LYRA degradation after 3 years in orbit

Talk outline

-I- Introduction

-II- Detector degradation studies (unit 2, diamond)

-III- Detector degradation studies (unit 3 & 1, silicon)

-IV- Lesson learned from on-ground proton tests

- LYRA detectors: PIN Diamond vs PIN Si (AXUV)
- LYRA filters: UV interferential filters (Ly-α and Hz)

-V- Conclusions

Ali BenMoussa[1,2], B. Giordanengo[1], S. Gissot[1] , I.E. Dammasch[1] and M. Dominique[1]

– 1 – Solar-Terrestrial Center of Excellence (STCE), ***ali.benmoussa@stce.be**

– 2 – Royal Observatory of Belgium (ROB)

esww9, PROBA2 splinter session, November 06 2012, Brussels, Belgium

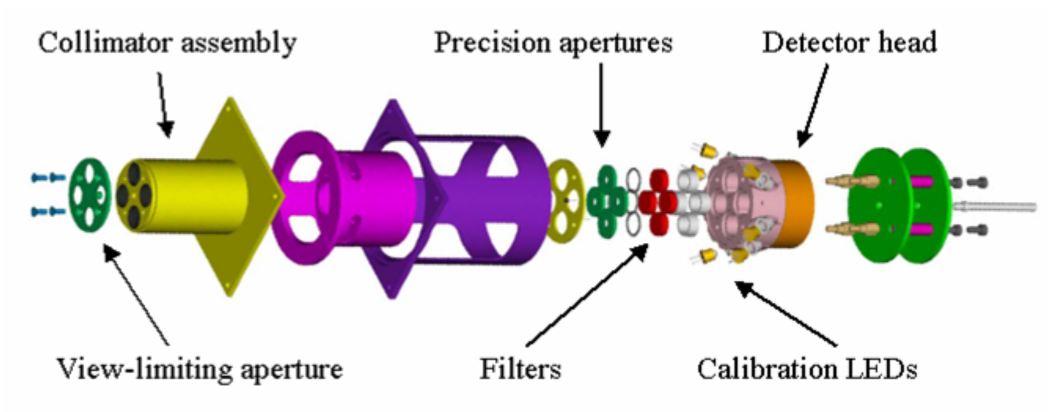
-I- Introduction

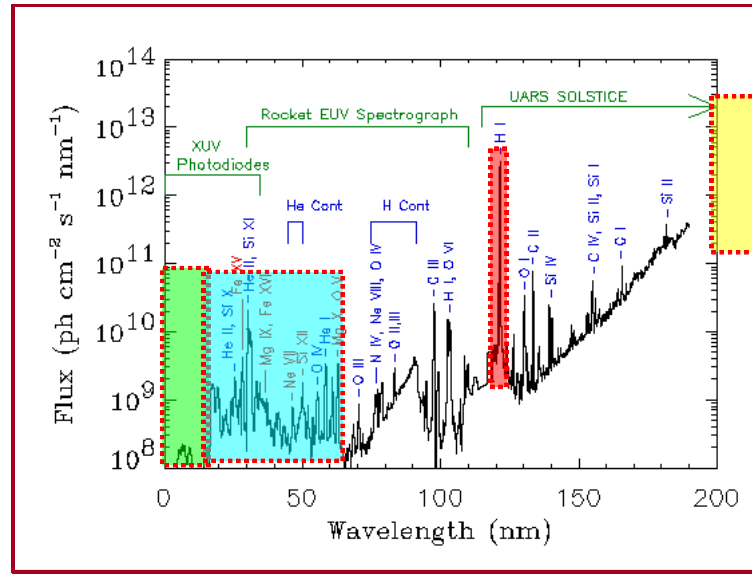
Institutes

- Royal Observatory of Belgium (Brussels, BE)
  Principal Investigator, overall design, onboard software specification, science operations, Calibration (Detectors, Filters)
- PMOD/WRC (Davos, CH)
  Lead Co-Investigator, overall design and manufacture
- Centre Spatial de Liège (BE)
  Lead institute, project management
- IMOMEC (Hasselt, BE)
  Diamond detectors
- Max-Planck-Institut für Sonnensystemforschung (Lindau DE)
  Calibration
- science Co-Is: BISA (Brussels, BE), LPC2E (Orléans, FR)…

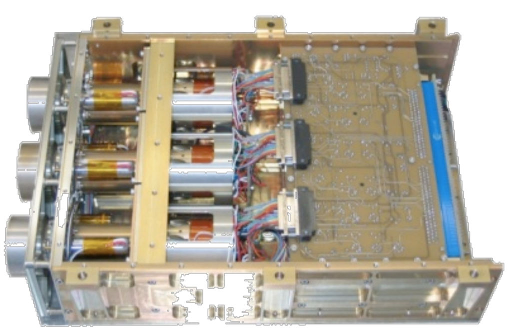
LYRA (**L**arge **Y**ield **Ra**diometer) onboard PROBA2 (launched in Nov. 2^{nd} 2009)

-I- LYRA highlights

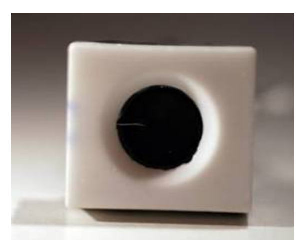
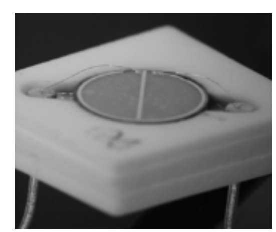
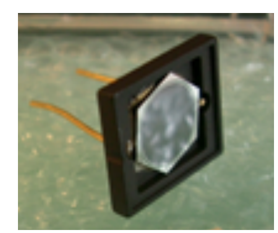




- LYRA = 3 units (redundancy), 4 channels/unit
- 4 detectors per unit total 12 detectors
- 2 calibration LEDs/detector → 24 LEDs (12 VIS, 12 UV)

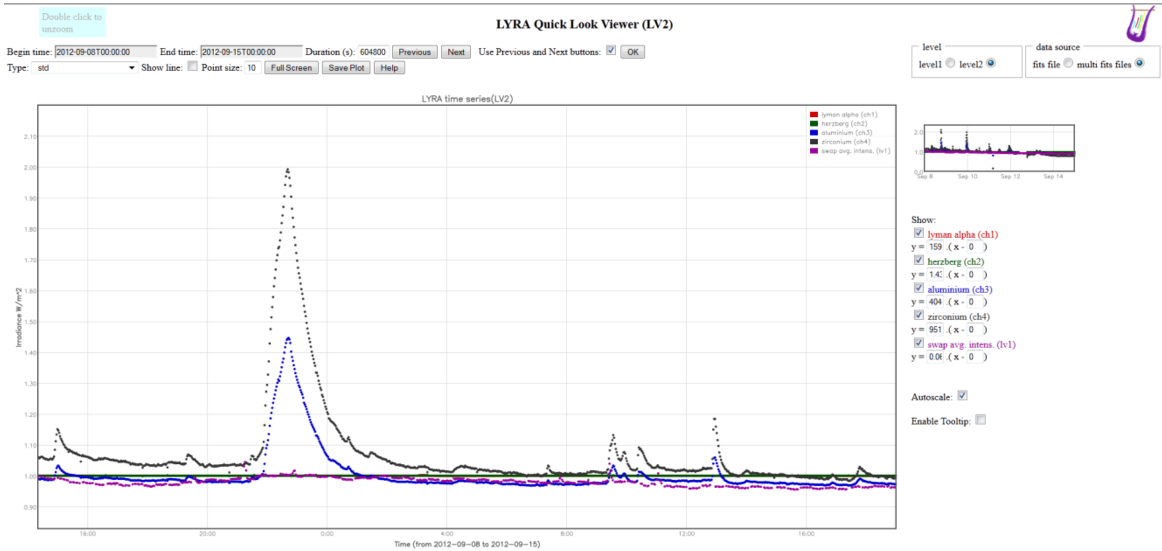


LYRA detectors: Diamond (PIN, MSM) and Silicon (PIN)

BenMoussa et al. Physica St. Solidi (a) **201**, (2004) 2536
BenMoussa et al. Nuclear Inst & Methods A-**568**, (2006) 398
BenMoussa et al. Meas. Sci. Technol. **17**, (2006) 913-917
BenMoussa et al. Semi. Science & Techn. **23**, (2008) 035026
BenMoussa at al. "Pre-Flight Calibration of LYRA, the Solar VUV radiometer on board PROBA2". A&A **508** (2009) 1085-1094.

-I- LYRA daily operations (since Jan 06 2010)



http://proba2.sidc.be/lyra/LY-QLV/

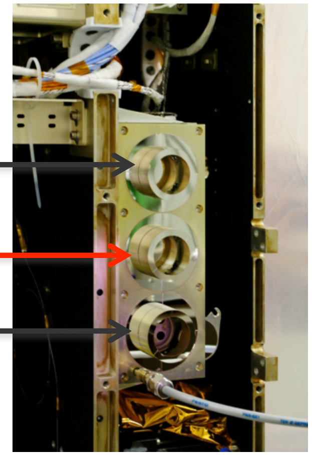
contact: swap_lyra@oma.be LYRA (PI): Marie Dominique; SWAP (PI): David Berghmans - ROB

-II- Detector degradation studies (unit 2, diamond)

unit 1 (C and Si, once per month)

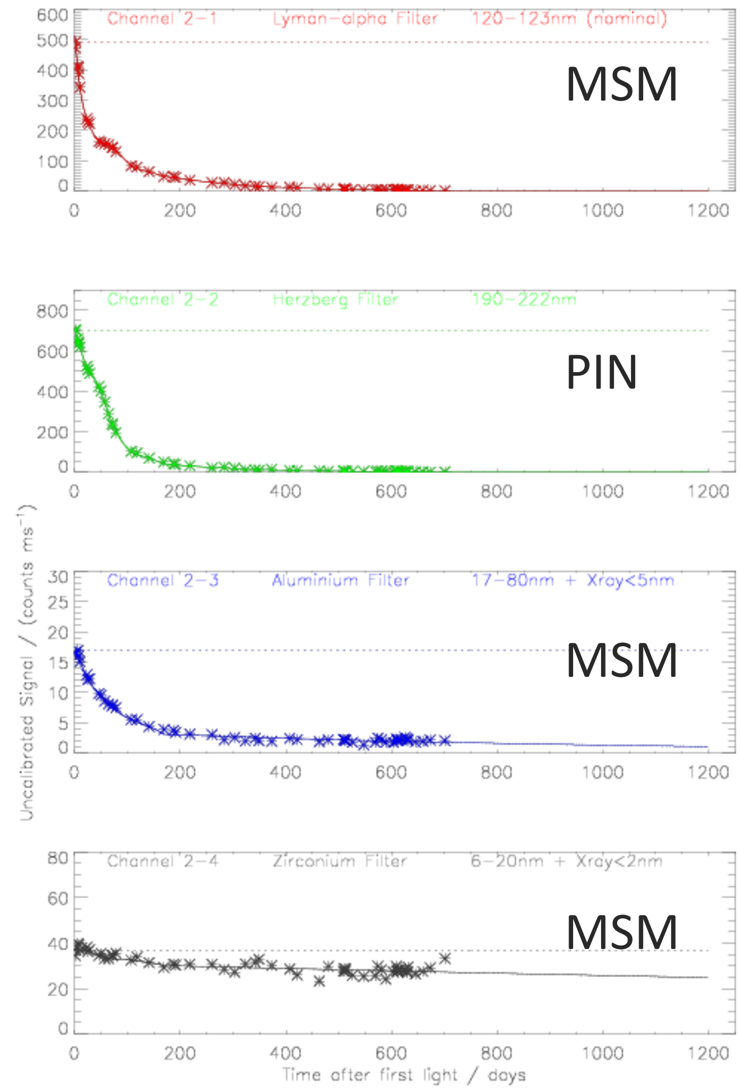
unit 2 (C, nominal)

unit 3 (Si, once per week)



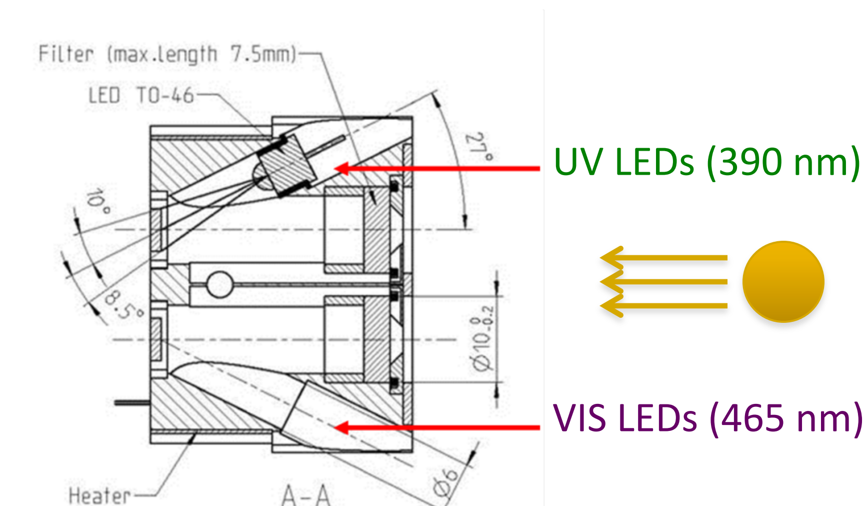
	Ly-alpha	Herzberg	Aluminium	Zirconium
Unit 1	50%	15%	20%	/
Unit 2*	>99%	>99%	90%	30%
Unit 3	34%	66%	57%	10%

unit 2 (*nominal) shows degradation since Jan 2010.



-II- Onboard calibration strategy

1. dark current measurements (closed doors, weekly),
2. LYRA benefits from VIS (465 nm) and UV (390 nm) LEDs to assess the detectors stability/ robustness (weekly),
3. acquision with one or two units in parallel (weekly with unit 3, monthly with unit 1),
4. off-pointings (ROB operations, 1/month),
5. cross-calibration with other instruments : TIMED/SEE, GOES, EVE/SDO.



LYRA Calibration LEDs

Detectors calibration sequence (4 channels):

- Dark current (20 min),
- UV Leds (20 min),
- VIS Leds (20 min),
- Dark current (20 min).

The sequence is then repeated.

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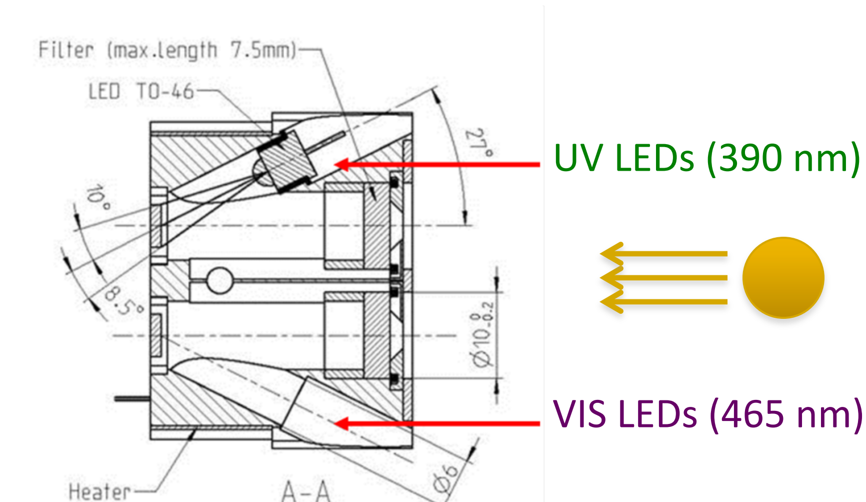

LYRA Calibration LEDs

<u>Detectors calibration sequence (4 channels):</u>

- Dark current (20 min),
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- VIS Leds (20 min),
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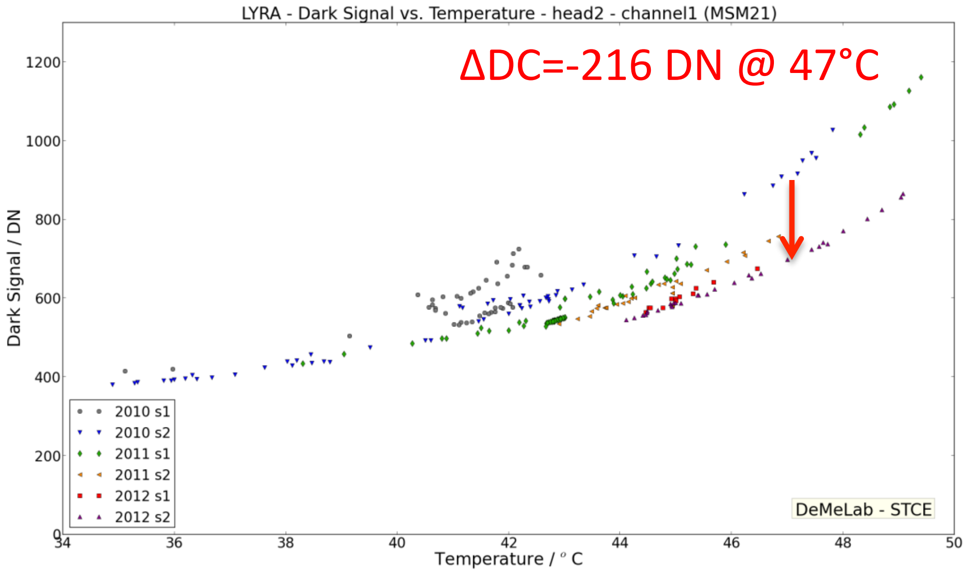
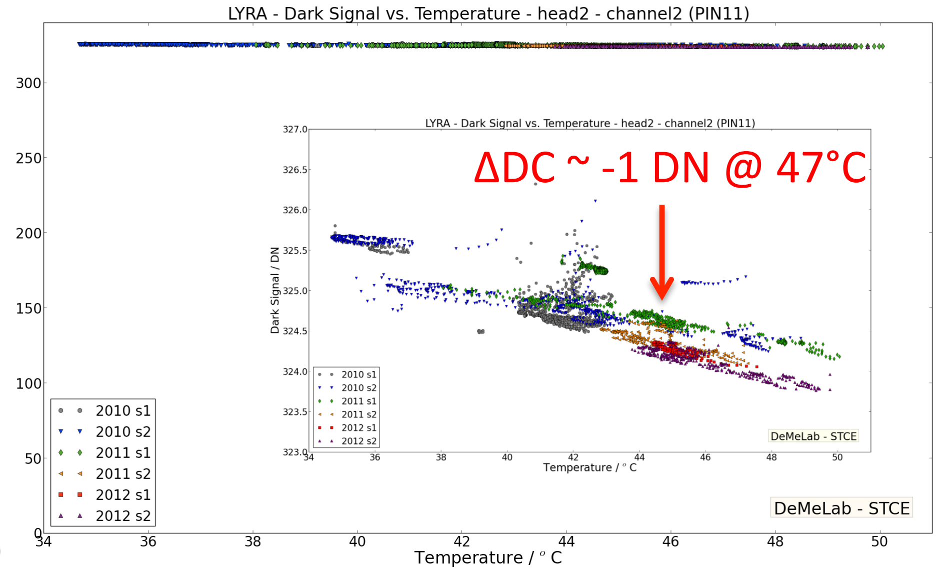
The sequence is then repeated.

-1- dark current vs temperature (unit 2, diamond)

MSM diamond



PIN diamond



Legend:

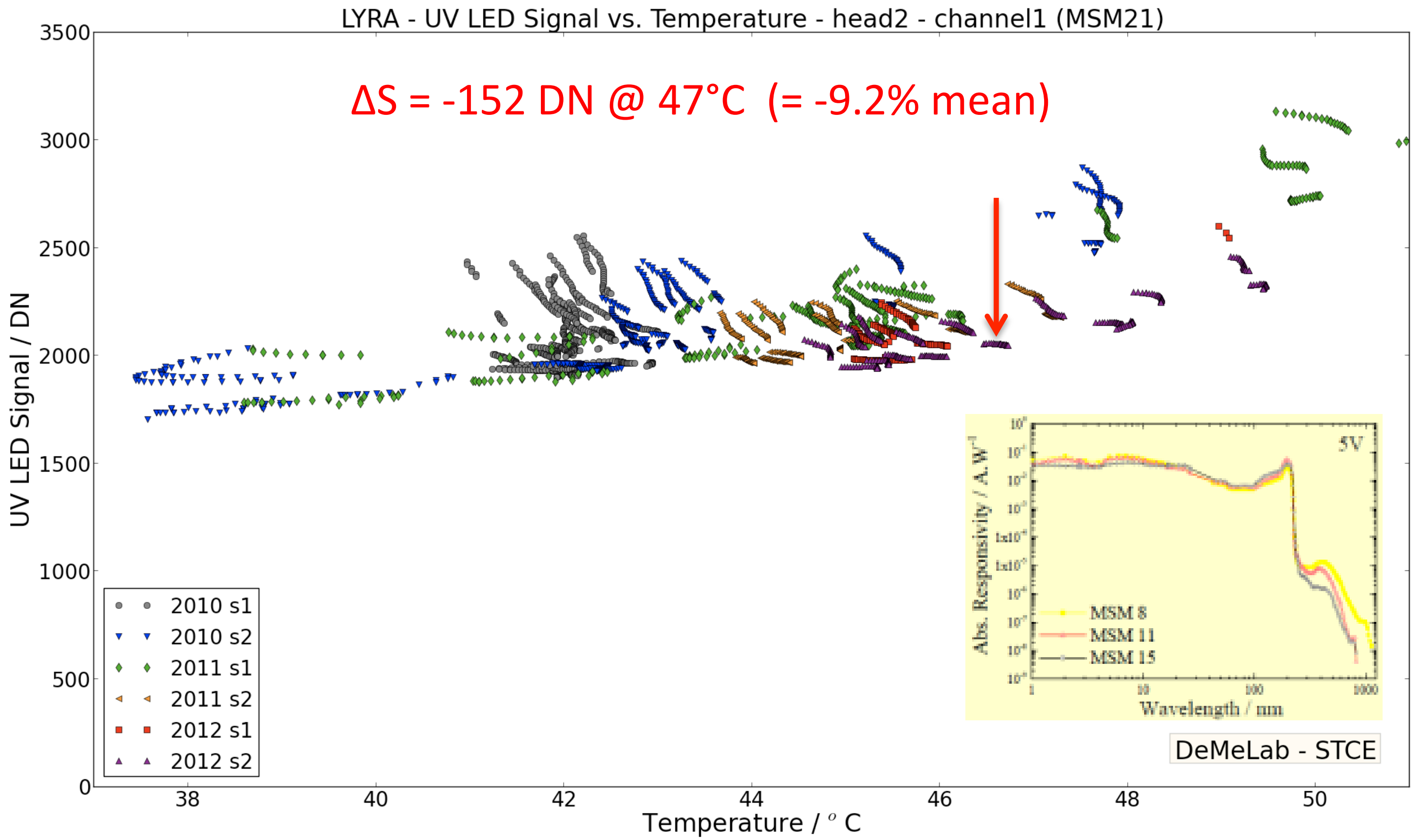
- grey : 1st sem. 2010
- blue: 2nd sem. 2010
- green: 1st sem. 2011
- orange: 2nd sem. 2011
- red: 1st sem. 2012
- purple: 2nd sem. 2012

IT = 50ms (20 Hz)

- Diamond MSM dark current increases vs temperature as expected, but decreases with time
  - ΔDC ~ -27% of the mean @ 47°C → recovery of the diamond MSM ?

  → cleaner diamond surface (TBC with ch2-3 and ch2-4),
- Diamond PIN dark current remains stable in orbit
  - ΔDC = -0.3% of the mean @ 47°C (=noise) → no PIN diamond detector degradation

-2- detector signal vs UV LEDs (unit 2, MSM diamond)



ch 2-1 signal increases vs Temperature (to be corrected from the UV LEDs T-dependency, see unit 3)

- signal (sub-gap) decreases with time (= LED-blind)→ possible recovery ?,
- TBC with VIS LED and others LYRA MSM channels (ch2-3 and ch2-4).

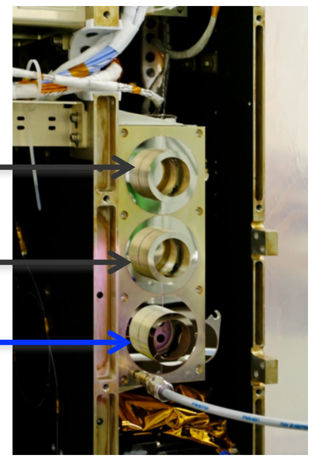
-III- LYRA degradation: unit 3 & 1 (Si detectors)

unit 3 shows also a strong degradation after only 375h Su exposure → Slowing down with time (?).

unit 1 (C and Si, once per month)

unit 2 (C, nominal)

unit 3 (Si, once per week)



	Ly-alpha	Herzberg	Aluminium	Zirconium
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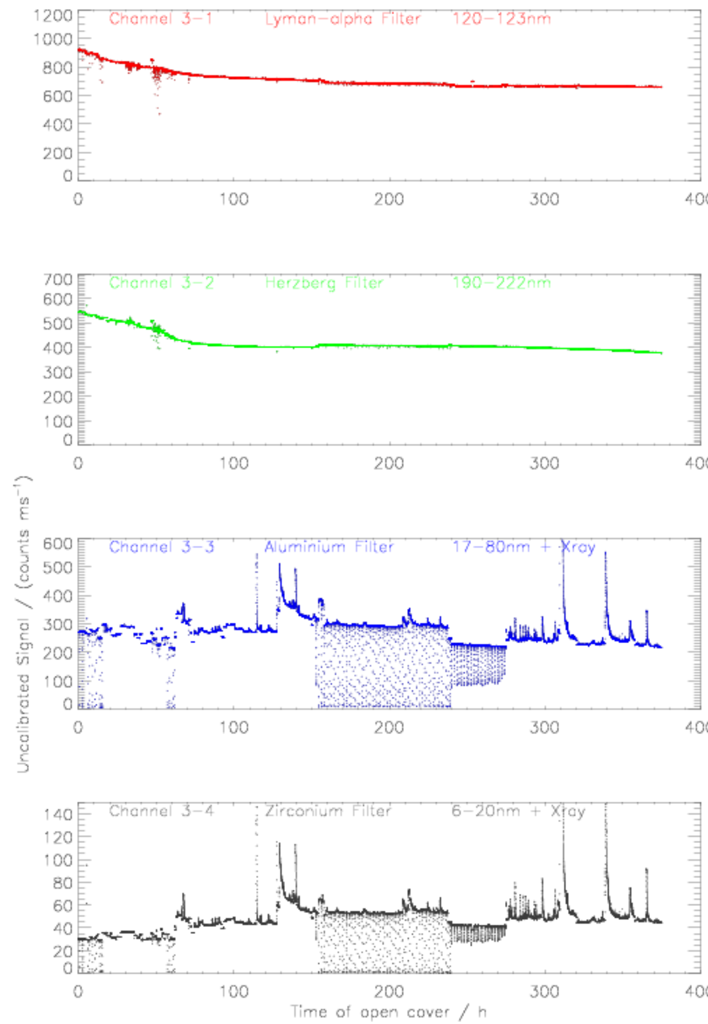
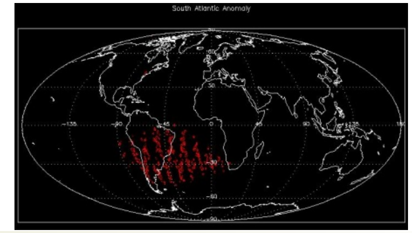
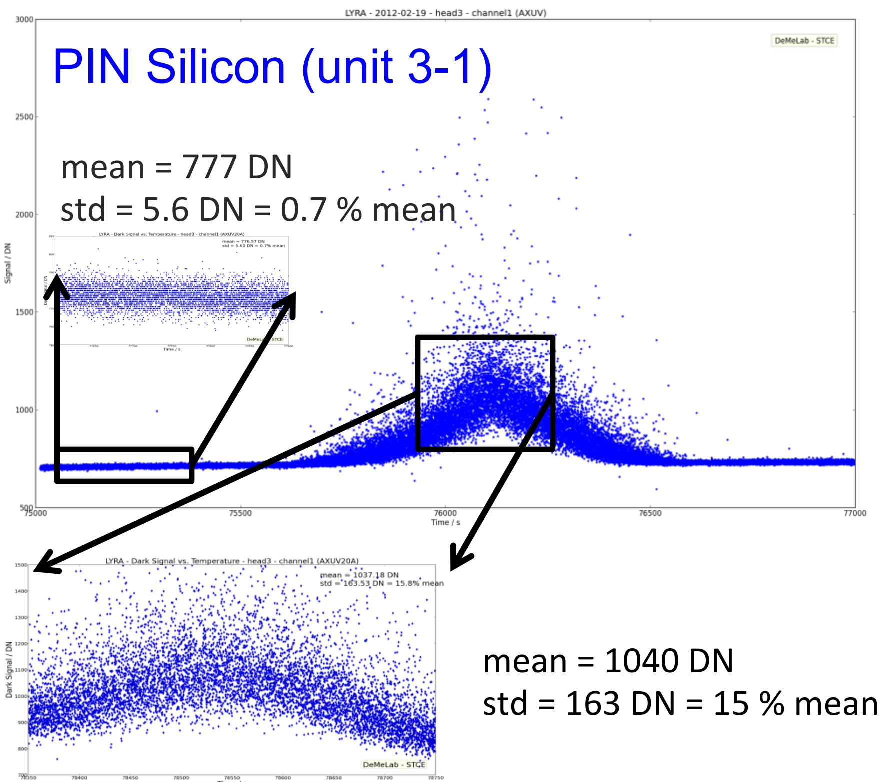


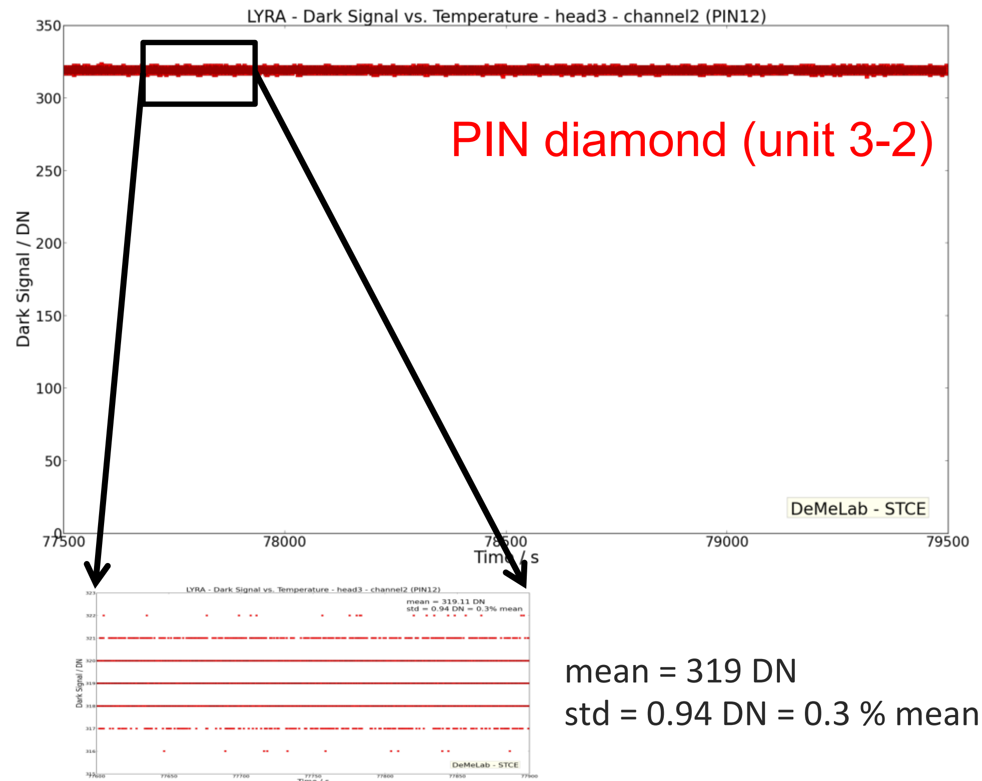
First 375 hours of unit 3 (January 2010 - March 2012)

South Atlantic Anomaly (SAA)



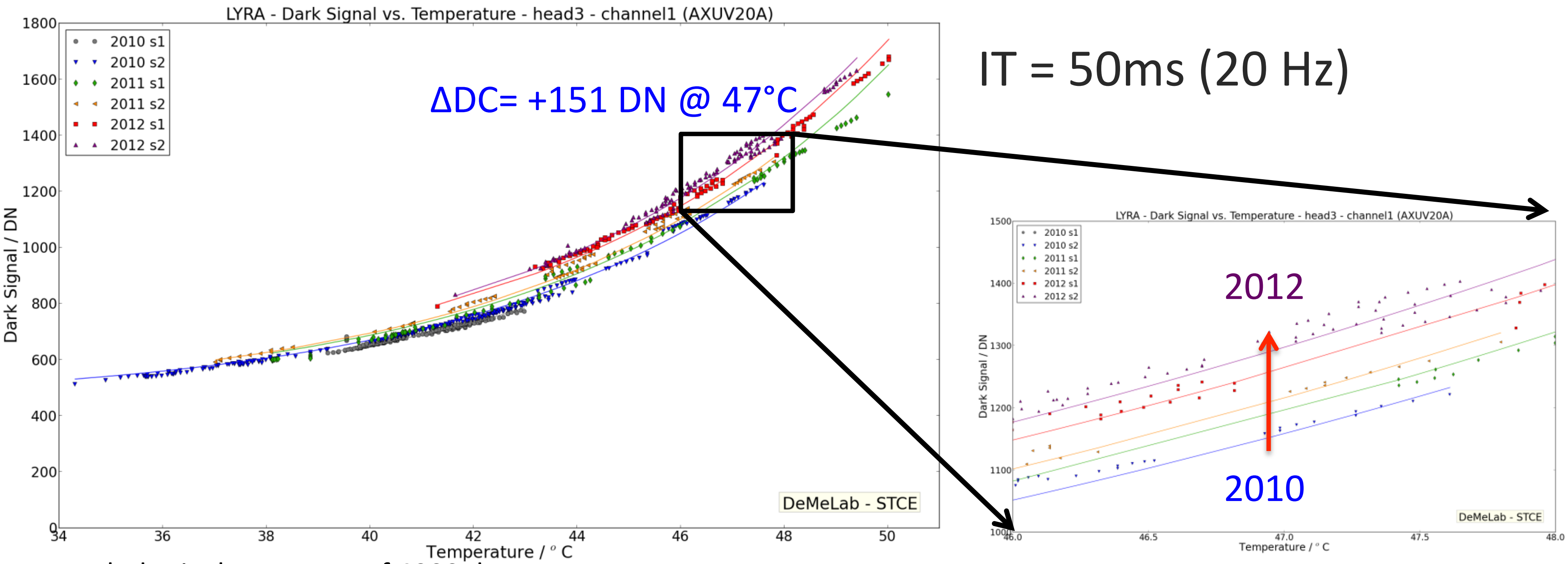
PROBA2 passes 3 times per day (on consecutive orbits) through the **South Atlantic Anomaly** during few minutes.





The SAA perturbs only the Silicon detectors, and not its PIN diamond ones. We may expect surface degradation and/or bulk displacement damage for LYRA PIN Si detectors (e.g. increase of the dark current).

Dark current vs temperature (unit 3-1, Si)



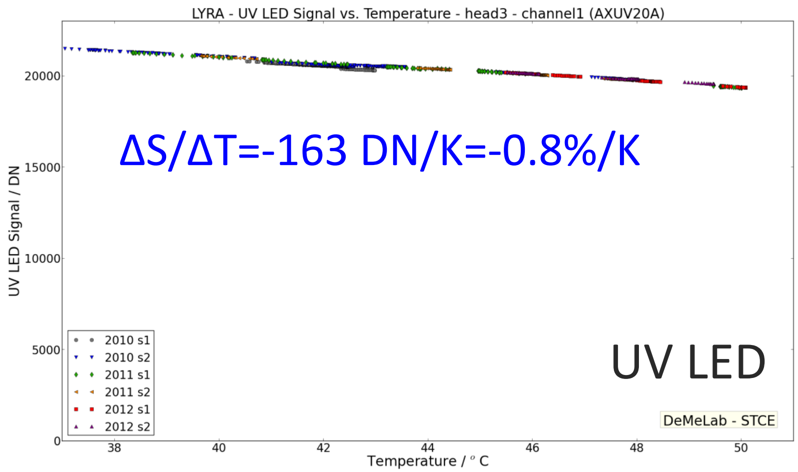
IT = 50ms (20 Hz)

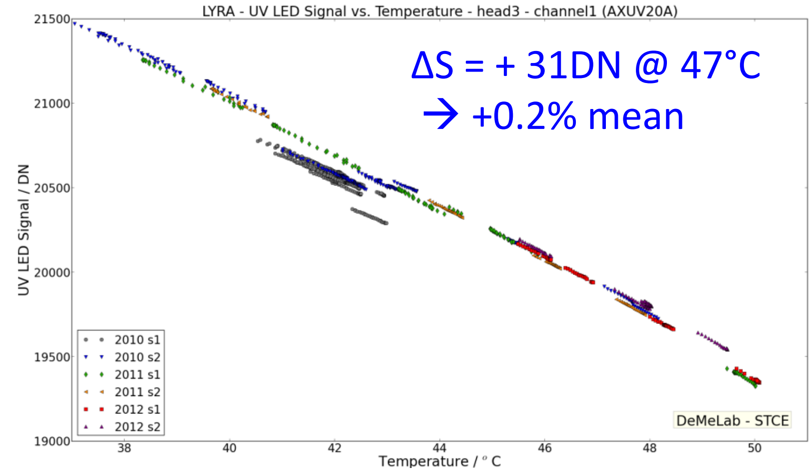
- each dot is the average of 4000 data pts

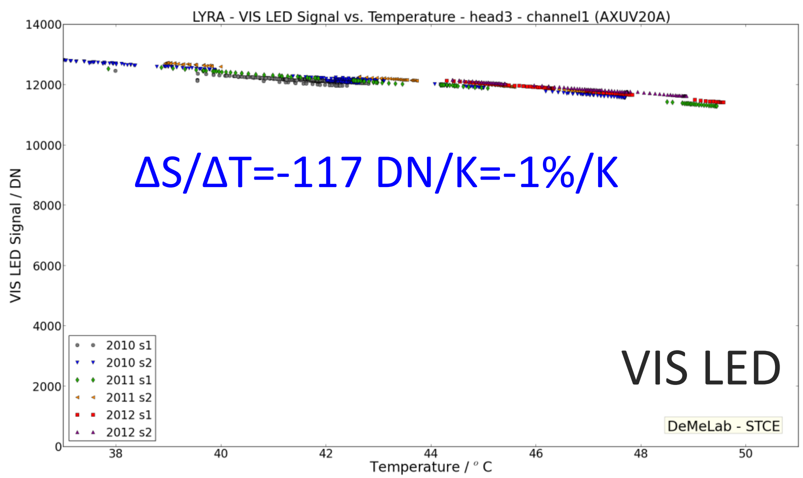
- The temperature during the mission is increasing (→ solar activity ?)
- There is a shift (increase) of the dark current curve vs Time for a given Temperature

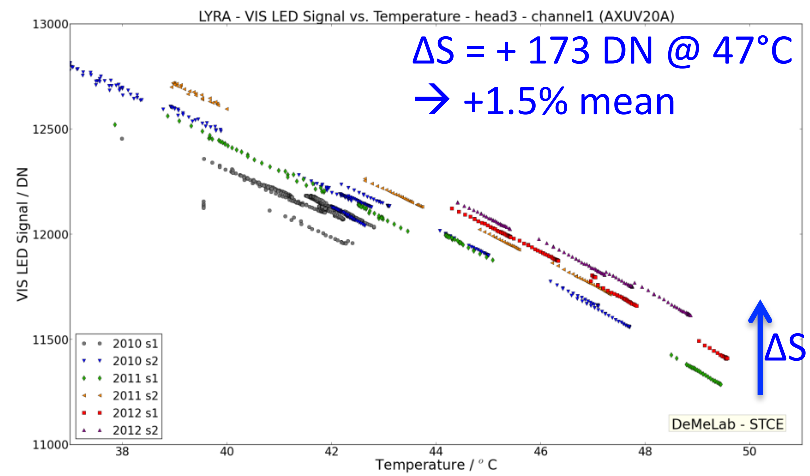
ΔDC = + 151 DN @ 47°C (~ +12% of the mean) → **<u>degradation of the PIN Si (ch3-1)</u>**

Detector signal vs LEDs (unit 3-1, Si)





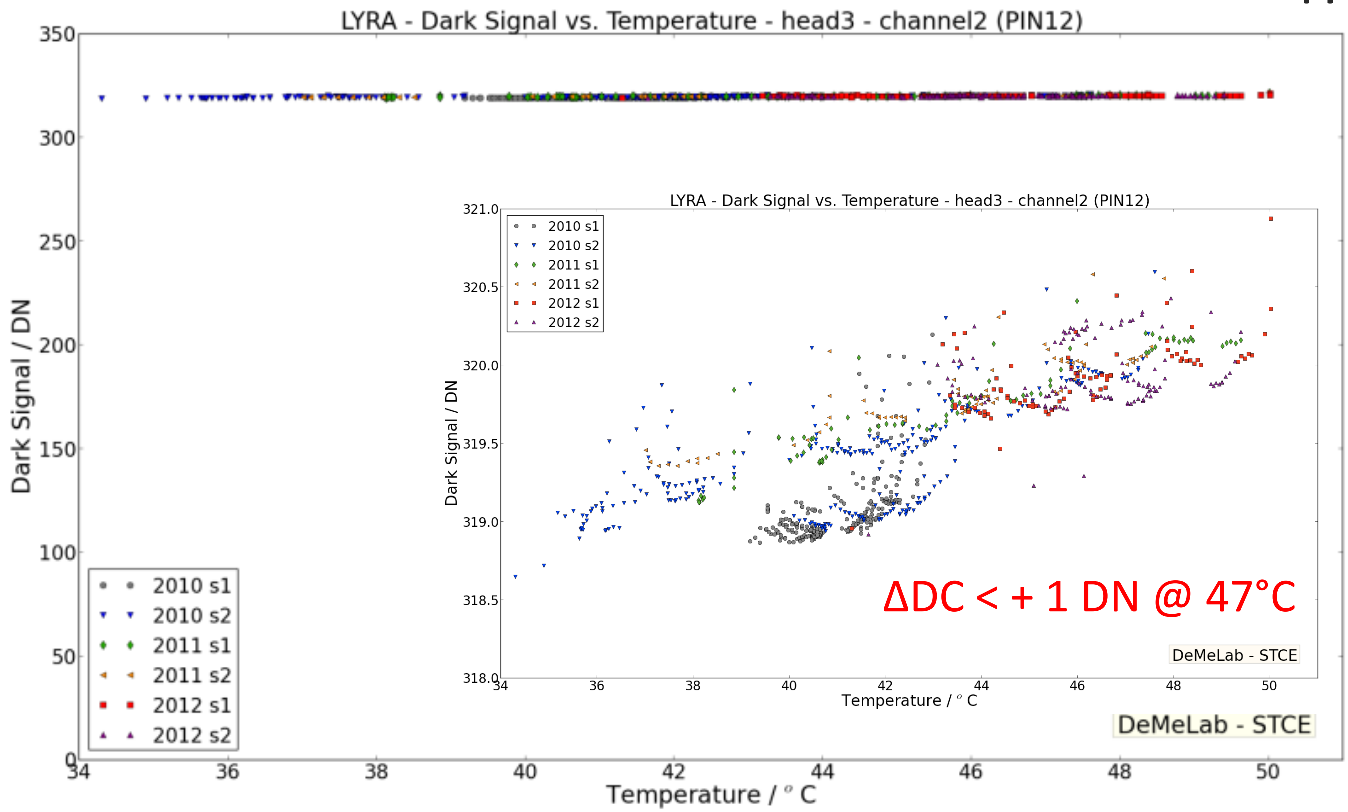




- The LEDs signal decreases with temperature, as expected.
- The UV LED shows good stability vs Time (→ VIS LED, signal increases slightly vs time)

Dark current vs temperature (unit 3-2, Diamond)

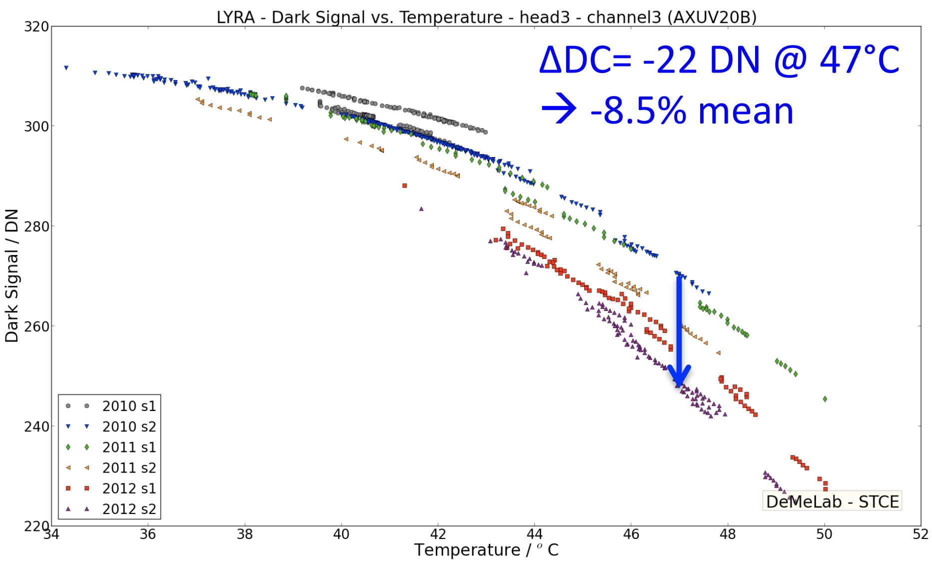
IT = 50ms (20 Hz)

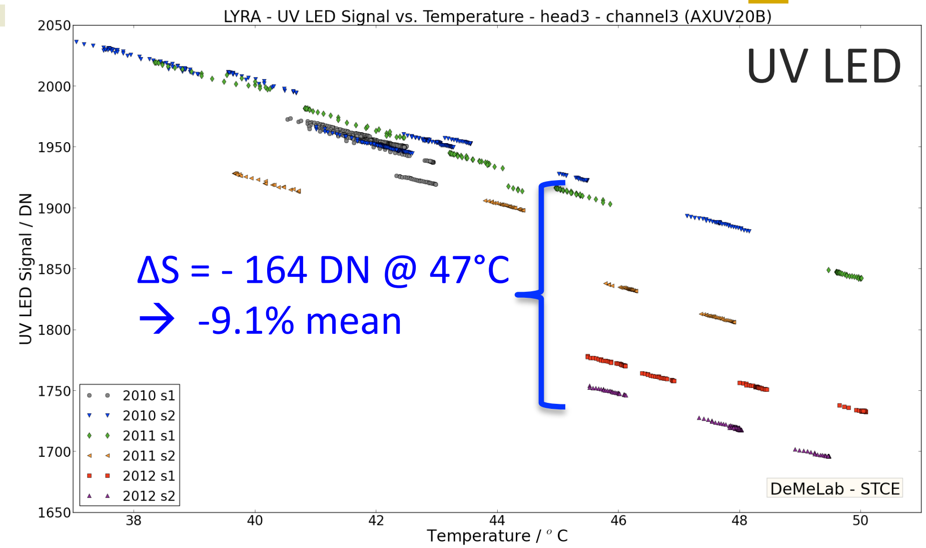


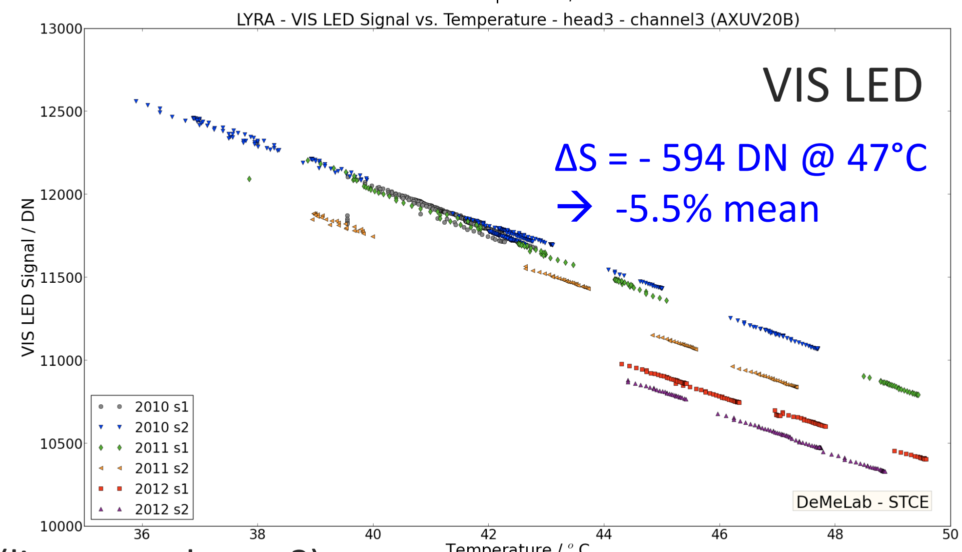
- idem as ch2-2 : Diamond PIN dark current remains stable after 3 years in orbit
  - ΔDC = +0.3% of the mean @ 47°C (=noise) → no diamond PIN detector degradation

Dark current and LEDs (unit 3-3, Si)

ISSUE !!!



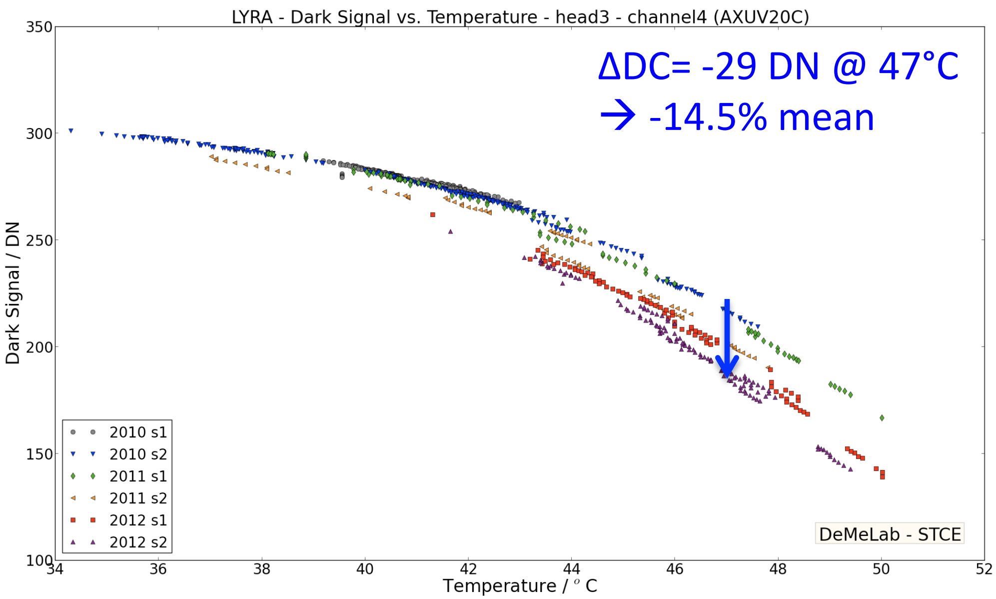


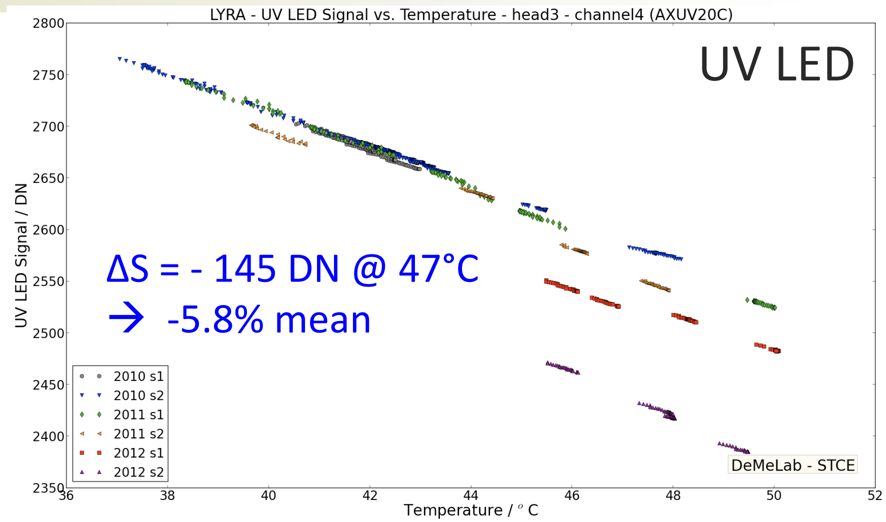


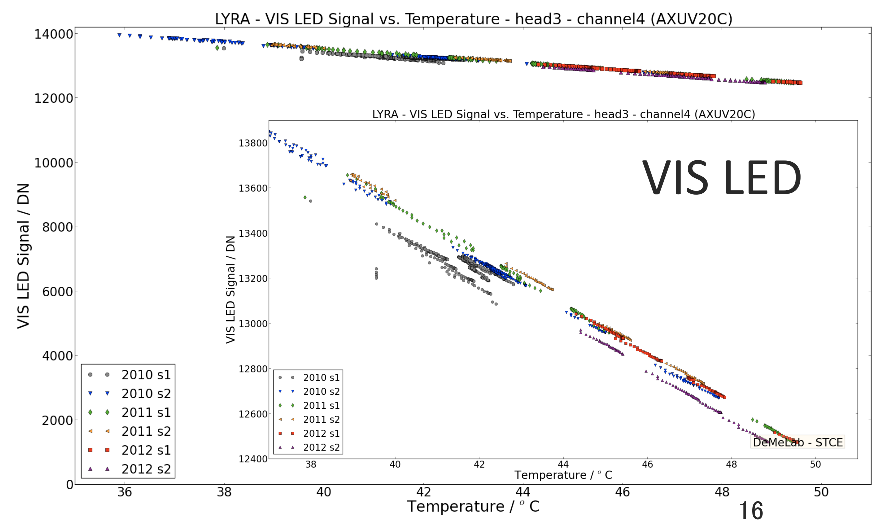
- DC of ch3-3 decreases vs temperature (not physics) and decreases with time.
- LEDs (corrected from DC) → large drift signal vs time (linear vs photon?).

Dark current and LEDs (unit 3-4, Si)

ISSUE !!!







The DC decreases with temperature (problem)

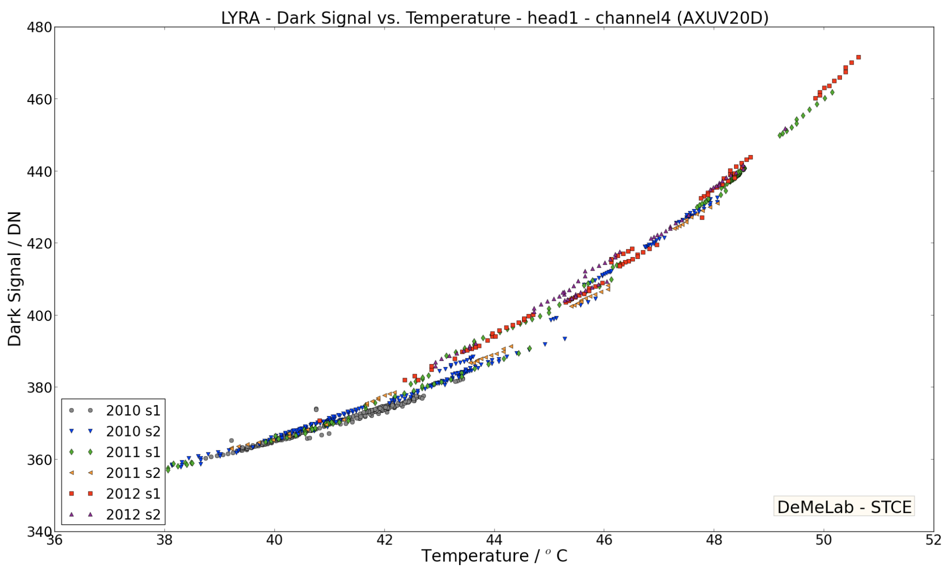
- large ΔDC vs time @ 47°C.
- LEDs → drift signal vs time only with UV LED.

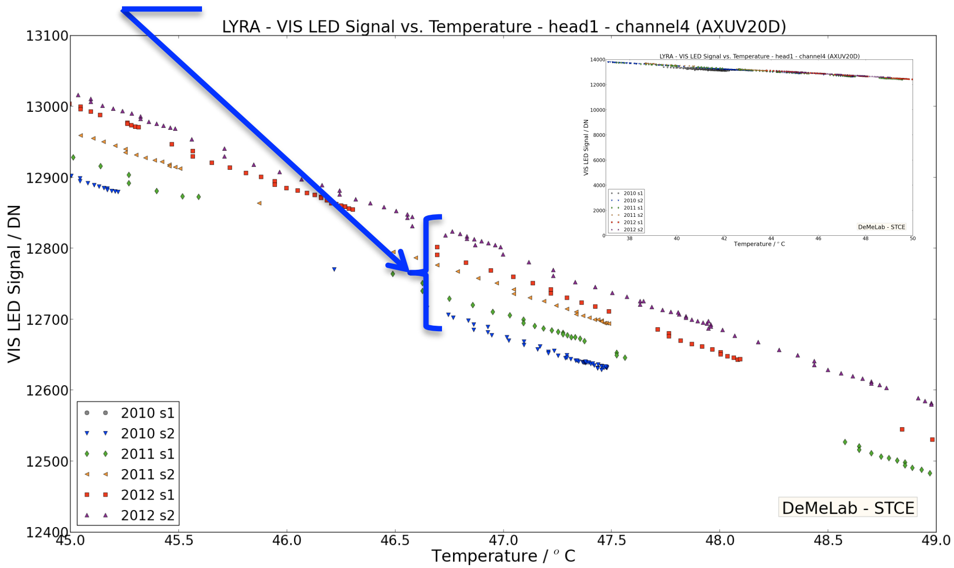
ΔS = - 53 DN @ 47°C → -0.4% mean

Dark current and VIS LED (unit 1-4, Si)

ΔDC = +1.2 DN (+ 0.3% mean) @ 47°C

ΔS = +118 DN (+ 0.9% mean) @47°C

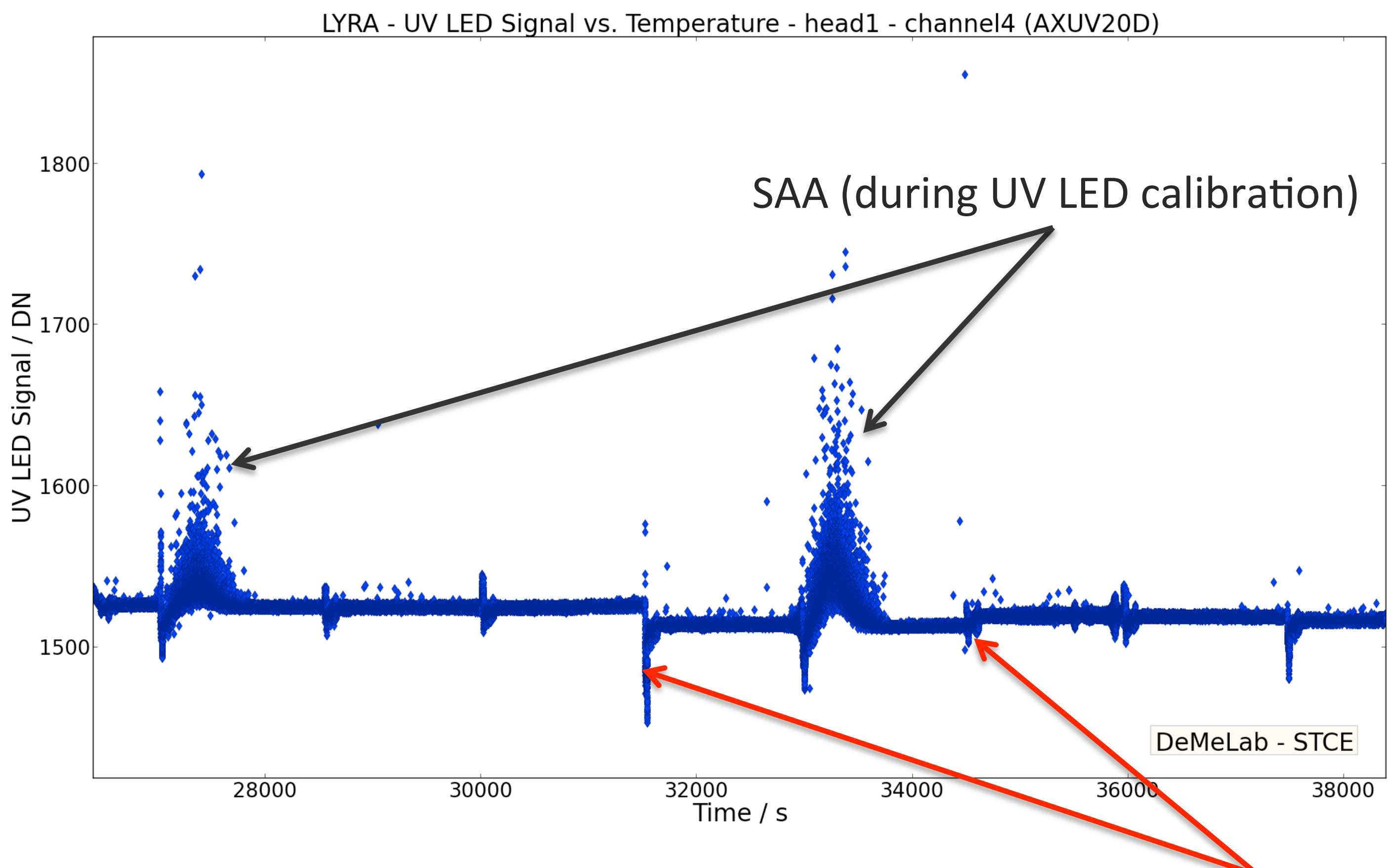




- The DC increases with temperature (ok) and there is no signal drift (noise) vs time for a given Temperature,
- VIS LED: the signal increases slightly (idem. ch3-1) with time but still negligible (below 1% at 47°C),

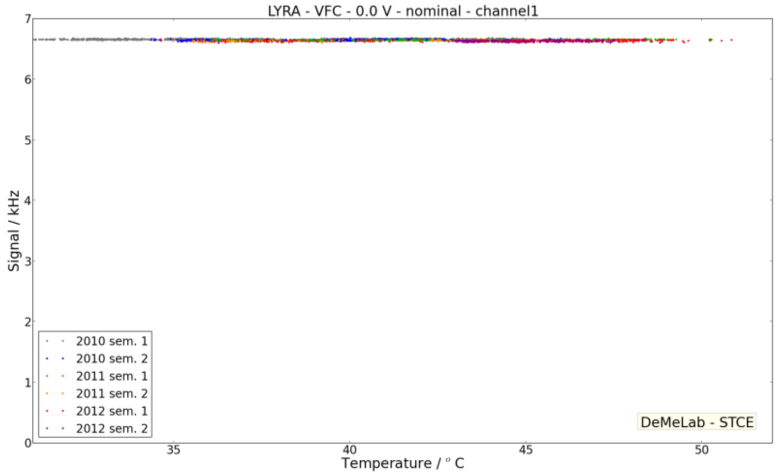
→ **No degradation of PIN Si detector (ch1-4)**

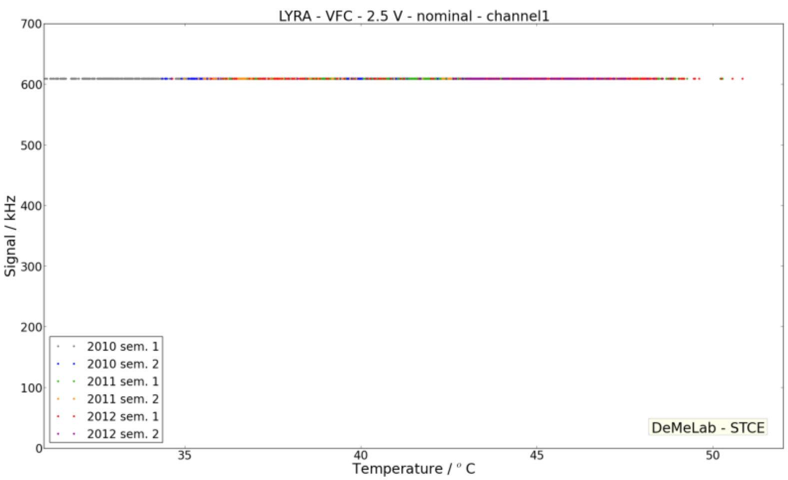
UV LED (unit 1-4, Si)



As observed, when illuminated by UV LED (only), ch1-4 signal shows spikes/jumps during LARs
→ UV LED is not well fixed/attached (TBC) → difficult to process the data.

LYRA electronics: VFC stability



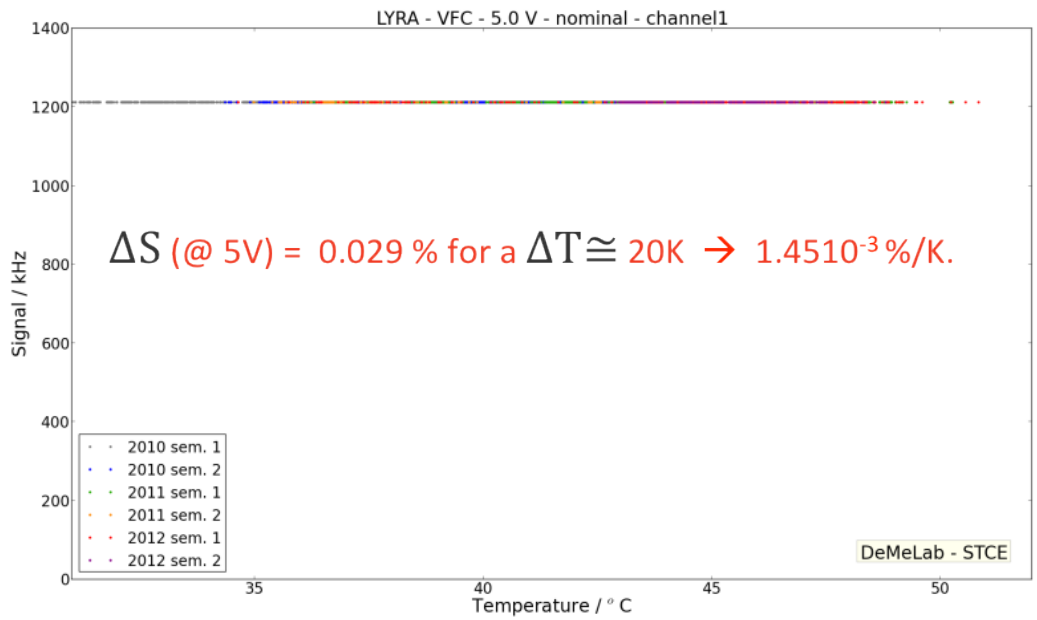


VFC : Voltage to Frequency Converters (ADC)

→ 3 calibration voltages at ~0V ; 2.5V and 5V

→ **High stability vs Temperature and vs Time (for the 8 VFC)**

→ **All bits are working well, TBC?**



“Summary” table

unit/ch	detector	DC vs T	ΔDC vs time (47°C)	ΔS UV LED (47°C)	ΔS VIS LED (47°C)
1-1, 1-2, 1-3	diamond	/	/	/	/
1-4	PIN Si (AXUV)	+	+0.3%	N/A	+0.9%
2-1	MSM diamond	+	-27%	-9.2%	/
2-2	PIN diamond	stable	-0.3%	LED-blind	LED-blind
2-3, 2-4	MSM diamond	/	/	/	/
3-1 (Ly-α)	PIN Si (AXUV)	+	+12%	+0.2%	+1.5%
3-2 (Hz)	PIN diamond	stable	+0.3%	LED-blind	LED-blind
3-3 (Al)	PIN Si (AXUV)	**- (?)**	-8.5%	-9.1%	-5.5%
3-4 (Zr)	PIN Si (AXUV)	**- (?)**	-14.5%	-5.8%	-0.4%

→ MSM diamond detector (ch2-1) seems to recover vs time (TBC ch2-3 and 2-4),
→ PIN diamond (ch2-2 and 3-2) are stable,
→ DC of PIN Si detectors degrade with time (with a drift of the LEDs signal for ch3-3 and 3-4),
→ ch1-4 (Si PIN) is not degraded

LYRA degradation: unit 2 (nominal)

-1- diamond detectors (e.g. PIN) are not degraded (or negligible). The main cause of LYRA unit 2 degradation should come from the optical filters:

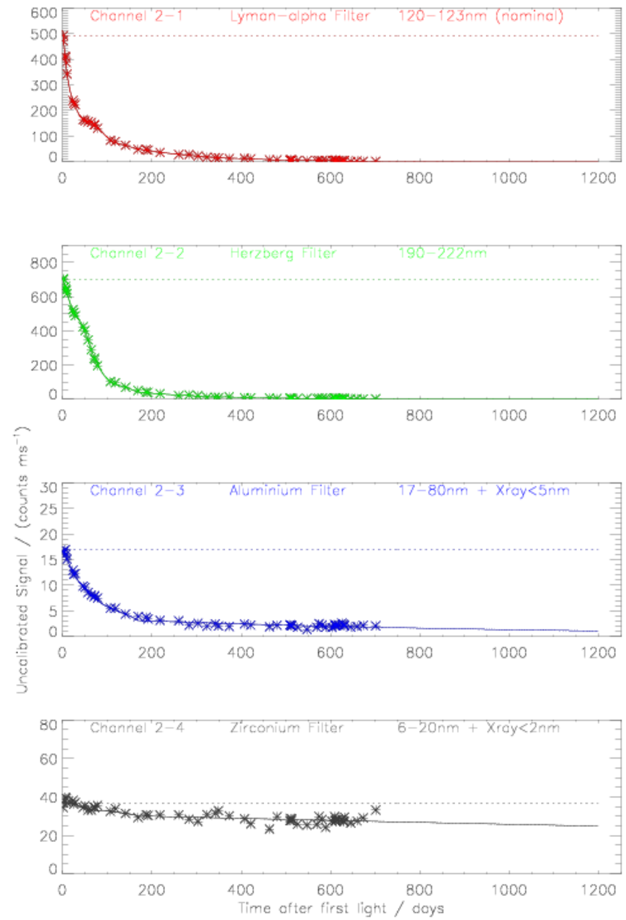
- Hypothesis 1 (accepted)

surface condensation and UV-induced polymerization of outgassing molecules (cleanliness issue),

- Hypothesis 2 (proposed)

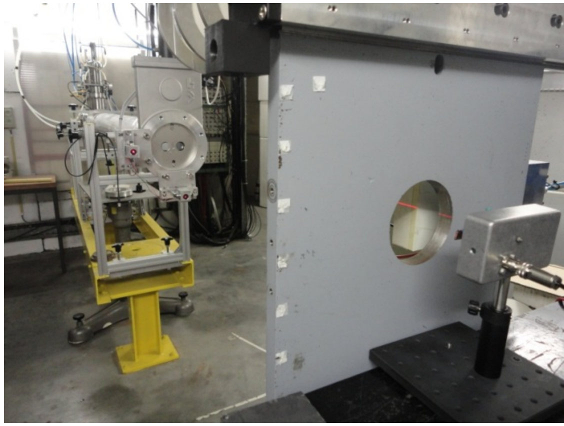
Contamination AND filter degradation due to UV and protons → difficult to assess with solar blind diamond detectors (i.e. cut off at around 225 nm).

→ What's about the LYRA detectors and VUV filter radiation tolerance (ch*-1 and ch*-2) ?



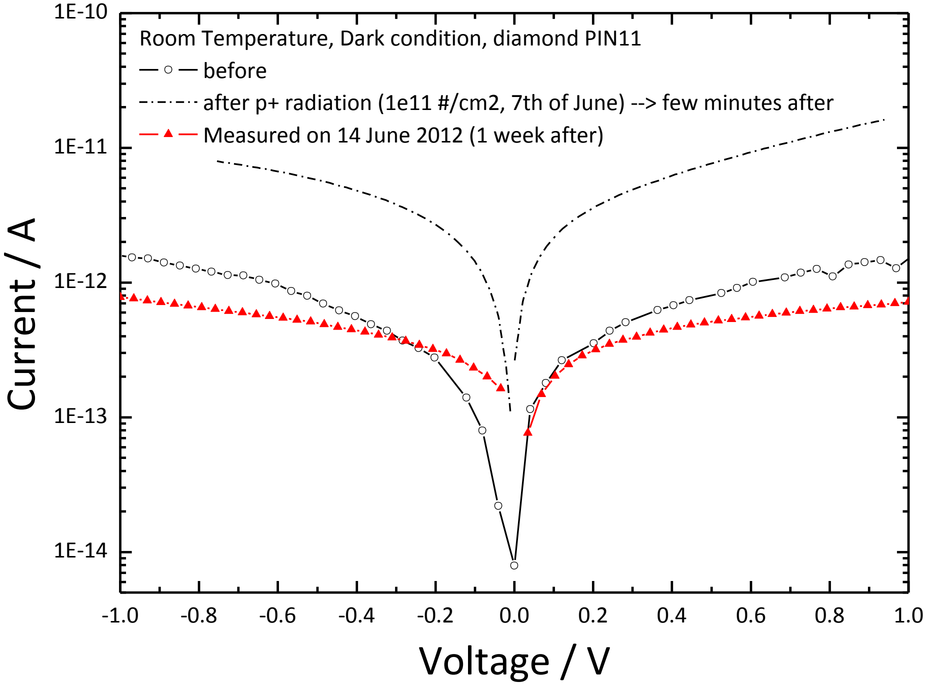
-IV- Lesson learned from on ground proton tests

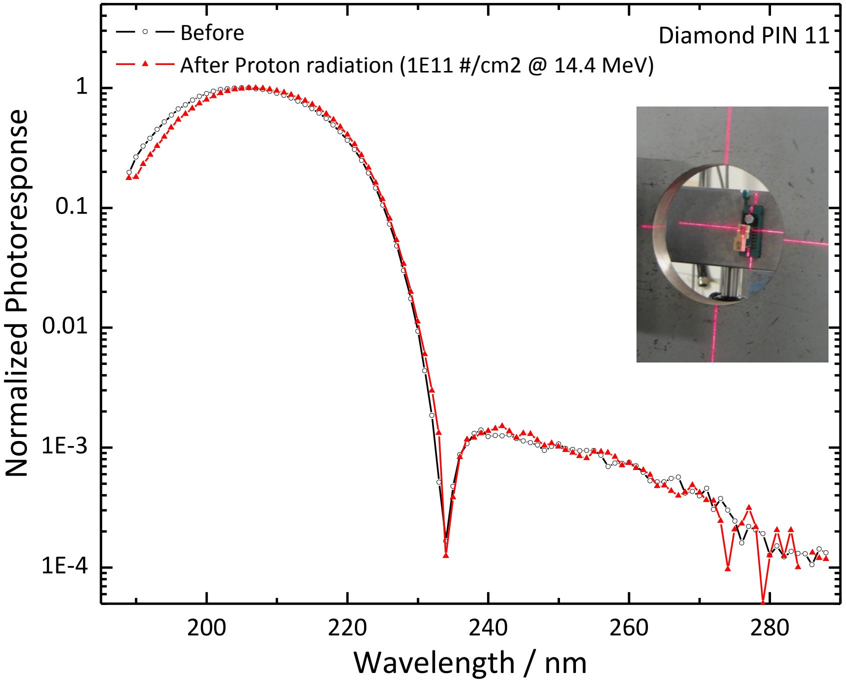
Light Ion Facility @ Cyclotron Research Center in Louvain-La-Neuve, Belgium.



- **Proton energy 14.4 MeV, Flux 1e8 p/cm2/s,**
  - Fluence 5e9 #/cm2
  - Fluence 1e10 #/cm2 (~ accumulated trapped proton fluence 10 MeV equiv. after 3 years in orbit (Spenvis)
  - Fluence 5e10 #/cm2 (~ “)
  - Fluence 1e11 #/cm2 (for detectors only)
- **Annealing (1 to several weeks)**

LYRA diamond PIN

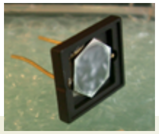


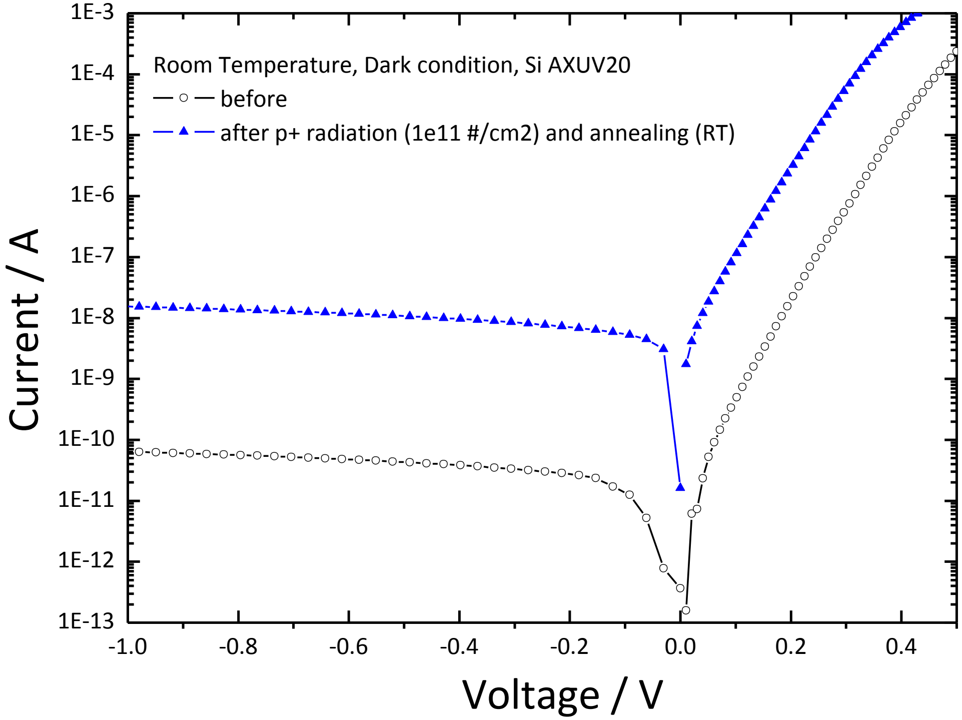


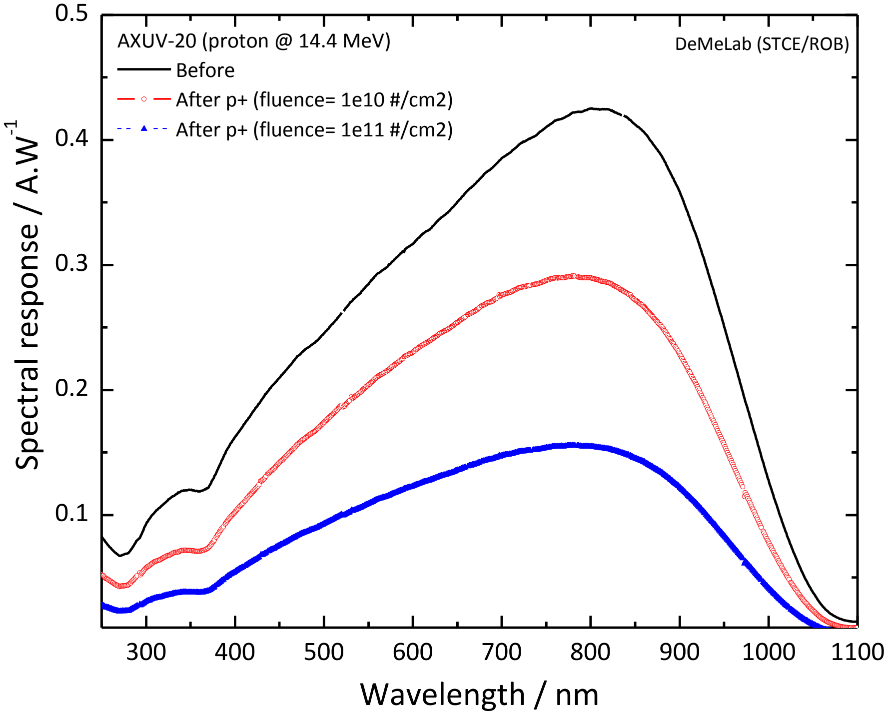
<u>Dark current (PIN11)</u>

DC increases (x7) due mainly to ionization but back to its pre-irradiation value after RT annealing (1 week). The diamond PIN's spectral response is not affected.

LYRA Si PIN photodiode (AXUV)

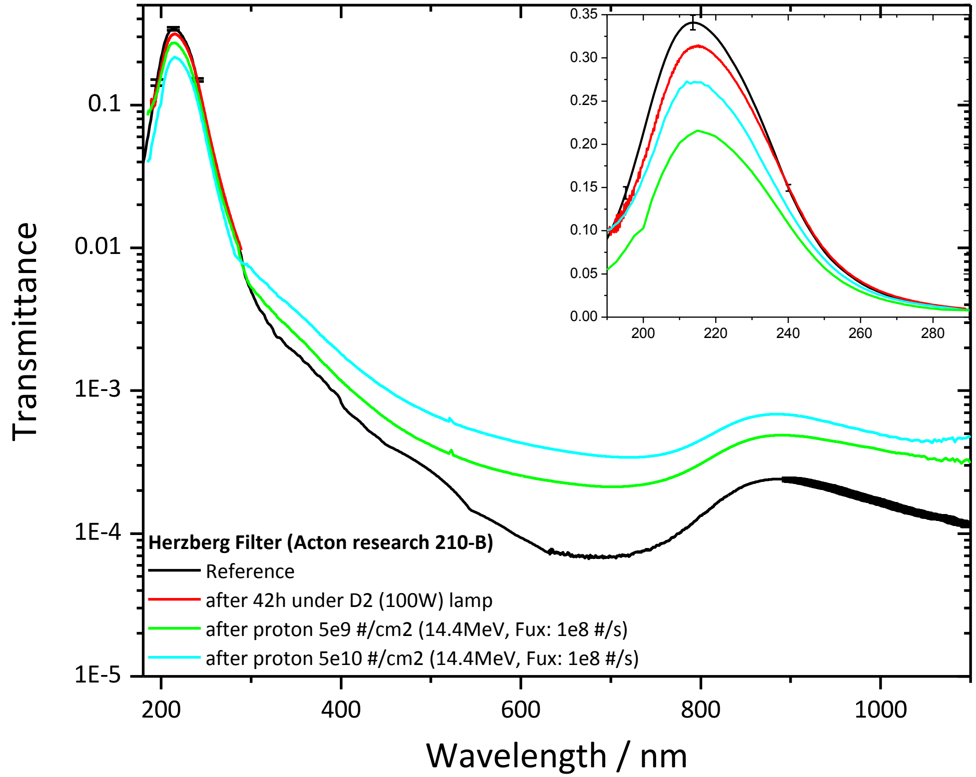


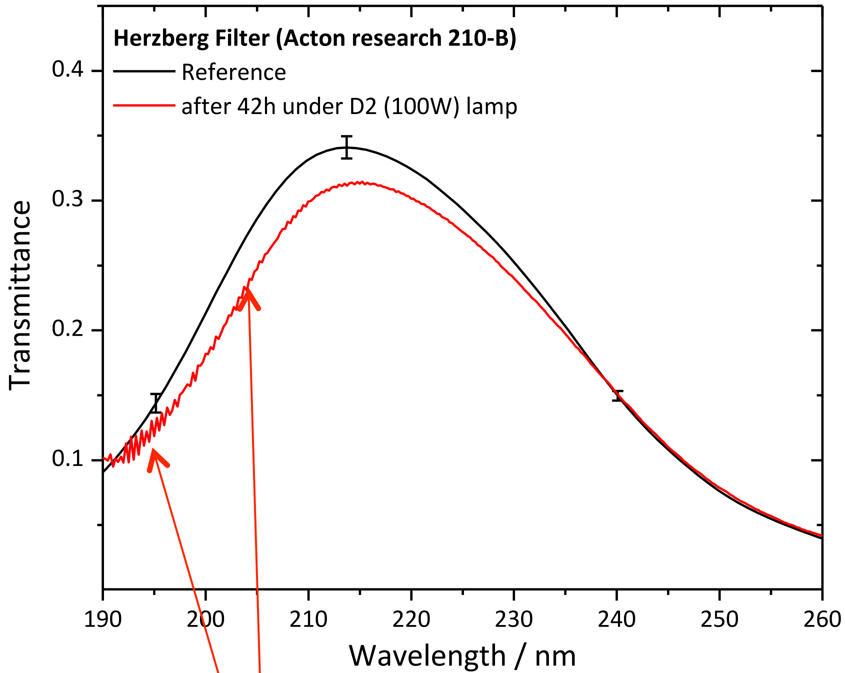




PIN Si dark current increases (x100) and the NUV-VIS spectral response decreases strongly (>60%, indep. λ)
→ **Permanent PIN Si detector degradation** (measured several weeks after radiation tests)

LYRA's filters (Hz) after UV & proton tests (@14.4 MeV)



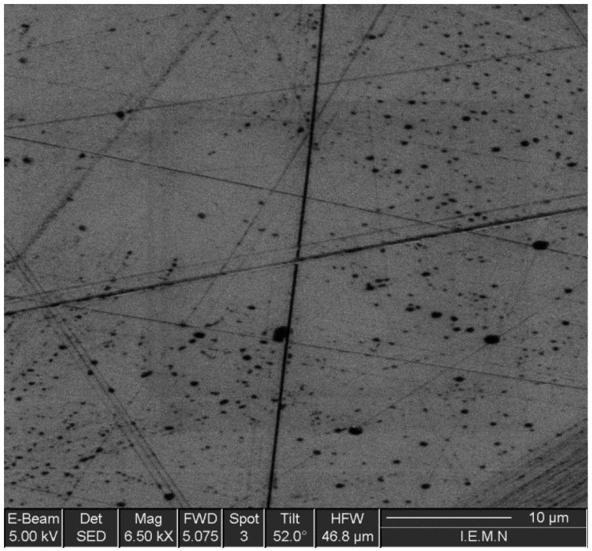


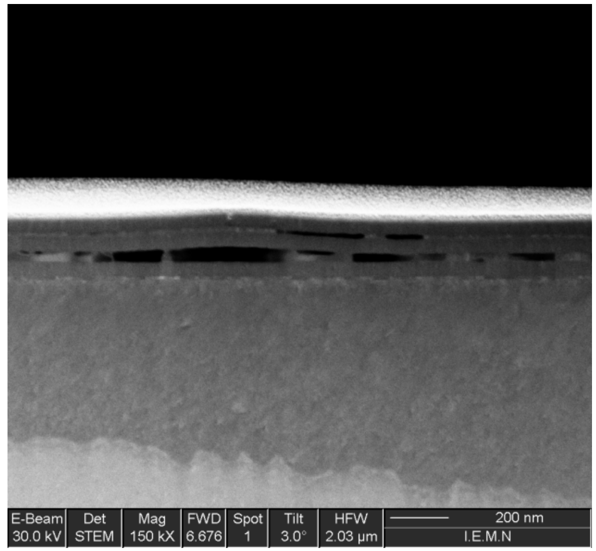
Herzberg filters at 214 nm:

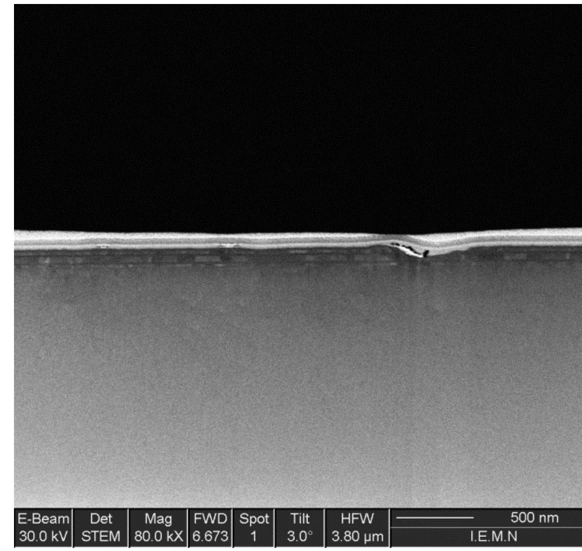
- Transmission decreases by ~10% after UV radiation (observation of interference fringes after 30h UV irradiation)

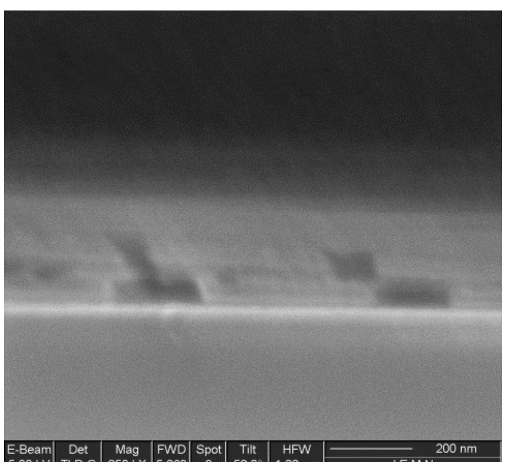
- Transmission decreases by ~37% after proton radiation.

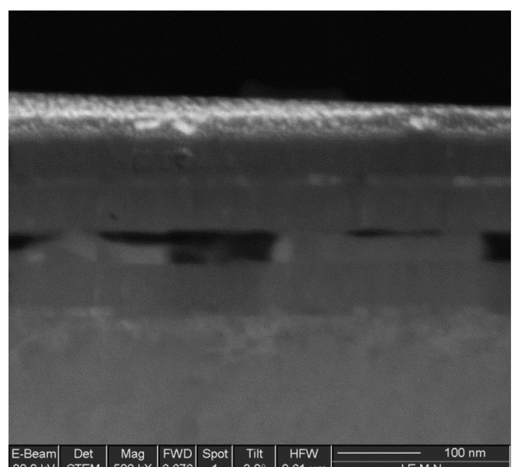
Hz filters: SEM images after proton tests

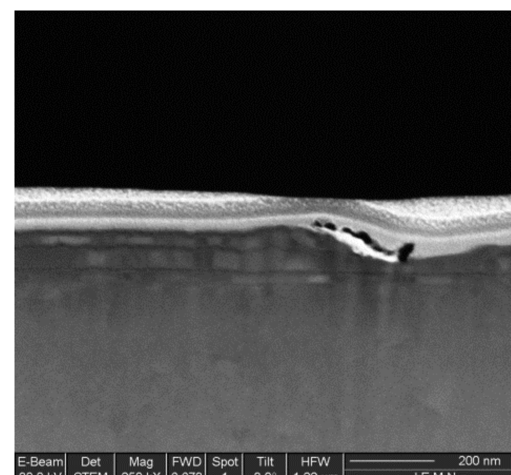






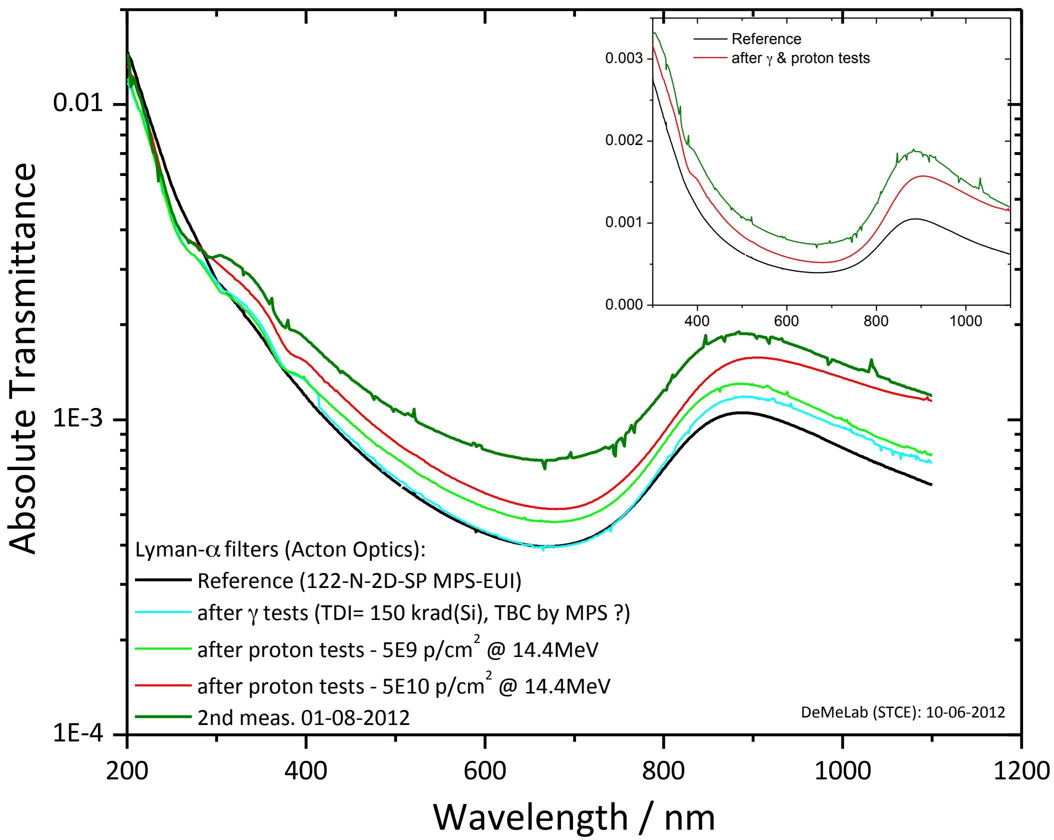


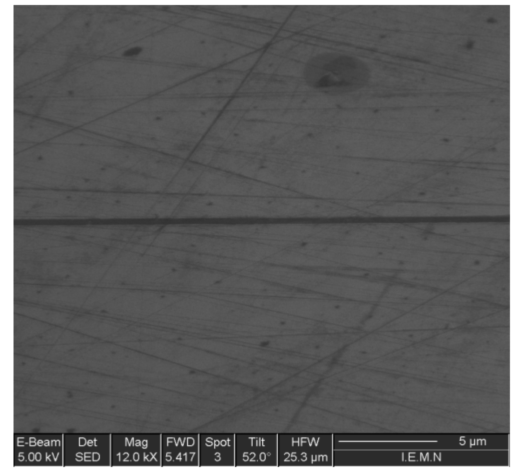


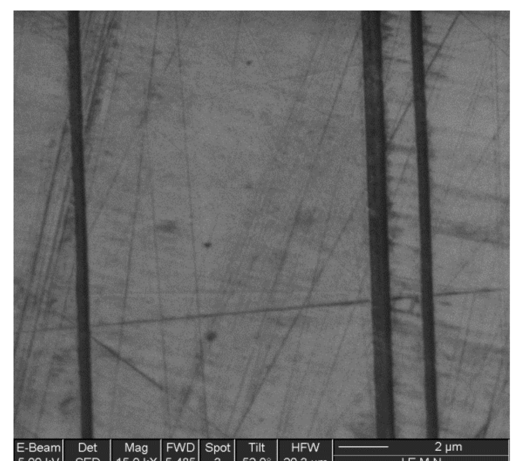


courtesy of IEMN / Dr A Soltani

LYRA-EUI's filters (Ly-a) after γ & proton tests (@14.4 MeV)







SEM: cracks observed on Al top coating

courtesy of MPS/ Dr U. Schuhle and IEMN / Dr A Soltani

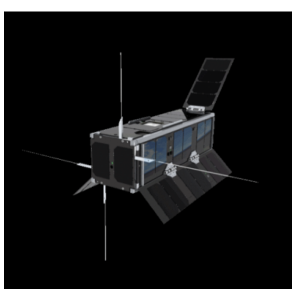
V - Conclusions

LYRA :

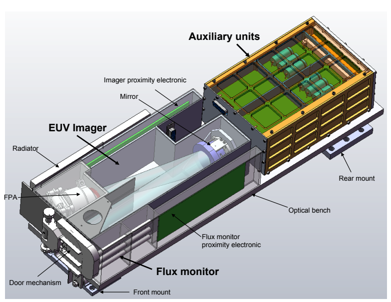
- Benefits from innovative UV diamond detectors (solar-blind and radiation hardened),
- Benefits from two in-flight calibration LEDs (stability/robustness),
- Unit 2 (nominal):
  - no degradation of the LYRA diamond detectors (PIN),
  - Degradation is due to optical filters contamination associated with ‘*possible’* structural degradation (TBC).
- Unit 3 (weekly):
  - PIN Si detectors show degradation: **dark current increases** vs time **(~10-15%)**,
  - The signal drift vs time with LEDs of ch3-3 and 3-4.
- Unit 1 (monthly):
  - PIN Si detector (ch1-4) is not degraded (but problem with UV LED).

There is a need of innovative technologies to meet the needs for future UV solar radiometers:

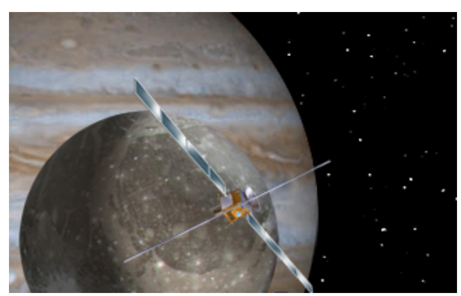
-**At STCE-DeMeLab,** development of new challenging WBGM detectors → MSM_{AlN} (with high stability @ Ly-α)



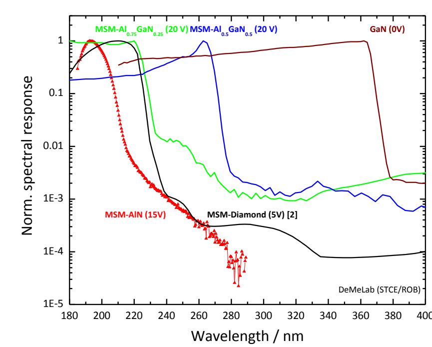
QB50 (Picasso) - 2013/14



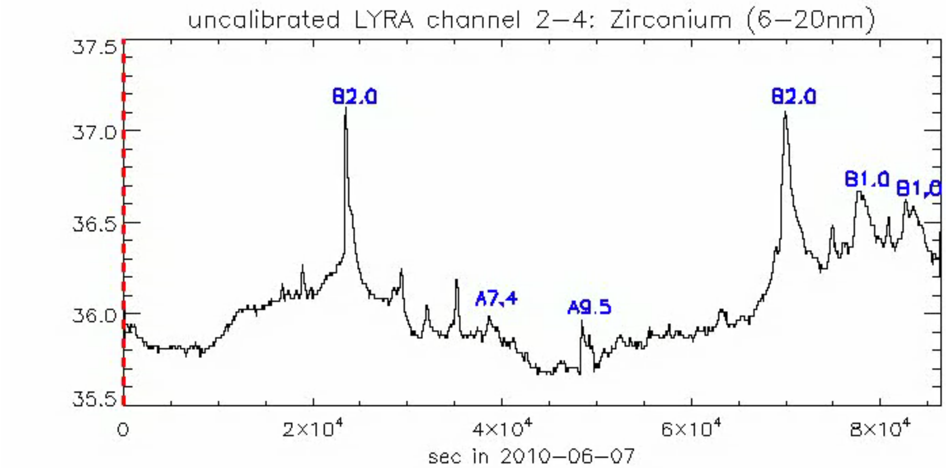
ESIO – prototype (2015)

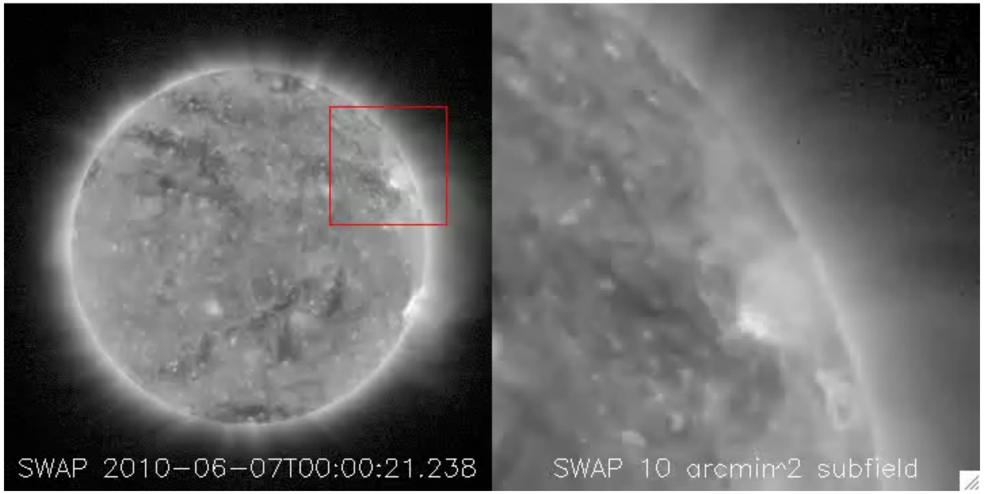


4S4J / JUICE - 2022



Thank you for your attention





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Max-Planck-Institut für Sonnensystemforschung

P.N.Lebedev Physical Institute of the Russian Academy of Science