This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

On automated flare detection: from science case to an operational method

F. Zuccarello[1], M. Korsós[2,4], R. Erdélyi[3,4]

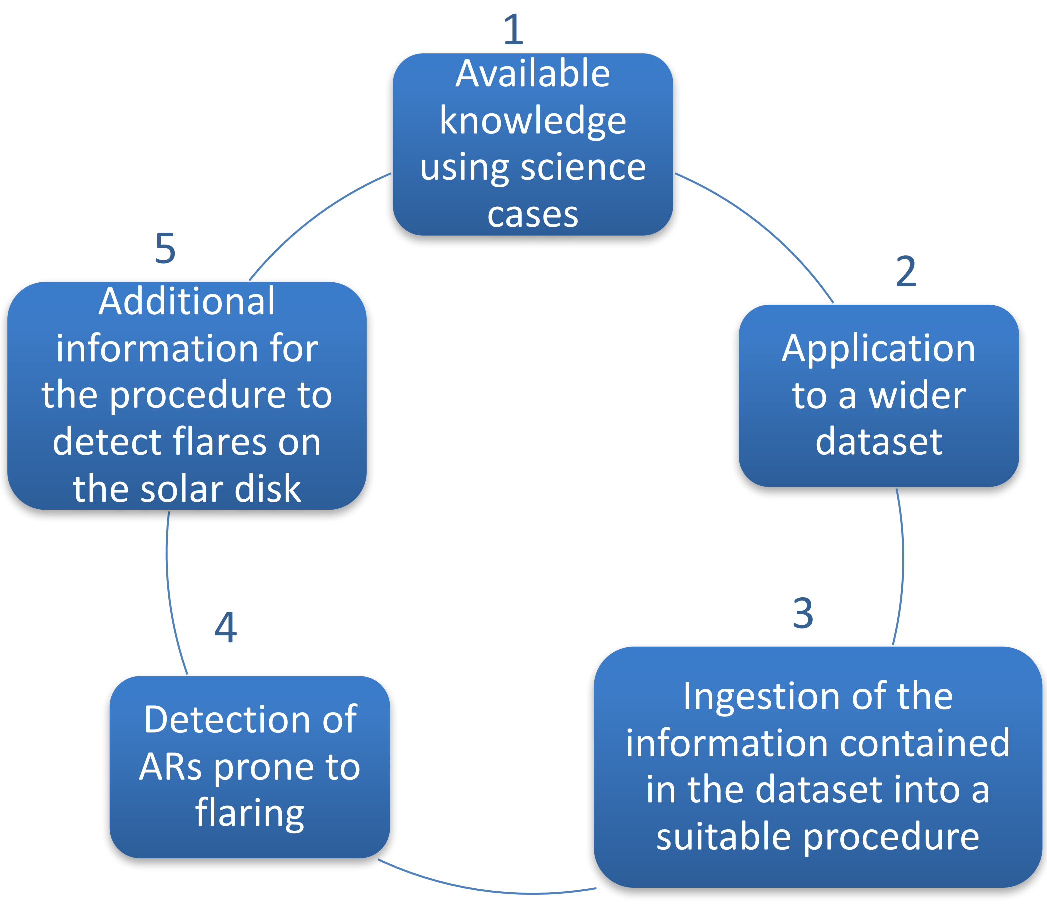
[1]University of Catania – Department of Physics and Astronomy "Ettore Majorana"
[2]Aberystwyth University, UK
[3]University of Sheffield, UK
[4]Hungarian Solar Physics Foundation

SPRING Workshop February 18-19, 2021

Outline of the talk

- ❑ The flow chart
- ❑ Description of the science cases and the methods used
- ❑ Distilling the results
- ❑ Application to a larger dataset and automated procedure
- ❑ Linkage between flare alert and flare detection
- ❑ Analysis of criticality, risks and operational solutions
- ❑ What should be done and the advantages of the approach

The flow chart



Description of the science cases

Analysis of 10 ARs observed between 2011 March 6 and 2013 June 24 using Level 1.5 SDO/HMI full-disk photospheric LOS magnetograms .

5 flaring ARs (hosting M- and X-flares)

AR	Start date	Start time UT	End date	End time UT	Subfield (arcsec)
AR 166	Mar 6, 2011	22:00	Mar 10, 2011	22:00	512×512
AR 283	Sep 3, 2011	22:00	Sep 7, 2011	22:00	512×512
AR 429	Mar 6, 2012	21:00	Mar 10, 2012	22:00	440×440
AR 515	Jul 1, 2012	01:00	Jul 5, 2012	04:00	400×400
AR 520	Jul 10, 2012	08:00	Jul 14, 2012	16:00	240×240

Zuccarello et al., submitted to JSWSC

Description of the science cases

5 non-flaring ARs (no flares or just B- and C-flares)

AR	Start date	Start time UT	End date	End time UT	Subfield (arcsec)
AR 267	Aug 6, 2011	02:00	Aug 10, 2011	02:00	240×240
AR 512	Jun 26, 2012	24:00	Jun 30, 2012	24:00	240×240
AR 589	Oct 13, 2012	14:00	Oct 17, 2012	14:00	512×512
AR 635	Dec 22, 2012	21:00	Dec 26, 2012	21:00	512×512
AR 775	Jun 19, 2013	10:00	Jun 23, 2013	10:00	240×240

Aim of the study was to **assess the eruptive potential** of ARs using three different methods and to determine any **significant difference** between the two classes of ARs using **some parameters**.

Description of the methods used in the science cases

❖ **Magnetic helicity evolution** (LaBonte et al., 2007; Smyrli et al, 2010)
Helicity injection in an AR can occur due to the emergence of new magnetic flux and/or the presence of a significant velocity component perpendicular to the magnetic field.

❖ **Fractal dimensions** (Abramenko et al., 2003; Ermolli et al., 2014)
This method focuses on the level of intermittency in surface magnetic field patterns that may be an indication of strong tangential discontinuities that may initiate reconnection events.

❖ **WG_M Method** (Korsós et al., 2019, 2020)
This method considers the properties of the horizontal gradient of the line-of-sight component of the magnetic field in ARs characterized by a δ configuration.

MAGNETIC HELICITY EVOLUTION

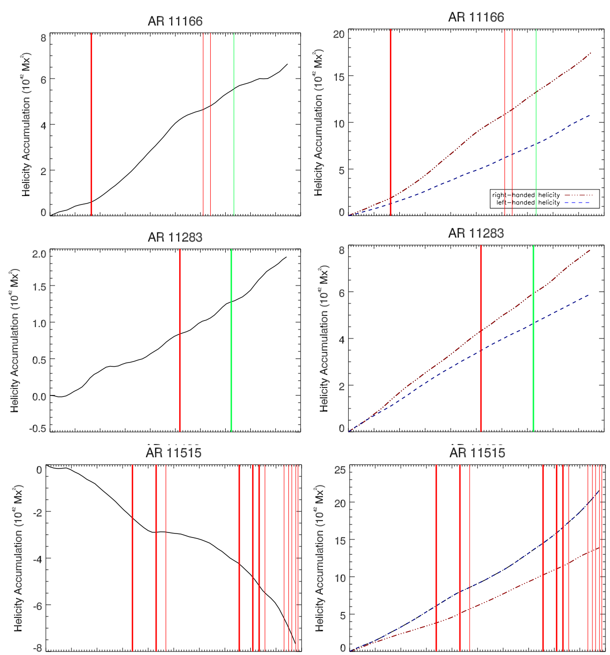
Main results:

- **flare-productive ARs** show a **continuous increase** of helicity accumulation

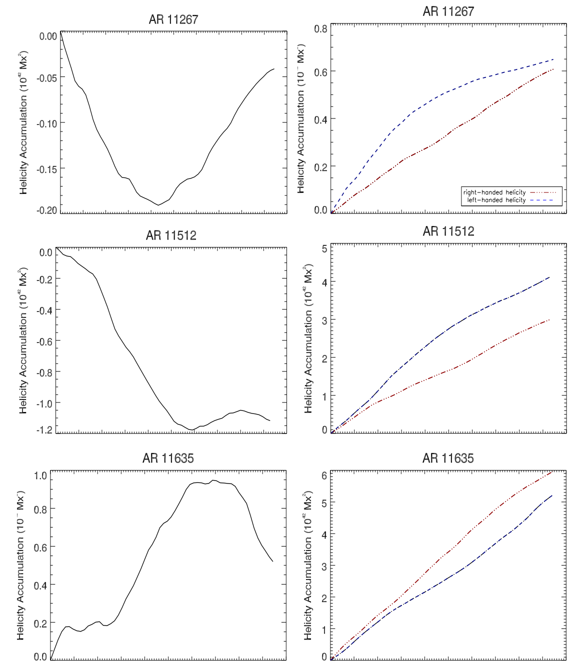
- **flare-quiet ARs** are characterized by **changes** in the helicity accumulation **trend**

- **lower values** (a factor 3 - 4) of the right-handed and left-handed magnetic helicity accumulation **in flare-quiet ARs** with respect to flare-productive ARs.

FLARING ARs



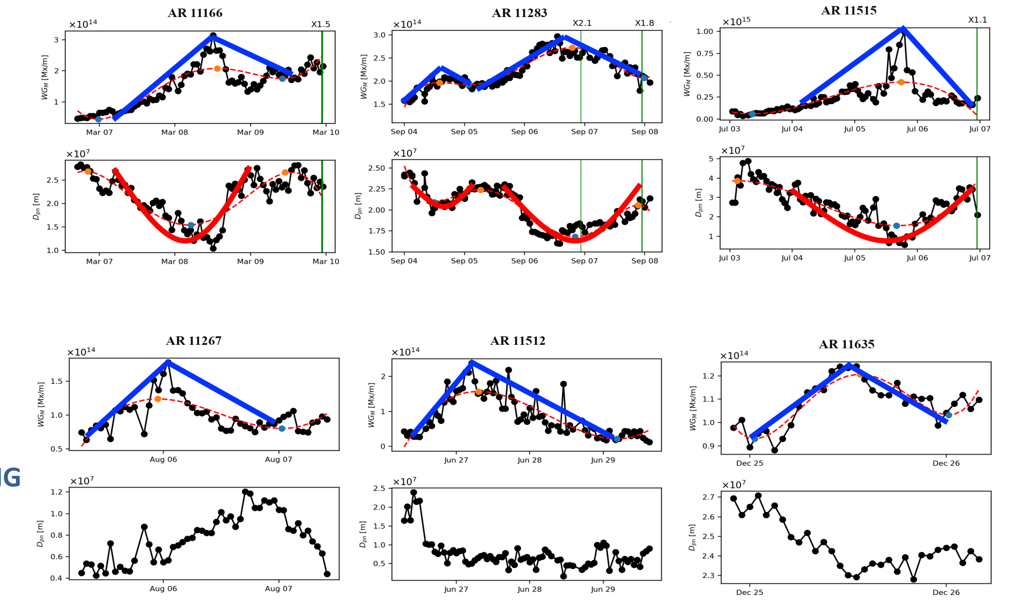
NON - FLARING ARs



WG_M Method

Main results

- **Presence of "inverted V-" and "U-shape" in WG_M and D_{pn} for flaring ARs**
- **Presence of "inverted-V-"**, but **absence of "U-shape"** in **non-flaring ARs**.



Distilling the results

The results obtained using these two methods point towards some specific behaviours of the parameters that have been analyzed:

- continuously increasing trend for magnetic helicity (both positive and negative)
- high values of H^+ and H^-
- presence of "Inverted-V" in plots of WG_M
- presence of "U-shape" in plots of D_{pn}

FLARING ARs

- varying trend of magnetic helicity
- lower values of H^+ and H^-
- presence of "Inverted-V" in plots of WG_M (but not always)
- absence of "U-shape" in plots of D_{pn}

NON- FLARING ARs

Application to larger dataset and automated procedure

- In order to validate these results, it is necessary to perform the same kind of analysis using a larger dataset:

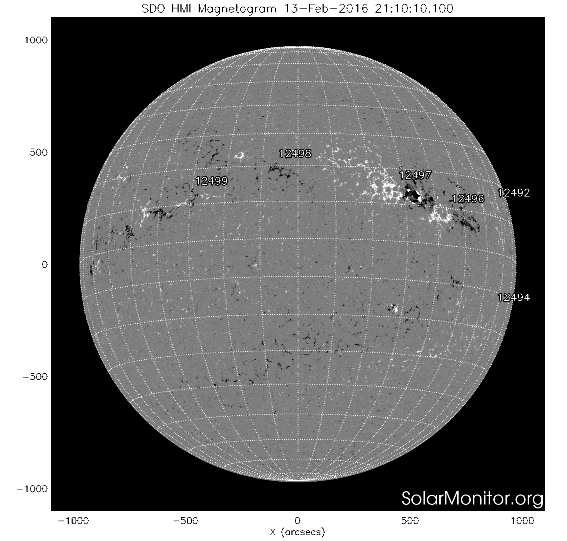
    - Other data acquired by HMI/SDO
    - Data acquired by MDI/SOHO
    - SSC (Sheffield Solar Catalogue: ssc.shef.ac.uk)
    - Lagrange mission (L5 - vector magnetograms, EUV)
    - etc.

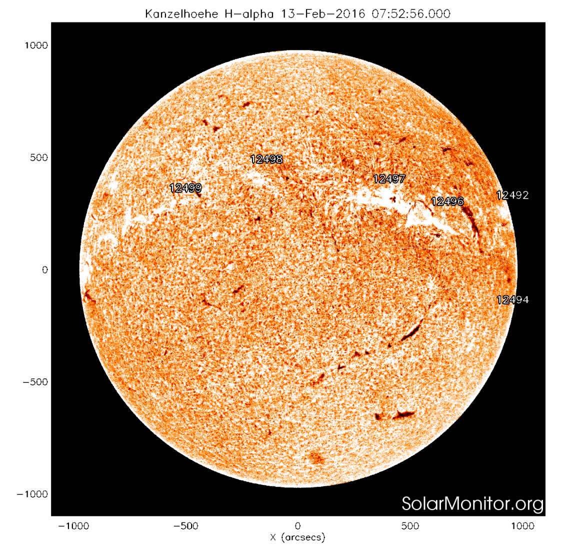
- The next step is to implement an automated procedure **(through machine learning or data clustering)** that can **recognize** the main features singled out in our previous analysis and that could allow to determine the **flaring probability of the ARs** (for caveats see Liu et al. Nature Astron 2021)

- A further step is to **apply this procedure to** **real-time data.**

Linkage between flare alert and flare detection

- The above procedure, starting from the analysis of real-time magnetograms, could indicate what are the ARs that with higher probability will give rise to flares
- The WG_M method can also provide the expected onset time and the corresponding GOES class of the flare
- This information could be used as a further **warning** parameter to help the detection of flares in Halpha (or even lower chromospheric) images - **through a timely switch-on of the flare-detection procedure** - besides than the parameters based on possible thresholds and/or photometric variations
- If this approach is validated, an estimation of the (additional) computing capacities of the SPRING telescopes should be taken into account (see also **SAMNet** as an alternative).

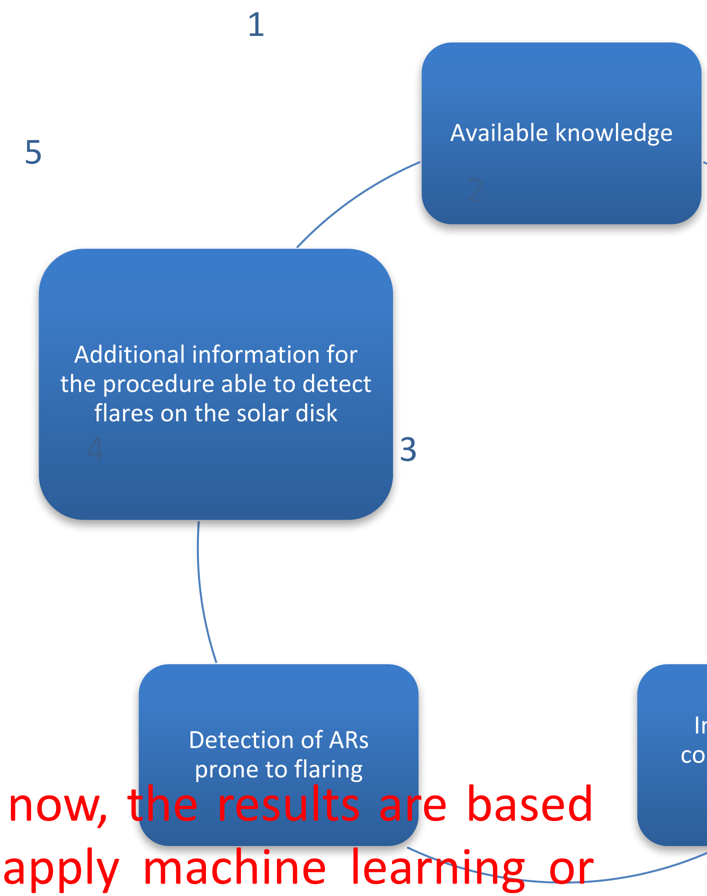




Criticality, risk factors and operational solutions

1. The dataset used is based on HMI/SDO observations → it is not possible to have real-time data - but - monitoring the Sun through SPRING (or SAMNet) could provide near real-time magnetograms

2. Necessity to further test the procedure to calculate H, H^+, H^- and WG_M for a larger dataset → it might be necessary to use a different dataset (e.g., MDI/SOHO or other) - but - it should be possible to train the procedure to use different dataset

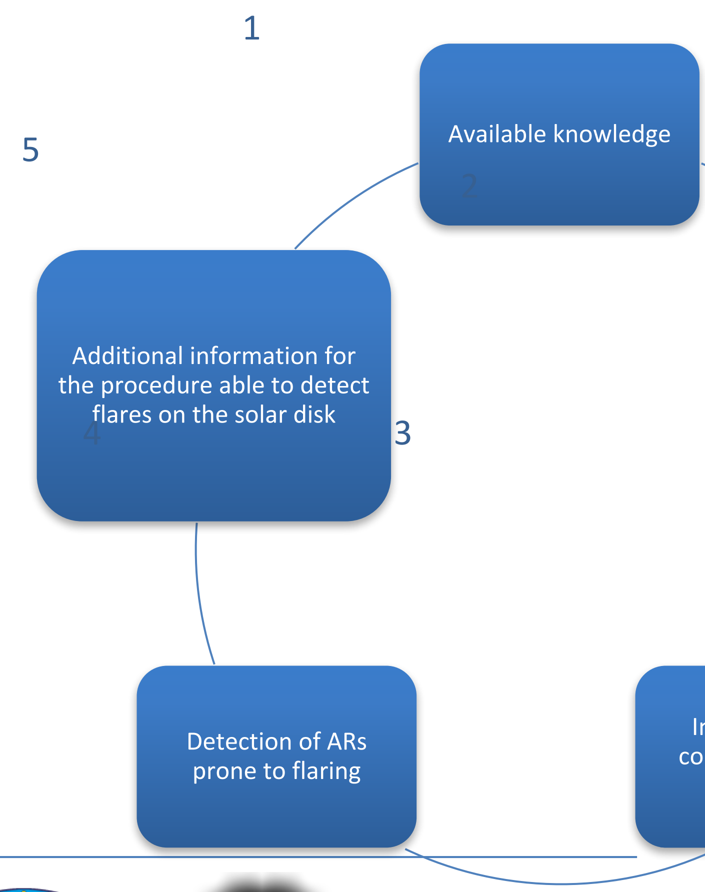


3. Search for the most suitable procedure → up to now, the results are based on a very limited dataset, not yet sufficient to apply machine learning or clustering algorithms - but - increasing the number of analyzed ARs a better situation can arise and these tools could be used

Criticality, risk factors and operational solutions

4. Detecting ARs prone to flaring → The procedure should translate the "right" parameters into flare alert - but - the increasing number of samples will help to validate it

5. Linking flare alert with flare detection in solar images → a critical factor is the time necessary to acquire data, process these data through the procedure and obtain the flare alert - but - it should be already possible to test the time necessary to shift to a pre-alerting situation



What should be done?

- Broaden the analysis to larger datasets

- Implement an automated procedure that, starting from *(real-time)* magnetograms, provides the values/trends of the parameters studied in previous works

- Implement a suitable procedure (machine learning, data clustering, …) that can further help in the determination of the *soon-flaring* ARs

- Check the feasibility of linking the flare alert with the algorithm used for flare detection

- Validate knowledge about expected flare occurrences in the context of improved flare detection (i.e., how much lead time is gained, estimate location, flare intensity, ...)

- Ultimately, construct operational facility (see e.g. SPRING, SAMNet)

The advantages of this approach

- The different sections leading to the final result can be running and tested in parallel
- LoS magnetograms could be sufficient to reach the final goal
- Self-sufficiency due to the cycle: data acquisition - application of the procedure - flare alert - flare detection