Toward Interplanetary Space Weather: Strategies for Manned Missions to Mars

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Challenges

I. 2030 context: an international human mission to Mars (or nearby asteroids and moons) may be a reality, with the Moon as a likely intermediate step.

II. 20-year progress from now: to generate diagnostics for operational forecasting.
Solar flares and Coronal Mass Ejections (CMEs) are the most important but so far the most difficult space weather events to predict.

**Flare**
Near central meridian (S16 E09)  
SOHO/EIT  
GOES:  
9:51-11:24 UT with peak X17.2 at 11:10 UT

**CME**  
(Coronal Mass Ejection)  
Halo frontsided CME  
V=2125 km/s  
Prominence to the South  
SOHO/LASCO C2 and C3
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**SPEs (solar particle events)**

solar protons > 10 pfu @$>10$ MeV.

Ex: SPE starting on **28 Oct. 2003** at 12:40 UT

Peak: $2.95 \times 10^4$ pfu on 29 Oct. 06:15 UT

(< $4 \times 10^4$ pfu from SPE Oct. 19 1989)

This event caused the damage on MARIE / 2001 Mars Odyssey
Mars orbital parameters ➔ Requirements

- **Sun-Earth-Mars angle**: space weather on the far side of the Sun.
- **Earth-Mars distance**: delay in telecommunications.
- **Sun-Mars distance**: behaviour of SEPs beyond 1 AU.

- Multi-viewpoint system.
- Onboard warning and forecasting system.
- Test of comprehensive simulations of the interplanetary medium to fit readings from numerous unmanned missions.
Recommendations for multi-spacecraft systems

1. Remote-sensing multi-viewpoint observations
   1. Coronal and heliospheric imaging: observe trajectories of CMEs.
   2. Improve shock speed and intensity estimates with radio spectrographs to observe type II radio bursts.
   3. Determine Parker spiral with Type III bursts tracking by triangulation.

2. In situ multi-spacecraft measurements
   1. Angular extent of ICMEs and co-rotating high-speed streams.
   2. Characteristics of SEP events.

Other systems
   – A monitoring platform at the Sun-Mars L1 point [Strizzi et al., 2001]
   – Living With a Star Solar Sentinels [Szabo, 2003]
   – Data sources from interplanetary missions.
Both the coronal dynamics and subsurface flows are solar activities to watch, as they may lead to instabilities, which result in solar flares and CMEs.

Developed algorithms

- **Detect EUV(quiescent/erupting) prominences:** Automated detection and 3D reconstruction of EUV prominences [Foullon, 2003; Foullon & Verwichte, 2006]

- **Associate filament activity observed in the 195Å high-cadence images:** Discovery of ultra-long-period oscillations in a solar EUV filament [Foullon et al. 2004] and period changes near to eruption [Foullon et al. 2009]; spatial characteristaion with period mapping algorithms [Foullon et al. 2010, in prep.].

3D reconstruction CR 1953

11.36 days (272.6 hr)
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**Developed algorithms**

- **Detect EUV(quiet/erupting) prominences:**  
  Automated detection and 3D reconstruction of EUV prominences [Foullon, 2003; Foullon & Verwichte, 2006]

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20-year progress from now: prospective research

FP7 Coordination on Space Work Program proposal (2009) on ‘Space Weather Applications of Solar Dynamics and Oscillations’ [Warwick contact: C. Foulon]

Promising applications of the developed algorithms to:
- full EIT/SOHO archive → long term solar cycle analysis, modelling
- images from other ongoing and future EUV instruments (identical bandpasses as EIT):
  → EUVI/SECCHI onboard STEREO (potential for exact reconstruction)
  → AIA/SDO (multi-wavelength and high temporal/spatial resolution).
- real time EUV images → forecasting

Generate space weather diagnostics based on coronal dynamics.

[Foullon & Verwichte, 2006]
Examples of recent research at Warwick

Exploiting wave solar data of coronal loops and prominences in the EUV (e.g. TRACE, SOHO/EIT, Hinode/EIS/SOT) and other wavelengths.

[Verwichte, Foullon and Van Doorsselaere, 2010]

[Harris, Foullon, Nakariakov and Verwichte, 2010, in preparation]

[Loop oscillations data points include also e.g. Nakariakov et al. 1999; Verwichte et al., 2004, 2009]
20-year progress from now: prospective research

Solar Dynamics Observatory (SDO)

AIA on board SDO provides rich pickings for studying coronal waves!

Full-sun 0.6 arcsec resolution images every 10 seconds in multiple bandpasses.

### AIA wavelength bands

<table>
<thead>
<tr>
<th>Channel</th>
<th>( \Delta \lambda \updownarrow )</th>
<th>Ion(s)</th>
<th>Region of Atmosphere*</th>
<th>Char. log(( I ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible</td>
<td>-</td>
<td>Continuum</td>
<td>Photosphere</td>
<td>3.7</td>
</tr>
<tr>
<td>1700Å</td>
<td>-</td>
<td>Continuum</td>
<td>Temperature minimum, photosphere</td>
<td>3.7</td>
</tr>
<tr>
<td>304Å</td>
<td>12.7</td>
<td>He II</td>
<td>Chromosphere, transition region,</td>
<td>4.7</td>
</tr>
<tr>
<td>1600Å</td>
<td>-</td>
<td>C IV+cont.</td>
<td>Transition region + upper photosphere</td>
<td>5.0</td>
</tr>
<tr>
<td>171Å</td>
<td>4.7</td>
<td>Fe IX</td>
<td>Quiet corona, upper transition region</td>
<td>5.8</td>
</tr>
<tr>
<td>193Å</td>
<td>6.0</td>
<td>Fe XII, XXIV</td>
<td>Corona and hot flare plasma</td>
<td>6.1, 7.3</td>
</tr>
<tr>
<td>211Å</td>
<td>7.0</td>
<td>Fe XIV</td>
<td>Active-region corona</td>
<td>6.3</td>
</tr>
<tr>
<td>335Å</td>
<td>16.5</td>
<td>Fe XVI</td>
<td>Active-region corona</td>
<td>6.4</td>
</tr>
<tr>
<td>94Å</td>
<td>0.9</td>
<td>Fe XVIII</td>
<td>Flaring regions</td>
<td>6.8</td>
</tr>
<tr>
<td>131Å</td>
<td>4.4</td>
<td>Fe VIII, XX+</td>
<td>TR + Flaring regions</td>
<td>5.7, 7.0, 7.2</td>
</tr>
</tbody>
</table>

*Absorption allows imaging of chromospheric material within the corona;
**FWHM, in Å
20-year progress from now: prospective research

Solar Dynamics Observatory (SDO) (2010 +10 years?)

Solar Orbiter (2017 +10 years?)

Adding Spectral Imaging of the Coronal Environment (SPICE) and in-situ connections.
Idea of a Super SDO:

- combining SDO imager capabilities: temporal, spatial resolutions (and AIA wavelength - possible trade-off with reduced number), including a Doppler magnetograph (like HMI)
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- *with LOS information*: time-resolved spatial coverage of Doppler shifts (SPICE/Solar Orbiter);
- and larger FOV.

The same idea but on the disk, where the relevant coronal structures to monitor are located.
Requirements for future systems

Super SDO

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Could be incorporated with others, e.g.

- 2-spacecraft HiRISE coronagraph (Damé) → a minimum constellation that could *carry/share traditional in-situ instruments* (solar wind analyzer, magnetometer and energetic particle detector); also at Mars L1 point useful for FAME (Coates).

- Super Earth SDO (Earth L1 point for Moon missions).

- Super Mars SDO (Mars L1 point)

or Super Sentinel SDO (far-side)
Challenges

2030 international context: a human mission to Mars (or nearby asteroids and moons) may be a reality, with the Moon as a likely intermediate step.

20-year progress from now: in space weather applications of solar dynamics and oscillations.

New Strategies for Space Exploration

Multi-viewpoint system: STEREO/Sentinel concept and/or Mars L1 point.

Super SDO package:
Enhanced SDO imaging capabilities: larger FOV with time-resolved spatial LOS information.

Potential links: with other projects, e.g. HiRISE, FAME.