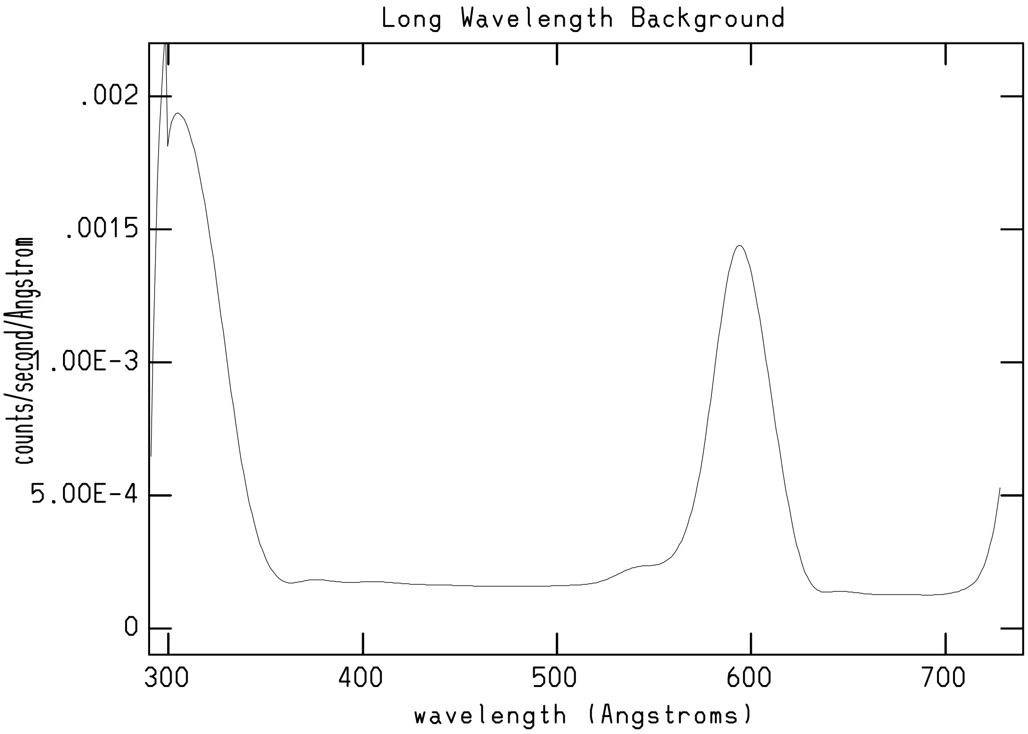

Figure 3-17: Spectrometer background count rate spectrum for LW

- The feature near 600 Å in the long wavelength plot includes both HeIat 584 Å in -1st order, as well as 304 Å in second order. It is slightly larger than 20 Å FWHM.
- The small "wiggles" in the background spectra are mostly artifacts of a polynomial fitting process, EXCEPT the small shoulder shortward of the 584/608 Å feature in the long wavelength channel. This is the 537 Å line of Helium I.

The spectra furnish estimates of B and $\sqrt{B}$ when multiplied by a spectral bin width w and an exposure time $\mathcal{T}$, but they do not contain representative levels of Poisson noise. Recall the discussion in section 3.6.2: the increase in noise due to background subtraction is proportional to $1/\sqrt{n}$, where n is the ratio of the background sampling area to the spectrum aperture. When using the integrated spectra for background estimates in S/σ calculations in the next section, a value of $n = 10$ should be used. The ratio of background to source signal near the geocoronal lines will still be of critical concern for any observation in these regions.

The background in spectral bins under a continuum is produced by simply rebinning the background spectrum at the desired resolution, but the proposer must justify the bin size used in terms of their science goals. For example, if the goal is a comparison to some model spectrum, the required signal-to-noise should be demonstrated over the entire spectral region to be fit. For lines in regions where the channel spectra overlap (140-190 Å, 280-380 Å), background count rates should be calculated separately for the bin size to be used in each each channel, and added, like the source count rates. Procedures for using background rates and counts to determine exposure times and signal quality are defined in section 3.7.

Example: Background for continuum sources To simulate the raw count background for observations of continuum sources, the background spectrum should be rebinned at the resolution required by science goals, and multiplied by the bin width and integration time. As an example, suppose a proposer wishes to create a background spectrum for a continuum source in the MW Spectrometer channel, with bins the size of a resolution element: 1 Å. The proposer can use the IRAF/EUV task **mkeuvspec** or any similar routine to rebin the background spectrum and convert it to cts/second. The standard IRAF task **imarith** can then be used to multiply by the integration time $\mathcal{T}$. The resulting background count spectrum appears in figure 3-18. for $\mathcal{T}$ = 60 ksec.

This background is relatively low compared to the source spectrum produced for our G191-B2B model, but the broad geocoronal features will dominate over features of the object spectrum for some continuum objects. An example is shown in figure 3-19, which is part of an actual raw spectrum from a 31K second observation of a white dwarf star. The airglow feature at 304 Å has many more counts that the 171 Å edge visible at the left.

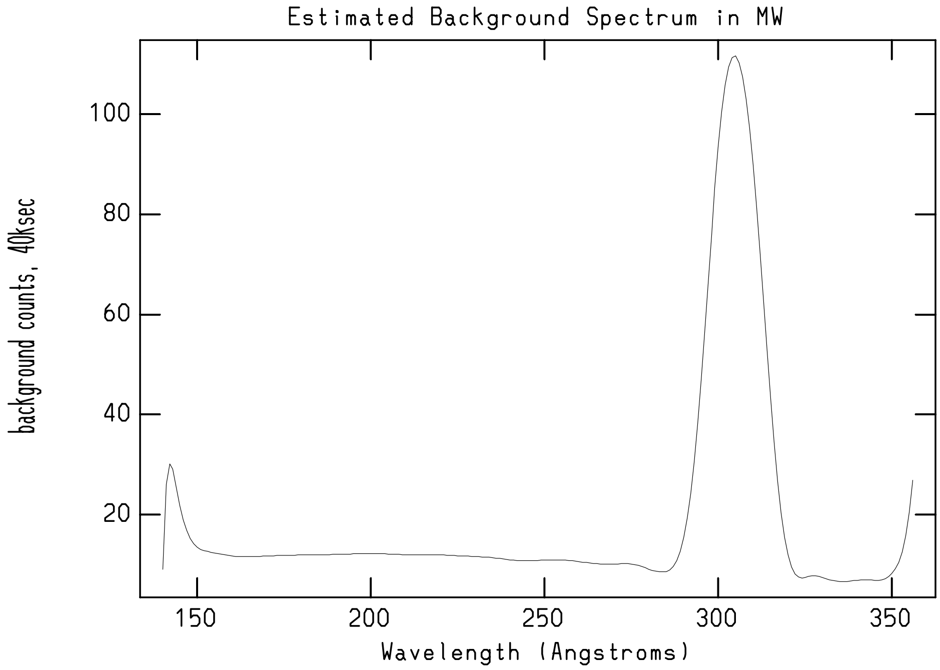

Figure 3-18: Simulated background spectrum for MW, scaled for a 40 ksec observation, in 1-Å bins.

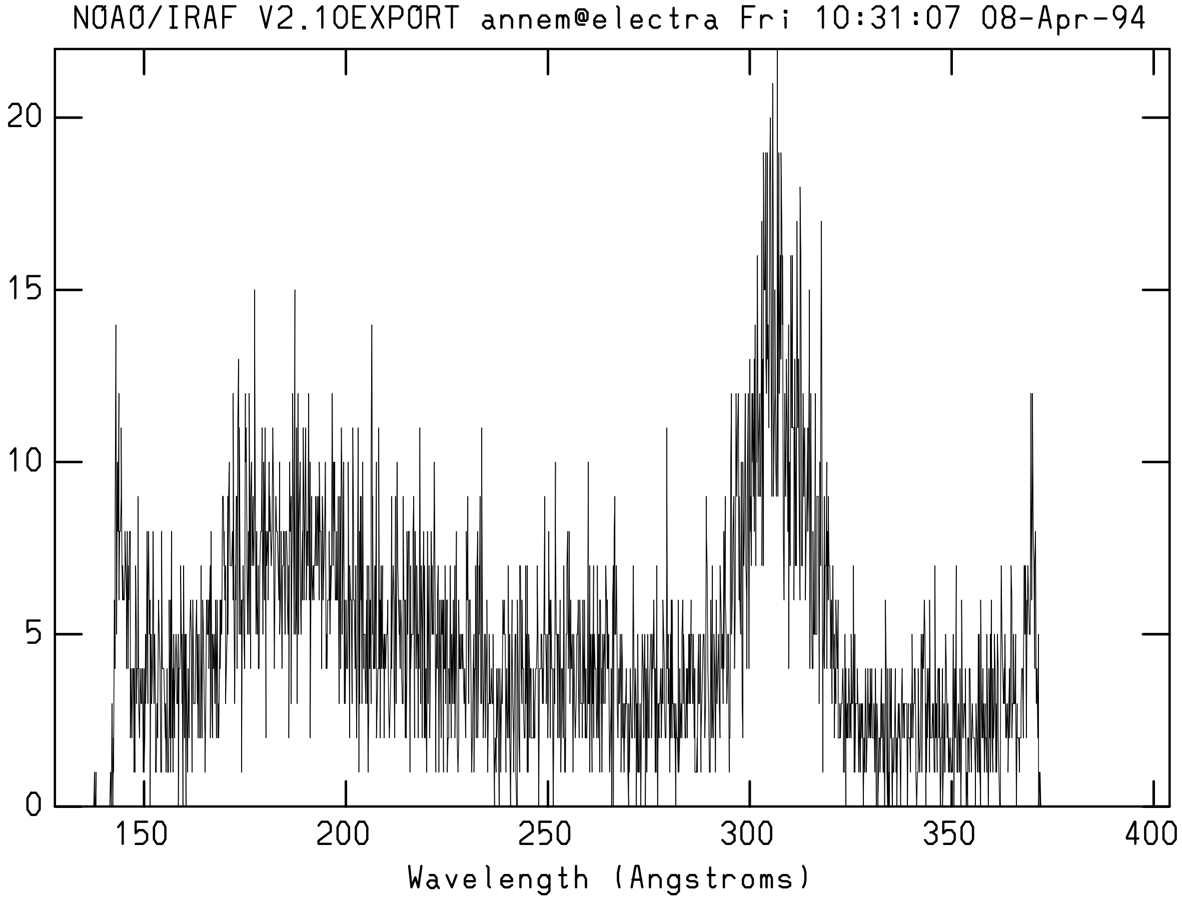

Figure 3-19: Raw spectrum of the white dwarf WD1845+019 in MW, showing typical background and noise level. No rebinning.

3.7 Detection Quality

Technical Justification of observations requires proposers to demonstrate that measurements with a signal-to-noise ratio adequate for their science program will be obtained for at least one wavelength in the spectrum of each target, using their source model and proposed integration time. This section presents formulas for calculating the signal (S), standard deviation (σ) and the signal-to-noise (S/σ), in terms of the instrument source count rate, background count rate, and integration time. We illustrate calculations for the emission and continuum sources, and invert the formula to calculate integration times from S/σ requirements.

The source signal in a bin is the difference between the total counts (T) and the background counts (B). The estimated standard deviation of the source counts (S) in a spectral bin is defined by:

$$\sigma_S(\lambda) = \sqrt{{\sigma_T}^2 + {\sigma_B}^2}$$

where σ_B denotes the standard deviation of the accumulated background, and σ_T is the standard deviation in the total counts, S + B. The uncertainties in S and B are given by $\sqrt{\mathrm{S}}$ and $\sqrt{\mathrm{B}}$. Applying this rule, and using the average in equation 3-3 as an estimate of the total background, we have:

$$\sigma_S = \sqrt{\mathrm{S} + \mathrm{B}(1 + 1/n)} \tag{3-6}$$

The signal-to-noise is estimated by the ratio of the number of signal counts to the signal deviation, S/σ_S. If the signal and background counts are written in terms of the count rates and the integration time, $\mathcal{T}$, we see that the signal-to-noise will increase as the square root of the observation time:

$$\frac{\mathrm{S}}{\sigma_S}(\lambda) = \frac{\sqrt{\mathcal{T}}\,\mathrm{S}'}{\sqrt{\mathrm{S}' + \mathrm{B}'(1 + 1/n)}} \tag{3-7}$$

where primes denote the rates of signal and background events in some spectral bin at wavelength λ. So to double the ratio S/σ_S one must multiply the observation time by a factor of four.

To calculate an exposure time from S/σ requirements, simply invert equation 3-7:

$$\mathcal{T} = \left(\frac{S}{\sigma_S}\right)^2 \times \frac{\mathrm{S}' + \mathrm{B}'(1 + 1/n)}{S'^2} \tag{3-8}$$

We can substitute one of the count rate expressions from equations 3-1 or 3-2 for the source count rate, S$'$.

Background and background count rates are obtained by multiplying the appropriate count rate per Å ($\mathcal{B}$ in equations 3-4 and 3-5) by the spectral bin width, (w) in Å and the time. Use the distributed background from section 3.6.3 for lines away from airglow or edges, and the background spectrum values for continuum or lines near airglow features. Expanding the expressions for S/σ and $\mathcal{T}$, we obtain formulas for signal quality in a single spectral bin, in terms of source flux, effective area, and time:

$$\frac{\mathrm{S}}{\sigma_S} = \frac{\mathcal{F}\mathrm{A}_{eff}\mathcal{T}}{\sqrt{\mathcal{F}\mathrm{A}_{eff}\mathcal{T} + \mathcal{B}w\mathcal{T}(1+1/n)}} \quad \text{(lines)} \tag{3-9}$$

or

$$\frac{\mathrm{S}}{\sigma_S} = \frac{\mathcal{F}\mathrm{A}_{eff}\ w\mathcal{T}}{\sqrt{\mathcal{F}\mathrm{A}_{eff}\ w\mathcal{T} + \mathcal{B}w\mathcal{T}(1+1/n)}} \quad \text{(continuum)} \tag{3-10}$$

for the S/σ ratio, and

$$\mathcal{T} = \left(\frac{\mathrm{S}}{\sigma_S}\right)^2 \times \frac{\mathcal{F}\mathrm{A}_{eff} + \mathcal{B}w(1+1/n)}{(\mathcal{F}\mathrm{A}_{eff})^2} \quad \text{(lines)} \tag{3-11}$$

or

$$\mathcal{T} = \left(\frac{\mathrm{S}}{\sigma_S}\right)^2 \times \frac{\mathcal{F}\mathrm{A}_{eff}\ w + \mathcal{B}w(1+1/n)}{(\mathcal{F}\mathrm{A}_{eff}\ w)^2} \quad \text{(continuum)} \tag{3-12}$$

for the integration time.

Example: Late star emission S/σ Evaluate the measurement quality for lines in the late type star example. Suppose we want to know what signal-to-noise would be achieved for the spectral line at 171.06 Å in a 40K second observation. Assuming the line is narrower than the resolution element $\Delta\lambda$, and multiplying equation 3-1 by $\mathcal{T}$, the number of counts in the short wavelength line after 40K seconds would be ~153. The background at 171 Å in SW was calculated in section 3.6 to be ~11 counts. With n = 10 for the ratio of background to spectrum height, we obtain a signal deviation of:

$$\sigma_{SW}(171.06) = \sqrt{153 + 11 \times (1.1)} = 13 \text{ counts},$$

so that the signal-to-noise ratio is about:

$$\frac{S}{\sigma_{SW}}(171.06) \simeq \frac{153}{13} \simeq 11.8$$

The same line would also be imaged in the MW channel, with about 242 signal counts and 12 counts in background, yielding a signal-to-noise of:

$$\frac{S}{\sigma_{MW}}(171.06) \simeq \frac{242}{\sqrt{242 + 12 \times (1.1)}} \simeq 16$$

The line has better signal-to-noise in the MW channel. For a line this far above the background, the S/σ is dominated by the source counts and hence the integration time.

Reverse this process to calculate an integration time. Suppose we require the S/σ ratio of the feature at 222 Å to be 5, and apply equation 3-8. Again, the bin size is assumed to be $\Delta\lambda$, which in the MW is 1 Å:

$$\mathcal{T} = 25 \times \left[\frac{1.08\times10^{-4} + 2.9\times10^{-4}\,(1.1)}{1.166\times10^{-8}}\right] = 9.15\times10^{5}\,\text{seconds.}$$

It requires quite a long observation.

Example: Continuum Detection Quality We have the signal count rate in the MW channel from our G191-B2B simulation in figure 3-7. To estimate signal-to-noise for some wavelength λ in a continuum, we will examine the signal near the O IV edge at 298 Å. Since we have a nice bright source, we will work at the limit of MW spectral resolution, and use 1-Å bins, the resolution shown in the figure. First, we apply equation 3-2 and the integration time to obtain the source counts in bins spanning the minimum and maximum of the edge feature. Since our original simulated spectrum has .2 Å bins, j in equation 3-2 is 5:

$$\mathrm{S}_{min} = \sum_{j=1}^{5} \mathcal{F}(\lambda_j)\,\mathrm{A}_{eff}(\lambda_j)0.2 \times \mathcal{T} = 6377\,\text{counts}$$

$$\mathrm{S}_{max} = \sum_{j=1}^{5} \mathcal{F}(\lambda_j)\,\mathrm{A}_{eff}(\lambda_j)0.2 \times \mathcal{T} = 6722\,\text{counts}$$

The background is mostly from the wings of the 304 Å airglow feature. We use the count rates from the MW background spectrum, integrated over a 1-Å bin on either side of the edge, and multiply by $\mathcal{T}$ = 40K seconds to get the integrated background in each bin. Letting $n = 10$, and applying equation 3-6 for the signal deviation to each side gives:

$$\sigma_{S_{max}} = \sqrt{6722 + 84(1.1)} = 82.5$$

$$\sigma_{S_{min}} = \sqrt{6377 + 71(1.1)} = 80.3$$

So the signal-to-noise is about 80 both above and below. When we subtract the source counts to get the height of the edge, in counts, the error for the edge detection is:

$$\sigma_{diff} = \sqrt{\sigma_{S_a}{}^2 + \sigma_{S_b}{}^2} = 115$$

This is a substantial percentage of the difference of 395 counts, despite the fact that both individual measurements had high S/σ.

3.8 Time-Critical Observations

Timing information for all photon detections and software tools for analysis of transient and periodic events will be available to Guest Observers. Besides limitations on photon event timing accuracy, the main constraints that will complicate the analysis of time-critical data arise from the interplay between source brightness, the ability to correct for instrument deadtimes, the source variability, and the intervals available for data acquisition.

3.8.1 Photon Timing Accuracy

Timing accuracy is fundamentally limited by the number of time-bits available in the spacecraft software format. The Explorer Platform clock is synchronized to ground UT within 1 msec, and event times are assigned by the payload electronics with an accuracy of 8 msec. If it is necessary to convert EUVE's photon arrival times to heliocentric times with accuracies better than 60 msec, knowledge of the spacecraft ephemeris is also required. The position information necessary for making these corrections is stored in the telemetry and is made accessible to the GO through the IRAF/EUV software tools.

Deadtime is primarily due to the limited capacity of the electronics and the capacity of the telemetry stream. The maximum count rate the telemetry can support is 437.5 cts/s. This is the *total* number of photon "slots" available to *all seven* detectors, which usually operate continuously. The geocoronal EUV background counts occupy a major fraction of these slots. The instrument software algorithm that assigns telemetry slots insures that some counts from each detector are recorded, but it is possible that some source photons will not be recorded if either a source or the background in that detector becomes very bright. The EGO Center may request the shutdown of one or more scanning telescope detectors during observations of very bright sources, such as the moon, or in the event of sudden increases in the background.

Another factor limiting the time resolution is the accuracy with which deadtime correction can be performed. Deadtime is monitored in the instrument software with a time resolution of 2 seconds, and can be corrected for at this interval. EGO Center reduction tools will be available to help observers reconstruct intrinsic light curves, but the practicality of correcting the count rates on small time scales will remain limited even after the best possible processing.

3.8.2 Counting Statistics and Observation Timing

The time resolution for even the brightest EUV sources will be limited by counting statistics and the partition of the observation time used in reductions. The EGO Center provides IRAF software tools to extract spectra at full resolution and to rebin them as desired. Proposers should make exposure and signal-to-noise calculations for each segment of the observation period that is to be analyzed separately.

Example: Variable Source Measurements Suppose an observer wished to monitor a variation in the flux at 303.8 Å in our model emission source. If this requires a 3–σ measurement for each observation, then using the instrument count rate from table 3-1 and the estimated background rate from the spectrum in section 3.6, and assuming a bin width of $\Delta\lambda = 1.0$ Å for MW, one can calculate the minimum acceptable integration time from equation 3-8:

$$\mathcal{T} = \frac{9\left[2.00\times 10^{-3} + 2.78\times 10^{-3}(1.1)\right]}{4.00\times 10^{-6}} \approx 11500 \text{ seconds}$$

So in spite of the high background, 4 such observations could be made in 50K seconds.

The longest strictly continuous integration time available is one orbit nighttime, which varies from 1800 to 2200 seconds. Proposers should request as much time as necessary for each observation, but should be aware that the observation will be interrupted once per orbit, for about 57 out of every 90 minutes. For strictly periodic sources, integration times up to half the period may be desired, and sources with a period closer to the orbital period of the satellite may require longer observations for adequate sampling. Uninterrupted observing time should be specifically requested, since long observations may otherwise be interrupted to service programs requiring shorter and more frequent observations.

Observations of events with very long, non-uniform periods, such as sudden brightening in CV stars, should be proposed as a targets of opportunity (TOO's); see section 3.9 below.

3.9 Targets of Opportunity (TOO)

Requests for targets of opportunity will fall into one of two classes:

1. conditional requests, where the opportunity is expected, but is not a regular or predictable event.
2. Observations of serendipitous events that may be bright in the EUV.

Any conditional proposal of the form "if condition A occurs, then observe target B" should be proposed for as a normal target, but should also be identified on the proposal information and target list forms as a conditional TOO. Investigators must provide clear, measurable criteria for deciding observability, and give their best estimate of when these conditions are expected to occur. The observer will be responsible for conducting any ground-based monitoring necessary to predict a sudden event in time for an observation request to be honored. Once a conditional TOO proposal is accepted by the EGO Peer Review Panel, the proposal's Principal Investigator must notify the EUVE Principal Investigator at Berkeley, at the EUVE Guest Observer Center, egoinfo@cea.berkeley.edu, as soon as the TOO is observable, and must present clear evidence that the criteria have been met.

In the case of an unanticipated TOO, a request must be submitted to the Project Office, addressed directly to the Project Scientist at GSFC. The request must identify the principal

Guest Observer and include the target location and a Scientific Justification. Prospective GO's should consult the current UCB/EUVE Call for Proposals for correct and complete instructions for submitting TOO proposals.

In either case, the Guest Observer must also notify the EUVE Principal Investigator at Berkeley as soon as the request is submitted, so that preparations can be made by the ESOC staff, pending approval. A response time in the EUVE exteneded mission will be on a best bet effort, but a response time of as little as 24 hours after approval may be possible.

3.10 Diffuse and Extended Sources

The Spectrometer may be used to observe sources whose light is spread diffusely across the aperture or extend across more than 1 arc minute in the field of view. Such sources include the moon, planetary atmospheres, emission nebulae, supernova remnants, and the ISM. Any source larger than 20 arc minutes should be considered a diffuse source. Sources smaller than 20 arc minutes may be considered extended sources. Objects that are significantly smaller than 1 arc minute, such as planets and comets can be observed as point sources.

Since the Spectrometer is a slitless instrument, the count rate per bin and line width for observations of diffuse or extended sources will be determined by the transmission of the wire-grid collimators and the size of the source. Most observations of diffuse ($> 20'$) sources will only be practical in the medium and long wavelength channels, where the collimators limit the width of spectral features, but spectral resolution will be somewhat degraded as a result. Even a "narrow" emission feature from a diffuse source will be 20 arc minutes wide, FWHM. Observations of extended sources smaller than 20 arc minutes may produce narrower features. Spectral observations of diffuse or extended sources will therefore require more observing time [27] than those of point emission sources.

Since the wire-grid collimators limit the field of view in the spectral direction only, angular resolution will be poor to non-existent for truly diffuse sources, such as the ISM. Extended sources produce spectra whose angular extent in the imaging direction is determined by their size along the direction tangent to the aperture radius, as projected onto the field of view. This is a different direction for each Spectrometer channel, and it means that angular extent can be minimized or maximized in only one channel for any given roll angle.

Figure 3-20 shows the relative positions of aperture plate openings, detectors, and the dispersion (X) and imaging (Y) directions on each detector in the DS/S. Roll angle is specified as the angle from a radius halfway between the LW and MW detectors and parallel to the deep survey filter bars, pointing toward the MW detector.

If a proposer wishes to align one of the Spectrometer channels with a particular source axis, the request should be made in the section of the Target Summary Form of the Target Summary Form set aside for special pointing requirements, by stating the direction and angle between north and the dispersion (spectral) direction for the channel to be aligned. For example, someone proposing to make observations of Jupiter might give the desired orientation of the long wavelength dispersion direction to the plane of the Io Torus as XX degrees west of north. Any requested Spectrometer roll angle may have to be adjusted to

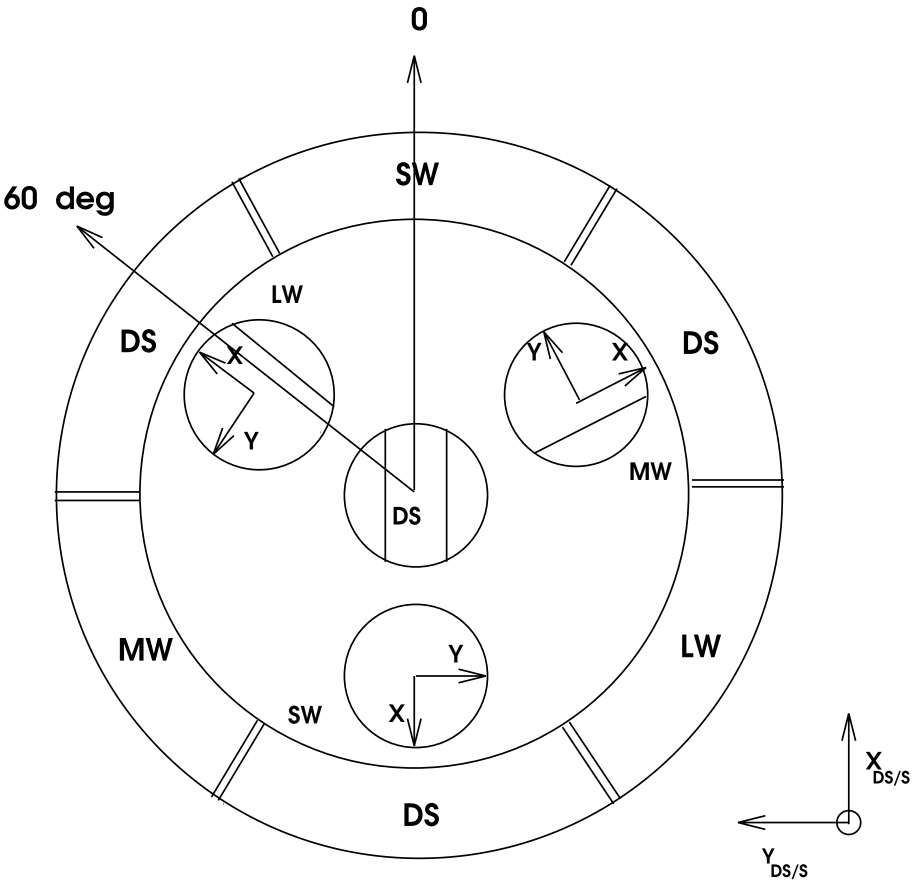

Figure 3-20: Orientation of Spectrometer detectors to DS/S aperture. Observer is looking *toward* the focal plane, from in front of the telescope.

conform to physical and time constraints imposed by the scheduling process (see section 4.2).

3.10.1 Models and Count Rates for Diffuse Source Simulations

Models used to simulate diffuse or extended objects should generally be two-dimensional, and give flux in units of photons/cm^2/sec/Å/sr, with the bin size clearly indicated on proposals. Since any extended source will produce wide spectral features, the formula used to estimate source count rates is derived from equation 3-2 for continuum sources. The expression for the instrument count rate in equation 3-2 becomes a double sum:

$$\mathrm{S}'_{diff} = \sum_{i=1}^{M} \sum_{j=1}^{N} \mathcal{F}_{ji}(\lambda) \mathrm{A}_{eff}(\lambda_i) \Delta\lambda_j \Delta\theta i \tag{3-13}$$

where $\mathcal{F}_{ji}(\lambda)$ is the (two-dimensional) flux distribution of the source in wavelength/image angle space, with the image axis oriented along the selected source axis. The spectral bin size is $\Delta\lambda_j = 20\overset{\frown}{'}$ for diffuse sources. This is equivalent to about 16 and 32 Å at FWHM in the medium and long wavelength channels, respectively. Smaller values of $\Delta\lambda_j$ will apply for sources smaller than 20 arc minutes in the spectral direction for each detector. The FWHM angular resolution element, $\Delta\theta i$ on the detector is approximately 20-25$\overset{\frown}{''}$, and the entire spectrum height is about 42$\overset{\frown}{''}$, or 10 pixels.

If the total flux from an extended (< 20 amin) source can be estimated from previous observations, it may be assumed for the Technical Justification that the target has a uniform surface brightness. Existing flux measurements from diffuse sources must be adjusted to compensate for the size of the instrument field of view before use in planning EUVE observations.

Proposers may use the one-dimensional first order effective areas in this expression. For extended sources, proposers should divide the angular extent of the source in the direction to be oriented along the imaging axis (Y) by the size of $\Delta\theta i$ to determine the value of M. For diffuse sources, proposer must decide how much of the Spectrometer detector height they wish to include in their "aperture", or how it should be divided to provide maximum coverage of the field of view in each part of the wavelength range.

Some extended sources may produce multiple spectra from brighter subregions, depending on separation and the source's orientation to the aperture, as noted above. See section 3.11 on evaluating multiple sources in the field of view.

3.10.2 Background for Diffuse Source Spectra

The background spectra in section 3.6 are in units of photon flux/Å and are only appropriate for point sources, as they represent a sum over the average spectrum height of $\Delta\theta i$. To estimate the background rate for an extended source at a single wavelength, multiply the background spectrum by the resolution element, $\Delta\lambda_j$ and the height of the object spectrum, h, in units of $\Delta\theta i$:

$$\mathrm{B}_{diff}(\lambda) = \sum_{j=1}^{N} \mathcal{B} \times h \times \Delta\lambda_j \tag{3-14}$$

where $\Delta\lambda_j$ is equivalent to $20\overset{\frown}{'}$ or the source size in the dispersion direction, whichever is less, and h is the spectrum height divided by $\Delta\theta i = 25 - 42\overset{\frown}{''}$. Then calculate the signal-to-noise or integration time as in section 3.7.

Because larger objects may leave little or no detector area available for sampling the background, observations of diffuse sources will in general result in poorly resolved, confused spectra unless accurate models of the spatial distribution of the source flux or background are available (see section 4.5.3).

3.11 Imaging Multiple Sources

Some binary sources and extended sources with internal structure may be observable with the EUVE Spectrometer. In these cases, Guest Observers will be interested in knowing whether the two objects can be resolved as separate spectra in the imaging direction. The full width at half maximum of the angular resolution is roughly $\widehat{25''}$ as of this writing. The angular separation of two sources must be at least this great for their light to be imaged as separate spectra. Technical Justification must be done separately for each part or object for which a spectrum is required.

To evaluate the possibility that spectra from different areas of a multiple or extended source may be resolved at specific wavelengths, see the information on angular resolution in table 3-2, columns four and five.

3.12 Quick Reference to Parameters and Equations

Numerical Constants

resolution element	$\Delta\lambda_{SW} \simeq 0.5$ $\Delta\lambda_{MW} \simeq 1.0$ $\Delta\lambda_{LW} \simeq 2.0$	Å Å Å
spectrum height	$\simeq$ 42 arc seconds	
distributed background	$B \simeq 5.4\times10^{-4}$ $B \simeq 2.9\times10^{-4}$ $B \simeq 1.7\times10^{-4}$	cts/sec/Å in SW cts/sec/Å in MW cts/sec/Å in LW

Symbol Definitions

$A_{eff}(\lambda)$	spectrometer channel effective area in cm^2. Function of λ
$\mathcal{F}(\lambda)$	model source flux at spectrometer aperture after ISM absorption
S'	source count rate in a spectral bin, in counts/sec.
S	Total source counts in a spectral bin after integration over time $\mathcal{T}$.
$\mathcal{B}$	Background count rate in cts/second/Å. Function of λ near airglow features and detector edges.
B'	background count rate in a spectral bin
B or $\overline{\mathrm{B}}$	accumulated background counts in a bin, averaged over n times the spectrum height
$\mathcal{T}$	integration time in seconds
T	total integrated signal from sources and background
$\Delta\lambda$	spectral resolution element in Å
$\Delta\theta i$	imaging resolution element, in arc seconds
n	ratio of background region height to spectrum height in the imaging direction
w	spectral bin width in Å
i	bin number in the imaging direction
j	bin number in the spectral direction

Formulas

S'_{em}	source count rate from emission line with width $< \Delta\lambda$	$S'_{em} = A_{eff}(\lambda) \times \mathcal{F}(\lambda)$
S'_{cont}	source count rate from continuum source using bin of width w Å	$S'_{cont}(\lambda) = \sum_{j=1}^{N} \mathcal{F}(\lambda_j)\, A_{eff}(\lambda_j) w_j$
B'	background count rate in a spectral bin	$B' = \mathcal{B}(\lambda) \times w$
B or $\overline{B}$	time integrated background counts in a bin, averaged over $n\times$ spectrum height	$B = \mathcal{B}(\lambda) \times w \times \mathcal{T}$
σ_S	standard deviation of integrated source signal	$\sigma_S = \sqrt{S + B(1 + 1/n)}$
$\frac{S}{\sigma_S}$ (lines)	Signal-to-noise ratio for lines with width $< \Delta\lambda$	$\frac{S}{\sigma_S}(\lambda) = \frac{\mathcal{F} A_{eff}\, \mathcal{T}}{\sqrt{\mathcal{F} A_{eff} \mathcal{T} + B(1+1/n)}}$
$\frac{S}{\sigma_S}$ (continuum)	Signal-to-noise ratio for continuum in bin of width w	$\frac{S}{\sigma_S} = \frac{\mathcal{F} A_{eff}\, w \mathcal{T}}{\sqrt{\mathcal{F} A_{eff} w \mathcal{T} + B(1+1/n)}}$
$\mathcal{T}$ (lines)	Integration time for emission lines of width $< \Delta\lambda$	$\mathcal{T} = \left(\frac{S}{\sigma_S}\right)^2 \times \frac{\mathcal{F} A_{eff} + B'(1+1/n)}{(\mathcal{F} A_{eff})^2}$
$\mathcal{T}$ (continuum)	Integration time for feature for continuum in bin of width w	$\mathcal{T} = \left(\frac{S}{\sigma_S}\right)^2 \times \frac{\mathcal{F} A_{eff}\, w + B'(1+1/n)}{(\mathcal{F} A_{eff}\, w)^2}$
S_{diff}	integrated source counts from diffuse or extended source in bin $\Delta\lambda_j \leq 20^{\frown\prime}$ wide and $\Delta\theta i$ high	$S_{diff} = \sum_{i=1}^{M} \sum_{j=1}^{N} \mathcal{F}_{ji}(\lambda) A_{eff} \mathcal{T} \Delta\lambda_j \Delta\theta i$
B_{diff}	integrated background counts for extended source with bin of width $\Delta\lambda_j$ and height h	$B_{diff}(\lambda) = \sum_{j=1}^{N} \mathcal{B} \times h \times \Delta\lambda_j$