Automated Kinematics Analysis of Off-Limb Coronal Bright Fronts

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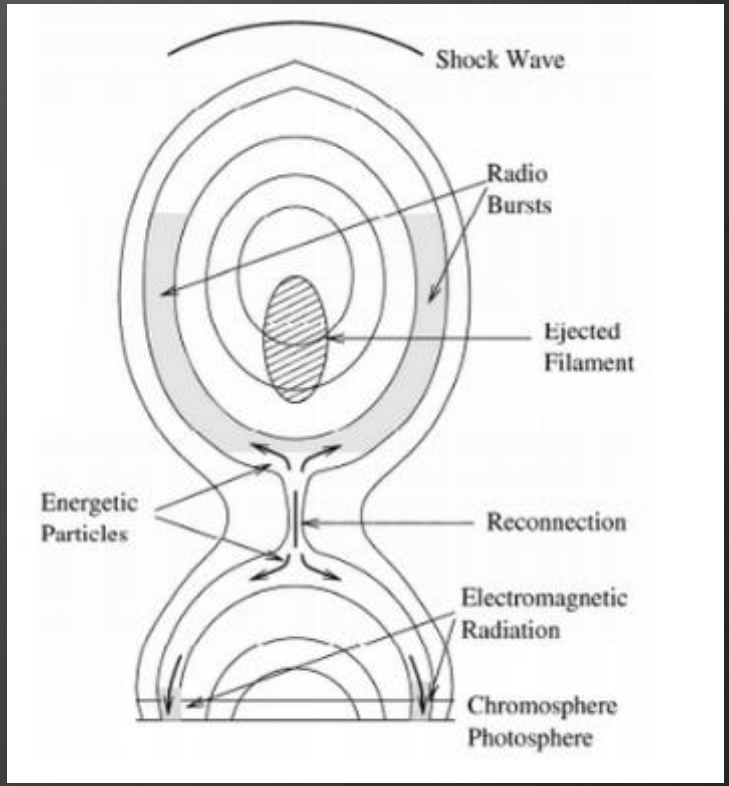
Outline

- Introduction to Coronal Bright Fronts (CBFs)
- Automatic Processing Procedures
  - Radial Wave Kinematics
  - Tangential Wave Kinematics
- Current Kinematics Information
- Next Steps with Geometric CBF Models
- Summary

Coronal Mass Ejections

- Massive solar explosions
- Can drive shock waves
- Release broadband electromagnetic radiation, including drifting radio bursts
- Release a cloud of charged particles
- Can couple with Earth's magnetic field



From *Space Physics: An Introduction to Plasmas and Particles in the Heliosphere and Magnetospheres,* Kallenrode (p. 192)

Solar Energetic Particle (SEP) Events

- Particles (mostly protons) accelerated by the CME
- Gain their energy from shocks very close to the sun, and/or interplanetary space
- Energetic particles can damage satellites and irradiate astronauts or polar airline routes
- Understanding CME shock kinematics is key in predicting and making informed decisions regarding SEP events

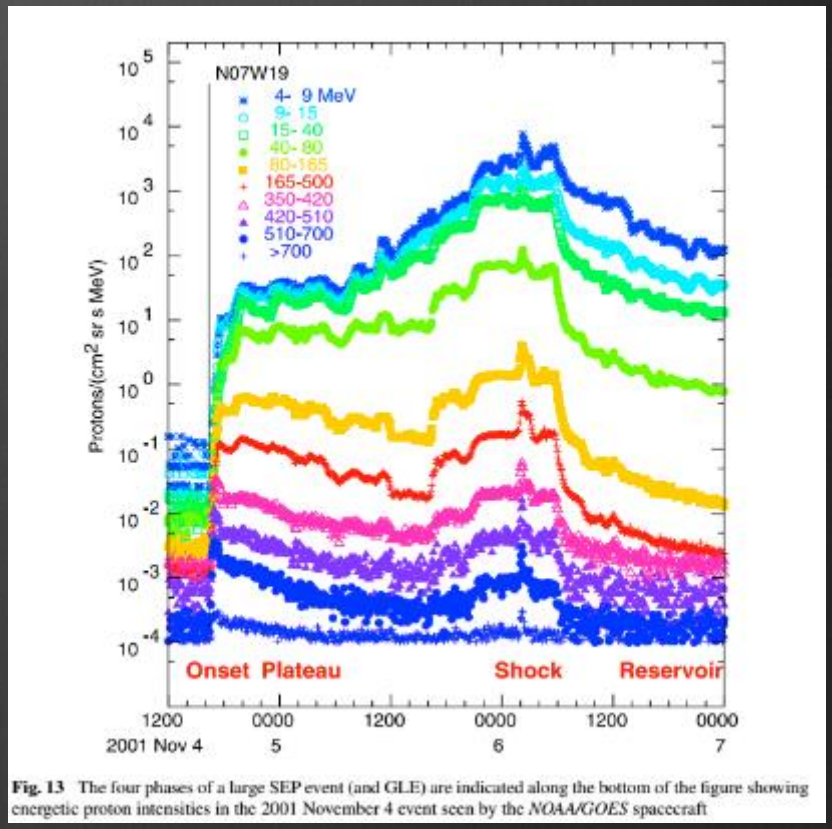
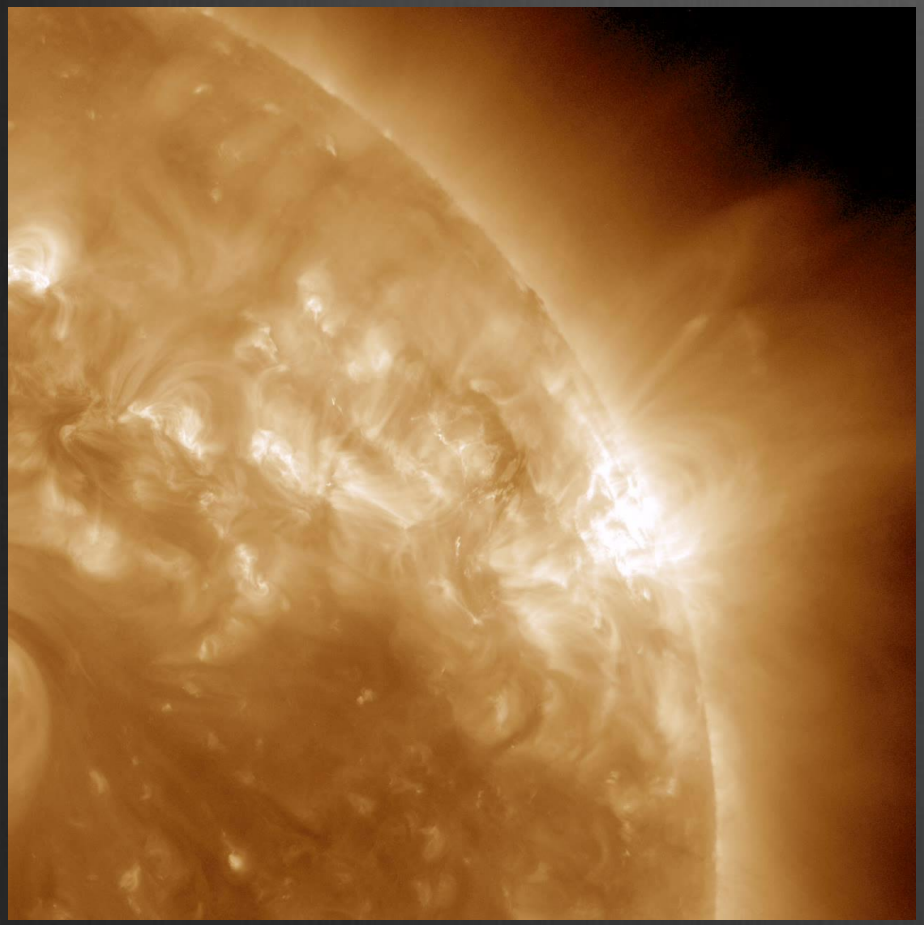


Fig. 13 The four phases of a large SEP event (and GLE) are indicated along the bottom of the figure showing energetic proton intensities in the 2001 November 4 event seen by the *NOAA/GOES* spacecraft

From D. Reames, Space Sci. Rev., **22** (2013)

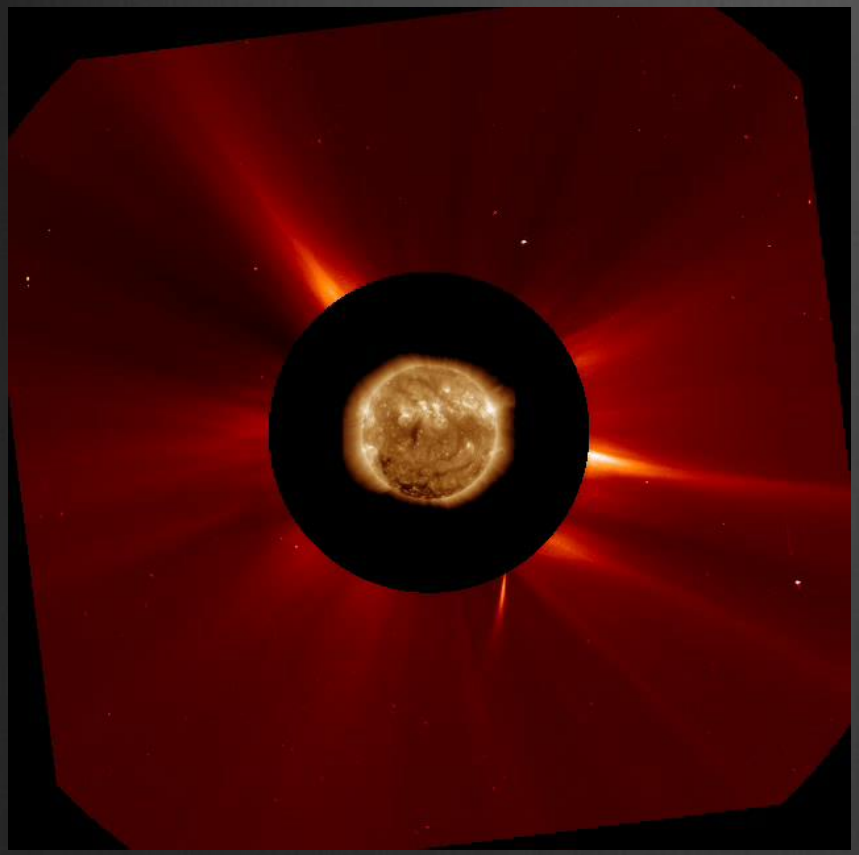
Coronal Bright Fronts (CBFs)



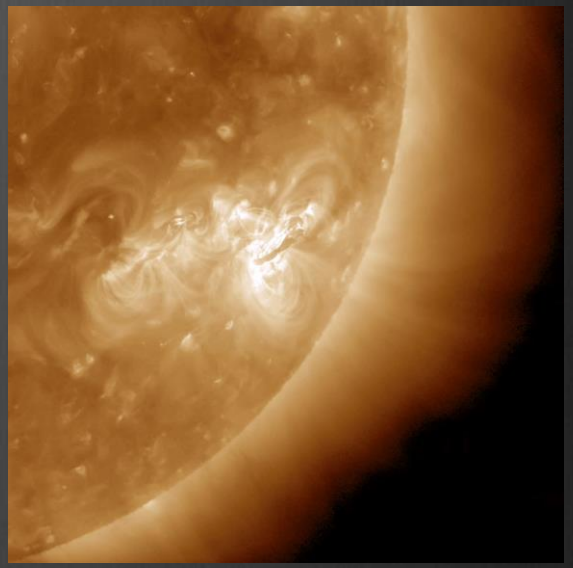
- Observed primarily in the 193 and 211 Å bands of the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO)
- Result of a compressive or shock wave in the low corona, driven by CMEs
- How efficient are these waves at accelerating particles to SEP energies?
- Our project aims to characterize off-limb CBF kinematics using automated image processing techniques

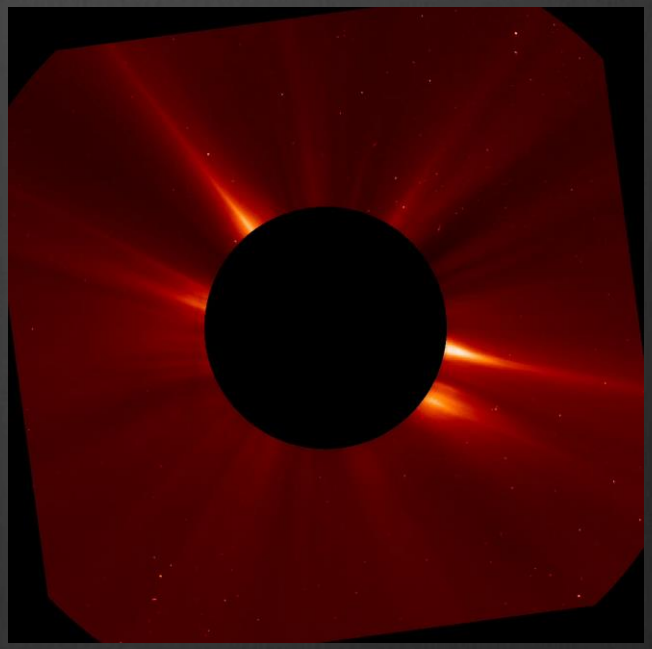
Coronal Bright Fronts (CBFs)

May 11, 2011 CBF Event LASCO C2



June 7, 2011
CBF Event
AIA 193 Å

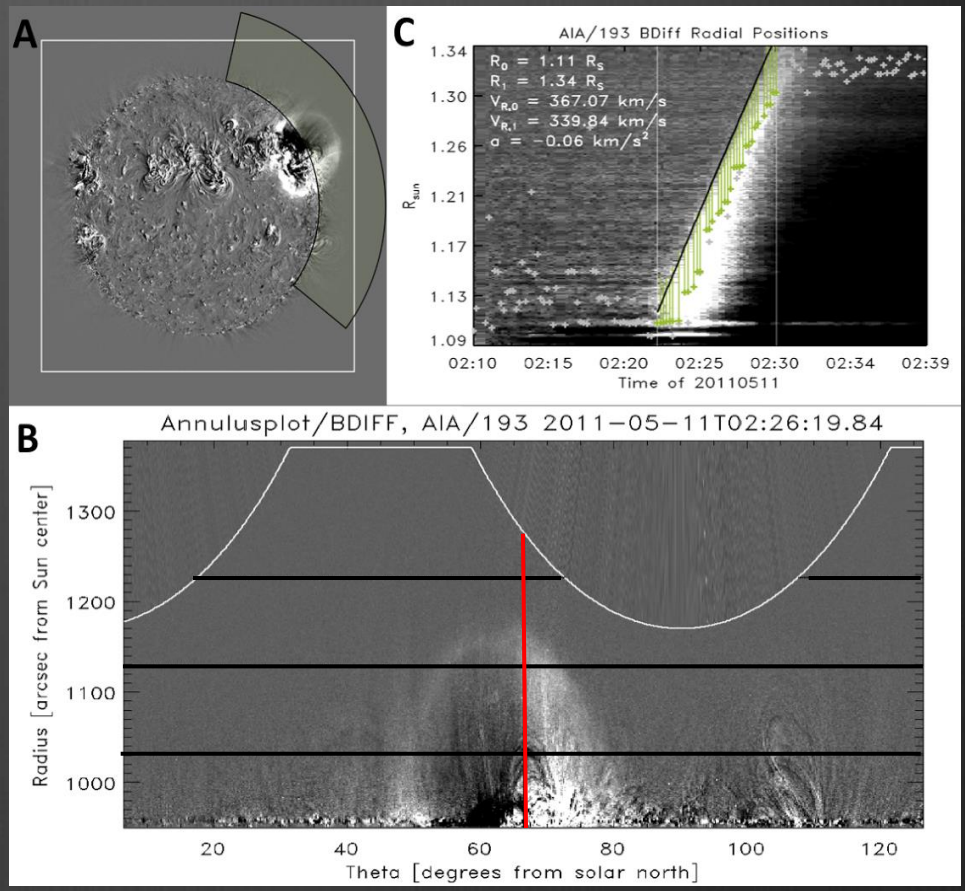




June 7, 2011
CBF Event
LASCO C2

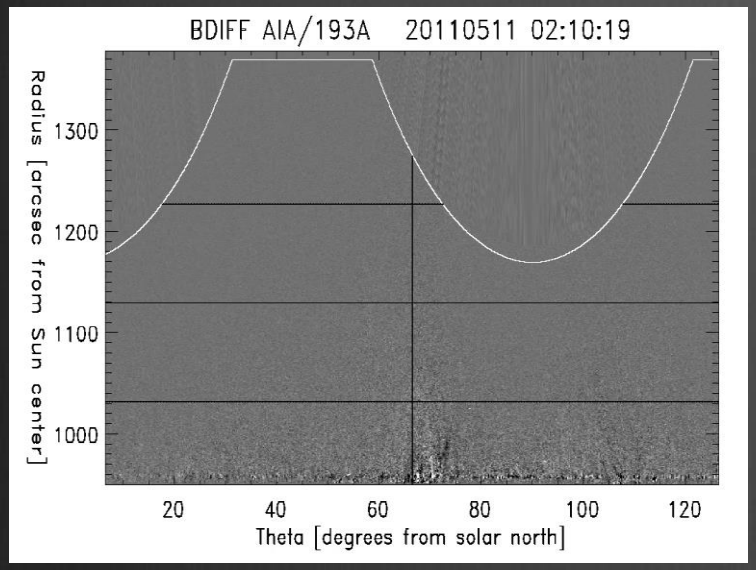
First Steps

- Before summer, two events were extensively studied 20110511 and 20100613
- Initial Goal: Process and add many new events to CBF database
- Prepared code for automation procedure

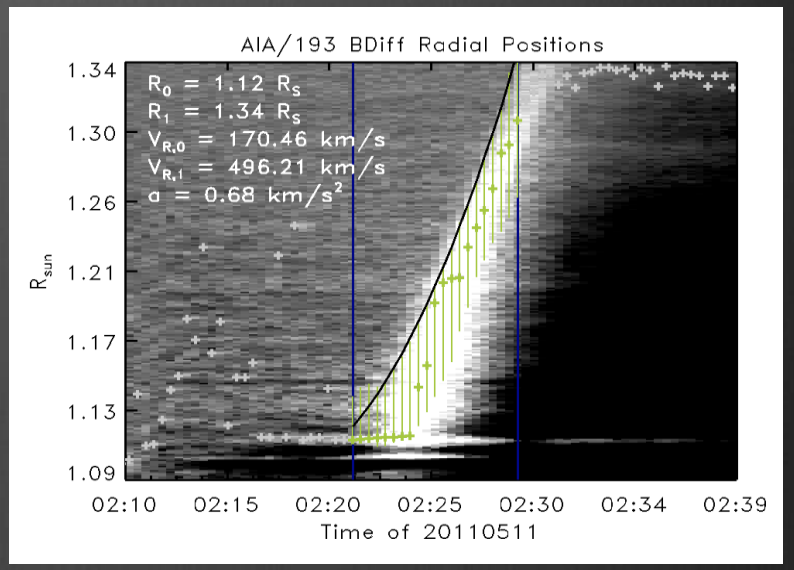


Processing pipeline from (A) Raw AIA 193 Å data to (B) Base Difference Images to (C) Pixel Intensities along red center line

Automated Kinematics Procedure

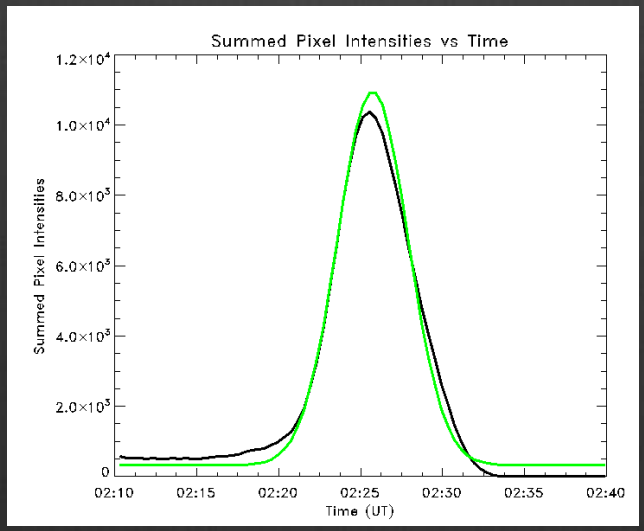


AIA Base Difference Movie of May 11, 2011 CBF



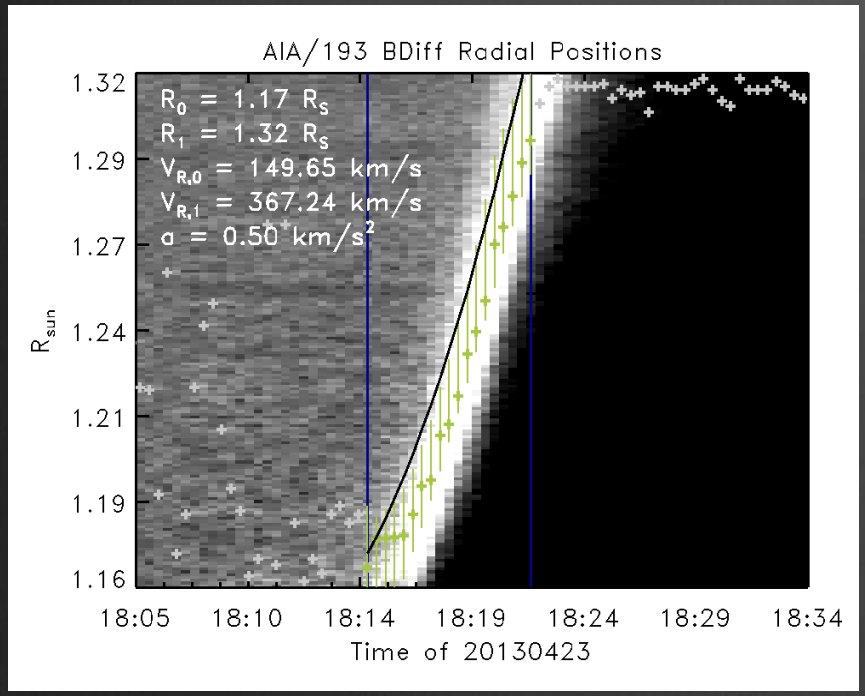
AIA Base Difference Radial Positions of May 11, 2011 CBF

Gaussian fit of summed pixel intensities used to find start and end times of CBF



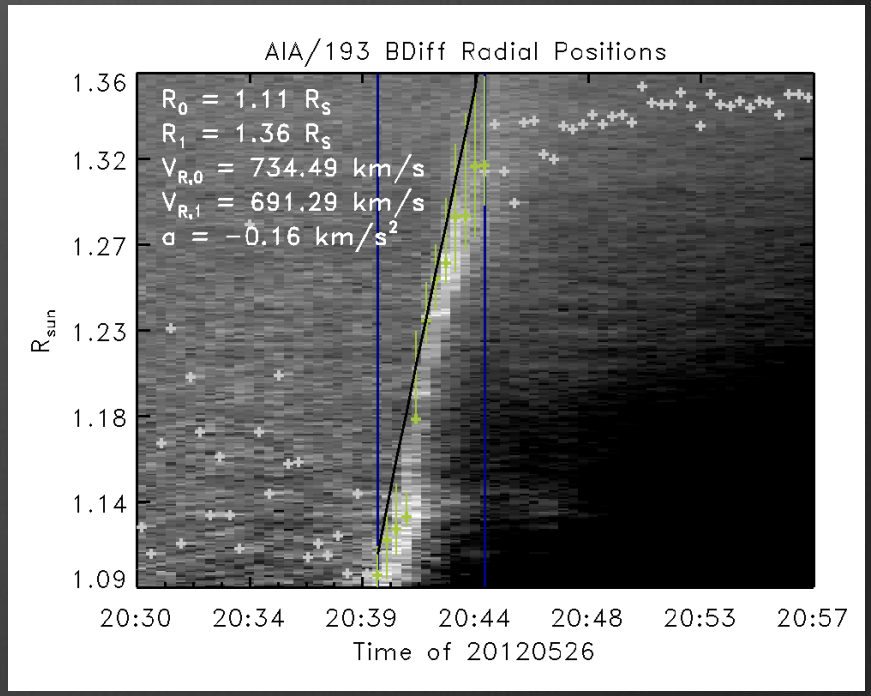
Radial Kinematics Data

20130423 CBF



- Large-scale, slower event with possible slight acceleration

20120526 CBF

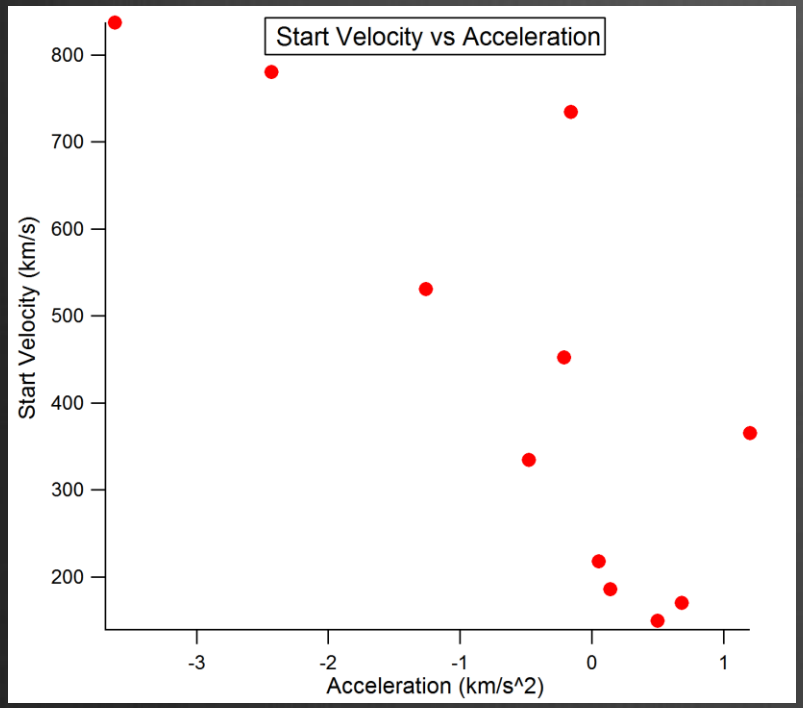


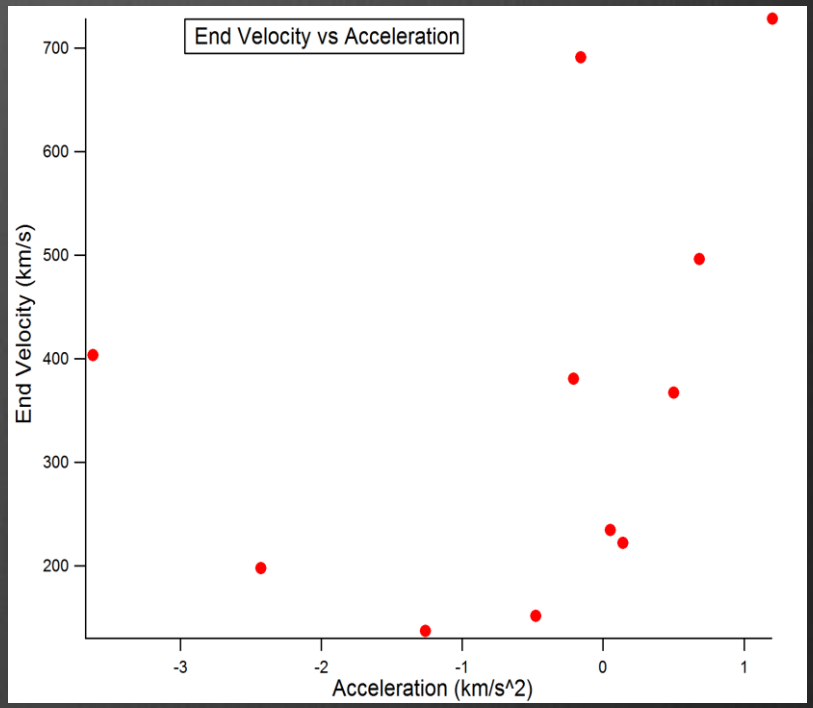
- Smaller, very fast event with possible slight deceleration

Radial Kinematics Data

Date	Start Position (R_S)	End Position (R_S)	Extent (R_S)	Mean Wave Thickness (R_S)	Start Velocity (km/s)	End Velocity (km/s)	Acceleration (km/s^2)	Relative Mean Wave Intensity
20110511	1.12	1.34	0.22	0.06	170.46	496.21	0.68	62.56
20140708	1.06	1.23	0.17	0.04	531.01	137.21	-1.26	70.49
20131212	1.11	1.32	0.21	0.06	452.68	380.73	-0.21	39.30
20130517	1.1	1.22	0.12	0.12	837.44	403.39	-3.62	41.56
20130423	1.17	1.32	0.15	0.03	149.65	367.24	0.5	84.20
20120915	1.12	1.25	0.13	0.04	334.74	151.96	-0.48	57.43
20120526	1.11	1.36	0.25	0.05	734.49	691.29	-0.16	21.55
20120424	1.1	1.26	0.16	0.04	780.68	197.62	-2.43	41.56
20110607	1.1	1.33	0.23	0.07	365.66	728.58	1.2	34.53
20110211	1.1	1.2	0.1	0.04	218.19	234.49	0.05	28.93
20110125	1.09	1.18	0.09	0.04	185.88	222.25	0.14	37.96
Mean	1.11	1.27	0.17	0.05	432.81	364.63	-0.51	47.28

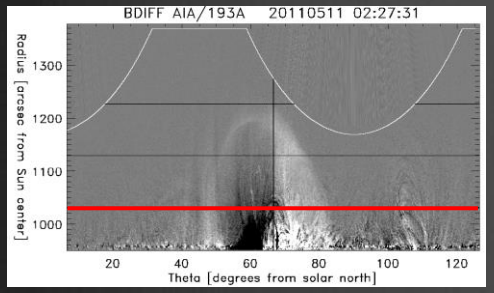
Radial Kinematics Data



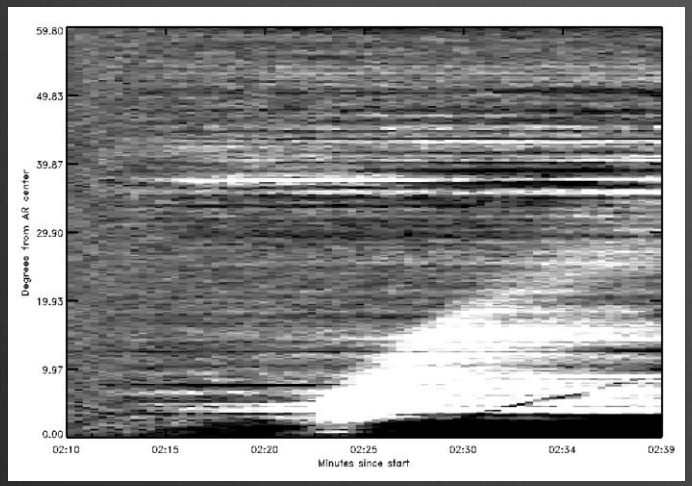


- Initially fast events tend to decelerate as they leave AIA's field of view
- Events with large end velocities tend to have positive acceleration

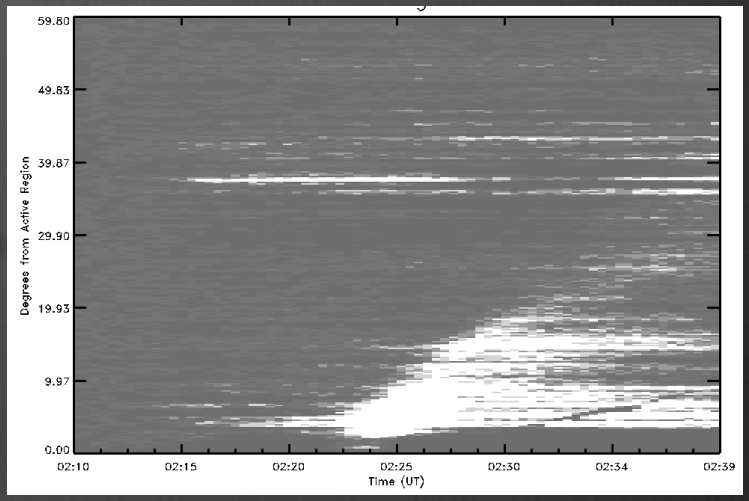
Tangential Kinematics Procedure



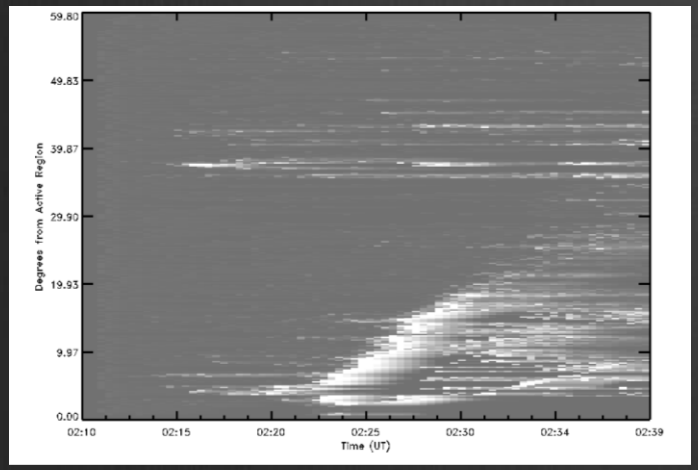
110511 Left Base Difference Image R = 1.086



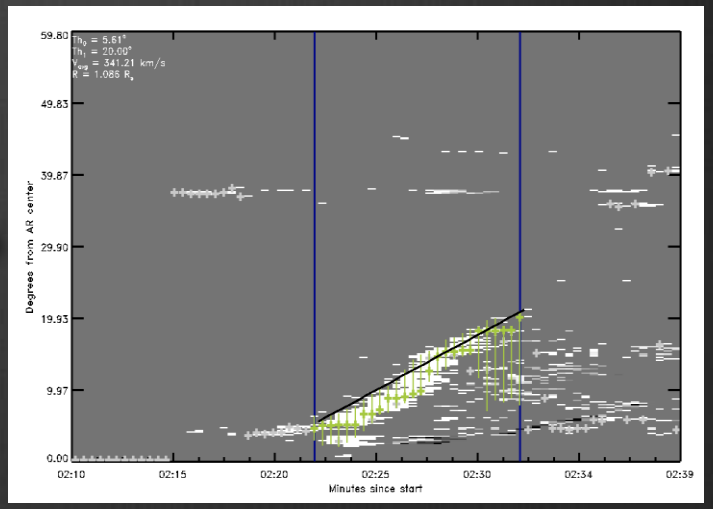
Binned 110511 Left Base Difference Data

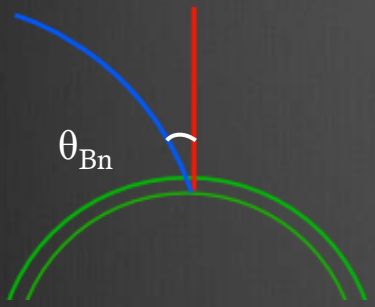


X-Gradient 110511 Left Base Difference Data



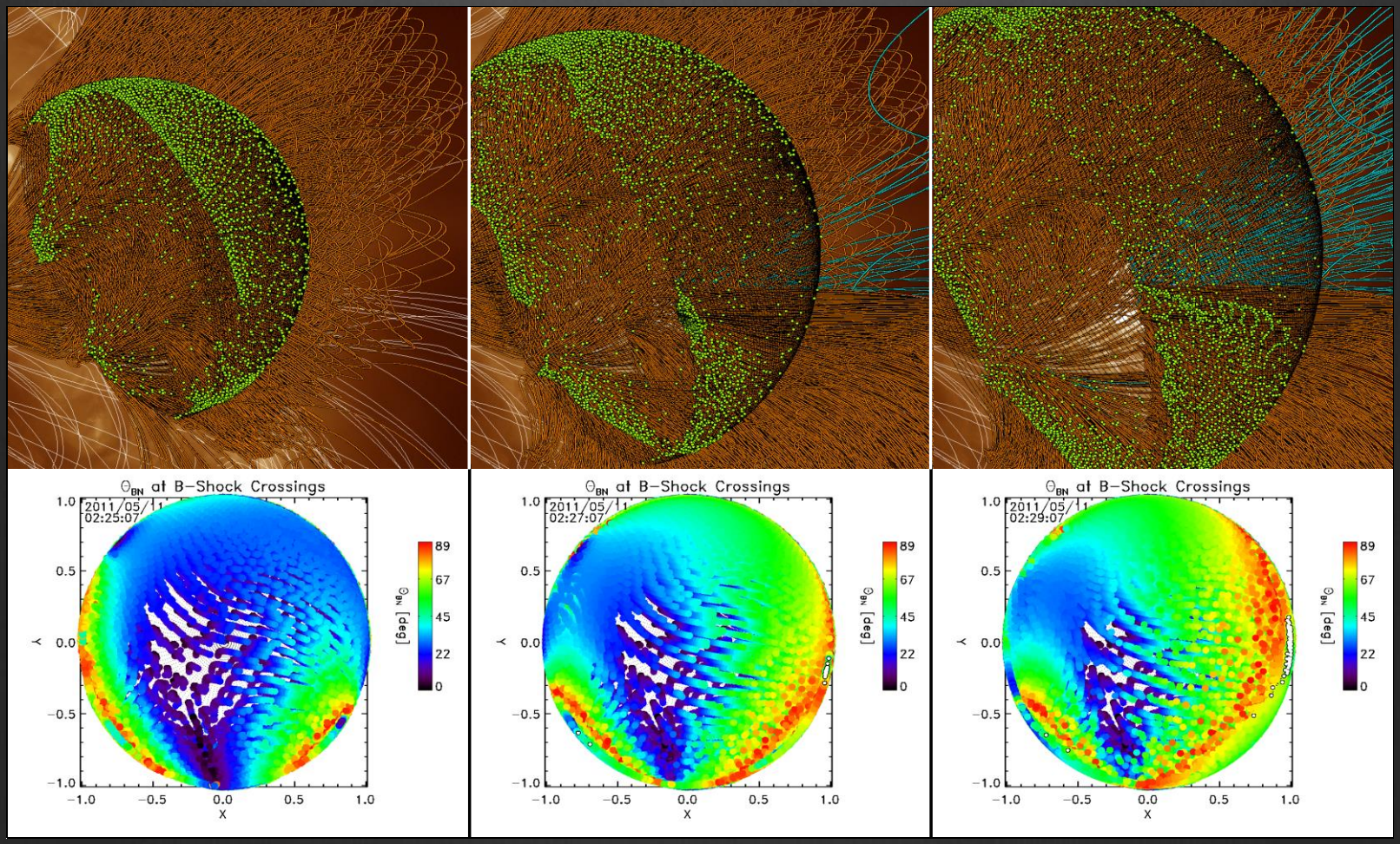
Filtered 110511 Left Base Difference Data





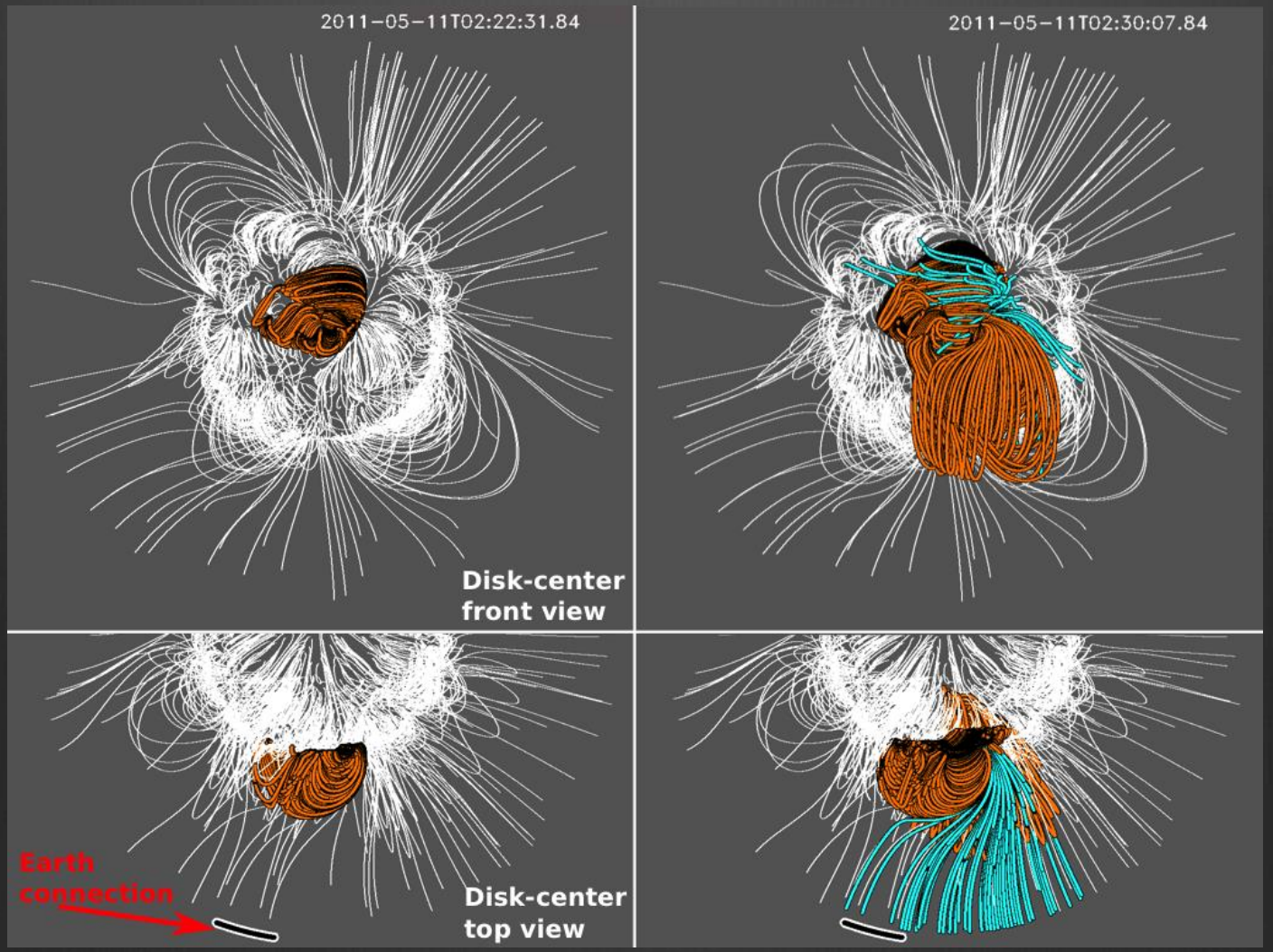
Next Steps

Kinematics Information will be used to drive time-dependent geometric models of CBFs, interacting with PFSS coronal magnetic field lines…



Next Steps

… and estimate heliospheric magnetic connectivity to Earth, etc.



Summary

- CBF kinematics information will drive geometric models providing insights to potential SEP acceleration in the lower corona
- Automated kinematics procedures has finished a pipeline of programs which can take event metadata to kinematics information
- On average, CBFs identified so far are decelerating in the lower corona with most speeds between 300-400 km/s
- Analyzed CBF events are added to a public database to be used as a research tool
- Radial kinematics could be improved by using a gradient based approach, current wave position centering location could be better chosen using an iterative technique

Acknowledgements

- A big thanks to:
  - My advisors, Kamen Kozarev and Patricia Jibben
  - The Solar REU Program, Henry “Trae” Winter and Katharine Reeves
  - Jonathan Sattelberger
- NSF-REU solar physics program at SAO, grant number AGS-1263241
- AIA:
  contract SP02H1701R from Lockheed-Martin to SAO

Questions?

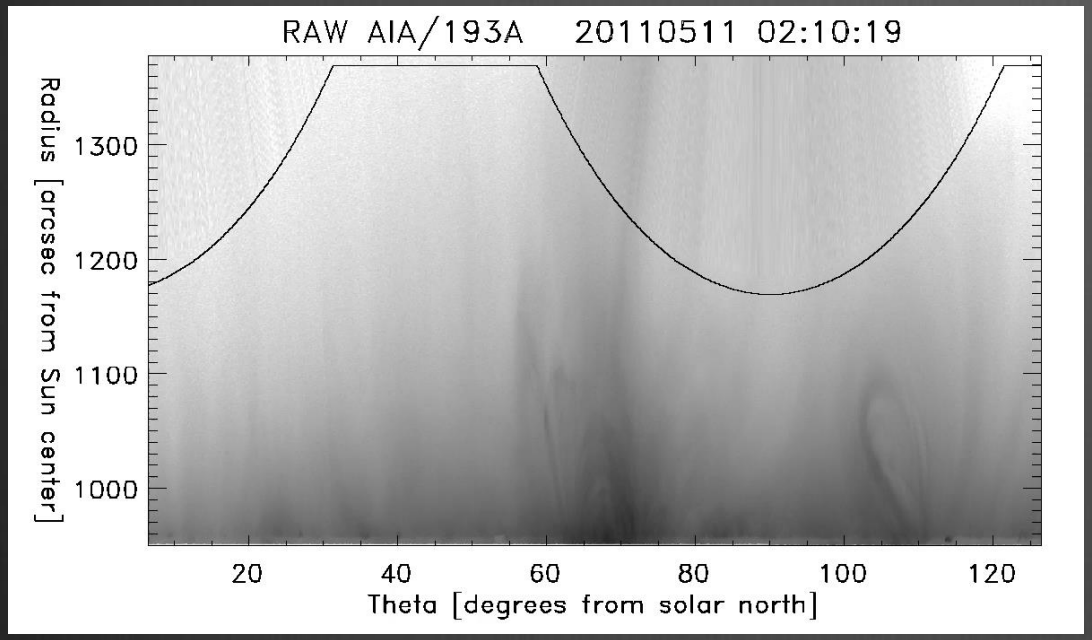
Current CBF Database at http://helio.cfa.harvard.edu/cashew/

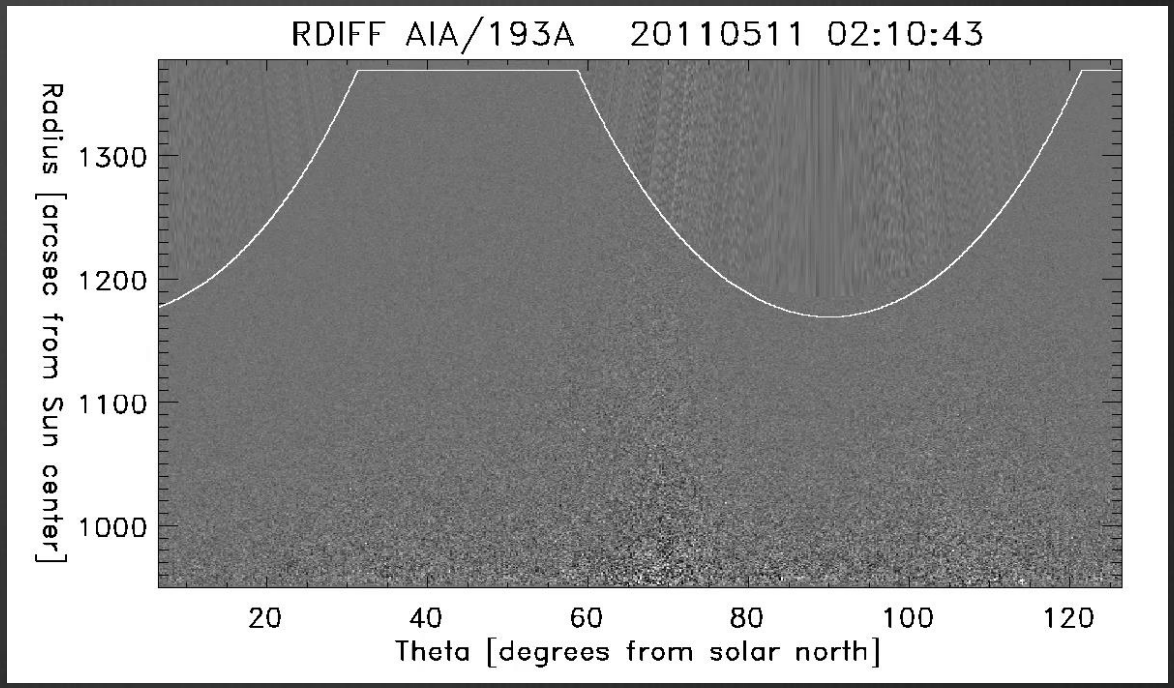
Welcome to the Solar Coronal Off-limb Wave Analysis Database and Repository.
The repository consists of data and information about solar coronal off-limb bright fronts related to CME shocks.
Feel free to contact me with any questions about the database.

OFF-LIMB CORONAL BRIGHT FRONTS DATABASE (CURRENTLY 30 EVENTS) LAST UPDATED ON Wed Aug 13 01:03:12 2014

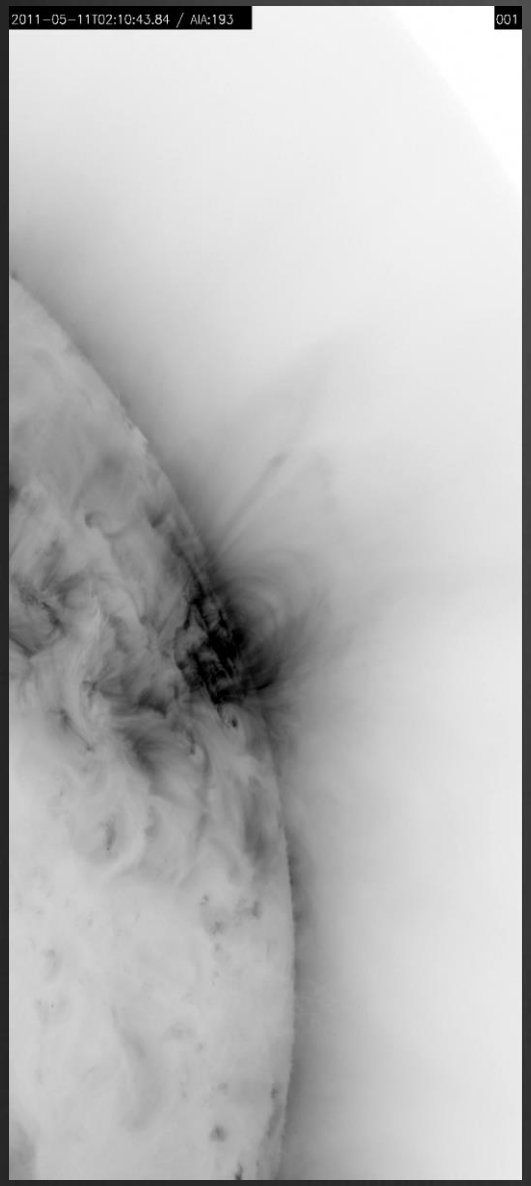
Date	Start (UT)	End (UT)	Flare Class	X (") East/ West	Y (")	Filament Erupt	Loop Erupt	Metric Radio Spectra			EUV Raw / Run Diff. Movies		EUV Annulus plot Raw / Run Diff. Movies		Kinematics		TEEM DEM Movies	PFSS / Shock Model
								eCallisto	Nancay	RSTN	AIA/193		AIA/193		Radial	Tangential		
2014/07/08	16:08	16:28	M6.5	-810	161	Yes	No	eCallisto			RAW	RDIFF	ARAW	ARDIFF		PNG		
2014/04/07	20:50	21:23		900	-608	Yes	No				RAW	RDIFF	ARAW	ARDIFF				
2014/02/25	00:40	00:55	X4.9	-972	-214	Yes	No			RSTN	RAW	RDIFF	ARAW	ARDIFF		PNG		
2014/01/08	03:40	03:52	M3.6	950	200	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF		PNG		
2013/12/12	03:03	03:33	B2.2	750	-400	Yes	No	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2013/12/07	07:17	07:36	M1.2	690	-270	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/11/19	10:17	10:42	X1.0	900	-220	No	Yes	eCallisto	NRH	RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/11/07	10:14	10:25		-999	100	No	Yes	eCallisto	NRH	RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/11/05	22:10	22:40	C1.5	-563	-203	No	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/10/29	21:40	22:10	X2.3	990	38	Yes	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/05/17	08:41	09:09	M3.2	-576	192	Yes	Yes	eCallisto	NRH	RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2013/05/01	02:28	02:45		-865	237	Yes	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2013/04/23	18:05	18:35		999	-399	No	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2013/04/11	06:54	07:20	M6.5	-200	200	No	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2012/10/07	20:15	20:45	C1.2	-932	378	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2012/09/15	22:50	23:20	B9.6	806	422	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2012/07/28	20:43	20:59	M6.1	-745	-662	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2012/05/26	20:30	20:58		899	416	No	No			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2012/04/24	07:39	07:55	C3.7	-1019	247	Yes	No	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2011/10/20	03:05	03:35	M1.6	1005	374	No	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	
2011/08/09	08:00	08:20	X6.9	883	269	Yes	No	eCallisto	NRH	RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2011/08/04	03:50	04:20	M9.3	564	186	Yes	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2011/06/07	06:20	06:40	M2.5	611	-355	Yes	No			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2011/05/11	02:20	02:35	B8.1	785	399	Yes	Yes	eCallisto		RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG	DEM	PSHOCK
2011/03/08	03:35	03:50	M1.5	-859	-309	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF		PNG		
2011/02/24	07:23	07:45	M3.5	-939	239	Yes	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF		PNG		
2011/02/11	12:30	13:00		-1073	11	Yes	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2011/01/28	00:45	01:15	M1.3	777	391	No	No			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2011/01/25	11:56	12:26		-955	-248	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF	PNG	PNG		
2010/06/13	05:34	05:49	M1.0	885	-422	No	Yes			RSTN	RAW	RDIFF	ARAW	ARDIFF		PNG		

CASHeW documentation
Contact

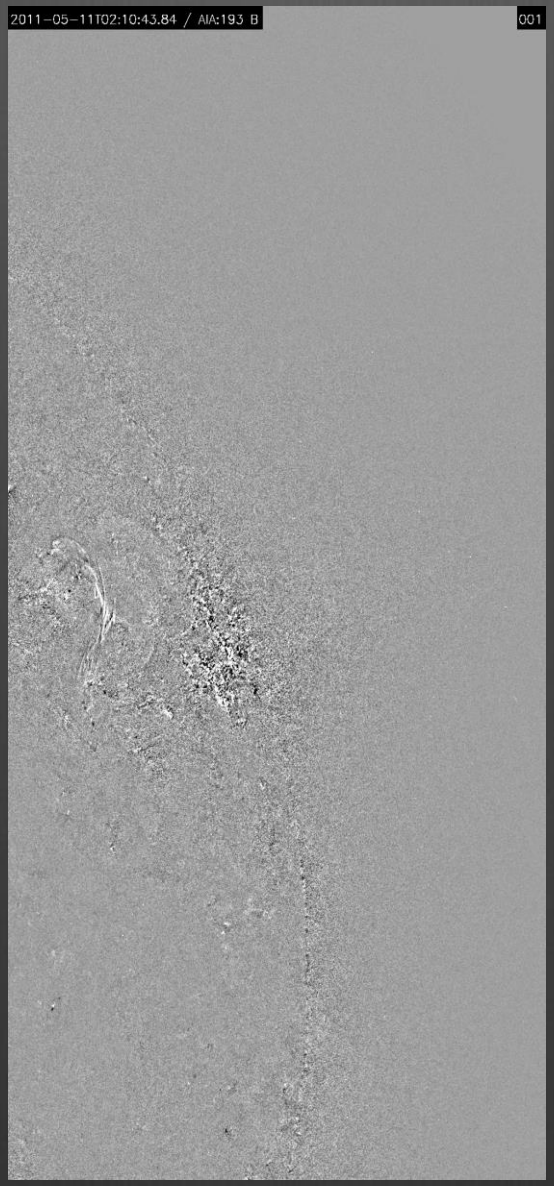

RAW AIA/193A 20110511 02:10:19
Radius [arcsec from Sun center]
1300
1200
1100
1000
20
40
60
80
100
120
Theta [degrees from solar north]


RDIFF AIA/193A 20110511 02:10:43
Radius [arcsec from Sun center]
1300
1200
1100
1000
20
40
60
80
100
120
Theta [degrees from solar north]

Raw



Base Difference



Running Difference