Radiation qualification and performance of the InGaAs vSWIR imaging sensor in the Venus Emissivity Mapper for VERITAS (NASA) and EnVision (ESA)

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  - VEM Instrument
  - Detector
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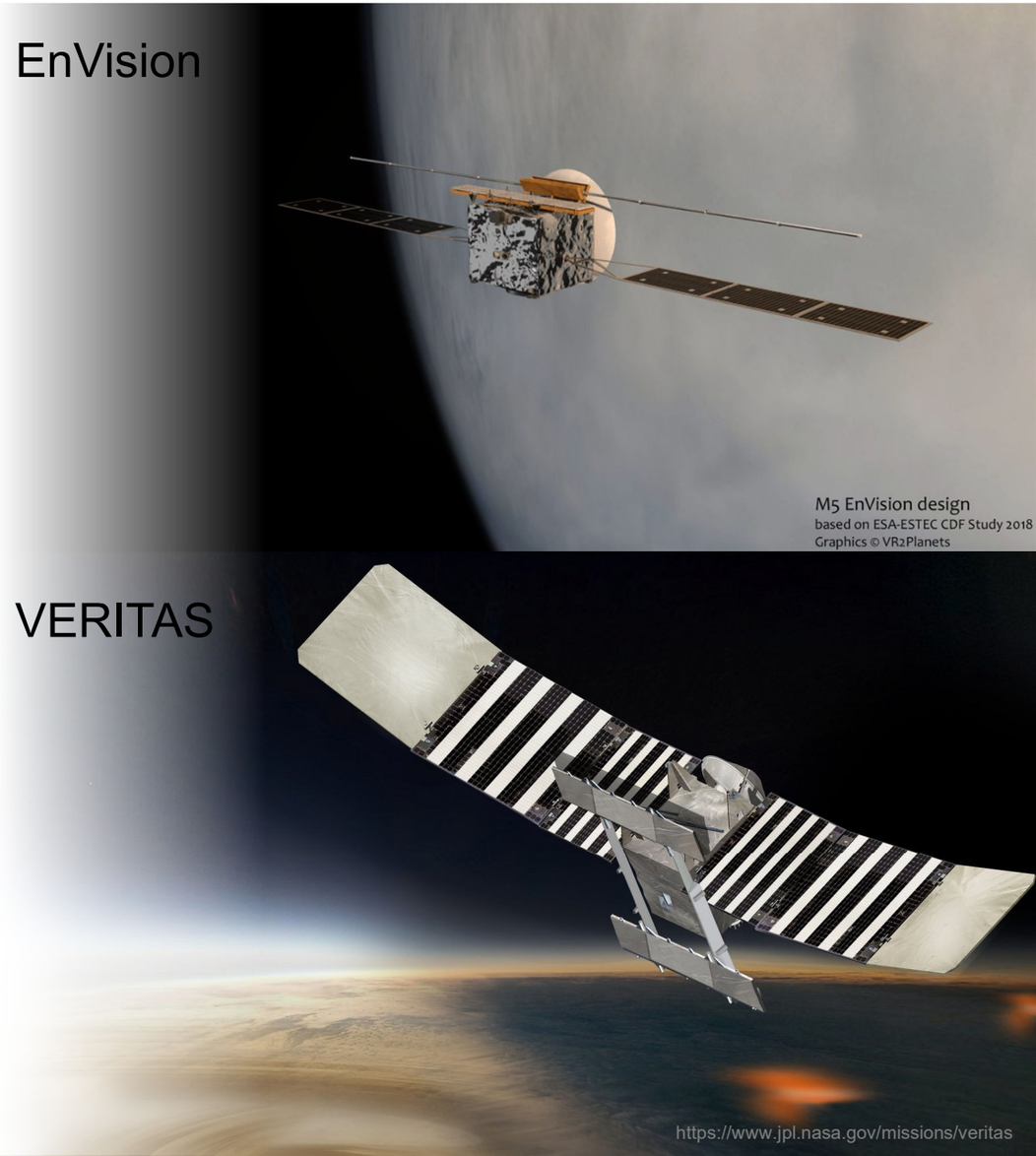
VERITAS and EnVision

- Discovery missions to planet Venus
- Both missions are set for a ~2031 launch
- Orbiters ~2.5t at launch

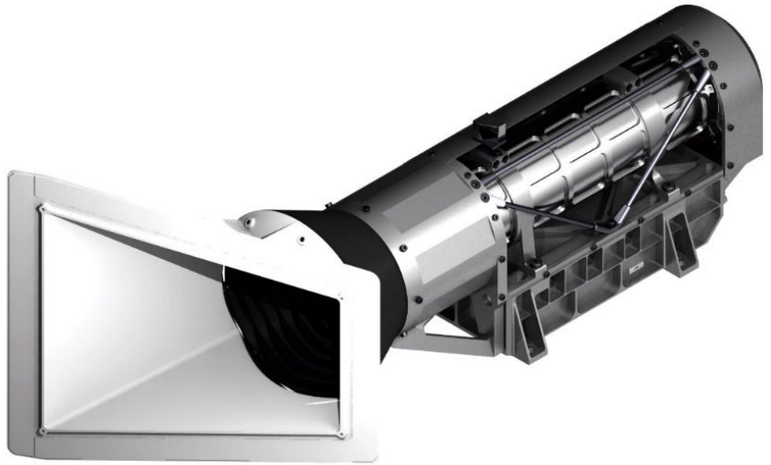
- Scientific objectives:
  - Past and present water
  - Recent and current volcanic activity
  - Geologic evolution of Venus
- This could answer main scientific questions
  - Did Venus have oceans?
  - How Venus lost its potential as a habitable world?
  - How paths of Venus and Earth diverged?



VEM Instrument

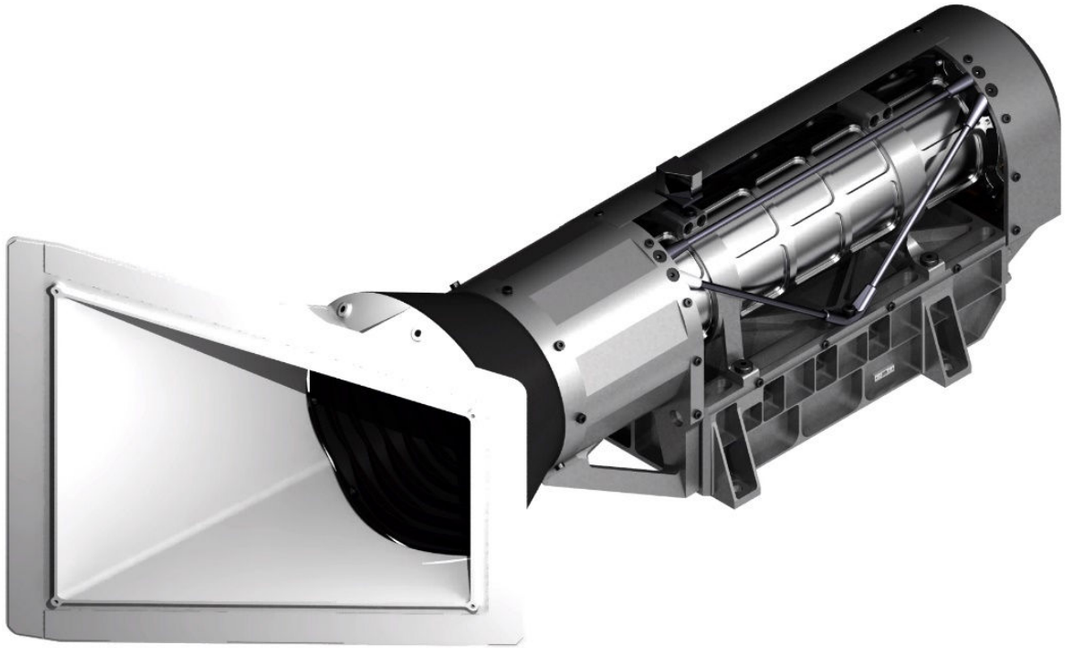
- Venus Emissivity Mapper (VEM)
- VERITAS: Two VEM instruments, 2x FoV (+Redundancy)
- EnVision: Single VEM instrument

- Surface mapping at different atmospheric CO_2 windows
- 14 atmospheric filter bands – 790 nm - 1510 nm
  - 6 for surface mapping
  - 3 for cloud composition
  - 2 for water abundance
  - 3 for stray light compensation

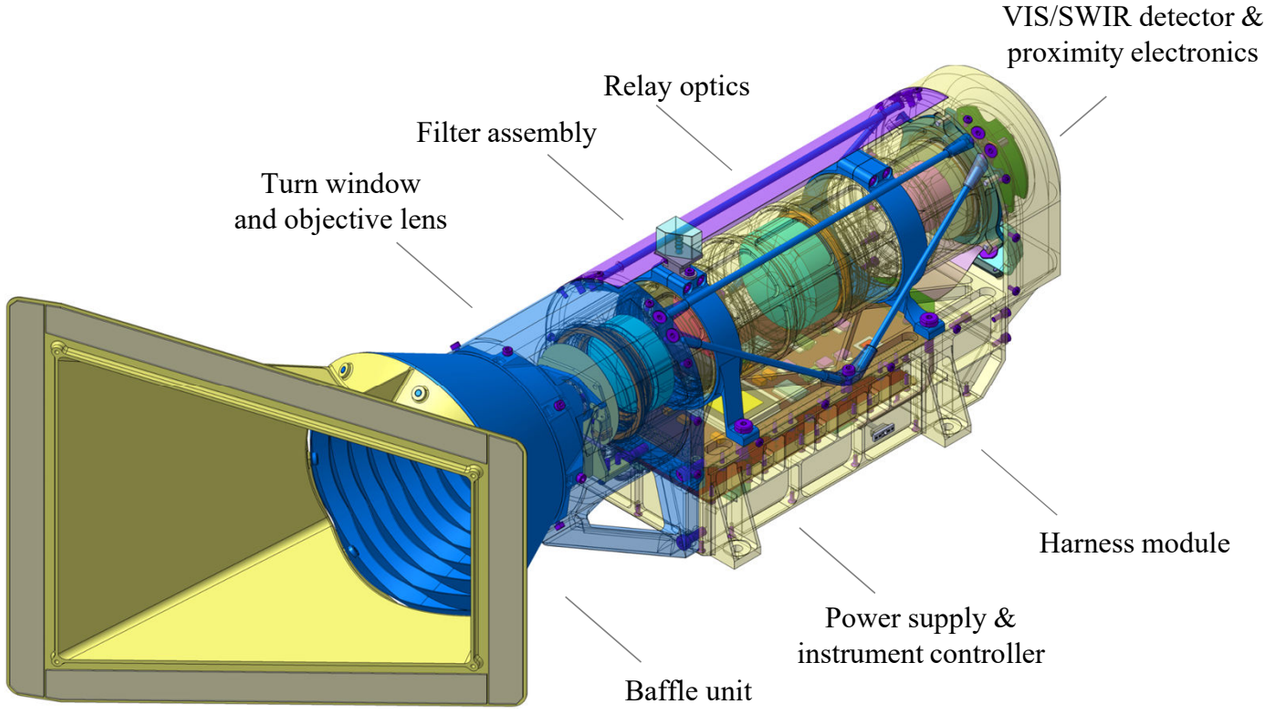


VEM instrument

VEM Instrument



Construction Render

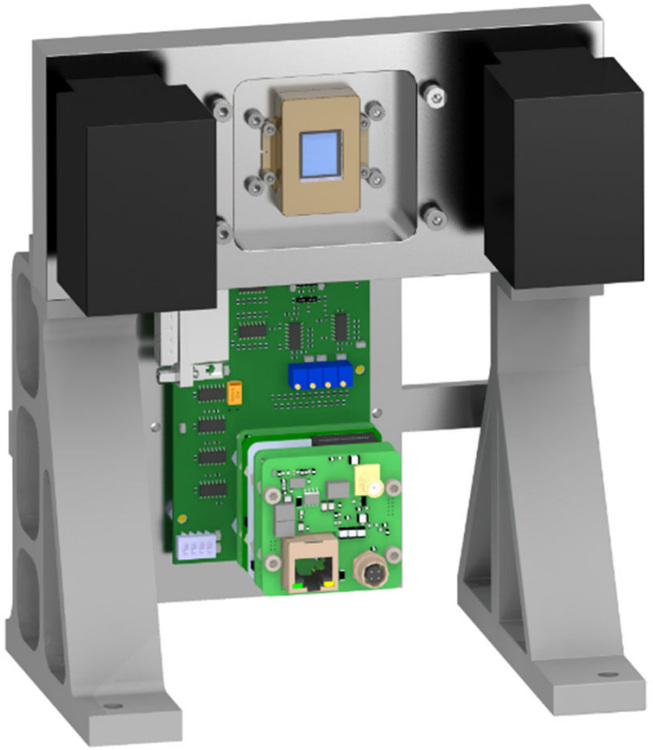


Construction Model

Detector

- Xenics XSW-640 vSWIR
- 640 x 512 pixels – 20µm pixel pitch
- Spectral sensitivity: 0.6 - 2.4µm
- Thermoelectric cooling (TEC)

- Extension board (DLR design)
  → power monitoring and latch-up protection



Proton Test

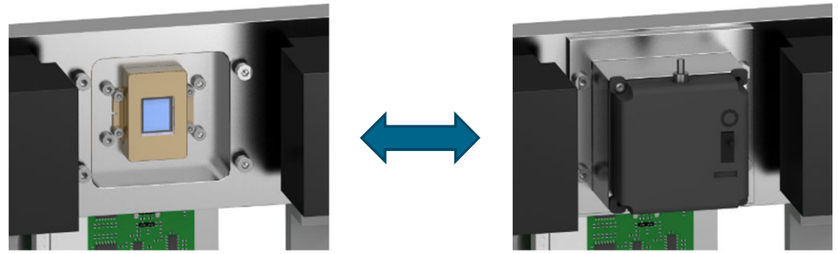
- At HZB Wannsee
- Proton Energy: 68 MeV
- Target Fluence: 2.80E+10 p+/cm²
- 10 irradiation steps
- ~10 hours irrad. + ~7 hours functional measurements
- Transport analysis: TNID of 9.13E+07 MeV/g (Si) / TID of 3.5 krad (Si)

Step No.	Flux [p+/cm²/s]	Fluence Steps	Fluence [p+/cm²]	Step Time [s]	Integral Time [s]	Integral Time [h]
1	7.78E+05	2.808E9	2.808E9	3588.8	3588.8	0.99689
2	7.78E+05	2.8825E9	5.6905E9	3468.8	7057.6	1.96044
3	7.78E+05	2.824E9	8.5145E9	3562.7	10620.3	2.95008
4	7.78E+05	2.883E9	1.13975E10	3467.4	14087.7	3.91325
5	7.78E+05	2.772E9	1.41695E10	3645.6	17733.3	4.92592
6	7.78E+05	2.93E9	1.70995E10	3363.1	21096.4	5.86011
7	7.78E+05	2.784E9	1.98835E10	3630.3	24726.7	6.86853
8	7.78E+05	2.801E9	2.26845E10	3598.6	28325.3	7.86814
9	7.78E+05	2.783E9	2.54675E10	3632.35	31957.65	8.87712
10	7.78E+05	2.874E9	2.83415E10	3465	35422.65	9.83962

Proton-Test sequence protocol

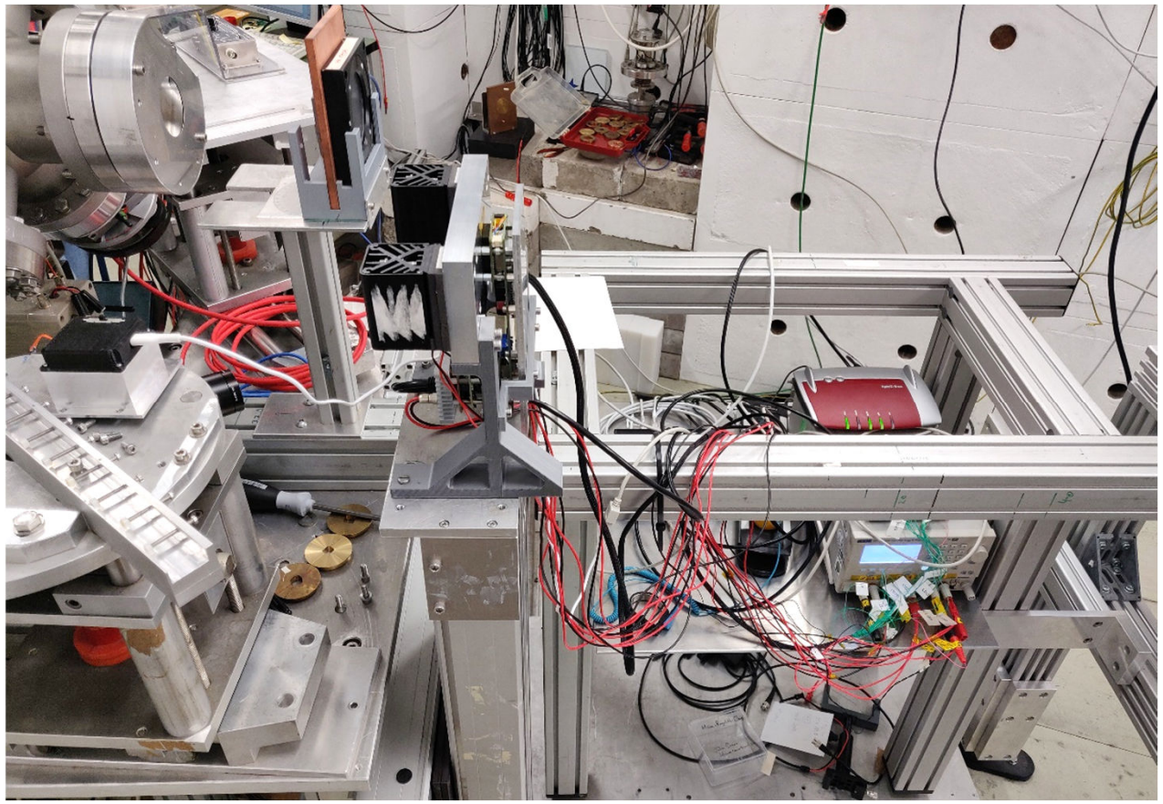
- **Characterization Measurements:**
  @ sensor temperatures: -10, 0, 10°C
  (1) LED illumination (870 nm)
  (2) Dark images
  (3) Image sequences (6x, 1 min each)

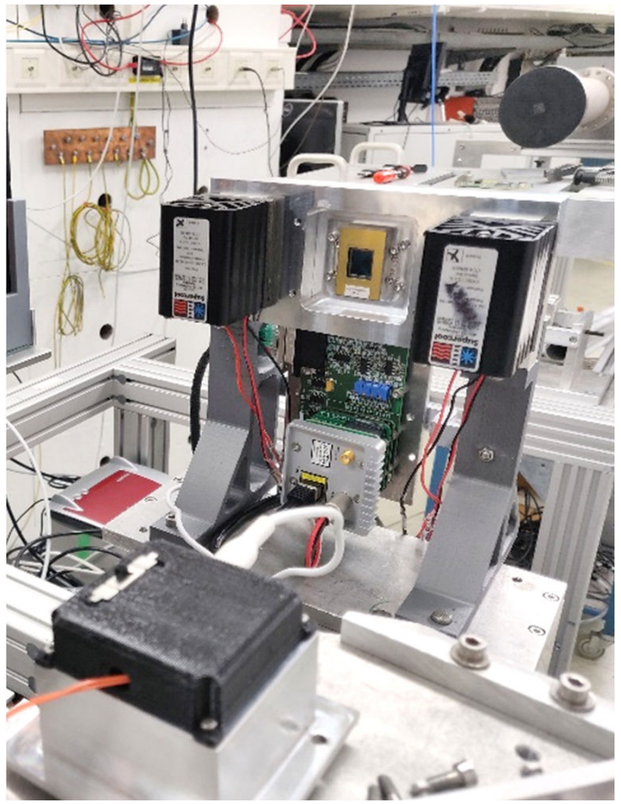
Functional Test for each step +
Live Sampling during irradiation

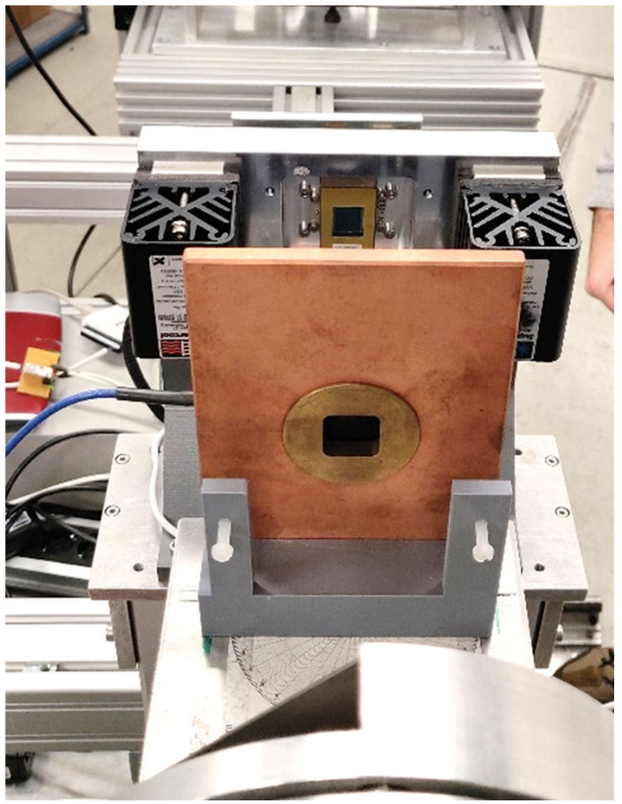


Proton Test

- Sensor installed at the HZB proton beamline







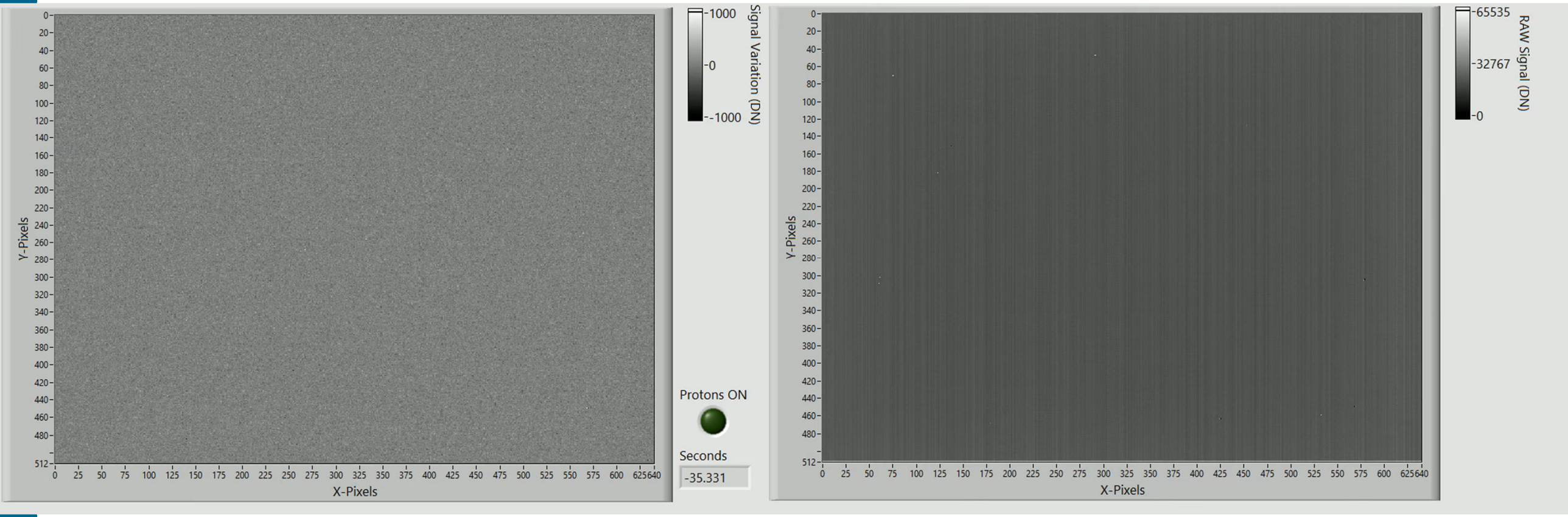
Proton Test

Live Images:
1ms exposure, 10°C sensor temp., 1Hz frame rate
(Dark Frame corrected, 16bit → 0…65535 DN)

→ 20x real time

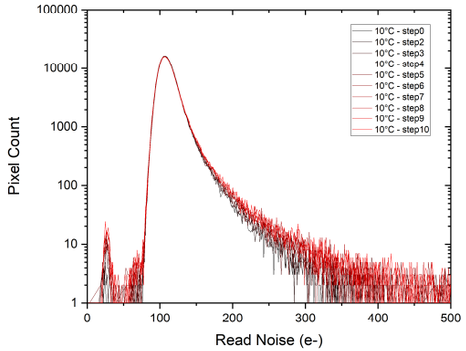
Dark corrected difference images

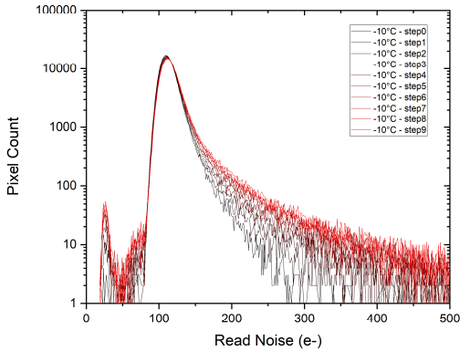
RAW images

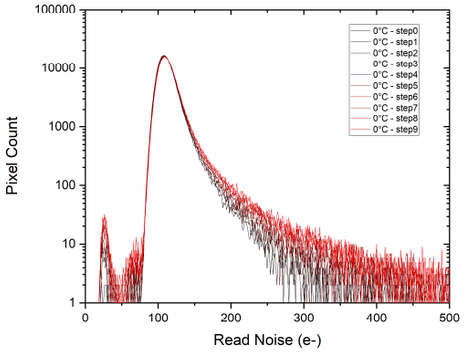


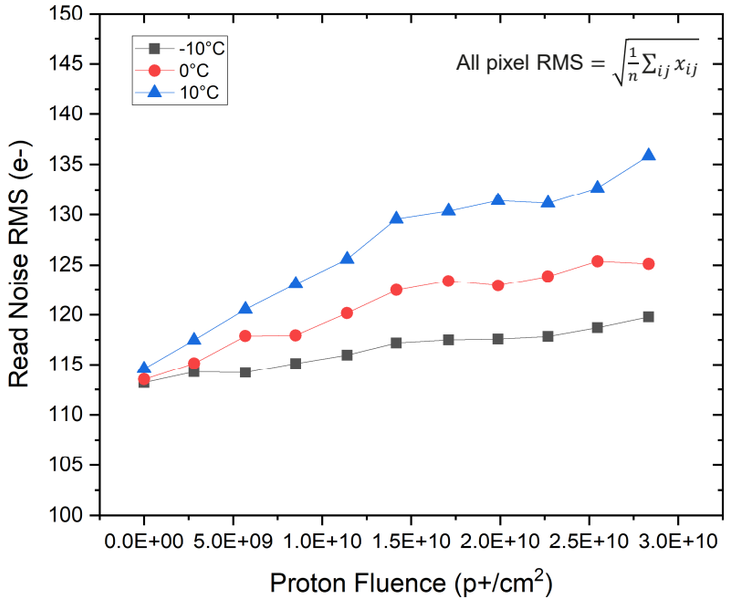
Read Noise

- Read Noise: noise generated during sensor readout
- Pixel standard deviation at zero exposure time
- ≦ 25% increase with proton irradiation (datasheet: 121 e-)

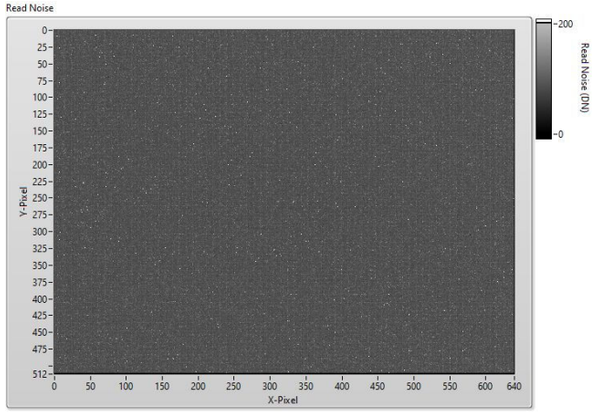




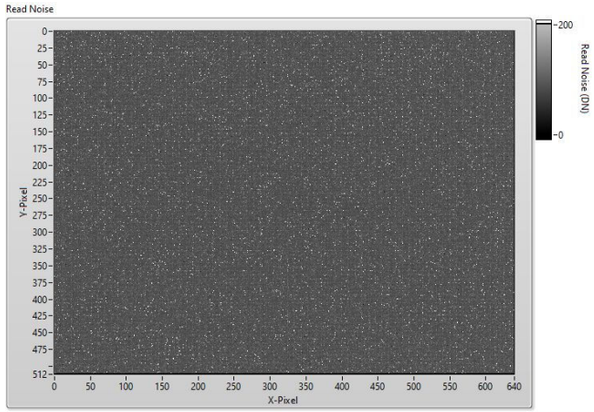




0°C, pre-Test Read Noise

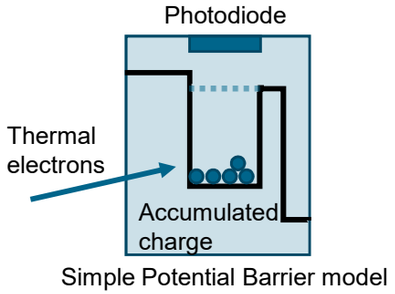


0°C, post-Test Read Noise



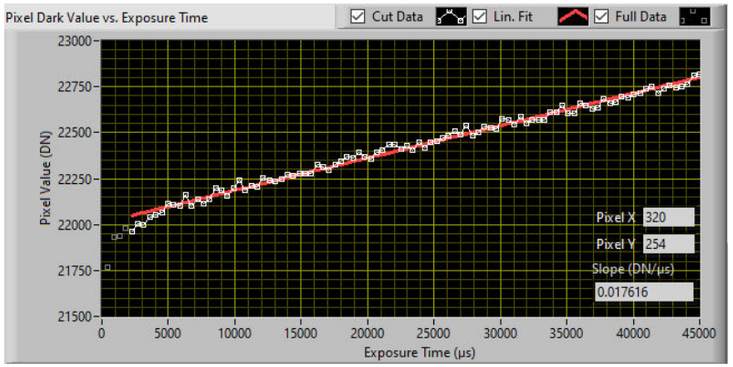
Dark Current

- Dark current: randomly generated charge without illumination → increases signal
- Pixel Dark Signal vs. Exposure Time → Dark Current
- Reduces dynamic range: $\mathrm{DR} = \frac{N_{FullWell} - N_{DarkCurrent}}{N_{Noise}}$



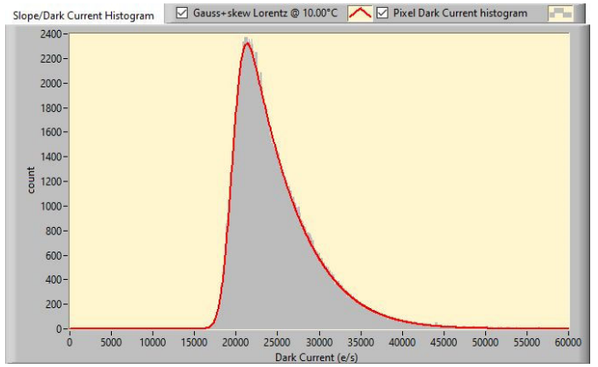
Simple Potential Barrier model

Measurement



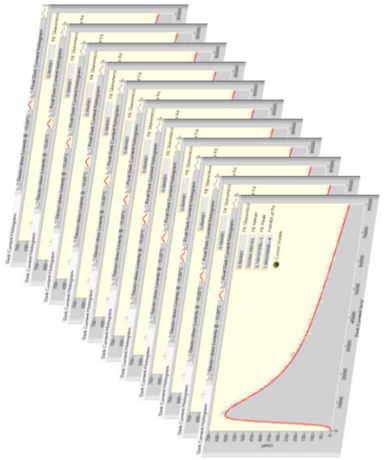
Single Pixel Dark Signal vs. Exposure time

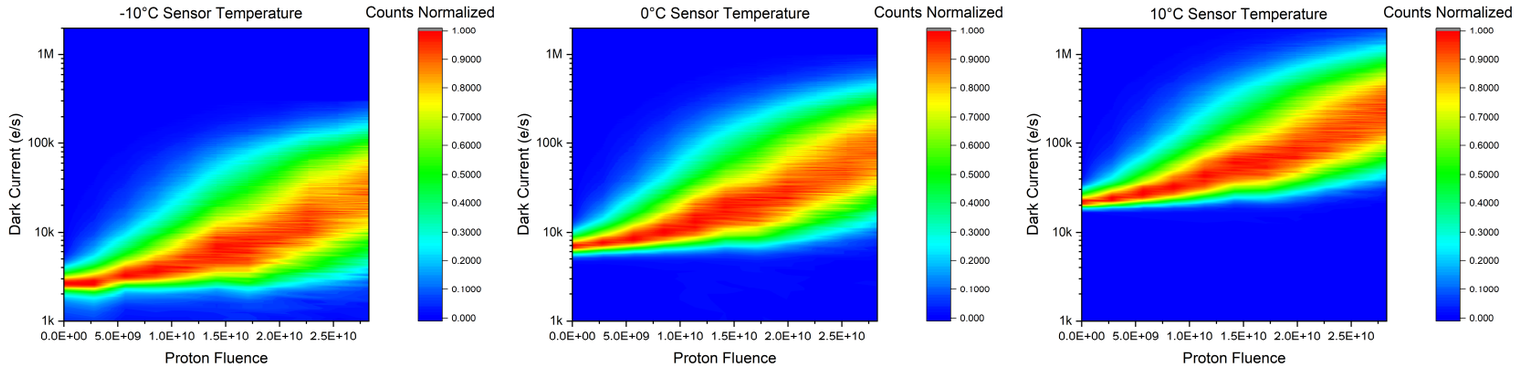
Slope

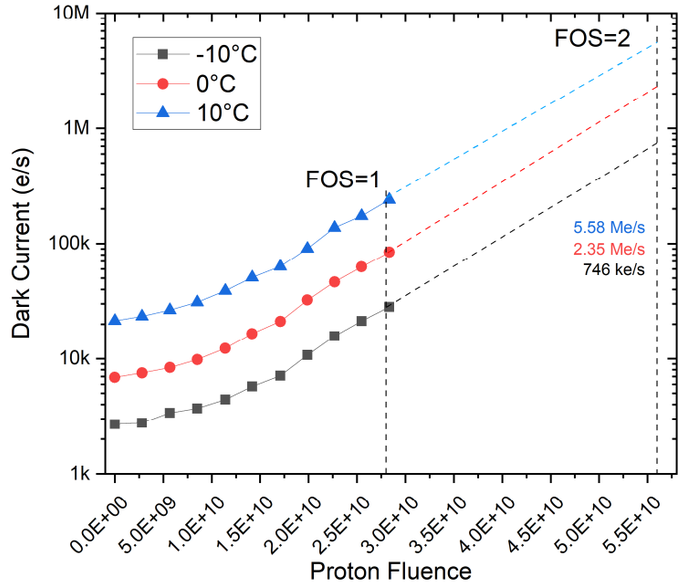


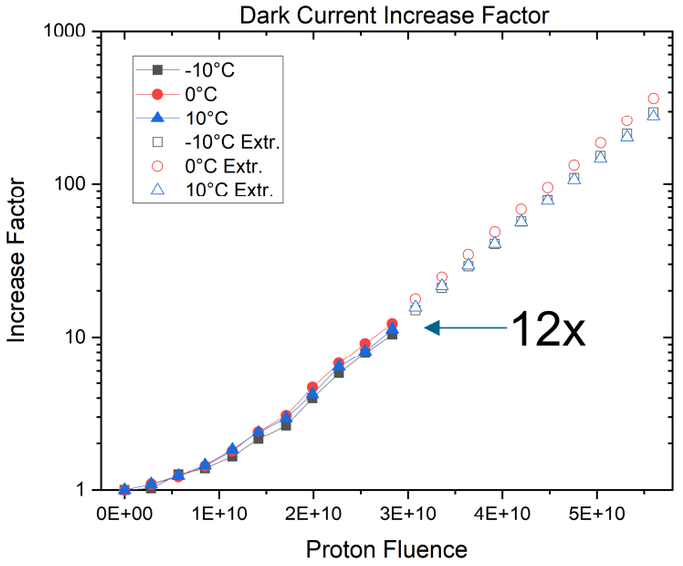
Dark Current of all Sensor Pixels

Dark Current



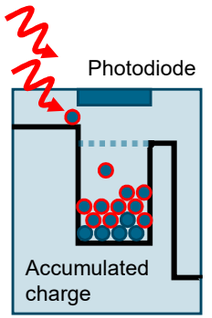






Light Sensitivity

- Dark current: randomly generated charge without illumination which increases signal level
- Sensitivity: Photo Signal = Light Image – Dark Image → Slope



Measurement

Single Pixel Linearity Measurement
Dark-Image corrected

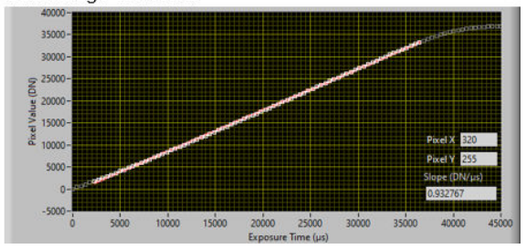
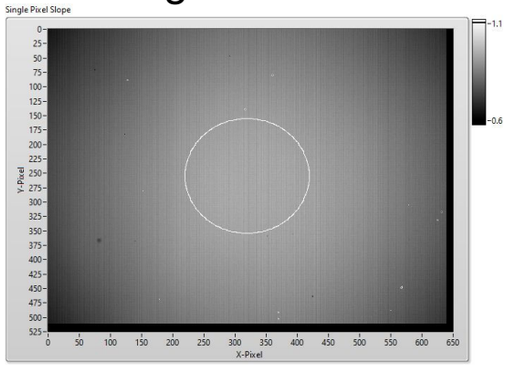
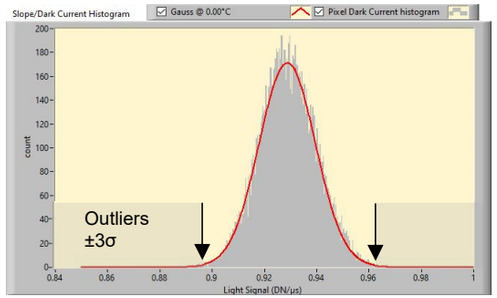
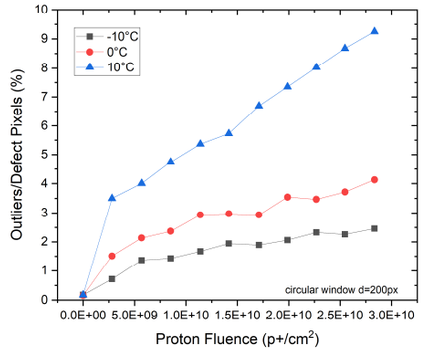
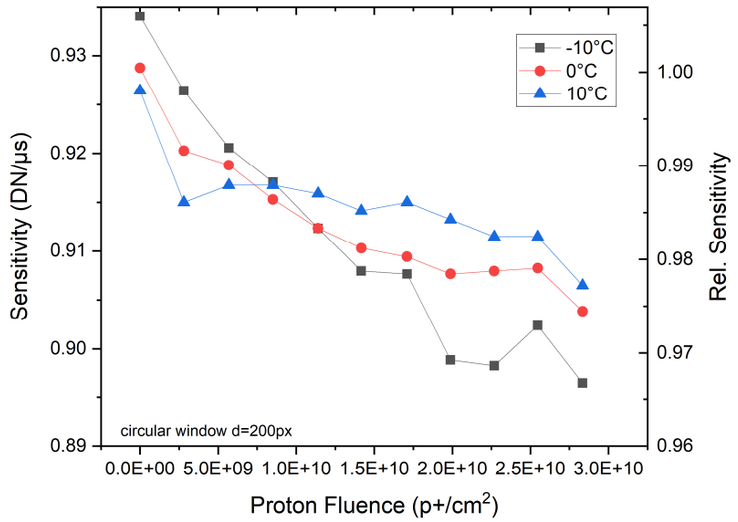


Photo Signal







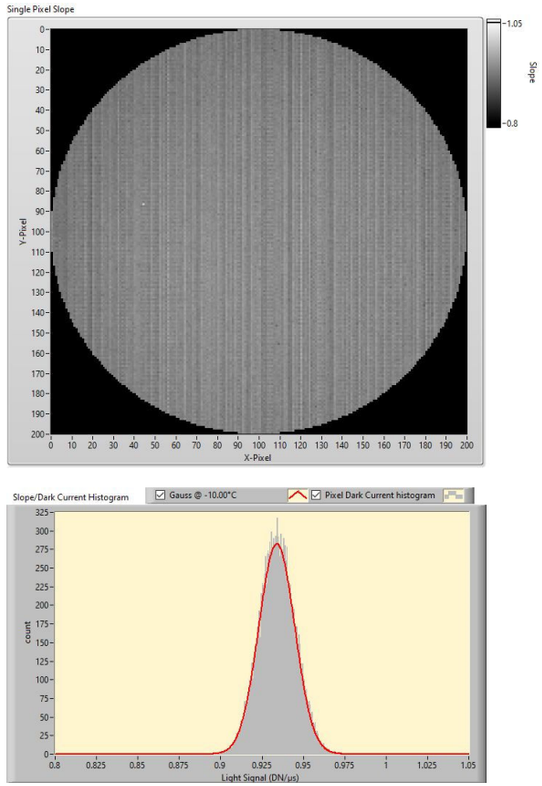


Light Sensitivity

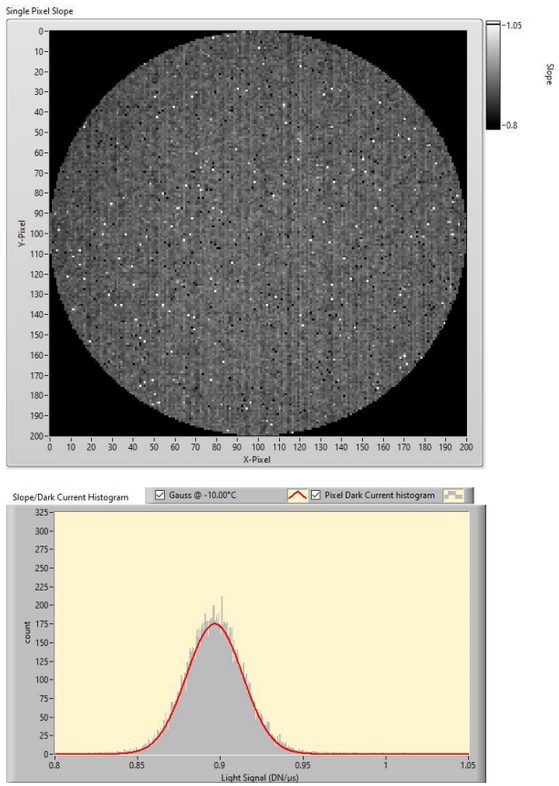
- Pixel sensitivity change @ -10°C sensor temperature

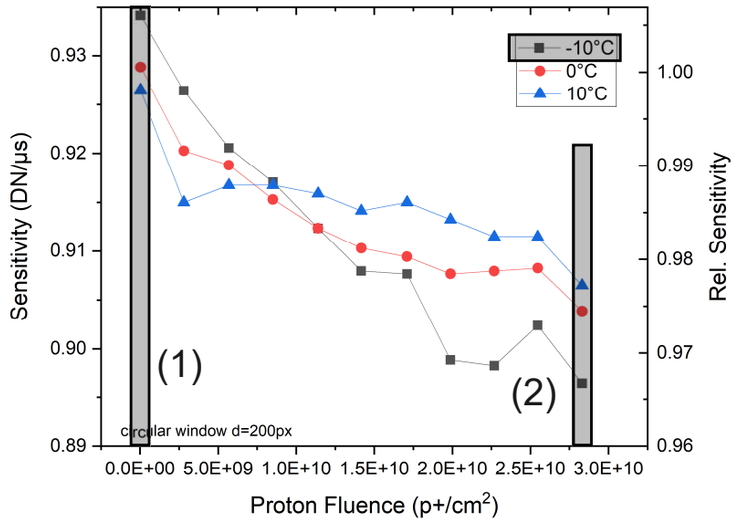
Visualized sensitivity

(1) before Proton Test



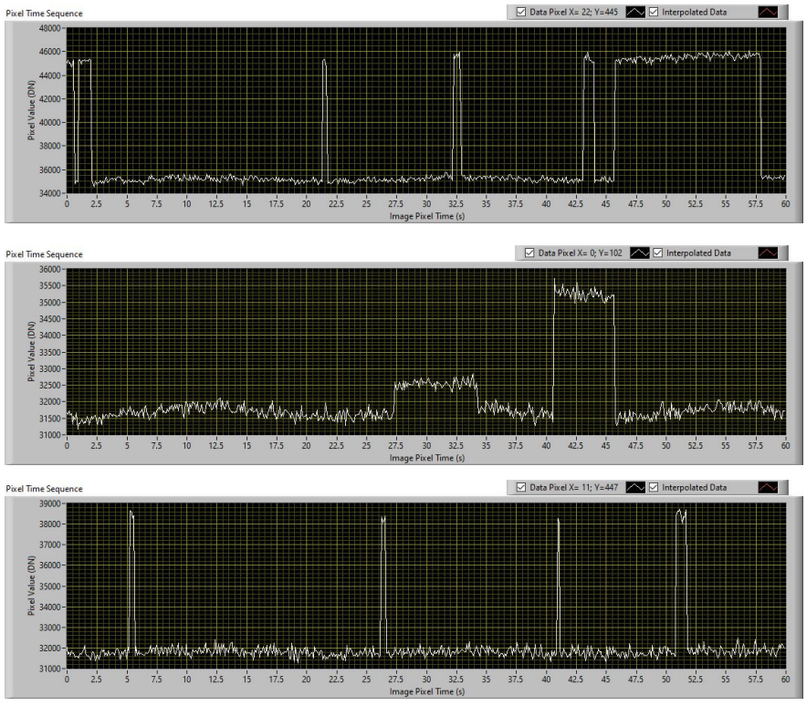
(2) after Proton Test



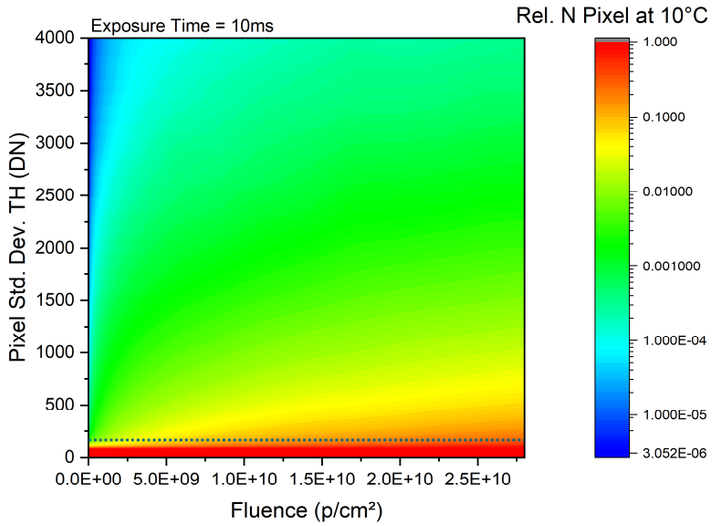


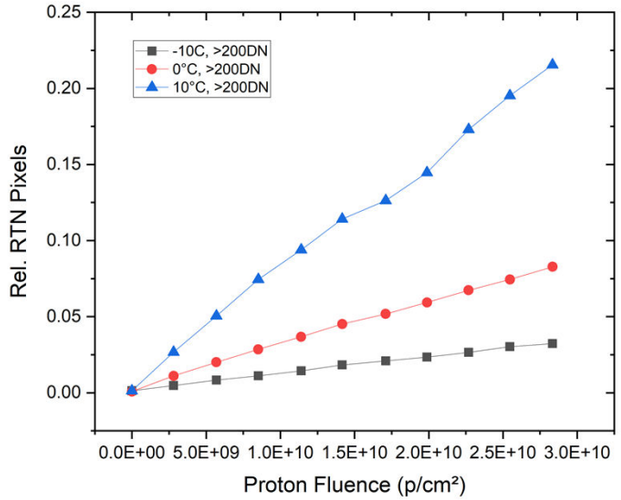
Random Telegraph Noise (RTN)

- Random Pixel Blinking due to Displacement Damage in InGaAs Lattice
- Number of RTN is linearly increasing with proton fluence
- For 0°C sensor target: RTN number ≦ 8 % of all pixels



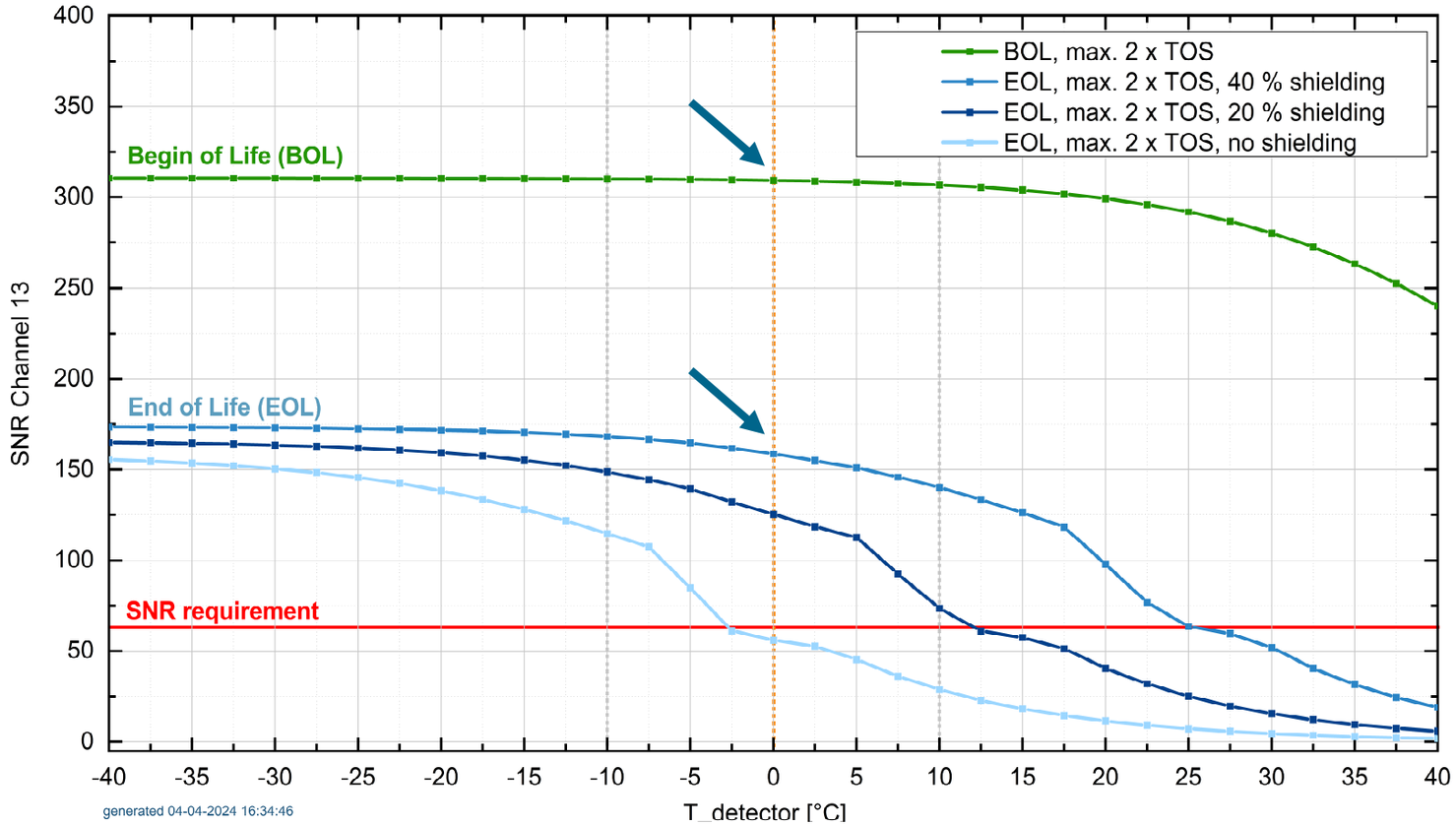
RTN in pixel dark signal for an image sequence





Signal to Noise

- SNR of weakest science channel over 5-year mission time
- Includes sensor degradation & optics contamination



Conclusion

- Detector was tested to end of life mission dose incl. design margin
  (6x EOL in prev. test)
- Proton Fluence 2.80E+10 p+/cm² → TNID of 9.13E+07 MeV/g / TID of 3.5 krad (Si)
- Evolution of all relevant image quality parameters was tracked
  - Read Noise → +25%
  - Dark Current → 12x increase
  - Sensitivity to Light → -3%
  - Pixel Defects (Random Telegraph Noise / Outliers) → ≦ 8-10 % (@ 0°C)

- Detector is able to fulfill the mission objectives in VERITAS & EnVision