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

Dr Markos Trichas, Airbus Defence & Space Future Programmes, UK
17 April 2015
Team

Industry: AIRBUS DEFENCE & SPACE

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

Academia: Imperial College London, UCL

Consultation: national grid, PARADIGM SERVICES BY ASTRIUM, inmarsat
UK/US Space Weather Impacts

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

1 - 2 days UK blackout
£10 billion

Lloyds, 2010
RAEng, 2013

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Satellite</th>
<th>Orbit</th>
<th>Cause (probable)</th>
<th>Effects seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 March 1985</td>
<td>Anik D2</td>
<td>GEO</td>
<td>ESD</td>
<td>Outage</td>
<td></td>
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<tr>
<td>October 1989</td>
<td>CME driven storm</td>
<td>TiROS-1</td>
<td>GEO</td>
<td>SEE</td>
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<tr>
<td>July 1991</td>
<td>ERS-1</td>
<td>LEO</td>
<td>SEE</td>
<td>Instrument failure</td>
<td></td>
</tr>
<tr>
<td>20 January 1994</td>
<td>Fast solar wind stream</td>
<td>Anik E1</td>
<td>GEO</td>
<td>ESD - note all three satellites were of same design</td>
<td>Outage (6 months)</td>
</tr>
<tr>
<td>20 January 1994</td>
<td>Fast solar wind stream</td>
<td>Anik E2</td>
<td>GEO</td>
<td>ESD - note all three satellites were of same design</td>
<td>Outage (6 months)</td>
</tr>
<tr>
<td>20 January 1994</td>
<td>Fast solar wind stream</td>
<td>Intelsat K</td>
<td>GEO</td>
<td>ESD - note all three satellites were of same design</td>
<td>Outage (6 months)</td>
</tr>
<tr>
<td>31 January 1997</td>
<td>Fast solar wind stream</td>
<td>Telstar 401</td>
<td>GEO</td>
<td>ESD</td>
<td>Total loss</td>
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<tr>
<td>19 May 1998</td>
<td>Fast solar wind stream</td>
<td>Galileo 4</td>
<td>GEO</td>
<td>ISD</td>
<td>Total loss</td>
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<tr>
<td>15 July 2000</td>
<td>CME driven storm</td>
<td>Astro-2 (ASC)</td>
<td>LEO</td>
<td>Atmospheric drag</td>
<td>Total loss</td>
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<tr>
<td>6 November 2001</td>
<td>CME driven storm</td>
<td>MAP</td>
<td>Interplanetary L2</td>
<td>SEE</td>
<td>Temporary outage</td>
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<tr>
<td>24 October 2003</td>
<td>CME driven storm</td>
<td>ADEOS/MODIS 1</td>
<td>LEO</td>
<td>ISD (solar array)</td>
<td>Total loss</td>
</tr>
<tr>
<td>26 October 2003</td>
<td>CME driven storm</td>
<td>SMART-1</td>
<td>LEO</td>
<td>SEE</td>
<td>Engine-switch-off and solar array noise</td>
</tr>
<tr>
<td>20 October 2003</td>
<td>Fast solar wind stream</td>
<td>DRTS/Kodama</td>
<td>GEO</td>
<td>ISD</td>
<td>Outage (2 weeks)</td>
</tr>
<tr>
<td>3 January 2005</td>
<td>Intelsat 904</td>
<td>GEO</td>
<td>ISD</td>
<td>Total loss</td>
<td></td>
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<tr>
<td>15 October 2006</td>
<td>Fast solar wind stream</td>
<td>Skylab 1</td>
<td>GEO</td>
<td>ISD</td>
<td>Total loss</td>
</tr>
<tr>
<td>5 April 2009</td>
<td>Fast solar wind stream</td>
<td>Galileo 15</td>
<td>GEO</td>
<td>ISD</td>
<td>Outage (6 months)</td>
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<tr>
<td>3 March 2012</td>
<td>CME driven storm</td>
<td>Spaceway 3</td>
<td>GEO</td>
<td>SEE</td>
<td>Outage (4 hours)</td>
</tr>
<tr>
<td>7 March 2012</td>
<td>CME driven storm</td>
<td>Skymart 2</td>
<td>GEO</td>
<td>SEE</td>
<td>Outage (1 day)</td>
</tr>
<tr>
<td>27 March 2012</td>
<td>GOES-13</td>
<td>GEO</td>
<td>ISD</td>
<td>Outage (1 day)</td>
<td></td>
</tr>
</tbody>
</table>
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

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

(RAE, 2013)
UK National Risk Register 2013/2014

Catastrophic (5)
- Coastal Floods
- Pandemic ‘Flu

Significant (4)
- Severe space weather

Moderate (3)
- Public Disorder
- Ash eruption

Minor (2)
- Severe Wildfires

Limited (1)

Low (1) Medium Low (2) Medium (3) Medium High (4) High (5)

 Courtesy of the Cabinet Office

Carrington: UK/US Operational Space Weather Mission

National Risk Register of Civil Emergencies
2013 edition

National Space Security Policy

17 April 2015, SWPC Annual Meeting, USA
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
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.”
### Mission Drivers

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronagraph</td>
<td>Critical for identifying Earth-directed CME</td>
</tr>
<tr>
<td>Heliospheric Imager</td>
<td>Critical for identifying Earth-directed CME, and imaging arrival at Earth</td>
</tr>
<tr>
<td>Particles/fields</td>
<td>Measurement of CIR approaching Earth.</td>
</tr>
<tr>
<td>EUVI</td>
<td>To image solar active centres, in particular to assess the potential for eruptions/flare at sites as the approach locations well connected to Earth</td>
</tr>
<tr>
<td>Magnetograph</td>
<td>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.</td>
</tr>
</tbody>
</table>

- 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

Carrington: UK/US Operational Space Weather Mission
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Payloads

Coronagraph

Magnetometer

Airbus DS Boom

Heliospheric Imager

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)
**Configuration**

Dimensions in stowed configuration

- **Falcon 9 Fairing**
- **Carrington: UK/US Operational Space Weather Mission**
- **17 April 2015, SWPC Annual Meeting, USA**
L5 Station

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>• Phase 0 study.</td>
</tr>
<tr>
<td></td>
<td>• UKSA &amp; NOAA/NASA agreement</td>
</tr>
<tr>
<td></td>
<td>• AO for instruments</td>
</tr>
<tr>
<td>2016</td>
<td>• Instrument selection</td>
</tr>
<tr>
<td></td>
<td>• Phase A/B starts</td>
</tr>
<tr>
<td>2017</td>
<td>• Mission selection</td>
</tr>
<tr>
<td></td>
<td>• Phase B2CD</td>
</tr>
<tr>
<td></td>
<td>• System PDR</td>
</tr>
<tr>
<td>2018</td>
<td>• System CDR</td>
</tr>
<tr>
<td></td>
<td>• Instrument CDR</td>
</tr>
<tr>
<td></td>
<td>• Launch procurement</td>
</tr>
<tr>
<td>2019</td>
<td>• S/C build integration &amp; test</td>
</tr>
<tr>
<td></td>
<td>• Instrument delivery</td>
</tr>
<tr>
<td>2020</td>
<td>• System integration</td>
</tr>
<tr>
<td>2021</td>
<td>• Launch</td>
</tr>
</tbody>
</table>
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
Questions?

For any queries:
markos.trichas@astrium.eads.net