



## Space-based instrument developments for UV solar observations (at ROB/STCE) - focus on detector technology -

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- I- Introduction – ROB/STCE –
- II- LYRA and SWAP onboard PROBA2 (on-orbit since 2009)
- III- SWORD: **Solar W**ide bangap semic**O**nductor **R**a**D**iometer (LYRA succ.)
- IV- EUI: **E**xtreme **U**ltraviolet **I**mager telescopes onboard Solar Orbiter (2018)
- V- General conclusions / Recommendations

Ali BenMoussa, B. Giordanengo, S. Gissot, I.E. Dammasch, M. Dominique et al.  
– 1 – Solar-Terrestrial Center of Excellence (STCE), Royal Observatory of Belgium (ROB) \*[ali.benmoussa@stce.be](mailto:ali.benmoussa@stce.be)



# I. STCE: Solar Terrestrial Center of Excellence

- STCE WP ROB A.5 : "Advanced Technology for Solar Observations" (lead by A. BenMoussa)
- STCE WP BISA A.4 : "Optics Laboratory facilities" (lead by D. Bolsee)

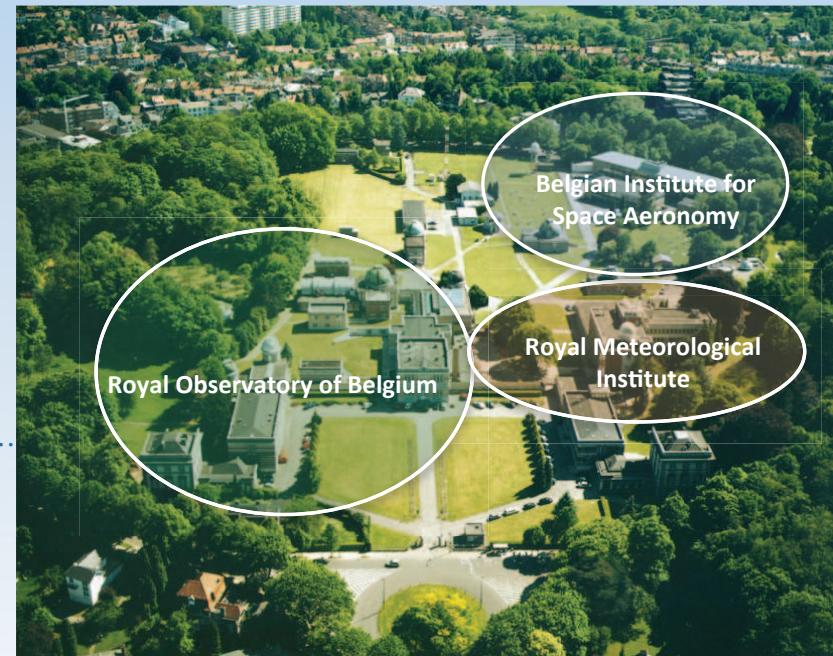
→ Dec 2014: "Space Technology & Calibration Laboratories"

## -1- High-quality characterization and calibration of space and ground-based instruments and their components:

- pre-flight calibration,
- onboard calibration procedures,
- & degradation assessment (lessons-learned).

## -2- Development of critical components for solar observations:

- Wide bandgap based photodetectors,
- CMOS - Active Pixel Sensor (APS),
- UV LEDs, optical filters (porous), signal processing (incl. compression),...

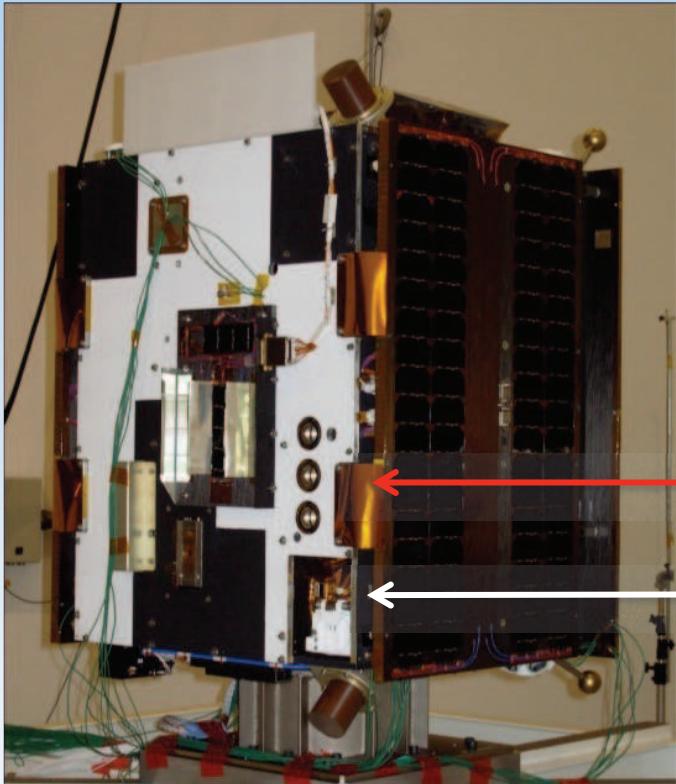


### Solar-Terrestrial Center of Excellence (STCE, Brussels):

- Royal Observatory of Belgium (ROB),
- Belgian Institute for Space Aeronomy (BISA),
- Royal Meteorological Institute of Belgium (RMIB).

## II. LYRA & SWAP onboard PROBA2

– Project for Onboard Autonomy –



PROBA2 fits in 120 kg, <1m<sup>3</sup> with peak power 120 W,

- **17** platform technology experiments and **4** science instruments:
- LYRA & SWAP focused on UV solar observations,
- TPMU & DSPL in-situ plasma instruments (space weather studies),
- controlled from ESA-Redu (Belgium) & remotely operated by ROB.

LYRA - Large Yield Radiometer



SWAP – Sun Watching using Active Pixel Sensor  
(EUV telescope)



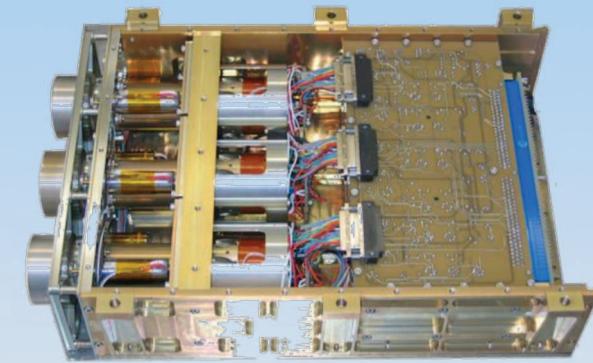
New functionalities for Space Weather Predictions: (<http://proba2.sidc.be>)

Fully in our hands e.g., off- pointing capabilities.

# LYRA highlights

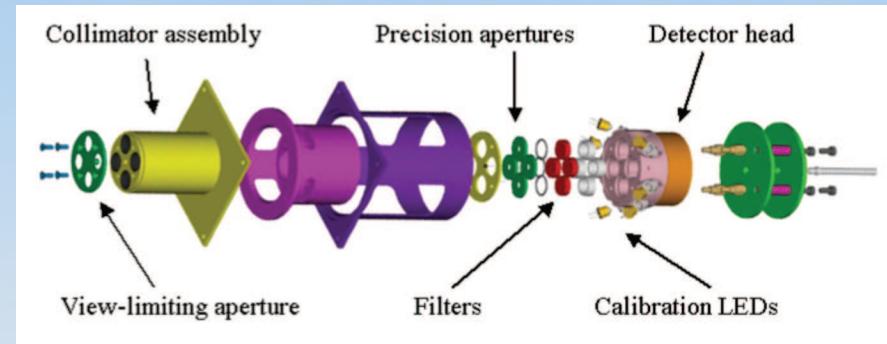


Dimensions: 32 x 22 x 8 cm<sup>3</sup>



Mass: 3.5 kg

Power with SWAP: 6 W



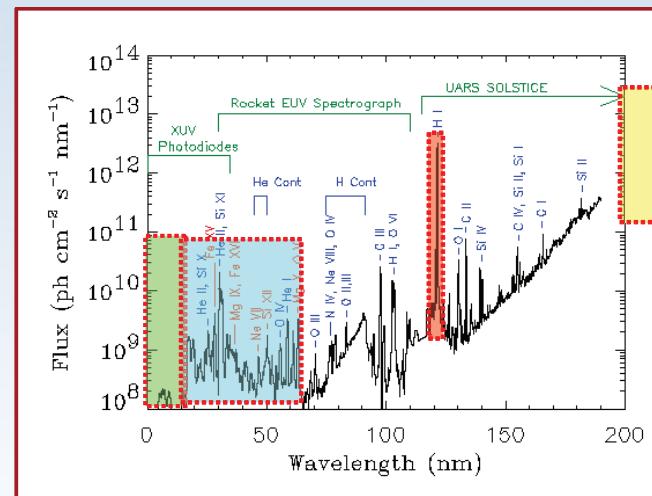
## LYRA:

- 3 units (redundancy concept)
- Wide bandgap detectors (diamond): PIN & MSM
- Silicon (Si-AXUV) reference photodiodes,
- 2 LEDs per detector (total: 24 LEDs),
- High cadence (up to 10 ms).

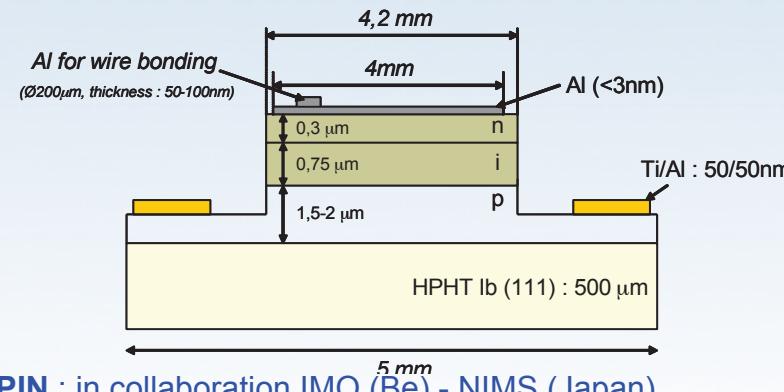
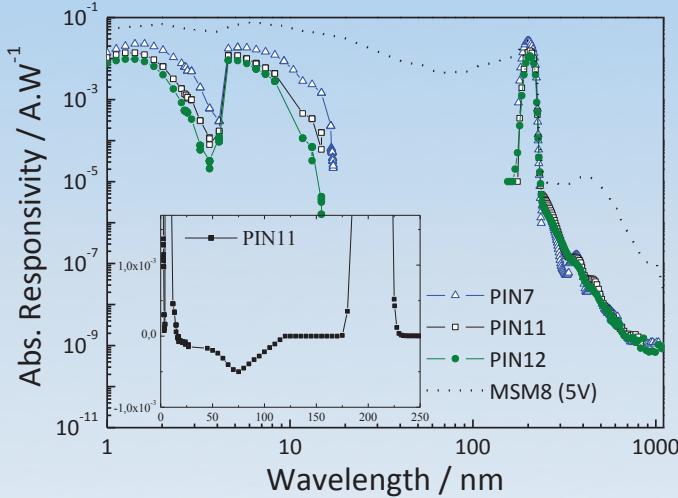
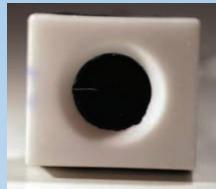


Calibrating LYRA at the Berlin synchrotron

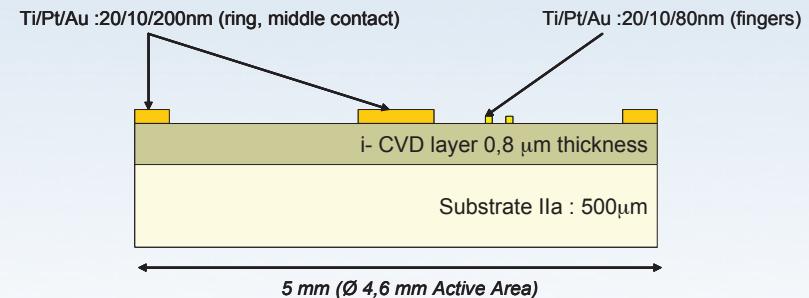
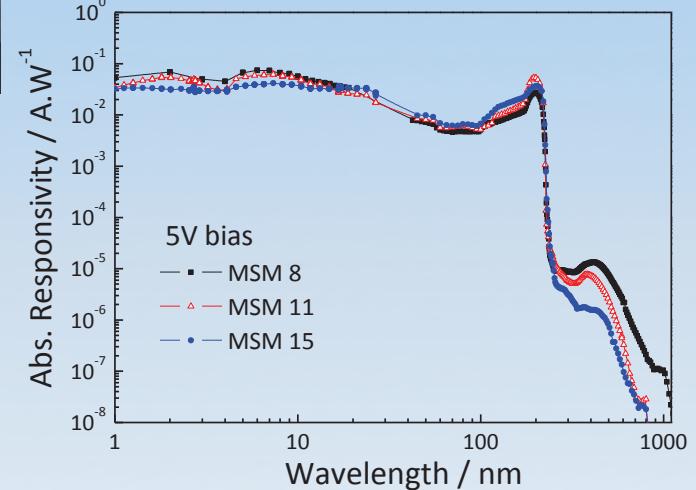
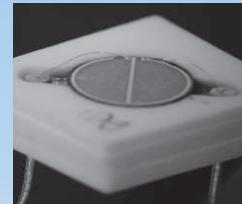
1 unit = 4 (broad-band)spectral channels



# Technological first: diamond detectors

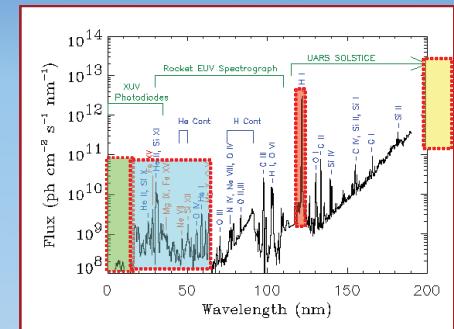


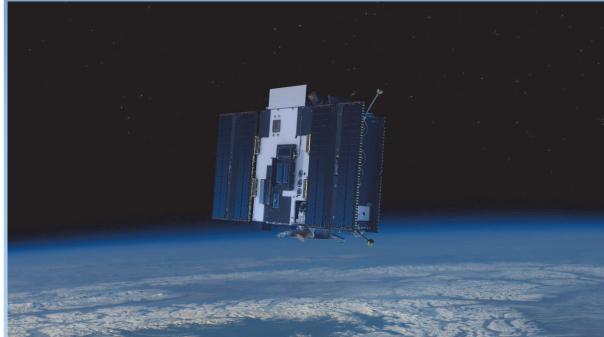
A. BenMoussa et al., (2006), Meas. Sci. Technol. 17 pp 913-917



**MSM** : in collaboration IMO-Garching Analytics GmbH

A. BenMoussa et al., (2006) Nuclear Inst & Methods A568, 398

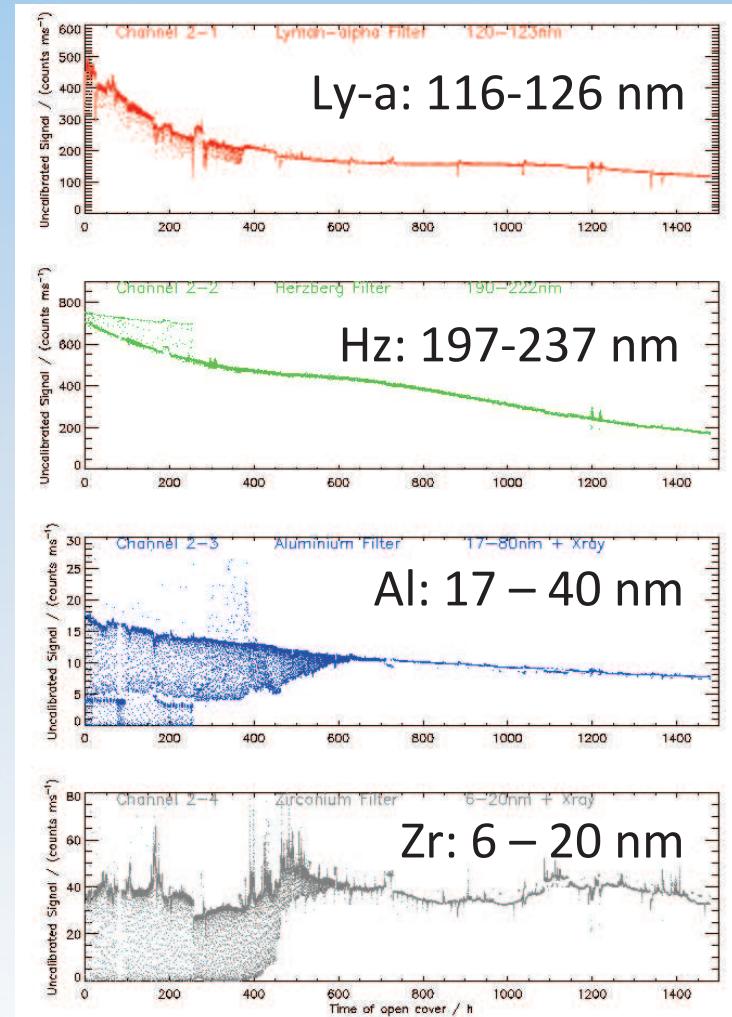
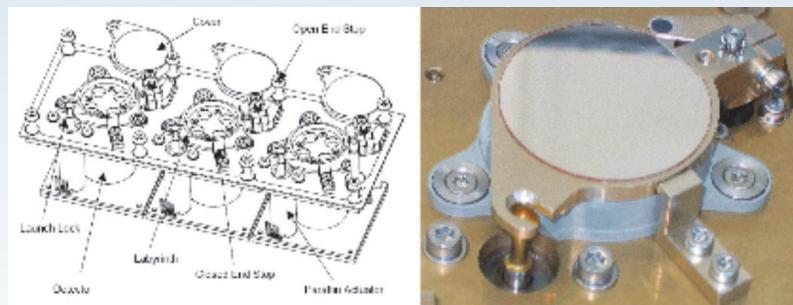




PROBA2 Launch: 2<sup>nd</sup> Nov 2009

LYRA has experienced **severe** degradation after launch (Nov 2009).

- surface condensation and UV-induced polymerization of outgassing molecules on the front optical filters (absorbing in the UV range).
- degradation model: 2 identified candidates, both in the front door mechanism (silicone & epoxy).



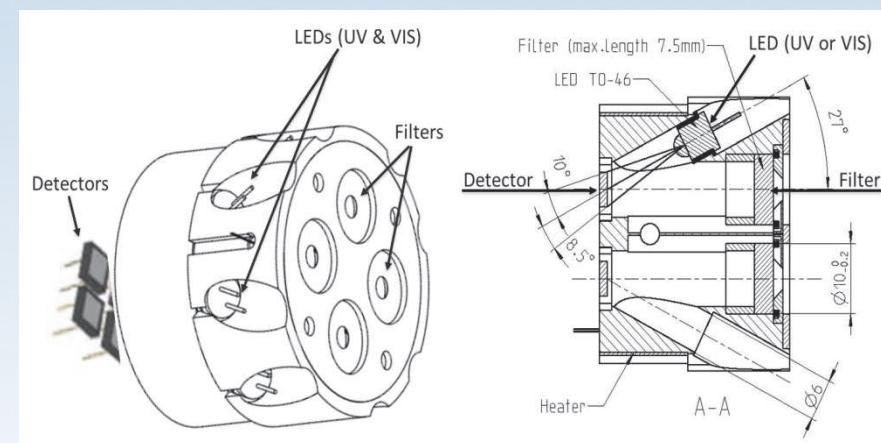
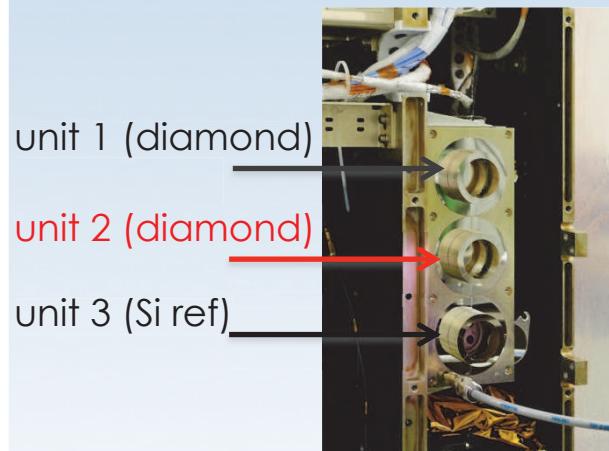
unit 2 (\*nominal) shows degradation since 2010

- But what's about the detectors ?

# LYRA: Onboard calibration strategy

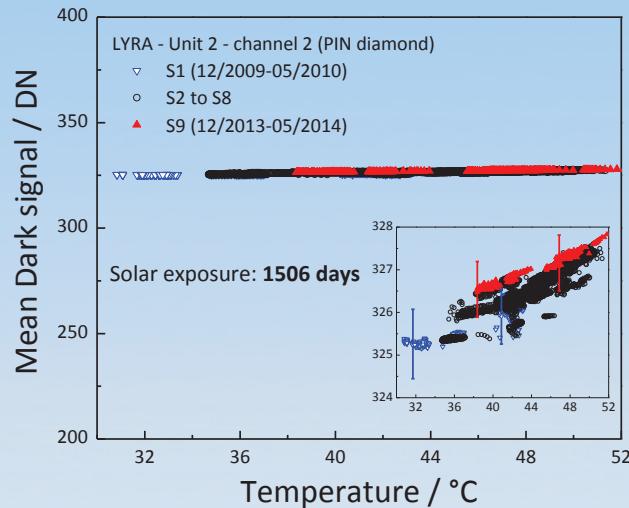
Hope for the best, expect the worst...

1. dark current measurements (closed doors),
2. VIS (470 nm) & UV (365 nm) LEDs to assess the detectors stability/robustness,
3. acquisition with one or two units in parallel,
4. intercalibration with other UV Solar instruments: TIMED/SEE, GOES, EVE/SDO,  
→ WG Inter-Calibration of EUV Instruments (<http://www.stce.be/euvworkshop2014>), 10-13 June 14.



LYRA detector head

# -1- Dark current vs Temp. after 5 years on orbit

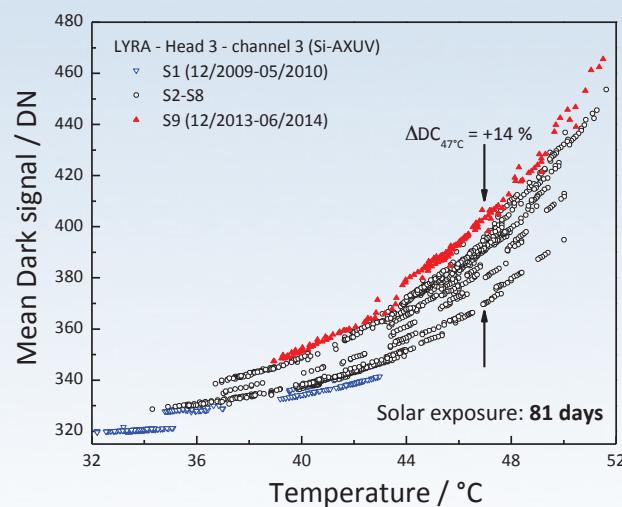


unit 2 (C\*) : 1506 days continuous acquisition



PIN diamond

- Diamond PIN DC remains stable in orbit  
 $\Delta DC = +0.2\% @ 47C$   
**→ no degradation**



unit 3 (Si-AXUV) : 81 days cumulated solar exposure

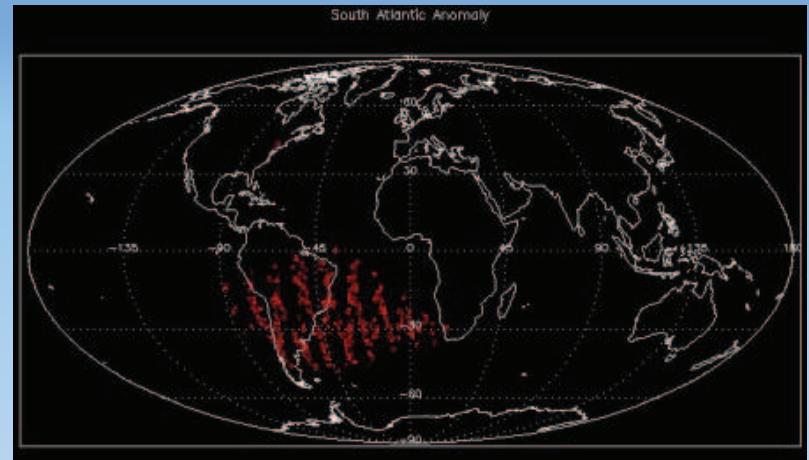


(PIN) Si-AXUV

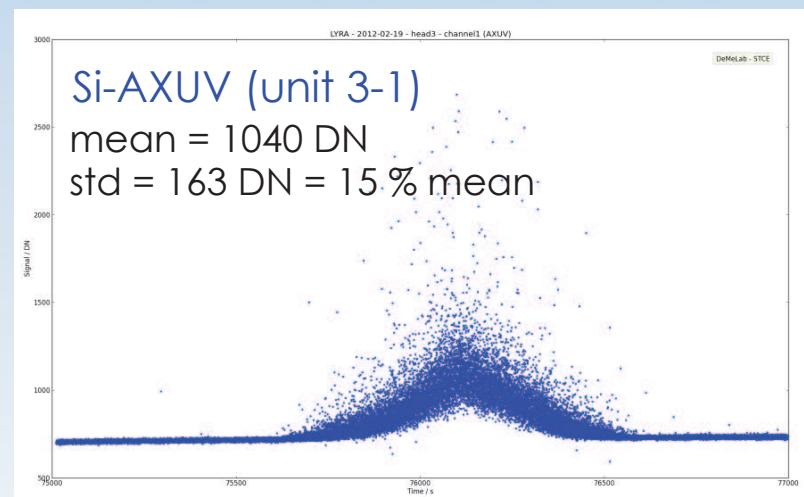
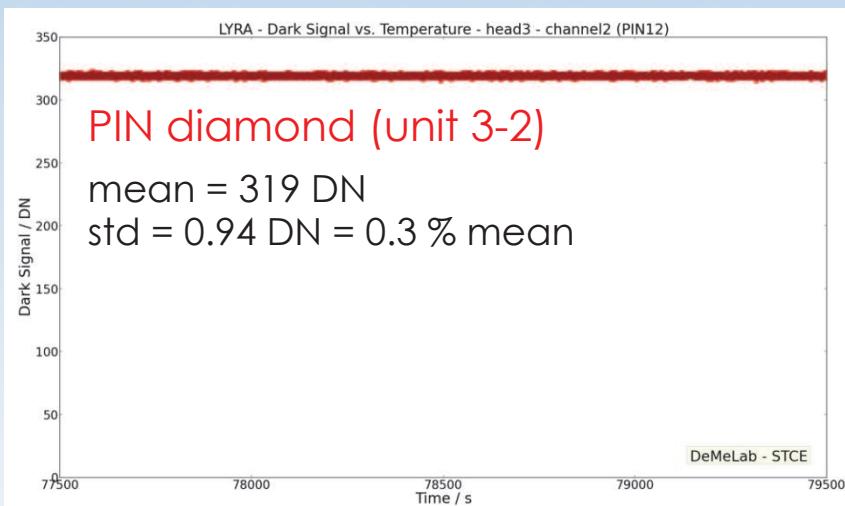
- DC of Si-AXUV increases vs time (idem ch 1 & 4)  
 $\Delta DC \sim +14\% @ 47^{\circ}C$   
**→ EUV radiation-induced ionization damages in the Si-SiO<sub>2</sub> interface (detector passivation layer)**

S1 is referring to the first semester period of LYRA on orbit i.e., from December 2009 until May 2010.  
Each dot is the average of 4000 data points acquired at 50 ms integration time.

# South Atlantic Anomaly (SAA)

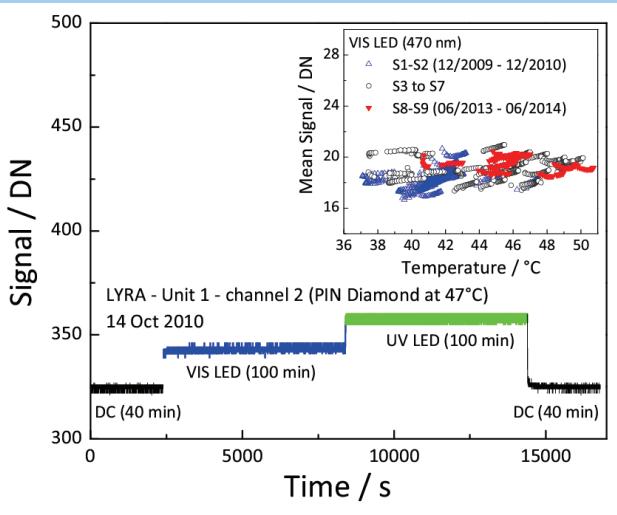


PROBA2 passes 6-8 times per day through the **South Atlantic Anomaly** during few minutes.

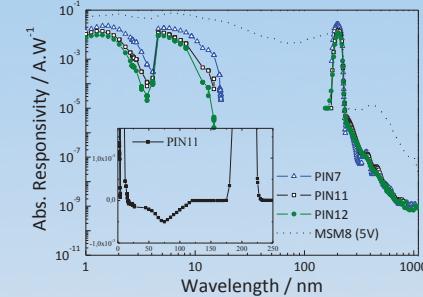


The SAA perturbs only the Si detectors, and not the PIN diamond ones (door closed).

## -2- LEDs vs Temperature

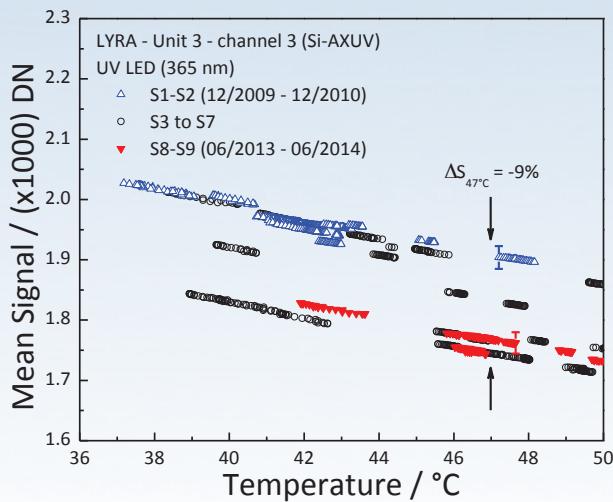


unit 2 ( $C^*$ ) : 1506 days cumulated solar exposure



PIN diamond

Diamond PIN DC (sub bandgap response) remains stable in orbit  
→ no degradation



unit 3 (Si-AXUV) : 81 days cumulated solar exposure



Si-AXUV

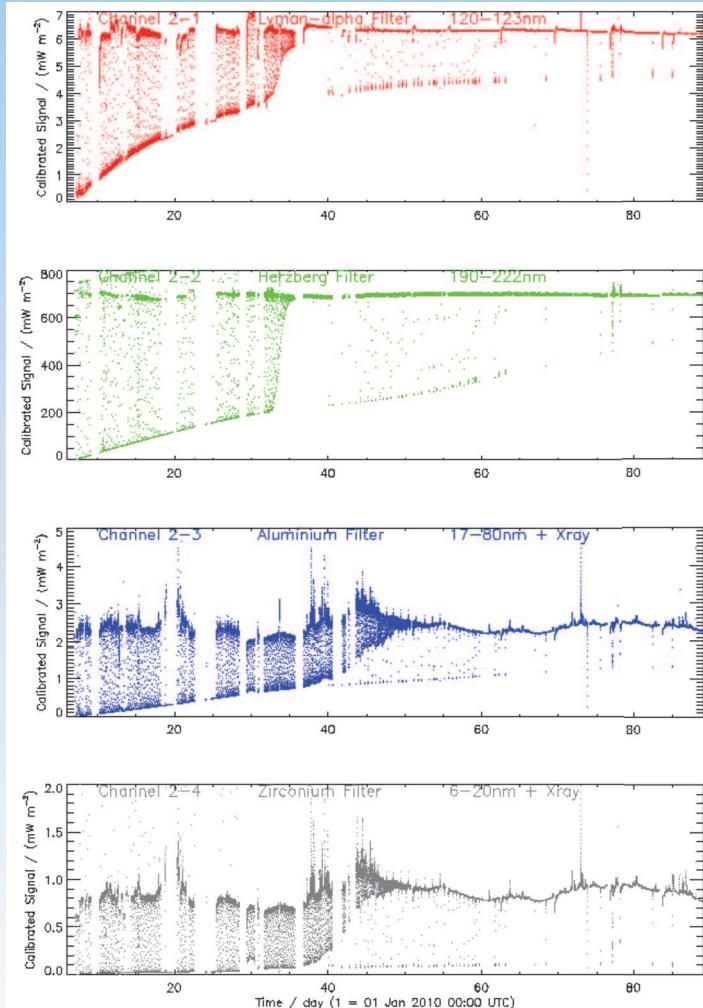
UV LED: -9% @ 47°C (corrected from DC)

VIS LED: -5.5 % @ 47°C

→ Surface (passivation layer) degradation during EUV exposition.

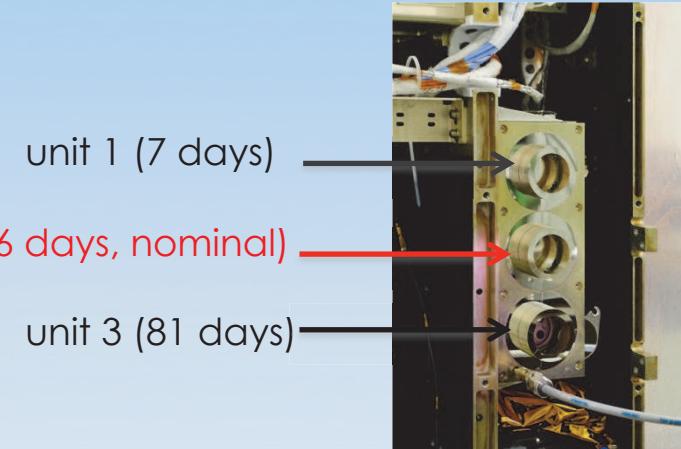
→ ch3-1 (Lyman-a, VUV): 1.5% and 2.5% with UV and VIS LEDs.

### -3- Parallel acquisition (redundancy concept)



Unit 2: corrected solar irradiance (mW/m<sup>2</sup>)

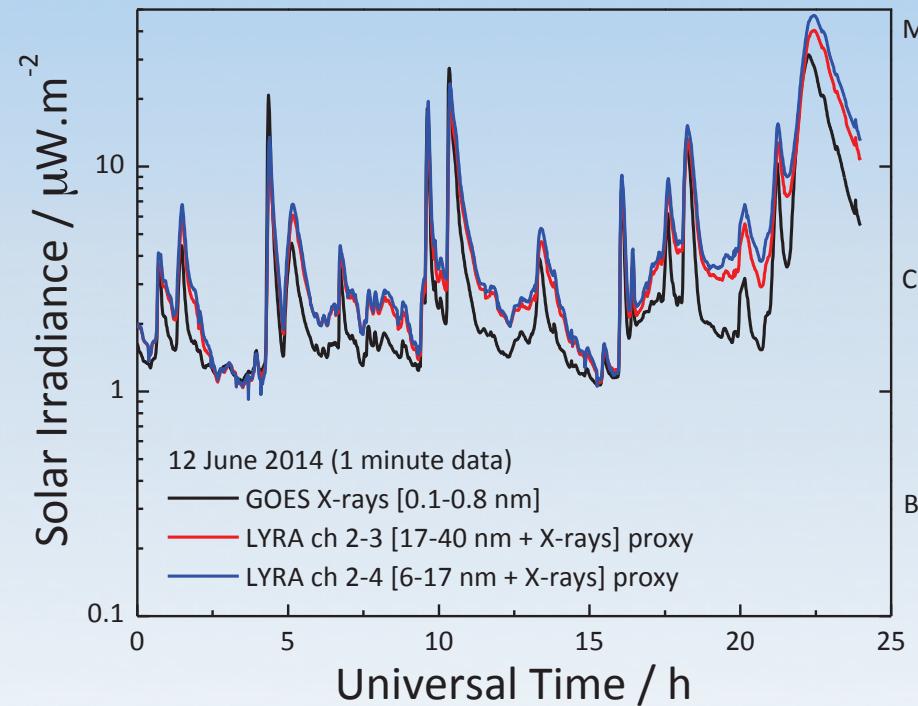
LYRA comprises three similar independent units.



The signal has been corrected from the dark-current, and the degradation-trend has been removed and converted to physical units (W/m<sup>2</sup>).

## and -4- Inter-calibration

Inter-calibration planning combines LYRA observations with currently operating UV solar instruments  
→ SOLSTICE/SORCE, SEE/TIMED, EVE/SDO, SWAP/PROBA2.

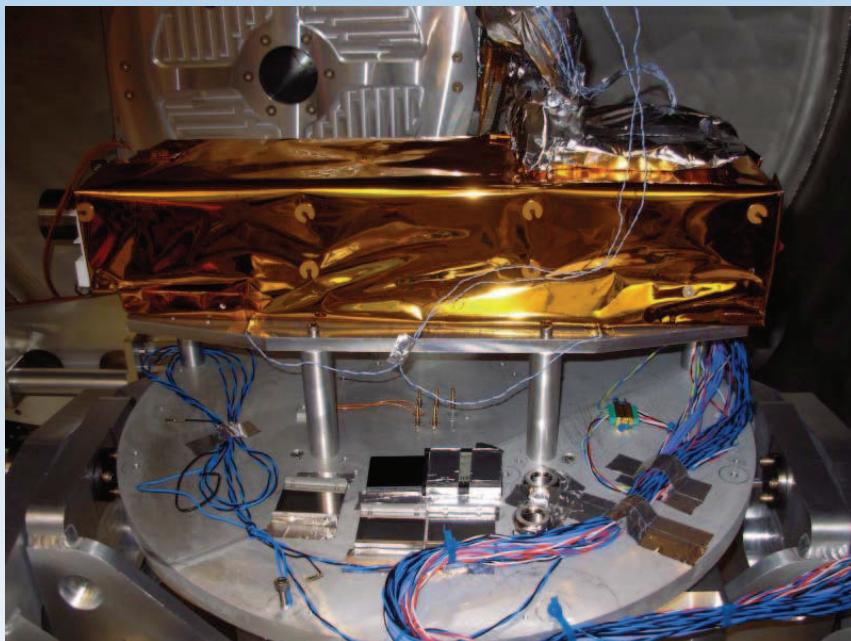


Comparison of the LYRA (EUV channels 3 & 4) proxies with NOAA's GOES X rays solar flux.

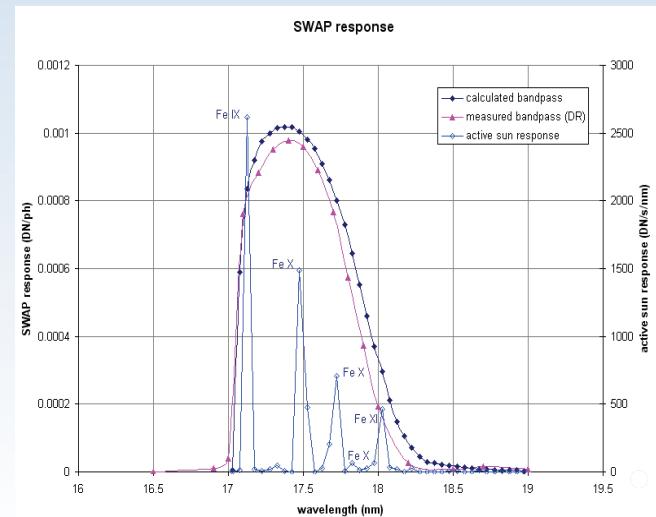
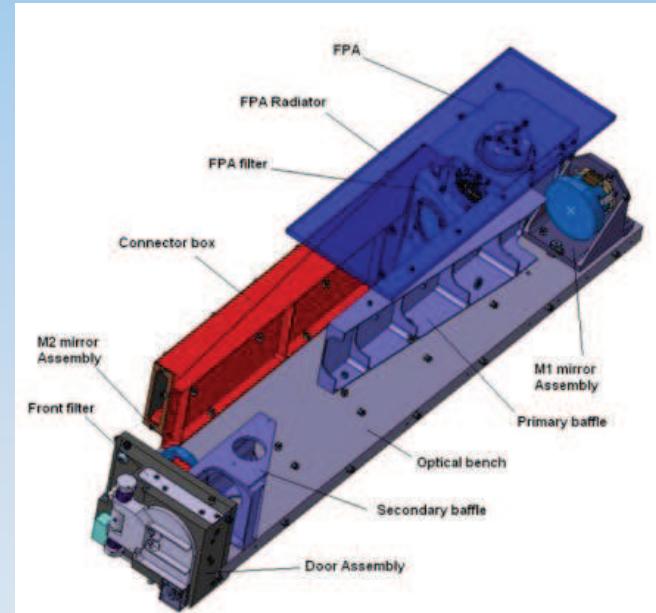
cf. <http://www.stce.be/euvworkshop2014> (M. Dominique, and I.E. Dammasch)

# SWAP: Sun Watcher using APS and image Processing

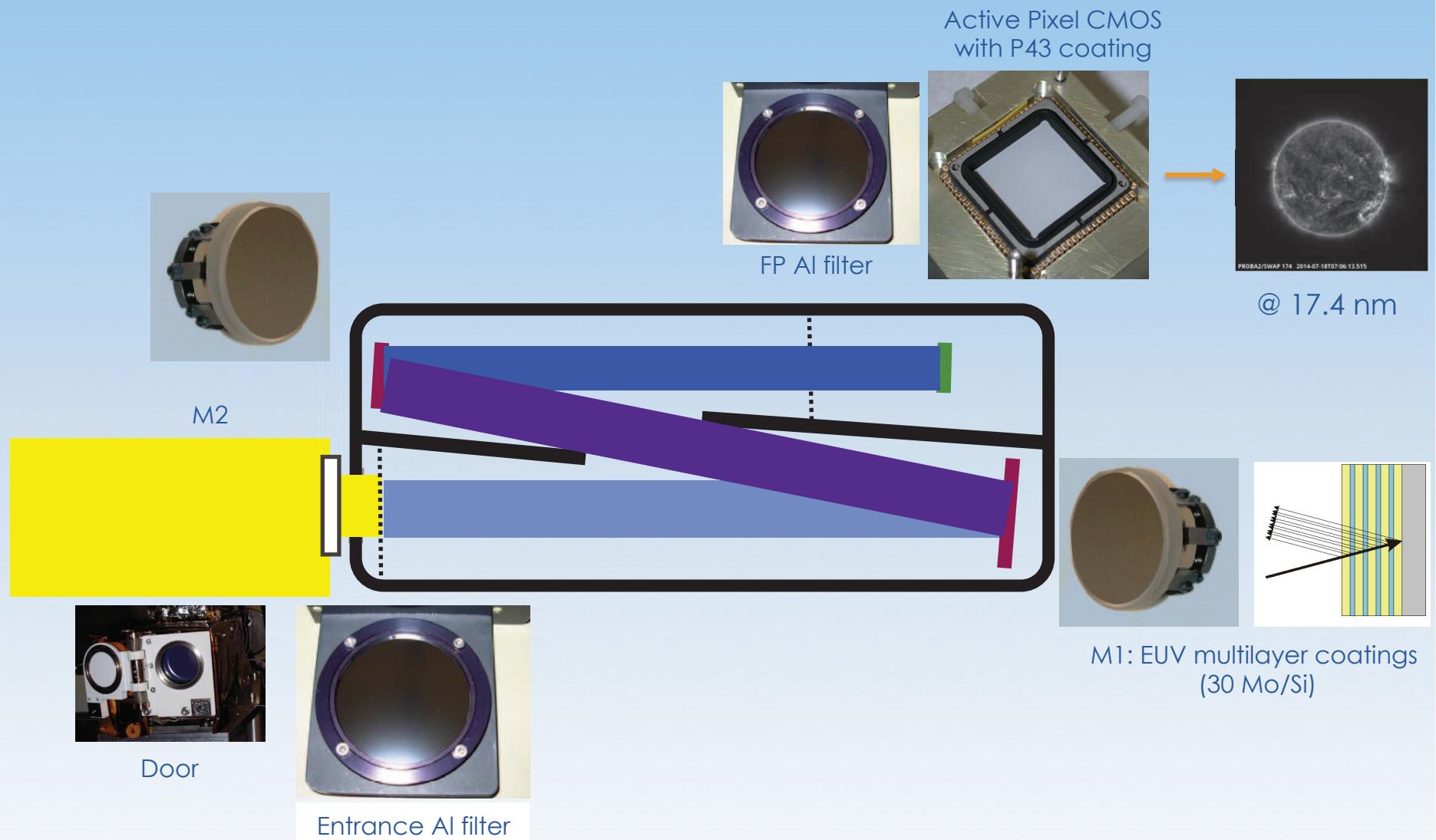
EUV telescope (centered @ 17.4 nm)  
Lightweight, off-axis, CMOS APS, large FOV,  
on-board autonomy (data processing).



Calibrating SWAP at the PTB/Bessy II synchrotron

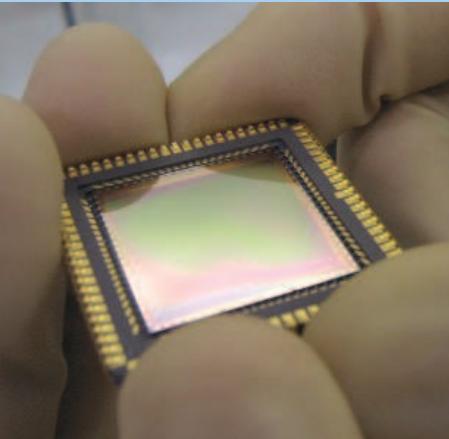


## SWAP: off-axis telescope (Ritchey-Chretien design)



- Focal Length :  $f = 1.173 \text{ m}$  ( $D_p = 33 \text{ mm}$ )

# CMOS APS: alternative for CCD

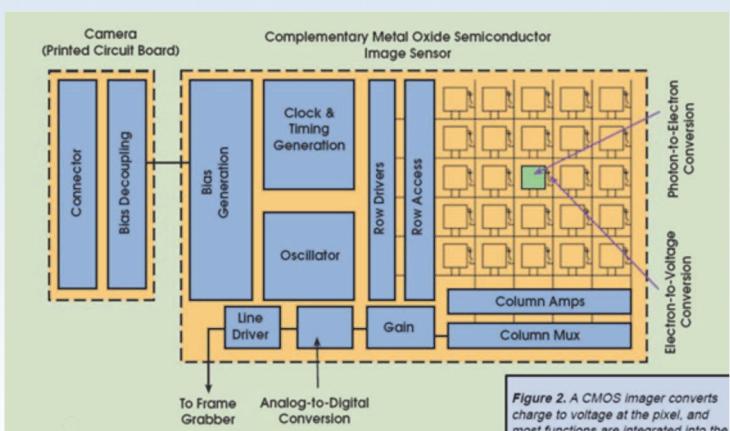


HAS (w/o P43)



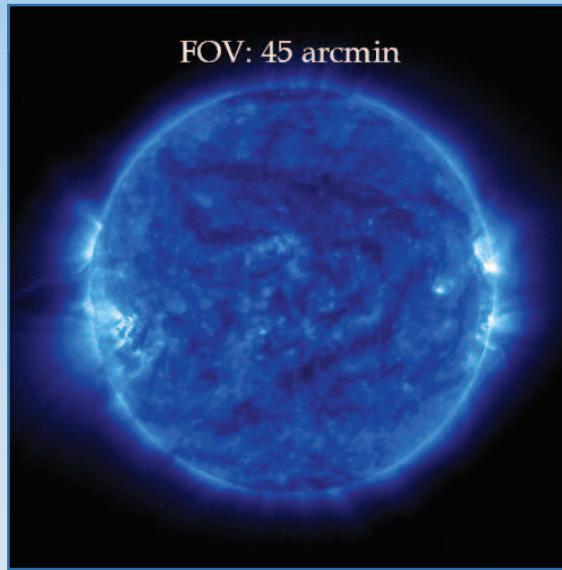
HAS (P43 coated)

- High Accuracy Startracker (HAS, 3T) by Fillfactory (B), now Cypress (US)
- 1024 x 1024 pixels (18  $\mu\text{m}$  x 18  $\mu\text{m}$  size)
- P43 coated for EUV sensitivity
- First used for solar physics in space
- **Pros:** Shutterless operations, radiation hardeness, low power consumption, faster readouts (several FPS), random addressing of pixels (windowing), Non Destructive Readout, lesser blooming, on-chip ADC, ...
- **Cons:** higher noise and DC, rolling shutter, ...



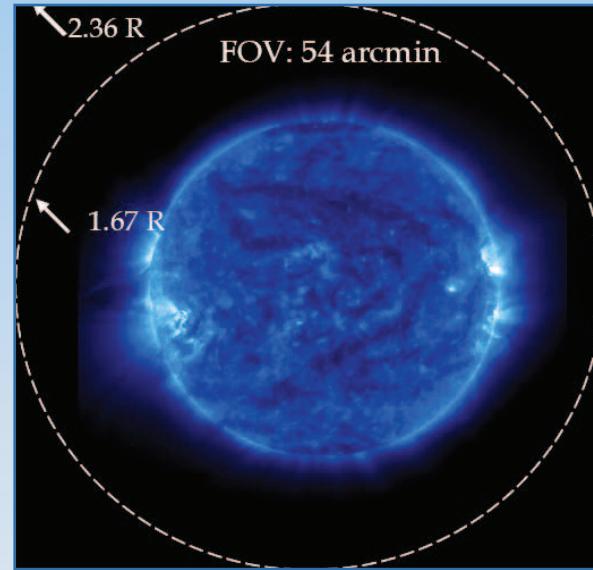
Architecture of a CMOS APS

# EIT



- 1024 x 1024 CCD
- FOV: 0.75 degree
- 17.1 nm, 19.5nm, 28.4nm, 30.4nm
- fixed sun-centering
- at L1
- 12 min cadence
- 

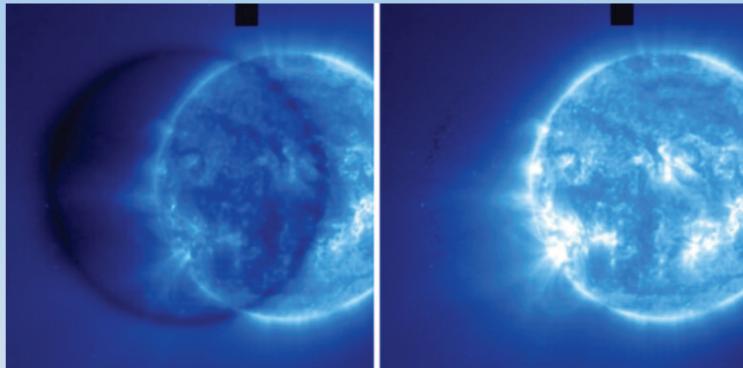
# SWAP



- 1024 x 1024 coated CMOS APS
- FOV: 0.9 degree
- 17.4 nm
- flexible off-pointing
- protected by magnetosphere
- 1 min cadence

# SWAP detector degradation (APS vs CCD)

EIT

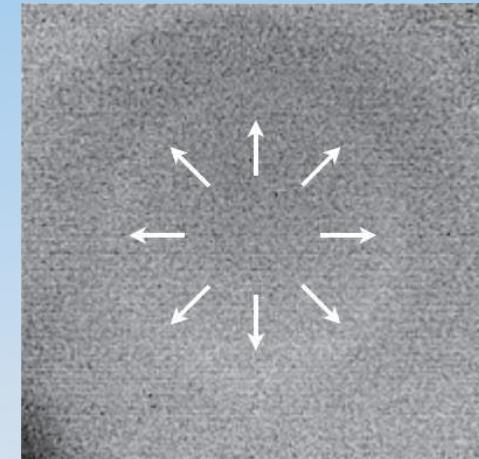


Ex: CCD images from EIT / SOHO (off-pointing, 2002)

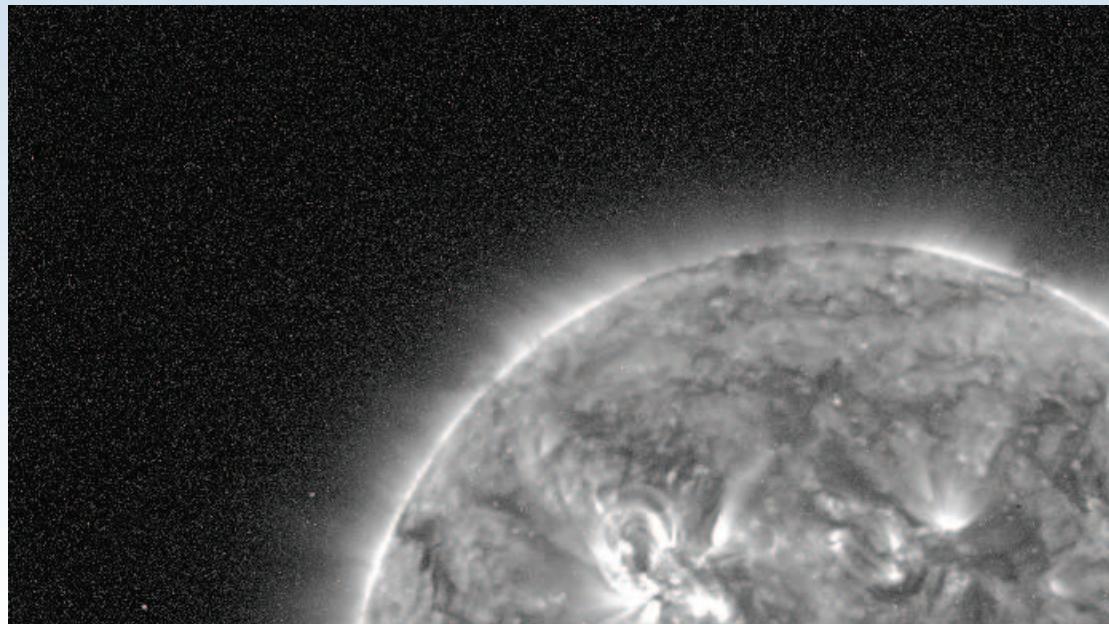
SWAP



2 onboard VIS LEDs



LEDs image ratio (2010-2012):  
0.1% decrease (not seen in EUV)



SWAP has experienced negligible  
degradation after launch

SWAP bright / hot pixels:

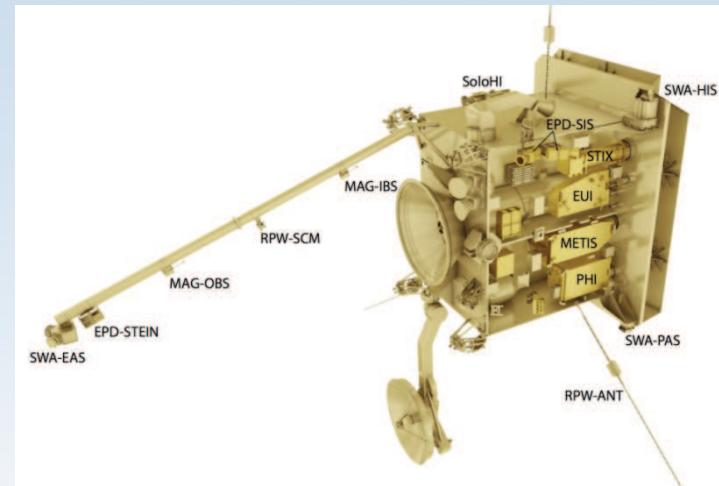
- rate of increase ~ 6100 pixels / year
- acceptable: removed during image calibration

# Next solar instruments

- SWORD: EUV-VUV solar radiometers for Cubesat platform
- EUI: EUV-VUV solar telescopes onboard Solar Orbiter (launch 2018)



QB50-Cubesat



Solar Orbiter – 2017 (back up 2018)

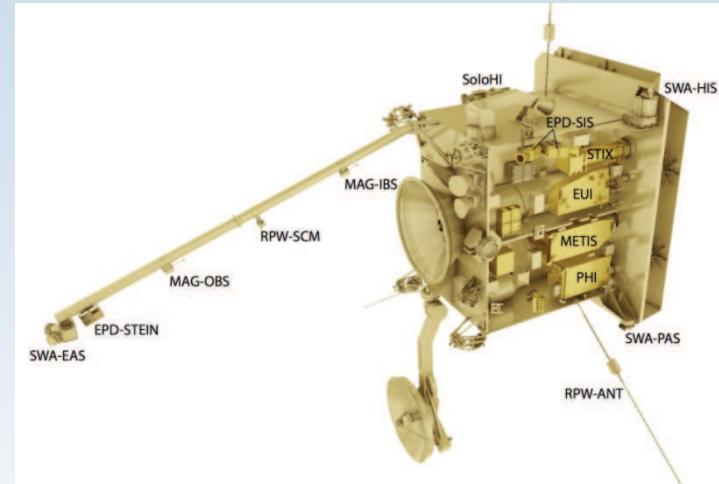
- Scientific progress often depends on technology developments

# Next solar instruments

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QB50-Cubesat



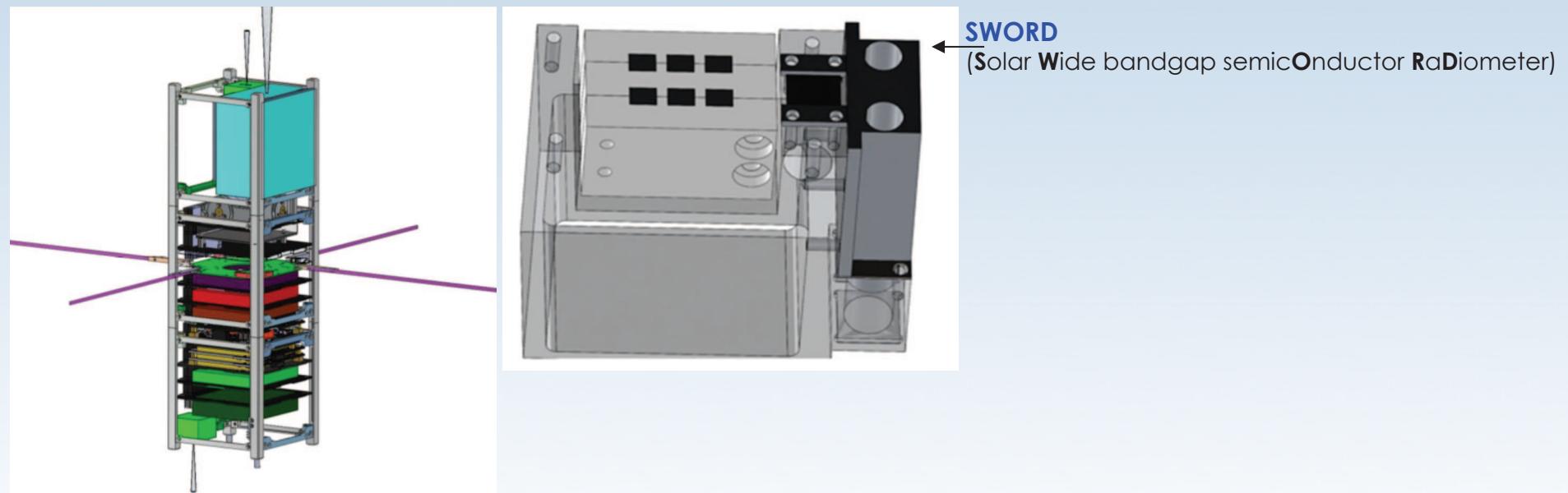
Solar Orbiter – 2017 (back up 2018)

- Scientific progress often depends on technology developments

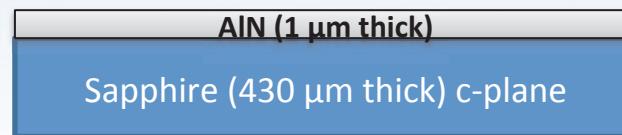
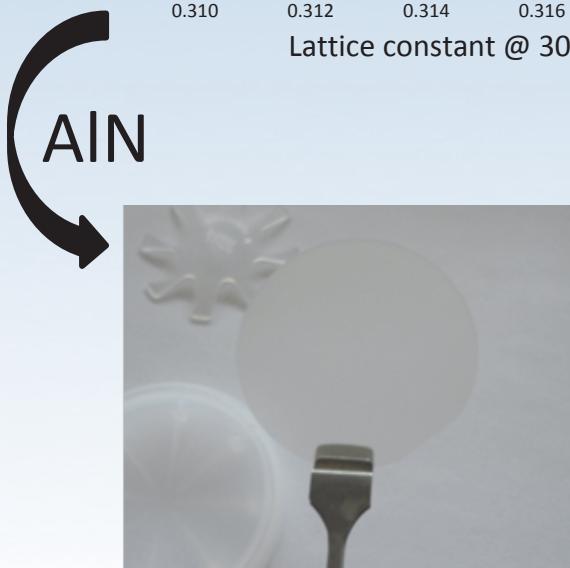
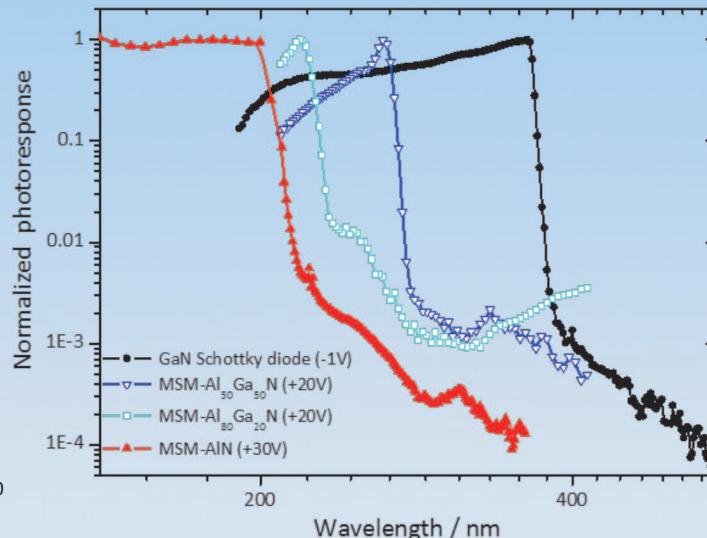
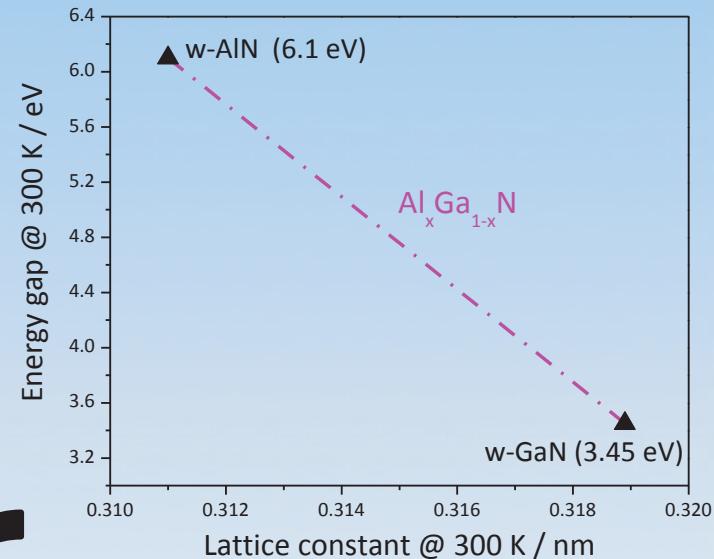
# SWORD - proof of concept -

Large area photodetectors with "improved UV stability" are needed

**SWORD** (**Solar Wide bandgap semicOnductor RaDiometer**) an EUV-VUV Solar radiometer (LYRA successor).

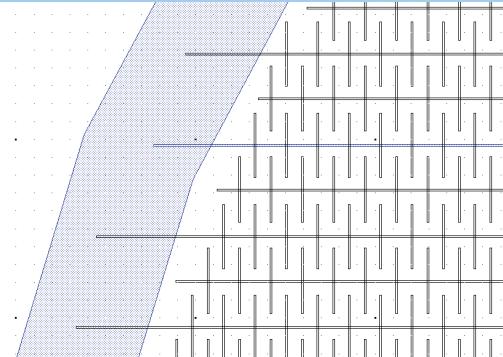
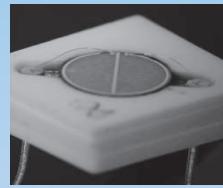


# Large WBGM based-photodetectors: interest for $\text{Al}_x\text{Ga}_{1-x}\text{N}$

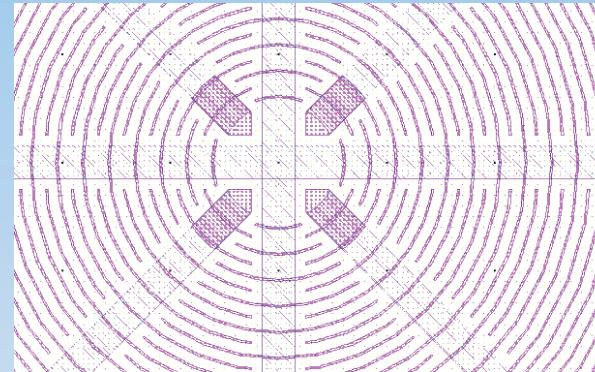


Left: AlN layer on sapphire substrate (2 inches from DOWA, Japan), right: a schematic cross-section.

# Challenge: MSM geometry optimization for stability

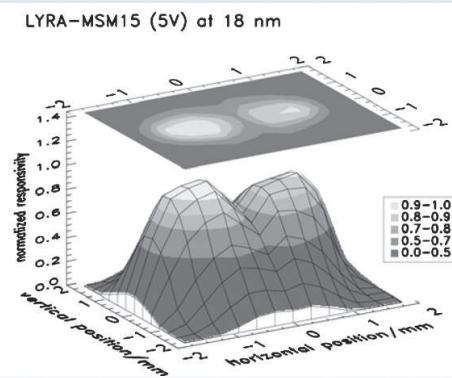
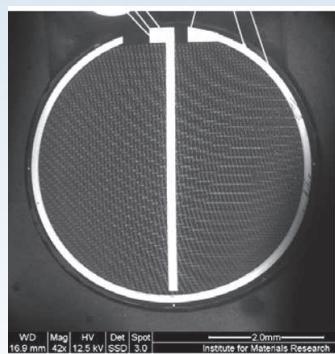
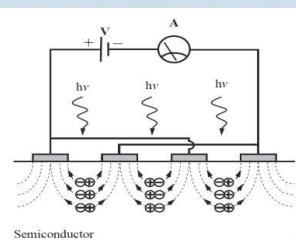


Cross structure (cf. LYRA/PROBA2)  
→ space between electrodes  $\sim 15 \mu\text{m}$



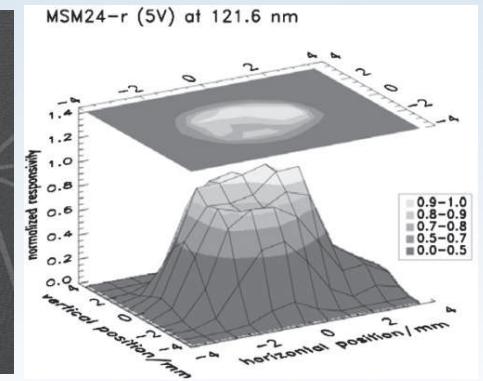
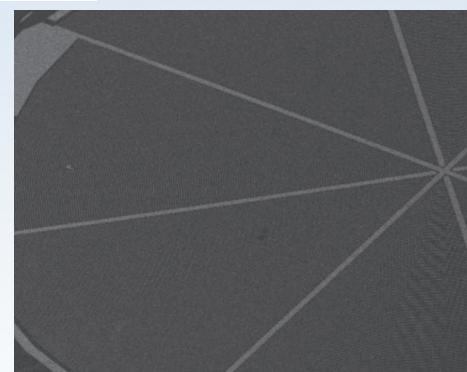
Circular structure  
→ space between electrodes  $5 \mu\text{m}$

- $\varepsilon$  homogeneity between electrodes is increased,
- risk of short circuit is reduced.



LYRA MSM

A. BenMoussa et al. Nuclear Inst & Methods A-568, pp. 398, 2006



New MSM

A. BenMoussa et al. Semicon. Sci. and Techn., 23, pp. 035026, 2008.

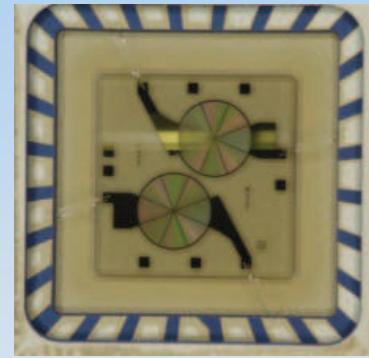
# Large MSM AlN for space applications



4.3 mm Ø



3 mm Ø



2 mm Ø



1.1 mm Ø

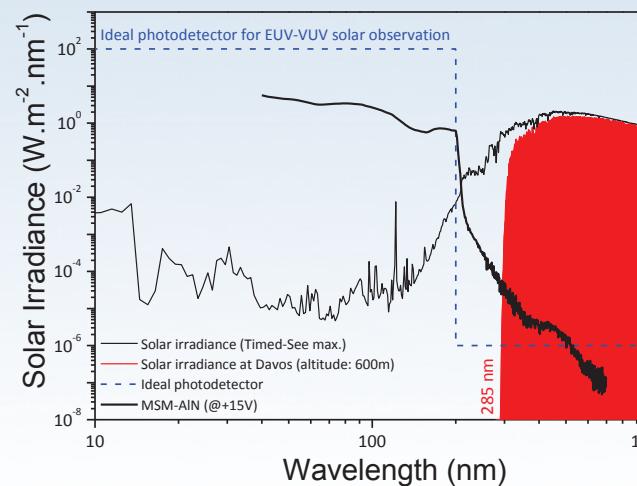
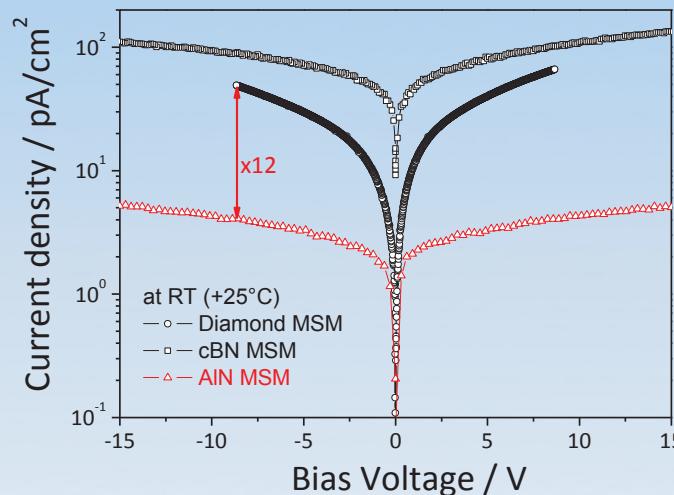
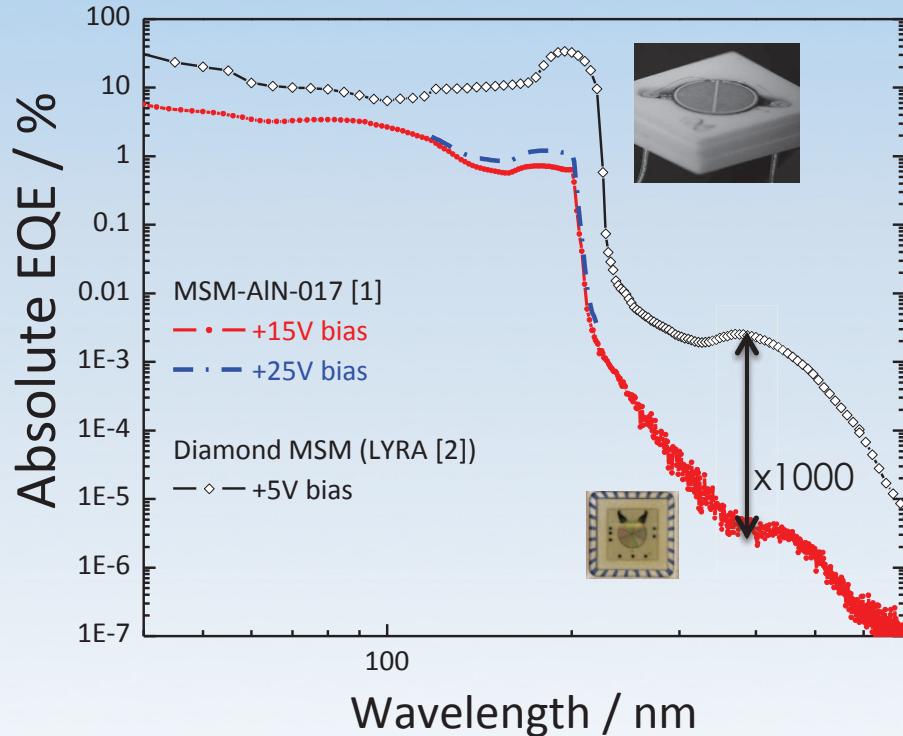
## Detector parameters.

### *Detector characteristics*

Denomination	MSM-AlN-0xx
Active layer / Substrate	1 µm AlN (undoped)/430 µm Al <sub>2</sub> O <sub>3</sub> (c-plane)
Active area	1.1 to 4.3 mm diameter (on 5 × 5 mm <sup>2</sup> )
Electrodes (thickness)	Ni/Mo/Au (5/40/200 nm)
Width/Space (fill factor)	2 µm/5 µm (62%)
Bias operation	+15 V (+25 V)
Passivation	10 nm AlO <sub>x</sub> (cf. MSM-AlN-022)

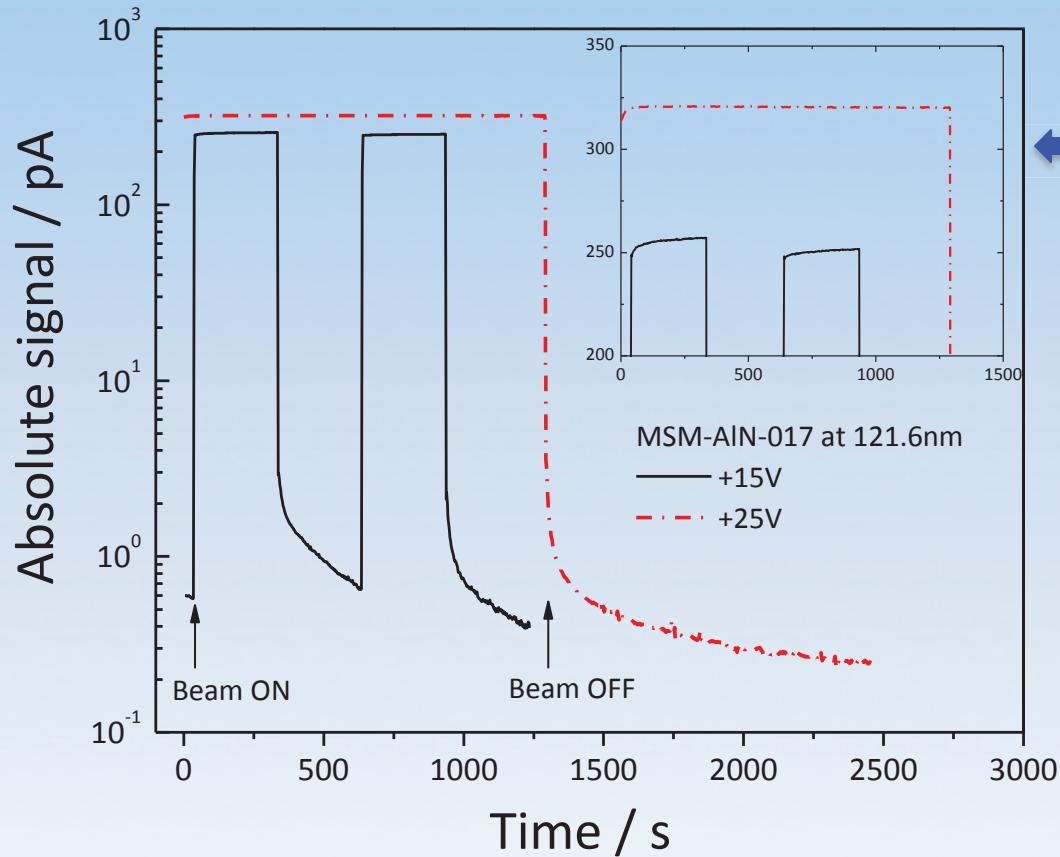
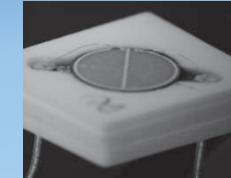
# Diamond vs AlN MSM

Characterization at ROB/STCE (DeMeLab, 190 – 700 nm) and calibration at PTB-MLS (40 – 225 nm).

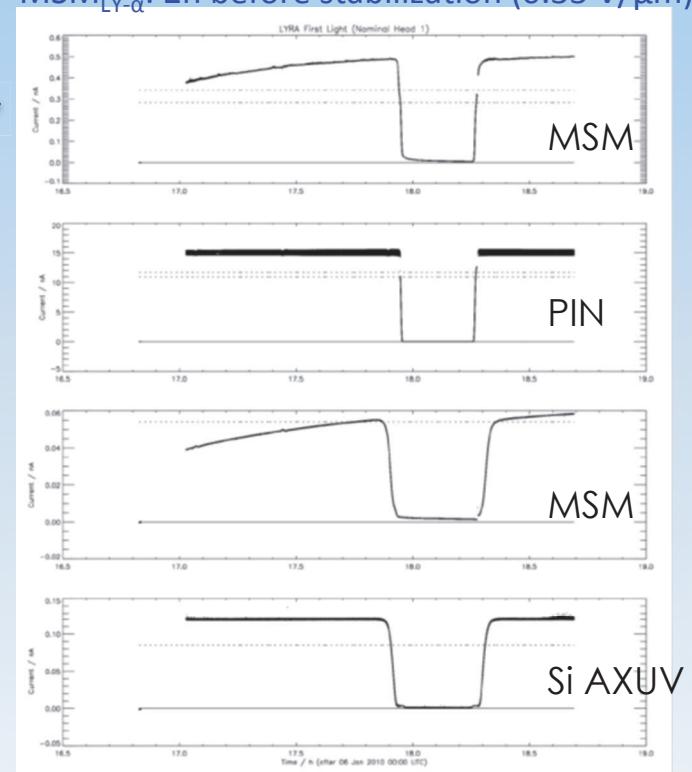


- [1] A. BenMoussa, T. Saito et al. NIMB 312, pp. 48–53, 2013.
- [2] A. BenMoussa et al., NIMA 568, pp.398–405, 2006.

# Stability tests



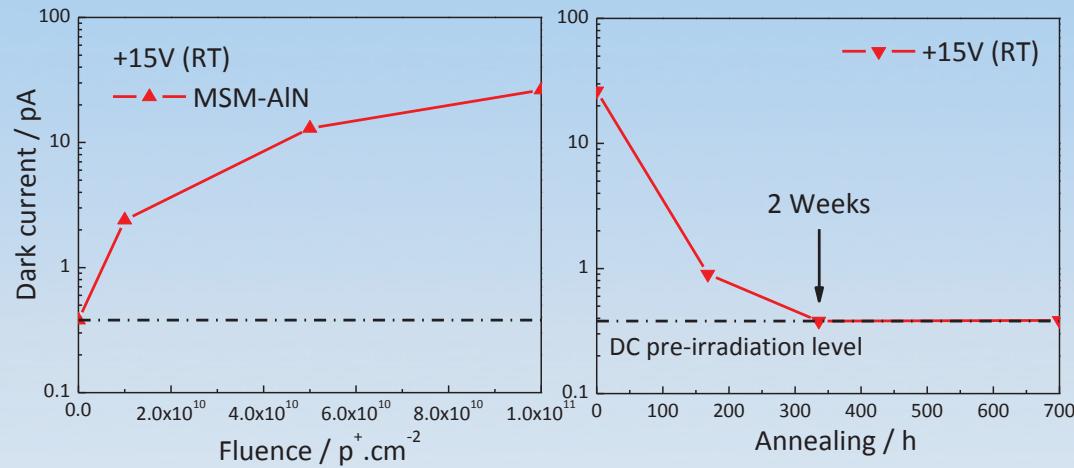
LYRA Unit 1  
MSM<sub>Ly- $\alpha$</sub> : 2h before stabilization (0.33 V/ $\mu$ m)



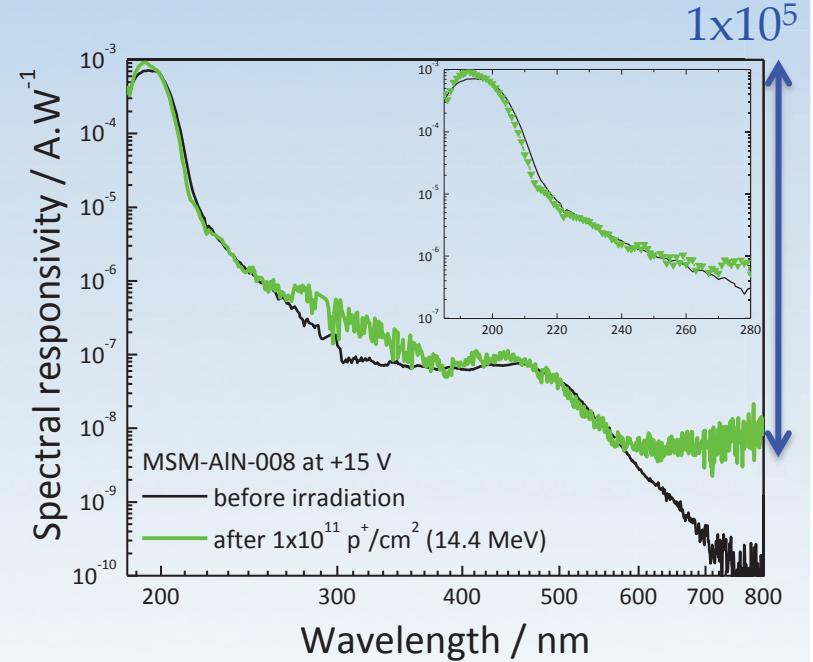
The time to reach a stable signal varied depending on the applied bias:

- +15 V (3V/ $\mu$ m) the signal increases during the first 60 s approximately,
- +25 V (5V/ $\mu$ m) the stability is improved with a signal drift of less than 0.03% at Ly- $\alpha$ .

# Proton damage tests (14.4 MeV)



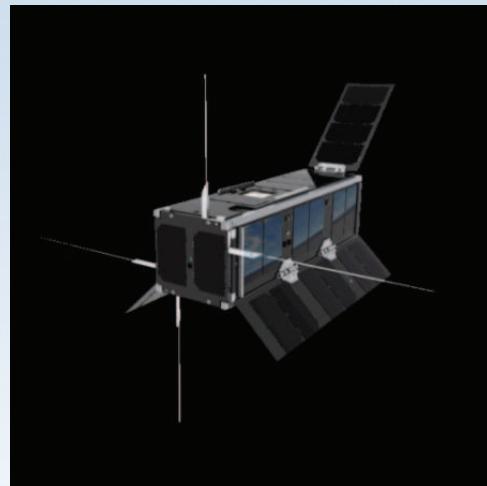
After irradiation, the DC decreases back to its pre-irradiated value after 2 weeks annealing at RT ( $\rightarrow$  recombination).



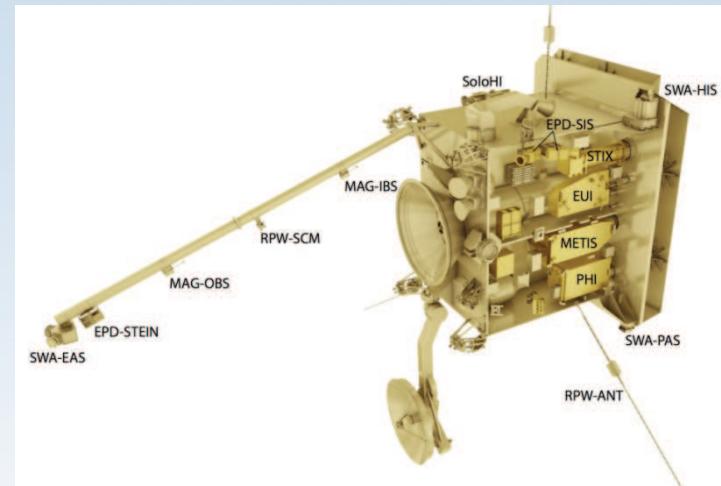
Sub-bandgap photoresponse increases slightly  
 $\rightarrow$  displacement damage

# Next solar instruments

- SWORD: EUV-VUV solar radiometers for Cubesat platform
- EUI: EUV-VUV solar telescopes onboard Solar Orbiter (launch 2018)



QB50-Cubesat

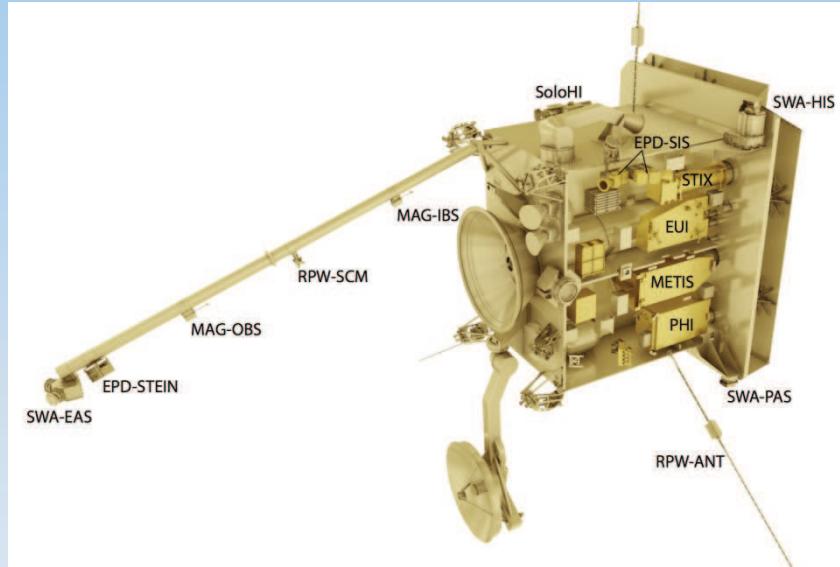


Solar Orbiter – 2017 (back up 2018)

- Scientific progress often depends on technology developments

# Introduction: Solar Orbiter

**Mission goals:** Study the Sun and investigate the link between the Sun and interplanetary space.



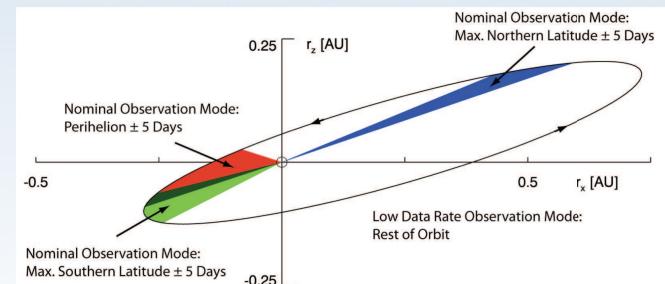
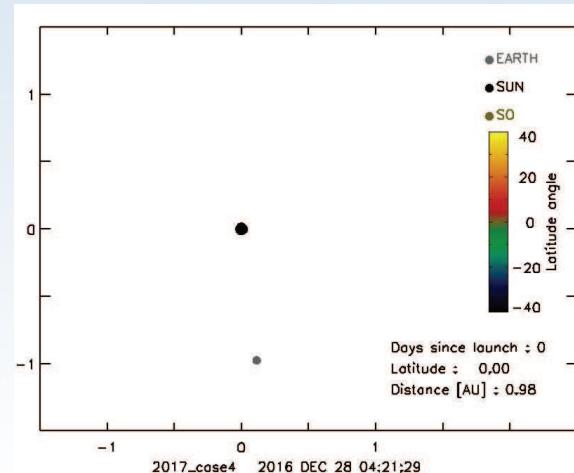
- Launch Oct 2018, ESA/NASA
- Nominal mission duration : 7.4 years (incl. cruise phase 3.4 years),
- 10 instruments: 4 in-situ and 6 remote sensing (op. only 3x10 days)
  - Total mass (payloads) = 190.4 kg
  - Power availability= 250 W

... EUI : Extreme Ultraviolet Imager

- Mass = 23.5 kg
- Power= 30 W



Elliptical orbit (168 day-long, 16 orbits / + 3 years ext. mission), perihelion **0.28 AU** ( $45 \times 10^6$  km), inclination **34°**(polar region)

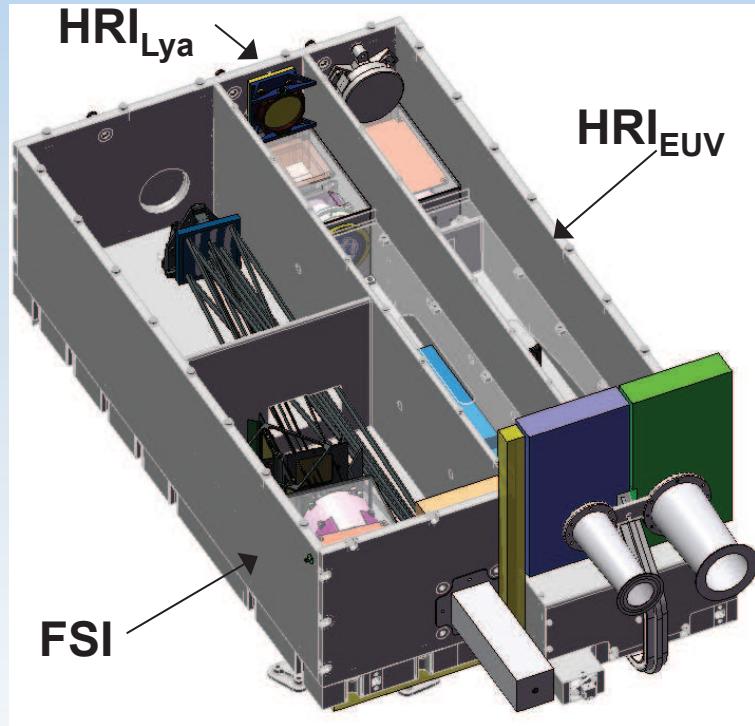


First orbit



# EUI : Extreme Ultraviolet Imager telescopes

**Goals:** EUI will provide image sequences of the solar atmospheric layers from the chromosphere into the corona.



Mass: 23.5 kg, Power: 30 W, Telemetry: 20.5 kbps (over 30 days/orbit)

EUI is composed of three channels:

Channel	Parameter	Values
FSI	Passbands	17.4 nm & 30.4 nm
	FOV	3.8 arcdeg ( $\Leftrightarrow$ 2 Sun Ø)
	Resolution (2 px)	9 arcsec ( $\Leftrightarrow$ 1800 km, 3k <sup>2</sup> px)
	Cadence	600 s
HRI <sub>EUV</sub>	Passbands	17.4 nm
	FOV	0.28 arcdeg ( $\Leftrightarrow$ 15% Sun Ø)
	Resolution (2 px)	1 arcsec ( $\Leftrightarrow$ 240 km, 2k <sup>2</sup> px)
	Cadence	$\geq$ 1-2 s
HRI <sub>Lya</sub>	Passband	121.6 nm (H Lyman-alpha)
	FOV	0.28 arcdeg ( $\Leftrightarrow$ 15% Sun Ø)
	Resolution (2 px)	1 arcsec ( $\Leftrightarrow$ 200 km, 2k <sup>2</sup> px)
	Cadence	$\leq$ 1 s

FSI: 174 A

HRI<sub>EUV</sub>: 174 A

Consortium:

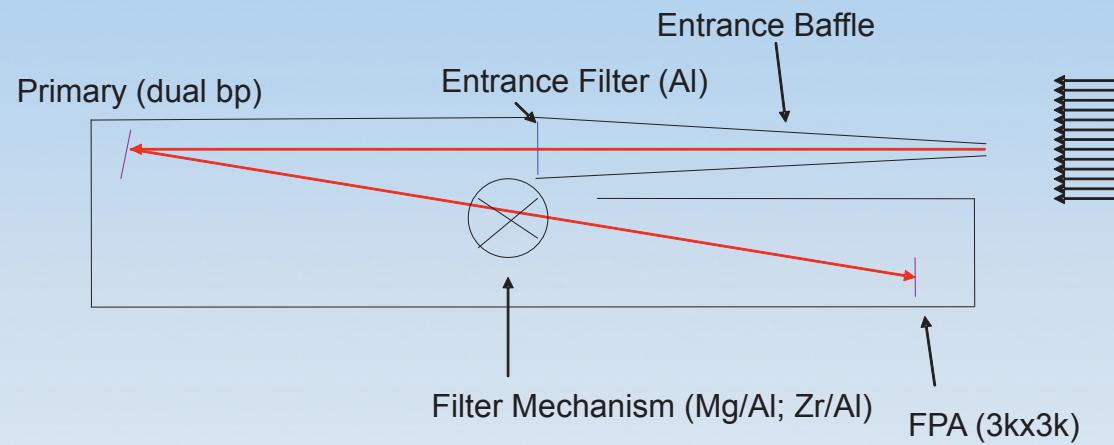


pmod wrc



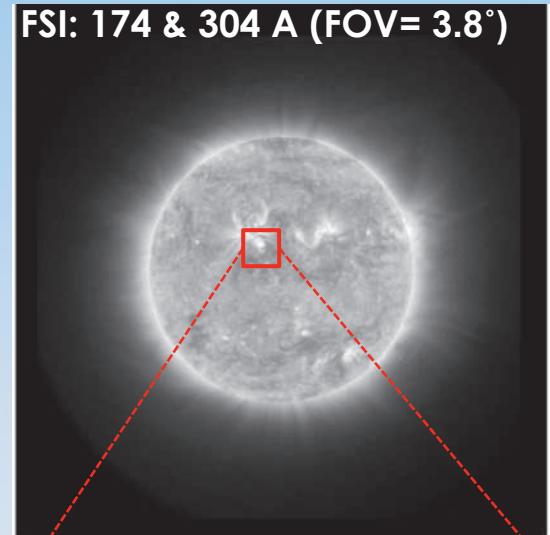
# Design overview

Full Sun Imager – FSI – ( $f = 462.03$  mm, 5.5 mm Ø)

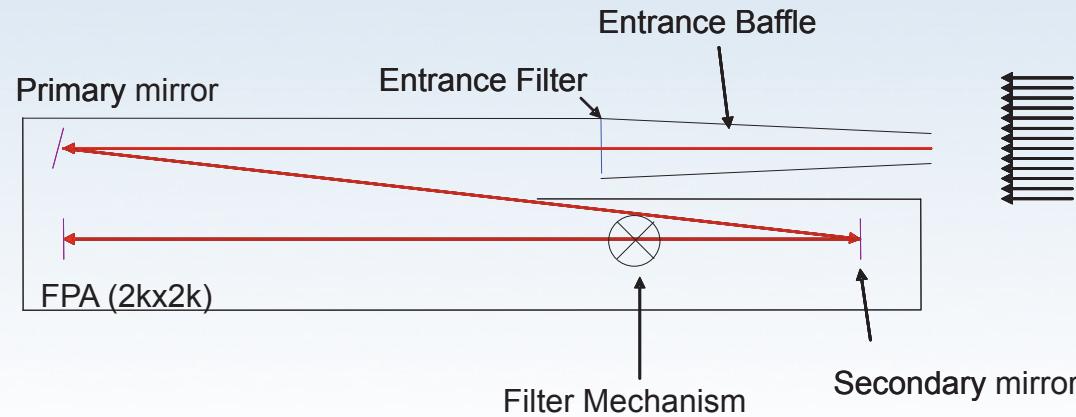


at perihelion (0.28 AU)

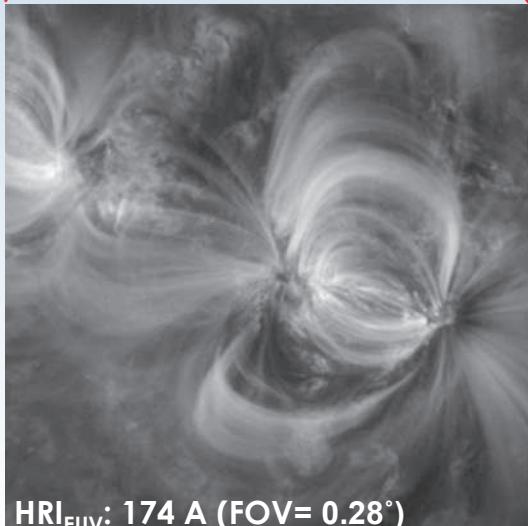
FSI: 174 & 304 Å (FOV= 3.8°)



High Resolution Imager – HRI – ( $f = 4187$  mm, 47.4 mm Ø)

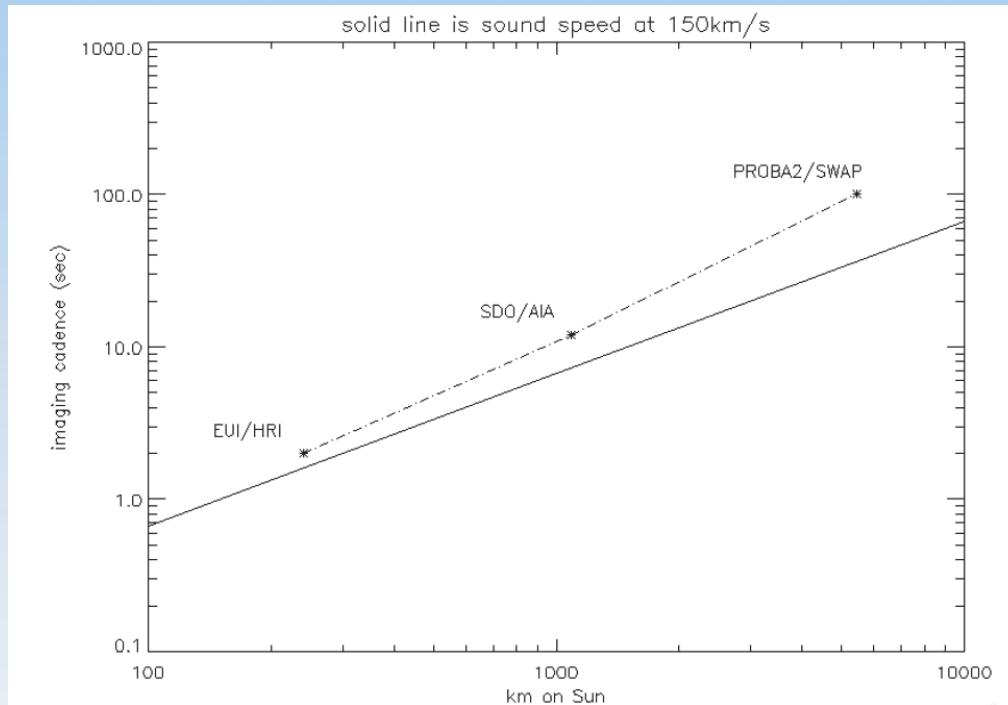


HRI<sub>EUV</sub>: 174 Å (FOV= 0.28°)



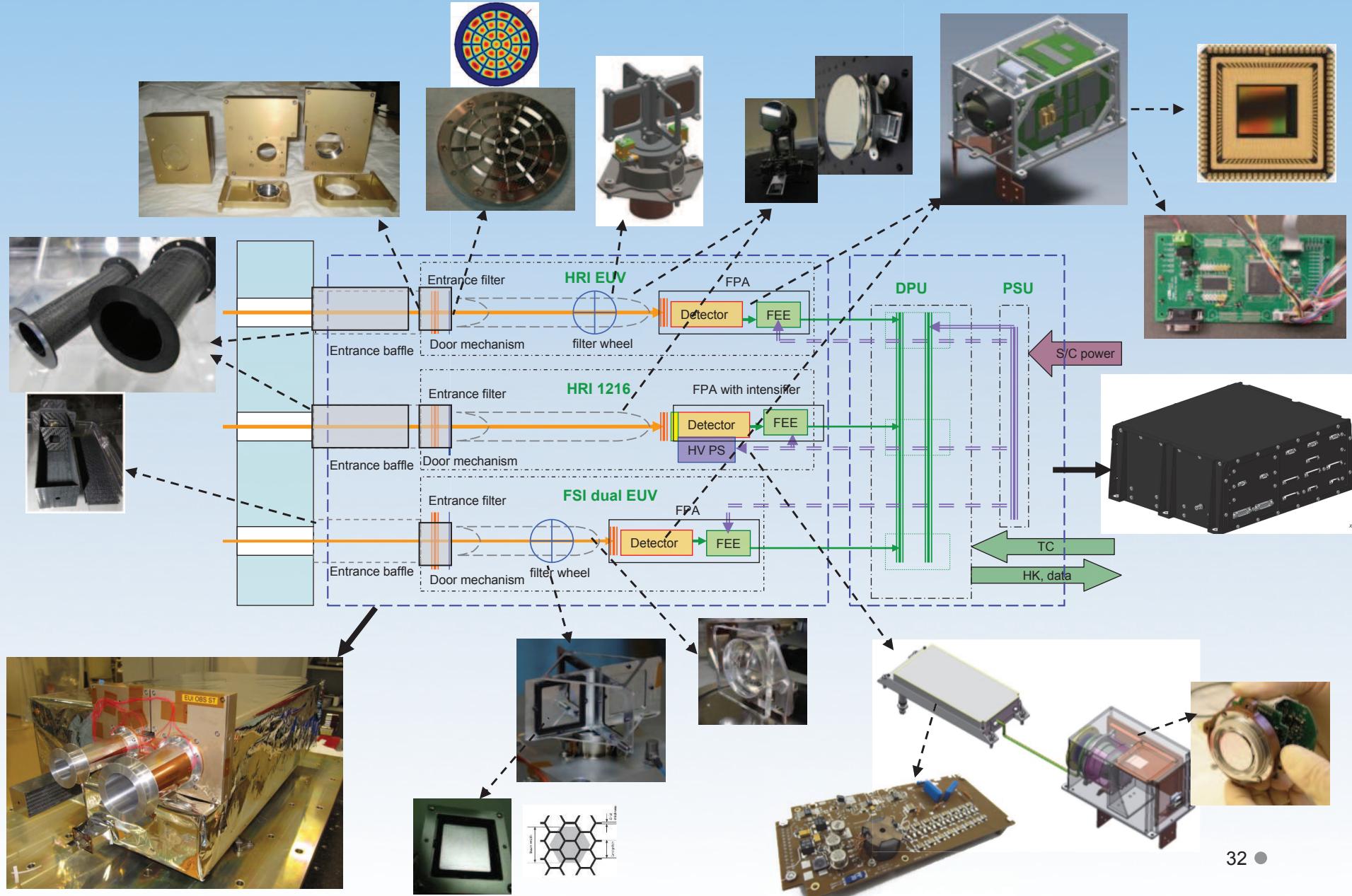
N.B. SWAP/PROBA2 FOV=0.9° (AIA/SDO 0.6°)

# Spatial & time resolutions

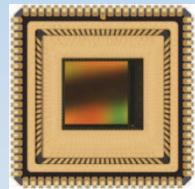


- SWAP/PROBA2 : Spatial resolution = 5000 km on the Sun (cadence of 100 s),
- AIA/SDO : 1090 km on the Sun with 12 s cadence,
- HRI/EUI : 240 km (perihelion) with 1-2 s cadence.

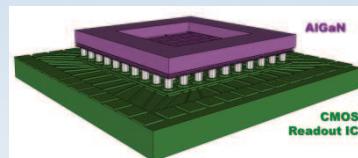
# Technological development



# Detectors development for EUI



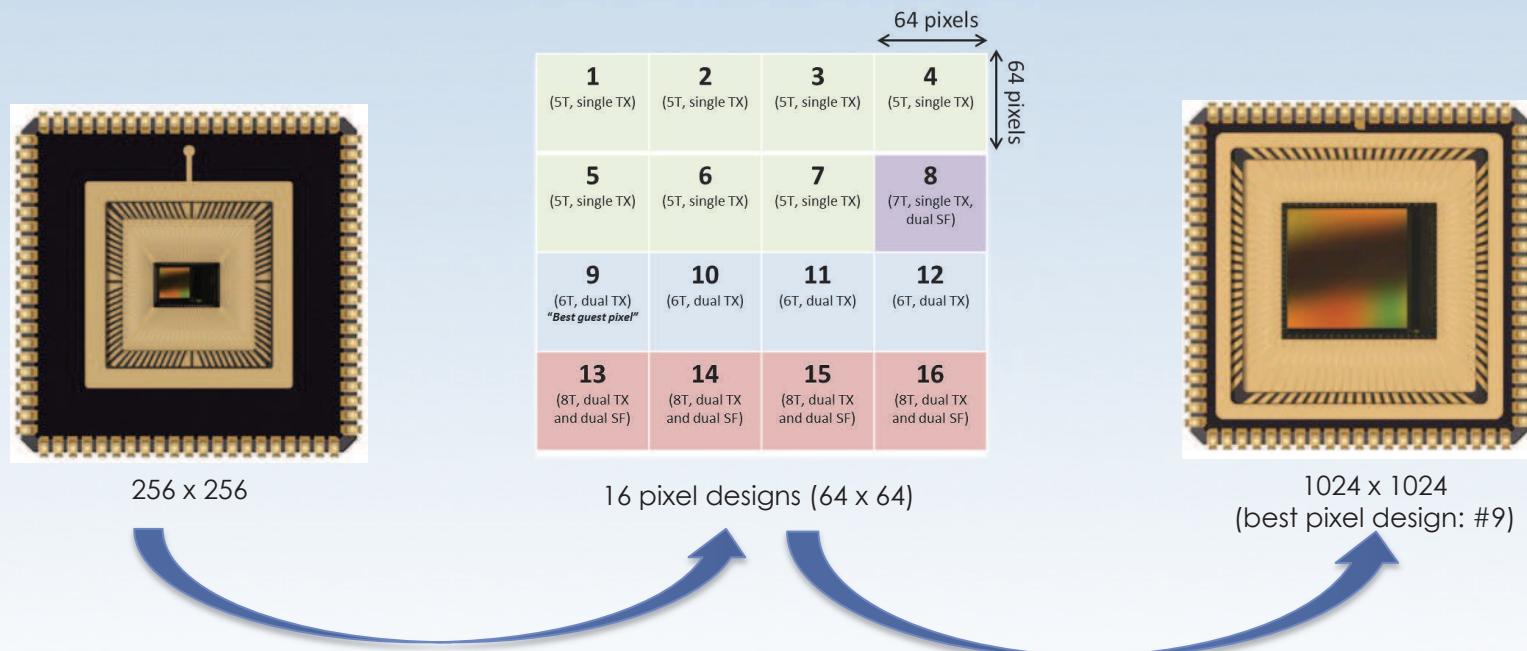
- 1- APSOLUTE – Si backside illuminated CMOS APS
- 2- BOLD – AlGaN 2D arrays (not yet mature for EUI)



# Prototype development: APSOLUTE

APS Optimized for Low-noise and Ultraviolet Tests and Experiments

- **Concept:** Two CMOS APS are designed (Si, 10 µm pixel pitch)
  - ✓ 256x256 sensor, containing 16 test pixel variants in blocks of 64x64 pixels.
  - ✓ 1024x1024 sensor, containing the “best guess pixel” variant.



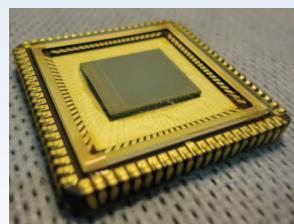
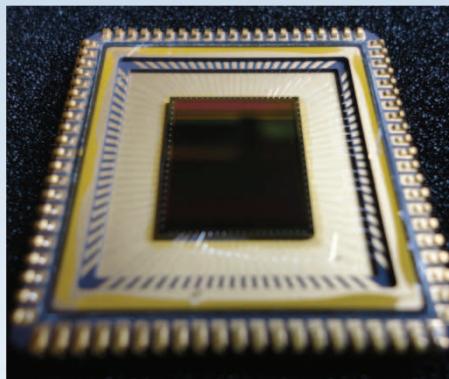
34

# Prototype development: APSOLUTE

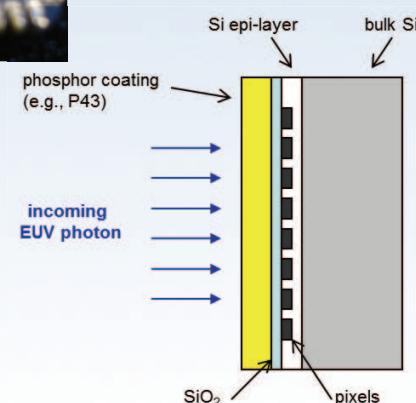
## ■ Back-side illuminated approach:

- Test chip (Monolithic) on **SOI** (SOITEC) material, 0.18  $\mu\text{m}$  technology (TS)
- Si epilayer: 3  $\mu\text{m}$  thick → Increase the EUV sensitivity
- Dual pixel read out (2 columns gain amplifiers) → Low read noise, high DR

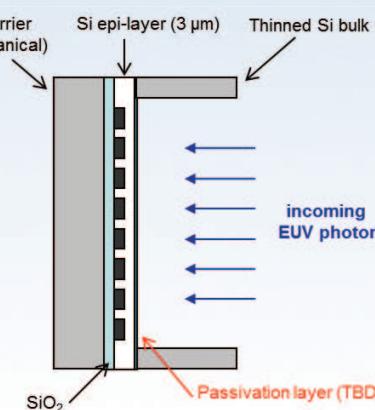
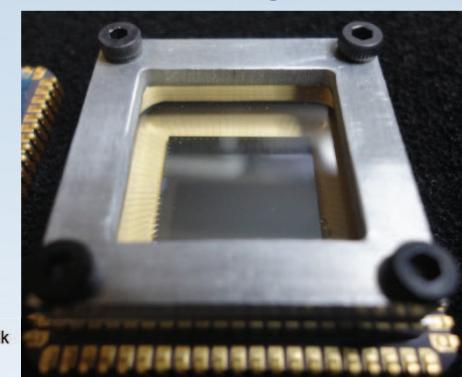
Front-side illuminated imagers (HRI<sub>Ly-a</sub> micro-channel plate)



+ backup with P43



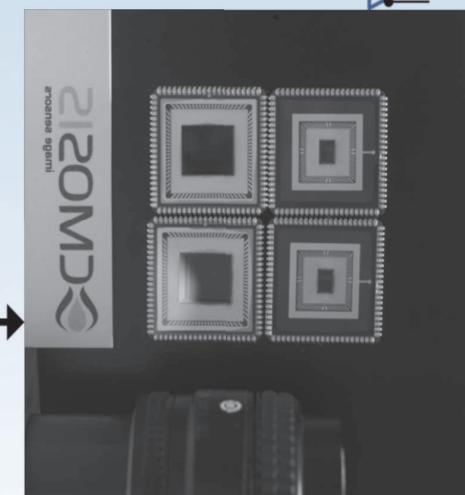
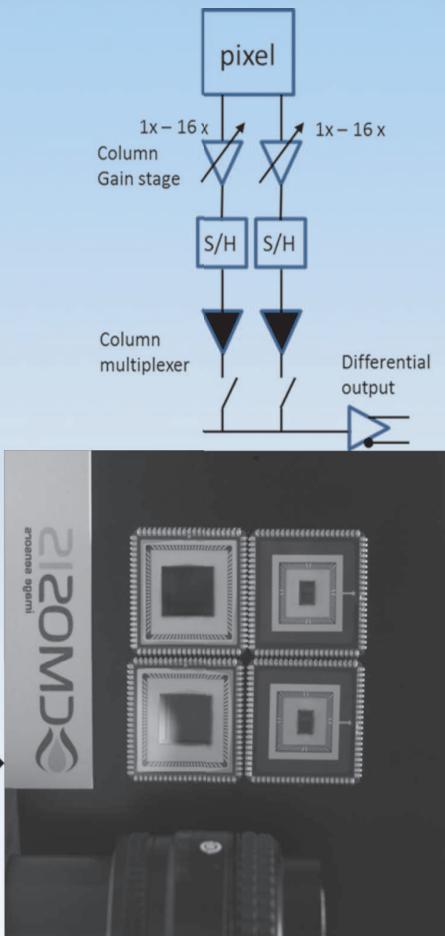
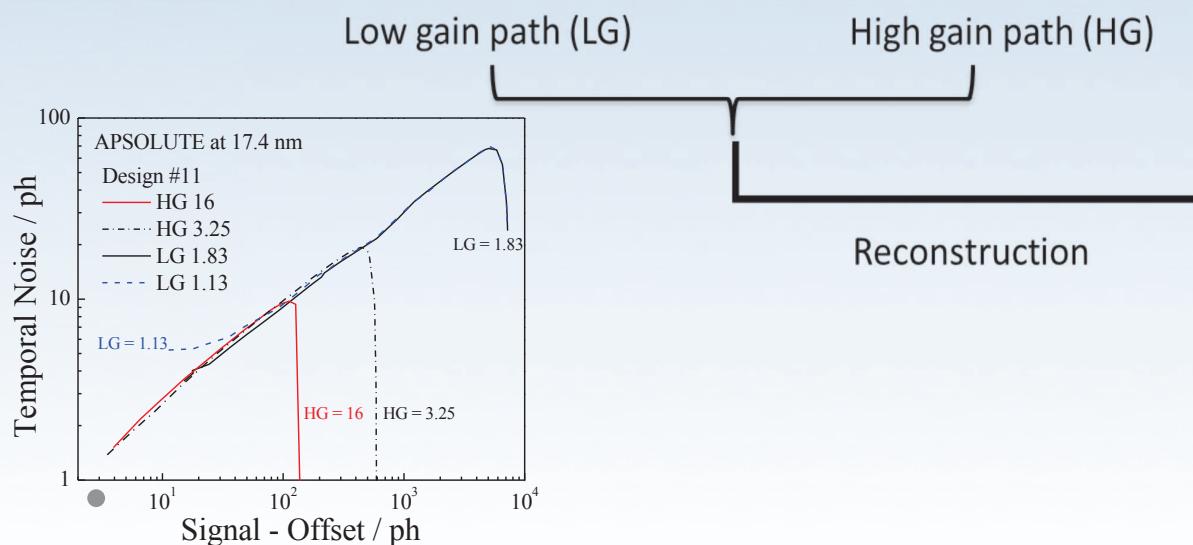
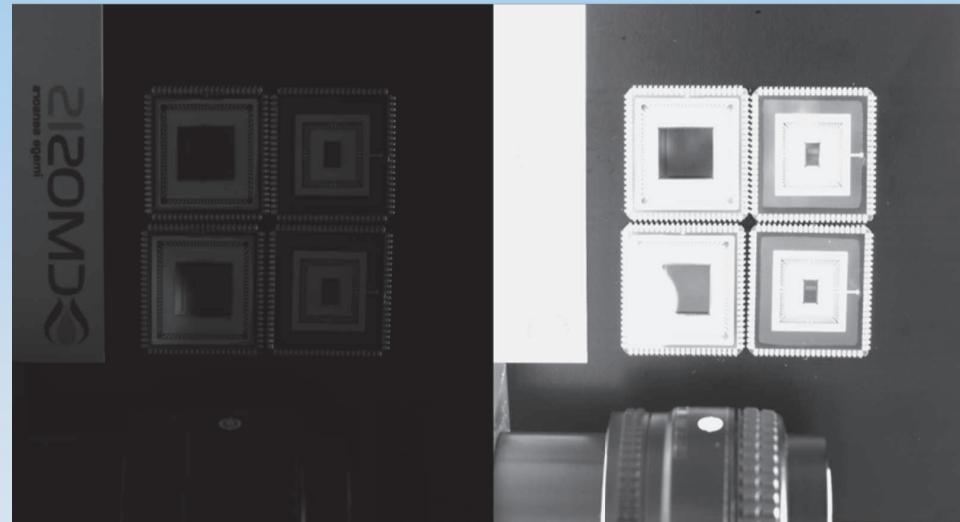
Back-side illuminated imager (FSI & HRI<sub>EUV</sub>)



Si epi thickness:

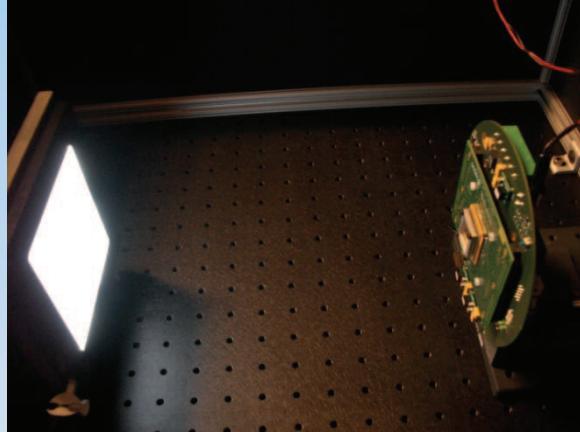
- 2.75  $\mu\text{m}$  (250 nm etched)
- 2.60  $\mu\text{m}$  (400 nm etched)

# APSOLUTE: Dual gain operation (LG, HG)

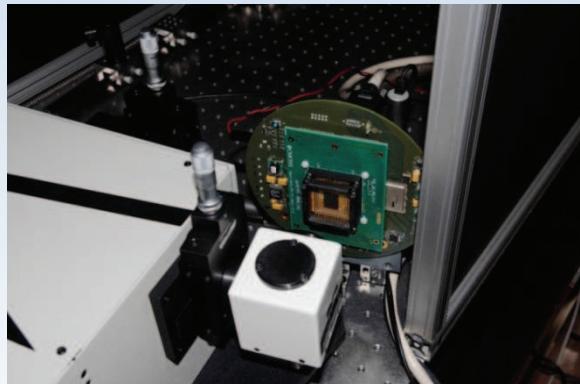
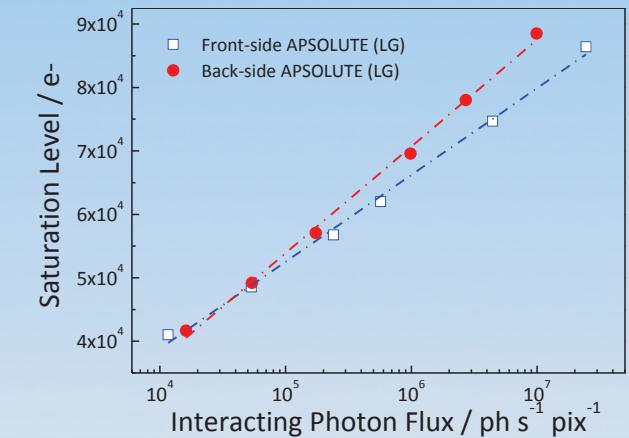
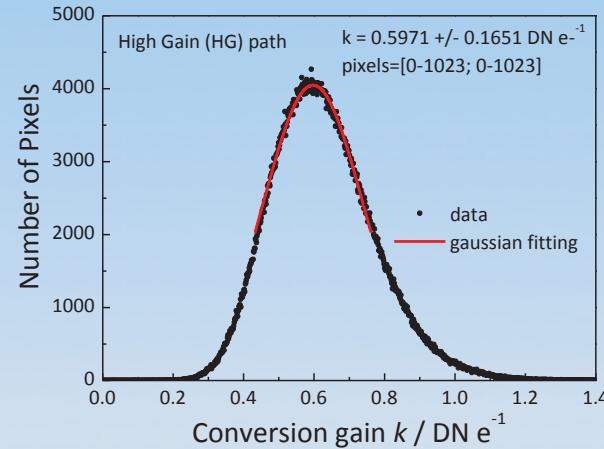


High Gain Columns set to **3.25x gain**  
Low Gain Columns set to **1.13x gain**

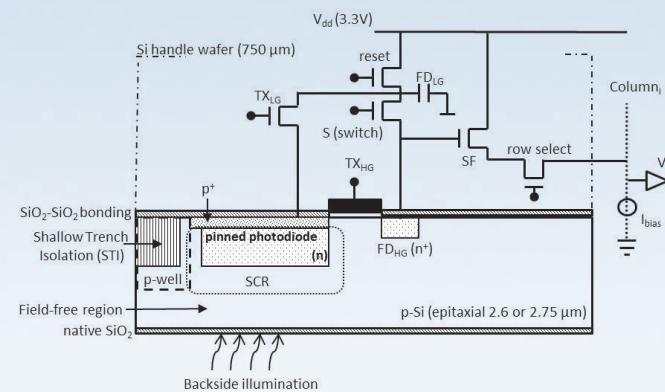
# Characterization in the visible range @ DeMeLab (STCE)



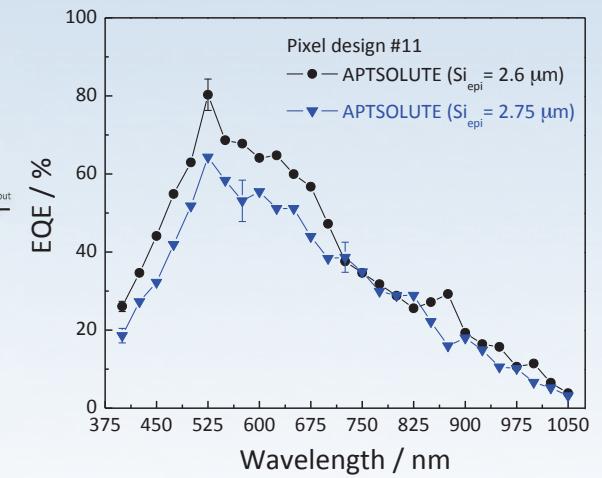
White Flat Dome Illuminator (2D arrays LEDs)



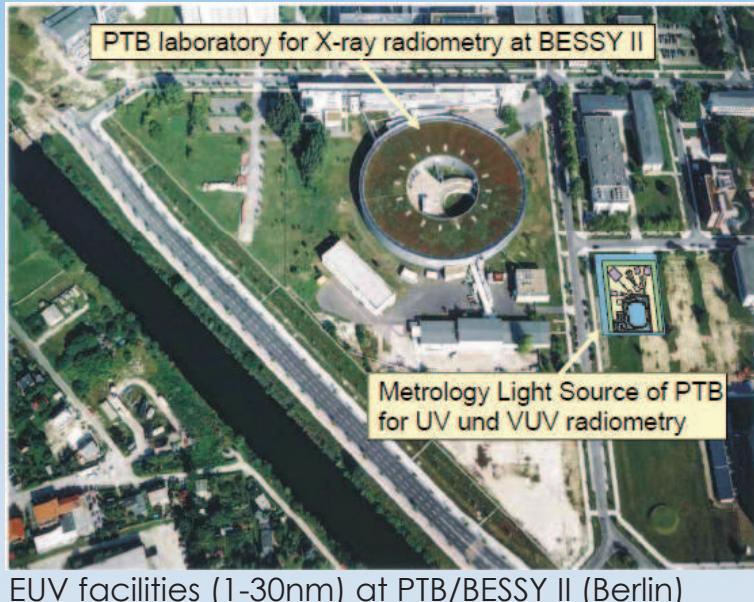
Monochromator & Integrating sphere



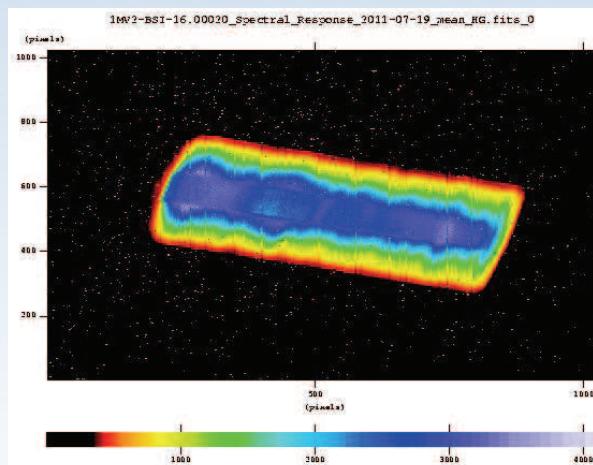
Representation of the 6-T PPD pixel design



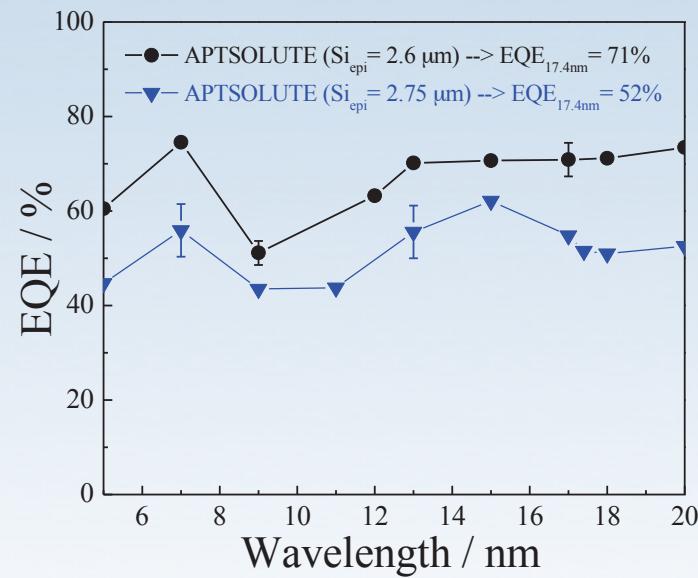
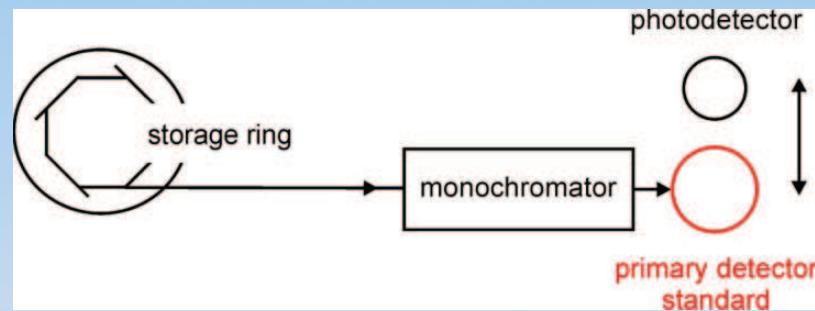
# Calibration in the EUV-VUV ranges (PTB/BESSY II synchrotron)



EUV facilities (1-30nm) at PTB/BESSY II (Berlin)



PTB beam at 17.4 nm on 1k x1k APSOLUTE



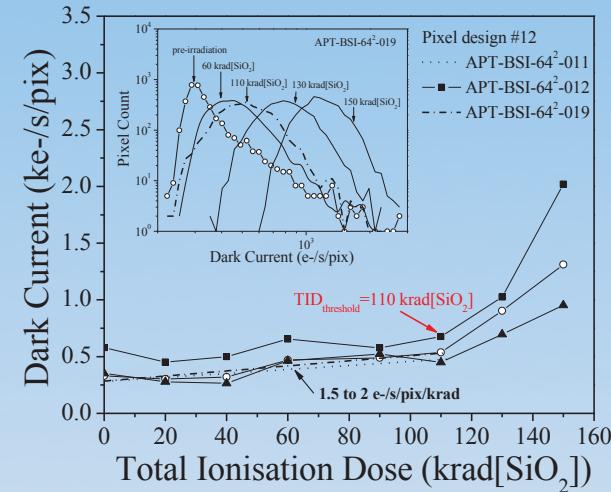
# Irradiation Damage @ CRC (Be)



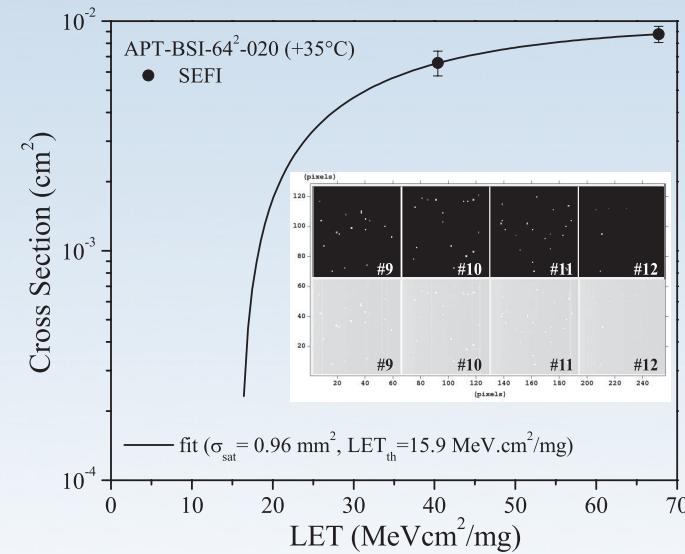
**GIF:** Gamma Irradiation Facility



**HIF:** Heavy Ions Facility (SEE)



$\text{Co}^{60}$  (1 krad/h, up to 150 krad[SiO<sub>2</sub>]) → TID threshold = 110 krad[SiO<sub>2</sub>]



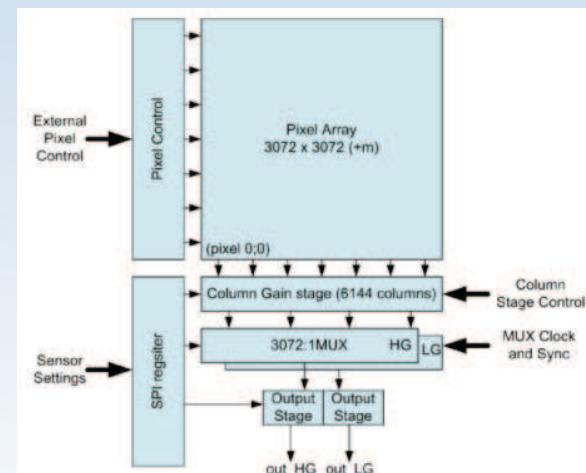
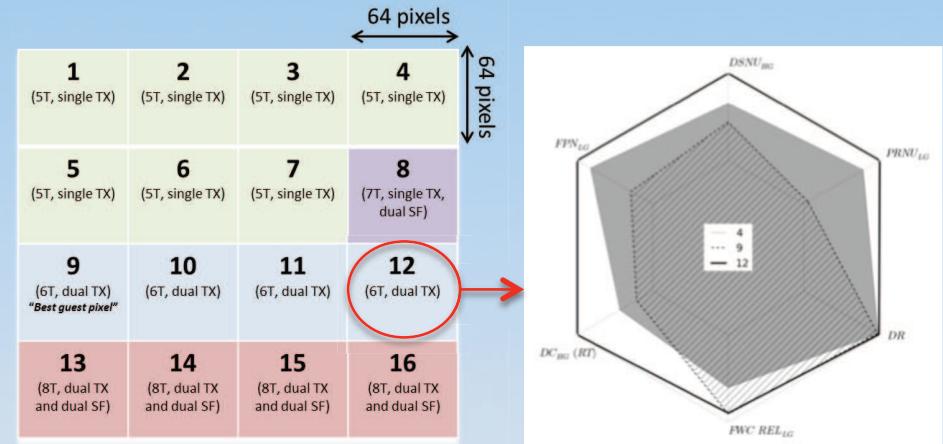
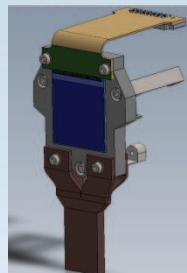
1	2	3	4
(ST, single TX)	(ST, single TX)	(ST, single TX)	(T1, single TX, dual SF)
5	6	7	8
(ST, single TX)	(ST, single TX)	(ST, single TX)	(T1, single TX, dual SF)
9	10	11	12
(6T, dual TX) "Best guess pixel"	(6T, dual TX)	(6T, dual TX)	(6T, dual TX)
13	14	15	16
(8T, dual TX and dual SF)	(8T, dual TX and dual SF)	(8T, dual TX and dual SF)	(8T, dual TX and dual SF)

Low penetration cocktails, LETs up to 67.7 MeVcm<sup>2</sup>/mg → NO LATCH UP but SEFI (single event failure interrupt) → recover after power cycling

# From Prototype to Flight Model

All requirements (RN<5 e- rms, >50% QE, 10 FPS, >80ke...) have been met

- Selection of the **best** pixel design (#12)
- Upgrade of APSOLUTE-1:
  - larger pixel array sizes (**3kx3k**),
  - triple redundancy implementation (SEFI),
  - passivation layer (**Al<sub>2</sub>O<sub>3</sub>**),
  - packaging, flex/connector, Temp. diode.

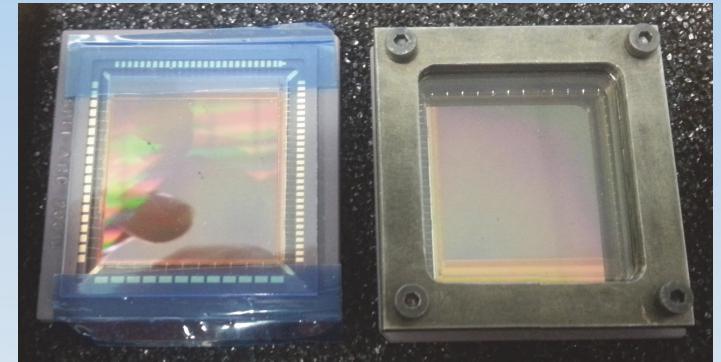


FSI device tests are ongoing at ROB/STCE. BSI under processing (October 2015).

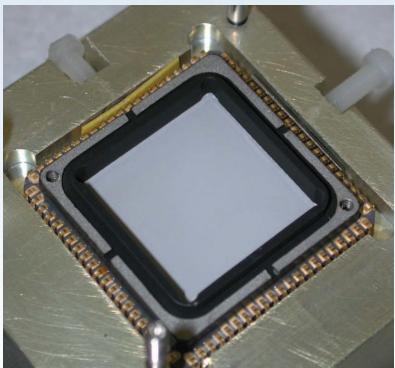


## Detector back up: EUV phosphor coatings (since 2011)

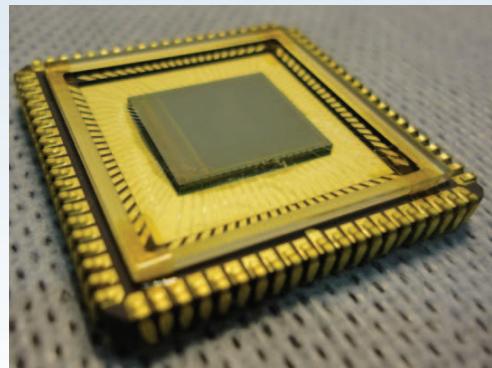
- 5 Apsolutes (1kx1k) & 2 ISPHI (2kx2k) sent to AST (UK) for EUV coating deposition:
  - with P43 (baseline for FSI and HRI<sub>EUV</sub>)
  - with P46 (comparison study)
- **Irradiation damage studies (CRC, Belgium)**
  - ✓ LIF (proton) @ CRC
    - ✓ Fluence up to  $4 \times 10^{11}$  p/cm<sup>2</sup> (cf BSI prototypes).
- **EUV calibration (PTB/BESSY II, Germany)**



ISPHI detectors (2kx2k, front side from CMOSIS)  
→ for PROBA3 ASPIICS coronagraph



P43 detector on SWAP/PROBA2 (15  $\mu\text{m}$ )

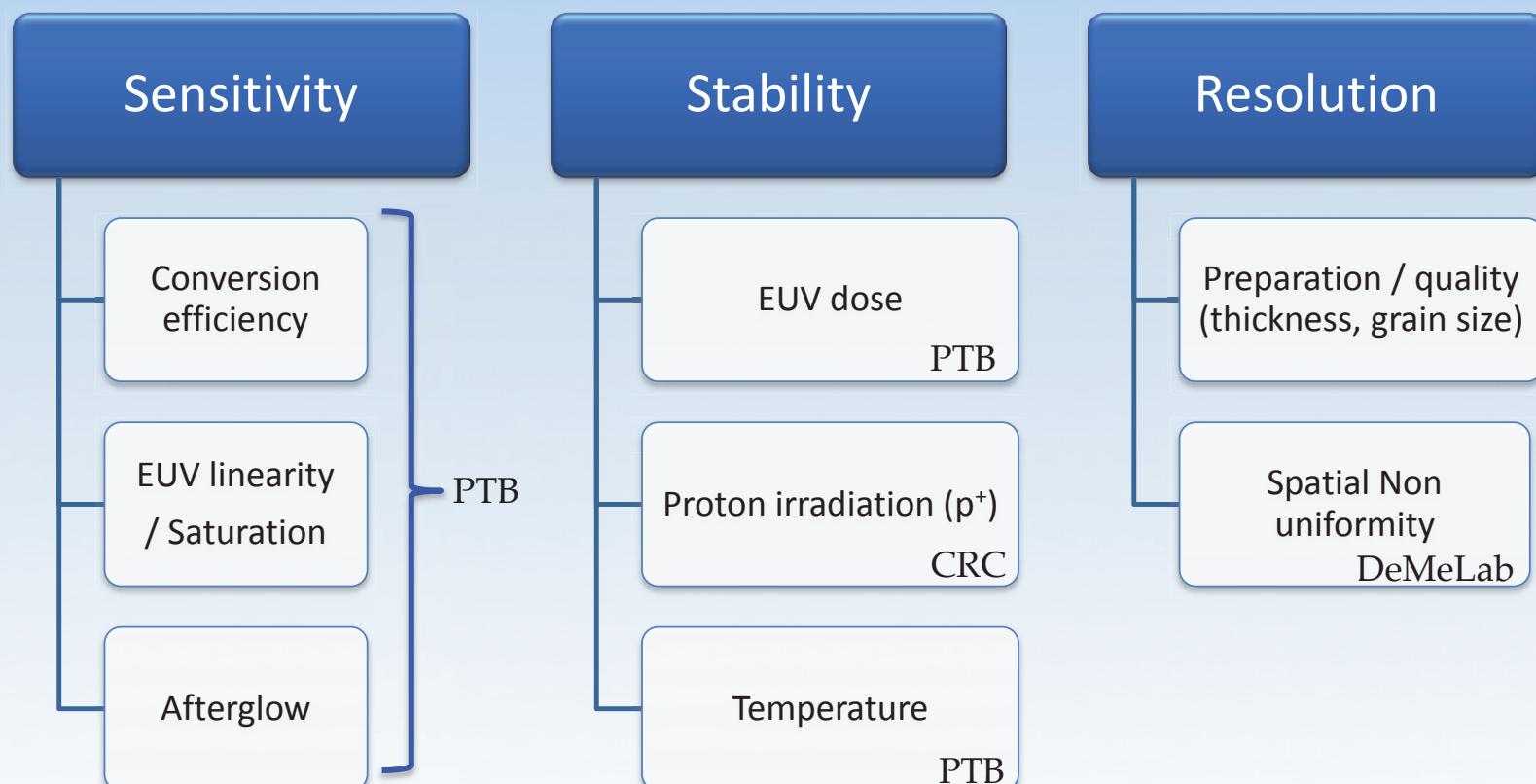


P43 detector on APSOLUTE (thinner 5-6  $\mu\text{m}$ )

P43/46 coating are exposed to radiation and converts the EUV photons into visible light (550 nm).

# Study of EUV coating

## ■ Summary of the work: **Ongoing activities**





# General Conclusions

→ LYRA has experienced **severe** degradation after launch

- presence of contaminant species on the optical filter surface,
- In-flight detector monitoring demonstrates:
  - diamond detectors (PIN and MSM) **have not been degraded** after 5 years on orbit,
  - Si-AXUV reference detectors show damage in its oxide passivation layers (EUV photons).

→ SWAP has experienced **negligible** degradation after launch

In-flight detector monitoring shows:

- Hot pixel detections (6100 per year, acceptable),
- Change in visible photoresponse of the CMOS APS → not seen in EUV images yet

→ Development of new wide bandgap AlN MSM detectors

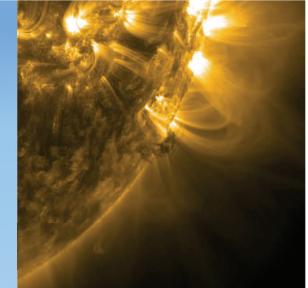
- 1.1 to 4.3 mm Ø , 2 µm width and 5 µm space between the interdigitated electrodes,
- **Stable @ +25V** under brief irradiation at Ly- $\alpha$ ,
- Proton tests → no significant degradation after 14.4 MeV proton up to  $1 \times 10^{11} p^+/\text{cm}^2$ .

→ Development of APSOLUTE: EUV CMOS APS for EUI on board Solar Orbiter

- FSI and BSI fully characterized @ DeMeLab (EUV, TID, LIF and HIF) → Selection of the '**best**' **pixel design** (#12)
- EUV sensitivity demonstrated (EQE > 50% @ 17.4nm),
- FM detectors(3kx3K) and backup detectors (2kx2k) ready soon for EUV characterization: **ongoing activities ...**

The success of PROBA2 mission should encourage to defend a more "pioneering/innovative" approach against trends towards an "industrial/minimal-risk" approach.

# Recommendations\*



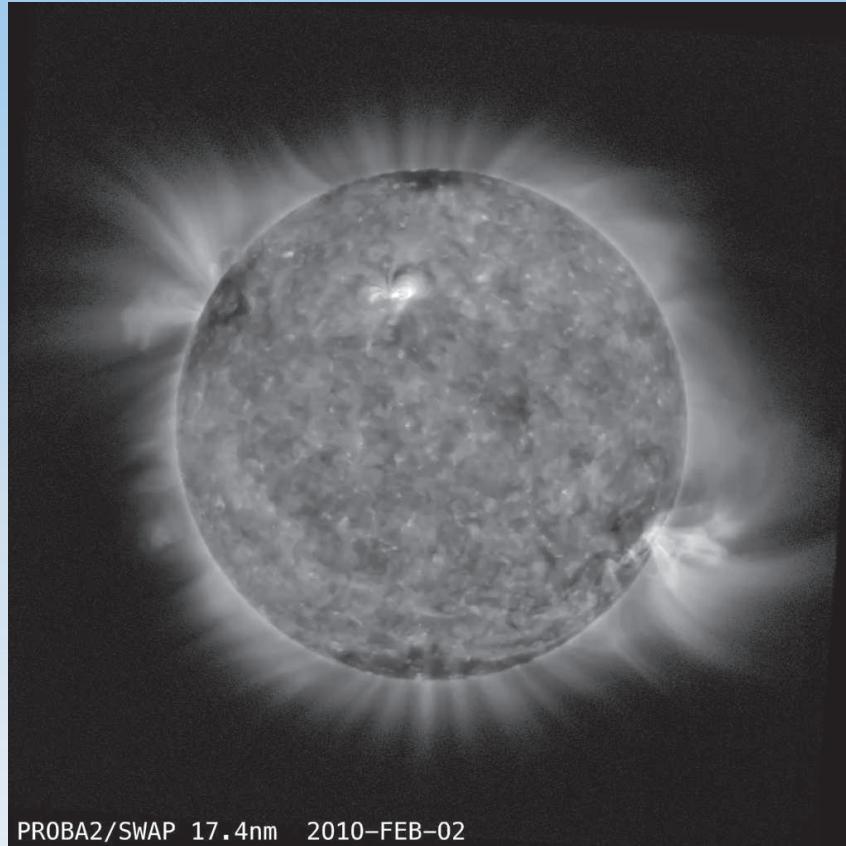
Credit AIA/SDO

- Degradation of space-based instruments could be complex, and contamination is a particular concern for UV solar instruments
  - irreversible → not possible to clean on orbit
- Strategies to minimize contamination / degradation:
  - 1- Extreme cleanliness control (at instrument & S/C levels)
    - Including careful **material selection** (low outgassing), minimization of organic material (bake-out), **design** (purging with large venting hole, door, heater for detector bake-out, cold cup around the detector, ... )
  - 2- Stability of the instrument radiometric calibration
    - Intensive **preflight calibration** is crucial: synchrotron light source (primary standard), irradiation damage studies to predict/ mitigate on orbit performance/degradation.
    - On board LEDs and door for detectors monitoring, **redundancy concept** (filter wheels), **inter-calibration** (e.g., others UV space-based instruments, rocket underflights using similar instruments, invariant sources in space → Sun is highly variable in the EUV-VUV range).
  - 3- Technological developments still needed
    - Diamond and AlN based UV photodetectors (LYRA, SWORD) → can reduce the impact of UV radiation exposure, p<sup>+</sup>, ...
    - CMOS APS (front and back-side illuminated, SWAP, EUI) → **alternative** to CCD (APS is more robust),
    - but **progress still needed** e.g., detector passivation, UV LEDs, optical filters & mirrors, onboard data processing (computing capabilities for cosmic ray removal, compression, automatic detection events, ...).

Prevention is far better and much cheaper than cure

\* A. BenMoussa et 41 coauthors, "On orbit degradation of solar instruments", Solar Physics, 288 (1), pp. 389-434, 2013.

# Thank You For Your Attention



SWAP evolving EUV corona @ 17.4 nm (02/2010 – 02/2014), courtesy of D. Seaton (SWAP PI)

## THE EVOLVING EUV CORONA



Special thanks to

Dr A. Soltani (IEMN) & all partners i.e., LYRA, SWAP and EUI teams.