Study of the 3D CME geometry and kinematics using multiple viewpoints and uncertainty analysis.

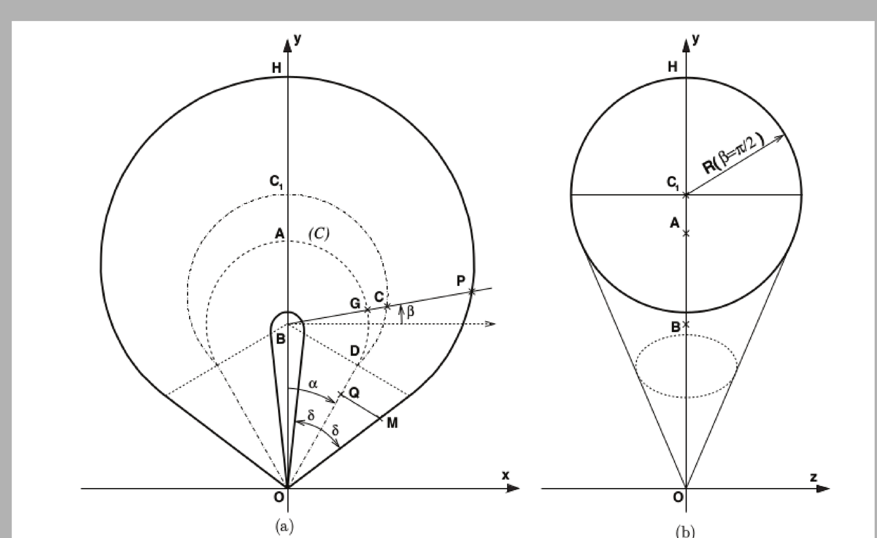
Eleni Nikou* & Jie Zhang

George Mason University, Department of Physics and Astronomy, 4400 University Drive, Fairfax, VA 22030, USA

*enikou@gmu.edu

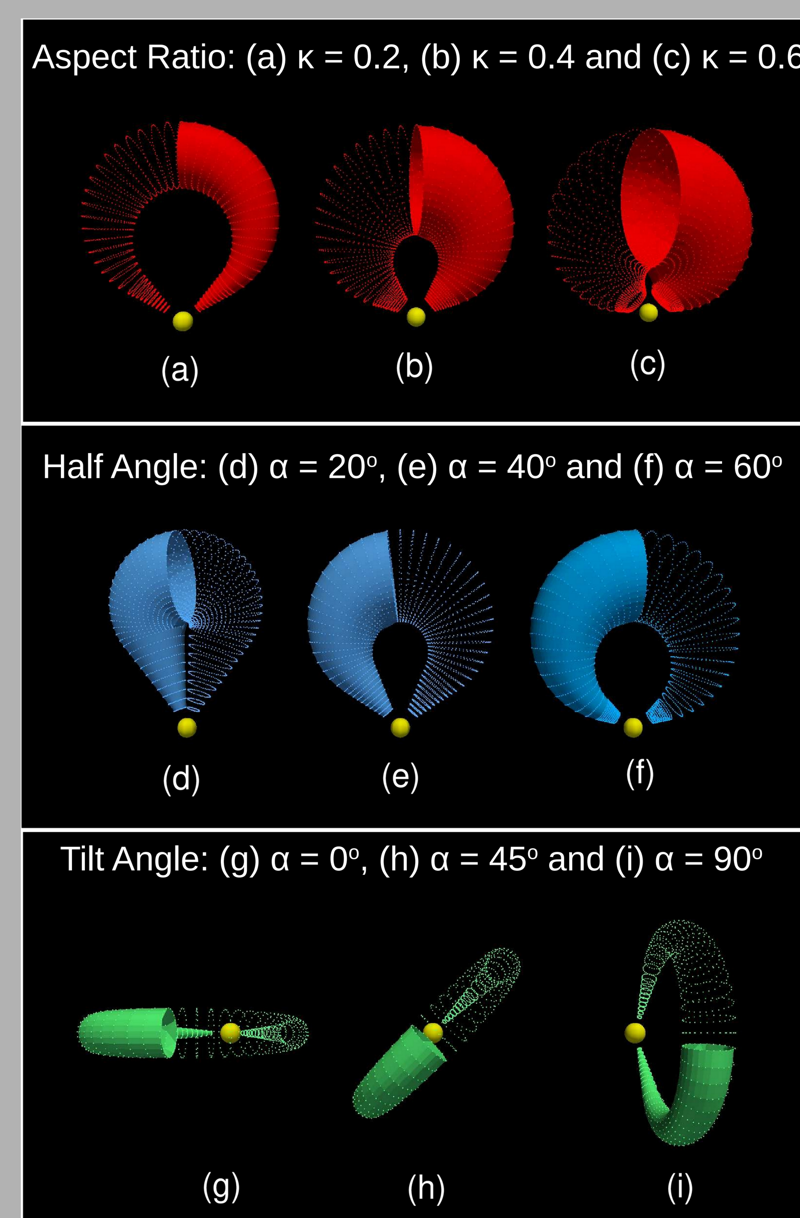
Abstract: Coronal mass ejections (CMEs) are large-scale solar eruptions that carry plasma and magnetic field into the interplanetary space. Studying their initial stages and evolution is of great importance since they are one of the space weather drivers. Most CMEs show a two front structure that consists of the ejecta and the shock. In this work we study the 3D evolution and kinematics of the ejecta in the outer corona using multi-viewpoint white light observations. COR2/ STEREO, C2 and C3/ LASCO data are used to study the CMEs. To track the CMEs we use a fitting tool that applies the MPFIT minimization IDL routine and combines multi-viewpoint observations with the Graduated Cylindrical Shell model (GCS model) point cloud to obtain the best values of the geometric parameters of each model along with their uncertainties. The evolution of the propagation direction and size of CMEs along with their uncertainties is analyzed and presented.

3D Forward Modeling of CMEs Graduated Cylindrical Shell Model (GCS model)

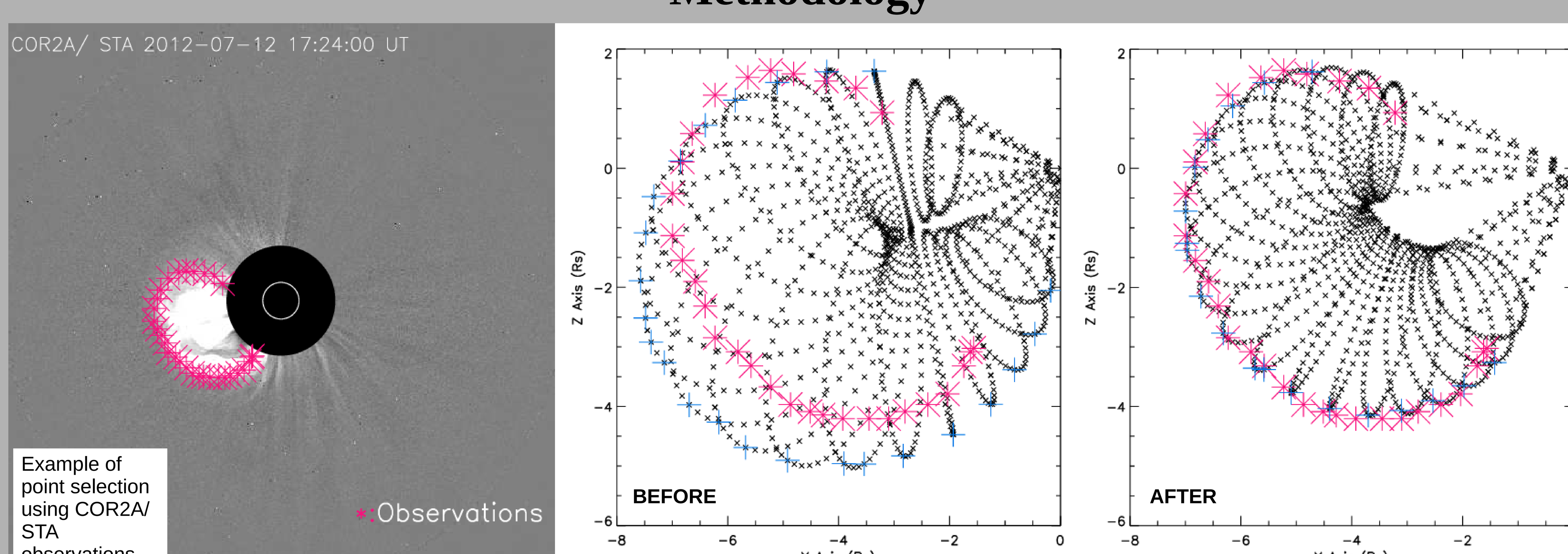


Face-on (a) and edge-on (b) cuts of the GCS model for the CME ejecta, (Thernisien et al. 2006, 2009, 2011). The GCS model depends on six free parameters that are responsible for its shape, propagation direction and orientation. The shape is defined by the leading edge height (h_l), aspect ratio (κ) and half angle (α). The propagation direction is defined by the longitude (φ) and latitude (θ) while the orientation by the tilt angle (γ). Image courtesy, Thernisien et al. 2011.

How do the GCS free parameters affect the shape of the ejecta?



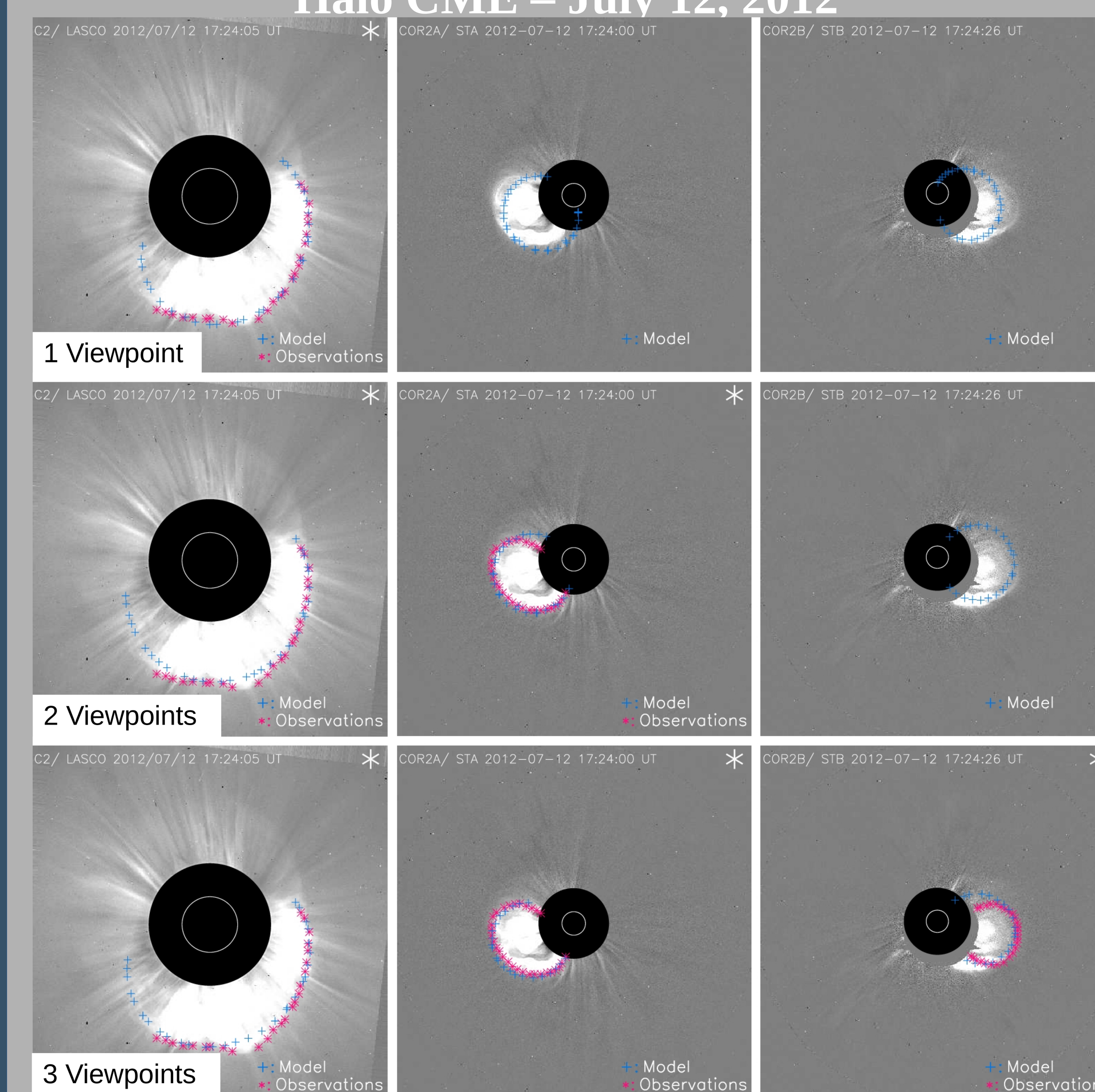
Methodology



We use the MPFIT IDL routine which performs Levenberg-Marquardt least-squares minimization, (Markwardt, C. B. 2009; https://pages.physics.wisc.edu/~craigm/idl/fitting.html) in order to find the best fitting values for each of the geometric parameters of the ejecta as described by the GCS model along with their uncertainties. Data from COR2A/ STA, COR2B/ STB and C2, C3/ LASCO have been used and in the following section the results after using this method are presented.

How does the number of viewpoints contribute to the uncertainties of the CME geometric parameters?

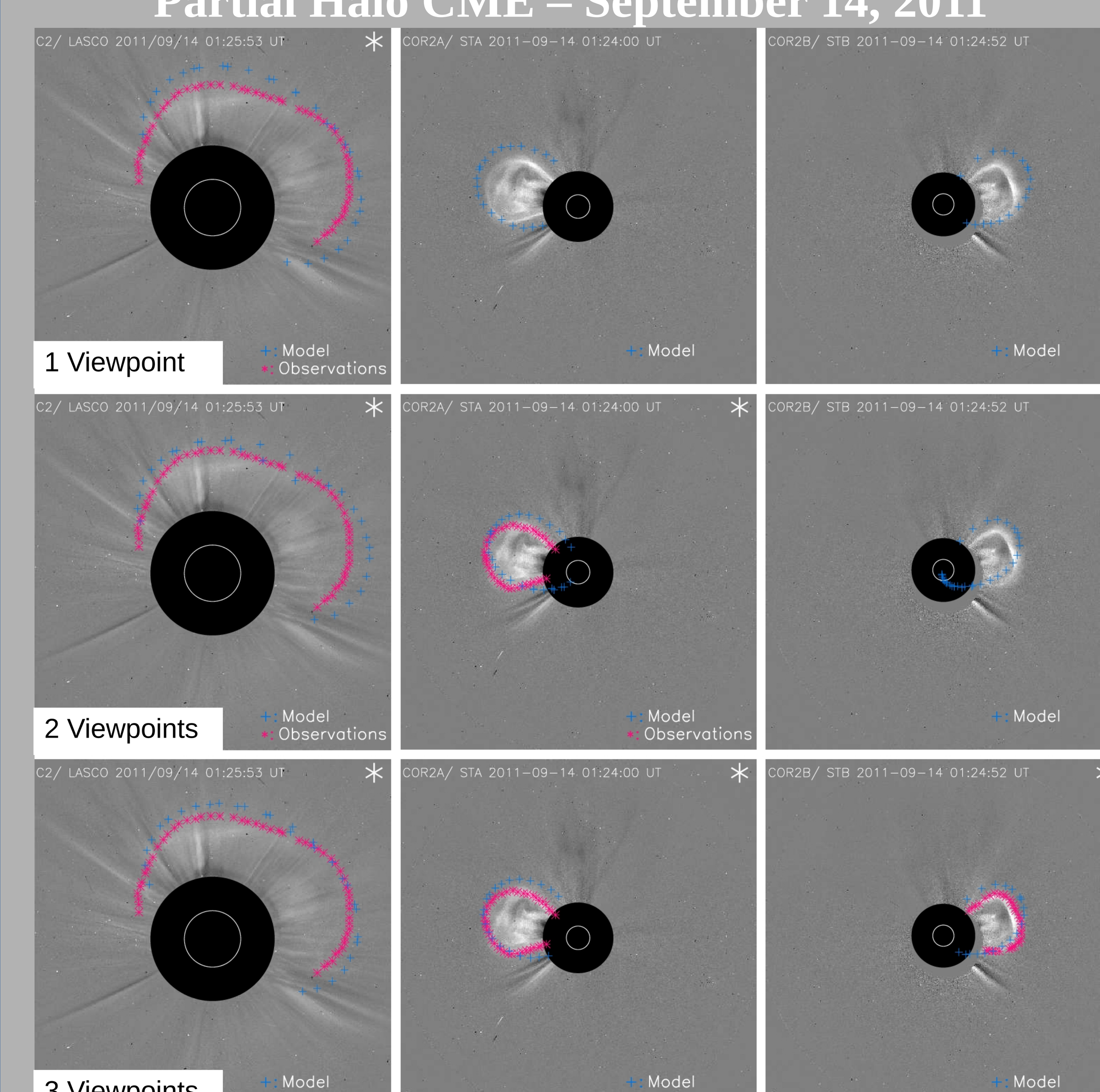
Halo CME – July 12, 2012



CME geometric parameter values along with their uncertainties for one, two and three viewpoints.

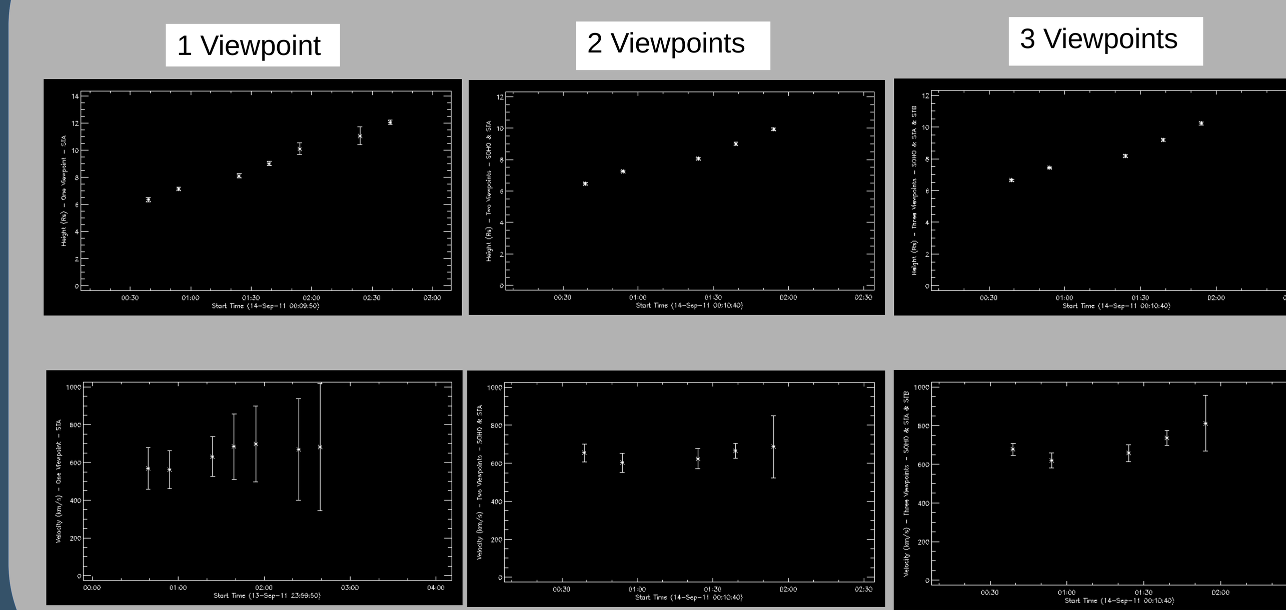
17:24 UT	Initial Guess	Longitude(deg) 20	Latitude (deg) -20	Tilt Angle (deg) 40	Height (Rs) 8	Aspect Ratio 0.4	Half Angle (deg) 40
Values							
	STA	STB	C2	STA+C2	STB+C2	STA+STB	STA+STB+C2
Longitude	9.57	-1.59	10.33	3.91	7.36	10.44	4.33
Latitude	-15.85	-19.60	-24.63	-13.98	-18.50	-14.56	-16.12
Tilt Angle	40.32	28.55	57.50	68.87	39.05	36.01	38.53
Height	7.48	7.95	6.55	7.48	8.37	7.76	7.64
Aspect Ratio	0.39	0.43	0.73	0.79	0.40	0.42	0.63
Half Angle	39.45	15.40	22.75	3.01	13.67	39.12	12.22
Uncertainties							
	STA	STB	C2	STA+C2	STB+C2	STA+STB	STA+STB+C2
Longitude	10.18	31.64	9.61	1.65	1.13	2.15	1.12
Latitude	1.90	3.33	12.12	0.94	0.85	0.72	0.73
Tilt Angle	6.03	21.45	0.02	5.57	6.43	0.16	0.18
Height	0.34	1.04	1.21	0.125	0.11	0.09	0.08
Aspect Ratio	0.13	0.096	0.35	0.001	0.00	0.05	0.0577
Half Angle	0.00	31.56	35.39	2.52	2.75	6.66	4.73

Partial Halo CME – September 14, 2011

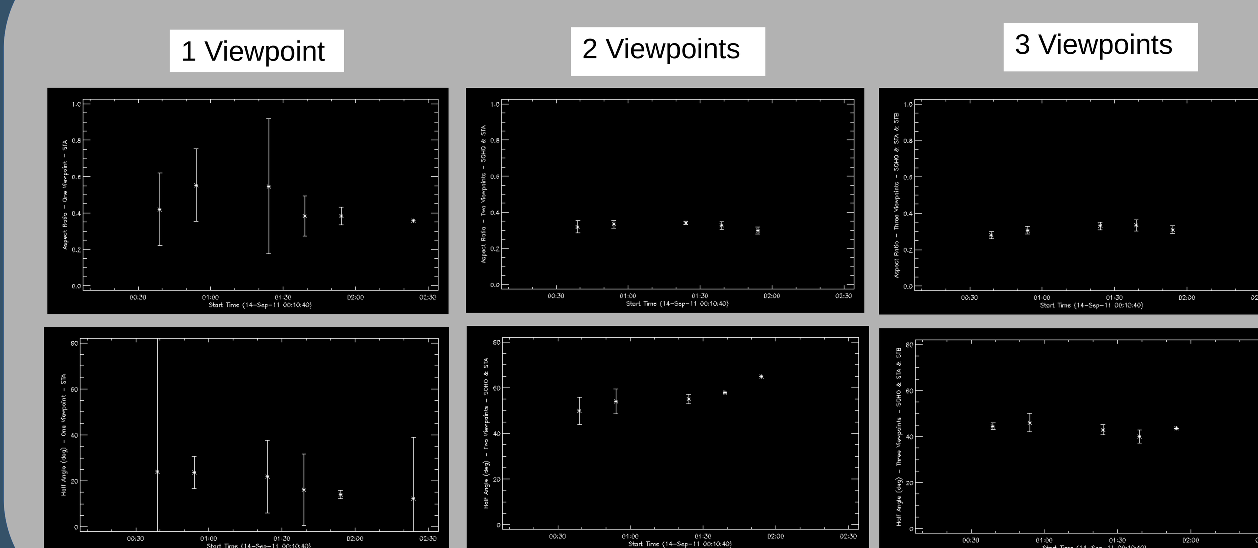


01:24 UT	Initial Guess	Longitude(deg) 15	Latitude (deg) 20	Tilt Angle (deg) -45	Height (Rs) 8	Aspect Ratio 0.35	Half Angle (deg) 25
Values							
	STA	STB	C2	STA+C2	STB+C2	STA+STB	STA+STB+C2
Longitude	17.06	18.10	17.10	22.54	18.90	11.56	18.80
Latitude	24.15	19.45	17.22	20.30	16.13	21.99	18.22
Tilt Angle	-41.74	0.68	-40.10	-31.16	-35.90	-39.27	-38.89
Height	8.03	7.96	9.03	8.23	8.77	7.96	8.48
Aspect Ratio	0.40	0.50	0.35	0.34	0.27	0.40	0.34
Half Angle	17.07	15.23	36.43	55.34	49.43	18.56	41.24
Uncertainties							
	STA	STB	C2	STA+C2	STB+C2	STA+STB	STA+STB+C2
Longitude	18.66	38.90	0.58	0.76	0.71	5.18	0.01
Latitude	2.22	4.58	0.92	0.62	0.01	0.84	0.56
Tilt Angle	32.50	20.79	1.45	1.31	1.44	0.19	1.57
Height	0.17	1.33	0.12	0.07	0.10	0.10	0.06
Aspect Ratio	0.37	0.14	0.01	0.01	0.03	0.09	0.02
Half Angle	15.82	42.86	1.25	2.05	3.43	13.60	2.30

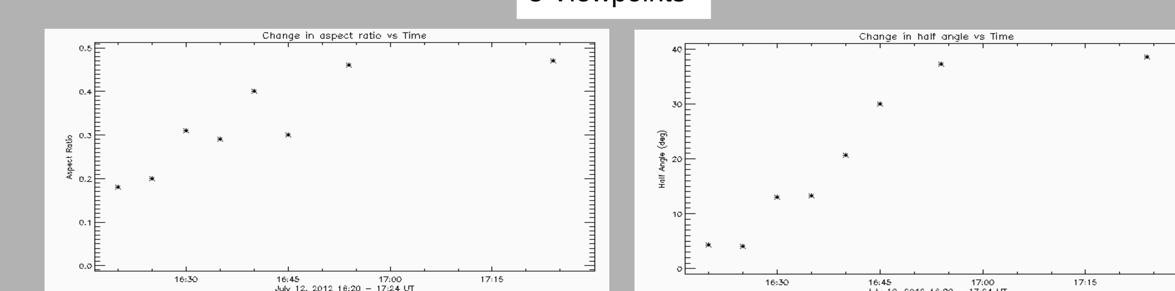
Kinematics – Partial Halo CME



CME size in the Outer Corona – Partial Halo



Bonus Graphs: How does the size of the July 12, 2012 CME in the inner corona change over time? Early evolution – Height < 8 Rs



Conclusions

- **Longitude** needs at least two viewpoints for an accurate measurement.
- **Latitude** can not be well determined using only SOHO/ LASCO in the case of a halo CME, but there are better results when STEREO is used, especially when the separation angle between the spacecraft and the Earth is ~90°.
- **Tilt angle** can be determined using SOHO/ LASCO in the case of halo CMEs, but can not be accurately determined using only STEREO.
- **Height** measurements show small uncertainty regardless of the number of viewpoints, although having three viewpoints gives us the most accurate measurement, but calculating velocities using only one viewpoint results in high errors.
- **Aspect ratio** and **Half angle** need at least two viewpoints for an accurate measurement.

- CMEs in the outer corona expand in a self-similar way.
- During the early CME evolution, both aspect ratio and half angle increase over time in the current Sun-centered GCS model and this needs to be taken into consideration when focusing on its initial stages.
- More CMEs are being analyzed and the results will be available in the near future.

Acknowledgement

EN is supported by the DKIST Ambassadors program. Funding for the DKIST Ambassadors program is provided by the National Solar Observatory, a facility of the National Science Foundation, operated under Cooperative Support Agreement number AST-1400405.