nüvü camēras

every photon counts

Overview of Nüvü Camēras's technology

NTCO AGM 2017 meeting

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Presented by

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Agenda

01 Our Technology: EMCCD 101
- Electron Multiplication on the CCD
- Excess Noise Factor and Photon Counting
- Clock Induced Charges
- EMCCD types and architectures

02 Our Products
- CCCP controllers
- HNü and EMN2 cameras
- Upcoming developments

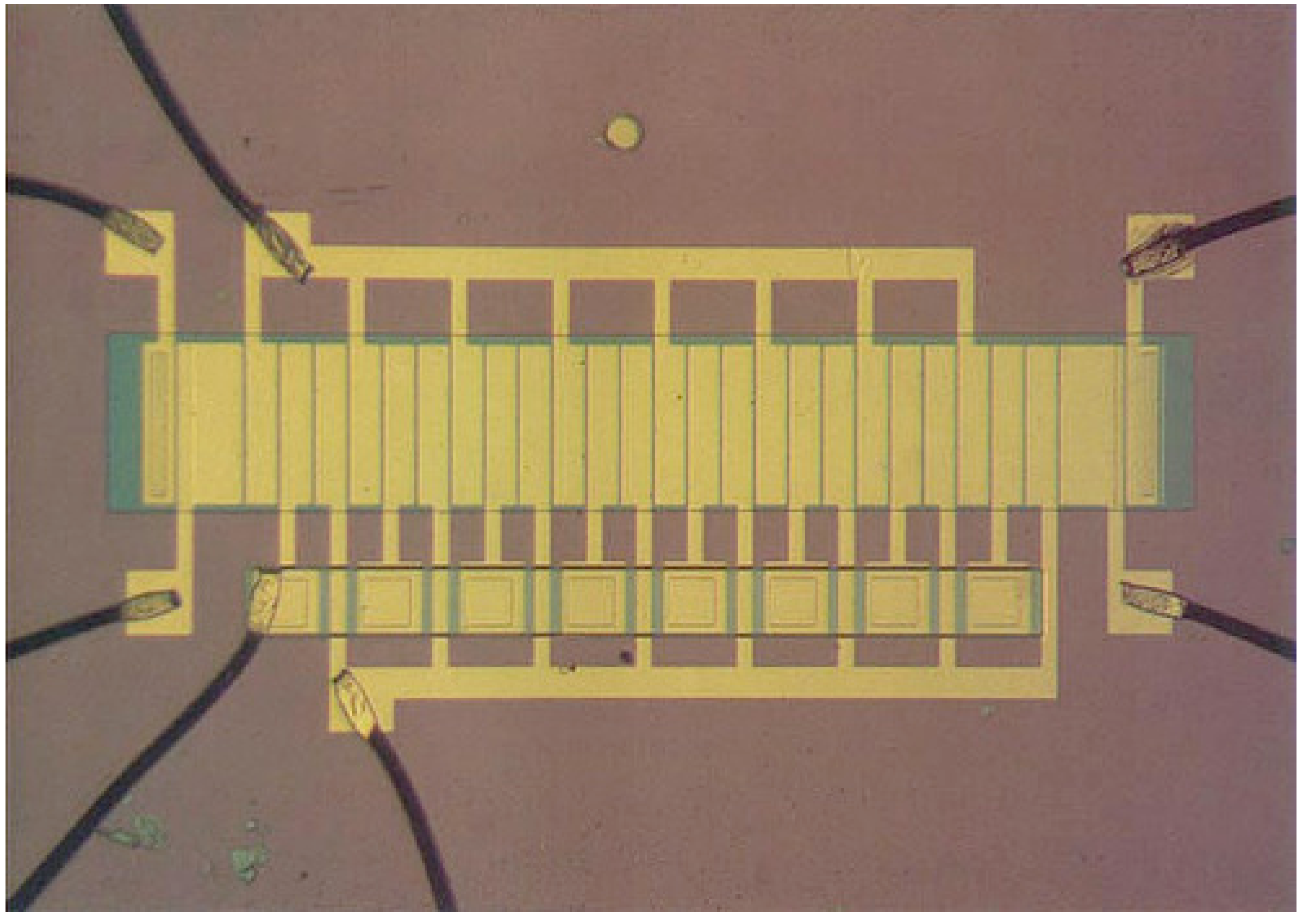
03 Astronomical Applications
- Brief overview

04 Conclusions

Our Technology
EMCCD 101

EMCCD 101

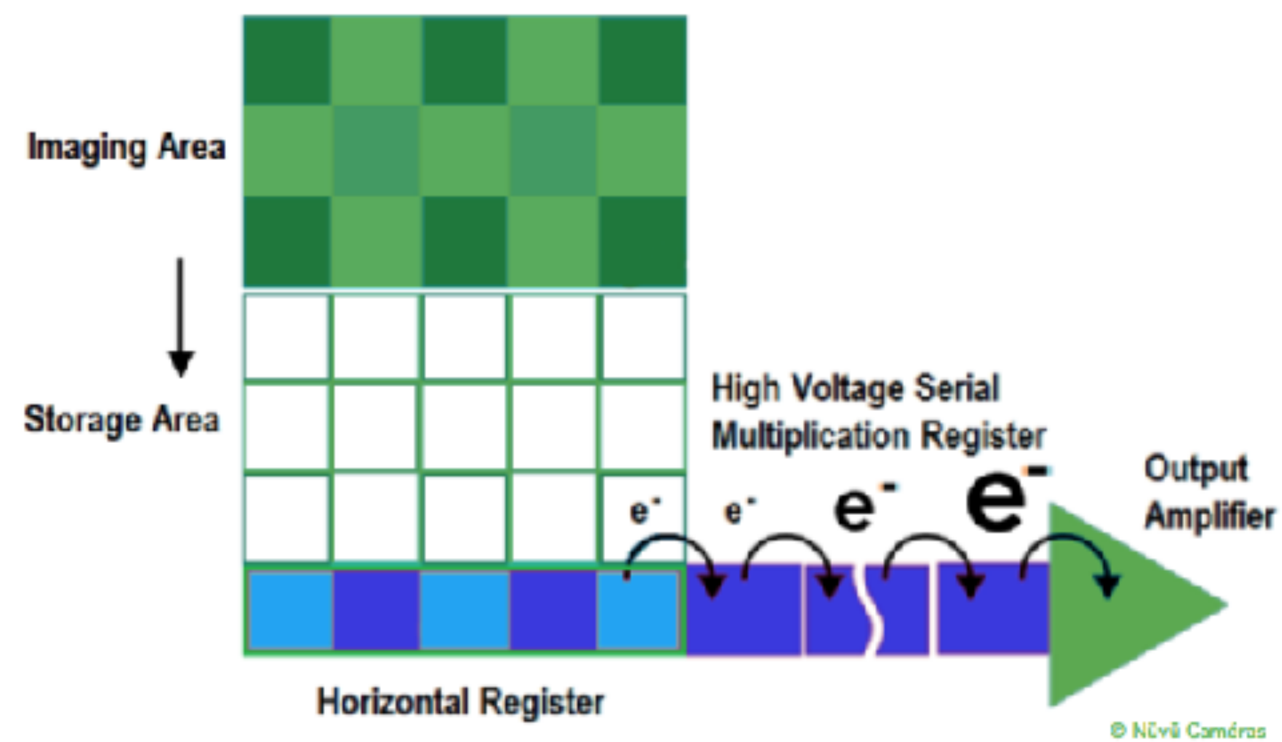
The CCD



EMCCD 101

The CCD

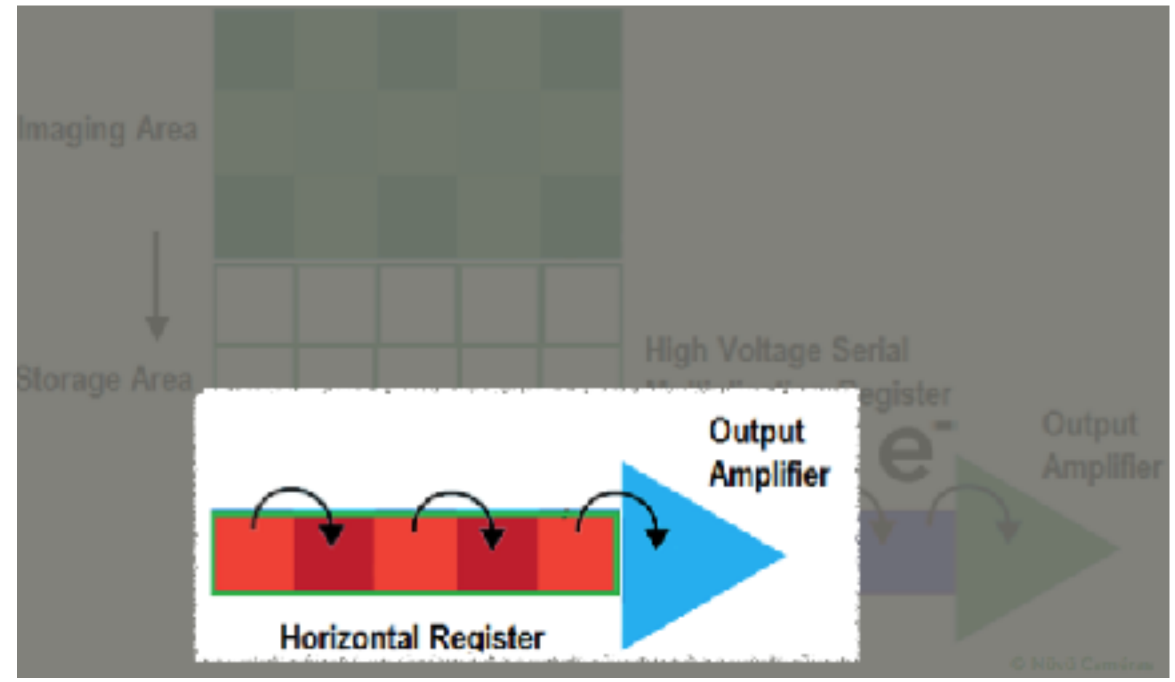
- Electron Multiplying Charge Coupled Device
- Detector architecture similar to frame-transfer CCDs
- Imaging area collects light and traps resulting photo-electrons
- Storage area allows to quickly transfer images to a light-shielded region once the integration time has elapsed
- One by one, each pixel line is transferred to the horizontal register

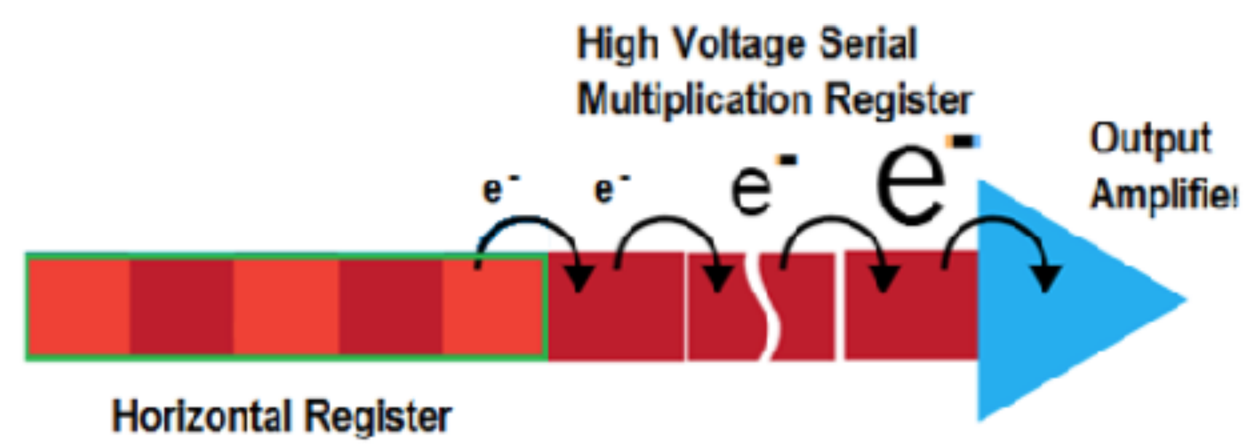


EMCCD 101

The CCD

- In a standard CCD camera, the contents of each pixel would then be sent through the output amplifier
- In low light applications, the readout noise from the output amplifier becomes significant at high readout rates or when light level is very low
- That problem is alleviated by an added Electron Multiplication register
  - Allows to propel the weak signals over the noise floor
  - Makes readout noise negligible

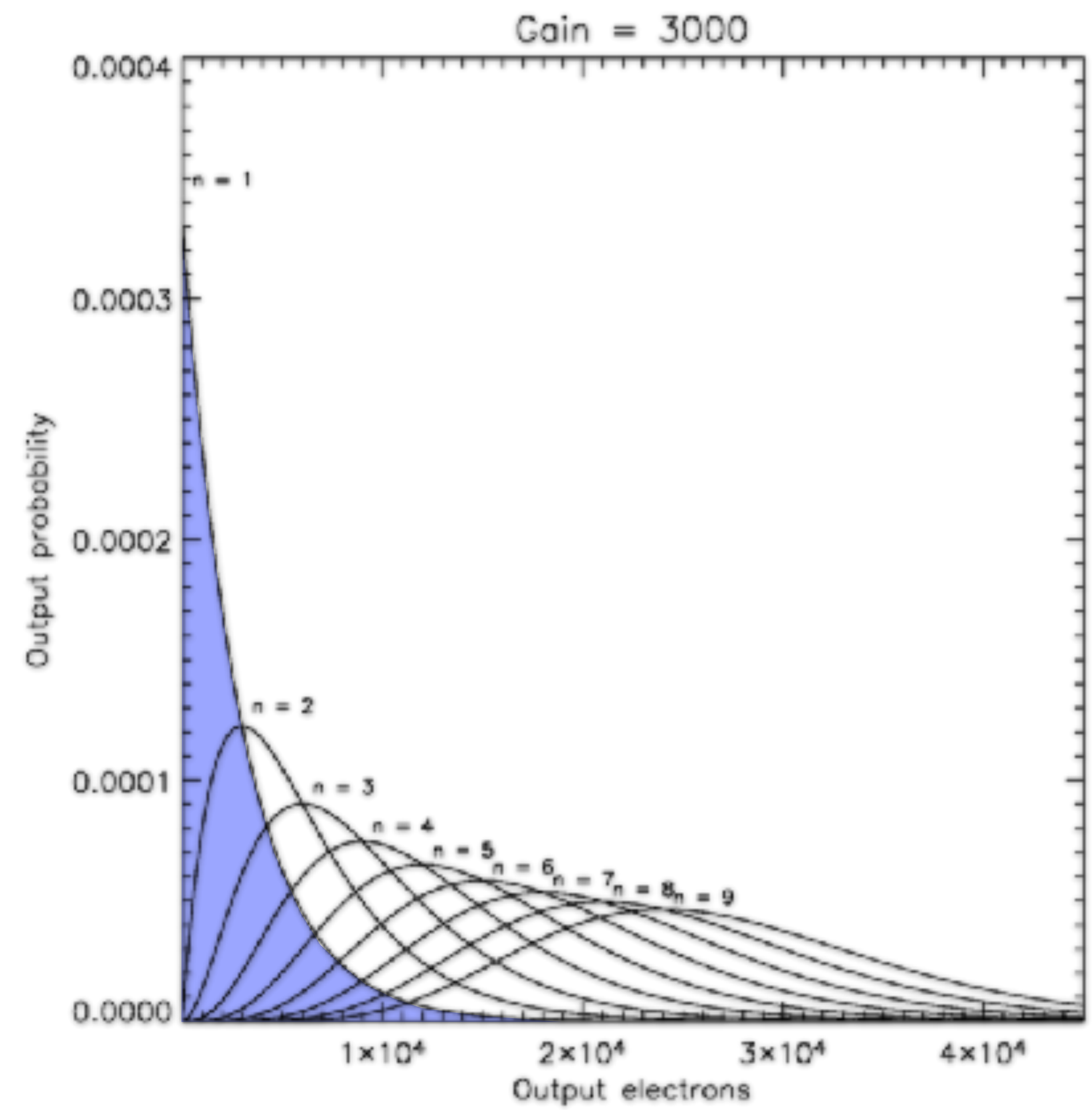




EMCCD 101

Excess noise factor

- The gain has a statistical behaviour
- This behaviour induces an Excess Noise Factor (ENF) of sqrt(2)
- The uncertainty in the gain value induces the ENF
- The effect of the ENF on the SNR is the same as if the QE would be halved



$$\mathrm{SNR} = \frac{\mathrm{QE} * \mathrm{S}}{\sqrt{\mathrm{QE} * \mathrm{S} + \mathrm{NT} + \mathrm{C} + \sigma^2}}$$

EMCCD 101

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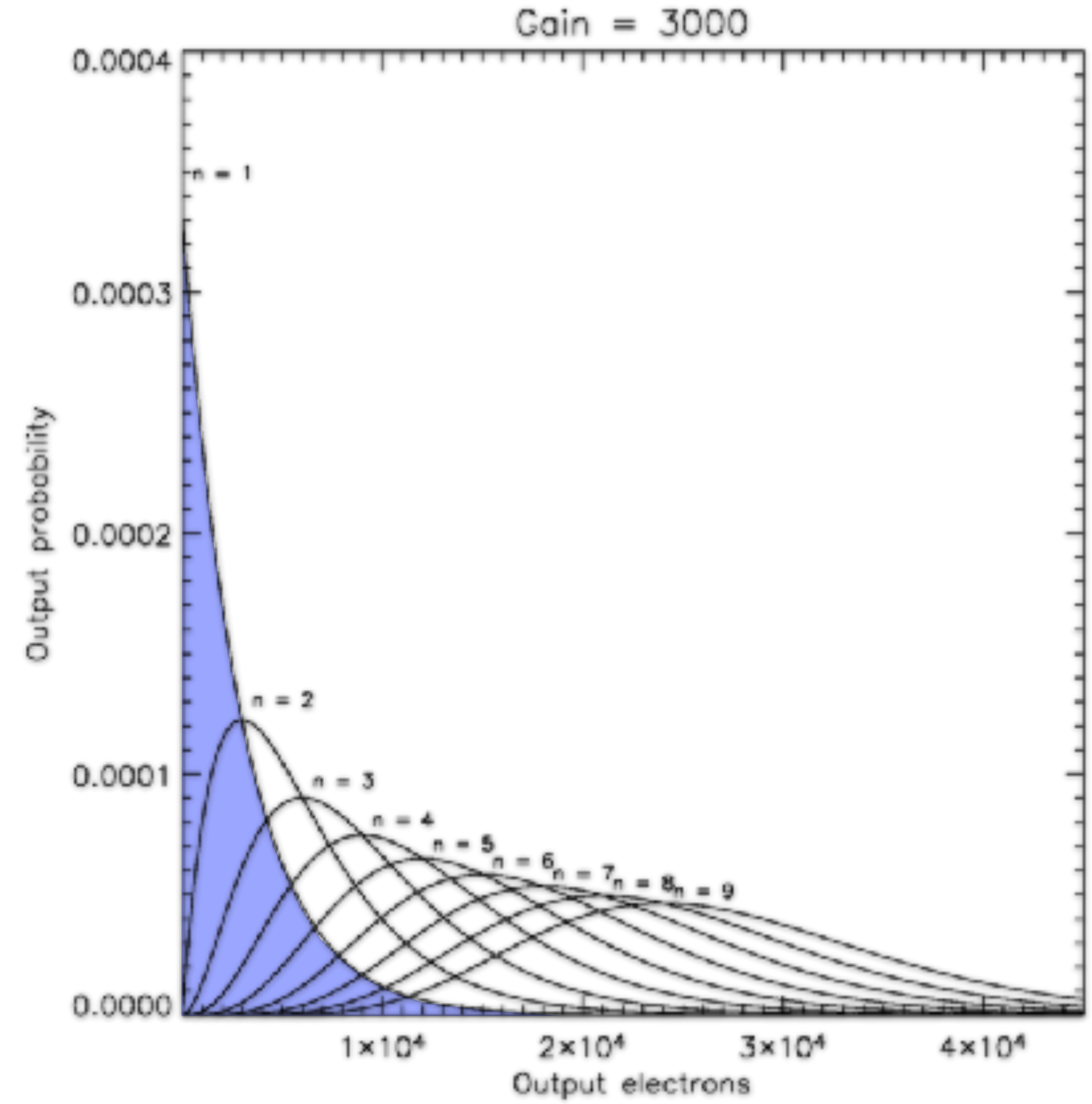

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- This behaviour induces an Excess Noise Factor (ENF) of sqrt(2)
- The uncertainty in the gain value induces the ENF
- The effect of the ENF on the SNR is the same as if the QE would be halved

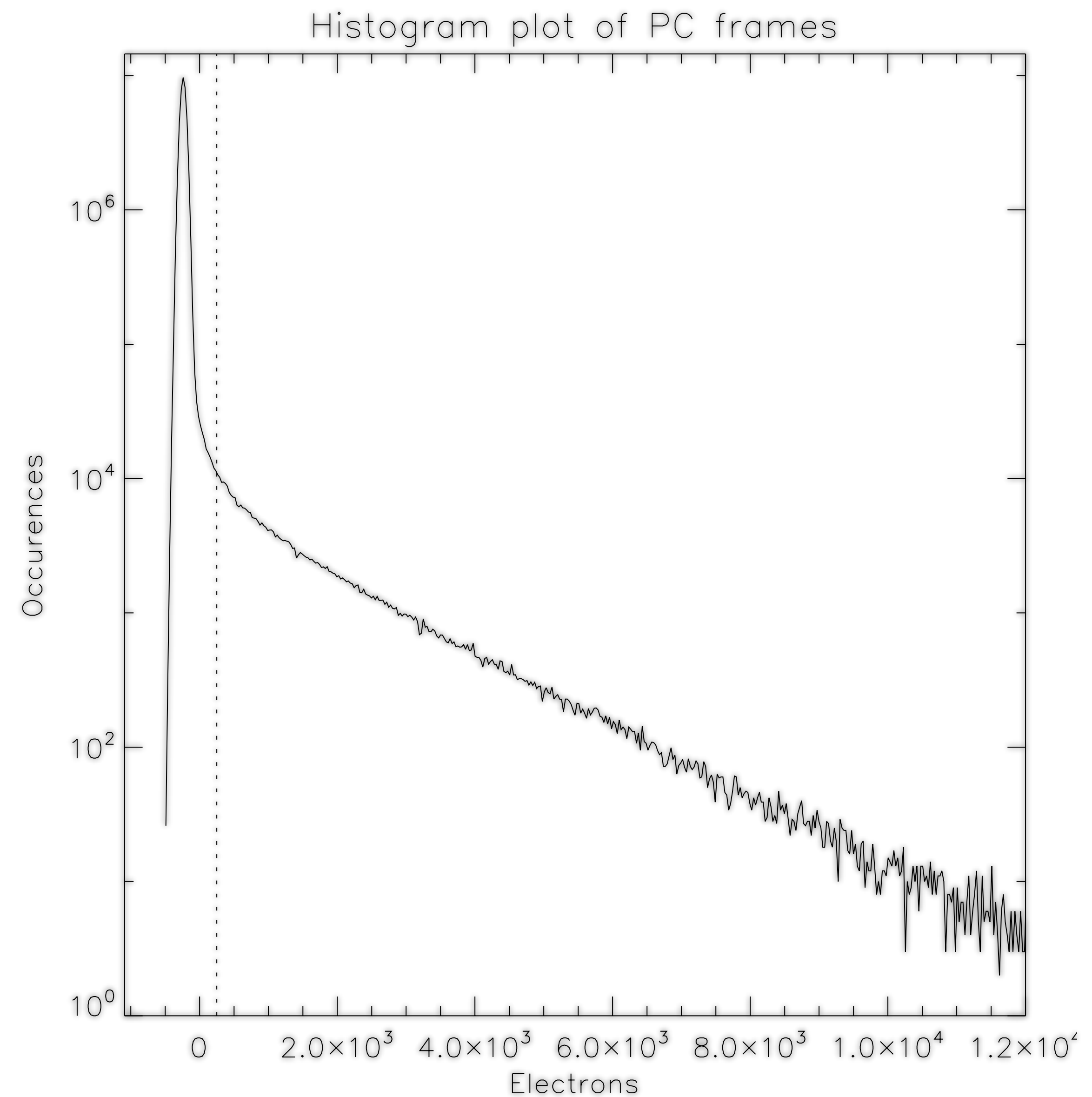
$$\cancel{\mathrm{SNR} = \frac{\mathrm{QE} * \mathrm{S}}{\sqrt{\mathrm{QE} * \mathrm{S} + \mathrm{NT} + \mathrm{C} + \sigma^2}}}$$

$$\mathrm{SNR} = \frac{\mathrm{QE} * \mathrm{S}}{\sqrt{\mathrm{F}^2 * (\mathrm{QE} * \mathrm{S} + \mathrm{NT} + \mathrm{C}) + \frac{\sigma^2}{\mathrm{G}^2}}}$$

EMCCD 101

Photon Counting

- Photon Counting operation involves applying a threshold to the pixel's output value
- The threshold is chosen according to the read-out noise
- Some events are below the threshold and can't be counted. They are lost.
- G is not part of the equation: no more ENF!
- No more σ too!
- However, binary pixel



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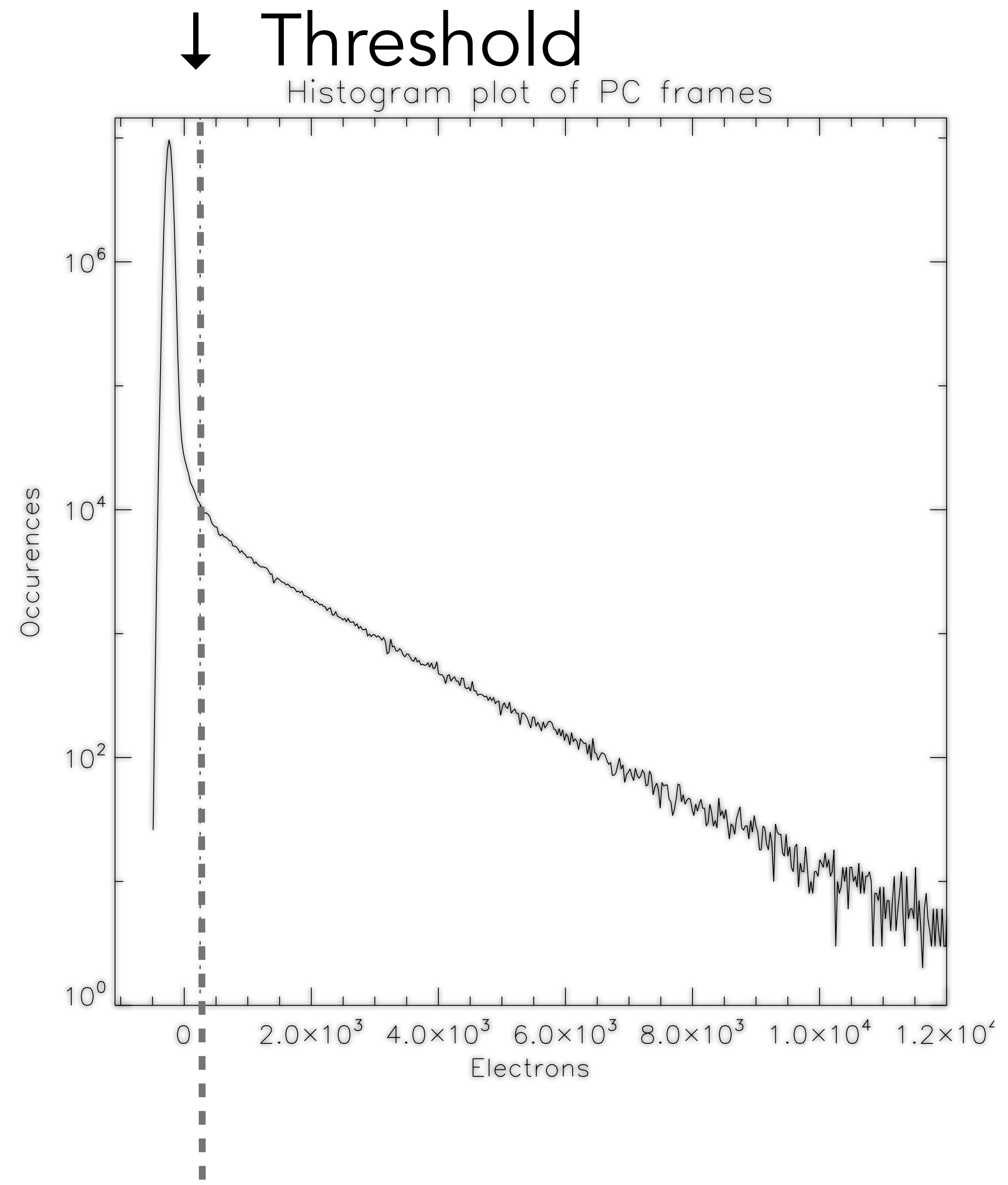

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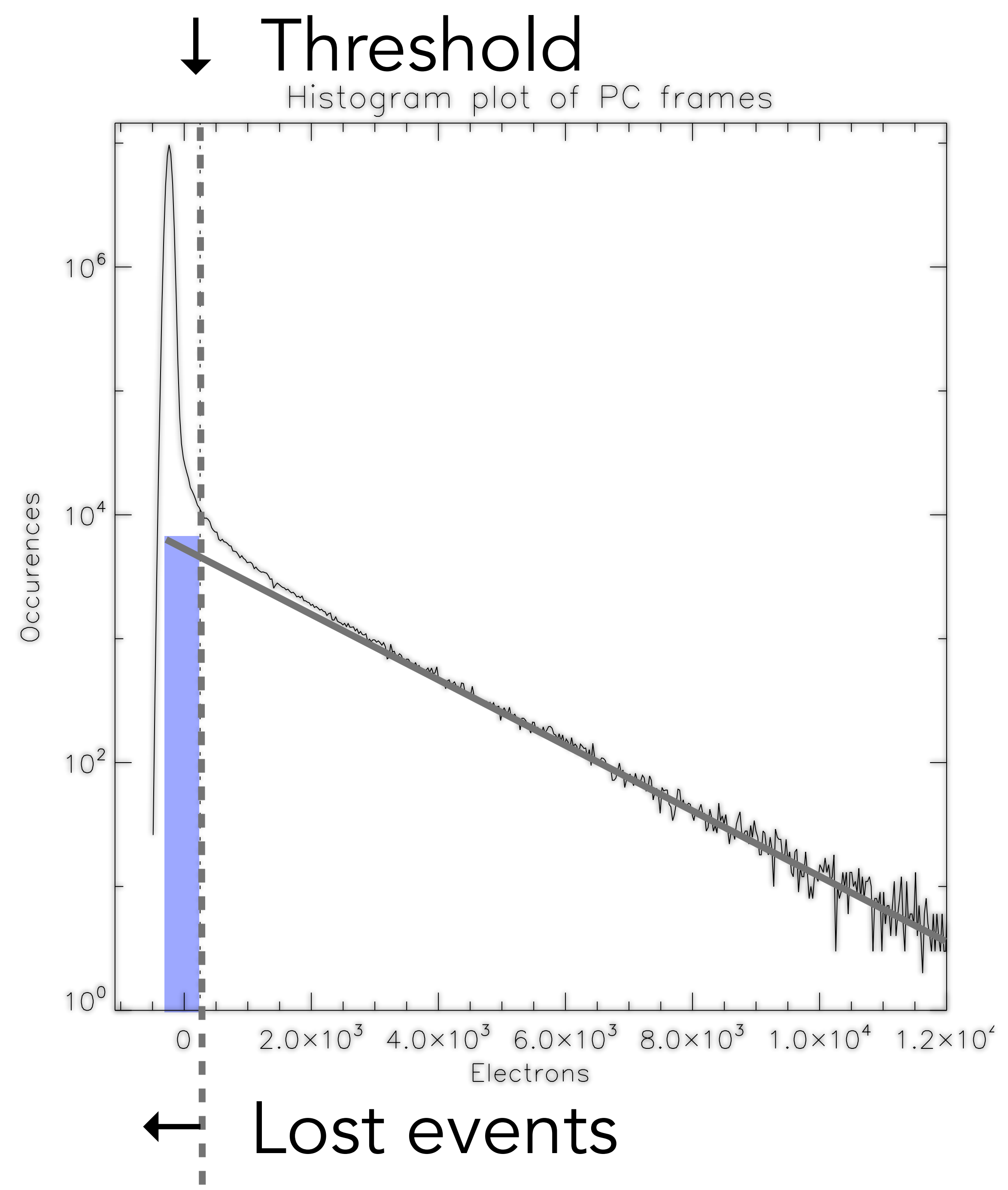
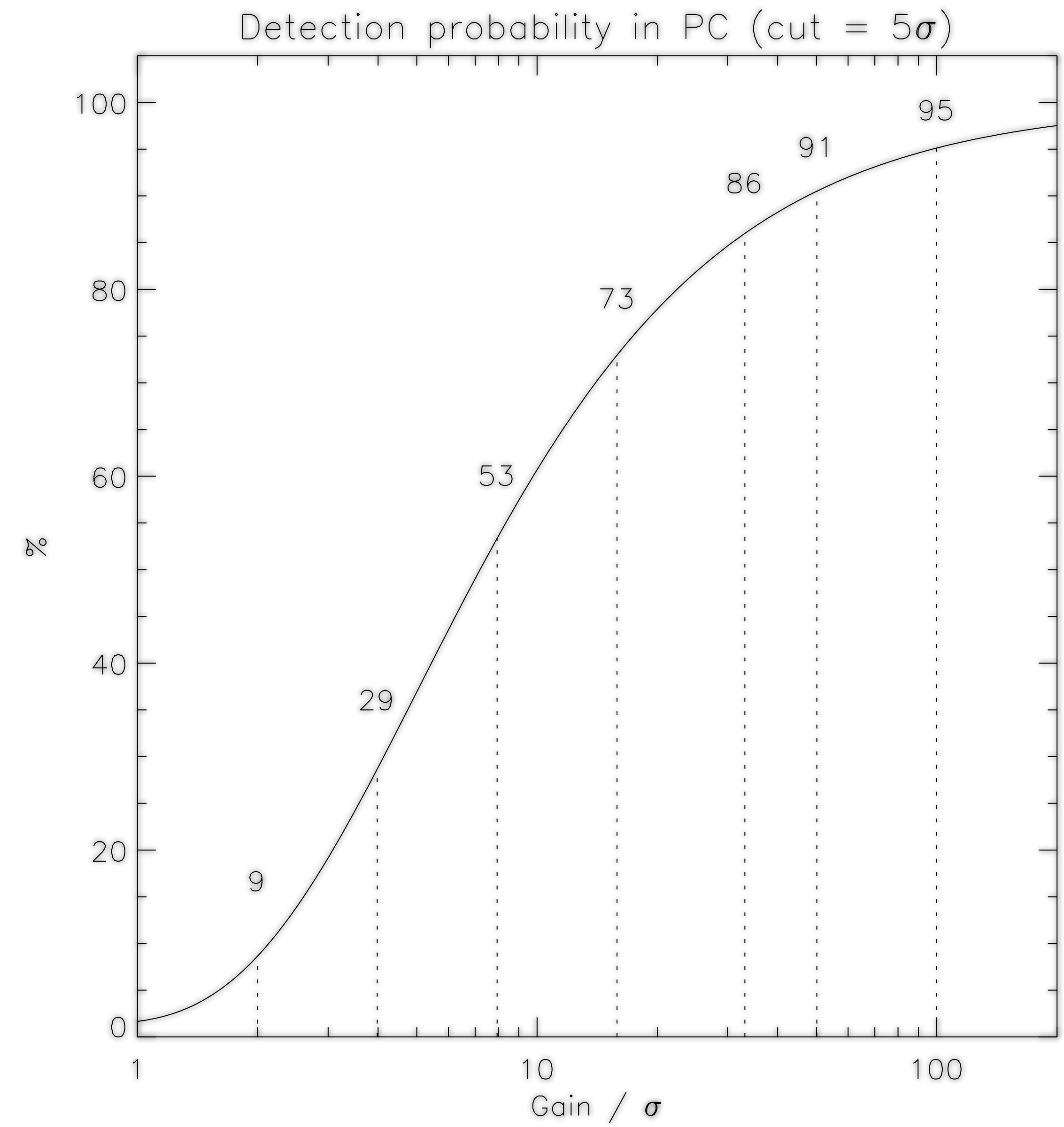


nüvü caméras

EMCCD 101

Photon Counting



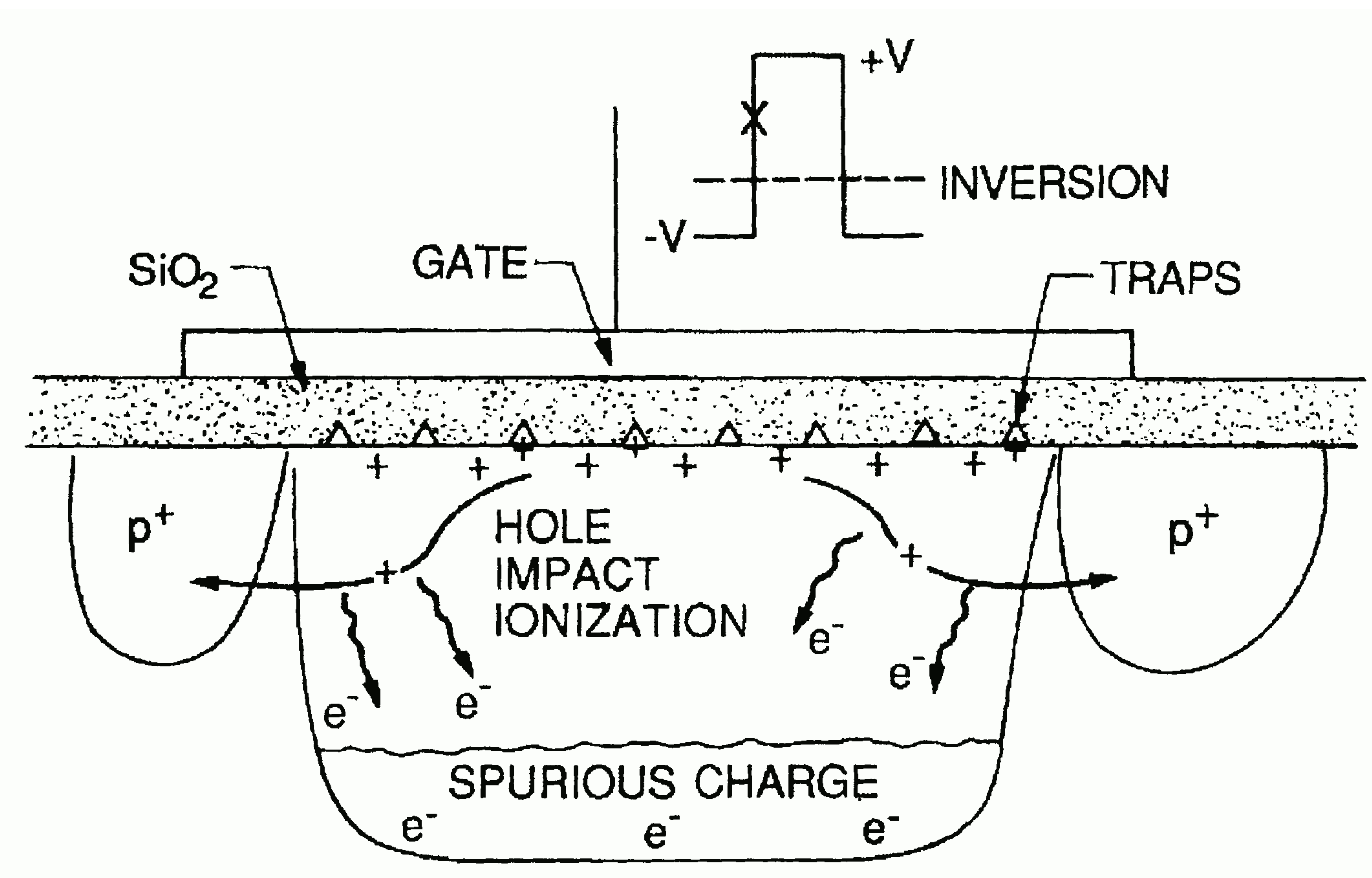
- In PC, the detection limit is a function of the ratio EM gain over the read-out noise
- A high EM gain is mandatory for an efficient PC operation

$$\mathrm{SNR} = \frac{\mathrm{QE} * \mathrm{DP} * \mathrm{S}}{\sqrt{\mathrm{DP} * (\mathrm{QE} * \mathrm{S} + \mathrm{NT} + \mathrm{C})}}$$

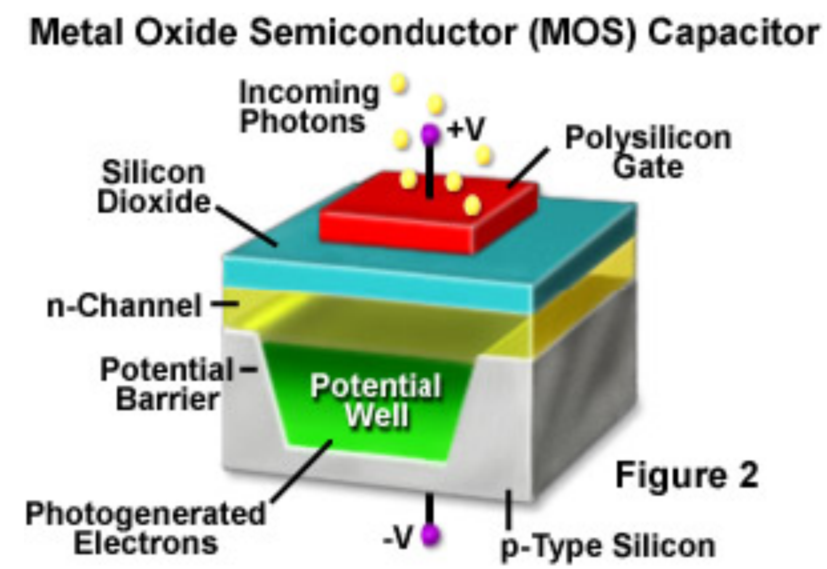
EMCCD 101

Clock Induced Charges

- The CIC is generated by the impact ionisation of the *holes* during the clock transition.



Janesick 2001



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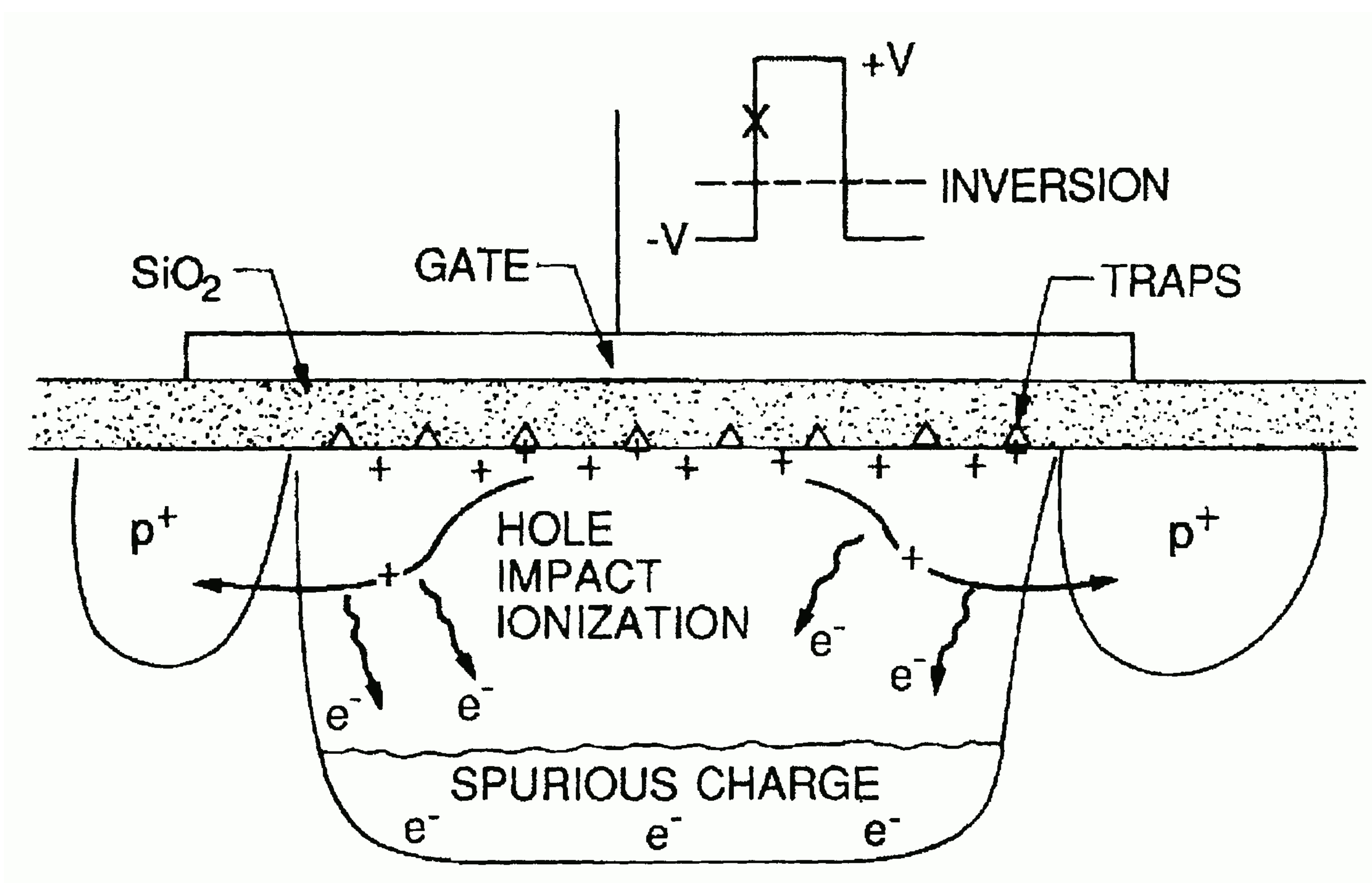

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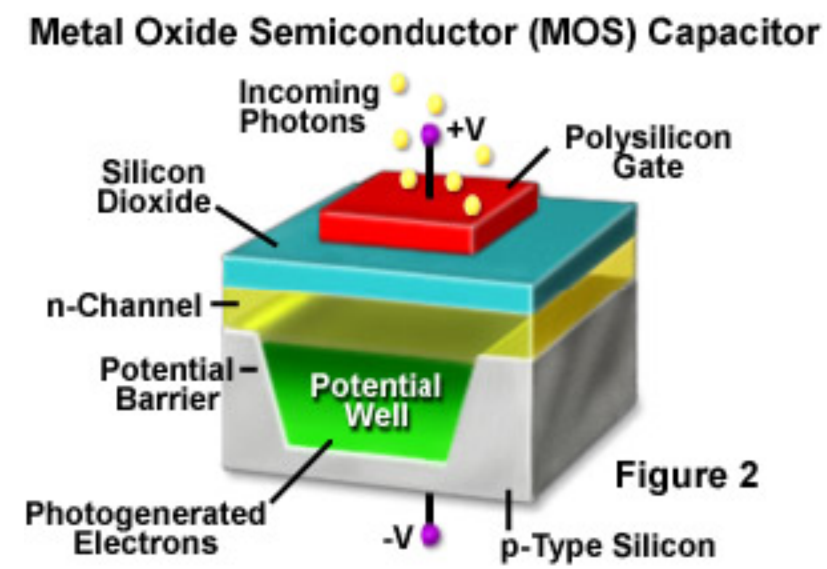
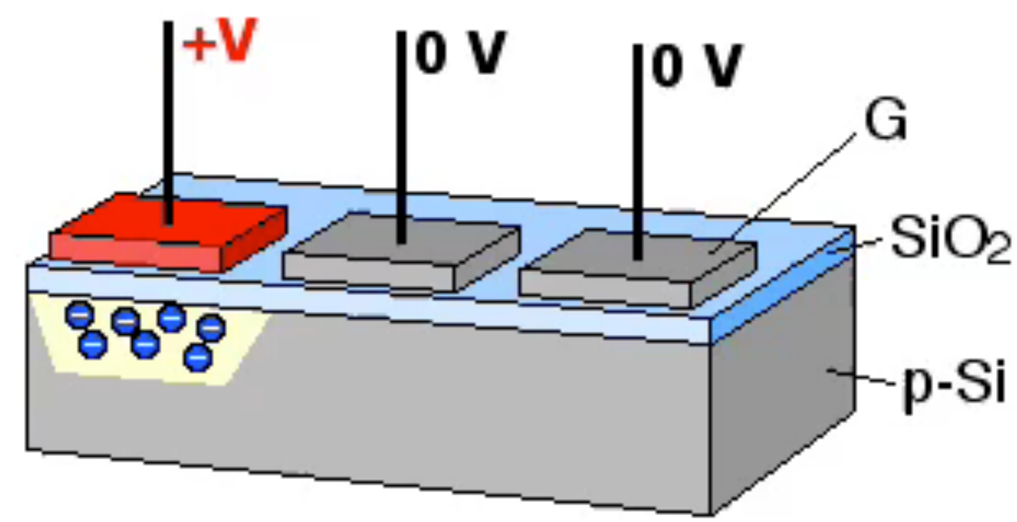
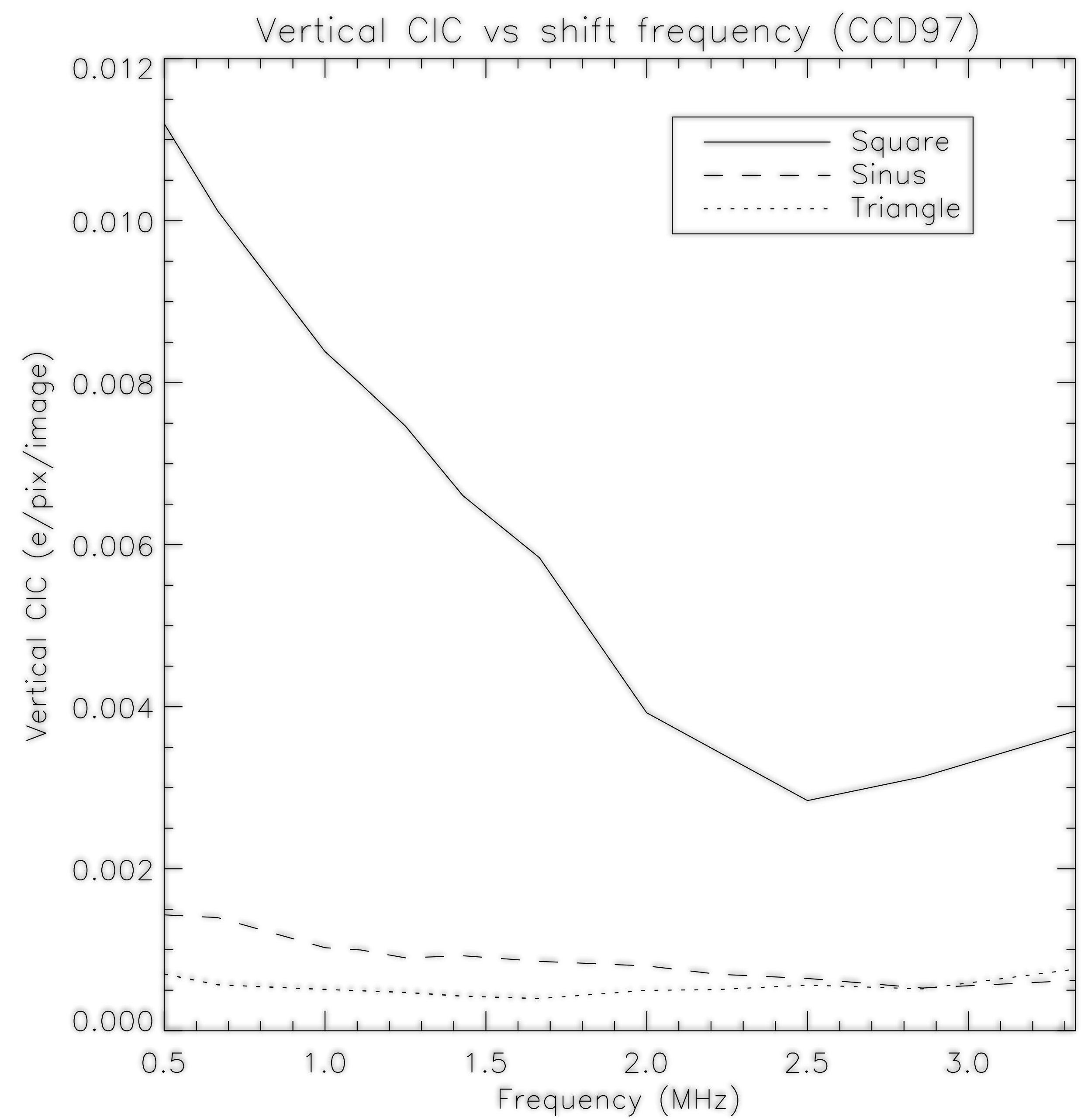




EMCCD 101

Clock Induced Charges

- Sinusoidal and triangular clocks almost completely suppress the CIC generated during the vertical transfer (<0.001 ē/ pix/image)



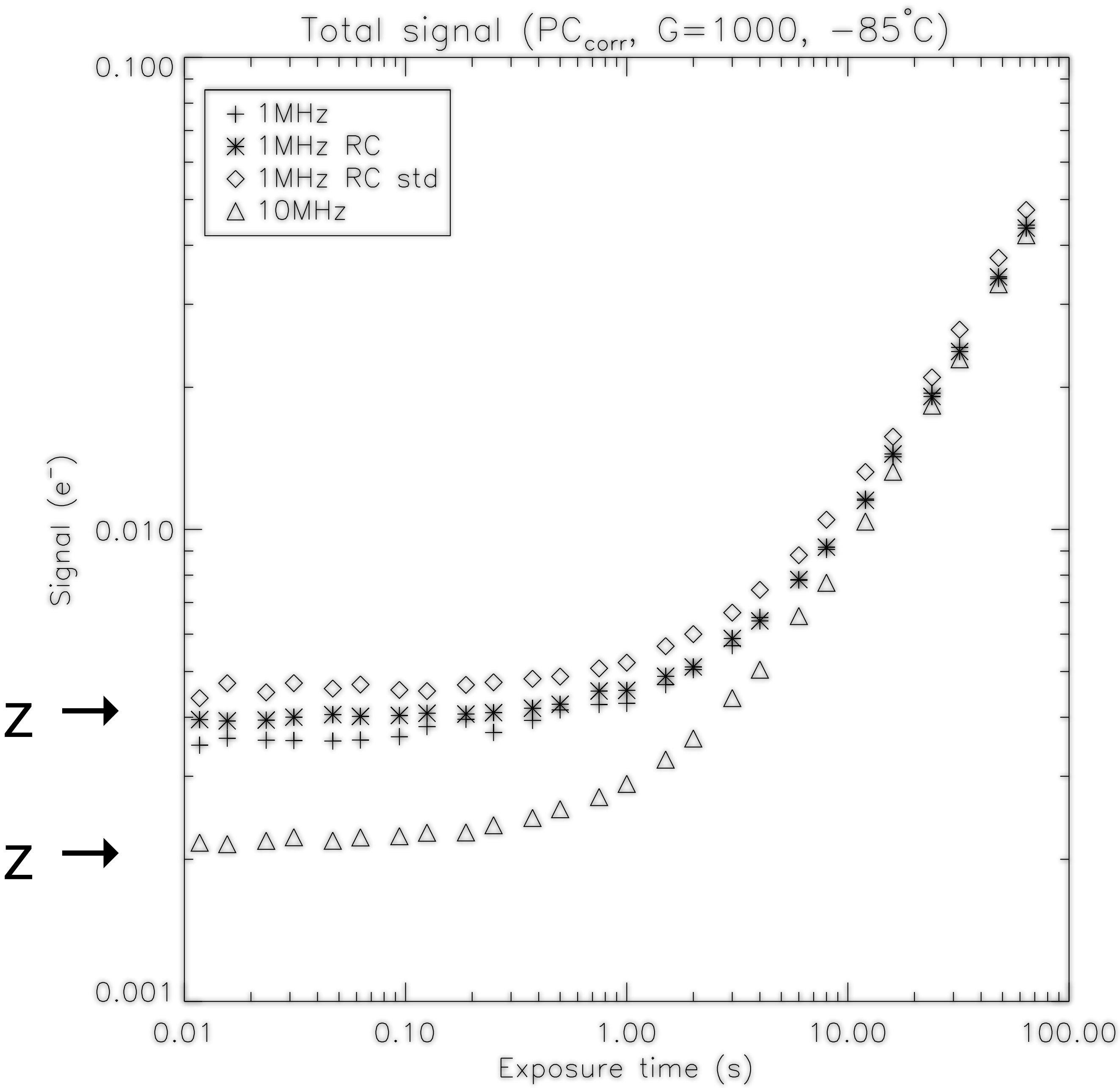
EMCCD 101

Clock Induced Charges

- When read-out noise is negligible, lower read-out speed ≠ lower noise!

1 MHz →

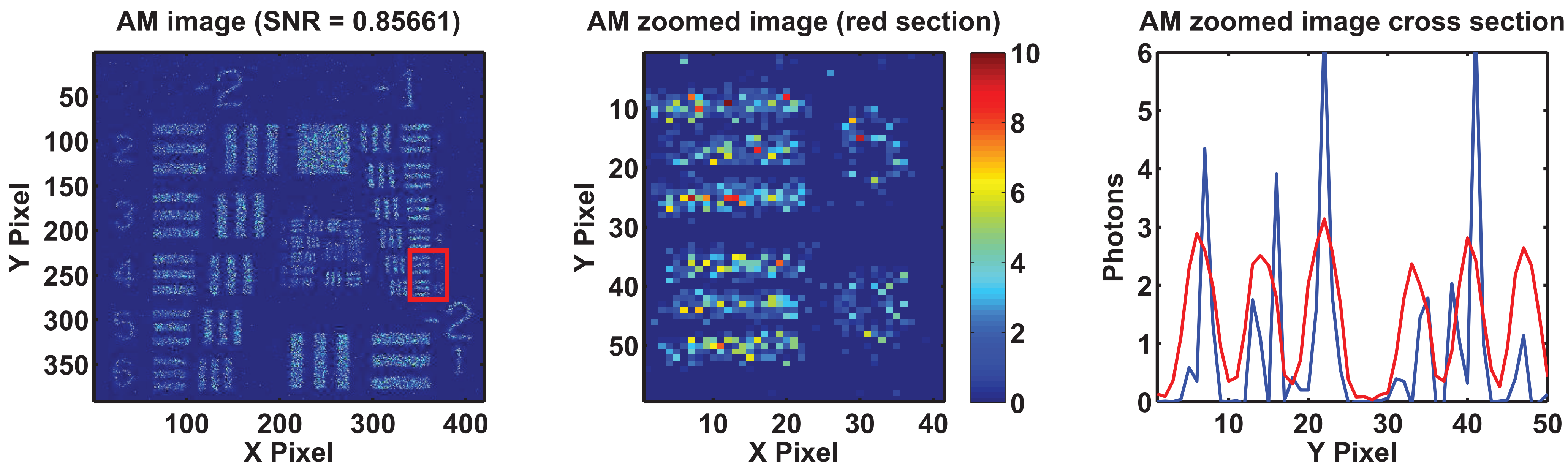
10 MHz →



nüvü cameras

EMCCD 101

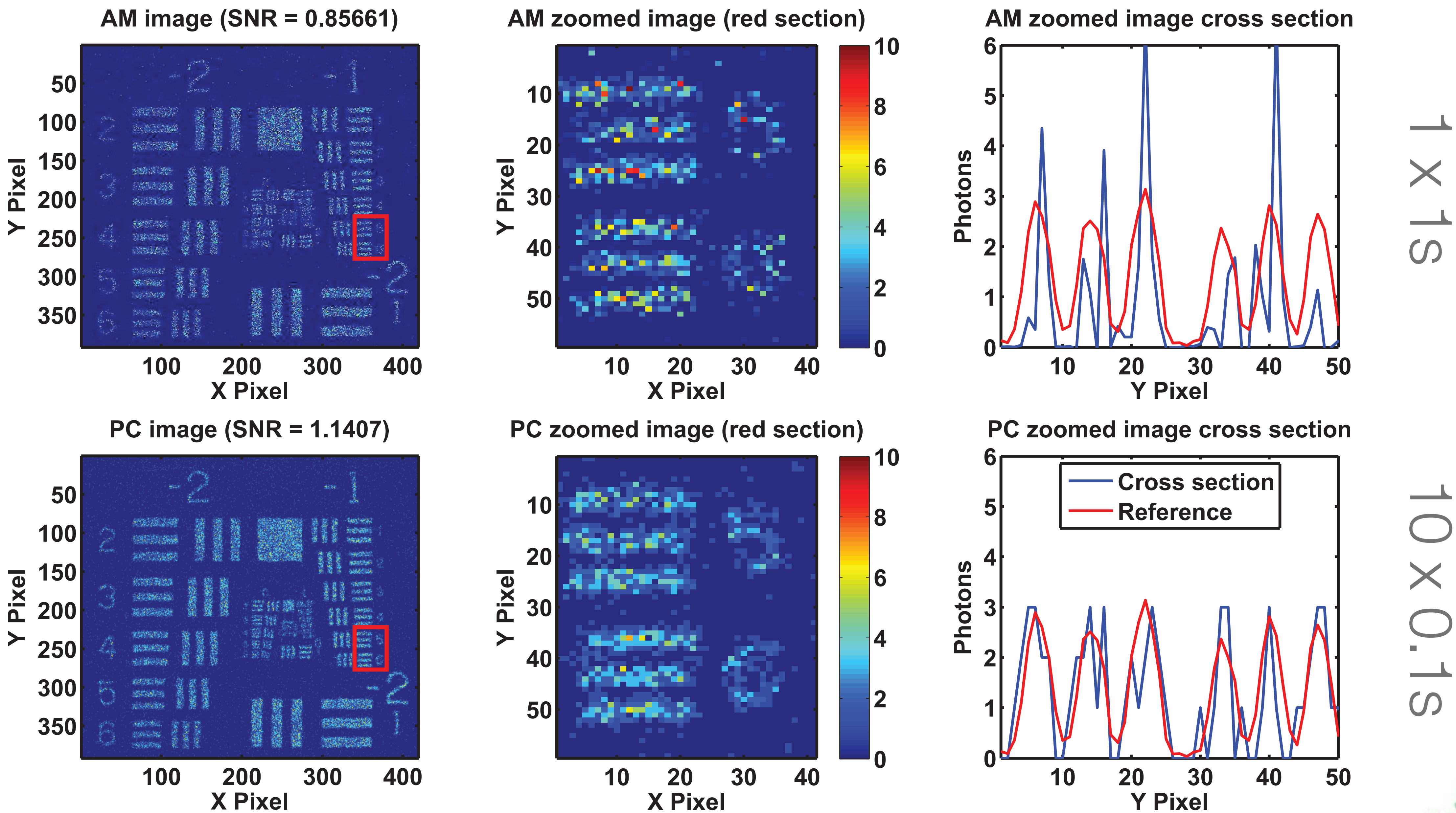
Efficiency



1 x 1s

EMCCD 101

Efficiency



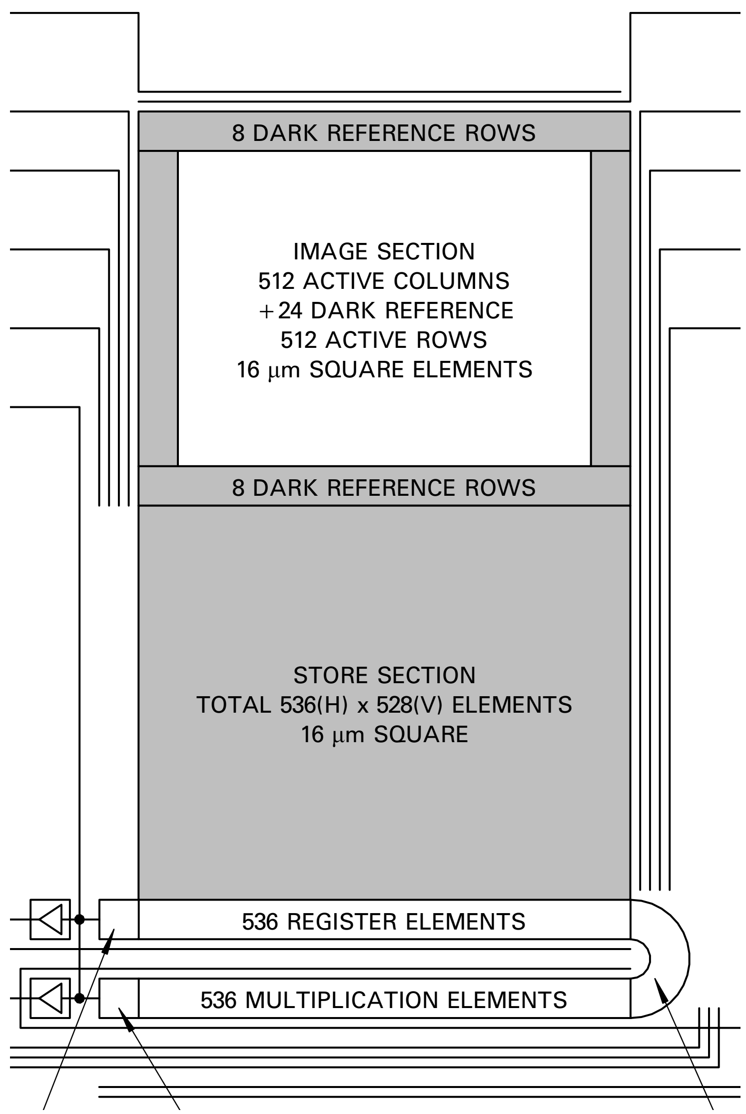
EMCCD 101

Architecture

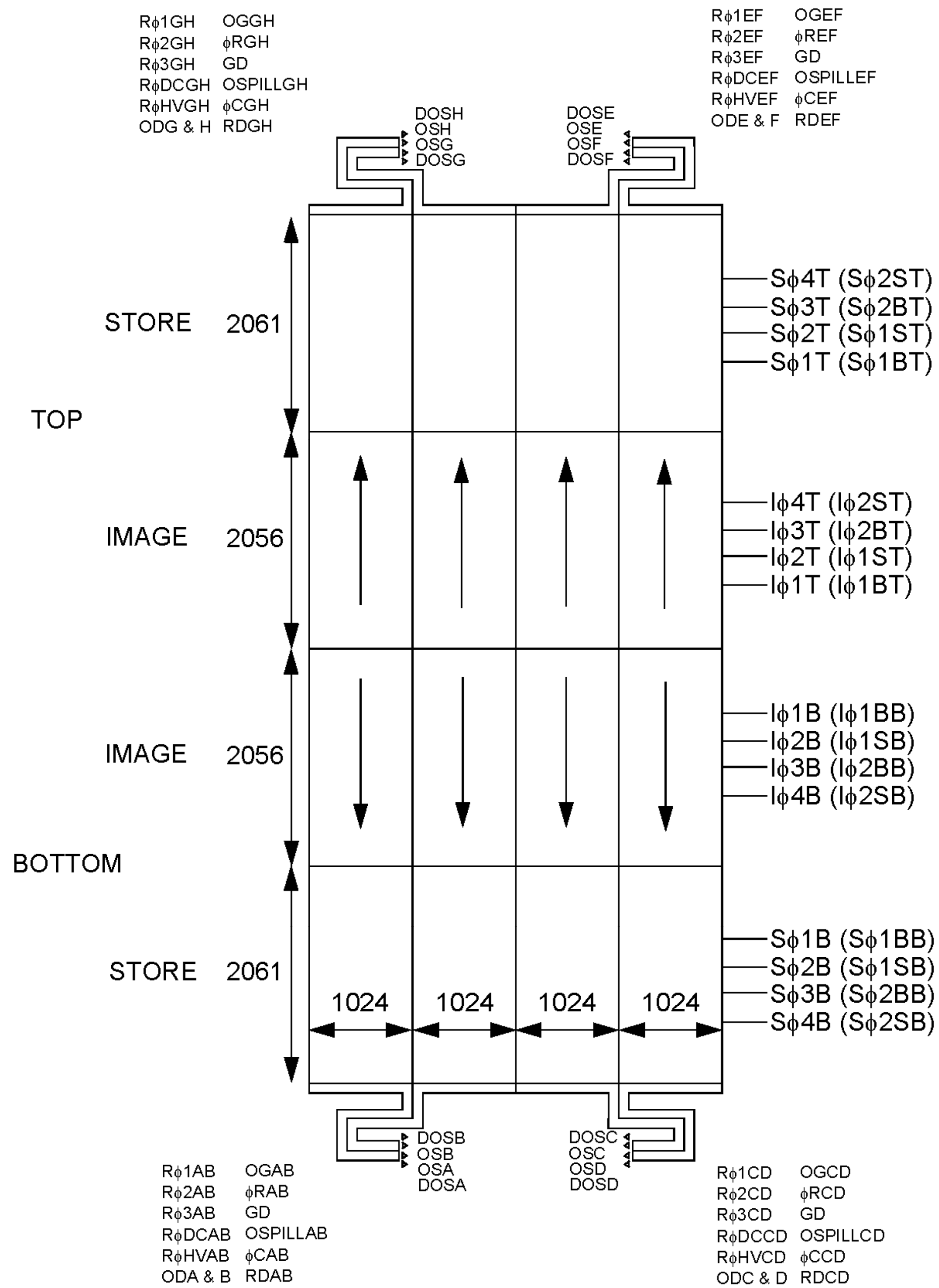
	CCD60	CCD97	CCD201-20	CCD207	CCD220	CCD282
Pixels	128^2	512^2	1024^2	1600^2	240^2	4096^2
Sorties	1x EM	1x EM 1x Conv	1x EM 1x Conv	1x EM 1x Conv	8x EM	8x EM
Arch.	FT	FT	FT	FF	S-FT	S-FT
FPS	1000	65	16	5	2000	4
ROI/ mROI ?	Yes	Yes	Yes	Yes	No	No

EMCCD 101

Architecture



Frame Transfer



Split Frame Transfer

Our Products

Our Products

- CCCP controller (Nüvü's technology)
- EMN2 cameras (customizable)
- HNü cameras (flagship product)
- CCCPs (space) controller

Our Products

- CCCP controller (Nüvü's technology)
- EMN2 cameras (customizable)
- HNü cameras (flagship product)
- CCCPs (space) controller New!

nüvü cameras

Our products

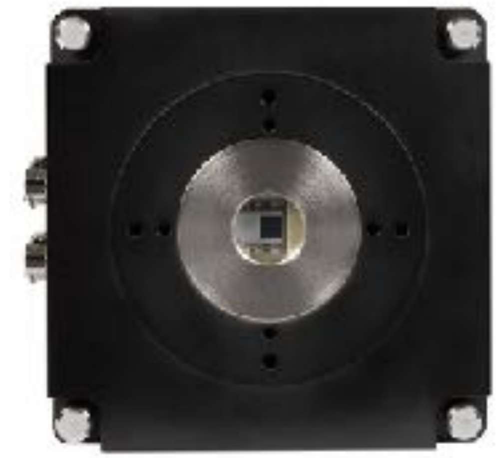
CCCP controller

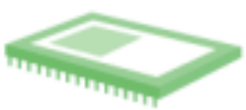
EMCCD controller

- Controller, integrated in all Nüvü's cameras, generates less clock-induced charges (the dominant source of noise @ moderate and high frame rate)
  - Greater photon counting performance
- Precise temperature control
  - Stable EM gain

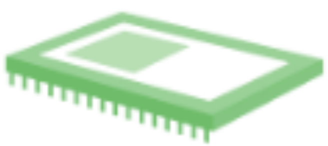
Our products

HNü cameras



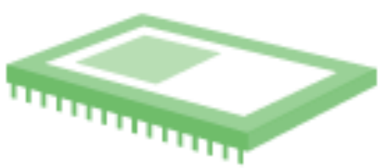


HNü 128 is optimized for the highest frame rate (1 kfps)



HNü 512 is balanced for optimal frame rates (63 fps), field of view and minimal noise

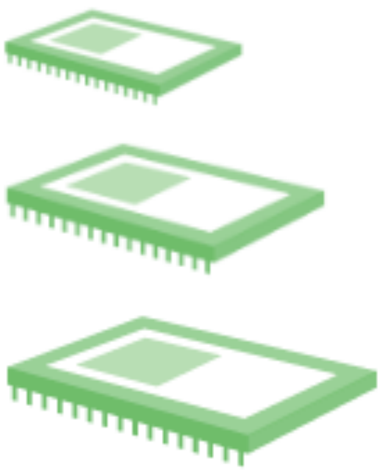
HNü 1024 is optimized for the largest field of view, lower frame rate (16 fps)



- ThermoElectric Cooling (air or liquid dissipation)
  - -85°C by air cooling, ≤-90°C liquid cooling
  - "AO" variant: -60°C cooling, optimized for high fps
- CameraLink or GigE interface
- Optimized for easy integration into most systems (Metric and imperial mounting holes on face plat)

Our products

EMN2 cameras



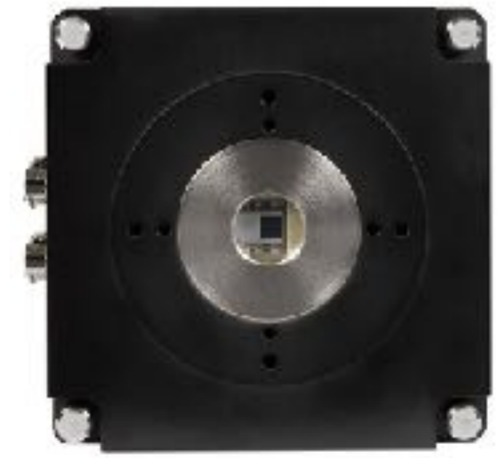
Same sensor sizes and connectivity as for the HNü

Can support custom sensors

- Made for special projects, customized read-out, detector test and development (mostly astro and space agencies)
- Allow for colder detector temperatures
- Liquid nitrogen cooled

Our products

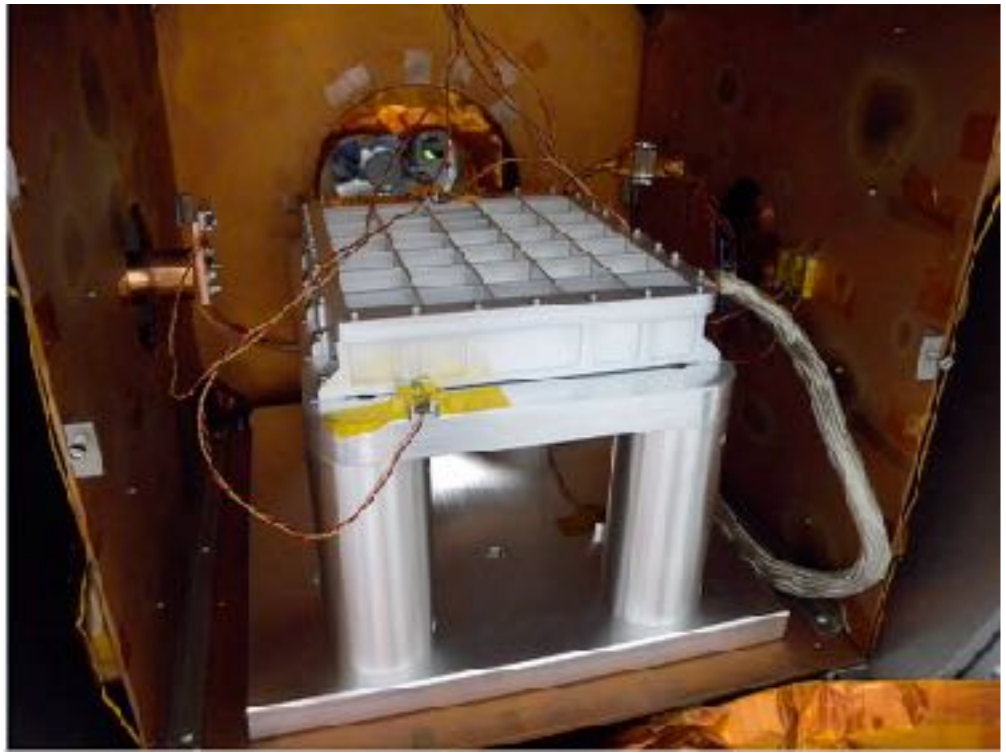
Cameras



- λ/10 window custom coating available, C-Mount standard, centred chip, built-in shutter
- Binning, ROI & mROI selection, Cropped-sensor mode
  - mROI: multiple ROI, several 100's fps even with 1024^2 (developed for PESTO)
- Standard CCD and EMCCD channels (512 & 1024)
- NüPixel software, drivers for third-party software (Biomed), SDK (C/C++), for Linux and Windows

Our products

CCCPs controller



- Yield the same low light performance as the commercial controller, built with **only** Space Qualified components
- PCB routed according to IPC2221-2222 Class 3 (highest reliability and repeatability)
- Designed with best practices to sustain vibrations
- Compatible with the commercial software suite
- CSA TRL-5 (Thermal, Vacuum, SQ by design)

ABB nüvü cameras

Our products

CCCPs controller

To be presented at the Canadian SmallSat symposium (Toronto, Feb. 2018)

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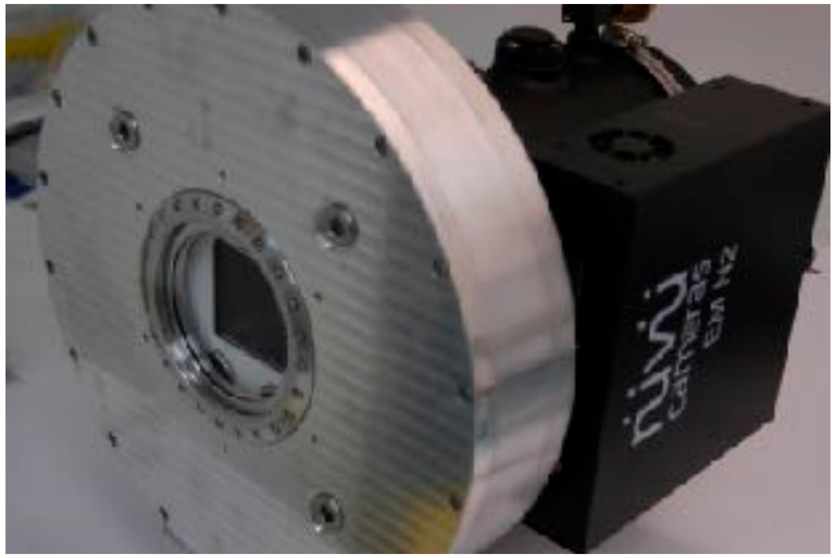
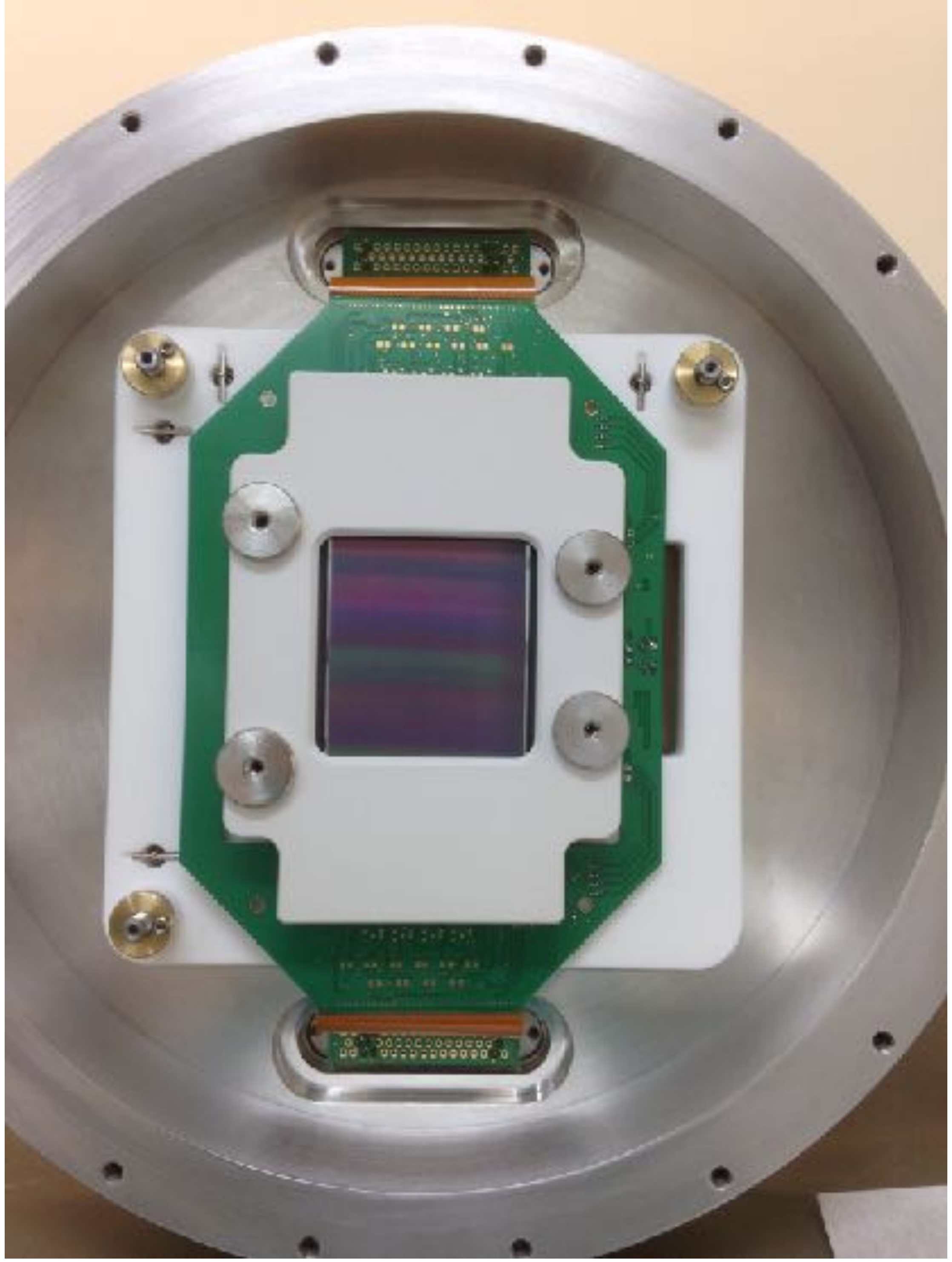
Our products

Upcoming products developments

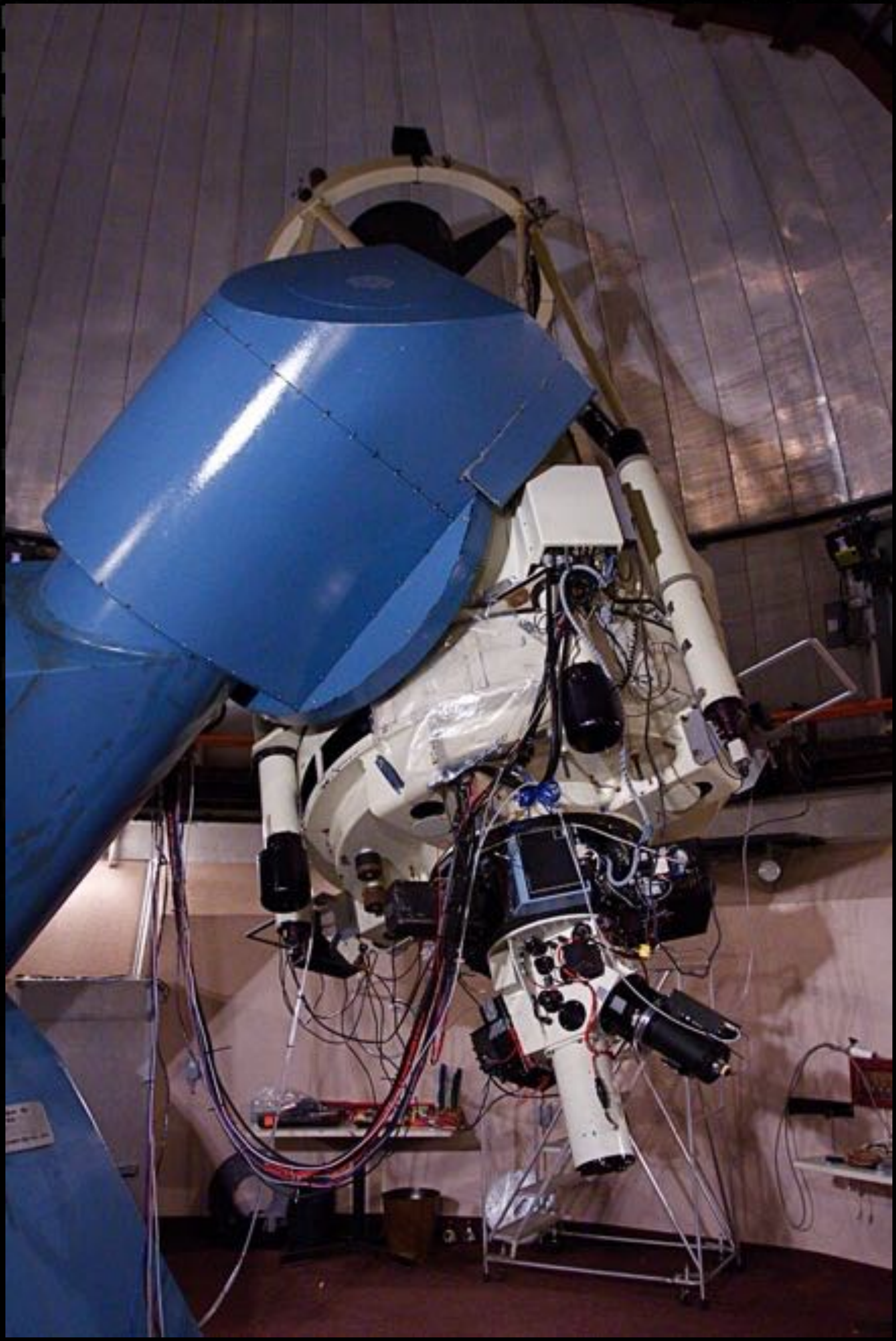


- 4k x 4k camera
    - To be presented at SPIE Astro (Austin TX, June 2018)
- mROI with individual EM gain per ROI under development
    - For 128, 512, and 1024 cameras
- 30 MHz read-out tests
    - 1.5 kfps on the 128, optimized for AO
    - Other sensors TBD



nüvü cameras

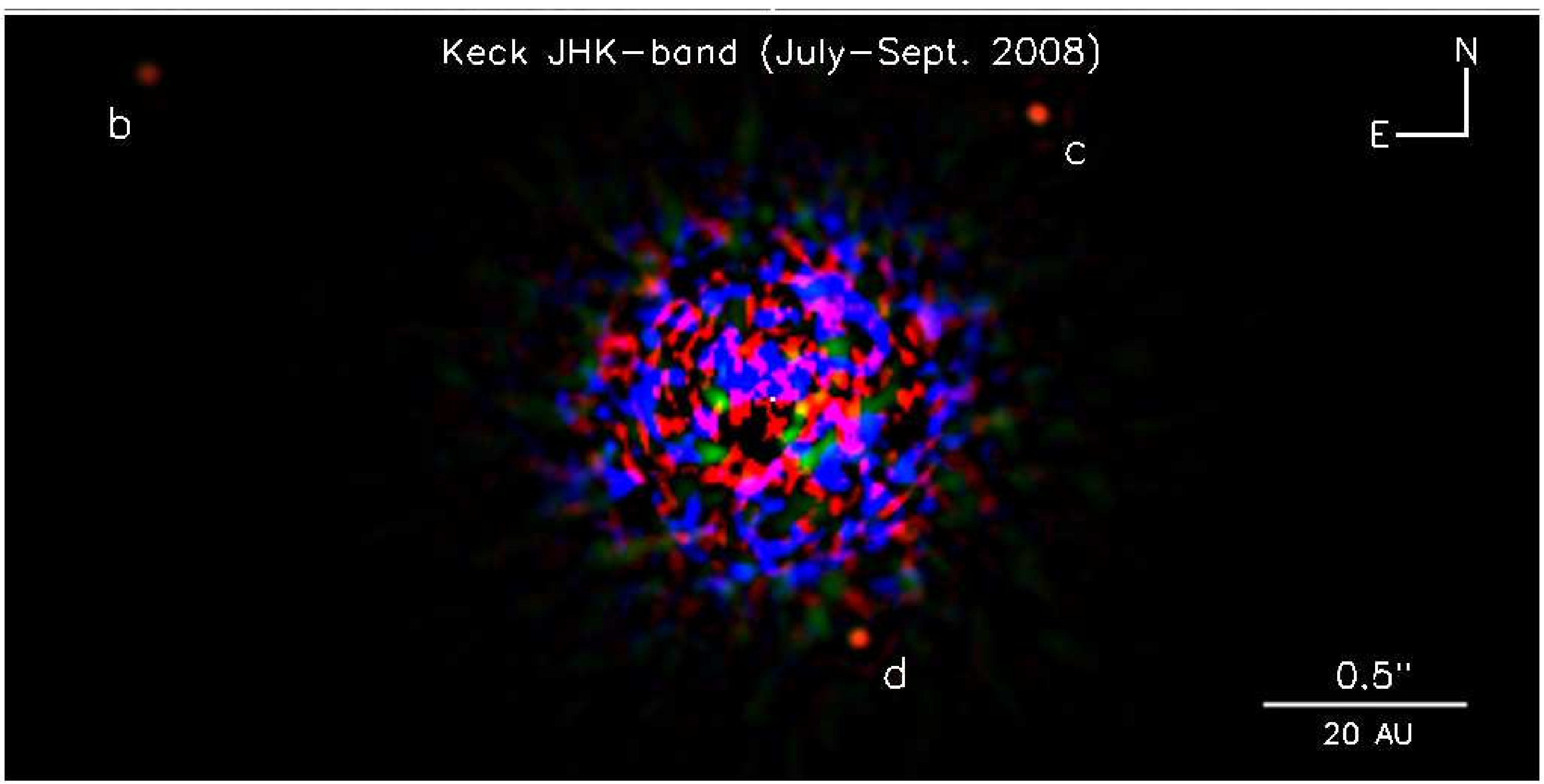
Astronomical Applications



Applications

Direct imaging of exoplanets

- Direct imaging of exoplanets
- 10-9 contrast
- For a mag 8 star, > mag 30 for the planet! (comparable to HUDF)
- 10 — 100 hours of integration per planet



Marois et al. 2008

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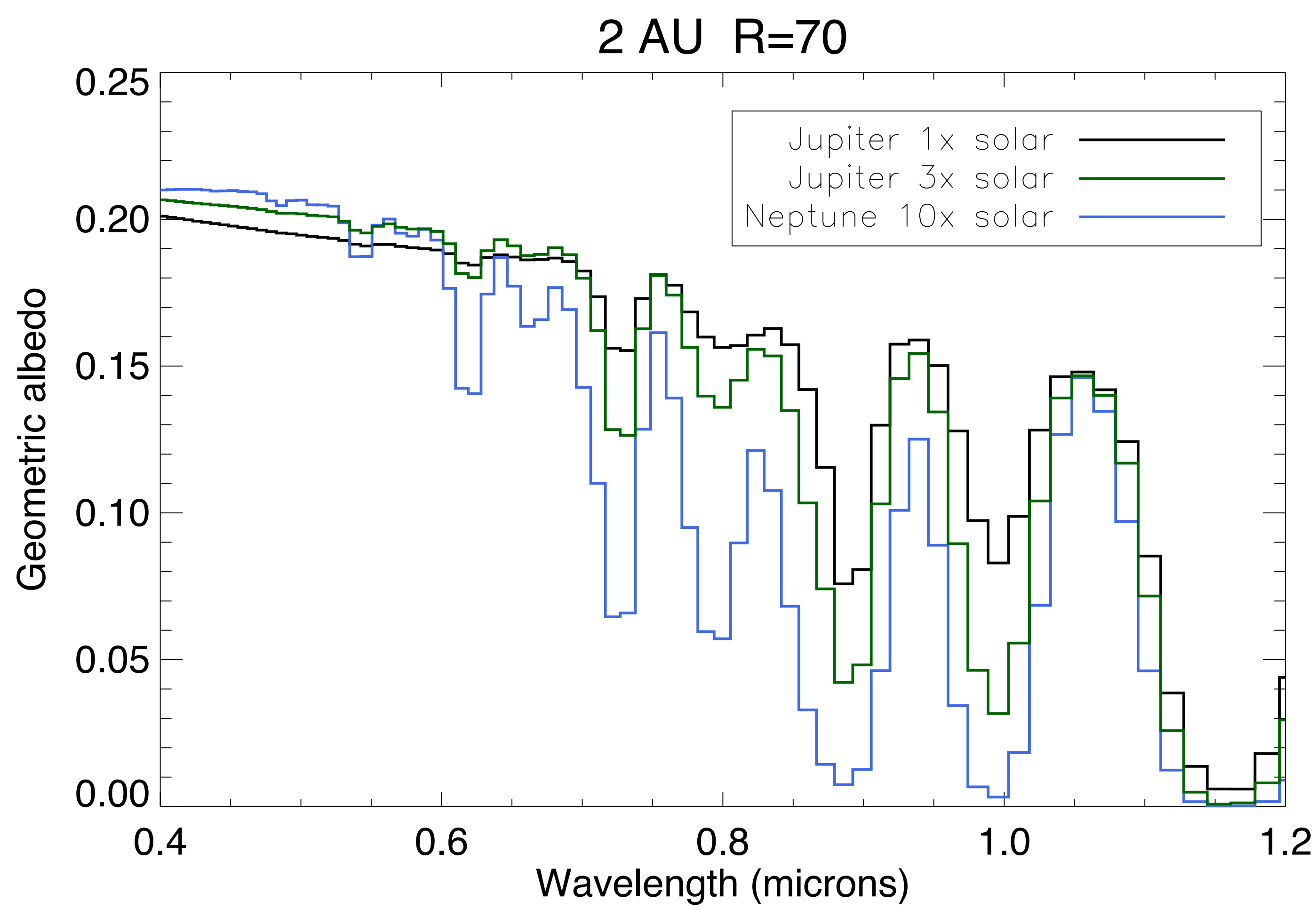
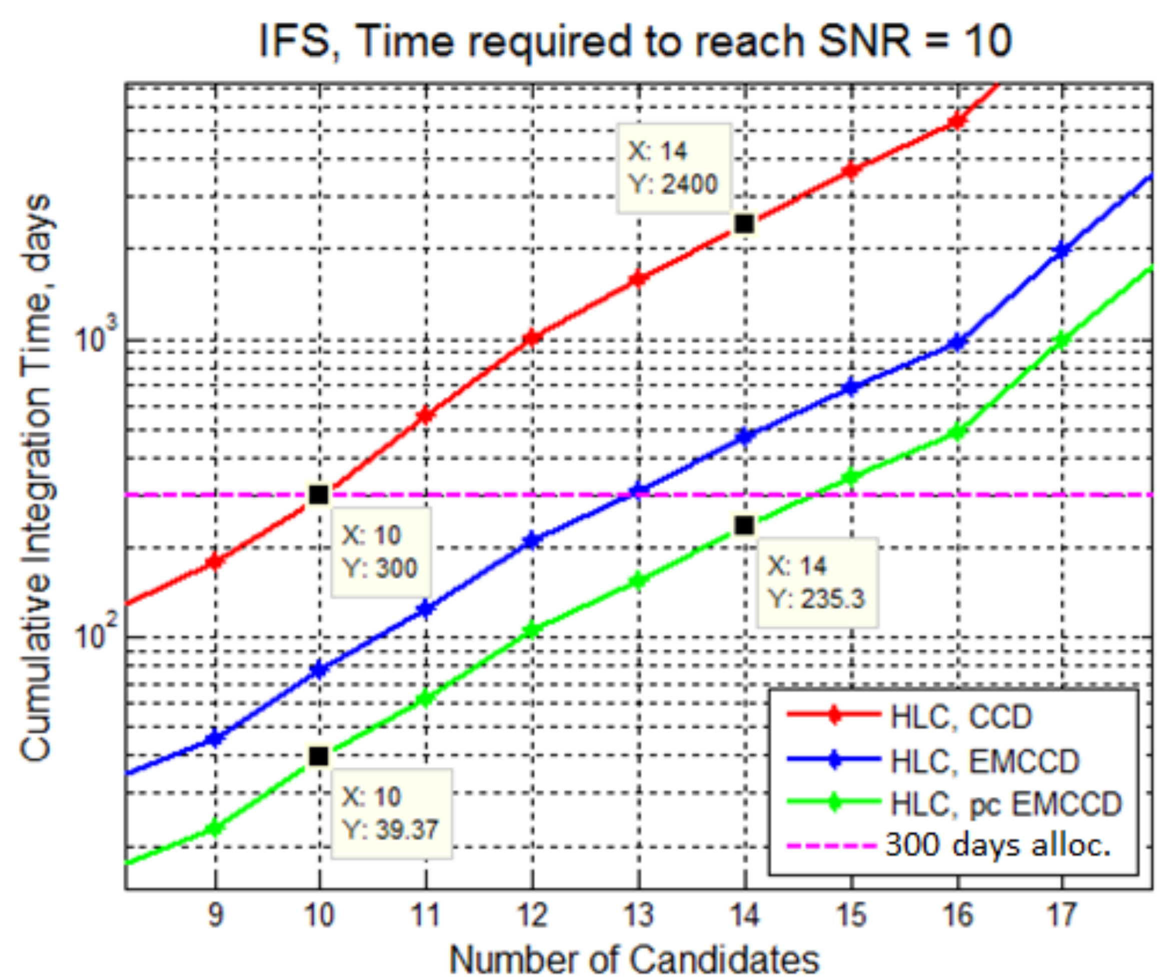


Cahoy et al. 2010

Applications

Direct imaging of exoplanets

- WFIRST
  - Models shows that by comparison with the CCD, the use of an EMCCD would reduce the acquisition time by ~90%
  - For the lifespan of the mission, the number of detected exoplanets increases by 50%



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Applications

Direct imaging of exoplanets

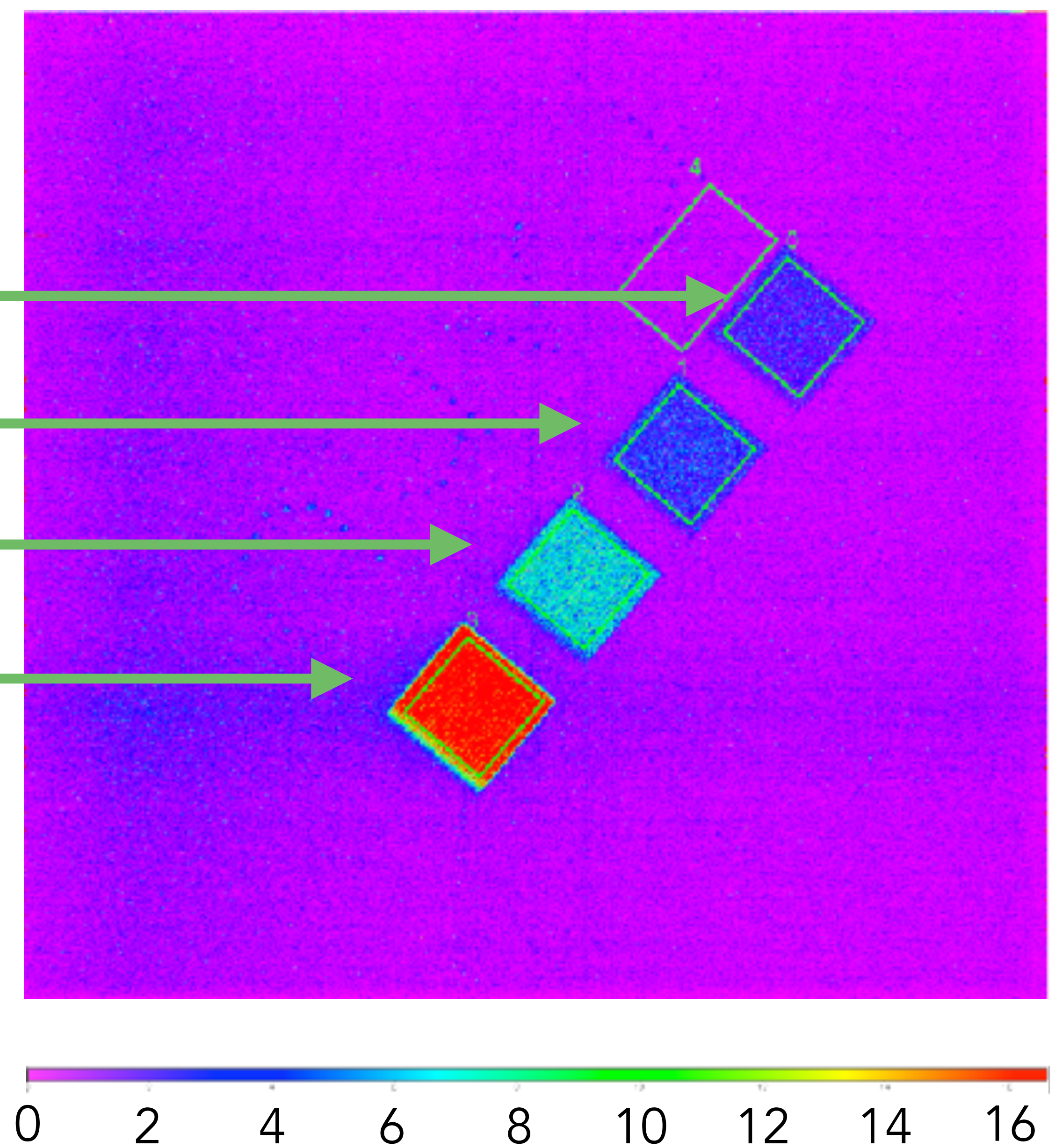
2 photons/pixel/h

3 photons/pixel/h

5.5 photons/pixel/h

19.5 photons/pixel/h

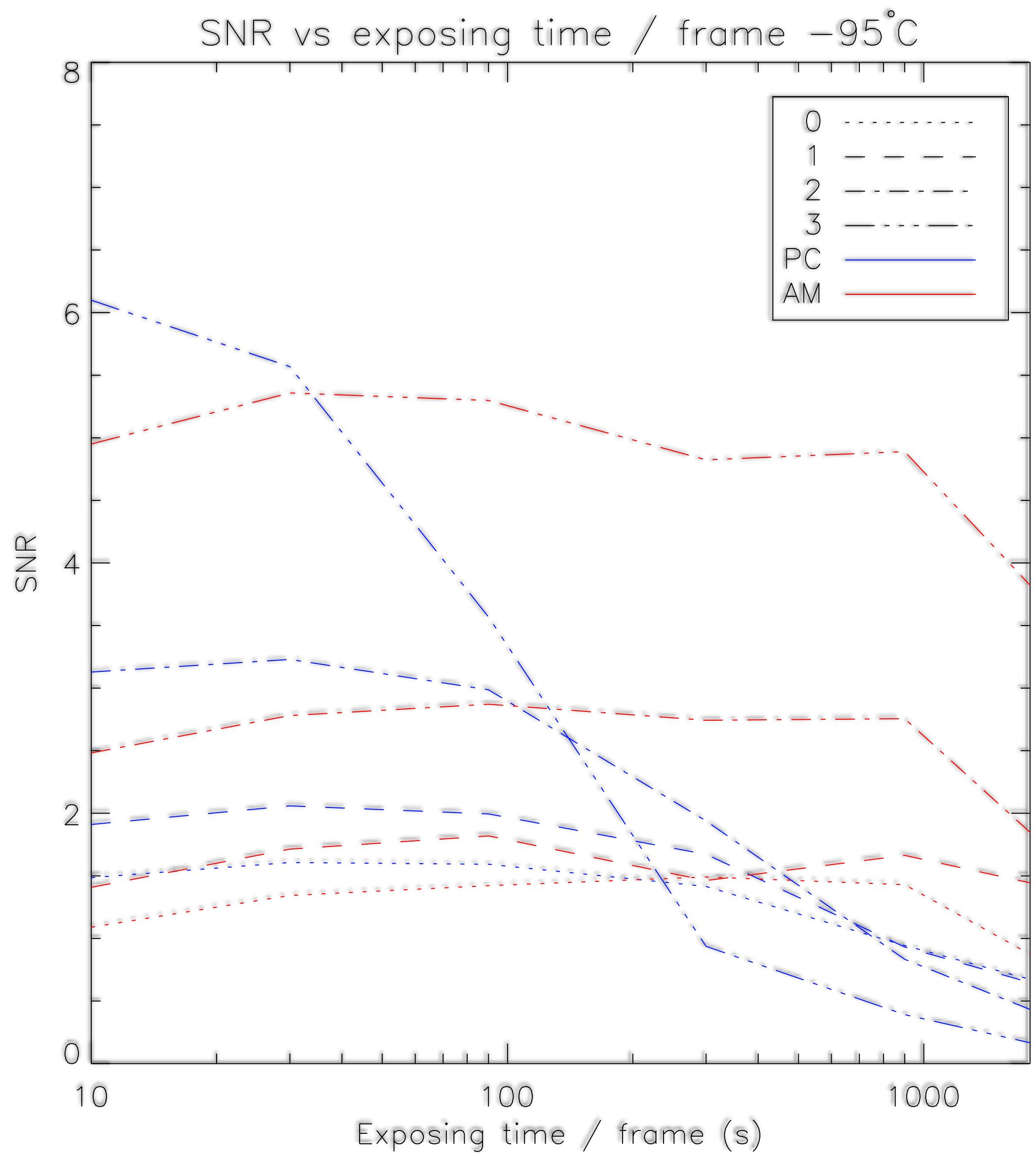
120 * 90s images: 3 hours of total integration



Data @ -95°C, ē/pixel/h (including dark current)

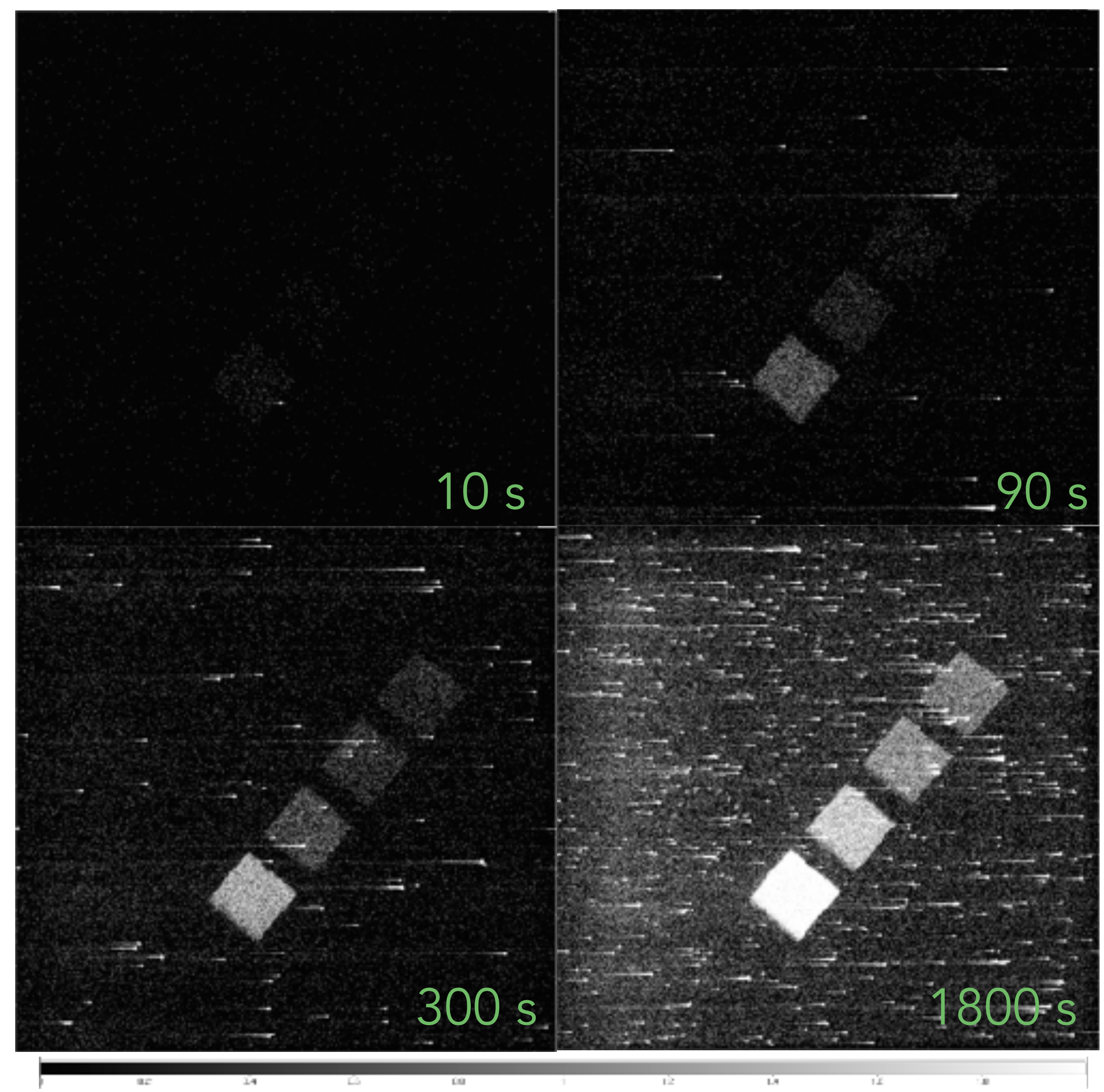
Applications

Direct imaging of exoplanets



1080 360 120 36 12 6

Number of frames



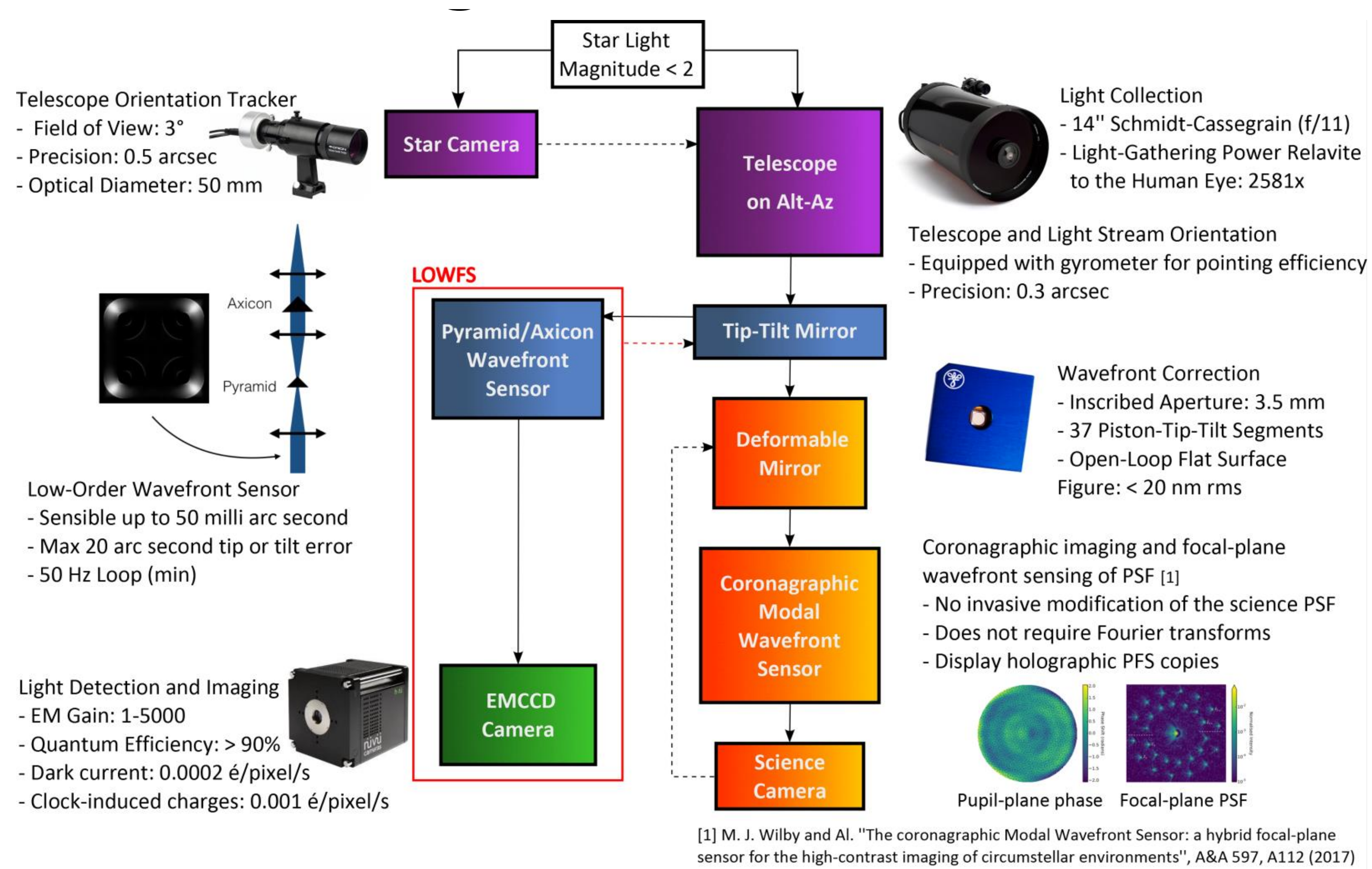
0 1 2

ē/pixel/image

Applications

Direct imaging of exoplanets

- High-Contrast Imaging Balloon System
- LOWFS
  - HNü 128 AO modified for vacuum operation
- Coronagraph
  - Space controller with HNü 512 AO cryostat



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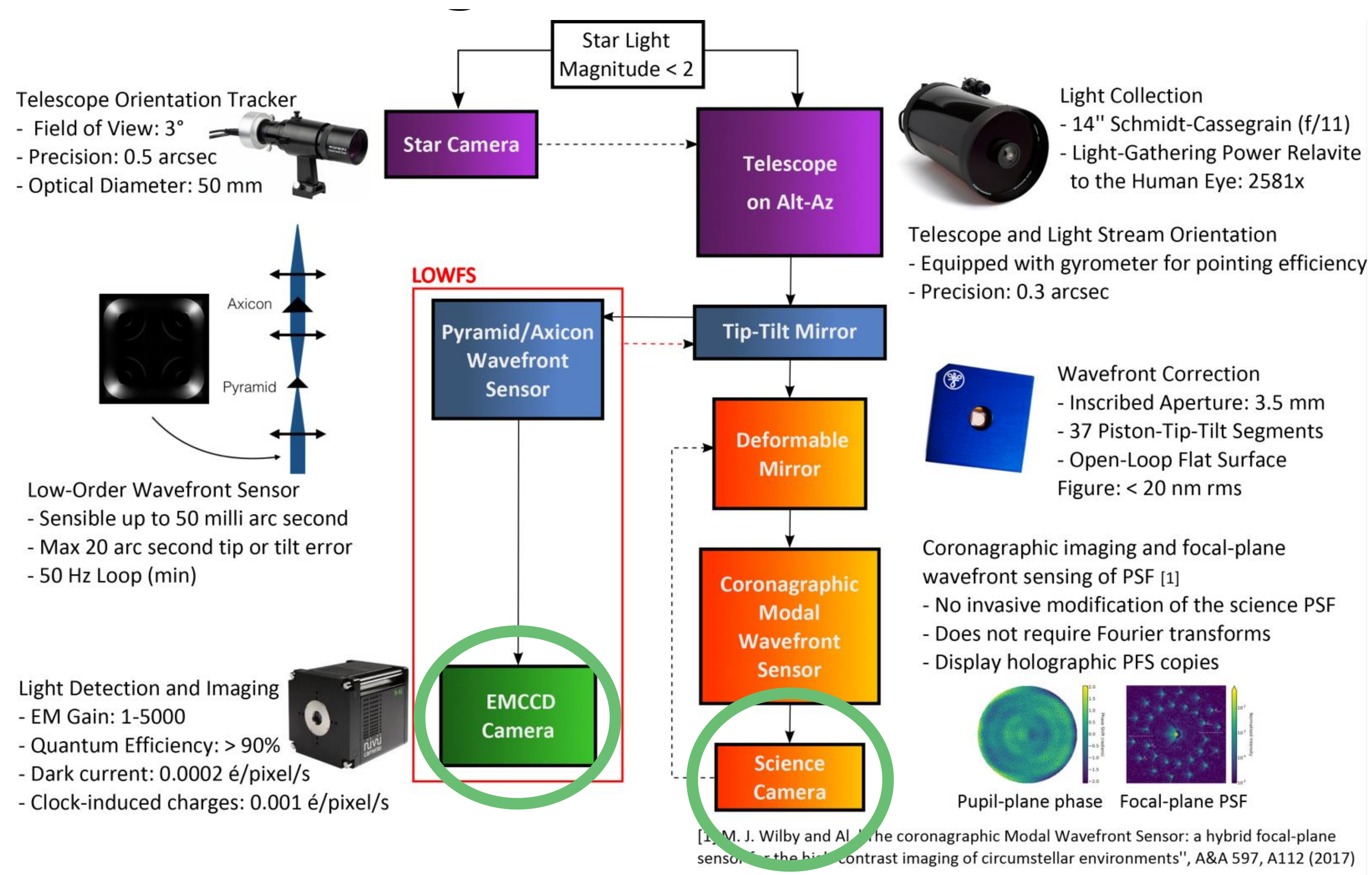
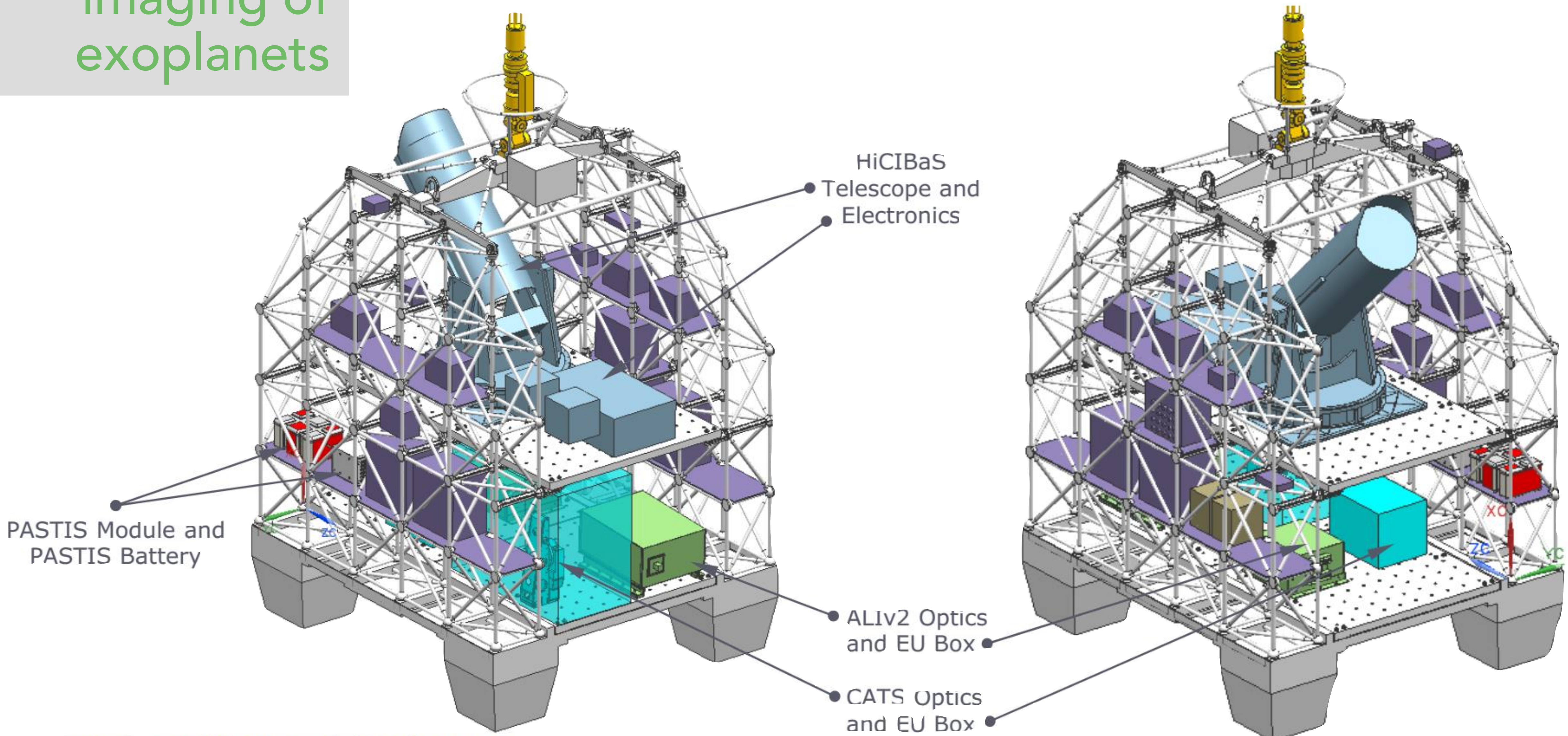


Applications

Direct imaging of exoplanets

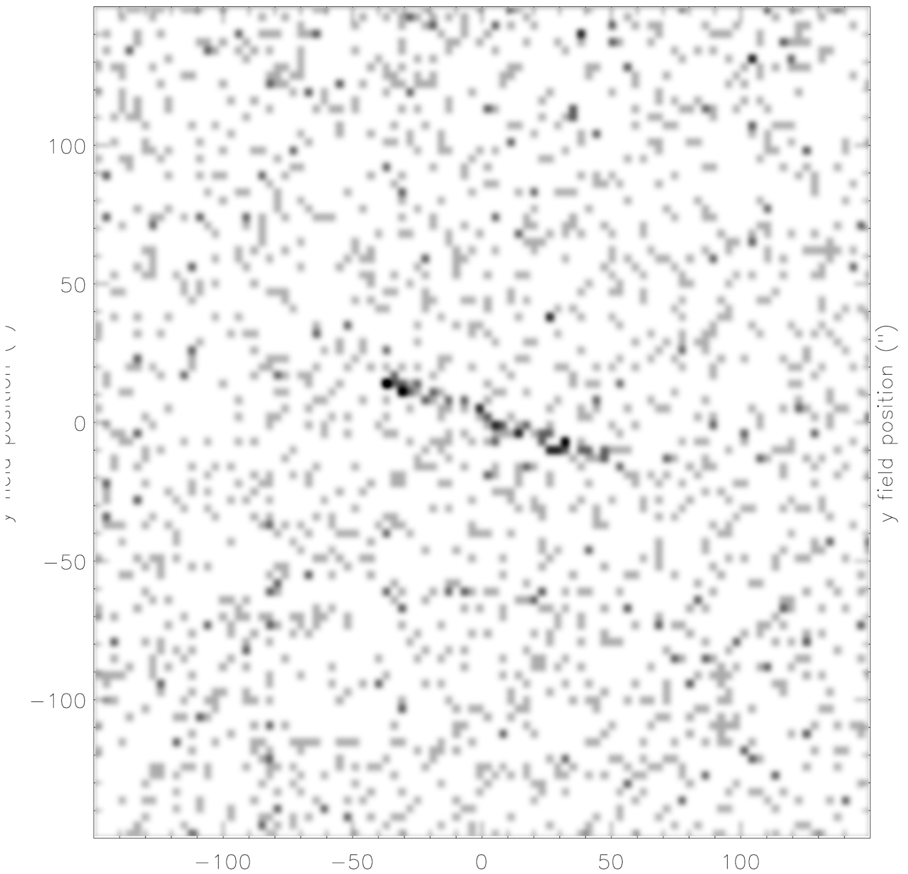


*Purple = CARMEN Gondola Subsystems

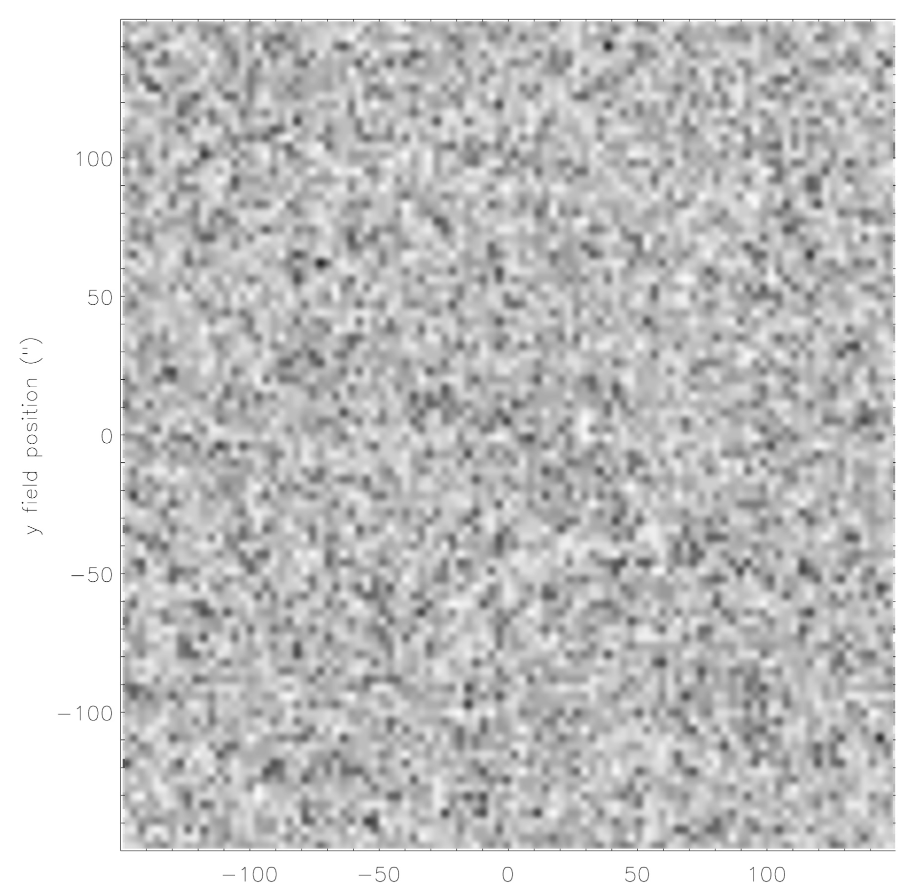
Applications

SSA

- Search for orbital debris
- For moving objects against a bright background, the SNR increases with lower integration times!



EMCCD



CCD 2ē

Université de Montréal

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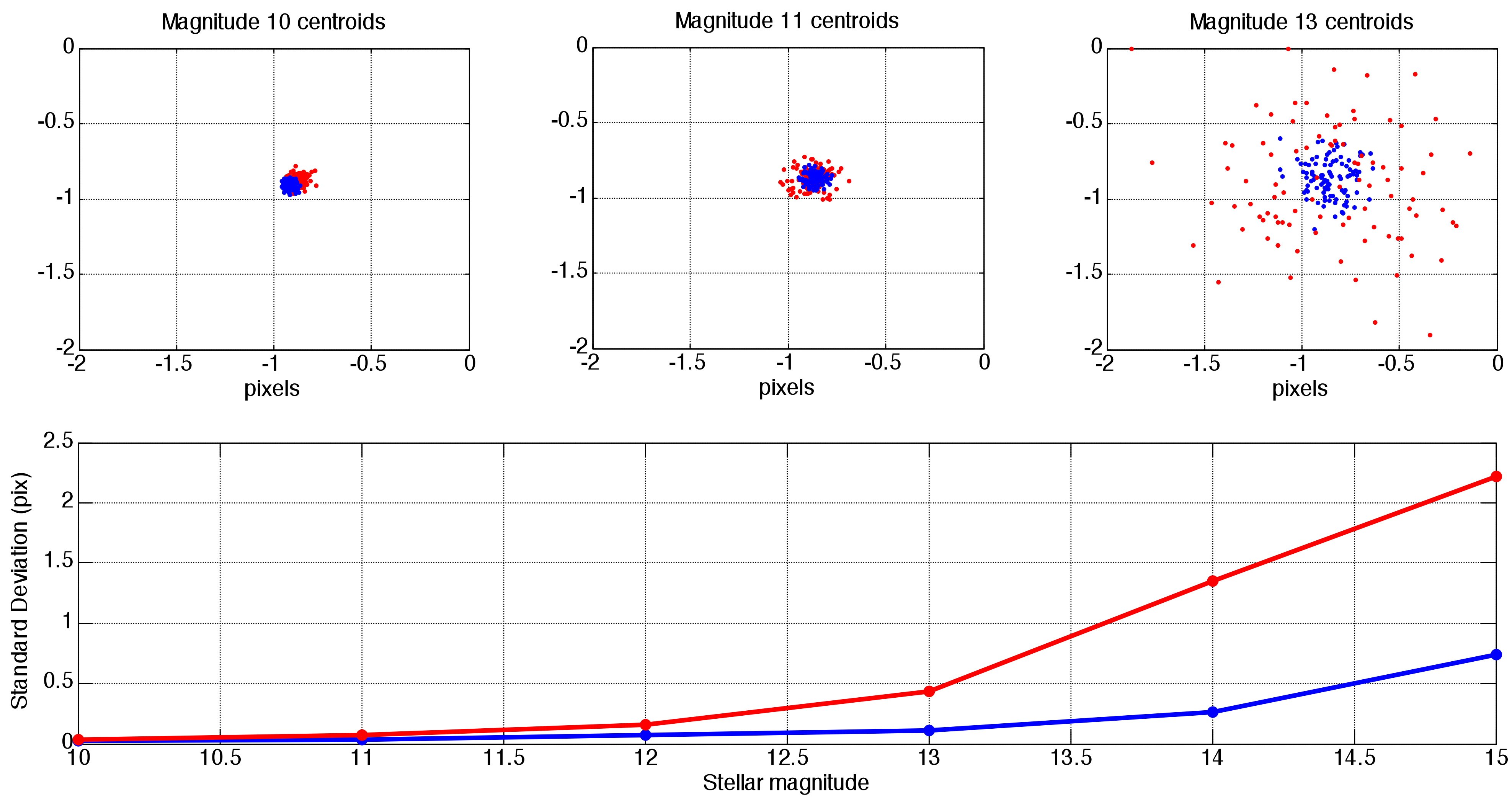
Applications

SSA

10Hz data



CCD (red) vs. EMCCD (blue)

Applications

SSA

10Hz data

Applications

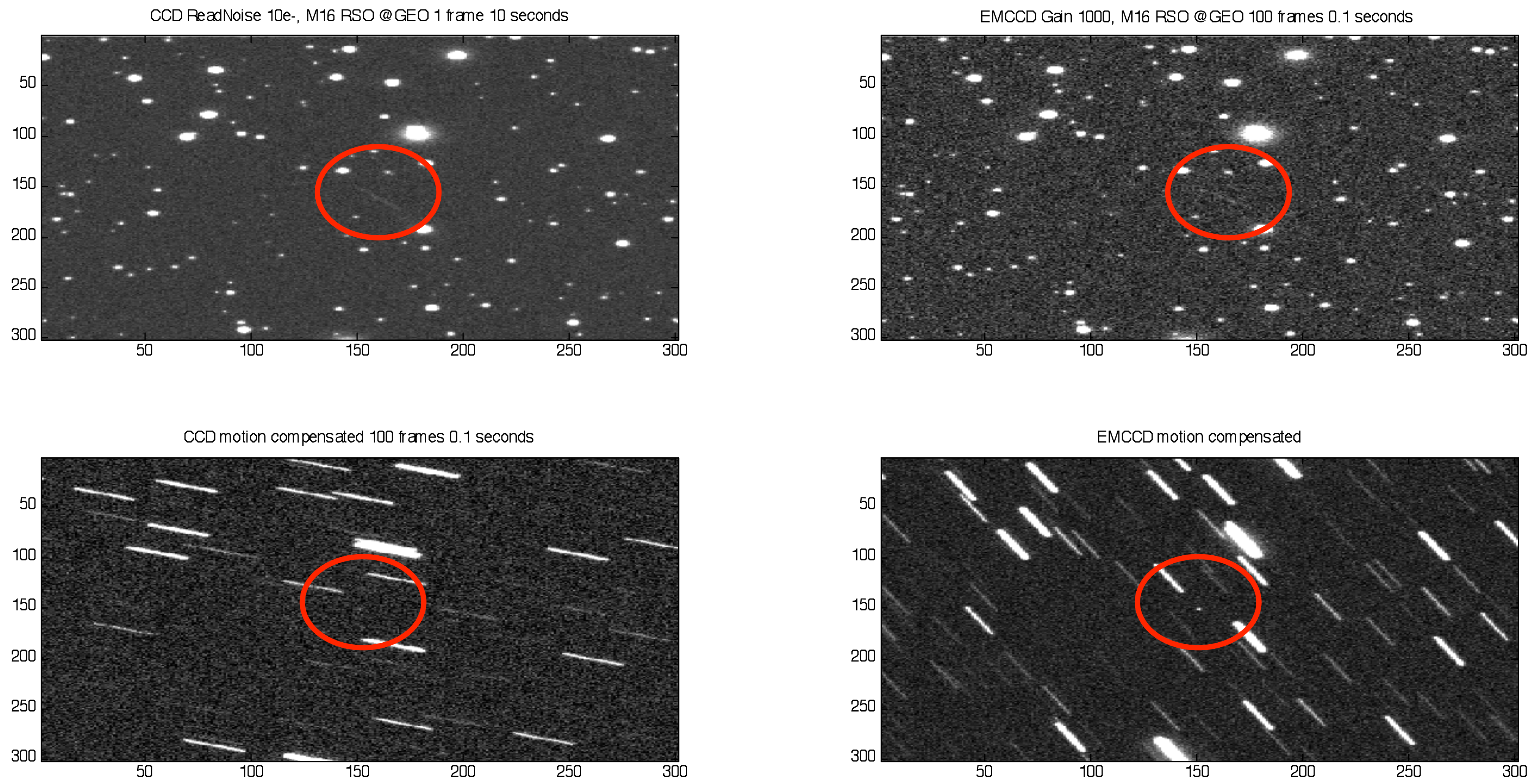
SSA

10Hz data

Applications

SSA

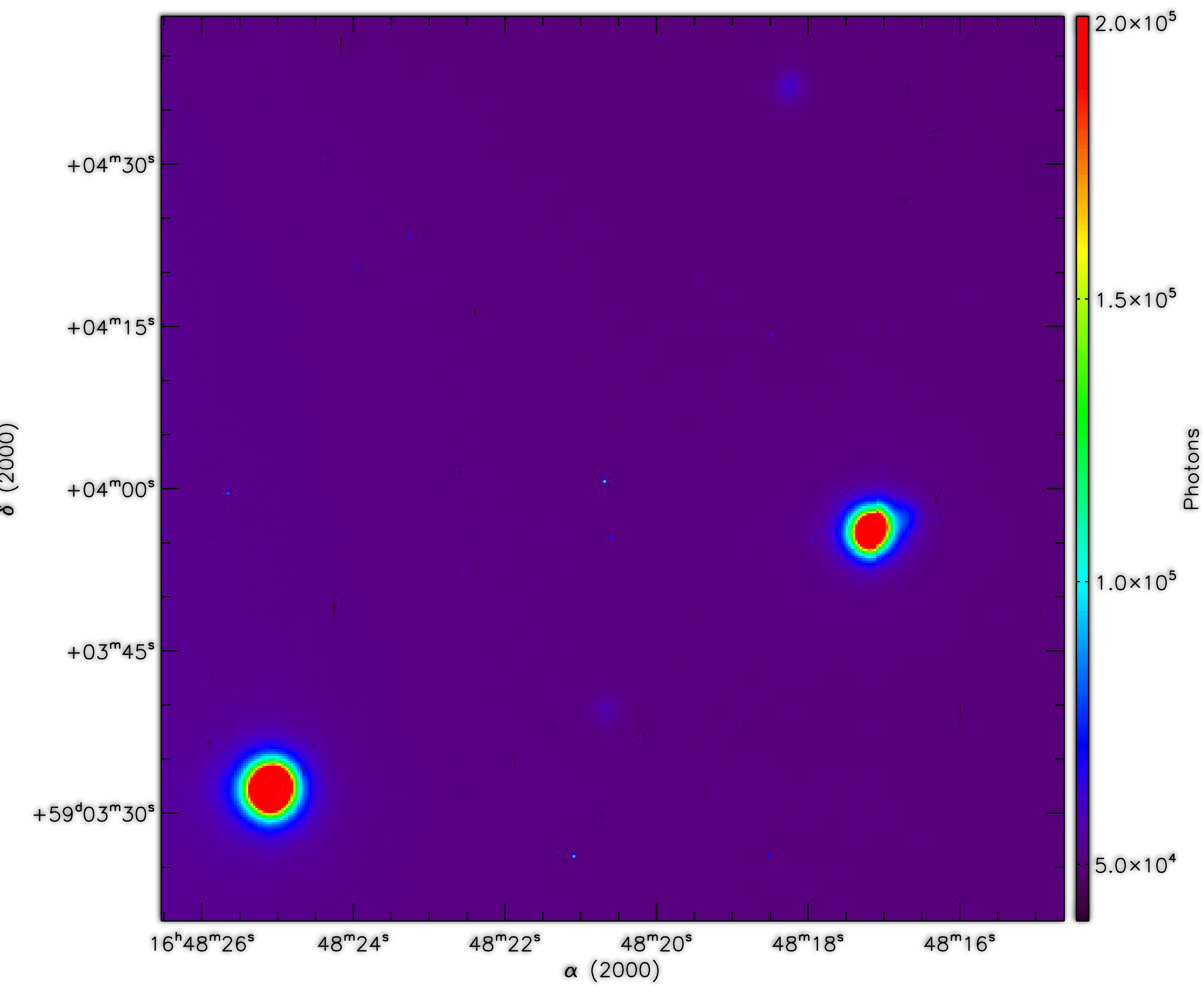
10Hz data



Applications

Fast differential photometry

30 fps, offline averaging



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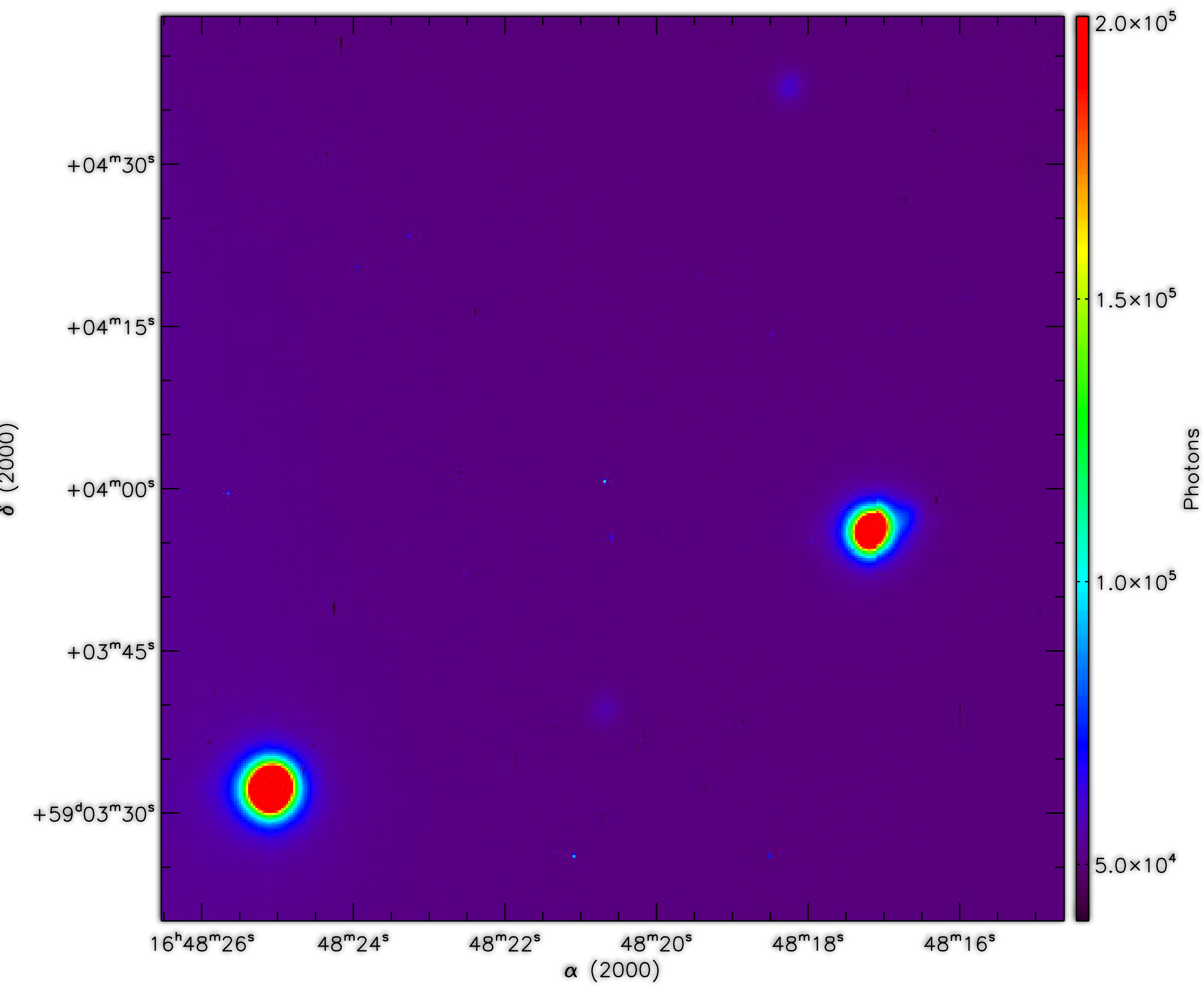

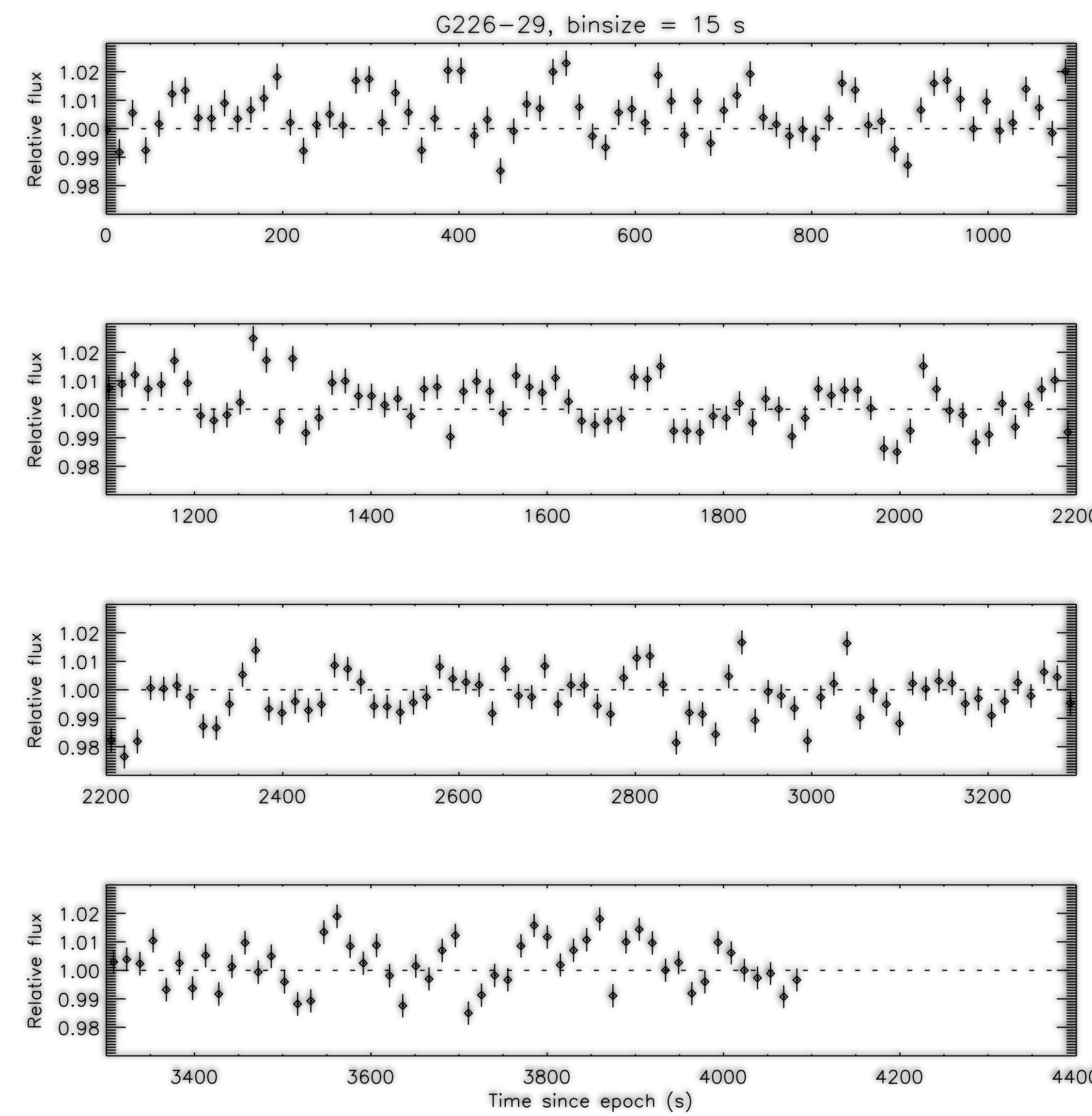

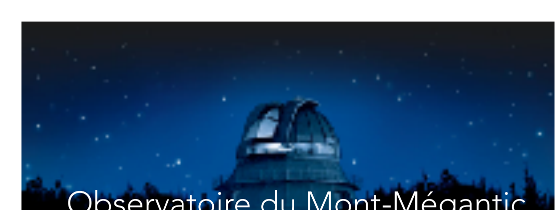

Applications

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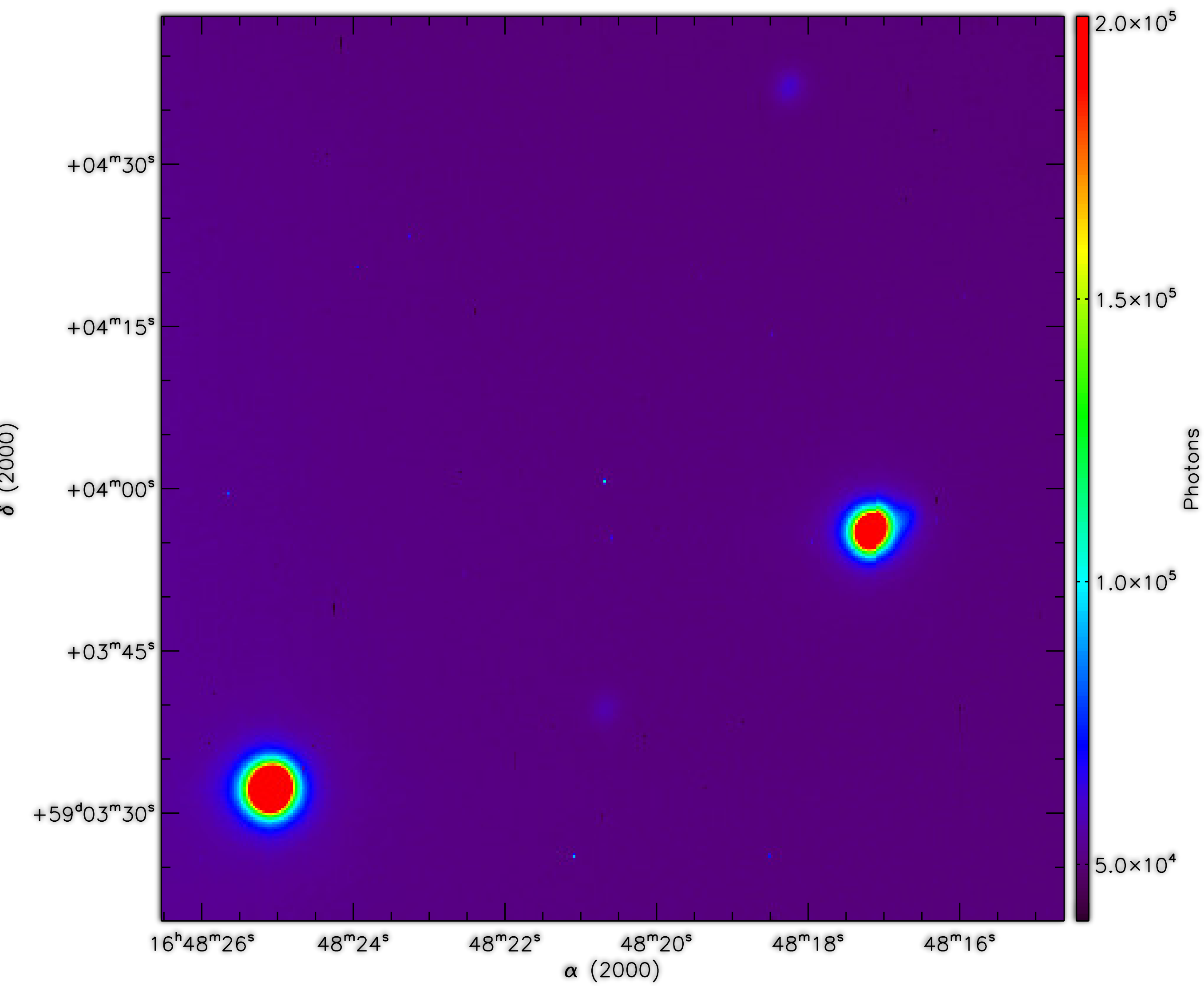
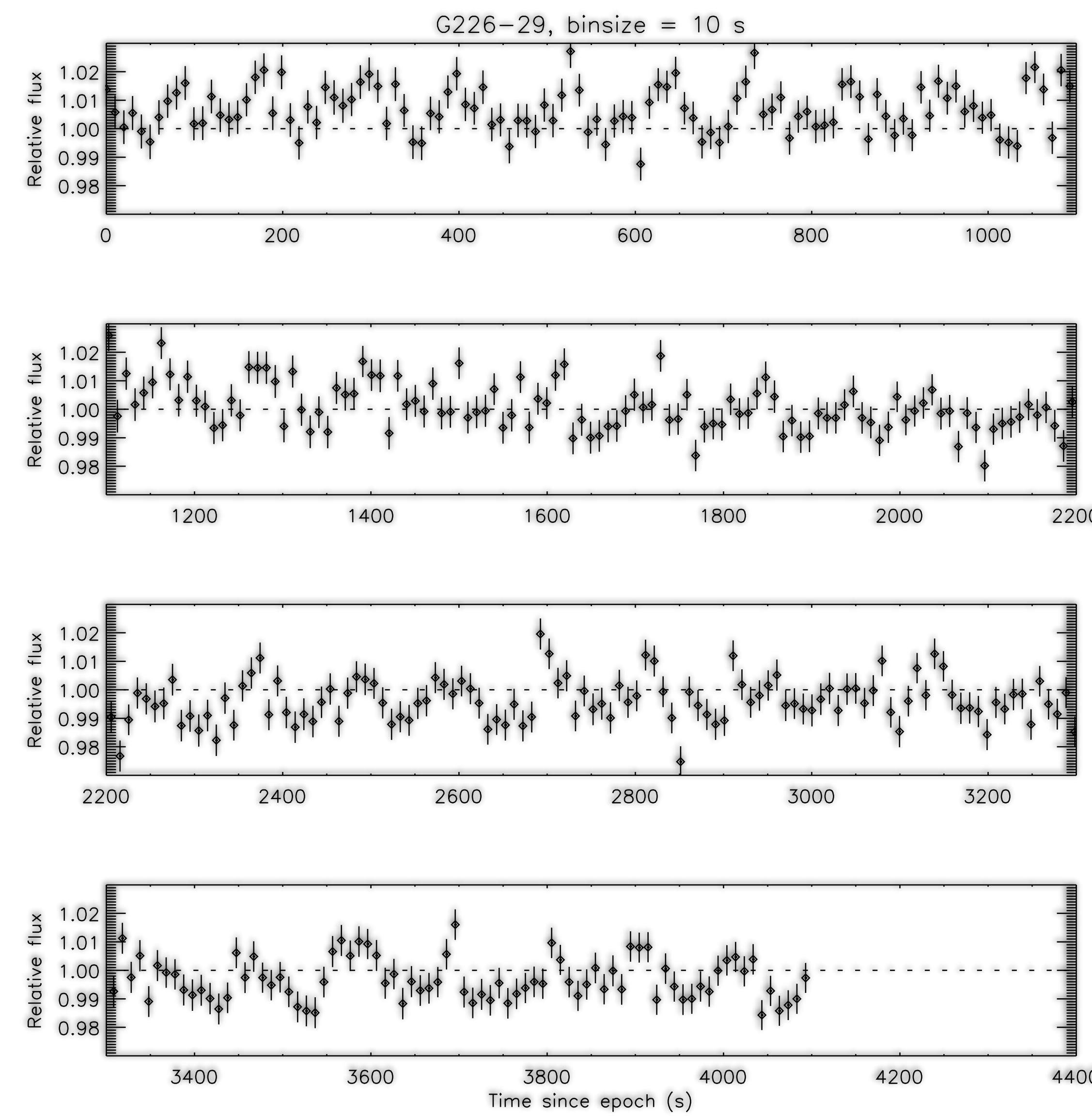
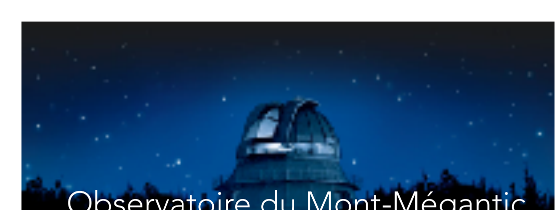


30 fps, offline averaging



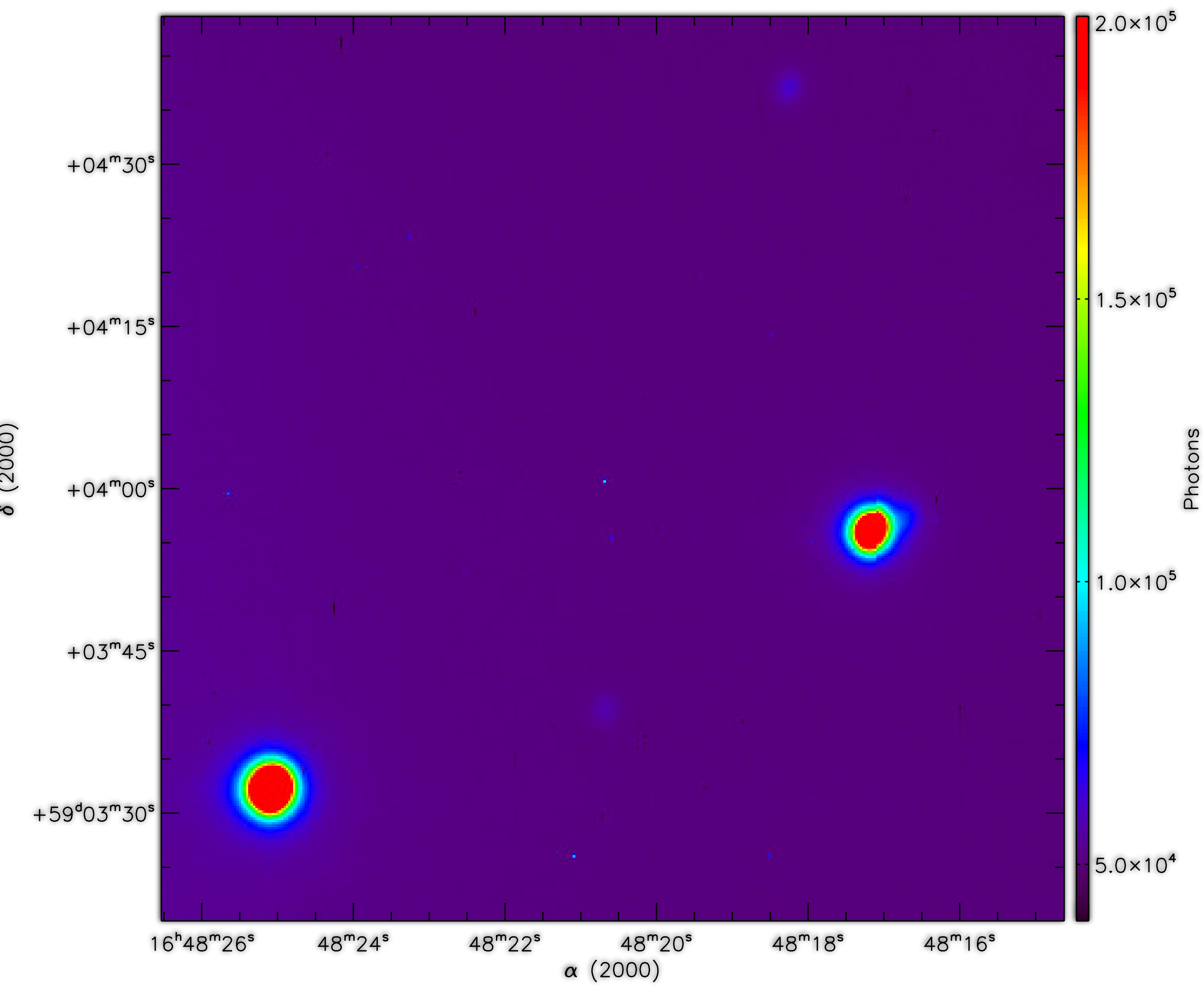


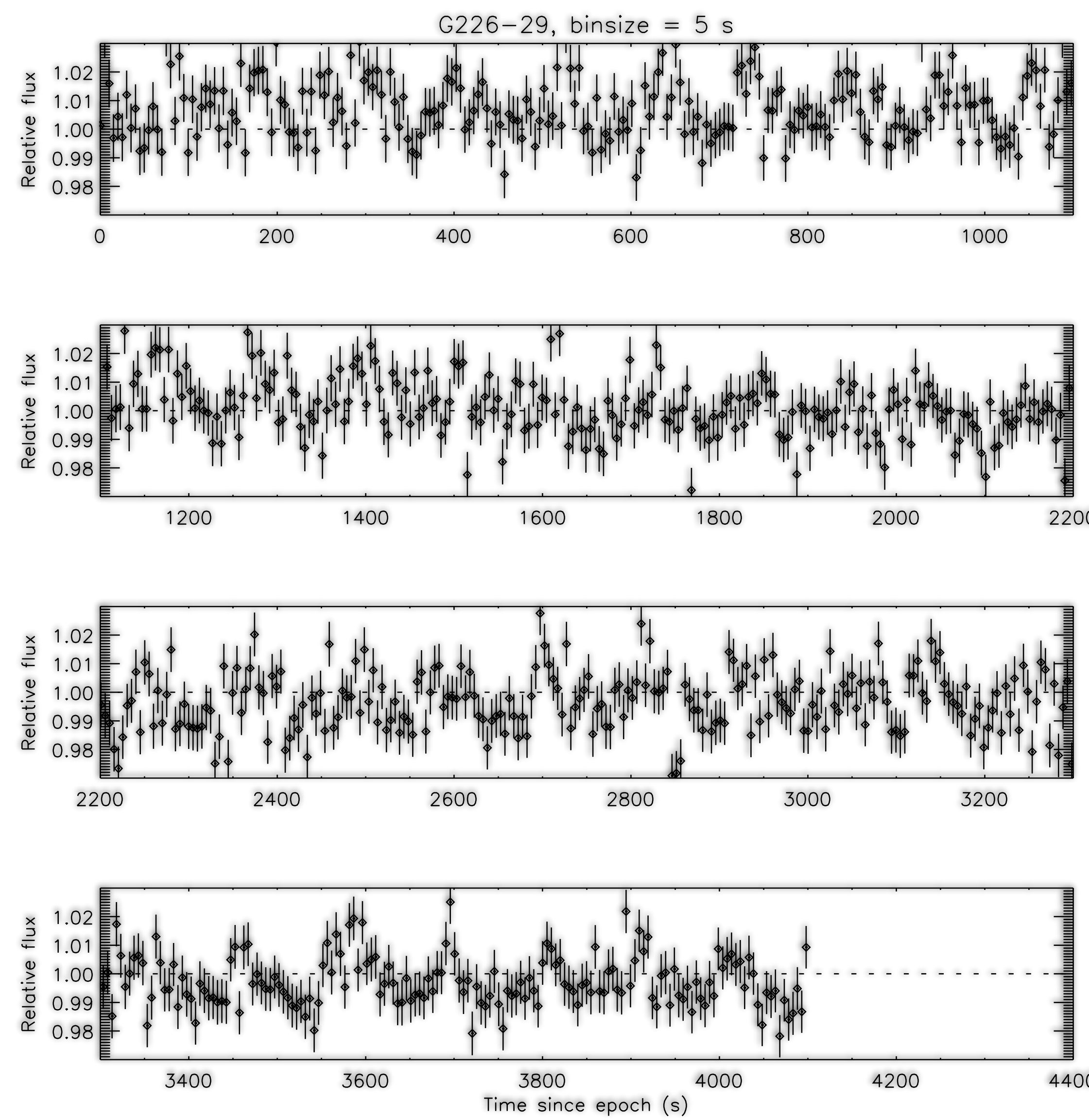
nüvü caméras

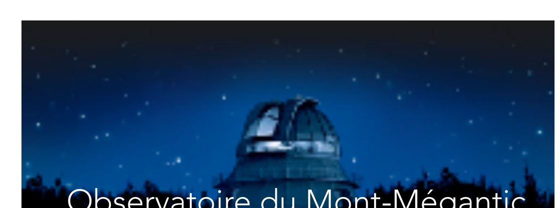
Applications

Fast differential photometry

30 fps, offline averaging







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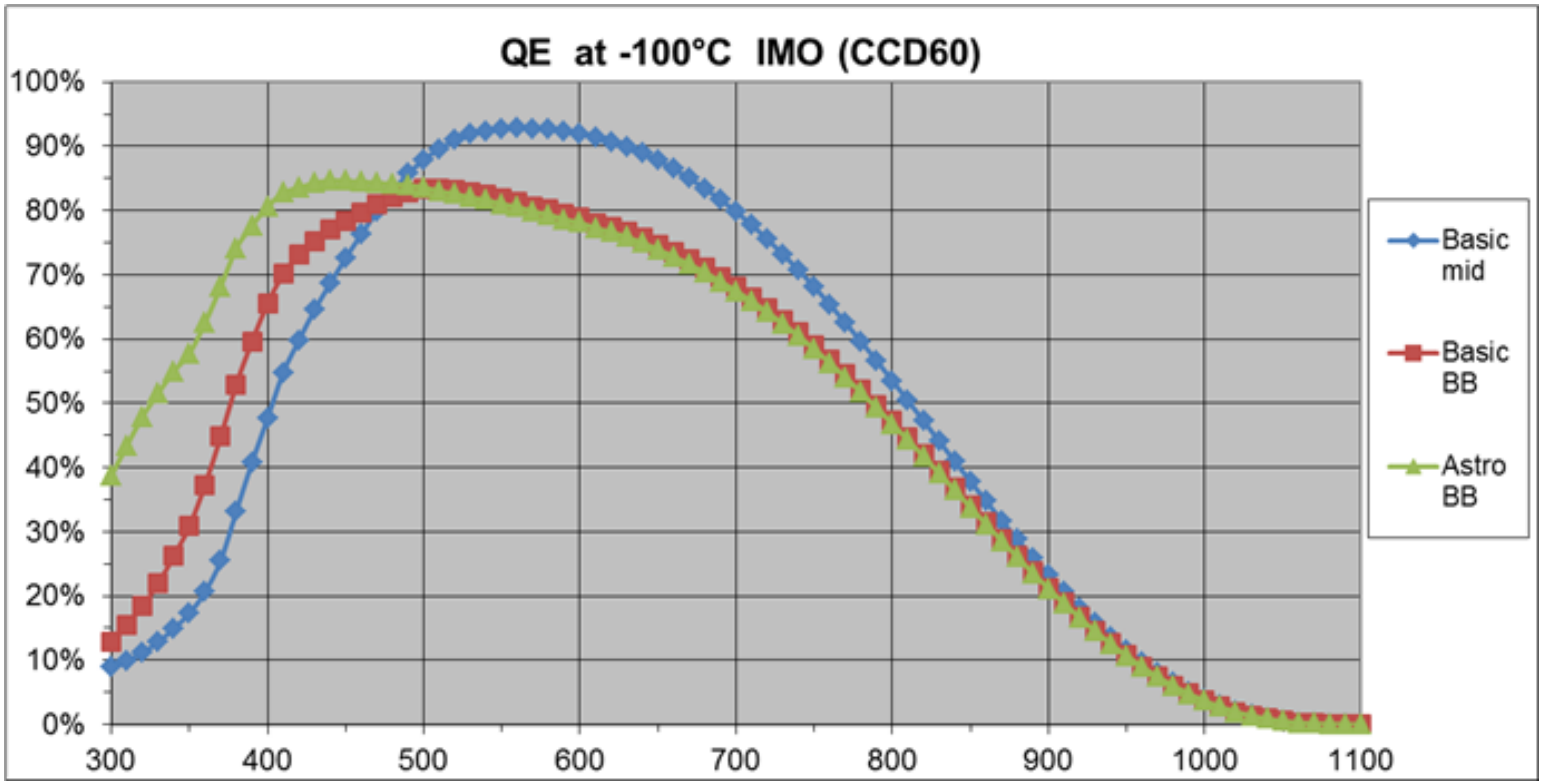
Applications

UV imaging

- An EMCCD is a CCD
- Spectral responses are similar



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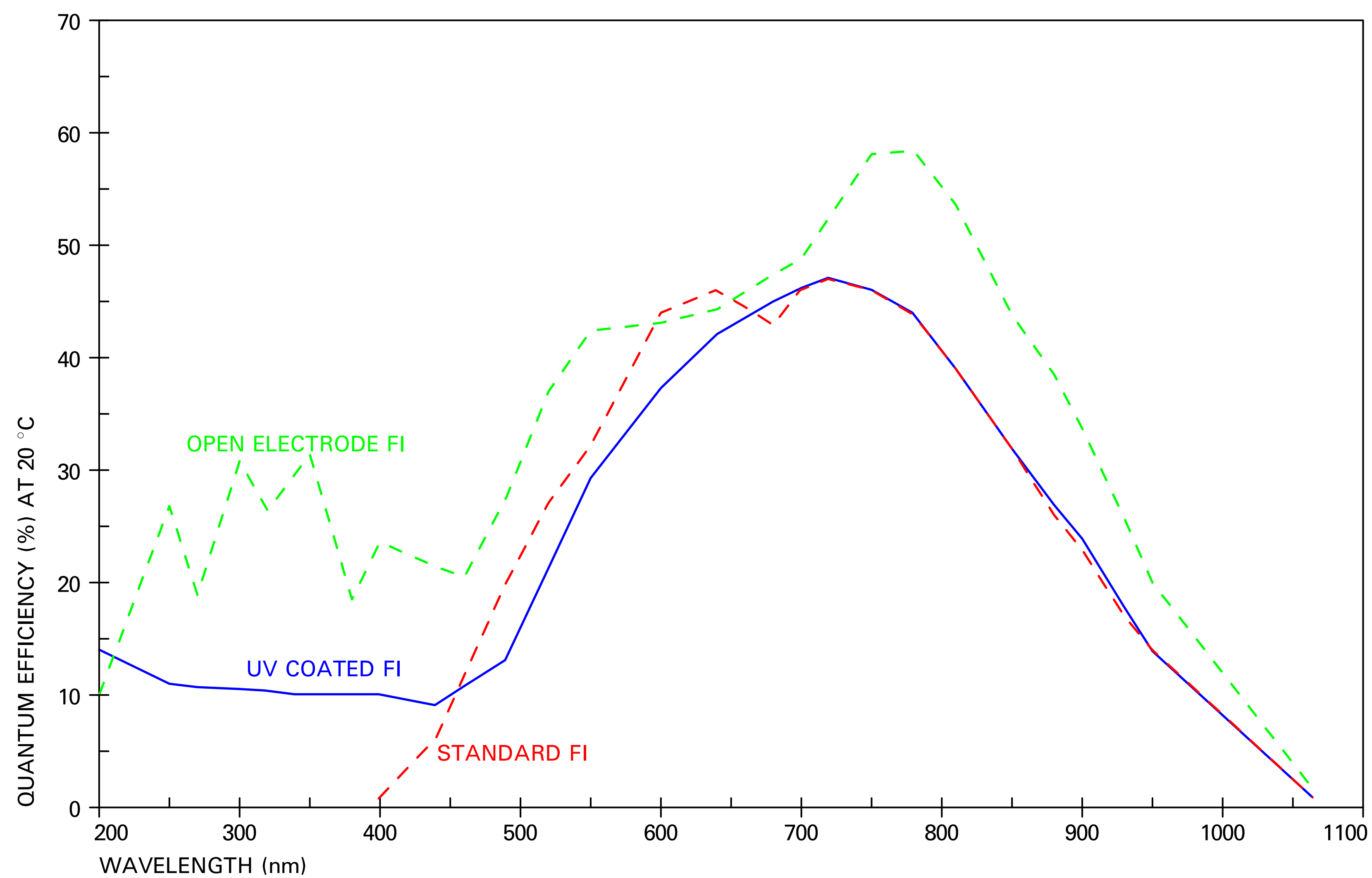
Applications

UV imaging

- LUMOGEN® coating can be applied to enhance UV response to ~50% of the green response of the EMCCD

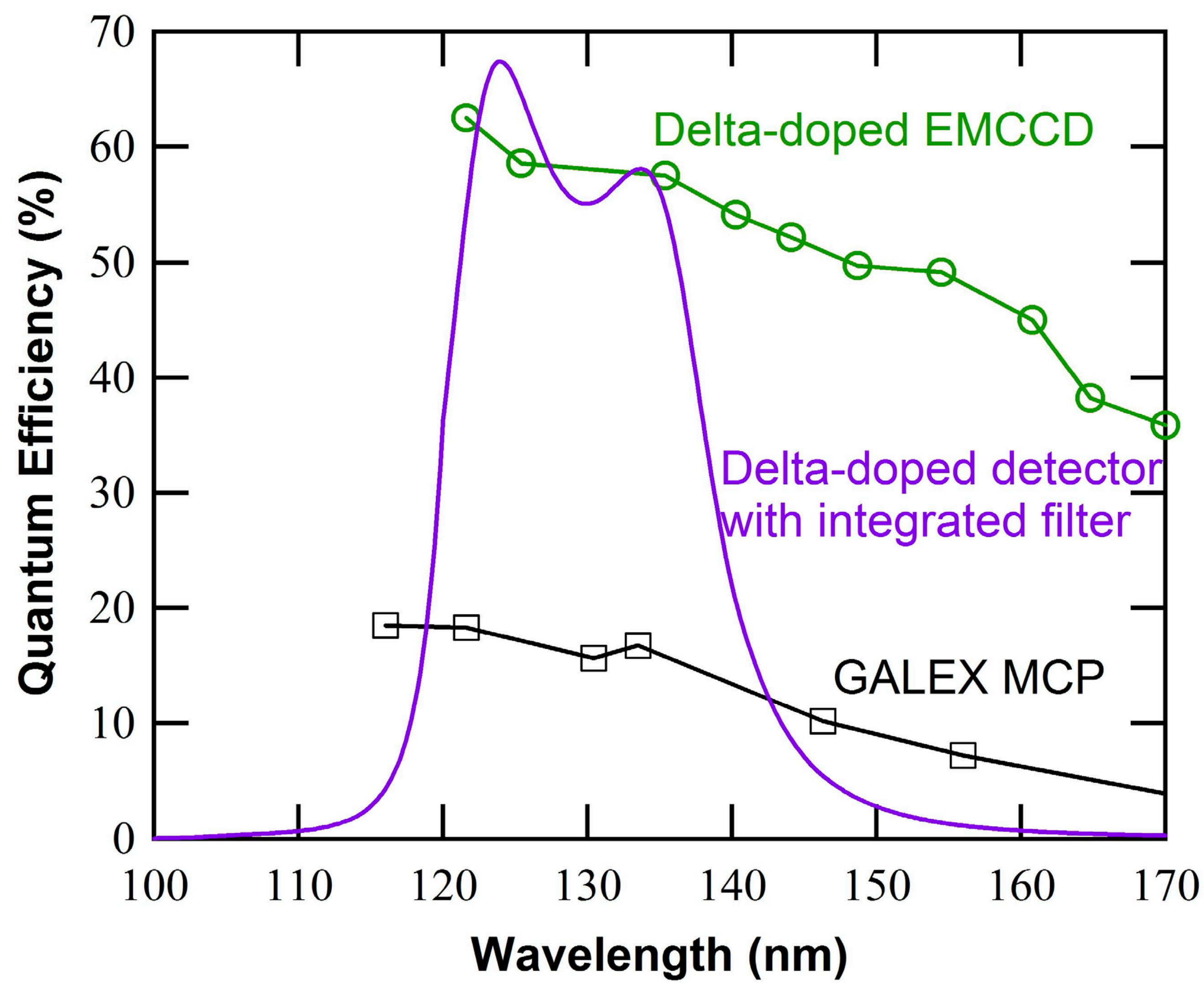


Front-Illuminated CCD response with Lumogen®

Applications

UV imaging

- Delta-doped EMCCDs, in development at JPL/NASA allow for high UV response with respect to MCPs



Nikzad et al. 2016

Conclusions

- Our products are optimized for high sensitivity in low light applications
- Commercial cameras
  - Ease of use, high cooling performance, versatile software suite and SDK, laboratory applications and B2B
- Space controller
  - World's first SQ EMCCD controller
  - Foreseen for SSA and coronagraph applications
- 4k x 4k development
  - Largest EMCCD, opens-up new possibilities in spectroscopy, wide field surveys, large format medical imaging

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Conclusions

- Open innovation
  - We concentrate on what we are good at: building cameras
  - We support our clients and partners in getting the most out of our technology
  - Product customization, development of new features upon request to better suit our client's needs
  - Looking forward to play an active role in NTCO!

nüvü
camēras

every photon counts