POLARIMETRIC AND GEOMETRIC LOCALIZATION:
SPACE WEATHER TOOLS TO CALCULATE CME VELOCITY IN 3D SPACE

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The STEREO Space Weather Beacon provides highly compressed and binned image data in near-real-time. This data provides a sufficient signal-to-noise ratio for space weather forecasting.

**Beacon**: $256 \times 256$

2008-12-12 1422 UT

**Science**: $2048 \times 2048$
The COR2 instrument provides early warning of an approaching CME. Its field-of-view is sufficiently large that we can observe the temporal development of a CME, even for very fast CMEs.

Heliocentric radius (AU)  0.9597  0.9941  1.003
Heliographic (HEEQ) longitude  66.285  0.000  -71.660
Heliographic (HEEQ) latitude  -1.985  -7.182  -2.923
Separation angle with Earth  66.226  71.447
Separation angle A with B  137.668
Geometric and Polarimetric Localization
Example taken from CME observed on 2010 March 14 at 0708 UT; manually selected CME and leading-edge boundaries are superimposed on COR2 beacon image.
Geometric Localization [Pizzo and Biesecker, 2004]
The locator algorithm should quickly determine CME location and velocity and run in nearly automated mode; therefore, it must be simple, robust, and easy to use.
Geometric Localization
The program automatically chooses a plane that contains the spacecraft and cuts through the two images of the CME.
Geometric Localization
By applying geometric localization to a stack of planes, we can delineate the region of 3D space wherein the CME is contained.
Polarimetric Localization

CME polarization is measured using three polarizers. The measured polarization fraction within a CME can be related to the source location relative to the plane of the sky [Moran and Davila, 2004].
Polarimetric Localization
This technique yields only the distance from the plane of the sky, $|X|$. In other words, for a fixed elongation angle, an object in front of or behind the plane of the sky can have the same $P_{frac}$.
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\[
\begin{align*}
\text{HCl lon}=97.7 & \quad \text{HCl lat}=90.0 \\
2010-03-14 07:08:35 & \\
\downarrow \uparrow
\end{align*}
\]
Polarimetric Localization

Note that polarimetric localization biases the CME location toward the spacecraft plane of sky.
Polarimetric Localization

Using polarization data from two spacecraft will remove the ahead-of/behind plane-of-sky ambiguity.
Localization Results
Location of CME within 3D space on 2010 March 14 at 0708 UT.

- **WEST**: HCl lon=187.7, HCl lat=0.0
- **EARTH**: HCl lon=97.7, HCl lat=−7.2
- **TOP**: HCl lon=97.7, HCl lat=90.0
Velocity summary for CME of 2010 March 14.

<table>
<thead>
<tr>
<th>Speed (km·s⁻¹)</th>
<th>Latitude (° N)</th>
<th>Longitude (° W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cent (PL-A)</td>
<td>153 ± 9</td>
<td>21 ± 2</td>
</tr>
<tr>
<td>cent (PL-B)</td>
<td>149 ± 7</td>
<td>22 ± 3</td>
</tr>
<tr>
<td>cent (GL)</td>
<td>195 ± 42</td>
<td>21 ± 8</td>
</tr>
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<td>----------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>cent (PL-A)</td>
<td>278 ± 57</td>
<td>−8 ± 5</td>
</tr>
<tr>
<td>cent (PL-B)</td>
<td>232 ± 30</td>
<td>4 ± 10</td>
</tr>
<tr>
<td>LE (GL)</td>
<td>247 ± 39</td>
<td>5 ± 3</td>
</tr>
</tbody>
</table>
Velocity Summary
Centroid speed for 12 CMEs.
Velocity Summary
Leading-edge speed for 12 CMEs.
Velocity Summary
Direction of propagation (longitude) for 12 CMEs.

![Graph showing longitude distribution for 12 CMEs with data points for years 2007 to 2009, months 5 to 11, days 23 to 31, and spacecraft delta values from 9 to 127.](image)
Velocity Summary
Direction of propagation (latitude) for 12 CMEs.
CONCLUSIONS

Both localization techniques are . . .
► straightforward to apply,
► usable in near-real time—A temporal sequence of COR2 beacon images for a single CME can be analyzed in less than 10 minutes.

The random error in the computed CME velocity . . .
► does not appear to depend on spacecraft separation;
► is frequently less than 10%.

From such analyses we can readily compute the centroid, leading-edge, and expansion velocities for the CME.
CONCLUSIONS

Geometric localization . . .

► requires two spacecraft;
► is totally geometric in nature, that is, it makes zero assumptions about CME shape.
CONCLUSIONS

Polarimetric localization...

- requires only one spacecraft;
- requires well-known equations of Billings [1966];
- is biased to the plane of sky.
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Both localization techniques promise a substantial improvement in our capability to locate and characterize CMEs for forecasting.
FINAL THOUGHTS

Geometric and polarimetric localization will shortly be undergoing a limited amount of verification and validation. By October 2011 they will be “tools” within NOAA/SWPC. In that context, these techniques will provide . . .

- initial forecasts of CME velocity;
- supplemental inputs, alongside a standard cone model based on SOHO data, to WSA/Enlil.
Space weather forecasting takes place in real time! Therefore . . .

- forecasting techniques must work with real-time data. Real-time data . . .
  - is heavily compressed and binned;
  - frequently has significant gaps in coverage.
- science data and after-the-fact beacon data may be useful for slow CMEs; however, for worst-case CMEs, such data will not be available until after the CME has impacted Earth.
- forecasting techniques must be simple. Forecasters do not have the time to do several trial and error runs in order to find the best ellipse to a fuzzy halo observed by SOHO.
We were warned ... Oops, data gap