Precision Quantum Efficiency Measurements on 1.7 Micron NIR Devices for JDEM/SNAP

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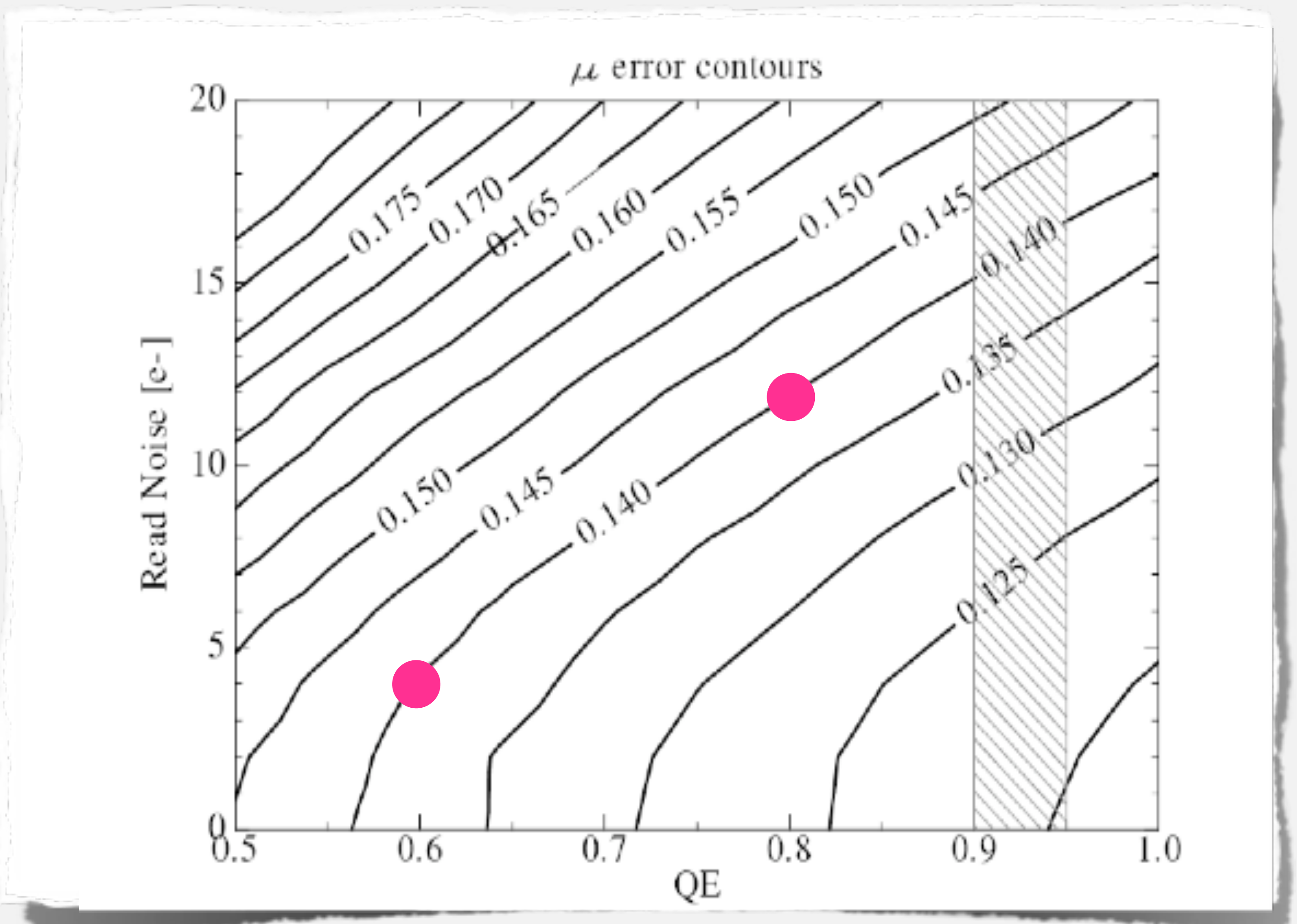
- I will present quantum efficiency measurements performed at the University of Michigan on 2048 × 2048 1.7 μm HgCdTe FPAs produced for the SNAP project by Teledyne (and Raytheon).

- The Michigan QE measurement set-up has undergone several changes (and improvements) over the past years and systematic uncertainties could be reduced from ~10% to about ~2%.

Detector QE impacts JDEM program:

High QE improves speed and performance

Any boost of detector QE translates directly into improved statistical accuracy
For SN measurements: earlier detection and smaller μ error



Higher QE relaxes read-noise requirements
(for const. μ error)

Matt Brown,
PhD thesis, Univ. of Michigan 2007

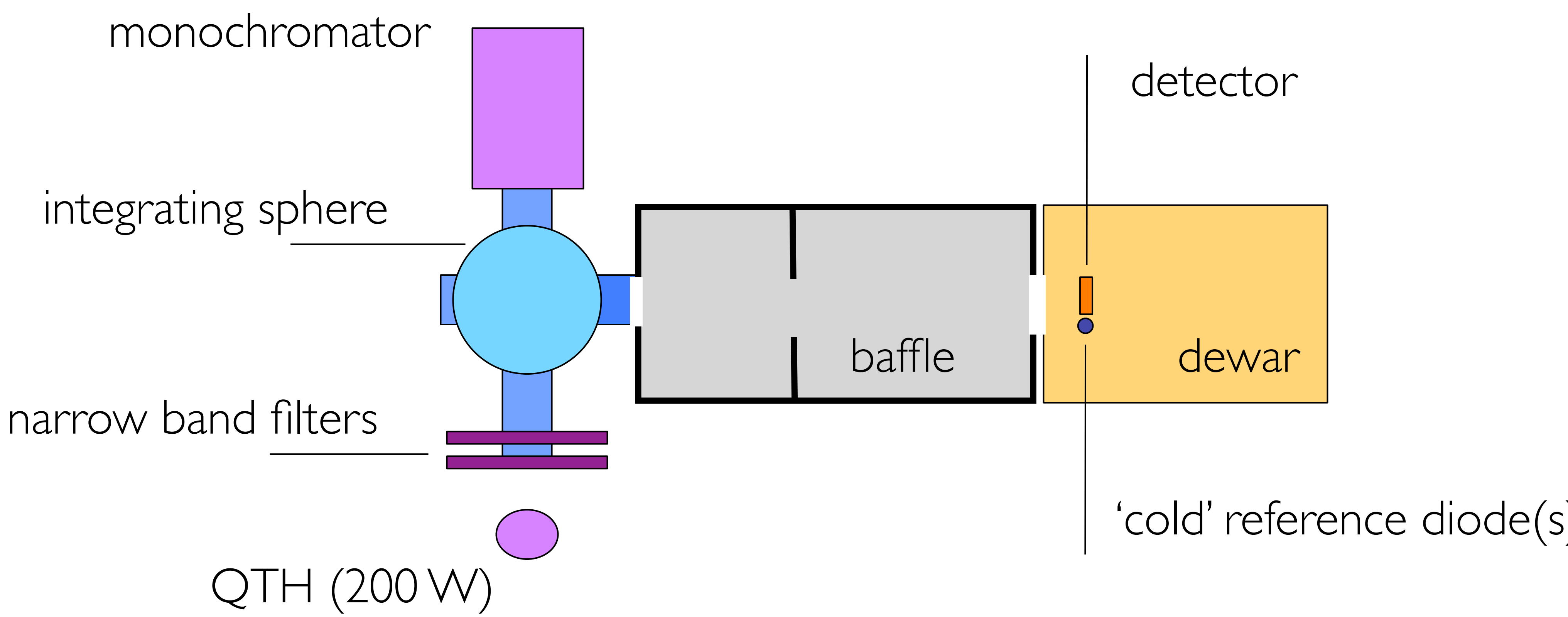
Measurement of (absolute) QE at 2% level is challenging.

Is it necessary?

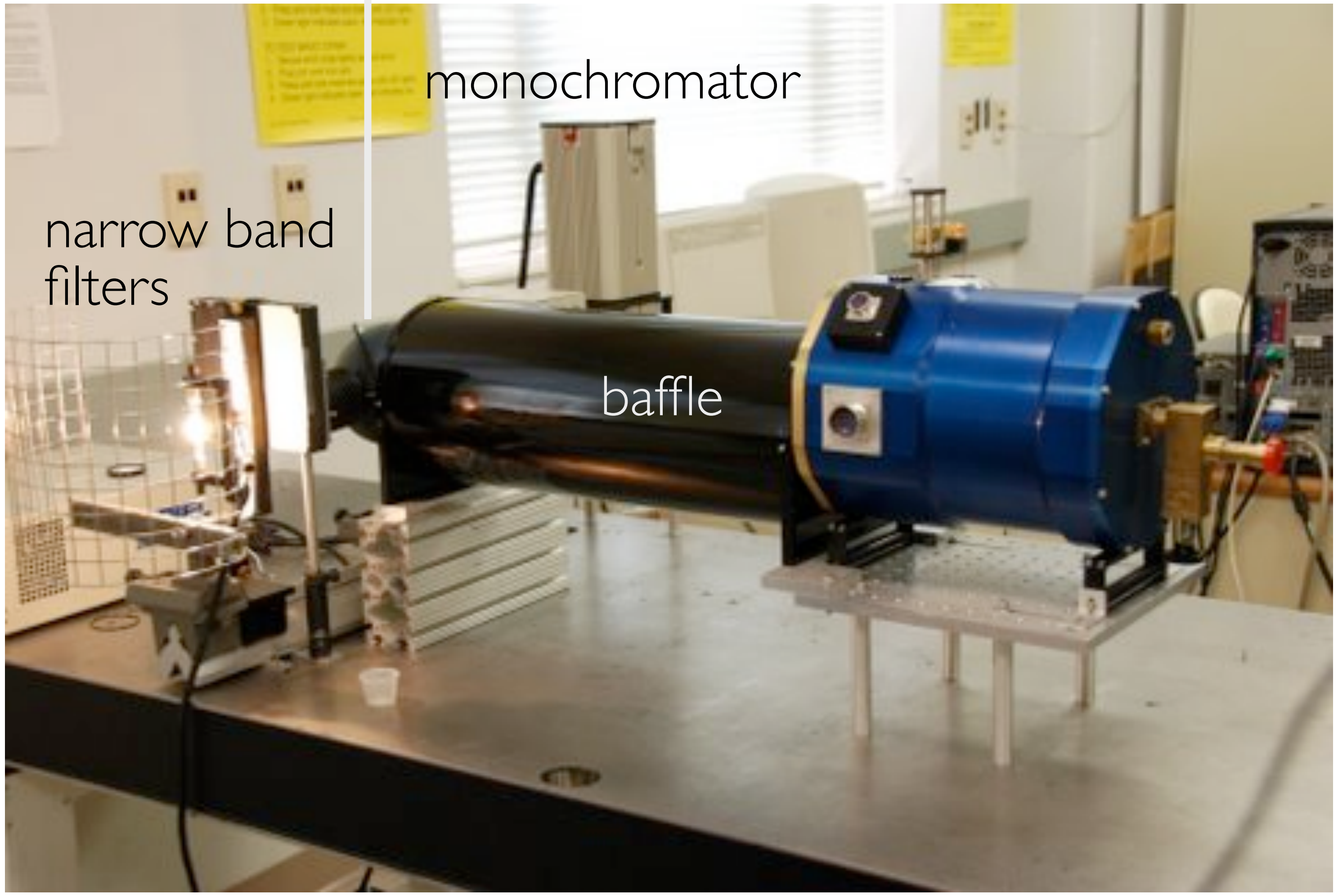
YES!

- Tracing of manufacturing progress
- Evaluation of QE uniformity (response) across detector
- Monitoring detector performance (w/ time)

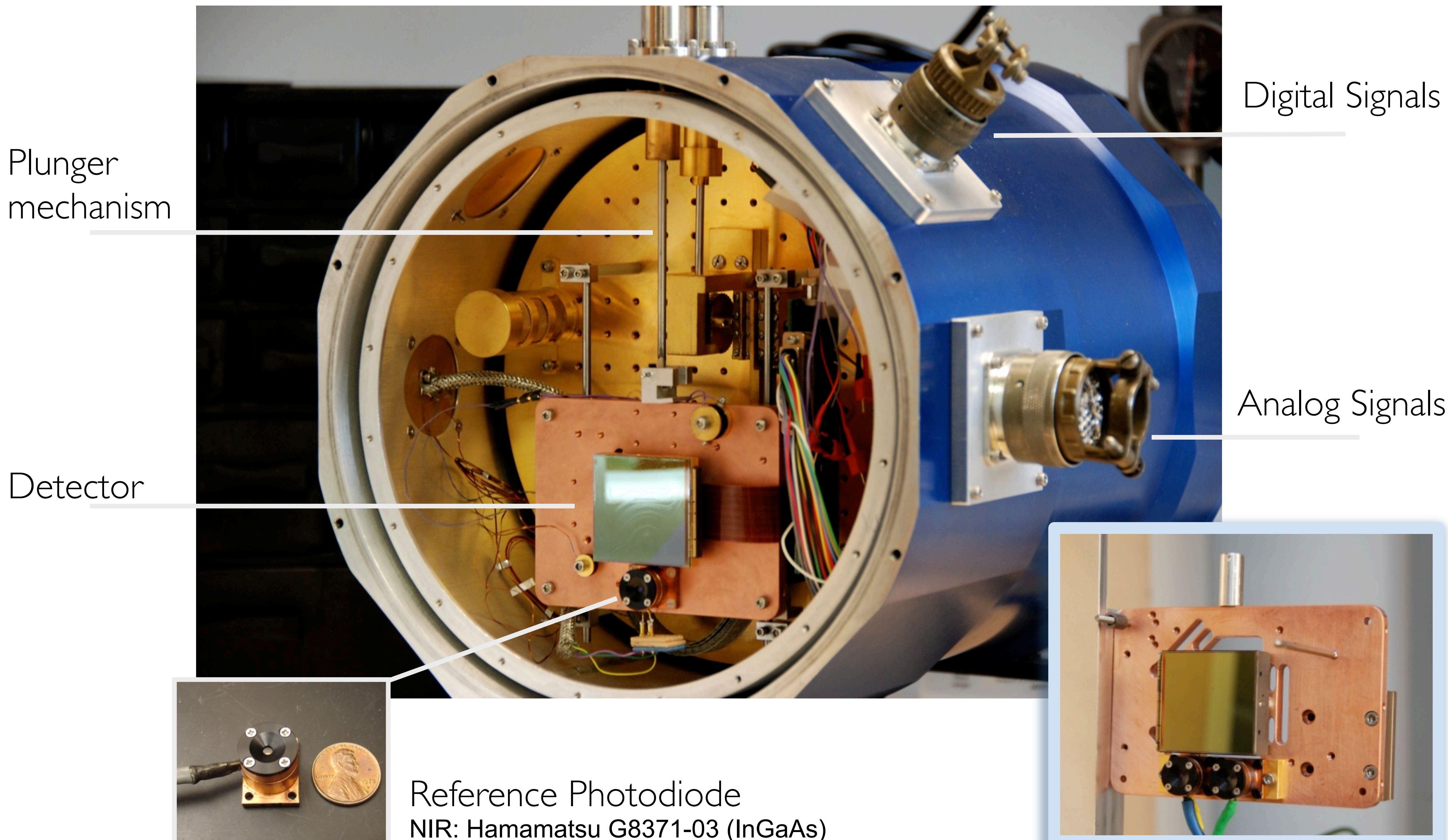
Measurement Set-up



MEASUREMENT SET-UP

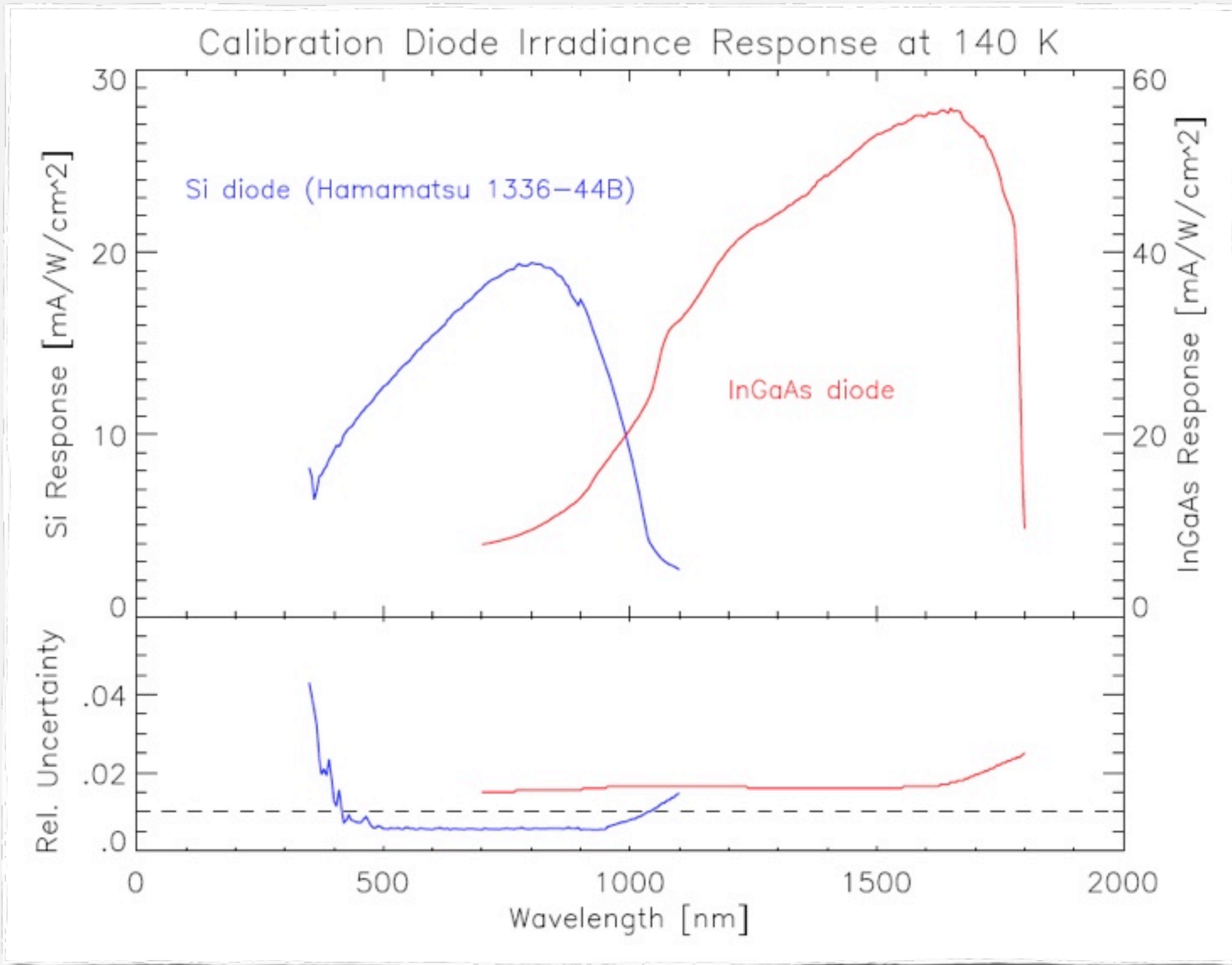


DETECTOR MOUNTED INSIDE DEWAR



Reference Photodiode
NIR: Hamamatsu G8371-03 (InGaAs)

Reference Diode Calibration



Nick Mostek
PhD thesis

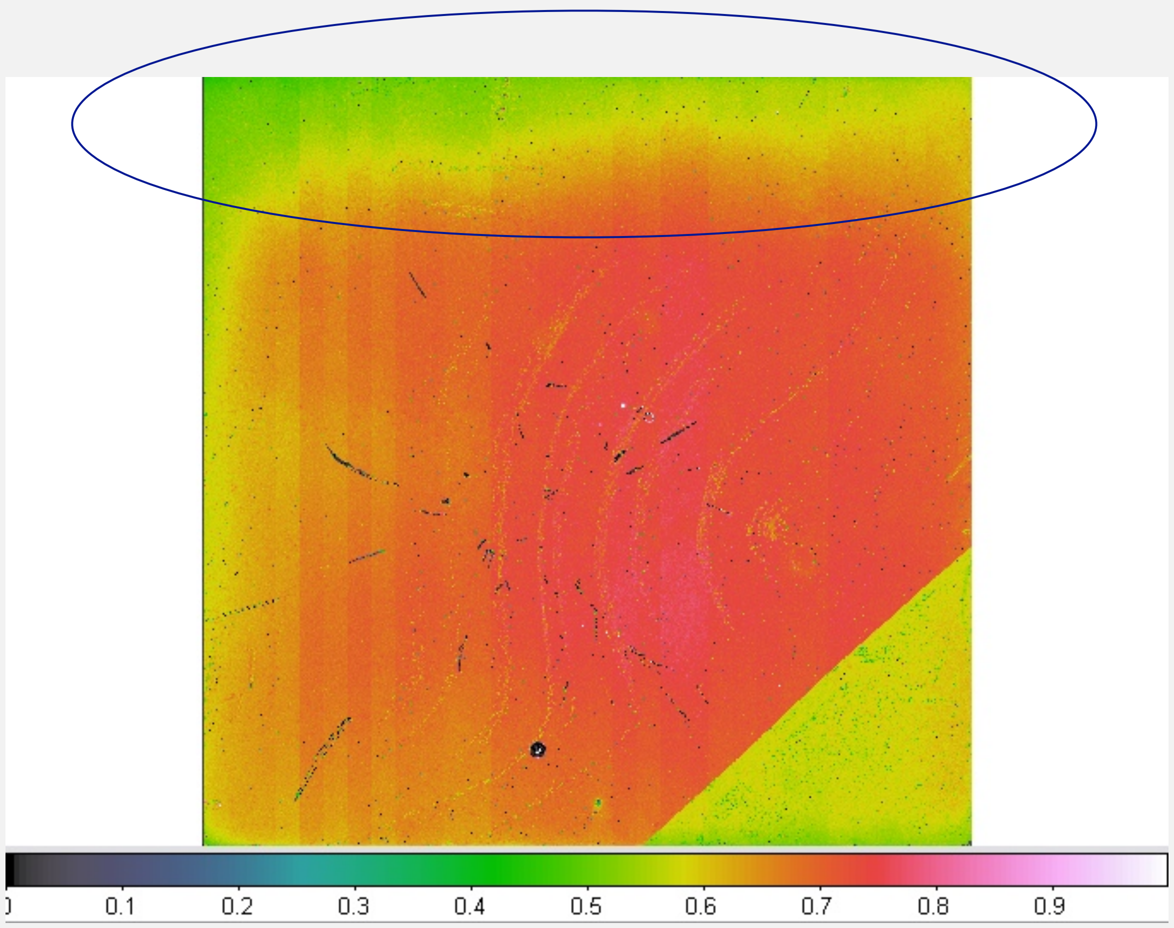
Indiana University
(2007)

The upper figure shows the calibration curves for the reference diodes used at UM. Note that the InGaAs curve is scaled by a factor 1/2. The lower figure shows the fractional calibration error.

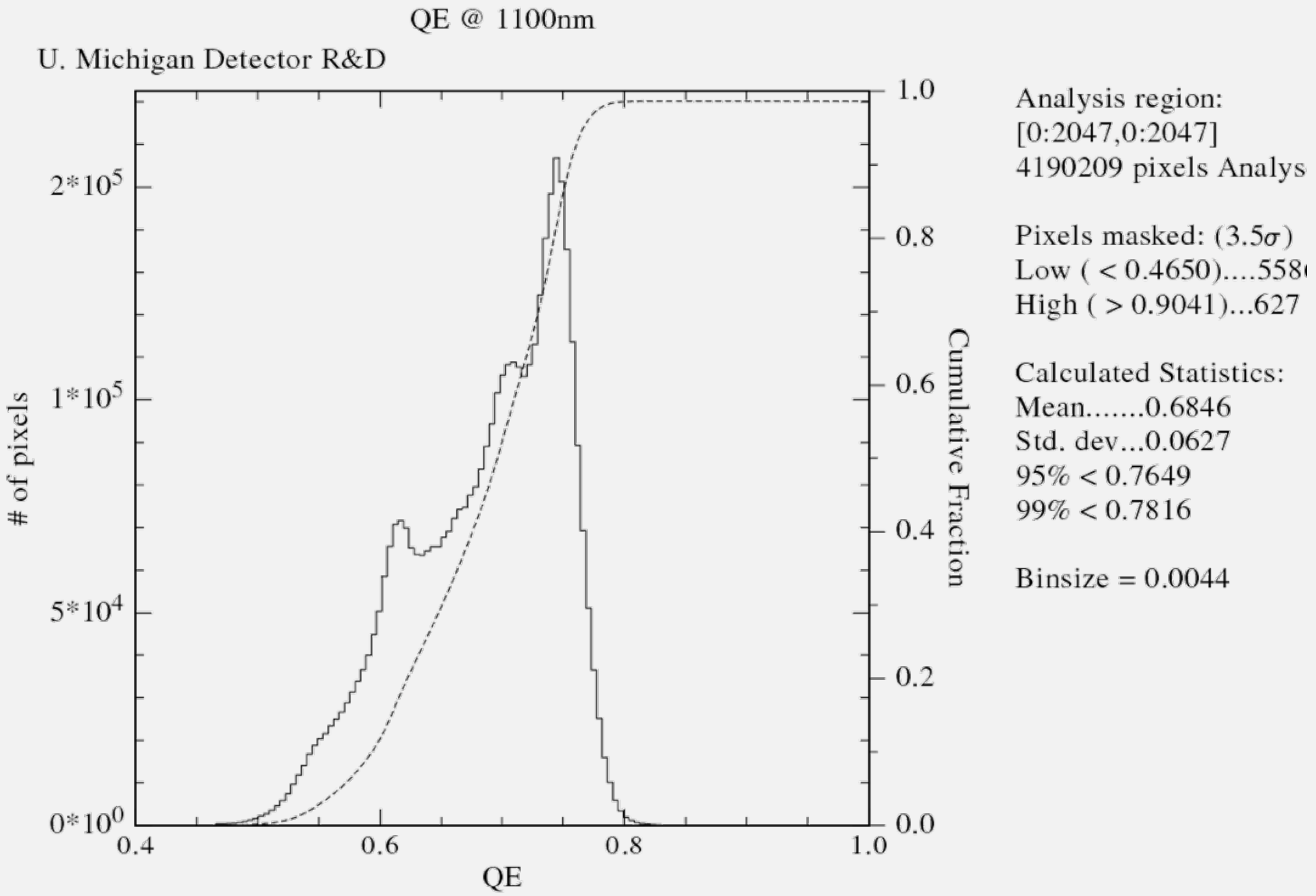
SNAP FPA 103

What is the cause of apparent non-uniformity?

Detector response or illumination?

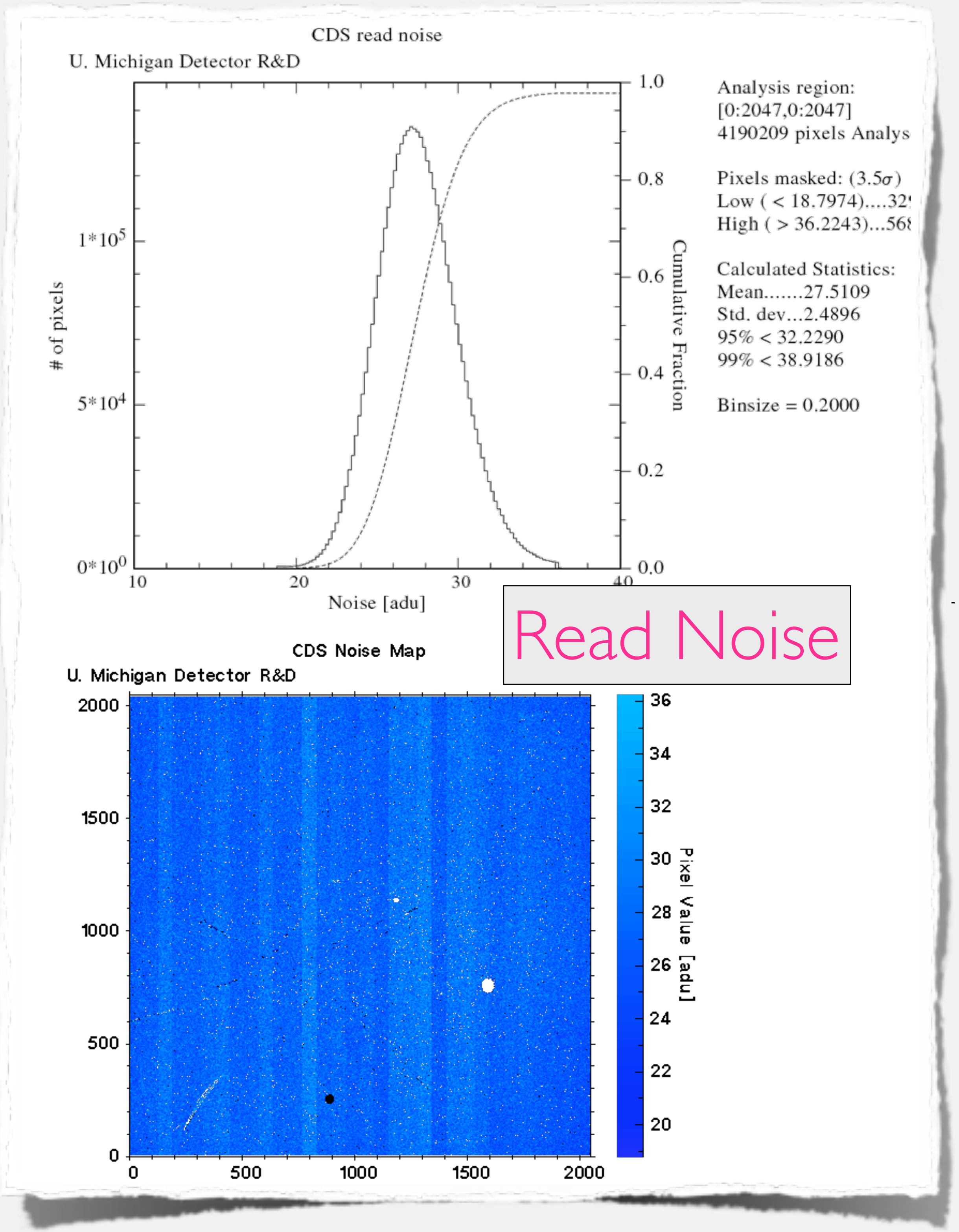


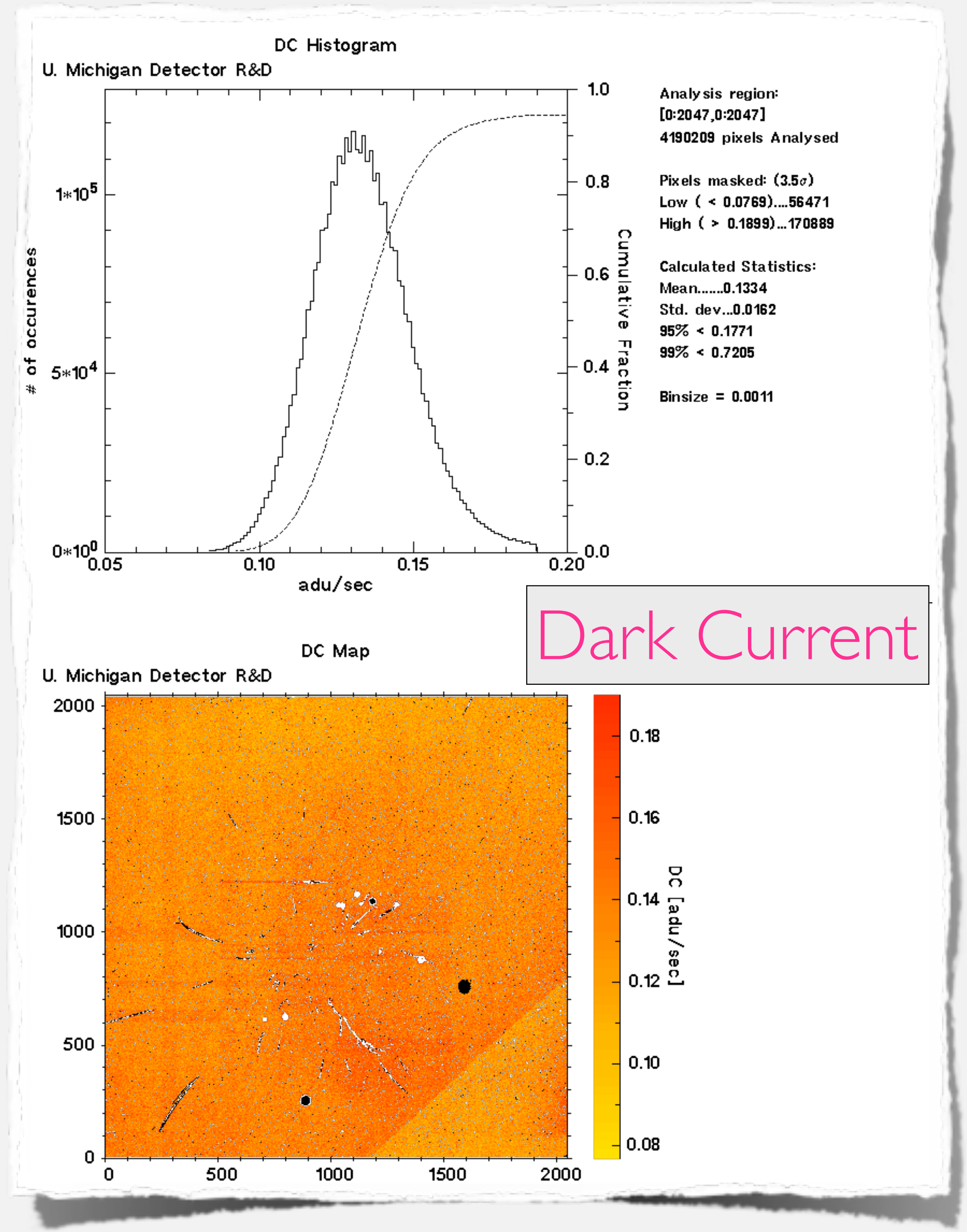
QE map



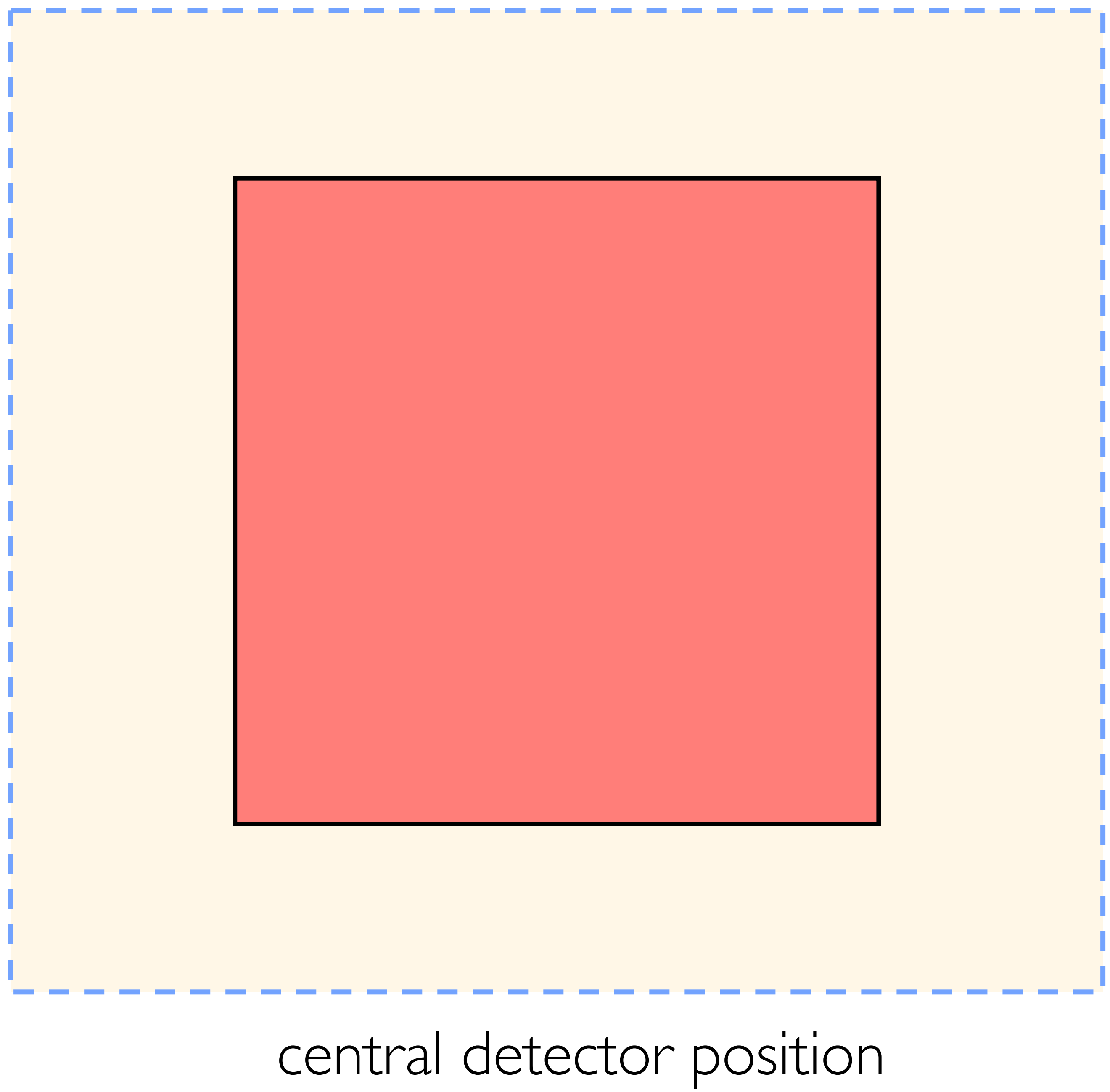
SNAP FPA 103 Characteristics

Non-uniformity apparent in QE not reflected in other tests:

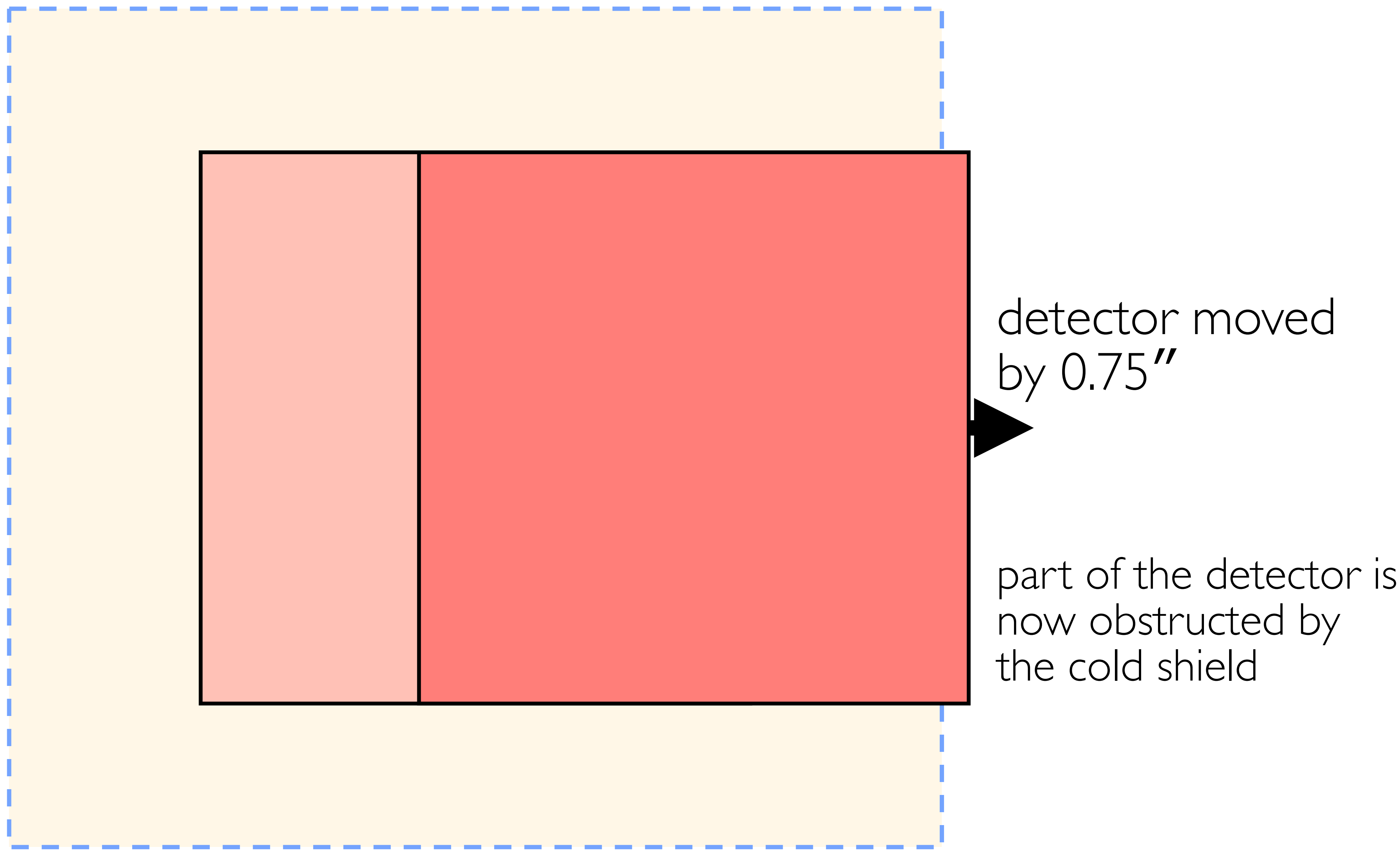




Test illumination uniformity by measuring QE at different detector positions

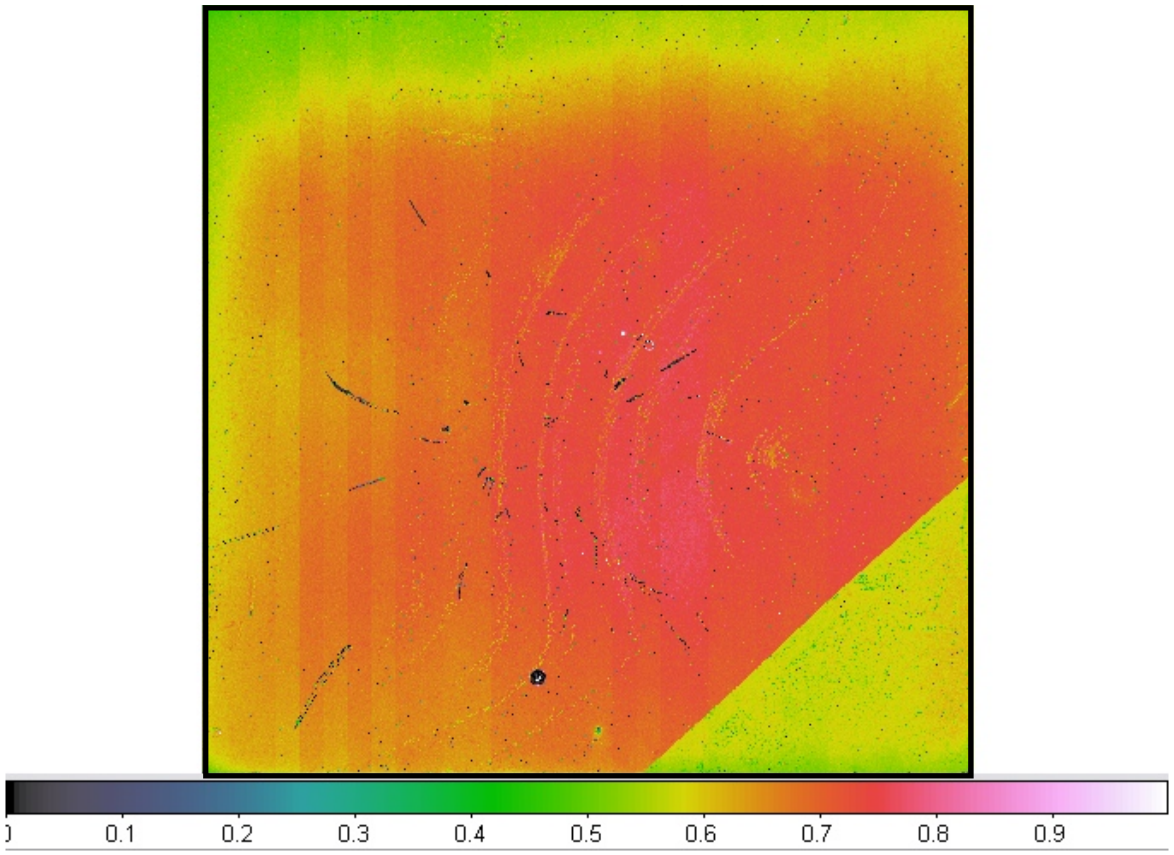


Test illumination uniformity by measuring QE at different detector positions

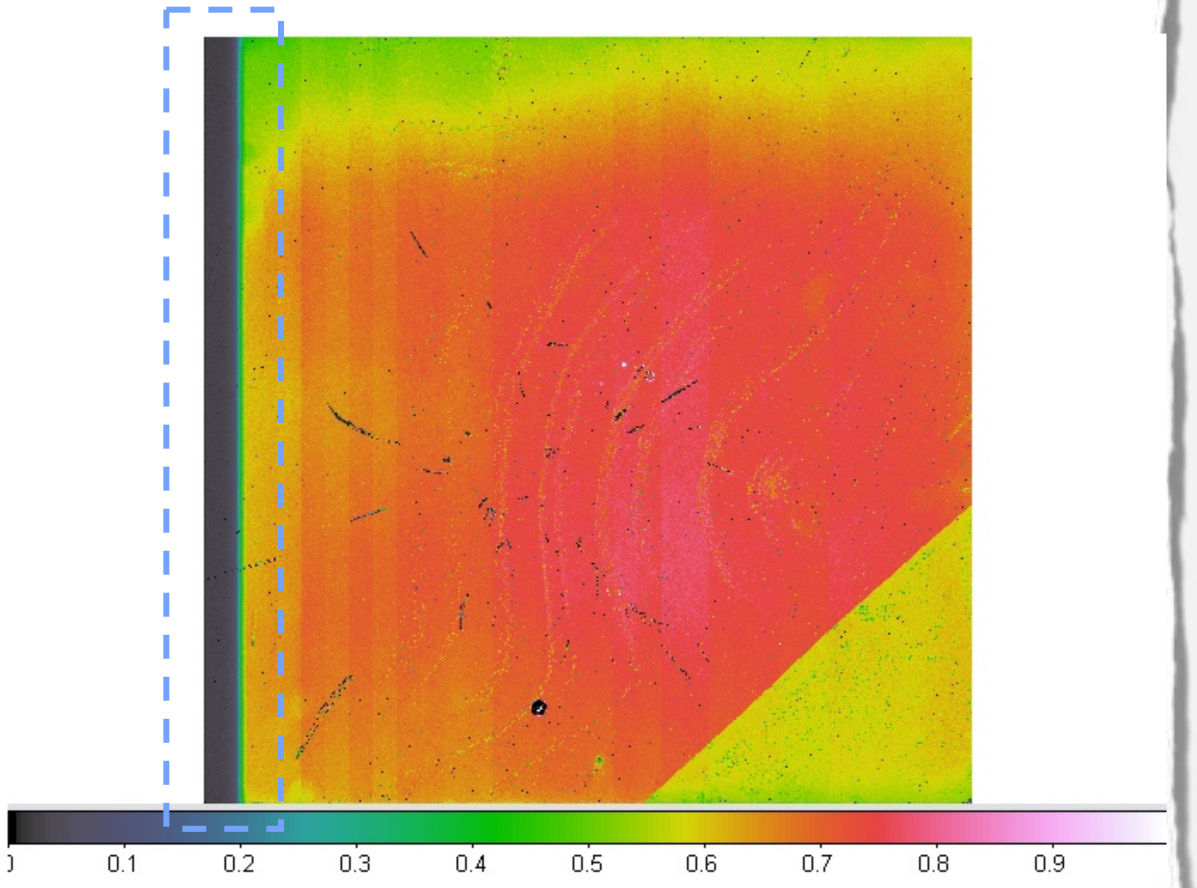


TEST ILLUMINATION UNIFORMITY BY MEASURING QE AT DIFFERENT DETECTOR POSITIONS

part of the detector is now obstructed by the cold shield

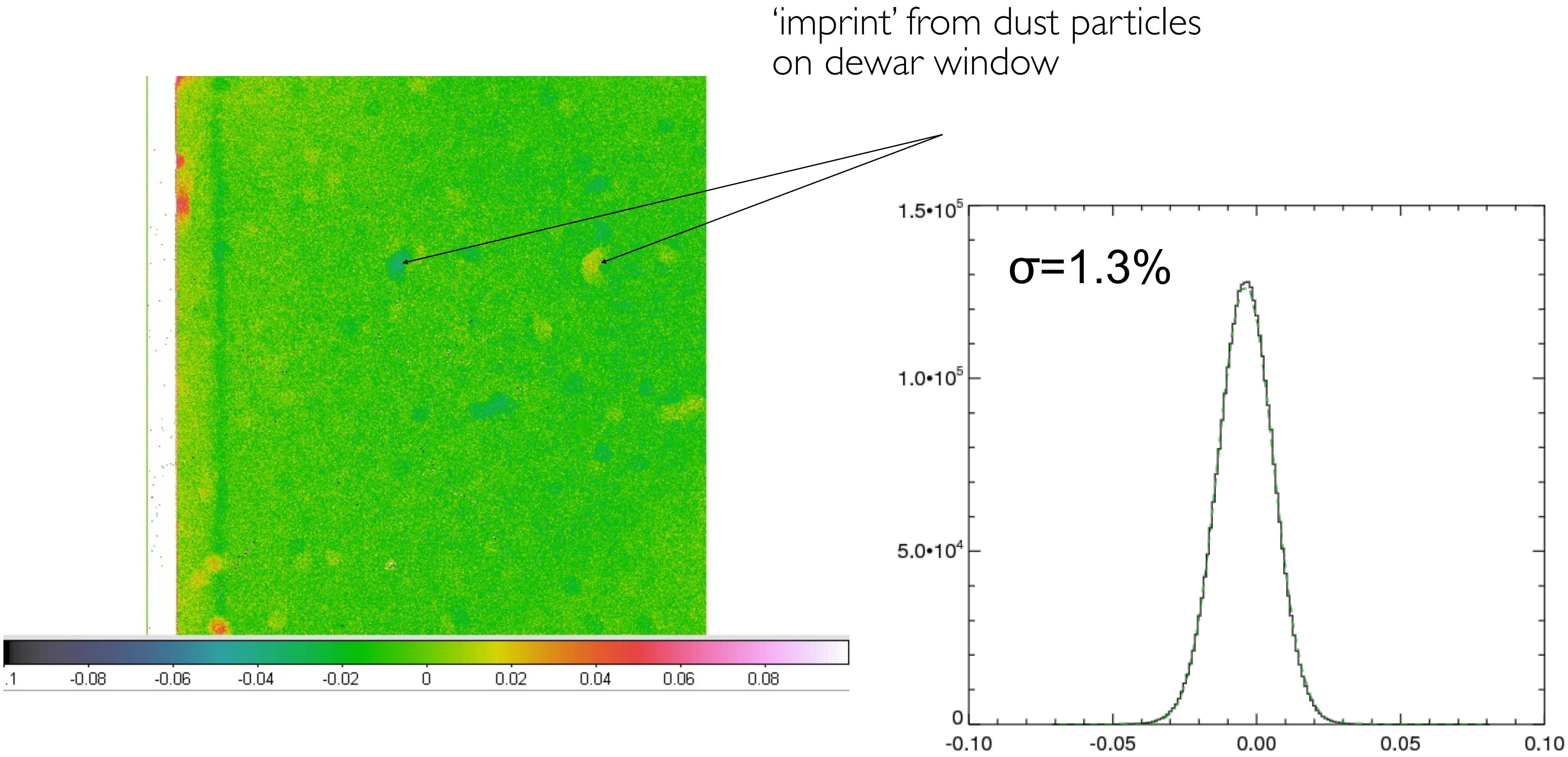


central detector position

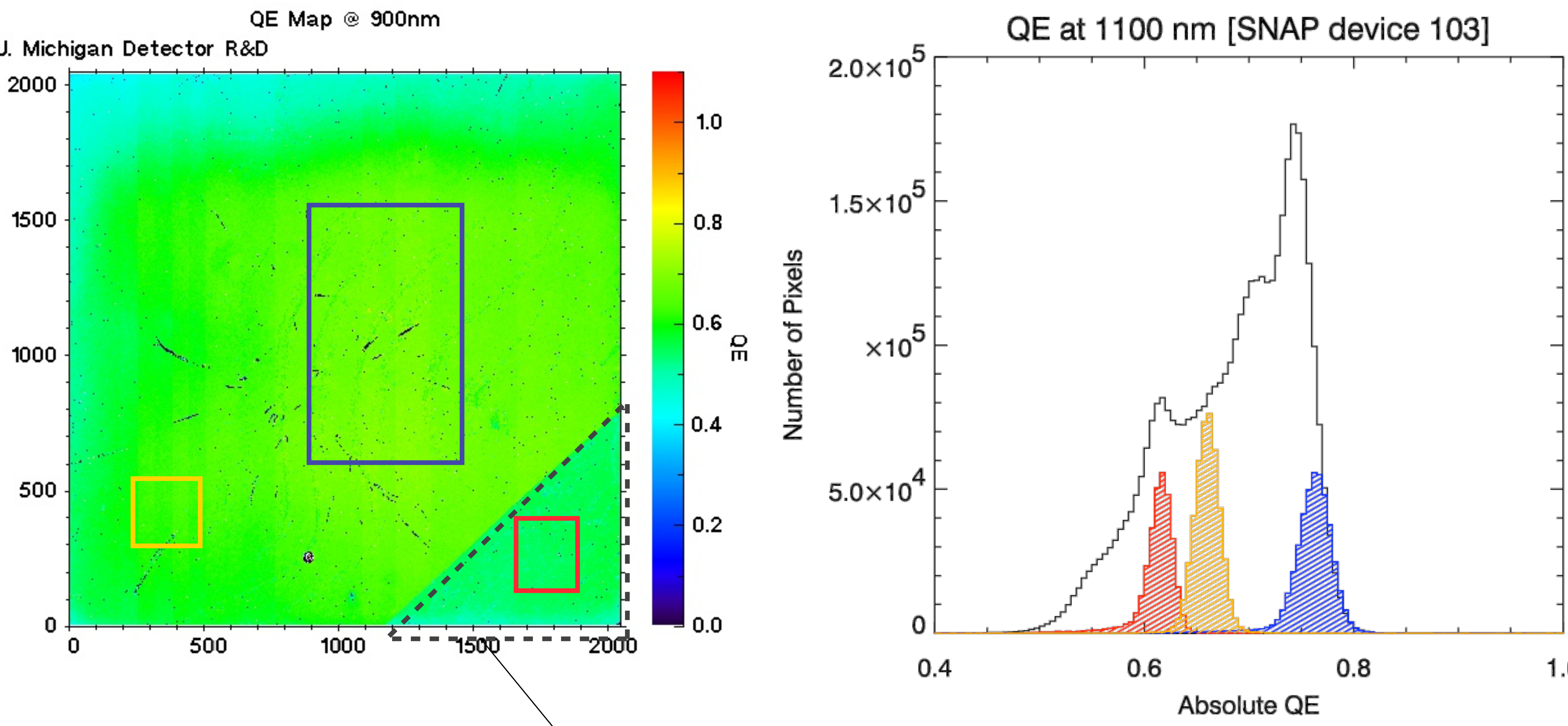


detector moved by 0.75″

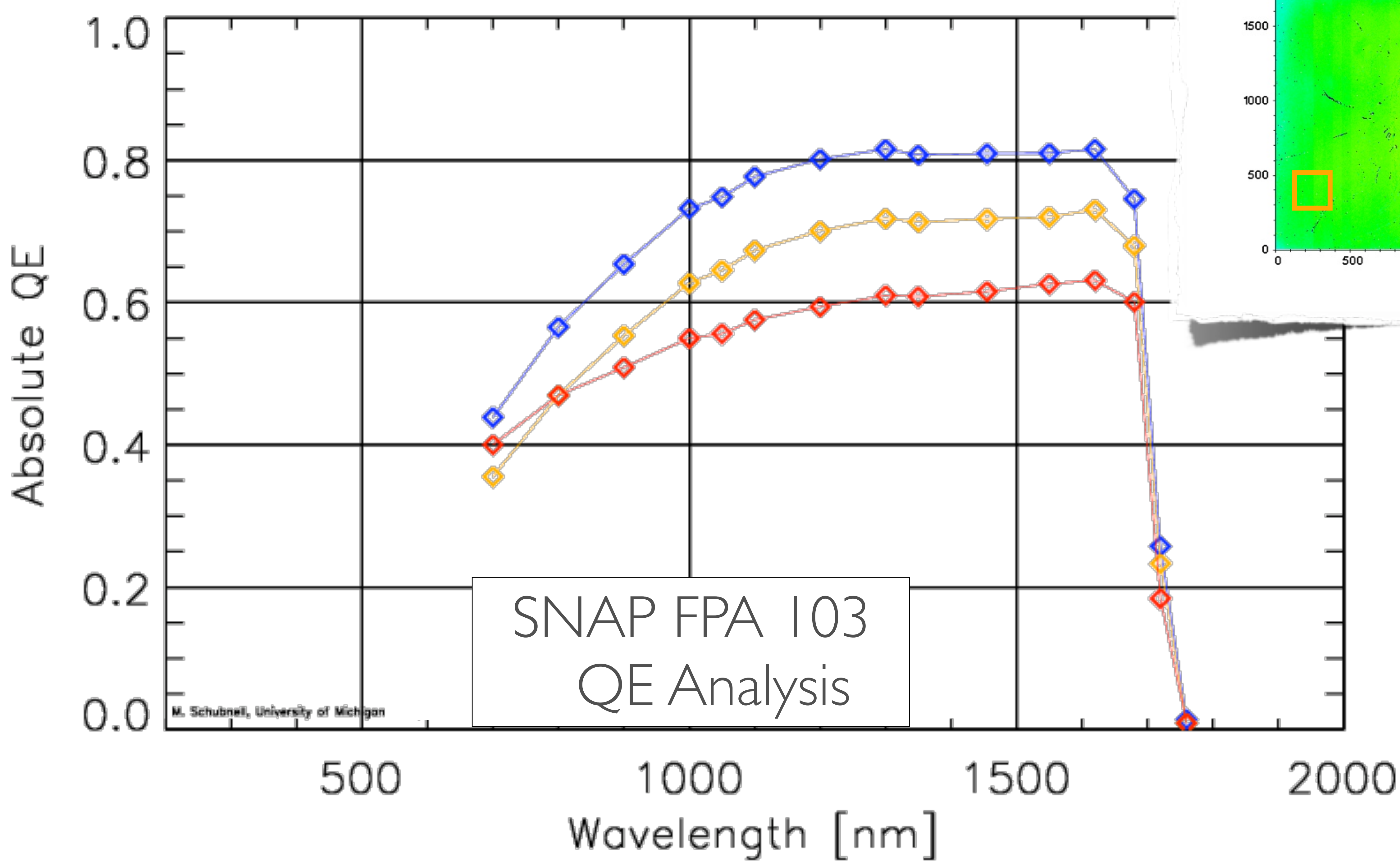
Subtracting the two QE maps from each other results in uniform residuals

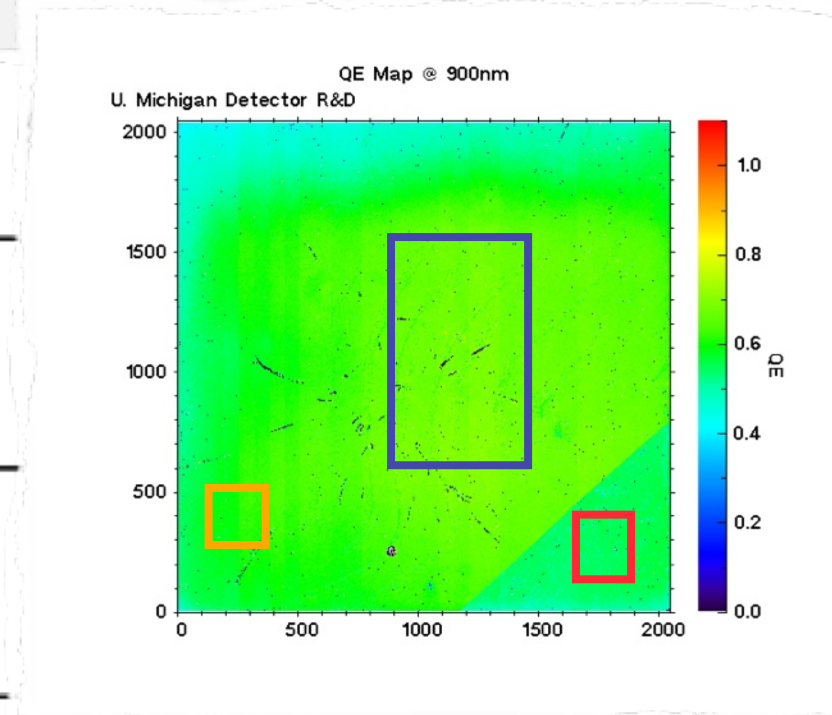


Select three distinct regions for QE analysis



no AR coating


1.0
0.8
0.6
0.4
0.2
0.0
Absolute QE
500
1000
1500
2000
Wavelength [nm]
M. Schubnell, University of Michigan
SNAP FPA 103
QE Analysis


QE Map @ 900nm
U. Michigan Detector R&D
2000
1500
1000
500
0
0
500
1000
1500
2000
1.0
0.8
0.6
0.4
0.2
0.0
QE

Now Let Us Take a Look at the Systematic Uncertainties

Possible Systematic Uncertainties

Non-uniformity of illumination

Stray light (baffle, dewar window edges etc.)

Reference photo diode calibration and position

Radiation through (and from) warm dewar window

Conversion gain measurement

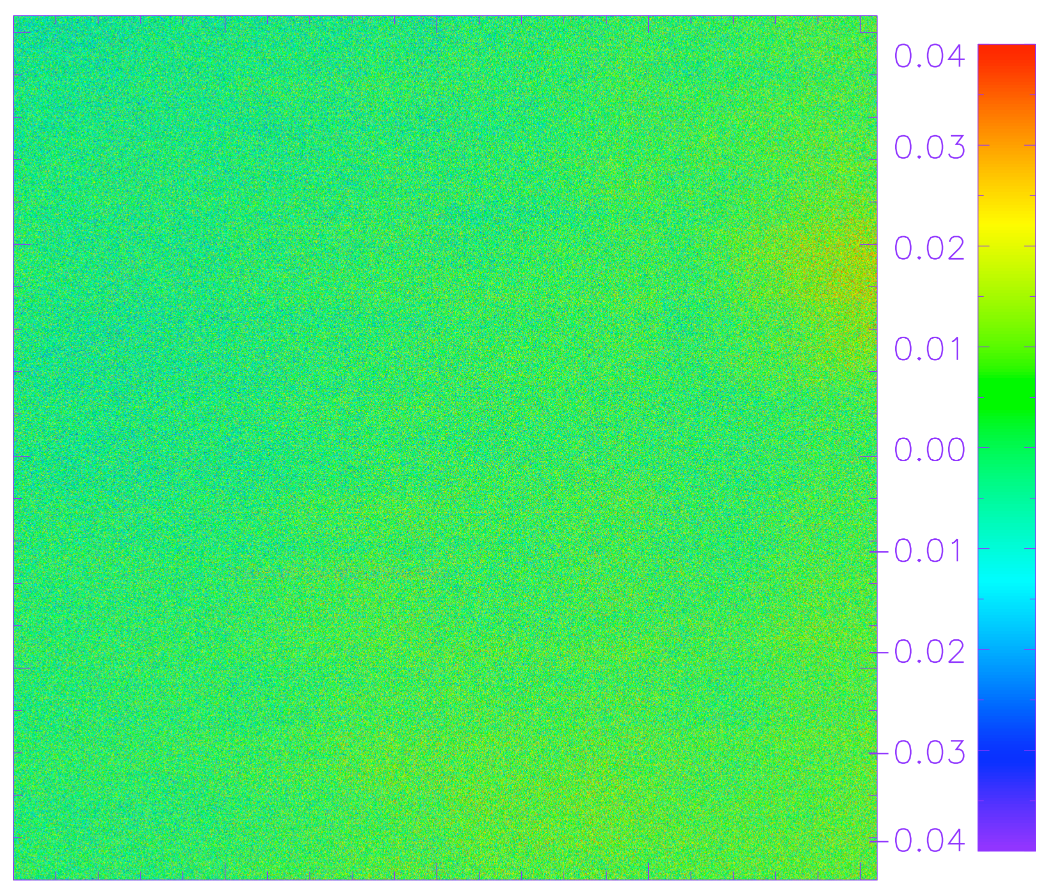
Exposure time length

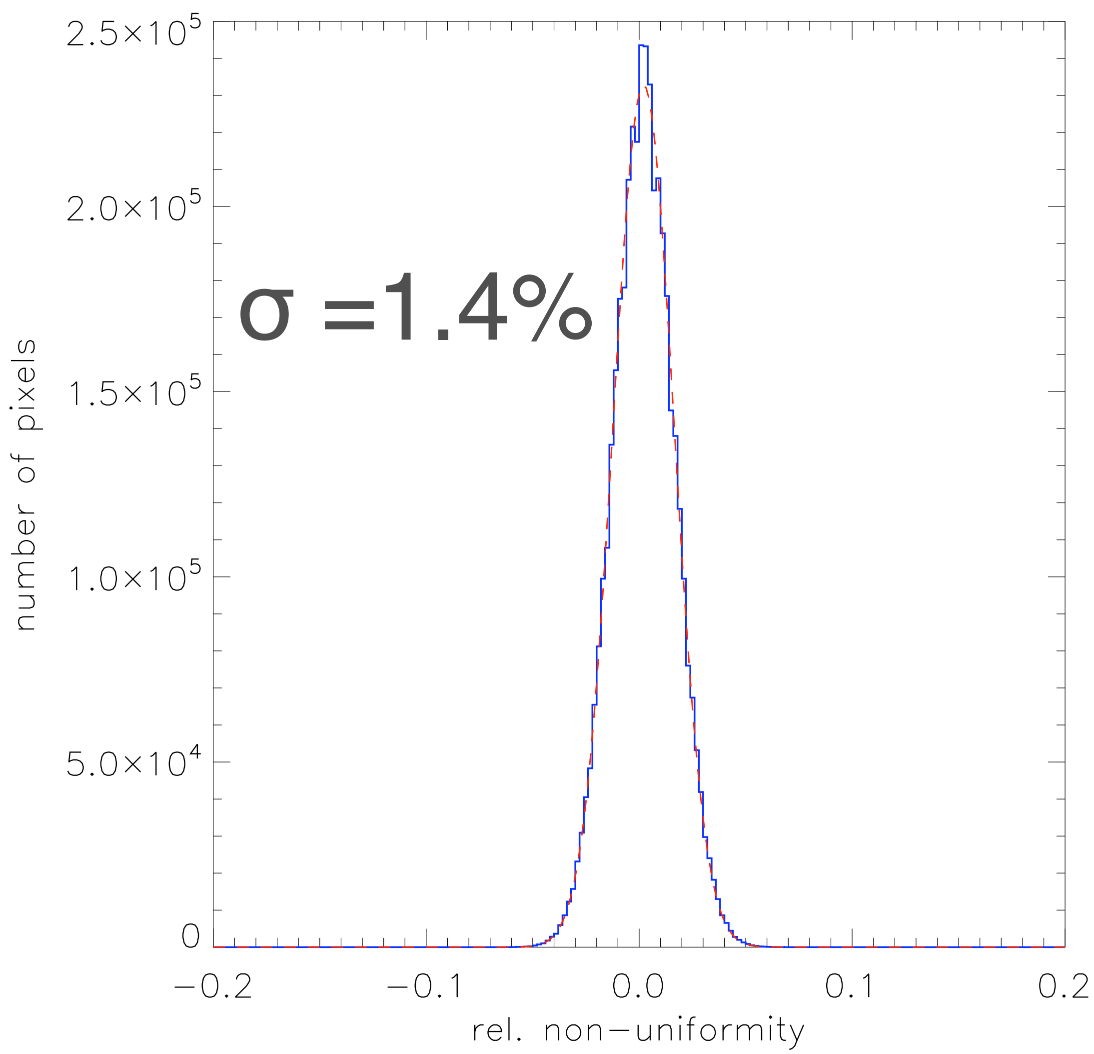
Filter / monochromator calibration

Absolute QE Measurement - Error Budget

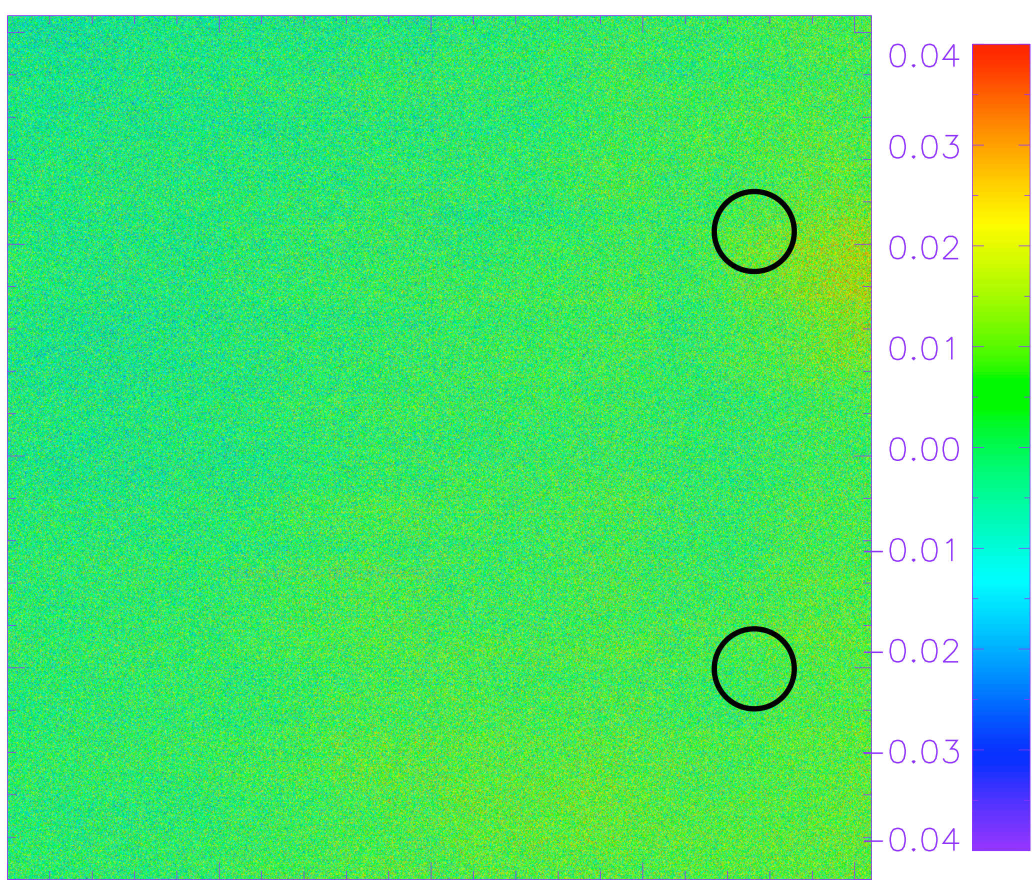
quantity	rel. uncertainty (QE)	how obtained
photo diode calibration	< 1% Si diode (500 nm - 950 nm) < 1.5 % InGaAs (700 nm -1600 nm) < 2 % InGaAs (1600 nm - 1750 nm)	propagated from NIST data + transfer error
illumination uniformity & stability	1.4%	measured
conversion gain	1%	measured
filter / monochromator calibration	< .5% / (<.5%)	measured / estimated
thermal background (warm baffle)	< .5%	estimated
exposure time & geometry	<< 1%	measured

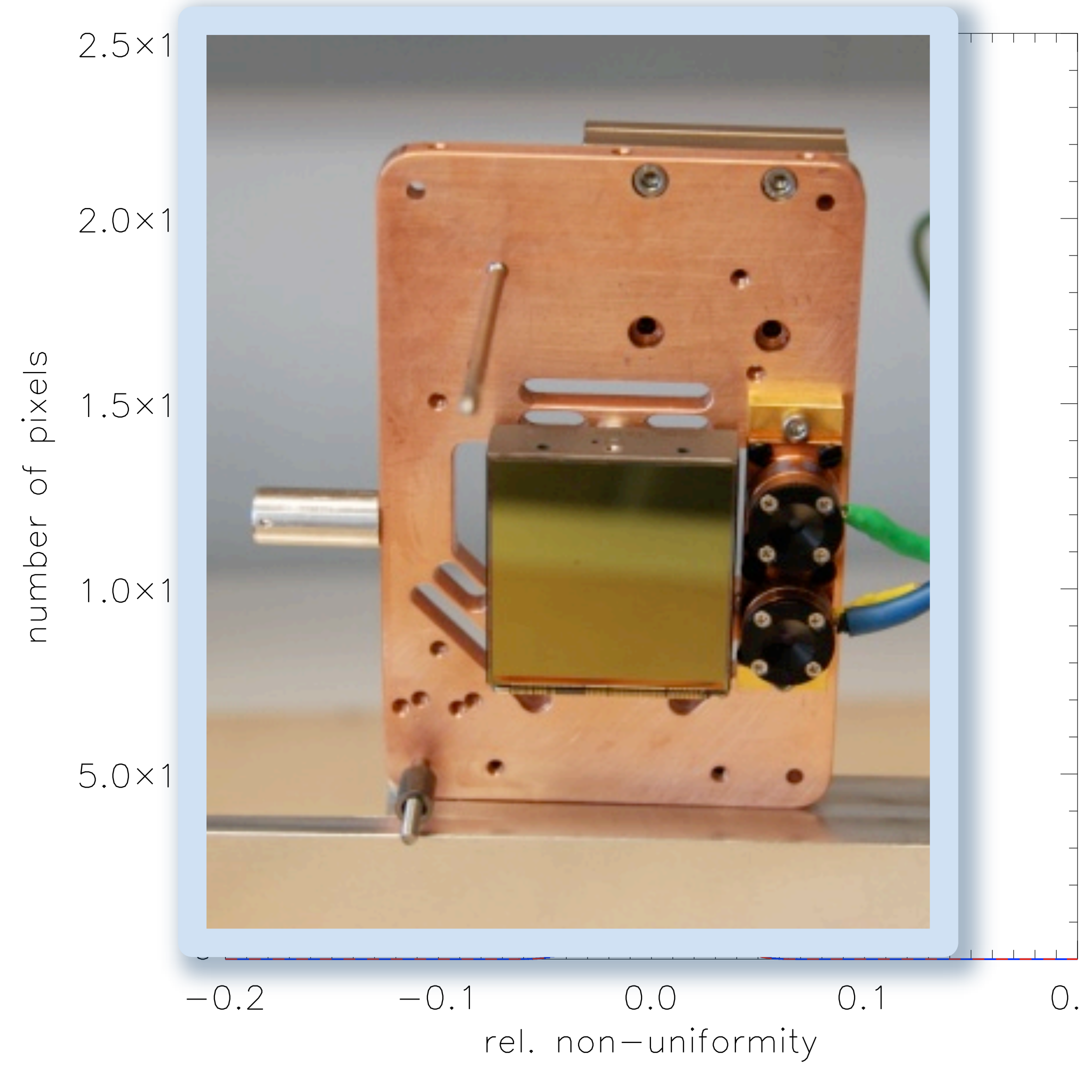
ILLUMINATION UNIFORMITY





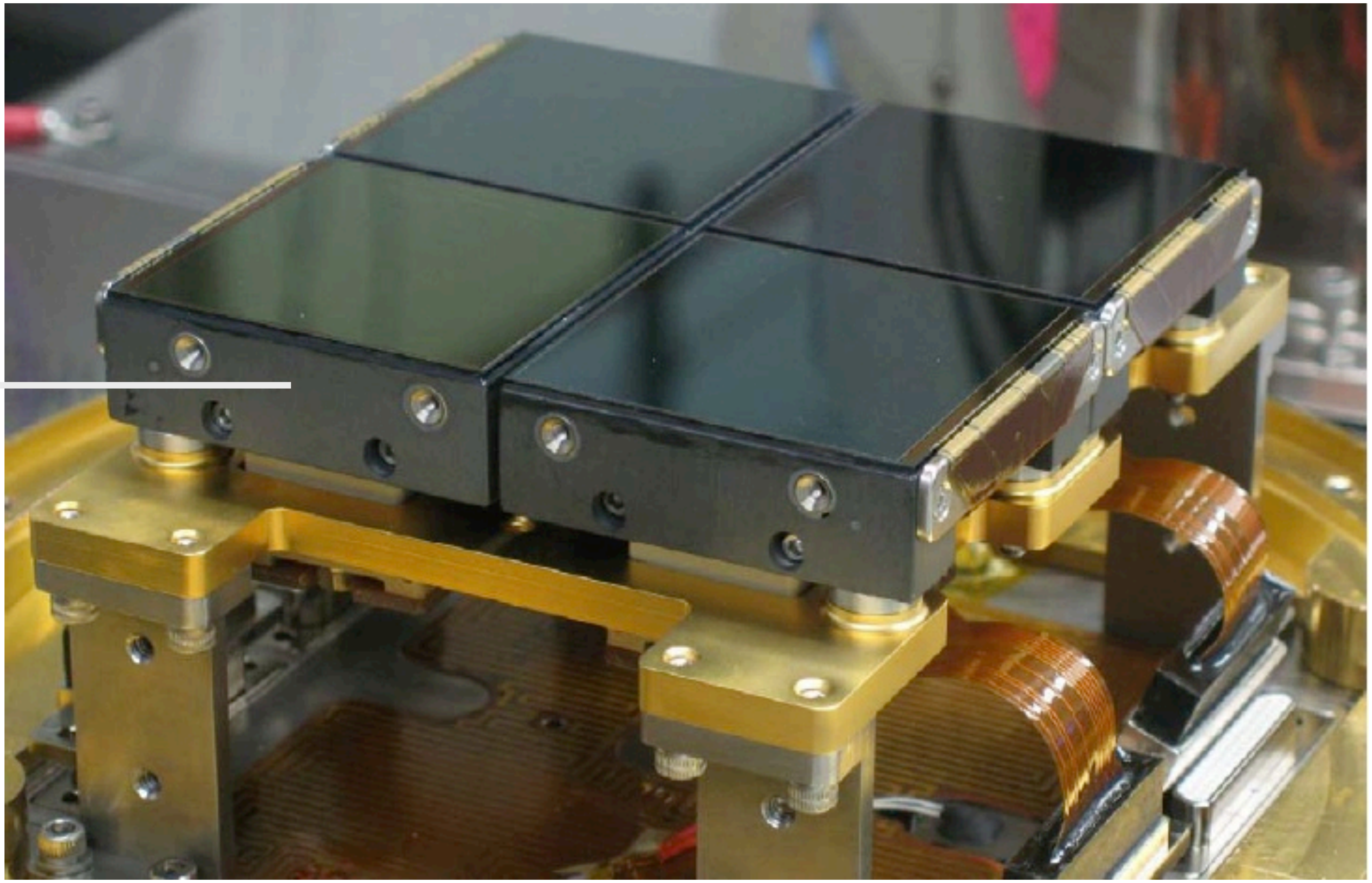
ILLUMINATION UNIFORMITY





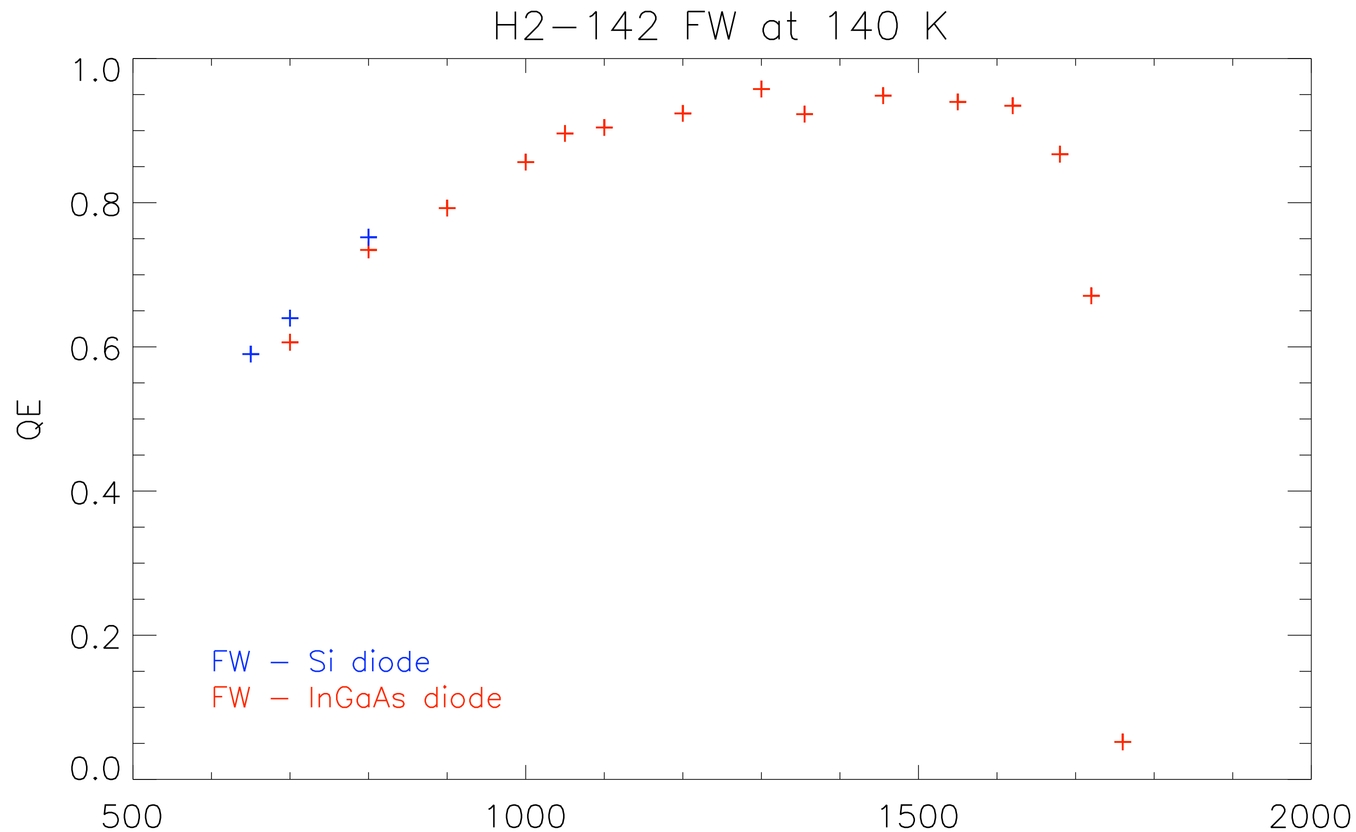
1.7 micron 2k x 2k HgCdTe detectors developed for the SNAP project by TIS mounted onto the mission specific SiC packaging developed at UM

SiC

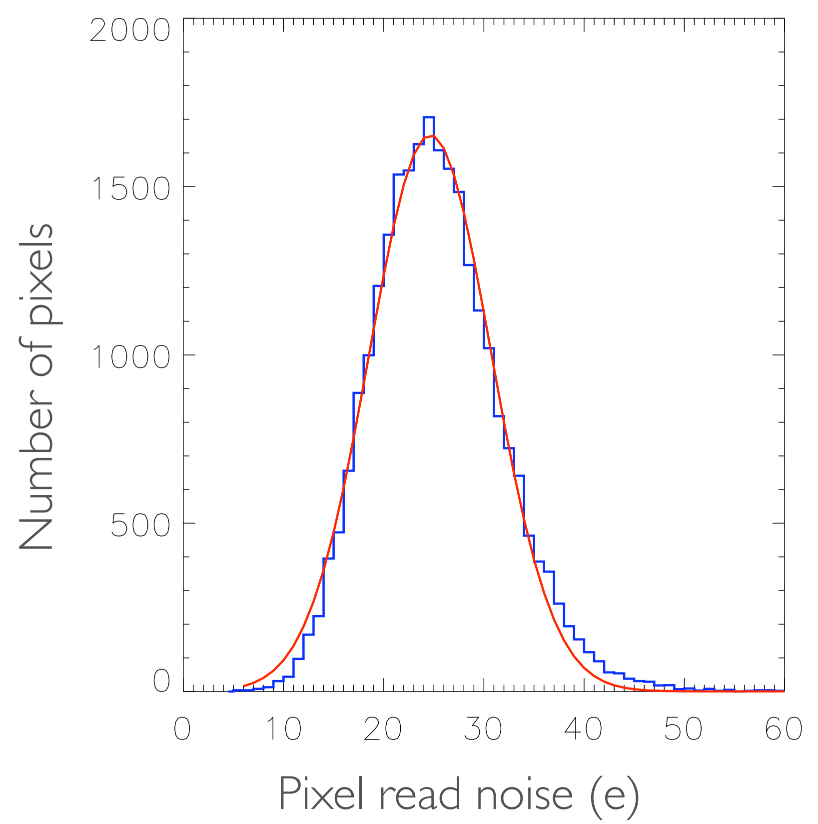


Measurements of gain, read noise, dark current and QE made in our lab did not identify any effect of the new detector package material on the detector characteristics.

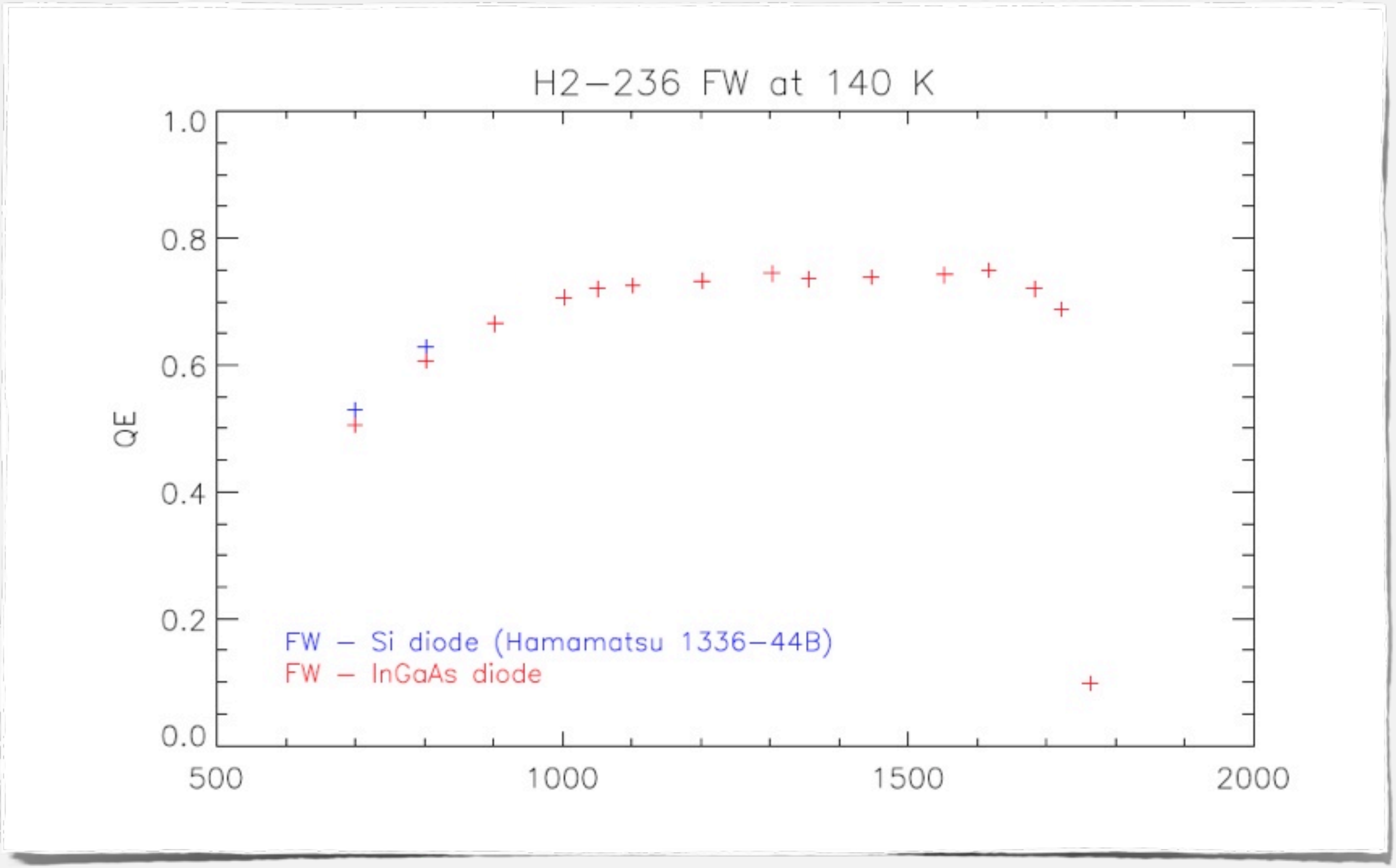
H2-142



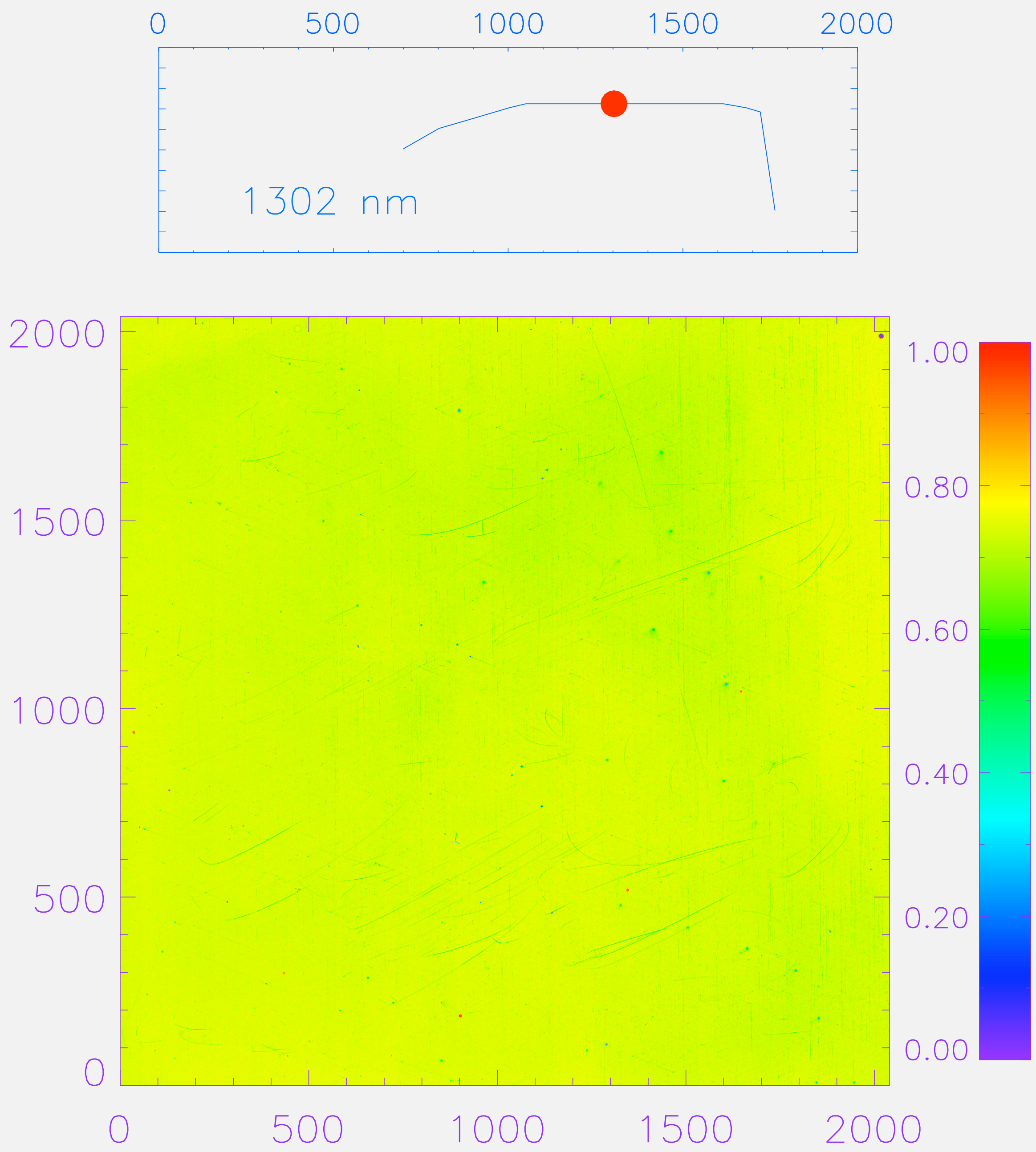
CDS read noise (average) : 24.7 e



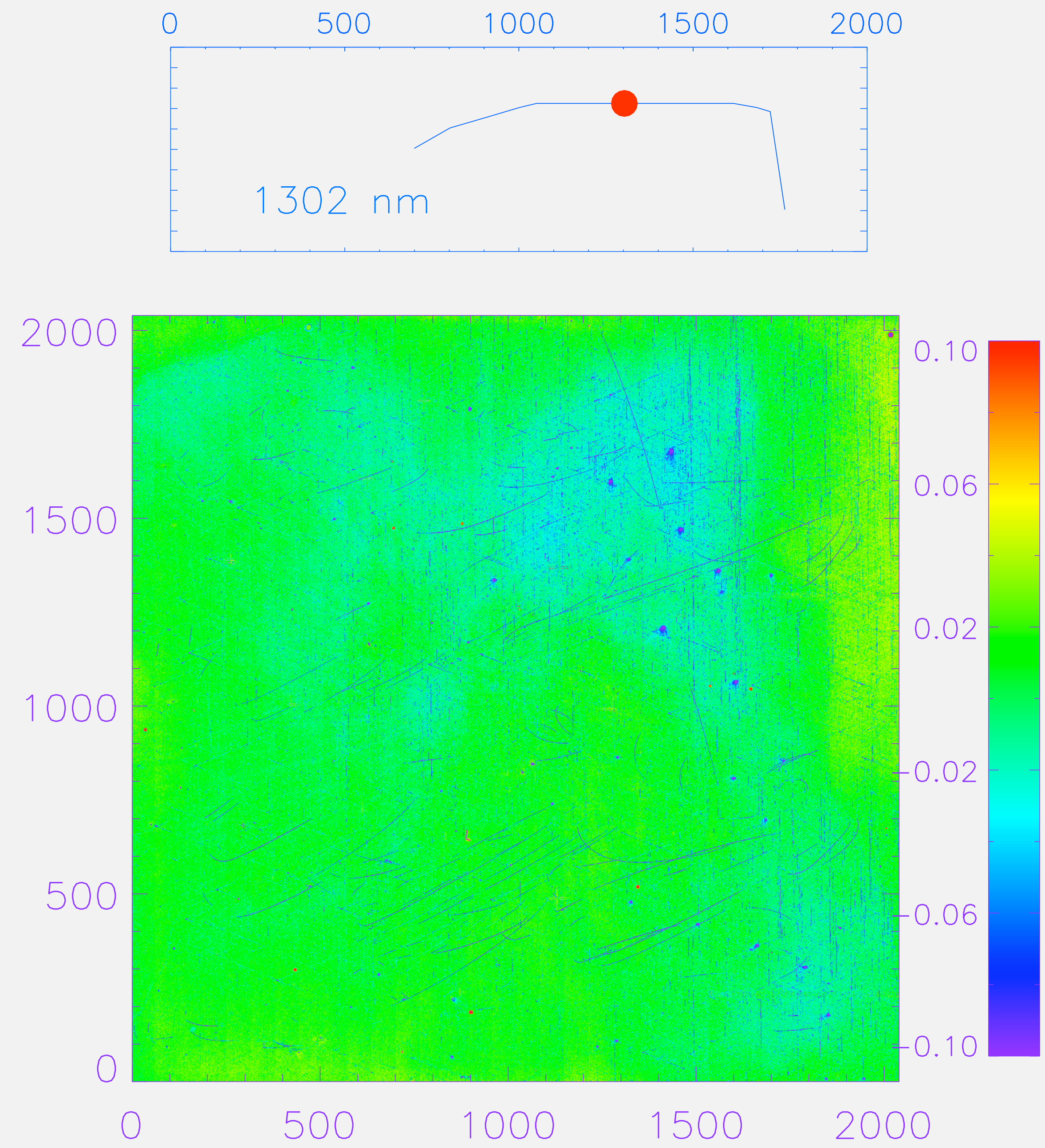
H2-236 QE


H2−236 FW at 140 K
QE
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
1500
2000
FW − Si diode (Hamamatsu 1336−44B)
FW − InGaAs diode

H2RG-236 QE MAPS

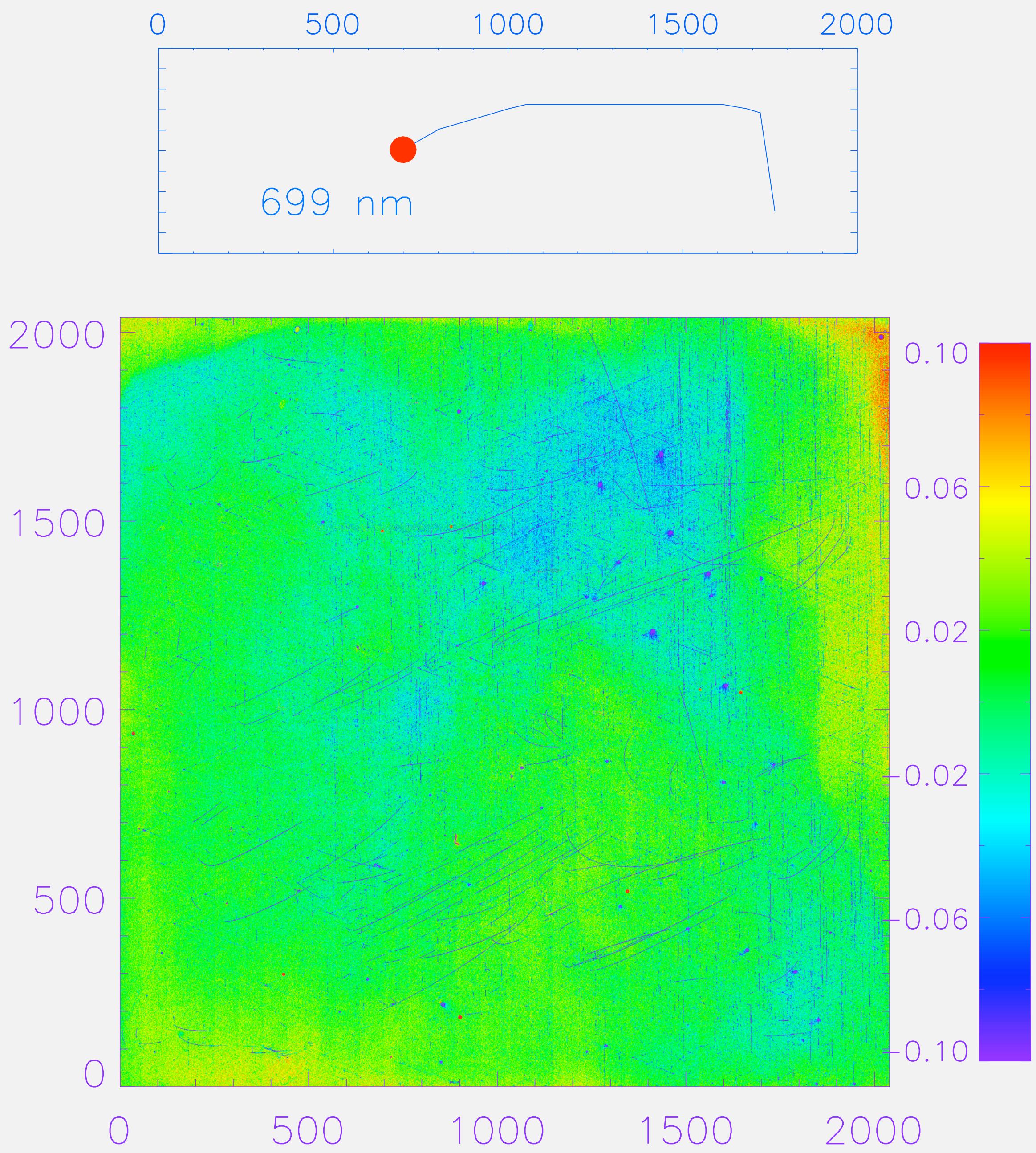


Absolute QE

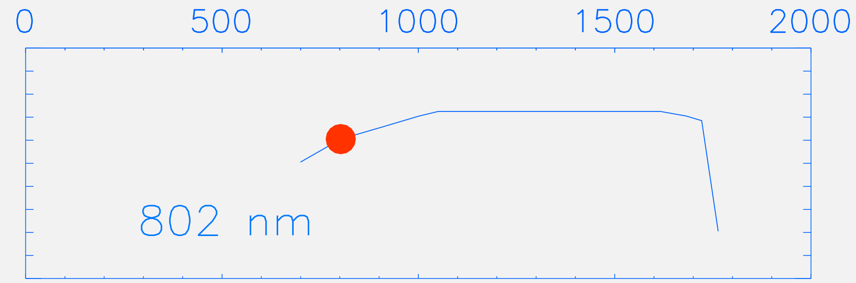


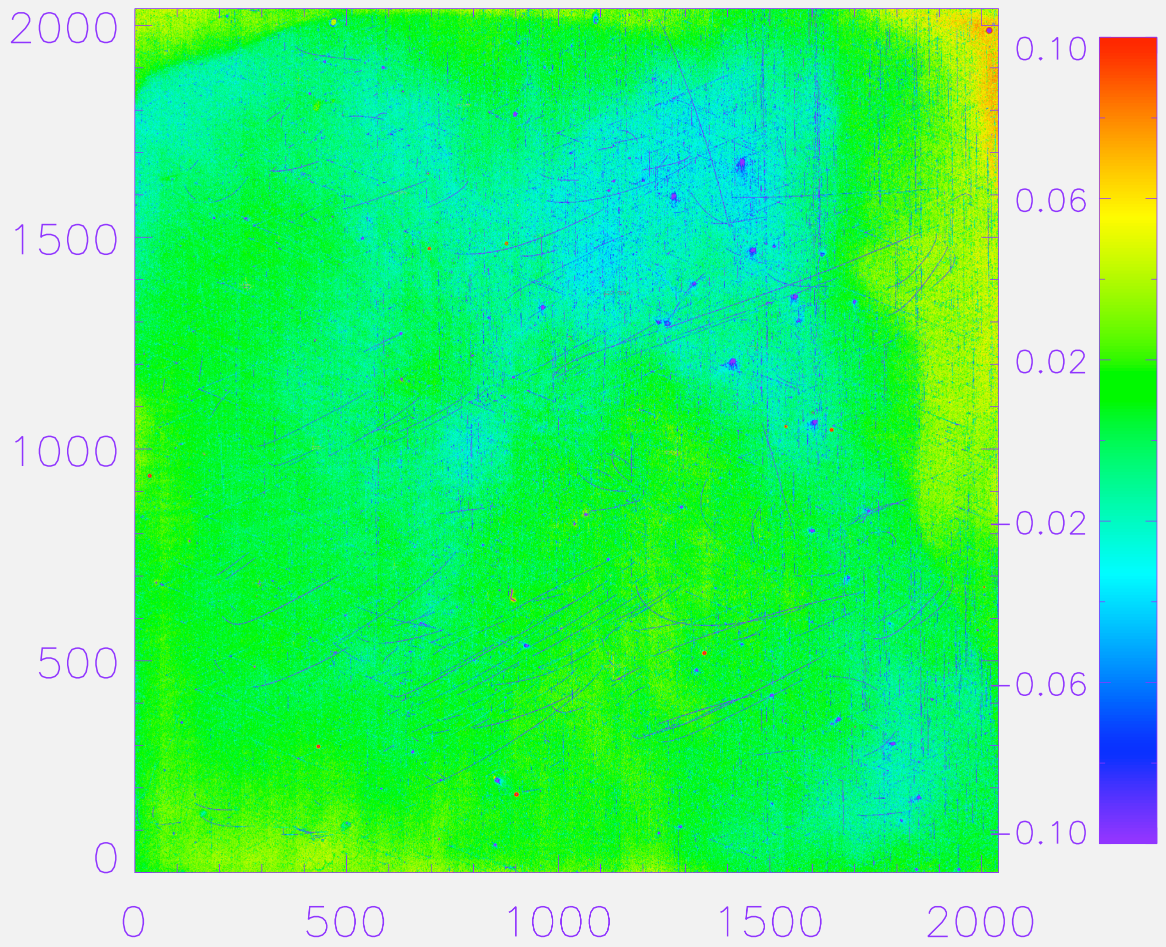
Relative deviation from mean QE reveals percent level structure

QE MAP H2RG-236

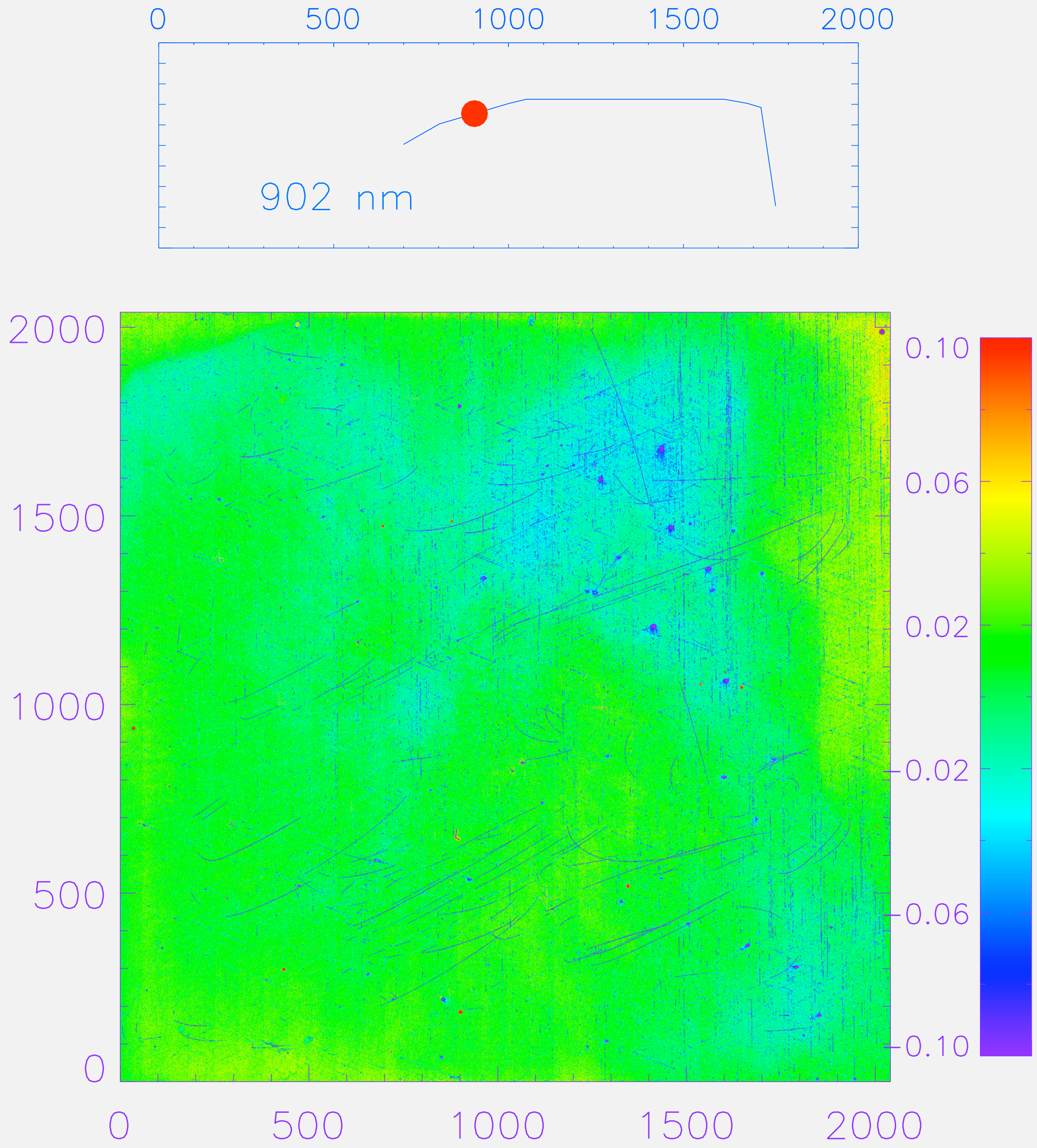


QE MAP H2RG-236

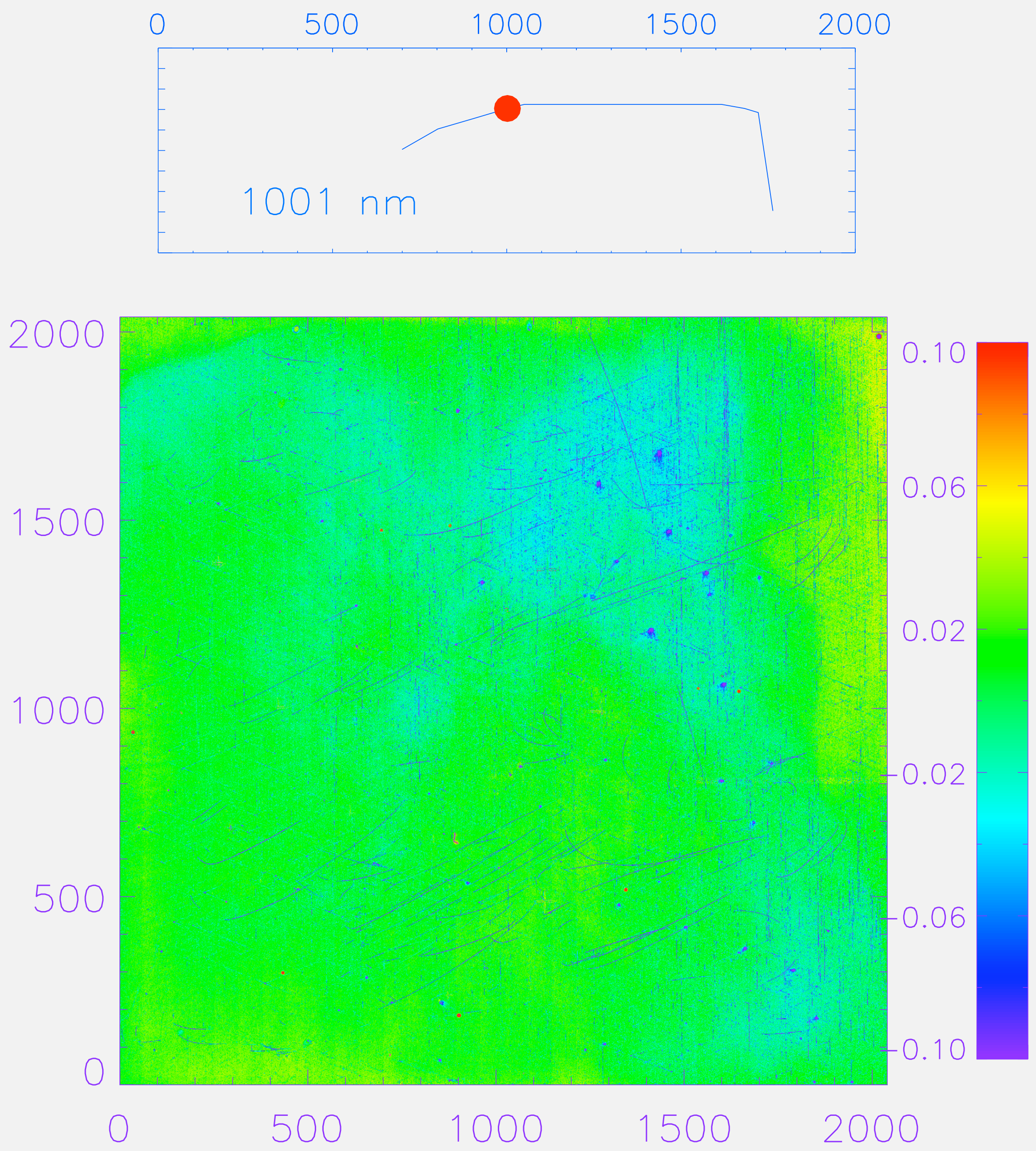




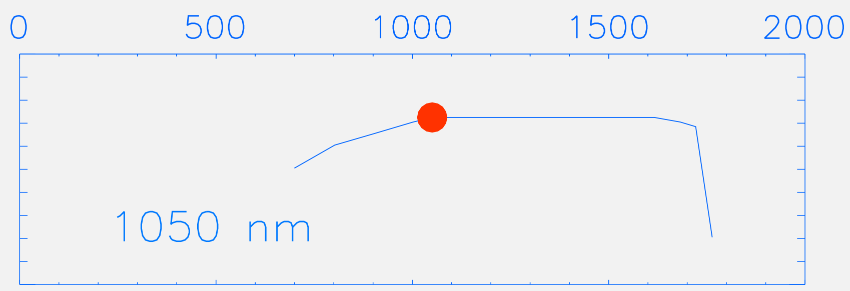
QE MAP H2RG-236

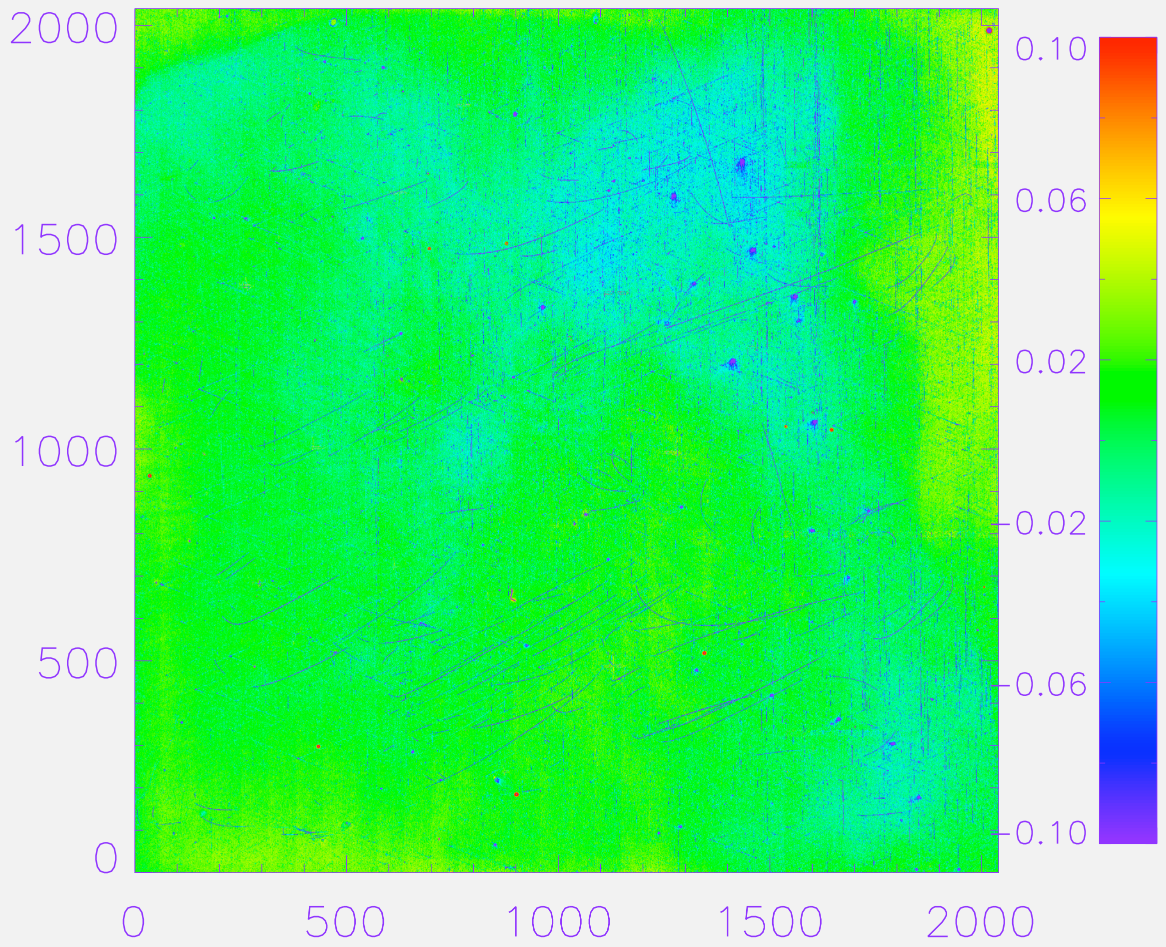


QE MAP H2RG-236

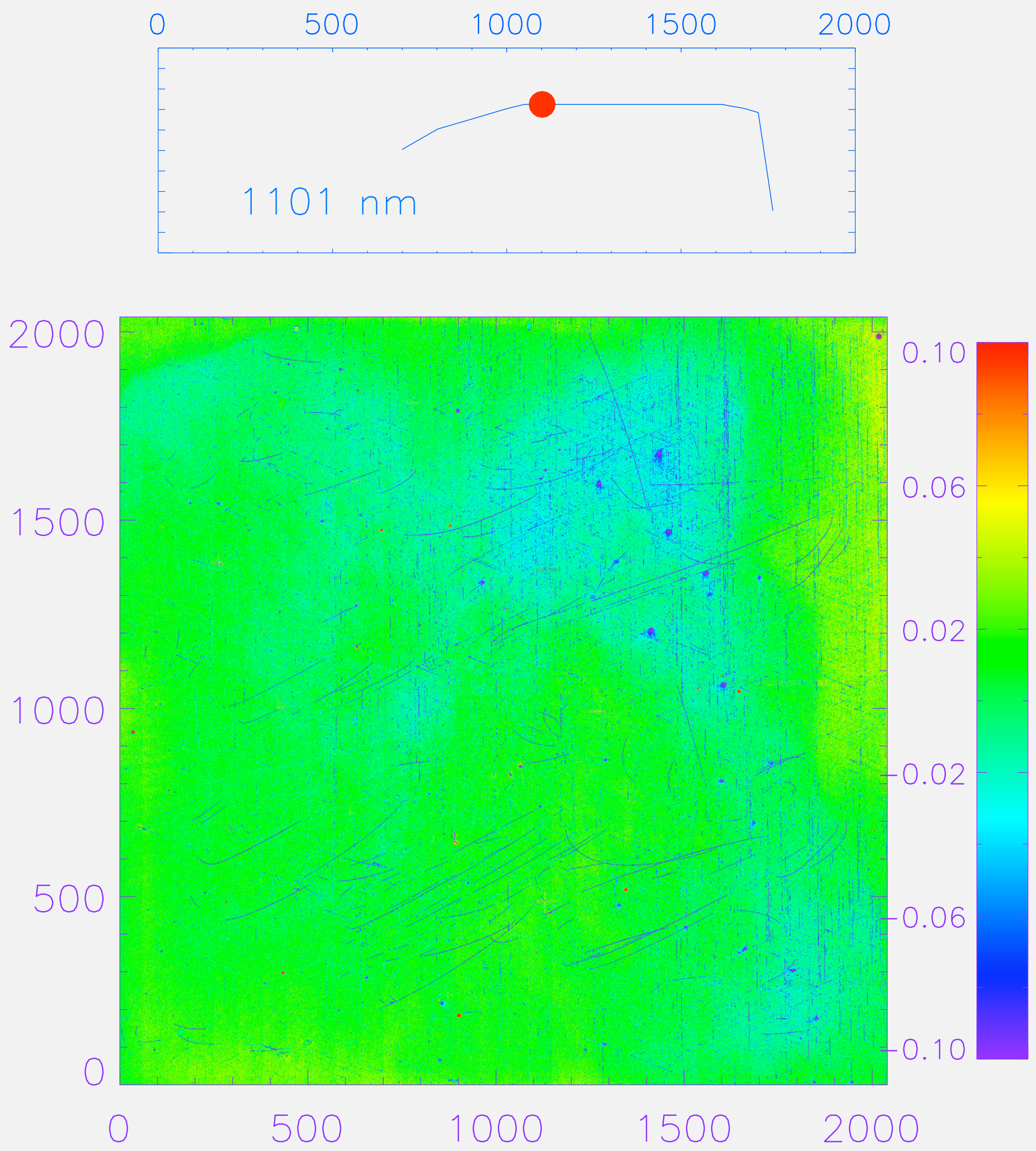


QE MAP H2RG-236

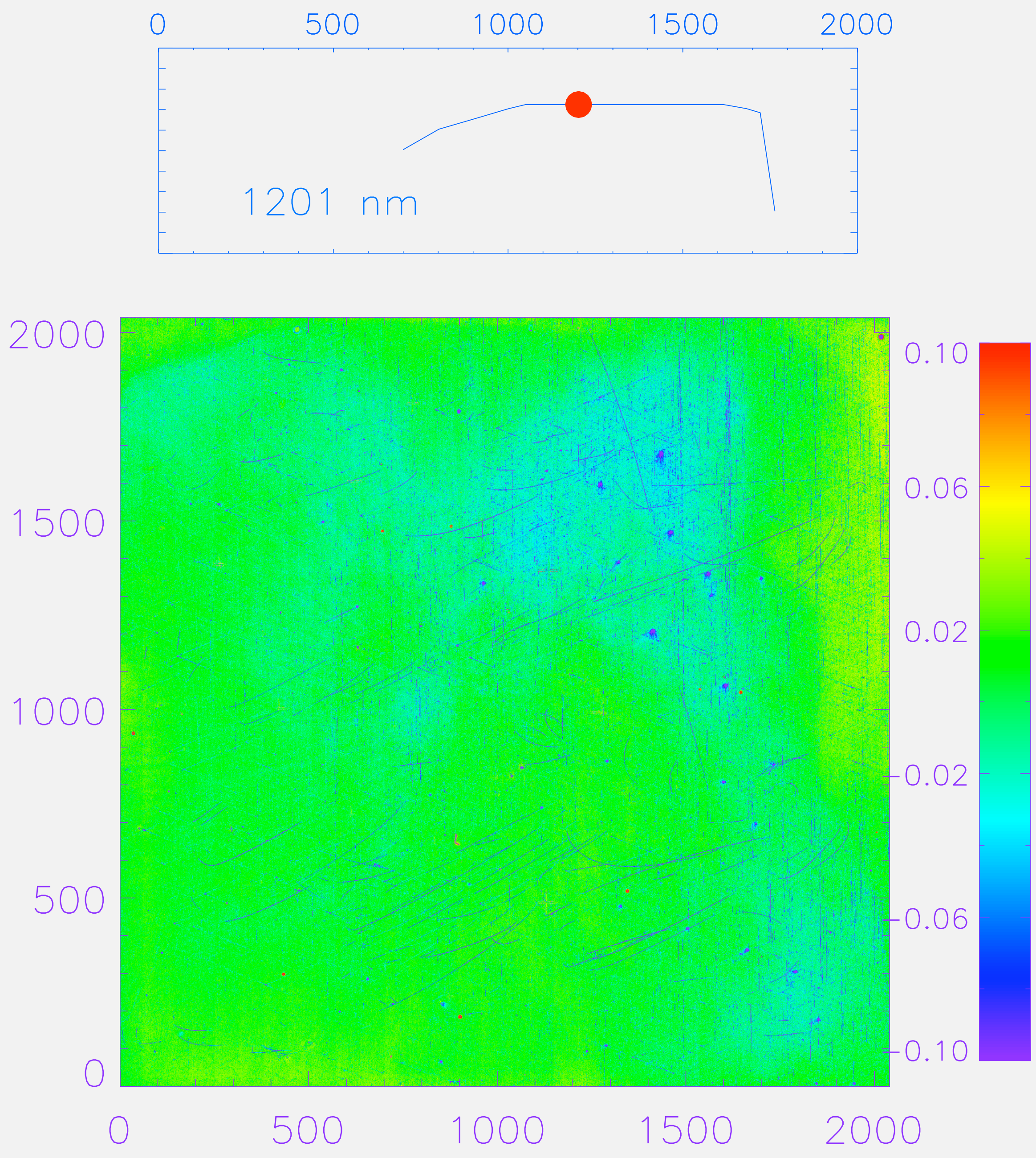




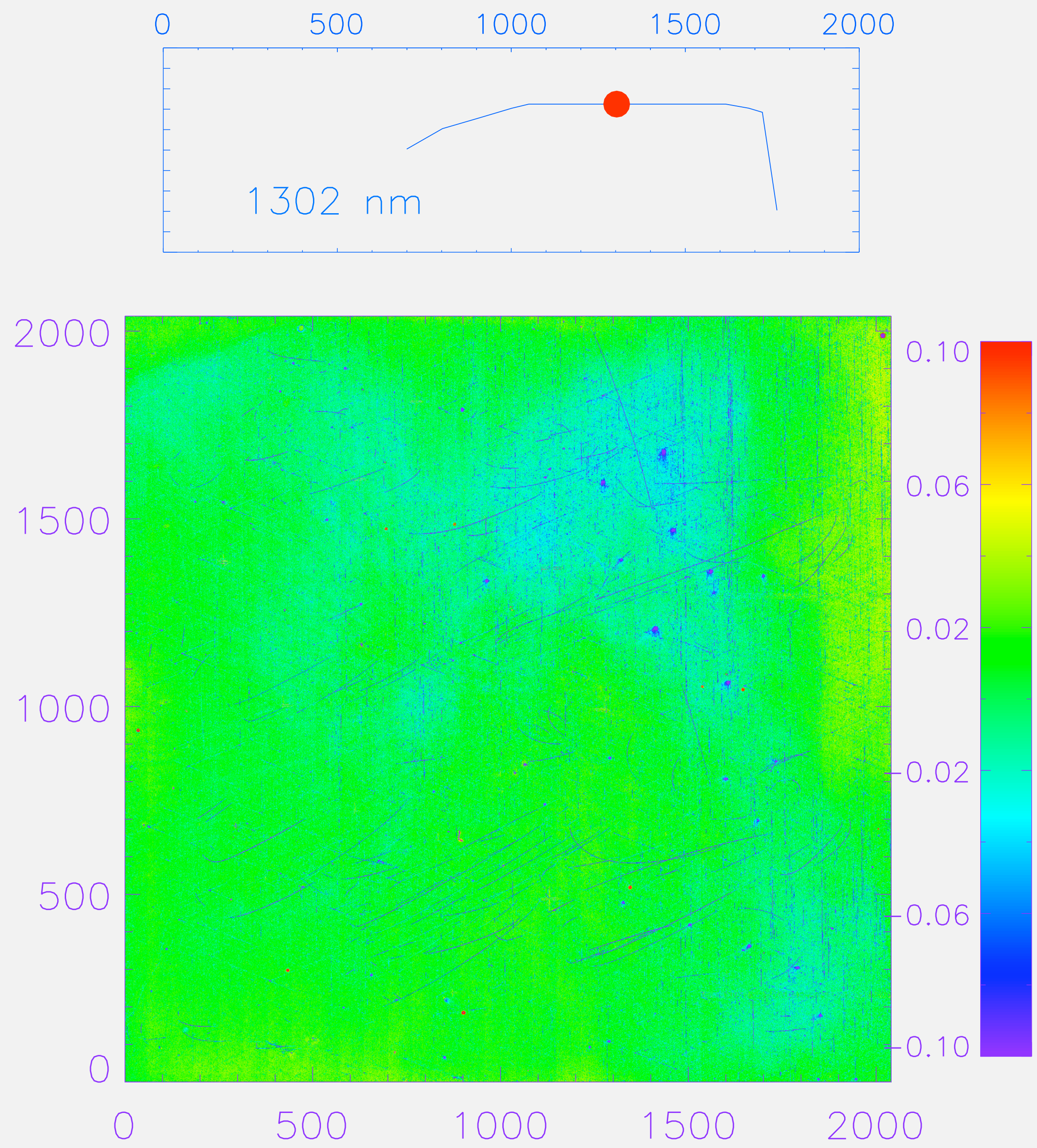
QE MAP H2RG-236



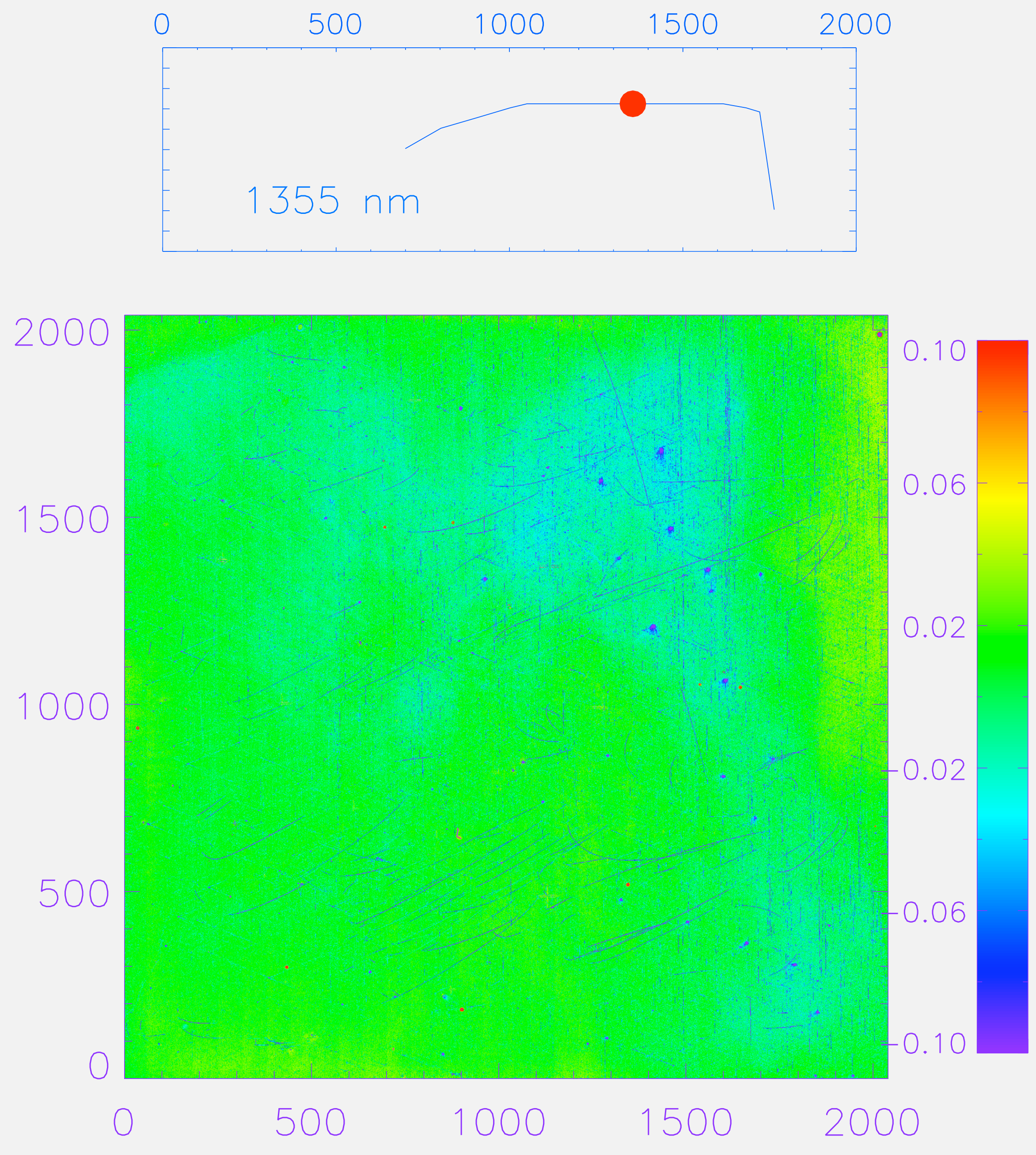
QE MAP H2RG-236



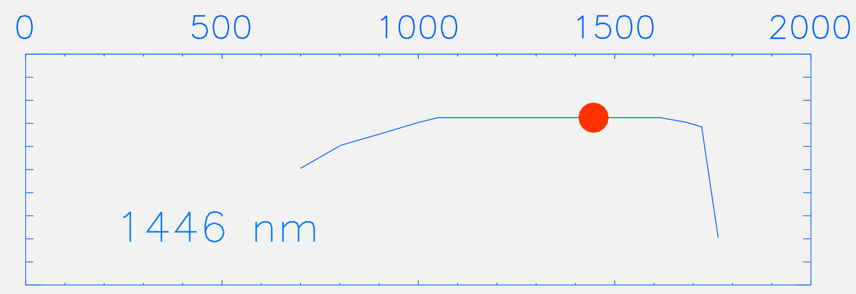
QE MAP H2RG-236

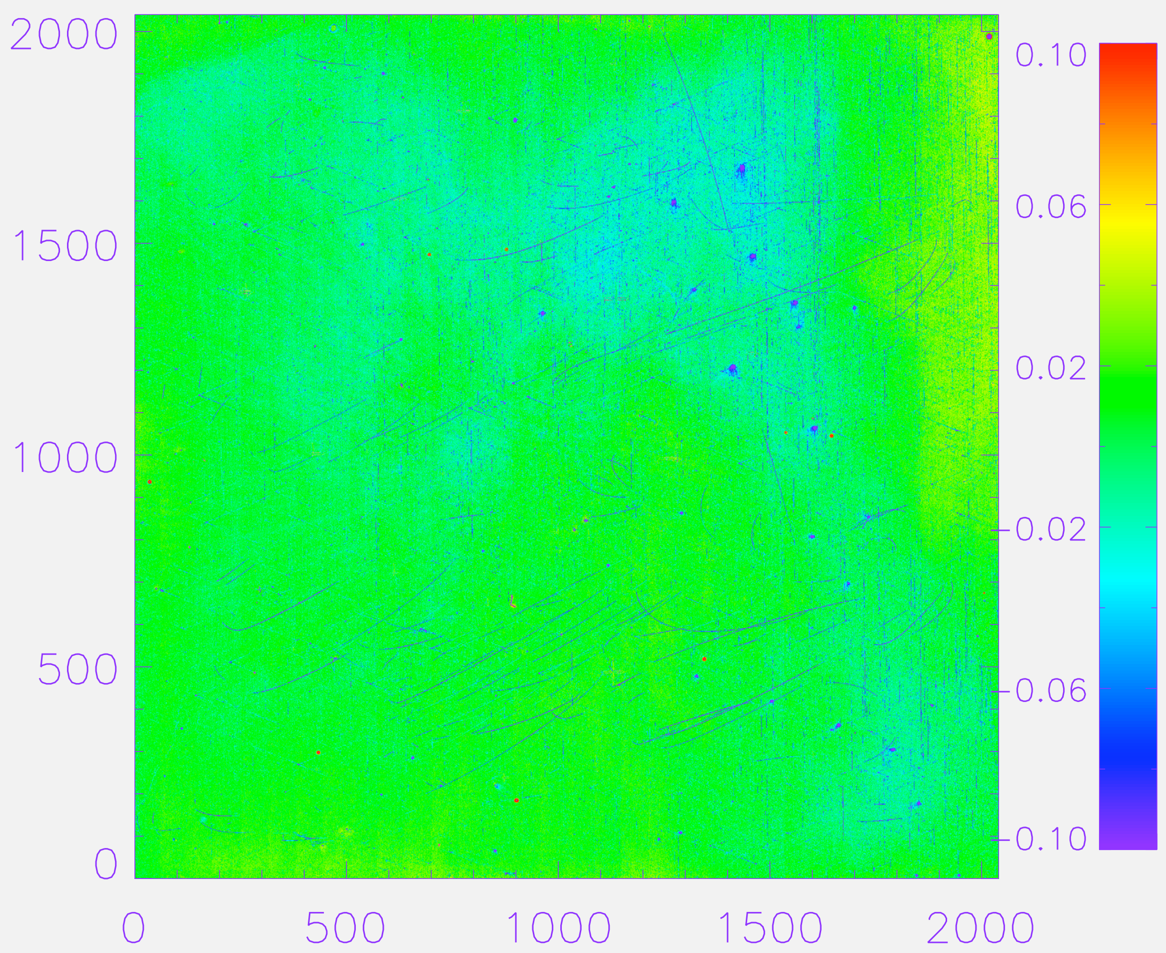


QE MAP H2RG-236

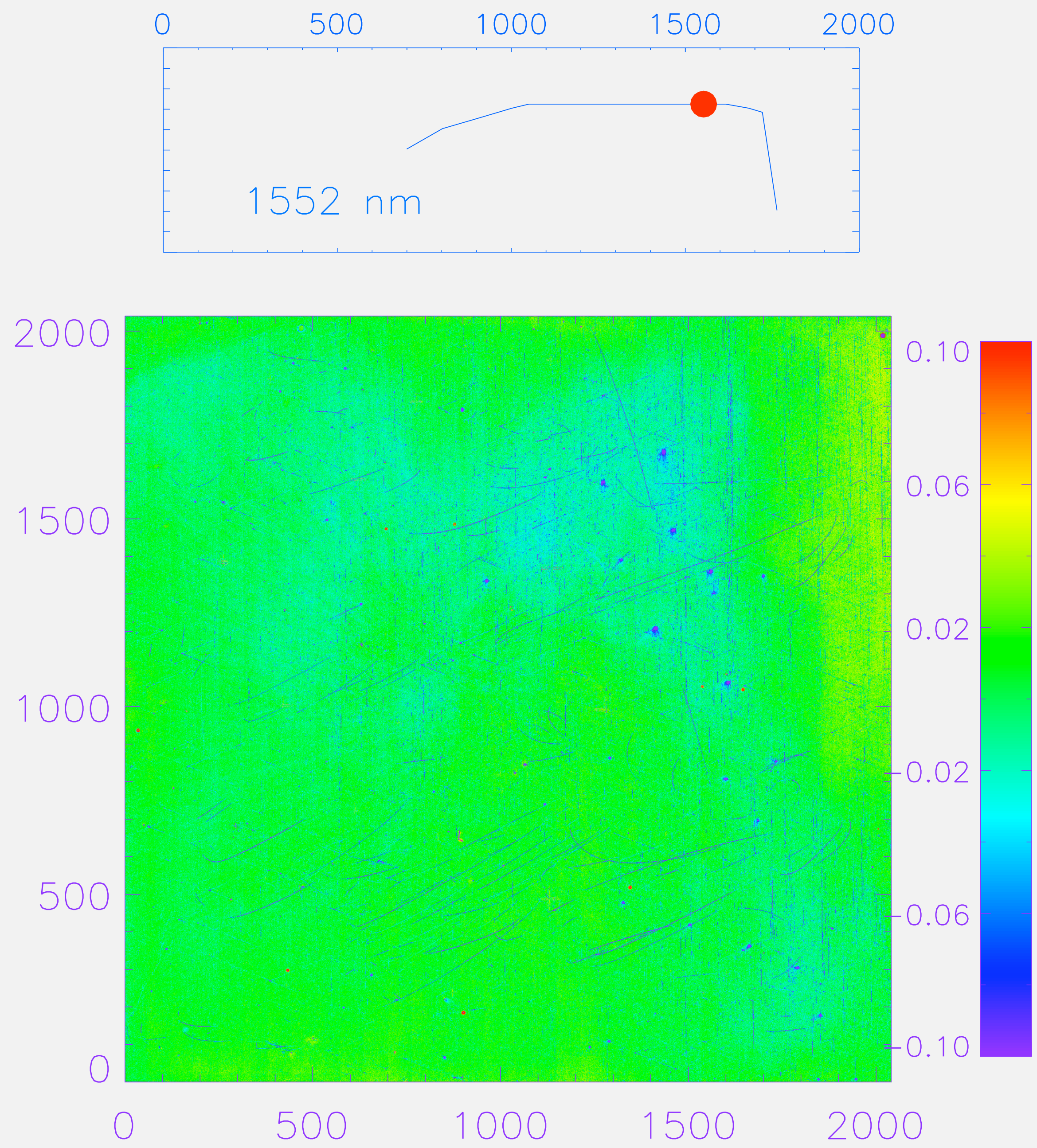


QE MAP H2RG-236

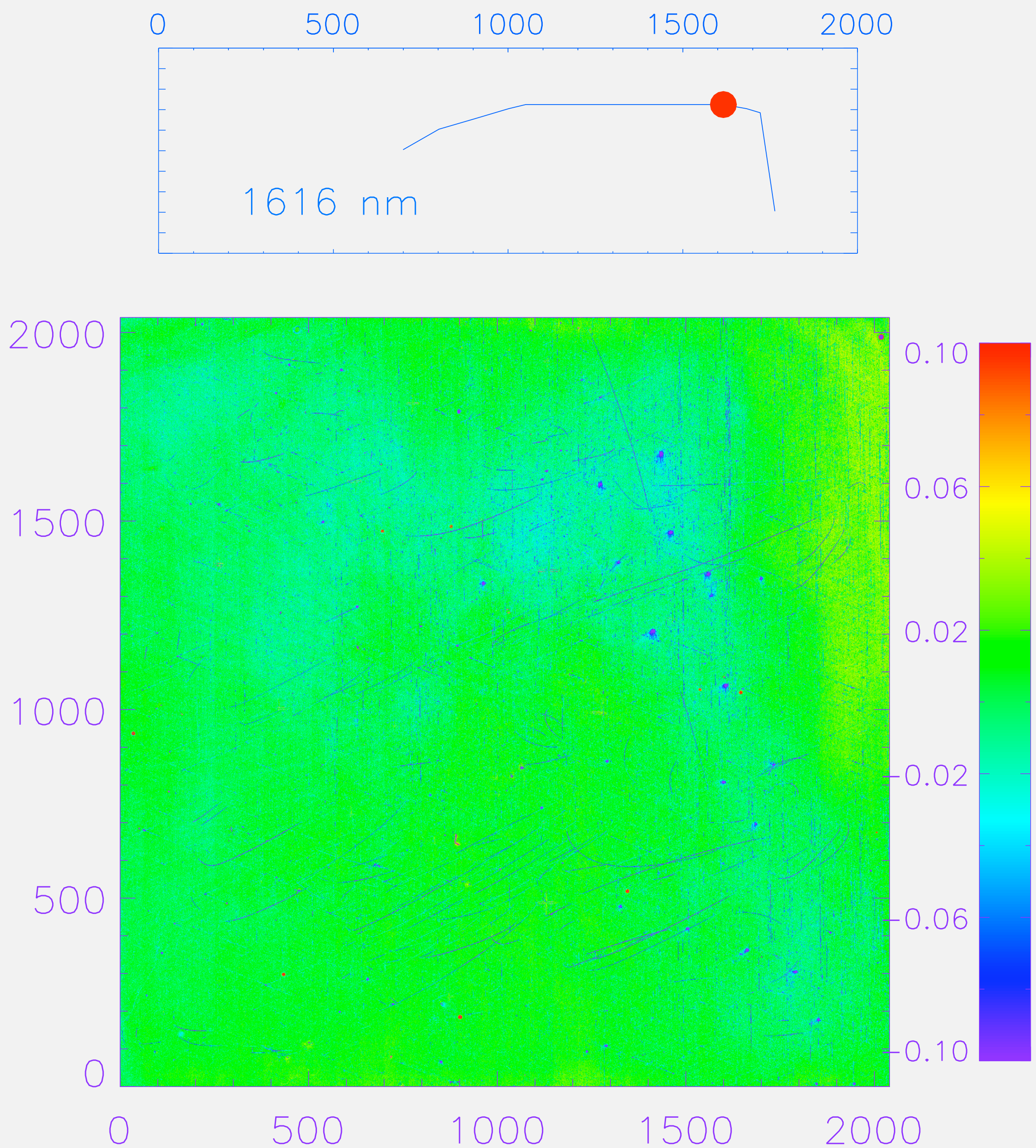




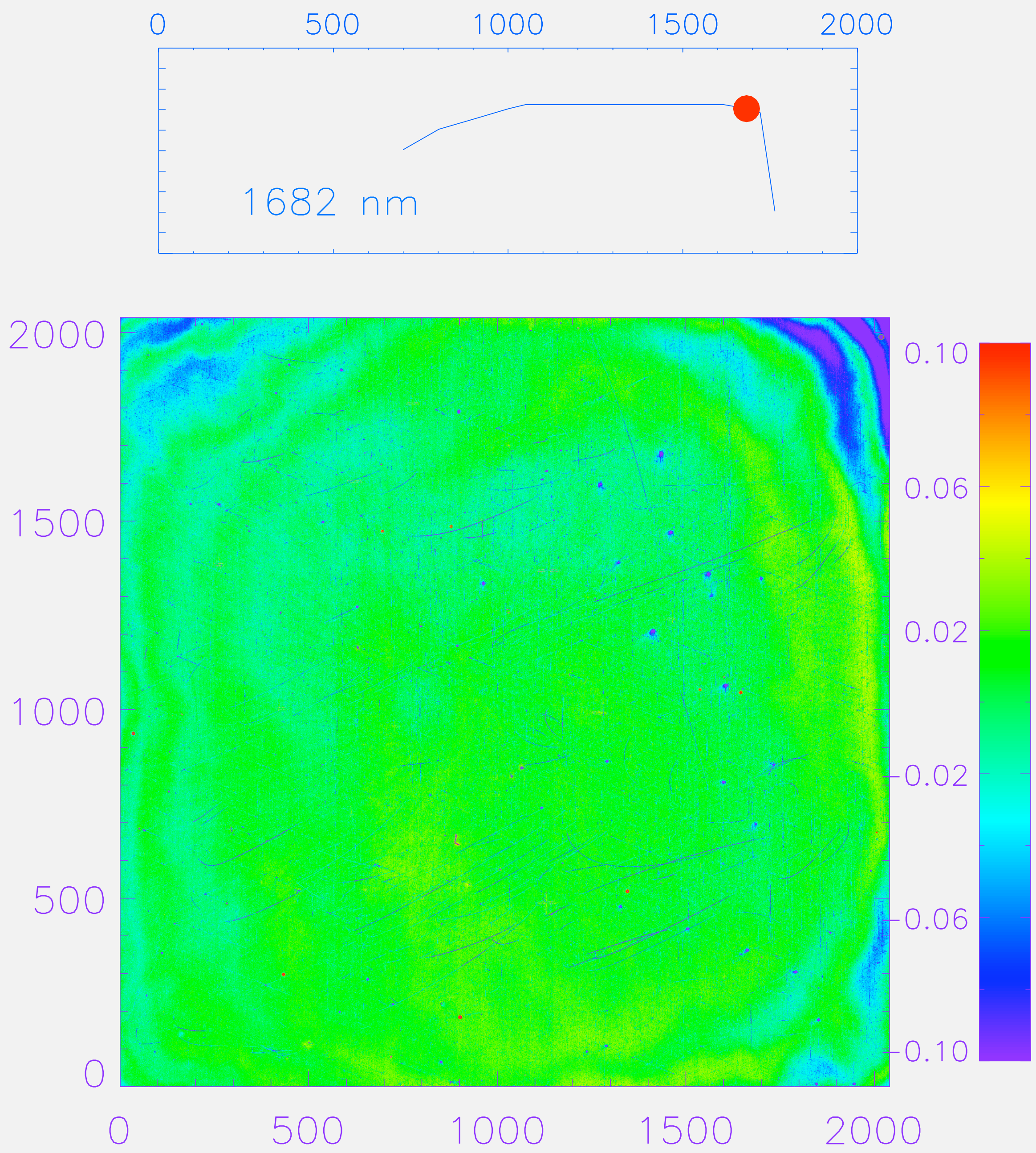
QE MAP H2RG-236



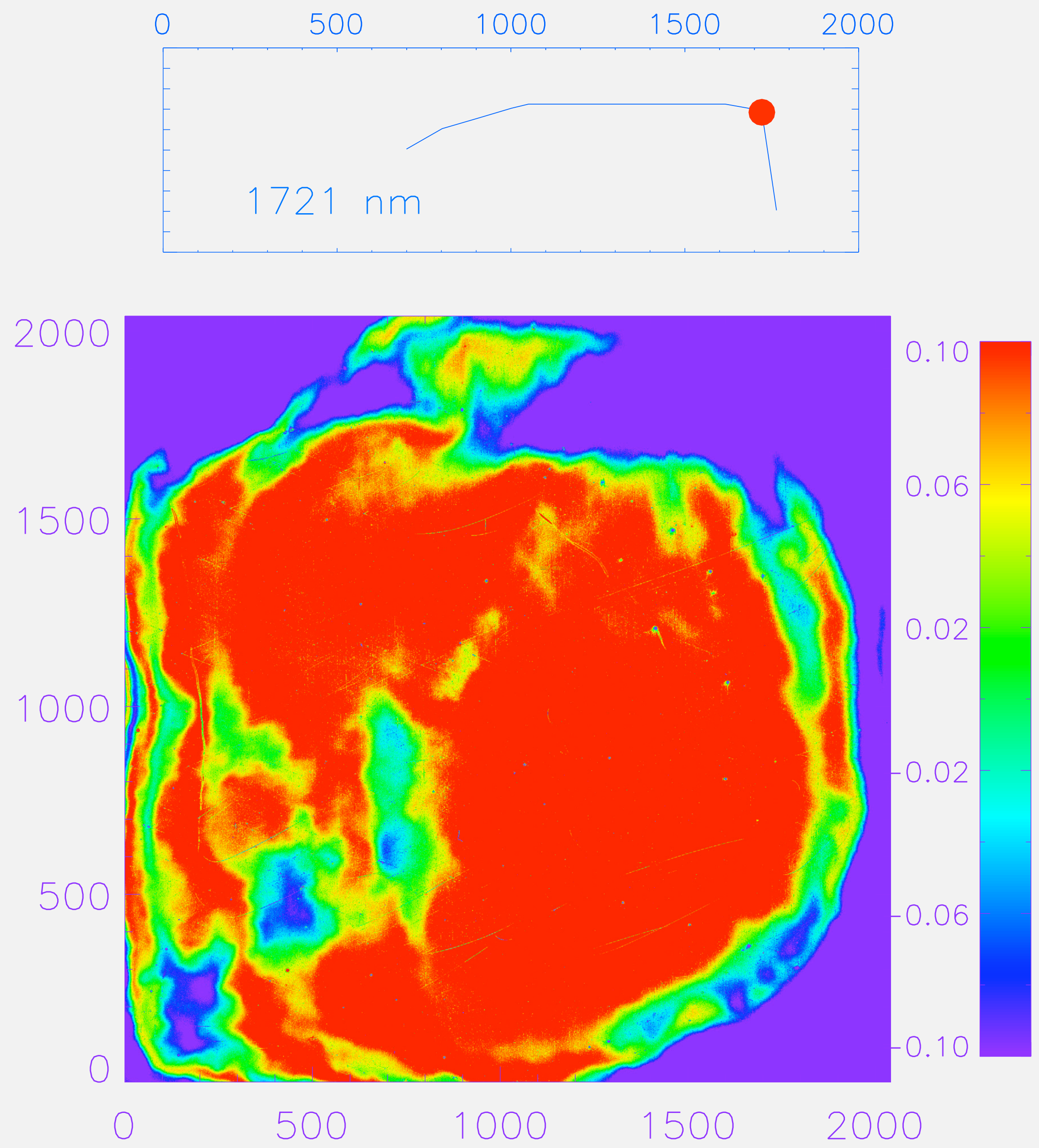
QE MAP H2RG-236



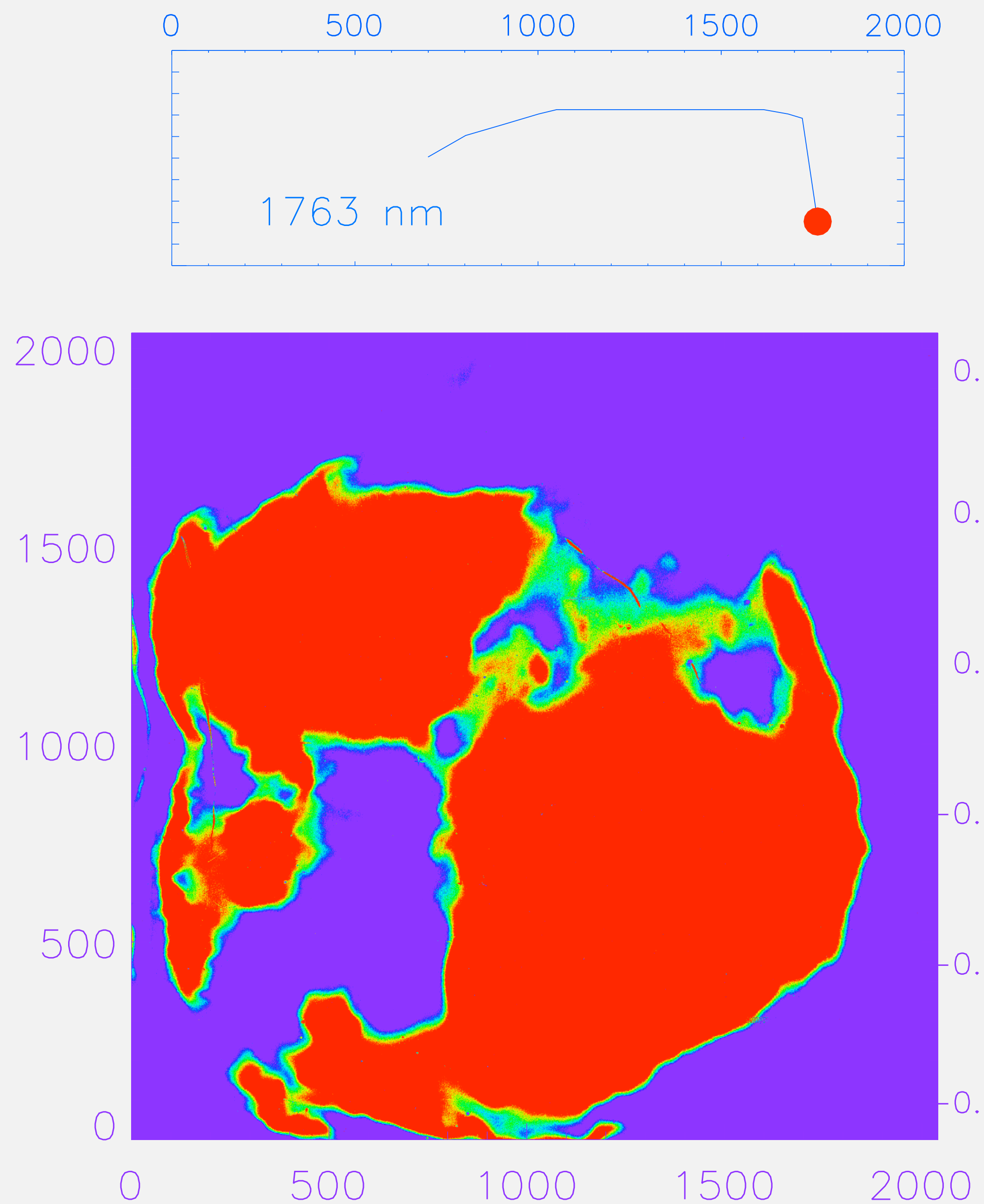
QE MAP H2RG-236



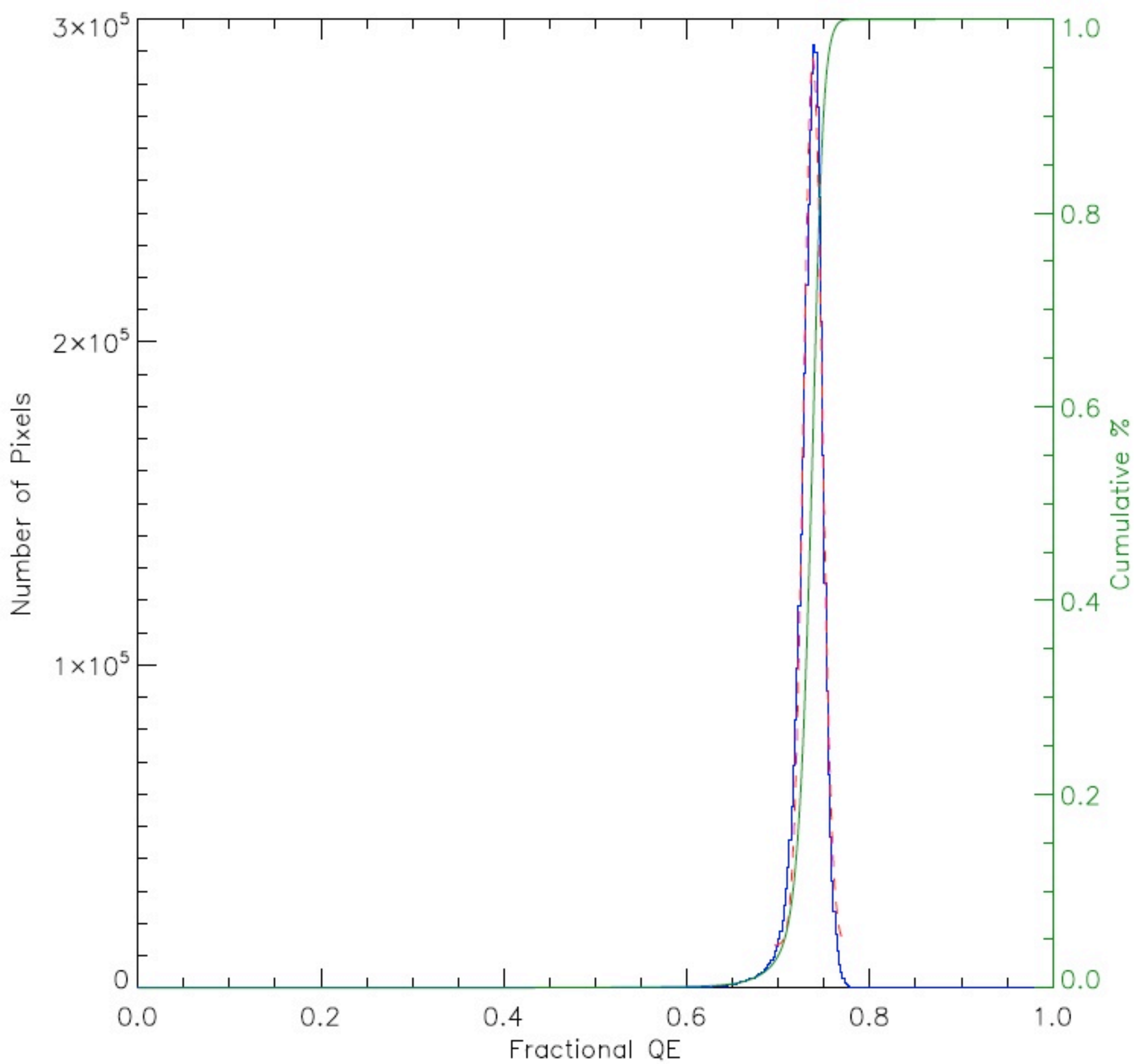
QE MAP H2RG-236



QE MAP H2RG-236



H2RG-236: EXCELLENT QE UNIFORMITY



H2RG-236

Quantum Efficiency

Wavelength: 1300 nm

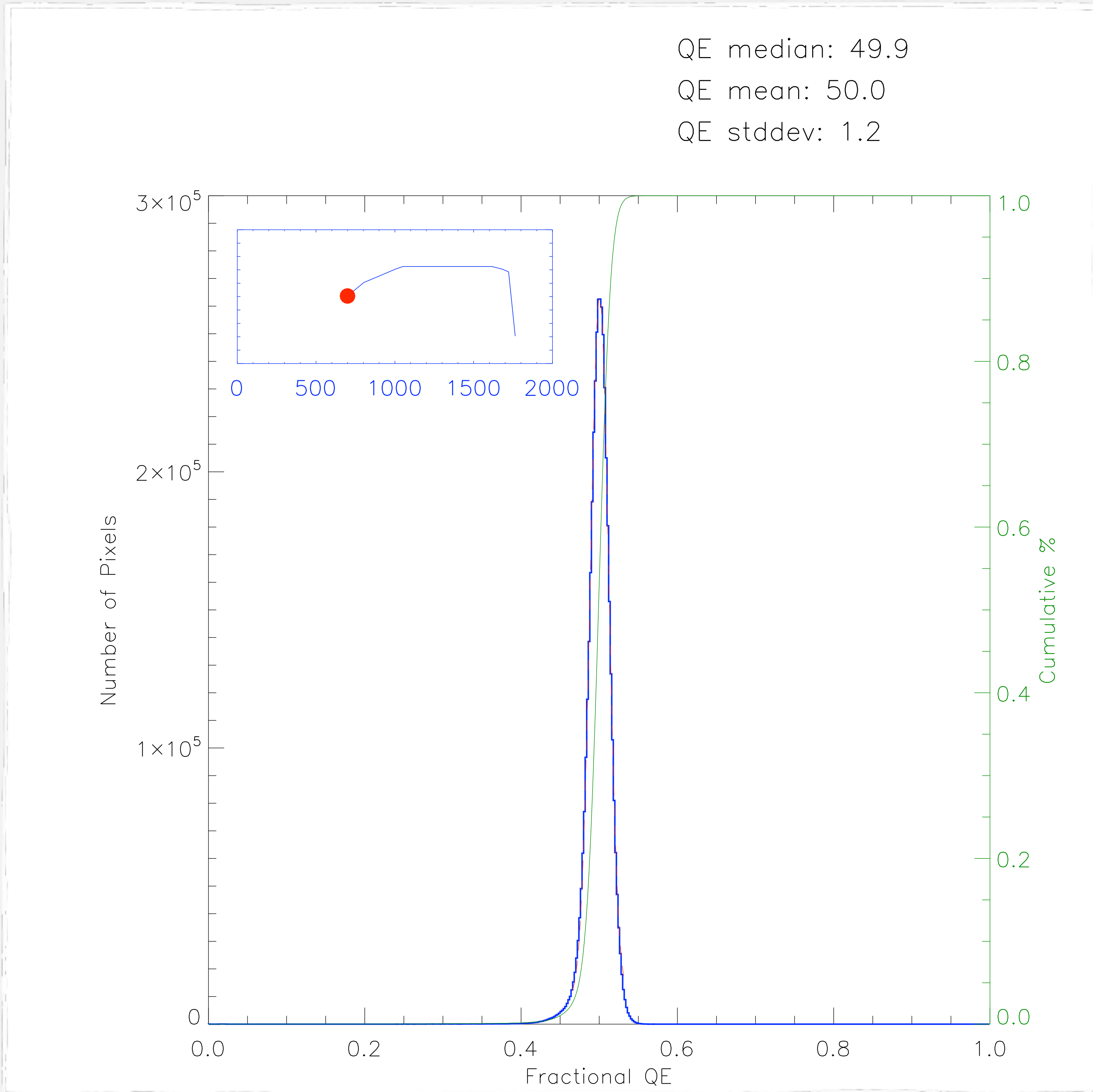
QE mean: 0.74

QE median: 0.74

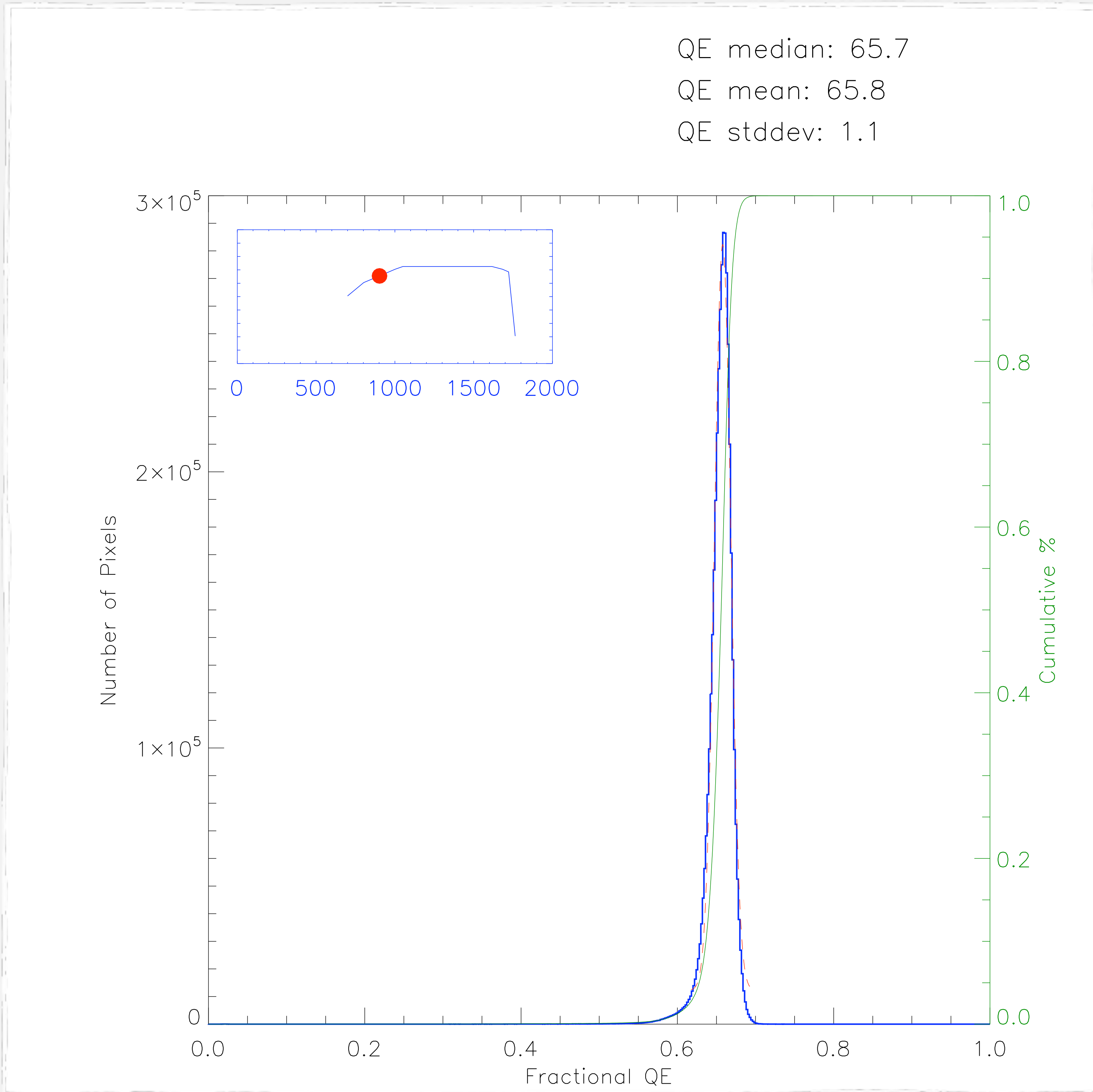
QE stdev: 0.01(1.4%)

PIX (QE>35%): 99.98

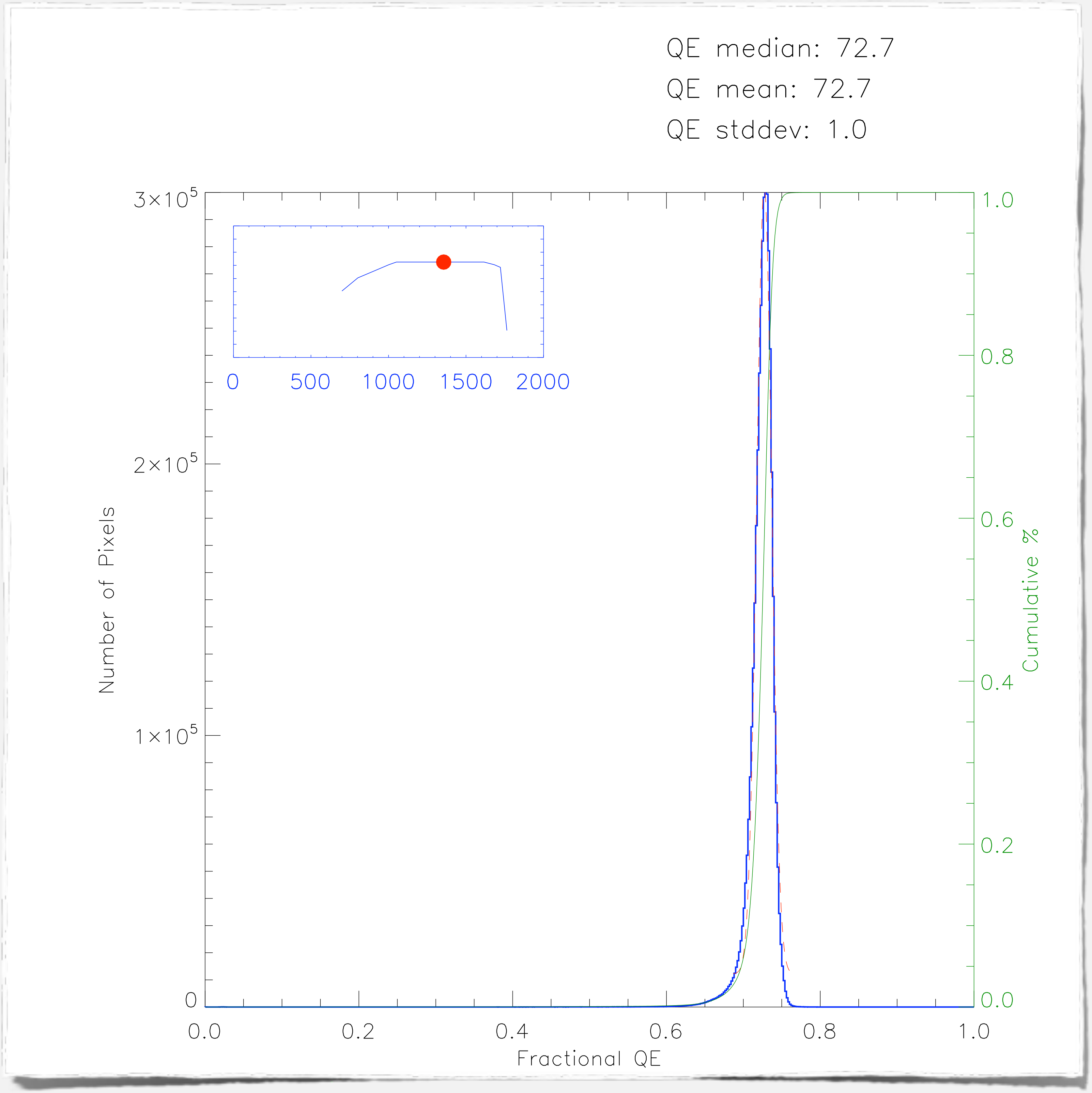
PIX (QE>50%): 99.94

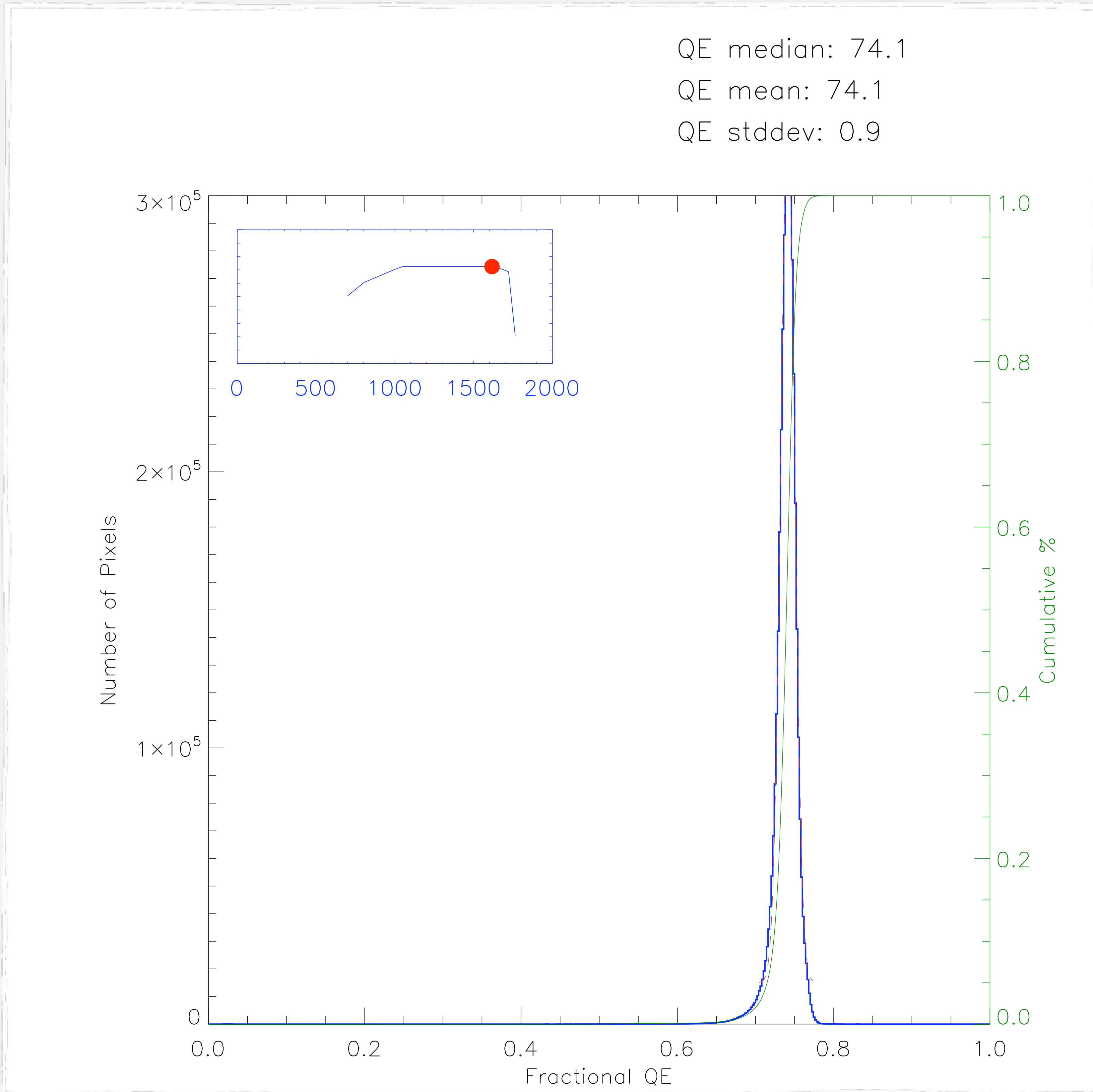


QE median: 49.9
QE mean: 50.0
QE stddev: 1.2
3×10^5
2×10^5
1×10^5
0
Number of Pixels
0 500 1000 1500 2000
0.0 0.2 0.4 0.6 0.8 1.0
Fractional QE
1.0 0.8 0.6 0.4 0.2 0.0
Cumulative %

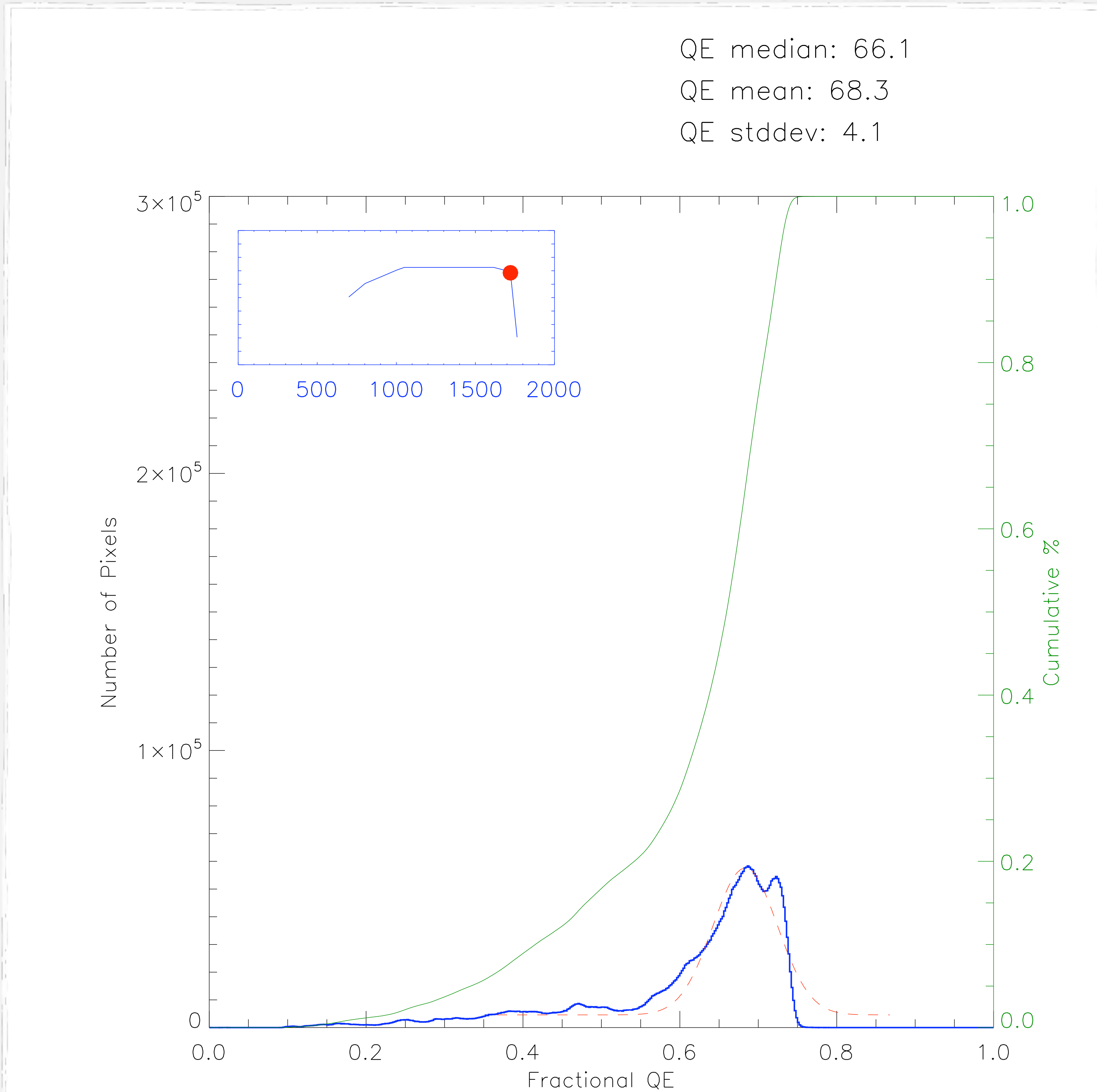


QE median: 65.7
QE mean: 65.8
QE stddev: 1.1
3×10^5
2×10^5
1×10^5
0
Number of Pixels
0 500 1000 1500 2000
0.0 0.2 0.4 0.6 0.8 1.0
Fractional QE
1.0
0.8
0.6
0.4
0.2
0.0
Cumulative %


QE median: 72.7
QE mean: 72.7
QE stddev: 1.0
3×10^5
2×10^5
1×10^5
0
Number of Pixels
0.0
0.2
0.4
0.6
0.8
1.0
Fractional QE
Cumulative %
0
500
1000
1500
2000



QE median: 74.1
QE mean: 74.1
QE stddev: 0.9
0
500
1000
1500
2000
Number of Pixels
3×10^5
2×10^5
1×10^5
0
Cumulative %
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Fractional QE



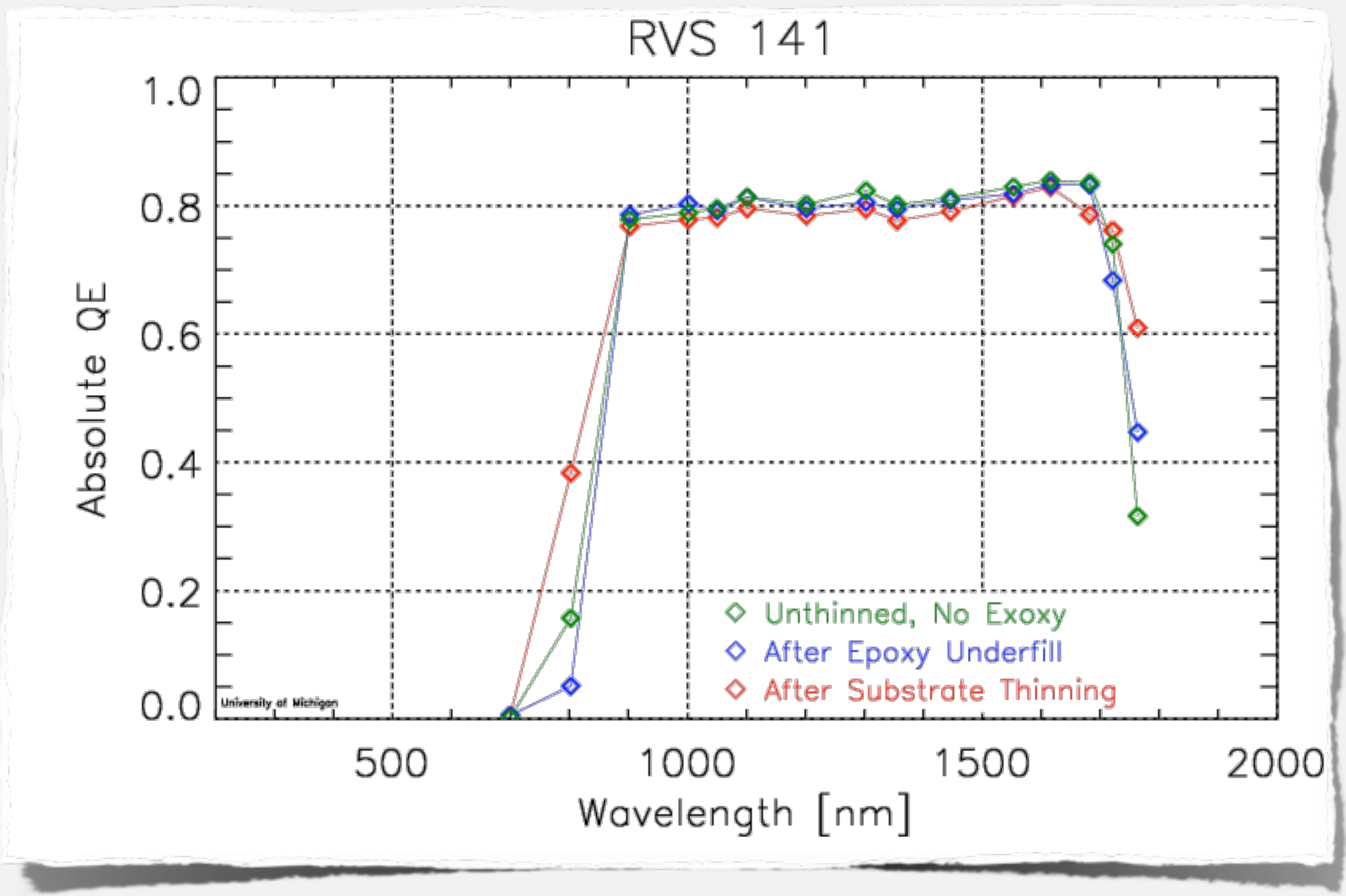
QE median: 66.1
QE mean: 68.3
QE stddev: 4.1
3×10^5
2×10^5
1×10^5
0
Number of Pixels
0 500 1000 1500 2000
0.0 0.2 0.4 0.6 0.8 1.0
Fractional QE
1.0 0.8 0.6 0.4 0.2 0.0
Cumulative %

Long term stability

Raytheon 1k x 1k device

Selected to demonstrate and monitor substrate removal

- 3 measurements over 10 months.
- QE stable to 1% through epoxy underfill and substrate thinning!
- Adding epoxy changed conversion gain but not QE.



Summary

- QE set-up at University of Michigan capable of measuring <u>absolute QE</u> to ~ 2%.
- Illumination uniformity <1% across the device (in-situ verified)
- Absolute QE measured with cold reference diodes at the FPA position.

- Detailed QE studies on several runs of H2RG 2k x 2k HgCdTe detectors produced for SNAP by TIS were characterized:
  - High and spatially uniform QE has been achieved (e.g SNAP-142, SNAP-236)
  - Most recent production run resulted in very tight QE distribution (σ_{QE} < 1.5% over wavelength range of interest) → reflects measured pixel to pixel uniformity