Near Real-time Coronal Mass Ejection Alerts for Early Warning Forecasting of Solar Energetic Particle (SEP) Events

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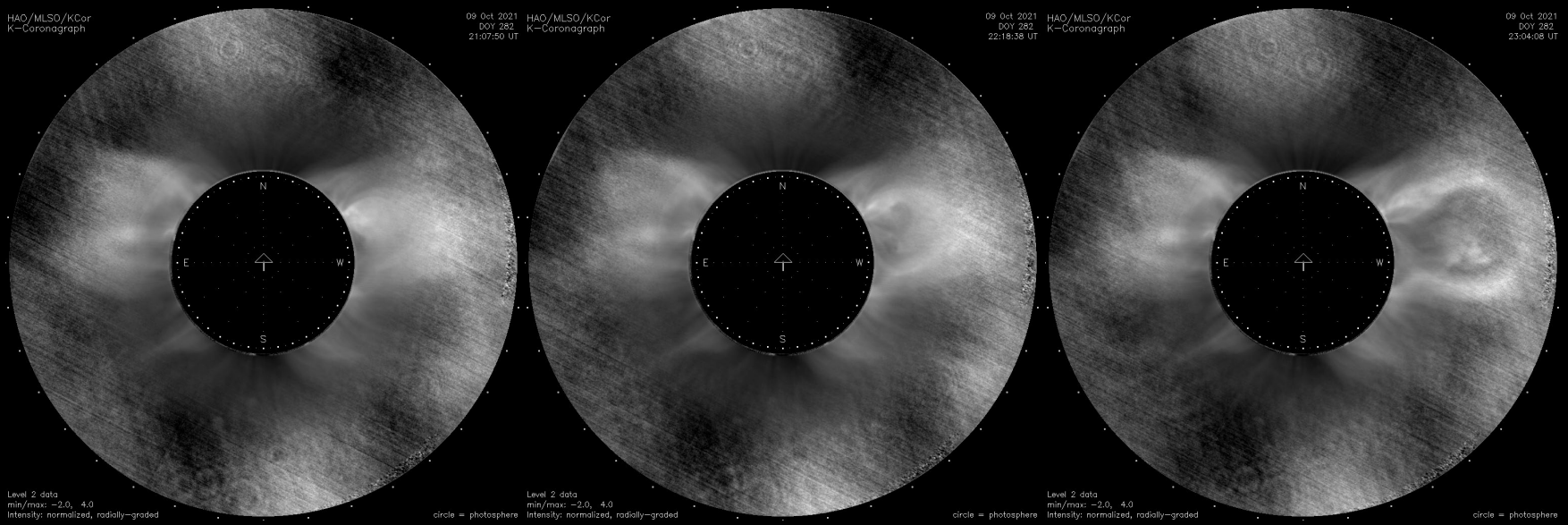
COSMO K-Coronagraph

- Observes low and middle corona 1.05 to 3 $R_\odot$
- High cadence — 15 seconds
- Low data latency — 2.5 minutes to get fully calibrated data with CME detection code
- 🚫 Duty cycle affected by night, weather, volcanic eruptions
- Human (observer) alerts
- Automated CME detection alerts

9 October 2021 CME seen in Mauna Loa Solar Observatory (MLSO) K-Coronagraph (K-Cor) images



Motivation for a Near-real-time CME Detection System

- St.Cyr et al. (2017) studied the Jan 1, 2016 SEP-associated CME and found that its speed could be determined in MLSO K-Cor images a full 19 minutes before the CME was visible in the LASCO field-of-view.
- They asked: “Why has no one attempted to use a coronagraph as an early warning device for SEP events?”
- What is needed: low corona observations, high cadence, low data latency, good duty cycle

St. Cyr et al., 2017, 10.1002/2016SW001545

K-Cor CME detection system

- Bill Thompson adapted a version of the Solar Eruptive Event Detection System (SEEDS) software for use with K-Cor level-2 polarization brightness images.
  - Remap data and create running differences
  - Identify *regions of interest* (ROIs)
  - Track persistence of ROI and look for a leading edge of the CME
  - Test for upward motion to verify the presence of a CME
- Caveats:
  - Code is designed to detect a CME in formation stage for early warning, not to track or characterize CMEs.
  - Code identifies the CME core for many CMEs. In low corona the CME front is still forming and may not be easily detected. The brighter feature is often the CME core.

Thompson et al. 2017, 10.1002/2017SW001694

K-Cor CME detection system

- Always running, fully automated code run in coordination with realtime pipeline and observer alerts at MLSO with the instrument.
- JSON alerts for NASA Community Coordinated Modeling Center (CCMC)
  - Detection
  - Potential cancellation by observer interaction
  - Interim reports with position and velocity plots
  - Summary report
- CME-alert email list: mlso_data_requests@ucar.edu

False alarms

- Human-generated alerts have fewer false alarms: 12.2% vs 22.6% for automated detection code
- Vast majority of false alarms due to rising loops and/or prominences that stall or fade below 2 solar radii
- Some due to noise from sky conditions or instrument

Goal: Decrease the number of false alarms. Working to reduce instrument noise.

Improving CME detection

- Work to upgrade the CME detection code
  - Adding capability to report CME accelerations and start times
  - Reorganizing how tracking data are stored to allow more flexibility in tracking multiple features and avoid missing multiple concurrent CMEs
  - Creating a CME database
  - Improve detection: vary thresholds used to find ROIs; vary time difference between subtractions; vary averaging
- Reduce noise in K-Cor images
  - Make use of noise reduction algorithms
- Need to further reduce K-Cor instrument noise
  - New tapered occulters and new objective lens with a better finish will be installed
  - Work with HAO engineers to improve optical alignments and light dump near occulter

CME alerts for SEP-associated CMEs seen in K-Cor

- Ian Richardson has an updated list of Solar Energetic Particle Events that include ~25 MeV protons observed at STEREO from the HET instruments and at SOHO from the ERNE and COSTEP instruments.
- 31 SEP-producing CMEs since Dec 2013 occurred when K-Cor was observing:
  - 20 of these events were detected by the automated code (run in simulation mode for events before 2020).
  - 2 additional events were detected by the MLSO observers. Records since 2016 indicate that MLSO observers detected all but one of the SEP-producing CMEs.
  - 7 were very faint CMEs and missed detection in near-real-time.
  - 2 were too faint to be seen in K-Cor.

CME alerts for SEP-associated CMEs seen in K-Cor

Date	Time of K-Cor alert	Time of LASCO first CME image	Time between LASCO and KCor CME alert †	Time between LASCO and alert
2013-12-09	19:36:47	19:36:05	> 0 min 52 sec	< 39 min 8 sec
2013-12-16	20:49:09	21:39:14	< 50 min 5 sec	< 90 min 5 sec
2014-02-11	19:00:30	19:24:05	< 23 min 26 sec	< 63 min 26 sec
2014-09-24	21:04:20	21:30:06	< 25 min 46 sec	< 65 min 46 sec
2014-10-14	18:50:24	18:48:06	> 2 min 18 sec	< 37 min 42 sec
2015-02-08	22:30:10	22:36:06	< 5 min 54 sec	< 45 min 54 sec
2015-03-05	22:11:19	22:24:05	< 12 min 46 sec	< 57 min 46 sec
2016-01-01	23:11:55	23:24:04	< 12 min 9 sec	< 52 min 9 sec
2017-04-18	19:31:23	19:48:05	< 16 min 42 sec	< 56 min 42 sec
2021-05-07	19:07:06	19:24:05	< 16 min 59 sec	< 56 min 59 sec
2021-07-09	17:37:43	17:48:05	< 8 min 22 sec	< 48 min 22 sec
2021-07-15	21:31:18	21:36:05	< 4 min 22 sec	< 44 min 22 sec
2021-11-01	01:25:14	02:00:06	< 34 min 52 sec	< 74 min 52 sec
2022-01-31	23:48:21	00:12:05	< 23 min 44 sec	< 63 min 44 sec
2022-02-02	00:22:15	01:25:48	< 63 min 33 sec	< 103 min 33 sec
2022-03-10	19:35:59	18:48:05	> 37 min 54 sec	< 2 min 6 sec
2022-03-31	18:45:57	19:12:05	< 26 min 8 sec	< 66 min 8 sec
2022-05-11	18:35:33	18:36:05	< 0 min 32 sec	< 40 min 32 sec
2022-06-13	03:03:37	03:12:11	< 8 min 34 sec	< 48 min 34 sec
2022-10-02	20:38:27	20:36:05	> 2 min 22 sec	< 37 min 38 sec

- Average time between CME alert and LASCO 1st image of the CME:
  - 14 min 49 sec BEFORE APPEARS IN LASCO
  - 54 min 49 sec BEFORE LASCO including 40 min LASCO latency
- K-Cor CME alerts provide first warning for most of the SEP-producing CMEs occurring during K-Cor observations (9 were not detected)

† red indicates LASCO time was before KCor time

Future observations

K-Cor alerts will continue to be useful and the K-Cor 1.05 – 3 $R_\odot$ FOV fills in most of the observing gap in CCOR data.

- ngGONG (NSO/NCAR partnership) includes network of ground-based coronagraphs. A network of 5 coronagraphs would provide good coverage for forecasting CMEs.
- Low data latency space-based mission with orbit that has minimal solar eclipses would also provide the high duty cycle needed for forecasting. See St. Cyr et al. 2017.
- Upcoming CCOR coronagraph will have lower data latency than LASCO, but CCOR has a higher inner field-of-view (3.6 $R_\odot$ vs. 2.1 $R_\odot$ for LASCO). CMEs need to travel farther to be seen in CCOR. This additional time significantly reduces the advantage of the lower CCOR latency.

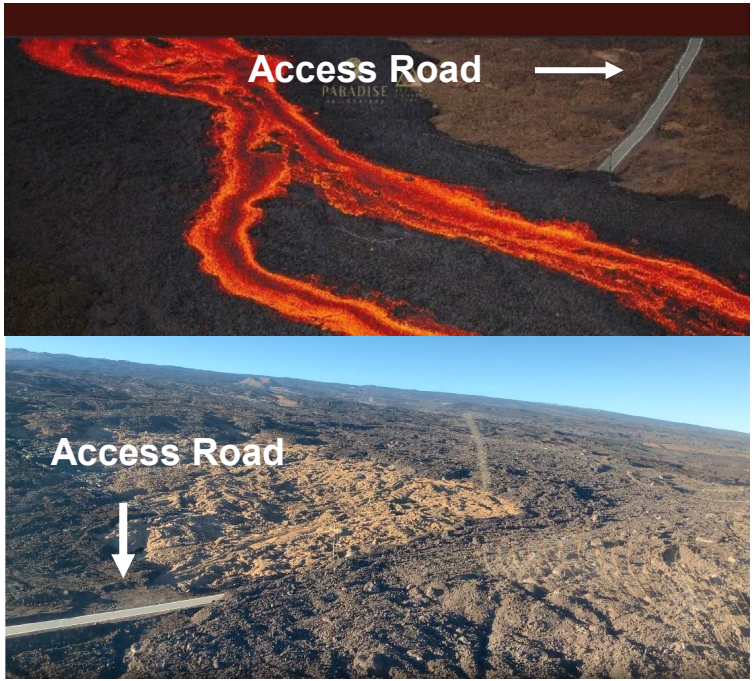
We're hiring!

- Interested in working with data like KCor? The Mauna Loa Solar Observatory group in Boulder is hiring a Data Scientist to work on data analysis and calibration algorithms development.
  - Work with the MLSO team to develop science data products from new instrumentation.
  - Help develop higher-level MLSO data products and community software tools for all MLSO instruments.
  - Improve existing calibration algorithms and verify the quality of the final science data.
  - Design software noise filtering algorithms to enhance signal and reduce noise in MLSO data.
  - Develop visualization tools for combining MLSO data with other ground-based and NASA data products and with model output for community use.
  - Create software to automatically detect solar activity, such as solar flares, in MLSO data. Modify existing coronal mass ejection (CME) detection software to work with a variety of MLSO images and use tools like machine learning to improve CME detection.

Thanks!

- Michael Galloy— mgalloy@ucar.edu
- mlso_data_requests@ucar.edu
- MLSO website — https://www2.hao.ucar.edu/mlso

MLSO vs volcano



Timeline

- Last observations before volcano cut road on 25 Nov 2022
- Volcano erupts on 28 Nov 2022 and cuts access road
- Observations 30 Mar 2024 and 9 April 2024 in support of eclipse and Parker Solar Probe
- Approval and funding for road repair underway, hopeful reopening in early 2025