# Enabling Detector Technologies for a Flagship UVOIR mission

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# UV/Vis detector(s) for a new Flagship Mission

Large telescopes with large FOVs require large detectors *(e.g. 4m f/3 with 30 arc min fov results in a detector size of 10 cm)*

High QE trades directly with telescope area

Spatial resolution must match angular resolution of instrument – *more pixels!*

UV sky is dark, SNR is dominated by detector dark current and/or readout noise.

High dynamic range is needed to broaden science targets and overlap previous mission measurements

# Other desirable attributes

- Long lifetime
- Radiation hardness
- Response stability and uniformity for high SNR observations
- Low out-of-band response
- Low operational complexity *(e.g. high voltage, cyrogenics, vacuum pumps and doors etc.)*
- Reasonable power and mass

# Photon counting

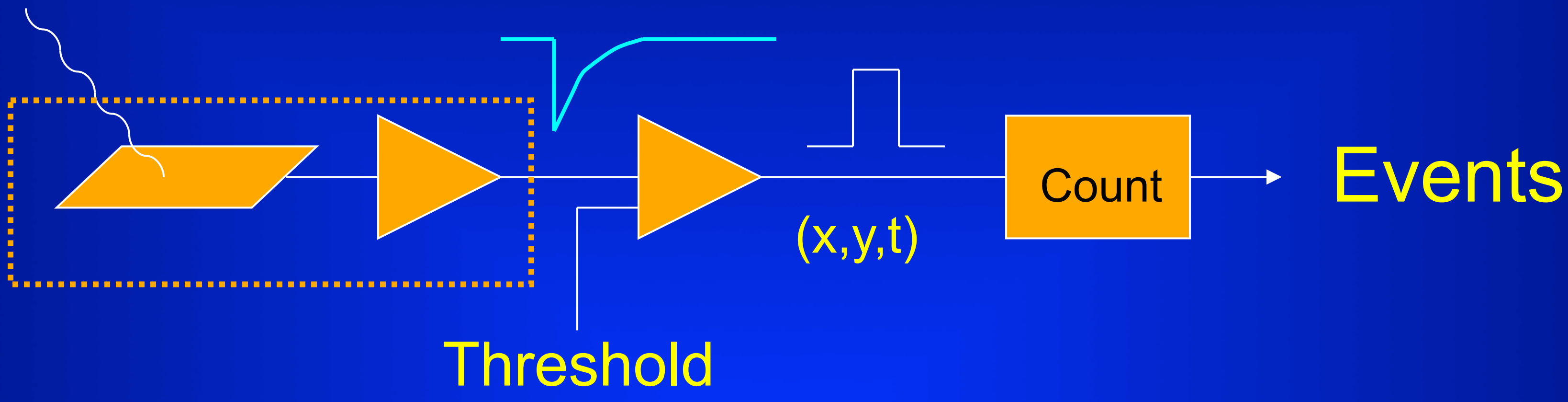
Eliminates readout nose

Better for "photon starved" measurements (spectroscopy, interferometry, fast frame rates, diffuse backgrounds)

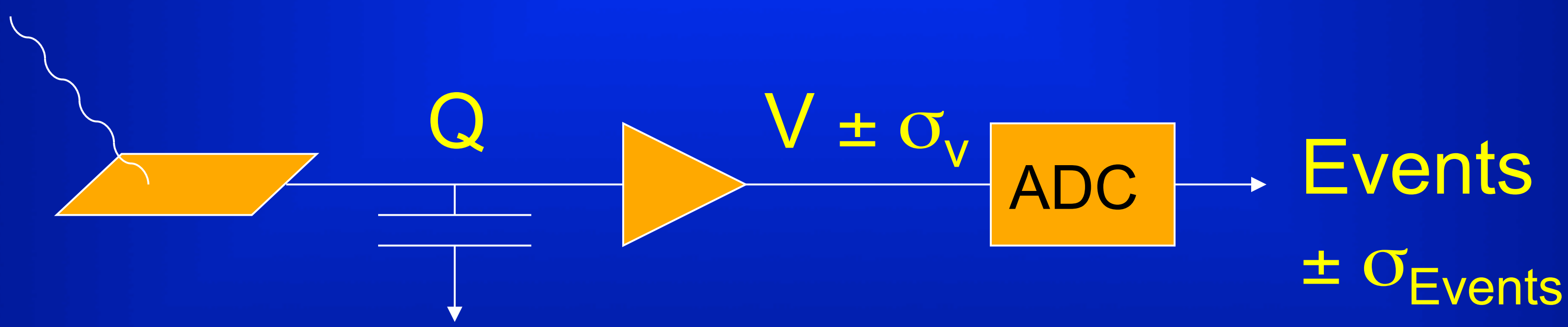
If event time is measured, can relax pointing control requirements if pointing knowledge is retained

Can often improve SNR of measurement, even if QE is lower

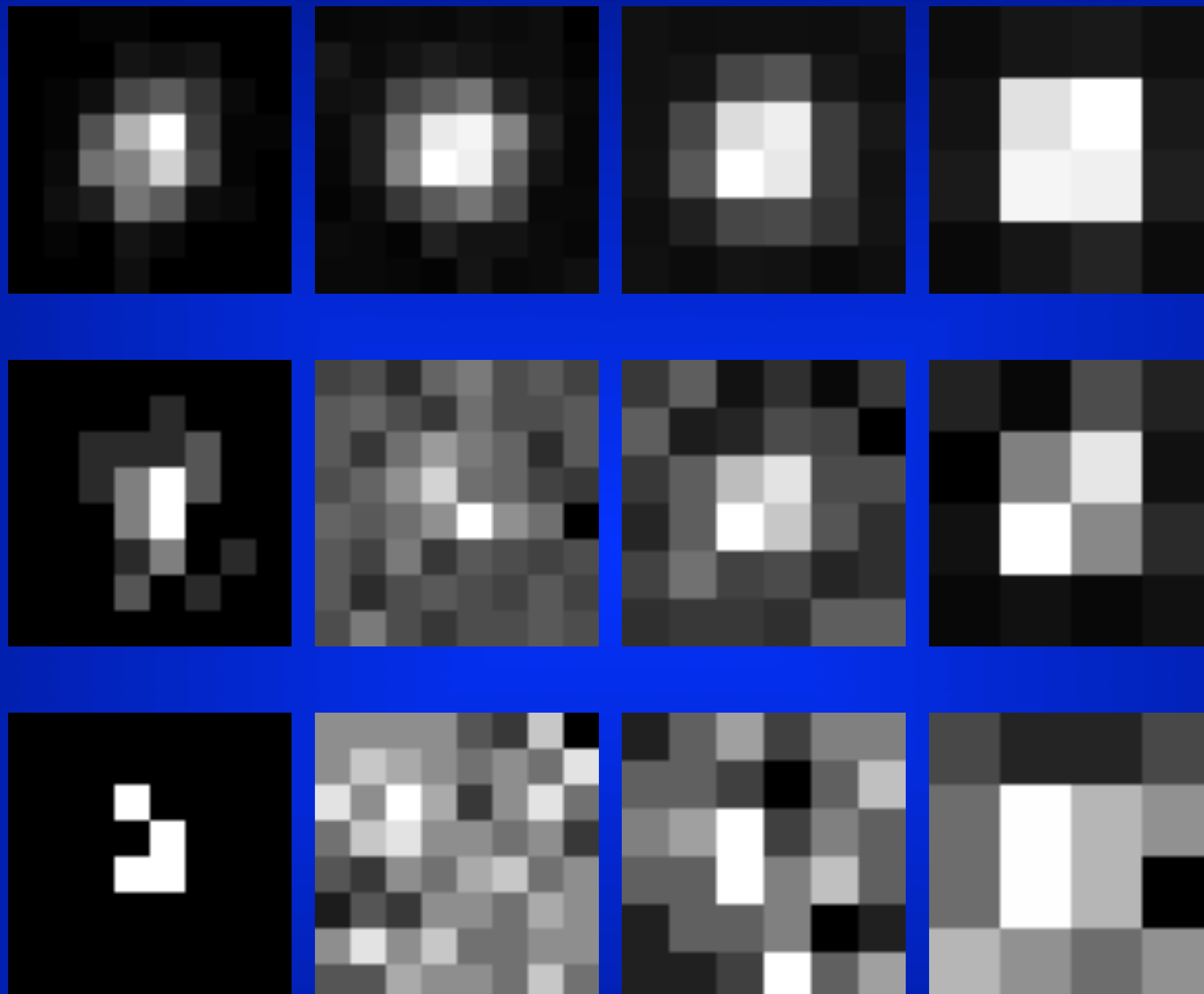
# Photon Counting




# Charge integrating



# Photon Counting example: centroid in presence of noise



1000 photons

100 photons

10 photons

| 8 x 8 | 8 x 8 | 6 x 6 | 4 x 4 |
|---|---|---|---|
| Noiseless | 2.5 $e^-$ rms | 2.5 $e^-$ rms | 2.5 $e^-$ rms |
| 35% QE | 90% QE | 90% QE | 90% QE |

# "Heritage" MCP detectors

| *Strengths* | *Weaknesses* |
| --- | --- |
| Good FUV QE | NUV/optical QE |
| Photon counting | Limited lifetime |
| Large area | Limited count rate |
| Rad hard | Non-uniform response |
| Solar blind | Spatial distortions |
| Curved focal planes | High voltage |
| Temporal resolution | Vacuum operation |

# "Heritage" CCD detectors

*Strengths*

- Superb optical QE
- Dynamic Range
- Uniform response
- Small pixels
- Geometric stability

*Weaknesses*

- Readout Noise
- Radiation ageing
- Cyrogenic contamination
- Red response (for UV)
- Cosmic ray sensitivity
- Focal plane tiling

# MCP detector progress

## Atomic layer deposition (ALD) to functionalize micropore surface

*Larger plates* — *Longer lifetime*

*Lower background* — *Opaque photocathodes*

## Better readout anodes and electronics

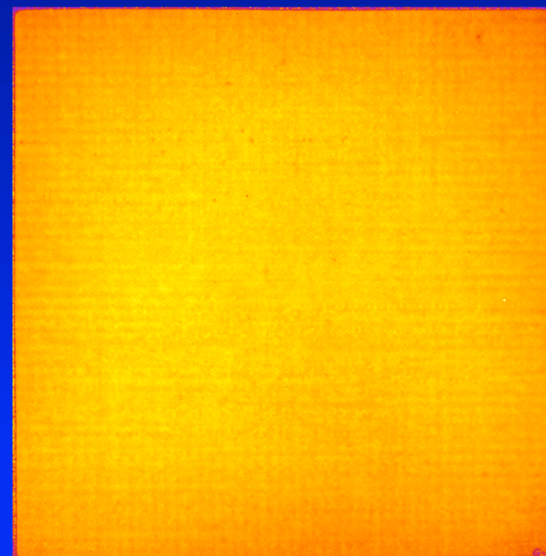
*Higher count rates* — *Lower gain (longer life)*

*Lower HV* — *Less distortion*

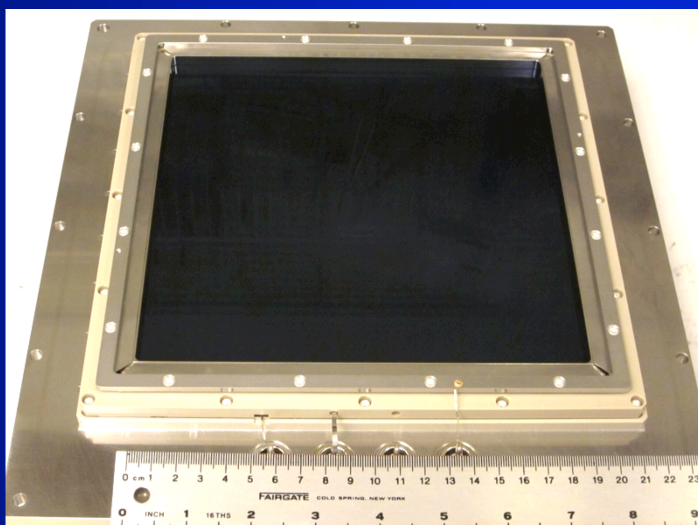
## Better MCPs

*More uniform* — *Smaller pores*

# 20 cm borosilicate glass ALD MCP

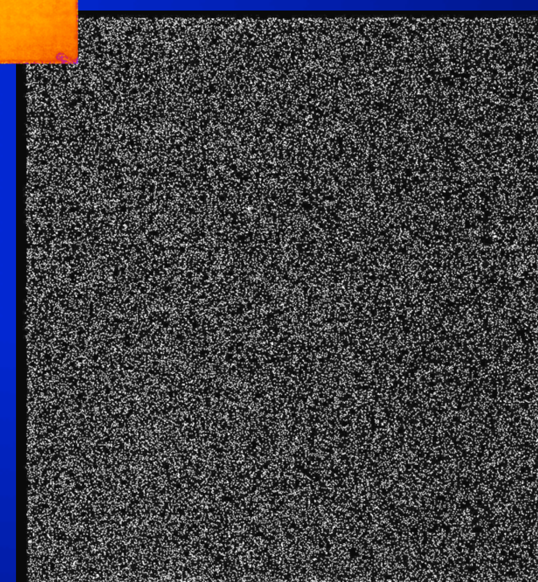


**Average gain image “map” has <15% overall variation.**
20cm MCP pair, average gain map image 20µm pore, 60:1 L/d ALD-MCP



20cm ALD 20µm pore MCP pair in detector with a cross delay line imaging readout.

*Overall background ~5x better than standard glass MCPs (<$K^{40}$)*

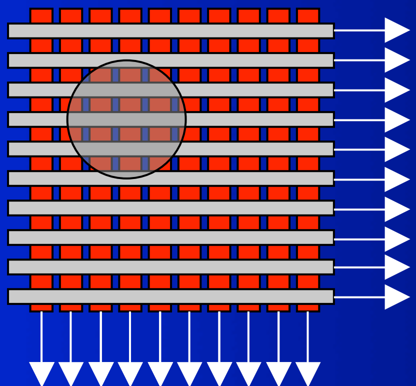


20cm MCP pair background, 2000 sec, 0.055 cnts sec$^{-1}$ cm$^{-2}$. 2k x 2k imaging.

# MCP readout improvements

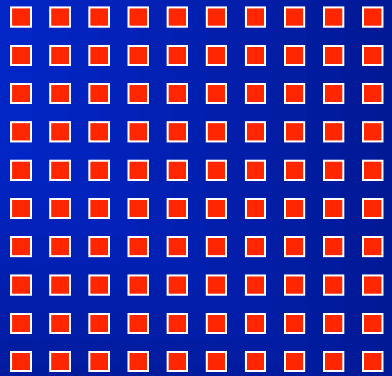
Cross Strip (SAT development to TRL 6)

- *50 mm detector, ASIC low power electronics*
- *5 MHz global rate, 50 kHz local rate*
- *15µm FWHM spatial resolution*
- *$10^6$ Gain,  HV=2500V*

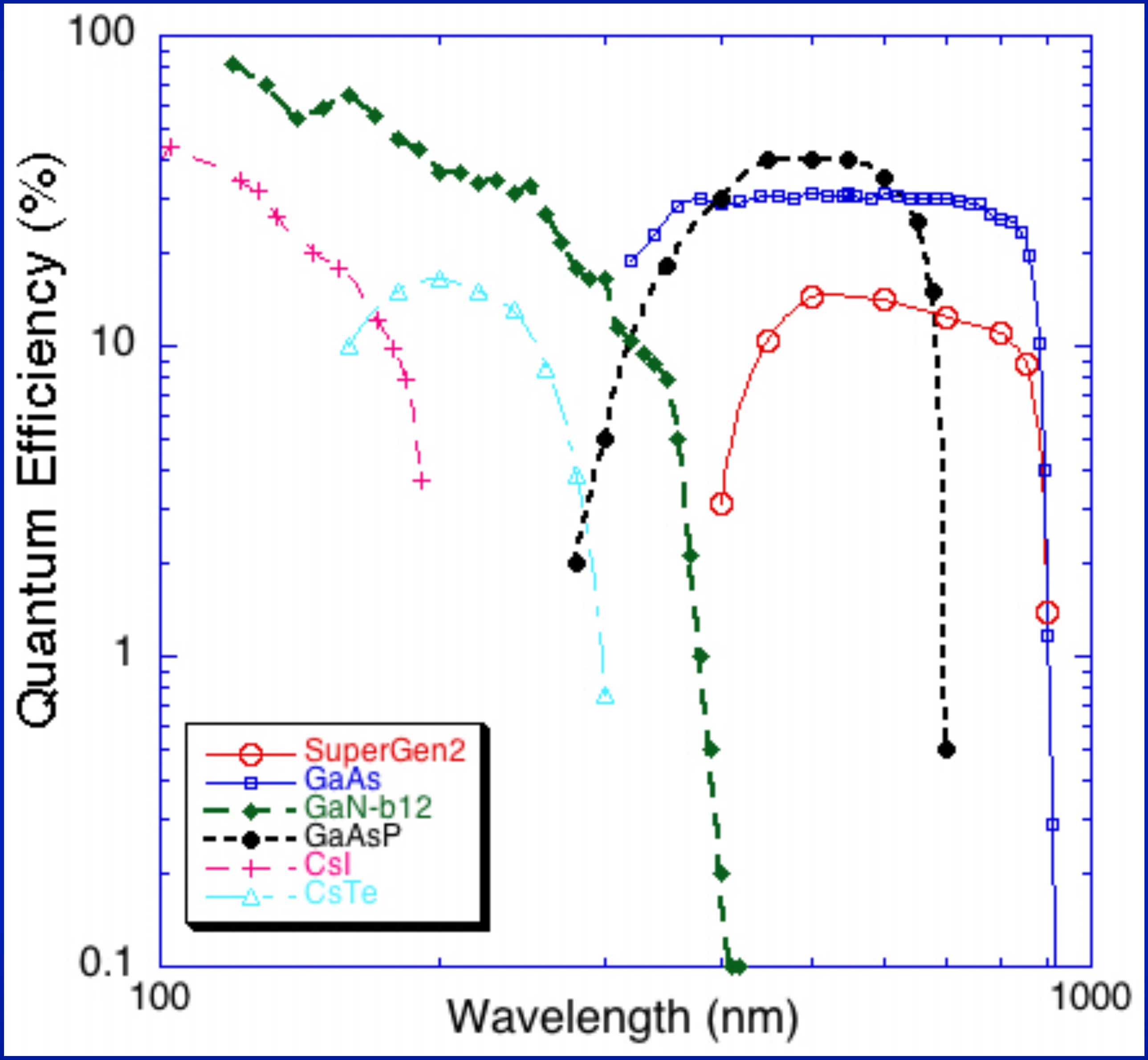


Timepix pixellated ROIC (with CERN)

- *$10^4$ Gain*
- *40 MHz $cm^{-2}$ global rate, 100kHz local*
- *4 side buttable – can tile anode plane*

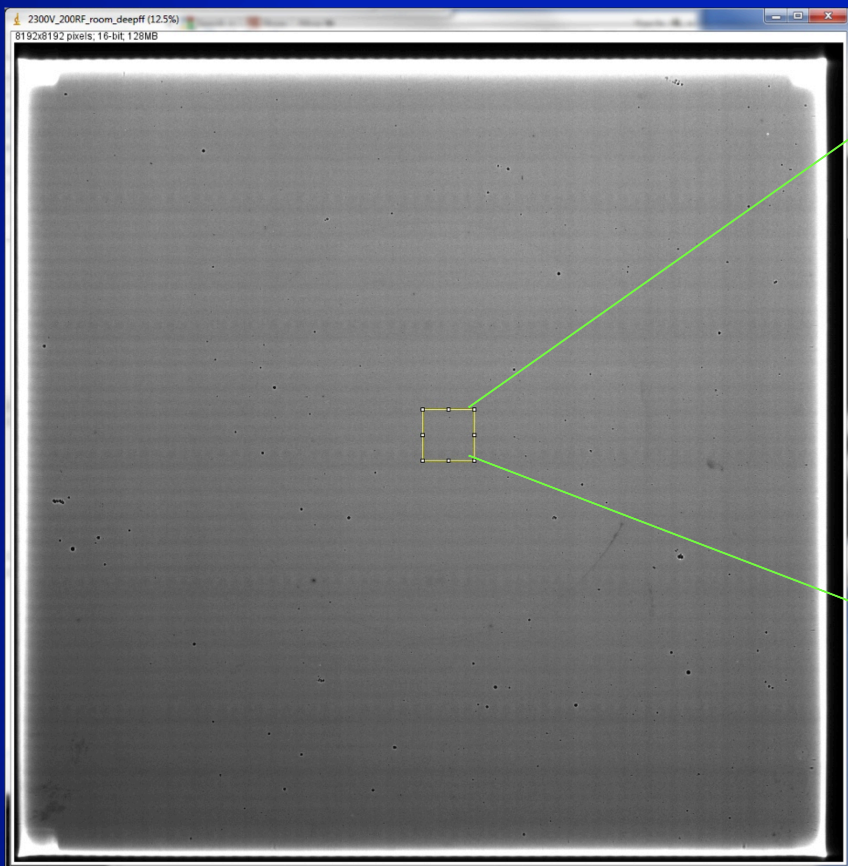


# Photocathode QE



# 50mm XS detector

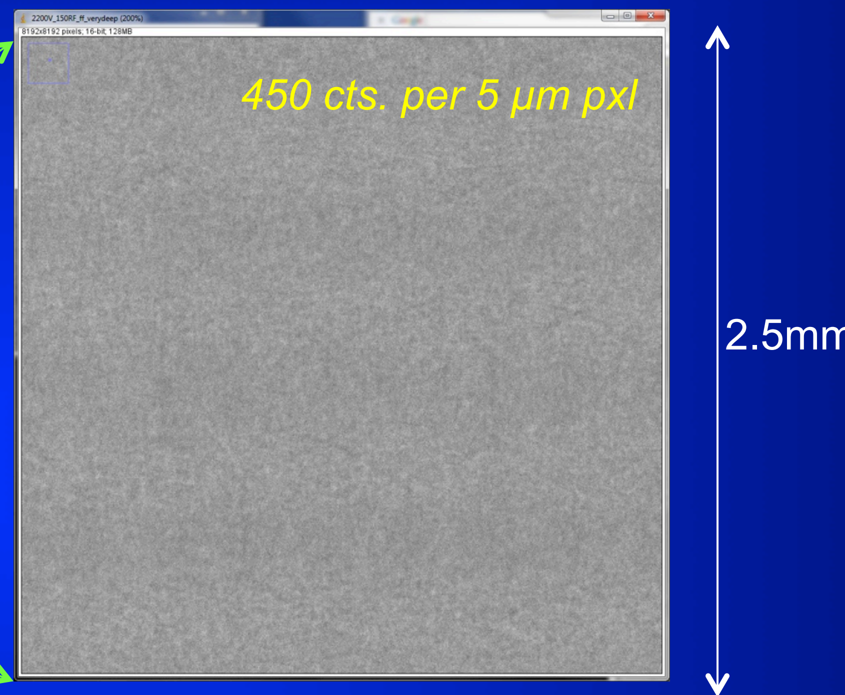
## Response uniformity (PXS-II lab electronics)

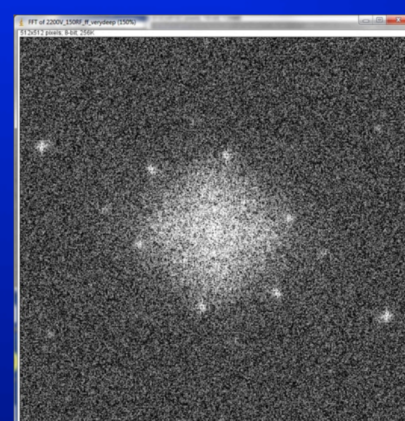


Deep UV flat (8k x 8k)

16 hours at 600 kHz

Photonis MCPs, 10µm pores on 12 µm centers.



*FFT of above image showing residual power at high spatial frequencies – 10µm/cycle*

# CCD detector progress

Surface engineering via MBE Delta Doping and ALD coatings

- *High (> 50%!), stable QE in FUV/NUV*
- *Anti-reflection coatings over defined bandpasses*
- *Diminished red response for specialized bandpasses*

Can be applied to all back-illuminated Silicon devices: CMOS, APDs, EM-CCDs, p-CCDs, PIN Arrays

# *High Performance Silicon Imagers*
# Through Back illumination
# *With Band structure Engineering using MBE and with ALD-AR coatings*

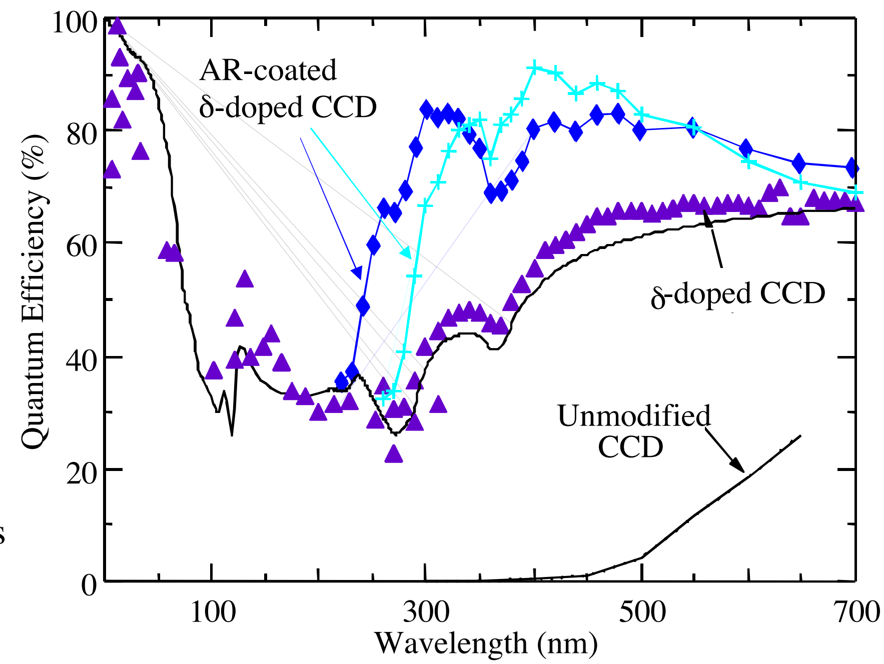
Shouleh Nikzad, NASA JPL

Molecular Beam Epitaxy (MBE) passivation and Atomic Layer Deposition (ALD) coatings uniquely enable atomic-level engineering of surfaces/interfaces to achieve high efficiency, stable and tailorable response, and low dark current in back-illuminated silicon arrays.

This is true for UV/Visible/NIR and especially true in UV where absorption happens within nanometers of the surface

We use MBE for delta doping/superlattice doping to achieve 100% internal QE (reflection limited) and ALD for AR coatings and visible blind coating to tailor the response. Versatile techniques applicable to essentially all silicon detectors and imagers including CCDs, EMCCDs, P-channel CCDs, CMOS, PIN arrays, Avalanche Photodiode Arrays (APDs)

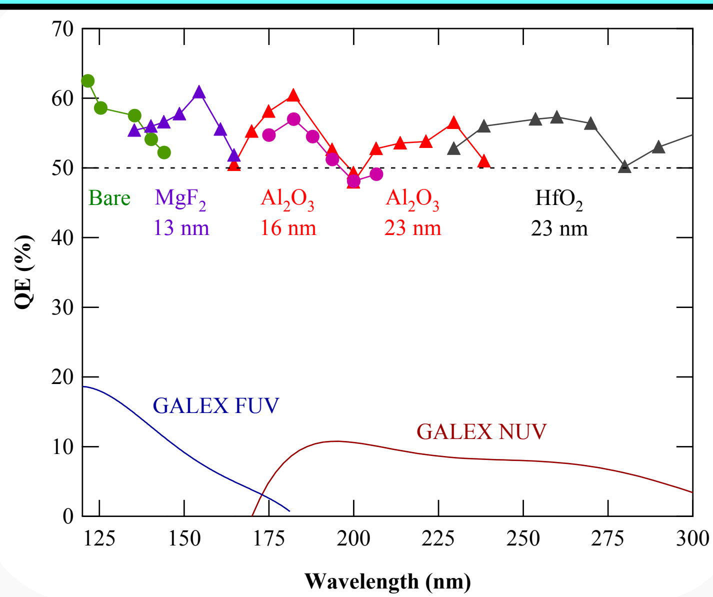
100% Internal QE of Bare Delta doped CCDs



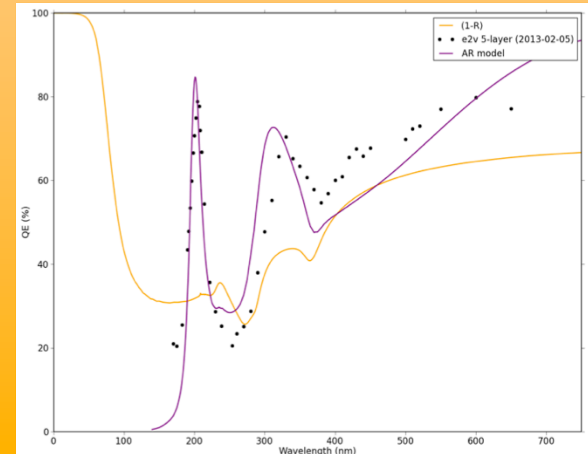

*See next slides for examples of tailored response on ALD coated delta doped arrays…..*

# Examples of UV/Vis/NIR Detectors with Tailorable Response through Precision Control of Delta doping and ALD Coatings

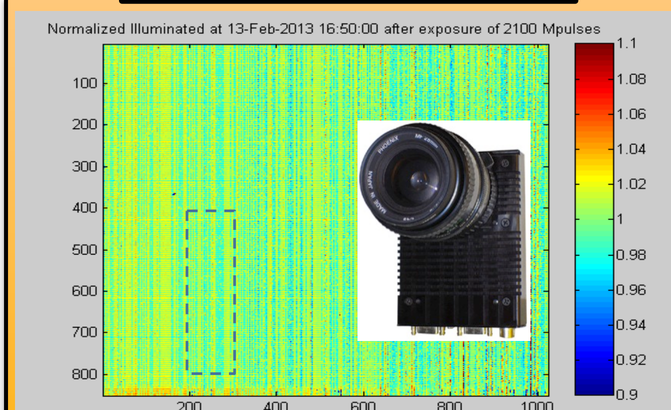
## ≥50% UV QE on conventional CCDs & EMCCDs




## Photon Counting Detector Optimized for Balloon UV Window

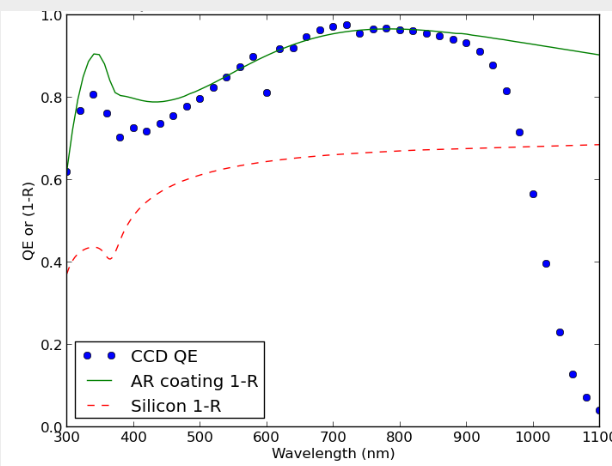


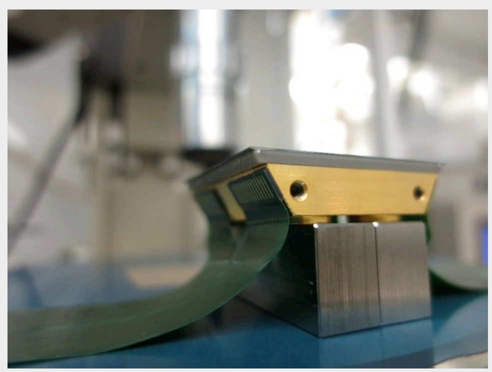

## Ultrastable response




>2 Billion 193 nm laser pulses at full saturation. No measureable change (within 1%) shown on delta doped /SL doped + ALD on CMOS

## Broadband Response for Space and Ground-based Astronomy

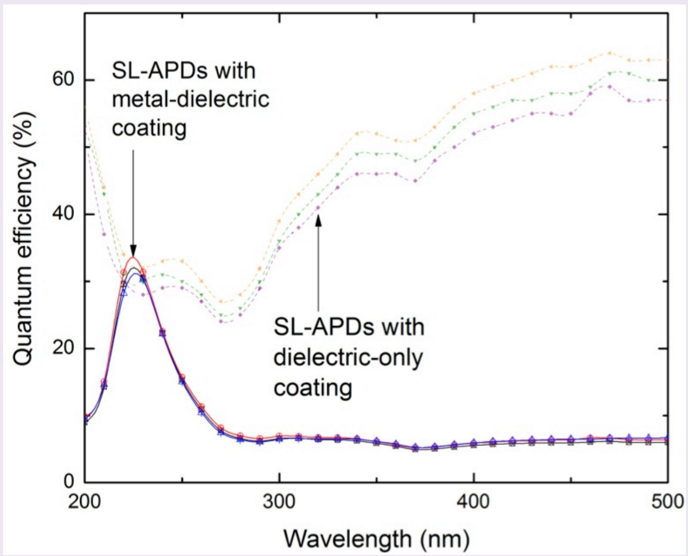


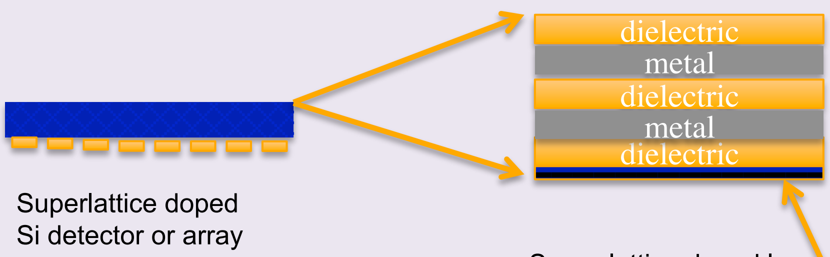



Delta doped and AR coated STA n-channel CCDs for WaSP at Palomar

# *High Efficiency Silicon Detectors with High Out-of-band Rejection Ratio*

*Measured QE and Rejection in a delta doped/superlattice(SL) doped avalanche phodiode (APD)*




Superlattice doped
Si detector or array
with integrated
filter

Super-lattice doped layer
Grown on back illuminated Si
Detectors using Molecular beam
Epitaxy (MBE)

## Description

Combining MBE passivation and ALD coatings for Integrated “red” rejection filters on high efficiency Si detectors

## Performance or capability

~4 orders of magnitude rejection

High efficiency in band

Tailorable response in Si

## Applications

UV Imaging and Spectroscopy

Particle detection

X ray detectors

# Other photon counting technologies

EM-CCDs

*Single photon counting limits dynamic range*

APD arrays in silicon

*Geiger mode suffers from crosstalk, limited rates, tricky biasing*

APD arrays in HgCdTe

*Can operate in linear mode because of low amplification noise*

*Requires cryogens.*

MKIDs

*Quasiparticle excitation, therefore intrinsic energy resolution*

*Response UV to IR*

*Cryogenic - 100 mK*

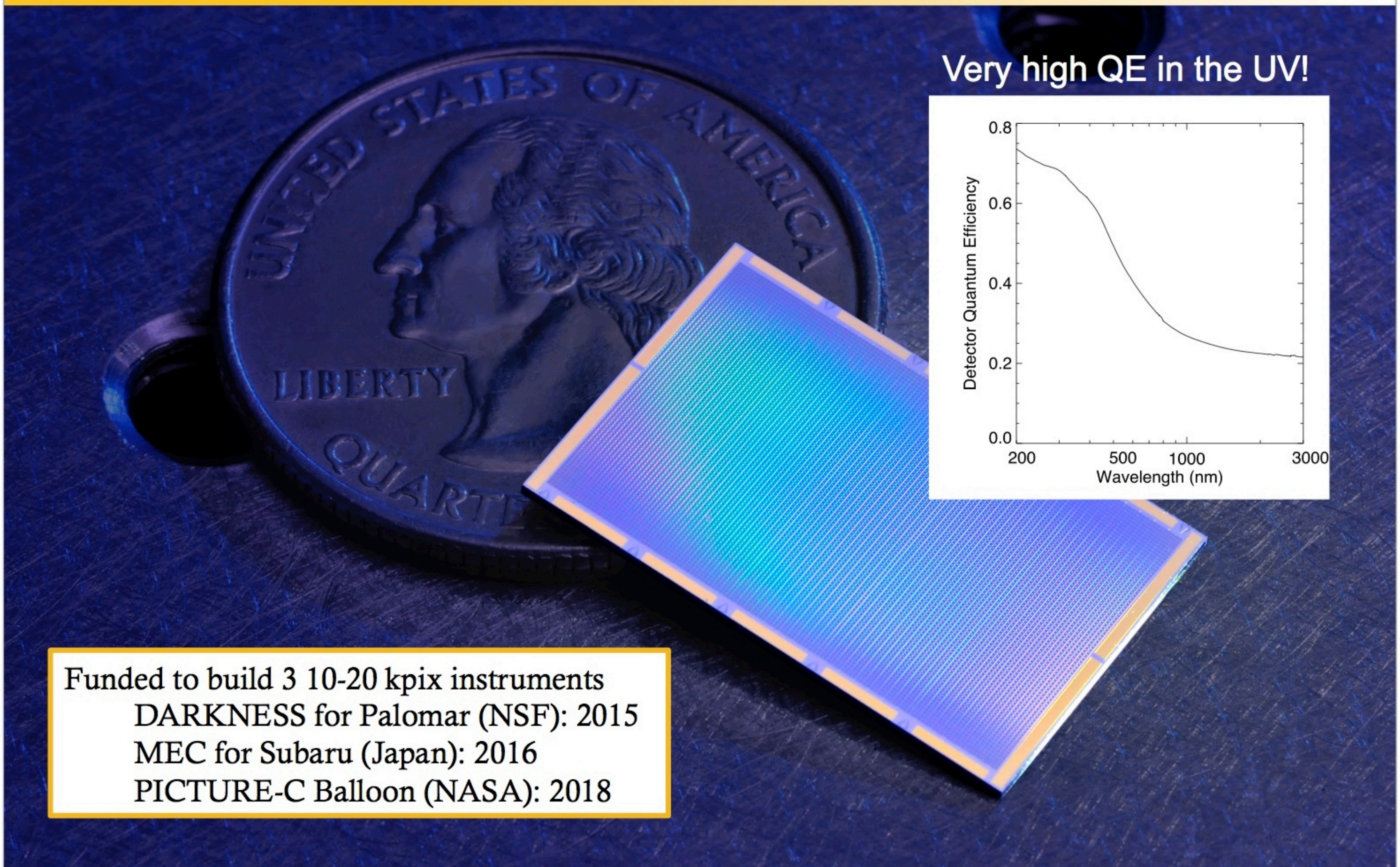
*20 kpixels devices exist, Megapixel possible*

# Cryogenic Detectors

Ben Mazin, UCSD

Mazin Lab at UCSB
http://goo.gl/ePAvg

## Microwave Kinetic Inductance Detectors




Intrinsic spectral resolution R>20, high QE, no read noise or dark current. 100 mK operating temperature. Formats up to the Megapixel range are possible. Operation below 130 nm requires significant redesign.

# Conclusions

Given the recent progress made in the "standard" heritage detector types, most likely large, modern MCP detectors will be chosen for Flagship FUV instruments, CCDs for the optical instruments, and there will be a battle for the NUV crossover.

Photocathode improvements can still have a significant impact in overall instrument performance

Optical/NIR photon counters need their TRL increased significantly before becoming a Flagship detector

# Backup Slides

# Microchannel Plate Detectors

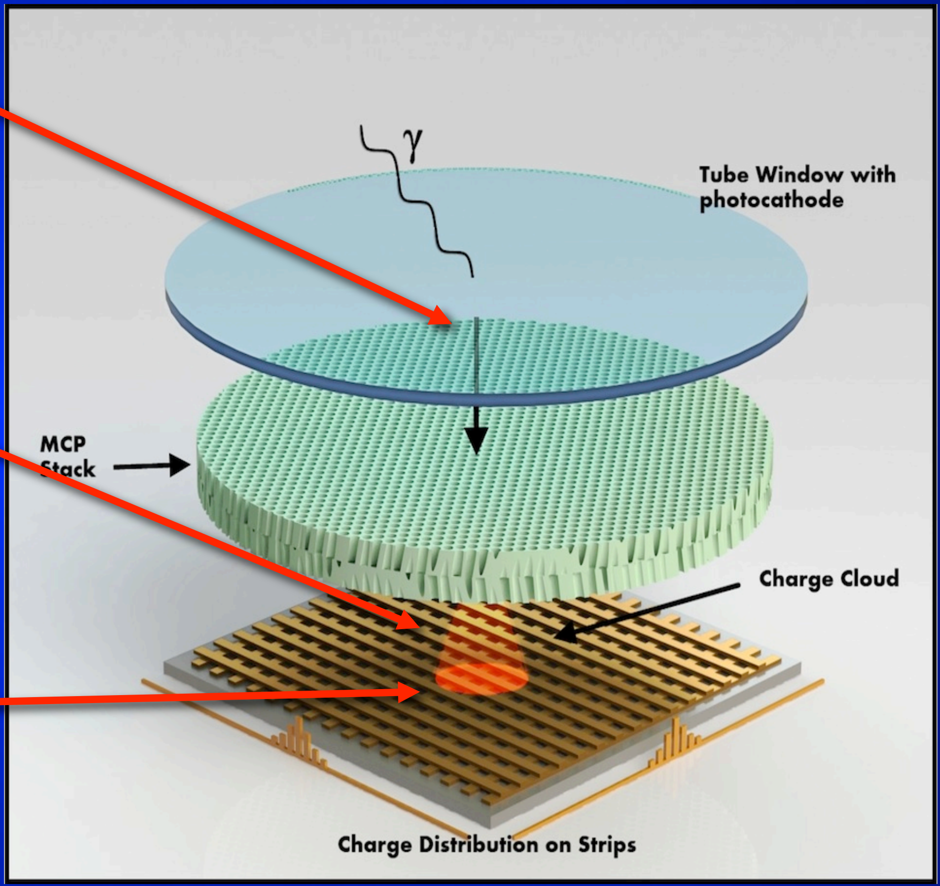
Photocathode converts photon to electron
(ALD, Photocathodes APRA 2013, 2008 )

MCP(s) amplify electron by $10^4$ to $10^7$

(MCPs with ALD, APRA 2011)

Patterned anode measures charge centroid

(XS and ASIC readouts, APRA 2007
XS electronics ASIC, SAT 2011)



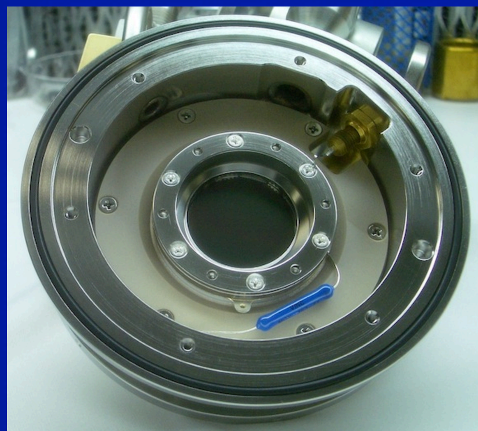

*Photocathodes*

Alkali halides, Multialkali, GaAs, GaN

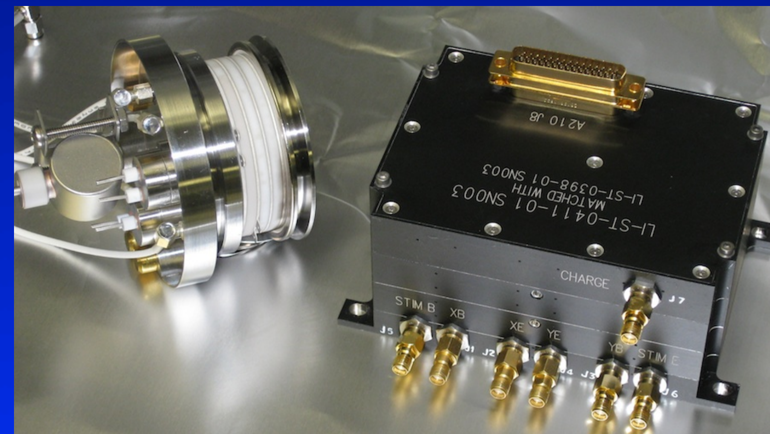
*Readouts*

Cross strip, Cross delayline, ASIC (Medipix or Timepix), Phosphor.

# UV + MCP Detectors on Recent Missions

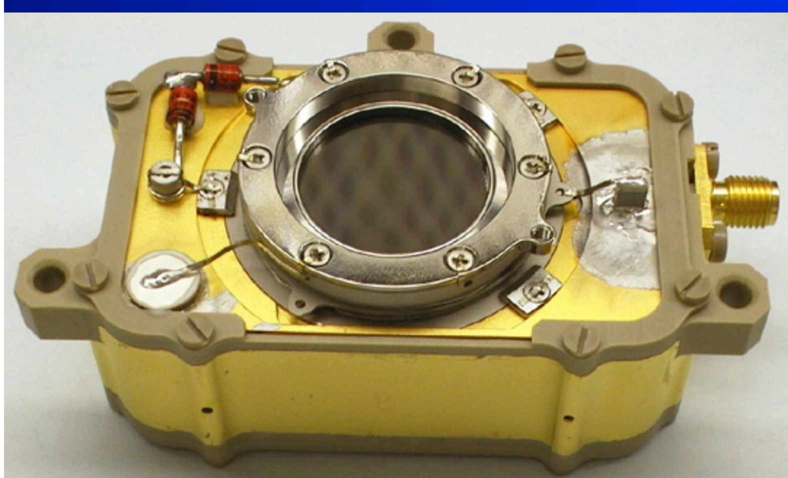


NRL-JPEX rocket, 25mm cross strip, ~18µm FWHM resolution, 22-25nm spectrometer flown 2008.



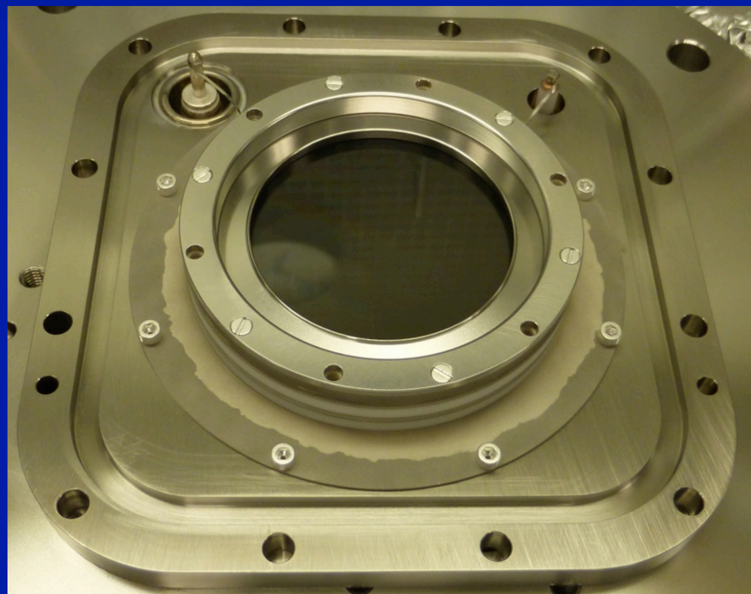

SSULI x 3, 40mm cross delay line, 2009 – present, UV spectrometer, 80 – 170nm, 512 x 512.

Rosetta – ROSINA-RTOF. TOF mass spectrometer, < 300ps time resolution.

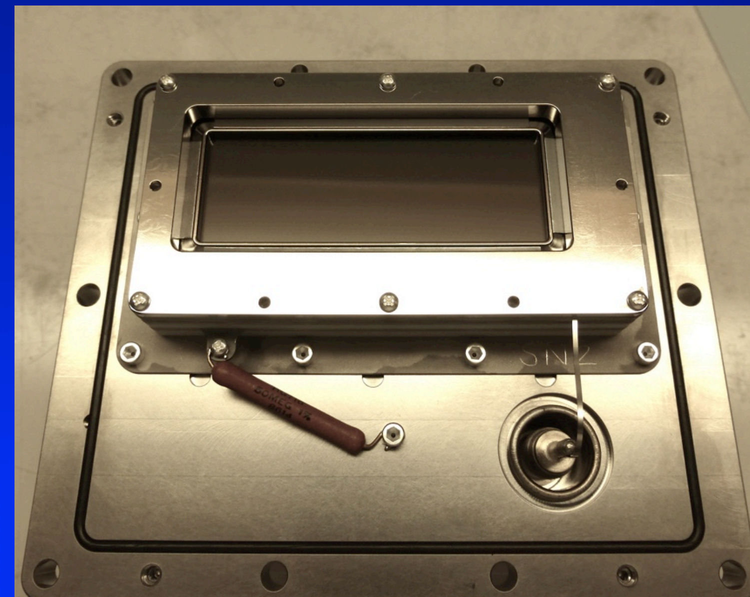


Rosetta Alice, Pluto Persi-ALICE, LRO-LAMP, JUNO-UVS. Delay line up to 2048 x 512, 50 – 180nm, CsI & KBr. Hig curved (7cm R) - spectrometers.

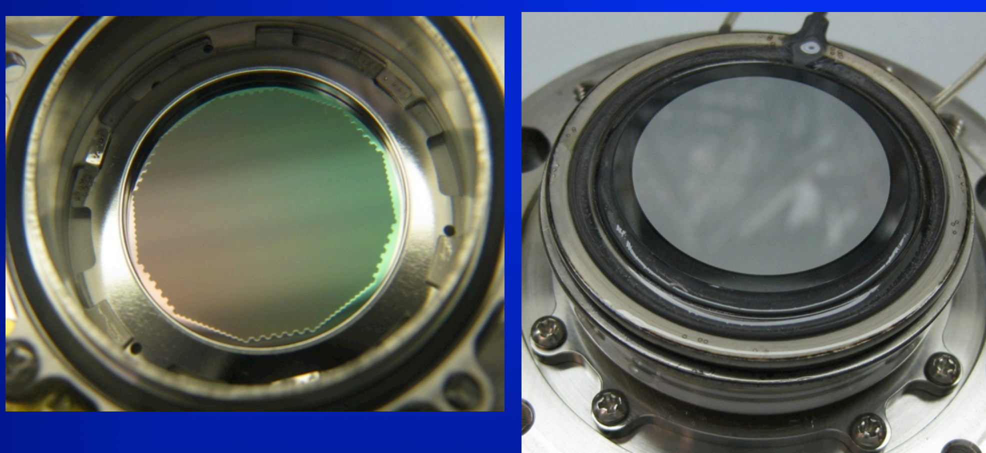
# UV MCP Detectors for Impending Missions



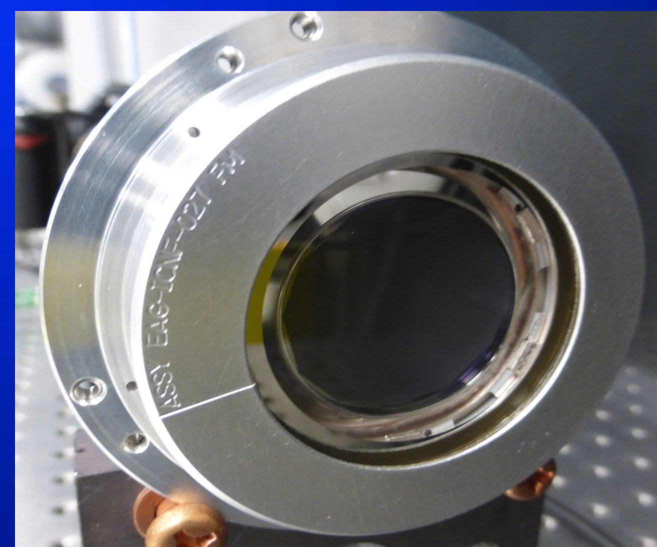
GOLD- SMEX, 40mm cross delay line



ICON-SMEX – EUV, XDL



SPICE – Solar Orbiter, 25mm MCP/Phosphor/CCD



ICON-SMEX – FUV, ICCD