Characterization of Coronal Mass Ejection Deflection using Coronagraph Image Sequences

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Motivation

- When analyzing CMEs in real time for space weather forecasting, a lack of sufficient coronagraph images can make it difficult to determine the CME's longitude.
- In these cases, usually the location of strong disk signatures (for example, an associated flare) is used to estimate the CME's propagation direction.
- Although not an unreasonable assumption, many observational and modeling studies have shown that CMEs can deflect by ten or more degrees from the source location.
- Results from CME ensemble modeling by the NASA/GSFC Space Weather Research Center show that variation of the CME's position by ten degrees can change the arrival time at 1 AU by several hours.
- To date there has not been a statistical analysis of measured near-Sun CME 3D deflection using STEREO – that I am aware of…

Procedures and Tools

- CCMC's DONKI – searched CMEs during 2010-2014
- Selection criteria
  1. CMEs with speeds greater than 1,000 km/s
  2. Isolated event – not overlapping with another CME
  3. Each event had to have a minimum of six images in two out of three SC (SOHO, STEREO A and B)
  4. Pairs of images from different spacecraft must have less than a ten minute time difference
  5. We want a range of CME widths and positions, so we did not restrict these parameters.

Procedures and Tools

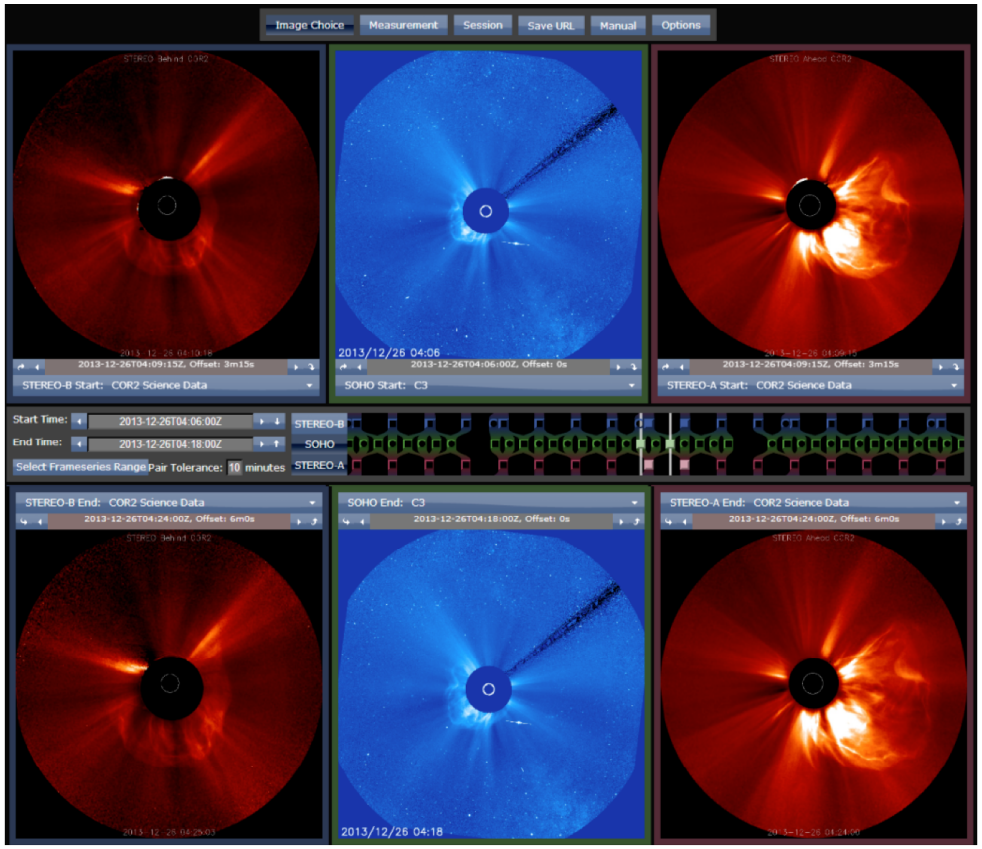
- 18 events:
  - Speeds 1,000 – 2,950 km/s
  - Widths 56-184°
  - Range of positions

DONKI Activity ID*	DONKI Speed *(km/s)*	DONKI Longitude	DONKI Latitude	DONKI Width
Year 2012 – 8 Events				
01-02T15:12	1152	99	-17	100
01-23T04:00	2211	26	41	124
01-26T05:30	1082	72	60	60
03-04T11:24	1540	-48	25	120
06-14T14:09	1364	-9	-20	100
07-12T16:54	1480	6	-9	150
07-17T14:25	1100	54	-30	90
07-23T02:36	2930	138	-10	160
Year 2013 – 10 Events				
03-23T12:39	1200	168	-30	56
04-21T16:39	1000	100	10	80
05-13T02:54	1200	-94	20	60
05-17T09:24	1400	-40	13	96
06-13T04:09	1253	171	-25	86
07-22T06:24	1000	157	30	140
08-17T19:24	1081	73	-15	82
11-07T10:39	2100	-135	-13	184
12-12T03:54	1060	51	-31	80
12-26T03:40	1600	-134	-31	180

Important: DONKI entries are (near) real time measurements; in this study we have STEREO science data - building another database of manual CME measurements

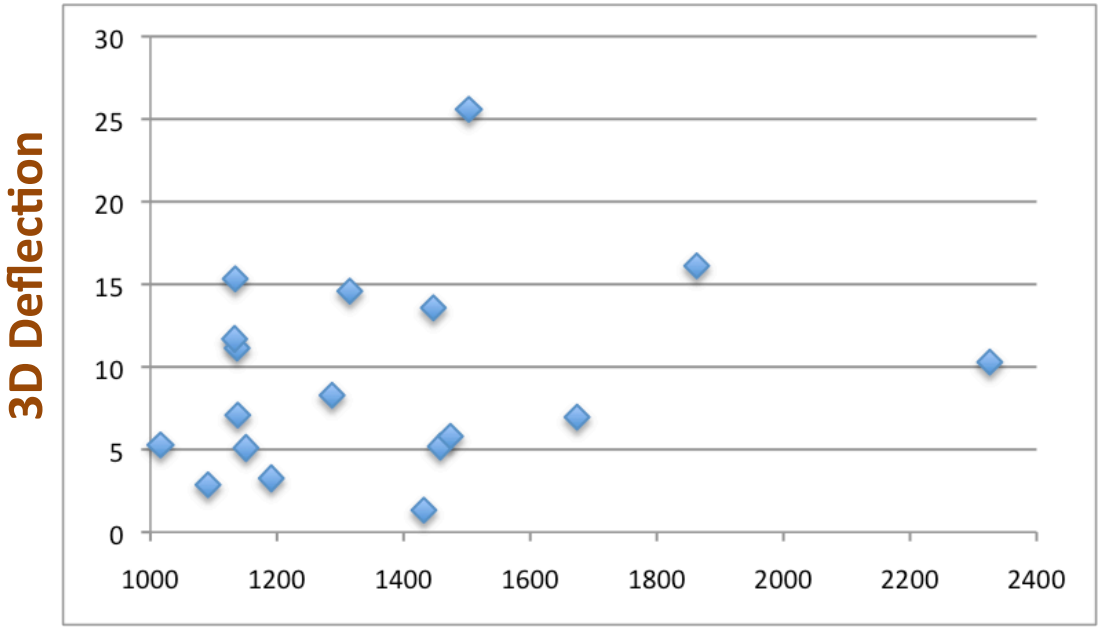
Procedures and Tools

- StereoCat – CCMC triangulation tool; cone model
  - Frameseries mode: width is allowed to vary with time
- We assume that a change in position is deflection
  - Not accounting for rotation or non-uniform expansion



Initial strategy - avoid the halo SC, not much more to it
(will come back to this later)

Preliminary Results I:
Deflection (in corona) and Average CME Speed

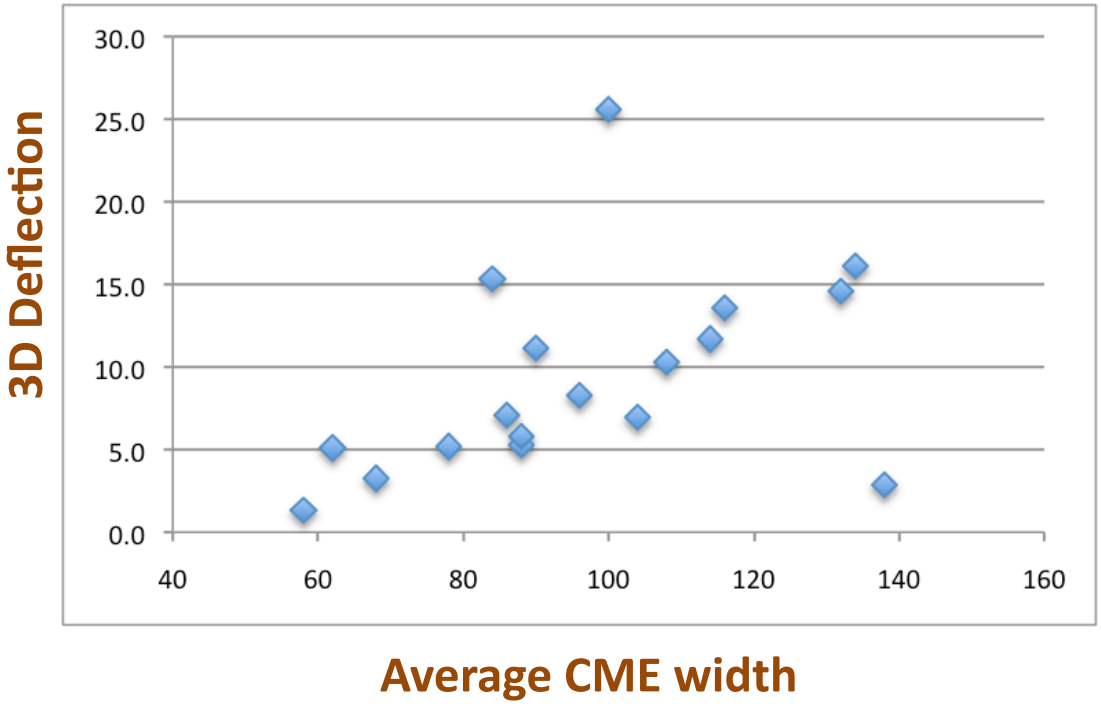


	Average Speed	Deflection
01-02T15:12	1134	15.3
01-23T04:00	1503	25.6
01-26T05:30	1138	7.1
03-04T11:24	1447	13.6
06-14T14:09	1287	8.3
07-12T16:54	1458	5.2
07-17T14:25	1016	5.3
07-23T02:36	2326	10.3
03-23T12:39	1191	3.3
04-21T16:39	1151	5.1
05-13T02:54	1674	7.0
05-17T09:24	1474	5.8
06-13T04:09	1432	1.3
07-22T06:24	1091	2.9
08-17T19:24	1137	11.1
11-07T10:39	1863	16.1
12-12T03:54	1133	11.7
12-26T03:40	1315	14.6

Due to availability of overlapping images between the different spacecraft, the height of the first and last measurements varies between events.

- Three events with <5 degrees; 8 events with >10 degrees; 1 event >20 degrees
- Lots of scatter – as to be expected

Preliminary Results II:
Deflection (in corona) and Average CME Width

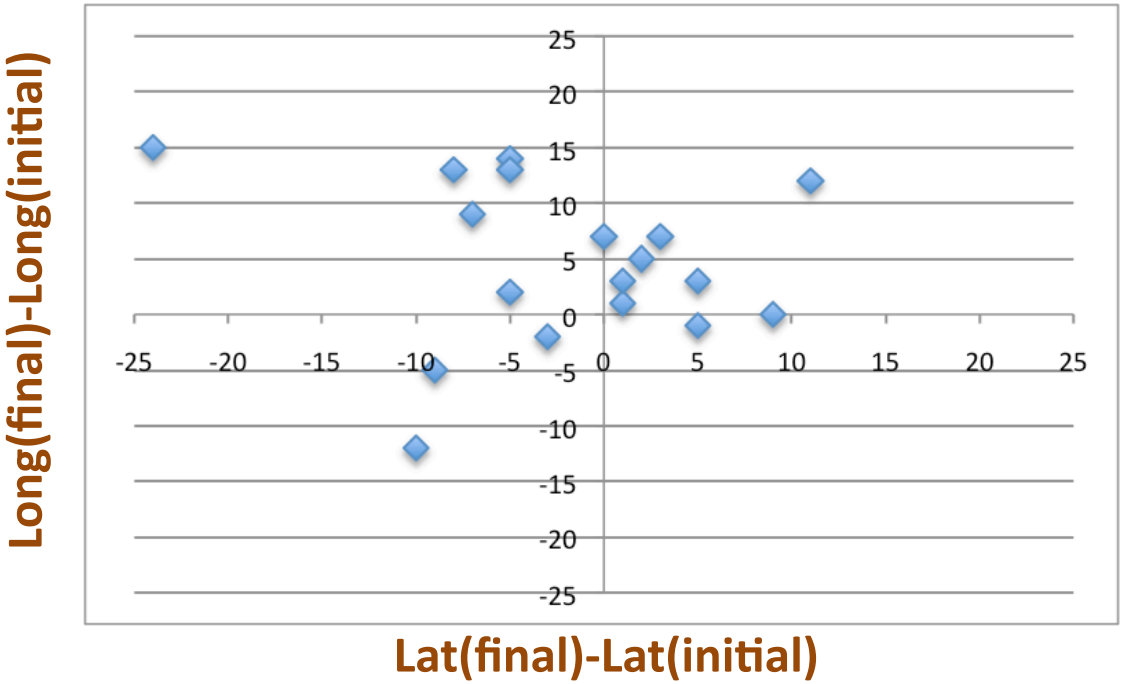


	Average Width	Deflection
01-02T15:12	84	15.3
01-23T04:00	100	25.6
01-26T05:30	86	7.1
03-04T11:24	116	13.6
06-14T14:09	96	8.3
07-12T16:54	78	5.2
07-17T14:25	88	5.3
07-23T02:36	108	10.3
03-23T12:39	68	3.3
04-21T16:39	62	5.1
05-13T02:54	104	7.0
05-17T09:24	88	5.8
06-13T04:09	58	1.3
07-22T06:24	138	2.9
08-17T19:24	90	11.1
11-07T10:39	134	16.1
12-12T03:54	114	11.7
12-26T03:40	132	14.6

Due to availability of overlapping images between the different spacecraft, the height of the first and last measurements varies between events.

- Better trend than seen for CME speed

Preliminary Results III:
Change in Latitude and Change in Longitude



	dLat	dLong
01-02T15:12	-10	-12
01-23T04:00	-24	15
01-26T05:30	3	7
03-04T11:24	-5	14
06-14T14:09	9	0
07-12T16:54	-5	2
07-17T14:25	2	5
07-23T02:36	-9	-5
03-23T12:39	-3	-2
04-21T16:39	5	-1
05-13T02:54	0	7
05-17T09:24	5	3
06-13T04:09	1	1
07-22T06:24	1	3
08-17T19:24	-7	9
11-07T10:39	11	12
12-12T03:54	-5	13
12-26T03:40	-8	13

Due to availability of overlapping images between the different spacecraft, the height of the first and last measurements varies between events.

- Lots of scatter

Coronal Hole Influence Parameter (CHIP)

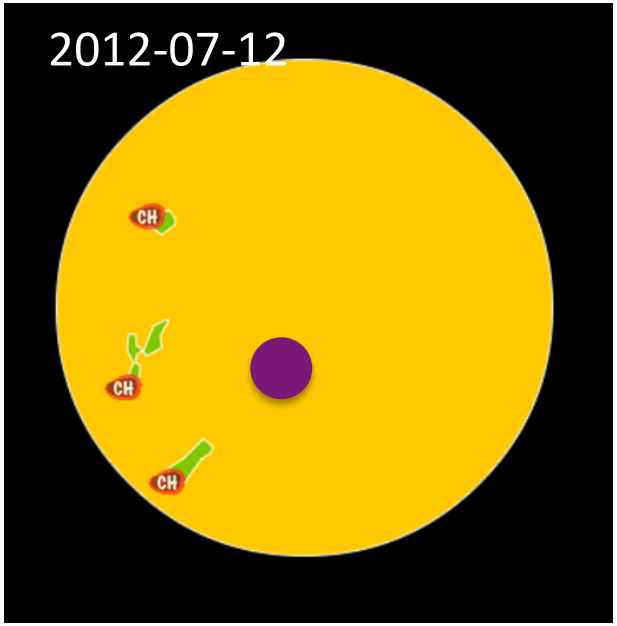
$$\boldsymbol{F} = \sum_{\mathrm{CHs}} \boldsymbol{f} = \frac{\langle B \rangle A}{d^2} \hat{\boldsymbol{e}},$$

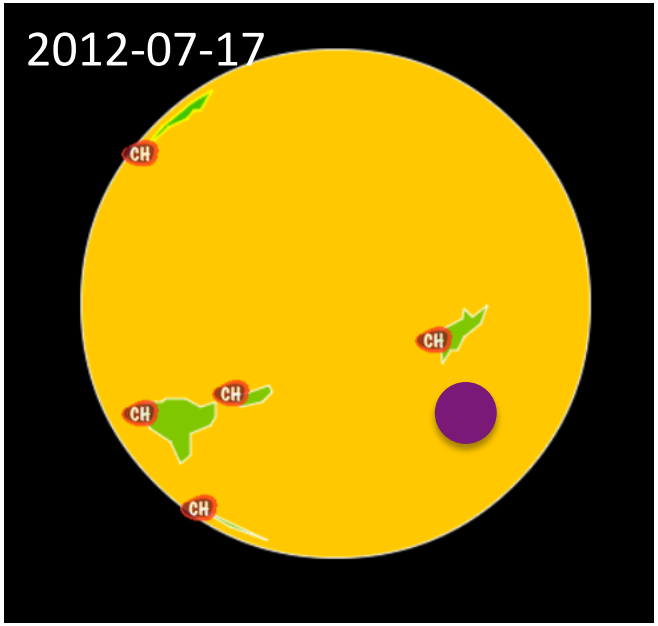
- Can explain how disk-center source locations of CMEs lack flux rope signatures at Earth – deflected away to give glancing blow like limb CME
- Published results for CMEs in Solar Cycle 23 - we need more recent events in order to compare…

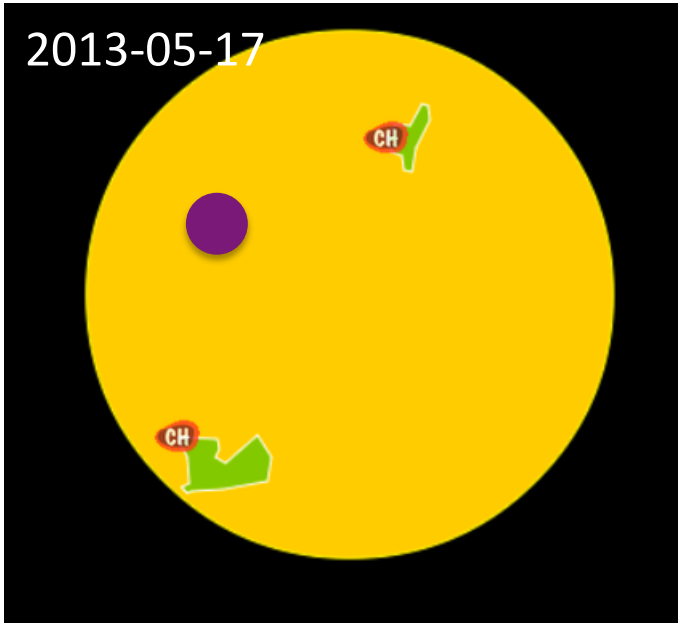
Gopalswamy et al. 2009, Mohamed et al. 2012, Makela et al. 2013

Weak Deflection (< 5°)

Purple circle is average lat/long in corona, not source location!



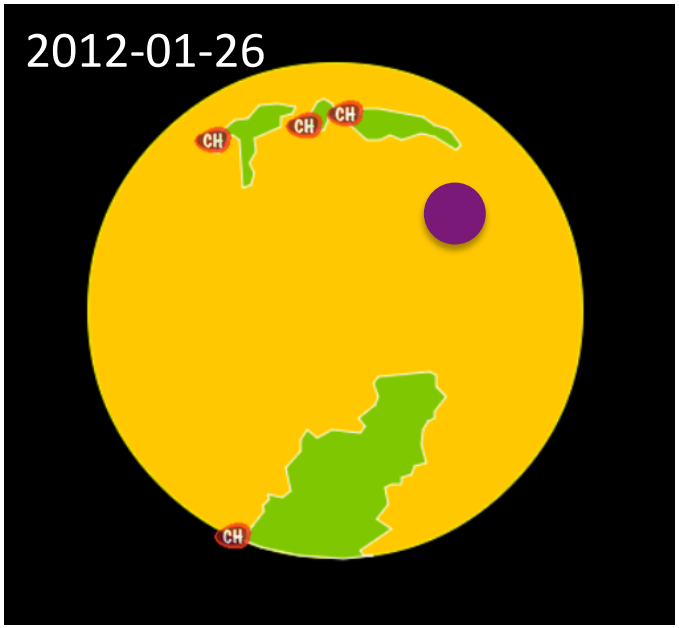


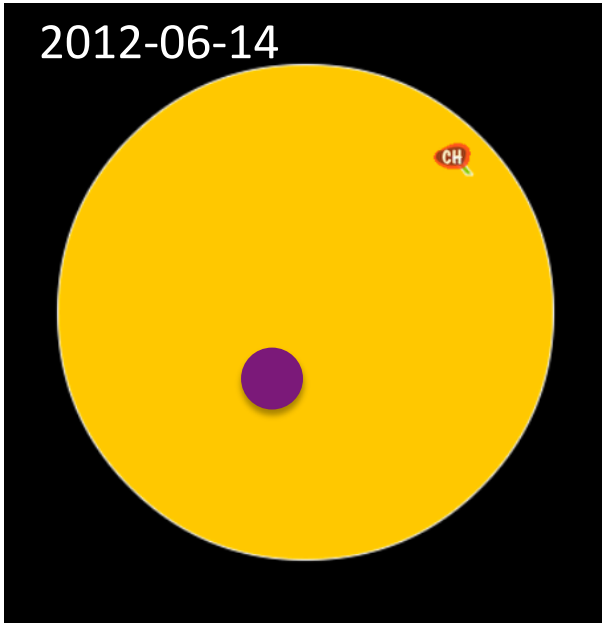


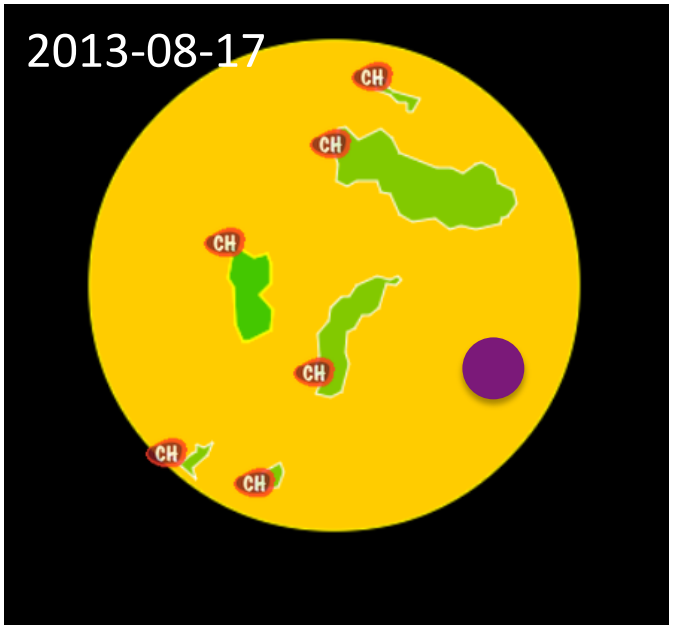
Deflection	**5.2**	**5.3**	**5.8**
Lat, Long	**-16, -5**	**-31, 48**	**12, -44**

Moderate Deflection

Purple circle is average lat/long in corona, not source location!



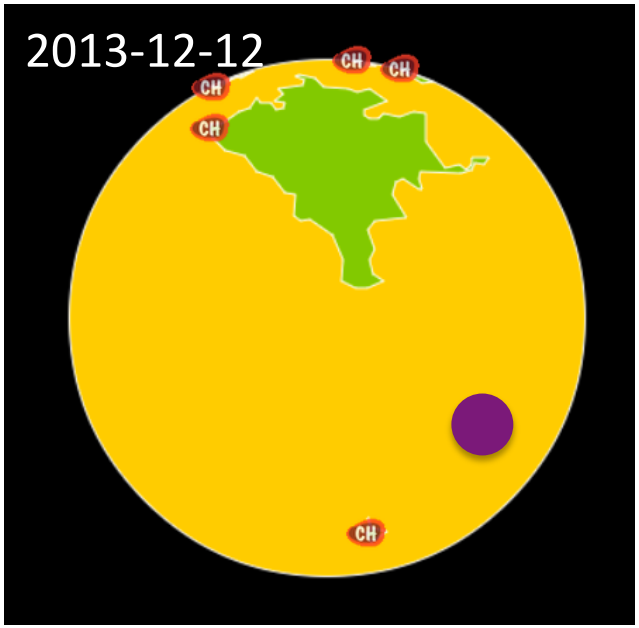


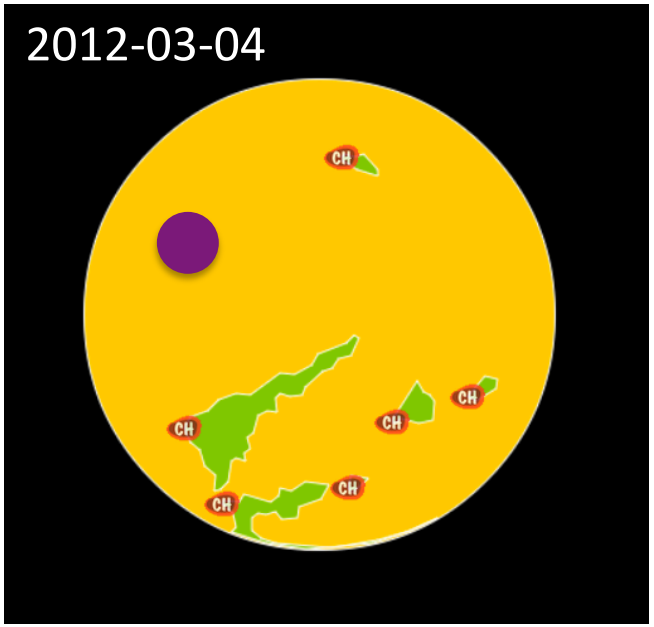


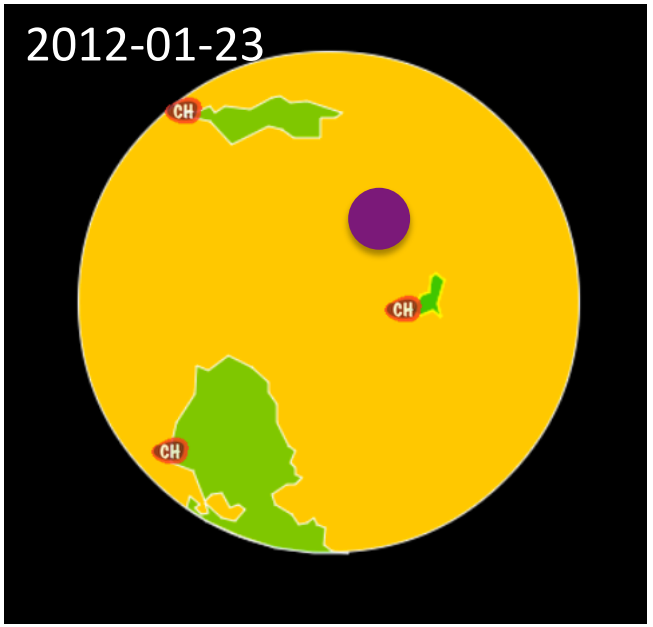
Deflection	**7.1**	**8.3**	**11.1**
Lat, Long	**68, 69**	**-24, -3**	**-16, 68**

Moderate to Strong (> 20°) Deflection

Purple circle is average lat/long in corona, not source location!







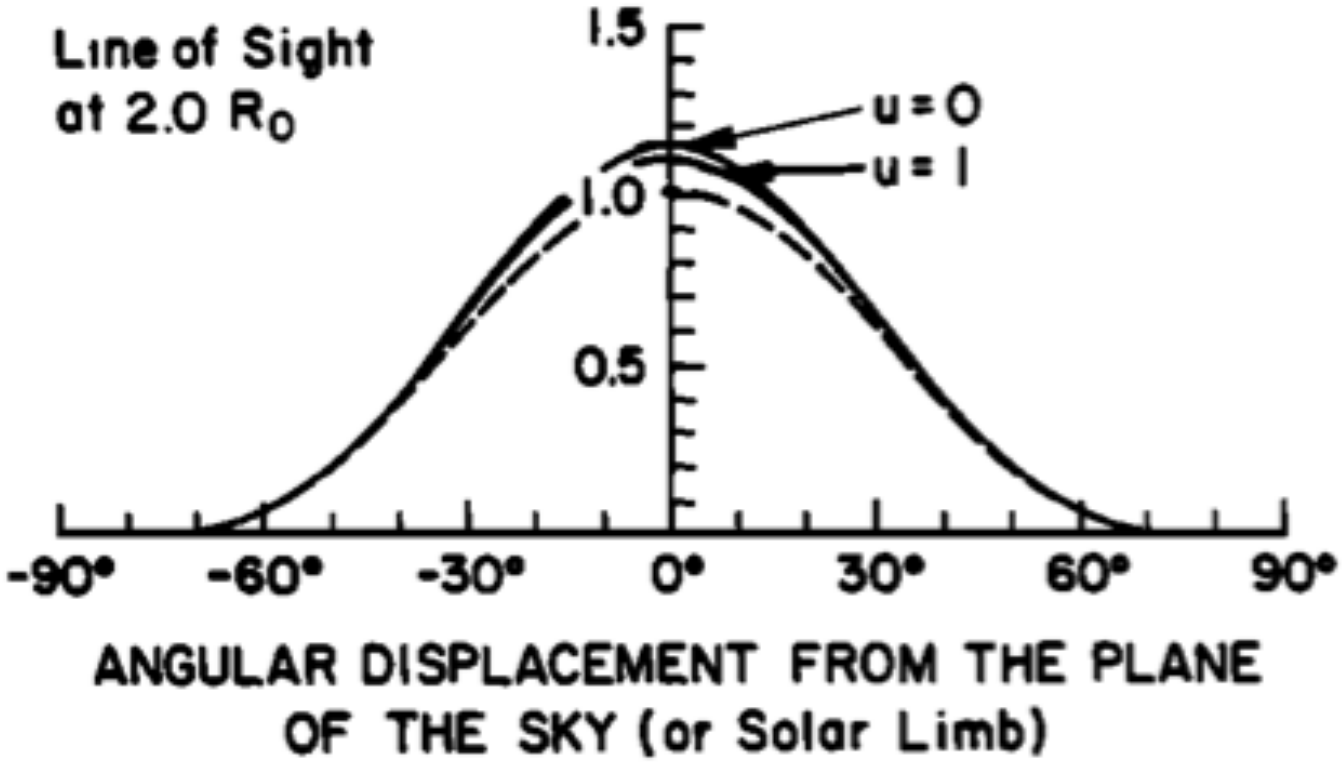
Deflection	**11.7**	**13.6**	**25.6**
Lat, Long	**-36, 55**	**24, -54**	**27, 13**

Barbara Thompson's slide!

Another factor to consider: *What part of the CME can be seen?*

Hundhausen et al. 1993: scattering efficiency of a point as a function of angle from the plane of the sky. Curve is normalized relative to plane of sky scattering from "point source" Sun.
A feature 30° out of the plane of the sky has only half the overall scattering amplitude of a feature in the plane of the sky. For points >45° , scattering amplitude is very low.

Features* >60° *away will not be seen in coronagraph images, and are effectively invisible.



Introducing a Confidence Factor (?)

- Not in selection criteria, but will introduce for new events

Separation between CME and SC POS:
<15° = High
15-30° = Medium
>30° = Low

Spacecraft 2 \ Spacecraft 1	High	Medium	Low
High			
Medium	1	1	
Low	4	10	2

DONKI Activity ID*	Separation to POS for SC1, SC2, SC3	DONKI Speed *(km/s)*	DONKI Longitude	DONKI Latitude	DONKI Width
Year 2012 – 8 Events					
01-02T15:12	SOHO 9.0 STB 59.9 STA 81.4	1152	99	-17	100
01-23T04:00	STA 7.8 STB 49.6 SOHO 64.0	2211	26	41	124
01-26T05:30	SOHO 18.0 STA 53.8 STB 84.0	1082	72	60	60
03-04T11:24	STB 20.5 SOHO 42.0 STA 67.3	1540	-48	25	120
06-14T14:09	STB 17.4 STA 36.7 SOHO 81.0	1364	-9	-20	100
07-12T16:54	STA 24.4 STB 31.1 SOHO 84.0	1480	6	-9	150
07-17T14:25	STA 23.2 SOHO 36.0 STB 78.9	1100	54	-30	90
07-23T02:36	STB 17.2 SOHO 48.0 STA 73.32	2930	138	-10	160
Year 2013 – 10 Events					
03-23T12:39	STB 39.0 STA 54.1 SOHO 78.0	1200	168	-30	56
04-21T16:39	SOHO 10 STB 27.9 STA 55.7	1000	100	10	80
05-13T02:54	SOHO 4.0 STA 39.7 STB 42.2	1200	-94	20	60
05-17T09:24	STB 11.7 SOHO 50.0 STA 86.7	1400	-40	13	96
06-13T04:09	STB 41.4 STA 58.3 SOHO 81.0	1253	171	-25	86
07-22T06:24	STB 25.3 SOHO 67.0	1000	157	30	140

Future Work

- Add more events to test trends
- Getting at the physical explanation for the trends by a detailed coronal hole analysis study with Karin Muglach
- Separation of rotation, expansion, deflection…Teresa?

- Use the results of this study to select appropriate ranges of latitudes and longitudes in CME ensemble modeling based on CME speed, width, location, and
- How to incorporate coronal hole observations more systematically in real time CME analysis for space weather forecasting?