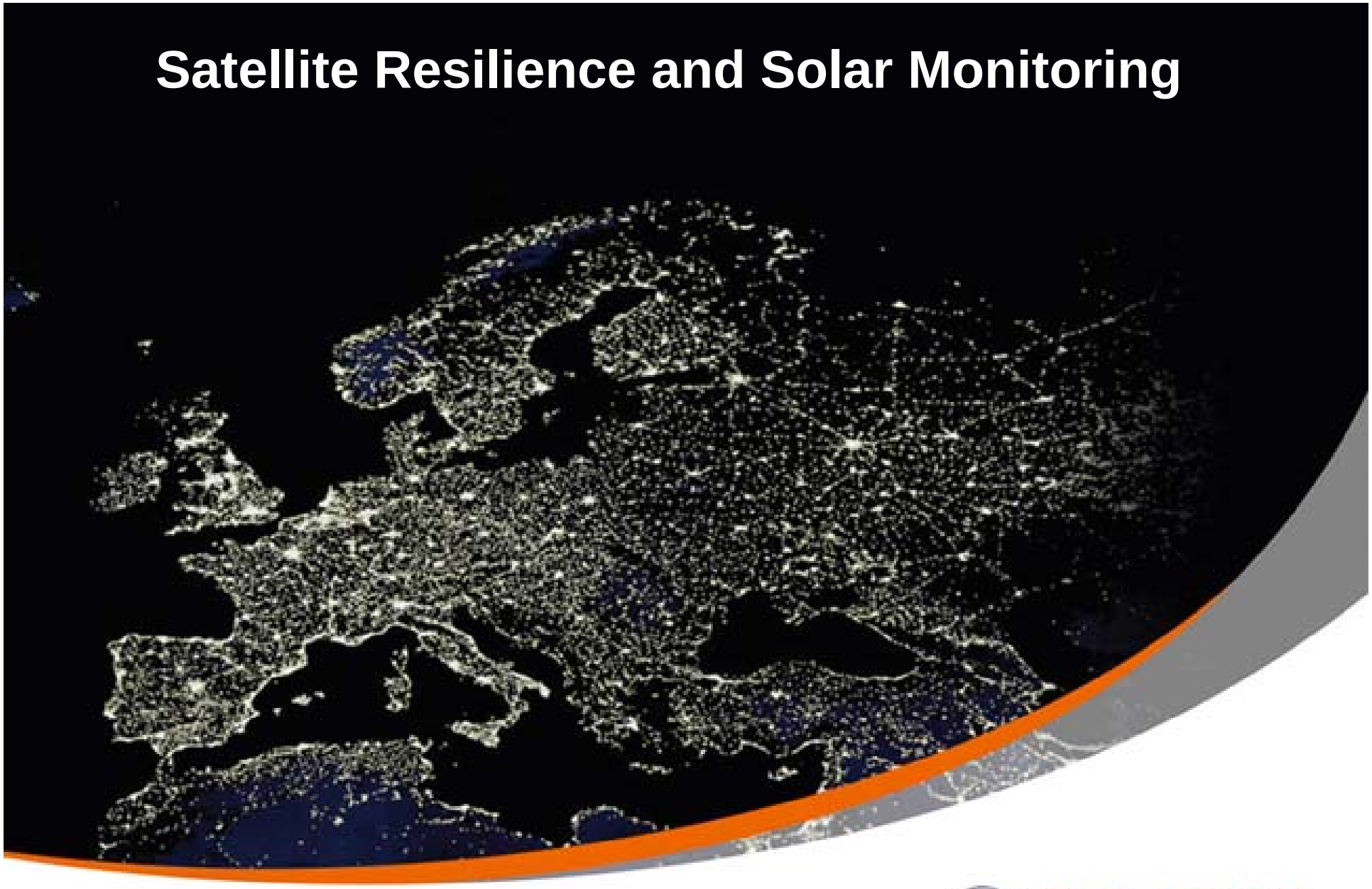
Satellite Resilience and Solar Monitoring

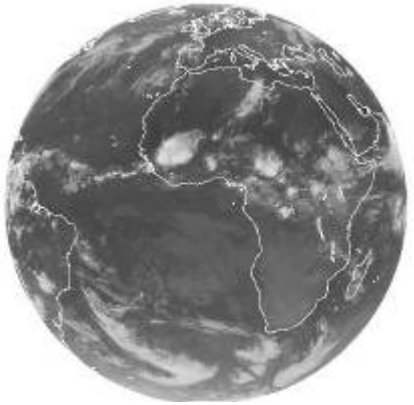


Together pioneering excellence

ASTRIUM
AN EADS COMPANY

Rationale for Space System Resilience

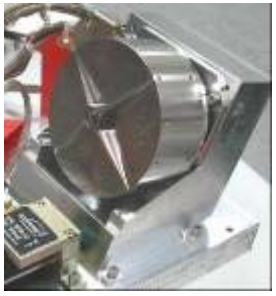
- Space is increasingly seen a part of the critical **inter**national infrastructure, providing communications, navigation, timing, surveillance, meteorology, etc.



- This increasing international reliance on space systems justifies additional efforts to make them more robust

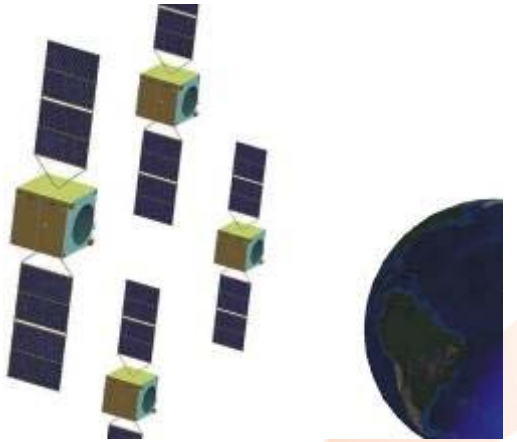
Resilience Options

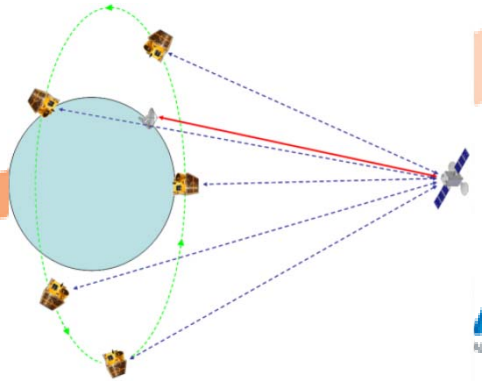
- System level redundancy
  - E.g. Galileo and GPS
- Proliferation
  - Satellites
  - Frequencies
  - Ground stations
- Dual redundant satellite design
  - Primary and back-up components
- Alternate hardware options
  - E.g. Wheels and magnetorquers
- Multiple memory locations
- Burst circumvention circuitry
- Autonomy/Safe modes
  - To accommodate outages at ground station or in communications path
- Spare satellites
- Inter-satellite links
- Launch on demand



Wheel

Magnetorquer

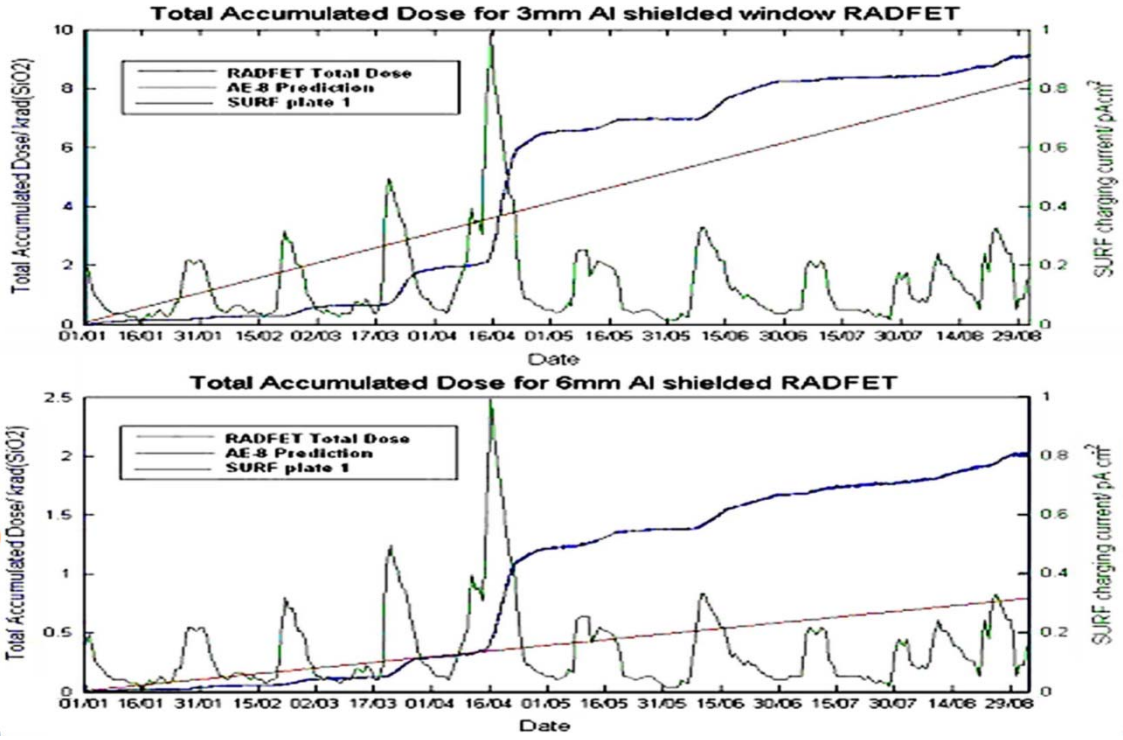


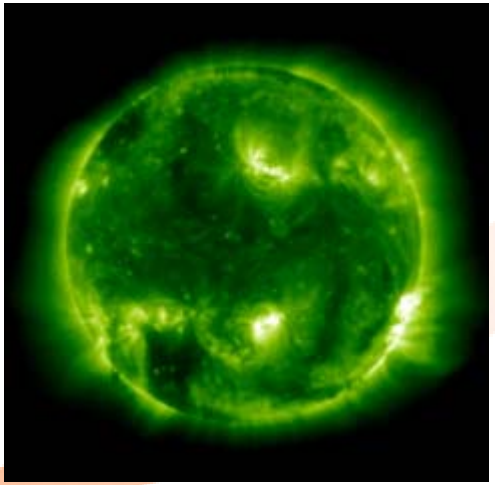


ASTRIUM

Total Dose Accumulation

- This is the accumulated radiation dose data from the Giove-A satellite, showing a periodic increment roughly once per month
- This is the result of an active region on the sun, (which rotates with this period)
- We can design for this level of activity

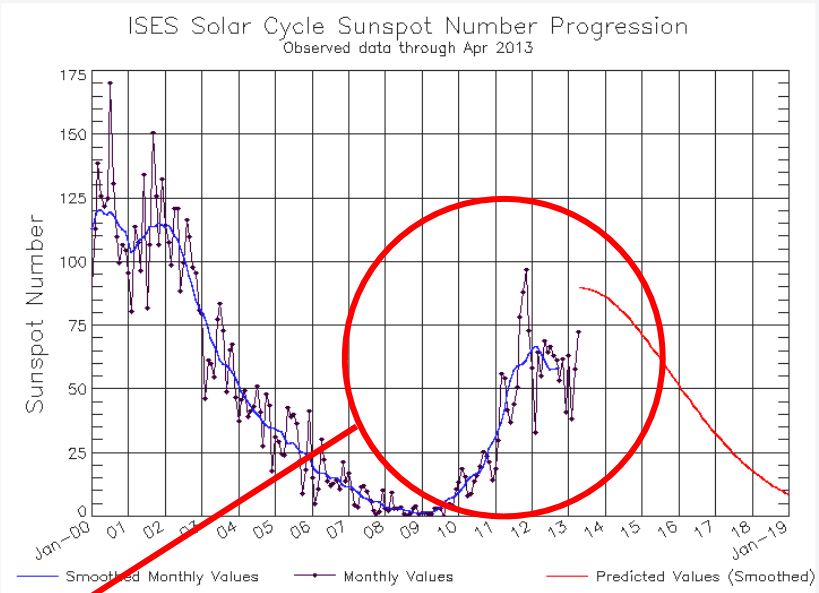


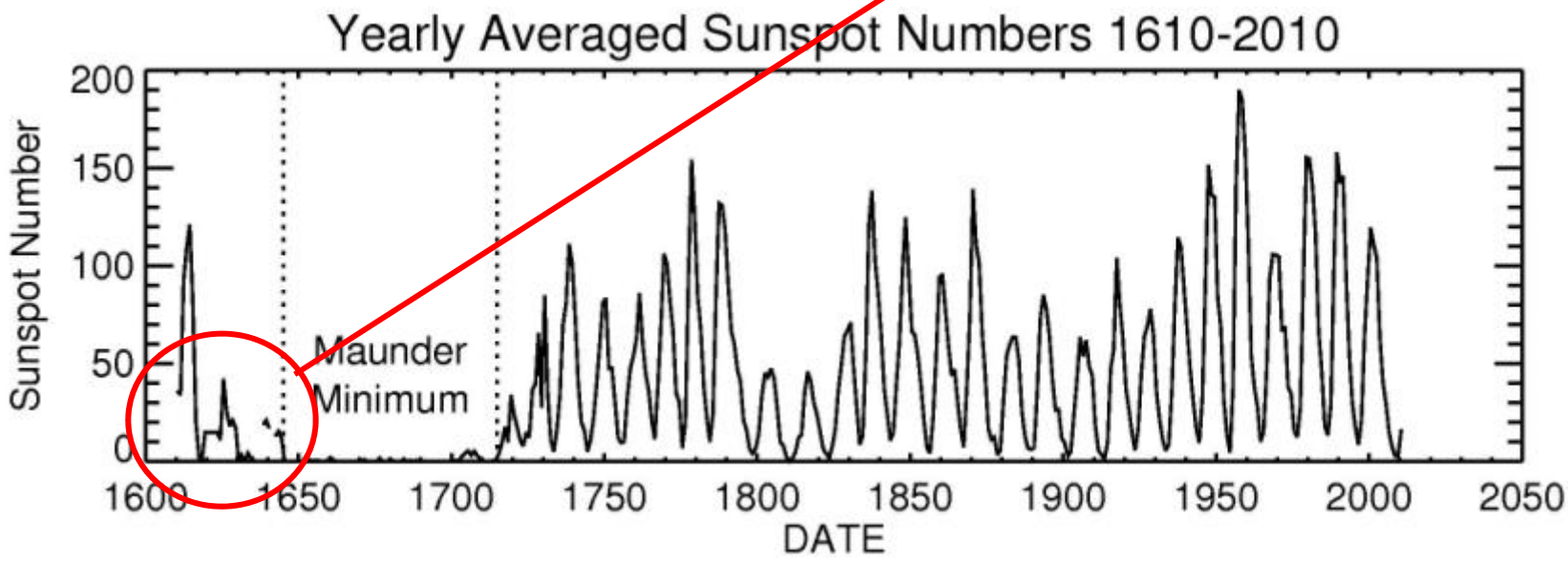


ASTRIUM
AN EADS COMPANY

Current Solar Activity

- An improved understanding of the behaviour of the sun would enable better forward prediction
- Is there a parallel between current solar activity (top right) and the onset of the Maunder minimum (below)?
- If so, this forward prediction will be tricky…..

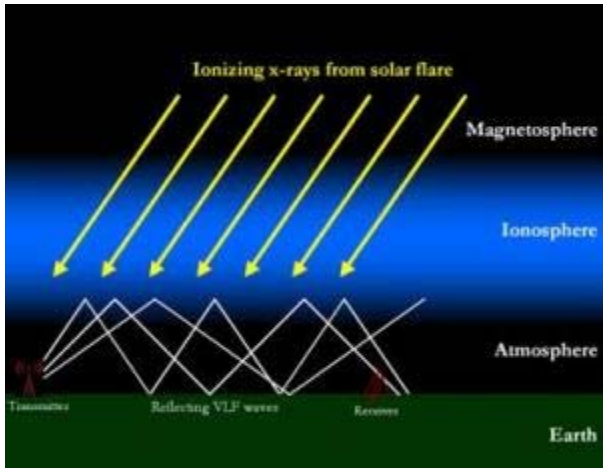


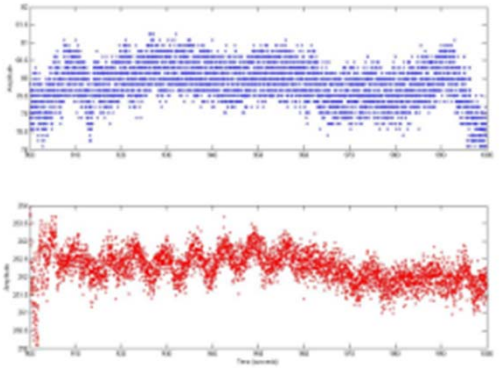


And supposing the Sun burps…

Potential effects:

- Temporary or permanent disruption to satellite operations
- Temporary disruption to the communications path to the satellites
- Temporary outages at the ground stations



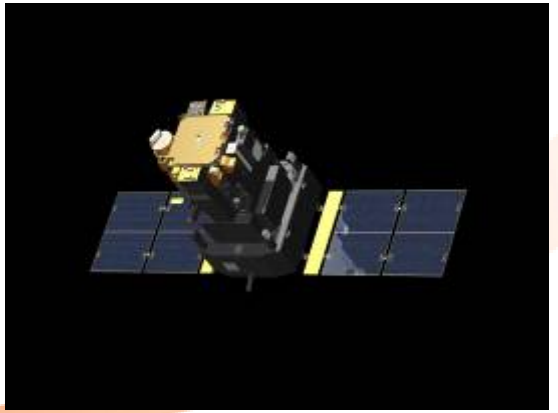


The risk we currently face

- The ACE and SOHO missions are “venerable” and cannot last forever
- The Stereo missions are drifting and so cannot maintain observations of the Earth-Sun line indefinitely
- We could be left without in-situ monitoring of the Sun’s activity
- A “civilisation changing event” costing $1-2 trillion could occur without warning

ACE

SOHO



STEREO

Space Weather Mission Objectives

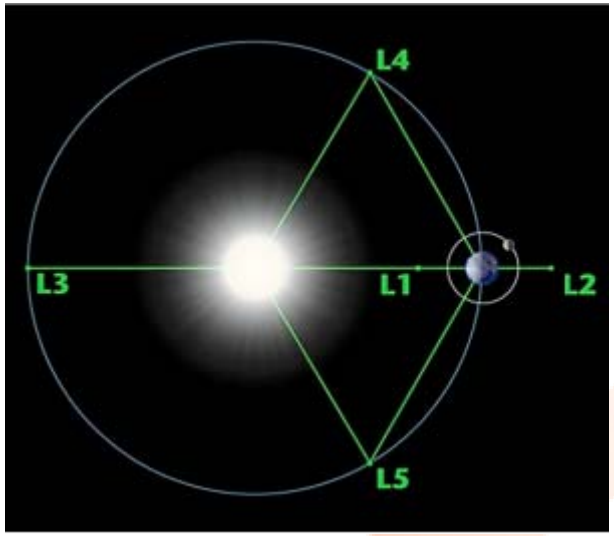
- Observations of the Sun are required for determining the location, speed, spatial extent, mass, and magnetic alignment of interplanetary solar eruptions likely to impact Earth's magnetosphere

- Mission Level Objectives:
  - Real-time space weather monitoring
  - Availability – 24/7/52, for perhaps 15 years
  - Schedule – As rapid as possible to reduce the time that critical functionality from missions such as ACE, SOHO and Stereo is unavailable

ASTRIUM
AN EADS COMPANY

Mission Concept

- **A comprehensive monitoring capability requires satellites stationed at both L1 and L4/L5**
  - The L4/L5 mission would provide initial warning of an impending solar-induced event
  - The L1 mission would provide information on the magnetic polarity of the flare and hence the potential coupling into the Earth's magnetosphere
- **Why two missions?**
  - L4/L5 imager can predict a collision but it cannot predict the interaction with the Earth's magnetic field
  - L1 in-situ mission alone cannot give sufficiently early warning of an event. From no-alert to 'Red Alert' in 90 minutes is too short for serious action!



Lagrange Points

ASTRIUM
AN EADS COMPANY

Mission Concept

- We envisage small, simple, heritage-based satellites carrying existing, single-instrument payloads

- **L4/L5 Off-Axis Imager(s)**

  - Pathfinder: STEREO
  - Instrument: Heliospheric Imager
  - Orbit: Ideally L4 and L5

- Mission: Observation of Solar event and early prediction of event interaction with the Earth

- Result: ‘Amber Alert’ status
  - 48hr warning that something is going to hit Earth

- **L1 Line-Of-Fire Detector**

  - Pathfinder: SOHO/Cluster
  - Instrument: In-situ magnetometer and plasma detectors
  - Orbit: Probably close to L1

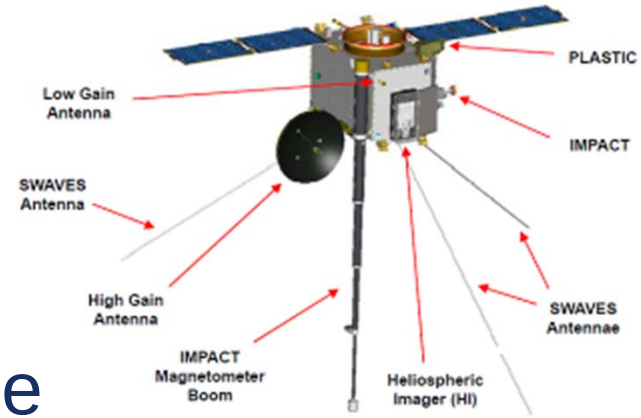
- Mission: Determine magnitude of the event and predict penetration of Earth’s magnetic field
  - Determine direction of CME magnetic field

- Result: ‘Red Alert’ status
  - Short-term (~90 minute) warning of ‘the big one’

ASTRIUM
AN EADS COMPANY

L1 Mission Payload

- Magnetometer and Plasma Instrument Package
  - Total Mass = <5 kg
- Magnetometer likely to require deployable boom like Stereo

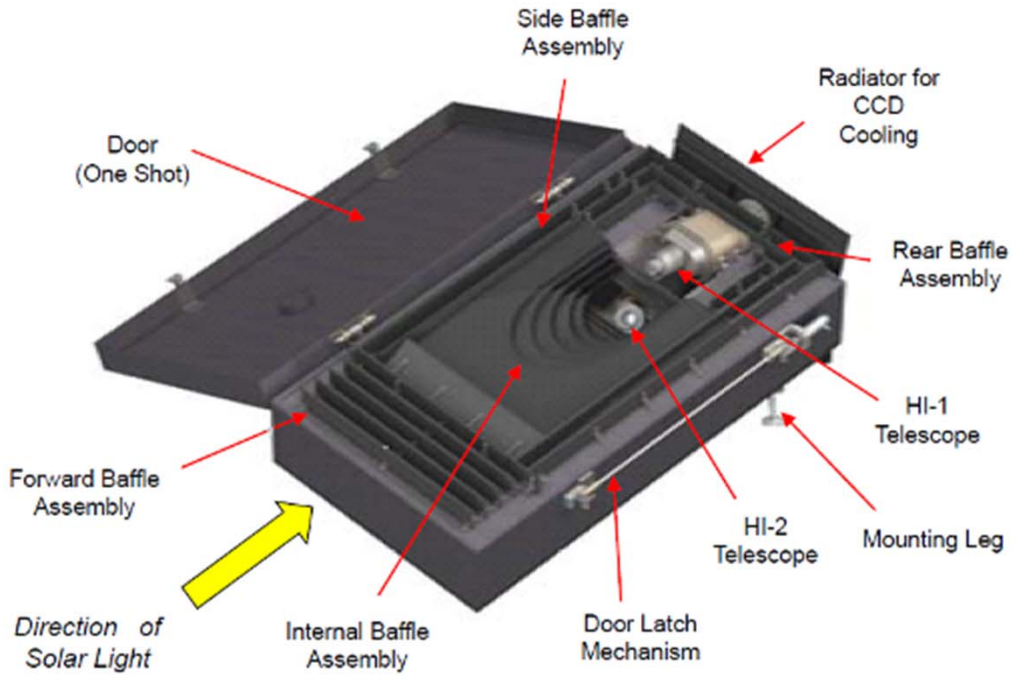


Stereo Satellite

Example Instrument Characteristics	
L1 Mission	
Magnetometer	•Established heritage on deep space missions •Nominal range +/- 256 nT full scale, 12-bit resolution per axis, 0.0625 nT digital resolution per sample •An 0.1 nT relative accuracy and 2.0 nT absolute accuracy •Mass 1 kg, power 1 Watt, data rate ~300 bps
Plasma Detector	•Electrostatic analyzer with energy range from 0.1-22 keV •One instrument covers entire range oTwo heads for 3 axis stabilized design, oHeritage on many spaceflight missions oEnergy range and accuracy well within heritage sensors •Mass 3.5 kg, power 4.0 Watts, data rate ~600 bps per unit •Faraday cup design

L4/L5 Mission Payload

- Heliospheric Imager Instrument
  - Mass = 16.3 kg
  - Dimensions = 840 x 550 x 260 mm.



Heliospheric Imager

ASTRIUM
AN EADS COMPANY

Ground Segment and CONOPS

- The mission objectives for continuous coverage will require a network of at least 3 ground stations, suitably dispersed geographically around the globe

- Since the spacecraft are at large distances from Earth, large antennas will sometimes be needed if high-data rates from the satellites are required for image transfer

- Chilbolton and Goonhilly are candidate locations in UK

Operations

- Mission operations should be automated as far as possible
- Sensor data should be processed on-board as far as possible to reduce data rates
  - This would be feasible from “parked” positions
- Higher data rate modes could be used in time of crisis

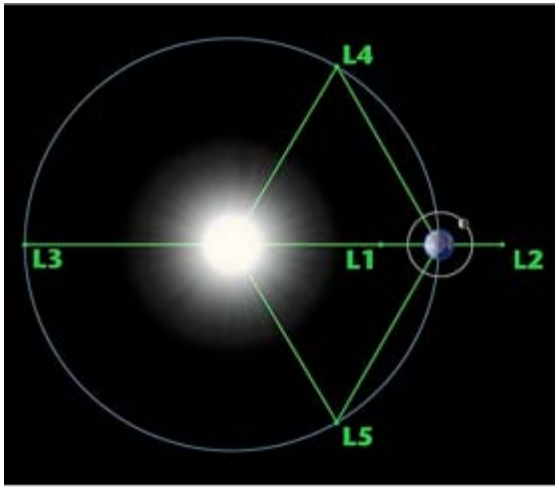
Launch Phase Only

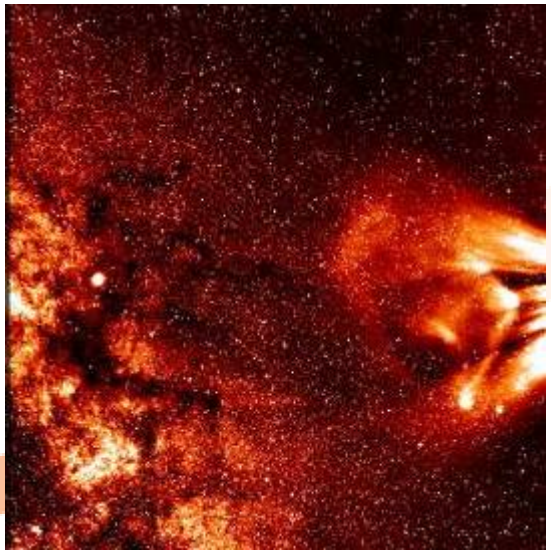
Routine Operations

ASTRIUM
AN EADS COMPANY

Conclusions

- The key space segment elements of an operational Solar Weather Alert Measurement and Impacts mission can be delivered at low cost via a series of single payload spacecraft
- Most payload and platform elements already exist and can be rapidly integrated such that this mission could be operational in less than 3 years
- The system would not be targeted at flying new payloads and delivering new science, although it would improve the state of knowledge in the field
- ItI would provide information required to decision makers to respond to solar events and would be complementary to planned science missions
- We recommend a short feasibility study to refine the mission design and CONOPS





ASTRIUM
AN EADS COMPANY

THANK YOU

Together pioneering excellence

ASTRIUM
AN EADS COMPANY