Solar activity and space weather research in Bulgaria

Rositsa Miteva
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Bulgarian Academy of Sciences
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17-Jan-2024 AIRA seminar/Romania

Outlook

I. Science topics, infrastructure, projects

- Bulgarian Academy of Sciences
- Institute of Astronomy
- Solar group

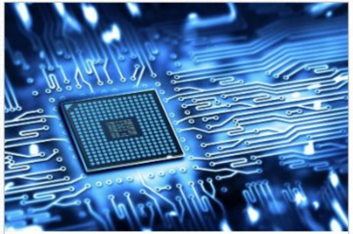
https://astro.bas.bg/
https://nao-rozhen.org/

II. Selected results

- Statistics, correlations, catalogs

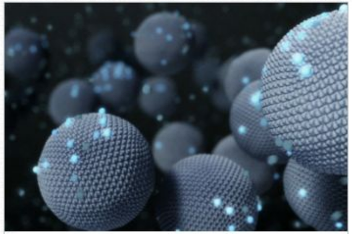
https://catalogs.astro.bas.bg/

I. Bulgarian Academy of Sciences

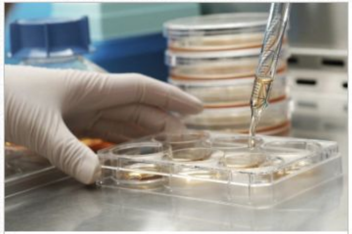


Information and Communication Sciences and Technologies

Energy Resources and Energy Efficiency



Nanosciences, New Materials and Technologies



Biomedicine and Quality of Life

Biodiversity, Bioresources and Ecology

Climate Change, Hazards and Natural Resources

Astronomy, Space Research and Technology

Cultural-Historical Heritage and National Identity

Man and Society

1869

INSTITUTE OF ASTRONOMY AND NATIONAL ASTRONOMICAL OBSERVATORY

founded in Romania

http://bas.bg/

48%

48% of the scientific output of Bulgaria

42

research units (institutes)

2023: H-index Bulgaria: 330

8

academic specialized units

9

specialized units

245

H-index BAS

Institute of Astronomy with NAO - BAS

1958: Independent unit ‘Astronomy‘ at BAS
1995: Institute of Astronomy founded

Research units

- Sun & Solar system
- Star & Stellar systems
- Galaxies & Cosmology

Staff

- ~50 scientific
- ~30 technical+support
- ~10 administration

Links:

https://astro.bas.bg/

https://nao-rozhen.org/

https://www.youtube.com/@instituteofastronomyandnao6152

https://www.instagram.com/instituteofastronomybas/

https://www.facebook.com/ianaoban

Institute of Astronomy with NAO - BAS

Infrastructure

- Sofia https://astro.bas.bg/
- AO-Belogradchik (1976) https://www.astro.bas.bg/AOBel/index.php
- NAO-Rozhen (1981) https://nao-rozhen.org/

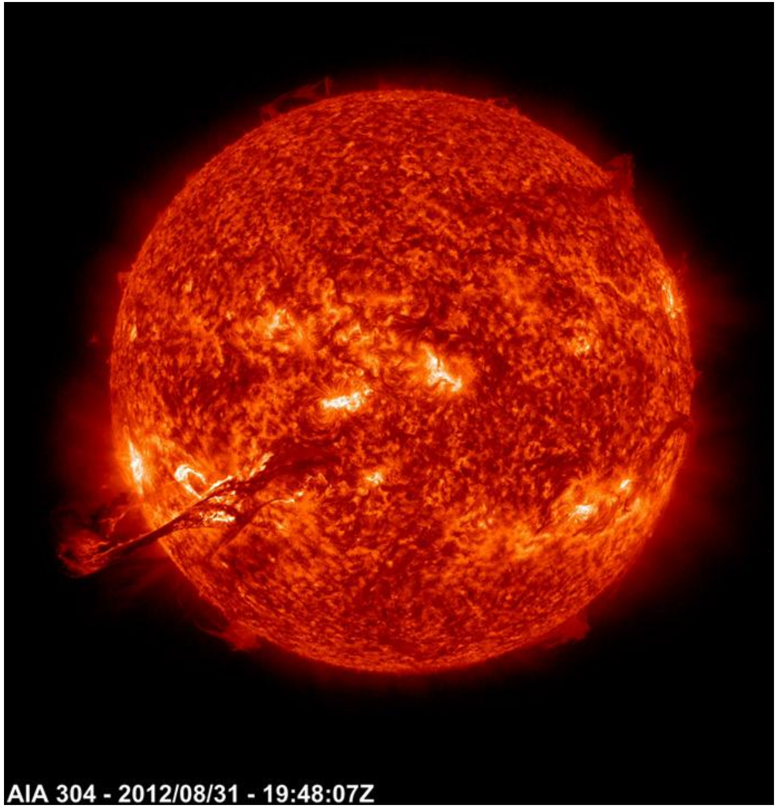

History: Solar research in BG

Topics of research (1990s, 2000s)

- Solar activity: filament eruptions
- Total solar eclipses
- Theoretical research (2D MHD models)

http://edu-pro.astro.bas.bg/sun/?lang=en

https://helio.astro.bas.bg/



https://sdo.gsfc.nasa.gov/gallery/main/item/157

Present: Sun & space weather group

Topics of research (2010 - now)

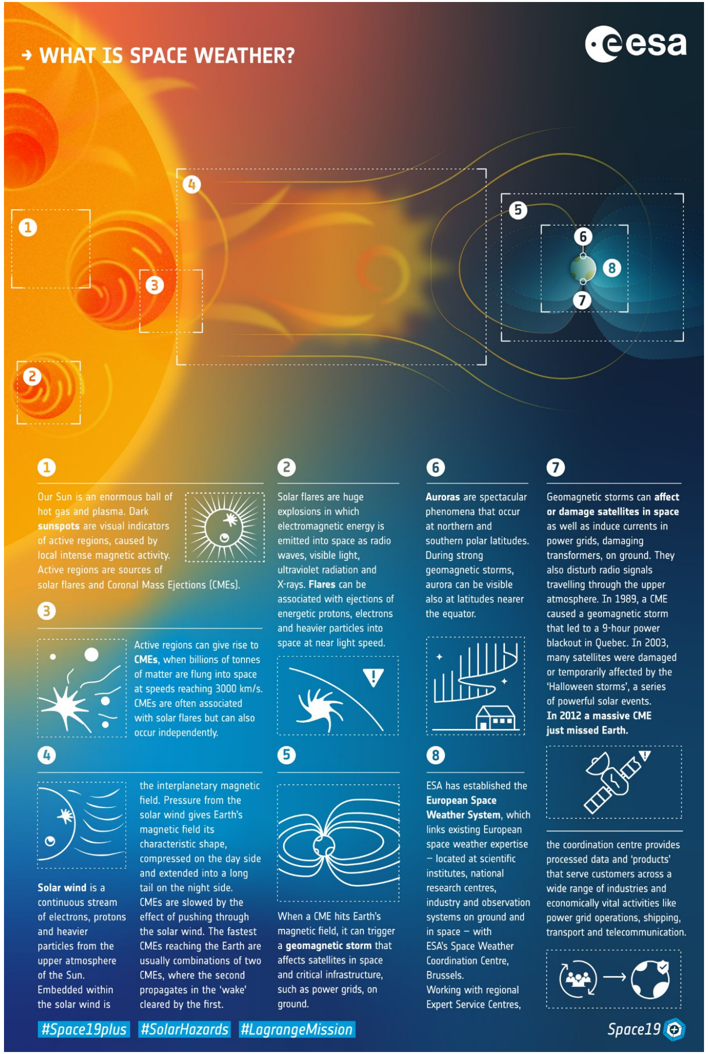
- Solar activity: solar flares, filaments, radio bursts
  - multiwavelength analysis

- Space weather
  - particles (data analyses, modeling & forecasting)
  - geomagnetic storms (statistics)

- Machine learning in solar/space weather

http://edu-pro.astro.bas.bg/sun/?lang=en

https://helio.astro.bas.bg/



Solar group team

Permanent staff

Kamen Kozarev, Associate Professor

Rositsa Miteva, Associate Professor

Momchil Dechev, Associate Professor

Nikola Petrov, Associate Professor

Tsvetan Tsvetkov, Assistant Professor

Oleg Stepanyuk, Postdoc

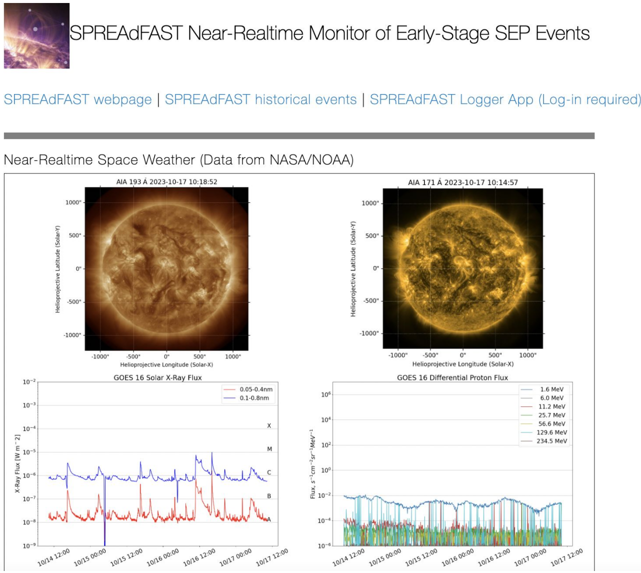
+5 PhD students

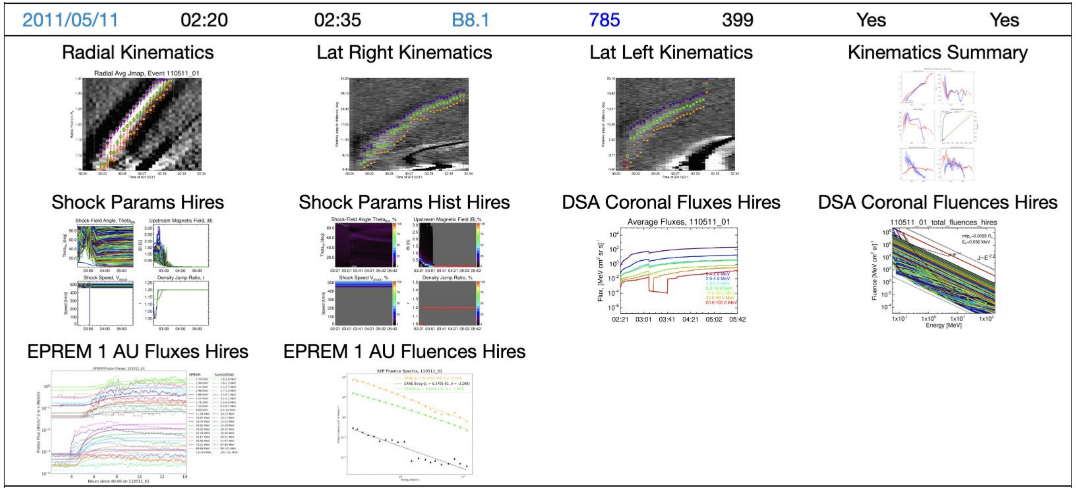
Completed science projects

- **SPREADFAST**

https://spreadfast.astro.bas.bg/synoptic/

Prototype of of a **forecasting** system, based on physics-based model for acceleration of solar energetic particles and their transport to Earth **(ESA project)**;
featured in a SEP review
(Whitman et al. 2023)





Completed science projects

- **STELLAR**

https://stellar-h2020.eu/

Team
- IANAO - Bulgaria
- ASTRON - Netherlands
- DIAS - Ireland
- TUS - Bulgaria

Visits, collaborations, schools on solar & space weather radio astronomy, incl. antenna & signal processing technologies

STELLAR

The Institute of Astronomy and National Astronomical Observatory is proud to collaborate with the Netherlands Institute for Radio Astronomy (ASTRON), the Dublin Institute for Advanced Studies (DIAS), and the Technical University of Sofia (TUS) on a transformative project for training the next generation of Bulgarian radio astronomers.

The project **"Scientific and Technological Excellence by Leveraging LOFAR Advancements in Radio astronomy" (STELLAR)**, funded by EU's Horizon 2020 Twinning program, will significantly increase the LOFAR technical and scientific expertise at TUS and IANAO. It will allow IANAO and TUS to develop and strengthen collaborations with ASTRON and DIAS.

> **STELLAR is a major step towards the realization, utilization, and further development of a LOFAR station in Bulgaria.**

STELLAR will achieve its objectives through carefully planned trainings for IANAO and TUS staff at ASTRON and DIAS, including lectures, workshops, summer schools, and research staff exchanges.

> STELLAR will have a multiplicative effect for the Bulgarian astronomical and geophysical community as a whole through the development of RA, SW, and radio technology training curricula for Bulgarian scientists and engineers, thus ensuring development of RA, SW, and radio technology training curricula for Bulgarian scientists and engineers, and a strong sustainable effect of the project.

IANAO in collaboration with TUS comprise a synergy of: scientists, specializing in the solar and astronomy fields of research, on the one hand, and a larger pool of engineers and technically oriented staff on the other. Both teams will benefit from close collaboration with the highly experienced staff of ASTRON and DIAS. The Bulgarian participants in the project consist of young, early stage researchers and staff in their active years of research. **The focus brought by LOFAR technology and science will open a new exciting direction for scientific research and technological development in the area.**

Project Duration

The project started on September 1, 2020, and will run for 36 months.

Contacts

Questions? Email kkozarev at astro dot bas dot bg.

The STELLAR project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952439. It is coordinated by the Institute of Astronomy, Bulgarian Academy of Sciences.

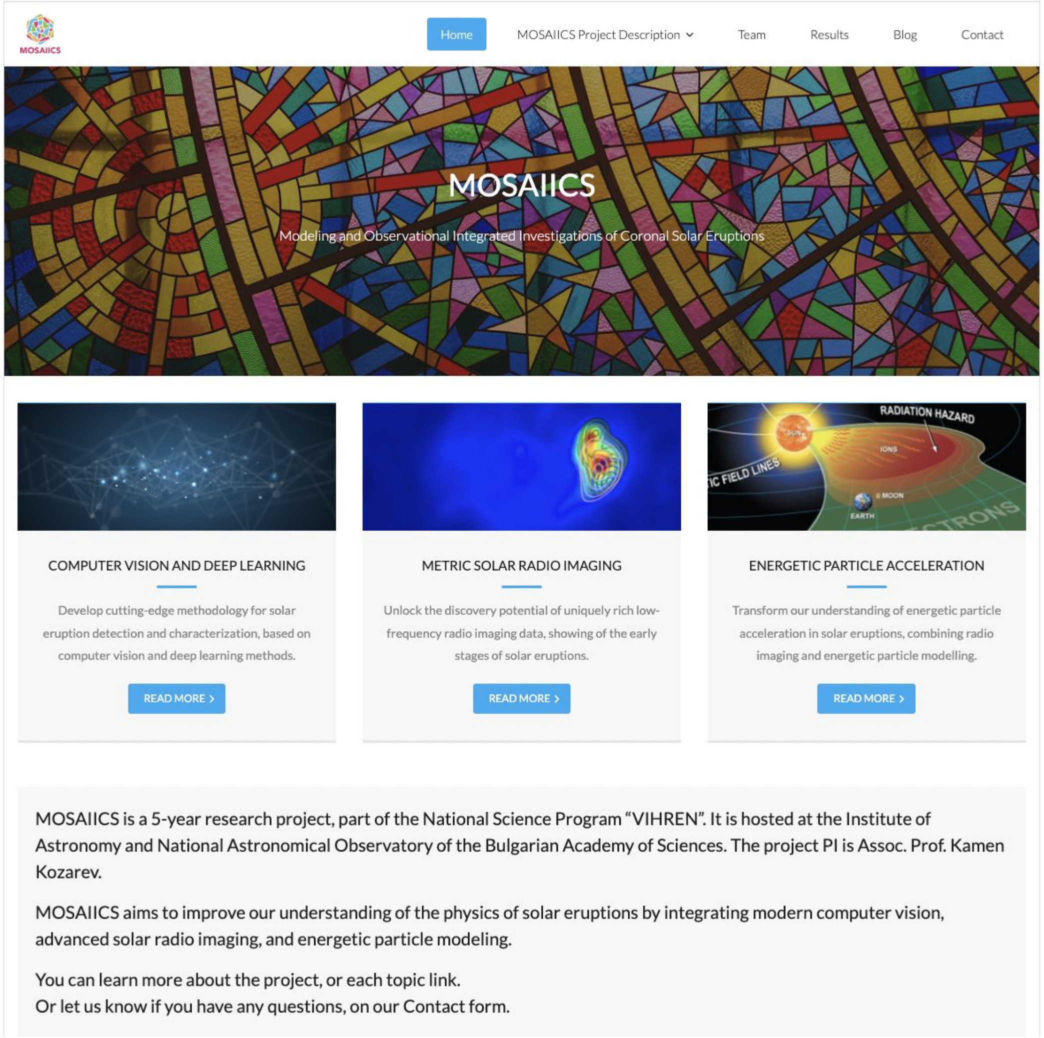
Ongoing science projects

- **MOSAIICS:**

Modeling and Observational Integrated Investigations of Coronal Solar Eruptions

(Bulgarian National Science Fund)

https://mosaiics.astro.bas.bg/



Ongoing science projects

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J. Space Weather Space Clim. 2022, **12**, 20
© O. Stepanyuk et al., Published by EDP Sciences 2022
https://doi.org/10.1051/swsc/2022020

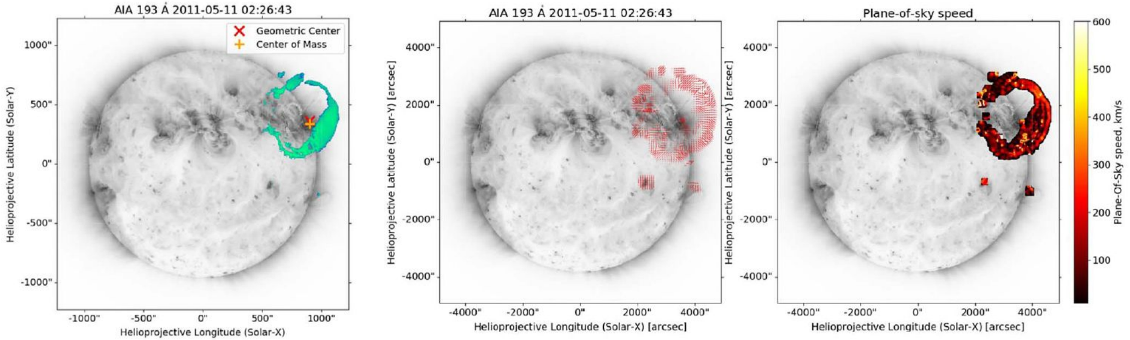
JSWSC
Available online at:
www.swsc-journal.org

RESEARCH ARTICLE OPEN ACCESS

Multi-scale image preprocessing and feature tracking for remote CME characterization

Oleg Stepanyuk*, Kamen Kozarev, and Mohamed Nedal

Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Tsarigradsko Chausee Blvd 72, Sofia 1784, Bulgaria

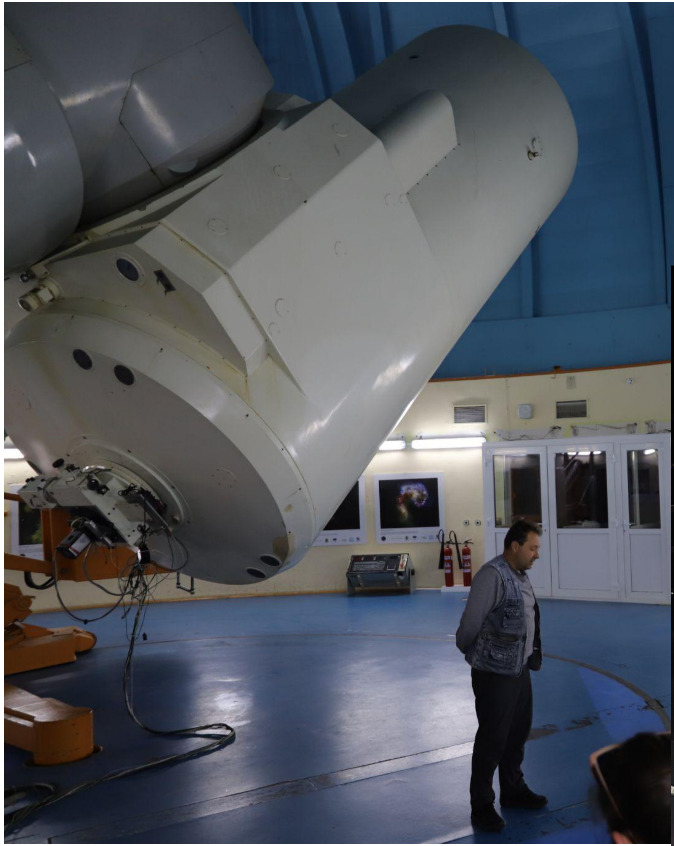


Infrastructure

NAO-Rozhen

- **2 m telescope**
- **1.5 m telescope**
- 30-cm chromospheric solar telescope (commissioning)
- Radio station (in progress)
- Neutron monitor (in progress)
- Weather station, etc.

https://nao-rozhen.org/



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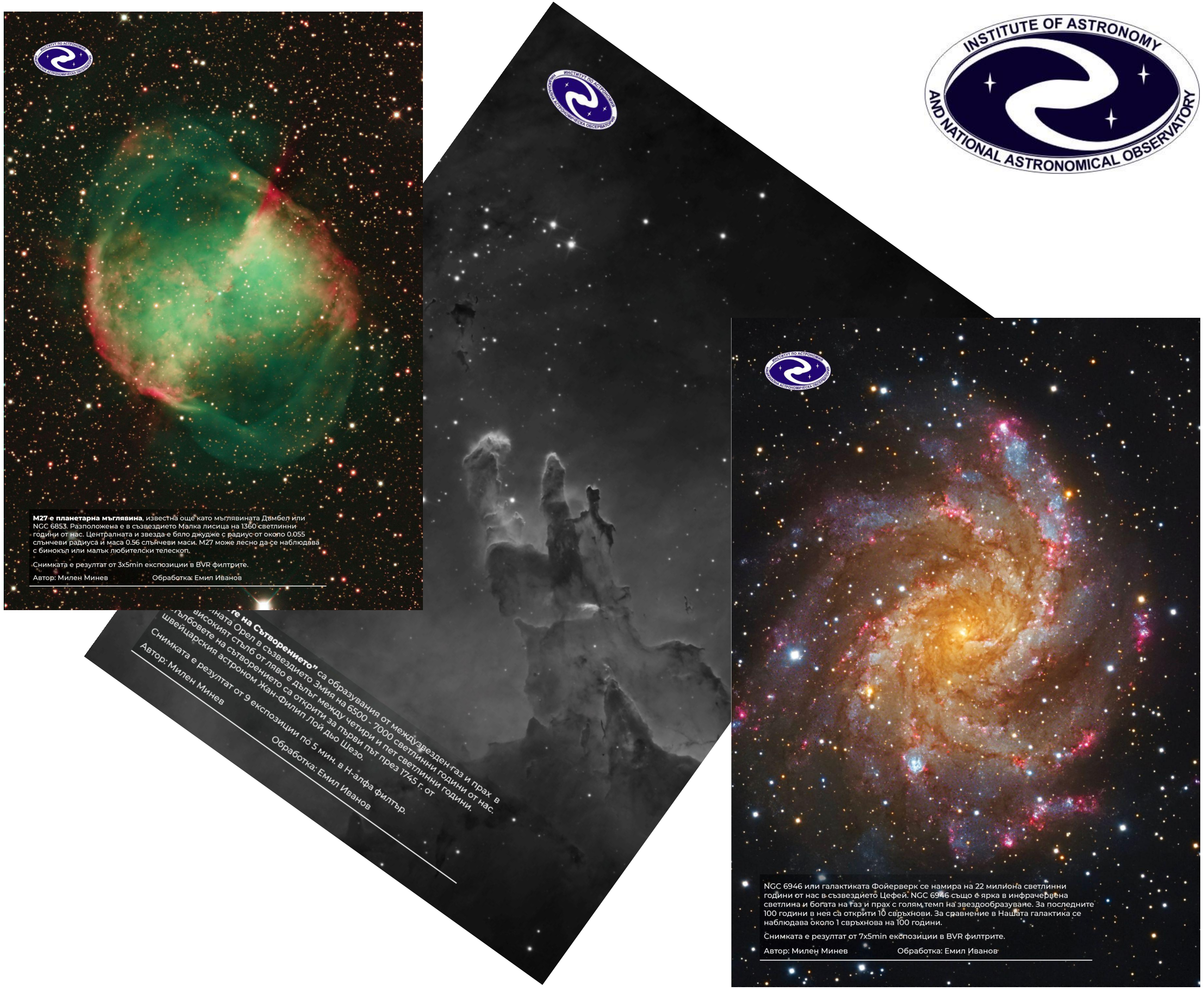

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https://helio.astro.bas.bg/observations

https://ui.adsabs.harvard.edu/abs/2021POBeo.100..137P/abstract

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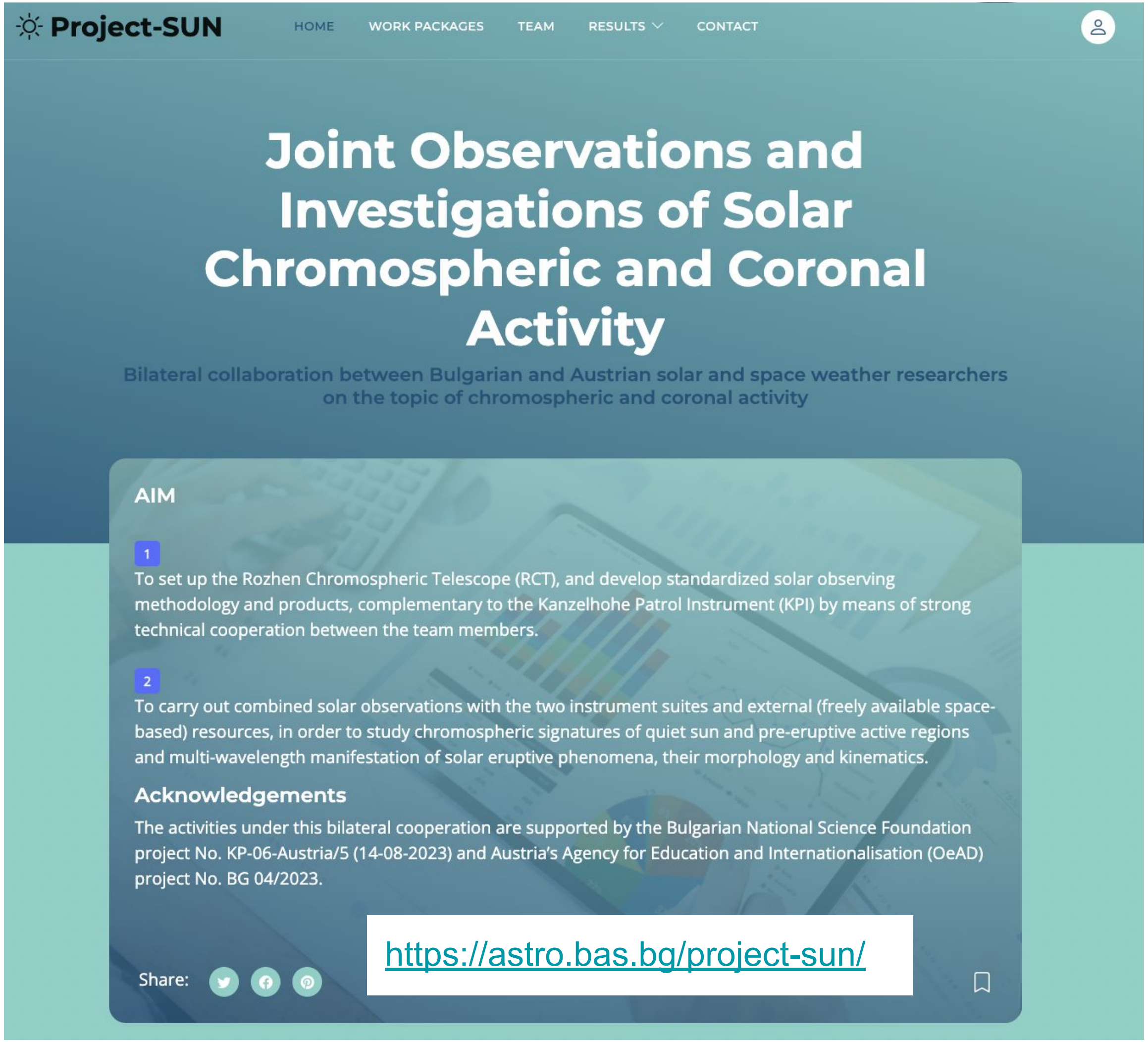

https://astro.bas.bg/project-sun/

Infrastructure

LOFAR-BG

https://lofar.bg/bg/

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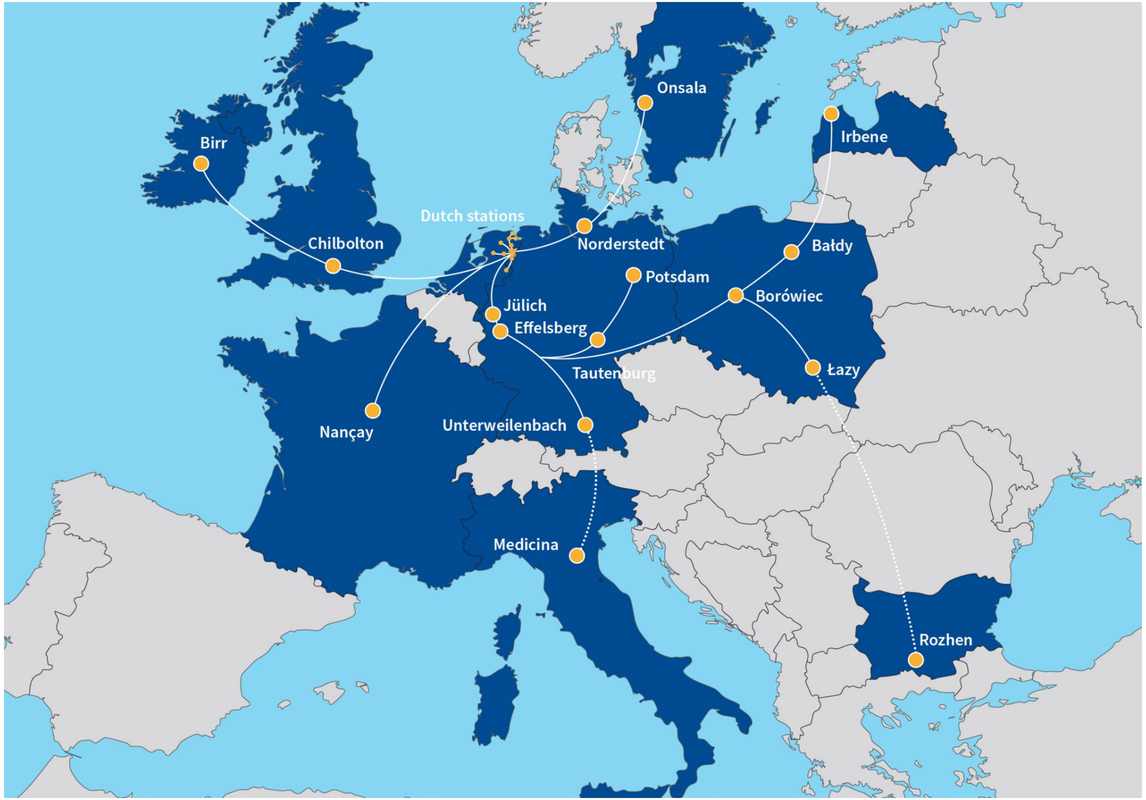

Infrastructure

LOFAR

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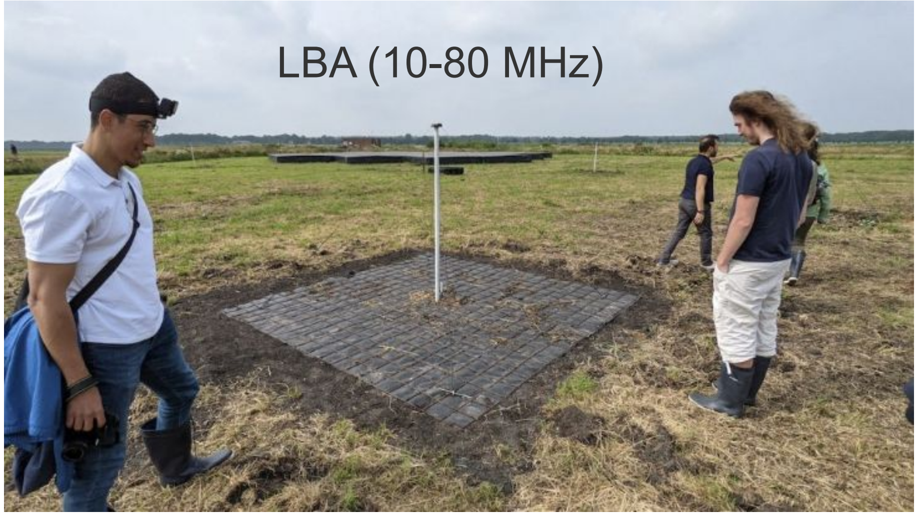

https://www.astron.nl/telescopes/lofar/

Infrastructure

https://lofar.ie/

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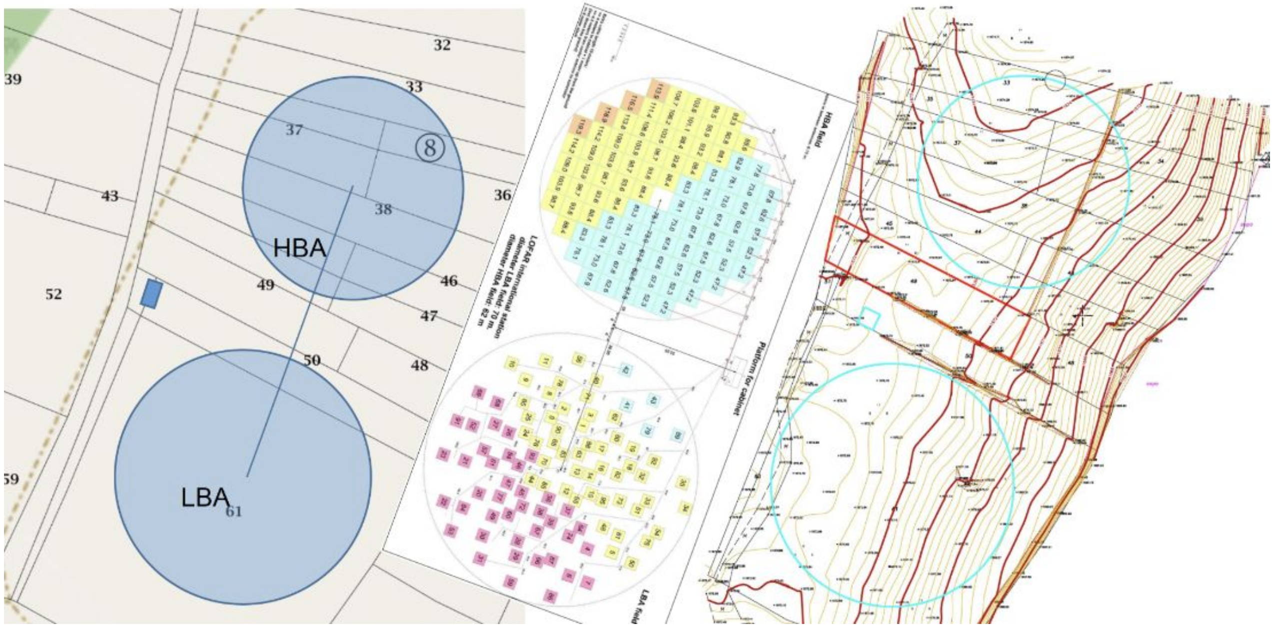
LOFAR-BG https://lofar.bg/bg/



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LOFAR-BG https://lofar.bg/bg/

Bilateral collaborations

Regional:

- Serbia

Active events on the Sun, ***catalogs of proton events*** and electron Signatures…

Europe:

- Netherlands & Ireland (LOFAR)
- Austria (optical)

The ***origin of solar energetic particles***: solar flares vs. coronal mass ejections
solar chromospheric and ***coronal activity***

Worldwide:

- India (radio)

Eruptions, flows and waves in the solar atmosphere and their ***influences on the space weather***

- Egypt (space weather)

relationship between major ***space weather phenomena*** in solar cycles 23 and 24
space weather effects at near Earth environment - from remote observations and in situ particle forecasting to impacts on satellites

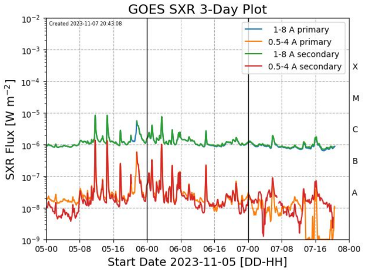
http://edu-pro.astro.bas.bg/sun/?page_id=368

II. Space weather drivers

Solar flares

- EM emission
- ‘flash’ on images
- light-curves in soft X-rays

(GOES scale: X, M, C,...)



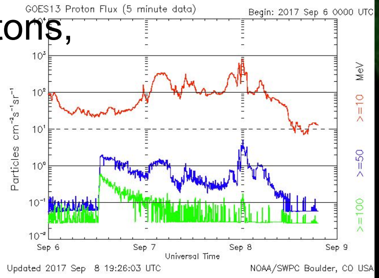
Coronal mass ejections

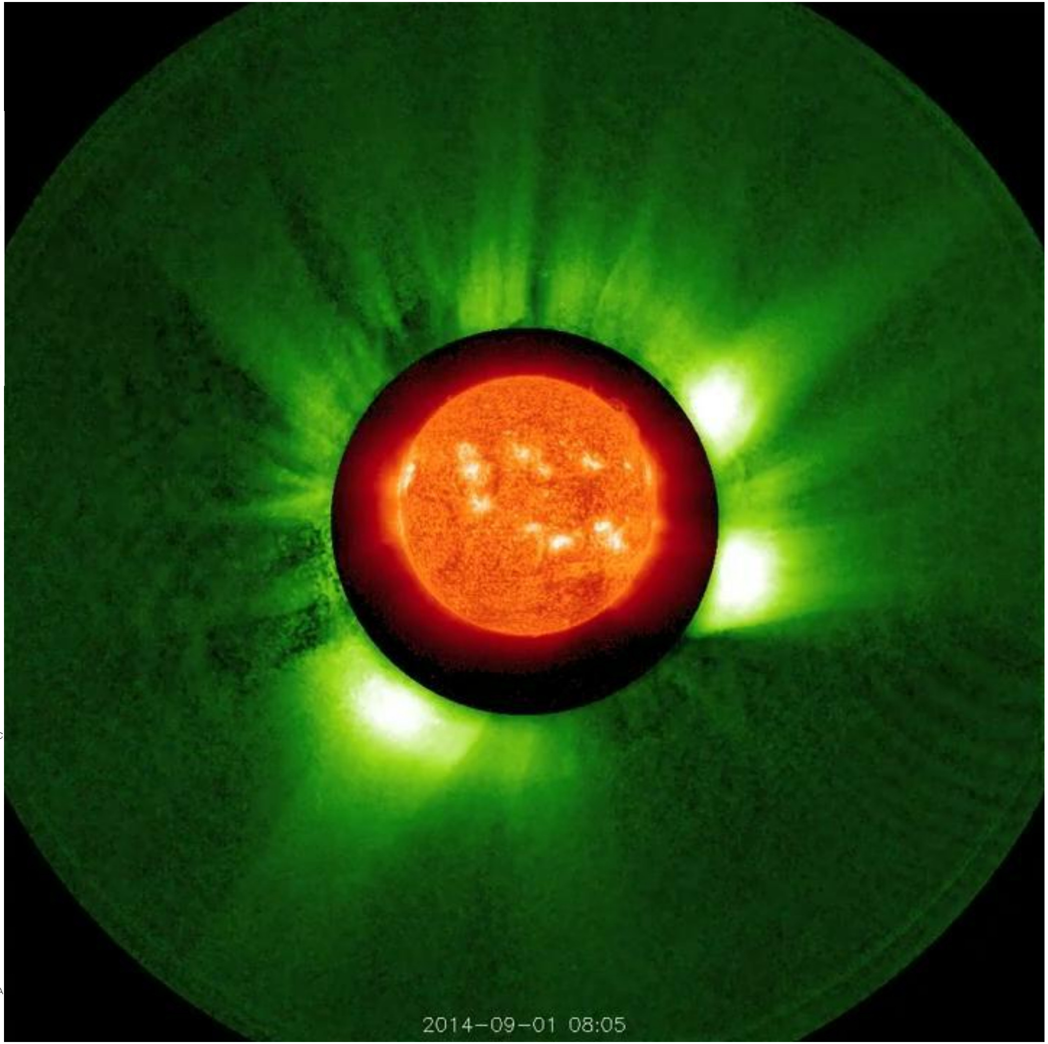
- mass expelled into IP space
- ‘bubbles’ on images
- white-light imagers

(speed, angular width, direction of propagation)

Solar energetic particles

- in situ observation of protons, electrons, heavy ions
- ’snow’-effect on images
- flux-time curves



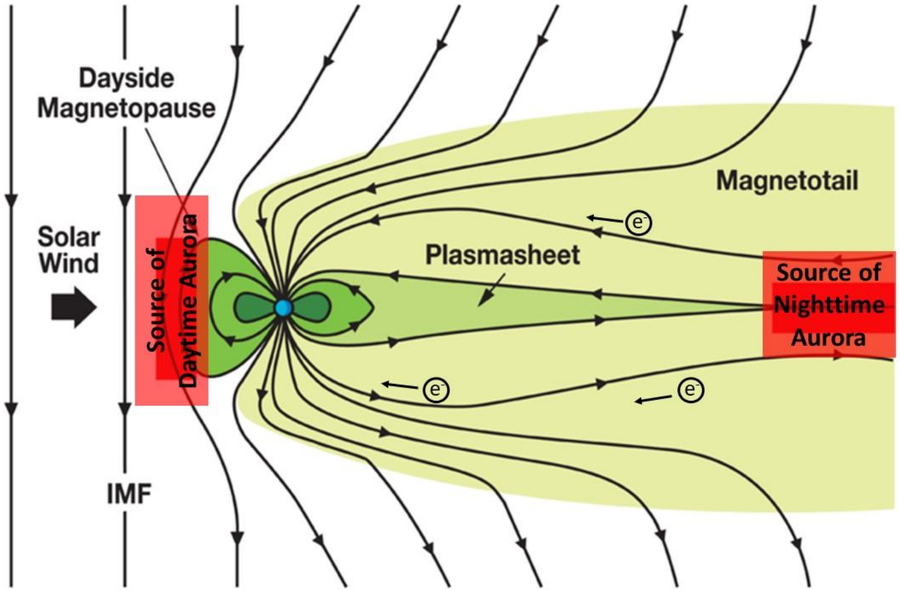


https://stereo.gsfc.nasa.gov/gallery/selects.shtml

II. Space weather drivers

Geomagnetic storms

☀️disturbance of planetary magnetic field due to magnetized solar plasma
☀️Auroras
☀️time variation of geomagnetic indices



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

Aurora: 5/6-Nov-2023, near Varna, Bulgaria
Credit: Yanko Nikolov (IANAO)

Open-access catalogs

https://catalogs.astro.bas.bg/

CATALOGS OF SOLAR ENERGETIC PROTONS AND SPACE WEATHER EVENTS

AIM | PROTON EVENTS | SXR FLARES | RADIO BURSTS | GEOMAGNETIC STORMS | TYPE II BURSTS

Home

This website will contain the information on SOHO/ERNE proton events, GOES solar flares, emission signatures of in situ ACE/EPAM electron events and particle-related geomagnetic storms over solar cycles 23 and 24 (1996-2019).

The catalogs are still under construction!

Contact: rmiteva [at] nao-rozhen.org

Catalogs of Solar Energetic Protons and space weather events 2024 . Powered by WordPress

Results: **Proton events**

- Correction to SOHO/ERNE flux:

SC23+24 : https://www.astro.bas.bg/AIJ/issues/n33/RMiteva.pdf

- Energy dependence trends; selected channels

https://doi.org/10.1063/1.5091228

https://www.astro.bas.bg/AIJ/issues/n31/RMiteva.pdf

SC23 : http://space.bas.bg/SES/archive.html

(catalog under completion)

CATALOGS OF SOLAR ENERGETIC PROTONS AND SPACE WEATHER EVENTS

AIM | PROTON EVENTS | SXR FLARES | RADIO BURSTS | GEOMAGNETIC STORMS | TYPE II BURSTS

Solar Cycle 23 – Protons

Show 10 entries

Search:

Year	m	d	Class	flare start	flare max	latitude	longitude	CME onset	CME speed	CME AW	Channel 1	onset UT	peak UT	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8	Channel 9	Channel 10
1996	7	9	X2.6	09:05	09:11	-10	30	gap	gap	gap	0.004401	09:44	10:52	0.002427	0.001022	0.000979	no	no	no	no	no	no
1996	8	13	u	u	u	u	u	16:09	620	153	0.008504	18:15	22:03	0.005586	0.002268	0.001914	0.00121	0.000892	no	no	no	no
1996	11	26	B9.0	20:48	24:32	u	u	21:36	548	78	0.001545	24:31	26:39	0.000702	0.000657	no	no	no	no	no	no	no
1996	11	27	u	u	u	u	u	u	u	u	0.001879	14:33	15:11	0.000916	0.000431	no	no	no	no	no	no	no
1996	11	28	C1.3	15:35	17:32	u	u	16:50	984	101	0.009031	19:38	22:12	0.005472	0.001592	0.00116	0.000721	no	no	no	no	no
1996	11	29	u	u	u	u	u	u	u	u	0.006815	05:30	13:49	0.002708	0.001147	0.000987	no	no	no	no	no	no
1996	11	30	u	u	u	u	u	u	u	u	0.02436	06:22	07:13	0.013896	0.004013	0.003175	0.001388	0.000415	no	no	no	no
1996	11	30	M1.0	20:16	20:44	-6	47	n	n	n	0.002383	23:29	28:38	0.00101	0.000519	no	no	no	no	no	no	no
1996	12	24	C2.1	13:03	13:11	5	95	13:29	325	69	0.010562	15:05	18:06	0.006228	0.003103	0.002215	0.001172	0.000794	0.000459	no	no	no

Showing 1 to 9 of 9 entries

Previous Next

Note: Only a preview of the results during 1996 is shown. The channel selected for the proton event identification is Channel 2.

Abbreviations:

- AW – angular width
- CME – coronal mass ejection
- gap – data gap
- no – no proton event
- u – uncertain

Notations:

- all times are in UT
- Channels (in MeV): **1**: 14-17; **2**: 17-22; **3**: 21-28; **4**: 26-32; **5**: 32-40; **6**: 40-51; **7**: 51-67; **8**: 64-80; **9**: 80-101; **10**: 101-131
- class: flare peak in GOES soft X-ray flux (W/m^2)
- CME speed: linear speed (km/s) from https://cdaw.gsfc.nasa.gov/CME_list/index.html
- flare latitude: North (positive); South (negative)
- flare longitude: West (positive); East (negative)

Results: **Solar flares**

Flares with solar/space weather events
(sunspots, CMEs, particles, radio bursts)

1) X-class flares

SC23+24 (175)
https://www.astro.bas.bg/AIJ/issues/n35/RMiteva.pdf

Eruptive versus confined X-class flares in solar cycles 23 and 24

Rositsa Miteva
Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, BG-1784, Sofia
rmiteva@astro.bas.bg

(Submitted on 16.01.2021; Accepted on 04.03.2021)

Abstract. A systematic analysis on the properties of all GOES X-class solar flares (SFs) in solar cycles 23 and 24 (1996−2019) is performed. The occurrence rates and parameters of the eruptive and confined SFs are presented. The aspect of eruptivity versus confinement is investigated with respect to the co-occurrence of coronal mass ejections (CMEs), radio emissions, energetic protons and geomagnetic storms. The absence of interplanetary type III radio bursts, in addition to the lack of CMEs, is found to be a very good proxy for confinement, in contrast to the sunspot type of the parent active region, as both eruptive and confined SFs are predominantly of β-γ-δ magnetic type. The remaining parameters, protons and geomagnetic storms, imply observing from a specific location in the heliophere and thus are biased for Earth-reaching phenomena. Finally, the relationships between the two types of SFs and the considered here solar activity phenomena are discussed in view of previous studies.

Key words: solar flares (SFs) - coronal mass ejections (CMEs) - interplanetary type III radio bursts (IP III) - solar energetic particles (SEPs) - geomagnetic storms (GSs)

Bulgarian Astronomical Journal 35, 2021

2) M-class flares

SC23+24 (2177)
https://doi.org/10.3390/universe8010039

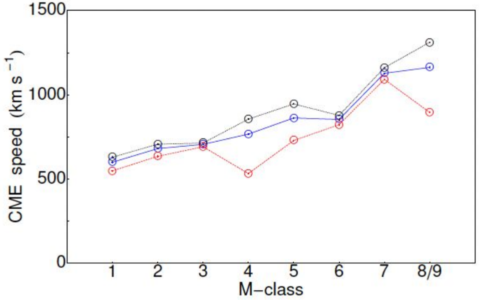
universe MDPI

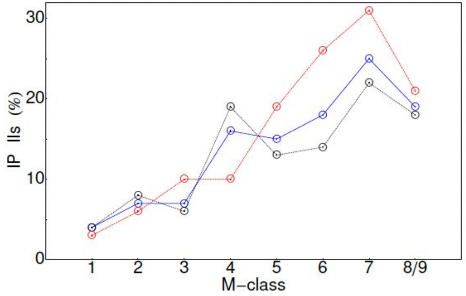
Article

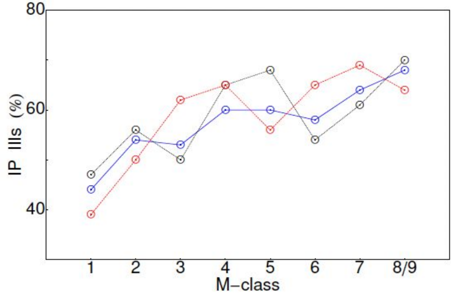
M-Class Solar Flares in Solar Cycles 23 and 24: Properties and Space Weather Relevance

Rositsa Miteva [1,*] and Susan W. Samwel [2]

Solar Event	SCs23 + 24
SFs	2177 (100%)
CMEs	889 (41%)
β	655 (30%)
β-γ	481 (22%)
β-γ-δ	663 (30%)
SEPs	133 (6%)
SEEs	247 (11%)
IP-III	1078 (50%)
IP-II	148 (7%)



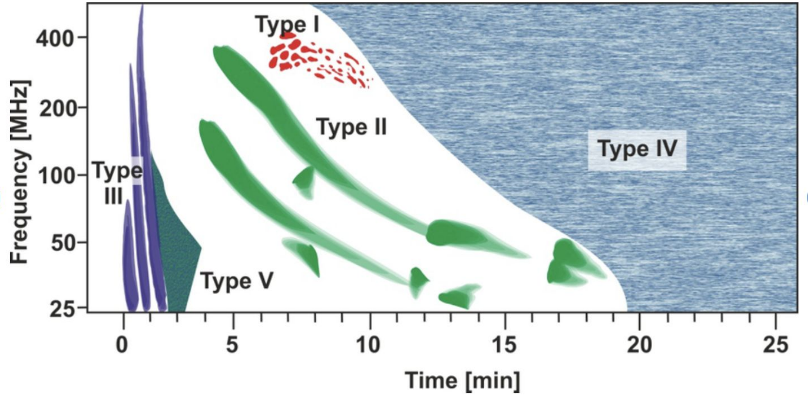




Results: **Radio bursts**

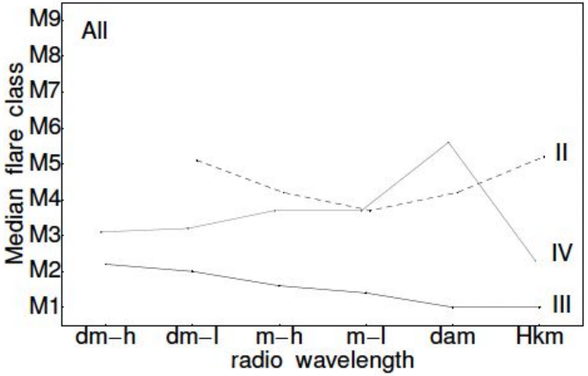
Type II, III, IV bursts of solar electron events
SC23+24 (832)

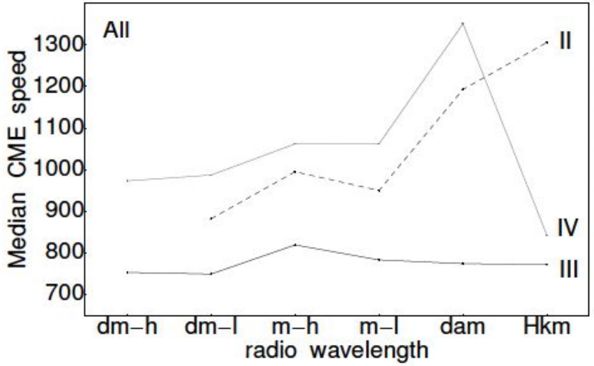
- Histograms vs. radio frequency
- Occurrence rates vs. radio frequency
- Flare, CME trends vs. radio frequency



https://link.springer.com/article/10.1515/acgeo-2016-0028

dm-h (3–1 GHz)
dm-l (1000–300 MHz)
m-h (300–100 MHz)
m-l (100–30 MHz)
dam (30–3 MHz)
Hkm (3 MHz–20 kHz)





universe

Article
Solar Radio Bursts Associated with In Situ Detected Energetic Electrons in Solar Cycles 23 and 24

Rositsa Miteva [1,*], Susan W. Samwel [2] and Svetoslav Zabunov [3]

https://doi.org/10.3390/universe8050275

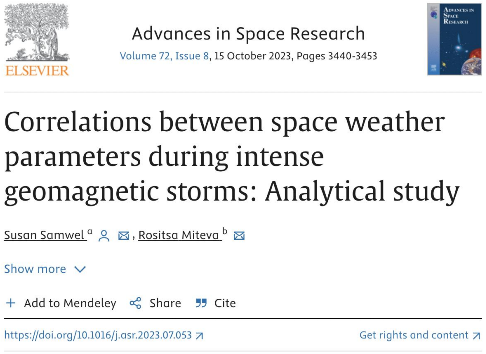
Results: **Geomagnetic storms**

1) Major GSs

(top 50):
https://doi.org/10.1016/j.asr.2020.07.006

2) Intense GSs (|Dst|>100 nT)

SC23+24 (111):
Correlation with solar & IP parameters:
https://doi.org/10.1016/j.asr.2023.07.053


Advances in Space Research
Volume 72, Issue 8, 15 October 2023, Pages 3440-3453

Correlations between space weather parameters during intense geomagnetic storms: Analytical study

Susan Samwel [a], Rositsa Miteva [b]

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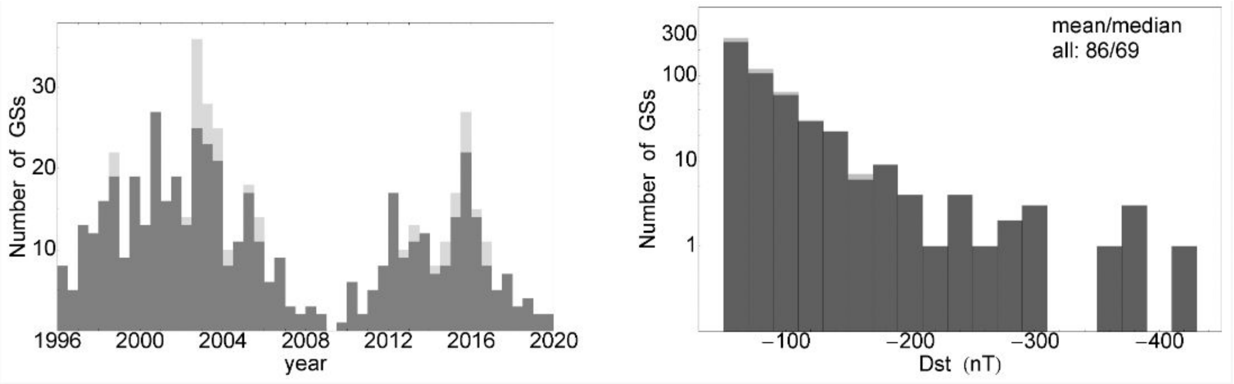
https://doi.org/10.1016/j.asr.2023.07.053 · Get rights and content

- strong correlation between |Dst| and both B_{total} and $|B_z|$;
- moderate correlation between |Dst| and solar wind parameters, except with solar wind density N_{SW} which shows almost no correlation;
- the |Dst| is highly correlated with $|V_{SW}B_z|$ when compared with its correlation with V_{SW} and $|B_z|$ separately;
- with the exception to V_{ICME} which shows high correlation with |Dst|, the solar activity parameters (V_{CME}, AW, and I_{SXR}) show weak/no correlation with |Dst|;
- poor correlations are found between the parameters (flux and fluences) of the solar energetic particles, whether protons or electrons, with |Dst|.

3) Weak GSs (|Dst|>50 nT)

SC24 (171):
https://astro.bas.bg/conf_proc/book_XIIIBSAC.pdf

SC23+24 (546):
https://doi.org/10.3390/atmos14121744



New topic: **Space weather effects on satellites**

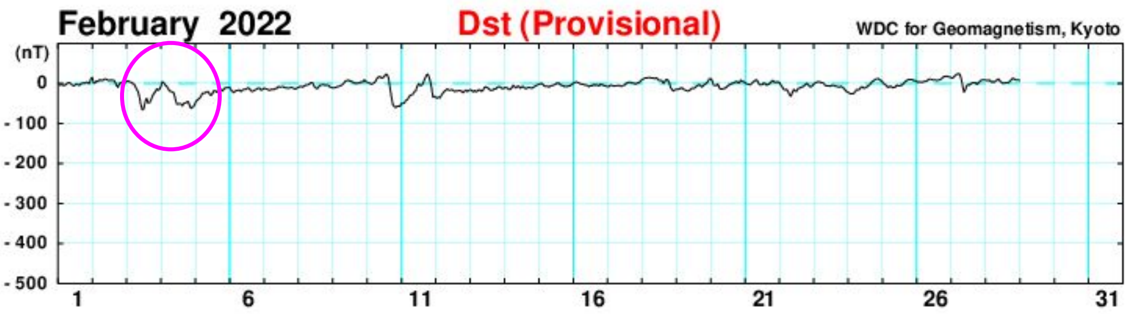
https://doi.org/10.3390/astronomy2030012

SpaceX: Starlink

Orbit:
210 km orbit (VLEO)

Facts:
2022-02-03
38/49 loss
minor geo-storms:
-66, -62 nT

Possible causes on the failure:
(1) Increased atmospheric drag - increased mass density
(2) GSs in close succession



Although the majority of the previous research [57–62] concluded that the notable Starlink failure was due to the increased atmospheric drag, ranging from 20–30% up to 150% at the staging orbit of 210 km, some doubts are raised if that it is the sole cause [63]. Despite the fact that the latter also estimated an increased thermospheric mass density by 35%, these authors proposed that GSs occurring in close succession (within about one day) are accountable for more negative SW effects on spacecraft operation and stability. The effects of the atmospheric drag on LEO satellites has been the topic of intense research, e.g., [48,49] and the references therein. Although it is well known that GSs lead to a global increase in the thermospheric neutral density, Joule heating due to EUV flare emission, and particle precipitation cause additional expansion in the 100–200 km region (or VLEO) [62].

New topic: **Space weather effects on satellites**

Focus:
solar (solar flares) & (near-Earth) IP contributions (protons, electrons) at the time of selected Starlink launches

Aim:
in order to evaluate the additional impact of the EM and radiation environment on satellite stability

Input:
Timing of all (~100) Starlink launches 2019-2022 => 15 with Dst <=-25 nT

https://doi.org/10.3390/astronomy2030012

Table 2. Starlink launches and accompanied magnetospheric and IP phenomena: date (yyyy-mm-dd) and time (hh:mm) of the Starlink launches; day (dd), nearest hour (hh), and value (in nT) of the Dst index of the GS; day/time/speed (in km s^{-1}) of the ICME; day/time/speed (in km s^{-1}) of the IP shock, density jump at the shock surface (in cm^{-3}); day/time/value (in nT) for B_z component. All times are in UT. No reported events are denoted with 'no'.

Starlink Launch		GS Dst	ICME	IP Shock		B_z
Date	hh:mm	dd/hh/nT	dd/hh/km s^{-1}	dd/hh/km s^{-1}	cm^{-3}	dd/hh:mm/nT
2020-04-22	19:31	20/13/−59	20/09/330	20/01:33/336	6.7	20/11:52/−15
2020-10-06	11:30	05/22/−40	05/17/350	no	no	05/19:34/−9
2020-10-24	15:32	24/07/−38	no	no	no	23/20:16/−12
2021-02-16	04:00	17/06/−54	no	no	no	13/03:07/−12
2021-03-04	08:25	03/05/−39	no	no	no	01/04:05/−14
2021-03-14	10:01	14/10/−43	no	no	no	13/05:06/−13
2021-05-26	18:59	27/09/−28	26/05/410	26/11:45/369	10.9	27/06:15/−11
2021-12-02	23:12	02/23/−25	no	no	no	02/15:02/−5
2022-01-19	02:03	19/04/−44	19/05/610	18/22:58/820	1.2	19/05:05/−6
2022-02-03	18:13	03/11/−66	02/16/460	01/22:27/543	4.2	03/09:37/−19
2022-04-29	21:27	30/08/−37	no	no	no	27/13:01/−11
2022-05-13	22:08	13/22/−39	no	no	no	11/19:55/−10
2022-07-07	13:11	07/23/−81	07/12/380	no	no	07/12:48/−16
2022-09-05	02:10	04/17/−72	no	no	no	04/05:24/−10
2022-12-28	09:34	27/16/−68	no	no	no	26/12:24/−10

New topic: **Space weather effects on satellites**

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Article

Space Weather Effects on Satellites

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Results:

➔ Minor to moderate effects due to solar flares, particle radiation & IP plasma density, B-field, velocity

Open ?s:

➔ Double GSs as a possible cause for satellite failure

Table 3. Starlink launches and accompanied solar/SW phenomena: date (yyyy-mm-dd) and time (hh:mm) of the Starlink launches; SF day/start/peak/end time/class; SEP day/peak time; SEE day/peak time. All times are in UT. Abbreviations: on: ongoing; pr: preceding; s: start time; su: succeeding.

Starlink Launch		SFs	SEPs	SEEs
Date	hh:mm	dd/hh:mm/class	dd/hh:mm	dd/hh:mm
2020-04-22	19:31	no	no	no
2020-10-06	11:30	no	no	no
2020-10-24	15:32	no	no	no
2021-02-16	04:00	no	no	no
2021-03-04	08:25	no	no	no
2021-03-14	10:01	no	no	no
2021-05-26	18:59	26^{on}/18:51/18:58/19:47/B7.0	no	no
2021-12-02	23:12	no	no	no
2022-01-19	02:03	no	no	18^{on}/$19{:}26^{s}$
2022-02-03	18:13	02^{pr}/17:42/17:47/17:59/C1.1	no	03^{su}/22:35
2022-04-29	21:27	29^{su}/22:42/22:56/23:14/C3.0	29^{on}/17:03	29^{on}/09:12
2022-05-13	22:08	13^{on}/22:07/22:26/22:34/C2.6	no	no
2022-07-07	13:11	no	no	no
2022-09-05	02:10	05^{on}/01:53/02:05/02:19/C5.0	no	no
2022-12-28	09:34	22^{on}/09:34/09:42/09:49/C2.4	no	no

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EU-Horizon 2020 (twinning project): STELLAR (Scientific and Technological Excellence by Leveraging LOFAR Advancements in Radio Astronomy) https://stellar-h2020.eu/

Ministry of Education, Bulgaria: LOFAR-BG https://lofar.bg/

Thank you for your attention!

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