Statistical Properties of Solar Filament Eruptions

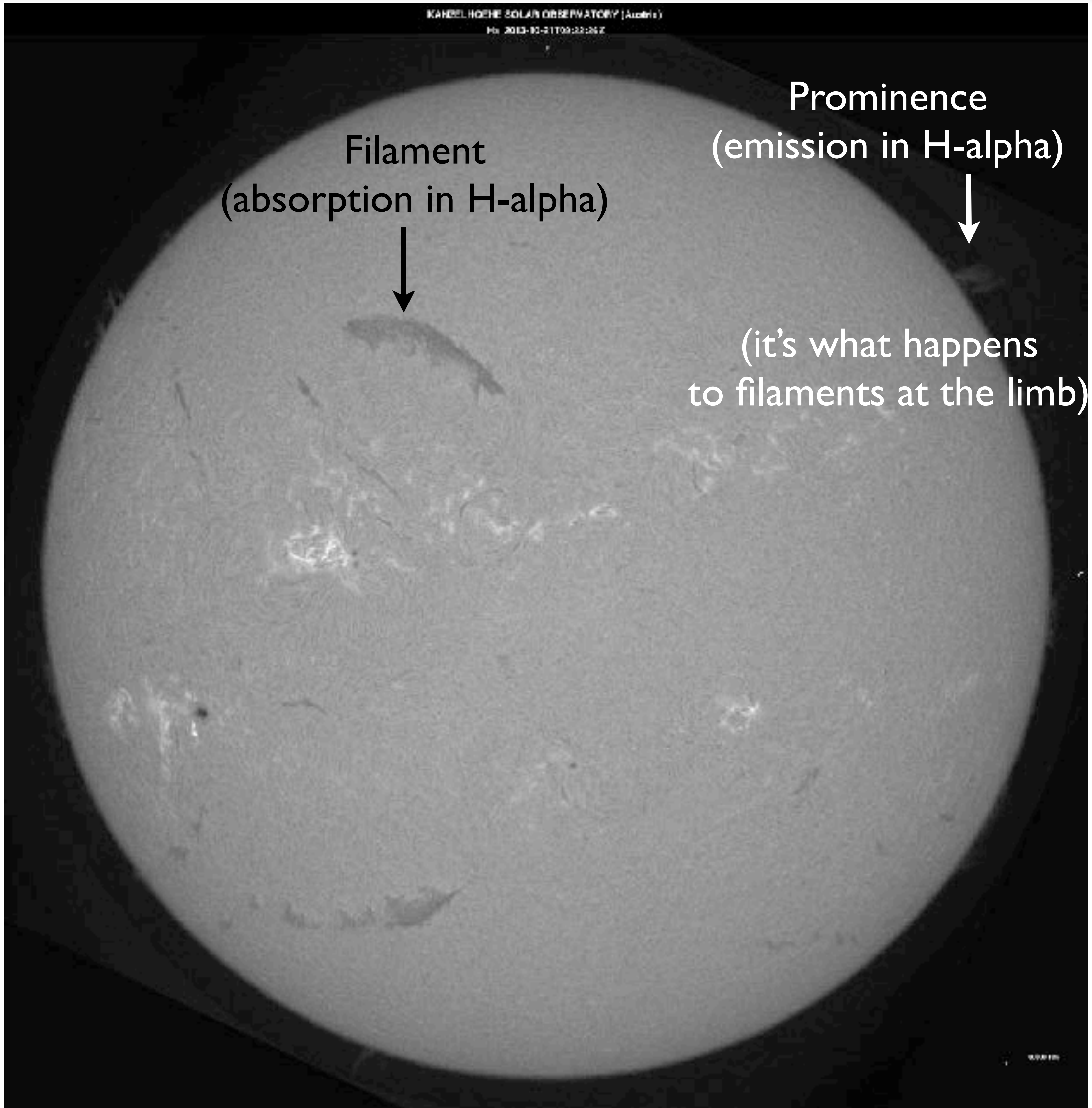
Kathy Reeves
Harvard-Smithsonian Center for Astrophysics

Collaborators: Ashna Aggarwal* (William & Mary/UCLA), Nicole Schanche (CfA/St. Andrews), Kaitlin Evans* (UMD), Patrick McCauley (CfA/U. Sydney), Sean McKillop (CfA), Yingna Su (Purple Mountain Observatory)

* = Solar REU Student

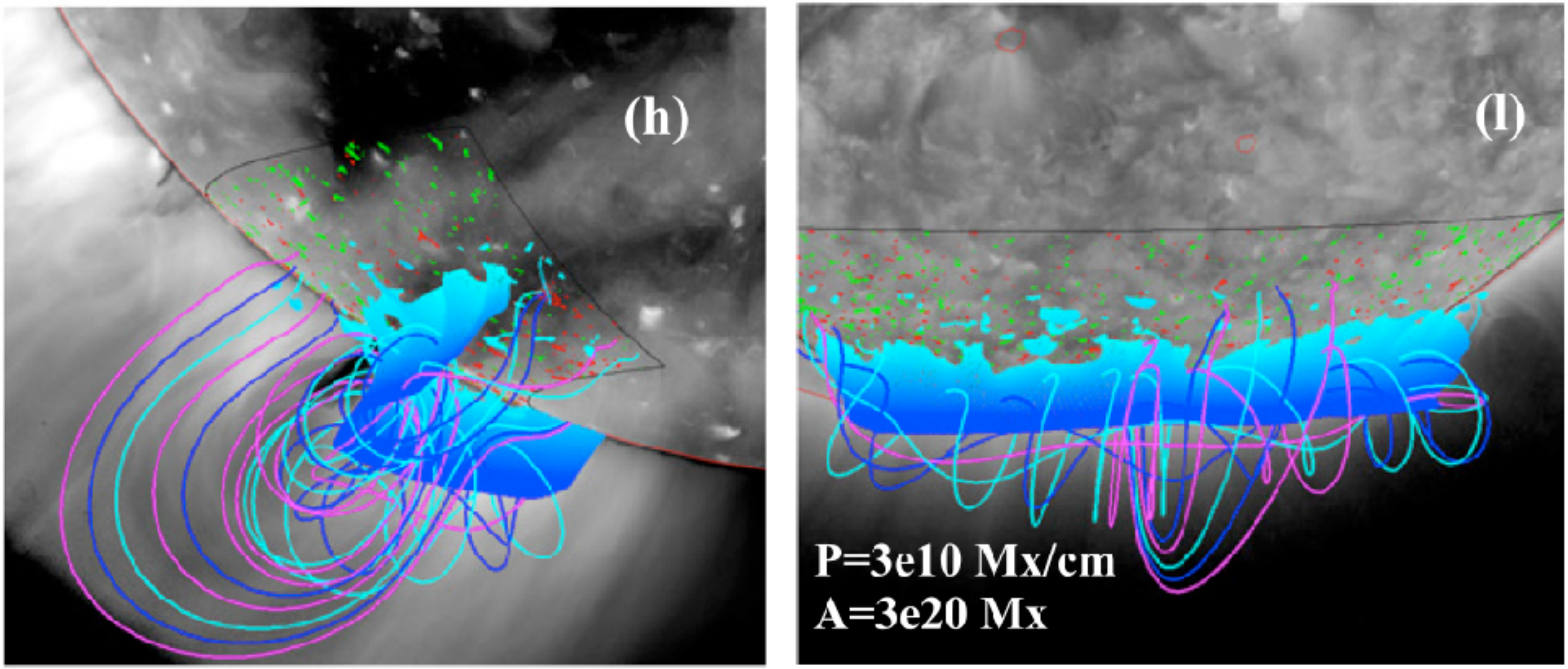
Funding provided by: NSF-DIBBS program, award #1443061, NASA grant #NNX12AI30G,
NSF AGS-1560313 (CfA Solar REU program)

Solar filaments



Filament structure

Su, Y. N. et al. ApJ, 2015



- Cool material suspended in the concave upward "dips" of a twisted magnetic field

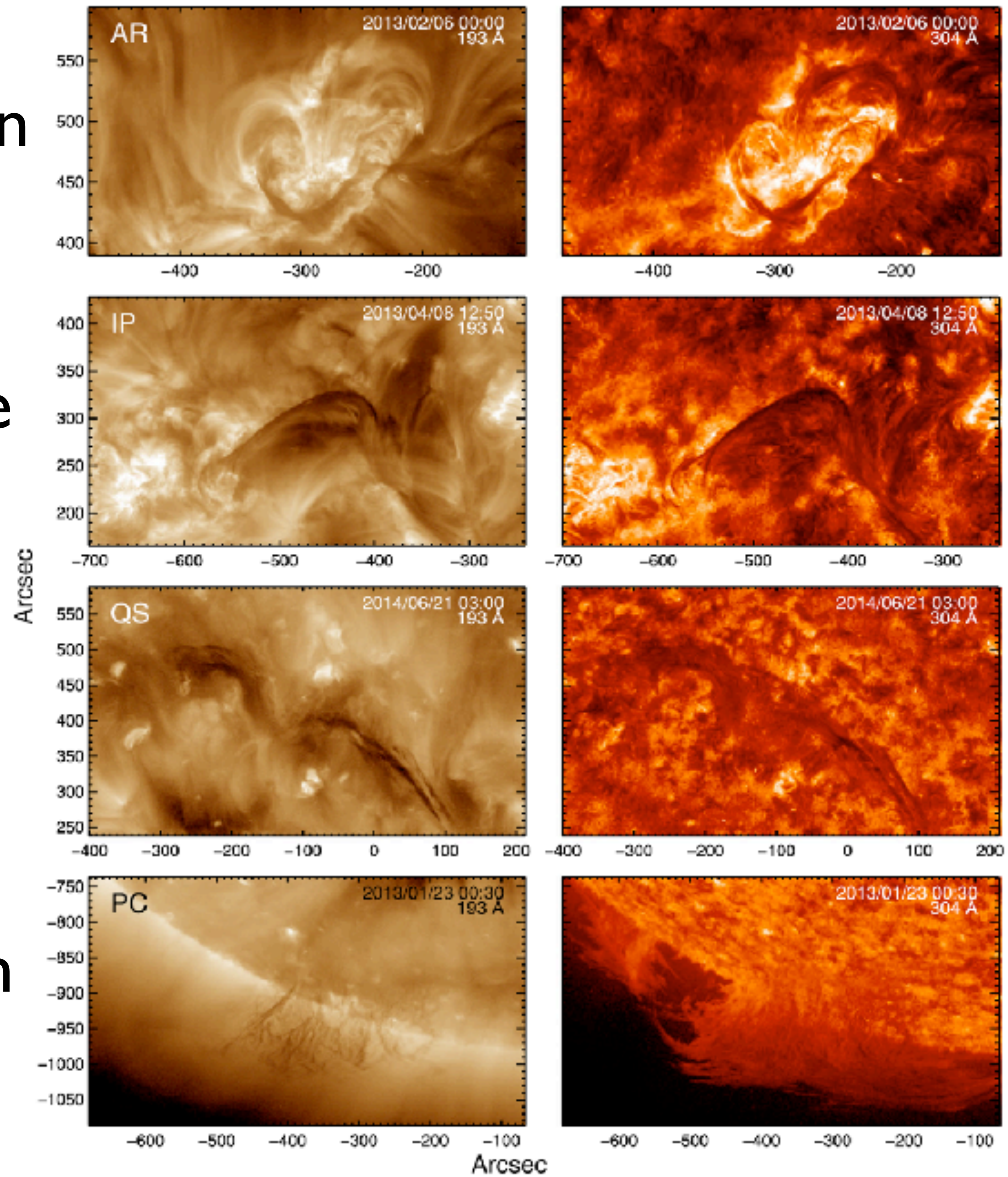
Filament environments

Active Region

Intermediate

Quiet Sun

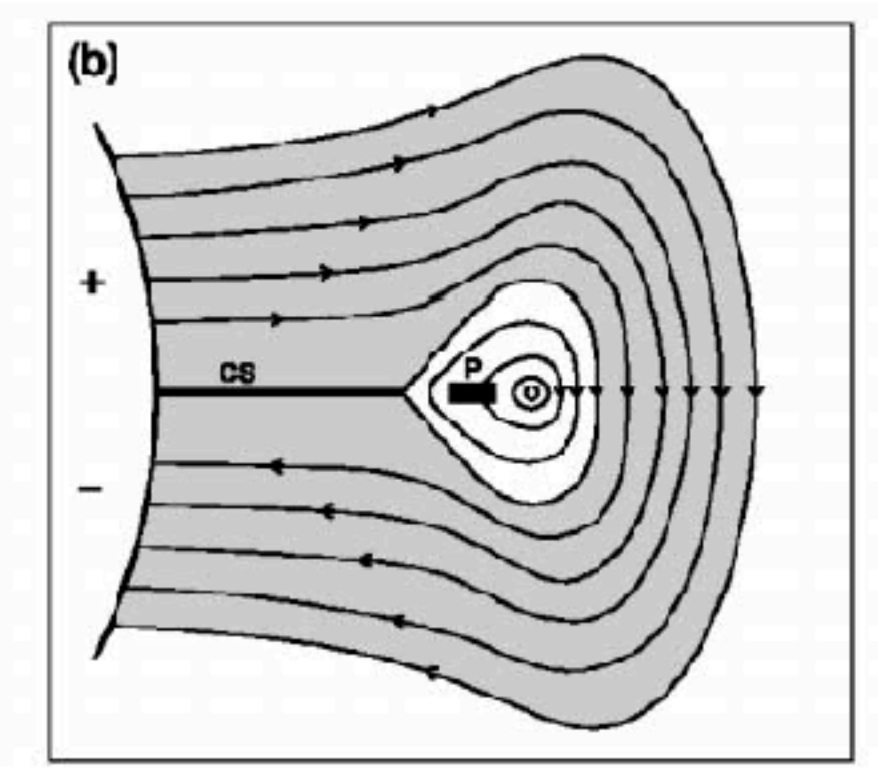
Polar Crown



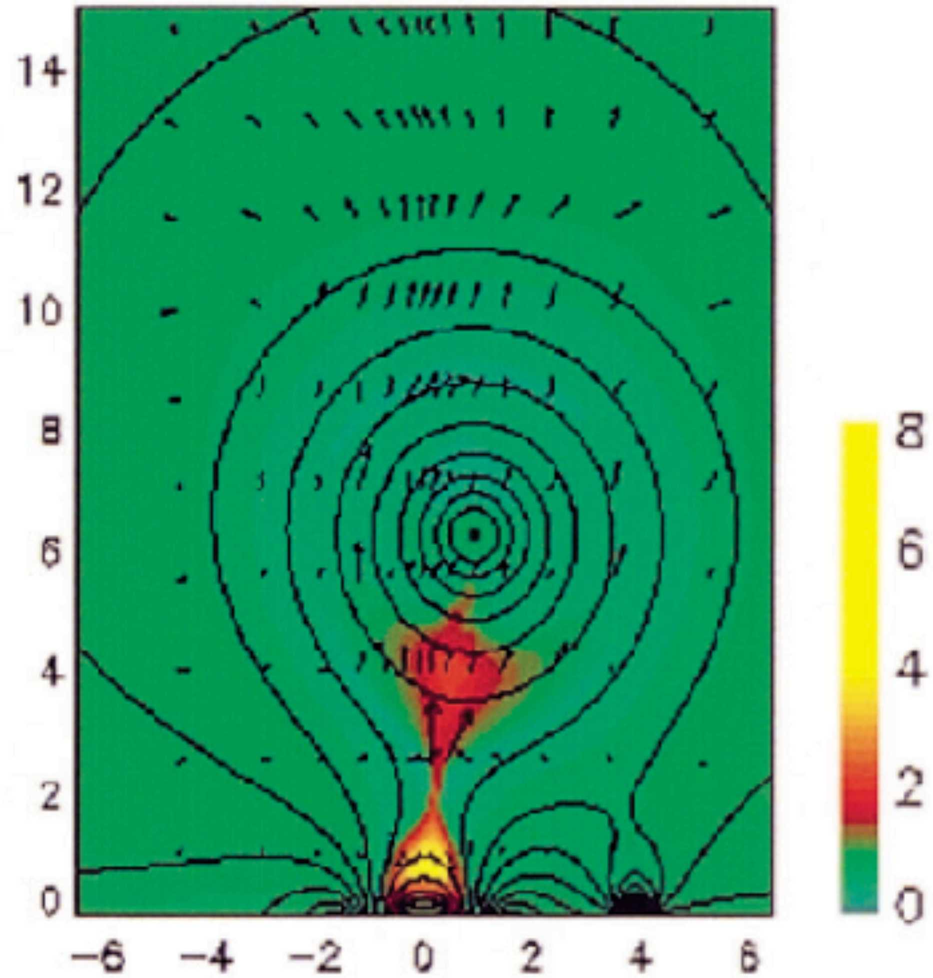
McCauley et al.
SolPhys, 2015

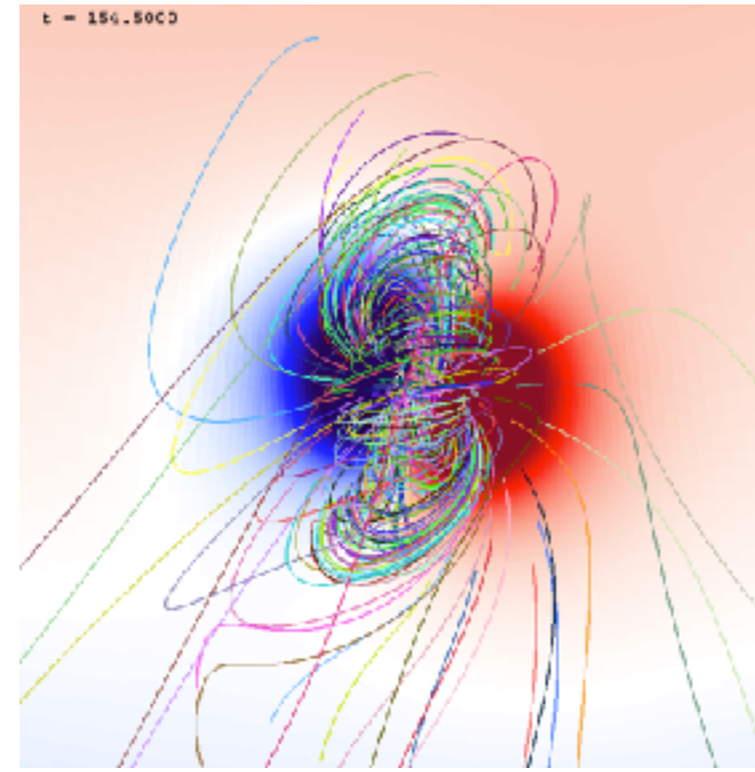
External triggers

Low & Zhang, ApJL, 2002



Chen & Shibata, ApJ, 2000





Mass Draining

Mass drains, B force overcomes g force

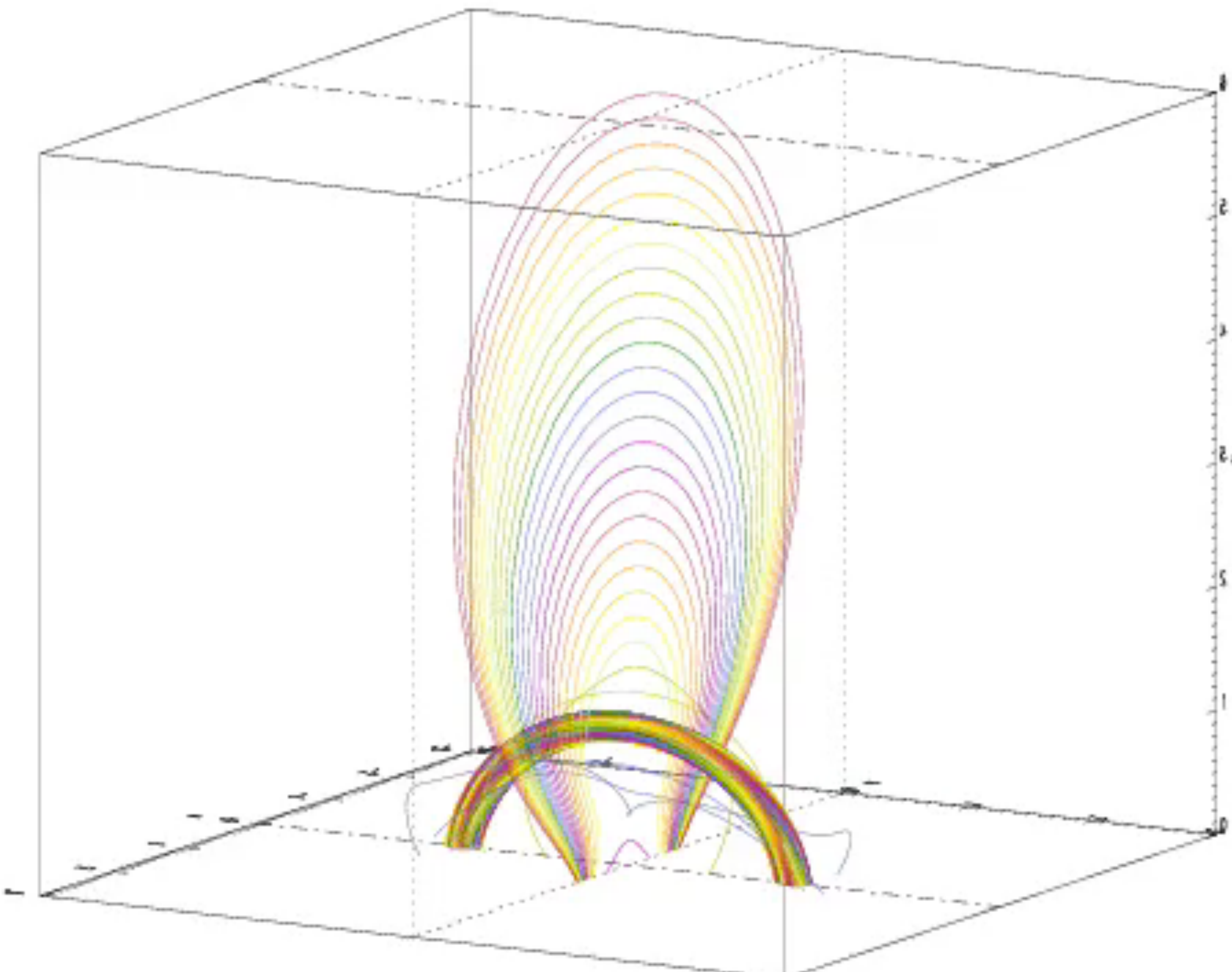
Emerging Flux

Emerging B-field disrupts overlying B-field

Flux Cancellation

Cancelling B-field disrupts overlying B-field

flux rope stability



Decay index of overlying field determines stability

$$n = -\frac{d(\ln \mathbf{B})}{d(\ln h)}$$

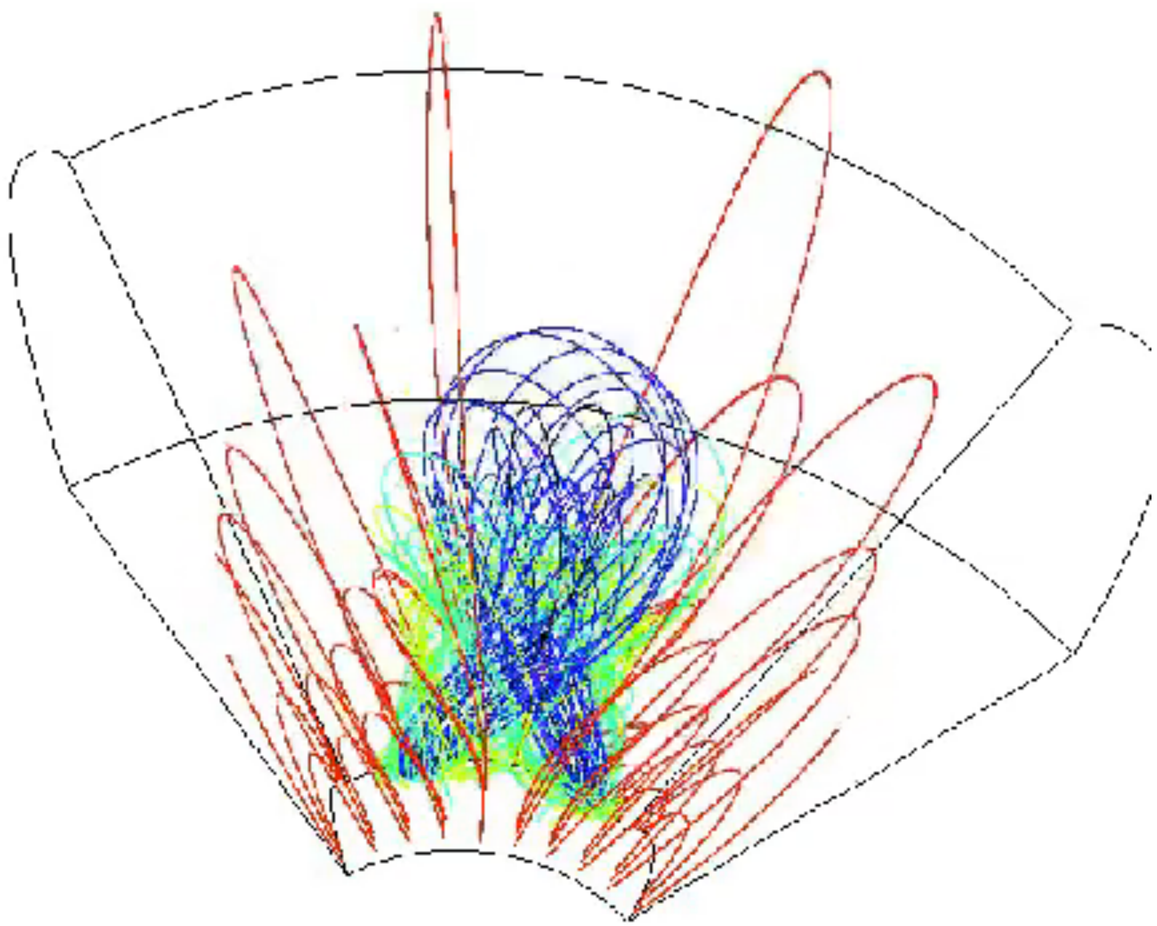
Critical value >1-2, depending on solar conditions

Török & Kliem, ApJ, 2005

MHD instabilities

Fan & Gibson, ApJ, 2007

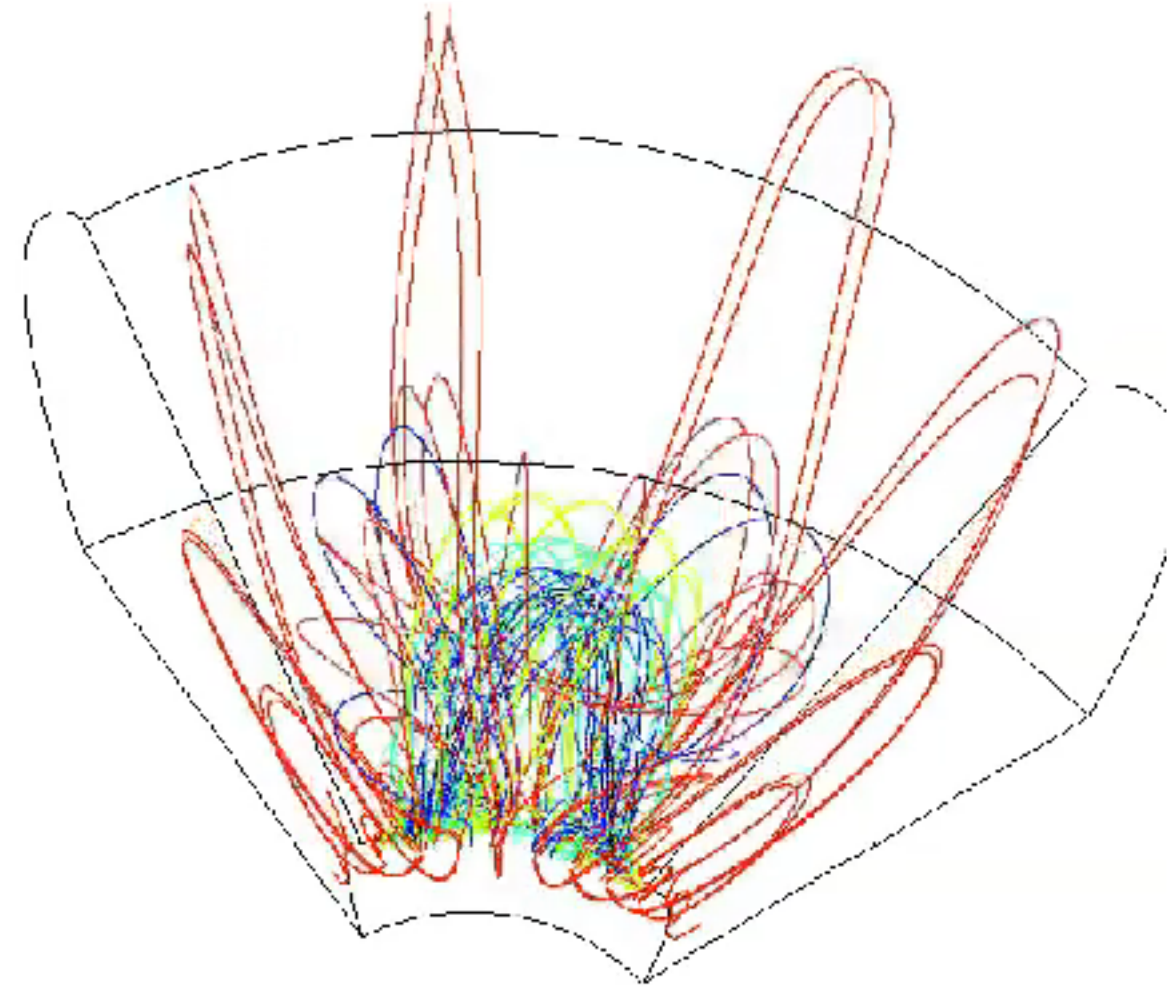
kink instability



Case K: t = 121 (R_S/V_{A0})

Kink instability has a faster speed

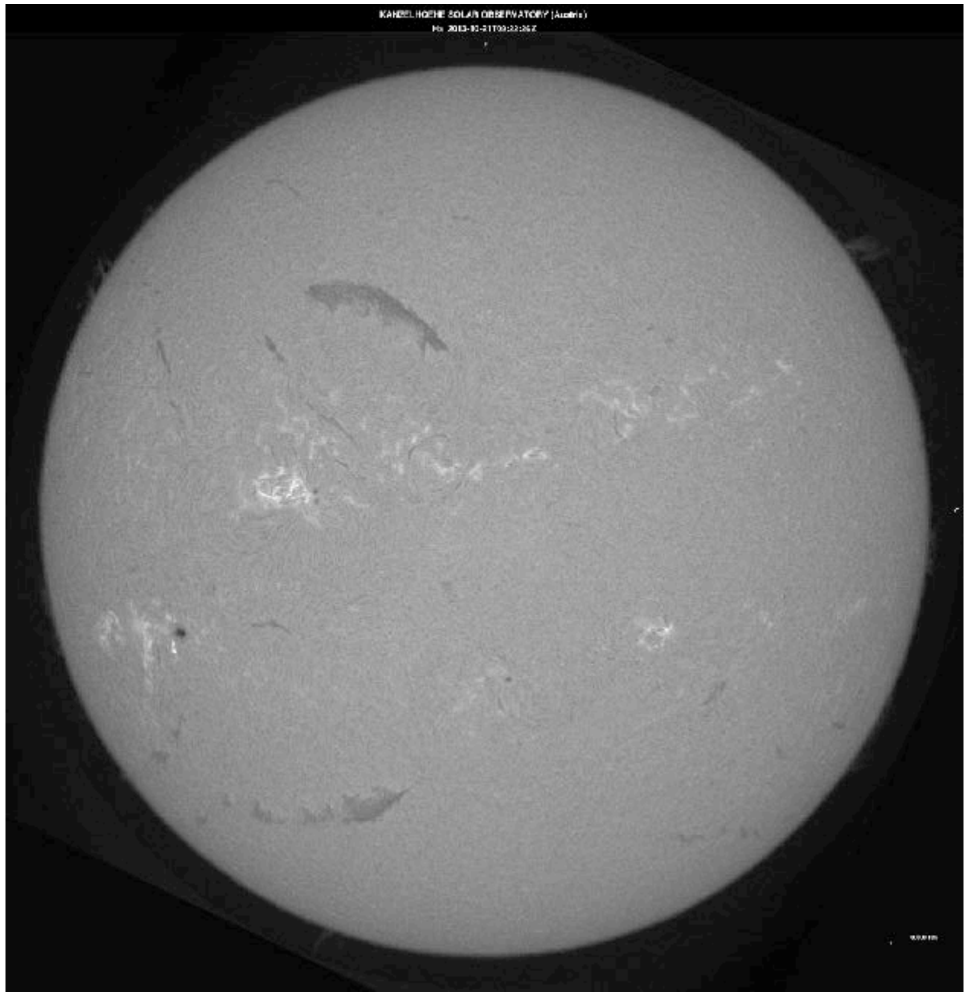
torus instability

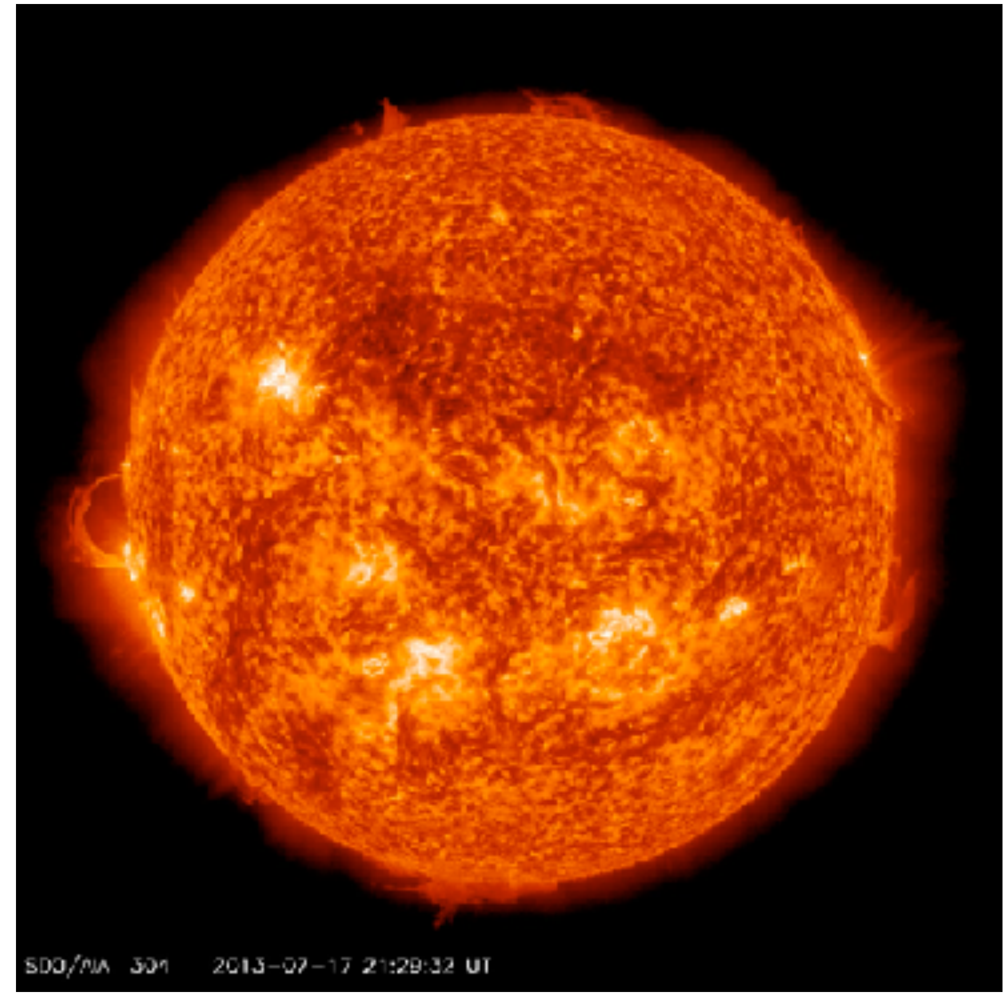


Case T. t 108 (R_S/V_{A0})

Torus instability has a larger critical decay index

Data sources



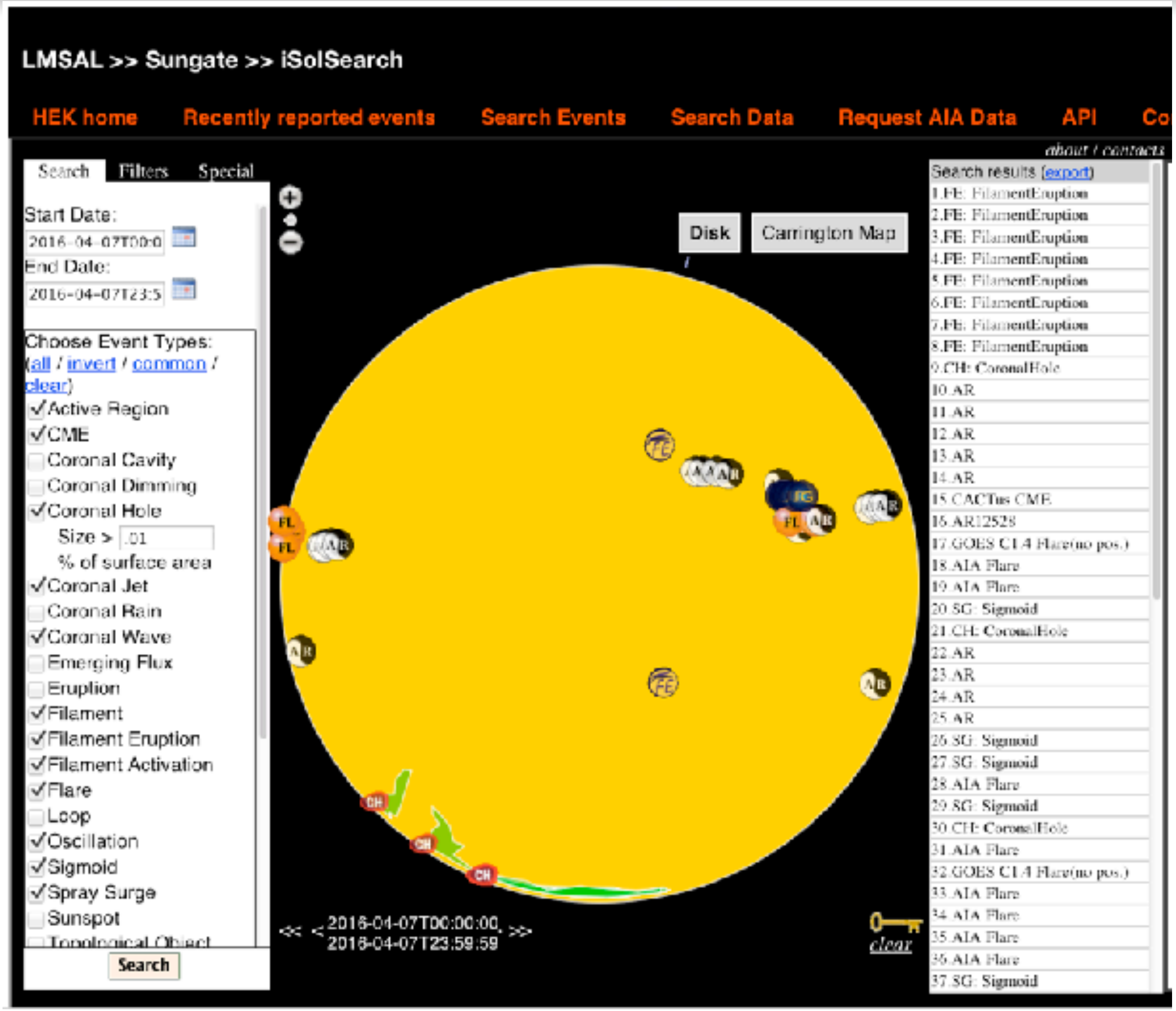


H-alpha data
•Big Bear Solar Observatory
•Kanzelhöhe Solar Observatory

Global H-alpha Network

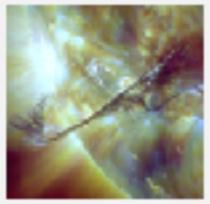
Extreme ultraviolet data
•Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory

Meta-data sources



Heliophysics Event Knowledgebase
https://www.lmsal.com/isolsearch

Meta-data sources



AIA Filament Eruption Catalog

AIA at SAO | AIA at LMSAL | SDO at GSFC

Display Key | Contact | Show Plots

The AIA Filament Eruption Catalog includes basic information and a number of observational characteristics for many events during the SDO mission. Click the "Display Key" button for details on what is contained in the table. Movies and comments are available by clicking on the icons next to each entry. These events were culled from the Heliophysics Event Knowledgebase (HEK). The catalog table may be downloaded as a tab delimited text file or as an IDL save file. A collection of the highest rated events is also available as a YouTube Playlist or as a downloadable TAR file.

Show 10 entries

Search:

ID	Start (UT)	Δt (hrs)	X (")	Y (")	Rating	Type	Symmetry	Direction	Twist	Writhe	Threads	Cavity	Flares	CME (km/s)	Behind Limb	Eruption
1004	2014/09/20 23:20:23	06	-325	334	3.0	QS	S?	R	N	N	Y	N	C: 1	0300	D	F
1003	2014/09/20 04:25:11	01	18	224	2.0	QS	S	NR?	N	N	Y	N	N	N	D	F?
1002	2014/09/19 17:30:35	02	-1012	-293	2.0	AR	S	R	N?	N	Y?	D?	C: 1	0385	L	P
1001	2014/09/19 08:10:11	04	-512	-208	3.0	IP?	?	?	Y	N	Y	N	N	N	D	C
1000	2014/09/12 23:15:35	02	-785	-307	3.0	IP	S	R	N	N	Y	N	N	0624	D	P
0999	2014/09/09 23:50:23	02	1043	203	3.0	QS	S	R	Y?	Y?	N	N	N	0355	L	P
0998	2014/09/02 11:10:03	09	30	651	5.0	TE	S	R	Y	N	Y	N	N	0319	D	F
0997	2014/08/18 10:30:35	06	-782	632	3.0	QS	S	R	Y	N	Y	N	N	0108	L	P
0996	2014/08/15 15:20:23	05	265	190	4.5	TE	S?	R?	?	N	Y	N	N	0252	D	F
0995	2014/08/03 16:56:03	04	-515	67	3.0	QS	S?	R	Y	N	Y?	N	N	0322	D	F

Showing 1 to 10 of 923 entries

First | Previous | 1 | 2 | 3 | 4 | 5 | Next | Last

Events were culled from the Heliophysics Event Knowledgebase (HEK), and support for this work was provided by NASA through grant NNX12AI30C. If you publish work using this catalog, please cite McCauley et al. (2015).

CfA Filament Eruption Catalog

904 filament eruptions observed by SDO between 06/2010 and 09/2014

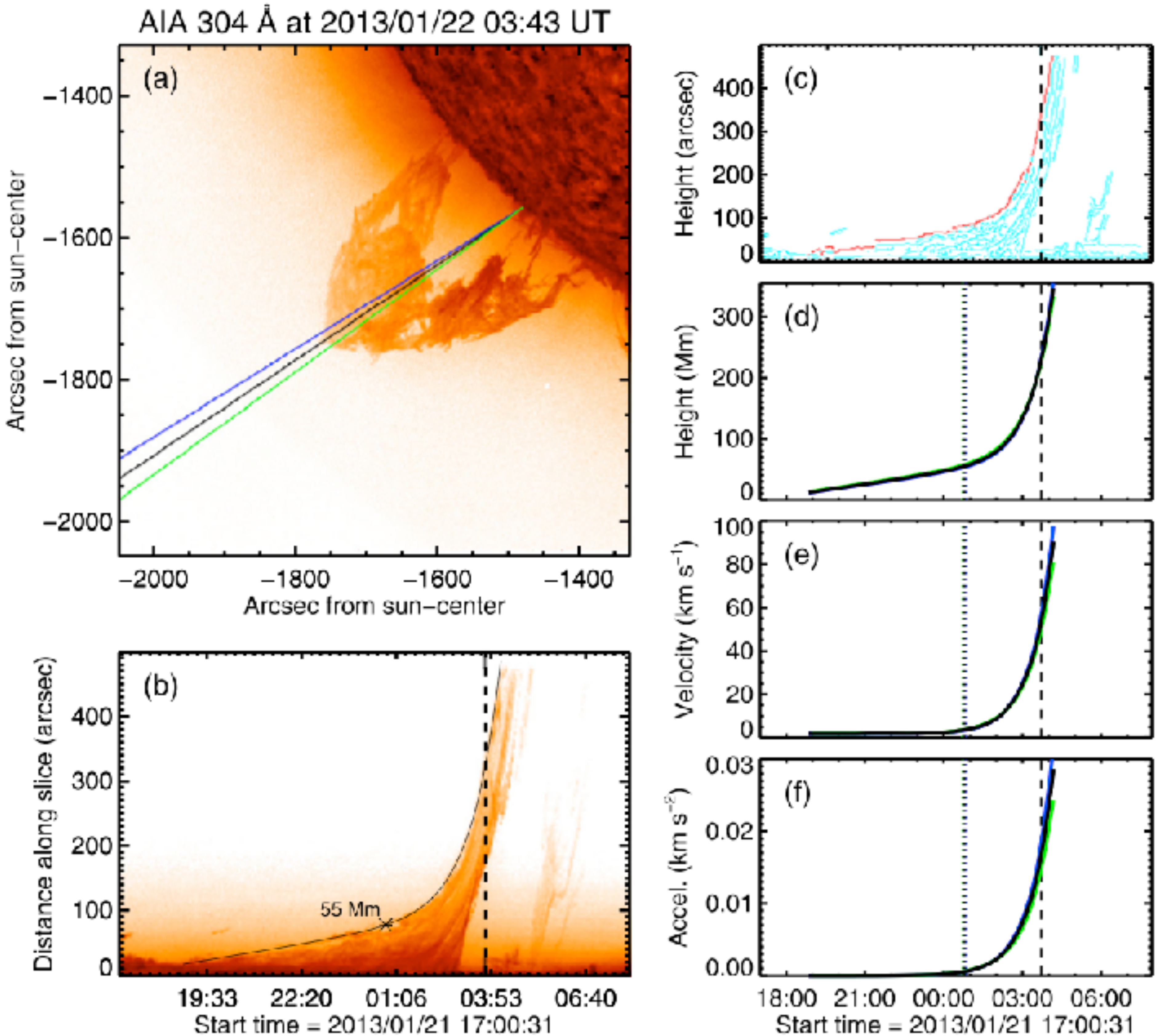
http://aia.cfa.harvard.edu/filament/

statistical investigations

kinematics of filament eruptions

McCauley, P. I., Su, Y. N., Schanche, N., Evans, K. E*., Su, C., McKillop, S., & Reeves, K. K. (2015). *Solar Physics*, **290**(6), 1703–1740

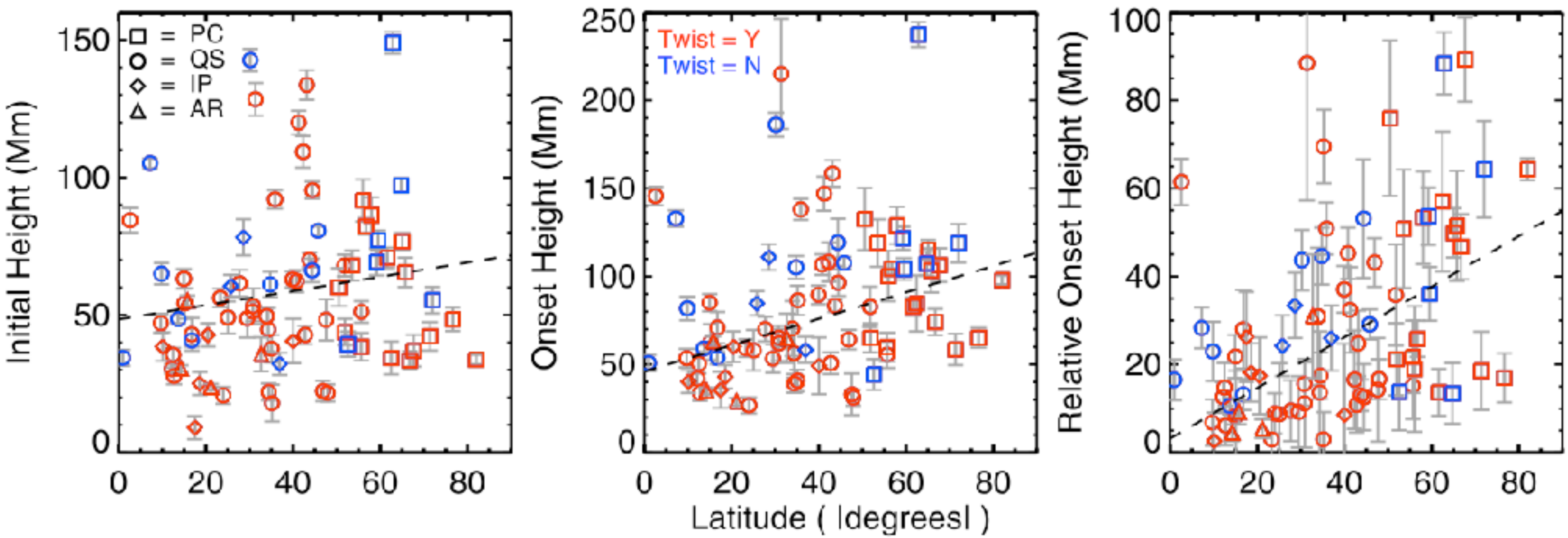
eruption kinematics



McCauley et al.
SolPhys, 2015

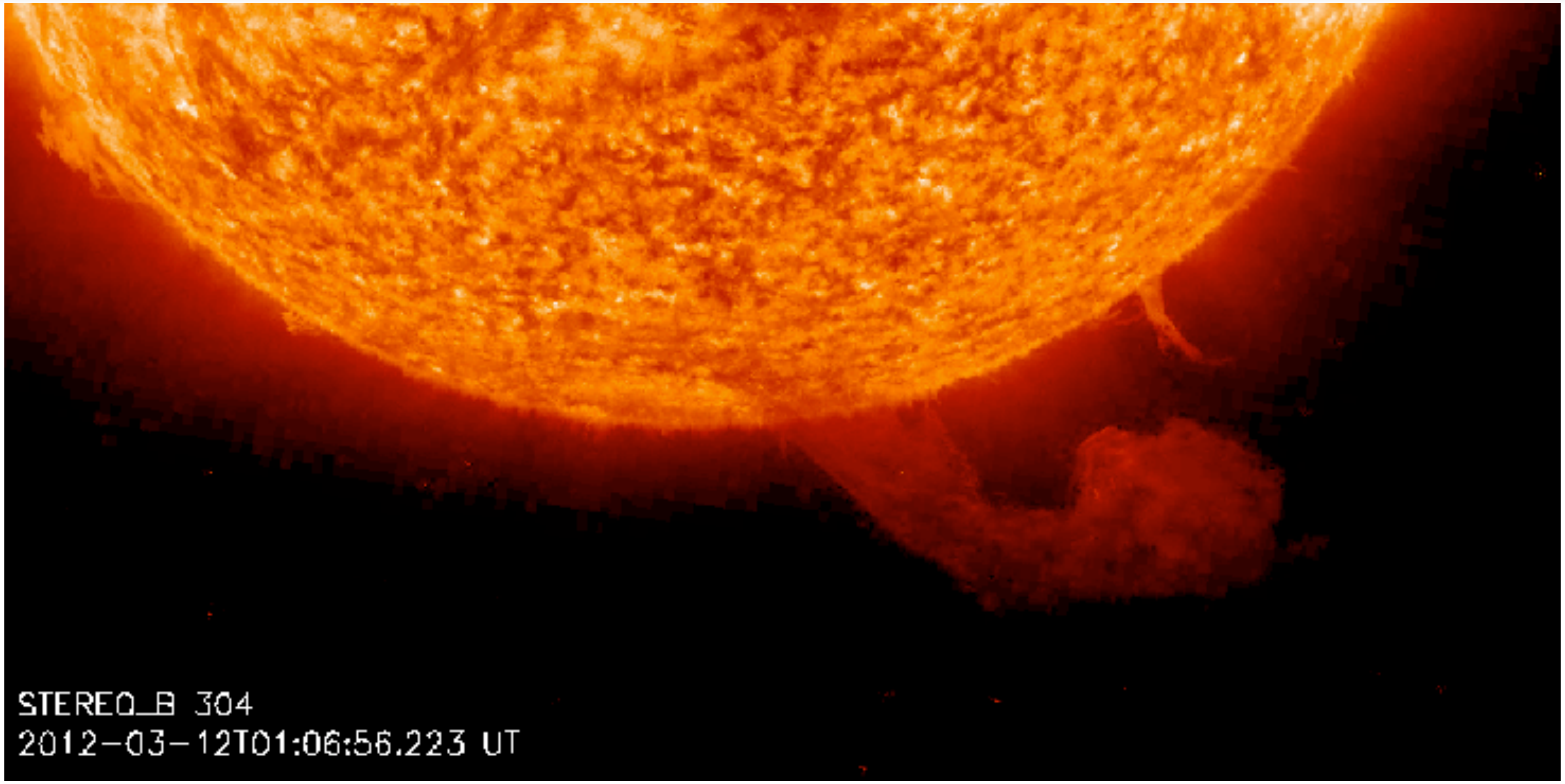
Latitude dependence

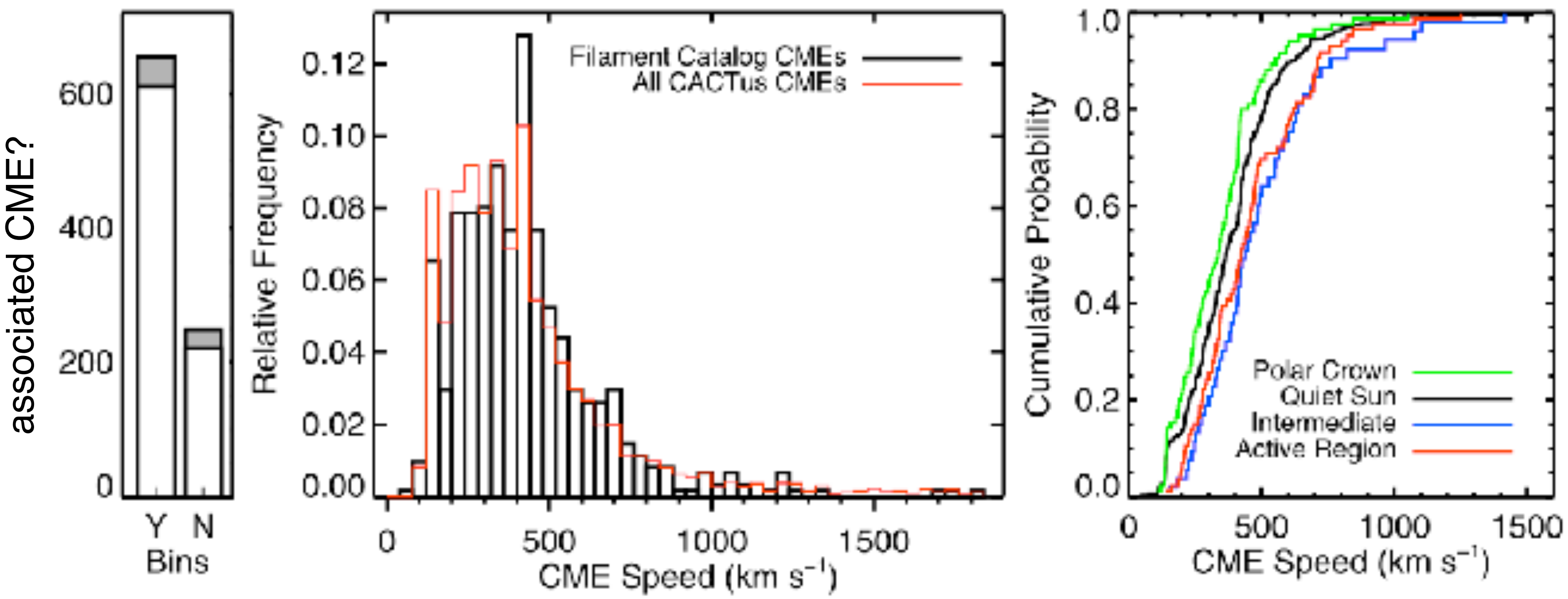
McCauley et al.
SolPhys, 2015



Onset height increases with latitude

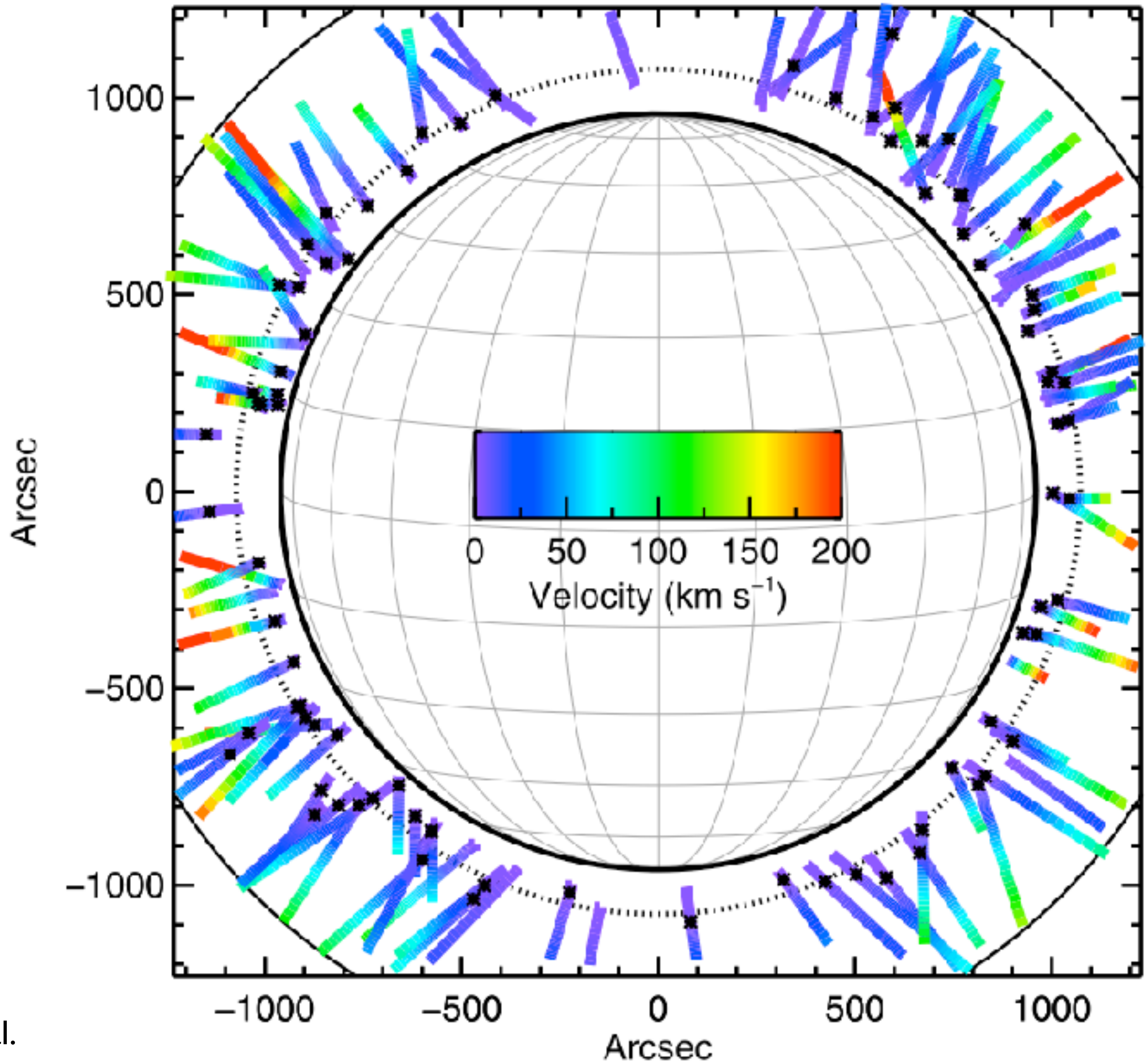
Connection with CMEs





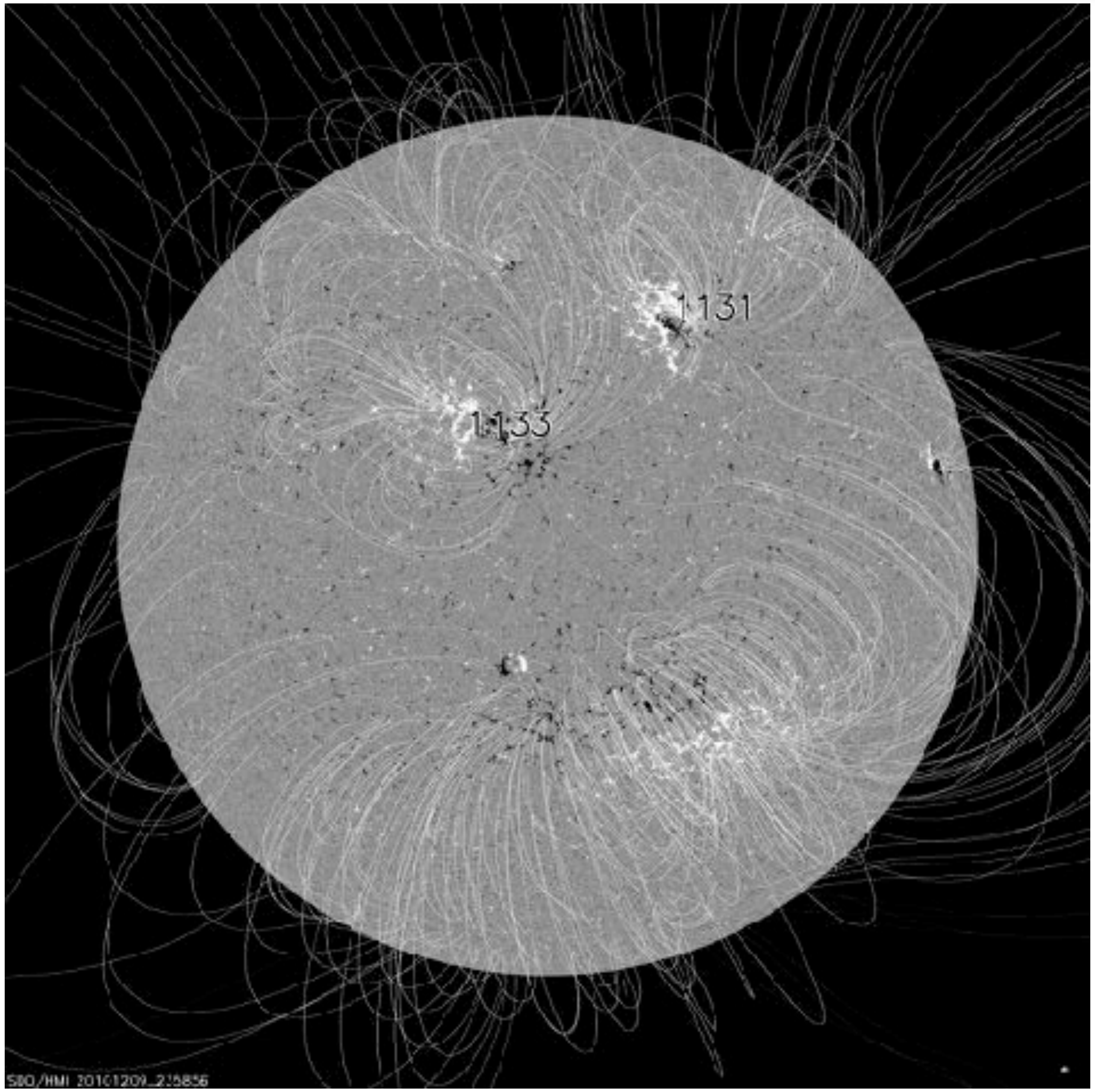
McCauley et al.
SolPhys, 2015

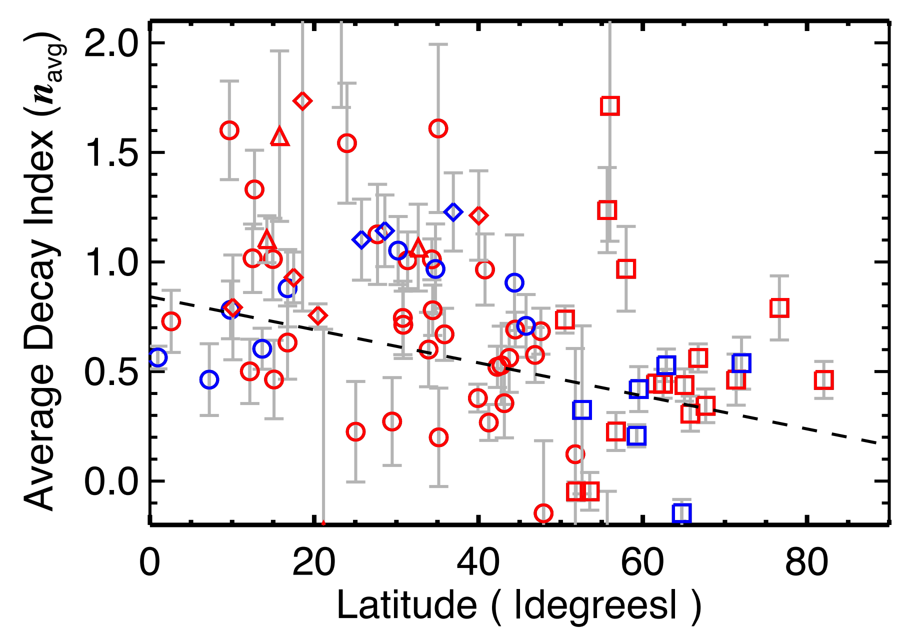
eruption velocity and location

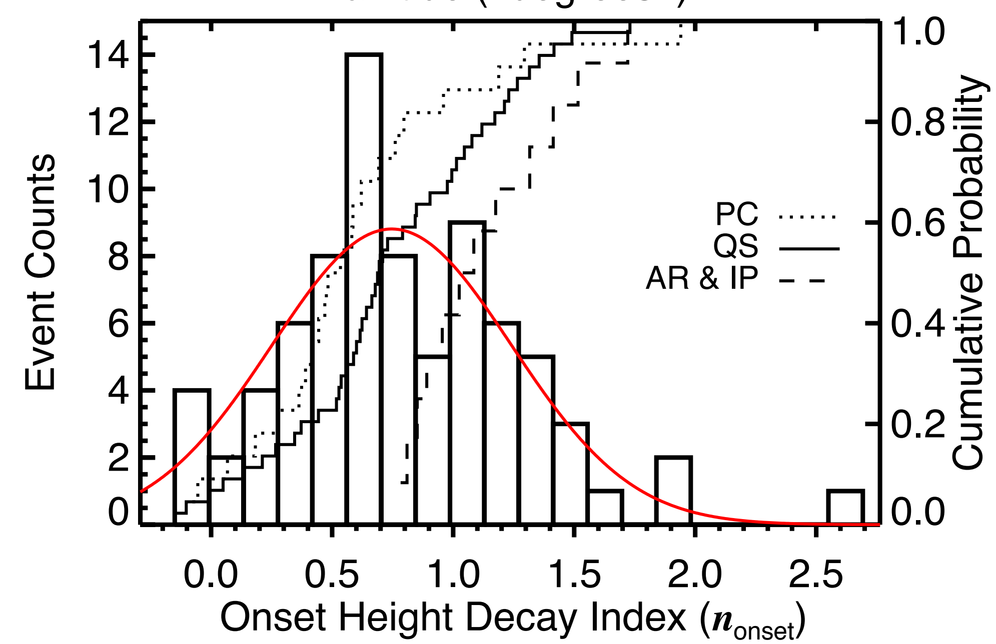


McCauley et al.
SolPhys, 2015

Decay index



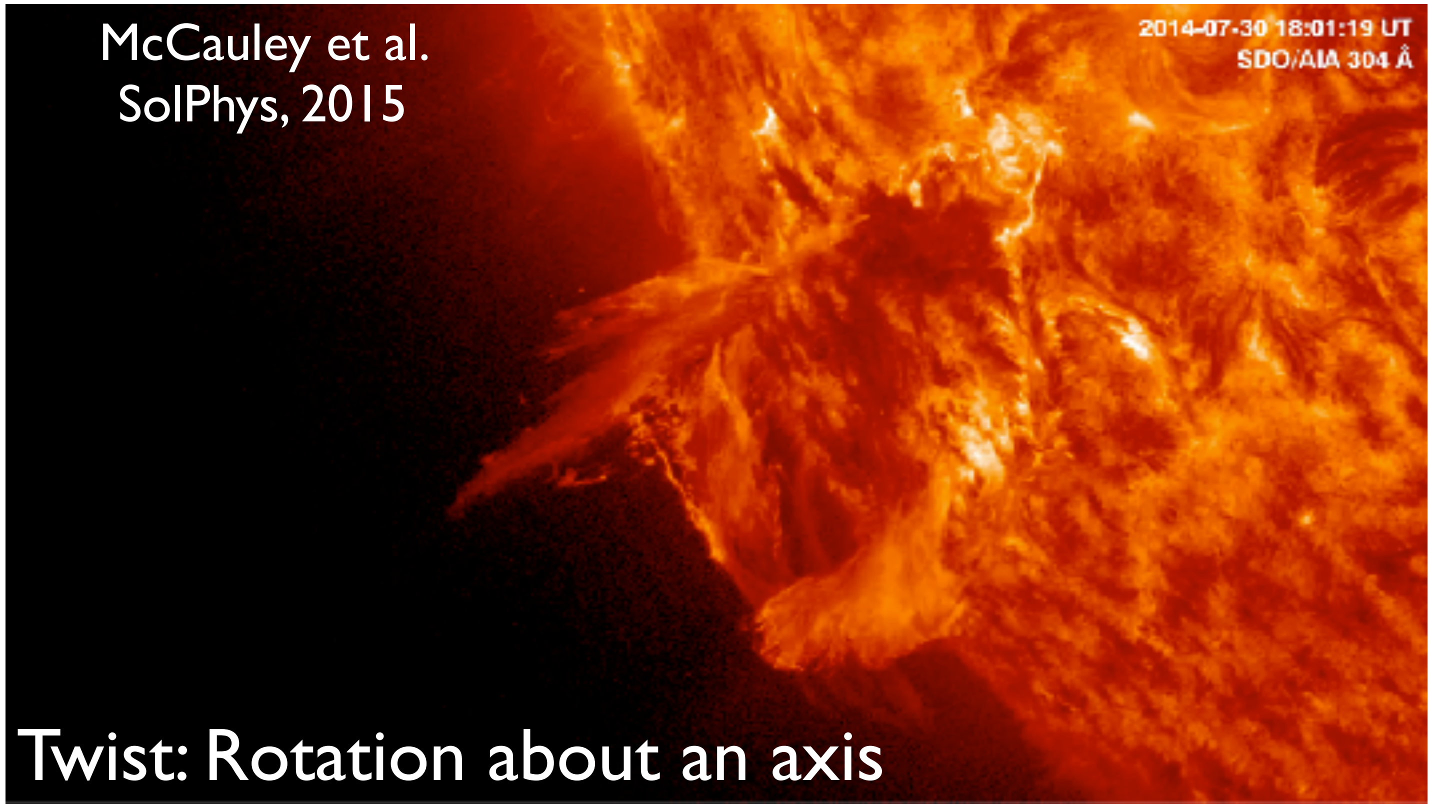


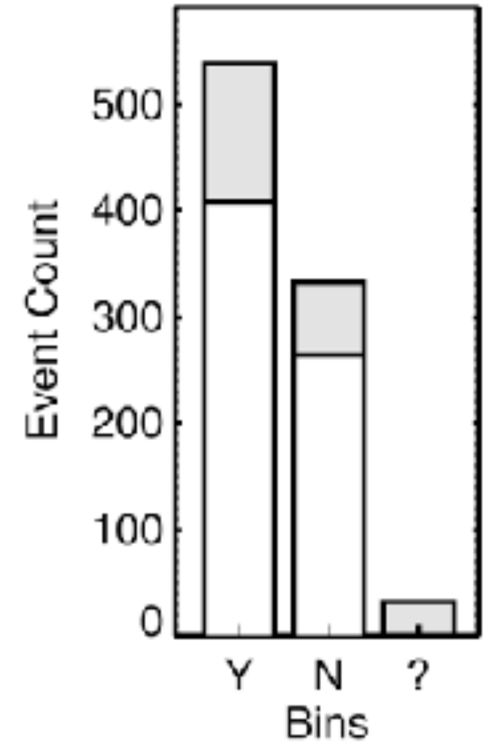


Decay index decreases with latitude, explaining higher onset heights at high latitudes

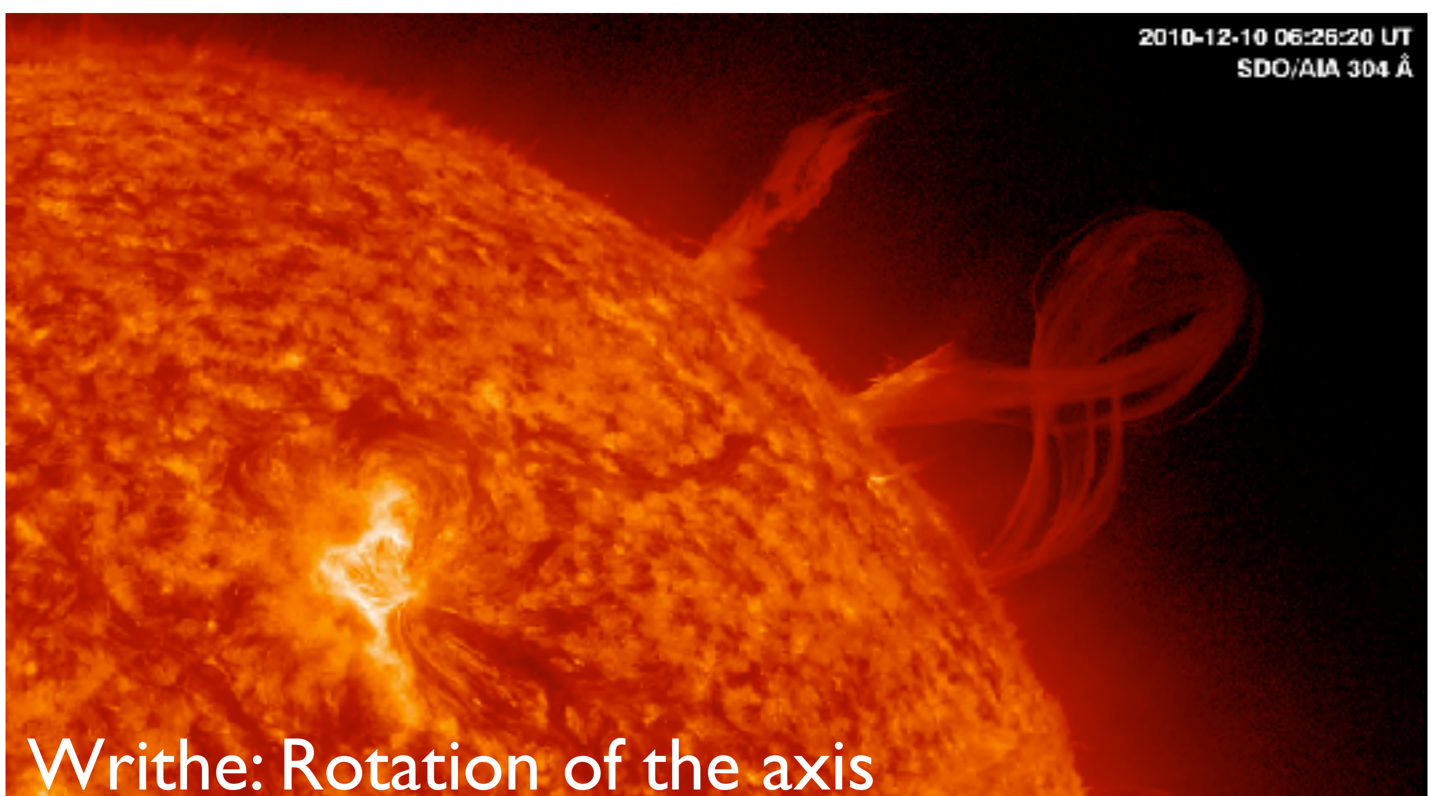
Many eruptions have a decay index of <1, indicating that an external mechanism rather than an ideal instability is the trigger

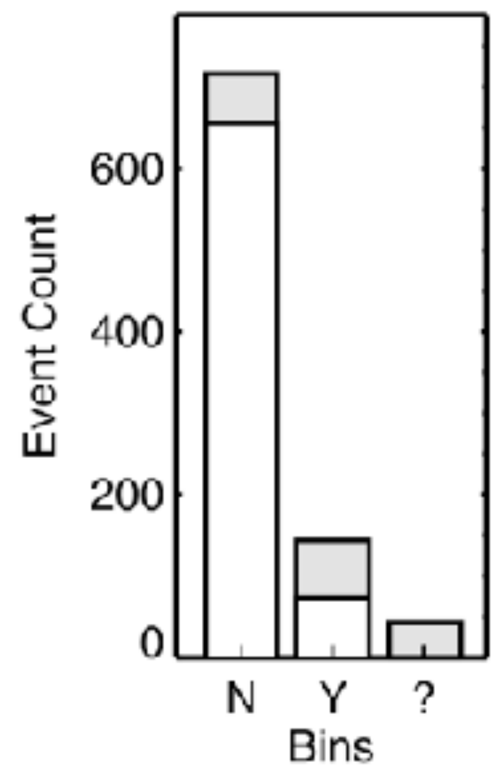
Twist and writhe





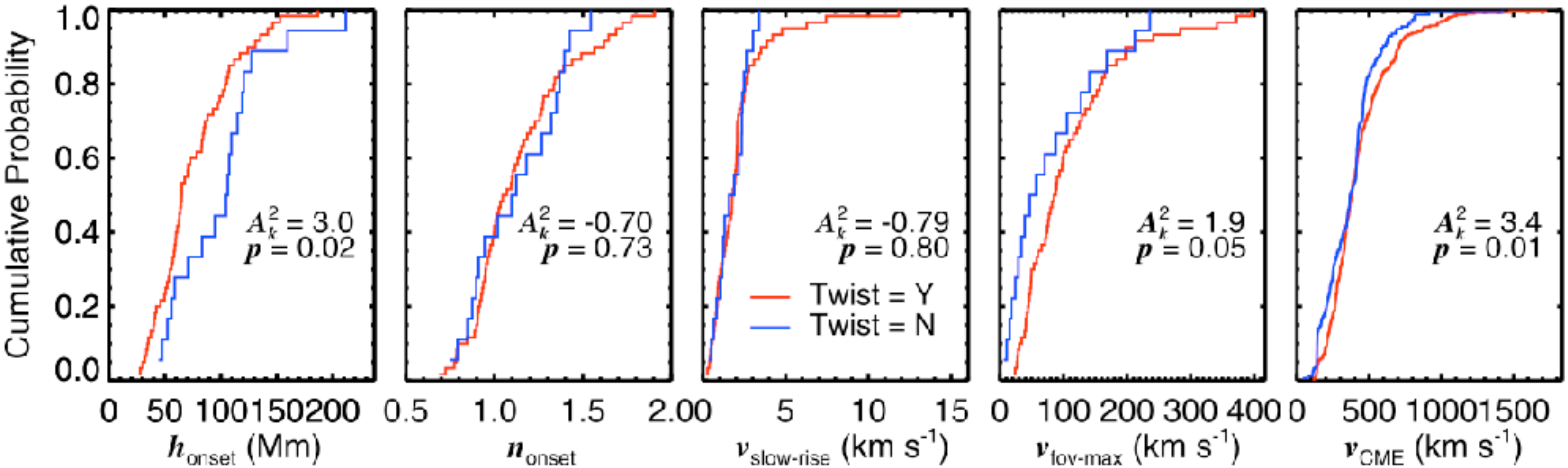
Many filament eruptions exhibit some form of twist

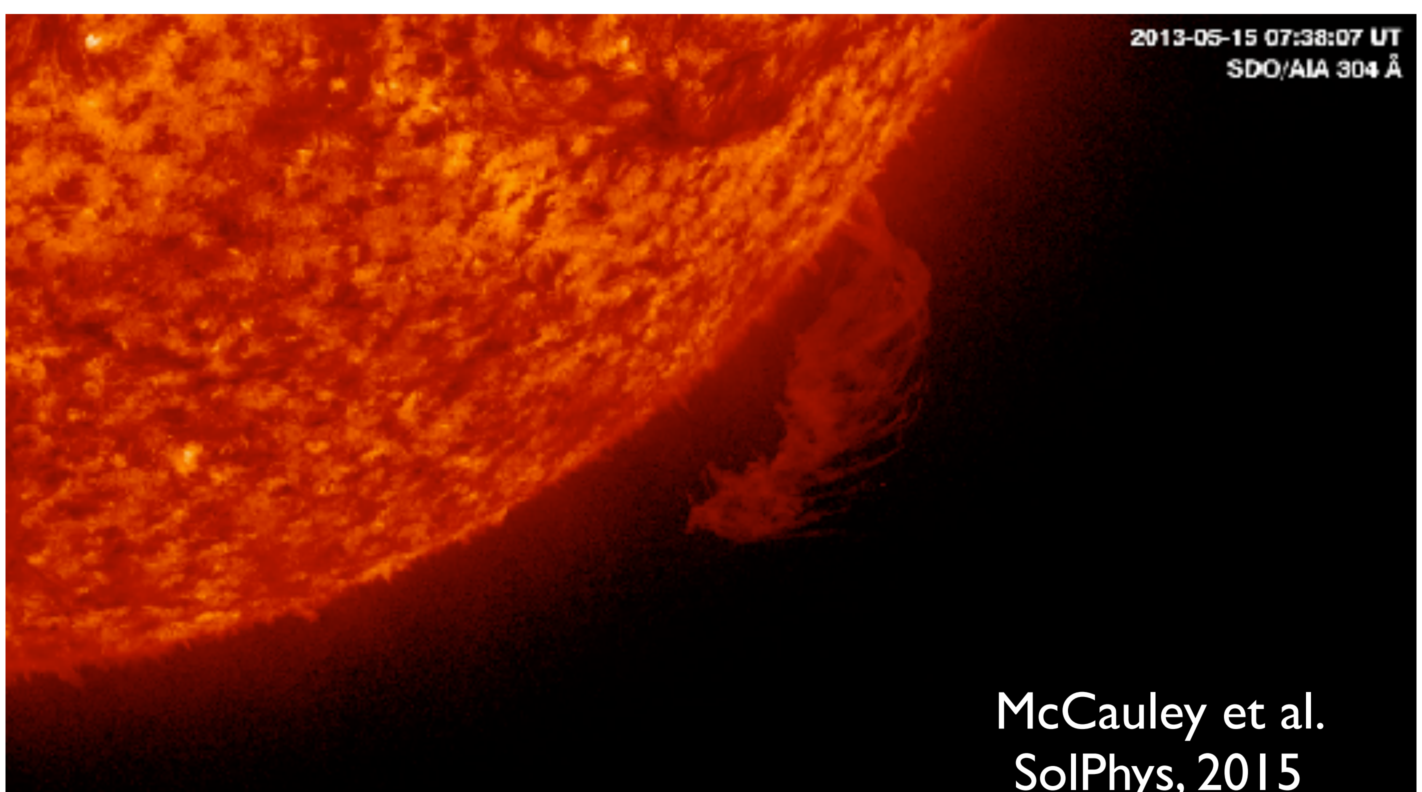




Writhe is less common, but may be misclassified as twist in some cases

Twist vs. no twist





Twisted eruptions are more likely to be faster (like the kink instability) and have higher onset heights

No noticeable difference in decay index.

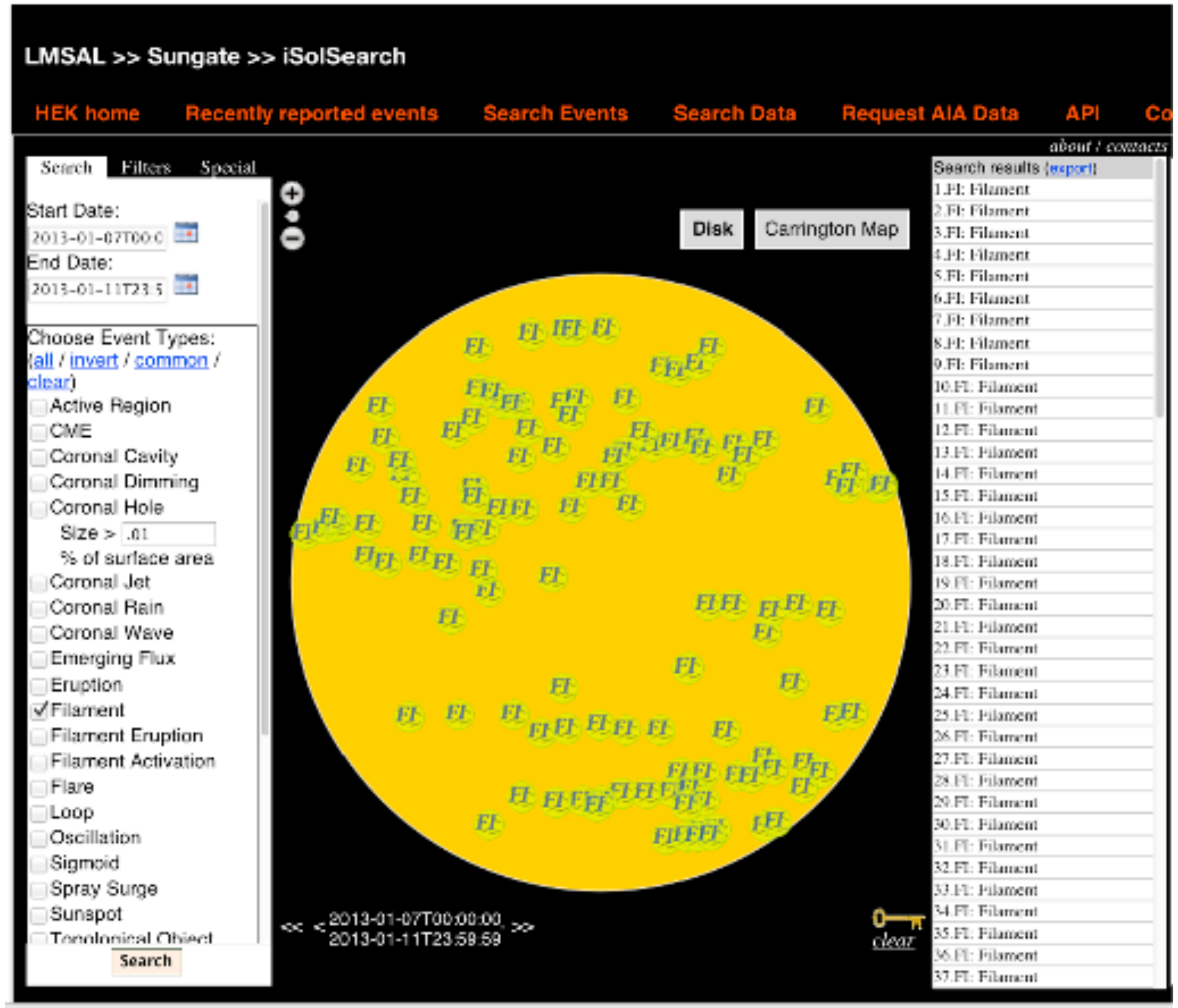
statistical investigations

Why do filaments erupt?

Aggarwal, A.*, Schanche, N., Reeves, K. K., Kempton, D., Angryk, R.

(Submitted to ApJS)

HEK filaments



filament properties:

center position

polygon shape

bounding box

length

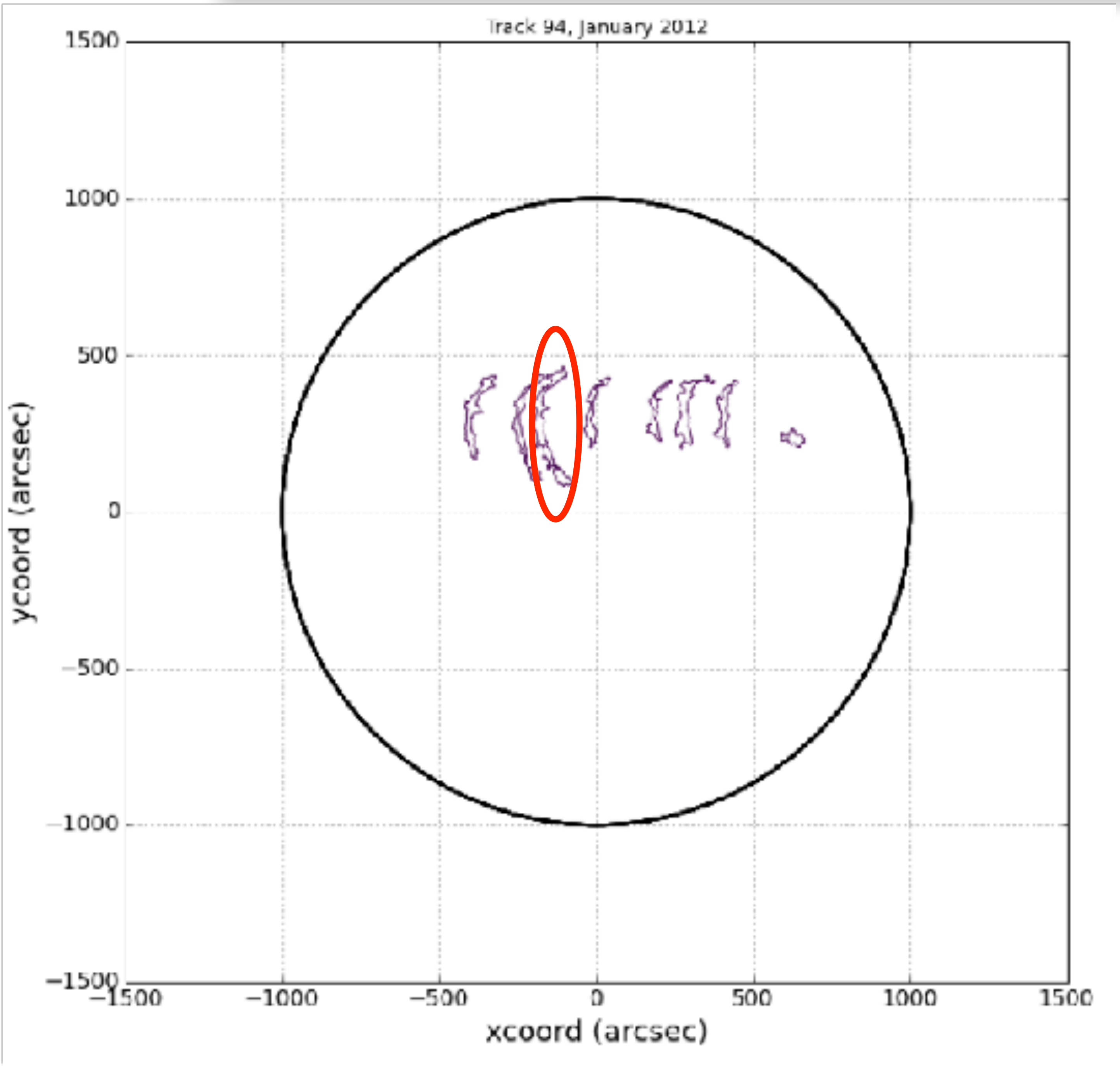
tilt

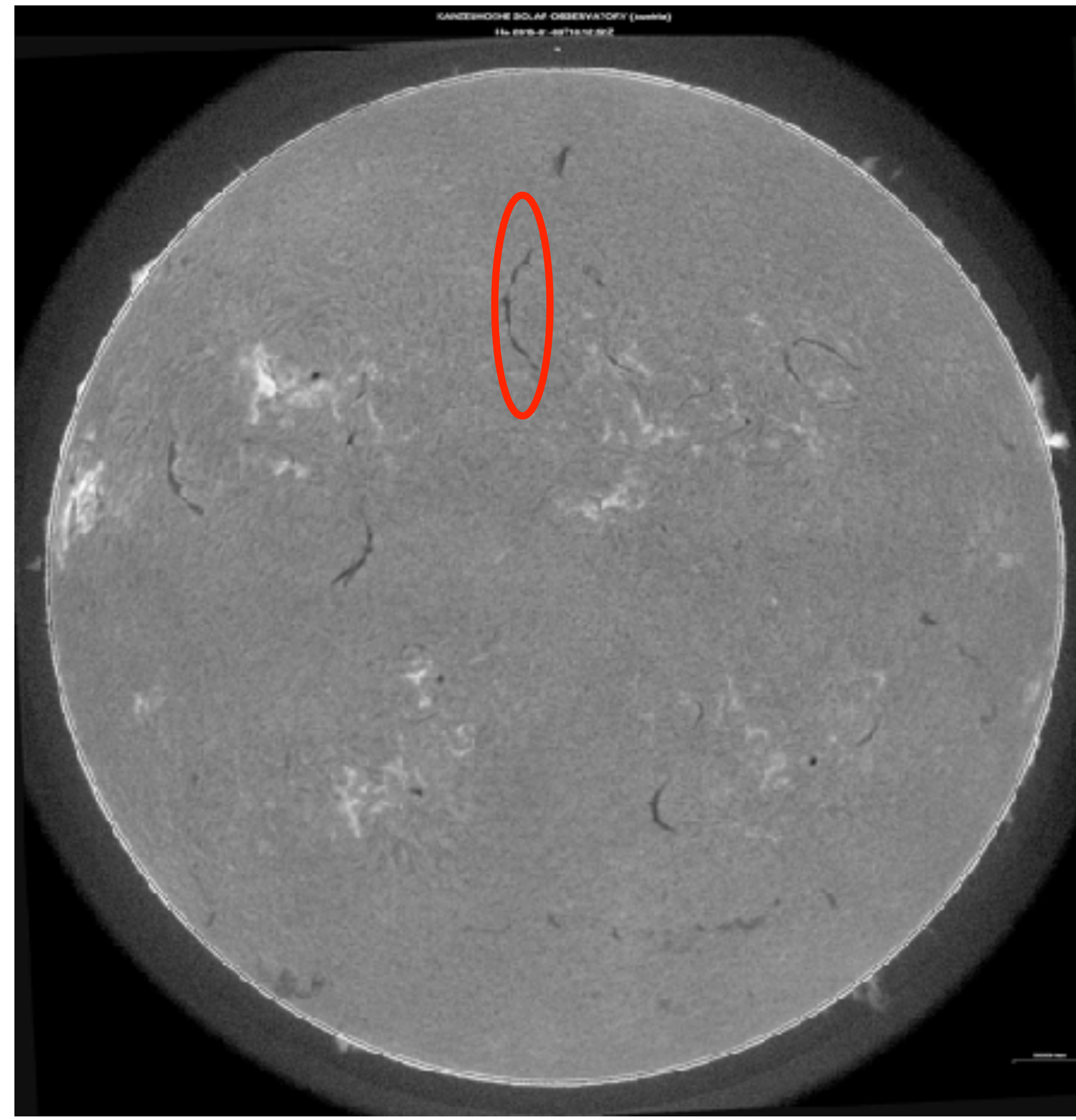
chirality

number of barbs

HEK filament tracking algorithm (Bernasconi, Rust, and Hakim, 2005) records each filament instance, but we need to associate instances as filaments rotate across disk

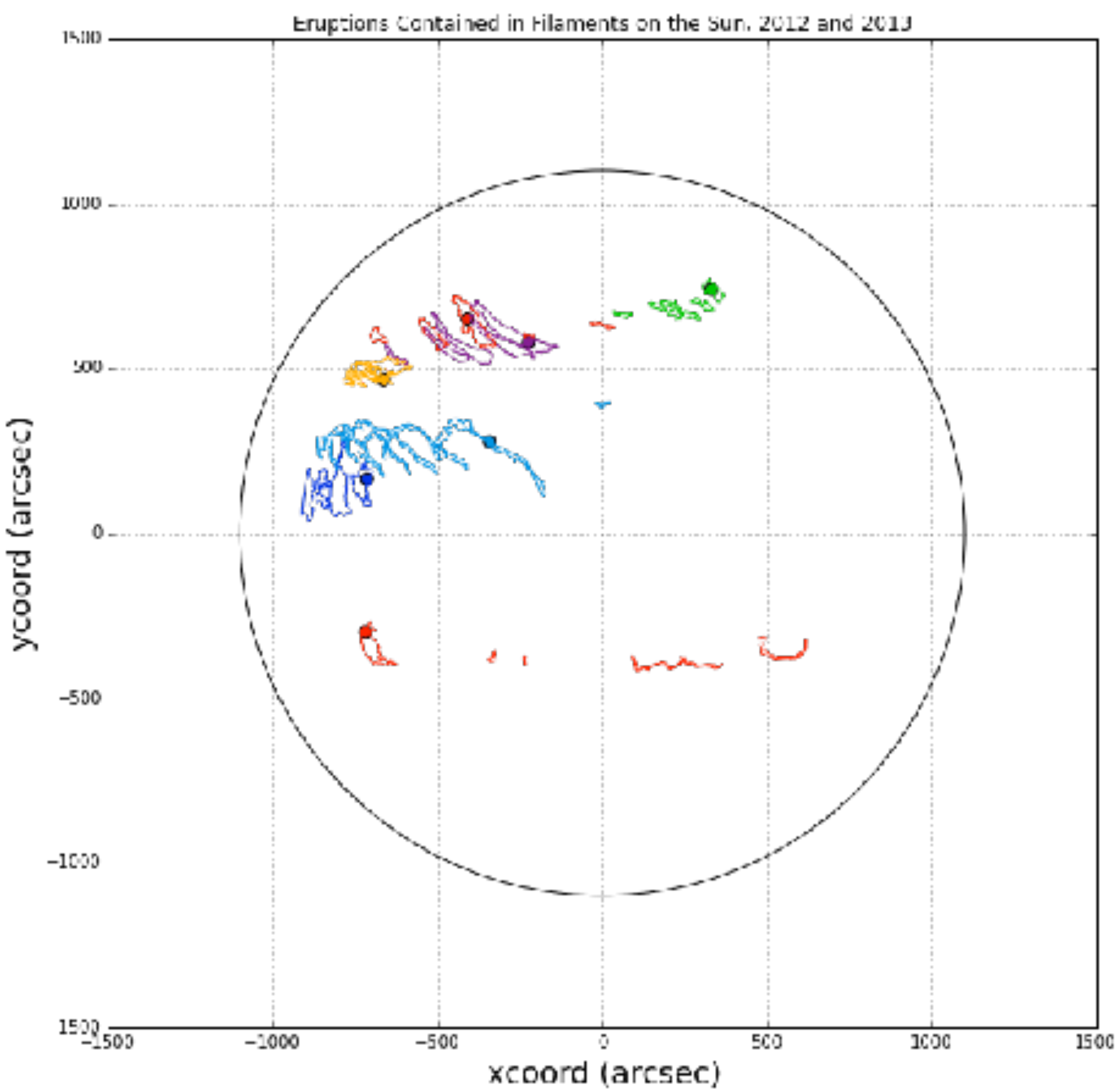
Filament tracking



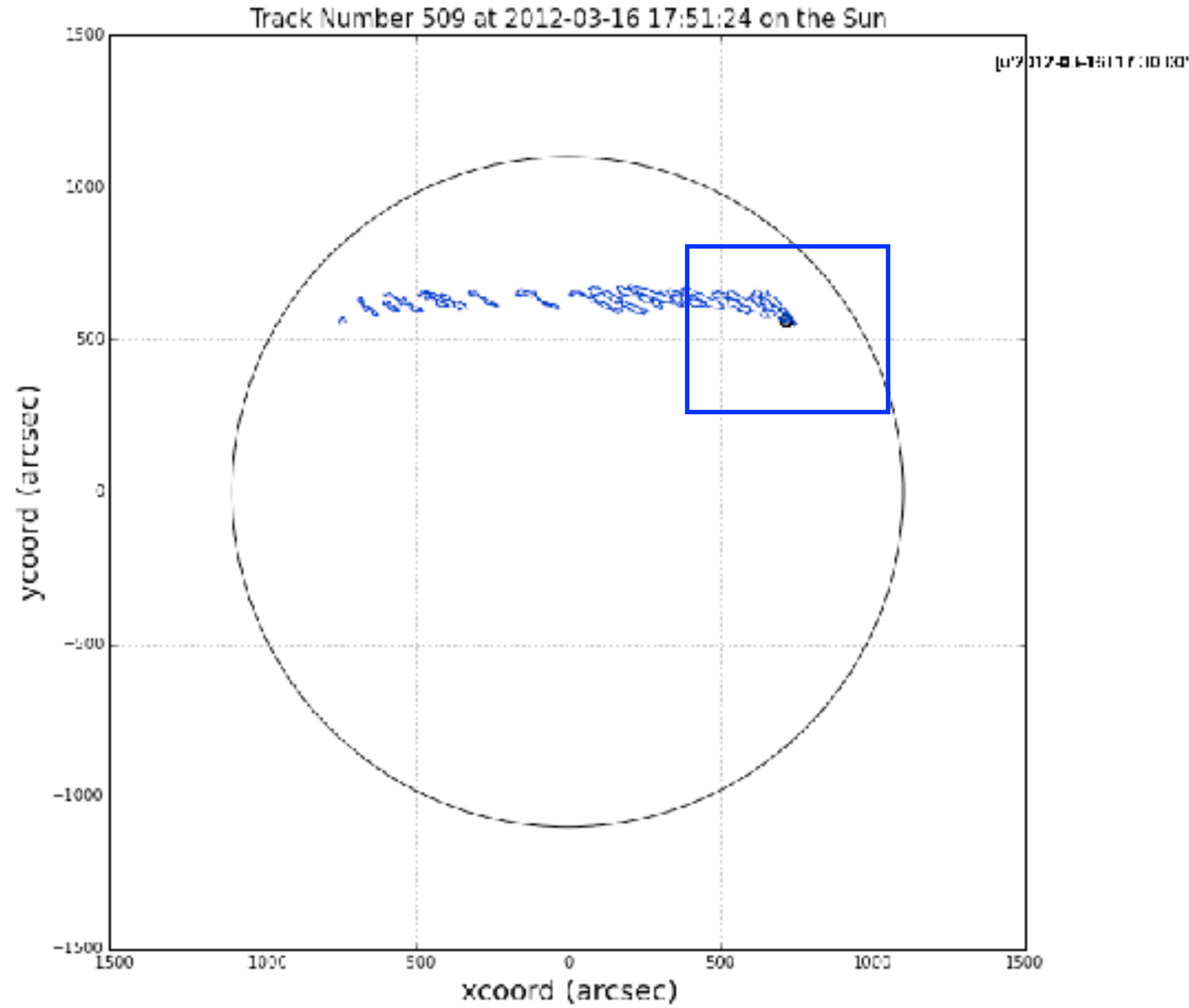


Tracking agolrithm (Kempton et al. 2015) associates filament instances into tracks

Eruption matching

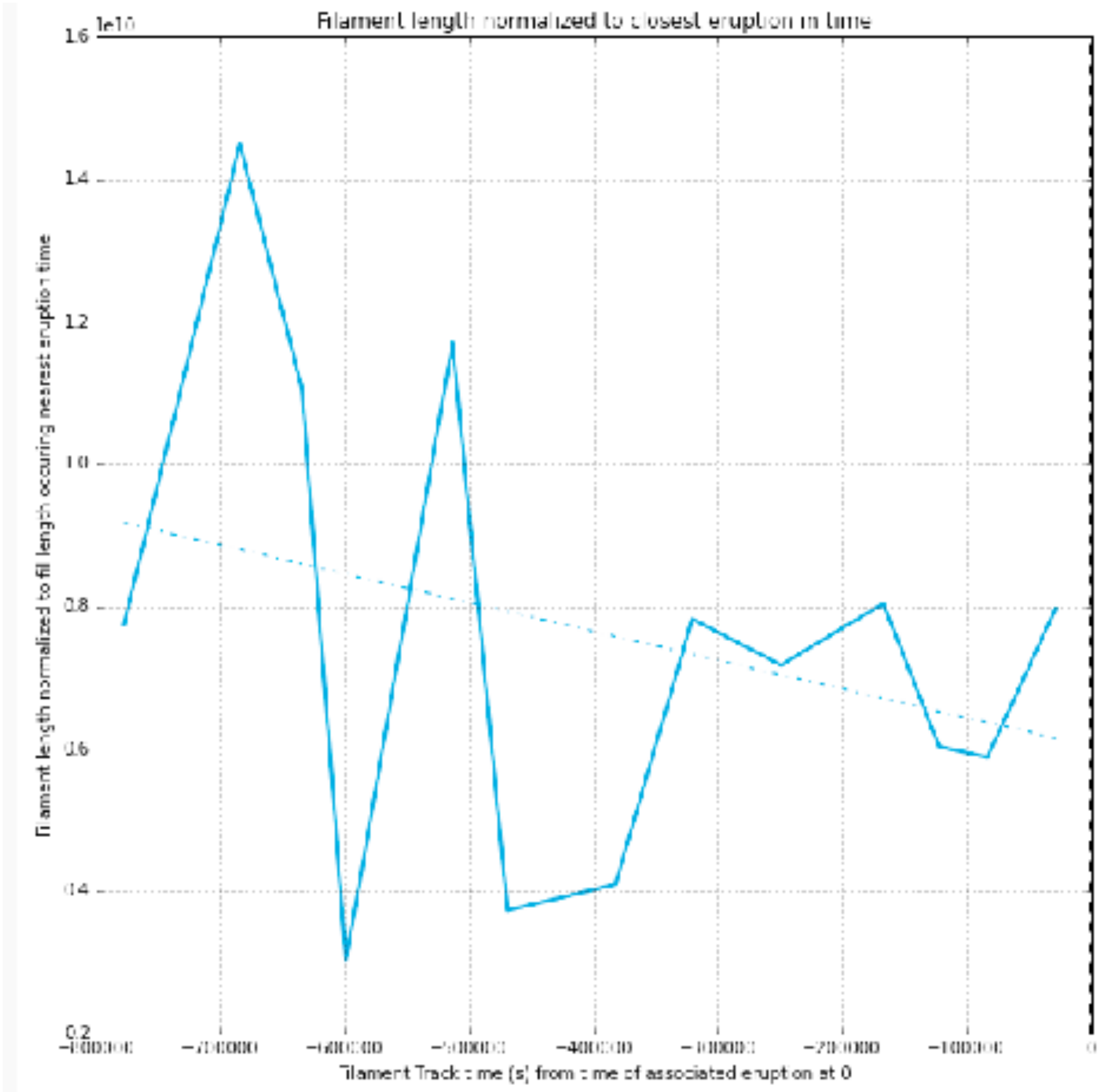


Eruption center within a filament polygon within +/- 12 hours



Filament polygon intersects eruption bounding box within +/- 12 hours

Filament properties

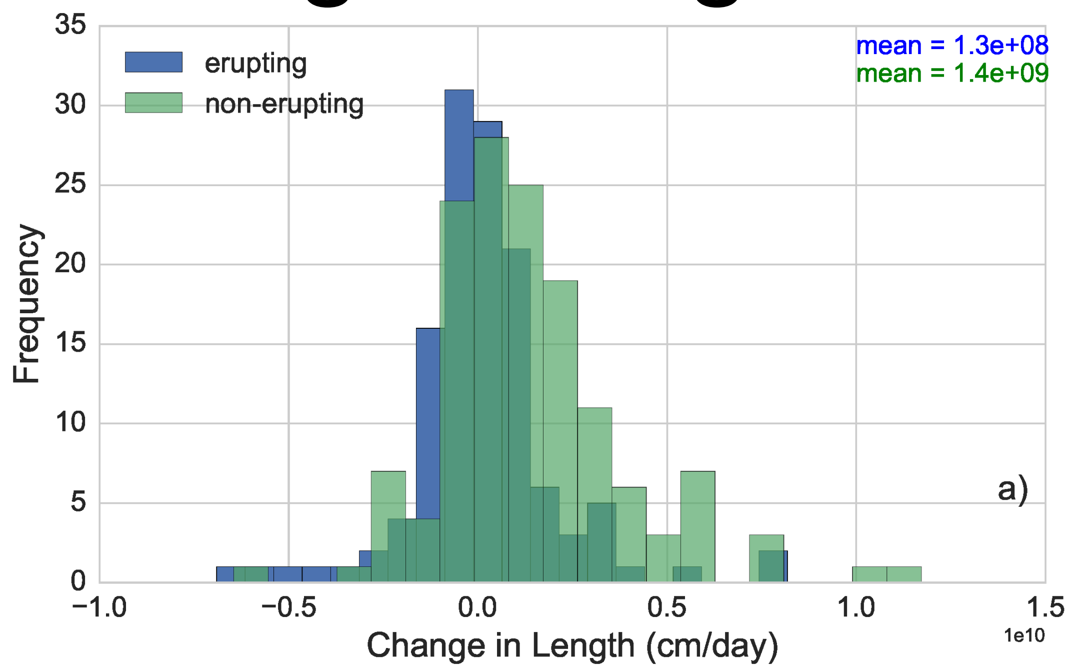


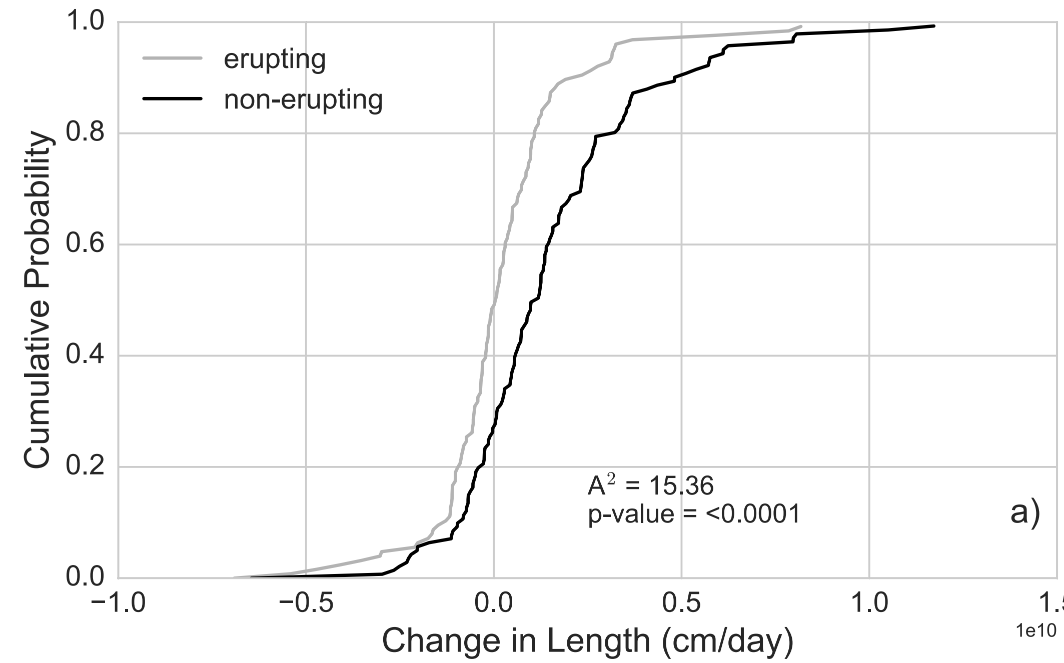
filament properties:

area (mean,stdev, skew,slope)
length (mean,stdev, slope)
L/W (mean,stdev, slope)
tilt (mean,stdev,skew, slope)
chirality (mean,stdev, skew, slope)
barbs (mean,stdev, skew,slope)
latitude (mean)

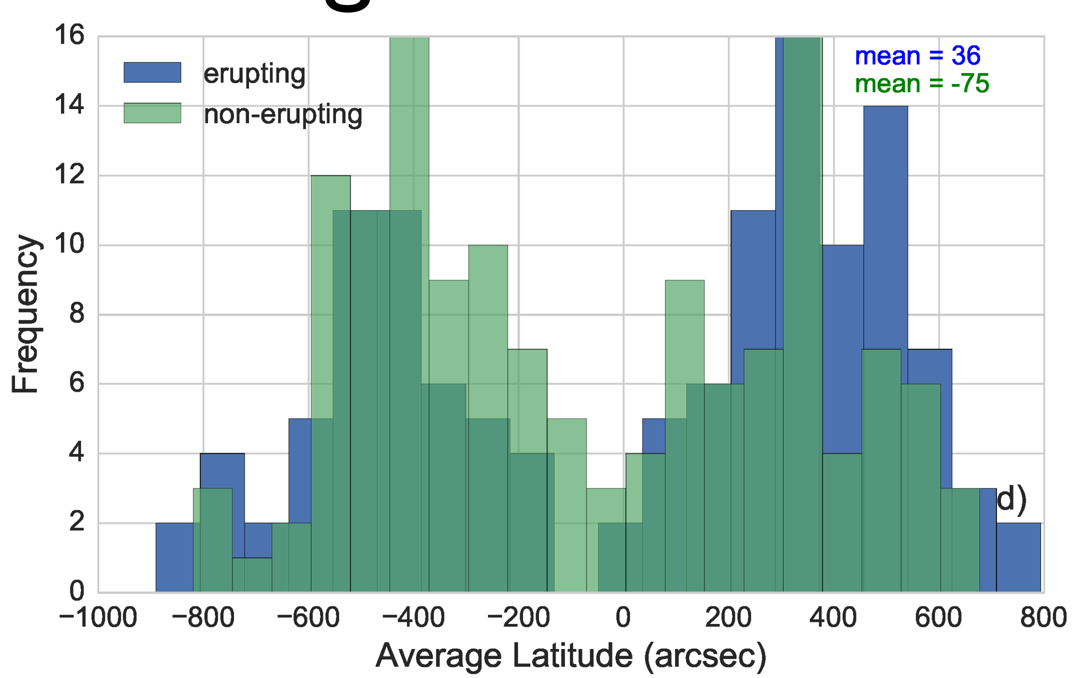
Anderson Darling Test

Change in Length

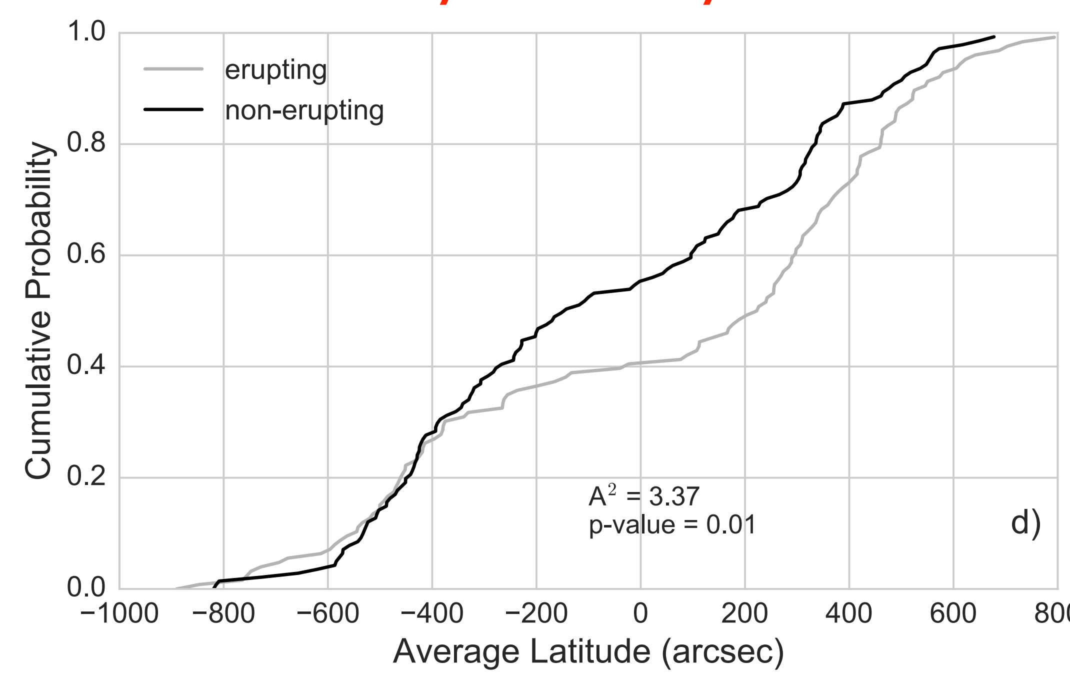




Average Latitude

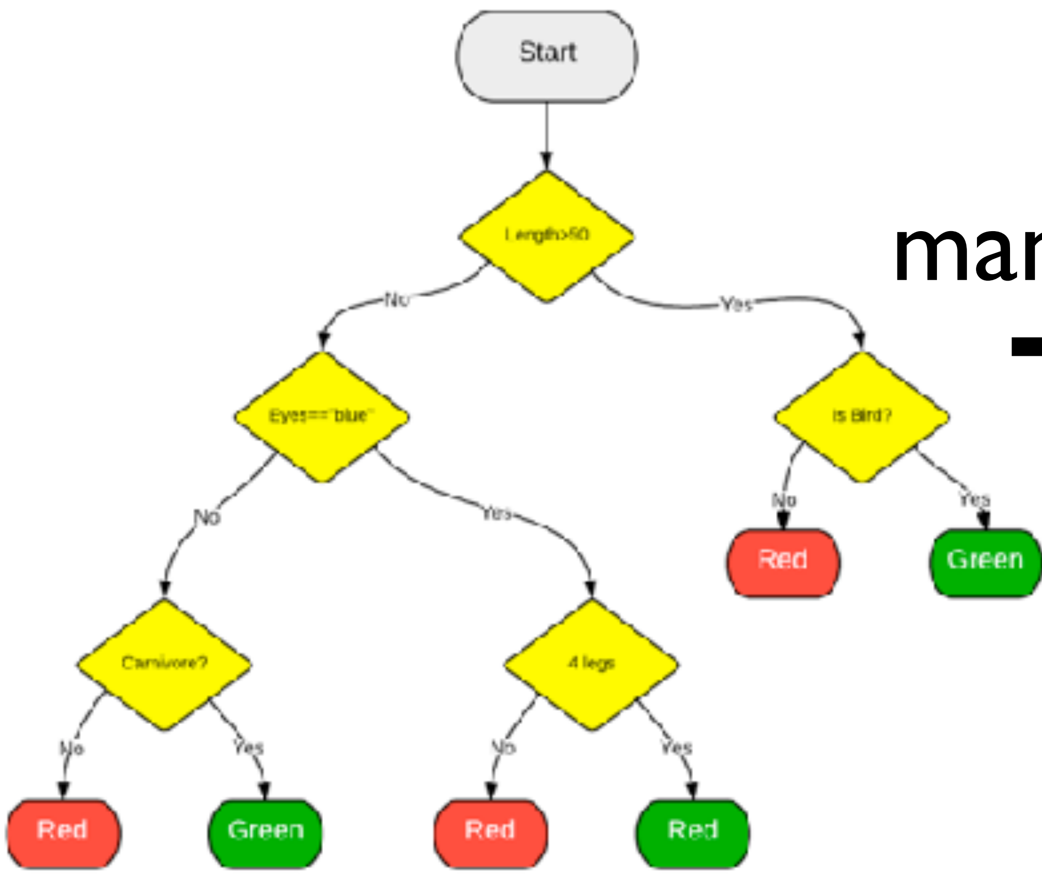


Probably a solar cycle effect



Random forest

decision tree



many trees

random forest

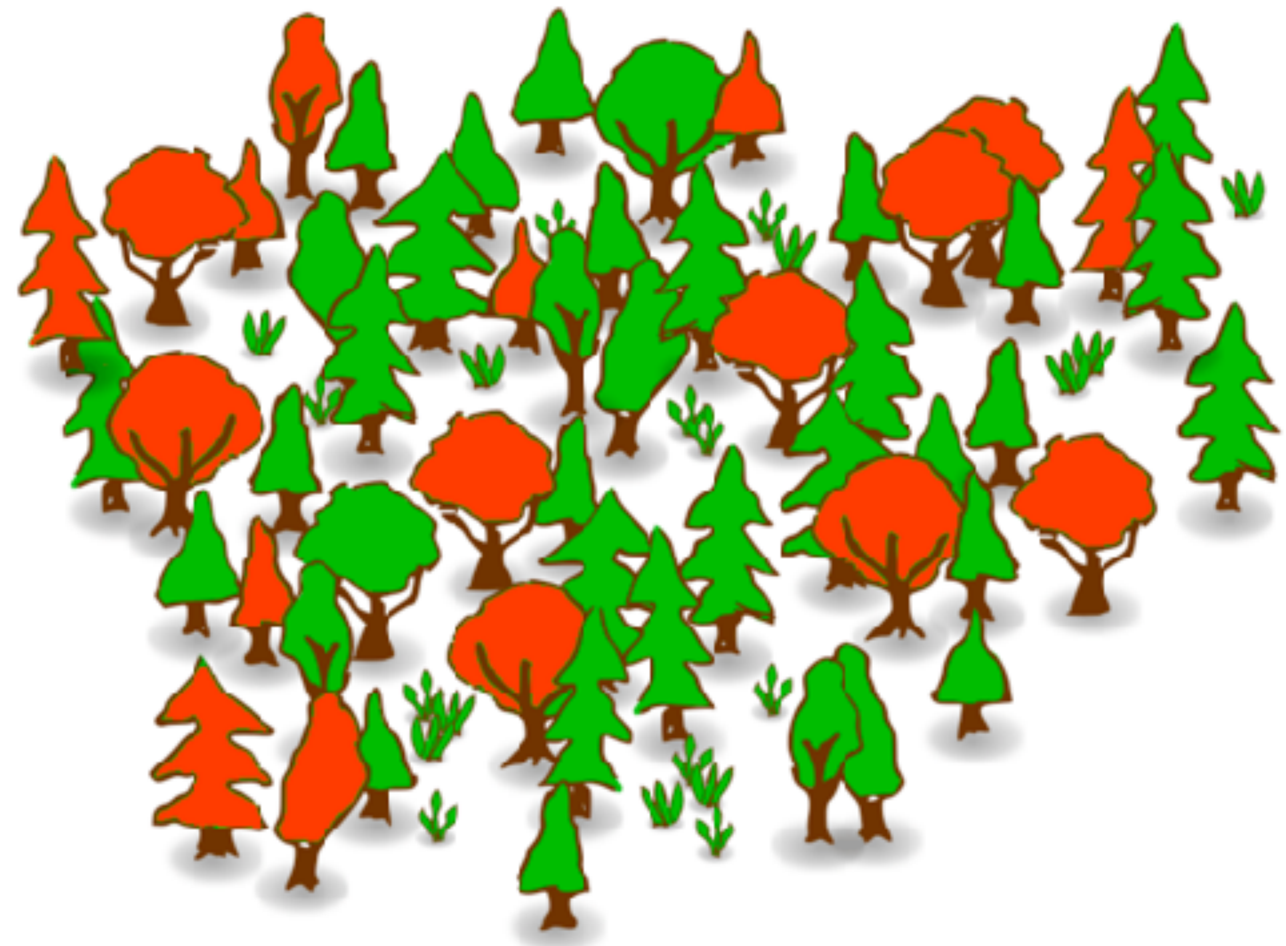
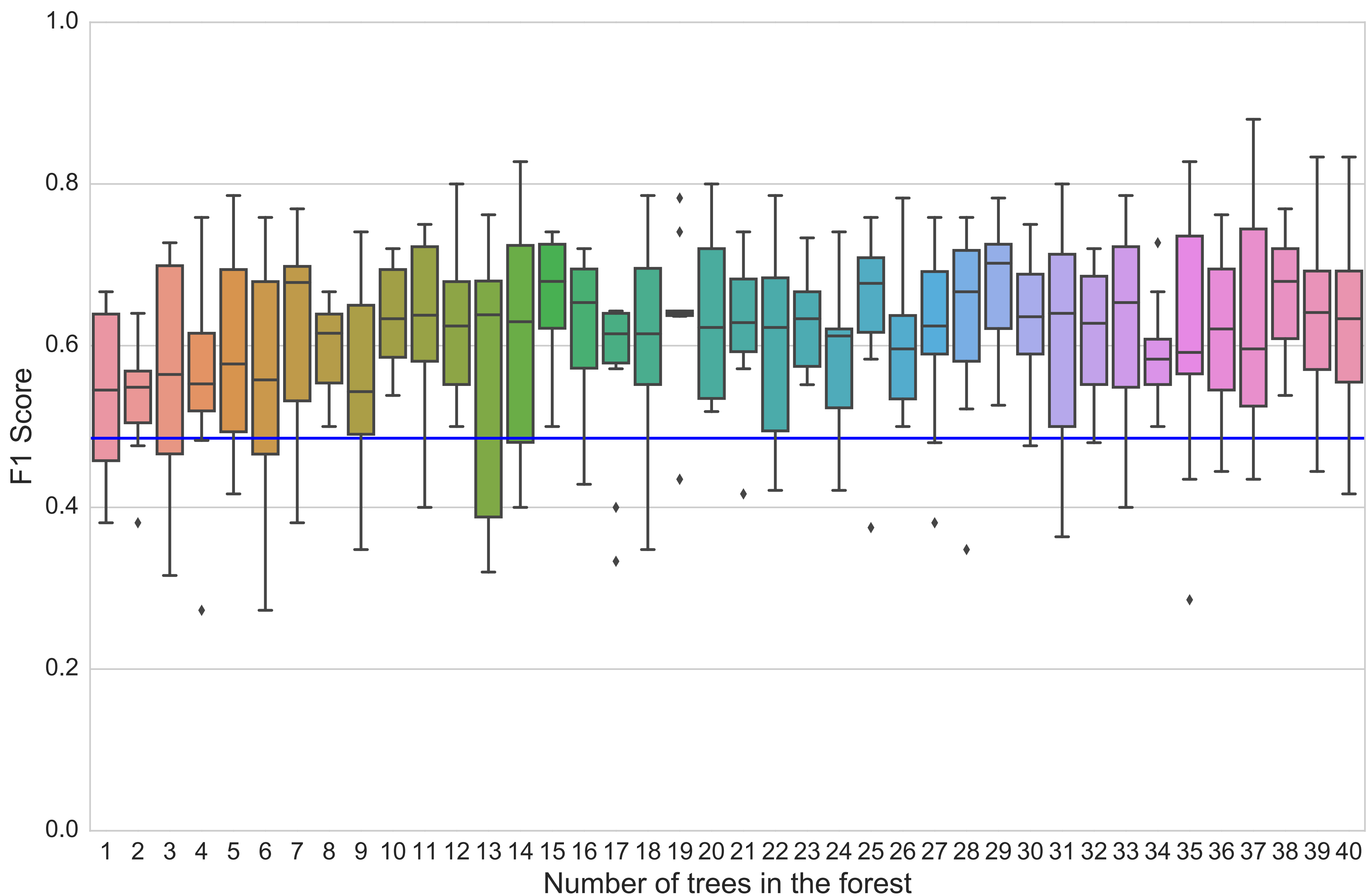


image credit: http://blog.yhat.com/posts/random-forests-in-python.html

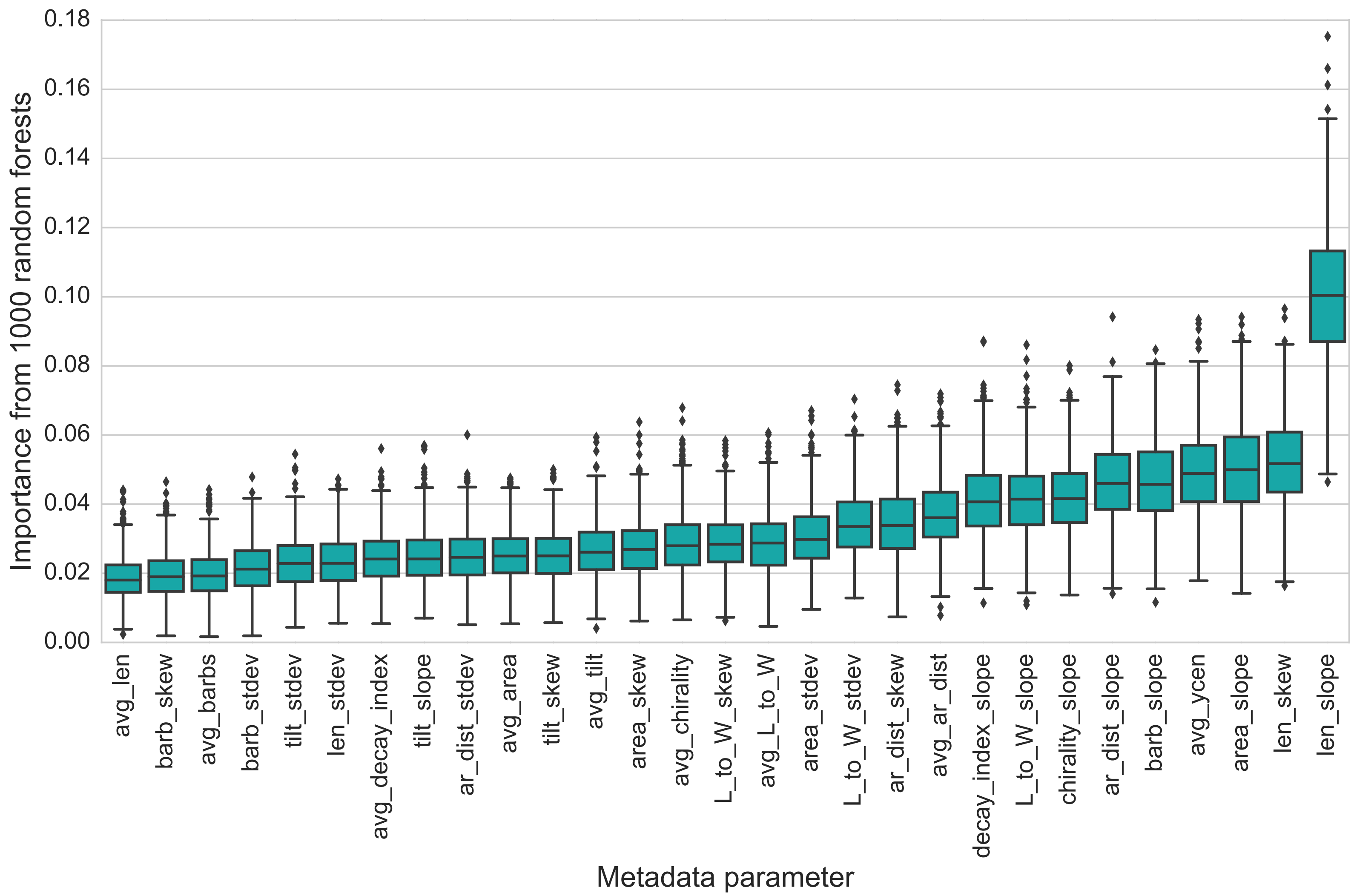
Random forest



Forests of 25 trees give a ~60% accuracy. Better than guessing randomly at 49%.

Feature importance

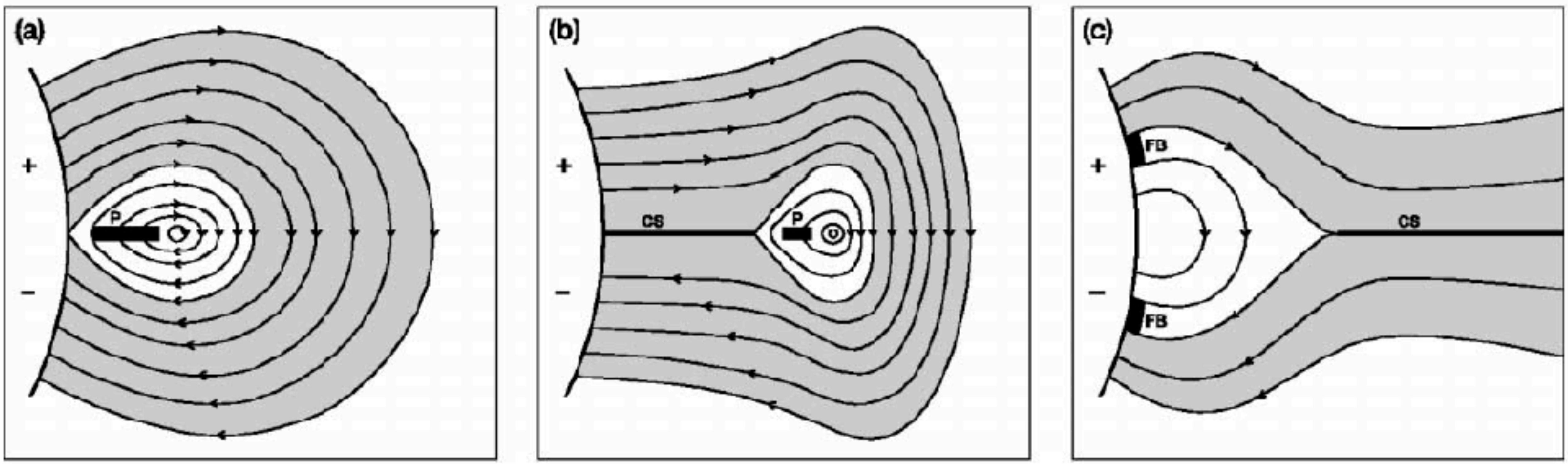
Random Forest



AD Test

Feature	A^2	p-value
len_slope	15.36	< 0.0001
area_slope	8.16	0.0004
barb_slope	5.98	0.002
len_skew	4.25	0.007
ar_dist_slope	3.82	0.009
L_to_W_slope	3.55	0.01
avg_ycen	3.37	0.01
L_to_W_stdev	1.56	0.07
decay_index_slope	1.45	0.08

Possible trigger mechanism



Filaments that get smaller are more likely to erupt → Mass draining is a possible triggering mechanism

Conclusions

- Polar crown filaments have higher eruption onset heights, possibly due to lower decay indexes
- Eruptions with twist have faster speeds and lower onset heights, implicating a kink instability
- Twist in filament eruptions does not seem to be related to magnetic asymmetry
- Parameters such as filament length and area tend to decrease before an eruption, implicating mass draining as a trigger