Radiation Belt Environmental Indicators for the Safety of Space Assets

SafeSpace Newsletter

Issue 5, Months 25-30

Dear Reader,

*Have you visited our **SafeSpace Service website**?*

It is accessible at http://www.safespace-service.eu and includes the main features of our prototype forecasting Service. If you have visited and used our Service Page, we would very much appreciate your feedback through our user satisfaction form, which can be found here.

Your feedback is invaluable, as it will help us to improve the Service, making it more user-friendly and more effective with regard to the users' needs. Thank you for your time and consideration!

Moreover, as the fifth semester of the SafeSpace project has been very productive, we are proud to share with you all our latest progress in the related Work Packages (WPs).

The SafeSpace consortium consists of the following partners, from academia and industry: National and Kapodistrian University of Athens (NKUA), Office National d'Etudes et de Recherches Aérospatiales (ONERA), Katholieke Universiteit Leuven (KUL), Institute of Atmospheric Physics Ustav Fyziky Atmosfery AV CR, v.v.i. (IAP), Centre National de la Recherche Scientifique (CNRS), Institut royal d'Aéronomie Spatiale de Belgique Royal Belgian Institute for Space Aeronomy (IASB-BIRA), Thales Alenia Space – España (TAS), and Space Applications & Research Consultancy Sandberg & Co Private Company (SPARC).

Project Progress and Outcomes

Propagating geoeffective solar wind structures to Earth (WP2 - CNRS, KULeuven, ONERA, IAP)

Work Package 2 of SafeSpace is now completed. The first part consisted in building, testing and validating a modelling pipeline which, based on several modelling tools, allows to predict solar wind parameters at the Lagrangian L1 point solely based on solar magnetograms. A second part (task 2.4) consisted in predicting geomagnetic indices based on these L1 parameters and using machine learning algorithms (neural networks). These indices serve as input to other modelling tools in Work Package 3. All interfaces have been defined, implemented and permitted propagating and forecasting solar perturbations all the way from the solar surface to near-Earth. The 1D component of the pipeline is now essentially operational.

Inner magnetosphere dynamics (WP3 – BIRA-IASB, IAP, NKUA, ONERA)

Work Package 3 of SafeSpace has also progressed toward its successful completion. It has been focused on defining a model of internal drivers for a space weather service prototype dedicated to the radiation belts, including an accurate description of the background plasma density and its variability; on updating a model of wave-particle interactions using previous and new observations, on developing a novel machine learning model for the radial diffusion coefficients and using a new background plasma density model; on improving the existing Salammbô electron radiation belt model according to new definition of interplanetary as well as magnetospheric drivers; on producing high fidelity past history of radiation belt dynamics and therefore a realistic initial state for more accurate predictions; on verifying the stability of assimilation tool and Salammbô code and their convergence for various solar wind conditions for future use in prototyping activities. The work on the tasks of work package 3 has resulted in a submission of a study on "Efficient computation of wave-particle interactions for a dynamic description of the electron radiation belt diffusion" by N. Dahmen et al. to a respected international journal.

Space Safety Service (WP4 - ONERA, TAS-E, CNRS, SPARC, NKUA, IAP, IASB)

This work package focuses on the implementation of a space weather prototype to provide products and parameters outputs matching the end users' requirements. It defines a space weather end-user service and relevant products, dedicated to Earth's radiation belts. It focuses on prototyping a web-based electron radiation belt nowcasting and forecasting tool, taking into account solar / interplanetary magnetic field (IMF) as well as internal magnetospheric dynamics from WP2 and WP3. It provides radiation belt activity indices suitable for an early warning system that can fulfil end-user requirements.

Service products definition

This task is fully completed since September 2021. It has allowed gathering space industries, space agencies and spacecraft operators requirements in terms of space weather services. While this activity focuses on all requirements addressing all type of space weather effects on space systems (Single Event Effects, Total doses, Electrostatic Discharges, atmospheric drag, communication interruption and navigation accuracy) SafeSpace concentrates on predicting energetic electrons, meaning that the prototype addresses internal charging risks on space systems.

Data management plan

A first version of the data management plan (DMP) was delivered in June 2020. Since last Fall, it has been updated to track all software and data specificities being updated and produced in the SafeSpace project. A series of meetings was organized with all individual teams to ensure the document is uniform and coherent. The Opidor tool was used to drive the team in their writing and to stick to the FAIR logic (Figure 1).

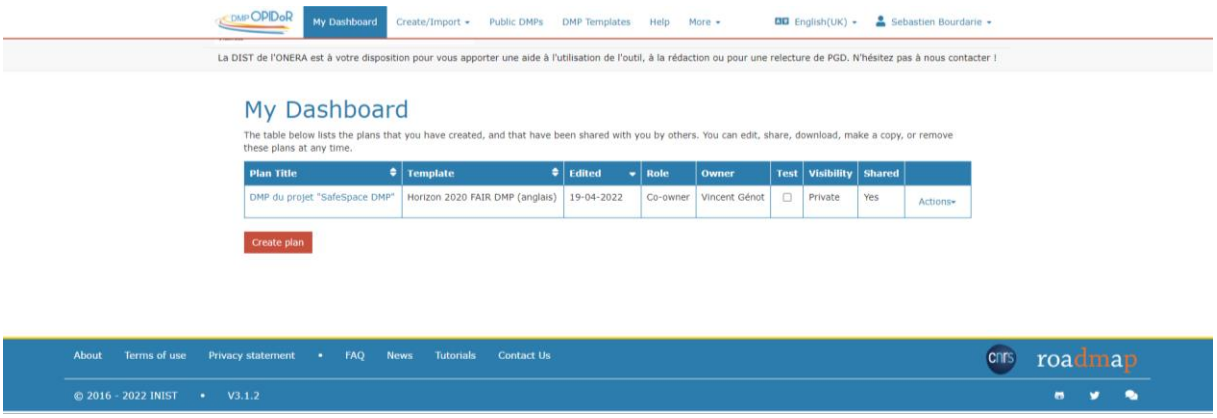

Figure 1: *SafeSpace DMP on Opidor tool*

The DMP will be reviewed again before the end of the project for a last check of its consistency with all tools having been developed and all data produced (file format, data location, data accessibility).

Prototyping radiation belt nowcast and forecast

This task is devoted to chaining the radiation belt data assimilation tool with the outputs from WP2 and WP3. An overview of the activity is provided in Figure 2.

First, in-situ data retrieval has been set up. Two partners are providing input data to this WP. These data include GSAT-EMU, GOES16-MPSH. The data are made available on a dedicated web site accessible by the team and new data files are added in the database on a daily basis in an automated mode. Then, in-situ data

are pre-processed and are stored all together in a single daily file that can be ingested straightaway by the data assimilation tool.

Second, solar wind predictions are produced daily in an automated mode, where MULTI-VP (from WP2) is linked with an 1D-Magnetohydrodynamic (MHD) code (also within WP2). To account for modeling uncertainties, an ensemble of 21 members of solar wind parameters, including the velocity, the density and the IMF, are produced. Each daily run includes 2 days in the past, the current day and 4 days in the future. All the data are exchanged within the team via a dedicated web site. With the file naming being standardized in the Interface Control Documents (ICDs) and reported in the DMP, one can easily find when the job is finished, i.e. when the data file is made available, in order to chain next models in the prototype (the ONERA Neural Network - ONN).

Third, the ONN computes the magnetic activity index, Kp, resulting from the solar wind conditions and accounting for the solar wind uncertainties. An ensemble of 21 members is produced, i.e. 21 values of Kp are computed, which reflect the uncertainties in the predictions. As before, the data are shared on a dedicated web site following an agreed standard. The availability of the Kp datafile indicates that the run is completed and the chaining can continue.

Fourth, radiation belt physical processes are computed from solar wind conditions and from magnetic activity. To account for solar wind uncertainties as well as radiation belt modeling uncertainties, the ensemble is expanded to 210 members for each individual physical processes. The coefficients are made available daily on the dedicated wed site and can be accessed by the team. The first one is the calculation of the radial diffusion coefficients. The NKUA EMERALD model runs daily and produces the radial diffusion coefficients for relativistic electrons based on solar wind parameters. The second physical process is the wave-particle interaction diffusion coefficients. To do so, the plasma density and the wave amplitude are computed daily based on/using the magnetic activity index, Kp. Then the wave-particle interaction coefficient is computed daily on a high performance computer (HPC).

Fifth and last point, the data assimilation tool is set-up and is currently running on HPC in a non-automated mode. It has been very recently finalized, following the final checks.

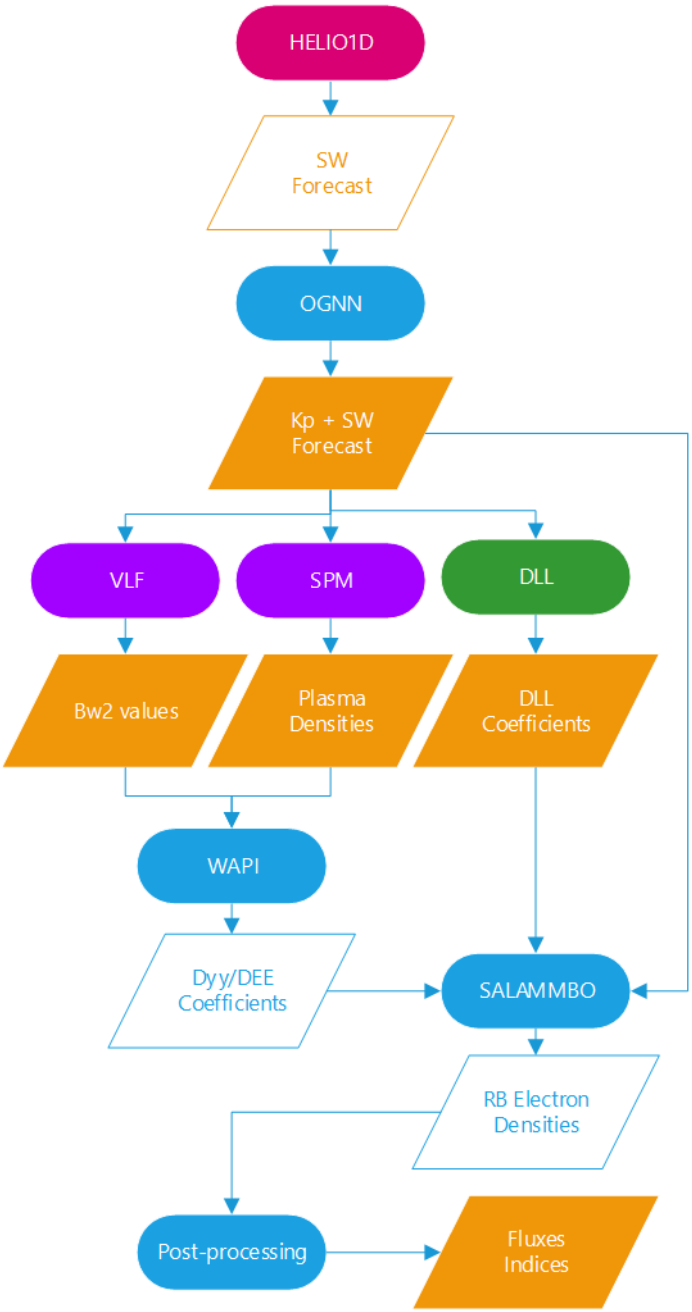

Figure 2: SafeSpace pipeline.

Radiation belt activity indices and warnings

Because the electron fluxes may vary depending on the location, long term databases have been used to investigate on daily energetic electron fluence values at GEO and MEO (navigation orbits).

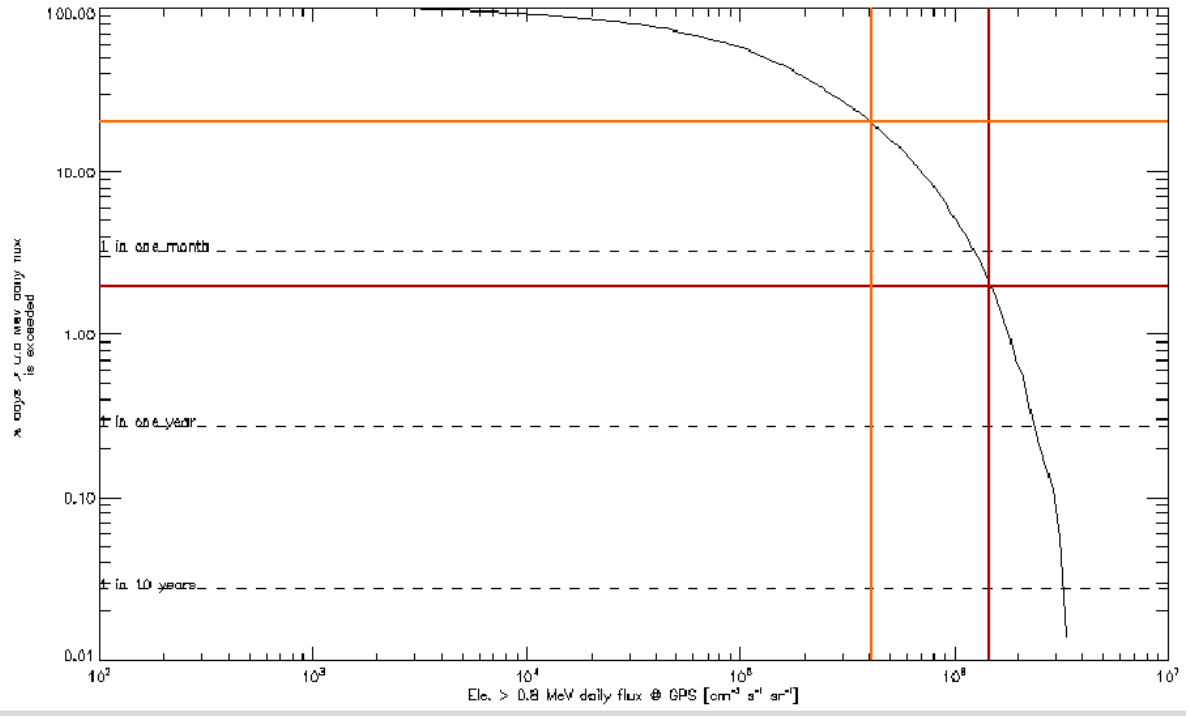

Figure 3: *Complementary cumulative distribution function of daily energetic electron flux at GPS altitude. Red threshold indicates the flux value that is exceeded no more than 2% of time on average and the orange threshold indicates the flux value that is exceeded no more than 20% of time on average.*

This analysis has been extended to LEO orbit as well. Clearly, one single activity index cannot cover accurately all orbits and dedicated ones have to be set. From statistical analysis, it is then possible to define thresholds above which it is possible to raise an alarm. It has been decided to define three levels of risk, "quiet", "moderate" and "active", where "active" level should be raised no more than 2% of the time and "moderate" level no more than 20% (Figure 3). A mockup for the web site, where the activity indices are currently available is shown in Figure 4. Iterations between the service providers and end-users are expected before the end of the project.

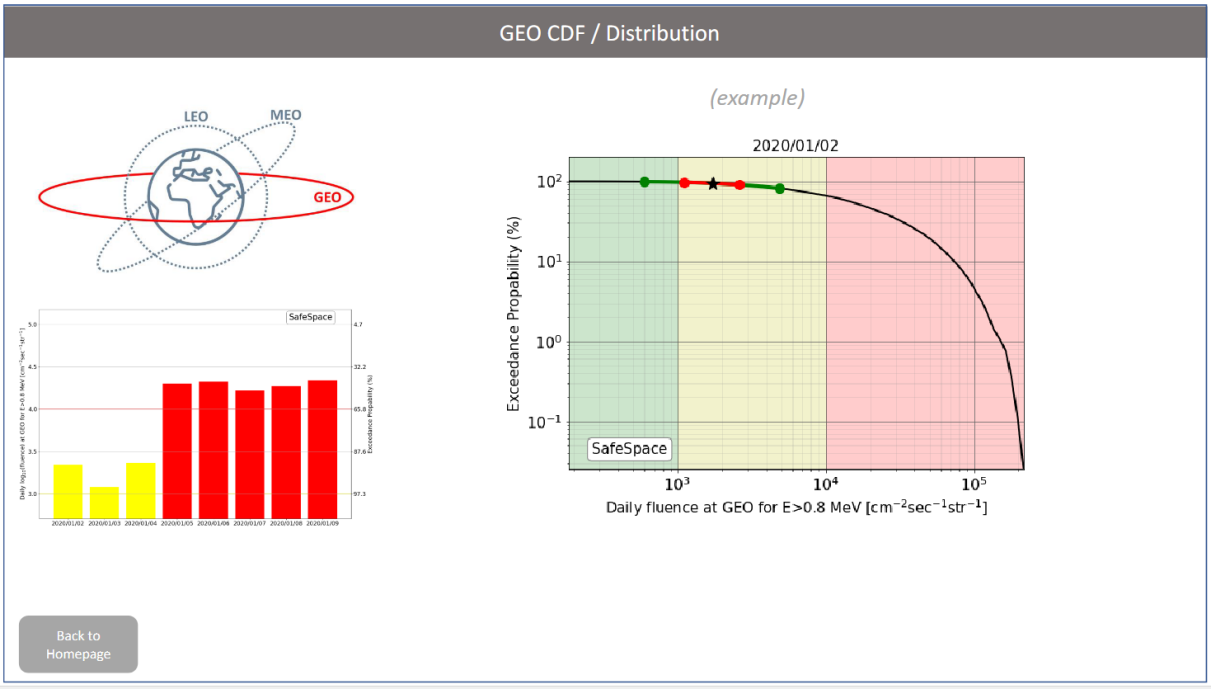

Figure 4: Mockup of the second level page of the prototype.

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Evaluation and Verification (WP5 - TAS-E, SPARC, KU LEUVEN)

Definition of evaluation method

This task is dedicated to setting up the method of evaluating the SafeSpace service. A procedure is under definition..

Exploitation, dissemination, and communication (WP6 - NKUA, ONERA, KU LEUVEN, IAP, BIRA-IASB, TAS-E, CNRS, SPARC)

This Work Package is devoted to the exploitation and dissemination of results to the scientific community, the space industry and spacecraft operators, and, furthermore, to the deployment of a range of communication tools, techniques and activities appropriate for different public audiences.

The Detailed plan for the exploitation, dissemination and communication of project activities and results is constantly adapting to the pandemic conditions, in order for the project to receive maximum public exposure through several channels and activities. The activities of the past six months are described hereafter.

Web presence

As always, you may find this newsletter along with several information regarding project details, description, goals, participants, news and additional useful facts on our user-friendly SafeSpace website, which is regularly updated with new information

Scientific dissemination of results

The past six months have been very productive publication-wise. SafeSpace peer-reviewed publications are provided on the project website. Oral and poster presentations from international conferences during the last 6 months may be found on the website as well:

The SafeSpace team has disseminated the Project results in scientific publications, as well as through presentations in Conferences and Workshops. Since the start of the Programme, there have been 11 publications in open access scientific journals, and 43 oral and poster presentations in Conferences, Seminars and Workshops worldwide. You can view all available material below.

Scientific Publications

2022 Annales Geophysicae

The "SafeSpace" database of ULF power spectral density and radial diffusion coefficients: dependencies and application to simulations

Christos Katsavrias, Afroditi Nasi, Ioannis A. Daglis, Sigiava Aminalragia-Giamini, Nourallah Dahmen, Constantinos Papadimitriou, Marina Georgiou, Antoine Brunet, and Sebastien Bourdarie (2022). The "SafeSpace" database of ULF power spectral density and radial diffusion coefficients: dependencies and application to simulations. *Annales Geophysicae*, 40, 379–393, 2022.
https://doi.org/10.5194/angeo-40-379-2022 – View Published PDF

Space Weather

Radiation Belt Model Including Semi-Annual Variation and Solar Driving (Sentinel)

Christos Katsavrias, Sigiava Aminalragia-Giamini, Constantinos Papadimitriou, Ioannis A. Daglis, Ingmar Sandberg and Piers Jiggens (2022). Radiation Belt Model Including Semi-Annual Variation and Solar Driving (Sentinel). *Space Weather*, 20, e2021SW002936.
https://doi.org/10.1029/2021SW002936 – View Published PDF

Oral Presentations

2022

Advanced Prediction of the Outer Van Allen Belt Dynamics and a Prototype Service: the H2020 SafeSpace project

Daglis, I. A. and the SafeSpace Team: Advanced Prediction of the Outer Van Allen Belt Dynamics and a Prototype Service: the H2020 SafeSpace project , EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-6518, https://doi.org/10.5194/egusphere-egu22-6518, 2022.

Radial diffusion coefficients database in the framework of the SafeSpace project: A Machine Learning model and the application to radiation belt simulations

Daglis, I. A., Katsavrias, C., Aminalragia-Giamini, S., Nasi, A., Dahmen, N., Brunet, A., Bourdarie, S., and Papadimitriou, C.: Radial diffusion coefficients database in the framework of the SafeSpace project: A Machine Learning model and the application to radiation belt simulations, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-6555, https://doi.org/10.5194/egusphere-egu22-6555, 2022.

On the Generation of Pi2 Pulsations due to Plasma Flow Patterns Around Magnetosheath Jets

Katsavrias, C., Raptis, S., Daglis, I., Karlsson, T., Georgiou, M., and Balasis, G.: On the Generation of Pi2 Pulsations due to Plasma Flow Patterns Around Magnetosheath Jets, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-5502, https://doi.org/10.5194/egusphere-egu22-5502, 2022.

Radiation belt model including semi-annual variation and Solar driving (SENTINEL)

Aminalragia-Giamini, S., Katsavrias, C., Papadimitriou, C., Daglis, I., Sandberg, I., and Jiggens, P.: Radiation belt model including semi-annual variation and Solar driving (SENTINEL), EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-9577, https://doi.org/10.5194/egusphere-egu22-9577, 2022.

Coordinated observations of relativistic electron enhancements following the arrival of consecutive Corotating Interaction Regions

Nasi, A., Daglis, I. A., Katsavrias, C., Sandberg, I., Li, W., Allison, H., Miyoshi, Y., Imajo, S., Mitani, T., Hori, T., Shprits, Y., Kasahara, S., Yokota, S., Keika, K., Shinohara, I., Matsuoka, A., and Kasahara, Y.: Coordinated observations of relativistic electron enhancements following the arrival of consecutive Corotating Interaction Regions, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-536, https://doi.org/10.5194/egusphere-egu22-536, 2022.

SafeSpace: Making Space a Safer place for Europe's assets

On Thursday, March 31st, 2022, Prof. Ioannis Daglis, participated in the Workshop "EU-funded R&I for Space Sciences" of DG Defense Industry and Space (DEFIS) of the European Commission, with a presentation on "SafeSpace: Making Space a Safer place for Europe's assets".

Public engagement

Both *face-to-face and virtual public outreach activities were organized during the past semester:*

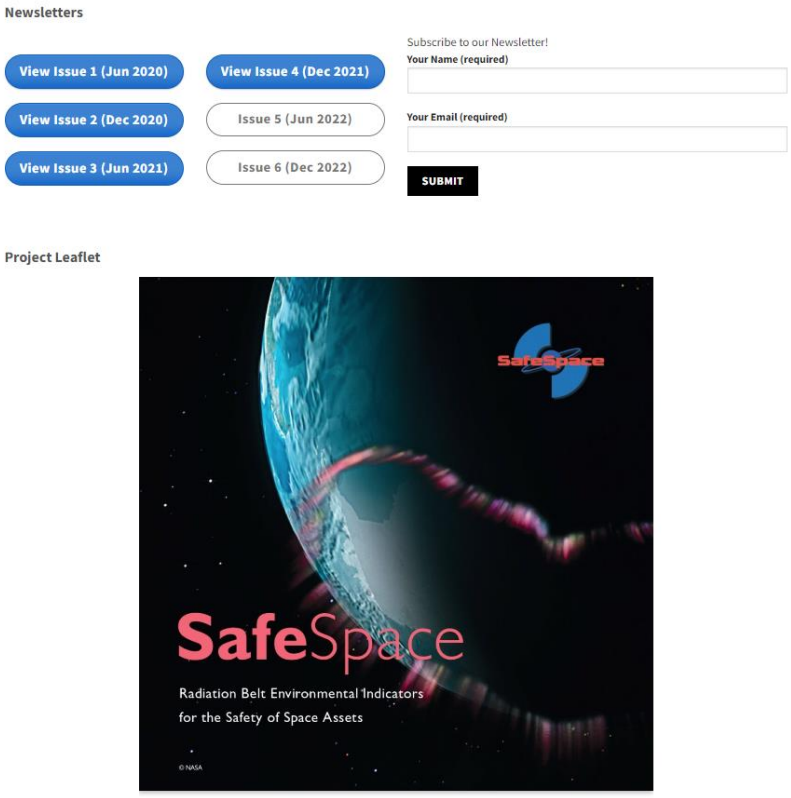
- *A music Concert titled "Detecting and feeling the sounds of space" by composer Lina Tonia was performed on Friday, February 18, 2022, at 21:00. The event was hosted at the Theoharakis Foundation, under the auspices of the Hellenic Space Center. The concert was an introduction to the*

music produced by the planets Earth, Saturn and Jupiter, and included the premiere of the works "Electron Emissions" and "Radiation Belts". The opening talk was given by Prof. Ioannis Daglis, while the composer, Lina Tonia gave a talk on the music analysis of the musical compositions that were presented (please see next photos from this event).

- *The team has also utilized the 100 Mentors platform to communicate space with high school pupils.*

  Ms. Konstantina Moutsouroufi gave a talk about life in space for the 1st High School of Komotini on Friday, January 21, 2022 at 11:00.

SafeSpace Electronic Newsletter past issues, as always, are available on the project's website along with the SafeSpace Leaflet (see below). Everyone who would like to receive our semi-annual newsletter is able to subscribe at any time.



SAFESPACE

"Radiation Belt Environmental Indicators for the Safety of Space Assets"

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