Automated detection of Coronal Mass Ejections in SWAP images using Parabolic Hough Transform

Ritesh Patel

Indian Institute of Astrophysics, Bangalore

Contributors:

Dipankar Banerjee, Elke D'Huys, Marilena Mierla, Matt West, Vaibhav Pant

Outline

1. SWAP
2. Automated CME detection algorithms
3. CACTus
4. iCACTus
5. Test Cases
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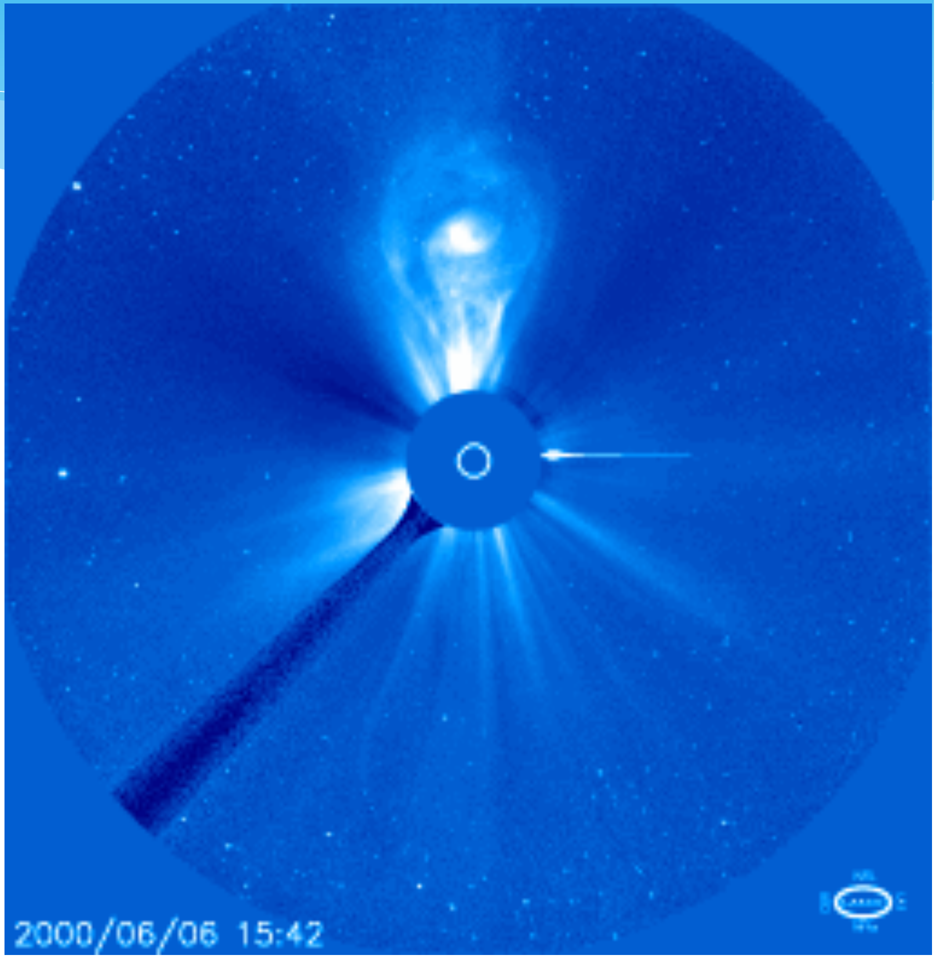
Coronal Mass Ejection (CME)

Coronal Mass Ejection is an observable change in coronal structure that occurs on time scales between a few minutes to several hours and involves the appearance and outward propagation of new, discrete and bright white-light features in the coronagraph field of view. (***Hundhausen A J et.al 1984***)

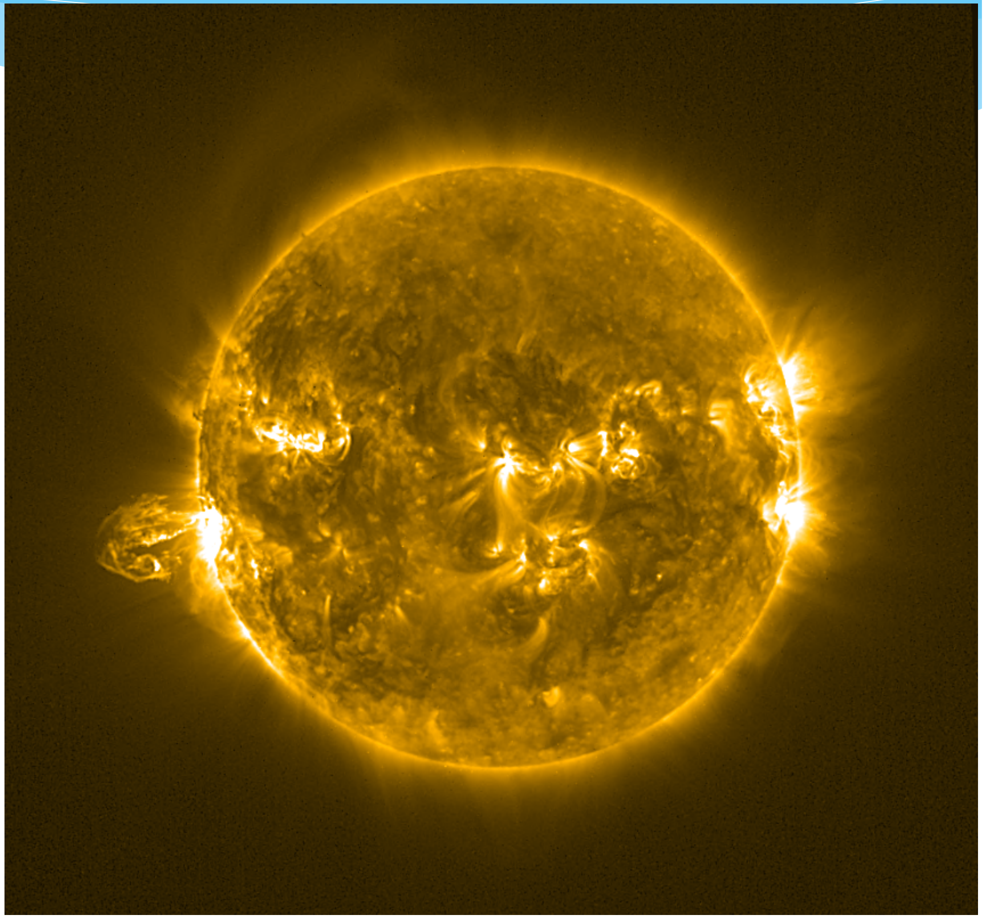


CME seen in LASCO C3

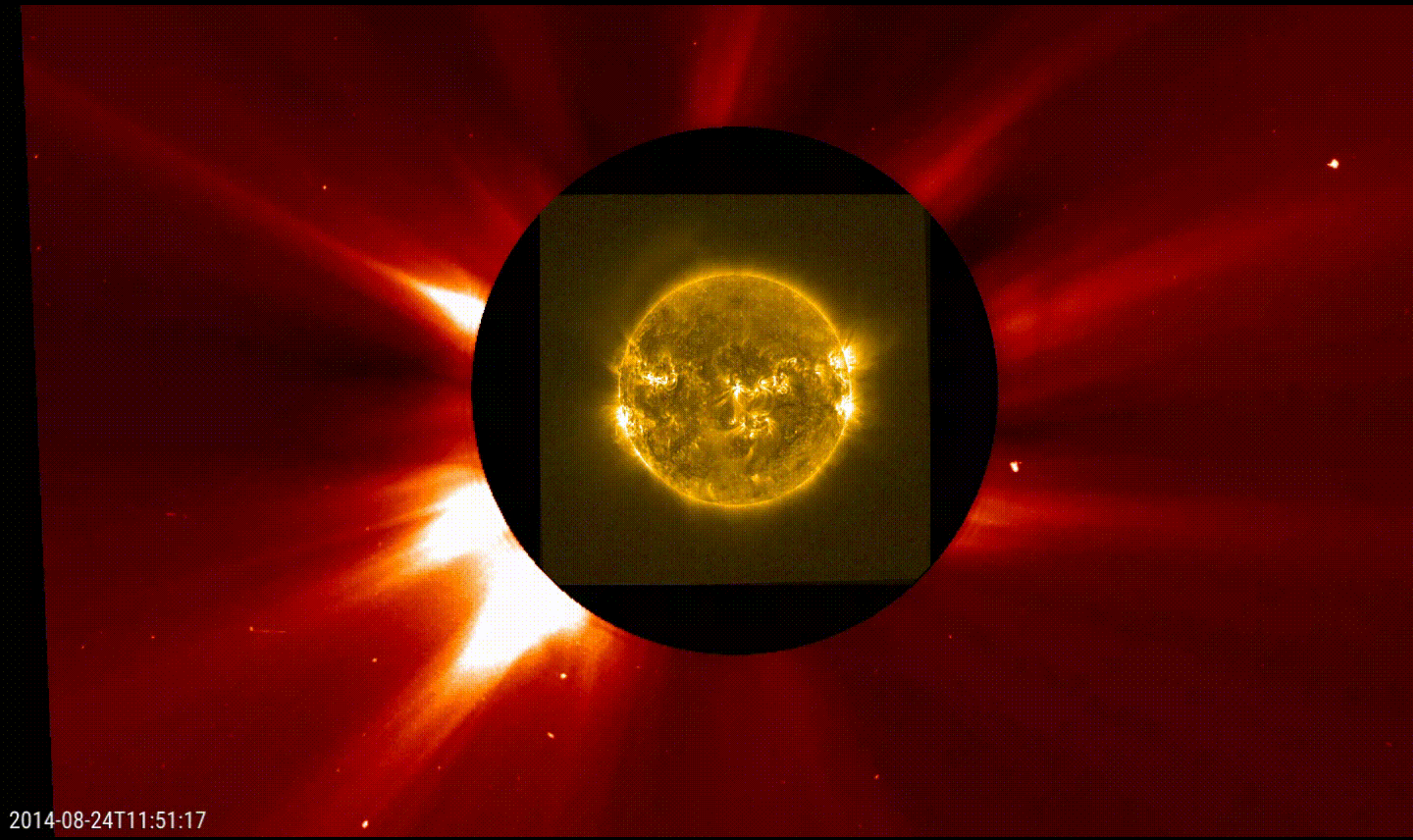
Credit: NASA

The Sun Watcher using Active Pixel System detector and Image Processing (SWAP)

* Field of View: upto $1.7R_\odot$
* Wavelength: 17.4nm
* Pixel scale: 3.2”/pixel
* Image size: 1024x1024
* Cadence: 1-2 minutes



Credit: Royal Observatory of Belgium


2014-08-24T11:51:17

Automated CME detection algorithms

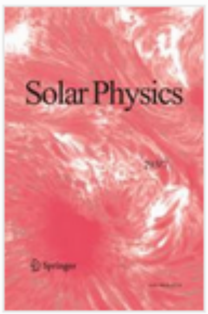
On Ground:

- ❑ **CACTus**- It uses Hough transform and detect CME bright structure motion (Robbrecht and Berghmans, 2004; Pant et al., 2016).
- ❑ **SEEDS**- It isolates leading edge of CMEs by intensity thresholding thereby tracking CMEs in subsequent images (Olmedo et al. 2008).
- ❑ **ARTEMIS**- It detects CMEs from the synoptic Carrington maps (Boursier et al. 2009)
- ❑ **CORIMP**- It employs a dynamic CME separation technique followed by multi-scale edge detection technique to identify the CME (Morgan, Byrne, and Habbal, 2012; Byrne et al., 2012).

On Board:

- Onboard automated CME detection logic for Multi Element Telescope for Imaging and Spectroscopy (***METIS***) is proposed (Bemporad et al. 2014).

Springer Link



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Onboard Automated CME Detection Algorithm for the Visible Emission Line Coronagraph on *ADITYA-L1*

Authors | Authors and affiliations

Ritesh Patel, Amareswari K, Vaibhav Pant, Dipankar Banerjee, Sankarasubramanian K., Amit Kumar

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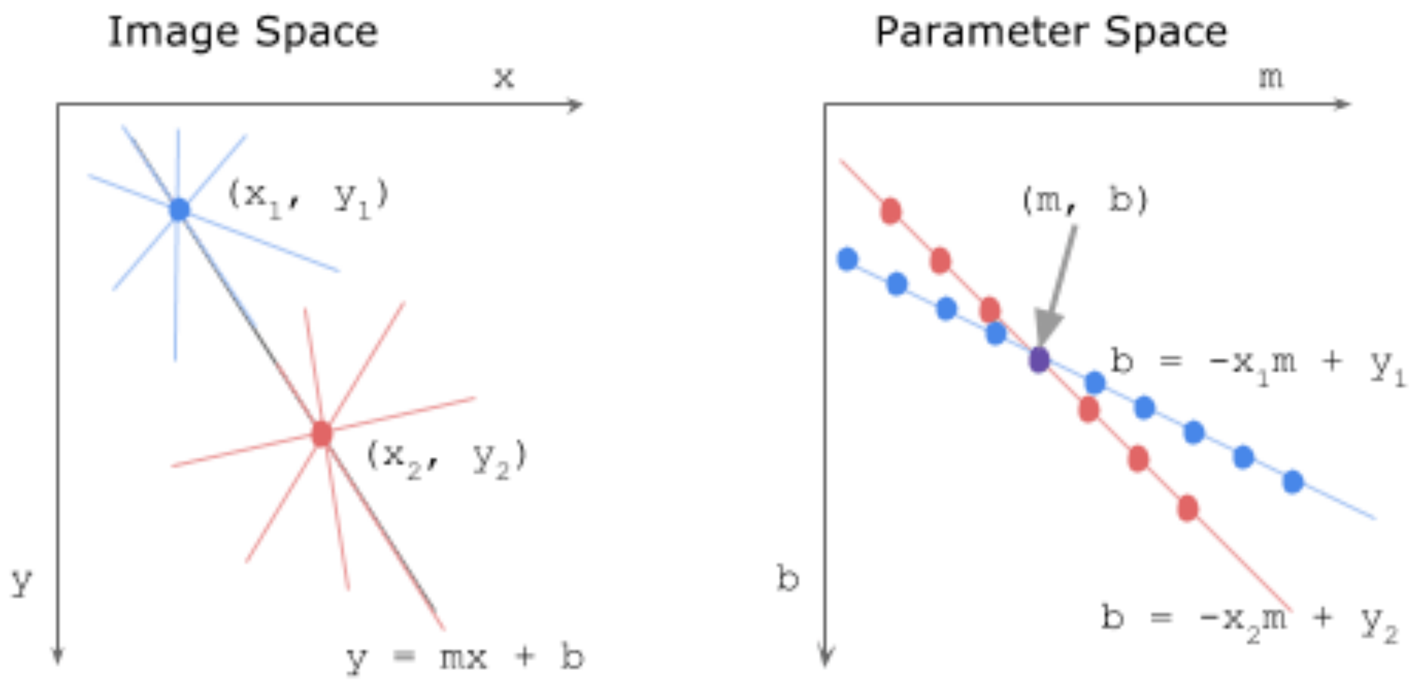
CACTus

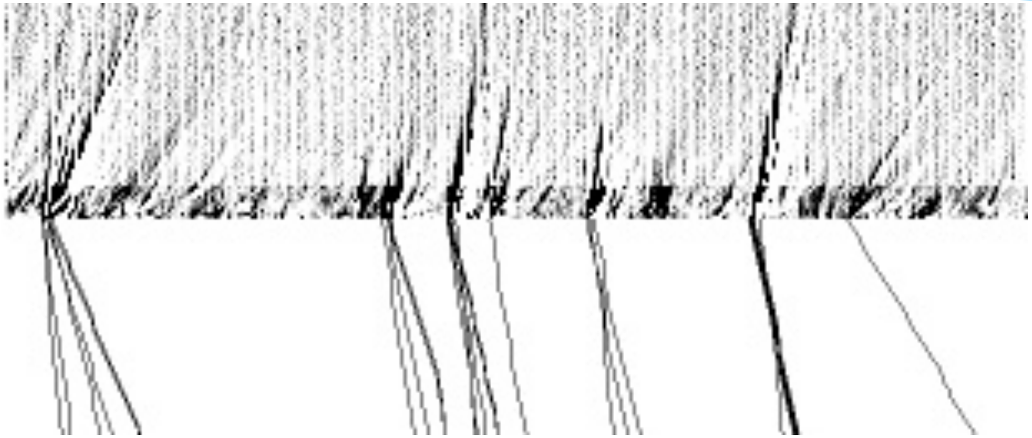
* It uses **linear** Hough transform to detect CMEs in polar transformed running difference coronagraph images (Robbrecht and Berghmans, 2004; Pant et al., 2016)



Implementation of Hough transform to detect line in image.

CACTus

- CACTus was initially implemented in LASCO-C2 and C3 images and was later extended to STEREO/COR2 and Heliospheric Imager images.

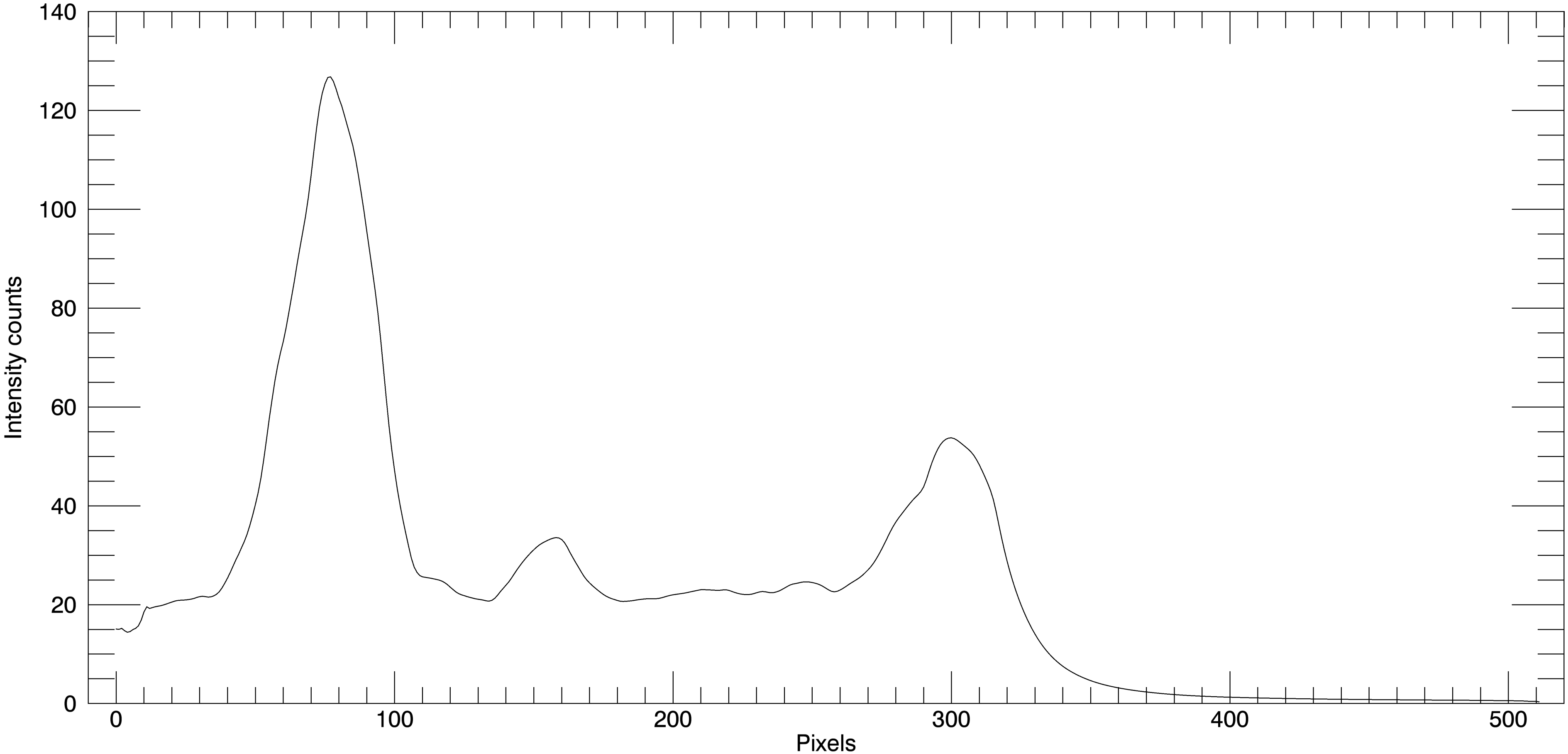


Courtesy : Robbrecht and Berghmans, 2004

Top: example of a (time, height) slice through the datacube at a given angle. *Bottom: the corresponding ridges (set upside down) detected* in this slice using the Hough transform. The horizontal range runs from 9 to 14 November 2003. In both panels the vertical range corresponds to the combined C2/C3 field of view (FOV). The inclination angle of the ridges corresponds to the propagation velocity.

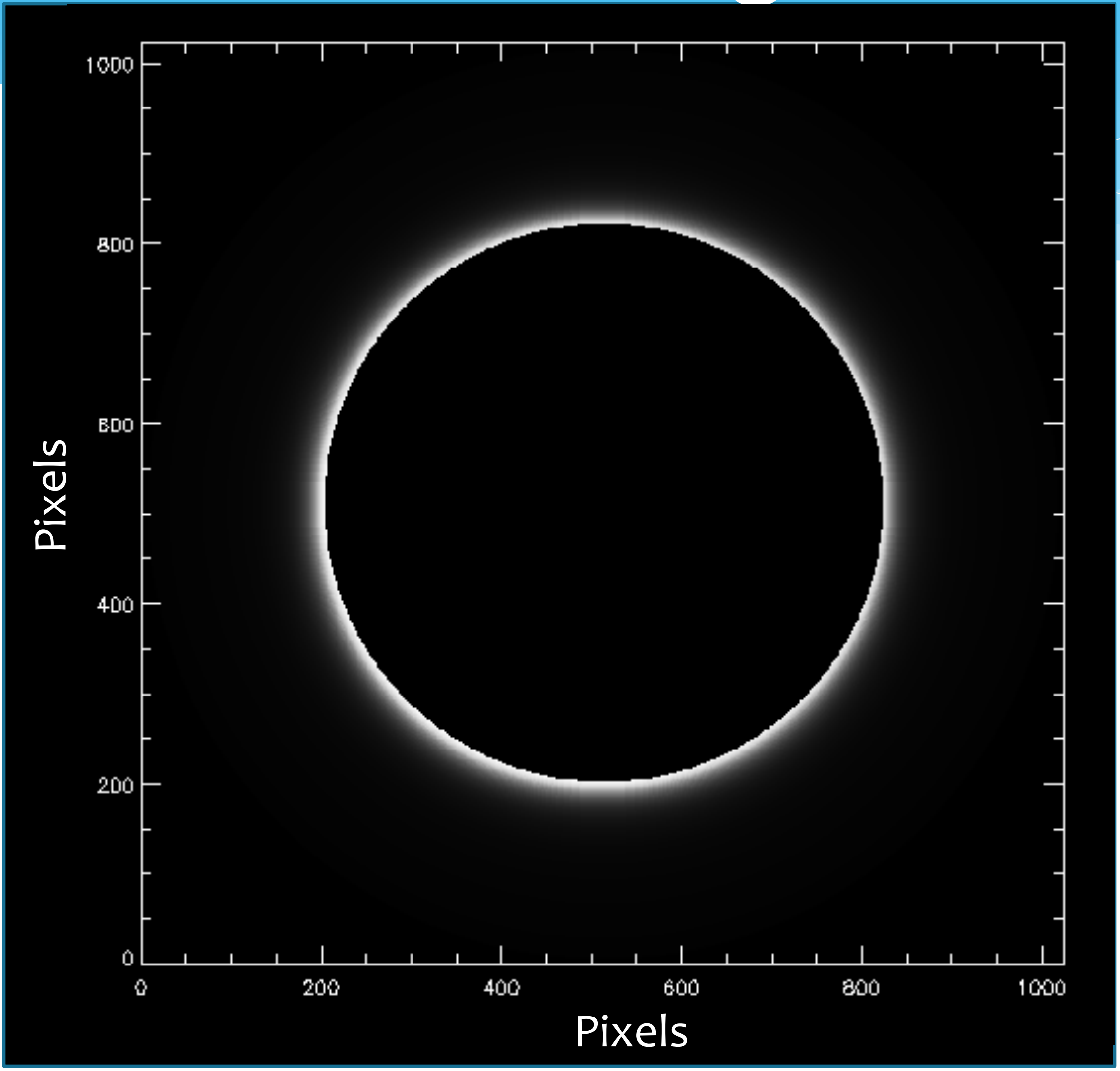
Inner-corona CACTus

iCACTus


Intensity counts
Pixels
0
20
40
60
80
100
120
140
0
100
200
300
400
500

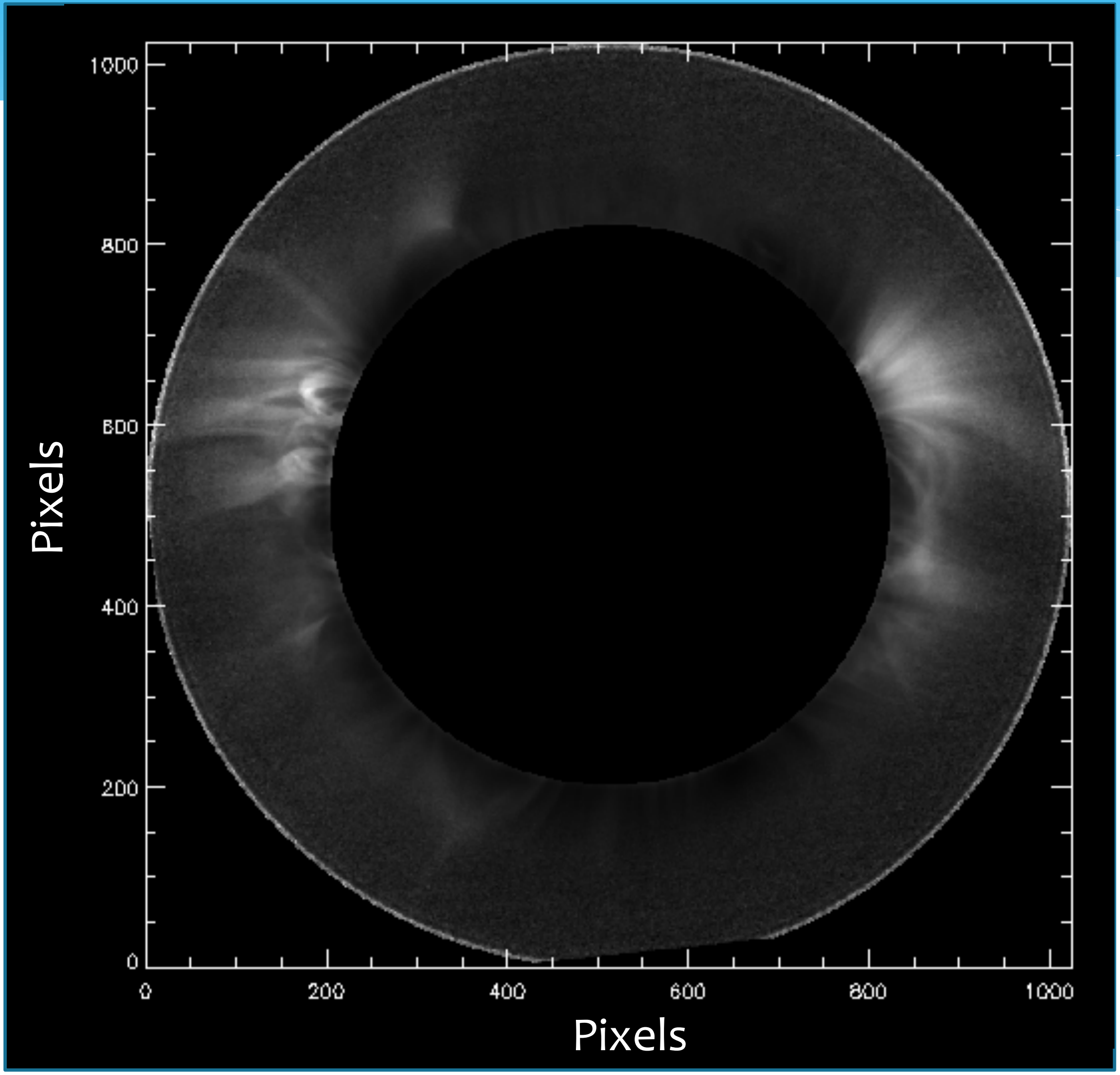
SWAP image

Uniform Background

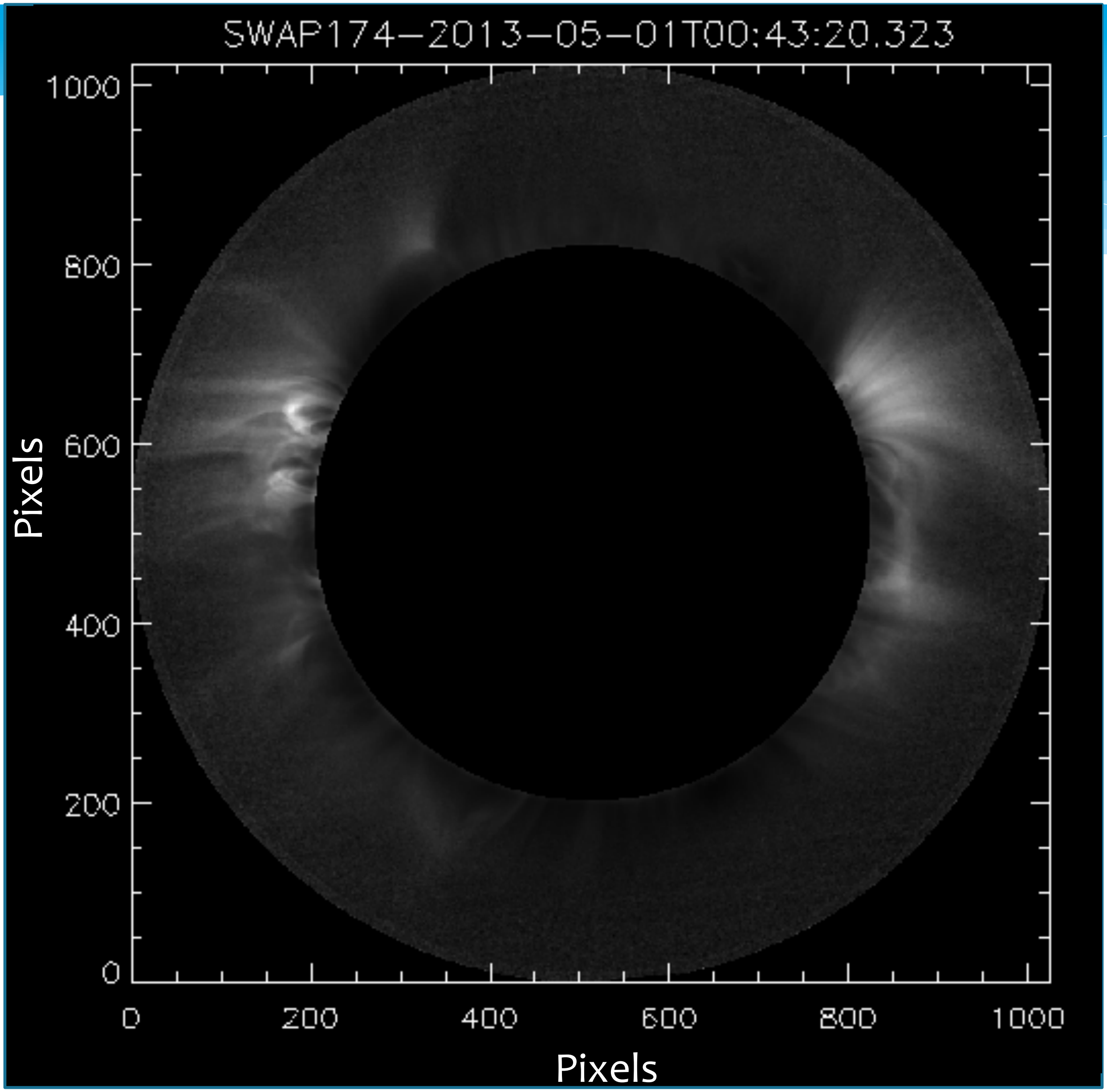


Uniform background prepared by using the radial profile

Radial filter and disk masking



SWAP image after radial filtering

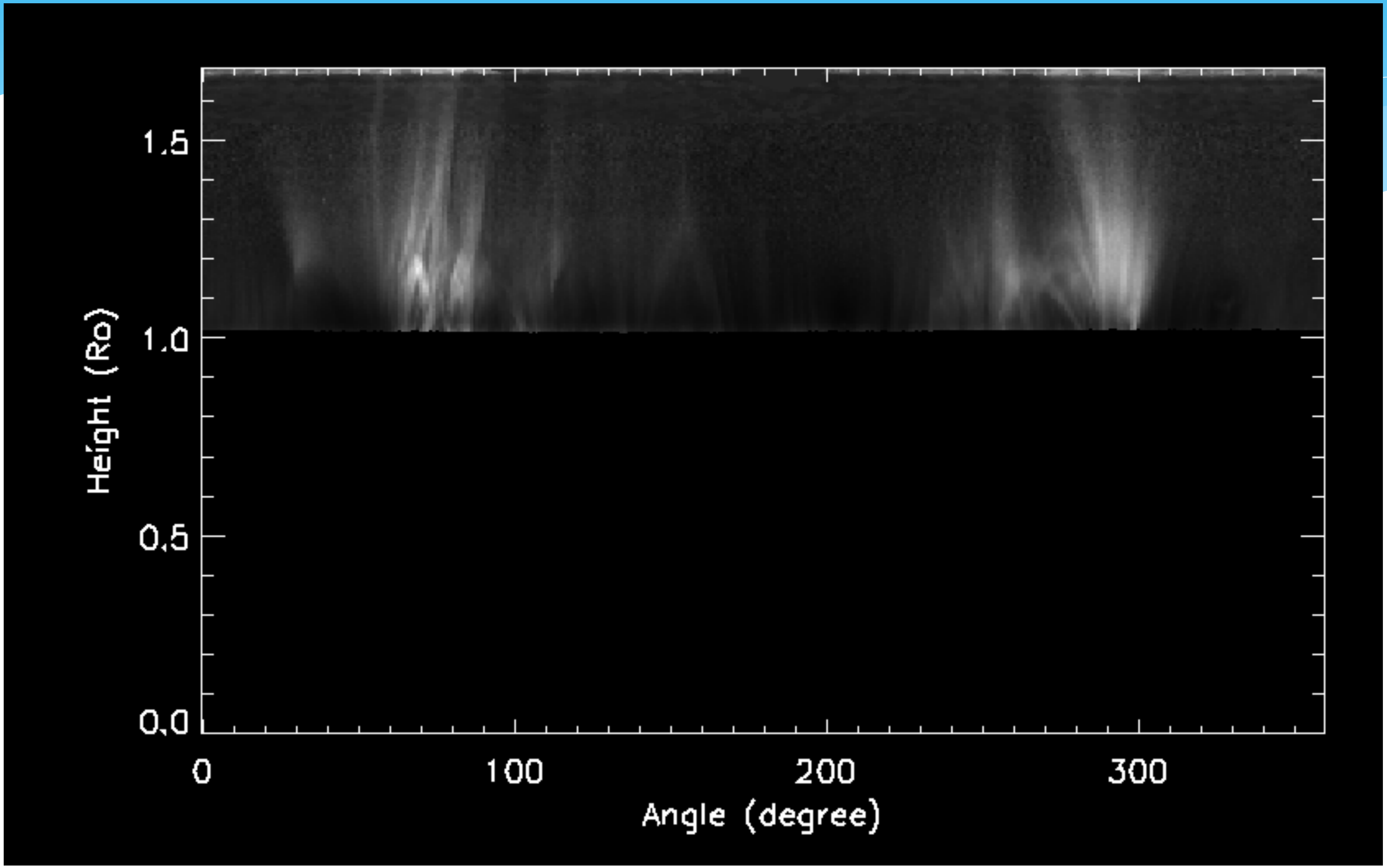


CME observed by SWAP on 2013-05-01

Motion Filtering

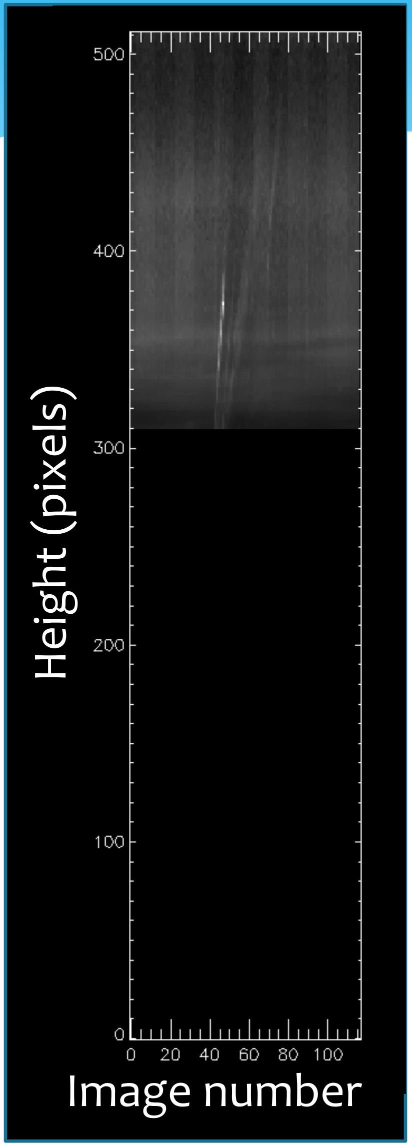
* The motion filtering technique using Fourier Transform has been used by DeForest *et al* (2014) in order to separate the inbound waves in solar corona using STEREO COR-2A data.
* The coronagraph images were converted from Cartesian (x, y, t) to polar (r, ɵ, t) coordinates such that the radial motion is in vertical direction. Fourier Transform of distance-time (r-t) map at each ɵ, will generate a k-ω map i.e. wavenumber v/s frequency map.

Motion Filtering

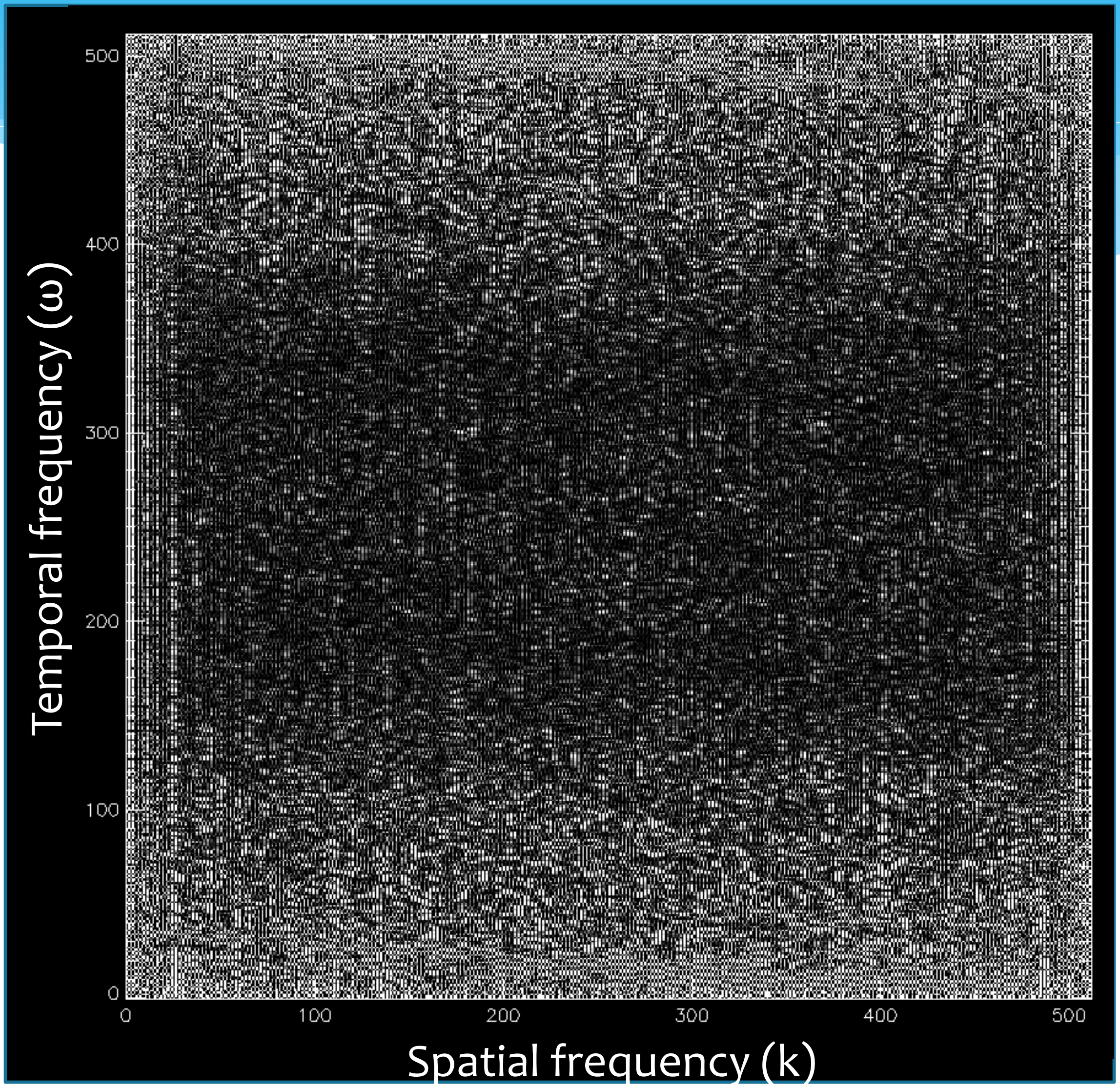


SWAP image in polar coordinates

Motion Filtering



Height-time plot at 76 degree



Fourier Transform of the height-time plot

Motion Filtering

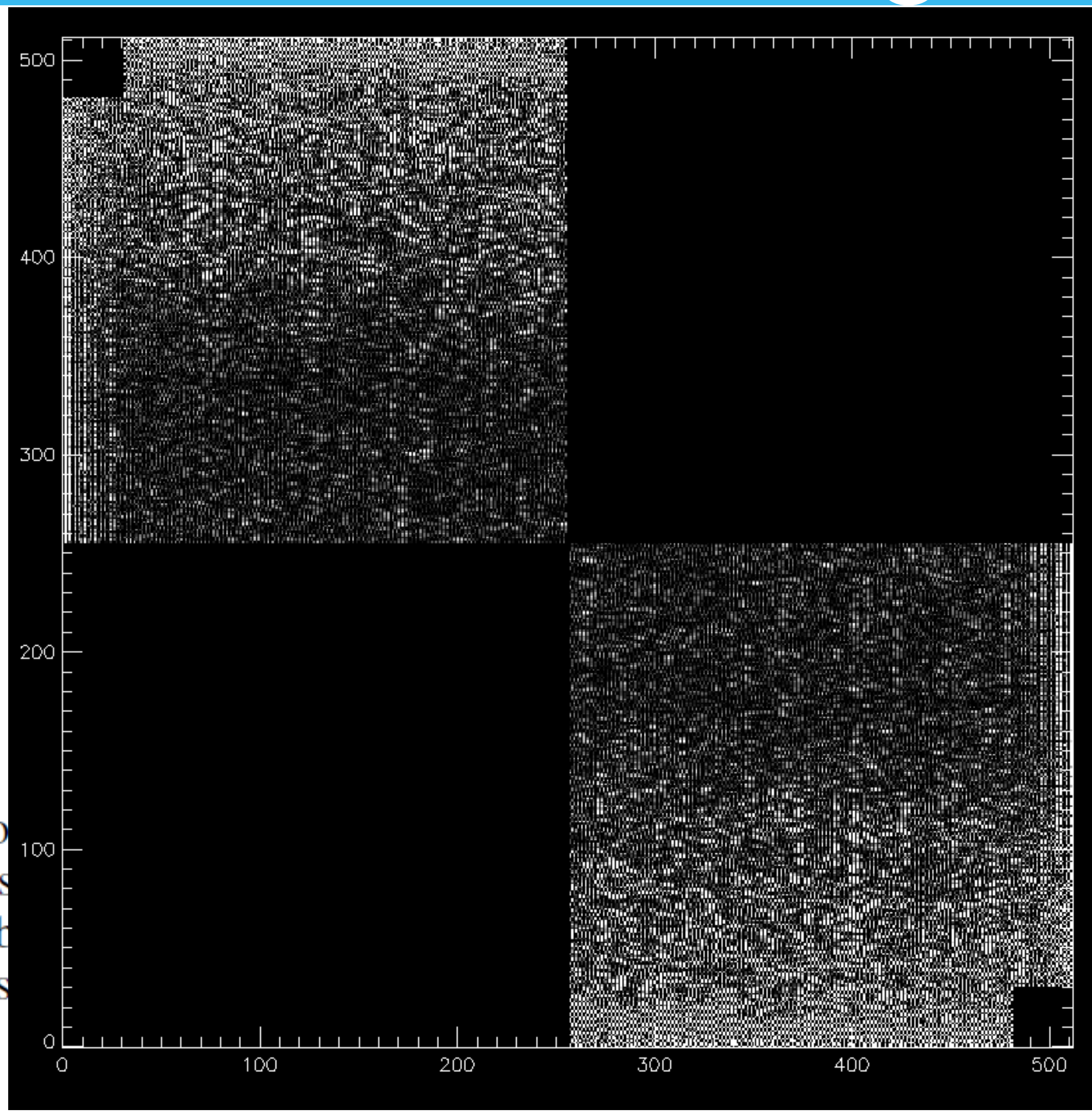
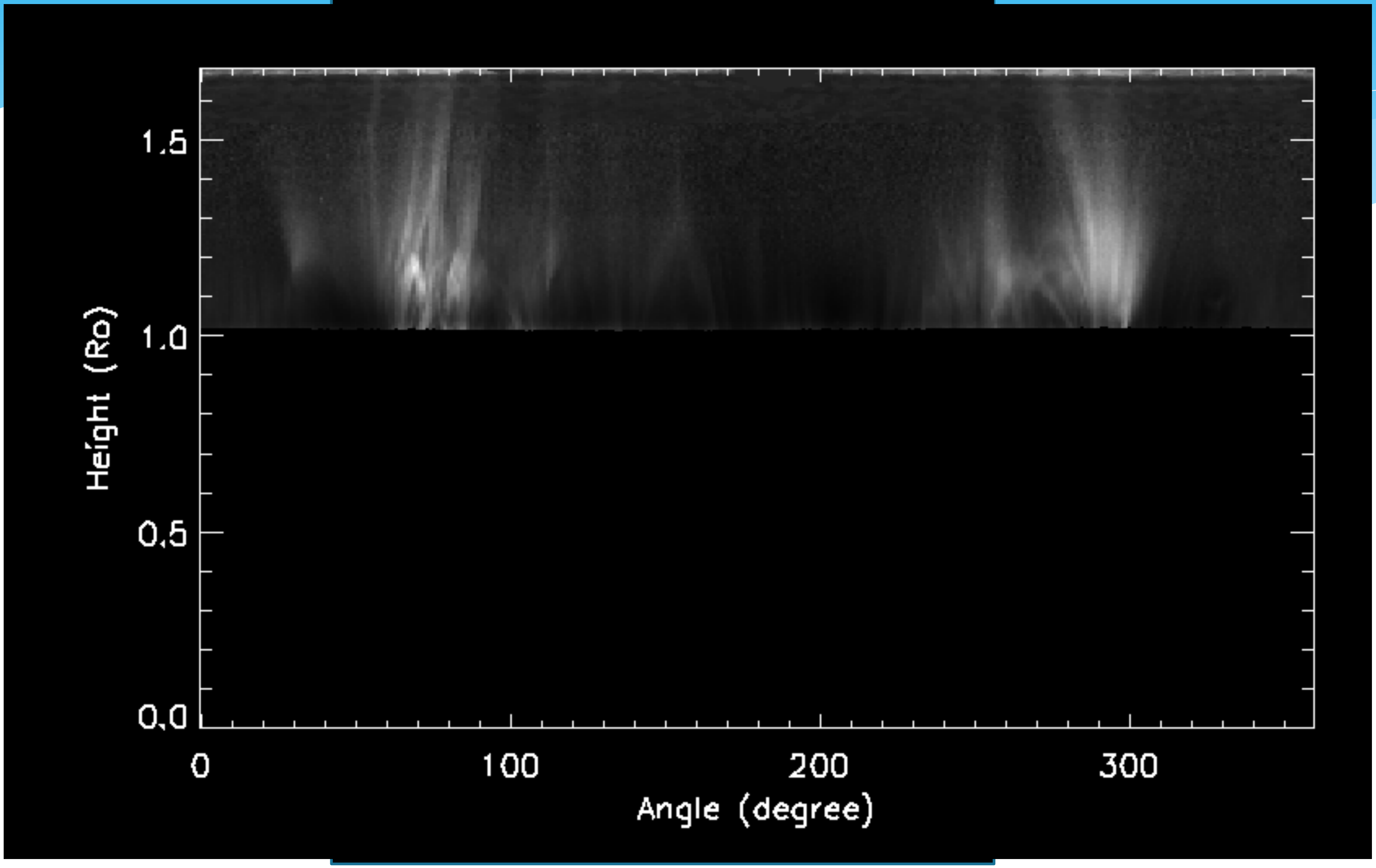


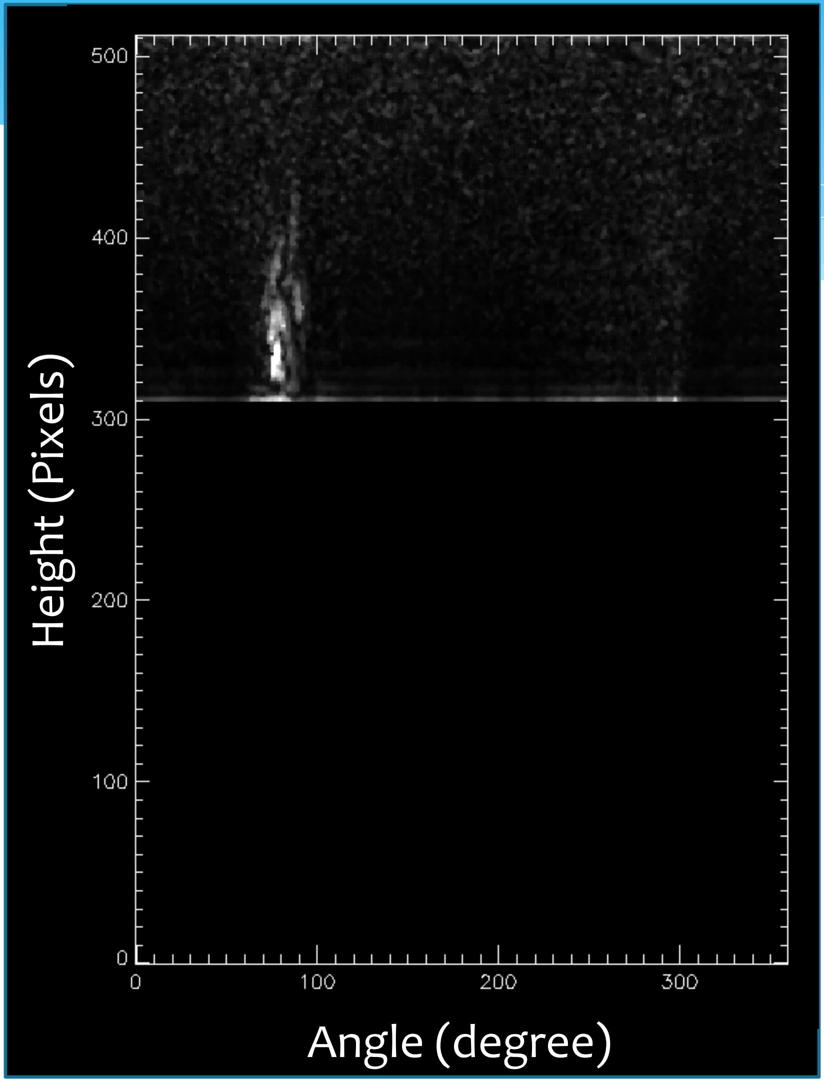
Figure … speed and
directio… nsformed to
features… segmented
into inb… peed to $2V$
doubles…

Motion Filtering



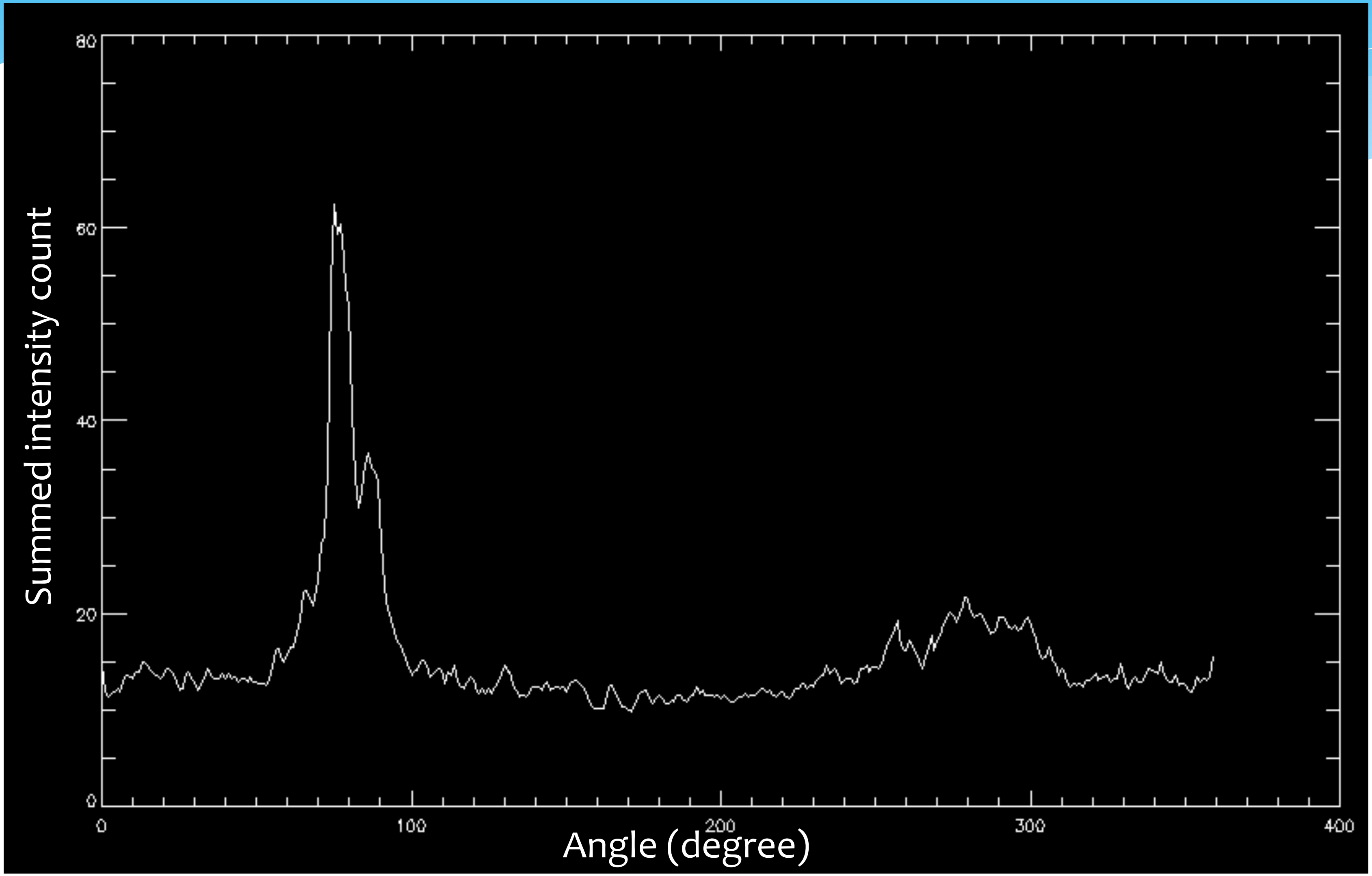
After application of motion filter

Motion Filtering

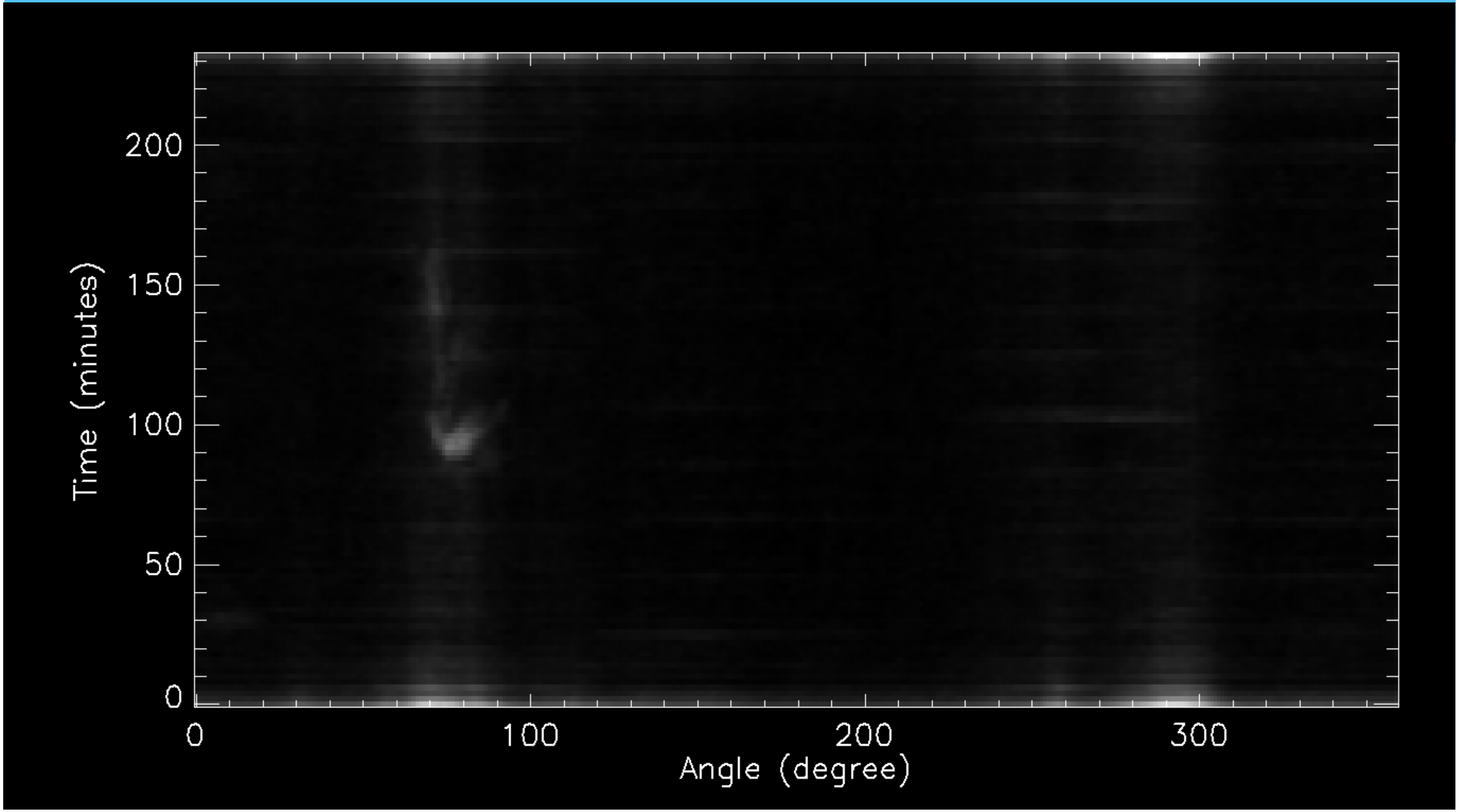


After application of motion filter

Reducing to 1-D

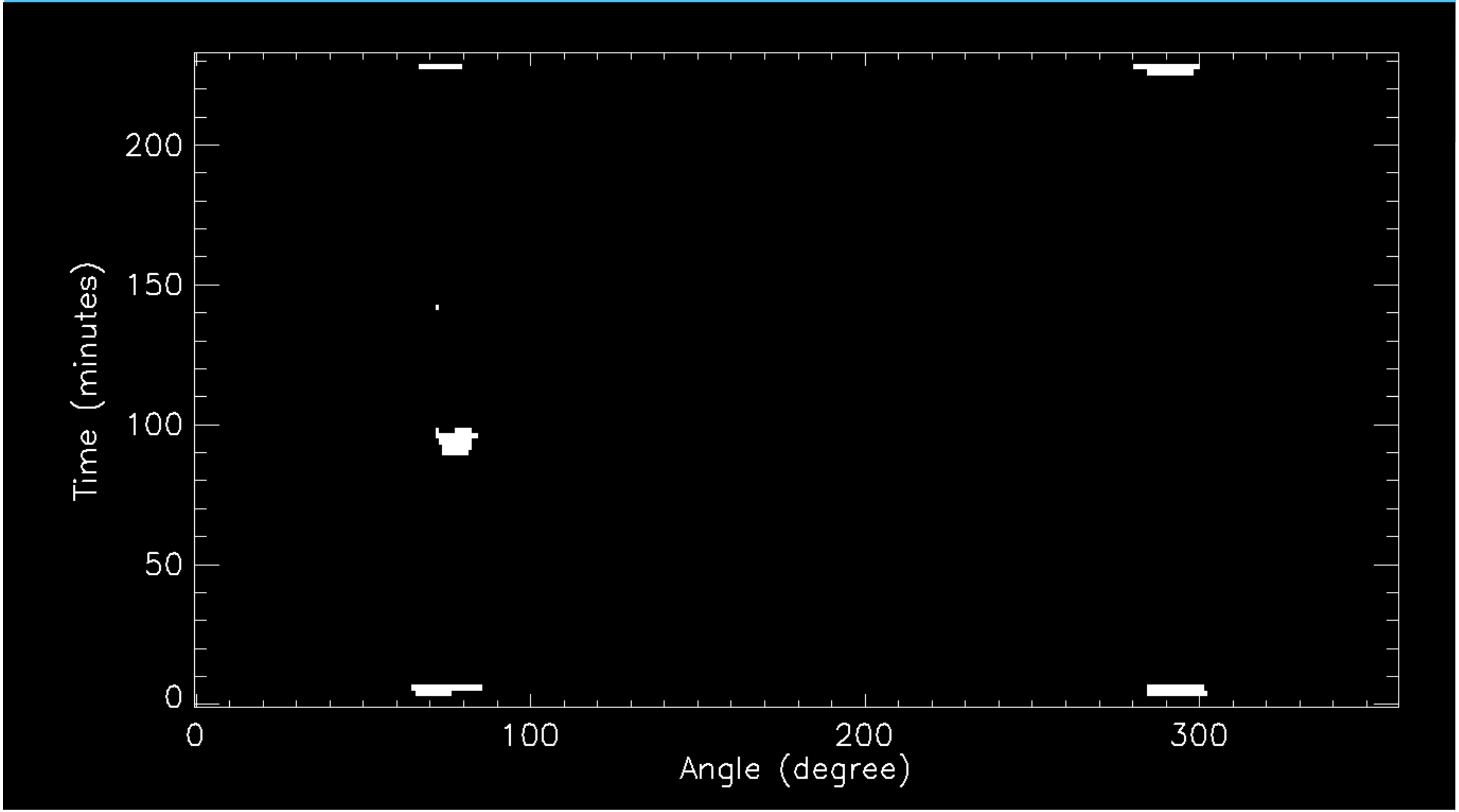


Creating CME map



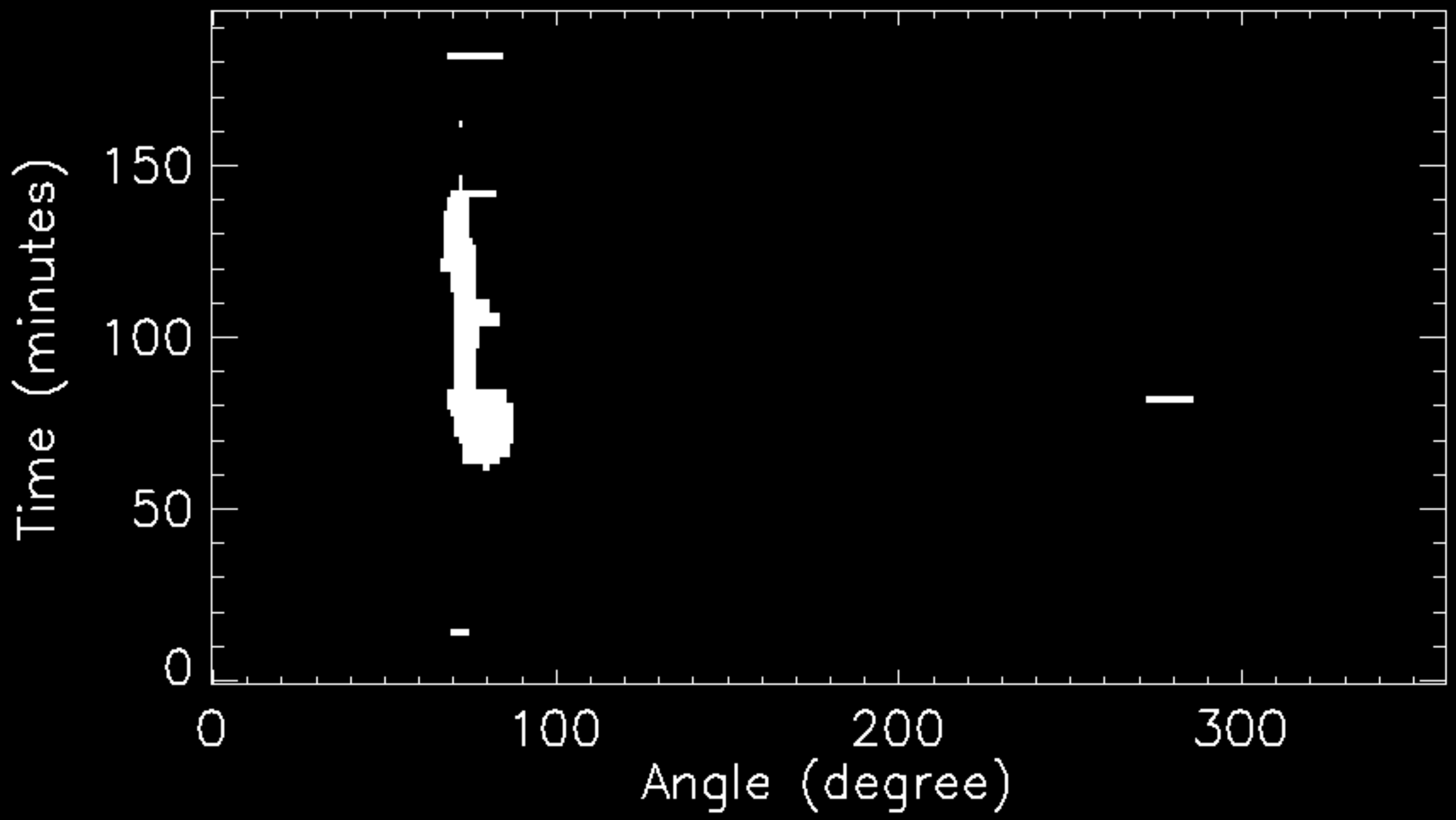
CME map created from 1-D curves

Creating CME map



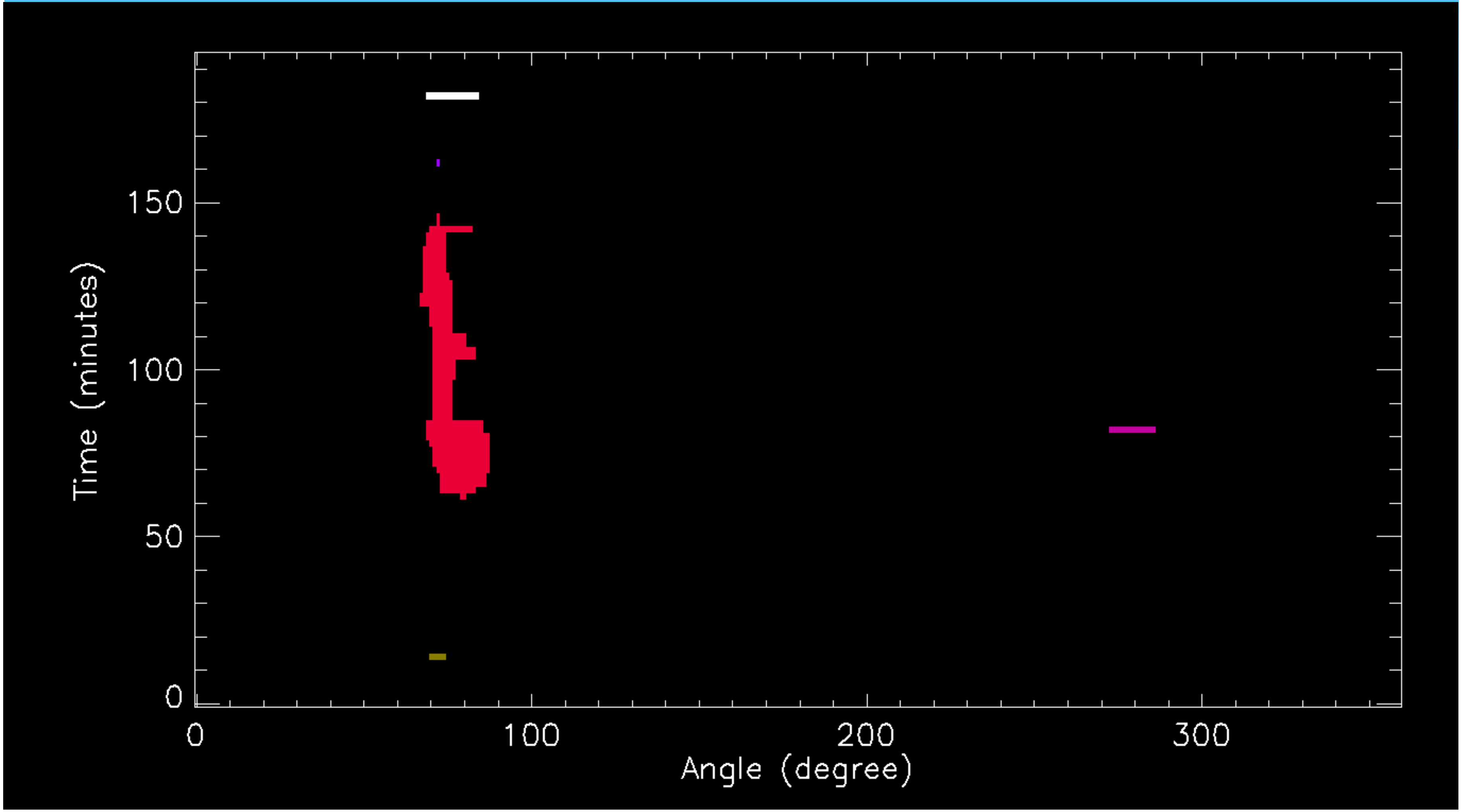
CME map after intensity threshold of mean(cme_map)+3.25*stdev(cme_map)

Creating CME map

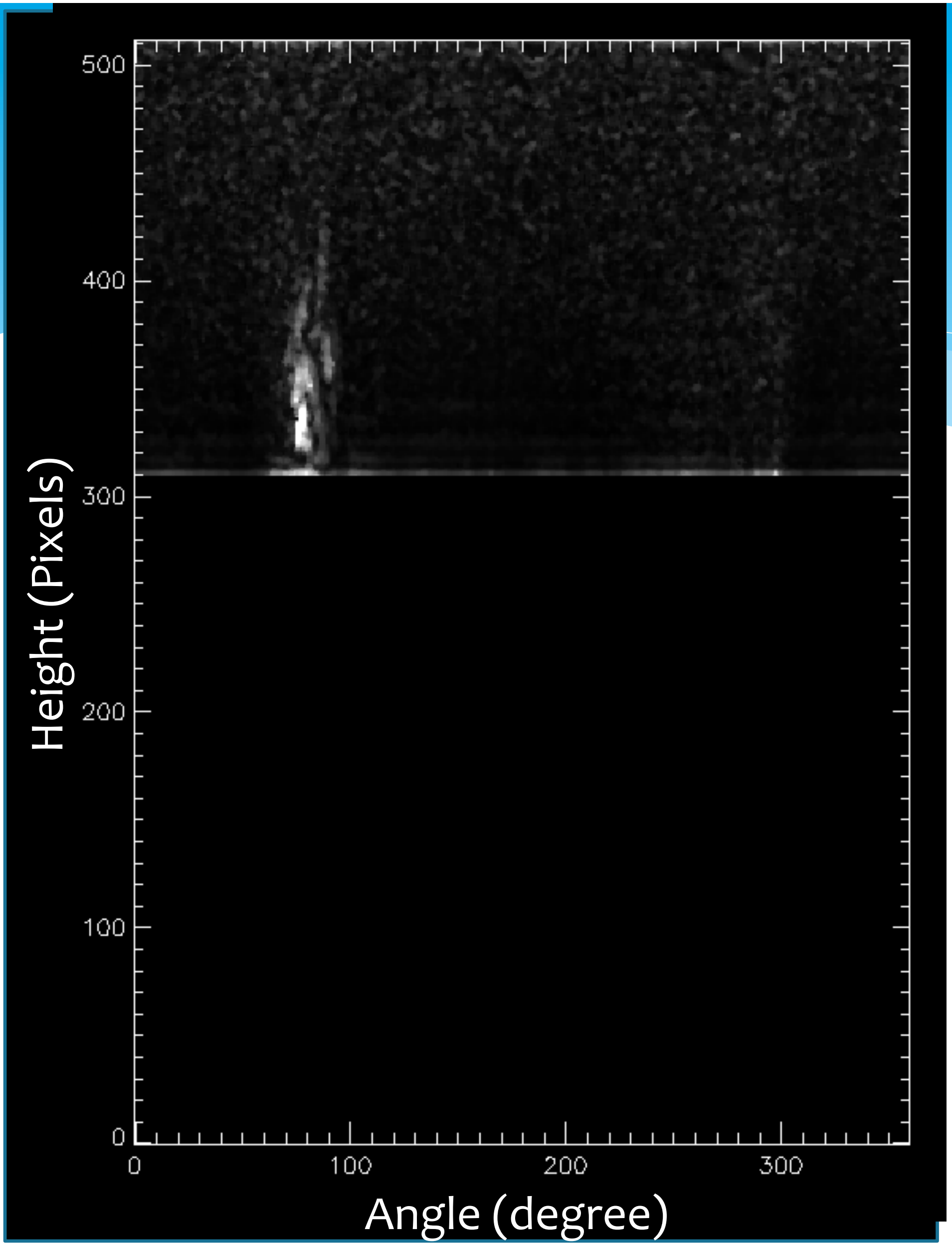


CME map after ignoring the top and bottom 10 images

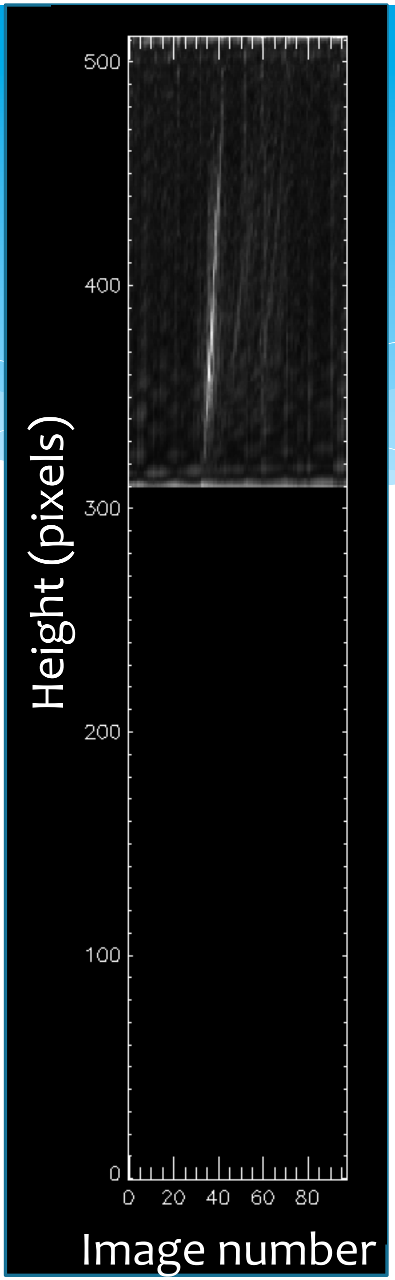
Creating CME map



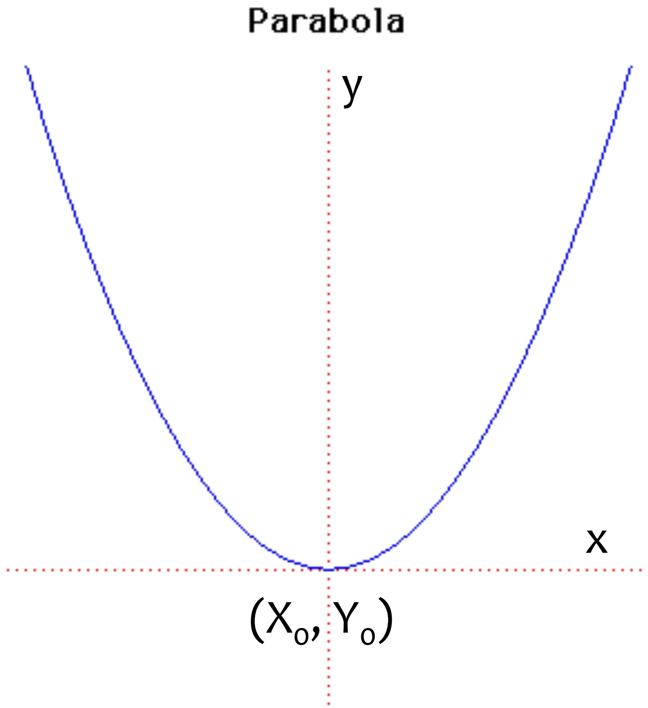
Labelled regions in CME map



Motion filtered image

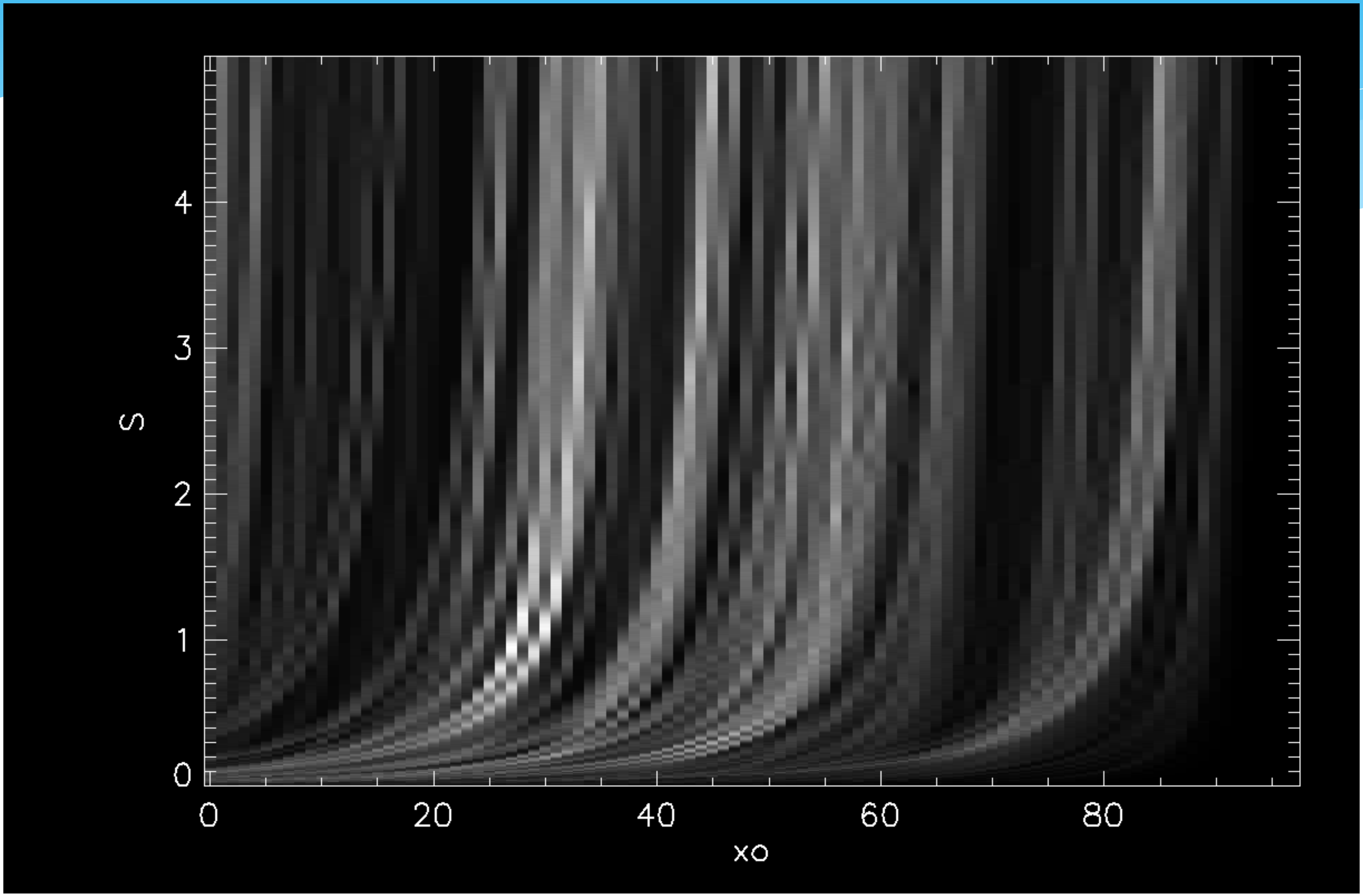


Height-time plot with intensity summed along width of CME



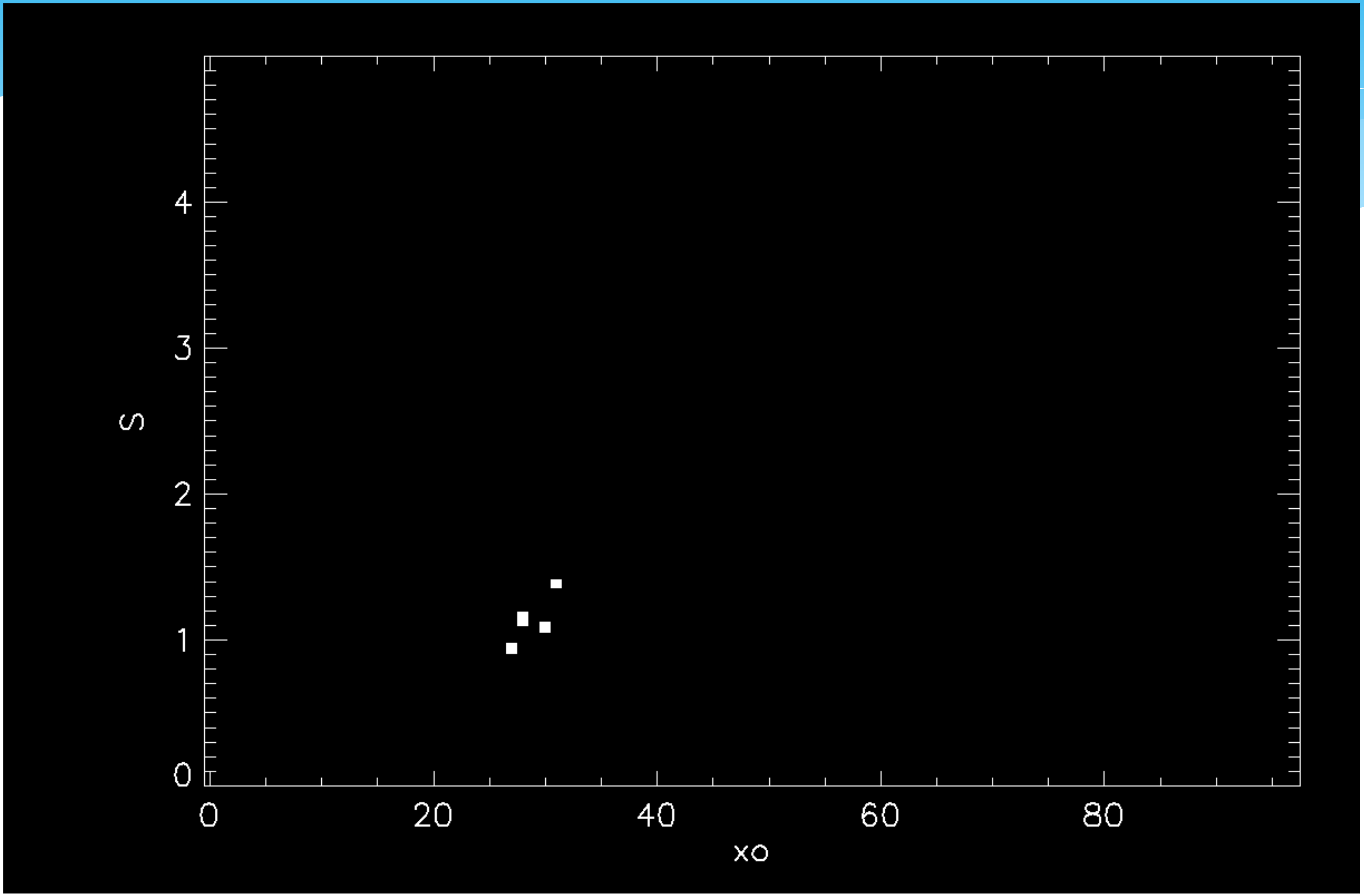
- Detect parabola of the form: $(y-y_0) = S*(x-x_0)^2$
- Parameters: y_0, x_0, S and θ (Ballard 1980).
- CMEs are accelerated in inner corona, so θ is fixed.
- y_0 is set at $1R_\odot$.
- $x_0=x-\sqrt{[(1/S)*(y-y_0)]}$
- Thus, a 4-D problem can be reduced to 2-D problem.

Parabolic Hough Transform



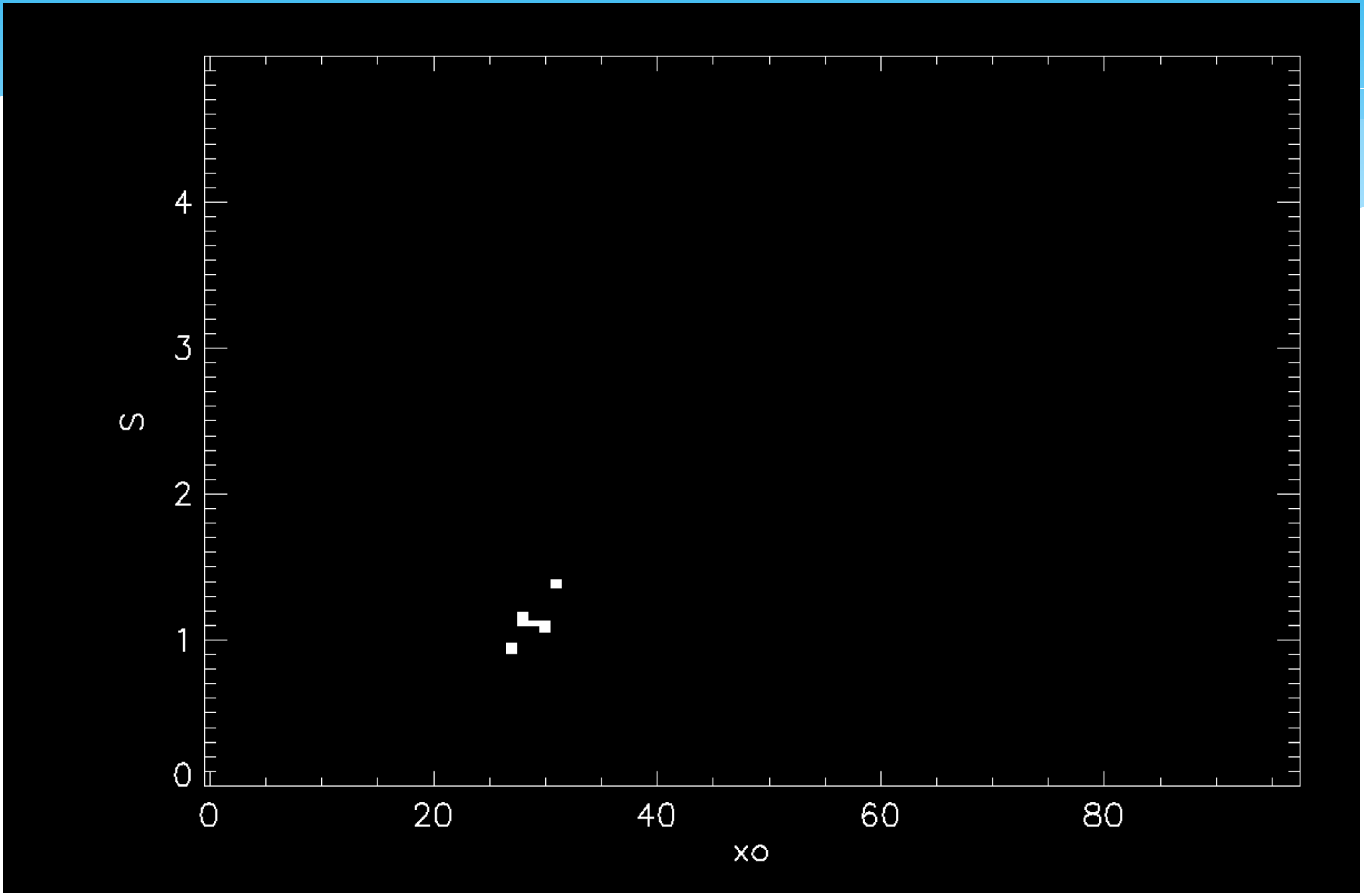
Parameter (Hough) space for the parabolic Hough transform

Parabolic Hough Transform

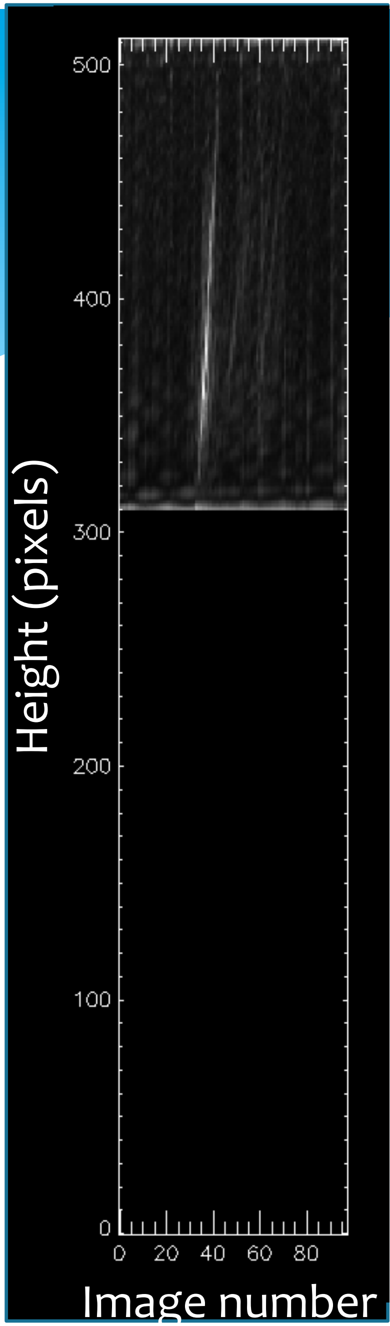


Parameter (Hough) space after applying 0.9*maximum intensity threshold

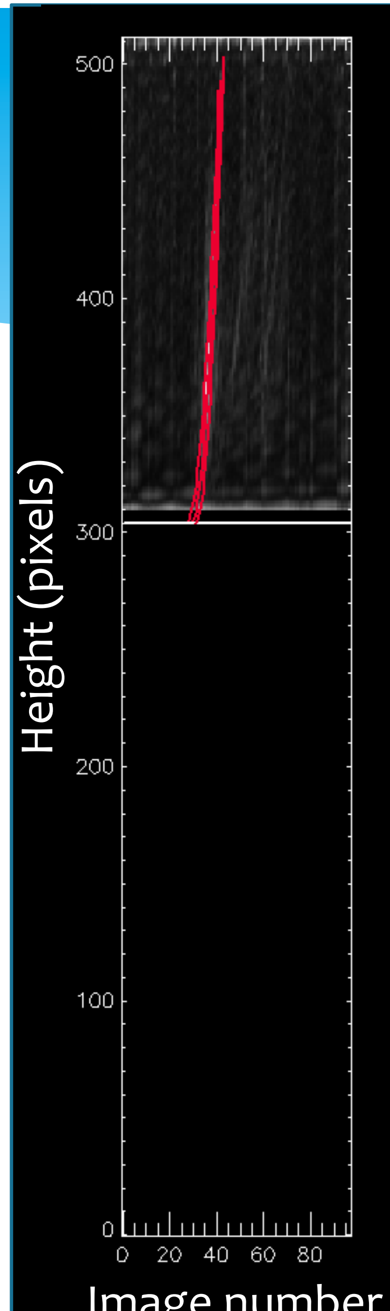
Parabolic Hough Transform



Parameter (Hough) space after applying 0.9*maximum intensity threshold and morph_close

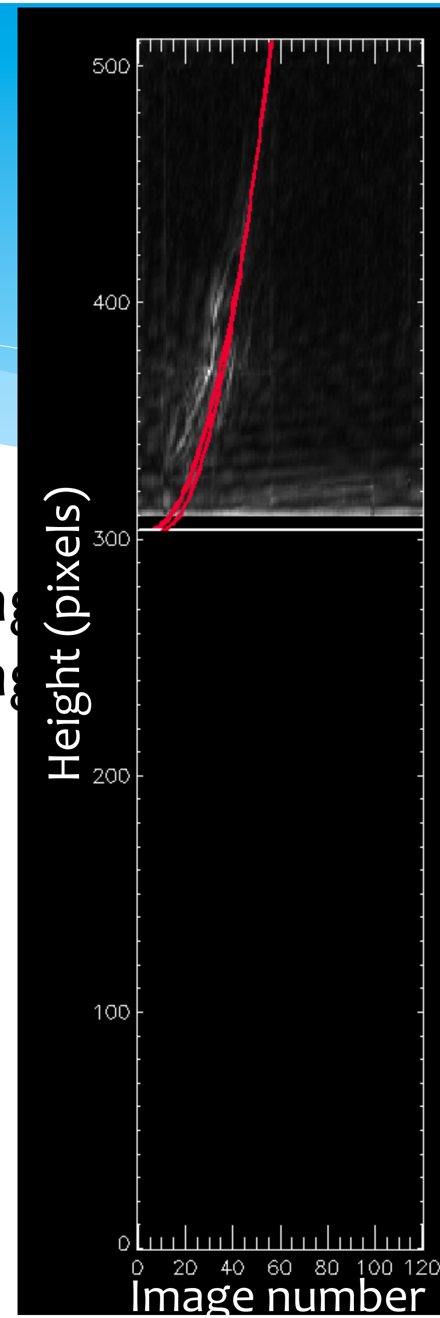


Height-time plot



Detected parabolas

- Averag… km/s
- Averag… = 326 m/s²



Test Cases

```
#    CME: CME number
"#     t0: onset time, earliest indication of liftoff"
"#     pa: principal angle, counterclockwise from North (degrees)"
#      v: mean velocity (km/s)
#     vm: velocity calculated manually (km/s)
#  mindv: lowest velocity detected within the CME
#  maxdv: highest velocity detected within the CME
#    acc: Mean acceleration (m/s^2)
#   mina: lowest acceleration detected within the CME
#   maxa: highest acceleration detected within the CME
#    acm: acceleration calculated manually (m/s^2)
```

Sno.	CME_Date	CME	t0	pa	vm	v	mindv	maxdv	acm	acc	mina	maxa	remarks
1	24-11-2011	1	11:28	287	99	102	96	105	67	34	29	35	slow; more iterations.
2	25-11-2011	1	08:12	290	379	574	394	716	1253	1107	521	1623	
3	25-11-2011	2	08:05	115		909	560	1203		3365	1077	5981	FALSE
4	25-11-2011	3	08:56	113		1291	1232	1425		6341	5931	6692	FALSE
5	01-02-2012	1	14:54	267	424	483	403	560	609	782	532	1076	
6	01-02-2012	2	15:09	75		797	439	1134		2177	612	4347	FALSE
7	16-04-2012	1	17:57	81	234	279	151	382	269	262	74	457	
8	16-04-2012	2	21:04	76		349	301	391		424	280	547	FALSE
9	08-07-2012	1	16:58	254	221	482	204	709	-343	808	137	1584	Deceleration! (But accelerating in LASCO C2 FOV
10	08-07-2012	2	17:32	293		578	388	746		1143	460	1890	FALSE
11	31-08-2012	1	19:57	114	564	333	298	366	-135	363	270	470	Deceleration! (Halo and accelerating in C2 FOV)
12	31-08-2012	2	22:00	103		507	306	714		906	314	1838	FALSE
13	01-05-2013	1	02:23	76	408	321	280	405	367	326	253	521	
14	15-05-2013	1	01:59	80	321	558	419	723	928	1141	584	1857	
15	21-06-2013	1	03:04	110	343	380	273	575	677	511	234	1264	
16	21-06-2013	2	17:20	287		586	452	723		1188	725	1857	FALSE
17	24-08-2014	1	12:03	124	417	482	456	509	760	712	636	787	
18	31-03-2014	1	08:03	262	308	454	370	508	758	646	437	778	
19	31-03-2014	2	09:28	79		568	567	571		969	961	976	FALSE

Summary

* An automated method (iCACTus) has been developed to detect and track CMEs in SWAP images.
* First time use of parabolic Hough transform to derive the kinematics of CMEs has been demonstrated.
* This algorithm is missing faint CMEs in its current form but can be further improved.
* A catalogue of CMEs in EUV images can be developed after reducing the fraction of false detections which will be the first of its kind.

References

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thank you!