LYRA Calibration Methods: New Spectra

IED, 25 Oct 2006
rev. 21 Sep 2007 (additional sample spectra)
rev. 07 Apr 2008 (updated responsivities)
rev. 18 Jul 2008 (new spectra, incl. SORCE)

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 an earlier version of Figure 0 (see next page). 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. (Please note **Update** next page!) Nominal intervals are marked in red.- 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. The initial assumption that zero solar input should lead to zero LYRA output has been dropped. 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 polynomials 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 numerical 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.

Update:

After communication with the team from TIMED/SEE and SORCE, a new set of solar sample spectra was constructed. Apparently, the above-mentioned samples high and max had been largely over-estimated, especially in the very short wavelengths, while the sample min had been underestimated.

- Since the time when the input for the LYRA Radiometric Model was first constructed (2005), TIMED/SEE spectra have been recalibrated, currently using data products version 9.

- Additionally, it was suggested to use SORCE spectra for the longer wavelength part (i.e. above 116 nm).

- Since solar irradiance generally decreased during the last years, a new minimum could be selected and used from end-June 2008.

- The advantages are: Hopefully more realistically expected variations; a set of actually differing spectra for the Herzberg channels and the NUV-VIS-IR extension; in the end, smoother calibration curves result.

The seven samples now used for the simulations are the following (1 nm – 116 nm taken from TIMED/SEE, 116 nm – 2400 nm taken from various SORCE instruments):

omin	24 Feb 2005	(old) solar minimum
ohig	11 Nov 2003	(old) high solar flux
nmin	29 Jun 2008	(new) solar minimum
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

The TIMED/SEE part of pre1, fla1, pre2, fla2 is unchanged. The SORCE parts for pre1 and fla1 (as well as for pre2 and fla2) are identical, since SORCE only offers observations on a daily basis, while TIMED/SEE offers several (~14) observations per day. The old max sample spectrum is deleted, since it is covered by fla1. Spectrum nmin is introduced to cover the current solar minimum. Samples omin and ohig include the most recently calibrated TIMED/SEE spectra for the “old” dates.

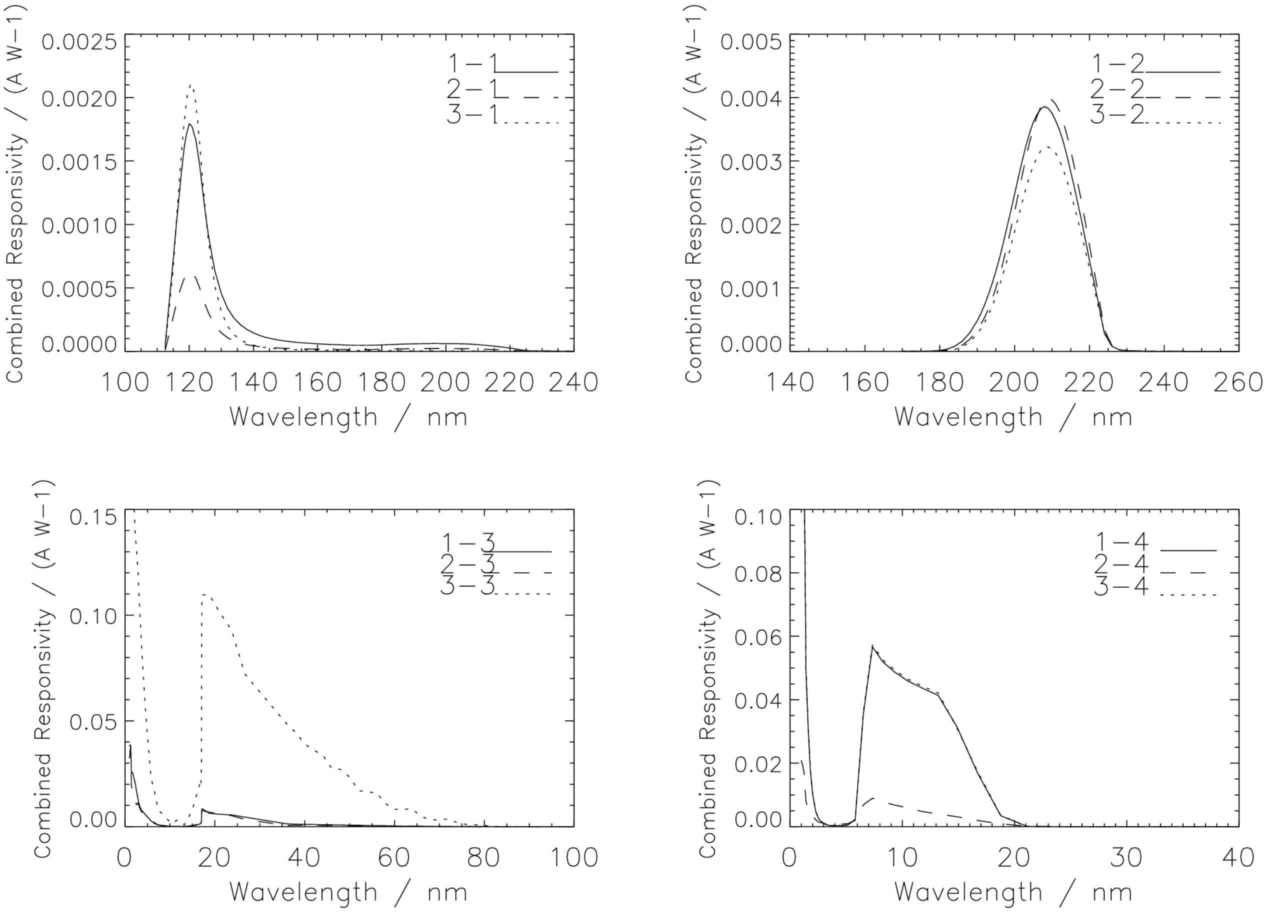

Figure 0. LYRA channel responsivities, similar to those presented at the Davos meeting, but updated with the latest responsivity measurements: Combination of filter and detector effects measured as a function of wavelength. *-1 = Lyman-alpha channels, *-2 = Herzberg channels, *-3 = Aluminium channels,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

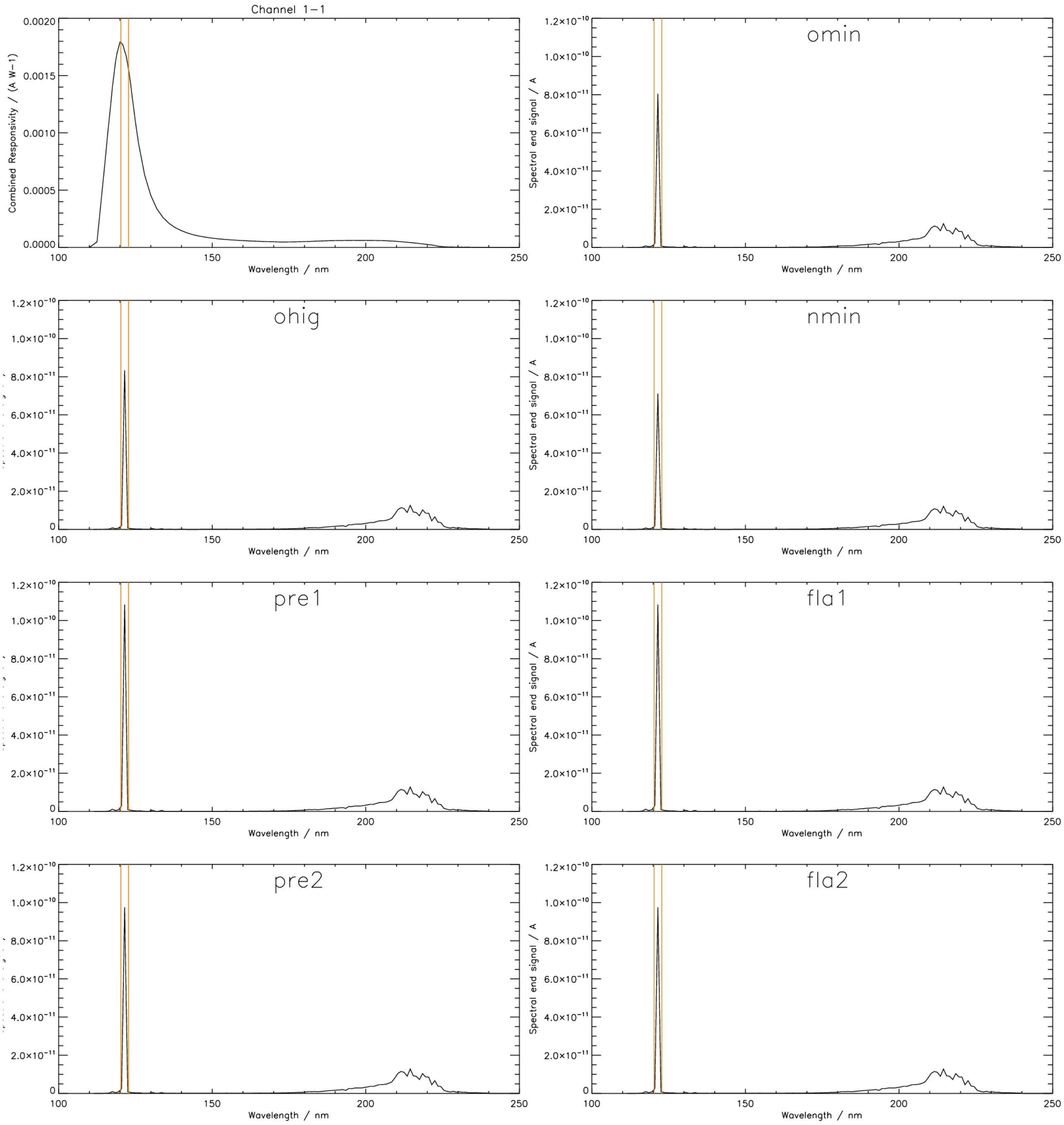

Figure 1-1. Measured responsivity and simulated output for LYRA channel 1-1
Ly XN + MSM12 (121.5 +/- nm)

```
sample  total        pure                      residual     solar
------  -----------  --------------------      -----------  ---------------
omin    0.306999 nA  0.0831912 nA (27.1%)      0.223808 nA  0.00690130 Wm-2
ohig    0.314070 nA  0.0861396 nA (27.4%)      0.227930 nA  0.00714568 Wm-2
nmin    0.288722 nA  0.0735911 nA (25.5%)      0.215131 nA  0.00610500 Wm-2
pre1    0.345851 nA  0.112272  nA (32.5%)      0.233579 nA  0.00931232 Wm-2
fla1    0.345894 nA  0.112272  nA (32.5%)      0.233621 nA  0.00931232 Wm-2
pre2    0.333334 nA  0.100799  nA (30.2%)      0.232536 nA  0.00836111 Wm-2
fla2    0.333352 nA  0.100799  nA (30.2%)      0.232553 nA  0.00836111 Wm-2
```

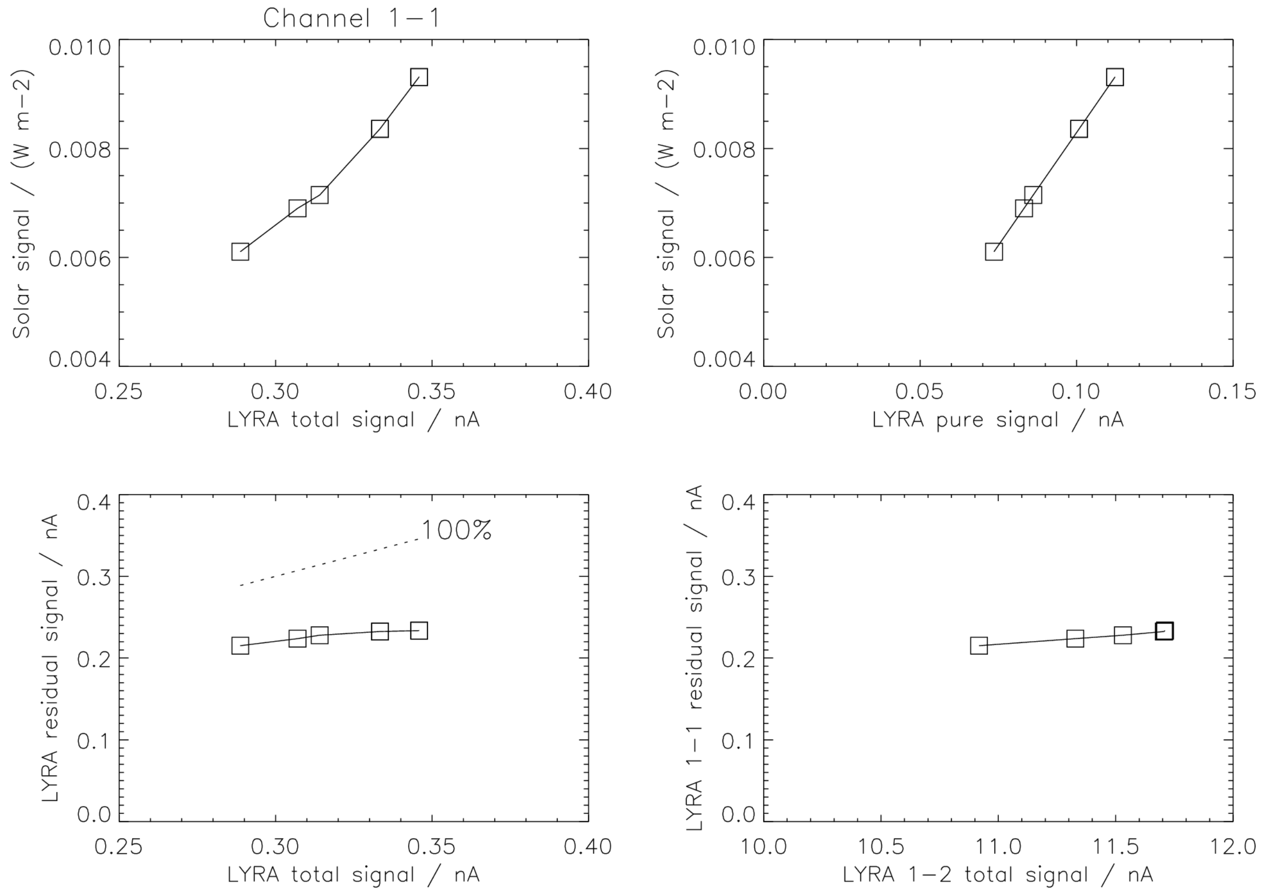

Figure 1-1a. Simulated relations between input and output for LYRA channel 1-1.

The functional relation between the solar signal and the LYRA total signal is almost linear (see upper left image). The reason for the small difference 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 be estimated with the help of the output signal from LYRA channel 1-2 by using a linear polynomial (see lower right image):
*[LYRA 1-1 residual signal / nA] = -0.0353757 + 0.0229111 * [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 (see lower left image):
*[LYRA 1-1 residual signal / nA] = 0.128112 + 0.309659 * [LYRA 1-1 total signal / nA]*
Instead of using a linear polynomial, linear interpolation can also be used. - All 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 by a linear polynomial (see upper right image):
*[“Lyman-alpha” solar signal / (W m-2)] = 0.0829142 * [LYRA 1-1 pure signal / nA]*

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three SORCE 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 linear factors, the estimation error is within 1.1% for the first variant, 3.3% for the second, and 0.06% for the third.

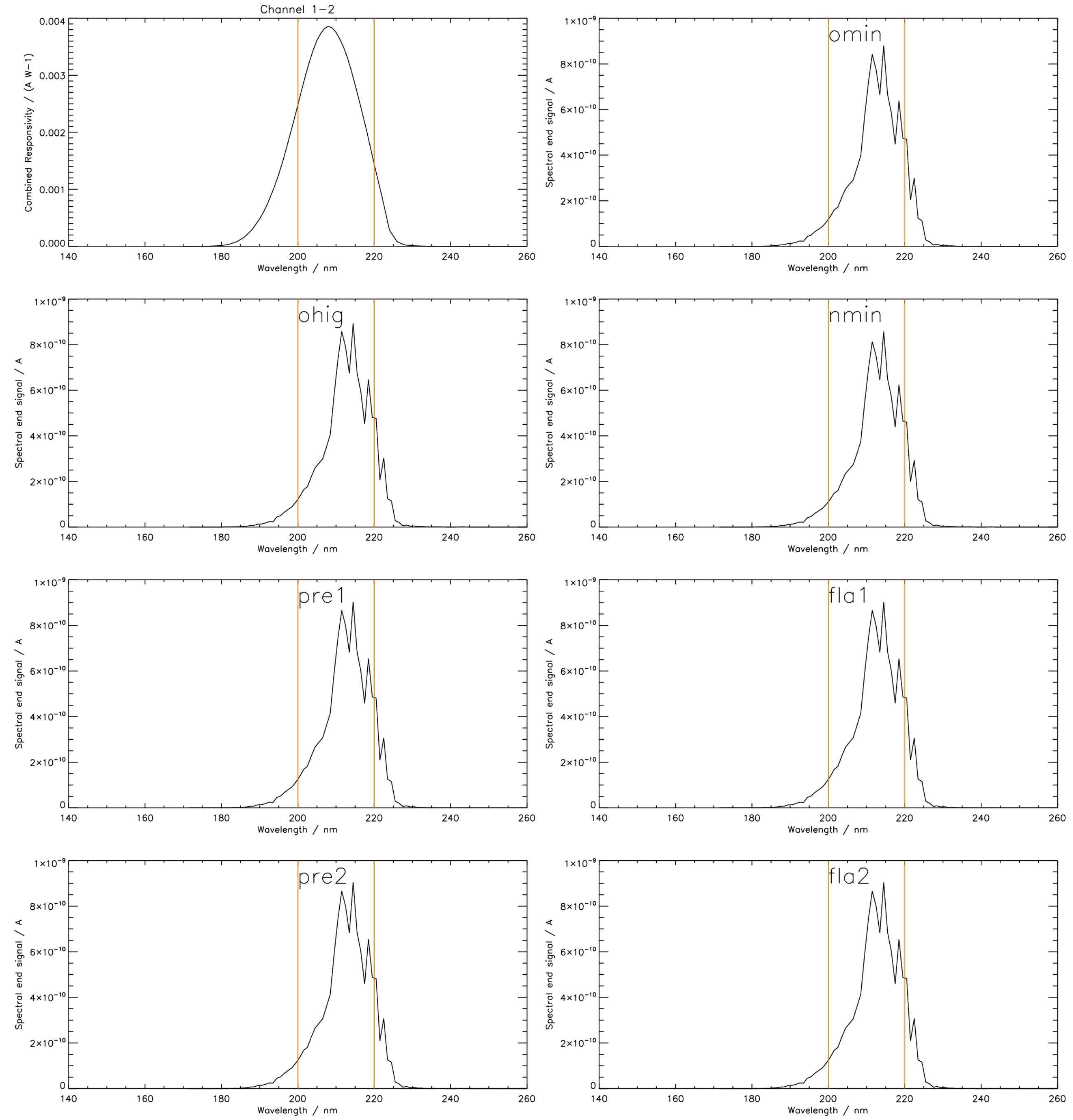

Figure 1-2. Measured responsivity and simulated output for LYRA channel 1-2
Herzberg + PIN10 (200-220 nm)

```
sample  total       pure                residual     solar
------  ----------  ------------------  ----------   -------------
omin    11.3279 nA  9.49506 nA (83.8%)  1.83286 nA   0.461334 Wm-2
ohig    11.5310 nA  9.66663 nA (83.8%)  1.86439 nA   0.469345 Wm-2
nmin    10.9177 nA  9.14279 nA (83.7%)  1.77495 nA   0.445404 Wm-2
pre1    11.7095 nA  9.81582 nA (83.8%)  1.89369 nA   0.476369 Wm-2
fla1    11.7095 nA  9.81582 nA (83.8%)  1.89369 nA   0.476369 Wm-2
pre2    11.7056 nA  9.81157 nA (83.8%)  1.89406 nA   0.476294 Wm-2
fla2    11.7056 nA  9.81157 nA (83.8%)  1.89406 nA   0.476294 Wm-2
```

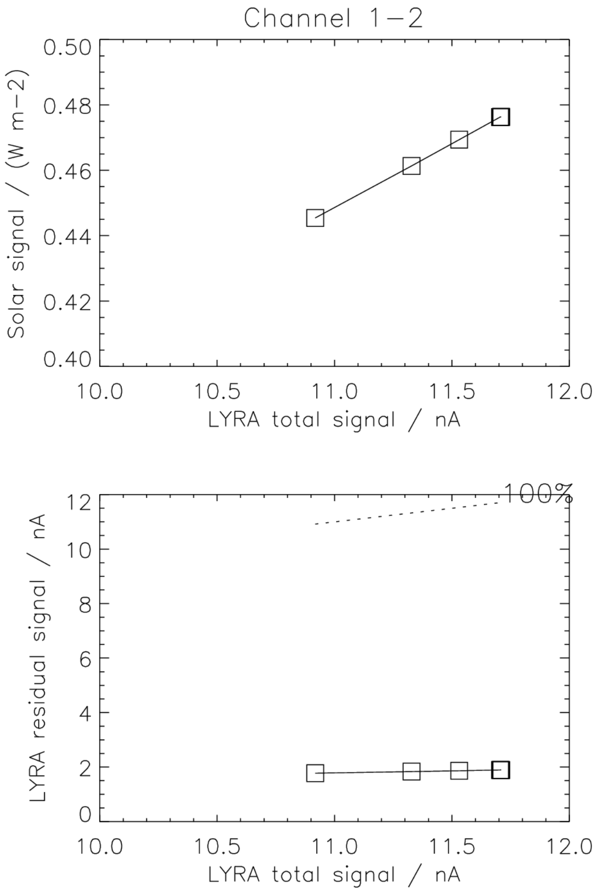

Figure 1-2a. Simulated relations between input and output for LYRA channel 1-2.

The functional relation between the solar signal and the LYRA total signal appears to be straightforward. The pure signal or the residual signal can be estimated by a linear polynomial (see lower image). Following the scheme of channel 1-1, the residual signal is calculated as:
*[LYRA 1-2 residual signal / nA] = 0.115535 + 0.151833 * [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 by a linear polynomial (see upper right image):
*["Herzberg" solar signal / (W m-2)] = 0.0227568 + 0.0462129 * [LYRA 1-2 pure signal / nA]*

Remarks: 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 0.02%. - The behavior of samples pre1, fla1, pre2, fla2 is approx. identical, thus there are only four significantly different data points. Please note the consequence for channel 1-1: While there is a different total and pure (Lyman-alpha) signal response for the last four samples, i.e. pre1,fla1 vs. pre2,fla2, the residual signal is approx. identical, because it is dominated by longer wavelengths - like the channel 1-2 signal.

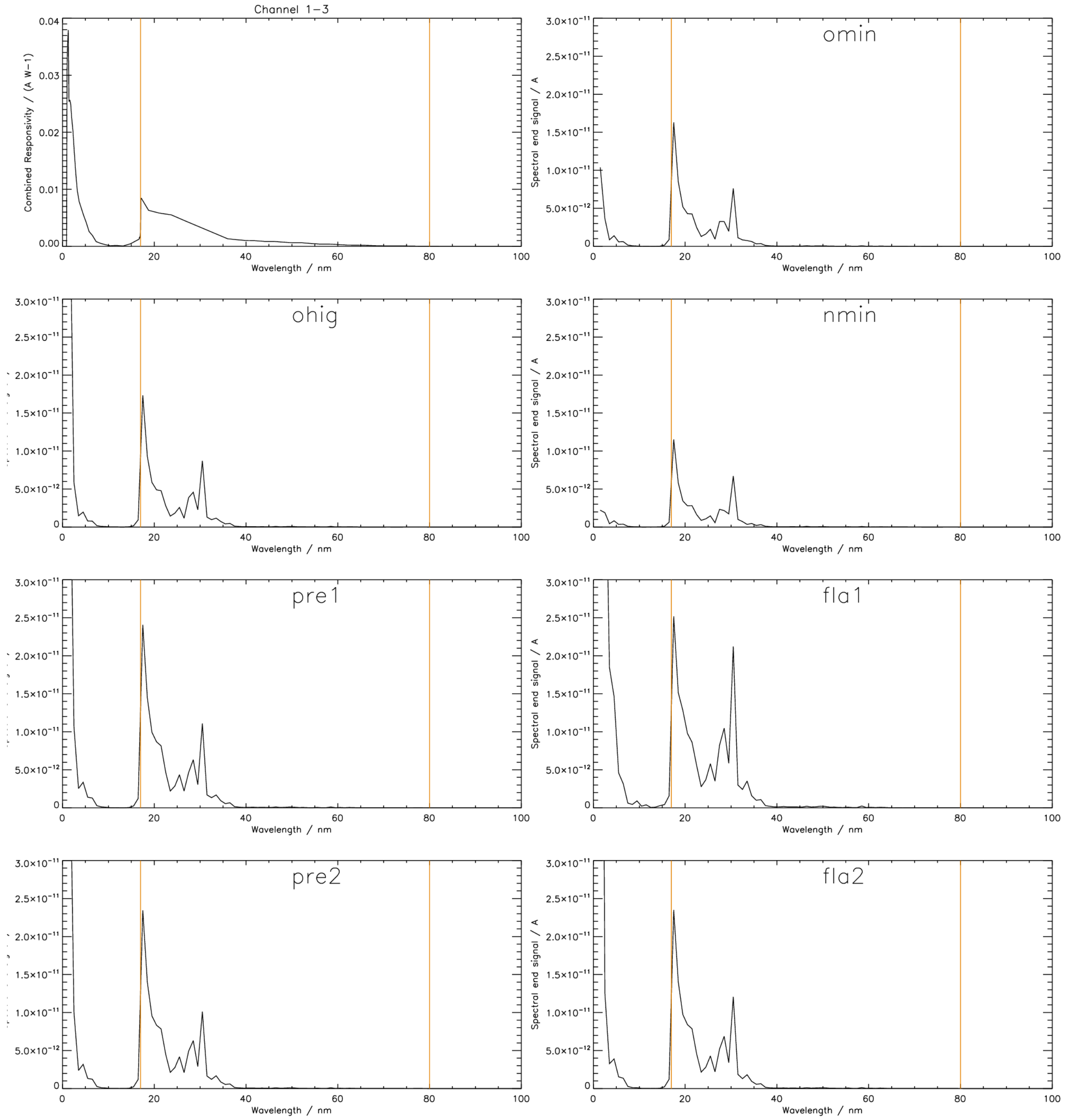

Figure 1-3. Measured responsivity and simulated output for LYRA channel 1-3
Aluminium + MSM11 (17-80 nm)

```
sample  total         pure                    residual        solar
------  ------------  --------------------    ------------    ----------------
omin    0.0870922 nA  0.0682700 nA (78.4%)    0.0188222 nA    0.00225541 Wm-2
ohig    0.140272  nA  0.0777611 nA (55.4%)    0.0625104 nA    0.00263286 Wm-2
nmin    0.0560824 nA  0.0490087 nA (87.4%)    0.0070737 nA    0.00171904 Wm-2
pre1    0.194409  nA  0.115238  nA (59.3%)    0.0791705 nA    0.00376518 Wm-2
fla1    1.77233   nA  0.154482  nA ( 8.7%)    1.61785   nA    0.00570166 Wm-2
pre2    0.183451  nA  0.111148  nA (60.6%)    0.0723025 nA    0.00362499 Wm-2
fla2    0.279541  nA  0.116044  nA (41.5%)    0.163496  nA    0.00394254 Wm-2
```

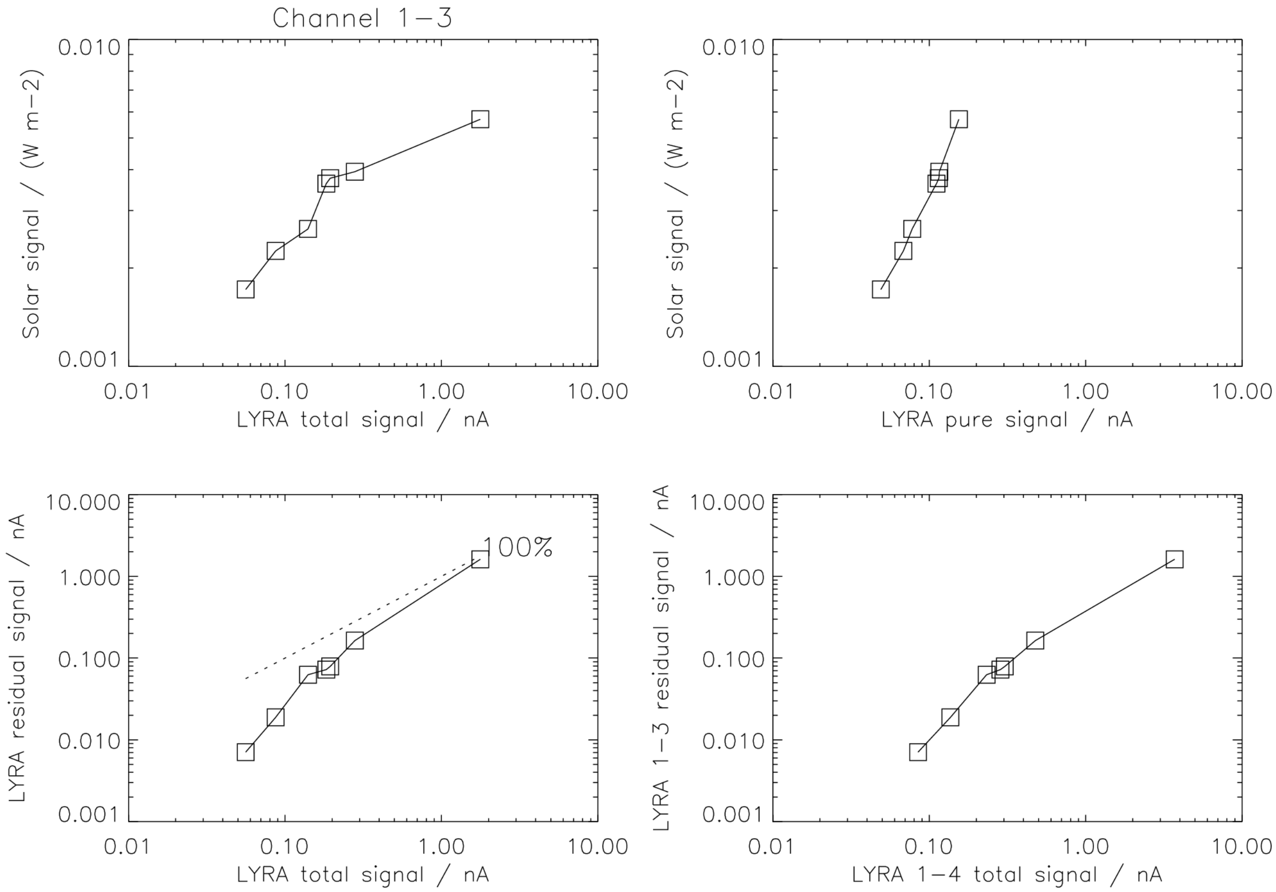

Figure 1-3a. Simulated relations between input and output for LYRA channel 1-3.

The functional relation between the solar signal and the LYRA total signal is still not quite straightforward (but much less irregular than before the last update, compare upper left image). The reason for nonlinearity 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 the relationship as shown in the lower right image:

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

On the other hand, it can also be estimated as a function of the total signal from LYRA channel 1-3 itself (see lower left 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 nonlinear 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). - For the small subset of these channels' solar events which are similar to the "fla1" simulation data (i.e., flares), 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. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 7.1%, without logarithm to 9.7%.

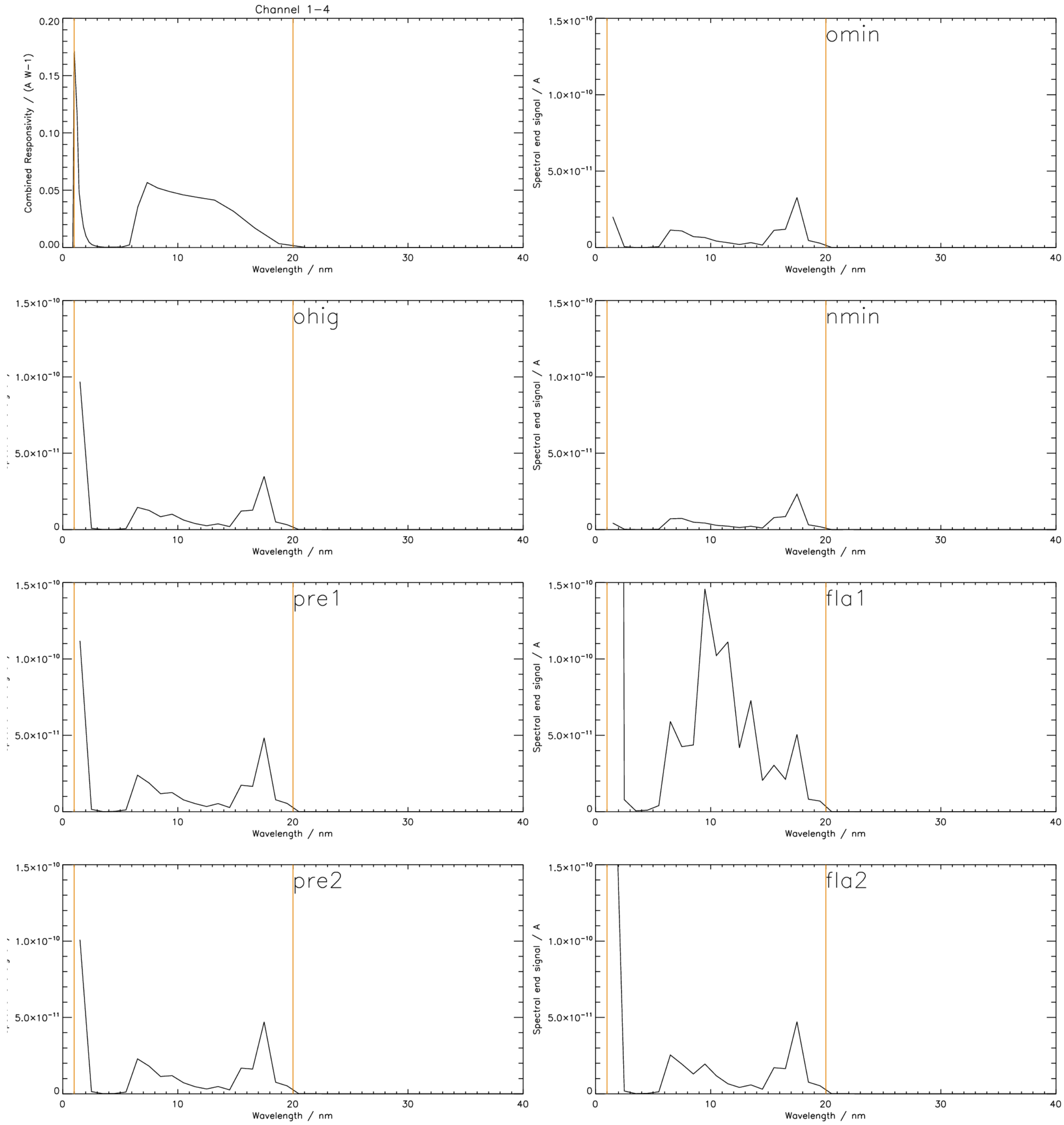

Figure 1-4. Measured responsivity and simulated output for LYRA channel 1-4
Zr(300nm) + AXUV20D (1-20 nm)

```
sample  total        pure                    residual          solar
------  -----------  ------------------      --------------    ---------------
omin    0.136499 nA  0.134531 nA (98.6%)     0.00196869   nA   0.00106140 Wm-2
ohig    0.232485 nA  0.230504 nA (99.1%)     0.00198032   nA   0.00144558 Wm-2
nmin    0.084770 nA  0.082836 nA (97.7%)     0.00193408   nA   0.00068972 Wm-2
pre1    0.304130 nA  0.302066 nA (99.3%)     0.00206363   nA   0.00208323 Wm-2
fla1    3.70439  nA  3.70230  nA (99.9%)     0.00208367   nA   0.0132763  Wm-2
pre2    0.285312 nA  0.283253 nA (99.3%)     0.00205941   nA   0.00198338 Wm-2
fla2    0.476250 nA  0.474187 nA (99.6%)     0.00206241   nA   0.00261203 Wm-2
```

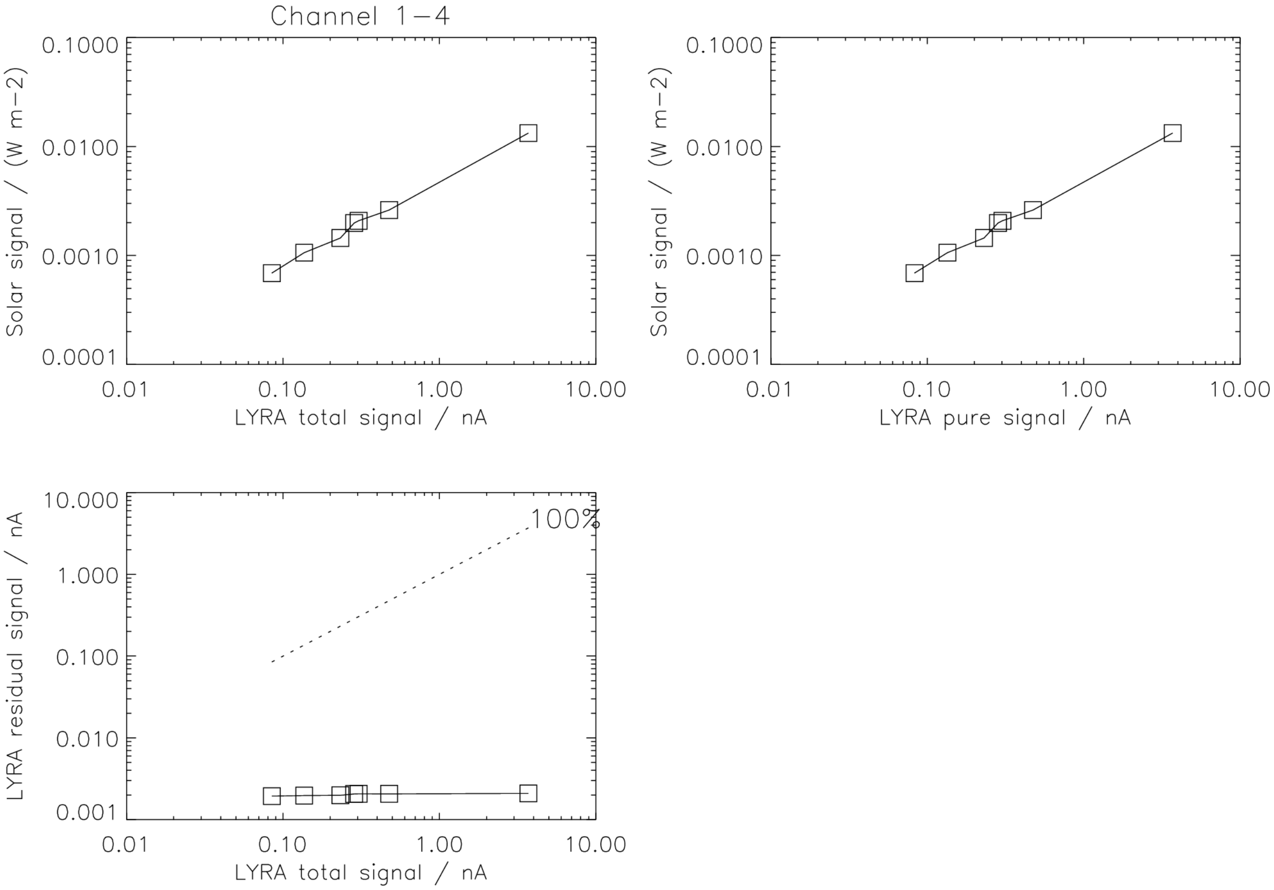

Figure 1-4a. Simulated relations between input and output for LYRA channel 1-4.

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 almost negligible (see lower figure) and can simply be set to the average. Following the usual scheme:

[LYRA 1-4 residual signal / nA] = 0.00202271

The pure signal can be estimated as the difference, which is almost 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 (caused by the averaging) is below 0.2%, but this is unrealistic. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 8.6%.

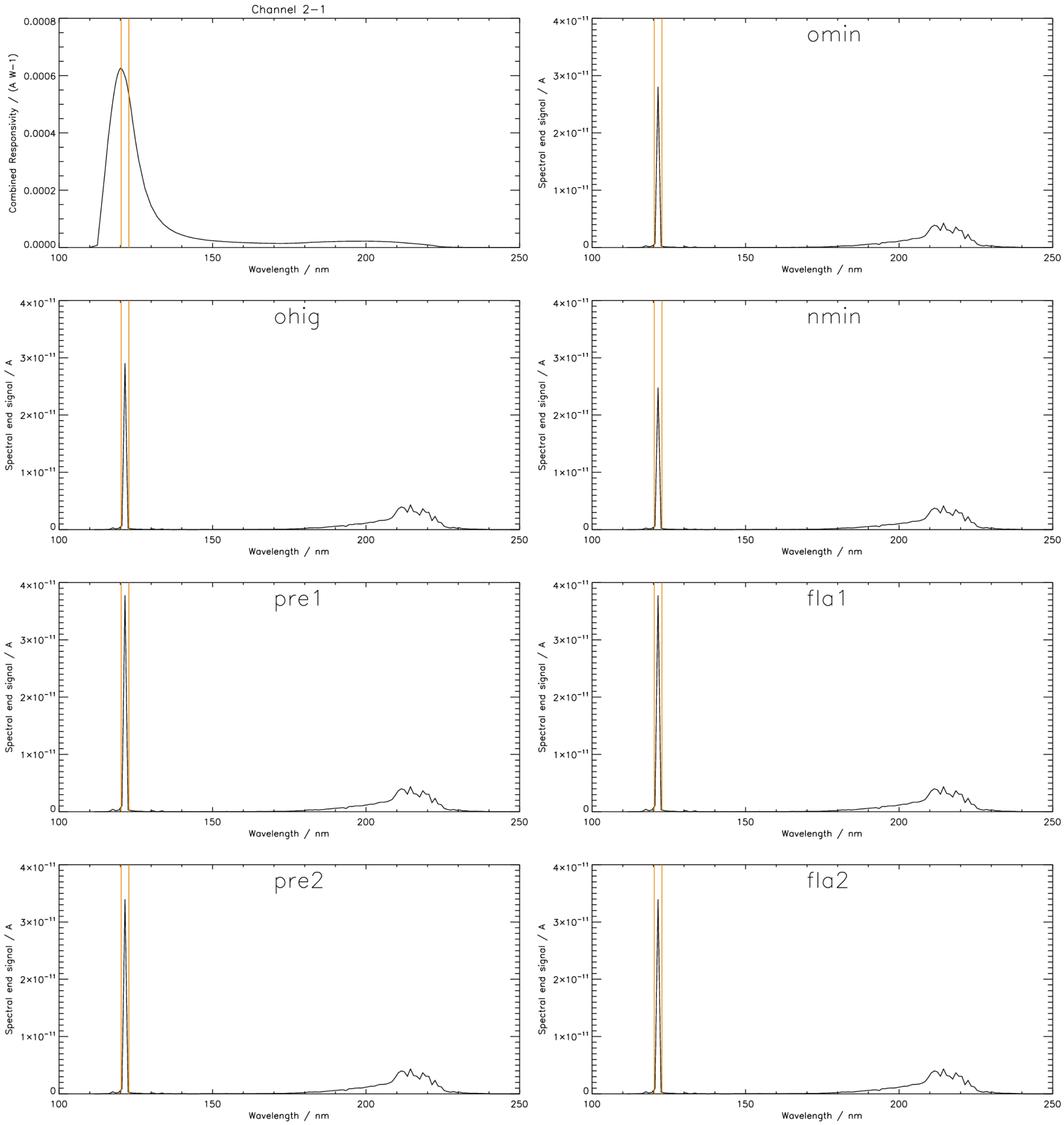

Figure 2-1. Measured responsivity and simulated output for LYRA channel 2-1
Ly XN + MSM21 (121.5 +/- nm)

```
sample  total        pure                  residual      solar
------  -----------  --------------------  -----------   ---------------
omin    0.107620 nA  0.0289875 nA (26.9%)  0.0786326 nA  0.00690130 Wm-2
ohig    0.110074 nA  0.0300149 nA (27.3%)  0.0800593 nA  0.00714568 Wm-2
nmin    0.101259 nA  0.0256423 nA (25.3%)  0.0756166 nA  0.00610500 Wm-2
pre1    0.121120 nA  0.0391210 nA (32.3%)  0.0819987 nA  0.00931232 Wm-2
fla1    0.121130 nA  0.0391210 nA (32.3%)  0.0820089 nA  0.00931232 Wm-2
pre2    0.116771 nA  0.0351230 nA (30.1%)  0.0816484 nA  0.00836111 Wm-2
fla2    0.116774 nA  0.0351230 nA (30.1%)  0.0816514 nA  0.00836111 Wm-2
```

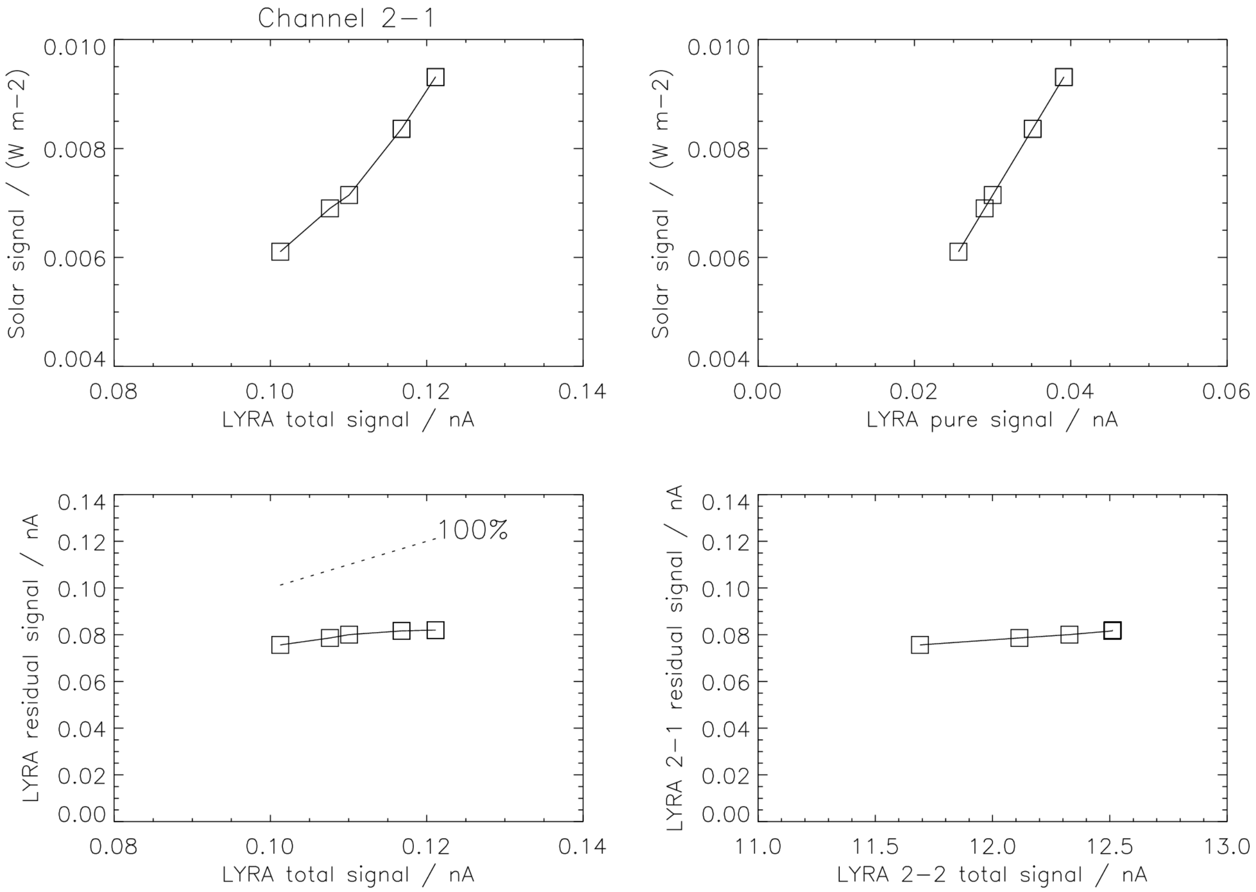

Figure 2-1a. Simulated relations between input and output for LYRA channel 2-1.

The functional relation between the solar signal and the LYRA total signal is almost linear (see upper left image). The reason for the small difference 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 be estimated with the help of the output signal from LYRA channel 2-2 by using a linear polynomial (see lower right image):

*[LYRA 2-1 residual signal / nA] = -0.0135830 + 0.00762035 * [LYRA 2-2 total signal / nA]*

On the other hand, it can also be estimated as a linear function of the total signal from LYRA channel 2-1 itself (see lower left image):

*[LYRA 2-1 residual signal / nA] = 0.0452721 + 0.307910 * [LYRA 2-1 total signal / nA]*

Instead of using a linear polynomial, linear interpolation can also be used. - All variants will be tested in the commissioning phase, before one will eventually be selected.

The pure signal can be estimated as the difference:

[LYRA 2-1 pure signal / nA] = [LYRA 2-1 total signal / nA] – [LYRA 2-1 residual signal / nA]

And the solar signal can again be estimated from the pure signal by a linear polynomial (see upper right image):

*[“Lyman-alpha” solar signal / (W m-2)] = 0.237946 * [LYRA 2-1 pure signal / nA]*

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three SORCE 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 linear factors, the estimation error is within 1.1% for the first variant, 3.4% for the second, and 0.06% for the third.

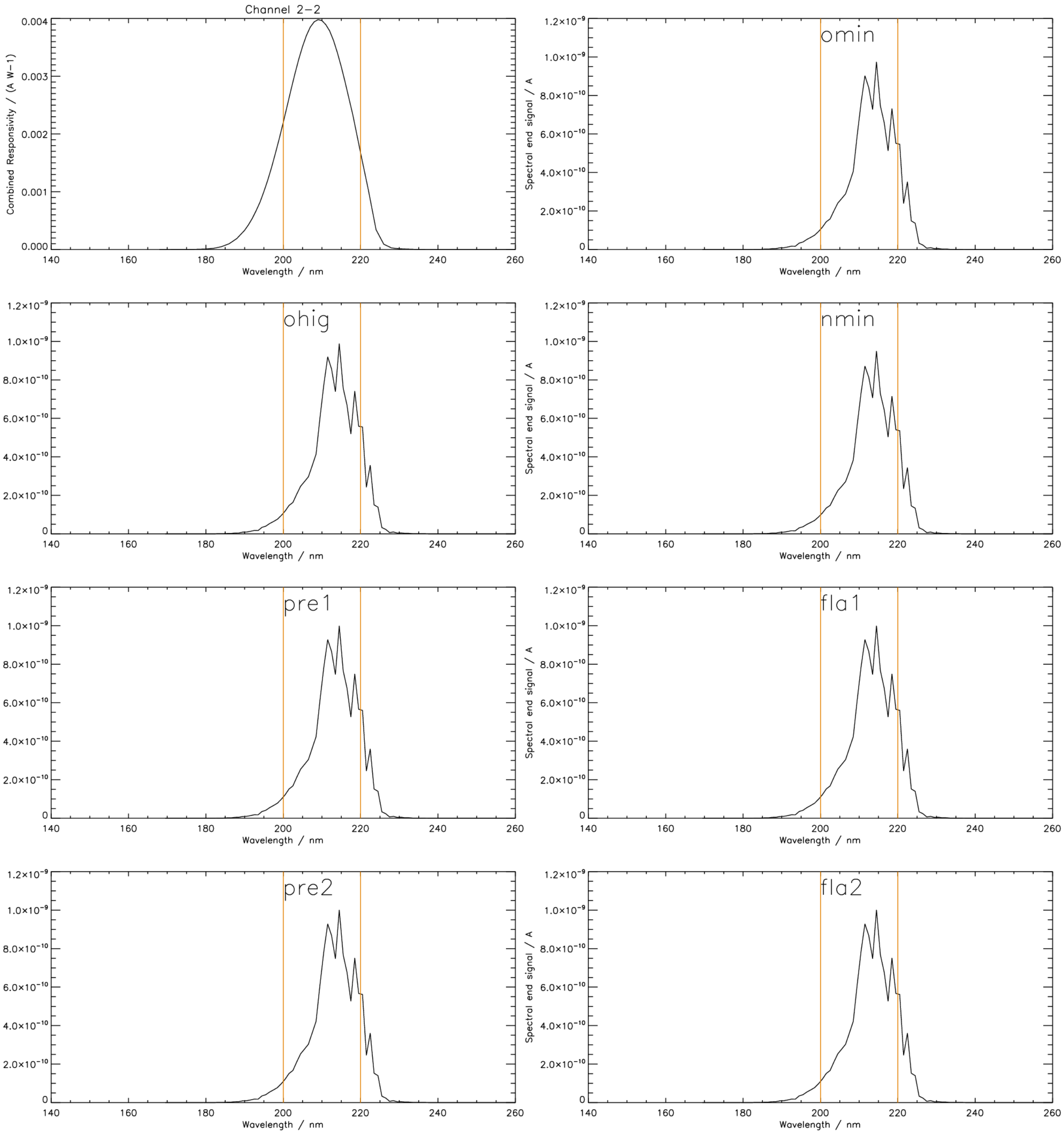

Figure 2-2. Measured responsivity and simulated output for LYRA channel 2-2
Herzberg + PIN11 (200-220 nm)

```
sample  total       pure                residual     solar
------  ----------  ------------------  ----------   -------------
omin    12.1142 nA  10.1644 nA (83.9%)  1.94973 nA   0.461334 Wm-2
ohig    12.3278 nA  10.3455 nA (83.9%)  1.98226 nA   0.469345 Wm-2
nmin    11.6903 nA   9.7972 nA (83.8%)  1.89309 nA   0.445404 Wm-2
pre1    12.5120 nA  10.5015 nA (83.9%)  2.01049 nA   0.476369 Wm-2
fla1    12.5120 nA  10.5015 nA (83.9%)  2.01049 nA   0.476369 Wm-2
pre2    12.5102 nA  10.4984 nA (83.9%)  2.01184 nA   0.476294 Wm-2
fla2    12.5102 nA  10.4984 nA (83.9%)  2.01184 nA   0.476294 Wm-2
```

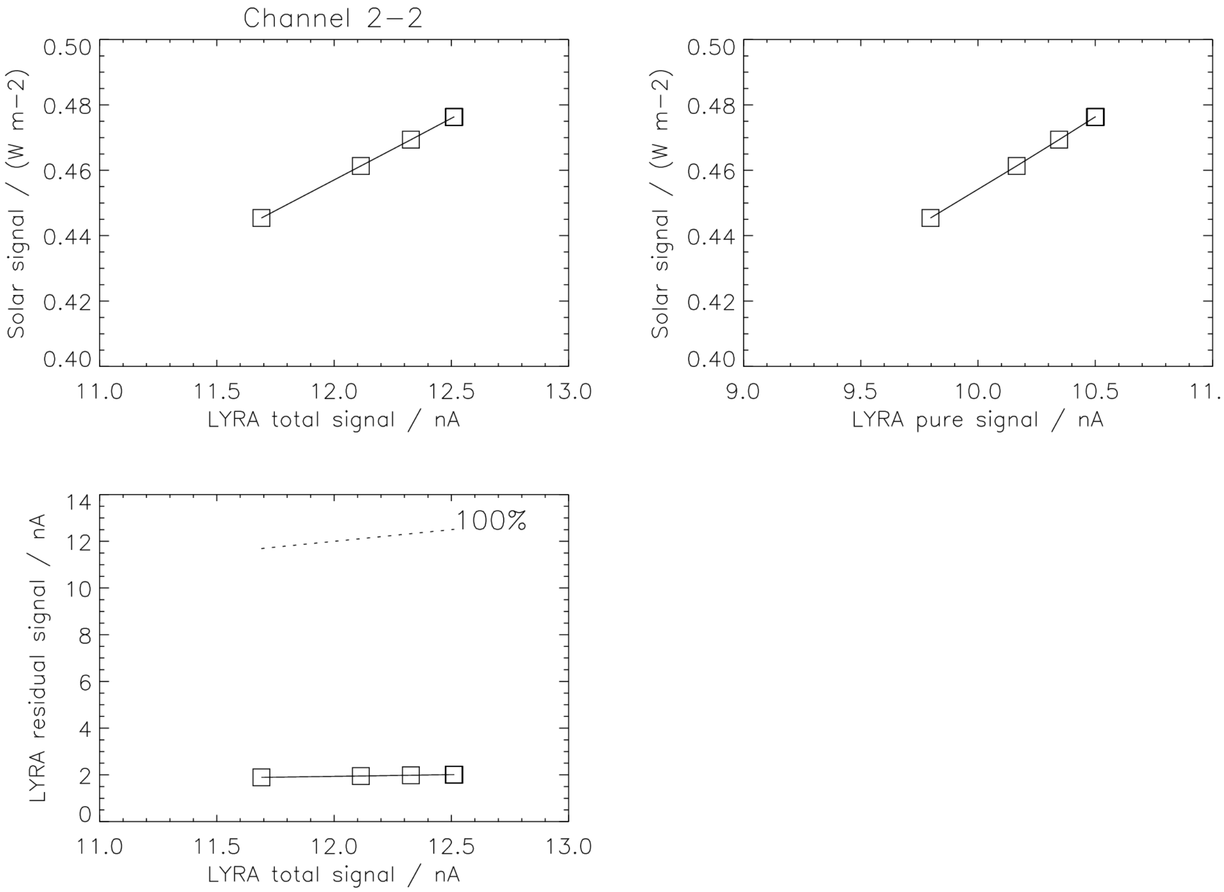

Figure 2-2a. Simulated relations between input and output for LYRA channel 2-2.

The functional relation between the solar signal and the LYRA total signal appears to be straightforward. The pure signal or the residual signal can be estimated by a linear polynomial (see lower image). Following the scheme of channel 2-1, the residual signal is calculated as:

*[LYRA 2-2 residual signal / nA] = 0.194055 + 0.145183 * [LYRA 2-2 total signal / nA]*

The pure signal can be estimated as the difference:

[LYRA 2-2 pure signal / nA] = [LYRA 2-2 total signal / nA] – [LYRA 2-2 residual signal / nA]

And the solar signal can be estimated from the pure signal by a linear polynomial (see upper right image):

*["Herzberg" solar signal / (W m-2)] = 0.0133344 + 0.0440908 * [LYRA 2-2 pure signal / nA]*

Remarks: 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 0.02%. - The behavior of samples pre1, fla1, pre2, fla2 is approx. identical, thus there are only four significantly different data points. Please note the consequence for channel 2-1: While there is a different total and pure (Lyman-alpha) signal response for the last four samples, i.e. pre1,fla1 vs. pre2,fla2, the residual signal is approx. identical, because it is dominated by longer wavelengths - like the channel 2-2 signal.

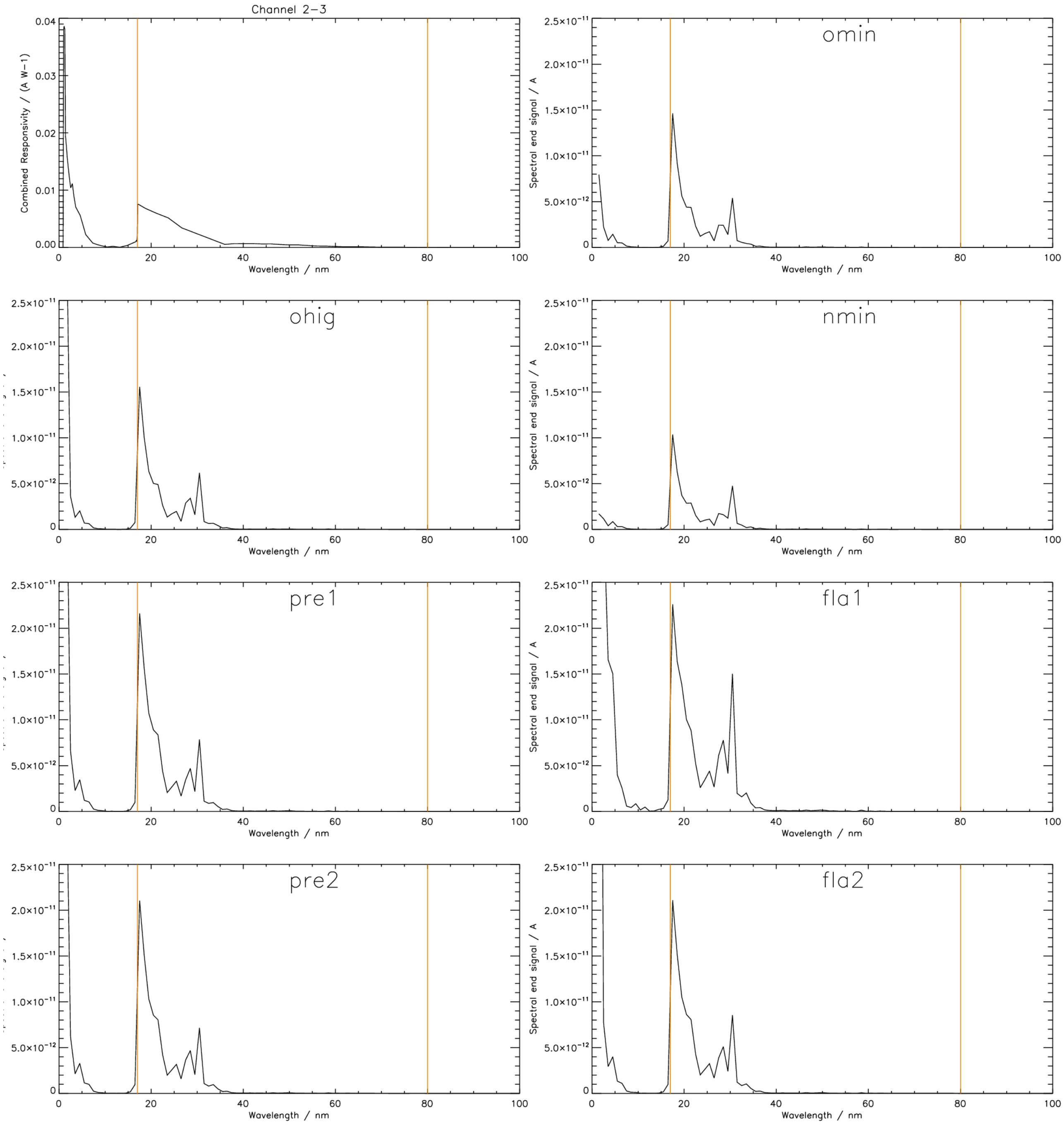

Figure 2-3. Measured responsivity and simulated output for LYRA channel 2-3
Aluminium + MSM15 (17-80 nm)

```
sample  total         pure                  residual      solar
------  ------------  --------------------  ------------  ----------------
omin    0.0747480 nA  0.0602369 nA (80.6%)  0.0145111 nA  0.00225541 Wm-2
ohig    0.116045  nA  0.0681402 nA (58.7%)  0.0479051 nA  0.00263286 Wm-2
nmin    0.0482399 nA  0.0427239 nA (88.6%)  0.0055161 nA  0.00171904 Wm-2
pre1    0.163001  nA  0.102442  nA (62.8%)  0.0605590 nA  0.00376518 Wm-2
fla1    1.37035   nA  0.132347  nA ( 9.7%)  1.23801   nA  0.00570166 Wm-2
pre2    0.154173  nA  0.0988576 nA (64.1%)  0.0553156 nA  0.00362499 Wm-2
fla2    0.227546  nA  0.102436  nA (45.0%)  0.125110  nA  0.00394254 Wm-2
```

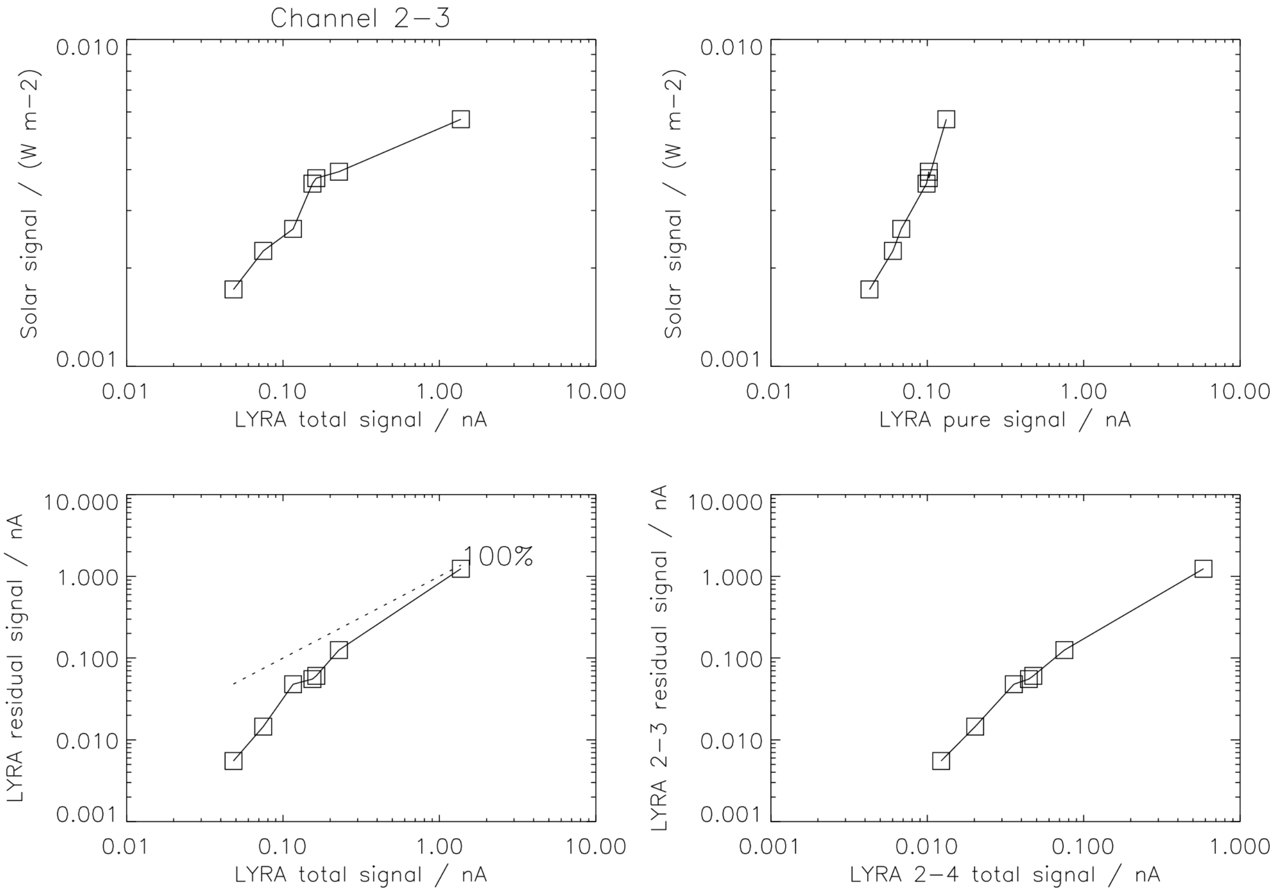

Figure 2-3a. Simulated relations between input and output for LYRA channel 2-3.

The functional relation between the solar signal and the LYRA total signal is still not quite straightforward (but much less irregular than before the last update, compare upper left image). The reason for nonlinearity 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 2-4; not as simple as in the case of channel 2-1, but with linear interpolation between the points of the relationship as shown in the lower right image:

[LYRA 2-3 residual signal / nA] = interp[LYRA 2-4 total signal / nA]

On the other hand, it can also be estimated as a function of the total signal from LYRA channel 2-3 itself (see lower left image):

[LYRA 2-3 residual signal / nA] = interp[LYRA 2-3 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 2-3 pure signal / nA] = [LYRA 2-3 total signal / nA] – [LYRA 2-3 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 nonlinear 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). - For the small subset of these channels' solar events which are similar to the “fla1” simulation data (i.e., flares), 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. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 9.5%, without logarithm to 11.5%.

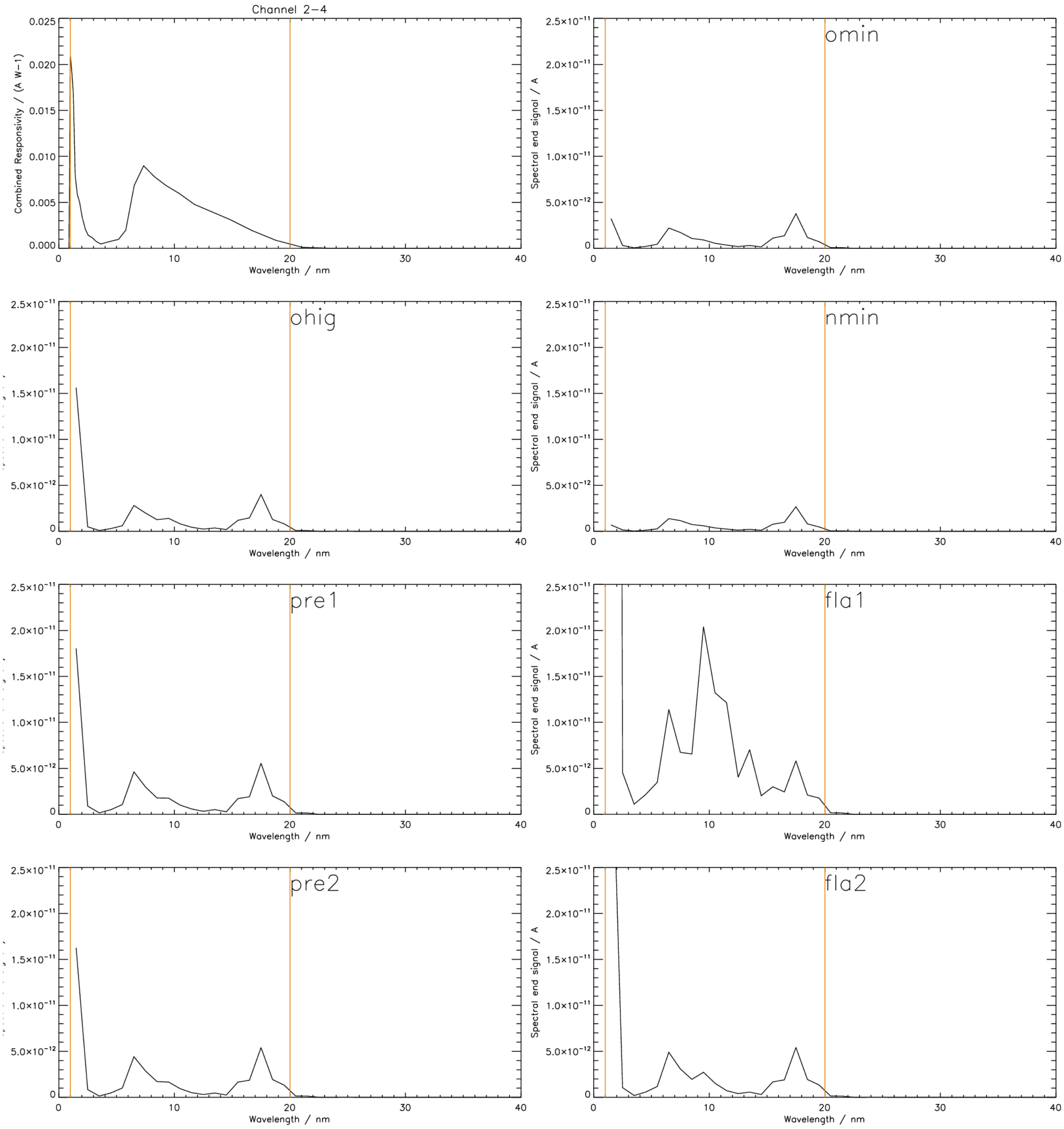

Figure 2-4. Measured responsivity and simulated output for LYRA channel 2-4 Zr(150nm) + MSM19 (1-20 nm)

```
sample  total         pure                   residual        solar
------  ------------  ---------------------  -------------   ---------------
omin    0.0202507 nA  0.0198091 nA (97.8%)   0.00044157 nA   0.00106140 Wm-2
ohig    0.0358174 nA  0.0353516 nA (98.7%)   0.00046579 nA   0.00144558 Wm-2
nmin    0.0122674 nA  0.0118852 nA (96.9%)   0.00038221 nA   0.00068972 Wm-2
pre1    0.0475856 nA  0.0469921 nA (98.8%)   0.00059347 nA   0.00208323 Wm-2
fla1    0.583394  nA  0.582767  nA (99.9%)   0.00062678 nA   0.0132763  Wm-2
pre2    0.0445960 nA  0.0440140 nA (98.7%)   0.00058198 nA   0.00198338 Wm-2
fla2    0.0752788 nA  0.0746944 nA (99.2%)   0.00058444 nA   0.00261203 Wm-2
```

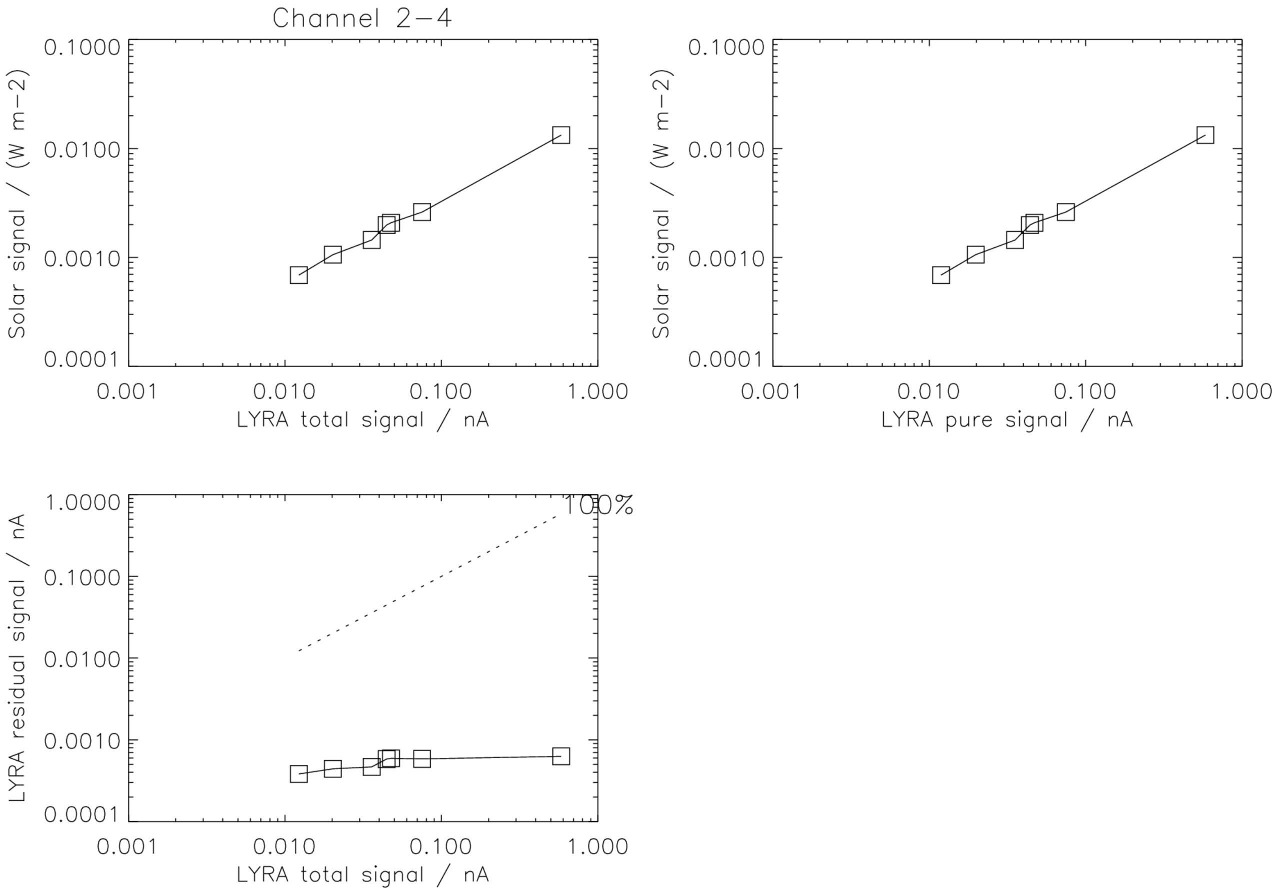

Figure 2-4a. Simulated relations between input and output for LYRA channel 2-4.

The functional relation between the solar signal and the LYRA total signal looks straightforward. Since the purity of the Zirconium channels is always around 100%, the residual signal is almost negligible (see lower figure) and can simply be set to the average. Following the usual scheme:

[LYRA 2-4 residual signal / nA] = 0.000525212

The pure signal can be estimated as the difference, which is almost the total signal:

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

Remarks: Due to the linear interpolation, the estimation error (caused by the averaging) is below 1.2%, but this is unrealistic. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 9.5%.

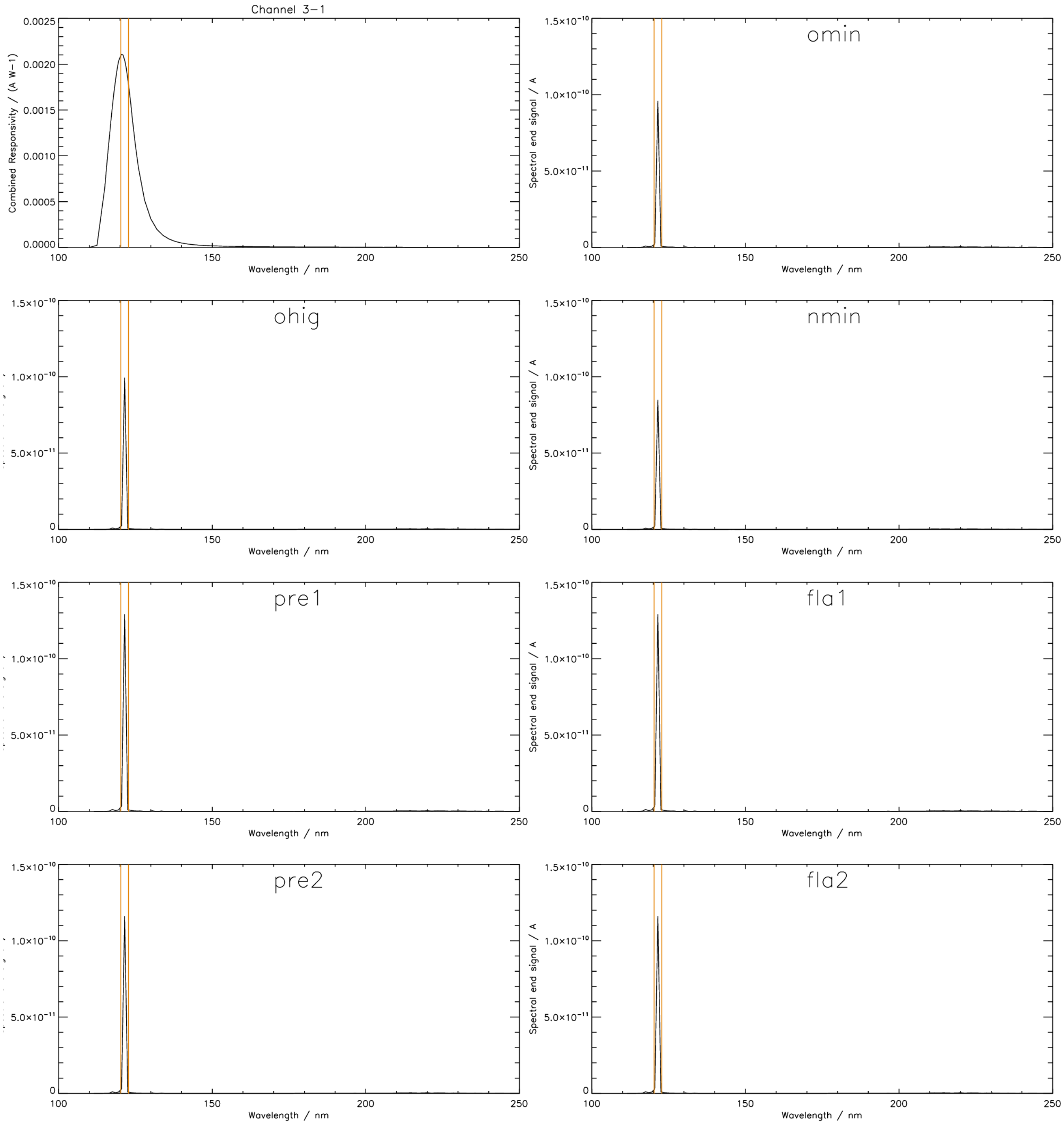

Figure 3-1. Measured responsivity and simulated output for LYRA channel 3-1
Ly N+XN + AXUV20A (121.5 +/- nm)

```
sample  total        pure                    residual      solar
------  -----------  --------------------    ------------  ---------------
omin    0.281019 nA  0.0990736 nA (35.3%)    0.181946  nA  0.00690130 Wm-2
ohig    0.284401 nA  0.102585  nA (36.1%)    0.181816  nA  0.00714568 Wm-2
nmin    0.269166 nA  0.0876394 nA (32.6%)    0.181527  nA  0.00610500 Wm-2
pre1    0.316782 nA  0.133704  nA (42.2%)    0.183078  nA  0.00931232 Wm-2
fla1    0.316808 nA  0.133704  nA (42.2%)    0.183104  nA  0.00931232 Wm-2
pre2    0.302820 nA  0.120042  nA (39.6%)    0.182778  nA  0.00836111 Wm-2
fla2    0.302828 nA  0.120042  nA (39.6%)    0.182786  nA  0.00836111 Wm-2
```

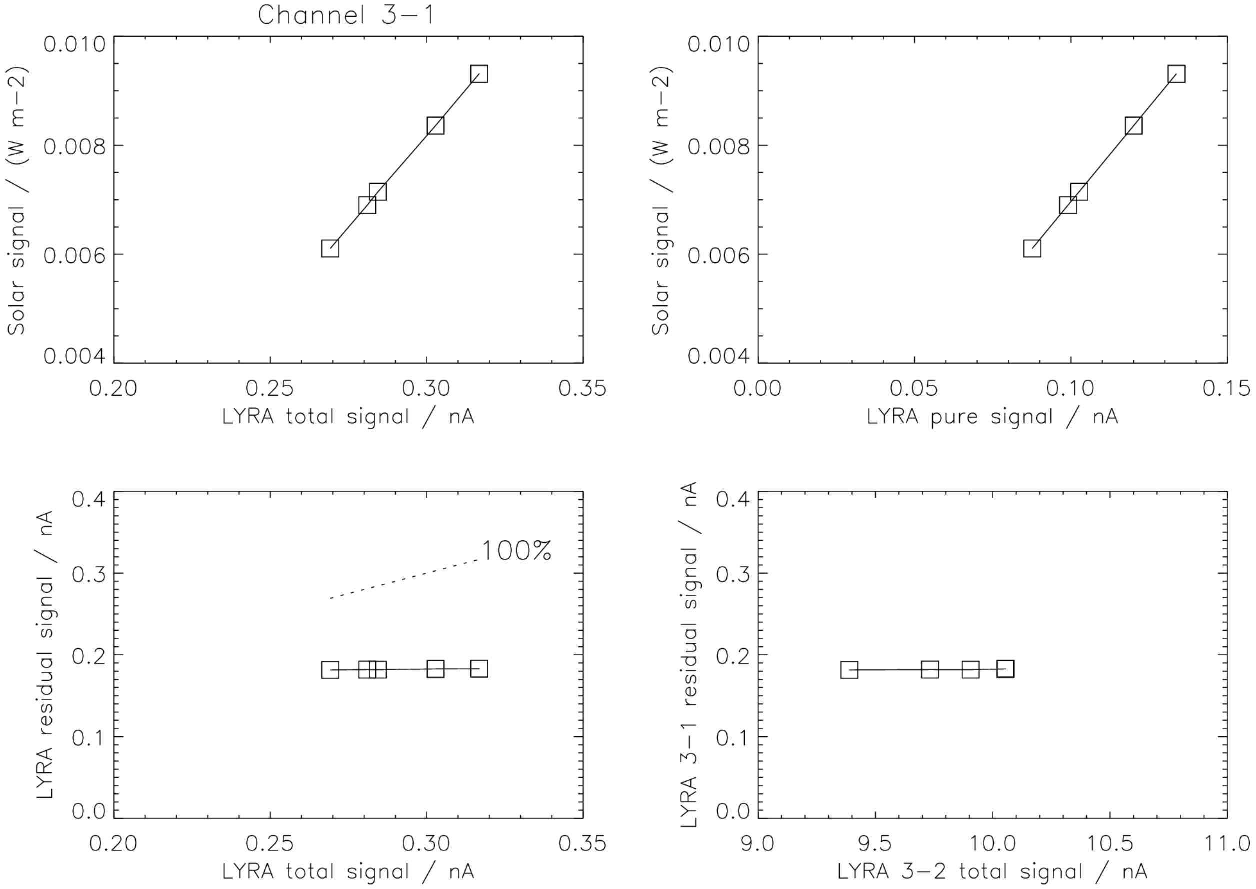

Figure 3-1a. Simulated relations between input and output for LYRA channel 3-1.

The functional relation between the solar signal and the LYRA total signal is almost linear (see upper left image). The reason for the small difference is a contamination due to the influence of the visual and infrared, which is not part of the nominal interval around the Lyman-alpha line. But this residual signal can be estimated with the help of the output signal from LYRA channel 3-2 by using a linear polynomial (see lower right image):

[LYRA 3-1 residual signal / nA] = 0.160460 + 0.00222130 * [LYRA 3-2 total signal / nA]

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

[LYRA 3-1 residual signal / nA] = 0.172118 + 0.0348196 * [LYRA 3-1 total signal / nA]

Please note: Apparently, the long-wavelength contamination is basically independent from channel 3-1 or 3-2 signal variations, it hardly varies at all, thus the relatively large constants and small linear factors. The residual may as well be set to the average signal 0.182433, see table last page. - Instead of using a linear polynomial, linear interpolation can also be used. - All variants will be tested in the commissioning phase, before one will eventually be selected.

The pure signal can be estimated as the difference:

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

And the solar signal can again be estimated from the pure signal by a linear polynomial (see upper right image):

[“Lyman-alpha” solar signal / (W m-2)] = 0.0696250 * [LYRA 3-1 pure signal / nA]

Remarks: Defining 2.5 nm around 121.5 nm as nominal interval leads to just three SORCE 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 linear factors, the estimation error is within 0.7% for the first variant, 0.3% for the second, 0.7% for the third, and 0.05% for the fourth.

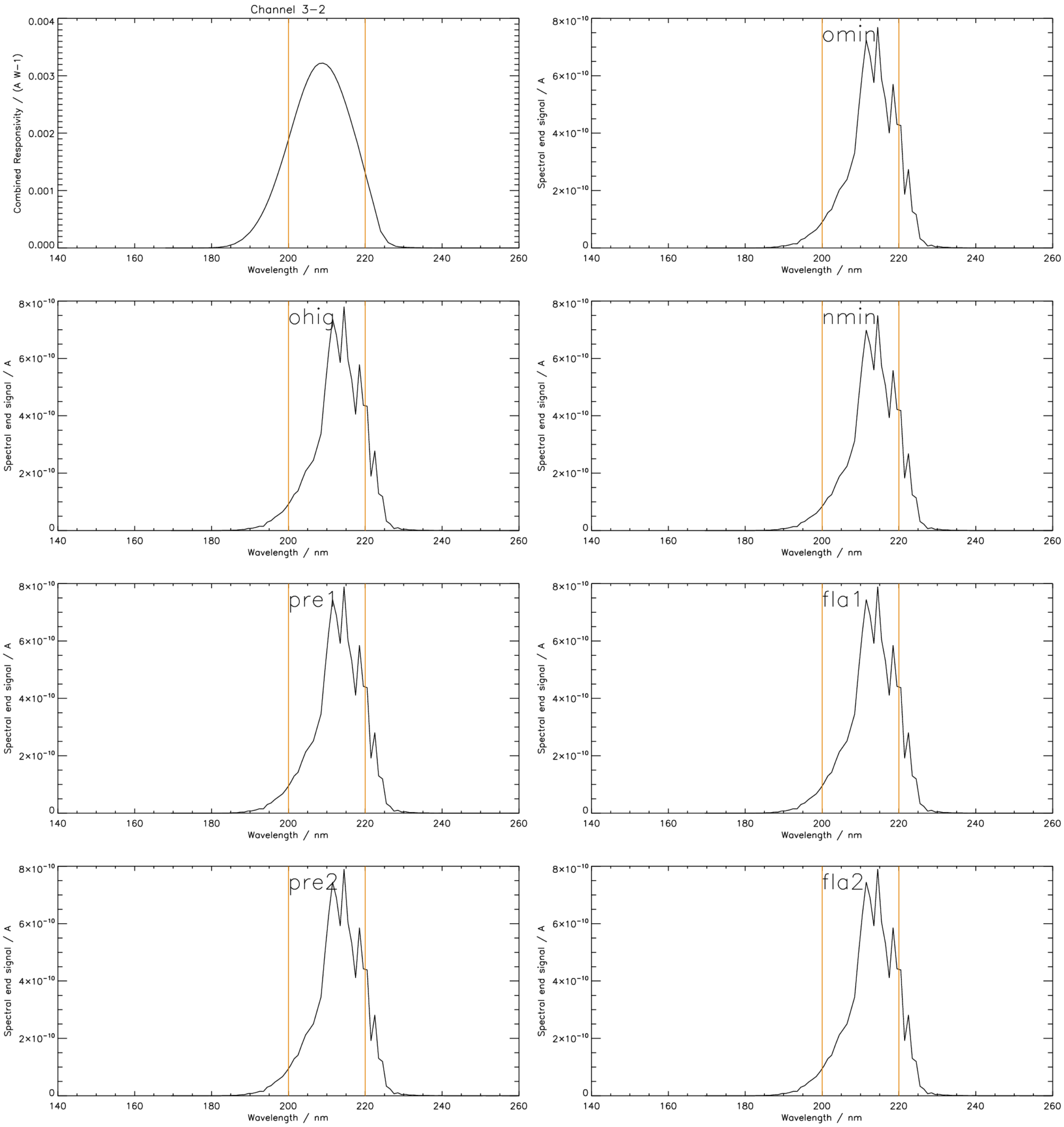

Figure 3-2. Measured responsivity and simulated output for LYRA channel 3-2
Herzberg + PIN12 (200-220 nm)

```
sample  total       pure                  residual     solar
------  ----------  ------------------    ----------   -------------
omin    9.73302 nA  8.13731 nA (83.6%)    1.59571 nA   0.461334 Wm-2
ohig    9.90555 nA  8.28307 nA (83.6%)    1.62248 nA   0.469345 Wm-2
nmin    9.38890 nA  7.84033 nA (83.5%)    1.54857 nA   0.445404 Wm-2
pre1    10.0550 nA  8.40909 nA (83.6%)    1.64592 nA   0.476369 Wm-2
fla1    10.0550 nA  8.40909 nA (83.6%)    1.64592 nA   0.476369 Wm-2
pre2    10.0531 nA  8.40616 nA (83.6%)    1.64690 nA   0.476294 Wm-2
fla2    10.0531 nA  8.40616 nA (83.6%)    1.64690 nA   0.476294 Wm-2
```

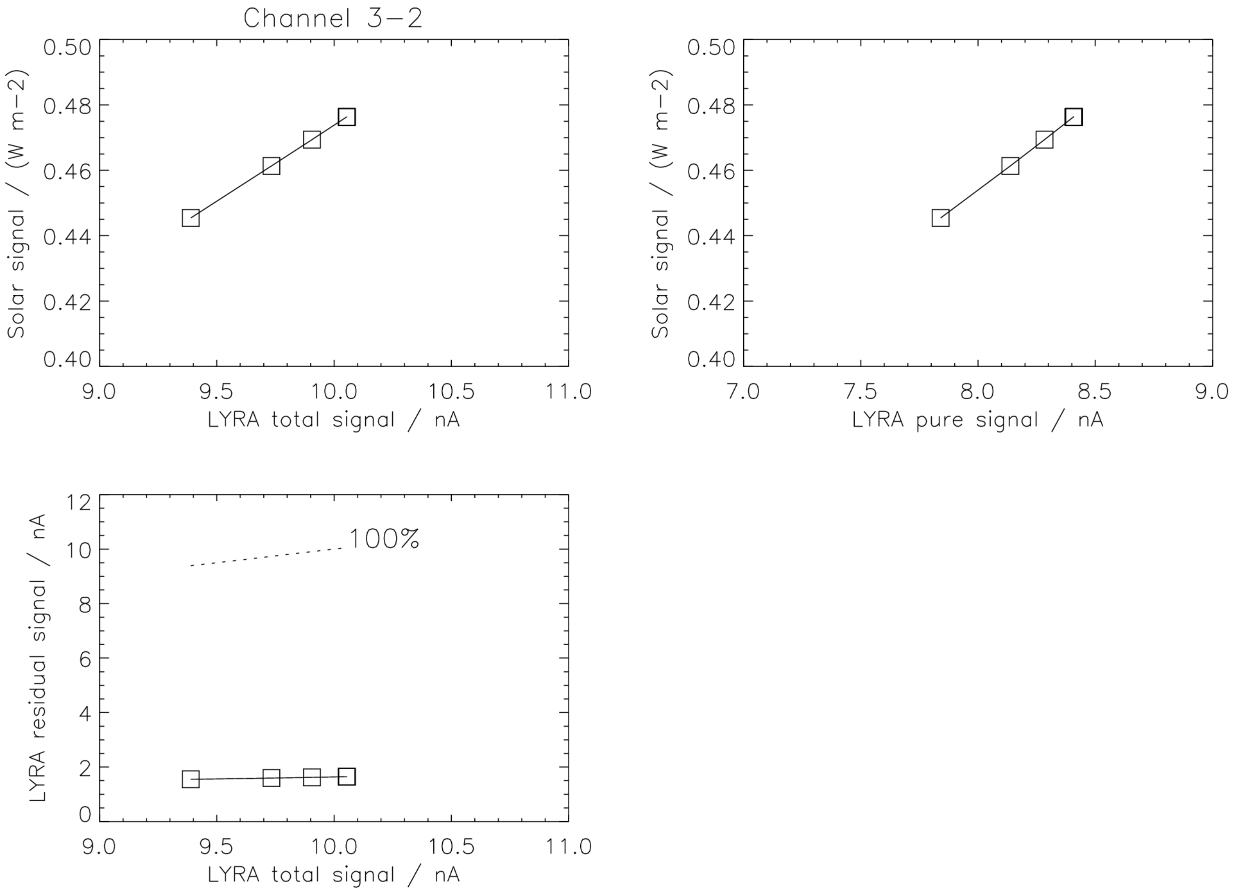

Figure 3-2a. Simulated relations between input and output for LYRA channel 3-2.

The functional relation between the solar signal and the LYRA total signal appears to be straightforward. The pure signal or the residual signal can be estimated by a linear polynomial (see lower image). Following the scheme of channel 3-1, the residual signal is calculated as:
*[LYRA 3-2 residual signal / nA] = 0.153016 + 0.148481 * [LYRA 3-2 total signal / nA]*

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

And the solar signal can be estimated from the pure signal by a linear polynomial (see upper right image):
*["Herzberg" solar signal / (W m-2)] = 0.0169567 + 0.0546320 * [LYRA 3-2 pure signal / nA]*

Remarks: 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 0.02%. - The behavior of samples pre1, fla1, pre2, fla2 is approx. identical, thus there are only four significantly different data points. Please note the consequence for channel 3-1: While there is a different total and pure (Lyman-alpha) signal response for the last four samples, i.e. pre1,fla1 vs. pre2,fla2, the residual signal is approx. identical, because it is dominated by longer wavelengths - like the channel 3-2 signal. (This argument is weaker here than for channels 1-1 and 2-1, though, since in 3-1 the residual is approx. the same in *all* cases; see above.)

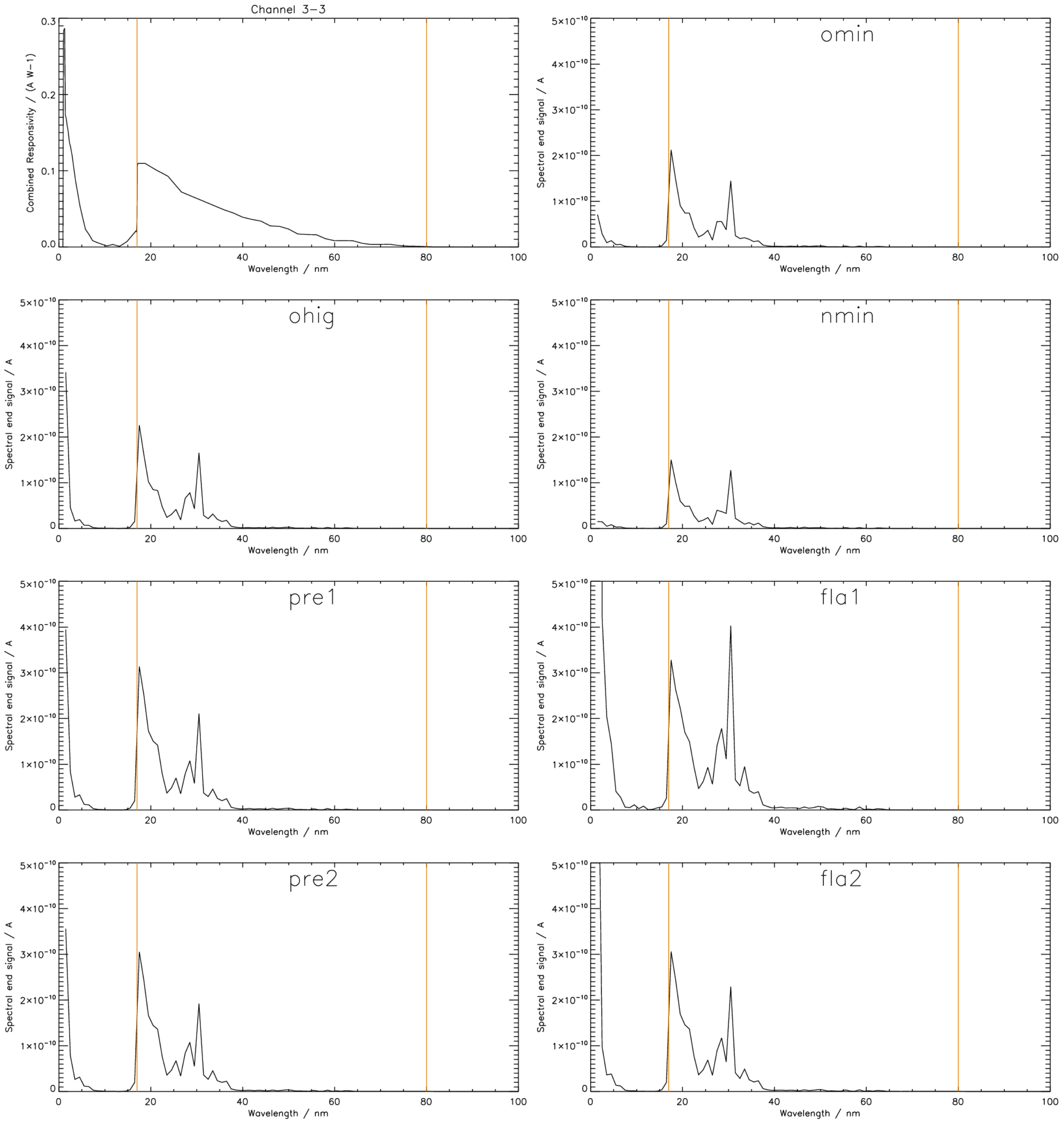

Figure 3-3. Measured responsivity and simulated output (min, high, max) for LYRA channel 3-3.
Aluminium + AXUV20B (17-80 nm)

```
sample  total        pure                  residual       solar
------  -----------  -------------------   ------------   ---------------
omin    1.33875  nA  1.17565  nA (87.8%)   0.163105   nA  0.00225541 Wm-2
ohig    1.82018  nA  1.35076  nA (74.2%)   0.469419   nA  0.00263286 Wm-2
nmin    0.926361 nA  0.852770 nA (92.1%)   0.0735906 nA   0.00171904 Wm-2
pre1    2.59768  nA  1.99496  nA (76.8%)   0.602722   nA  0.00376518 Wm-2
fla1    14.0374  nA  2.76441  nA (19.7%)   11.2730    nA  0.00570166 Wm-2
pre2    2.47385  nA  1.92050  nA (77.6%)   0.553353   nA  0.00362499 Wm-2
fla2    3.20341  nA  2.01814  nA (63.0%)   1.18527    nA  0.00394254 Wm-2
```

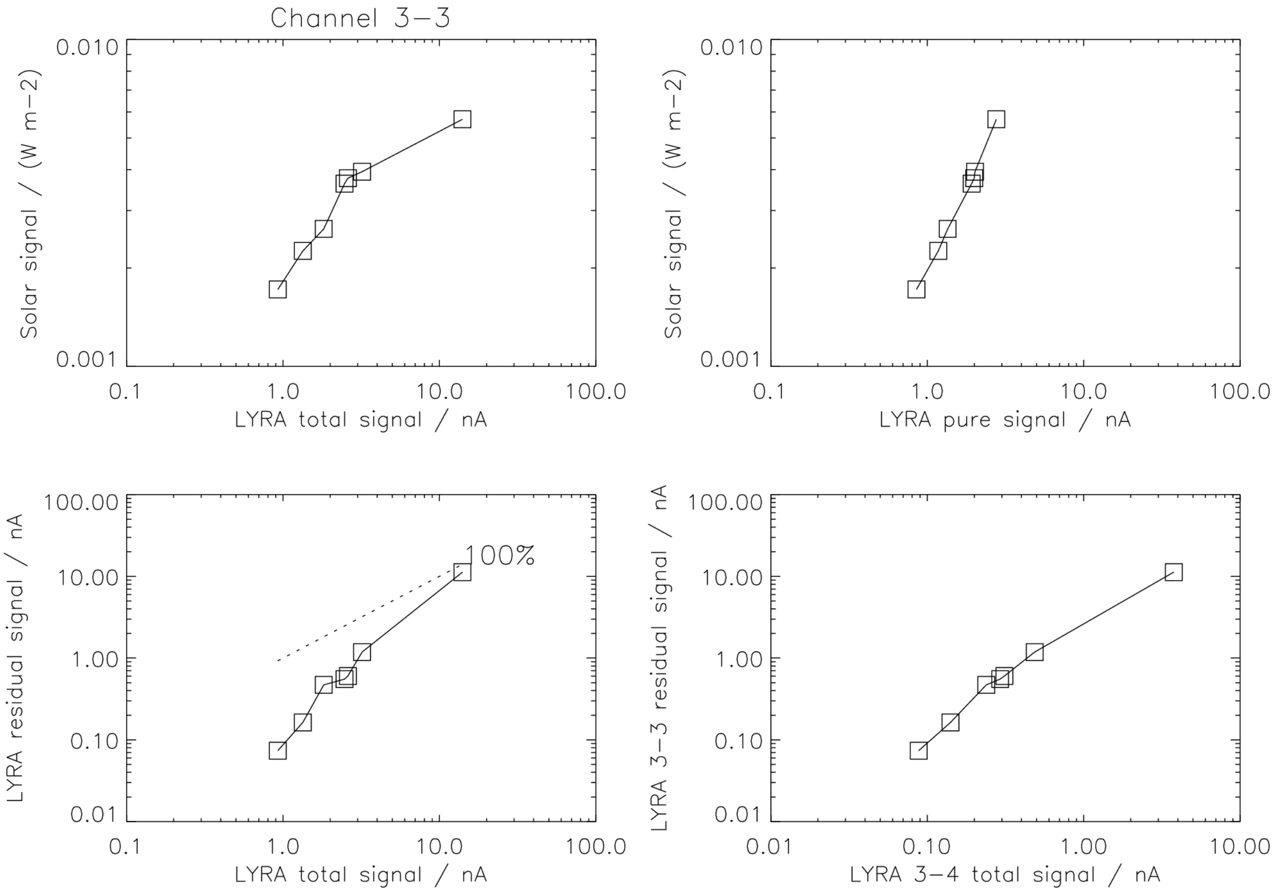

Figure 3-3a. Simulated relations between input and output for LYRA channel 3-3.

The functional relation between the solar signal and the LYRA total signal is still not quite straightforward (but much less irregular than before the last update, compare upper left image). The reason for nonlinearity 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 3-4; not as simple as in the case of channel 3-1, but with linear interpolation between the points of the relationship as shown in the lower right image:

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

On the other hand, it can also be estimated as a function of the total signal from LYRA channel 3-3 itself (see lower left image):

[LYRA 3-3 residual signal / nA] = interp[LYRA 3-3 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 3-3 pure signal / nA] = [LYRA 3-3 total signal / nA] – [LYRA 3-3 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 nonlinear 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 40 nm (see Figure 2-3). - For the small subset of these channels' solar events which are similar to the “fla1” simulation data (i.e., flares), 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. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 5.2%, without logarithm to 7.4%.

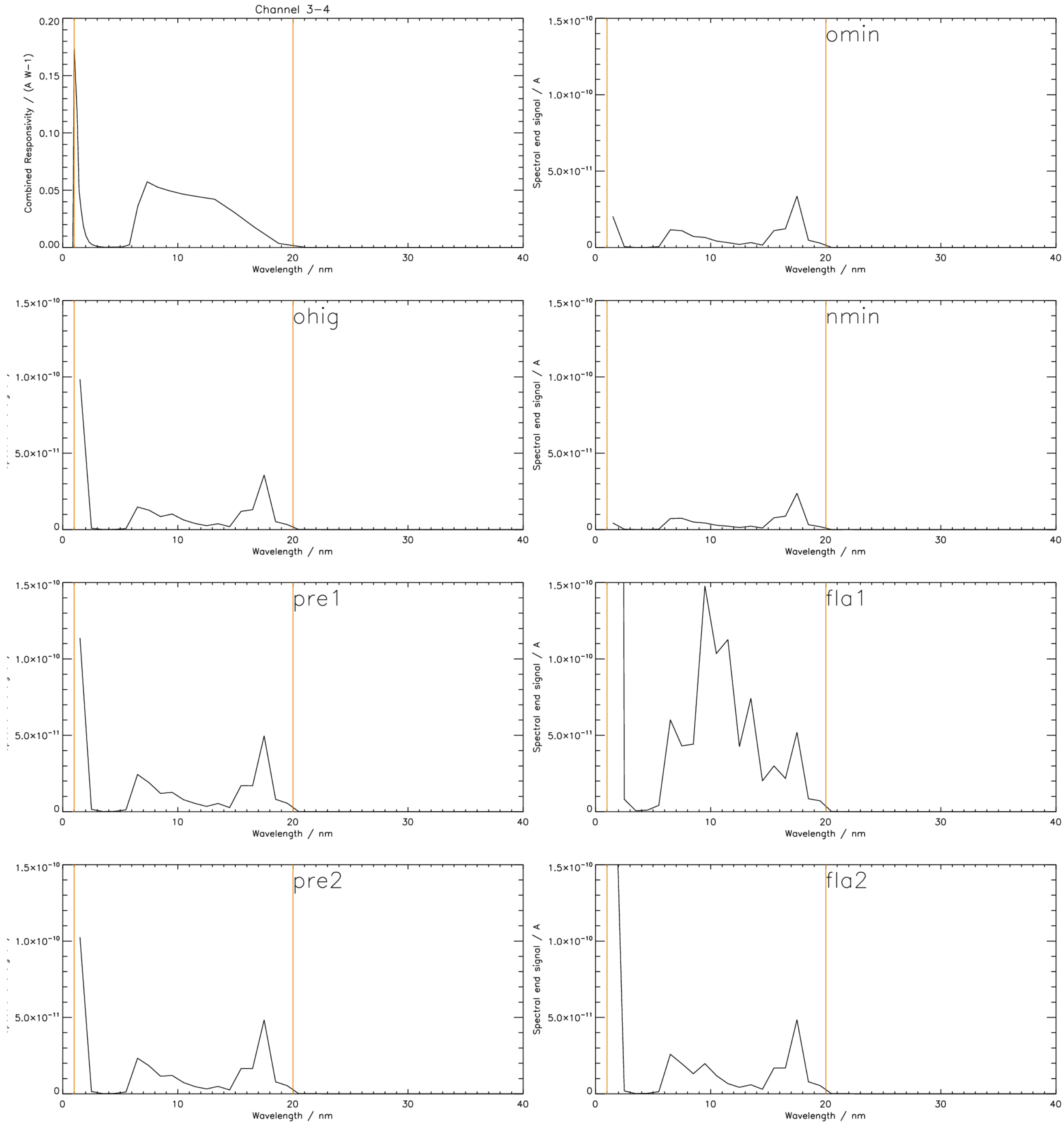

Figure 3-4. Measured responsivity and simulated output for LYRA channel 3-4
Zr(300nm) + AXUV20C (1-20 nm)

```
sample  total         pure                  residual        solar
------  ------------  --------------------  -------------   ---------------
omin    0.140740  nA  0.136890  nA (97.3%)  0.00385079 nA   0.00106140 Wm-2
ohig    0.238299  nA  0.234436  nA (98.4%)  0.00386263 nA   0.00144558 Wm-2
nmin    0.0881131 nA  0.0843017 nA (95.7%)  0.00381144 nA   0.00068972 Wm-2
pre1    0.311208  nA  0.307252  nA (98.7%)  0.00395656 nA   0.00208323 Wm-2
fla1    3.76597   nA  3.76199   nA (99.9%)  0.00398082 nA   0.0132763  Wm-2
pre2    0.292085  nA  0.288129  nA (98.6%)  0.00395597 nA   0.00198338 Wm-2
fla2    0.486117  nA  0.482159  nA (99.2%)  0.00395817 nA   0.00261203 Wm-2
```

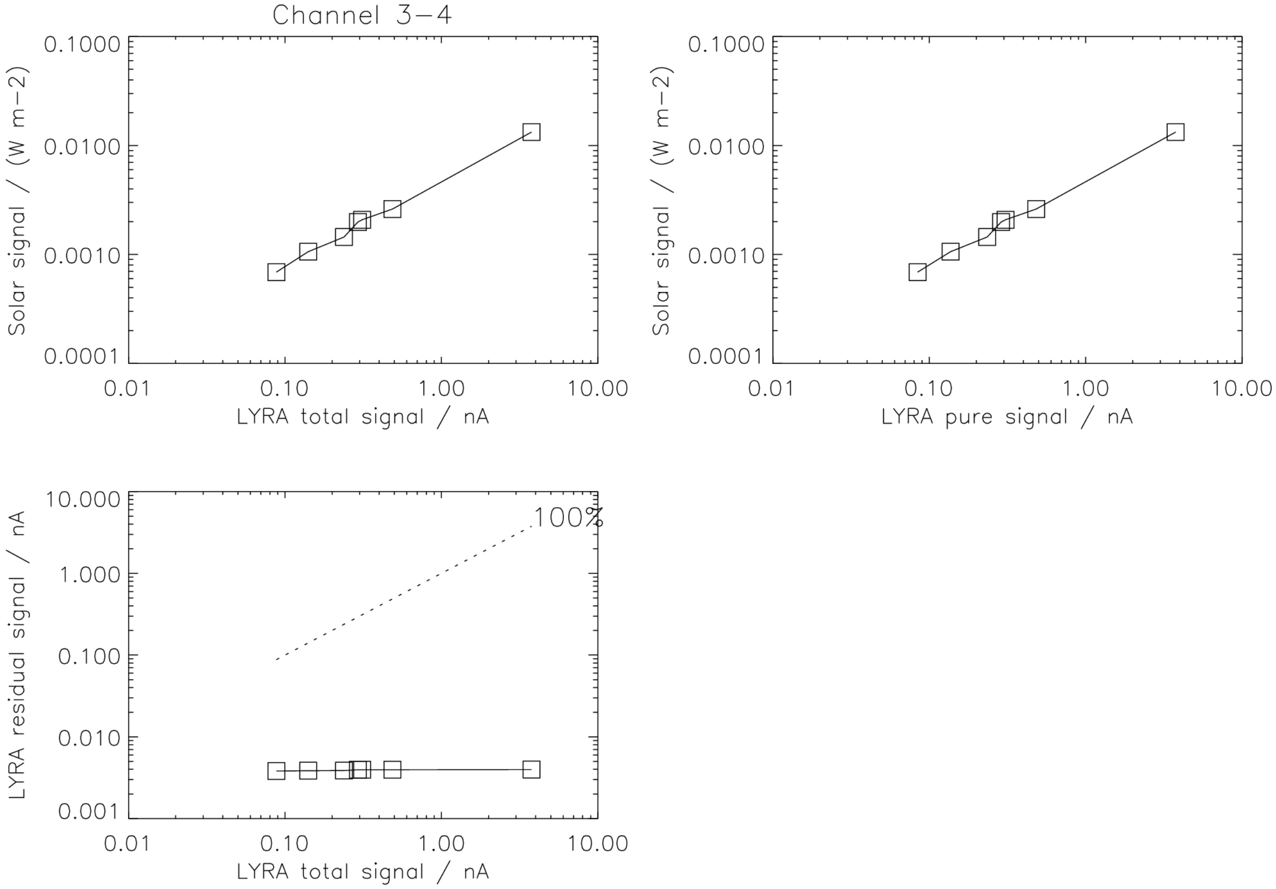

Figure 3-4a. Simulated relations between input and output for LYRA channel 3-4.

The functional relation between the solar signal and the LYRA total signal looks straightforward. Since the purity of the Zirconium channels is always around 100%, the residual signal is almost negligible (see lower figure) and can simply be set to the average. Following the usual scheme:
[LYRA 3-4 residual signal / nA] = 0.00391062

The pure signal can be estimated as the difference, which is almost the total signal:
[LYRA 3-4 pure signal / nA] = [LYRA 3-4 total signal / nA] – [LYRA 3-4 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 3-4 pure signal / nA]

Remarks: Due to the linear interpolation, the estimation error (caused by the averaging) is below 0.2%, but this is unrealistic. If fitted by a linear polynomial on the logarithms of pure and solar signals, the error would go up to 8.6%.