LYRA flare strengths over time

IED 30 Jul 2019, updated 03 Oct 2019

All April 2019, LYRA ch2-3 stayed around a baseline of about 2.25e-03 W/m2, LYRA 2-4 stayed around 0.78e-03 W/m2, see here:
  http://solwww.oma.be/users/dammasch/flares/overallApr2019.png
Meanwhile, GOES jumped from 1.86e-08 up to 9.66e-08 W/m2 between 19:33 and 19:34 UTC on 18 Apr 2019. So this was the moment where GOES re-calibration came into effect.

The linear relationship between GOES and LYRA (ch2-3 and ch2-4) flares across several orders of magnitude are the foundation of the proxy that the LYRA team presents on the website
  http://solwww.oma.be/users/dammasch/GoesVsLyra.html

To confirm that the relationship between LYRA and GOES flares still holds, two B1.3 flares, one from before, one from after the re-calibration are compared.

Before: 13 Apr 2019, 02:28 UTC, GOES jumps from 5e-08 to 1.3e-07 (which is an "old" B1.3 flare). The difference is 8e-08.
  http://proba2.oma.be/lyra/data/Flarelist/flare20190413_0790.png
In parallel, LYRA ch2-3 jumps from 2.270 to 2.275e-03, thus a difference of 5e-06. LYRA ch2-4 jumps from 0.811 to 0.817e-03, thus a difference of 6e-06. LYRA jumps were always similar between ch2-3 and ch2-4, and to compare them with GOES flare strengths, one had to take the jump differences and not the absolute values, because LYRA ch2-3 and ch2-4 have a relatively high baseline of EUV irradiance. This background is meanwhile basically *estimated* because of EUV degradation, but until now it was assumed that the flare SXR contribution degraded much less. Please compare the figure on page 2 of this old report here:
  http://solwww.oma.be/users/dammasch/IED_20110922_EstimatingGoesFlares_ext.pdf
Whether the situation has indeed changed will be treated in this report.

After: 19 Apr 2019, 16:13 UTC, GOES jumps from 9e-08 to 1.3e-07 (which is a "new" B1.3 flare). The difference is 4e-08, i.e. half of the jump mentioned above; with the B1.3 level remaining constant, the jump is smaller, because the baseline after the re-calibration is higher.
  http://proba2.oma.be/lyra/data/Flarelist/flare20190419_2390.png
In parallel, LYRA ch2-3 jumps from 2.262 to 2.264e-03, thus a difference of 2e-06. LYRA ch2-4 jumps from 0.793 to 0.796e-03, thus a difference of 3e-06. Again, the LYRA channels are similar, and they show a smaller jump in LYRA for a smaller jump in GOES. The relationship mentioned in the old report still seems to work.

To further test this relationship, two groups of flares, again *before* and *after* the GOES re-calibration, were observed. The first group was taken from an active week 20-25 Mar 2019, the second group was taken from an active week 03-10 May 2019. Various tests were made to study the relationship between LYRA ch2-3 and LYRA ch2-4 vs. GOES with and without background. The results can be found in the table at the end of this report.

The basic assumption of the 2011 report mentioned above is that the GOES curve can be estimated from the LYRA curves via a simple linear factor:
  GOES = 0.015*LYRA3 , GOES = 0.018*LYRA4 , LYRA4/LYRA3 = 0.8
Thus, in a linear fit, the first component (“a”) should be close to zero; in a logarithmic fit, the second component (“b”) should be close to one. As can be seen in the table at the end of this report, this is the case for the linear fits; the logarithmic fits work better for GOES values with background subtracted. *Figure 1* on the next page shows the log-fits *before* and *after*, for LYRA4 and GOES without background.

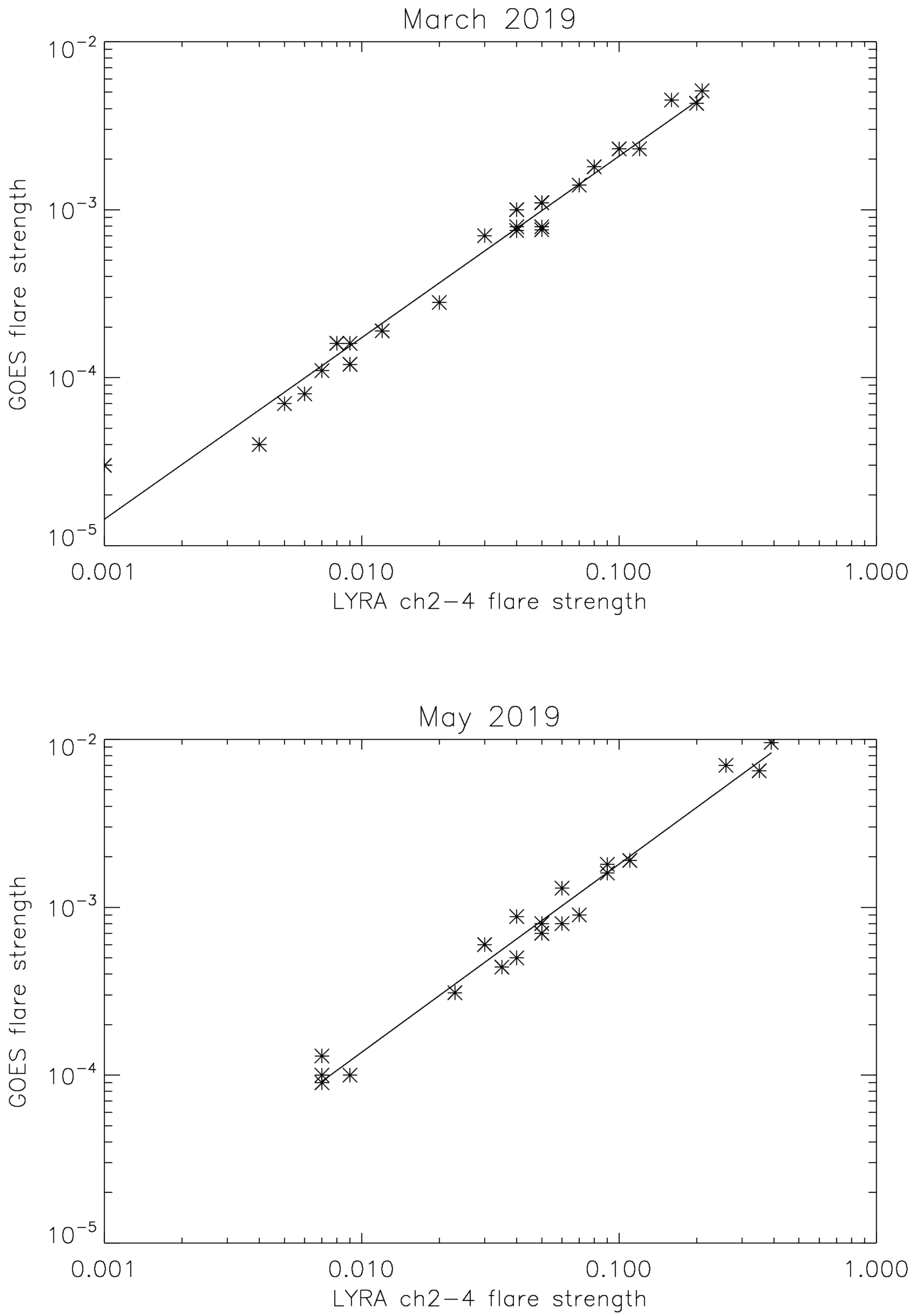


Figure 1: As an example, GOES vs. LYRA4 net flare strengths (i.e. pre-flare backgrounds subtracted), on a logarithmic scale, with fit, before and after GOES re-calibration.

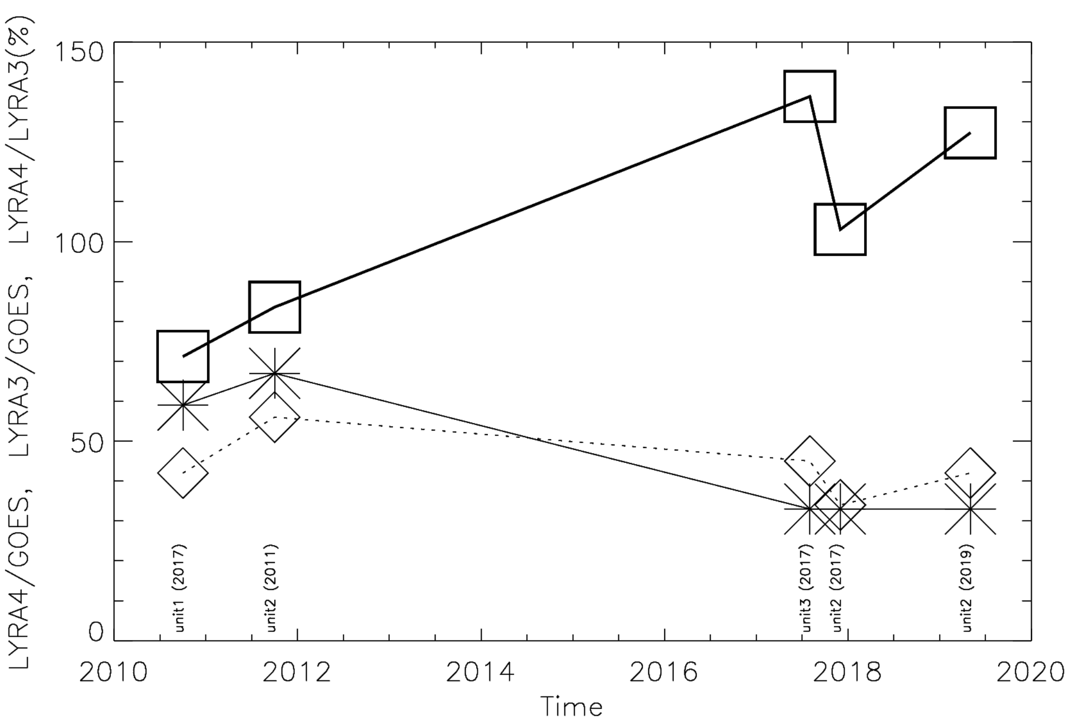
(*Attention, possible source of confusion:* When trying to convert LYRA into GOES, I use the factors as mentioned above. In the following I want to demonstrate how the LYRA flare strengths change relative to GOES, the latter assumed constant. Therefore I use the *inverse* of the above-mentioned factors.)

The results of the fits of the active weeks are as follows:
- the subtraction of LYRA background is necessary (as before)
- the linear fits show a correlation ~ 99%, with or without GOES background
- the logarithmic fits show a better correlation, a better power law, a better consistence with the linear fits when the GOES background is subtracted
- there is no significant difference *before* (March 2019) and *after* (May 2019) GOES re-calibration
- **but:** there are significantly different values for the relations LYRA3/GOES, LYRA4/GOES, LYRA4/LYRA3 as compared to 2011.

March 2019:	LYRA3/GOES	= 32, 34, 35 (lin-fit with, lin-fit without, log-fit without GOES backgr)
	LYRA4/GOES	= 40, 42, 39
	LYRA4/LYRA3	= 122%, 110% (lin-fit, log-fit)
May 2019:	LYRA3/GOES	= 33, 33, 29
	LYRA4/GOES	= 42, 43, 42
	LYRA4/LYRA3	= 128%, 138%
but Sep 2011:	LYRA3/GOES	= 67
	LYRA4/GOES	= 56
	LYRA4/LYRA3	= 80%

In a flare campaign performed in September 2017, all three LYRA units were used.
http://solwww.oma.be/users/dammasch/IED_20170706_FlareWatchApr2017.pdf
LYRA unit 2 is used (and degraded) more than unit 3; unit 1 at that time is almost not used at all (and least degraded). A separate analysis of EUV and SXR components in flares showed that - compared to the nominal unit 2 - the SXR component was less degraded in ch3-4 and ch1-4, and SXR as well as EUV components were less degraded in ch1-3. The cause is probably the massive degradation of all LYRA channels above 20nm as a function of exposure time.

Considering the different exposure times of units 1, 2, 3, the following image emerges *(Figure 2)*:



So it appears that LYRA flare strengths also degraded, and in channel 3 more so than in channel 4, but much slower than for quiet (EUV) situations; compare *Figure 5* with LYRA unit 2 degradation over time at the end of this report. For ch2-3, only 1% of the original output is left, for ch2-4, 17% is left. For the flare strengths much more is left: ~ 40% for ch2-3, ~ 60% for ch2-4, considering *Figure 2* or the fitted trend in *Figure 3*.

To further quantify the flare strength degradation, a series of 84 flares (most of them M1.0) were analyzed across the whole LYRA time in space so far, i.e. 2010 to 2019. The next figure shows the flare-strength factors LYRA3/GOES and LYRA4/GOES (all without background). The data points are fitted with a curve 1/x for ch2-3 and a linear curve for ch2-4. As one can see, the single observations of 2011, 2017 and 2019 (inserted as larger squares) are consistent with the trend, compare *Figure 3* below.

The question remains why there is such a large variety in the flare-strength factors. How is it possible that the same GOES flare strength (e.g. M1.0) can lead to LYRA flare strengths which are more than a factor 2 apart? A possible explanation is that the flares have different temperatures. The GOES channel used here responds in the spectral range 0.1-0.8nm. LYRA3 responds in a spectral range below 5nm; the rest is mostly degraded. LYRA4 responds below 2nm and a range 6-20nm. Therefore it can be assumed that hotter flares - coming from shorter wavelengths - lead to a weaker LYRA flare strength; cooler flares - coming from longer wavelengths - lead to a stronger LYRA flare strength. This hypothesis was tested by estimating the flare temperatures with the help of the ratio of the two GOES x-ray channels and a formula from White et al., *Solar Physics 227 (2005)*. It says: Let B4 (0.05-0.4nm) and B8 (0.1-0.8nm) be the two GOES x-ray flux channels. Then R=B4/B8 is their ratio, and the flare temperature can be estimated as

$$T(R) = 3.15 + 77.2*R - 164.0*R^2 + 205.0*R^3$$

The coefficients are taken from Thomas et al., *Solar Physics 95 (1985)*.

When the LYRA flare-strength factors are detrended (i.e. the fitted effect of exposure in space is subtracted), there is indeed a good correlation between the factors and the estimated temperature: -70% for ch2-3, -74% for ch2-4, see *Figure 4* below.

As a consequence of the observed degradation of LYRA flare strengths, the factors for the GOES-LYRA proxy should be updated, e.g.

GOES = 0.030*LYRA3 , GOES = 0.025*LYRA4

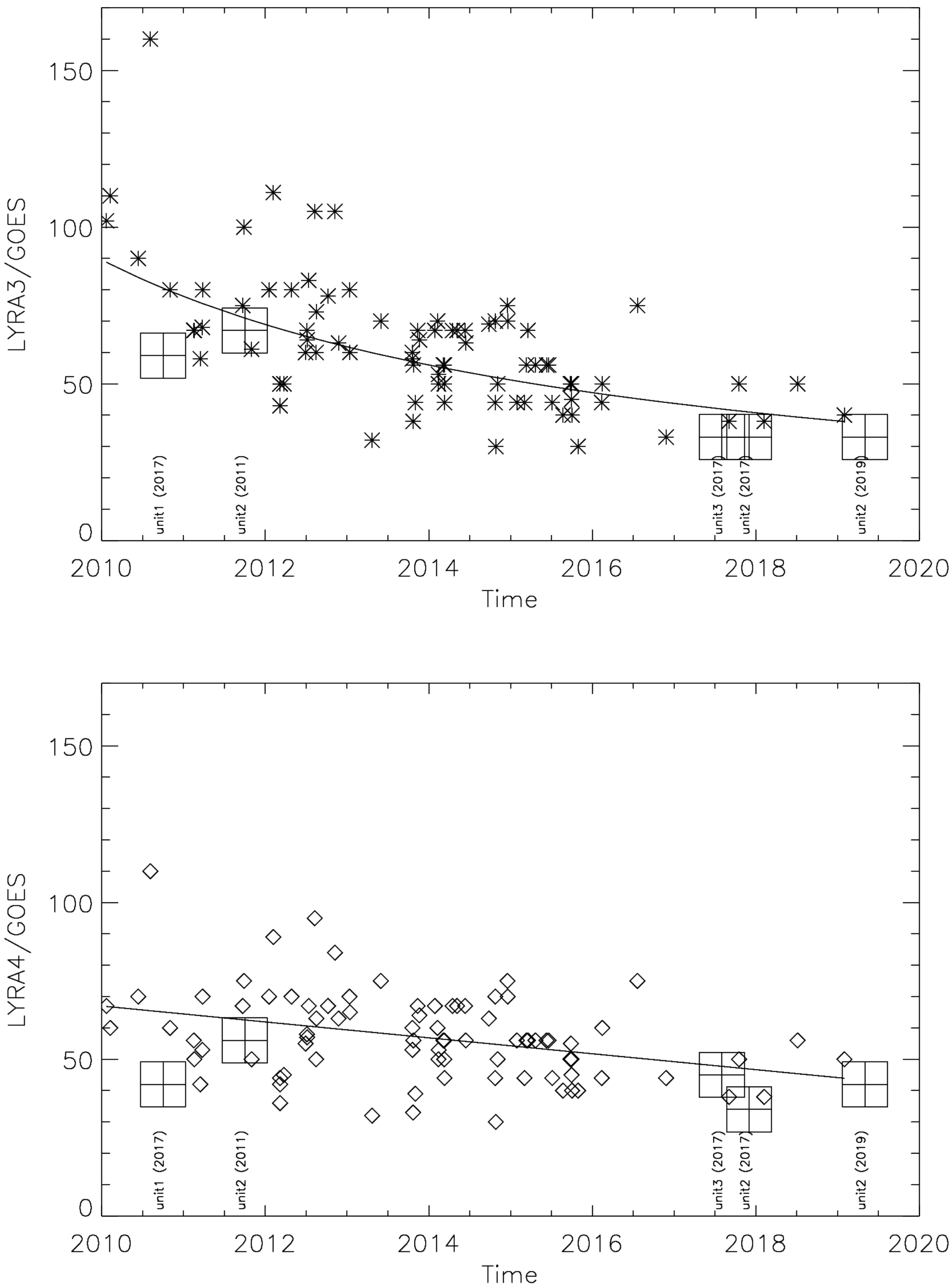
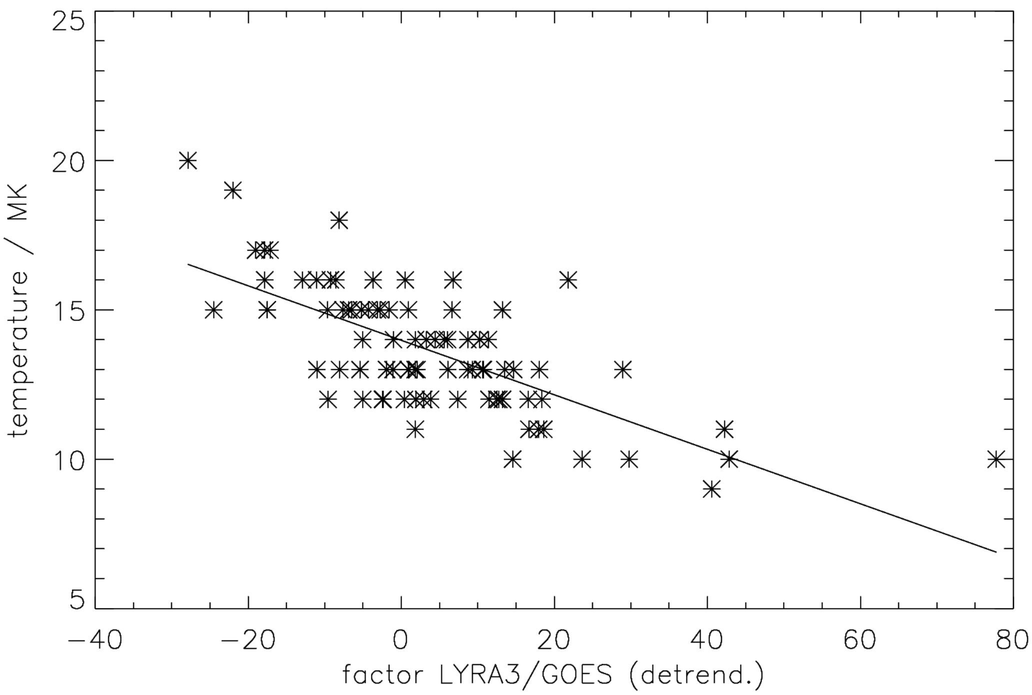


Figure 3: LYRA flare strength factors vs. time in space, with their fits. Single observations 2011, 2017, 2019 inserted. The smaller degradation of unit 1 is taken into account. “unit 3 (2017)” for LYRA4 should be further to the left (less degraded); for LYRA3, the position is consistent.



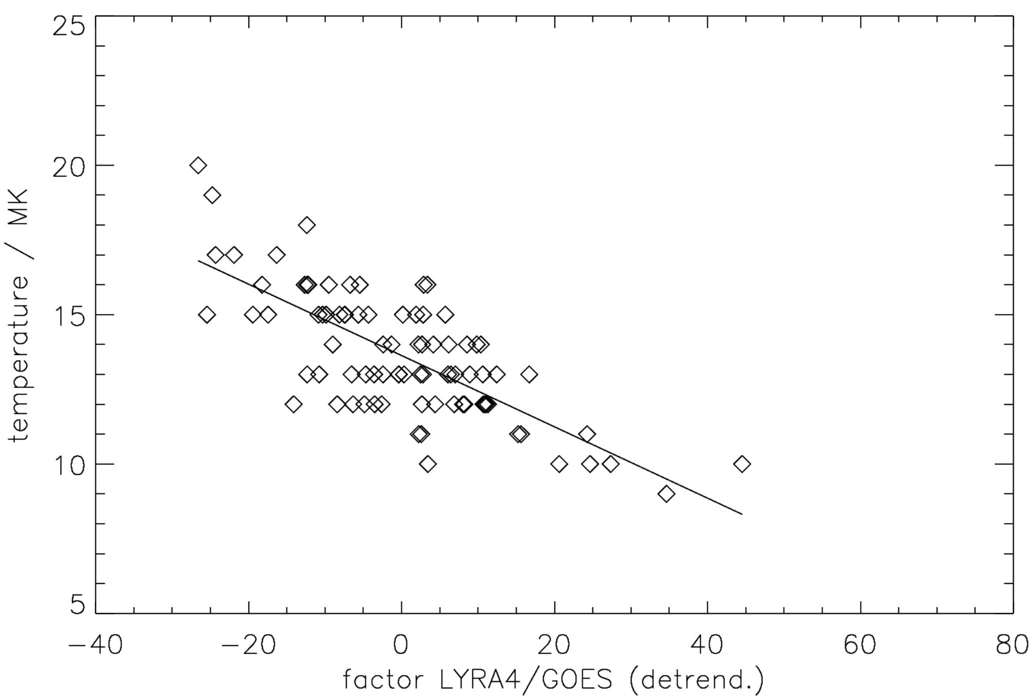
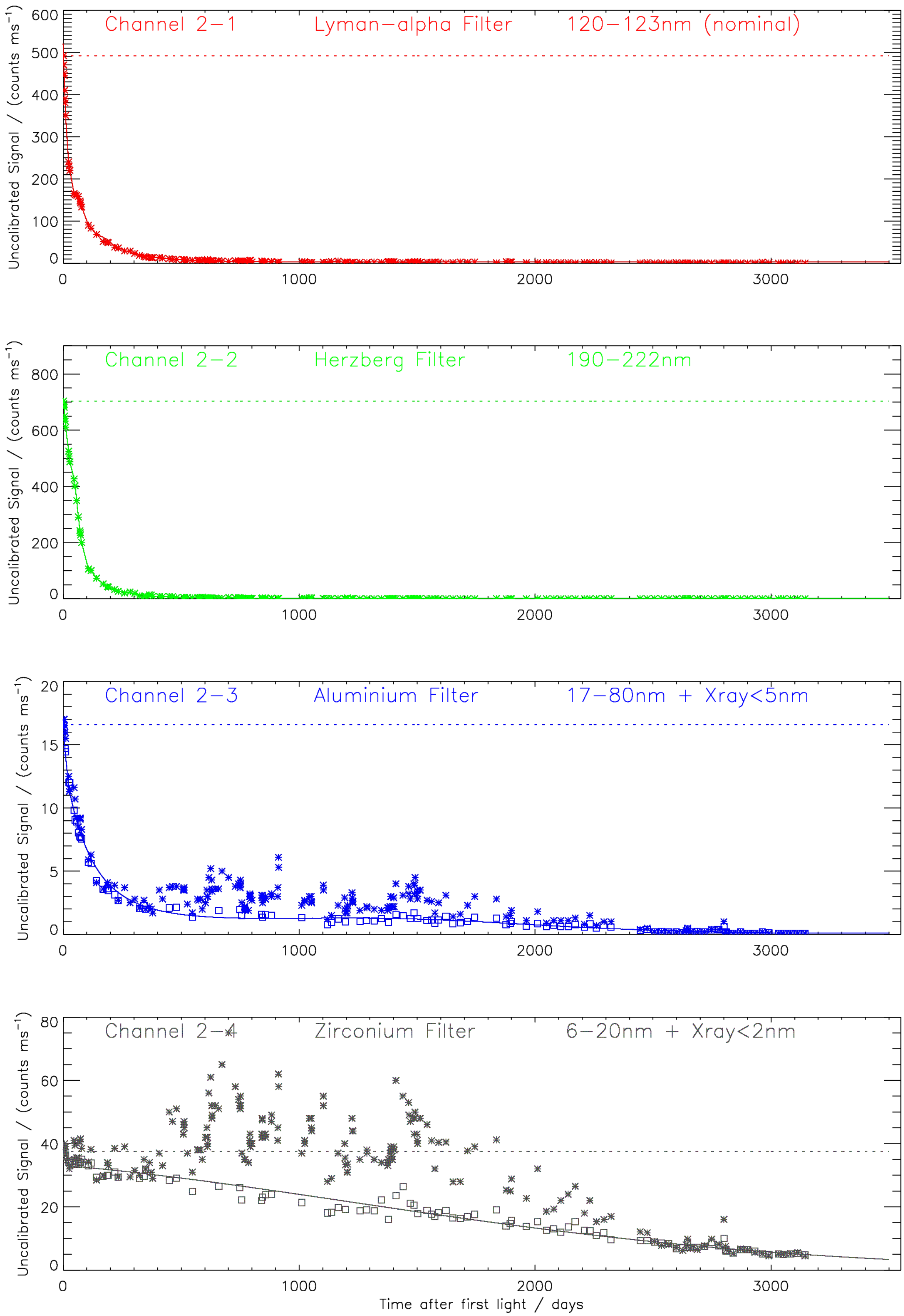


Figure 4: Flare temperatures vs. corrected LYRA/GOES flare-strength factors.

Figure 5 (next page): Degradation of LYRA nominal unit 2, quiet Sun observations (not flares!)



Channel 2−1
Lyman−alpha Filter
120−123nm (nominal)
Uncalibrated Signal / (counts ms^{-1})
Channel 2−2
Herzberg Filter
190−222nm
Uncalibrated Signal / (counts ms^{-1})
Channel 2−3
Aluminium Filter
17−80nm + Xray<5nm
Uncalibrated Signal / (counts ms^{-1})
Channel 2−4
Zirconium Filter
6−20nm + Xray<2nm
Uncalibrated Signal / (counts ms^{-1})
Time after first light / days

March 2019

linear fit: GOES = a + b*LYRA
logarithmic fit: GOES = a * LYRA^b , log(GOES) = log(a) + b*log(LYRA)

lin: GOES with back vs. LYRA ch3
a = -4.71844e-05
b = 0.0316063
corr = 0.991219

lin: GOES without back vs. LYRA ch3
a = -0.000141670
b = 0.0293870
corr = 0.990328

log: GOES with back vs. LYRA ch3
log(a) = -3.99758 , a = 0.0183601
b = 0.841400
corr = 0.972801

log: GOES without back vs. LYRA ch3
log(a) = -3.54984 , a = 0.0287293
b = 1.05580
corr = 0.991563

lin: GOES with back vs. LYRA ch4
a = -2.13068e-05
b = 0.0257860
corr = 0.988098

lin: GOES without back vs. LYRA ch4
a = -0.000117530
b = 0.0239739
corr = 0.987151

log: GOES with back vs. LYRA ch4
log(a) = -4.11365 , a = 0.0163480
b = 0.858941
corr = 0.965862

log: GOES without back vs. LYRA ch4
log(a) = -3.68440 , a = 0.0251122
b = 1.08089
corr = 0.987300

lin: LYRA ch4 vs. LYRA ch3
a = -0.000605641
b = 1.21698
corr = 0.996010

log: LYRA ch4 vs. LYRA ch3
log(a) = 0.0912680 , a = 1.09556
b = 0.968091
corr = 0.995373

May 2019

linear fit: GOES = a + b*LYRA
logarithmic fit: GOES = a * LYRA^b , log(GOES) = log(a) + b*log(LYRA)

lin: GOES with back vs. LYRA ch3
a = -5.33817e-05
b = 0.0302558
corr = 0.973317

lin: GOES without back vs. LYRA ch3
a = -0.000228024
b = 0.0298826
corr = 0.974848

log: GOES with back vs. LYRA ch3
log(a) = -3.64841 , a = 0.0260324
b = 0.969509
corr = 0.979036

log: GOES without back vs. LYRA ch3
log(a) = -3.35630 , a = 0.0348640
b = 1.14657
corr = 0.980306

lin: GOES with back vs. LYRA ch4
a = -0.000105488
b = 0.0237119
corr = 0.981121

lin: GOES without back vs. LYRA ch4
a = -0.000277220
b = 0.0233939
corr = 0.981594

log: GOES with back vs. LYRA ch4
log(a) = -3.97574 , a = 0.0187653
b = 0.945257
corr = 0.984494

log: GOES without back vs. LYRA ch4
log(a) = -3.73454 , a = 0.0238841
b = 1.12078
corr = 0.988323

lin: LYRA ch4 vs. LYRA ch3
a = 0.00164401
b = 1.28412
corr = 0.998378

log: LYRA ch4 vs. LYRA ch3
log(a) = 0.325280 , a = 1.38442
b = 1.01934
corr = 0.988332