HMRM: A highly miniaturised radiation monitor

ESA/ESTEC radiation and plasma monitoring workshop

May 13-14th, 2014

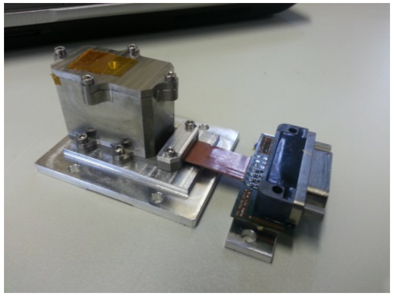
Contact: Sev.gunes-lasnet@stfc.ac.uk

RAL Space

Science & Technology Facilities Council Technology

Imperial College London

Overview



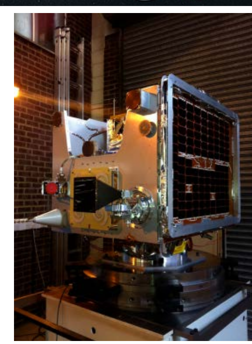
- HMRM: A Highly Miniaturised Radiation Monitor, designed by the Rutherford Appleton Lab and Imperial College London
- HMRM design and competitive characteristics
- Performances
- Flight in 2014 and next steps

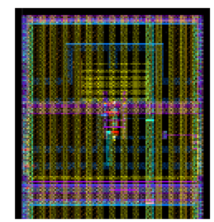
HMRM – The context

- Existing sensors fall into two classes
    - “Low” resource requirements / dose data
    - “High” resource requirements / “scientific” grade data

Credit: Sandia national lab

Credit: SREM





????

- HMRM objectives: Bridge the gap through miniaturisation without sacrificing the radiation data quality
- Radiation data temporally resolved, particle flux and spectra

RAL Space

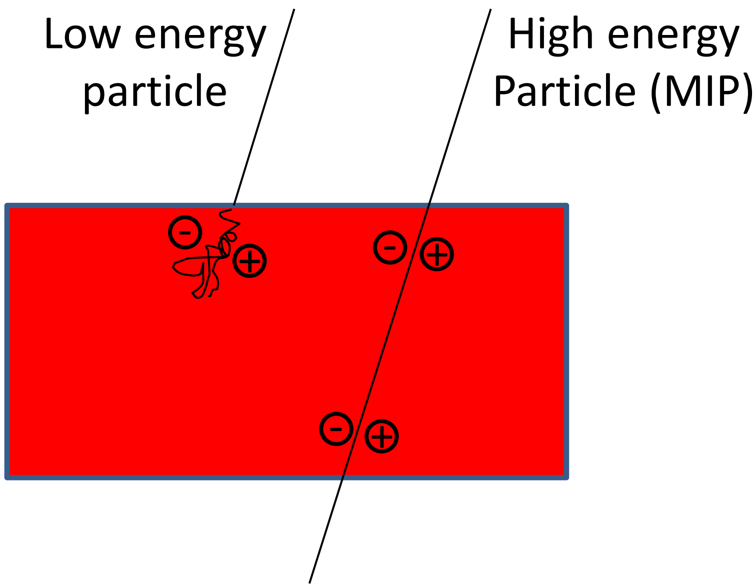
Science & Technology Facilities Council Technology

Imperial College London

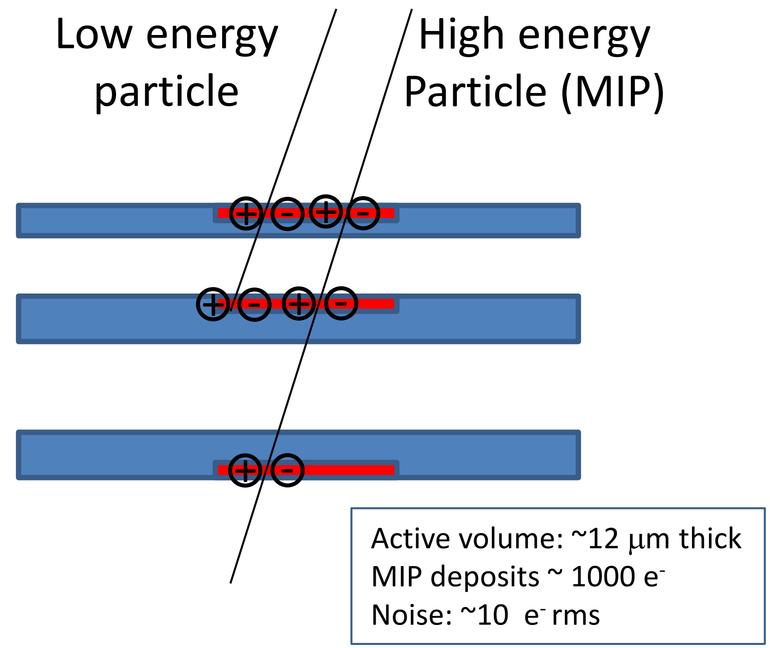
ESA/ESTEC radiation and plasma monitoring workshop, May 2014

State of the art sensing: Sensor Tradeoff

PIN Silicon Diode

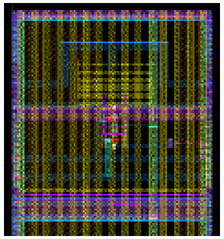


Active Pixel Sensor



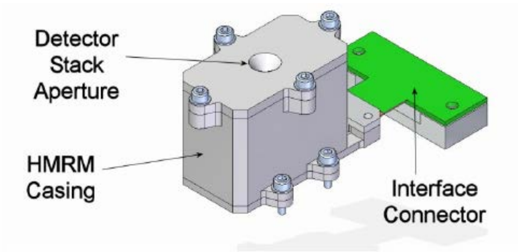
- Ambiguity exists where the energy deposited in the detector by a low energy particle is the same as the energy deposited by a MIP passing through the detector
- Active volume of APS detector: 12 μm with 50-500 μm substrate
- Active volume of Silicon diode: > 50 μm
- With APS sensors, judicious selection of Silicon substrate thickness allows the dE/dx curve to be sampled and uniquely identify the particle species and energy

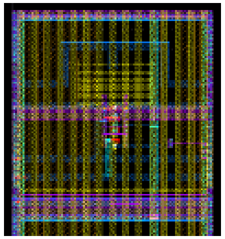
State of the art sensing and standard interfaces

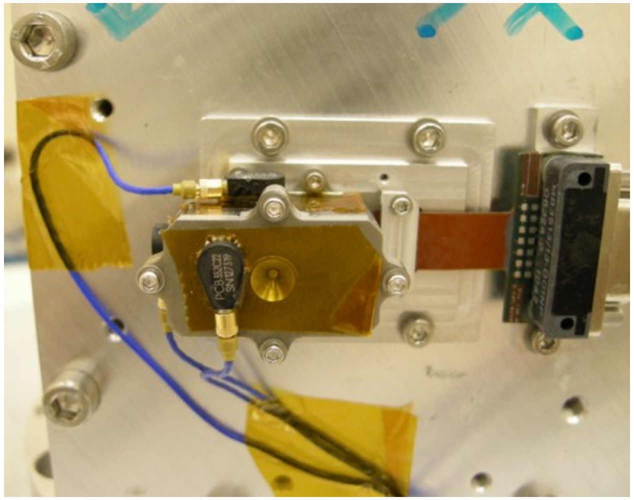


- State of the art sensing
  - 0.18µm CMOS image sensor technology
  - Digital and analogue read out
  - Integrated DAC, temperature sensor
  - All integrated into a very small mixed asic
  - Used in a stack configuration in HMRM
- Standard interface for the integrated stacked monitor
  - CAN standard interface
  - CCSDS compliant TM frames
  - Requires 5V power line

HMRM – the Highly Miniaturised Radiation Monitor as it exists now

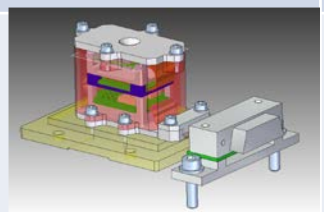
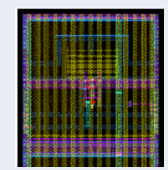






- Electron energy range: 35 keV-6MeV
- Proton energy range: 600 keV-500MeV
- Mass: 52g
- Power: < 1W
- Typical particle rate 10e8 #/cm2/s
- Stacked monitor and detector ASIC

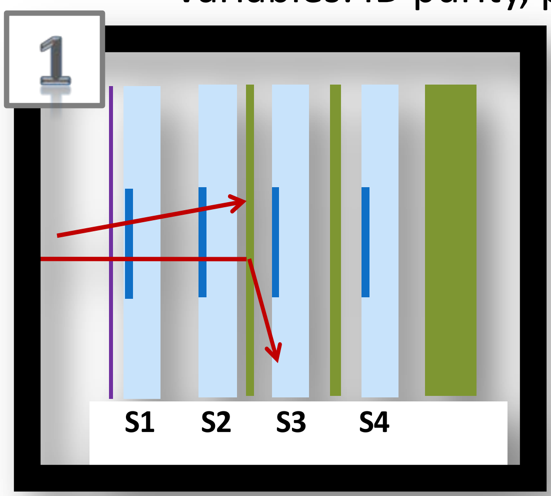
Design Summary – integrated / chip

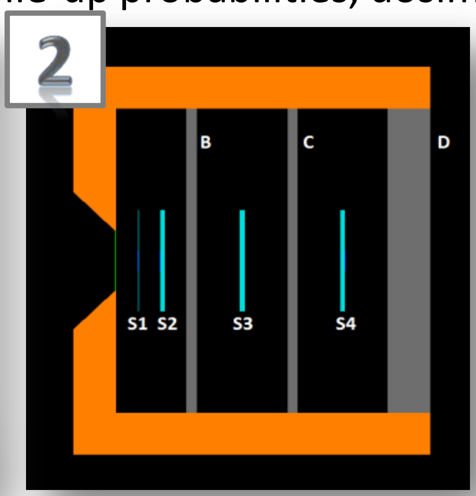
Characteristic	Specification	
Sensing element	50 x 50 array of 20 μm x 20 μm , APS detectors	
Configuration	Either single chip, or integrated monitor	
Mass	Integrated monitor: 52g (including fasteners and connector) in a stack configuration	Single Chip: 0.8 g
Power	1 W (TBC) depending of number of detectors in stack	Single Chip: < 200 mW per ASIC
Volume	Integrated monitor: 20x25x30mm	Single chip (unpackaged): 2.54x10x0.6 mm
Radiation measurements	Integrated Monitor: Dose Dose rate Particle radiation spectra: • Electrons: 0.06 – 6 MeV • Protons: 1 – 500 MeV 	Single Chip: Dose Dose rate 
Maximum flux	10^8 #/cm^2/s	
Aux. measurement	Temperature	
Interface	Integrated Monitor: Data: TM/TC CCSDS CAN Power: 5 V (standard)	Single Chip: Data: CMOS logic I/O Power: 3.3 V + 0.3V references

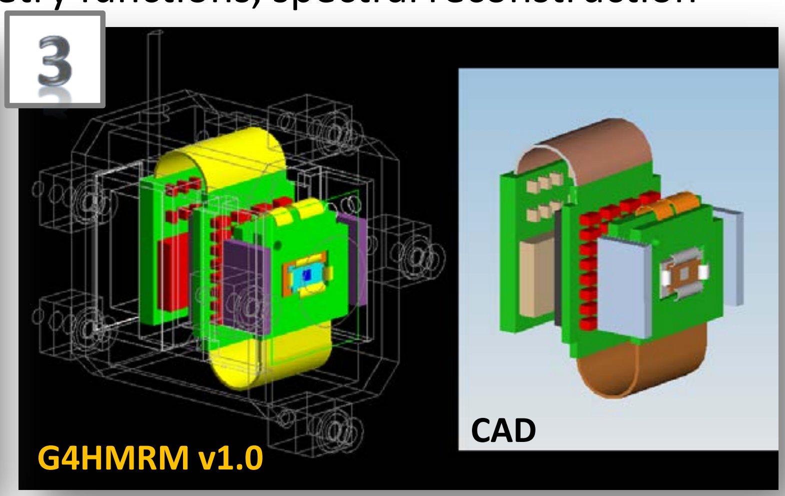
Performances - Geometry design

1. **Conceptual design:** APS telescope with low threshold for e/p discrimination
   - Parameters: number of sensors and shields, depletion thickness, aperture size
   - Variables: energy thresholds, sensitive area, particle ranges and dE/dx
2. **Optimisation** with preliminary simulation geometry of particle telescope
   - Parameters: dimensions/materials for wafers, shields, casing, window, algorithms
   - Variables: thresholds, effective area, efficiency and purity for PID
3. **Validation** with <u>full simulation geometry</u> in 5 reference orbits
   - Parameters: algorithm tables (on-board and ground segment)
   - Variables: ID purity, pile-up probabilities, dosimetry functions, spectral reconstruction

see E. Mitchell's thesis

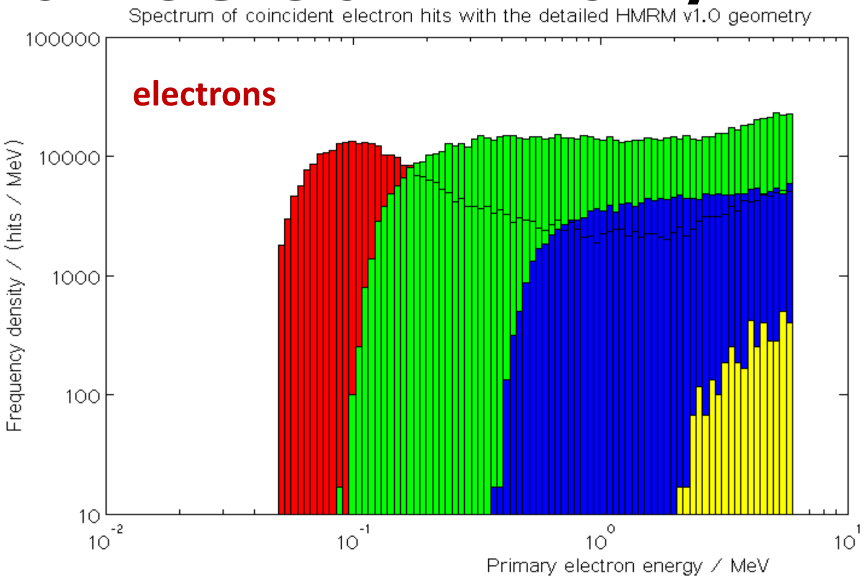


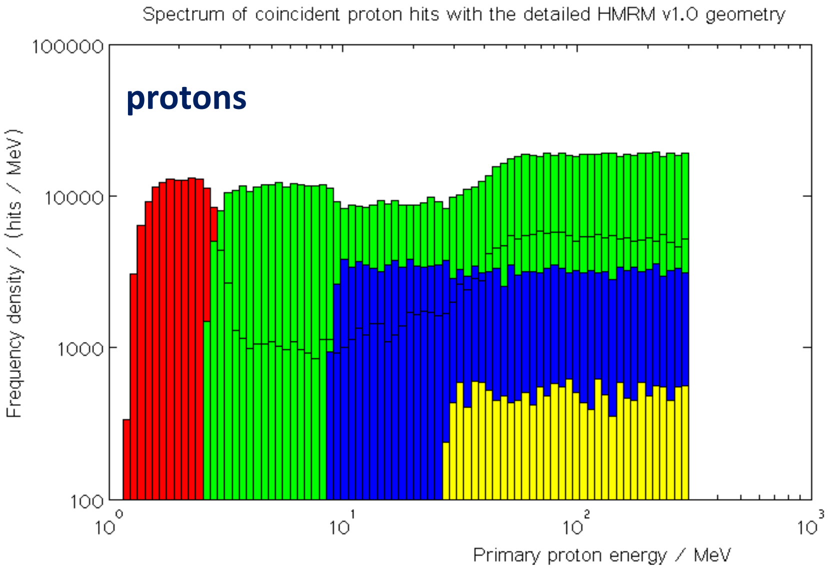




Simulated performance summary

- **Electron threshold: 63 keV**
- **Proton threshold: 1.3 MeV**
- **Maximum omni/d flux: 1×10^8 cm^{-2}s^{-1}**
- **Dosimetry**
  - Count rate on front sensor
  - Dose rate on all sensors
  - Also cumulative lifetime doses
- **On-board alerting functions**
  - 3 programmable particle 'channels'
- **Offline spectral reconstruction**
  - Electron/proton energy spectra

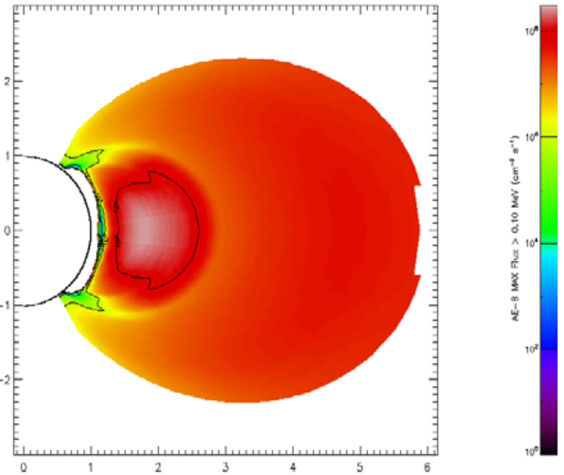




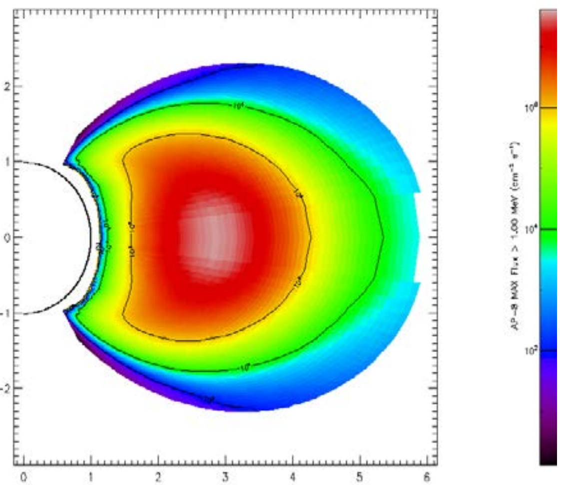
HMRM REFERENCE ORBITS

ORBIT D (23,222 km, 56° MEO, 14 hrs x3)

electrons >100 keV



protons >1 MeV



SPENVIS AE-08, AP-08

orbit	type	altitude	incl.	period	comment
A	LEO	700 km	98°	1.65 hrs	SSO; weather, remote sensing
B	MEO	400-4,000 km	83°	2.19 hrs	Elliptical; space science
C	MEO	10,000 km	0°	5.79 hrs	"Optimal" earth observation MEO
D	MEO	23,222 km	56°	14.07 hrs	Navigation
E	GEO	35,786 km	0°	23.93 hrs	Communications, meteorology

MEOs are most challenging (orbits B, C, D)

orbit	max e/s	max p/s
A	10,000	7
B	100,000	200
C	100,000	30,000
D	100,000	200
E	30,000	1

Maximum instantaneous flux

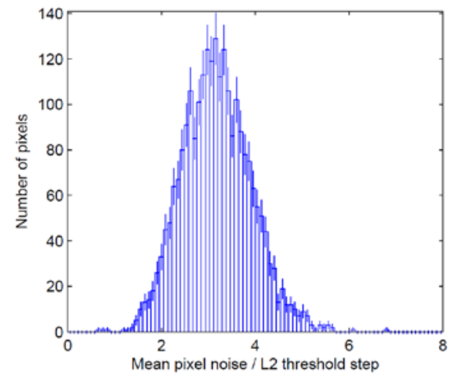
HMRM count rates: geometrical factor AEF ~ $0.1mm^2$

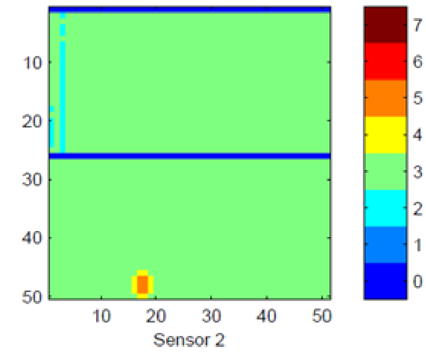
Instantaneous omnidirectional flux of $10^8\ cm^{-2}s^{-1} \rightarrow 10^5$ c/s

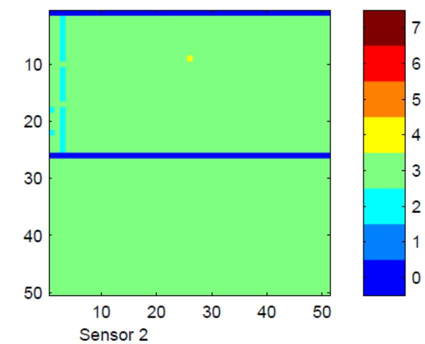
With dynamic shuttering, the HMRM can cope with this count rate and retain PID capability (i.e. low pile-up)

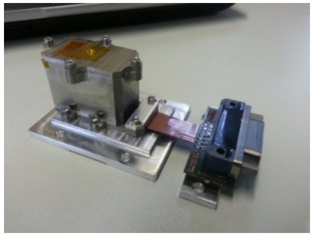
Achievements to date

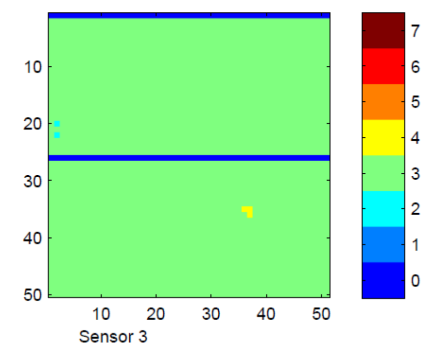
- Completed TRP contract
- HMRM integrated as part of Tech Demo Sat -1 payload, launch June 2014
- Monitor performance functionally characterised
- Tests with ^{241}Am, ^{90}Sr and ^{55}Fe have demonstrated performance





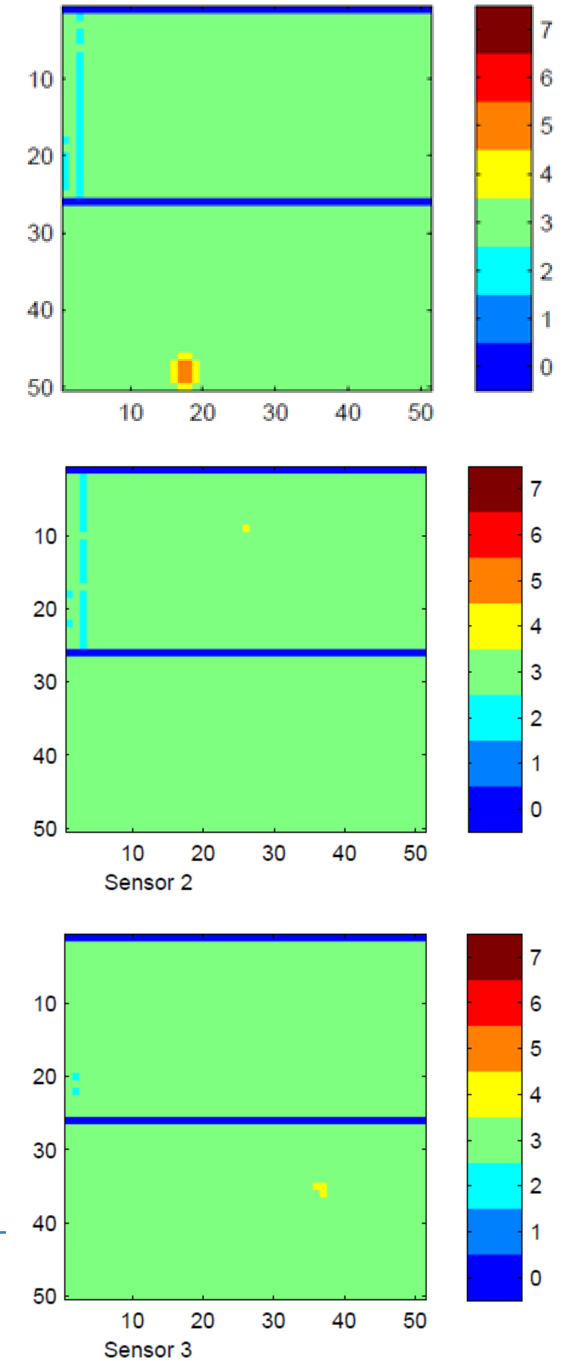






Functional testing

- HMRM has been exposed to two radiation sources: An ^{241}Am (alpha particle source) and a ^{90}Sr (beta particle source)
  - Hits are clearly visible in the detectors images.
  - Exposure to the ^{90}Sr, which gives more penetrating electrons, has enabled observing coincident (S2, S3) hits. A larger-deposit is observed on the back sensor as expected for a slowing down electron.
  - The two dark rows of pixels visible in the detectors images have been corrected after optimisation of the readout waveform timing.
- **The results with alpha and beta particle sources have confirmed that the prototype with a configuration of two stacked detectors is fully functional.**



Performances summary

- Electron Energy Range 35 keV – 6 MeV
- Proton Energy Range 600 keV – 500 MeV
- Maximum Particle Flux 10^8 #/s/cm^2 guaranteed by its electronic shutter technique
- Heavy Ion Detection: Detection and count; configurable range of energy detected by threshold tuning in HMRM algorithm

- State of the art sensing
  - 0.18µm CMOS image sensor technology, patented radiation hard techniques
  - Digital and analogue read out; integrated DAC, temperature sensor
  - All integrated into a very small mixed asic
  - Used in a stack configuration in HMRM

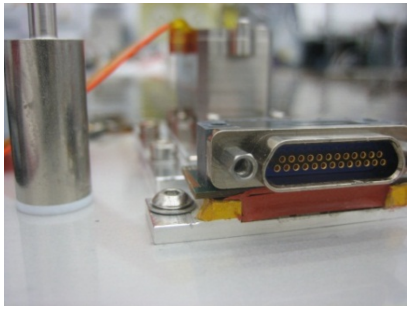
- **The results with alpha and beta particle sources have confirmed that the prototype with a configuration of two stacked detectors is fully functional.**

- **Calibration with Fe55 is ongoing and beam line testing scheduled for Q3 2014**

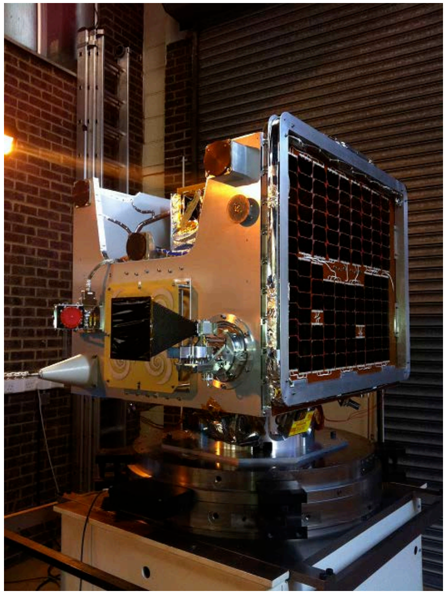
HMRM 2014 flight

- 2014 validation flight has been successfully secured : **TDS-1 (SSTL)**
  - HMRM delivered successfully to SSTL TDS-1
  - Electrical acceptance tests on TDS-1 fully successful
  - Mounted on the spacecraft, awaiting launch Q3 2014
  - Commissioning preparation has started
  - Operations start Q4 2014

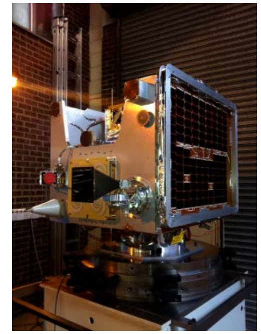
- **HMRM TDS-1 in orbit demonstration flight will acquire in situ data and provide valuable return of experience on HMRM operations**

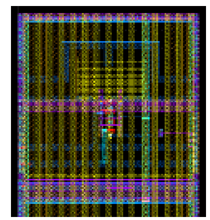


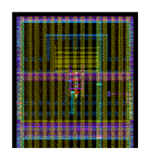
HMRM fitted on TDS-1 at SSTL, Q1 2013



HMRM bridges the gap







Status and way forward

- <u>Status:</u>

- Functional sensing ASIC available now; v3 optimised will be available Q4 2014, with lower power consumption
- Integrated stacked monitor EM available now and flying on TDS-1 this year

- Further Fe55 calibration ongoing now and beam line testing scheduled for Q3 2014
- In-orbit demonstration secured on-board TDS-1, launch Q4 2013

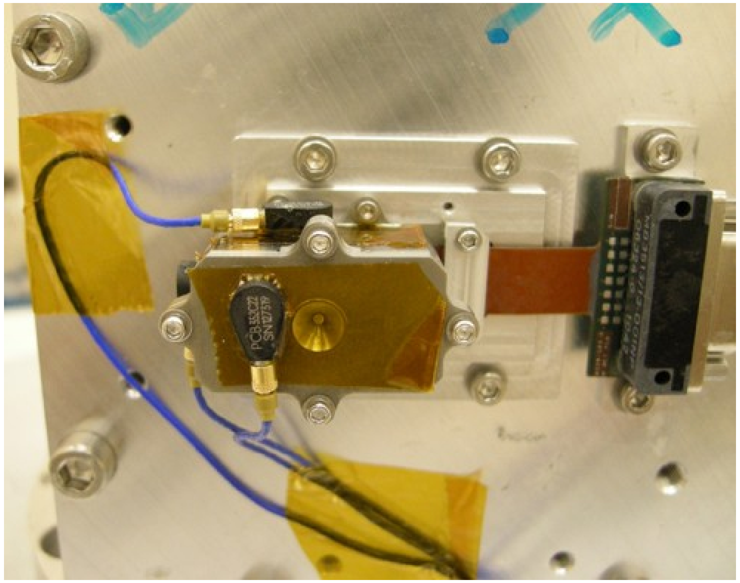
- <u>Way forward:</u>

- Qualified HMRM availability target: 2016, qualification strategy supported by ESA – aiming to be fast track

- Interested customers who have already expressed their support:
  - ESA
  - NASA /JPL
  - CNES &ONERA
  - SSTL
  - Japan
  - Airbus space and defense and ThalesAleniaSpace

Conclusions

- HMRM bridges the gap between scientific grade radiation data instruments and radfets, without sacrificing data quality, for the mass budget of a matches box



- HMRM state of the art sensing mixed ASIC is readily available
- Integrated stacked monitor version EM available
- Qualification strategy supported by ESA, target FMs for 2016
- If you are interested, contact sev.gunes-lasnet@stfc.ac.uk