Analysis of the spectral degradation of the PROBA2/LYRA instrument

M. Dominique + LYRA team

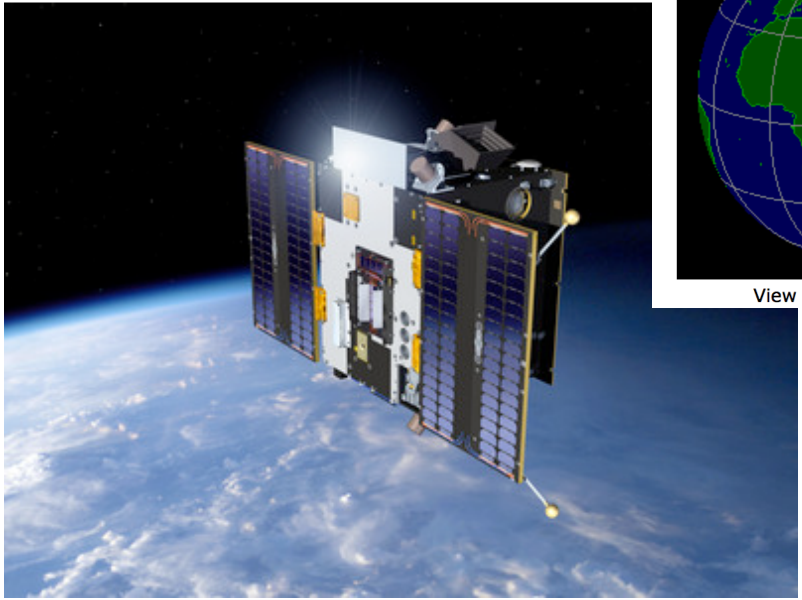
PROBA-2: an ESA solar micro-satellite

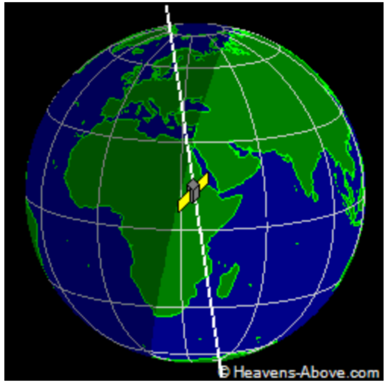
PROBA2:

- Launched on November 9, 2009.
- 2 solar instruments: SWAP and LYRA.

Orbit:

- Heliosynchronous dawn-dusk,
- 725 km altitude,
- Duration of 100 min,
- Occultation season:
    - From October to February,
    - Maximum duration 20 min per orbit.

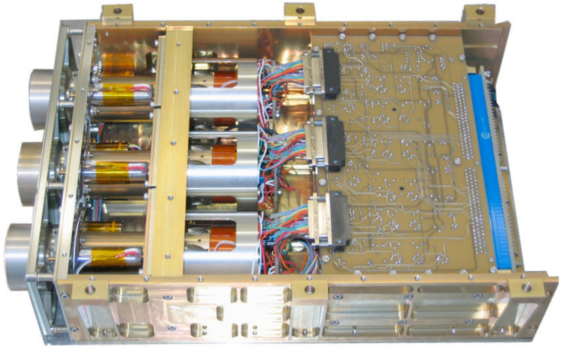


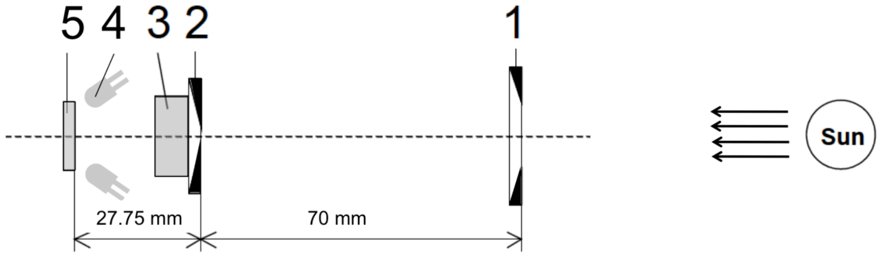


View from above satellite

ORB - KSB

LYRA highlights





- **3 redundant units** protected by independent covers,
- **4 broad-band channels** in each unit,
- High acquisition cadence: **nominally 20Hz,**
- 3 types of detectors:
  - Standard silicon,
  - 2 types of **diamond detectors**, MSM and PIN:
    - radiation resistant,
    - blind to radiation > 300 nm,
- **Calibration LEDs** with λ of 370 and 465 nm.

Details of LYRA channels

Channel	Filter label	Detector	Bandwidth	Purity
Unit 1				
1-1	Lyman-α [122XN]	MSM Diamond	120-123 nm	26%
1-2	Herzberg [220B]	PIN Diamond	190-222 nm	95%
1-3	Aluminium (158 nm)	MSM Diamond	17-80 nm + $<$ 5 nm	96.8%
1-4	Zirconium (300 nm)	AXUV Si	6-20 nm + $<$ 2 nm	97%
Unit 2				
2-1	Lyman-α [122XN]	MSM Diamond	120-123 nm	25.7%
2-2	Herzberg [220B]	PIN Diamond	190-222 nm	95%
2-3	Aluminium (158 nm)	MSM Diamond	17-80 nm + $<$ 5 nm	97.2%
2-4	Zirconium (141 nm)	MSM Diamond	6-20 nm + $<$ 2 nm	92.2%
Unit 3				
3-1	Lyman-α [122N+XN]	AXUV Si	120-123 nm	32.5 %
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3-3	Aluminium (158 nm)	AXUV Si	17-80 nm + $<$ 5 nm	96.6%
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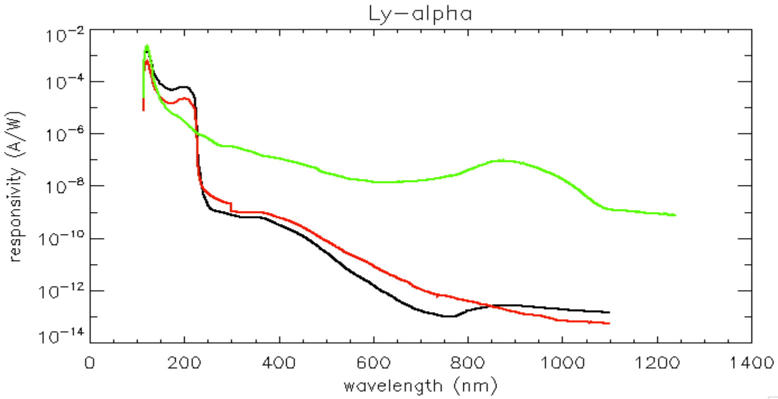
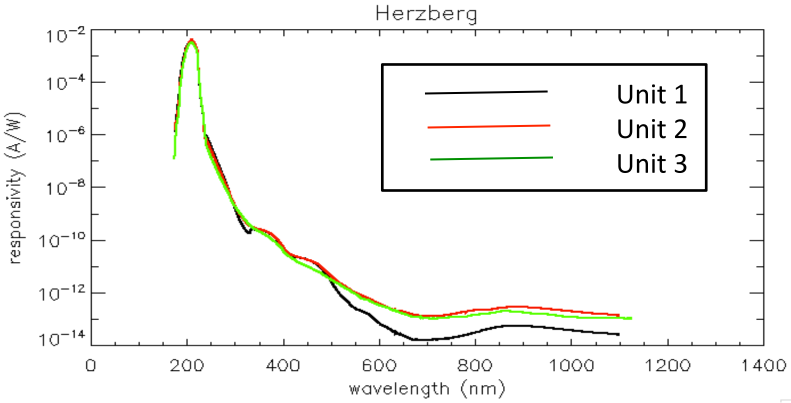
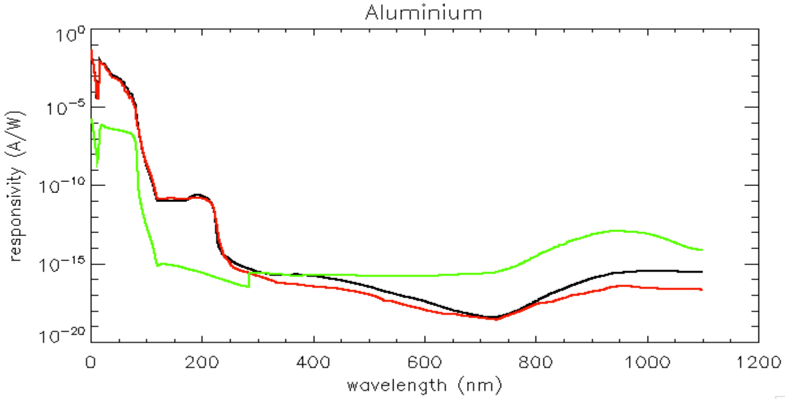
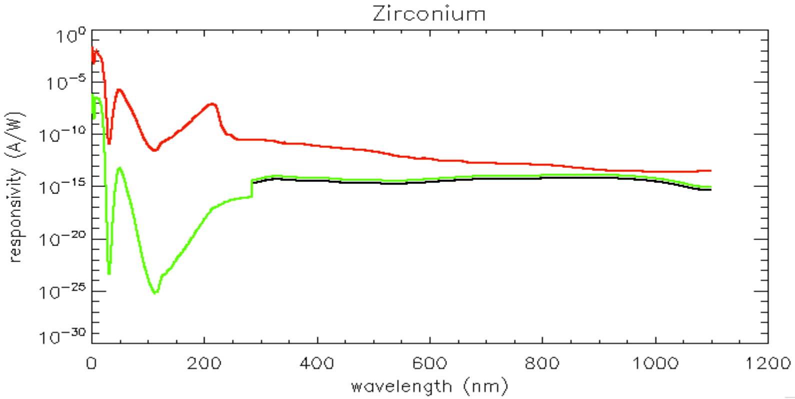
Filter + detector responsivity



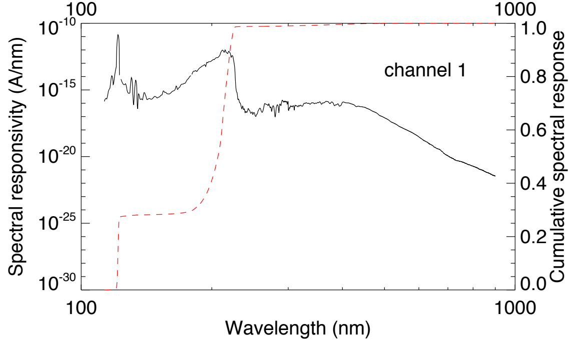




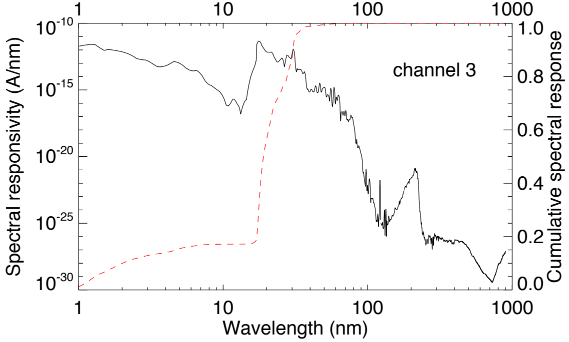


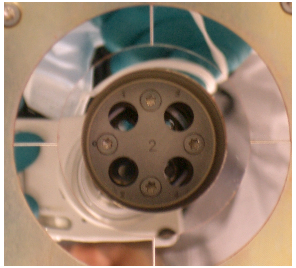
Details of LYRA channels multiplied by a quiet Sun spectrum

Channel 1 – Lyman alpha
120-123 nm

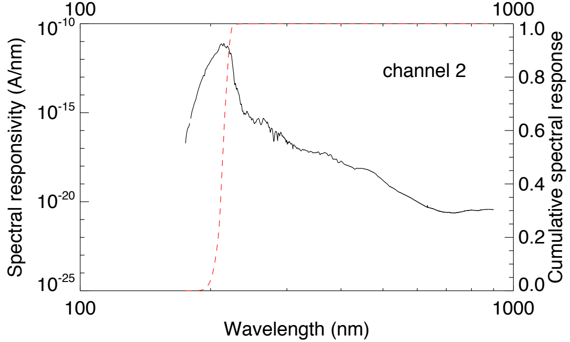


Channel 3 – Aluminum
17-80 nm + 0.1-5nm

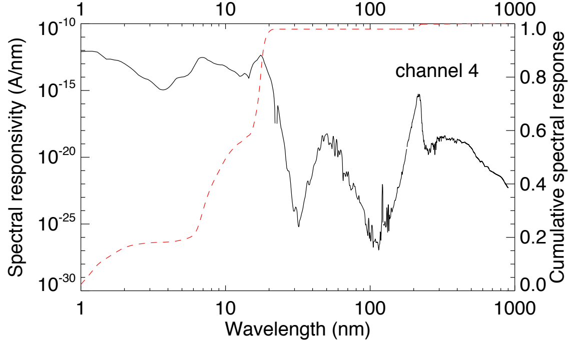




Channel 2 – Herzberg
190-222 nm



Channel 4 – Zirconium
6-20 nm + 0.1-2nm



Calibration

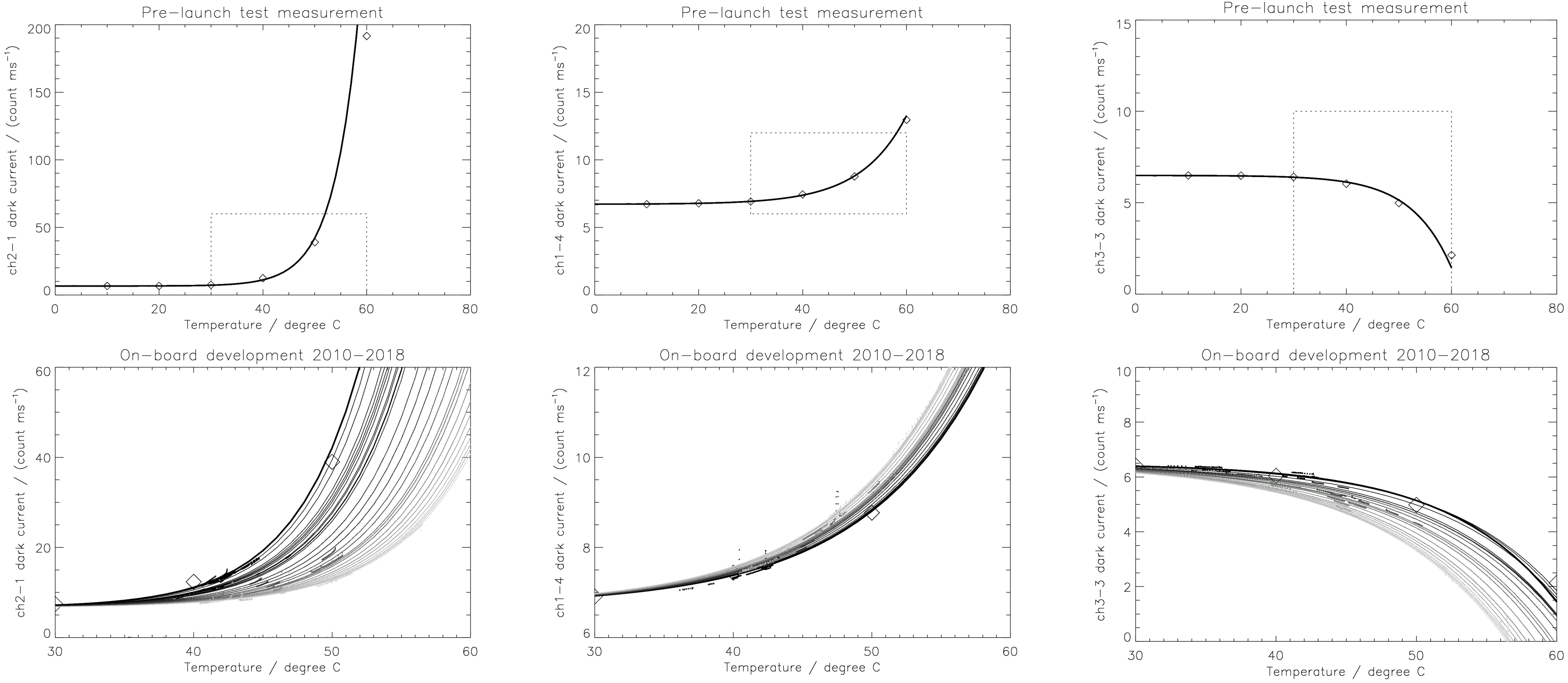
Includes:

- Dark-current subtraction,
- Rescaling to 1 AU,
- Additive correction for degradation,
- Conversion from the measured photocurrents (A) into irradiance units (W/m^2), assuming a linear relationship between the two.

Dark current evolution

$$DC = f(T) = a + \exp(b*T + c)$$

With a and b changing with time



$$i = i_{\mathrm{s}} + i_{\mathrm{d}} = \frac{A}{T} \int_t \int_\lambda E(\lambda, t) F(\lambda) D(\lambda) \mathrm{d}\lambda \mathrm{d}t + i_{\mathrm{d}}, \tag{2.2}$$

where

- i is the measured photocurrent, defined as the sum of the solar [i_{s}] and dark current [i_{d}] contributions,
- λ is the wavelength,
- t is the time and is integrated over an exposure,
- A is the aperture area, *i.e.* the exposed detector area,
- T is the total exposure time (nominally 50 ms),
- $E(\lambda, t)$ is the solar spectral irradiance,
- $F(\lambda)$ is the filter transmittance,
- $D(\lambda)$ is the detector spectral responsivity,

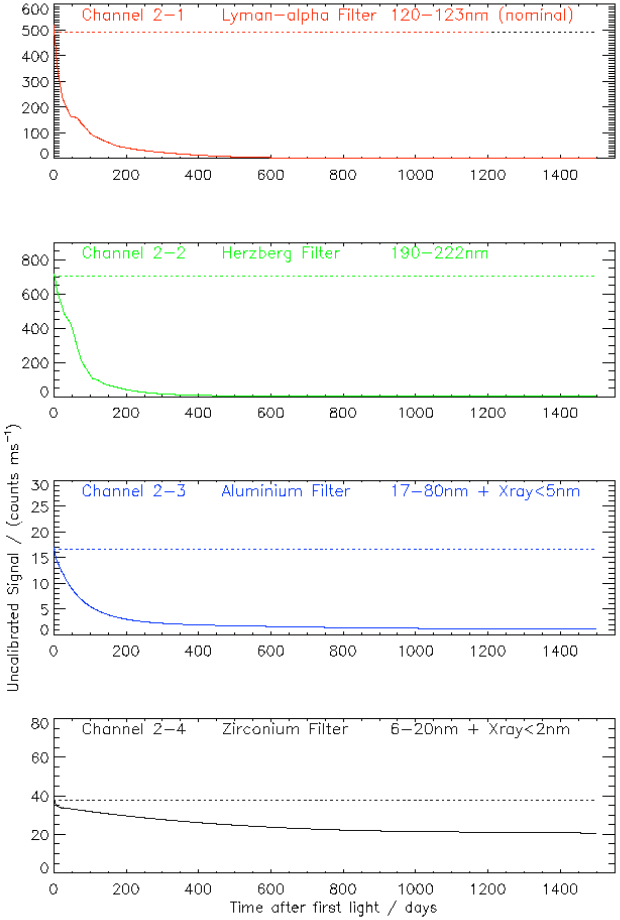
$$E_{cal} = \frac{i_{uncal} - i_d + corr}{i_{uncal}^{FL} - i_d^{FL}} E_{cal}^{FL} \tag{2}$$

where:

- E_{cal} and E_{cal}^{FL} are the spectral irradiances covering one LYRA channel (in W/m^2) for respectively the current measurement and the first light reference
- i_{uncal} and i_{uncal}^{FL} are the unprocessed solar irradiance (in counts/ms) for respectively the current measurement and the first light reference
- i_d and i_d^{FL} are the dark current measurements (in counts/ms) for respectively the current measurement and the first light reference
- $corr$ is the corrective term for degradation

$$E_{cal}^{FL} = \frac{i_{uncal}^{FL} - i_d^{FL}}{\frac{A}{T} \int_t \int_\lambda E_S(\lambda, t) F(\lambda) D(\lambda) d\lambda dt} \int_\lambda E_S d\lambda$$

Degradation



	Unit 1	Unit 2	Unit 3
Channel 1 – Lyman-α	65%	<0.5%	57%
Channel 2 – Herzberg	64%	<0.5%	2%
Channel 3 – Aluminum	60%	1%	10%
Channel 4 – Zirconium	72%	13%	52%

The degradation is spectrally dependent and mostly affects the filters.

Likely caused by the carbon or/and the silicon contamination.

Model of contamination

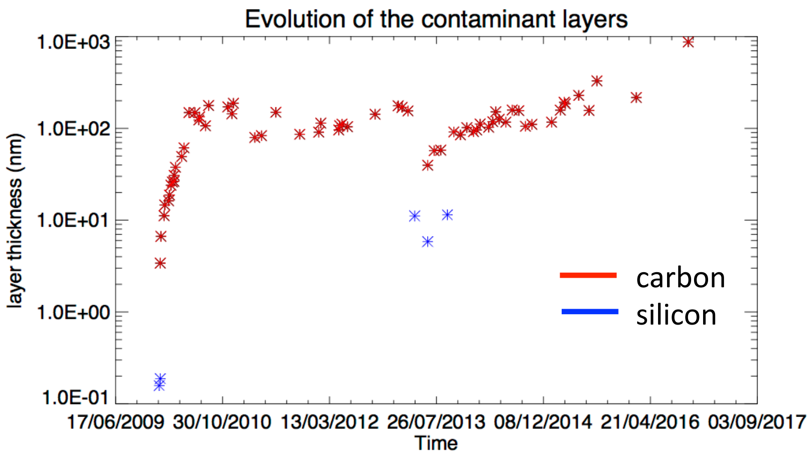
$$i = i_s + i_d = \frac{A}{T} \int_t \int_\lambda E(\lambda, t) F(\lambda) \exp\left(-\sum_i \sigma_i(\lambda) L_i\right) D(\lambda) \mathrm{d}\lambda \mathrm{d}t + i_d \quad (4.1)$$

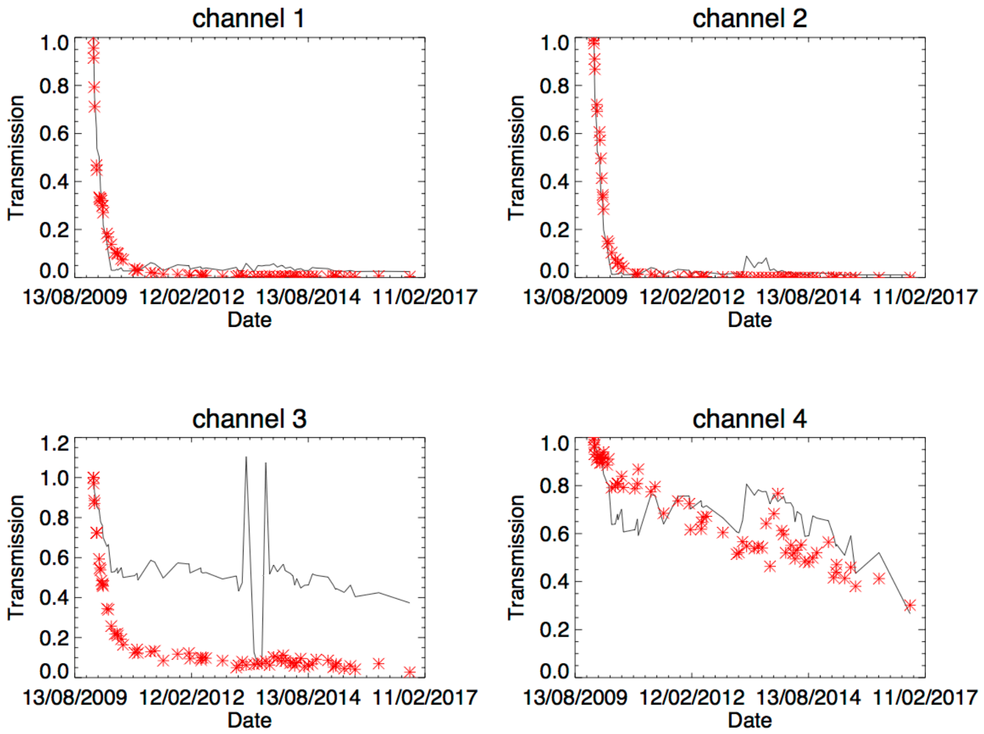
where :

- i is the photocurrent
- A is the exposed detector aera
- T is the total exposure time
- E is the solar spectral irradiance
- F is the filter transmittance
- D is the detector responsivity
- σ_i is the absorption cross-section of the contaminant i
- L_i is the thickness of the contaminant i

For a given unit, L_i can be deduced from the loss of signal in the four channels at any time.

Evolution of the contamination: unit 2





- Contamination dominated by the carbon.
- An additional source of degradation seems to be present in channel 3. Possibly oxidation.

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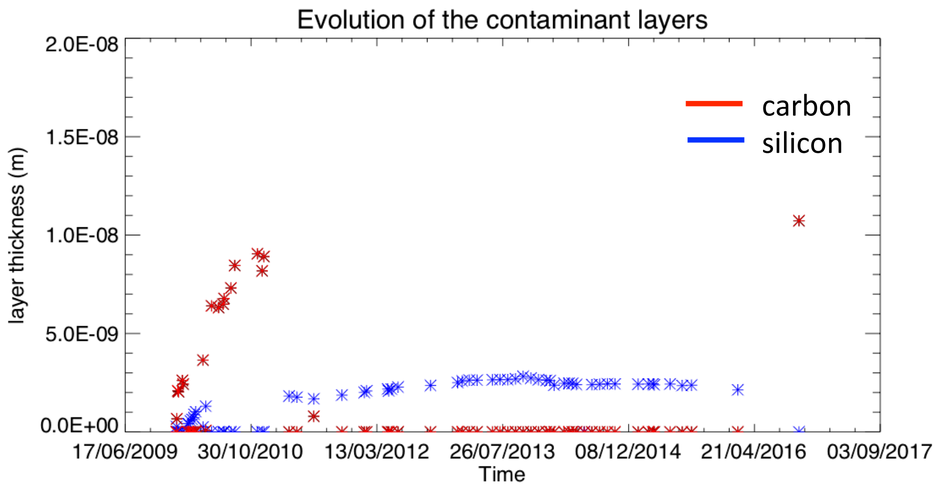
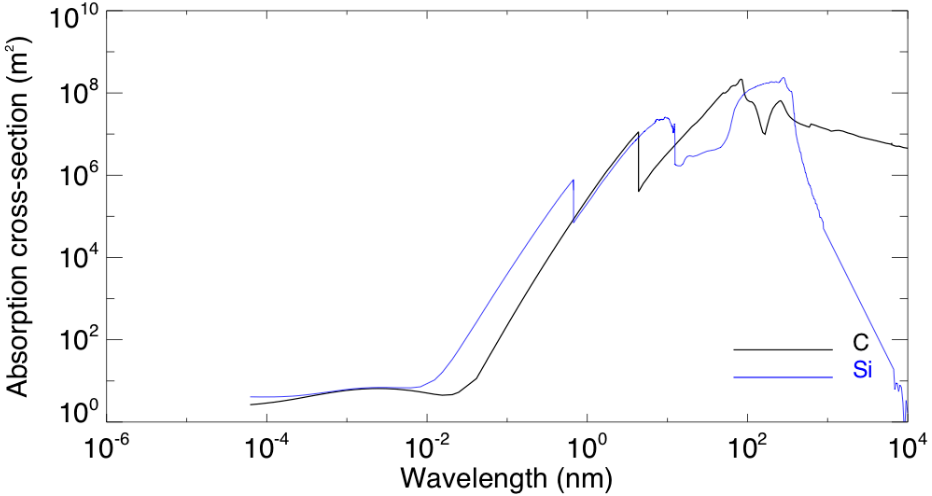
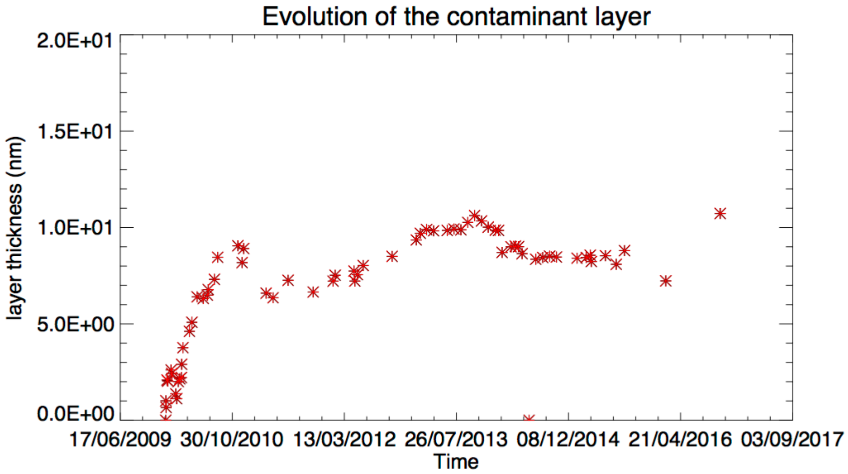
Evolution of the contamination: unit 1



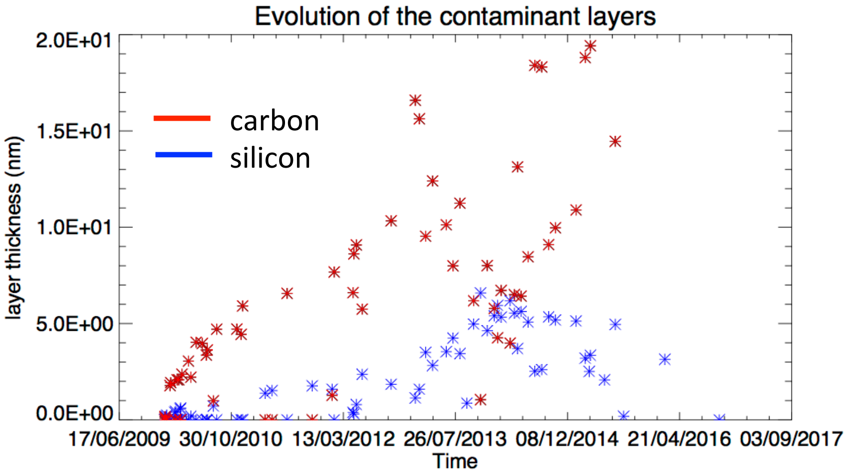


Evolution of the contamination: units 1 and 3

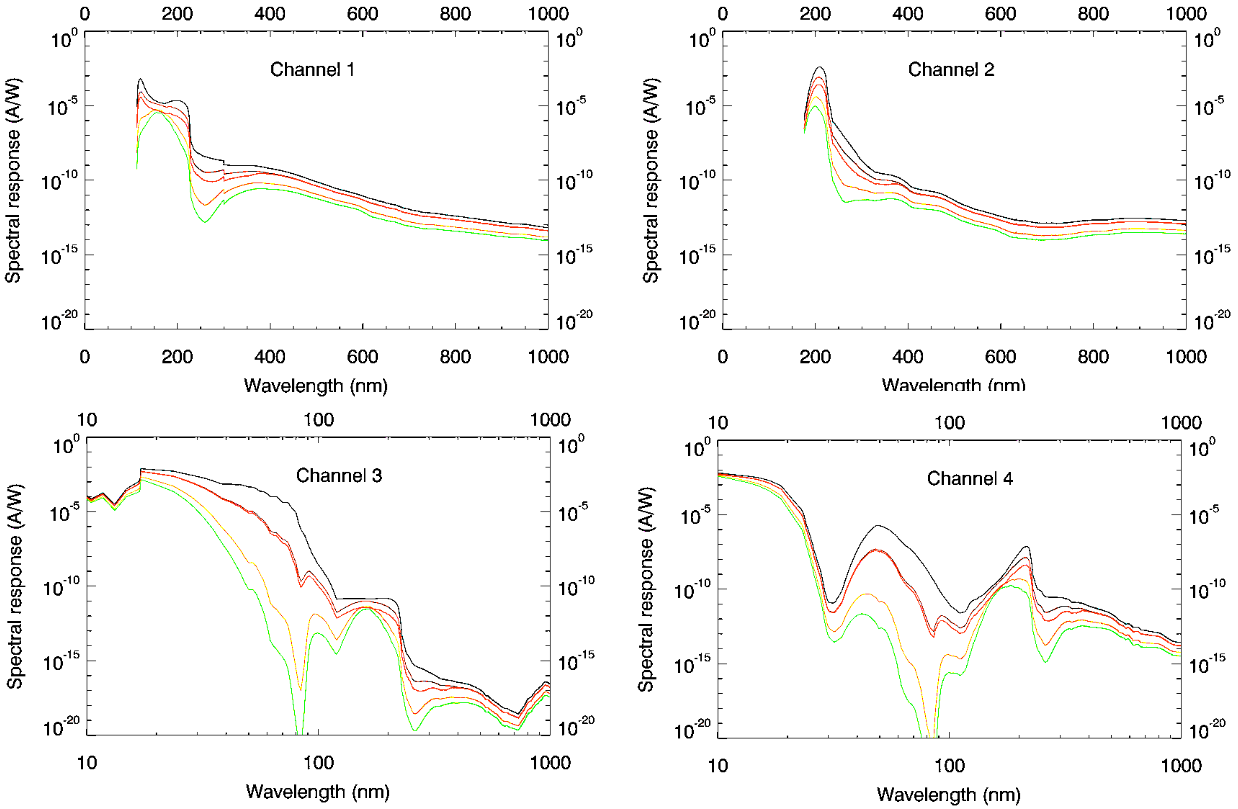


Unit 1: only considering the contamination by the carbon.

Unit 3: contamination by both the carbon and the silicon.



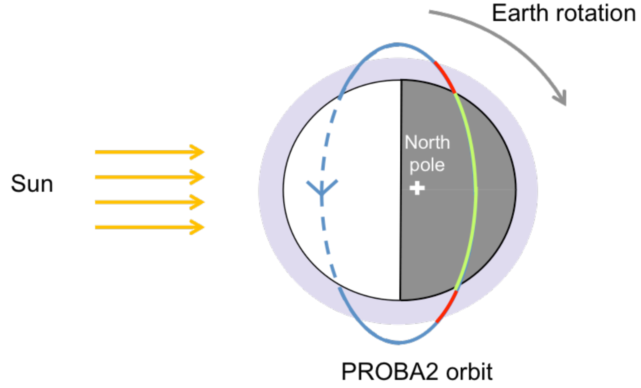
Effect of the contamination on the spectral response

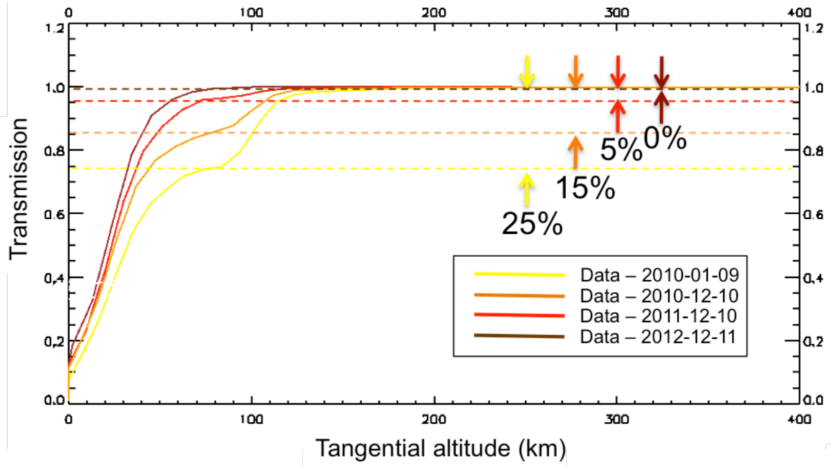


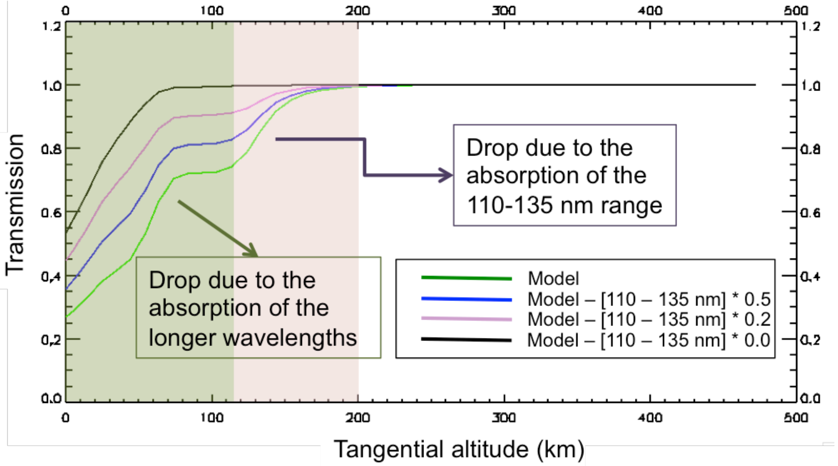
- Channels 3 and 4 become less and less sensitive to EUV.
- The peak of responsivity in channel 1 shifts from Lyman-α to ~150 nm.

6 January 2010
24 March 2010
15 May 2013
15 May 2014
25 February 2015

Impact of spectral degradation on occultation measurements

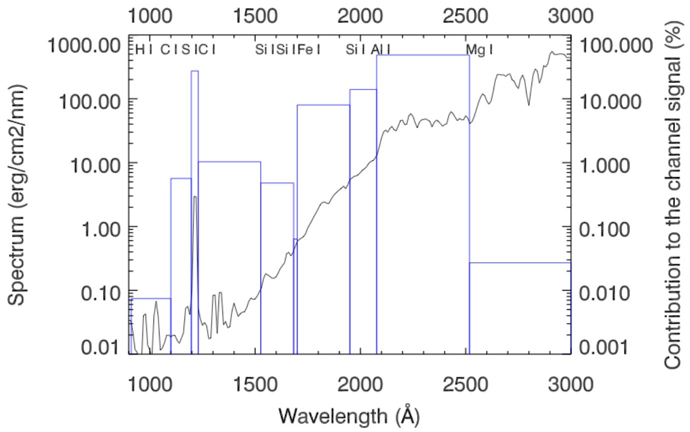


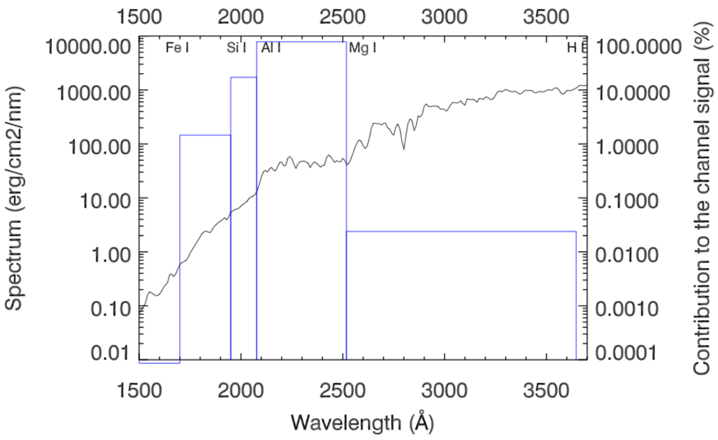




Supplementary material

Annexe: main contributors channels 1 and 2





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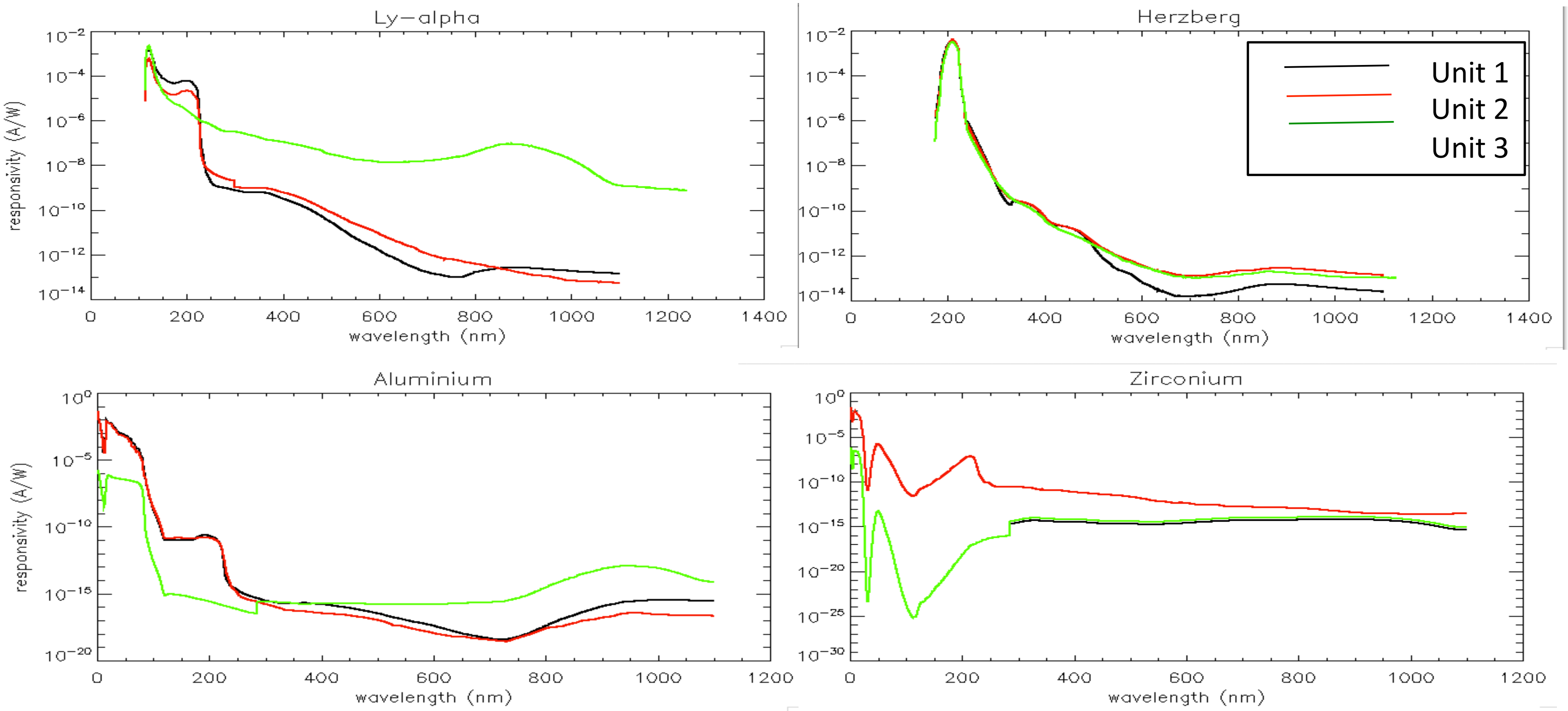
Filter + detector responsivity

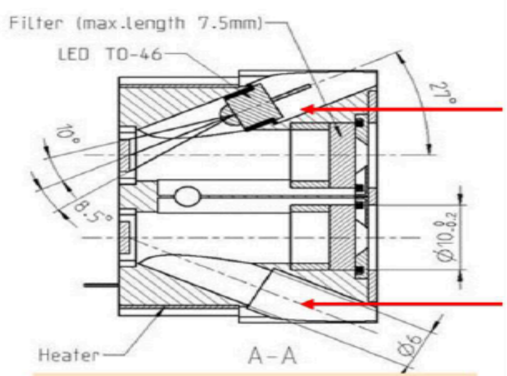


Operation: systematic campaigns

	Integra-tion time	Units	Cover status	LED status	Pointing	Occur-ence
Range	10ms ➔ 10s	max. two at a time	open / close	off / 375nm / 465nm	0° (Sun) ➔ 3°	
Nominal	50 ms	U2	open	off	Sun	N/A
Back-up A	50ms	U2+3	open	off	Sun	1 / 2weeks
Back-up B	50ms	U2+1	open	off	Sun	1 / 3months
Calibra-tion	50ms	1) U2+1 2) U2+3	close	off (DC) on (LED)	N/A	1/ 2weeks
Paving	50ms	-	open	off	From 0° to 3°	occasio-nal

IV. LYRA onboard calibration

1. LYRA benefits from VIS (465nm) and UV (375nm) in-flight calibration LEDs to assess the MSM detectors stability/robustness bi-weekly),
2. Dark current measurements (closed doors, bi-weekly),
3. Off-pointings (occasionally),
4. Acquision with one or two units in parallel (unit1: 1x / 3months, unit3:1x / 2 weeks),
5. Cross-calibration with other instruments : Solstice/Sorce, Goes15 and Eve/SDO.



LYRA Calibration LEDs

VIS LED

- 10° Angle near UV LED
- Peak WL = 375 nm
- I_F = 10mA@3.5V

UV LED

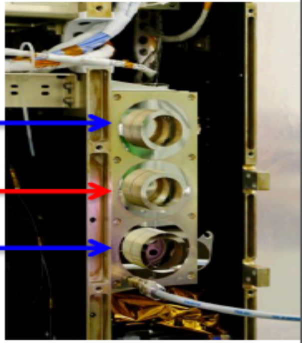
- 20° Angle UV LED
- Peak WL = 235 nm
- I_F = ?

→ Not available (VIS LEDs @ 465nm)

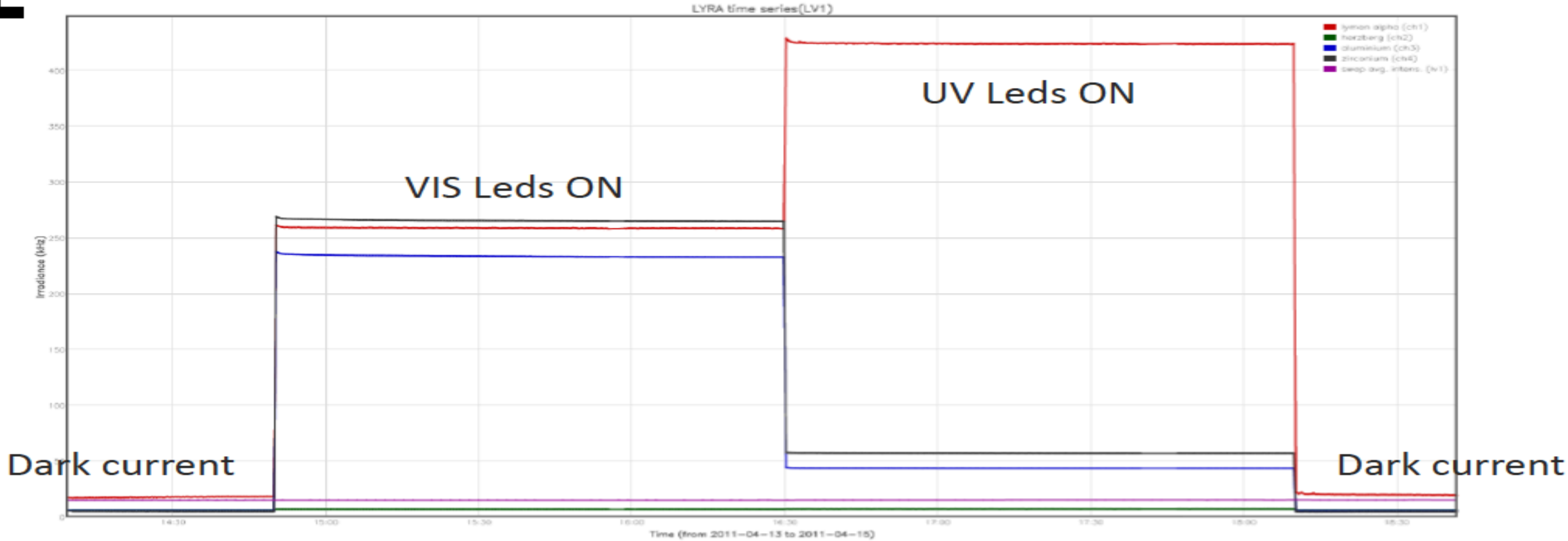
Unit 1 (x1/ 3 months)

Unit 2 (nominal)

Unit 3 (x1/ 2 weeks)



IV. LYRA standard calibration: LEDs



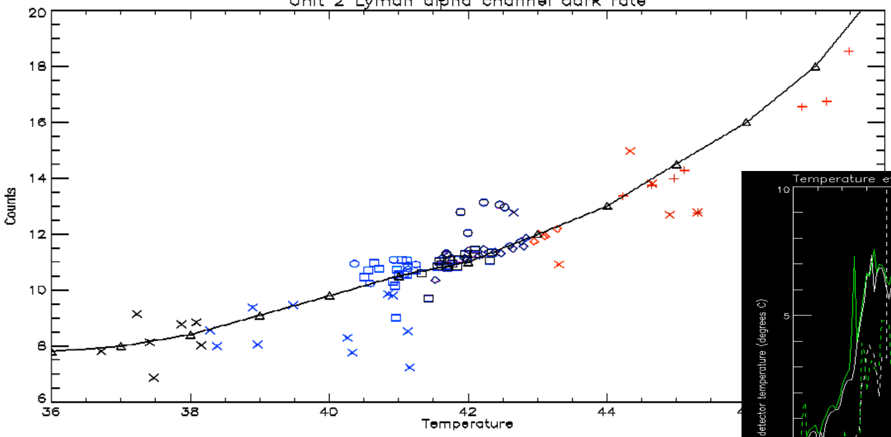
This plot shows the standard calibration observing sequence (4 channels).
The dark current is measured for 20 minutes, then the VIS LED is switched on for 20 minutes, then the UV LED, and finally another 20 minutes of dark current. The sequence is then repeated.

Status after >1year : the detector signal when illuminated by LEDs is almost constant.

Dark current evolution

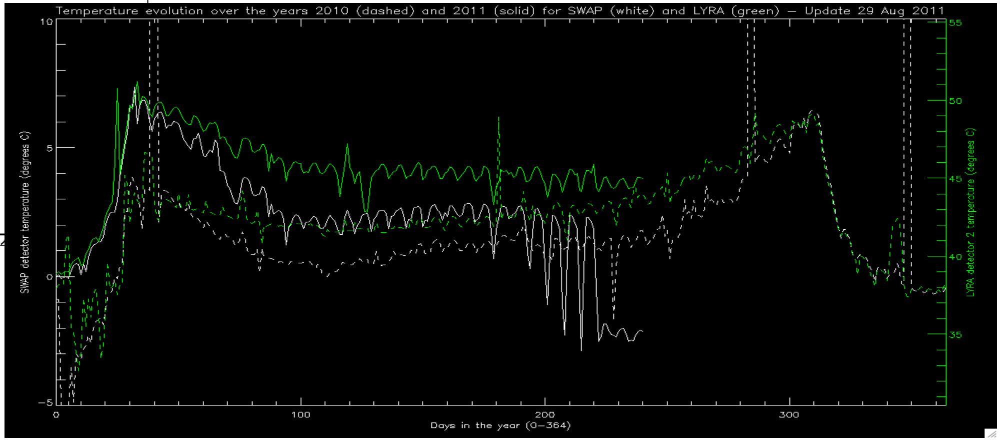
Variations correlated with temperature evolution

Dark current in Lyman alpha



I. Dammasch + M. Snow

Temperature evolution



A. De Groof