Critical component degradation and in-flight calibration of EUI onboard Solar Orbiter

Talk outline

1 Introduction to Solar Orbiter mis
and environment
2 The EUI instrument & degradatic
detector, filter, LED
4 Cleanliness & contamination
5 Conclusions

DeMeLab
detector measurements laboratory

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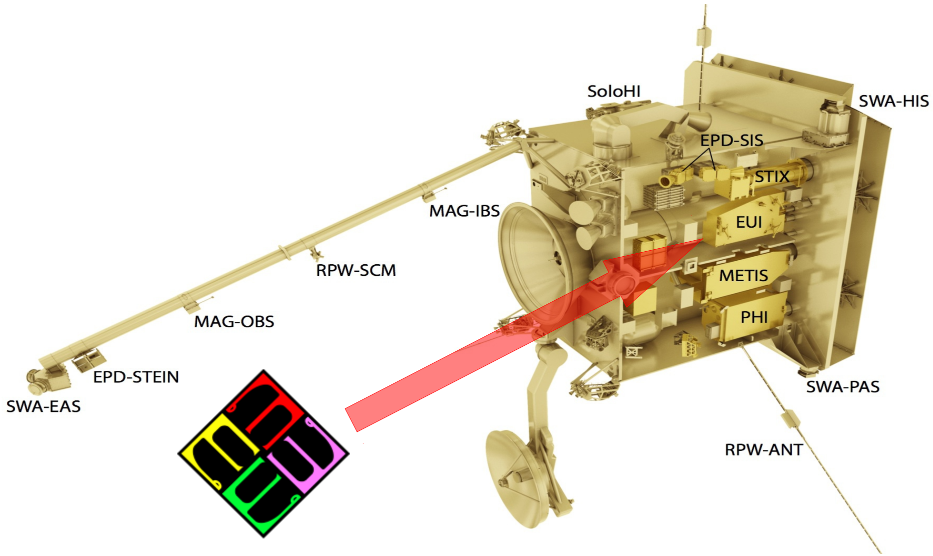
STCE workshop on degradation and inter-calibration of instruments observing in the SXR-EUV range, 11/06/2014

Solar Orbiter S/C overview

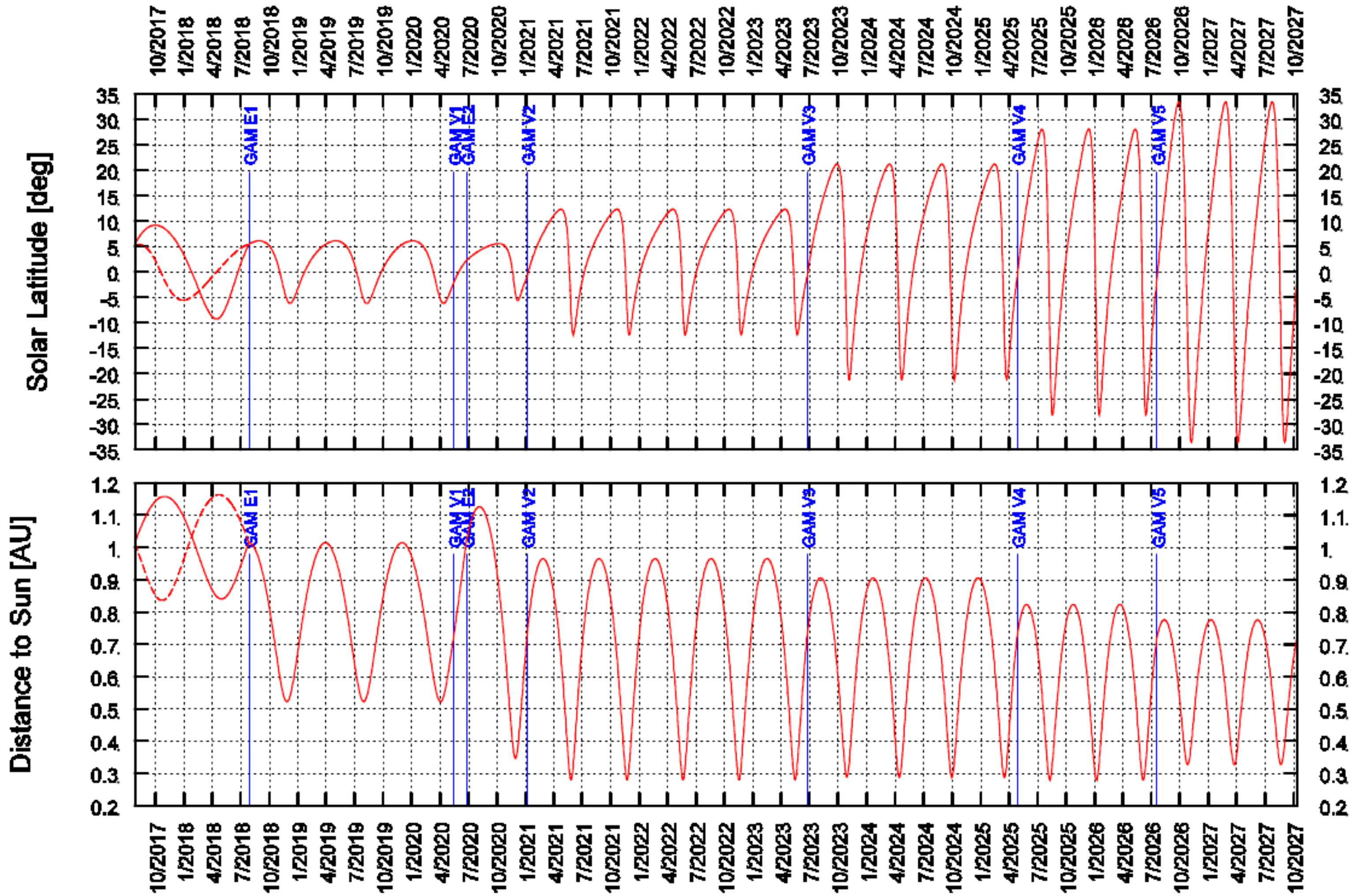


- 10 instruments:
  - 6 Remote-sensing instruments operational during 3 x 10 day science windows per orbit
  - 4 In-situ instruments operational continuously

- Current launch date (baseline): July 2017 on Ariane 5
- Highly eccentric orbit around the Sun
- 3 year Cruise Phase:
  - Gravity Assist Manoeuvres at Venus & Earth to reach operational orbit

  Nominal Mission = 3.5 years, Extended Mission = 3 years
- Daily ground contact (except for conjunction periods, longest = 61 days)

S/O mission profile and orbits (July 2017 launch)



S/O mission profile and orbits

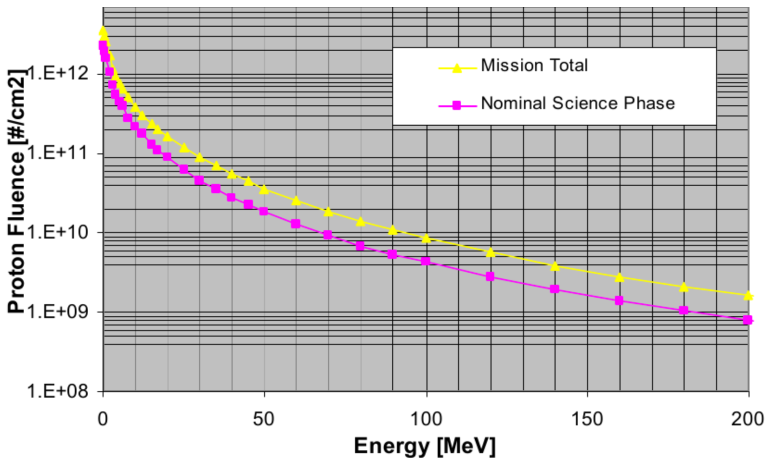
- SO S/C will approach the Sun 12 times below 0.3 AU and 16 times below 0.4 AU in an overall duration of 10.2 years.
- The duration that the spacecraft will stay below these distances is 102 and 406 days, respectively.
- High temperature variations
  - Increased outgassing
- High fluxes UV, e^-, p^+ :
  - Increased degradation of materials
  - Increased photo-deposition

Solar Orbiter Environment: main characteristics

- Solar and Planetary Electromagnetic Radiation (EUV)

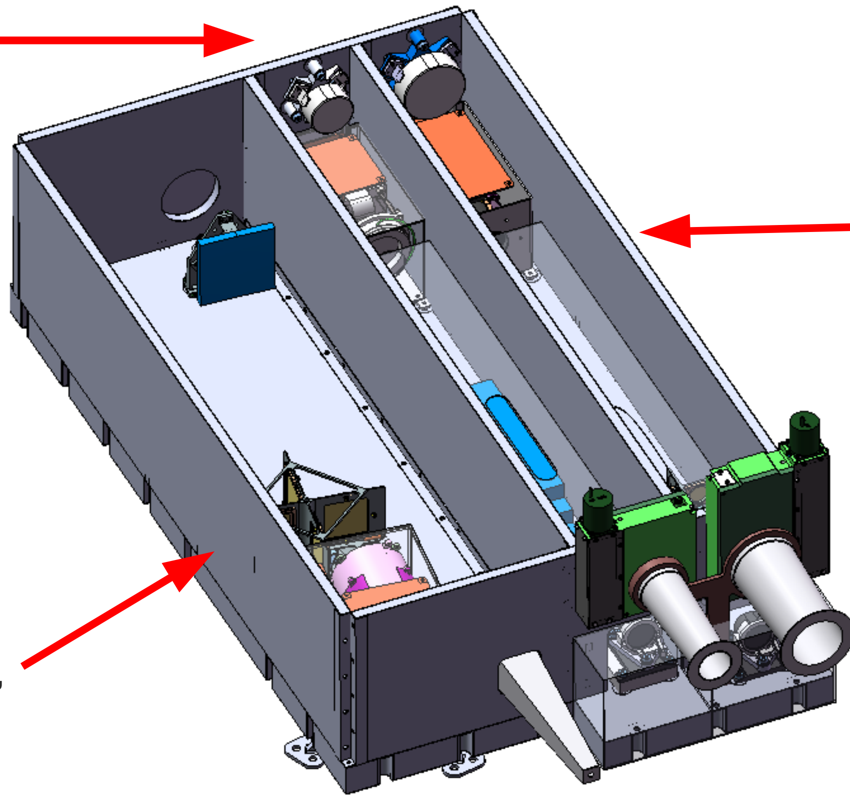
Type	Wavelength (nm)	At the Earth's distance		Solar Orbiter Mission	
		Average Flux (W/m^2)	Worst-Case Flux (W/m^2)	Average Flux (W/m^2)	Worst-Case Flux (W/m^2)
Near UV	180-400	118	177	323	2250
UV	< 180	2.3×10^{-2}	4.6×10^{-2}	6.3×10^{-2}	0.6
UV	100-150	7.5×10^{-3}	1.5×10^{-2}	2.1×10^{-2}	0.2
EUV	10-100	2×10^{-3}	4×10^{-3}	5×10^{-3}	5×10^{-2}
X-Rays	1-10	5×10^{-5}	1×10^{-4}	1.4×10^{-4}	1×10^{-3}
Flare X-Rays	0.1-1	1×10^{-4}	1×10^{-3}	3×10^{-4}	1×10^{-2}

- Energetic Particle Radiation
  - Total mission proton fluence:1-4 e11 p+/cm2
  - TID: 150 krad [Si]



EUI-OBS unit overview & channel specificities

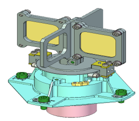
High Resolution Imager (HRI/Ly-α)
- 121.6 nm
- 1 arcsec resolution (2kx2k, 10µm pix)
- 1-2 s cadence



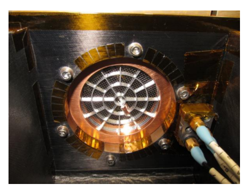
High-Resolution Imager (HRI/EUV)
- 17.4 nm
- 1 arcsec resolution (2kx2k, 10µm pix)
- 1-2 s cadence
- Low photon flux (limited by small aperture)

Full-Sun Imager (FSI)
- Dual-band 17.4 / 30.4 nm
- 9 arcsec resolution (3kx3k,
- 10µm pix)
- min 10 s cadence

HRI-EUV



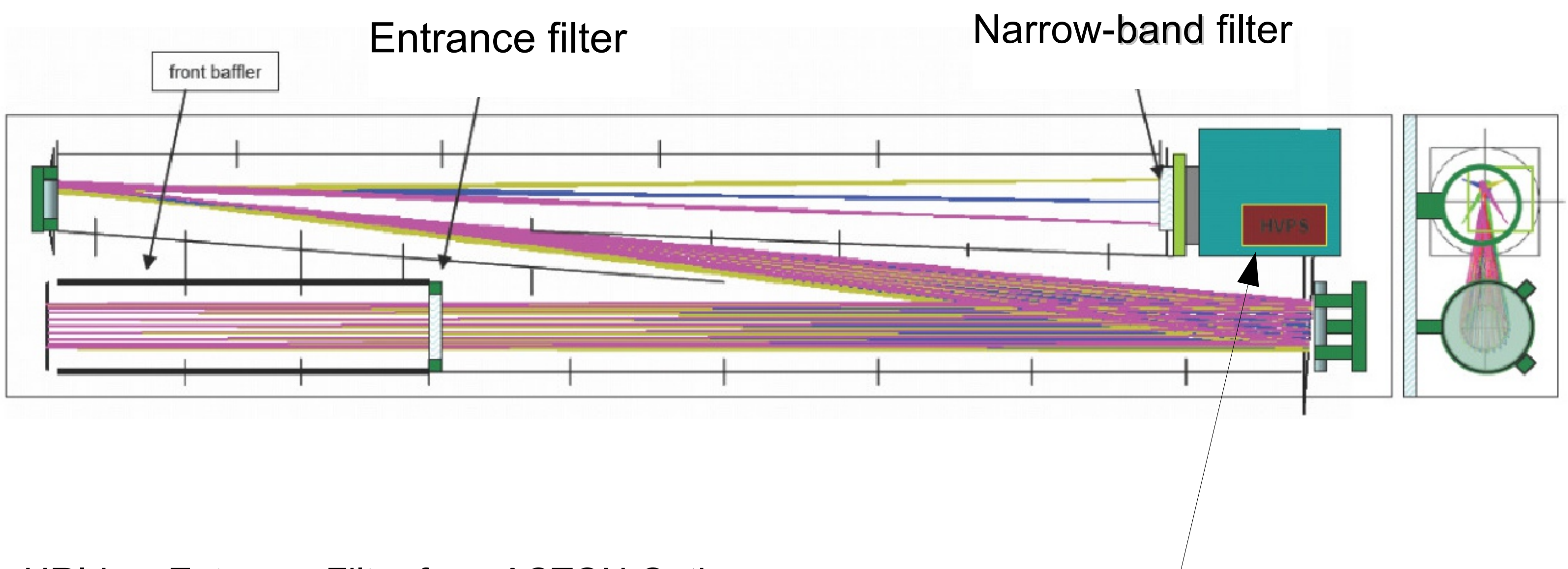
Focal filters: LUXEL filters
150 nm Aluminum with 20 lpi Ni mesh grid on dedicated Aluminum frame



Aluminum foil with Ni mesh

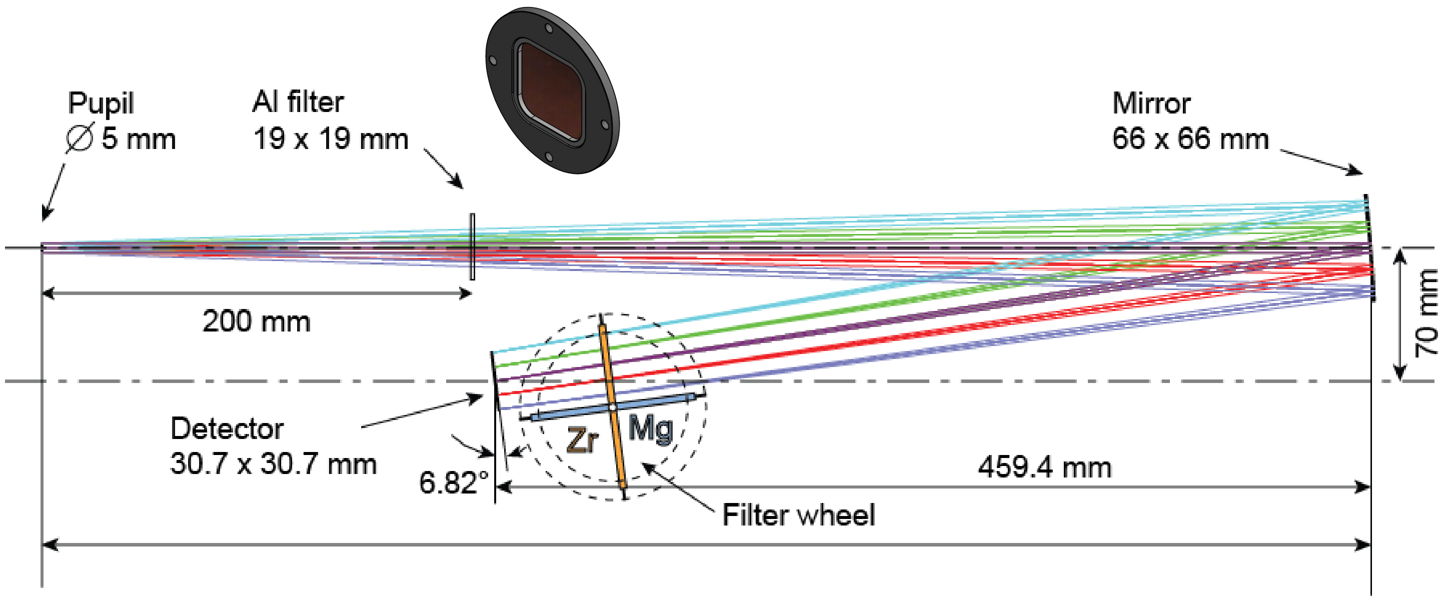
- Based on an off-axis Gregory telescope optimized in length and width
- entrance baffle reduces the heat input reaching the entrance foil filter

HRI-Ly α



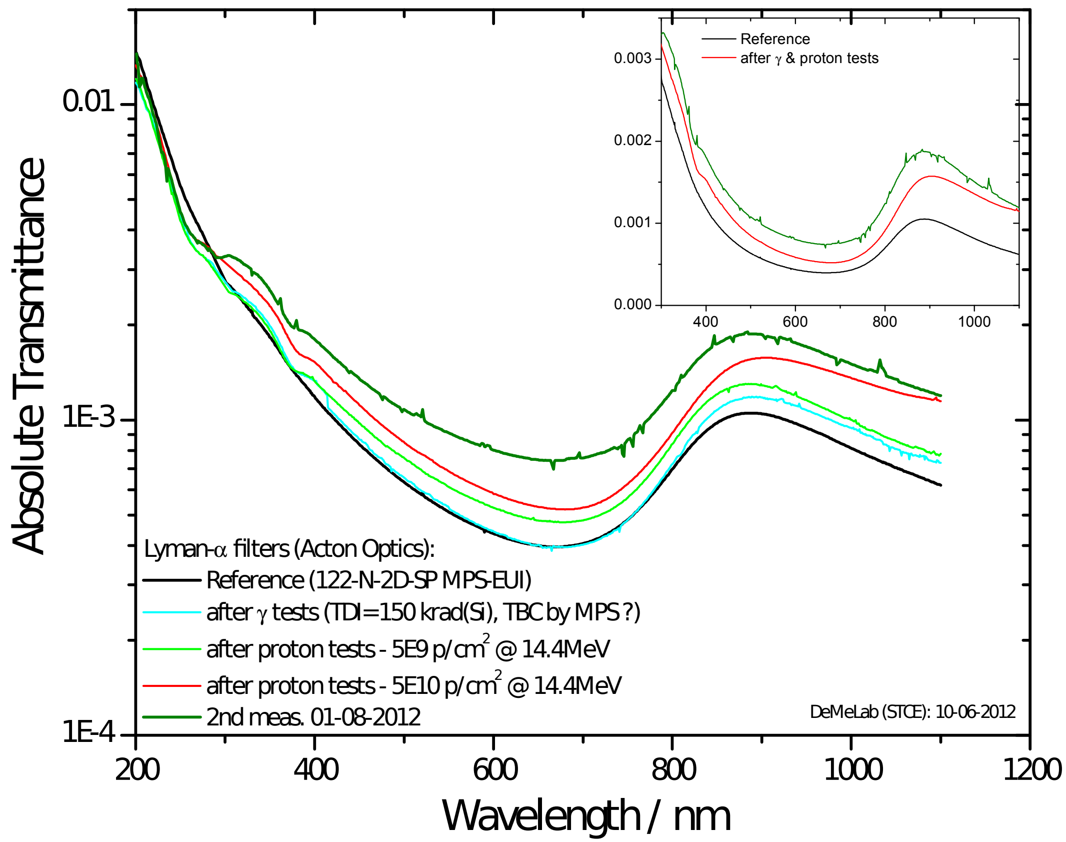
- HRI-Lya Entrance Filter from ACTON Optics & Coatings,type FN-122-N, now procured by Pelham.
- “open-faced” filter having the interference coating on one side of the MgF2 substrate
- MCP & High-voltage units
- FPA: APSOLUTE front-side detector

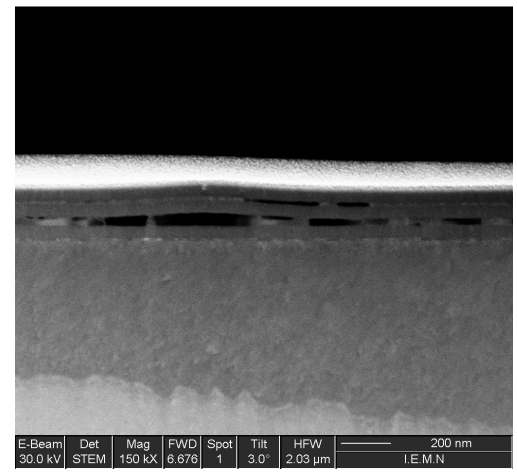
Full-Sun Imager

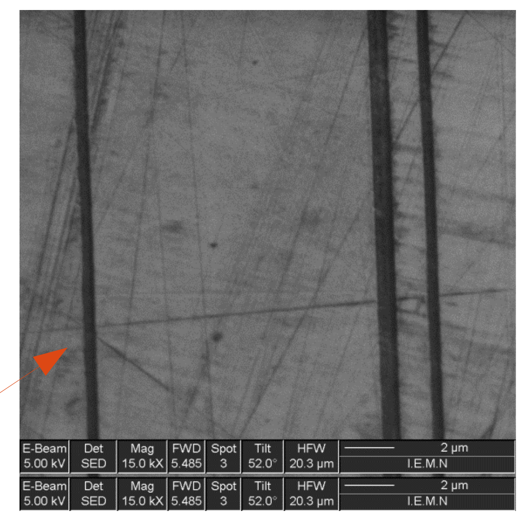


- FSI unit is based on a Herschelian telescope optimized with a 5 mm diameter aperture pupil located at the front section of the FSI entrance baffle.
- Entrance filter: LUXEL filter
  - Custom frame
  - Hexagonal mesh
- Multilayer structure on filter wheel
  - Al/Zr/Al
  - Al/Mg/Al

HRI-Ly-α entrance filter after proton fluence irradiation







SEM: cracks observed on Al top coating
may explain the increase of the visible transmission after proton irradiation.

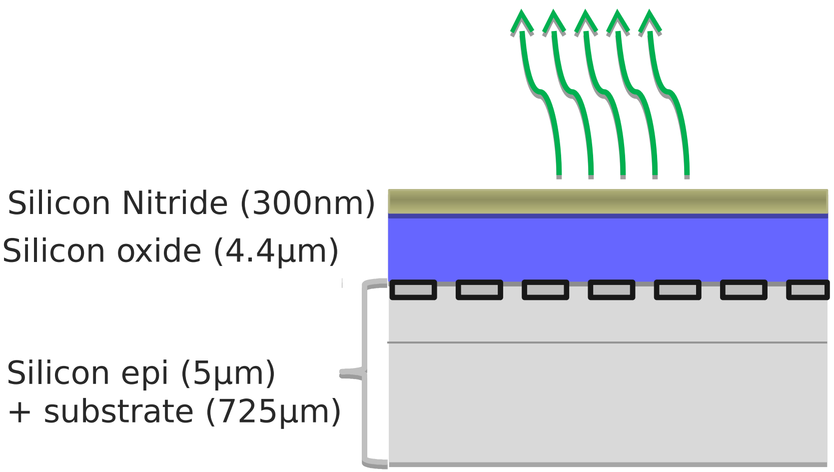
BSI vs FSI image sensors

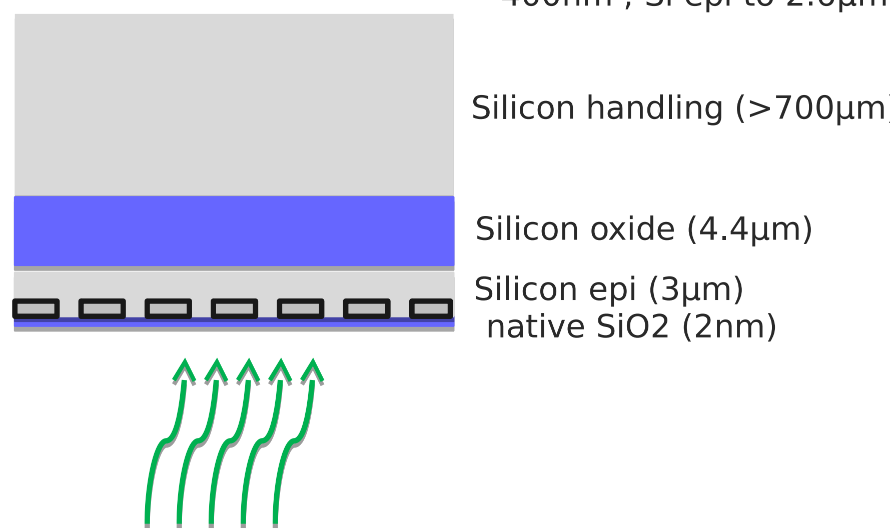
- Provided by CMOSIS sub-contractor
- Test chip (Monolithic) on SOI (SOITEC) material, 0.18µm technology (TS)
- 10 µm pixel pitch pinned photodiode (PPD) based on 4T pixel design
- Thinned (250 and 400nm etch) for back-side illumination optimized for EUV sensitivity
- Dual-gain pixel read out

Back side imager (BSI), Baseline

Remark: BSI are etched to:
- 250 nm ; Si epi to 2.75µm
- 400nm ; Si epi to 2.6µm

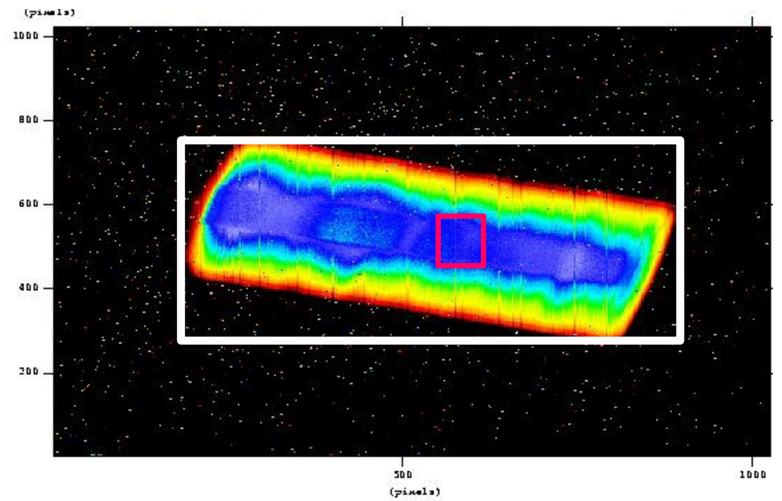
Front side imagers (FSI)

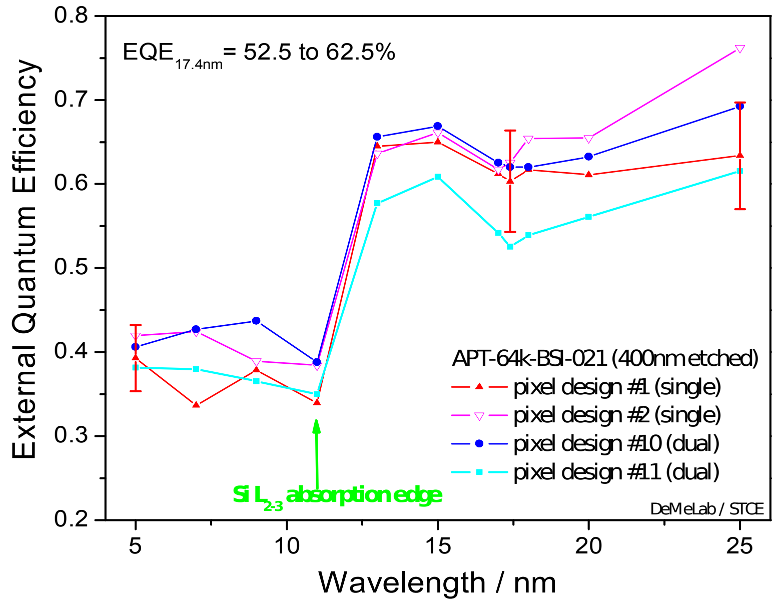




Detector and instrument-level calibration measurements

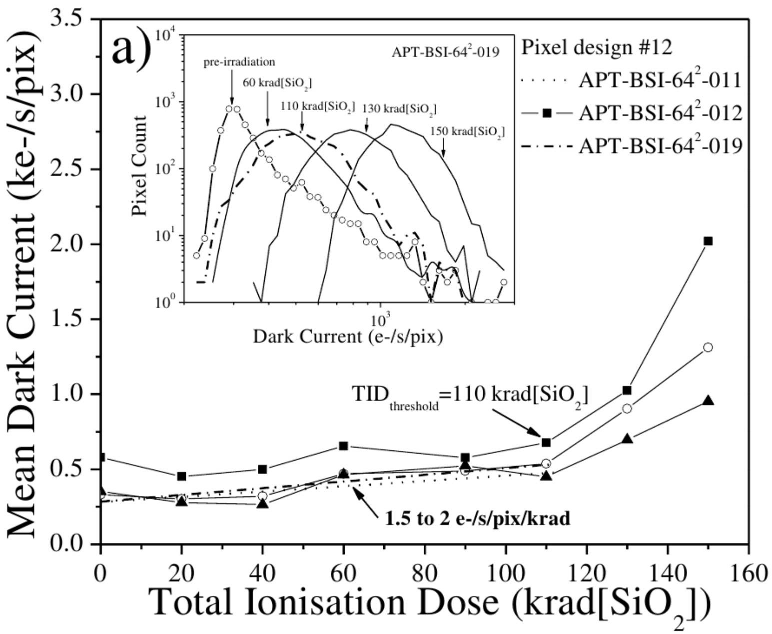
- APSOLUTE-1 & 2 parameters to estimate [Requirements]
  - Visible
    - Dual gains
    - Full Well [> 80 ke-]
    - Linearity
    - Visible(LED)-to-EUV degradation mapping
  - EUV
    - **EQE [>50%] measured at PTB/BESSY-II**
    - Lag & Stability
    - Flat field (challenging)
  - Dark measurements
    - DC, FPN offsets, Read Noise [<5 e-]
- Robustness to SO environment
  - TID with γ and p+ [>100 krad [Si]]
  - Displacement damages
- Used for best pixel design selection



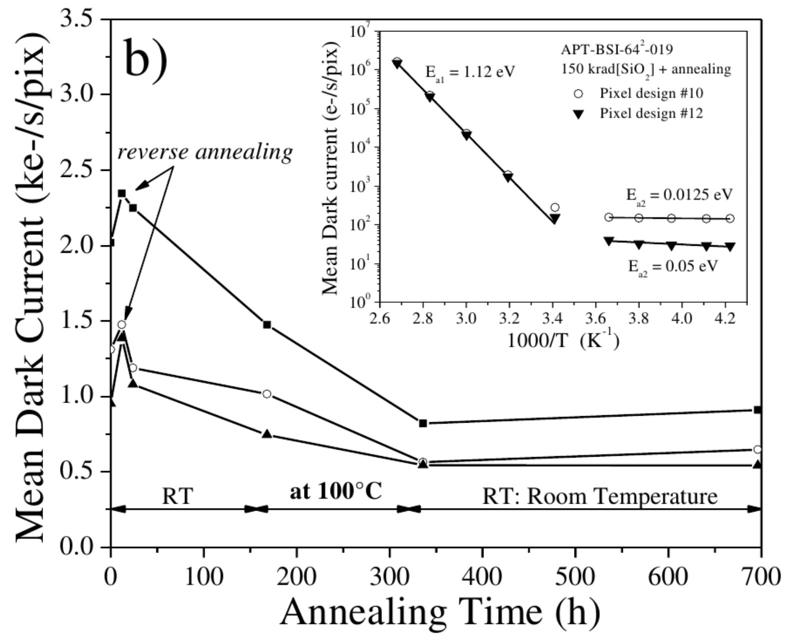


APSOLUTE-I detector degradation

TID effects on Dark Current



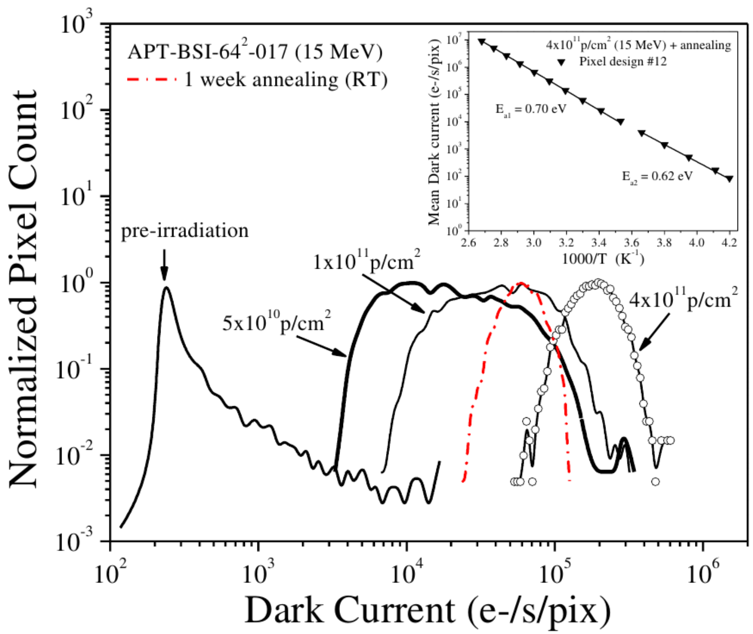
Annealing; recovery after 2 week at RT



From *BenMoussa et al.*, IEEE Transactions on Electron Devices, 2013, 60, 1701-1708

APSOLUTE-I detector degradation (2)

Displacement damage effects on DC

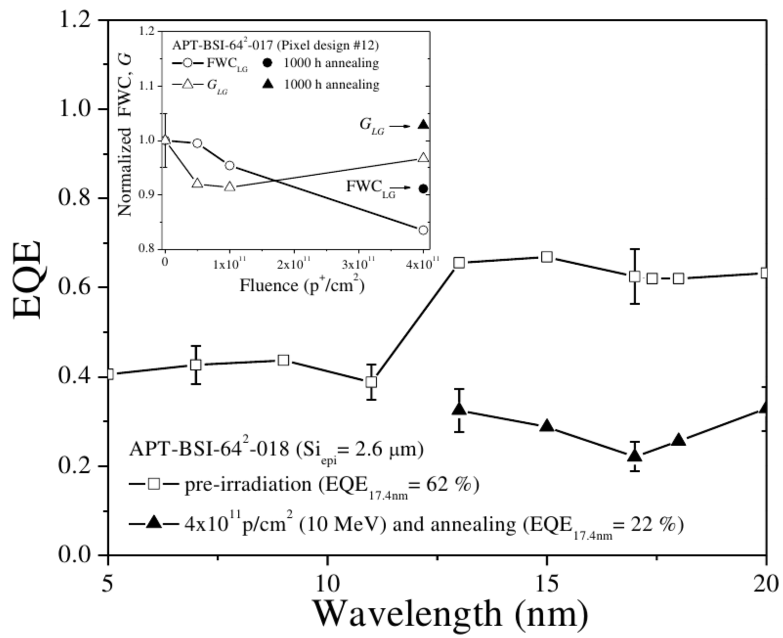


- No full DC recovery
- Permanent damages

From *BenMoussa et al.*, IEEE Transactions on Electron Devices, 2013, 60, 1701-1708

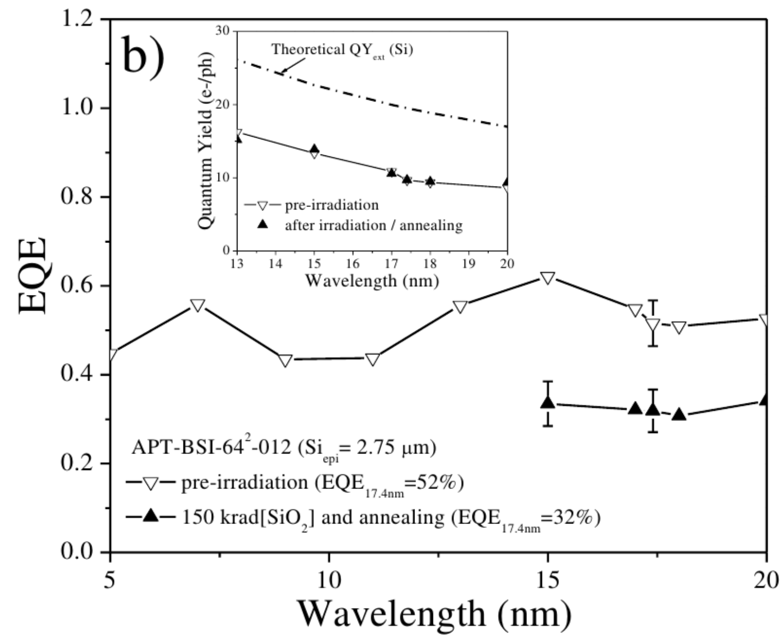
APSOLUTE-I detector degradation (3)

Displacement damage effects on EQE



TID on EQE

(permanent damages)



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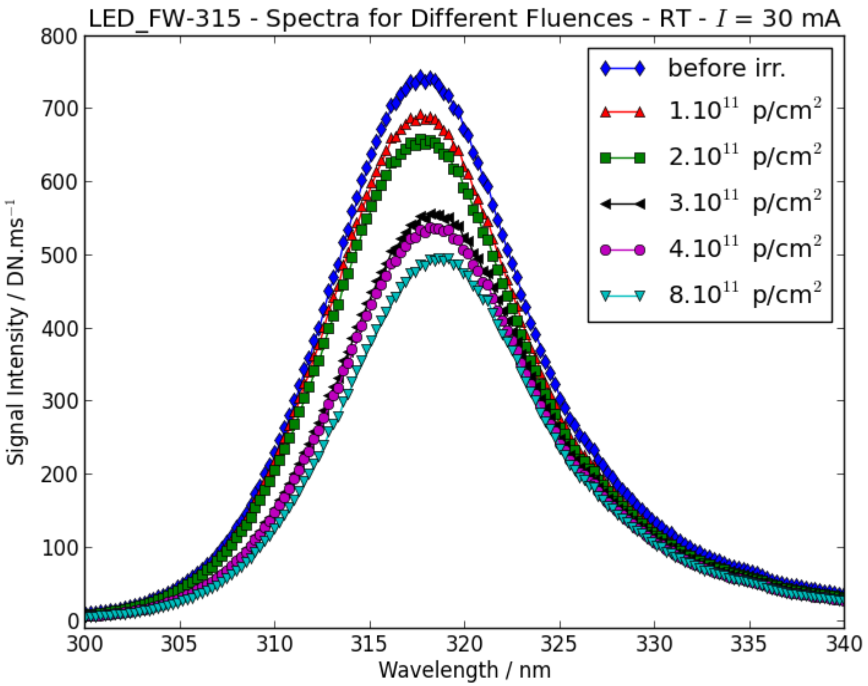
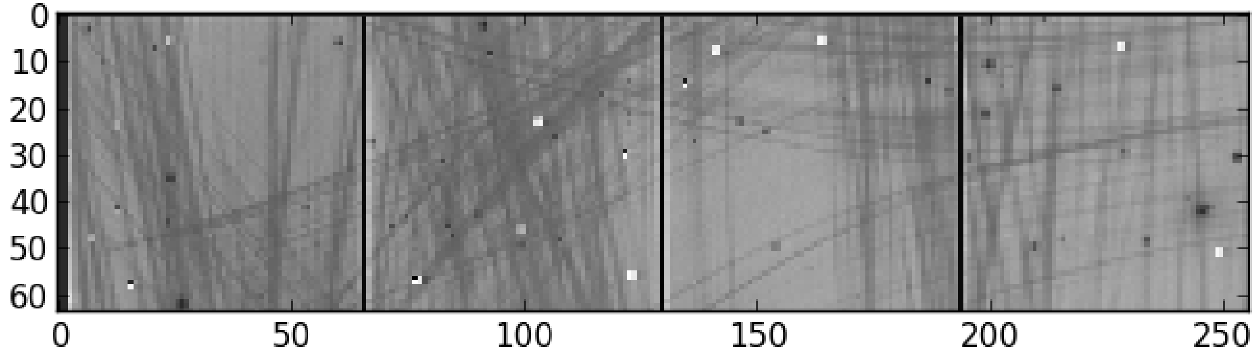
Onboard calibration LEDs degradation tests



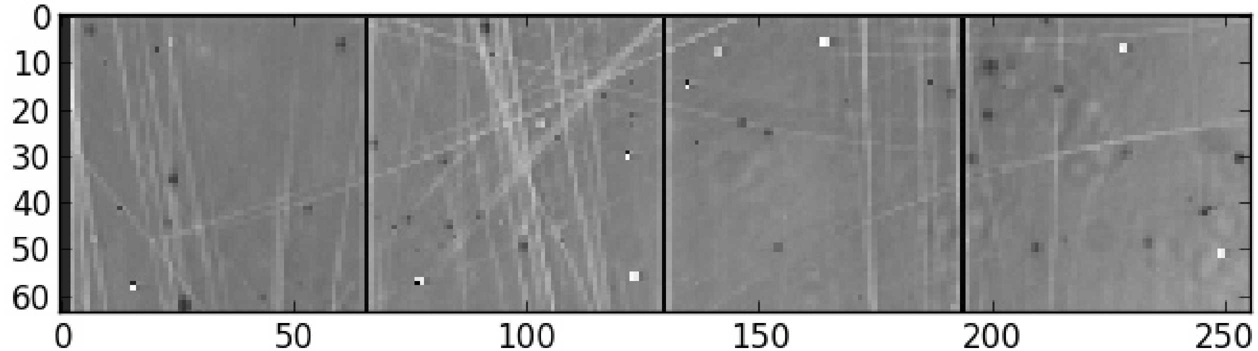
- Robustness against proton irradiation
- Used for flat-field computation, to be compared with ground EUV flat-fields
- Visible LED used on-board

LEDs (2): wavelength-dependance

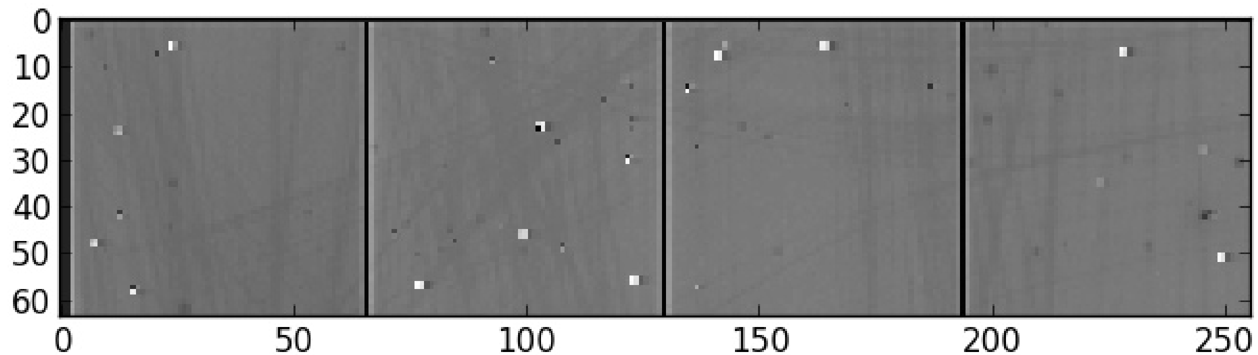
BSI 64K imager illuminated with LED_FW-315 nm from SETI with a forward current I_F = 50 mA



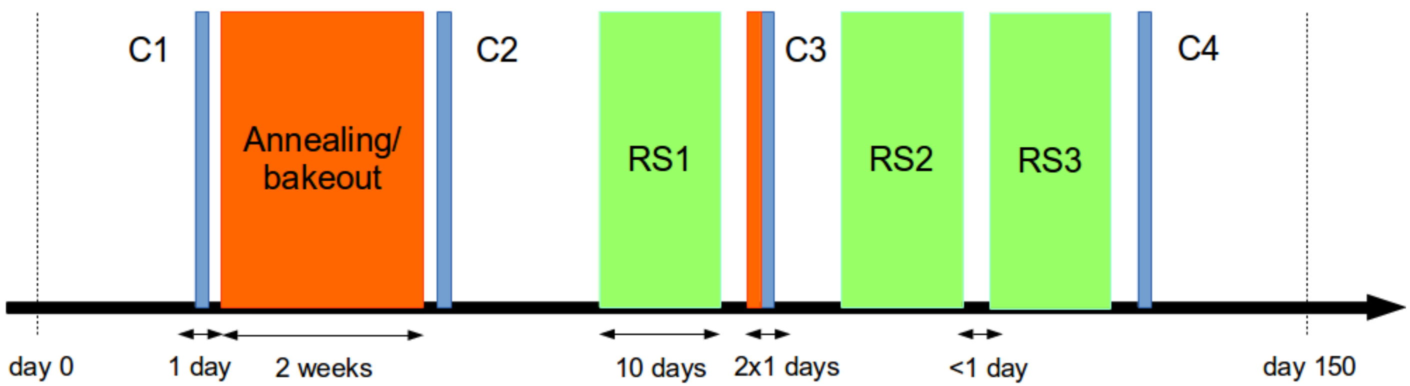
Same with LED_FW-355 nm from SETI



Same with 62621 LED from Micropac, forward current I_F = 0.1 mA



EUI orbit profile & duty cycle



- Onboard calibration campaigns: EUI will perform pre-(lossy)compression calibration autonomously
  - Flat-field and dark offsets onboard update (requires approval by EUI operator)
    - Implemented on-board only if high relative difference are detected in calibration products.
  - Off-pointing (and rolls) maneuvres for inflight EUV flat field estimations
- C1,C2: annealing efficiency assessment
- Degradation monitoring:
  - Dark current
  - Full Well
  - RTS pixels

Cleanliness/contamination

- Careful contamination control (Solar Orbiter Cleanliness WG led by U. Schühle, MPS)
- EUI sensitive areas on optical-path:
  - Entrance filter (2 surfaces)
  - Mirrors (2 surfaces for HRI, 1 for FSI)
  - Focal plane filter (2 surfaces)
  - Detector entrance window (1 surface)

Cleanliness of EUI at S/C delivery

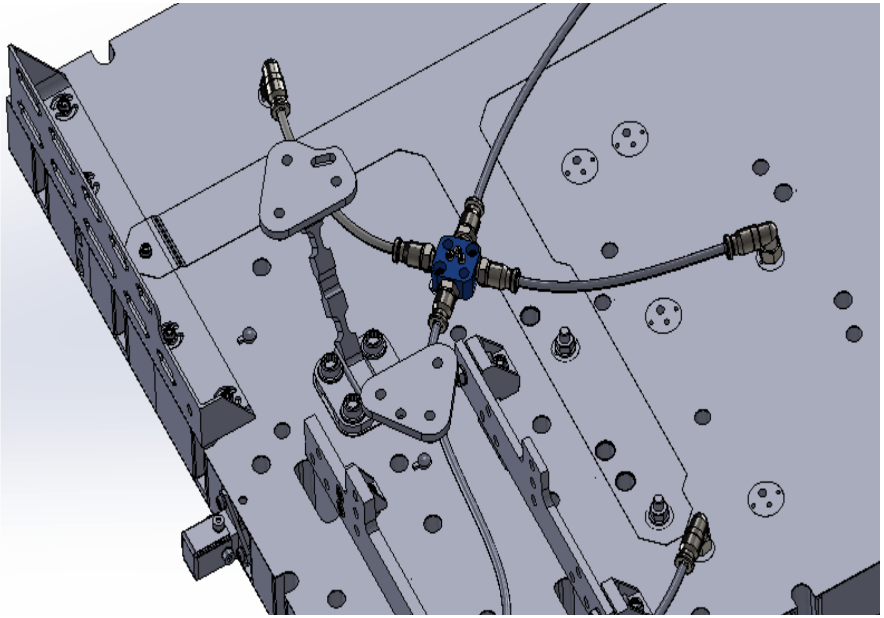
- Limitations of contamination on EUI sensitive areas

Sensitive Area	Limit molecular [ng/cm²]		Limit: particulate [ppm]	
	Delivery	EOL	Delivery	EOL
Entrance baffle	50	370	54	300
Mirrors, filters, internal surfaces	50	370	54	100
External H/W (MLI, E-Box)	100	370	100	300

- The Entrance Filter is the first critical optical element of the EUI telescopes
  - permanently exposed to solar irradiation during orbit
  - strong UV radiation that can lead to polymerization of organic contaminants.
- Purging procedures
  - Gas (N2) quality grade control
  - Purging flow rate control to avoid damage (limited ΔP) on foil filters
  - Repressurization of vacuum chamber after bake-out
- Particular and molecular witness samples (PFO, witness plates)
  - to monitor cleanliness cleanliness at all AIT activities (after assembly, vibration, vacuum/bakeout tests…)

Purge system requirements

- “after EUI delivery almost continuous purging of the EUI structural housing with clean and dry nitrogen gas until launch. “
- “longest duration **without purging shall be limited to 30 minutes per any 24 hours**, except during the vacuum tests sequences.”
- “ For the purging to be interrupted, the external environment shall be equivalent to ISO class 8 with a relative humidity of 55 ± 10%.”



Conclusion

- EUI just passing CDR
- ROB-DeMeLab working on EUI subsystems (detectors, filters, LEDs) and inflight calibration
- Thank you !