White-Light Flares: A Proposed Improvement to Known Classic Reduction Methods

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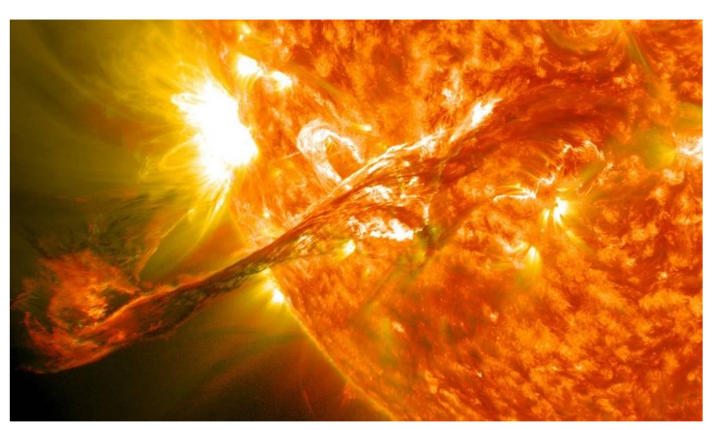
Abstract: Solar flares are explosive phenomena in the solar corona where a large amount of energy is suddenly released by means of radiation, particle acceleration and plasma heating, among other physical processes. In the last decades multi-wavelength observational studies have given different constraints to the energy transfer models during solar flares, in particular the so called white-light flares (WLF), where an enhancement of the continuum emission or white light (WL) is observed. These particular events have challenged the scientific community with different theoretical and observational issues, in particular in the physical processes behind their generation and their influence on the different layers of the solar atmosphere. In this work an observational method is introduced in order to identify WLF events and estimate, in a consistent way, the WL excess flux. A comparison with the classical reduction methods is performed based on synthetic and real observations, which allows the direct comparison of the advantages/drawbacks between these different observational treatments. We find that classical techniques are not capable to remove the intrinsic solar-noise and in some extreme cases unphysical and non-instrumental signals can be created, which could lead to an inaccurate estimation of the energy emitted during WLFs. This is important improvement made by this work in the means to develop a standard observational method for this kind of phenomena.

Introduction: White-light Flares

In the last decades multi-wavelength observational studies have given different constraints to the energy transfer models during a solar flare, in particular the so called *white-light flares* (WLF), where an enhancement of the white light (WL) continuum emission can be observed. Machado 1986 based on the presence of spectral features such as Balmer and Paschen jumps and strong WL continuum-hard X rays (HXR)-microwave correlations, proposed a classification of the WLF in two different types, which has been studied for some events in a semi-empirical framework. Several observational studies have pushed the WL-HXR correlation forward to include timing, relative horizontal positions, and more recently, height.



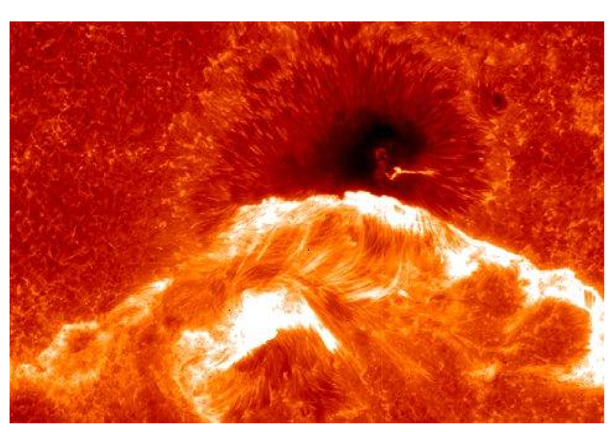


Fig 1. (*Left*) Solar flare observed at the extreme ultraviolet by the *Atmospheric Imaging Assembly* (AIA) on board the *Solar Dynamic Observatory* (SDO). (*Right*) White light flare over an Active Region observed by HINODE

Analysis:

Nowadays several observational methods have been applied to measure the white-light excess from continuum images, giving as a result considerable differences in the estimated energy associated with the flaring event. These techniques are divided in three parts; In the first part differences between images are considered in order to localize the kernels of emission. In our notation, the discrete index (i) denotes a particular frame taken at a certain time which will be temporarily separated from the next frame by the cadence of the instrument. Three differentiation schemes are considered in this work:

Normal $I_{Diff} = I_i - I_{i-2}$

Average $I_{Diff} = I_i - I_{Avg}$

Integration

$$I_{Diff} = \begin{cases} I_i - I_{i-1}, & i < i_{max} \\ I_i - I_{1+1}, & i > i_{max} \end{cases}$$

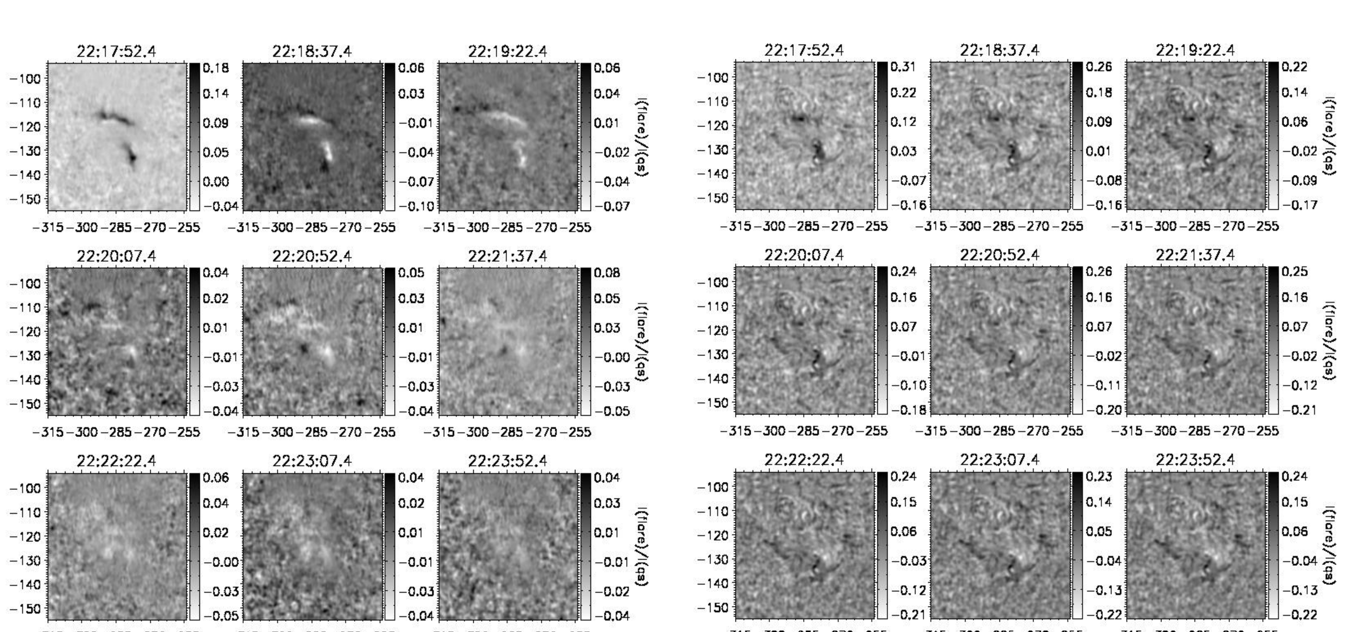


Fig 2. (*Left*) Normal differences (*Right*) Average differences of the white-light flare SOL-2011-09-06T22:20.0

The second step includes a masking procedure which usually relies on geometrical and intensity threshold assumptions regarding the white light emission detected in the previous step. Common masking procedures are the following:

Geometries

1. Circles
2. Ellipses
3. Squares

Threshold

A. N-times the Quiet-Sun-Intensity
B. Background Logarithm
C. Instrumental number

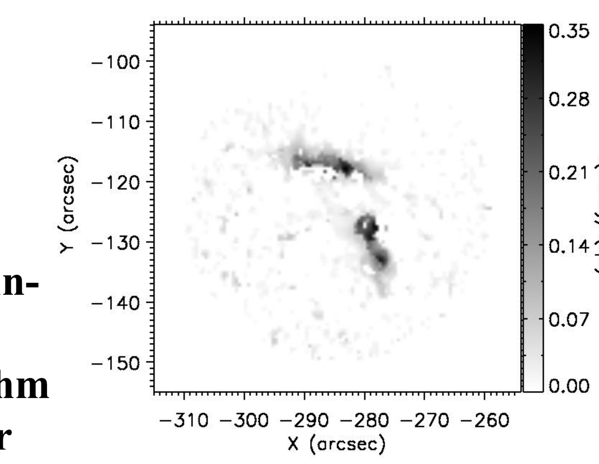


Fig 3. Integration differences + reconstructed signal + circle mask + N-times the Quiet-Sun Intensity for the flaring event SOL-2011-09-06 T22:20.0

Finally, the third step requires the estimation of the white light flare flux itself. This includes either the normal intensitygrams, their differences or, in our procedure, a simple integral reconstruction algorithm to remove the possible emerging artifacts in the final flux estimation. A flow diagram describing this numerical procedure is the following:

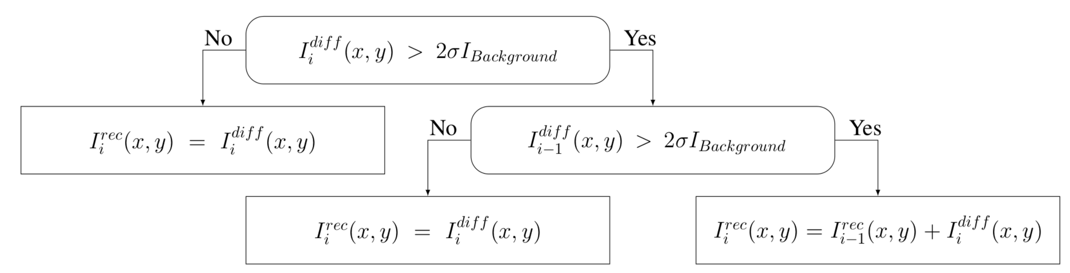


Fig 4. Signal-reconstruction algorithm

Synthetic data:

In order to understand the differences and the advantages of each one of the observational procedures, a control test case (synthetic data) is required, allowing in this way a quantitative analysis of the reliability of the different observational approaches.

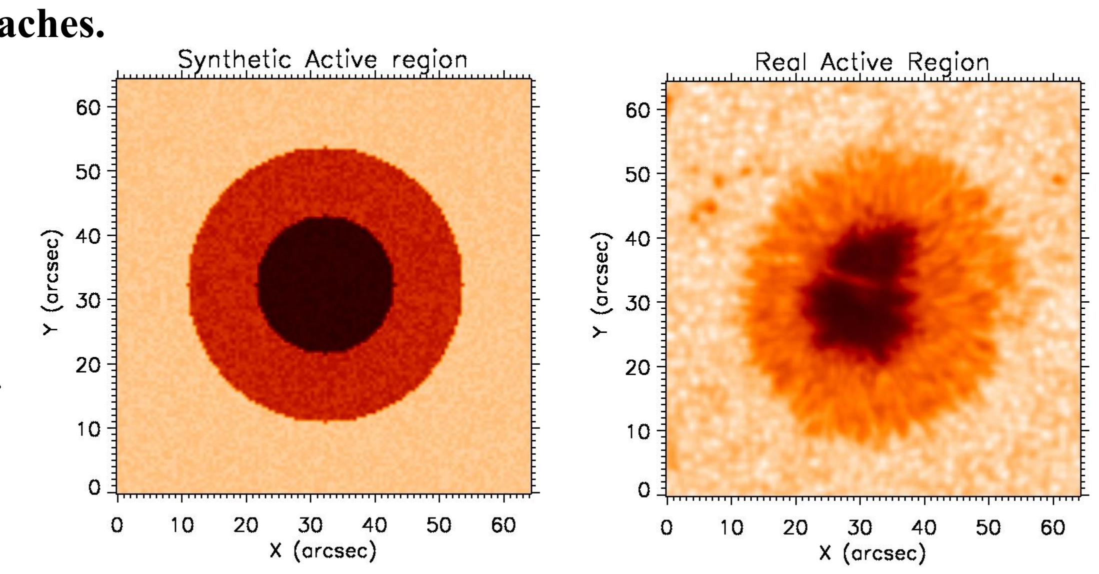


Fig 5. Synthetic (*left*) and observed (*right*) active region, preserving the observational intensity values for the different parts of the sunspot.

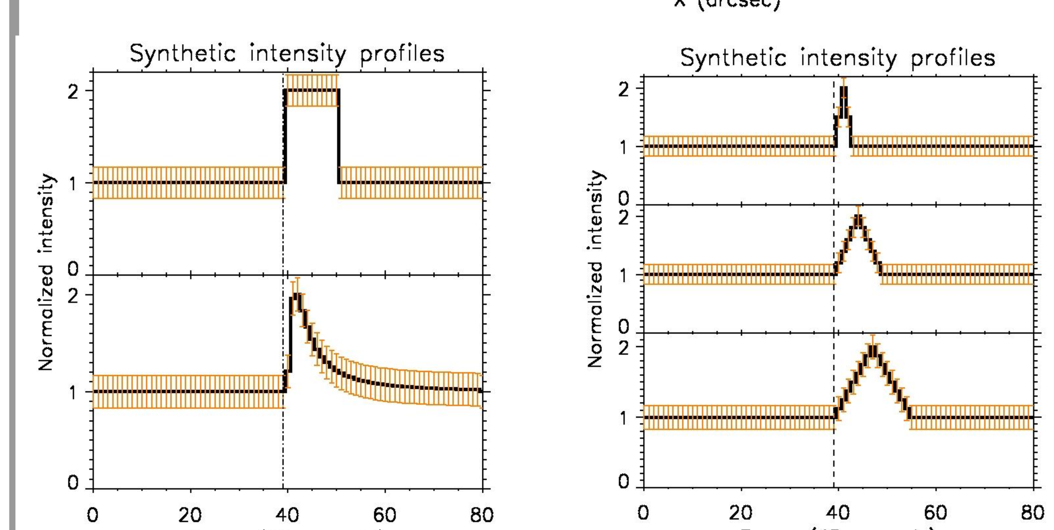


Fig 6. Synthetic flare light curves. Considered shapes include three symmetrical triangular functions with different duration, a step-like and a Planck-like functions for the emission excess. All the profiles have been degraded to take into account the finite cadence of the instrument (HMI).

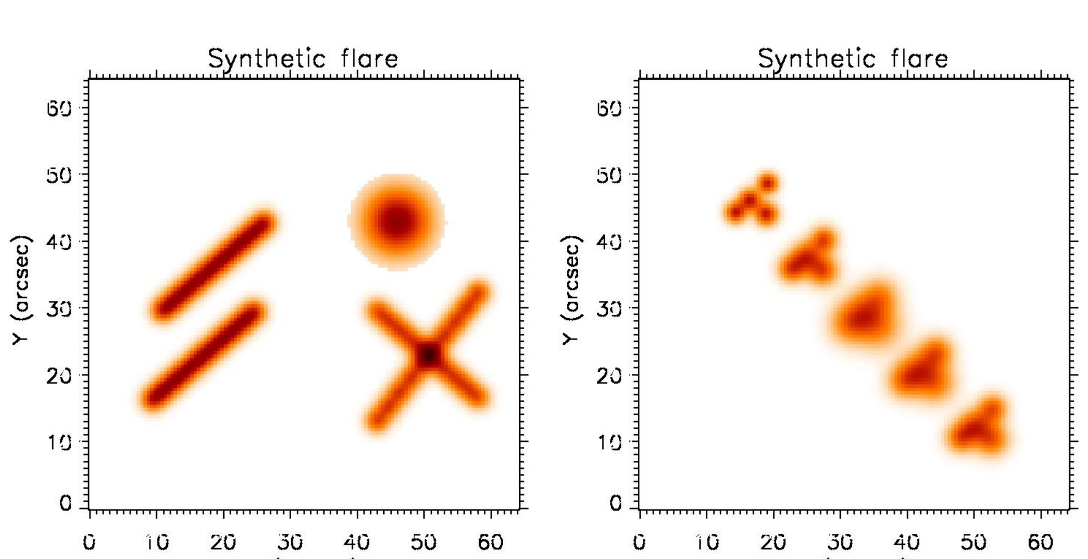
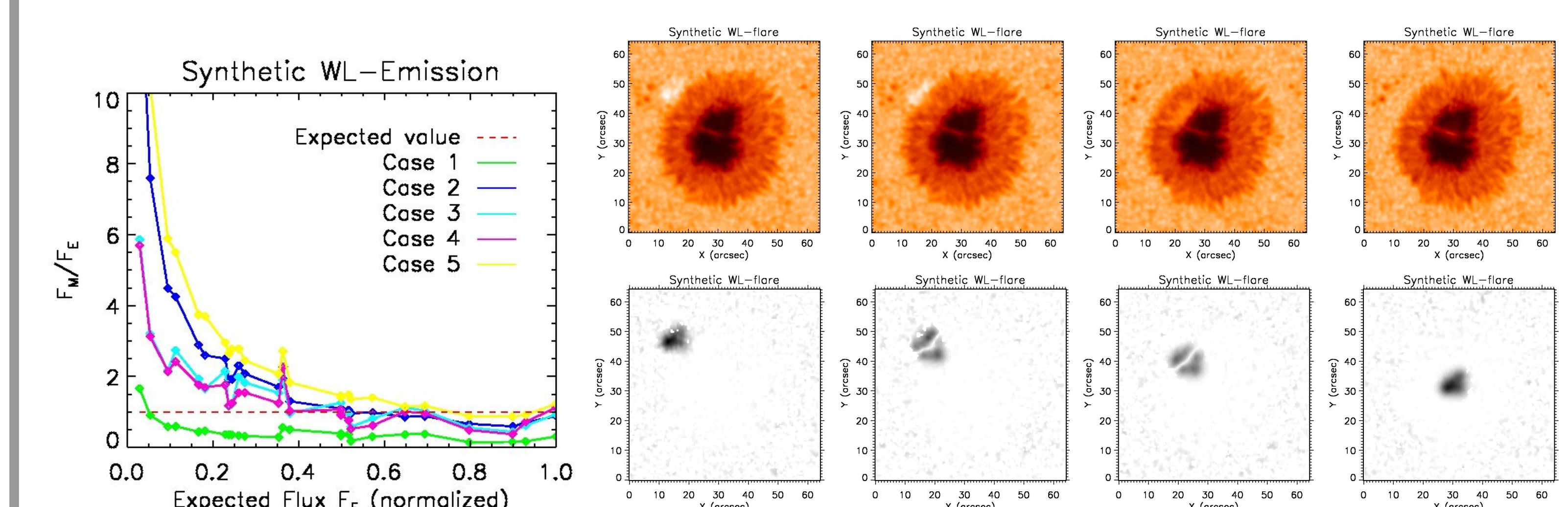


Fig 7. Different geometrical configurations for the generated synthetic flares. These also includes movements of the emission kernels in the field of view and changes itself frame-to-frame.

Results & Discussion:n

We have tested the reduction methods with 25 different types of synthetic white light flares (5 geometries x 5 light curves). For the white light excess estimation our comprehensive approach included 3 types of backgrounds (no spot, synthetic spot, observational spot), 5 differences methods, 5 types of masks and 3 different measurements performed over intensitygrams, their differences, and via the integral reconstruction algorithm (see Fig. 4). This means, that we have measured the synthetic-white-light-excess over the 25 synthetic white light flares in 265 cases. A sample of the resulting measurements is present in Fig. 8, where the x-axis show the expected flux values for each flare (normalized to the brighter synthetic event) and the y-axis shows the measured value normalized by its corresponding expected value.



	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
Step 1	NORMAL	INTEGRATION	INTEGRATION	INTEGRATION	NORMAL
Step 2	(1,A)	(1,-)	(1,A)	(1,A)	(1,-)
Step 3	INTENSITY	INTENSITY	INTEGRAL	INTENSITY	DIFFERENCES

Fig 8. White Light synthetic emission flux recovered using different combination of the reduction methods sample. Each colored line represents a procedure (lower table). Upper-left plot shows the 5 best behaved procedures. Upper-right panels show the synthetic intensitygrams and their integrated differences.

The initial results of this work can be summarized by the following points:

- Fig. 8 shows that the considered procedures behave similarly for high flux events, where the contrast ratio is higher.
- In the case of low energy flares the measurements are harder and all the procedures seem to recover spurious signals due to the low contrast in the intensity maps. In the high flux end of the diagram, all the considered methods seem to underestimate the excess flux. This is the case for all the measurements using the normal differences scheme (Case 1), as a direct consequence of the artifacts introduced by this procedure (Fig. 2).
- These results are directly related with the question, *do all flares are white-light flares?*, due to the fact that the majority of flares present the "Big-flare syndrome", which is that the White-Light excess is often observable during only the most energetic events. However, this does not imply that some White-Light emission may be present in all the occurring flares.
- As a next step, we will apply this methodology to real observations in combination with measurements an EUV, Soft and Hard X-Rays to perform a statistical analysis between the different observables during a White-Light flaring event.

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