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Characterization of white light, SXR and HXR kernels emissions in white light flares observed by SDO/HMI and RHESSI

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Abstract: Solar flares are explosive processes in the solar atmosphere due to the sudden release of magnetic energy. They are characterized by brightness increases in the optical- and radio-wavelengths, movement of vast amounts of solar mass, generation of X-rays and γ-rays. In particular, some solar flares show an increase in white-light emission, as was shown by Carrington in 1859. We analyzed the white light emission and its correlation with X-ray kernels at 6-12, 12-25 and 25-50 keV using SDO/HMI and RHESSI data. We restrict our analysis to flares which have a GOES classification larger than M 1.0, in the period between 1 October 2010 and 31 July 2012. We found that WLF and X-ray fluxes have a semi-logarithmic correlation.

Introduction:

White-light emission during flares is an open question in solar physics as the main radioactive process is unknown and they are deterrents authors have propouse different models explain it. Some of those models are: Overionization in the chromosphere (Hudson 1972; Aboudarham & Henoux 1986), Radiative backwarming processes (Machado et al. 1989), Proton energy losses (Najita & Orrall 1970; Zharkova et al 1993), Thick-target model (e.g., Unsöld 1968).

Is believe know the enhancement in the continuum intensity during a flare has a temporal correlations with the Hard X-Ray emission [4, 7], relative positions [2] and heights [1, 6]. Those lead to some questions:

- **Do exist a correlation between intensities (energies)?**
- **Do all the flares are white-light flares?**
- **Is there any special feature in the XR emission to produce a WLF?**
- **Is the WLF a particular kind of flare?**

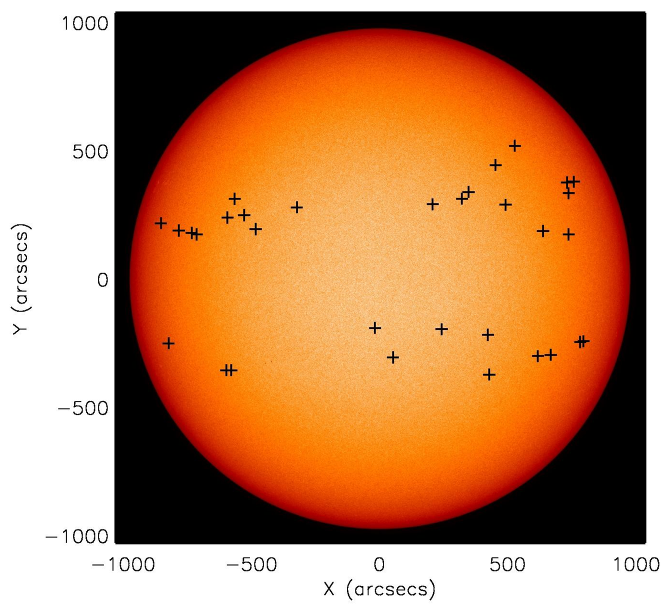


Table 1
Weighted Mean, and Its Associated Standard Deviation, of the *RHESSI* Quiet-Sun Photon Flux

Energy (keV)	Weighted Mean ($\times10^{-4}$ photons s^{-1} cm^{-2} keV^{-1})	σ
3–6	−31.17 (330.99)	±170.19 (±207.25)
6–12	5.97 (−5.24)	±4.75 (±8.46)
12–25	0.51 (−0.73)	±0.94 (±1.34)
25–50	0.02 (0.14)	±0.40 (±0.63)
50–100	−0.08 (−0.74)	±0.29 (±0.54)
100–200	−0.01 (−0.79)	±0.22 (±0.42)

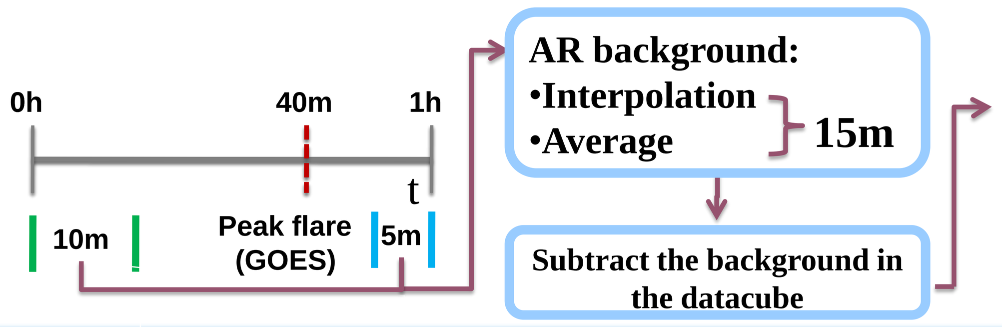
Note. The previous values (Hannah et al. 2007b) are given in brackets.

Month (year)	M class	X class
October (2010)	1	0
November	0	0
December	0	0
January (2011)	0	0
February	3	1
March	2	1
April	0	0
May	0	0
June	0	0
July	1	0
August	0	1
September	5	1
October	0	0
November	1	1
December	2	0
January (2012)	0	0
February	0	0
March	0	0
April	1	0
May	2	0
June	2	0
July	6	0
Total		31

Fig 1: **The top-left image show the positions where each White-Light Flare (WLF) was hosted over and image taken by SDO/HMI in January 14 of 2011 that were a spotless day. The bottom-left table is the X-ray quiet sun emission taken from Hannan et al (2010). The right table show all flares that had an enhancement in the continuum intensity in the first part of the current solar circle.**

Observations:

SDO/HMI: **During October of 2010 and 31 July of 2012 we analyzed all flares (97) with GOES class greater than M1 that were observed by SDO/HMI and RHESSI. The time range was one hour with the pick of the flare in 1-8 Å at the fourty minute.**



$$I_{i+1} - I_i$$

RHESSI observations:

For each WLF we reconstruct RHESSI images within the following energies intervals 6-12, 12-25 and 25-50 keV with integration time of 45 seconds. At 70, 80 and 90 % of the peak emission in each band we computed the flux.

Quiet Sun observations:

To compare the fluxes from HMI and RHESSI , we got the quiet Sun emission from both instruments . For HMI we took 1:30h (120 frames) of observations during the spotless day in Junuary 14 of 2011 taking into account that this time range is 15-30 times of a WLF. For RHESSI we used the fluxes data from Hannah et al. (2010) that are show in figure 1 (*bottom-left*).

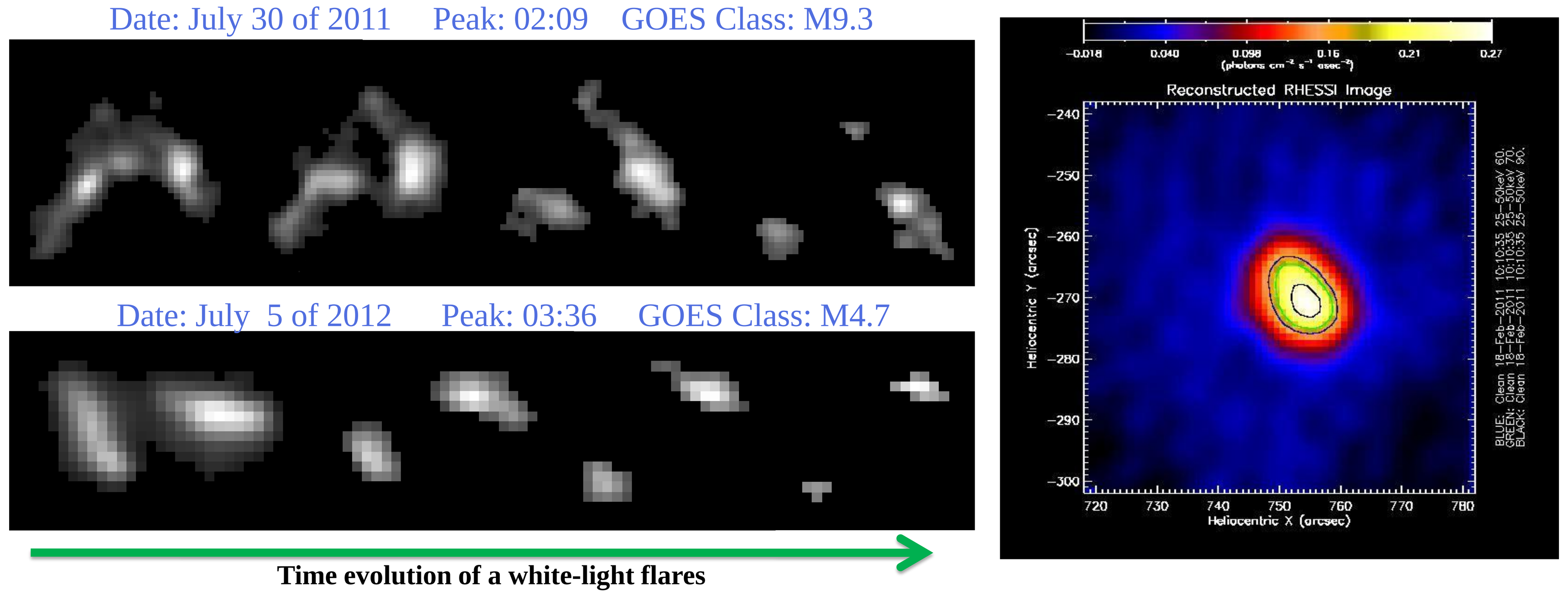


Fig 2: **Time evolution of a white-light flare (*left*) observed by SDO/HMI at 6173 Å and RHESSI in the first part of the current solar cycle. Those images are the active region which hosted flare. Each one was made with different parameters taking into account each flare has different intensities in WL emission. The right image is an example of a RHESSI images in 25-50 keV with the contours at 70 %(blue), 80 % (green) and 90 % (black) of the peak.**

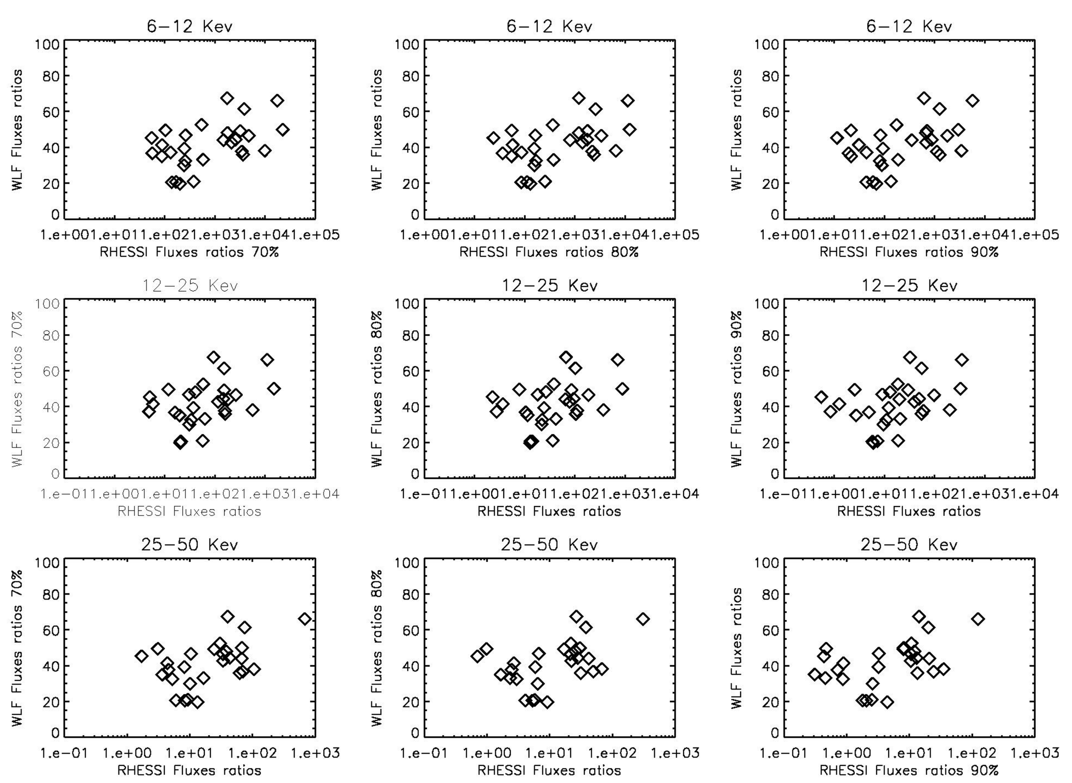


Fig 3: **Graphics of WLF fluxes Vs. RHESSI fluxes unitless for energies bands 6-12, 12-25 and 25-50 keV at 70, 80 and 90% of the emission peak.**

Discussion:

White-light (WL) and Hard X Ray (HXR) emissions are correlated. This implies that the processes creating HXR and WL are correlated. In figure 3 are plots of WLF fluxes and X-ray fluxes. One of those energy ranges is SXR (6-12 kev), the second one is mixed between SXR and HXR (12-25) and the last one is HXR. The observations show that our sample of WLF has a semi-logarithmic correlation. Also, in the figure 4 (right) the three X-class flare have had strong, medium and small enhancement. It shows that there is another physical mechanism that produces WL emission.

$$\text{White light ratios} = \text{RHESSI ratios} = \frac{(F_{fl} - F_{QS})}{F_{QS}}$$

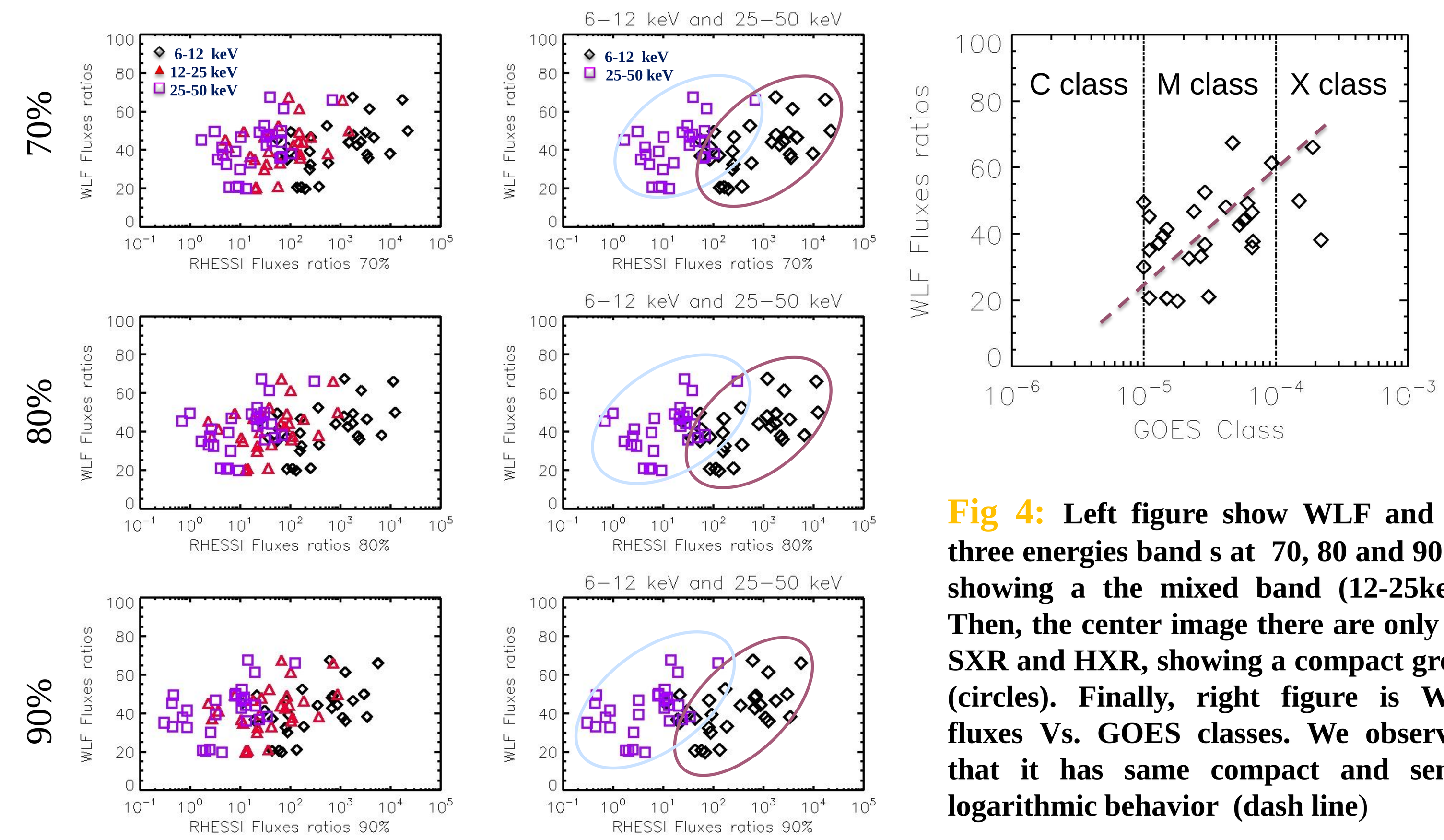


Fig 4: **Left figure show WLF and the three energies band s at 70, 80 and 90% , showing a the mixed band (12-25keV). Then, the center image there are only the SXR and HXR, showing a compact group (circles). Finally, right figure is WLF fluxes Vs. GOES classes. We observed, that it has same compact and semi--logarithmic behavior (dash line)**

Summary and future work:

- **Using up-to-date observations, we have selected a sample of 220 flares of the current Solar Cycle observed by both SDO and RHESSI. All flares had GOES classification above the M1 level. From this initial sample, 31 events showed an enhancement in the WL continuum emission above the Quiet Sun reference level.**
- **Using data from SDO/HMI we constructed time-evolution plots of the Active Regions for these 31 selected events (figure 2, left). For this procedure 3 different reduction methods were applied to recognize the White Light signal in each event (Frame-to-Frame differences, Interpolation Differences and Averaging Differences). Flux measurements were performed using a masking procedure over the intensitygrams, Quiet Sun background emission using a sample of 120 frames of a "spotless" day in 2011.**
- **The X-ray fluxes were computed using RHESSI data, over contours of 70, 80 and 90%, and in the energy ranges of 6-12, 12-25 and 25-50 keV. A normalization procedure was applied using the RHESSI Quiet Sun observations as reported by Hannah et al (2010).**
- **A SDO-RHESSI scatter plot was derived from the described observations and the derived ratios of the emissions (WL-XR). This plot also was constructed for the GOES flux, showing that the resulting sample is fairly homogeneous.**
- **The next step in this work consists of the construction of similar scatter plots for events without a clear enhancement in the continuum emission (i.e. not WLF) in order to recognize possible differences in the distribution shape.**

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