University of Leicester
Space Research Centre

High TRL Photon Imaging Detector
for Space Situational Awareness Applications

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Scope

- Overview of photon counting applications
- Space situational awareness applications
- Project aims and objectives
- New detector technologies
  - Photocathodes – enhanced QE and lifetime
  - Microchannel plate – higher lifetime & efficiency
  - Square format image tubes – low mass, high fill factor
  - Image readout – high temporal and spatial resolution
  - Adaptive electronics – scene-dependent optimisation
- Success criteria
- Partner heritage
- Summary

Imaging photon-counting applications

- Space situational awareness applications
  - Faint object tracking
  - Space weather
    - imaging and spectroscopy of planetary aurora and limb
    - magnetospheric charge exchange emission
- Space science applications
  - high resolution imaging and spectroscopy
    - optical and UV planetary science and astronomy
- Additional terrestrial applications
  - Biological and medical sciences
    - time resolved spectroscopy e.g. fluorescence lifetime imaging
  - High energy physics
    - picosecond timing for Cherenkov detection
  - Materials analysis
    - semiconductor testing
  - Defence and security sectors
    - neutron imaging, 3D imaging, low light level surveillance, threat detection.

Space situational awareness: Faint object tracking

Slow frame rate CCD

- Detector sums:
  - Object counts
  - Diffuse background
  - Readout noise
- Low frame rate →sums over all Δt
- Object signal competes with sky background

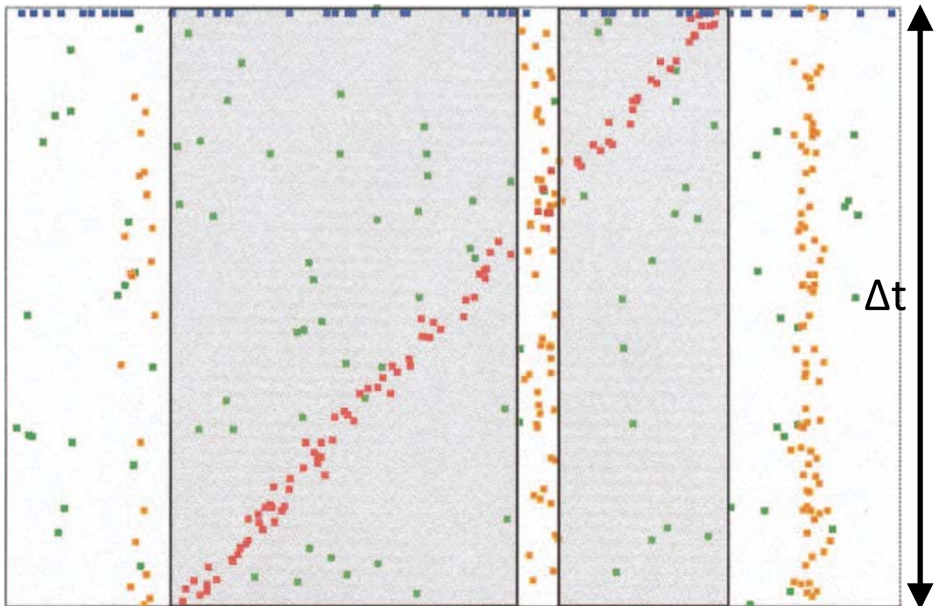


Figure credit: Priedhorsky, Applied optics 44(3), 423

Horizontal axis: space
Vertical axis: time
Object counts: red
Diffuse background: green
Readout noise: blue
Detector sums grey region

Space situational awareness: Faint object tracking

Higher frame rate CCD

- Detector sums:
  - Object counts
  - Diffuse background
  - Readout noise
- Multiple frames over Δt
- Object signal competes with:
  - lower sky background
  - Higher readout noise

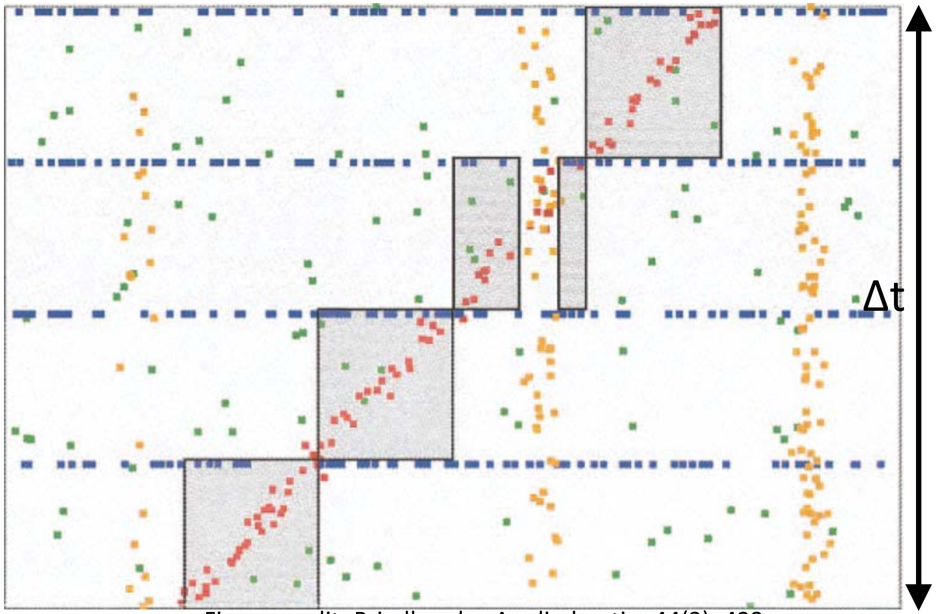


Figure credit: Priedhorsky, Applied optics 44(3), 423

Horizontal axis: space
Vertical axis: time
Object counts: red
Diffuse background: green
Readout noise: blue
Detector sums grey region

Space situational awareness: Faint object tracking

Photon counting detector

- Sub-ns time resolution

  ≡ very high frame rate

- No readout noise
- Sky background:
  - summed only per resolution element

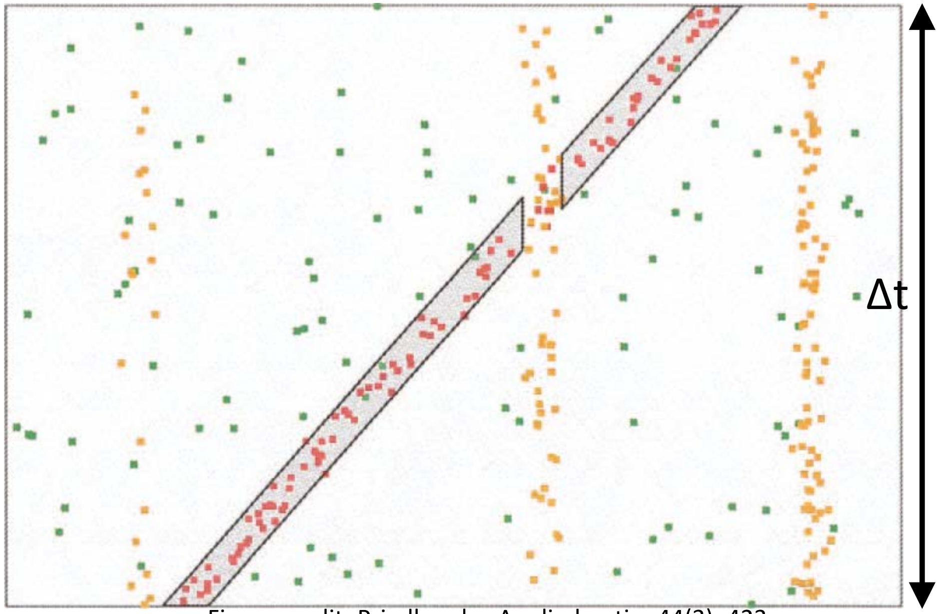
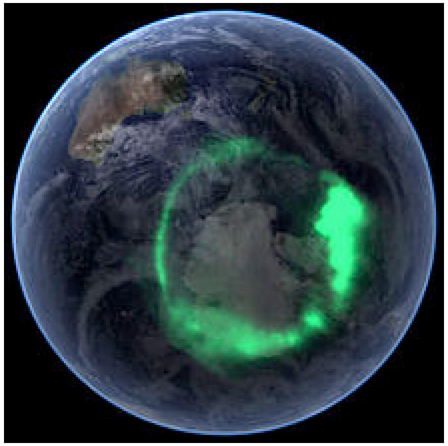


Figure credit: Priedhorsky, Applied optics 44(3), 423

Horizontal axis: space
Vertical axis: time
Object counts: red
Diffuse background: green
Readout noise: blue
Detector sums grey region

Space situational awareness: Space weather

- Techniques to measure solar wind interaction
- Predictions for effects on:
  - Satellite health and survival
  - Space and terrestrial communications
  - Terrestrial weather
- Auroral and limb imaging



Aurora Australis from NASA IMAGE satellite

- Magnetospheric charge exchange emission
  - Open-faced detector with soft x-ray photocathode

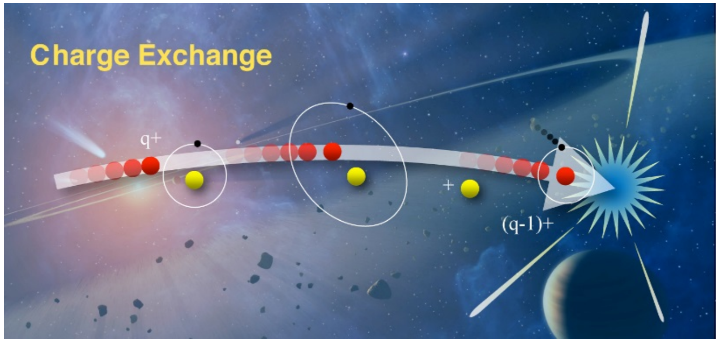


Image credit: D. Bodewits (University of Maryland)

Project Aim

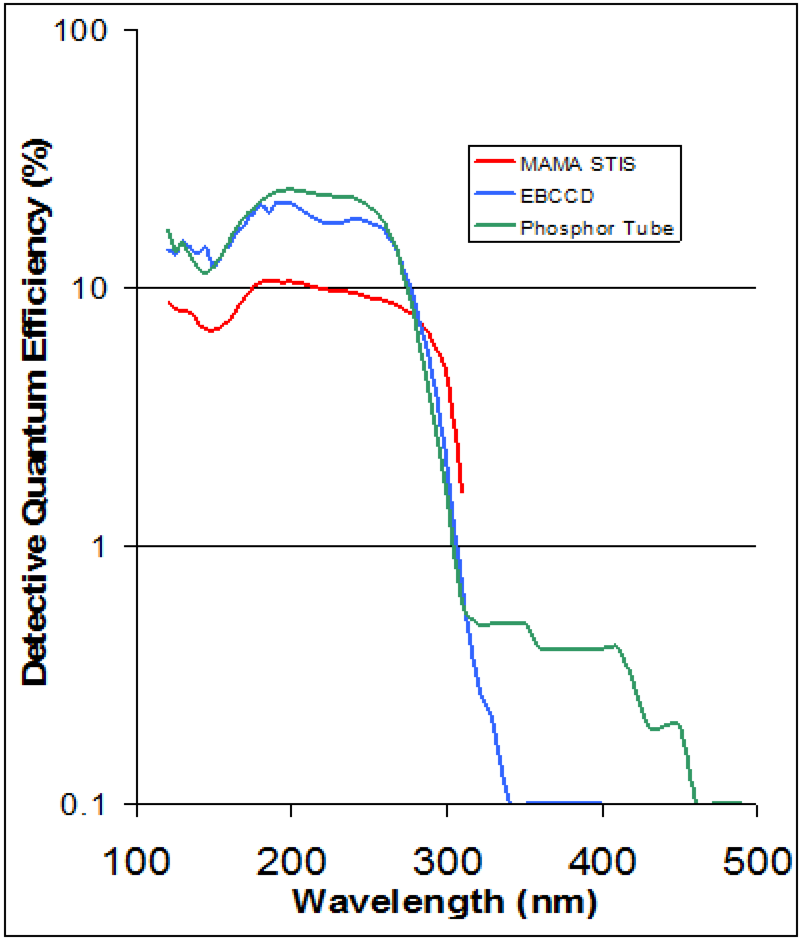
- Develop high TRL technology demonstrator
  - Combine latest technological developments
  - Covering all aspects of detector performance
  - Improved photo-response (efficiency)
  - Imaging performance (rate/resolution trade-off)
  - Sub-nanosecond single photon timing
  - Mechanical format for high density packing
  - Enhanced detector lifetime

Project Objectives

- UV solar-blind photocathode technology
  - Photek's state-of-the-art cut-off of optical wavelengths
  - allows UV detection at photon counting sensitivity at high background light levels
- Enhanced MCP performance using atomic layer deposition (ALD)
  - Enhanced detector lifetime, quantum efficiency, lower noise, higher signal dynamic range, lower HV
- Square tube, thin wall, low mass detector design
  - high fill factor, detector arrays with low dead area.
- High speed capacitive division image readout (C-DIR)
  - low complexity, cost-effective, centroiding image readout
  - Enhanced count rate, image resolution, and time resolution performance
- Adaptive digital processing electronics
  - scene dependent optimisation for enhanced dynamic range
  - digital filtering for real-time count rate vs image resolution trade-off
- Demonstrator system combining enabling technologies
  - TRL 6 typically required for entry into space missions
- Performance goals:
  - Resolution: ≤10 µm FWHM, photon rate: ≥5 Mcount/s, lifetime >10C/cm^2 ≡ ~10^{14} event/cm^2

Photocathode developments

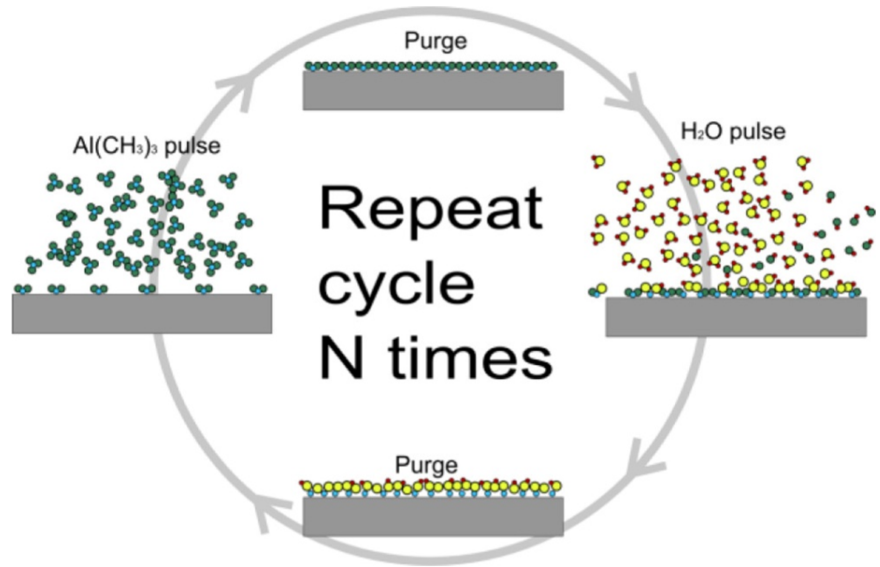
- Solar-blind CsTe photocathode
  - Photek world-leading performance
- Optical wavelength rejection
- Cut-off of two orders of magnitude >350 nm.
- Peak quantum efficiency (QE) at 254 nm 9% (HST) →34%
- Applications in the scientific, commercial and military sectors
- Detection of distant, faint UV sources
  - Auroral imaging, UV astronomy
  - flames, jet engines, missile plumes
  - high level of optical background rejection (cf. CCD red leak)



MCP enhancement using Atomic Layer Deposition

- Production of very thin, pinhole-free conformal films
- Two step, sequential, self-limiting process
- Two precursors react to produce atomic scale films

Alumina deposition

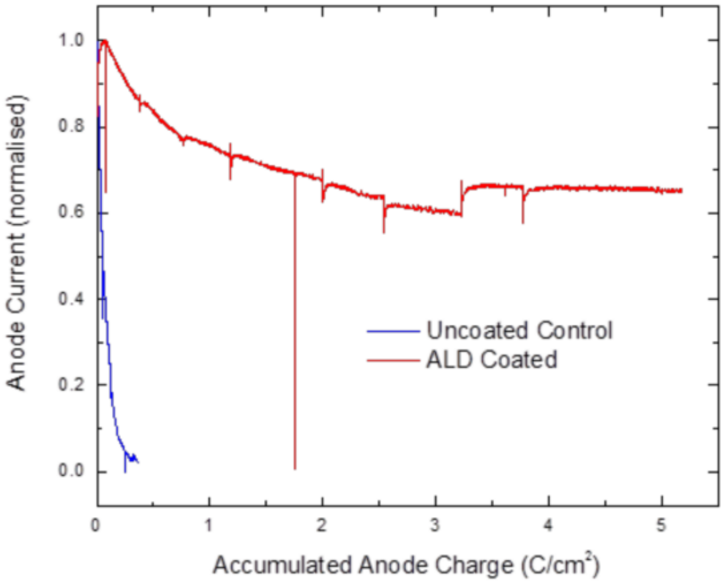


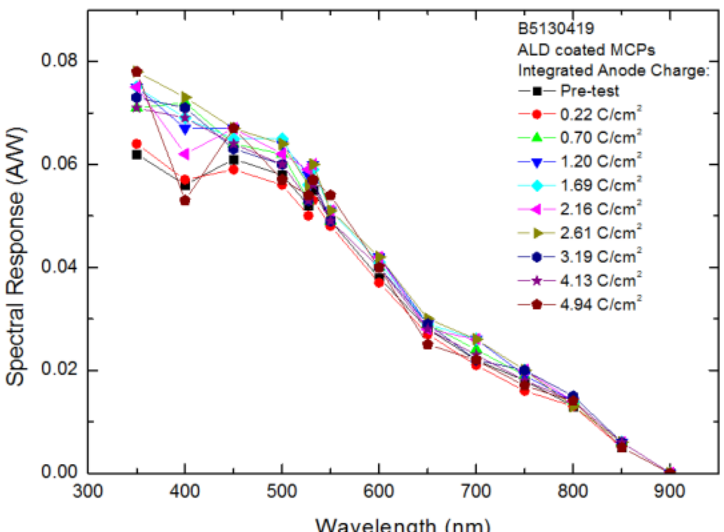
Courtesy: SPIE Newsroom, 8 May 2012

- Low vacuum (viscous flow)
- Elevated temperature (100’s °C)

ALD enhanced MCPs

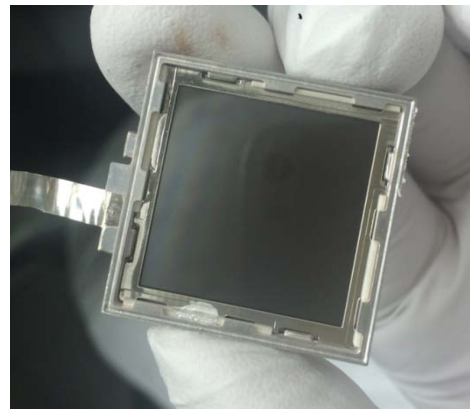
- ALD coating of conventional MCPs
  - several monolayers of material
- Enhance the secondary electron yield (SEY)
- Improved QE due to “first electron bounce” statistic
  - ALD coating enhances MCP QDE by over 20%
- lower operating voltage due to the higher SEY
- increased detector lifetime due to reduced MCP outgassing
  - ALD seals in adsorbates on the MCP surface
  - Reduces ion feedback which causes QE loss

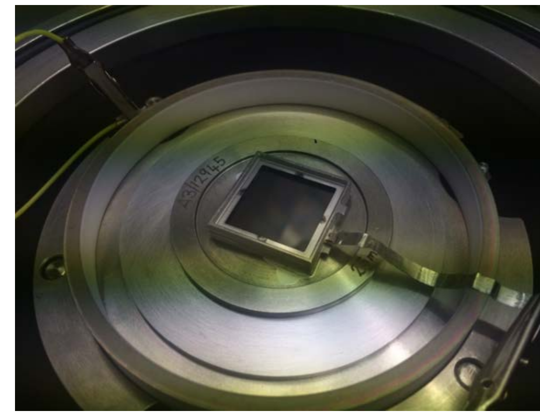


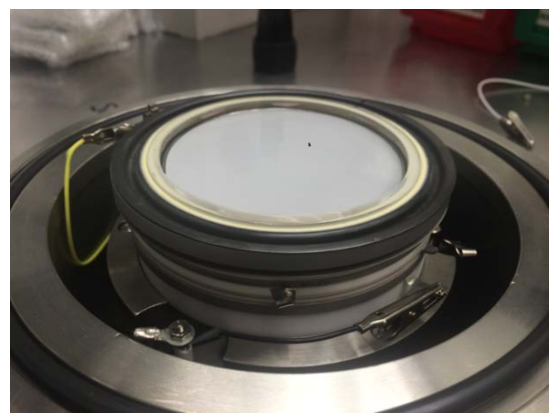


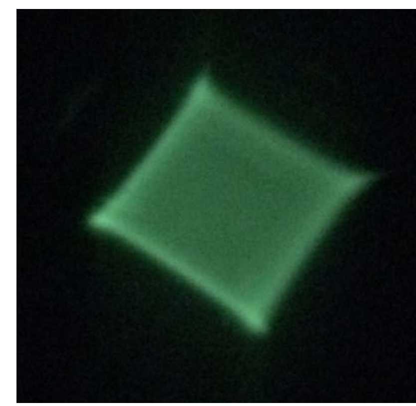
Square format MCP detector

- Thin-walled square tube recently developed
- Application-friendly square image format
- Easier close packing of tube arrays
- Smaller dead space between active readout regions
- Project aim: enhance TRL for space mission adoption

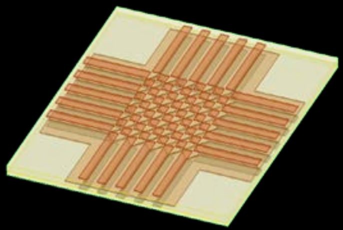








CERN, 18th December 2014



C-DIR

precision photon imaging and timing readout

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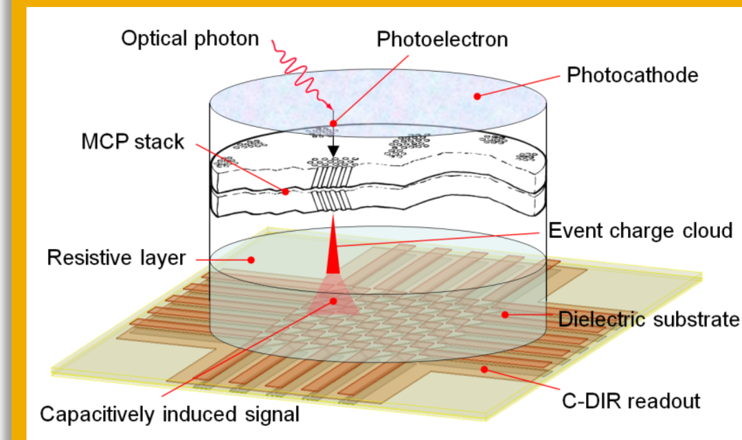
C-DIR – the "Capacitive Division Image Readout"

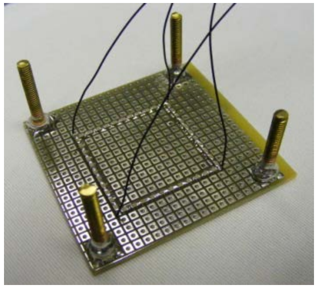
Capacitive division – breakthrough performance

- A new concept in centroiding readouts
- Purely capacitive – picosecond timing potential
- No resistive noise – no partition noise
- 25 x 25 mm² C-DIR – pattern capacitance of <8 pF!
- Very low total noise (<200 e^- rms at τ=250ns)
  → 1000 × 1000 pixel² at 10^6 electrons.
- Simple linear algorithm – minimal processing
- Excellent linearity - utilize >80% of anode
- Capacitances intrinsic in pattern geometry

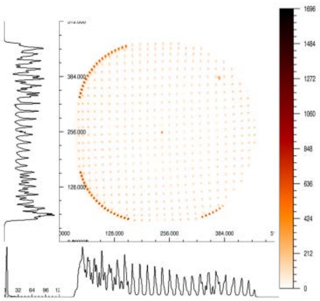


- Event charge is localized on resistive layer
- Transient signal induced through dielectric
- Dielectric substrate part of vacuum housing
- Induced signal sensed by C-DIR readout
- C-DIR - a capacitively coupled electrode array

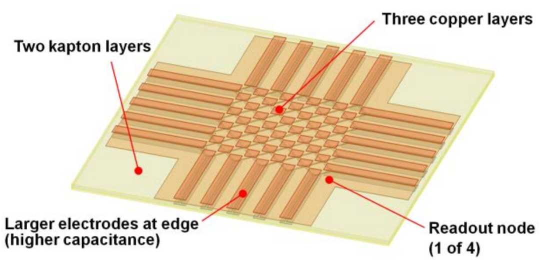
Proof-of-concept prototype



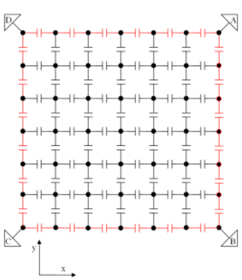
Prototype image data



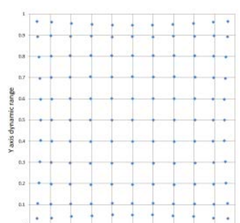
Optimised flex-PCB C-DIR readout



C-DIR equivalent circuit



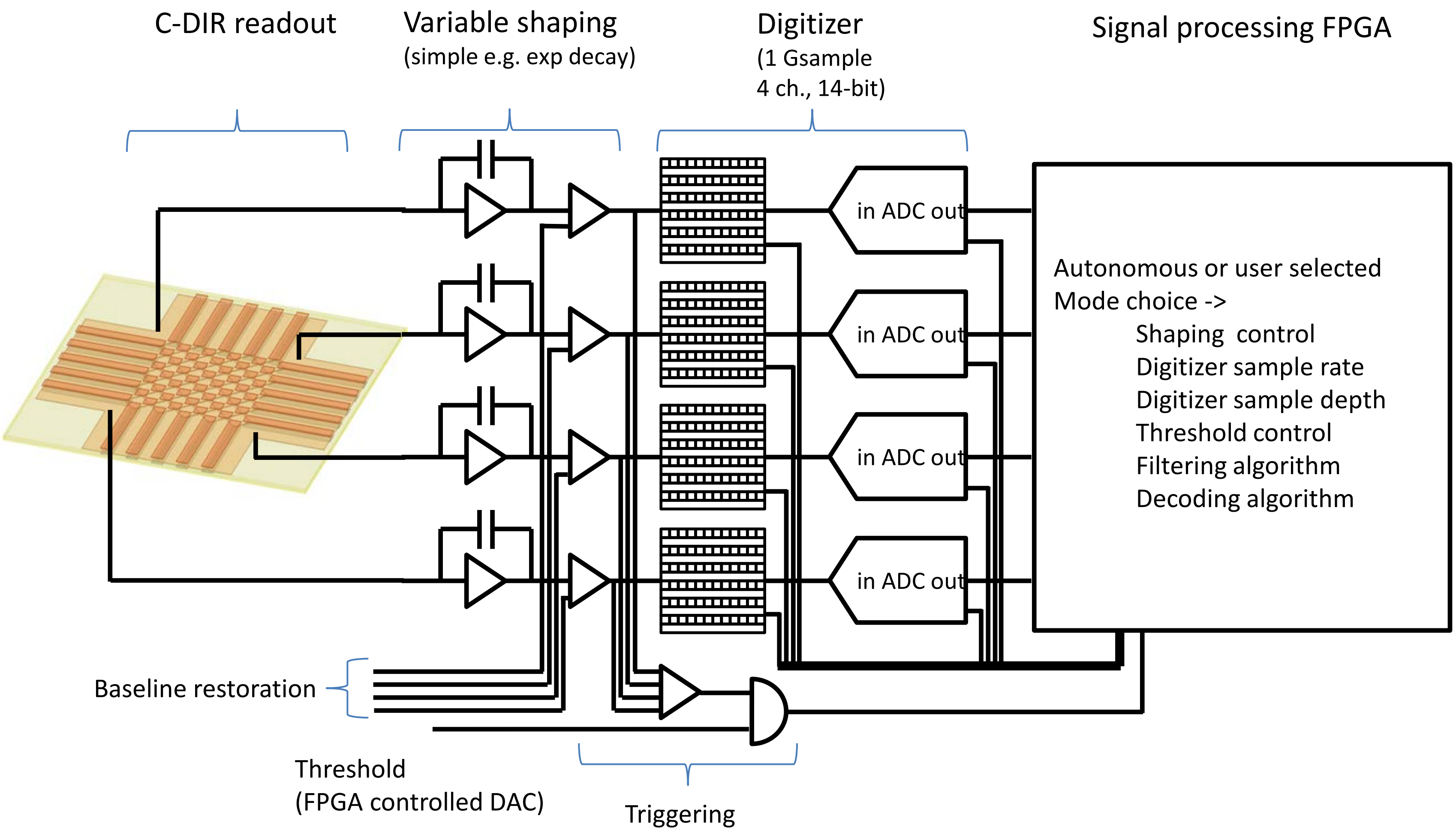
Linearity simulation



Applications

- Wide-field fluorescence lifetime imaging (FLIM)
- Sub-nanosecond photon-timing/imaging
- pptv trace gas measurement using BBCEAS
- UV astronomy – imaging and spectroscopy
- TOF applications in materials science
- Ring Imaging Cherenkov detectors for HEP

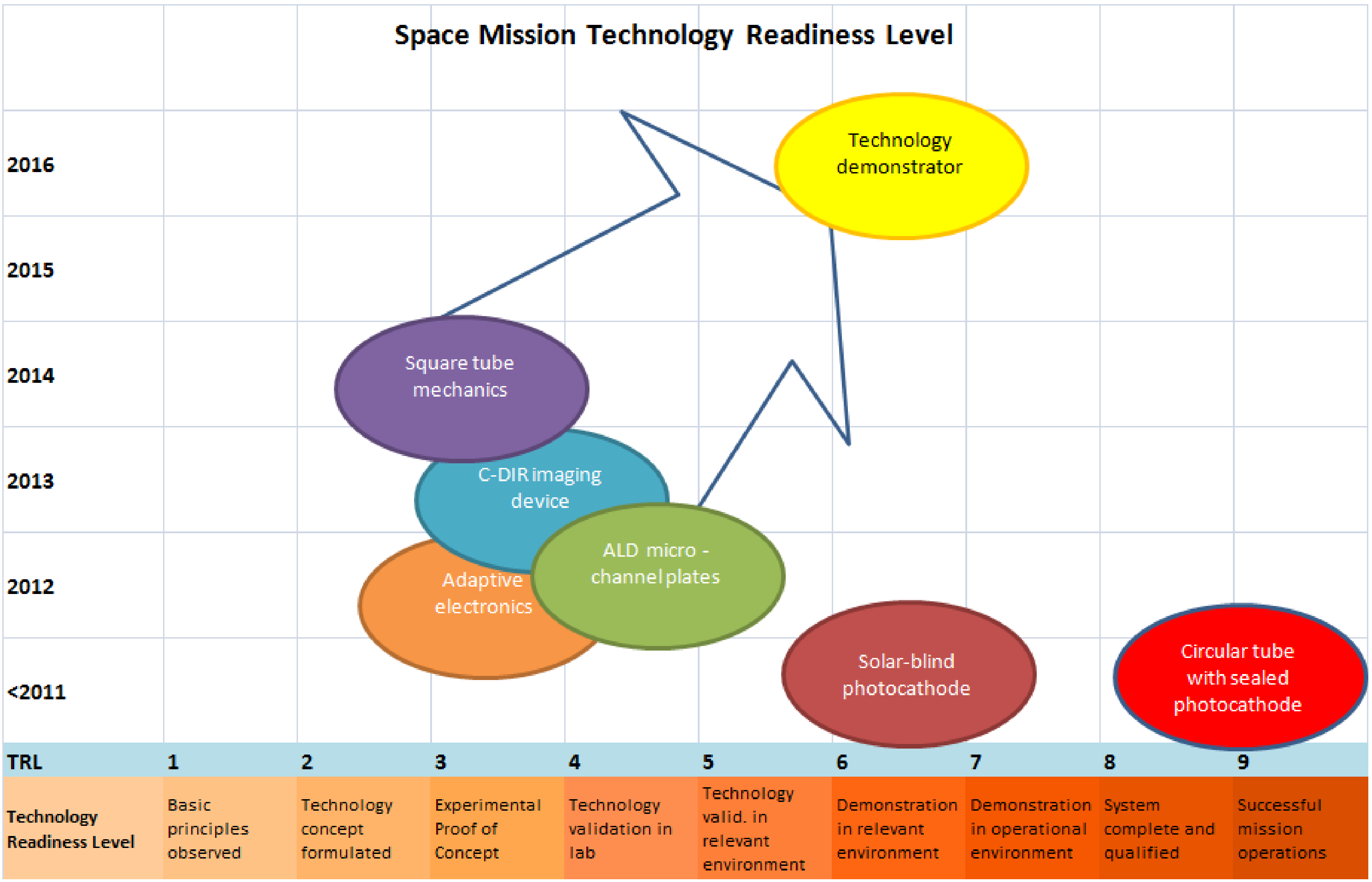
Adaptive Electronics



Success Criteria

- Combination of enabling technologies
  - In a single device at TRL 6
  - As a fallback – 2 devices (circular and square formats)
- Detector performance goals:
  - Resolution: $\leq$10 µm FWHM
  - photon count rate: $\geq$5 Mcount/s
  - lifetime >10C/cm^2 $\equiv$ ~10^{14} event/cm^2
- Adoption in space mission proposal(s)
  - Enquiries very welcome

Success Criteria (2)



Project partner heritage

- University of Leicester, Space Research Centre
  - MCP detectors for X-ray/UV astronomy
    - Exosat-CMA
    - ROSAT-WFC
    - AXAF-HRI
    - J-PEX
- Photek Ltd.
  - Custom space qualified MCP tubes for astronomy, EO and space weather
    - ACE – Advanced Composition Explorer
    - XMM – Optical Monitor
    - MSX-UVISI – Detector
    - TIMED-GUVI – Global Ultraviolet Imager
    - DMSP-SSUSI – Special Sensor Ultra-violet Spectrographic Imager
    - Astrosat-UVIT – Ultra-Violet Imaging Telescope

Summary

- Assembly of state-of-the-art detector technologies
  - Enhanced QE, life time, imaging, square format
  - Scene adaptive performance optimization
  - Aimed at Space situational awareness applications
    - Faint object tracking
    - Space weather
  - High TRL demonstrator for early mission adoption

Acknowledgements

- University of Leicester
  - Steven Leach – Project Scientist
- Photek Ltd.
  - Martin Ingle – Project manager