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Energy Distribution Heating Events Observed by HRIEUV During the May 2020 Solar Orbiter Perihelion

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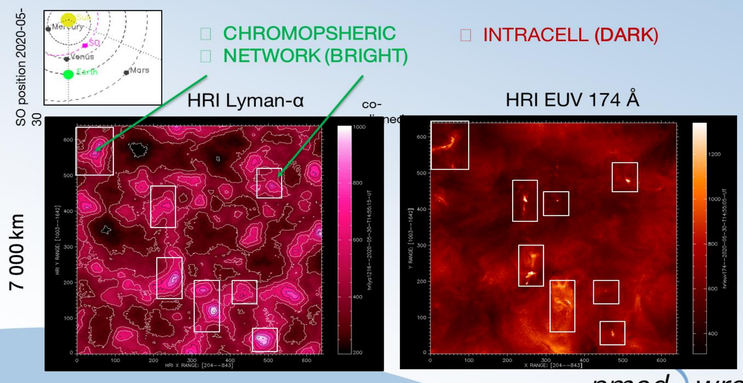
High resolution observations of the solar corona with the EUI telescope onboard the Solar Orbiter mission during the perihelion campaign at 0.56 AU revealed omnipresent impulsive quiet-un emissions in the 174 A filter, at previously unresolved temporal/spatial scales. Individual brightenings of the smallest linear size till 0.2Mm show temporal variability within tens of seconds. These EUV quiet sun brightenings, which have been nicknamed campfires, appear as individual quiet-Sun events or simultaneous / consecutive clusters situated along quiescent loops, where usually steadier emission is expected. The emission measure varies strongly almost in every pixel during the 260 sec observation time.
The thermal energy content of individual impulses is calculated from observed emission enhancements and the derived temperature. EUV telescopes indicates heating events observable in coronal iron lines. The observed energy contents vary in the range 10^{21}–10^{24} ergs, which is in agreement with the lower limit estimation of Parker’s nanoflare heating scenario.

I. Campfires are located above the chromospheric network: Berghmans et al, A&A, 2021, in press

EUI HRI Campfires ZOOM

1st Solar Orbiter Perihelion: 30-05-2020, 14:55 – 15:00 UT, 5 sec cadence

- Smallest campfire event [2 pxl] EUV enhancements



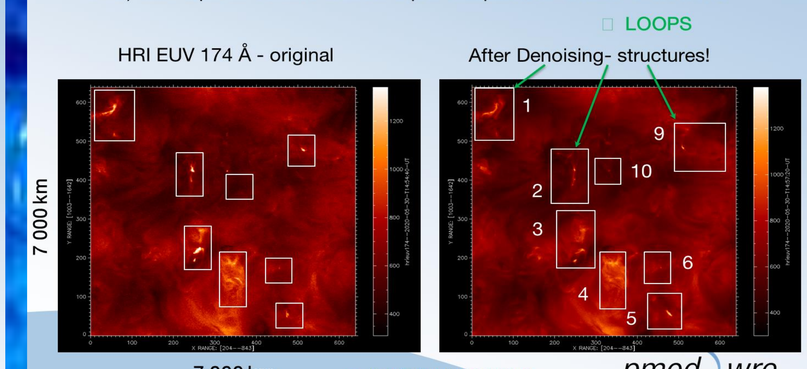
3.5 EIT HR PIXELS

pmod wrc

II. Image processing reveals campfires are the loop brightenings, Berghmans et al, A&A, 2021, in press

Nanoflares Structures Extraction

- We applied the image processing (eigenvalues decomposition in space and time) technique to reduce noise and put campfires structures in evidence



3.5 EIT HR PIXELS

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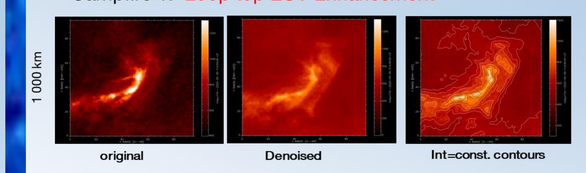
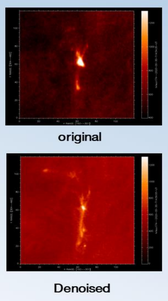
III. EIT nanoflares observed as bright dots have an intrinsic variety of structures, Berghmans et al, 2021

Nanoflares ZOOM 1: Variety of structures

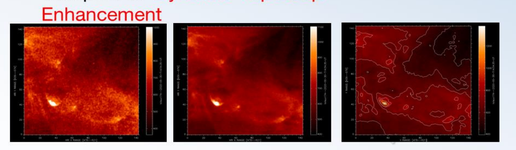
Campfire 1: Loop top EUV Enhancement



Campfire 2: Multi-loop event



Campfire 9: Dynamic Top Loop Enhancement



EUI HRI sheds light on inner nanoflare structure < 1 EIT PIXEL

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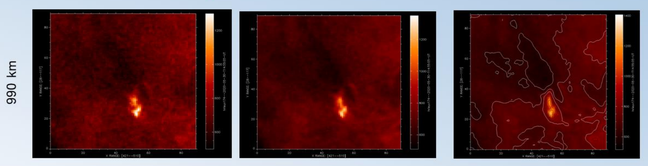
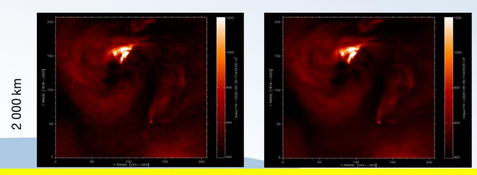
II. EIT and CDS nanoflares observed as bright dots have an intrinsic variety of structures, Berghmans et al,

Nanoflares ZOOM 2: Dynamic events

Campfire 5: EUV nanojet



Campfire 23: Brightening at loop footpoints

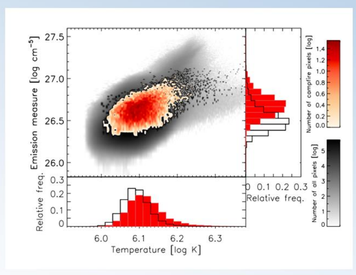


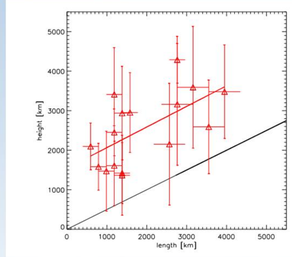
We observe both footpoint and loop top EUV brightenings!

Visual examination shows the simultaneous or sequential propagation of luminance in the loop as predicted (Priest, 2000).

IV. Emission Measure, temperature and Vertical extend of campfires

Berghmans , P.Antollin, D. Long et al. 2021





Usually unknown parameter - vertical extend
Zhukov , Mierla, Auchere et l., 2021, A&A, in press

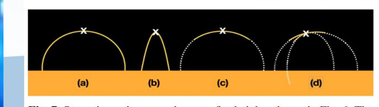


Fig. 7. Scenarios to interpret the campfire heights shown in Fig. 6. The yellow solid lines are the observed campfires, the dotted lines are the invisible loop segments, and the white cross is the triangulation point.

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V. Thermal Energy per pixel

Thermal Energy

Energy of impulsive EUV brightening: is determined from the observed ΔEM increase in the pixels.

$$\Delta E_{th} = 3k_B T\sqrt{\Delta M l w q h}.$$

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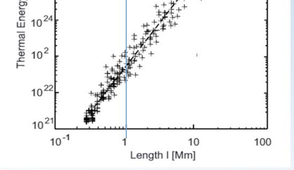
Event occupies only partial coronal volume



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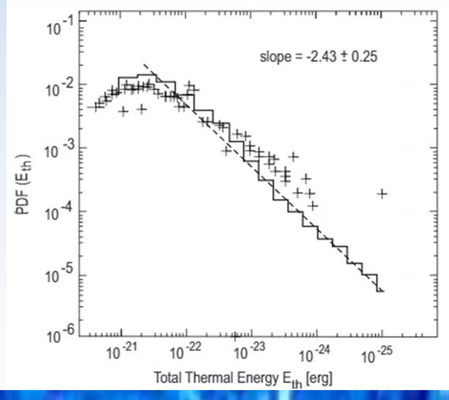
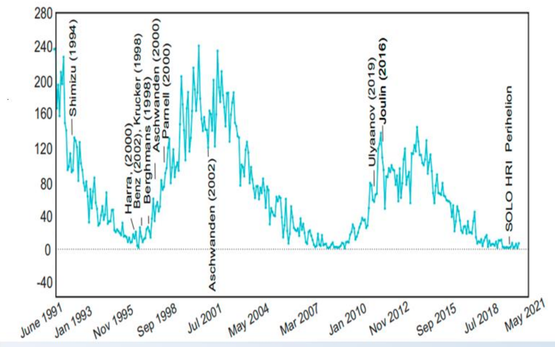
VI. Campfires Thermal Energy per event

Main findings





VII. Campfires Thermal Energy

Picoflares energy range

Index α	Energy erg	Number of frames	Temporal resolution,s	Number of events	Instrument	Paper
1.54	10^{28} -10^{32}			3.0×10^4	SMM/HXRBS	Crosby et al. (1993)
1.74	10^{25} -10^{30}	60	24	1.0×10^4	YOHKOH/SXT	Shimizu et al. (1997)
2.0	10^{24} -10^{27}	173	66	1.0×10^4	EIT	Berghmans et al. (1998)
1.79	10^{24} -10^{26}	173	125	281	TRACE	Aschwanden et al. (2000b)
1.7	10^{25} -10^{27}			1.1×10^3	CDS	Harra et al. (2000)
2.4	10^{23} -10^{26}	13	115	5.0×10^3	TRACE	Parnel and Jupp (2000)
2.3	10^{25} -10^{27}	21	128	1.2×10^4	EIT	Benz and Krukcer (2002)
1.8	10^{25} -10^{27}	31	80	5.0×10^3	TRACE	Aschwanden and Parnell (2002)
1.73	10^{23} -10^{28}	700	120	2.0×10^5	AIA	Joulin et al. (2016)
2.18	10^{23} -10^{25}	300	12	1.0×10^5	AIA	Ulyanov et al. (2019)
2.3	10^{20} -10^{25}	50	5	1.5×10^3	HRI	SOLO 1st perihelion

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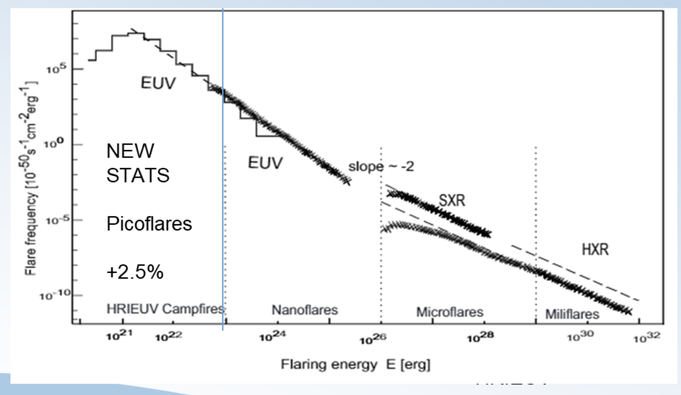
VIII. Coronal heating by flares – updated by new EUI HRI events M. Aschwandedn 2010 plot

Coronal heating by Flares

Extended energy range toward small energies

Observed campfires venets contribute extra to the coronal heating of about 2.5 %



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Campfires impact on on coronal heating

Conclusions

- The thermal energy content of campfires detected here with the threshold ≥ 5σ has been evaluated at the peak of emission measure enhancements.
- The energy distribution of thermal energy per event is approximate power law. At low energies, approaching picoflare value of 10^{21} ergs, the distribution is influenced by the instrument resolution.
- At high energies the thermal energy content is limited by 10^{26} ergs per observed event due to 260 sec total observational time.
- The existence of picoflares is compliant with the necessary power balance in solar corona and the quantities of free magnetic energy deposited for heat.
- EUI campfires are a new picoflare extension of the flare-like events family

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