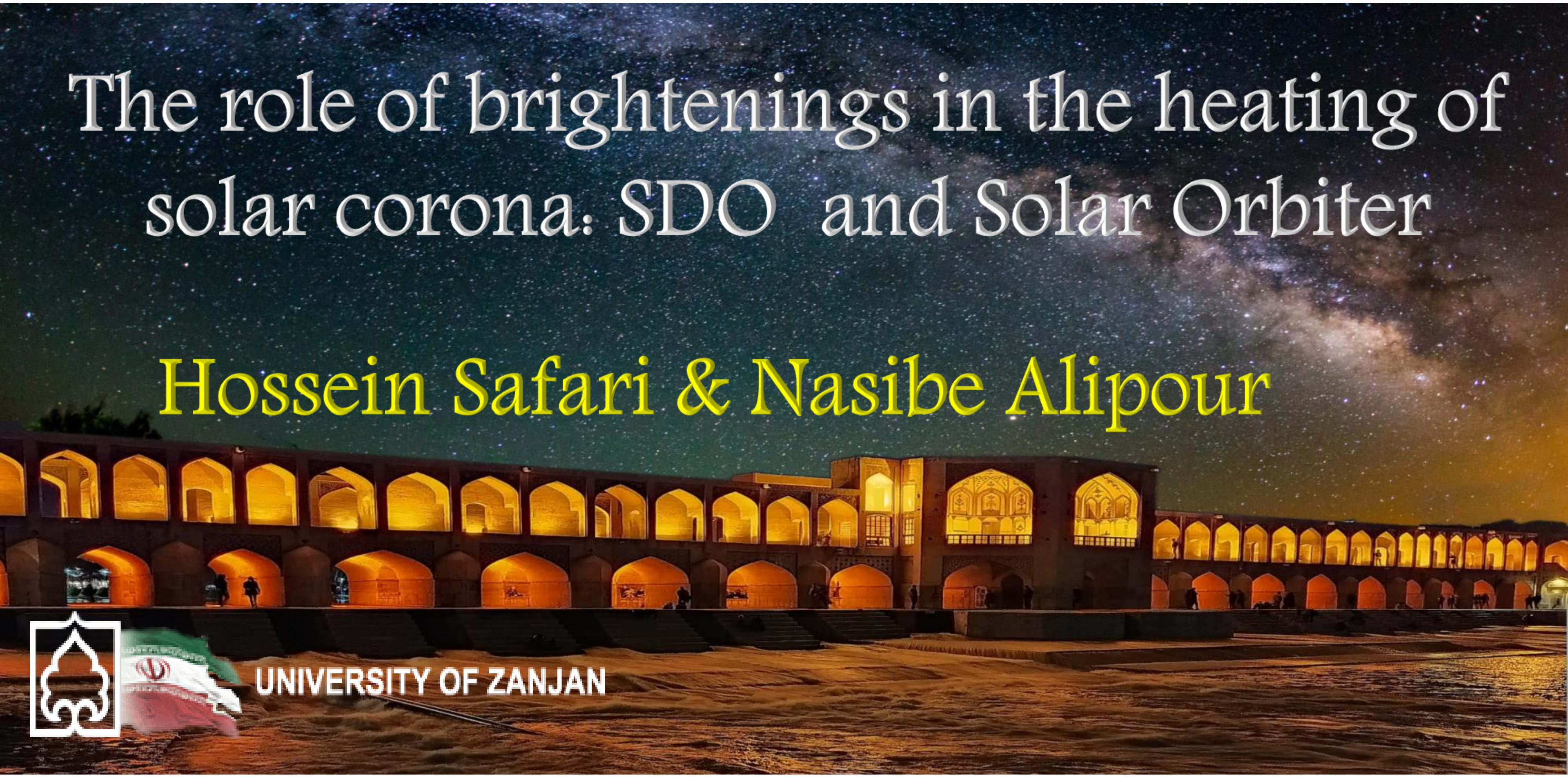
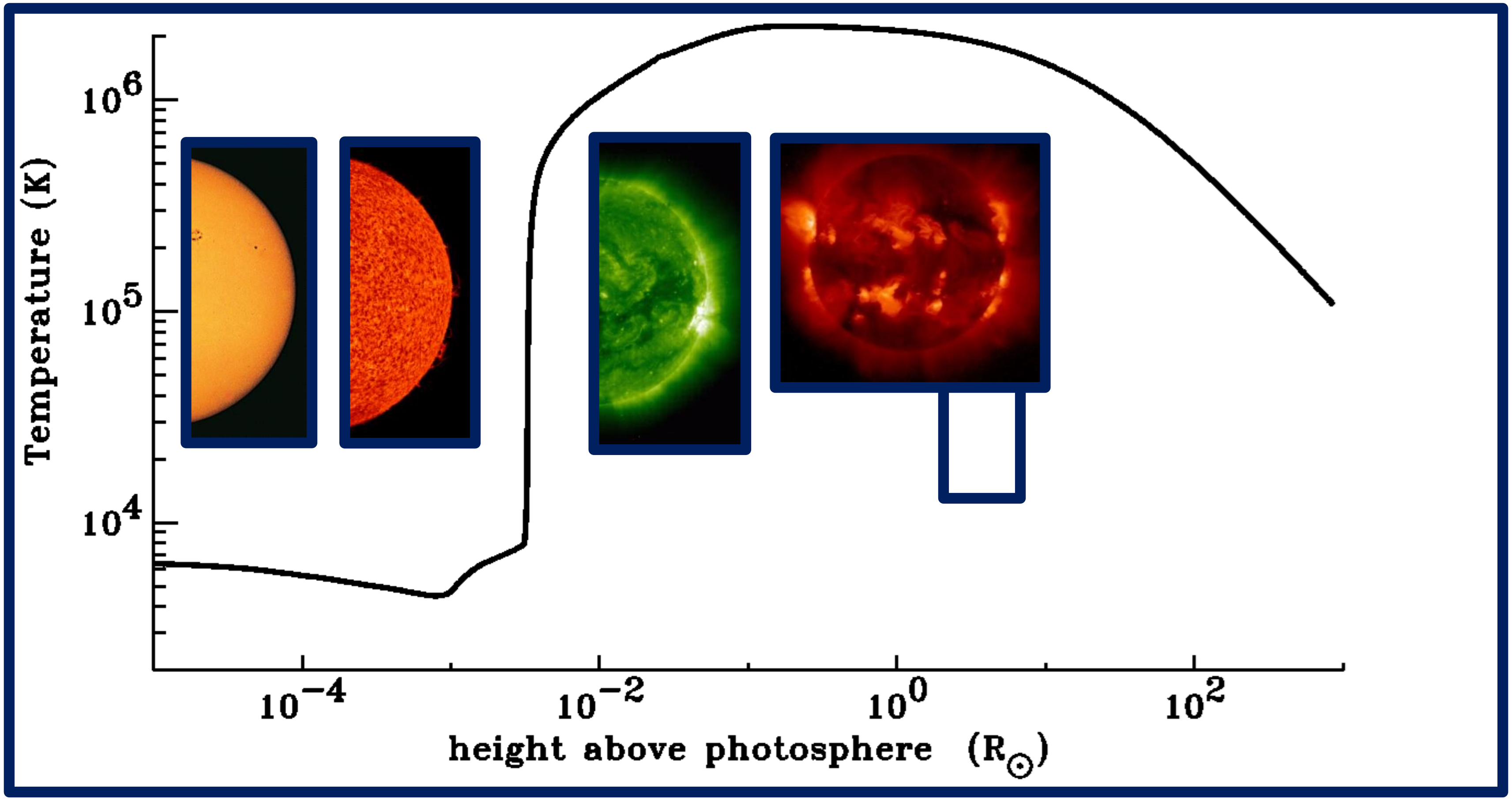


The role of brightenings in the heating of solar corona: SDO and Solar Orbiter

Hossein Safari & Nasibe Alipour

UNIVERSITY OF ZANJAN

Coronal Heating Puzzle

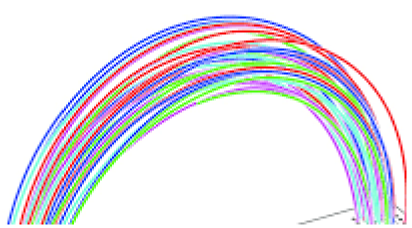


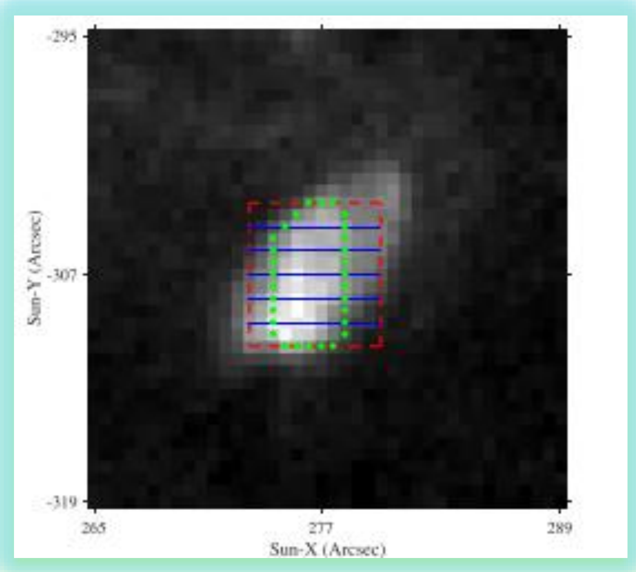
Coronal Heating:
Small Scale Events

- ❑ Coronal Bright Points (CBPs) ➔ mini ARs
- ❑ Campfires ➔ the most miniature flares
- ❑ …

Brightenings: CBPs and campfires

- Solar CBPs and campfires (the most miniature flares) are ubiquitous in the quiet Sun. They may release magnetic energy to heat the solar corona, but their contribution to the energy flux has not been determined yet.





Machine Learning: Automatic Detection of CBPs and Campfires

We develop a method based on Zernike moments (ZMs) and machine learning (support vector machine classifier) for automatic identification and tracking of CBPs and campfires observed by Solar Dynamics Observatory and Solar Orbiter/EUI.

D=0.56au
30 May 2020

Mission highlights: The closest ever images of the Sun, the first ever close-up images of the Sun's polar regions

Zernike moments (ZMs)

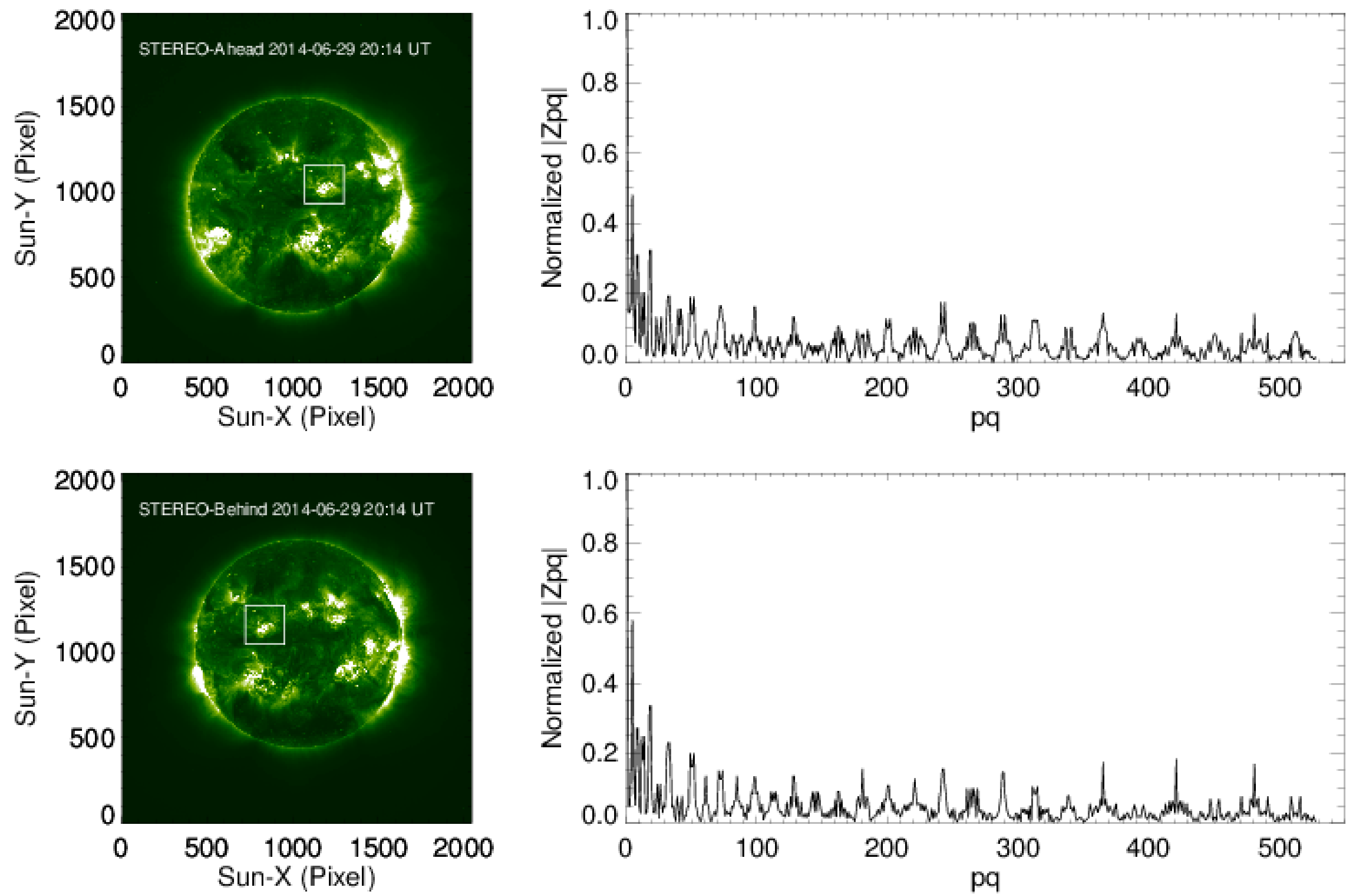
$$\boldsymbol{V_{pq}(r,\theta) = S_{pq}(r)e^{iq\theta}} \qquad p-|q| = even \qquad |q| < p \qquad (x^2+y^2) < 1$$

$$\int_0^{2\pi}\int_0^1 V_{nm}(r,\theta)V_{pq}(r,\theta)\, rdrd\theta = \left\{ \begin{array}{ll} \dfrac{\pi}{p+1} & p=n, q=m \\ 0 & other \end{array} \right\}$$

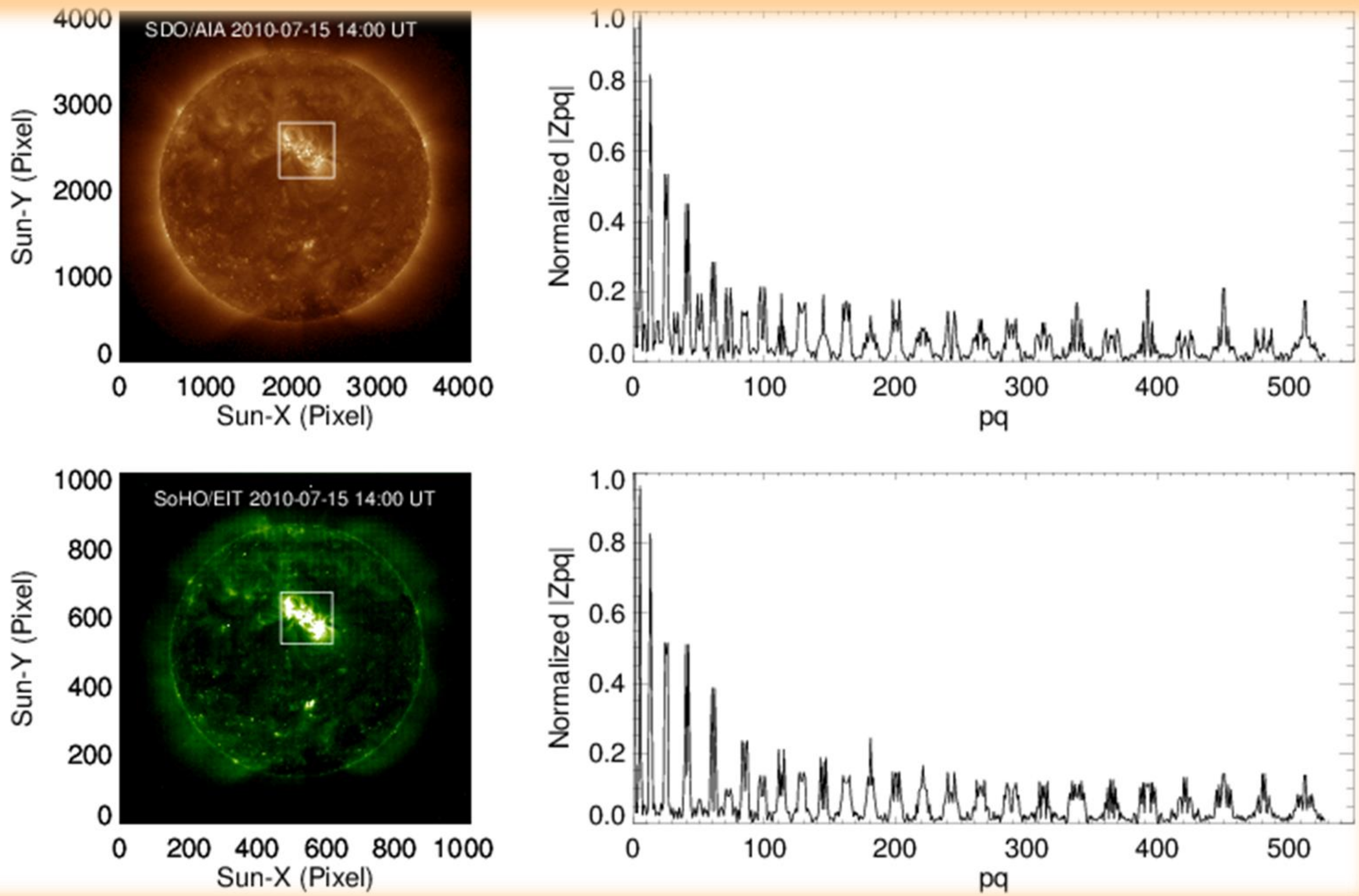
$$\boldsymbol{S_{pq}(r) = \sum_{k=0}^{\frac{p-q}{2}} (-1)^k \frac{(p-k)!}{k!\left(\frac{(p+q)}{2}-k\right)!\left(\left(\frac{p-q}{2}\right)-k\right)!} r^{p-2k}}$$

$$Z_{pq} = \frac{p+1}{\pi}\int_0^{2\pi}\int_0^1 V_{pq}(r,\theta)f(r,\theta)rdrd\theta$$

Properties of ZMs: rotation invariance



Properties of ZMs: scale & translation invariance



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Prediction of Flares within 10 Days before They Occur on the Sun

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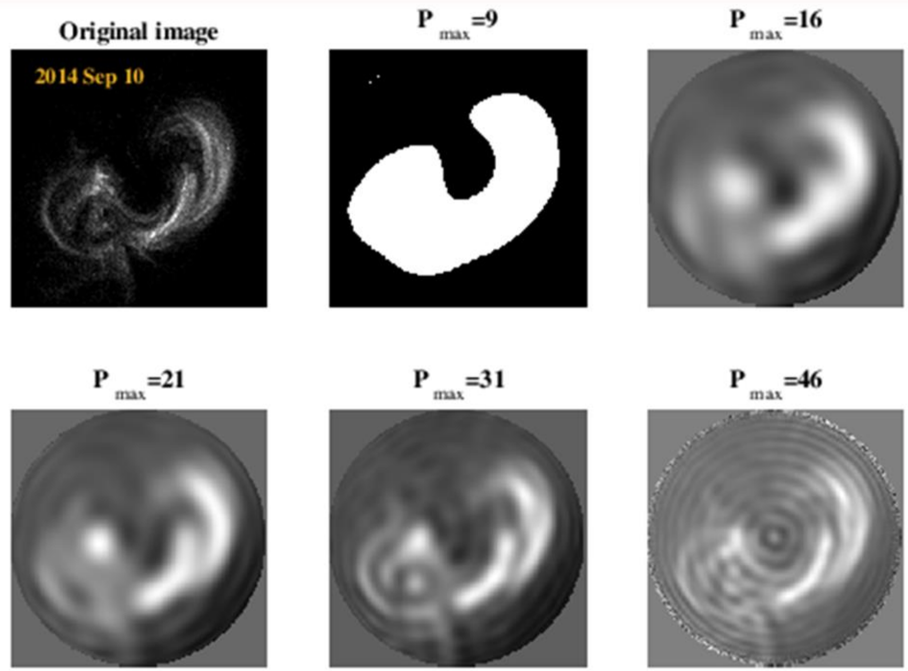
Reconstruction error



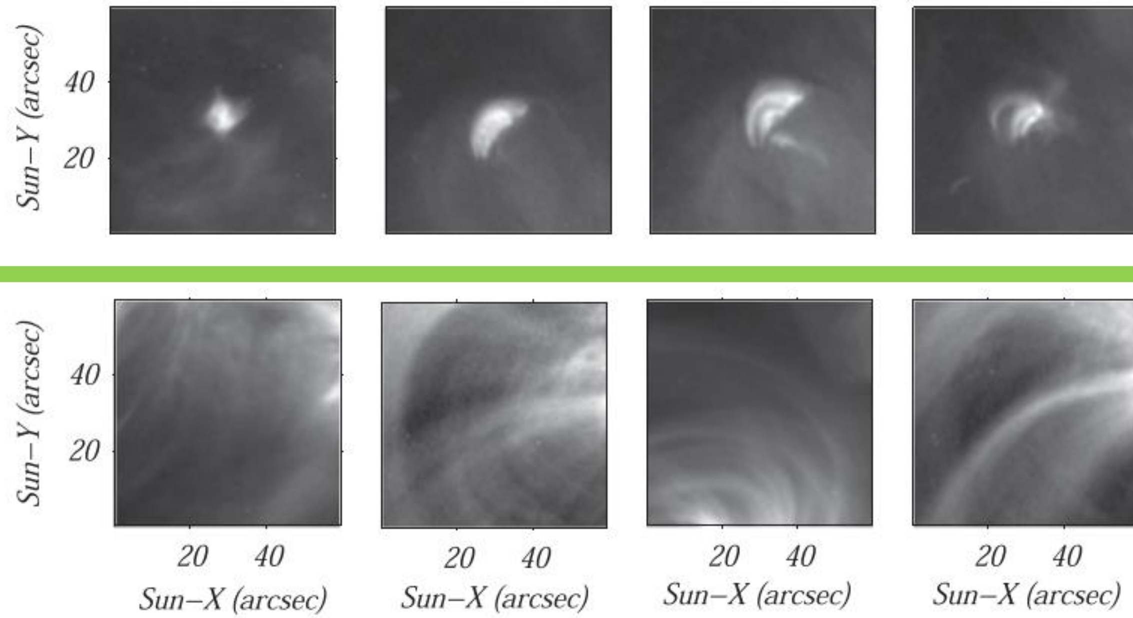
The main reasons for using ZMs:

- The Zernike Polynomials ➔ 2D orthogonal and complete set functions ➔ ZMs are unique and independent signatures.
- A finite number of ZMs➔ reconstruction of the original image
- **ZMs**➔ less sensitive to the noise of the image.
- |ZM|➔ rotation invariant
- image normalization➔ ZMs can be made into scale and translation invariants.
- ZMs ➔ geometry and morphology of the object

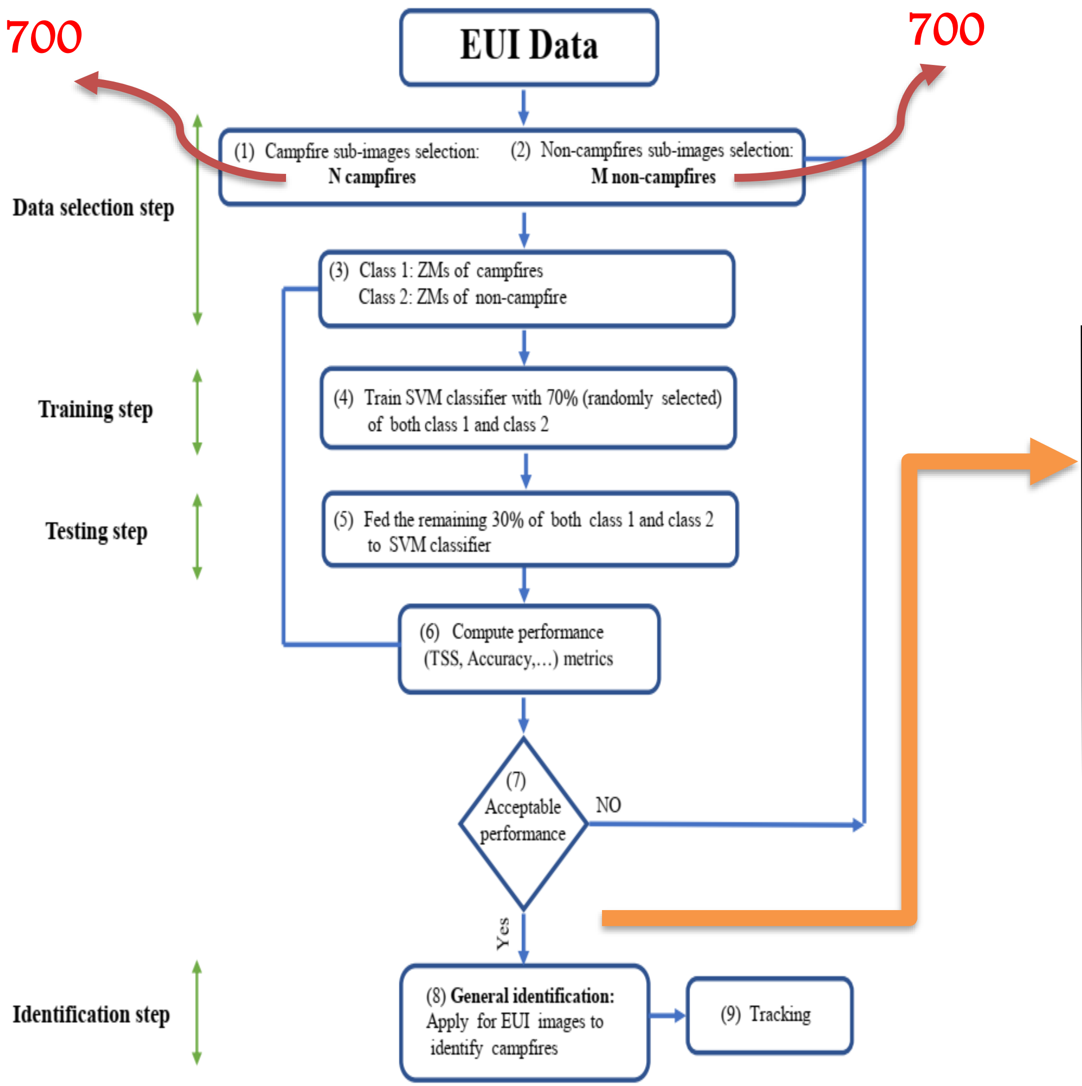
Support vector machine (SVM)

- The SVM, a high-performance classification method originally designed for the two class statistics problems, was developed based on a decision boundary that separates the training points. Two hyperplanes (parallel to the decision boundary) with the maximum margin included the least error in classification. The SVM with the Gaussian kernel function was applied to identify CBPs and campfires.

Campfires: EUV brightenings, events that contain the small-scale loops, elongated loops, loop apexes, and contact points



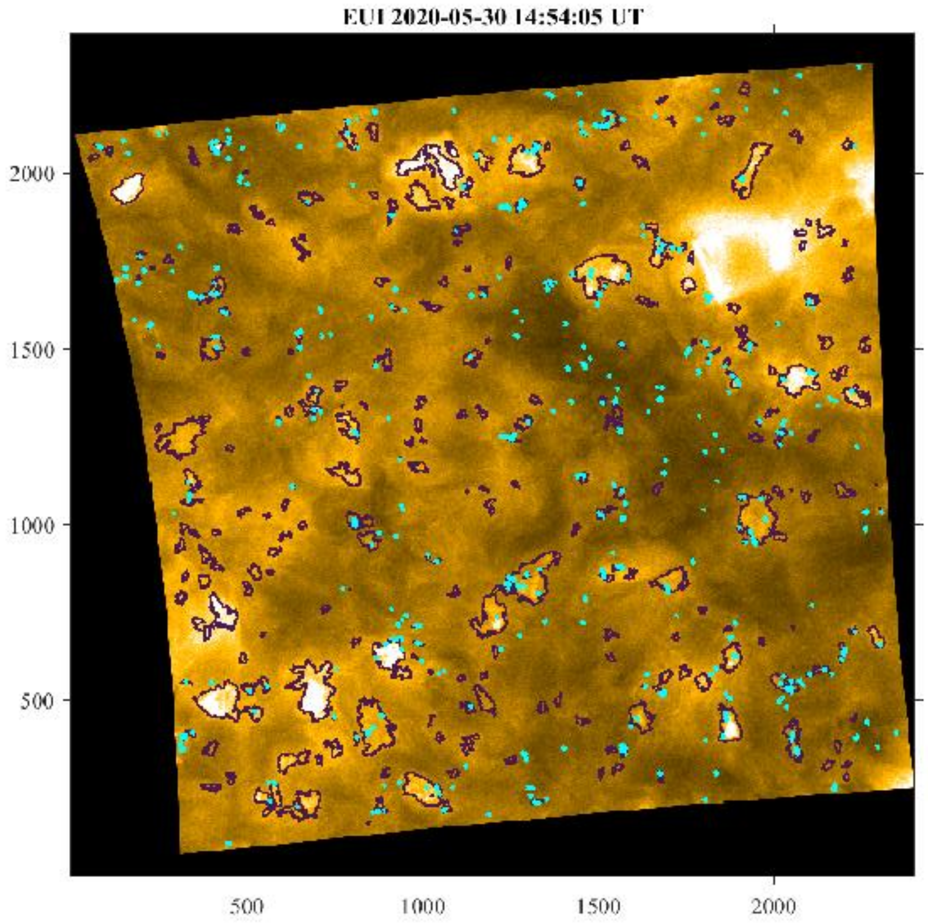
Non-Events



A schematic flowchart with nine primary steps for identification and tracking method of campfires.

Score	Mean
Recall positive	0.93±0.02
Recall negative	0.96±0.01
Precision positive	0.96±0.01
Precision negative	0.93±0.02
f1 score positive	0.95±0.01
f1 score negative	0.95±0.01
Accuracy	0.95±0.01
Heidke Skill Score (HSS)	0.90±0.02
True Skill Statistic (TSS)	0.90±0.02

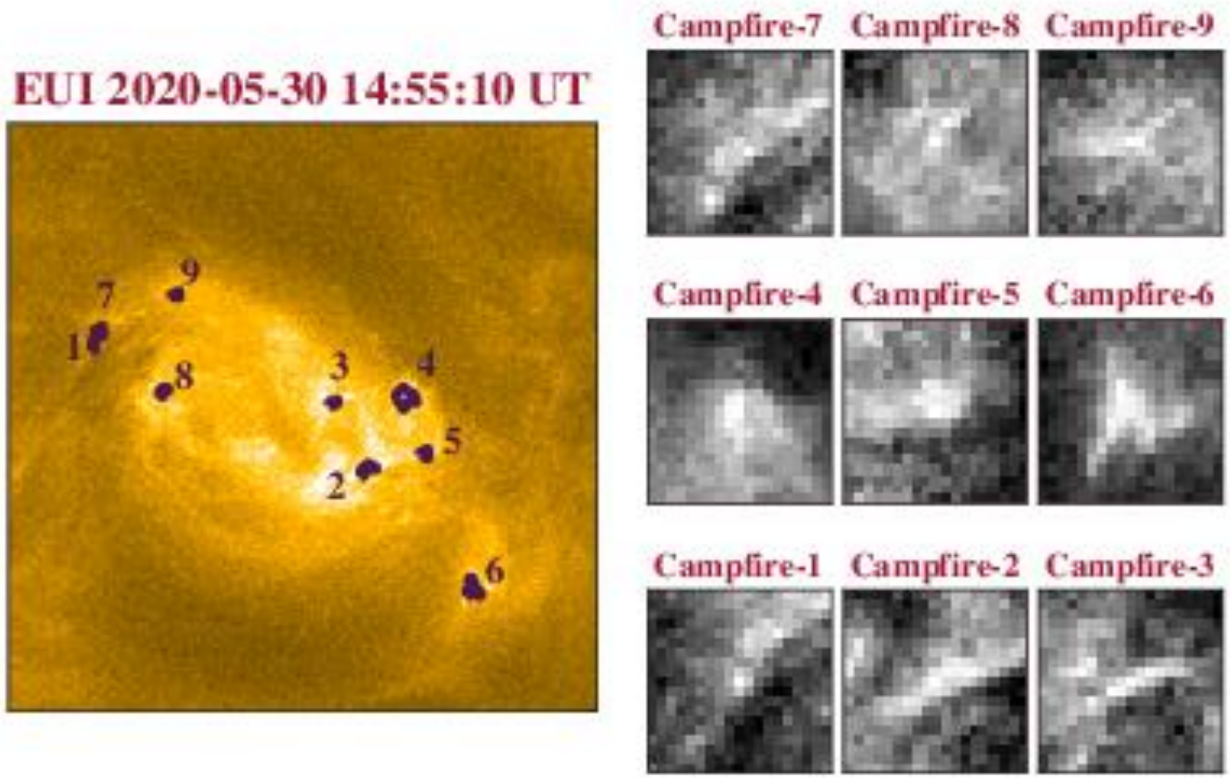
Coronal campfires: Solar Orbiter

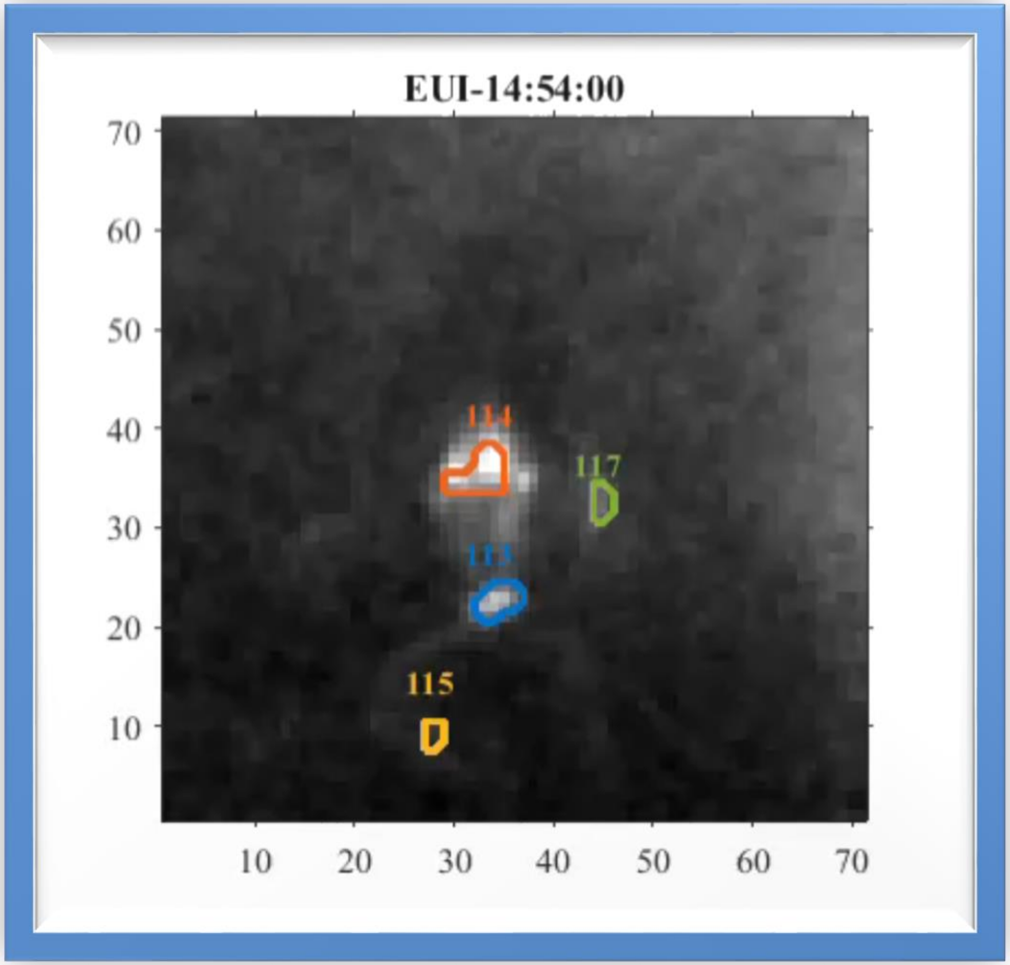


Number of Coronal Bright Points: 314

Number of Campfires: 411

Campfires associated with a CBP





EUI-14:54:00
70
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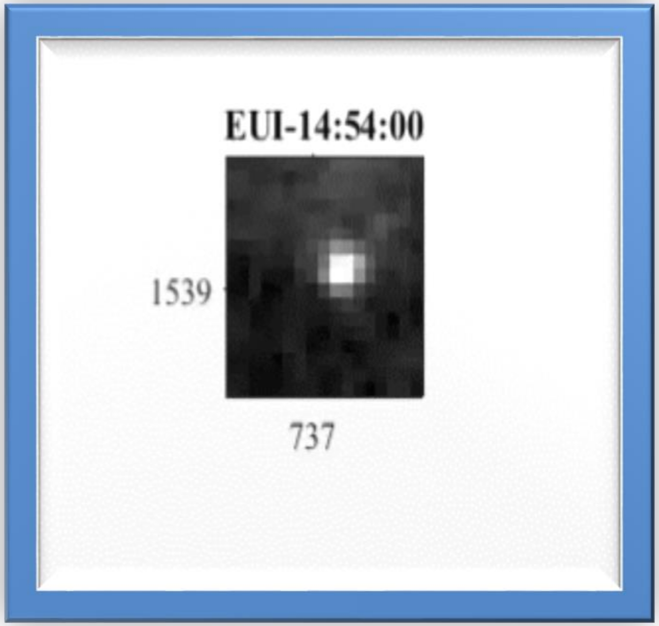
114
117
113
115



EUI-14:54:00
1539
737

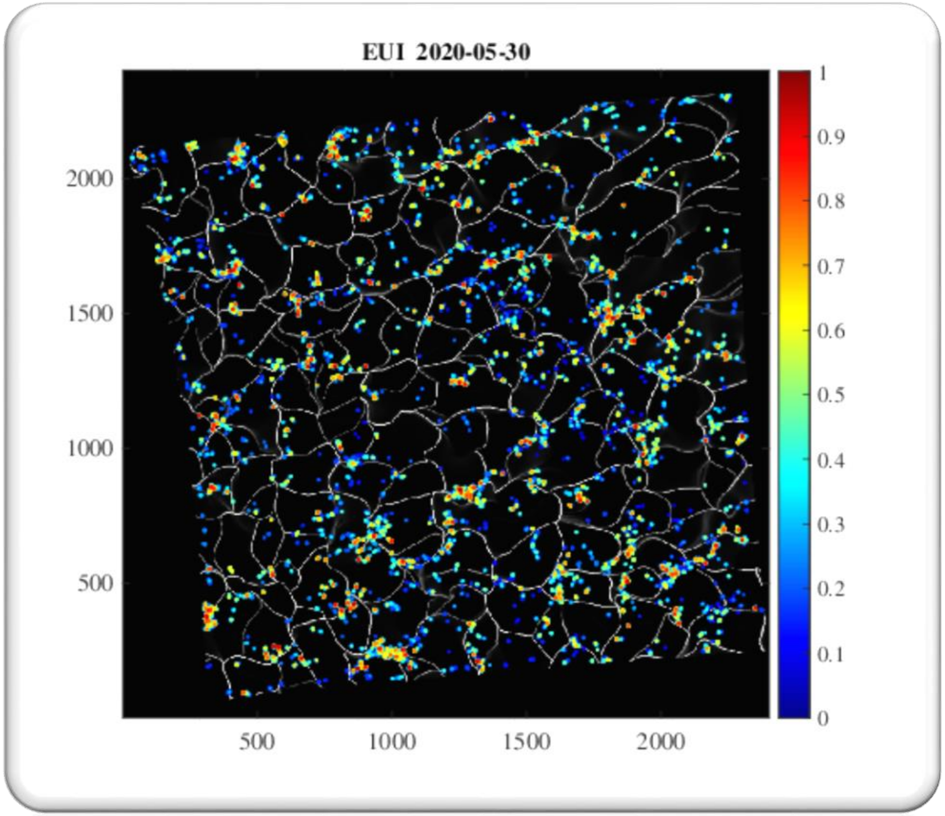
Statistics of campfires:

A sequence of 50 EUI at 174 A images

Features	Numbers
Campfires	9282
Campfires > 5 sec	3250
Campfires associated with CBPs	4354
Campfires without CBPs	4928

Birthrate: 9282/(Area×245 s) = 2.2e-16 $m^{-2}s^{-1}$
Area=1.7204e+17 m^{-2}

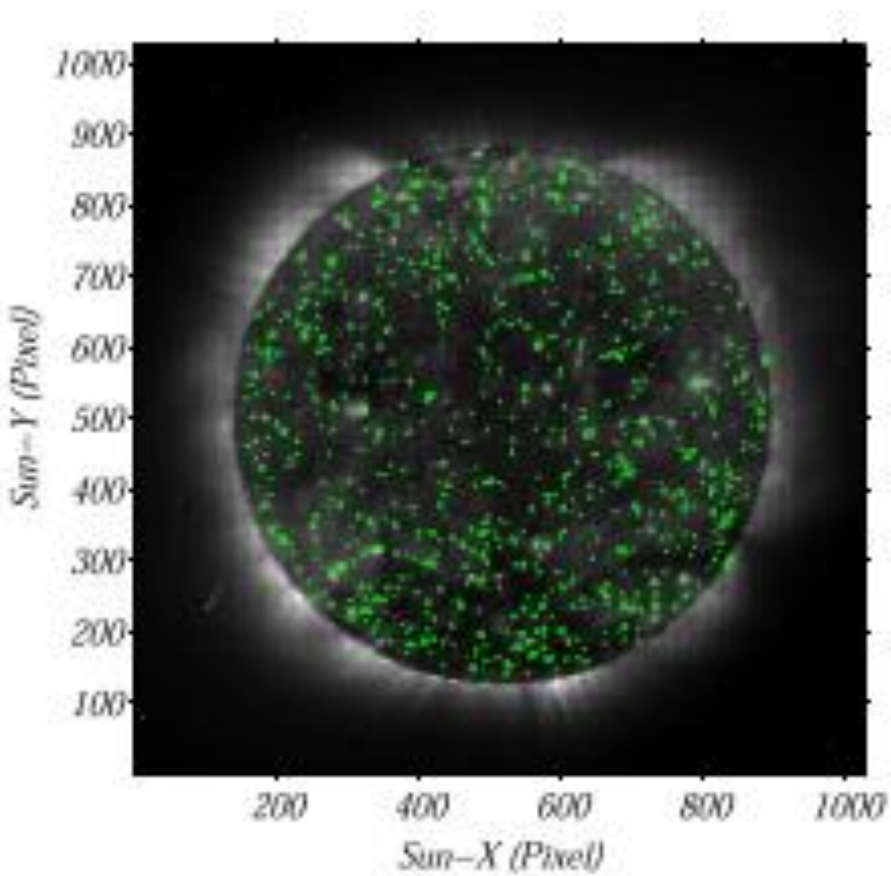
Campfires Locations and Supergranules



Statistics of CBPs:

More than 140,000 CBPs for 8 years

SDO AIA at 171 A



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Energetics of Solar Coronal Bright Points

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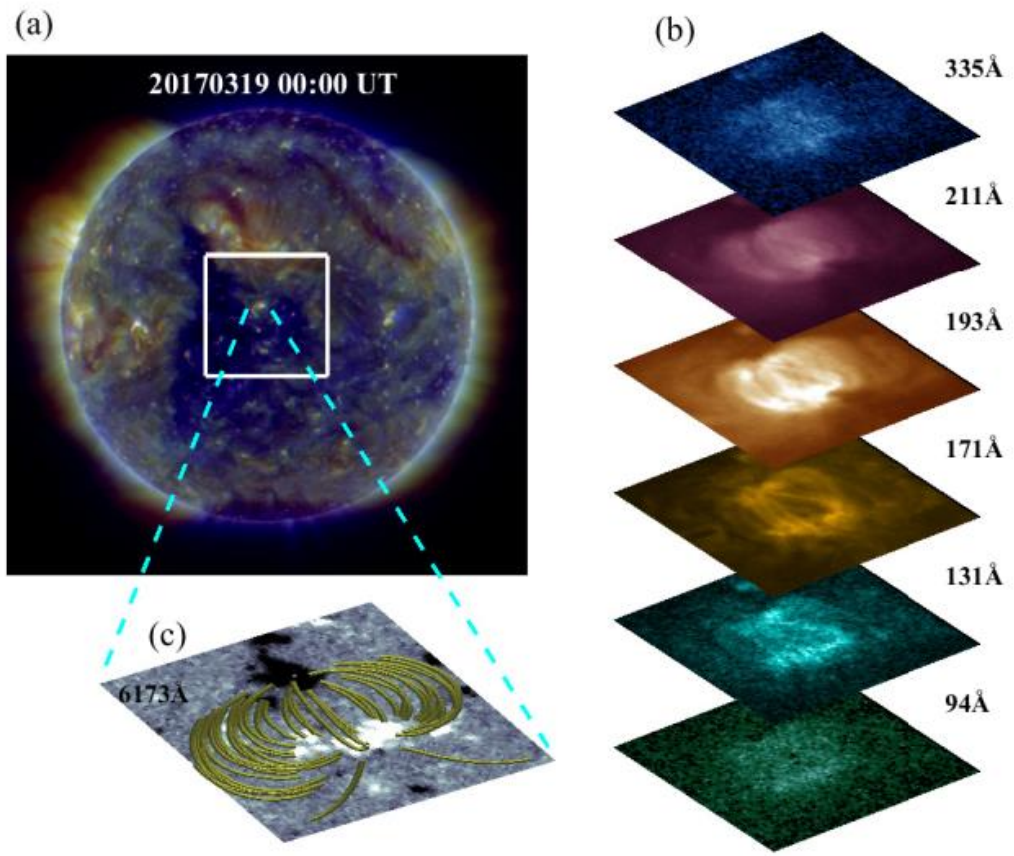


Energy–loss flux

- Radiation and conductive loss flux

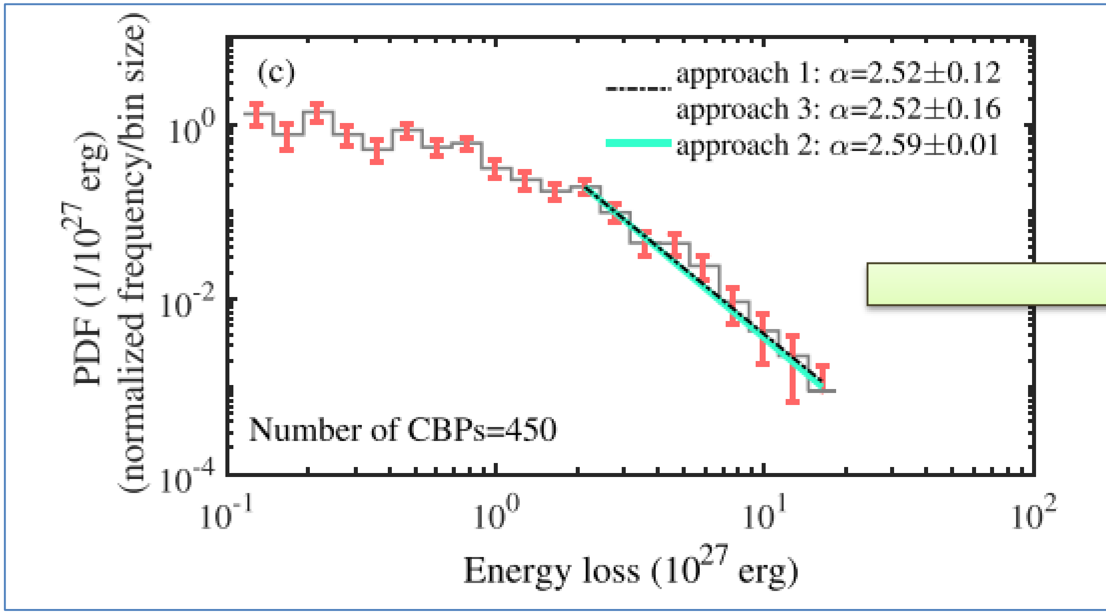
$$p_{loss} = p_r + p_c$$

$$p_r = n_e^2 \Lambda(T) V$$

$$p_c = \frac{2}{7} \kappa T^{\frac{7}{2}} \frac{A_{cross}}{l_{1/2}}$$

$$A_{cross} = f A_{CBP}$$

$$f = 0.12$$



$\boldsymbol{\alpha = 2.59}$

CBPs total energy-loss flux$=(4.84 \pm 1.6) \times 10^3 \text{erg cm}^{-2}\text{ s}^{-1}$

Withbroe $= 3 \times 10^5 \text{erg cm}^{-2}\text{ s}^{-1}$ ratio=**1.6%**

$$W(E_{\min} \le E \le E_{\max}) = \int_{E_{\min}}^{E_{\max}} \frac{dN}{dE} E dE$$

Extrapolate to nanoflaers $= 2.35 \times 10^5 \text{erg cm}^{-2}\text{ s}^{-1}$

So, contribution of the small scale energetic events to heat the quiet Sun is about **78%!**

References :

Alipour, N., Mohammadi, F., & Safari, H. 2019, ApJS, 243, 20

Alipour, N., & Safari, H. 2015, ApJ, 807, 175

Alipour, N., Safari, H., & Innes, D. E. 2012, ApJ, 746, 12

Amari, T., Aly, J., Luciani, J., Boulmezaoud, T., & Mikic, Z. 1997, SoPh, 174, 129

Amari, T., Luciani, J.-F., & Aly, J.-J. 2015, Natur, 522, 188

Aschwanden, M. J. 2004, Physics of the Solar Corona. An Introduction (Berlin: Springer)

Aschwanden, M. J. 2010, SoPh, 262, 235

Aschwanden, M. J. 2016, ApJS, 224, 25

Aschwanden, M. J., & Boerner, P. 2011, ApJ, 732, 81

Aschwanden, M. J., Boerner, P., Caspi, A., et al. 2015a, SoPh, 290, 2733

Aschwanden, M. J., Boerner, P., Ryan, D., et al. 2015b, ApJ, 802, 53

Farhang, N., Safari, H., & Wheatland, M. S. 2018, ApJ, 859, 41

Farhang, N., Wheatland, M. S., & Safari, H. 2019, ApJL, 883, L20

Honarbakhsh, L., Alipour, N., & Safari, H. 2016, SoPh, 291, 941

Raboonik, A., Safari, H., Alipour, N., & Wheatland, M. S. 2017, ApJ, 834, 11


Thank you