TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

SOLAR PHYSICS UTOV

Solar flare forecasting algorithms: R and D values for SDO/HMI LoS magnetograms

Berrilli F., Cicogna D., Jefferies S., Murphy N., Del Moro D., Giovannelli L., Calchetti Daniele

https://www.fisica.uniroma2.it/~solare/en

We present two main topics:

1. the update of **Schrijver's R Algorithm** in order to use full resolution HMI/SDO LoS magnetograms, create a flaring/non-flaring catalogue preserving original Schrijver's statistics (from MDI/SOHO Cycle 23 to HMI/SDO Cycle 24), and calibrate R for HMI/SDO Cycle 24;

2. a new topological parameter (**D value**) based and tested on HMI/SDO LoS magnetograms.

Active Regions Describers

1. *R value*: proxy for the presence of electrical currents in the AR polarity separation line

2. *Area*: dimension of the AR

3. *U-Flux*: value of the unsigned magnetic flux in the AR

4. *Perimeter Area Relation*: complexity of the perimeter of the AR

5. *Many others*: Fragmentation index, number of fragments that make up the AR; Dist N, distance between magnetic field peak points

6. *D value*: topological proxy of the AR based on the number of PILs.

HMI/SDO line-of-sight (LoS) magnetograms into two different sets

SET A

FLARING ACTIVE REGIONS

i) 98 magnetograms
ii) 24 hours before the peak flare time
iii) Only flares with peak magnitude $\geq 10^{-5}$ W m^{-2}
iv) No multiple flares
v) One magnetogram for each AR
vi) Flares occurred in AR within 45 degrees from the center of the solar disk

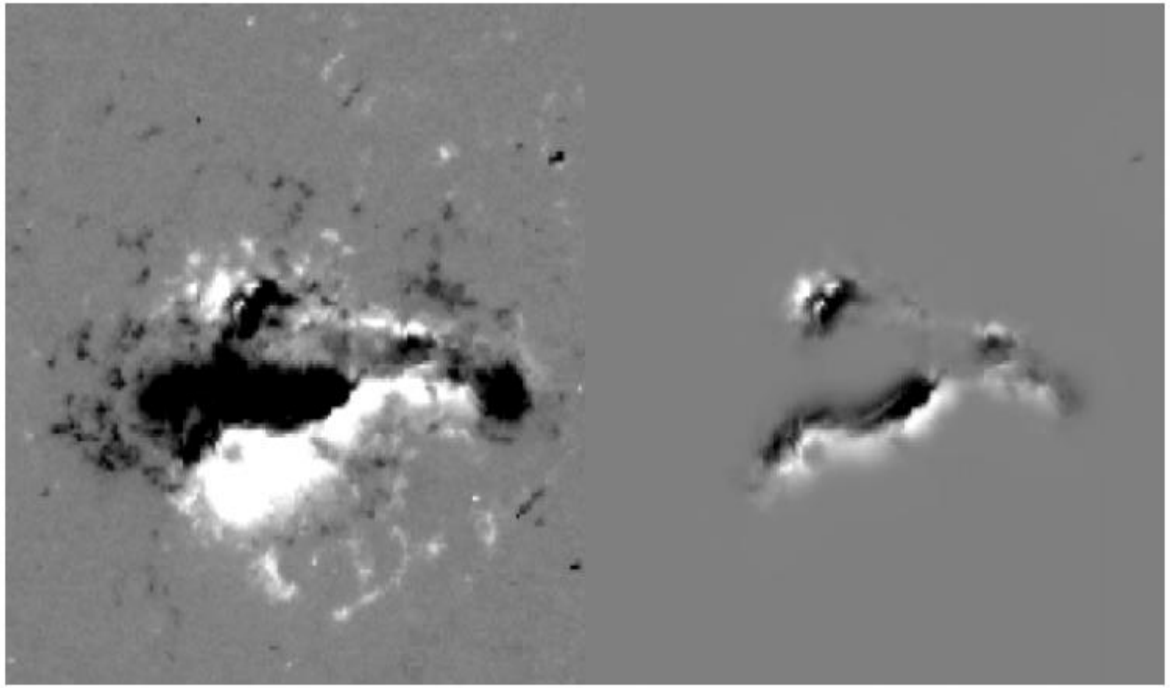
SET B

NON-FLARING ACTIVE REGIONS

i) 732 magnetograms
ii) No M or X-type flares within 24 hours
iii) More magnetograms for the same AR if at least 24 hours between them
iv) The non-flaring AR within 20 degrees from the center of the solar disk.

R value: computation method

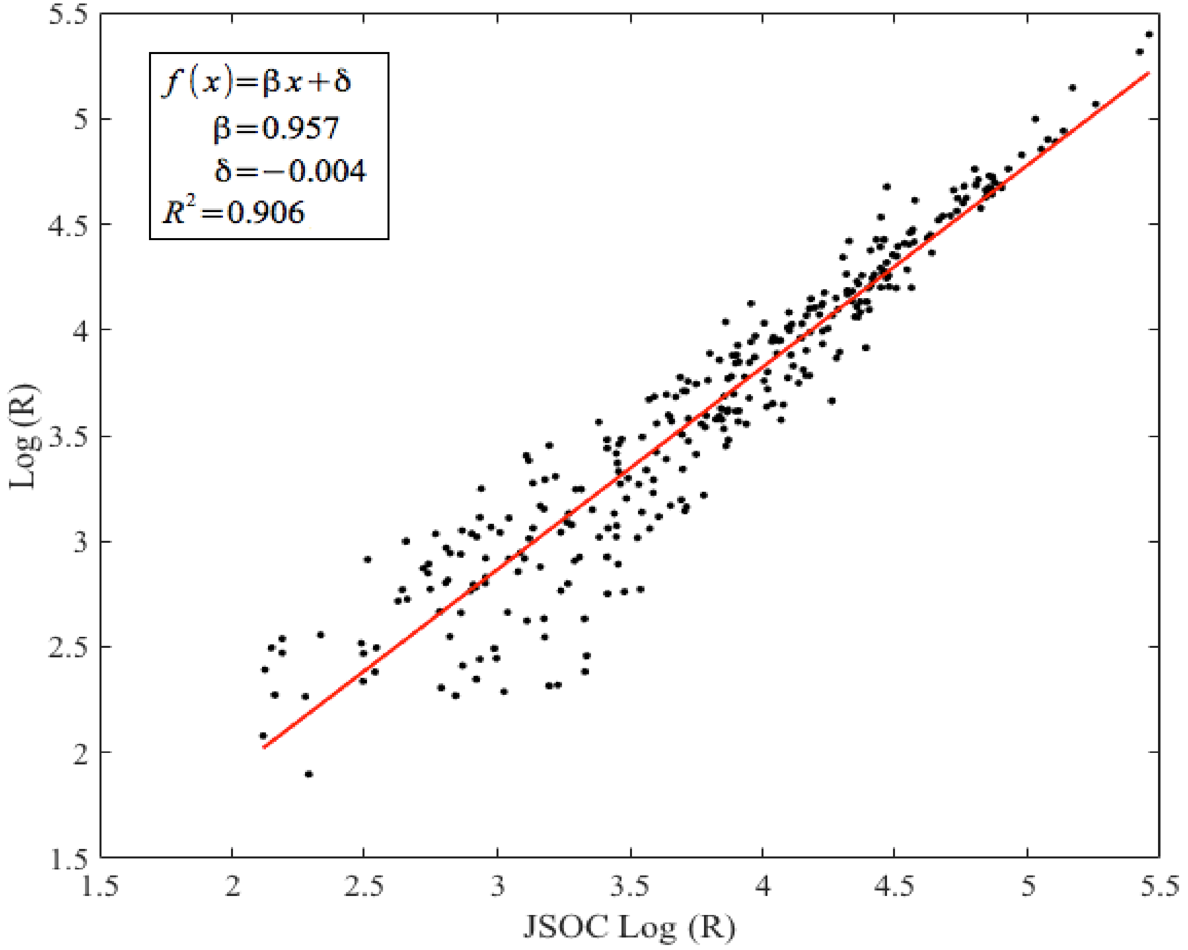
1. Two bitmaps from the original magnetograms
2. The bitmaps are dilated with kernels of 3x3 pixels where a strong field is present
3. The two dilated bitmaps are overlapped
4. This final bitmap is convolved with a Gaussian to obtain a weighed map
5. The map is multiplied by the absolute value of the flux
6. The final value must be multiplied by the area of HMI pixel to obtain the R value in Maxwells
7. For simplicity is take the log of the R value



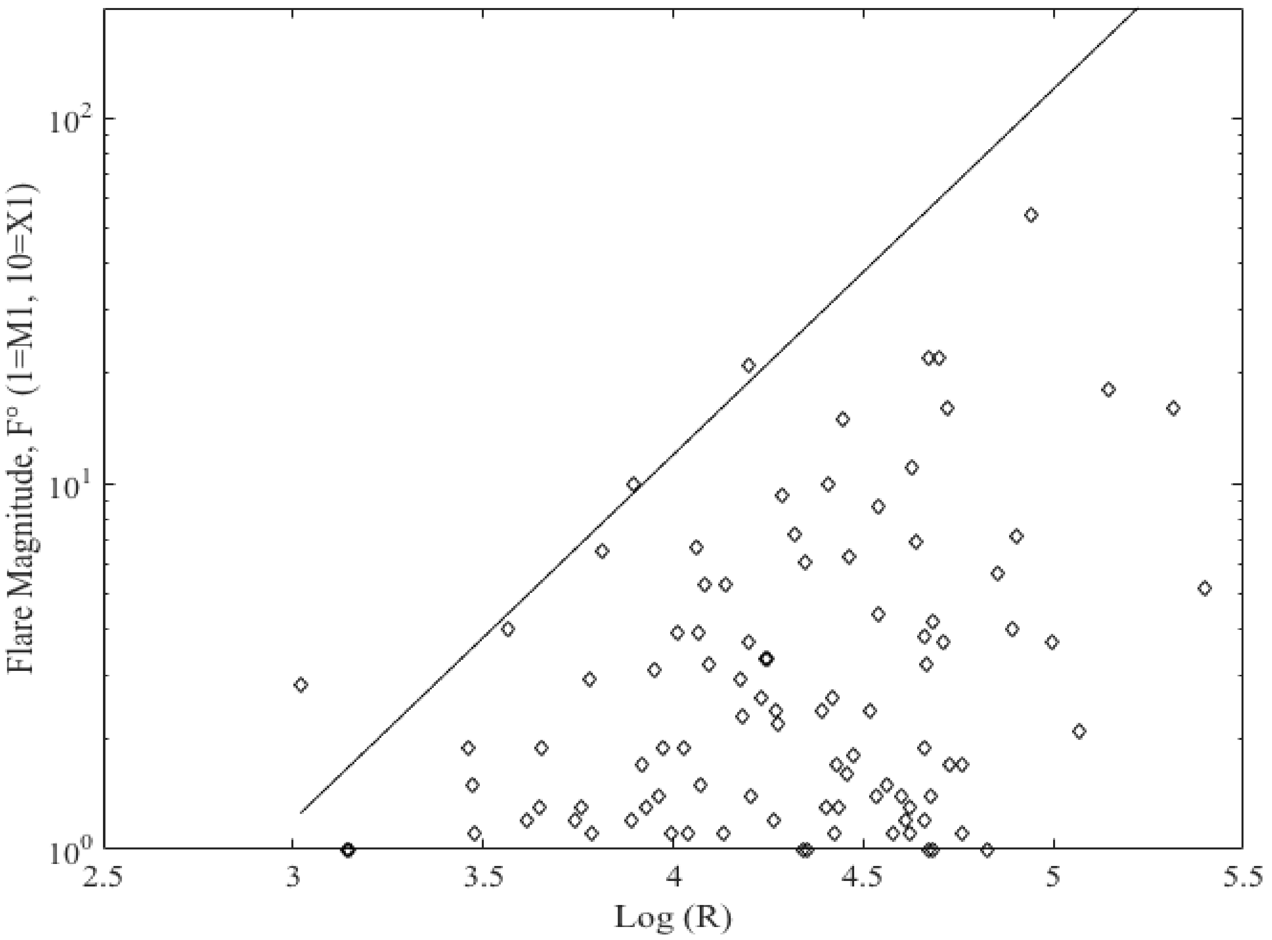
Schrijver, 2007

Currents associated to **elongated Polarity Inversion Lines** (PIL) with strong magnetic fields of opposite polarity immediately adjacent to the line.

Calibration of R value for SDO/HMI LOS magnetograms

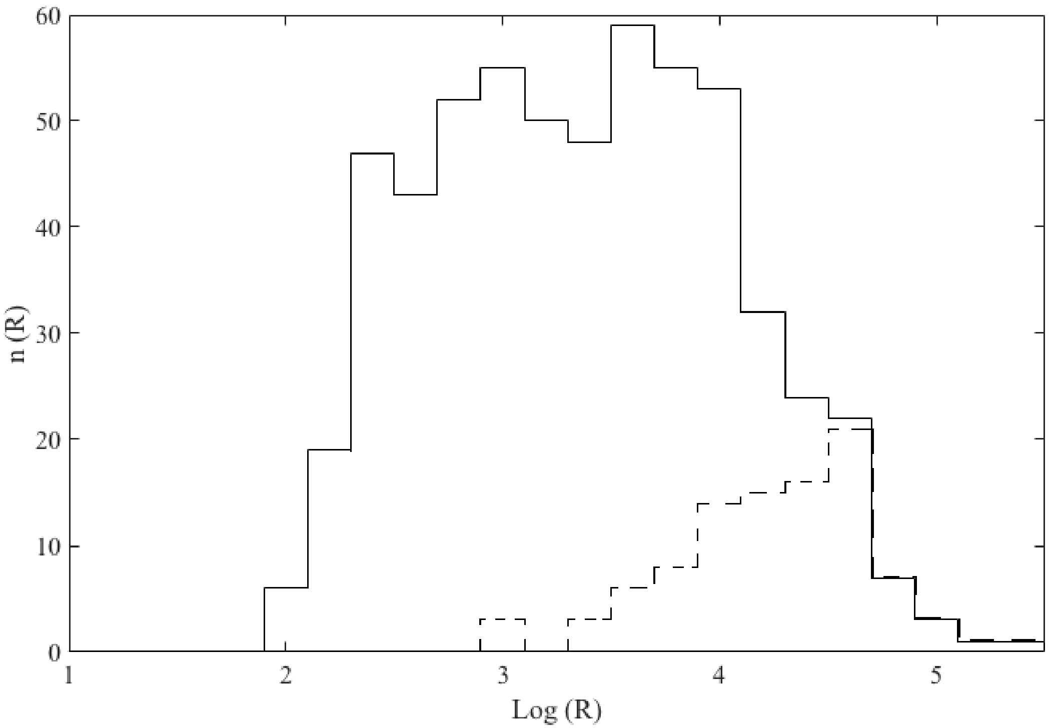


The header of HARPs contains an evaluation of the R value (JSOC-R). We compare JSOC-R value and R derived by our algorithm.

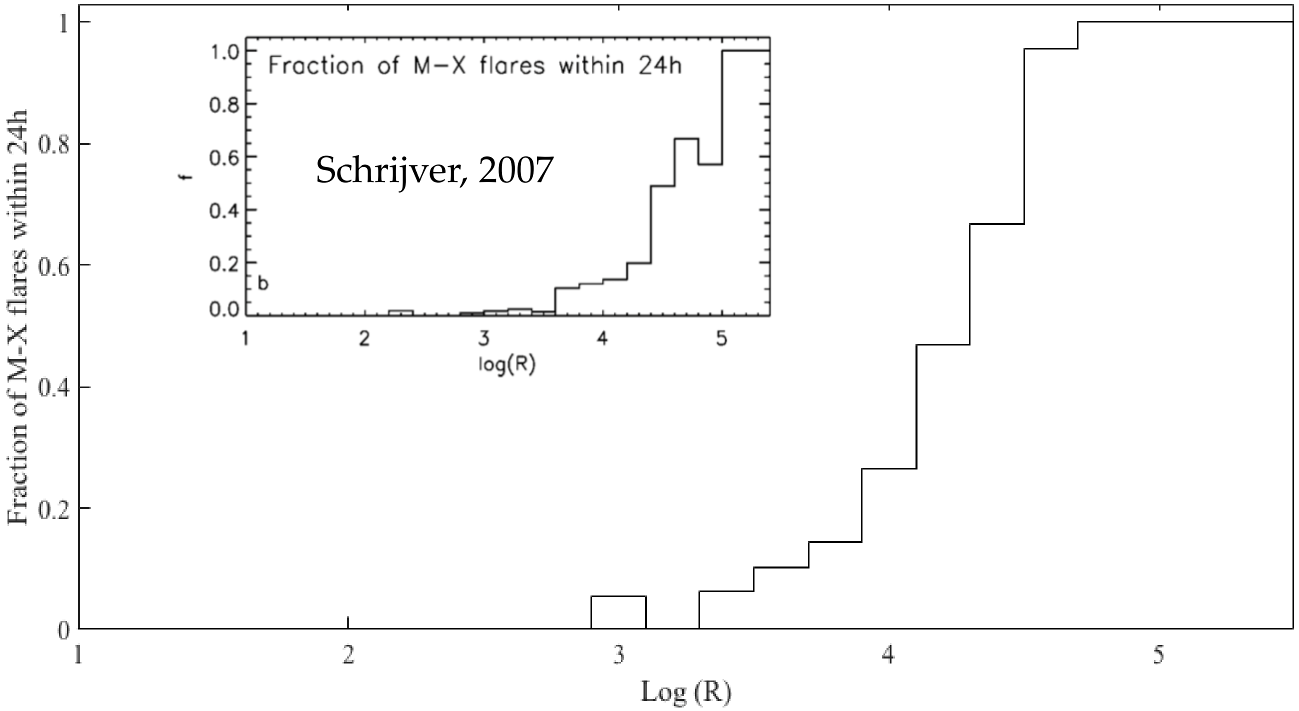


The distribution of flare size vs R derived by our algorithm confirms the Scrijver's idea that R value indicates the maximum energy available for flares in a given AR.

Cycle 24 SDO/HMI R value analysis



Histogram of *logR* for the 830 Cycle 24 flaring AR magnetograms (solid line) and for the subset of M or X-class within 24 h flaring active regions (dashed line). The 252 regions with *R* = 0 are not shown.

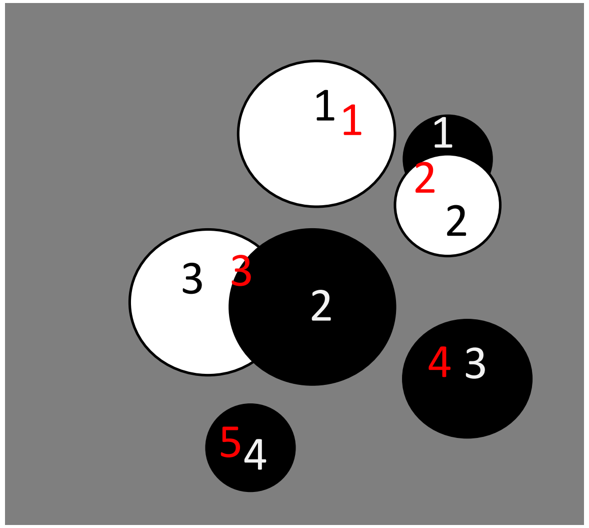


Fraction of all active regions with at least one M or X-class flare within 24 h as a function of logR (*upper*, this work and *lower*, Scrijver, 2007)). Cycle 23 and 24 present different statistics.

D value: computation method

1. Two binary masks for each polarity from the HMI LoS magnetogram
2. Label assigned to every connected region (fragment) in each mask
3. f_t as total number of positive and negative fragments
4. Unsigned binary mask (UBM)
5. Labelling procedure applied to the UBM, finding a second number, f_u
6. The D value is $D = f_t - f_u$.

D as number of fragments including PILs.



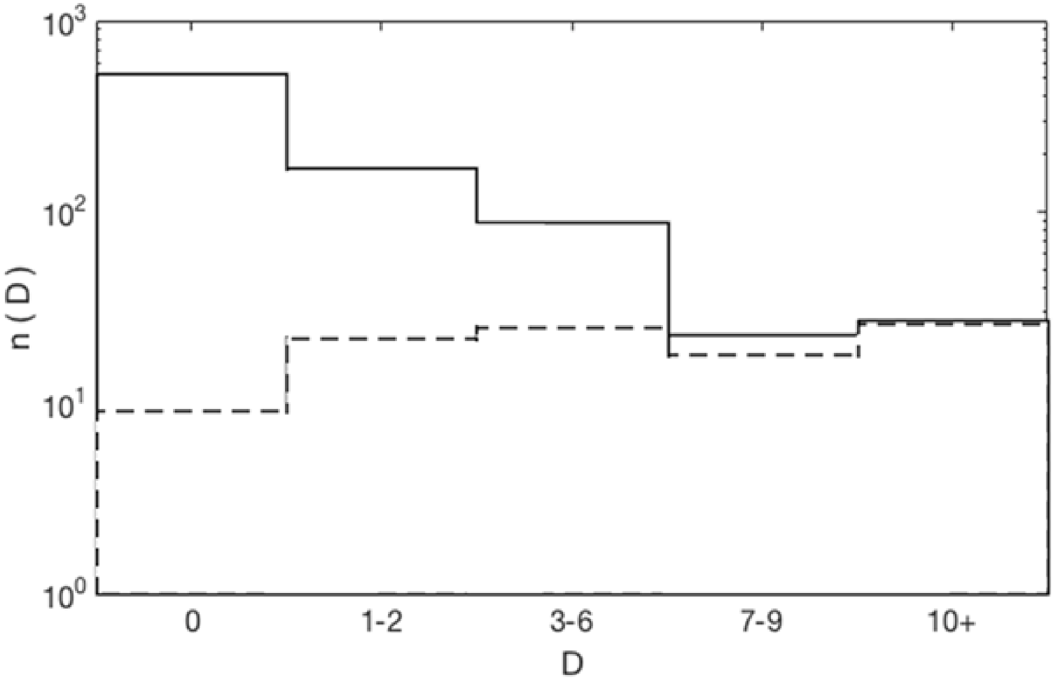
$f_t = 3 + 4 = 7$

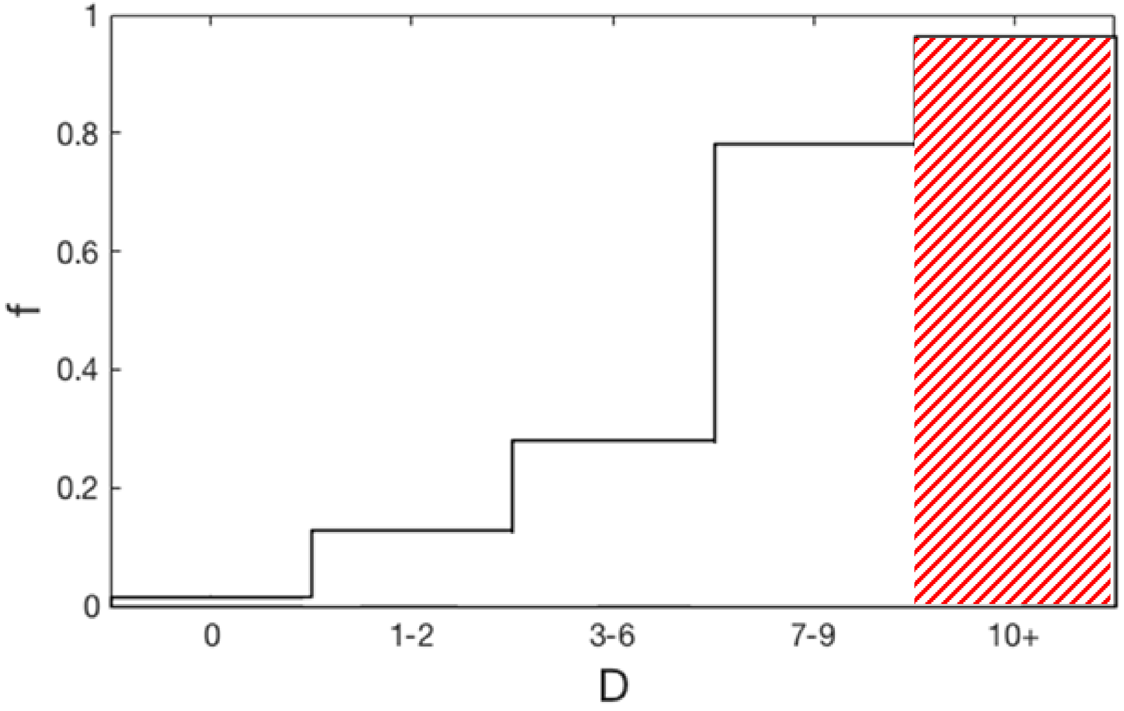
$f_u = 5$

$D = f_t - f_u$

$D = 7 - 5 = 2$

Cycle 24 SDO/HMI D value analysis





Left: Histogram of D for the 845 ARs and for the subset of flaring regions. *Right*: Fraction of all ARs with at least one major flare (greather than M-class) within 24 h as a function of D.

It is important to note that when D value is >10 the AR is flaring with P close to 1 (0.96).

Probability flare from Cycle 24 SDO/HMI R and D values

			R		
Class	log R ≈ 3.0 (%)	log R ≈ 3.5 (%)	log R ≈ 4 (%)	log R ≈ 4.5 (%)	log R ≈ 5 (%)
M1	∼ 0	4	8	33	92
X1	0	0	∼ 0	2	17

			D		
Class	D ≈ 1 (%)	D ≈ 3 (%)	D ≈ 5 (%)	D ≈ 7 (%)	D ≥ 10 (%)
M1	9	22	36	70	96
X1	0	∼ 0	7	20	25

Cycle 24 SDO/HMI D and R results

Results of the logistic regression method and comparison with other works that apply Machine Learning algorithms to forecast the behavior of a given active region. The active regions set was divided into a training set and a test set with ratio approximately 70% to 30%

	This work	Bobra	Song	Ahmed
Time interval	**48 h**	48 h	24 h	48 h
Class-imbalance ratio	**7.46**	16.5	2.23	15.85
Accuracy	**0.937**	0.973	0.873	0.975
Precision positive	**0.694**	0.797	0.917	0.877
Precision negative	**0.977**	0.983	0.860	0.980
Recall positive	**0.833**	0.714	0.647	0.677
Recall negative	**0.951**	0.989	0.974	0.994
f1 positive	**0.758**	0.751	0.758	0.764
f1 negative	**0.964**	0.986	0.913	0.987
TSS	**0.784**	0.703	0.620	0.512

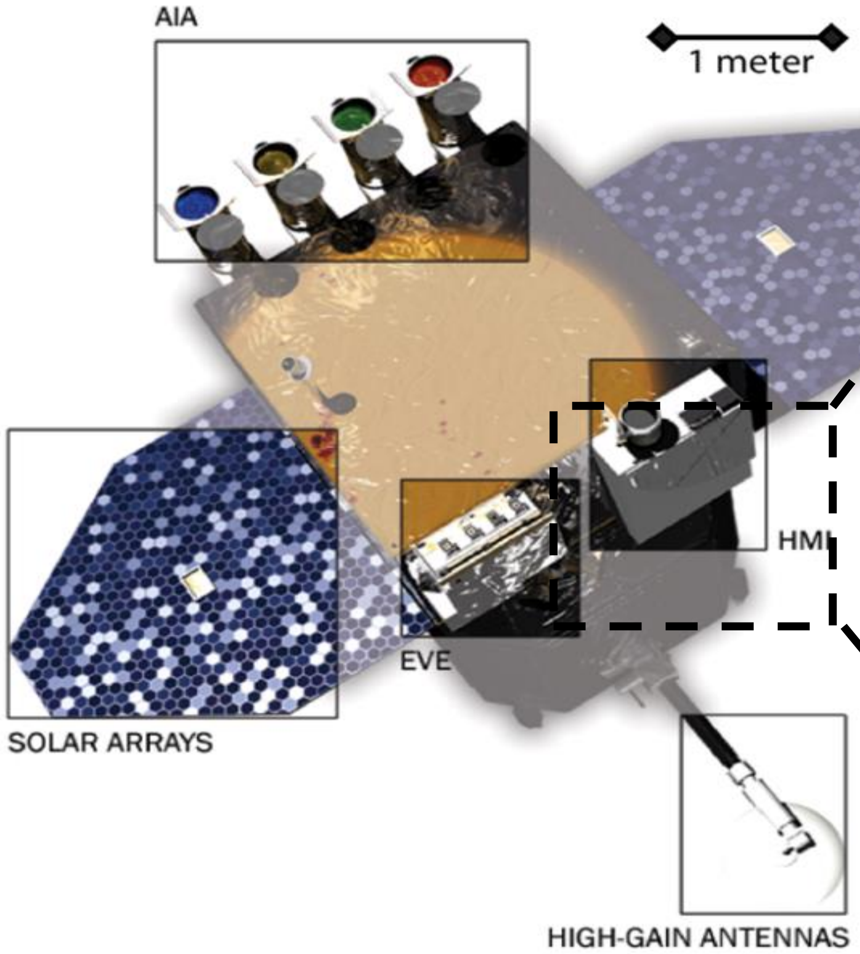
Conclusions

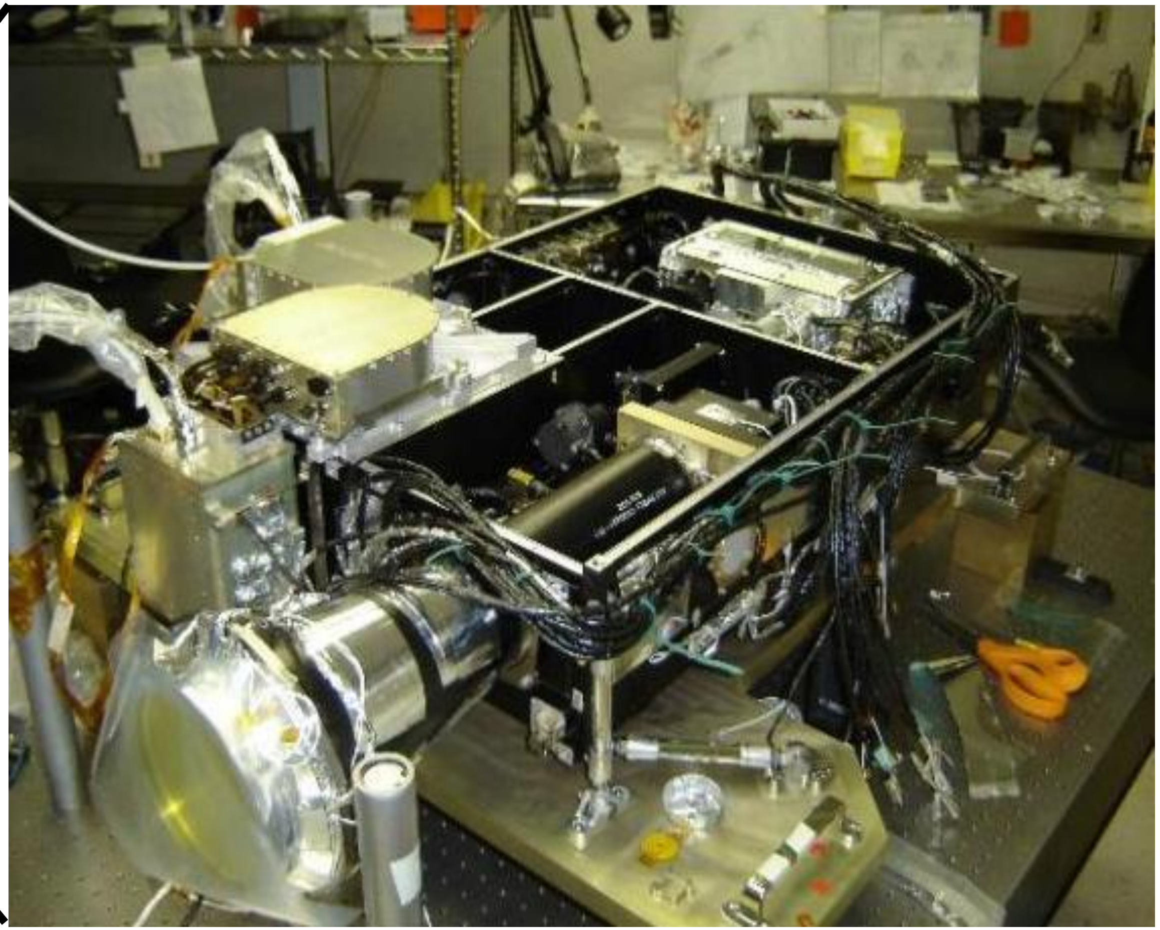
- We developed a new algorithm to compute R with **full-resolution** HMI/SDO LoS magnetograms
- We developed a new **topological parameters** D as number of fragments including PILs
- Results of the new R are consistent with SHARP R
- D is a good descriptors for flare activity (D>10, 96% flaring region)
- D and R together provide better results for flare forecasting (TSS=0.784)

- Systematic observations with MOF-based instruments (TSST, MOTH, VAMOS) during 25^{th} cycle

Backup Slides

The magnetograms were taken from the **Joint Science Operations Center**, that collects data products from the **Solar Dynamics Observatory** (SDO) satellite. There are obtained from the analysis of the filtergrams of the **Helioseismic and Magnetic Imager** (HMI) instrument on board the SDO satellite.

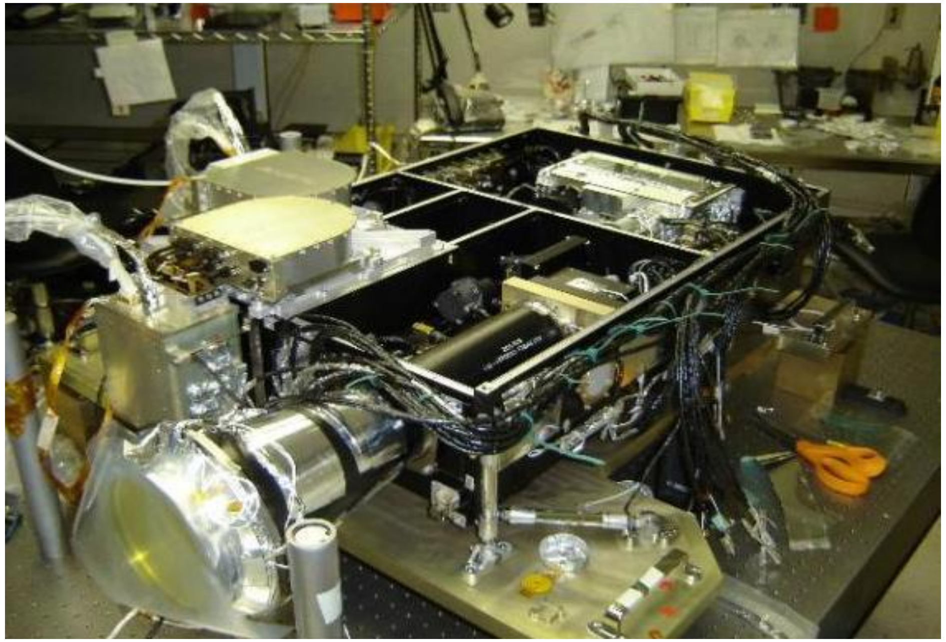


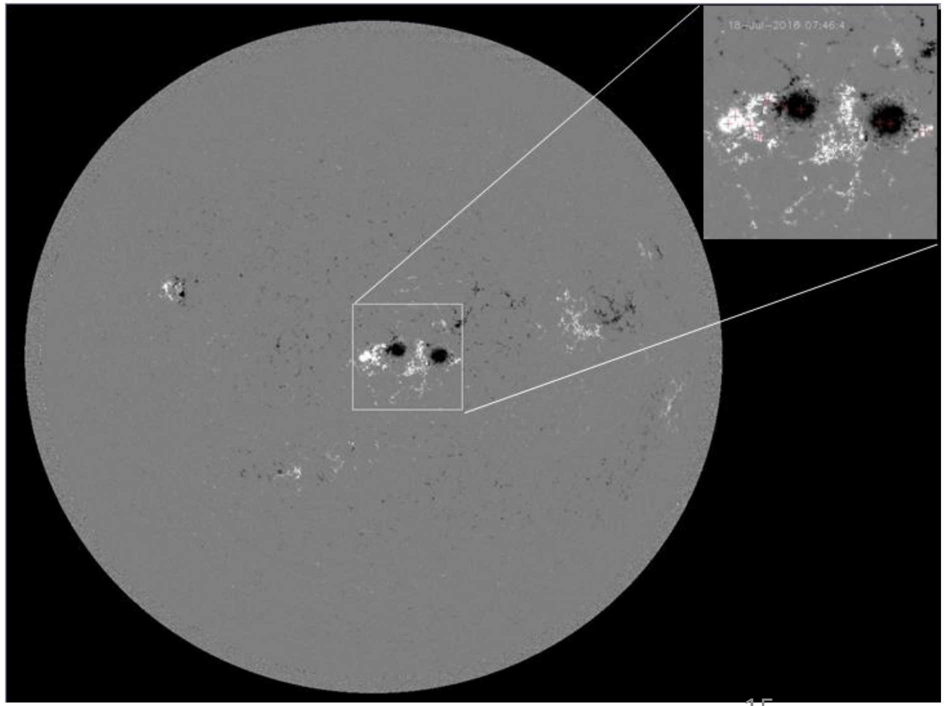


The Helioseismic and Magnetic Imager (HMI) is designed to measure the Doppler shift, the LOS magnetic field and both intensity and vector magnetic field at the solar photosphere using the 617.3 nm Fe I absorption line and a resolution of 0.5” per pixel.

Scientific goals:

- new informations about the flux emergence and removal in the ARs
- study the coronal magnetic structure
- investigate the solar wind
- study the dynamics of the convective zone
- better understanding of the dynamo that produce the global field
- test how the Sun is structured longitudinally





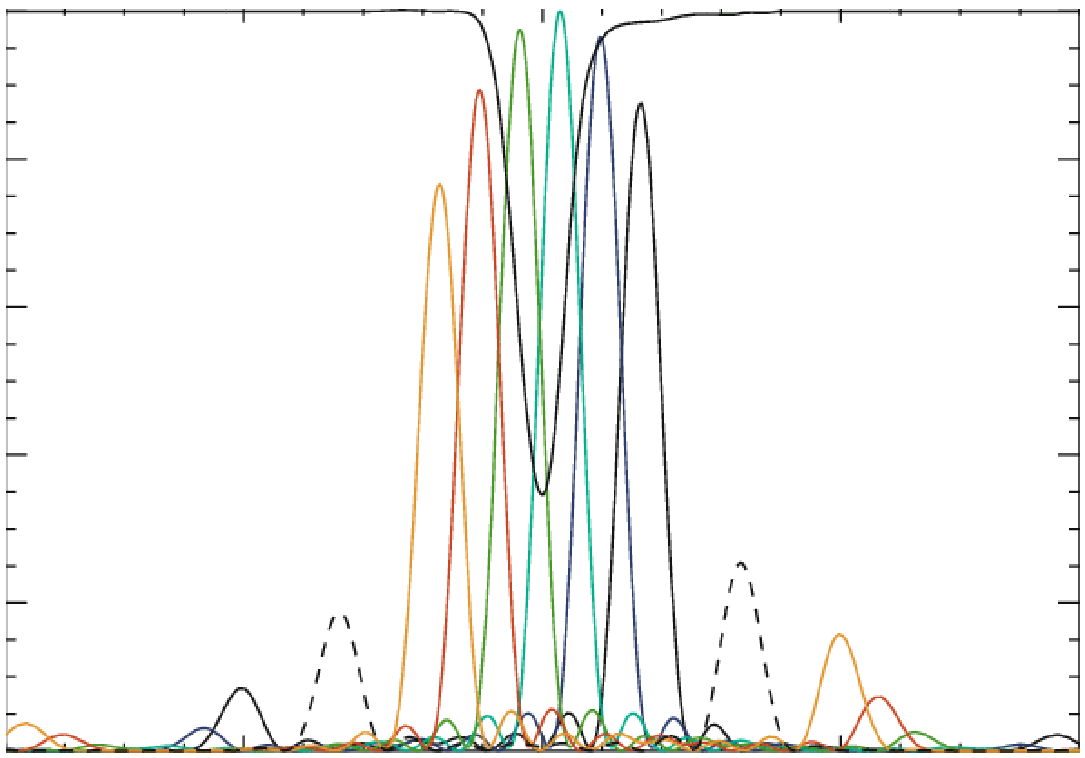
The full-disk HMI/SDO magnetogram and the active region zone cutting up.

HMI/SDO observes the Sun at the Fe I 617.3 nm line and returns full-disk maps of line-of-sight (LOS) observables including the magnetic flux density, velocities, Fe I line width, line depth, and continuum intensity.

These data are estimated through an algorithm (the MDI-like algorithm, hereafter) that combines observables obtained at six wavelength positions within the Fe line.

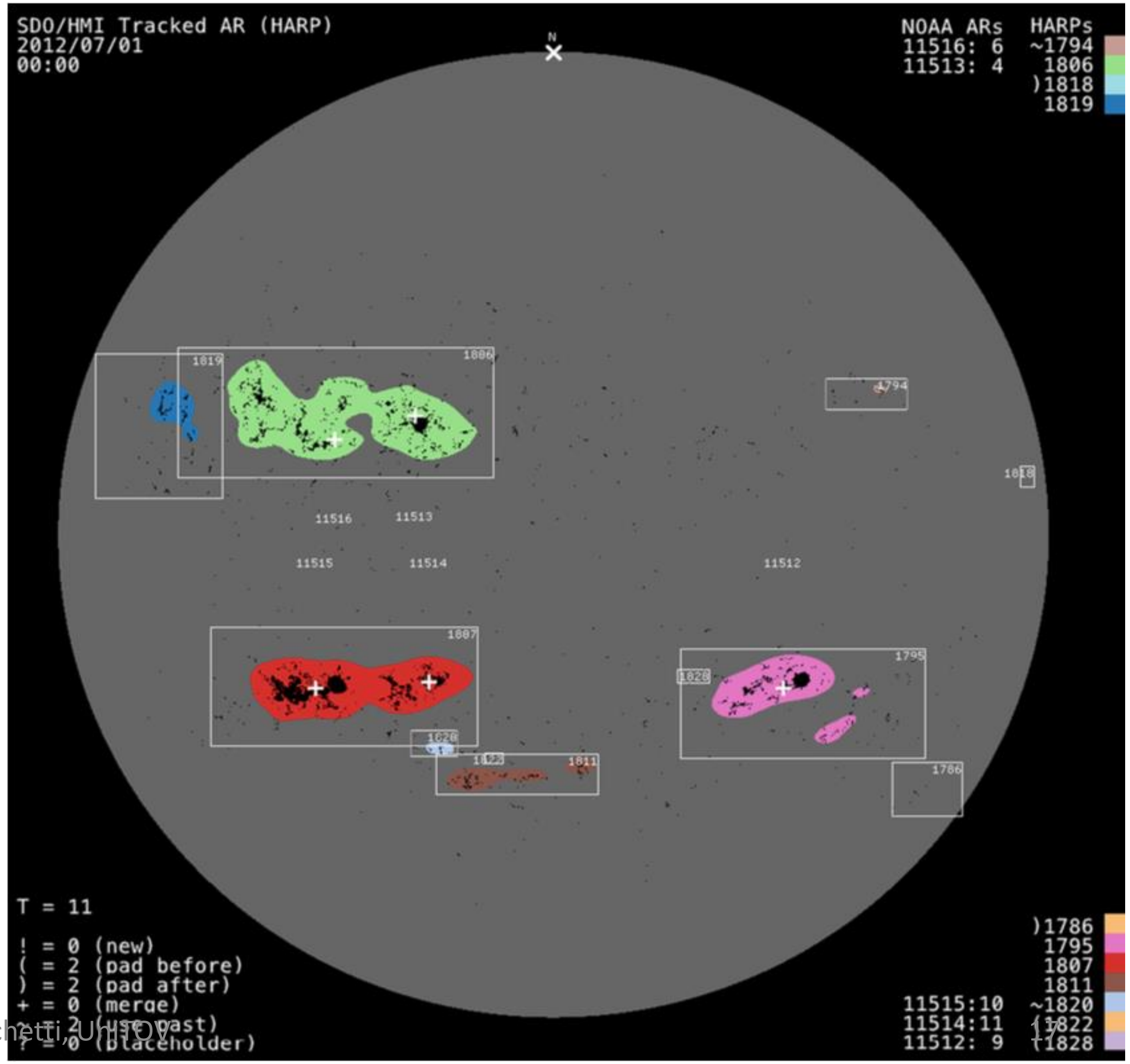
To properly interpret such data, it is important to understand any effects of the instrument and of the pipeline that generates these data products.

See Cohen et al. (2015). Understanding the Fe I Line Measurements Returned by the Helioseismic and Magnetic Imager (HMI). Solar Physics. 290. 10.1007/s11207-015-0654-7.



Example of HMI sampling-position profiles obtained from the wavelength-dependence calibration procedure (these profiles vary across the CCD and depend on the tuning angles used). Six tuning positions are shown here with respect to the Fe I solar line (black line) at disk center and at rest, on top of the continuum tuning position (dashed line). The continuum tuning position can be used to estimate the solar continuum intensity. The Fe I line profile was provided by R.K. Ulrich and obtained at the Mount Wilson Observatory.

HMI uses an automated code to identify and track coherent magnetic structures at the size of an active region (HMI Active Region Patches, **HARPs**) using the line- of-sight magnetic field obtained from the filtergrams. HARPs follow a region from the day before they emergence to one day after their decay.



The code:

1. Identifies the magnetically active pixels
2. Groups these pixels into patches
3. Follows the evolution of the AR with a near real time (NRT) patch
4. After the decay of the associated region forms the definitive patch

From the HARPs are derived the Space weather HARPs

http://jsoc.stanford.edu/new/HMI/HARPS.html

For the prediction of solar flares, an AR can belong to on of two classes:

1. **positive class**: the active region produces one or more flares in a given time interval

2. **negative class**: the active region does not produce any flares in the same interval

Time interval: usually, for operational reasons, is chosen a 24-hour interval.

Different features extracted from the magnetic field of the active regions have been used as descriptors of the behavior of the active regions in order to find the conditions that allow to separate the two classes.

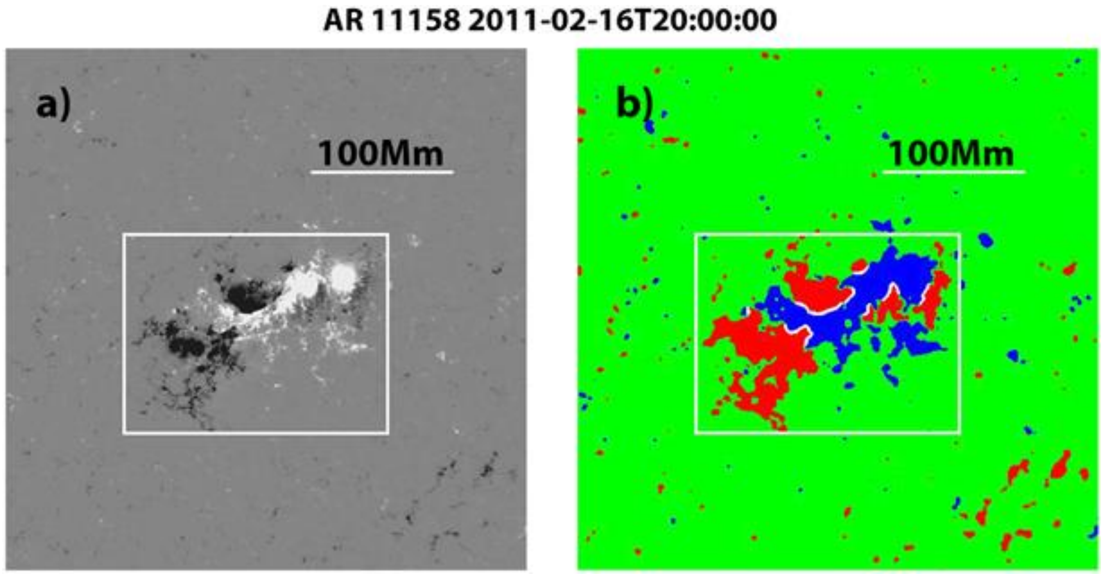
Keyword	Description	Formula	*F*-Score	Selection
TOTUSJH	Total unsigned current helicity	$H_{c_{\rm total}} \propto \sum \lvert B_z \cdot J_z \rvert$	3560	Included
TOTBSQ	Total magnitude of Lorentz force	$F \propto \sum B^2$	3051	Included
TOTPOT	Total photospheric magnetic free energy density	$\rho_{\rm tot} \propto \sum \left(\boldsymbol{B}^{\rm Obs} - \boldsymbol{B}^{\rm Pot}\right)^2 dA$	2996	Included
TOTUSJZ	Total unsigned vertical current	$J_{z_{\rm total}} = \sum \lvert J_z \rvert dA$	2733	Included
ABSNJZH	Absolute value of the net current helicity	$H_{c_{\rm abs}} \propto \left\lvert \sum B_z \cdot J_z \right\rvert$	2618	Included
SAVNCPP	Sum of the modulus of the net current per polarity	$J_{z{\rm sum}} \propto \left\lvert \sum^{B_z^+} J_z dA \right\rvert + \left\lvert \sum^{B_z^-} J_z dA \right\rvert$	2448	Included
USFLUX	Total unsigned flux	$\Phi = \sum \lvert B_z \rvert dA$	2437	Included
AREA_ACR	Area of strong field pixels in the active region	$\text{Area} = \sum \text{Pixels}$	2047	Included
TOTFZ	Sum of *z*-component of Lorentz force	$F_z \propto \sum (B_x^2 + B_y^2 - B_z^2) dA$	1371	Included
MEANPOT	Mean photospheric magnetic free energy	$\overline{\rho} \propto \frac{1}{N} \sum \left(\boldsymbol{B}^{\rm Obs} - \boldsymbol{B}^{\rm Pot}\right)^2$	1064	Included
R_VALUE	Sum of flux near polarity inversion line	$\Phi = \sum \lvert B_{LoS} \rvert dA$ within R mask	1057	Included
EPSZ	Sum of *z*-component of normalized Lorentz force	$\delta F_z \propto \frac{\sum (B_x^2 + B_y^2 - B_z^2)}{\sum B^2}$	864.1	Included
SHRGT45	Fraction of Area with shear > 45°	Area with shear > 45° / total area	740.8	Included

One of the characteristics of the magnetic reconnection process is the presence of **electric currents** incorporated in a magnetic flux.

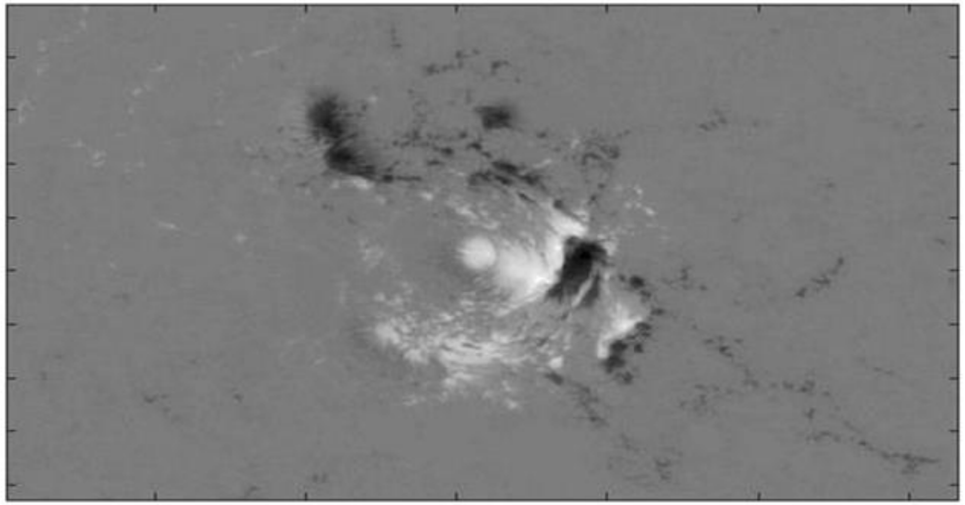
Magnetograms can show the existence of the currents as they appear associated to **elongated Polarity Inversion Lines** (PIL) with strong magnetic fields of opposite polarity immediately adjacent to the line.

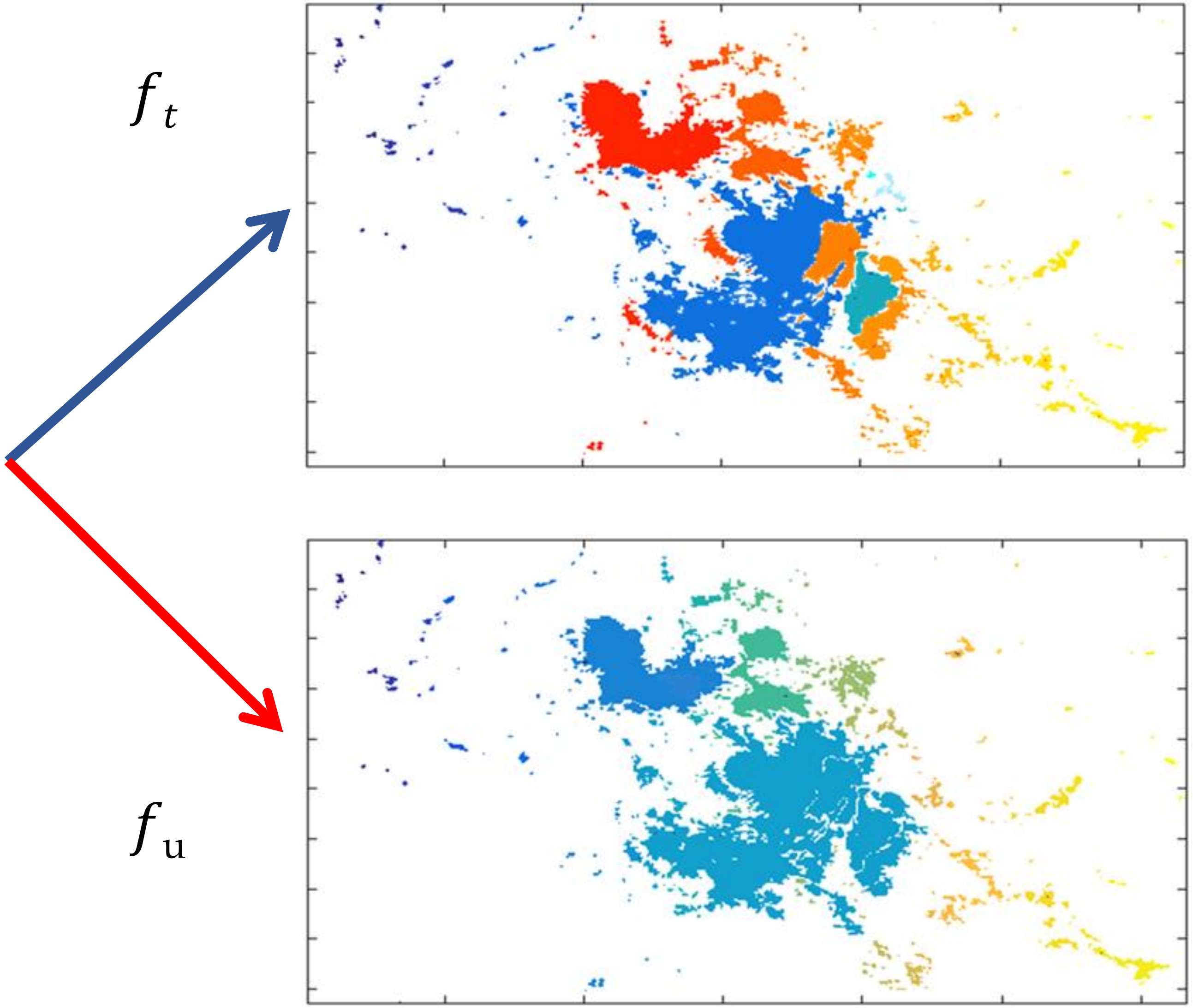
The **R value** was introduced by **Schrijver** in 2007 to work with the **LoS magnetograms of the MDI instrument**, active mostly during the solar cycle 23.

The **R value** separate the positive class of flaring Ars from the negative class of non-flaring Ars due to the presence or absence of currents.

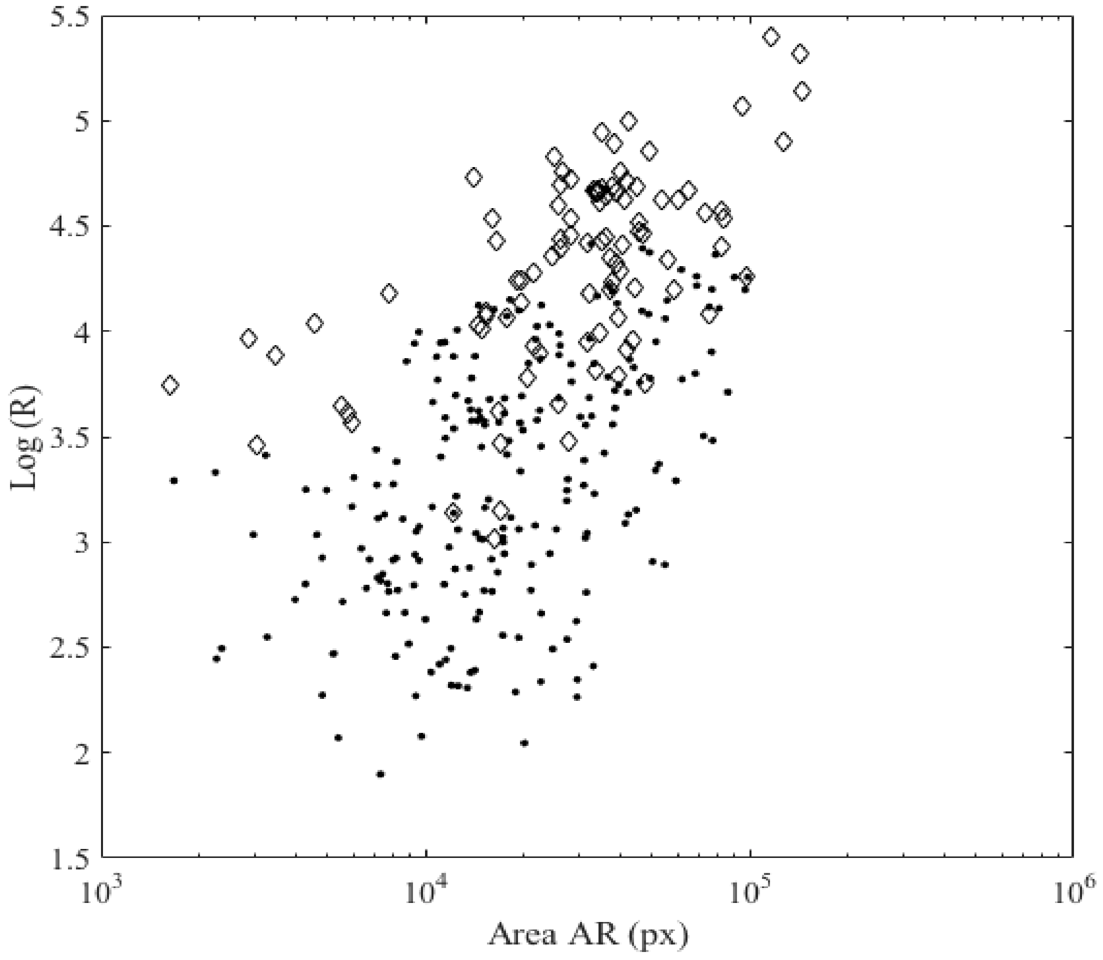


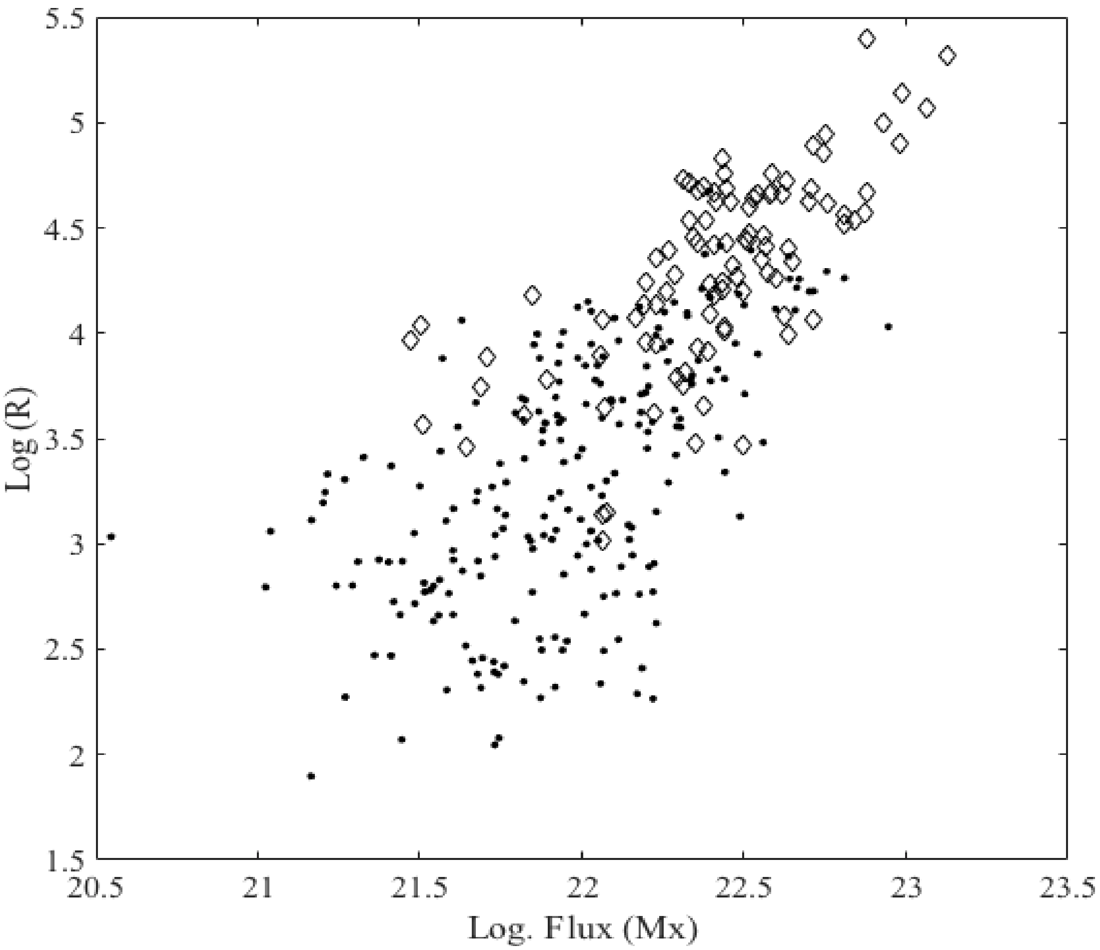
Two binary masks are created for each polarity from the HMI LoS magnetogram.



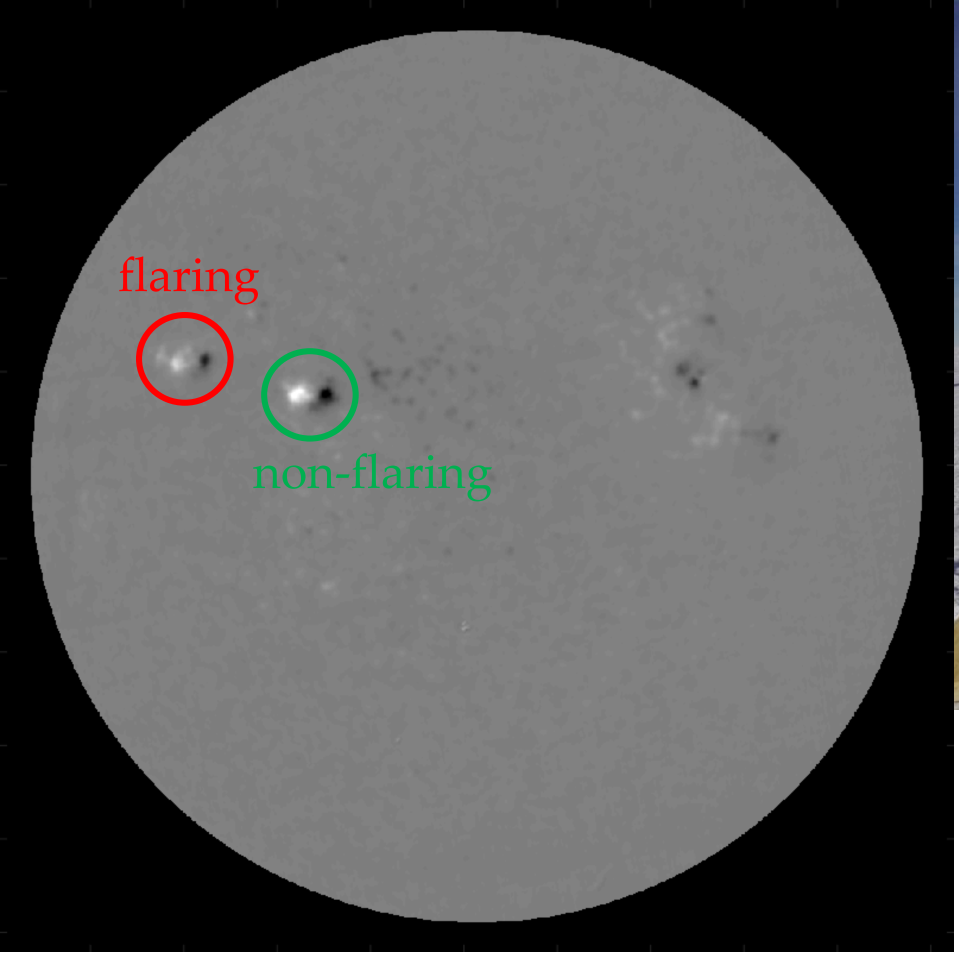


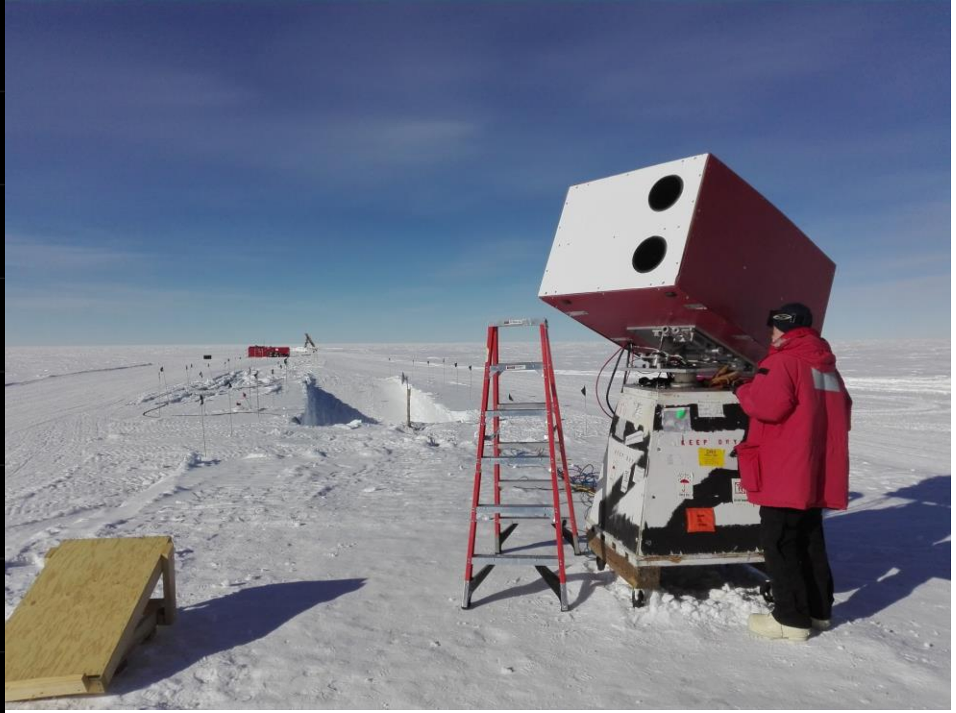
Calibration of R value for SDO/HMI LOS magnetograms





Two scatter diagram, *logR* vs the total area of the AR and *logR* vs the unsigned total AR fluxes. AR with M or X-class flares are shown by diamonds, all other AR by dots.

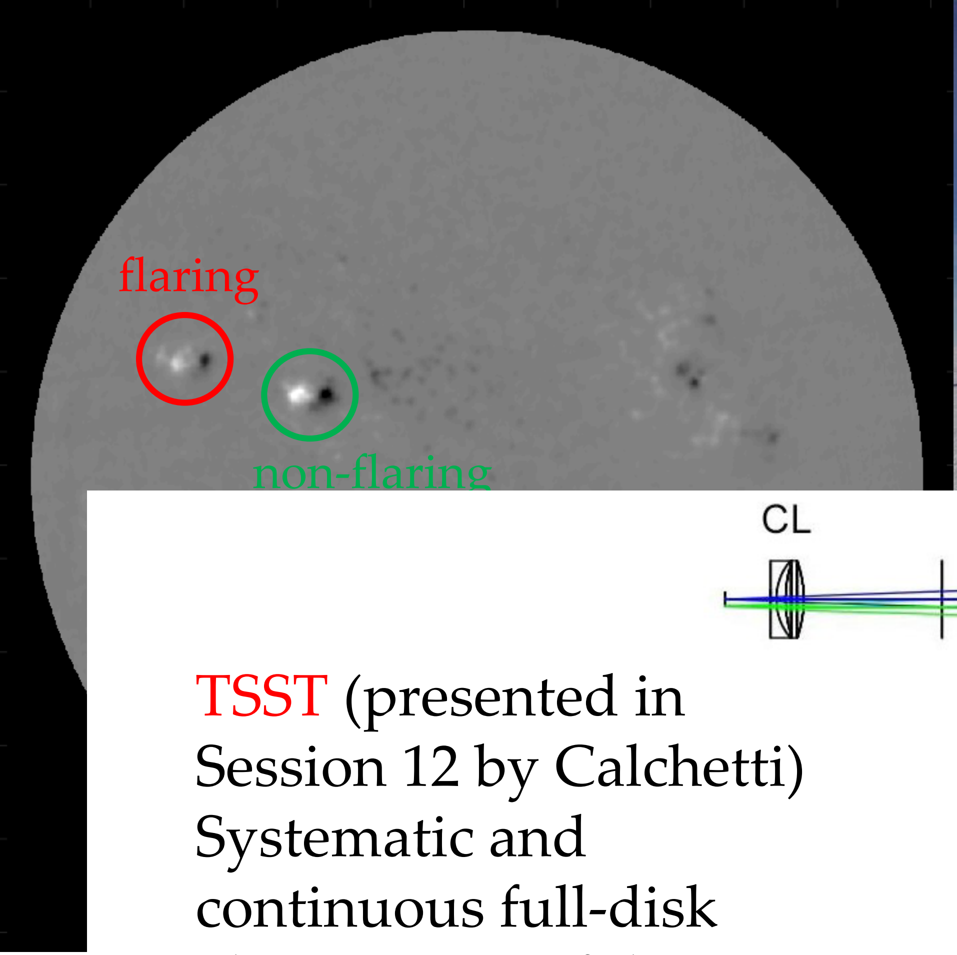


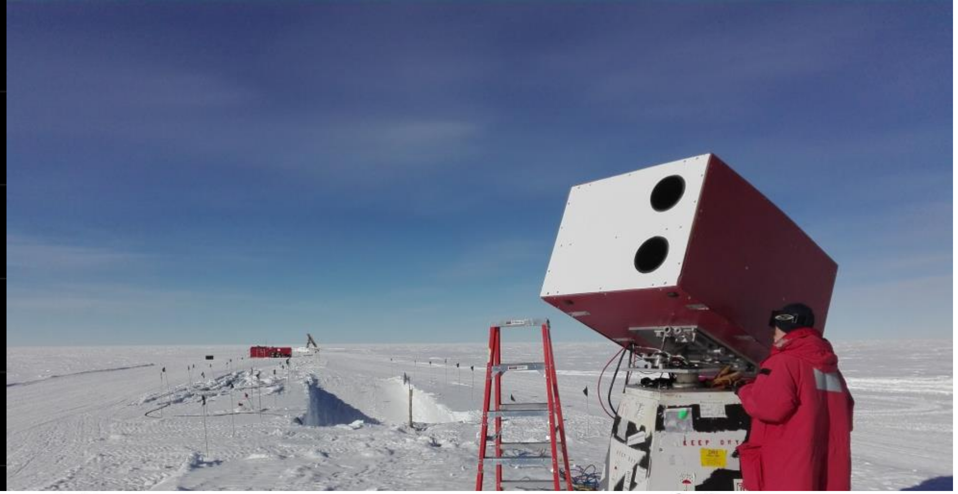


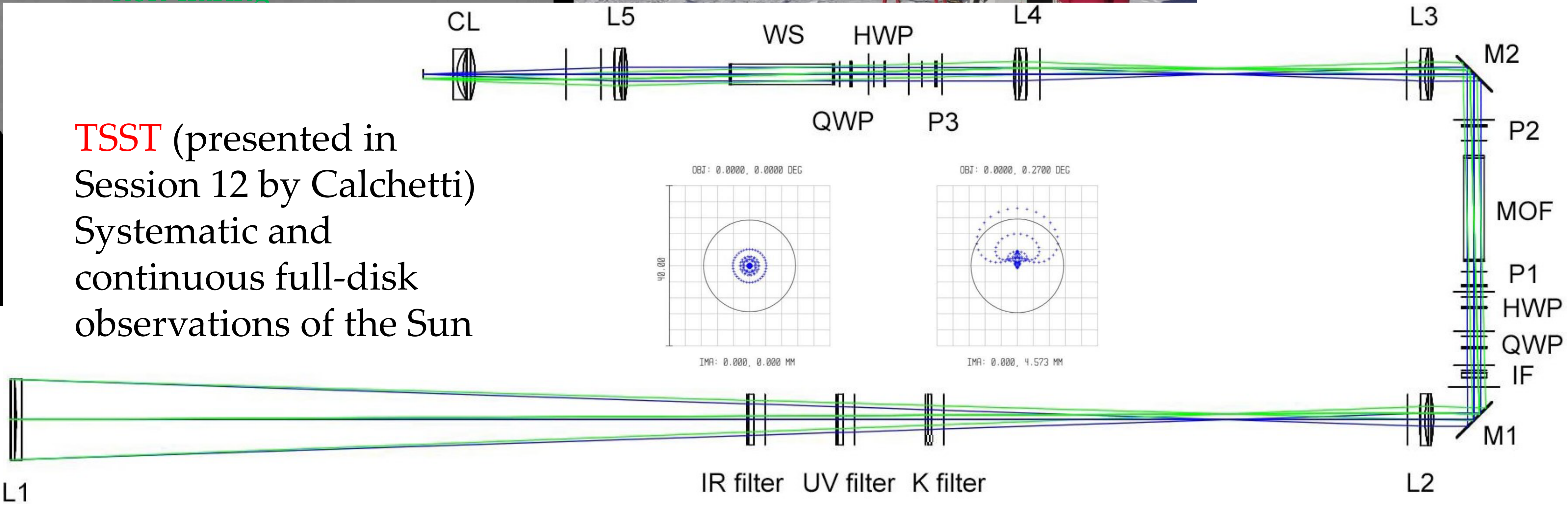
2017 Antarctic MOTH campaign

Flaring Region AR12628: D=1

Non-Flaring Region AR12627: D=0







TSST (presented in Session 12 by Calchetti)
Systematic and continuous full-disk observations of the Sun