Sunspot dynamics prior to flares

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SOLAR AND STELLAR FLARES

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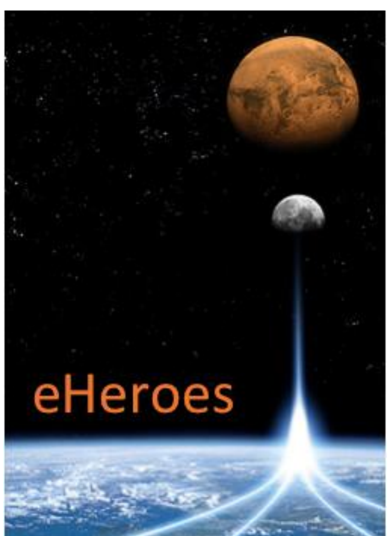


SEVENTH FRAMEWORK PROGRAMME

KONKOLY

Flare forecast strategies - morphological properties

- Inversion line of high magnetic gradient (Schrijver, 2007)
- GWILL (Gradient-Weighted Inversion Line Length (Mason and Hoeksema, 2010)
- Maximum horizontal gradient and the length of neutral line (Cui et al., 2006)
- Length of strong-shear main neutral line, net electric current arching from one polarity to the other, flux-normalized measure of the field twist.
  (Falconer et al., 2002)
- Total magnetic energy dissipated in a unit layer per unit time (Jing et al., 2006); Shear (Cui et al., 2007)
- Effective connected magnetic field (Georgoulis and Rust, 2007)
- Weighted (integrated) lengths of strong-shear and strong-gradient lines

  (Falconer et al. 2008)
- Spot areas, magnetic fluxes and average magnetic field (Wang and Zhang, 2008)
- The total unsigned magnetic flux and the total magnetic dissipation

  (Song et al., 2009)
- Number of singular points (Huang et al., 2010; Yu et al., 2010a)

Flare forecast strategies - helicity

- Specific peak helicity flux (LaBonte et al. 2007)
- Helicity injection (Wang, 2007)

Small-scale structures, fractal analysis:

- Characteristic variations shortly prior to flares (Abramenko et al., 2003; Georgoulis, 2005)
- Correlation between the generalized fractal dimension and the flare index (Criscuoli et al., 2009)
- Sceptic - the fractality and turbulence properties do not distinguish flare-active and flare-quiet active regions. (Georgoulis, 2012)

Flare forecast strategies - dynamic precursors

- A quantity for the description of the magnetic field dynamics: $\mathbf{E} = \mathbf{u} \times \mathbf{B}$, Liu et al.(2008)
- Increase of the vertical field strength and current density and an about ~8° approaching of the magnetic flux towards the vertical. Murray et al. (2012)

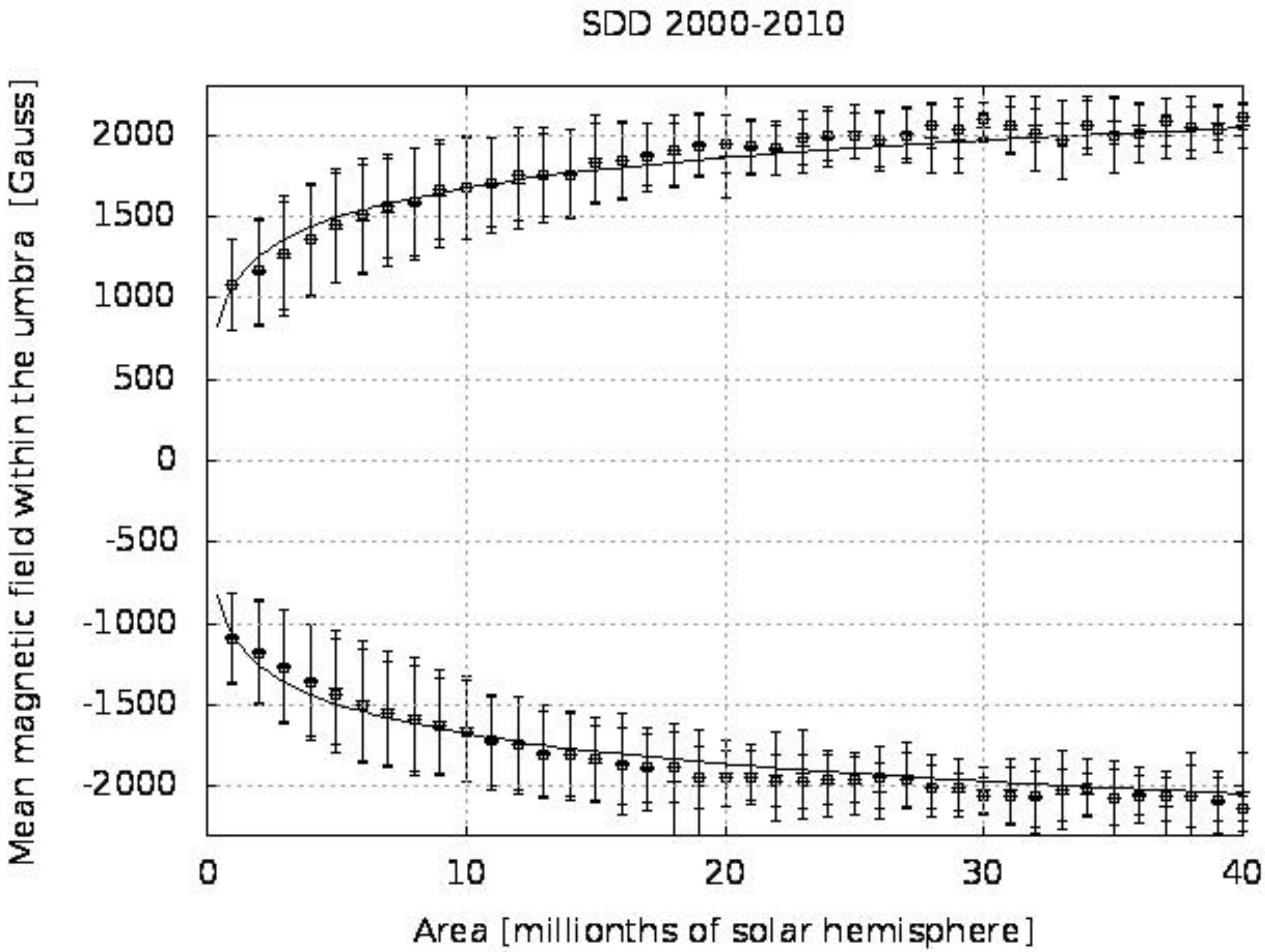
The majority of the listed methods use magnetograms.

Present method:

Tracking the dynamics of sunspots
input data: SDD

SDD-(SOHO/MDI - Debrecen Data)

Area – magnetic field relationship in sunspots at the solar disc center (within |10º|)



The fitted curve:

$$B_{mean} \equiv f(A) = K_1 \cdot ln(A) + K_2$$

where: $|K_1| = 265$ gauss

$|K_2| = 1067$ gauss

Korsos,Baranyi,Ludmany, 2014 ApJ, 789, 107

We define a **proxy quantity for the horizontal gradient** of the magnetic field between two sunspots of opposite polarities having corrected areas A_1 and A_2 at a distance d from each other:

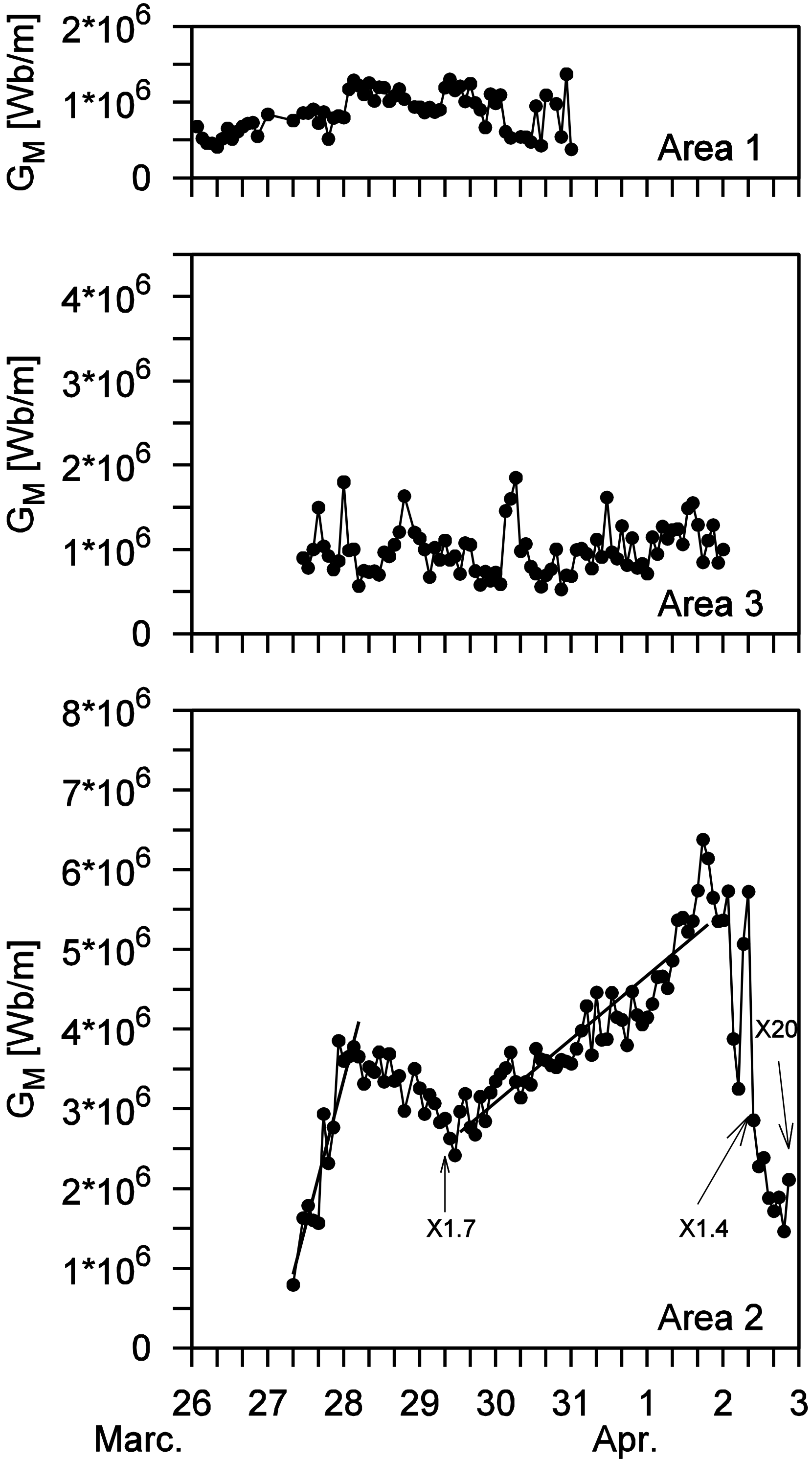
flux amount

$$G_M = \left| \frac{\overbrace{f(A_1) \cdot A_1}^{\text{}} - f(A_2) \cdot A_2}{d} \right|$$

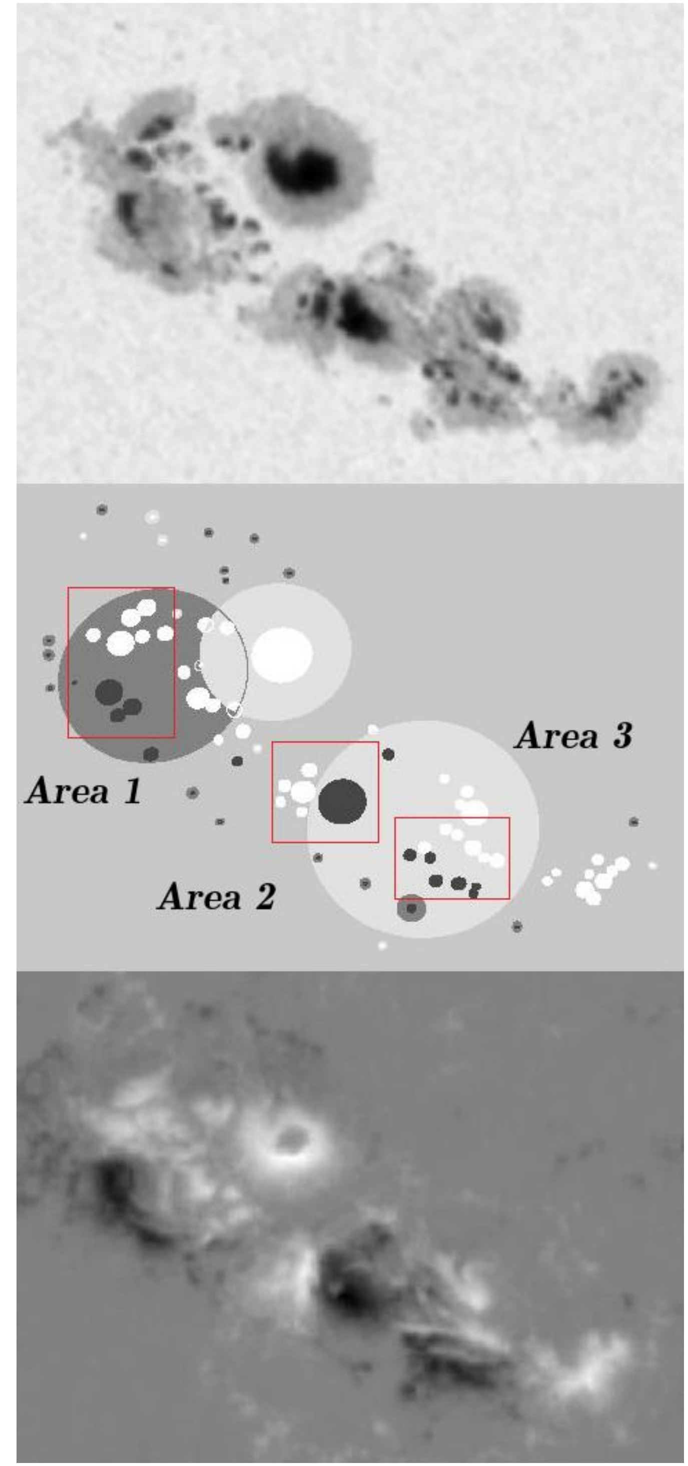
$$B_{mean} \equiv f(A) = K_1 \cdot ln(A) + K_2$$

We follow the variation of G_M in the area of highest magnetic gradient.

Korsos,Baranyi,Ludmany, 2014 ApJ, 789, 107



NOAA 9393



Korsos,Baranyi,Ludmany, 2014 ApJ, 789, 107

After the case studies, statistics

Features of interest:

- Steep rise of G_M

- High maximum of G_M

- Decrease of the G_M until the flare with strong fluctuation

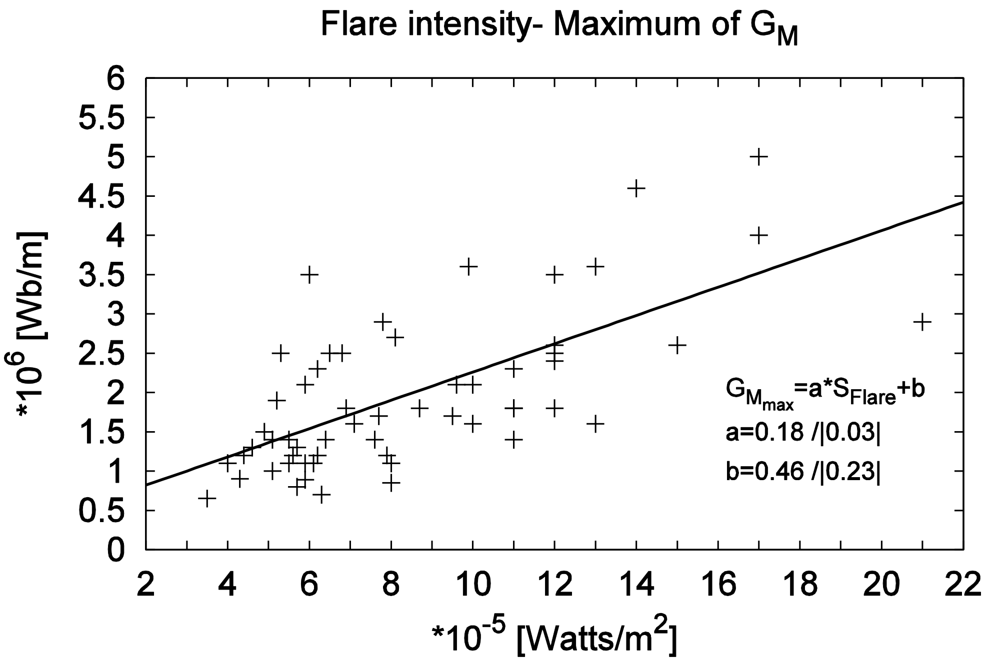
- Variation of G_M consists of the variation of d and flux

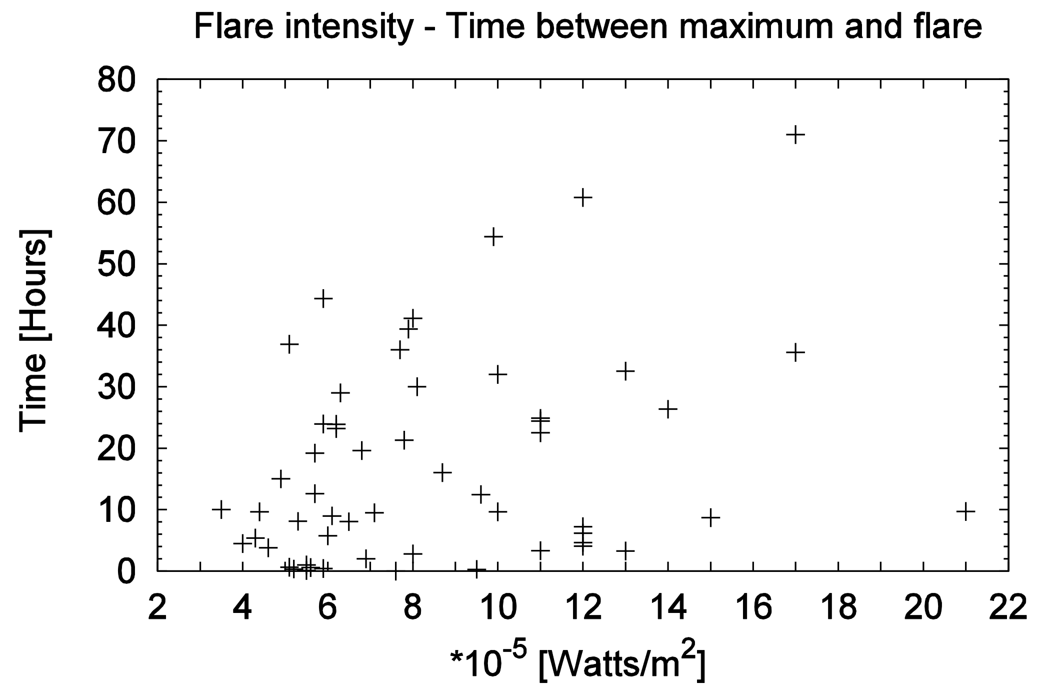
What is the predicting value of the G_M variation? Time? Intensity?

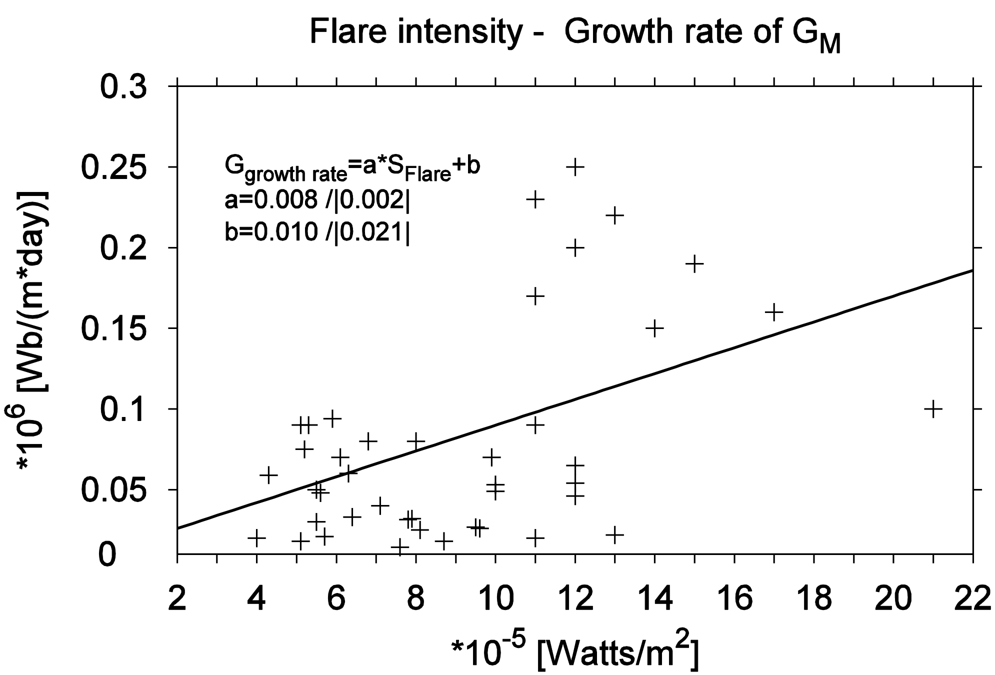
Statistics of 53 cases (one X-flare in each, within ±60º CMD)

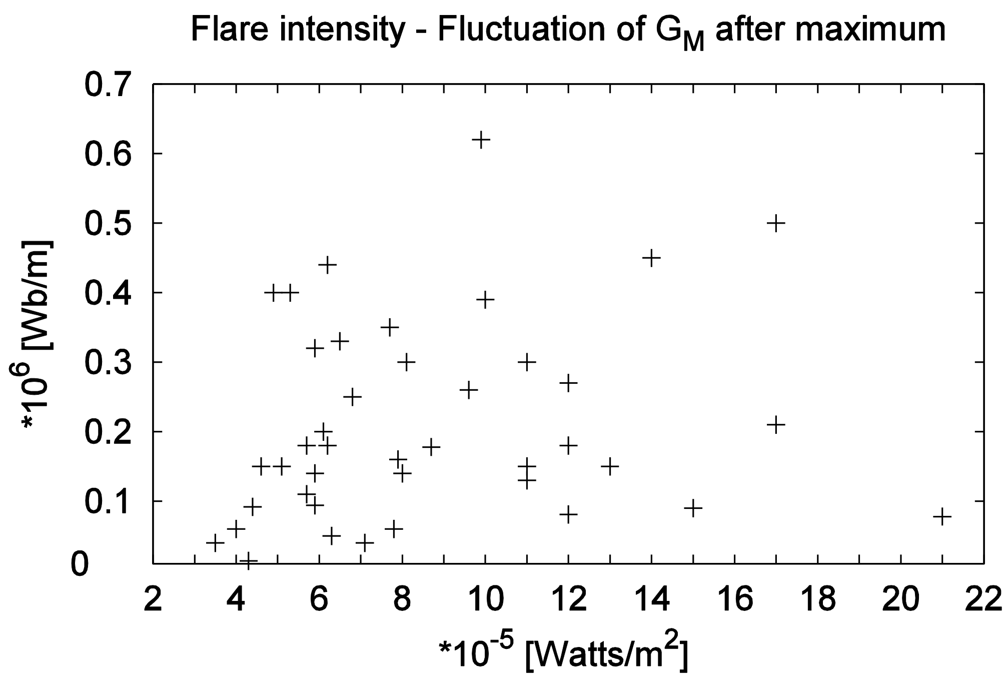
Korsos,Baranyi,Ludmany, 2014 ApJ, 789, 107

Relationships between the behavior of G_M and flare intensity – 53 cases









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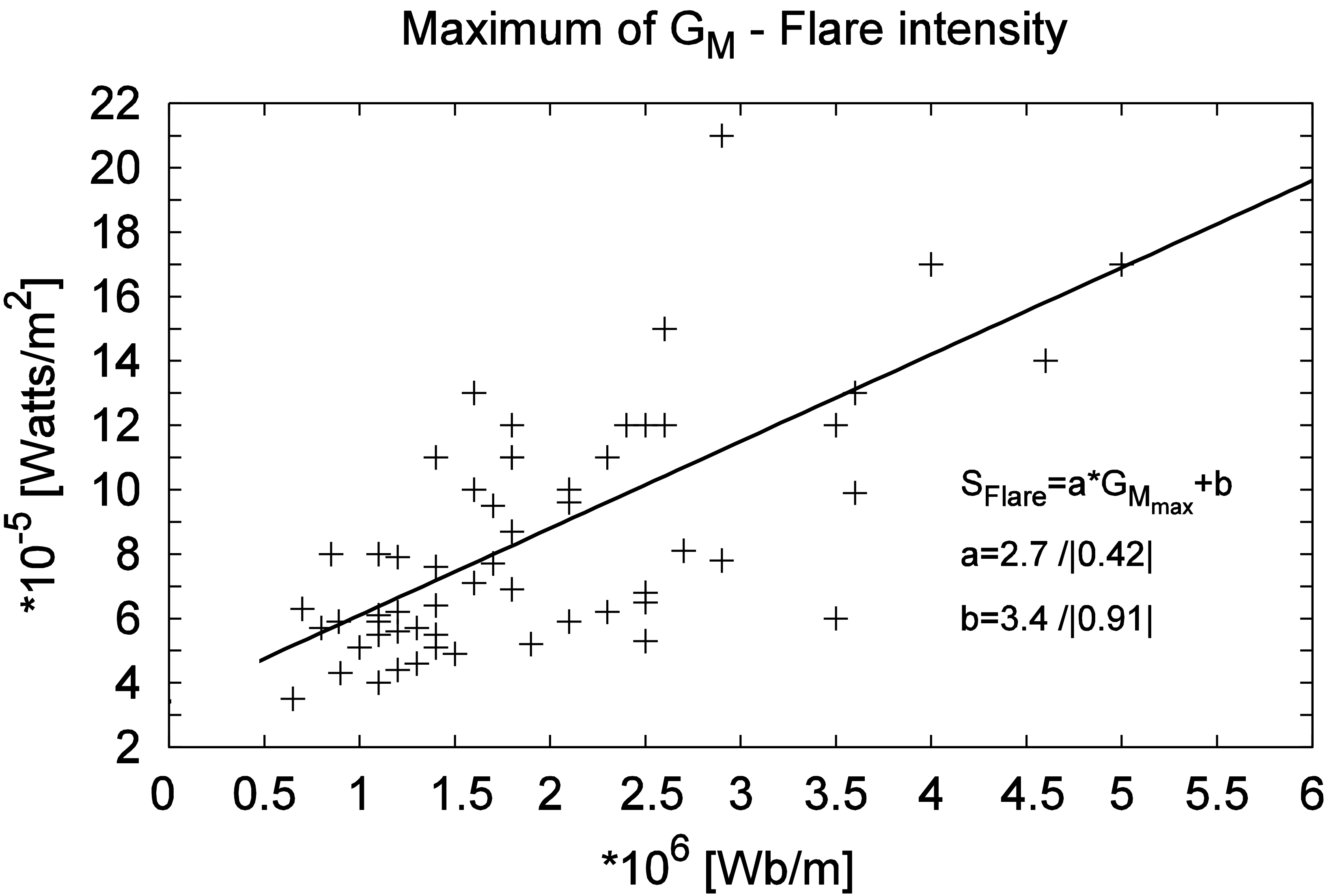
Inverse relationships to predict the flare intensity

The flare intensity can be estimated from the maximum of G_M.

Relationship between the proxies of the free energy and the released energy.



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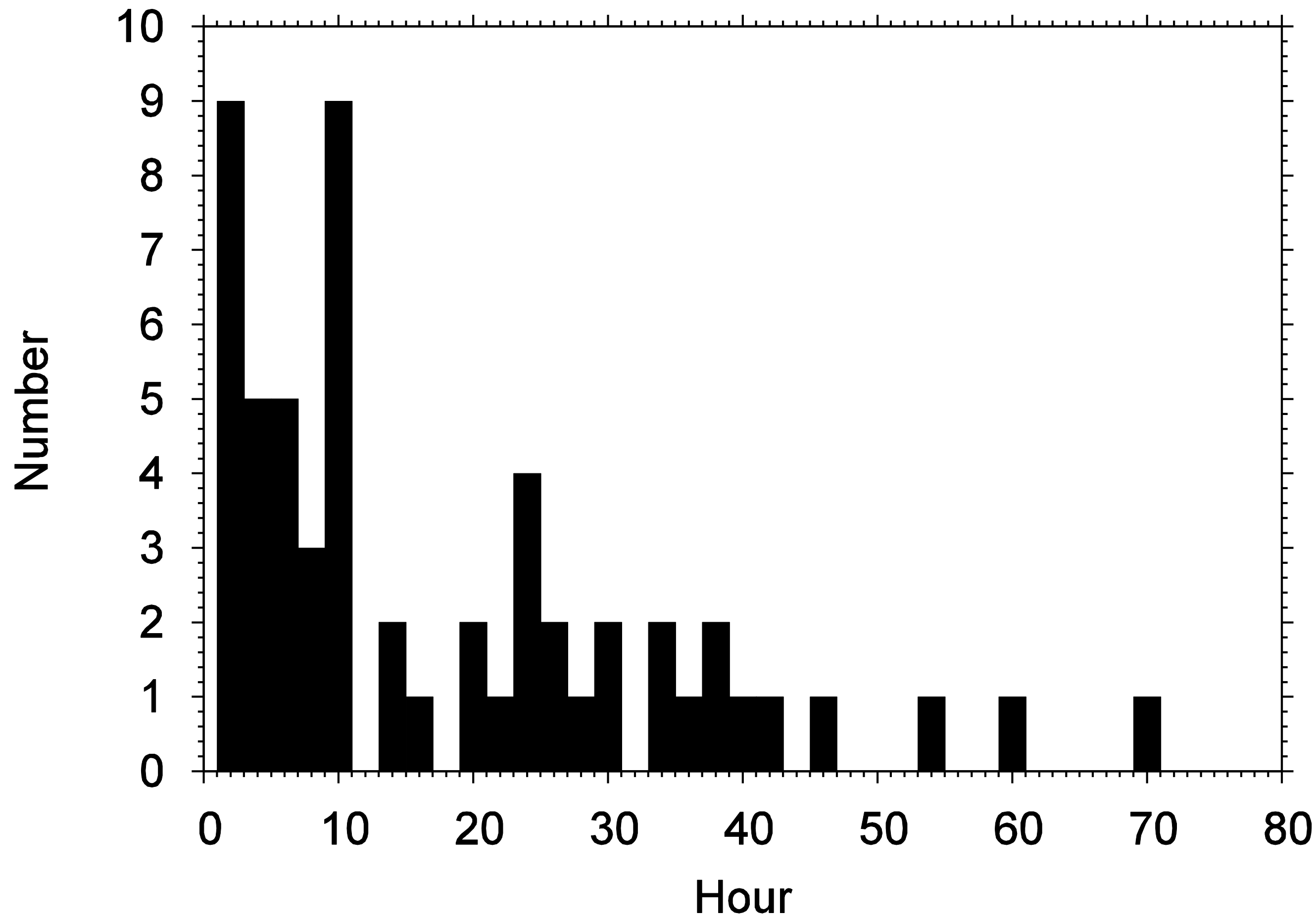
Time differences between the maxima of G_M and flare onsets in the 53 cases studied



Most probable time: 10 hours after the G_M maximum

Korsos,Baranyi,Ludmany, 2014 ApJ, 789, 107

Up to now:

G_M between pairs of spots was considered

Next step:

Nearby groups of spots of opposite polarities in the domain of the highest gradient.

Generalized selection criteria of the considered spots

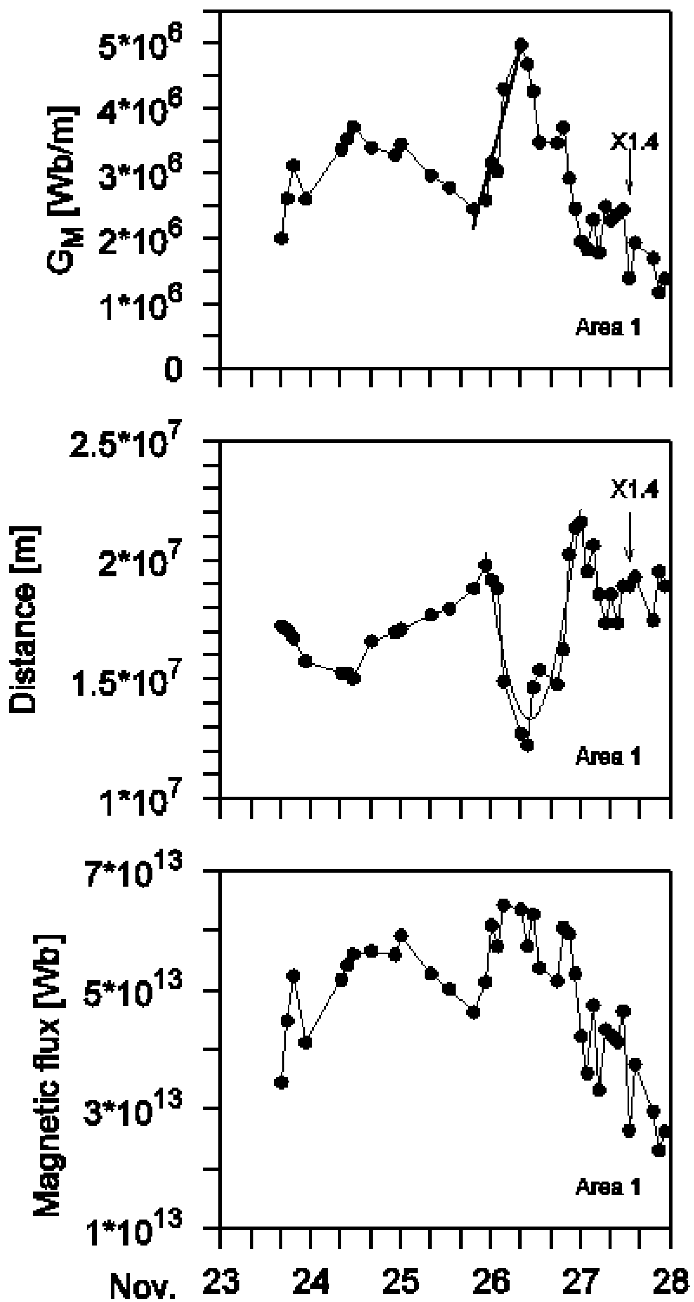
- A new spot (*min. 2 MSH*) emerges close (*within 45 Mm*) to an existing spot of opposite polarity in the region of strongest magnetic gradient. This area will be traced.

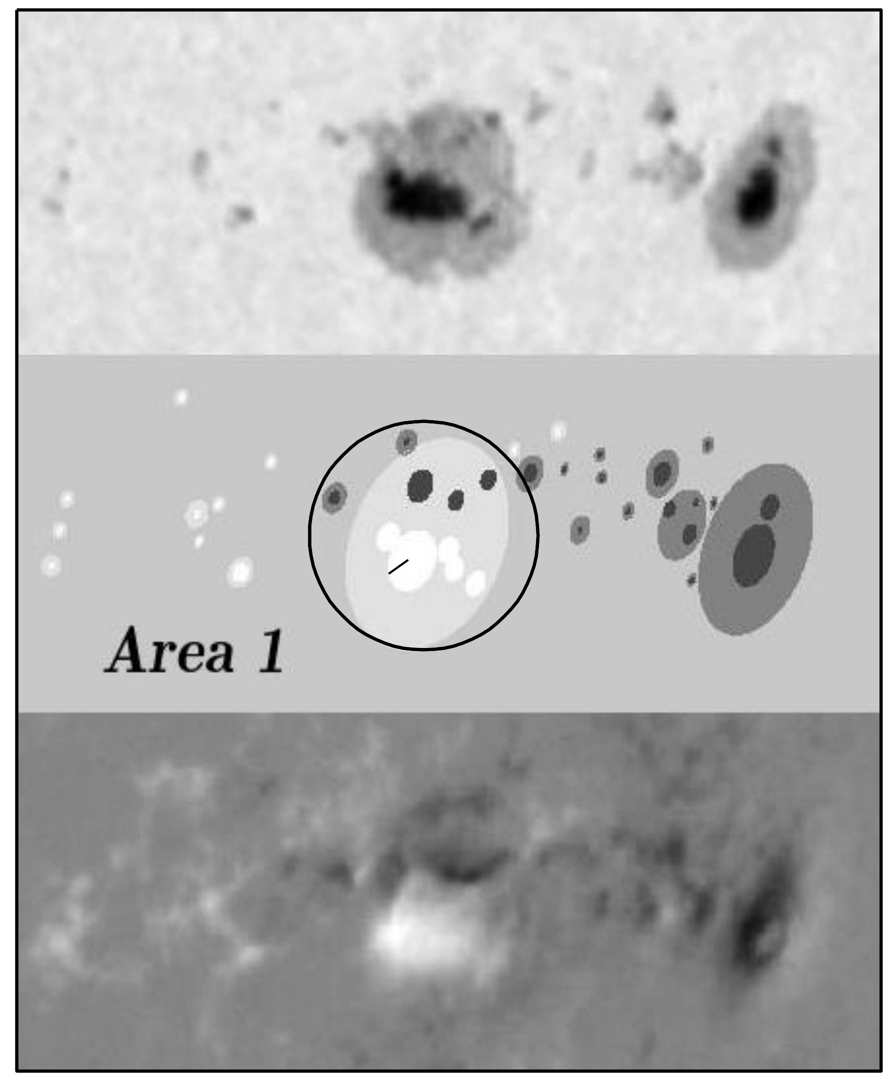
- The center of this studied area is fixed!

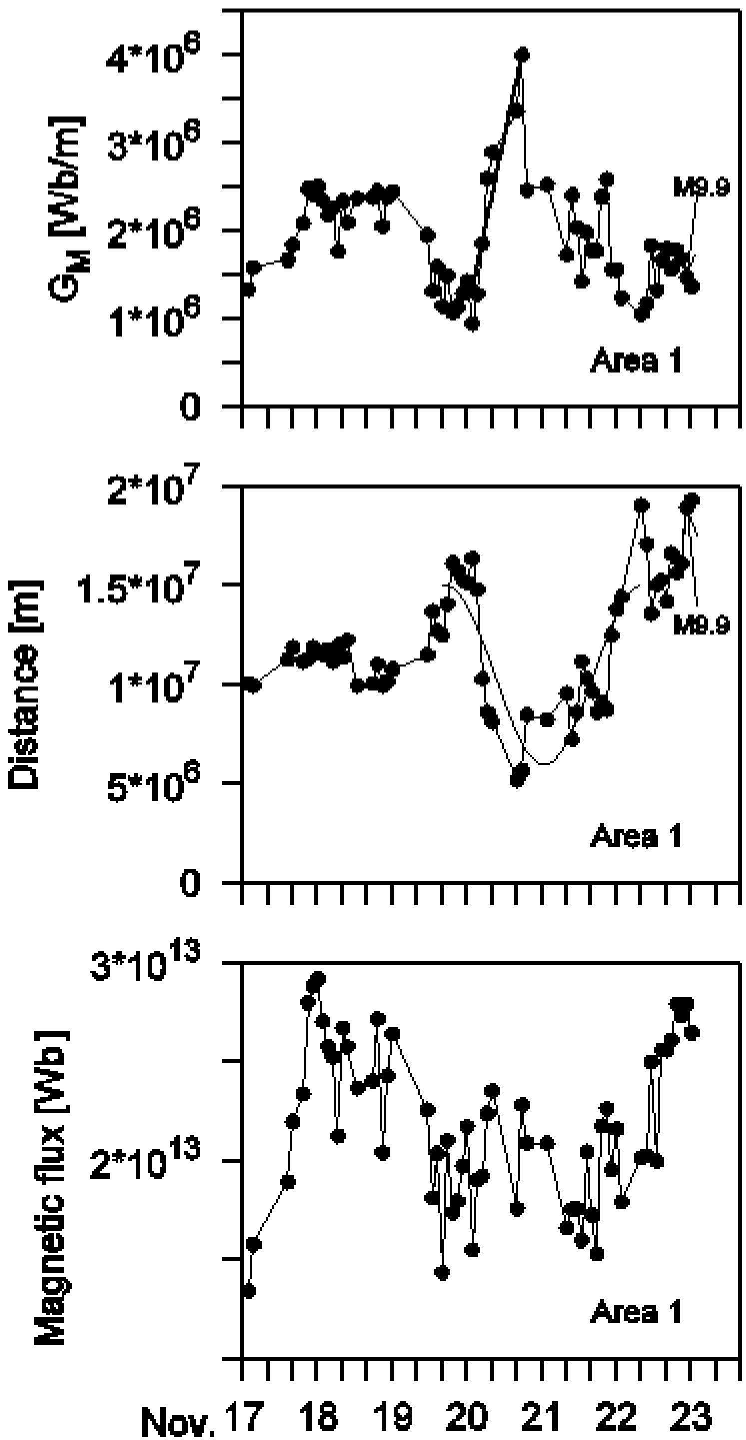
- The radius of the area under study is five times larger than the radius of the larger umbra at the first time. Afterwards, all spots are taken into account within this region and the $\boldsymbol{G_M}$ is computed from their summarized data.

NOAA 8771

Spot groups of opposite polarities

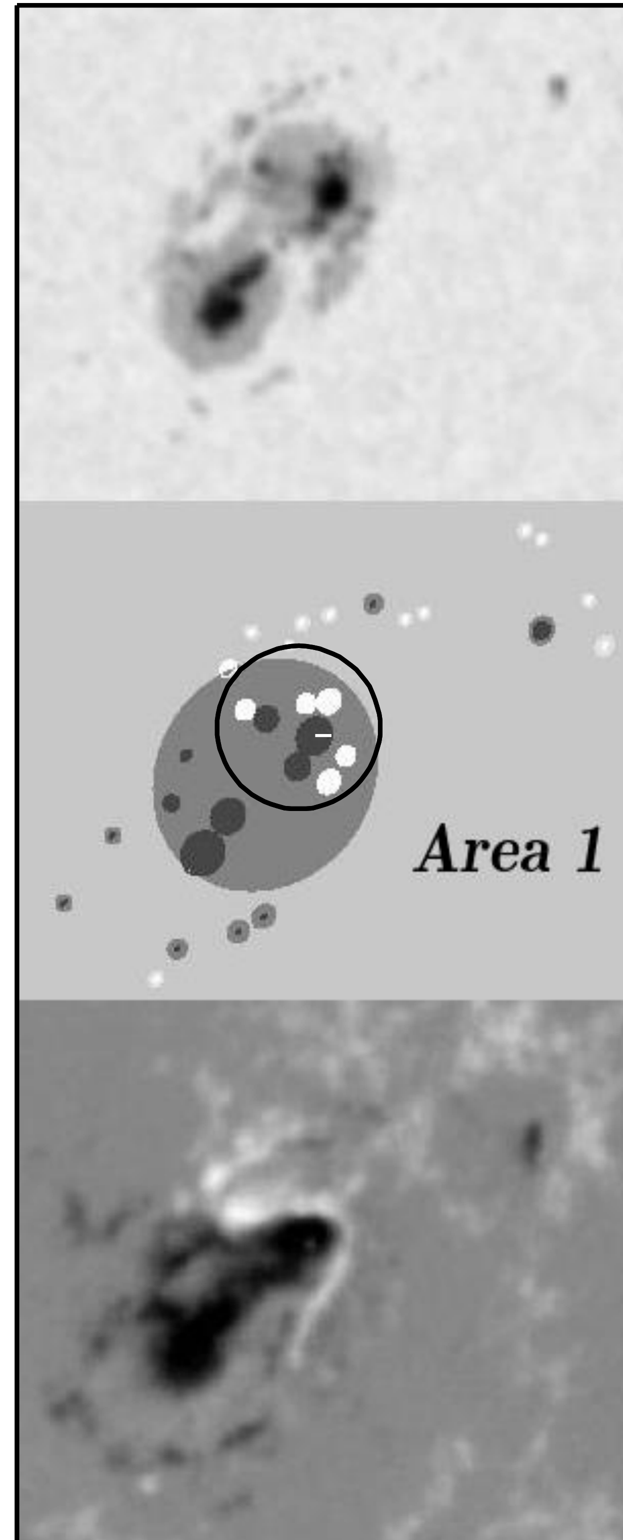






NOAA 9704

Spot groups of opposite polarities



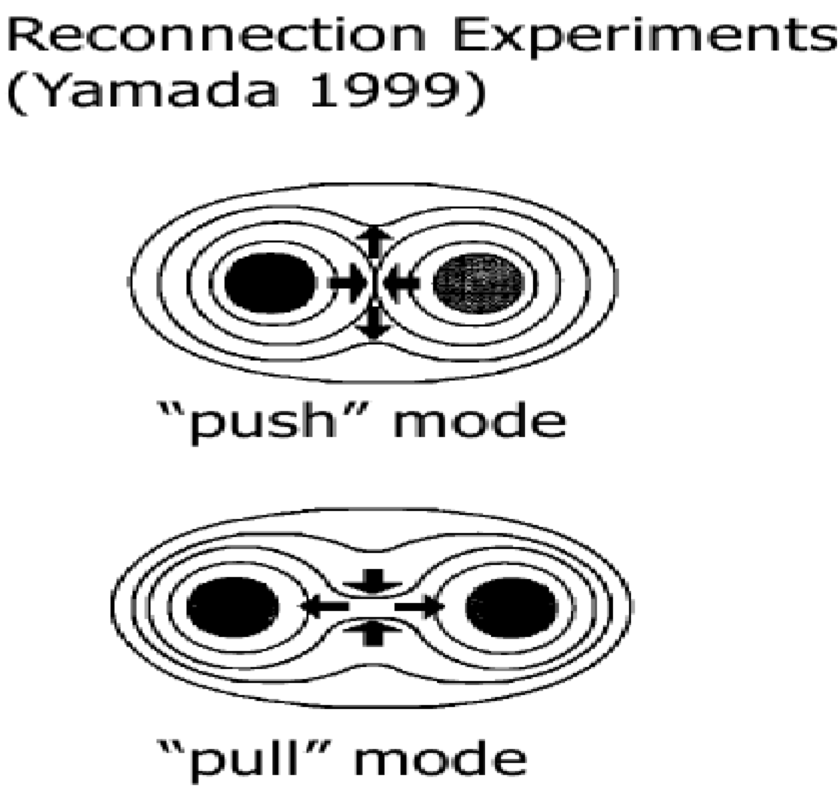
An unexpected phenomenon, two phases prior to the flare onset:

At first approaching <u>and then receding</u> fluxes of opposite polarities prior to flares

Two similar results:

"... flare reconnection on a vertical current sheet is caused by the diverging flows that remove magnetic flux and plasma from the reconnection site. "
A theoretical result of Kusano et al. (2012, ApJ, 760, 31)

Pull-mode of reconnection identified in laboratory experiments. Yamada (1999)



Variation of the distance between the subgroups of opposite polarity

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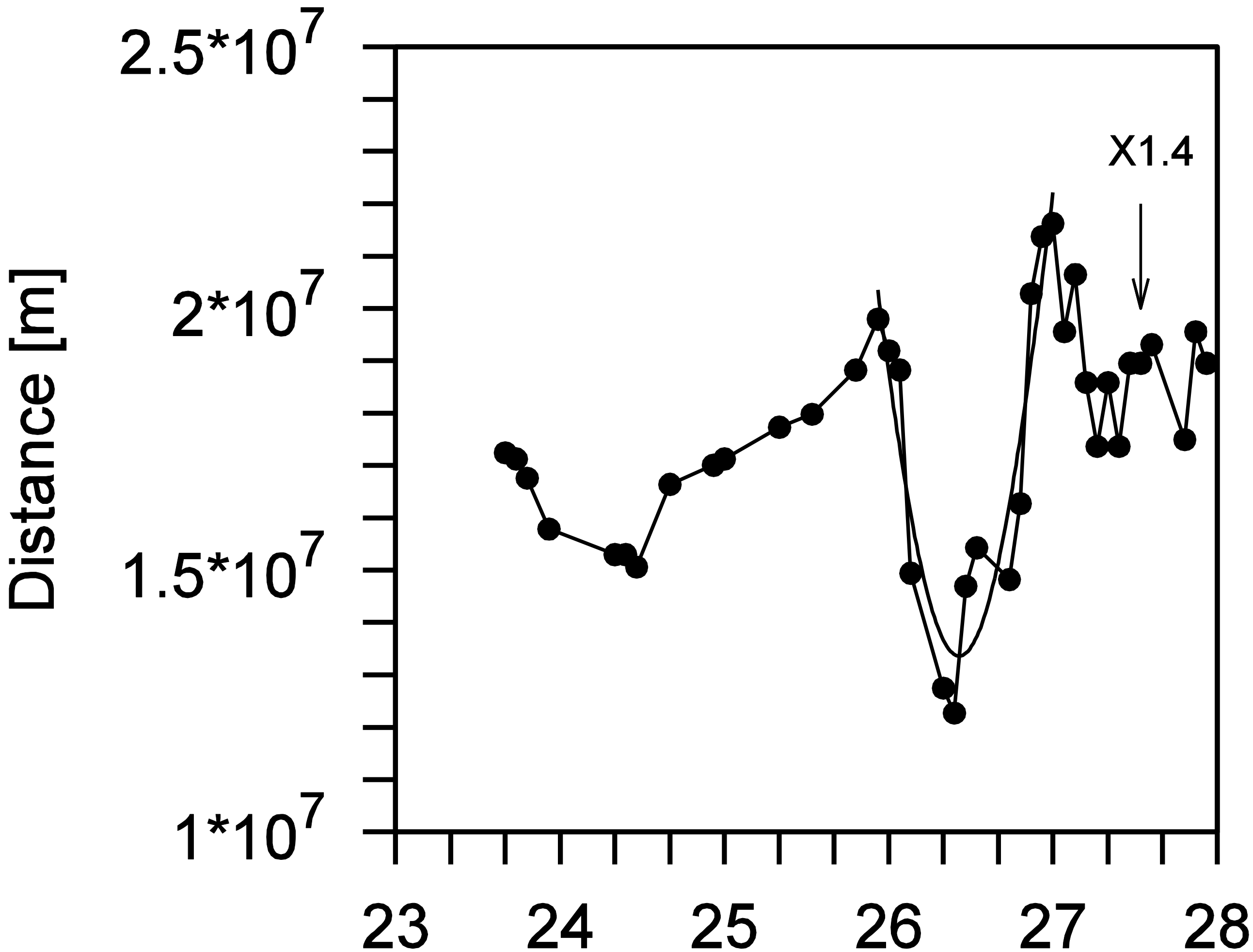
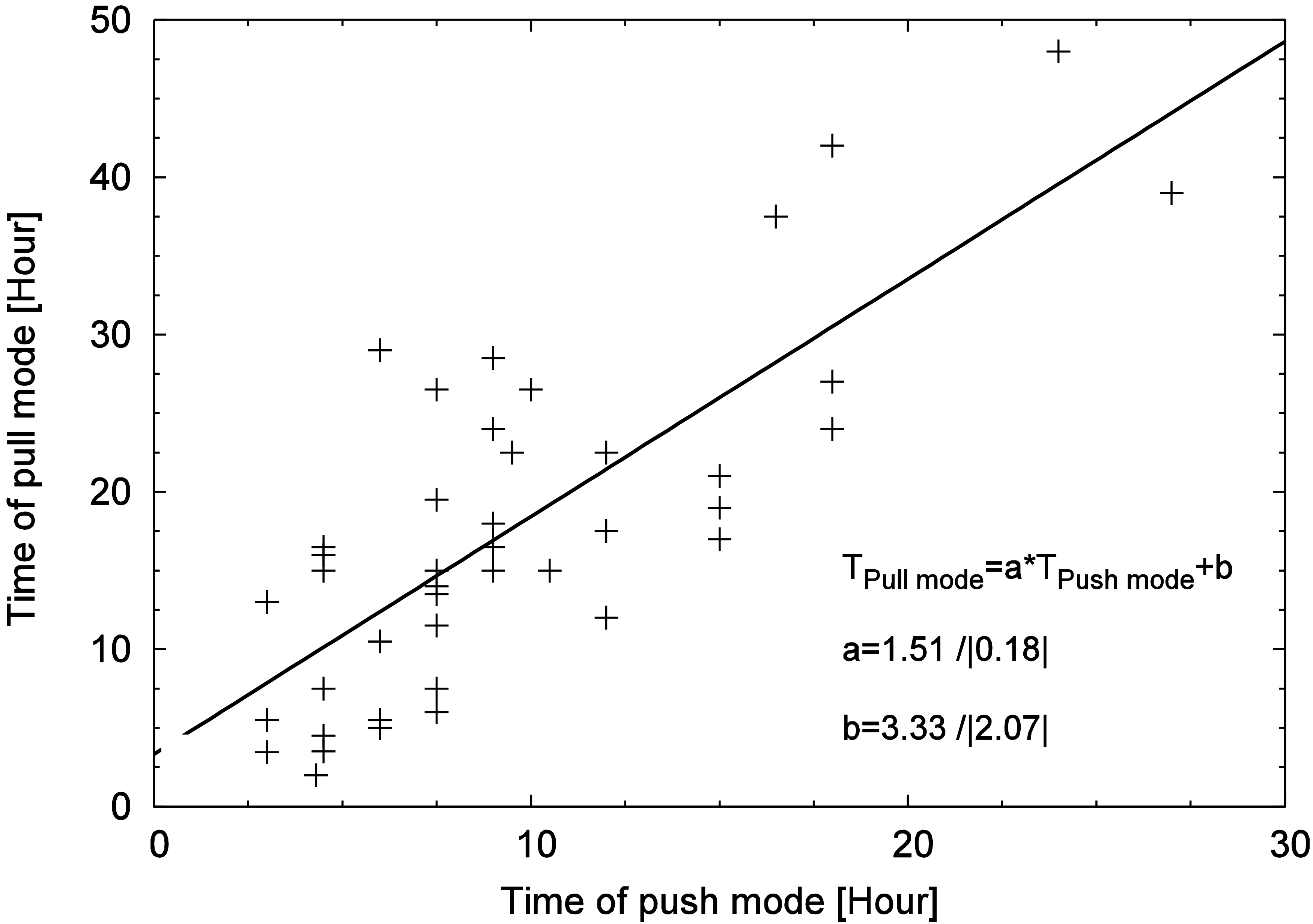
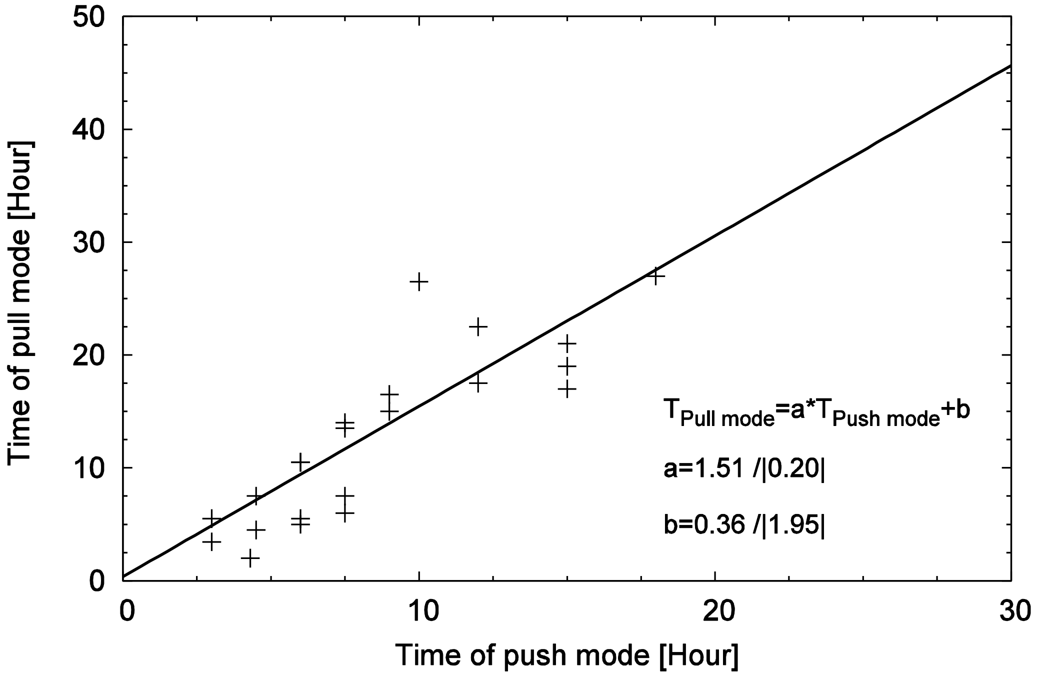


After an approaching motion the subgroups recede until the flare

Relationship between the time of approaching and the time from the closest position until the flare onset

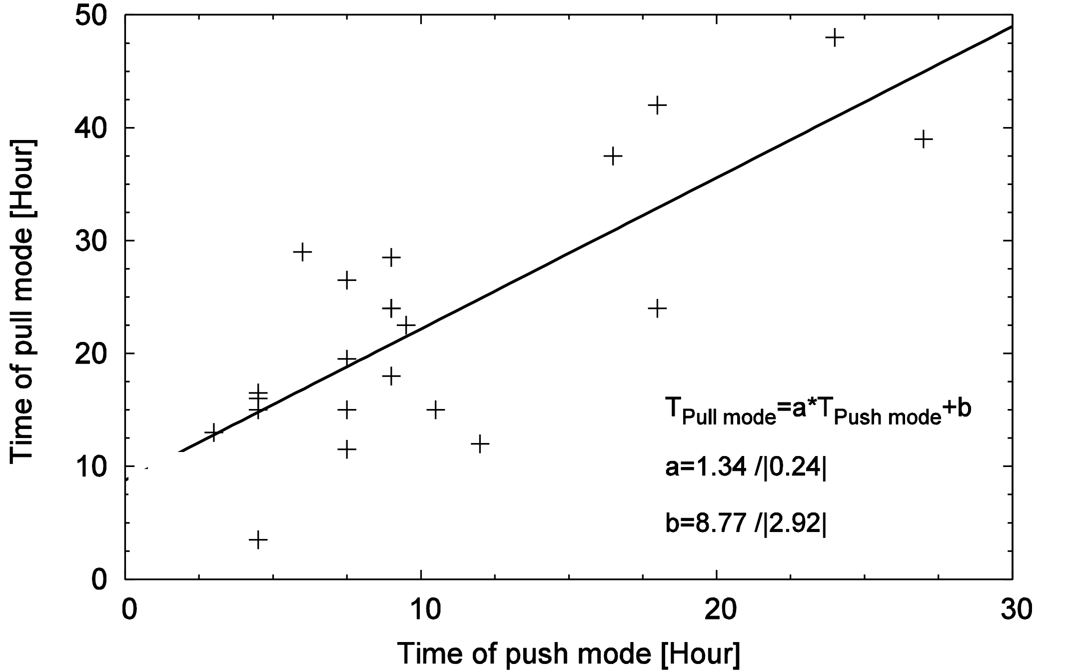


Relationship between the time of approaching and the time from the closest position until the flare onset for spots…….

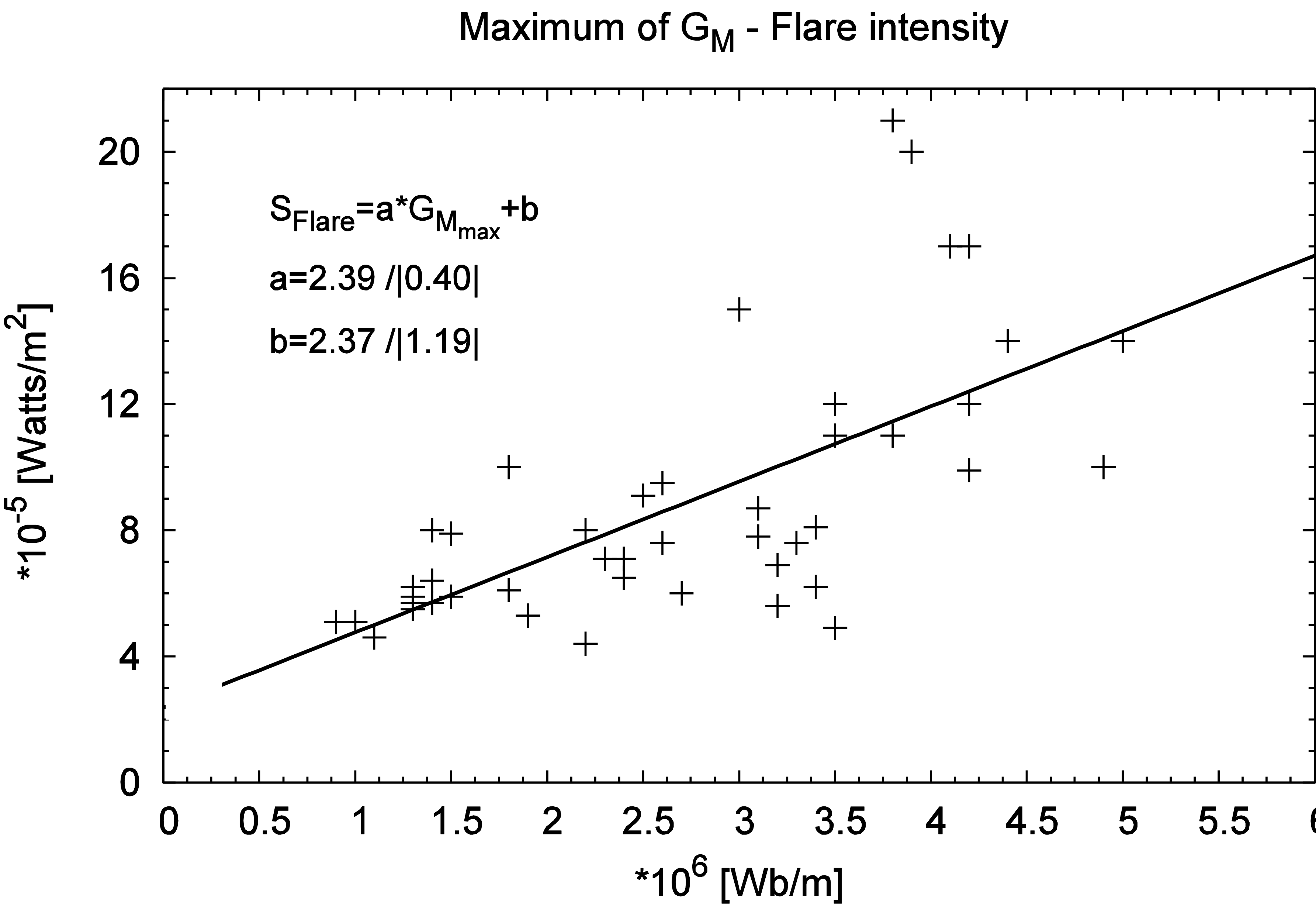


….younger than 3 days

….older than 3 days.

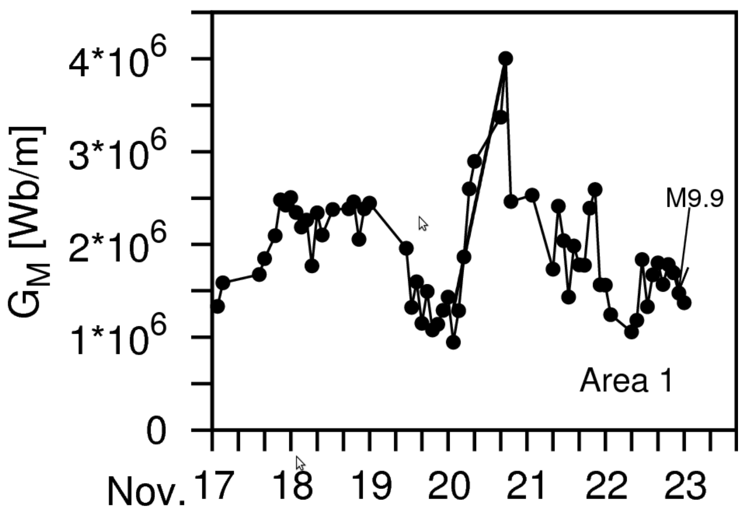


Relationship between the strength of the flare (the peak of soft X-ray flash) and the previous maximum of G_M determined by using subgroups of spots.

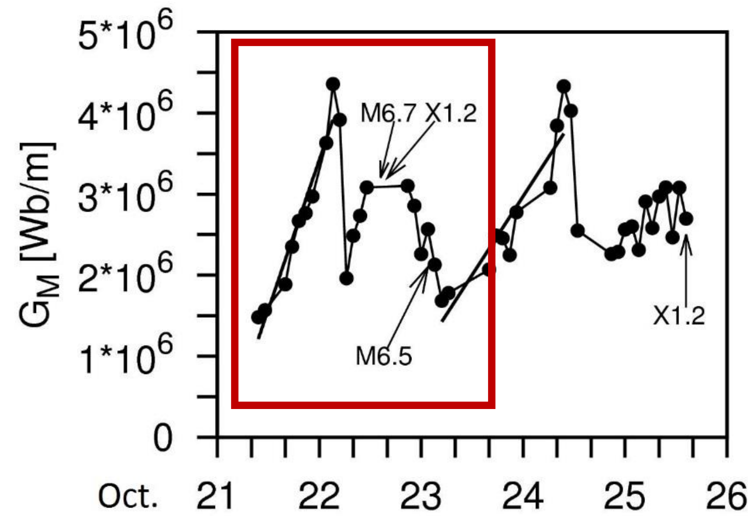


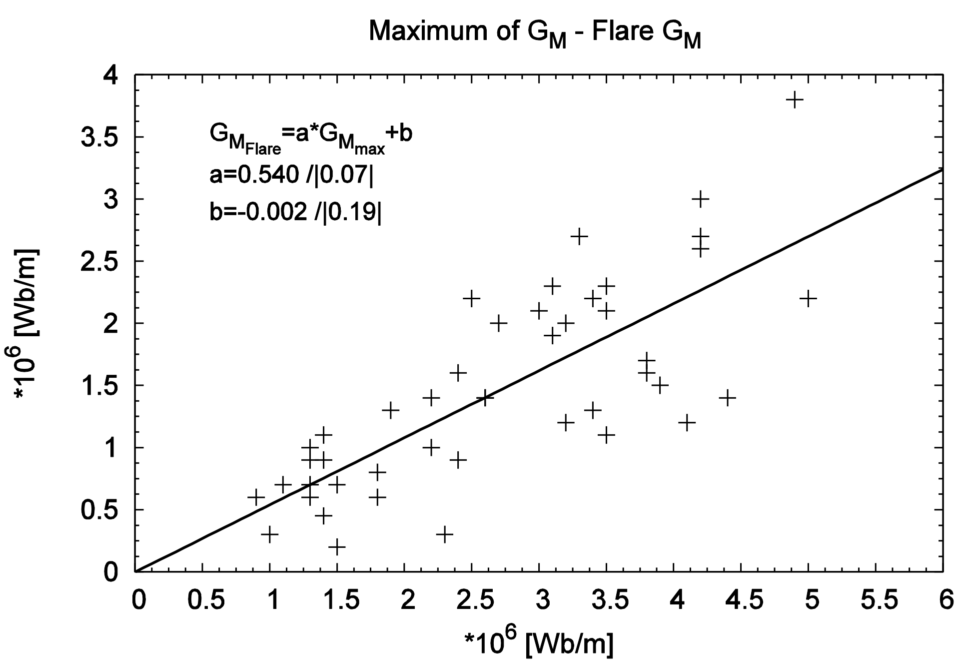
Relationship between the previous maximum of G_M determined and the value of G_M at the flare onset by using subgroups of spots.

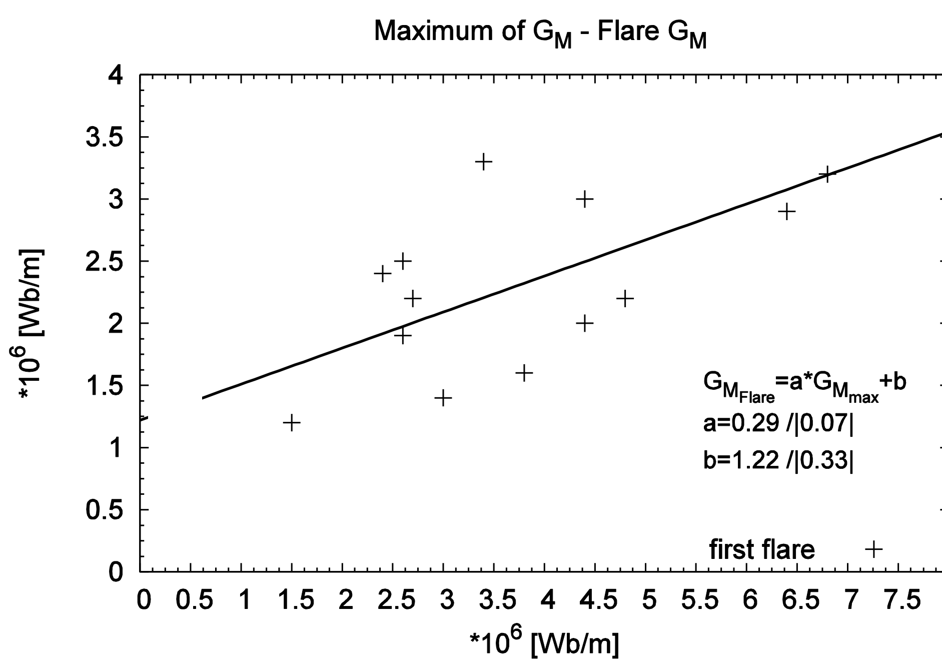
NOAA 8771



NOAA 9672







Conclusions

Tracking of the following quantities may be promising for flare forecast:

- Horizontal gradient of magnetic field (G_M) between spots,
- Steep increase of G_M → for warning,
- High maximum of G_M → for the assessment of flare intensity,
- Decrease of G_M after maximum → for warning,
- Time of Push mode vs. Time of Pull mode → Time,
- Maximum of G_M *vs.* the value of G_M where the flare happens.

Limitations of the method:

- It is only suitable for energetic flares above M5.

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Thank you for your attention!