

Templates for the RGS Background

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1 Introduction

The analysis of RGS spectra of extended sources is often hindered by the difficulty of subtracting a suitable background. The SAS standard method (i.e. the 'rgsspectrum' task) extracts the background spectrum from off-axis regions supposedly free of source emission. While this assumption is effectively correct for point-like sources, given the small size of the RGSs FOV in the direction perpendicular to the dispersion (5.5 arcmin on the sky), in the case of moderately extended objects this background spectrum can be substantially contaminated by the source. This leads therefore to wrong results, for example in the determination of the intensity of the emission lines.

Previous work on this subject has been performed by T. Tamura, who derived RGS background templates as event files from empty field observations [1]. The event files which form these templates had been previously filtered for low-background periods. In order to apply them to a given observation it has to be filtered with the same criterion, often implying a substantial reduction in the exposure time.

The purpose of the present study is to continue this work, using a similar method, but extending its applicability to all observations without any restriction in the background level, avoiding the need for any previous filtering of the data.

The background spectra derived from these template event files also have a S/N ratio far better than the background derived from the observation itself for two reasons: higher equivalent exposure time, and larger geometrical area (the template spectra used the SAS task 'rgsbkgmodel' are extracted from 100% of the PSF, i.e. from the full FOV). The use of the model will then improve the detectability of weak sources and of weak spectral features.

All the examples and tests shown in this report have been obtained with an IDL version of the task. It has been shown that the SAS task 'rgsbkgmodel' (to be implemented in SAS 6.1) provides the same results.

2 Outline of the procedure

The new background templates have been built according to the following procedure:

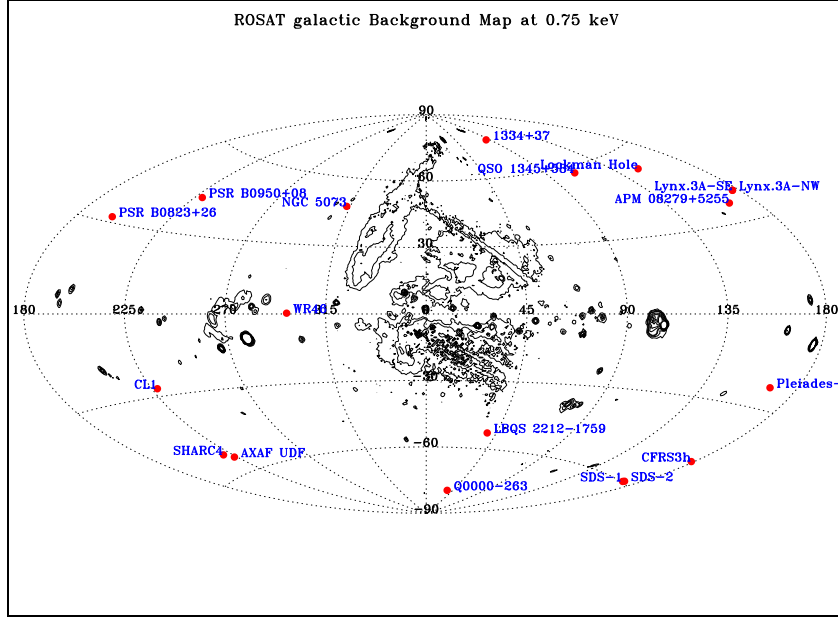


Figure 1: ROSAT Galactic Background map at 0.75 keV showing the fields used for the background templates.

- a. Selection of suitable empty fields.
- b. Uniform processing of the data.
- c. Merging of individual event files.
- d. Definition of the “background level indicator”.
- e. Use of this indicator to derive the model background spectrum applicable to a given observation.

The procedure was exactly the same for both RGSs and both spectral orders.

Two important assumptions have been made:

- i. The “cosmic” background is the same for all the observations included in the template.
- ii. A reliable “background level indicator” can be derived for all the observations, even for extended objects.

2.1 Selection of empty fields

The observations used to build the templates were selected according to the following criteria:

- Long exposure time (> 45 ksec)

Table 1: Final Sample

Obs. Id.	Target	Rev	R.A.	Dec.	l	b	T _{RGS1}	T _{RGS2}
01030603	Q0000-263	466	00 03 22.7	−26 03 05	35.9	−79.2	49.4	47.8
01123701	SDS-1*	118	02 18 00.1	−04 59 46	169.8	−59.7	60.0	58.7
01123710	SDS-1*	119	02 18 00.2	−04 59 45	169.8	−59.7	64.1	62.6
01123703	SDS-2*	120	02 19 36.2	−04 59 45	170.4	−59.5	60.7	62.9
00411701	CFRS3h	218	03 02 38.6	+ 00 07 30	177.5	−48.3	49.9	48.4
01080606	AXAF UDF	384	03 32 28.0	−27 49 01	223.6	−54.4	64.0	62.0
01080607	AXAF UDF	385	03 32 26.8	−27 48 49	223.6	−54.4	91.7	88.9
01080618	AXAF UDF	386	03 32 27.9	−27 48 40	223.6	−54.4	60.4	58.9
01080619	AXAF UDF	386	03 32 28.0	−27 48 19	223.6	−54.4	52.9	51.7
01080621	AXAF UDF	388	03 32 29.3	−27 48 30	223.6	−54.4	60.7	59.2
01080623	AXAF UDF	389	03 32 28.2	−27 48 24	223.6	−54.4	86.4	84.1
01078604	SHARC4	310	03 37 45.0	−25 22 16	219.9	−52.8	61.5	59.7
00947801	Pleiades-1*	134	03 47 18.3	+ 24 22 44	166.4	−23.3	50.0	48.6
00689401	CL1	332	05 33 44.6	−24 10 51	227.7	−27.2	63.4	62.0
01032606	PSR B0823+26	436	08 26 50.7	+26 37 17	197.0	+31.7	49.4	48.3
00928002	APM 08279+5255	437	08 31 41.3	+52 45 05	165.8	+36.2	100.2	97.6
00851502	Lynx.3A NW	342	08 49 07.2	+44 51 37	175.7	+39.2	50.2	48.6
00851503	Lynx.3A SE	342	08 49 18.1	+44 49 31	175.8	+39.2	50.1	48.9
01032608	PSR B0950+08	442	09 53 08.9	+07 55 24	228.9	+43.7	82.1	79.9
00227401	Lockman Hole	344	10 52 44.5	+57 28 51	149.3	+53.1	82.2	79.8
00227402	Lockman Hole	345	10 52 44.6	+57 28 53	149.3	+53.1	63.4	61.6
01091101	WR46	397	12 05 21.1	−62 03 04	297.6	+00.3	75.0	72.7
01109806	NGC 5073	471	13 19 20.6	−14 50 45	313.0	+47.5	52.4	51.0
01096608	1334+37	276	13 34 36.1	+37 54 38	85.6	+75.9	66.6	65.0
01096610	1334+37	282	13 34 36.2	+37 54 37	85.6	+75.9	86.5	83.8
01122502	QSO 1345+584	273	13 47 39.6	+58 12 39	109.2	+57.4	54.8	53.5
01066602	LBQS 2212-1759	173	22 15 32.0	−17 44 09	39.3	−52.9	47.0	45.7
01066601	LBQS 2212-1759	173	22 15 32.1	−17 44 06	39.3	−52.9	59.0	56.9
01066606	LBQS 2212-1759	356	22 15 31.3	−17 44 08	39.3	−52.9	107.5	109.6
Total exposure time (ksec)							1901.5	1858.4

* Observations with RGS1 CCD#7 data; total exposure time 234.8 ksec

- No source in the image by checking the spatial profile
- No spectrum visible in the Beta/PI image
- No peculiar background region (as in ROSAT galactic background maps, see Fig. 1)

The final sample is listed in Table 1.

2.2 Uniform processing of the data

All the observations were processed with SAS 5.3, using the on-axis coordinates and the default binning in beta: betabinref=0.03578524 rad, betabinwidth=1.208e-05 rad, 3400 channels. No relevant changes in the SAS RGS reduction tasks have been implemented since SAS 5.3 (up to SAS 6.1). Therefore these event files, as well as the template spectra generated from them can be used with any observation processed with SAS 5.3 or later.

2.3 Merging of individual event files

The individual event files were merged using standard SAS tasks (e.g. evlistcomb) and adhoc IDL procedures.

The final merged event files contain 6132731 events for RGS1 and 7561642 events for RGS2. Sizes are 460 Mb for RGS1, and 523 Mb for RGS2. These event files and the spectra extracted from them with 100% of the PSF are shown in Figs. 2 and 3.

Note the low counts in CCD#7 of RGS1. Due to its early failure (September 2000) only four of the observations contain data of this CCD (marked with * in Table 1), and therefore its exposure time is \approx eight times lower than for the rest of the chips (see Table 2).

2.4 Definition of a background level indicator

The “Background level indicator” (hereafter **BLI**) has been defined as the **countrate in the off-axis region of CCD#9**:

`XDSP_CORR < -3.E-4 rad or XDSP_CORR > 3.E-4 rad`

This region corresponds roughly to ± 1 arcmin from the on-axis position.

Due to the large size of the merged event files, in order to save processing time and to avoid memory problems, they were divided into 16 separate event files for each RGS, with different values of the BLI (as defined above):

`<0.01, 0.01-0.02, 0.02-0.04, 0.04-0.6, 0.06-0.08, 0.08-0.1, 0.1-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-2.0, 2.0-4.0, 4.-6.0 and > 8.0 counts/sec`

First and second order spectra have been extracted from each of these event files with the standard SAS task 'rgsspectrum', using 100% of the PSF for the spatial extraction, and 90% of the pulse-height distribution.

The shape of the background template spectra depends clearly of the value of the BLI as shown in Figs. 5 and 6, therefore, if the background light curve of a given observation is known, it should be possible to reproduce its background spectrum using a suitable combination of the templates.

The procedure to derive a model background for a given observation would be as follows:

- Compute the CCD#9 off-axis light curve of the observation.

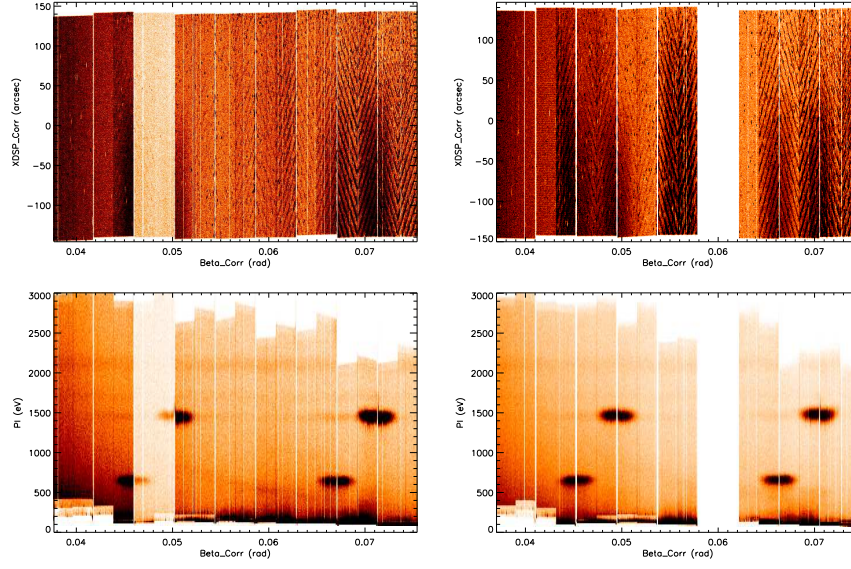


Figure 2: Final merged Event Files (left: RGS1; right: RGS2). Note the horizontal stripes in the Beta/PI plane due to fluorescence lines of Al $K\alpha$ (1486 eV), Au $M\alpha$ (2123 eV) and Si $K\alpha$ (1739 eV) in the detector housing.

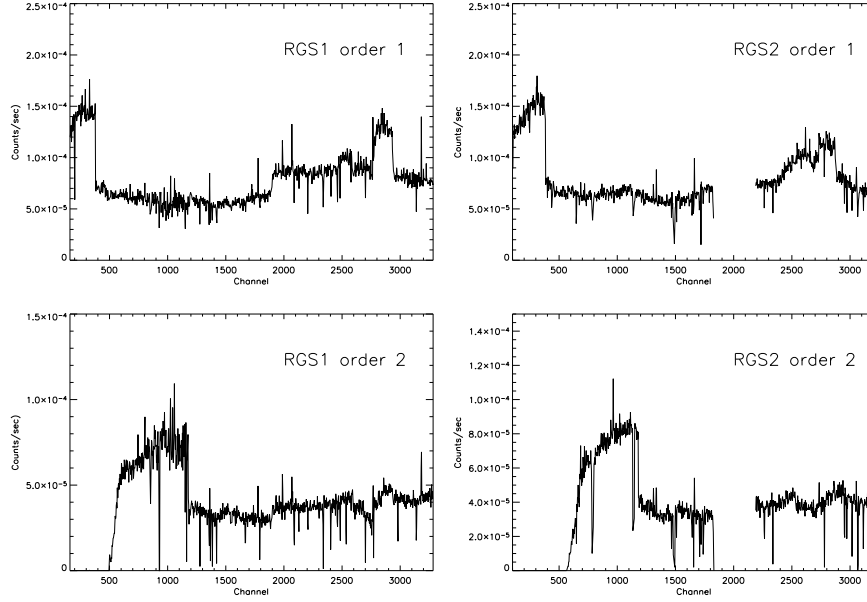


Figure 3: First (top) and second (bottom) order extracted spectra from the final merged event files (left: RGS1; right: RGS2). Spectra have been extracted for 100% of the PSF without any background subtraction.

Table 2: Characteristics of the template event files

BLI	RGS1					RGS2		
	Size	events	Texp	events CCD#7	Texp CCD#7	Size	events	Texp
$\text{BLI} \leq 0.01$	19064	144978	99.1	2681	14.9	35416	363494	172.3
$0.01 < \text{BLI} \leq 0.02$	27460	220400	152.0	3307	19.0	43652	458217	215.4
$0.02 < \text{BLI} \leq 0.04$	69464	611102	410.7	7489	41.6	88344	973918	448.6
$0.04 < \text{BLI} \leq 0.06$	59252	527129	343.4	5932	31.8	51776	568022	250.7
$0.06 < \text{BLI} \leq 0.08$	32416	283071	175.6	2585	13.9	24360	254889	106.7
$0.08 < \text{BLI} \leq 0.1$	18796	158720	90.6	1906	8.3	15504	153566	60.2
$0.1 < \text{BLI} \leq 0.2$	37648	396093	180.5	8638	29.7	36524	442039	150.1
$0.2 < \text{BLI} \leq 0.4$	32964	413452	125.4	11454	26.1	34476	466096	118.9
$0.4 < \text{BLI} \leq 0.6$	23260	314880	68.3	9770	14.9	24496	353198	66.2
$0.6 < \text{BLI} \leq 0.8$	16812	232512	39.6	6774	8.1	19976	294302	44.6
$0.8 < \text{BLI} \leq 1$	14552	204700	28.4	3124	2.9	15216	224186	27.6
$1 < \text{BLI} \leq 2$	41304	741382	70.8	13020	8.4	46244	853942	73.6
$2 < \text{BLI} \leq 4$	36688	712809	36.2	15316	4.4	42092	835246	39.3
$4 < \text{BLI} \leq 6$	20148	379802	10.5	15439	2.6	20112	381654	10.1
$6 < \text{BLI} \leq 8$	26368	527477	10.5	23222	2.8	28308	574650	10.9
$\text{BLI} > 8$	7600	102823	1.6	7448	0.8	10184	162718	2.7

Integration times are in ksec and file sizes in Kb

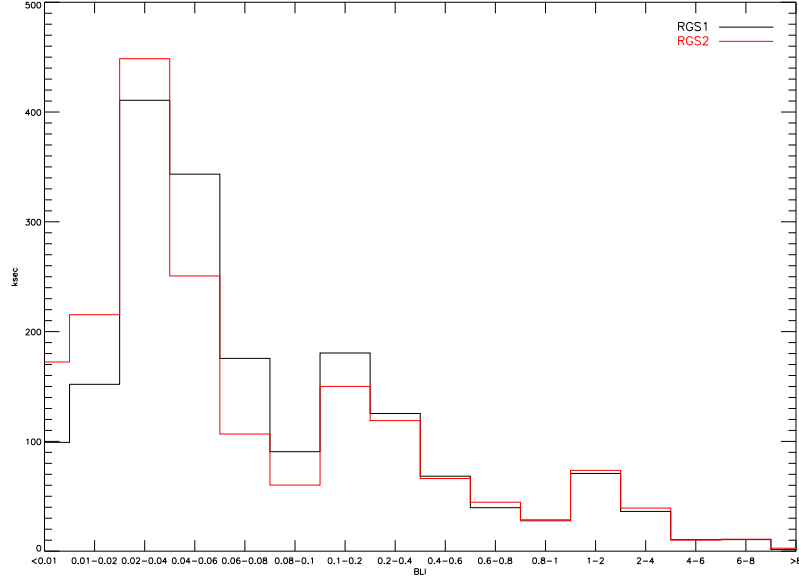


Figure 4: Distribution of the templates exposure times for the 16 different BLIs

- b. Compute the fraction of the light curve in each of the above sixteen pre-defined BLI levels.
- c. Combine the template spectra weighting them by the corresponding fractions.

Note that the final background model spectrum does not need any additional normalisation. The background model is determined **entirely** by the time-variable background within the observation.

This background can be applied to any source region extraction size, since the appropriate scaling is done through the **BACKSCALE** column.

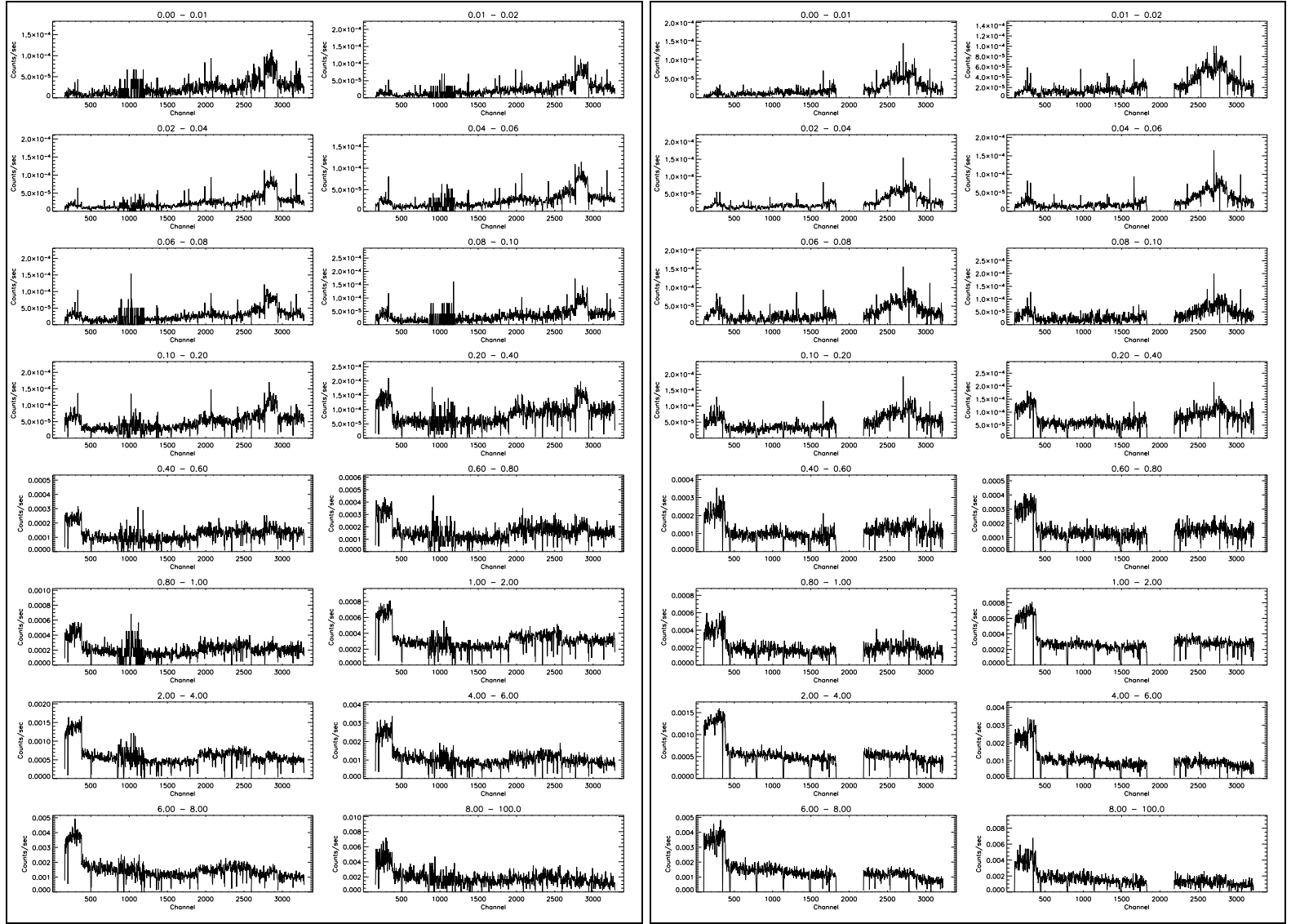


Figure 5: First order spectra extracted from the individual event files (100% of PSF, no background correction); left: RGS1, right: RGS2. Each spectrum is labeled with the corresponding BLI.

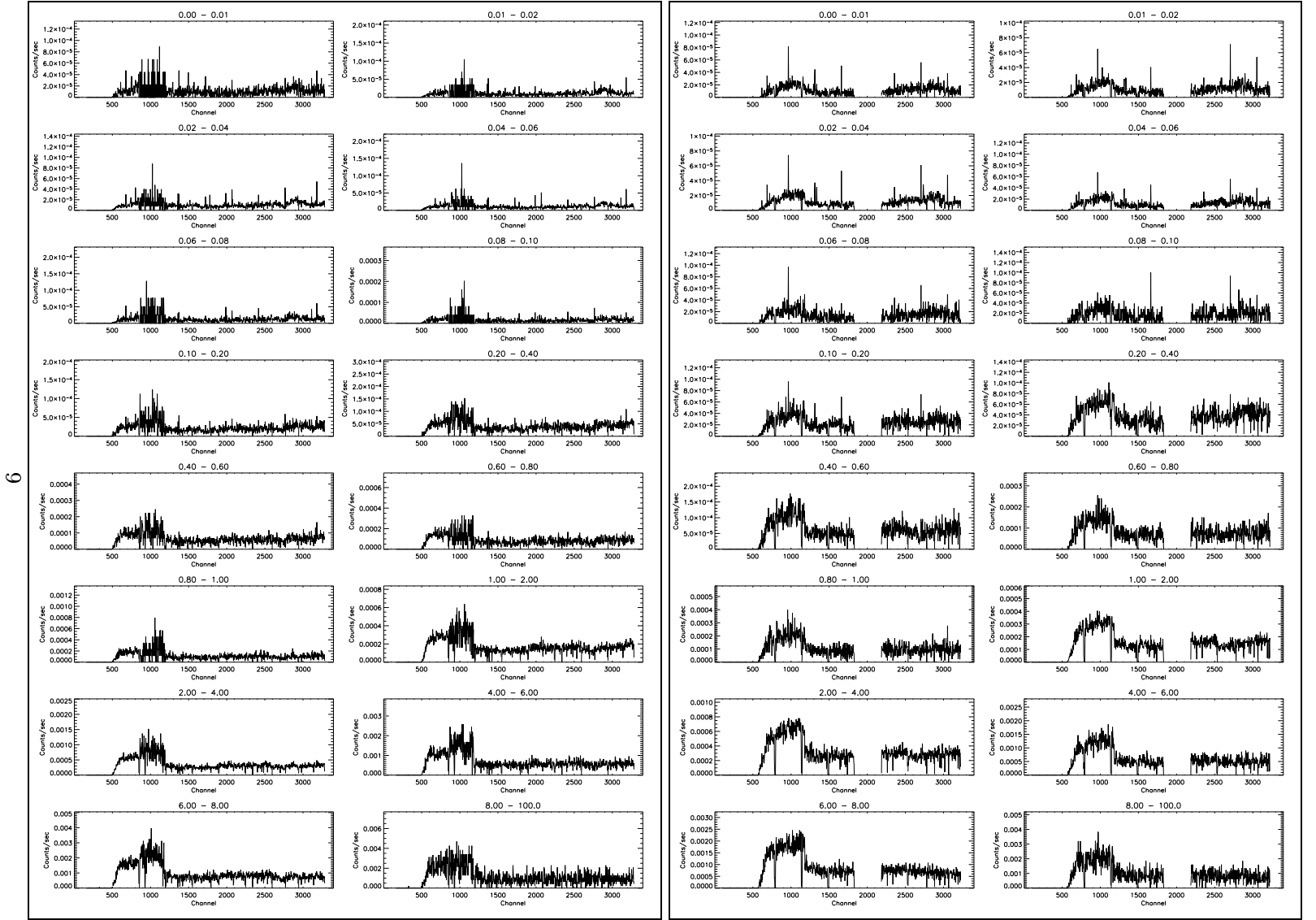


Figure 6: Second order spectra extracted from the individual event files (100% of PSF, no background correction); left: RGS1, right: RGS2. Each spectrum is labeled with the corresponding BLI.

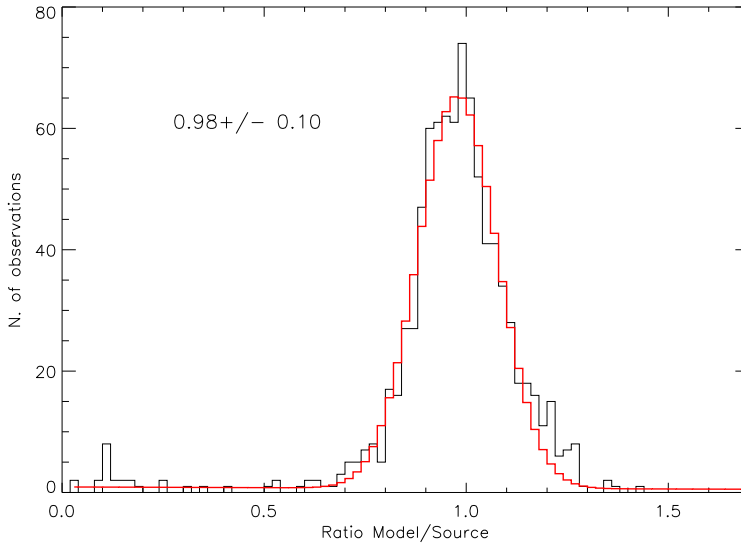


Figure 7: Histogram of the ratio of the countrates of the model background and the source spectrum for the 946 observations identified as 'blank' fields. The red line shows a gaussian fit to the data.

3 Discussion

3.1 General results

The test that would better show the validity of the method is the comparison of the background model with the source spectrum extracted from blank fields.

We have computed the RGS1, first order, model background model for a set of 1540 observations. For all of them the source spectrum has been extracted from the full FOV of the RGS (i.e. 100% of the PSF). If it is of course difficult to identify 'blank' fields, since contamination by weak sources falling within the RGS FOV can never be ruled out. We have tried to do it by comparing the source and the SAS-background countrate, being left with a final sample of 946 observations (61% of the initial sample) that we consider as 'empty' fields.

The average ratio of the countrates of the model background and the source for this sample is 0.98 ± 0.10 (1σ) (see Fig. 7).

The 80 observations for which the ratio model/source is below 0.8 correspond in most cases to sources filling the RGS field of view that were erroneously identified as blank fields (e.g. the Cygnus Loop, Vela, some clusters of galaxies). On the other hand, there are 50 observations (5% of the sample) with a value of this ratio larger than 1.2, i.e. for which the model overestimates the actual background.

Detailed examples of the application of this method to different types of observations are shown in the next Section.

3.2 Source contamination of the background light curve

One of the basic assumptions of the procedure is that the light curve of the off-axis region of CCD#9 represents the true background of the observation. While this is the case for point-like sources, some contamination might exist for extended sources, in particular if the Si XIII lines are strong.

To check the validity of this assumption, the background light curve has been derived following an alternative method: excluding the events in the first-order PI selection region, i.e. excluding those that might come from the source. Model background derived from both methods have been compared for a data set of extended objects with different sizes.

Out of sixteen cases studied, only two show a significant difference, that is, the background is overestimated due to source contamination of the **BLI**: Kepler's SNR (35% difference) and MSH11-54 (4%). All the other cases show differences $<3\%$. We therefore conclude that the filtering in PI is not strictly necessary.

3.3 Applicability to post-cooling data

One point to be checked is if these templates, built from data taken prior to July 2002, are valid for observations taken after the RGS cooling performed in November 2002.

This test should ideally be performed by comparing the quality of the model for two observations of the same field, preferably a blank one, with similar exposure times and radiation rates.

Unfortunately, such a pair of observations seems quite difficult to find and the test has been performed using pairs of data of three different targets taken before and after the RGS cooling exercise. Model background spectra have been also derived for a number of post-cooling observation of blank fields.

The conclusion of the test is that there is no significant difference in the quality of the background model for observations taken before and after the RGS Cooling of November 2002. We therefore conclude that the current templates are applicable to recent observations as well.

4 Examples

4.1 Control Sample: Empty fields

A first test was run applying the method to empty fields, i.e. observations in which there is no source in the EPIC FOV bright enough to produce significant signal in the RGSs. Spectra have been extracted from 100% of the PSF.

We show here three representative examples. For each observations we show the standard projections of the corresponding event files both for RGS1 and RGS2, the RGS1 CCD#9 off-axis light curve, and the first and second order spectra for both instruments (extracted spectra in black, model background in green).

In the examples shown in this section all the data points of the model background are plotted while, for clarity, the data plotted for the source spectrum and the SAS background are the average of three and five original data points, respectively.

4.1.1 Hubble Deep Field (Blank field)

ObsId 01115504 (Fig. 8). Exposure time: 89 ksec. Low background with a few flares.

The exposure times of the model background spectra are 234 and 240 ksec for RGS1 and RGS2, respectively.

The model reproduces fairly well the field spectrum, except for a weak emission in the source near 22 Å, that is barely visible in the Beta/PI image.

4.1.2 LMC2-f5 (Supergiant shell in the LMC)

ObsId 00944111 (Fig. 9). Exposure time: 12 ksec. High background.

The exposure times of the model background spectra are 79 and 72 ksec for RGS1 and RGS2, respectively.

The model reproduces well the field spectrum.

4.1.3 Pleiades (Star Cluster, only weak sources within the RGS FOV)

ObsId 01123901 (Fig. 10). Exposure time: 60 ksec. Low background with numerous flares.

The exposure times of the model background spectra are 186 and 177 ksec for RGS1 and RGS2, respectively.

This example has been chosen for having data in RGS1 CCD#7. Due to the contribution of faint sources within the RGS FOV there some small differences between the model and the field spectrum, in particular a noticeable emission line around 18 Å.

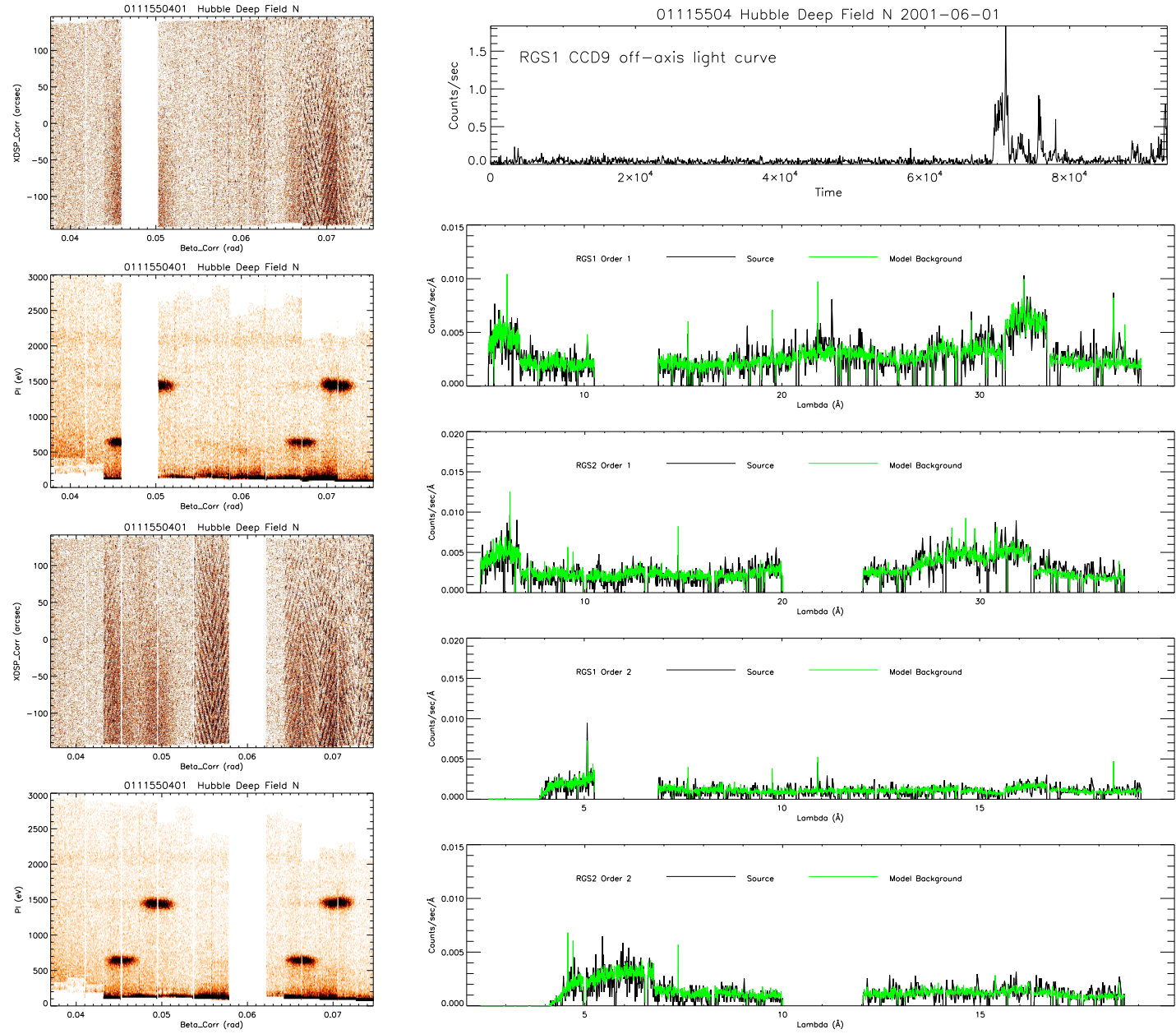


Figure 8: Results for the Hubble Deep Field

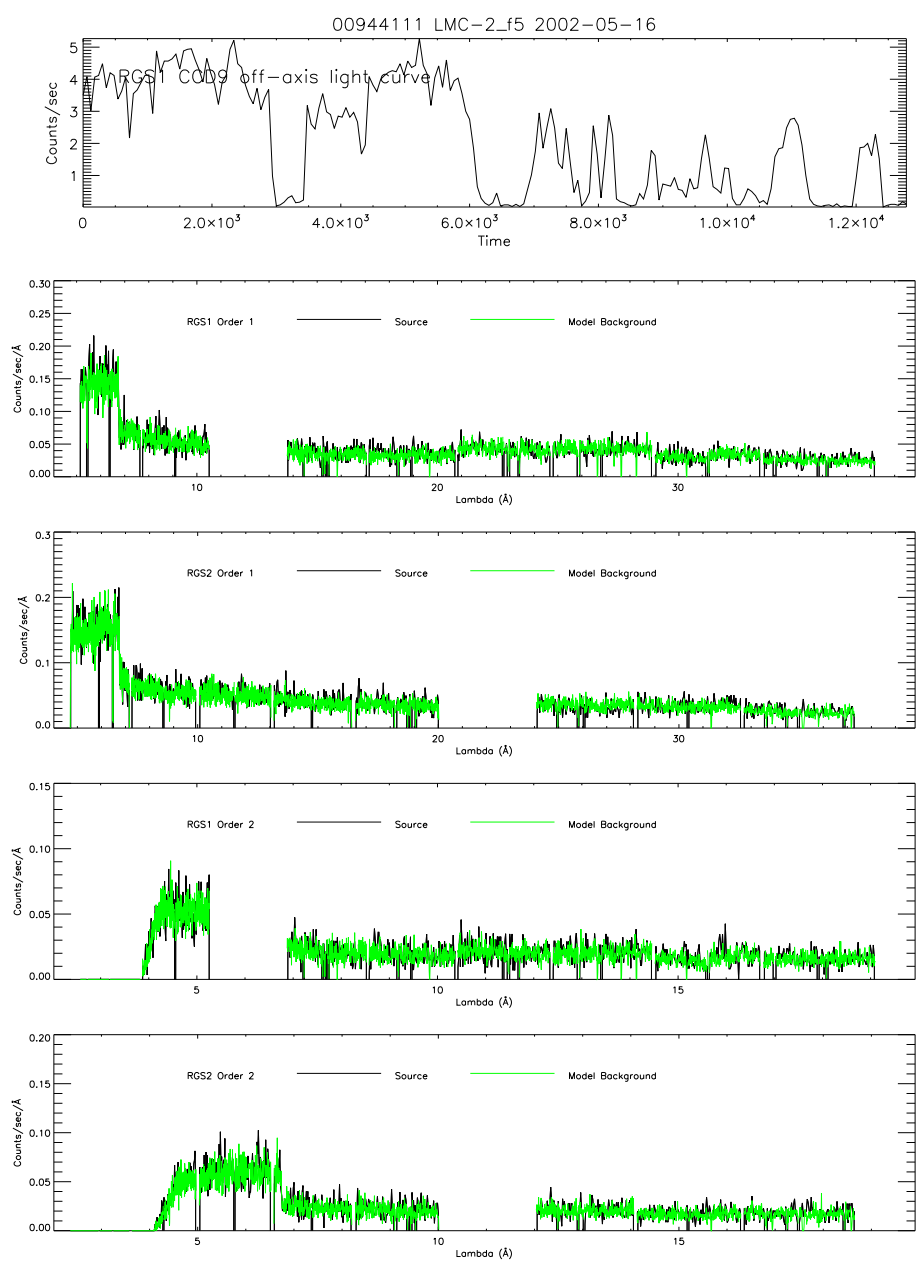
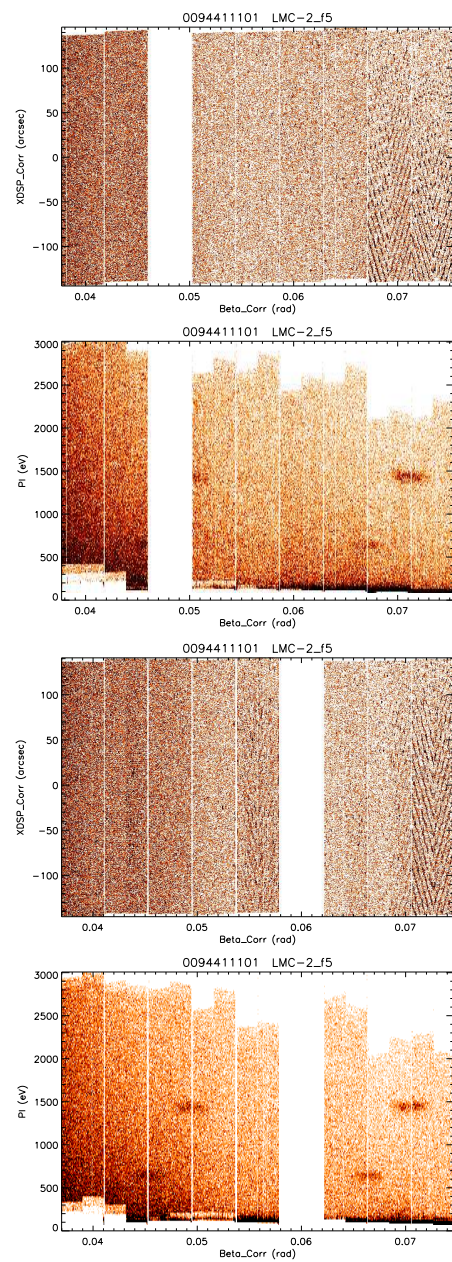


Figure 9: Results for LMC2-f5

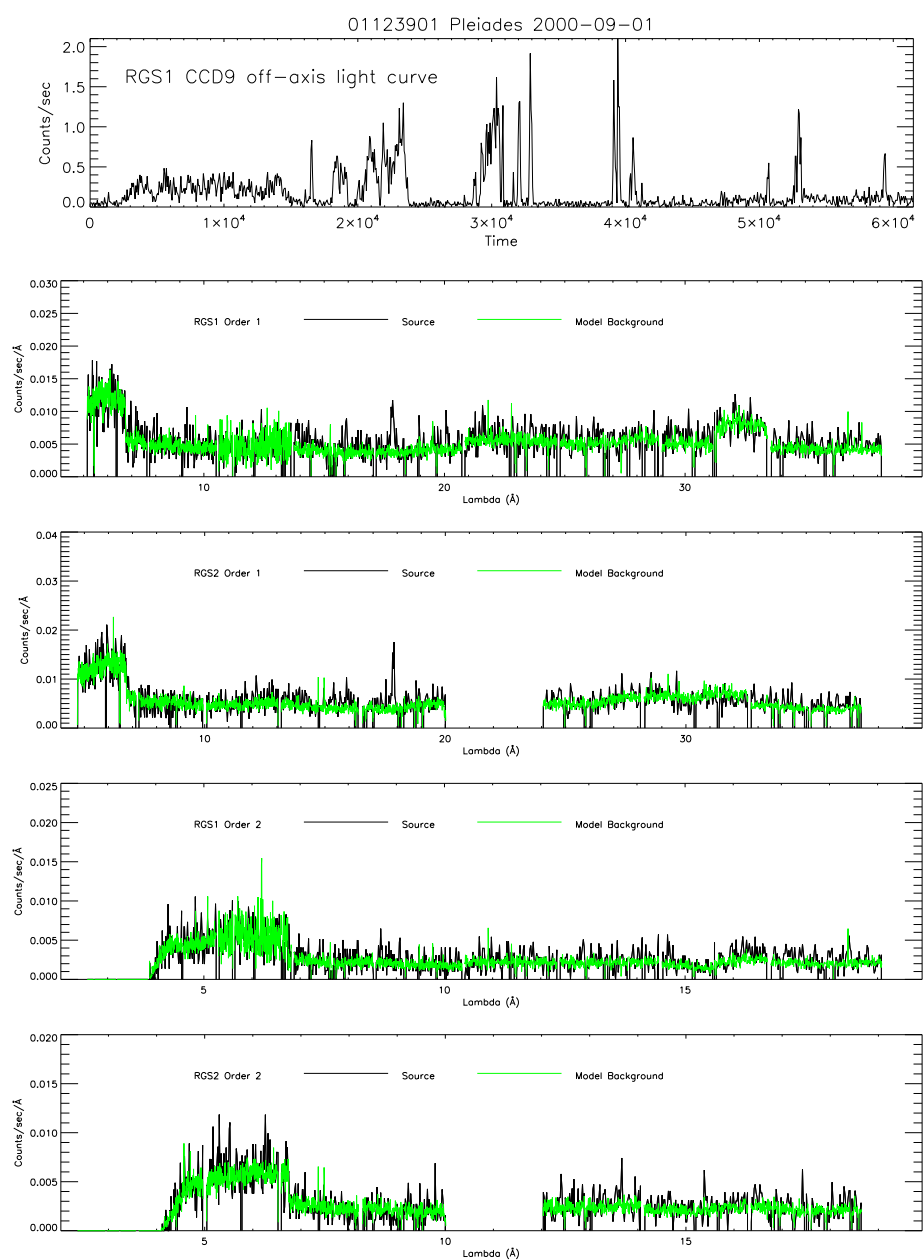
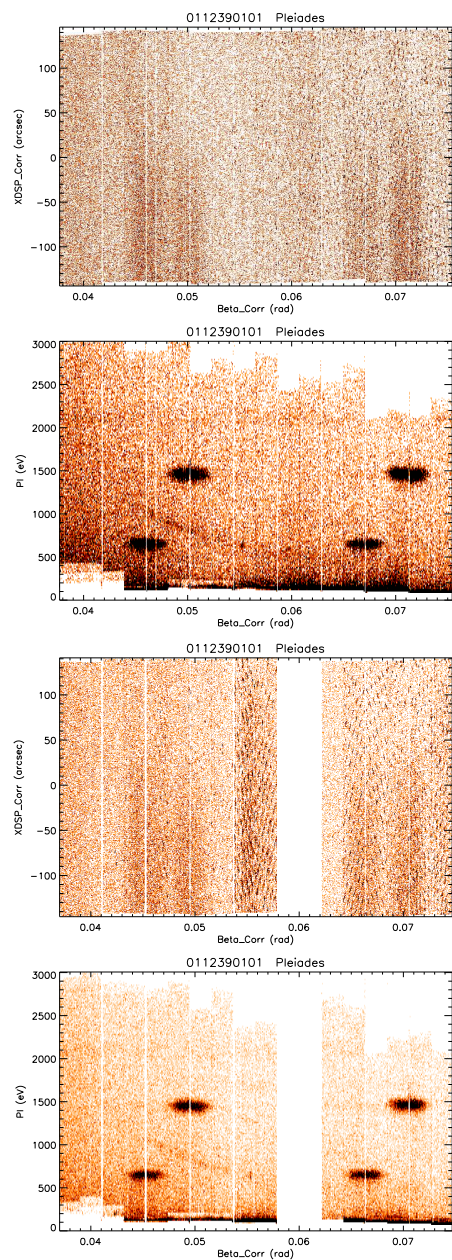


Figure 10: Results for the Pleiades field

4.2 Weak Point Sources

In the examples presented here, the source spectrum has been extracted from 95% of the PSF. Shown in red is the SAS-computed background corresponding to >99% of the PSF.

4.2.1 OY Car (Dwarf Nova)

ObsId 00990203 (Fig. 11). Exposure time: 53 ksec. Low background with a few flares. Data in RGS1 CCD#7.

The exposure times of the model background spectra are 217 and 212 ksec for RGS1 and RGS2, respectively.

The spectrum of the source is clearly visible. What is worth to remark in this example is the improvement in the signal-to-noise ratio of the background with respect to the standard SAS extraction, due both to the largest geometrical area and the longest exposure time of the model spectrum.

4.2.2 PQ Gem (Cataclysmic Variable)

ObsId 01095103 (Fig. 12). Exposure time: 35 ksec. Moderate background with flares.

The exposure times of the model background spectra are 141 and 129 ksec for RGS1 and RGS2, respectively.

The same comment as for the previous example applies here: there is a substantial improvement in the quality of the background that would result in a better detectability of weak spectral features.

4.2.3 NGC 6251 (Seyfert 2 Galaxy)

ObsId 00563402 (Fig. 13). Exposure time: 49 ksec. Moderate background with variations.

The exposure times of the model background spectra are 160 and 153 ksec for RGS1 and RGS2, respectively.

The model background agrees well with the SAS background but, as in the two previous cases, has a much higher signal-to-noise ratio.

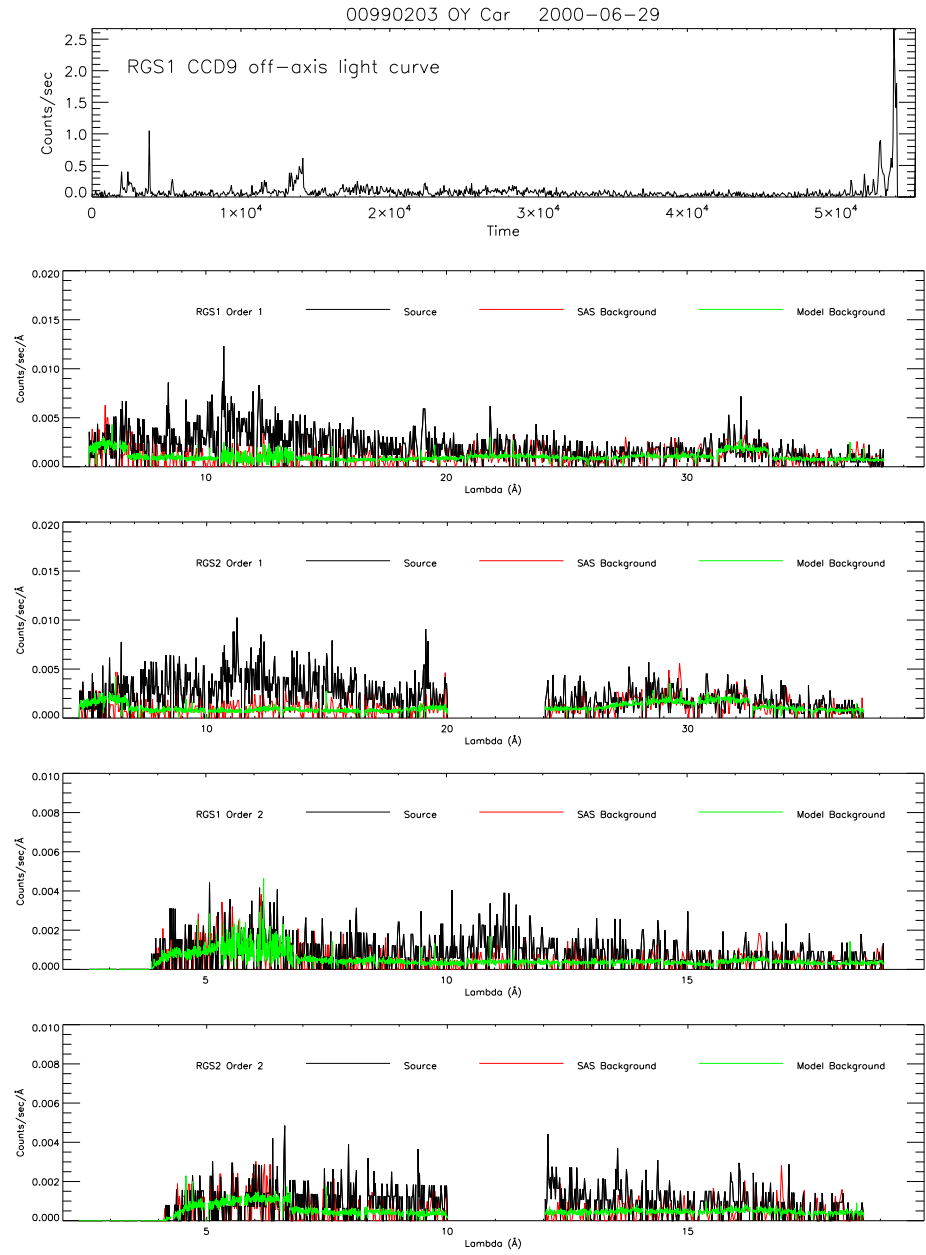
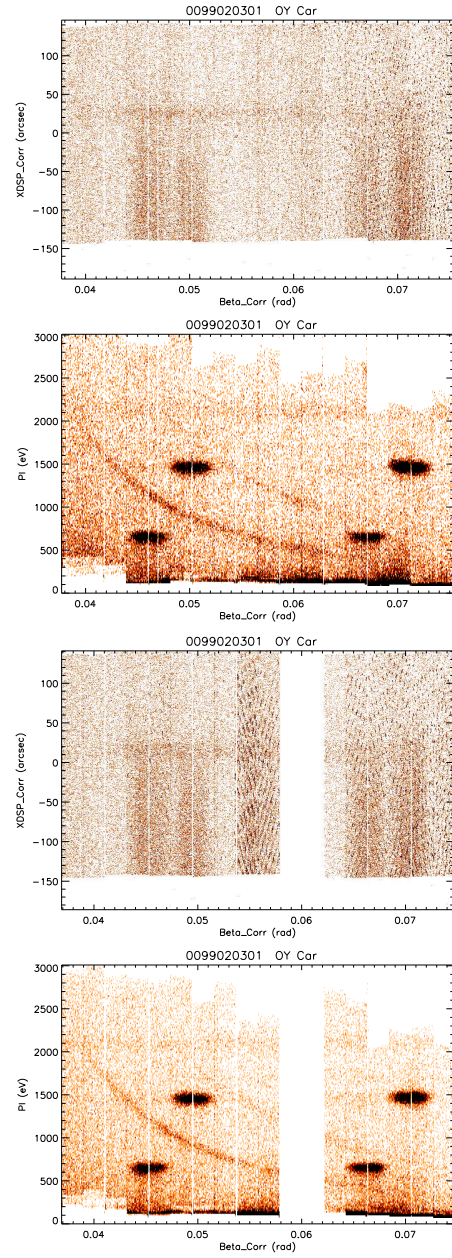


Figure 11: Results for OY Car

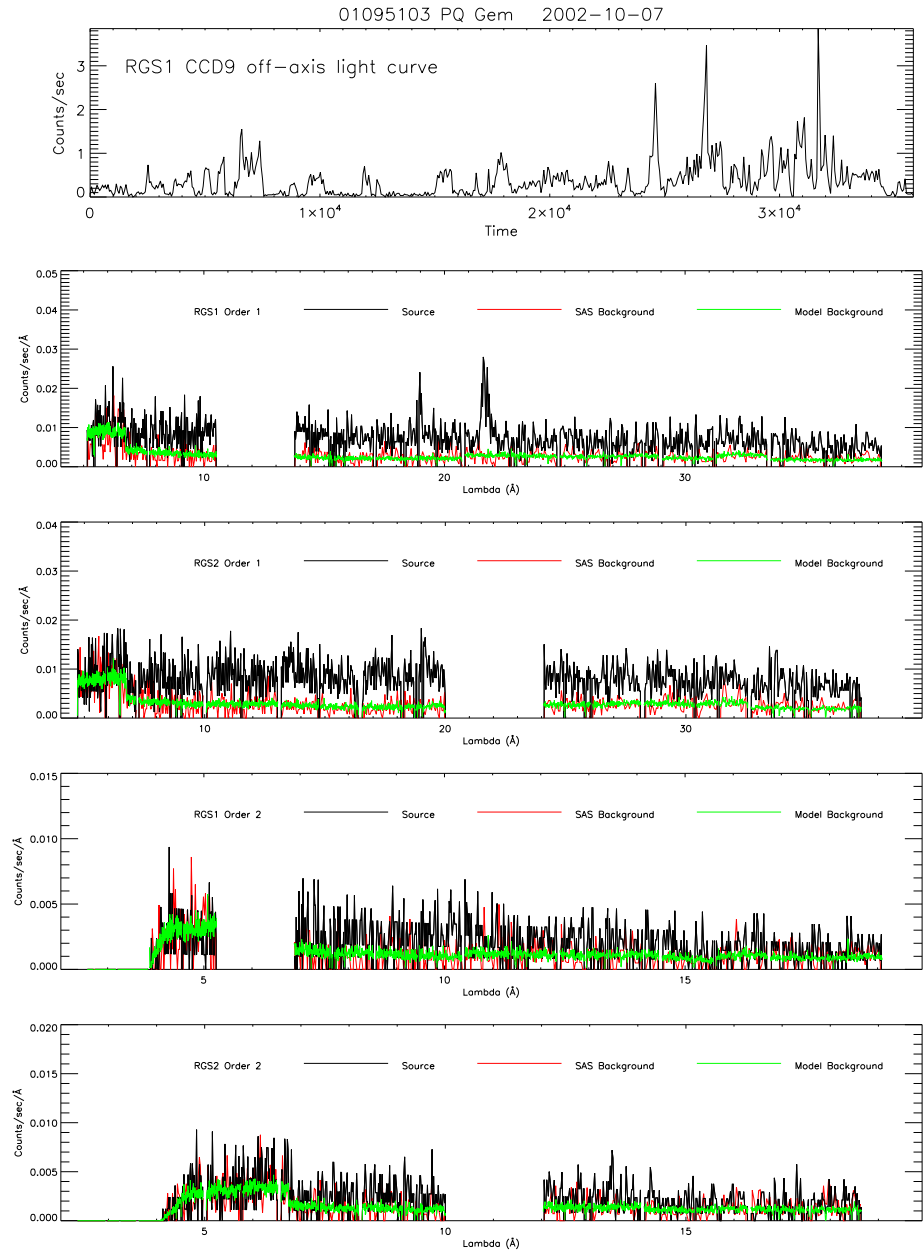
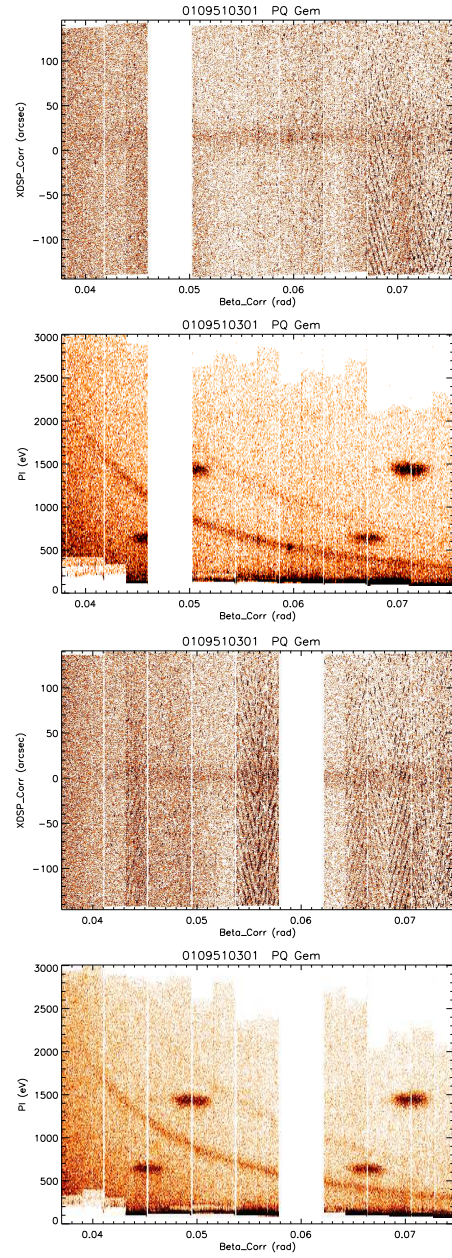


Figure 12: Results for PQ Gem

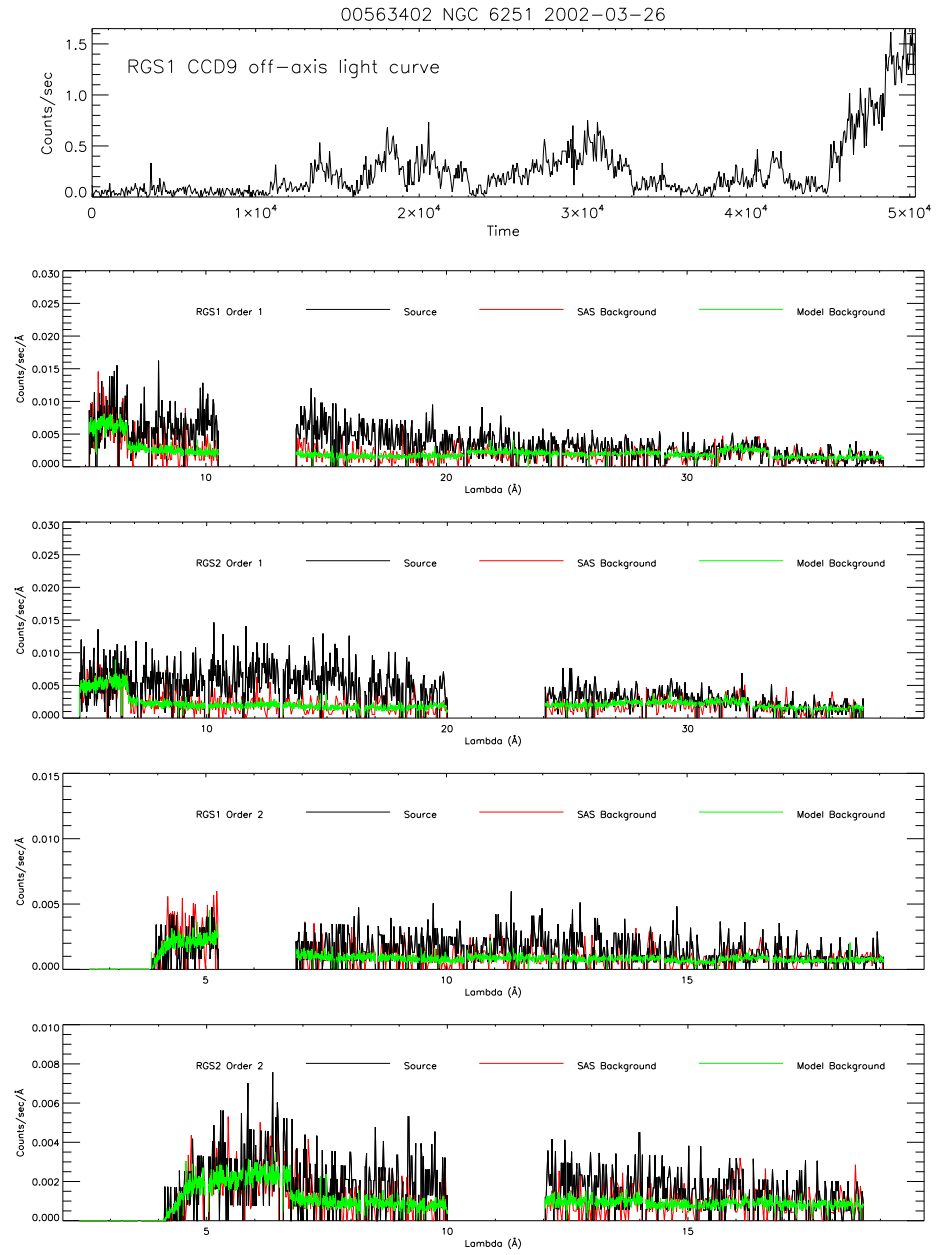
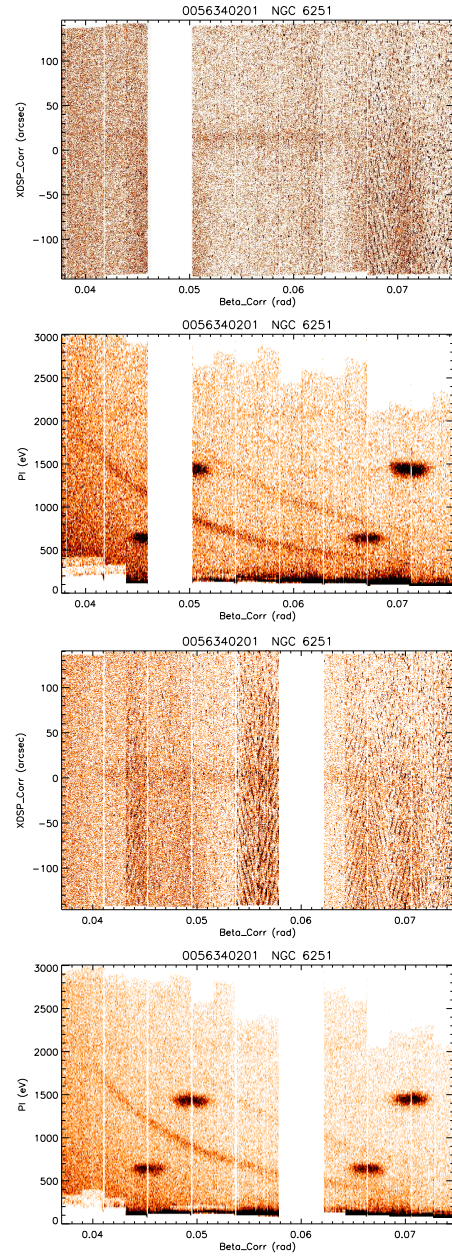


Figure 13: Results for NGC 6251

4.3 Extended Sources

The examples in this section have been derived using a 99% of the PSF for the source spectrum and >99% for the SAS background. In all these examples the source extension has been estimated from the cross-dispersion profiles.

4.3.1 2E 0519-69.0 (Supernova Remnant)

ObsId 01130005 (Fig. 14). Exposure time: 47 ksec. Low background with variations. The cross-dispersion source extent is approximately 1.5 arcmin.

The exposure times of the model background spectra are 226 and 217 ksec for RGS1 and RGS2, respectively.

In this example, despite the relatively small geometrical extension of the source, the SAS-background shows some contamination in the region 10–25 Å. The use of this background would lead to an underestimation of the emission line fluxes.

4.3.2 N132D (Supernova Remnant)

ObsId 01293411 (Fig. 15). Exposure time: 27 ksec. Low background. The cross-dispersion source extent is approximately 2.6 arcmin.

The exposure times of the model background spectra are 209 and 210 ksec for RGS1 and RGS2, respectively.

The situation is in this example worse than in the previous one: the SAS background shows strong emission lines coming from the source itself. Any measurement of the line fluxes would be clearly wrong if this background is used. On the other hand, no background subtraction at all would also be erroneous, since the level of the spectral continuum would be overestimated.

4.3.3 Sersic 159-03 (Cluster of Galaxies)

ObsId 01478001 (Fig. 5). Exposure time: 126 ksec. Low background with a very strong flare. The cross-dispersion source extent is approximately 1.8 arcmin.

The exposure times of the model background spectra are 208 and 206 ksec for RGS1 and RGS2, respectively.

Again, the SAS background is strongly contaminated by the source.

4.3.4 Abell 3827 (Cluster of Galaxies)

ObsId 01496701 (Fig. 16). Exposure time: 25 ksec. Low background with a few flares. According to the spatial profile, which does not show any structure, the source seems to fill the RGS FOV.

The exposure times of the model background spectra are 228 and 214 ksec for RGS1 and RGS2, respectively.

Also in this example, the SAS background is strongly contaminated by the source.

5 References

[1] Tamura, T., den Herder, J.W., González-Riestra, R. 2003, XMM-SOC-CAL-TN-0034 (<http://xmm.vilspa.esa.es/docs/documents/CAL-TN-0034-1-0.ps.gz>).

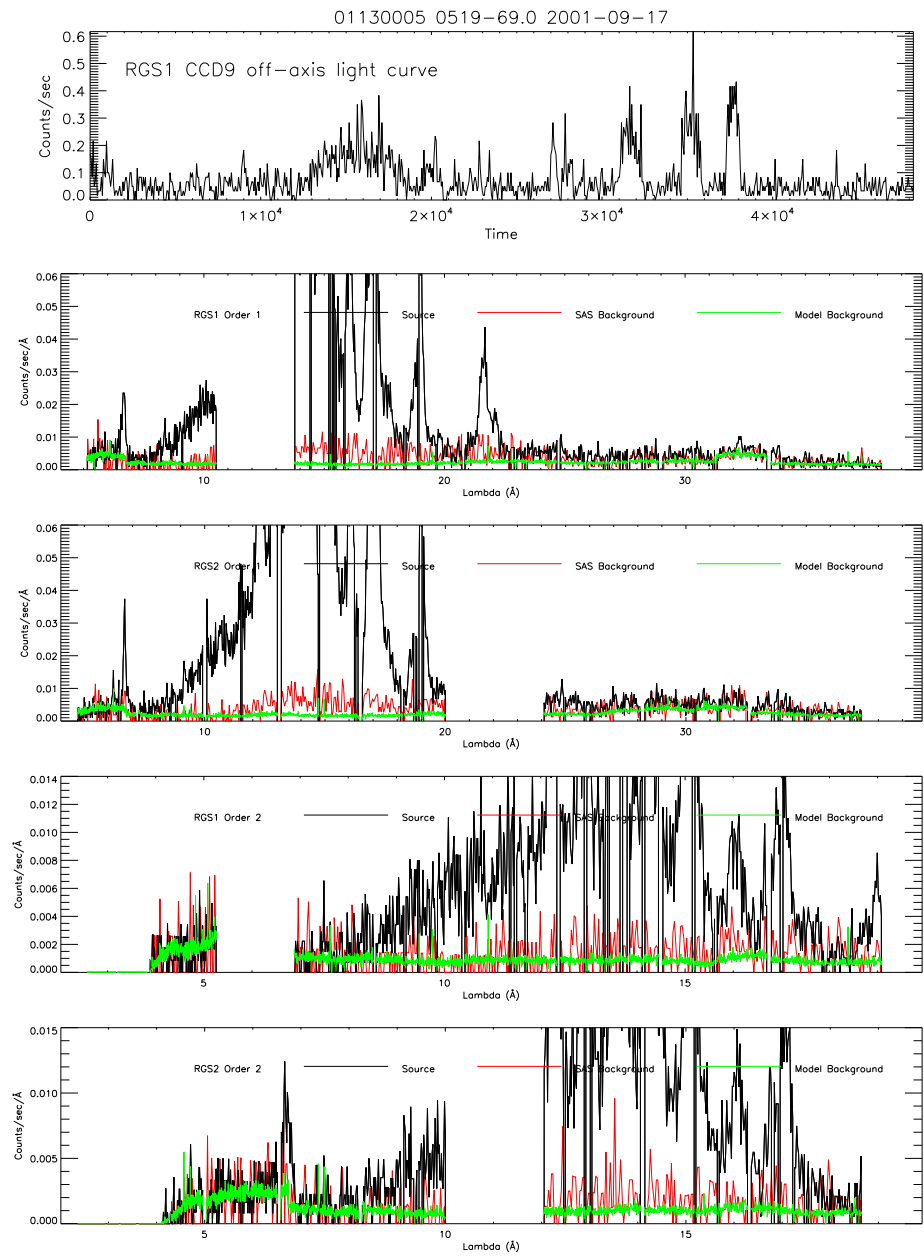
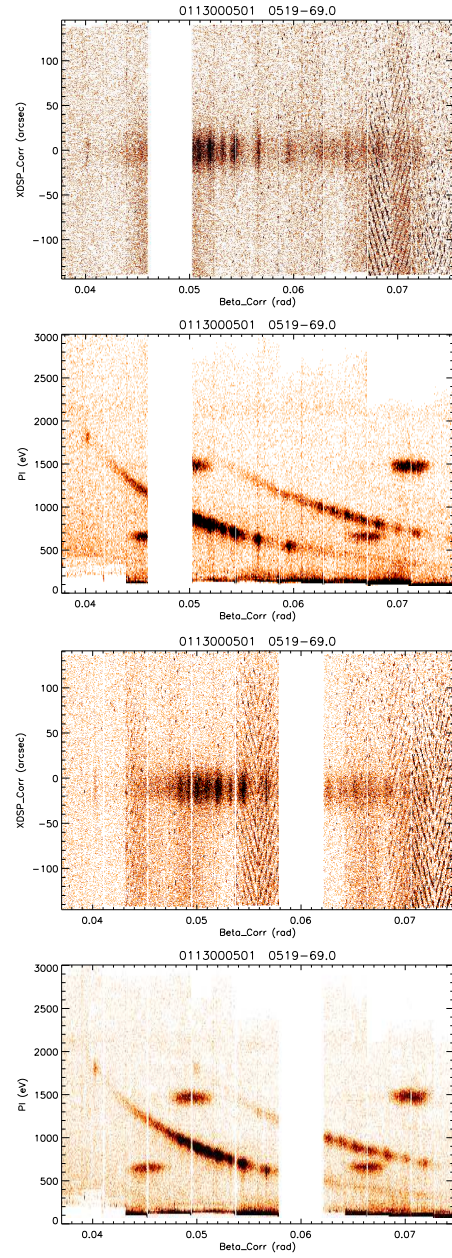


Figure 14: Results for 2E 0519-69.0

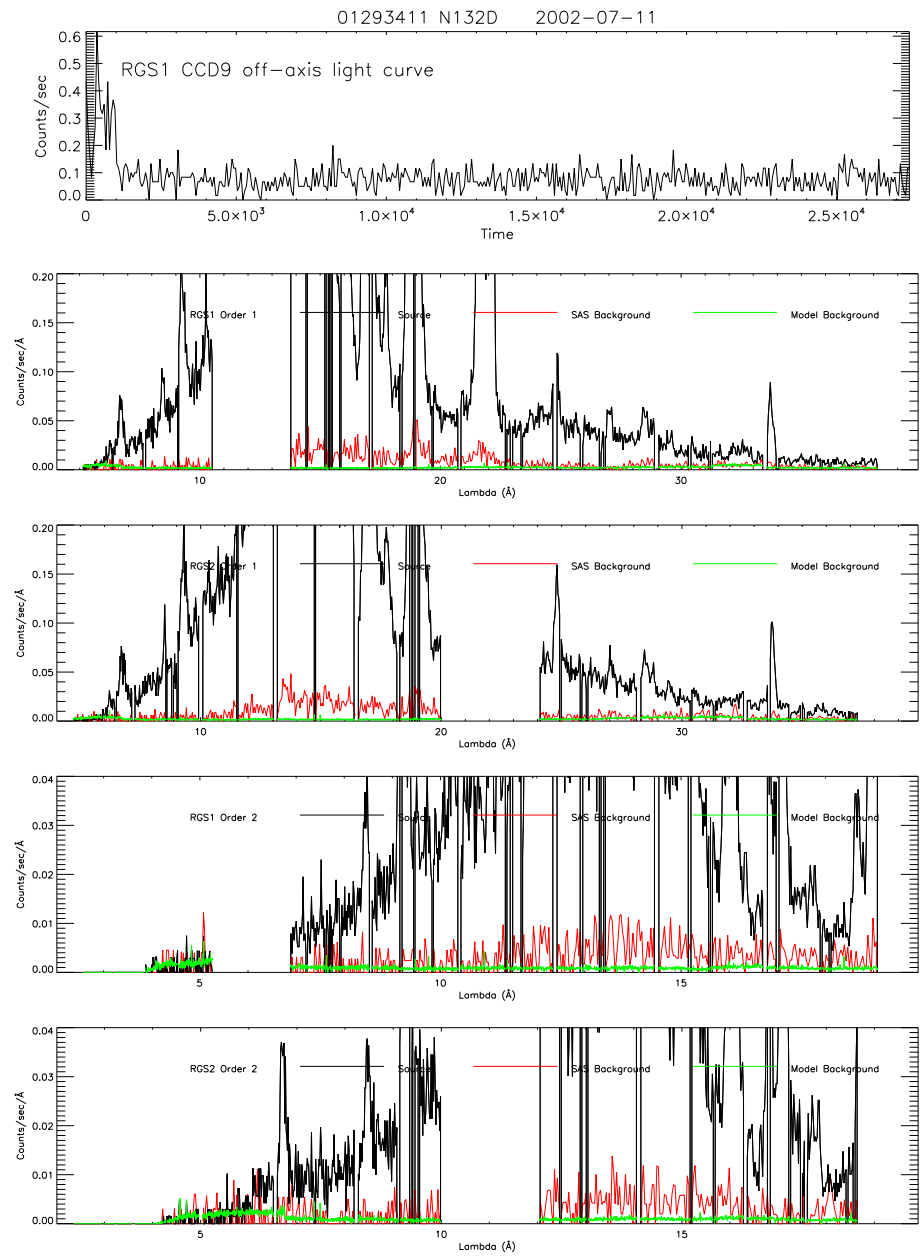
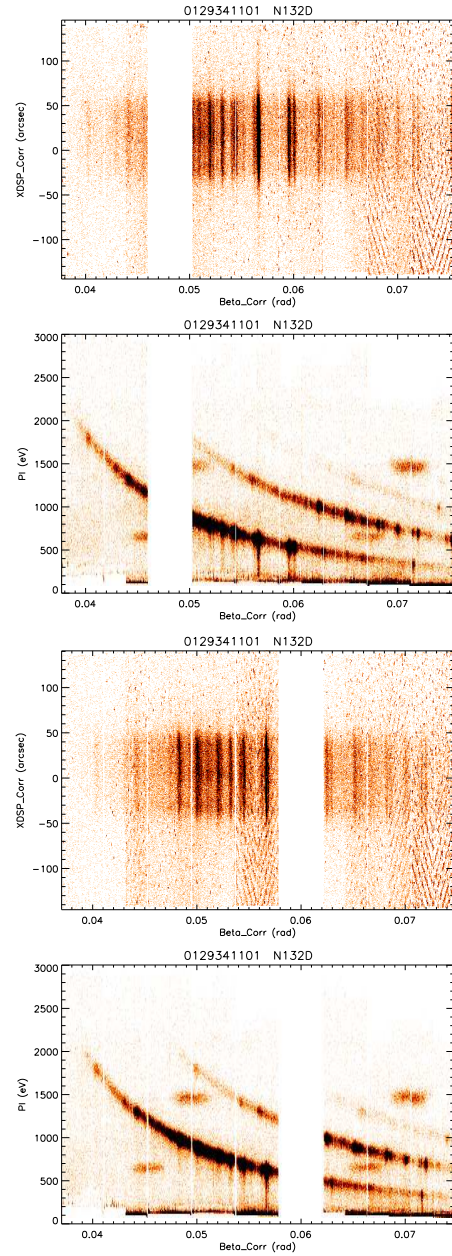


Figure 15: Results for N132D

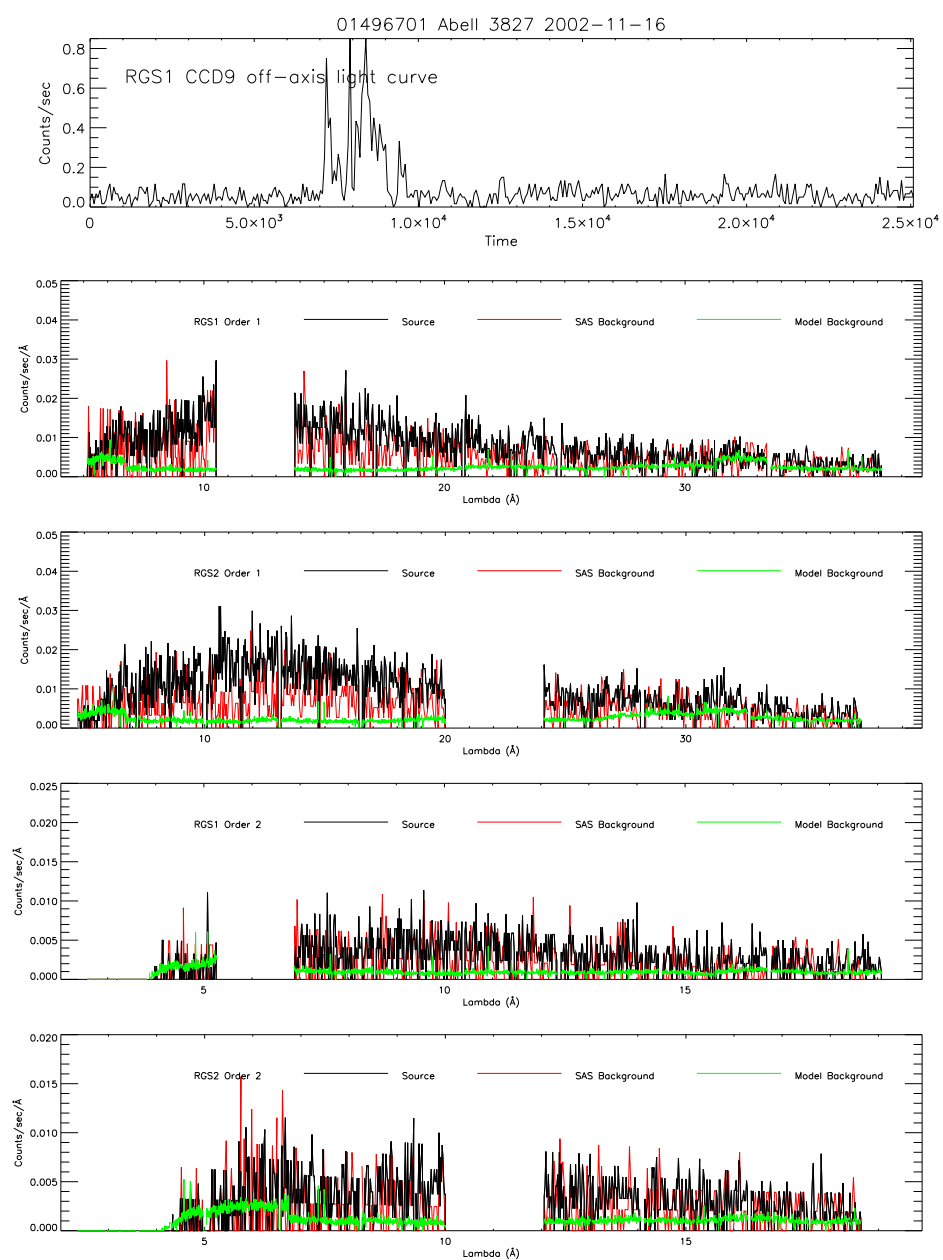
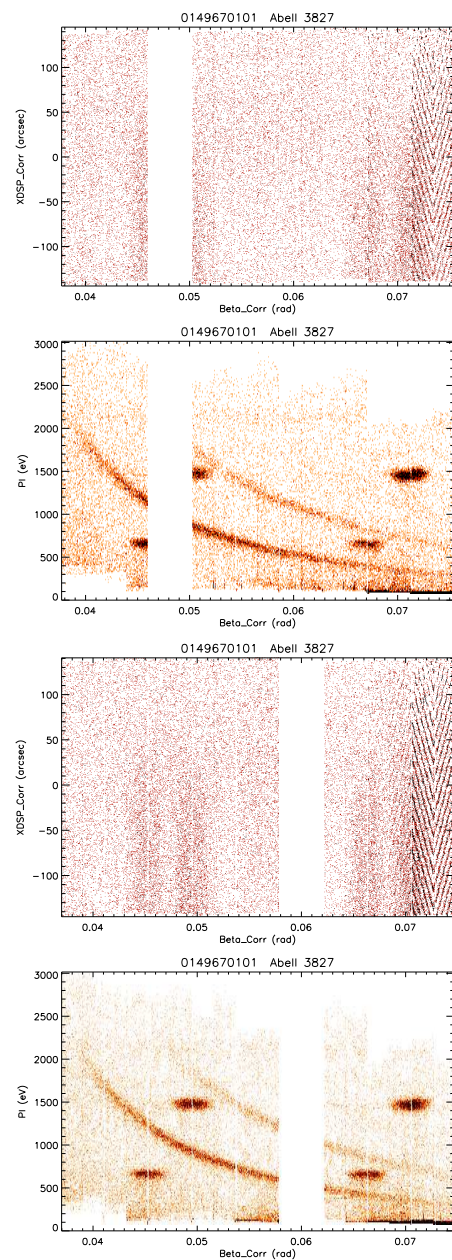


Figure 16: Results for Abell 3827