



First results of a 2000+ FPS
OCAM² camera : OCAM^{2K}

FIRST LIGHT IMAGING SAS

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OCAM² heritage

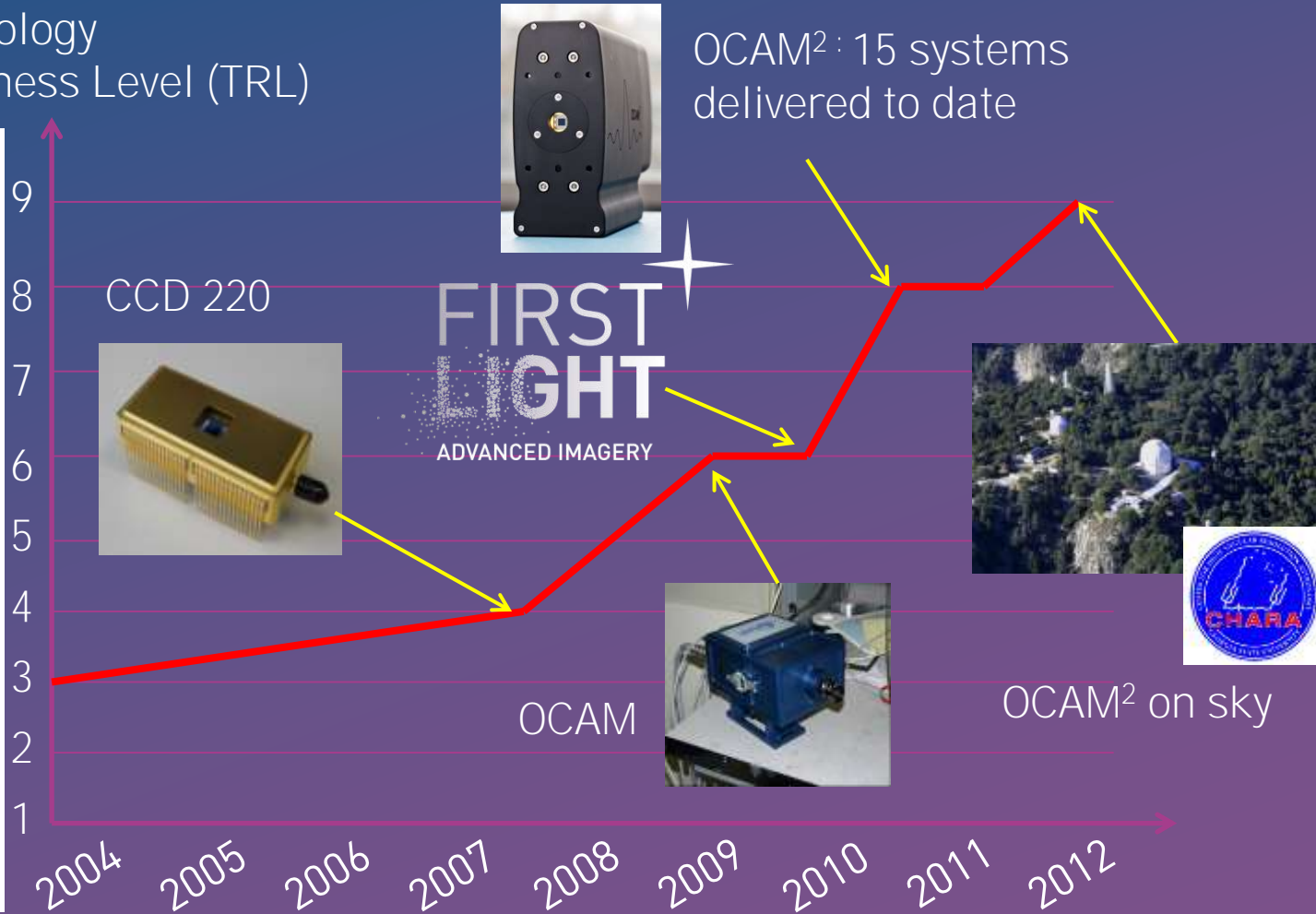
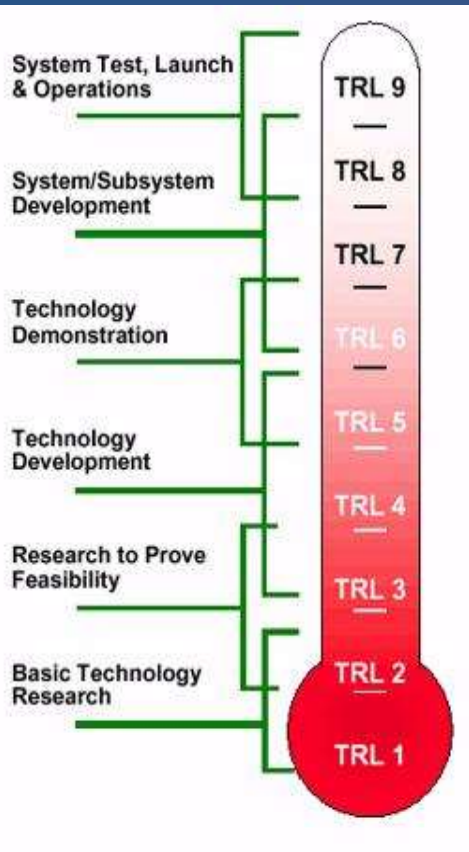
- Initially the OCAM program comes from the OPTICON detector development
- FP6/FP7 & ESO funding for ESO XAO system (SPHERE)



- 2009 : OCAM & technology transfer to First Light Imaging, LAM spinoff
- 2011 : OCAM² is commercially available
- 2013 : OCAM^{2K} is ready and in production

OCAM2 technology path

Technology
Readiness Level (TRL)



First Light Business

The biggest telescopes in the world.

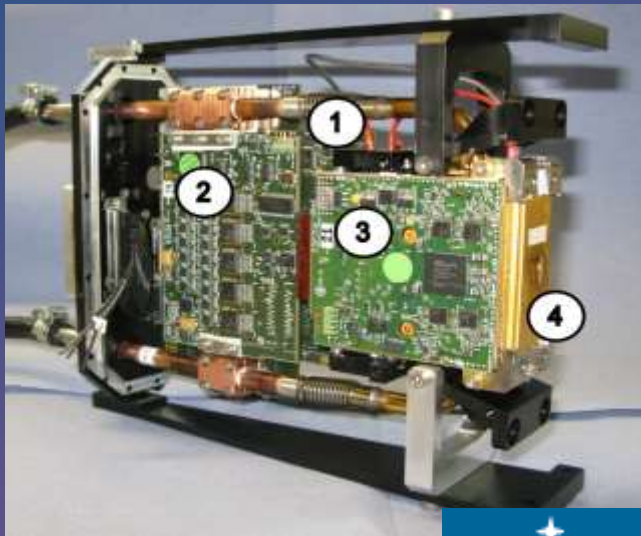
The sharpest labs and institutes.

Some advanced industrial companies.

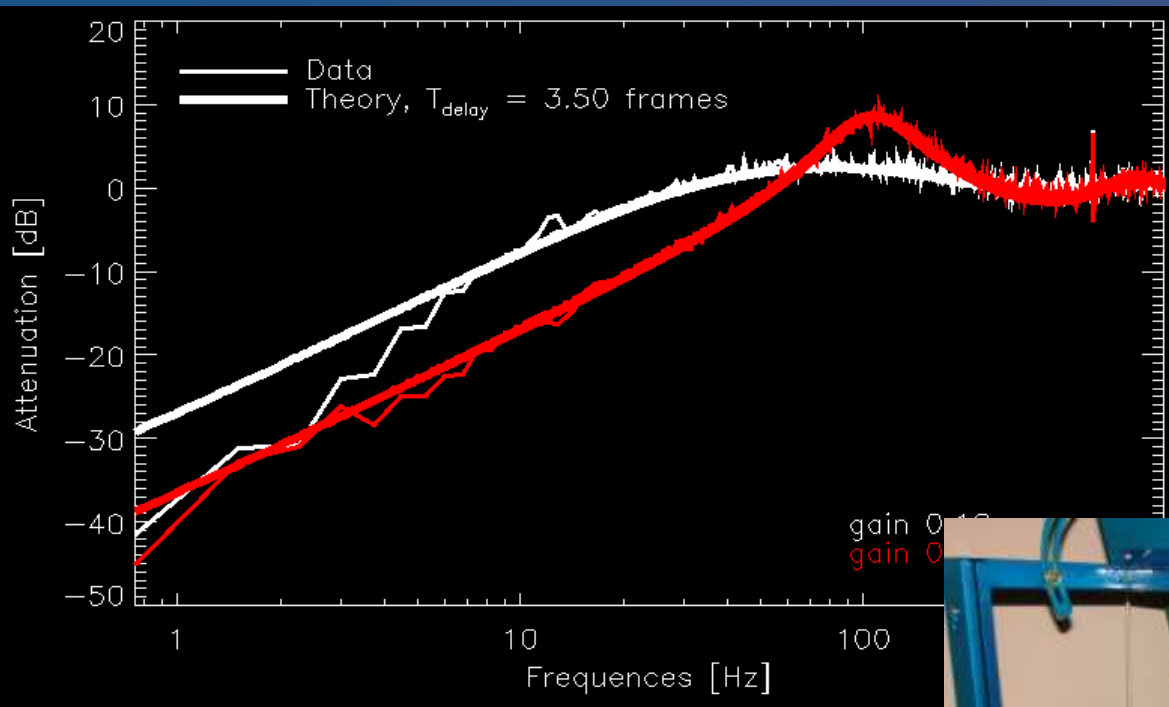


ESO Wavefront Sensor

First light has been subcontracted for the design of the critical elements of the ESO WFS (OCAM2 IP)

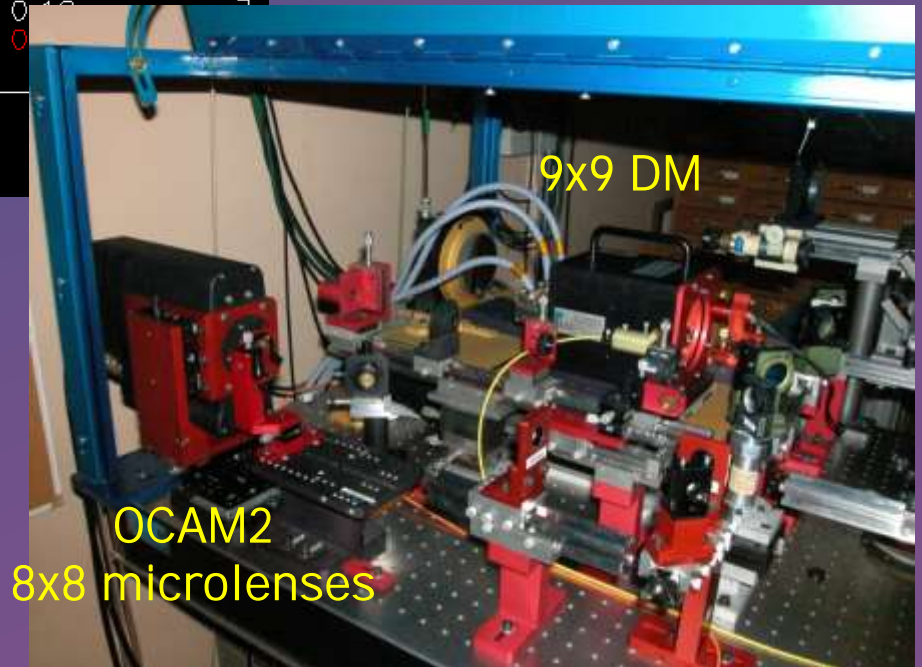


OCAM2 closed loop on the sky - ONERA



Rejection transfer function of the AO loop system. Sampling frequency is 1503 Hz.
Shakti RTC

Courtesy of T. Fusco & al., SPIE Amsterdam 2012 [8447-68]



OCAM2 Results on CHARA

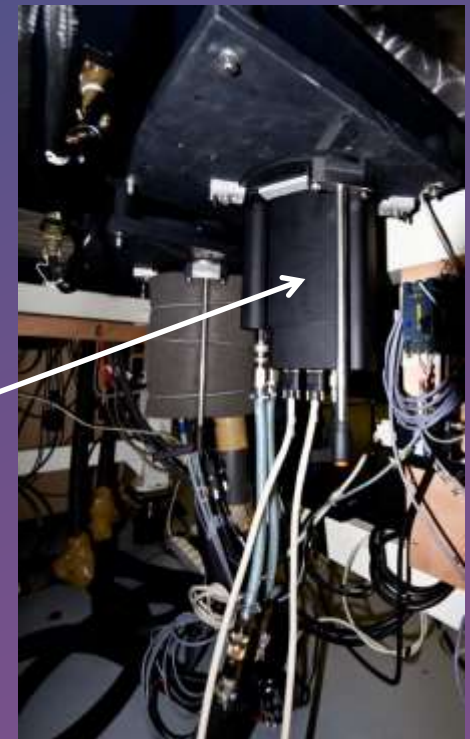
Telescopes (6 x 1m)



Delay lines

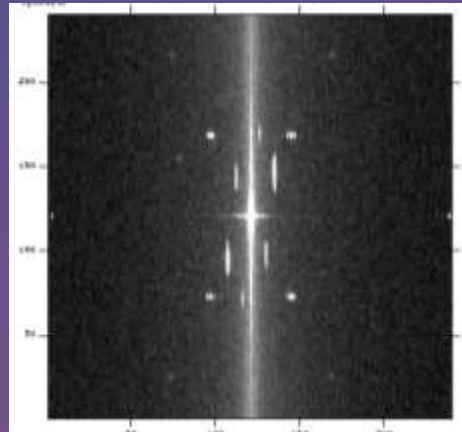


Beam recombinator focus



HD58923 FFT
3T observation
Photon counting mode

Results courtesy of
P. Berio
Obs. Côte d'Azur



OCAM2

OCAM2 performance

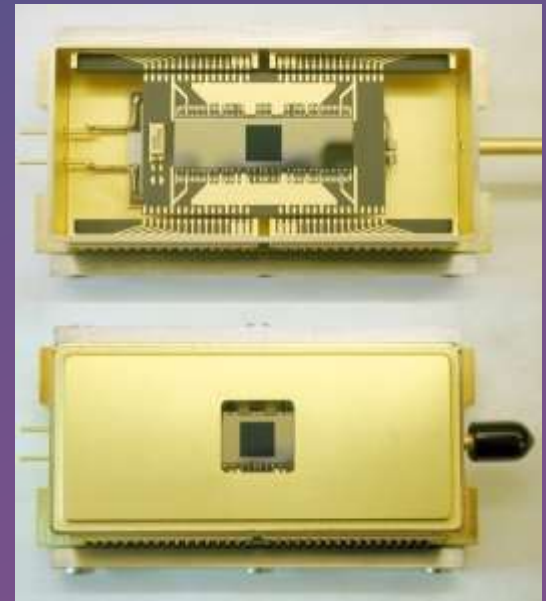


Test measurement	Result	Unit
Nominal speed (full frame)	1503	FPS
Mean readout noise	~ 0.13	e-
Dark signal at 1503 fps	< 0.01	e-/pix/ frame
Dark signal at 25 fps	~ 0.05	e-/pix/ frame
Detector operating temperature	- 45	°C
Peak Quantum Efficiency at 650 nm	94	%
Linearity at gain x1000 from 10 to 150 ke	<3	%
Image area Full Well Capacity at gain x1, 1503 fps	300	ke ⁻
Parallel CTE at gain x1, 1503 fps	>0.99995	N/A
Serial CTE at gain x1, 1503 fps	0.99994	N/A

See A04ELT2 paper for detailed performances :
<http://ao4elt2.lesia.obspm.fr/spip.php?article552>

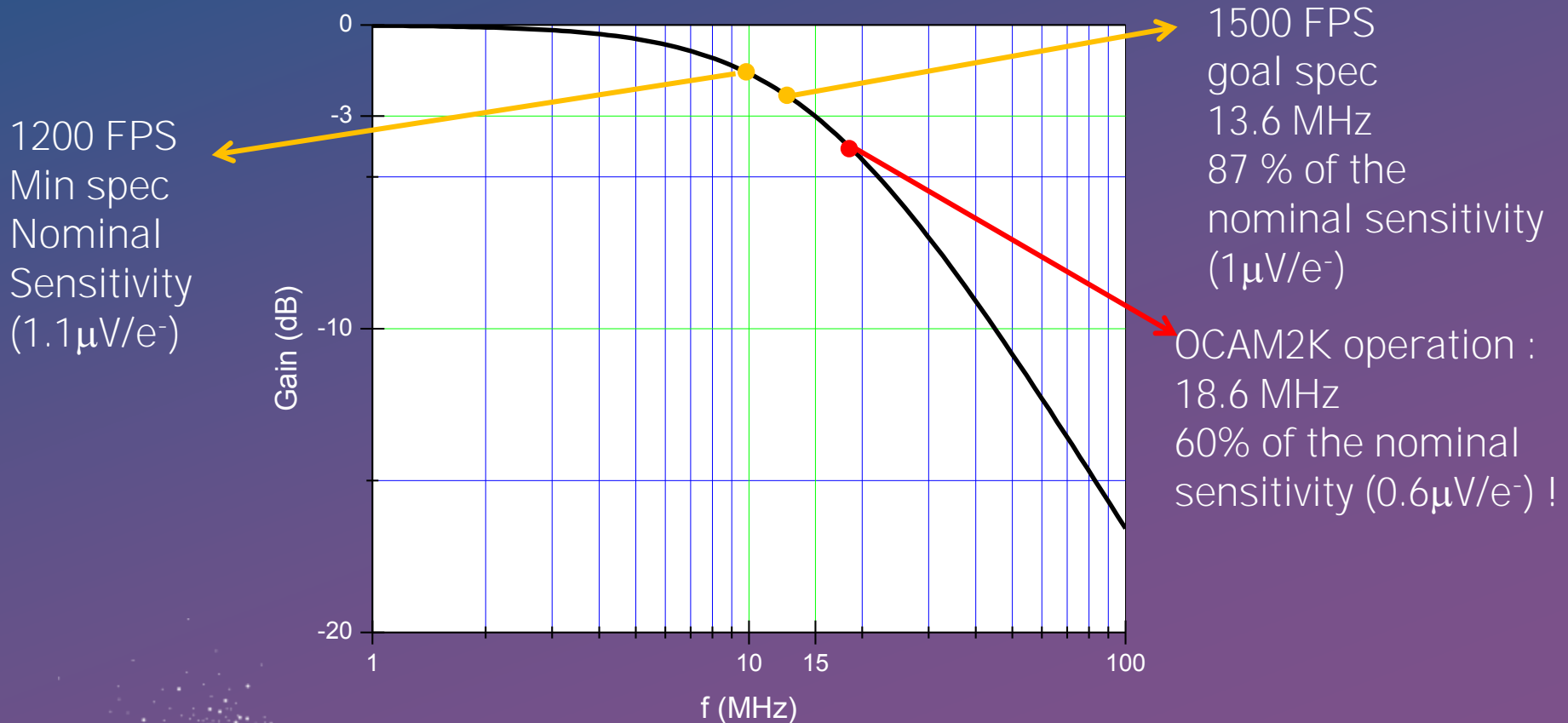
OCAM^{2K} project

- Development carried by First Light Imaging with internal resources
- Goal : increase the OCAM2 camera speed to more than 2000 FPS.
- Need to overcome the CCD intrinsic limitations: designed for 1200 FPS min, 1500 goal
- 18.6 Mpixel rate : unprecedented L3CCD readout speed



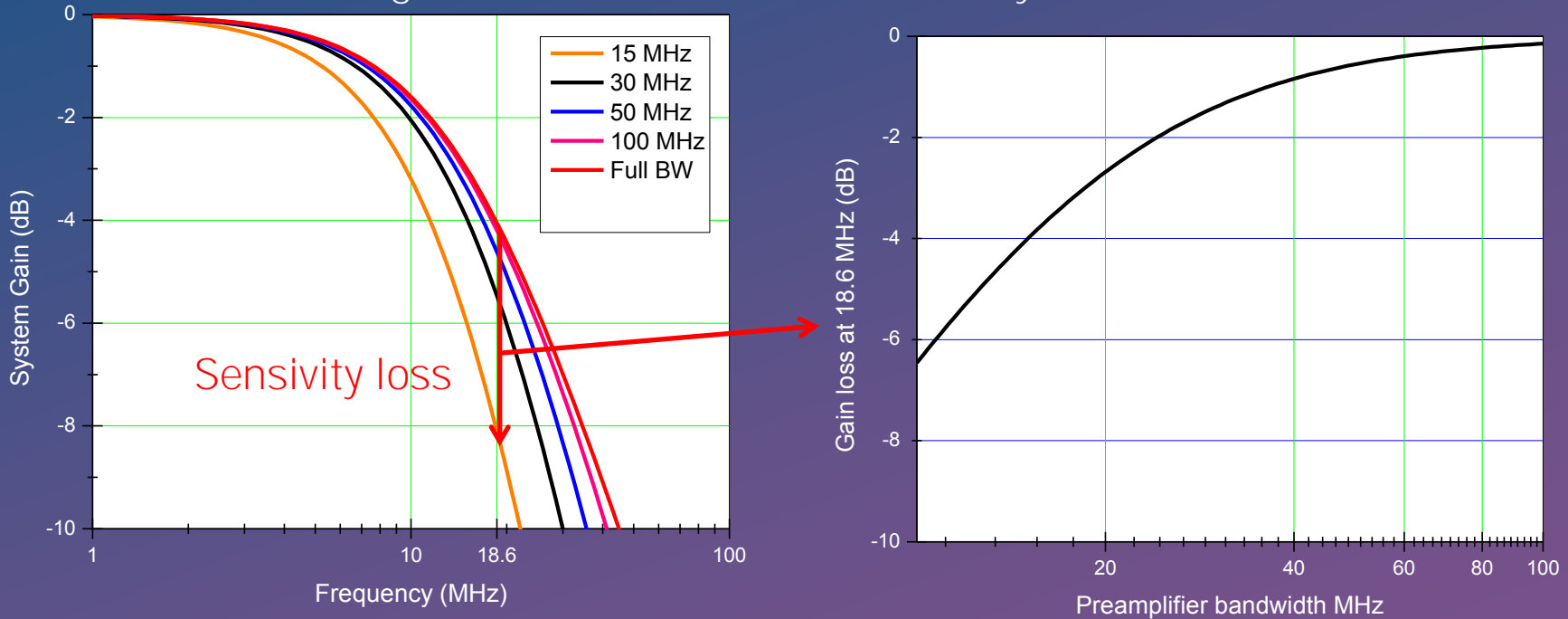
CCD limitations

- Output amplifier designed for 15MHz bandwidth
- 2000+ FPS needs a 18MHz+ operation...



Electronics constraints [1]

Second stage bandwidth... & second order systems

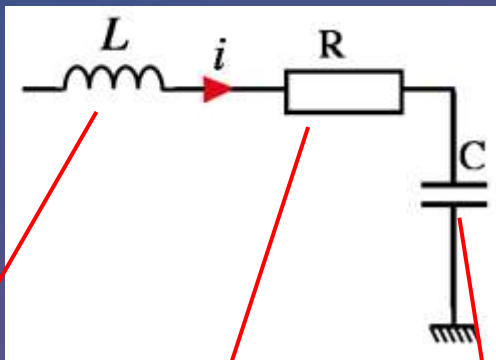


Conclusion : overall sensitivity scales with second stage bandwidth when the first stage (CCD amp) is used below the cutoff frequency.
OCAM^{2K} uses advanced high bandwidth (100MHz) low noise amplifiers

Electronics constraints [2]

CCD drive @ 18.6 MHz... is not simple

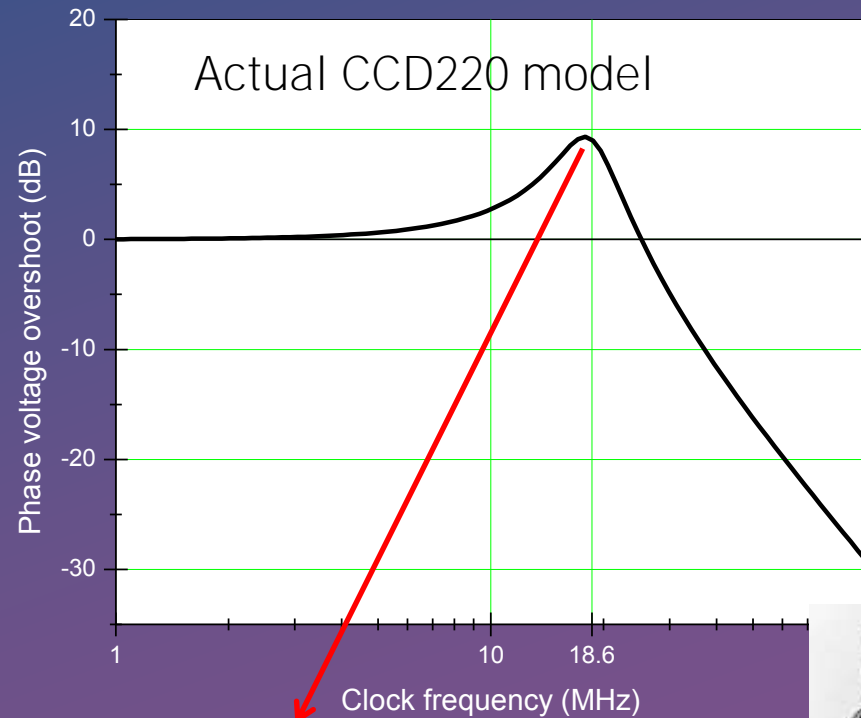
CCD phase model (simplified)



Package parasitics

Bondings, metal & silicon tracks

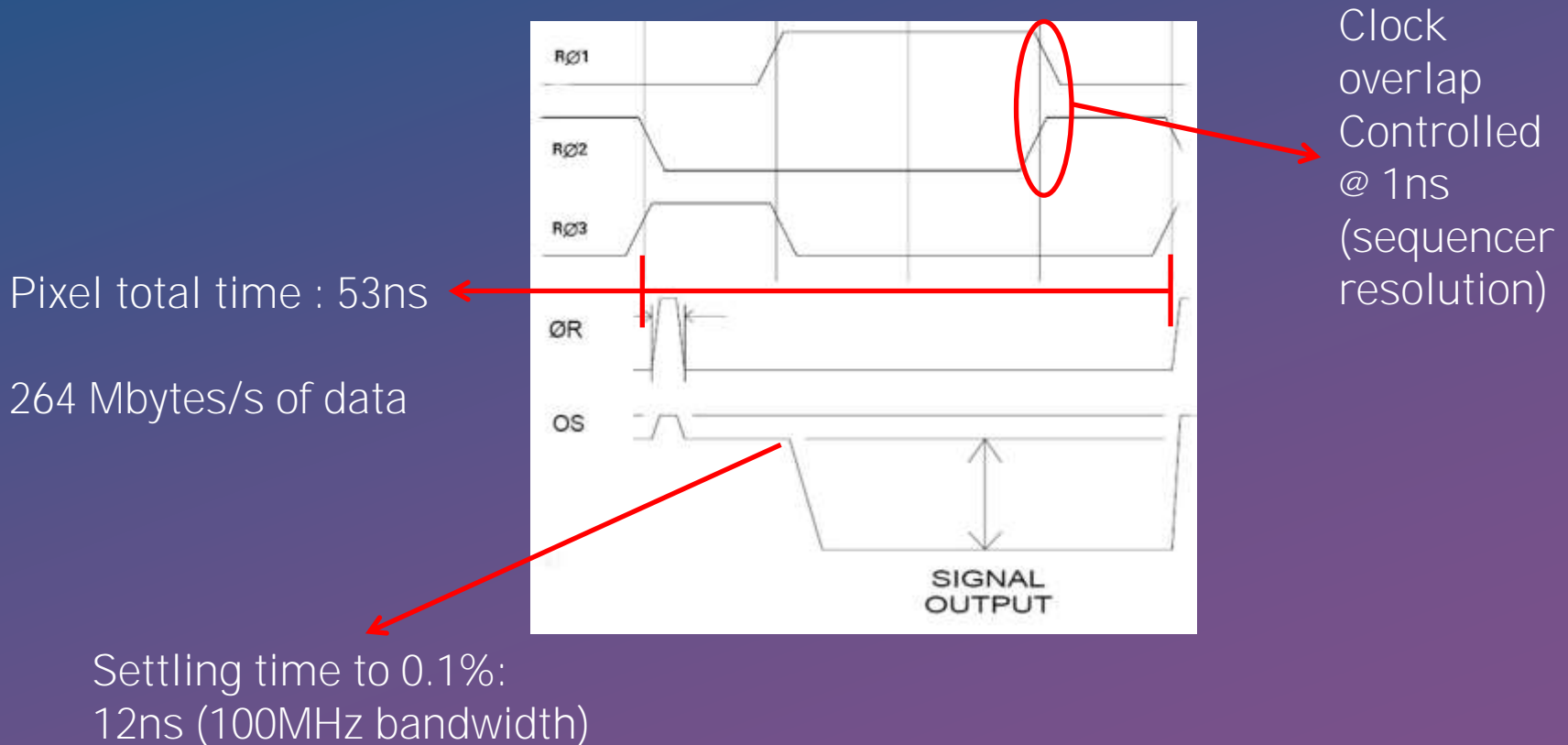
Actual CCD phase



" I believe we've had a problem here
" This is Houston, say again please
" Houston, we've had a problem, a CCD220 fried

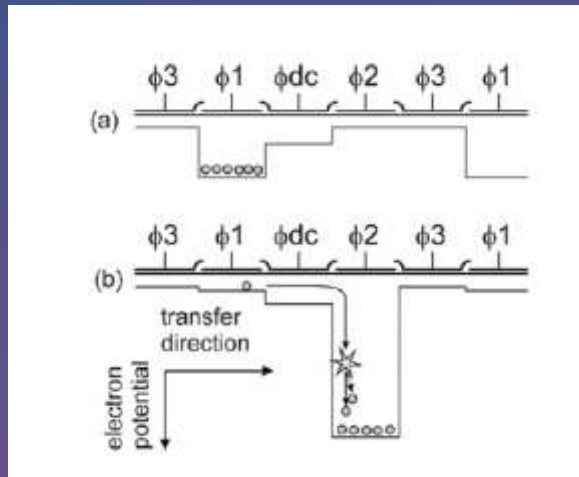
Electronics constraints [3]

CCD drive @ 18.6 MHz... is not simple

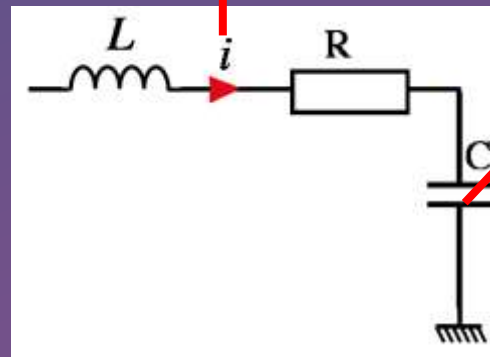


Electronics constraints [4]

- HV Phase control: drive a $\sim 100\text{pF}$ CCD phase with near 45V amplitude at
- 18.6 MHz with millivolt amplitude control...



$i=600\text{mA} \dots P=30\text{ W} !$



$Z=85\text{ ohms}$

Very challenging...

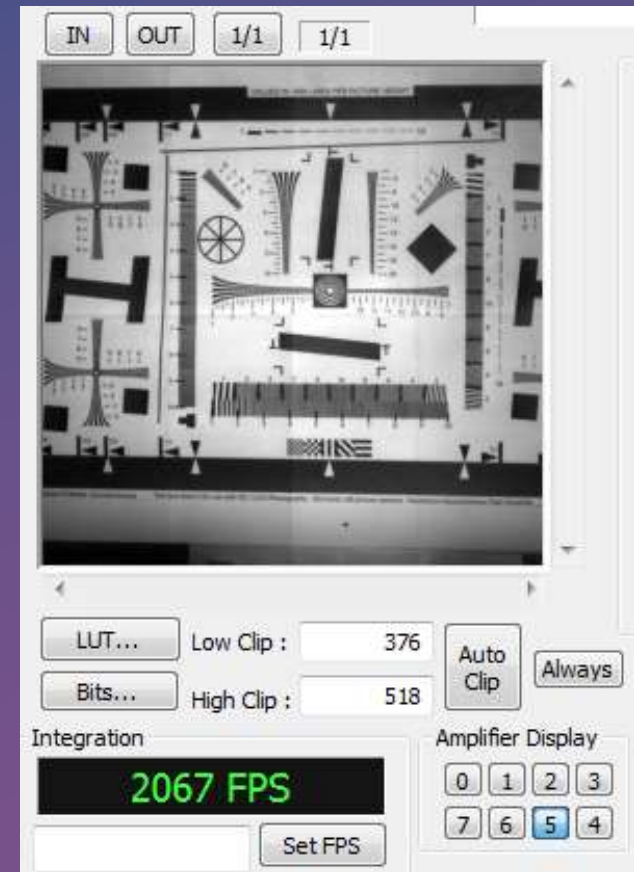
- Effect of sensitivity loss on noise
- Effect of bandwidth increase on noise
- Effect of « overclocking » on Charge Transfer Efficiency
- Power dissipation increase
- Overall performances...

E pur si muove!*

* © Galileo

- 2067 FPS full frame

Just put a F1 in your AO loop !

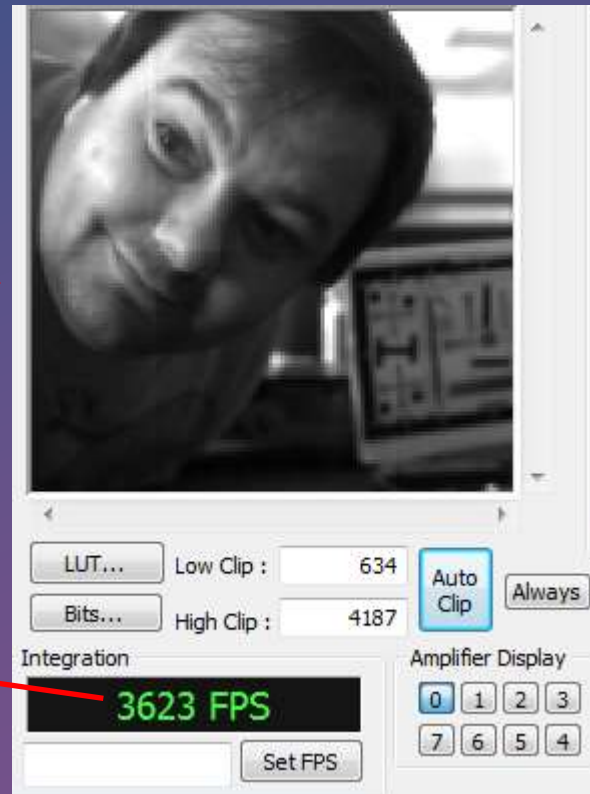


E pur si muove velocemente !*

* © Galileo, approx

The fastest WFS ever

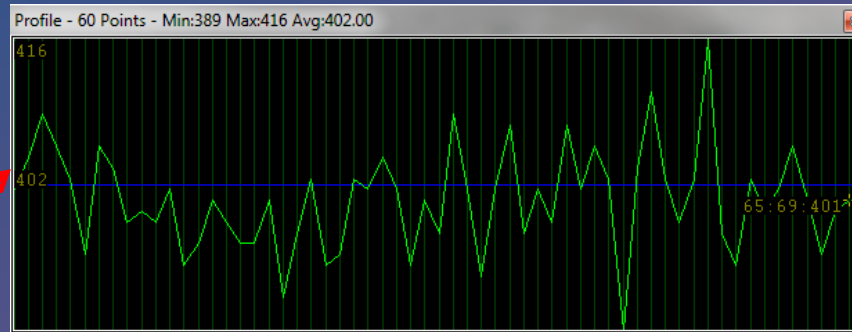
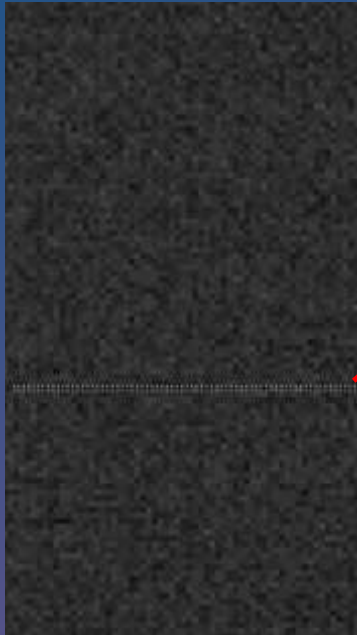
And it makes
images !



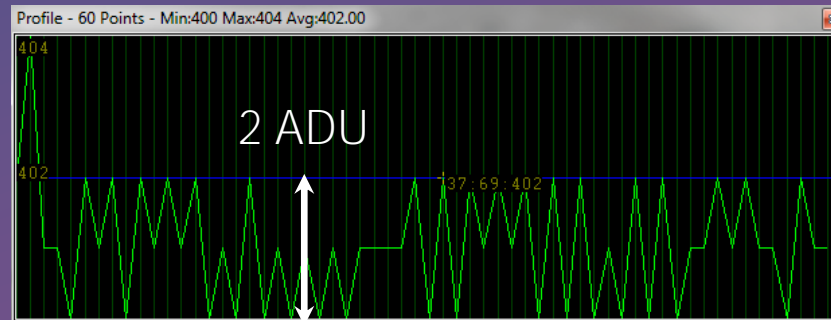
3623 FPS in binning mode
(120x120 pixels)



No noise structure

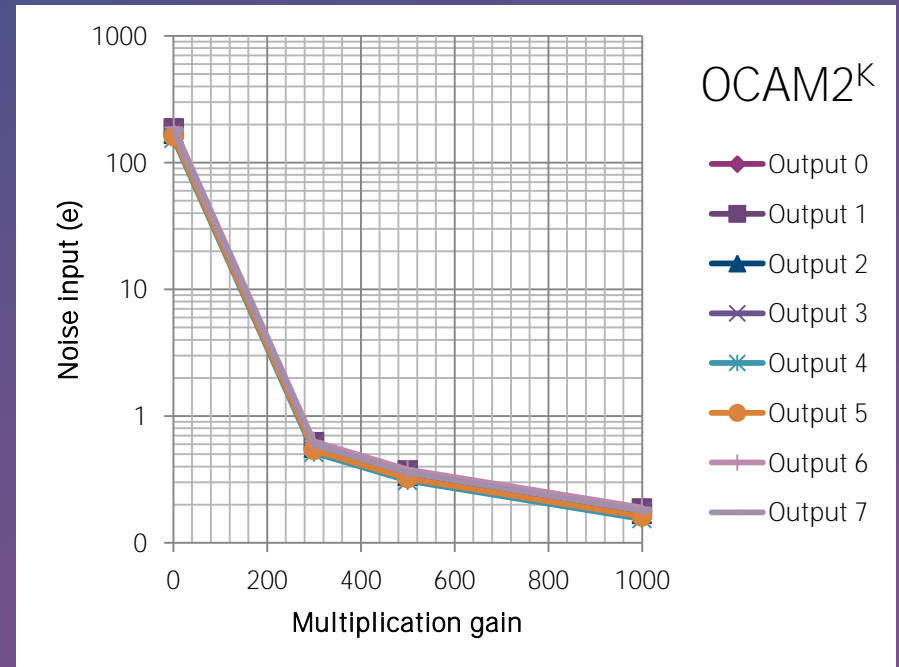
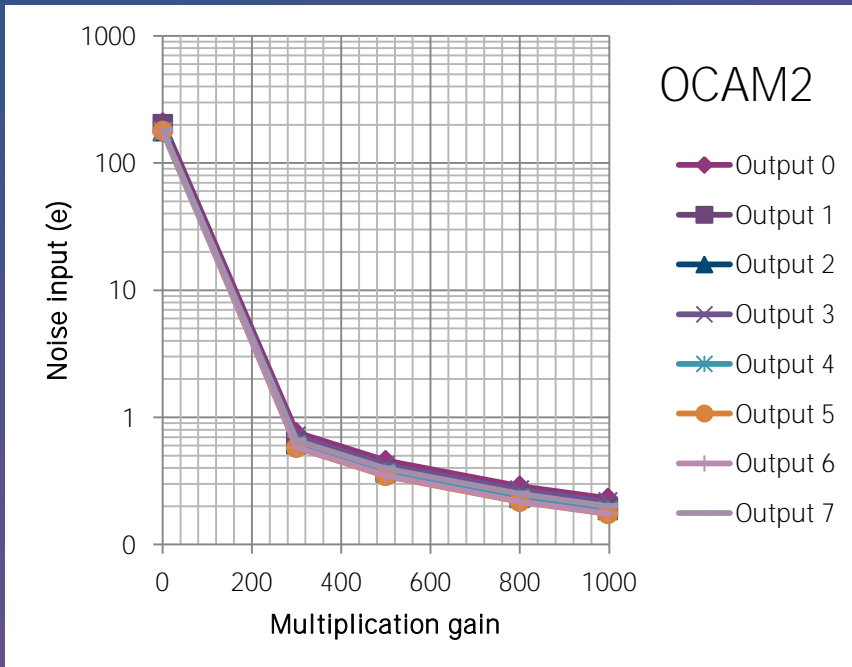


Residual FPN (2000 images avg)

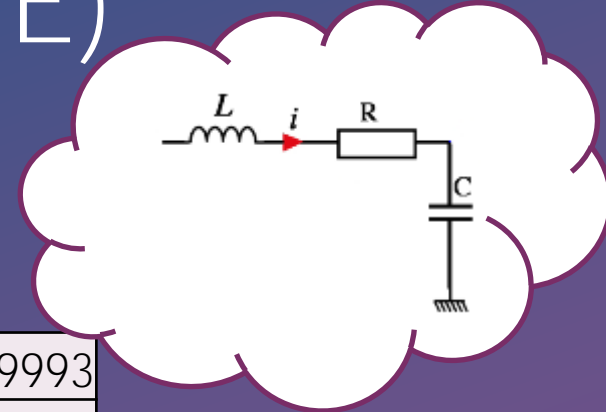


Measurements

- Measured noise : no noise degradation, made possible with better preamp and sensivity loss countermeasures



Parallel Charge Transfer Efficiency (PCTE)



OCAM²

1	0.999946
2	0.999950
3	0.999957
4	0.999958
5	0.999949
6	0.999946
7	0.999954

OCAM^{2K}

1	0,999993
2	0,999963
3	0,999956
4	0,999977
5	0,999979
6	0,999955
7	0,999987

No noticeable PCTE degradation
in spite of a faster readout

Dark

OCAM²

Output	Gain x	Dark (e/pixel/frame)
0	644	0.0025
1	644	0.0020
2	642	0.0017
3	586	0.0032
4	613	0.0023
5	708	0.0016
6	767	0.0019
7	645	0.0029
Mean	656	0.0023

OCAM^{2K}

Output	Gain x	Dark (e/pixel/frame)
0	610	0,0031
1	644	0,0023
2	520	0,0018
3	491	0,0021
4	615	0,0022
5	657	0,0019
6	574	0,0005
7	570	0,0024
Mean	585	0,0020

No significant variation, dark is constant and negligible
Dark is CIC (Clock induced charge) limited as expected
No increase of CIC due to faster clocking

OCAM² vs OCAM^{2K}

Test measurement	OCAM ²	OCAM ^{2K}	Unit
Nominal speed (full frame)	1503	2067	FPS
Mean readout noise (full frame, full speed)	0.13	0.13	e-
Pure Latency	60	43	μs
Dark signal at 1503 fps	0.0023	0.002	e-/pix/ frame
Detector operating temperature	- 45	-45	°C
Peak Quantum Efficiency at 650 nm	94	94	%
Linearity at gain x1000 from 10 to 150 ke	<3	<3	%
Image area Full Well Capacity at gain x1, 1503 fps	300	300	ke ⁻
Parallel CTE at gain x1, 1503 fps	0.9999	0.9999	N/A
Serial CTE at gain x1, 1503 fps	0.9999	0.9999	N/A



Winner by 2K-0

Implementation ideas for ELTs

And Smaller telescopes

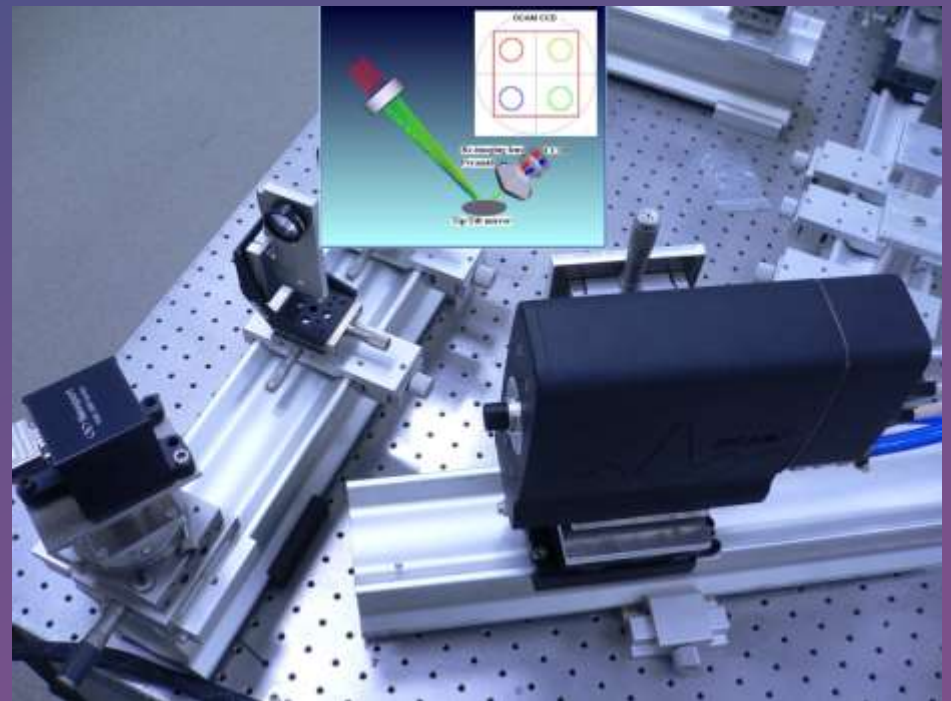
Pyramid WFS :

see 2 previous talks of Valentina Viotto & Fernando Quiros-Pacheco

Poster 13429

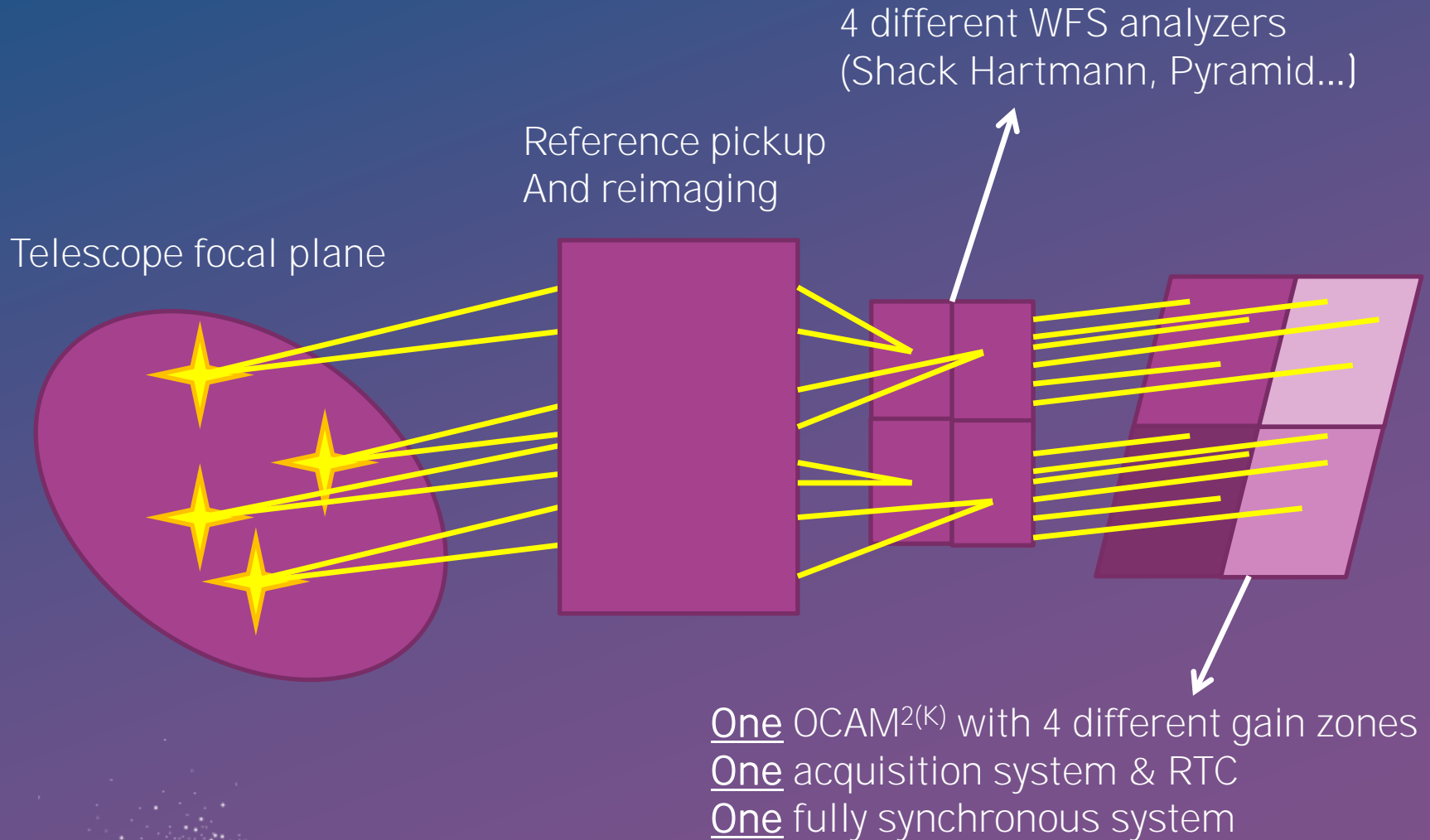
Kacem El Hadi :

Pyramid WFS with an OCAM² => up to 80x80 subapertures, 2KHz, subelectron read noise !



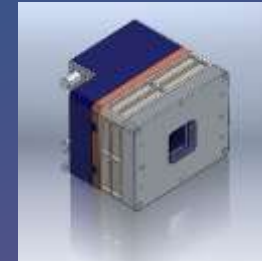
Implementation ideas for ELTs

And Smaller telescopes



FLI WFS development roadmap

Q3 2011 : *First Light Imaging created*



OCAM 3

Refer to P. Feautrier/G. Finger
invited talk (yesterday)

*“Visible and Infrared Wavefront Sensing
detectors review”*

OCAM



OCAM II



Conclusion

- OCAM^{2K} is now ready and showed more than 2000 FPS frame rate (full frame)
- Overall performance is globally better than OCAM² cameras in spite of the increased speed
- OCAM^{2K} benefits from OCAM² heritage and enters in production **now**



www.firstlight.fr

You're welcome to see OCAM2K in operation on the FLI booth

FLI will offer fresh beers after the talks (today, ~18h30 to 20h00)