CURVED DETECTORS : CHARACTERISATION AND NOISE PROPERTIES

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R&D seminar, February 1st 2018

Wide field astronomy

Wide field optical system (typically Schmidt designs): observation of transients, planets, ...

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Curved focal planes

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Additional field flatteners

Kepler focal plane, 42 flat CCDs

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WIDE FIELD ASTRONOMY

Wide field optical system (typically Schmidt designs):
observation of transients, planets, ...

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CURVED FOCAL PLANES

BUT NOW ...

atteners

Kepler focal plane,
42 flat CCDs

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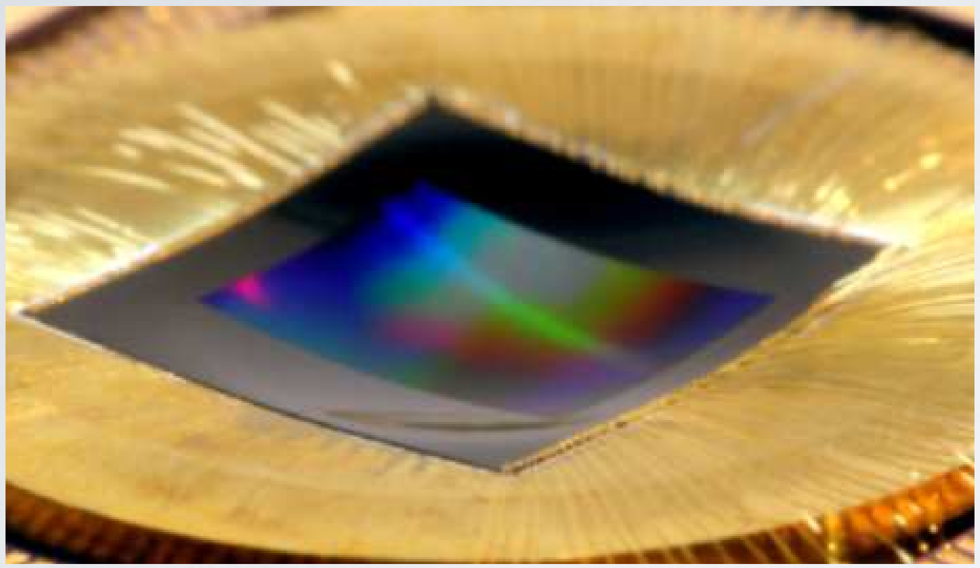
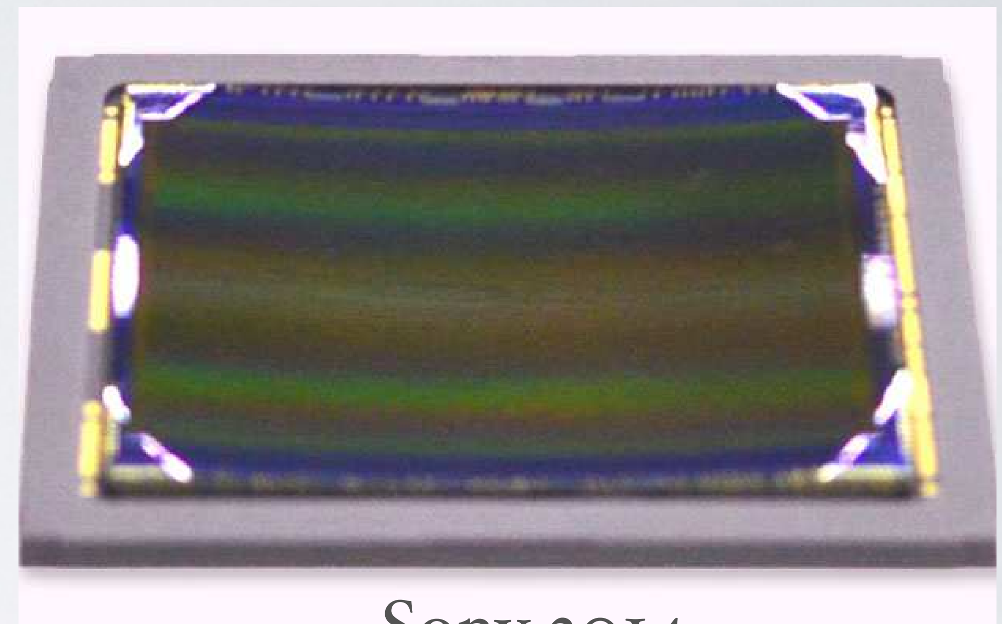
CURVED DETECTORS DEVELOPMENT

A new way of solving the problem



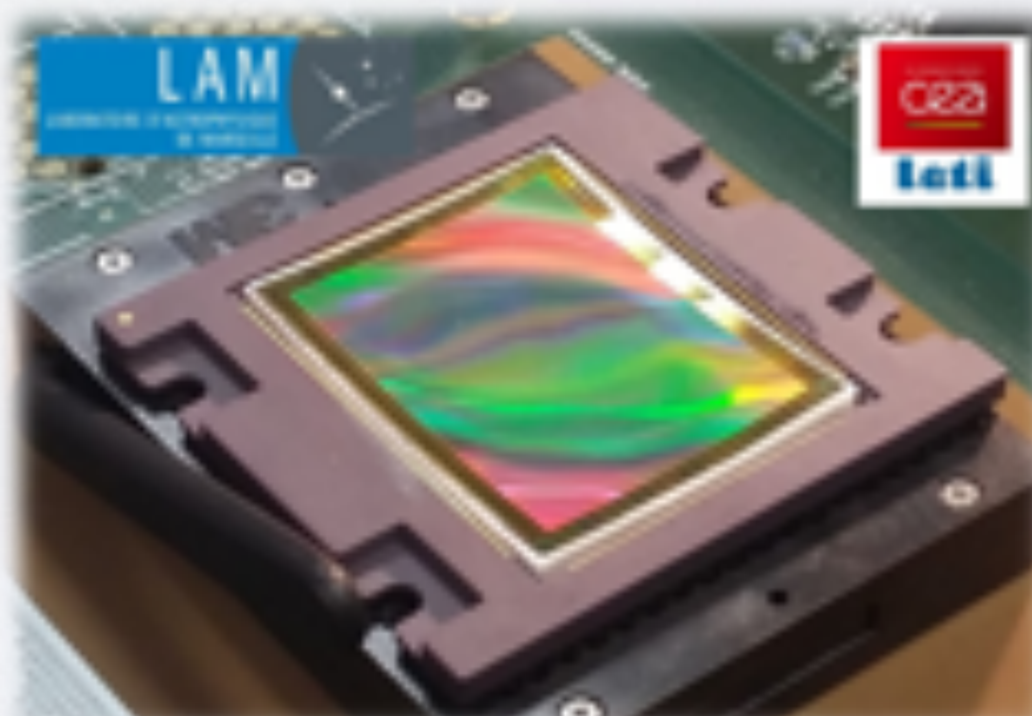
Microsoft 2017



Sony 2014

Many advantages:

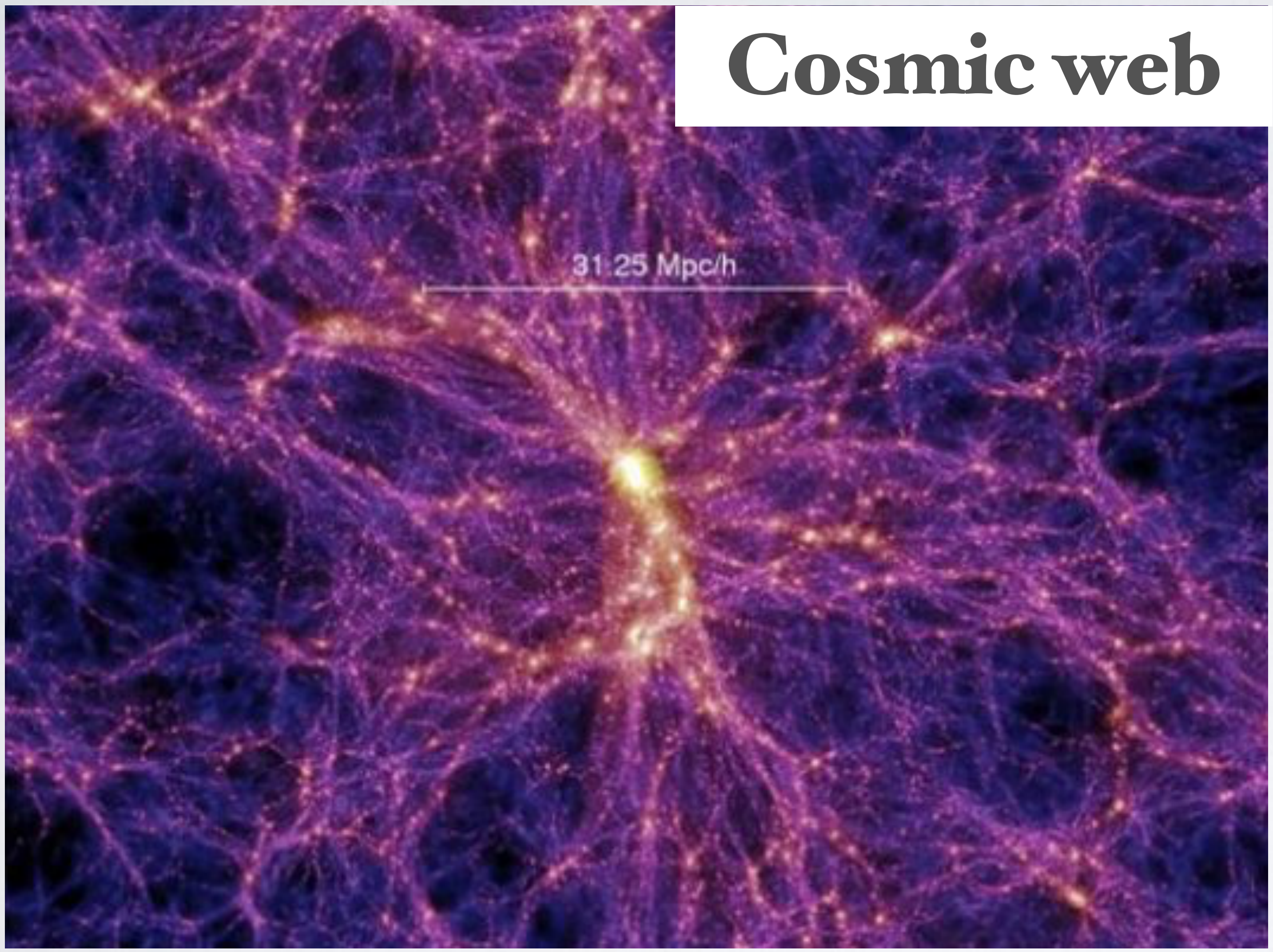
- smaller and **more compact systems**
- **better throughput**



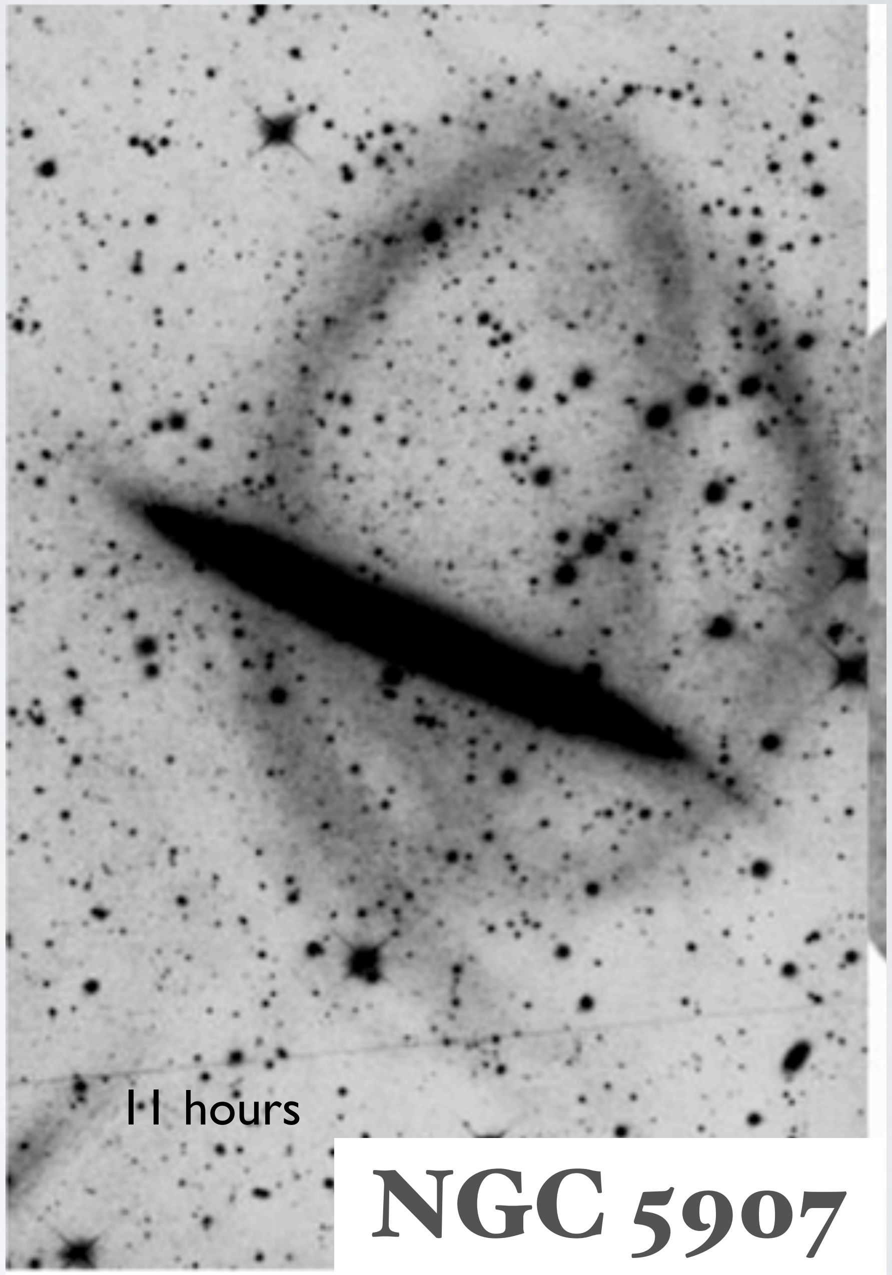
LAM/CEA Leti 2017

MESSIER: EXAMPLE FOR ASTRONOMY

Observing ultra-low surface brightness objects (35 mag/arcsec²)



Springel, 2015



0.5m f/8.1
Martinez Delgado et al. 2008

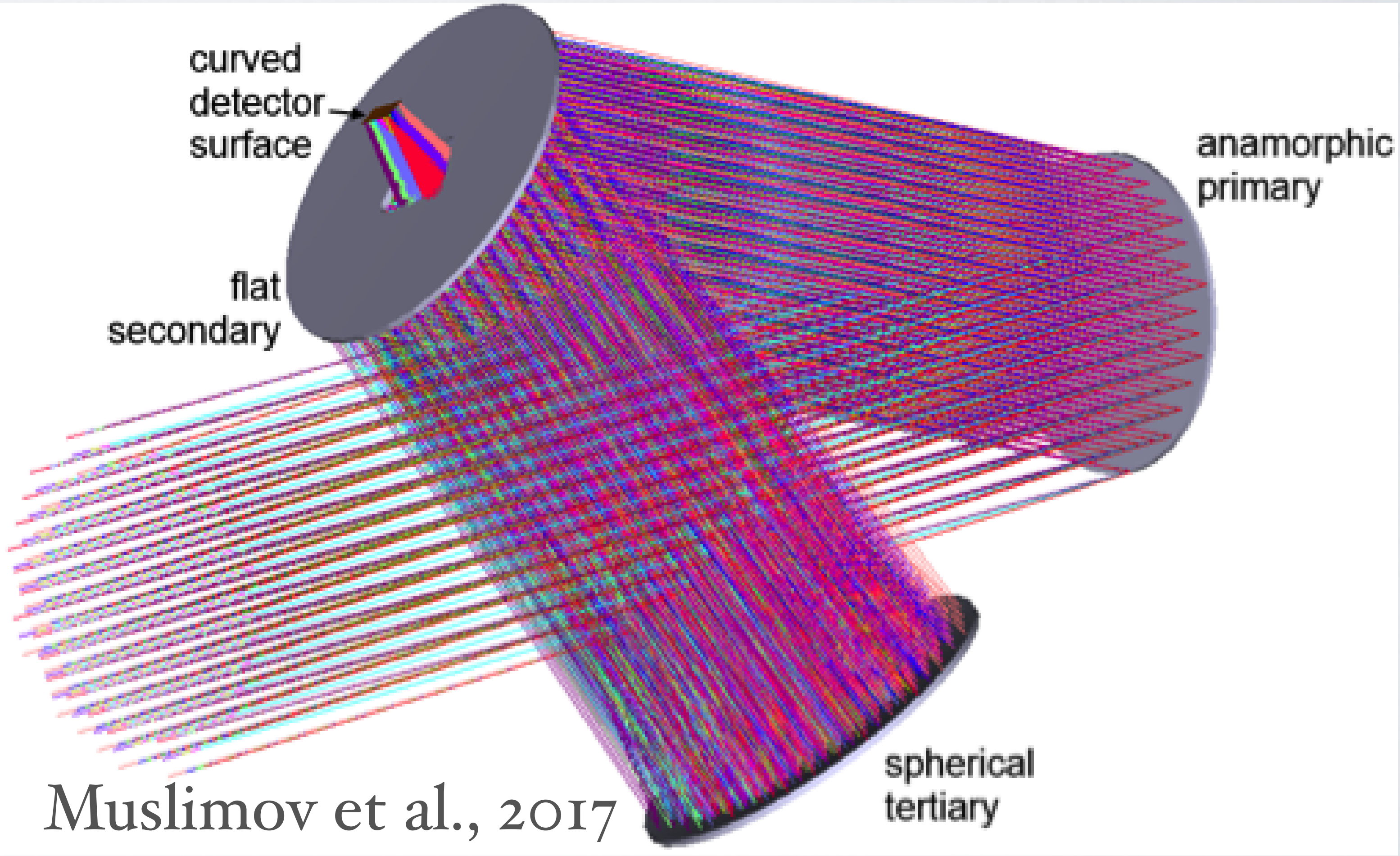
Messier: example for astronomy

Requirements:

1. Low PSF wings
2. No refractive surfaces (low UV background)

Parameter	Symbol	Value (pathfinder)
Field of view	FoV	$1^{\circ}\!.6 \times 2^{\circ}\!.6$
f-ratio	Ω	2.5
Primary diameter	M1	356 mm
Distortion	ϵ	<0.5% (in one direction)
Spot rms radius	ρ	<12μm

Pathfinder design



Muslimov et al., 2017

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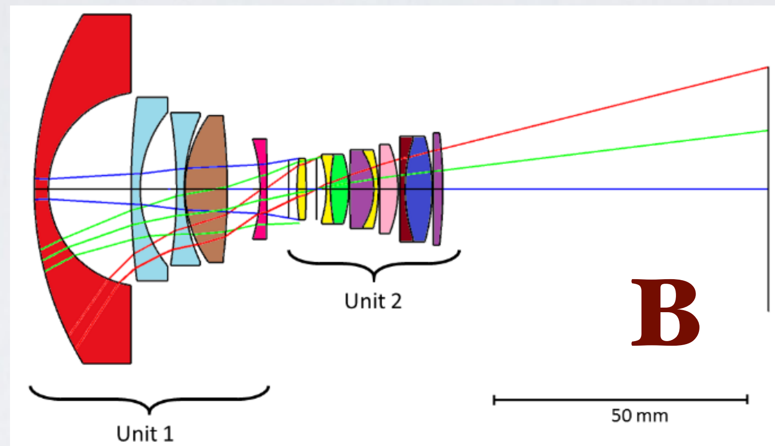
FISHEYE OBJECTIVE: COMMERCIAL APPLICATION

Slide from Wilfried Jahn's PhD talk

Reference



FISHEYE OBJECTIVE: COMMERCIAL APPLICATION

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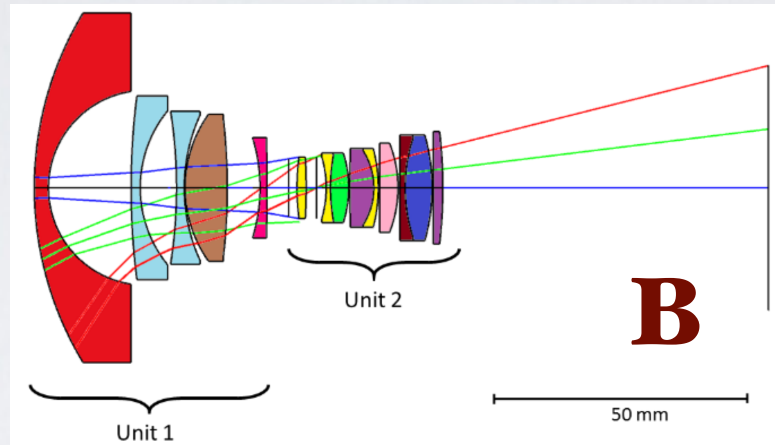

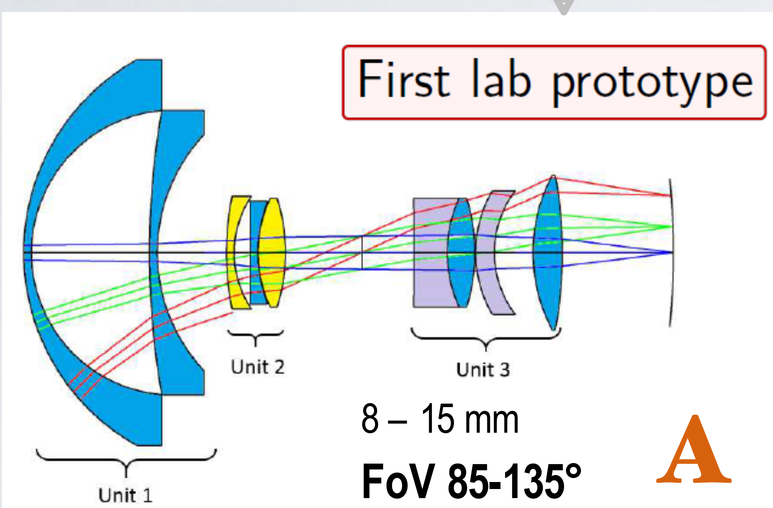

8 – 15 mm

FoV 85-135°

Concave sensor R = 150-345 mm

FISHEYE OBJECTIVE: COMMERCIAL APPLICATION

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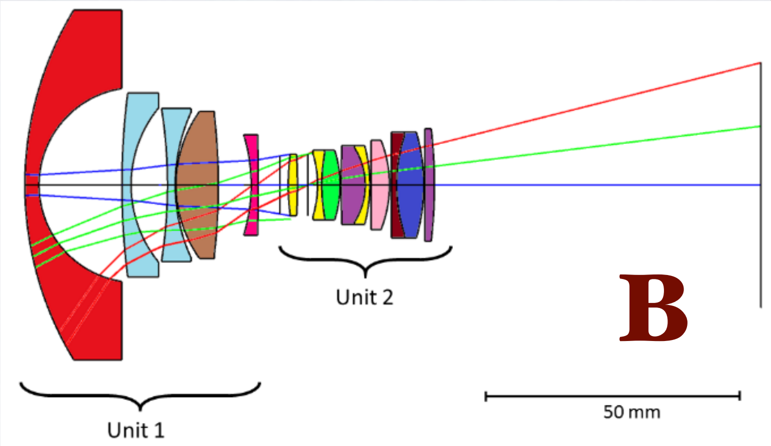
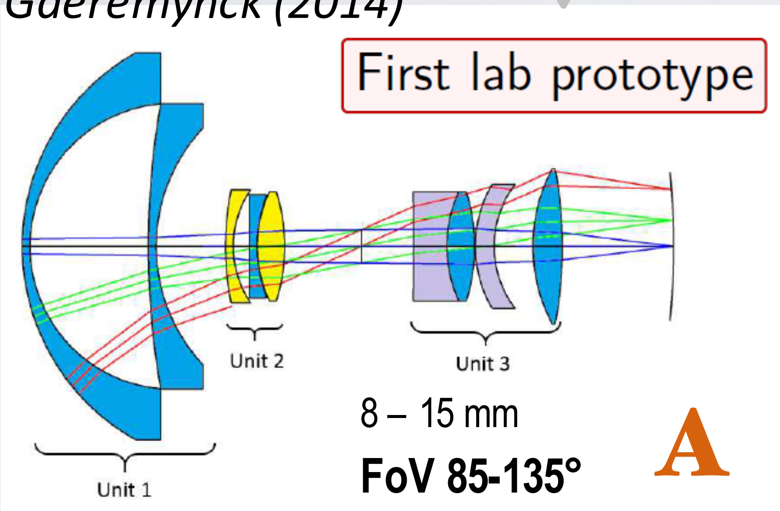


Gaeremynck (2014)



8 – 15 mm

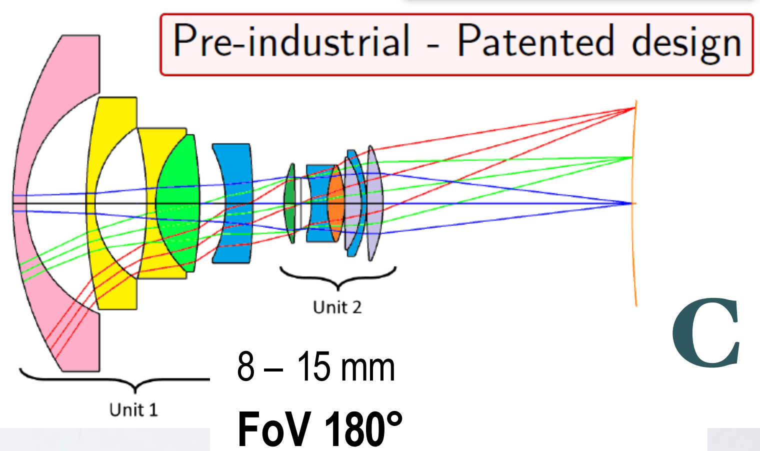
FoV 85-135°

Concave sensor R = 150-345 mm

A

2

Patent n° 1658104

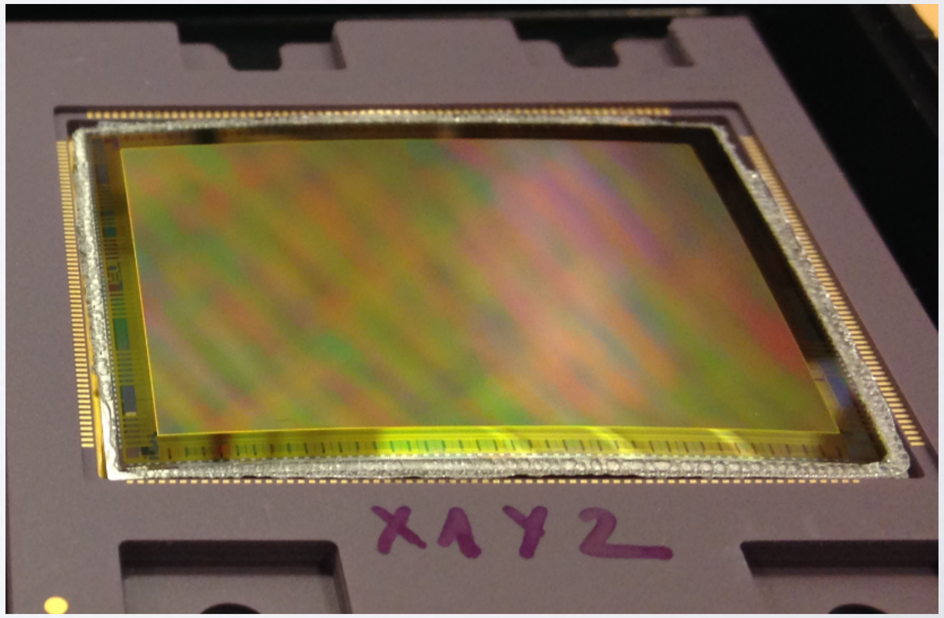


8 – 15 mm

FoV 180°

Convex sensor R = 280 mm

Radius: 150 mm concave
Fully functional



Fisheye objective: performances

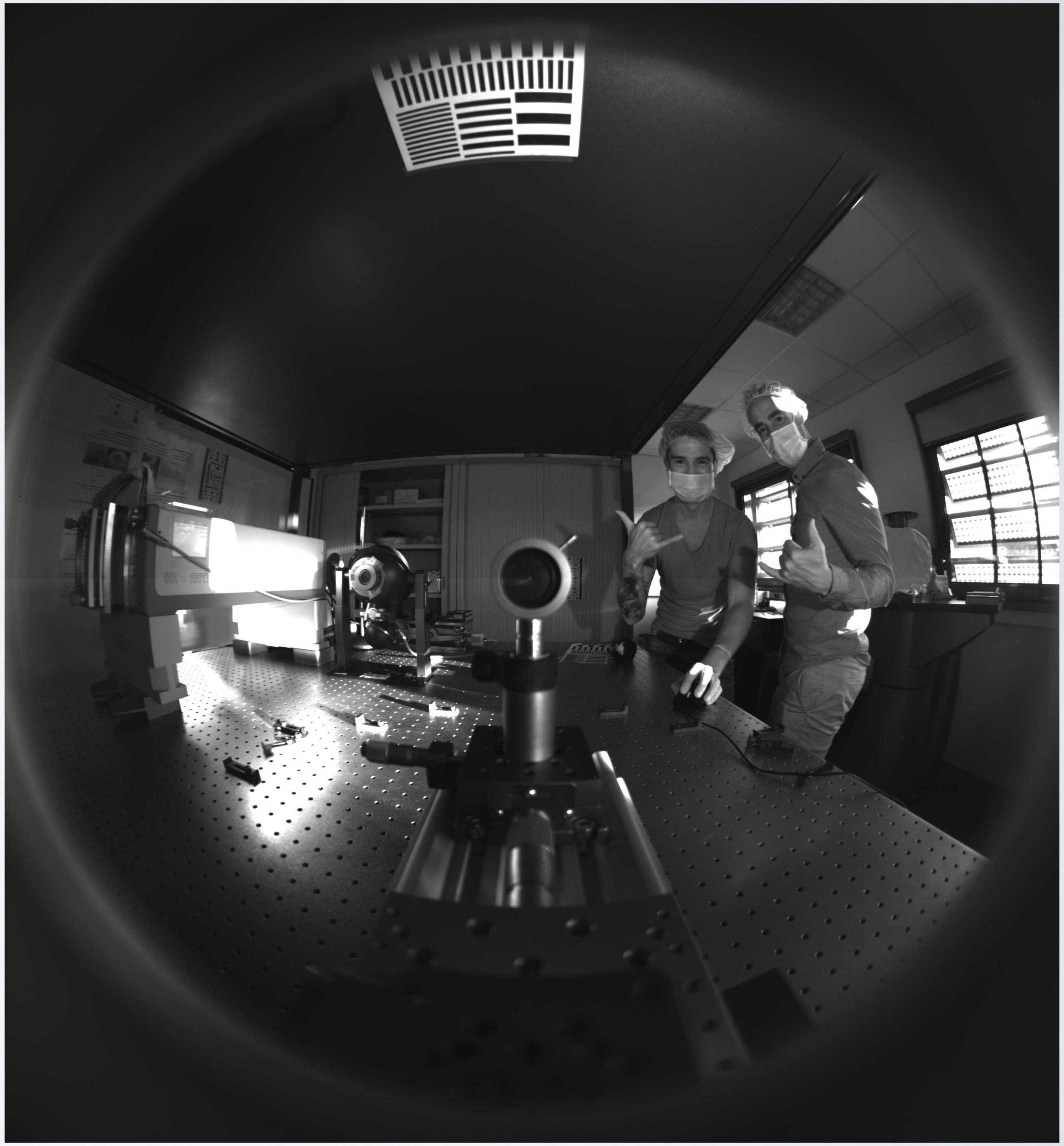
Parameters	A	C VS Canon objective B	
Sensor radius	150 - 343 mm concave	280 mm convex	flat
FoV	134° - 84°	175°	
Focal range	8.5 - 14.7 mm	8.2 - 15.1 mm	
Aperture	4.2	4.2	
Image size [mm]	22 mm diagonal	24 - 44 mm diagonal	
Number of lenses	9	11	14
Number of materials	3	7	11
Aspherical surface	No	No	Yes
Vignetting off-axis	10 %	No	50 %

Jahn et al., 2018 (in prep.)

AMAZING PICTURES

A

C



Jahn's Thesis

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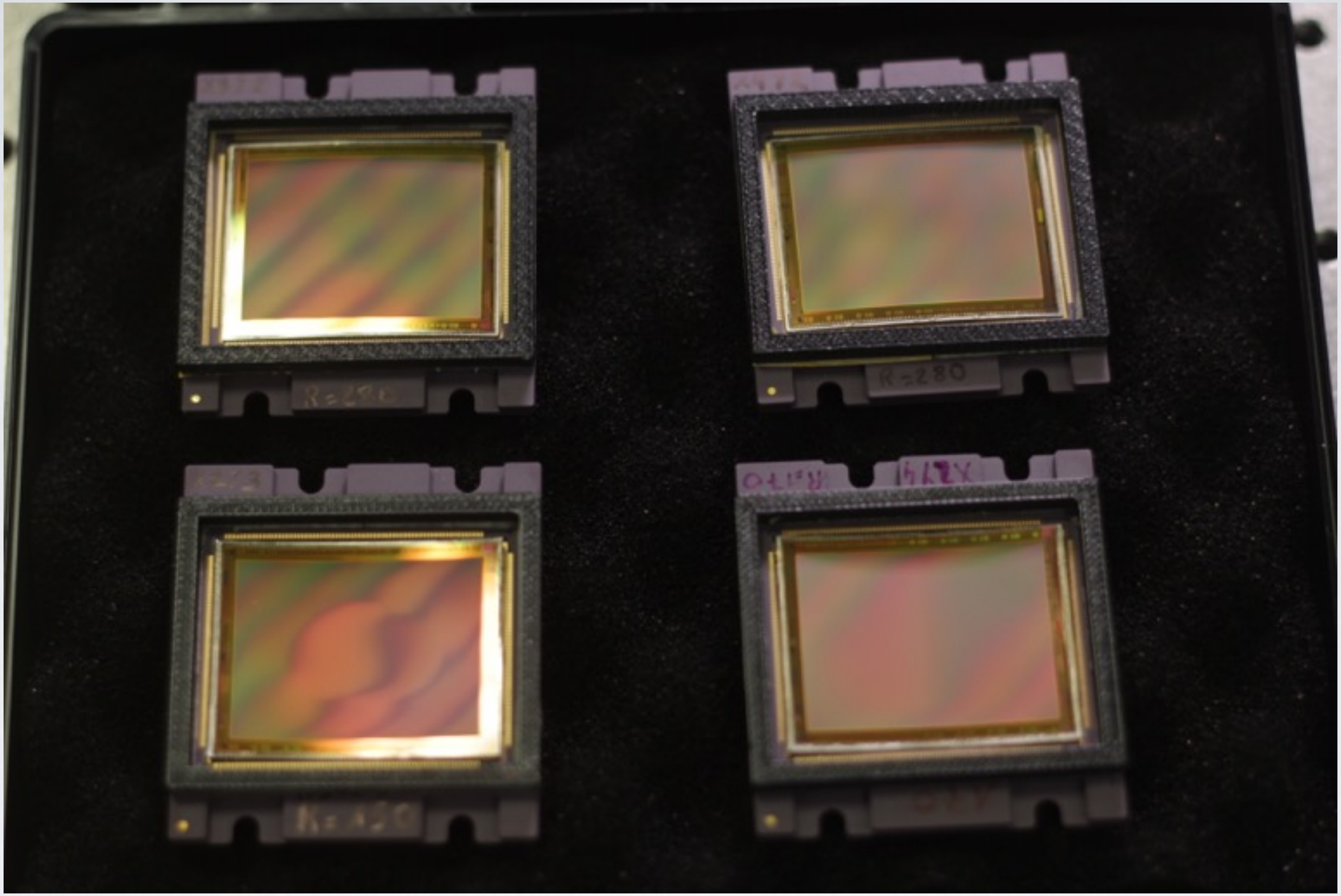
Many detectors produced



CMOSIS CMV20000, 5120x3840 pixels of 6.4 um

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Many detectors produced

We want to know their performances

Characterisation

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WHAT DOES CHARACTERISATION MEAN?

Evaluation of the characteristic noise components and dark current impact.

Evaluation of the conversion factor between digital number (DN) and number of electrons that originated it (gain DN/e^-).

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Typical quantities

gain

Electrons generated due to light

$$S_{tot} = kN_e + S_{off}$$

offset/**bias** signal

Observed signal

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Typical noise equation

The noise variance on each pixel is:

readout noise (RON)

$$s_{tot}^2 = k^2 s_r^2 + k^2 s_e^2 = k^2 s_r^2 + k^2 N_e$$

total noise called **temporal noise**

shot noise

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WHAT IS THE DARK CURRENT?

Due to thermal agitation of electrons.

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Depends on temperature

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Have to be **stable** within 1°C
during characterisation

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How to measure the dark current

Recipe:

Expose in the darkness for different exposure time

$$S_{tot} = m\, t_{exp} + S_{off}$$

fit this relation

The dark current is the slope m.

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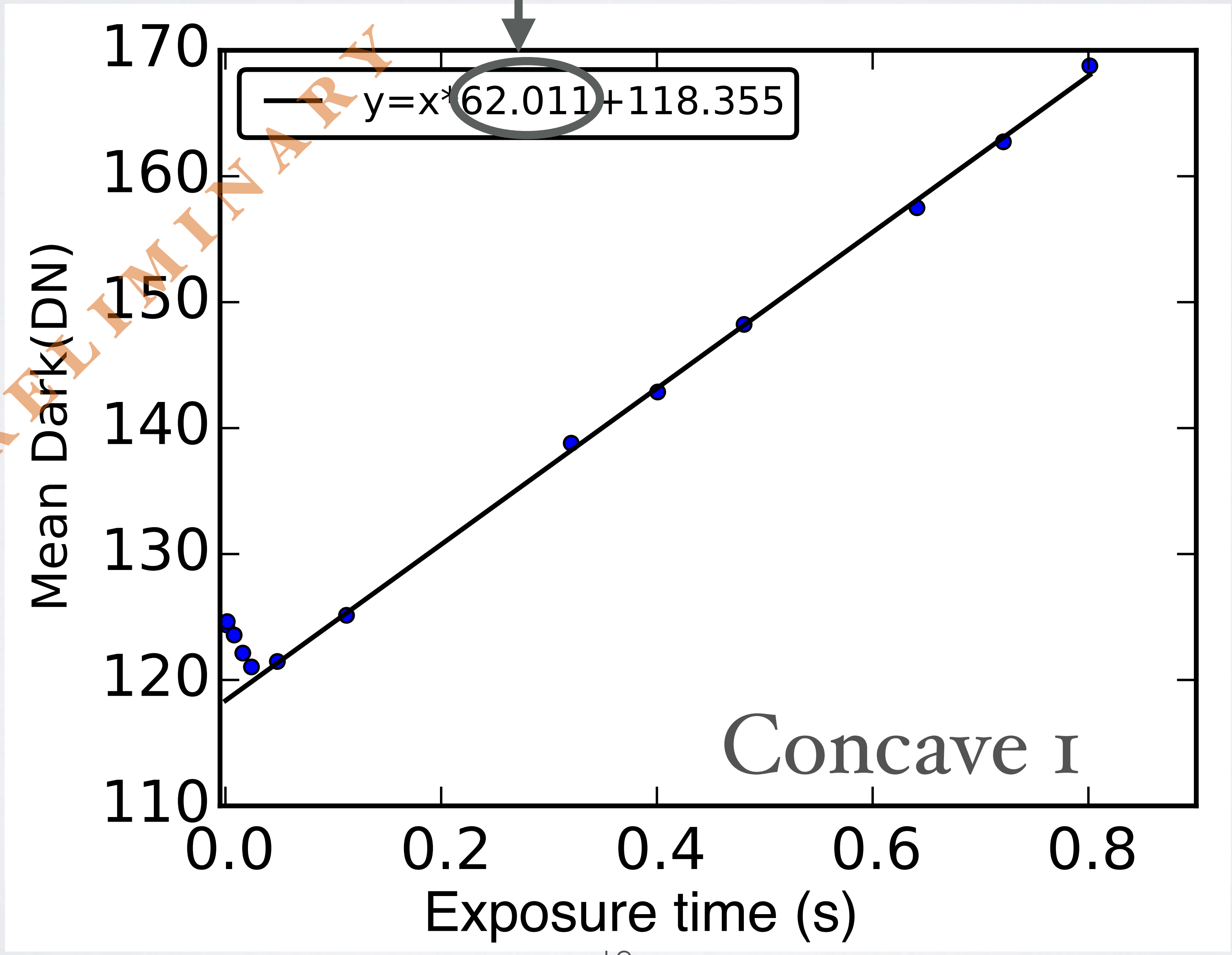
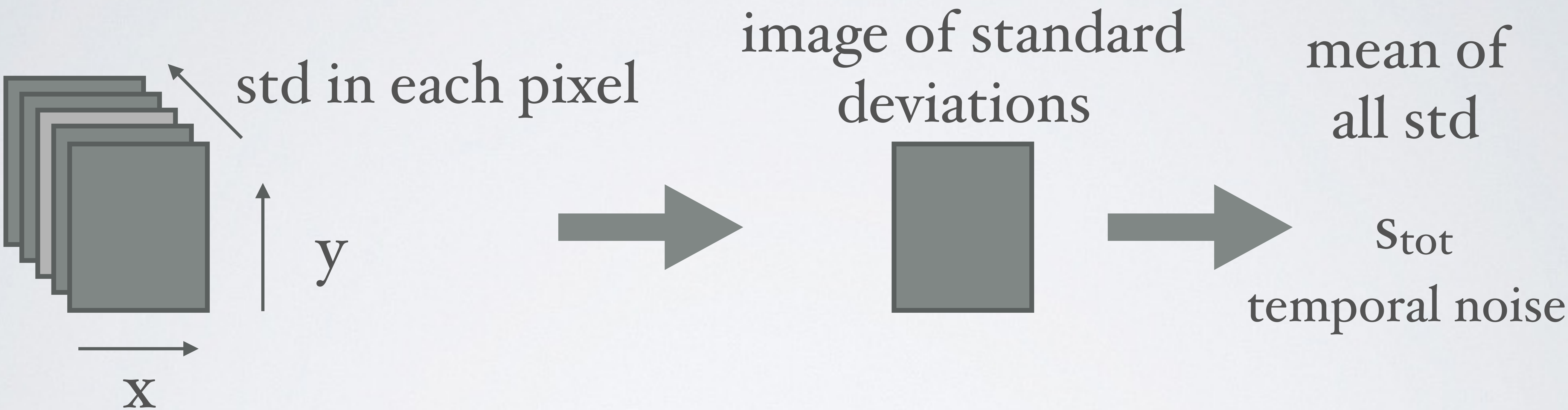
How to measure the dark current

We always acquire 30 images and compute the median image

$S_{tot} = m\, t_{exp} + S_{off}$



How to measure the Temporal Noise



How to estimate the Gain

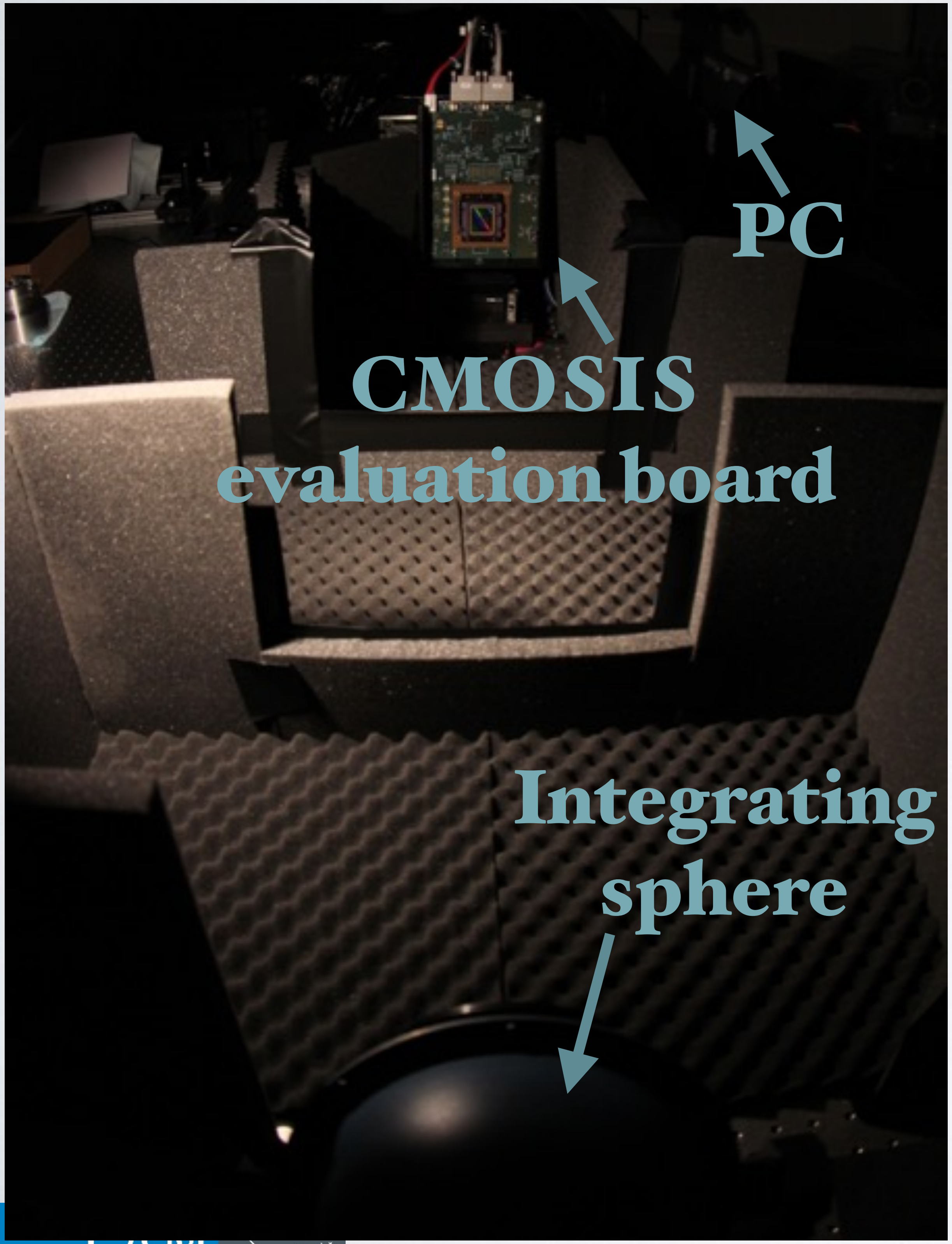
$$s_{tot}^2 = k^2 s_r^2 + k^2 N_e = const + k(S_{tot} - S_{off})$$

Temporal noise variance vs signal =
linear relation

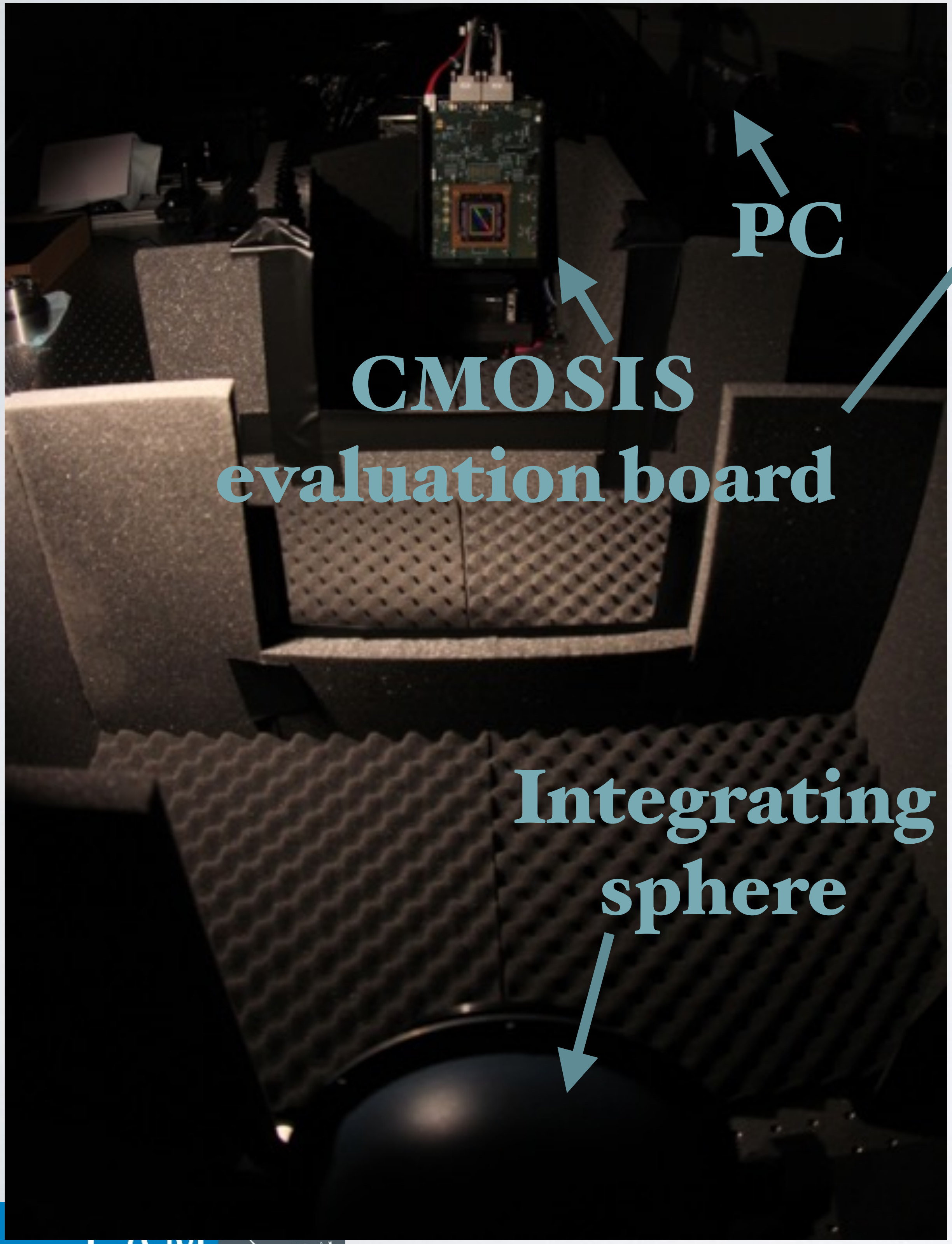
Recipe:

Expose to uniform and stable illumination for different exposure time

SET-UP USED

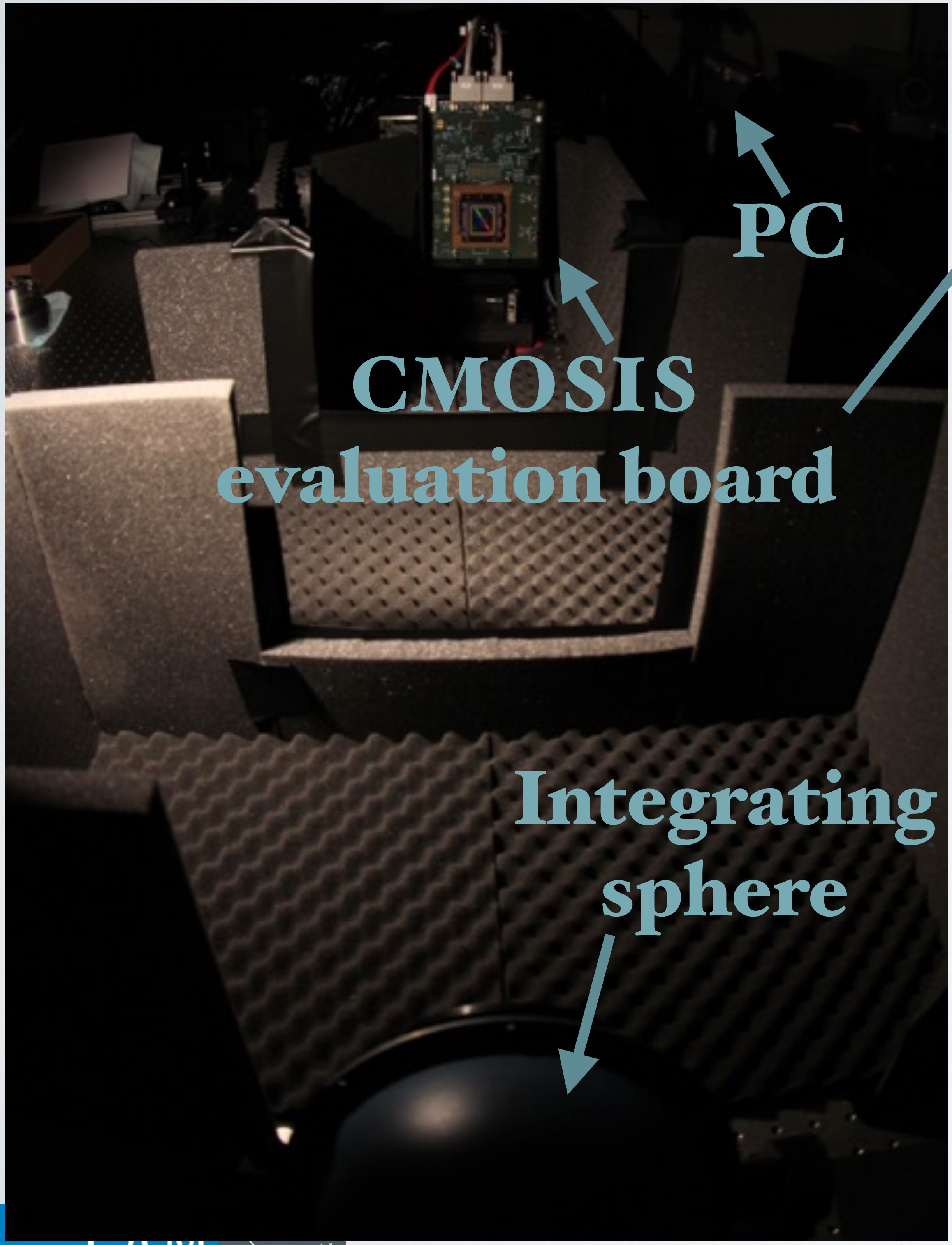


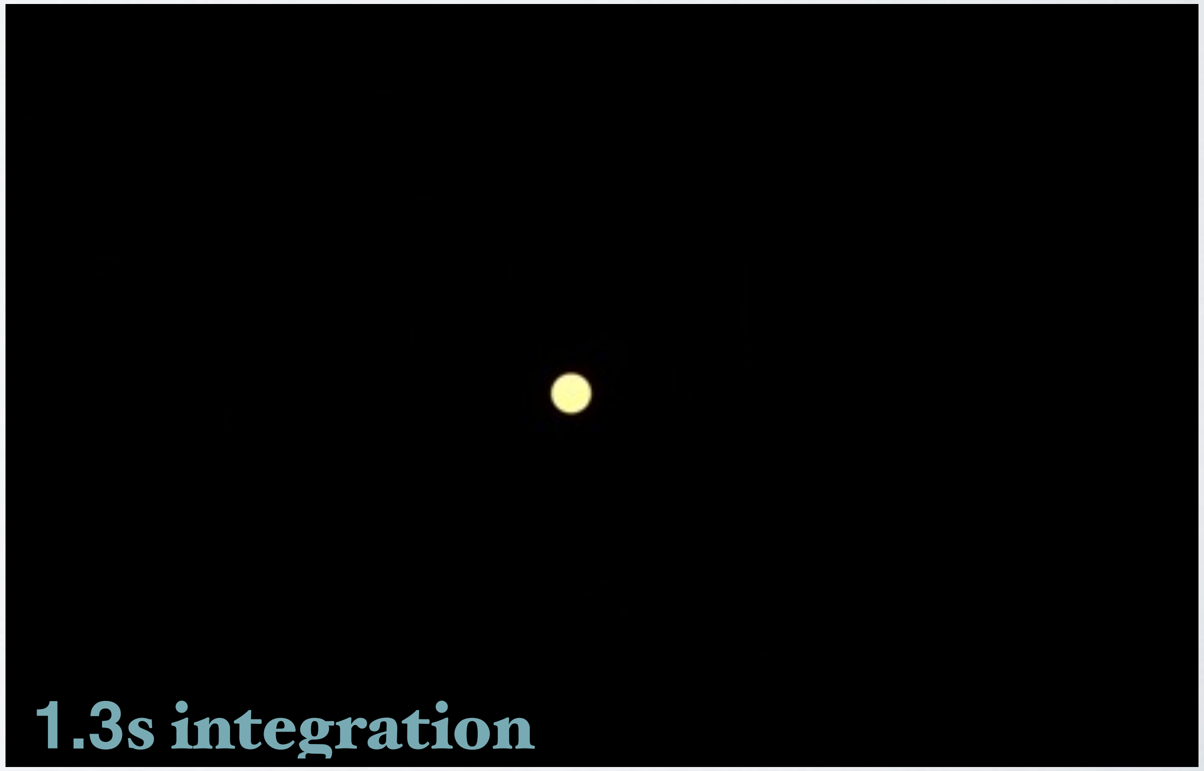
SET-UP USED


PC
CMOSIS
evaluation board
Integrating
sphere


Light baffle
20s integration

SET-UP USED





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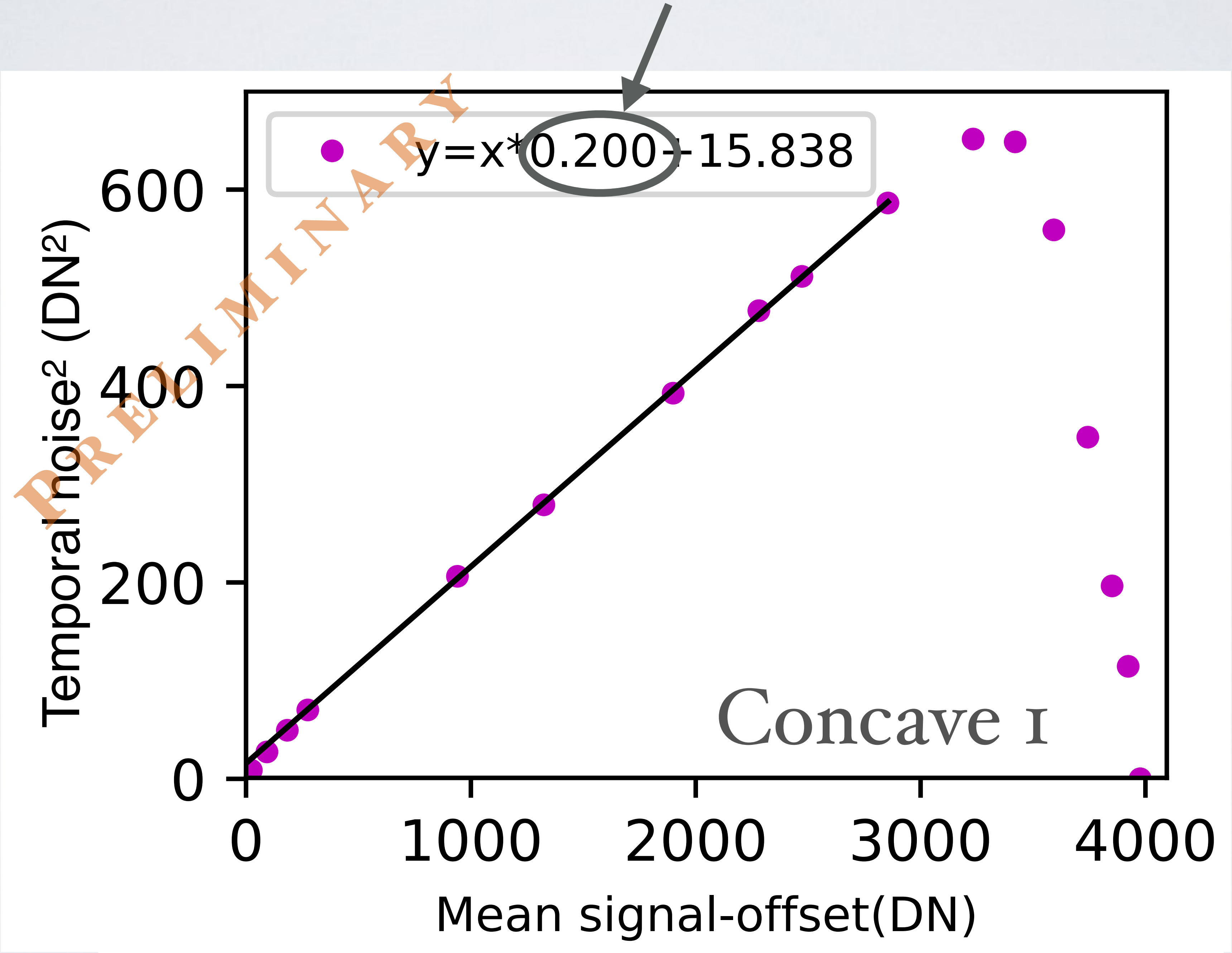
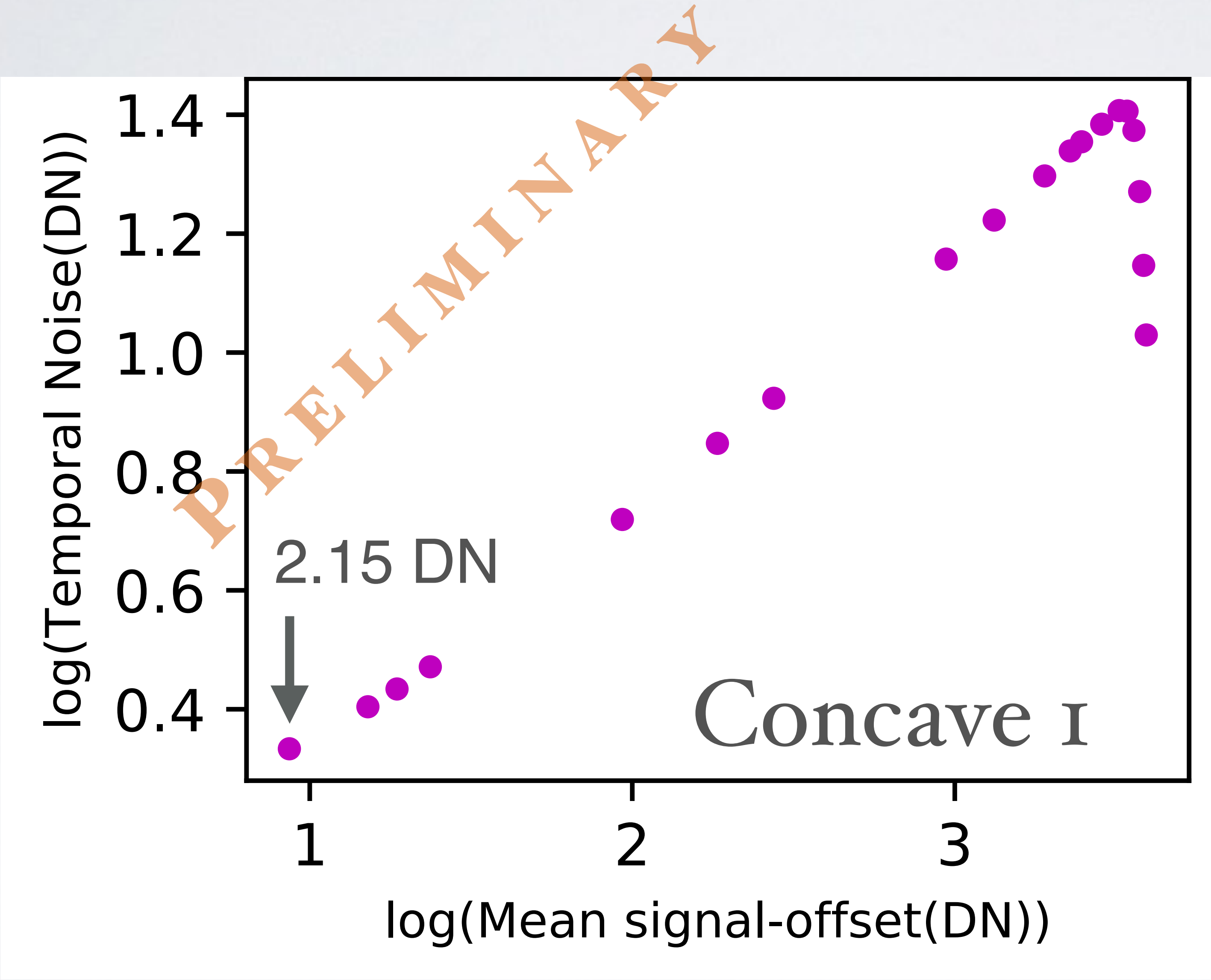
How to estimate the Gain

$$s_{tot}^2 = const + k(S_{tot} - S_{off})$$



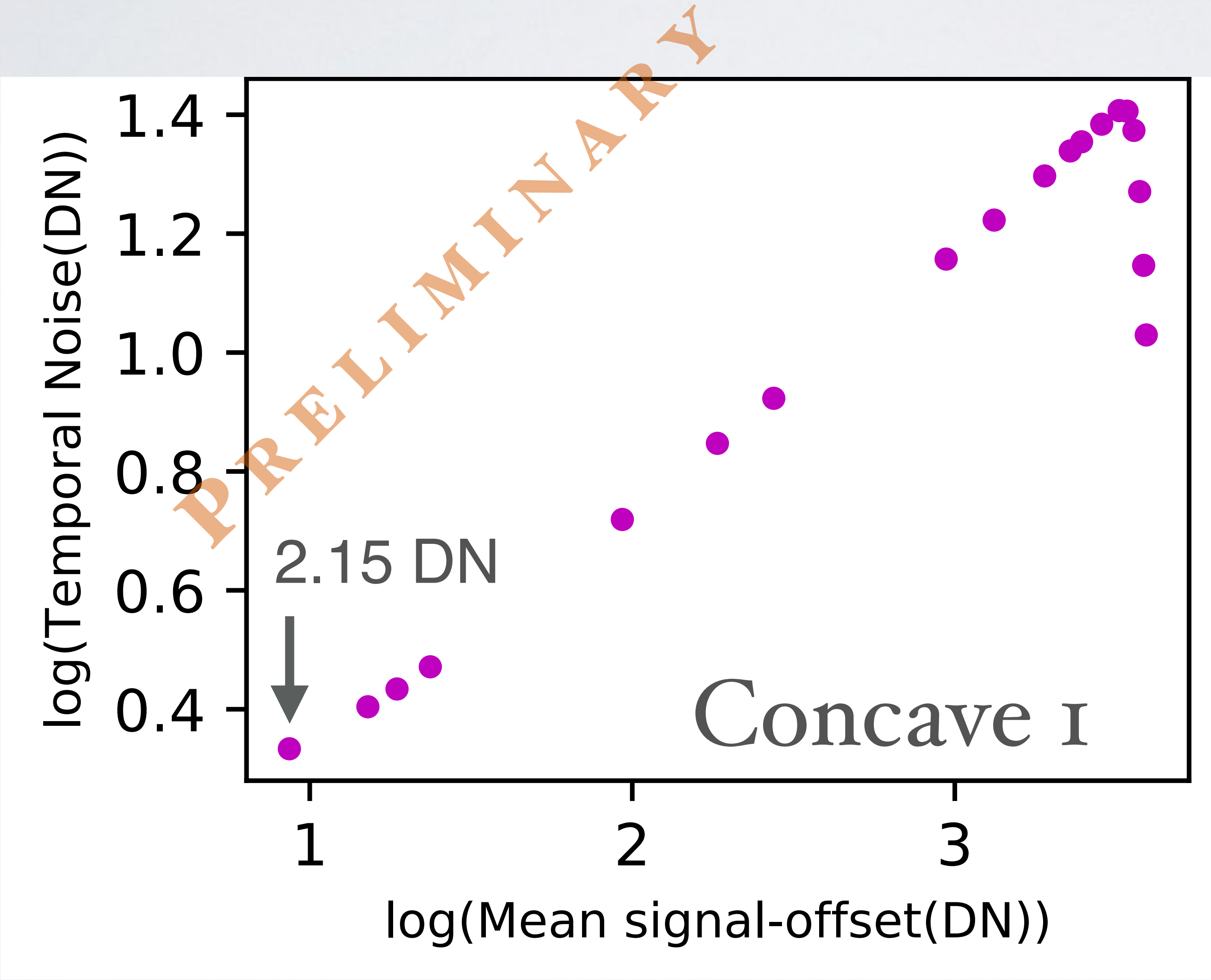
How to estimate the RON

$$s_{tot}^2 = const + k(S_{tot} - S_{off})$$



How to estimate the RON

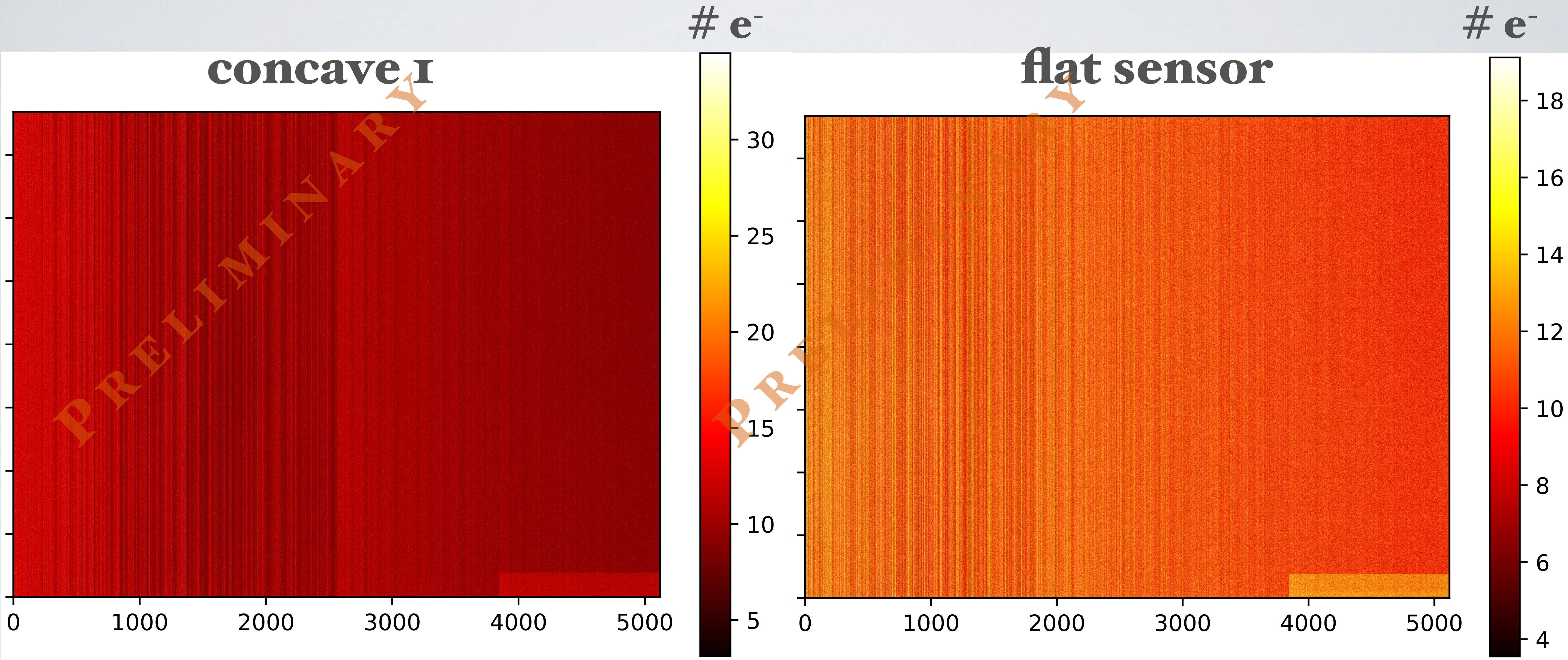
$$s_{tot}^2 = const + k(S_{tot} - S_{off})$$



Using equivalent plot from dark exposures:

s_r = 1.99 DN
@ 0.0002s

Example results: RON map comparison



RON = 10 e^-

RON = 11 e^-

Very similar performances

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RESULTS FOR ALL OF THEM

PRELIMINARY

	Flat	Concave 1	Convex x3y2	Convex x4y2	Concave x2y3
Radius (mm)	no	150	280	280	150
Bias (e^-)	605.7±23.4	623.0 +-24.0	644.0±25.3	600.9±24.4	608.4±23.2
Dark current (e^-/s)	249.6±1.9	310.0+3.5	330.0±4.2	194.3±0.8	199.4±0.9
Gain (DN/e^-)	0.220±0.003	0.200 ±0.002	0.214±0.003	0.210±0.002	0.190±0.002
RON (e^-)	11	10	9	10	10
Saturation (DN)	4095	4095	4095	4095	3951
Dynamic range (dB)	64.74	66.26	66.61	66.03	66.48

Noticed that:
many saturated columns and fixed specific 2D pattern for high exposure time

CONCLUSIONS AND NEXT STEPS

Curved detectors have similar characteristics to the flat ones (noise, gain, dynamic range, ...)

↓

NO CLEAR PERFORMANCE DEGRADATION IN THE CURVING PROCESS

- Process for industrial manufacturing of curved detectors is moving forward
- Possible developments toward tunable radius of curvature
- **Demonstrate their potential in wide field astronomy** (MESSIER, ...)

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THANK YOU!

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