Investigating the Robustness of the CORIMP CME Catalog Against Other Automated Catalogs and Manual Case Studies

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ABSTRACT

CMEs are long known to be significant drivers of adverse space weather at Earth, but the physics governing their propagation is not fully understood. text. text. text.

Key words. Sun? – CMEs? – Image processing?

1. Introduction

2. Events

Selection of events from the semi-automated (rigorous) analysis of Byrne et al. (2009) ; for comparison of variety of CMEs, alongside the results of the other manual and automated catalogs.

2.1. Arcade eruption: 2000 January 2

The CME that erupted off the south-east limb of the sun on 2000 Jan. 2 from ~06:06 UT in LASCO exhibited an arcade-type structure consisting of multiple bright loops. CORIMP identified the bulk of the CME through the LASCO field-of-view (FoV) to $\sim 24\,R_\odot$. However it may be deemed the third in a series of four CMEs that occurred in succession off the south-east limb, that CORIMP failed to separate due to their spatial and temporal overlap (essentially a smaller CME in between two large ones connects their detections along with a fourth smaller one afterwards - see Appendix for discussion on this limitation). This therefore serves as a prime example of the need to inspect the catalog output before blindly trusting the quoted values listed in Table 2.1. The CORIMP height-time measurements reveal a non-linear trend indicative of an early acceleration that the Savitzky-Golay filter determined to decrease from ~ 50 to $0\,m\,s^{-2}$ as the velocity levels off at a maximum in the range of ~ 500 to $600\,km\,s^{-1}$, consistent with the measurements of Byrne et al. (2009) shown in their Fig. 6. The quadratic (and linear) fits in CORIMP agree with a maximum velocity in this range
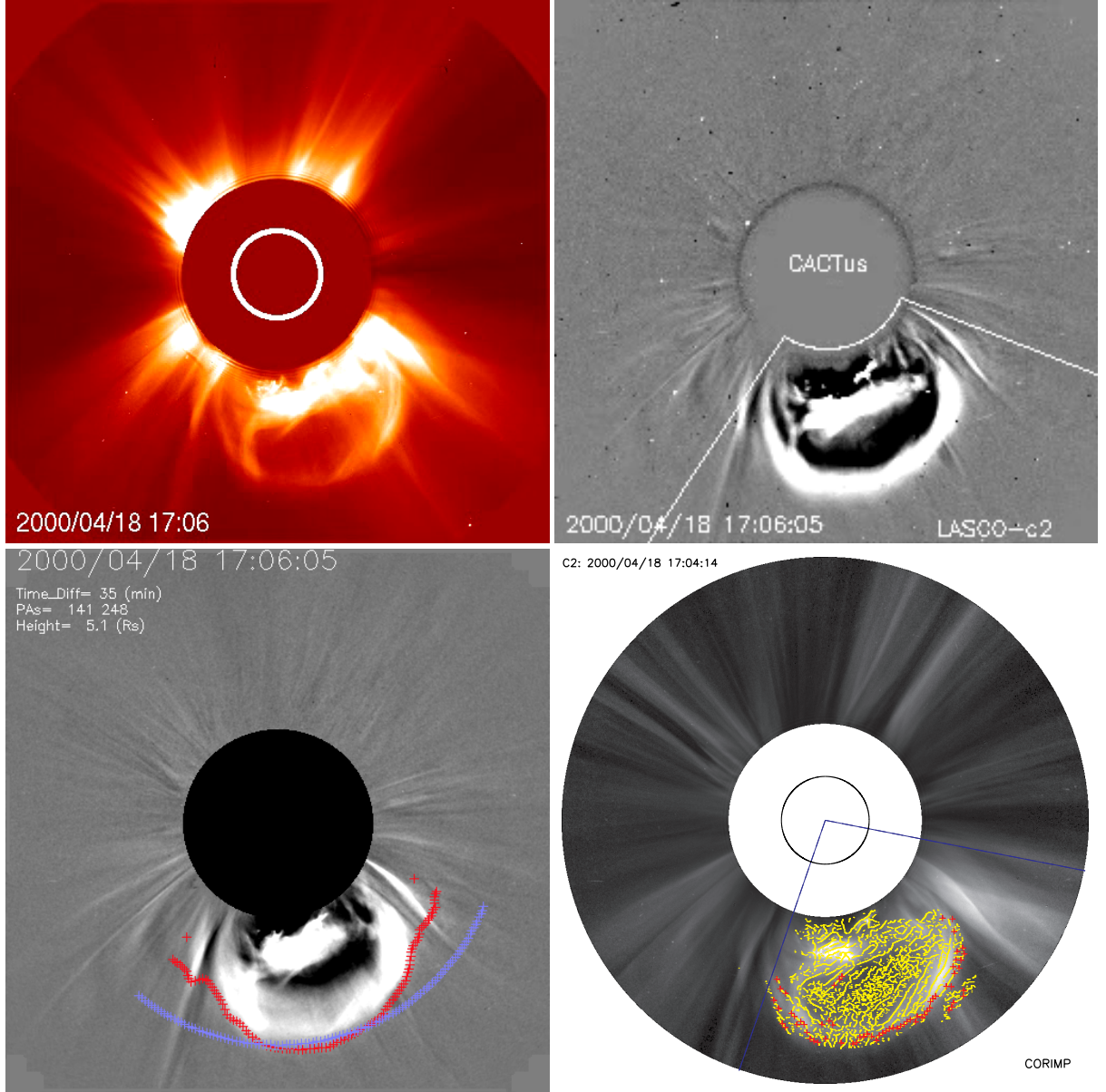
Fig. 1. LASCO/C2 observations of a CME on 2000 Apr. 18 at 17:06 UT. *Top left:* Level 2 processed image taken from the CDAW catalog. *Top right:* Running difference image taken from the CACTUS catalog with the angular span of the CME detection indicated in white. *Bottom left:* Running difference image taken from the SEEDS catalog with the CME front detection highlighted in red (and the extended 'half-max lead' in purple). *Bottom right:* NRGF processed image taken from the CORIMP catalog with the angular span of the CME detection indicated in blue, the pixel-chained CME structure in yellow, and the CME front in red.

of ~ 500 to $600\,km\,s^{-1}$ and an acceleration in the range of $\sim \pm 20\,m\,s^{-2}$. CACTUS determined a linear velocity in the range 548 to $744\,km\,s^{-1}$; CDAW determined an overall acceleration of $21.6\,m\,s^{-2}$; and
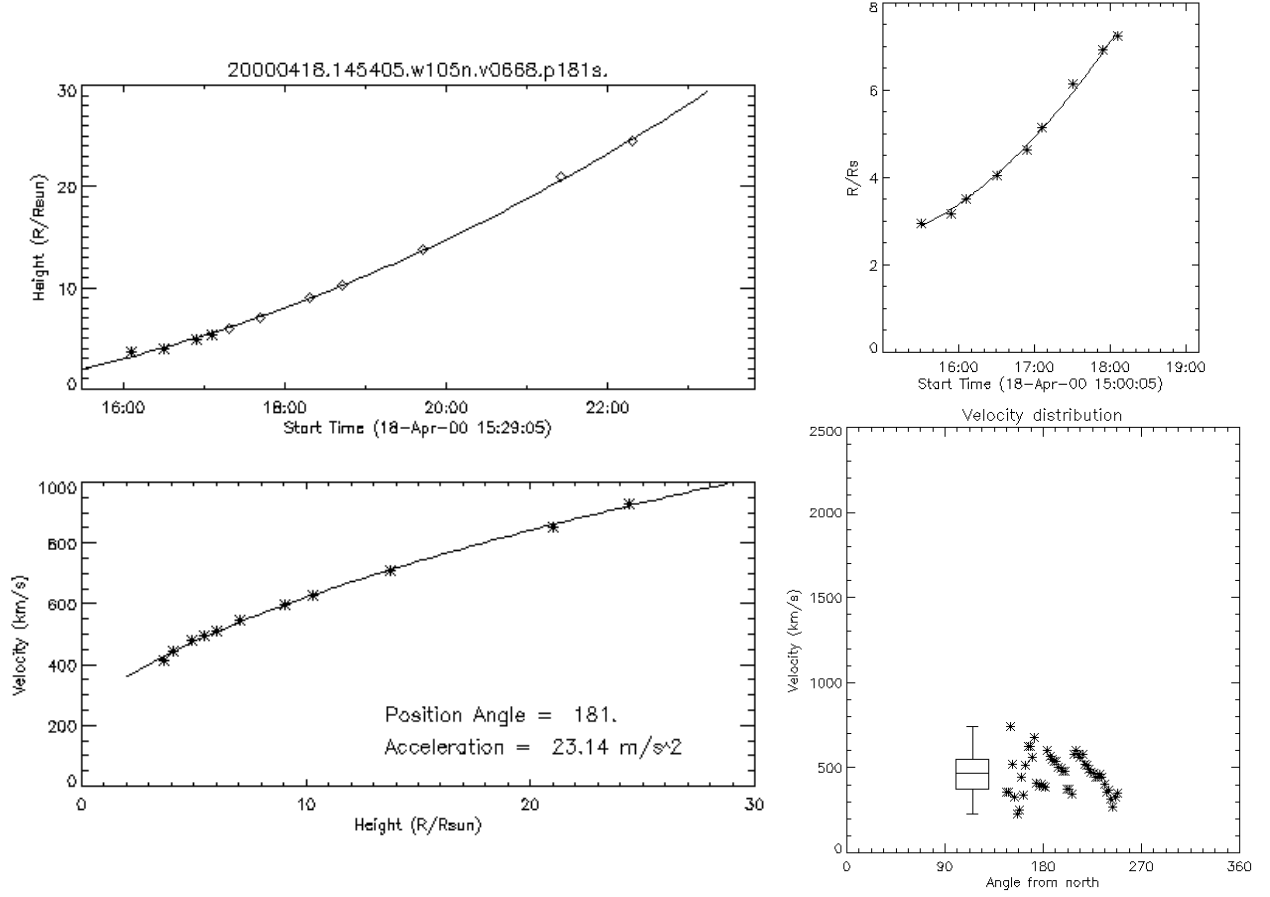
Fig. 2. The kinematic outputs for the 2000 Apr. 18 CME from the CDAW, SEEDS and CACTUS catalogs. *Top left:* The CDAW catalog height-time measurements of the CME chosen manually along the running-difference bright front (at position angle 181) with a second-order fit. *Bottom left:* The corresponding CDAW velocity profile plotted against height, showing an acceleration of $23.14 \, m \, s^{-2}$. *Top right:* The automated SEEDS height-time measurements and second-order fit resulting in an acceleration of $17.7 \, m \, s^{-2}$, in the LASCO/C2 field-of-view. *Bottom right:* The automated CACTUS velocities determined along the angular span of the CME, with a corresponding box-and-whisker plot to highlight the median ($463 \, km \, s^{-1}$) and interquartile range.

31 SEEDS determined an acceleration in the C2 FoV of $18.6 \, m \, s^{-2}$ (or linear velocity of $292 \, km \, s^{-1}$).
32 Therefore, all may be deemed in relative agreement with the corresponding results of the CORIMP
33 CME catalog. Note that the slightly lower angular width in CORIMP is due to the exclusion of part
34 of the questionable streamer deflection/interaction along the southern flank of the CME.

Comparison for LASCO CME on 2000 Jan. 02 from ~06:06 UT

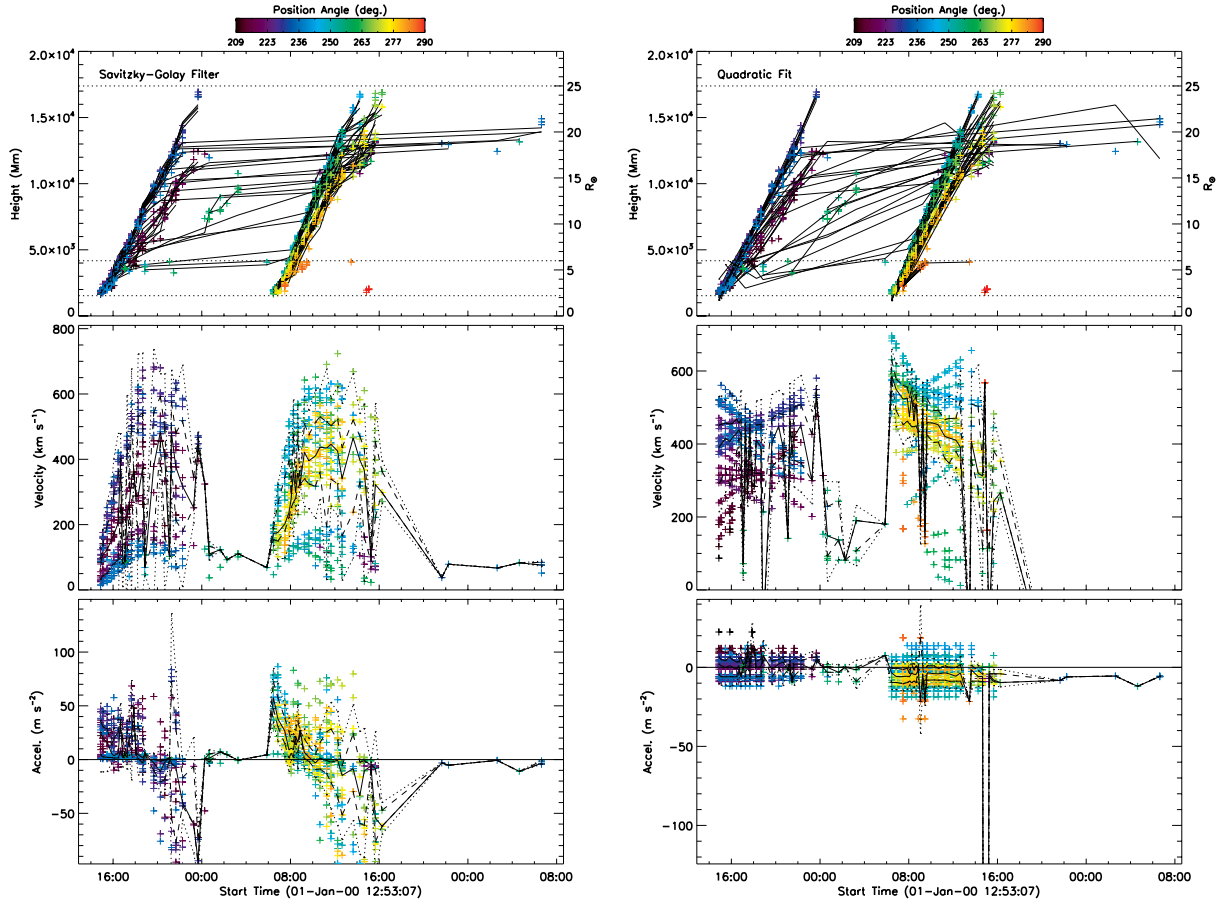| Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	253	107	603	21.6
CORIMP	250	81 (83)	454 (743)	1 (-17, 14)
CACTUS	250	106	548 (744)	–
SEEDS	257	96	292	18.6

Table 1. Table 20000102

Fig. 3. Kinematic plots of the 2000 Jan. 2 CME from the automatic detection and tracking in the CORIMP catalog. The top plot shows the height-time measurements with a colorbar to indicate the angular span of the data points. The middle and bottom plots show the velocity and acceleration profiles of the CME with the median (solid line), interquartile range (inner dashed lines) and upper and lower fences (outer dashed lines) over-plotted. The left plots are determined by a Savitzky-Golar filter applied to the height-time measurements with a 7-point window, while the right plots are determined with a second-order (quadratic) fit.

2.2. Gradual/expanding CME: 2000 April 18

The CME that erupted off the south limb of the sun on 2000 Apr. 18 from ~14:54 UT in LASCO exhibited a typical 3-point structure of leading CME front, cavity and bright core. CORIMP identified the bulk of the CME through the LASCO field-of-view (FoV) to $\sim 25\,R_\odot$, though it lost a portion of the faint southern-most CME front in the latter C3 observations. A western portion of material also erupted as the delayed northern flank of the CME, that appears as a somewhat secondary height-time profile in the CORIMP kinematic plots (at position angles $\sim 250°$ towards the red end of the colorbar). The CORIMP height-time measurements (Fig. **??**) reveal a non-linear trend indicative of an early acceleration that the Savitzky-Golay filter determined is approximately $\sim 20\,m\,s^{-2}$ as the velocity increases to over $\sim 400\,km\,s^{-1}$, before the data gaps cause a large scatter in the derived kinematics, e.g., an artificial acceleration peak of $> 100\,m\,s^{-2}$. The initial increasing velocity profile up to a maximum in the range ~ 600 to $800\,km\,s^{-1}$ by $\sim 20:00$ UT agrees with that of Byrne et al. (2009) as shown in their Fig. 7. The quadratic (and linear) fits in CORIMP are not as prone to the scattering effects of the data gap, and thus derive a, slight lower, maximum velocity range of ~ 500 to $550\,km\,s^{-1}$ and an acceleration in the range of $\sim \pm 15\,m\,s^{-2}$. CACTUS determined a linear velocity in the range 463 to $744\,km\,s^{-1}$; CDAW determined an overall acceleration of $23.1\,m\,s^{-2}$; and SEEDS determined an acceleration in the C2 FoV of $17.7\,m\,s^{-2}$ (or linear velocity of $338\,km\,s^{-1}$). Therefore, by inspection, all may be deemed in relative agreement with the corresponding results of the CORIMP CME catalog.

Comparison for LASCO CME on 2000 Apr. 18 from ~14:54 UT

Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	195	105	668	23.1
CORIMP	210	98 (98)	431 (537)	4 (-11, 15)
CACTUS	198	102	463 (744)	–
SEEDS	195	108	338	17.7

Table 2. Table 20000418

2.3. Impulsive CME: 2000 April 23

The large and fast CME that erupted off the west limb of the sun on 2000 Apr. 23 from ~12:54 UT in LASCO underwent a hugely impulsive acceleration as it exploded into the corona. CORIMP identified the bulk of the CME through the LASCO field-of-view (FoV) to $\sim 20\,R_\odot$ after which the CME front became too faint. Strong streamer deflections occurred to the north and south flanks of the CMEs, with very faint material visible as a full halo around the east limb separate to the bulk flux-rope structure in the west. The CORIMP height-time measurements reveal an initial acceleration that the Savitzky-Golay filter determined to be $>150\,m\,s^{-2}$ dropping quickly to a range of -100 to $0\,m\,s^{-2}$, as the velocity decreases from ~ 1000 to $500\,km\,s^{-1}$; though this is an underestimate since the filter overly smoothes the (relatively under-sampled, fast event) data. The quadratic fits in CORIMP better handle this data, and derive an initial velocity range of $\sim 1200 - 1500\,km\,s^{-1}$ (with the linear fits also deriving $\sim 1200\,km\,s^{-1}$). The resulting deceleration is determined to have a median of $\sim -50\,m\,s^{-2}$, reaching as low as $\sim -150\,m\,s^{-2}$. CACTUS determined a linear velocity in the range 1114 to $1849\,km\,s^{-1}$; CDAW determined an overall deceleration of $-48.5\,m\,s^{-2}$; and
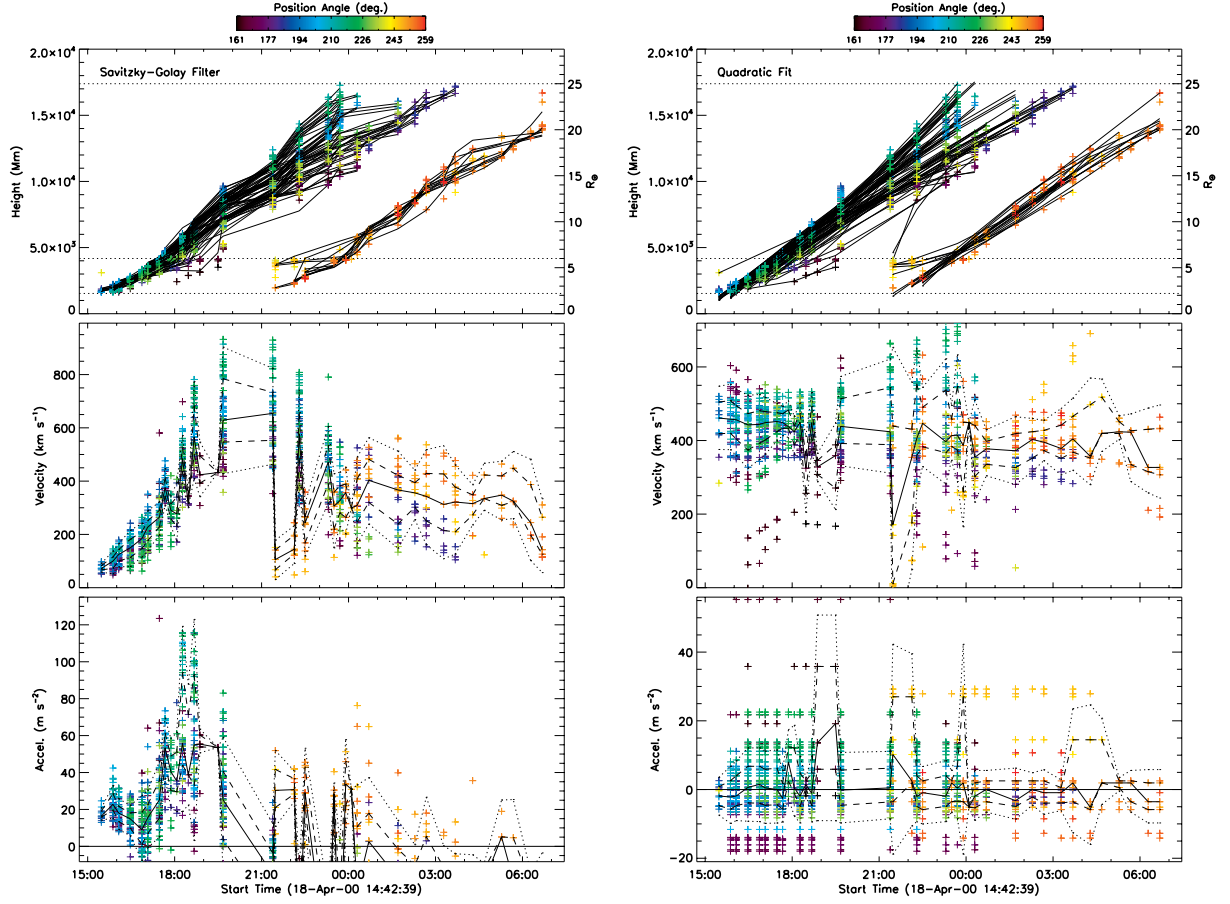
Fig. 4. Kinematic plots of the 2000 Apr. 18 CME from the automatic detection and tracking in the CORIMP catalog, as in Fig. 3.

68 SEEDS determined an deceleration in the C2 FoV of $-8.5\,m\,s^{-2}$ (or linear velocity of $594\,km\,s^{-1}$).

69 Therefore, by inspection and careful consideration of the low sampling of the event, all may be

70 deemed in relative agreement with the corresponding results of the CORIMP CME catalog.

Comparison for LASCO CME on 2000 Apr. 23 from ~12:54 UT

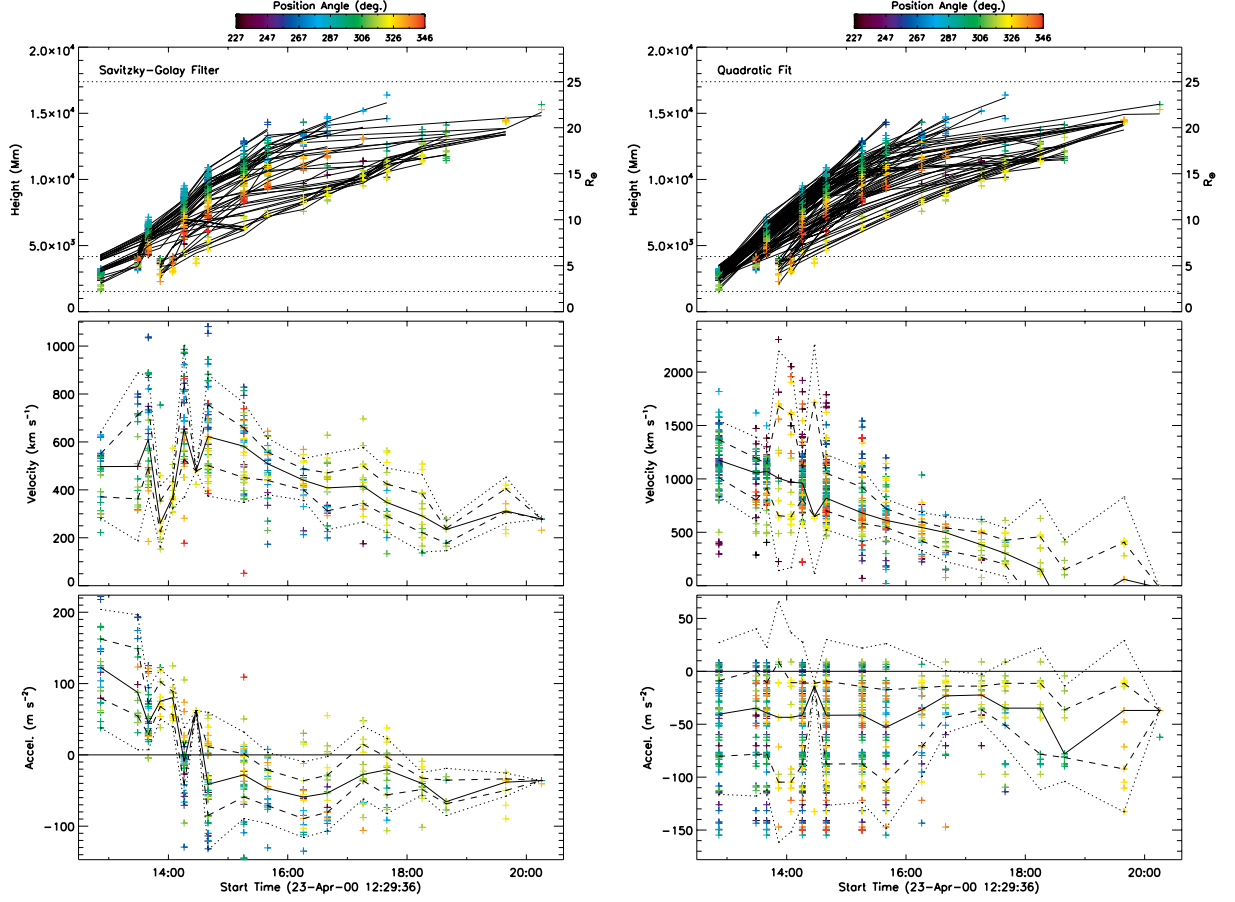| Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	281	360	1187	-48.5
CORIMP	287	119 (125)	836 (1706)	-11 (-154, 50)
CACTUS	144	360	1114 (1849)	–
SEEDS	275	130	594	-8.5

Table 3. Table 20000423

Fig. 5. Kinematic plots of the 2000 Apr. 23 CME from the automatic detection and tracking in the CORIMP catalog, as in Fig. 3.

2.4. Faint CME: 2001 April 23

The CME that erupted off the southwest limb of the sun on 2001 Apr. 23 from ~12:54 UT in LASCO appeared relatively faint behind multiple streamers in the line-of-sight, some of which deflected especially along the southern flank of the CME. CORIMP identified the bulk of the CME through the LASCO field-of-view (FoV) to ~ $20\,R_\odot$ after which the CME front became too faint. However this CME is the first of two CMEs that occurred in close succession off the southwest limb, that CORIMP failed to separate due to their spatial and temporal overlap (plus some ejecta ahead of this CME was detected from ~ 08:16 UT). Thus the kinematics profiles must be inspected rather than trusting the quoted catalog values listed in Table 4. Looking at the relevant portion of the plots in Fig. 6, in the time interval ~12:00 – 18:00 UT, the CORIMP height-time measurements reveal an initial acceleration that the Savitzky-Golay filter determines to be ~ $20\,m\,s^{-2}$ dropping to scatter about zero, as the velocity levels off at a maximum in the range of ~ $350-400\,km\,s^{-1}$; though this is an underestimate since the algorithm picks up the material ahead of the CME front first. The quadratic fits to the data in the same time interval are more dominated by the overall deceleration of the CME (approx. $-10\,m\,s^{-2}$), as the velocity appears to drop from an initial range of ~ $400-$

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Comparison for LASCO CME on 2001 Apr. 23 from ~12:39 UT

Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	228	91	530	-0.7
CORIMP	232	72 (74)	187 (283)	3 (-13, 15)
CACTUS	231	88	459 (602)	–
SEEDS	224	77	408	-46.6

Table 4. Table 20010423

$600\,km\,s^{-1}$ to $\sim 200-250\,km\,s^{-1}$. The linear fits are less trustworthy as they tend to fit across the two CMEs and preceding ejected material. CACTUS determined a linear velocity in the range 204 to $339\,km\,s^{-1}$; CDAW determined an overall acceleration of $5.7\,m\,s^{-2}$; and SEEDS determined a deceleration in the C2 FoV of $-46.6\,m\,s^{-2}$ (or linear velocity of $408\,km\,s^{-1}$) however it loses the CME front in the final frames which accounts for this erroneously large deceleration. Therefore, by inspection and careful consideration of the appropriate measurements of this event, all may be deemed in relative agreement with the corresponding results of the CORIMP CME catalog.
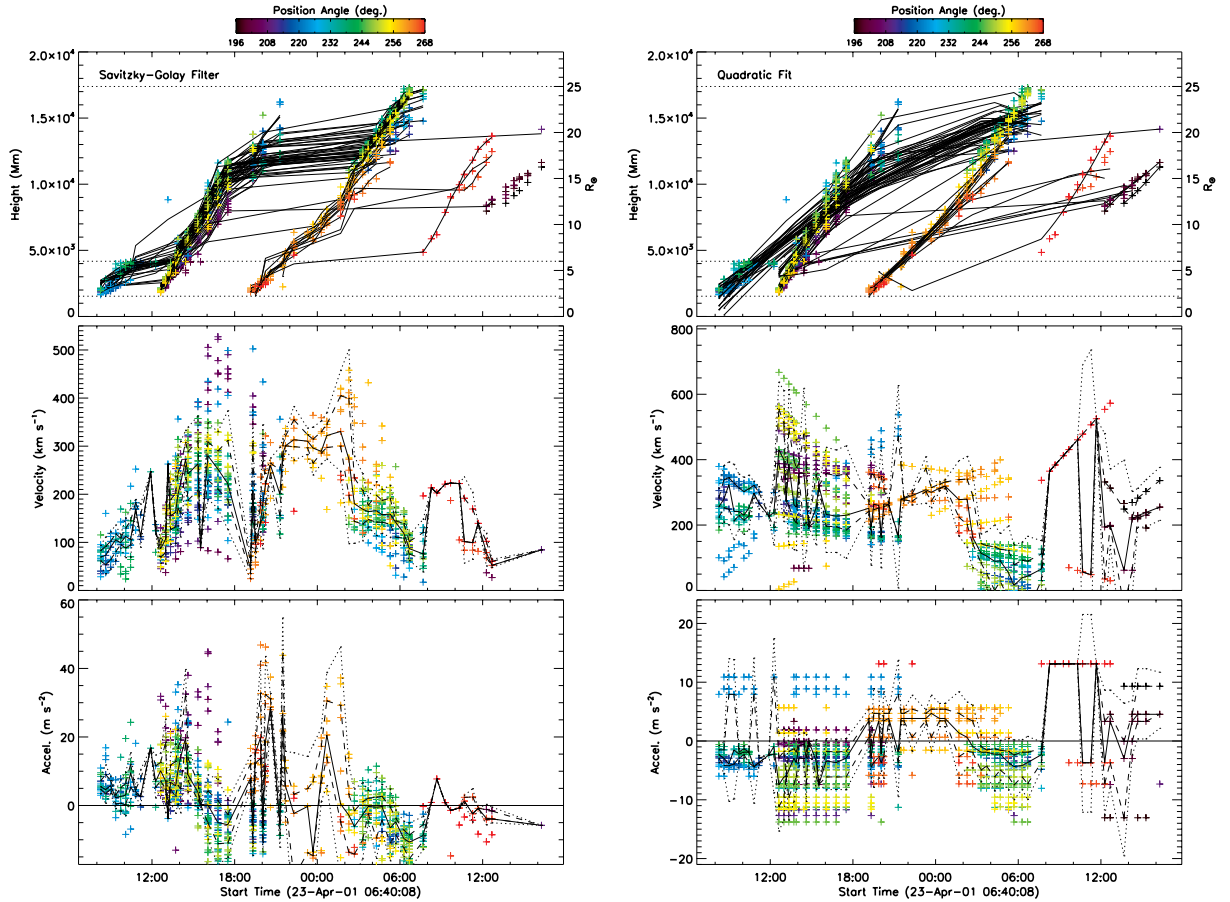
Fig. 6. Kinematic plots of the 2001 Apr. 23 CME from the automatic detection and tracking in the CORIMP catalog, as in Fig. 3.

93   *2.5.*

Comparison for LASCO CME on 2002 Apr. 21 from ~01:26 UT

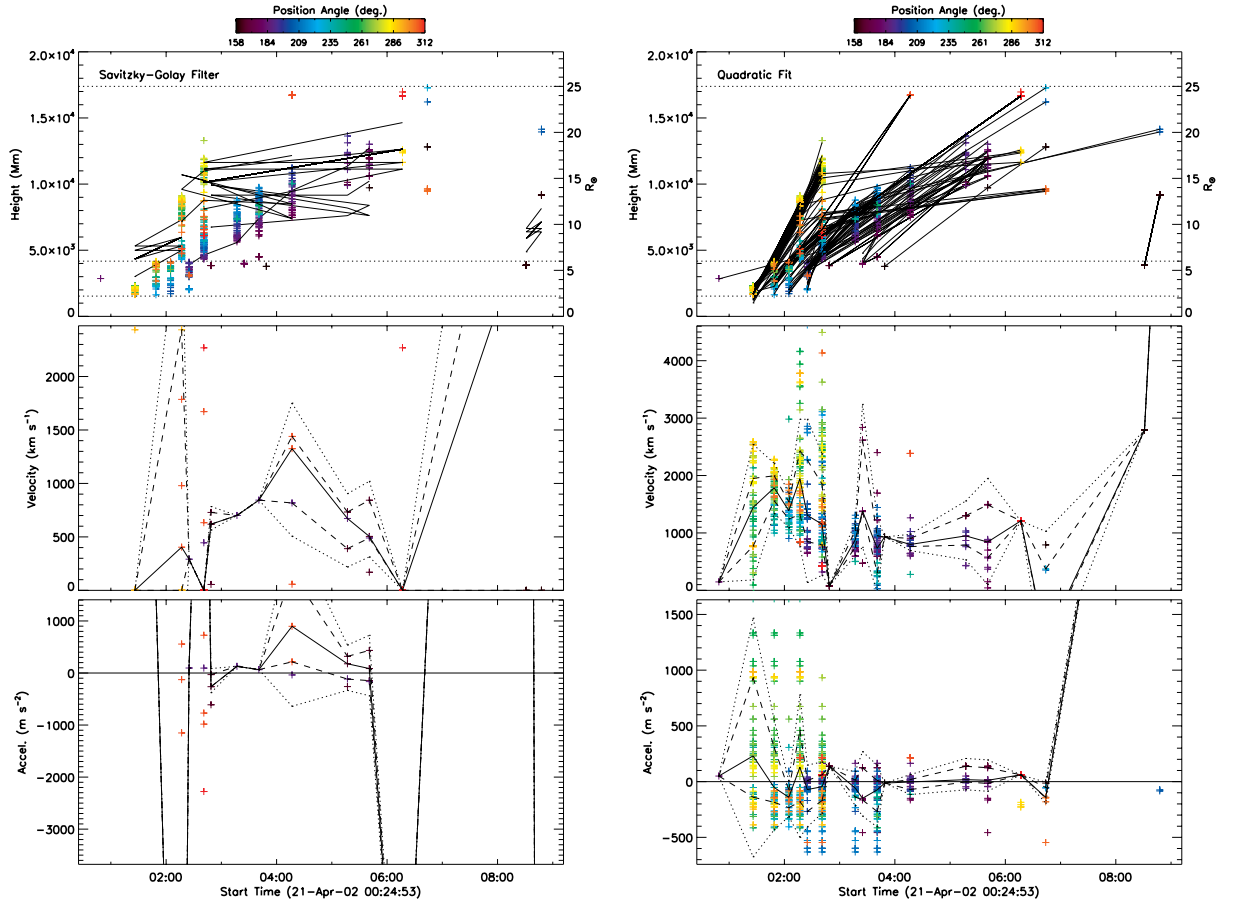| Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	282	360	2393	-1.4
CORIMP	235	154 (177)	1129 (2300)	61 (-619, 345)
CACTUS	322	352	1103 (1913)	–
SEEDS	250	186	703	31.8

Fig. 7. Kinematic plots of the 2002 Apr. 21 CME from the automatic detection and tracking in the CORIMP catalog, as in Fig. 3.

Comparison for LASCO CME on 2004 Apr. 01 from ~23:04 UT

Catalog	CPA [deg.]	AW [deg.]	Lin. Speed [$km\,s^{-1}$]	Accel. [$m\,s^{-2}$]
CDAW	59	79	460	7.1
CORIMP	58	42 (44)	401 (502)	2 (-22, 18)
CACTUS	60	70	485 (829)	–
SEEDS	60	59	261	19.7

2.6.

3. Conclusions

4. Appendix: Clustering Techniques to Separate Overlapping CME Detections

Acknowledgements.

References

Byrne, J. P., P. T. Gallagher, R. T. J. McAteer, and C. A. Young. The kinematics of coronal mass ejections using multiscale methods. *A&A*, **495**, 325–334, 2009. 10.1051/0004-6361:200809811, 0901.3392. 2, 2.1, 2.2