The catalogue of solar failed eruptions

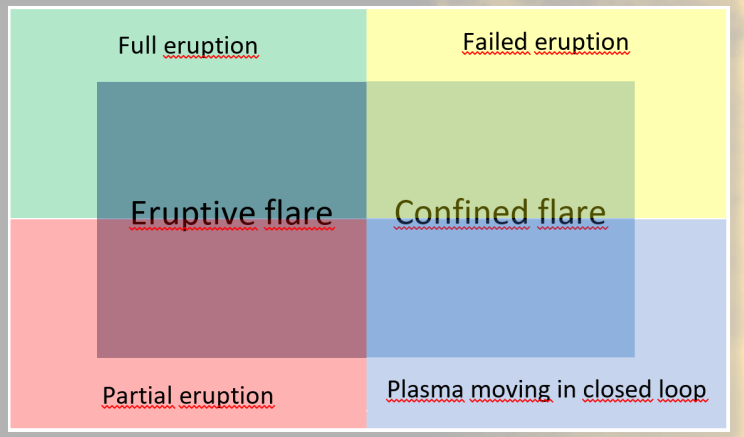
Mrozek, T.[1,2], Gronkiewicz, D.[3], Kołomański[1], S., Stęślicki, M.[2]

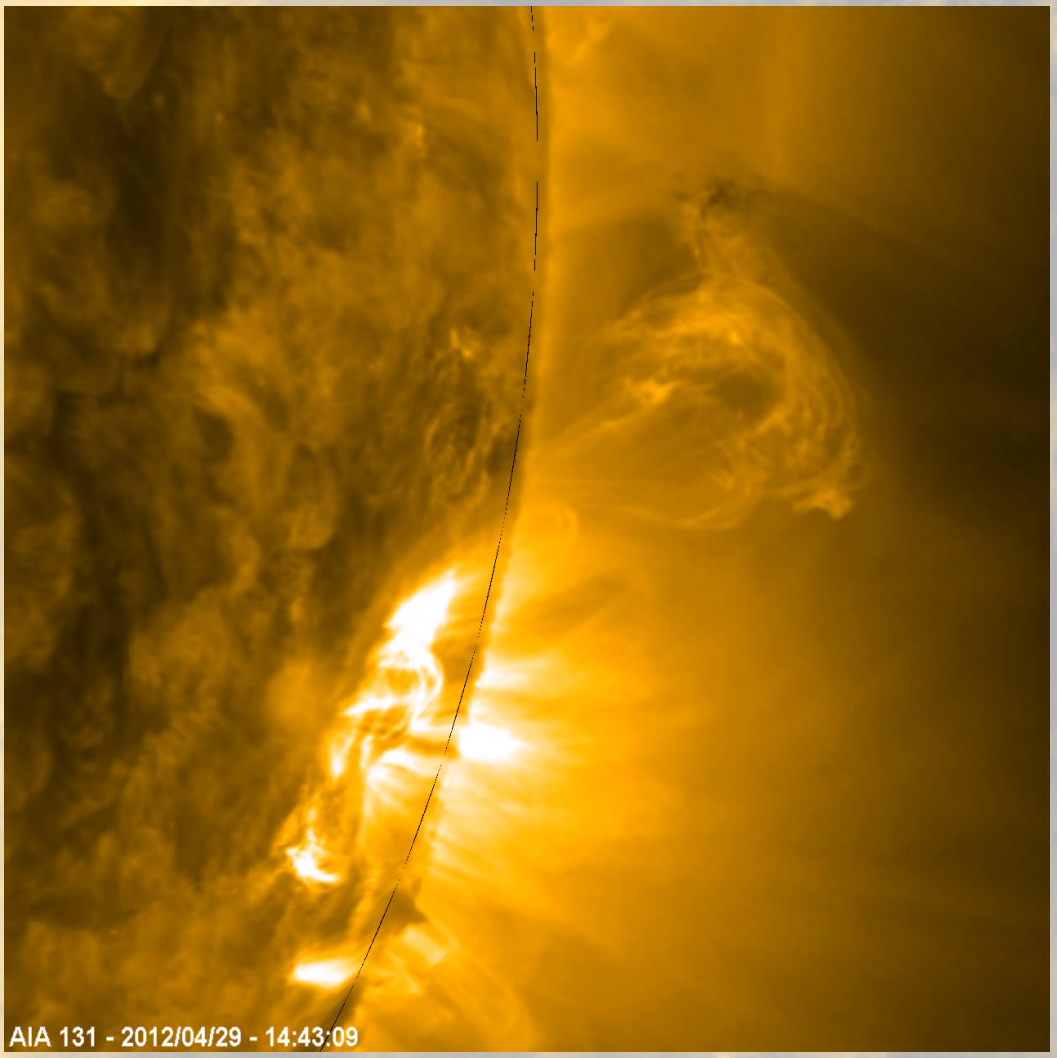
[1]*Astronomical Institute, University of Wrocław*
[2]*Solar Physics Division, Space Research Centre PAS*
[3]*Nicolaus Copernicus Astronomical Center PAS*

What is a failed eruption?

Gilbert, H. R., Alexander, D., & Liu, R. 2007, Sol. Phys., 245, 287:

1. ***Full*** - most (≥ 90%) of filament mass and magnetic structure is erupted.
2. ***Partial***:
   - class A – the eruption of the entire magnetic structure with small amount or even no mass.
   - class B – the partial eruption of magnetic structure with some or none mass.
3. ***Failed*** - neither of mass nor magnetic structure escapes from the Sun. (No CME) – eruption stops after initial acceleration.





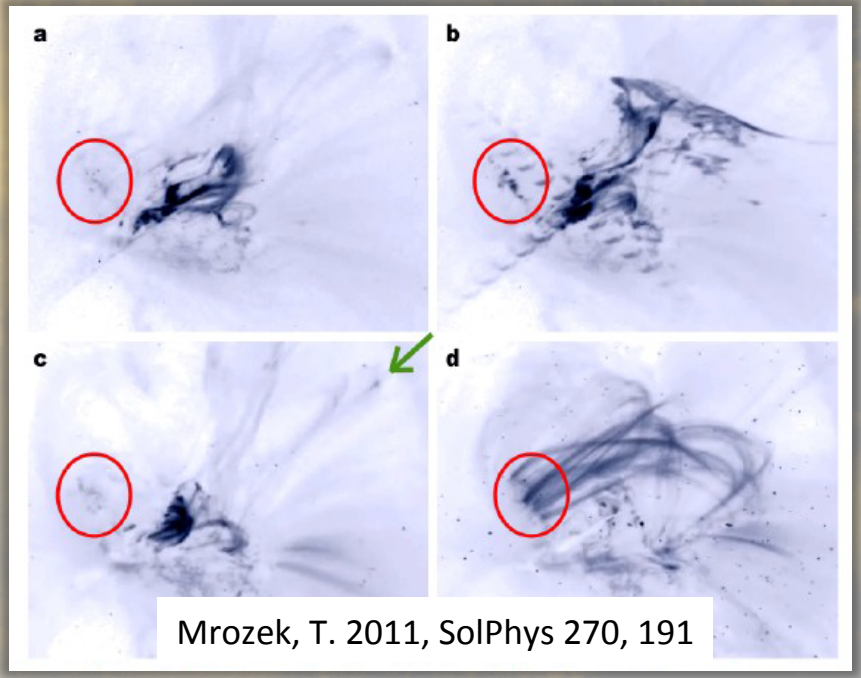
Why failed eruptions?

Failed eruptions are not Earth-affecting, but they might help us to define boundary conditions for CME occurence.

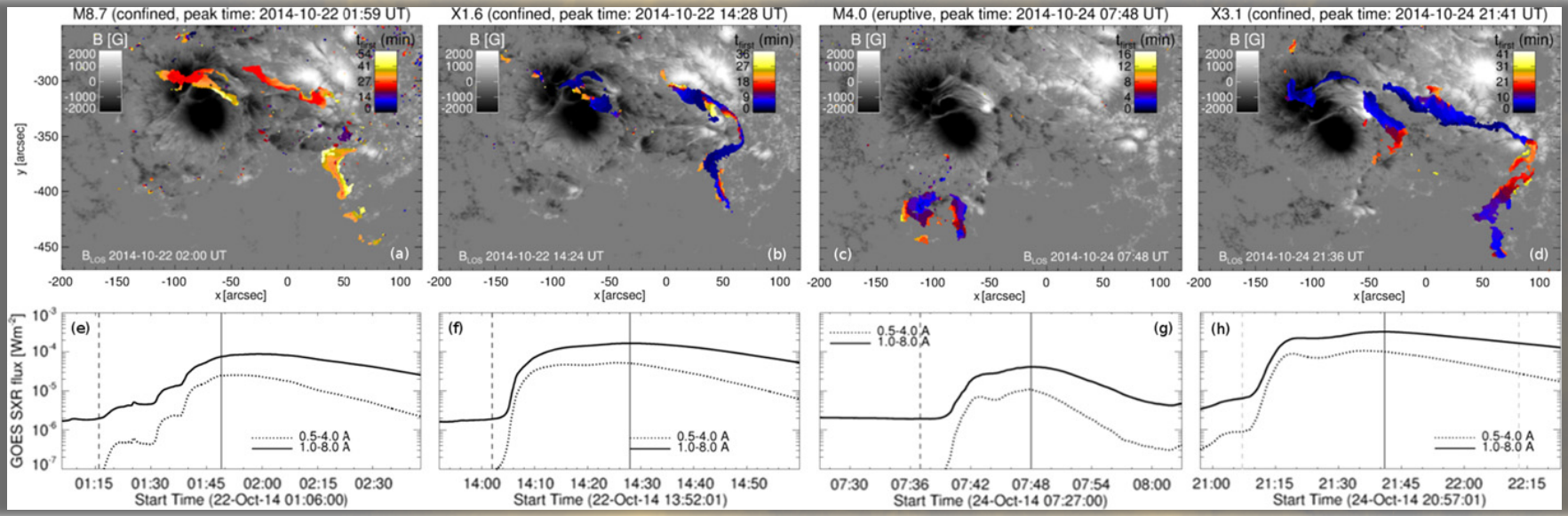
- Which mechanism(s) is(are) responsible for stopping eruptions?
- Interaction between magnetic structures
- Particle acceleration in interaction region

AR12192, flare-rich and CME-poor

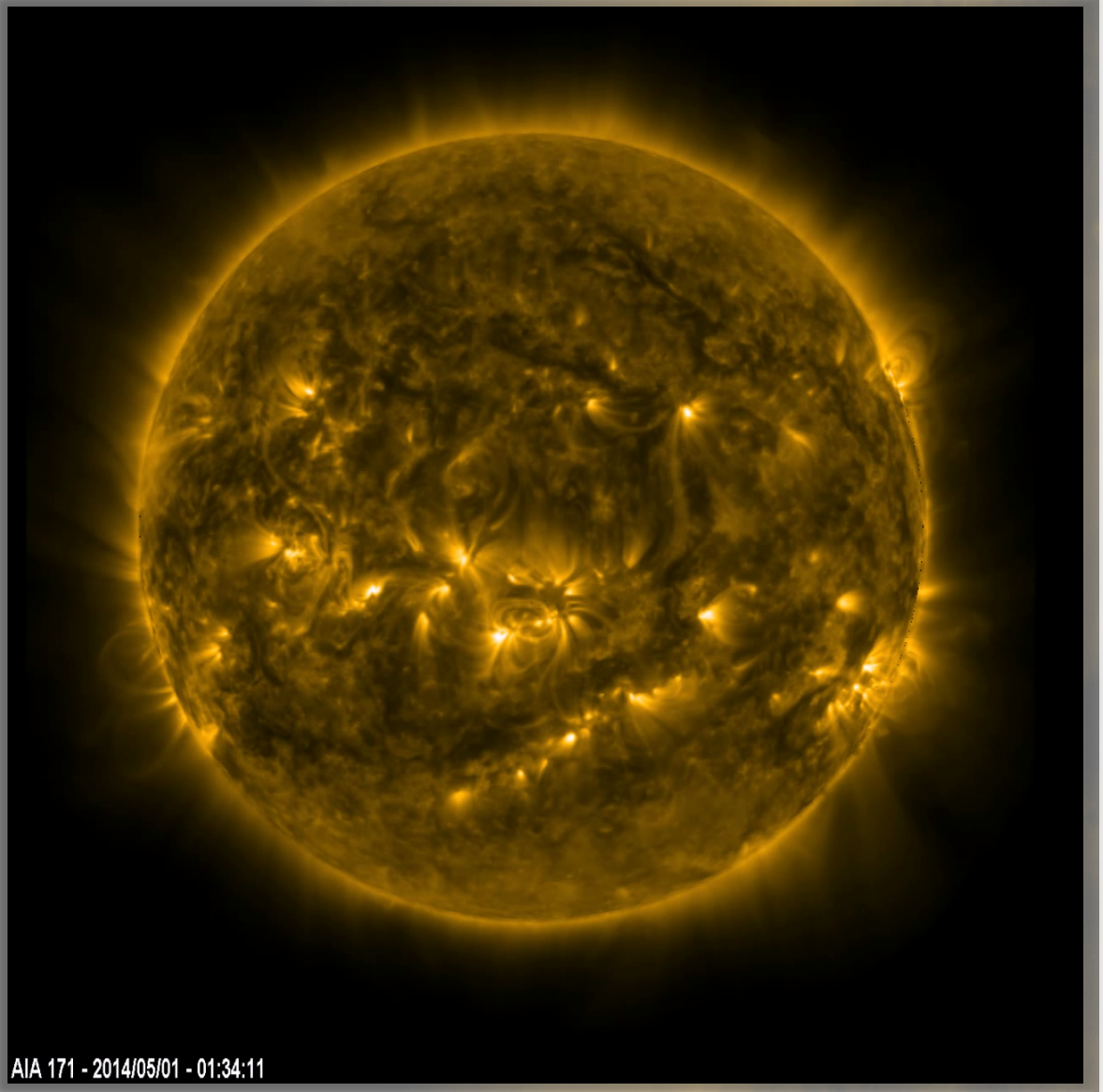
Sun, X., et al. 2015, ApJ 804, L28
Thalmann, J.K., et al. 2015, ApJ 801, L23



Mrozek, T. 2011, SolPhys 270, 191



The aim



The aim is to analyse hundreds of failed eruptions. We do not focus on strong events only, but we want to have a broad overview of phenomena.

SDO/AIA:

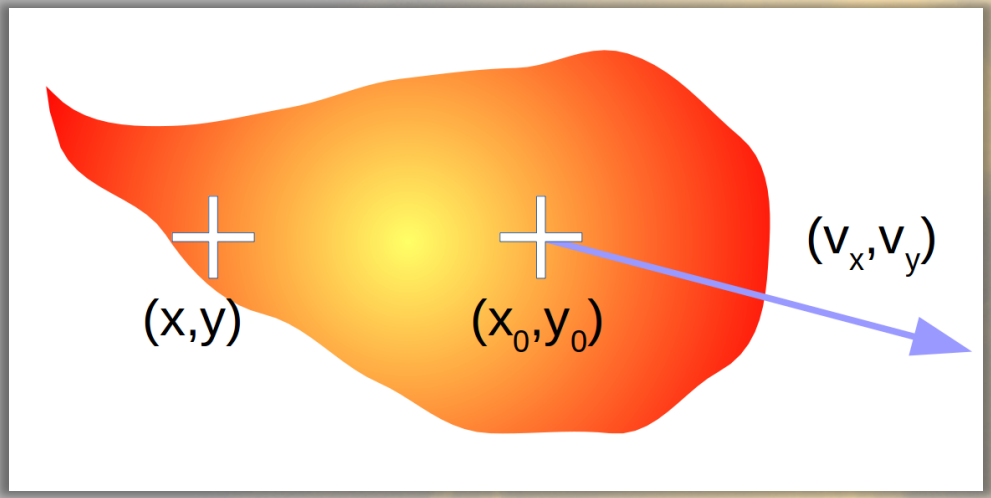
- 4 telescopes
- 4096 by 4096 full-disk images (0.6 arcsec/pixel)
- 12 s cadence
- **1.5 TB of data/day** – basic problem for downloading and analysing data

Our choice:
Synoptic – Lev.1.5 compressed to 1024x1024, 2 min. cadence,
1 MB/image

Two steps have been taken:

1. To construct method for **automatic search for eruptive/ moving features** on the basis of SDO/AIA observations.
2. To **classify found events** and to built a catalogue.

Searching for moving structures



Moving feature with initial brightness distribution R(x,y).

Its brightness is modulated with time by φ(t).

Starting position (x_0,y_0) is moving with velocity (v_x,v_y). Then brightness may be represented with:

$$I(x,y,t)=R(x-x\downarrow 0,\ y-y\downarrow 0\ )\varphi(t)=I\downarrow 0\ (x,y)\varphi(t)$$

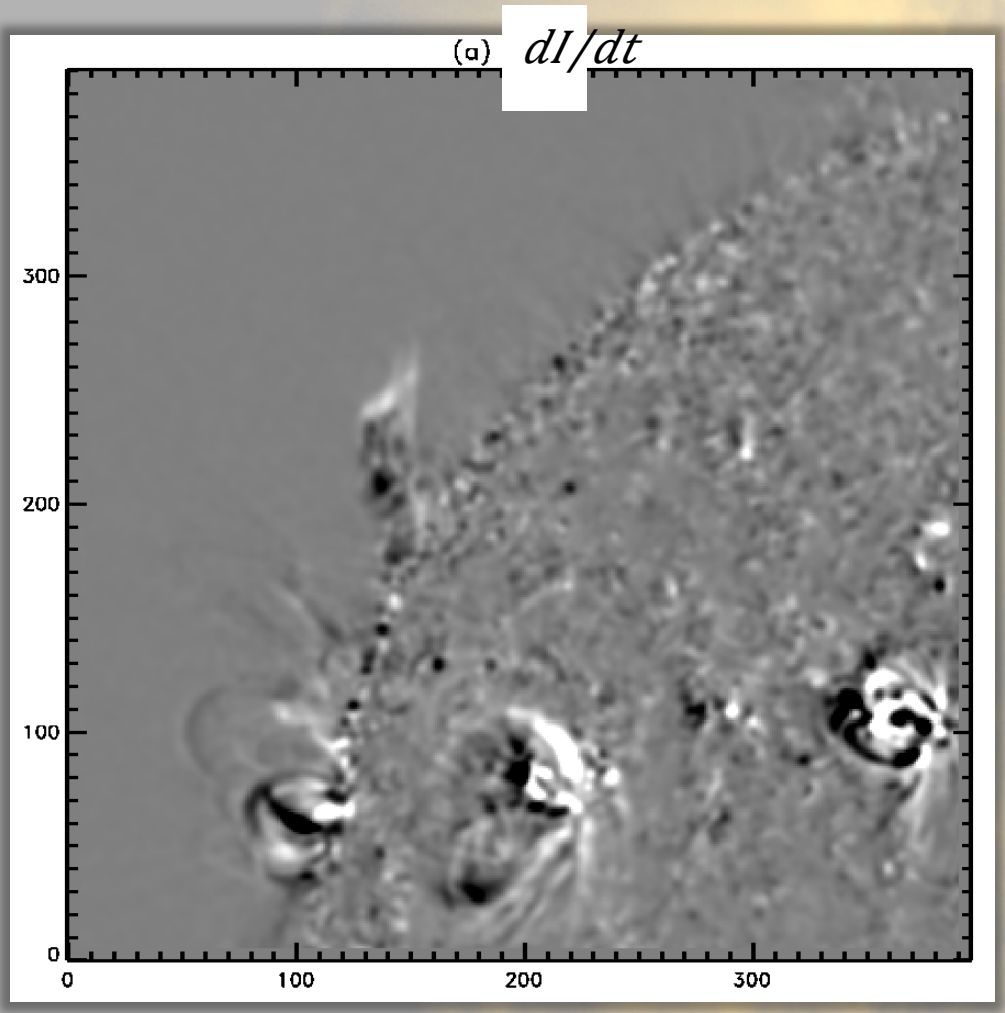
Differential image:

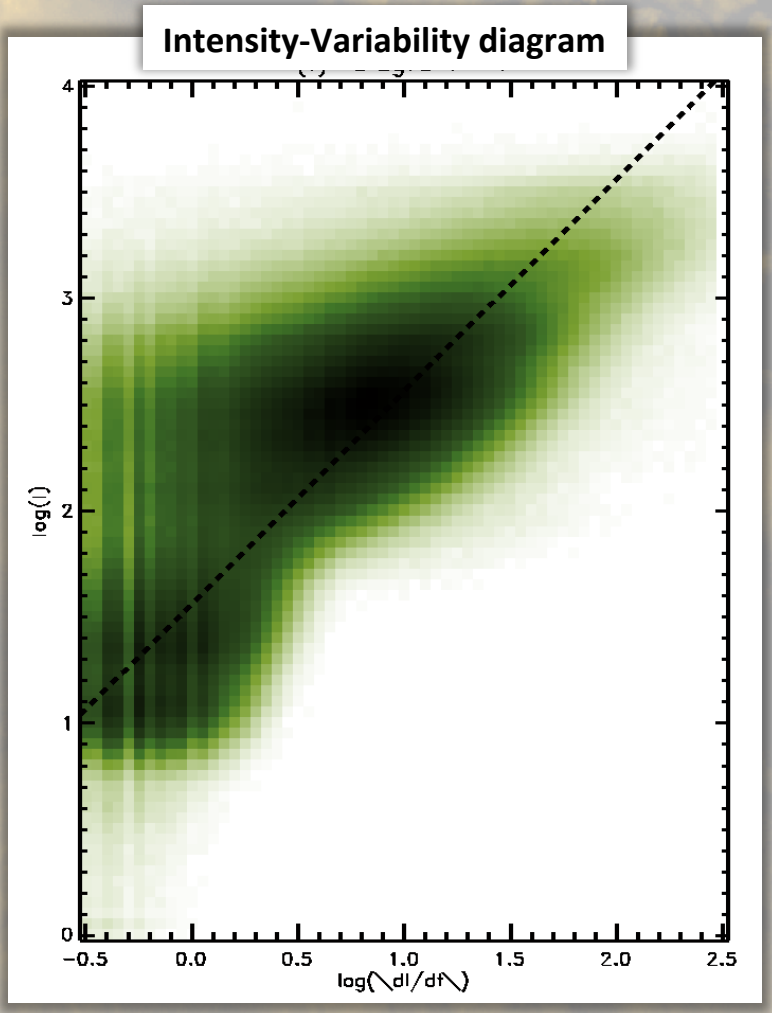
$$I\downarrow t=dI(x,y,t)/dt=-\varphi(t)\cdot(v\circ\nabla I\downarrow 0\ )+I\downarrow 0\ d\varphi(t)/dt$$

change of position

change of brightness

Searching for moving structures





Most variable are brightest features – using derivative only will lead to detection of all bright features (loops, active regions, flares) which is not our aim.

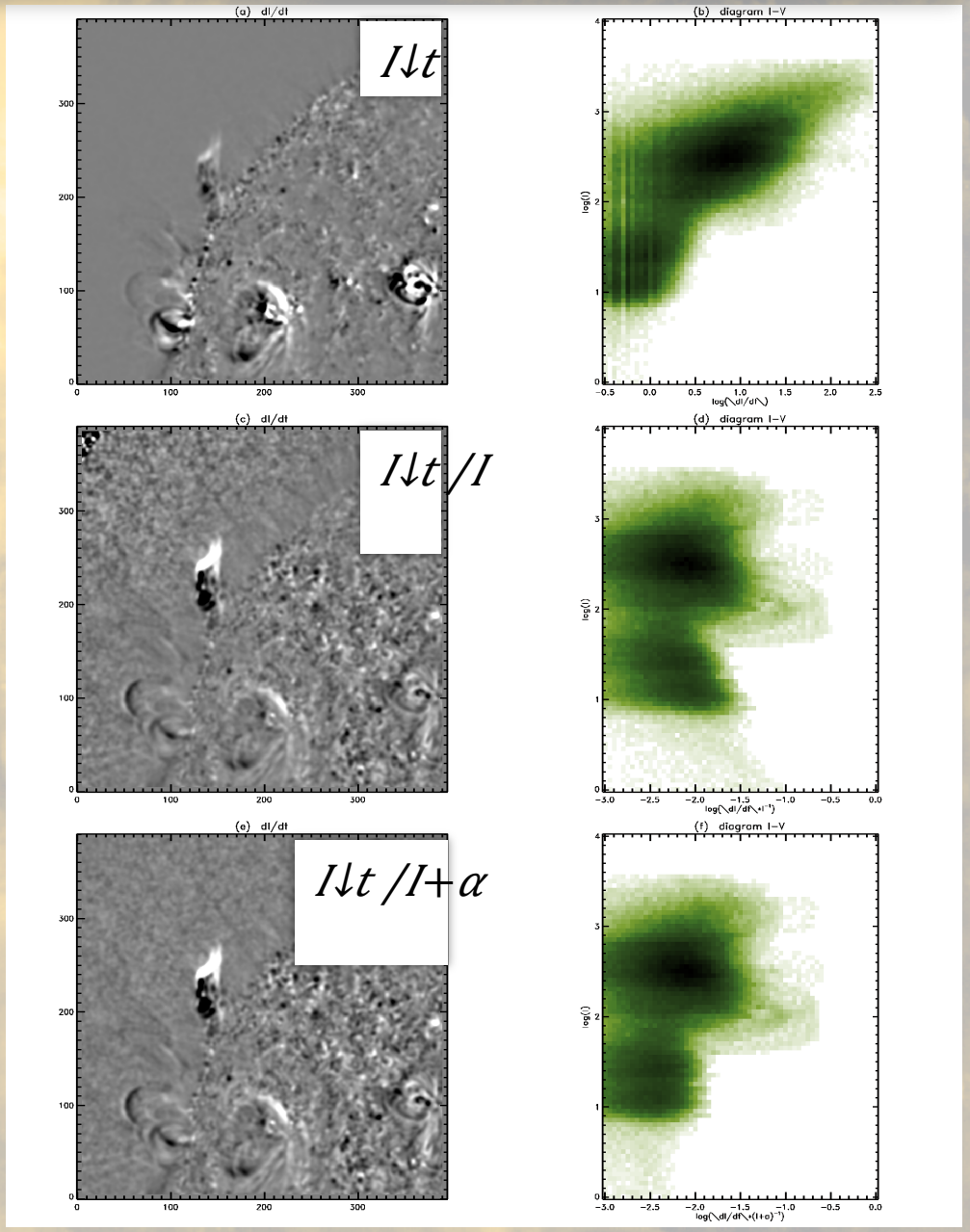
Searching for moving structures

$$I\downarrow t\uparrow norm = I\downarrow t \,/ I + \alpha = J\downarrow t$$

$$I\downarrow tt\uparrow norm = I\downarrow tt \,/ I + \alpha = J\downarrow tt + J\downarrow t\uparrow 2$$

For next step we constructed (arbitrarily) a **variablility index** which was used to separate slow- and fast-changing structures:

$$V = \sqrt{\square} J\downarrow t\uparrow 2 + 1/4\, J\downarrow tt\uparrow 2$$



Searching for moving structures

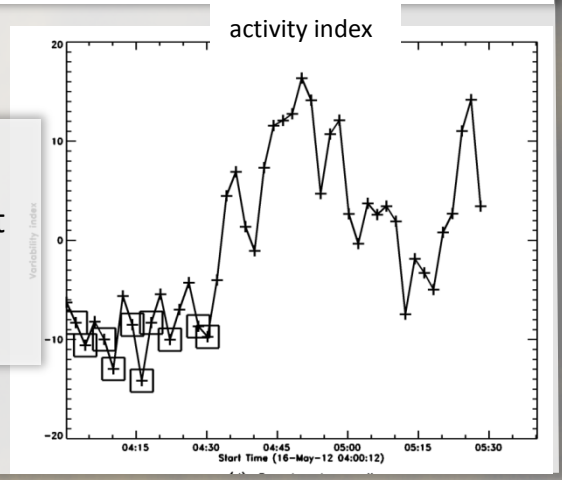
On the basis of measured state of each pixel $\boldsymbol{x}=(\boldsymbol{I},\boldsymbol{V})$ we want to classify it to one of classes E (eruptive) or Q (quiet).

Let's assume that $P(Q)\approx 1$, and classify pixels as Q or E. Having number of E-pixels we calculate $\boldsymbol{P(Q)=1-P(E)=1-n\downarrow erupt\,/n\downarrow total}$, and run algorithm again with new value of $P(Q)$. Usually, after 3 steps $P(Q)$ had stabilized.

$$V\downarrow mean\,(t\downarrow k)=1/n\downarrow x\, n\downarrow y\, I$$

$$\Sigma$$

activity index: $A(t\downarrow i)=I\downarrow mean\,(t\downarrow k)-I\downarrow mean\ /\sigma\downarrow I\downarrow mean$



we can estimate $P\ x\square Q$ assuming that **several images in sequence do not contain eruptions**

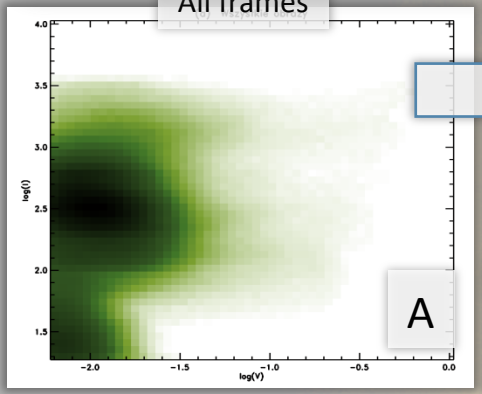
$$\boldsymbol{PE\square x\ =1-P(Q)P(x\,|\,Q)/P(x)}$$

probability that **pixel of state $\boldsymbol{x=(I,V)}$ belongs to class E**

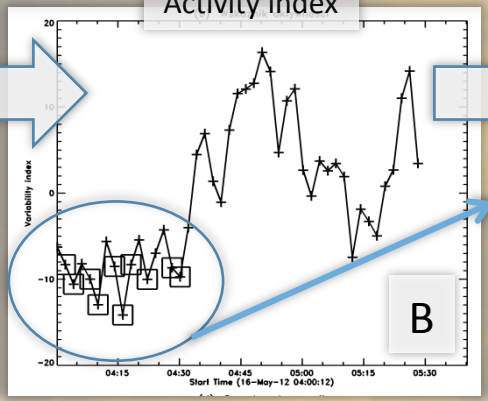
normalized distribution of $\boldsymbol{x=(I,V)}$ for entire sequence of images

Searching for moving structures

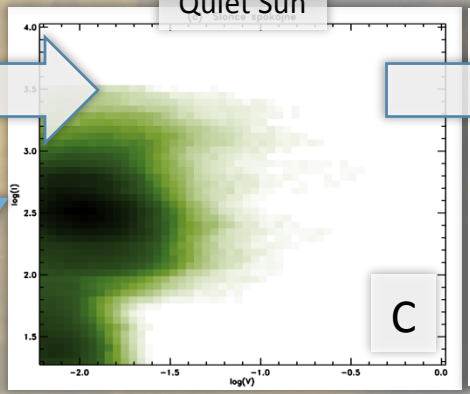
All frames



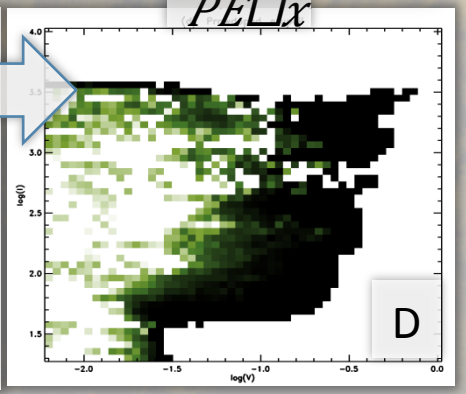
Activity index



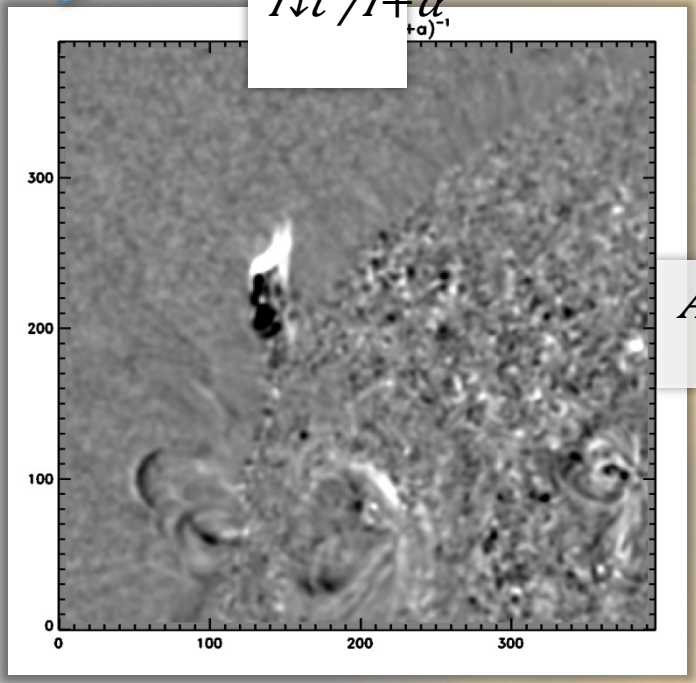
Quiet Sun



PE□x

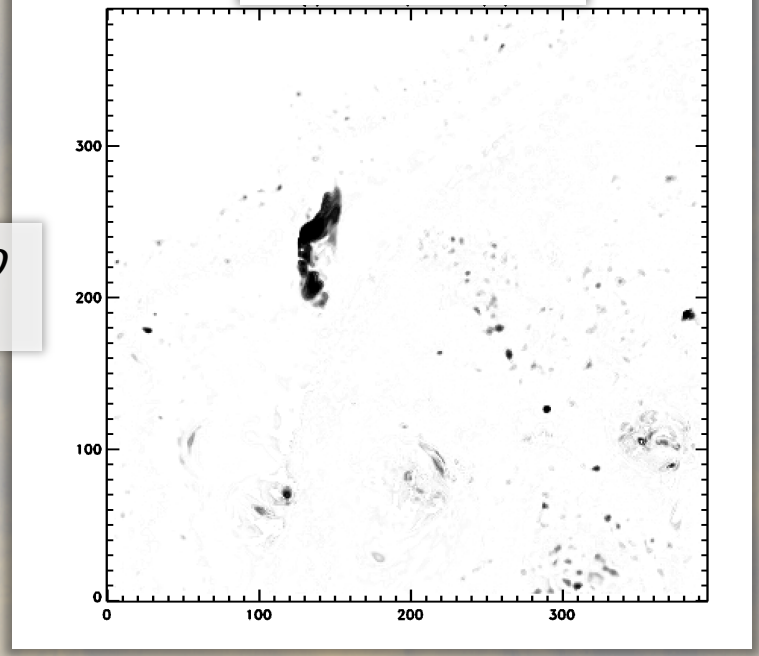


$I\downarrow t\ /I+\alpha$

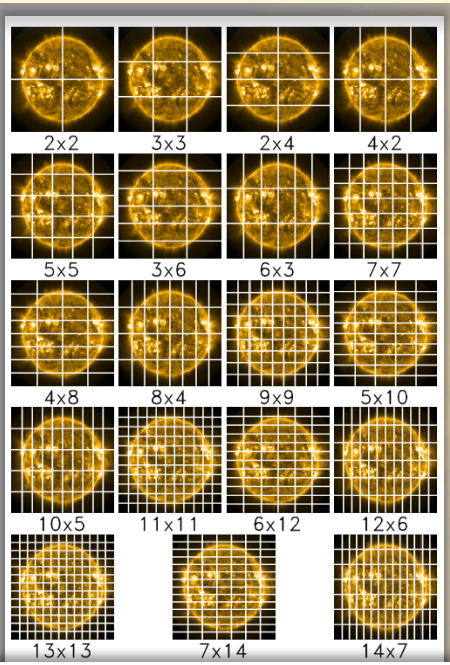


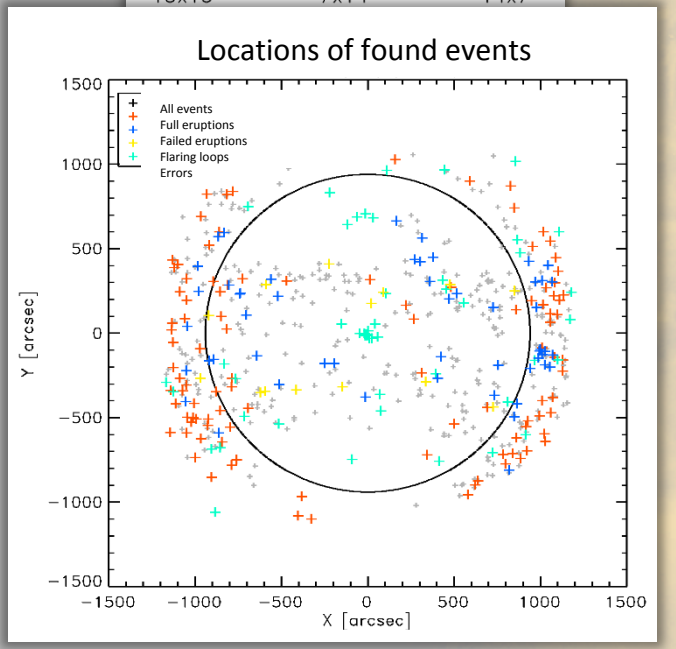
$A\ B/\ C=D$

probability of eruption



Searching for moving structures





E-pixels were searched (in 3h-long data packs) within frames of various size to avoid edge effects.
Area of eruption was calculated with simplest growth algorithm (slow).

Possible eruption was recognized when selected area:

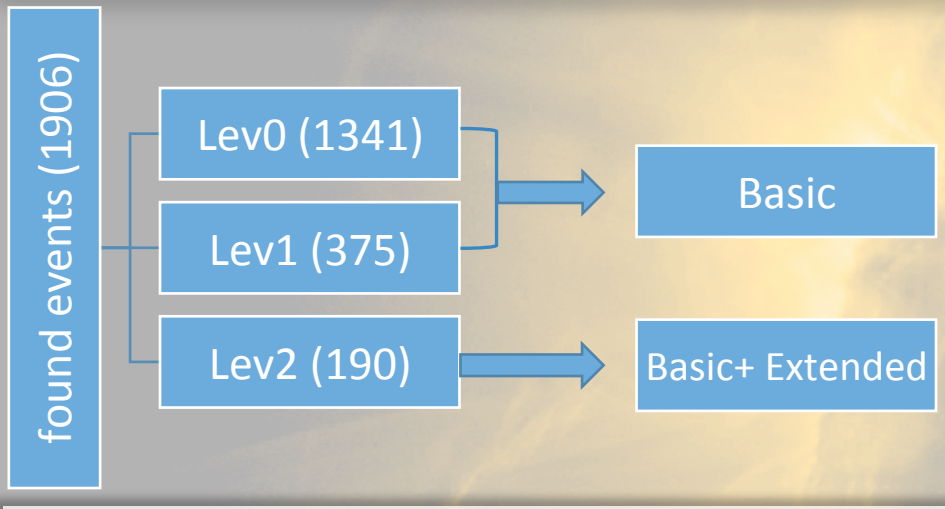
1. for each pixel: $PE\square x > 0.35$
2. was visible on 8 or more consecutive frames
3. was greater than 600 arcsec^2 on at least one frame
4. mean value of brightness was above 30 DN on at least one frame
5. showed change of centroid position greater than 25 arcsec.

We have foud that our algorithm is **slower but more effective** than algorithm described by Hurlburt, N. 2015 (arXiv:1504.03395) and Hurlburt, N. & Jaffey, S. 2015 (arXiv:1504.04660)

1 APR 2012 – 1 APR 2013: **1906 moving features have been recognized and classified**

Classification of found events was made by user. We did not use authomatic feature recognition (but we tried).

Classification and catalogue structure

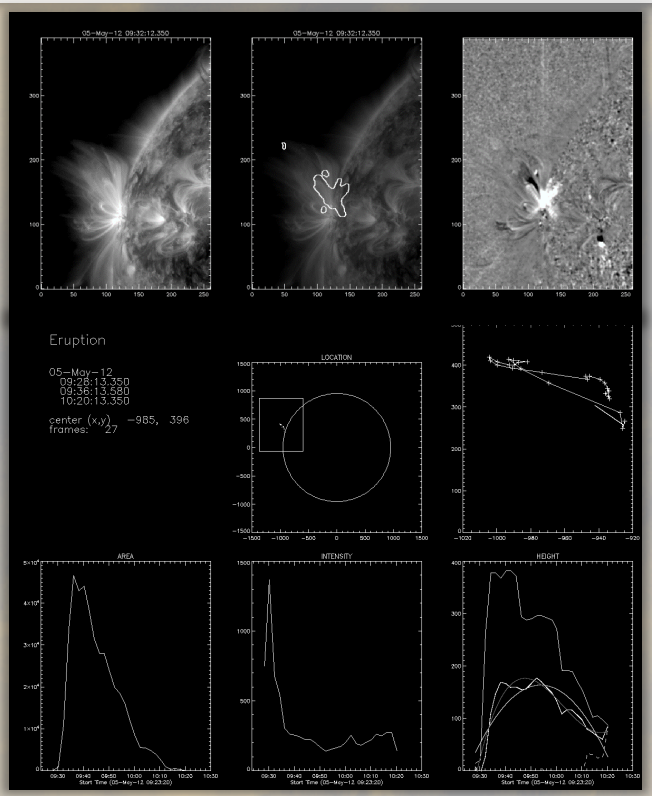


Found events were divided into three groups:

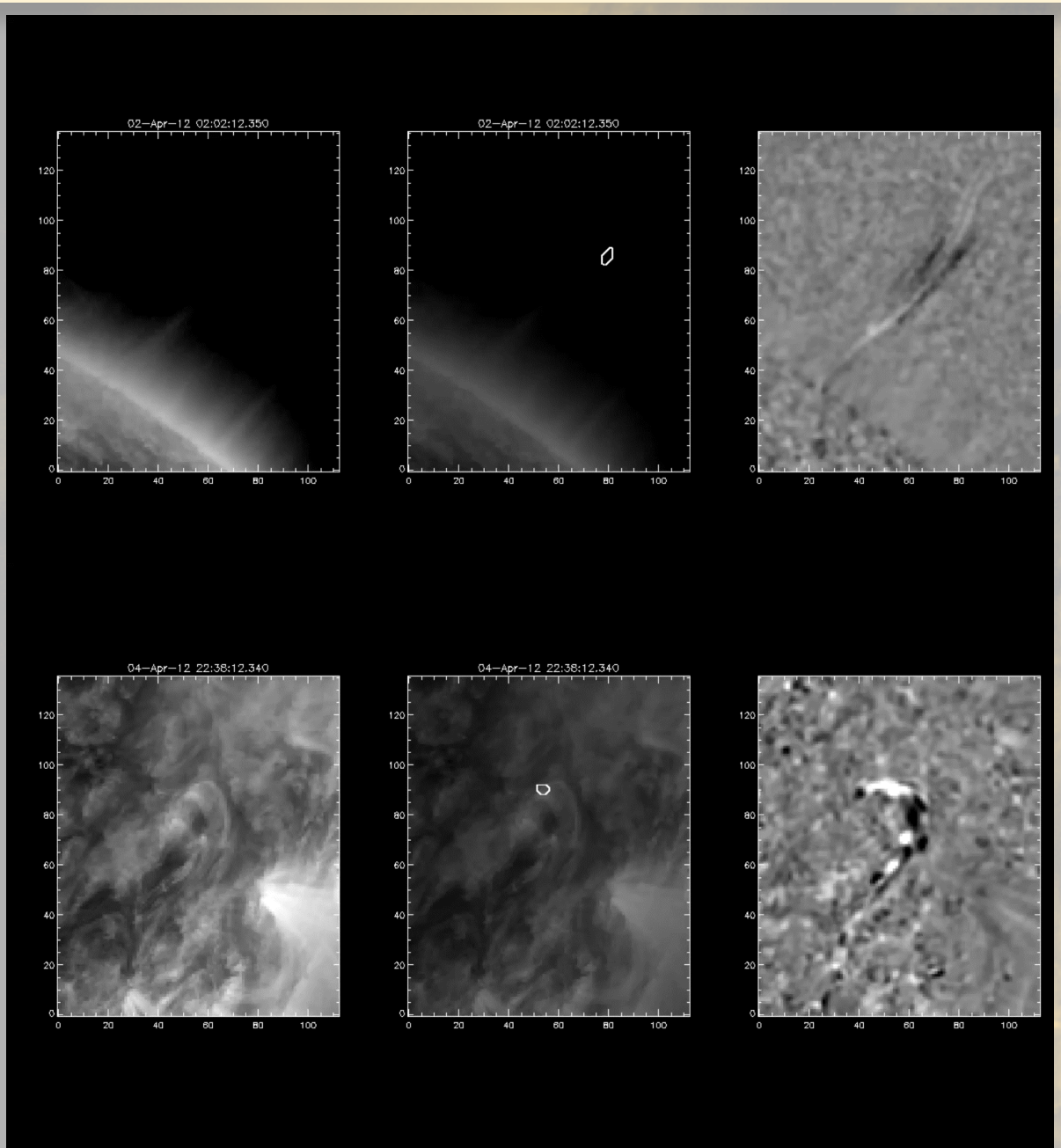
- **Level 0**: small mass movements, waves, small changes of loops brightness, small scale jets etc.
- **Level 1**: succesful eruptions, interesting events (e.g. oscillating structures)
- **Level 2**: failed eruptions

Basic data products are

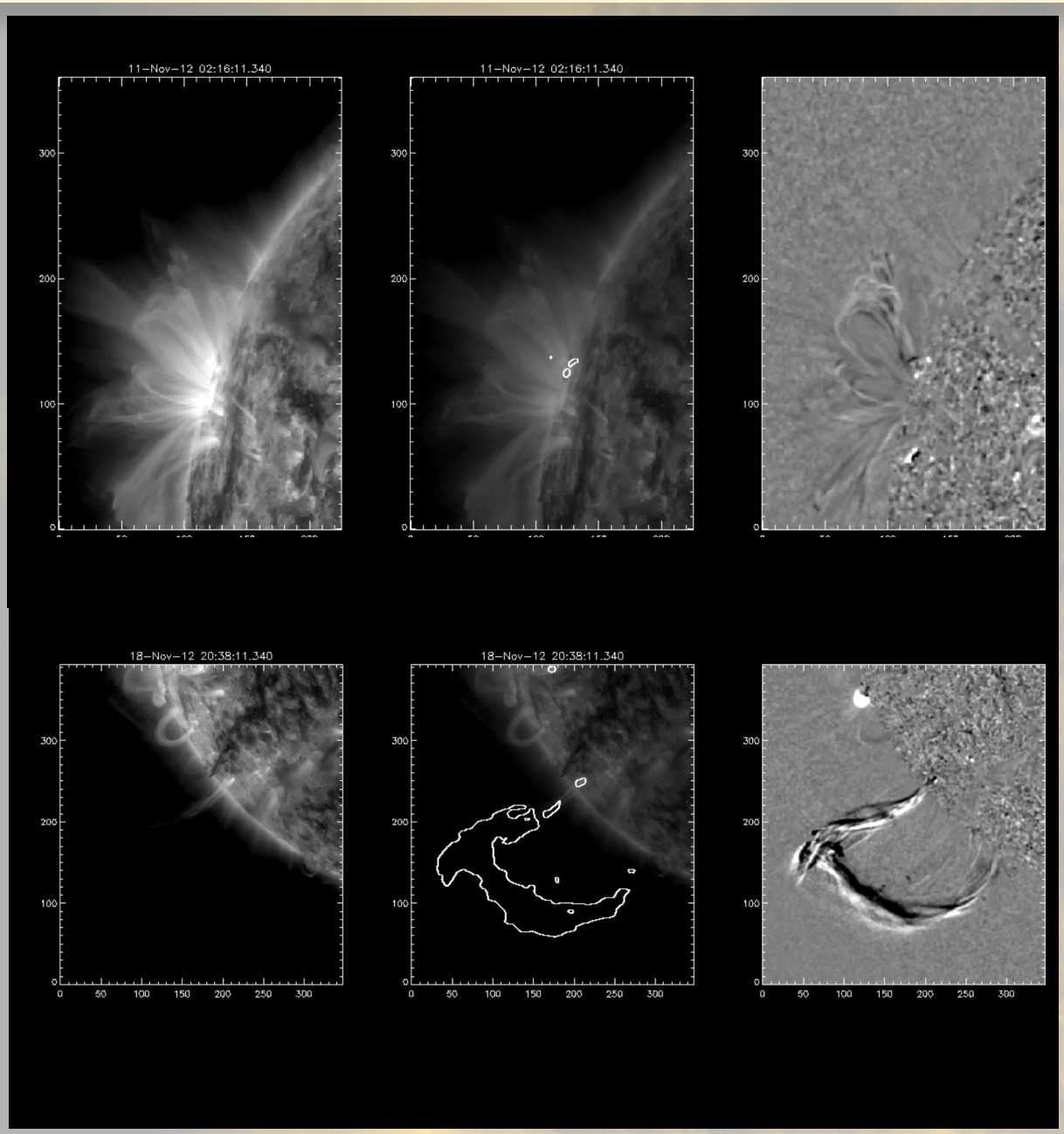
- **triple plots** presenting image, image with overlayed eruptive pixels area, differentia image
- eruption **start, maximum of the area, and end times, heliocentric coordinates**
- positions of **centroid of moving structure, area and intensity**
- authomaticaly determined **height of eruption front, centroid, and back** with second order polynomial fit – the intention was to select authomaticaly structures that were failed eruptions – partial succes
- **IDL save files** with even more parameters will be available



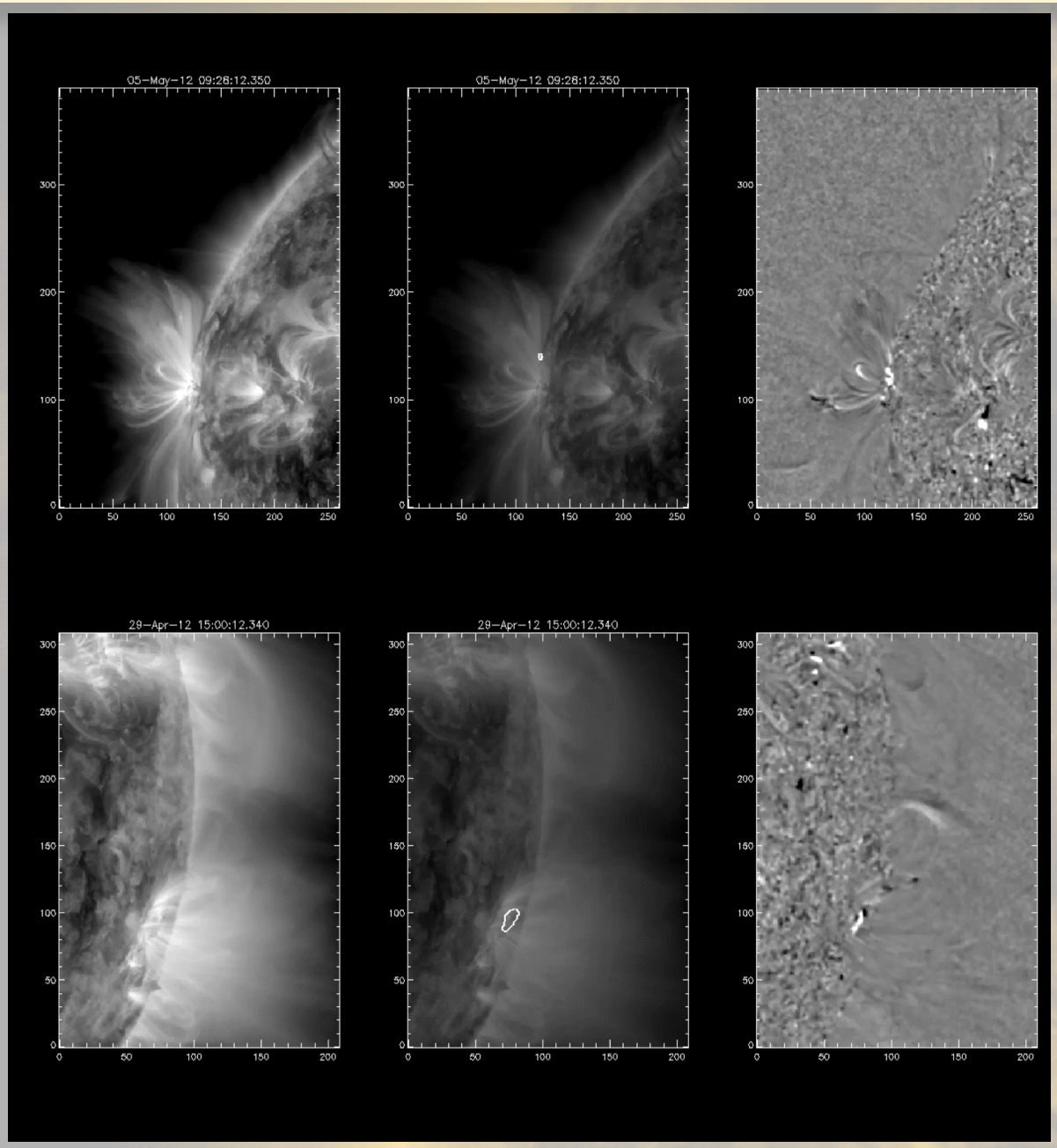
Small/unclassified events (Level 0)



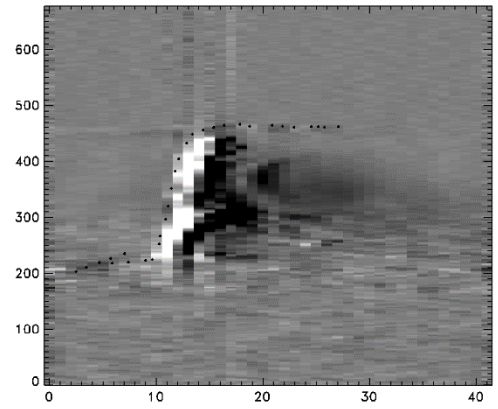
Full/partial eruptions (Level 1)

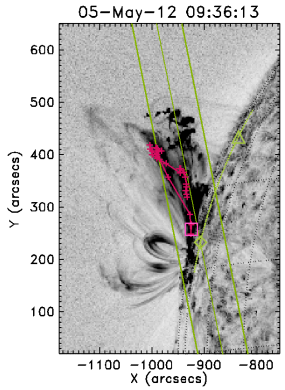


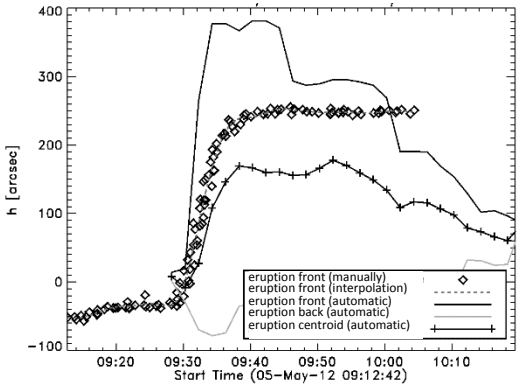
Failed eruptions (Level 2)

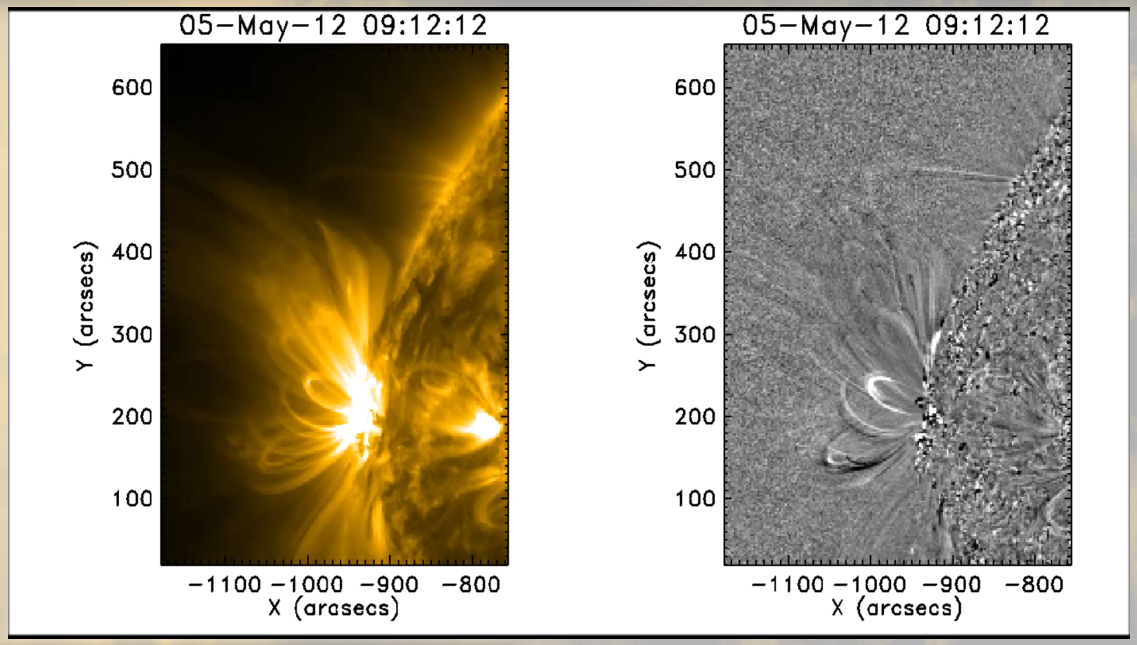


Extended data products (failed eruptions only)







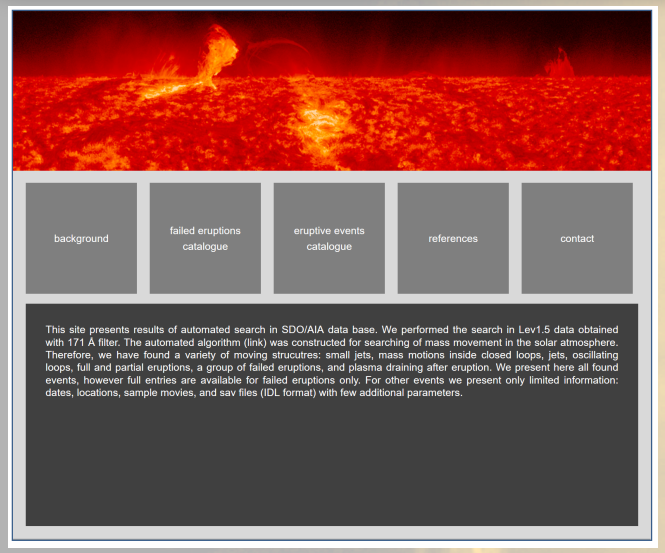


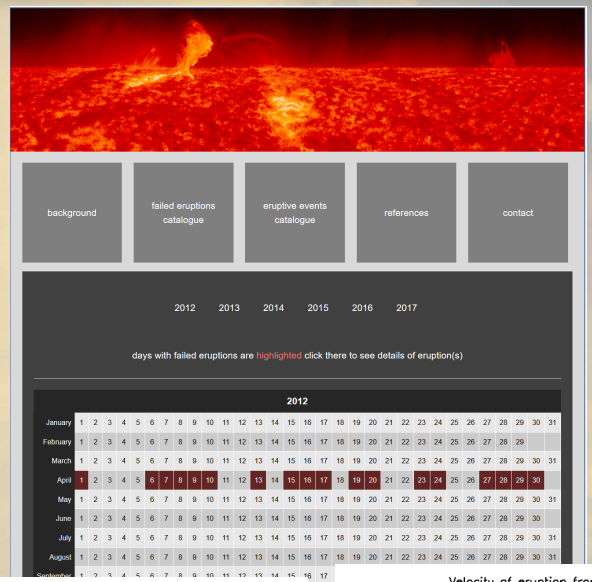
Start 2012/05/05 09:10
Max 2012/05/05 09:36
End 2012/05/05 11:00
Centroid [heliocentric] -925, 257
Inclination[deg] 120
Kinematics h(t), V(t), a(t)
Accompanying flare yes
Accompanying flare class C8.0
RHESSI light curve
AIA movies
FE class 110110001
References No
Remarks

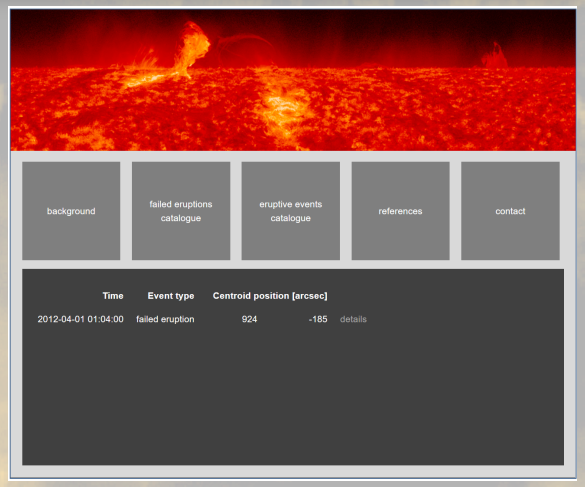
FE classification scheme:

- morphology (jet-like, buble-like, other)
- flare related (yes/no)
- visible interaction with overlying field (yes/no)
- sequence of events (yes/no)
- inclination
- max speed
- max height

The catalogue (www.eruptivesun.com)



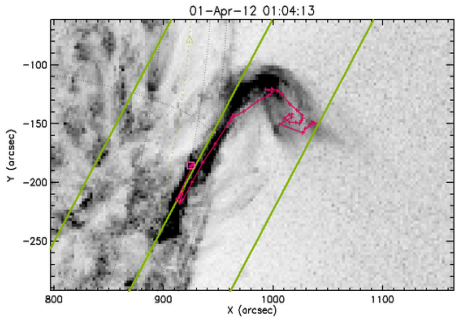


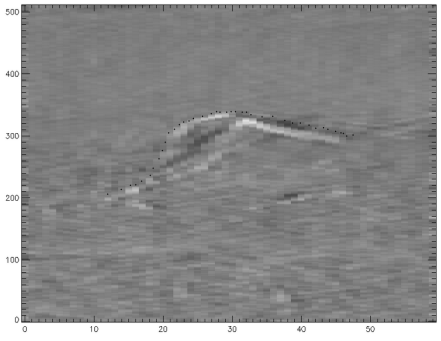


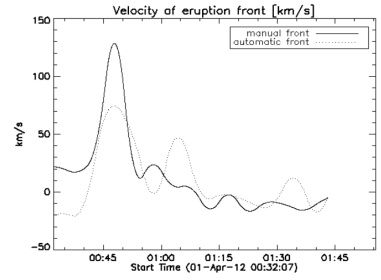
2012-04-01 01:04:00

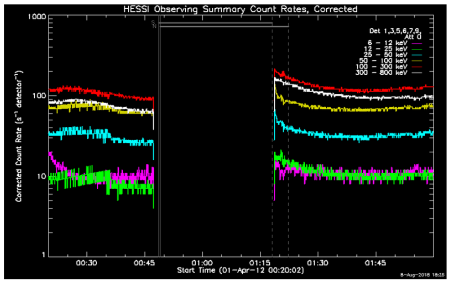
Event catalog classification: failed eruption

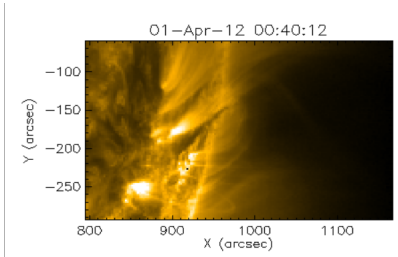
start:	2012-04-01 00:20:00
time of the largest structure:	2012-04-01 01:04:00
end:	2012-04-01 02:00:00
highest registered speed (km / s):	128
structure height during maximum velocity (thousands of km):	126
time of maximum velocity:	2012-04-01 00:47:50
highest registered deceleration (m / s^2):	-601
structure height during maximum deceleration (thousands of km):	126
time of maximum deceleration:	2012-04-01 00:50:31
inclination:	74°

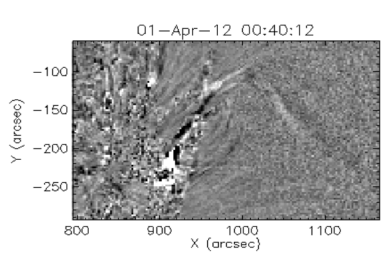








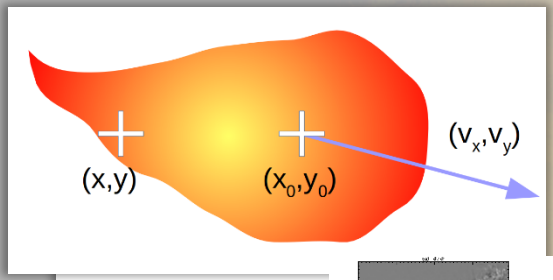


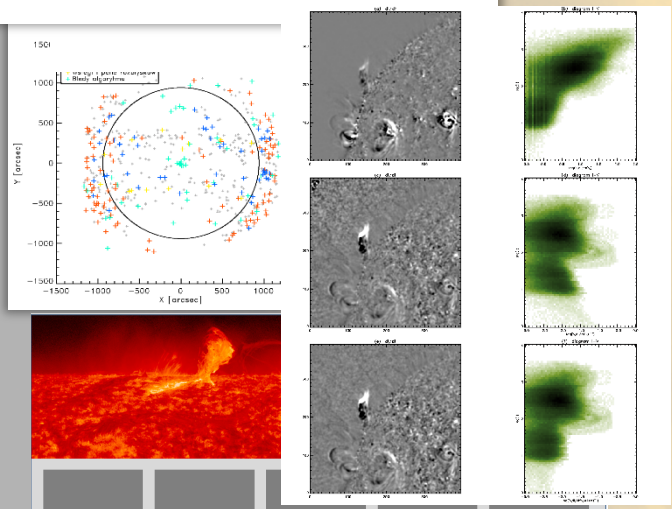


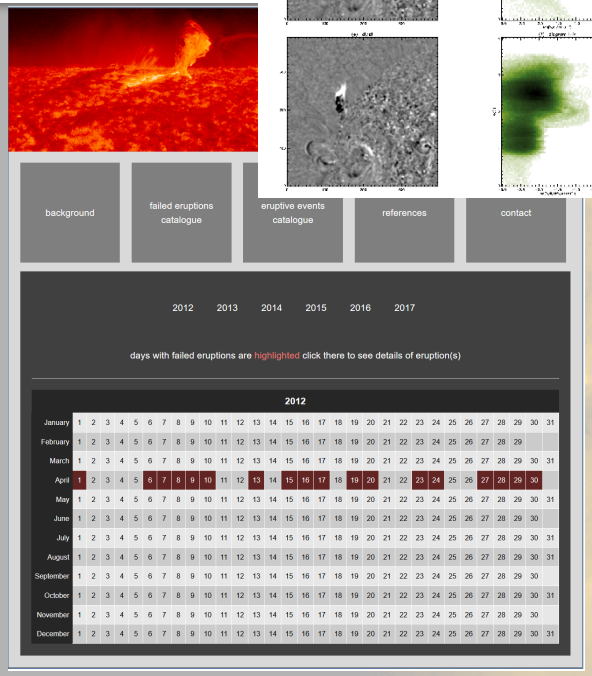
Start Pause Faster Slower Step Reverse Swing Mode: OFF

Displaying 17 of 60 24

Final remarks







- SDO/AIA data base for time period 2012 – 2016 have been searched for eruptive events with an automatic algorithm **(~10000 events, ~1000 full eruptions, ~800 failed eruptions**). Until the end of 2018 we will look over the entire data base.

- Found events (1 APR 2012 – 1 APR 2013) have been classified and collected in the catalogue. The failed eruption class is investigated with more details.

- Problems:
  - we have to abandon (restrict?) working with full resolution data (problems with server connection, huge amount of data to download)
  - a lot of events that need to be classified by hand (all found: 2000+/year, failed eruptions: 200+/year)

- The first version of catalogue will be available on September/October 2018 (www.eruptivesun.com)