Understanding solar eruptions: an observational perspective on space weather

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Lockheed Martin Advanced Technology Center

Solar-C; 2013/11/11; Takayama, Japan
Space weather user objectives:

• For space assets (energetic-particle impacts on S/C and astronauts) and for radio communications (including navigation and timing):
  • forecast with at least 24-h lead time when an eruption of specified magnitude will go off, and what the associated energetic particles populations and shocks will be that propagate earthward.

• For long ground-based conductors, including electric power grids:
  • forecast with at least 24-h lead time what the magnetic properties are of the field erupting into the heliosphere towards Earth-Sun L1 [because L1 is far too close].
In solar-physics terms:

- Objectives: 24h ahead of time,
- forecast the timing and magnitude of flares and eruptive events,
- specify the field geometry of the erupting rope and of the overlying field, and
- predict pathways and population properties of energetic particles.

- Needs: understanding of the injection, storage, and release of energy into active-region coronae, and their surrounding fields.
- Data: active-region details [Solar-C] and global-Sun field [e.g., SDO, STEREO, SoHO, to drive coronal-heliospheric model].
2010/08/01

Saturday, November 9, 2013
Destabilizing B

Energy buildup/storage
Energy conversion/release

Field configuration reaches non-equilibrium state

How much?
When?
In what form?
Destabilizing B

Need to understand:
* energy released in flares (down to QS microflaring of $10^{24}$ ergs): O(0.5x total atmospheric losses).
* energy released in flares from C1 upward: 1% of total radiated energy.
* Why so little for larger events?
* Power laws link small and large. Are all events “similar” and thus to be understood together?

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Need to understand:
energy partitioning over
* spectral irradiance,
* bulk kinetic (CME),
* energetic particles (reconnection & shock)
and geometry of the erupting and overlying field and their interactions
Destabilizing B

Flux/rope emergence
Modified shear
Modified 'external' field

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Saturday, November 9, 2013
Destabilizing B

Dynamo: flux emergence

 Flux/rope emergence

 Flux transport: random walk, large-scale flows

 Modified shear

 Eruption elsewhere: “sympathy”

 Modified ‘external’ field

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Tether cutting

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X-ray flare, eruption

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torus/kink instability

plasma properties: set rise speed, spatial limit → SEP, CME

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SEP, CME

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| “Strong” field | X-ray flare, eruption | **?** |

SEP, CME

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Destabilizing B

- Flux/rope emergence
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Field configuration reaches non-equilibrium state
Destabilizing B

Continuous, high-res. observing
Photosphere/chromosphere  Chromosphere/corona  Large f.o.v. X/EUV context

Flux/rope emergence  Modified shear  Modified ‘external’ field

Field configuration reaches non-equilibrium state

Assimilation-driven model field
Destabilizing B

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Photosphere/chromosphere
Chromosphere/corona

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Need lots of telemetry from Solar-C with context observations by SDO/STEREO supported by assimilative models (NLFFF, magnetofrictional, MHD)
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Needs: matching resolutions on ARs; coordinated multi-instrument observing within Solar-C and with other observatories; LARGE TELEMETRY VOLUME!; investement in multiple field-modeling [NLFFF\textarrow{\rightarrow}MHD] advances.
Potential field  Traced loops  Best-fit QGR-NLFFF


<table>
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<tr>
<th>Time</th>
<th>$E_P$ ($\times 10^{22}$ erg)</th>
<th>$E_F$ ($\times 10^{22}$ erg)</th>
<th>$E_{tot}$ ($\times 10^{32}$ erg)</th>
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<tbody>
<tr>
<td>14:23:40</td>
<td>4.97</td>
<td>0.45</td>
<td>5.43</td>
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<tr>
<td>15:00:00</td>
<td>4.90</td>
<td>0.72</td>
<td>5.62</td>
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<tr>
<td>15:01:20</td>
<td>4.86</td>
<td>0.58</td>
<td>5.44</td>
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<tr>
<td>15:01:30</td>
<td>4.86</td>
<td>1.55</td>
<td>6.41</td>
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<tr>
<td>15:01:40</td>
<td>4.94</td>
<td>1.07</td>
<td>6.01</td>
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<tr>
<td>15:02:25</td>
<td>4.98</td>
<td>0.14</td>
<td>5.11</td>
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<td>15:02:45</td>
<td>4.97</td>
<td>0.25</td>
<td>5.23</td>
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<td>15:03:06</td>
<td>5.02</td>
<td>0.34</td>
<td>5.35</td>
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<td>15:04:00</td>
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<td>0.42</td>
<td>5.53</td>
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<tr>
<td>15:04:19</td>
<td>5.18</td>
<td>0.28</td>
<td>5.45</td>
</tr>
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GOES 15 X-Rays:

- $\alpha > 0$
- $\alpha < 0$
Potential field


Traced loops

Best-fit QGR-NLFFF

\[ \alpha > 0 \]

\[ \alpha < 0 \]
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Forecasting space weather

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