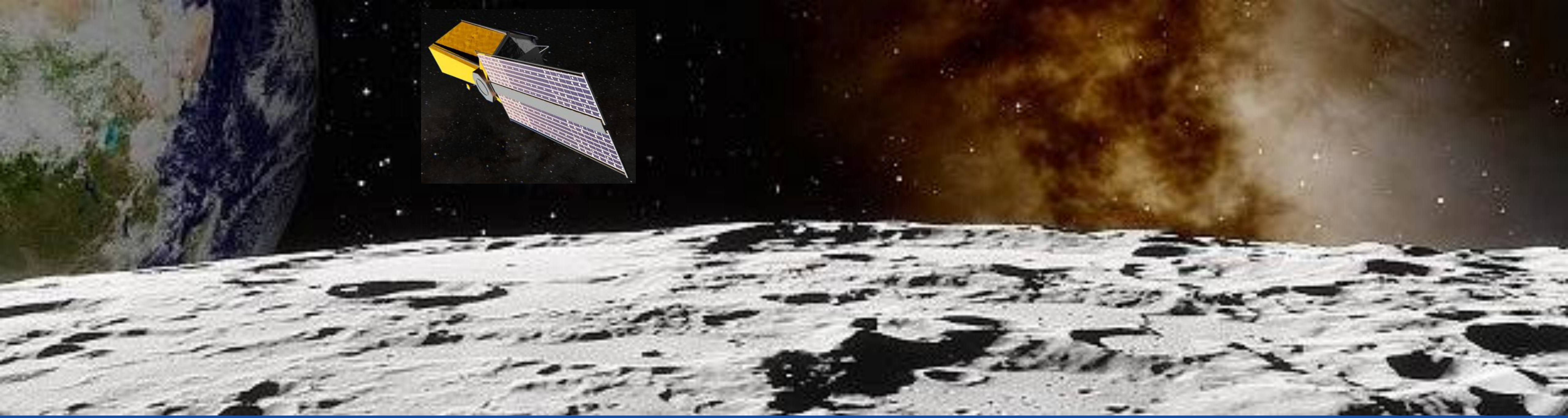


High Dynamic Range Photon-Counting UV Detectors

M. Uslenghi, S. Farina, L. Schettini, G. Toso, M. Fiorini, S. Incorvaia (1)

L. Nassi, A. Ciavarella-Ciavarella, G. Borghi, M. Carminati, C. Fiorini (2)

A.J. Corso, M.G. Pelizzo (3)

(1) INAF IASF-Mi

(2) Politecnico di Milano

(3) CNR IFN, Università di Padova

UV detectors for HWO

- HWO Wavelength Coverage spans ~90–2500 nm
- It includes the **FUV ~90–200 nm** band:
  - UV multi-object spectrograph with FUV imaging (FoV ~2′×2′) -> FUV channel
- This FUV capability is essential for many HWO science objectives.
- Unfortunately, from a technological point of view, this range is challenging, in particular for detectors
- Moreover, the development of UV detectors has lagged behind that of IR and visible detectors, partly due to limited commercial and military interest, which in turn leads to reduced funding for R&D
- Astronomical applications also present unique requirements, as the flux of FUV photons from typical astronomical sources is 6 to 9 orders of magnitude lower than that of visible photons, contamination and stray light are issues

UV Multi-Object Spectrograph

UV/Vis multi-object spectroscopy and FUV imaging

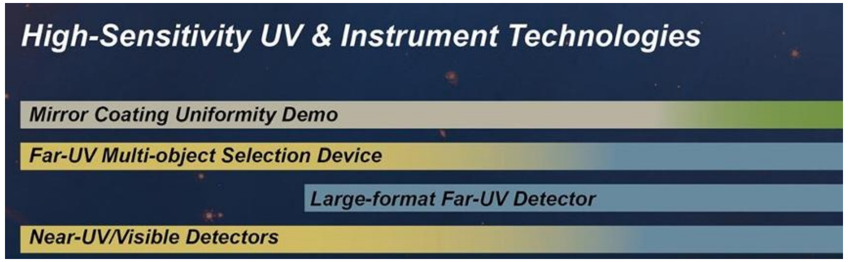
Bandpass	~90 – 700 nm
Field-of-View	$\sim 2' \times 2'$
Apertures	$\sim 840 \times 420$
R ($\lambda/\Delta\lambda$)	~500–60,000

UV detectors for HWO

HWO Requirements:

- Large format → (8k × 8k pixels)
- high quantum efficiency → (>50% peak)
- out of band rejection
- low noise/high SNR properties -> photon counting (but…also need to be able to handle high flux)
- very low background

The first-generation instruments for HWO are foreseen to be passively cooled, for the second generation cryogenic ERDs are considered -> but the requirements are challenging (large array, R~140 in visible & R~90 in IR), will it be possible to meet them? Not obvious, high risk



From the Technology Roadmap

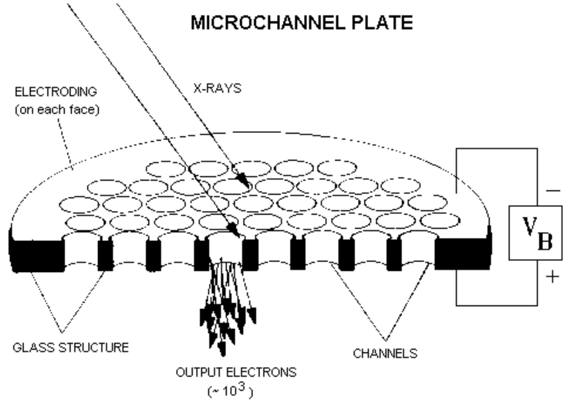
UV Multi-Object Spectrograph

UV/Vis multi-object spectroscopy and FUV imaging

Bandpass	~90 – 700 nm
Field-of-View	~2′ × 2′
Apertures	~840 × 420
R (λ/Δλ)	~500–60,000

MCP detectors

MCP-based detectors have been for a long time the detectors of choice for astronomical applications in this range



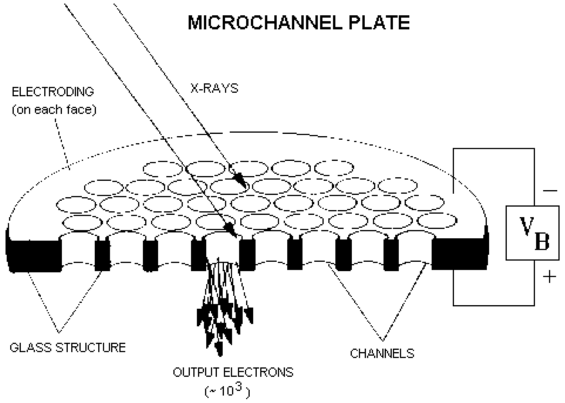
\+ Photocatode / e^- readout system

Extensive space heritage: EUVE, FUSE, GALEX, HST (STIS, COS), ICON, GOLD, …

- ✓ Good efficiency in the EUV/FUV
- ✓ Solar blindness (rejection of VIS light, 6-9 order of magnitude, even 12)
- ✓ Low dark counts
- ✓ Photon counting
- ✓ Time resolution down to 10ps
- ✓ Good spatial resolution < 10µm
- ✓ Large sensitive areas (even curved surfaces)
- ✓ No cooling required
- ✓ Radiation tolerant

MCP detectors

MCP-based detectors have been for a long time the detectors of choice for astronomical applications in this range



+ Photocatode / e^- readout system

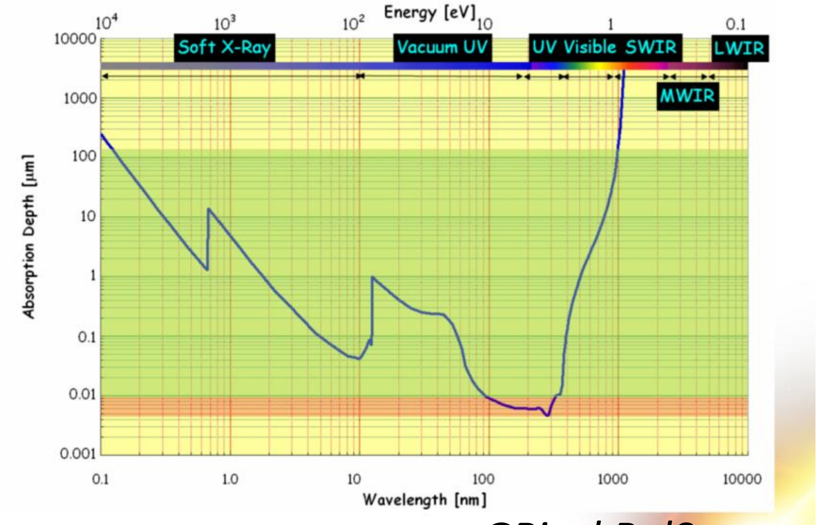
Extensive space heritage: EUVE, FUSE, GALEX, HST (STIS, COS), ICON, GOLD, …

Drawbacks:

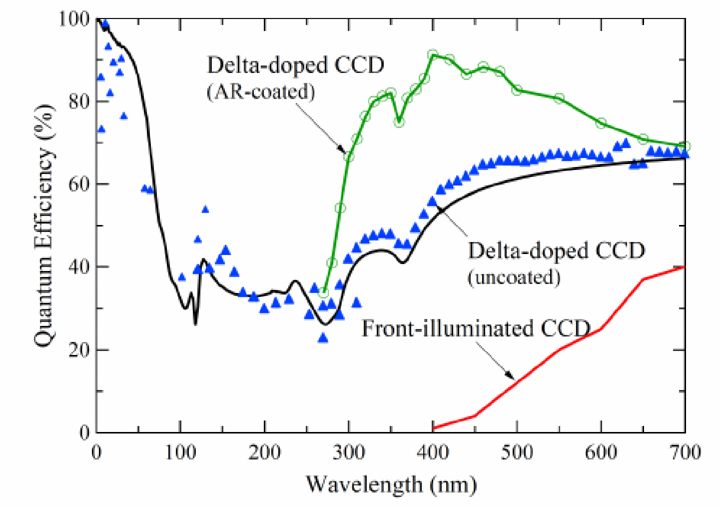
- Limited dynamic range
- Limited lifetime
- Fragility (cathastrofic failure due to thermal runaway…)
- Operation at high voltages
- Depending on the readout system: issues with non linearity, geometric distortion, …

Solid State vs Photoemissive detectors

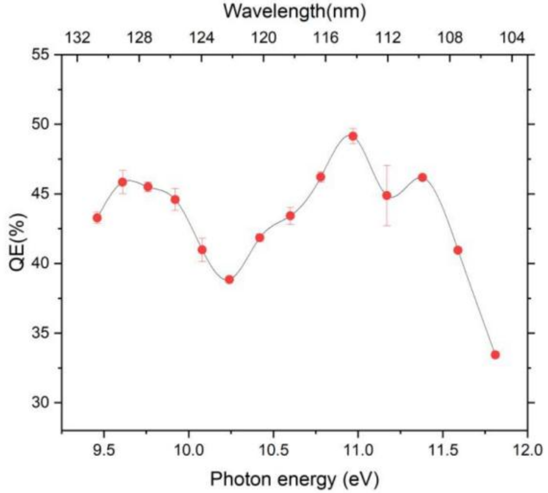
In the past the QE of Si detectors was very low, but development has been done and with appropriate AR coating and doping profile optimization it is possible to realize high efficiency detectors



Delta-doping



GPixel PulSar



*2022 JINST **17** T08004*

Solid State vs Photoemissive detectors

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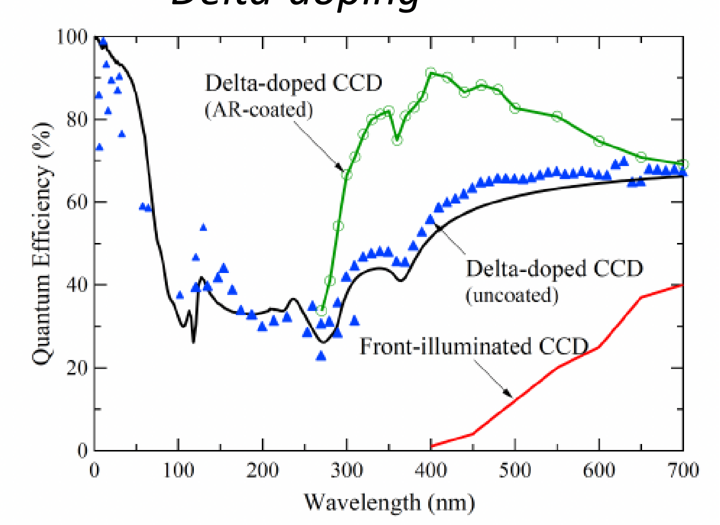
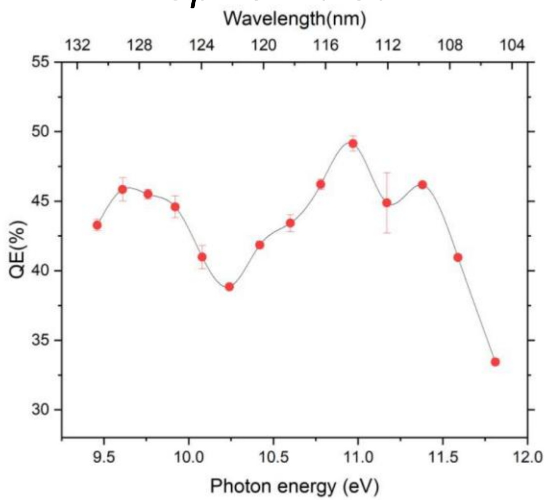
Si Photon counting detectors?

- EMCCD
- Sub-electron noise CMOS
- SPAD array

Delta-doping



Gpixel PulSar



*2022 JINST **17** T08004*

Solid State vs Photoemissive detectors

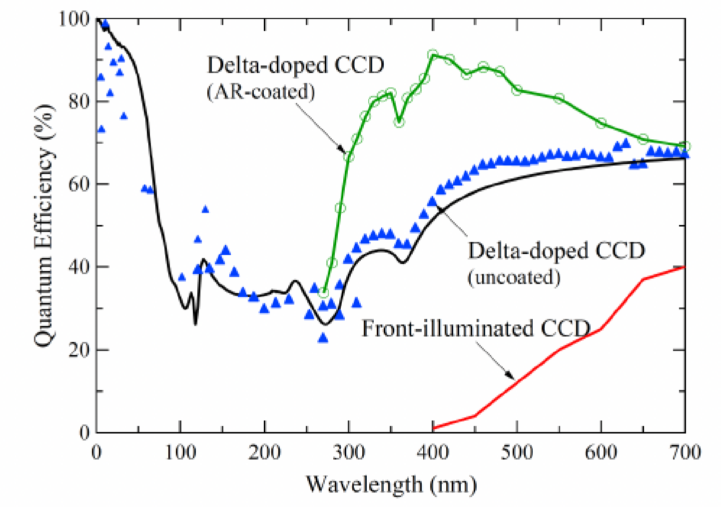
In the past the QE of Si detectors was very low, but development has been done and with appropriate AR coating and doping profile optimization it is possible to realize high efficiency detectors

Unfortunately, the Si is also very sensitive to visible light → filters
(MCP results in less strict requirements for stray light suppression and filtering)

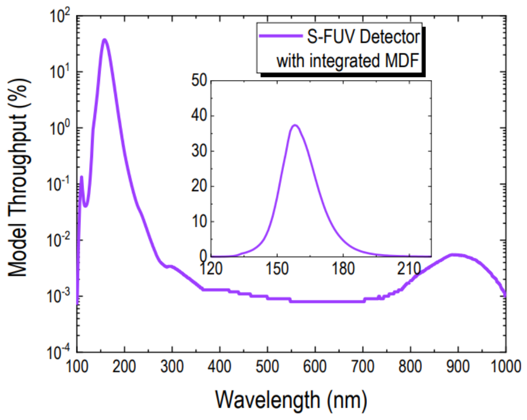
Si Photon counting detectors?

- EMCCD
- Sub-electron noise CMOS
- *SPAD array*

Delta-doping

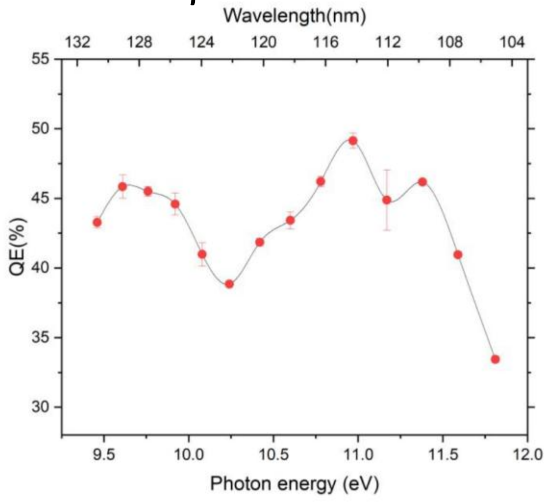


integrated metal dielectric filter



SPIE, Volume 10709

Gpixel PulSar



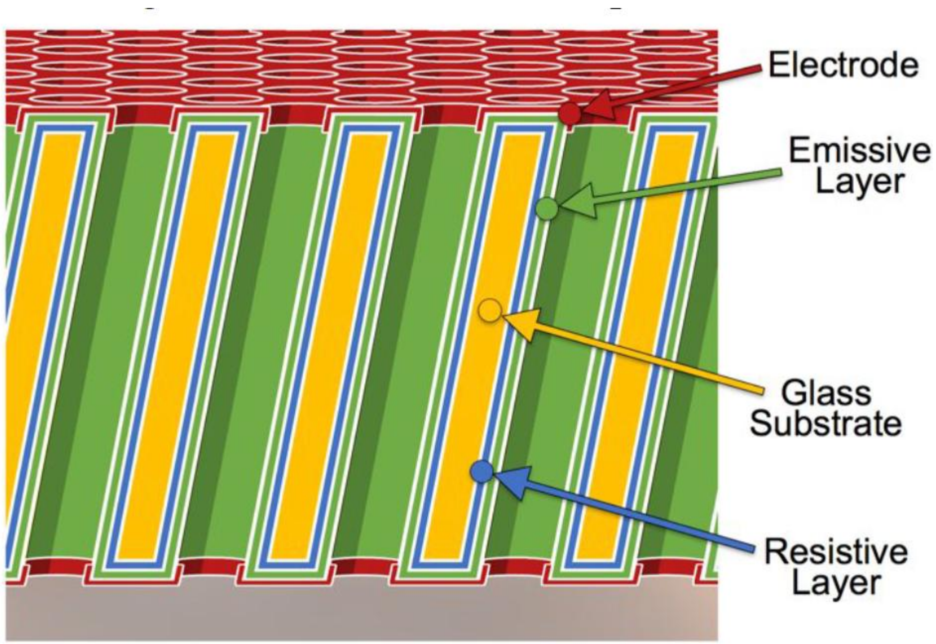
*2022 JINST **17** T08004*

New generation MCP

In the last years, new production techniques have revolutionized MCPs

Instead of traditional lead glass → **borosilicate substrates** (several meterials with different characteristics available) are now used and **ALD** allows optimization of their characteristics with high secondary emission layer (Al2O3 or MgO)

- ALD process significantly improves detector **lifetime**
- High secondary emission coefficient results in better multiplication → **better PHD**
- Robustness of the ALD and substrate material
- **high local event rate capacity**
- Significantly **reduced risk** of thermal runaway
- **Less background** cts
- ALD MCPs enable deposition of various photocathode materials (**possible QE improvement**)



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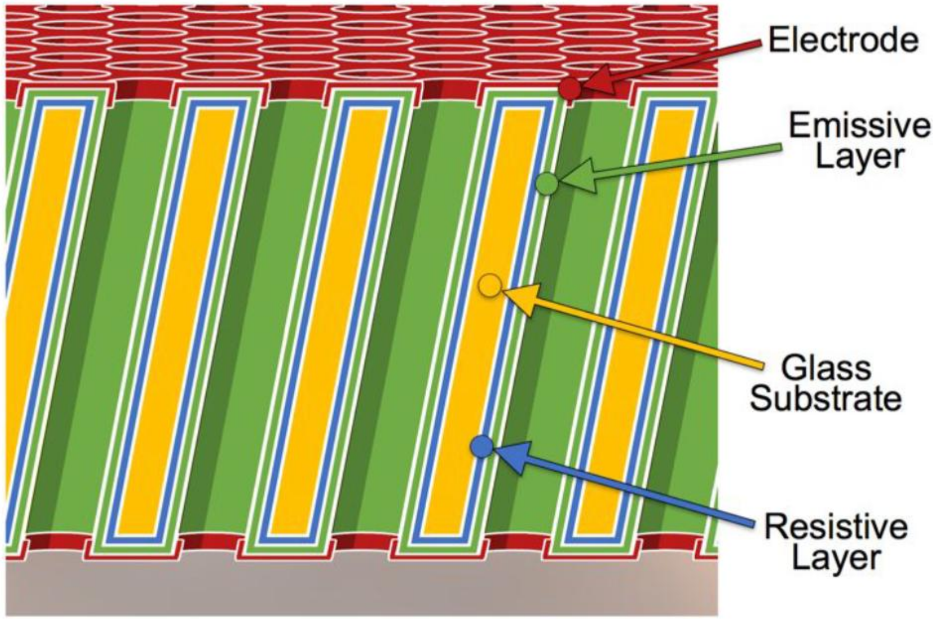


A **new kind of readout system** is necessary to fully exploit the potential of these devices

New Readout System for New generation MCPs

The readout system shall not limit the relevant performance that the MCP can deliver

A crucial parameter that governs several of the less-than-ideal MCP-based detectors characteristics is the gain at which MCPs is operated → lower gain results in:

- higher dynamic range
- longer lifetime
- lower HV

New generation MCPs

The readout system shall not limit the relevant performance that the MCP can deliver

A crucial parameter that governs several of the less-than-ideal MCP-based detector characteristics is the gain at which MCPs is operated → lower gain results in:

- higher dynamic range
- longer lifetime
- lower HV

We developed a new detector based on MCPs with a readout system integrated into an ASIC, MIRA - *MIcrochannel plate Readout ASIC*, designed specifically for this application by Politecnico di Milano:

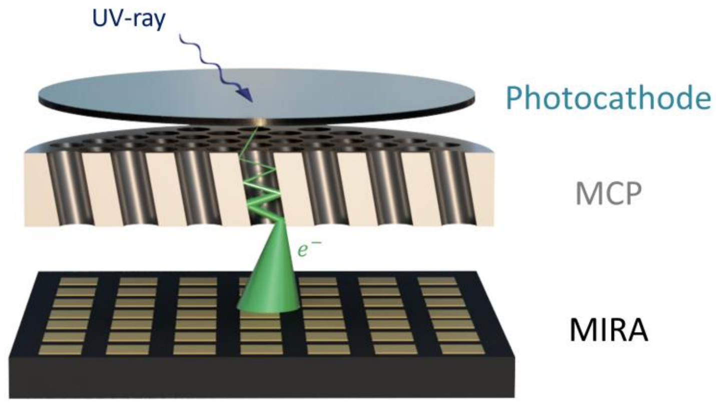
- low noise of the readout electronics allows the use of **3 to 6 orders of magnitude lower gain** than traditional detectors
- High **detector lifetime and gain stability** (combined with ALD MCPs,an improvement of **7-8 orders of magnitude** can be achieved)
- High **dynamic range**, up to 10^5 photons/s/pixel
- Use of **lower voltage** levels: over **5-8 times** lower
- **No geometric distortion,** each pixel is indepentent
- Compactness: all the electronics, including photon event detection, is on chip

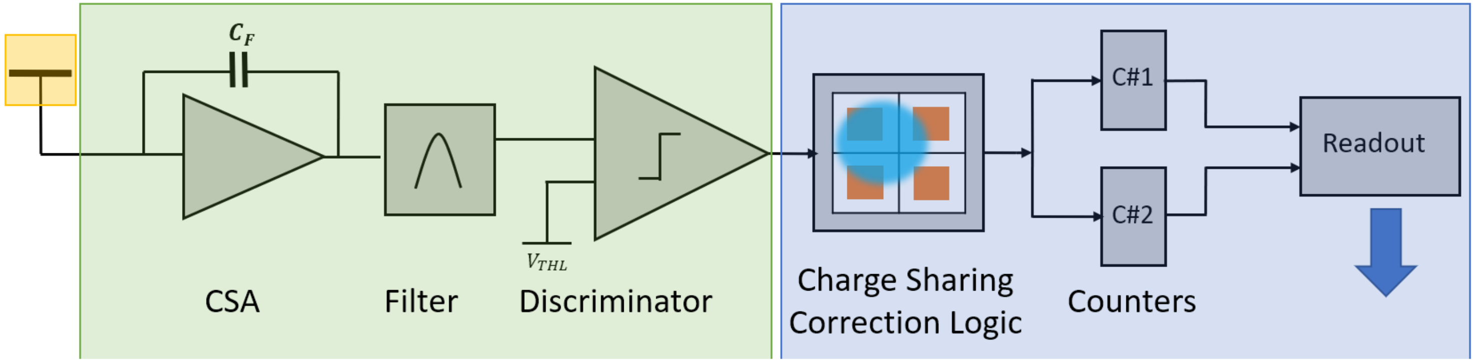
PLUS - PLanetary Ultraviolet Spectrometer, founded with the **"Activities for the scientific community for the Solar System and Exo-Planets" - ASI-INAF** Agreement 2018-16 for technological R&D for new generation UV spectrographs

MIRA:

- Single pixel chain composed of **analog** portion and **digital** portion
- **Analog portion**: collecting anode, CSA, filter and discriminator
- **Digital portion**: 17-bit counters, charge sharing logic (2 modes)
- **Frame based readout** based on serial peripheral interface (SPI)

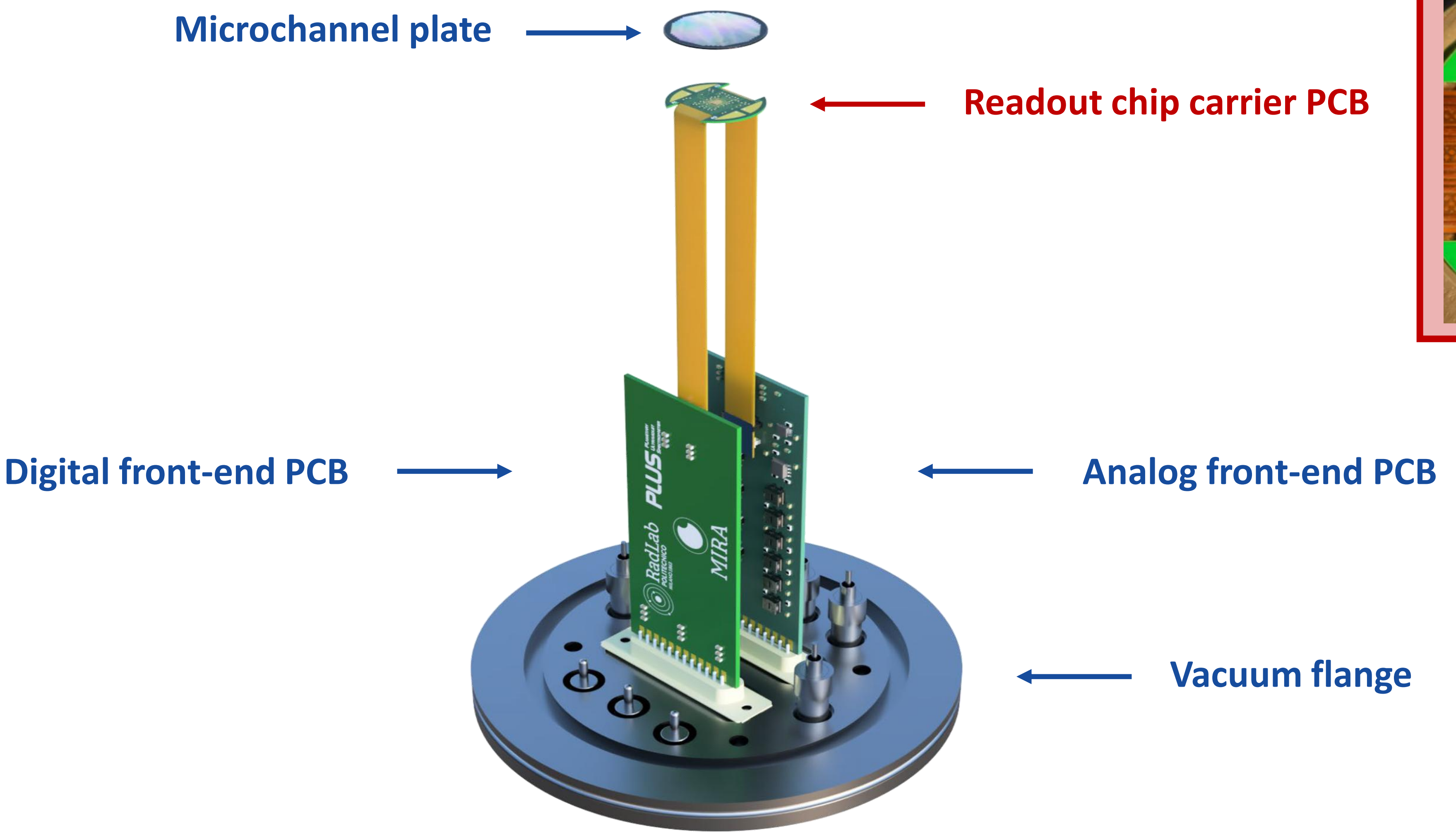
Matrix size	32 x 32
Spatial resolution	35 µm
Readout noise	20 e-
Counter bits	17
Dynamic range	100 kcps/pixel





FABBRICA, Edoardo, et al. MIRA: a Low-Noise ASIC with 35 µm Pixel Pitch for the Readout of Microchannel Plates. IEEE Transactions on Nuclear Science, 2024.

The in-vacuum electronic system



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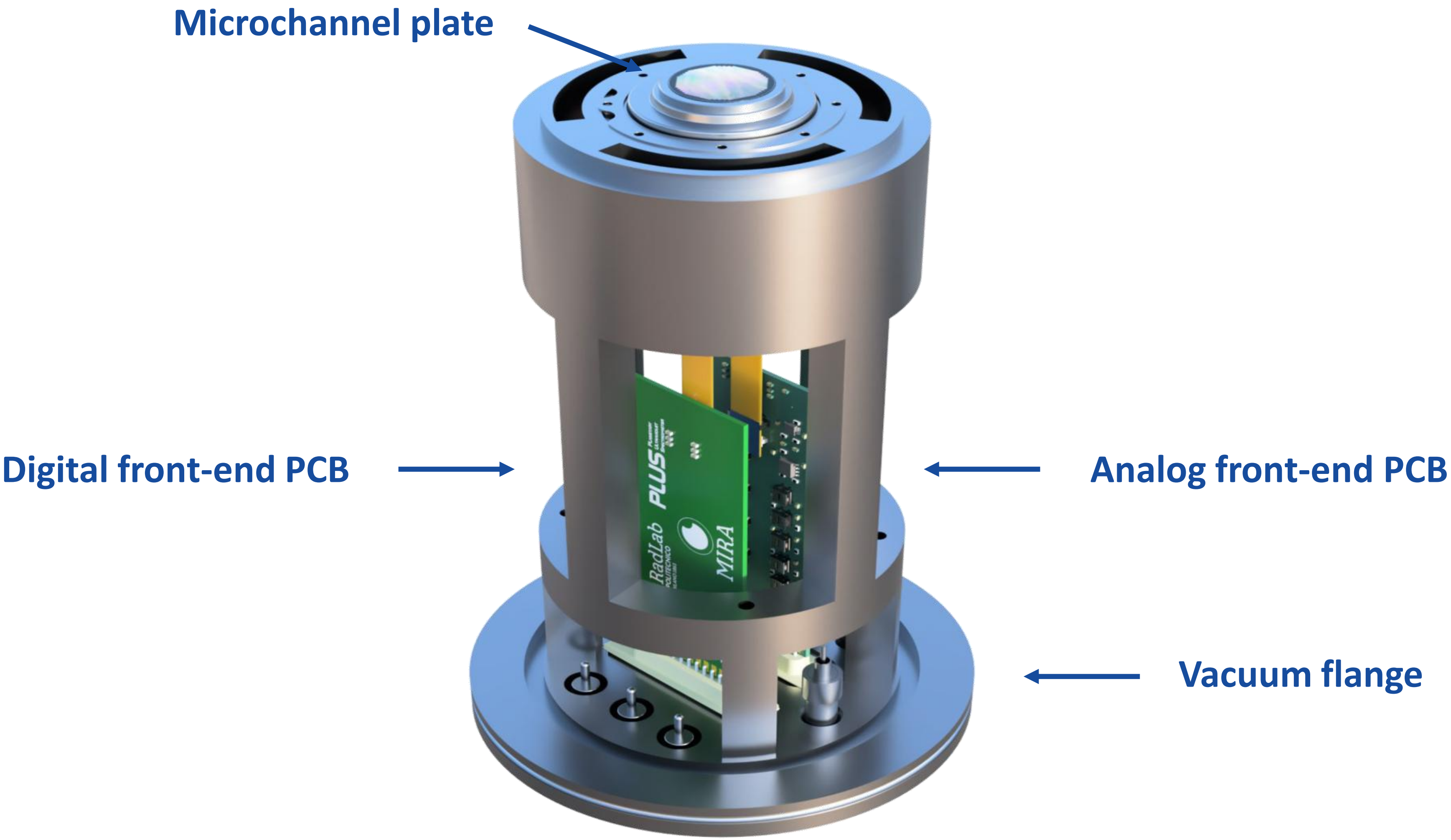

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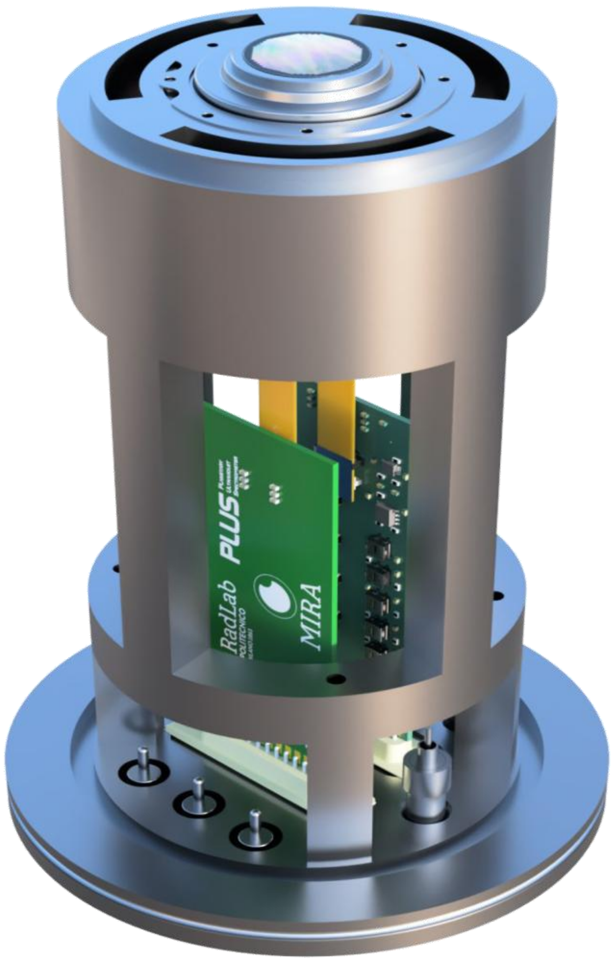
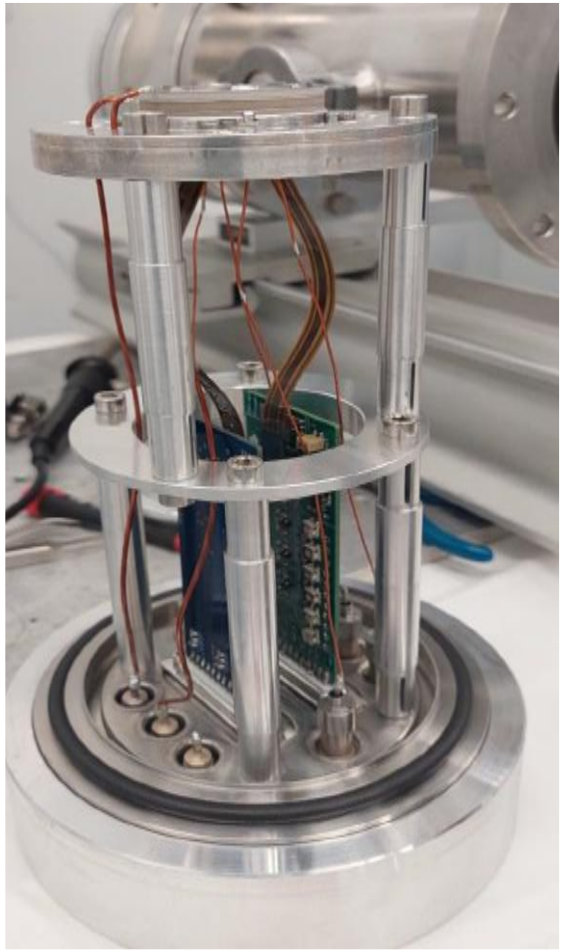
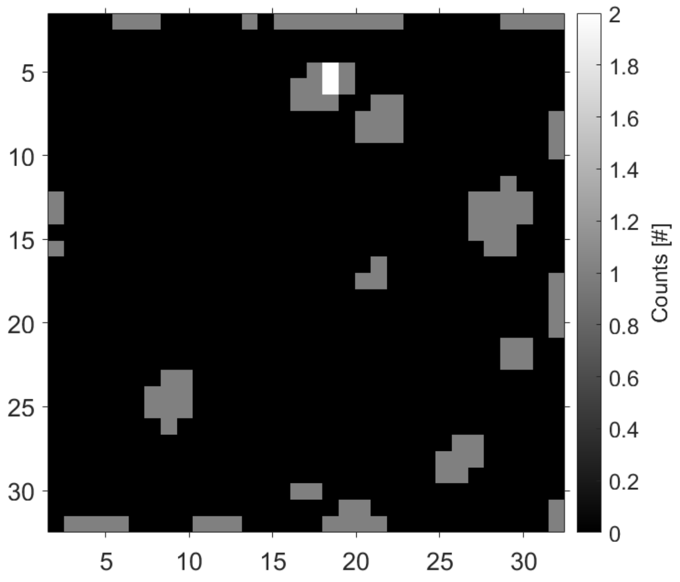


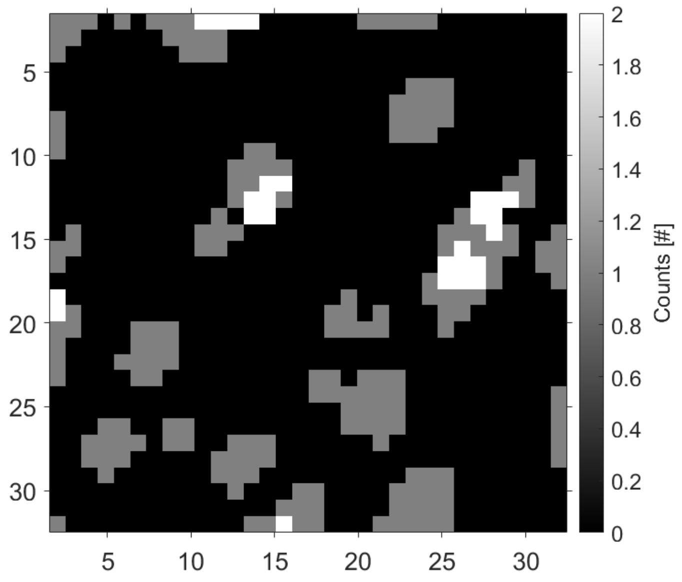


Single-photon footprint

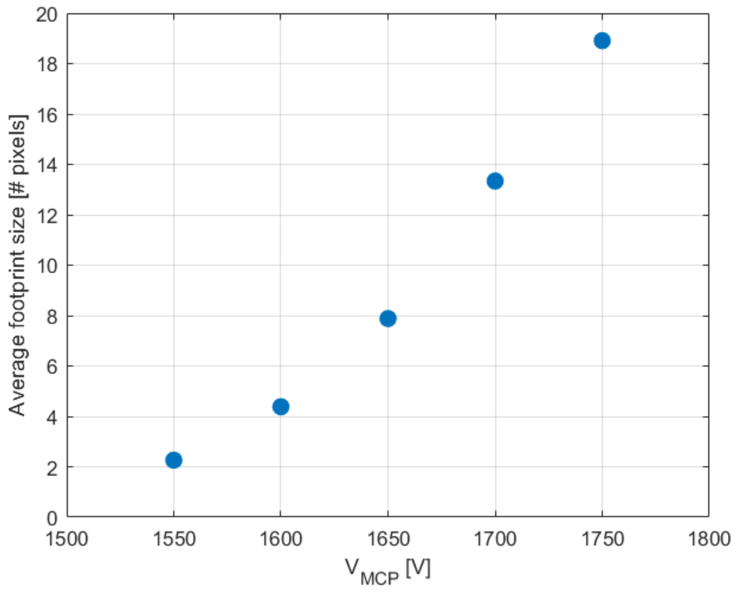
Vmcp = 1600 V Vgap = 1000 V



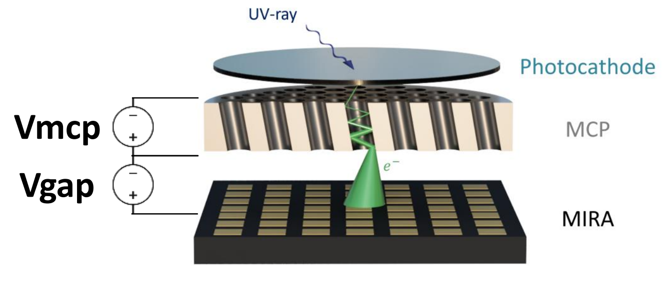
Vmcp = 1650 V Vgap = 1000 V



Footprint size vs Vmcp

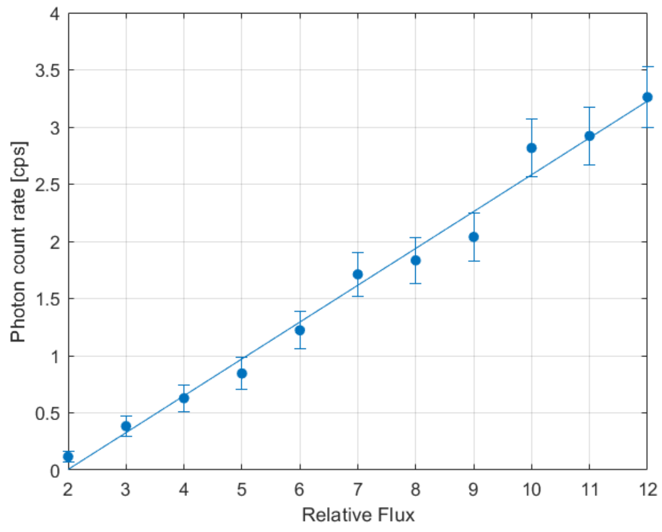


- MCP stimulated with a UV LED at 245 nm positioned externally to the vacuum chamber
- Each single photon generates a footprint in the detector
- Footprint size increases with increasing microchannel plate voltage

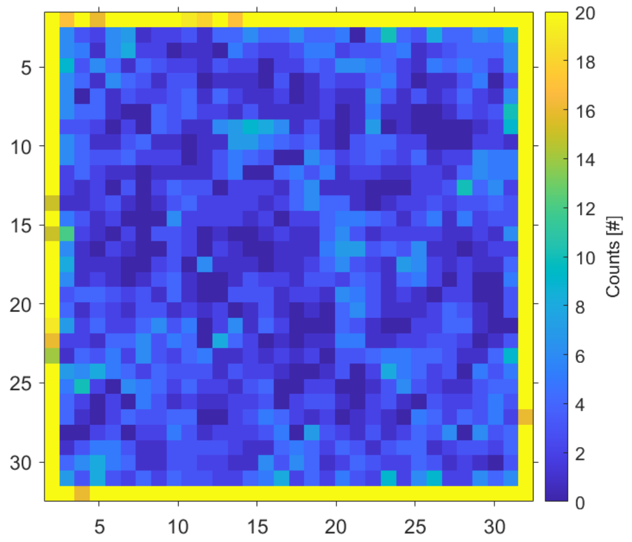


Linearity, uniformity and resolution

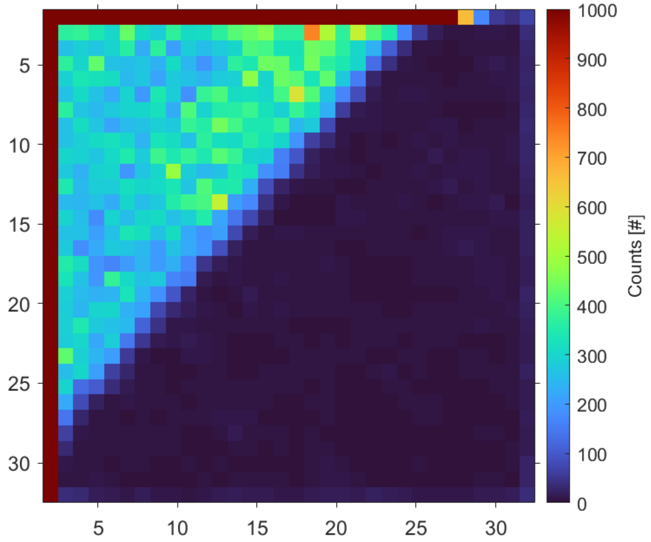
Linearity at low rates



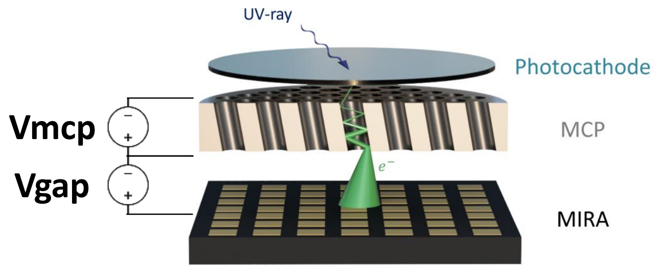
Uniformity at low rates



Spatial resolution



- **Linearity test:** variable photon flux of the LED
- **Spatial resolution:** measured with the knife edge technique (x: 1.2 pixels, y: 0.9 pixels)



R&D

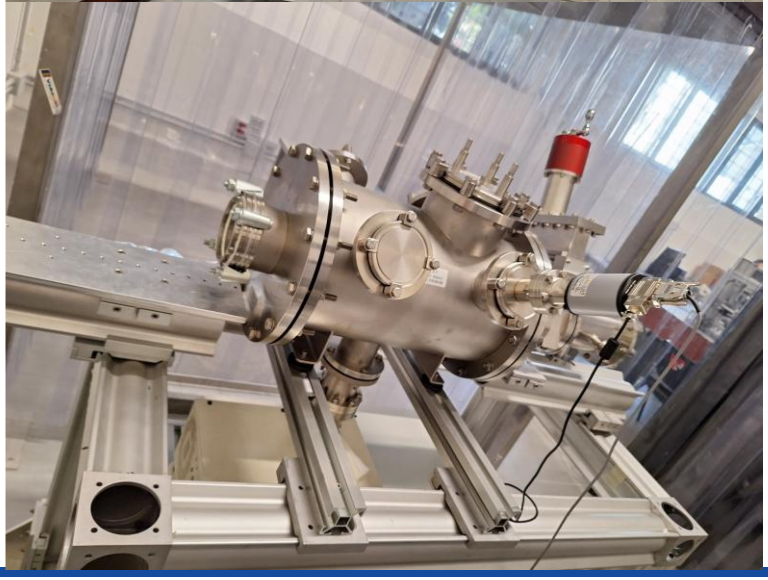
- As a result of this program, we identified several issues that needed to be addressed in order to develop an effective prototype, suitable for a comprehensive analysis of the limitations of this technology:
    - Power consumption
    - Thermal design
    - Materials outgassing
    - Improvement of the photon event recognition algorithms

- We also recognized that a dedicated R&D effort was needed to fully explore the potential of this architecture, rather than focusing prematurely on optimizing the prototype for a specific instrument.
- The goal is now to reach TRL 5, and only afterwards — when the risks are significantly more under control — consider a possible optimization for a specific application. From the outset, however, the development of the ASIC will be guided by its scalability.

Work in progress

We were awarded a Technogrant under the **2024 INAF Fundamental Research Call** with the proposal CLUMP — *Compact, Low-power, Ultraviolet Microchannel Plate Photon-counting detector* — through which we resumed our activities.

- A **new version of the MIRA** sent to production, solving several issues
- New **mechanical structure** to allow an easier mounting and demounting of the system
- New version of the **in vacuum PCBs** to improve the outgassing and avoid MCP damage



A new facility for the characterization of UV detectors is currently under development at IASF Milan, funded through the INAF call for the improvement of space laboratories. The facility — VULCAN (Vacuum Ultraviolet Laboratory for detectors Characterization And integratioN) — will support detector testing and integration activities.

A new version of MIRA, featuring enhanced photon detection algorithms, is currently under study. Additional funding will be required to implement it. Continued support needed to bring the system to TRL 5 (-> **PRORIS 2025 *proposal***)

Thank you for your attention !