



The CCOR Coronagraph Series for Space Weather Forecast



Focus on CCOR-2 On Board SWFO-L1 (SOLAR-1)



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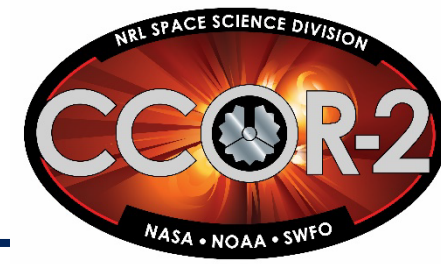
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Overview



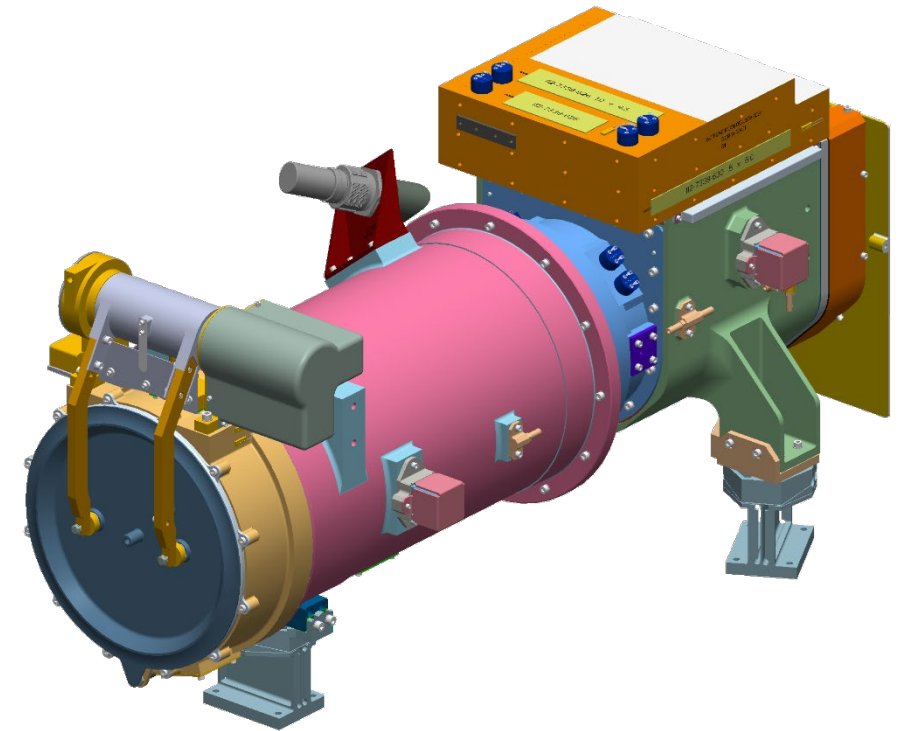
- **CCOR-2 vs CCOR-1**
- **Space Weather and science products**
- **Movies**
- **Post Launch Commissioning**

The CCORs in a Nutshell



- CCOR is a series of space borne solar coronagraphs that are used by NOAA's Space Weather Prediction Center (SWPC) to monitor the Sun's corona activity, detect CMEs, and predict the Space Weather at Earth.
- Two CCORs were built, and a third one is in the making.
- CCOR-1: GOES-U; Launched: Jun 25, 2024
 - In service since Apr 2025
- CCOR-2: SWFO-L1; Launch: this Tuesday Sep 23, 2025
 - Will be in service in Apr 2026
- CCOR-3: ESA's Vigil, at L5; launch expected in 2031
 - Service start expected in 2032
- **The data are (or will be) publicly available through NOAA's SWPC and NCEI websites.**
 - **Additional products also available at ccor.nrl.navy.mil**

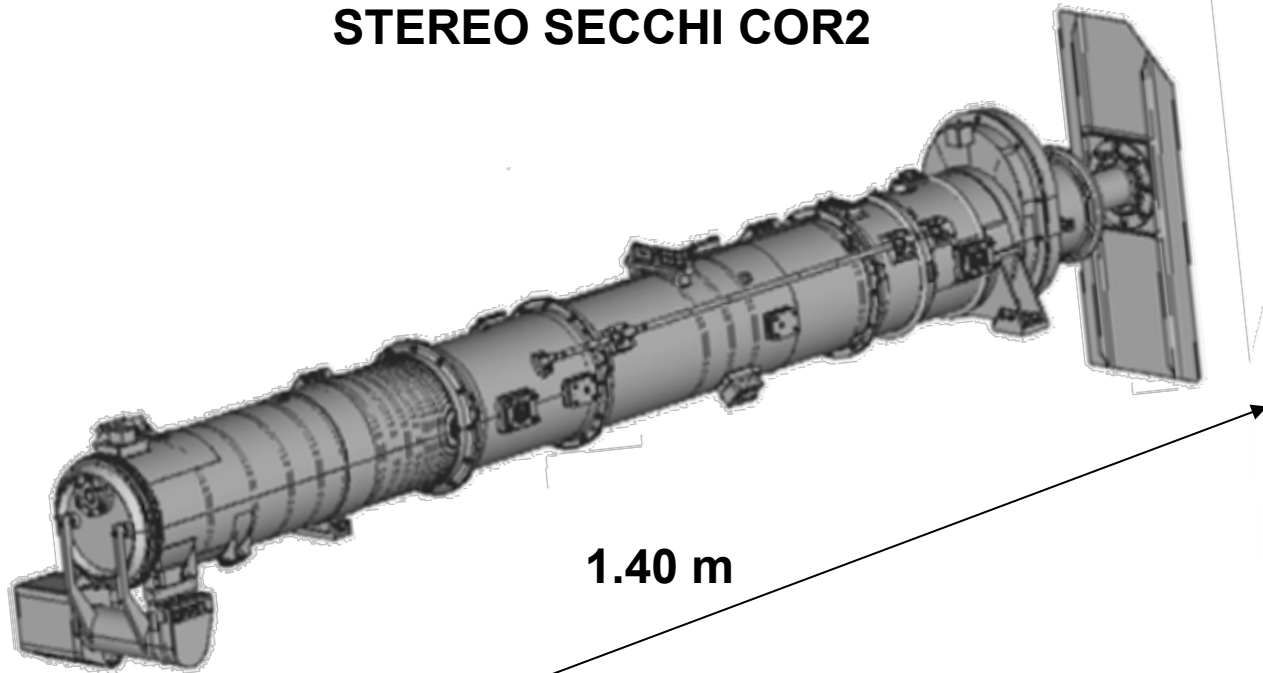
CCOR-2 (SWFO-L1)



Lyot vs Compact Design

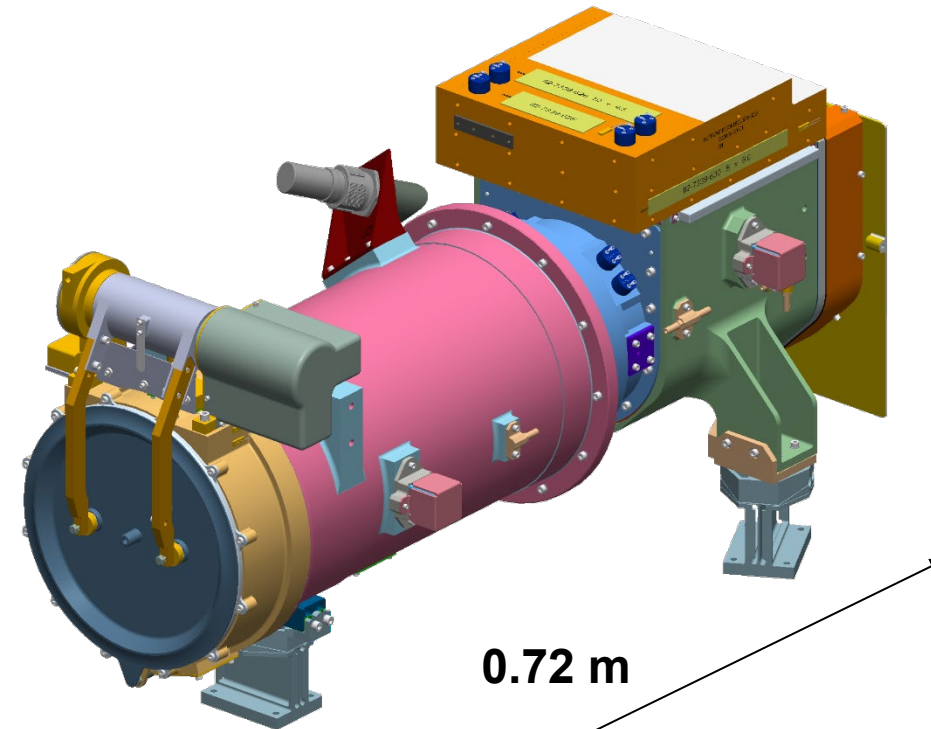


STEREO SECCHI COR2



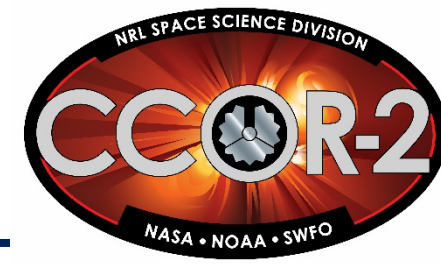
1.40 m

CCOR-2 (SWFO-L1)

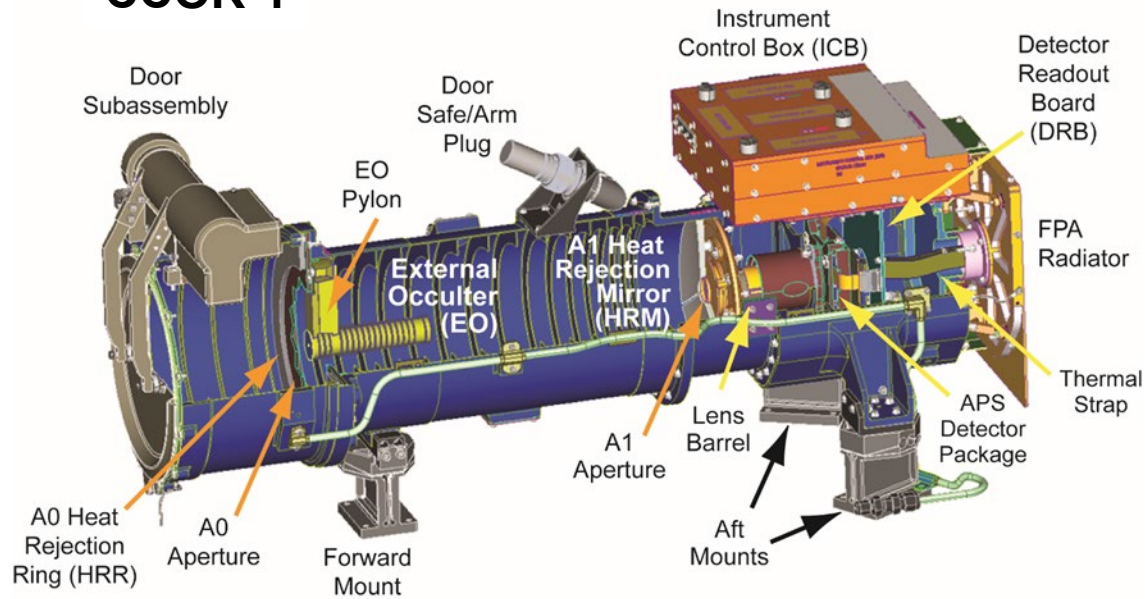


0.72 m

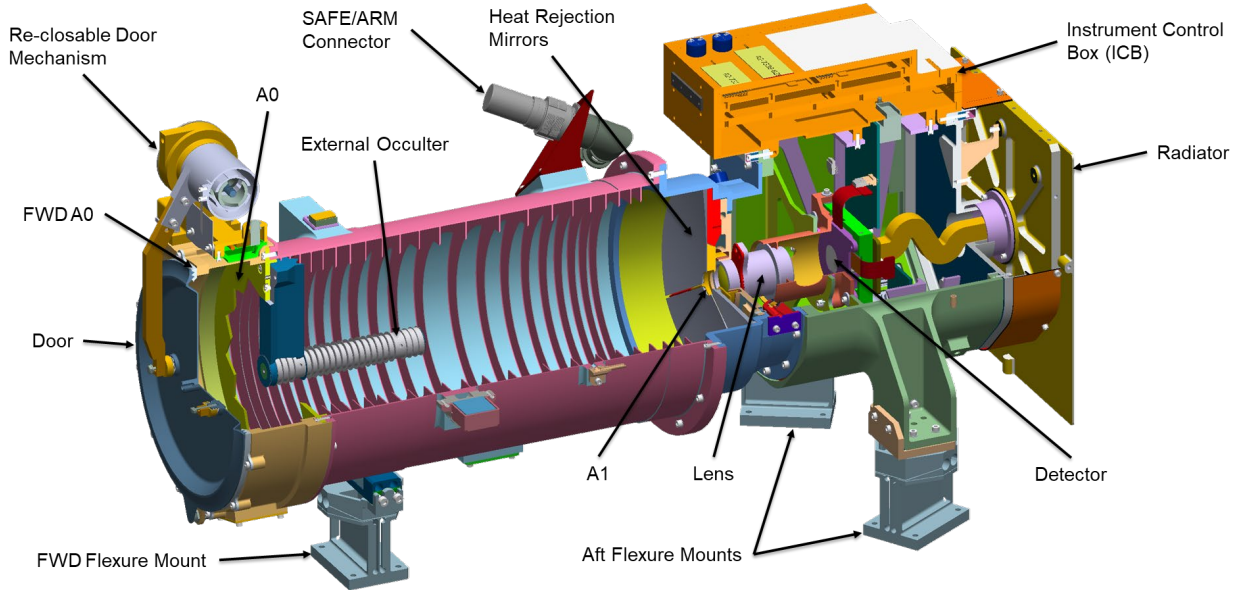
CCOR-1 vs CCOR-2



CCOR-1



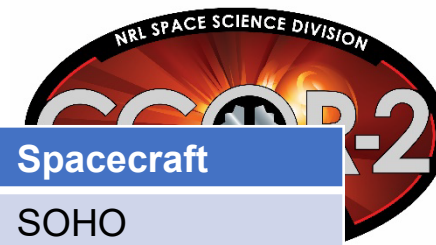
CCOR-2



CCOR-1 versus CCOR-2 (and CCOR-3)

- Field-of-view (FOV): CCOR-2's larger FOV will provide more images of the fastest CME's ensuring they are well observed and enabling more accurate modeling
- Spatial Resolution: CCOR-2's larger FOV comes at the expense of spatial resolution: 50 arcsec for CCOR-1, 70 for CCOR-2
- GEO versus L1 orbit: **CCOR-1 experiences eclipses** that result in images with increased stray-light on 42% of the days of the year. **CCOR-2 will NOT experience eclipses as it will be at L1.**
- CCOR-3 has the same optical design as CCOR-2. It will be at L5, providing a side view of the Sun-Earth line.

Present and Future Coronagraph Assets



Past/Present
Future

Instrument	FOV [Rsun]	Orbit	Cadence [min]	Launch	Sponsor	Spacecraft
LASCO C2 C3	2 – 30	L1	12	1995	NASA-ESA	SOHO
SECCHI COR-1	1.3 – 4	1AU, off the Sun Earth line	15	2006	NASA	STEREO
SECCHI COR-2	2 – 15			2006	NASA	STEREO
Metis	1.7 – 3	0.28 to 0.91AU		2020	ESA	Solar Orbiter
LST SCI	1.1 – 2.5	Sun-synch (720km)		2022	China	ASO-S (Kuaifu-1)
VELC	1.05 – 3	L1		2023	ISRO (India)	Aditya
CCOR-1	4.0 – 22	Earth, geosynch.	15	Jun 2024	NOAA	GOES-U
CODEX	3 – 10	LEO (ISS)		2024	NASA	ISS
ASPIICS	1.08 – 3	LEO		2024	ESA	Proba-3
PUNCH NFI	6 – 32	LEO	8	Apr 2025	NASA	PUNCH
CCOR-2	3.3 – 26	L1	15	Jun 2025	NOAA	SWFO-L1
CCOR-3	3.3 – 26	L5	15	2031	NOAA	VIGIL (ESA)

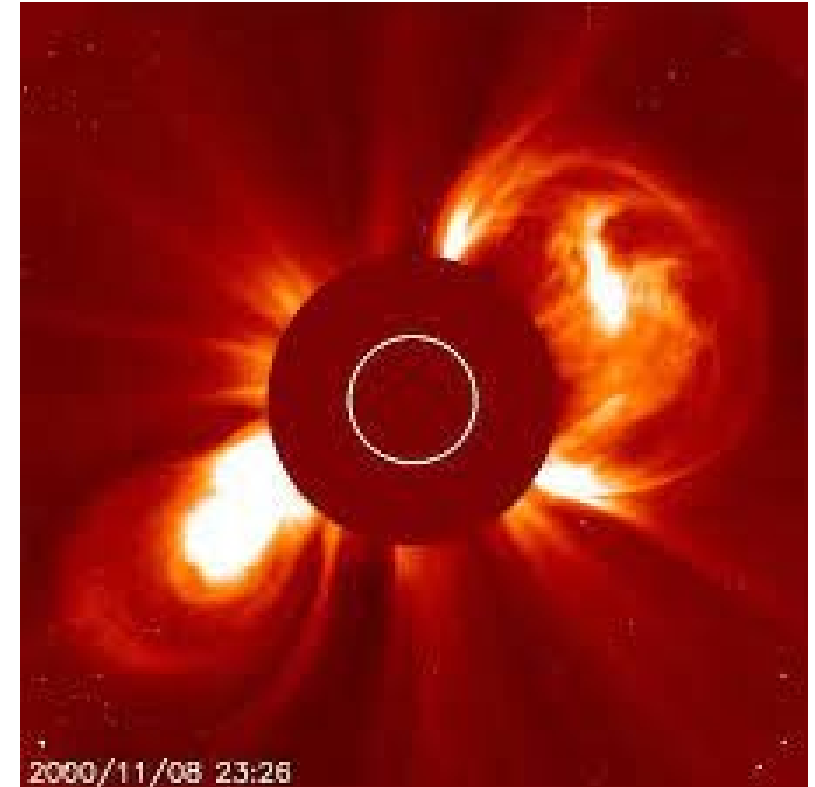
Same as WISPR →

Req't Title	CCOR-1	CCOR-2 and CCOR-3
Radial Scene Coverage	4.0 to 22 R_{sun} (actual)	3.3 to 26 R_{sun} (actual)
Image Spatial Resolution, Unbinned	≤ 54 arcsec with $> 10\%$ MTF	≤ 70 arcsec with $> 10\%$ MTF
Detector	2048 x 1920 pixels APS	2048 x 1920 pixels APS
Image Cadence, Nominal Operations	15 min	15 min
Instrument Bandpass	450 to 750 nm	450 to 750 nm

Coronal Mass Ejections (CMEs)



- **CMEs are optically thin large-scale solar phenomena that are traditionally observed by white-light coronagraphs as enhanced intensity structures. The intensity increase is due to photospheric light that is Thomson scattered off the electrons forming the CME body and integrated over the line-of-sight (Hundhausen, 1993).**
- **Due to strong projection effects, CMEs morphology greatly depends on the viewpoint. This makes CMEs a rather tricky object to measure (Burkepile et al., 2004; Cremades and Bothmer, 2004).**

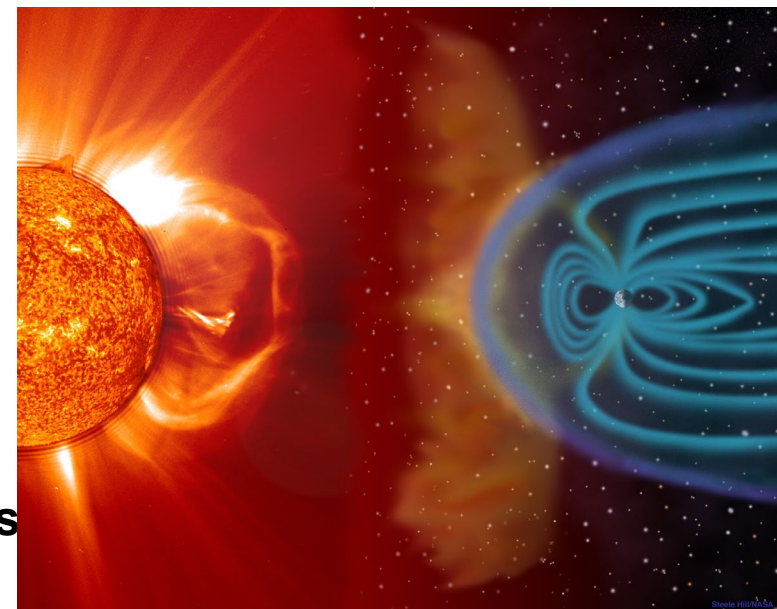


The eruption of two CMEs on Nov. 8, 2000 recorded from NASA's LASCOR coronagraph

Objectives of CME Forecasting



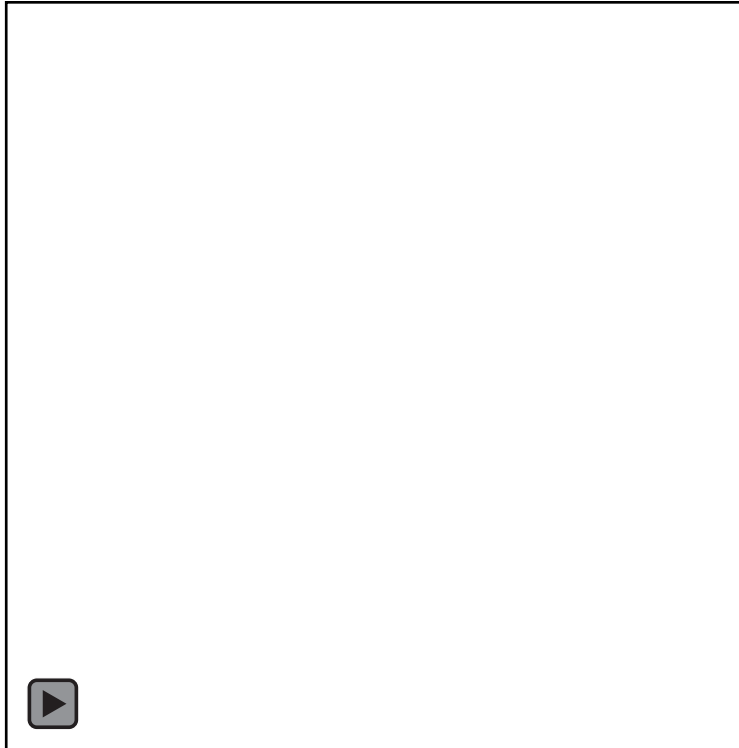
- Objectives of space weather forecasting of coronal mass ejections (CMEs)
 - Determining whether the coronal mass ejections (CMEs) are Earth-bound
 - Determining the CME internal magnetic field configuration, the time of arrival (ToA), and the velocity on arrival (VoA).
 - Magnetic field configuration is currently not achievable by remote sensing measurements
 - ToA and VoA currently are derived from coronagraphic and heliospheric observations of propagating plasma transients Sun-Earth Line (SEL)
 - The off the Sun-Earth Line (off-SEL) from the Solar Terrestrial Relations Observatory (STEREO) mission demonstrated improvement of ToA from >12 h to $+6$ h from pre-STEREO (Millward et al., 2013; Colaninno et al., 2013). VoA accuracy is still relatively low.



Solar Observations – Coronal Mass Ejections (CMEs)

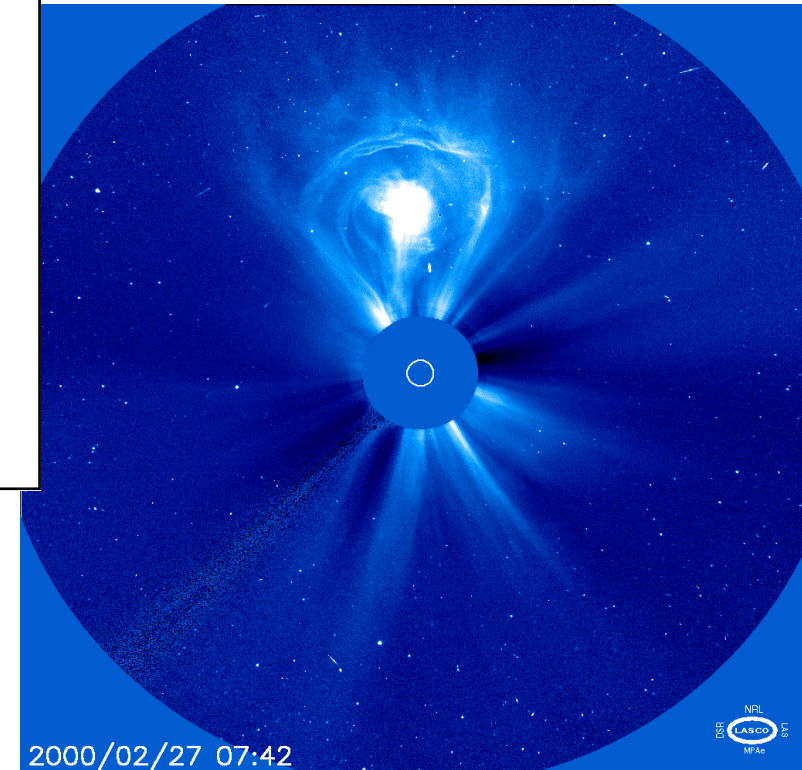


- These are transient plasma structures moving outward through the solar corona
- Plasma and magnetic field
- Speed $\sim 300\text{-}3400$ km/s
- Mass $\sim 10^{11}\text{-}10^{16}$ grams
- The excess mass is visible due to Thomson scattering of photospheric light off free electrons in the CME volume
- Halo events show a ring of excess brightness and move either directly towards or directly away from the Earth
- Limb events are all other events. They generally miss the Earth and thus do not cause any space weather activity in its vicinity.

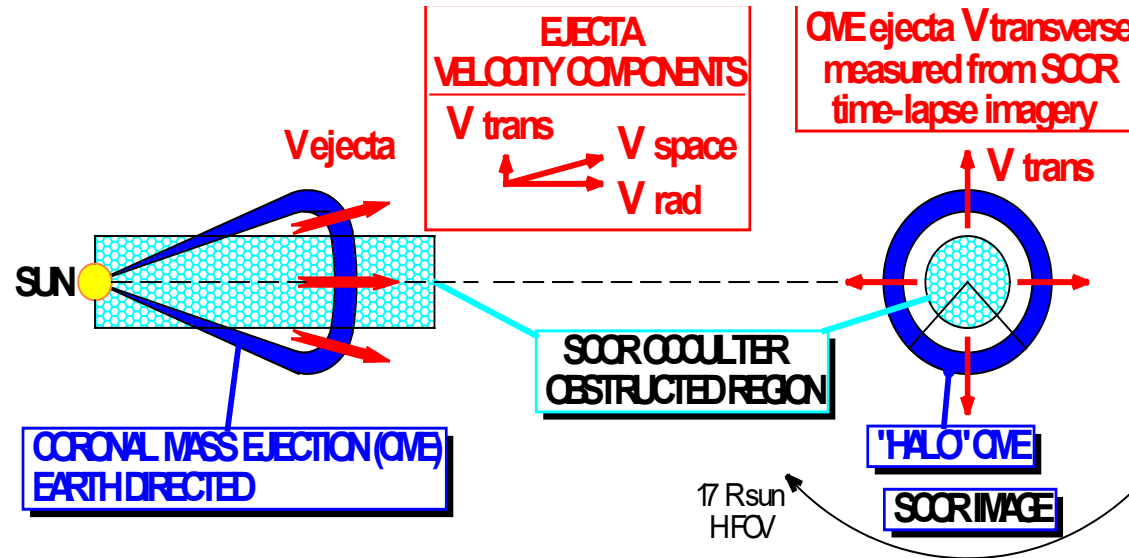
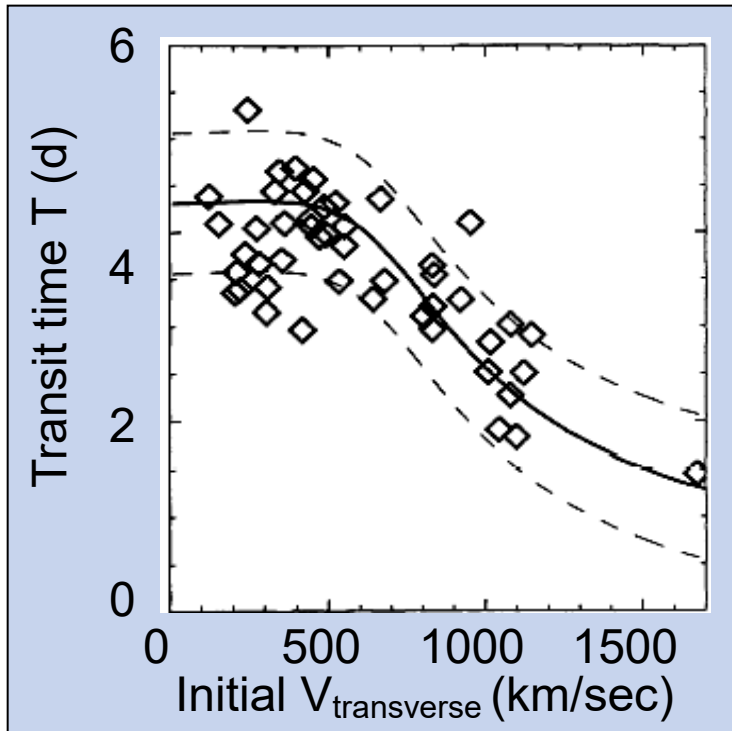
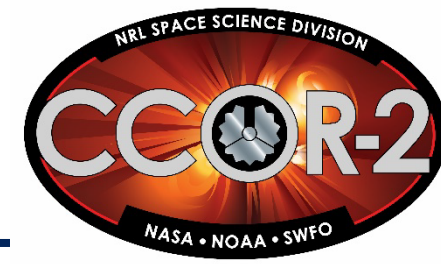


A classic limb CME

The halo CMEs of May 2024

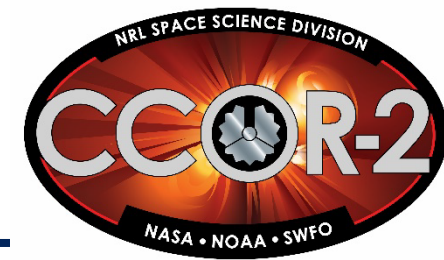


Halo CME Transit Time Prediction

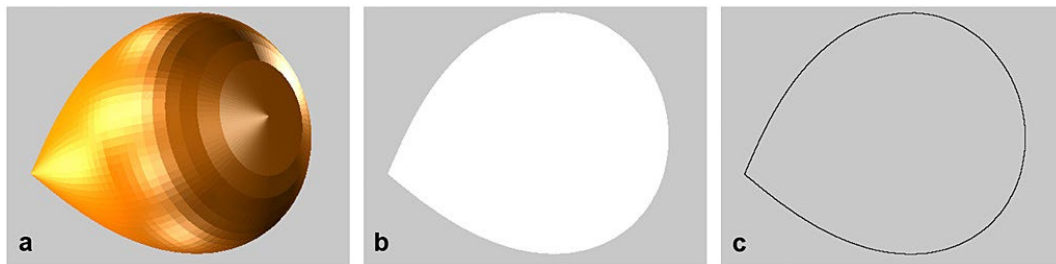


Average error in transit time of fast CMEs: $T = \pm 10.7$ hr (Gopalswamy et al 2001)

CME Analysis Tool

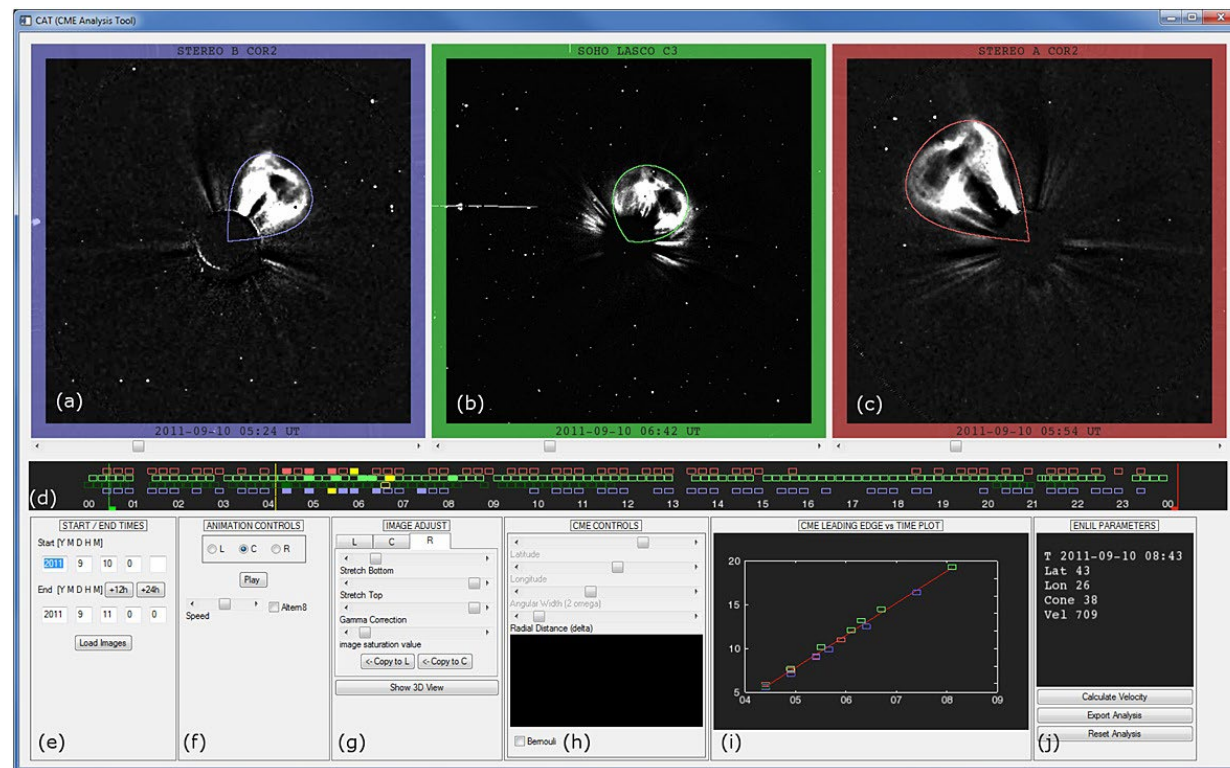


“CAT: An operational software tool for the analysis of coronagraph images: Determining CME parameters for input into the WSA-Enlil heliospheric model”, Millward et al., Space Weather, Vol. 11, 57–68, 2013



3-D lemniscate

10 September 2011 CME event. The left column shows matches to STEREO-B COR2 for times of 04:24, 05:39, and 07:24 UT down the column, respectively. The center column shows matches to LASCO C2 for a time of 04:24 UT and then LASCO C3 for times of 05:30 and 06:18 UT. The right column shows matches to STEREO-A for times of 04:54, 05:24, and 05:54 UT.



From the CAT Tool to the Heliospheric Model



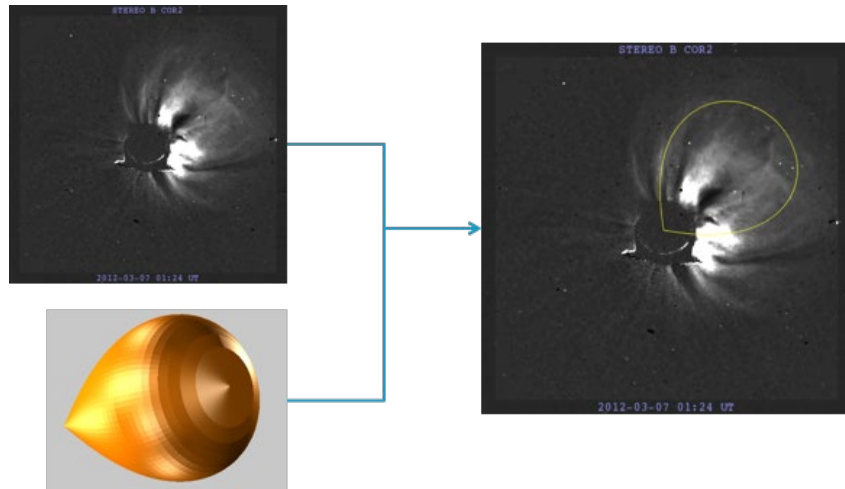
WSA-ENLIL Model

First numerical space weather model at SWPC

- Predicts arrival of CMEs at Earth
 - Including coronagraph data reduced error in arrival time from ± 12 hrs to ± 7 hrs

Requires coronagraph-type data as input

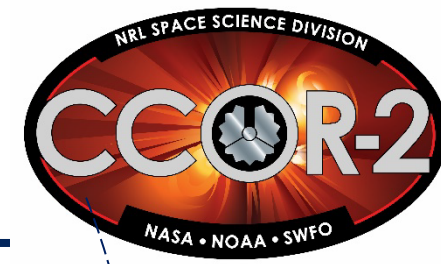
- This enables Geomagnetic Storm Watch product



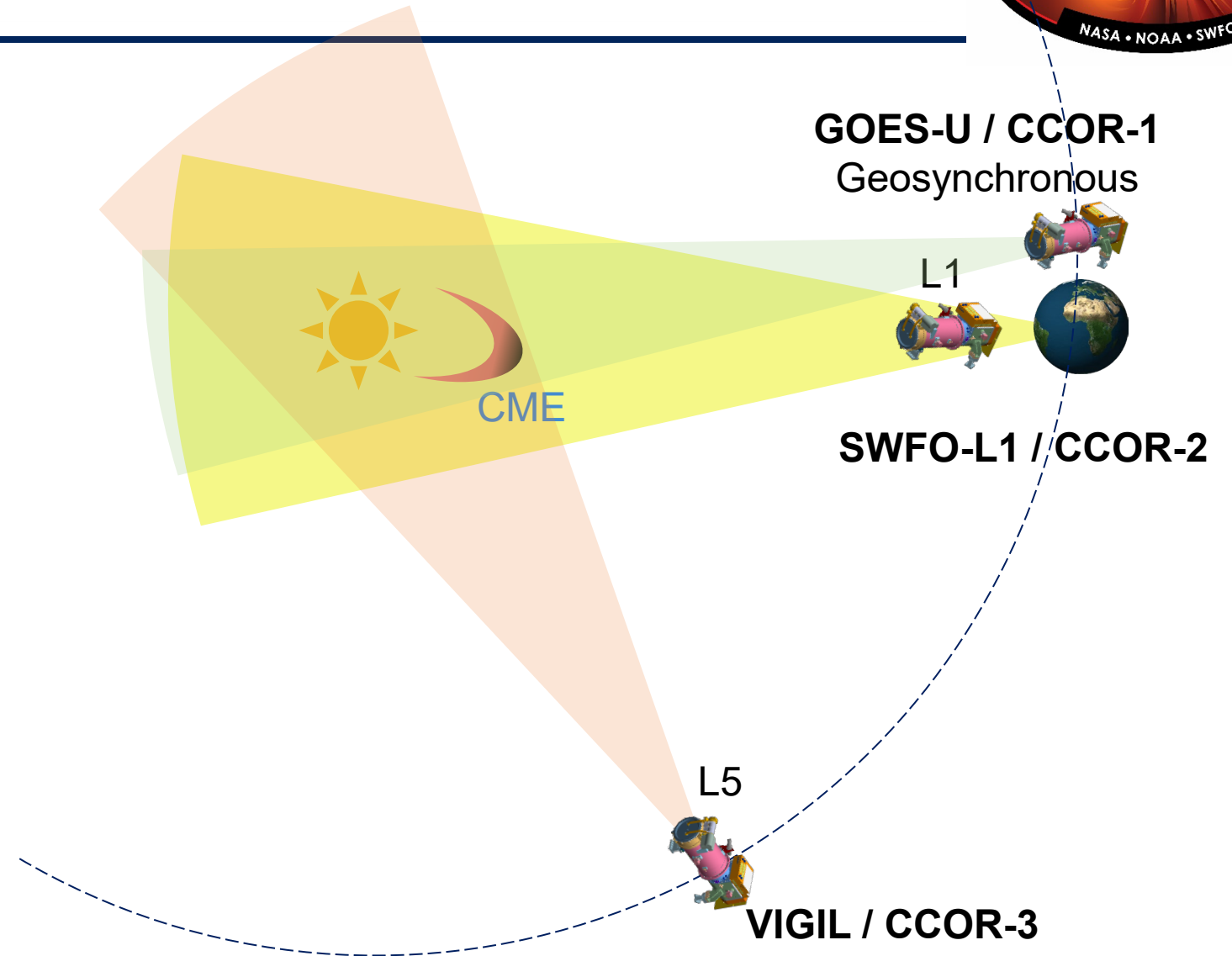
3-D lemniscate



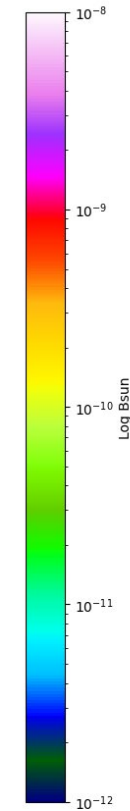
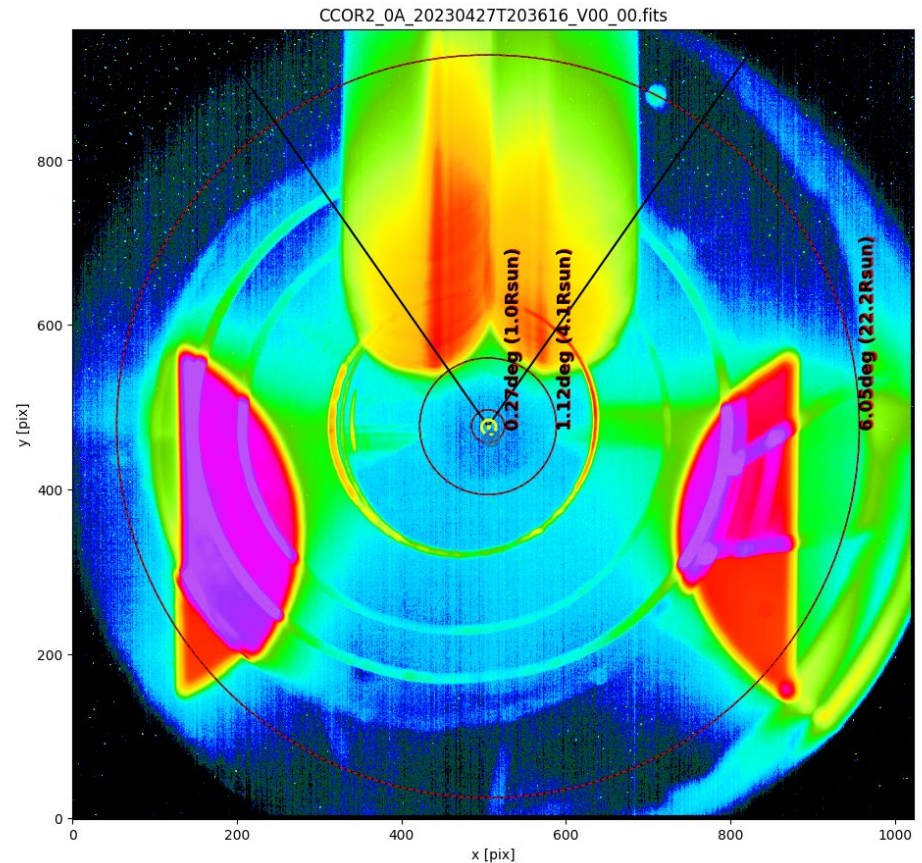
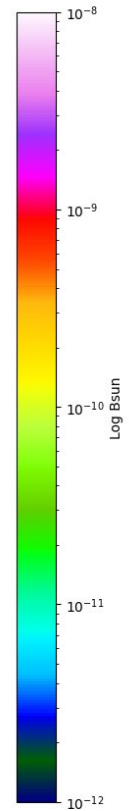
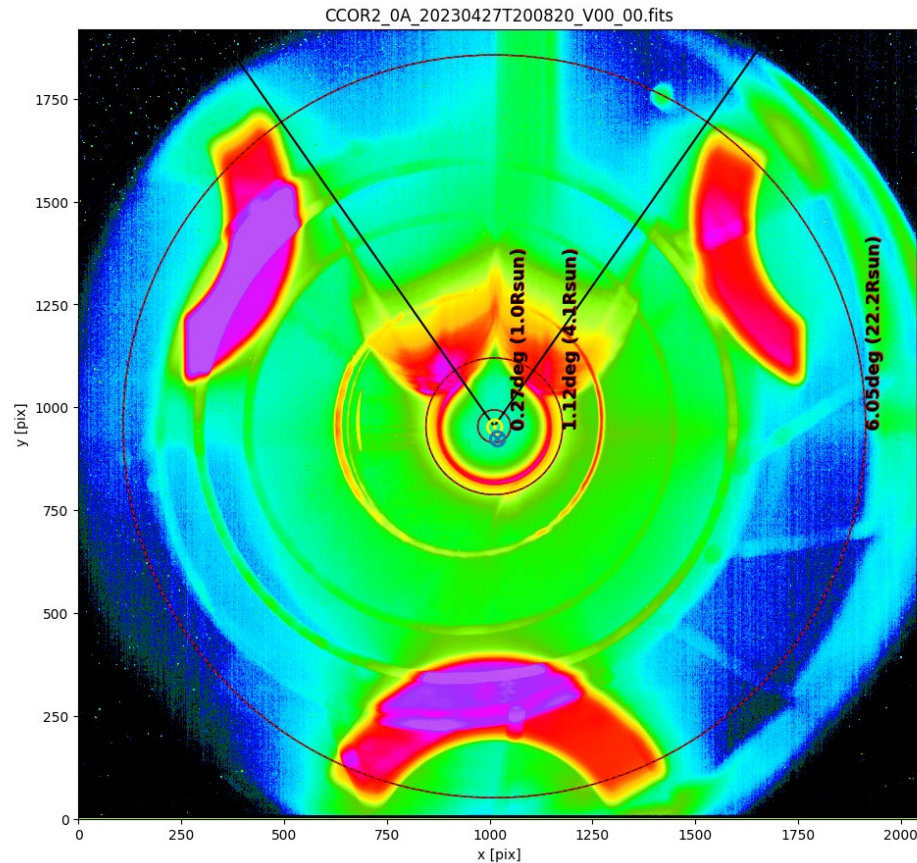
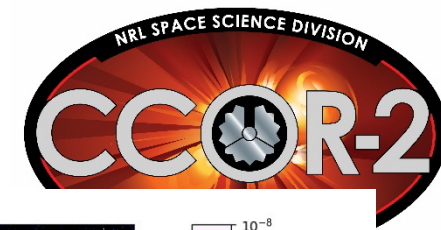
Side View Provided by CCOR-3



- STEREO SECCHI clearly demonstrated the advantage of looking at the corona from multiple view points.
- The ability to triangulate the direction and speed of CMEs will improve the prediction of the possible impact at Earth.

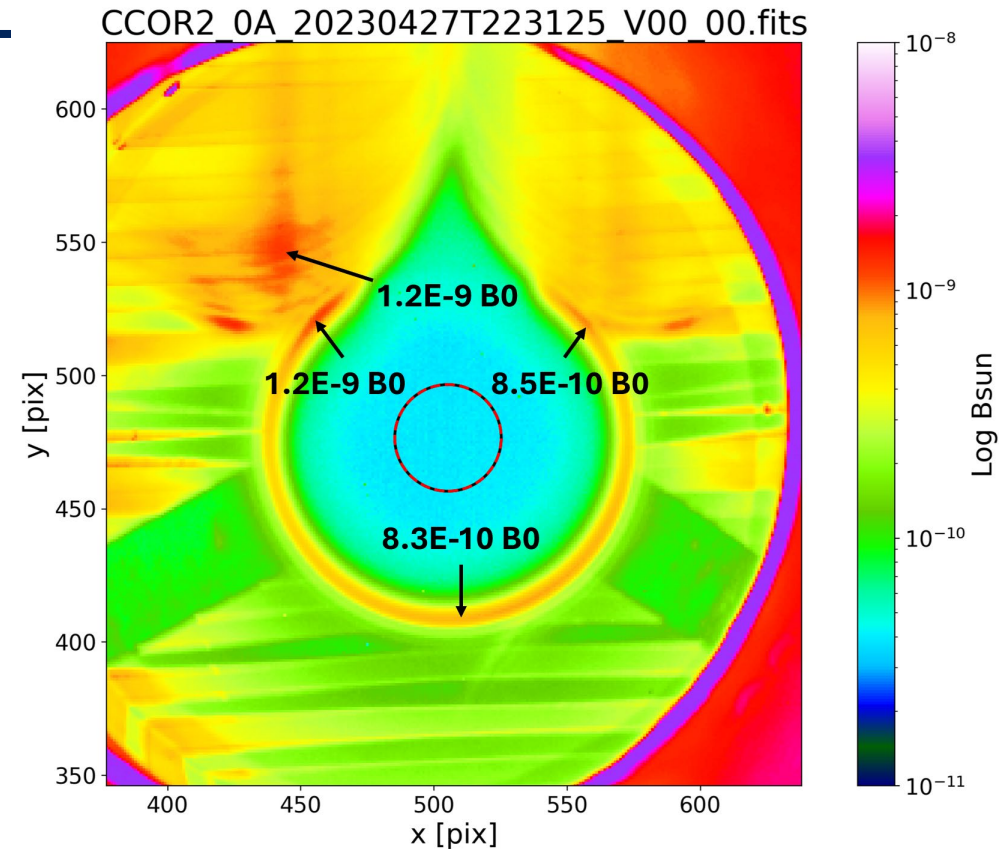
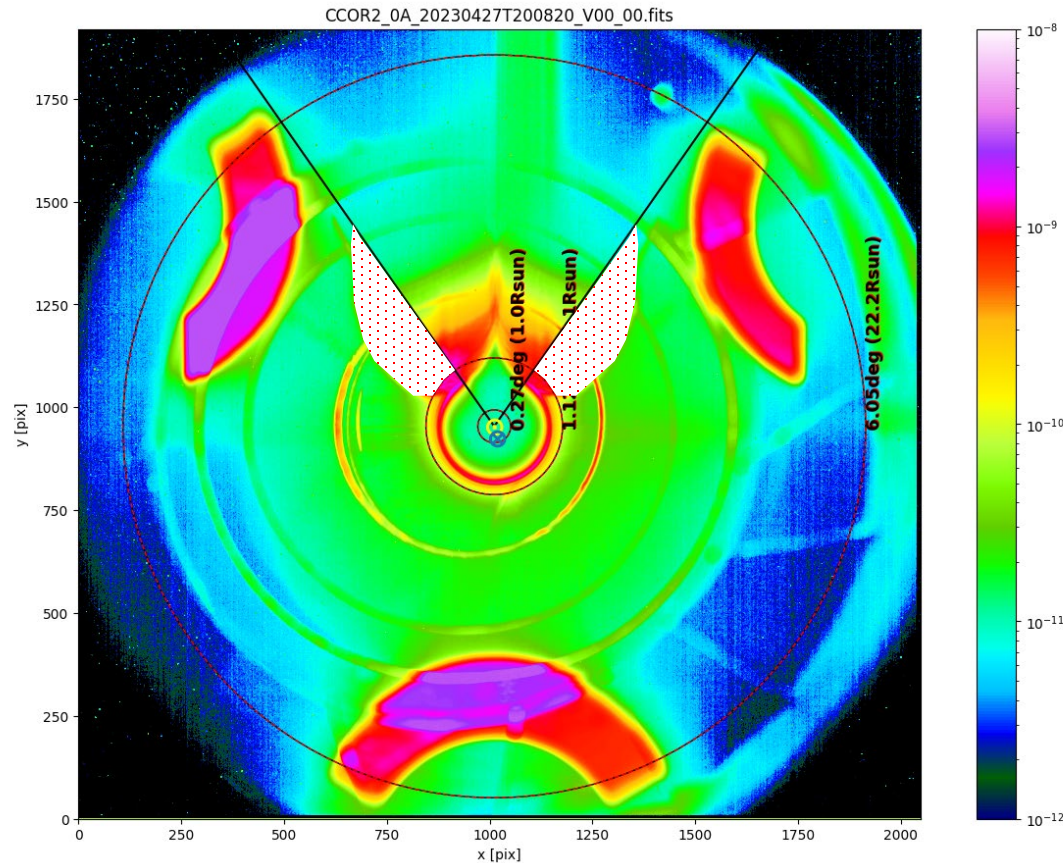


Pylon Area, Post-Environment



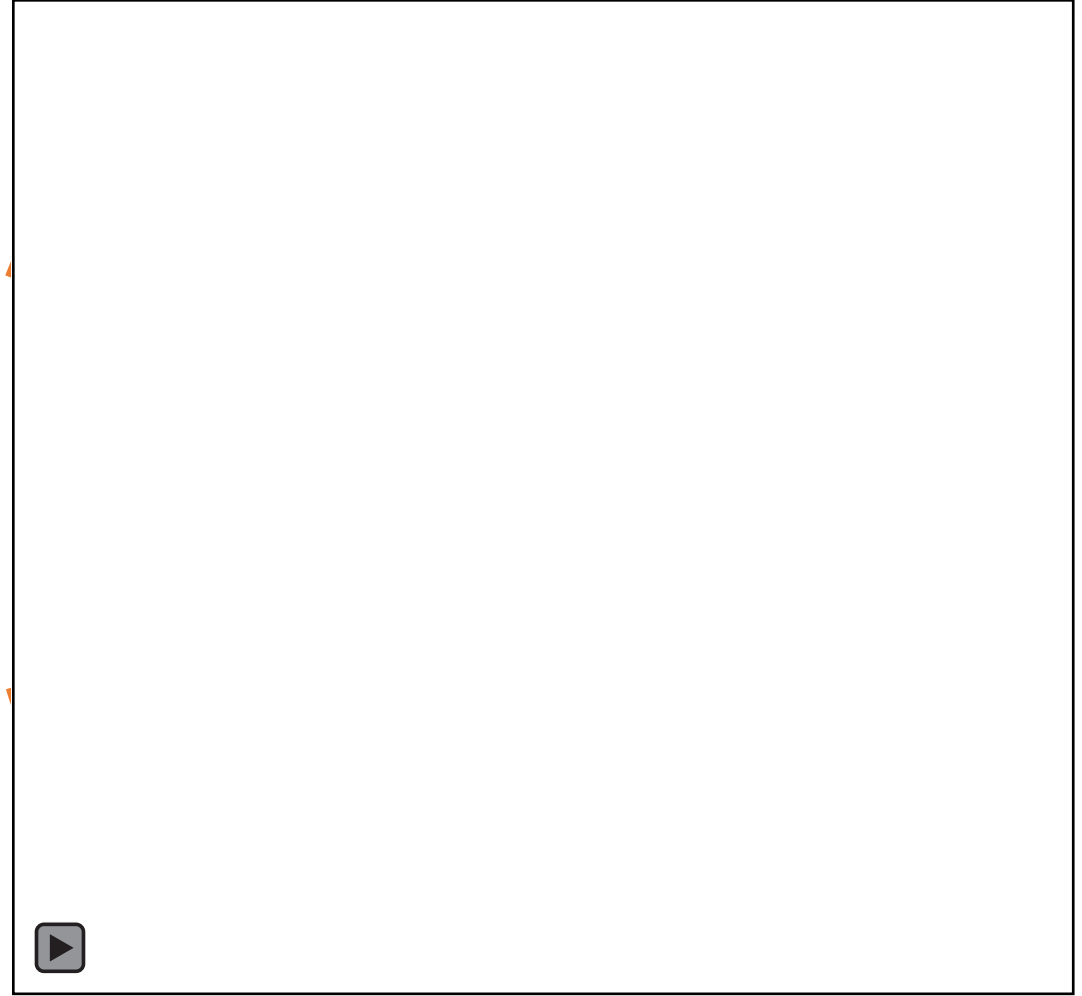
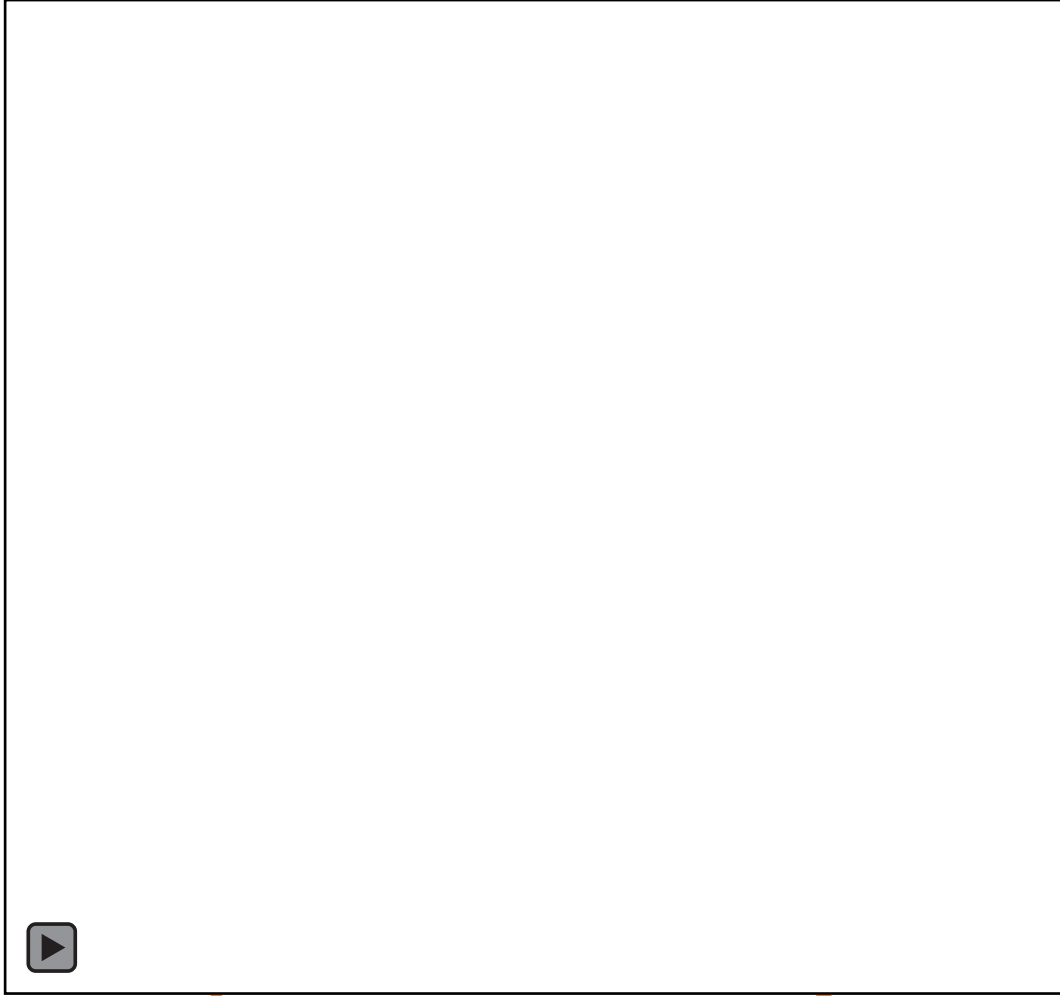
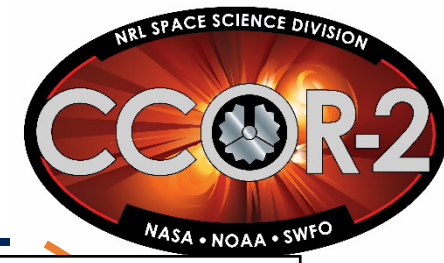
- The requirement is not met in some regions near the pylon and occulter.
- **Waiver RFW-CCOR2-0010 approved by NASA/NOAA.**
 - Rationale: It represents less than 6% of the required FOV coverage.

Pylon Area, Post-Environment



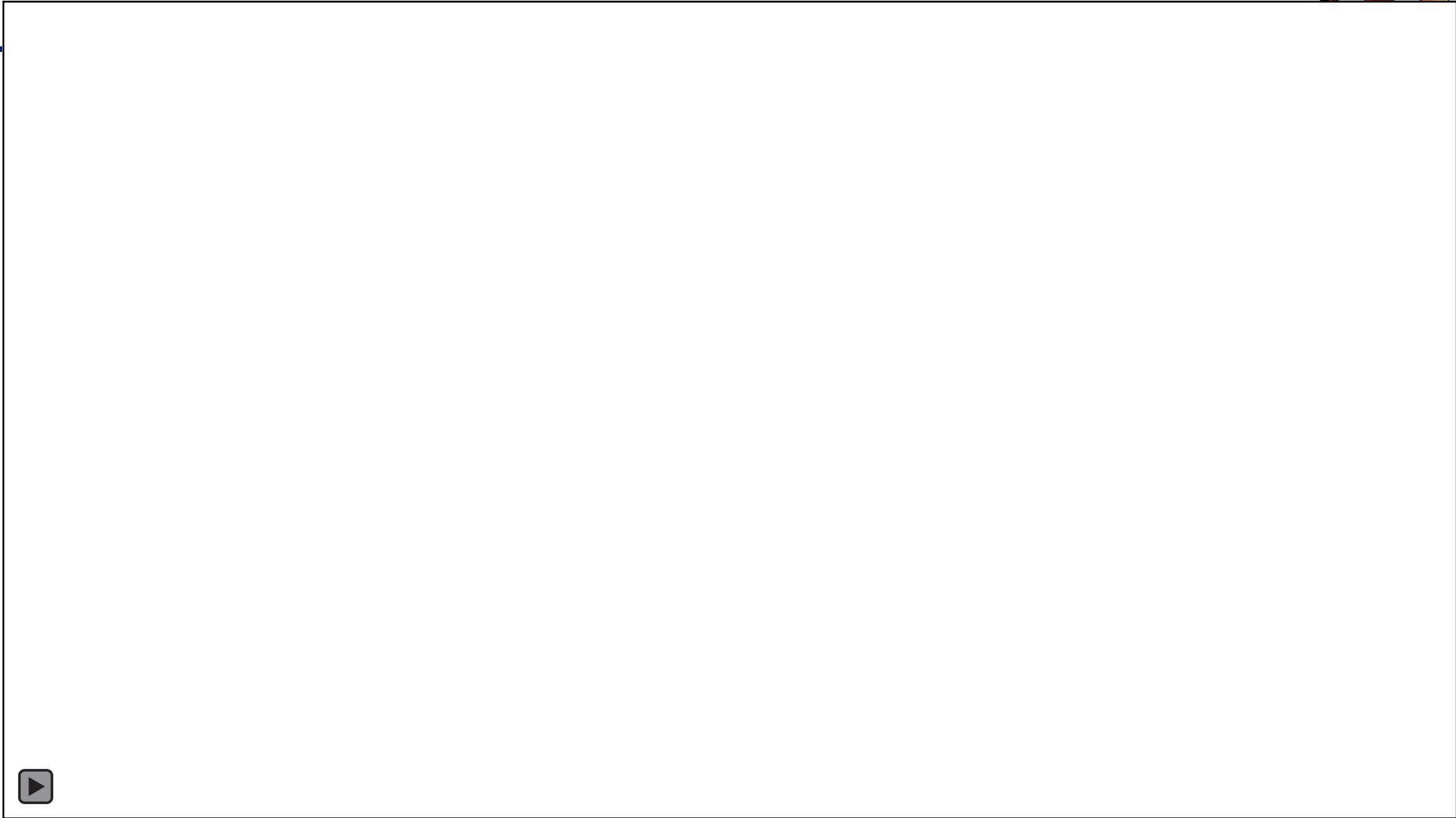
- The requirement is not met in some regions near the pylon and occulter.
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 - Rationale: It represents less than 6% of the required FOV coverage.

Observing a Halo CME with CCOR-1 and CCOR-2

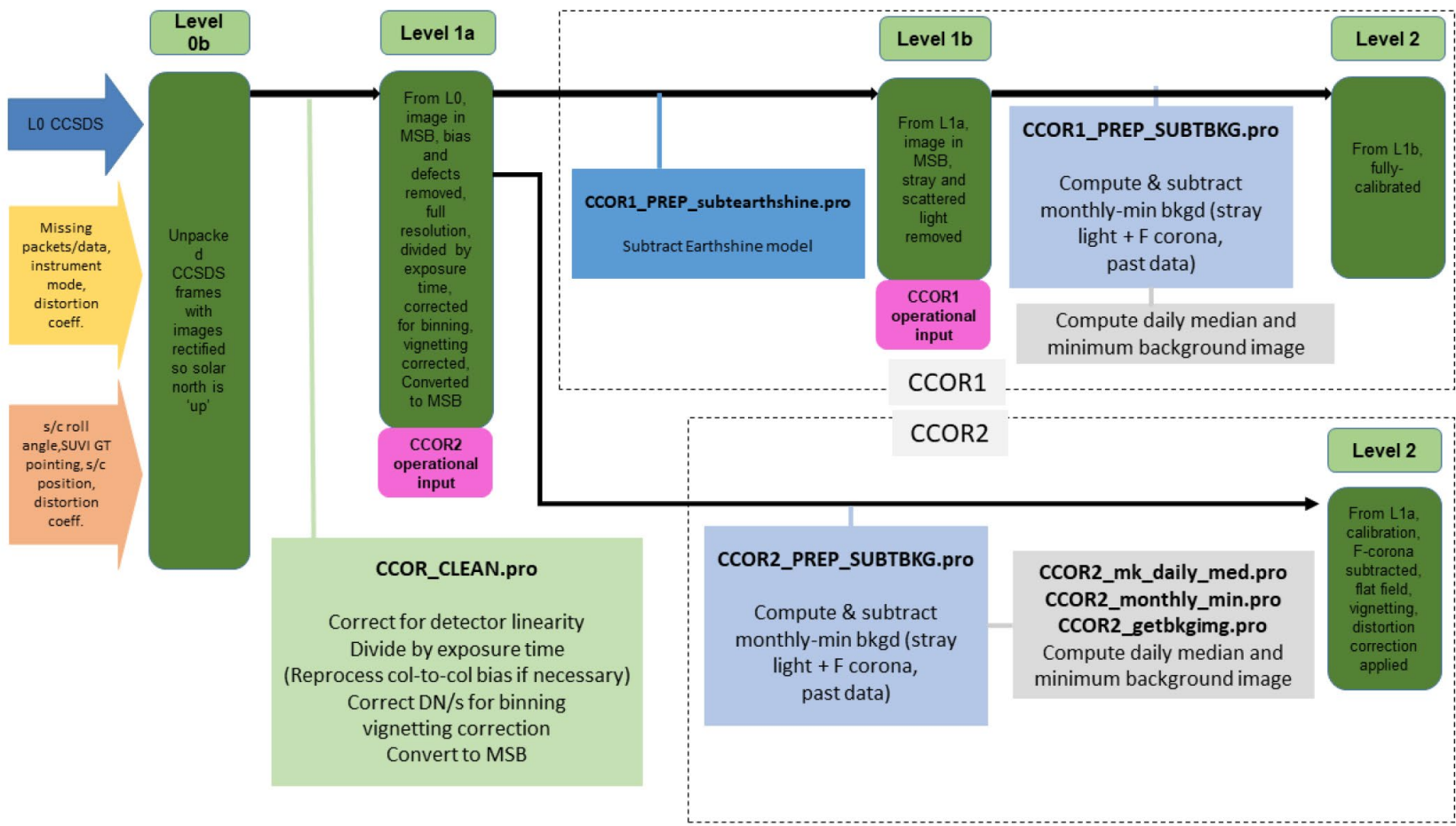
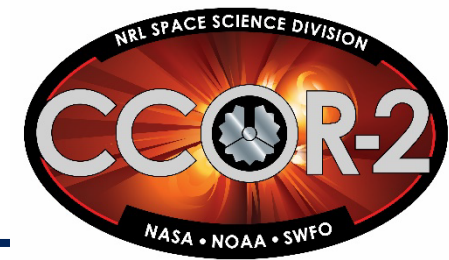


Halo CME, Feb 17 2000, minimum background subtracted.

LASCO C3 Compared to CCOR-1

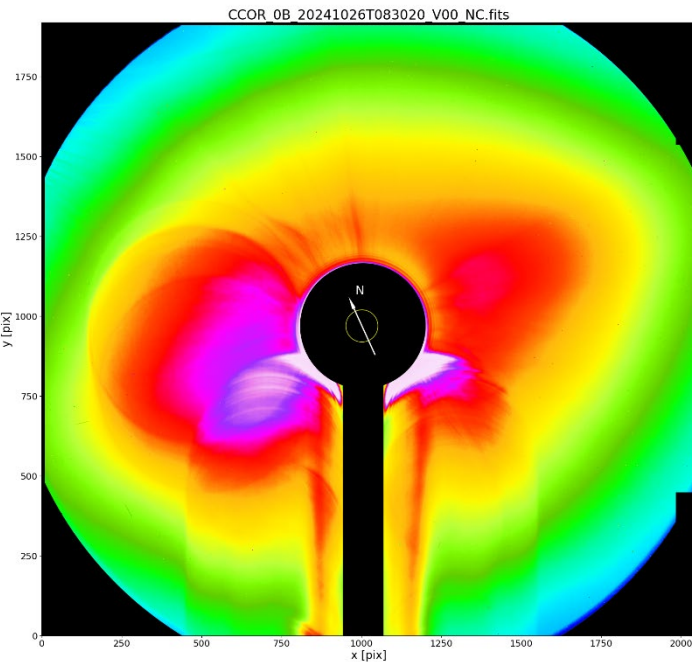
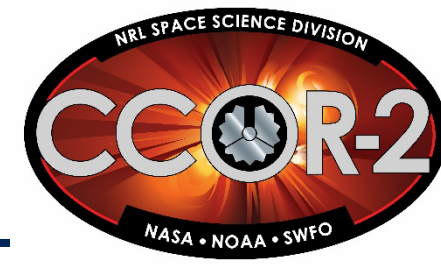


Ground Processing / Data Levels



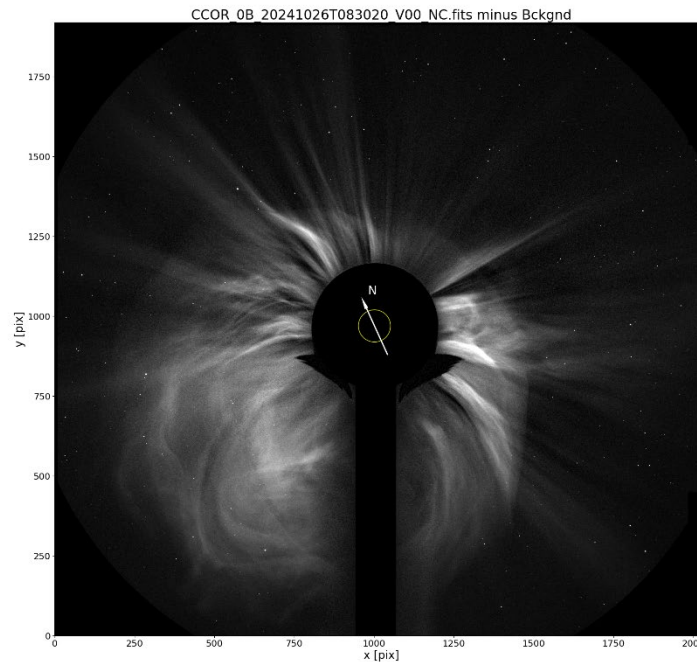
- NRL provided the Ground Processing Algorithm (GPA) to NCEI and SWPC.
- The GPA is based on legacy code initially developed for LASCO and SECCHI COR2.
 - SWPC → Operational pipeline
- NCEI → Science pipeline/retrospective
 - Objective of the GPA:
 - Calibrate the data in physical units
 - Remove instrumental stray-light and F-corona to allow observing the dynamic K-corona

Data Level Visual Comparison

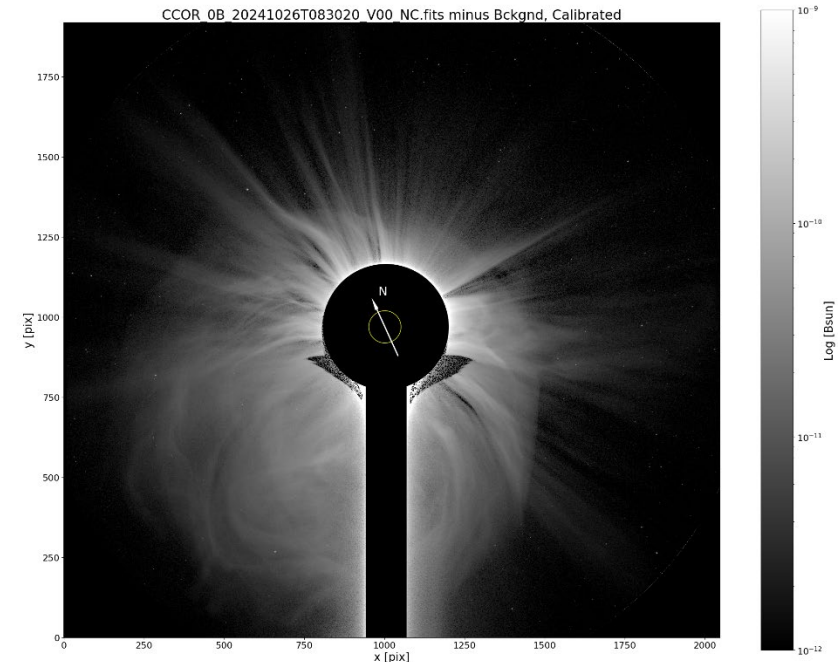


Level 0b

F-corona and instrument stray-light dominates; the K-corona is not visible.



A background that is computed based on past data of one day to a few weeks is subtracted. In this example, it takes the minimum of one day of data.



Level 2

The vignetting due to the pylon and occulter is corrected and the brightness is converted to units of Mean Solar Brightness.

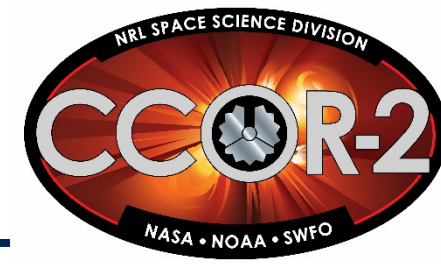
Post Launch Commissioning Timeline



Days	Date	Activity	Door State
0	Tue 9/23/2025	Launch	Closed
5	Sun 9/28/2025	Power On	Closed
7	Tue 9/30/2025	Thermal characterization	Closed
8	Wed 10/1/2025	Offset vs temperature	Closed
9	Thu 10/2/2025	Bias subtraction test	Closed
10	Fri 10/3/2025	Annealing	Closed
17	Wed 10/8/2025	Dark current	Closed
17	Wed 10/8/2025	Photon Transfer Curve	Closed
30 - 97	10/23 to 12/29/ 2025	SC Zone of Reduced Com (ZoRC) CCOR imaging for 10 hours, standby for the rest	Closed
120	Wed 1/21/2026	First light	Closed to Open
122	Fri 1/23/2026	Line of sight optimization	Open, from now on
126	Tue 1/27/2026	Exposure time optimization	
128	Thu 1/29/2026	Roll calibration	
129	Fri 1/30/2026	SEP scrubbing test	
131	Sun 2/3/2026	Double exposure test	
134	Wed 2/4/2026	Star calibration start	
149	Thu 2/19/2026	Beta Product Validation	
180	Sun 3/22/2026	End of Commissioning	
211	4/22/2026	Provisional Product Validation	

Image trending

Conclusions



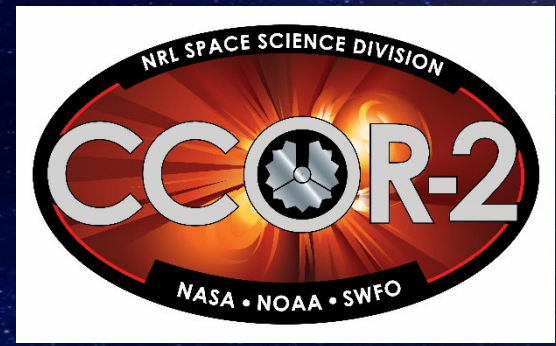
- **CCOR-2 tested: behaves as expected**
 - Instrument performances 👍
 - Spacecraft interface 👍
 - Ground processing algorithm 👍
- **CCOR-2 first light expected on Wed Jan 21, 2026.**
- **CCOR-2 planned to go operational in April 2026.**
 - Beta-maturity product validation: Feb 19, 2026.
 - Provisional-maturity product validation: Apr 22, 2026
- **CCOR instrument paper submitted to Space Science Reviews:**
 - Pre-print available on arXiv: <https://arxiv.org/abs/2508.13467>

Looking forward to first light on Jan 21, 2026

Data Access



- NOAA:
 - <https://www.ncei.noaa.gov/products/space-weather/swfo>
 - <https://noaa-nesdis-swfo-ccor-1-pds.s3.amazonaws.com/index.html>
- NRL website: <https://ccor.nrl.navy.mil>

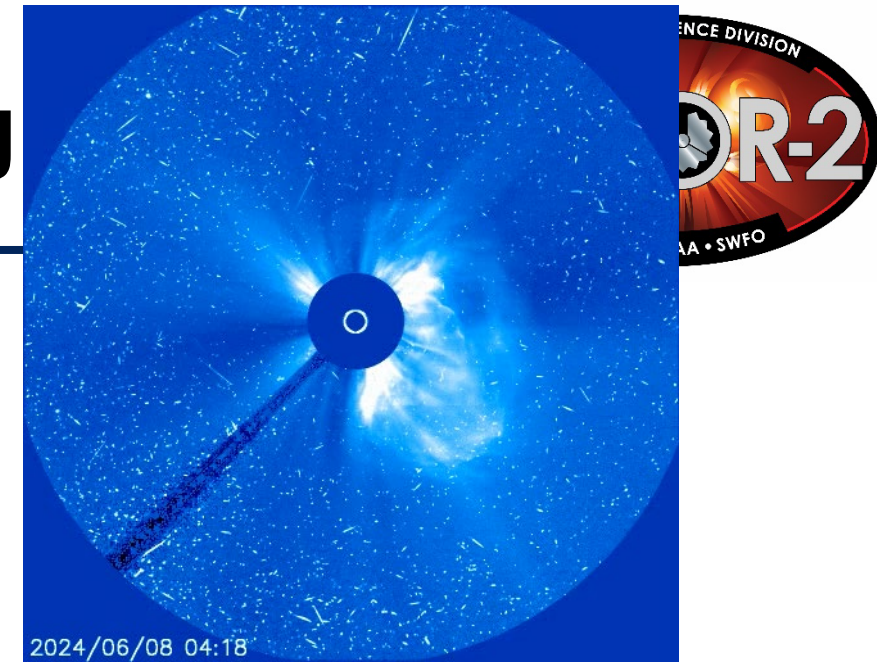


Backups

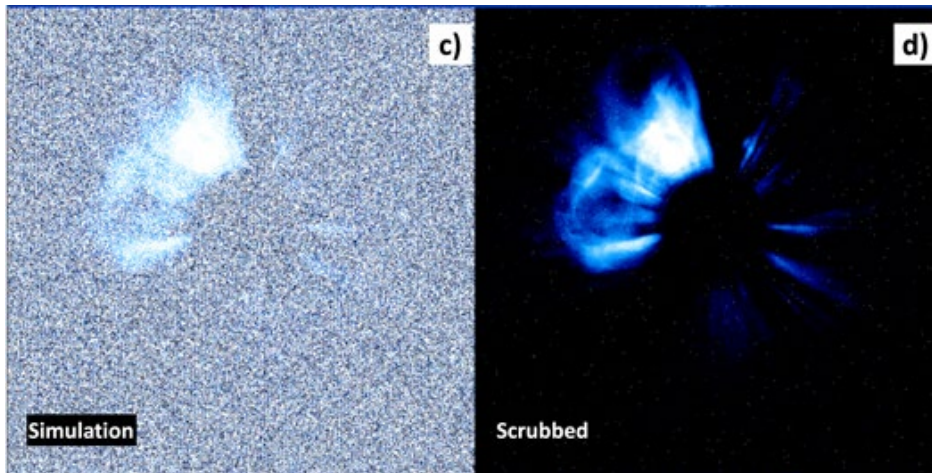


Solar Energetic Particle Scrubbing

- The CCOR flight camera implements on-board SEP scrubbing
- The constraints/requirements are:
 - Capture the coronal scene during a S4 radiation storm
 - Maintain Signal to Noise Ratio
- The CCOR-2 pixel corruption rate vs SEP flux rate is estimated based on 6 SECCHI COR2 S3 events, scaled to S4.



LASCO C3 image presenting “snow-like” noise during a proton storm.



Simulation, (c) showing 75% of pixel impacted, and (d) resulting scrubbed image, using 26 exposures. From Crump et al, 2019 Res. Notes AAS 3 183.

		Integration Time (sec)	Acquisition Time (sec)
Single Image Exposure Time=		2.7	
# of Single Images, Major Storm=	22	59.4	62.1
# of Single Images, Minor Storm=	16	43.2	45.9
# of Single Images, No Storm=	10	27	29.7

Number of single image exposure vs SEP storm level settings for CCOR-2.