Analysis of Signal-to-Noise Ratio (SNR) in Coronagraph Observations of Coronal Mass Ejections (CMEs)

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Introduction and Outline

This Quick View presents methods and results from an analysis of Signal-to-Noise Ratio (SNR) requirements for the solar coronagraph development project SCOPE (Solar Coronagraph for OPErations), funded under ESA Contract Nos. 4000116072/15/NL/LF and 4000119365/17/NL/LF as part of ESA's GSTP Programme.

Aims

The aim is to derive the performance level of a comparable established instrument like LASCO/C3 and to assess what can be expected in automatic detection of CMEs with different levels of artificially generated noise applied.

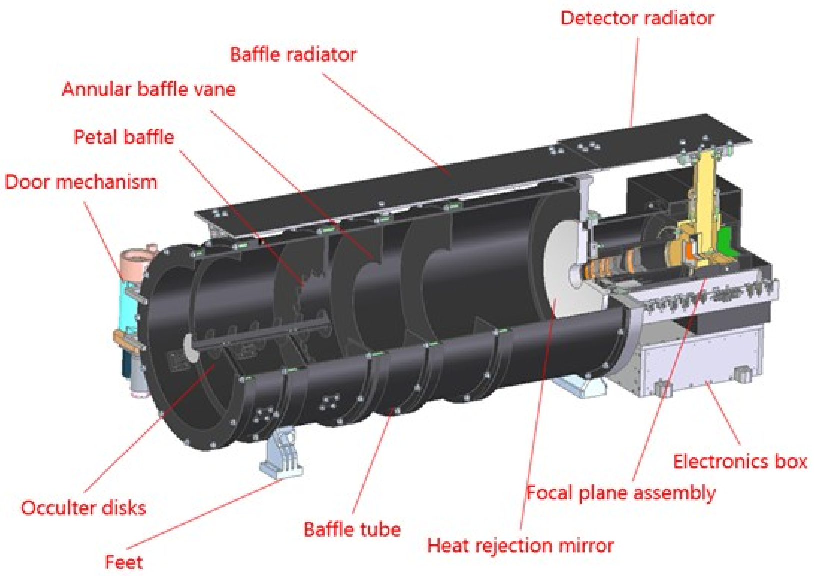
Methods

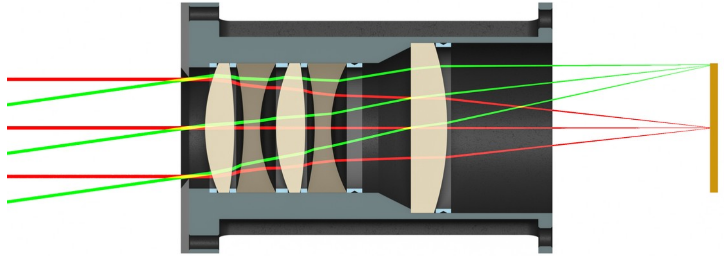
1) Analysis of observational data from SOHO/LASCO/C3

2) Analysis of simulated CME images with the automatic detection tool CACTus

SCOPE - Solar Coronagraph for OPErations

- Development of a novel coronagraph for operational space weather
- Field of View (FOV) from 2.5 to 30 R_{sun}, similar to SOHO/LASCO/C3
- Compact design consisting of one section each of baffles, lenses, and the detector
- The concept has been described in Middleton, K. F., et al., 2016: A *Coronagraph for Operational Space Weather Prediction*, International Conference on Space Optics, vol. 18





SNR as a Trade Parameter

SNR is a crucial parameter in the trade between different aspects of a coronagraph‘s performance:

1) The ability to detect features like CMEs in an image
2) The stray light budget
3) The light collecting power → physical dimension/mass
4) The exposure time → multiple exposure scheme for SEP reduction

Methods of Analysis

The SNR is studied in two ways:

1) Inspection of images from SOHO/LASCO/C3 and determining the SNR of CMEs therein
→ establish baseline performance of current data

2) Creation of artificial simulations with a range of SNR and testing the detection of CMEs with the operational detection software CACTus (Robbrecht and Berghmans, 2009)
→ Determine if any particular behaviour or artefacts at different levels of SNR can be found

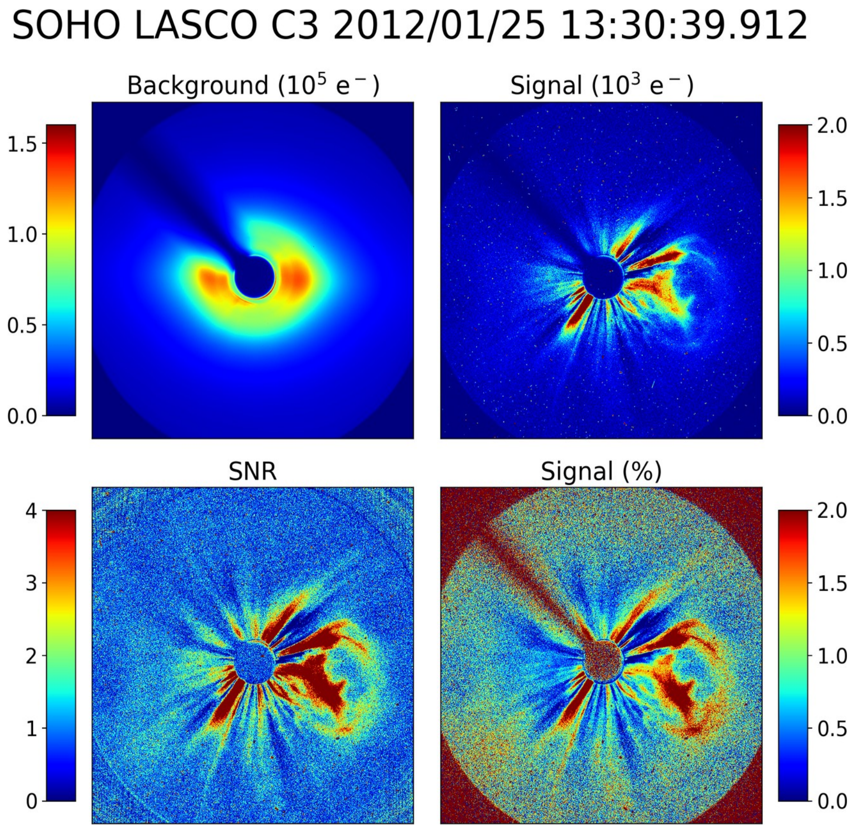
Processing of LASCO/C3 Data

- 8 CME-events in January and July 2012 are selected, which include events of different brightness and vantage points.
- In Level 0.5 data, the image is selected where the CME-apex extends furthest into the FOV.
- A background image is generated using data within +/- 12 hours of that image, and subtracted to obtain the CME-„signal“.
- The signal and background are converted from ADU to photoelectrons using the conversion factor of 13 e-/ADU (Morril et al., 2006).
- The SNR is computed assuming shot noise limit.

Results for LASCO/C3 Data

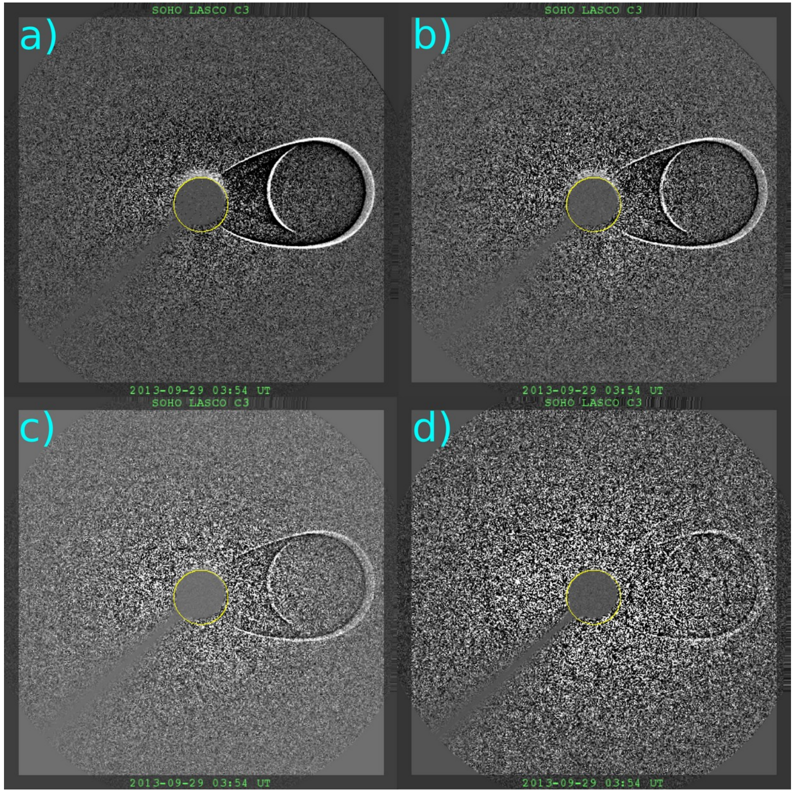
The Figure shows the event of 2012-Jan-25, with the background and signal in photoelectrons (e^-) in the top row, and SNR and signal percentage in the bottom row.

- At the CME leading edge close to the outer FOV limit of 30 R_{Sun}, SNR is found in the range of 1 to 4.
- The corresponding apex brightness is between 0.75% and 2% of the background K+F-corona.



Generation of Simulated Data

- Simulated data is based on LASCO/C2 and C3, using a Level-0.5 dataset to obtain FITS-header information.
- An artificial CME is computed using GCS in SolarSoft (Thernisien, 2011).
- A K+F-corona background is computed using a model from Baumbach (1937), plus an out-of-ecliptic falloff.
- For each SNR value, the data is scaled to photoelectrons, and Poisson-noise is added.
- Additionally, „null simulations“ are computed without a CME but at the same absolute noise levels.



The Figure shows some results, as difference images, with SNR of a) 4, b) 2, c) 1 and d) 0.5 at the CME apex.

Results for Simulated Data 1/2

- 54 events were analysed, with 3D-CME-velocities between 700 km/s and 2100 km/s, and SNR between 10 and 0.5.
- CACTus correctly identifies the CME in most cases.
- In some cases, false detections of CMEs and flows were made, or the CME classified as a flow.

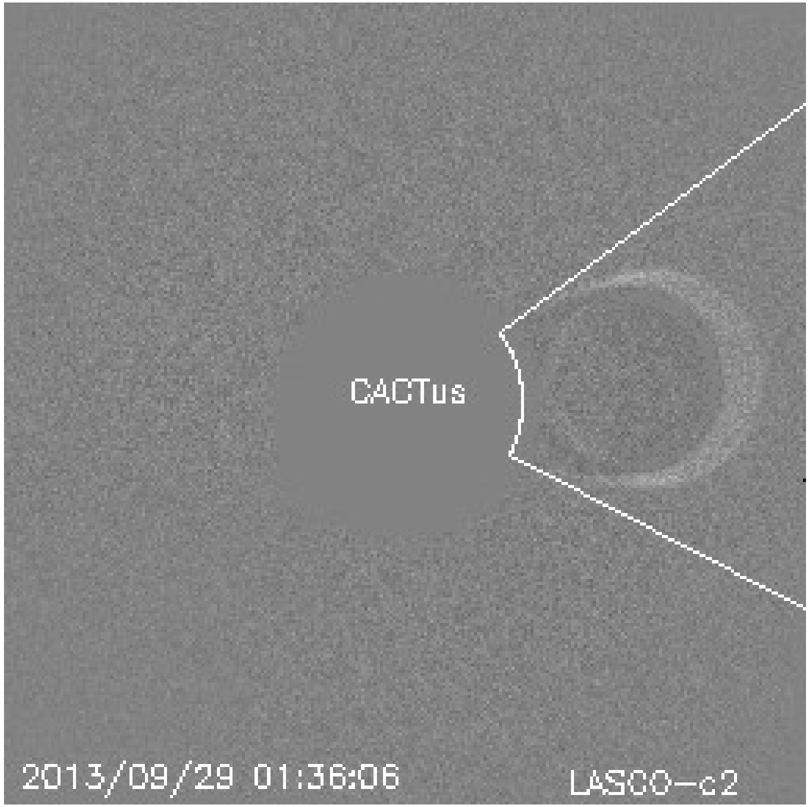


Figure: A successful detection by CACTus, showing the detected range of position angles in an artificial LASCO/C2 image.

Results for Simulated Data 2/2

- In some cases at low noise, halo-CMEs were classified as a flow instead of a CME.
- At high velocities, detection failed because of fixed limits of CACTus, requiring a larger number of images with the CME in the FOV.
- The equivalent null-simulations produced no detections, although with slight tuning of CACTus parameters, false detections were again produced.

Figure: An extreme example showing a large number of false detections within the noise:
a) Detection list, b) detection plot.

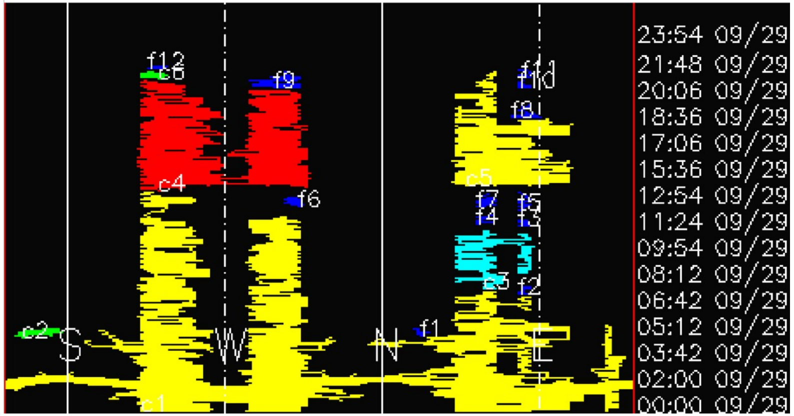
a)

# CME	t0	dt0	pa	da	v	dv	minv	maxv	halo?
0006	2013/09/29 21:25	00	230	014	1812	0039	1736	1838	
0005	2013/09/29 21:25	07	075	068	1302	0372	0686	1894	
0004	2013/09/29 21:25	07	270	098	1508	0349	0710	2016	II
0003	2013/09/29 10:00	03	065	044	0505	0099	0405	0694	
0002	2013/09/29 05:36	00	164	026	0336	0005	0328	0345	
0001	2013/09/29 01:36	14	144	360	0290	0052	0234	0383	IV

# Flow	t0	dt0	pa	da	v	dv	minv	maxv	halo?
0012	2013/09/29 22:00	00	232	010	1812	0062	1689	1838	
0011	2013/09/29 21:30	00	082	006	1667	0050	1602	1736	
0010	2013/09/29 20:42	01	082	006	1602	0102	1511	1755	
0009	2013/09/29 20:42	01	299	028	1736	0118	1488	1886	
0008	2013/09/29 19:00	01	083	016	1275	0046	1225	1358	
0007	2013/09/29 12:42	01	060	010	1059	0316	0512	1532	
0006	2013/09/29 12:42	01	310	010	1080	0195	0694	1302	
0005	2013/09/29 12:30	01	082	006	0851	0200	0686	1157	
0004	2013/09/29 11:42	01	059	008	0662	0105	0553	0811	
0003	2013/09/29 11:36	00	082	006	0839	0037	0791	0892	
0002	2013/09/29 07:30	00	082	006	0464	0499	0347	1453	
0001	2013/09/29 05:06	00	023	008	0340	0004	0336	0347	

#EOF

b)



Summary and Conclusions

- Observations of CMEs from LASCO/C3 were analysed, as well as simulated LASCO/C2 and C3 data.
- In C3 observations, SNR was found between 1 and 4 at the CME apex near the outer FOV limit of C3.
- CACTus was able to detect the simulated CMEs in most cases. At low SNR, false classification as a flow is possible.
- False detections in the noise were found for some events.

The results support the technical specifications of SCOPE, aiming at SNR=4 for a relative CME-brightness of 1% of the K+F-corona at 30R_{sun}.

A paper of this work is currently under review for a topical issue on space weather instrumentation at JSWSC.

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