

# Solar activity and space weather research in Bulgaria

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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/>

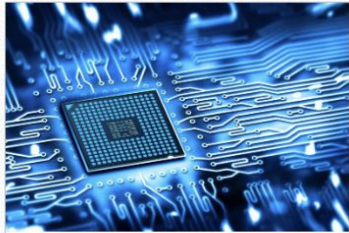
<https://nao-rozhen.org/>

## II. Selected results

- Statistics, correlations, catalogs

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

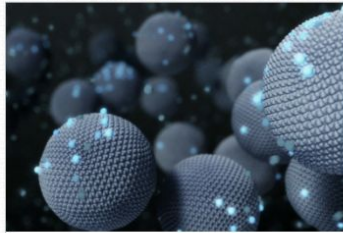
# I. Bulgarian Academy of Sciences



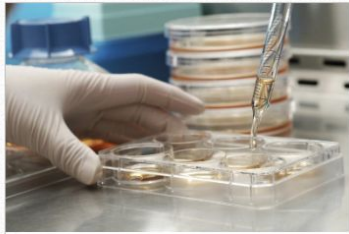
Information and Communication Sciences and Technologies



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

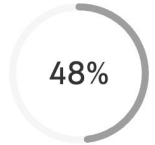


Man and Society



founded in Romania

<http://bas.bg/>



48% of the scientific output of Bulgaria

42

research units (institutes)

2023: H-index  
Bulgaria: 330

8

academic specialized units

9

specialized units



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

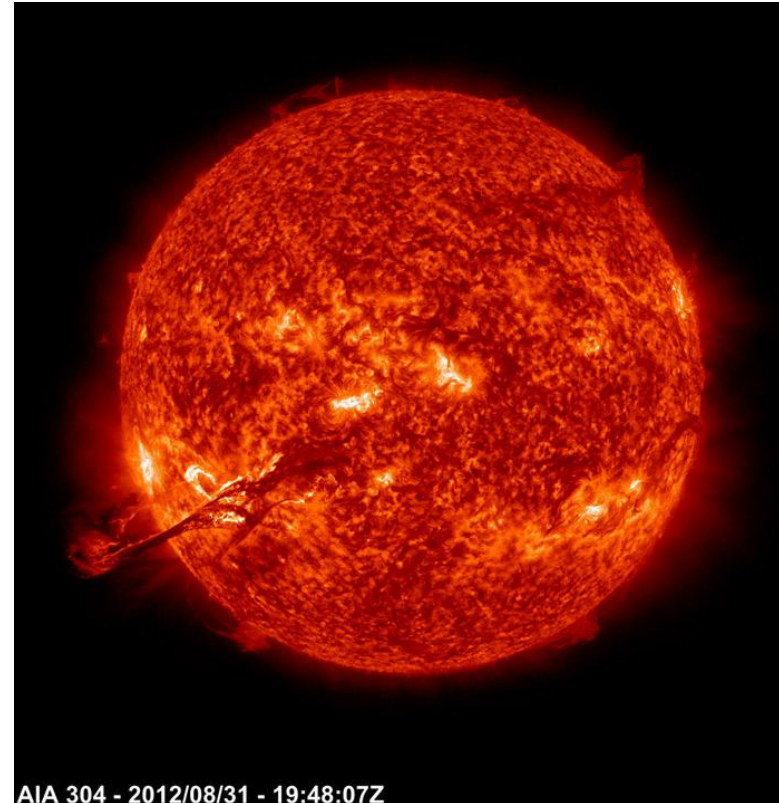


## Topics of research (1990s, 2000s)

- 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/>



AIA 304 - 2012/08/31 - 19:48:07Z

<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/>

**→ WHAT IS SPACE WEATHER?**

**1** Our Sun is an enormous ball of hot gas and plasma. Dark sunspots are visual indicators of active regions, caused by local intense magnetic activity. Active regions are sources of solar flares and Coronal Mass Ejections (CMEs).

**2** Solar flares are huge explosions in which electromagnetic energy is emitted into space as radio waves, visible light, ultraviolet radiation and X-rays. Flares can be associated with ejections of energetic protons, electrons and heavier particles into space at near light speed.

**3** Active regions can give rise to CMEs, when billions of tonnes of matter are flung into space at speeds reaching 3000 km/s. CMEs are often associated with solar flares but can also occur independently.

**4** The interplanetary magnetic field. Pressure from the solar wind gives Earth's magnetic field its characteristic shape, compressed on the day side and extended into a long tail on the night side.

**5** Solar wind is a continuous stream of electrons, protons and heavier particles from the upper atmosphere of the Sun. Embedded within the solar wind is the interplanetary magnetic field. Pressure from the solar wind gives Earth's magnetic field its characteristic shape, compressed on the day side and extended into a long tail on the night side. CMEs are slowed by the effect of pushing through the solar wind. The fastest CMEs reaching the Earth are usually combinations of two CMEs, where the second propagates in the 'wake' cleared by the first.

**6** Auroras are spectacular phenomena that occur at northern and southern polar latitudes. During strong geomagnetic storms, aurora can be visible also at latitudes nearer the equator.

**7** Geomagnetic storms can affect or damage satellites in space as well as induce currents in power grids, damaging transformers, on ground. They also disturb radio signals travelling through the upper atmosphere. In 1989, a CME caused a geomagnetic storm that led to a 9-hour power blackout in Quebec. In 2003, many satellites were damaged or temporarily affected by the 'Halloween storms', a series of powerful solar events. In 2012 a massive CME just missed Earth.

**8** ESA has established the European Space Weather System, which links existing European space weather expertise – located at scientific institutes, national research centres, industry and observation systems on ground and in space – with ESA's Space Weather Coordination Centre, Brussels. Working with regional Expert Service Centres, the coordination centre provides processed data and 'products' that serve customers across a wide range of industries and economically vital activities like power grid operations, shipping, transport and telecommunication.

**ESA**

**#Space19plus #SolarHazards #LagrangeMission**

**Space19**

# 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

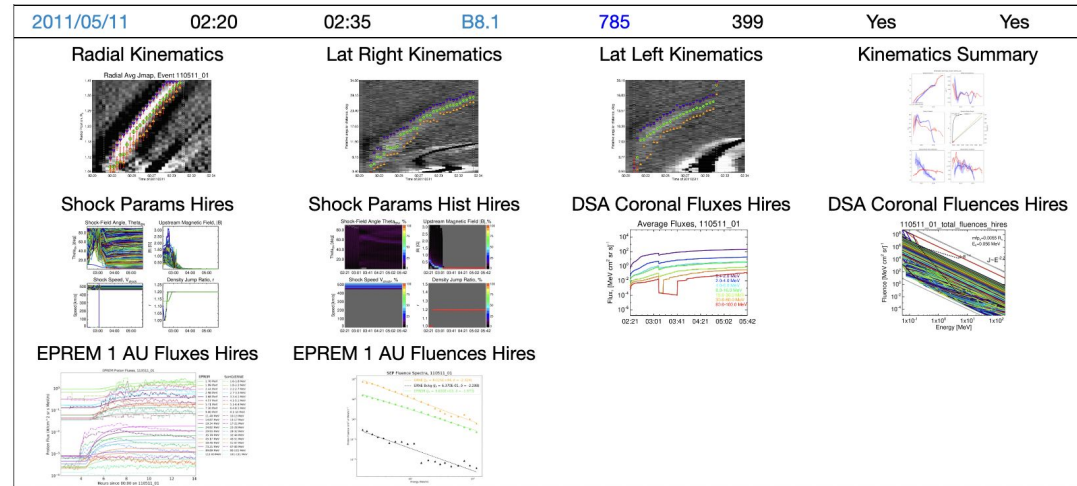
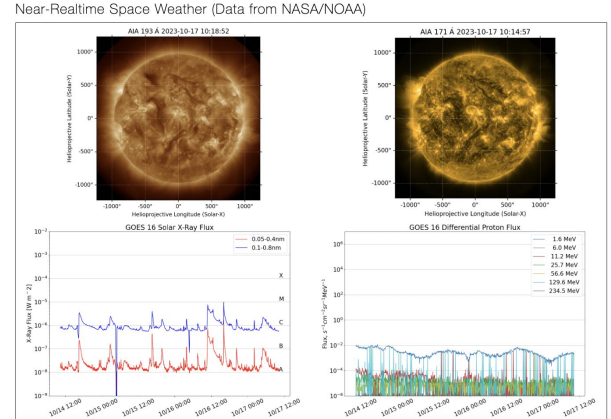


# Completed science projects

- **SPREADFAST**

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

Prototype of 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



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@astro.bg](mailto:kkozarev@astro.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/>

Home MOSAIICS Project Description Team Results Blog Contact

## MOSAIICS

Modeling and Observational Integrated Investigations of Coronal Solar Eruptions

### COMPUTER VISION AND DEEP LEARNING

Develop cutting-edge methodology for solar eruption detection and characterization, based on computer vision and deep learning methods.

READ MORE >

### METRIC SOLAR RADIO IMAGING

Unlock the discovery potential of uniquely rich low-frequency radio imaging data, showing the early stages of solar eruptions.

READ MORE >

### ENERGETIC PARTICLE ACCELERATION

Transform our understanding of energetic particle acceleration in solar eruptions, combining radio imaging and energetic particle modelling.

READ MORE >

MOSAIICS is a 5-year research project, part of the National Science Program “VIHREN”. It is hosted at the Institute of Astronomy and National Astronomical Observatory of the Bulgarian Academy of Sciences. The project PI is Assoc. Prof. Kamen Kozarev.

MOSAIICS aims to improve our understanding of the physics of solar eruptions by integrating modern computer vision, advanced solar radio imaging, and energetic particle modeling.

You can learn more about the project, or each topic link.  
Or let us know if you have any questions, on our Contact form.

# Ongoing science projects



- **MOSAIICS:**

Modeling and Observational Integrated Investigations of Coronal Solar Eruptions

(Bulgarian National Science Fund)

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

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](http://www.swsc-journal.org)

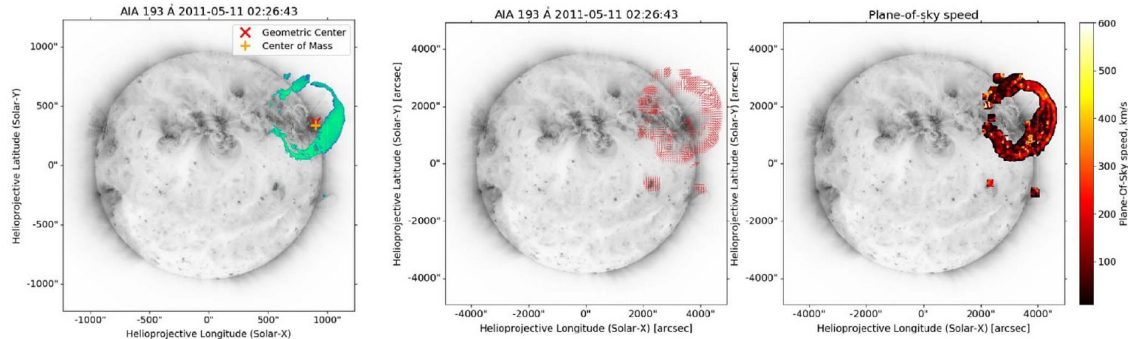
RESEARCH ARTICLE

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 Chaussee Blvd 72, Sofia 1784, Bulgaria

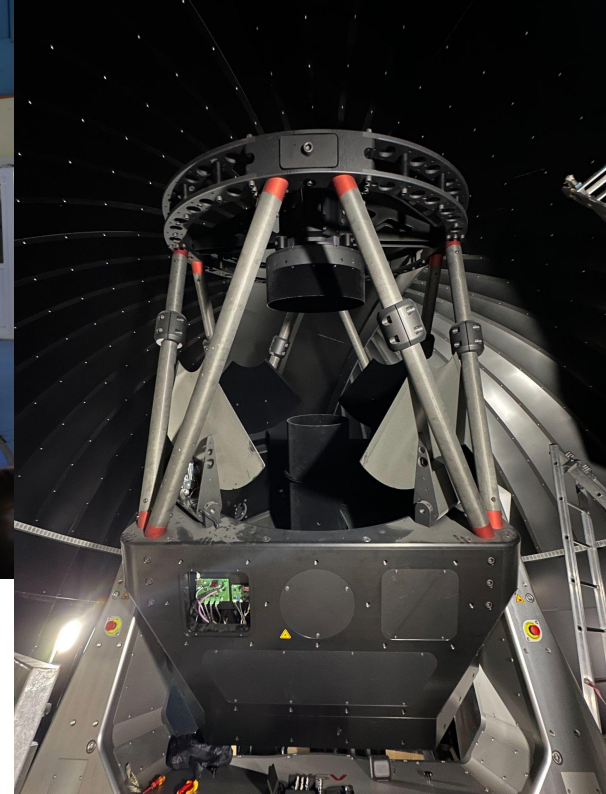


# Infrastructure

## 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/>



# Infrastructure

## NAO-Rozhen

- 2-m telescope
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<https://nao-rozhen.org/>



M27 е планетарна мъглявина, известна още като мъглявината Джобел или NGC 6853. Разположена е в съзвездие Медуза, около на 3500 светлинни години от нас. Централната и звезда е бело джудже с радиус от около 0.005 слънчеви радиуса и маса 0.26 слънчеви маса. M27 може лесно да се наблюдава с бинокулар или малък любителски телескоп.  
Снимката е резултат от 3x5min експозиции в BVR филтрите.  
Автор: Милена Минева      Обработка: Емил Иванов



Пиларите на Съвременното образование се образуват от межзвезден газ и прах в звездната мъгла Слънце в съзвездие Орел. Те са с височина около 6300-7000 светлинни години от нас. Аproxимативно на същото разстояние се намират и големите слънчеви години от нас. Снимката е резултат от 9 експозиции по 5 мин. в H-алфа филтър.  
Автор: Милена Минева      Обработка: Емил Иванов



NGC 6946 или галактиката Фойерверк се намира на 22 милиона светлинни години от нас в съзвездие Цирейс. NGC 6946 също е крак в интергалаксията светлина и богата на газ и прах с голям темп на звездообразуване. За последните 100 години в нея са открити 10 супернови. За сравнение в Нашата галактика се наблюдава около 3 супернови на 100 години.  
Снимката е резултат от 7x5min експозиции в BVR филтрите.  
Автор: Милена Минева      Обработка: Емил Иванов

# 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://helio.astro.bas.bg/observations>



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

# Infrastructure

## NAO-Rozhen

- 2-m telescope
- 1.5 m telescope
- **30-cm chromospheric solar telescope**



## 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.

### Acknowledgements

The activities under this bilateral cooperation are supported by the Bulgarian National Science Foundation project No. KP-06-Austria/5 (14-08-2023) and Austria's Agency for Education and Internationalisation (OeAD) project No. BG 04/2023.

Share:



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





# 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.

## LOFAR-BG

<https://lofar.bg/bg/>

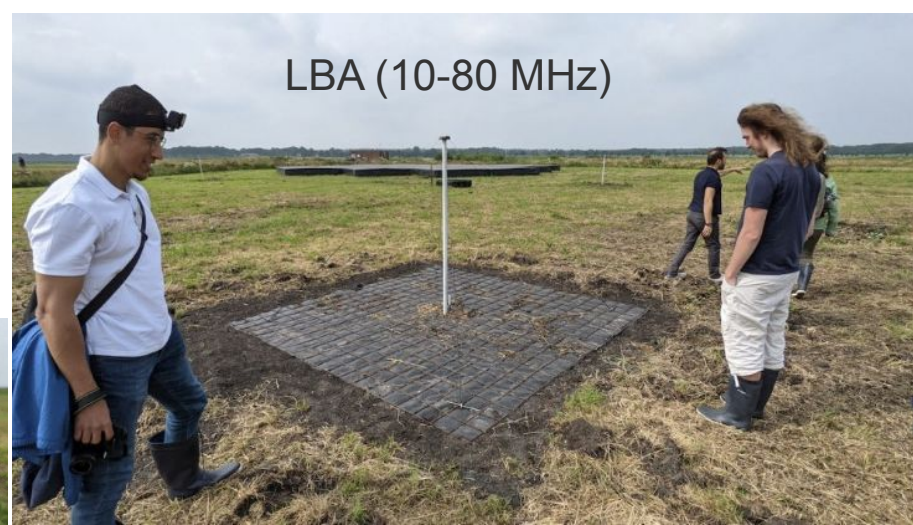


# Infrastructure

## LOFAR

### NAO-Rozhen

- 2-m telescope
- 1.5 m telescope
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- **Radio station (in progress)**
- Neutron monitor (in progress)
- Weather station, etc.



# Infrastructure

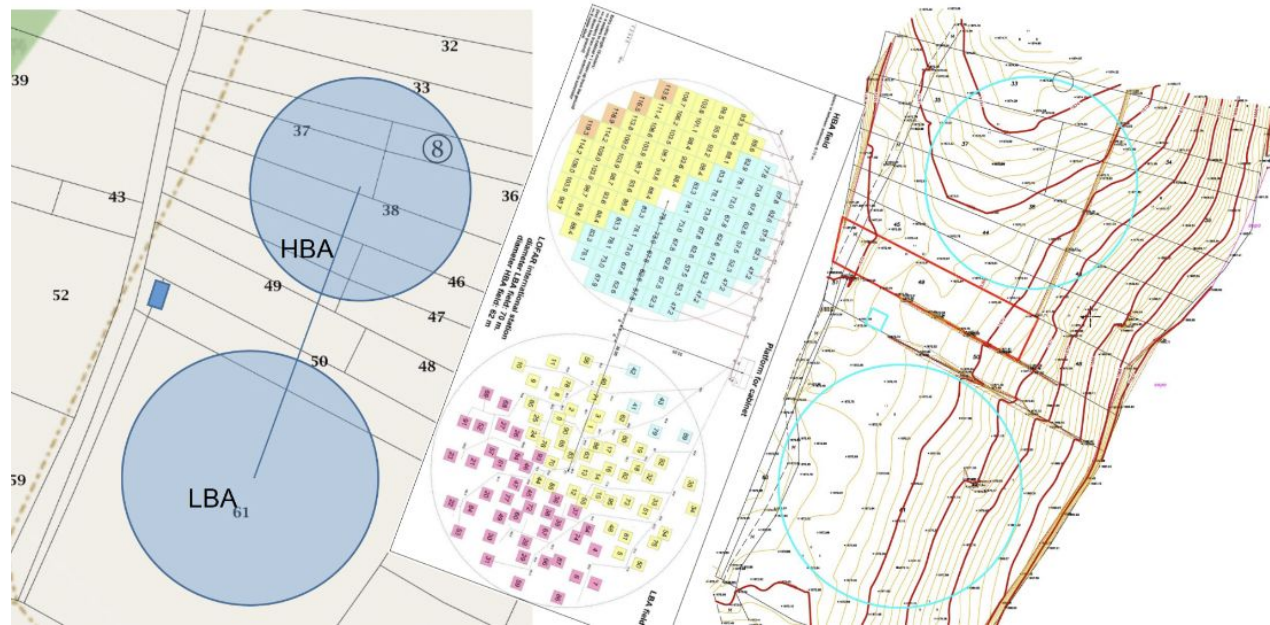
<https://lofar.ie/>



## NAO-Rozhen

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

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



# 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.

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

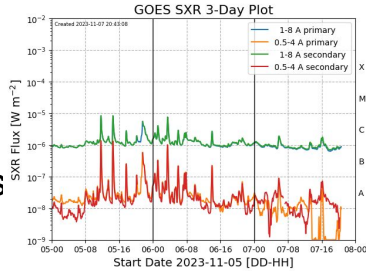
**space weather effects** at near Earth environment - from remote observations and in situ particle forecasting to impacts on satellites

[http://edu-pro.astro.bas.bg/sun/?page\\_id=368](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,...)

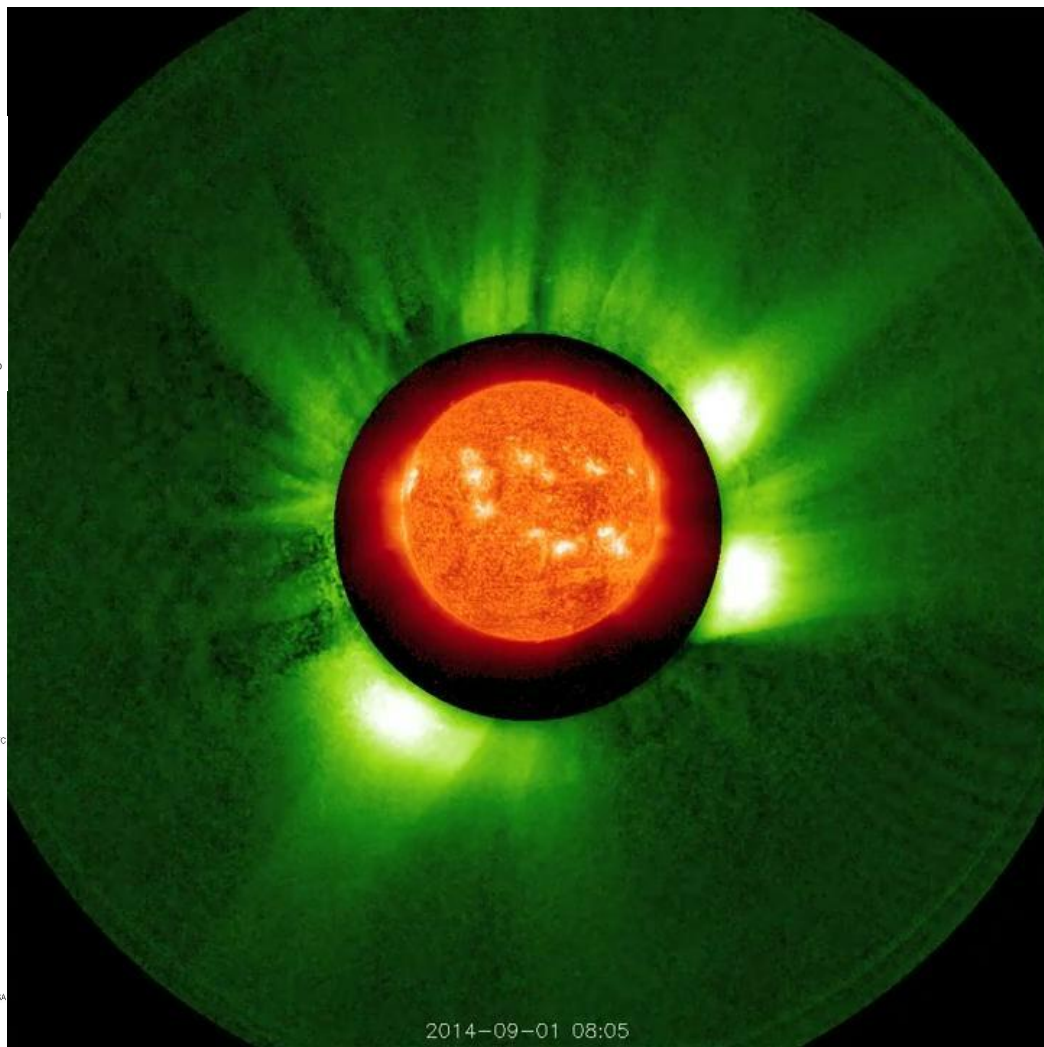
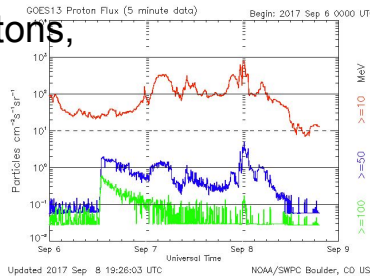


## Coronal mass ejections

- ★ 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



# II. Space weather drivers

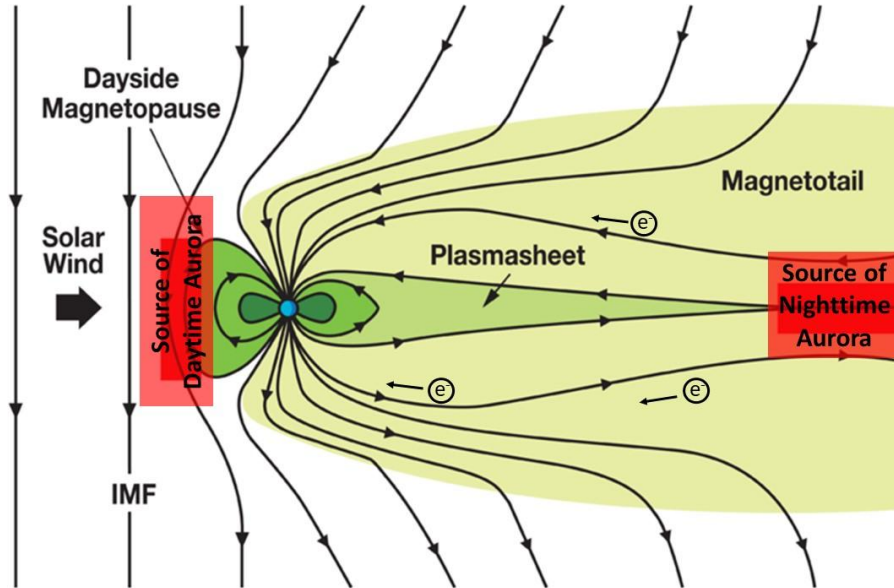


## Geomagnetic storms

☀ 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](mailto:rmiteva@nao-rozhen.org)



# 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  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	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	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	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	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	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	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	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	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	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](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>

## 2) M-class flares

SC23+24 (2177)

<https://doi.org/10.3390/universe8010039>

### 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  $\beta$ - $\gamma$ - $\delta$  magnetic type. The remaining parameters, protons and geomagnetic storms, imply observing from a specific location in the heliosphere 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



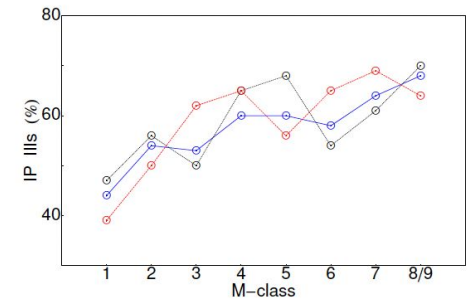
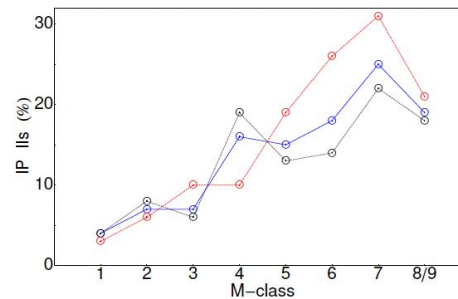
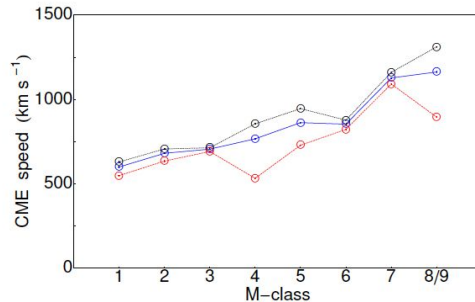
universe



Article

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

Rositsa Miteva <sup>1,\*</sup> and Susan W. Samwel <sup>2</sup>

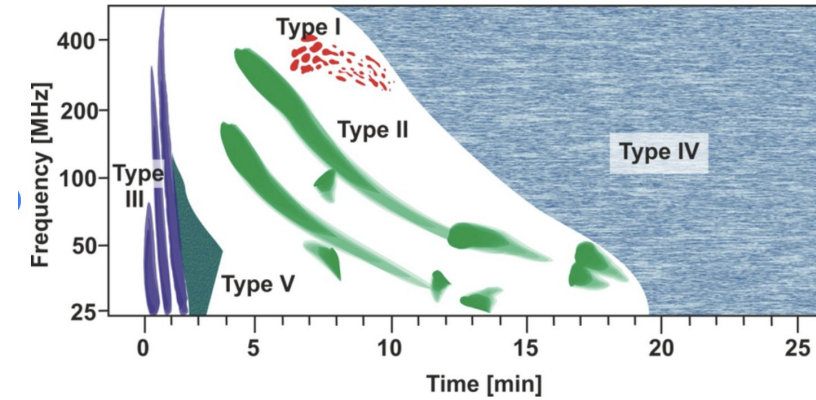


Solar Event	SCs23 + 24
SFs	2177 (100%)
CMEs	889 (41%)
$\beta$	655 (30%)
$\beta$ - $\gamma$	481 (22%)
$\beta$ - $\gamma$ - $\delta$	663 (30%)
SEPs	133 (6%)
SEEs	247 (11%)
IP-III	1078 (50%)
IP-II	148 (7%)

# Results: Radio bursts

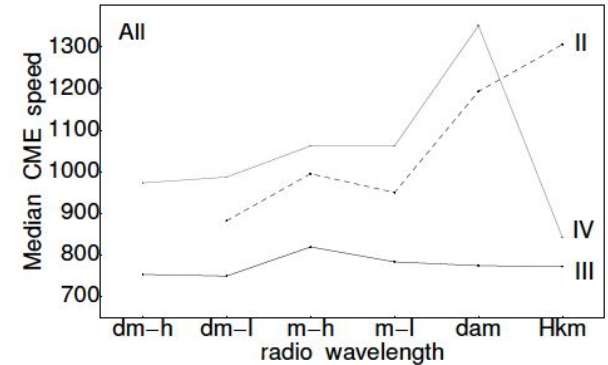
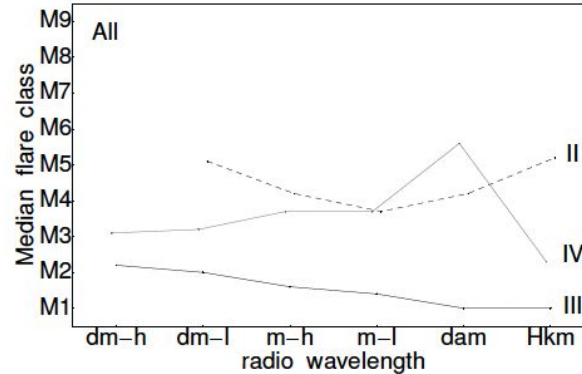
Type II, III, IV bursts of solar electron events  
SC23+24 (832)

- 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)



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

Rositsa Miteva<sup>1,\*</sup>, Susan W. Samwel<sup>2</sup> and Svetoslav Zabunov<sup>3</sup>

<https://doi.org/10.3390/universe8050275>

# Results: Geomagnetic storms



## 1) Major GSs

(top 50):

<https://doi.org/10.1016/j.asr.2020.07.006>



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<sup>a</sup>, Rositsa Miteva<sup>b</sup>

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<https://doi.org/10.1016/j.asr.2023.07.053>

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- 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  $|Dst|$ .

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

SC23+24 (111):

Correlation with solar & IP parameters:

<https://doi.org/10.1016/j.asr.2023.07.053>

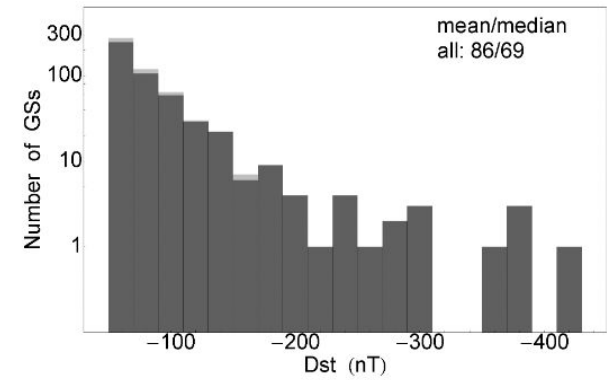
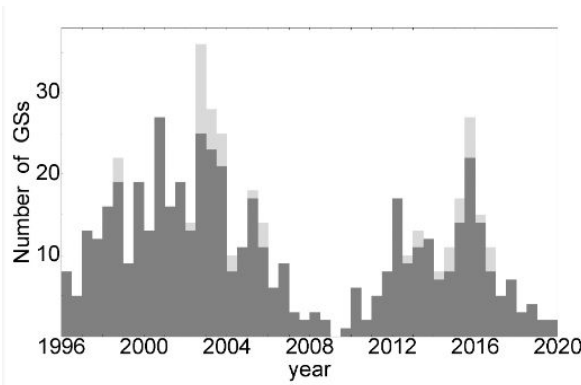
## 3) Weak GSs ( $|Dst| > 50$ nT)

SC24 (171):

[https://astro.bas.bg/conf\\_proc/book\\_XIIIBSA\\_C.pdf](https://astro.bas.bg/conf_proc/book_XIIIBSA_C.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

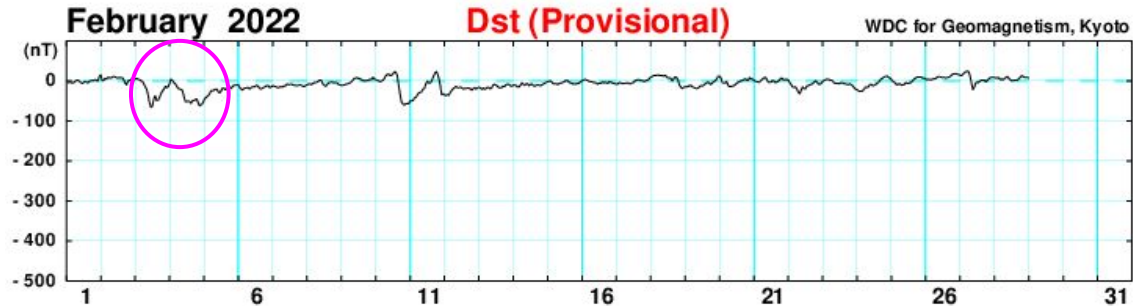
38/49 loss

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



<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  $\text{km s}^{-1}$ ) of the ICME; day/time/speed (in  $\text{km s}^{-1}$ ) of the IP shock, density jump at the shock surface (in  $\text{cm}^{-3}$ ); 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/ $\text{km s}^{-1}$	dd/hh/ $\text{km s}^{-1}$	$\text{cm}^{-3}$	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

**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

# New topic: Space weather effects on satellites



<https://doi.org/10.3390/astronomy2030012>

Article

## Space Weather Effects on Satellites

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  - <sup>2</sup> National Research Institute of Astronomy and Geophysics (NRIAG), Helwan 11421, Egypt; samwelsw@nriag.sci.eg
  - <sup>3</sup> European Innovation Council and SMEs Executive Agency (EISMEA), 1049 Brussels, Belgium; stela.tkatchova@ec.europa.eu
- \* Correspondence: rmiteva@nao-rozhen.org

**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.

### 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

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 <sup>on</sup> /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 <sup>on</sup> /19:26 <sup>s</sup>
2022-02-03	18:13	02 <sup>pr</sup> /17:42/17:47/17:59/C1.1	no	03 <sup>su</sup> /22:35
2022-04-29	21:27	29 <sup>su</sup> /22:42/22:56/23:14/C3.0	29 <sup>on</sup> /17:03	29 <sup>on</sup> /09:12
2022-05-13	22:08	13 <sup>on</sup> /22:07 /22:26/22:34/C2.6	no	no
2022-07-07	13:11	no	no	no
2022-09-05	02:10	05 <sup>on</sup> /01:53/02:05/02:19/C5.0	no	no
2022-12-28	09:34	22 <sup>on</sup> /09:34/09:42/09:49/C2.4	no	no

# Acknowledgements

SCOSTEP/PRESTO 2020 grant <https://scostep.org/presto/>  
'On the relationship between major space weather phenomena in solar cycles 23 and 24'

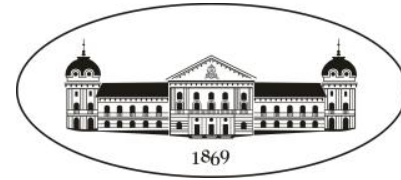
Interacademy bilateral project (BAS): Bulgaria-Egypt  
'On space weather effects at near Earth environment - from remote observations and in situ particle forecasting to impacts on satellites'  
IC-EG/08/2022-2024'

Bulgarian National Science Fund: Bulgaria-Austria  
'Joint observations and investigations of solar chromospheric and coronal activity' KP-06-Austria/5 (14-08-2023)

European Space Agency (ESA): <https://spreadfast.astro.bas.bg/>

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/>



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STELLAR





# Thank you for your attention!



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<https://astro.bas.bg/>

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