# In-situ particle environment monitoring

## Operational needs and the state of the art

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**L5 Consortium Meeting, London** **11th - 14th May, 2015**

# Plan

- Operational needs and measurement requirements
- Key challenges
- Brief overview of the state of the art
- Instruments and techniques currently under development

# Requirements - L1/L5

- NOAA/ESA-SSA customer requirements
  - http://swe.ssa.esa.int/web/guest/documents
- Continuous data flow, 24 hours per day, seven days a week.
- Minimum requirement is 96% coverage per day with no data gap exceeding 15 minutes
- Characterization of low energy ion particle population with at least one complete set of measurements every 5 minutes. Data available for use in operations within 5 minutes after completion of the measurement
- Necessary housekeeping data sent in real time
- > 10 year mission

# Requirements - L1/L5

- Plasma Ion Measurement
  - At least one measurement of the solar wind velocity vector (Vx, Vy, Vz), average ion temperature, and ion density moments every minute
  - Velocity range 200 to 2000-km/sec with 5% relative accuracy
  - Temperature range: 40,000 to 2,000,000 K with 20% relative accuracy
  - Density range: 1 to 100 $cm^{-3}$, with 20% absolute accuracy

# Requirements – GEO/MEO

- Functional
  - Detect electrons and ions from the ambient plasma environment.
  - In the event of instrument shut-down, data for the last 24-hour period before the shut-down shall be recoverable
  - Data compression both with and without loss of resolution
  - Data shall be summarised by means of moments of the particle distributions (e.g. Maxwellian temperature and density).
  - Equipment reliability (probability of non-failure during mission) shall be better than 97%
  - > 10 year geostationary mission

# Requirements – GEO/MEO

- Performance
  - The energy range of detected electrons and ions shall be 30eV to 30keV
  - The monitor shall have a differential flux dynamic range of $>10^4$
  - Differential fluxes of electrons and ions range $10^5 – 10^9$ /cm2/sr/keV/s shall be able to be measured.
  - Time resolution for a complete measurement over all energies and both species shall be able to be commanded to less than 30s
  - Total mass of all sensors plus electronics shall be < 0.5kg

# Key challenges

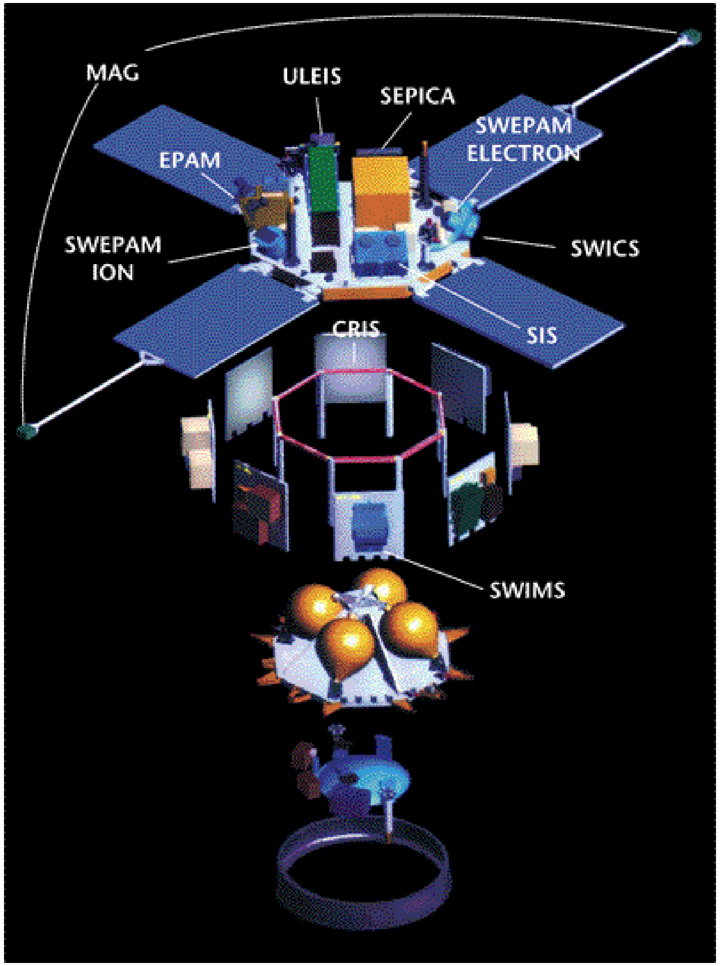
- Reliability
- Real time measurements
- On-board intelligence
- Saturation issues
- Autonomy – operator intervention
- Recovery – data for assessment
- Capabilities - science vs monitoring trade-off
  - Rapidly advancing technology, TechDem is crucial
  - Cross calibration between instruments on different missions

# State of the art

- Solar Wind – Operational
  - ACE, WIND
  - DSCOVR
  - STEREO
- Solar Wind – Development
  - Solar Orbiter
  - Solar Probe
- GEO, MEO
  - GOES
  - Van Allen Probes

# ACE: Advanced Composition Explorer

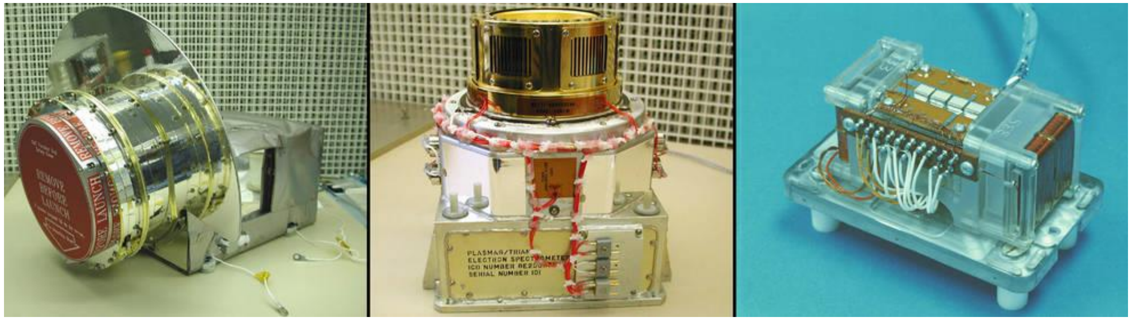
- CRIS: The Cosmic Ray Isotope Spectrometer for the Advanced Composition Explorer (in PDF format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998
- EPAM: Electron, Proton, and Alpha Monitor on the Advanced Composition Explorer Spacecraft (in PDF format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998
- MAG: The ACE Magnetic Field Experiment (in PDF format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998
- SEPICA: The Solar Energetic Particle Ionic Charge Analyzer (SEPICA) and the Data Processing Unit (S3DPU) for SWICS, SWIMS and SEPICA (in PDF format) - In *Space Science Reviews*Volume 86, Nos. 1-4, 1998
- SIS: The Solar Isotope Spectrometer for the Advanced Composition Explorer (in PDF format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998
- SWEPAM: Solar Wind Electron Proton Alpha Monitor (SWEPAM) for the Advanced Composition Explorer (in HTML format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998
- SWICS and SWIMS: Investigation of the Composition of Solar and Interstellar Matter Using Solar Wind and Pickup Ion Measurements with SWICS and SWIMS on the ACE Spacecraft (in PDF format) - In*Space Science Reviews* Volume 86, Nos. 1-4, 1998
- ULEIS: The Ultra Low Energy Isotope Spectrometer(ULEIS) for the ACE Spacecraft (in PDF format) - In *Space Science Reviews* Volume 86, Nos. 1-4, 1998




Images: Courtesy NASA

# Deep Space Climate Observatory (DSCOVR)

- PlasMag
  - Fluxgate vector Magnetometer,
  - Faraday Cup solar wind positive ion detector and
  - Top-hat Electron Spectrometer
- National Institute of Standards and Technology Advanced Radiometer (NISTAR)
- Earth Polychromatic Imaging Camera (EPIC)



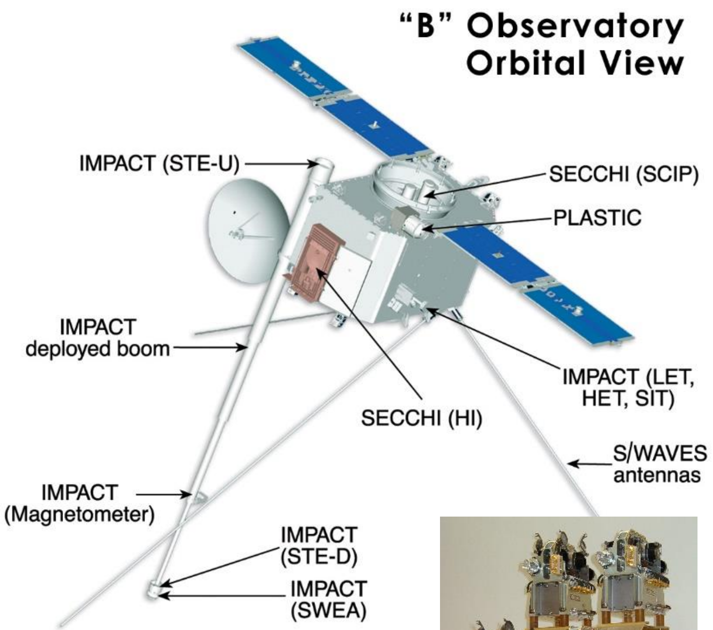
Images: Courtesy NASA

# Stereo

- http://stereo-ssc.nascom.nasa.gov/cgi-bin/bib_ui

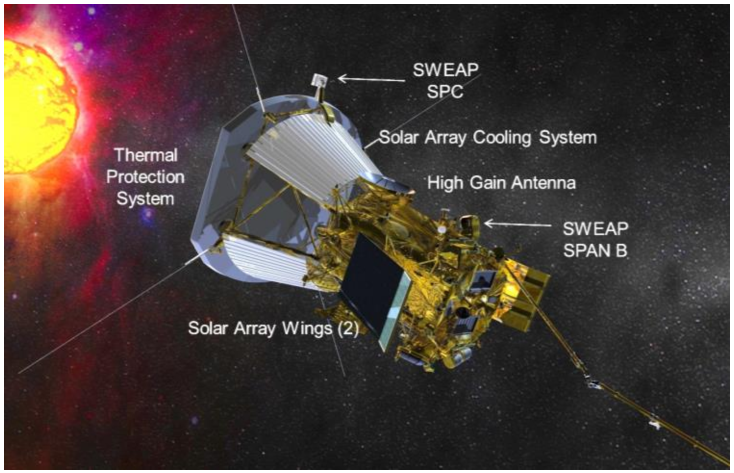
- In situ Measurements of PArticles and CME Transients (IMPACT)
- Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI)
- PLAsma and SupraThermal Ion Composition (PLASTIC)
- STEREO/WAVES (S/WAVES)

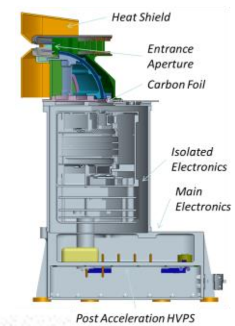
- IMPACT
  - SWEA (Solar Wind Electron Analyzer)
  - STE (Suprathermal Electron Telescope)
  - MAG (Magnetometer)
  - SEPT (Solar Electron Proton Telescope)
  - SIT (Suprathermal Ion Telescope)
  - LET (Low Energy Telescope)
  - HET (High Energy Telescope)

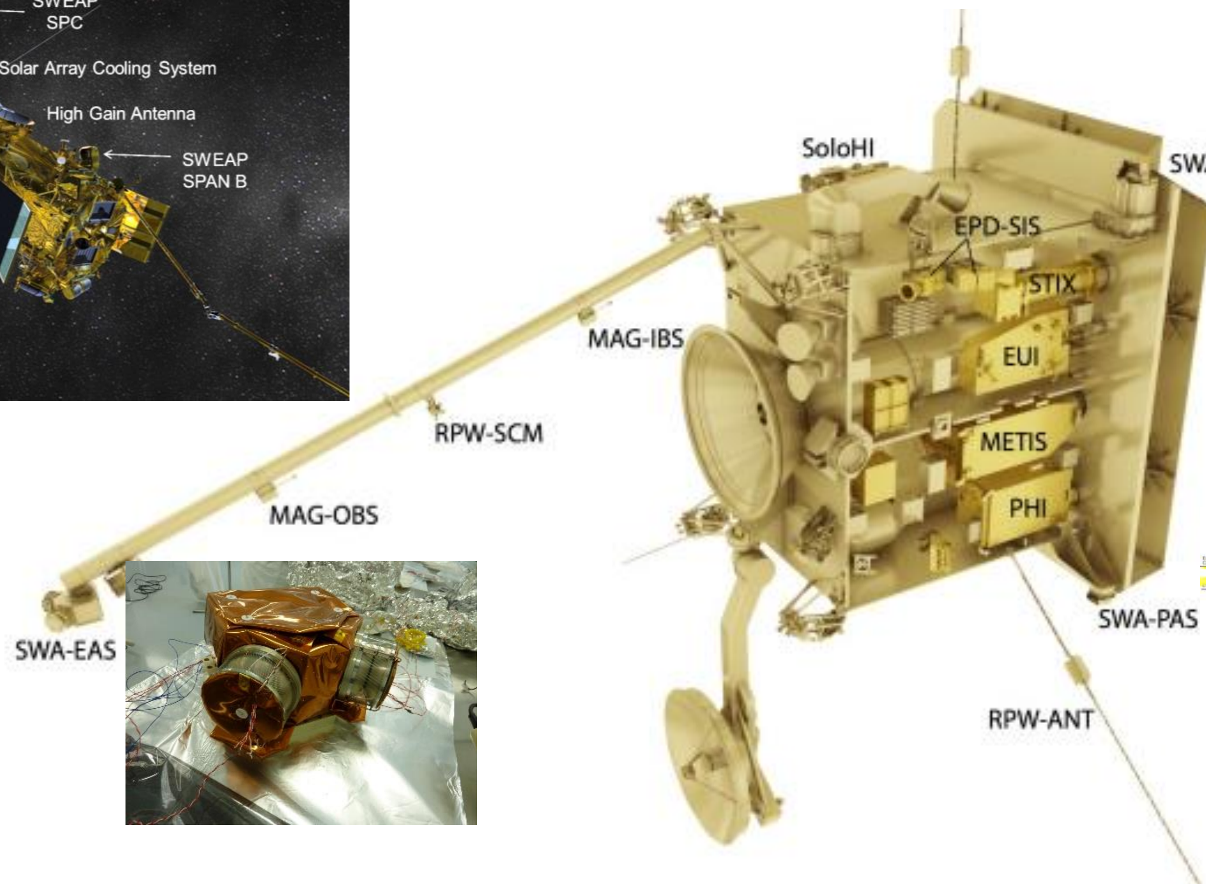


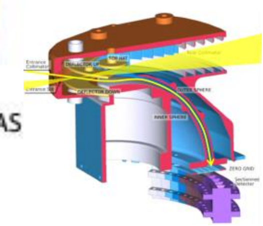

Images: Courtesy NASA

# Solar Orbiter – Solar Probe Plus



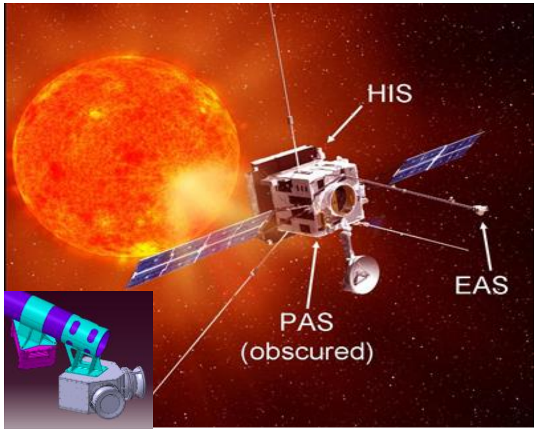



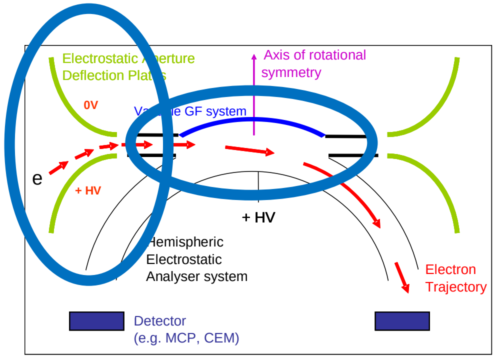



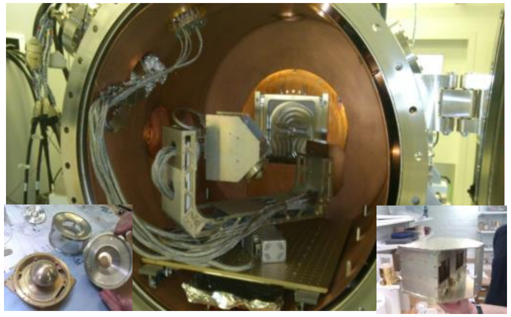



# SWA-EAS Implementation

- SWA Instrument
  - HIS, PAS, EAS
  - Suite Instrument Science
  - EAS lead
- SWA-EAS Sensor
  - Two Boom Mounted Top Hats with enhanced features
  - Size reduced by 1/√2 compared to Cluster PEACE LEEA
  - Deflector plates, Variable Geometric Factor System
  - High speed High Voltage modulation



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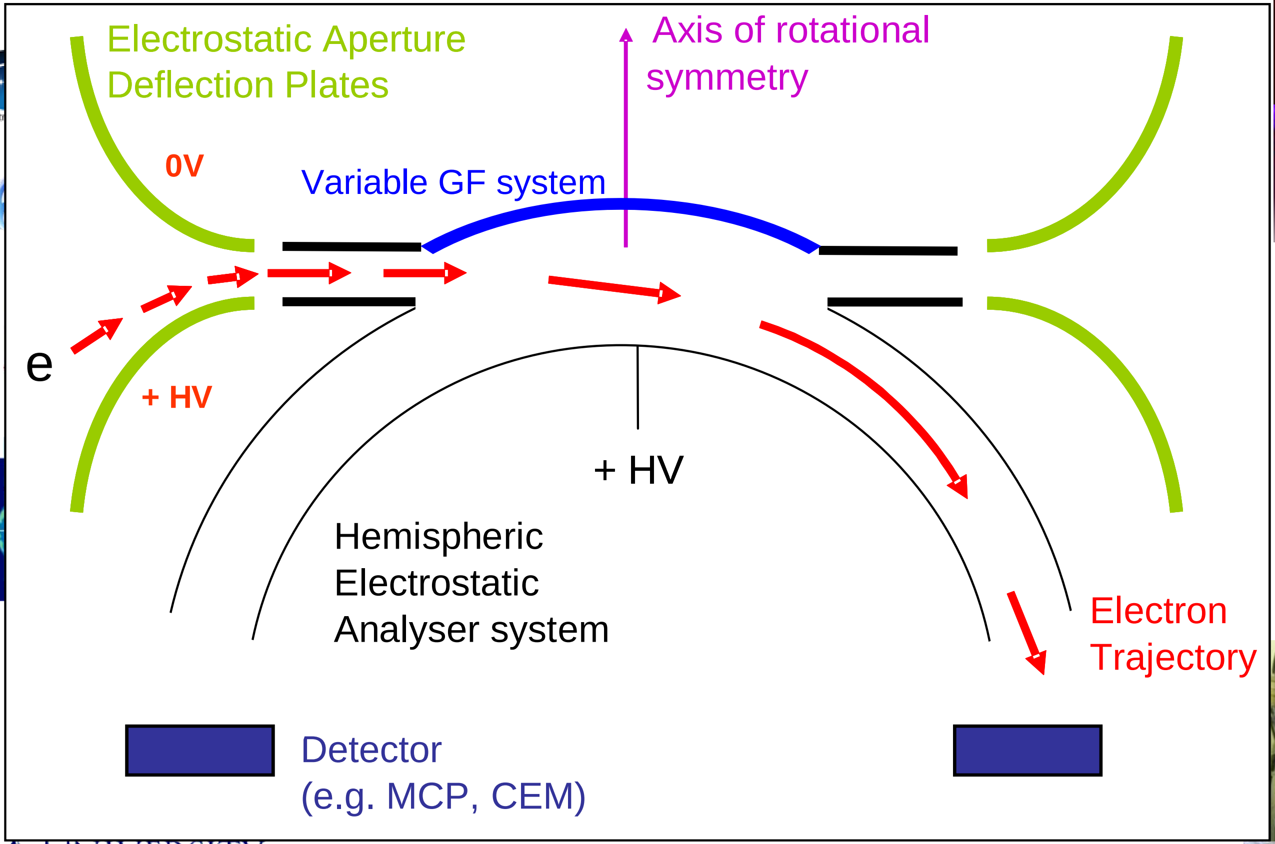


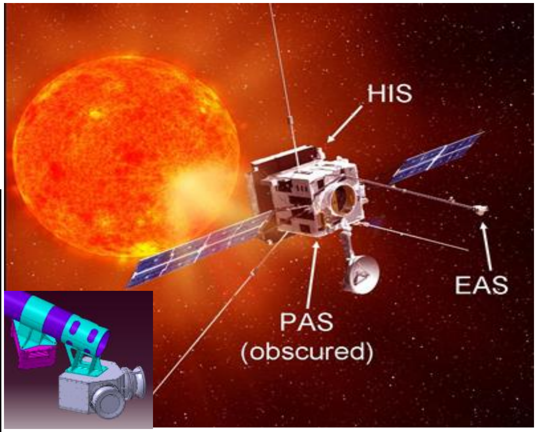


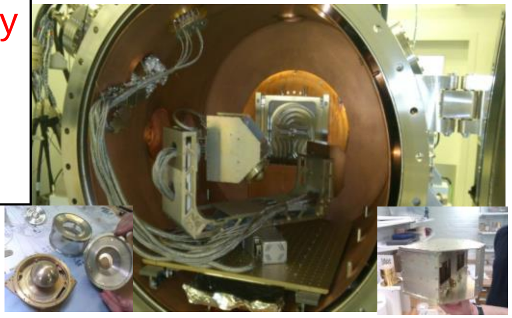

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# Solar Wind Ions – L5

## •Instrument Summary

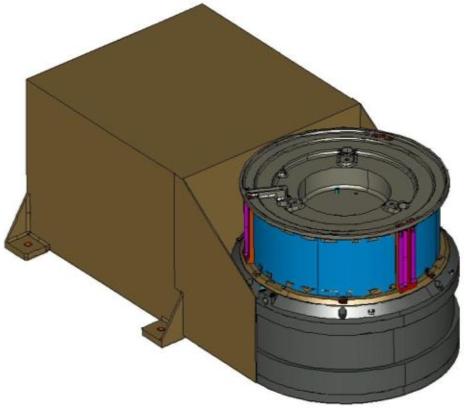
- The instrument will measure solar wind proton density, velocity, temperature

– Data Processing

- Production of 3D data
- Production of onboard moments (n, T, v)

– Solar Orbiter SWA-EAS derivative

- Modified to change geometric factor
- Modified to operate with ions instead of electrons
- Modified for slower, lower resource operations
- Modified to have data processing in the unit
- Modified for new thermal requirements



*Artists impression of a single head ion sensor based on SWA-EAS, with an electronics box housing sensor electronics and significant additional data processing electronics*

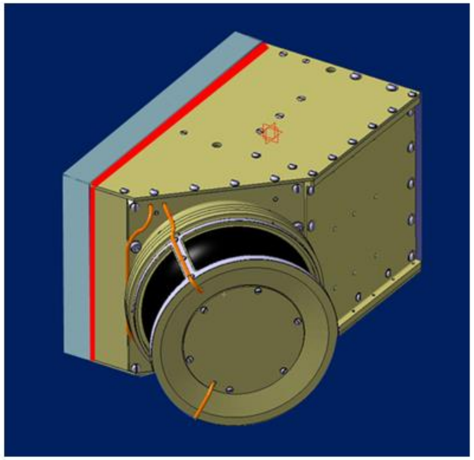
| Design Element | Parameter | Unit |
|---|---|---|
| | | |
| Sensor Mass | 2.2 | Kg |
| DPU/Interface/Thermal/Radiation | 1.8 | Kg |
| Total (incl 20% margin) | 4.8 | kg |
| | | |
| Sensor Power | 2.0 | W |
| DPU Power | 4.3 | W |
| Total (primary power, 10% margin) | 6.9 | W |
| | | |
| Telemetry | 2,000 | Bit/sec |
| | | |
| Sensor-DPU unit dimensions | 300 x 180 x 120 (l,w,h) | mm |
| | | |

| Measurement Characteristic | Value | Unit |
|---|---|---|
| | | |
| Angular Coverage /Resolution | 45 x 45; 5x5 | deg |
| Energy Coverage/Resolution | 20-5,000, 13% | eV |
| Cadence | ~1 | min |
| | | |

# Solar Wind Electrons

## •Instrument Summary

- Data Processing
  - Production of 3D data
- Solar Orbiter SWA-EAS derivative
  - Modified to produce 2 separate sensors heads
  - Modified to provide basic data processing in the sensor heads
  - Modified for slower, lower resource operations
  - Modified for new thermal requirements



*Artists impression of a single head sensor based on SWA-EAS, with added volume for additional data processing electronics (grey)*

| Design Element | Parameter | Unit |
|---|---|---|
| | | |
| EAS Single Sensor | 3.5 | Kg |
| Total (DPU boards, 10% margin) | 4.9 | kg |
| | | |
| EAS Single Sensor Power | 3.3 | W |
| Estimate for DPU electronics | 2 | W |
| 2 x EAS single sensors | 10.6 | W |
| | | |
| Telemetry (pair of sensors) | 2,500 | Bit/sec |
| | | |
| EAS Single sensor-DPU | 240 x 160 x 170 (l,w,h) | mm |
| | | |

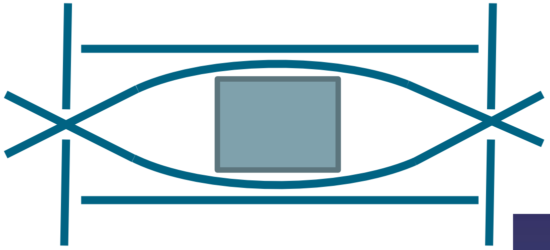
| Measurement Characteristic | Value | Unit |
|---|---|---|
| | | |
| Angular Coverage /Resolution | 45 x 360; 5x11 | deg |
| Energy Coverage/Resolution | 20-5,000, 13% | eV |
| Cadence | ~1 | min |
| | | |

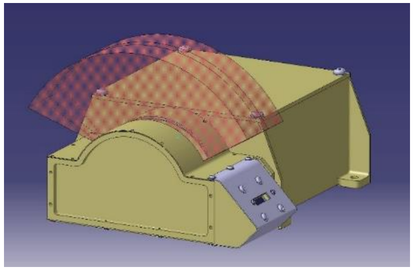
# Hot Plasma Environment Monitor (HOPE-M)

## Key requirements

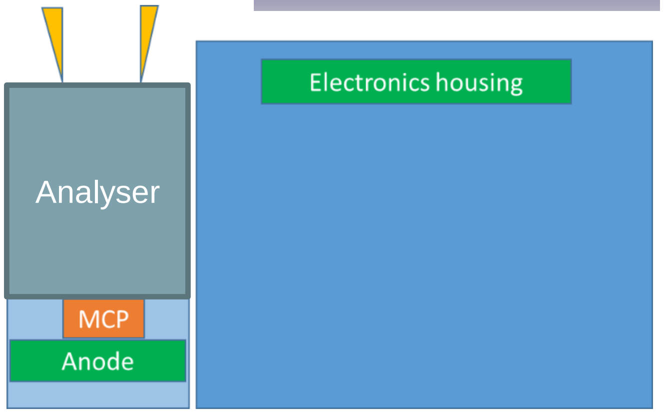
- Telecoms satellites at GEO
- Surface charging monitor, post-anamoly data
- Combined electrons and ions
- 30 eV – 30 keV
- Low resource: 0.5 kg
- Compact digital electronics
  - Complex capabilities, rad hard memory
- 15 year lifetime

# Hot Plasma Environment Monitor (HOPE-M)
## Design overview





- 2 x Bessel box variants
  - Compact geometry
  - Considerable design flexibility
    - Ability to “tune” performance
    - High/low analyser constants
  - Used on STRV
- ± 22° x ± 60° Field of view
- Modular design
  - Analyser head, electronics box
- Single MCP, polarity flipping
- Four readout channels
- Silicon detector development in parallel



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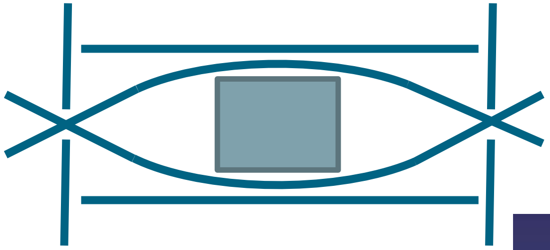
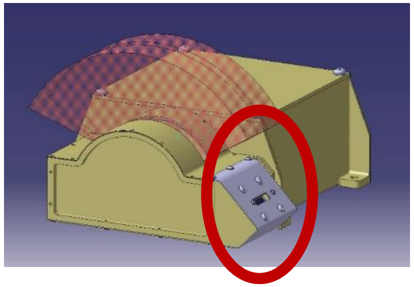
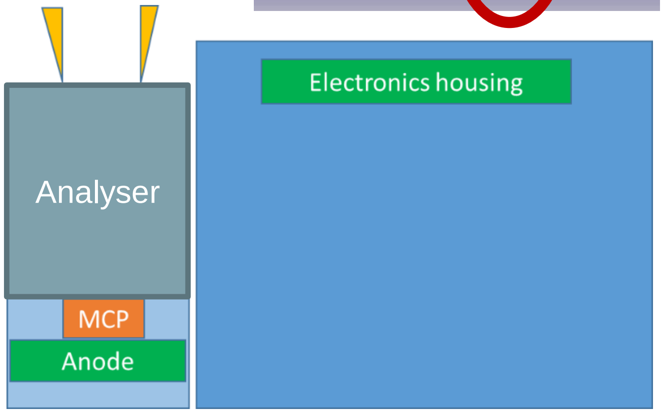
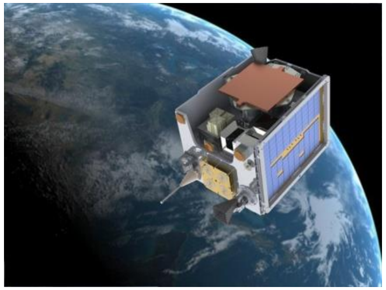




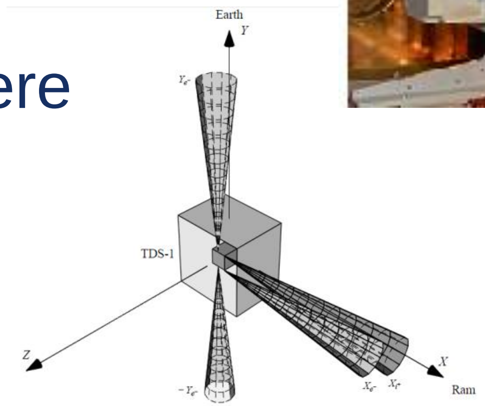


# TechDemoSat ChaPS

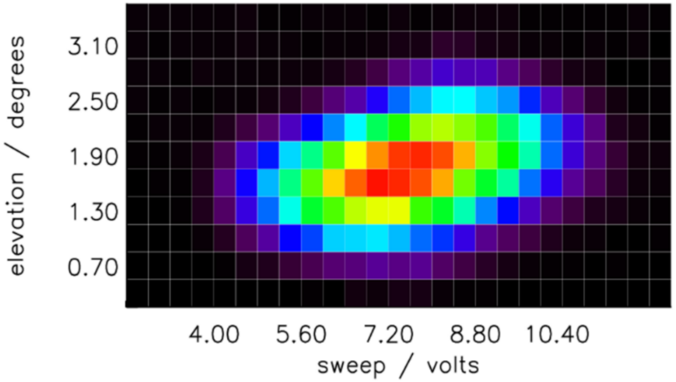
**Dhiren Kataria, Andrew Coates, Hubert Hu, Richard Cole, Mark Hailey, Eric Ueberschaer**

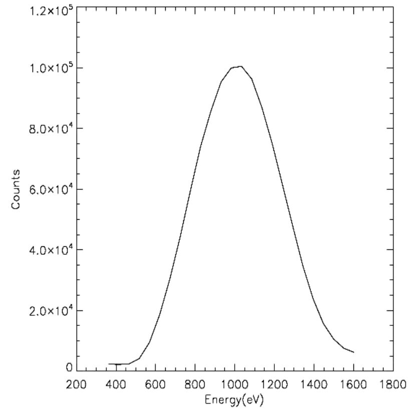


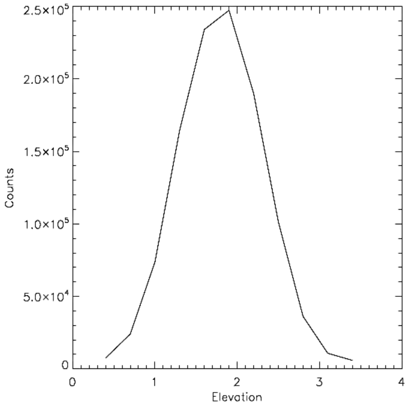
- ChaPS (Charged Particle Spectrometer)
  - Suite of miniaturised Bessel Boxes
  - Electron and ion analysis
- Three modes
  - Electrons in the auroral regions
  - Electrons and ions in the ionosphere
  - Spacecraft potential
- Delivered March 2012
- Launched July 2014

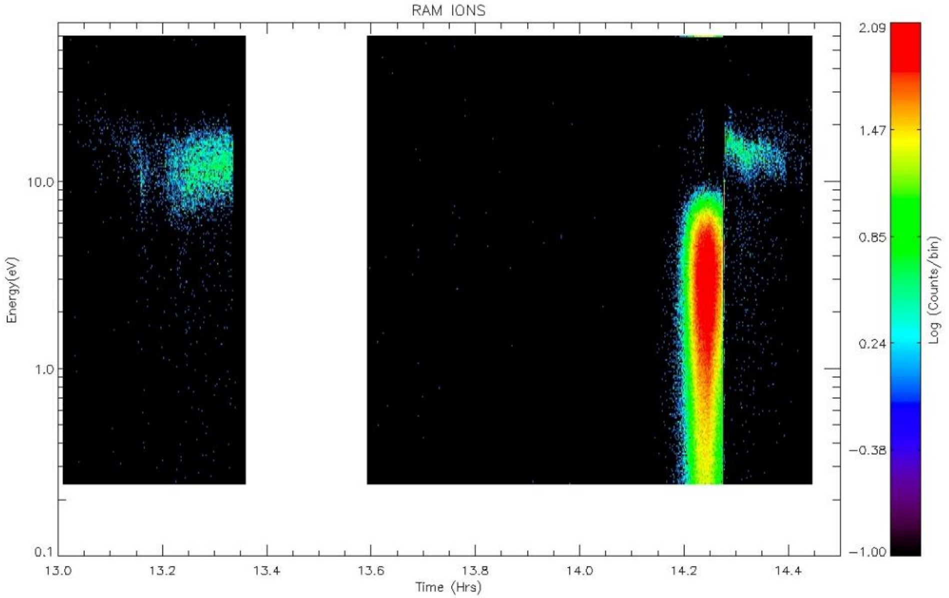


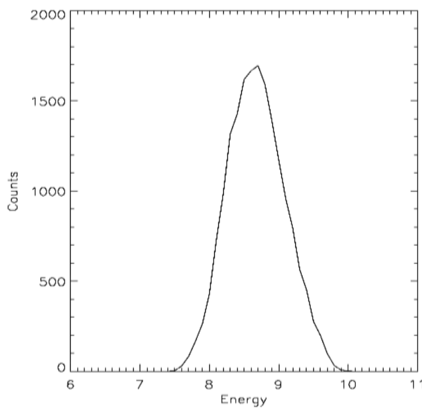
# Data from ChaPS



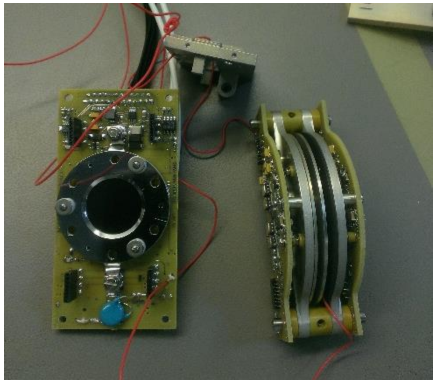



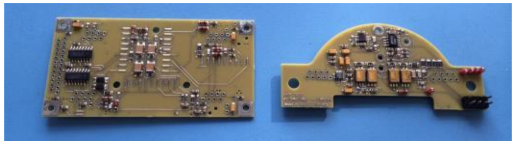



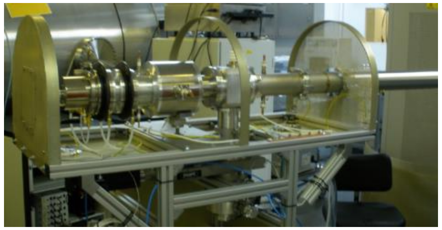



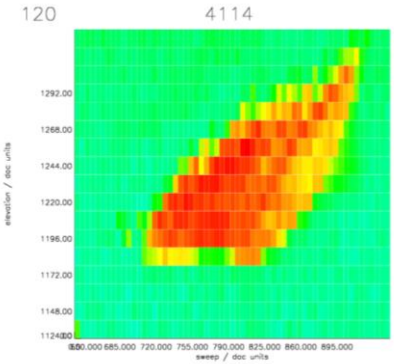
# HOPE-M breadboard

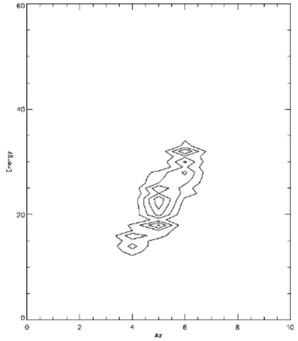


- HV modulator and front end electronics integrated and tested with ions
- Throughput issues
  - Widened acceptance on one channel
  - Removed detector aperture – increased noise
  - DAC offset, beam stability
- Reconfigured for further testing







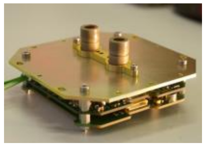



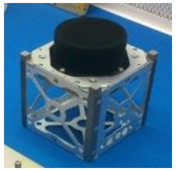
# Performance parameters

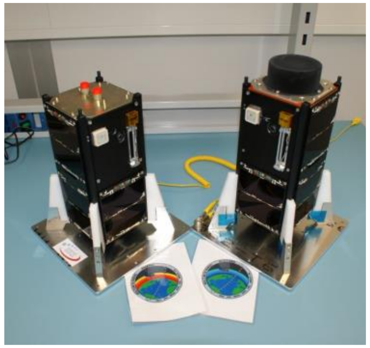
| | ChaPS - Magnetosphere | HOPE-M (breadboard) |
|---|---|---|
| Primary sampling region | Auroral Electrons at the poles | GEO |
| Particle Type | Electrons | Electrons, Ions |
| Key View direction | N-S | Earth pointing |
| | | |
| PROPERTIES | | |
| Energy range (eV) | 10 to 4,000 eV | 30 to > 30,000 eV |
| Energy resolution (%) | < 40 | < 30 |
| | | |
| Elevation acceptance | < 1.8° | ± 11° |
| Azimuth acceptance | < 20° | ± 60° |
| | | |
| Energy Sweep time | 1s | 30s |
| Energy Sweep steps | 64x4 | 64 |

# CubeSats

- Rapidly changing/developing landscape
- Technologies at high TRL – high reliability CubeSat COTS solutions and high TRL miniaturised payloads
- Number of Interplanetary CubeSat studies
  - Phase 1 21012 NASA study
    - Report to NASA office of the chief technologist
  - Recent ESA ITT - piggyback to an asteroid
  - White paper to piggyback to L1 on ISRO Aditya mission, education and training, technical exchange
- Significant advantages at L5 vantage point







# A note on heritage and TRL

- Heritage and HOPE – the two approaches
  - High TRL sensors, innovation with heritage
  - Enabling technology, e.g. CubeSats
  - Enables ubiquitous network of monitors

# Summary

- Operational needs and requirements reasonably well understood
- Clear need for upstream as well as GEO, MEO and even LEO orbits
- State-of-the-art instruments under development on science missions - High TRL
- Paths for adoption of innovative concepts
  - Novel instrument variants, miniaturised electronics, CubeSats
  - Enhanced performance at lower resource

# Faraday Cups and Electrostatic Analysers

- Fast
- Simple mechanical design
- Large
- Stable

- Fast ion 3-D -125 ms
- Top-hat designs are complex but alternative simpler geometries have been adopted
- Compact
- Needs HV
- Lifetime - MCPs