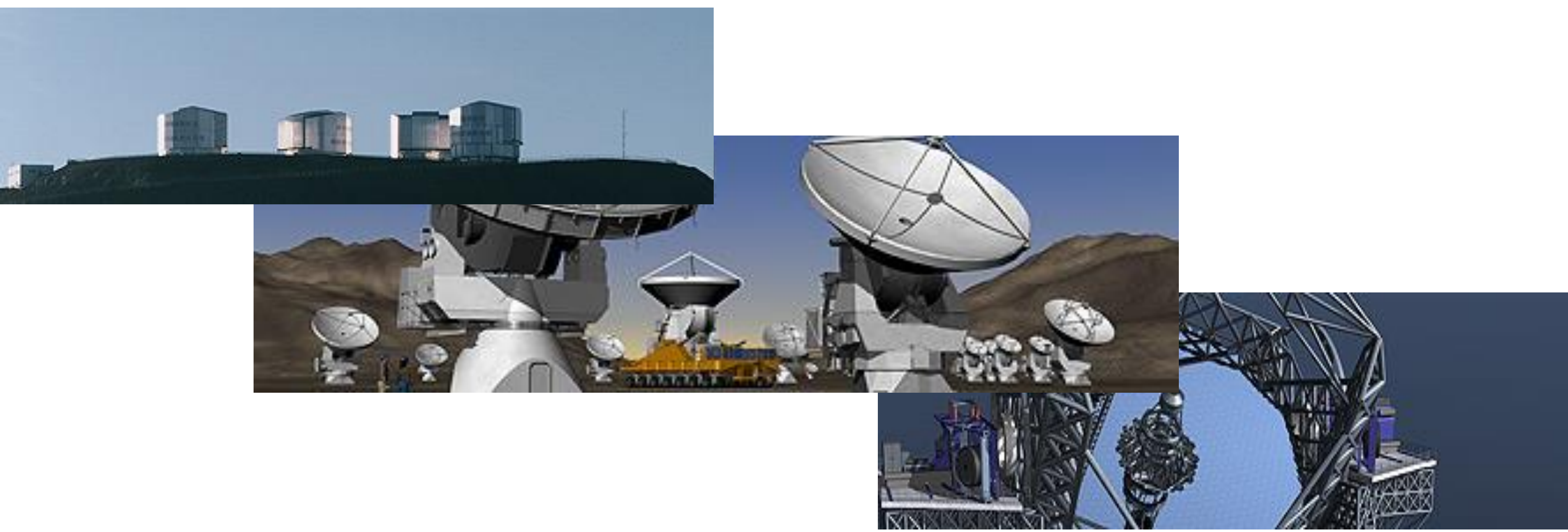
European Southern Observatory

Introduction to the organisation

An evolving organisation

The beginning...			Building up expertise...	Among world leaders	
1954	1962	1976	1989	1998	present
ESO Declaration	ESO Convention	3.6-m Telescope	New Technology Telescope	Very Large Telescope	ALMA E-ELT ->

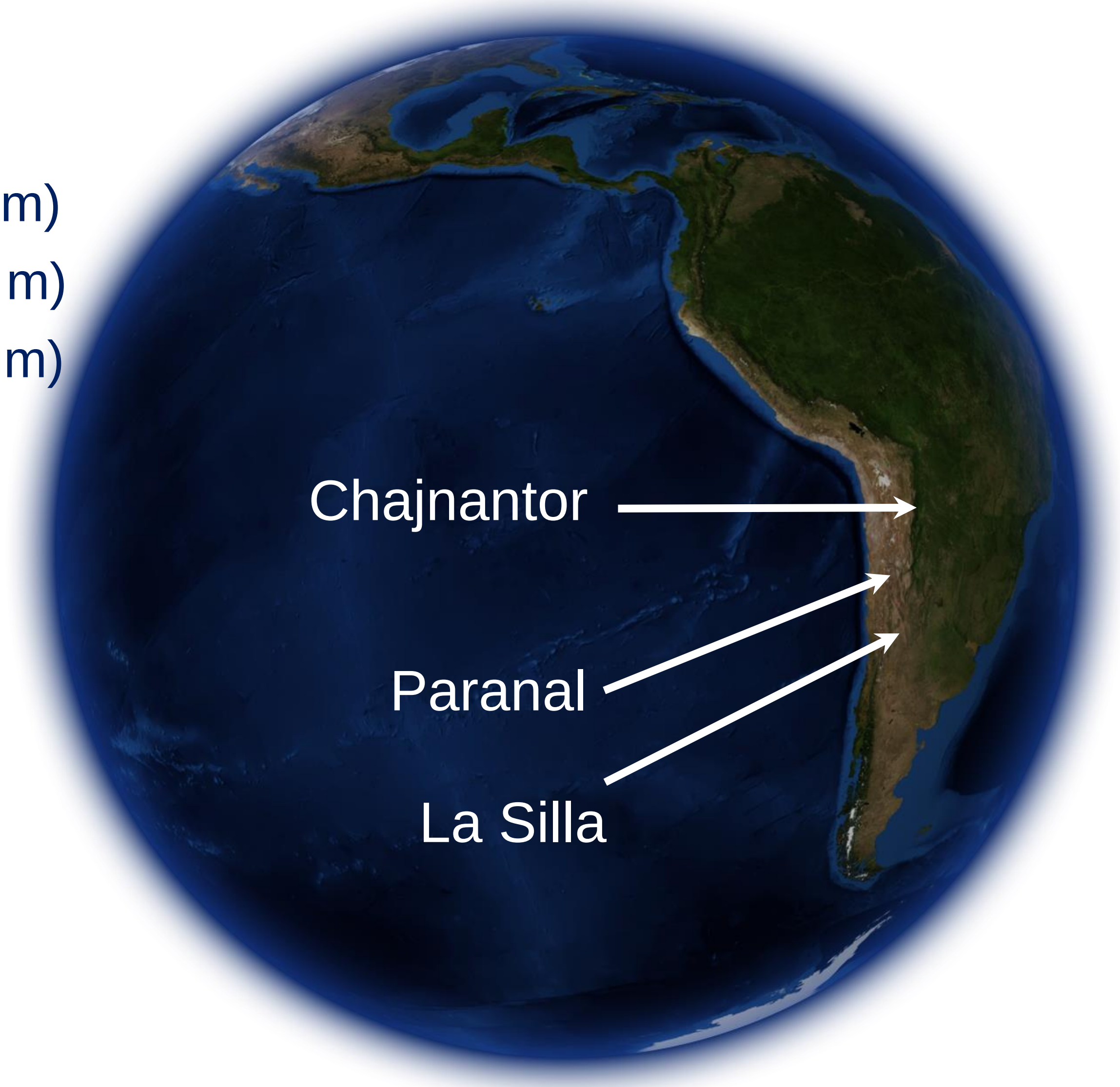


ESO today

- 16 member states
- Collaborations with Chile, US, East Asia, Canada
- ~ 680 staff at 5 main sites
  - Garching headquarters
  - Cerro Paranal Observatory(VLT)
  - Chajnantor (ALMA)
  - Vitacura (Santiago office)
  - La Silla Observatory (original site)

ESO's observatory sites in Chile

- Paranal (2600 m)
- La Silla (2400 m)
- Chajnantor (5000 m)

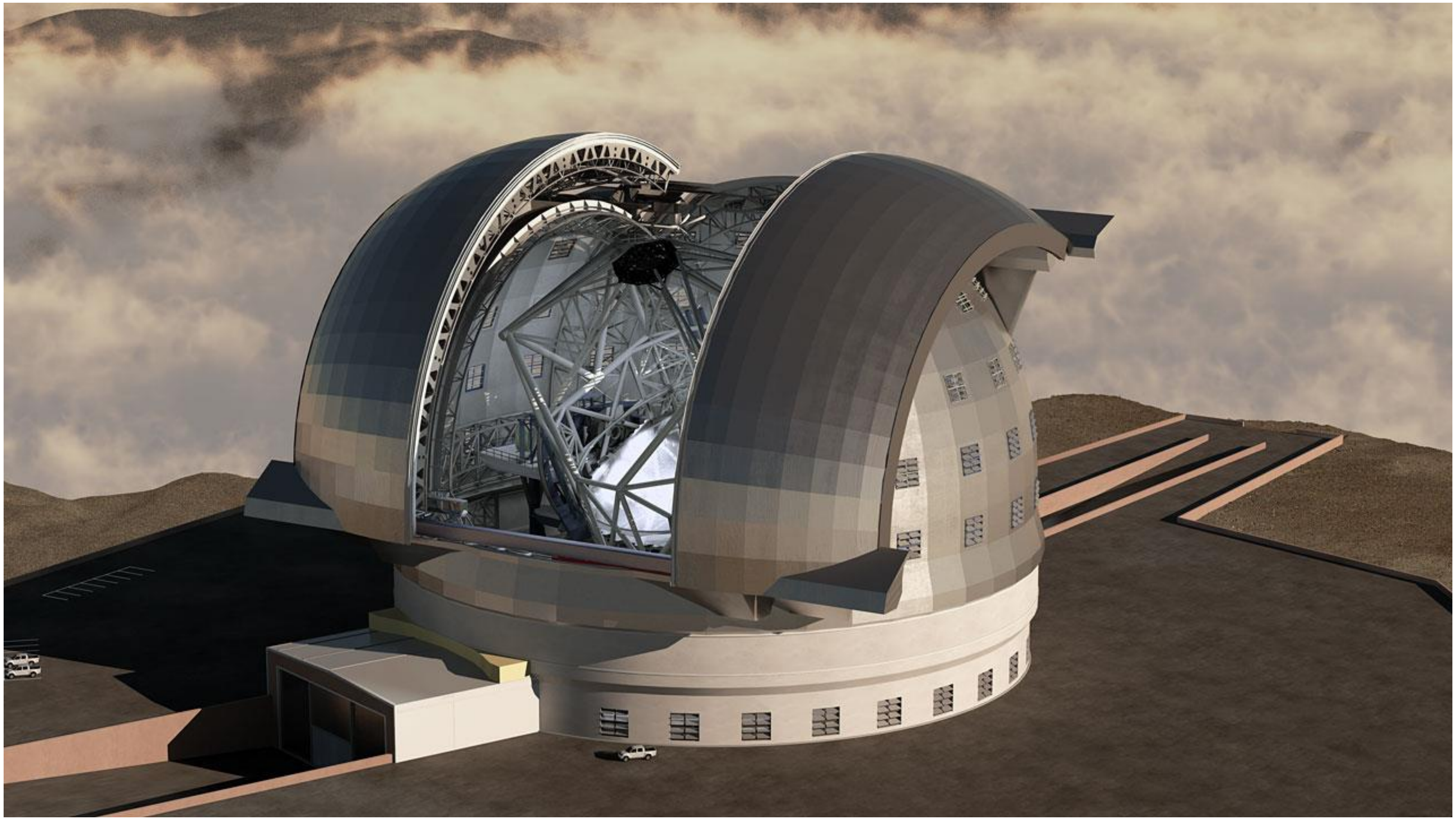


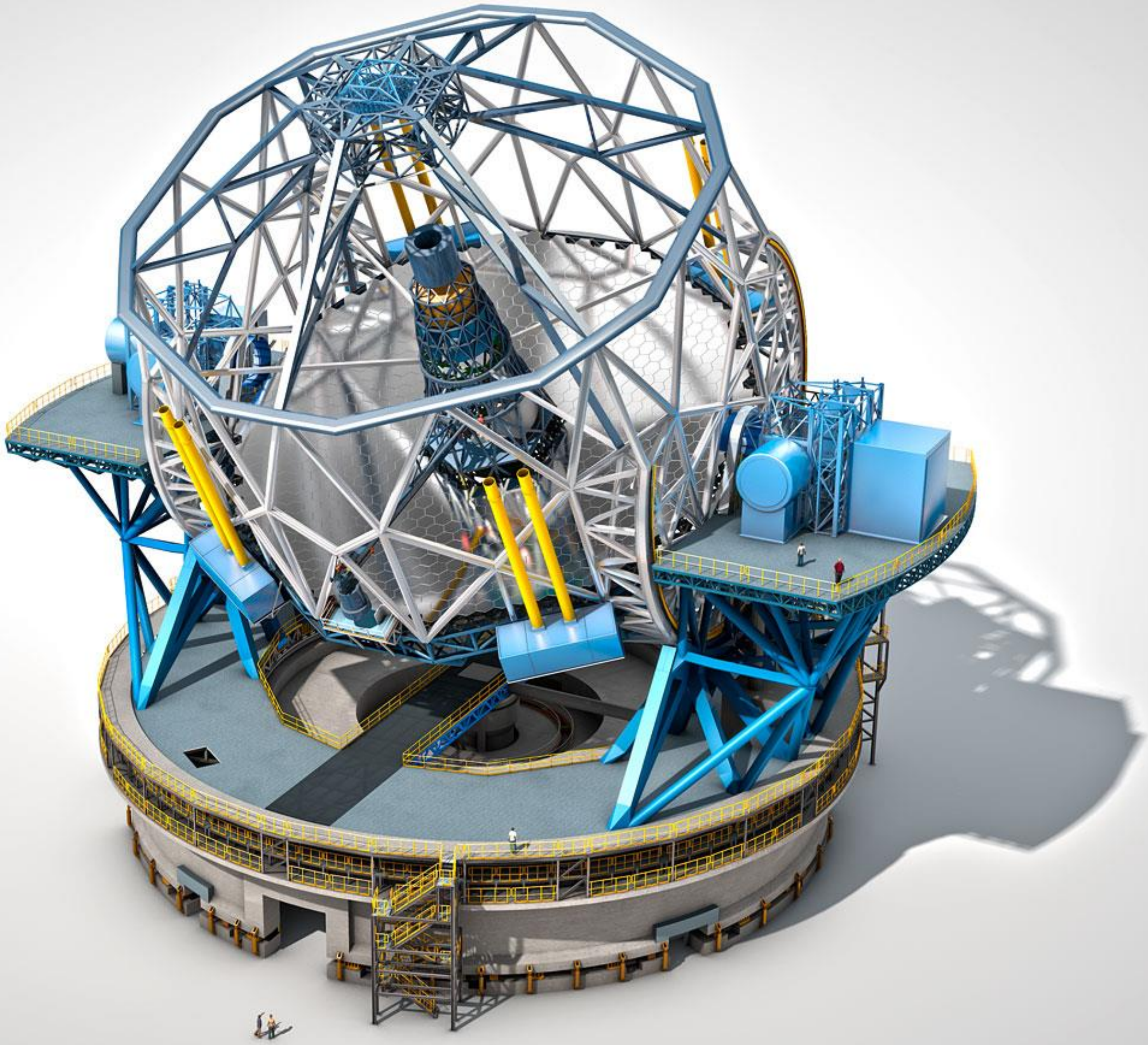
Paranal and the ESO Very Large Telescope

About 60 000 litres of water are consumed at Paranal each day, with two delivery trucks making the daily trip from Antofagasta.

This is Cerro Chajnantor, at 5000-m altitude in the Atacama Desert.

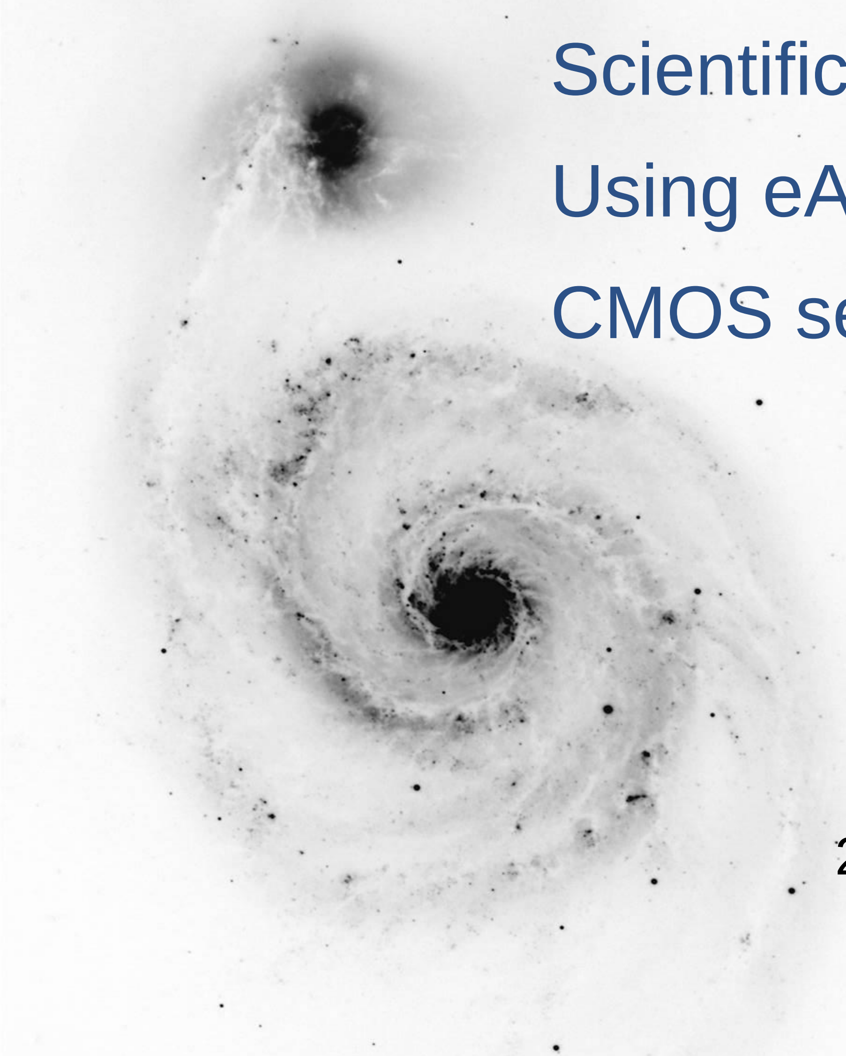
European Extremely Large Telescope

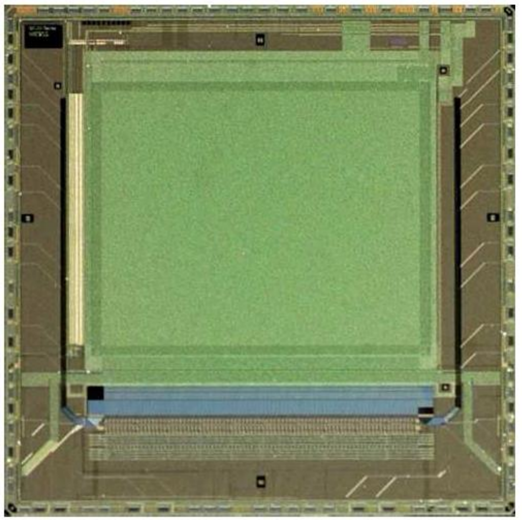





Cerro Armazones
Cerro Paranal

CERN EIROforum CMOS workshop





Scientific Imaging Using eAPD hybrid CMOS sensors

Simon Tulloch

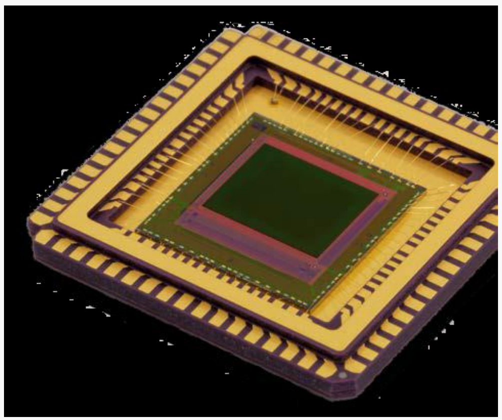
ESO

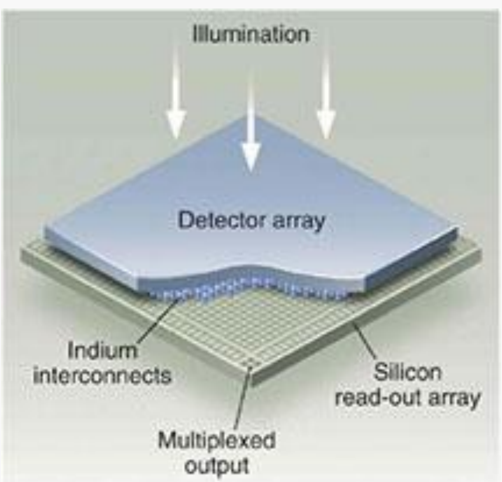
25/26 June 2018

The Saphira from Leonardo

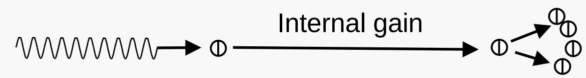
Currently being used for high-speed wavefront sensing at ESO. Potential science applications also.

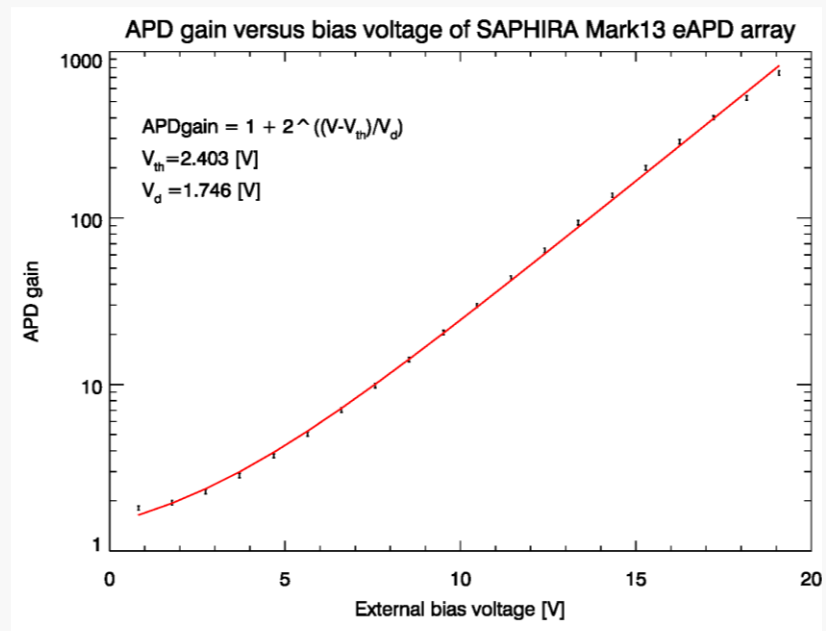
Saphira, 320 x 256 x 24µm pixels





Larger versions are being developed (1k x 1k x 15µm).





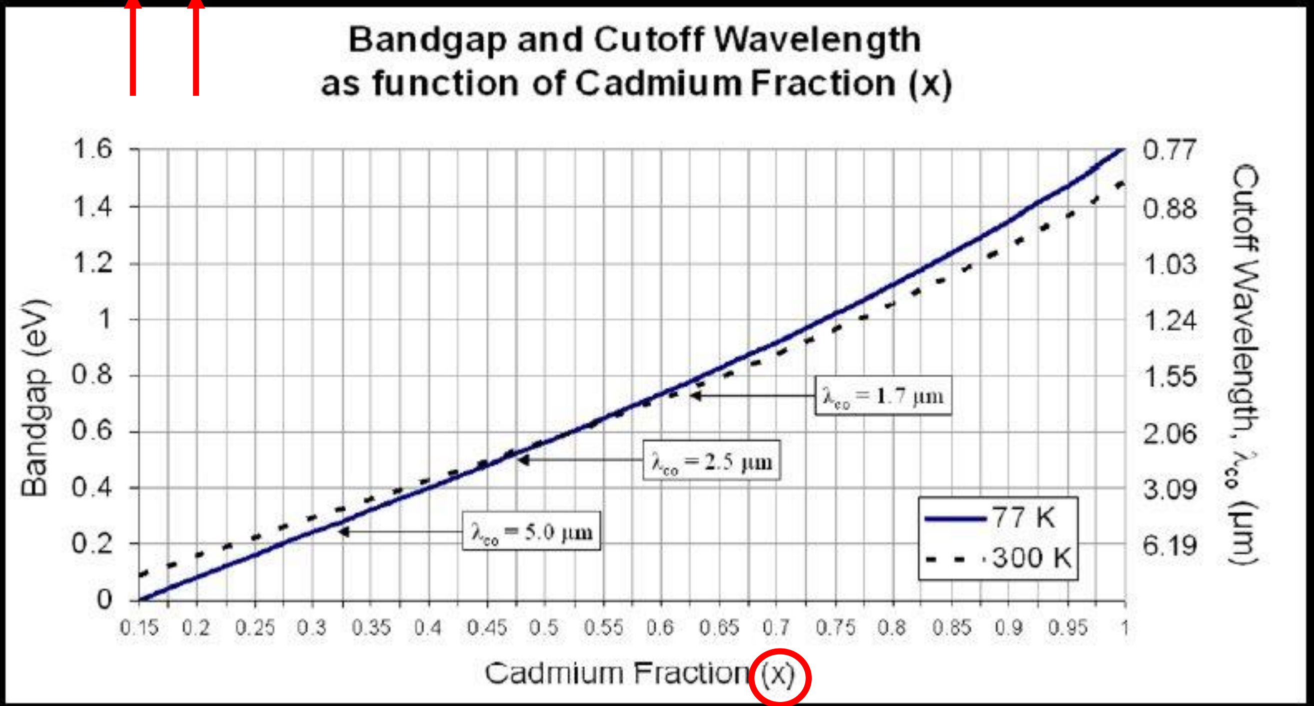
High gains possible with modest bias voltages

Mercury Cadmium Tellurium

Also known as HgCdTe or "MCT". From visible to Mid-IR sensitivity.

Tunable Wavelength: Valuable property of HgCdTe

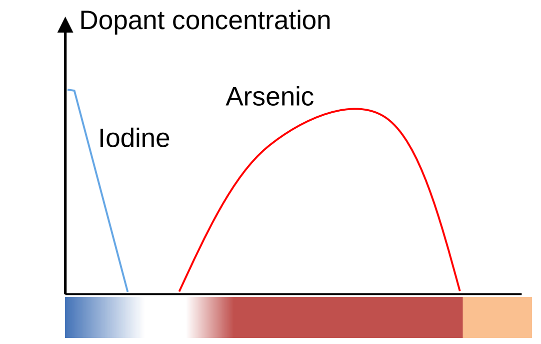
$Hg_{1-x}Cd_xTe$ Modify ratio of Mercury and Cadmium to "tune" the bandgap energy



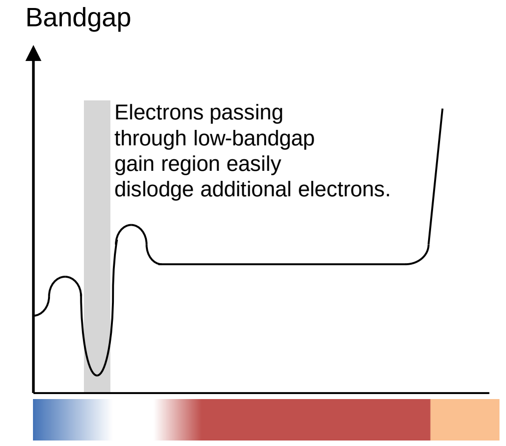
$$E_g = -0.302 + 1.93x - 0.81x^2 + 0.832x^3 + 5.35 \times 10^{-4} T(1-2x)$$

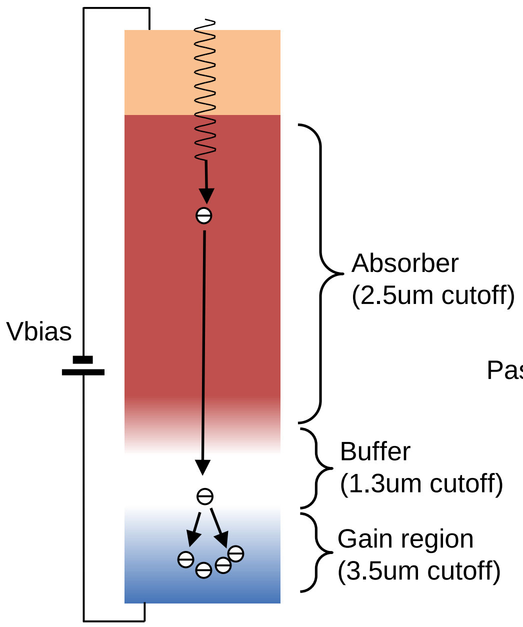
G. L. Hansen, J. L. Schmidt, T. N. Casselman, J. Appl. Phys. 53(10), 1982, p. 7099

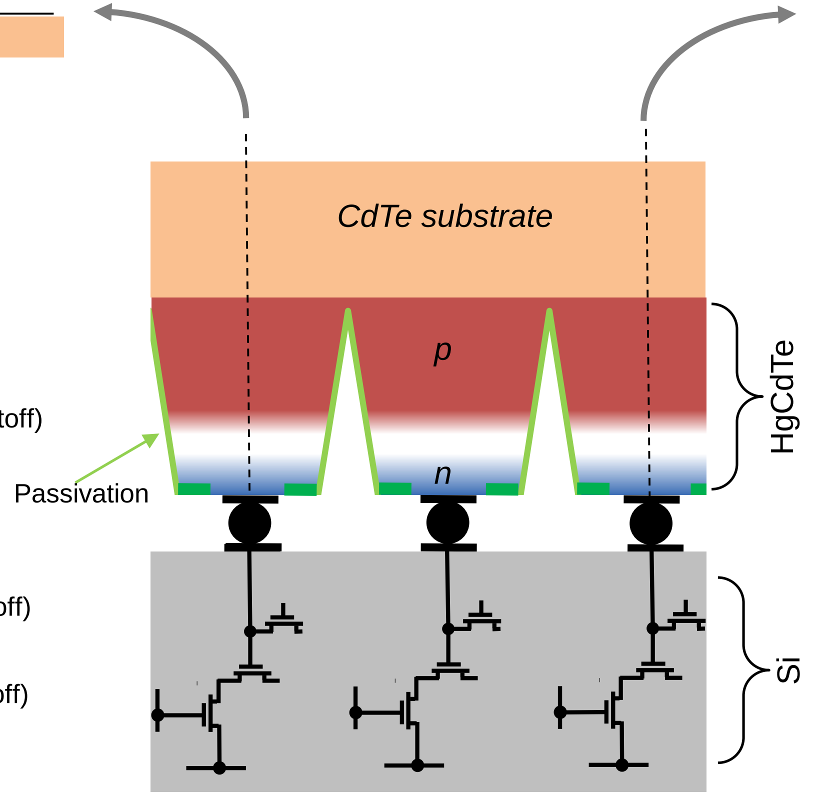
In-pixel charge amplification



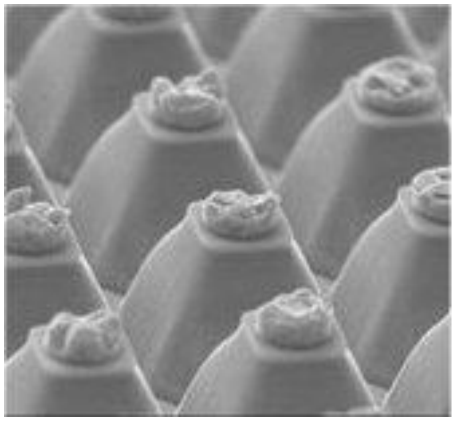
Requires "Bandgap engineering". The cutoff wavelength of the HgCdTe material is modulated throughout the depth of the sensor.



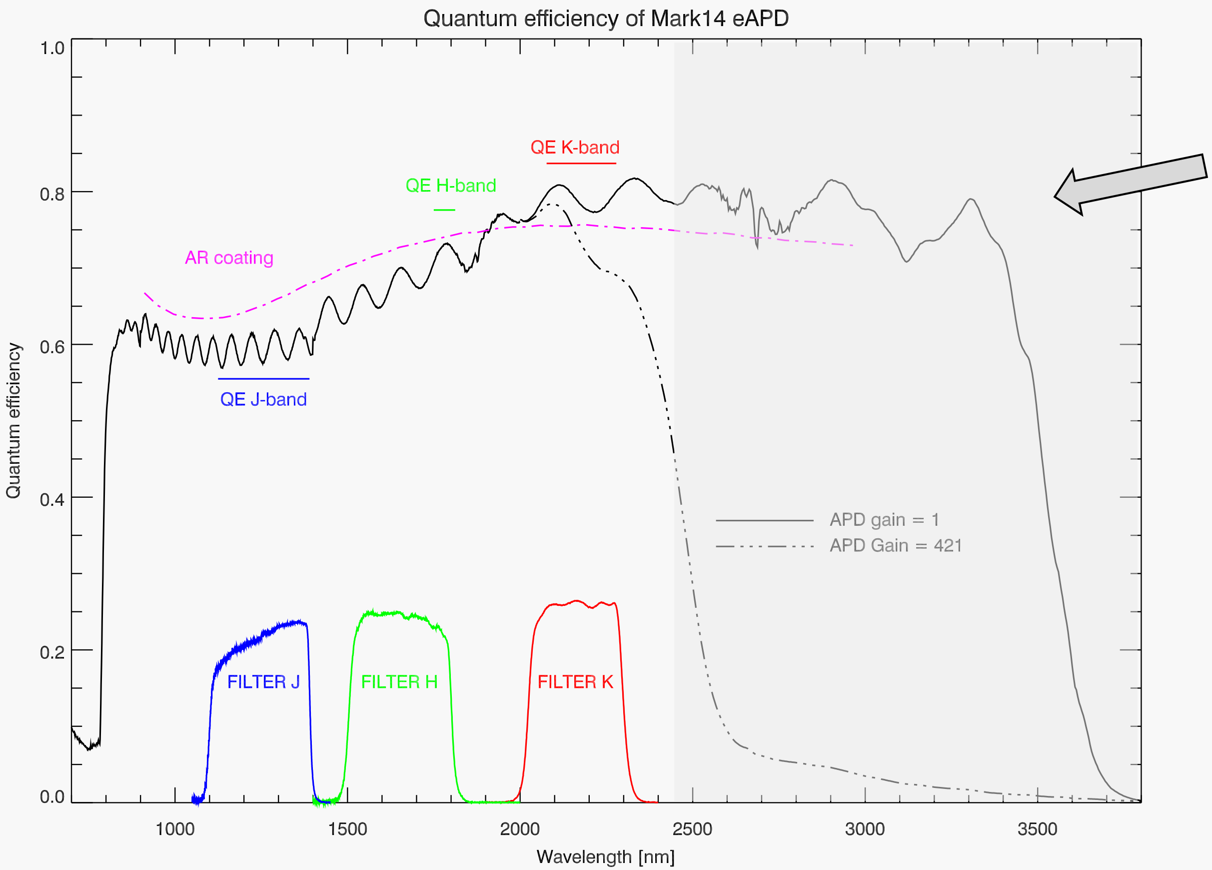




Mesa structures prevent crosstalk between pixels



Quantum efficiency



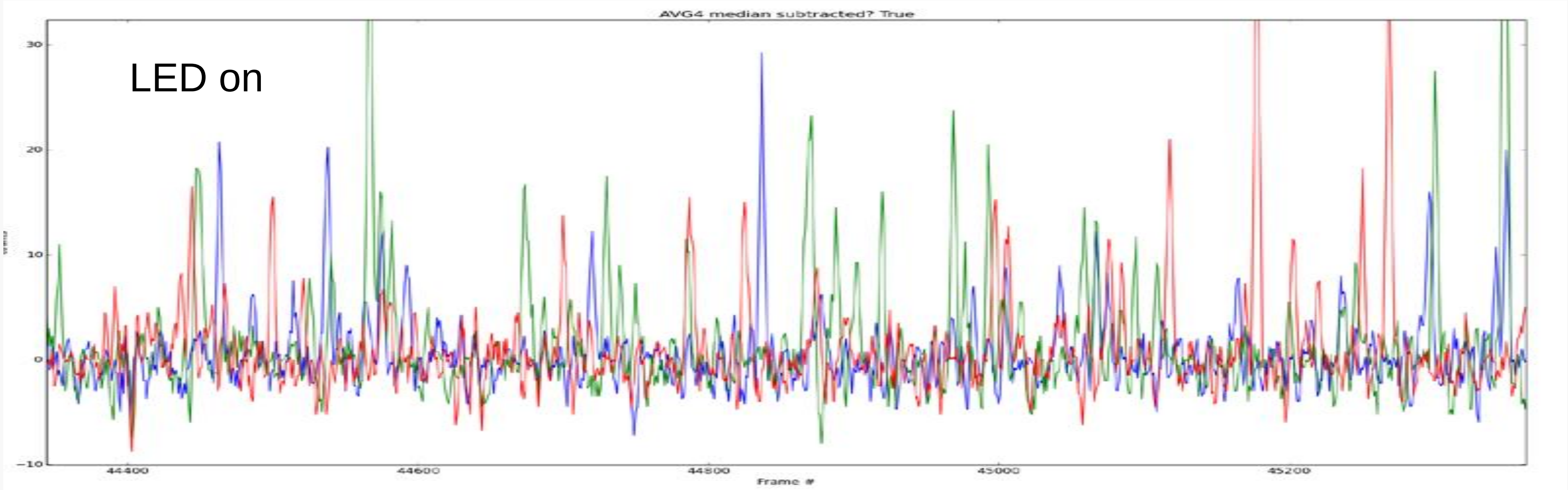
At APD gain=1, photons are absorbed within the multiplication layer itself. response extends to 3.5um.

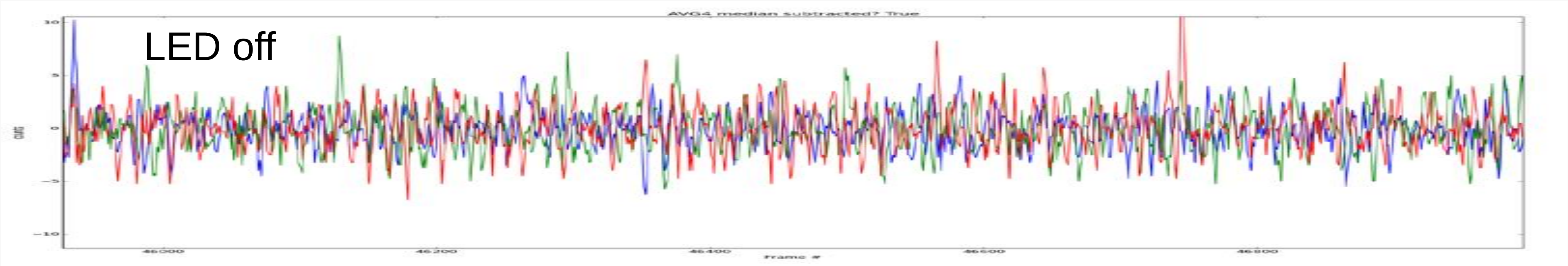
When gain is applied the photoelectrons produced in this region will experience a variable gain depending on the depth at which they are created.

Important to block photons beyond 2.5um with an external filter.

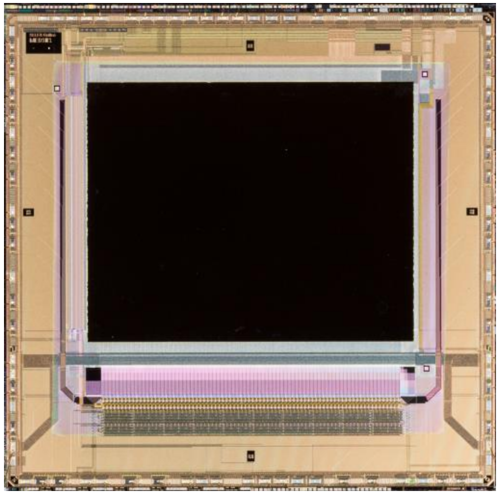
Photon counting demonstrated

Values of 3 pixels under weak illumination plotted as a function of frame number (read-reset-read mode)

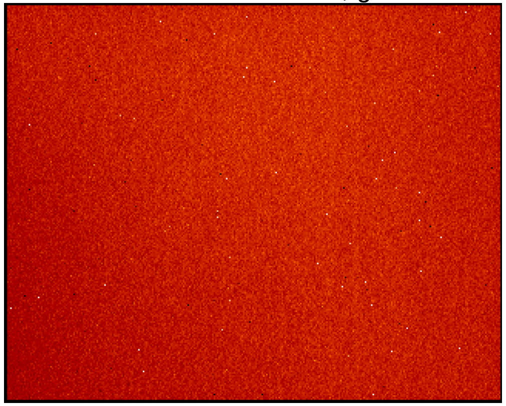




Saphira Characteristics



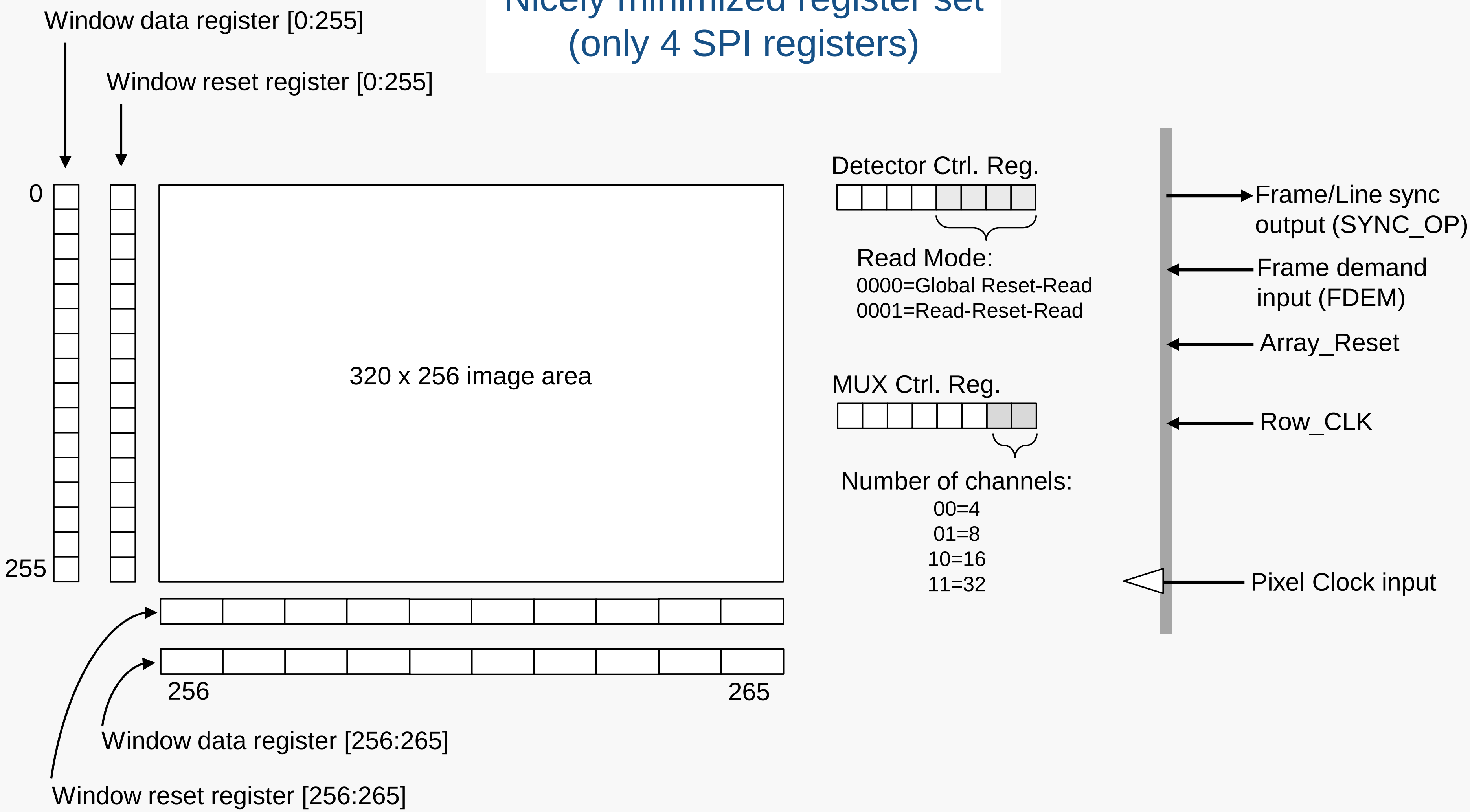
H-band flatfield. 90Kelvin, gain=102



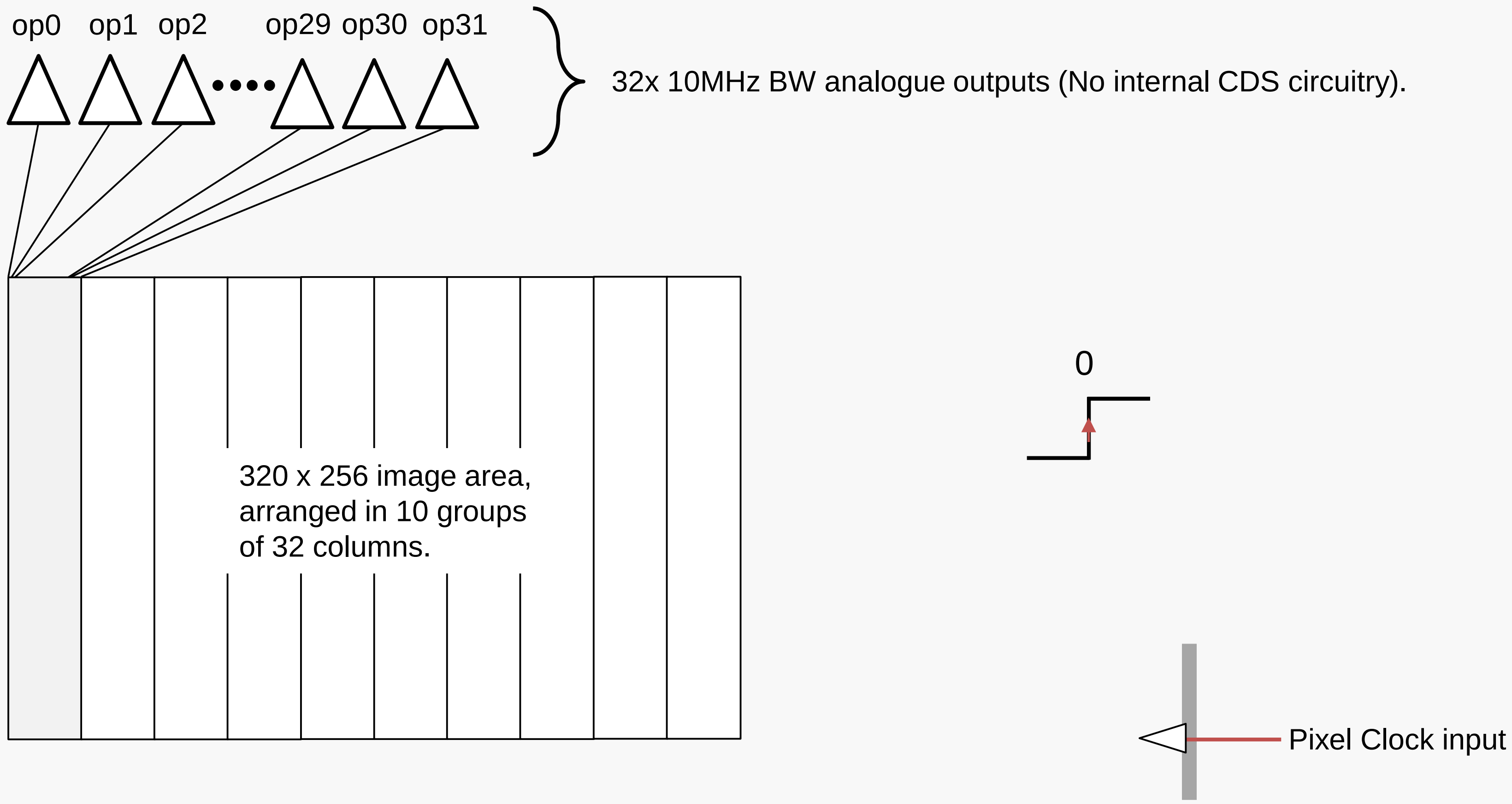
- Silicon : HgCdTe Hybrid sensor
- Metal Organic Vapor Phase Epitaxy
- Avalanche Photodiode Array
- 320 x 256 x 24um pixels
- Internal gain ~600 @20V bias
- BW 1-2.5um
- 10MHz analogue bandwidth
- 4,8,16 or 32 analogue outputs
- 2kHz frame rate for 128 x 128 window
- Effective read noise < 1e^-
- 3T pixels
- 150mW power at full speed and gain
- Node sensitivity 6.6uV/e
- 175ke full well
- Low glow
- 10^{-3} e pix^{-1} s^{-1} dark current (at low gain)
- Excellent cosmetics even at high gain
- Efficient, highly simplified operation.
- Global and line reset modes.

Key Registers/Pins

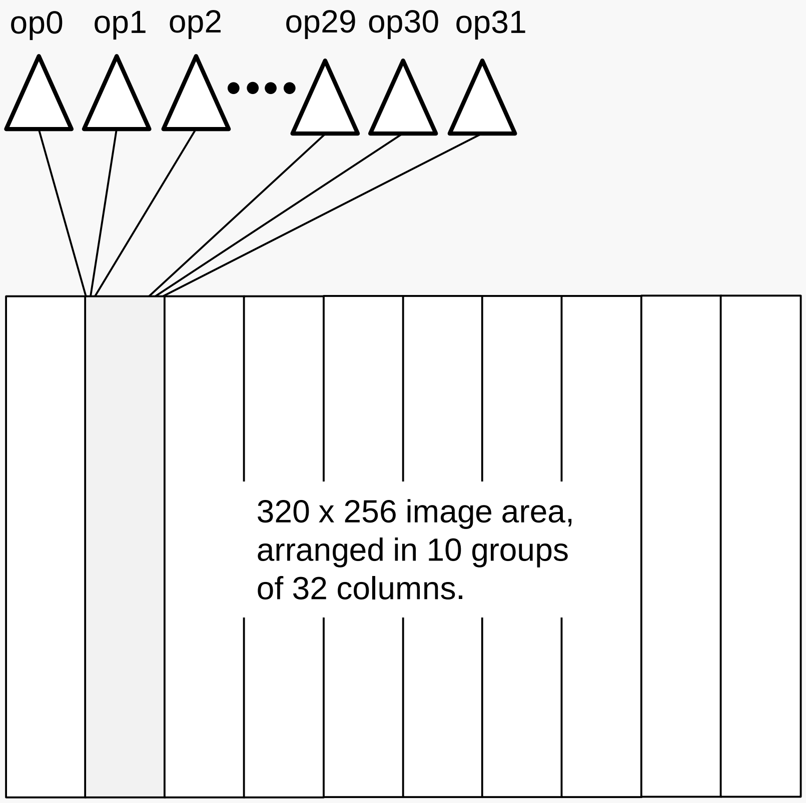
Nicely minimized register set
(only 4 SPI registers)

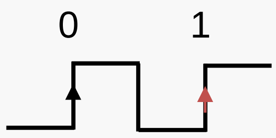


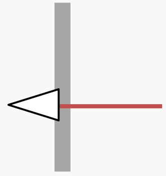
Output Multiplexing



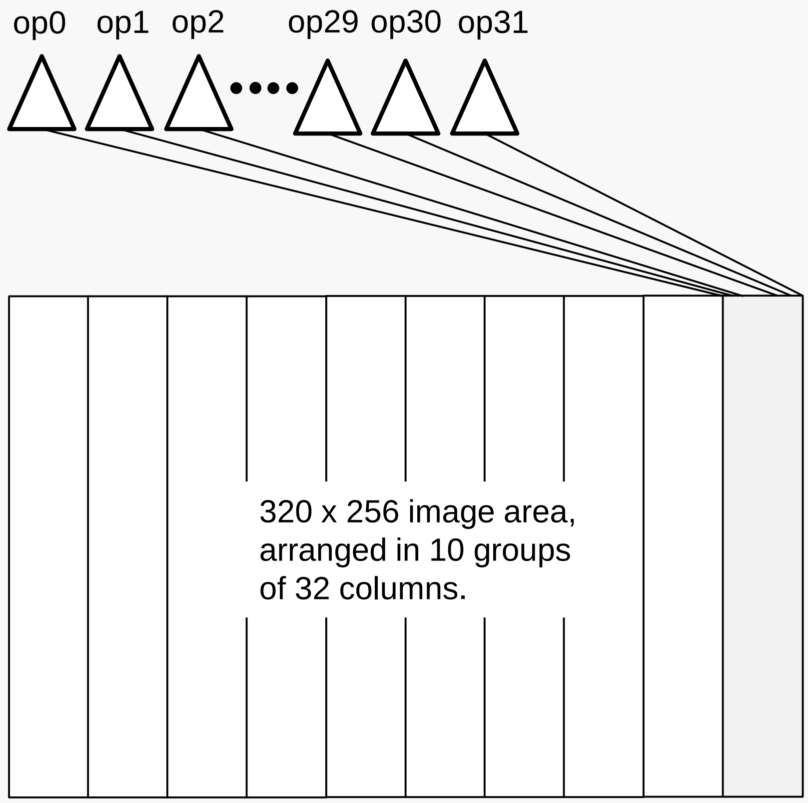
Output Multiplexing



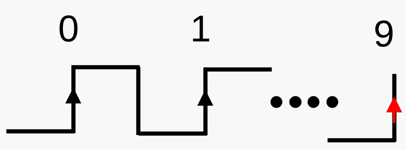


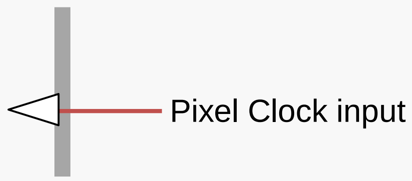


Output Multiplexing



10 clock transitions reads a complete line

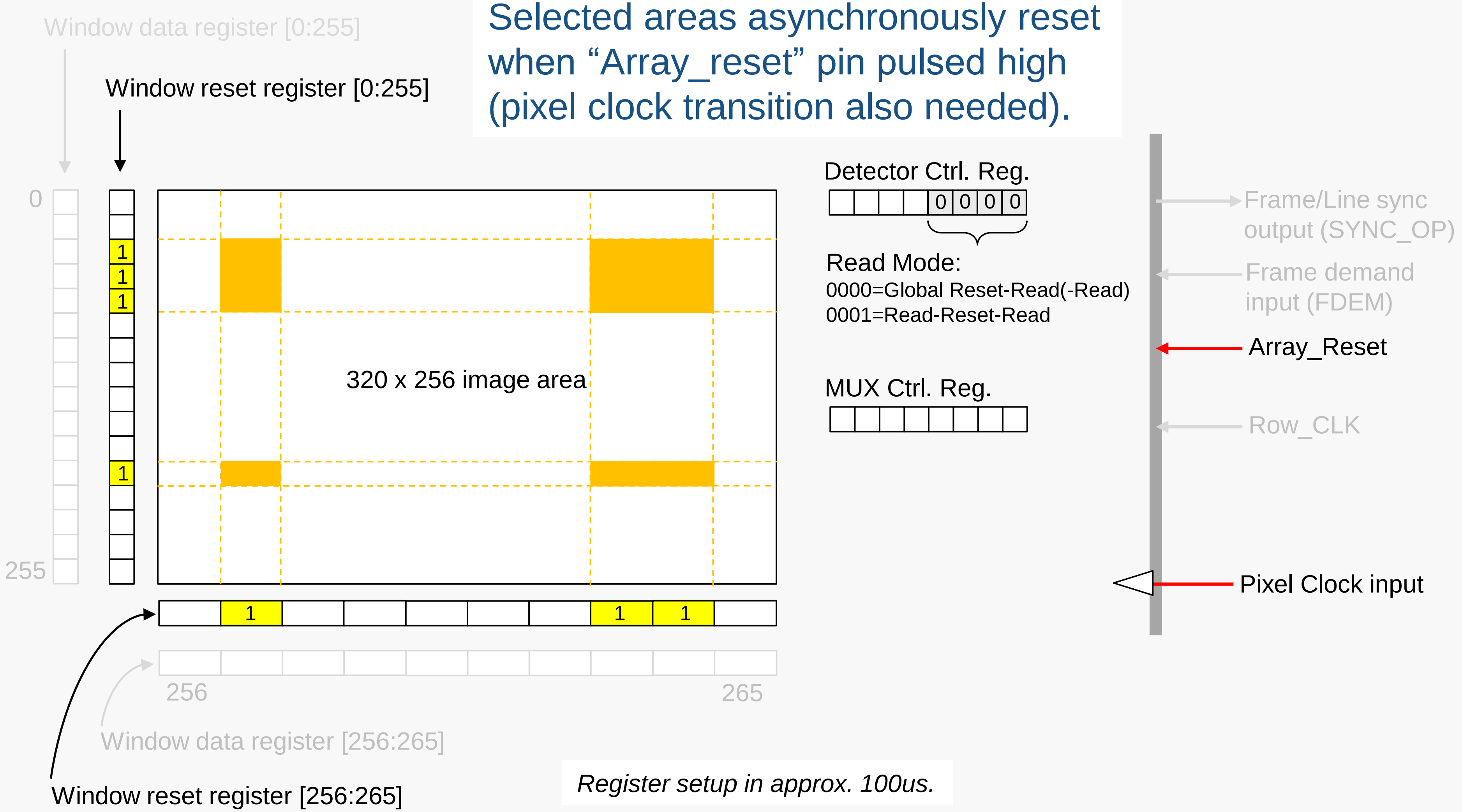




Full multiplex advantage for objects falling entirely within one column group: up to 20kHz frame rate.

Window reset register

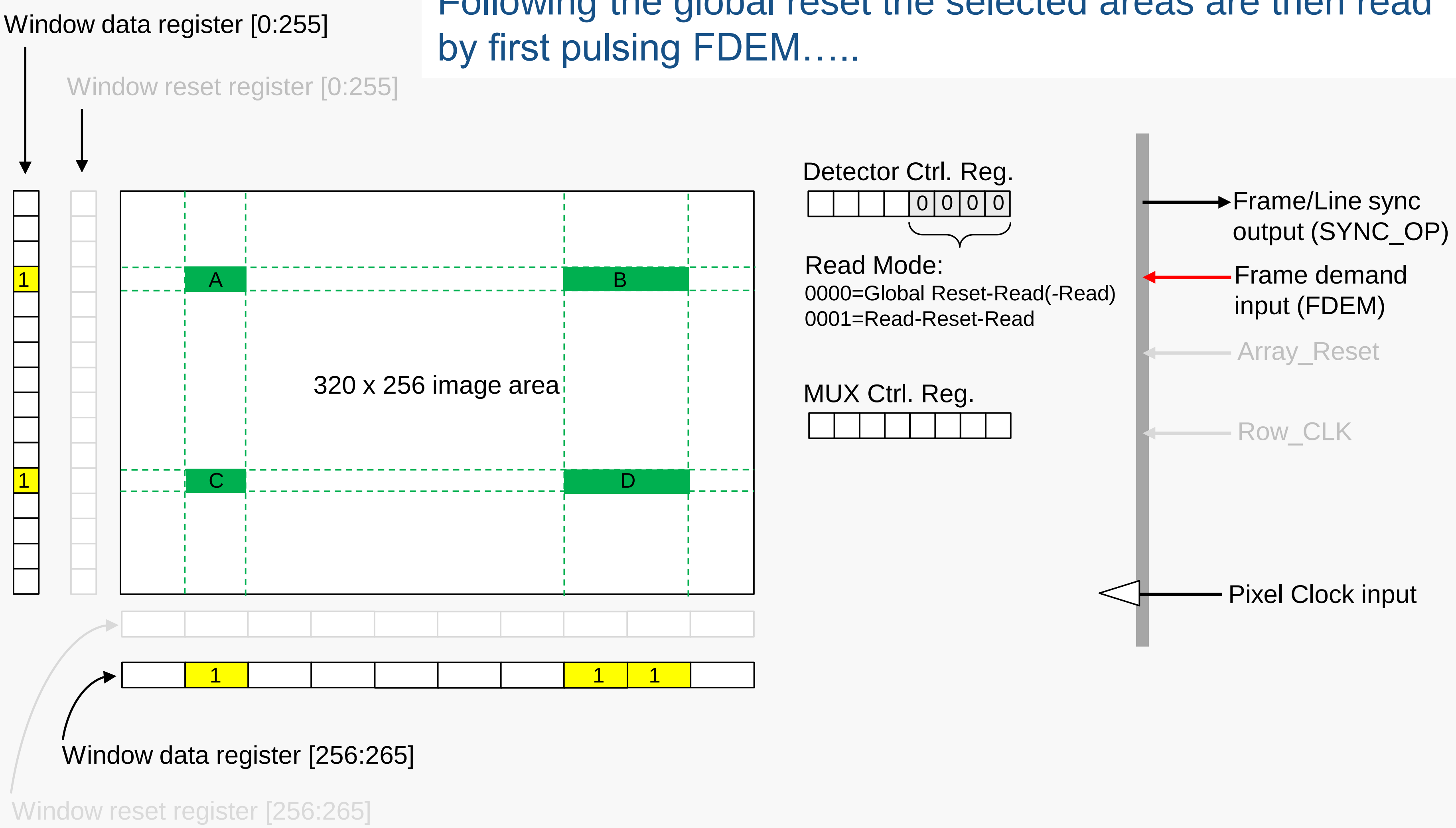
Selected areas asynchronously reset when "Array_reset" pin pulsed high (pixel clock transition also needed).



Register setup in approx. 100us.

Global Reset-Read(-Read-Read…)

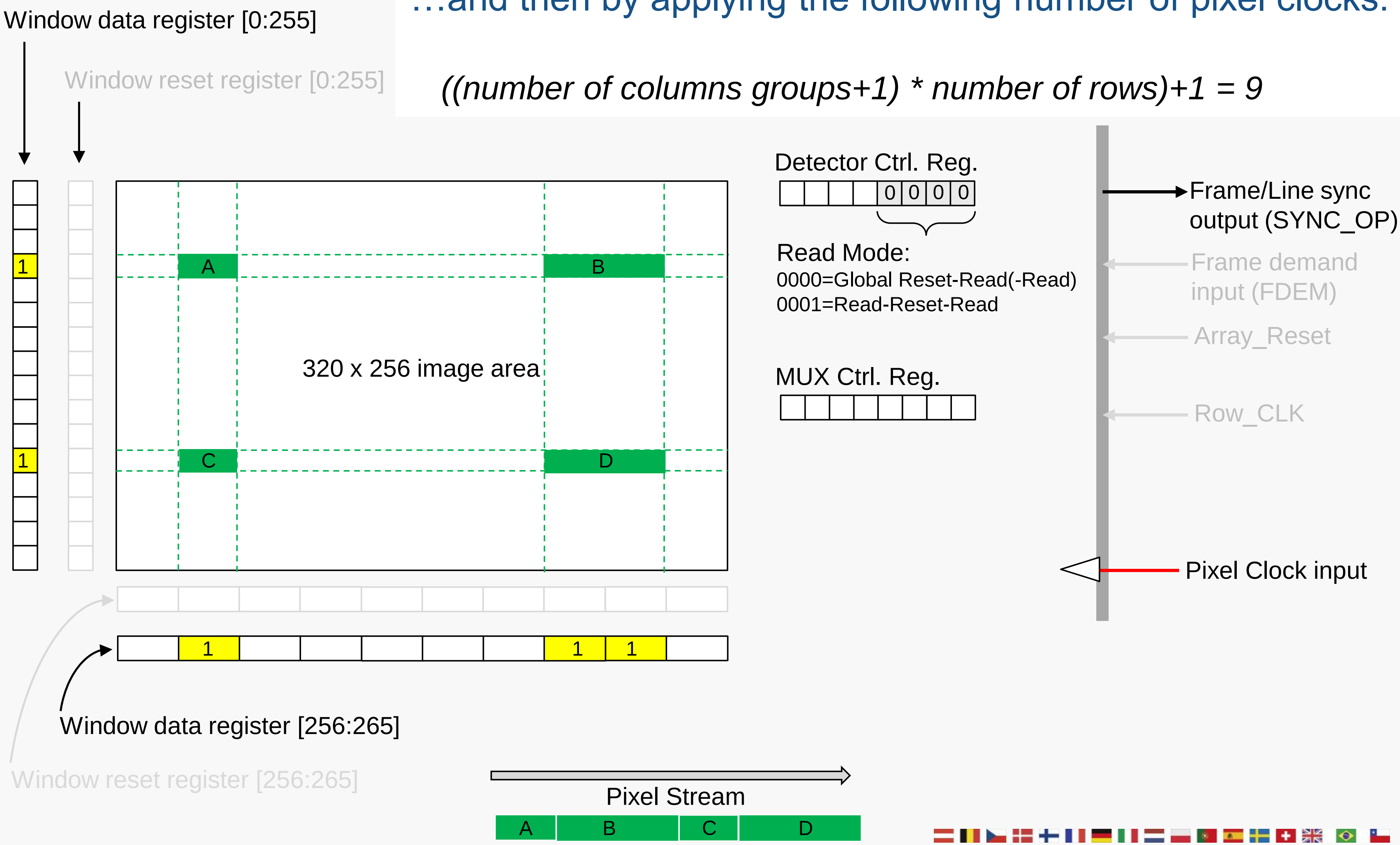
Following the global reset the selected areas are then read by first pulsing FDEM…..



Global Reset-Read(-Read-Read…)

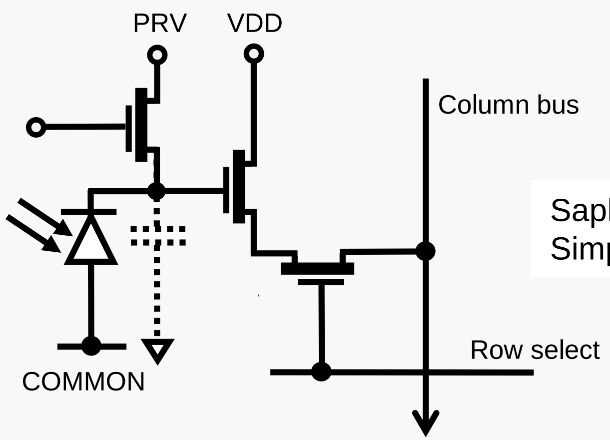
…and then by applying the following number of pixel clocks:

*((number of columns groups+1) * number of rows)+1 = 9*

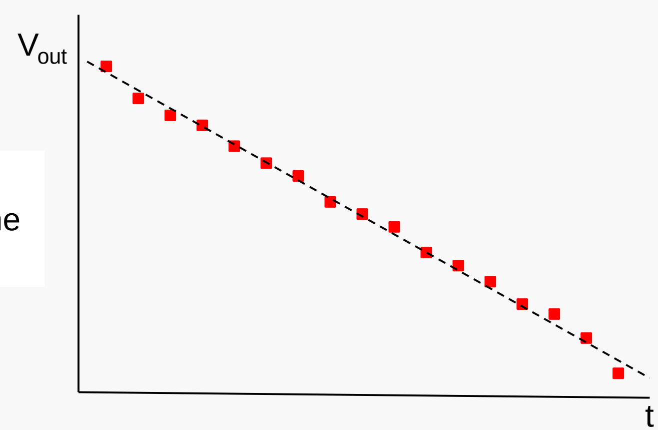


Global Reset-Read(-Read-Read…)

The sequence of FDEM followed by 9 clock transitions can be repeated as many times as necessary for implementation of “sample down the ramp”.

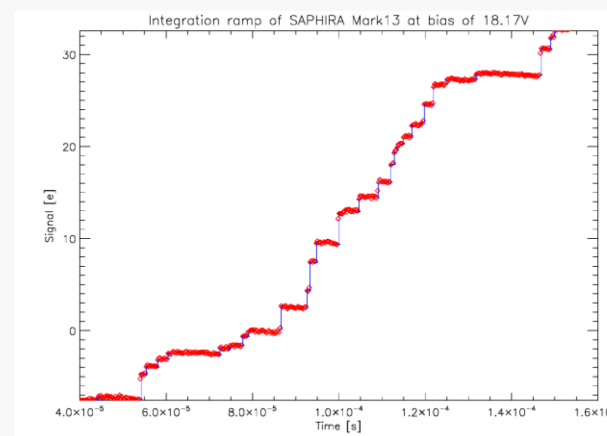


Saphira collects electrons.
Simple 3T unit cell.



Least squares fit to integration ramp done in external FPGA.

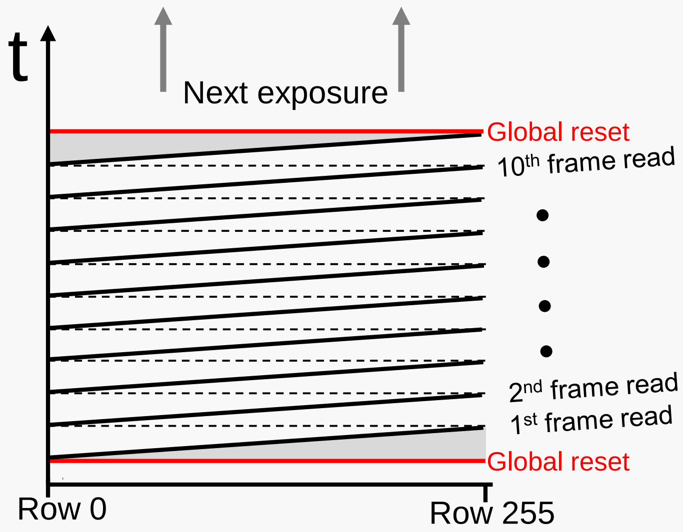
More interestingly, with the internal gain set high, the integration ramp becomes an integration “staircase”. Individual photon events become visible.

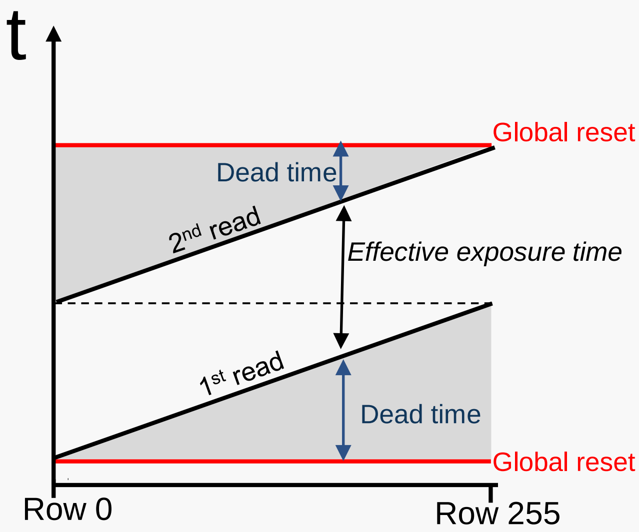


Global Reset-Read(-Read) Speed limitation

If exposure time >> read time then only a small amount of signal goes undetected.

If we push the frame rate to the maximum then we just use a single pair of reads during each exposure. In this case 50% of the signal is undetected.

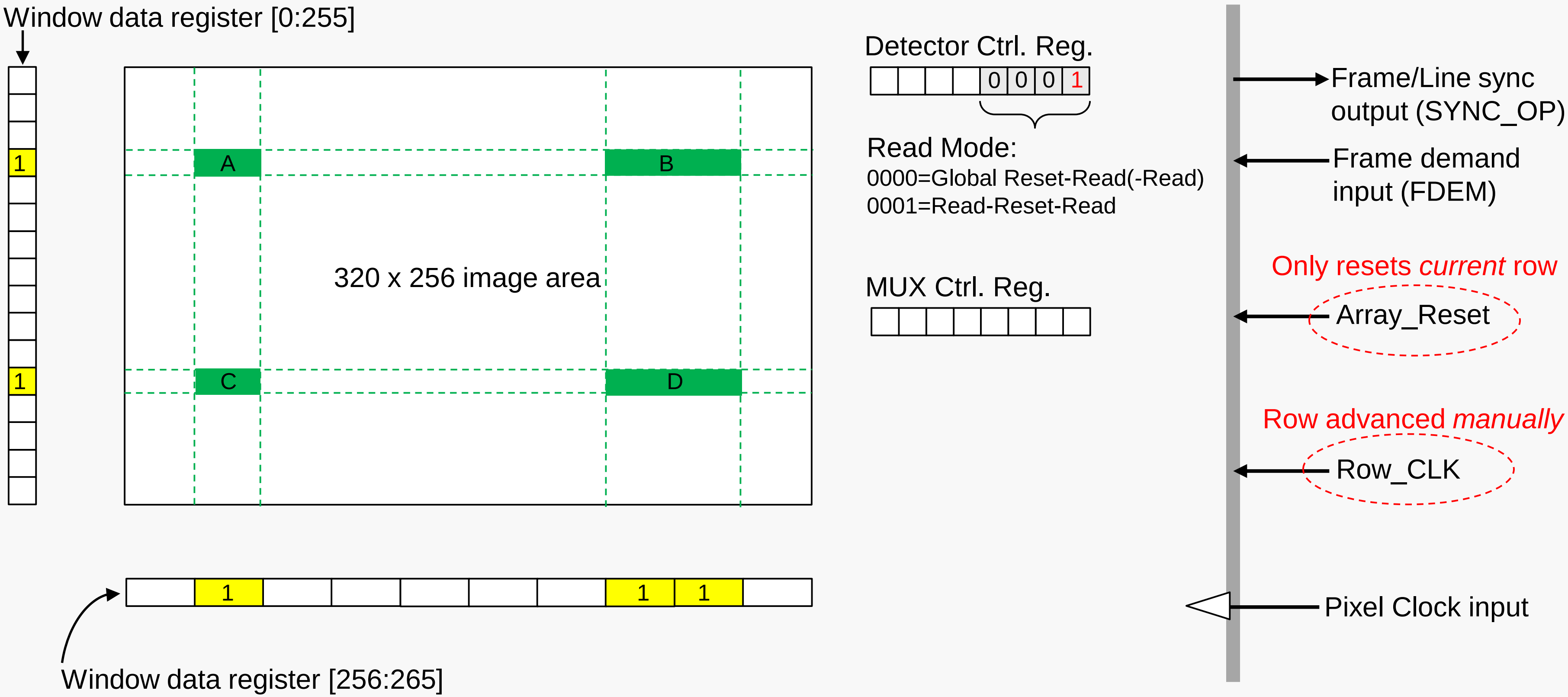




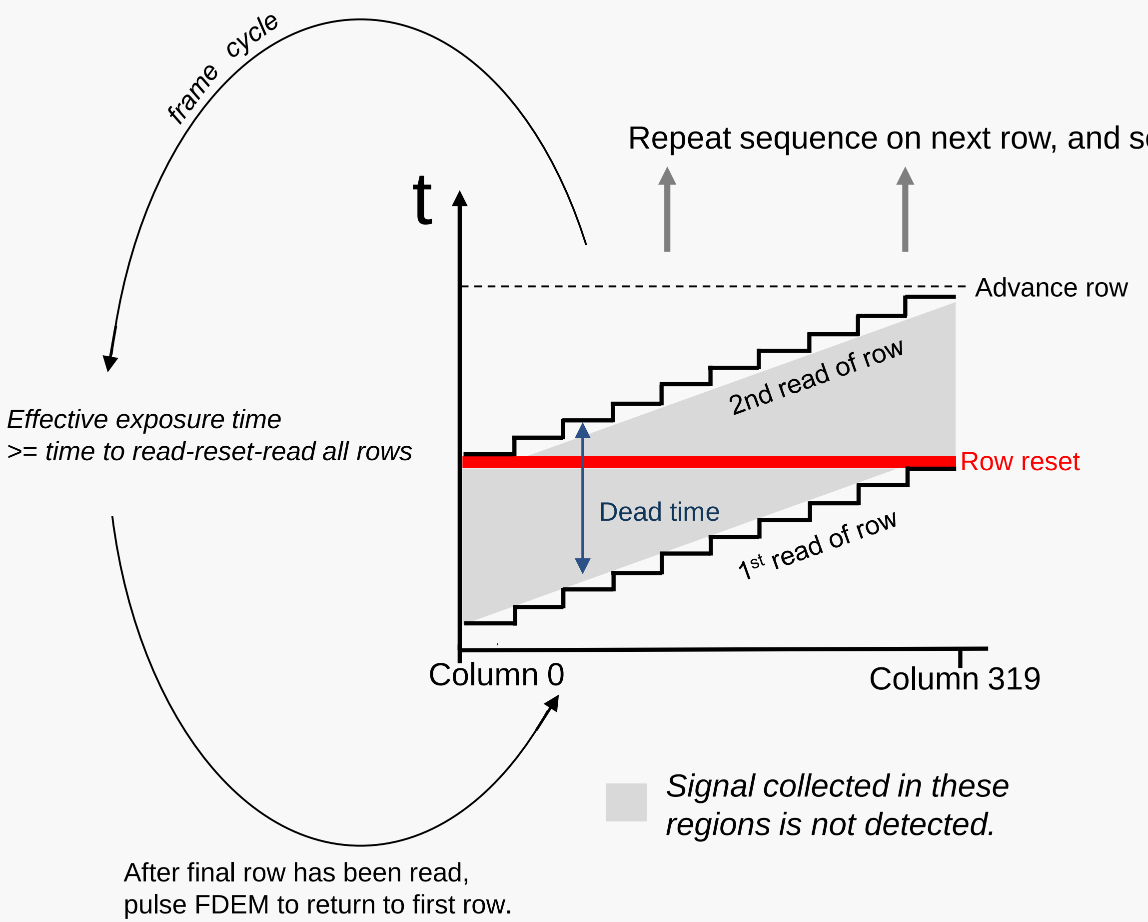
Signal collected in these regions is not detected.

Read-Reset-Read Mode

In this alternative mode, the row advance is under user control and the reset is only applied to the current row. Multiple reads of current row now possible. Maximum frame rate can be achieved with no loss of efficiency.



Read-Reset-Read Mode

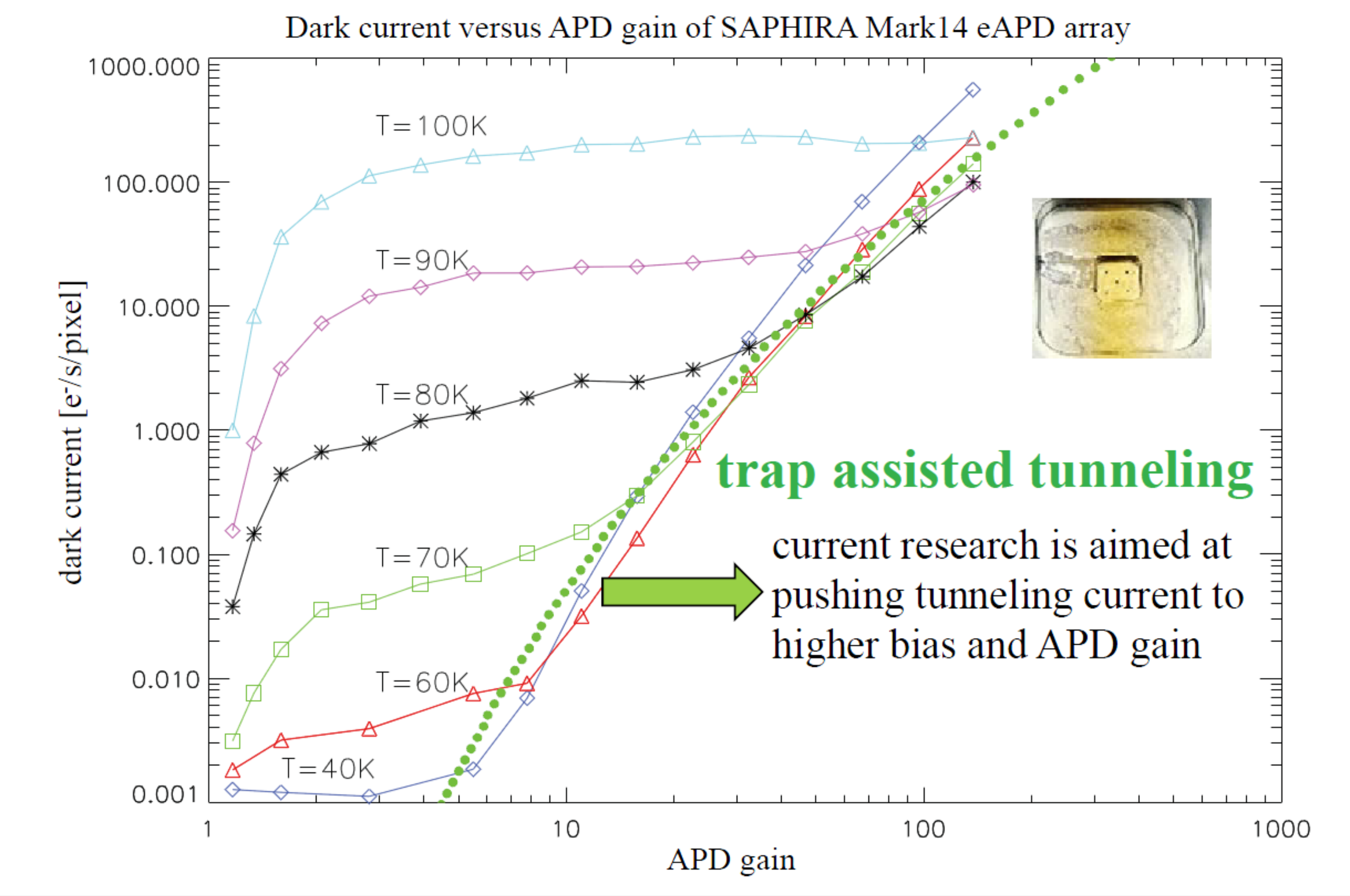


This gives maximum observing efficiency at high frame rates. The "dead time" fraction is now at most =

1/(number of rows in the image)

Dark Current

This is the major barrier for the scientific use of eAPD technology

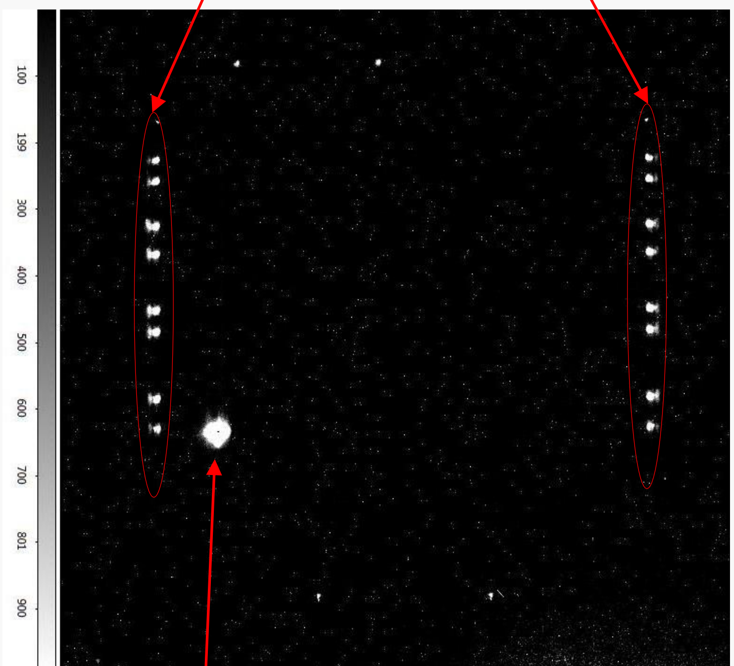


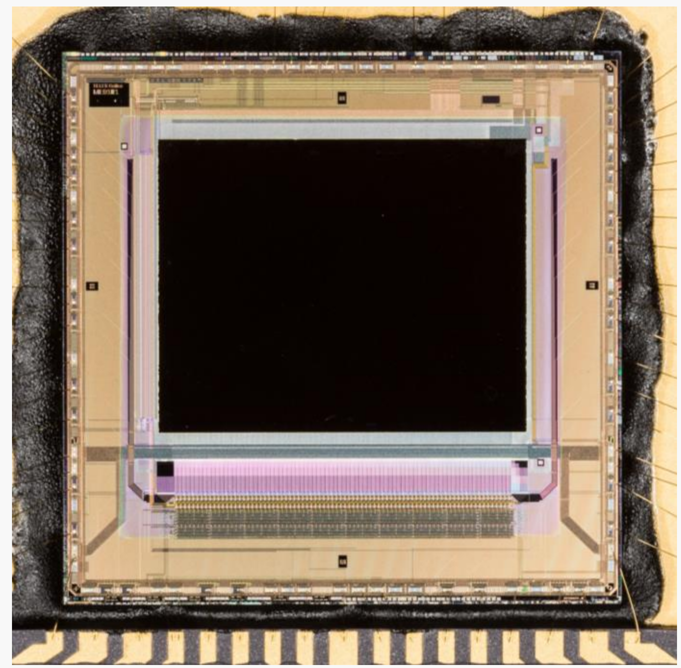
Gert Finger, ESO

Glow

Additional metal shielding will be added on future devices.

Inadequately shielded video buffers





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Unconnected transistor mask error

Future Science device

- Very much dependent on reducing glow and dark current
- NASA funded 3-year program between Leonardo, Selex Galileo and U.of Hawaii
- 1k x 1k x 15um device for low-background space-based astronomy
- 3.3V logic compatible, 3-side buttable
- Reference pixels for common mode noise rejection.

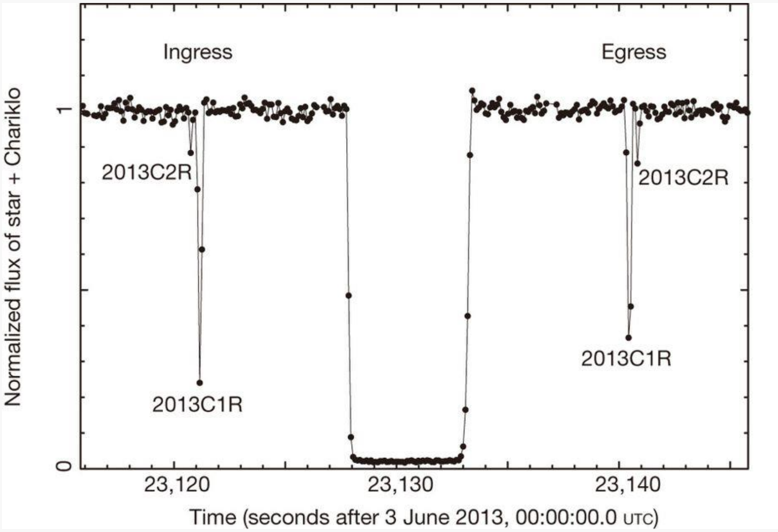
Ground based applications also, in regimes where we are detector noise limited:

High resolution spectroscopy

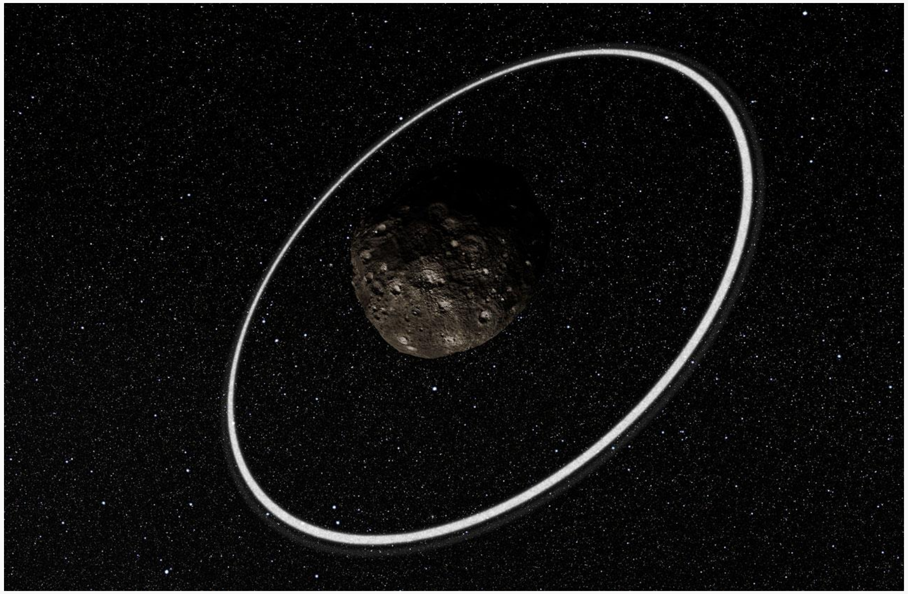
High Time Resolution Astrophysics

Science cases: rapid photon starved events

Fast occultations



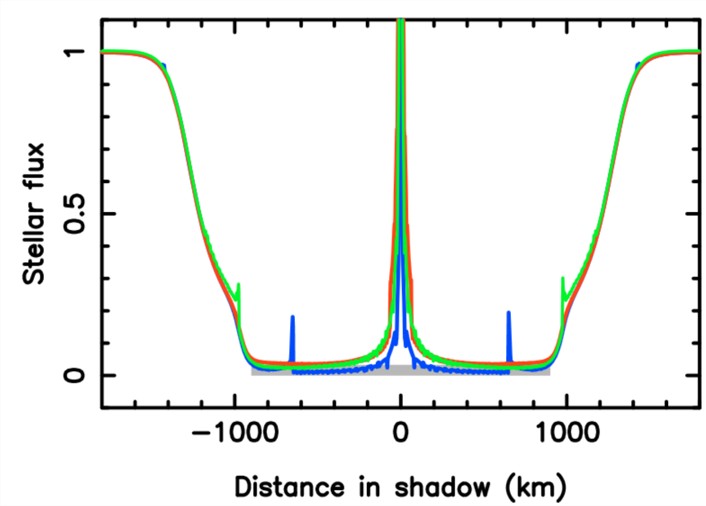
F. Braga-Ribas, Brazil National Observatory

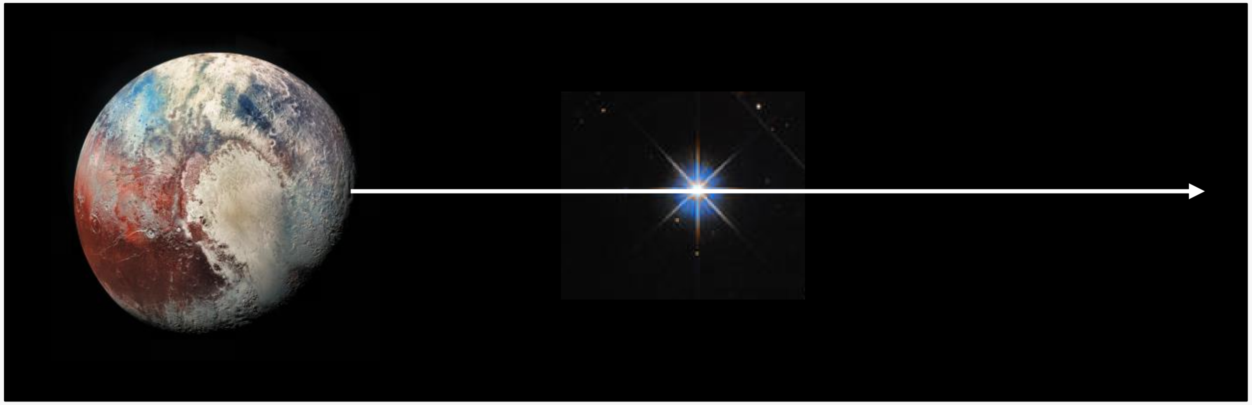


Artists impression of Chariklo asteroid

Science cases: rapid photon starved events

Fast occultations: detection of planetary atmospheres





Transit of Pluto

Science cases: rapid photon starved events

Compact binaries : millisecond flickering

Jets from accreting black holes

Mass transfer onto white dwarf