Towards a better understanding of the Magnetic field of Coronal Magnetic Eruptions (CMEs)

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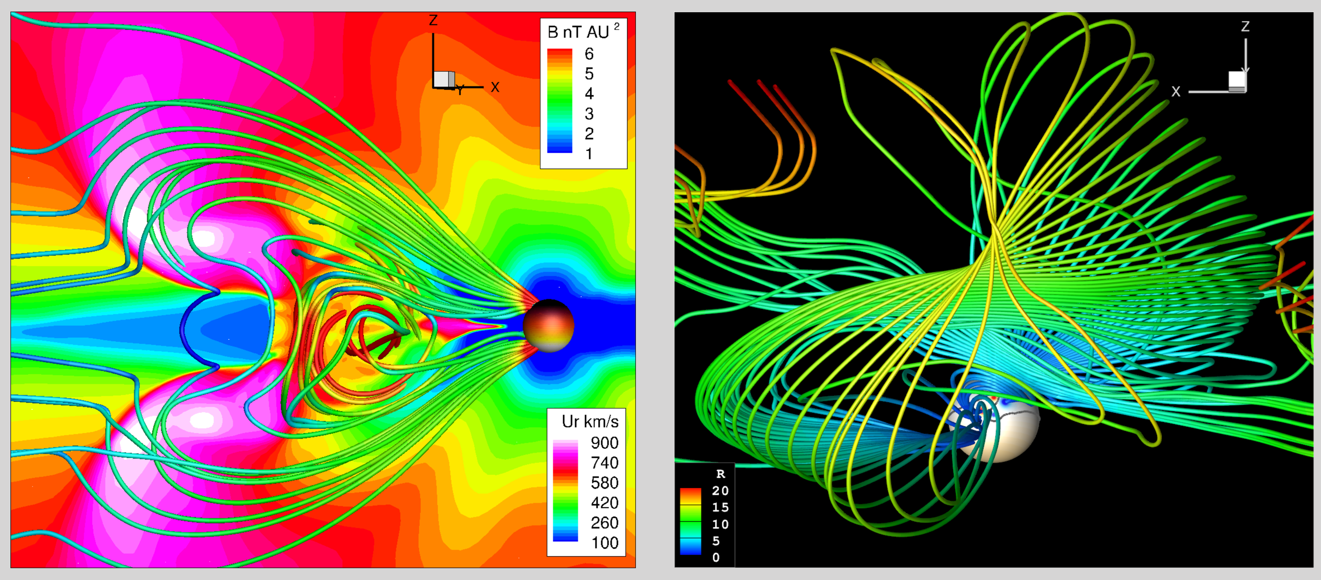
Tools

In the two following works, two numerical simulations of structurally different CMEs are used: (1) a CME with writhed magnetic field lines and minimum twist, and (2) a CME with a twisted flux rope structure. Our aim is to gain insight into the structure of the CMEs' magnetic field through the use of synthetic spacecraft data for location that actual data are not available, as well as taking advantage from having access to the actual structure (i.e. the simulated CME) in order to validate the our studies.



Three-dimensional magnetic field lines of the two simulated CMEs as they reach the upper corona. Left: Twisted magnetic flux rope three hours after its initiation from Lugaz & Farrugia (2014). The color shows the radial velocity. Right: Writhed magnetic ejecta four hours after its initiation from Al-Haddad et al. (2011). The color shows the radial distance of the magnetic field lines.

Multi-spacecraft Investigation of Twisted and Writhed Coronal Mass Ejections

Al-Haddad et al., *Astrophysical Journal*, 2019a

Project

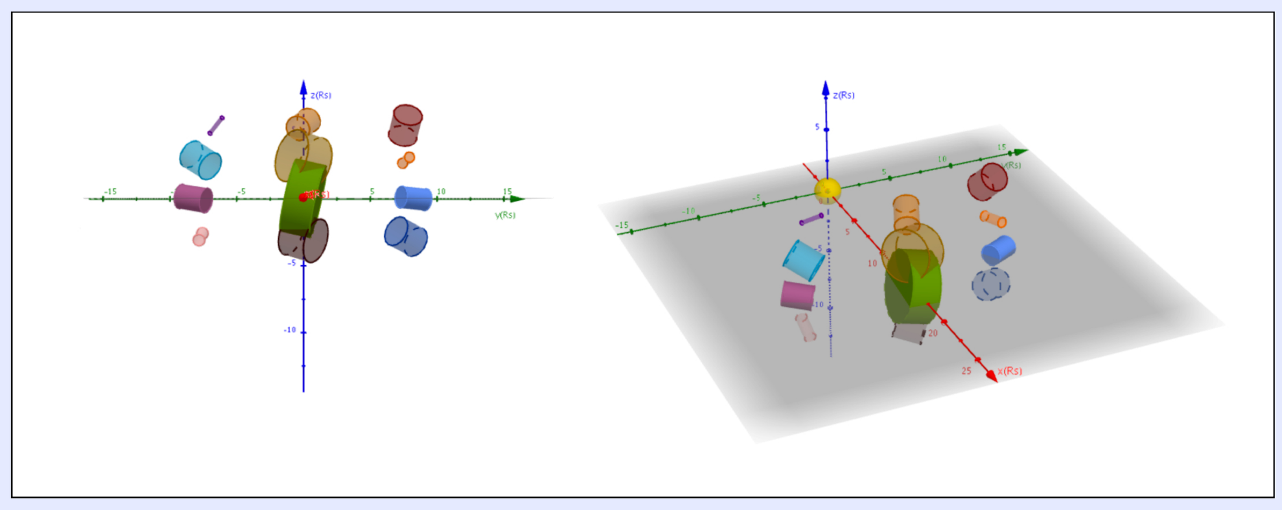
We perform reconstructions and fittings of the magnetic field in the two simulated CMEs and compare the outcome of the fitting techniques with the actual structure of the simulated CMEs. Reconstructions are performed at 12 different locations using the Grad–Shafranov reconstruction technique and a force-free fitting technique. These locations correspond to different impact parameters, as well as different longitudinal planes in the CME "legs."

Results

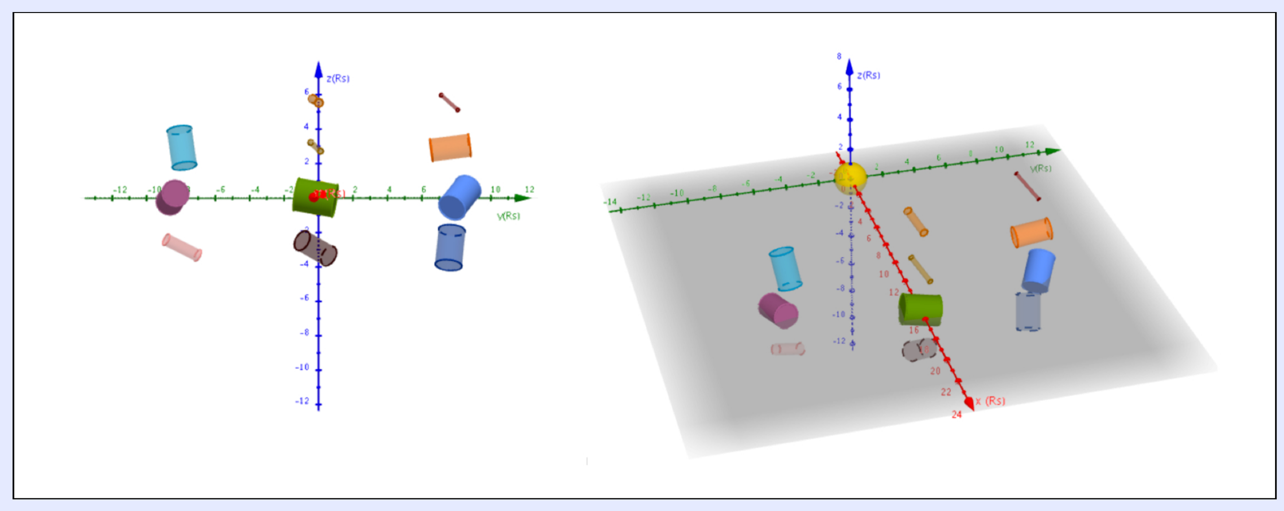
For all 12 cases, a "decent" reconstruction is obtained. All reconstructed magnetic structure have the same sign of helicity, have relatively low impact parameter (even when it should be high) and, correctly low inclination.

Combining 3 spacecraft within one longitudinal plane gives a more or less consistent picture of the global morphology. However, combining 3 spacecraft on different latitudes does not.

Applying the same test on the twisted flux rope CME yields comparable results: good reconstructions in the symmetry plane (ecliptic), good reconstruction of the impact parameter but poor reconstruction of the CME orientation when away from the ecliptic.



Global view of the reconstructed cases for the writhe simulation (top), and twist simulation (bottom). The left panel provides a front view, from the direction of the propagation of the CME, of the reconstructed cases. The right panel provides a top view.



Discussion & Conclusions

We have found that a writhed CME is nearly indistinguishable from a flux rope CME based on multi-spacecraft measurements. This is because (1) different measurements in the same latitudinal plane (parallel to the reconstructed CME axis) at low impact parameters are consistent with a twisted flux rope with a curved axis, and this is true for both types of CMEs; (2) measurements at high impact parameter are not consistent with a single flux rope, for both types of CMEs; and (3) measurements in different latitudinal planes at low impact parameters are approximately consistent with a flux rope with a radius of curvature becoming smaller for larger impact parameters. Therefore, we conclude that the fact that flux rope models of CMEs can fit most (or all) CME in situ measurements at 1au does not, in any way, preclude another magnetic morphology from doing so as well.

Evolution Of CME Properties In The Inner Heliosphere: Prediction For Solar Orbiter And Parker Solar Probe

Al-Haddad et al., *Astrophysical Journal*, 2019b

Project

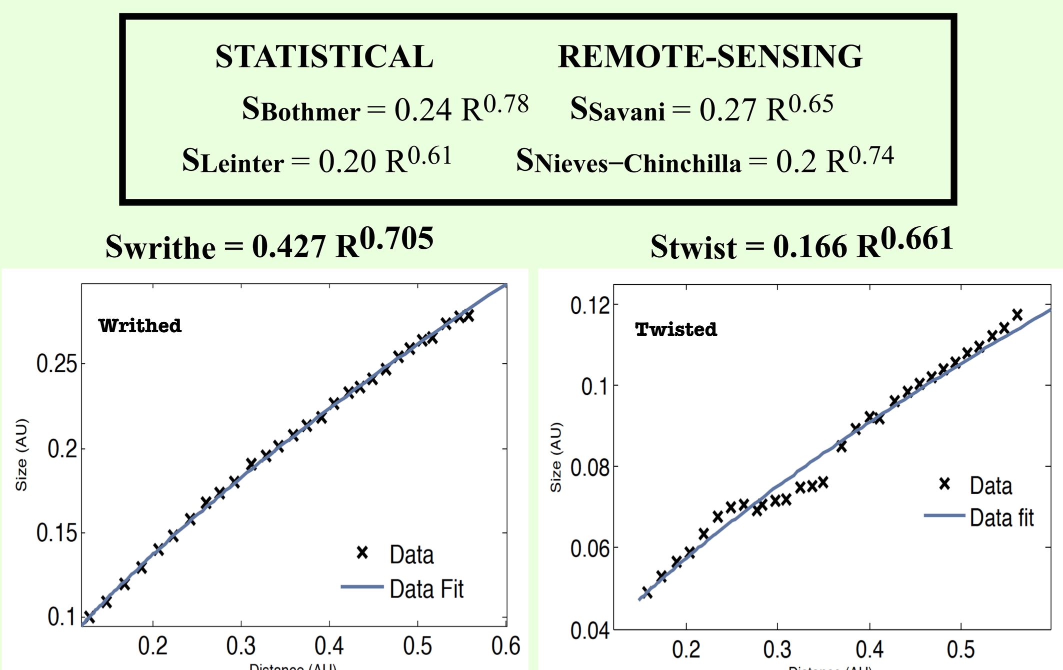
In this work, we describe the evolution of simulated CME data in the inner heliosphere. We focus on the properties of two CMEs initiated with writhed as well as twisted ejecta. We determine the radial evolution of the CME properties (size, speed, strength) and compare with results from statistical studies based on observations in the inner heliosphere by Helios and Messenger. We find that the evolution of the radial size and magnetic field strength is nearly indistinguishable for twisted flux rope as compared to writhed CMEs.

Radial Size of the CME

- CME radial size increases as the CME propagates. This is consistent with the CME staying in approximate total pressure balance with the solar wind.
- Results consistent with previous studies, primarily remote-sensing.

STATISTICAL	REMOTE-SENSING
$S_{Bothmer} = 0.24\ R^{0.78}$	$S_{Savani} = 0.27\ R^{0.65}$
$S_{Leinter} = 0.20\ R^{0.61}$	$S_{Nieves-Chinchilla} = 0.2\ R^{0.74}$

$S_{writhe} = 0.427\ R^{0.705}$ $S_{twist} = 0.166\ R^{0.661}$



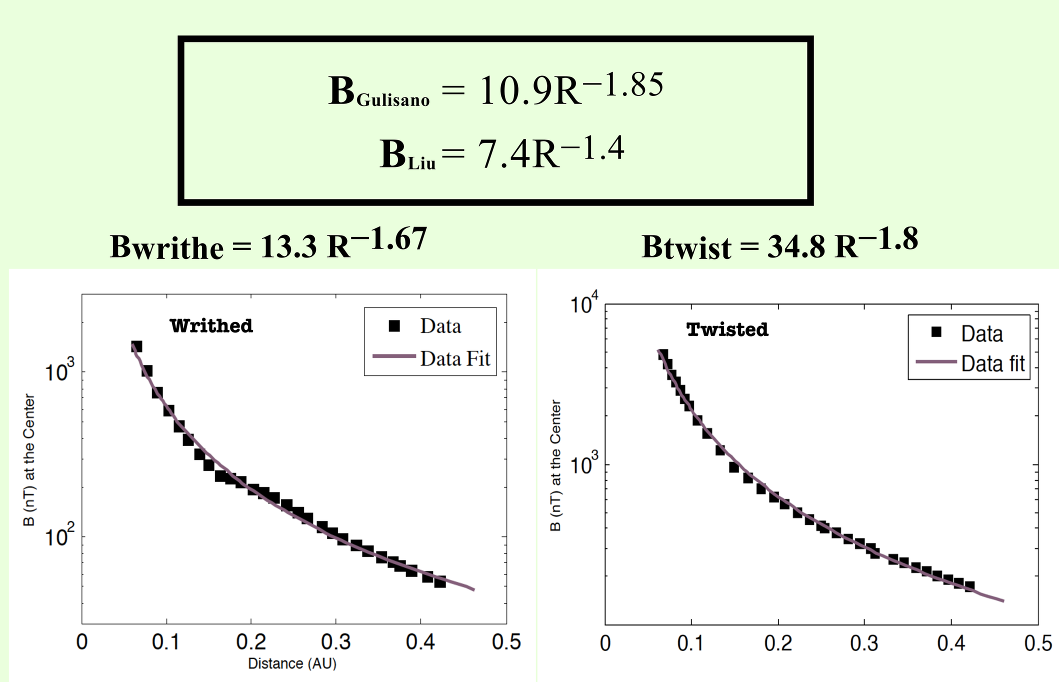
B at the Center of the CME

- CME magnetic field changes as it expands.
- It was shown theoretically, that, if $S \propto R^a$, then $B \propto R^{-2a}$ (Gulisano et al. 2010).
- Here, B decrease is slightly steeper.

$B_{Gulisano} = 10.9R^{-1.85}$

$B_{Liu} = 7.4R^{-1.4}$

$B_{writhe} = 13.3\ R^{-1.67}$ $B_{twist} = 34.8\ R^{-1.8}$



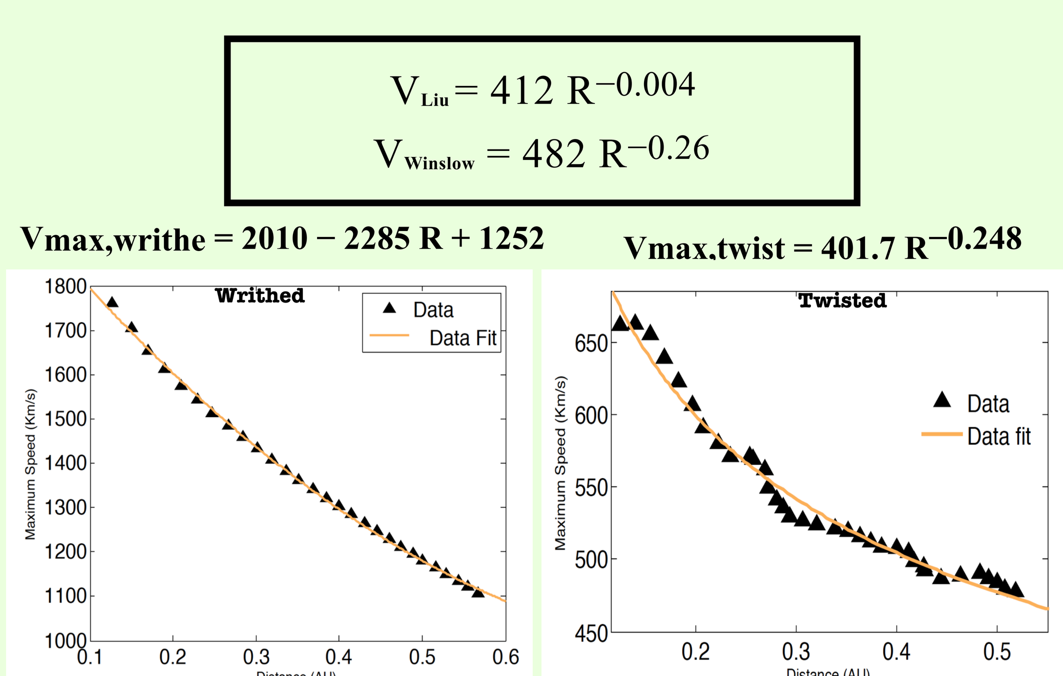
Maximum Speed of the CME

- Few studies have focused on CME speed.
- Many studies on individual events.
- Different functions for best-fit of twisted vs. writhed CME.

$V_{Liu} = 412\ R^{-0.004}$

$V_{Winslow} = 482\ R^{-0.26}$

$V_{max,writhe} = 2010 - 2285\ R + 1252$ $V_{max,twist} = 401.7\ R^{-0.248}$



Discussion & Conclusions

Results from simulations presented here are consistent with previous studies: based on statistical analysis and specific case studies. This is based on two simulations with different initiation mechanisms and different solar wind models. This is consistent with the fact that the evolution of the CME properties with radial distance is primarily constrained by the change in the solar wind and interplanetary magnetic field with distance, rather than the internal structure of the CME's magnetic field.