Enhanced Performance Low Resource In-situ Sensors for Space Weather

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Mullard Space Science Laboratory
University College London, UK

D3S Workshop, ESOC, Darmstadt, 24th October, 2019

Research at MSSL

- **Department of Space and Climate Physics, University College London**
- **Research groups supported by specialist engineers conduct our scientific research:**
  - Astrophysics
  - Climate Physics
  - Magnetospheric Physics
  - Planetary Science
  - Solar and Stellar Physics
  - Theory
  - In-situ Detection Systems
  - Photon Detection Systems
  - Imaging
  - Cryogenic Physics

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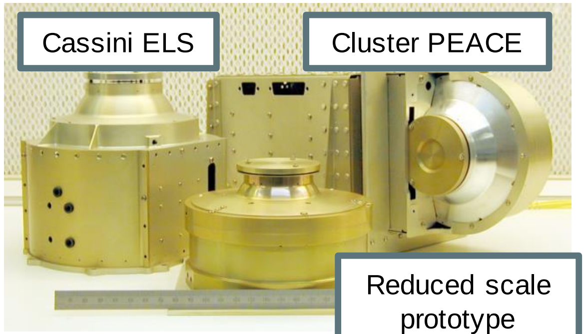
  - Theory
  - In-situ Detection Systems
  - Photon Detection Systems
  - Imaging
  - Cryogenic Physics

In-situ Instrumentation

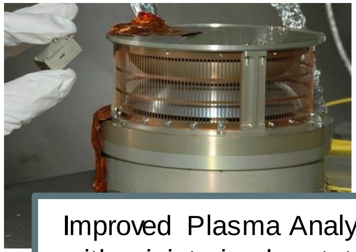
- Strong plasma instrumentation heritage
  - Planetary environments: Cassini, Venus and Mars Express (built by SWRI), Mars 96 (launcher failed), AMPTE-UKS
  - Magnetospheric missions: Cluster, Double Star, Polar, CRRES, STRV, QB50
  - Cometary studies: Giotto
  - Technology Demonstration: TechDemoSat
- Top-hats, with enhanced capabilities
  - Solar Orbiter, SMILE (built by NSSC, China)
- Highly miniaturised particle sensors
  - DISCOVERER, CIRCE

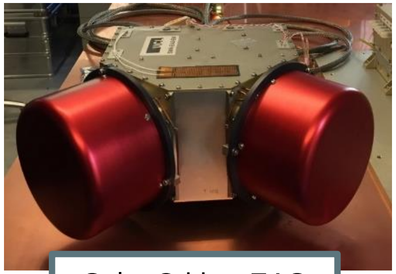

FONEMA on MARS96

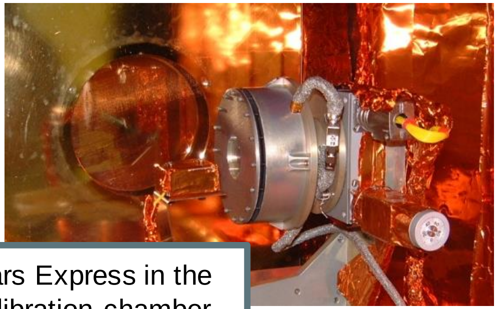

Cassini ELS

Cluster PEACE

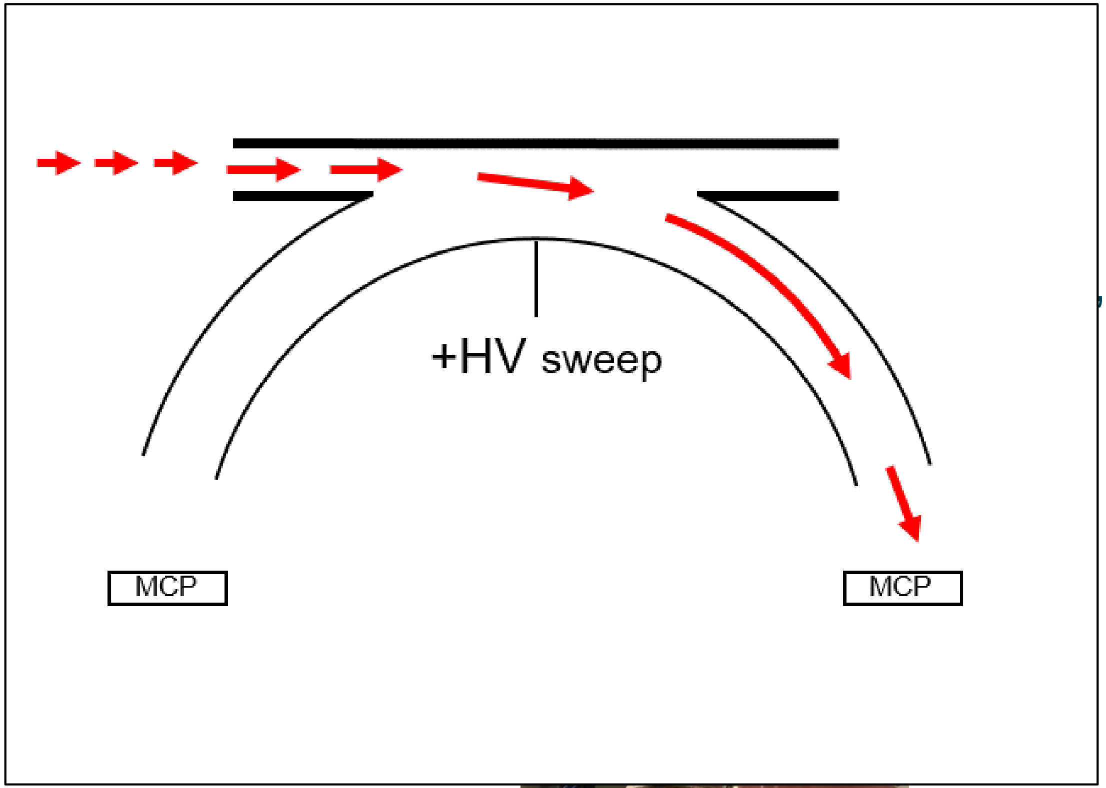
Reduced scale prototype


Improved Plasma Analyser with miniaturised prototype

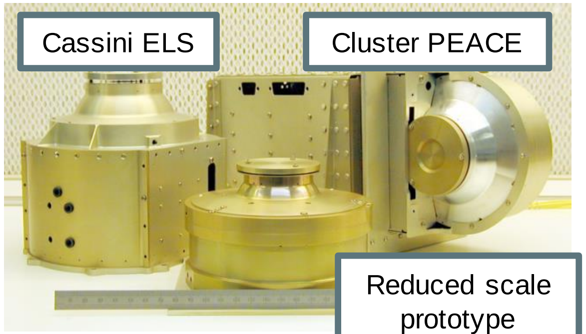

Solar Orbiter EAS


Mars Express in the calibration chamber

In-situ Instrumentation




FONEMA on MARS96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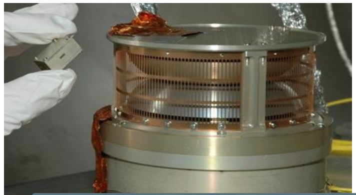
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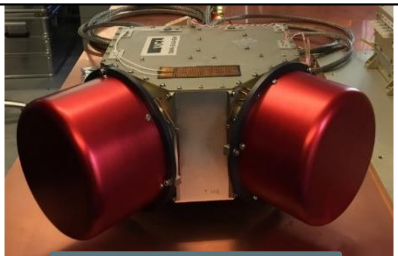
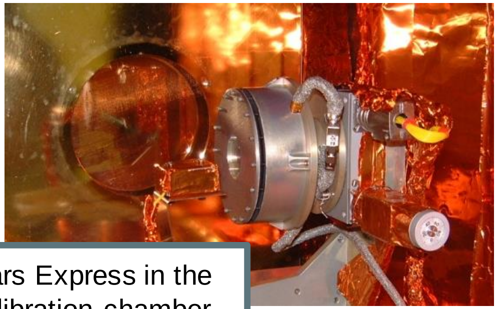
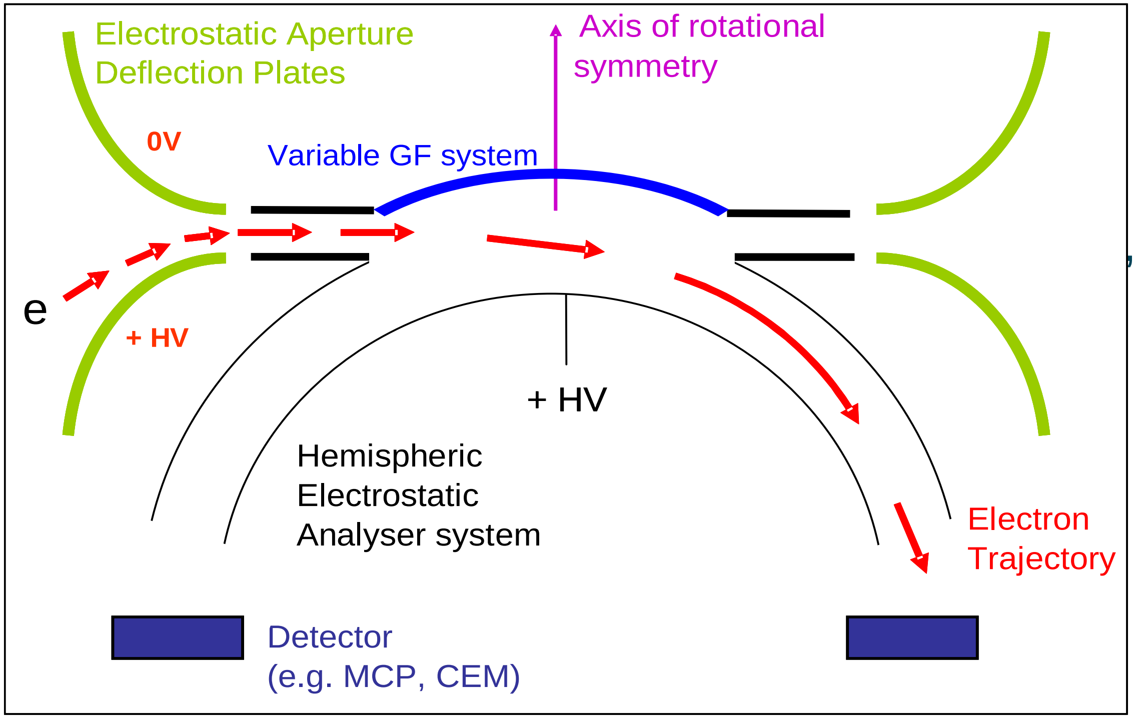

Solar Orbiter EAS


Mars Express in the calibration chamber

In-situ Instrumentation

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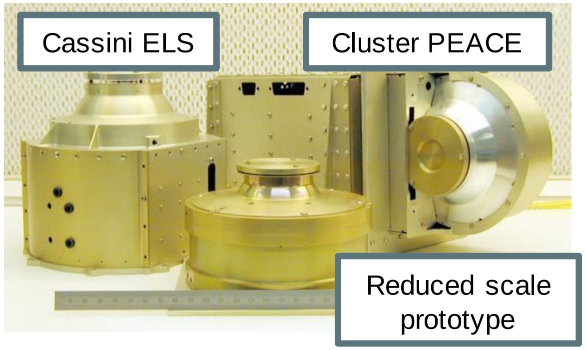
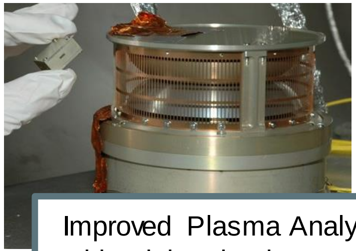

Cassini ELS

Cluster PEACE

Reduced scale prototype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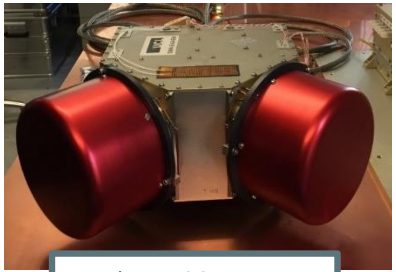
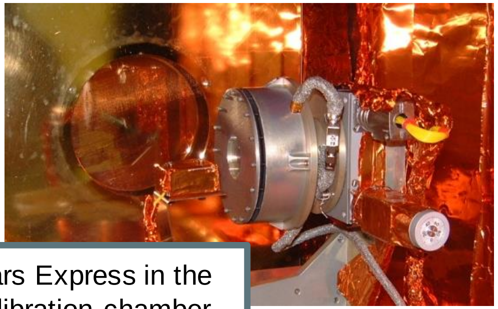
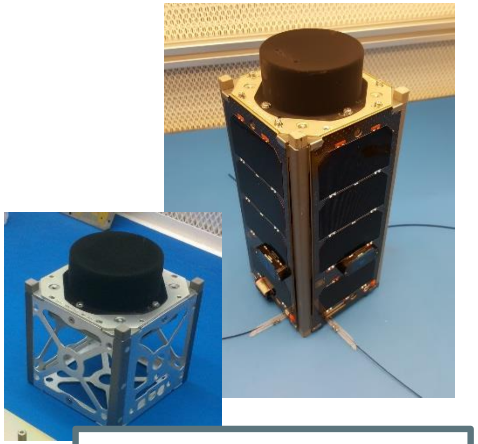

Solar Orbiter EAS

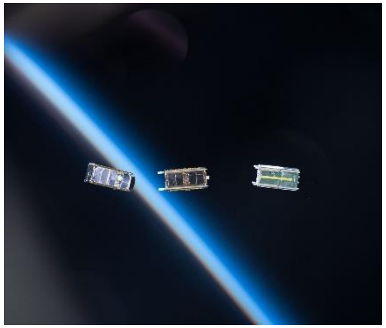

Mars Express in the calibration chamber

The Future is Small and a bit about CubeSats

- Honey, I shrunk the satellite
  - Prof. Bob Twiggs - Stanford
  - Professor Jordi Puig-Suari - CalPoly
- MSSL CubeSat R&D programme initiated in 2008
  - Technology demonstration – platform for innovation
  - Science
  - Education and Outreach
- “Small” things at MSSL
  - UCLSat – Launched in June 2017
  - Highly miniaturised sensor systems

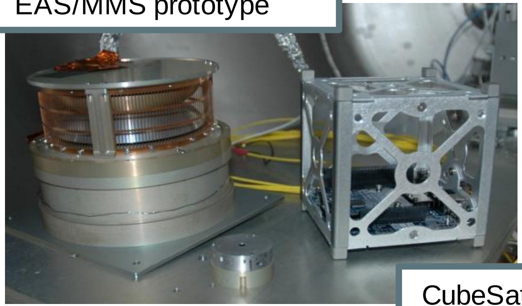


UCLSat and Ion and Neutral Mass Spectrometers for QB50



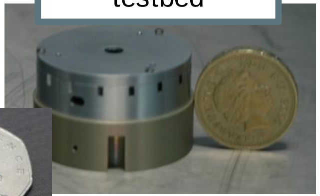
Instrument Miniaturisation

- Driven by CubeSat and Space Weather
- Generic technology development
  - Electronics miniaturisation – HV, readout, digital
  - Detection systems – combined e-ion
- Alternative geometries to top-hats
  - Cylindrical, Bessel box
- Technology demonstration
  - UK TechDemoSat
  - QB50 mission

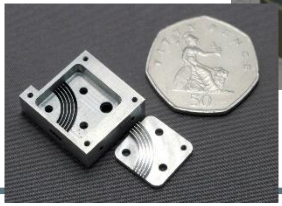


Improved Plasma Analyser EAS/MMS prototype

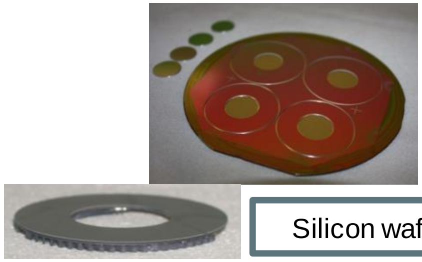
CubeSat



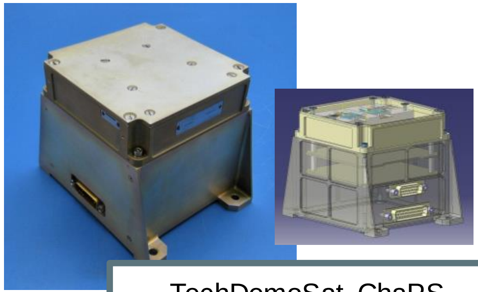
EJSM prototype testbed



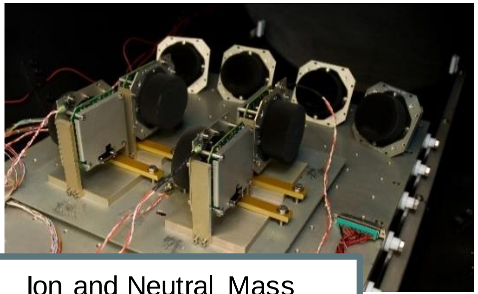
High temporal resolution proof-of-concept analyser



Silicon wafer analyser



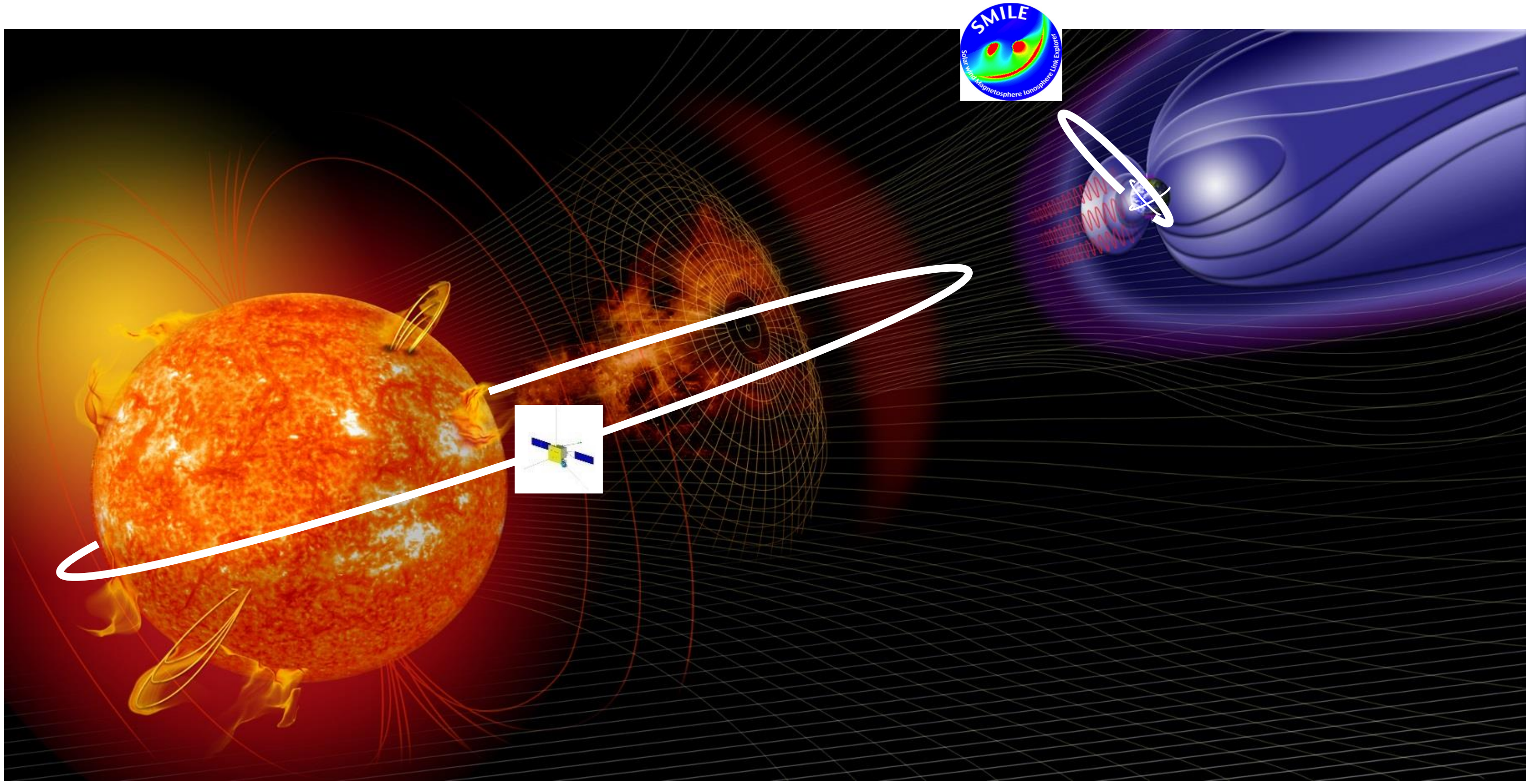
TechDemoSat ChaPS instrument and CAD model



Ion and Neutral Mass Spectrometers for QB50

Current missions and Space Weather Science

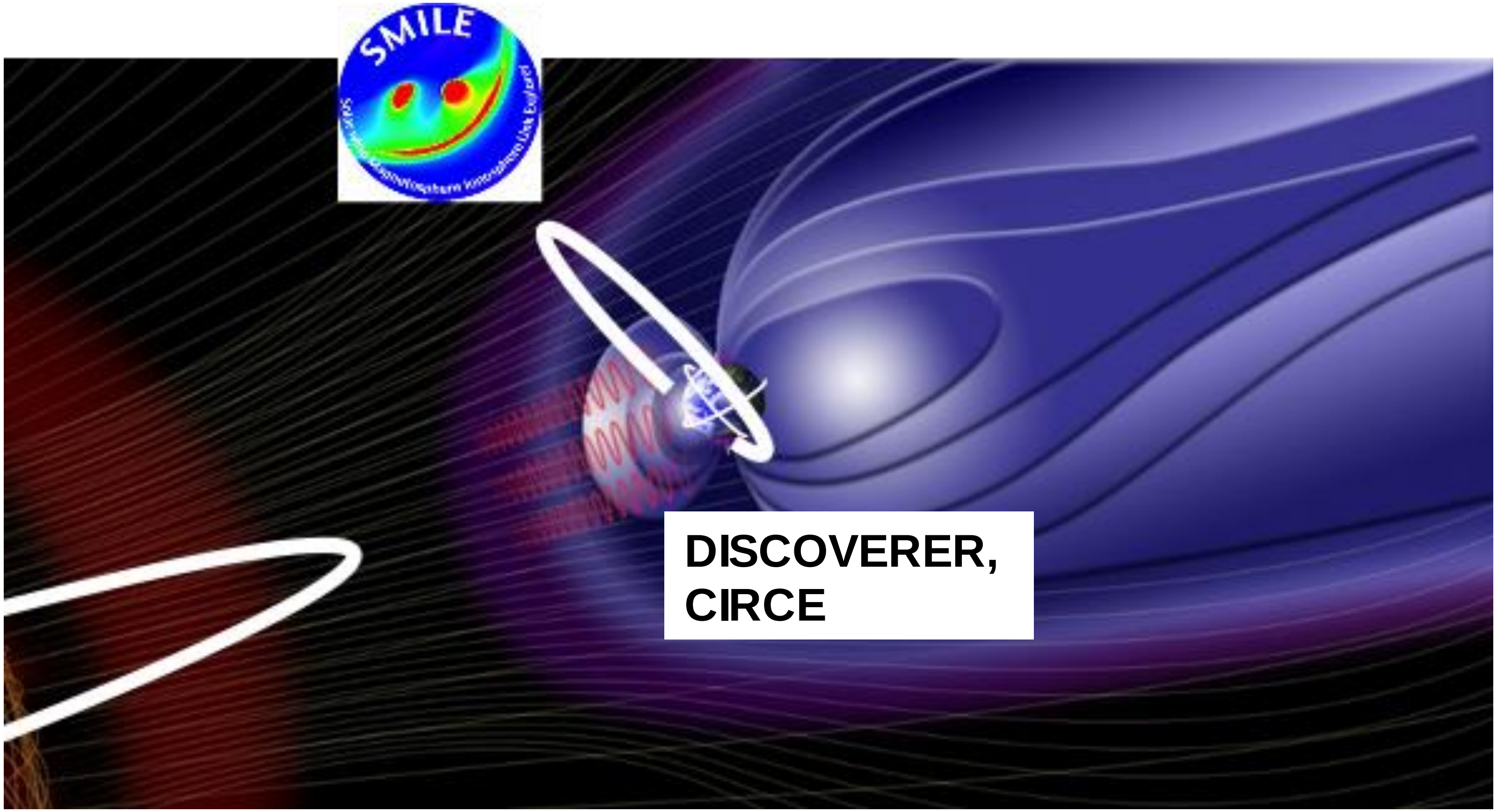
"Source to sink"



Background Image credit: NASA

Current missions and Space Weather Science

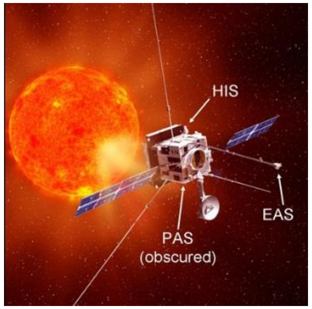
“Source to sink”



Background Image credit: NASA

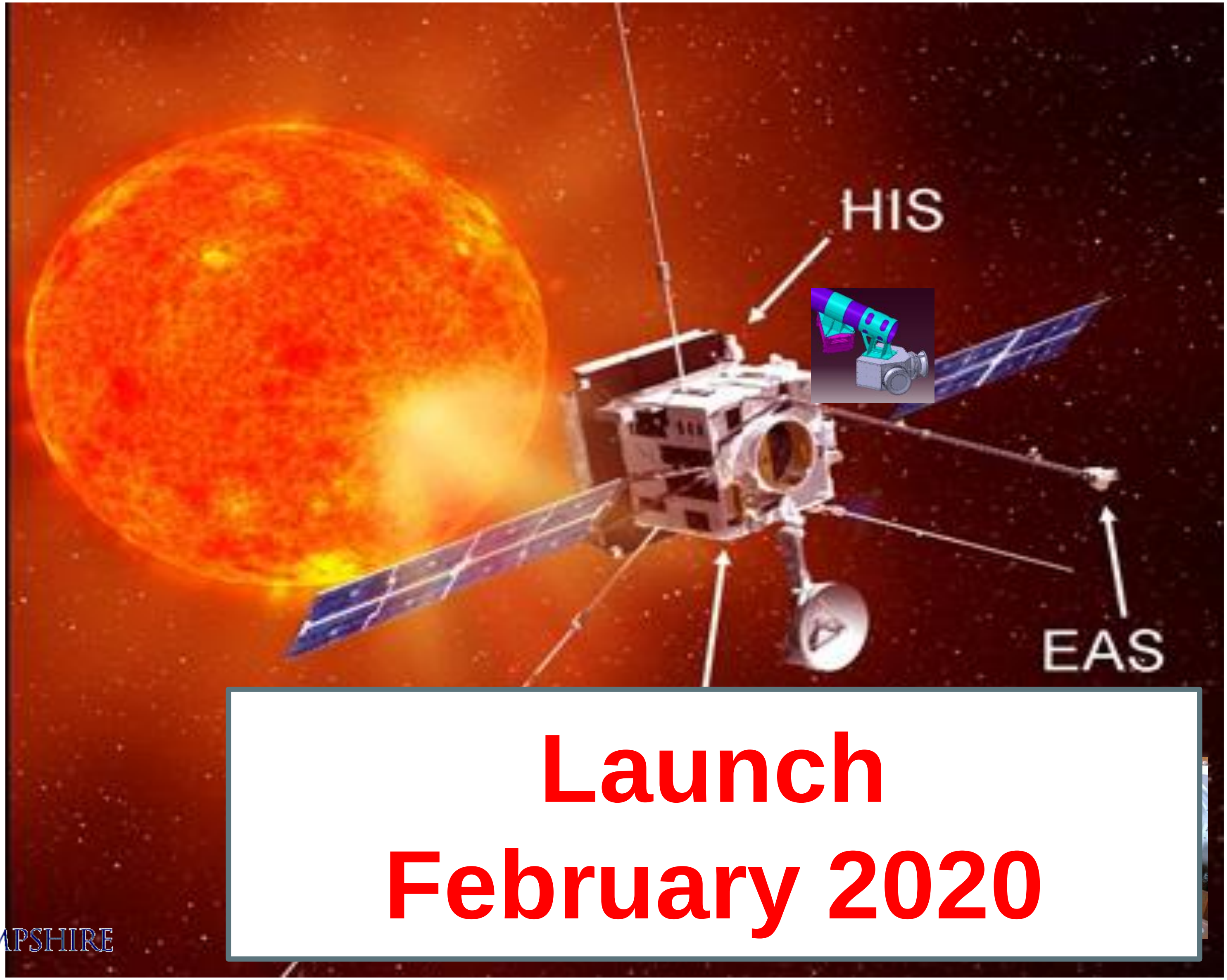
Flight Missions – ESA and Cornerstone

- Solar Orbiter Mission - ESA M-class, launch Feb. 2020
  - Solar Wind Analyser (SWA) Suite
- SMILE - ESA S-class, launch 2023
  - Solar Wind Light Ion Instrument
- LGR (Phase A/B1 study) – ESA SSA
  - Solar Wind Ion Analysers
- Daedalus (Phase 0 study) – ESA Earth Observation
  - VLEO - <150 km altitude
  - Electron, Ion and Neutral particle Analysers
- JUICE, ESA - ESA L-class, launch 2022
  - Detections System for Energetic particle instrument



Solar Orbiter

SMILE

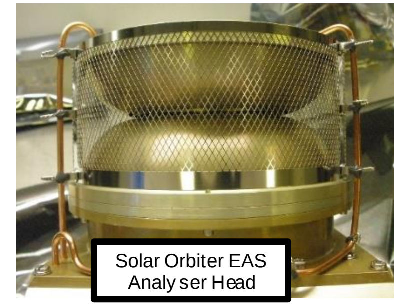


Launch
February 2020

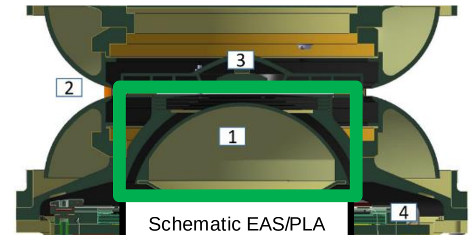
D3S Workshop, ESOC, Darmstadt, 24th October, 2019

LGR PLA Overview

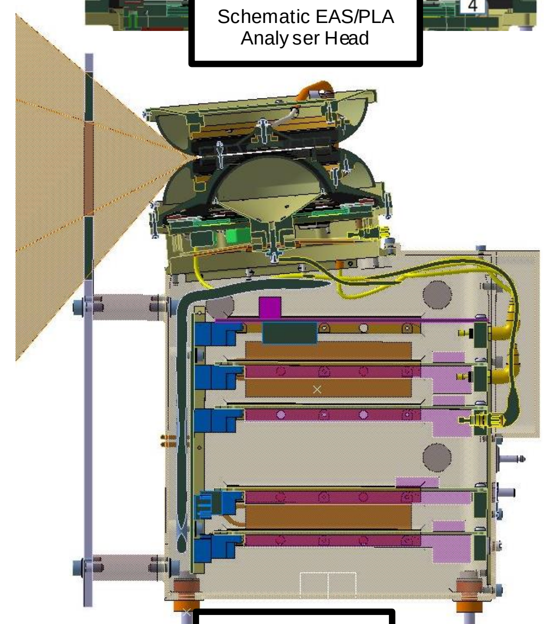
- PLA design based largely on EAS top-hat design
- EAS to PLA
  - Optics - Small change to radius of inner hemisphere
  - Detector sub-system configured for ions (based on heritage)
  - Dual polarity HV, with negative voltage on inner hemisphere (low-risk development of existing single polarity design)
  - HV sweep modulator (based on EAS) with ± 4 kV up from + 2 kV



Solar Orbiter EAS Analyser Head



Schematic EAS/PLA Analyser Head



PLA CAD model

MSSL In-situ instruments

Energy Range table

	Energy Range			
Particle species	0.1 – 70 (eV)	0.03 – 5 (keV)	0.01 – > 30 (keV)	30 – >1000 (keV)
Electrons	ChaPS	EAS, ChaPS	PEACE, ELS, TEA, HOPE-M bb	SWAN bb
Ions	INMS, ChaPS	ChaPS	PLA, HOPE-M bb	SWAN bb
Neutral Atoms	INMS			
Energetic particles				JUICE – JENI, JoEE, SWAN bb

Particle detection systems spreadsheet

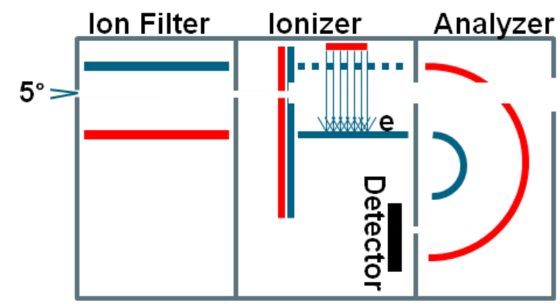
Geometry	Top-hat geometry				Bessel box			Cylindrical	
Instrument	**Cassini ELS**	**PEACE LEEA**	**EAS**	**PLA**	**ChaPS-High**	**ChaPS-Low**	**HOPE**	**INMS**	**INMS-DISC**
Particles detected	Electrons	Electrons	Electrons	Ions (Electrons)	Electrons	Electrons / Ions	Ions	Ions/ Neutrals	Ions/ Neutrals
K Factor	6.14	6.14	6.14	12 (tbd)	60/120	2.4	60	2.8	2.8
Geometric Factor (cm^2sreV/eV)	$8x10^{-4}$	$1.6x10^{-4}$	$8.5x10^{-5}$	$8.5x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	$6x10^{-4}$	$6x10^{-4}$
Energy Resolution	0.167	0.128	0.128	0.075	0.3	0.056	0.3	0.06/0.12	0.06/0.12
Energy Acceptance	0.59eV – 26.4KeV	0.59eV – 26.4KeV	0.78eV – 5KeV	50eV – 43KeV	6/12eV – 2/4KeV	0.24 – 67eV	50eV – 43KeV	0.28 – 78eV	0.28 – 230eV
Angular Resolution	5.27° x 20°	2.79° x 15°	2.79° x 11.25°	2-4° x 5°	1.7° x 20°	1.5° x 20°	2° x 22.5°	1.3° x 2.0°	1.3° x 2.0°
Field of View steering	A	S	E	E	-	-	E	E	E
Angular Acceptance	5.27° x 160	2.79° x 179.4°	±45° x 360°	±45° x 45°	1.7° x 20°	1.5° x 20°	±11.25° x 60°	1.3° x 7.0°	1.3° x 7.0°

Particle detection systems spreadsheet

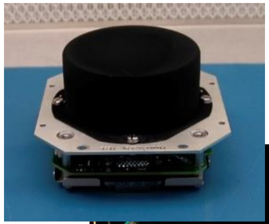
Geometry	Top-hat geometry				Bessel box			Cylindrical	
Instrument	**Cassini ELS**	**PEACE LEEA**	**EAS**	**PLA**	**ChaPS-High**	**ChaPS-Low**	**HOPE**	**INMS**	**INMS-DISC**
Mass	1.4 kg	1.9 kg	3.5 kg	2.4 kg	0.85 kg		0.65 kg	0.22 kg	~0.35 kg
Power	2W	2W	3.5W	2.5W	0.95W		1.4W	0.9W	0.9W
Data interface	-	-	Spacewire	Spacewire/ as required	CANbus		As required	RS232	RS232
Accomodation	-	-	Mission dependent	Sun facing/ Mission dependent	-		External to satellite/ Mission dependent	Ram direction	Ram direction
ICD available	-	-	Y	Y			N	Y	Y
TRL	9	9	8	5	9		5	9	5
Breadboard development	-	-	1 year	1 years	-		1-2 years	-	1 year
Flight model development	-	-	2 years	3 years	-		1-2 years mission dependent	6 months	1 year/ Mission dependent

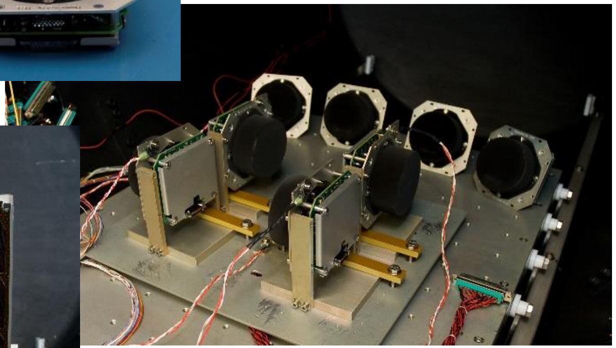
QB50 INMS – Overview

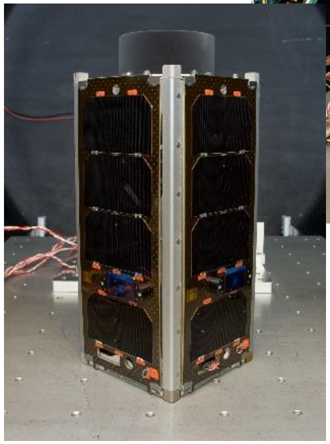
Dhiren Kataria, Alan Smith, Robert Wicks, Ben Taylor, Craig Leff, Rahil Chaudery, Peter Coker, Hubert Hu, Mark Hailey, Andy Malpuss, Duncan Rust



- Ion and Neutral Mass Spectrometer
  - Alternate pino-pong between ions and neutral particles
- Measure density of dominant species
  - O, O_2, N_2, NO
- 220 gms, 0.3U
- 28 (ISS) + 6 (PSLV) satellites launched in mid-2017
- MSSL built 11 INMS sensors

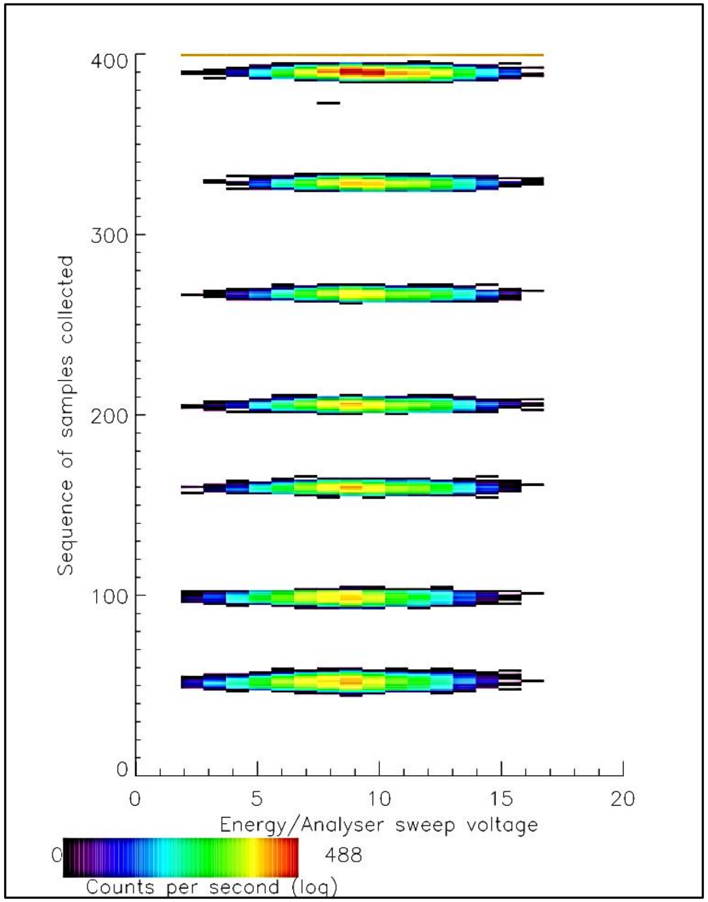






Data from Phoenix (Taiwan)

- Satellite in Y-Thomson spin
  - Particles enter aperture when instrument faces spacecraft ram direction measured only
- Data from 16th January 2018
  - Instrument set for O+
  - X-axis – Voltage (Energy)
  - Y-axis - Time

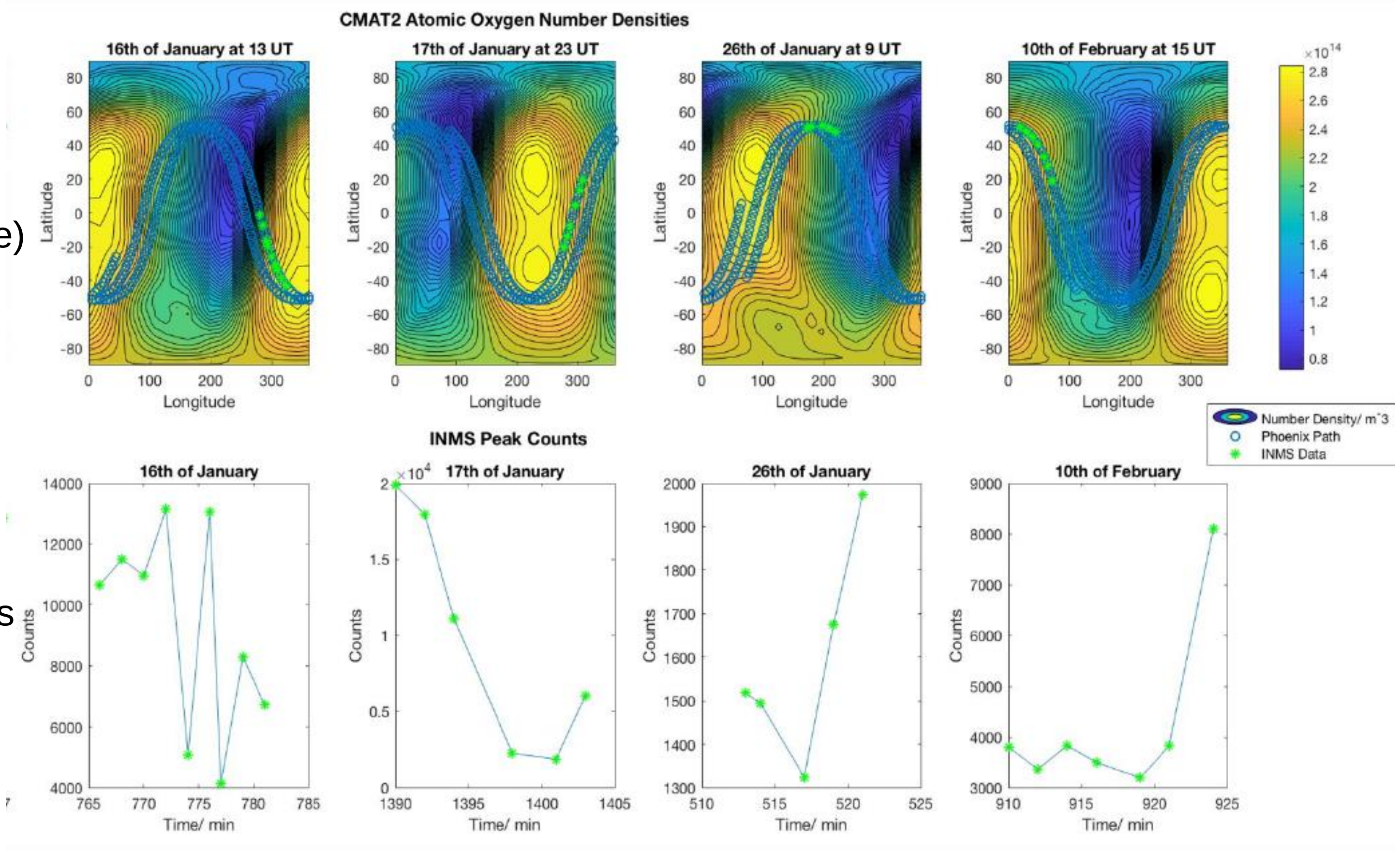


Comparison with CMAT2 –

Data taken in conjunction with January 2018 World Radar Day

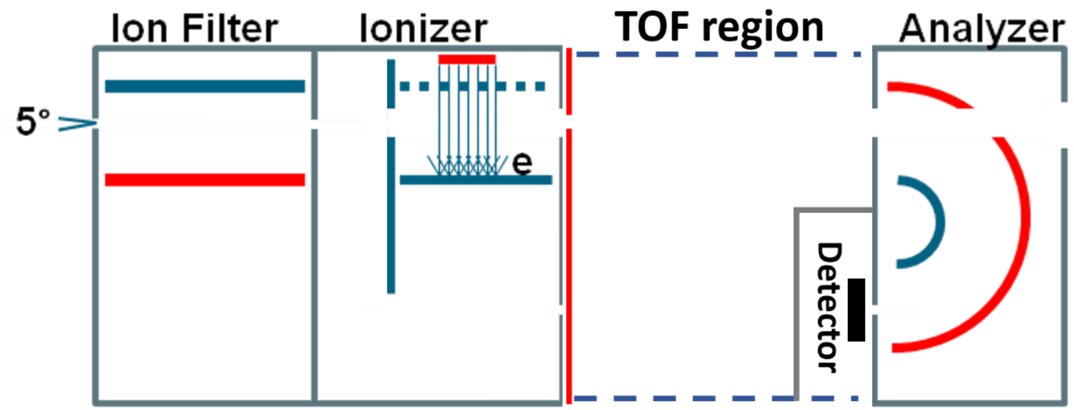
UPPER panels: CMAT2 data overlaid with satellite path (blue) and data from INMS (green)

Lower panels: INMS peak counts from each Y-Thomson spin



Anna Apsit, Masters thesis, 2018

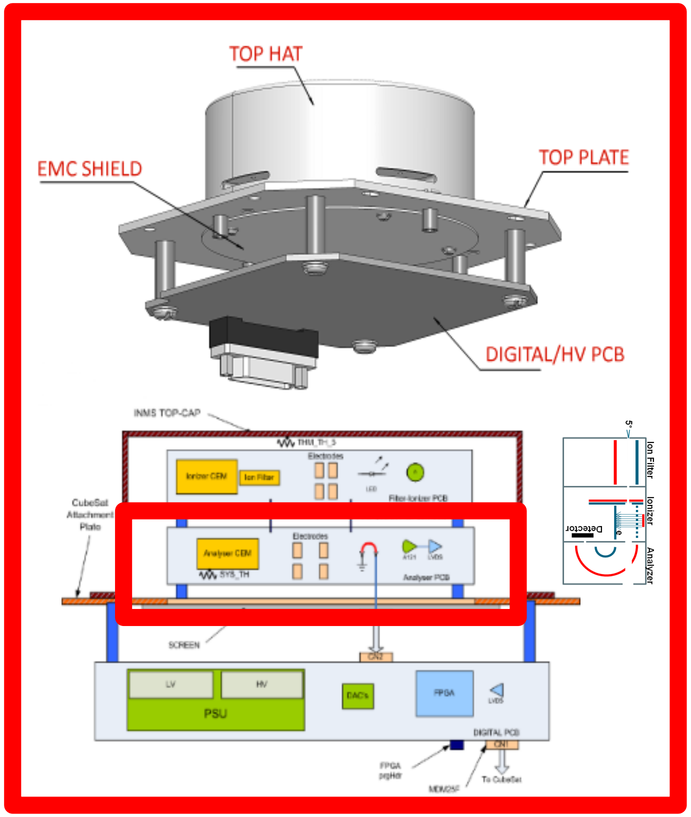
DISCOVERER



- INMS for SOAR
  - Satellite for Orbital Aerodynamics Research
  - Time-of-flight
  - In-flight velocity measurement
    - Needs high resolution position knowledge
- INMS for wind tunnel
  - Largely identical to SOAR INMS
  - Design iterations for milli-eV measurements

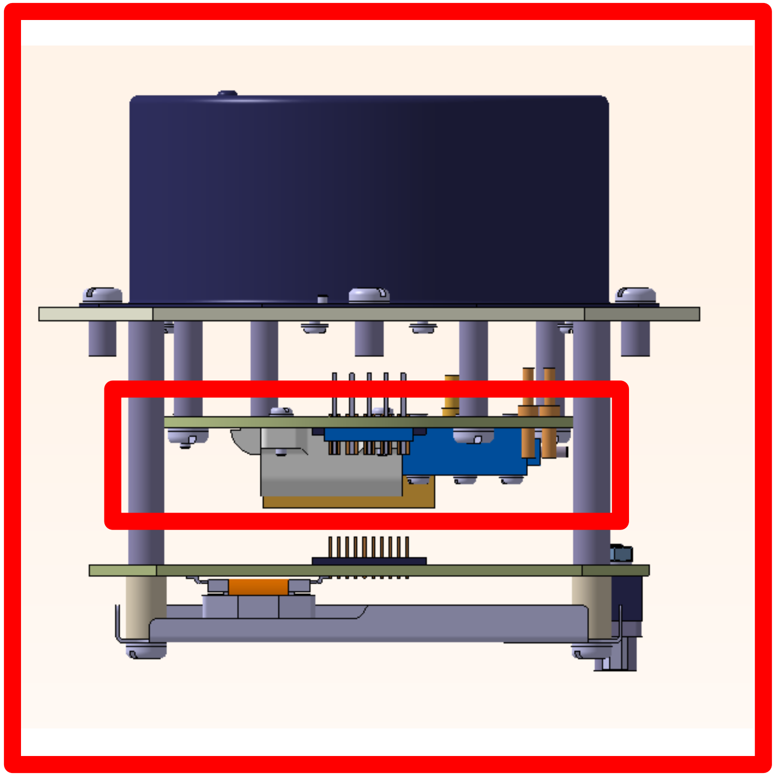
DISCOVERER

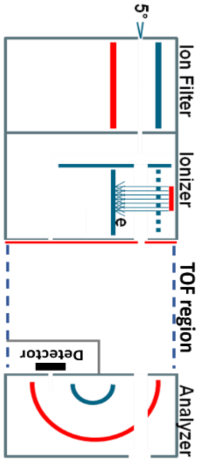
QB50 design



DISCOVERER design

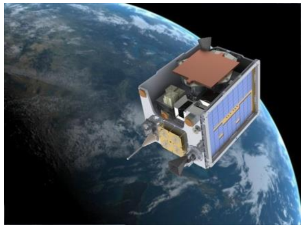
Red-boxed section shifted down to provide 40 mm time-of-flight length





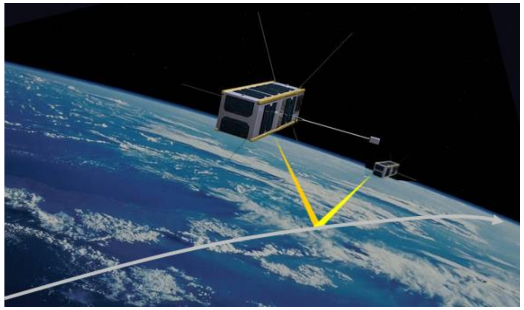
Flight Missions – CubeSat and TechDemo

- TechDemoSat Mission, UK – launched 26th June, 2014
  - Technology Demonstration mission
  - Charged Particle Spectrometer (ChaPS)



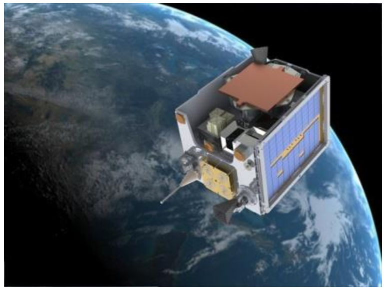
- QB50 Mission, EU FP7, launched May/June 2017
  - Ion and Neutral Mass Spectrometer (INMS)
  - UCLSat – 2U CubeSat

- CIRCE – UK, launch January 2020
  - 2 6U CubeSats, 1 QB50 INMS unit on each
- DISCOVERER – EU H2020, launch Aug. 2020
  - 3U CubeSat, INMS with enhanced capabilities

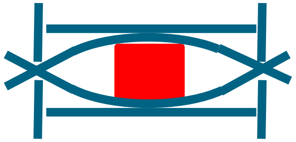


ChaPS – Overview

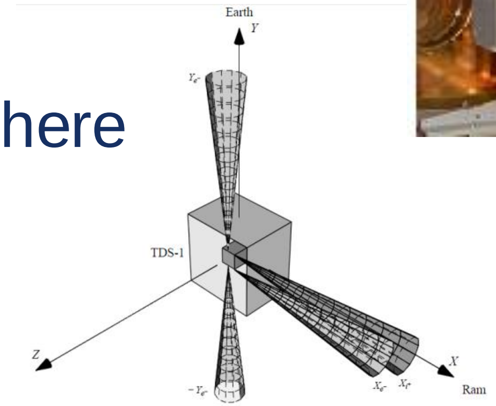
PI: Dhiren Kataria



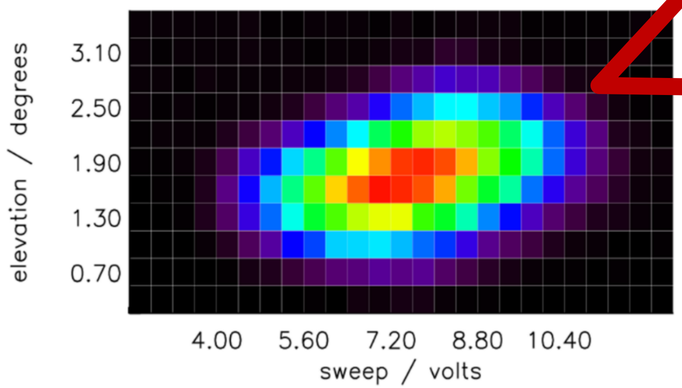
- ChaPS (Charged Particle Spectrometer)
  - Suite of miniaturised Bessel Boxes
  - Electron and ion analysis



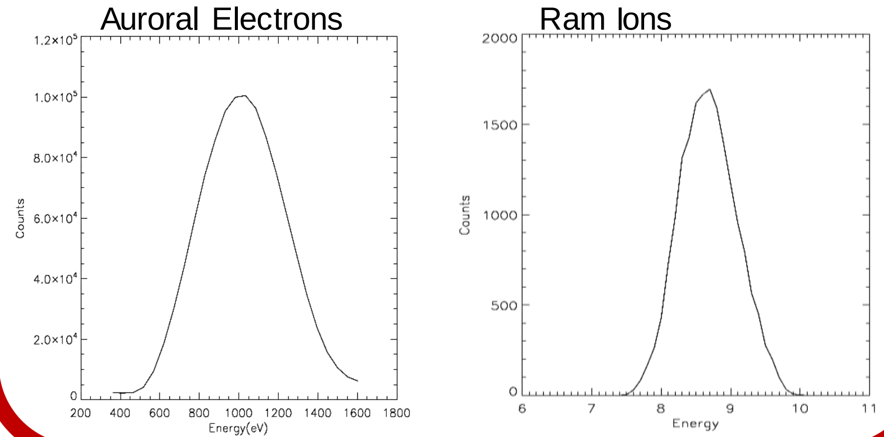
- Three modes
  - Zenith-Nadir Electrons in the auroral regions
  - Photo-electrons in the tehrmosphere
  - Ram ions in the thermosphere
- Delivered March 2012
- Launched July 2014



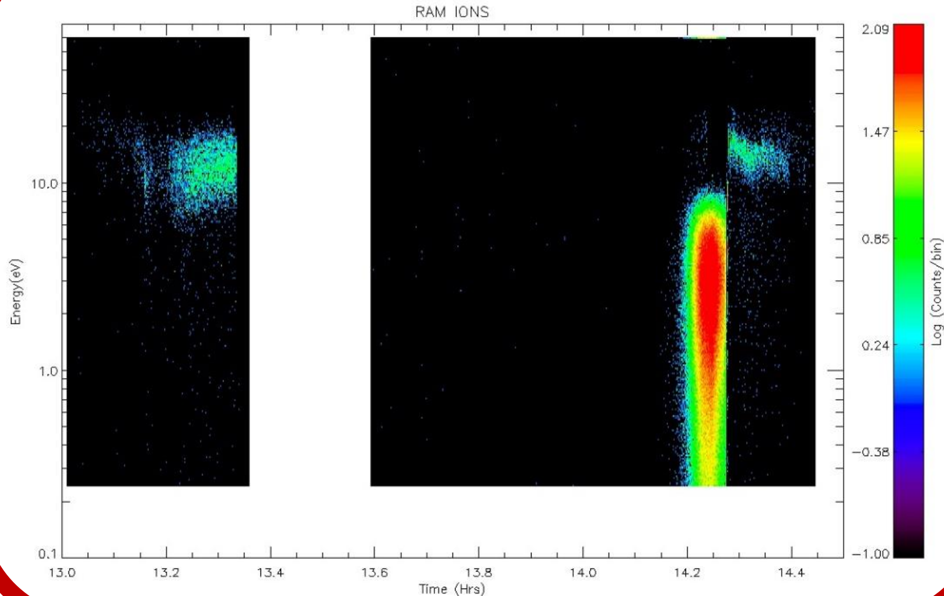
Data from ChaPS

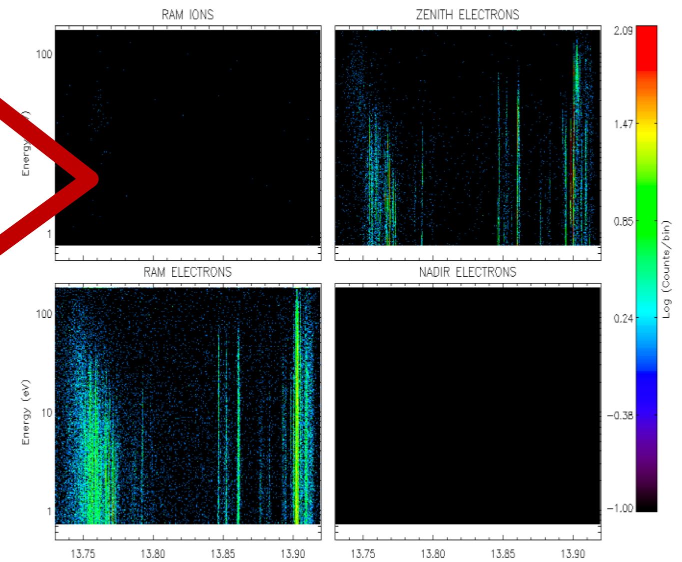


Ground Calibration Performance



Ram Ions observed at LEO



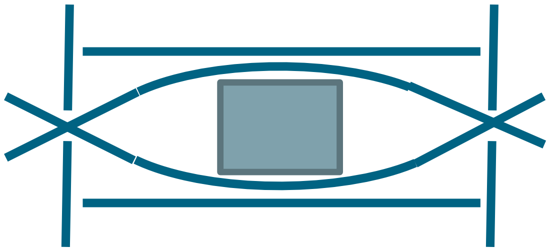


Hot Plasma Environment Monitor (HOPE-M)
ESA Phase A/B breadboard development contract

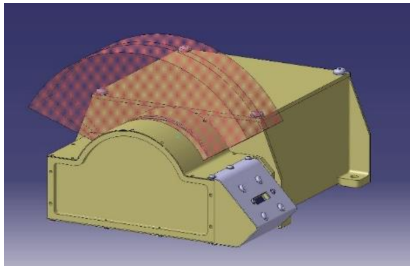
- Requirements
  - – Telecoms satellites at GEO
  - – Surface charging monitor, post-anamoly data
  - – Combined electrons and ions
  - – 30 eV – 30 keV
  - – Low resource: 0.5 kg
  - – Compact digital electronics
    - Complex capabilities, rad hard memory
  - – >10 year lifetime

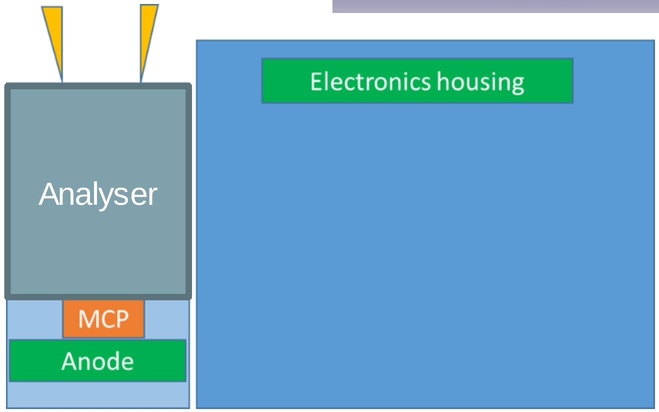
Hot Plasma Environment Monitor (HOPE-M)

Design overview

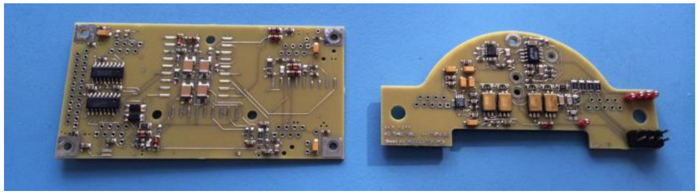


- 2 x Bessel box variants
  - Compact geometry
  - Considerable design flexibility
    - Ability to “tune” performance
    - High/low analyser constants
  - Used on STRV
- ± 22° x ± 60° Field of view
- Modular design
  - Analyser head, electronics box

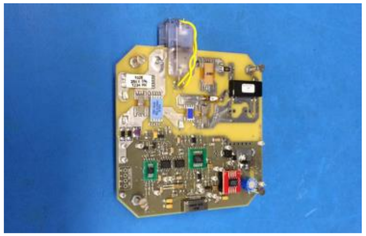


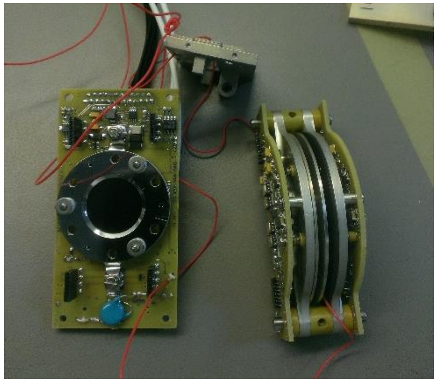


Hot Plasma Environment Monitor (HOPE-M)
Current status



- Phase A/B completed. Final report submitted February 2016
- Light leak issues remain to be resolved. Design changes implemented. Currently awaiting internal resources
- Requires ASIC development for 0.5 kg
- 0.65 kg without ASIC
- Attractive package for NanoSat missions, particularly CubeSats





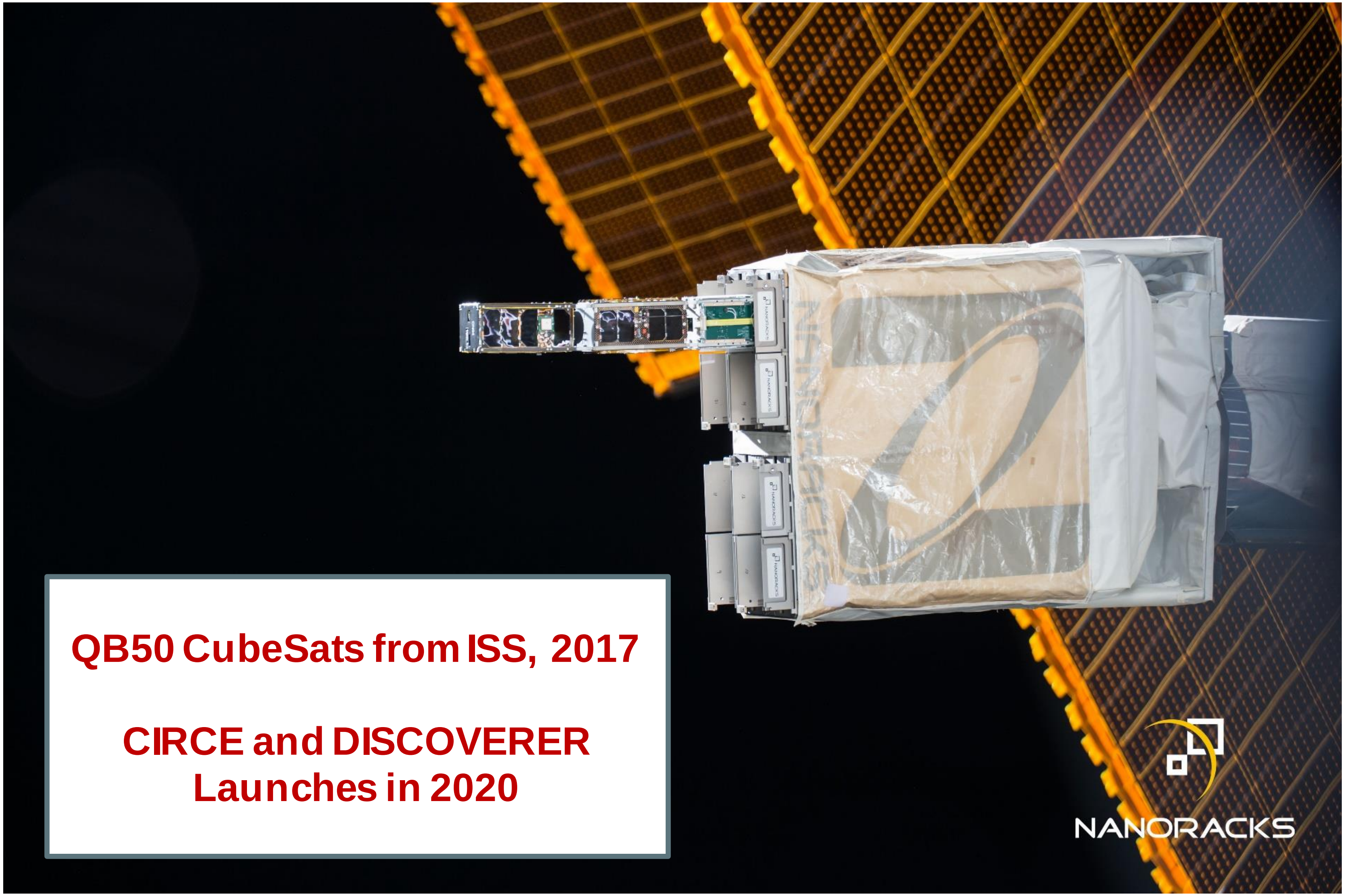
In-situ Detection systems Group

Research
Dhiren Kataria
Gethyn Lewis

Missions support
Andrew Malpuss
Theophile Brochant De Villiers

PhD students
Hubert Hu – part time

Large project teams
Engineers, driven by requirements from plasma, planetary Scientists. Typical teams of 15-30 people



QB50 CubeSats from ISS, 2017

CIRCE and DISCOVERER Launches in 2020

- Thank you