LYRA Output: Expected Variations

IED 16 Apr 2008
(rev. 22 May and 29 May,
updated 01 Aug and 19 Sep 2008 with new sample spectra,
rev. 21 Oct 2008)

The purpose of this report is to estimate the expected output of the LYRA channels and the interrelated solar values. It consists of three sections and four appendices:

1. Radiometric model predictions over time

The evolution of the radiometric model has lead to rather stable predictions – with respect to the order of magnitude - for output signals and purities in all cases. Notable differences are the Lyman-alpha channels 1-1 and 3-1, and the Aluminium channels 1-3 and 2-3. For details, see Table 1.

The changes between the second and the third column can be explained by values given in the report “LYRA Responsivity: Update”, available here:
http://solwww.oma.be/users/dammasch/IED_20080115_LYRA_Responsivity_Update.pdf

The major change in Channel 3-1 is due to the inclusion of longer wavelengths and the channel's responsivity assumed higher here, following the Davos test analysis. In all other cases, the long-wavelength inclusion only leads to minor changes (<2%, mostly <<1%). Thus, the changes are mainly induced by flatfield simulations and updated responsivities.

Changes between the first and the second column are due to the differences between separate filter and detector performances and their measured combined performance, once the channels were integrated.

Original sample spectra named “min” and “high” (used from 2005 to early 2008) had to be updated meanwhile, due to changes in TIMED/SEE calibration (Version 9 used now). The place of the original “max” is taken by “fla1”, which originates from the same day. A new minimum sample spectrum originating from June 2008 was added; compare updated report:
http://solwww.oma.be/users/dammasch/IED_20080718_Calibration_Methods.pdf
and compare Table 1a.

channel	“min” 2005	“high” 2005	“min” 2006	“high” 2006	“min” 2007	“high” 2007
1-1 *Lyman XN + MSM12*	0.139 (37%)	0.161 (44%)	0.240 (24%)	0.267 (30%)	0.294 (23%)	0.325 (29%)
1-2 *Herzberg + PIN10*	12.75 (86%)	12.77 (86%)	12.57 (83%)	12.59 (83%)	11.65 (84%)	11.66 (84%)
1-3 *Aluminium + MSM11*	0.120 (61%)	5.264 (3%)	0.086 (58%)	4.945 (3%)	0.066 (61%)	3.923 (3%)
1-4 *Zr(300nm) + AXUV20D*	0.530 (99%)	15.37(100%)	0.699(100%)	19.09(100%)	0.608(100%)	16.30(100%)
2-1 *Lyman XN + MSM21*	0.115 (39%)	0.135 (46%)	0.104 (21%)	0.114 (26%)	0.103 (23%)	0.114 (29%)
2-2 *Herzberg + PIN11*	13.80 (83%)	13.82 (83%)	13.75 (84%)	13.76 (84%)	12.48 (84%)	12.49 (84%)
2-3 *Aluminium + MSM15*	0.127 (73%)	3.821 (6%)	0.074 (59%)	3.837 (3%)	0.059 (62%)	3.059 (3%)
2-4 *Zr(150nm) + MSM19*	0.111 (99%)	2.878(100%)	0.094(100%)	2.772(100%)	0.083(100%)	2.399(100%)
3-1 *Lyman N+XN + AXUV20A*	0.132 (46%)	0.156 (54%)	0.113 (81%)	0.148 (84%)	0.261 (31%)	0.293 (38%)
3-2 *Herzberg + PIN12*	10.02 (85%)	10.22 (85%)	10.15 (83%)	10.16 (83%)	10.02 (84%)	10.03 (83%)
3-3 *Aluminium + AXUV20B*	1.072 (75%)	34.95 (6%)	1.090 (72%)	36.83 (5%)	0.918 (73%)	30.29 (6%)
3-4 *Zr(300nm) + AXUV20C*	0.530 (99%)	15.37 (88%)	0.710(100%)	19.31(100%)	0.619 (99%)	16.56(100%)

Table 1: Expected LYRA channel output signals (in nA), and purities.
The table demonstrates the evolution of the radiometric model predictions over time. - Each column shows the simulated output after using a solar minimum spectrum (“min”) and a solar maximum spectrum (“high”) as input, incl. the outputs' purities (%). Purity is defined as the theoretical output of the nominal channel interval relative to the total expected output, i.e., including spectral “contaminations”. - The first column shows simulations using separate expected filter and detector performances (status of 2005). The second column shows simulations performed after BESSY 2006 campaigns, with channel configurations fixed as decided (status of 2006). The third column shows simulations using updated responsivities of several nominal bandpasses according to the BESSY 2007 campaign, adjustments due to flatfield simulations, and inclusion of updated longer-wavelength responsivities according to on-ground tests in Davos (status of 2007).

The following simulation results from the LYRA Radiometric Model (status of 2008) can only partially be compared to older results above, because they use new "minimal" and "maximal" solar sample spectra.

ch.#	filter	detector	min. signal	max. signal
1-1	*Lyman XN*	*MSM12*	0.289 (25.5%)	0.346 (32.5%)
1-2	*Herzberg*	*PIN10*	10.918 (83.7%)	11.710 (83.8%)
1-3	*Aluminium*	*MSM11*	0.056 (87.4%)	1.772 (8.7%)
1-4	*Zr(300nm)*	*AXUV20D*	0.085 (97.7%)	3.704 (99.9%)
2-1	*Lyman XN*	*MSM21*	0.101 (25.3%)	0.121 (32.3%)
2-2	*Herzberg*	*PIN11*	11.690 (83.8%)	12.512 (83.9%)
2-3	*Aluminium*	*MSM15*	0.048 (88.6%)	1.370 (9.7%)
2-4	*Zr(150nm)*	*MSM19*	0.012 (96.9%)	0.583 (99.9%)
3-1	*Lyman N+XN*	*AXUV20A*	0.269 (32.6%)	0.317 (42.2%)
3-2	*Herzberg*	*PIN12*	9.389 (83.5%)	10.055 (83.6%)
3-3	*Aluminium*	*AXUV20B*	0.926 (92.1%)	14.037 (19.7%)
3-4	*Zr(300nm)*	*AXUV20C*	0.088 (95.7%)	3.766 (99.9%)

Table 1a: Expected LYRA total output signals (in nA), and purities.

When the most recent expectations, as shown in Table 1a, are compared with earlier expectations in Table 1, the values are in good agreement for channels 1 and 2, they are somewhat lower for channel 3 (approx. a factor 2 for the maximum signal), and much lower for channel 4 (approx. a factor 4 for the maximum and a factor 8 for the minimum signal). This is caused by calibration changes carried out in the meantime by TIMED/SEE, especially with respect to very short wavelengths.

2. Expected variations in LYRA signals and reconstructed solar signals

The radiometric model has been simulated with the help of seven TIMED/SEE and SORCE sample spectra. Results were described in the report "LYRA Calibration Methods: New Spectra", available here:
http://solwww.oma.be/users/dammasch/IED_20080718_Calibration_Methods.pdf

The upper and lower boundaries of simulated results can be found in Table 2.

Here are some speculations on the nature of solar signals, and subsequently expected LYRA output:

Statistical analysis of SOHO/SUMER data has shown that radiances follow a log-normal distribution (*Dammasch et al., Space Sci Rev 87, 161-164, 1999*). Transition-region lines display the highest radiance variation, covering several orders of magnitude; chromospheric and coronal lines vary less. This holds for quiet-Sun areas; active regions introduce additional variations, as does – most probably – the solar cycle.

SUMER is able to observe radiances in 1 arcsec resolution. When observing the Sun as a star, it might be expected that the log-normal variation evens out – given the radiances are evenly distributed. But it can be doubted if this is really the case. For example, SUMER whole disk observations in H I Ly5 (93.7 nm) taken within half a year during the solar minimum in 1996 indeed show little variation. Nevertheless, the effect of (rare) active regions on the irradiance was clearly visible. - SUMER radiance observations of Continuum (<160 nm) or cool neutral lines, like Si I, display less variability than Lyman lines. Therefore, the irradiance can also be expected to vary less. Both Lyman alpha and Continuum emission may react to flares, but this reaction has to be put in relation to their ubiquitous radiation. - On the other hand, plasma monitored by the Aluminium and Zirconium channels, both with a strong X-ray contribution, will be of a rather singular character. Therefore their signal is closer to the logarithmic distribution mentioned above, even when observed all over the Sun, see *lower:upper* boundary relations in Table 2.

ch.	total / nA	pure / nA	solar / (W m⁻²)
1-1	[0.289, 0.346]	[0.074, 0.112]	[0.0061,0.0093]
1-2	[10.918,11.710]	[9.143, 9.816]	[0.4454,0.4764]
1-3	[0.056, 1.772]	[0.049, 0.154]	[0.0017,0.0057]
1-4	[0.085, 3.704]	[0.083, 3.702]	[0.0007,0.0133]
2-1	[0.101, 0.121]	[0.026, 0.039]	[0.0061,0.0093]
2-2	[11.690,12.512]	[9.797,10.502]	[0.4454,0.4764]
2-3	[0.048, 1.370]	[0.043, 0.132]	[0.0017,0.0057]
2-4	[0.012, 0.583]	[0.012, 0.583]	[0.0007,0.0133]
3-1	[0.269, 0.317]	[0.088, 0.134]	[0.0061,0.0093]
3-2	[9.389,10.055]	[7.840, 8.409]	[0.4454,0.4764]
3-3	[0.926,14.037]	[0.853, 2.764]	[0.0017,0.0057]
3-4	[0.088, 3.766]	[0.084, 3.762]	[0.0007,0.0133]

Table 2. Simulated intervals of LYRA channel signals and solar signals.
Values for channel *-1 (Lyman alpha) appear to be "linearly" (or uniformly) distributed.
Values for channel *-2 (Herzberg) appear to be "linearly" (or uniformly) distributed as well, but with an even smaller relative variation.
Values for channel *-3 (Aluminium) appear to be "logarithmically" distributed (*lower:upper* ~ 1:25 for total, still ~ 1:3 for pure and for solar).
Values for channel *-4 (Zirconium) appear to be "logarithmically" distributed (*lower:upper* ~ 1:45 for total and pure, ~ 1:20 for solar).
For all channels, sample spectrum "nmin" leads to the lower, "fla1" leads to the upper boundary.

How can *extended intervals* be calculated that contain – with some safety – the majority of signals to be expected, once LYRA is in space? It appears not recommendable to calculate standard deviations from just seven data points, of which several are even from the same day.

For channels 3 and 4, TIMED/SEE observations were used. SEE observes the Sun for about 3 minutes per orbit of 97 minutes, thus approx. 14 to 15 times per day. Here, Level3A data were used that are not averaged over the day and have no flares removed. - For channels 1 and 2, SORCE observations were used. SORCE also performs observations in the order of minutes, but the data used here were averaged over the day.

To give an impression about the daily variation, SORCE data averages were multiplied with SEE variations of the Lyman-alpha range for channel 1, and with variations of a proxy range (173-193 nm) for channel 2, since the Herzberg range (200-220 nm) is not observed by SEE.

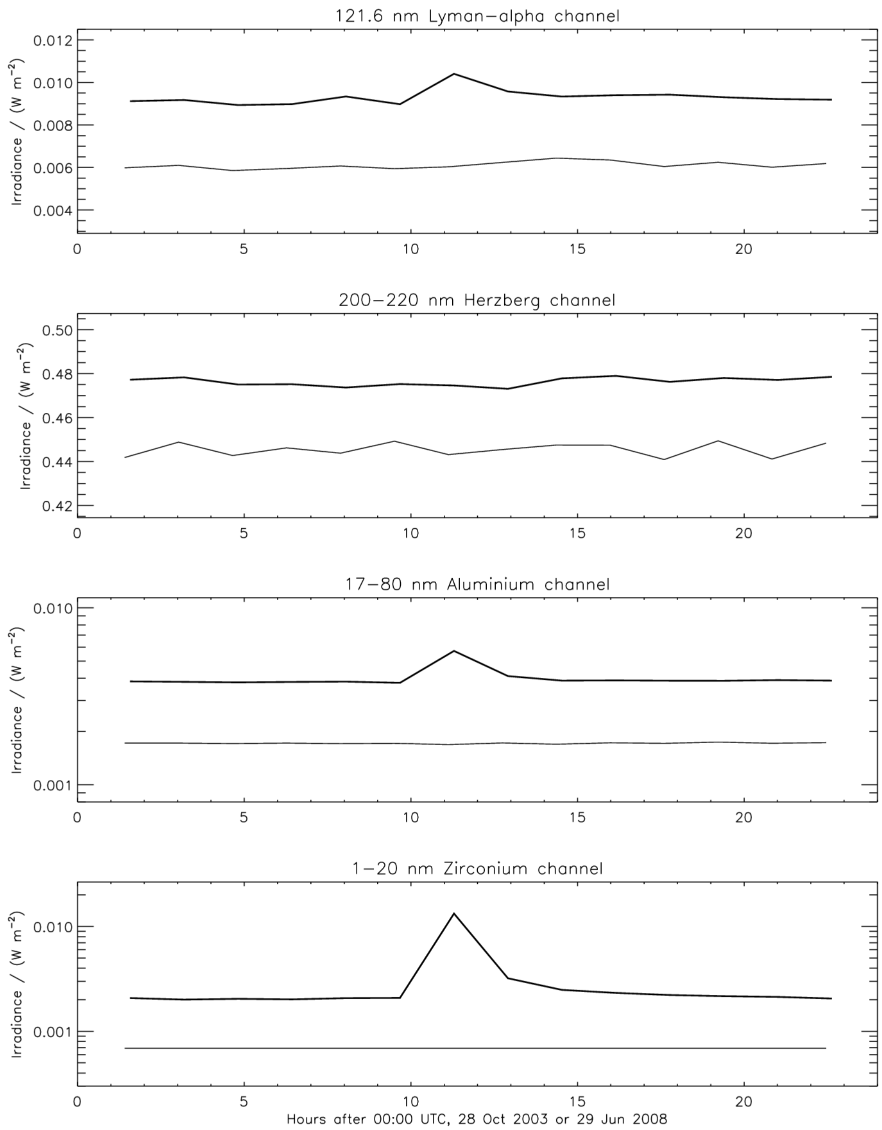

Figure 1: Shown is the daily irradiance development (partially simulated), for the "maximum" observation (thick, above) of 28 Oct 2003, including an X17 flare, and for the "minimum" observation (thin, below) of 29 Jun 2008. Channels 1 and 2 are on a linear scale, channels 3 and 4 on a logarithmic scale. The irradiance ranges displayed per channel are the extended intervals as selected below (cf. Table 3, "solar" columns).

Next, the estimation of extended intervals shall be described in detail.

Channel *-1 (Lyman alpha): The pure signal and the solar signal vary less than *lower:upper* ~ 1:2. The total signal consists of approx. 60-80% contamination from longer wavelengths which varies even less. The lower Lyman-alpha boundary stems from a solar-minimum spectrum of 2008. Spectra from a more active time in 2003 lead to ~ 50% higher signals without flares; a major flare adds another amount of ~25%. At this stage it must also be noted that larger variations are possible in LYRA data than for SORCE or SEE, since LYRA's integration time is rather in the order of seconds than minutes. - Therefore, to estimate a safe interval of values to be expected, it is suggested to triple the observed interval, symmetrically around its center. In other words, the interval observed between SORCE minimum and maximum is appended above the maximum and below the minimum: e.g., the 0.0032 interval [0.0061,0.0093] becomes the 0.0096 interval [0.0029,0.0125], compare the last columns called "solar / (W m^{-2})" of channel *-1, in Table 2 and 3.

Channel *-2 (Herzberg): As mentioned, the longer-wavelength signal varies, relatively, even less. Again, to estimate a safe interval of values to be expected, it is suggested to triple the observed interval, symmetrically around its center.

Channel *-3 (Aluminium): The total signal contains a possible contamination, basically from the very short (~ 1 nm) X-ray range. This contamination ranges from ~10% (quiet) to ~90% (flare), thus the larger variation within the total signal (~ 1:25) as compared to the pure and solar signal (~ 1:3). Due to this "logarithmic" distribution, it is suggested to limit an extended interval below with half the minimum and above with twice the maximum sample values.

Channel *-4 (Zirconium): Total and pure signal vary almost identically, due to almost 100% purity. But LYRA values can be expected to vary more (~ 1:45) than solar values (~ 1:20), because of the relatively higher responsivity in the very short (~ 1 nm) and dynamic X-ray range. Since all signals show a "logarithmic" distribution, it is again suggested to limit an extended interval below with half the minimum and above with twice the maximum sample values. - See Table 3 and Figure 1.

ch.	total / nA	pure / nA	solar / (W m^{-2})
1-1	[0.232, 0.403]	[0.036, 0.150]	[0.0029,0.0125]
1-2	[10.126,12.501]	[8.470,10.489]	[0.4144,0.5074]
1-3	[0.028, 3.544]	[0.024, 0.308]	[0.0008,0.0114]
1-4	[0.042, 7.408]	[0.041, 7.404]	[0.0003,0.0266]
2-1	[0.081, 0.141]	[0.013, 0.052]	[0.0029,0.0125]
2-2	[10.868,13.334]	[9.092,11.207]	[0.4144,0.5074]
2-3	[0.024, 2.740]	[0.021, 0.264]	[0.0008,0.0114]
2-4	[0.006, 1.166]	[0.006, 1.166]	[0.0003,0.0266]
3-1	[0.221, 0.365]	[0.042, 0.180]	[0.0029,0.0125]
3-2	[8.723,10.721]	[7.271, 8.978]	[0.4144,0.5074]
3-3	[0.463,28.074]	[0.426, 5.528]	[0.0008,0.0114]
3-4	[0.044, 7.532]	[0.042, 7.524]	[0.0003,0.0266]

Table 3. Extended intervals of LYRA channel signals and solar signals.
Channel *-1 (Lyman alpha): All intervals are tripled around their center.
Channel *-2 (Herzberg): All intervals are tripled around their center.
Channel *-3 (Aluminium): All intervals are extended to 50% of the *lower* and 200% of the *upper* limit.
Channel *-4 (Zirconium): All intervals are extended to 50% of the *lower* and 200% of the *upper* limit.

To demonstrate that these choices are reasonable, time series from the SORCE and TIMED/SEE instruments are presented below in Figure 2. The data between 2003 and 2008 are used here as a kind of a plausibility check.

The Level3A data browser for SEE data can be found at their website
http://lasp.colorado.edu/see/see_data.html

The data browser for SORCE can be found on their website
http://lasp.colorado.edu/sorce/sorce_data_access/

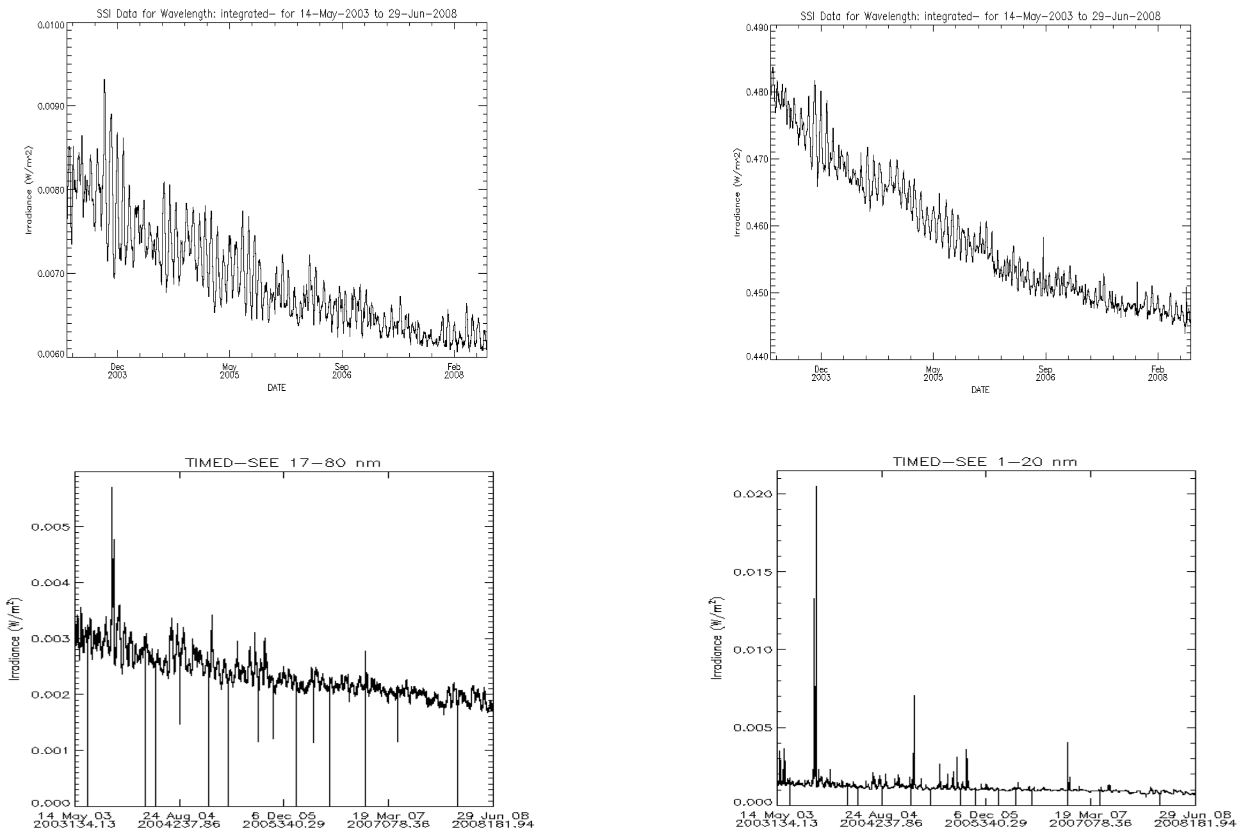

Figure 2: Series of SORCE and TIMED/SEE data comparable to LYRA channels *-1, *-2, *-3, *-4.
For the Lyman-alpha channel *-1, the majority of data fall within the 0.0060-0.0100 range. For the Herzberg channel *-2, the majority of data fall within the 0.4400-0.4800 range. Not considering the zero measurements, the values corresponding to the Aluminium channel *-3 fall within a 0.0010-0.0060 range. Likewise, the values corresponding to the Zirconium channel *-4 fall within 0.0010-0.0200. So all sample and extended intervals appear plausible. (Values in W/m²)

3. Software and warning flags

The following warning flags are suggested to go along with calibrated solar values - either for a certain time during commissioning, or maybe permanently. Together with a “no warning” flag (W:0) they could correspond to different levels of trust (e.g., error percentages).

W:0 – total, pure, and solar signal inside sample interval (Table 2)	– safe value with nominal uncertainty
W:1 – total, pure, or solar signal outside sample interval (Table 2)	– unsafe extrapolated value
W:2 – total, pure, or solar signal outside extended interval (Table 3)	– implausible extrapolated value
W:3 – total, pure, or solar signal negative	– impossible value

Eventually, there could be a four-digit “warning” (or “reliability”) string in each line of a level-2 data file, printed at the side of the four columns with the calibrated values, like, e.g., *2100*, meaning that channel *-1 is outside the extended interval, channel *-2 is outside the sample interval but inside the extended interval, and channels *-3 and *-4 are safely inside the sample interval.

At the end of this report, three sets of data and an IDL program are presented. As an example, the calibration of head 2 is demonstrated.

The first data set (Appendix 0) consists of simulated data from the level-0, housekeeping, and state databases. The next set (Appendix 1) is a simulated level-1 file. Both sets consist of (fantasized but realistic) ancillary data and 104 lines of plausible solar data in ascending order. The file notation and the headers takes up thoughts expressed in the *LYRA Data Management Plan* and the FITS file concept. The level-0 data structure is modeled after an SVT5 example named *BINLYRA_3_SVT5_2007.12.18T11.03.55_NOMINAL_HEAD1.txt*.
Per data line, it includes the time stamp (in s), a running number, four columns of LYRA channel counts, and the integration time (in ms).

The first data line is constructed to lead to an “impossible” warning flag, later in level-2. The second line is half the minimum extended interval, the last line is double the maximum extended interval, so these lines are constructed such that they must lead to “implausible” or “impossible” warning flags, which - in fact - they do. The rest of the data (lines 3-103) cover the extended interval from minimum to maximum in 100 equal steps, where channels *-1 and *-2 are on a linear scale, and channels *-3 and *-4 are on a logarithmic scale. These total signals were transformed backwards to LYRA counts that can be expected in the level-0 database. In the rightmost column of the level-0 data appears the integration time in ms. Since by this procedure the smallest solar values (or frequencies) are associated with the smallest integration times, and vice versa, these tables give an idea about the lowest and highest counts to be expected – the highest counts representing twice the highest flare value integrated with 10 s exposure time probably being not a realistic estimate.

These data - lines 3-103 - are also shown in Fig. 3 (next pages). The dotted lines mark the safe interval (W:0), the crosses are values inside the extended interval (W:1). The rest, (W:2) - which may happen when the total signal is within the extended interval, but solar signals drop out – is denoted by straight lines.

The next data set (Appendix 2) is the corresponding level-2 file. It is automatically constructed by the IDL software and results from suggested calibration procedures, in this case for LYRA head 2. It includes much of the level-1 FITS header, the timestamps from the level-1 file, four columns of calibrated data, and finally the string with the warning message.

The last data set (Appendix 3) is the corresponding level-3 file. While level-2 is the standard science product of LYRA, presenting solar irradiances in full instrumental resolution as commanded for acquisition, FITS level-3 files consist of 1-minute averages.

Finally, there is (slightly commented, see Appendix 4 and 5) the calibration software, two IDL programs called *calculate_calibration_lev2.pro* and *calculate_calibration_lev3.pro*.

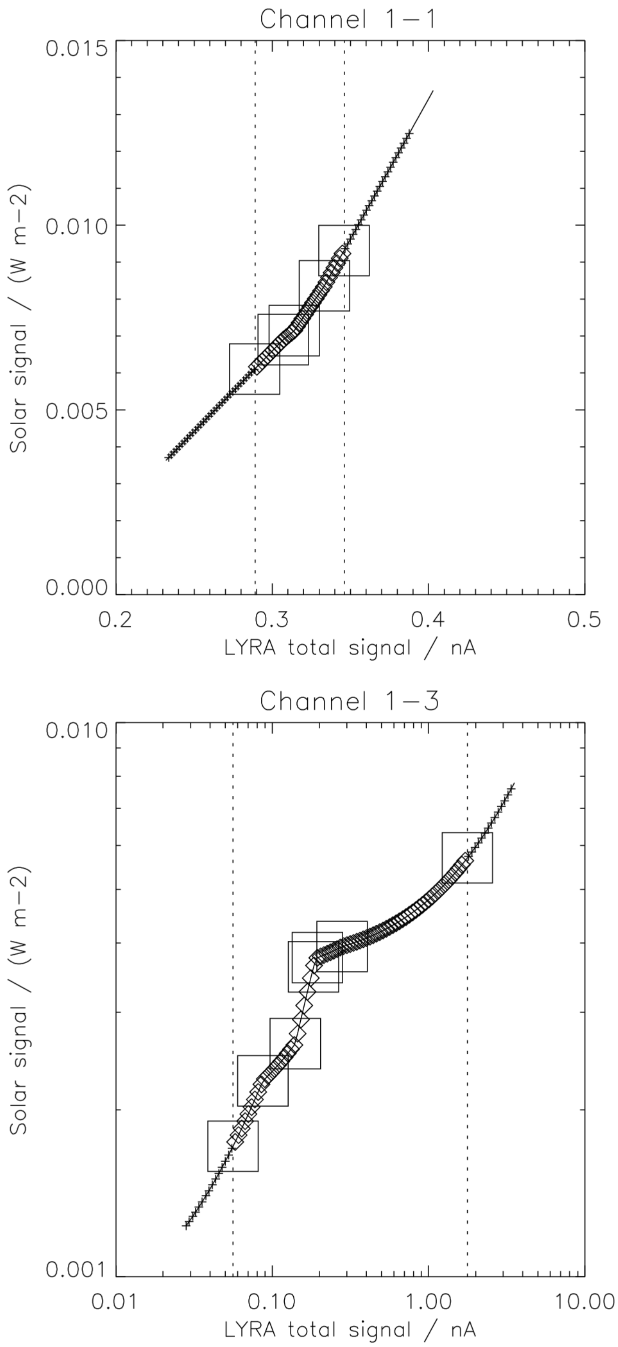

Figure 3a: Data input (in nA) vs. output to level-2 file, simulated for LYRA head 1.
To make these figures comparable with figures in the *LYRA Calibration Methods:New Spectra* report, cf.
http://solwww.oma.be/users/dammasch/IED_20080718_Calibration_Methods.pdf
as well as to Tables 2 and 3 above, total signals are not shown in counts or frequencies, but in currents. The sample interval used for calibration is marked with diamonds (plus vertical dotted lines). The extended interval is marked with crosses, anything outside by a straight line. The large boxes represent up to seven different TIMED/SEE and SORCE samples. - Compared to earlier versions, there are no more dubious data points, and the calibration curves are monotonic. The sudden increase in channel *-3 is caused by the onset of flares and the corresponding contamination due to very short wavelengths.

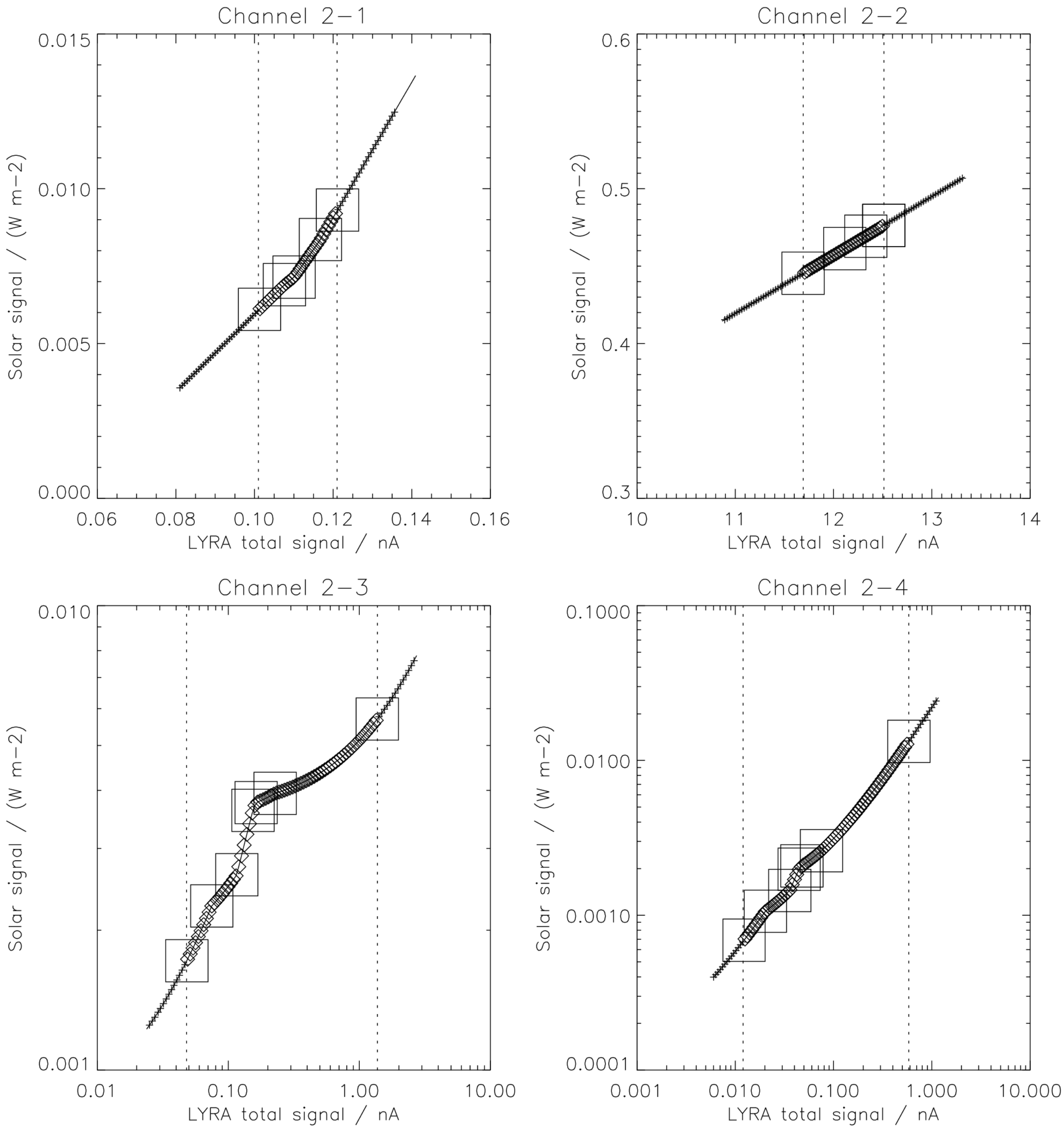

Figure 3b: Data input (in nA) vs. output to level-2 file, simulated for LYRA head 2.
(Compare captions Fig. 3a)

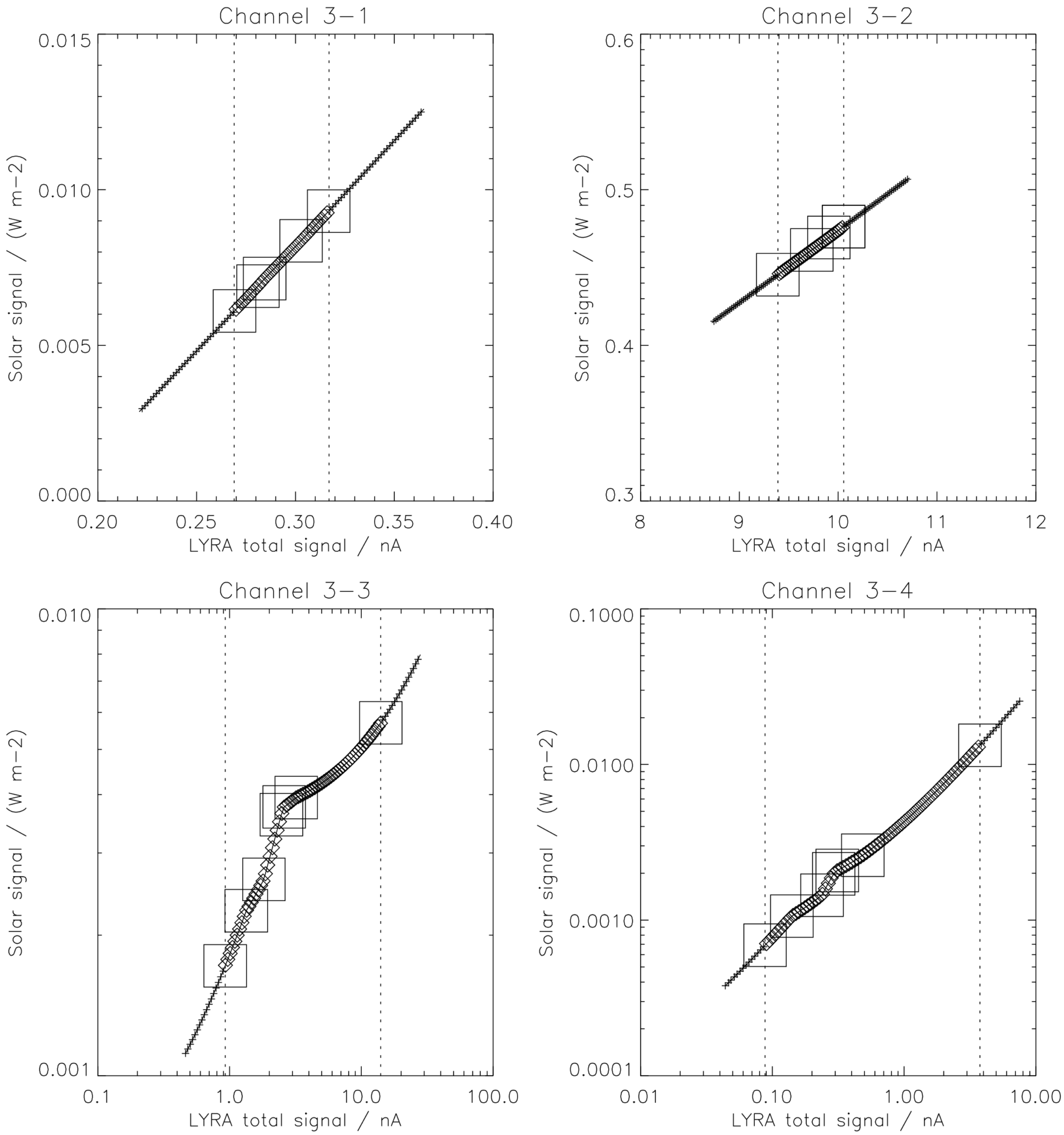

Figure 3c: Data input (in nA) vs. output to level-2 file, simulated for LYRA head 3.
(Compare captions Fig. 3a)

Appendix 0: Simulated Level-0 Data

Appendix 1: Simulated Level-1 Data

Appendix 2: Simulated Level-2 Data

Appendix 3: Simulated Level-3 Data

Appendix 4: IDL Level-2 Calibration Software

Appendix 5: IDL Level-3 Calibration Software