LYRA Output: Expected Variations

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(rev. 22 May and 29 May,
updated 01 Aug and 19 Sep 2008 with new sample spectra,
rev. 21 Oct 2008,
updated **30 Jul 2009** after re-definition of Zr channel)

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:

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 1a.

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 and higher 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 1b.

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 1a: 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 LYRA Radiometric Model simulation results (status of 2008 and 2009) can only partially be compared to older results above, because they use new “minimal” and “maximal” solar sample spectra. The main differences from 2008 to 2009 are due to the re-definition of the Zr channels, the inclusion of the 0.5 nm value of the TIMED/SEE spectra, and some modifications within the long-wavelength responsivities; for details see the various reports.

ch.#	filter	detector	"min" 2008	"max" 2008	"min" 2009	"max" 2009
1-1	*Lyman XN*	*MSM12*	0.289 (25.5%)	0.346 (32.5%)	0.283 (26.0%)	0.340 (33.0%)
1-2	*Herzberg*	*PIN10*	10.918 (83.7%)	11.710 (83.8%)	10.918 (83.7%)	11.710 (83.8%)
1-3	*Aluminium*	*MSM11*	0.056 (87.4%)	1.772 (8.7%)	0.054 (86.7%)	2.079 (7.0%)
1-4	*Zr(300nm)*	*AXUV20D*	0.085 (97.7%)	3.704 (99.9%)	0.085 (91.4%)	5.373 (14.1%)
2-1	*Lyman XN*	*MSM21*	0.101 (25.3%)	0.121 (32.3%)	0.100 (25.7%)	0.119 (32.8%)
2-2	*Herzberg*	*PIN11*	11.690 (83.8%)	12.512 (83.9%)	11.690 (83.8%)	12.512 (83.9%)
2-3	*Aluminium*	*MSM15*	0.048 (88.6%)	1.370 (9.7%)	0.049 (88.6%)	1.745 (7.8%)
2-4	*Zr(150nm)*	*MSM19*	0.012 (96.9%)	0.583 (99.9%)	0.012 (86.1%)	0.787 (12.5%)
3-1	*Lyman N+XN*	*AXUV20A*	0.269 (32.6%)	0.317 (42.2%)	0.269 (32.5%)	0.317 (42.1%)
3-2	*Herzberg*	*PIN12*	9.389 (83.5%)	10.055 (83.6%)	9.389 (83.5%)	10.055 (83.6%)
3-3	*Aluminium*	*AXUV20B*	0.926 (92.1%)	14.037 (19.7%)	0.907 (91.8%)	16.701 (16.1%)
3-4	*Zr(300nm)*	*AXUV20C*	0.088 (95.7%)	3.766 (99.9%)	0.087 (89.4%)	5.375 (14.1%)

Table 1b: Expected LYRA total output signals (in nA), and purities.
When the most recent expectations, as shown here in Table 1b, are compared with earlier expectations in Table 1a, 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 (status of 2008). - In the 2009 columns, the inclusion of the shortest TIMED/SEE spectral value in the simulation raises the expected signal in flare situations (“max”) in channels *-3 and *-4. The re-definition of the Zr channel *-4 to include only 6-20 nm instead of 1-20 nm lowers its expected purity in flare situations. Channels *-1 and *-2 show only minor changes which are due to updates in responsivity.

2. Expected variations in LYRA signals and 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 Channels", available here:
http://solwww.oma.be/users/dammasch/IED_20090616_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 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	[0.283, 0.340]	[0.074, 0.112]	[0.0061,0.0093]
1-2	[10.918,11.710]	[9.143, 9.816]	[0.4454,0.4764]
1-3	[0.054, 2.079]	[0.047, 0.147]	[0.0017,0.0057]
1-4	[0.085, 5.373]	[0.078, 0.757]	[0.0006,0.0034]
2-1	[0.100, 0.119]	[0.026, 0.039]	[0.0061,0.0093]
2-2	[11.690,12.512]	[9.797,10.502]	[0.4454,0.4764]
2-3	[0.049, 1.745]	[0.044, 0.136]	[0.0017,0.0057]
2-4	[0.012, 0.787]	[0.011, 0.099]	[0.0006,0.0034]
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	[0.907,16.701]	[0.832, 2.692]	[0.0017,0.0057]
3-4	[0.087, 5.375]	[0.078, 0.757]	[0.0006,0.0034]

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* ~ 1:60 for total, still ~ 1:8 for pure and 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 relative 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.

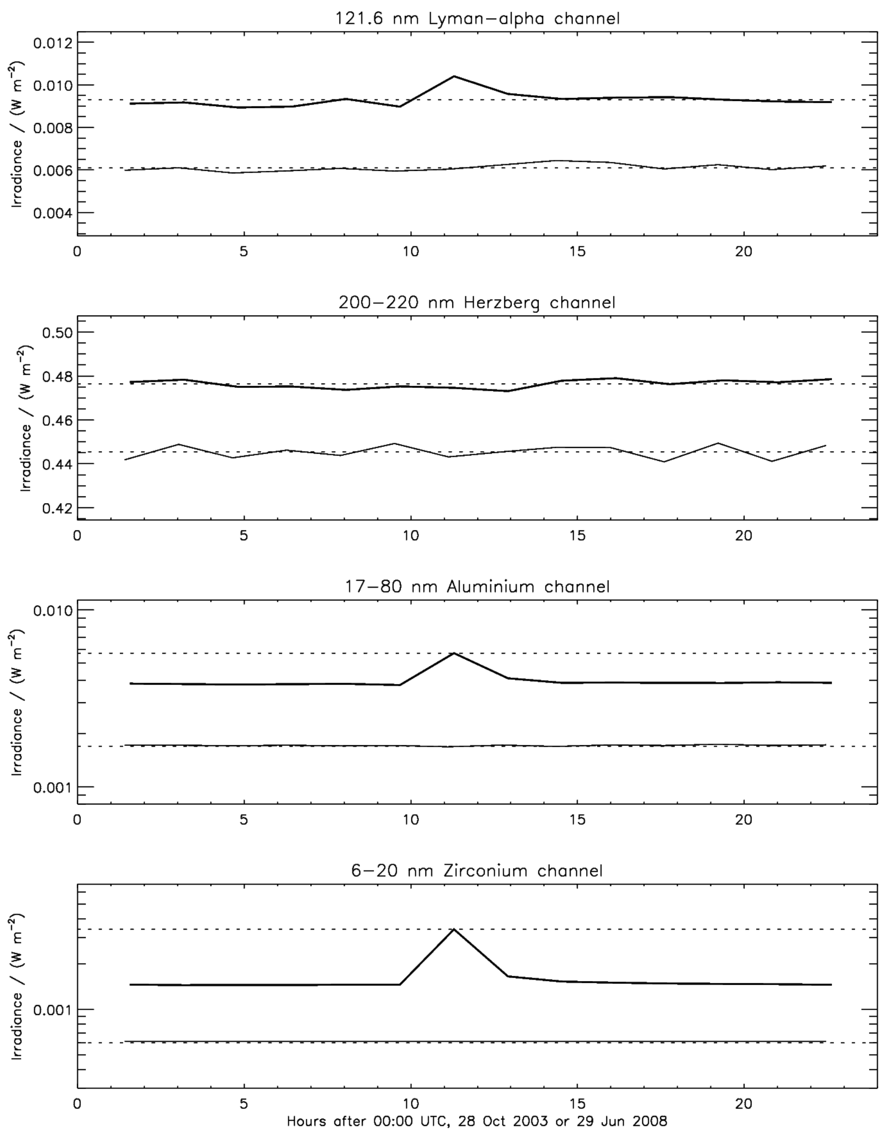

Figure 1: Shown is the daily irradiance development (partially simulated), for the "maximum" observation (thick, above) of 28 Oct 2003, including an X17 flare, and for the "minimum" observation (thin, below) of 29 Jun 2008. Channels 1 and 2 are on a linear scale, channels 3 and 4 on a logarithmic scale.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

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 (< 5 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): After re-definition, the total signal also contains a possible contamination, basically from the very short (< 2 nm) X-ray range. This contamination also ranges from ~10% (quiet) to ~90% (flare), thus the larger variation within the total signal (~ 1:60) as compared to the pure and solar signal (~ 1:8). Due to this "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	[0.226, 0.397]	[0.036, 0.150]	[0.0029,0.0125]
1-2	[10.126,12.502]	[8.470,10.489]	[0.4144,0.5074]
1-3	[0.027, 4.158]	[0.023, 0.294]	[0.0008,0.0114]
1-4	[0.042,10.746]	[0.039, 1.514]	[0.0003,0.0068]
2-1	[0.081, 0.138]	[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, 3.490]	[0.022, 0.272]	[0.0008,0.0114]
2-4	[0.006, 1.574]	[0.005, 0.198]	[0.0003,0.0068]
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	[0.453,33.402]	[0.416, 5.384]	[0.0008,0.0114]
3-4	[0.043,10.750]	[0.039, 1.514]	[0.0003,0.0068]

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.

Outside the simulated intervals, the solar values will be calibrated by linear extrapolation. Thus they are less safe and will receive a warning code (see next section).

To demonstrate that the interval 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 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/

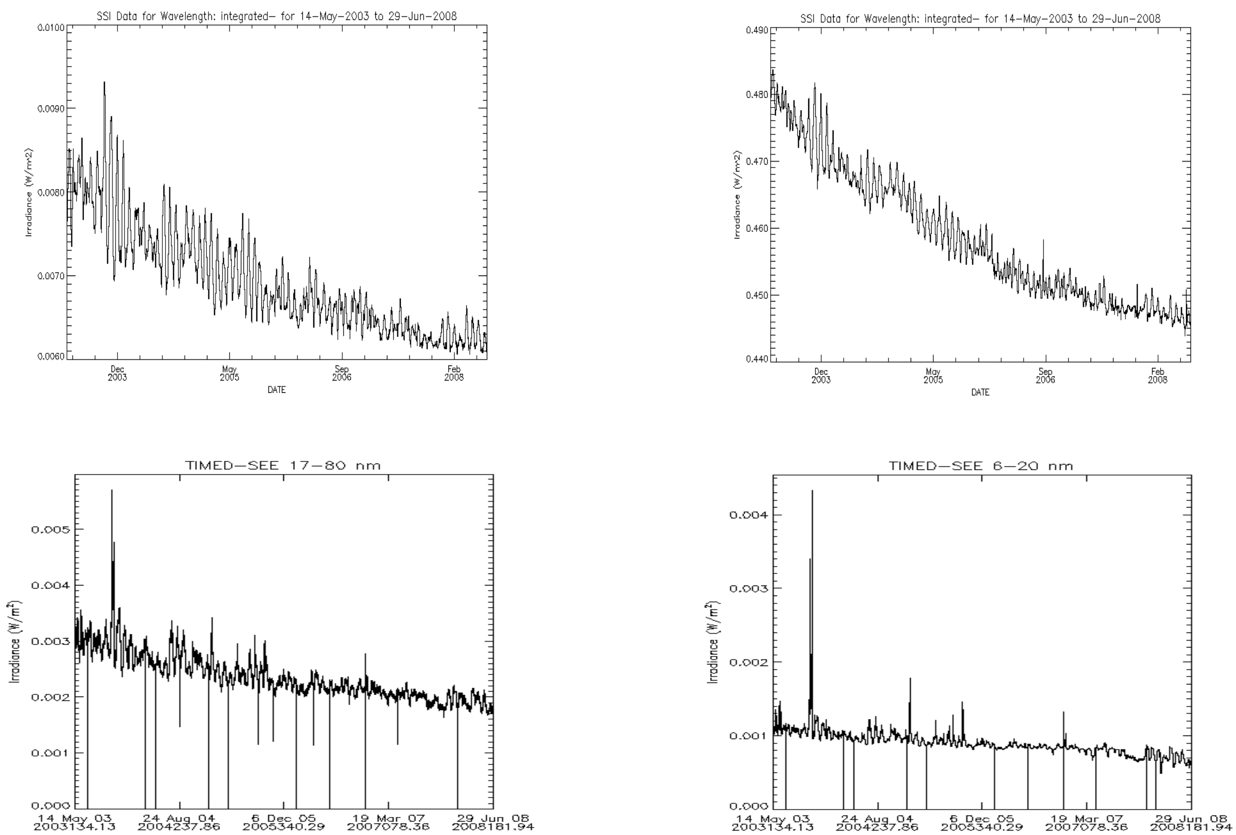

Figure 2: Series of SORCE and TIMED/SEE data comparable to LYRA channels *-1, *-2, *-3, *-4.
For the Lyman-alpha channel *-1, the majority of data fall within the 0.0060-0.0100 range. For the Herzberg channel *-2, the majority of data fall within the 0.4400-0.4800 range. Not considering the zero measurements, 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 0.0005-0.0045. So all sample and extended intervals appear plausible. - Values are in W/m².

3. Software and warning flags

The following warning flags are suggested to go along with published calibrated solar values - either for a certain time during commissioning, more probably as a permanent feature within Lev2 and Lev3 FITS files. Together with a "no warning" flag (W:0) they will correspond to different levels of trust (e.g., error percentages).

W:0 – total and solar signal inside sample interval (Table 2)	– safe value with nominal uncertainty
W:1 – total or solar signal outside sample interval (Table 2)	– unsafe extrapolated value
W:2 – total or solar signal outside extended interval (Table 3)	– implausible extrapolated value
W:3 – total or solar signal <0 or >999	– impossible value

Eventually, there will be a four-digit "warning" string (or "reliability" code) in each line of a Lev2 or Lev3 "standard" data file, printed at the side of the four columns with the calibrated values from the four channels, 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. - In the end, this warning string will become a five-digit string, because it will be preceded by one digit that denotes the reliability of the time-stamp interpolation (TBD).

At the end of this report, three sets of data for the three LYRA heads are presented (Figures 3a, 3b, 3c). The examples correspond to the FITS file presented in the report *Introduction to LYRA FITS Files,*
http://solwww.oma.be/users/dammasch/IED_20090803_LyraFitsIntroductionExample.pdf

The data (lines 1-2496 for head 1 in Figure 3a, lines 2497-4992 for head2 in Figure 3b, lines 4993-7488 for head 3 in Figure 3c) cover the extended interval of the LYRA total signal from minimum to maximum in 2495 equal steps, where channels *-1 and *-2 are on a linear scale, and channels *-3 and *-4 are on a logarithmic scale. The dotted lines mark the safe intervals (W:0 inside, W:1 outside; W:2 would be outside these figures), both for total LYRA signal and solar signal; the (up to seven) different values from LYRA radiometric model simulations with TIMED/SEE and SORCE sample spectra are marked with squares.

Compared to earlier versions, there are no more dubious data points, and the calibration curves are monotonic. The sudden slowdown of the nominal solar signal in channel *-3 and *-4, relative to the total LYRA signal, is caused by the onset of flares and the corresponding contamination due to SXR wavelengths; the highest two values (squares) are from flare spectra.

Please note that - while the structure of all three figures is identical – it is the intervals of the LYRA total signal that vary; this is caused by the different responsivities due to the different technical components of the channels (e.g. silicon or diamond detector, thickness of filters).

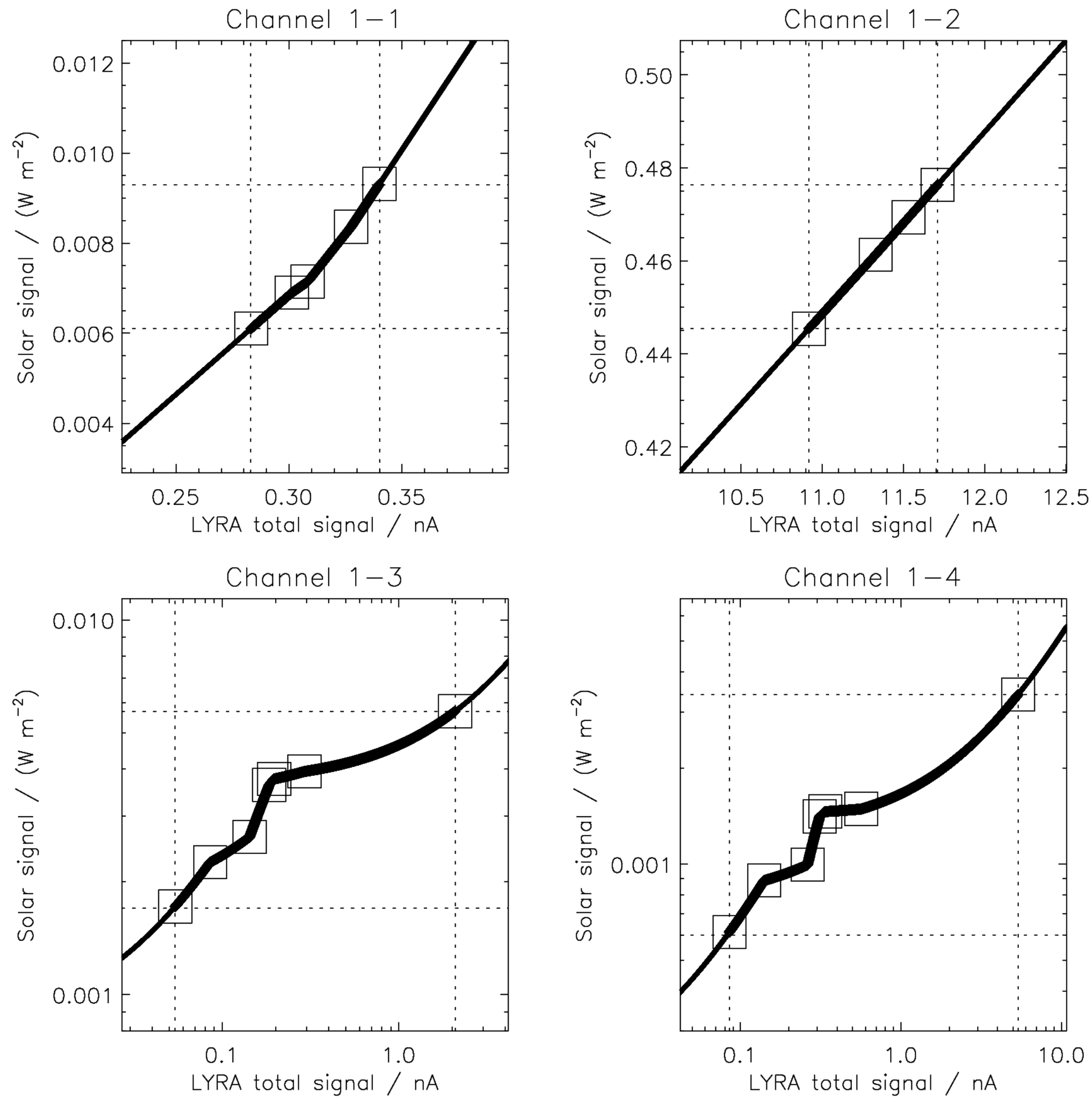

Figure 3a. Input to Lev2 FITS file (converted to nA) vs. output from Lev2 FITS file (in W/m²), simulated for LYRA head 1.

(To make these figures comparable with figures in the *LYRA Calibration Methods* report, as well as to Tables 2 and 3 above, total signals are not shown in frequencies - which is the real input from Lev1 to Lev 2 - but in detector currents.)

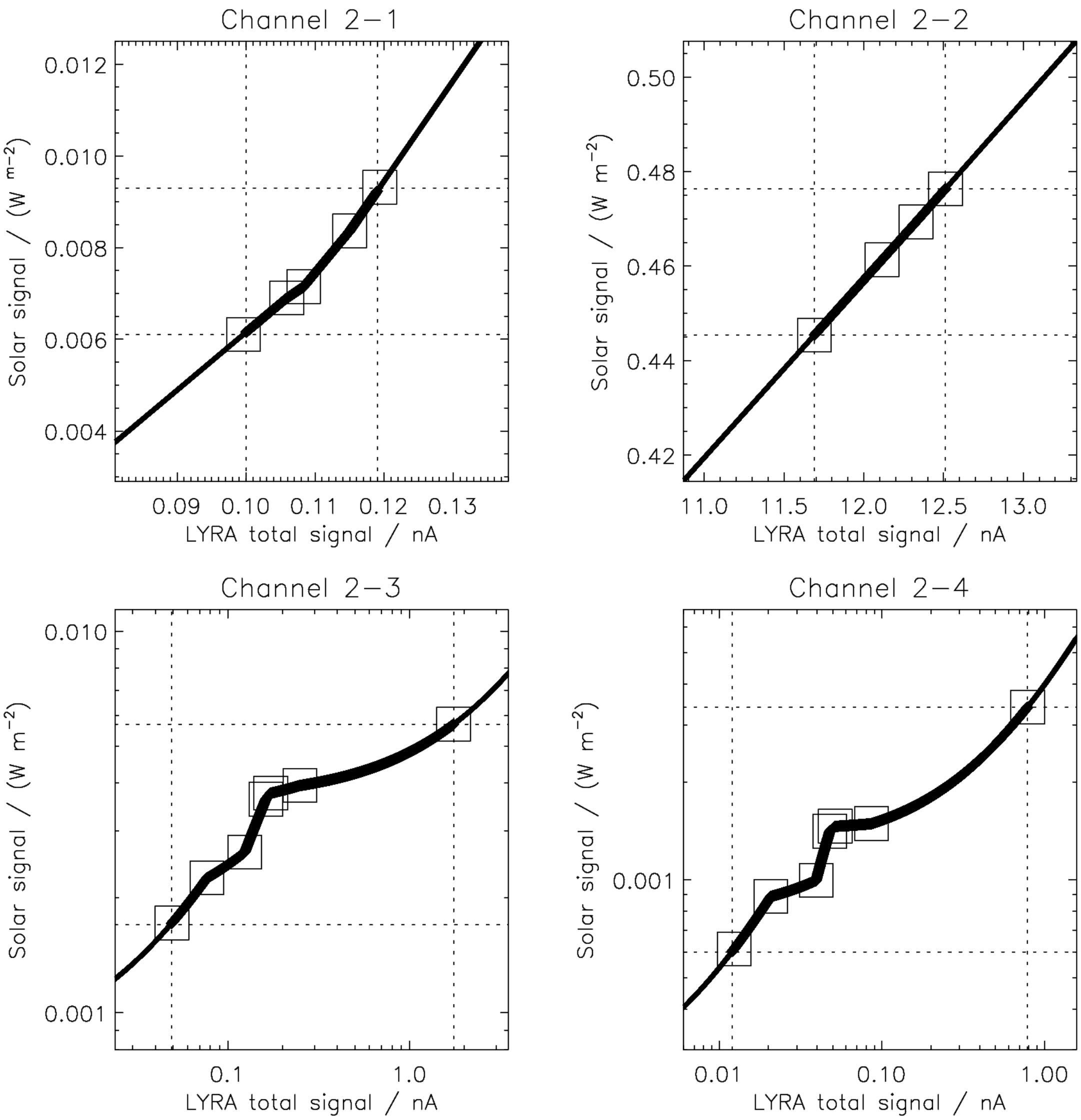

Figure 3b. Input to Lev2 FITS file (converted to nA) vs. output from Lev2 FITS file (in W/m²), simulated for LYRA head 2.

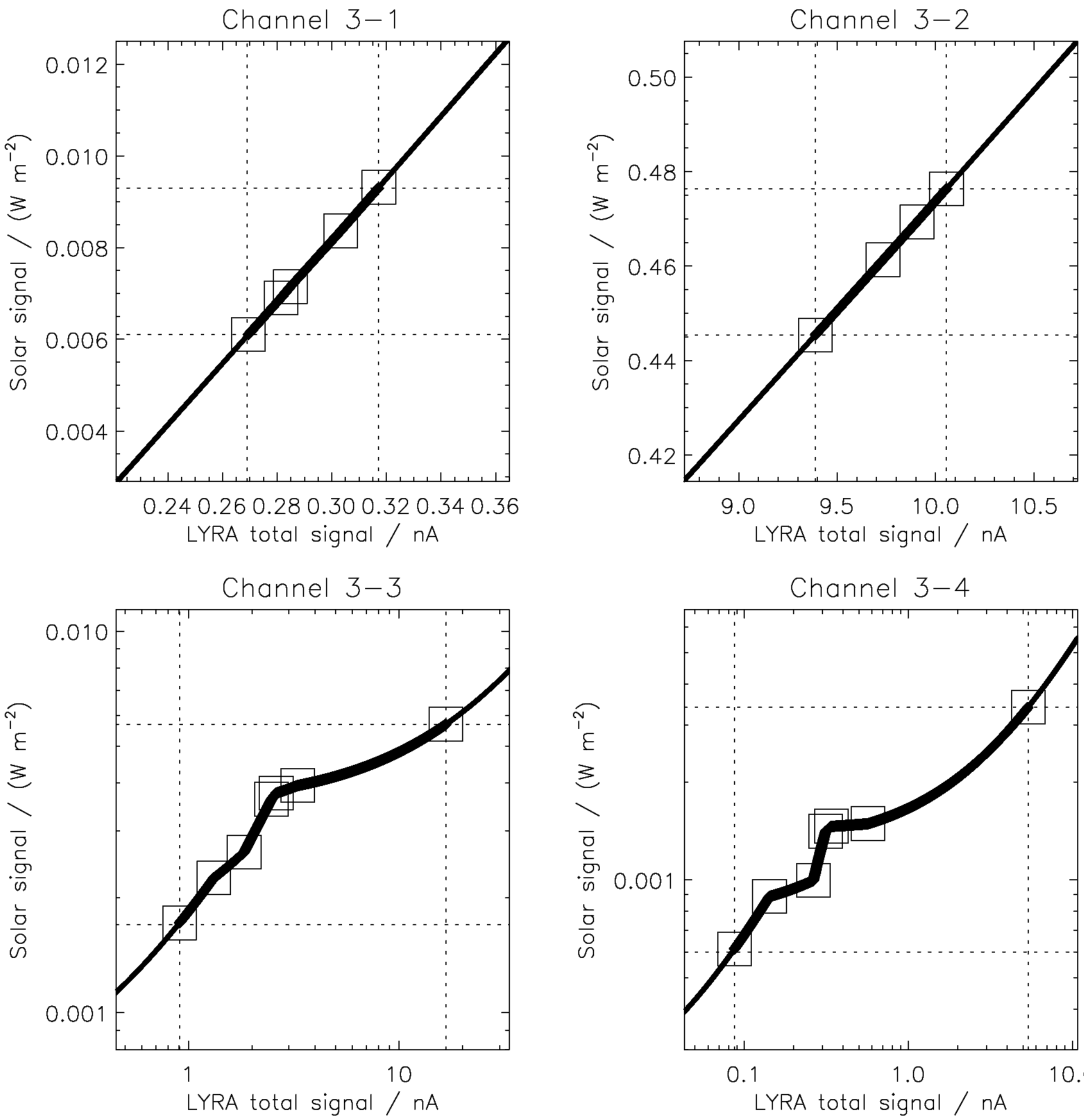

Figure 3c. Input to Lev2 FITS file (converted to nA) vs. output from Lev2 FITS file (in W/m²), simulated for LYRA head 3.