On the magnetic structure of solar active regions and their space weather impact

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Bilateral project: Bulgaria-Austria https://astro.bas.bg/project-sun/
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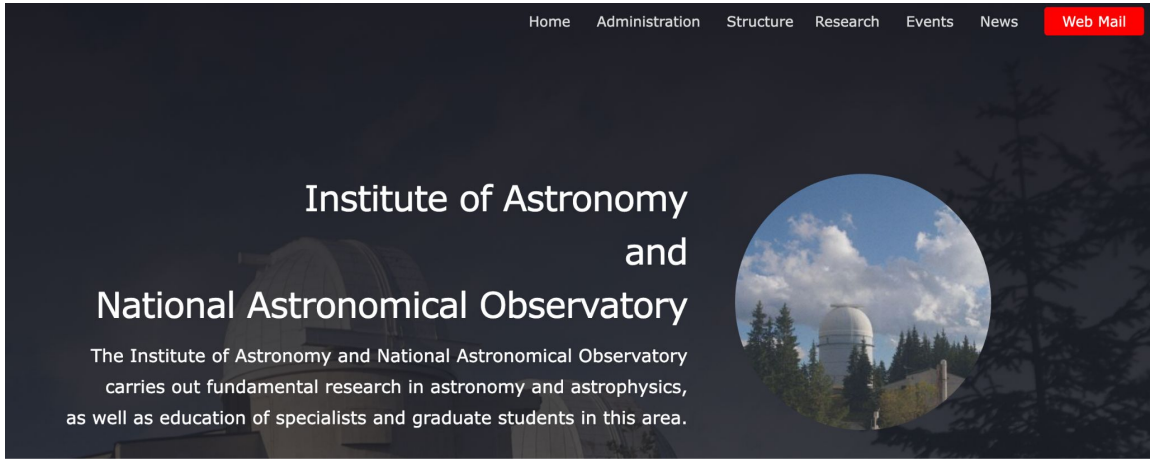
ФОНД НАУЧНИ ИЗСЛЕДВАНИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

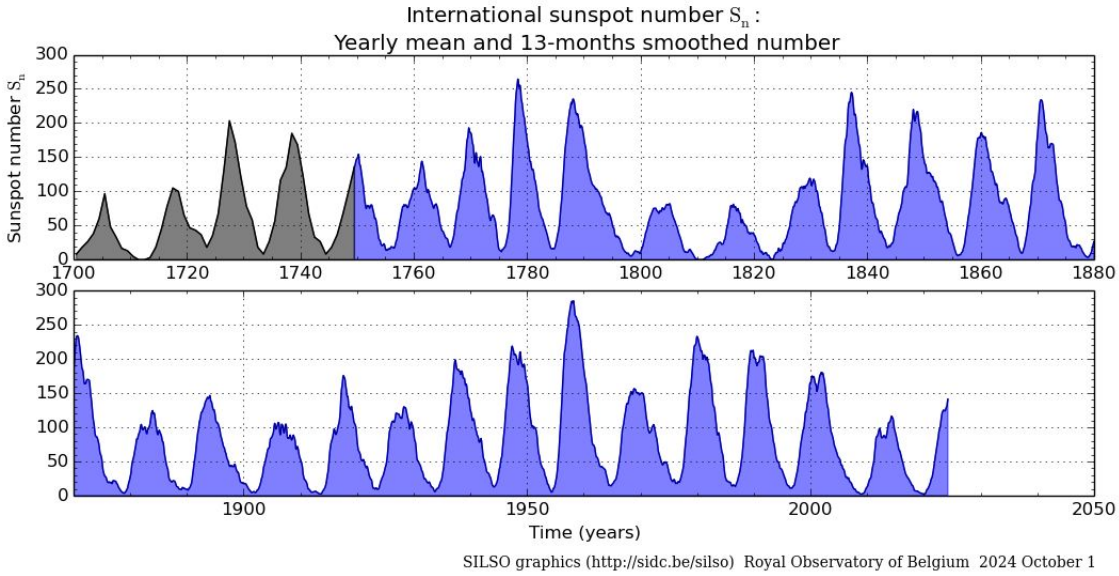
Contents

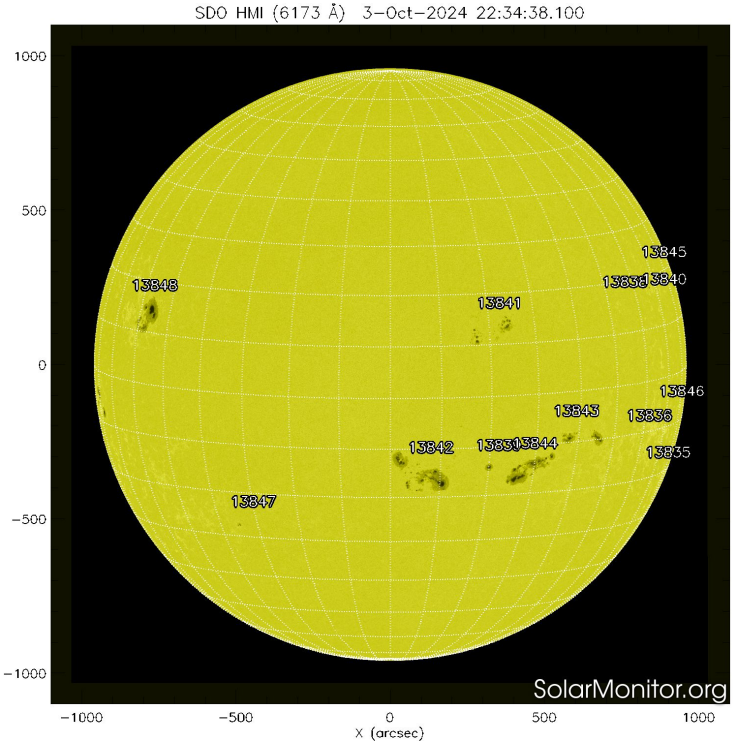
- Overview: Space weather @ IANAO-BAS
- BG-AT bilateral project
- Geoeffective active regions
- Results
- Outlook



https://astro.bas.bg/

Sunspots: proxy for solar activity

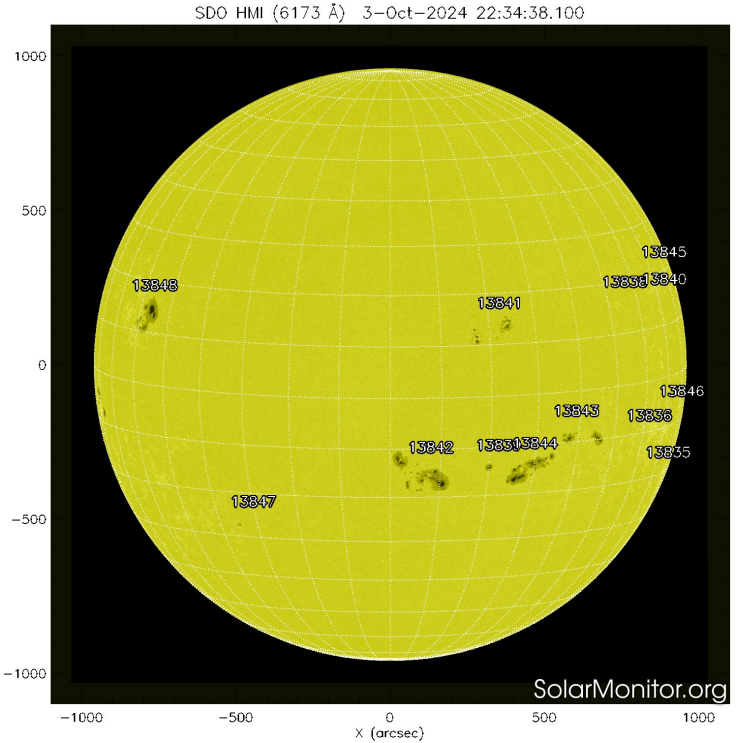




https://solarmonitor.org/

Active regions

“the totality of observable phenomena in a 3D volume represented by the extension of magnetic field from the photosphere to the corona. . .” [van Driel-Gesztelyi et al. 2015] including EM emissions and strong twisted magnetic field emergence.



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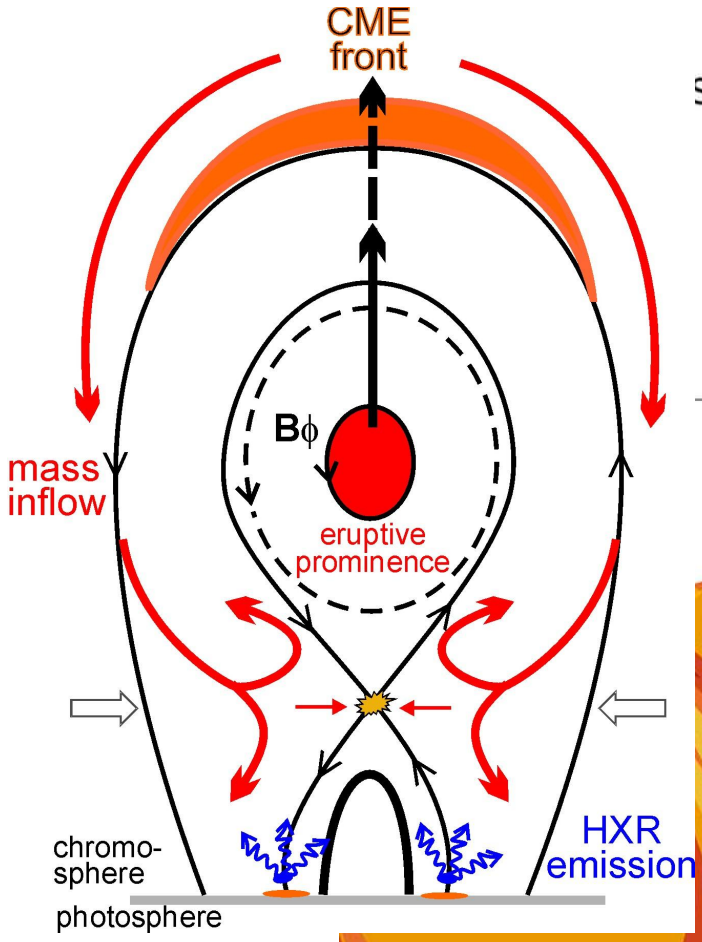


https://www.astro.gla.ac.uk/cartoons/thumbs.html

S

Coronal Mass Ejection

The outer solar atmosphere, the corona, is structured by strong magnetic fields. Where these fields are closed, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles of gas and magnetic fields called coronal mass ejections. Solar material streams out through the interplanetary medium, impacting any planet or spacecraft in its path.

Solar Prominence

A solar prominence is a large, bright feature that extends outward from the Sun's surface. Prominences are anchored to the Sun's surface in the photosphere, and extend outwards into the Sun's hot outer atmosphere, called the corona

Solar Storms

Solar storms occur when the Sun emits huge bursts of energy in the form of solar flares and coronal mass ejections. These phenomena send a stream of electrical charges and magnetic fields toward the Earth at a speed of about three million miles per hour

Solar Flare

A solar flare is an intense burst of radiation coming from the release of magnetic energy associated with sunspots. They are bright areas on the sun and can last from minutes to hours.

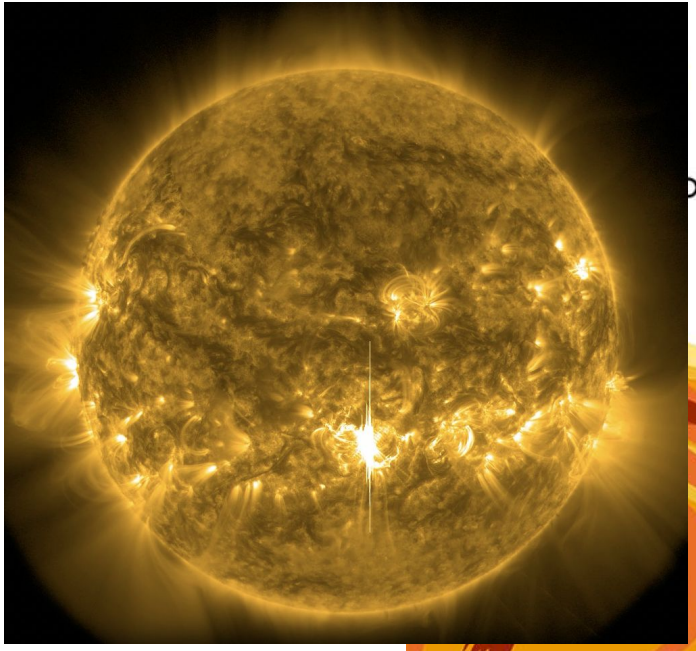
Sunspot

Sunspots are dark areas on the solar surface that contain strong magnetic fields that are constantly shifting.

https://science8sc.weebly.com/solar-flares.html

Solar Events

Mass = **1.9x10^30 kg**
Diameter = **865000 mi**



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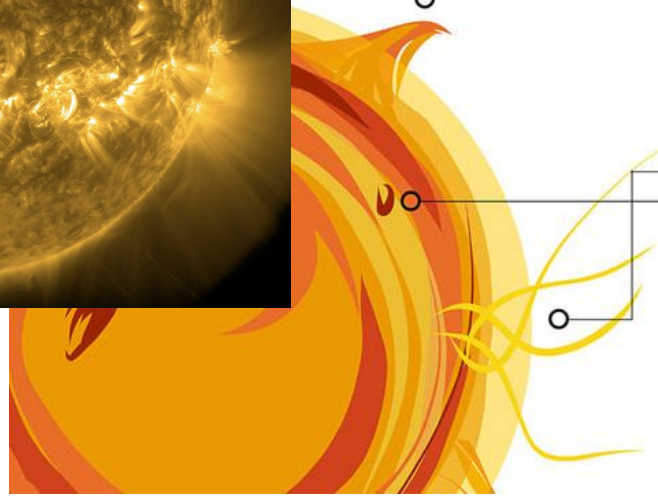

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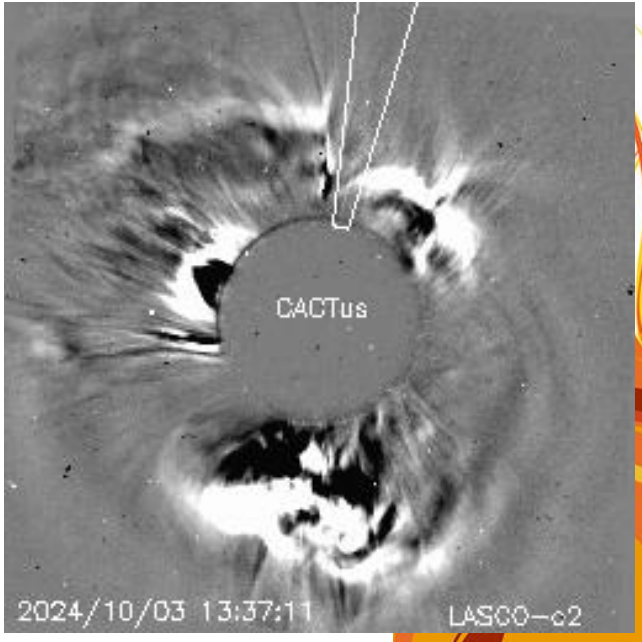
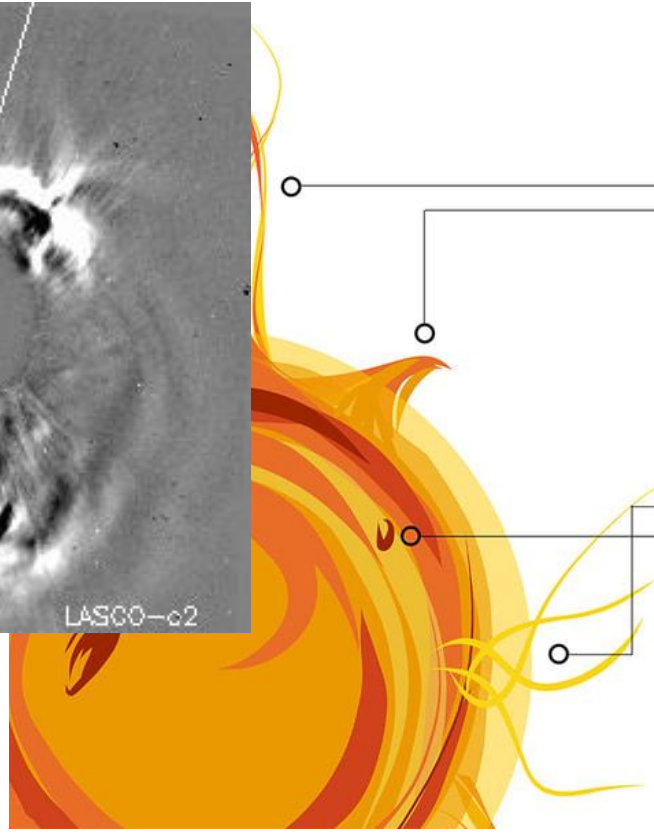


https://www.sidc.be/cactus/catalog/LASCO/2_5_0/qkl/2024/10/CME0016/CME.html



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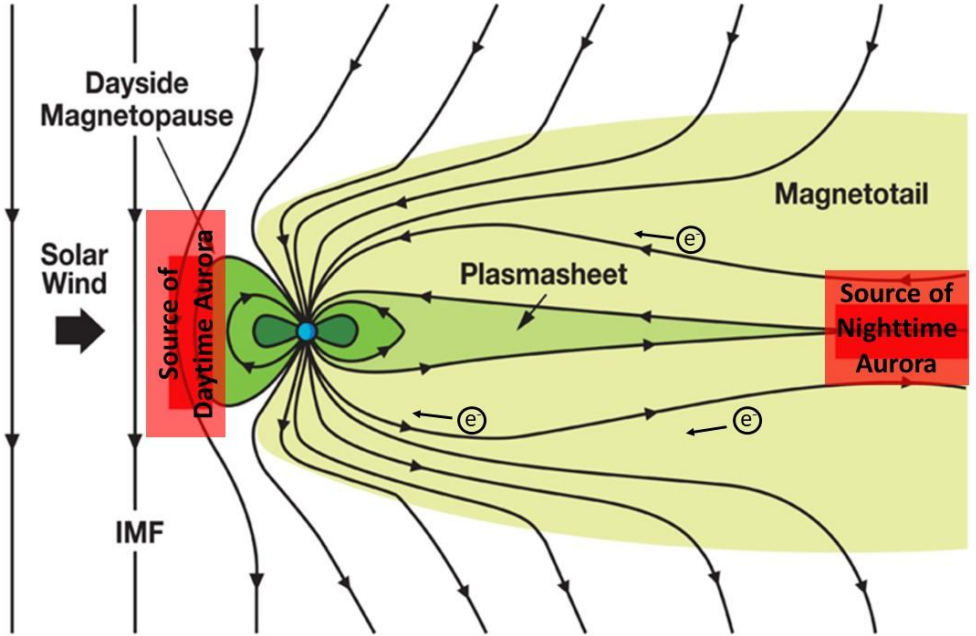
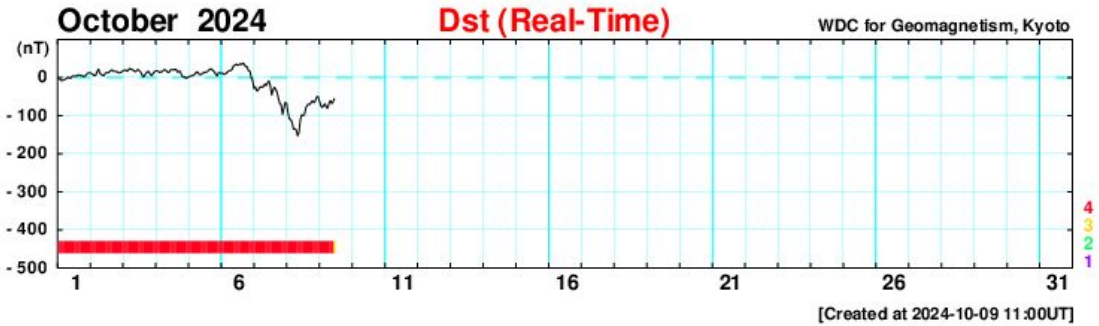
Geomagnetic storm (GS)

major disturbances in the terrestrial atmosphere caused by the reconnection process between the incoming plasma ejecta in the solar wind and the planetary magnetosphere



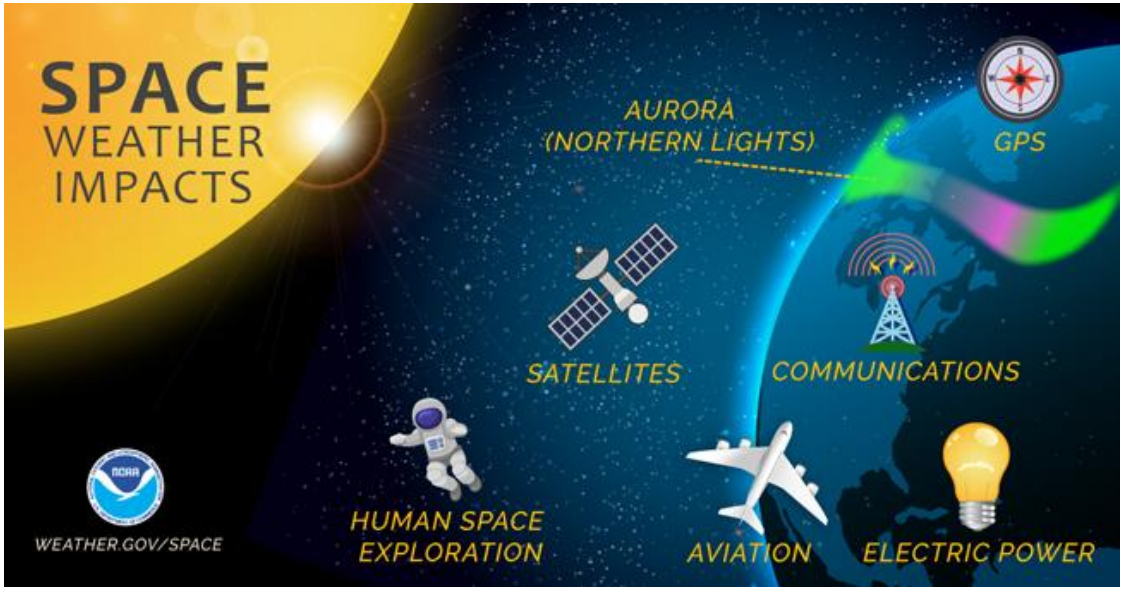


https://wdc.kugi.kyoto-u.ac.jp/dst_realtime/202410/index.html

https://www.swpc.noaa.gov/content/aurora-tutorial

Space weather (SW)

‘conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health’
US National Space Weather Program, The Strategic Plan of Space Weather (1995)



Summary of SW effects

Flares (EM emission):

- Satellite signal degradation and loss;
- Radio blackouts;
- Increased atmospheric drag

CMEs (magnetized plasma, shock waves):

- Geomagnetic storms
- Induced currents

Energetic particles:

- Cumulative radiation effects (total ionizing dose and displacement damage dose);
- Single-event upsets/single-event effects;
- Surface discharges;
- Deep dielectric charging;
- Solar cell degradation, material aging/surface damage to materials

https://www.weather.gov/safety/space

https://astro.bas.bg/project-sun/

Bulgarian-Austrian project

Project-SUN HOME WORK PACKAGES TEAM RESULTS CONTACT

Joint Observations and Investigations of Solar Chromospheric and Coronal Activity

Bilateral collaboration between Bulgarian and Austrian solar and space weather researchers on the topic of chromospheric and coronal activity

AIM

1

To set up the Rozhen Chromospheric Telescope (RCT), and develop standardized solar observing methodology and products, complementary to the Kanzelhohe Patrol Instrument (KPI) by means of strong technical cooperation between the team members.

2

To carry out combined solar observations with the two instrument suites and external (freely available space-based) resources, in order to study chromospheric signatures of quiet sun and pre-eruptive active regions and multi-wavelength manifestation of solar eruptive phenomena, their morphology and kinematics.

Collaboration with:

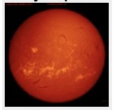
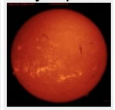
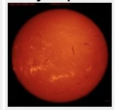
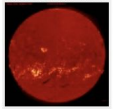
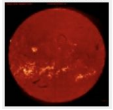
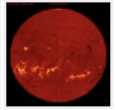
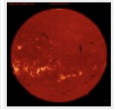
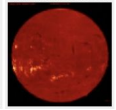
KSO Kanzelhöhe Observatory

Synoptic Archives

Navigation Data Doc

Chromosphere - last two weeks

October 02, 2024 Solar Ephemeris for 13:11 UTC: P = 26.05°,

Oct-02	Oct-01	Sep-30	Sep-29	Sep-28	Sep-27
	R = 257	R = 197	R = 156	R = 158	R = 193
	06:52 Synoptic	**08:31** Synoptic	**06:35** Synoptic	**06:54** Synoptic	**11:07** Synoptic
					
	Normalized	Normalized	Normalized	Normalized	Normalized
					

http://cesar.kso.ac.at/

https://astro.bas.bg/project-sun/

Project structure

Work Packages

Work Package #1

Technical support of NAO-Rozhen Chromosphere Telescope and observation campaigns with KSO facilities

- Task 1.1: Telescope installation
- Task 1.2: Data processing
- Task 1.3: Observation Campaign
- Task 1.4: Image enhancement

Work Package #2

Joint investigations of solar chromospheric and coronal activity

- Task 2.1: Chromospheric Signatures of Quiet Sun and Pre-Eruptive Configurations
- Task 2.2: Multi-wavelength study of solar activity phenomena, their morphology and kinematics

Work Package #3

Dissemination of the project results

- Task 3.1: Project web-site
- Task 3.2: Scientific dissemination

Solar observations in Bulgaria

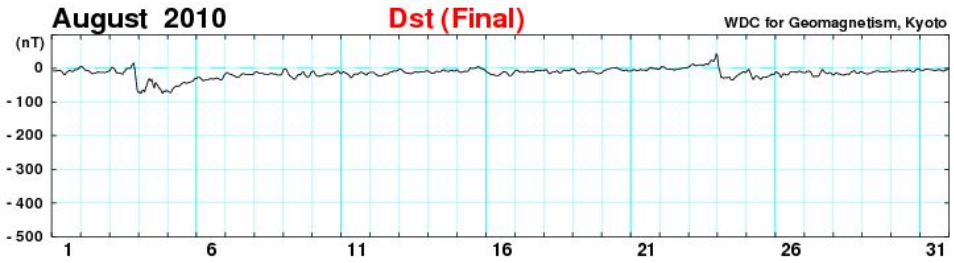
Statistical analyses of historical events

Aim

Which AR parameters are geo-effective?

AR

IP space &
(I)CMEs



GS

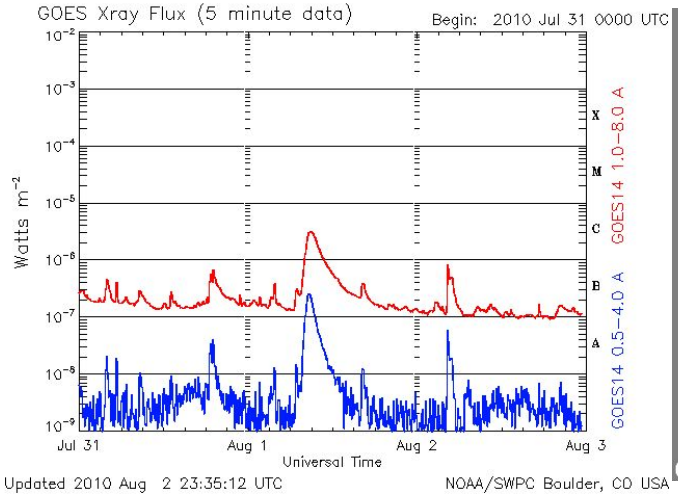
Methodology

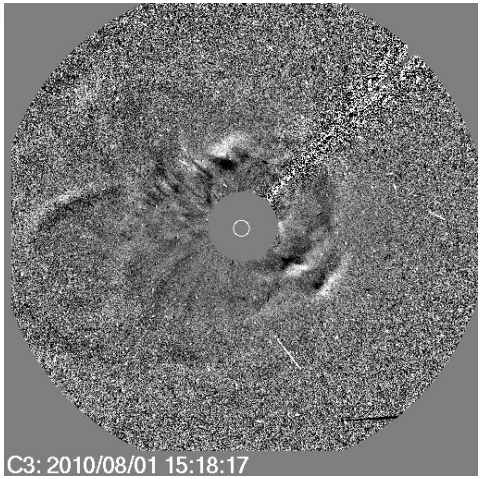
1. Selection: all geo-storms in SC24+
Association between GSs, CMEs, SFs, and ARs

SDO/HMI (after 2009-present),

- AR: SHARP data product

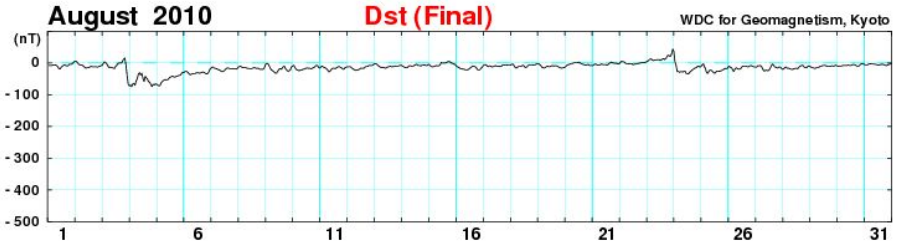
http://jsoc.stanford.edu/HMI/HARPS.html





2. Correlations

- SF: SXR class
- CME: speed & angular width



- GS: Dst

https://doi.org/10.1007/s11207-014-0529-3

SHARP parameters

1. USFLUX (Maxwell): Total unsigned flux
2. MEANGAM (Degrees): Mean inclination angle, gamma
3. MEANGBT (Gauss/Mm): Mean value of the total field gradient
4. MEANGBZ (Gauss/Mm): Mean value of the vertical field gradient
5. MEANGBH Gauss/Mm Mean value of the horizontal field gradient
6. MEANJZD (mA/(m^2)): Mean vertical current density
7. TOTUSJZ (Amperes): Total unsigned vertical current
8. MEANALP (1/Mm): Mean twist parameter, alpha
9. MEANJZH (G^2)/m: Mean current helicity
10. TOTUSJH (G^2)/m: Total unsigned current helicity
11. ABSNJZH (G^2)/m: Absolute value of the net current helicity
12. SAVNCPP (Amperes): Sum of the Absolute Value of the Net Currents ...
13. MEANPOT (Ergs/cm^3): Mean photospheric excess magnetic energy density
14. TOTPOT (Ergs/cm^3): Total photospheric magnetic energy density
15. MEANSHR (Degrees): Mean shear angle for B_total
16. R_VALUE (Maxwell): Unsigned Flux R (Schrijver, 2007)

https://doi.org/10.1007/s11207-014-0529-3

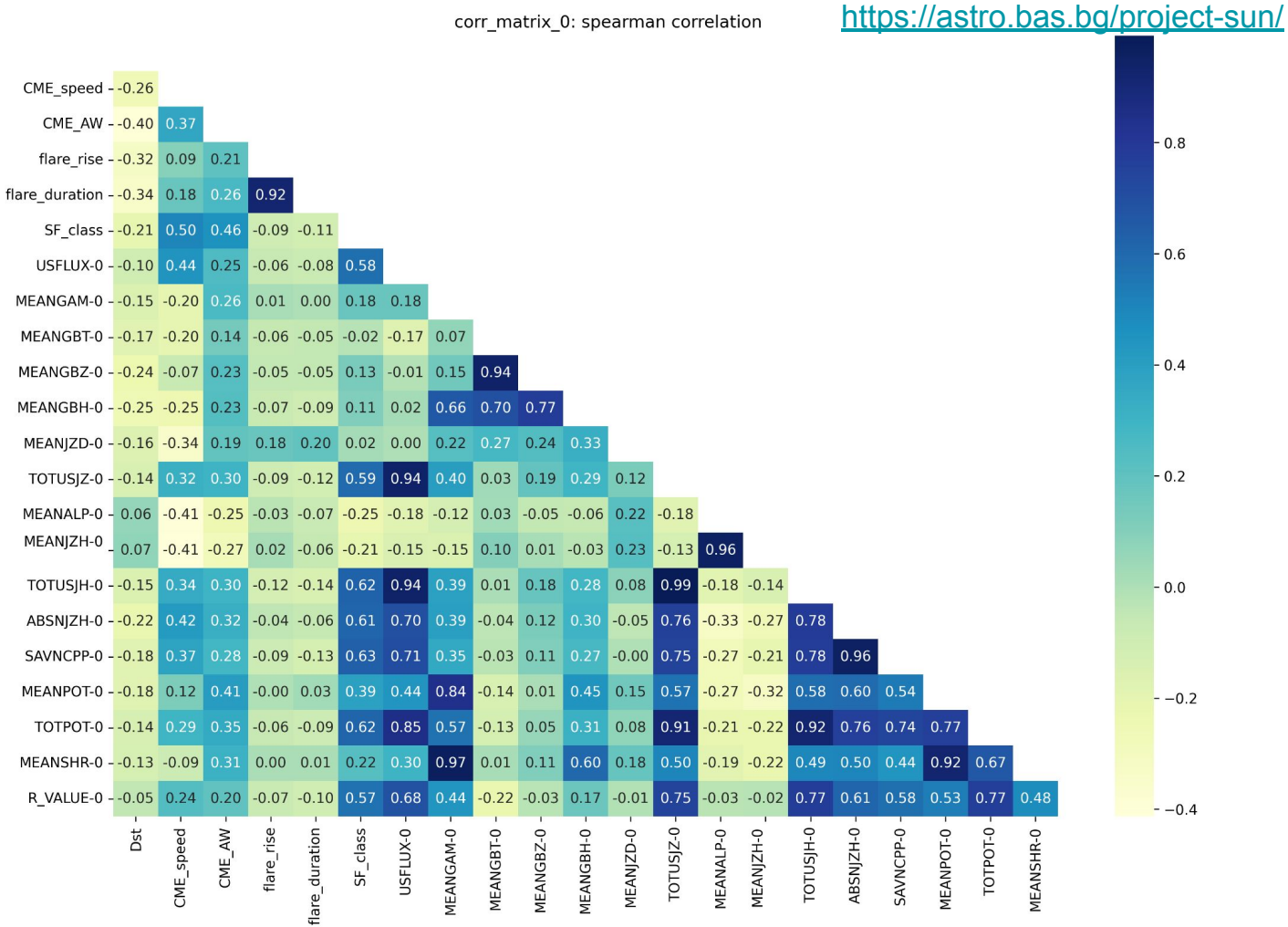
SHARP parameters

Keyword	Description	Unit[a]	Formula[b]
USFLUX	Total unsigned flux	Mx	$\Phi = \sum \lvert B_z \rvert \, \mathrm{d}A$
MEANGAM	Mean angle of field from radial	Degree	$\overline{\gamma} = \frac{1}{N} \sum \arctan(\frac{B_h}{B_z})$
MEANGBT	Horizontal gradient of total field	G Mm^{-1}	$\overline{\lvert \nabla B_{\mathrm{tot}} \rvert} = \frac{1}{N} \sum \sqrt{(\frac{\partial B}{\partial x})^2 + (\frac{\partial B}{\partial y})^2}$
MEANGBZ	Horizontal gradient of vertical field	G Mm^{-1}	$\overline{\lvert \nabla B_z \rvert} = \frac{1}{N} \sum \sqrt{(\frac{\partial B_z}{\partial x})^2 + (\frac{\partial B_z}{\partial y})^2}$
MEANGBH	Horizontal gradient of horizontal field	G Mm^{-1}	$\overline{\lvert \nabla B_h \rvert} = \frac{1}{N} \sum \sqrt{(\frac{\partial B_h}{\partial x})^2 + (\frac{\partial B_h}{\partial y})^2}$
MEANJZD	Vertical current density	mA m^{-2}	$\overline{J_z} \propto \frac{1}{N} \sum (\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y})$
TOTUSJZ	Total unsigned vertical current	A	$J_{z_{\mathrm{total}}} = \sum \lvert J_z \rvert \, \mathrm{d}A$
MEANALP	Characteristic twist parameter, α	M m^{-1}	$\alpha_{\mathrm{total}} \propto \frac{\sum J_z B_z}{\sum B_z^2}$
MEANJZH	Current helicity (B_z contribution)	G^2 m^{-1}	$\overline{H_c} \propto \frac{1}{N} \sum B_z J_z$
TOTUSJH	Total unsigned current helicity	G^2 m^{-1}	$H_{c_{\mathrm{total}}} \propto \sum \lvert B_z J_z \rvert$
ABSNJZH	Absolute value of the net current helicity	G^2 m^{-1}	$H_{c_{\mathrm{abs}}} \propto \lvert \sum B_z J_z \rvert$
SAVNCPP	Sum of the modulus of the net current per polarity	A	$J_{z_{\mathrm{sum}}} \propto \lvert \sum^{B_z^+} J_z \, \mathrm{d}A \rvert + \lvert \sum^{B_z^-} J_z \, \mathrm{d}A \rvert$
MEANPOT	Proxy for mean photospheric excess magnetic energy density	erg cm^{-3}	$\overline{\rho} \propto \frac{1}{N} \sum (\boldsymbol{B}^{\mathrm{Obs}} - \boldsymbol{B}^{\mathrm{Pot}})^2$
TOTPOT	Proxy for total photospheric magnetic free energy density	erg cm^{-1}	$\rho_{\mathrm{tot}} \propto \sum (\boldsymbol{B}^{\mathrm{Obs}} - \boldsymbol{B}^{\mathrm{Pot}})^2 \, \mathrm{d}A$
MEANSHR	Shear angle	Degree	$\overline{\Gamma} = \frac{1}{N} \sum \arccos(\frac{\boldsymbol{B}^{\mathrm{Obs}} \cdot \boldsymbol{B}^{\mathrm{Pot}}}{\lvert \boldsymbol{B}^{\mathrm{Obs}} \rvert \lvert \boldsymbol{B}^{\mathrm{Pot}} \rvert})$

Results

⇒ 64 events
semi-automatic code

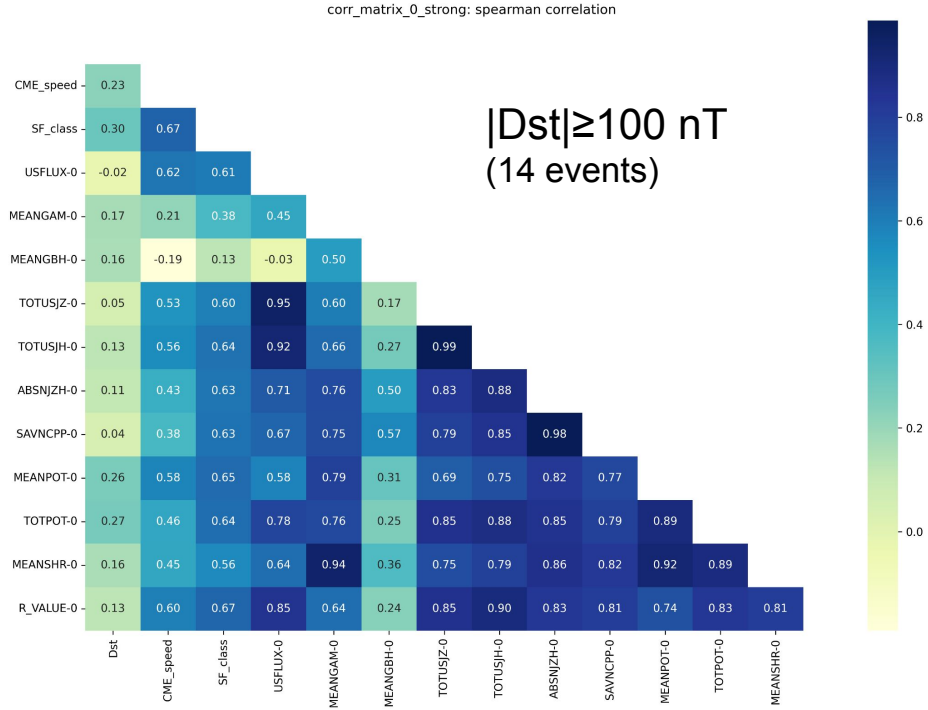
The SHARP parameters for the total flux, current, current helicity, magnetic energy density, and shear angle show ***moderate-to-strong*** correlations also with the SF class and the CME parameters ***but not with the Dst index***.



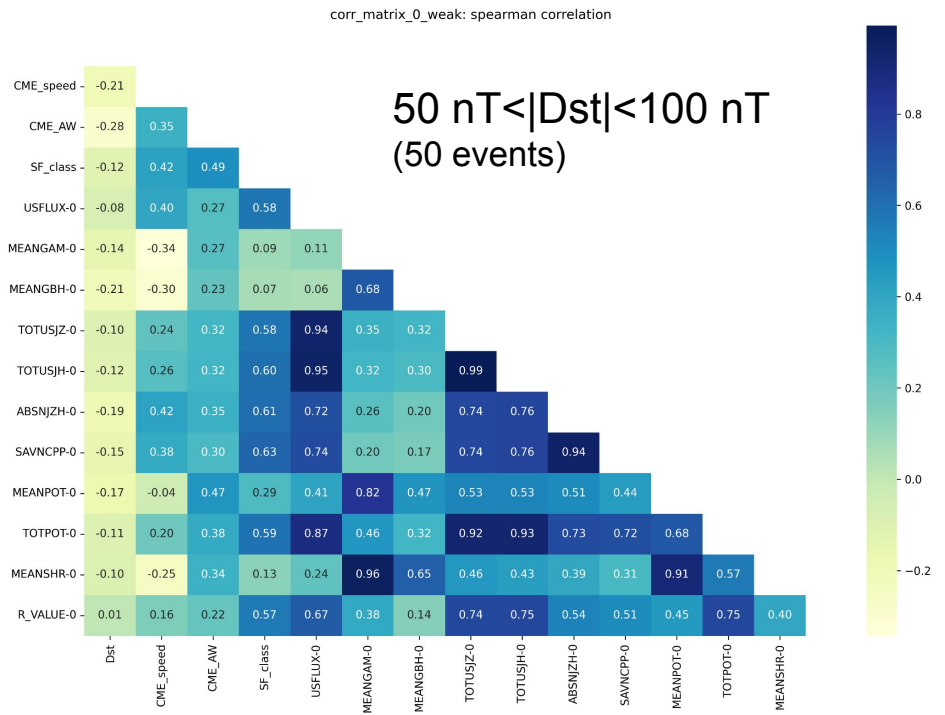
https://doi.org/10.3390/atmos15080930

https://astro.bas.bg/project-sun/

Results



|Dst|≥100 nT
(14 events)



50 nT<|Dst|<100 nT
(50 events)

https://doi.org/10.3390/atmos15080930

https://astro.bas.bg/project-sun/

Outlook

- Setting up an automatic procedure for multi-parameter analyses (completed)
- Apply to confined (e.g. no CME) vs. eruptive solar flares in SC24:

  ~50 X-class flares (Miteva 2021) ⇒ 2 confined

  ~750 M-class flares (Miteva & Samwel 2022) ⇒ ~350 confined

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