ABC Guide to the *Ginga* Data Analysis

The ISAS Ginga Archive Team

May 21, 2004

Chapter 1

Introduction

Ginga is the 3rd X-ray astronomy satellite of Japan developed under the Japan-UK-US collaboration (Makino and the Astro-C team 1987). It was operated for ~4.7 yrs since the launch in February 1987. All the Ginga analysis software were originally developed on the main-frame computers and all the Ginga data were archived on them. However, because astronomical data analysis is now done under the network computer environment, we ported the archive and the analysis software to the UNIX environment. This makes it possible to analyze the Ginga data in the modern network computing environment.

The ISAS Ginga archive consists of 3 parts: LAC, ASM, and GBD archives. In this document, we describe how to reduce the LAC data in the archives with the associated analysis software. ASM and GBD data analysis will be described elsewhere. Description of the *Ginga* satellite and the LAC instruments are given in the appendix.

1.1 Overview of the Analysis

Basis of the LAC archive is the first-reduction files (FRFs), which were originally developed to distribute the LAC data among the Ginga team. We have transfered the FRFs to the UNIX environment and have converted them to the fits format (fits-wrapped FRF). Attitude, orbit, and HK (house keeping) data are also included in the FRFs. LAC data analysis starts with selection of the good time intervals (GTIs) defined by source visibility and background level. A tool will be supplied to calculate the GTIs. Referring to GTIs, spectral files (ascii format) and timing files (fits format) are calculated from the FRFs. Because the ascii format of the spectral files is unique to the LAC data, we afford a tool to convert it to the standard fits format. The tool also produces an appropriate response matrix to the spectral file in the fits format. In this procedure, background can be subtracted using several different methods (Hayashida et al. 1989). Model fitting will be done with general purpose tools, e.g. XSPEC. Some of the timing analysis may be done with the timing files using general tools, e.g. FTOOLS. However, we also supply some tools for the timing analysis, because the dead-time correction is mission dependent. Analysis flow of the LAC data is summarized in figure 1.1.

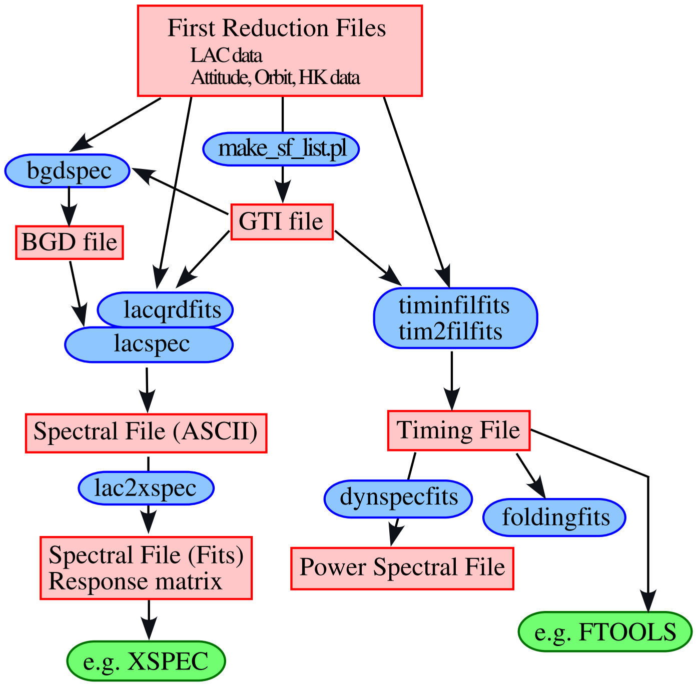

Figure 1.1: Flow of the LAC data analysis. Input and output files are indicated in red. Analysis tools available from the Ginga archive are indicated in blue, and the general purpose tools are in green.

1.2 Retrieving the LAC Data and Software

LAC data, software, and calibration files may be down-loaded from the DARTS home page[1] at ISAS. Step-by-step description of how to down-load the data is given in the web page. When the archive is retrieved, you will find four directories as below:

- `frf`: first reduction files of LAC.
- `frf_bgd`: those of suggested background data.
- `lacdump`: summary lists of the LAC housekeeping and attitude.
- `lacdump_bgd`: those of suggested background data.

The directory name is self-explanatory. '`lacdump`' contains summary lists of the LAC HK data and attitude for your convenience. If it is necessary from some reasons, the summary lists can be generated by yourself from FRFs. Except for blank sky observations, data of suggested background observations are also provided.

To run the *Ginga* analysis software you must set the environment variables GINGA_FRFDIR and GINGA_CALDIR to the directories where you put the FRFs and the calibration files, respectively.

[1] `http://www.darts.isas.ac.jp/`

Chapter 2

Structures of Data Files

2.1 Spectral Files

When we calculate an energy spectrum, ascii format spectral files are used as an interim output. For example, 'lacspec', 'bgdspec', and 'lacqrdfits' output ascii spectral files. The ascii file can contain multiple energy spectra, each of which is referred to as a sub-file. When we convert the ascii file to a fits format file using 'lac2xspec', each sub-file is output as a different extension in the fits format file. All the sub-files have appropriate header records, in which the parameters used to extract the energy spectrum are written under the COMMENT keyword.

There is another type of ascii file, called a monitor file. The monitor file contains spectra from each counter and layer. Thus multiple sets of 16 spectra can be kept in a monitor file in MPC-1 mode. This file is used only as a background file, and does not have corresponding fits format file.

2.2 Timing Files

Timing files are in fits format, and are output by 'timinfilfits', 'tim2filfits' and 'lacqrdfits'. Number of data extension is equal to or larger than that specified in the input parameter file as a pair of DATA-END. When the time resolution of the original data becomes larger than that specified in the input parameter, a new data extension is automatically created and the time resolution is set to the smallest available value.

A TIME column represents the elapsed time in unit of second since the time defined in the keyword TSTART. A FLAG column is used to indicate data continuity. A value F in the column indicates presence of a data gap before the data bin, while T indicates the data are continuous.

There are two kinds of timing file: Mode-1 and Mode-2. In Mode-1 files, several corrections such as aspect, dead time, and background may be applied to the data. Thus the data written in the fits file, which are in unit of count/bin, are not necessarily in integer. Column names RATE-1(ERROR-1), RATE-2(ERROR-2), etc., are selected for Mode-1 files. Number of columns is equal to that of the energy band specified in the input parameter file. In Mode-2 files, no correction can be applied to the data. Thus the data in the files are always in integer, and a column name of COUNTS is selected. Mode-2 files are useful to keep the file size small especially for the PC mode data.

We describe below important keywords in the timing files.

MJDREF: This keyword indicates the reference time adopted for each mission. LAC uses a reference time of January 1, 1987, 00:00:00 (UT).

TSTART: Epoch of the timing file in unit of second measured from `MJDREF`.

ONTIME: Three different definition was used in LAC for the total observation time: REAL TIME, LIVE TIME, and EFFECTIVE TIME. REAL TIME indicates a simple sum of the on-source time. Applying dead time correction we obtain LIVE TIME. If we multiply an average transmission to LIVE TIME, we obtain EFFECTIVE TIME. We adopt REAL TIME for the definition of `ONTIME`. A leap second is considered if it occurred during the observations.

COMMENT: All the other header information of a timing file, which was produced in the original LAC softwares on a main-frame computer, is collected under this keyword.

Chapter 3

Data Selection

Before starting data analysis, we need to select only the data (or time interval) appropriate for your purpose of the analysis. This can be done either manually or by using a script. We first explain the '`lacdump`' file, which is required to generate good time interval using a script and is also essential for manual selection.

3.1 '`lacdmp`' file

The '`lacdmp`' file (ascii dump file) summarizes house keeping and attitude information. Meanings of the columns and recommended values for GTIs are summarized bellow.

SF: Sequence number of the super frame.

DATE and TIME: Self-explanatory. They are given in UT.

BR: Bit rate, either `H` (high), `M` (medium), or `L` (low).

MODE: Mode of the instruments. Usually, a LAC mode, which is either `MPC1`, `MPC2`, `MPC3` or `PC`, is listed. However, some other modes, such as `ACS` (attitude control system) or `PCHK` (programmable command check), may be indicated if the satellite is not in the observation mode.

GMU : Coarse gain, middle and upper discriminator levels represented by a single character. For example, `LHH` means coarse gain is low, middle and upper discriminators are set both high. Lower level discriminator is usually set low when the coarse gain is low, and set high when the coarse gain is high.

ACM: Attitude status, either `NML`, `SL+`, `SL-`, `S36` or `MAN`, meaning normal pointing, clockwise slew, counter-clockwise slew, slew 360°, and maneuver. Data analysis is usually done for `NML`, but is also possible for `SL+` and `SL-`.

S/E: LAC direction either `SKY`, `NTE` (night earth), or `DYE` (day earth).

LAC-L: Total count rate (counts/SF) of LAC in lower energy channel (ch0–31). Note that the count rate is defined for per SF (super frame) basis. Thus the count rate in this column is bit-rate dependent.

LAC-H: Same as `LAC-L`, but is defined for higher channels (ch32–47).

SUD: Count rate of Surplus of Upper Discriminator.

PIMN: Count rate of PI Monitor.

RIG: Cut-off rigidity. This value is a local measure of the relative strength of the geomagnetic field which cut-off the penetration of cosmic-rays. Standard value for GTI is >10 GeV/c. Lower `RIG` means higher charged particle background. You may select lower `RIG` if your analysis is not affected for higher background, e.g. because of the brightness of the source.

EELV: Angle between the Earth limb and the pointing direction of the satellite. Elevation angle appropriate for GTI is >5.0 deg. If you select lower elevation angle, your data may be affected by solar X-rays scattered by the atmosphere.

LAC DIRECTION: LAC pointing direction (right ascension and declination in equinox B1950).

TARGET: Target source name. Only the brightest source is indicated. Note that more than a single source could be in the LAC field of view.

TRANSMISSION: Transmission of the collimator for the target source.

SPIN AXIS: The z-axis direction (right ascension and declination in equinox 1950).

3.2 GTI File

In the case of LAC data analysis, GTIs (good time intervals) are usually defined with the PASS numbers and SFs. Thus GTIs consist of pairs of start and end SF for the specified PASS number. The file which contains GTIs is sometimes called a region file. A region file is usually included as a part of the input parameter file in many of the LAC software. The easiest way to create a region file is to use a PERL script '`make_sf_list.pl`'. By default, '`make_sf_list.pl`' outputs two files: '`sf_list`' and '`lacdmpfile`'. '`sf_list`' is the region file, and '`lacdmpfile`' is a copy of the LAC dump file of the accepted time intervals. '`make_sf_list.pl`' outputs a help message if no argument is specified.

Here, we show an example to make two region files for the observations of Vela X-1, one for on-source data and the other for background data. You can find these files under the '`sample`' directory. We first show an example for a source region file. Although the following example shows input parameters in plural lines, but you should type them in a single line.

```
ginga>> make_sf_list.pl '$bit eq M && $mode =~/MPC2/ && $elv > 5.0 &&
$src=~/VELA X-1/ && $rig>=10 && $ut>=880222190000 && $ut<=880224040000 &&
$trns>= 0.85'
```

Note that `ginga>>` is a system prompt and is not a part of the input command. The formula which defines the data selection criterion needs to be input with the PERL format. See the help message for the list of the variables you can use in the selection criteria and their meanings. The region file of your 0th version is output to '`sf_list`'. Meaning of the parameters in this output file is explained in the next chapter. You may need to delete some of the PASSes which you do not need, and you should also add the `TGT` keyword. The keyword `TGT` must be followed by right ascension and declination of the source (in unit of degree in equinox B1950) and the target X-ray source name. The source name is treated as a comment and does not affect the output. For example:

```
'TGT' 135.0550 -40.3569   'VELA X-1'
```

If you want to separate a region file as several sub-files, you need to insert a pair of `DATA` and `END`. For example:

```
'DATA'
'PASS' S8802230639 / SUB FILE 1
------------------
'END'
'DATA'
'PASS' S8802240639 / SUB FILE 2
------------------
'END'
```

It is recommended to rename the region file (`'sf_list'`) to, e.g. `'VELAX-1_REGION.DATA'`.

We take a similar procedure for the BGD region file,

```
ginga>> make_sf_list.pl '$mode =~/MPC1/ && $elv > 5.0 && $rig>=10 &&
&dist(138.14,-42.20)<0.5 &&$ut>=880220175000 && $ut<=880222040000'
```

In this case, you do not need to add the `TGT` keyword, because this is a BGD region file. You need to add `DATA` and `END` at the beginning and the end of the file. For example:

```
'DATA'
'PASS'  ------------------
-----------------------------
'END'
```

It is recommended to rename the region file ('`sf_list`') to, e.g. '`VELAX-1_BGD.DATA`'.

Chapter 4

Preparation for the Analysis

4.1 Input Parameters

We explain the meaning of the input parameters which are used to make spectral files and timing files. In the explanation below, the heading of each item shows an example of the parameter specification.

`'RIG' 10.0 999.0 :`
: Minimum and maximum of the cut-off rigidity in unit of GeV/c.

`'ELV' 5.0 180.0 :`
: Minimum and maximum of the elevation angle (in unit of degree) between the earth limb and the LAC pointing direction.

`'TRN' 0.1 :`
: Minimum transmission to the target source.

`'BIT' 'ANY' :`
: Selection of the bit rate. Available parameters are `'HI'`, `'MED'`, `'LOW'`, and `'ANY'`. `'HI'` means only the high bit rate data are accepted, and `'MED'` for medium bit rate and `'LOW'` for low bit rate. `'ANY'` means no data selection is made with the bit rate.

`'LAC' 3 3 3 3 3 3 3 3 'INIT' 0 :`
: Specifies the selection of LAC counters and LAC mode. The eight numbers following `'LAC'` indicate choice of the counters and layers of LAC. The eight numbers take one of `0`, `1`, `2`, or `3`. `0` means the corresponding counter is not used. `1` and `2` mean only the middle and top layers are used respectively, and `3` means both layers are used. In MPC-2 mode, only the first and 5th numbers are meaningful, and only `0` and `3` are valid. In MPC-3 mode, only the first number is meaningful. The following parameter (`'INIT'` in this example) is used to specify the data mode. Possible values are `'MPC1'`, `'MPC2'`, `'MPC3'`, `'PC'`, and `'INIT'`. `'INIT'` is used to adopt the first LAC mode appeared in the data. The last parameter (`0` in this example) is a flag to indicate whether or not MPC-1 and MPC-2 mode data are mixed. `1` means to combine MPC-1 and MPC-2 mode data, while `0` means they are treated separately. When `1` is specified, data mode parameter of `'MPC1'` and `'MPC2'` produces the same results.

`'COR' 0 0 0 0 0 0 0 :`

These 7 flags indicate various corrections to be applied to the data. The corrections are, from left to right, background subtraction (`1`:yes, `0`:no), aspect correction (`1`:yes, `0`:no), dead time correction (`1`:yes, `0`:no), channel to keV conversion (`1`:yes, `0`:no), data unit (`0`:counts, `1`:counts/sec, `2`:counts/sec/cm^2), 'Cal On' data selection (`0`:yes, `1`:no), telemetry delay correction (`1`:yes `0`:no). The 6th flag was originally prepared to select the data when the calibration isotope inside LAC was turned on. However, this parameter should be always 0, because the LAC calibration isotope was never turned on. The 7th flag should be always 0, because the telemetry delay is already corrected for the FRFs. For mode-2 timing file, the flags from first to fifth should be set to 0.

`'ENG' 1 '22.0, 35.0' :`

Energy scale information. The first parameter should be always 1. In this example, 35.0 ch (in 0-47ch full scale) is defined to correspond to 22.0 keV.

`'BGD' 1 ' ''BGD file name'' 1 ''NONE'' ' :`

This specifies the background file name and its subtraction method. The 1st parameter indicate background subtraction method: `1` for the simple method, `2` for the SUD-sort method, `3` for the Hayashida method. The 2nd parameter is the background file name, which is required for the simple (`1`) and SUD-sort (`2`) method. Note that the file name is double-quoted. The file name is followed by the sub-file number (`1` in this example). The last argument (`''NONE''` in this example) is a dummy, but needs to be specified.

`'SUD' 1111 1111 4.6 9.8 0.4 37.0 :`

This line specifies how to calculate the SUD rate (counts/sec/counter). The first eight integers specify the LAC counters to be used to calculate the SUD rate. The following four numbers are minimum and maximum of SUD rate, its interval, and the threshold energy. The last parameter means to use data above 37 keV as SUD. In this example, all the eight detectors of LAC are used to calculate SUD and data with SUD (>37 keV) =4.6–9.8 cnts/s/counter are grouped with 0.4 cnts/s/counter intervals.

`'BUS' 46 50 54 58 62 66 70 74 78 82 86 90 94 98 :`

This line specifies how the data are grouped with the SUD rate. Boundaries of SUD rate are specified in unit of 0.1 cnts/s/counter in integer. This line overlied the parameter specified in the `'SUD'` line.

`'1BIN' 4.0 :`

This specifies time resolution of the timing file in unit of second.

`'PHSEL' '00111111 11111111 11111111 11111111 11111111 11111111' :`

This line indicates selection of energy channel for a timing file. In a timing file, you can create up to 10 energy bands, which are specified by this `'PHSEL'` line. `1` means to use the energy channel, and `0` not to use. The energy channels are specified in 0-47 ch basis. Thus `'1111'` corresponds to one MPC-3 channel. For PC mode, first 32 ch indicate PC-L and the next 16 ch for PC-H. You can specify up to 10 `'PHSEL'` lines.

`'PC' 1 1 1 1 :`

For mode-2 timing file, this `'PC'` keyword is used to specify the energy channel instead of `'PHSEL'` keyword. The 4 flags correspond to LAC-ALAC-BPC-LPC-H, respectively; `1` means to use and `0` means not to use the data.

`'TGT' 297.66 -4.98 'KES73' :`
: Right ascension and declination (in unit of degree in equinox of B1950), and the name of the target X-ray source. The target name is treated as a comment in the software.

`'OUT' 'FILE NAME' 'OLD' :`
: This specifies the output file name and its status. The file status is mostly ignored, but some program recognizes it. Note that an existing file may be overwritten without warning.

`'PLT' 1, 1 0 1.0 50.0, 1 1 1000.0 0.0 :`
: This is used to control the output plot. The 9 parameters are `plot level`, `XLOG`, `XAUT`, `XSCAL1`, `XSCAL2`, `YLOG`, `YAUT`, `YSCAL1`, `YSCAL2`. Meanings of these parameter are summarized bellow.

`plot level`: `0`:no plotting, `1`:make output plot

`XLOG`: This defines the x-coordinate of the plot. For spectral file, `0` means linear scale, `1` means log scale. For timing file, `0` means to make a histogram, `1` means to plot data point with errors.

`XAUT`: For spectral files, `0` means fixed scaling, and `1` means automatic scaling. For timing files, this parameter defined the number of bin in X-axis.

`XSCAL1`: For spectral files, this defines a minimum of X-axis if `XAUT=0`, or a ratio between the maximum and the minimum of X-axis if `XLOG=XAUT=1`. For timing files, this is a dummy and has no meaning.

`XSCAL2`: For spectral files, this defines the maximum of X-axis if `XAUT=1`. For timing files, this is a dummy.

`YLOG`: This defines the y-coordinate of the plot; `0` means a linear scale, `1` means a log scale.

`YAUT`: `0` means fixed scaling and `1` means automatic scaling in Y-axis.

`YSCAL1`: This defines a minimum of Y-axis if `YAUT=0`, or a ratio between the maximum and the minimum of Y-axis if `YLOG=YAUT=1`.

`YSCAL2`: This defines a maximum of Y-axis when `YAUT=0`.

4.2 LACDMP and FRFPLOT

Both `LACDMP` and `FRFPLOT` are used to know the overall status of the LAC data. These dump list and plot work complementary, and are useful to determine the good time intervals.

4.2.1 LACDMP

`LACDMP` files are already included in the '`lacdump`' directory. However, if you need a new `LACDMP` file, you can make it using the tool '`lacdmp`'. You need to input the pass numbers of the data you want the dump list.

```
'S8802230639'
'S8802240639'
```

You can find the above example in the file '`sample/lacdmp.input`'.

To run '`lacdmp`', type the following command.

```
ginga>> lacdmp < lacdmp.input > lacdmp.out
```

Note that `ginga>>` is a system prompt and is not a input command. The result will be written in '`lacdmp.out`' file in the above example.

4.2.2 FRFPLOT

'`frfplot`' makes a graphic output of the monitor data. Following is an example of the input file (`sample/frfplot.input`).

```
frfplot.ps/vps                                        /file name
'S8802230639'   1 999 512                             /pass number
  10                                                  /number of graph
1.0 'LAC' 3 3 3 3 3 3 3 3   0 20             16.0 /LAC  CH(LYR)  PH  BIN
1.0 'LAC' 3 3 3 3 3 3 3 3  20 47             16.0 /LAC  CH(LYR)  PH  BIN
0.5 'TRN'                                    16.0 /transmission
0.5 'RIG'                                    16.0 /cut off regidity
1.0 'LWD' 1 1 1 1 1 1 1 1  0 0 0 0 0 0 0 1 1 16.0 /LWD  CH     LYRID BIN
1.0 'GWD' 1 0 0                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'GWD' 0 1 0                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'GWD' 0 0 1                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'AWD' 1 0               1 1 1            16.0 /AWR  S LYR        BIN
1.0 'AWD' 0 1               1 1 1            16.0 /AWR  S LYR        BIN
'S8802240639'   1 999 512                             /pass number
  10                                                  /number of graph
1.0 'LAC' 3 3 3 3 3 3 3 3   0 20             16.0 /LAC  CH(LYR)  PH  BIN
1.0 'LAC' 3 3 3 3 3 3 3 3  20 47             16.0 /LAC  CH(LYR)  PH  BIN
0.5 'TRN'                                    16.0 / transmission
0.5 'RIG'                                    16.0 /cut off regidity
1.0 'LWD' 1 1 1 1 1 1 1 1  0 0 0 0 0 0 0 1 1 16.0 /LWD  CH     LYRID BIN
1.0 'GWD' 1 0 0                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'GWD' 0 1 0                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'GWD' 0 0 1                              16.0 /GWD  SC.PC.SOL2   BIN
1.0 'AWD' 1 0               1 1 1            16.0 /AWR  S LYR        BIN
1.0 'AWD' 0 1               1 1 1            16.0 /AWR  S LYR        BIN
```

The input parameters are structured as follows. First line specifies the output file name and the output device. In this example, PS file with portrait orientation (VPS) is selected as an output device. This program uses PGPLOT to make graphic outputs and the device specification should obey the PGPLOT convention. Second line and the followings are two sets of parameters (in this example), each starting with the pass number. The pass number line specifies the pass number, start and end super frame numbers (defaults are 1 and 999), length of X-axis (default is 256 bin). This line also indicate start of a set of input parameters which controls the graphic output. Next line indicates the number of graphic outputs for the pass, which is followed by the lines defining the output. Number of lines to define the graphic output must be equal to the number of graphics specified in the previous line. In the graphic definition lines, following parameters must be specified in order: relative (vertical) size of the graph, name of the item to plot, detailed parameters for the plot, width of the output bin (in unit of second). Possible names of the plot item and the parameters they take are described below.

'LAC': Plot the LAC main data. First eight integers specify the combination of the eight detectors of LAC. `0` means no use, `1` to use only the middle layer, `2` to use only the top layer, and `3` to use both layers. The next two integers mean minimum and maximum of PH channels.

'LWD': Plot the LAC monitor data. The 17 parameters specify how to add detectors and monitor data: LAC0, LAC1, LAC2, LAC3, LAC4, LAC5, LAC6, LAC7, L1, R1, S23, V1, V2, EV, ANT, SUD, and PIM. `0` means not to add, `1` means to add the data.

'GBD': Plot the GBD-related data. The 3 parameters indicate whether or not to add SC, PC, SOL-2 data by `1/0`.

'ASM': Plot the ASM data. First two parameters correspond Y1 and Y2, and the following 3 parameters to W1, W2, W3. It is indicated by `1/0` to add the data or not.

'TMP': Plot the HK temperature data. Two arguments, either `0` or `1`, may follow this key word. These arguments specify whether or not to plot the HK temperature of LAC0–3 and LAC4–7 by `0/1`.

'TRN': Plot the LAC transmission for the target source.

'RIG': Plot the cut-off rigidity

'MAG': Direction of geomagnetic filed in satellite coordinate.

'EAR': Direction of earth center in satellite coordinate.

'HIT': Plot the altitude of the satellite.

'POS': Plot the position (longitude and latitude) of the satellite.

To run '`frfplot`', input parameters must be supplied from the standard input.

```
ginga>> frfplot < frfplot.input > frfplot-1_dummy
```

An example of the graphic output is shown in figure 4.1. Various messages may be output to the log file, '`frfplot-1_dummy`'. If everything goes well, you may simply delete the log file. If something goes wrong, this file may be useful to identify the cause of the errors.

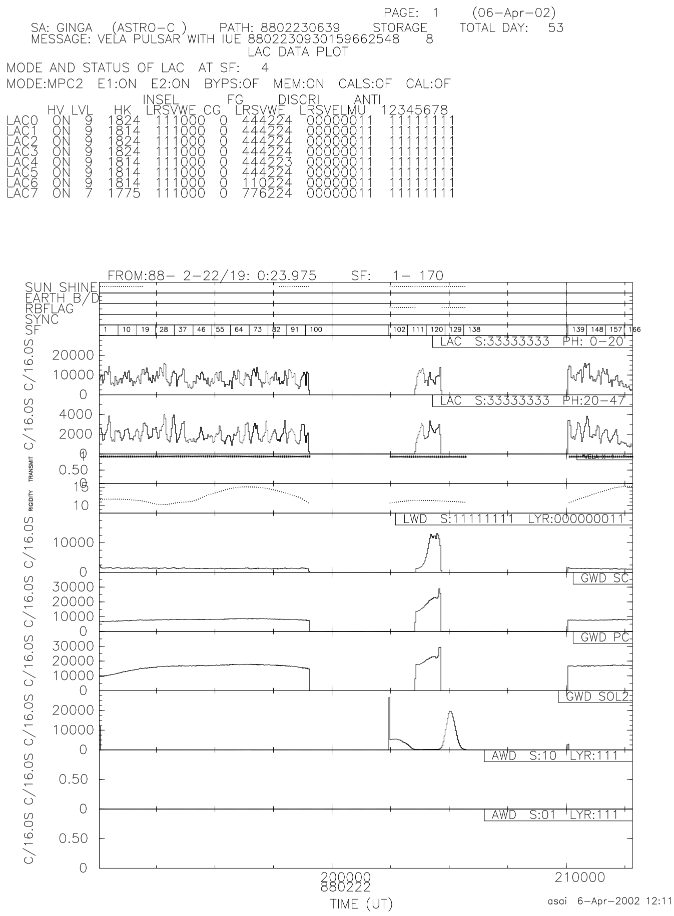

Figure 4.1: An example of the graphic output of '`frfplot`' obtained for the input parameters shown in the text. The output can be many pages, but only the first page is shown.

Chapter 5

Spectral Analysis

5.1 Making the Spectral Files

When we make the spectral files, we need to select appropriate subtraction methods of the background. There are 3 methods in the background subtraction: simple, SUD-sort, and Hayashida methods. Different software are used for these three methods.

5.1.1 Simple Method

As indicated by the name, this is the most simplest method to subtract background. In this method, a constant background is used, although the actual background may show time variations during the observations. This is simple, but may not be very accurate. You need a separate background observation appropriate for the source to use this method.

In this method, we first make a background (BGD) spectrum, called a monitor file, and then calculate the source spectrum taking the monitor file as a background. In the monitor file, raw spectra before summation on counters or layers are stored. Thus, a total of 16 spectra from each counter and layer are stored in MPC1 mode. A program '`lacspec`' is used for both steps. An example of the input file to make a BGD spectrum is as follows.

```
vela_bgd-1.ps/vps  / output graph
'MONI'  'VELAX-1_BGD_MONI1.SPEC' / monitor file of BGD spectrum
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0           / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   0  0  1  1  1  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CAL
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'PLT' 1 , 1  0  1.0  50.0, 1 1 1.0E+1 1.0E-1 /
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'VELAX-1_BGD.SPEC' / spectral file of BGD
'FILE'  'VELAX-1_BGD.DATA' / region data of BGD
```

These files ('`lacspec-1.input`' and '`VELAX-1_BGD.DATA`') are found under the '`sample`' directory. Note that the monitor file is output to the file specified by `'MONI'` key word, not `'OUT'` key word. The file specified by `'OUT'` may be useful to see the shape of the background spectrum, which is summed for counters and layers.

To run '`lacspec`', you need to supply the input parameters from the standard input.

```
ginga>> lacspec < lacspec-1.input > lacspec-1_dummy
```

Various messages during the process are output to a log file 'lacspec-1_dummy' in this example. This file may be useful to identify the problems when something goes wrong. Otherwise, you may simply delete it.

Next, we make a source spectrum using 'VELAX-1_BGD_MONI1.SPEC' as a background file. An example of the input file to make a source spectrum is as follows.

```
vela_1.ps/vps /output graph
'MONI'  'MONI.SPEC' /  work file
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0           / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   1  1  1  1  1  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CAL
'BGD'   1, ' ''VELAX-1_BGD_MONI1.SPEC'', 1, ''NONE'' ' / method, BGD file
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'PLT' 1 , 1  0  1.0  50.0, 1 1 1.0E+1 1.0E-1 /
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'VELAX-1_SPEC1.FILE' / source spectral file
'FILE'  'VELAX-1_REGION.DATA' /
```

These files ('lacspec-2.input' and 'VELAX-1_REGION.DATA') are found under the 'sample' directory. Note that the monitor file created in the previous step is specified with 'BGD', and the resultant source spectrum is output to a file specified with 'OUT'.

To run 'lacspec', type the following command:

```
ginga>> lacspec < lacspec-2.input > lacspec-2_dummy
```

'lacspec-2_dummy' is a log file for the output messages. 'VELAX-1_SPEC1.FILE' is the output source spectrum. Plot of the source spectrum is found in 'vela_1.ps' (figure 5.1). You may proceed to "Getting Started with XSPEC" for preparation of the spectral fitting.

5.1.2 SUD-sort Method

In this method, we use plural background data sorted according to the SUD count rate. SUD rate is a count rate of LAC exceeding the upper discriminator, and is a good indicator of the charged particle flux. Because a significant fraction of the LAC background is due to the charged particles, a good correlation is found between the SUD rate and the background level. Thus, both the on-source data and the background data should have similar SUD rate to subtract background accurately. For this purpose, we need to sort both the on-source and background data with SUD rate and to subtract corresponding background from the data.

We first make BGD spectra sorted according to the SUD rate. The BGD spectra are stored in a single file, called SUD-sorted monitor file, which contains several sub-groups, each corresponding to a BGD spectrum (with a different SUD level). Sub-groups of SUD rate are specified by 'SUD' and 'BSU' parameter. We use 'bgdspec' to create the SUD-sorted BGD file. Following is an example of the input parameters to make a background file of Vela X-1.

```
vela_bgd-2.ps/vps       /output graph
'MONI'  'VELAX-1_BGD_MONI2.SPEC' /  SUD sorted monitor file of BGD spectrum
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0           / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
```

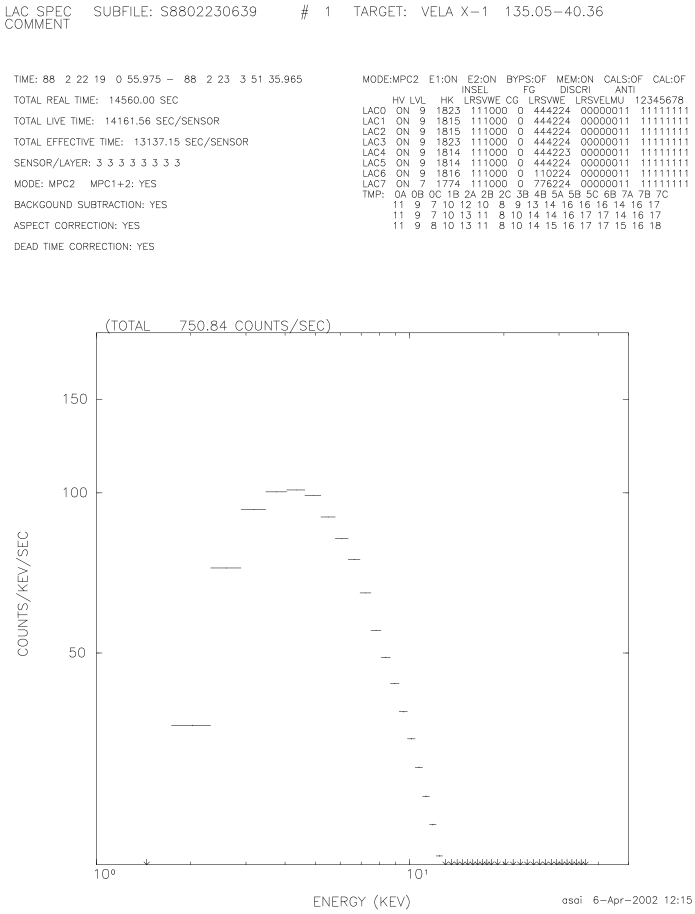

Figure 5.1: An example of the output of ‘lacspec’ obtained for the input parameters ‘lacspec-2.input’ listed in the text.

```
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   0  0  1  1  1  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CAL
'SUD'   1 1 1 1  1 1 1 1    4.6  9.8 0.4 37.0 / SSUD
'BSU'   46 50 54 58 62 66 70 74 78 82 86 90 94 98/
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'PLT'  1 , 1  0  1.0  50.0, 1 0 1.0E-1 1.0E+1  /LVL,X/Y(LOG,AUT,SCAL1,2)
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'VELAX-1_BGD2.SPEC' / spectral file of BGD
'FILE'  'VELAX-1_BGD.DATA' / region file of BGD
```

You can find these examples (`bgdspec.input` and `VELAX-1_BGD.DATA`) under the '`sample`' directory. Note that the name of the SUD-sorted BGD file must be specified as an argument of the key word `'MONI'`. The file specified for `'OUT'` is just a total background (not sorted for SUD). This may be useful to see the overall shape of the BGD spectrum, but cannot be used as an SUD-sorted BGD file.

To run ‘`bgdspec`’, type the following command:

```
ginga>> bgdspec < bgdspec.input > bgdspec_dummy
```

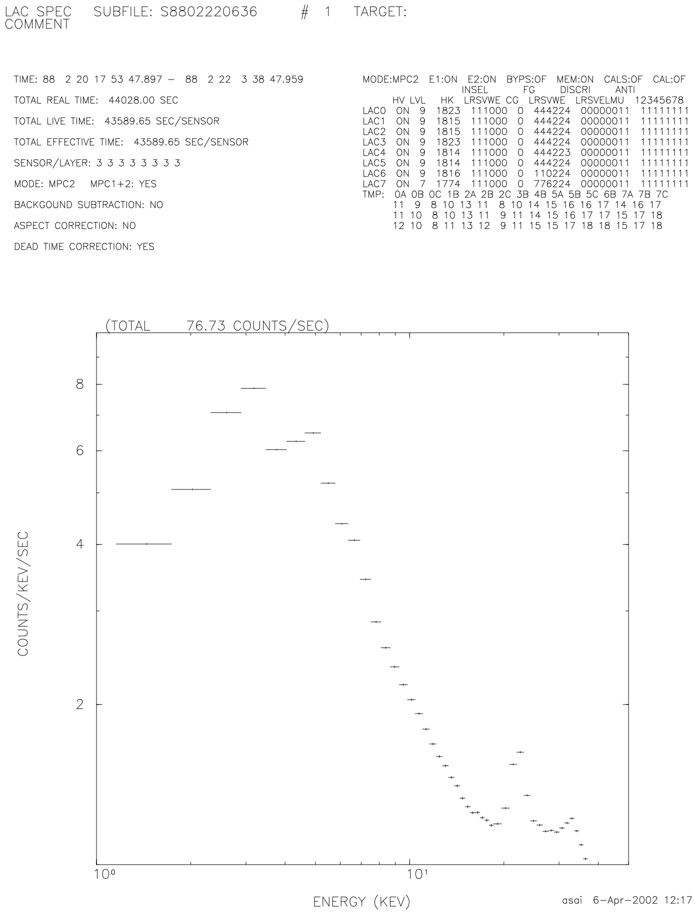

Figure 5.2: An example of the output of '`bgdspec`' obtained for the input parameters '`bgdspec.input`' listed in the text. '`bgdspec`' creates an SUD-sorted monitor file, but plots only the total BGD spectrum as shown here.

The output file '`bgdspec_dummy`' is a kind of a log file describing the status of each execution step. This log file may be useful, if something goes wrong, to identify the cause of errors. Otherwise, this file may be simply deleted. The SUD-sorted BGD file is output to '`VELAX-1_BGD_MONI2.SPEC`'. The total BGD spectrum is plotted in '`vela_bgd-2.ps`' (figure 5.2).

We next make an on-source spectrum using '`VELAX-1_BGD_MONI2.SPEC`' as a background file. This can be done with '`lacspec`'. If the BGD subtraction method 2 is specified (i.e. SUD-sort method), '`lacspec`' sorts the on-source data according to the SUD levels specified in the input parameters, and subtracts corresponding background from the SUD-sorted on-source data. The SUD-sorted data are summed up to a single spectrum before output. An example of the input file is listed below:

```
vela_2.ps/vps              /output graph
'MONI'  'MONI.SPEC' / work file
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0            / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
```

```
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   1  1  1  1  1  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CAL
'SUD'   1 1 1 1  1 1 1 1    4.6  9.8 0.4 37.0 / SSUD 12
'BSU'   46 50 54 58 62 66 70 74 78 82 86 90 94 98/
'BGD'   2, ' ''VELAX-1_BGD_MONI2.SPEC'', 1, ''NONE'' ' / BGD subtraction method and file name
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'VELAX-1_SPEC2.FILE' /
'FILE'  'VELAX-1_REGION.DATA' /
```

You can find these examples (`lacspec-3.input` and `VELAX-1_REGION.DATA`) under the '`sample`' directory.

To run '`lacspec`', type the following command:

```
ginga>> lacspec < lacspec-3.input > lacspec-3_dummy
```

'`lacspec-3_dummy`' is a log file, which describes the status of the job. You may simply delete this file upon successful completion. The final on-source spectrum is output to '`VELAX-2_SPEC1.FILE`', which is plotted in vela_2.ps (figure 5.3). You may proceed to §5.2 for the preparation of spectral fitting.

If you analyze a very bright source, some of the LAC scaler may have been overflowed. The scaler is a kind of counter to count up the number of counts in each energy channel. Because LAC uses non-reset scaler, this overflow may be corrected in the course of spectral calculation. This can be done with '`lacspec`' by specifying the key `'SPL'`.

5.1.3 Hayashida Method

In the previous subsection, we explained that the BGD count rate is correlated with the SUD rate. However, BGD rate show still some scattering even for the same SUD count rate. This is the reason we need the real background observation for the SUD-sort method. Hayashida et al. (1991) studied in detail the correlations of the BGD count rate with various HK and orbit parameters, and succeeded to reproduce the BGD rate for each energy channel with these parameters. This means that we can reproduce the BGD data without the BGD observations.

In Hayashida method, you need to select appropriate parameter files for your observations. This is because the available sets of the parameters depend on the LAC mode and the source brightness. Please see the comments in the `'RMK'` lines for the selection of the parameter files.

Hayashida method produces the light curve and the timing file simultaneously with the energy spectrum. Input parameters for these are distinguished by the following key words. These key words take a second key word to further distinguish the parameters.

SPC: plot/output energy spectrum

CHT: plot/output light curve

TIF: output timing file

If you are not interested in the timing file, just delete the `'TIF'` key words. An example of the input file for hayashida Method is as follows.

```
lacqrd-1.ps/vps          / output graph
'CALFILE' 'CARD.LACQR.NORMAL8' / normal data selection
'TRP'  0.0   0.5  0.05   / PROPORTIONAL TO TRAPPED PARTICLES C/SEC/S
'CHK' 'SFL'   1 1 1  / SOLAR CONTAMI  POS,IMPOS,BOTH
'CHK' 'ELV'  10.0 180.0  / ELEVATION ANGLE
```

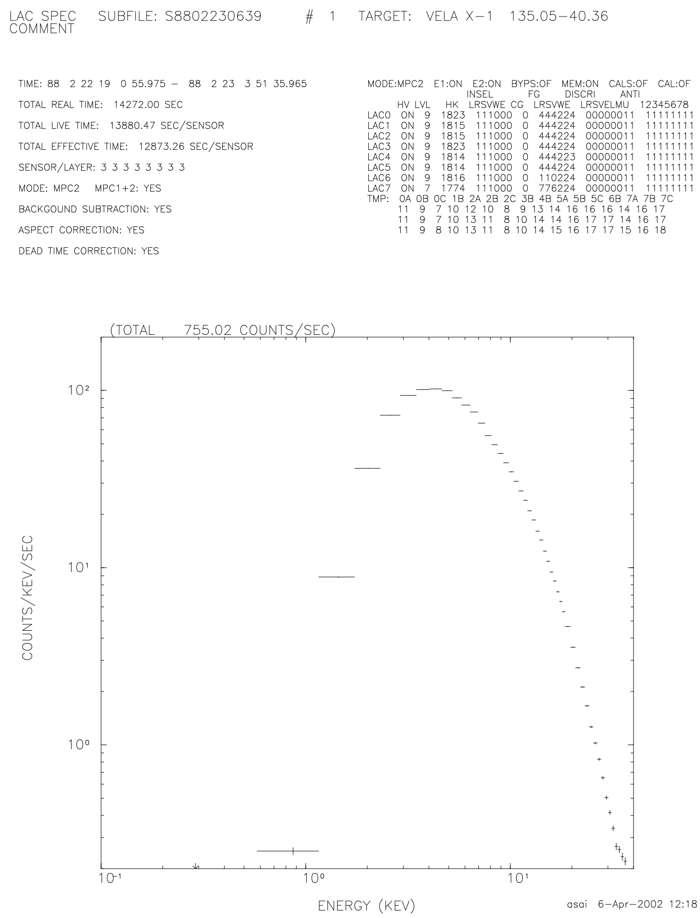

Figure 5.3: An example of the output spectrum of '`lacspec`' calculated with the BGD subtraction method 2. The BGD file, SUD-sorted monitor file, is plotted in figure 5.2.

```
'CALFILE' 'CARD.LACQR.BGD590SU'/
'RMK' '   BGD590   : 5PARAMETERS FOR MPC1 MODE                '
'RMK' '              MADE AT 1990.6       '
'RMK' '   BGD590SU : 5PARAMETERS FOR MPC2,MPC3 ( AND MPC1 )'
'RMK' '                                 MADE AT 1990.6    '
'RMK' '        USE MID MODELED BY ORBITAL POSITION AND REAL SUD '
'RMK' '   BGD590ML : 5PARAMETERS FOR MPC2,MPC3 ( AND MPC1 )'
'RMK' '                                 MADE AT 1990.6    '
'RMK' '        USE SUD AND MID MODELED BY ORBITAL POSITION '
'RMK' '                                                  '
'RMK' '  MPC1 MODE ONLY  ...   BGD590                     '
'RMK' '  MPC2 MODE AND/OR MPC3 MODE ...  BGD590SU         '
'RMK' '  FOR VERY BRIGHT SOURCES    ...  BGD590ML         '
'RMK' '                                                  '
'RMK' '  MODELS WERE MADE BASED ON THE DATA UPTO MAY 1990  '
'TAB' 'CARD.LACQR.DIRBGTAB' / DATA FOR SUD AND MID
'COR'  1  1  1  1    / BGD ,ASPCT,DEADTIME,DELAYTIME
'TIM'  128 /SAMPLIN BIN (SEC)  IF  -1 1SF  -2 1/2 SF -4 1/4 SF
'SUD' 1 1 1 1  1 1 1 1 ,2.0  22.0  1.0  ,37.0, 0.0 /
'PIM' 1 1 1 1  1 1 1 1 ,0.5  10.5  0.5 , 0.0 /
'MID' 1 1 1 1  1 1 1 1  2  8 , 0.0  30.0 1.0 , 0.0 /
'SPC' 'CNT'  1 /
'SPC' 'ENG'   1 ,       ' 22.1  35.2' /
```

```
'SPC' 'PLT'   1 ,       1    0   1.0 50.0,   1    1 10000.0 0.0 /
'SPC' 'LAC' 3 3 3 3  3 3 3 3     'MPC2'          1 /
'SPC' 'OUT' 'VELAX-1_SPEC3.FILE'  'OLD'    /   source spectral file
'SPC' 'MON' 'SPEC.MONI'  'OLD'  0 / work file
'CHT' 'WRK' 'COEF1.WORK'  /
'CHT' 'PLM' 1.0  0.0  0.0                 /
'CHT' 'PAR' 1,'LAC'  3 3 3 3 3 3 3 3  0  7 /
'CHT' 'PLP' 1, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 2,'LAC'  3 3 3 3 3 3 3 3  8 15 /
'CHT' 'PLP' 2, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 3,'LAC'  3 3 3 3 3 3 3 3 16 31 /
'CHT' 'PLP' 3, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 4,'LAC'  3 3 3 3 3 3 3 3  0 31 /
'CHT' 'PLP' 4, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'TIF' 'ENG' 1,   ' 22.1  35.2 '     /
'TIF' 'OUT'  'VELAX-1_TIMING0.fits'  'OLD' / output timing file
'CALFILE'  'LACQRT1' /  LAC counter and energy channel specifications for the timing file
'FILE'  'VELAX-1_REGION-1.DATA' / region data
'GO' /
```

You can find these files (`lacqrd-1.input` and `VELAX-1_REGION-1.DATA`) under the '`sample`' directory. Note that you cannot specify more than a single data block in the region file in Hayashida method. The number of characters of the parameter file name must not exceed 36. If the file name is longer, use symbolic link to reduce the total length of the file name.

To use Hayashida method, run '`lacqrdfits`' as follows:

```
ginga>> lacqrdfits < lacqrd-1.input > lacqrd-1_dummy
```

'`lacqrd-1_dummy`' is a log file describing the status of the job. You may simply delete this file upon successful completion.

'`VELAX-1_SPEC3.FILE`' is the output source spectrum. The timing file calculated simultaneously has a relatively low time resolution. The shortest bin width available in this program is a quarter superframe, which is 1 s, 8 s, and 32 s for H-, M-, and L-bit rates, respectively. If you want to make a timing file with a higher time resolution using Hayashida method, please see §6.1.3.

The source spectrum and the light curve are plotted in '`lacqrd-1.ps`' in the above example. Some other information are also output to the PS file. We show graphic outputs of '`lacqrd-1.ps`' in figure 5.4.

You may proceed to §5.2 at this stage for the preparation of spectral fitting.

5.2 Preparation of Response Matrix

The spectral file calculated in the previous section is an ascii file with LAC-specific format. We need to convert the spectral file into the fits format, which is readable with general purpose fitting tools, such as XSPEC. We also need a response matrix to perform model fitting. These can be done with '`lac2xspec`'. '`lac2xspec`' converts the ascii spectral file into the fits format and calculats response matrix associated to the spectral file. With these two files, model fitting can be done with XSPEC. Usage of '`lac2xspec`' is explained below. Note that '`lac2xspec`' is an FTOOL and that you need to set up a parameter file.

1. Prepare a parameter file '`lac2xspec.par`' under the directory of '`pfiles`', and set the directory to '`PFILES`' environmental variable:

   ```
   ginga>> cp $GINGA_CALDIR/lac2xspec.par ~/pfiles
   ginga>> setenv PFILES ~/pfiles
   ```

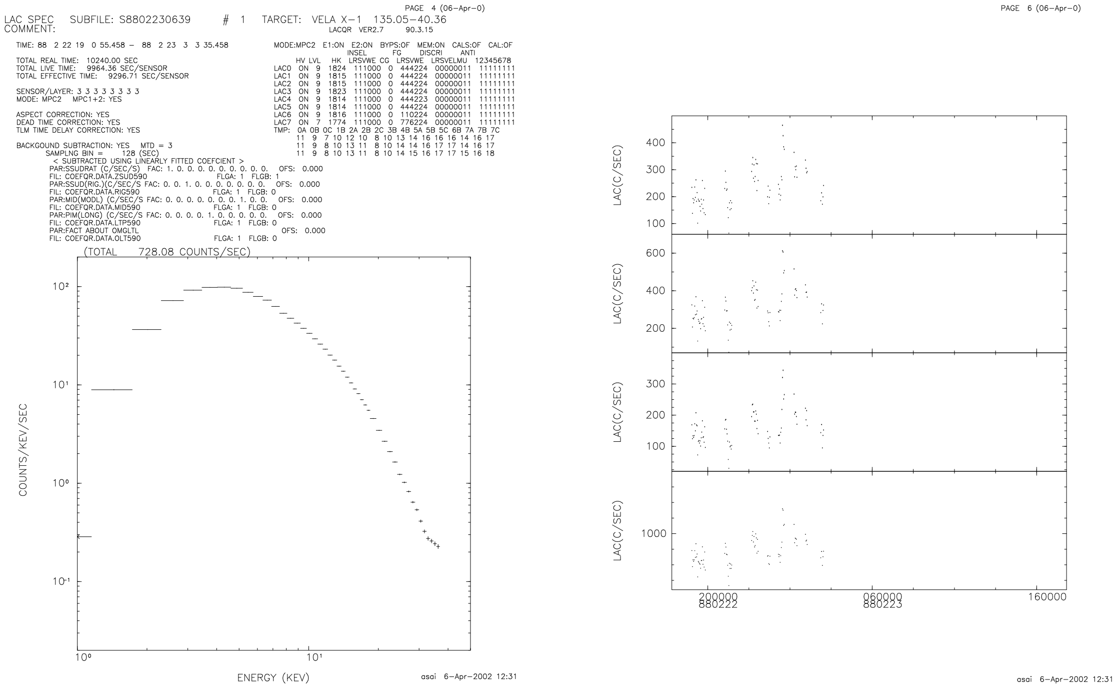

Figure 5.4: An example of the graphic output of '`lacqrdfits`' is shown. See text for the input parameters to obtain this output. Some other information is written to the graphic output.

2. Convert the ascii spectral file into fits format and calculate a relevant response matrix. The response matrix includes both rmf and arf files.

```
ginga>> lac2xspec
lac2xspec ver 2.0 (2000-2-29)
Name of the ASCII GINGA spectral file[GINGA.SPEC] VELAX-1_SPEC2.FILE
Sub file number[1]
Data number[1]
Systematic error (usually 0.01)[0.01]
Name of the Output XSPEC format PHA file name[GINGA.pha]
VELAX-1_SPEC2.pha
Name of the Output XSPEC format RMF name[GINGA.rsp] VELAX-1_SPEC2.rsp
...........................
...........................
... written the PHA data Extension
```

3. Perform model fitting using the fits-format spectral file and the response matrix. You can use the general purpose fitting tool, such as XSPEC, for this purpose. See the web page of HEASRAC [1] for XSPEC.

[1] `http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html`

Chapter 6

Timing Analysis

First step of the timing analysis is to create timing files. Timing files have a fits format and can be analyzed with the FTOOls. We also supply some tools for the timing analysis specific to the *Ginga* satellite.

There are two kinds of timing files: mode-1 and mode-2. Mode-1 timing files are usually used for the MPC mode data. We can apply various corrections, e.g. background subtraction, dead time and aspect corrections, to the data. On the other hand, mode-2 timing files have a compressed format and are used for PC mode data. No correction can be applied to the data in mode-2 format. You can still make mode-1 files with PC data, but file size becomes significantly larger.

6.1 Mode-1 Timing Files

As the case of the spectral analysis, three different methods are available for the background subtraction in calculating the timing files. These are simple, SUD-sort, and Hayashida methods. We explain below how to create timing files with these background subtraction methods. If you are not interested in the background subtraction, simply specify `0` as the first parameter of the `'COR'` keyword in the examples below.

6.1.1 Simple Method

In this method, the background is assumed to be constant. Just a constant value is subtracted from each channel of count history data. This method may be used when the time variations of the background is not important, e.g. to calculate the pulse amplitude in the folded light curve.

We first prepare the background file, and then calculate the timing file. The background file used to create the timing file is same as that used for spectral file. If you already have a simple background (a monitor file), you can proceed to the next step to calculate the timing file.

We show an example for Vela X-1. An input file to calculate the background file is as follows:

```
/NULL              / no output graph
'MONI'  'VELAX-1_BGD_MONI1-TIM.SPEC' / monitor file of BGD spectrum
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0            / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
```

```
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   0  0  1  1  0  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL=0,CAL
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'DUMMY.SPEC' /  dummy spectral file
'FILE'  'VELAX-1_BGD.DATA' / region data of BGD
```

You can find above files (`lacspec-tim1.input` and `VELAX-1_BGD.DATA`) under the '`sample`' directory. Note that the fifth parameter of the `'COR'` key word must be `0`: `CNTSCL=0`.

To run '`lacspec`', type the following command:

```
ginga>> lacspec < lacspec-tim1.input > lacspec-tim1_dummy
```

'`lacspec-tim1_dummy`' is a log file of the job status. You may simply delete this file upon successful completion. This log file might be useful to identify the causes if something goes wrong. '`VELAX-1_BGD_MONI1-TIM.SPEC`' is the output background file (so-called monitor file).

Next, we make a timing file using '`VELAX-1_BGD_MONI1-TIM.SPEC`'. An example of the input file is shown below. Please see §4.1 for the meaning of the parameters.

```
/NULL     / no output graph
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0            / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   1  1  1  1  0  0  1/BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CALSEL
'BGD'   1,  ' ''VELAX-1_BGD_MONI1-TIM.SPEC'', 1, ''NO NAME   '' '/
'PHSEL' '00111111 00000000 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 11111111 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 00000000 11111111 11111111 00000000 00000000'
'PHSEL' '00000000 00000000 00000000 00000000 11111111 11111111'
'PHSEL' '00111111 11111111 11111111 11111111 11111111 11111111'
'TRN'   0.01/
'OUT'  'VELAX-1_TIMING1.fits' / output timing file
'LAC' 3 3 3 3  3 3 3 3  'MPC2'  1 / SENSER,MODE
'BIT'  'ANY' / BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'1BIN'  16.0  /   SEC/BIN
'FILE'  'VELAX-1_REGION.DATA'  /    region file
```

You can find above files (`timinfil-1.input` and `VELAX-1_REGION.DATA`) in the '`sample`' directory. Note that the fifth parameter of the `'COR'` key word must be `0`: `CNTSCL=0`. It is recommended not to make a graphic output when you make a timing file, because the output can become very large.

Type the following command to run '`timinfilfits`':

```
ginga>> timinfilfits< timinfil-1.input > timinfil-1_dummy
```

'`timinfil-1_dummy`' is a log file describing the status of the job. You may simply delete this file upon successful completion. This file might be useful when something goes wrong. '`VELAX-1_TIMING1.fits`' conforms to a fits format of timing files. You can use the FTOOLS to analyze the data.

6.1.2 SUD-sort Method

In this method, we use plural set of background data sorted according to the SUD count rate as the case of the spectral analysis. Because the SUD rate is time variable, time variations of the background is incorporated through the SUD variations. This method is useful to make (1) a light curve longer than about an hour, (2) a hardness-ratio history, (3) a color-color diagram, etc.

At first, we make an SUD-sorted BGD file. This BGD file is same as those used in the spectral analysis. If you already have one, skip this step. The sub-groups of SUD rate are specified by `'SUD'` and `'BSU'` key words. Next, we make a timing file using the BGD file. An example of the input parameter file is shown below for Vela X-1:

```
/NULL   /no output graph
'MONI'  'VELAX-1_BGD_MONI2-TIM.SPEC'/ SUD sorted monitor file of BGD spectrum
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0           / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'           / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0               / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1               / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   0  0  1  1  0  0 / BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL=0,CAL
'SUD'   1 1 1 1  1 1 1 1    4.6  9.8 0.4 37.0 / SSUD
'BSU'   46 50 54 58 62 66 70 74 78 82 86 90 94 98/
'LAC'   3 3 3 3  3 3 3 3  'MPC2'  1 /
'BIT'  'ANY'/ BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'OUT'   'DUMMY.SPEC' /     dummy spectral file
'FILE'  'VELAX-1_BGD.DATA' / region data
```

You can find these examples (`bgdspec-tim.input` and `VELAX-1_BGD.DATA`) under the '`sample`' directory. Note that the fifth parameter of the keyword `'COR'` must be `0`: `CNTSCL=0`.

Type the following command to run '`bgdspec`':

```
ginga>> bgdspec < bgdspec-tim.input > bgdspec-tim_dummy
```

'`bgdspec-tim_dummy`' is a log file describing the status of each execution step. You may simply delete this file upon successful completion.

In the example above, '`VELAX-1_BGD_MONI2-TIM.SPEC`' is the output BGD file. Next, we calculate a timing file using the BGD file. An example of the input parameter file is listed below. The BGD file is specified in the `'BGD'` key word, and it is also necessary to specify the `'SUD'` and `'BSU'` key words in the SUD-sort method.

```
/NULL         /no output graph
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0           / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'           / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0               / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1               / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   1  1  1  1  0  0  1/BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CALSEL
'BGD'   2,  ' ''VELAX-1_BGD_MONI2-TIM.SPEC'', 1, ''NO NAME   '' '/
'SUD'   1 1 1 1  1 1 1 1    4.6  9.8 0.4 37.0 / SSUD 12
'BSU'   46 50 54 58 62 66 70 74 78 82 86 90 94 98/
'PHSEL' '00111111 00000000 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 11111111 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 00000000 11111111 11111111 00000000 00000000'
'PHSEL' '00000000 00000000 00000000 00000000 11111111 11111111'
'PHSEL' '00111111 11111111 11111111 11111111 11111111 11111111'
'TRN'   0.01/
'OUT'  'VELAX-1_TIMING2.fits' / output timing file
'LAC' 3 3 3 3  3 3 3 3  'MPC2'  1 / SENSER,MODE
'BIT'  'ANY' / BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'1BIN'  16.0  /   SEC/BIN
'FILE'  'VELAX-1_REGION.DATA'  /     region file
```

You can find these examples (`timinfil-2.input` and `VELAX-1_REGION.DATA`) under the '`sample`' directory.

Type the following command to run '`timinfilfits`':

```
ginga>> timinfilfits< timinfil-2.input > timinfil-2_dummy
```

'`timinfil-2_dummy`' is a log file which describes the execution status. '`VELAX-1_TIMING2.fits`' is the output timing file in the fits format. You can use the FTOOLS to brows and to analyze the data.

6.1.3 Hayashida Method

As explained in §5.1.3, a timing file can be created simultaneously with the spectral file using '`lacqrdfits`'. However, time resolution of the file is limited to low. Using the method explained here, you can make a timing file with any time resolution.

It is necessary to take 2 steps to calculate a timing file with the BGD subtraction of Hayashida method. First step is to create the BGD timing file using '`lacqrdfits`'. Time resolution of this timing file is rather low. Second step is to create the timing file subtracting this BGD file (with appropriate interpolation) using '`timinfilfits`'. It is clear that the data selection in these 2 steps must be identical. Furthermore, you need to select appropriate parameter files in this method. Please see the 'RMK' lines in the input data file for the selection of the appropriate parameter files. Below is a list of the special input key words in Hayashida method.

'SPC': plot/output energy spectrum

'CHT': plot/output light curve

'TIF': output timing file

An example of the input file of the first step is as follows:

```
/NULL              /no output graph
'CALFILE' 'CARD.LACQR.NORMAL8' / normal data selection
'TRP'  0.0   0.5  0.05   / PROPORTIONAL TO TRAPPED PARTICLES C/SEC/S
'CHK' 'SFL'   1 1 1  / SOLAR CONTAMI  POS,IMPOS,BOTH
'CHK' 'ELV'  10.0 180.0  / ELEVATION ANGLE
'CALFILE' 'CARD.LACQR.BGD590SU'/
'RMK' '   BGD590  : 5PARAMETERS FOR MPC1 MODE               '
'RMK' '              MADE AT 1990.6      '
'RMK' '   BGD590SU : 5PARAMETERS FOR MPC2,MPC3 ( AND MPC1 )'
'RMK' '                              MADE AT 1990.6    '
'RMK' '        USE MID MODELED BY ORBITAL POSITION AND REAL SUD '
'RMK' '   BGD590ML : 5PARAMETERS FOR MPC2,MPC3 ( AND MPC1 )'
'RMK' '                              MADE AT 1990.6    '
'RMK' '        USE SUD AND MID MODELED BY ORBITAL POSITION '
'RMK' '                                                    '
'RMK' '  MPC1 MODE ONLY  ...   BGD590                      '
'RMK' '  MPC2 MODE AND/OR MPC3 MODE ...  BGD590SU          '
'RMK' '  FOR VERY BRIGHT SOURCES    ...  BGD590ML          '
'RMK' '                                                    '
'RMK' '  MODELS WERE MADE BASED ON THE DATA UPTO MAY 1990  '
'TAB' 'CARD.LACQR.DIRBGTAB' / DATA FOR SUD AND MID
'COR'  1  0  1  1    / BGD ,ASPCT,DEADTIME,DELAYTIME
'TIM'  8 /SAMPLIN BIN (SEC)  IF  -1 1SF  -2 1/2 SF -4 1/4 SF
'SUD' 1 1 1 1  1 1 1 1 ,2.0  22.0  1.0  ,37.0, 0.0 /
'PIM' 1 1 1 1  1 1 1 1 ,0.5  10.5  0.5 , 0.0 /
'MID' 1 1 1 1  1 1 1 1  2  8 , 0.0  30.0 1.0 , 0.0 /
'SPC' 'CNT'  1 /
```

```
'SPC' 'ENG'   1 ,       ' 22.1  35.2' /
'SPC' 'PLT'   1 ,       1    0   1.0 50.0,   1    1 10000.0 0.0 /
'SPC' 'LAC' 3 3 3 3  3 3 3 3     'MPC2'           1 /
'SPC' 'OUT' 'DMMY.FILE'  'OLD'    /   dummy output file
'SPC' 'MON' 'SPEC.MONI'  'OLD'  0 /  work file
'CHT' 'WRK' 'COEF1.WORK'  /
'CHT' 'PLM' 1.0  0.0  0.0                 /
'CHT' 'PAR' 1,'LAC'  3 3 3 3 3 3 3 3  0  7 /
'CHT' 'PLP' 1, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 2,'LAC'  3 3 3 3 3 3 3 3  8 15 /
'CHT' 'PLP' 2, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 3,'LAC'  3 3 3 3 3 3 3 3 16 31 /
'CHT' 'PLP' 3, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'CHT' 'PAR' 4,'LAC'  3 3 3 3 3 3 3 3  0 31 /
'CHT' 'PLP' 4, 3.0 ,  0 1  0.0 0.0  0.0 0.0   /
'TIF' 'ENG' 1,   ' 22.1  35.2 '     /
'TIF' 'OUT'  'VELAX-1_BGD_TIMING.fits'  'OLD' /
'CALFILE'  'LACQRT48' /
'RMK' '   Use LACQRT48 for MPC-1 and MPC-2 mode.'
'RMK' '   Use LACQRT12 for MPC-3 mode.          '
'FILE'  'VELAX-1_REGION-1.DATA' / region file
'GO' /
```

You can find these examples (`lacqrd-2.input` and `VELAX-1_REGION-1.DATA`) under the '`sample`' directory. Note that the number of data blocks in the region file must be only one. Number of characters of the parameter file name must be no more than 36. In the `'COR'` key word line, BGD subtraction flag should be '`1`'. Aspect correction flag has no meaning here, because this is a background data. Dead time and delay time correction flags should be same as those for '`timinfilfits`'.

Type the following command to run '`lacqrdfits`':

```
ginga>> lacqrdfits < lacqrd-2.input > lacqrd-2_dummy
```

'`lacqrd-2_dummy`' is a log file describing the status of each execution step. This file may be simply deleted upon successful completion. '`VELAX-1_BGD_TIMING.fits`' is the output BGD timing file.

Next, we make a timing file using above BGD file. An example of the input file is as follows:

```
/NULL   / no output graph
'RIG'  5.0 20.0/ MIN/MAX CUT-OFF RIGIDITY
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0            / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'BIT'   'ANY'            / BITRATE SELECTION , 'ANY', 'HI' 'MID', 'LOW'
'SYNC'  0                / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'ENG' 1   '22.1,35.2'   / ENERGY SCALE,  LEVEL, ' DATA '
'COR'   1  1  1  1  0  0  1/BGDSBT,ASPECT,DTIME,ENGSCAL,CNTSCL,CALSEL
'BGD'   3,  ' ''VELAX-1_BGD_TIMING.fits'', 1, ''NO NAME   '' '/
'PHSEL' '00111111 00000000 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 11111111 00000000 00000000 00000000 00000000'
'PHSEL' '00000000 00000000 11111111 11111111 00000000 00000000'
'PHSEL' '00000000 00000000 00000000 00000000 11111111 11111111'
'PHSEL' '00111111 11111111 11111111 11111111 11111111 11111111'
'TRN'   0.01/
'OUT'  'VELAX-1_TIMING3.fits' / output timing file
'LAC' 3 3 3 3  3 3 3 3  'MPC2'  1 / sensor,MODE
'BIT'  'ANY' / BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'1BIN'  0.5  /   SEC/BIN
'FILE'  'VELAX-1_REGION-1.DATA'  /      region data
```

You can find these examples (`timinfil-3.input` and `VELAX-1_REGION-1.DATA`) under the '`sample`' directory. Note that the bin width of the BGD timing file is usually much longer than the bin width of the on-source timing file. The BGD timing file is appropriately interpolated in the course of the subtraction.

Type the following command to run 'timinfilfits':

```
ginga>> timinfilfits < timinfil-3.input > timinfil-3_dummy
```

'timinfil-3_dummy' is a log file describing the status of the job. 'VELAX-1_TIMING3.fits' is the output, BGD-subtracted timing file in a fits format. You can use the FTOOLS to analyze the timing data.

6.2 Mode-2 Timing Files

In the mode-2 timing files, the count data are stored in integer. This means that no data correction can be applied to the data. However, this reduces the file size considerably compared to the mode-1 files. In this section, we show an example for X1636–53. As listed below, input parameter file is very similar to that of mode-1.

```
/NULL    / no output graph
'RIG'  7.0 19.0/ MIN/MAX CUT-OFF RIGIDITY
'ELV'   3.0   999.0     0  /MIN, MAX,  -1/0/1/2=ANY/SKY/DARK/BRIGHT
'TMP'  -30.0   60.0   20.0/ MIN/MAX AVE TEMP, MAX TEMP GRADIENT
'TRN'    0.01             / MINIMUM TRANSMISSION OF THE TARGET SOURCE
'SYNC'  0                 / MINIMUM NUMBER OF BAD FRAMES
'ACE'   1                 / 1=ONLY FOR POINTING MODE,  0=FOR ANY MODE
'ENG'  1   '22.1,35.1'   / ENERGY SCALE,  LEVEL, ' DATA '
'PLT' 0 / no output graph
'TGT'  249.24, -53.66,    'X1636-53'  /
'OUT'   'X1636_time.fits' / output timing file
'COR'   0 0 0 0 0 0 1  /BGDSBT, ASPECT, DTIME, ENGSCAL, CNTSCL, CALSEL,MODE
'PC'        1   0 ,    1   0   / LAC A ,B   ,   PCL, PCH
'PC'        1   0 ,    0   1   / LAC A ,B   ,   PCL, PCH
'PC'        0   1 ,    1   0   / LAC A ,B   ,   PCL, PCH
'PC'        0   1 ,    0   1   / LAC A ,B   ,   PCL, PCH
'BIT'  'HIGH'  / BIT RATE SELECTION   'ANY' 'HI' 'MED' 'LOW'
'1BIN'   0.0078      /   SEC/BIN
'DATA'
  'PASS' 'R8708200310' /                DATA-1
  'B'    53/
  'E'    67    63  63 /
  'B'    71/
  'E'   192    63  63 /
'END'
'DATA'
  'PASS' 'S8708200411' /                DATA-2
  'B'    20/
  'E'    55    63  63 /
  'B'   160/
  'E'   356    63  63 /
  'B'   385/
  'E'   620    63  63 /
'END'
'DATA'
  'PASS' 'R8708200414' /                DATA-3
  'B'     3/
  'E'    47    63  63 /
  'B'    51/
  'E'   185    63  63 /
'END'
```

You can find this example under the 'sample' directory (tim2fil.input).

To run 'tim2filfits', type the following command:

```
ginga>> tim2filfits < tim2fil.input > tim2fil_dummy
```

'`tim2fil_dummy`' is a log file for the job status. The output timing file is '`X1636_time.fits`' in this example.

6.3 Calculating Power Spectrum

A tool to calculate a power spectrum is available in the *Ginga* archive. It is very important to estimate the Poisson fluctuation level in calculating the power spectrum, which is affected by the dead-time. Because the nature of the dead-time varies from detector to detector, it is difficult to estimate the Poisson fluctuation level accurately with general tools such as FTOOLS. If an accurate estimation of the Poisson level is important, you should use the tool we explain here.

The program, '`dynspecfits`', calculates average power spectra. Below is the list of the key words used in the input parameter file and brief explanations.

`'PLT'`: Control items to plot and their appearance. Meaning of the parameters is:

- **`LYL`:** If `LVL=0`, only the average power spectrum is plotted. If `LVL=1`, ensemble averages of every `NFOLD` power spectrum are also plotted in addition to the total spectrum.
- **`XLOG`:** Log (1,2) or linear (`0`) scale in the X-axis. If `XLOG=2`, the frequency bins will be combined so that they are log-equispaced with ratio specified by XSCALE1.
- **`XAUT`:** Recommended to set `1`.
- **`XSCALE1`:** If `XLOG=2`, this determines the ratio of the width of two successive frequency bins. If `XLOG=1`, this indicate the ratio of maximum/minimum values of Y-axis. Otherwise, it specifies minimum value in X-axis.
- **`XSCALE2`:** Maximum value in X-axis. Ignored unless `XLOG=0`.
- **`YLOG`:** Log (`1`) or linear(`0`) scale in Y-axis.
- **`YAUT`:** Recommended to set `1`.
- **`YSCALE1`:** If `YLOG=1`, this is ratio of maximum/minimum values of Y-axis.

`'BIN'`: The first parameter `NBIN` is the number of data bin per Fourier transform. The second parameter `NFOLD` is meaningful only when `LVL=1` in `'PLT'` key word. Ensemble averages of every `NFOLD` spectrum are plotted in the graphic output.

`'DMP'`: Specify the output file (ascii format) for the power spectrum.

`'FILE'`: Input Timing file and the data extension.

`'BSEL'`: Selection of the energy channel in the timing file.

`'MAT'`: Specify the bin summation factor. Time series data in the timing file are summed by this factor before processing. This key word is use to reduce the time resolution of the timing file.

`'GO'`: Indicate start of the processing.

An example of the input file of '`dynspecfits`' is shown below:

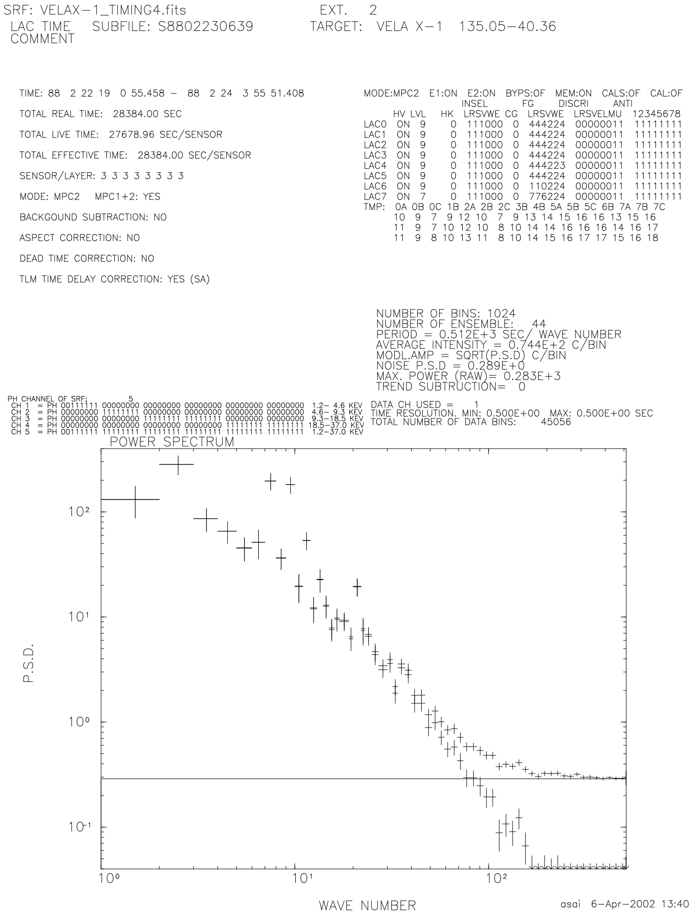

Figure 6.1: An example of the graphic output of '**dynspecfits**' is shown. See text for the input parameters to obtain this output. Two power spectra, with and without subtraction of the Poisson fluctuation level, are plotted.

```
dynspec.ps/vps      /output graph
'PLT'  0  2 1 1.08  0.  1 1  1.0E4    /LVL,X(LOG,XAUT,SCAL1,2),Y(LOG---
'DMP' 'dynspec.out' / output file of POWER SPECTRUM DENSITY and SIGMA
'BIN'   1024,   1,    1,  1 / NBIN, NFOLD,  W.N.1, D.W.N
'FILE' 'VELAX-1_TIMING4.fits' 2 / FILE NAME, Data Extension
'BSEL'   1  0  0  0  0     0  0  0  0  0 /
'MAT'        1/
'GO'   /
```

You can find this example under the '`sample`' directory (`dynspec.input`).

To run '`dynspecfits`', type the following command:

```
ginga>> dynspecfits < dynspec.input > dynspec_dummy
```

'`dynspec_dummy`' is a log file of the job status, and may be deleted upon successful completion. Graphic output of this example is shown in figure 6.1.

6.4 Epoch Folding Analysis

A tool for the epoch folding analysis, '`foldingfits`', is available from the *Ginga* archive. You can apply either geocentric or heliocentric corrections to the photon arrival time in the course of the analysis. Note that baricentric correction is not supported in this tool. When the count data in the timing file are redistributed in the phase bins, the conut data may be subdivided according to the overlap with the phase bins. Thus, if the time resolution of the timing file is close to the width of the phase bin, the calculated χ^2 values may include some systematics.

List of the key words available in '`foldingfits`' is given below.

'PERIOD': This specifies the initial trial period (in unit of second, `P0`), increment of the trial period (`D0`), number of the trial period (`NP`), number of the phase bin in the folded light curve (`NL`), and the correction level for the photon arrival time. Here, the correction level means no correction (`0`), geocentric correction (`1`), and heliocentric correction (`2`).

'FILE': Input timing file and the data extension.

'BSEL': Selection of the energy channel.

'GO': Indicate start of the processing.

An example of the input parameter file for '`foldingfits`' is shown below:

```
folding.ps/vps    /output graph
'PERIOD' 281.5, 0.5, 20, 10, 2/P0,D0,NP,NL,GEO/HELI
'FILE' 'VELAX-1_TIMING4.fits'  2  / FILE NAME, Data Extension
'GO'/
```

You can find this example in '`sample/folding.input`'.

To run '`foldingfits`', type the follwing command:

```
ginga>> foldingfits < folding.input > folding_dummy
```

'`folding_dummy`' is a log file for the job status. If you want a numerical output of the folded light curve, see this log file. Example of the graphic output is shown in figure 6.2.

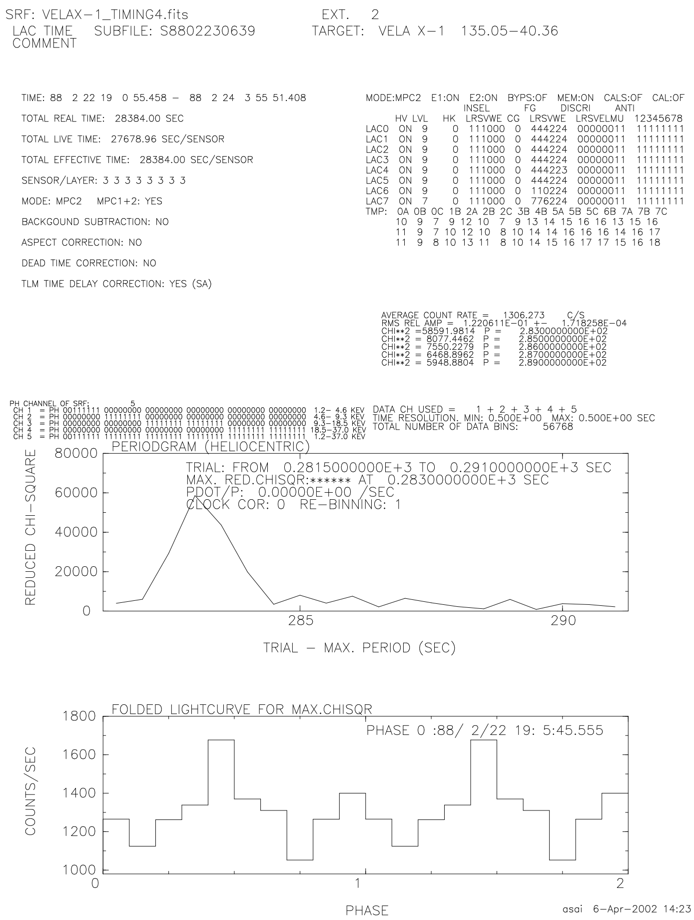

Figure 6.2: An example of the graphic output of '`foldingfits`' is shown. See text for the input parameters to obtain this output. The plot in the upper panel shows the change of red-χ^2 as a function of the trial periods. The lower panel shows the folded light curve at the period corresponding to the maximum χ^2 value.

Appendix A

The *Ginga* Satellite

Ginga is the 3rd X-ray astronomy satellite of Japan developed under the Japan-UK-US collaboration (Makino and the Astro-C team 1987). It was launched in February 1987 from the Kagoshima Space Center with the M-3S-II rocket, and was lost in November 1991 through reentry to the atmosphere. *Ginga* worked almost perfectly during its 4.7 year life and produced many valuable data. We summarize the parameters of *Ginga* in table A.

Ginga carried three scientific instruments, Large Area Counters (LAC; Turner et al. 1989), All Sky Monitor (ASM; Tsunemi et al. 1989), and Gamma-ray Burst Detector (GBD; Murakami et al. 1989). Descriptions of ASM and GBD will be given elsewhere. LAC was developed and fabricated under the collaboration between the Japanese institutes and the Leicester university. LAC achieved the largest effective area, 4000 cm^2, at that time. It produced good quality of data for various X-ray sources, especially for X-ray binaries including a black hole and a neutron star, and active galactic nuclei.

A.1 Attitude Control: Maneuver and Slew

Ginga can take two methods to change the attitude: maneuver and slew. Maneuver uses the magnetic torquers to change the attitude. This is slow because the torquers need to change the direction of the angular momentum of the satellite, but the satellite can rotate around any axis. On the other hand, slew changes the rotation speed of the momentum wheel to change the attitude. This is quick, but can rotate only around the Z-axis, along which the spin axis of the

Table A.1: Parameters of the *Ginga* satellite.

Size	$1.0 \times 1.0 \times 1.5$ m
Weight	420 kg
Power (Solar Cell output)	489W[1]
Down-link telemetry	UHF-band: max 65 kbps
	S-band: max 131 kbps
Attitude control	Bias momentum, 3-axis control
Orbit	Altitude 550 km, inclination 31°

[1]Values at the beginning of life.

wheel is aligned.

We usually use maneuver to move from one target to another. This maneuver sometimes take several hours. Slew is used to scan some region repeatedly. For example, we use scan to determine (one dimensional) position of the new X-ray source, or to produce (one dimensional) image along the Galactic plane. Slew is also used to make one complete rotation (slew 360°) to take the ASM data.

A.2 Real and Playback Data

Ginga can contact the ground station only five times a day, 10 minutes each. Thus most of the *Ginga* data are once stored in the on-board data recorder, and are reproduced during the contact to the ground station. The data once stored in the on-board recorder and are reproduced during the contact are called playback (or reproduced) data. On the other hand, data directly transfered to the ground station are called real data. Real data sometimes become noisy near the beginning and end of data when the satellite is close to the horizon.

A.3 Telemetry Bit Rate

Because most of the *Ginga* telemetry data are once stored in the data recorder, telemetry rate should be kept low to utilize the recorder capacity effectively. For this purpose, three different telemetry bit rates can be selected in *Ginga*, i.e. high, medium and low bit rate. In the medium bit rate, telemetry rate is reduced by a factor of 4 compared to that in high bit rate, and by a factor of 32 in the low bit rate. Data rates from all the instruments aboard *Ginga* are changed by these factors depending on the bit rate.

Appendix B

LAC

B.1 Introduction

LAC is the main instrument on board *Ginga* and comprises eight identical proportional counters with a total effective are of 4000 cm^2 covering the energy range from 2 to 37 keV. Their field of view is restricted by a mechanical collimator to $1^\circ \times 2^\circ$ (FWHM). Each of eight detectors has two separate X-ray sensing layers, i.e. top and middle layers. Soft X-ray photons below $\sim$4 keV are preferentially detected by the top layer, while the middle layer is sensitive to relatively hard photons above a few keV. Thus, the X-ray data can be separately accumulated from sixteen layers. A full description of the LAC is given in Turner et al. (1989).

B.2 Observation Modes

There are two main observation modes in LAC, i.e. MPC and PC modes. MPC mode is mainly used to get spectral data, while PC mode is used to obtain high time resolution data. Raw output data from LAC have 64 energy channels in MPC mode. This is compressed to 48 channel by combining in pairs the upper 32 channel on board. Because each detector has two layers, LAC produces in total of 16 sets of 48 channel data. These data may be further combined to reduce the data size, which defines sub modes of MPC mode: i.e. MPC-1, MPC-2 and MPC-3. Characteristics of the data modes are described below and the time resolution of each mode are summarized in Table B.2.

MPC-1 mode: The 16 sets of energy spectra in 48 channels are output to the telemetry as they are. This mode is useful for the accurate background subtraction, but has the lowest time resolution.

MPC-2 mode: The LAC counters are divided into two groups, LAC0–3 and LAC4–7. The 8 sets of spectra from each group are combined into a single spectrum. Thus we have two sets of spectra in 48 channel. The time resolution is improved by a factor of eight compared to the MPC-1 mode.

MPC-3 mode: Energy spectra from the two layers and eight counters are all combined. Furthermore, the 48 energy channels are reduced to 12 channels. The time resolution is improved by a factor of eight compared to the MPC-2 mode.

Table B.1: LAC modes and time resolution.

Mode	PH channel	High	Bit rate Medium	Low	Note
MPC-1	48	500ms	4s	16s	8 detectors by 2 layers
MPC-2	48	62.5ms	500ms	2s	4 detectors combined
MPC-3	12	7.8ms	62.5ms	250ms	8 detectors combined
PC-H		1.9ms	15.6ms	62.5ms	4 detectors combined
PC-L		0.98ms	7.8ms	31.3ms	4 detectors combined

PC mode: The analog to digital converter is by-passed in the PC mode, and three discriminator is used to produce count data in two channels. This reduces the dead time from 206μsec to 16.5μsec. The 8 counters are again divided into two groups. The count data are accumulated for each group. Because the discriminator level can be set independently for each group, we have 4 overlapping count data in total. The time resolution in higher channel is set twice as low as that in the lower channel to reduce the telemetry rate. The highest time resolution is 0.98/1.98 msec for the lower/higher channels, respectively.

B.3 Coarse Gain and High Voltage

LAC usually covers 2–37 keV with 48 channels. This energy coverage may be changed by selecting the coarse gain and the high voltage setting.

There are two choices in the coarse gain, high and low. The coarse gain is usually set to low to cover up to 37 keV. This energy range is reduced by a factor of two, if the coarse gain is set to high, with the upper bound of 18.5 keV. It is important to note that, although width of the energy bin reduces by a factor of 2, this does not change the energy resolution of the detector. It is especially useful to set the coarse gain high in MPC-3 mode.

The coarse gain setting is also important in the PC mode. In this mode we have three discriminator to determine the energy boundary of the two channels. Because each discriminator has only two settings (high and low), we sometimes changed the coarse gain simultaneously to get desired energy boundaries. We summarize the energy boundaries in PC mode in table B.3.

The upper bound of the energy range may be increased by changing the high voltage setting. This method was used to increase the energy coverage up to 70 keV. Although the upper bound may be changed almost continuously, we selected only 70 keV when we increase it. Because the particle background rate is high above $\sim$30 keV, meaningful data could be obtained at higher energies only for the bright sources.

B.4 Background

Because LAC is an non-imaging instrument, it has relatively high background. Typical total background rate ranges between 70–150 cnts/sec. The diffuse X-ray background and the charged particles are two main contributors to the background. We will mention some other contributors later. It is necessary to understand the nature of these two main background sources to get accurate subtraction of the background.

Table B.2: Energy (keV) of the discriminator levels.

Lever	CG-L		CG-H	
	H	L	H	L
Lower	1.53	1.19	0.77	0.60
Middle	15.7	5.67	7.94	2.86
Upper	24.3	17.9	12.3	9.05

The diffuse X-ray background has two component: the cosmic X-ray background (CXB) and the galactic ridge emission. The CXB is probably originated from the collection of the faint AGNs. Thus the CXB is considered to have global uniformity. However, when measured with the field of view of LAC, its fluctuation becomes noticeable. This fluctuation limits the reproducibility of the background. The ridge emission is a diffuse thermal emission along the galactic plane. This emission is negligible at higher galactic latitude. When a pointing direction of LAC is close to the galactic plane, it may be necessary to use background observation close to the pointing direction (preferably at the same galactic latitude). It is important to note that the ridge emission is not included in the background model of '`lacqrdfits`'.

The particle background shows large time variations. We use various monitor data or parameters to reproduce the particle background. One of the most useful data is the SUD rate. Because the particle background rate shows good correlation with the SUD rate, we use SUD rate to subdivide the data according to the background level. This is the basis of SUD-sort method of the background subtraction.

The large variations of the particle background are mainly due to the orbital motion of the satellite. In other word, the particle background level is mainly determined by the position of the satellite relative to the Earth. Because a typical observation lasts a day or more, background variations within an orbit are mostly smoothed out. However, because the orientation of the Ginga orbit precessed with 37-day period, background level also showed 37-day periodicity. If real observations are used as background, it is necessary to take account this periodicity to select appropriate background data.

Other than the diffuse X-ray and particle background, we sometimes need to pay attention to activation and the solar X-ray contamination. It is known that some of the materials used in LAC becomes radioactive during the SAA (South Atlantic Anomaly) passage. This means that background level increases through the SAA passage. The activation seems to decay rather quickly after the SAA, but some isotopes seems to have a decay time scale of a few hours. Thus, the background level becomes higher in the orbits that the satellite goes through the SAA.

The Sun is a powerful (soft) X-ray emitter and even a small contamination of the solar X-rays can become significant background of LAC. This can happen when the angle between the LAC pointing direction and the Sun is less than 90° and the Sun is active. Solar X-rays scattered within the collimator seem to get in the detector and become background. Because the solar panels of the satellite make shadow over the LAC, solar X-ray contamination is seen only selected counters. It is not difficult to identify the solar X-ray contamination unless the target source is bright. We simply look for step-wise variations of the count rate correlated to the day/night transition of the satellite. Because it is difficult to reproduce the solar X-ray contaminations, we need to discard the contaminated data.

Bibliography

[1] Hayashida, K. et al. 1989, Publ. Astron. Soc. Japan, **41**, 373.

[2] Makino, F., & the Astro-C team 1987, Astrophys. Lett., **25**, 223.

[3] Murakami, T. et al. 1989, Publ. Astron. Soc. Japan, **41**, 405.

[4] Tsunemi, H. et al. 1989, Publ. Astron. Soc. Japan, **41**, 391.

[5] Turner, M. J. L. et al. 1989, Publ. Astron. Soc. Japan, **41**, 345.