# MPS camera projects

MPS has more than 25 years experience in providing FPAs for space-based solar and planetary scientific missions, and for ground-based solar telescopes.



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# Selected projects

**Planetary:**

- Giotto: HMC (1986)
- Mars Pathfinder: IMP (1997)
- Rosetta: OSIRIS cameras (launched 2004)
- Cassini/Huygens: DISR camera (2005)
- Venus Express: VMC (launched 2005)
- Dawn: FC 1 and 2 (launched 2007)
- Phoenix: RAC (2008)

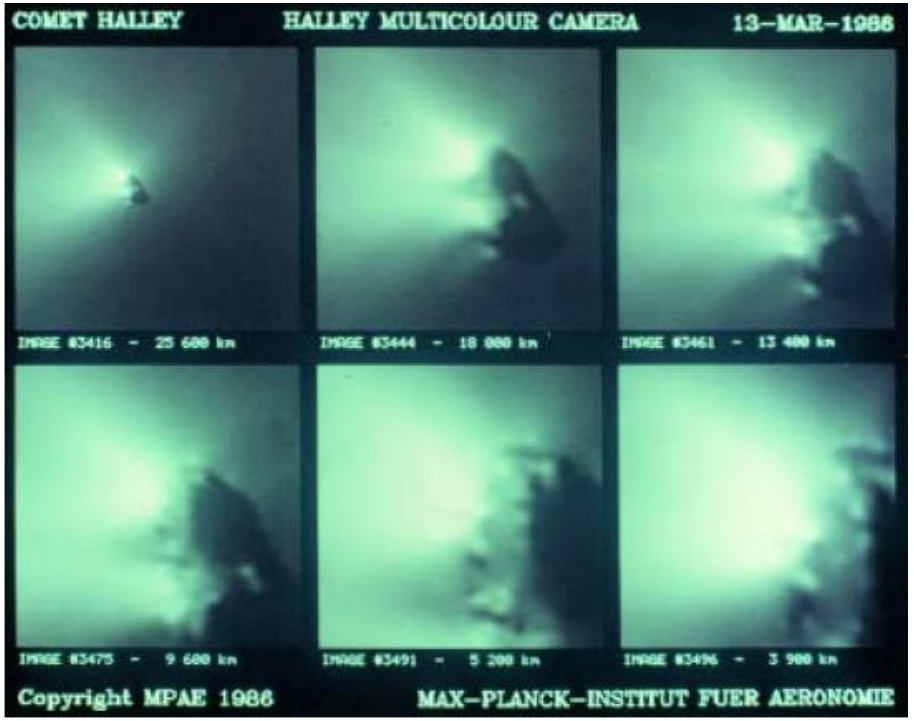
**Solar:**

- VTT, GREGOR: TIP 2 (ground-based, since 2005)
- Sunrise: SuFI (2009)
- RAISE
- SMESE
- Solar Orbiter EUI Lyman-Alpha camera
- Solar Orbiter: ISPHI
- Solar Orbiter METIS

# Giotto - HMC

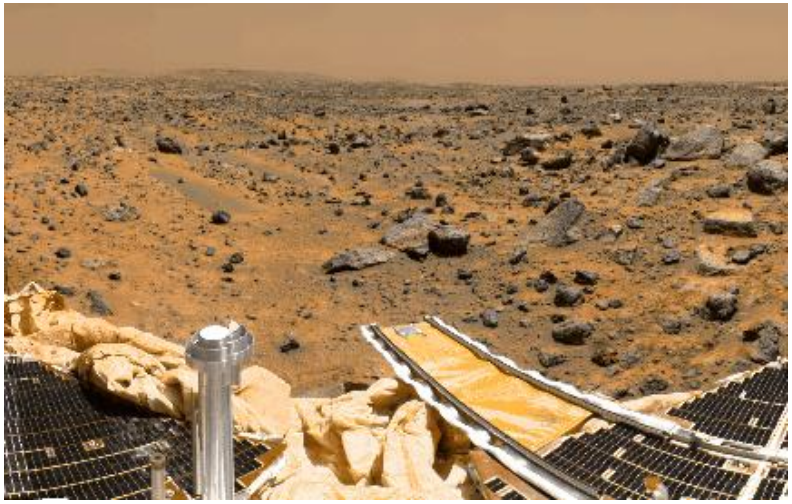
- Comet Halley flyby, 1986

The Halley Multicolour Camera (HMC) has recorded more than 2000 images. The 6 images shown on the right range between 6 min. and 1 min. before closest approach.



# Mars Pathfinder - IMP

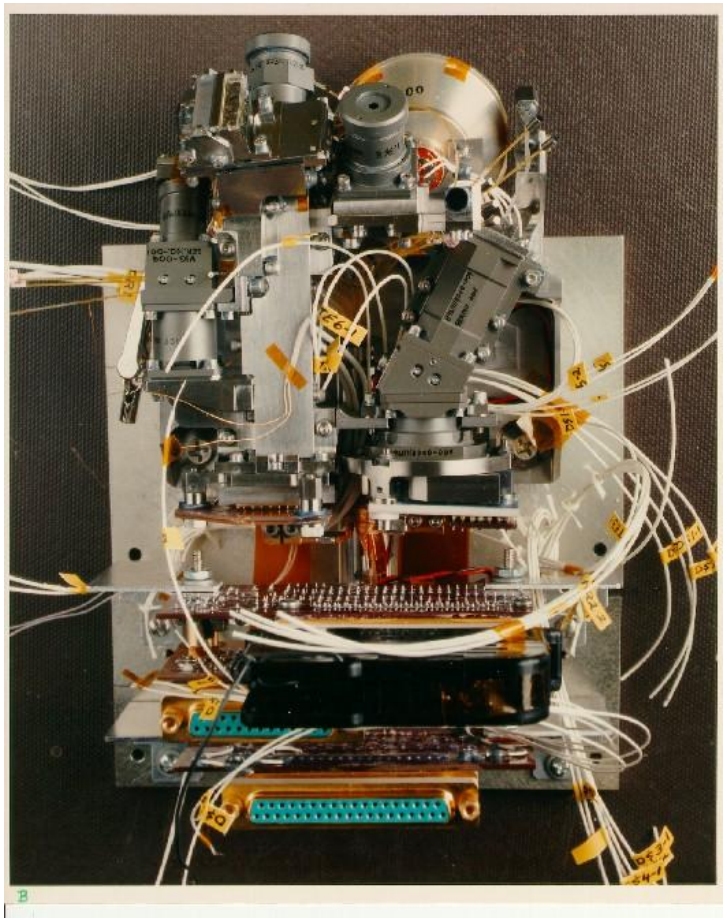
- NASA mission, mars landing 1997
- First successful deployment of a rover on the Martian surface.
- Imager for Mars Pathfinder (IMP) a stereoscopic camera mounted on top of an expandable pole on the lander unit.
- MPS has provided the CCD sensor and the readout board for IMP.



Segment of a panoramic image, recorded by the IMP.

# Cassini/Huygens - DISR camera

- NASA/ESA mission, launched 1997 to study Saturn and its moons
- DISR has recorded spectra of the Titan atmosphere during the descent of the Huygens probe (Jan, 2005)
- MPS was responsible for CCD detector and associated electronics Image compression board developed in collaboration with IDA



View of the open DISR instrument from above, during assembly

# Dawn - FC 1 and 2

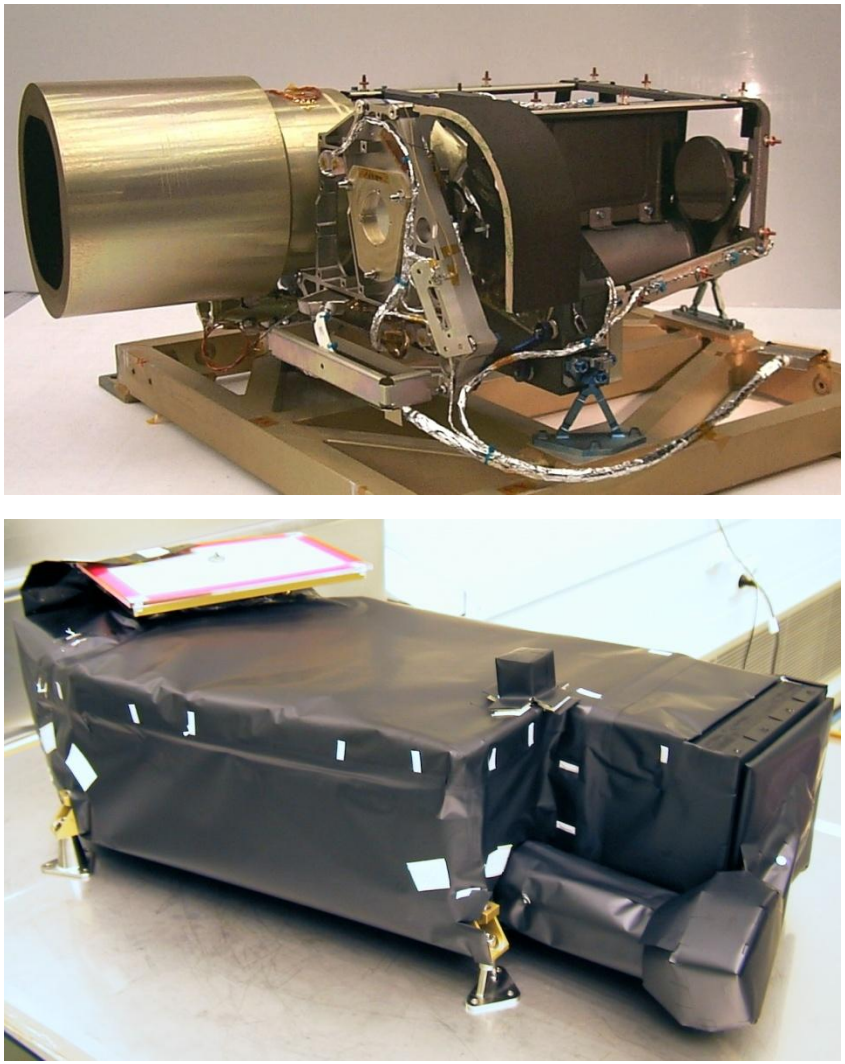
- Mission of the NASA discovery program to study Vesta and Ceres in the asteroid belt
- Has reached Vesta on July 16, 2011 and will arrive at Ceres in Feb 2015
- MPS has built the 2 identical Framing Cameras, with DLR and IDA (Braunschweig).

One of the FCs; 1k x 1k CCD with a huge range of integration times (1ms to 3.5 hours).

# Rosetta - OSIRIS

- The two OSIRIS cameras, the main scientific imaging system on the orbiter of ESA's Rosetta mission to comet 67P/Churyumov-Gerasimenko (encounter in 2014)

- FPA units built at MPS

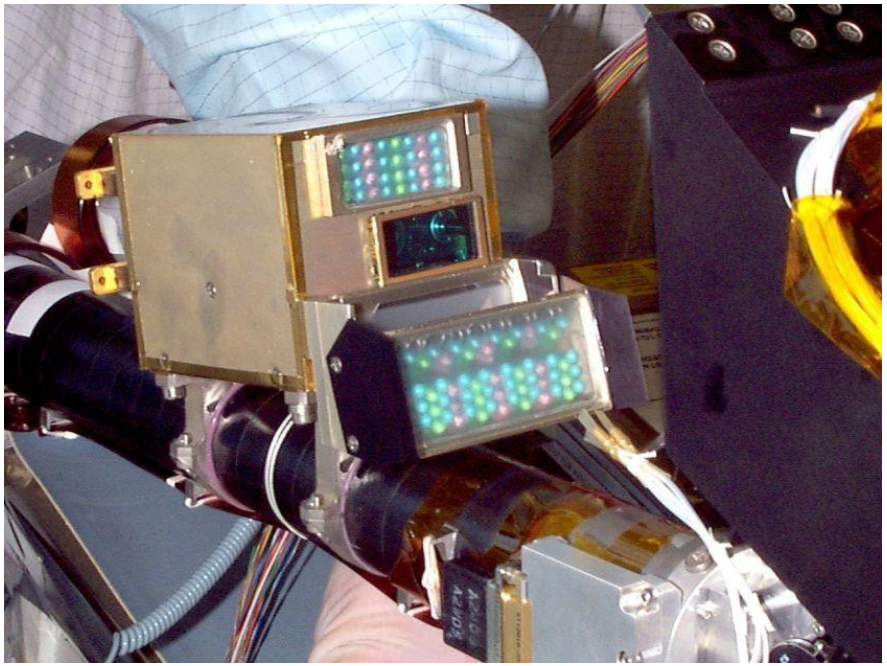


OSIRIS narrow-angle (top) and wide-angle (bottom) cameras

# Phoenix - RAC

- NASA mission to the Martian arctic region (landed on May 25, 2008)

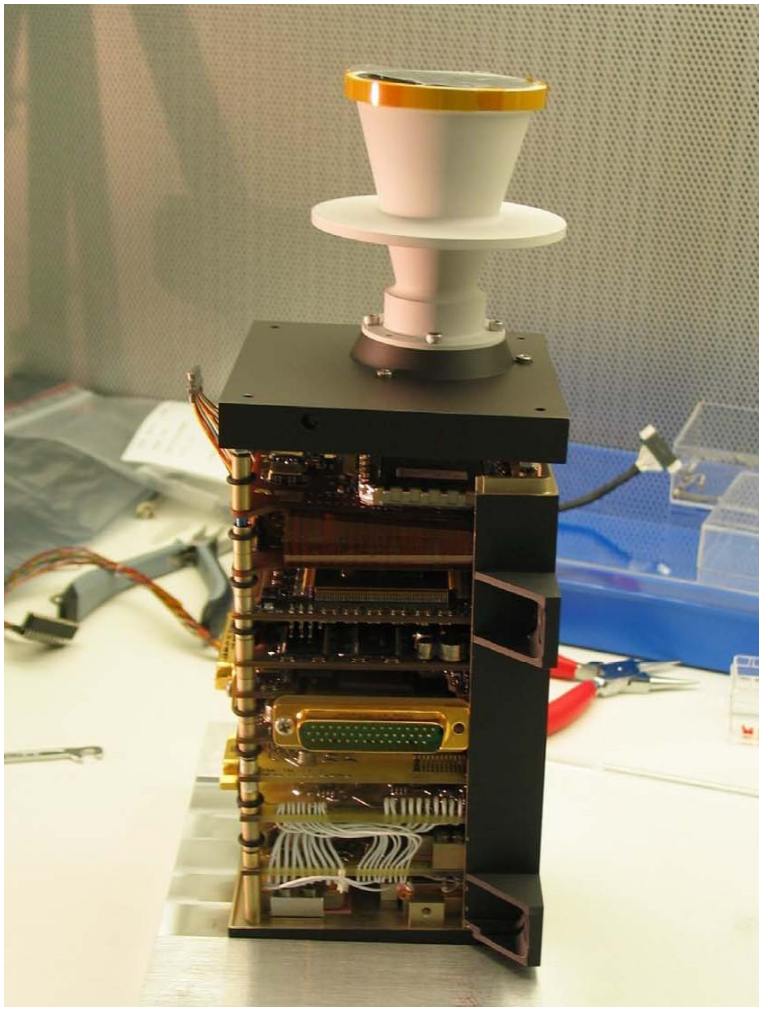
- MPS has contributed the Robotic Arm Camera (RAC), with the Univ. of Arizona



RAC with colored LEDS and microscope optics
allowing the study of Martian soil particles down to 50 µm.

# Venus Express - VMC

- ESA's first mission to Venus (launched on Nov 9, 2005)
- Venus monitoring camera (VMC) monitors the dynamics of the Venus atmosphere in 4 different spectral windows between the UV and the near-IR.
- VMC developed by MPS in coll. with IDA and DLR.



# VTT, GREGOR - TIP 2

- Based on 1k x 1k, HgCdTe CCD from Teledyne (former Rockwell)
- Used for ground-based near-IR solar spectro-polarimetry

# Sunrise - SuFI

- Adaptation of an off-the-shelf camera (PixelVision) for the Sunrise balloon flight experiment

- Hi-res observations in the 200-400nm range

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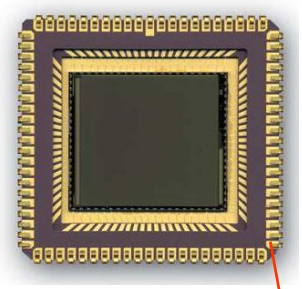
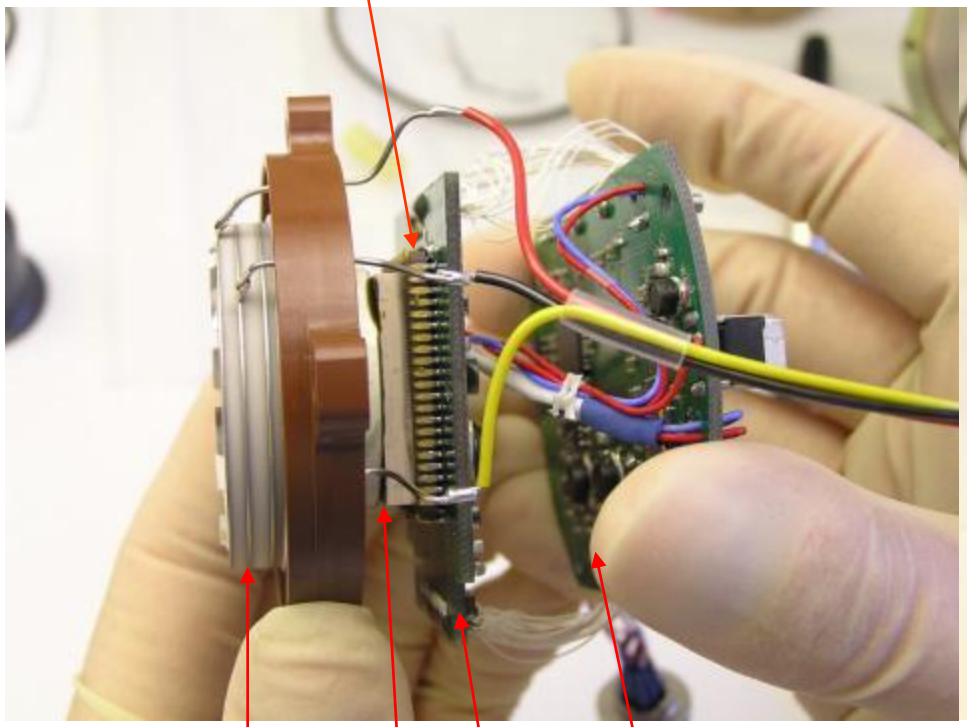
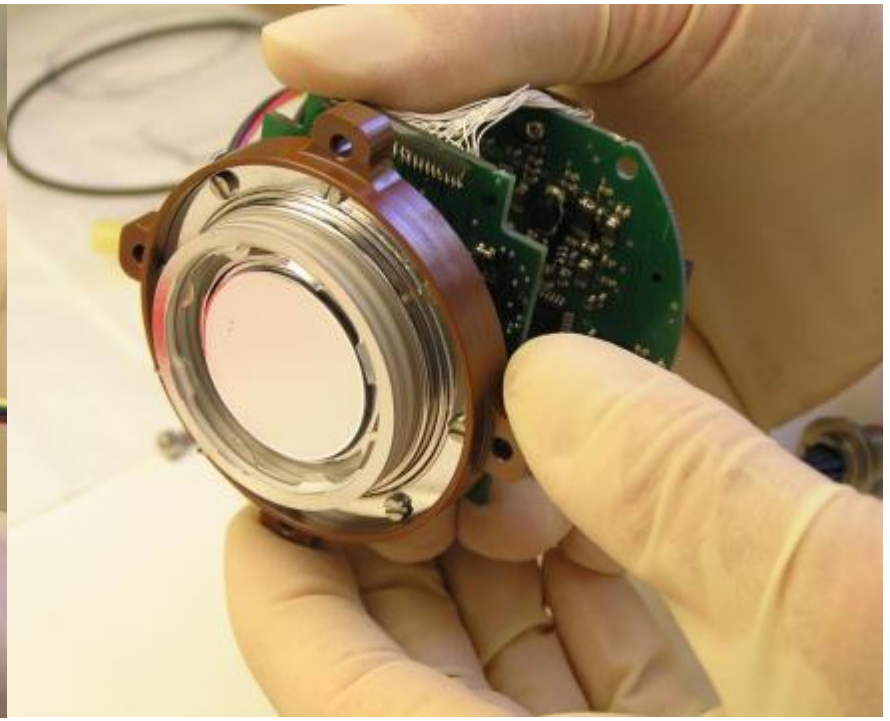
# VUV / EUV cameras with MCP intensifiers

# Intensified APS



STAR 1000
visible CMOS-APS sensor





MCP stack

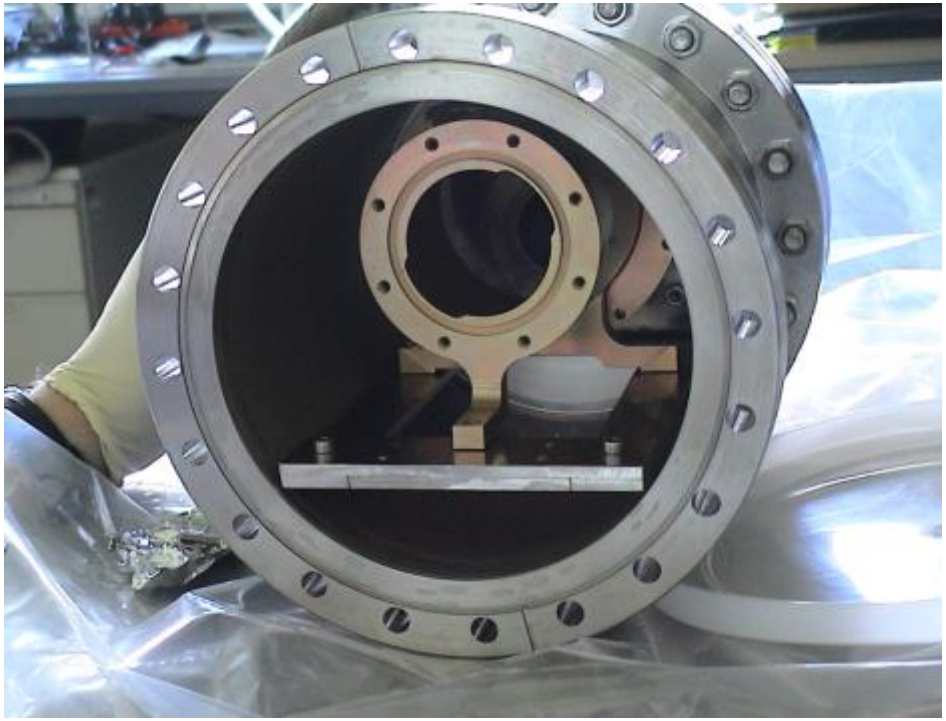
fiber optic blocks

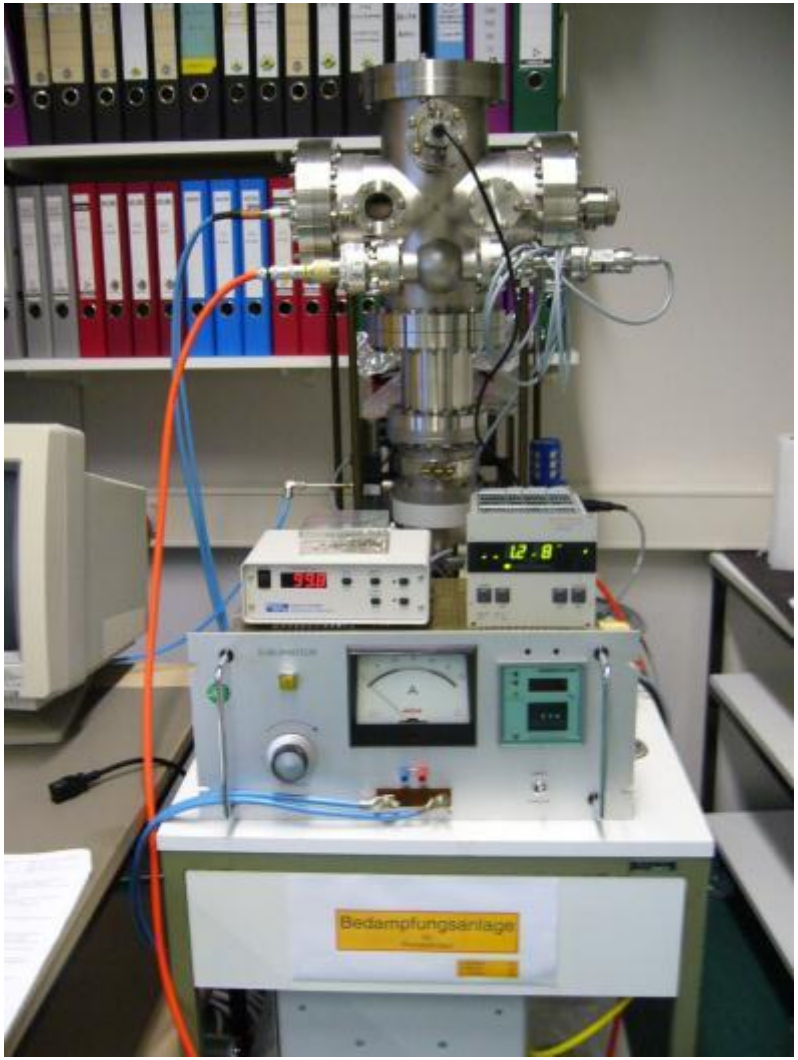
APS sensor board

FEE board

# Photocathode deposition chamber at MPS

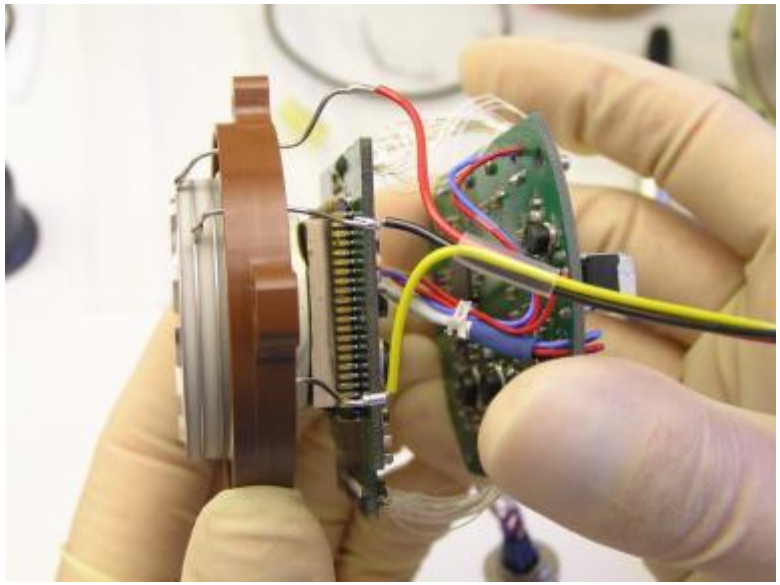
- done deposition of CsI and KBr
up to thickness of 1000 nm
with 1 nm resolution



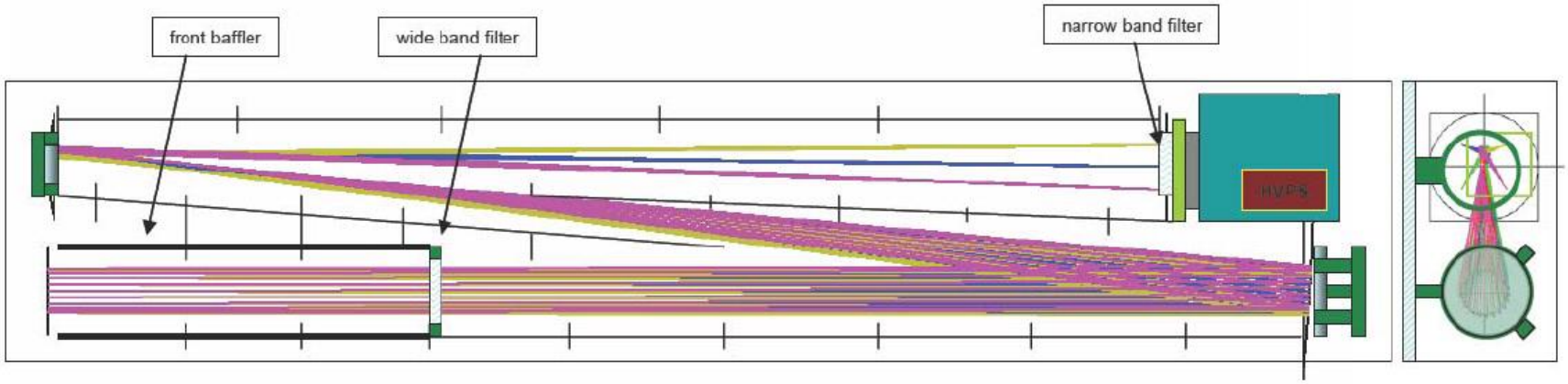


# R&D activities: Development of I-APS detector

- intensifier based on microchannel plates with KBr photocathode coating
- coupling with active pixel sensor (APS)
- APS electronic readout circuitry
- space qualification: vibration, acoustic, thermal, radiation hard

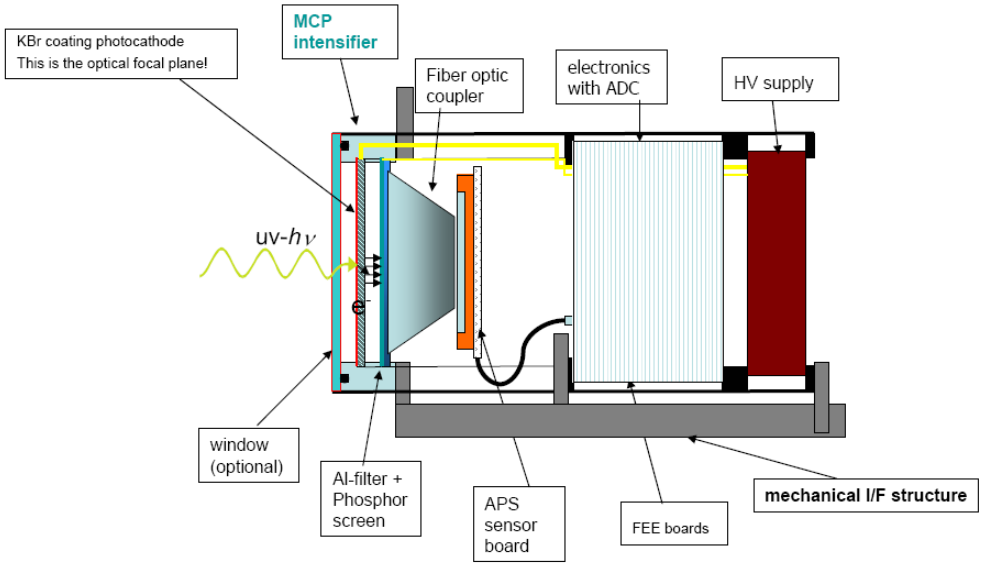


# Solar Orbiter EUI $HRI_{Ly\text{-}\alpha}$ detector




The Lyman-$\alpha$ detector:

a solar-blind intensified CMOS/APS camera



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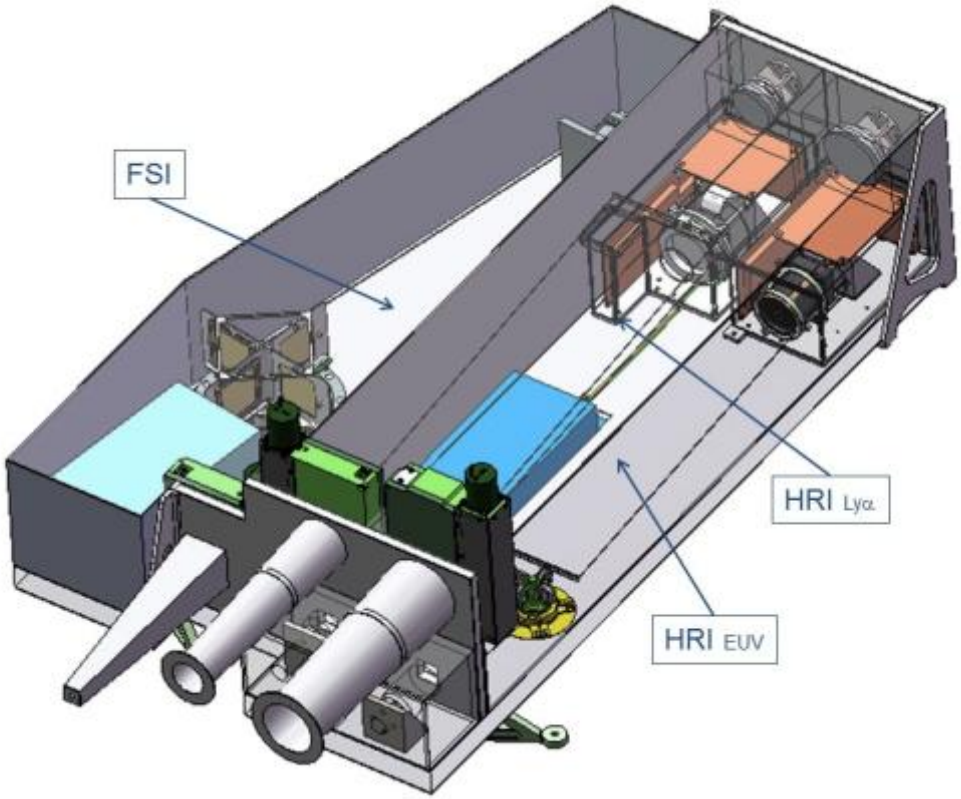
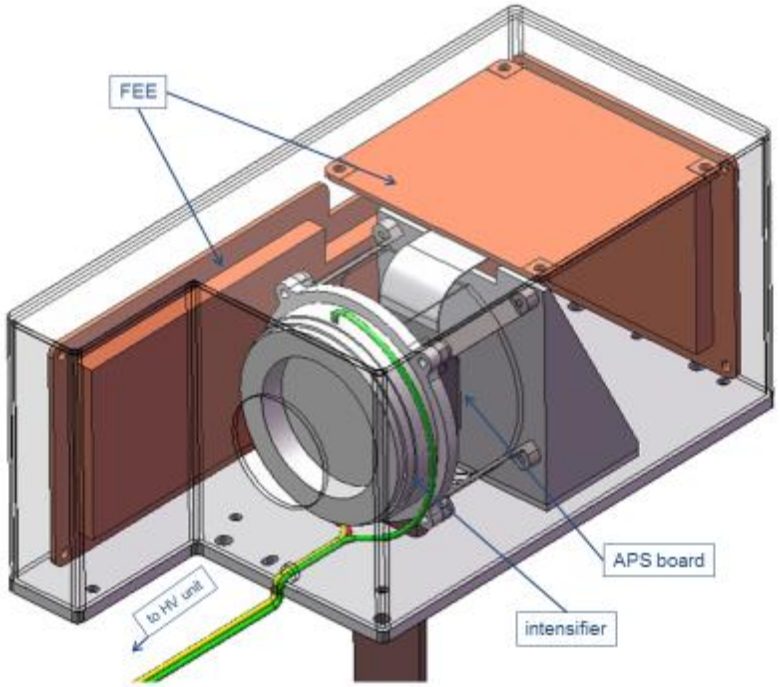
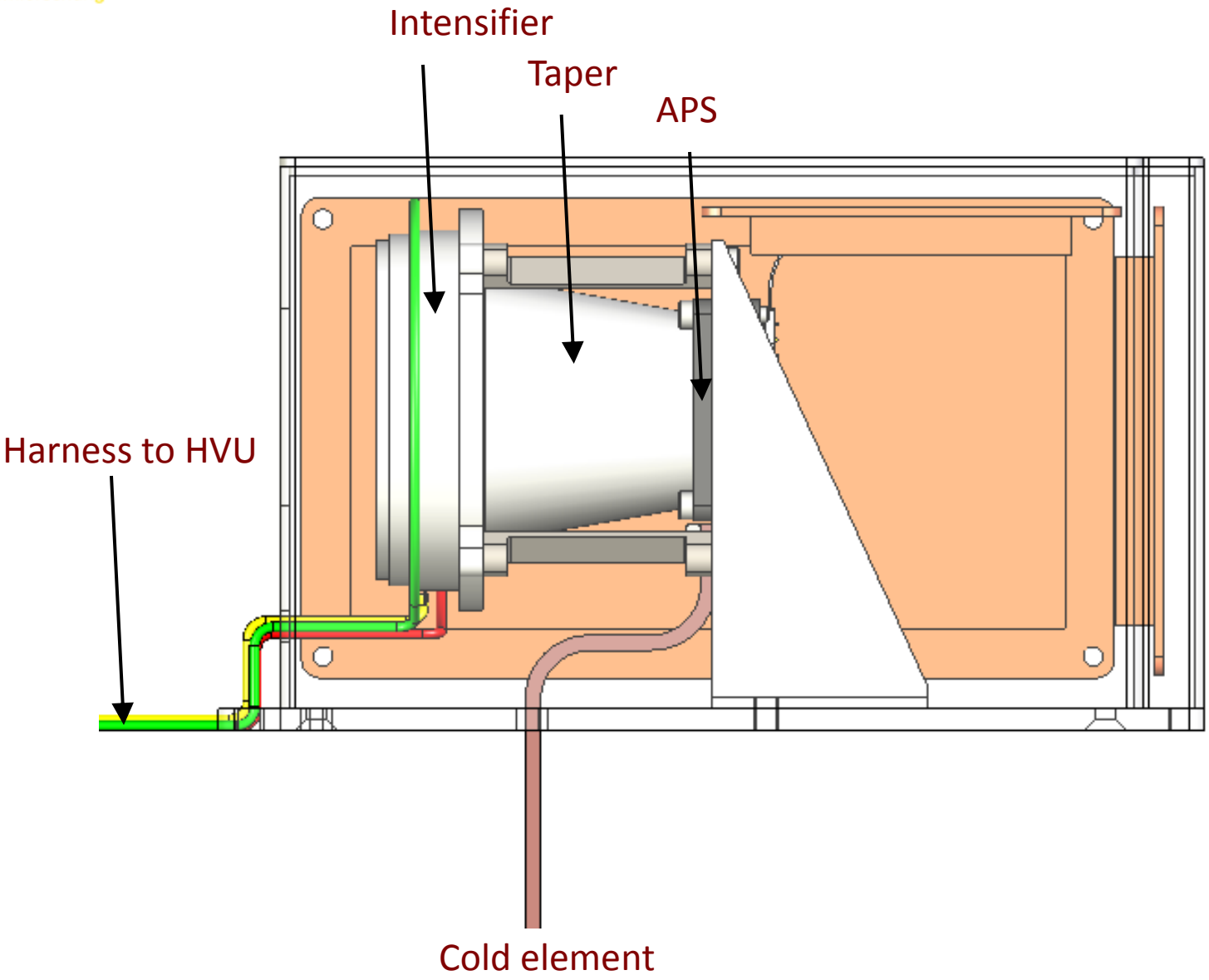
# EUI camera



# EUI camera



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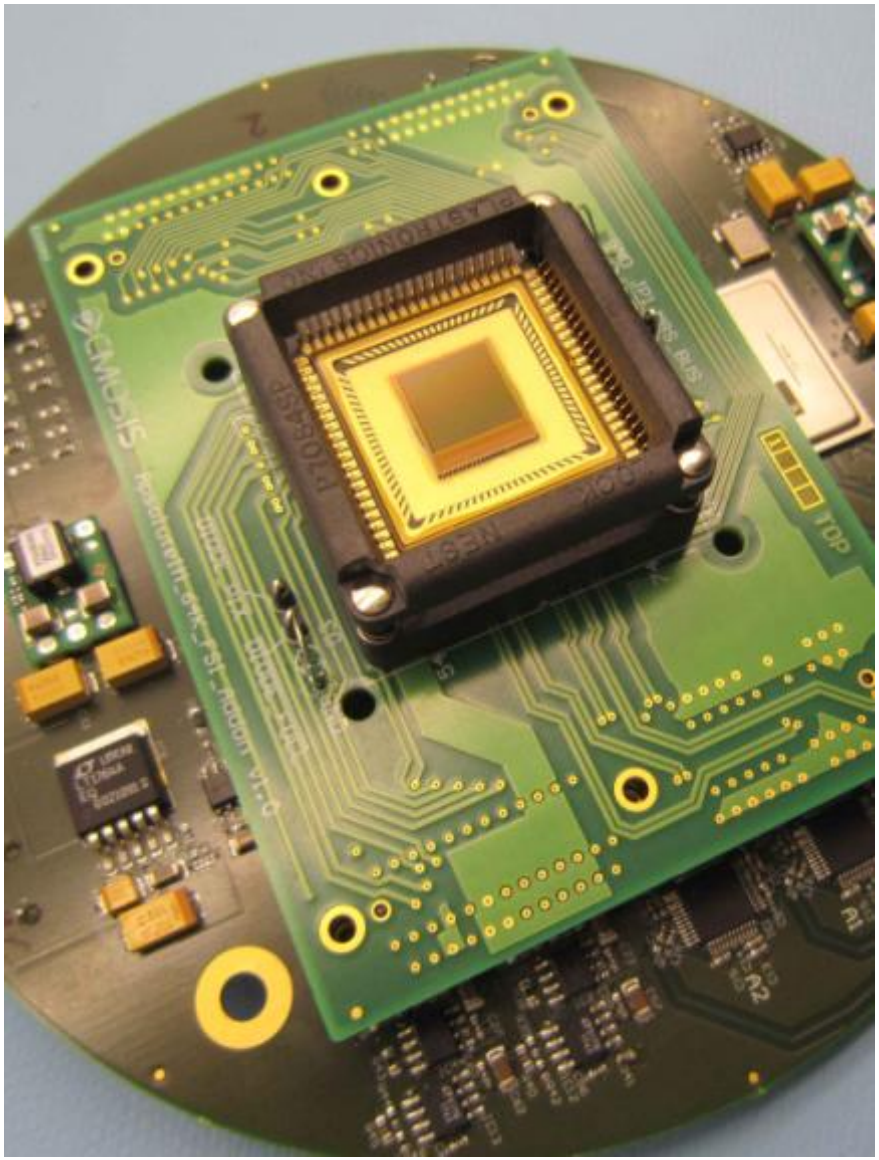
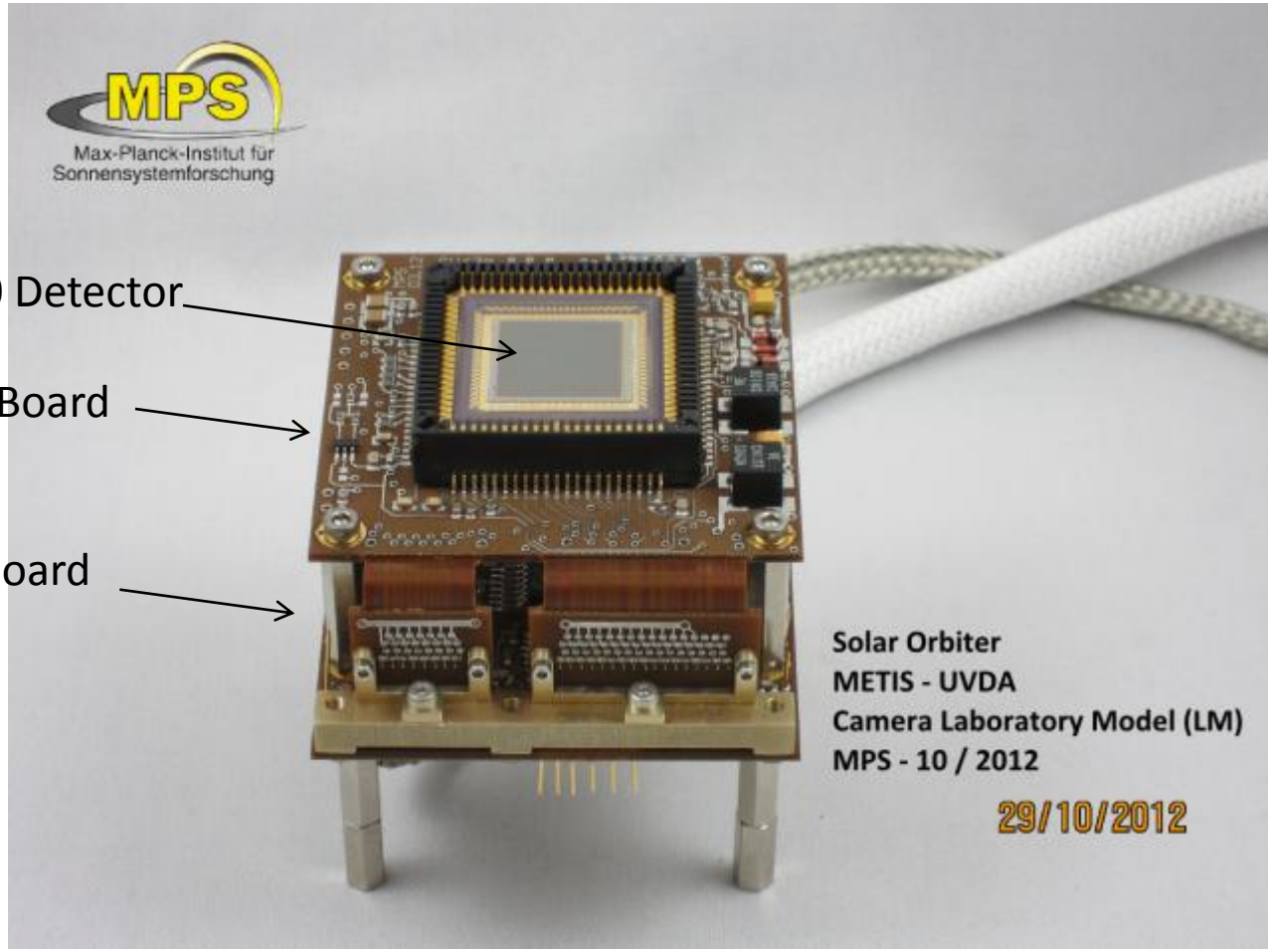
APSOLUTE sensor prototype
developed by CMOSIS

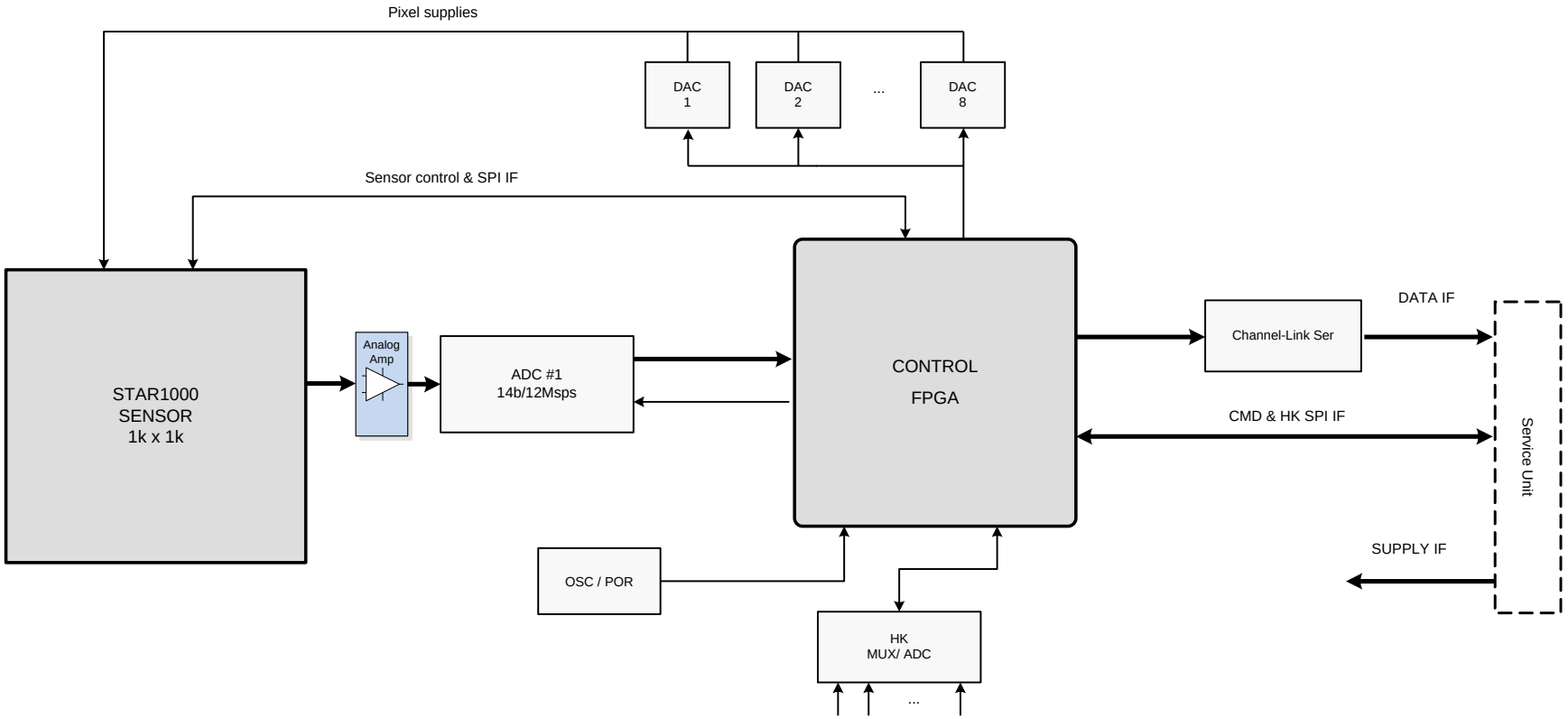



intensifier prototype
developed by PROXIVISION
(KBr photocathode)

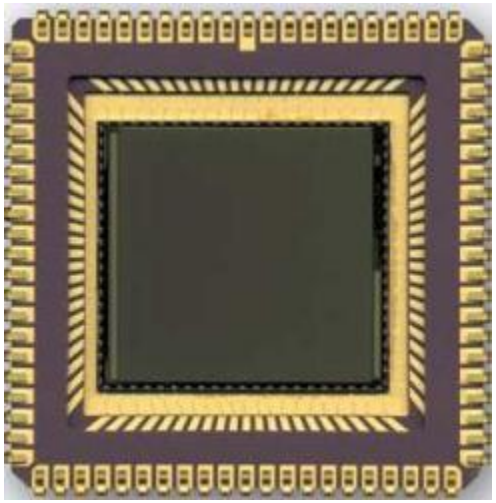
# METIS UVDA Camera Electronics



# METIS UVDA Camera Electronics: Block Diagram



# METIS UVDA Camera Electronics: STAR-1000 sensor



1k x 1k
15 x 15 µm²

| Parameter | Specification | Notes |
|---|---|---|
| Detector technology | CMOS Active Pixel Sensor | |
| Pixel structure | 3-T active pixel | Rad tolerant pixel design |
| Sensitive area format | 1024x1024 pixels | |
| Pixel size | 15x15 $\mu m^2$ | |
| Pixel output rate | 12 MHz | |
| Windowing | x- and y- addressing<br>random programmable | |
| Electronic shutter | Rolling shutter, Range 1:1024 | |
| Total dose rad. tolerance | > 250 krad/Si | |
| Proton radiation tolerance | ≥ 2.4 x $10^{11}$ proton/$cm^2$ @60 MeV | |
| SEU tolerance | >127.8 MeV $cm^3$ $mg^{-1}$ | |
| Spectral range | 400 – 1000nm | |
| Quantum efficiency x fill factor (450 to 750nm) | ≥ 30% | |
| Full well charge | 135.000 $e^-$ | |
| Linear range (within 1%) | 95 $ke^-$ | |
| Supply voltage | 5V | digital inputs are 3.3V compatible |
| Lid | Windowless | |

Proton DD: Quantum efficiency losses (~35% red) !

# METIS UVDA Camera Electronics

14-Bit ADC,  ENOB = 11.5 Bits, 69.2 dB dynamic range (DR)

STAR1000 Temporal Noise: ~1.2mV -> 9.2DN @14 Bit : ~65 dB DR

-> dynamic range of camera electronics: > 65 dB

- Use of external ADC
- Improved cleanliness of voltage supplies
- Adjustable detector voltages
- Optimized PCB layout
- Optimized ADC sampling (pipeline delay adjustable)
- Use of Space qualified parts while maintaining perf.
- Data transfer using Gray Code

# METIS UVDA Camera Electronics: Power Supply Requirements

| Supply Voltage ID | Nominal Level [V] | Tolerance | Ripple | Maximum Rise Time [ms] | Nominal Current [mA] | Peak Current (<5ms) | Input Capacitance [µF] |
|---|---|---|---|---|---|---|---|
| VCCI | 5.15 | ±5% | <1% | ≤50 | 123 | TBD | 130 |
| VSSI | -5.15 | ±5% | <1% | ≤50 | 82 | TBD | 15 |
| VCCD | 3.3 | ±5% | <1% | ≤50 | 76 | TBD | 30 |
| VCCA | 2.5 | ±5% | <1% | ≤50 | 83 | TBD | 15 |

# METIS UVDA Camera Electronics: Power & Mass

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## Power (measured on LM):

| | Unit | +5.15V ($V_{CCI}$)* | -5.15 V ($V_{SSI}$)* | +3.3 V ($V_{CCD}$) | +2.5 V ($V_{CCA}$) | Total Power (W) | Power incl. 20% contingency |
|---|---|---|---|---|---|---|---|
| **12 MHz Stand-by** | mA | 102 | -68 | 63 | 69 | 1.26 | 1.51 |
| | mW | 525.3 | 350.2 | 207.9 | 172.5 | | |

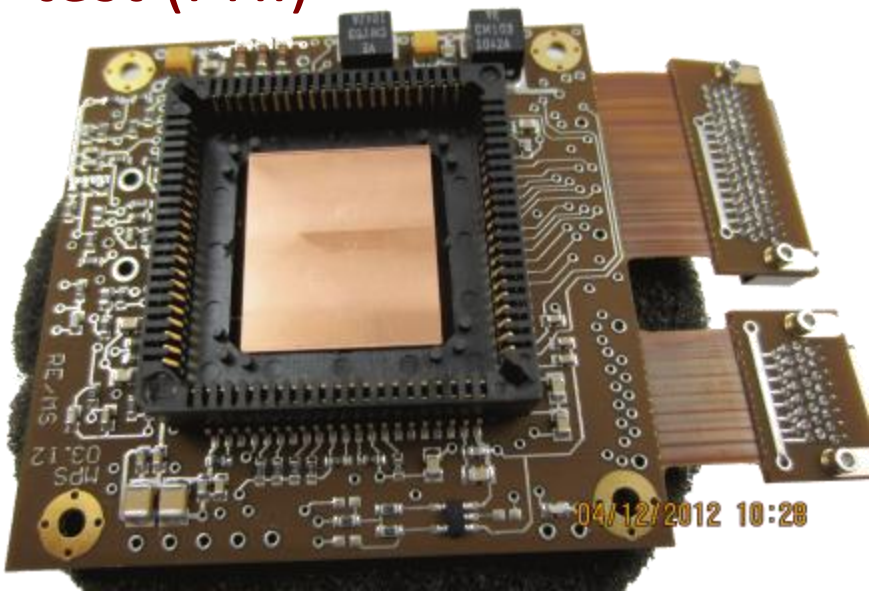
## Mass (measured on LM):

| Item: | Mass [g]: | Remark: |
|---|---|---|
| Sensor Board (incl. Sensor) | 48 | |
| FPGA Board (incl. FPGA) | 70 | |
| Cold Finger (copper stamp) | 29 | |
| Total incl. 10% contingency: | 161.7 | I/F harness not included ! |

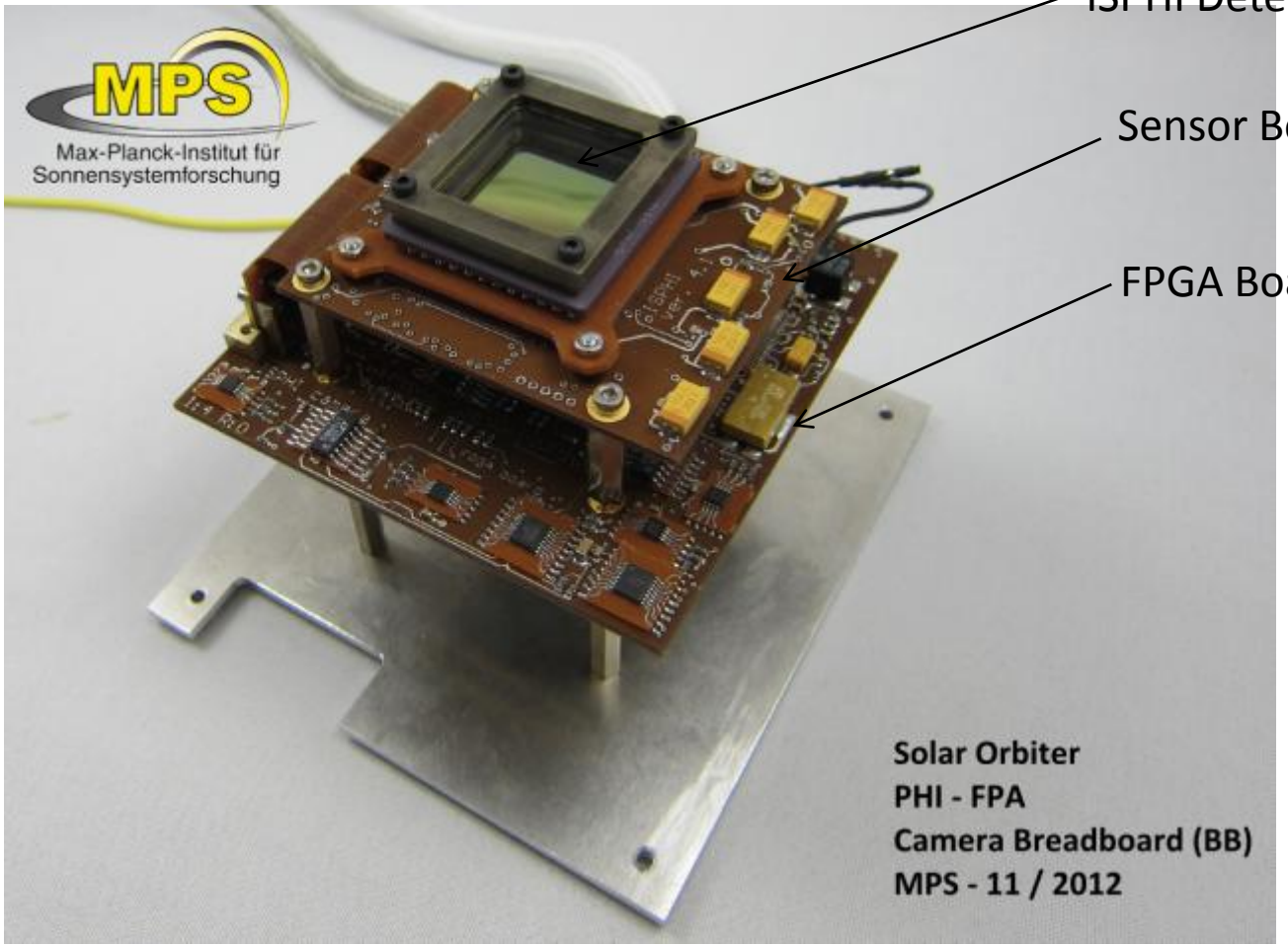
# METIS UVDA Camera Electronics

- radiation tolerant design (SO Specs.)
- channel link LVDS I/F
- LM – working, electrical testing in progress
- Cold Finger concept under test (PHI)
- planned LM delivery:

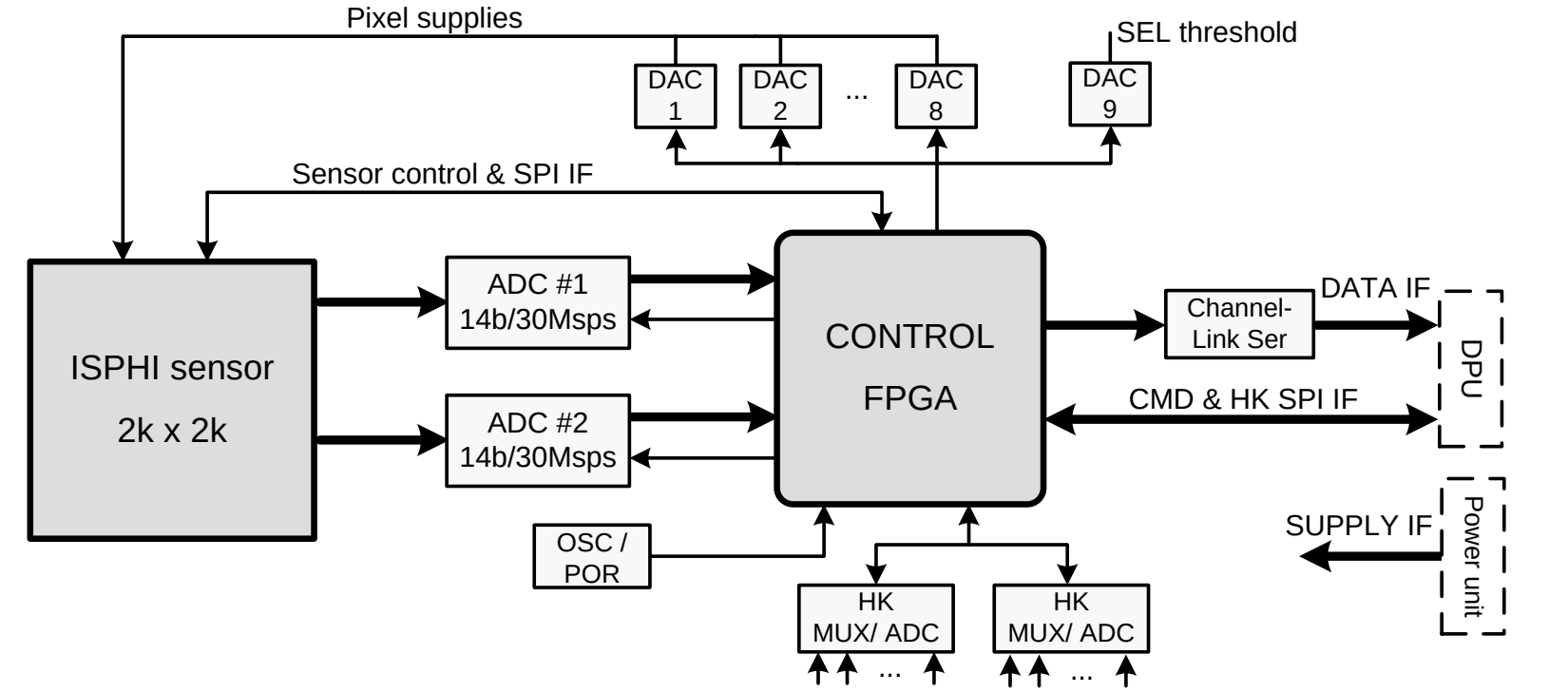
  End of Jan. 2013



# SO-PHI FPA Camera



# ISPHI FPA block diagram



# SO-PHI FPA Camera

- 2kx2k ISPHI sensor 10 fps readout
- channel link high speed LVDS I/F
- radiation tolerant design (SO Specs.)
- BB model ready, tested in TV
- external power supply – clean supply mandatory for performance !

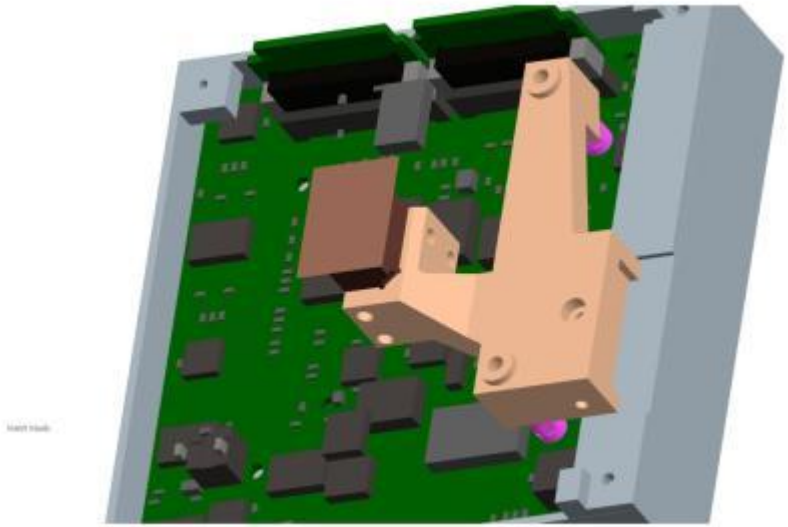
# SO-PHI FPA Camera: Power and Mass

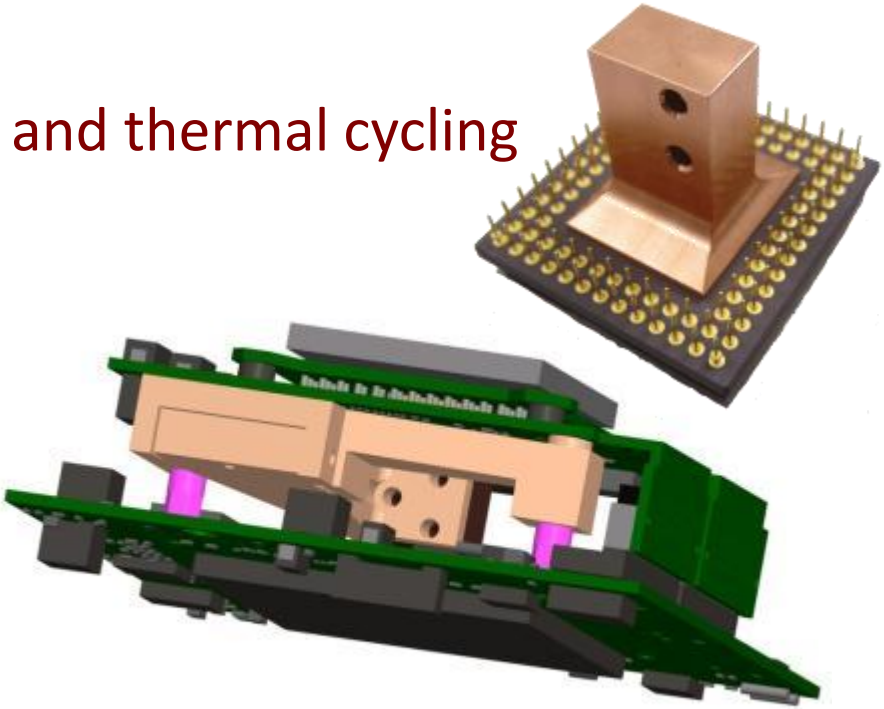
| | Unit | +5.15V ($V_{CCI}$)* | -5.15 V ($V_{SSI}$)* | +3.3 V ($V_{CCD}$) | +2.5 V ($V_{CCA}$) | +1.5 V ($V_{CCB}$) | Total Power (W) | Power incl. 20% contingency |
|---|---|---|---|---|---|---|---|---|
| 15 MHz Stand-by | mA | 50 | -30 | 170 | 70 | 20 | 1.18 | 1.41 |
| | mW | 257.5 | 154.5 | 561 | 175 | 30 | | |
| 15 MHz Acquiring | mA | 50 | -30 | 240 | 75 | 22 | 1.43 | 1.72 |
| | mW | 257.5 | 154.5 | 792 | 187.5 | 33 | | |
| 30 MHz Stand-by | mA | 50 | -30 | 180 | 80 | 34 | 1.26 | 1.51 |
| | mW | 257.5 | 154.5 | 594 | 200 | 51 | | |
| 30 MHz Acquiring | mA | 50 | -30 | 280 | 90 | 36 | 1.62 | 1.95 |
| | mW | 257.5 | 154.5 | 924 | 225 | 54 | | |

| Item: | Mass [g]: | Remark: |
|---|---|---|
| Sensor Board | 64.2 | |
| FPGA Board | 37.5 | |
| Cold Finger (copper stamp) | 70 | |
| Total: | 171.7 | |

# SO-PHI FPA Camera: Cold Finger Concept

- Copper stamp glued to sensor back
- Interface to instrument cold finger has to provide mechanical and thermal stress relief
- design under test at MPS in TV and thermal cycling

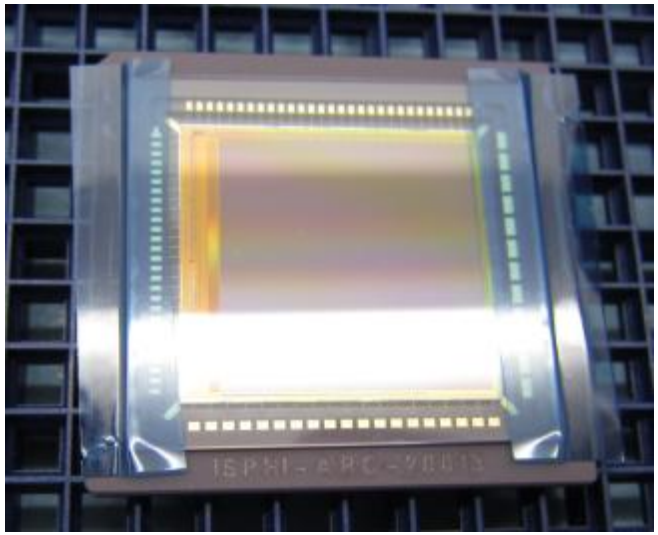




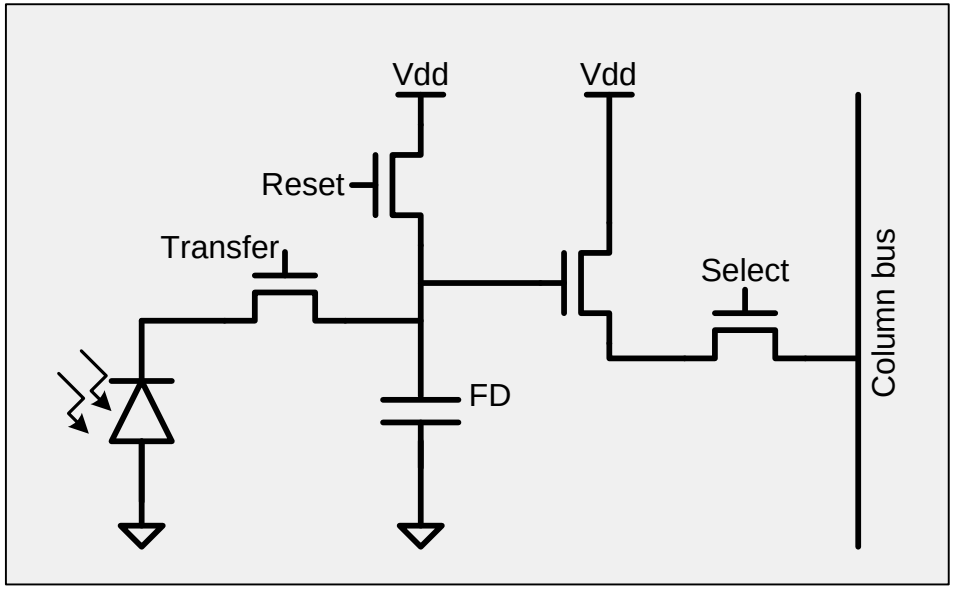
# CMOSIS ISPHI Rev. B

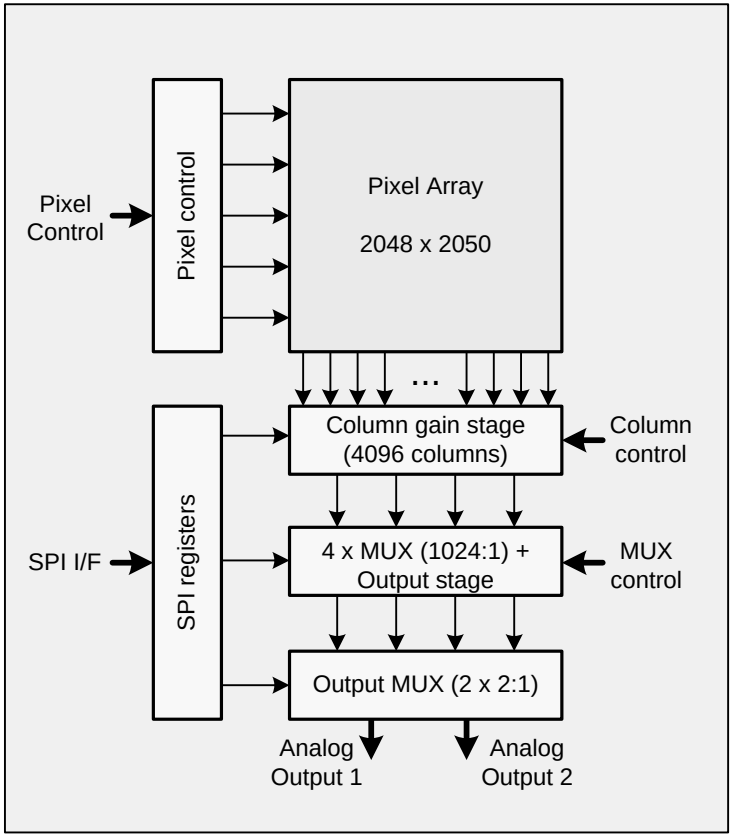
APS 2k x 2k, two analog outputs,
30 MHz 10 fps high speed readout, rolling shutter
no windowing capability in rows !

| **Parameter** | | Value |
|---|---|---|
| Frame rate | fps | 10 |
| Full Well | $ke^-$ | (60) 90 |
| Dark noise @ RT | $e^-$ | 57 |
| Dark current (293 K) | $e^-/s$ | 90 (TBC) |
| Sensitivity (617nm) | % | 42 – 60 |
| Non-linearity | % | < 2 |
| PRNU (local) | % | 1.4 |
| Power consumption | mW | 500 |

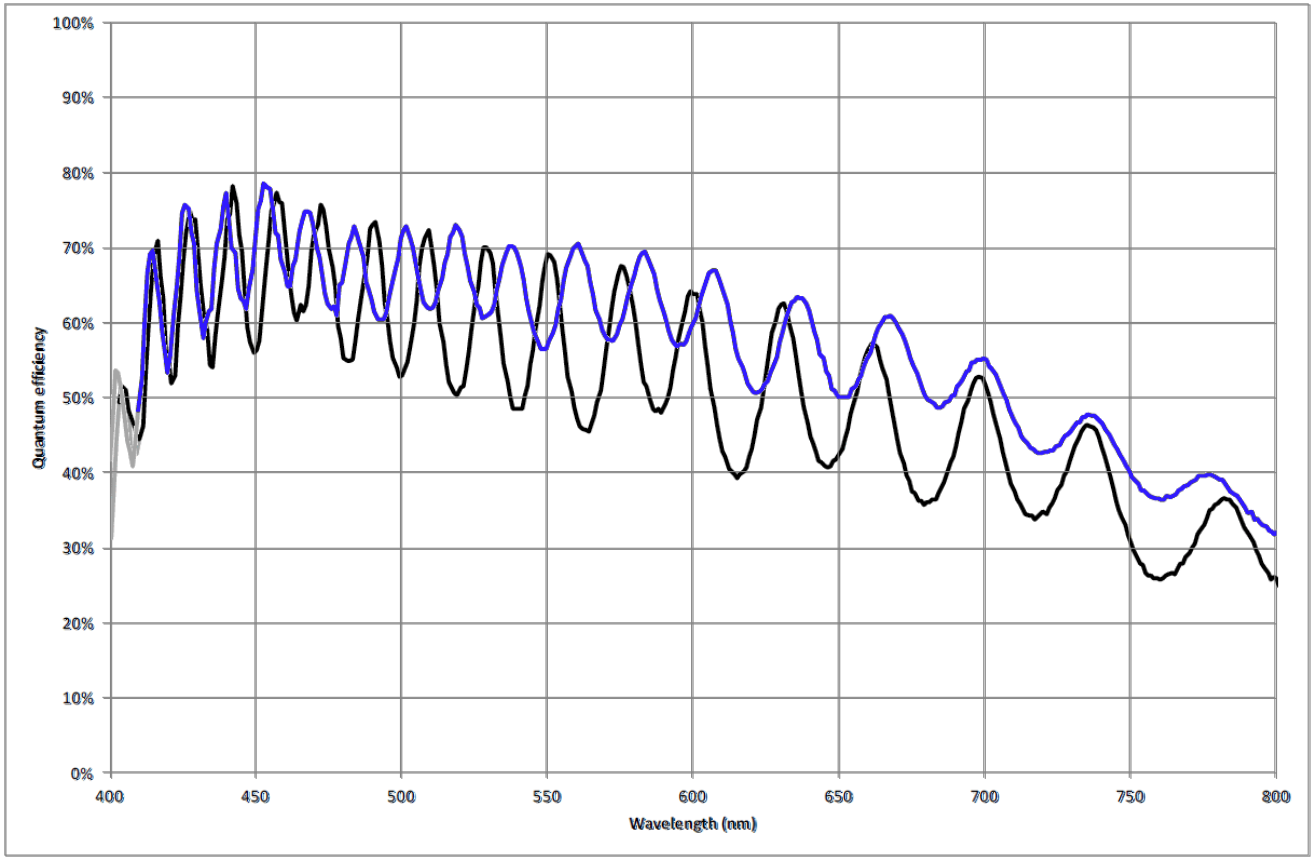


# ISPHI Pixel architecture



# ISPHI: Quantum Efficiency




- Spectral and spatial fringing due to interferences on dielectric stack on top of the photodiode
- ARC coating is applied on Rev. B devices for improvement (blue)

# CMOSIS ISPHI Radiation Tests

- Radiation tests performed
  - Total Ionizing Dose up to 154 krad(Si)

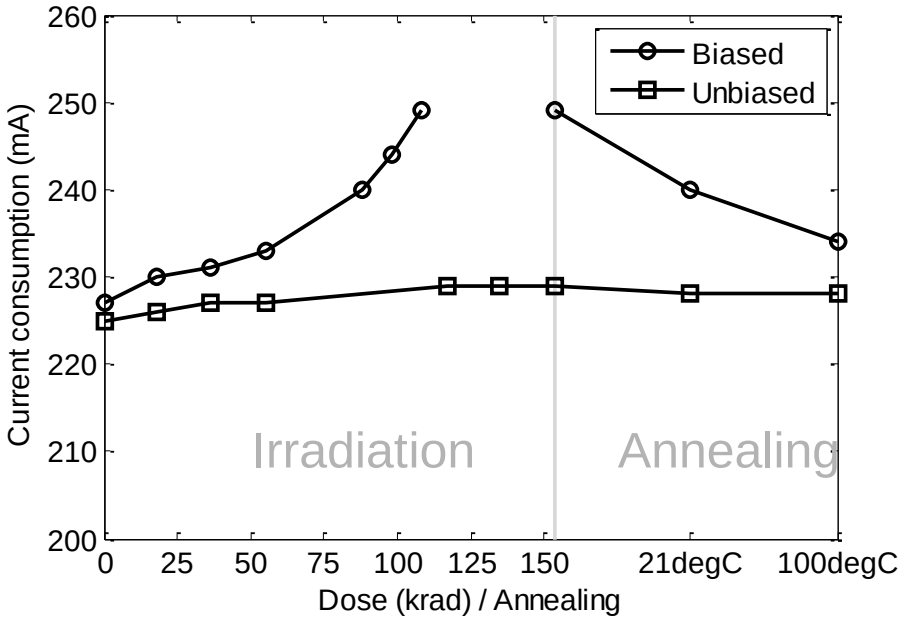
  CRC, Lovaine-La-Neuve, Aug. 2011
  - Displacement Damage at 10, 15, 20 MeV (4 $10^{11}$ $p^+/cm^2$)

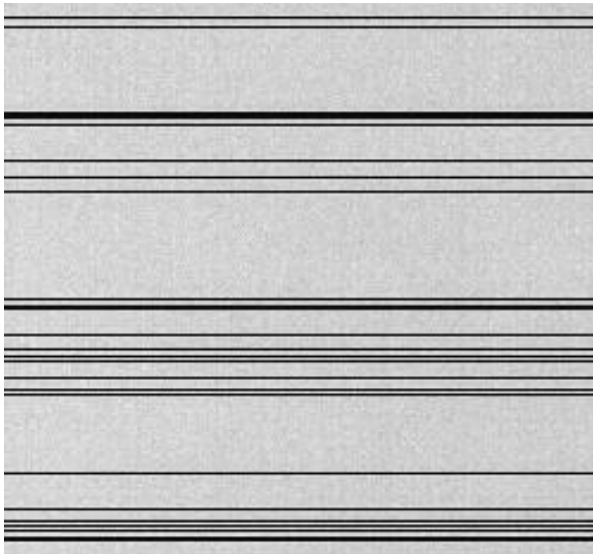
  LIF, IPNAS Liège, Nov. 2011
  - Single Event Effects pre-assessment with Californium-252

  ESA/ESTEC, Summer 2012

# ISPHI: TID radiation tests results

- Sensor is radiation tolerant up to 75 krad(Si)
- Minor degradation on dark current, dark current non-uniformity, consumption and sensitivity
- Annealing helps recovering affected parameters

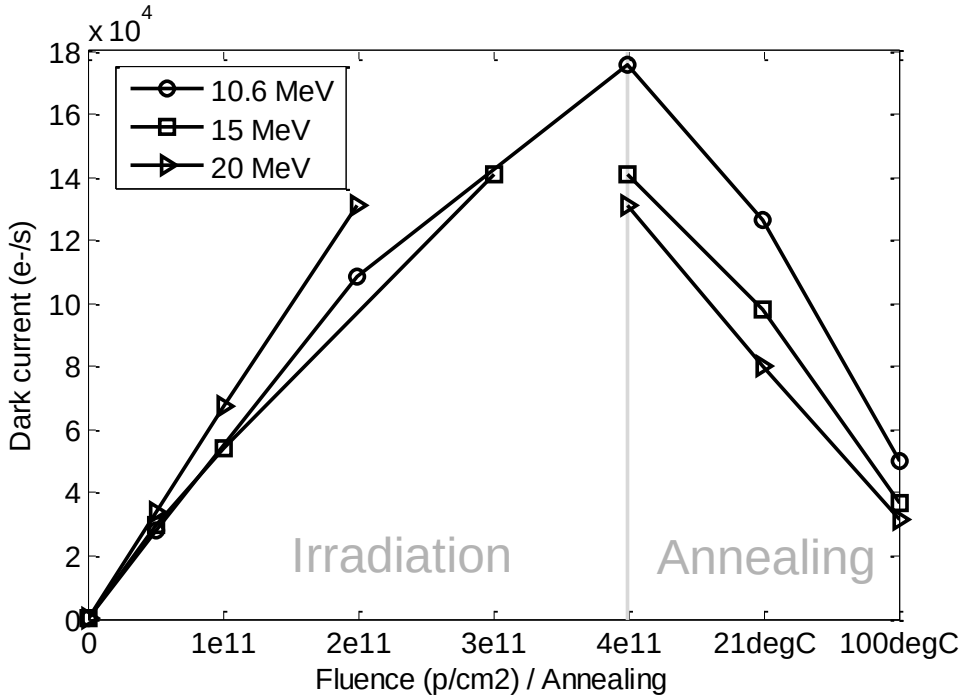


row defects above 75 krad(Si)

# ISPHI: Proton DD radiation tests results

- Permanent damage on 2 parameters
  - Dark current and Dark current non-uniformity
- Temporal damage on sensitivity, PRNU and consumption



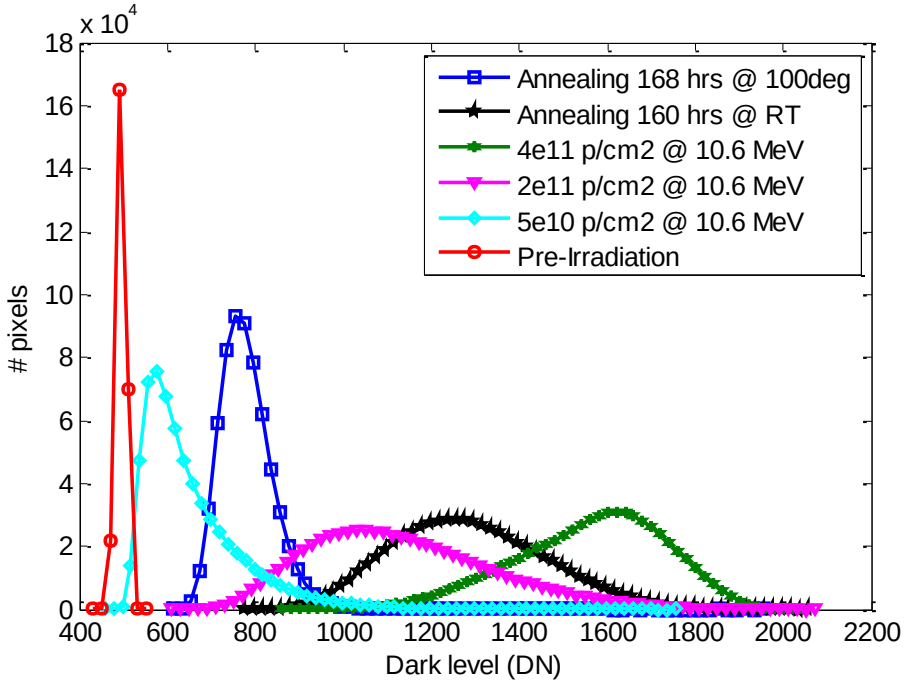

200 → $10^5$ → 5 $10^4$ $e^-$/s

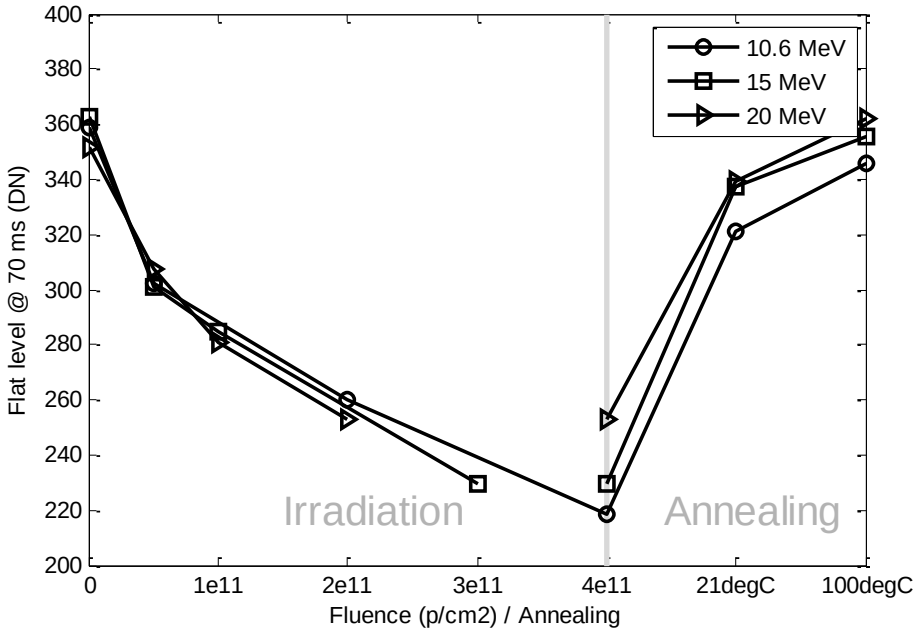
To deal with it:

- Lower temperature
- Short exposures
- Annealing helps
- Exp. lower fluence

# ISPHI: Proton DD radiation test results

- DC, Dark current non-uniformity and sensitivity after DD



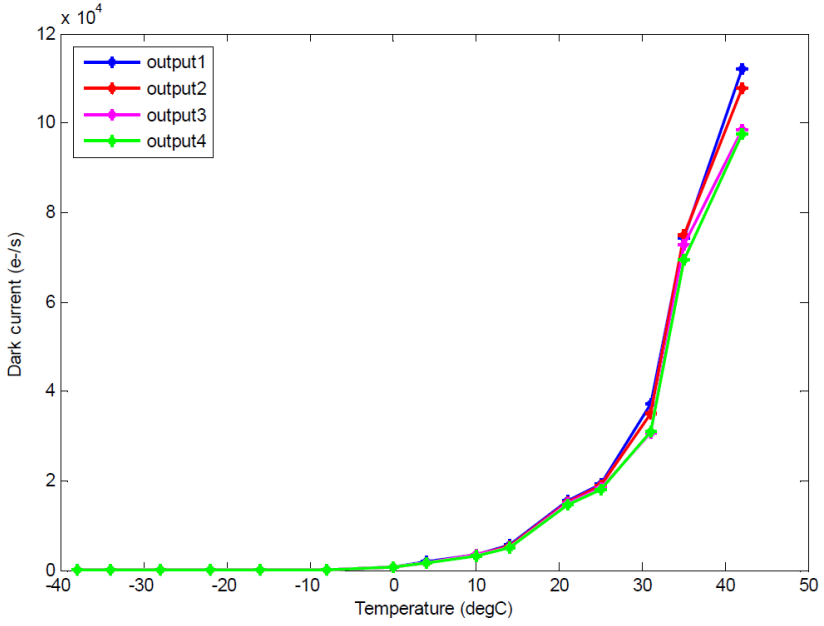

# SEE radiation test results

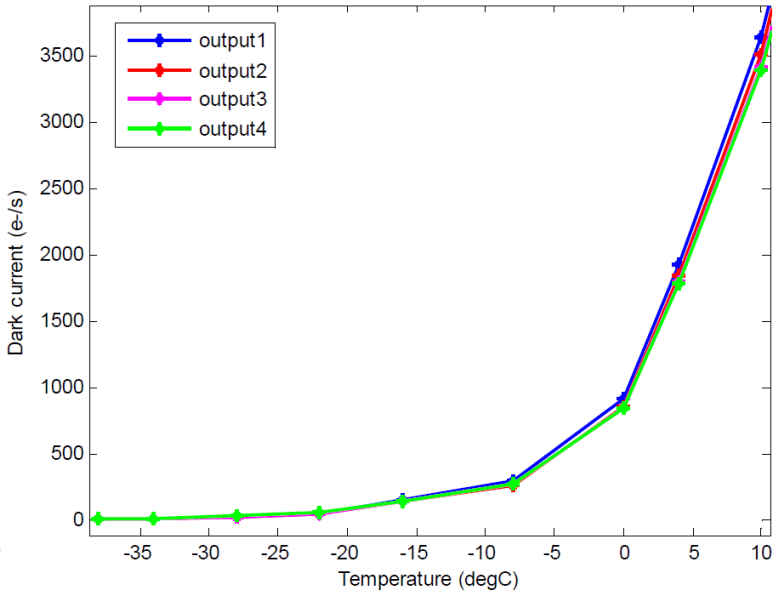
- Cf-252 allows pre-assessment of sensor SEE tolerance
  - Low penetration depth
- No latch-up occurred
- Seven single event upsets were detected
  - Sensor registers are not duplicated
  - Automatic recovery system of FPA electronics tested

- Heavy Ions test planned for Q1/2013

# ISPHI Dark Current vs. Temperature

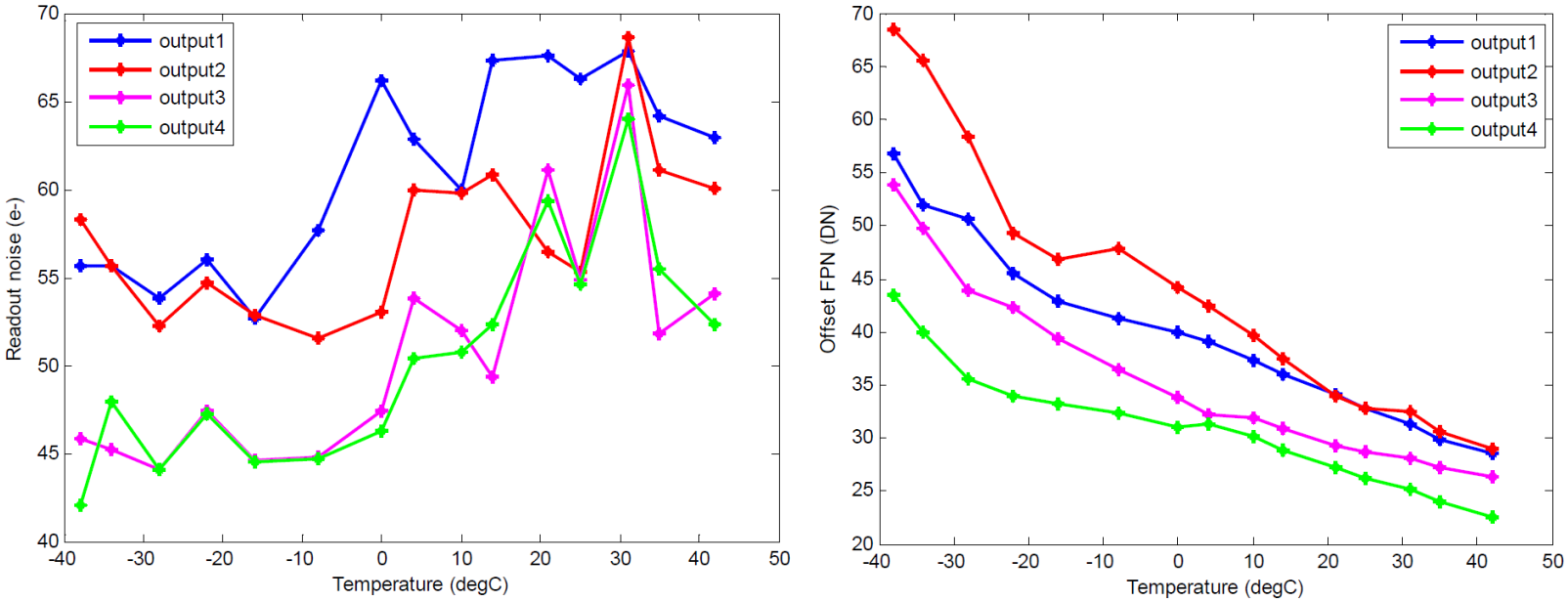
| Temperature | -28 | -8 | 0 | 25 | 40 |
|---|---|---|---|---|---|
| Dark current ($e^-$/s): Post Irradiation | 30 | 272 | 847 | 17980 | 97470 |
| Pre Irradiation | | | | 254 | |




Dark current vs. Temp. ISPHI 10029 a´fter irradiation (10.6 MeV, 4x10$^{11}$ p/cm$^2$, 213.2 krad [Si]$^2$ TiD)

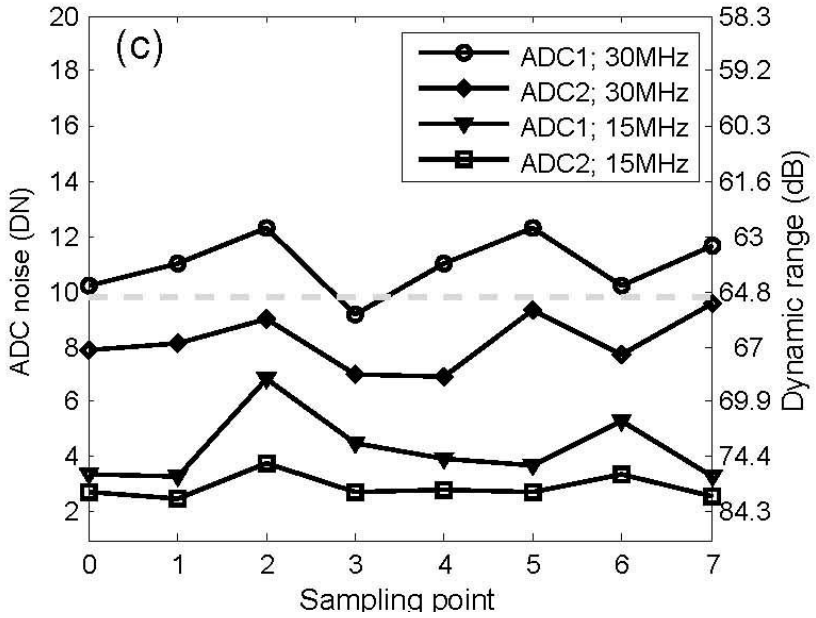
# ISPHI Readout Noise and FPN vs. Temp

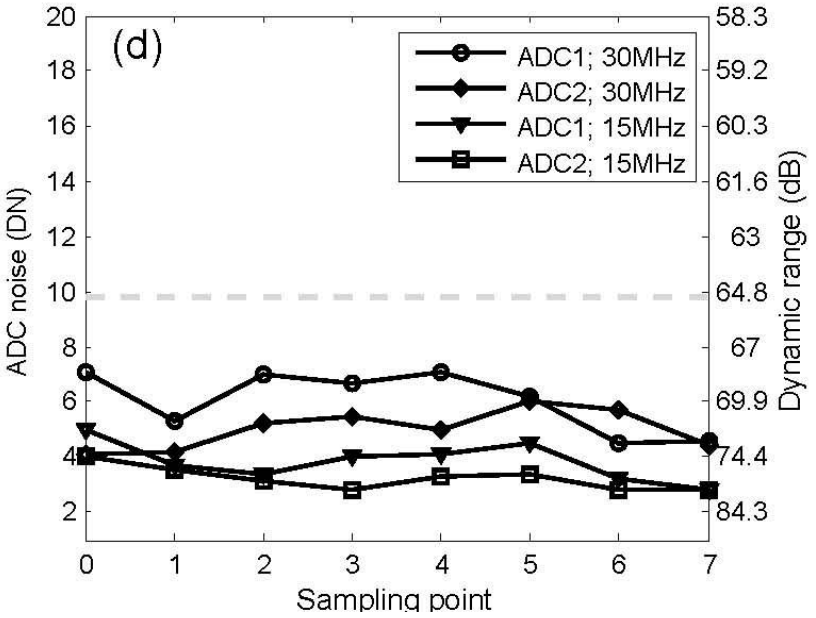



Readout Noise and FPN, ISPHI 10029 after irradiation (10.6 MeV, $4x10^{11}$ p/cm$^2$, 213.2 krad [Si]$^2$ TiD)

# Digitization noise

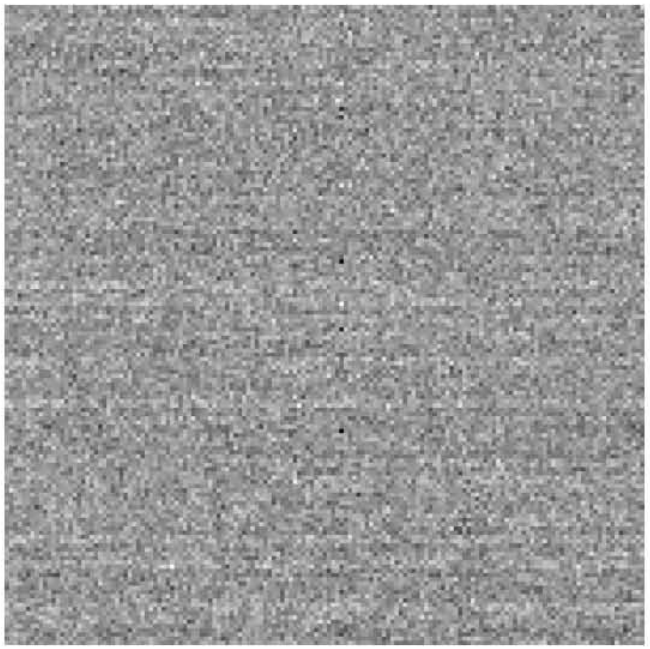
- Applying fixed input voltages to the ADCs
  - (c): Prototype after removal of interference pattern
  - (d): BB camera



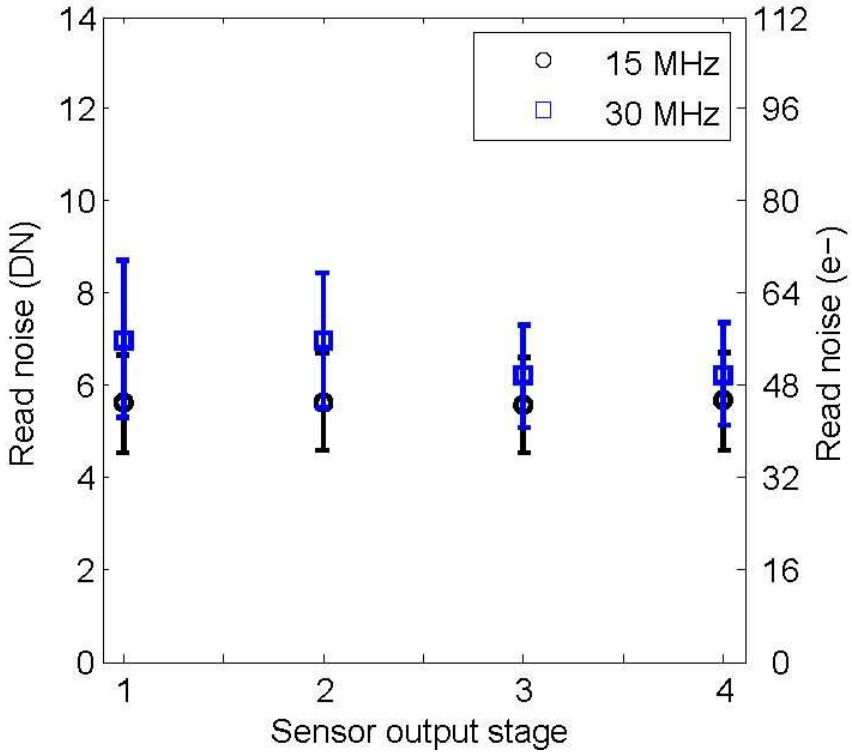



# Overall dark noise

- Including ISPHI and camera electronics

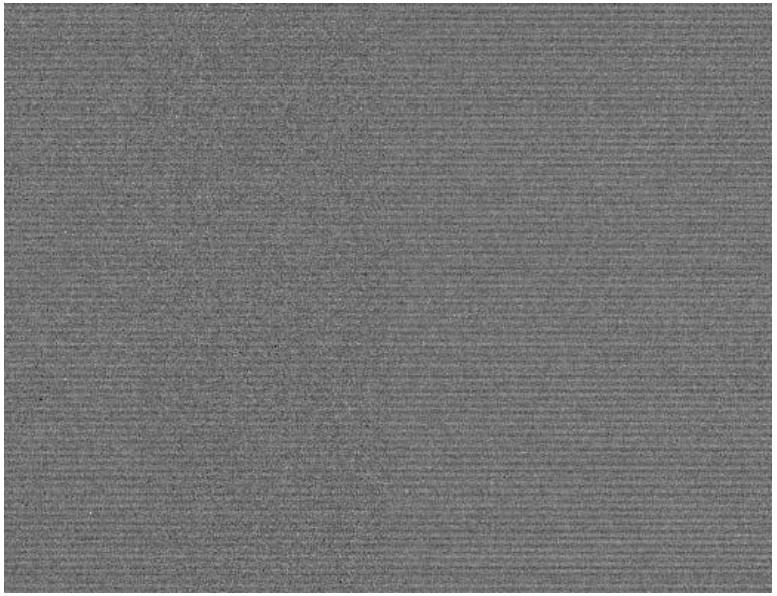


Dark image:
- Shortest exposure
- Subwindow




Total read noise versus output and operating frequency

# Dark noise and offset FPN



- Differential dark image

  FPN is removed

| | | Output 1 (DN) | Output 2 (DN) | Output 3 (DN) | Output 4 (DN) |
|---|---|---|---|---|---|
| 1 | Offset FPN | 19.1963 | 17.7866 | 16.858 | 16.6184 |
| 2 | Mean dark noise | 7.0072 | 6.9701 | 6.1966 | 6.2409 |
| 3 | Error bar of 2 | 2.432 | 1.8668 | 1.5192 | 1.5002 |

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# Back-up slides

# ISPHIv1: performance

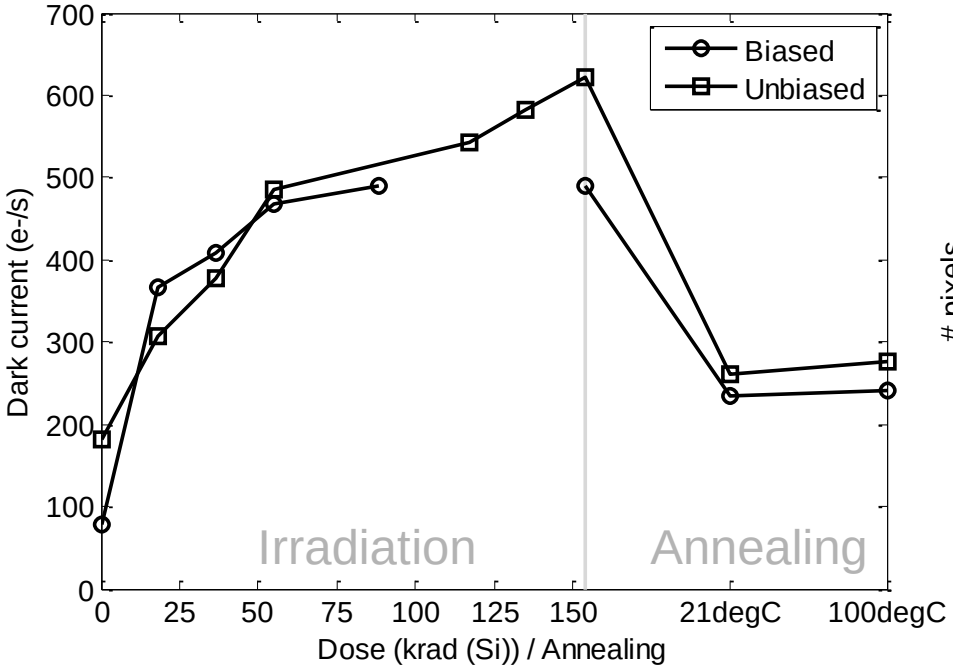
- APS - 2k x 2k on 10 µm$^2$ pixel pitch
- 4T pixel design with rolling shutter

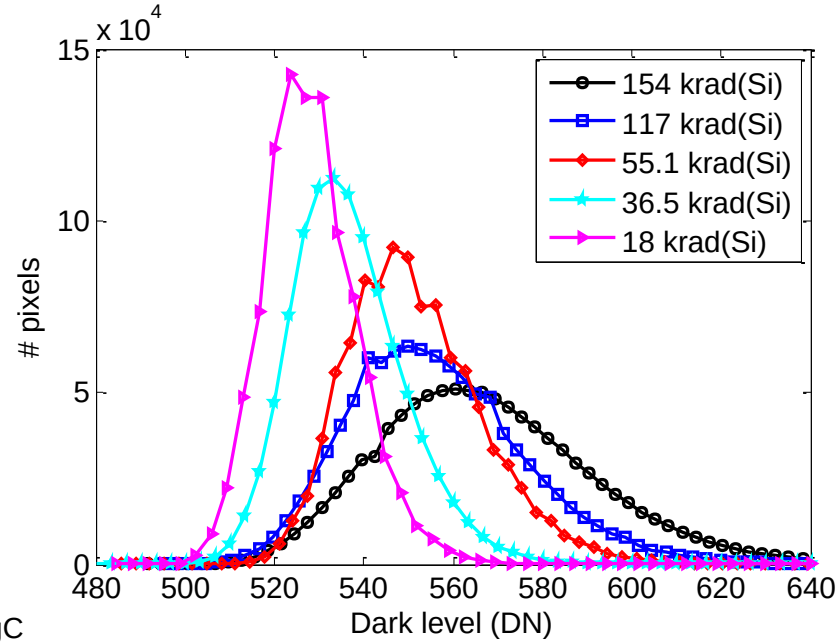
| | | Requirement | Result |
|---|---|---|---|
| Frame rate | fps | > 10 | 11** |
| Full Well | ke$^-$ | > 100 | 60 – 90 |
| Dark noise | e$^-$ | < 100 | 57 |
| Dark current (293 K) | e$^-$/s | < 200 | 90 |
| Sensitivity (617nm) | % | > 50 | 42 – 60 |
| Non-linearity | % | < 2 | < 2 |
| PRNU (local) | % | < 5 | 1.4 |
| Power consumption | mW | < 500 | 480 |

** Ghosting artifacts

# ISPHI radiation test results

- Dark current after TID

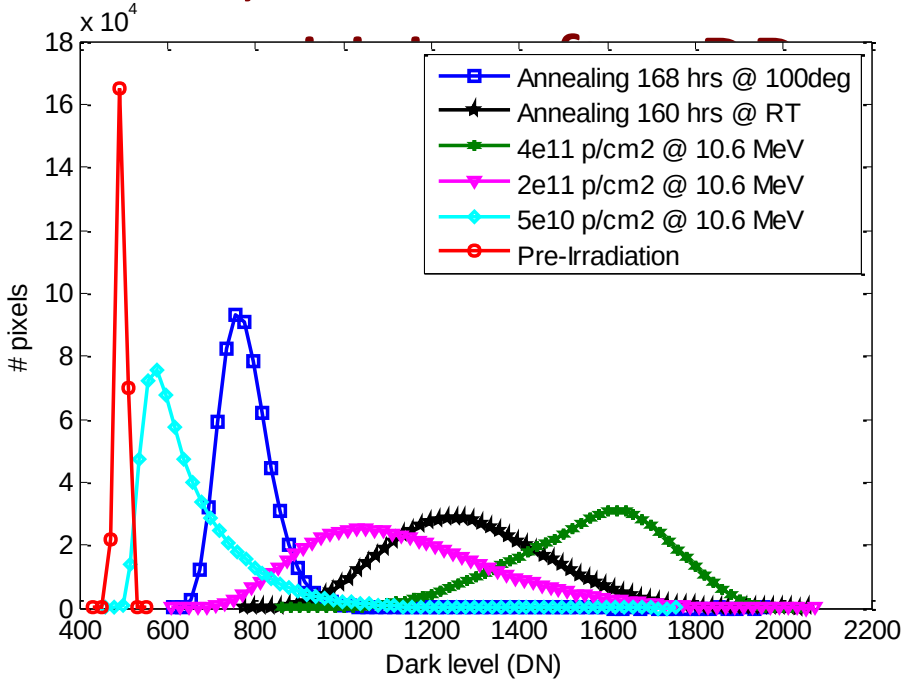


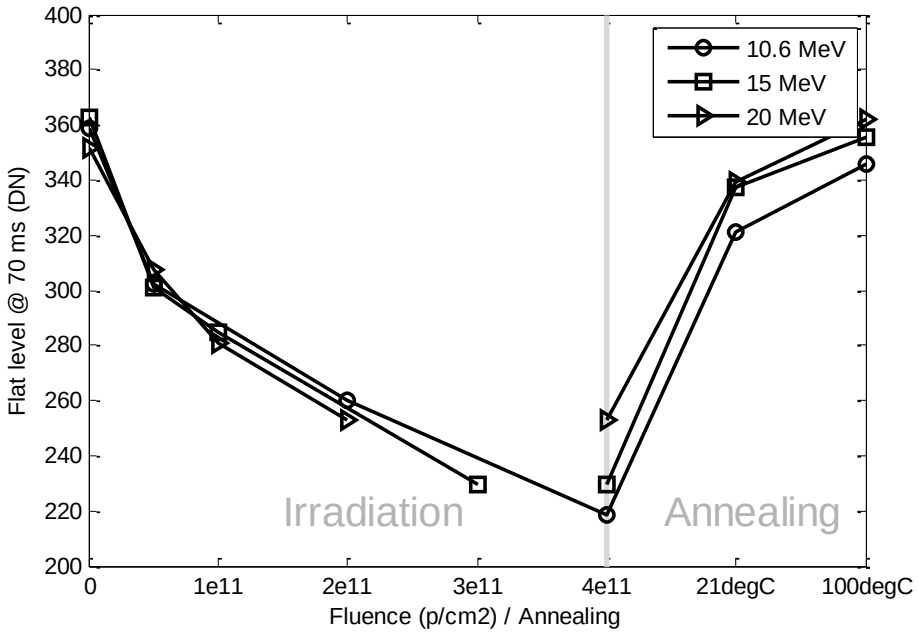




200 → 600 → 280 e-/s

# ISPHI radiation test results

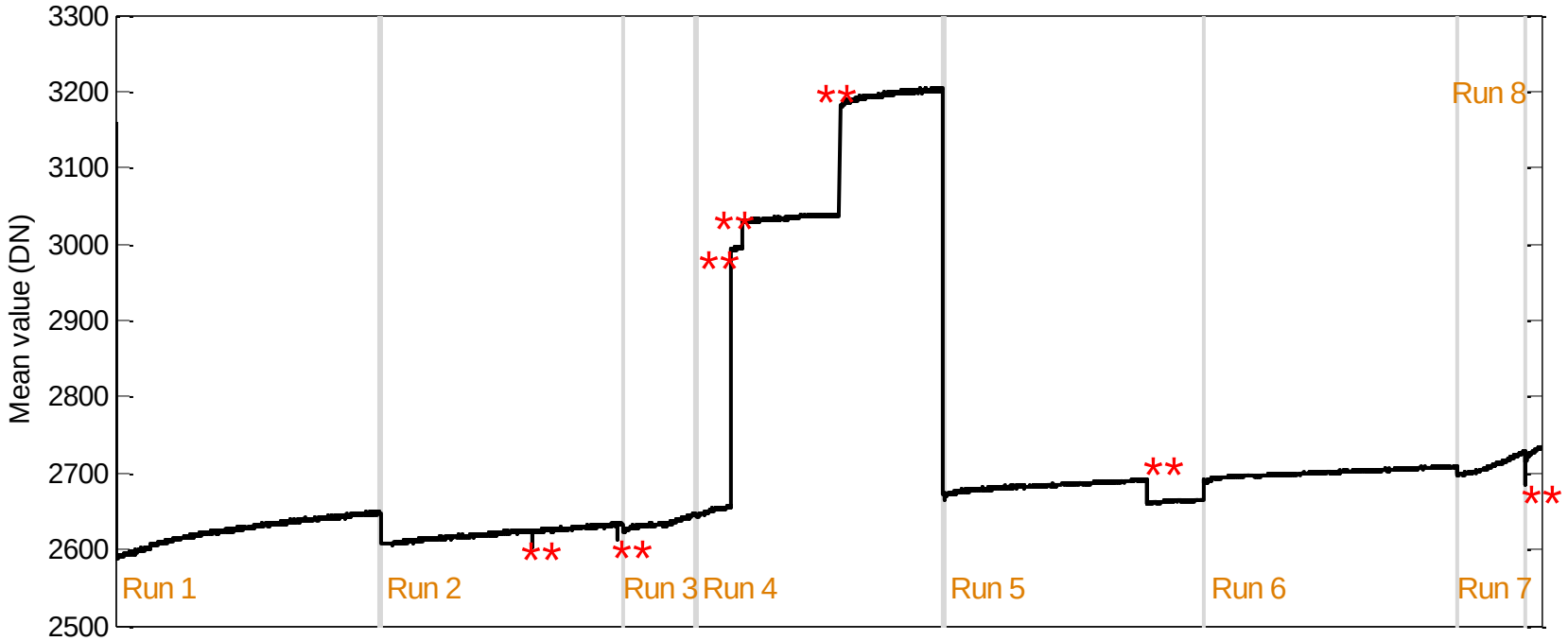
- DC, Dark current non-uniformity and



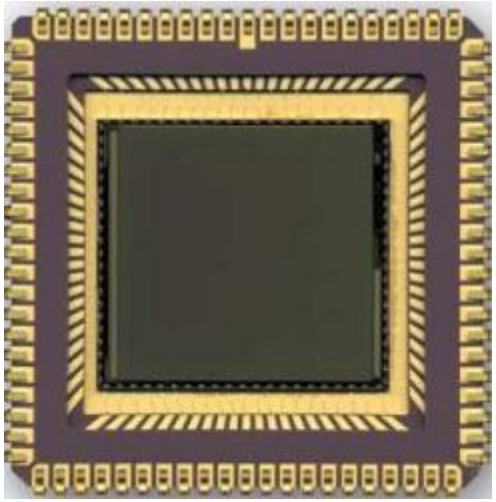




# ISPHI radiation test results

- Cf-252 SEE



# Back-up: STAR1000



1k x 1k
15 x 15 µm$^2$

| | |
|---|---|
| Frame rate | 11 fps |
| Full Well | 95 ke$^-$ |
| Readout noise | 47 e$^-$ |
| Dark current | 3135 e$^-$/s (+25 ° C) |
| Shutter | Rolling |
| Sensitivity | 20 % (frontside) |
| Power cons | 100 mW |
| Radiation hard | 230 krad (TID) |

Proton DD: Quantum efficiency losses (~35% red)

# SO radiation specification

| Requirement | Al shield | Value |
|---|---|---|
| TID* (Si) | 1 mm | 150 krad |
| | 2 mm | 73 krad |
| Proton fluence | - | $3.8\ 10^{11}$ p/cm$^2$ at 10 MeV |
| | | $8.8\ 10^{10}$ p/cm$^2$ at 30 MeV |
| | | $2.6\ 10^{10}$ p/cm$^2$ at 60 MeV |
| NIEL equivalent 10 MeV proton fluence | 1 mm | $3.6\ 10^{11}$ p/cm$^2$ |
| | 2 mm | $1.8\ 10^{11}$ p/cm$^2$ |
| SEU LET threshold | - | 25 MeV cm$^2$ / mg |
| SEL LET threshold | - | 60 MeV cm$^2$ / mg |

* New values for PHI: TID(Si) < 30 krad with 1 mm Al