STEREO Science Highlights

Beacon2Science: Enhancing STEREO/HI Beacon Data With Machine Learning for Efficient CME Tracking

J. Le Louëdec, M. Bauer, T. Amerstorfer, J. A. Davies, Space Weather, 23, e2025SW004440 (2025)

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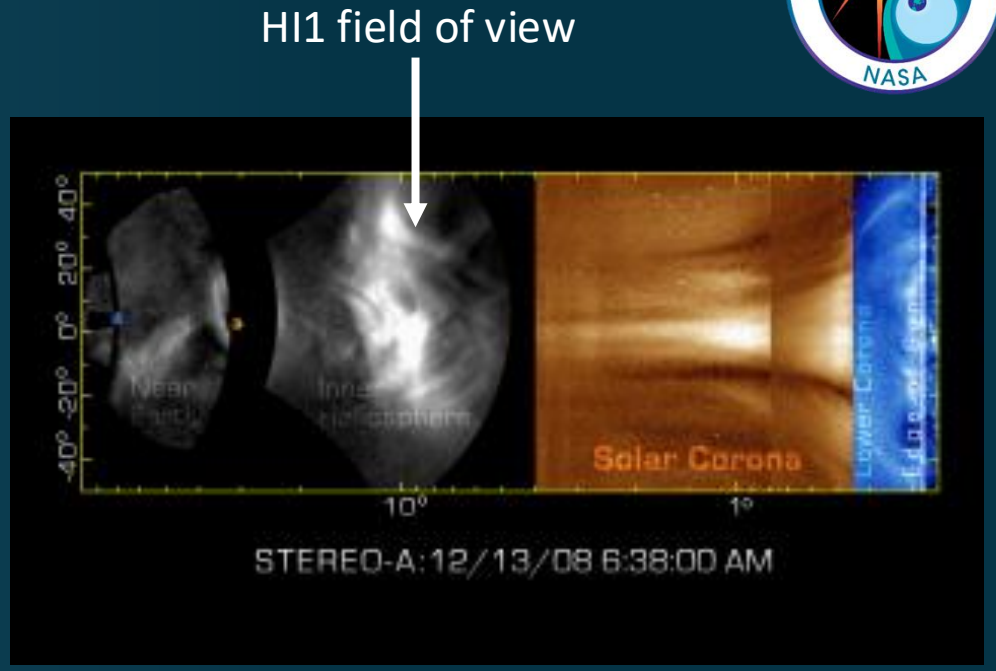
Background

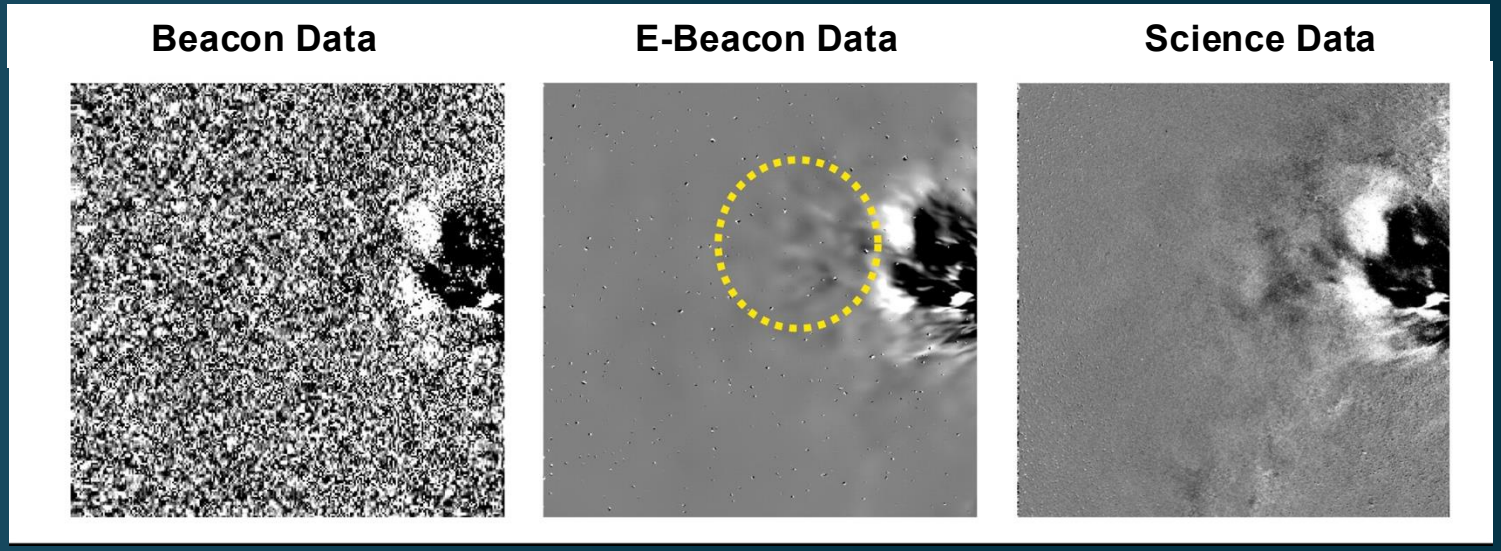
- Observing and forecasting coronal mass ejections (CMEs) in real-time is crucial due to the strong geomagnetic storms they can generate that can have a potentially damaging effect, for example, on satellites and electrical power systems.
- The *Solar TErrestrial RElations Observatory* (STEREO) mission has two data streams. The Beacon data is highly compressed but reaches the ground quickly and is intended for use in space weather prediction. The Science data is much higher quality, but is not available for 3-4 days due to telemetry limitations.
- *STEREO* Heliospheric Imagers (HI) observe the region of space between the Sun and Earth's orbit.
- With their near-real-time availability, *STEREO-A*/HI beacon data are perfect candidates for early forecasting of CMEs.
- However, previous work concluded that CME arrival prediction based on beacon data could not achieve the same accuracy as with high-resolution science data due to data gaps and lower quality.



Above: CME headed from Sun (right) to Earth (left) showing data from all 5 *STEREO-A*/SECCHI telescopes. Arrow shows the HI1 field of view, which contains the CME. Credit: NASA/GSFC/SwRI/STEREO

Analysis

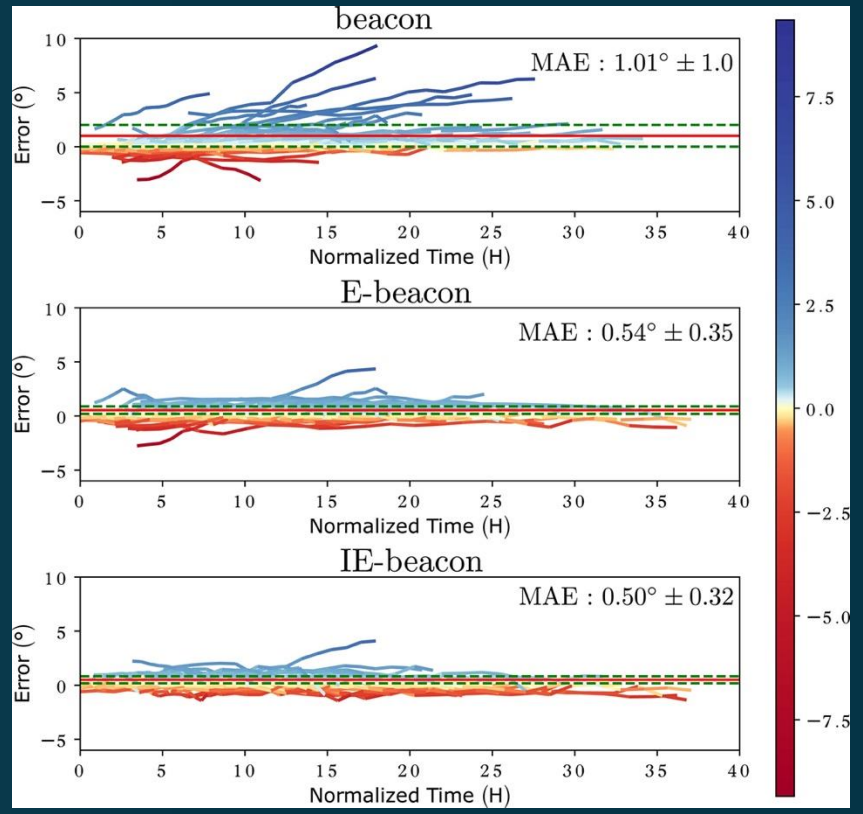
- This study uses novel machine-learning techniques to increase the spatial and temporal resolution, reduce the noise, and create intermediate images for smoother visualization.
- HELCATS WP2 HICAT catalog with 1,236 CME events was used for the training data set for a neural net; 48 CMEs were used to evaluate the results.
- The team developed methods for enhancing *STEREO-A*//HI1 data quality producing two new data sets
  - E-beacon data to improve signal to noise as compared to regular beacon data.
  - IE-Beacon data to produce data in time gaps between the low cadence beacon images.



Right: Comparison between beacon, E-beacon and science running difference images. The circled feature is not visible in the HI beacon data but is revealed in the enhanced E-beacon data. The Sun is out of the frame to the right, and the CME is moving leftwards into the solar system. *Credit:* Le Louëdec et al 2025

Findings

- The new E-beacon data greatly improves the signal-to-noise ratio over beacon data, showing that it is possible to recover meaningful information from beacon data and improve the visibility of CMEs in near-real-time despite the low bandwidth rate of the beacon mode.
- IE-beacon data consists of extra higher cadence running differences images that facilitate the tracking of features within the images due to smoother and smaller movement.
- Both E-beacon and IE-beacon bring significant improvement in tracking, with tracks closer to science data results, smoother tracks, and fewer large deviations far from the Sun due to low visibility and cadence.
- Large scale (multi-hour) data gaps in the beacon data (due to a lack of antenna coverage) are not, however, correctable and remain a challenge.



Above: Errors in tracking of CMEs using HI beacon data compared to version of the machine learning enhanced data E-Beacon and EI-Beacon data. The new data sets result in significantly lower errors. *Credit:* Le Louëdec et al 2025

Impacts

- This research is important for real-time predictions of CME arrival at Earth and other planets needed for accurate space weather predictions.
- The techniques are also important because they can be applied to data sets from the recently launched *PUNCH* (*Polarimeter to UNify the Corona and Heliosphere*) mission and the future *Vigil* space weather monitoring mission.
- Improved ability to predict CME arrival times and impacts can help us plan for and ameliorate space weather effects on spacecraft, power systems, communications, and astronauts.

Additional Info

- Publication information:

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