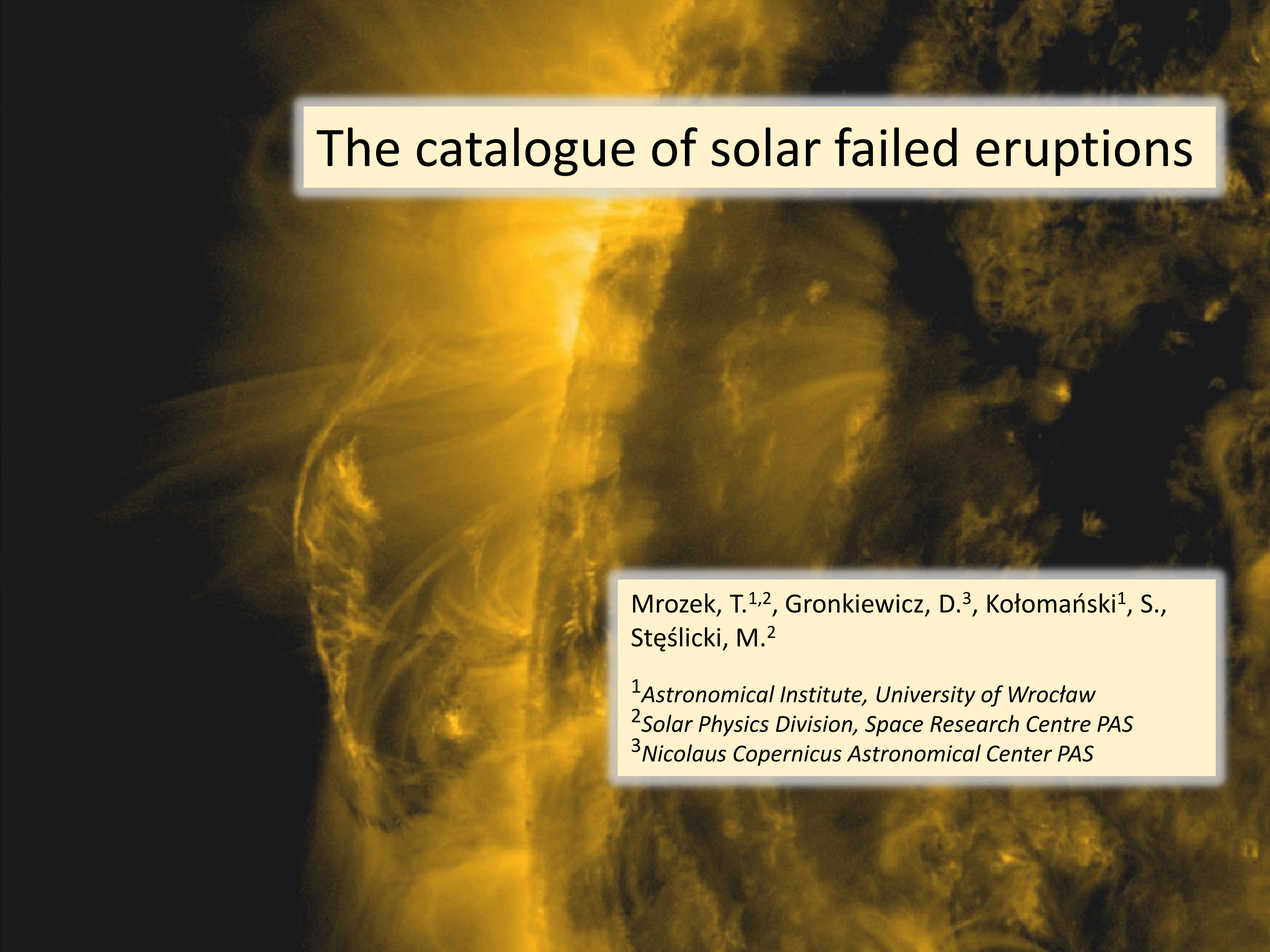


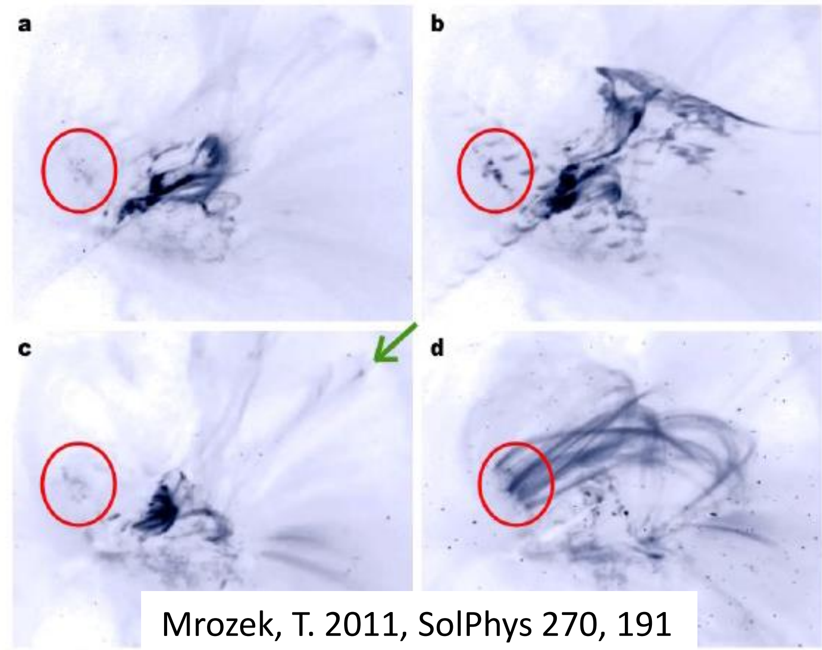
The catalogue of solar failed eruptions

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*

Why failed eruptions?

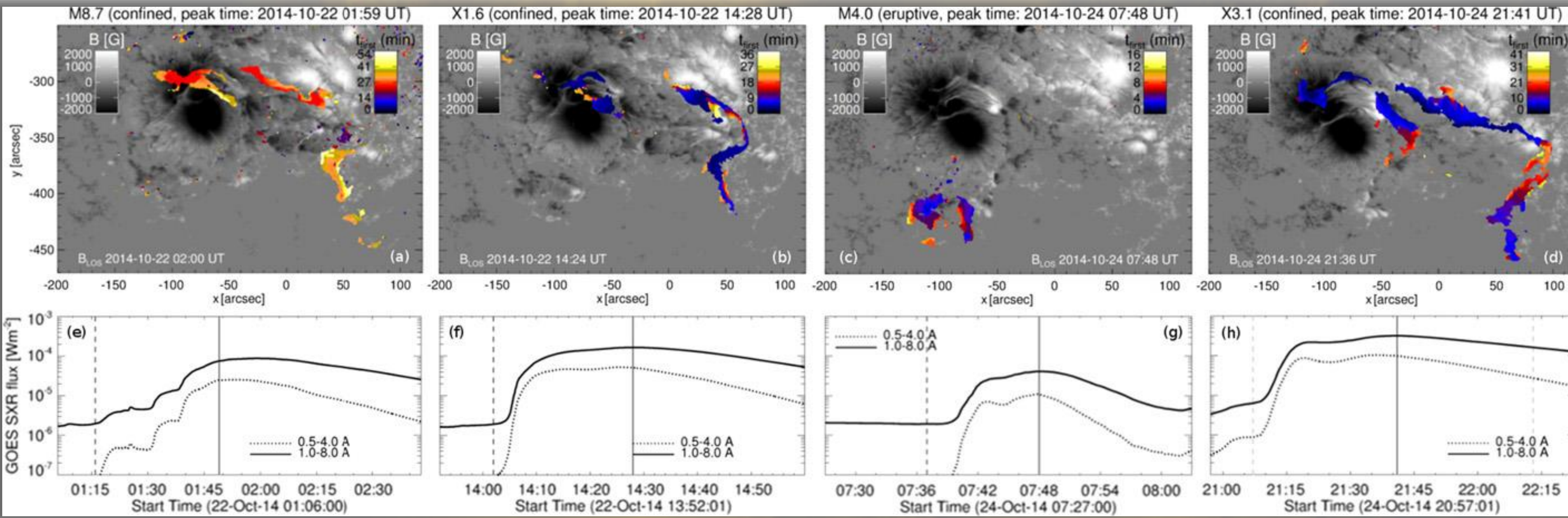
- Space weather (boundary conditions for CME)
- Which mechanism(s) is(are) responsible for stopping eruptions?
- Interaction between magnetic structures
- Particle acceleration in interaction region



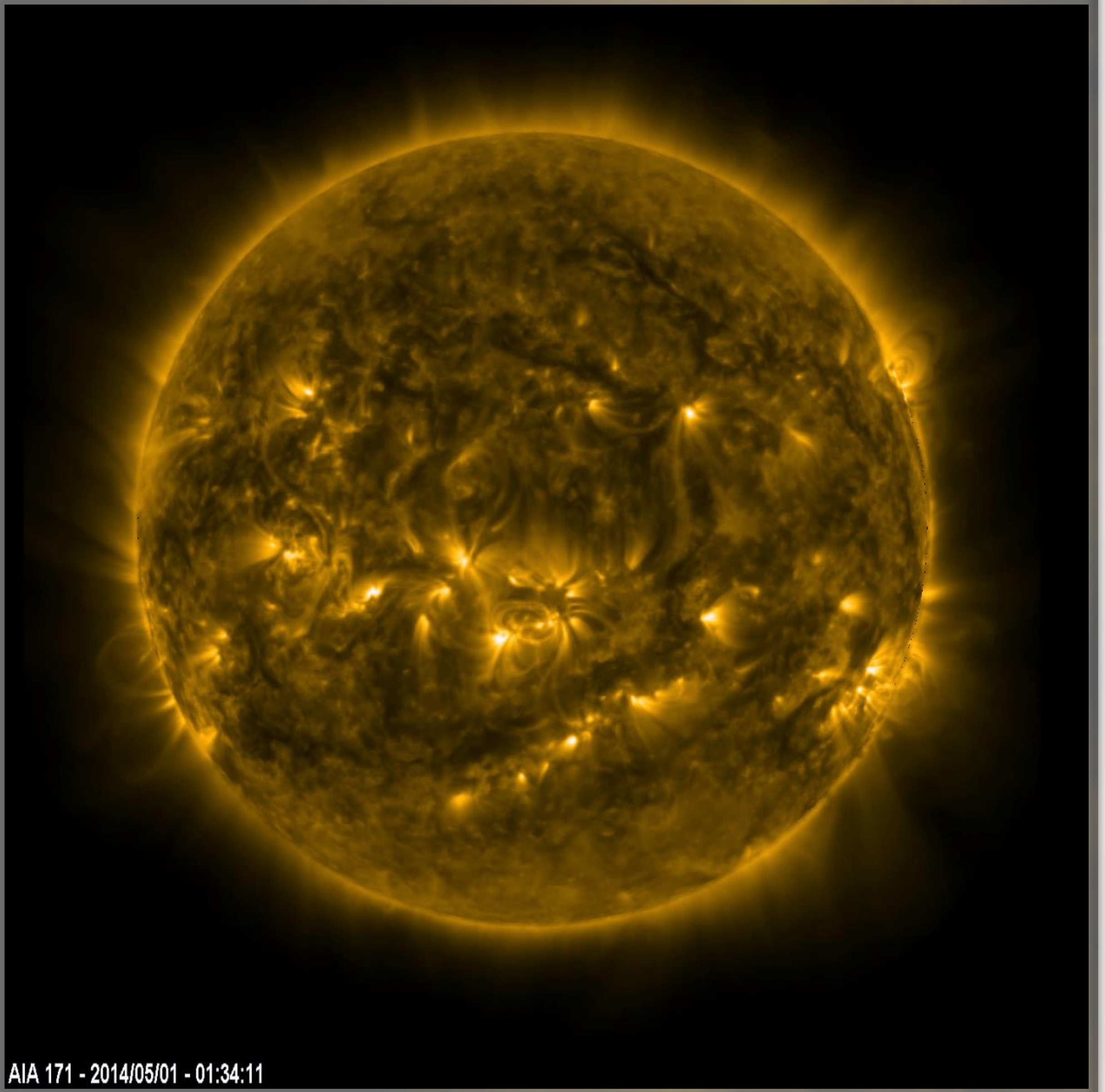
Mrozek, T. 2011, SolPhys 270, 191

AR12192, flare-rich and CME-poor

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



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.

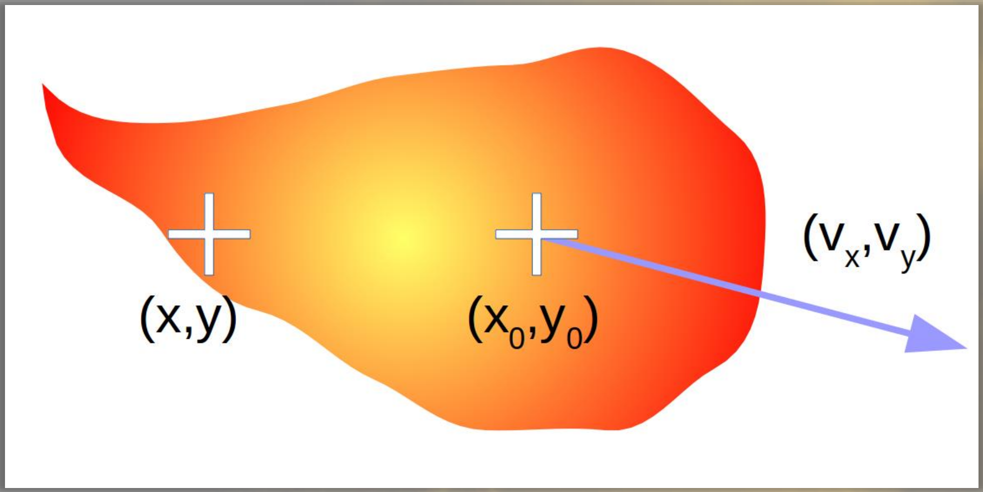
SDO/AIA:

- 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

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:

$$I(x,y,t) = R\big(x - x_{0,}y - y_0\big)\varphi(t) = I_0(x,y)\varphi(t)$$

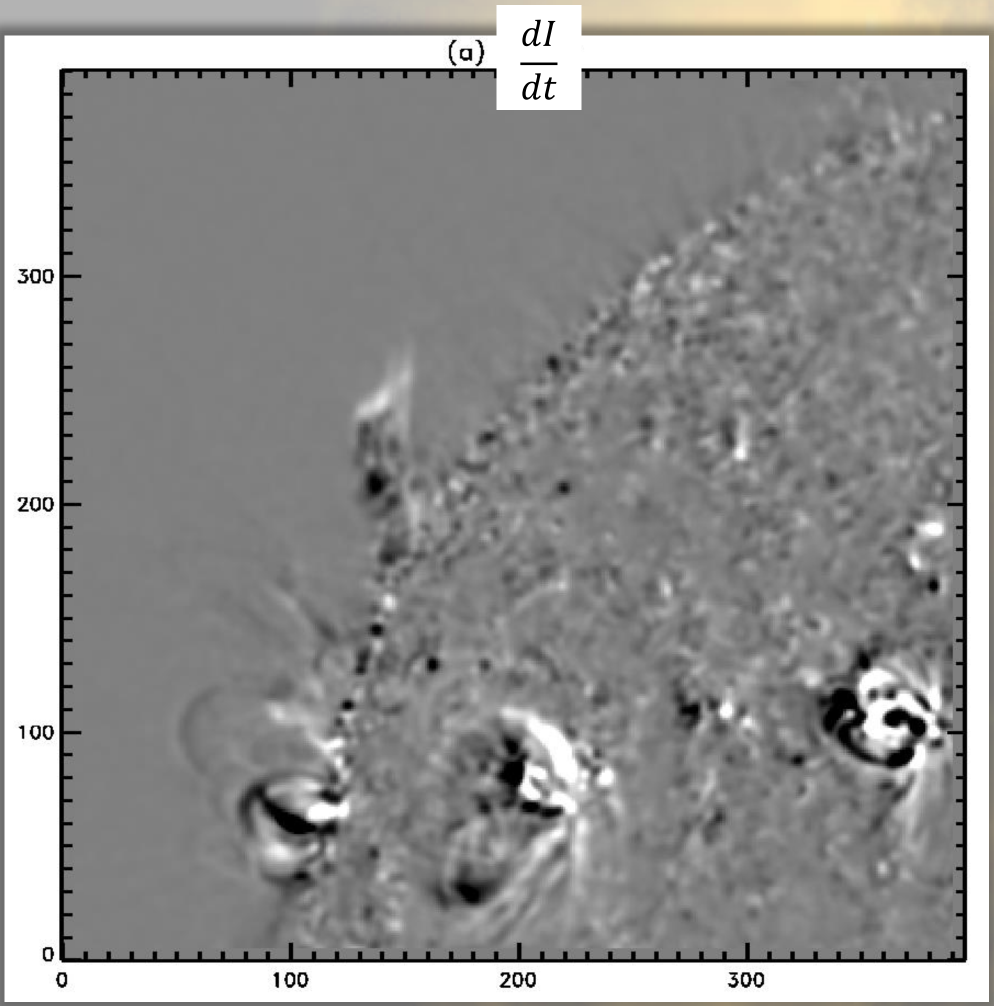
Differential image:

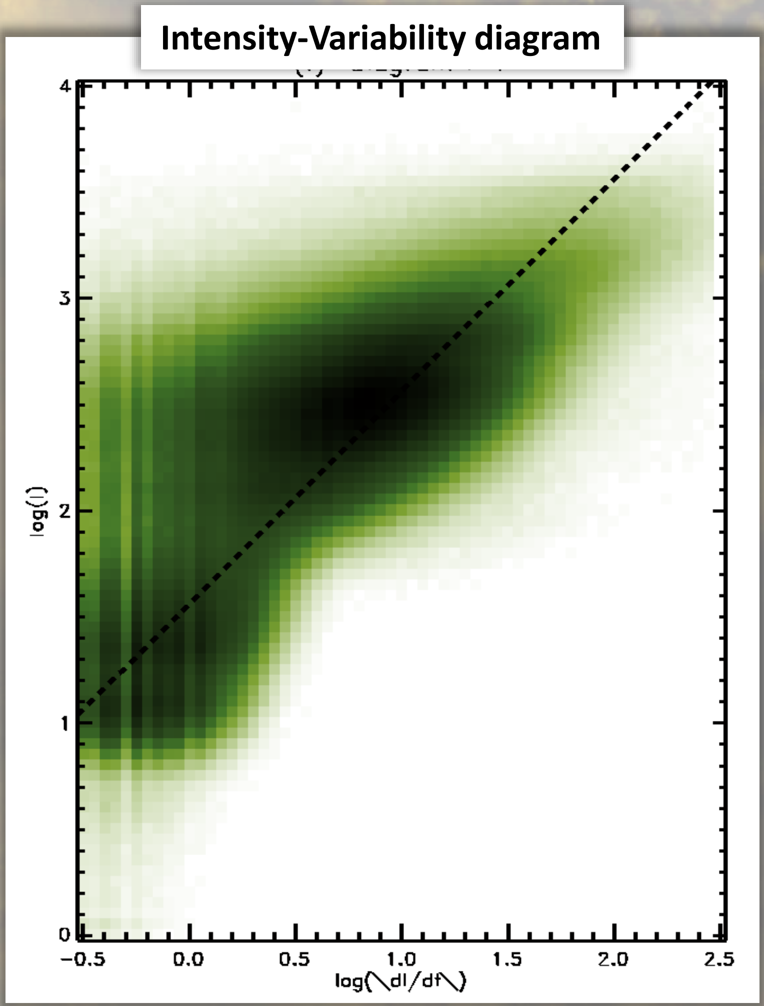
$$I_t = \frac{dI(x,y,t)}{dt} = -\varphi(t) \cdot (\vec{v} \circ \nabla I_0) + I_0 \frac{d\varphi(t)}{dt}$$

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.

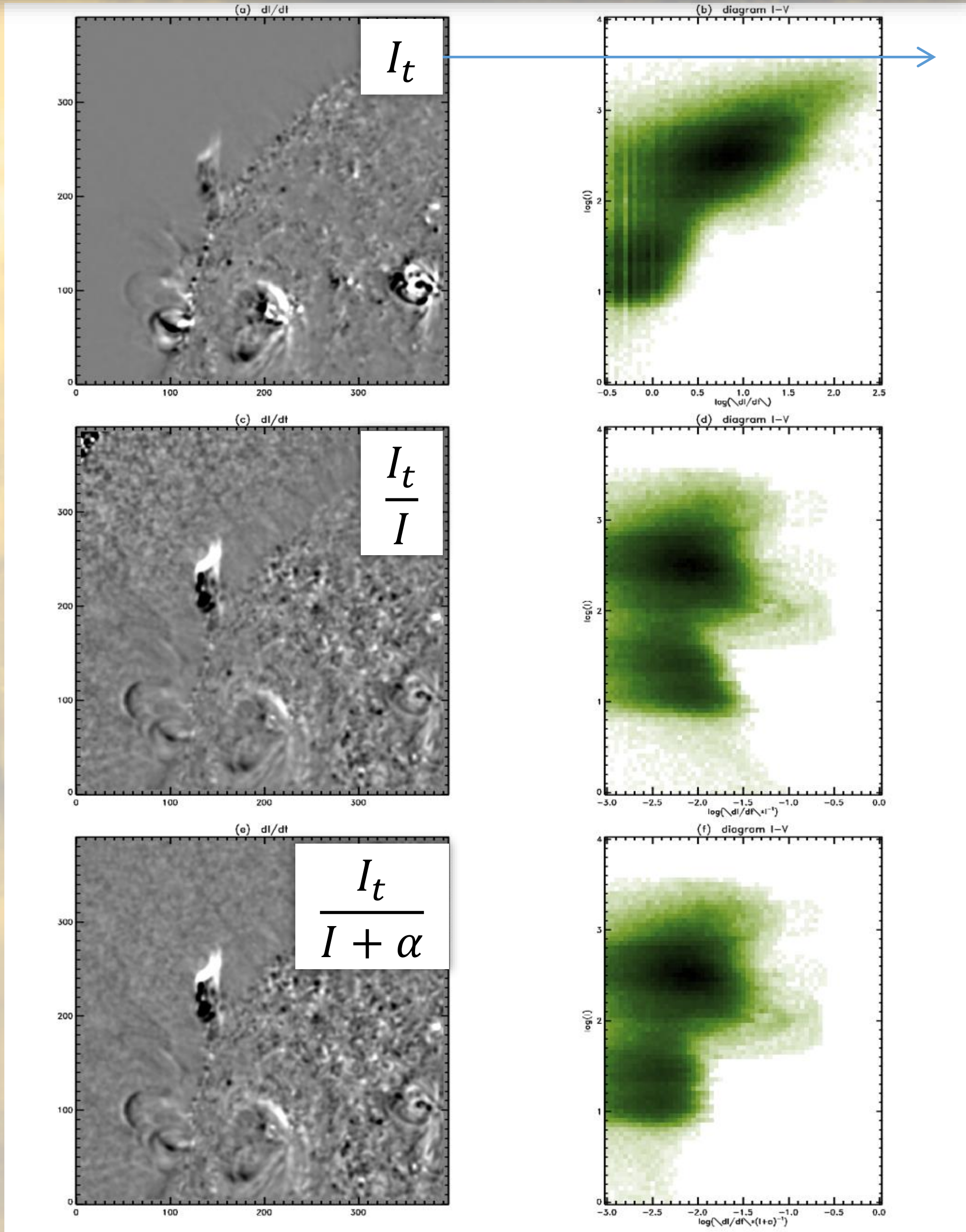
Searching for moving structures

$$I_t^{norm} = \frac{I_t}{I + \alpha} = J_t$$

$$I_{tt}^{norm} = \frac{I_{tt}}{I + \alpha} = J_{tt} + J_t^2$$

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

$$V = \sqrt{{J_t}^2 + \frac{1}{4}{J_{tt}}^2}$$



Searching for moving structures

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

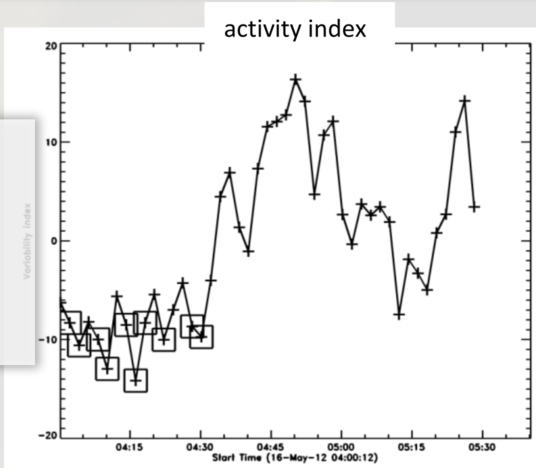
Let's assume that $P(Q) \approx 1$, and classify pixels as Q or E. Having number of E-pixels we calculate $\boldsymbol{P(Q) = 1 - P(E) = 1 - \frac{n_{erupt}}{n_{total}}}$, and run algorithm again with new value of $P(Q)$. Usually, after 3 steps $P(Q)$ had stabilized.

$$V_{mean}(t_k) = \frac{1}{n_x n_y} \sum_{i=1}^{n_x} \sum_{j=1}^{n_y} V(x_i, y_j, t_k)$$

$$I_{mean}(t_k) = \frac{1}{n_x n_y} \sum_{i=1}^{n_x} \sum_{j=1}^{n_y} I(x_i, y_j, t_k)$$

activity index:

$$A(t_i) = \frac{I_{mean}(t_k) - \overline{I_{mean}}}{\sigma_{I_{mean}}} + w \frac{V_{mean}(t_k) - \overline{V_{mean}}}{\sigma_{V_{mean}}}$$



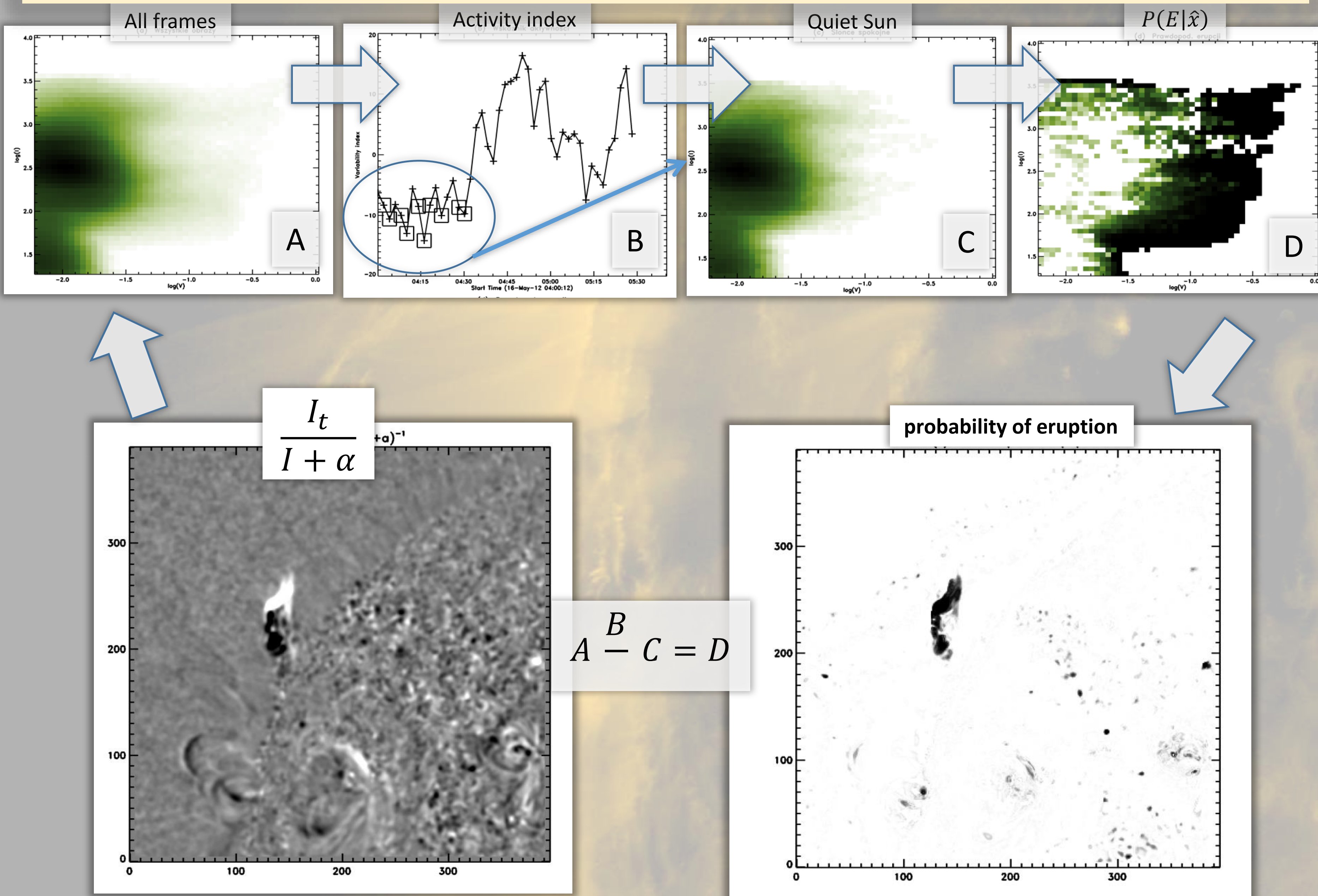
we can estimate $P(\hat{x}|Q)$ assuming that **several images in sequence do not contain eruptions**

$$\boldsymbol{P(E|\hat{x}) = 1 - \frac{P(Q)P(\hat{x}|Q)}{P(\hat{x})}}$$

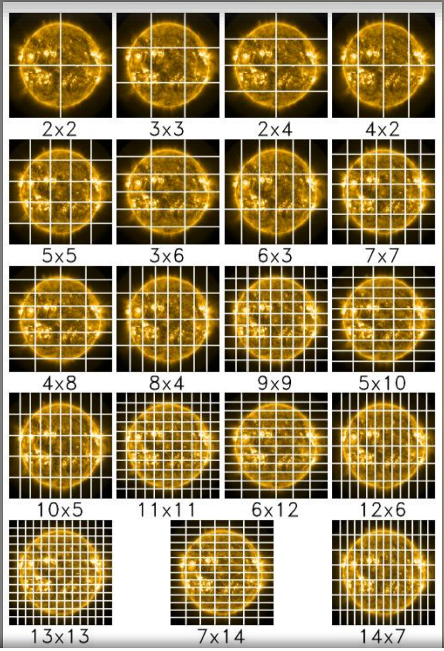
probability that **pixel of state $\hat{x} = (I, V)$ belongs to class E**

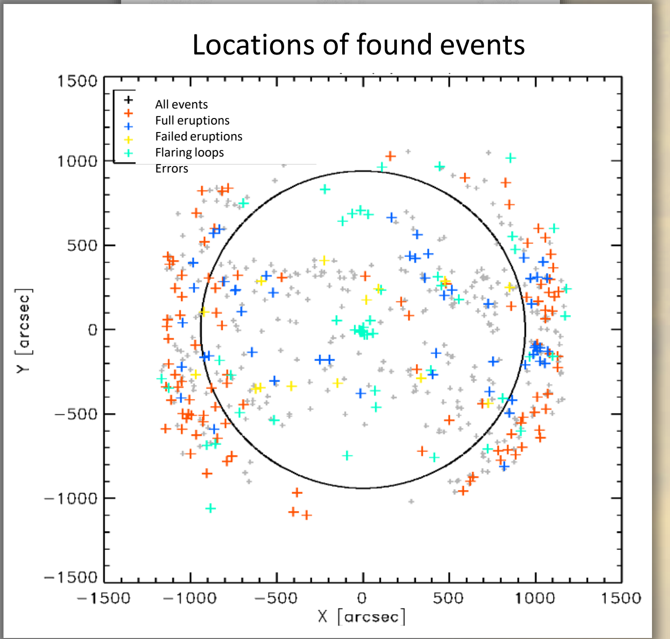
normalized distribution of $\hat{x} = (I, V)$ for entire sequence of images

Searching for moving structures



Searching for moving structures





E-pixels were searched 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:

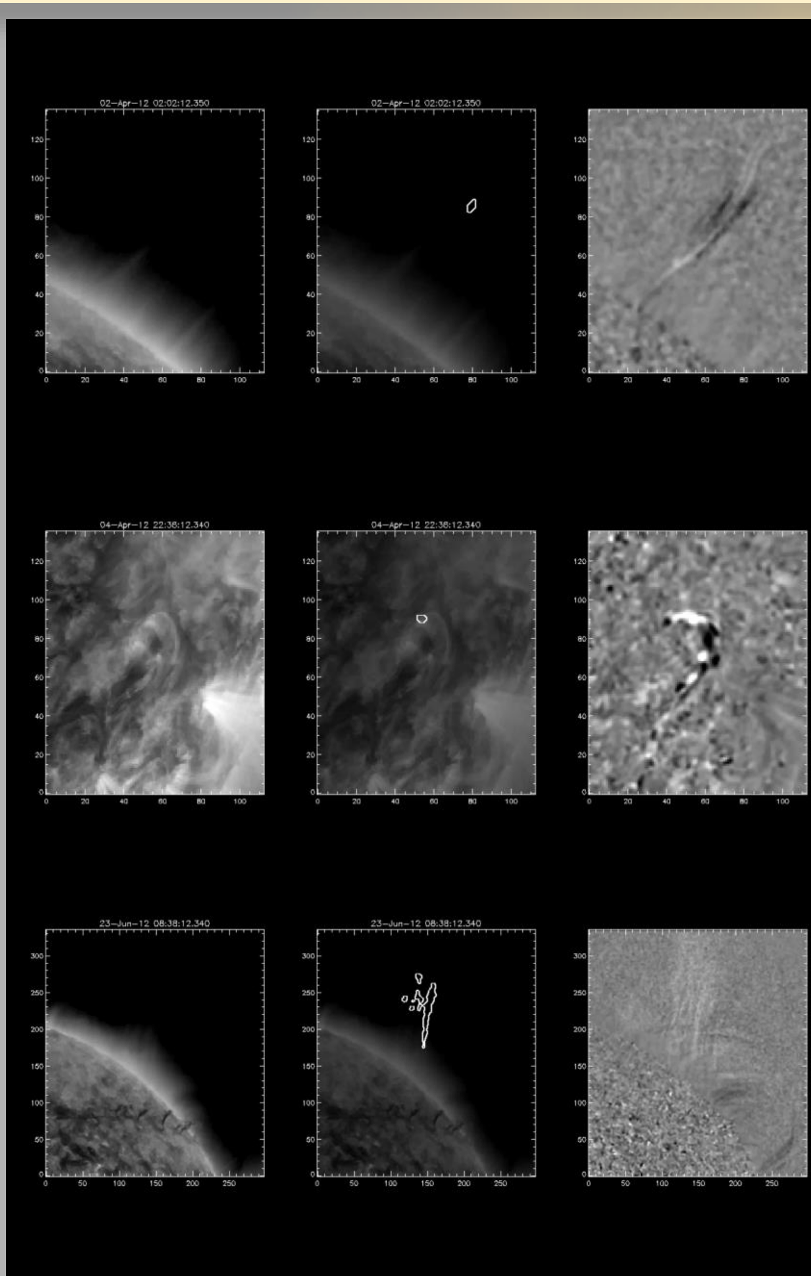
1. for each pixel: $P(E|\hat{x}) > 0.35$
2. was visible on 8 or more consecutive frames
3. was greater than 600 arcsec^2 on at least one frame
4. mean value of brightness was above 30 DN on at least one frame
5. showed change of centroid position greater than 25 arcsec.

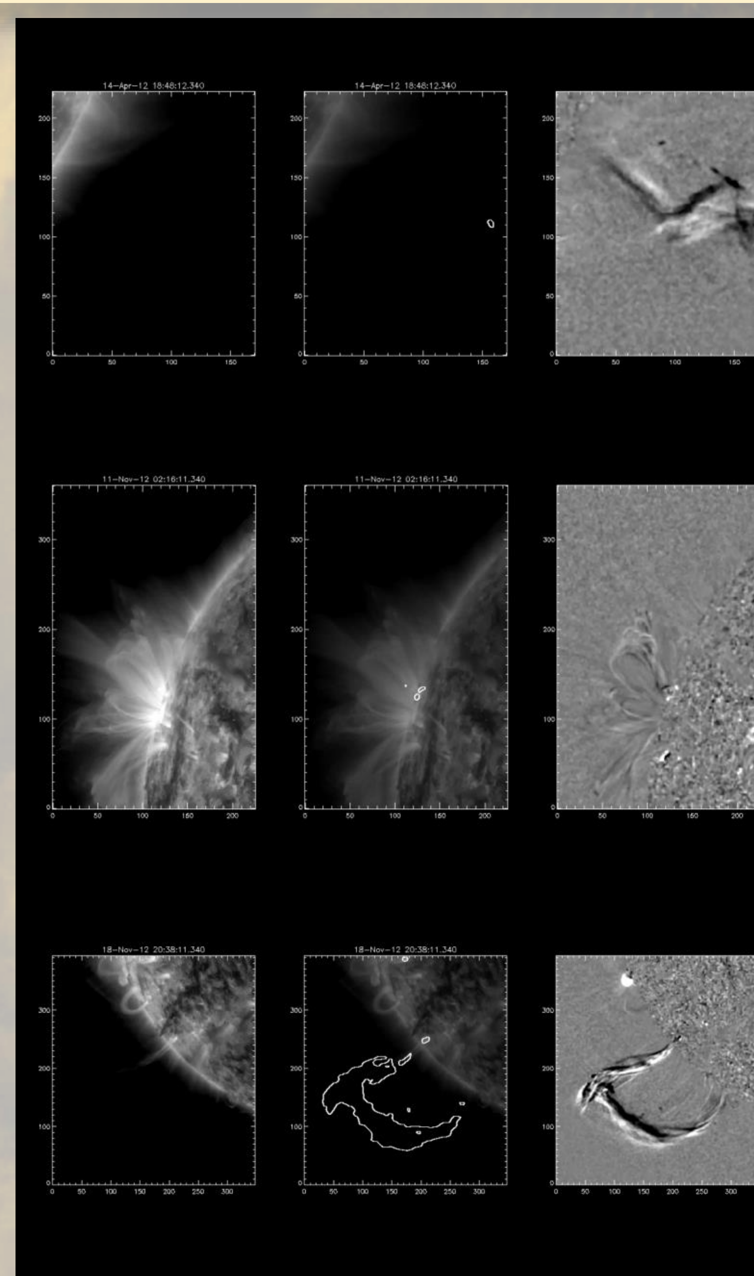
We have foud that our algorithm is **slower but more effective** than algorithm described by Hurlburt, N. 2015 (arXiv:1504.03395) and Hurlburt, N. & Jaffey, S. 2015 (arXiv:1504.04660)

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

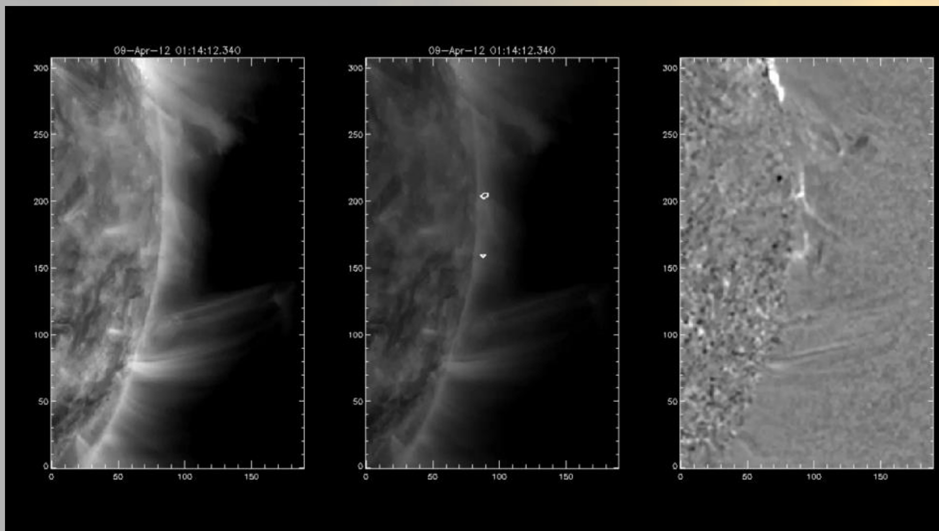
Classification of found events was made by user. We did not use authomatic feature recognition (but we tried).

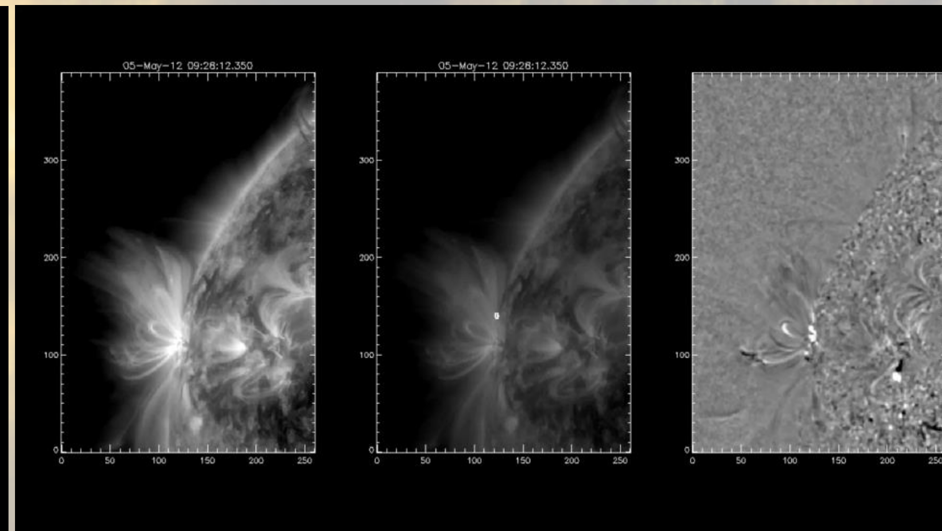
Level 0 and 1 examples

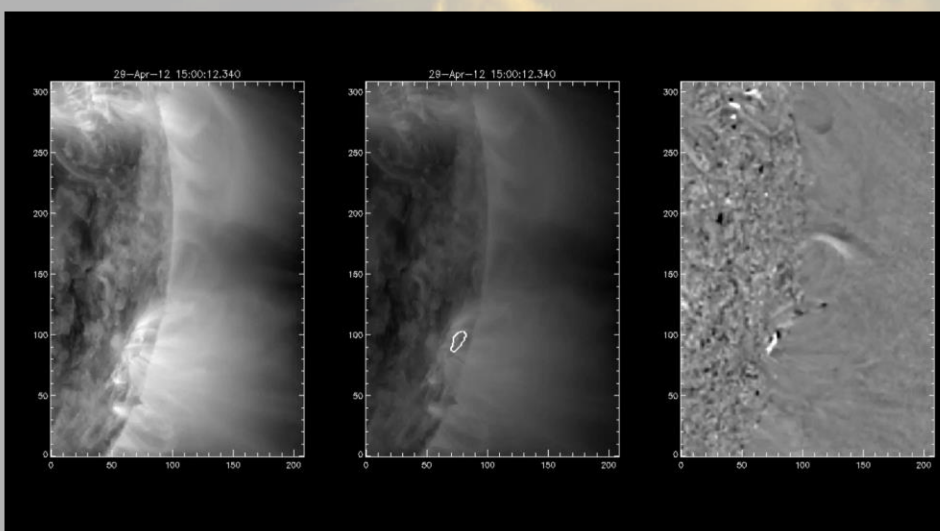


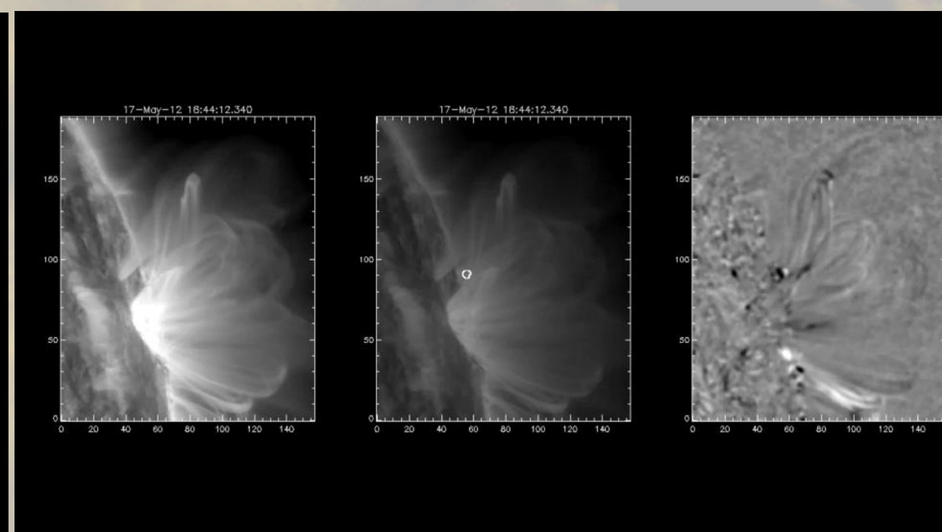


Level 2 examples

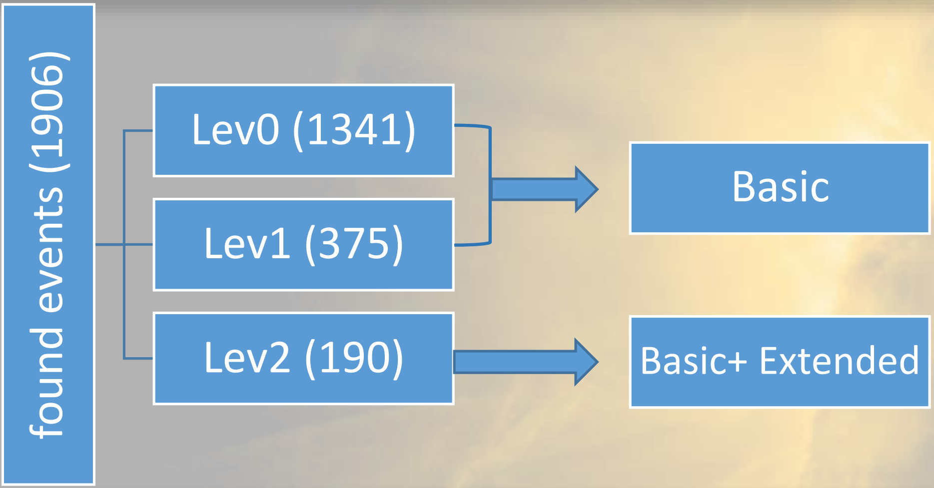








Classification and catalogue structure

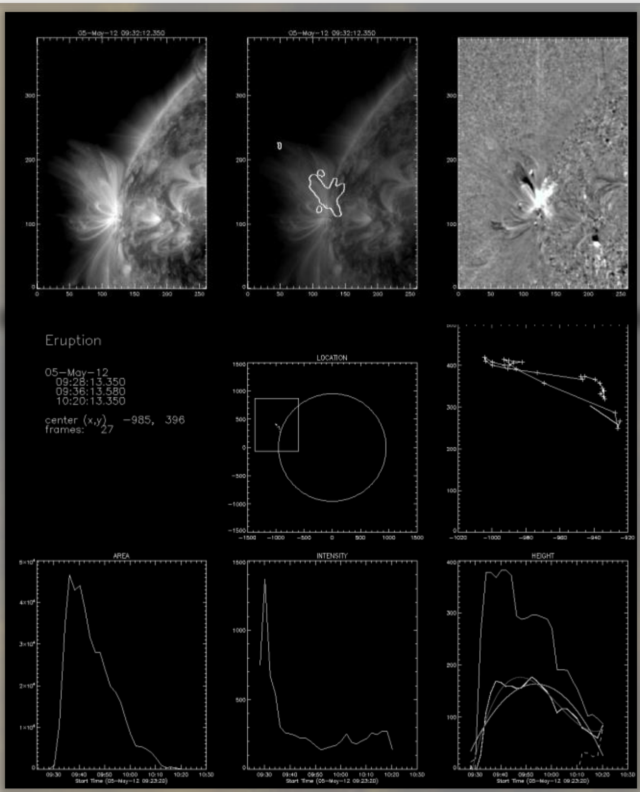


Found events were divided into three groups:

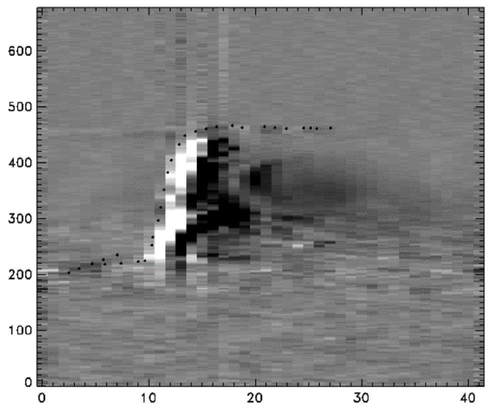
- **Level 0**: smal mass movements, waves from other regions, small changes of loops brightness, small scale jets etc.
- **Level 1**: succesful eruptions, interesting events (e.g. oscillating structures)
- **Level 2**: failed eruptions

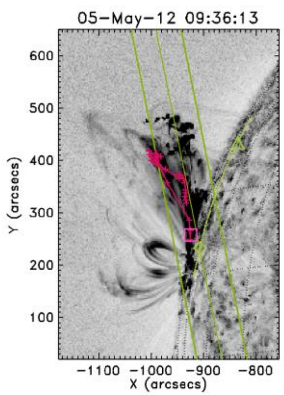
Basic data products are

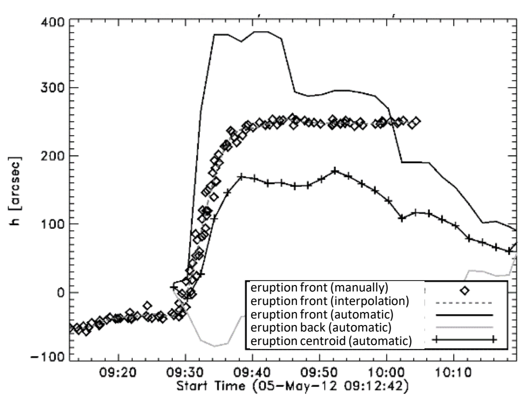
- **triple plots** presenting image, image with overlayed eruptive piksels area, differentia image
- eruption **start, maximum of the area, and end times, heliocentric coordinates**
- positions of **centroid of moving structure, area and intensity**
- authomaticaly determined **height of eruption front, 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

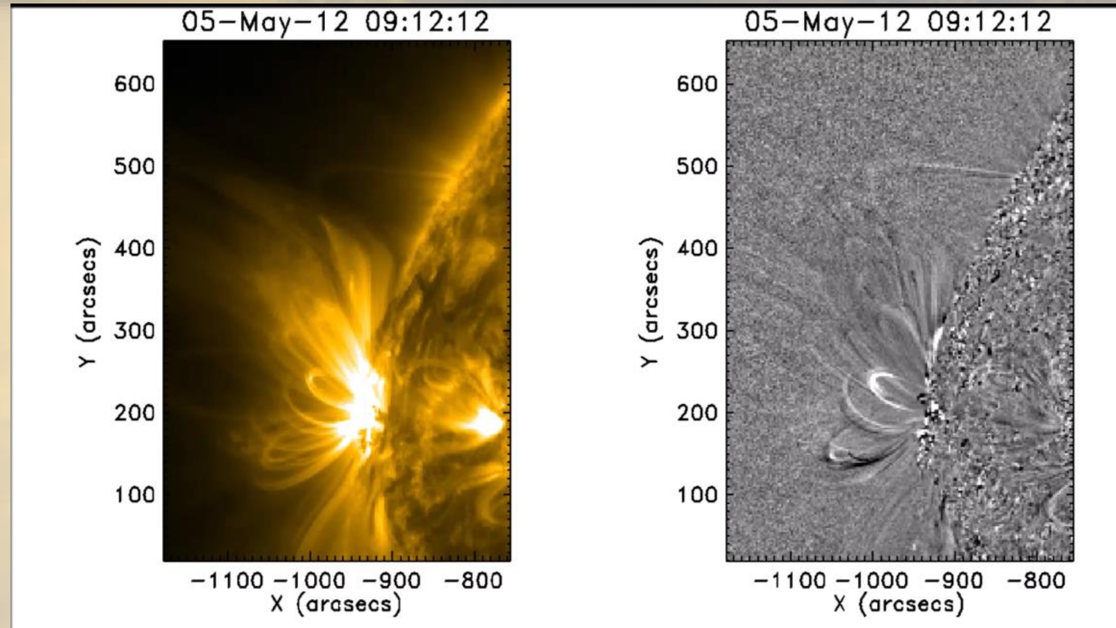


Extended data products









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

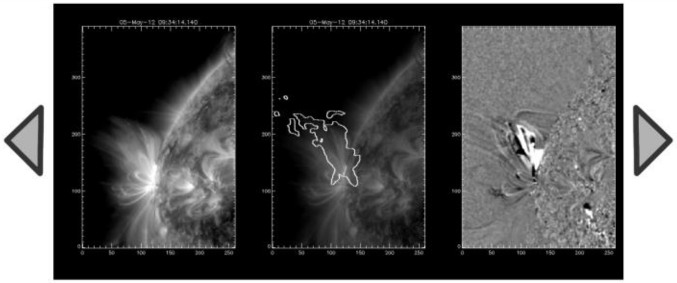
FE classification scheme:
- morphology (jet-like, buble-like, other)
- flare related (yes/no)
- visible interaction with overlying field (yes/no)
- sequence of events (yes/no)
- inclination
- max speed
- max height

Classification and catalogue structure

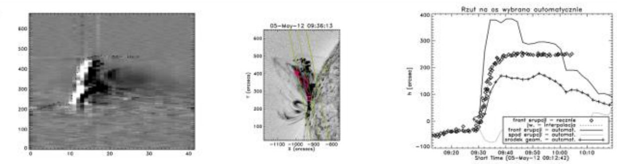
☑ Level 0 ☐ Level 1 ☐ Level 2 Submit

Time	Level	Centroid position [arcsec]		
2012-04-01 22:54:00	0	761	-686	details
2012-04-02 01:46:00	0	553	867	details
2012-04-02 09:00:00	0	-540	342	details
2012-04-02 10:18:00	0	-281	365	details
2012-04-02 12:14:00	0	-174	-189	details
2012-04-03 07:36:00	0	-357	354	details
2012-04-03 15:40:00	0	-273	345	details
2012-04-04 16:26:00	0	191	366	details
2012-04-04 17:30:00	0	194	443	details
2012-04-04 17:40:00	0	218	359	details
2012-04-04 22:14:00	0	744	-356	details
2012-04-05 02:42:00	0	314	404	details
2012-04-05 04:52:00	0	-909	-527	details
2012-04-05 12:14:00	0	393	414	details
2012-04-05 17:02:00	0	-864	590	details
2012-04-06 08:14:00	0	395	236	details
2012-04-06 09:54:00	0	1087	313	details
2012-04-06 14:26:00	0	655	-246	details
2012-04-06 14:48:00	0	336	366	details
2012-04-07 07:30:00	0	185	608	details
2012-04-07 07:32:00	0	746	-264	details
2012-04-07 13:48:00	0	582	251	details

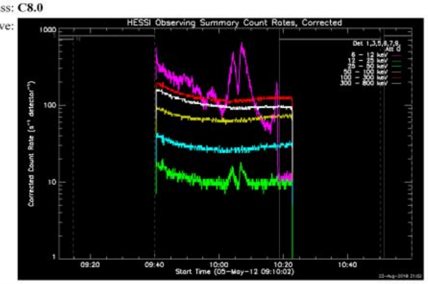
Start time : **2012-05-05 09:10:00**
Largest structure time: **2012-05-05 09:34:00**
End time: **2012-05-05 11:00:00**
Centroid coordinates (heliocentric) [arcsec]: **-699 168**
Inclination [deg]: **120**
Max deceleration time: **2012-05-05 09:36:00**
Max deceleration value [m/s^2]: **-20**



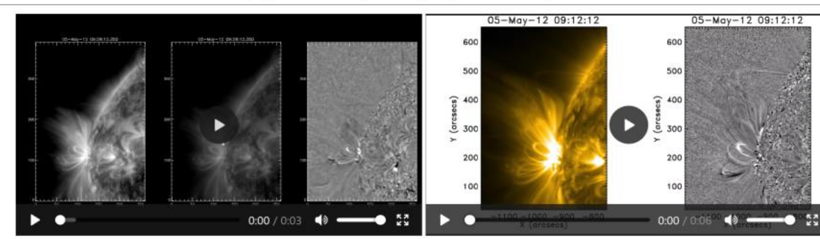
Kinematics:



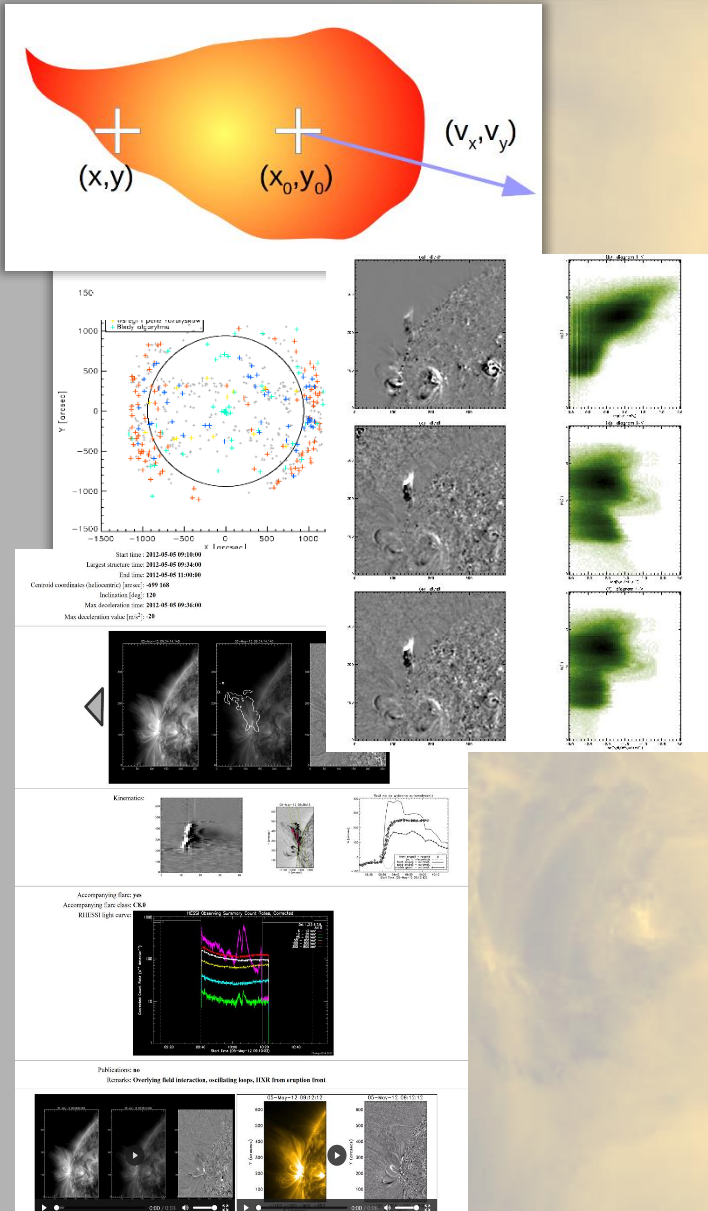
Accompanying flare: **yes**
Accompanying flare class: **C8.0**
RHESSI light curve:



Publications: **no**
Remarks: **Overlying field interaction, oscillating loops, HXR from eruption front**



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 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: 2500/year, failed eruptions: 200/year)

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