Infrared detectors for wavefront sensing

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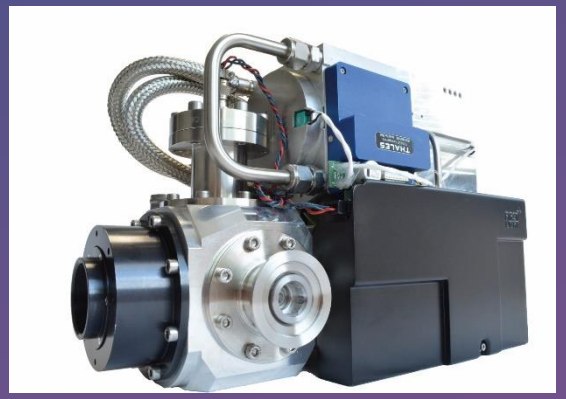
Short wave infrared WFSs

- LGS relaxes greatly visible WFS specs but need IR WFS for tip-tilt
- Better sky coverage
- Brighter stars
- Wider spectral badwidth (more photons)
- NCPA minimization
- Etc. See several presentations in this conference

SWIR NGS

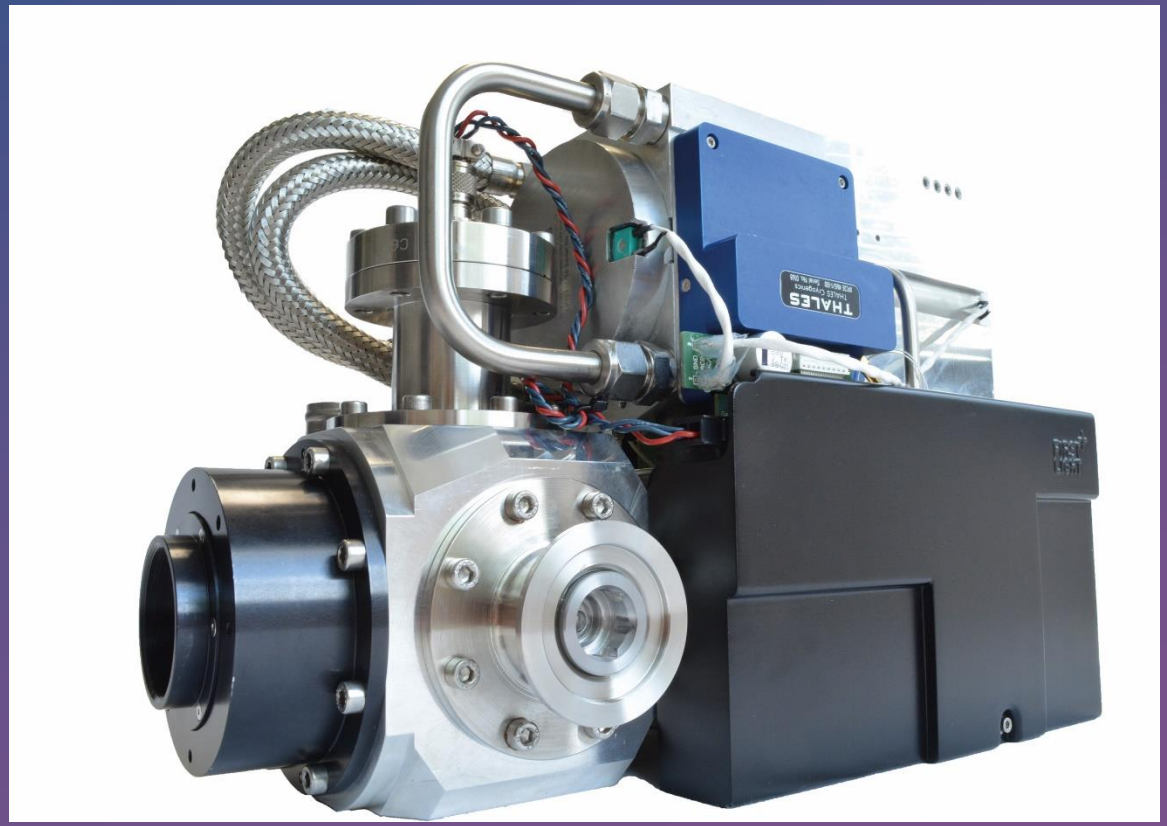
C-RED One
Ultimate performance
(High order WFS)



C-RED 2
High perormance wide FOV
(TT NGS & truth sensor)

C-RED One main features

C-RED One	
Sensor Type	HgCdTe (MCT)
Size	320X256 ; 24µm pixel pitch
Maximum Speed at full Frame	3500 fps
Mean Dark + RON	<1e at maximum speed and gain X30
Peak Quantum Efficiency	70% from 0.8 µm to 2.5µm
Operating Temperature	80K
Quantization	16 bits
Supported readout modes	Global single, global CDS, global NDR, Rolling single, rolling CDS, rolling IOTA
Windowing	Yes, multiple windowing



3 cameras delivered yet this year
2 other in production

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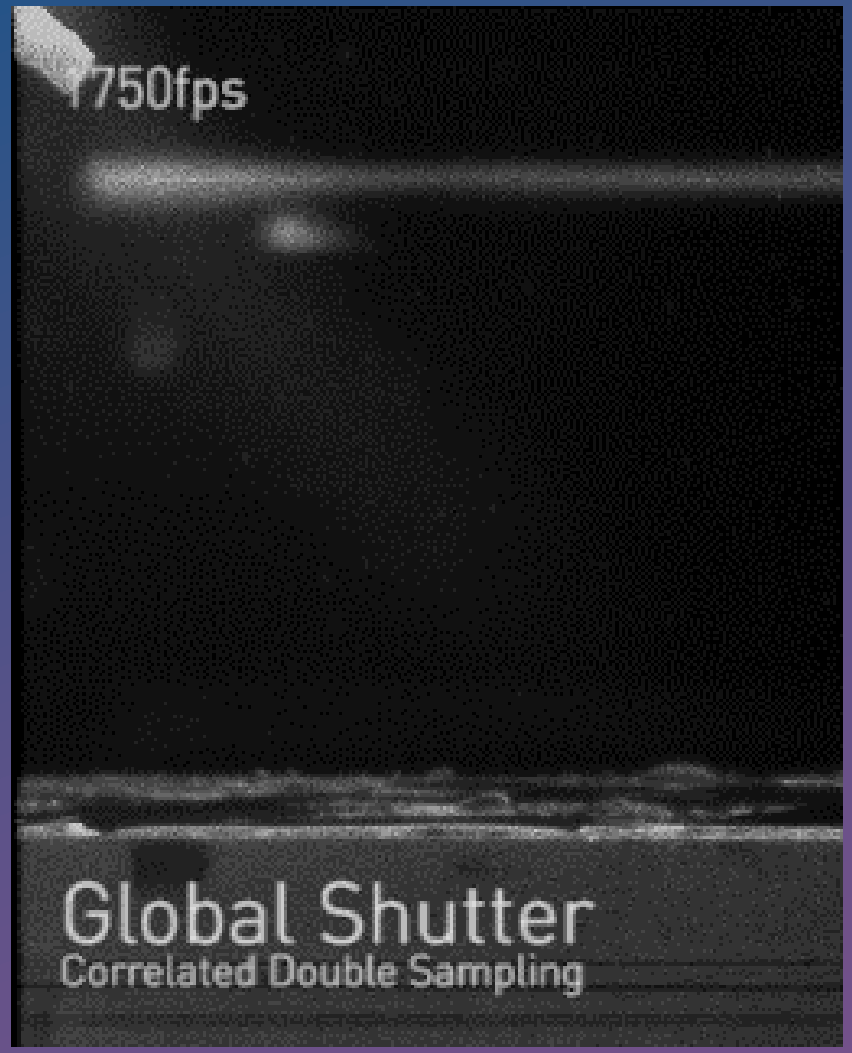
C-RED One

World speed record in IR imaging

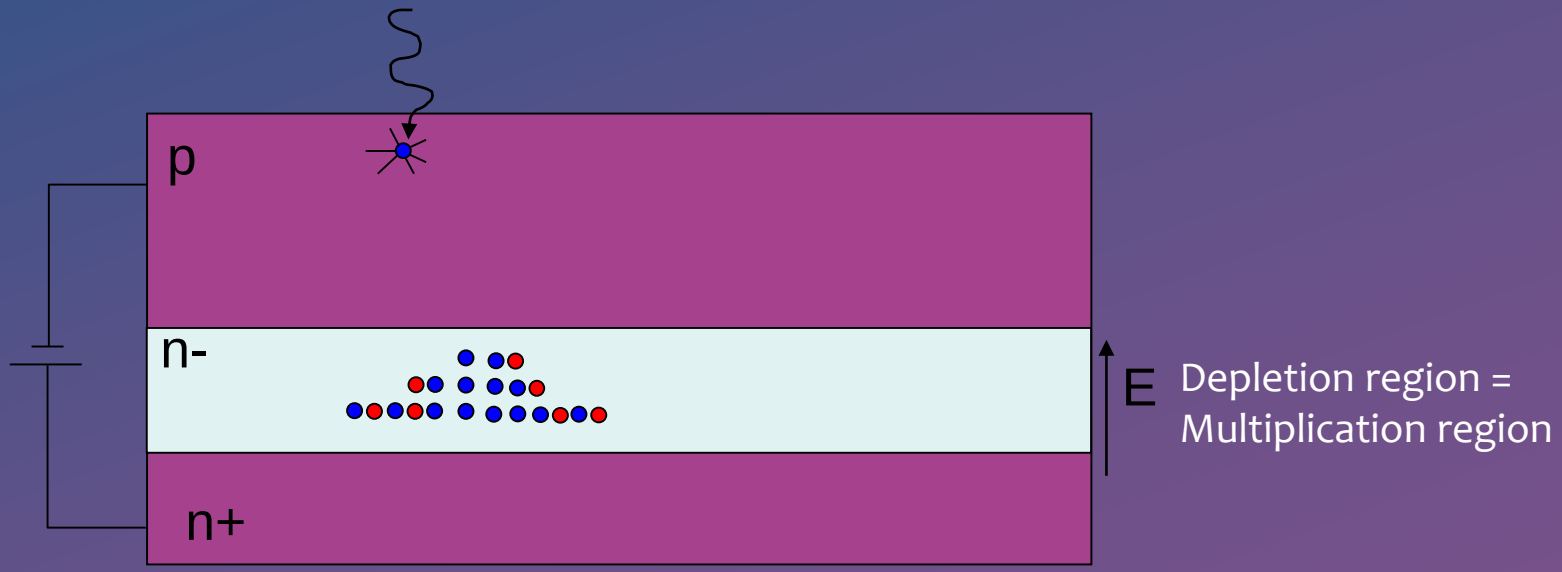


T = 85 K
320x256 pixels (full frame)
Pixel rate 10 MHz
CDS readout
1750 fps
Gain 1

Incredible cosmetics (no defective pixels at gain 1)

1750 FPS in DCS mode
3500 FPS in Single Read Mode

Avalanche Gain in MCT IR arrays



Courtesy of CEA Leti

Detector noise

In amplified detectors (gain M), the "input referred" noise is given by the quadratic sum of 2 terms:

$$\sigma_{in} = \sqrt{F * (QE * S + S_{dark}) + \left(\frac{\sigma_{readout}}{M}\right)^2}$$

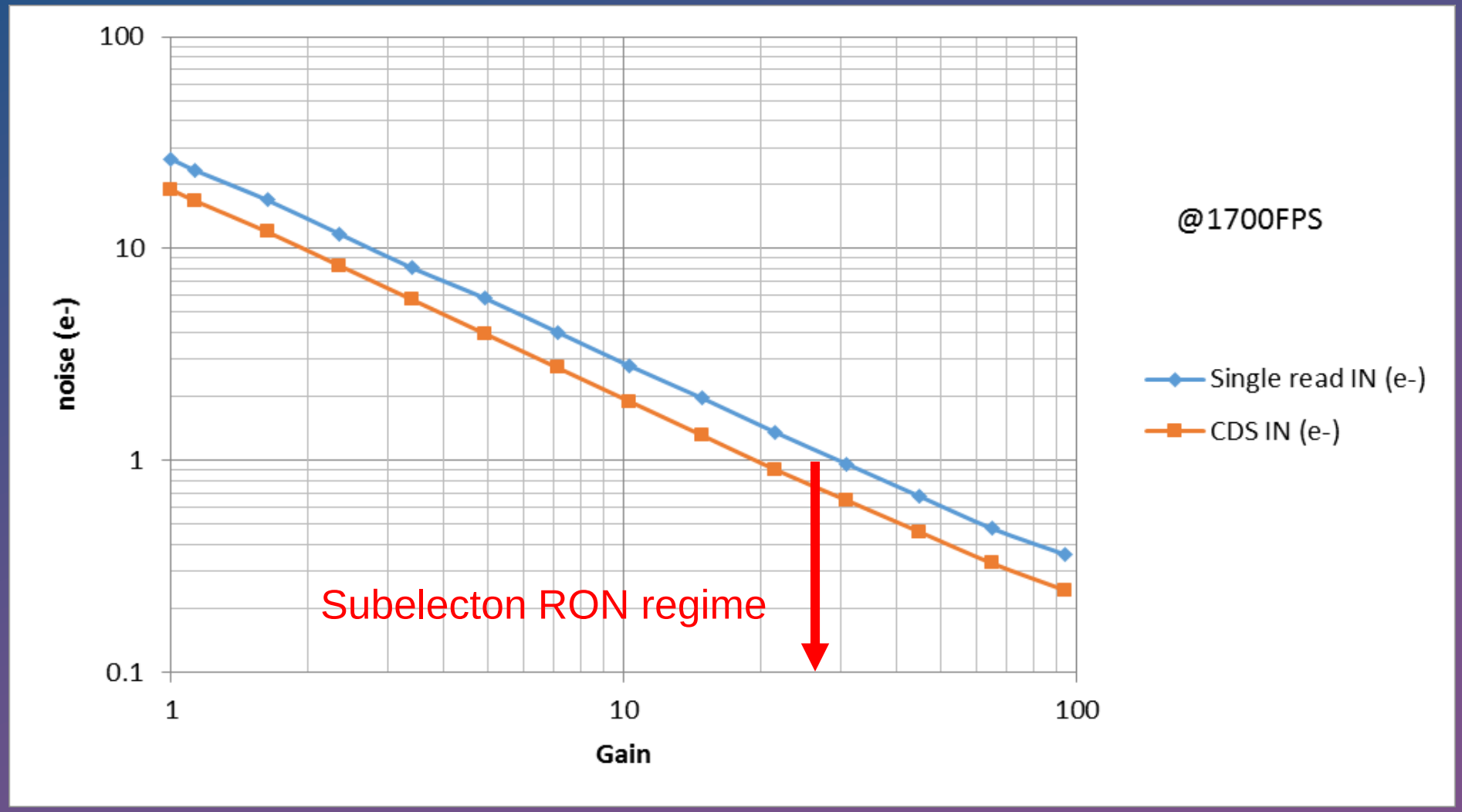
HgCdTe:
F= 1.1

Photon noise degraded by the excess noise F>1

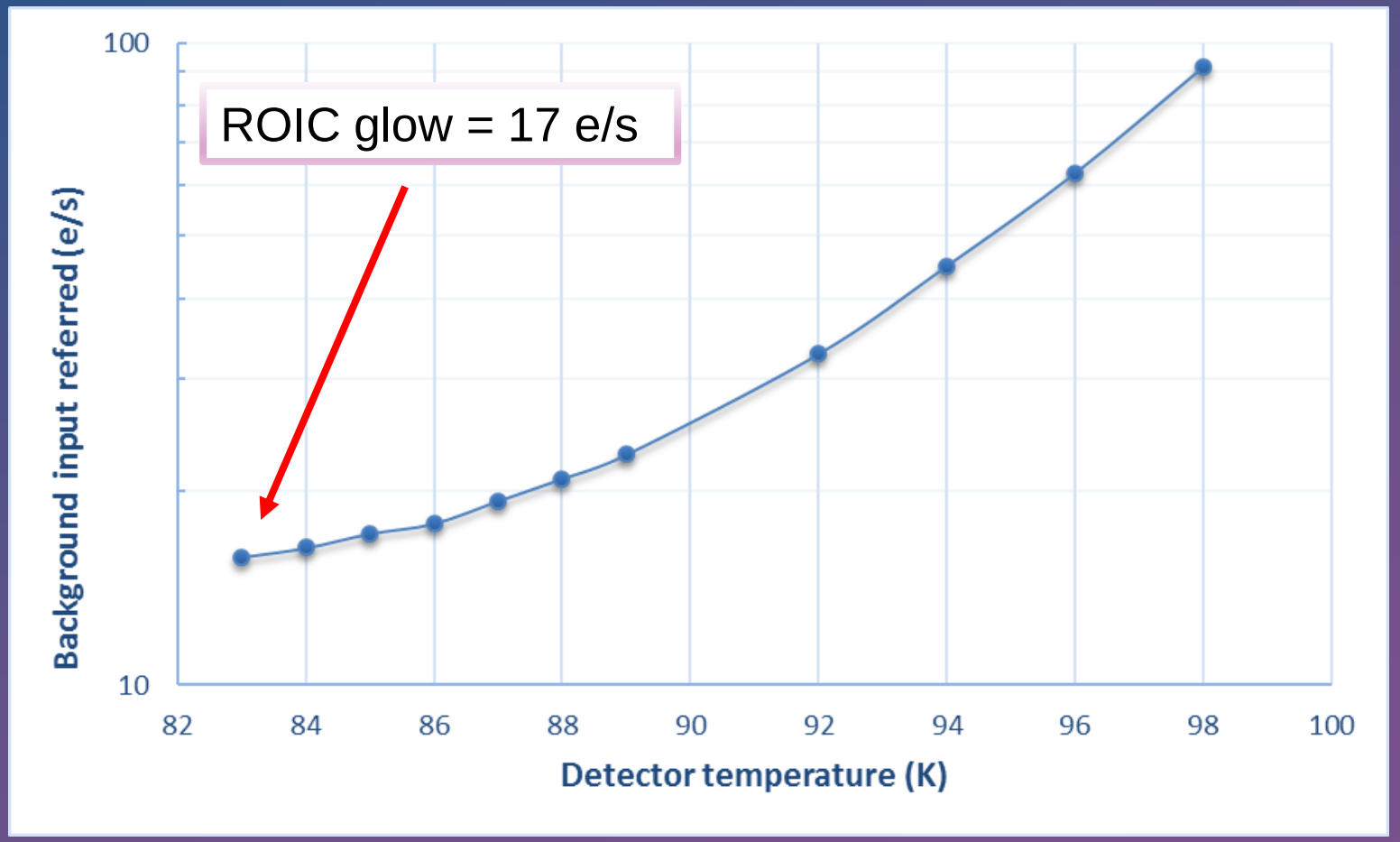
Ideal detector: photon noise only
QE = 100 %
F=1
$M \rightarrow \infty$ or $\sigma_{readout} = 0$

Input referred noise = Readout noise divided by M

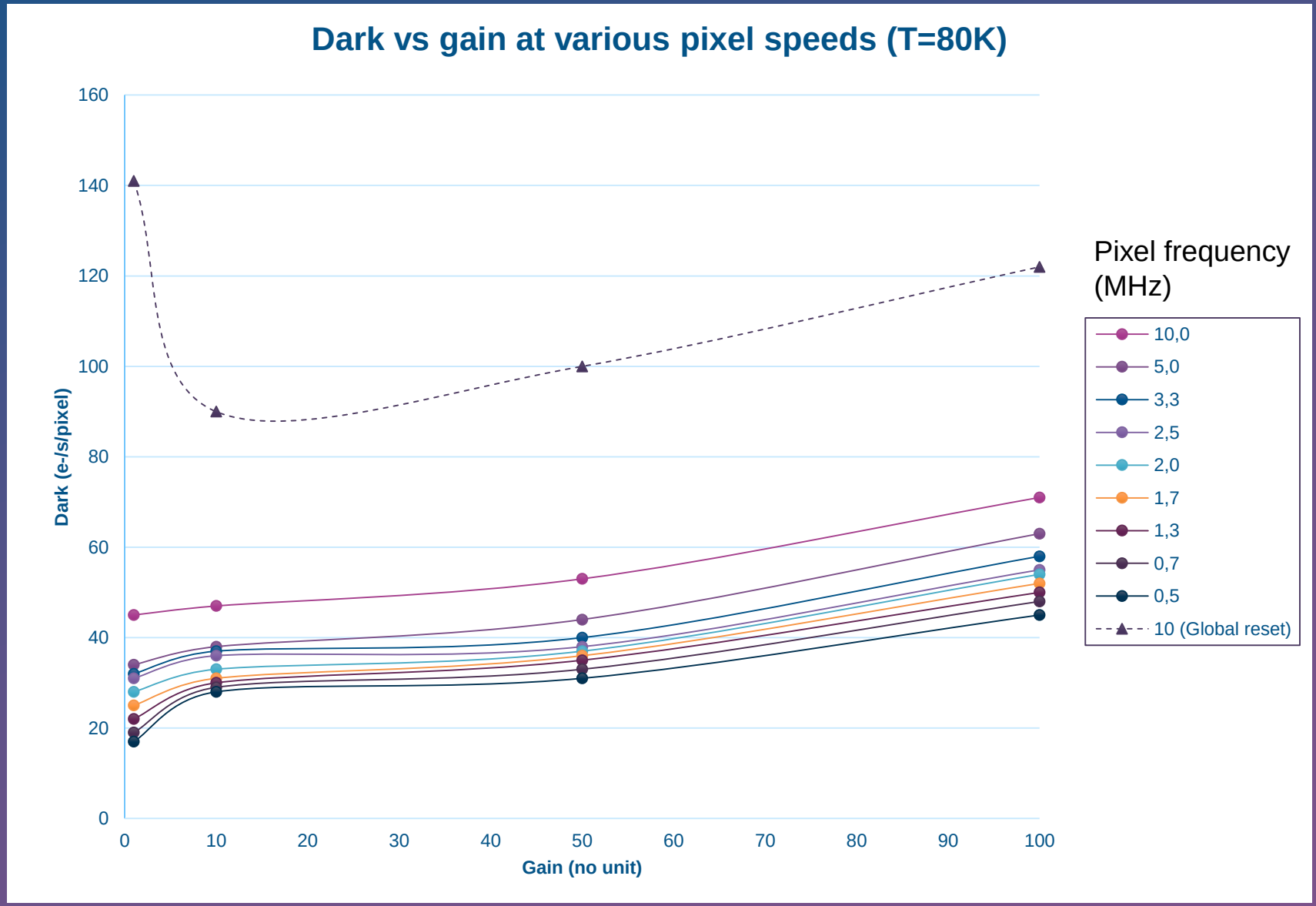
RON vs GAIN


100
10
1
0.1
noise (e-)
1
10
100
Gain
Subelecton RON regime
@1700FPS
Single read IN (e-)
CDS IN (e-)

C-RED One dark current vs. temperature



Dark vs readout speed



The wonderful world of detectors people

A world full of kind people

Where pets do incredible things

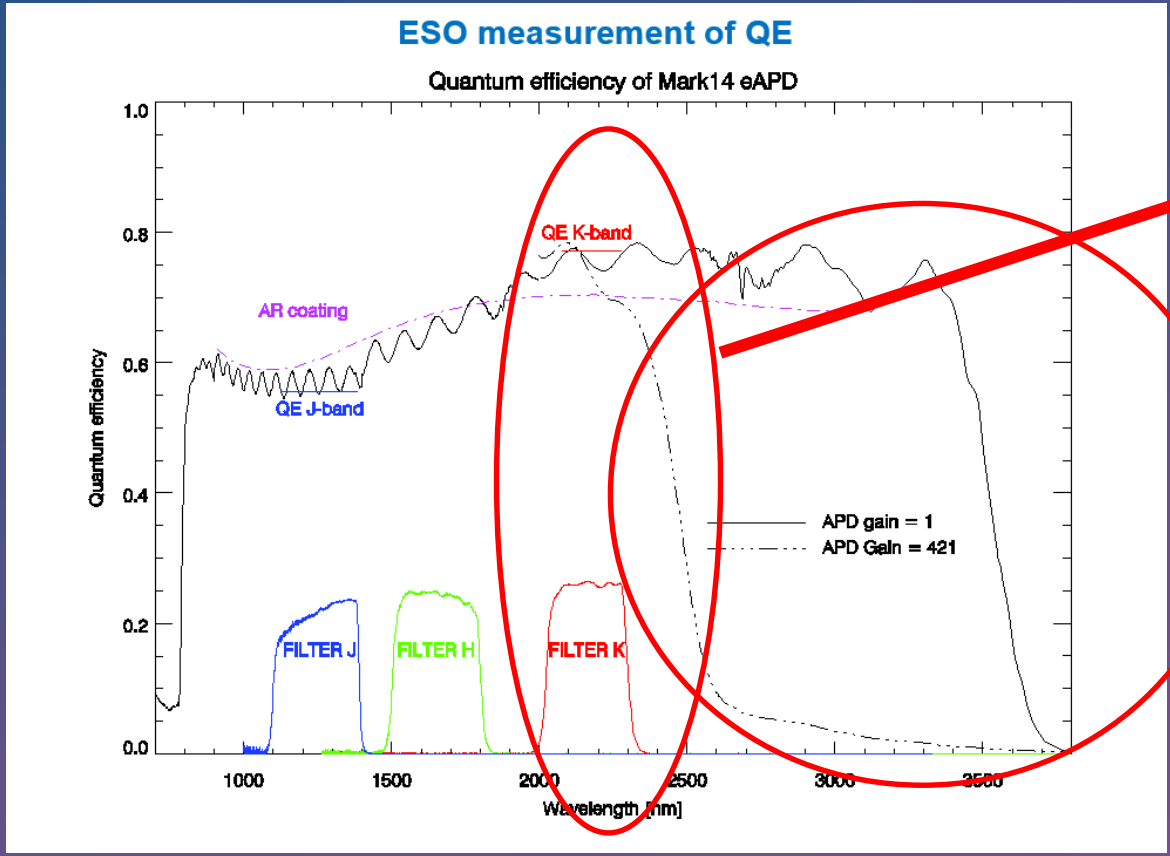
The wonderful world of detectors people

And detectors see through metallic cold plates… used to block the incoming light and measure the dark current …

The dark current measurement is not releavant in the infrared !

The real world…

In the real world, a detector does not look at a cold blackbody !



Courtesy of G. Finger (ESO)

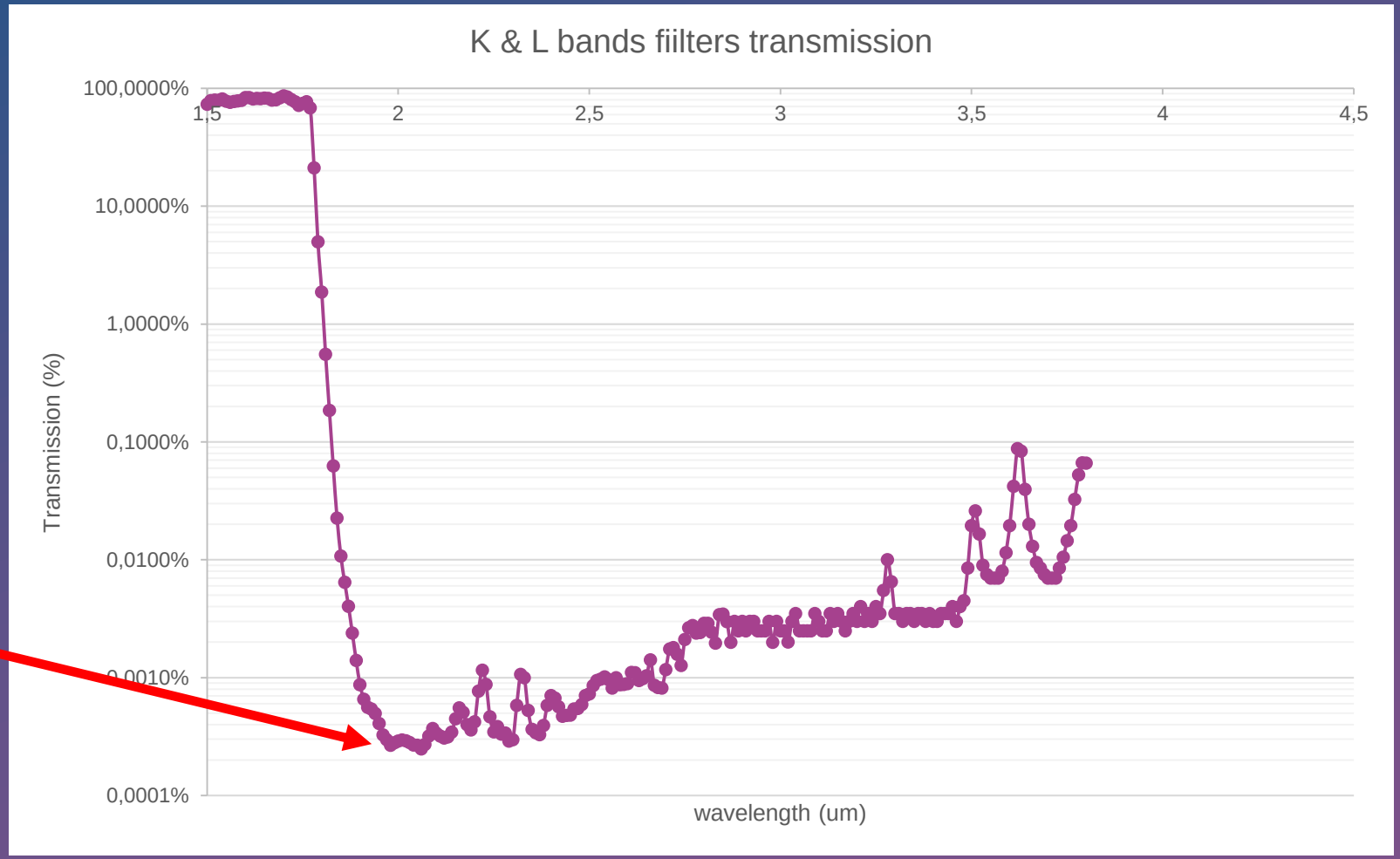
K band thermal background « pollution » => use cold optics to minimize the hot surface or Filter out

L band thermal background pollution => Filter out !

Background increases with the square of the beam aperture on the detector

Example of filter setup

J+H bands, F/4 beam

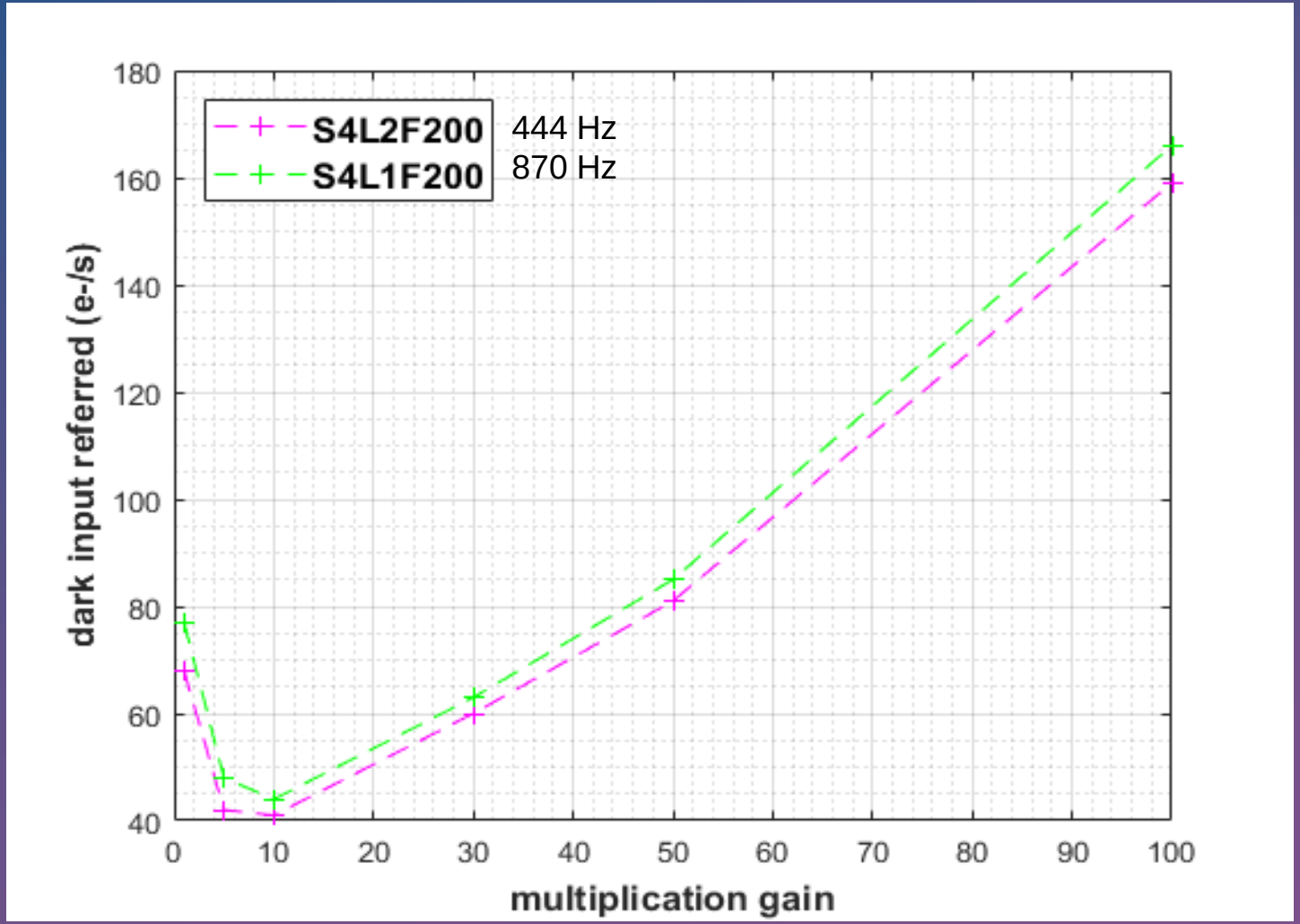


Near OD6 !

The real world…

F/4 beam
Hot mirror

H+K cold filters



Detector noise

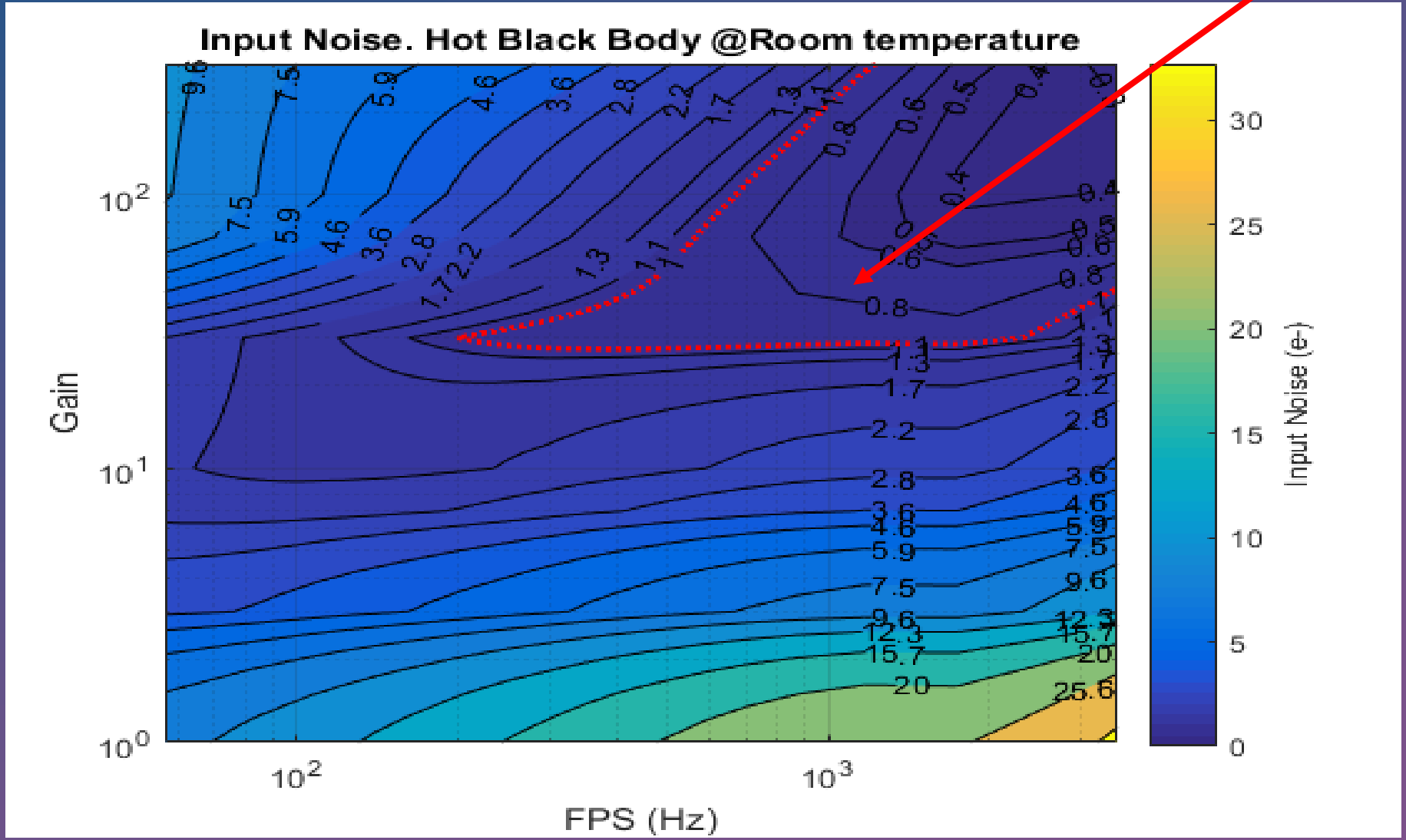
A more realistic approach for IR detectors

$$\sigma_{in} = \sqrt{F * \left(QE * S + S_{Background}\right) + \left(\frac{\sigma_{readout}}{M}\right)^2}$$

Includes dark
System dependent (filters, F#), and not only detector dependant = how good you are to put your detector in a « quiet » (ie: dark) environment !

C-RED One total noise

(worst conditions : F/4 beam, looking @ hot black body)



C-RED 2:

VERY

Fast, Low noise, low cost InGaAs.

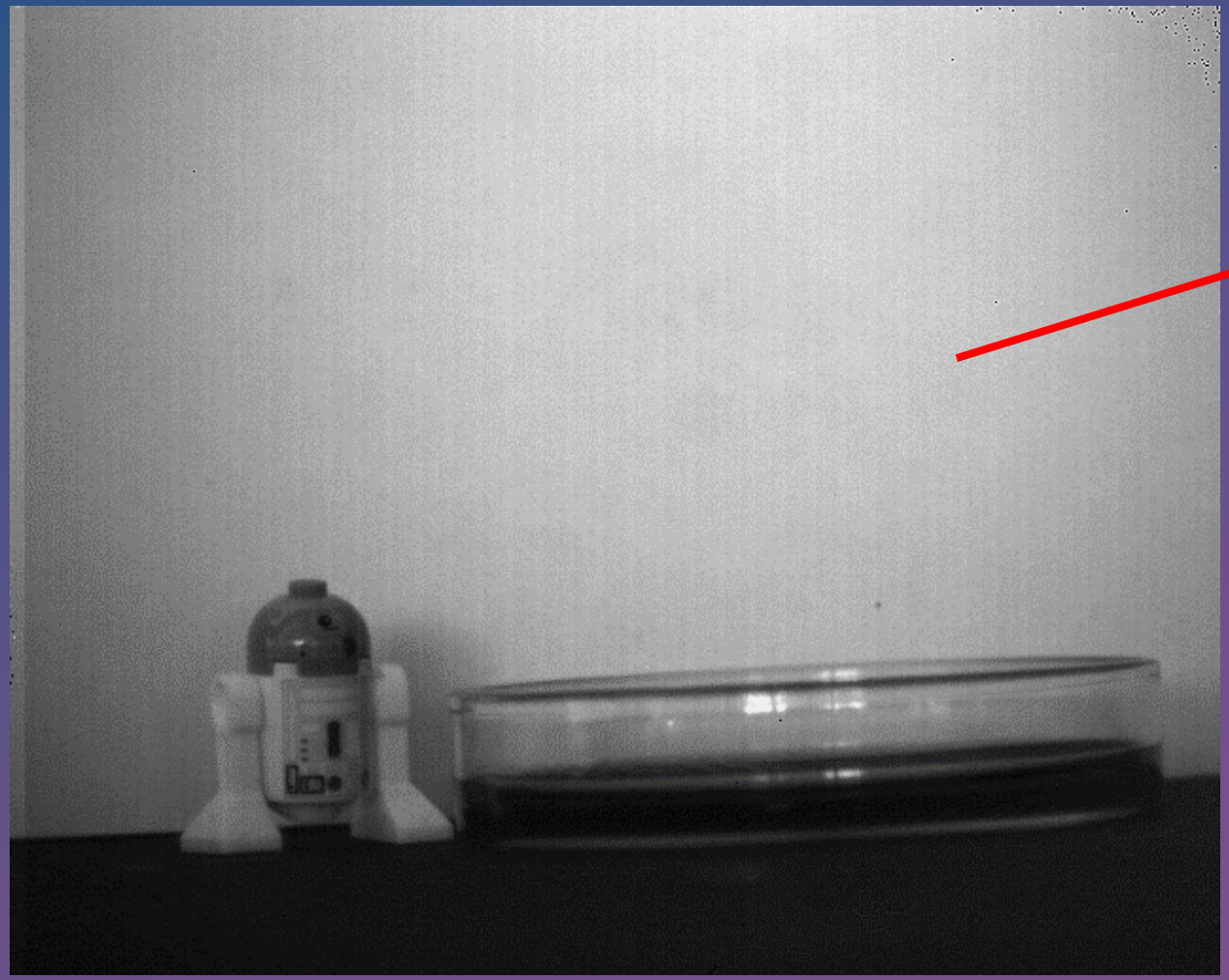
This project is supported by the "Investments for the future" program and the Provence Alpes Côte d'Azur Region, in the frame of the CPER.

C-RED 2 SWIR camera
Fast and Low Noise InGaAs

- 640x512 pixels, 15 μm pitch
- 0.9 to 1.7 μm (80% QE)
- 400 FPS full frame / 30 e- RON
- 25 FPS full frame / 10 e- RON
- Windowing & ROI
- < 1μs electronic shutter
- -40°C operation for low dark current
- Cameralink & USB3 interface
- Small size & weight (140x75x55 mm , 0.9 kg)

C-RED2 : The movie

(not featured in the next Star Wars movie)



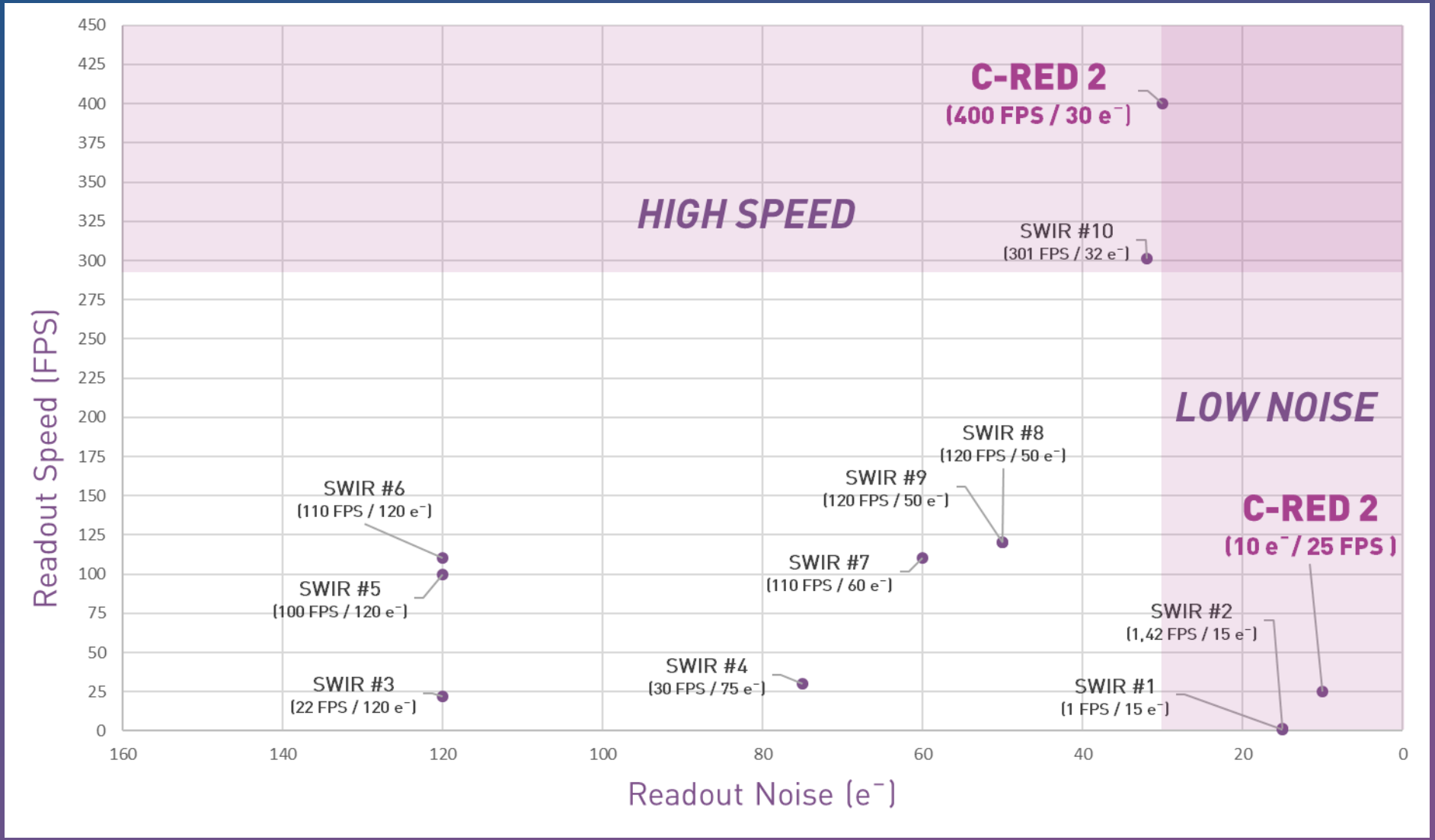
400 FPS played back in slow motion

CCD-like cosmetics (even on an ENG grade)

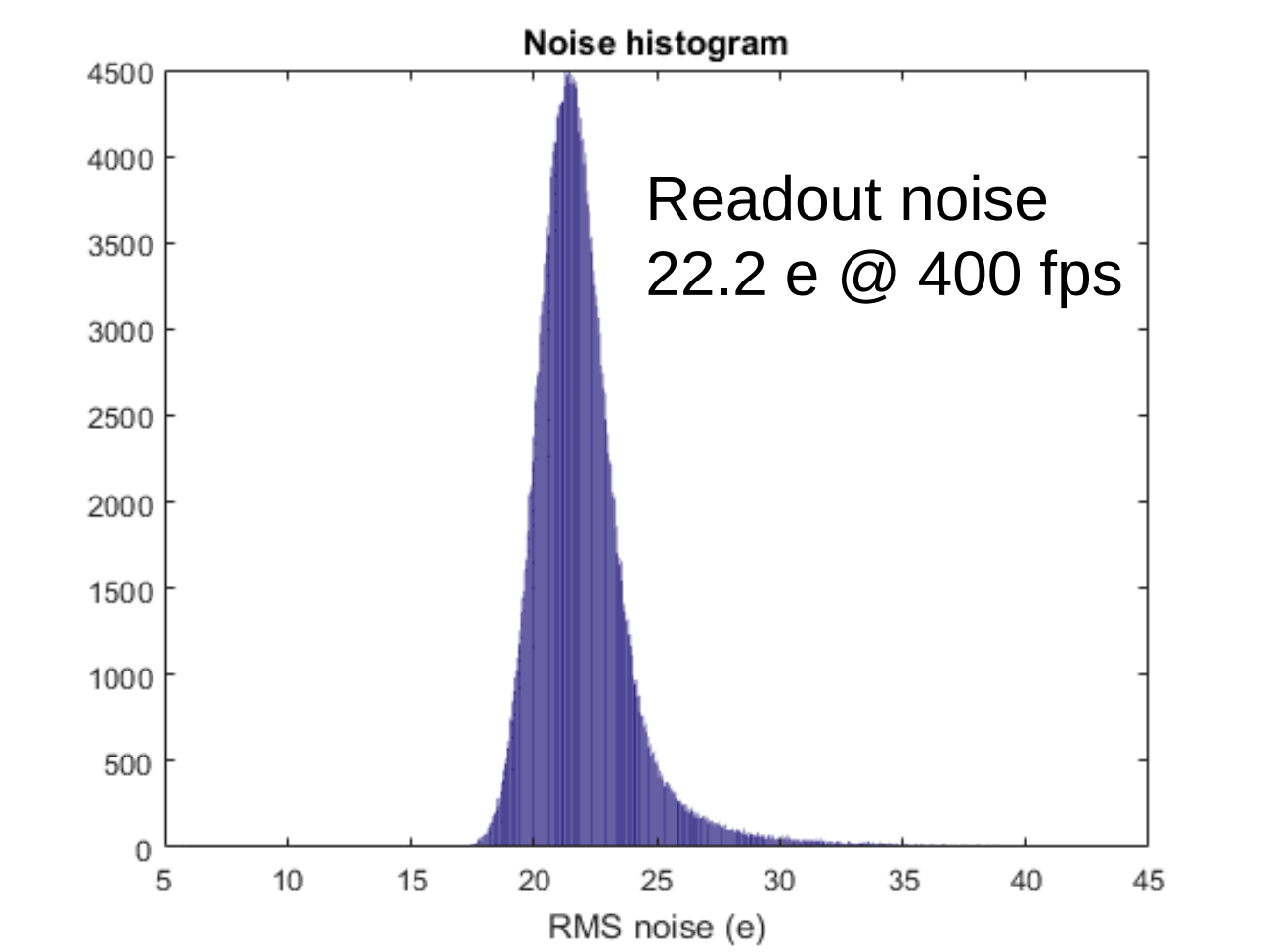
Operability better than 99.99 %

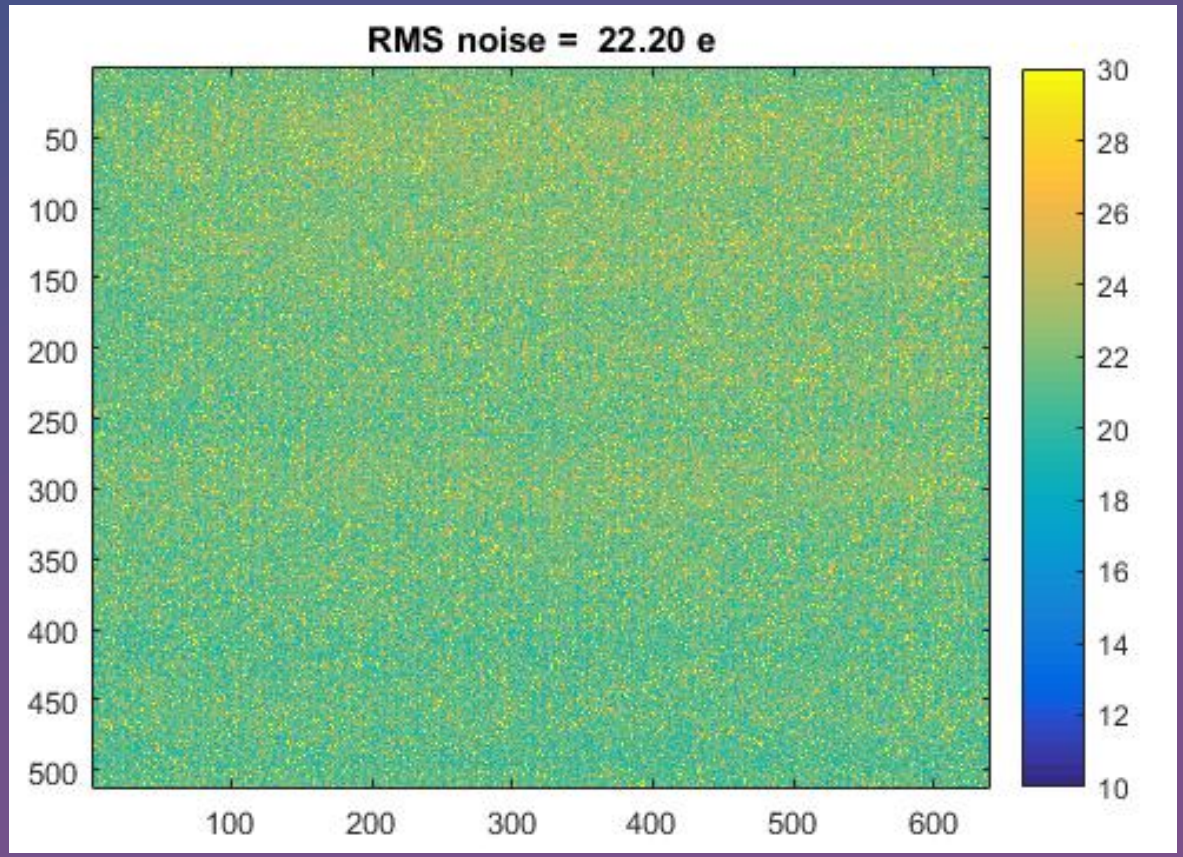
MOVPE epitaxy

C-RED 2 SWIR competitors

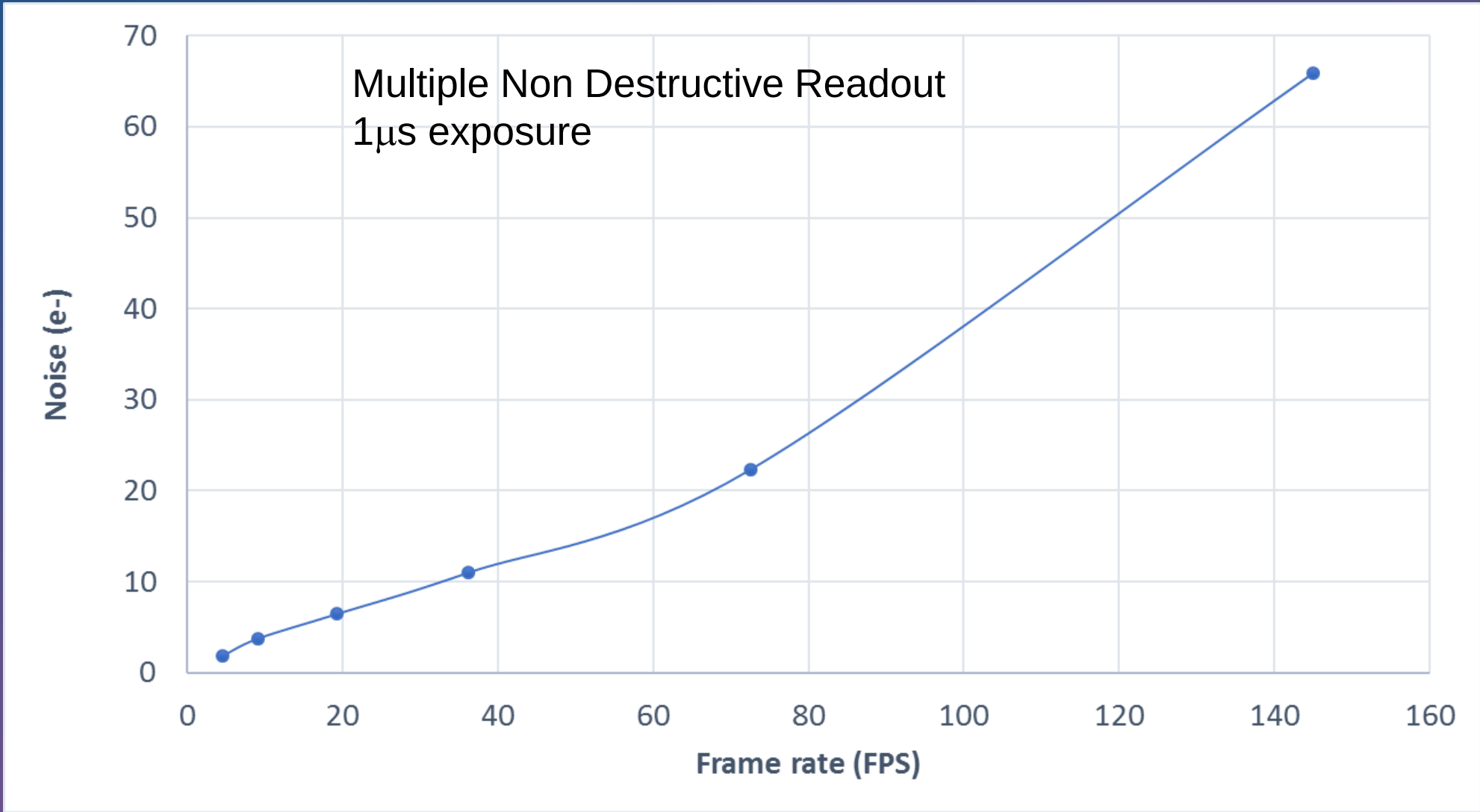


C-RED 2 readout noise at 400 fps

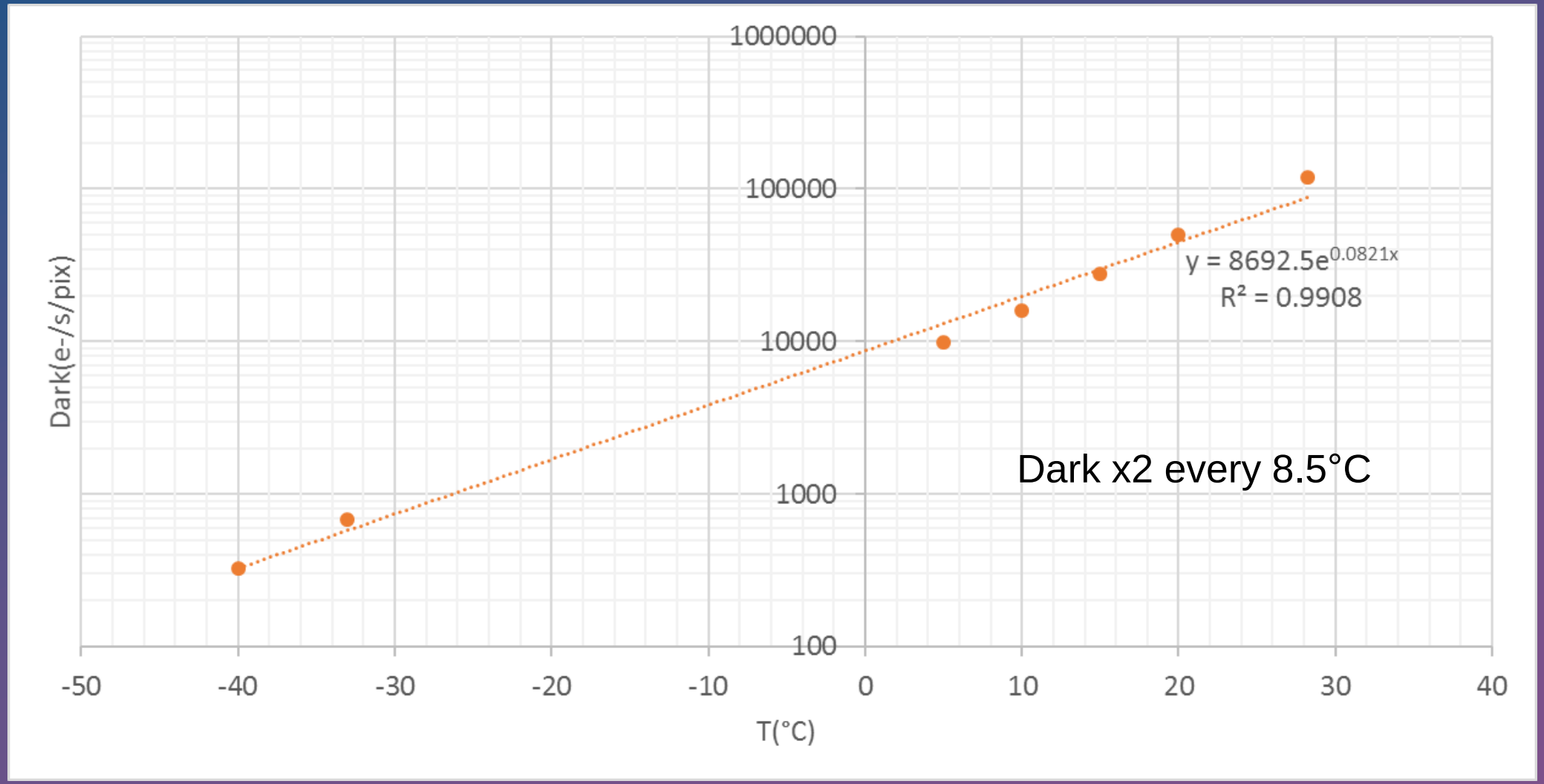




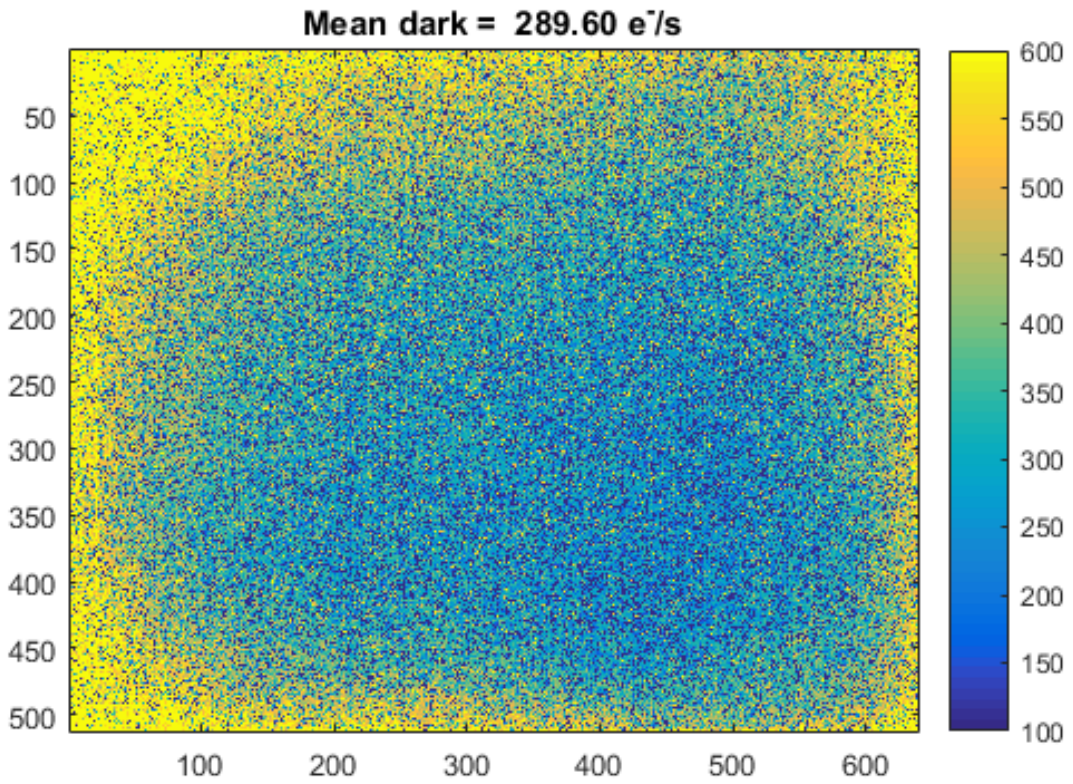
C-RED 2 noise vs. readout speed

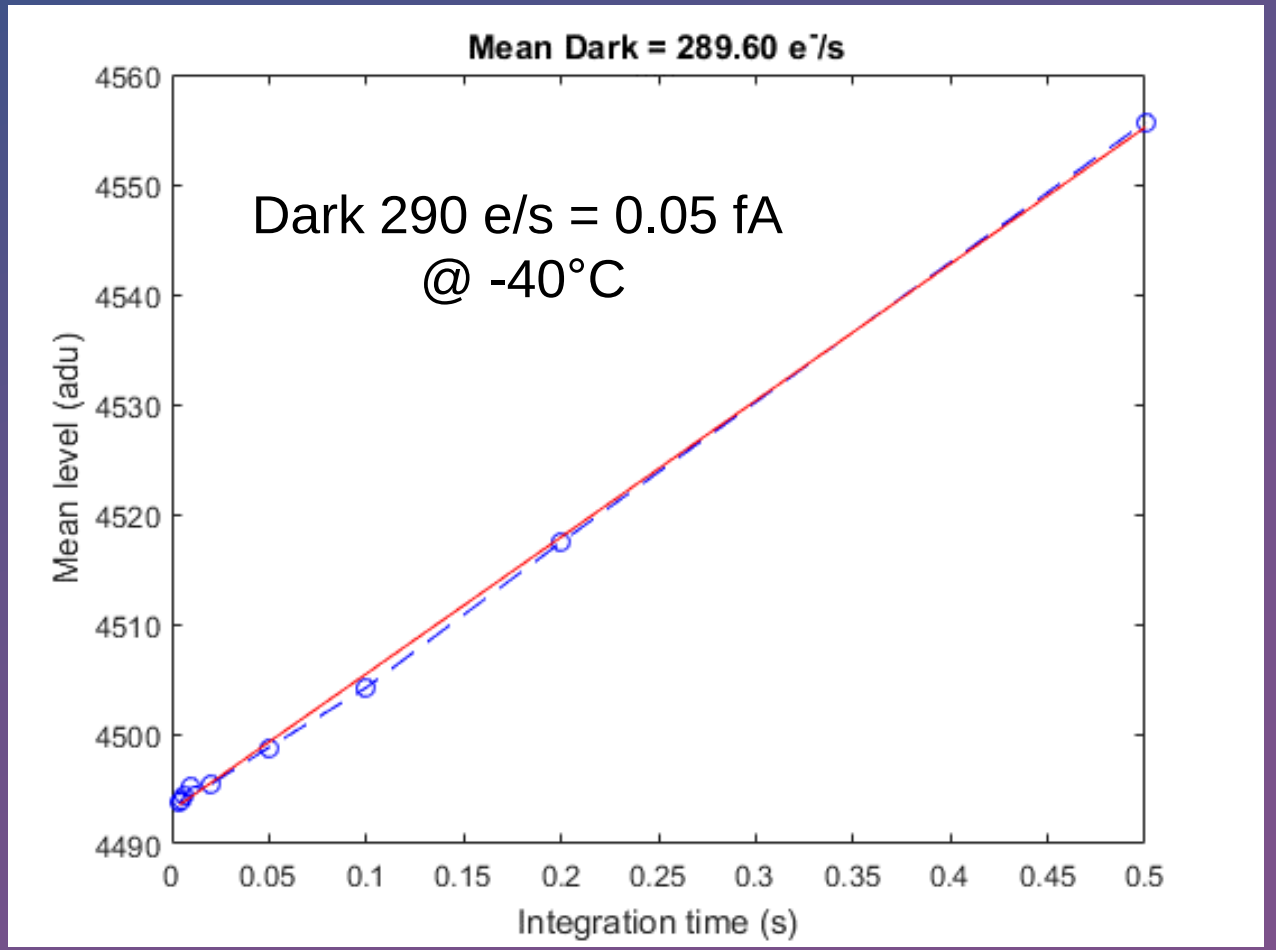


C-RED 2 measured dark vs. temperature



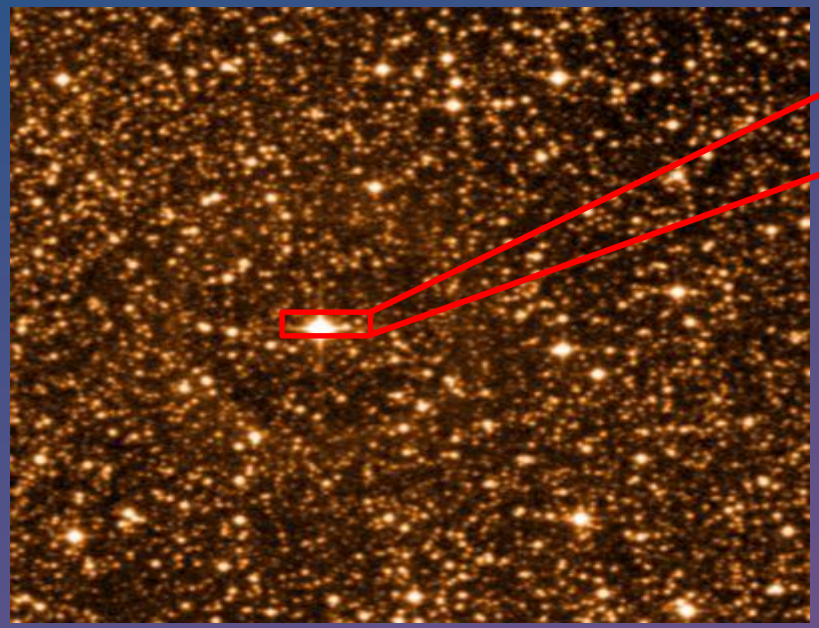
C-RED 2 dark at -40°C



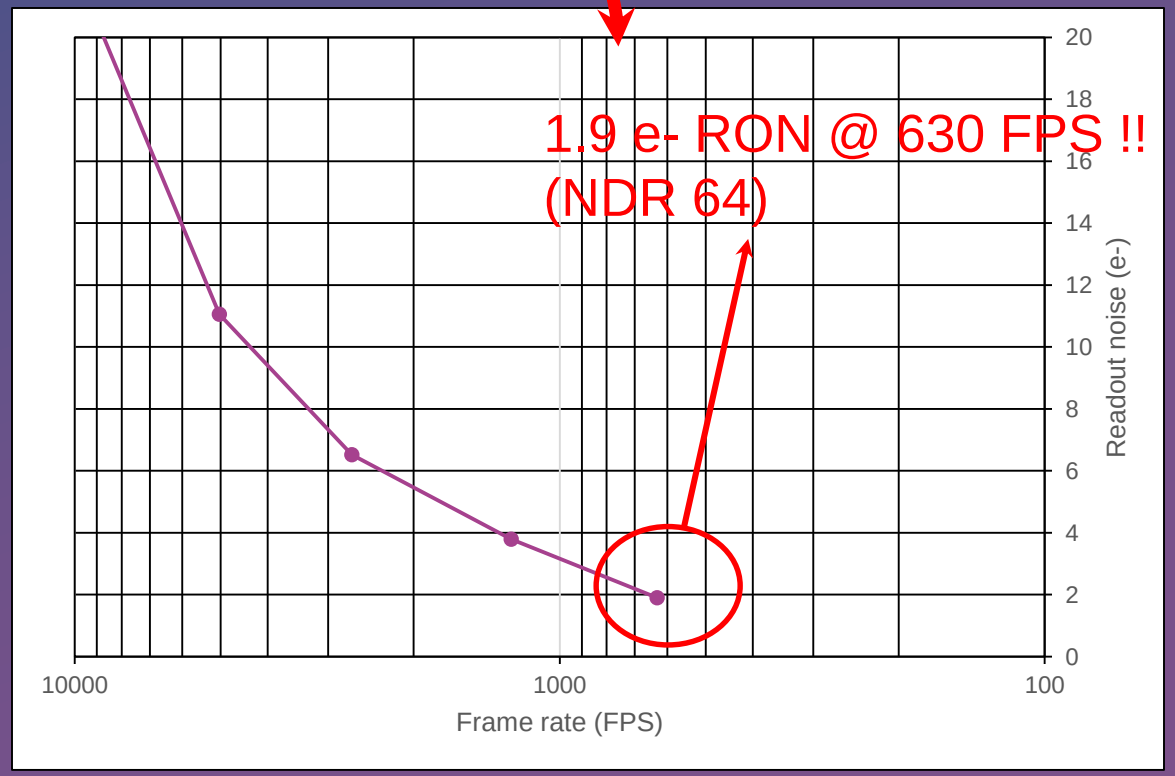


Example of Tip-Tilt WFS operation

Wide field recognition



Star selection & 32x4 ROI readout operation + NDR



Conclusion

- C-RED One is an infrared ready-to-use camera offering 320x256 Leonardo UK Saphira e-APD performances. Frame rate world record for an IR camera: sub-e noise 3500 FPS single read. 3 cameras delivered in 2017 (5 scheduled)
- C-RED 2 is a low cost 640x512 InGaAs camera offering 400 FPS & 22 e- readout noise. Noise is below 10 e- at 25 FPS NDR full frame. First deliveries at the end of september
- All these technologies are now mature and available at First Light Imaging.

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