A NEW MISSION FOR SPACE WEATHER MONITORING FROM THE SUN-EARTH LAGRANGE POINTS L1 AND L5

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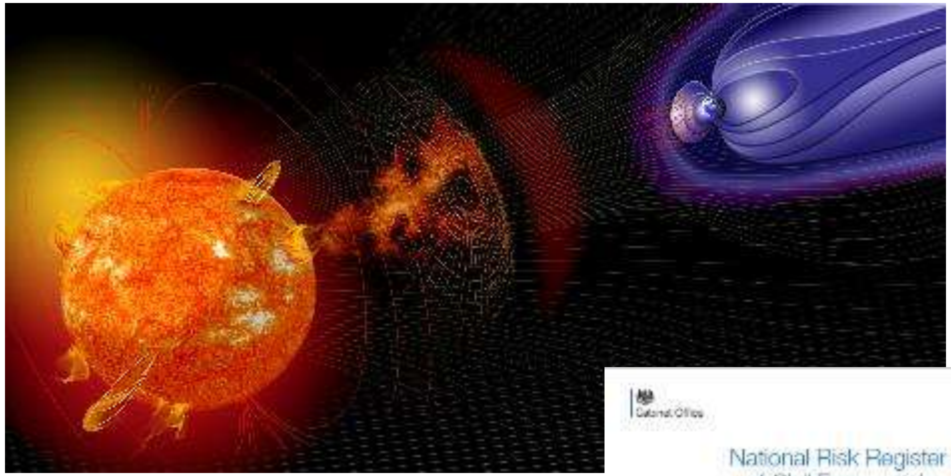
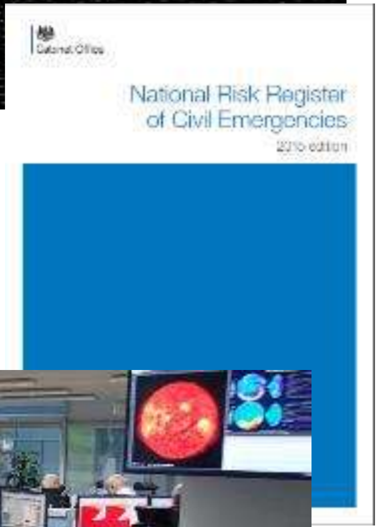
WHAT IS SPACE WEATHER?

- Multifarious phenomena generated on the Sun and in the solar wind can detrimentally impact the near-Earth system
    - Disrupt power distribution networks
    - Damage pipelines and aircraft electronics
    - Degrade radio communications
- Added to UK national risk register in 2011
    - Met Office “owns” the risk and provides operational predictions
- Several of the key spacecraft used for “operational” space weather prediction are well beyond their design lifetime

→ Growing interest in next generation of operational monitoring missions

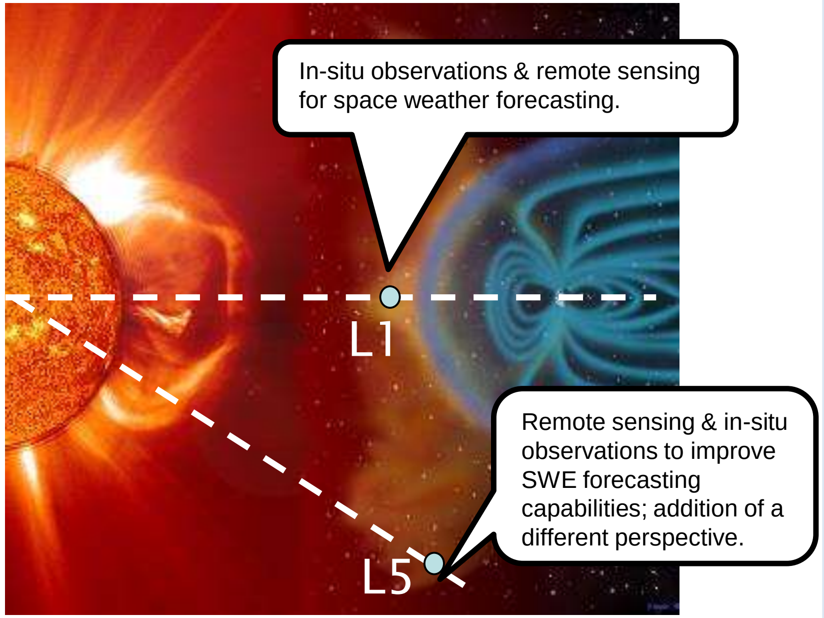


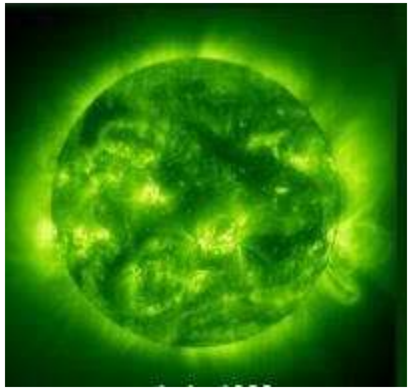
NASA



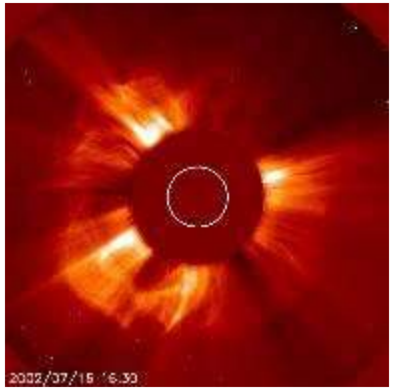
KEY REQUIREMENTS

- Ideally we want two perspectives:
  - Sample the interplanetary medium from upstream of the Earth, close to Sun-Earth line
  - See the face of Sun rotating towards the Earth
- High dynamic range coronal/heliospheric (visible light) images
  - → Minimal background light contamination
- High availability (>99%), high cadence, low latency
  - → 24/7 downlink
  - → Location(s) with (almost) perpetual view of the Sun
- Requirements from operational space weather forecasters drive selection of instruments
- All lead to spacecraft design drivers including pointing accuracy, data rate, mass, size, lifetime…





SOHO/EIT, ESA and NASA



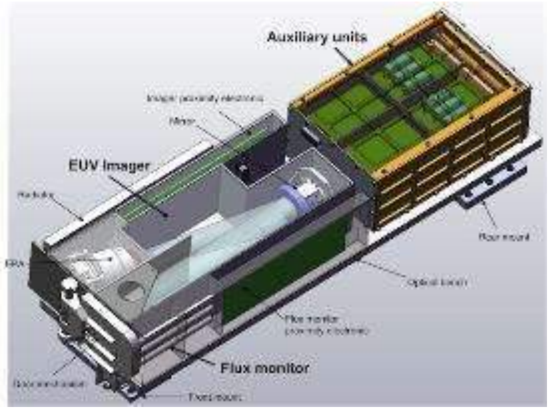
SOHO/LASCO, ESA and NASA

INSTRUMENTS

	Instrument	L1	L5
Remote sensing	Coronagraph	1	1
	Magnetograph	1	1
	Heliospheric Imager	2	1
	EUV Imager	1	1
	Radio Burst Spectrometer	1 (TBC)	1 (TBC)
In-situ measurements	Magnetometer	1	1
	Solar Wind Analyser	1	1
	Medium-energy ion detector	1 (T), 2(G)	1 (T), 2(G)
	High-energy ion detector	1 (T), 2(G)	-
	Medium-energy proton detector	1 (T), 2(G)	-
	High-energy proton detector	1 (T), 2(G)	1 (T), 2(G)
	Medium-energy electron detector	1 (T), 2(G)	1 (T), 2(G)
	High-energy electron detector	1 (T), 2(G)	-
	NEO Imager	1 (TBC)	1 (TBC)

(T) and (G) show Threshold and Goal levels

Compact coronagraph

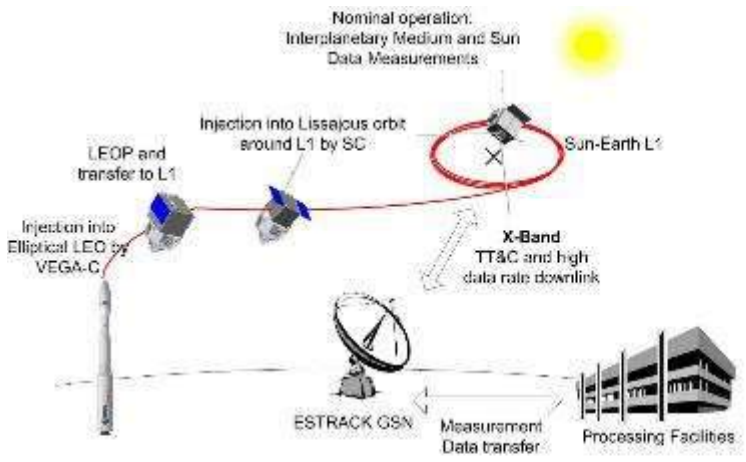


EUV Imager

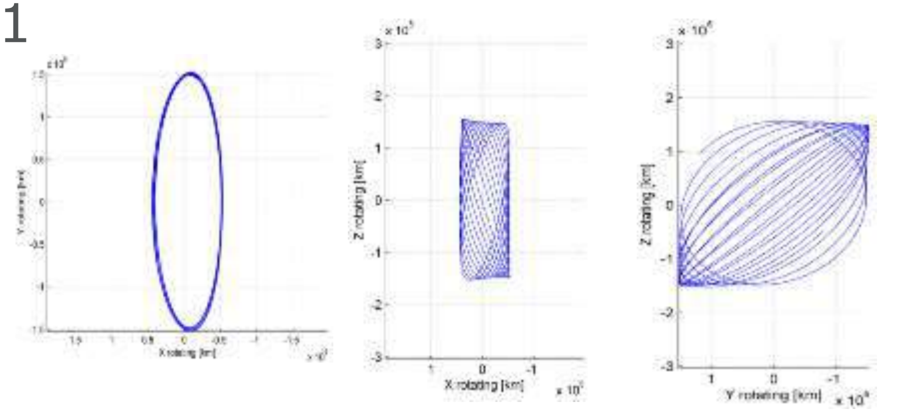
High energy proton and electron detector - NGRM

L1 MISSION CONCEPT IDENTIFICATION

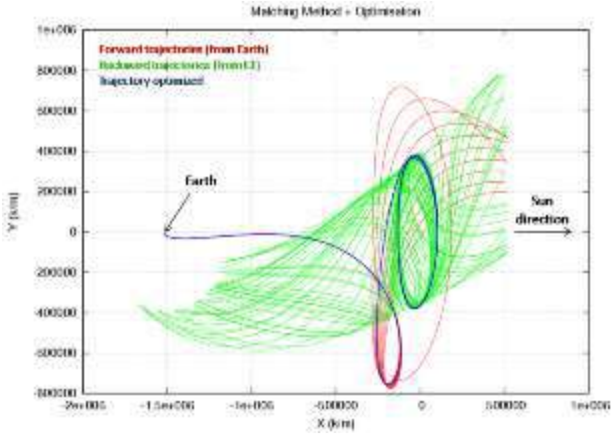
<table>
<tr><td>Number and location of s/c</td><td colspan="2">1: L1 only</td><td colspan="2">2: L1 + GEO</td><td colspan="2">2: L1 + SSO</td></tr>
<tr><td>Stabilisation</td><td colspan="3">Spin</td><td colspan="3">3–axis</td></tr>
<tr><td>Launcher</td><td colspan="2">Vega-C</td><td colspan="2">Soyuz
(or Ariane 6-2)</td><td colspan="2">Ariane 5
(or Ariane 6-4)</td></tr>
<tr><td rowspan="2">Transfer strategy</td><td colspan="2" rowspan="2">Direct</td><td colspan="2">Chemical</td><td colspan="2" rowspan="2">Electrical</td></tr>
<tr><td>Integrated</td><td>Separate module</td></tr>
<tr><td>Operational orbit</td><td colspan="2">Lyaponov</td><td colspan="2">(Quasi-)Halo</td><td colspan="2">Lissajous</td></tr>
<tr><td>Lifetime</td><td colspan="2">5 years</td><td colspan="2">10 years</td><td colspan="2">15+ years</td></tr>
<tr><td>Ground segment</td><td colspan="2">ESTRACK core
35 m dishes</td><td colspan="2">ESTRACK augmented
13-35 m dishes</td><td colspan="2">ESTRACK + US
13 – 15 m dishes</td></tr>
<tr><td>Communications architecture</td><td>S-S</td><td>S-X</td><td>X-X</td><td>X-Ka</td><td>Ka-Ka</td><td>Ku-Ku</td></tr>
</table>



GETTING TO L1



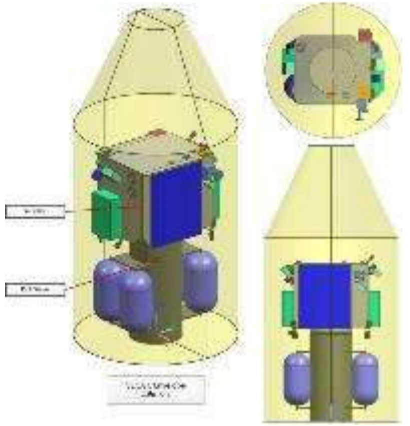
- Selected a small-amplitude Lissajous orbit
  - Remains close to Sun-Earth line, but rarely passes in front of Sun
- Search for optimal transfer from Earth by matching method
  - Forward propagation of stable manifold associated with large orbits
  - Backward propagation of stable manifold associated with small orbits
  - Optimise to find minimum insertion ΔV
- Looked for best solution for launch in 2021:
  - Departure ΔV = 2.8 km/s
  - Insertion ΔV = 151 m/s after 115 days
- Transfer stage based on LISA Pathfinder design

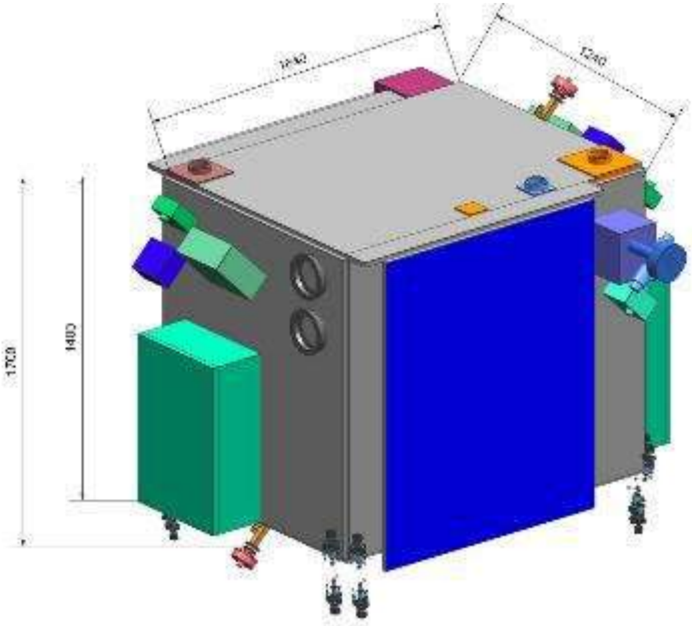


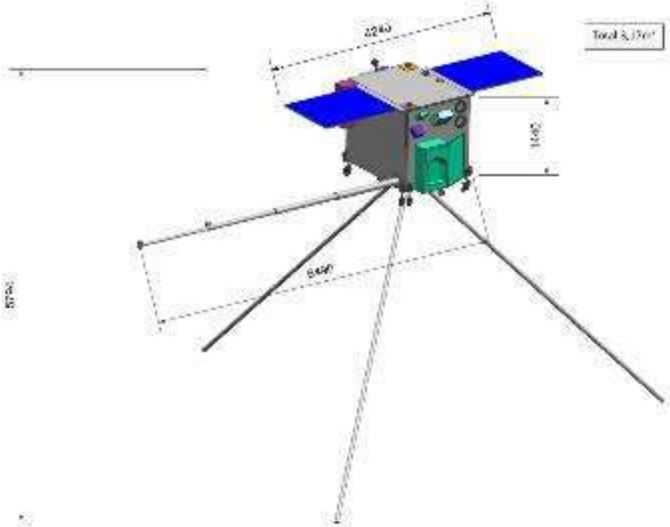
Phases	Manoeuvre	ΔV with gravity losses and margins (m/s)
LEOP	Launcher correction, nominal TCM	30
Departure Injection	Departure burn provided by S/C transfer stage	2819
Transfer navigation	Mid-course navigation	30
Orbit Injection	Orbit injection (HOI)	175
Routine operations	Orbit maintenance manoeuvre	11
	Attitude control - Reaction wheels off loading	10
Manoeuvre to avoid crossing Sun-Earth line	Manoeuvre for Sun-Earth line crossing	32
End-of-life	End-of life disposal (EAM)	7
TOTAL		**3130**

L1 SPACECRAFT ACCOMMODATION

- Main drivers are:
  - Pointing directions and field of view for instruments
  - Stray light
  - Magnetic cleanliness
  - Avoiding thruster plume impinging on instruments
  - Launcher fairing dimensions







Subsystem	Nominal [kg]	Margin [%]	Total [kg]
Electrical Power Subsystem	29.8	14.5%	34.1
Onboard Data Handling Subsystem	11.5	10.0%	12.7
Comms Subsystem	20.3	6.6%	21.6
Attitude and Orbit Control Subsystem	22.0	5.0%	23.1
Chemical Propulsion Subsystem	18.5	5.0%	19.4
Thermal Control Subsystem	15.1	19.9%	18.1
Harness	25.0	30.0%	32.5
Structure	75.0	20.0%	90.0
Platform total	**217.2**	**15.8%**	**251.5**
Sun Measurement Instruments	88.8	10.0%	97.7
In-Situ Measurement Units	41.8	10.0%	45.9
NEO Payload	14.0	10.0%	15.4
Payload total	**144.6**	**10.0%**	**159.0**
Spacecraft dry mass	**361.8**	**13.5%**	**410.6**
System margin		20.0%	82.1
Spacecraft dry mass + Margin			**492.7**
Propellant mass			54.0
Spacecraft wet mass			**546.7**
Launcher capability (VEGA-C)			2150.0
Transfer Module Wet Mass			1420.0
Launcher mass margin			**183.3**

AWAY FROM SUN-EARTH LINE MISSION CONCEPT IDENTIFICATION

<table>
<tr><th>Orbit / Location</th><td colspan="2">Heliocentric drifting</td><td colspan="3">Small horseshoe</td><td>Large horseshoe</td><td colspan="3">Small L5 orbit</td><td colspan="2">Large L5 orbit</td></tr>
<tr><th>Launcher</th><td colspan="4">Vega</td><td colspan="3">Soyuz
(or Ariane 6-2)</td><td colspan="4">Ariane 5
(or Ariane 6-4)</td></tr>
<tr><th>Transfer strategy</th><td colspan="4">Direct</td><td colspan="3">Via L1</td><td colspan="4">Lunar</td></tr>
<tr><th>Transfer duration</th><td colspan="4">~1 year</td><td colspan="3">~2 years</td><td colspan="4">~3 years</td></tr>
<tr><th>Transfer Module</th><td colspan="4">None</td><td colspan="3">Bi-propellant</td><td colspan="4">Electric</td></tr>
<tr><th>Lifetime</th><td colspan="4">5 year</td><td colspan="3">10 years</td><td colspan="4">15+ years</td></tr>
<tr><th>Communications architecture</th><td>S-S</td><td colspan="2">S-X</td><td colspan="2">X-X</td><td>X-Ka</td><td colspan="2">Ka-Ka</td><td colspan="2">Ka-Ku</td><td>Ku-Ku</td></tr>
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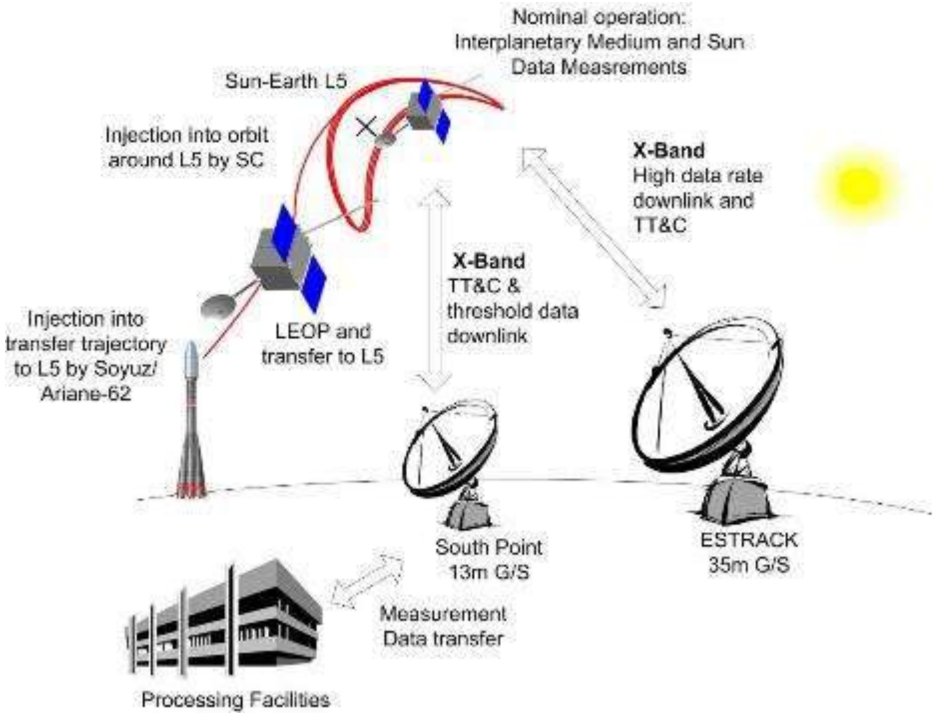
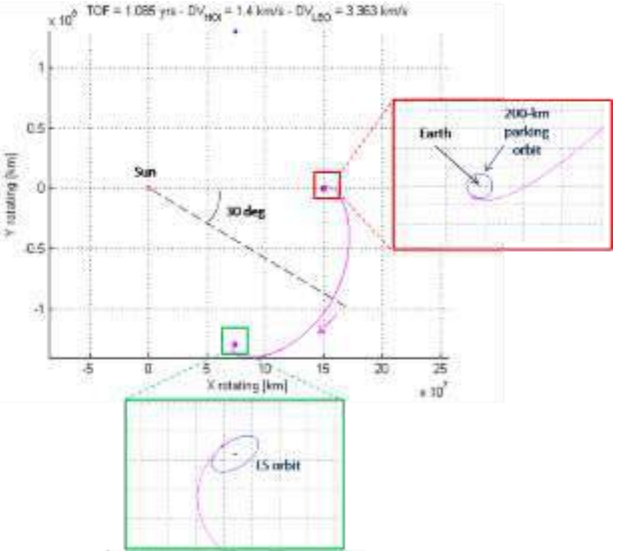
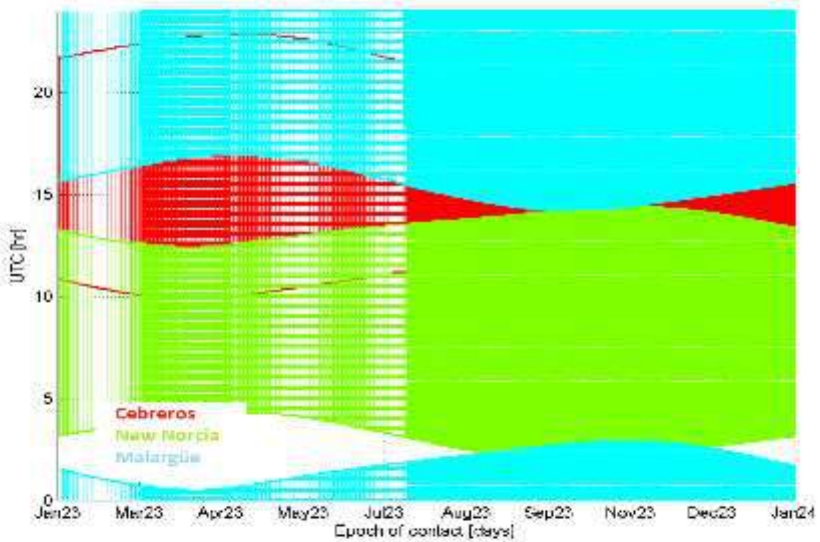


L5 MISSION ANALYSIS

- Wider range of choices of orbit
  - Trade off between ΔV and drift rate
- Launcher puts spacecraft into transfer orbit
  - Removes need for s/c propulsion stage
- Considered dual launch of L1 and L5 missions
- Further away → more demanding for communications
  - Bigger antenna, 35 m ground stations

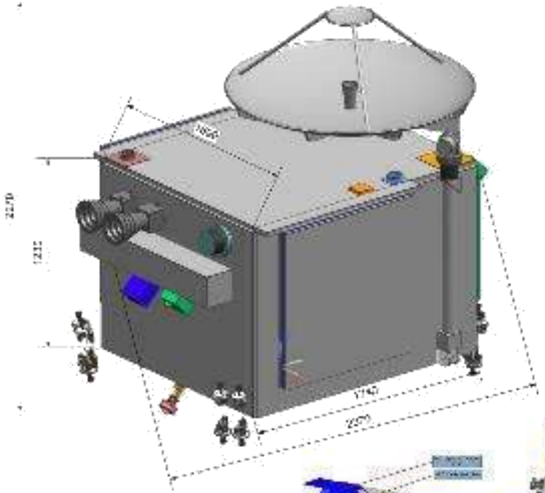


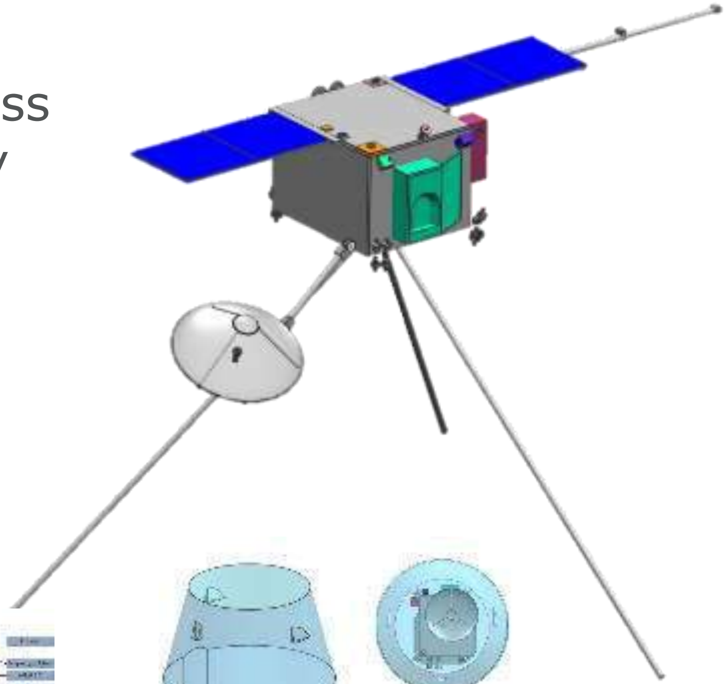


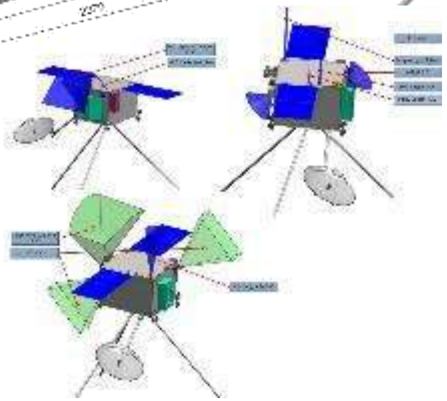
Target orbit	Transfer time [yrs]	ΔV at orbit insertion [m/s]	ΔV at launch from LEO [km/s]	Total ΔV [km/s]
L5 Small	3.025	520.034	3.259	3.779
	2.062	750.018	3.280	4.030
	1.085	1400.136	3.363	4.763
L5 Large	2.923	450.000	3.555	4.005
	1.958	650.000	3.640	4.290
	1.017	1210.000	3.866	5.076
Horseshoe Small	2.884	230.04	3.256	3.486
	1.937	354.92	3.273	3.628
	0.991	725.05	3.276	4.001
Horseshoe Large	2.834	310.009	3.424	3.734
	1.871	419.990	3.459	3.879
	0.906	750.006	3.555	4.305
Heliocentric drifting	2.708	N/A	3.271	3.271

L5 SPACECRAFT ACCOMMODATION

- Similar drivers to L1
- Soyuz launcher has significant spare mass and volume capacity



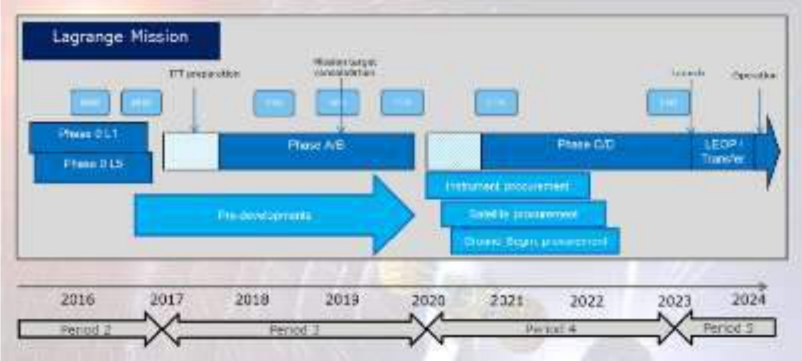




Subsystem	Nominal [kg]	Margin [%]	Total [kg]
Electrical Power Subsystem	32.1	14.2%	36.6
Onboard Data Handling Subsystem	11.5	10.0%	12.7
TT&C Subsystem	30.4	10.2%	33.5
Attitude and Orbit Control Subsystem	34.6	5.0%	36.4
Chemical Propulsion Subsystem	49.4	5.0%	51.9
Thermal Control Subsystem	15.1	19.9%	18.1
Harness	33.0	30.0%	42.9
Structure	84.5	20.0%	101.4
Platform total	**290.6**	**14.7%**	**333.4**
Sun Measurement Instruments	76.8	10.0%	84.5
In-Situ Measurement Units	28.5	10.0%	31.4
NEO Payload	14.0	10.0%	15.4
Payload total	**119.3**	**10.0%**	**131.2**
Spacecraft dry mass	**409.9**	**13.4%**	**464.7**
System margin		20.0%	92.9
Spacecraft dry mass + Margin			**557.6**
Propellant mass			391.0
Spacecraft wet mass			**948.6**
Launcher capability (Soyuz)			2050.0
Launcher mass margin			**1101.4**

CONCLUSIONS AND NEXT STEPS

- New operational Space Weather mission(s) are needed as ACE, SOHO, STEREO and DSCOVR come to the end of their lives
- We have shown how operational Space Weather mission(s) could be developed to meet these needs within a reasonable budget and timeframe
- Speculation: NOAA / NASA build replacement L1 mission, and Europe will add L5 capability?
- Strong interest in ESA "Lagrange Mission"
  - Especially from UK and Germany

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