Carrington-L5:
The UK/US Operational Space Weather Mission

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Team

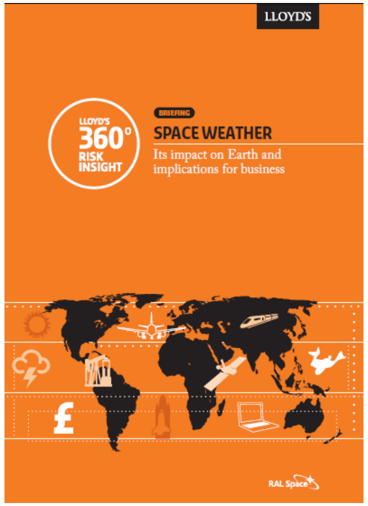
Industry: AIRBUS DEFENCE & SPACE

Institutions: RAL Space — Science & Technology Facilities Council, Rutherford Appleton Laboratory; Met Office

Academia: Imperial College London; UCL

Consultation: nationalgrid; PARADIGM SERVICES BY ASTRIUM; inmarsat

UK/US Space Weather Impacts

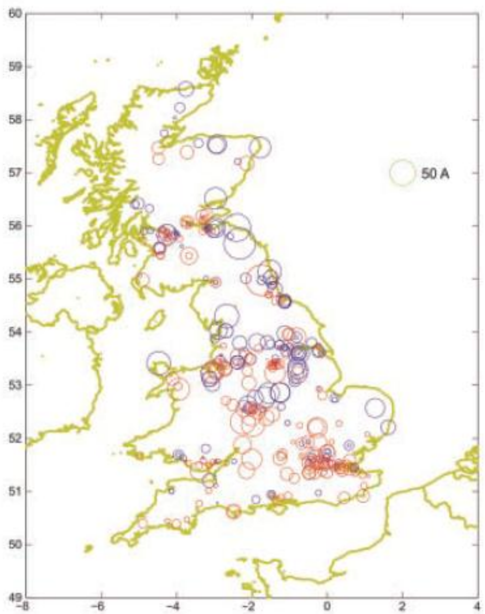


Lloyds, 2010

RAEng, 2013

Date	Event	Satellite	Orbit	Cause (probable)	Effects seen
8 March 1985		Anik D2	GEO	ESD	Outage
October 1989	CME-driven storm	TDRS-1	GEO	SEE	Outage
July 1991		ERS-1	LEO	SEE	Instrument failure
20 January 1994	Fast solar wind stream	Anik E1	GEO	ESD – note: all three satellites were of same basic design	Temporary outage (hours)
		Anik E2	GEO		6 months outage, partial loss
		Intelsat K	GEO		Temporary outage (hours)
11 January 1997	Fast solar wind stream	Telstar 401	GEO	ESD	Total loss
19 May 1998	Fast solar wind stream	Galaxy 4	GEO	ESD	Total loss
15 July 2000	CME-driven storm	Astro-D (ASCA)	LEO	Atmospheric drag	Total loss
6 Nov 2001	CME-driven storm	MAP	Interplanetary L2	SEE	Temporary outage
24 October 2003	CME-driven storm	ADEOS/MIDORI 2	LEO	ESD (solar array)	Total loss
26 October 2003		SMART-1	HEO	SEE	Engine switch-offs and star tracker noise
28 October 2003		DRTS/Kodama	GEO	ESD	Outage (2 weeks)
14 January 2005		Intelsat 804	GEO	ESD	Total loss
15 October 2006	Fast solar wind stream	Sicral 1	GEO	ESD	Outage (weeks)
5 April 2010	Fast solar wind stream	Galaxy 15	GEO	ESD	Outage (8 months)
13 March 2012	CME-driven storm	Spaceway 3	GEO	SEE?	Outage (hours)
7 March 2012		SkyTerra 1	GEO	SEE/ESD?	Outage (1 day)
22 March 2012		GOES15	GEO	ESD?	Outage (days)

1 - 2 days UK blackout
£10 billion



2003: 450 Spacecraft
- **10% outages, events**
- **11 Skynet-4 anomalous events in 48 hours**

2015: >1000 spacecraft
- **10% outages**
- **$30bn cost**
- **GNSS partial/complete loss for 3 days, UK cost ~£1 billion**

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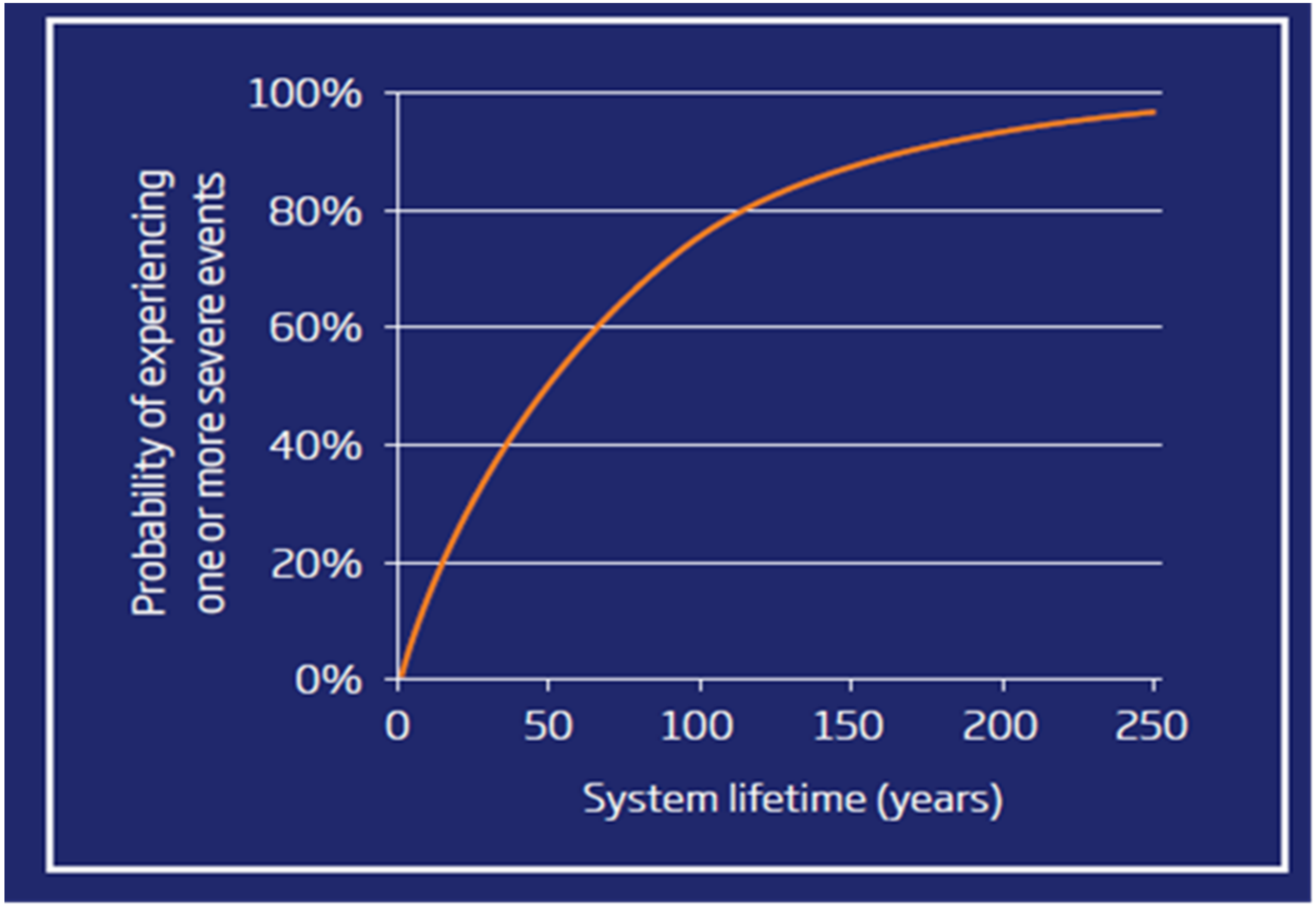
Space Weather Impact on Other UK Sectors

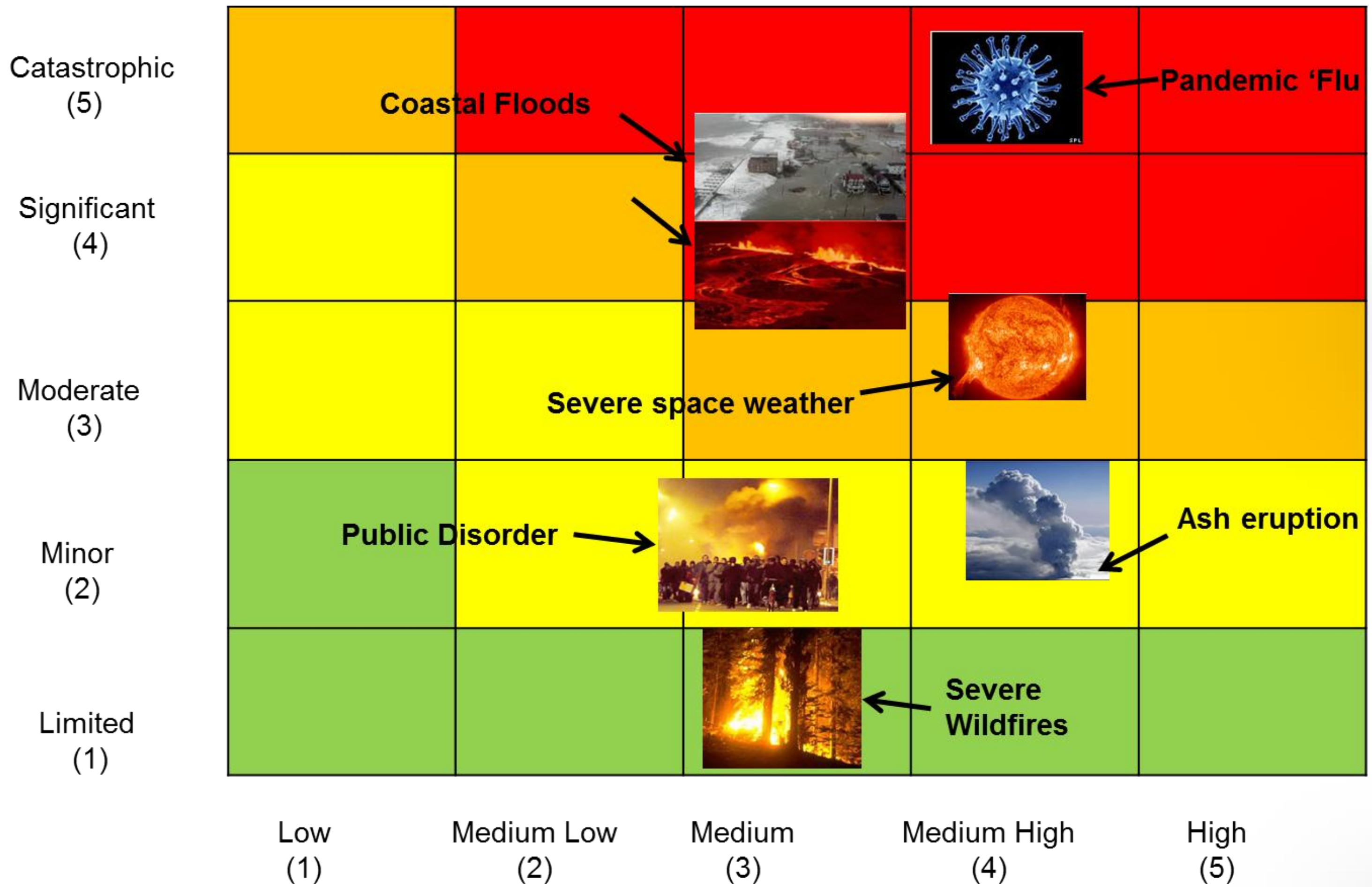
- Rail
- Phone/Radio/TV Networks
- Polar Flights
- Internet/Wireless Communications
- Pipelines
- Oil/Mineral Industries
- Finance
- Military Operations
- Human spaceflight
- Space tourism

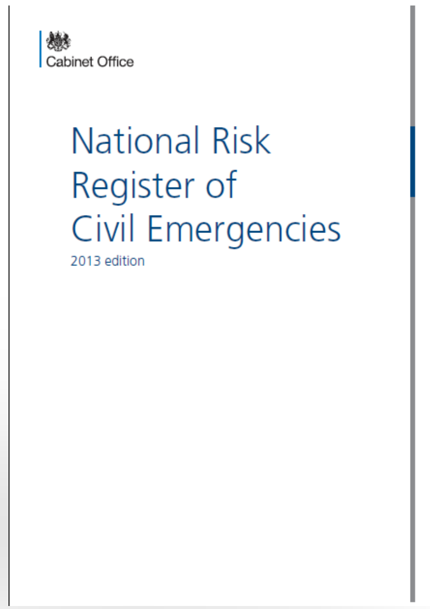


(RAE, 2013)

As technology advances, society becomes more vulnerable to SWE events.

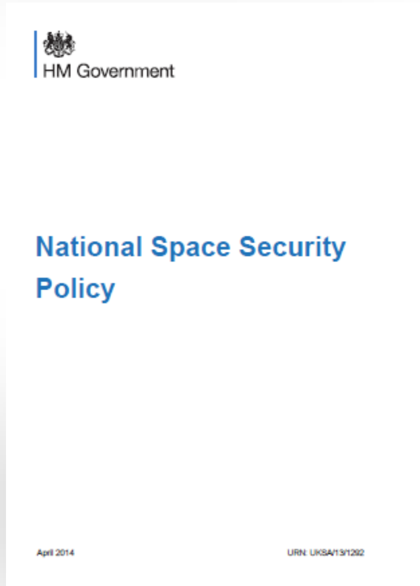
UK National Risk Register 2013/2014




Cabinet Office

National Risk Register of Civil Emergencies

2013 edition


HM Government

National Space Security Policy

Courtesy of the Cabinet Office

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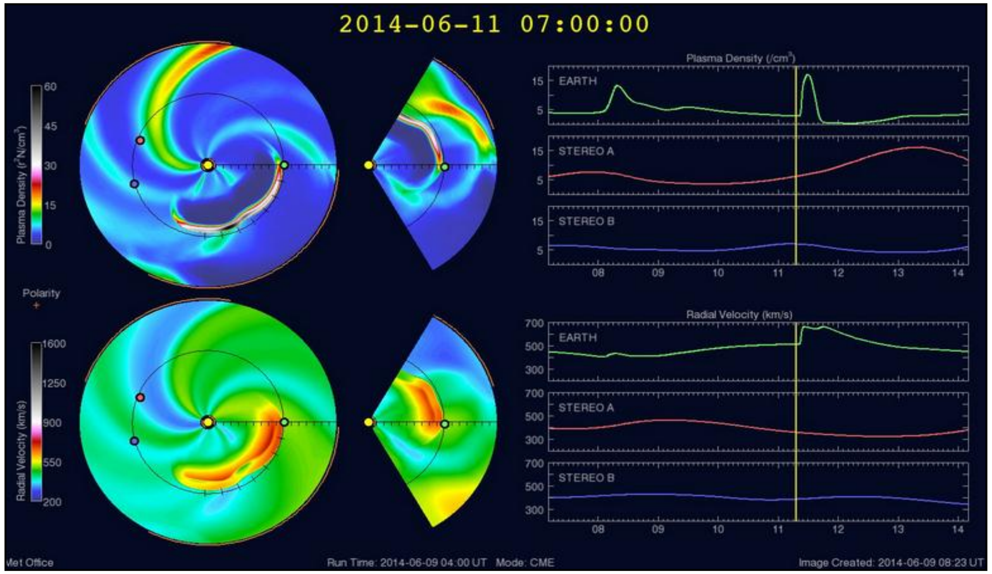
UK Met Office Space Weather Operations Centre (MOSWOC)



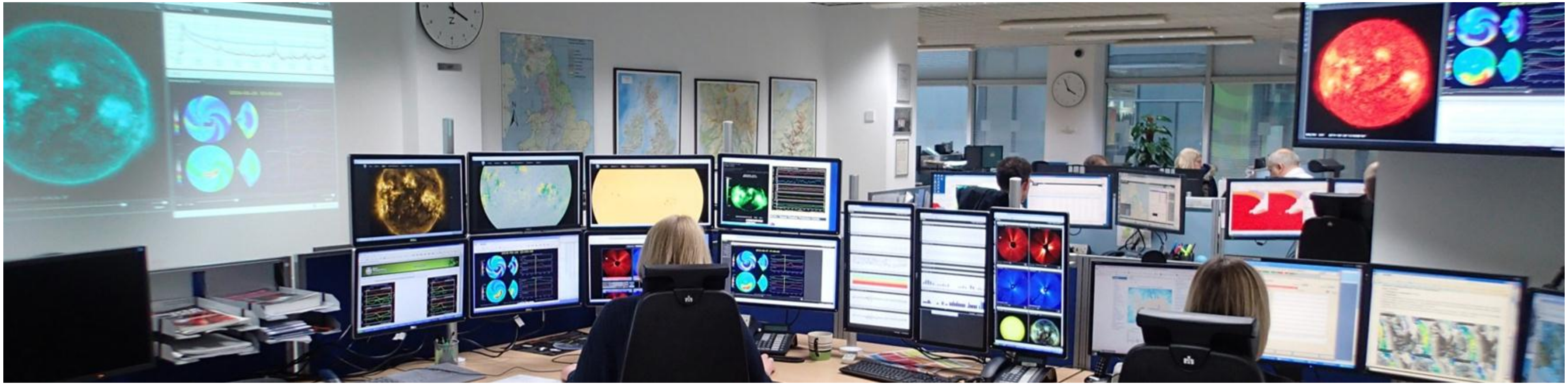
Embedded in Met Office Hazard Centre

- 24x7x365 – 29 April’14
- Full capability autumn October’14
- ~15 trained forecasters

Collaborate with academia not replicate

Operational collaboration with NOAA SWPC & BGS

- Daily forecast coordination

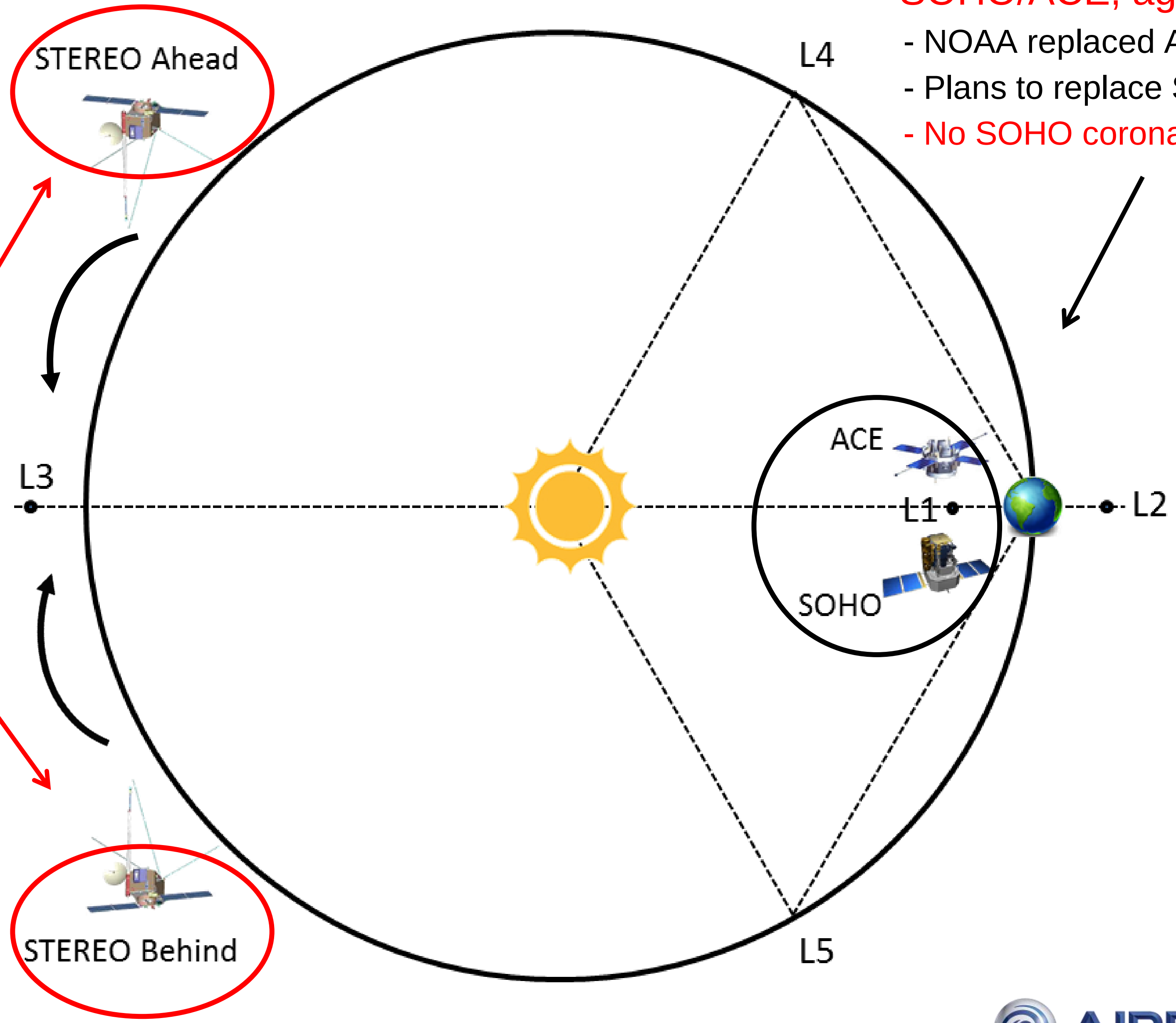


MOSWOC/SWPC Forecast input

SOHO/ACE, ageing rapidly

- NOAA replaced ACE in 2015
- Plans to replace SOHO by 2020
- No SOHO coronagraph

No replacement
L5 urgent need



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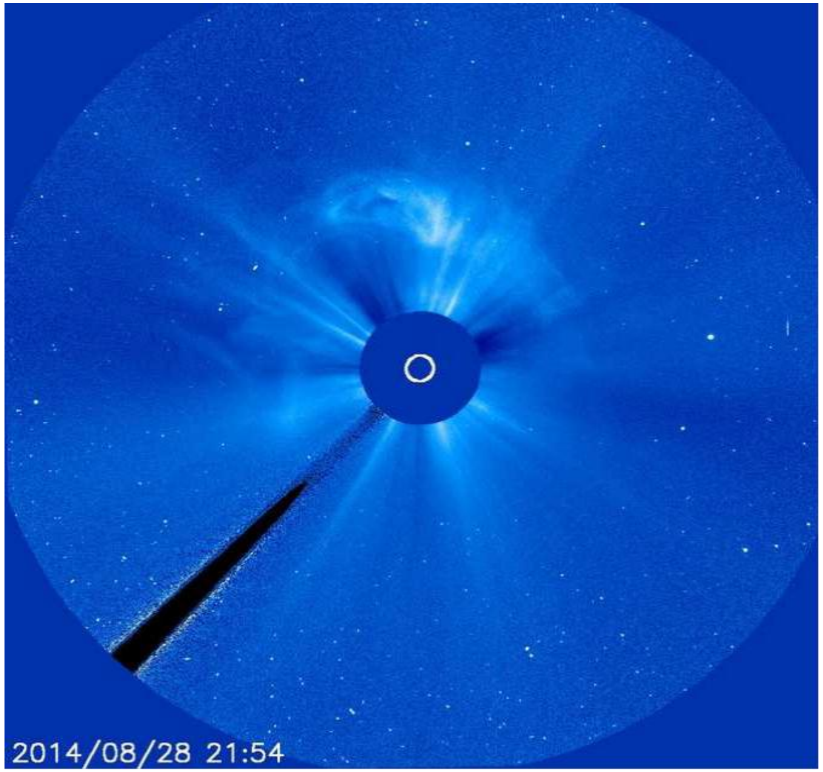
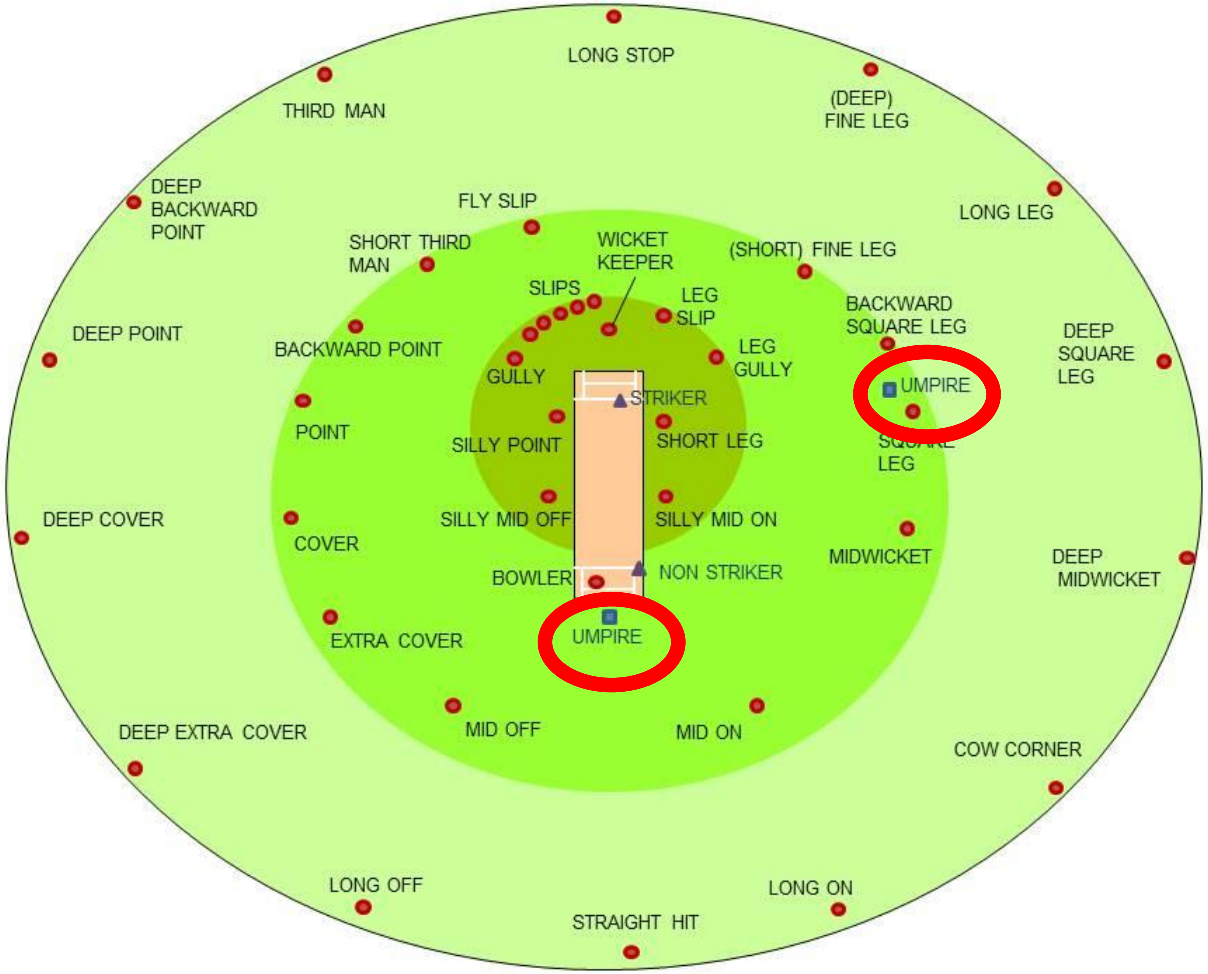
L5 & L1 Observations: The need for two umpires

From MOSWOC forecast 29/08/2014:

"SOHO LASCO C3 image showing an almost full halo CME. However it looks highly likely that this is from a back sided filament eruption, and so this CME is headed almost directly away from Earth."





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Mission Drivers

Instrument	
Coronagraph	Critical for identifying Earth-directed CME
Heliospheric Imager	Critical for identifying Earth-directed CME, and imaging arrival at Earth
Particles/fields	Measurement of CIR approaching Earth.
EUVI	To image solar active centres, in particular to assess the potential for eruptions/flare at sites as the approach locations well connected to Earth
Magnetograph	To image the magnetic structure of the photosphere at sites approaching locations well connected to Earth. Earth-directed events that originate in the field-of-view of the magnetogram, the data can be used to give an indication of the level of geomagnetic activity that will follow. Assess the potential for eruptions/flare.

- MOSWOC/SWPC operational requirements
- Lifetime: 10 years (<2 years transfer)
- 24/7 transfer of data (operational mission)
- UK/US bilateral (high UK/US heritage)
- High TRL platform/components/payloads,
- Low risk/cost
- Development in 6 years from P0 to launch

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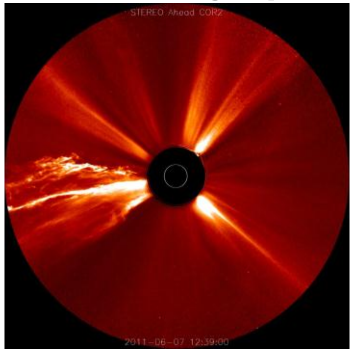
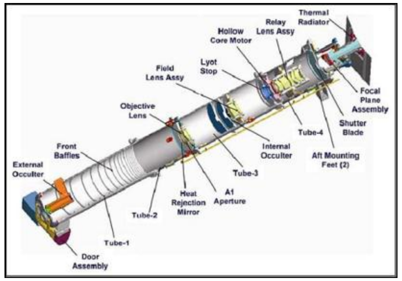
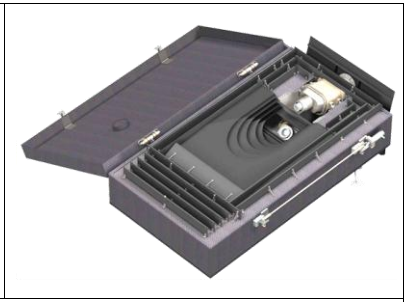
Payloads

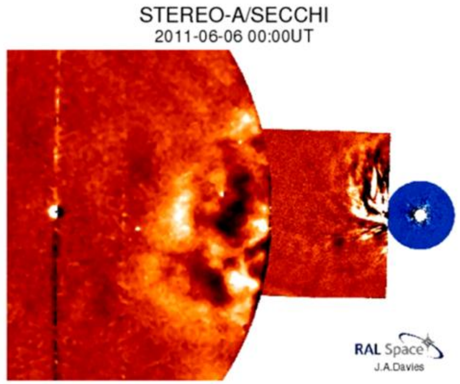
Coronagraph





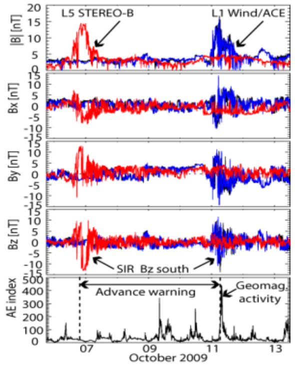


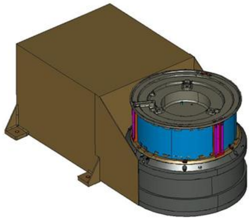
Heliospheric Imager

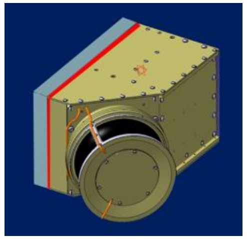


Airbus DS Boom

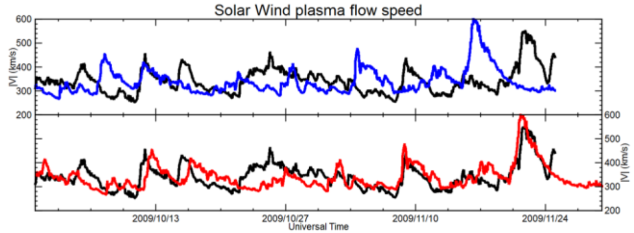
Magnetometer

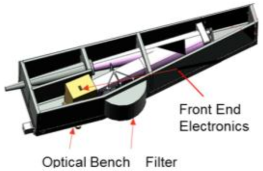


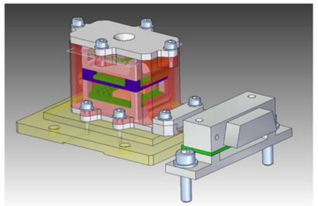




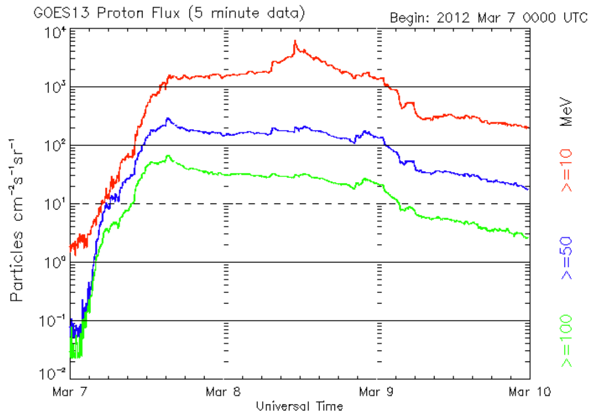
Plasma instrument

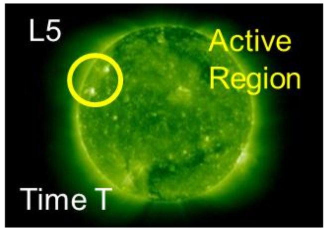


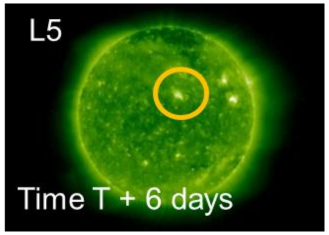


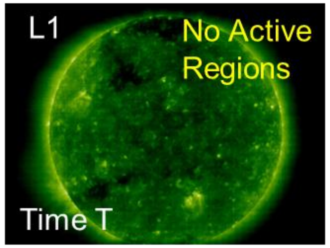


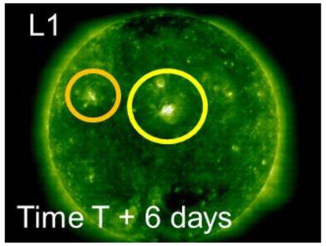
Radiation Monitor











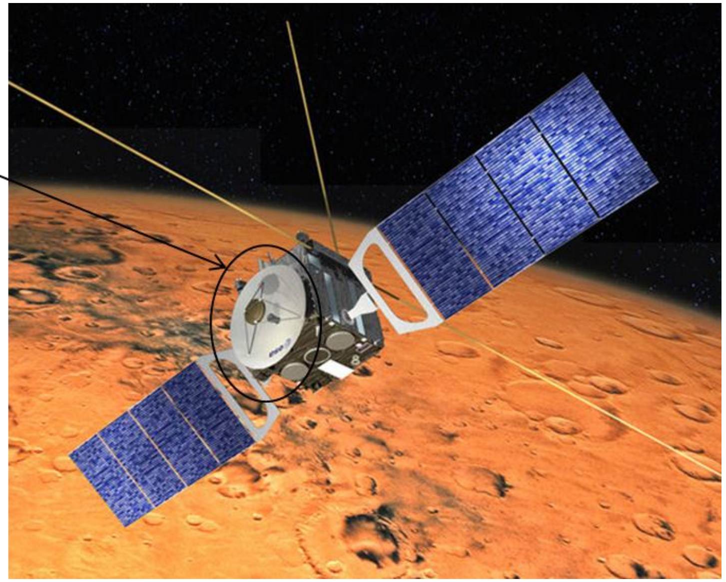
Magnetograph & EUVI

Design Trade-Offs

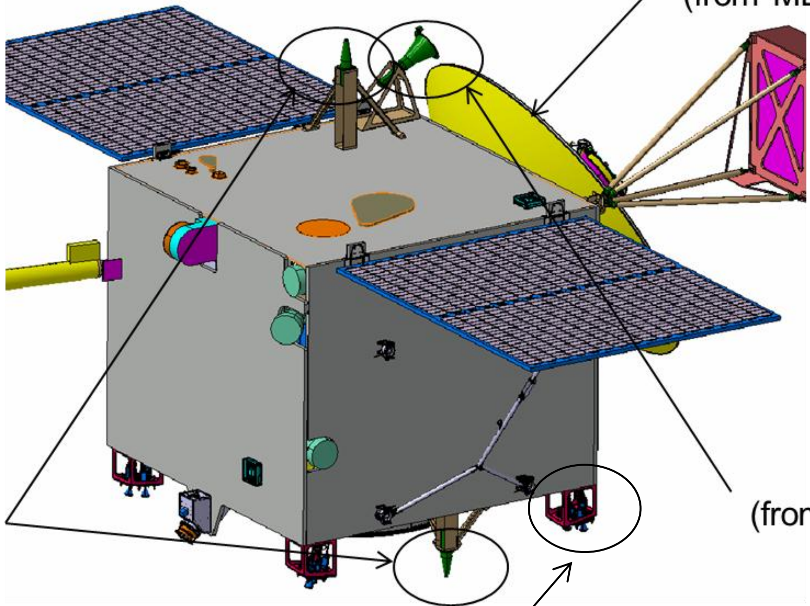
1. Direct injection by Falcon-9 to L5
2. Stopping manoeuvre at L5
3. Spacecraft mass up to 2300 Kg
4. Venus Express platform/propulsion
5. Sentinel-5P AOCS
6. Solar Orbiter avionics
7. Mars Express 1.6m antenna
8. 100% coverage with 4x15m ground stations
9. Daily download: 4.32 Gb (STEREO 5.6Gb)

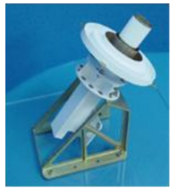
S5P STR

The Mars Express (MEX) Antenna



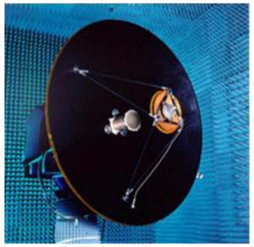
HGA (from MEX)





LGA (from LPF)

MGA (from LPF)

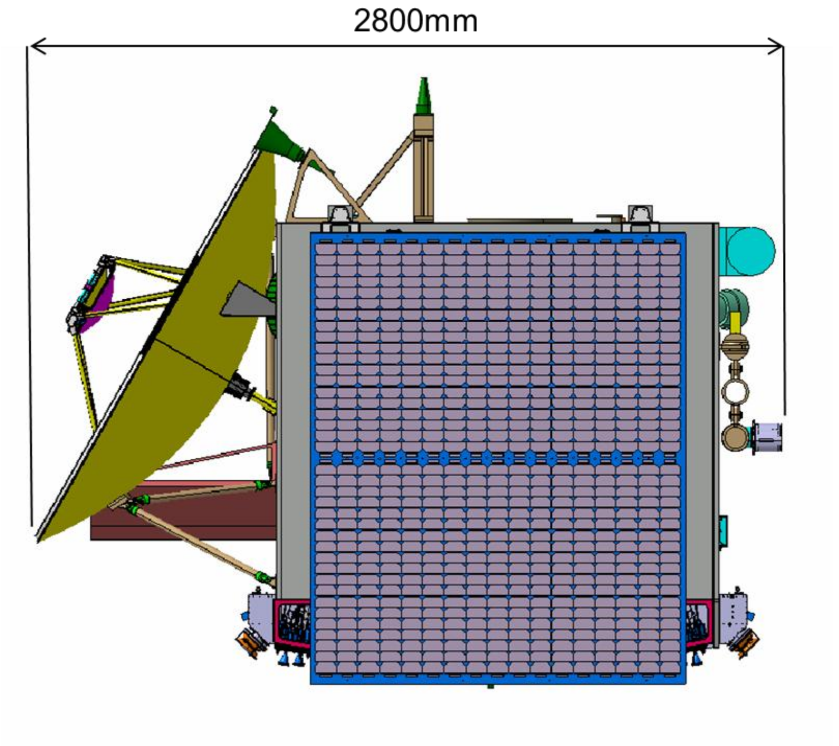


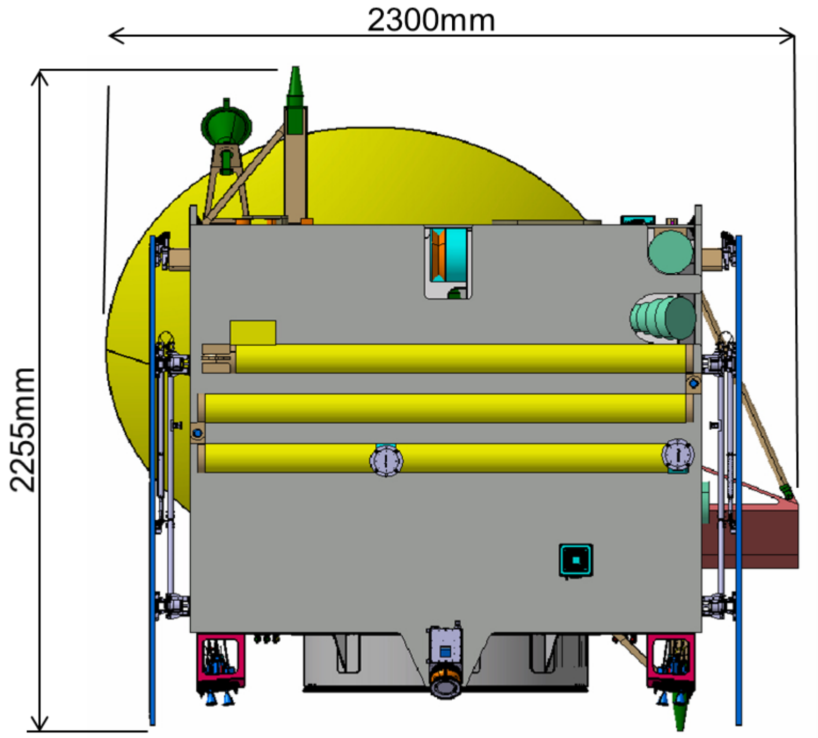
Solar Orbiter OBC/RIU

VEX Propulsion

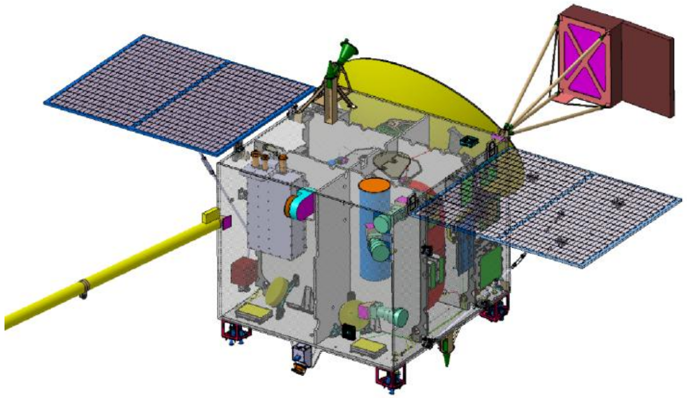
Configuration

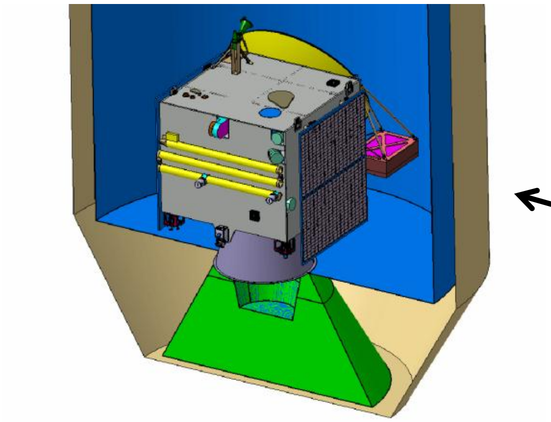
Dimensions in stowed configuration





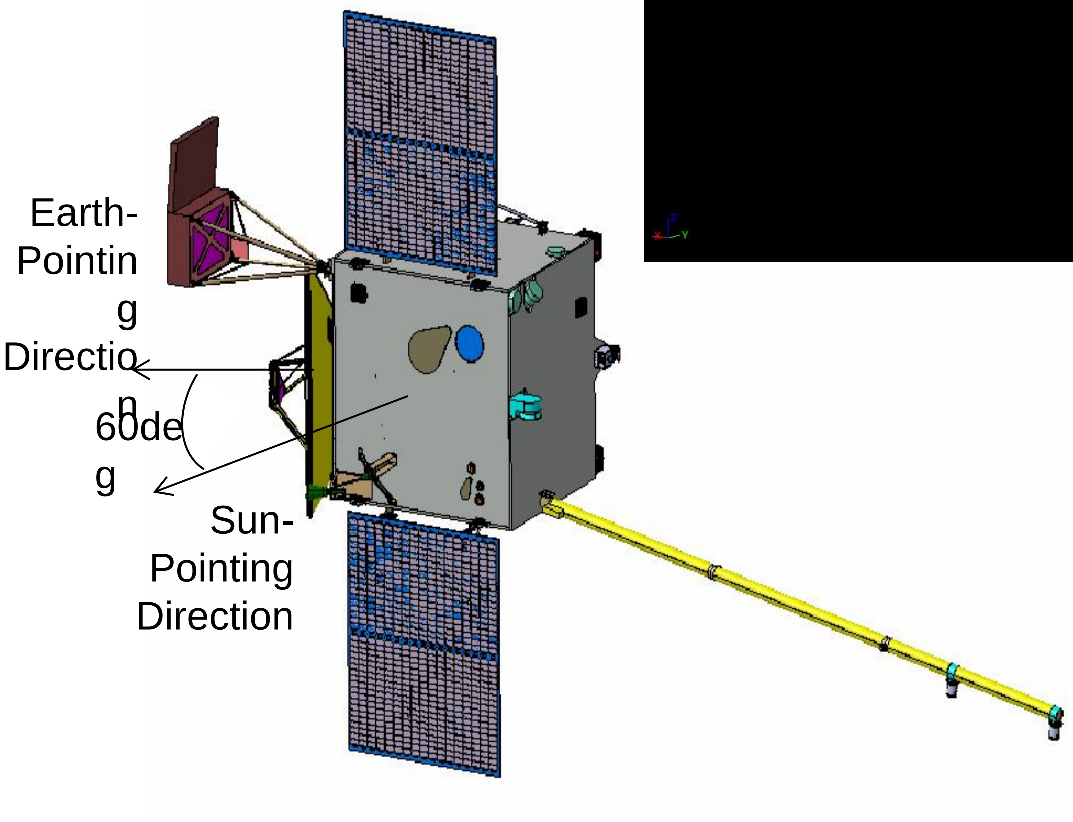
Internal Configuration





Falcon 9 Fairing

L5 Station



- Stable point
- Minimal AOCS requirements
- Continuous transfer of data to Earth
- Persistent monitoring of Sun
- Persistent monitoring of event propagation

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Cost & Schedule

- Mission Cost: £200M ($300M) (S/C, payloads, launcher, operations)
- UKSA:
  - $1.5M (04/2015-04/2016)
  - Cost-benefit analysis and Phase-0
  - Carrington team plus NOAA, SANSA
  - Expand consortium
- L5 Workshop in London (11 – 14 May)

Year	Schedule
2015	• Phase 0 study. • UKSA & NOAA/NASA agreement • AO for instruments
2016	• Instrument selection • Phase A/B starts
2017	• Mission selection • Phase B2CD • System PDR
2018	• System CDR • Instrument CDR • Launch procurement
2019	• S/C build integration & test • Instrument delivery
2020	• System integration
2021	• Launch

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Summary

- **A Sun-Earth Sentinel at L5**
- **First Operational Space Weather mission**
- **Addresses MOSWOC/SWPC requirements**
- **High UK/US heritage, high TRL, low risk, low cost**
- **Fast transfer to L5 for a 10-year mission**
- **24/7 operations**
- **Excellent research output**
- **Excellent opportunity for UK/US bilateral**
- **Excellent opportunity for other partners (e.g. Korea) to contribute**

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Questions?

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