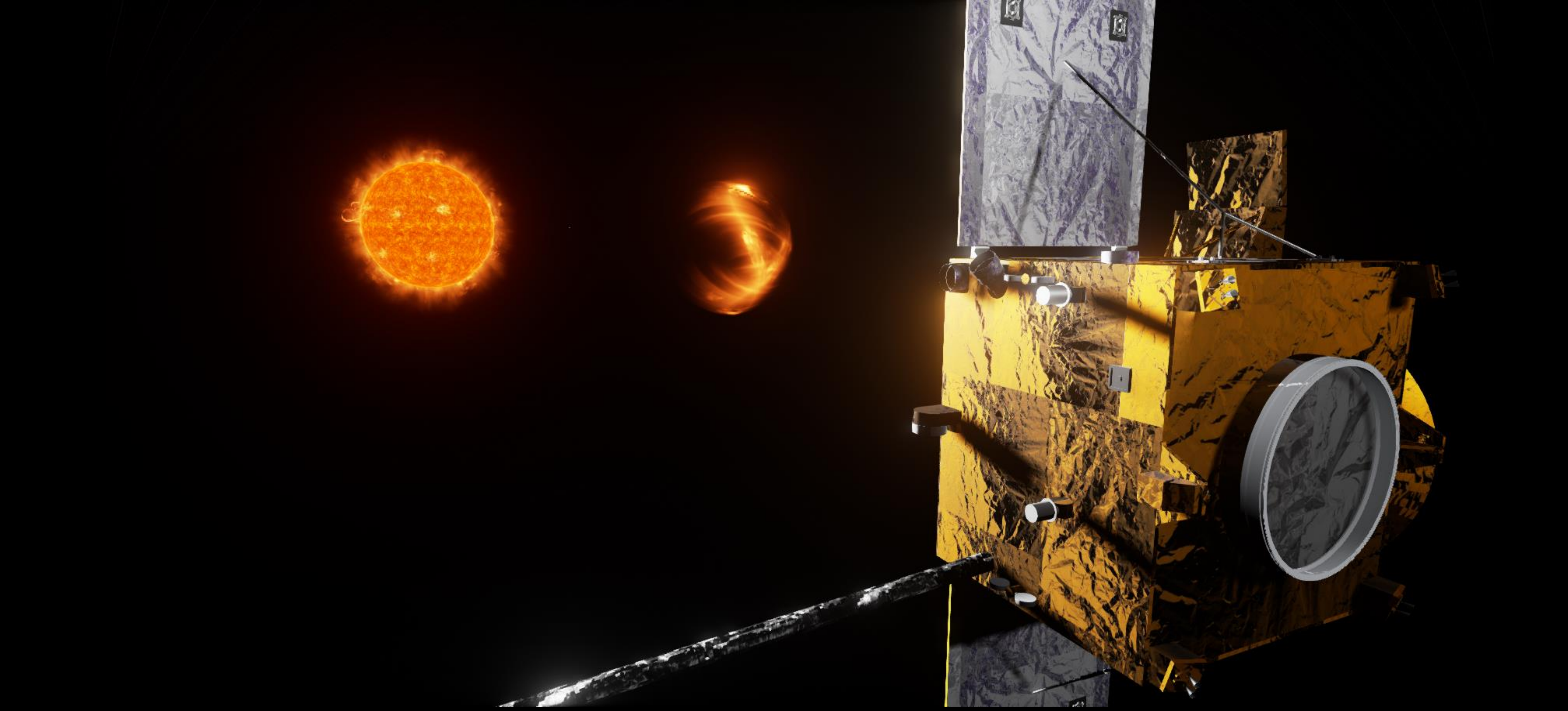


Carrington-L5:
The Next Generation Operational Space Weather Mission

Dr Markos Trichas, Airbus Defence & Space Future Programmes, UK
12 May 2015

AIRBUS DEFENCE & SPACE

Team

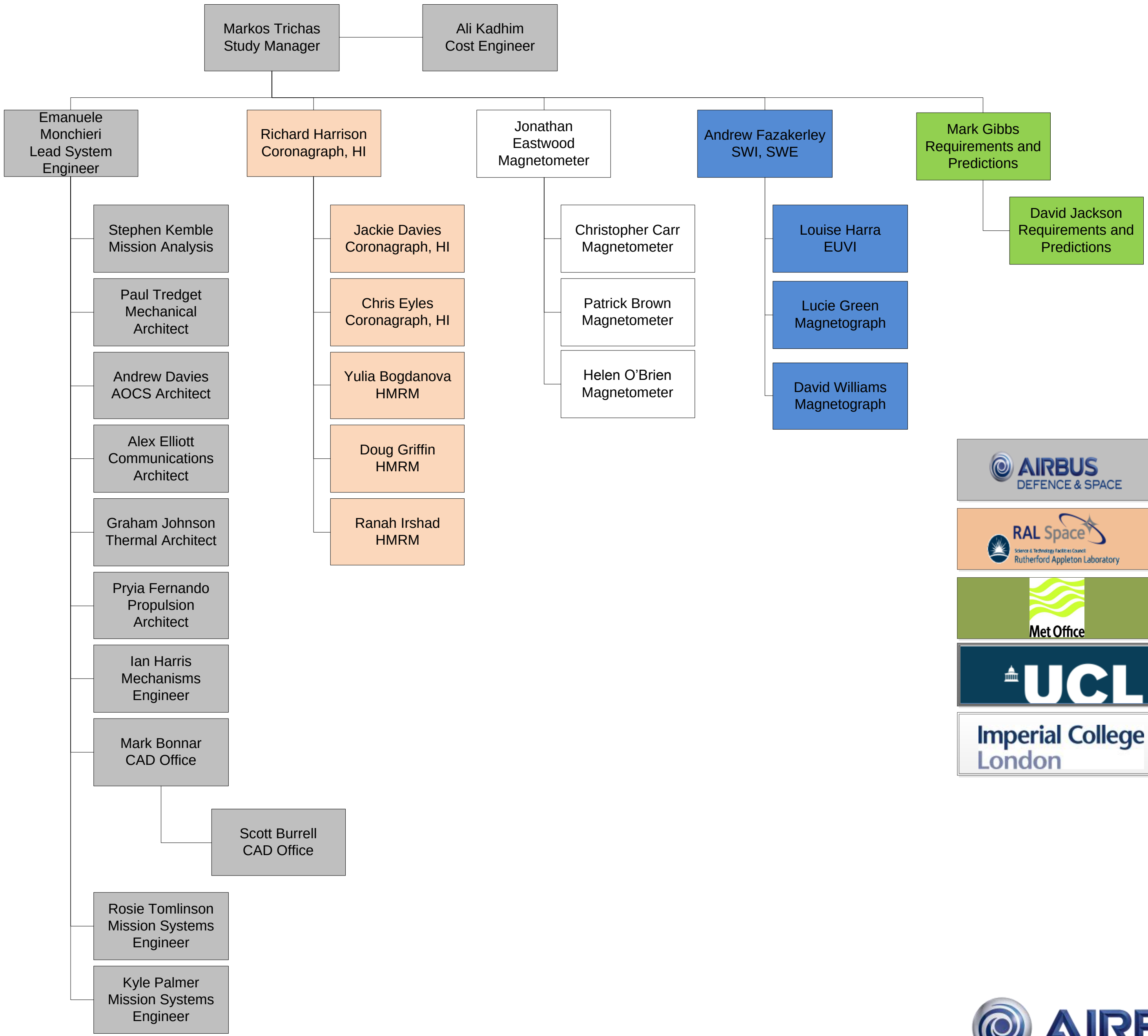
Industry: AIRBUS DEFENCE & SPACE

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

Academia: Imperial College London; UCL

Consultation: nationalgrid; PARADIGM SERVICES BY ASTRIUM; inmarsat

Team


Markos Trichas
Study Manager
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Emanuele Monchieri
Lead System Engineer
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Mission Analysis
Paul Tredget
Mechanical Architect
Andrew Davies
AOCS Architect
Alex Elliott
Communications Architect
Graham Johnson
Thermal Architect
Pryia Fernando
Propulsion Architect
Ian Harris
Mechanisms Engineer
Mark Bonnar
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Rosie Tomlinson
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Mission Systems Engineer
Richard Harrison
Coronagraph, HI
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HMRM
Ranah Irshad
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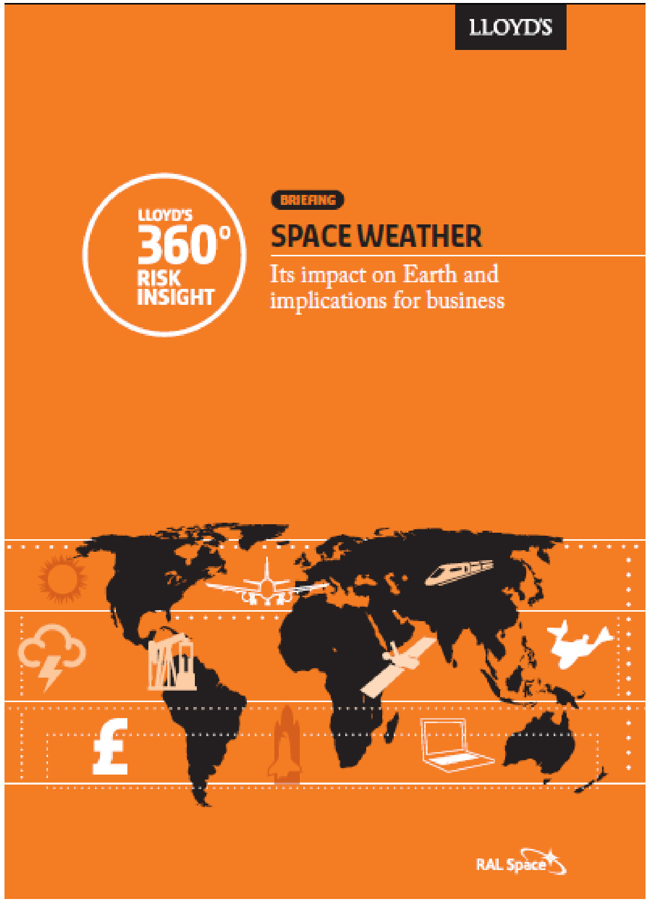
EUVI
Lucie Green
Magnetograph
David Williams
Magnetograph
Mark Gibbs
Requirements and Predictions
David Jackson
Requirements and Predictions

Space Weather:
Impacts and Requirements

Space Weather Impacts

RAEng study (2013) assessed mainly UK vulnerabilities



Lloyds, 2010

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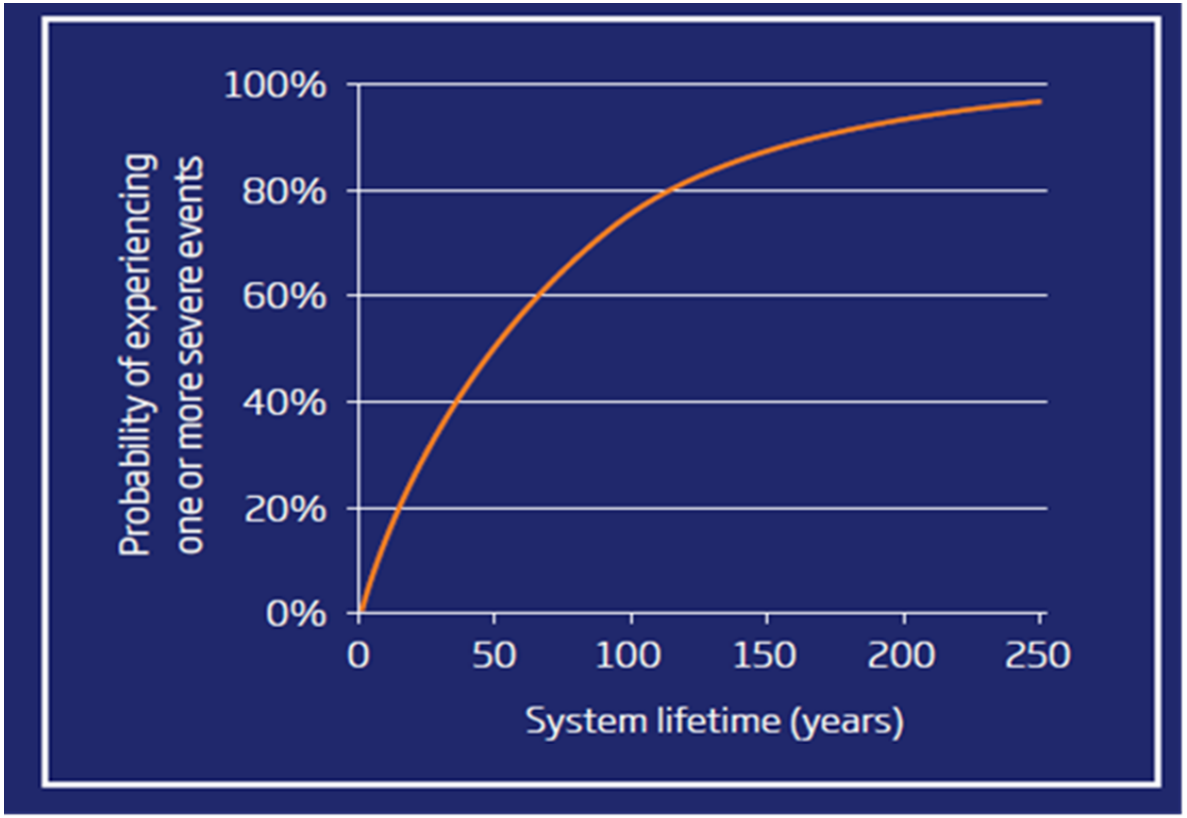
Space Weather Impact on Other Sectors

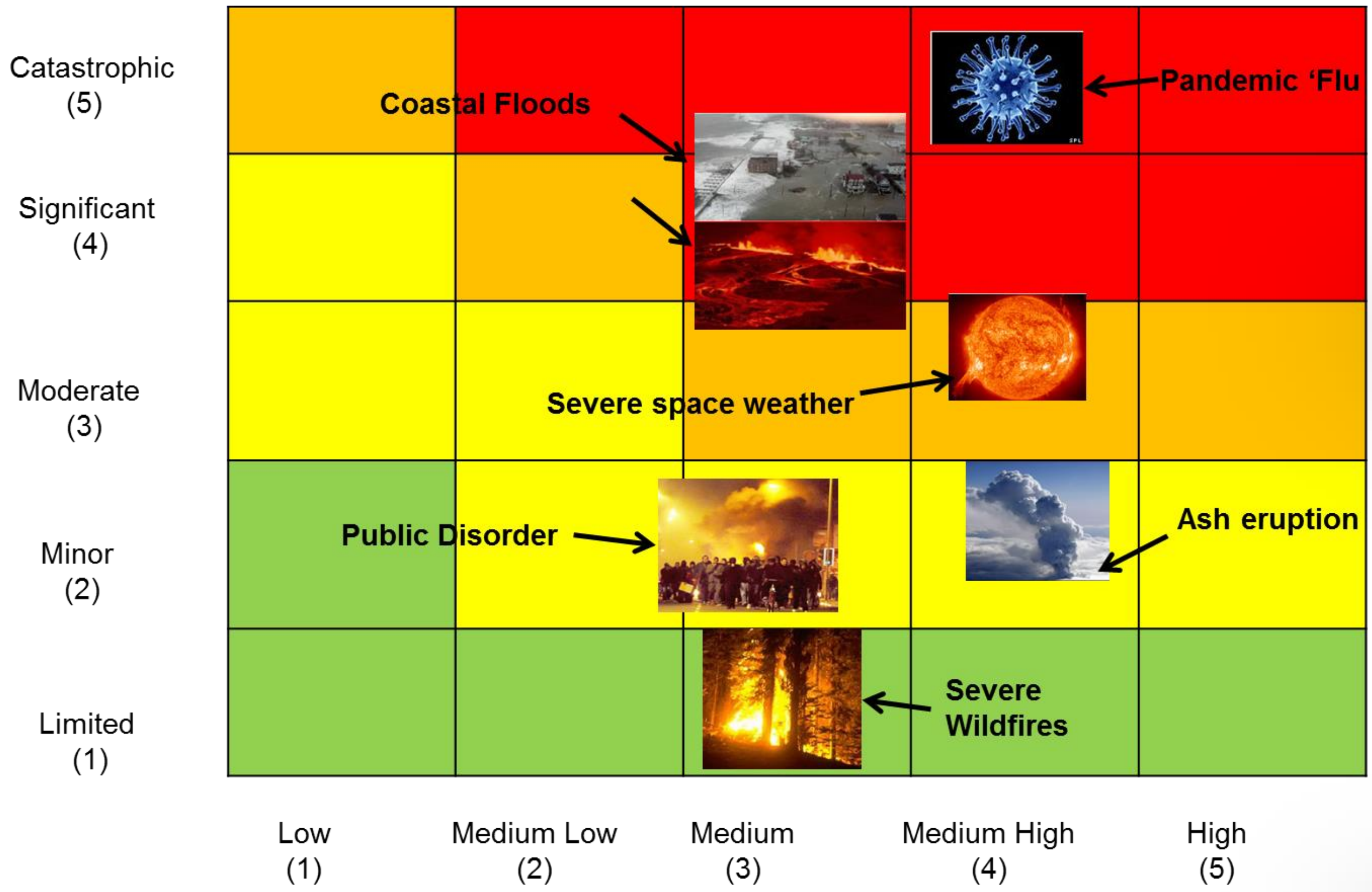
- Spacecraft
- Power Grids
- Navigation
- Rail
- Phone/Radio/TV Networks
- Polar Flights
- Internet/Wireless Communications
- Pipelines
- Oil/Mineral Industries
- Finance
- Military Operations
- Human spaceflight
- Space tourism

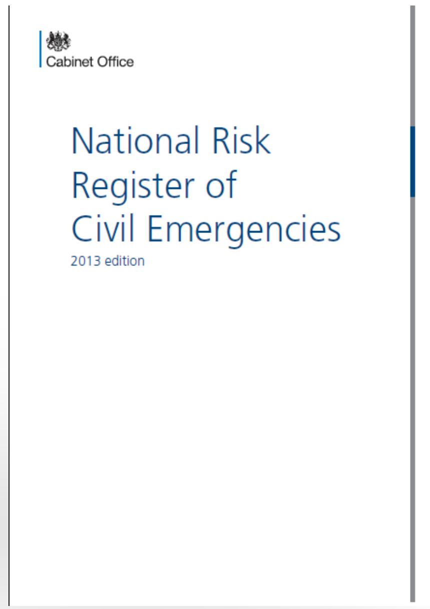


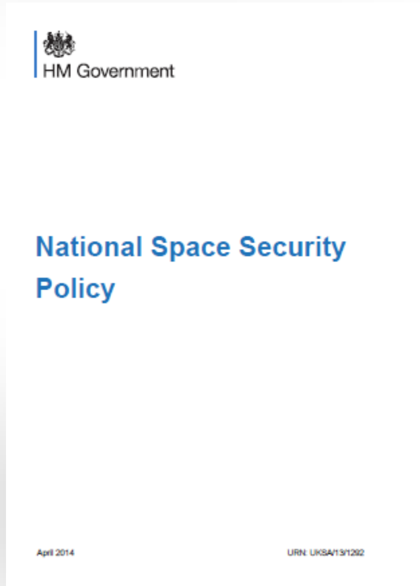
(RAE, 2013)

As technology advances, society becomes more vulnerable to SWE

UK National Risk Register 2013/2014







Courtesy of the Cabinet Office

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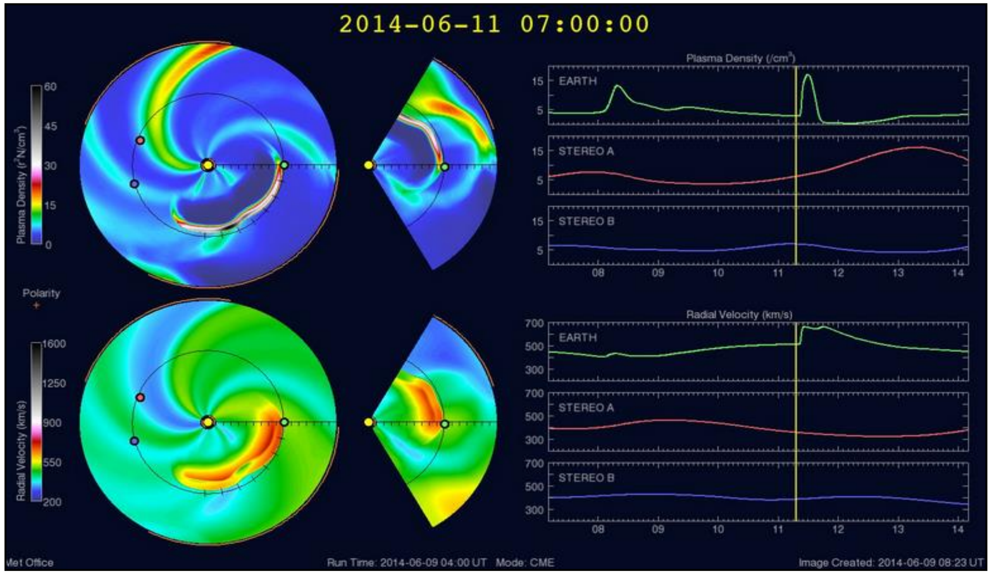
UK Met Office Space Weather Operations Centre (MOSWOC)

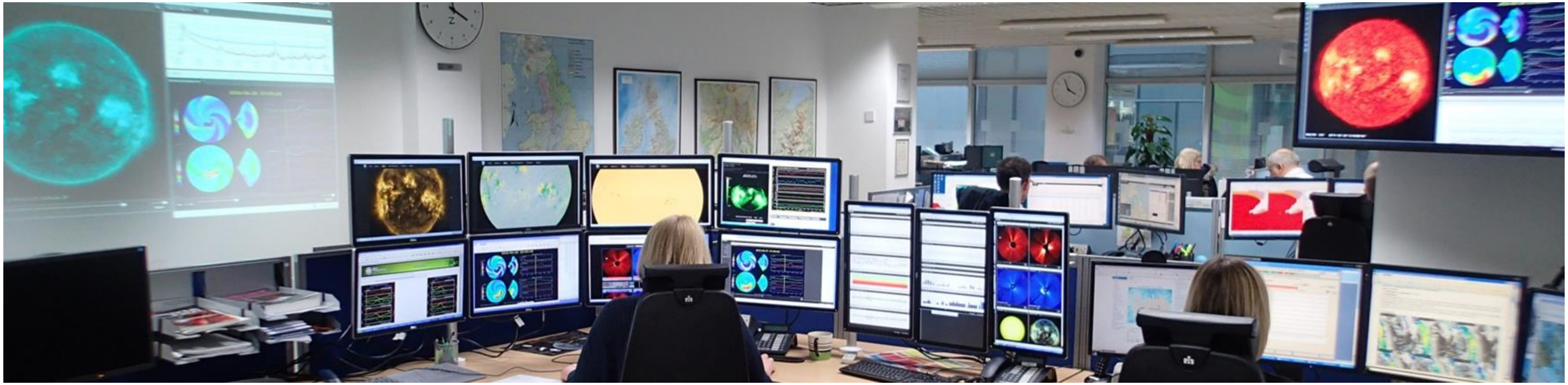


Embedded in Met Office Hazard Centre

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

Operational collaboration with NOAA SWPC & BGS

- Daily forecast coordination



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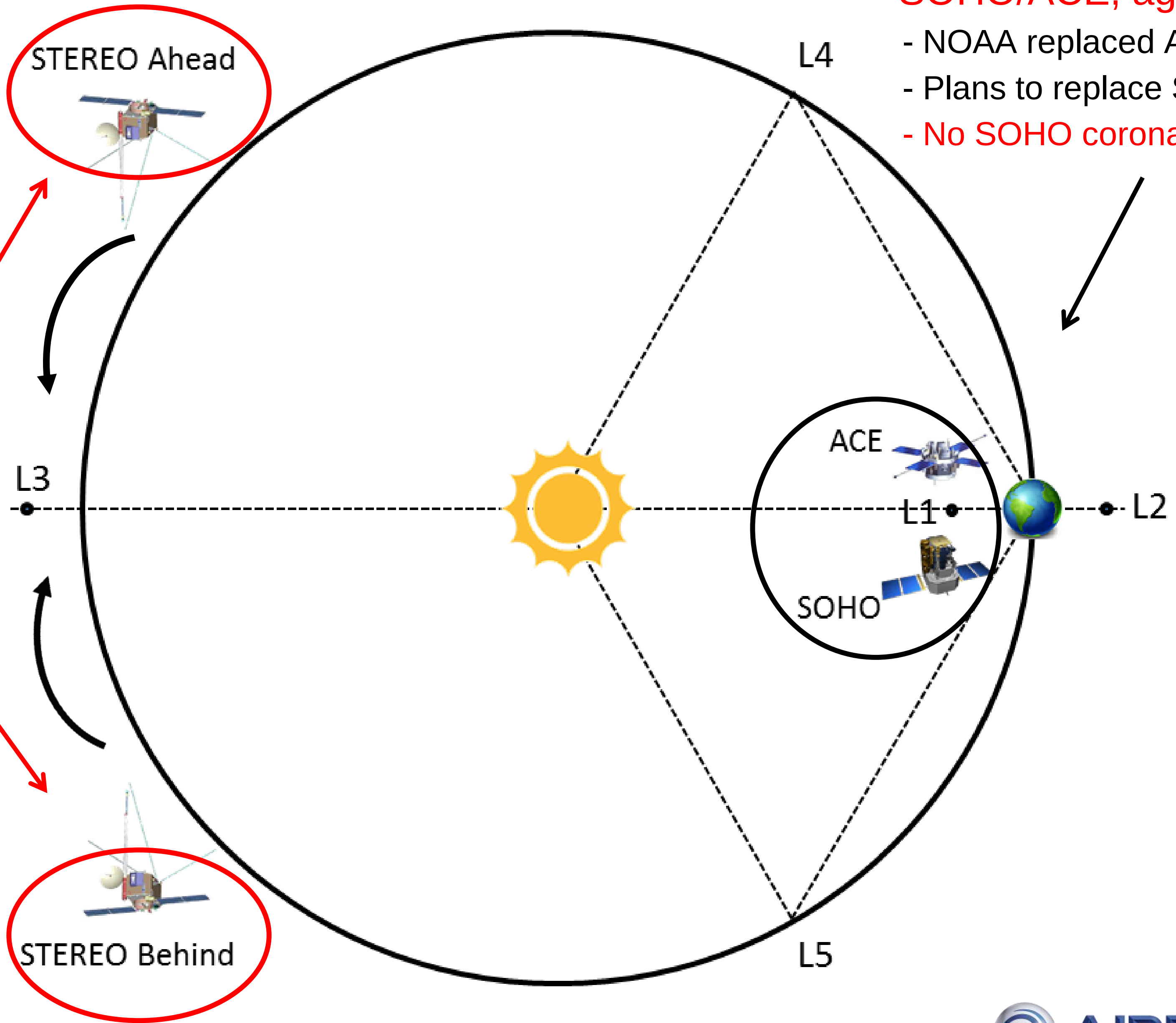
MOSWOC/SWPC Forecast input

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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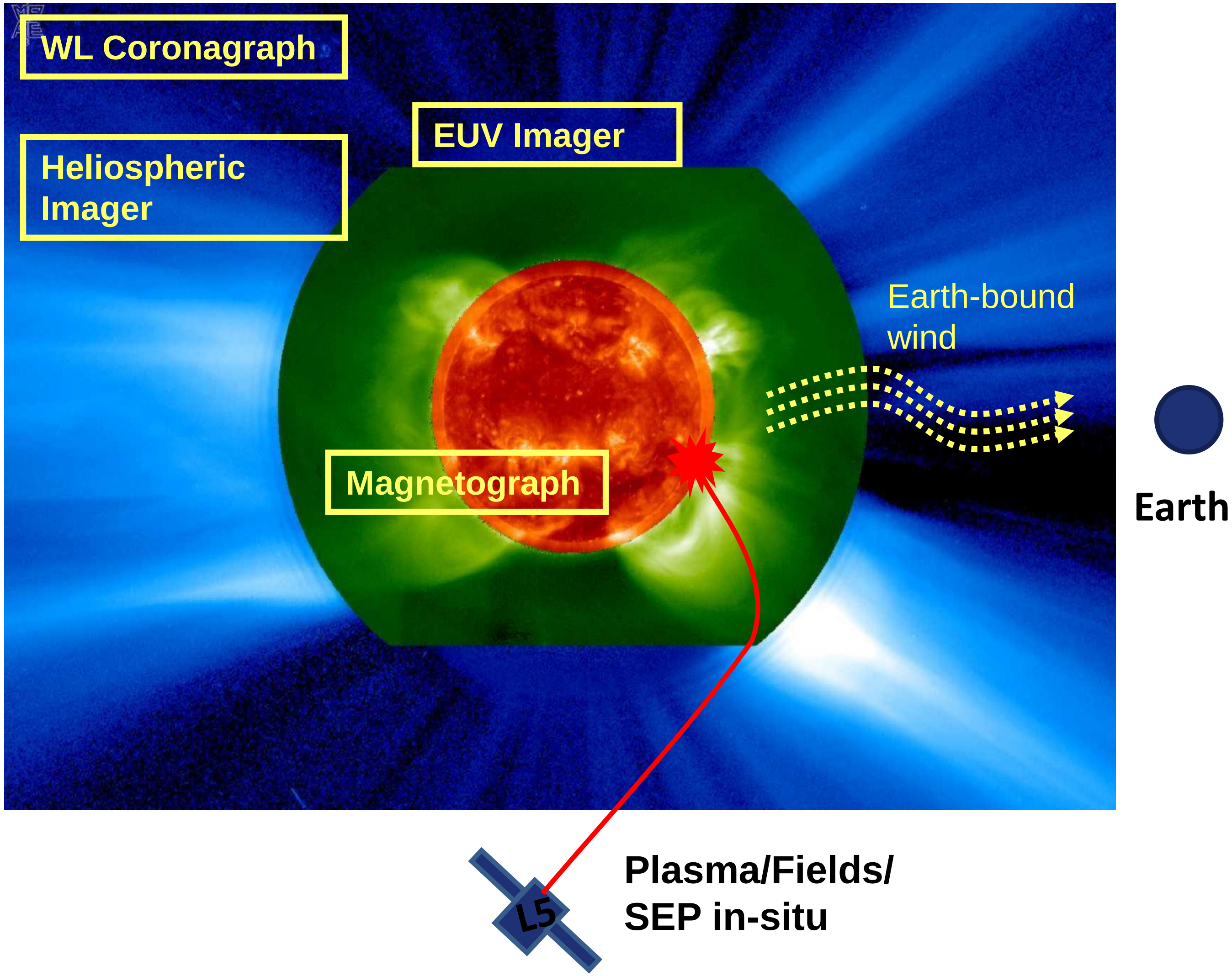
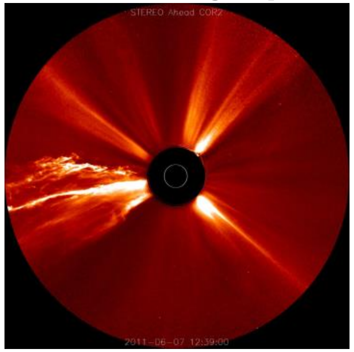
Mission drivers



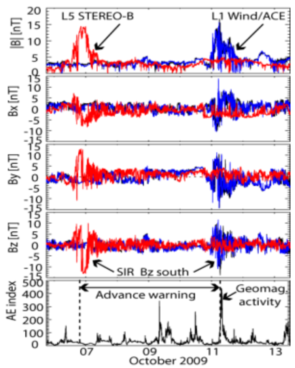
- Address MOSWOC/SWPC operational requirements
- Transfer time: up to 2 years
- Operational lifetime: 10 years
- Payload mass <100 Kg
- Operational mission
- Continuous transfer of data
- High UK/US heritage
- High TRL
- Low risk/cost
- UK/US bilateral
- Development in <6 years

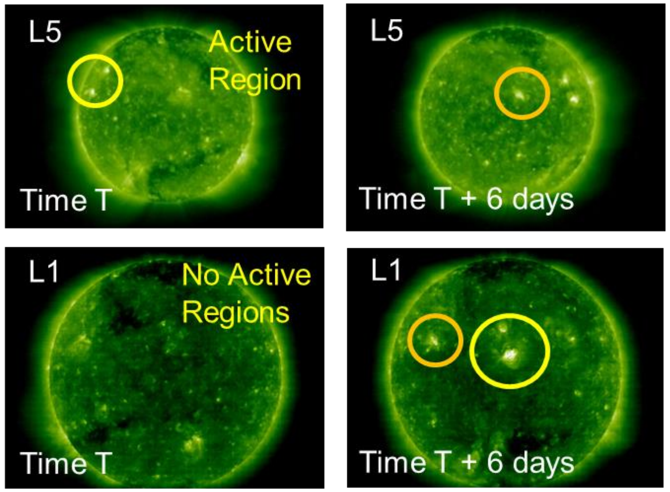
Payloads

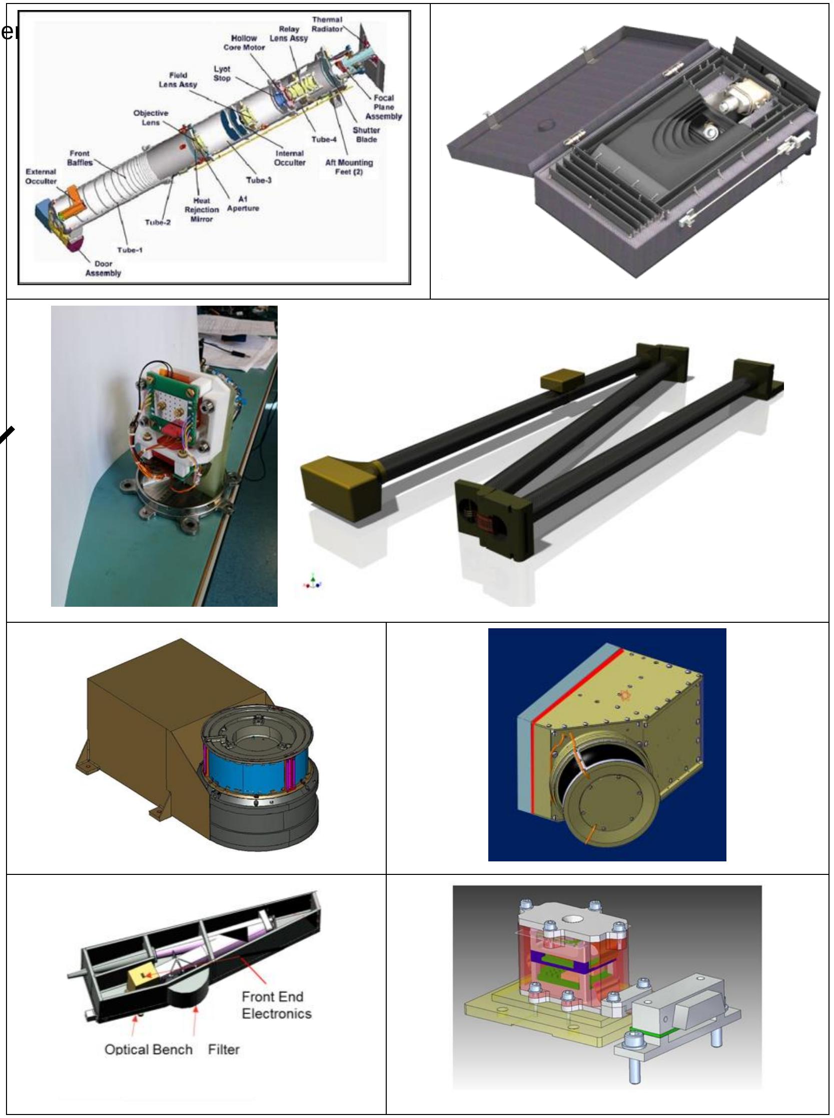
Coronagraph



Magnetometer

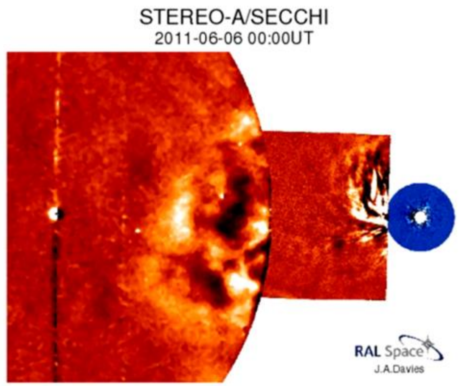




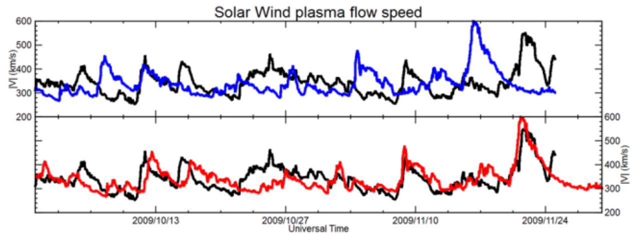


EUVI/Magnetograph

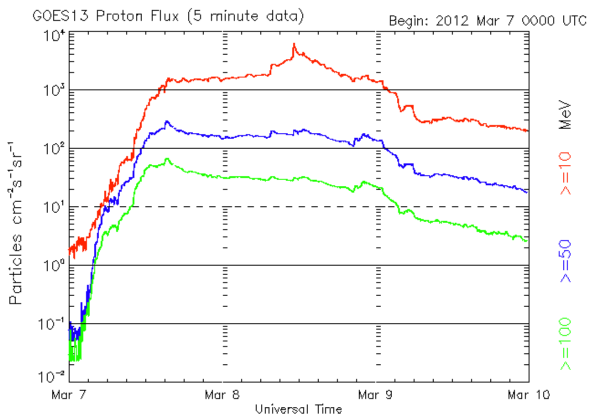
Heliospheric Imager



Plasma instrument



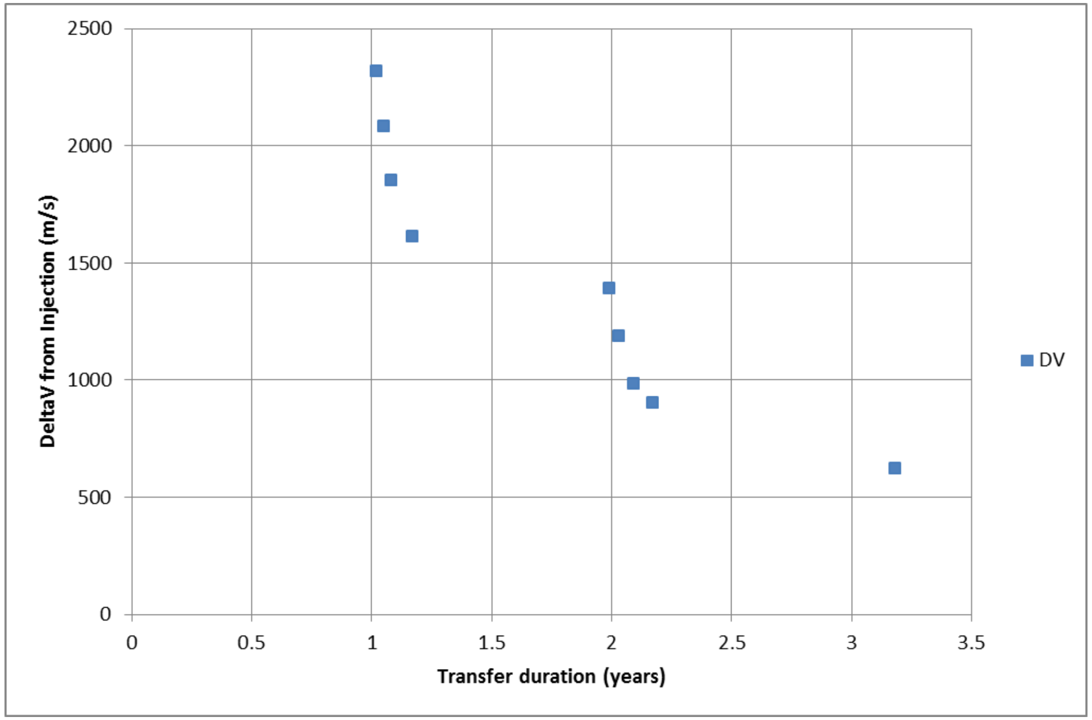
Radiation Monitor



Mission Analysis

Transfer

Stopping manoeuvre after 60 deg transfer – this achieves a semi-major axis of 1AU and eccentricity of close to zero



<u>Achieving Low energy Earth escape, options:</u>

1) Direct injection by launch vehicle

⇩

Direct escape option only requires stopping manoeuvre, strong relationship with transfer duration.

OR

2) Injection to initial Earth orbit (eg GTO) followed by escape manoeuvre.

⇩

Escape manoeuvre needs to be implemented by spacecraft or dedicated small propulsion stage

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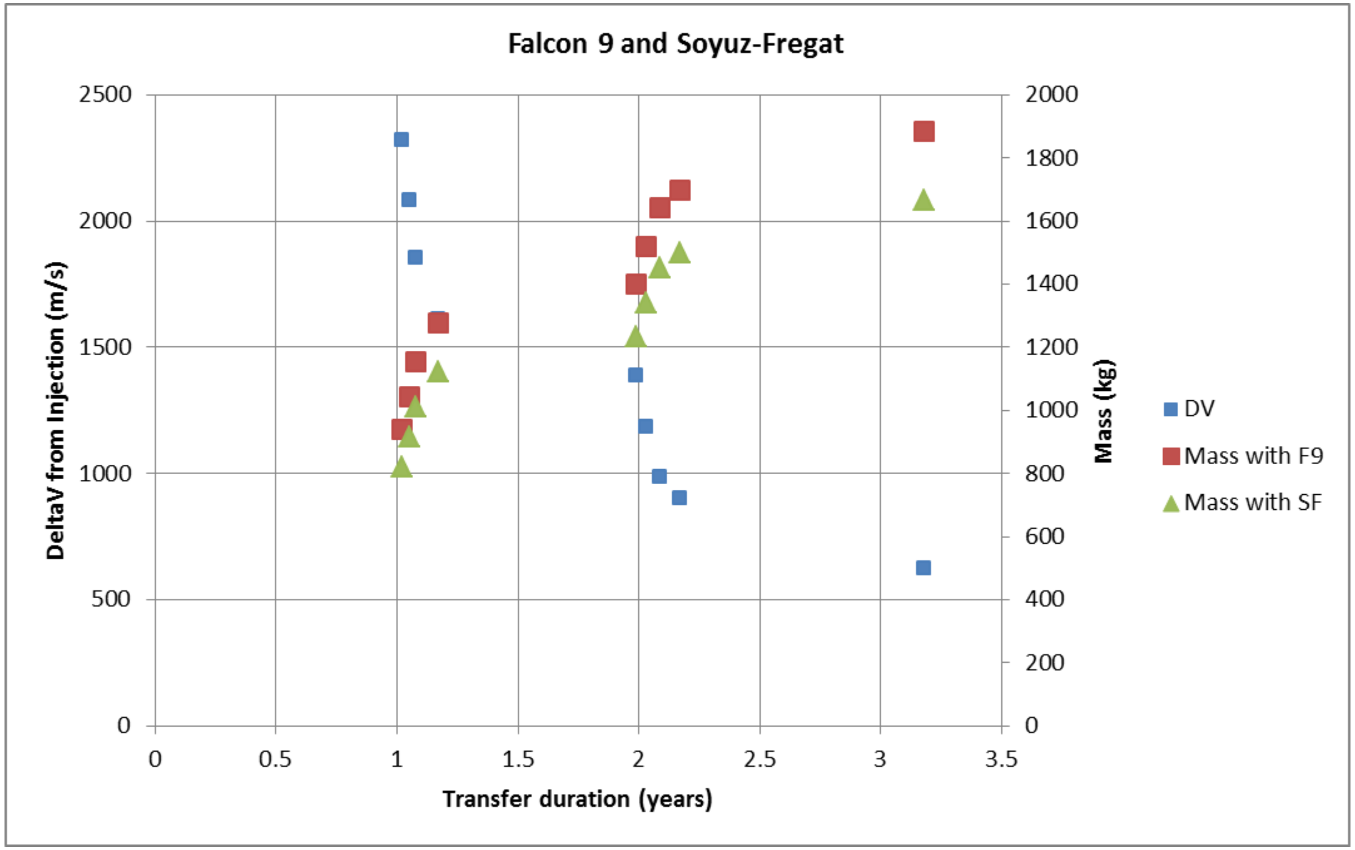
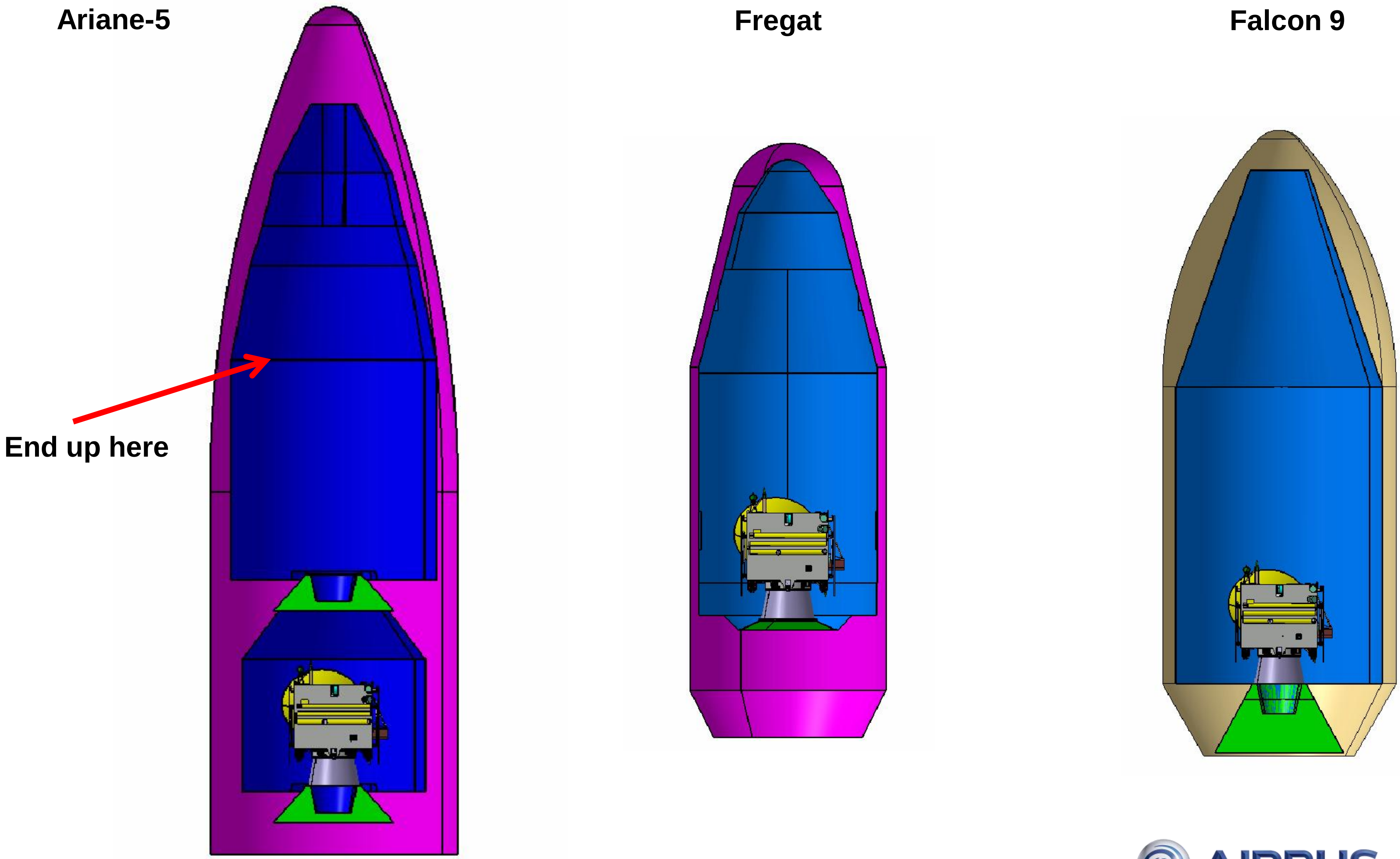
Launch and transfer options

- Cheap Launchers considered: Falcon 9, Fregat, Delta 2
- Ariane 5 (shared launch), GSLV considered
- On station mass target in region of 600-700kg
- To simplify spacecraft design direct injection is preferred
- Falcon 9, Soyuz Fregat, Delta 2 all have enough margin for the scenario considered
- Falcon 9 provides best mass margin. Delta II long term availability unclear. Fregat, Delta II more expensive

Mass at L5 vs transfer duration for Isp=290 secs



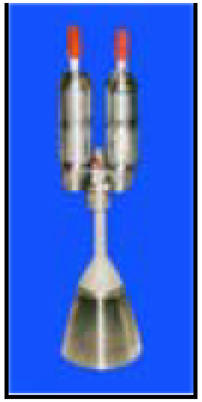
Baseline: Direct injection to Earth escape with Falcon 9


Ariane-5
Fregat
Falcon 9
End up here

Carrington Propulsion Description

- NSWEM propulsion design is based on Venus/Mars Express design heritage with the main exception of LAE
- Design relies heavily on the use of recurrent hardware from other programmes (E2000 & E3000), so that maximum financial advantage may be taken of bulk or batch procurement.
- Four pairs of 10N thrusters are used (4 prime, 4 redundant) to provide the required Delta_V.
- Single valve thrusters were selected with upstream thruster latch valve to allow redundancy to be exercised at thruster level. Therefor out of 8 thrusters, 7 thrusters are always available for the mission.
- Two low pressure transducers are provided to monitor fuel and oxidiser tank pressure during flight operations and a third to monitor regulator outlet pressure during the regulated operation phase. The fourth pressure transducer monitor the helium tank pressure.

E2000 Tank volume: 267 Litre
•MEOP 20 bar, Diameter 600mm
•PMD usable volume 0.6 litre
•Membrane with Comm. Tube
•Dry mass 13.3kg



LEROS LTT*: 10N
- Isp: 274 seconds
- Pressure: 8 to 20 bar
- MBIT: 0.15 N.s
- Status: Flight qualified

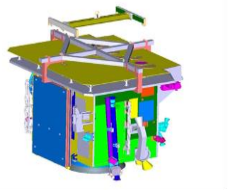
***Note**:
- VEX use10N dual valve Airbus DS thrusters, NSWEM baseline is MOOG LEROS Thrusters
- VEX use SNECMA PTs and NSWEM baseline PTs are from Ametek, USA as of E3000
- VEX use Conax PVs and NSWEM baseline design use Airbus DS PVs as of E3000

Platform

Platforms trade-off summary

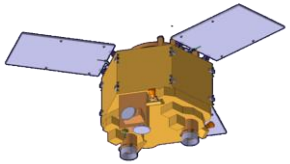
Airbus DS Product

Solar Orbiter



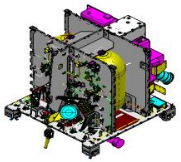
Mass / cost over our baseline.

Sentinel 5P/Astrobus250



Mass / cost C with baseline.

VEX/MEX

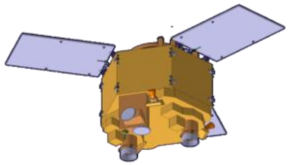


Mass / cost C with baseline.

E3000/EP

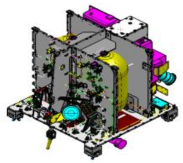
Mass / cost over our baseline.
EP mass within limits but cost above baseline

Sentinel 5P/Astrobus250



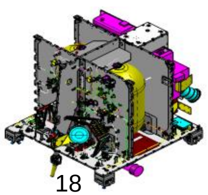
LEO platform not qualified
Propellant mass NC
LISA PF module required.

VEX/MEX



Propellant mass C with baseline.
Propulsion C with baseline

VEX/MEX



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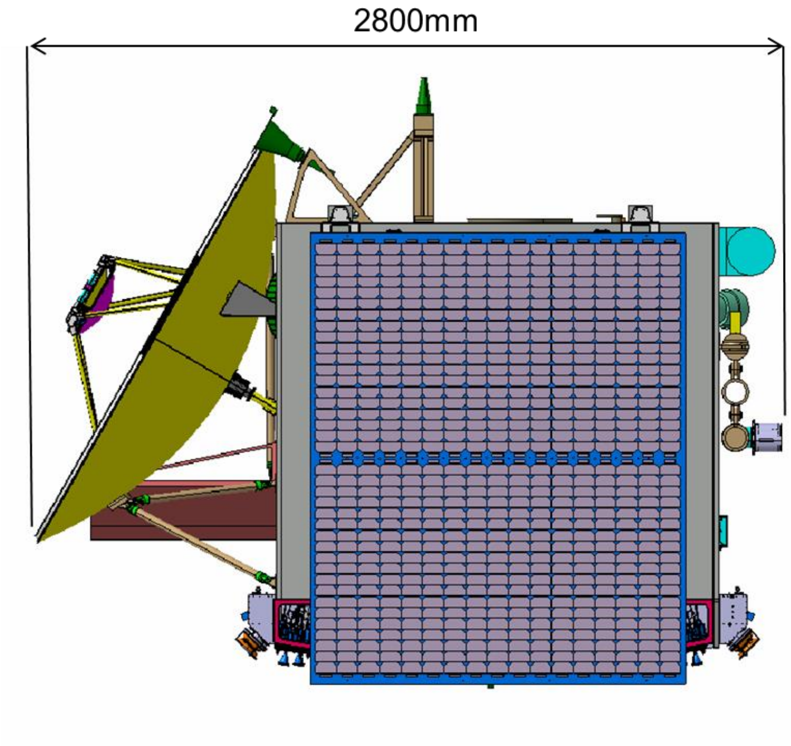
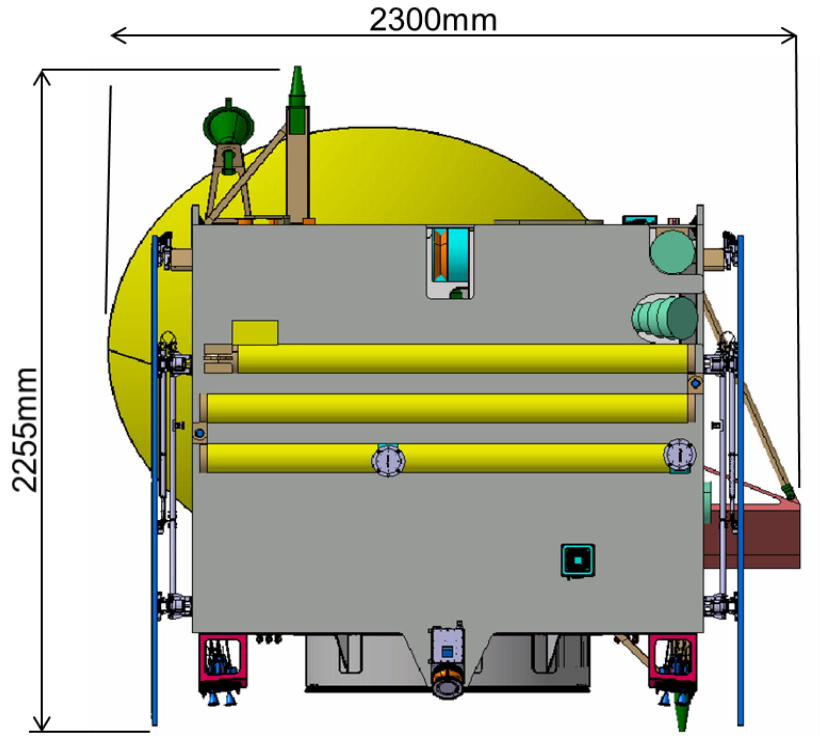
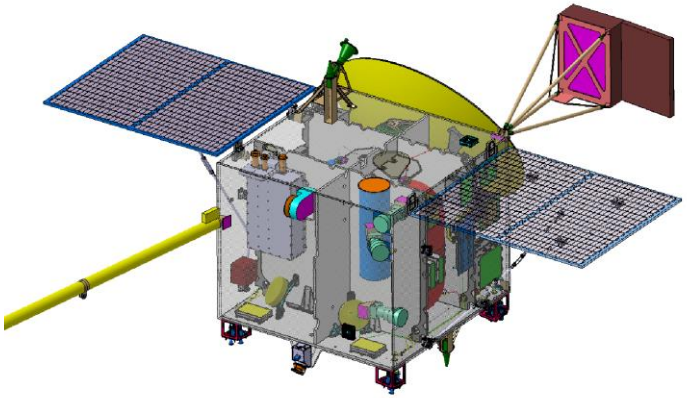
Configuration

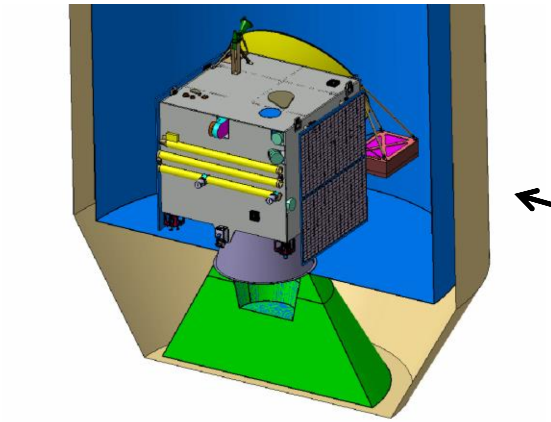
Dimensions in stowed configuration





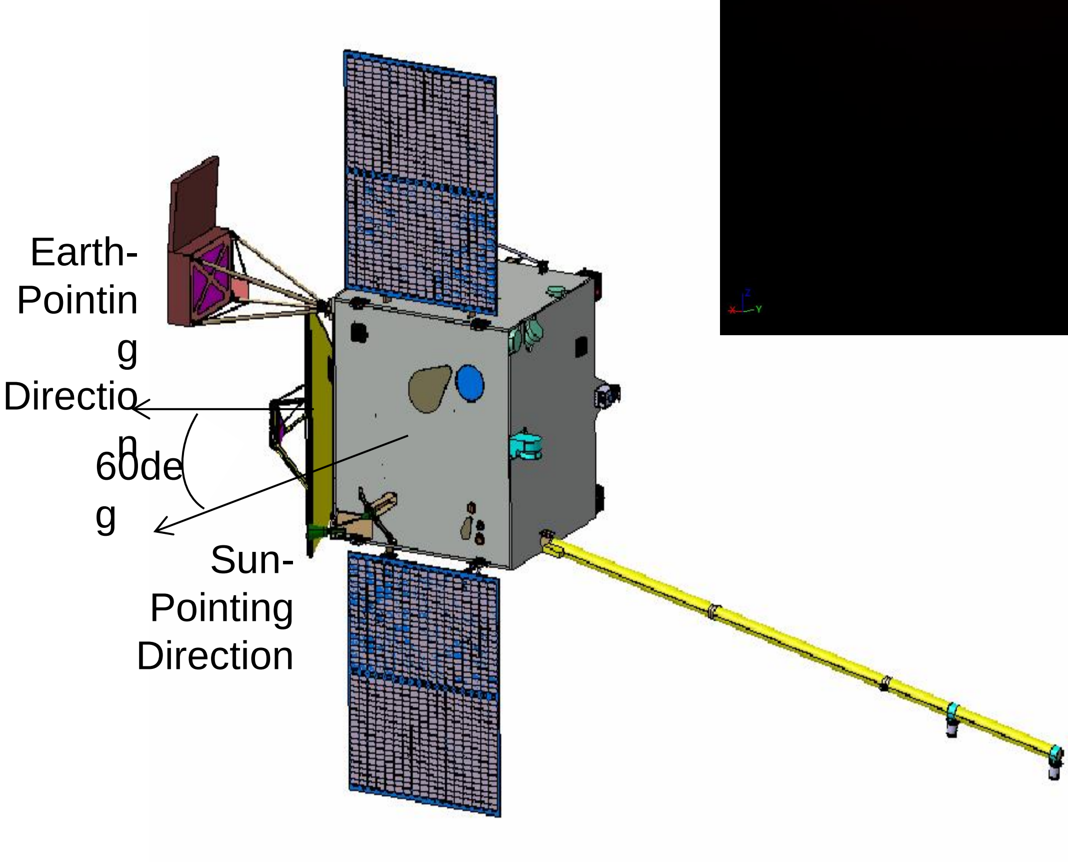
Internal Configuration





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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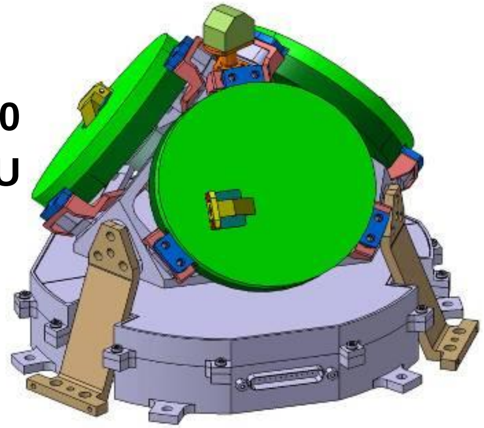
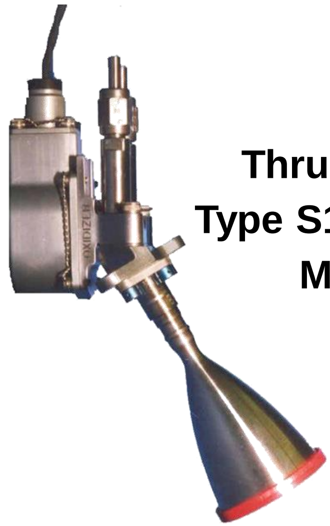
AOCS

AOCS
Overall configuration



Astrix 1020 IMU



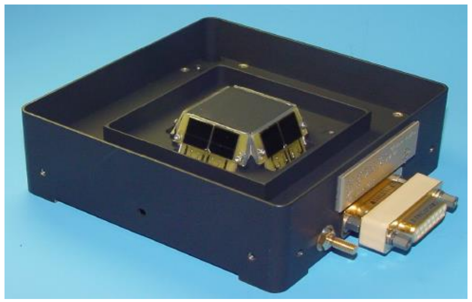
10N Thrusters Type S10-21 MOOG

Main Features

- Reuse of M/VEX wherever possible for cost reduction
- Same VEX thrusters configuration → 4 pair of 10N Thrusters, 10N Bi-propellant thruster Type S10-21
- AAS 13-046 Hydra Star Trackers (3 Optical Heads and 2 Electronic Units)
- 2 x Coarse Sun Sensors (TNO)
- 4 reaction wheels assembly, 12 Nms /0.075 Nm. (Teldix)
- Optional: 2 x IMU Astrix 1020 used for redundancy

STR

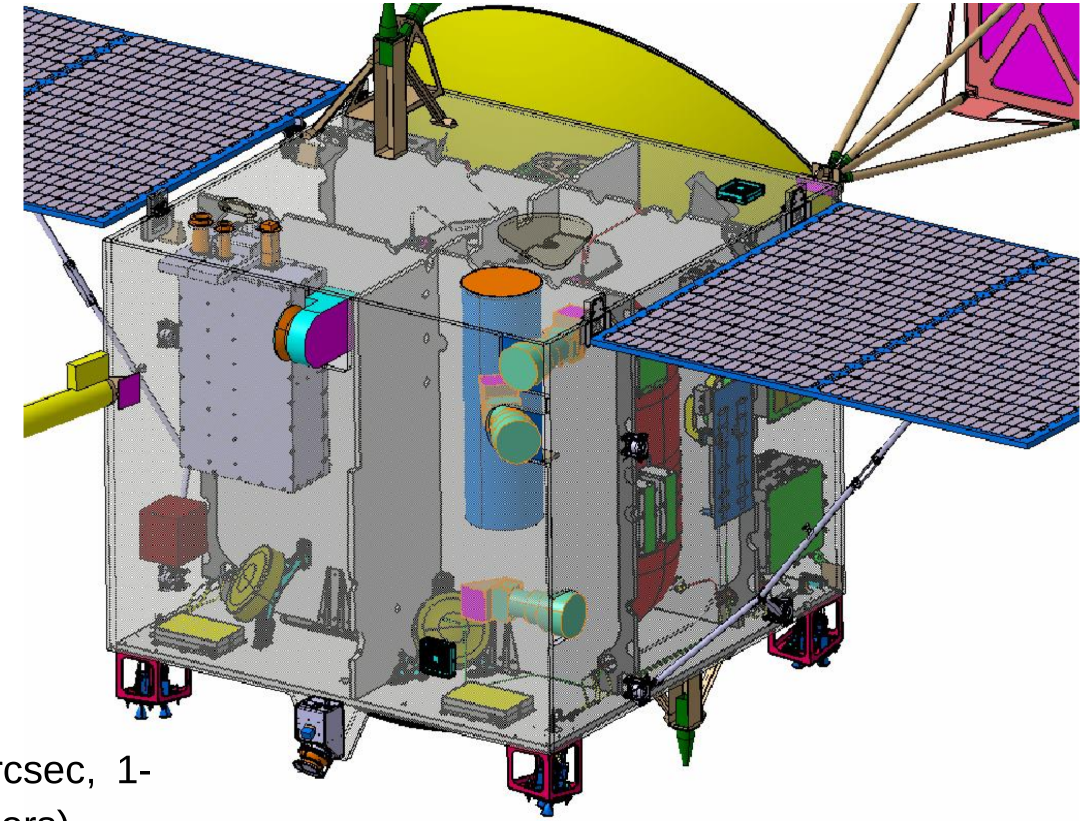
- **Required Performances**
  – APE → <0.06 degrees
  – RPE → <3 arcsec over 10s



Sun Sensors

Reaction Wheels

AOCS
Pointing Error



- **Required Performances**
  - **APE** → <0.06 degrees
  - **RPE** → <3 arcsec over 10s

- **Achieved Performances**
  - **APE** → with Star Trackers only at AOCS level:
    - X=0.6485 arcsec, Y=0.4901 arcsec, Z=0.7095 arcsec, 1-sigma (based on CarbonSat simulation, same sensors)
    - To guarantee the required performances, the Star Trackers are mounted very close to the Imagers to allow for accurate calibration
  - **RPE** → with Star Trackers plus IMUs as backup
    - X=0.5480 arcsec, Y=0.4418 arcsec, Z=0.4191 arcsec, 1-sigma (arcsec)
  - **High resilience to radiation environment**

Sodern Hydra STR

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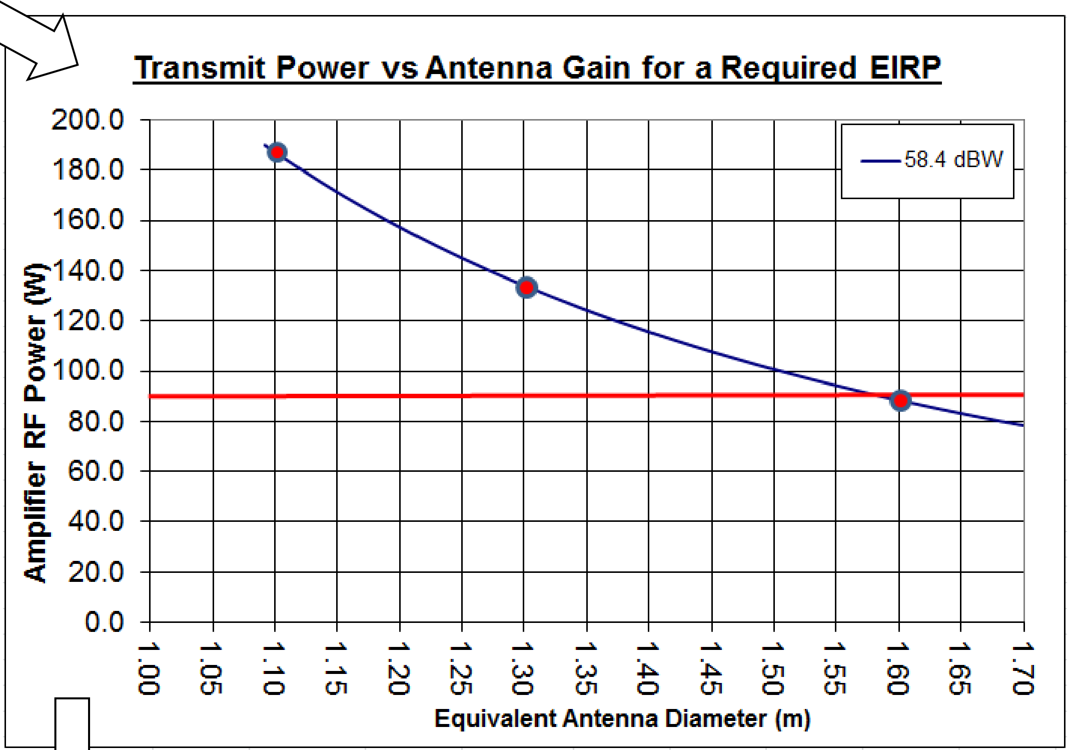
Communications

STEREO daily download: 5.6Gb
Carrington daily download: 4.32 Gb

Comms SS
HGA sizing and downlink data rate estimation

Assumptions:
- Nominal Case
- 15m GS antenna dish
- 40 kbits/s data rate
- 90W RF power
- Distance: 1AU (L5)



Spacecraft Antenna Size → 1.6m MEX Antenna

Data rate vs. phase vs. antennas size

Requirement
- Science data rate → 40kbits/s
- HK data rate → 0.4-10kbits/s

Total req. data rate → 41-**50kbits/s**

Phase	S/C Antenna	GS Antenna	Data Rate
LEOP	LGAs	35m	Up to 1.5kbits/s
Near Earth Comms. & Cruise	MGA	70m NASA	Up to 1.2kbits/s (at ~1.2AU)
L5 Arrival	HGA	15m	Up to 40kbits/s
L5 Arrival	HGA	35m	>50kbits/s
L5 Arrival (Safe/Hold Mode)	MGA	70m NASA	Up to 437bits/s

GS Analysis

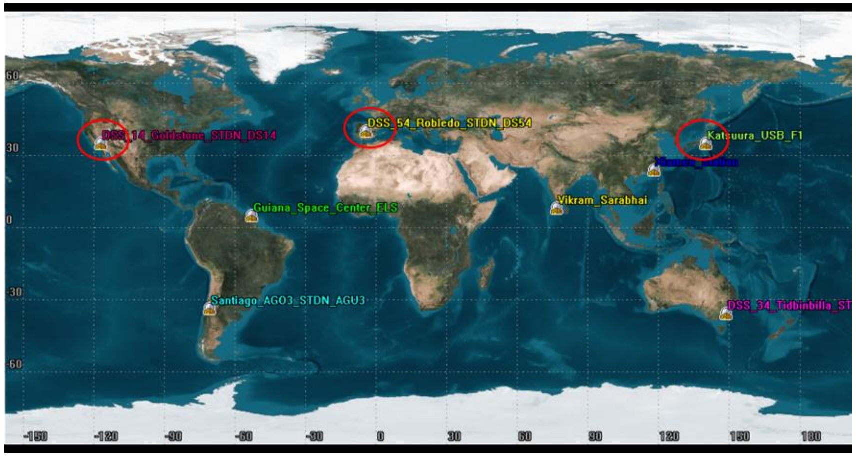
Ground Station Constellation	Total Duration	% of year
Equator 2 GS	25283209.52	80.12%
Equator 3 GS	29818824.88	94.49%
North 2 GS	17280409.08	54.76%
South 2 GS	25341473.06	80.30%
Global (2 North, 2 South, 2 Equator GS)	26034549.58	82.50%
Global (2 North, 2 South, 3 Equator GS)	31535510.04	100.00%

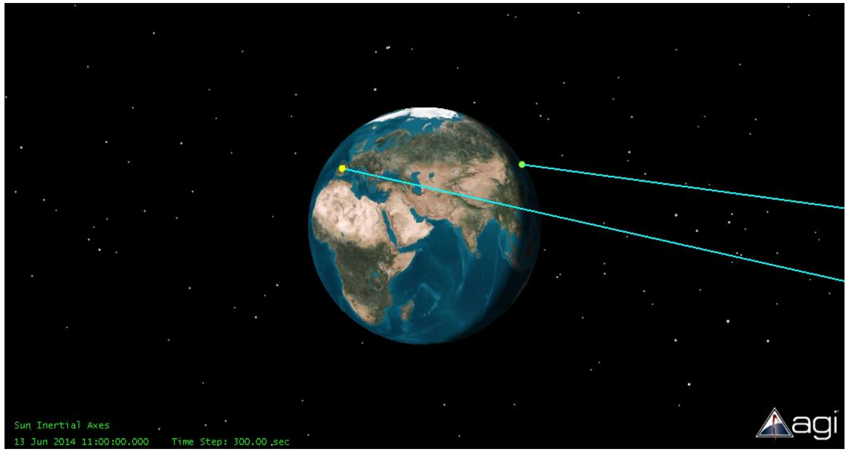
Example used ground stations have access to antennas:

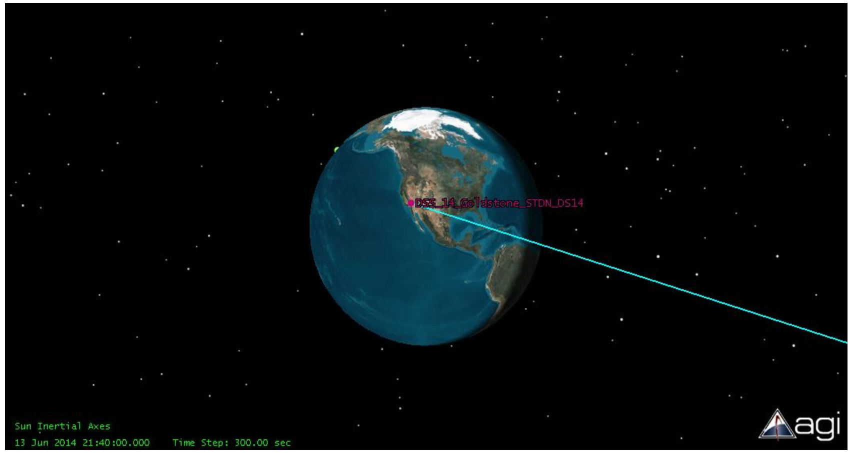
- Katsuura
- Goldstone
- Madrid

This setup allows 97.4% coverage.

Employing a 4th GS would allow to reach the required 100%.







DHS

DHS
Data Management

Parameter	Value	Unit
Generated science data	~40	kbits/s
Total amount of data per day	~4	Gbits
Maximum days of storage with no communications	2	days
Total amount of data to be stored	~8	Gbits
Available storage for each SSMM module	16	Gbits

Note: the science data are contemporaneously stored in both MM modules in order to avoid their loss in case a failure occurs

RIU from SOL-O Mission

OBC from SOL-O Mission

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Power

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Power SS

Parameter	LEOP	Near Earth Comms & Cruise Phase	L5 Arrival (Operational)
Mission Time	0 to a few months	Up to 2 years	Up to 10 years (including previous phases)
Required Max Peak Power [W]	691	730	853
Required Average Power [W]	528	561	574
Max Distance from the Sun	1 AU	1.22 AU (fast trip) 1.12 AU (slow trip)	1 AU

Assumptions:

✓ Degradation rate due to CME → 1%/year of solar cells efficiency

✓ Degradation due to ageing → EOL loss factors V = 0.94, I = 0.9

Parameter	LEOP	Near Earth Comms & Cruise Phase	L5 Arrival (Operational)
Max Generated Power [W] (Sun pointing)	1317	829 (at 1.22AU) 985 (at 1.12 AU)	865
Generated Power [W] (45deg wrt Sun rays)	932	586 (at 1.22 AU) 696 (at 1.12 AU)	611
EOL Battery Energy (Whr)	959	908	746

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Mass Budget

Mass Budget

Subsystem	CEB Total Mass	CEB+DMM Total Mass	Unit	Notes
Structure	149.8	164.5	kg	
Mechanisms	14.4	17.2	kg	
DHS	26.0	27.3	kg	
Thermal	32.0	33.5	kg	
Power	69.5	77.7	kg	
Comms	40.1	48.1	kg	
AOCS	32.8	34.4	kg	
Propulsion	56.9	59.7	kg	
Harness	23.1	23.1	kg	Assumed 5% of the dry mass
Total Dry Mass (excluding Payload)	444.4	485.6	kg	
Total Dry Mass (including Payload)	520.8	567.6	kg	
	System Margin	20	%	
Total Dry Mass (including system margin)	624.96	681.12	kg	
Propellant Mass (MMH+MON)	446.3	468.6	kg	Assumed 5% margin
Total Wet Mass	1071.26	1149.72	kg	

Payload Mass	CEB Total Mass	CEB+DMM Total Mass	Unit
WL coronagraph	10	11	kg
Heliospheric Imager	16	17.6	kg
Solar Wind Ions	4.8	5.3	kg
Solar Wind Electrons	4.9	5.4	kg
Magnetograph+ EUV Imager	35	36.5	kg
Magnetometer	5.5	6.1	kg
HMRM	0.2	0.22	kg
Total Payload Mass	76.4	82	kg

10% margin assumed for the payload.

VEX Wet Mass was around 1270kg

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Cost/Schedule

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Cost & Schedule

- Mission Cost: £200M (**S/C**, **payloads**, **launcher**, **operations**)
- UKSA IPSP:
  - Cost-benefit analysis and Phase-0
  - Carrington team plus NOAA, SANSA
  - Expand consortium

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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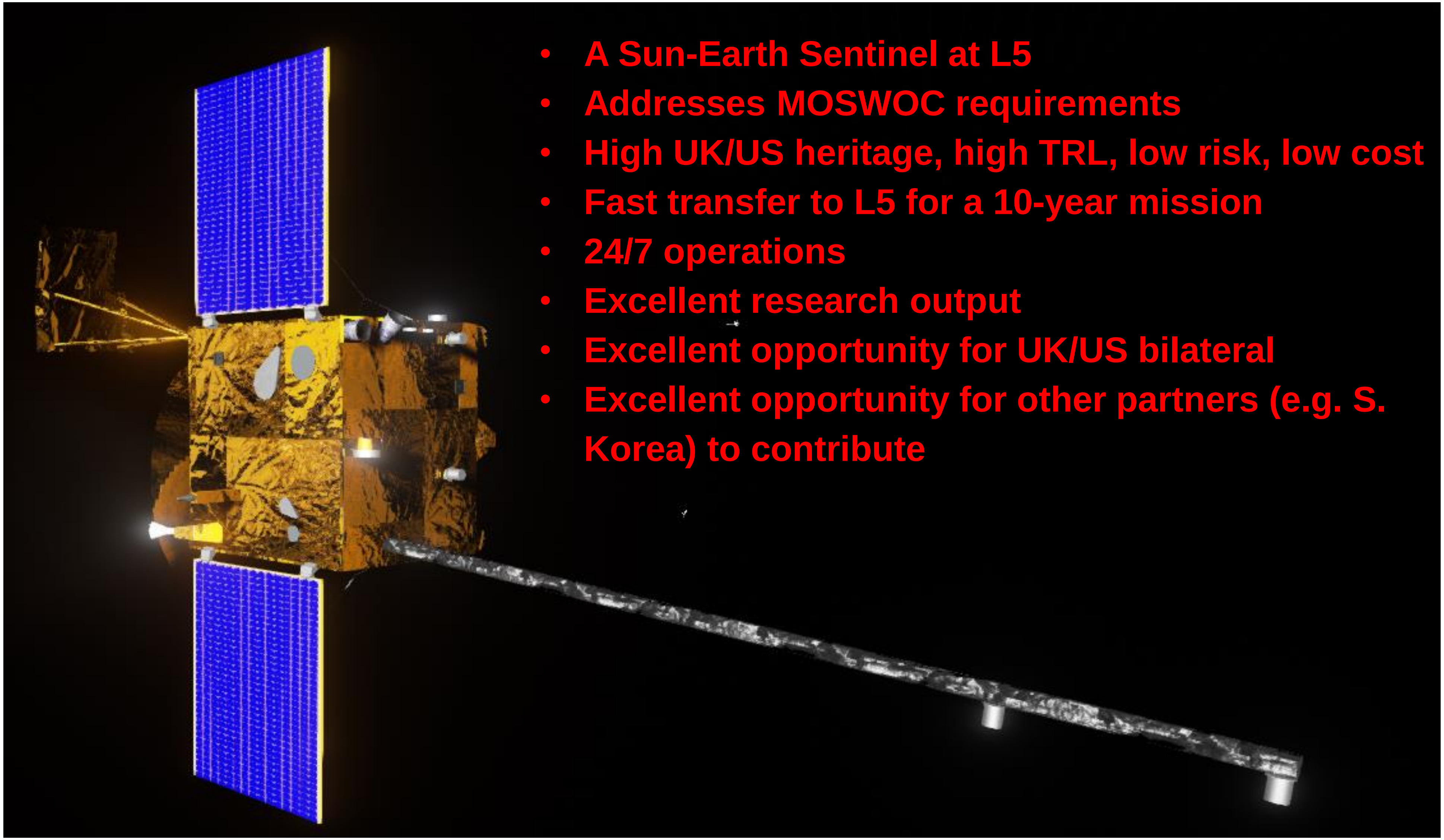
Summary



- **A Sun-Earth Sentinel at L5**
- **Addresses MOSWOC 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. S. Korea) to contribute**

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Questions?