Heliospheric Physics: Linking solar variations to the space environment at Earth

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Coronal Mass Ejections

Solar Energetic Particles

CME Plasma

Two fundamentally different interactions
Interactions provide coupling between chains.
CME signatures:

- Counter-streaming particles, electrons, ions
- Magnetic field rotations, low plasma-\(\beta\), small \(|\delta B|/B\)
- Dynamic signatures, shocks, expansion
- He/H enhancements, unusual charge states
New plasma composition tools from ACE

- Compositional information on solar wind plasma - probe solar origin solar wind of individual ejecta

- Most useful:
  - $\langle Q \rangle$ Fe very capable “sufficient CME identifier”. Measures coronal temperatures to 3 MK.
  - O7+/O6+ distinguishes plasma from solar sources of different temperatures, CME identifier
Fe and O charge states

- O7+/O6+ freezes in close to the Sun. In many cases, even before the temperature max.
- \(<Q> Fe freezes in later. Clear signal for “unusually heated plasma”.

### Three Observed Halo CMEs on SOHO

<table>
<thead>
<tr>
<th>CME of interest</th>
<th>Speed</th>
<th>Loc.</th>
<th>Flare</th>
<th>Flare UT</th>
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<tbody>
<tr>
<td>2002/04/15 04:06:06</td>
<td>714</td>
<td>S15W01</td>
<td>SF/M1.2</td>
<td>03:07</td>
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<tr>
<td>2002/04/17 08:26:05</td>
<td>1263</td>
<td>S14W34</td>
<td>2N/M2.6</td>
<td>07:46</td>
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<tr>
<td>2002/04/21 01:27:20</td>
<td>2495</td>
<td>S14W84</td>
<td>1F/X1.5</td>
<td>00:43</td>
</tr>
</tbody>
</table>

Difference Images

- **04/15 05:18 UT**
- **04/17 10:38 UT**
- **04/21 02:18 UT**
Plasma Data

- 3 CMEs, each driving a shock
  - CME1: large B, low T
  - CME2: consisting of several ejecta, large B, low T in part of ejecta
  - CME3: no simple signatures
V from SWEPAM And SWICS

\[ B_z [\text{gam}] \text{, southward} \]

\[ \text{IMF is marked in red} \]

\[ n \text{ [/cc]} \]

\[ T [\text{K}] \]

\[ |B| [\text{gam}] \]
Shocks:

Preliminary list from ACE plasma team:

- four forward shocks
- one potential reverse shock
Composition signatures

Compositional CME id (prelim)

Slow SW
Fast SW

Bi-directional Electrons (prelim)

Velocity

O7+/O6+

<Q> Fe

time [day of April 02]
Magnetospheric Drivers

- He/H exceeds 25% twice – He makes a significant contribution to ram pressure
- Pressure for protons, and including He.
- Bz negative is shown in red. Note: Bz negative and pressure peaks coincide.
Bz negative leads to Reconnection at Magnetopause
Magnetic Cloud (CME)

Top View

Side View

Cross-section

Ecliptic Plane

North

South

Solar Wind

Sun

Earth
CME1: Magnetic cloud

- Classic magnetic cloud signatures are evident
- There is compressed interplanetary field in front of the cloud
- CME – solar wind interactions are crucial.
• Possible magnetic clouds
Solar Particle Measurements

- Time History - Correlation with CMEs and shocks
- Acceleration near the Sun and in interplanetary Space
- Compositional Signatures
- Energy spectra and implications
Two Classes of Solar Particle Events

CME-Associated (Gradual Event)

Interplanetary Magnetic Field (IMF)

Sun

Shock

CME

Particle Flux

Earth

Proton-Rich
Long-Lived (Days)
60-180 Degrees Solar Longitude

Impulsive Flare-Associated (Impulsive Event)

Interplanetary Magnetic Field (IMF)

Sun

Particle Flux

Earth

Electron-Rich
Short-Lived (Hours)
30-45 Degrees Solar Longitude

Fe/O ~ 0.1

$^{3}\text{He}/^{4}\text{He} < 0.01$

Q(Fe) ~ 14

Fe/O ~ 1

$^{3}\text{He}/^{4}\text{He} \sim 0.1 - 1$

Q(Fe) ~ 20
Evidence for Multiple Episodes of Acceleration
Arrival Time Implies Particles Accelerated Very Close to the Sun

Onset at L1: 0140 UT
Travel time: >25 min (80 MeV)
Particles left Sun before 0123 UT, as seen from Earth
Flare occurred at 0043
CME first observed at 0127
⇒ Particles accelerated very close to the Sun
All Elements Share a Common Spectral Shape
Evidence for Two Components Accelerated at Different Times and Locations

All species show evidence of Two spectral components

The time history indicates the high-energy component was accelerated near the Sun, and the low-energy component in interplanetary space
Composition of SEPs

- The similarity of the composition of the 4/21 event with coronal abundances indicates a "gradual" SEP event rather than an "impulsive" event.
How does the size of the April 21 SEP event compare to others?
Summary

- Plasma signatures identify all 3 CMEs and reveal significant effects of their interactions
- Enriched He accounts for up to 50% of solar-wind pressure in the most geo-effective intervals
- Evidence for several separate shocks is found
- Several instances of local shock acceleration
- The last two CMEs produce “gradual” SEP events - one in the “top ten” of solar cycle 23
- SEP spectra show a knee at ~20 MeV/nuc, thereby reducing SEP effects on the deep atmosphere
We acknowledge the entire ACE team.
The following members of the ACE team provided data analysis for this presentation: Glenn Mason, Ruth Skoug, and Chuck Smith.
Mark Looper contributed PET data from SAMPEX.