LYRA Output: Expected Variations

IED 16 Apr 2008 (rev. 22 May and 29 May 2008)

The purpose of this report is to estimate the expected output of the LYRA channels and the interrelated solar values. It consists of four sections and three 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 theoretical performances and their real measured performance, once the channels were integrated.

channel	"min" 2005	"high" 2005	"min" 2006/07	"high" 2006/07	"min" 2008	"high" 2008
1-1 *Ly 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 *Ly 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 *Ly 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 2006/07). 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 2008).

2. Expected variations in LYRA signals and reconstructed solar signals

The radiometric model has been simulated with the help of seven TIMED/SEE sample spectra. Results were described in the report “LYRA Calibration Methods”, available here:
http://solwww.oma.be/users/dammasch/IED_20080407_LYRA_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 subsequent LYRA output, to be expected:

Statistical analysis of SOHO/SUMER radiances has shown that they 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 may be expected that the log-normal variation evens out – given the radiances are evenly distributed. But is this the case? 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 will 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 / Wm-2
1-1	[0.294, 0.349]	[0.068, 0.116]	[0.0056,0.0096]
1-2	[11.634,11.664]	[9.755, 9.755]	[0.4742,0.4742]
1-3	[0.066, 8.742]	[0.040, 0.427]	[0.0013,0.0111]
1-4	[0.285,25.035]	[0.283,25.032]	[0.0020,0.0975]
2-1	[0.103, 0.122]	[0.024, 0.040]	[0.0056,0.0096]
2-2	[12.469,12.491]	[10.453,10.453]	[0.4742,0.4742]
2-3	[0.059, 6.785]	[0.036, 0.397]	[0.0013,0.0111]
2-4	[0.045, 3.797]	[0.044, 3.796]	[0.0020,0.0975]
3-1	[0.261, 0.321]	[0.081, 0.138]	[0.0056,0.0096]
3-2	[10.013,10.031]	[8.365, 8.365]	[0.4742,0.4742]
3-3	[0.918,66.604]	[0.674, 6.889]	[0.0013,0.0111]
3-4	[0.292,25.443]	[0.288,25.439]	[0.0020,0.0975]

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) are basically influenced by only one sample spectrum; for the warning flags later on, +/- 10% will be considered as normal sample variation to avoid unnecessary messages
Values for channel *-3 (Aluminium) appear to be “logarithmically” distributed (*lower:upper* ~ 1:100 for total, still ~ 1:10 for pure and for solar).
Values for channel *-4 (Zirconium) appear to be “logarithmically” distributed (*lower:upper* ~ 1:85 for total and pure, ~ 1:50 for solar).
For channel *-1 and *-3, sample spectrum “min” leads to the lower, “max” leads to the upper boundary.
For channel *-4, spectrum “pre2” leads to the lower and, again, “max” leads to the upper boundary.

How can we calculate extended intervals 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.

Channel *-1 (Lyman alpha): The pure signal and the solar signal vary just by *lower:upper* ~ 1:2. The total signal consists of 70-80% contamination from longer wavelengths (only one sample) and thus varies even less. The lower Lyman-alpha boundary stems from a solar-minimum spectrum of 2005. Spectra from a more active time in 2003 lead to ~ 40% higher signals without flares; a major flare adds another amount of similar size. So to estimate a safe interval of values to be expected, it is suggested to double (TBC) the observed interval, symmetrically around its center, see Table 3. - For the total signal, a further extension is suggested by adding and subtracting 20% (TBC) of the above-mentioned residual signal.

Channel *-2 (Herzberg): An extension is suggested by adding +/- 20% (TBC) to the - more or less constant - sample value.

Channel *-3 (Aluminium): The total signal contains a possible contamination, basically from the very short (~ 1 nm) X-ray range. This contamination ranges from 30% (quiet) to 97% (flare), thus follows the larger variation within the total signal (~ 1:100) as compared to the pure and solar signal (~ 1:10). Due to this "logarithmic" distribution, it is suggested to limit an extended interval with half (TBC) the minimum and twice (TBC) 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 (~ 1:85) than solar values (~ 1:50), 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 with half (TBC) the minimum and twice (TBC) the maximum sample values. - See Table 3.

ch.	total / nA	pure / nA	solar / Wm-2
1-1	[0.228, 0.416]	[0.044, 0.140]	[0.0036,0.0116]
1-2	[9.316,13.974]	[7.804,11.706]	[0.3794,0.5690]
1-3	[0.033,17.484]	[0.020, 0.854]	[0.0007,0.0222]
1-4	[0.143,50.070]	[0.142,50.064]	[0.0010,0.1950]
2-1	[0.081, 0.145]	[0.016, 0.048]	[0.0036,0.0116]
2-2	[9.982,14.972]	[8.362,12.544]	[0.3794,0.5690]
2-3	[0.030,13.570]	[0.018, 0.794]	[0.0007,0.0222]
2-4	[0.023, 7.594]	[0.022, 7.592]	[0.0010,0.1950]
3-1	[0.198, 0.384]	[0.052, 0.166]	[0.0036,0.0116]
3-2	[8.015,12.023]	[6.692,10.038]	[0.3794,0.5690]
3-3	[0.459,133.21]	[0.337,13.778]	[0.0007,0.0222]
3-4	[0.292,25.443]	[0.288,25.439]	[0.0010,0.1950]

Table 3. Extended intervals of LYRA channel signals and solar signals.
Intervals for channel *-1 (Lyman alpha): The pure and solar signal intervals are doubled around their center; for the total signal, another +/- 20% of the residual signal are added.
Intervals for channel *-2 (Herzberg): For all intervals, +/- 20% are added
Intervals for channel *-3 (Aluminium): All intervals are extended to 50% of the *lower* and 200% of the *upper* limit.
Intervals for 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 TIMED/SEE instrument are presented below in Fig. 1. The data between 2002 and 2007 are used as 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*

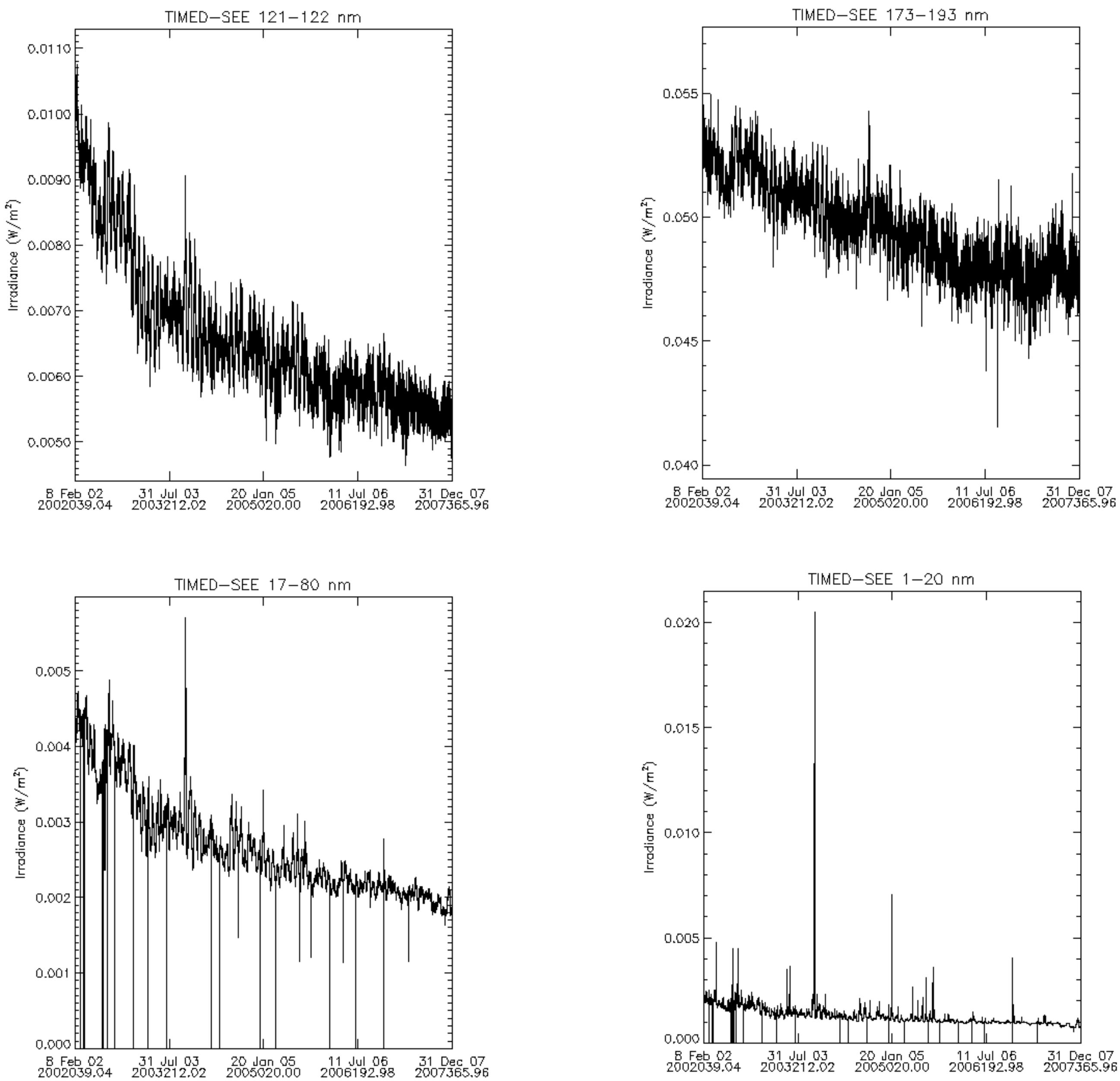

Figure 1: Series of TIMED/SEE data comparable to LYRA channels *-1, *-2, *-3, *-4.

For the Lyman-alpha channel *-1, it can easily be observed that the majority of data fall within the 0.0050-0.0100 range. So the sample and the extended interval appear plausible. - Please note that the second spectral interval is just a proxy: The Herzberg channel *-2 (200-220 nm) lies outside of the coverage of TIMED/SEE, but it can be assumed that the LYRA channel leads to results that are approx. a factor 10 higher than the 173-193-nm interval and have the same relative variation, so an interval 0.400-0.550 appears plausible. - 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. As with the last channel, this is considerably less (a factor 2 for *-3, and a factor 5 for *-4) than the upper boundaries of the “high” and “max” sample spectra; these could not be confirmed here. (All values in W/m^2)

3. Error estimation

The radiometric model was run using responsivity values with their resp. uncertainties added as well as subtracted. The upper and lower limits were thus calculated for all four channels of head 2 (head 1 and 3 TBD), using the sample spectra “high”, “pre1”, and “fla1”. The results are consistent for all samples. Purities are basically not influenced (< 0.2%), except for channel 2-1, where purity rises by approx. 2% for the lower uncertainty limit (less contamination), and falls by a similar amount for the upper limit (more contamination).

ch	error
2-1	15 %
2-2	5 %
2-3	0.4 %
2-4	0.3 %

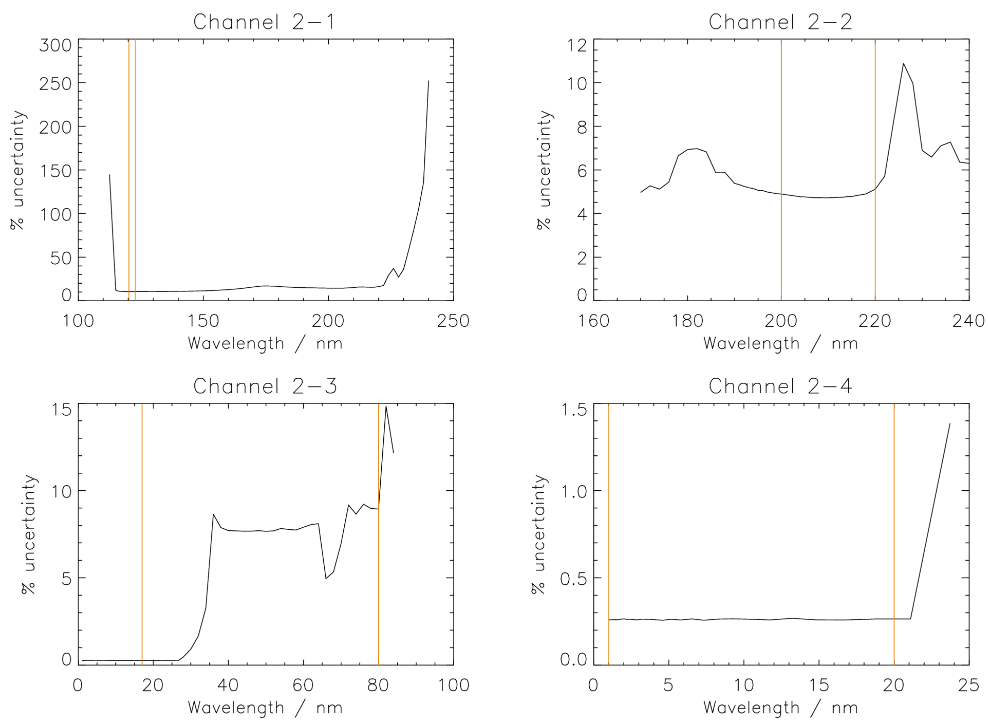

Figure 2: LYRA head 2 error estimation according to responsivity uncertainties.
2-1: While the uncertainty given for the nominal interval around Lyman-alpha is 11%, the large uncertainties at the borders of the measurements worsen this estimate to 15%.
2-2: The 5% uncertainty given for the nominal interval dominates the rest.
2-3: Since this channel is dominated by short wavelengths, the 8% uncertainty above 35 nm does not have much influence, instead the 0.3% value given for the interval below 25 nm (including also the very-short-wavelength contaminations around 1 nm) is more important.
2-4: Here, too, the uncertainty given for the nominal interval is 0.3%. - The question remains whether these very small uncertainties delivered by the 2006 BESSY GI campaign are realistic. - Maybe additional error sources exist that should be considered.
The uncertainty (here estimated as 5%) of the long NUV-VIS-IR wavelengths' theoretical responsivities have only negligible influence. - The red vertical lines mark the nominal intervals for each channel.

4. 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., *W: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, two data files and an IDL program are presented. As an example, the calibration of head 2 is demonstrated, heads 1 and 3 are to be completed later.

The first data file (Appendix 1) is a simulated level-1 file. It consists of a (fantasized) header block and 104 data lines of ordered data. The file notation and the header takes up some thoughts expressed in the *LYRA Data Management Plan*. The 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. 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 are transformed backwards to LYRA counts that can be expected in a level-1 data file. In the right column of the level-1 file appears the integration time in ms. Since by this procedure the smallest solar values (or current values) are associated with the smallest integration times, and vice versa, this table gives 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 page). 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 pure or solar signals drop out – is denoted by straight lines.

The second data file (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 header, the timestamps and running counter from the level-1 file, four columns of calibrated data, and finally the string with the warning message.

Finally, there is (slightly commented, see Appendix 3) the calibration software, an IDL program called *calculate_calibration1.pro*, so far restricted to head 2, head 1 and 3 TBD.

The structure of the level-1 and level-2 data files, and the parameters that have to be passed for calibration purposes are TBC.

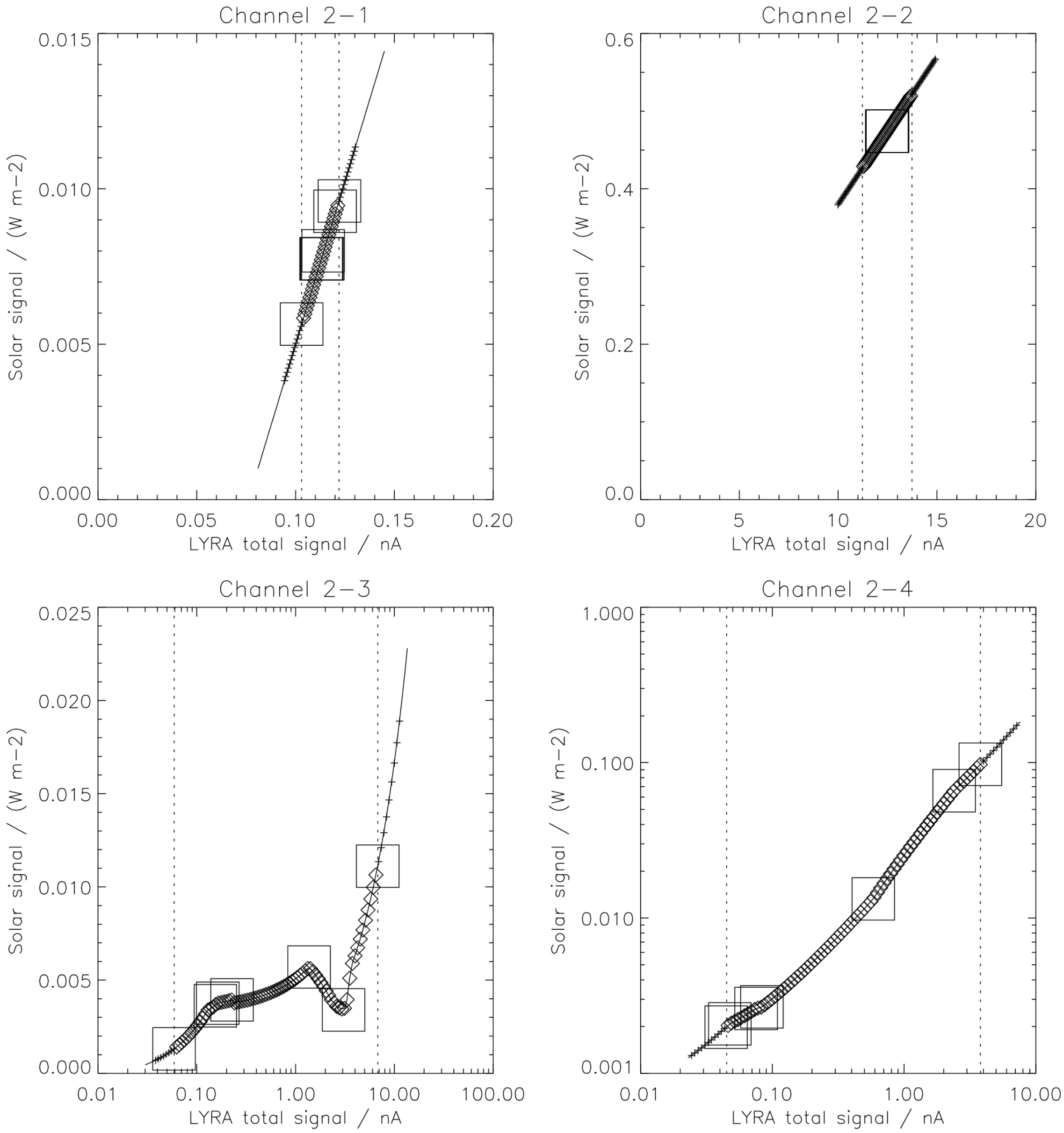

Figure 3: Simulated data, input from level-1 file (transformed) vs. output to level-2 file.
To make these figures comparable with figures in the *LYRA Calibration Methods* report, total signals are not shown in counts but in current/nA. The sample interval used for calibration is marked with diamonds (plus vertical dotted lines). The extended interval is marked with crosses, anything outside by a straight line. The large boxes mark the seven TIMED/SEE samples.

One should consider merging or deleting dubious data points (TBC), esp. in channel *-3. The aim should be to keep the calibration curve monotonic. While it is plausible that the growth of the pure (and solar) signal actually becomes slower after the onset of flares and the corresponding contamination due to very short wavelengths - i.e. for total signal > 0.15 nA - , the reversal appears implausible and would lead to LYRA yielding *lower* solar values while the counts within the Aluminium channel are rising.

Appendix 1: Simulated Level-1 Data File

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LYRA_20080511_120000_lev1.txt

2                        : LYRA head
-0.0276313 0.00414983    : VFC r0,r1 channel 1
-0.0272914 0.00414996    : VFC r0,r1 channel 2
-0.0274324 0.00414663    : VFC r0,r1 channel 3
-0.0276325 0.00414608    : VFC r0,r1 channel 4
0.0 0.0                  : pointing Y/arcsec Z/arcsec
TBD                      : spacecraft position
TBD                      : housekeeping
2008.05.11T12.00.00      : acquisition
2008.05.13T14.02.00 IED  : built date, place
01                       : software version

43200.010       1          0          0          0          0       10
43200.020       2       1045       2400         69        319       10
43200.030       3       2091       4802        140        638       10
43200.040       4       2107       4826        144        672       10
43200.050       5       2123       4849        149        708       10
43200.060       6       2139       4873        154        747       10
43200.070       7       2155       4897        160        787       10
43200.080       8       2171       4920        166        830       10
43200.090       9       2187       4944        172        876       10
43200.100      10       2203       4968        179        924       10
43200.110      11       2219       4991        186        975       10
43200.120      12       2235       5015        194       1030       10
43200.140      13       4501      10077        403       2174       20
43200.160      14       4533      10125        420       2296       20
43200.180      15       4565      10172        439       2425       20
43200.200      16       4597      10219        458       2562       20
43200.220      17       4629      10267        478       2707       20
43200.240      18       4661      10314        500       2861       20
43200.260      19       4693      10361        523       3024       20
43200.280      20       4725      10409        548       3196       20
43200.300      21       4757      10456        574       3379       20
43200.320      22       4789      10503        602       3573       20
43200.370      23      12053      26377       1579       9446       50
43200.420      24      12133      26495       1658       9990       50
43200.470      25      12213      26614       1742      10567       50
43200.520      26      12293      26732       1831      11178       50
43200.570      27      12373      26850       1925      11825       50
43200.620      28      12453      26969       2026      12511       50
43200.670      29      12533      27087       2133      13239       50
43200.720      30      12613      27205       2246      14009       50
43200.770      31      12692      27324       2367      14826       50
43200.820      32      12772      27442       2495      15691       50
43200.920      33      25705      55121       5264      33216      100
43201.020      34      25865      55358       5554      35160      100
43201.120      35      26025      55595       5862      37220      100
43201.220      36      26185      55831       6190      39402      100
43201.320      37      26345      56068       6539      41715      100
43201.420      38      26504      56305       6909      44166      100
43201.520      39      26664      56542       7303      46764      100
43201.620      40      26824      56778       7722      49516      100
43201.720      41      26984      57015       8167      52433      100
43201.820      42      27144      57252       8641      55524      100
43202.020      43      54608     114977      18287     117599      200
43202.220      44      54928     115451      19357     124542      200
43202.420      45      55248     115925      20494     131899      200
43202.620      46      55568     116398      21703     139695      200
43202.820      47      55888     116872      22988     147957      200
43203.020      48      56207     117345      24354     156712      200
43203.220      49      56527     117819      25806     165989      200
43203.420      50      56847     118292      27350     175821      200
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43203.620	51	57167	118766	28991	186240	200
43203.820	52	57487	119239	30735	197281	200
43204.320	53	144517	299282	81474	522454	500
43204.820	54	145317	300465	86403	553451	500
43205.320	55	146116	301649	91642	586299	500
43205.820	56	146916	302833	97212	621108	500
43206.320	57	147716	304017	103132	657996	500
43206.820	58	148515	305200	109426	697087	500
43207.320	59	149315	306384	116118	738512	500
43207.820	60	150114	307568	123230	782410	500
43208.320	61	150914	308752	130792	828929	500
43208.820	62	151714	309936	138830	878227	500
43209.820	63	305027	622239	294750	1860935	1000
43210.820	64	306626	624606	312917	1971655	1000
43211.820	65	308225	626974	332230	2088987	1000
43212.820	66	309825	629341	352761	2213324	1000
43213.820	67	311424	631709	374586	2345087	1000
43214.820	68	313023	634077	397788	2484715	1000
43215.820	69	314623	636444	422452	2632682	1000
43216.820	70	316222	638812	448671	2789485	1000
43217.820	71	317821	641179	476544	2955650	1000
43218.820	72	319420	643547	506174	3131736	1000
43220.820	73	642039	1291829	1075344	6636675	2000
43222.820	74	645238	1296564	1142313	7032161	2000
43224.820	75	648437	1301299	1213504	7451262	2000
43226.820	76	651635	1306034	1289184	7895386	2000
43228.820	77	654834	1310769	1369636	8366031	2000
43230.820	78	658032	1315504	1455159	8864780	2000
43232.820	79	661231	1320240	1546076	9393310	2000
43234.820	80	664430	1324975	1642726	9953396	2000
43236.820	81	667628	1329710	1745468	10546924	2000
43238.820	82	670827	1334445	1854690	11175896	2000
43243.820	83	1685063	3347950	4926996	29606062	5000
43248.820	84	1693060	3359788	5235567	31371882	5000
43253.820	85	1701056	3371626	5563596	33243140	5000
43258.820	86	1709053	3383464	5912308	35226132	5000
43263.820	87	1717049	3395302	6283004	37327528	5000
43268.820	88	1725046	3407140	6677077	39554408	5000
43273.820	89	1733042	3418977	7095997	41914232	5000
43278.820	90	1741039	3430815	7541326	44414992	5000
43283.820	91	1749035	3442653	8014740	47065064	5000
43288.820	92	1757032	3454491	8518002	49873360	5000
43298.820	93	3530056	6932657	18105984	105698704	10000
43308.820	94	3546049	6956333	19243438	112006120	10000
43318.820	95	3562042	6980009	20452612	118690128	10000
43328.820	96	3578035	7003684	21738016	125773272	10000
43338.820	97	3594028	7027360	23104472	133279352	10000
43348.820	98	3610021	7051036	24557094	141233616	10000
43358.820	99	3626014	7074712	26101296	149662848	10000
43368.820	100	3642007	7098387	27742872	158595376	10000
43378.820	101	3657999	7122063	29487954	168061216	10000
43388.820	102	3673992	7145738	31343054	178092336	10000
43398.820	103	3689985	7169414	33315134	188722448	10000
43408.820	104	7379970	14338828	66630268	377444896	10000

Appendix 2: Simulated Level-2 Data File

```
LYRA_20080511_120000_lev2_v02.txt

2                       : LYRA head
0.00000 0.00000         : pointing Y/arcsec Z/arcsec
TBD                     : spacecraft position
TBD                     : housekeeping
2008.05.11T12.00.00     : acquisition
2008.05.13T14.02.00 IED  : built date, place (level 1)
2008.05.14T14.27.00 IED  : built date, place (level 2)
01                      : software version (level 1)
02                      : software version (level 2)

43200.010       1      0.00000      0.00000      0.00000      0.00000 W:3333
43200.020       2      0.00000     0.186988      0.00000  0.000826814 W:3232
43200.030       3   0.00100702     0.379403  0.000459878   0.00125734 W:2122
43200.040       4   0.00114137     0.381326  0.000508100   0.00130323 W:2121
43200.050       5   0.00127573     0.383168  0.000568377   0.00135181 W:2121
43200.060       6   0.00141008     0.385091  0.000628654   0.00140445 W:2121
43200.070       7   0.00154444     0.387013  0.000700986   0.00145843 W:2111
43200.080       8   0.00167879     0.388856  0.000773318   0.00151647 W:2111
43200.090       9   0.00181315     0.390778  0.000845650   0.00157855 W:2111
43200.100      10   0.00194750     0.392701  0.000930038   0.00164333 W:2111
43200.110      11   0.00208186     0.394543   0.00101443   0.00171216 W:2111
43200.120      12   0.00221621     0.396466   0.00111087   0.00178639 W:2111
43200.140      13   0.00234637     0.398348   0.00120128   0.00186332 W:2111
43200.160      14   0.00248073     0.400271   0.00130375   0.00194564 W:2111
43200.180      15   0.00261508     0.402154   0.00141828   0.00203269 W:2100
43200.200      16   0.00274944     0.404036   0.00153281   0.00210709 W:2100
43200.220      17   0.00288379     0.405959   0.00165336   0.00216280 W:2100
43200.240      18   0.00301815     0.407841   0.00178597   0.00222196 W:2100
43200.260      19   0.00315250     0.409724   0.00192461   0.00228459 W:2100
43200.280      20   0.00328686     0.411646   0.00207530   0.00235067 W:2100
43200.300      21   0.00342121     0.413529   0.00223202   0.00242098 W:2100
43200.320      22   0.00355557     0.415411   0.00240079   0.00249551 W:2100
43200.370      23   0.00369076     0.417326   0.00257921   0.00257442 W:2100
43200.420      24   0.00382512     0.419216   0.00276969   0.00263080 W:1100
43200.470      25   0.00395947     0.421123   0.00297222   0.00266700 W:1100
43200.520      26   0.00409382     0.423013   0.00318681   0.00275535 W:1100
43200.570      27   0.00422818     0.424904   0.00340742   0.00286581 W:1100
43200.620      28   0.00436253     0.426810   0.00348203   0.00298293 W:1100
43200.670      29   0.00449689     0.428701   0.00356106   0.00310723 W:1000
43200.720      30   0.00463124     0.430591   0.00370280   0.00323869 W:1000
43200.770      31   0.00476392     0.432498   0.00377388   0.00337818 W:1000
43200.820      32   0.00489828     0.434388   0.00380255   0.00352586 W:1000
43200.920      33   0.00503347     0.436287   0.00383324   0.00368243 W:1000
43201.020      34   0.00516782     0.438185   0.00386572   0.00384838 W:1000
43201.120      35   0.00530218     0.440084   0.00390022   0.00402423 W:1000
43201.220      36   0.00543653     0.441974   0.00393696   0.00421050 W:1000
43201.320      37   0.00557089     0.443873   0.00378569   0.00440795 W:1000
43201.420      38   0.00570440     0.445772   0.00381128   0.00461719 W:1000
43201.520      39   0.00583876     0.447670   0.00383852   0.00483897 W:0000
43201.620      40   0.00597311     0.449561   0.00386750   0.00507390 W:0000
43201.720      41   0.00610747     0.451459   0.00389827   0.00532291 W:0000
43201.820      42   0.00624182     0.453358   0.00393105   0.00558678 W:0000
43202.020      43   0.00637618     0.455252   0.00396580   0.00586640 W:0000
43202.220      44   0.00651053     0.457151   0.00400280   0.00616275 W:0000
43202.420      45   0.00664489     0.459049   0.00404212   0.00647677 W:0000
43202.620      46   0.00677924     0.460944   0.00408392   0.00680953 W:0000
43202.820      47   0.00691360     0.462842   0.00412835   0.00716217 W:0000
43203.020      48   0.00704753     0.464737   0.00417559   0.00753587 W:0000
43203.220      49   0.00718189     0.466635   0.00422579   0.00793184 W:0000
43203.420      50   0.00731624     0.468530   0.00427918   0.00835150 W:0000
```

43203.620	51	0.00745060	0.470428	0.00433593	0.00879622	W:0000
43203.820	52	0.00758495	0.472323	0.00439623	0.00926748	W:0000
43204.320	53	0.00771923	0.474221	0.00446036	0.00976690	W:0000
43204.820	54	0.00785358	0.476116	0.00452853	0.0102961	W:0000
43205.320	55	0.00798777	0.478013	0.00460099	0.0108569	W:0000
43205.820	56	0.00812212	0.479910	0.00467803	0.0114512	W:0000
43206.320	57	0.00825648	0.481807	0.00475991	0.0120810	W:0000
43206.820	58	0.00839066	0.483702	0.00484697	0.0127485	W:0000
43207.320	59	0.00852502	0.485599	0.00493952	0.0135219	W:0000
43207.820	60	0.00865921	0.487496	0.00503789	0.0145476	W:0000
43208.320	61	0.00879356	0.489393	0.00514248	0.0156346	W:0000
43208.820	62	0.00892792	0.491290	0.00525366	0.0167866	W:0000
43209.820	63	0.00906219	0.493186	0.00537184	0.0180073	W:0000
43210.820	64	0.00919646	0.495082	0.00549748	0.0193009	W:0000
43211.820	65	0.00933073	0.496979	0.00563104	0.0206717	W:0000
43212.820	66	0.00946508	0.498875	0.00562081	0.0221244	W:0000
43213.820	67	0.00959936	0.500772	0.00545186	0.0236639	W:1000
43214.820	68	0.00973363	0.502669	0.00527224	0.0252952	W:1000
43215.820	69	0.00986798	0.504565	0.00508130	0.0270240	W:1000
43216.820	70	0.0100023	0.506462	0.00487833	0.0288560	W:1000
43217.820	71	0.0101365	0.508358	0.00466256	0.0307974	W:1000
43218.820	72	0.0102708	0.510255	0.00443318	0.0328547	W:1000
43220.820	73	0.0104051	0.512151	0.00418934	0.0350348	W:1000
43222.820	74	0.0105394	0.514048	0.00393012	0.0373452	W:1000
43224.820	75	0.0106737	0.515944	0.00379148	0.0397934	W:1000
43226.820	76	0.0108080	0.517841	0.00358851	0.0423879	W:1000
43228.820	77	0.0109423	0.519737	0.00352226	0.0451373	W:1000
43230.820	78	0.0110766	0.521634	0.00345183	0.0480508	W:1100
43232.820	79	0.0112109	0.523531	0.00348531	0.0511384	W:1100
43234.820	80	0.0113452	0.525427	0.00395471	0.0544103	W:1100
43236.820	81	0.0114795	0.527324	0.00510084	0.0578775	W:2100
43238.820	82	0.0116138	0.529220	0.00589638	0.0615518	W:2100
43243.820	83	0.0117481	0.531117	0.00630476	0.0654455	W:2100
43248.820	84	0.0118824	0.533014	0.00673888	0.0687750	W:2100
43253.820	85	0.0120167	0.534910	0.00720037	0.0721763	W:2100
43258.820	86	0.0121510	0.536807	0.00769096	0.0757807	W:2100
43263.820	87	0.0122853	0.538703	0.00821248	0.0796004	W:2100
43268.820	88	0.0124196	0.540600	0.00876689	0.0836481	W:2100
43273.820	89	0.0125539	0.542496	0.00935626	0.0879375	W:2100
43278.820	90	0.0126882	0.544393	0.00998278	0.0924830	W:2100
43283.820	91	0.0128224	0.546290	0.0106488	0.0973000	W:2100
43288.820	92	0.0129568	0.548186	0.0113568	0.102405	W:2111
43298.820	93	0.0130910	0.550083	0.0121095	0.107814	W:2111
43308.820	94	0.0132253	0.551979	0.0129096	0.113546	W:2111
43318.820	95	0.0133596	0.553876	0.0137602	0.119621	W:2111
43328.820	96	0.0134939	0.555772	0.0146644	0.126058	W:2111
43338.820	97	0.0136282	0.557669	0.0156256	0.132880	W:2111
43348.820	98	0.0137625	0.559566	0.0166474	0.140109	W:2111
43358.820	99	0.0138968	0.561462	0.0177337	0.147770	W:2111
43368.820	100	0.0140311	0.563359	0.0188884	0.155888	W:2111
43378.820	101	0.0141654	0.565255	0.0201160	0.164491	W:2121
43388.820	102	0.0142997	0.567152	0.0214209	0.173608	W:2121
43398.820	103	0.0144340	0.569049	0.0228082	0.183269	W:2222
43408.820	104	0.0454195	1.14337	0.0462432	0.354786	W:2222

Appendix 3: IDL calibration software (only for LYRA head 2; head 1 and 3 TBD)

```
; calculate_calibration1.pro
; ------------------------------------------------------------------------------
; IED 14 May 2008
; ------------------------------------------------------------------------------
; IDL program to create a
;   LYRA_yyyymmdd_hhmmss_lev2_vX.txt
; file containing
; - time stamp / s.ms
; - counter
; - data from channels 1, 2, 3, 4 / (W/m^2)
; - warnings for problematic or impossible values
; and a header with necessary information and metadata:
; - LYRA head 1, 2, or 3
; - pointing
; - spacecraft position
; - housekeeping
; - acquisition date
; - built date, place (lev1,lev2)
; - software version (lev1,lev2), etc.
; The program takes a LYRA lev1 data file, e.g. the simulated
;   LYRA_20080511_120000_lev1.txt
; as input, performs the necessary calibration conversions from counts to W/m^2
; and creates the LYRA lev2 data file as output.
; ------------------------------------------------------------------------------

filename='LYRA_20080511_120000_lev1.txt'
; in reality, this filename must be retrieved from a to-be-executed list

version='02'
; to be updated when version changes

close,1 & close,2
openr,1,filename

; read lev1 file header
filename_in=''
readf,1,filename_in
readf,1
readf,1,lyrahead
lyrahead=fix(lyrahead)
readf,1,vfc1r0,vfc1r1
readf,1,vfc2r0,vfc2r1
readf,1,vfc3r0,vfc3r1
readf,1,vfc4r0,vfc4r1
readf,1,solar_Y,solar_Z
scposition=''
readf,1,scposition
housekeeping=''
readf,1,housekeeping
acquisition=''
readf,1,acquisition
built=''
readf,1,built
swversion=''
readf,1,swversion
readf,1

; branch into three cases, or give error message
if (lyrahead eq 1) then goto,head1
if (lyrahead eq 2) then goto,head2
if (lyrahead eq 3) then goto,head3
print,'ERROR in file '+filename_in
print,'LYRA Head must be 1, 2, or 3'
goto,fin

; ------------------------------------------------------------------------------
; Calibration Head 1
```

```
; ----------------------------------------------------------------------------
head1:
; TBD
goto,fin

; ----------------------------------------------------------------------------
; Calibration Head 2
; ----------------------------------------------------------------------------
head2:
filename_out=strmid(filename_in,0,21)+'lev2_v'+version+'.txt'

; print lev2 file header
openw,2,filename_out
printf,2,filename_out
printf,2,' '
printf,2,strtrim(string(lyrahead),2)+'                         : LYRA head'
printf,2,strtrim(string(solar_Y),2)+' '+strtrim(string(solar_Z),2)+'         : pointing Y/arcsec
Z/arcsec'
printf,2,scposition
printf,2,housekeeping
printf,2,acquisition
printf,2,built+' (level 1)
printf,2,'2008.05.14T14.27.00 IED  : built date, place (level 2)
printf,2,swversion+' (level 1)
printf,2,version+'                       : software version (level 2)
printf,2,' '

d1=double(0)
d2=long(0)
d3=long(0)
d4=long(0)
d5=long(0)
d6=long(0)
d7=long(0)
while (not eof(1)) do begin
; read lev1 file line by line
 readf,1,d1,d2,d3,d4,d5,d6,d7
 c1=strtrim(string(d1),2)
; calculate lev2 file line by line:
; transform counts into frequency/kHz using integration time/ms
 c3=double(d3)/float(d7)
 c4=double(d4)/float(d7)
 c5=double(d5)/float(d7)
 c6=double(d6)/float(d7)
; transform frequency into tension/V using VFC parameters
 c3=vfc1r0+vfc1r1*c3
 c4=vfc2r0+vfc2r1*c4
 c5=vfc3r0+vfc3r1*c5
 c6=vfc4r0+vfc4r1*c6
; transform tension into current/nA using resistance/GigaOhm
 c3=c3/(1.037*10.)
 c4=c4/0.1969
 c5=c5/1.016
 c6=c6/(1.030*10.)
; transform current into solar irradiance/(W/m^2) according to
; "LYRA Calibration Methods" report, cf.
; http://solwww.oma.be/users/dammasch/IED_20080407_LYRA_Calibration_Methods.pdf
; In parallel, it is tested if total, pure, or solar signal values are:
; - within usual sample interval (0) = no warning
; - within extended interval     (1) = warning
; - out of extendes interval     (2) = implausible
; - negative                     (3) = impossible
; according to "LYRA OUTPUT: Expected Variations" report, cf.
; http://solwww.oma.be/users/dammasch/IED_20080416_LYRA_Expected_Variations.pdf
; The 4 warning digits for the 4 channels appear to the right of the calibrated
; value columns.
; channel 2-1
  warn1=0
  ch21tot=c3
  if (ch21tot lt 0.) then begin
   ch21sol=0.
```

```
    warn1=3
    goto,ch21fin
    endif
   if ((ch21tot lt 0.103) or (ch21tot gt 0.122)) then warn1=1
   if ((ch21tot lt 0.081) or (ch21tot gt 0.145)) then warn1=2
   ch21res=0.0671988+0.118280*ch21tot
   ch21pur=ch21tot-ch21res
   if (ch21pur lt 0.) then begin
    ch21sol=0.
    warn1=3
    goto,ch21fin
    endif
   if ((ch21pur lt 0.024) or (ch21pur gt 0.040)) then warn1=(1>warn1)
   if ((ch21pur lt 0.016) or (ch21pur gt 0.048)) then warn1=2
   ch21sol=0.237986*ch21pur
   if (ch21sol lt 0.) then begin
    ch21sol=0.
    warn1=3
    goto,ch21fin
    endif
   if ((ch21sol lt 0.0056) or (ch21sol gt 0.0096)) then warn1=(1>warn1)
   if ((ch21sol lt 0.0036) or (ch21sol gt 0.0116)) then warn1=2
   ch21fin:
   c3=ch21sol
; channel 2-2
   warn2=0
   ch22tot=c4
   if (ch22tot lt 0.) then begin
    ch22sol=0.
    warn2=3
    goto,ch22fin
    endif
   if ((ch22tot lt 11.232) or (ch22tot gt 13.728)) then warn2=1
   if ((ch22tot lt  9.982) or (ch22tot gt 14.972)) then warn2=2
   ch22res=0.162210*ch22tot
   ch22pur=ch22tot-ch22res
   if (ch22pur lt 0.) then begin
    ch22sol=0.
    warn2=3
    goto,ch22fin
    endif
   if ((ch22pur lt 9.408) or (ch22pur gt 11.498)) then warn2=(1>warn2)
   if ((ch22pur lt 8.362) or (ch22pur gt 12.544)) then warn2=2
   ch22sol=0.0453664*ch22pur
   if (ch22sol lt 0.) then begin
    ch22sol=0.
    warn2=3
    goto,ch22fin
    endif
   if ((ch22sol lt 0.4268) or (ch22sol gt 0.5216)) then warn2=(1>warn2)
   if ((ch22sol lt 0.3794) or (ch22sol gt 0.5690)) then warn2=2
   ch22fin:
   c4=ch22sol
; channel 2-3
   warn3=0
   ch23tot=c5
   if (ch23tot lt 0.) then begin
    ch23sol=0.
    warn3=3
    goto,ch23fin
    endif
   if ((ch23tot lt 0.059) or (ch23tot gt 6.785)) then warn3=1
   if ((ch23tot lt 0.030) or (ch23tot gt 13.570)) then warn3=2
   t23=[0.0589362,0.154173, 0.163001, 0.227546,1.37035,3.05886,6.78451]
   r23=[0.0226362,0.0553156,0.0605590,0.125110,1.23801,2.97598,6.38711]
   ch23res=interpol(r23,t23,ch23tot)
   ch23pur=ch23tot-ch23res
   if (ch23pur lt 0.) then begin
    ch23sol=0.
    warn3=3
    goto,ch23fin
```

```
    endif
   if ((ch23pur lt 0.036) or (ch23pur gt 0.397)) then warn3=(1>warn3)
   if ((ch23pur lt 0.018) or (ch23pur gt 0.794)) then warn3=2
   p23=[0.0363000, 0.0828718, 0.0988576, 0.102436,  0.102442,  0.132347,  0.397402]
   s23=[0.00131051,0.00340476,0.00362499,0.00394254,0.00376518,0.00570166,0.0111131]
   ch23sol=interpol(s23,p23,ch23pur)
   if (ch23sol lt 0.) then begin
    ch23sol=0.
    warn3=3
    goto,ch23fin
    endif
   if ((ch23sol lt 0.0013) or (ch23sol gt 0.0111)) then warn3=(1>warn3)
   if ((ch23sol lt 0.0007) or (ch23sol gt 0.0222)) then warn3=2
   ch23fin:
   c5=ch23sol
; channel 2-4
   warn4=0
   ch24tot=c6
   if (ch24tot lt 0.) then begin
    ch24sol=0.
    warn4=3
    goto,ch24fin
    endif
   if ((ch24tot lt 0.045) or (ch24tot gt 3.797)) then warn4=1
   if ((ch24tot lt 0.023) or (ch24tot gt 7.594)) then warn4=2
   ch24res=0.000639421
   ch24pur=ch24tot-ch24res
   if (ch24pur lt 0.) then begin
    ch24sol=0.
    warn4=3
    goto,ch24fin
    endif
   if ((ch24pur lt 0.044) or (ch24pur gt 3.796)) then warn4=(1>warn4)
   if ((ch24pur lt 0.022) or (ch24pur gt 7.592)) then warn4=2
   p24=[0.0440140, 0.0469921, 0.0746944, 0.0829392, 0.582767, 2.39874,  3.79595]
   s24=[0.00198338,0.00208323,0.00261203,0.00267627,0.0132763,0.0659849,0.0975310]
   ch24sol=interpol(s24,p24,ch24pur)
   if (ch24sol lt 0.) then begin
    ch24sol=0.
    warn4=3
    goto,ch24fin
    endif
   if ((ch24sol lt 0.0020) or (ch24sol gt 0.0975)) then warn4=(1>warn4)
   if ((ch24sol lt 0.0010) or (ch24sol gt 0.1950)) then warn4=2
   ch24fin:
   c6=ch24sol
   warn1=strtrim(string(warn1),2)
   warn2=strtrim(string(warn2),2)
   warn3=strtrim(string(warn3),2)
   warn4=strtrim(string(warn4),2)
   wmessage=' W:'+warn1+warn2+warn3+warn4
; print lev2 file line by line
 printf,2,c1,fix(d2),float(c3),float(c4),float(c5),float(c6),wmessage
 endwhile
goto,fin

; ---------------------------------------------------------------------------
; Calibration Head 3
; ---------------------------------------------------------------------------
head3:
; TBD
goto,fin

fin:
close,1 & close,2
end
```