Position Sensitive Detectors for space plasma and energetic particle instruments

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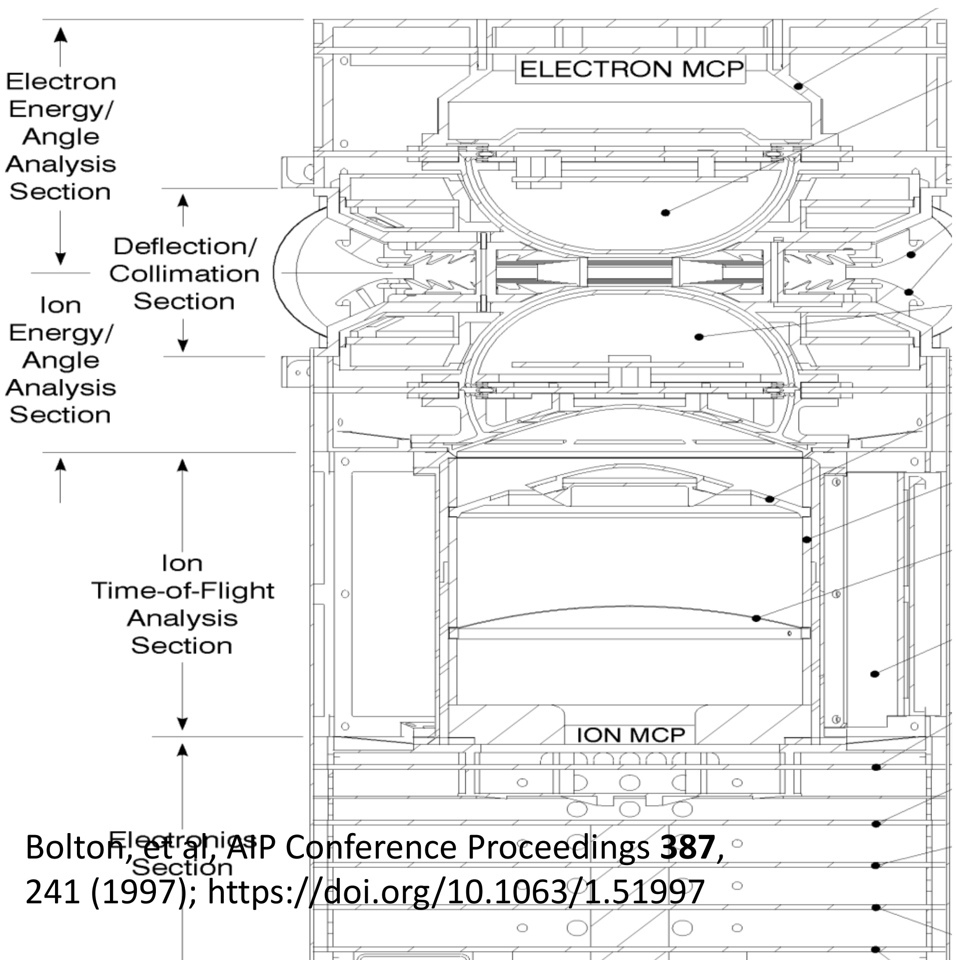
Plan

- Space-based particle instrumentation
  - Brief introduction – plasma and energetic particles
- Position sensing techniques
- A look at state-of-the-art and future requirements
  - The small satellite revolution
- Emerging technologies and potential exploitation

Particle energy and instrumentation

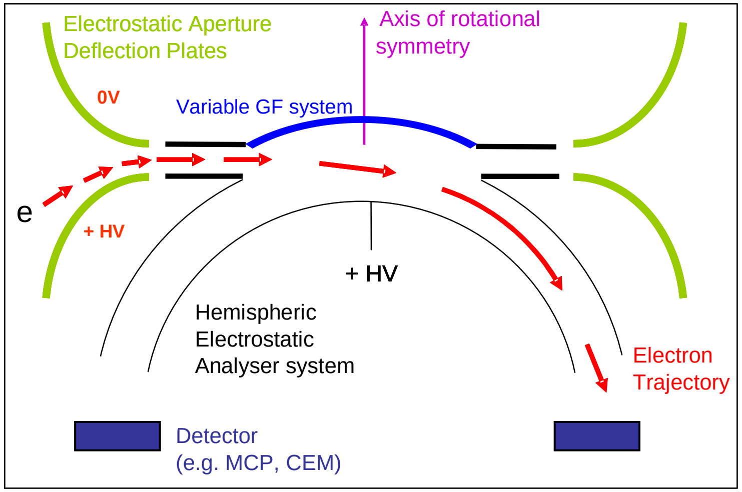
- Low energy. Typically < 50 keV
  - Plasma Analysers
  - Higher energies limited by high voltage requirements
- At higher energies, obtain energy by direct detection - interaction of particles with matter
- For a charged particle
  - Energy deposited is proportional to number of electron hole pairs created
  - dE/dx a MZ^2/E – can be used for particle identification by using two detectors
  - Lower energy detection limited by entrance window thickness
    - Different energy threshold for electrons and ions

Plasma Analysers - 1



Bolton, et al, AIP Conference Proceedings **387**, 241 (1997); https://doi.org/10.1063/1.51997

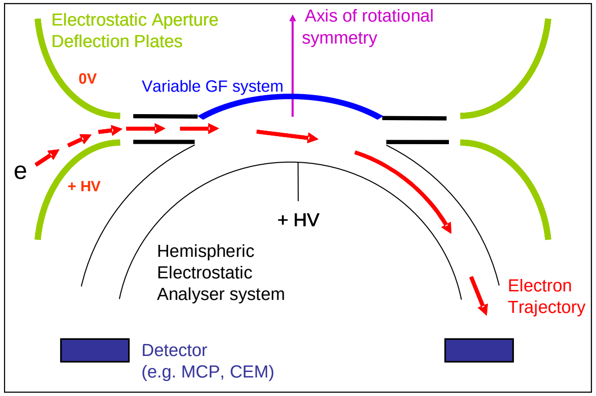
- Popular top-hat geometry
- Detectors of choice
  - Micro-channel plates
  - Channel Electron Multipliers
  - Silicon detectors with electrostatic pre-acceleration



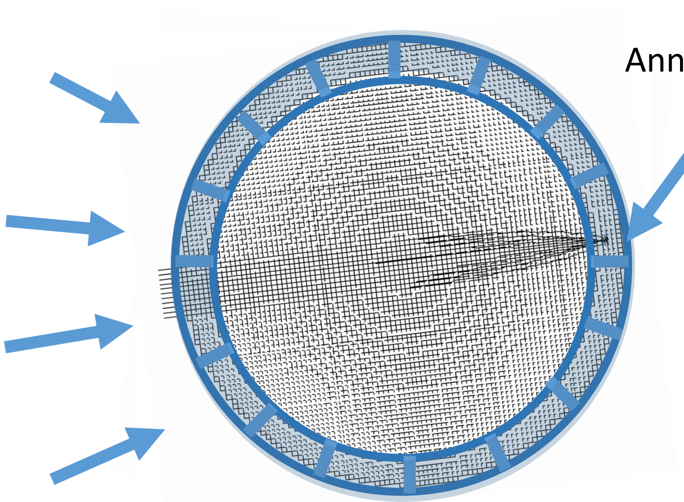
Owen et al, Astronomy & Astrophysics (2020), https://doi.org/10.1051/0004-6361/201937259

Top Hat Optics and detection

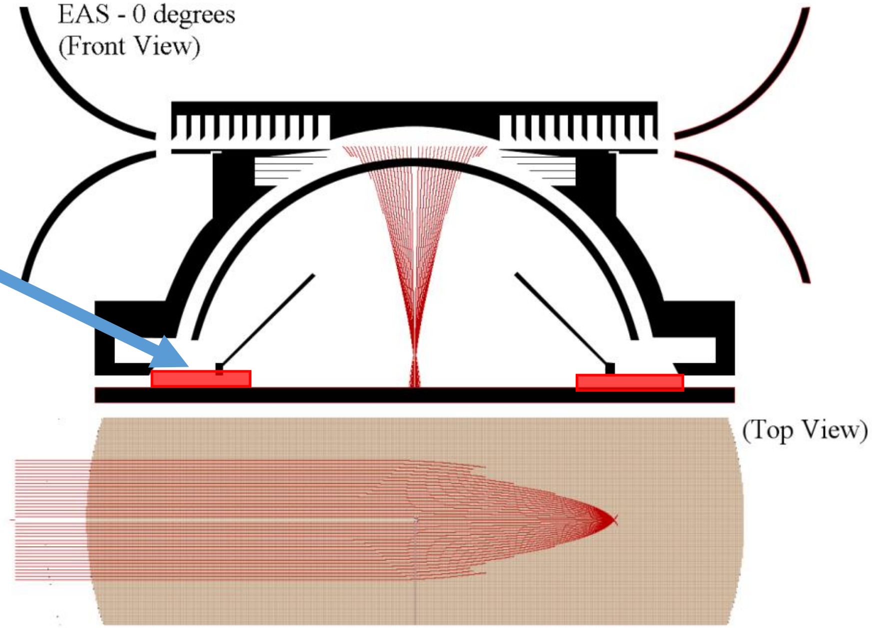
- EAS has 32 x 11.25° pixels
- PEACE has 12 x 15° pixels
- Cassini ELS had 8 x 20° pixels
- LGR PLA will have 9 x 5° pixels



Segmented detector for Polar/Azimuth



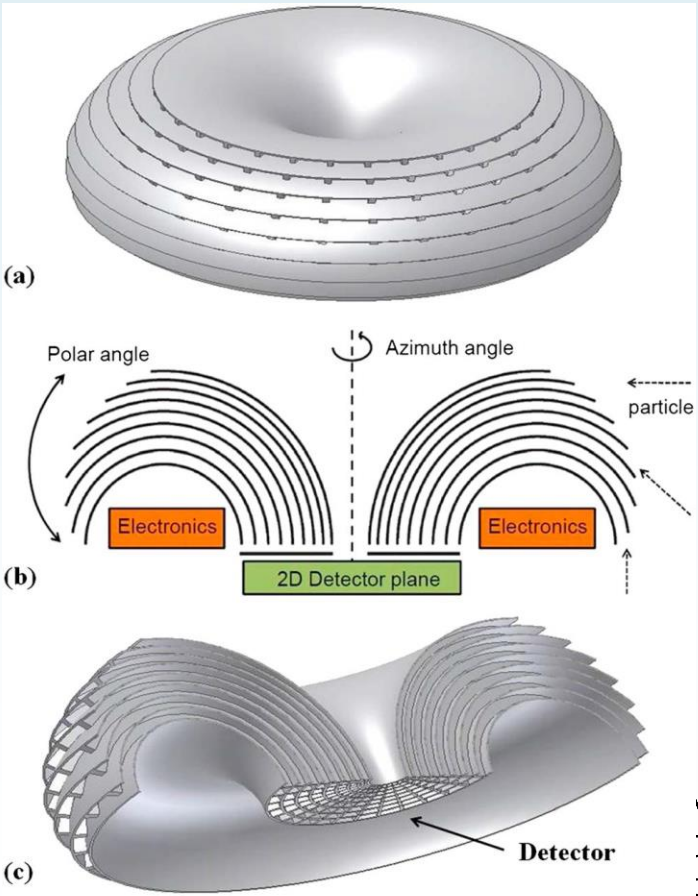
Annular MCP



IPA/EAS Charged Particle Optics
Collinson thesis, 2008

3-D plasma instrument

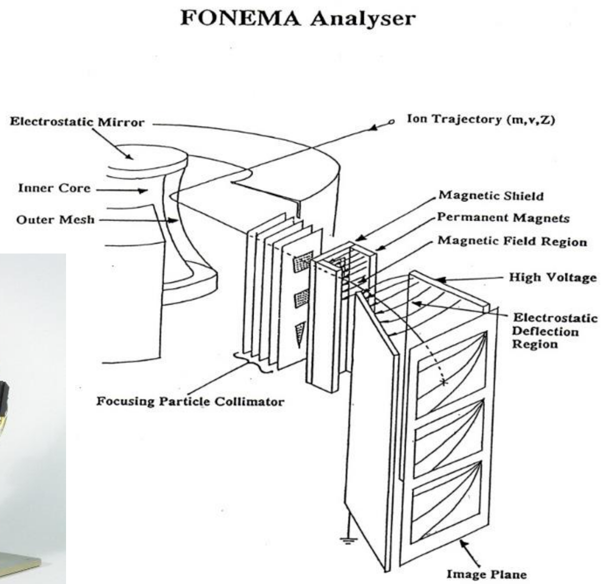
Laboratoire de Physique des Plasmas (LPP)

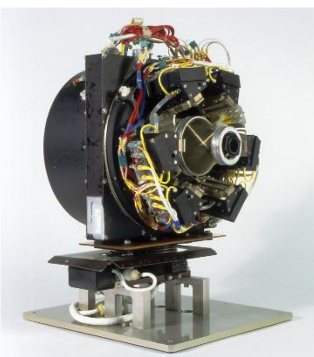


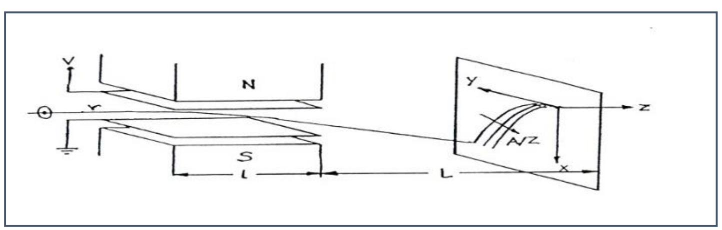
- MCP detector
- Segmented anode
- Simple leading edge discriminator ASIC readout
- 2 x 16 channel ASIC developed and flown on Solar Orbiter
- 128 channel planned for 3-D instrument

Morel, X., M. Berthomier, and J.-J. Berthelier (2017)
J. Geophys. Res. Space Physics, 122, 3397–3410
doi:10.1002/2016JA023596.

Plasma Analysers - 2

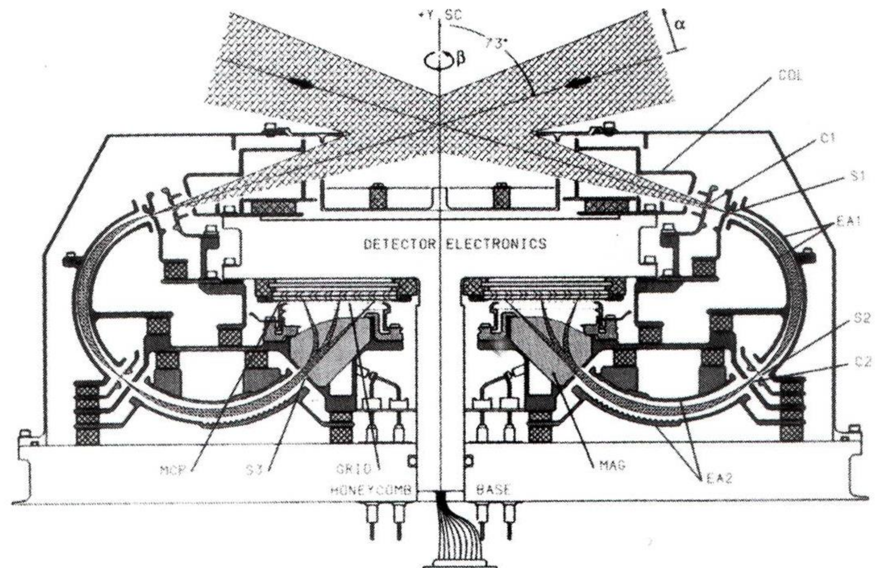






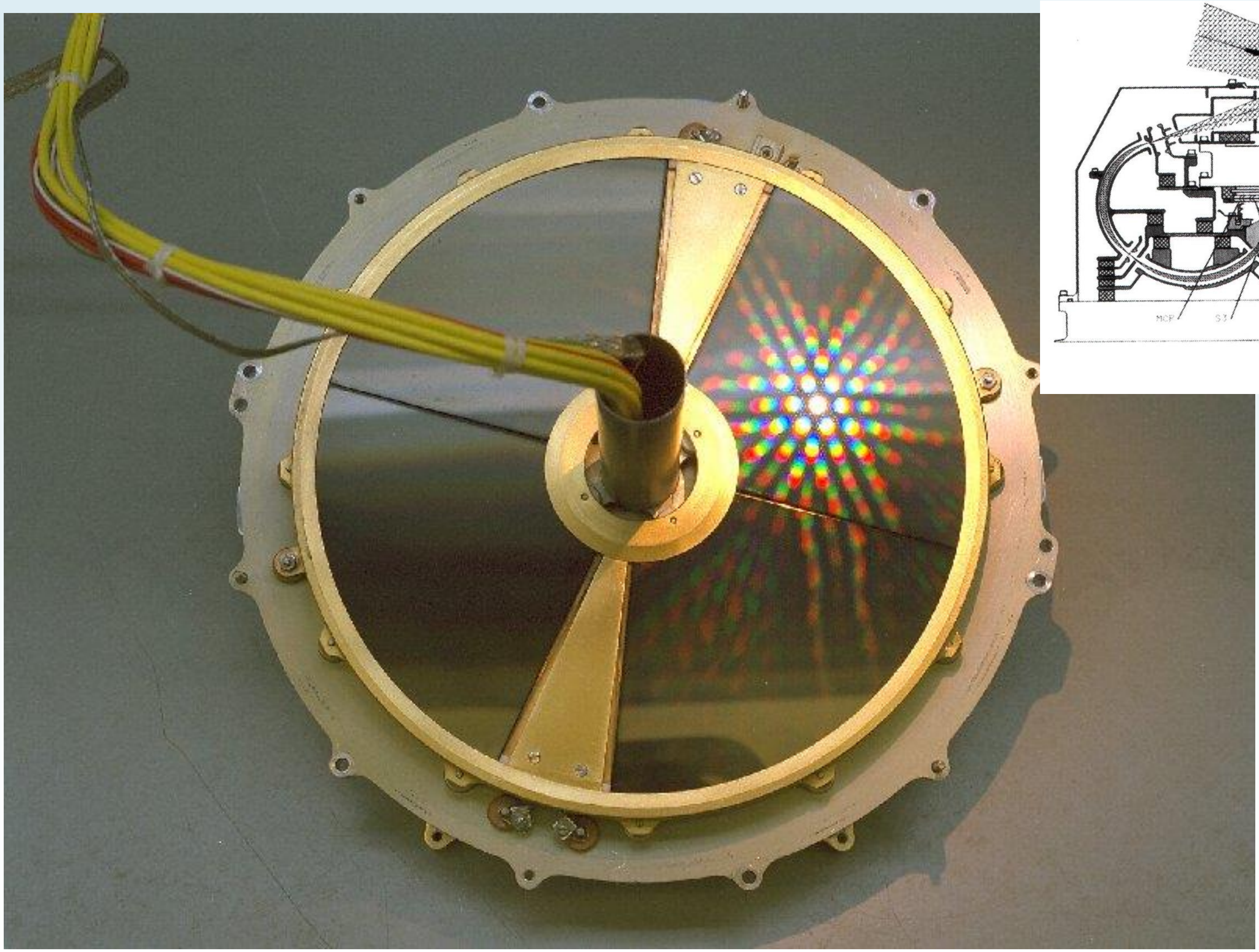
James, et al, Meas. Tech. in Space Plasmas. Particles, Geophysical Monograph, vol. 102 (1998)

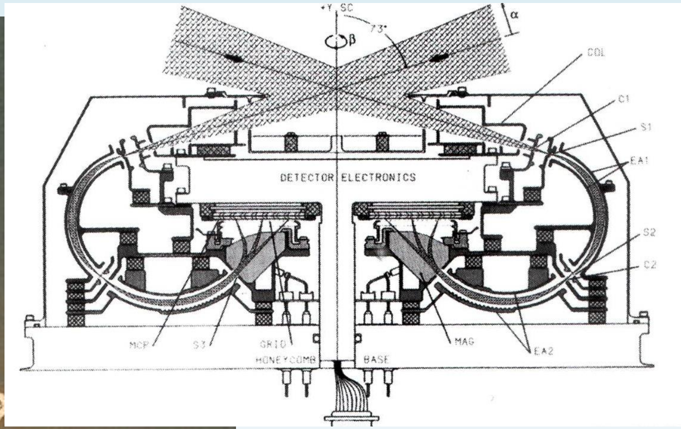
- Other geometries
- Detectors of choice
  - Micro-channel plates
  - Multiple Channel Electron Multipliers



TIMAS instrument, Shelley et al, Space Science Reviews, Vol 71 (1995)

TIMAS MCP



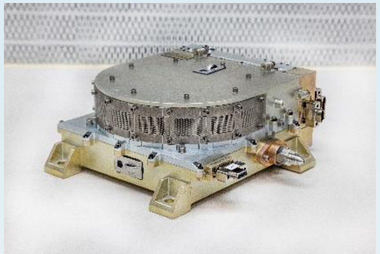

+Y SC
73°
β
α
COL
C1
S1
EA1
DETECTOR ELECTRONICS
S2
C2
MCP
S3
GRID
HONEYCOMB
BASE
MAG
EA2

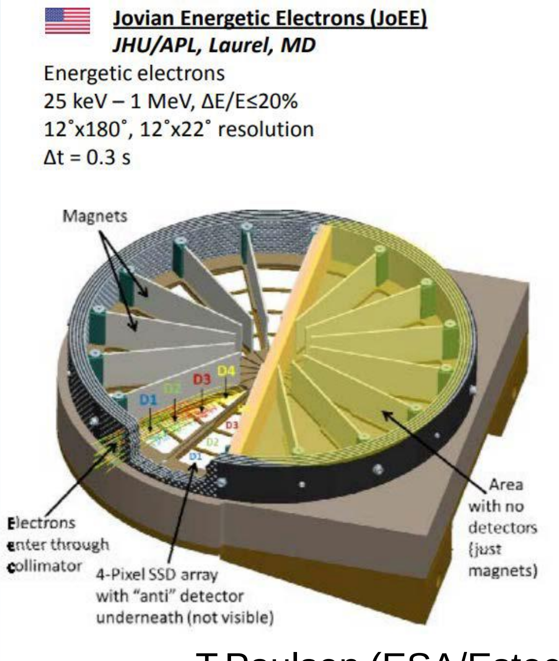
Position sensing techniques

- Segmented readout
- Charge splitting
  - Cluster PEACE technique
  - Capacitive splitting - DIME
- Charge sharing/centroiding
  - Resistive
  - Wedge and strip
  - Delay line
  - Vernier – fast timing, Lapington, J. et al, NIM-A (2002)
- Segmented – ASICs for FEE readout

Energetic particles

- Silicon, solid state, particle telescopes
- Push for larger angular field-of-views
  - Cluster RAPID
    - Multiple particle telescopes, Escoubet, C. P., et al (1997). Space Science Reviews, 79, 11–32 and references therein
  - JUICE JoEE mag spectrometer
    - Segmented Si detectors
- Medipix and Timepix
  - LUCID on UK TechDemoSat
  - ESA Proba mission
  - Others planned/in development
- Some work with CCDs but not flown



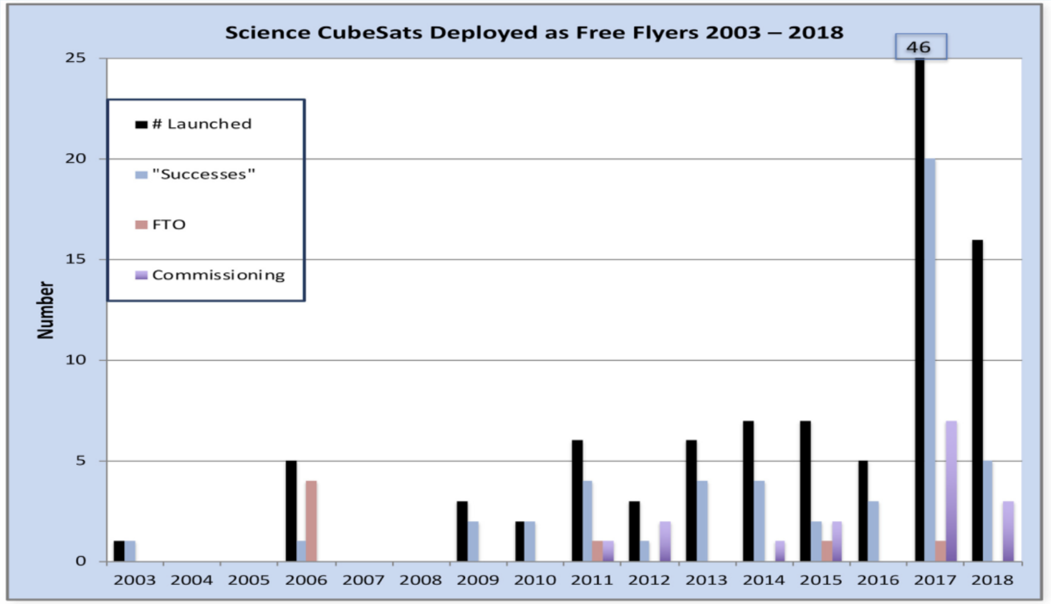


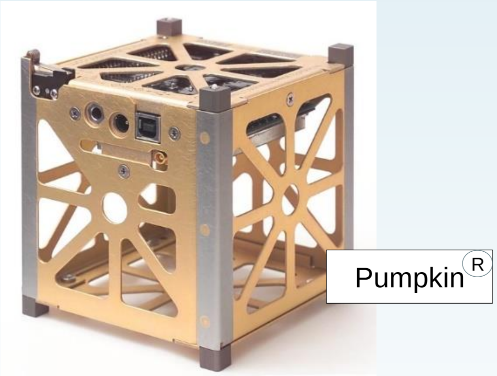
T.Paulsen (ESA/Estec), ESA/CERN (18 April 2018)

The Future is Small

and a bit about small satellites and CubeSats

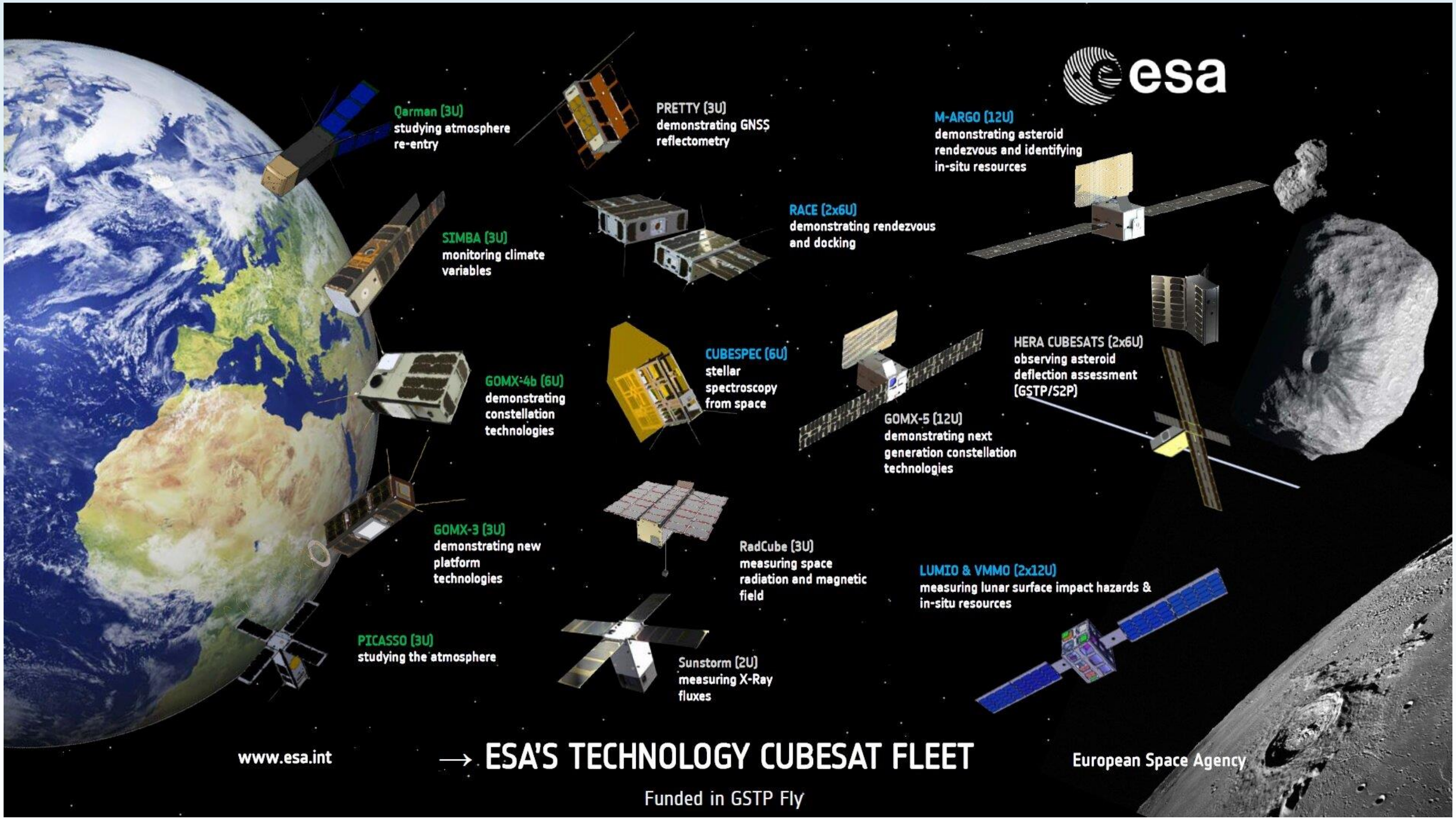
- Honey, I shrunk the satellite
  - “Shrink” payloads at MSSL





Small satellites for space science: A COSPAR scientific roadmap
Advances in Space Research, Volume 64, Issue 8, https://doi.org/10.1016/j.asr.2019.07.035

CubeSats at ESA

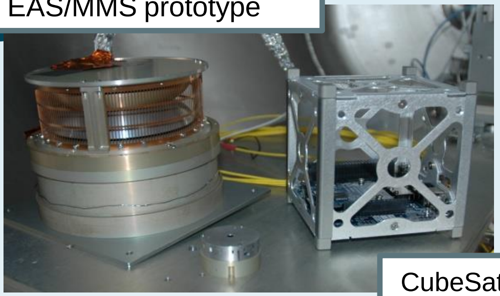


https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Technology_CubeSats

Instrument Miniaturi

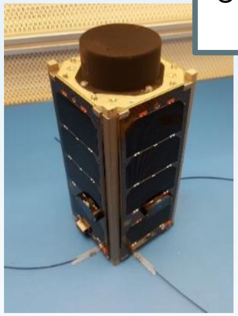
- Driven by Small Satellites and Space Weather
- Generic technology development
  - Electronics miniaturisation – HV, readout, digital
  - Detection systems – combined e-ion
- Alternative geometries to top-hats
  - Cylindrical, Bessel box

Improved Plasma Analyser EAS/MMS prototype

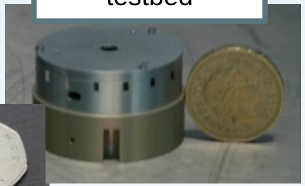


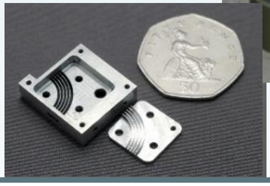
CubeSat

UCLSat and INMS for QB50

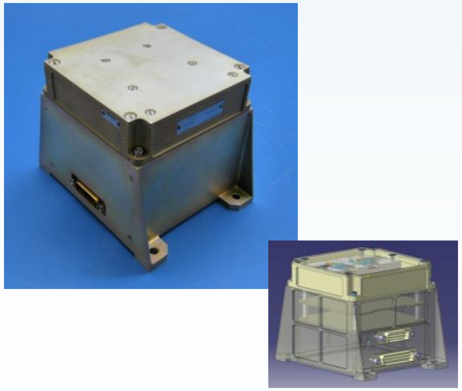


EJSM prototype testbed

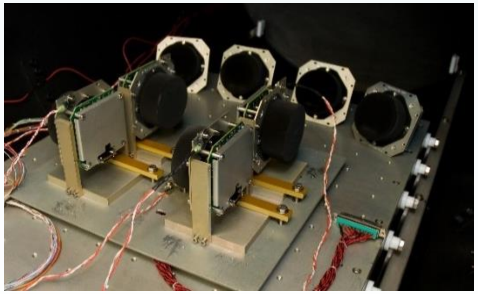




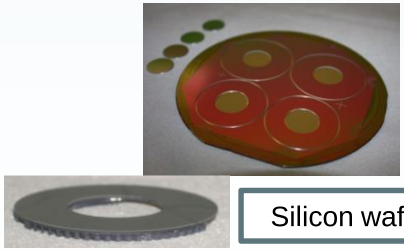
High temporal resolution proof-of-concept analyser



TechDemoSat ChaPS instrument and CAD model



Ion and Neutral Mass Spectrometers for QB50



Silicon wafer analyser

Instrument Miniaturi

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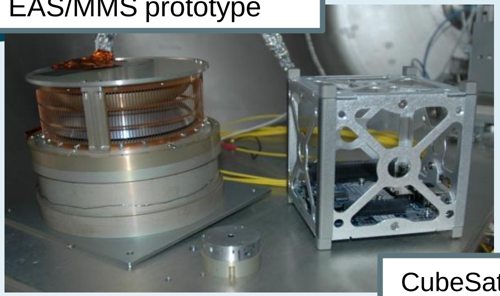
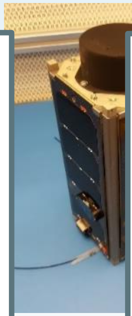


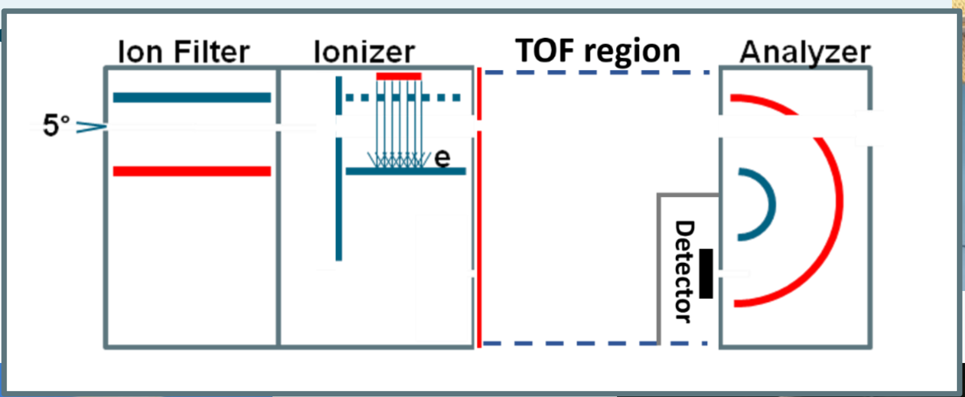
CubeSat

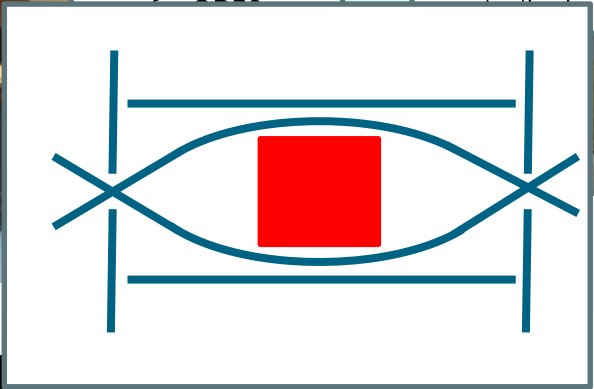
- Driven by Small Satellites and Space Weather
- Generic technology development
  - Electronics miniaturisation – HV, readout, digital
  - Detection systems – combined e-ion

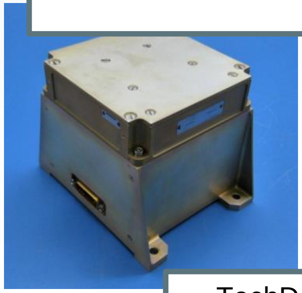
UCLSat and INMS



EJSM prototype







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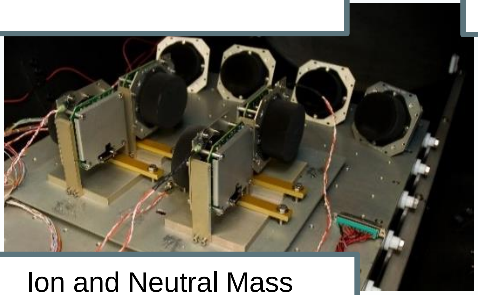

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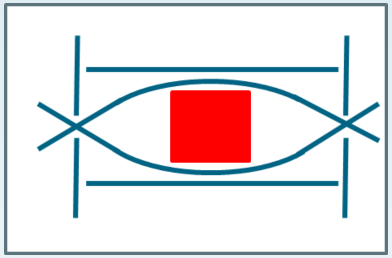
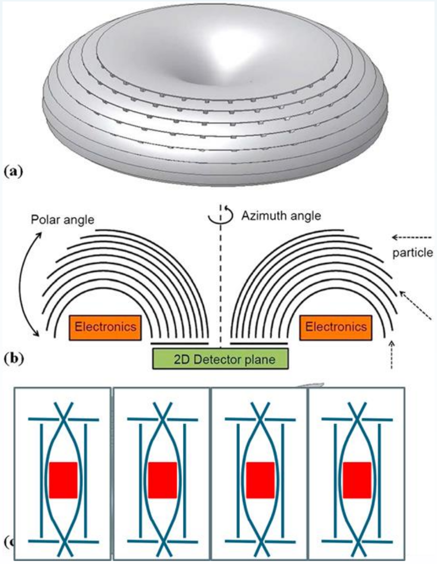
Future directions

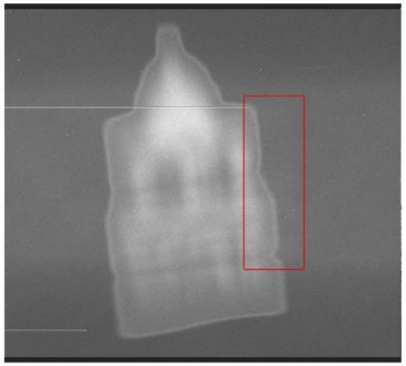


- Bessel box geometry is very promising
  - Demonstrated on UK TechDemoSat mission
  - Compact instrument development
    - ESA Space safety programme R&D
    - NASA solar sail missions
- Next push is compact 3-D suitable for CubeSats
  - Silicon micro-fabrication attempted
  - 3-D printing
  - PCB embedded systems
- Low resource position sensitive detector is key challenge



Promising position sensitive detection techniques

- Intensified CCD without the photocathode
  - Flown on SWARM mission, D. J. Knudsen, et al (2017), https://doi.org/10.1002/2016JA022571
  - Issues with unsealed MCPs
- Electron-bombarded CCDs with photocathode removed
  - Some testing carried out with direct detection CCD with Ni source
  - Bedington, Kataria, Walton, Journal of Instrumentation (2012), DOI: 10.1088/1748-0221/7/01/C01079
- Scintillator coupled to SiPM
- Detectors with very thin dead layer



Summary

- Traditionally, PSD requirements in space instruments not very challenging
- Instrument miniaturisation and small satellite
  - Need for moderate resolution - 50-100µ position, 0.5-1µs time
  - Small satellites provide opportunity for rapid development and technology demonstration
  - Current state-of-the-art in imaging detector development from other domains providing good opportunities for exploitation
- Alternative to MCP-based detectors would be attractive
  - Low energy, few eV to few KeV particularly challenging

QB50 CubeSats from ISS, 2017

Summary

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