LYRA Calibration Software

IED, 25 Oct 2006, rev. 21 Sep 2007

In an earlier report (*IED_20060818_LYRA_Radiometric.pdf*), it was considered how to calculate the solar signal (in absolute physical units, e.g., W m-2) from its corresponding LYRA channel output (e.g., converted to A). It was argued that this estimation must involve the (potentially variable) purity, the (constant) aperture size, and a factor (linear or else) that combines the integrals of filter transmittance and detector responsivity in the spectral interval of interest.

Simulations showed the following: For the Lyman-alpha channels (*-1), purity grows with irradiance. For the Herzberg channels (*-2), purities and resulting calibration factors appear to be constant. For the Aluminium channels (*-3), purity varies heavily with irradiance. For the Zirconium channels (*-4), purity appears to be constant but responsivity grows with irradiance.

The question was asked if one could use the LYRA channel signal itself to calculate calibration factors that depend on the signal strength, maybe in a non-linear way. This was discussed at the LYRA meeting in Davos (05/06 Oct 2006) on the basis of the information shown in Figure 0. It was suggested to try and use information from *other* LYRA channels instead, in order to enhance the purity of certain problematic channels. In particular, it is clearly visible from the spectral responsivities of the Lyman-alpha channels that they are influenced by the neighbouring longer-wavelength continuum around 180-230 nm. Likewise, it is visible that the spectral responsivities of the Aluminium channels are influenced by the neighbouring shorter-wavelength signals around 1-10 nm. Since these disturbing signals are in fact observed and measured by LYRA via the Herzberg and Zirconium channels, respectively, it was suggested to subtract these signals in an appropriate way.

In the following, I suggest an attempt for procedures and resulting software for all twelve LYRA channels. First, in Figures 1-1 etc., the measured combined responsivity is graphically presented for each channel together with seven simulated spectral output signals. These signals were simulated with the help of TIMED/SEE spectral data sets called “min”, “high”, “max”, “pre1”, “fla1”, “pre2”, and “fla2”, taken on different days and representing a variety of solar irradiances to be expected. A longer-wavelength extension concerning wavelengths above ~200 nm was added to the TIMED/SEE data sets; this extension does not vary. - Below these figures, the simulated values for the LYRA end signals are shown in a table: the “total” expected output signal, the “pure” signal of interest (defined by the nominal spectral interval of the channel), and the resulting “residual” difference signal (all in nA), together with the “solar” signal, i.e. the integrated input from the TIMED/SEE interval of interest (in W m-2). - Subsequently, methods are suggested to calculate the latter from the former.

The procedures suggested here are solely based on the seven data sets mentioned above, plus the assumption that zero solar input should lead to zero LYRA output. As soon as the assumed models look “reasonable”, linear interpolation between data points is suggested (channels *-3 and *-4) instead of assuming higher-order polynomial or exponential functions in the case of sublinear or superlinear relations. In the other cases, simple linear factors can be used (channels *-1 and *-2).

Figures 1-1a etc. show the relations between total or pure LYRA signals to the solar signal in the upper row, as well as the relation between the channel signal or – where applicable – the neighbouring channel signal and the residual signal in the lower row. The arguments are similar for all three heads (only the values vary), but different for all four channels.

In the case of higher values in the Aluminium channels (*-3), where more than 90% contamination have to be estimated and subtracted, the success appears doubtful, and the initial approach may be suggested, namely, using the signal of the channel itself (instead of the neighbouring channel) to deduce the pure signal.

The seven TIMED/SEE samples used for the simulations are the following:

min	24 Feb 2005	solar minimum
high	11 Nov 2003	high solar flux
max	28 Oct 2003	solar maximum
pre1	28 Oct 2003	before X17 flare
fla1	28 Oct 2003	briefly after X17 flare
pre2	03 Nov 2003	before X3.9 flare
fla2	03 Nov 2003	briefly after X3.9 flare

According to my information, these observations are "modeled" below 27 nm. - For the wavelength range above 193 nm up to 1 mm, spectral values from another source were added, identically for all seven samples.

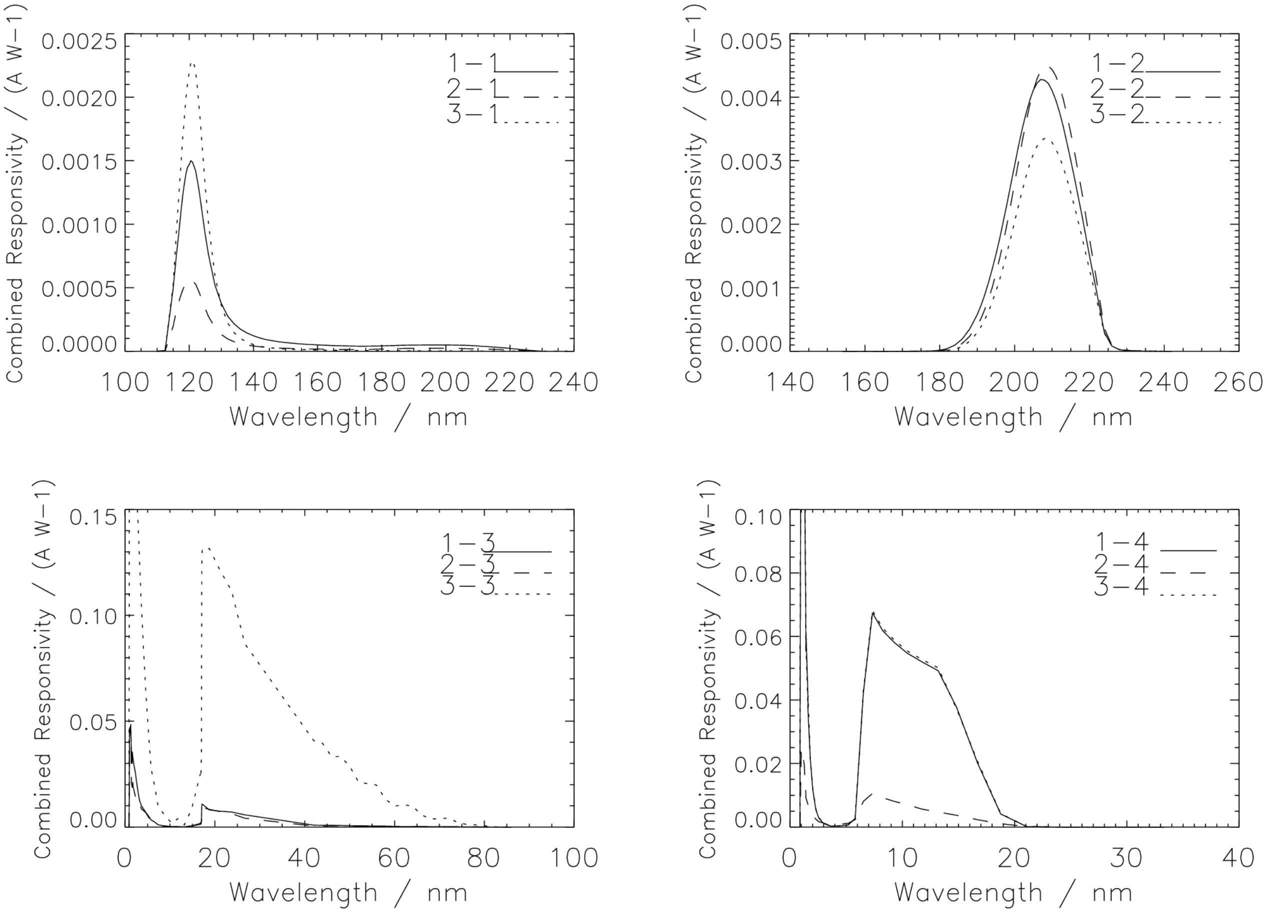

Figure 0. LYRA channel responsivities as presented at the Davos meeting: Combination of filter and detector effects measured as a function of wavelength. *-1 = Lyman-alpha channels, *-2 = Herzberg channels, *-3 = Aluminium channels, *-4 = Zirconium channels.

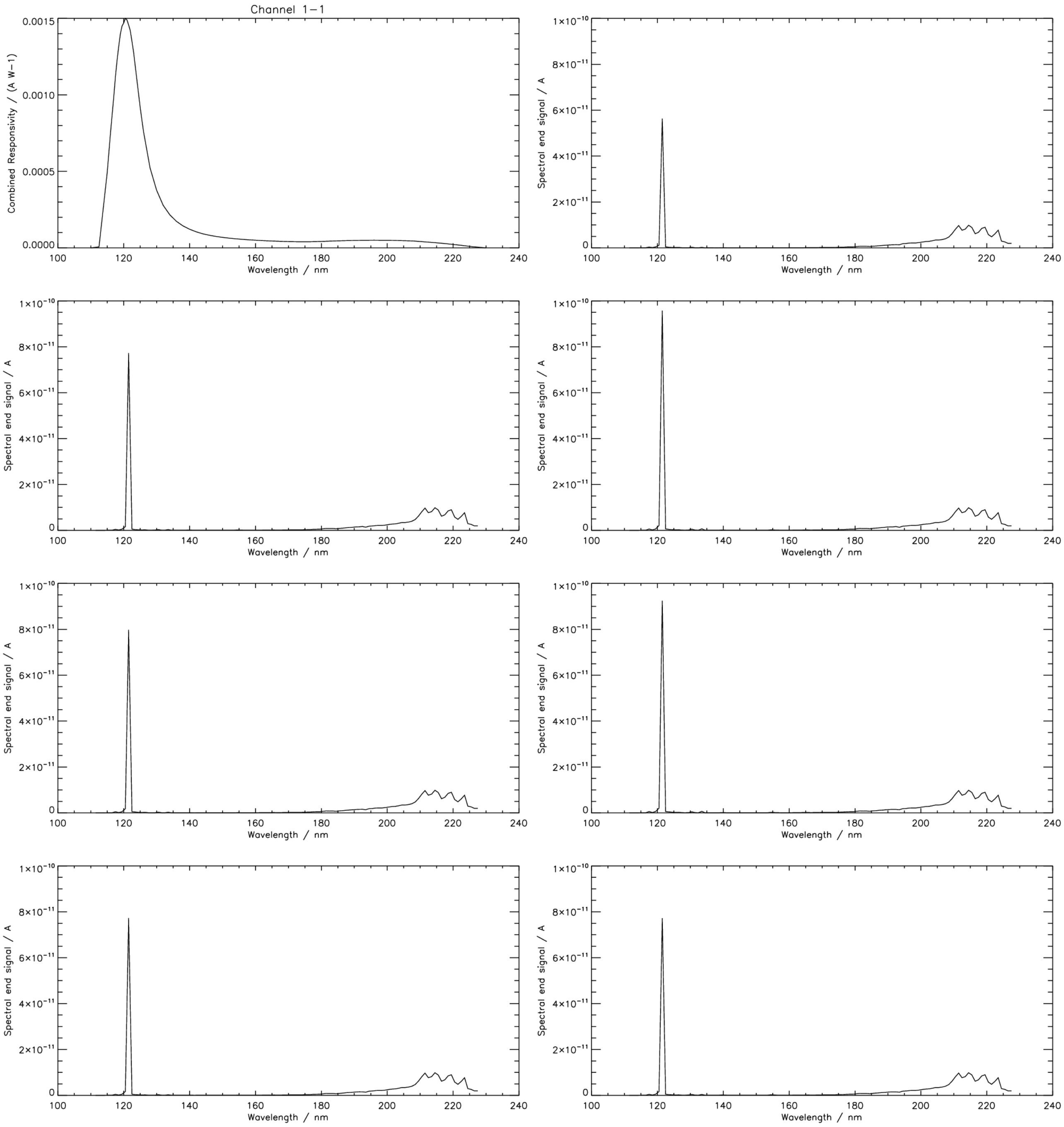

Figure 1-1. Measured responsivity and simulated output for LYRA channel 1-1
Ly XN + MSM12 (121.5 +/- nm)

```
sample  total        pure                  residual      solar
------  -----------  --------------------  -----------   ---------------
min     0.244548 nA  0.0578922 nA (23.7%)  0.186656 nA   0.00564762 Wm-2
high    0.270879 nA  0.0794356 nA (29.3%)  0.191444 nA   0.00774904 Wm-2
max     0.291520 nA  0.0985021 nA (33.8%)  0.193018 nA   0.00960818 Wm-2
pre1    0.271306 nA  0.0820728 nA (30.3%)  0.189233 nA   0.00800550 Wm-2
fla1    0.286160 nA  0.0951399 nA (33.2%)  0.191020 nA   0.00928009 Wm-2
pre2    0.268673 nA  0.0794669 nA (29.6%)  0.189207 nA   0.00775156 Wm-2
fla2    0.269712 nA  0.0793984 nA (29.4%)  0.190313 nA   0.00774487 Wm-2
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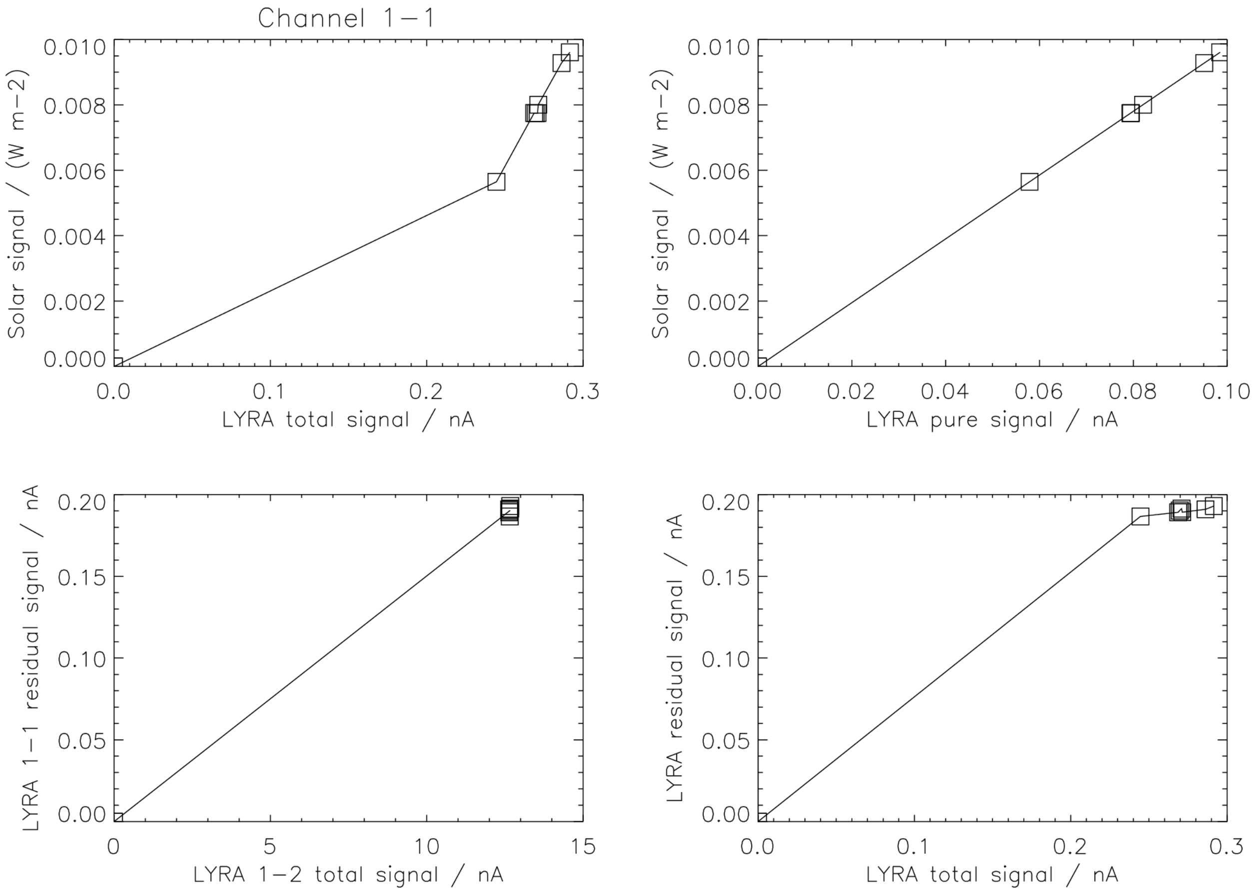

Figure 1-1a. Simulated relations between input and output for LYRA channel 1-1.

The functional relation between the solar signal and the LYRA total signal is obviously not straightforward (see upper left image). The reason is a contamination due to the influence of the interval 180-230 nm, which is not part of the nominal interval around the Lyman-alpha line. But this residual signal can obviously be estimated with the help of the output signal from LYRA channel 1-2 in a simple way (see lower left image):
*[LYRA 1-1 residual signal / nA] = 0.0150318 * [LYRA 1-2 total signal / nA]*
On the other hand, it can also be estimated as a linear function of the total signal from LYRA channel 1-1 itself, at least above 0.24 nA (see lower right image):
*[LYRA 1-1 residual signal / nA] = 0.156740 + 0.122803 * [LYRA 1-1 total signal / nA]*
Both variants will be tested in the commissioning phase, before one will eventually be selected.

The pure signal can be estimated as the difference:
[LYRA 1-1 pure signal / nA] = [LYRA 1-1 total signal / nA] – [LYRA 1-1 residual signal / nA]

And the solar signal can again be estimated from the pure signal in a simple way (see upper right image):
*[“Lyman-alpha” solar signal / (W m-2)] = 0.0975457 * [LYRA 1-1 pure signal / nA]*

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three TIMED/SEE data points (120.5, 121.5, and 122.5 nm), of which only 121.5 nm is significant. This means that the simulation is essentially based on one value; a small variation of the nominal interval would not lead to different simulation results. - Due to the simple linear factors, the estimation error is within 6.1% for the first variant, and 1.8% for the second.

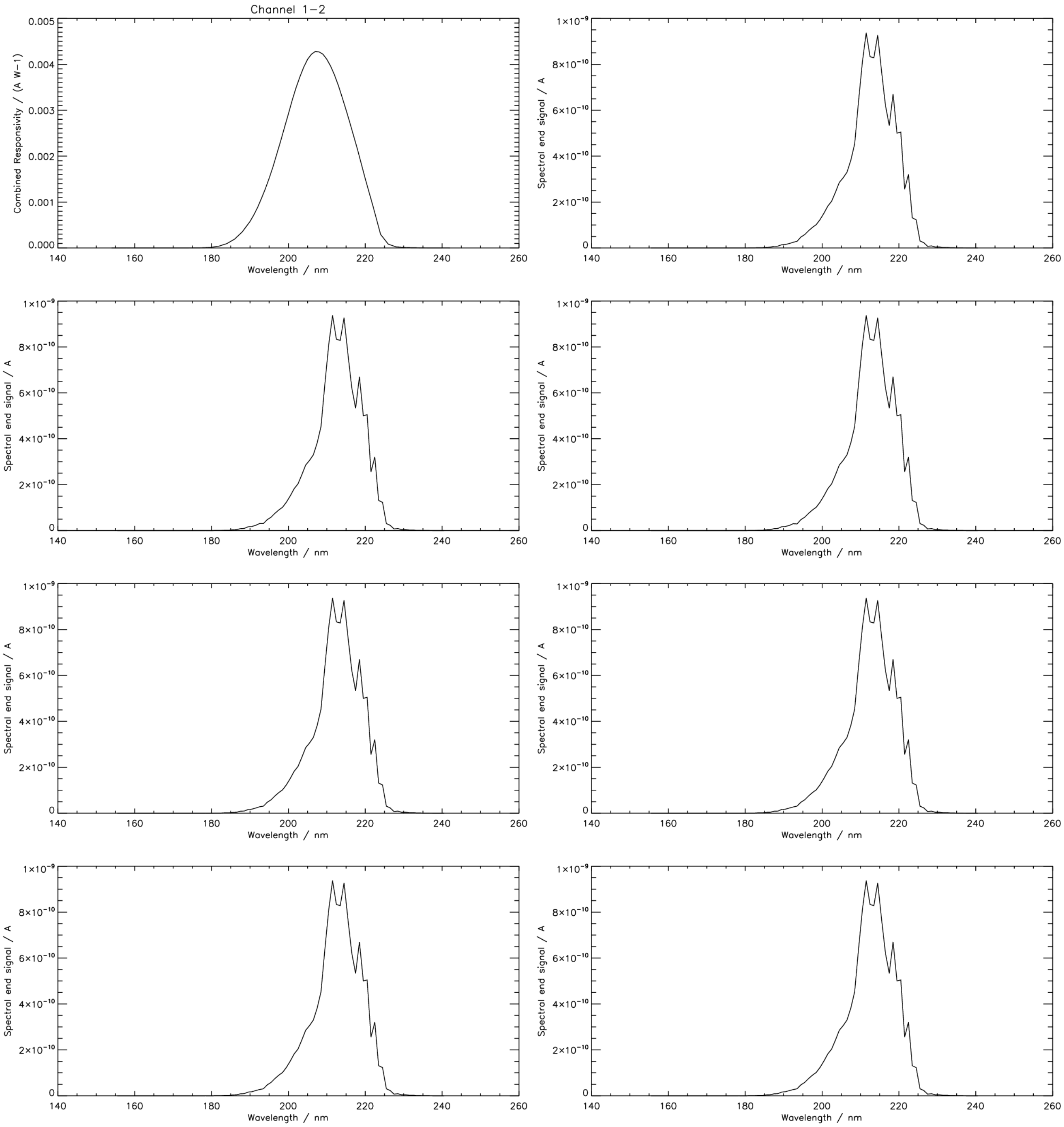

Figure 1-2. Measured responsivity and simulated output for LYRA channel 1-2
Herzberg + PIN10 (200-220 nm)

```
sample  total       pure                  residual     solar
------  ----------  ------------------    ----------   ------------
min     12.6509 nA  10.6056 nA (83.8%)    2.04531 nA   0.474210 Wm-2
high    12.6712 nA  10.6056 nA (83.7%)    2.06564 nA   0.474210 Wm-2
max     12.6694 nA  10.6056 nA (83.7%)    2.06385 nA   0.474210 Wm-2
pre1    12.6366 nA  10.6056 nA (83.9%)    2.03107 nA   0.474210 Wm-2
fla1    12.6357 nA  10.6056 nA (83.9%)    2.03014 nA   0.474210 Wm-2
pre2    12.6374 nA  10.6056 nA (83.9%)    2.03186 nA   0.474210 Wm-2
fla2    12.6369 nA  10.6056 nA (83.9%)    2.03136 nA   0.474210 Wm-2
```

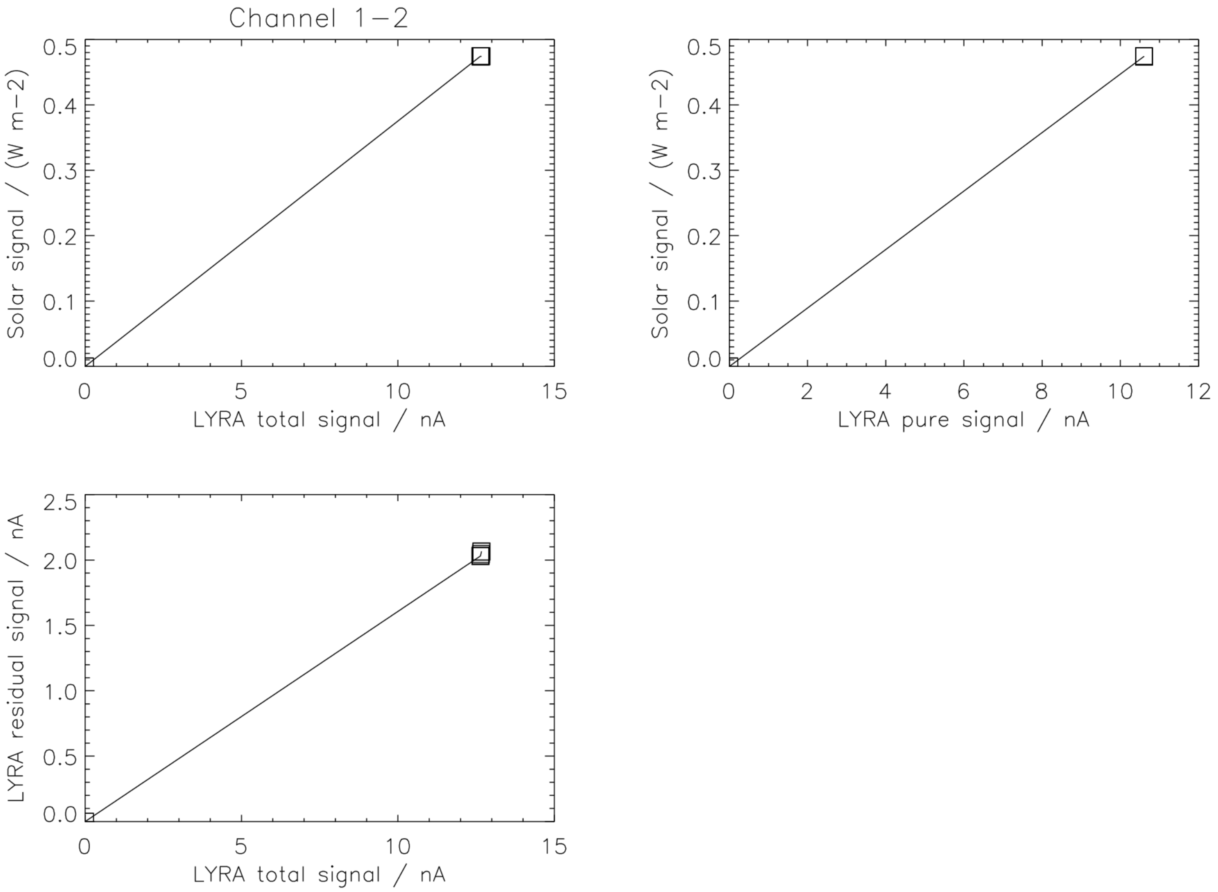

Figure 1-2a. Simulated relations between input and output for LYRA channel 1-2.

The functional relation between the solar signal and the LYRA total signal looks straightforward at first sight. The pure signal or the residual signal can simply be estimated by a linear factor (see table last page). Following the scheme of channel 1-1, the residual signal is calculated as:
*[LYRA 1-2 residual signal / nA] = 0.161499 * [LYRA 1-2 total signal / nA]*

The pure signal can be estimated as the difference:
[LYRA 1-2 pure signal / nA] = [LYRA 1-2 total signal / nA] – [LYRA 1-2 residual signal / nA]

And the solar signal can be estimated from the pure signal in a simple way (see upper right image):
*[“Herzberg” solar signal / (W m-2)] = 0.0447132 * [LYRA 1-2 pure signal / nA]*

Remarks: The estimate is actually only based on one sample instead of three, because the TIMED/SEE data extensions above 200 nm are identical. - If other limits of the nominal interval were chosen, the purity could naturally be improved (rough estimates):
200 – 220 nm => 84 % purity, 197 – 223 nm => 95 % purity, 195 – 225 nm => 98 % purity,
190 – 230 nm => 99.5 % purity, 180 – 230 nm => 99.9 % purity.

Despite the simple linear factors, the estimation error is within 0.2%. But since the estimates are based on identical spectra above 200 nm, this is probably unrealistic.

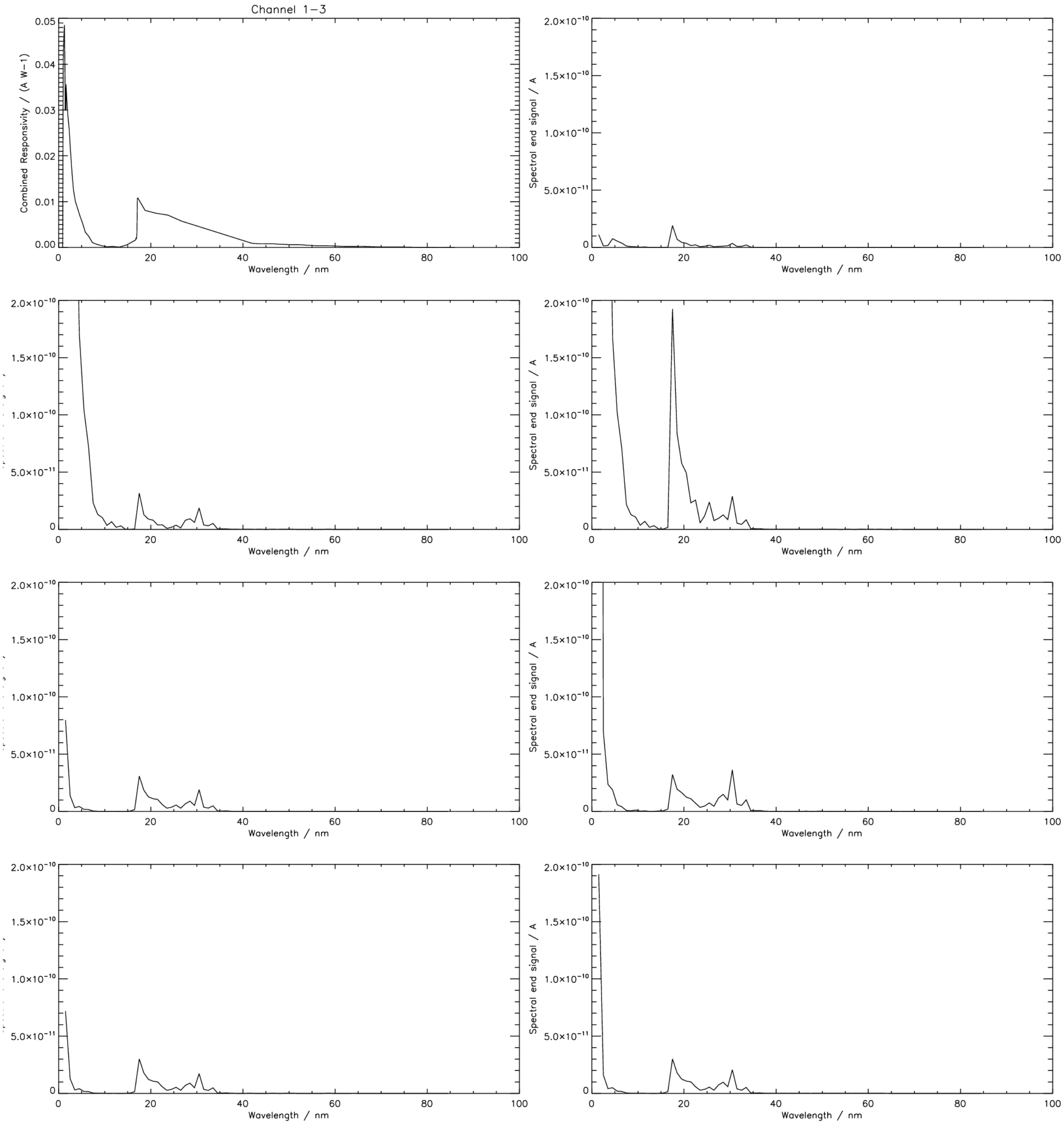

Figure 1-3. Measured responsivity and simulated output for LYRA channel 1-3 Aluminium + MSM11 (17-80 nm)

```
sample  total         pure                  rest          solar
------  ------------  --------------------  ------------  ---------------
min     0.0884238 nA  0.0540079 nA (61.1%)  0.0344159 nA  0.00131051 Wm-2
high    5.31929   nA  0.134685  nA ( 2.5%)  5.18460   nA  0.00340476 Wm-2
max     11.9076   nA  0.563424  nA ( 4.7%)  11.3442   nA  0.0111131  Wm-2
pre1    0.265421  nA  0.158384  nA (59.7%)  0.107037  nA  0.00376518 Wm-2
fla1    2.43881   nA  0.218661  nA ( 9.0%)  2.22015   nA  0.00570166 Wm-2
pre2    0.250350  nA  0.152666  nA (61.0%)  0.0976836 nA  0.00362499 Wm-2
fla2    0.383334  nA  0.160404  nA (41.8%)  0.222930  nA  0.00394254 Wm-2
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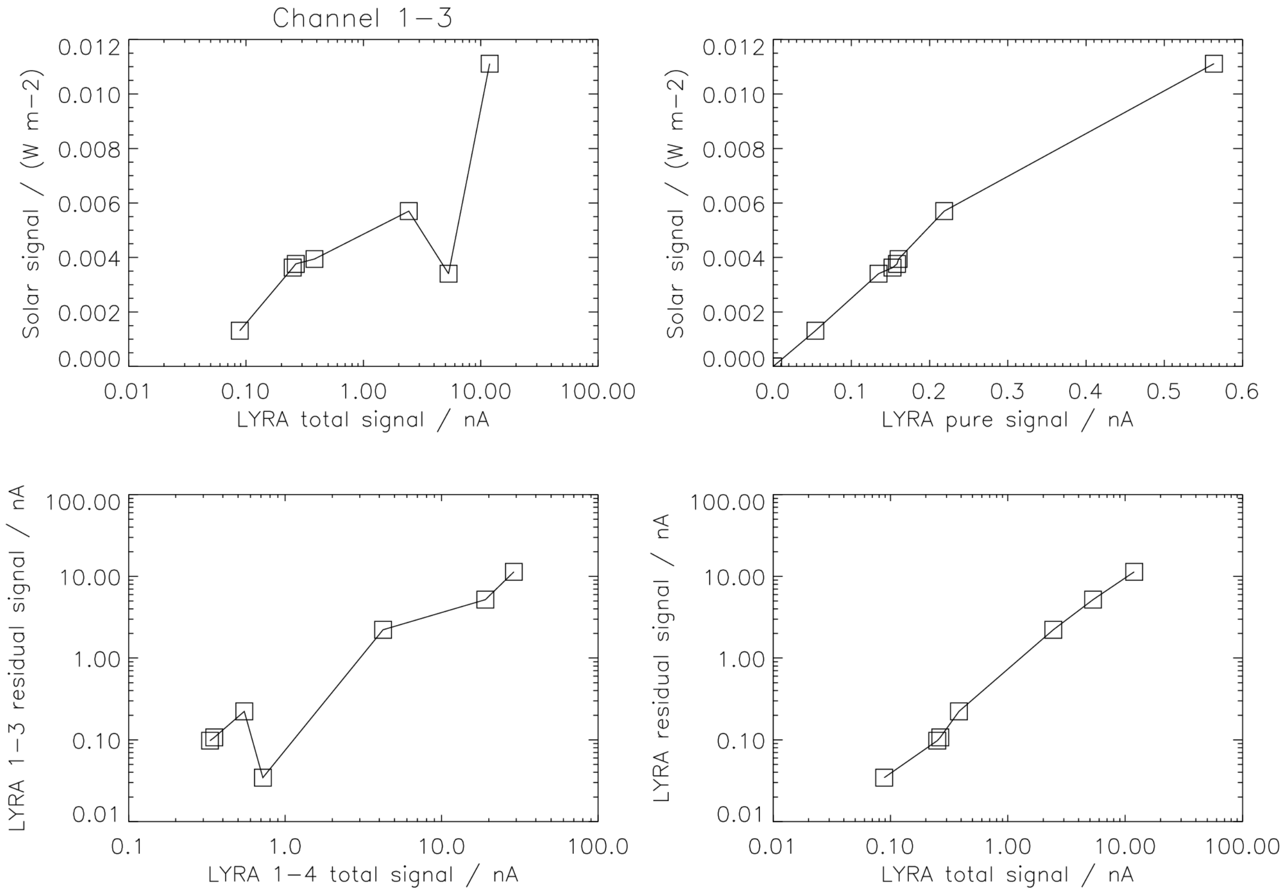

Figure 1-3a. Simulated relations between input and output for LYRA channel 1-3.

The functional relation between the solar signal and the LYRA total signal is obviously not straightforward (rather zigzag, see upper left image). The reason is a contamination due to the influence of the interval 1-10 nm, which is not part of the 17-80 nm nominal interval of the "Aluminium" channels. This residual signal can possibly be estimated with the help of the output signal from LYRA channel 1-4; not as simple as in the case of channel 1-1, but with linear interpolation between the points of a relationship as visible in the lower left image:

[LYRA 1-3 residual signal / nA] = interp[LYRA 1-4 total signal / nA]

On the other hand, it can also be estimated as an almost linear function of the total signal from LYRA channel 1-3 itself (see lower right image):

[LYRA 1-3 residual signal / nA] = interp[LYRA 1-3 total signal / nA]

Both variants will be tested in the commissioning phase, before one will eventually be selected.

The pure signal can be estimated as the difference:

[LYRA 1-3 pure signal / nA] = [LYRA 1-3 total signal / nA] – [LYRA 1-3 residual signal / nA]

And the solar signal can be estimated from the pure signal, again not in a simple way but with linear interpolation between the points of a slightly sublinear relationship as visible in the upper right image:

["Aluminium" solar signal / (W m-2)] = interp[LYRA 1-3 pure signal / nA]

Remarks: Although the channel interval nominally reaches up to 80 nm, effectively it appears to end at 35 nm (see Figure 1-3). - If a large subset of these channels' solar signal is similar to the "high" or "max" simulation data, then the uncalibrated data (before subtraction of the substantial short-wavelength contamination) will probably not be very meaningful. - Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

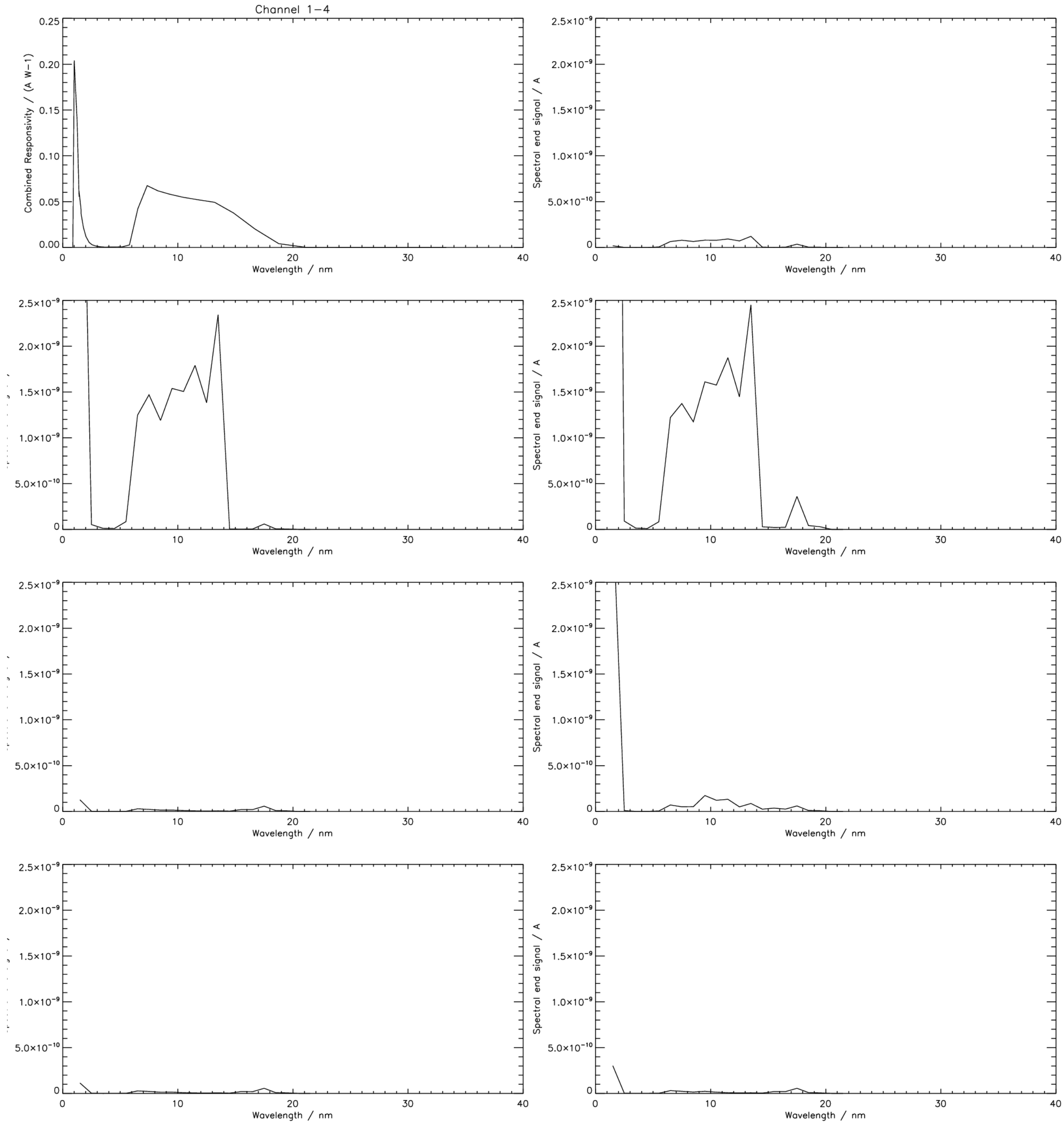

Figure 1-4. Measured responsivity and simulated output for LYRA channel 1-4
Zr(300nm) + AXUV20D (1-20 nm)

```
sample  total        pure                     rest              solar
------  -----------  ------------------       --------------    ---------------
min     0.720131 nA  0.720074 nA (100.%)      0.000057676 nA    0.00267627 Wm-2
high    19.0501  nA  19.0500  nA (100.%)      0.000131450 nA    0.0659849  Wm-2
max     28.9357  nA  28.9349  nA (100.%)      0.000804690 nA    0.0975310  Wm-2
pre1    0.352768 nA  0.352529 nA (99.9%)      0.000239170 nA    0.00208323 Wm-2
fla1    4.22397  nA  4.22371  nA (100.%)      0.000261569 nA    0.0132763  Wm-2
pre2    0.331056 nA  0.330826 nA (99.9%)      0.000229733 nA    0.00198338 Wm-2
fla2    0.547882 nA  0.547651 nA (100.%)      0.000231259 nA    0.00261203 Wm-2
```

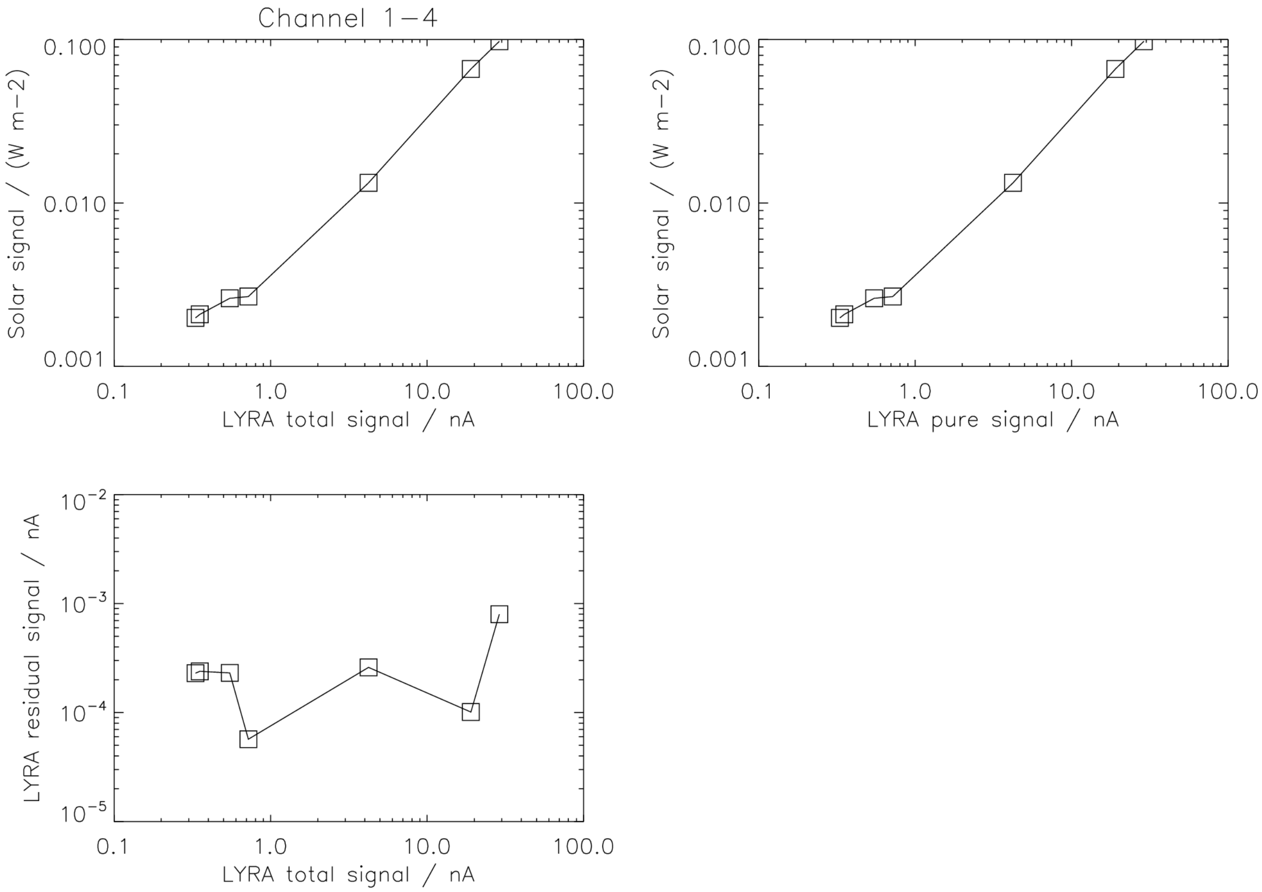

Figure 1-4a. Simulated relations between input and output for LYRA channel 1-4.

The functional relation between the solar signal and the LYRA total signal looks straightforward. Since the purity of the Zirconium channels is always around 100%, the residual signal is negligible (see lower figure) and can simply be set to zero. Following the usual scheme:
[LYRA 1-4 residual signal / nA] = 0

The pure signal can be estimated as the "difference", which is the total signal:
[LYRA 1-4 pure signal / nA] = [LYRA 1-4 total signal / nA] – [LYRA 1-4 residual signal / nA]

And the solar signal can be estimated from the pure signal with linear interpolation between the points of a slightly nonlinear relationship as visible in the upper right image:
["Zirconium" solar signal / (W m-2)] = interp[LYRA 1-4 pure signal / nA]

Remarks: Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

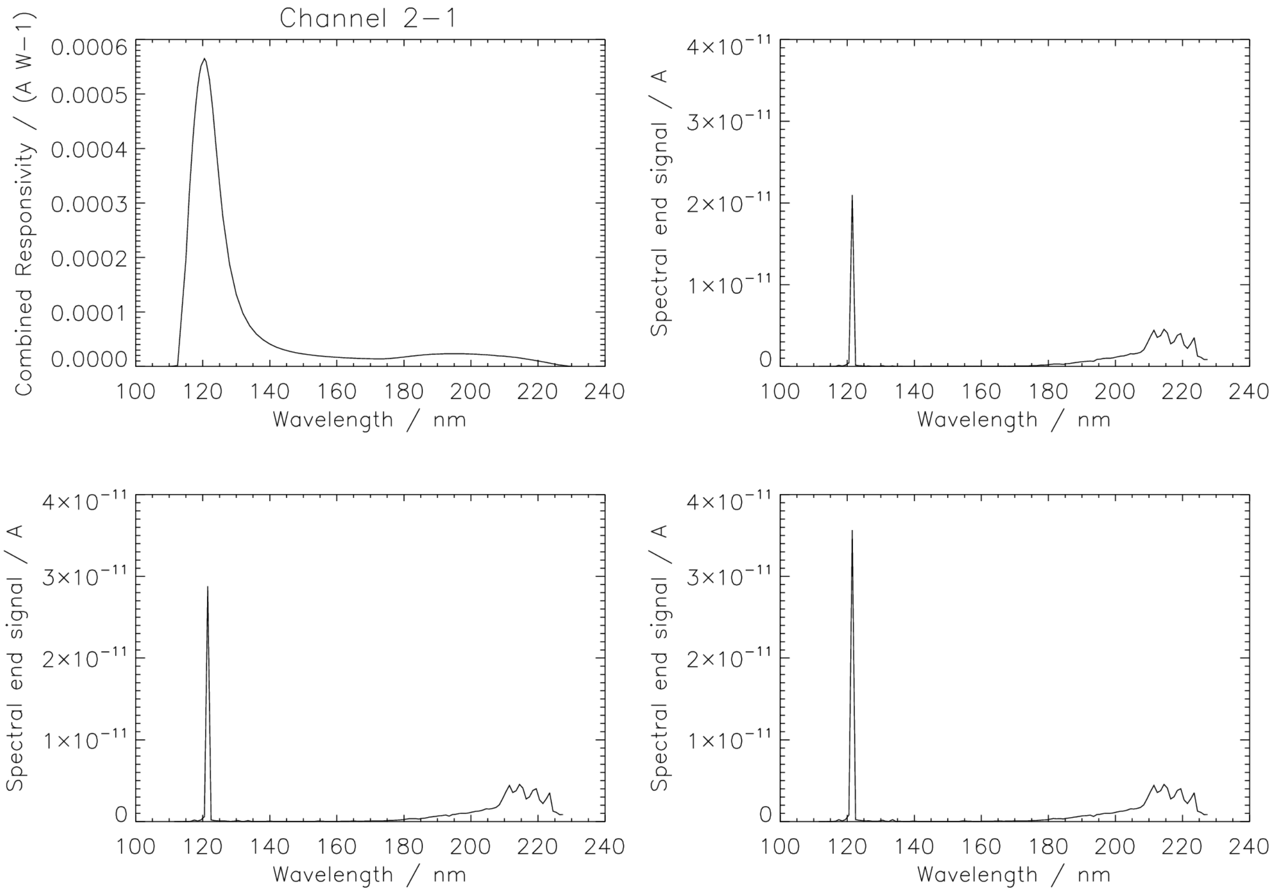

Figure 2-1. Measured responsivity and simulated output (min, high, max) for LYRA channel 2-1.

```
2-1: Ly XN + MSM21  (121.5 +/- nm)

sample  total        pure                   rest          solar
------  -----------  ---------------------  -----------   ---------------
min     0.105615 nA  0.0215646 nA (20.4%)   0.0840500 nA  0.00564762 Wm-2
high    0.115582 nA  0.0295895 nA (25.6%)   0.0859923 nA  0.00774904 Wm-2
max     0.123239 nA  0.0366925 nA (29.8%)   0.0865466 nA  0.00960818 Wm-2
```

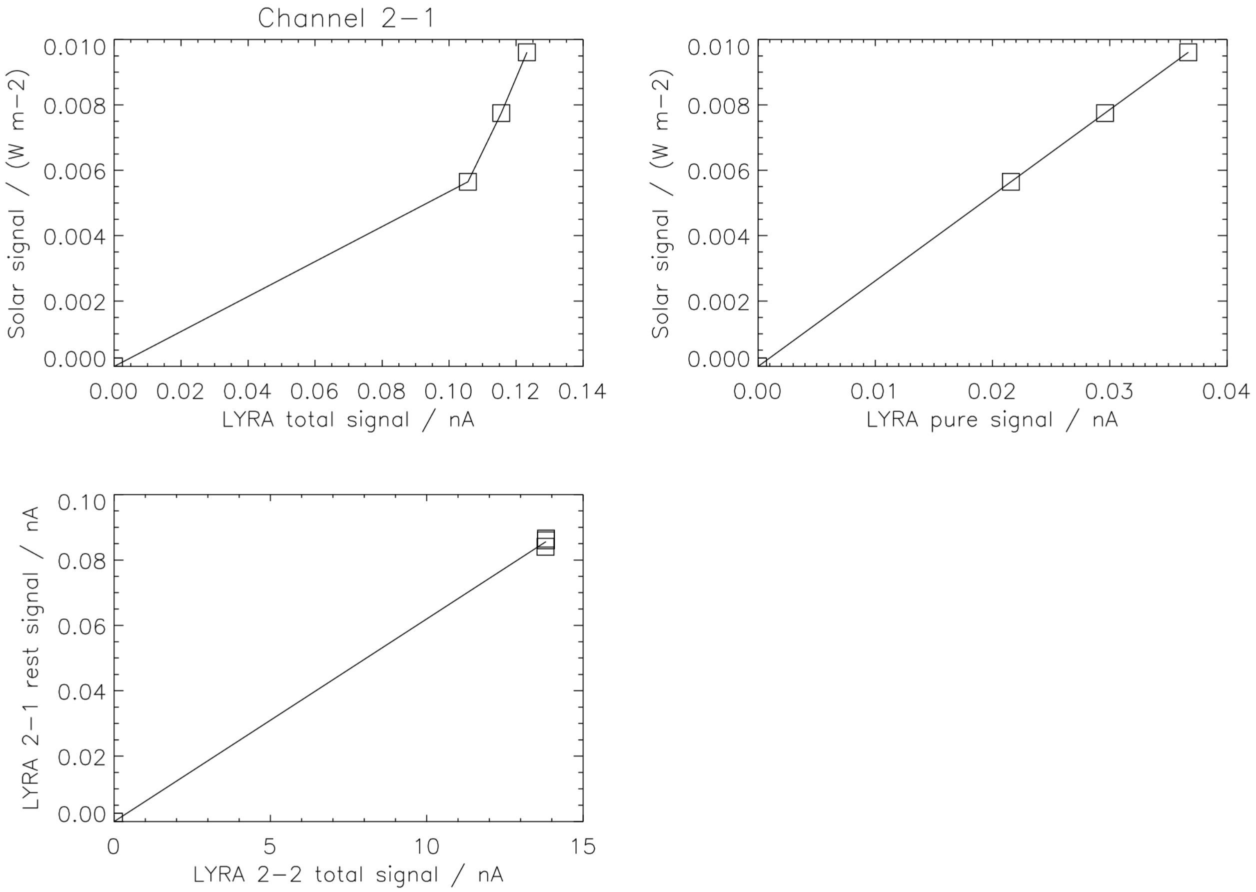

Figure 2-1a. Simulated relations between input and output for LYRA channel 2-1.

The functional relation between the solar signal and the LYRA total signal is obviously not straightforward (see upper left image). The reason is a contamination due to the influence of the interval 180-230 nm, which is not part of the nominal interval around the Lyman-alpha line. But this rest signal can obviously be estimated with the help of the output signal from LYRA channel 2-2 in a simple way (see lower image):
*[LYRA 2-1 rest signal / nA] = 0.0062 * [LYRA 2-2 total signal / nA]*

The pure signal can be estimated as the difference:
[LYRA 2-1 pure signal / nA] = [LYRA 2-1 total signal / nA] – [LYRA 2-1 rest signal / nA]

And the solar signal can again be estimated from the pure signal in a simple way (see upper right image):
*[“Lyman-alpha” solar signal / (W m-2)] = 0.262 * [LYRA 2-1 pure signal / nA]*

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three TIMED/SEE data points (120.5, 121.5, and 122.5 nm), of which only 121.5 nm is significant. This means that the simulation is essentially based on one value; a small variation of the nominal interval would not lead to different simulation results. - Due to the simple linear factors, the estimation error is within +/-6.9%.

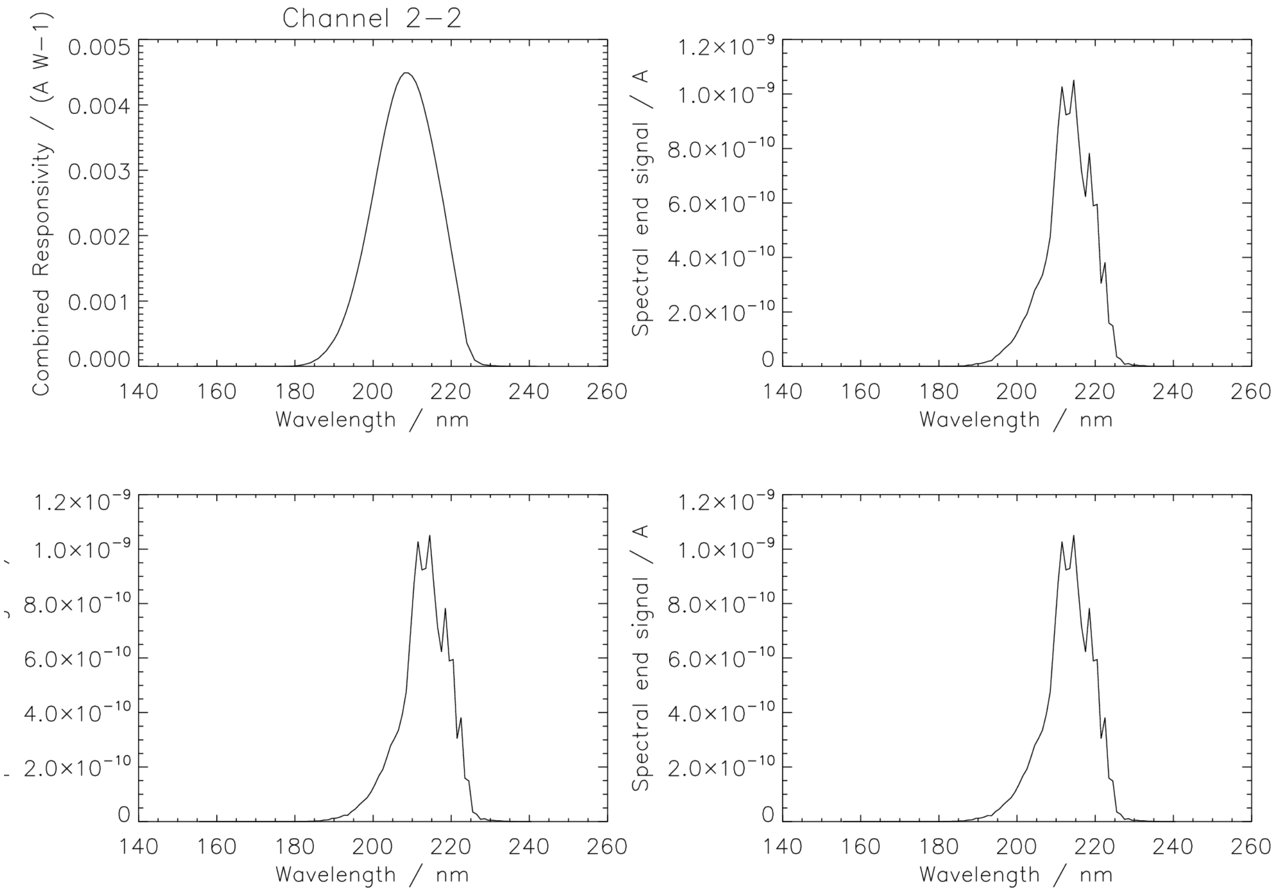

Figure 2-2. Measured responsivity and simulated output (min, high, max) for LYRA channel 2-2.

```
2-2: Herzberg + PIN11  (200-220 nm)

sample  total       pure                rest        solar
------  ----------  ------------------  ----------  -------------
min     13.7981 nA  11.5975 nA (84.1%)  2.20060 nA  0.474210 Wm-2
high    13.8125 nA  11.5975 nA (84.0%)  2.21499 nA  0.474210 Wm-2
max     13.8111 nA  11.5975 nA (84.0%)  2.21360 nA  0.474210 Wm-2
```

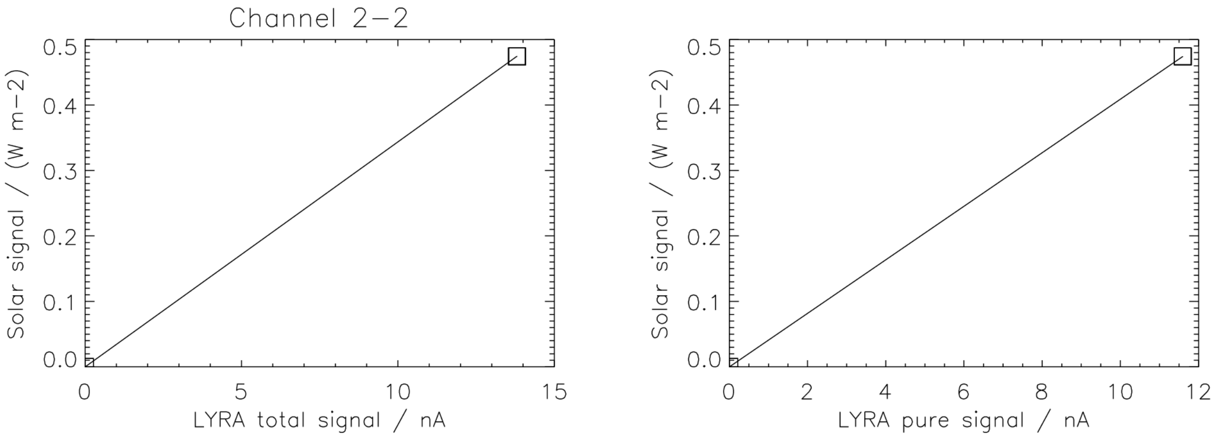

Figure 2-2a. Simulated relations between input and output for LYRA channel 2-2.

The functional relation between the solar signal and the LYRA total signal looks straightforward at first sight. No rest signal has to be calculated. The pure signal can simply be estimated by a linear factor (see table last page):
*[LYRA 2-2 pure signal / nA] = 0.840 * [LYRA 2-2 total signal / nA]*

And the solar signal can be estimated from the pure signal in a simple way (see upper right image):
*[“Herzberg” solar signal / (W m-2)] = 0.0409 * [LYRA 2-2 pure signal / nA]*

Remarks: The estimate is actually only based on one sample instead of three, because the TIMED/SEE data extensions above 200 nm are identical. - If other limits of the nominal interval were chosen, the purity could naturally be improved (rough estimates):
200 – 220 nm => 84 % purity, 197 – 223 nm => 95 % purity, 195 – 225 nm => 98 % purity,
190 – 230 nm => 99.5 % purity, 180 – 230 nm => 99.9 % purity.

Due to the simple linear factors, the estimation error is within +/-0.1%.

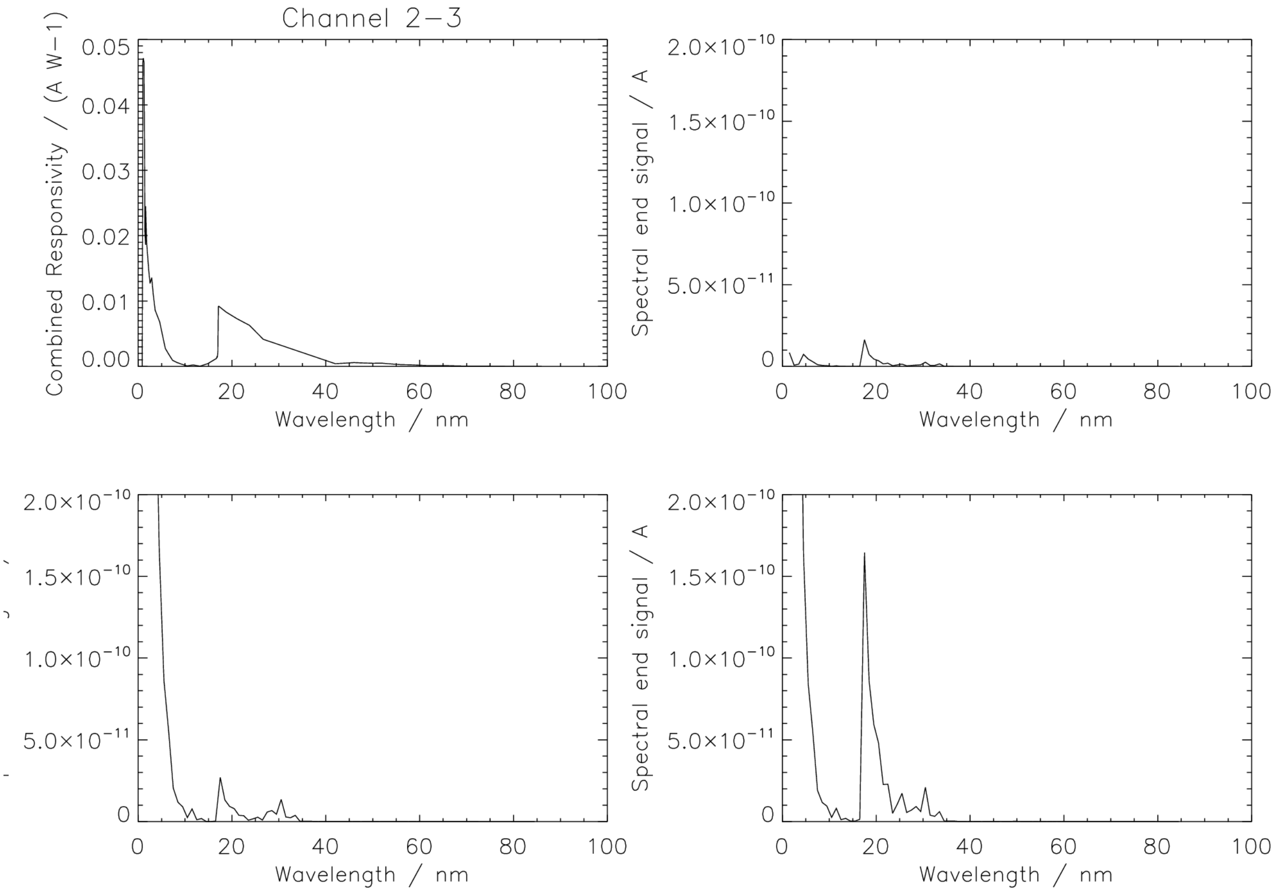

Figure 2-3. Measured responsivity and simulated output (min, high, max) for LYRA channel 2-3.

```
2-3: Aluminium + MSM15  (17-80 nm)

sample  total         pure                    rest          solar
------  ------------  --------------------    ------------  ---------------
min     0.0753576 nA  0.0468343 nA (62.1%)    0.0285233 nA  0.00131051 Wm-2
high    4.06936   nA  0.111929  nA ( 2.8%)    3.95743   nA  0.00340476 Wm-2
max     9.09185   nA  0.500883  nA ( 5.5%)    8.59096   nA  0.0111131  Wm-2
```

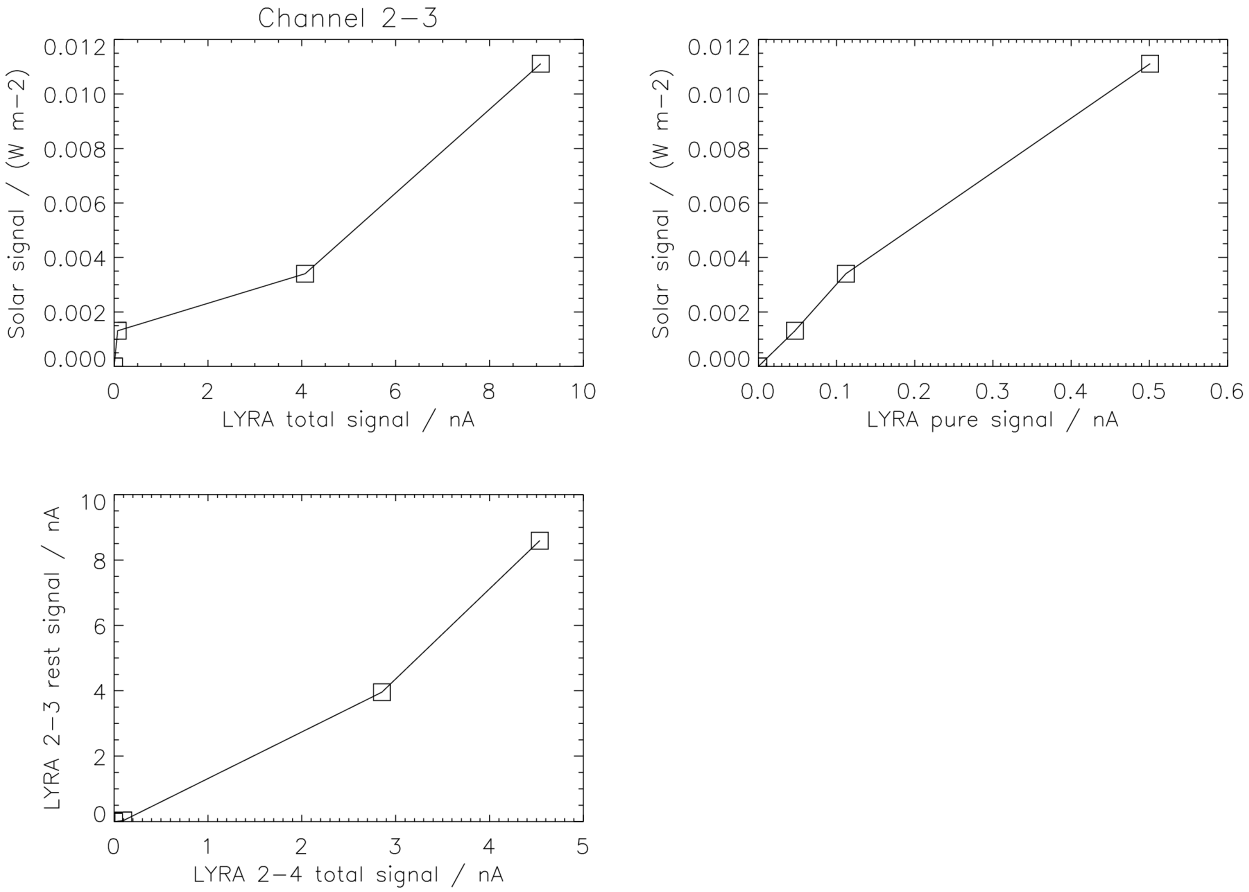

Figure 2-3a. Simulated relations between input and output for LYRA channel 2-3.

The functional relation between the solar signal and the LYRA total signal is obviously not straightforward (rather zigzag, see upper left image). The reason is a contamination due to the influence of the interval 1-10 nm, which is not part of the 17-80 nm nominal interval of the “Aluminium” channels. This rest signal can possibly be estimated with the help of the output signal from LYRA channel 2-4; not as simple as in the other cases, but with linear interpolation between the points of a superlinear relationship as visible in the lower image:
[LYRA 2-3 rest signal / nA] = interp[LYRA 2-4 total signal / nA]

The pure signal can be estimated as the difference:
[LYRA 2-3 pure signal / nA] = [LYRA 2-3 total signal / nA] – [LYRA 2-3 rest signal / nA]

And the solar signal can be estimated from the pure signal, again not in a simple way but with linear interpolation between the points of a slightly sublinear relationship as visible in the upper right image:
[“Aluminium” solar signal / (W m-2)] = interp[LYRA 2-3 pure signal / nA]

Remarks: Although the channel interval nominally reaches up to 80 nm, effectively it appears to end at 35 nm (see Figure 2-3). - If a large subset of these channels' solar signal is similar to the “high” or “max” simulation data, then the uncalibrated data (before subtraction of the substantial short-wavelength contamination) will probably not be very meaningful. - Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

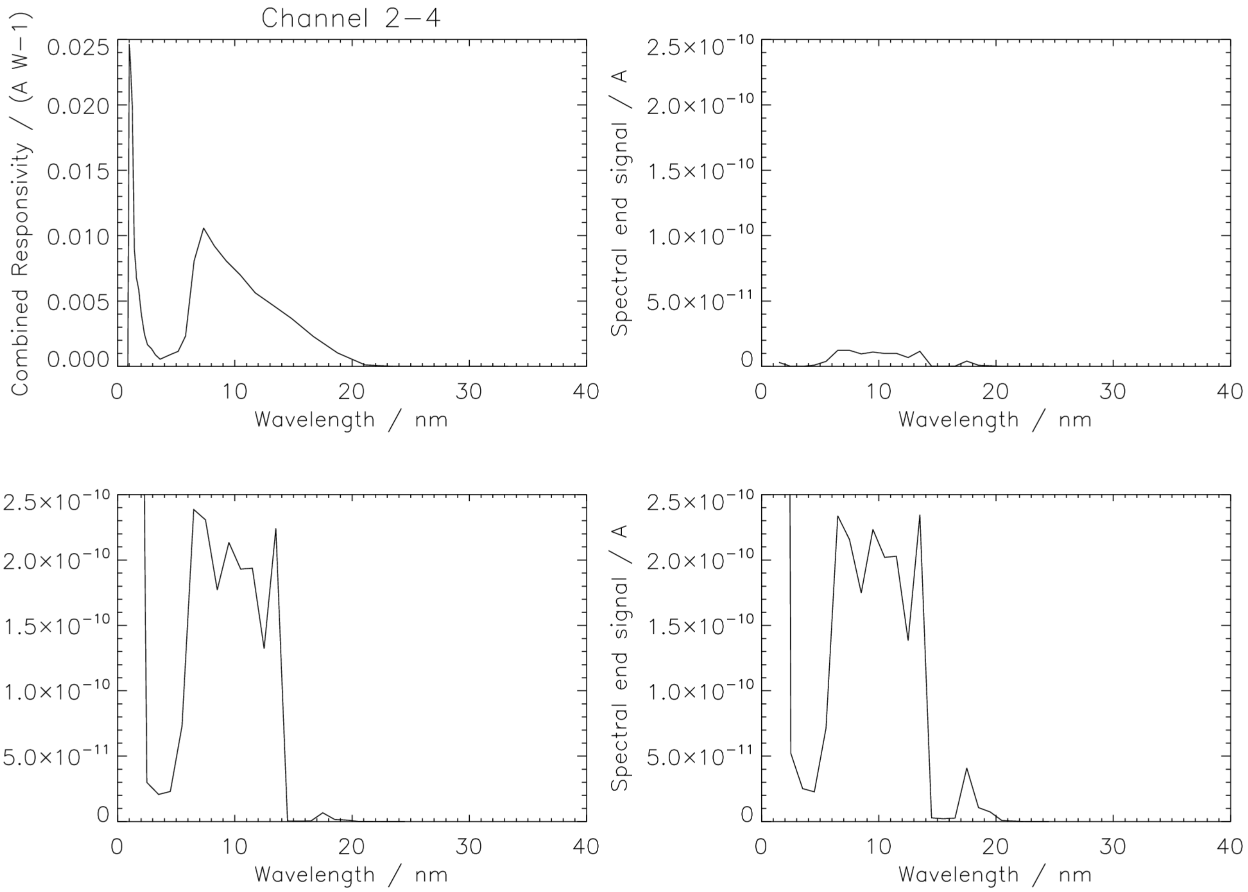

Figure 2-4. Measured responsivity and simulated output (min, high, max) for LYRA channel 2-4.

```
2-4: Zr(150nm) + MSM19  (1-20 nm)

sample  total         pure                    rest            solar
------  ------------  --------------------    -------------   ---------------
min     0.0980128 nA  0.0979311 nA (99.9%)   0.00008175 nA   0.00267627 Wm-2
high    2.85311   nA  2.85293   nA (100.%)   0.00018807 nA   0.0659849  Wm-2
max     4.53508   nA  4.53394   nA (100.%)   0.00114087 nA   0.0975310  Wm-2
```

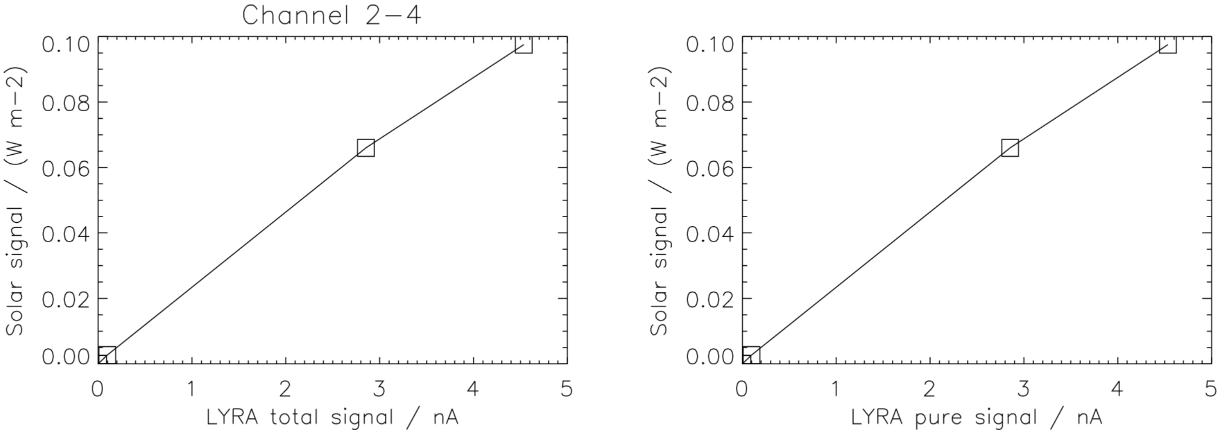

Figure 2-4a. Simulated relations between input and output for LYRA channel 2-4.

The functional relation between the solar signal and the LYRA total signal looks straightforward. No rest signal has to be calculated. Since the purity of the Zirconium channels is always around 100%, the pure signal can simply be estimated by the total signal:

[LYRA 2-4 pure signal / nA] = [LYRA 2-4 total signal / nA]

And the solar signal can be estimated from the pure signal with linear interpolation between the points of a slightly sublinear relationship as visible in the upper right image:

["Zirconium" solar signal / (W m-2)] = interp[LYRA 2-4 pure signal / nA]

Remarks: Appplication of a simple linear factor, in this case 0.0240, instead of interpolation would lead to an error of +/- 12%. - Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

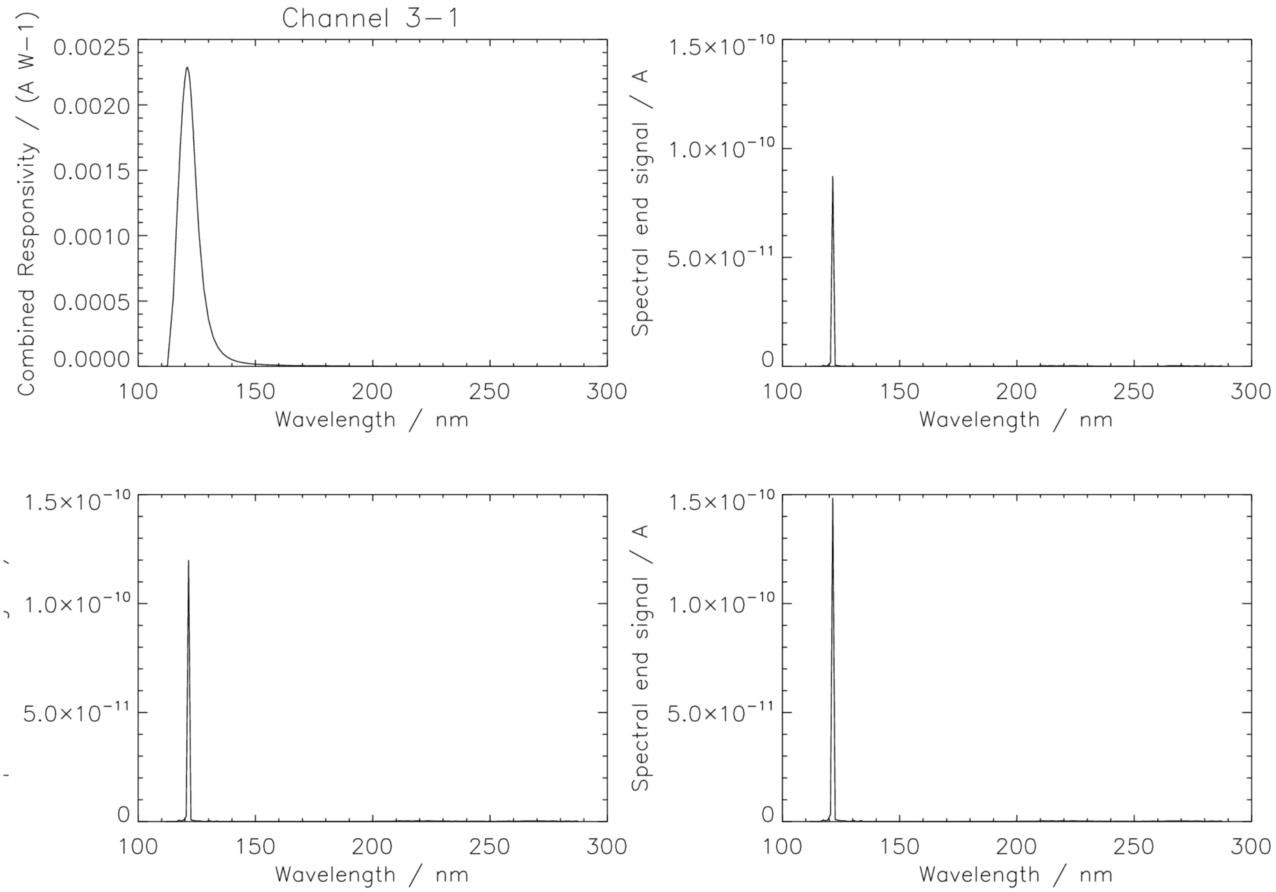

Figure 3-1. Measured responsivity and simulated output (min, high, max) for LYRA channel 3-1.

```
3-1: Ly N+XN + AXUV20A  (121.5 +/- nm)

sample  total        pure                  rest           solar
------  -----------  --------------------  ------------   ---------------
min     0.112943 nA  0.0897866 nA (79.5%)  0.0231564 nA   0.00564762 Wm-2
high    0.147934 nA  0.123199  nA (83.3%)  0.0247348 nA   0.00774904 Wm-2
max     0.178779 nA  0.152764  nA (85.4%)  0.0260155 nA   0.00960818 Wm-2
```

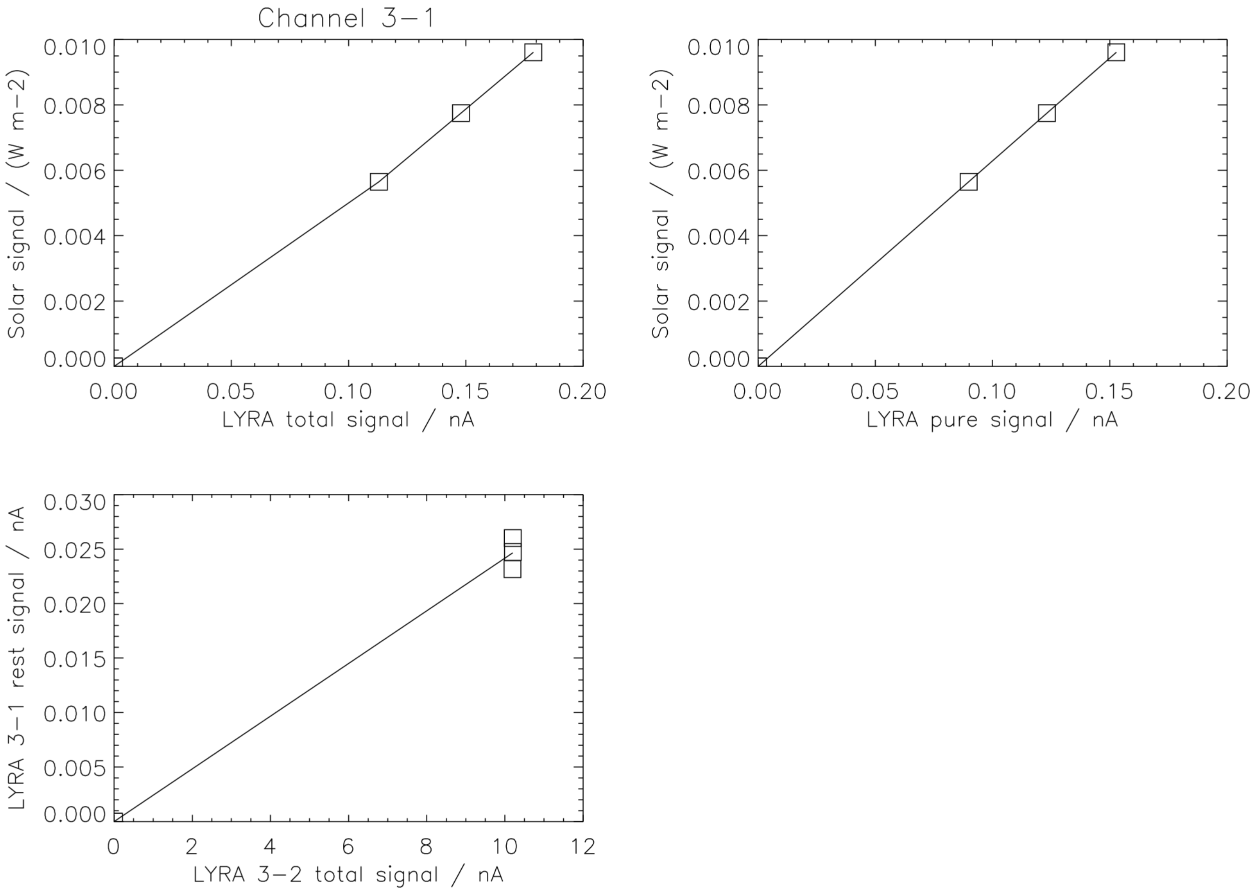

Figure 3-1a. Simulated relations between input and output for LYRA channel 3-1.

The functional relation between the solar signal and the LYRA total signal is not quite straightforward, although more so than for channels 1-1 or 2-1 (see upper left image). The reason is again a contamination due to the influence of the interval 180-230 nm, which is not part of the nominal interval around the Lyman-alpha line, but this contamination is smaller here due to the double filter, N+XN. This rest signal can obviously be estimated with the help of the output signal from LYRA channel 3-2 in a simple way (see lower image):
*[LYRA 3-1 rest signal / nA] = 0.0024 * [LYRA 3-2 total signal / nA]*

The pure signal can be estimated as the difference:
[LYRA 3-1 pure signal / nA] = [LYRA 3-1 total signal / nA] – [LYRA 3-1 rest signal / nA]

And the solar signal can again be estimated from the pure signal in a simple way (see upper right image):
*[“Lyman-alpha” solar signal / (W m-2)] = 0.0629 * [LYRA 3-1 pure signal / nA]*

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three TIMED/SEE data points (120.5, 121.5, and 122.5 nm), of which only 121.5 nm is significant. This means that the simulation is essentially based on one value; a small variation of the nominal interval would not lead to different simulation results. - Due to the simple linear factors, the estimation error is within +/-1.5%.

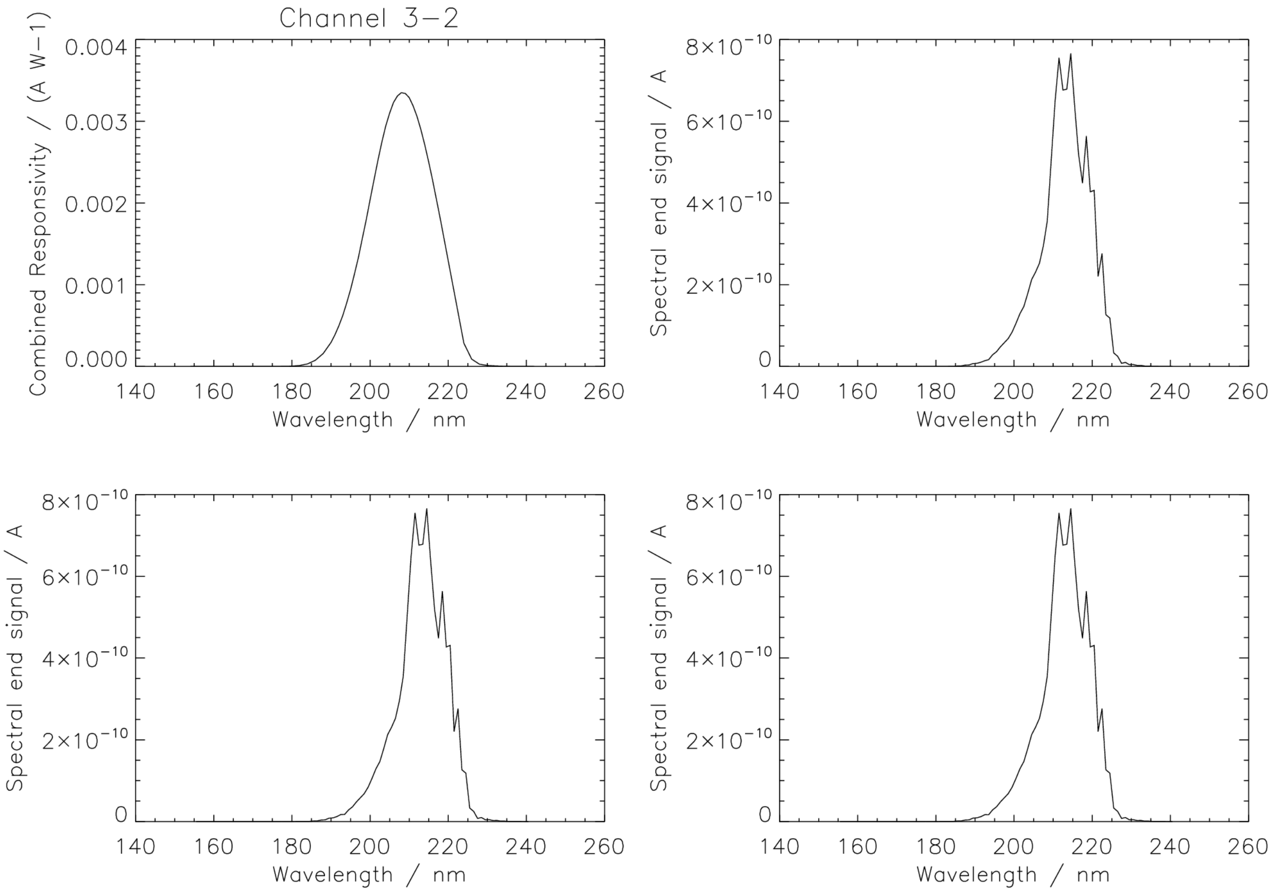

Figure 3-2. Measured responsivity and simulated output (min, high, max) for LYRA channel 3-2.

```
3-2: Herzberg + PIN12  (200-220 nm)

sample  total       pure                rest        solar
------  ----------  ------------------  ----------  -------------
min     10.1916 nA  8.53481 nA (83.7%)  1.65680 nA  0.474210 Wm-2
high    10.2020 nA  8.53481 nA (83.7%)  1.66717 nA  0.474210 Wm-2
max     10.2009 nA  8.53481 nA (83.7%)  1.66609 nA  0.474210 Wm-2
```

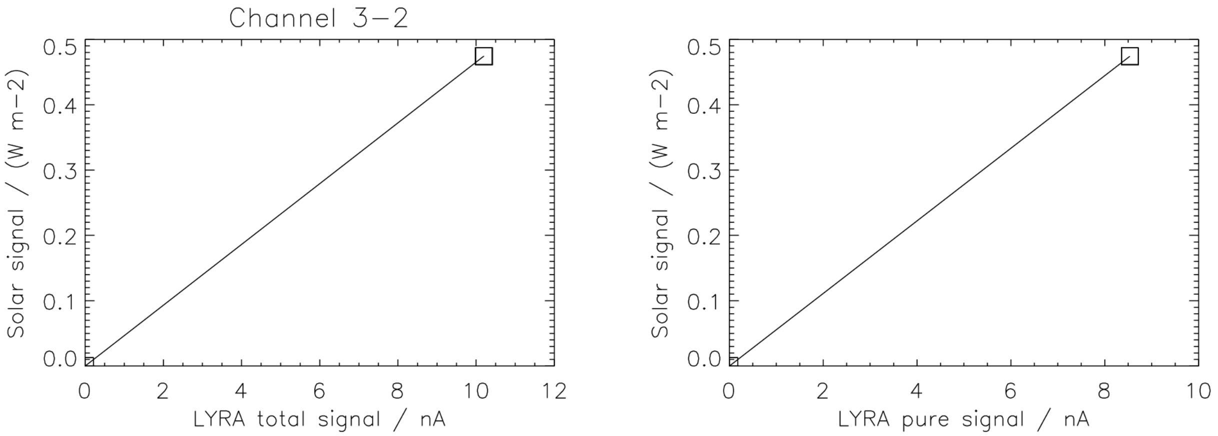

Figure 3-2a. Simulated relations between input and output for LYRA channel 3-2.

The functional relation between the solar signal and the LYRA total signal looks straightforward at first sight. No rest signal has to be calculated. The pure signal can simply be estimated by a linear factor (see table last page):
*[LYRA 3-2 pure signal / nA] = 0.837 * [LYRA 3-2 total signal / nA]*

And the solar signal can be estimated from the pure signal in a simple way (see upper right image):
*["Herzberg" solar signal / (W m-2)] = 0.0556 * [LYRA 3-2 pure signal / nA]*

Remarks: The estimate is actually only based on one sample instead of three, because the TIMED/SEE data extensions above 200 nm are identical. - If other limits of the nominal interval were chosen, the purity could naturally be improved (rough estimates):
200 – 220 nm => 84 % purity, 197 – 223 nm => 95 % purity, 195 – 225 nm => 98 % purity,
190 – 230 nm => 99.5 % purity, 180 – 230 nm => 99.9 % purity.

Due to the simple linear factors, the estimation error is within +/-0.1%.

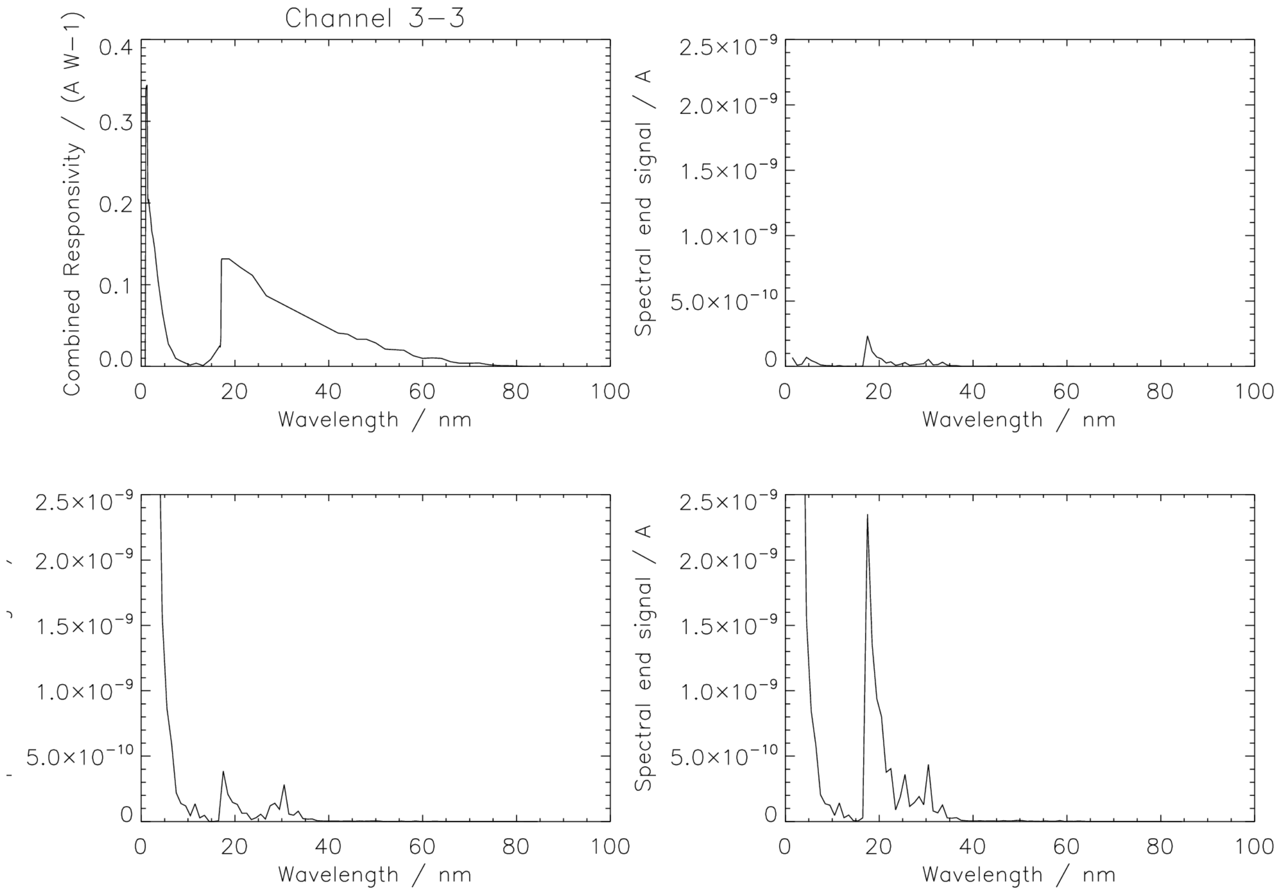

Figure 3-3. Measured responsivity and simulated output (min, high, max) for LYRA channel 3-3.

```
3-3: Aluminium + AXUV20B  (17-80 nm)

sample  total        pure                   rest          solar
------  -----------  -------------------  ------------  ---------------
min       1.10304 nA  0.820291 nA (74.4%)   0.282749 nA  0.00131051 Wm-2
high     36.7403  nA  2.07564  nA ( 5.6%)  34.6646   nA  0.00340476 Wm-2
max      80.8530  nA  8.36320  nA (10.3%)  72.4898   nA  0.0111131  Wm-2
```

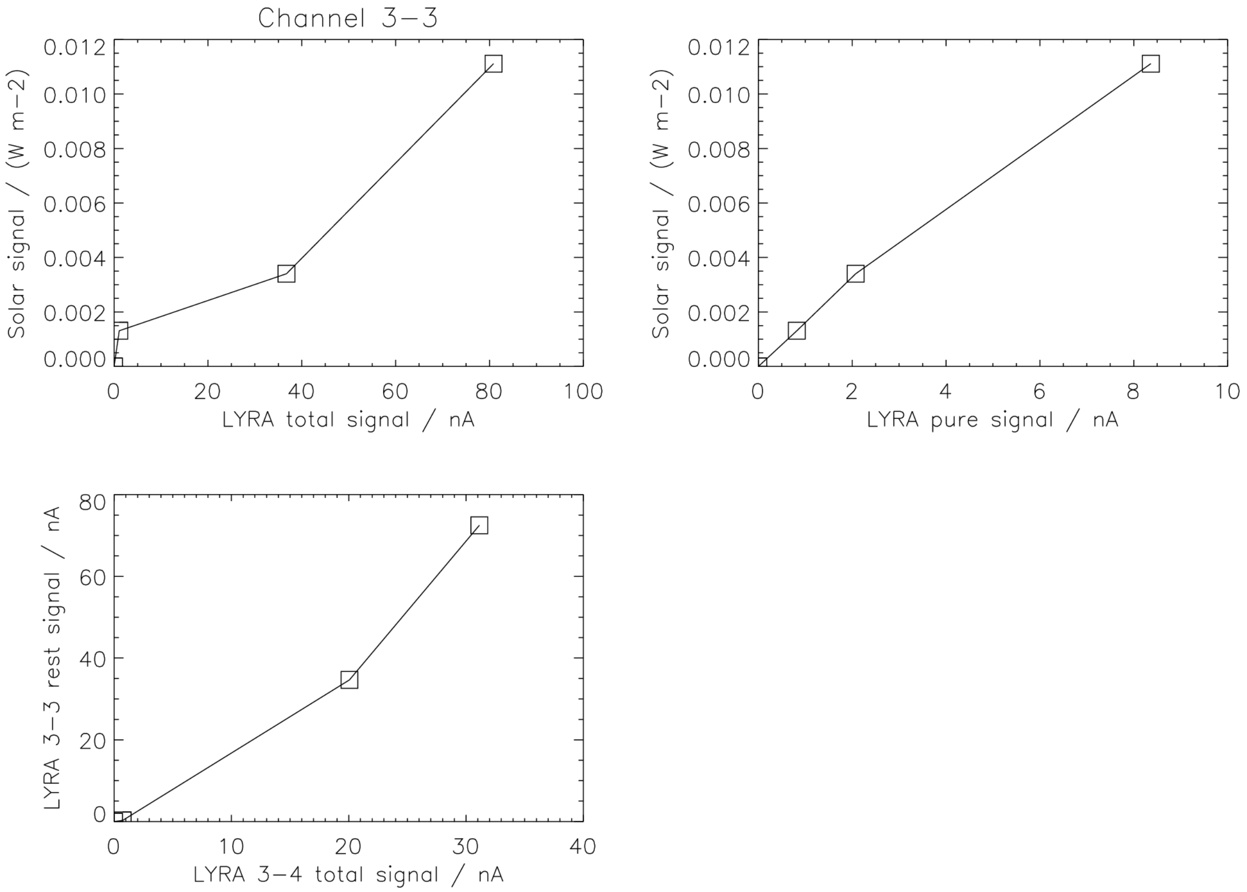

Figure 3-3a. Simulated relations between input and output for LYRA channel 3-3.

The functional relation between the solar signal and the LYRA total signal is obviously not straightforward (rather zigzag, see upper left image). The reason is a contamination due to the influence of the interval 1-10 nm, which is not part of the 17-80 nm nominal interval of the "Aluminium" channels. This rest signal can possibly be estimated with the help of the output signal from LYRA channel 3-4; not as simple as in the other cases, but with linear interpolation between the points of a superlinear relationship as visible in the lower image:
[LYRA 3-3 rest signal / nA] = interp[LYRA 3-4 total signal / nA]

The pure signal can be estimated as the difference:
[LYRA 3-3 pure signal / nA] = [LYRA 3-3 total signal / nA] – [LYRA 3-3 rest signal / nA]

And the solar signal can be estimated from the pure signal, again not in a simple way but with linear interpolation between the points of a slightly sublinear relationship as visible in the upper right image:
["Aluminium" solar signal / (W m-2)] = interp[LYRA 3-3 pure signal / nA]

Remarks: Although the channel interval nominally reaches up to 80 nm, effectively it appears to end at 35 nm (see Figure 3-3). - If a large subset of these channels' solar signal is similar to the "high" or "max" simulation data, then the uncalibrated data (before subtraction of the substantial short-wavelength contamination) will probably not be very meaningful. - Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

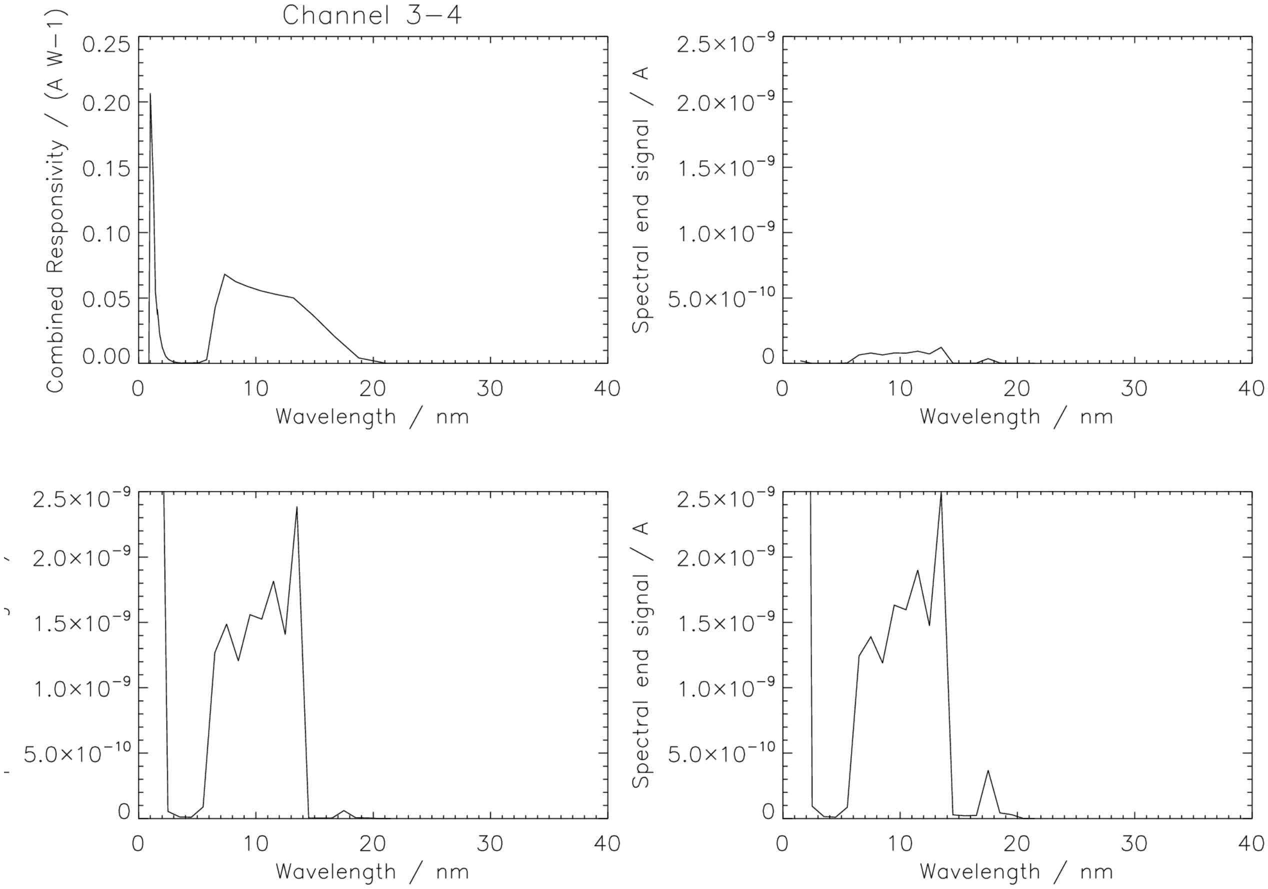

Figure 3-4. Measured responsivity and simulated output (min, high, max) for LYRA channel 3-4.

```
3-4: Zr(300nm) + AXUV20C  (1-20 nm)

sample  total         pure                  rest           solar
------  ------------  --------------------  -------------  ---------------
min       0.733590 nA   0.733524 nA (100.%)  0.00006645 nA  0.00267627 Wm-2
high    20.0586   nA  20.0585   nA (100.%)  0.00015277 nA  0.0659849  Wm-2
max     31.1312   nA  31.1303   nA (100.%)  0.00092371 nA  0.0975310  Wm-2
```

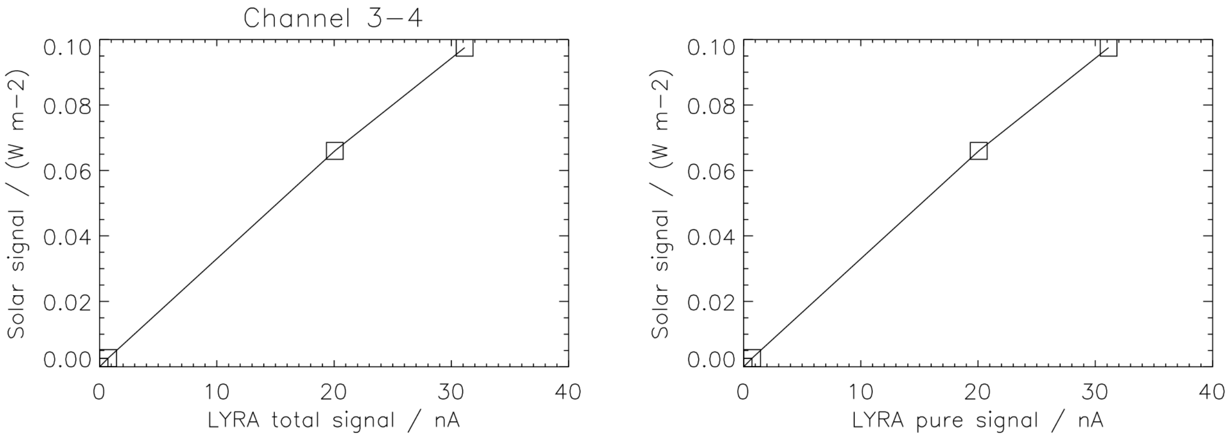

Figure 3-4a. Simulated relations between input and output for LYRA channel 3-4.

The functional relation between the solar signal and the LYRA total signal looks straightforward. No rest signal has to be calculated. Since the purity of the Zirconium channels is always around 100%, the pure signal can simply be estimated by the total signal:

[LYRA 3-4 pure signal / nA] = [LYRA 3-4 total signal / nA]

And the solar signal can be estimated from the pure signal with linear interpolation between the points of a slightly sublinear relationship as visible in the upper right image:

[“Zirconium” solar signal / (W m-2)] = interp[LYRA 3-4 pure signal / nA]

Remarks: Appplication of a simple linear factor, in this case 0.00336, instead of interpolation would lead to an error of +/- 8%. - Due to the linear interpolation, the estimation error is 0%, but this is unrealistic.

```
; calc_calib.pro
; ------------------------------------------------------------------------------
; IED  14 Nov 2006
; ------------------------------------------------------------------------------
; IDL program to calculate the calibrated solar values (in four intervals:
; Lyman-alpha, Herzberg, Aluminium, Zirconium), given one LYRA head and its
; four observed (or simulated) values.
; LYRA observations below zero are set to zero and an ERROR message is printed.
; LYRA observations above the interpolation range are extrapolated, and a
; WARNING message is printed in case it is more than 20% above.
; In case a result value is below zero, an ERROR message is printed.
; ------------------------------------------------------------------------------

t11=[0.244548,0.270879,0.291520]
t12=[12.6509,12.6712,12.6694]
t13=[0.0884238,5.31929,11.9076]
t14=[0.720131,19.0501,28.9357]
t21=[0.105615,0.115582,0.123239]
t22=[13.7981,13.8125,13.8111]
t23=[0.0753576,4.06936,9.09185]
t24=[0.0980128,2.85311,4.53508]
t31=[0.112943,0.147934,0.178779]
t32=[10.1916,10.2020,10.2009]
t33=[1.10304,36.7403,80.8530]
t34=[0.733590,20.0586,31.1312]
p11=[0.0578922,0.0794356,0.0985021]
p12=[10.6056,10.6056,10.6056]
p13=[0.0540079,0.134685,0.563424]
p14=[0.720074,19.0500,28.9349]
p21=[0.0215646,0.0295895,0.0366925]
p22=[11.5975,11.5975,11.5975]
p23=[0.0468343,0.111929,0.500883]
p24=[0.0979311,2.85293,4.53394]
p31=[0.0897866,0.123199,0.152764]
p32=[8.53481,8.53481,8.53481]
p33=[0.820291,2.07564,8.36320]
p34=[0.733524,20.0585,31.1303]
s11=[0.00564762,0.00774904,0.00960818]
s12=[0.474210,0.474210,0.474210]
s13=[0.00131051,0.00340476,0.0111131]
s14=[0.00267627,0.0659849,0.0975310]
s21=[0.00564762,0.00774904,0.00960818]
s22=[0.474210,0.474210,0.474210]
s23=[0.00131051,0.00340476,0.0111131]
s24=[0.00267627,0.0659849,0.0975310]
s31=[0.00564762,0.00774904,0.00960818]
s32=[0.474210,0.474210,0.474210]
s33=[0.00131051,0.00340476,0.0111131]
s34=[0.00267627,0.0659849,0.0975310]

oncemore:
head=0
read,'LYRA Head (1,2,3) ? ',head
if ((head gt 3) or (head lt 1)) then goto,oncemore
o1=0. & o2=0. & o3=0. & o4=0.
s1=0. & s2=0. & s3=0. & s4=0.
read,'LYRA observations [in nA] # # # # ? ',o1,o2,o3,o4

if (head eq 1) then begin
 if (o1 lt 0.) then begin
  print,'ERROR: Channel 1-1 negative'
```

```
 o1=0.
 endif
if (o1 gt 1.2*max(t11)) then $
 print,'WARNING: Channel 1-1 far above interpolation range'
if (o2 lt 0.) then begin
 print,'ERROR: Channel 1-2 negative'
 o2=0.
 endif
if (o2 gt 1.2*max(t12)) then $
 print,'WARNING: Channel 1-2 far above interpolation range'
if (o3 lt 0.) then begin
 print,'ERROR: Channel 1-3 negative'
 o3=0.
 endif
if (o3 gt 1.2*max(t13)) then $
 print,'WARNING: Channel 1-3 far above interpolation range'
if (o4 lt 0.) then begin
 print,'ERROR: Channel 1-4 negative'
 o4=0.
 endif
if (o4 gt 1.2*max(t14)) then $
 print,'WARNING: Channel 1-4 far above interpolation range'

s1=0.0975*(o1-0.015*o2)
if (s1 lt 0.) then begin
 print,'ERROR: Result 1-1 negative'
 s1=0.
 endif

s2=0.0447*(0.837*o2)

r13=t13-p13
if (o4 le t14(0)) then r3=o4*r13(0)/t14(0)
if (o4 ge t14(0)) and (o4 le t14(1)) then $
 r3=r13(0)+(o4-t14(0))*(r13(1)-r13(0))/(t14(1)-t14(0))
if (o4 ge t14(1)) then r3=r13(1)+(o4-t14(1))*(r13(2)-r13(1))/(t14(2)-t14(1))
p3=o3-r3
if (p3 le p13(0)) then s3=p3*s13(0)/p13(0)
if (p3 ge p13(0)) and (p3 le p13(1)) then $
 s3=s13(0)+(p3-p13(0))*(s13(1)-s13(0))/(p13(1)-p13(0))
if (p3 ge p13(1)) then s3=s13(1)+(p3-p13(1))*(s13(2)-s13(1))/(p13(2)-p13(1))
if (s3 lt 0.) then begin
 print,'ERROR: Result 1-3 negative'
 s3=0.
 endif

if (o4 le t14(0)) then s4=o4*s14(0)/t14(0)
if (o4 ge t14(0)) and (o4 le t14(1)) then $
 s4=s14(0)+(o4-t14(0))*(s14(1)-s14(0))/(t14(1)-t14(0))
if (o4 ge t14(1)) then s4=s14(1)+(o4-t14(1))*(s14(2)-s14(1))/(t14(2)-t14(1))
if (s4 lt 0.) then begin
 print,'ERROR: Result 1-4 negative'
 s4=0.
 endif

print,'LYRA Head 1 observations [in nA]
print,o1,o2,o3,o4
print,'corresponding solar values [in W m-2]
print,s1,s2,s3,s4
endif
```

```
if (head eq 2) then begin
 if (o1 lt 0.) then begin
  print,'ERROR: Channel 2-1 negative'
  o1=0.
  endif
 if (o1 gt 1.2*max(t21)) then $
  print,'WARNING: Channel 2-1 far above interpolation range'
 if (o2 lt 0.) then begin
  print,'ERROR: Channel 2-2 negative'
  o2=0.
  endif
 if (o2 gt 1.2*max(t22)) then $
  print,'WARNING: Channel 2-2 far above interpolation range'
 if (o3 lt 0.) then begin
  print,'ERROR: Channel 2-3 negative'
  o3=0.
  endif
 if (o3 gt 1.2*max(t23)) then $
  print,'WARNING: Channel 2-3 far above interpolation range'
 if (o4 lt 0.) then begin
  print,'ERROR: Channel 2-4 negative'
  o4=0.
  endif
 if (o4 gt 1.2*max(t24)) then $
  print,'WARNING: Channel 2-4 far above interpolation range'

 s1=0.262*(o1-0.0062*o2)
 if (s1 lt 0.) then begin
  print,'ERROR: Result 2-1 negative'
  s1=0.
  endif

 s2=0.0409*(0.840*o2)

 r23=t23-p23
 if (o4 le t24(0)) then r3=o4*r23(0)/t24(0)
 if (o4 ge t24(0)) and (o4 le t24(1)) then $
  r3=r23(0)+(o4-t24(0))*(r23(1)-r23(0))/(t24(1)-t24(0))
 if (o4 ge t24(1)) then r3=r23(1)+(o4-t24(1))*(r23(2)-r23(1))/(t24(2)-t24(1))
 p3=o3-r3
 if (p3 le p23(0)) then s3=p3*s23(0)/p23(0)
 if (p3 ge p23(0)) and (p3 le p23(1)) then $
  s3=s23(0)+(p3-p23(0))*(s23(1)-s23(0))/(p23(1)-p23(0))
 if (p3 ge p23(1)) then s3=s23(1)+(p3-p23(1))*(s23(2)-s23(1))/(p23(2)-p23(1))
 if (s3 lt 0.) then begin
  print,'ERROR: Result 2-3 negative'
  s3=0.
  endif

 if (o4 le t24(0)) then s4=o4*s24(0)/t24(0)
 if (o4 ge t24(0)) and (o4 le t24(1)) then $
  s4=s24(0)+(o4-t24(0))*(s24(1)-s24(0))/(t24(1)-t24(0))
 if (o4 ge t24(1)) then s4=s24(1)+(o4-t24(1))*(s24(2)-s24(1))/(t24(2)-t24(1))
 if (s4 lt 0.) then begin
  print,'ERROR: Result 2-4 negative'
  s4=0.
  endif

 print,'LYRA Head 2 observations [in nA]
 print,o1,o2,o3,o4
 print,'corresponding solar values [in W m-2]
```

```
 print,s1,s2,s3,s4
 endif

if (head eq 3) then begin
 if (o1 lt 0.) then begin
  print,'ERROR: Channel 3-1 negative'
  o1=0.
  endif
 if (o1 gt 1.2*max(t31)) then $
  print,'WARNING: Channel 3-1 far above interpolation range'
 if (o2 lt 0.) then begin
  print,'ERROR: Channel 3-2 negative'
  o2=0.
  endif
 if (o2 gt 1.2*max(t32)) then $
  print,'WARNING: Channel 3-2 far above interpolation range'
 if (o3 lt 0.) then begin
  print,'ERROR: Channel 3-3 negative'
  o3=0.
  endif
 if (o3 gt 1.2*max(t33)) then $
  print,'WARNING: Channel 3-3 far above interpolation range'
 if (o4 lt 0.) then begin
  print,'ERROR: Channel 3-4 negative'
  o4=0.
  endif
 if (o4 gt 1.2*max(t34)) then $
  print,'WARNING: Channel 3-4 far above interpolation range'

 s1=0.0629*(o1-0.0024*o2)
 if (s1 lt 0.) then begin
  print,'ERROR: Result 3-1 negative'
  s1=0.
  endif

 s2=0.0556*(0.837*o2)

 r33=t33-p33
 if (o4 le t34(0)) then r3=o4*r33(0)/t34(0)
 if (o4 ge t34(0)) and (o4 le t34(1)) then $
  r3=r33(0)+(o4-t34(0))*(r33(1)-r33(0))/(t34(1)-t34(0))
 if (o4 ge t34(1)) then r3=r33(1)+(o4-t34(1))*(r33(2)-r33(1))/(t34(2)-t34(1))
 p3=o3-r3
 if (p3 le p33(0)) then s3=p3*s33(0)/p33(0)
 if (p3 ge p33(0)) and (p3 le p33(1)) then $
  s3=s33(0)+(p3-p33(0))*(s33(1)-s33(0))/(p33(1)-p33(0))
 if (p3 ge p33(1)) then s3=s33(1)+(p3-p33(1))*(s33(2)-s33(1))/(p33(2)-p33(1))
 if (s3 lt 0.) then begin
  print,'ERROR: Result 3-3 negative'
  s3=0.
  endif

 if (o4 le t34(0)) then s4=o4*s34(0)/t34(0)
 if (o4 ge t34(0)) and (o4 le t34(1)) then $
  s4=s34(0)+(o4-t34(0))*(s34(1)-s34(0))/(t34(1)-t34(0))
 if (o4 ge t34(1)) then s4=s34(1)+(o4-t34(1))*(s34(2)-s34(1))/(t34(2)-t34(1))
 if (s4 lt 0.) then begin
  print,'ERROR: Result 3-4 negative'
  s4=0.
  endif
```

```
 print,'LYRA Head 3 observations [in nA]
 print,o1,o2,o3,o4
 print,'corresponding solar values [in W m-2]
 print,s1,s2,s3,s4
 endif

end
```