NEWSLETTER

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Content

DWD Measurement Campaign

The Deutscher Wetterdienst (DWD) hosted the final BIOSPHERE measurement campaign at the Meteorological Observatory Lindenberg (MOL-RAO) in Lindenberg (Tauche), a rural flatland site in northeastern Germany. MOL-RAO is a globally significant atmospheric research supersite, renowned for its extensive infrastructure, advanced instrumentation, and comprehensive range of measured parameters.

A key advantage of this location is its exceptional logistical, technical, and maintenance capabilities, as well as its expertise in field measurements. As such, DWD Lindenberg provided optimal conditions for the final BIOSPHERE campaign. All SCR measurement instruments—including PTB's muon detectors (MUDOS3 and DECOS2), NPI's neutron detector, and two ADVACAM Timepix micro-telescopes—were installed in a PTB trailer, 40 meters from the radiation measurement platform. This platform also housed TOC (Total Ozone Column) and UV instruments: one UV-BTS spectrometer (Gigahertz-Optik), three Brewer UV spectrometers (DWD), a DWD UV-BTS spectrometer, a Bentham DTM300 double monochromator (DWD), and additional UV instruments from BIRA-IASB.

Another key feature of the Lindenberg site is the extensive dataset of atmospheric parameters measured continuously. Regular balloon soundings every six hours provide vertical profiles of temperature, pressure, and humidity, essential for simulating vertical flux profiles of cosmic ray particles (muons, protons, ions, photons, and electrons) using ground-based SCR data.

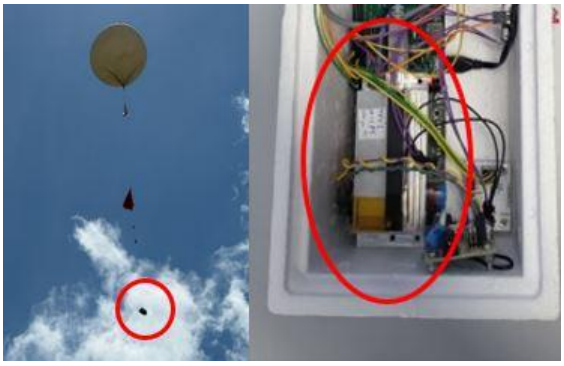
ADVACAM, NPI, PTB, BIRA-IASB, and DWD team during campaign setup on January 14th, 2025, at the DWD Meteorological Observatory Lindenberg.

Due to these unique advantages—outstanding infrastructure and a rich atmospheric dataset—the campaign was extended by one month, running from 15 January to 27 May 2025 instead of the initially planned 1 February to 30 April 2025.

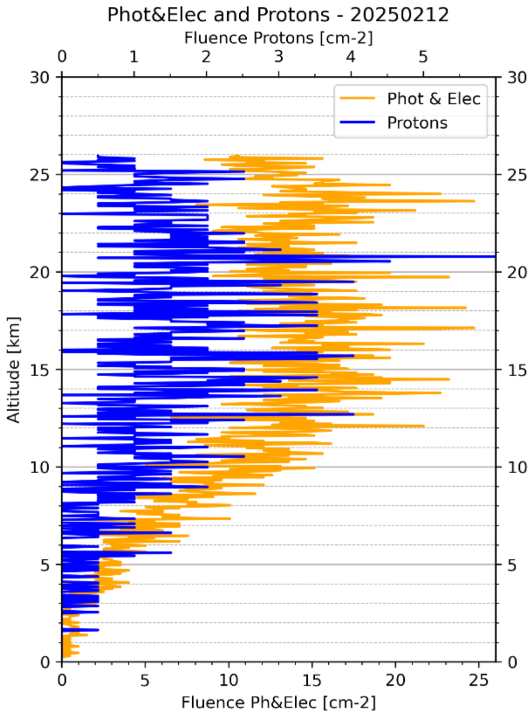
A third highlight was the opportunity to compare three reference UV spectrometers. In addition to DWD's BTS2048-UV and

Bentham DTM300, BIRA-IASB deployed a second Bentham DTM300, along with a GUV and UV-Pyranometer that had been used in previous BIOSPHERE campaigns. This made Lindenberg campaign with the most extensive UV instrument suite to date. The TOC measurement suite was similarly robust, with Gigahertz-Optik's BTS2048-UV used in all four BIOSPHERE campaigns, DWD's three Brewer spectrometers, one BTS2048-UV, and one Dobson instrument, providing highly redundant and thus high-quality TOC and UV Index measurements.

Another major innovation in this campaign was a new balloon-borne experiment. Leveraging MOL-RAO's expertise, DWD operated weather balloons equipped with standard radiosondes (Vaisala RS41) and a special SCR payload: the N2TP (NPI 2xTimepix Payload), developed in collaboration with ADVACAM and NPI Prague. These balloons reached altitudes up to 35 km, with three successful flights—two exceeding 25 km. Data from the TPX and TPX2 ADVACAM "Timepix" instruments yielded promising vertical fluence profiles for photons, electrons, protons, muons, and neutrons, supporting validation of SCR simulations.

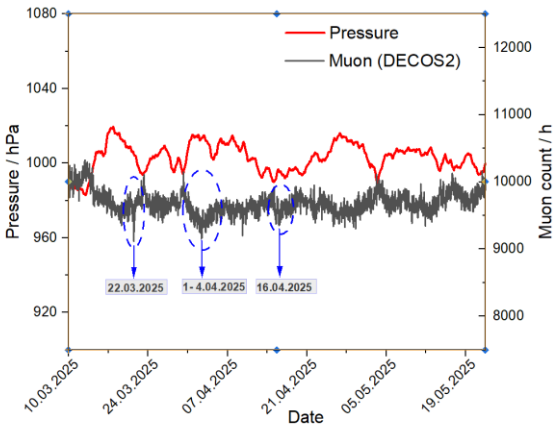


N2TP payload ascending with a DWD weather balloon (left). Close-up of the payload: TPX2 (silver and yellow) and TPX (black) instruments measuring particle fluxes.



Results from the February 12, 2025 flight: Timepix TPX instrument vertical fluence profiles for photons & electrons (orange) and protons (blue), up to 25 km altitude.

During the four-month campaign, several moderate solar particle events (SPEs) were recorded. The PTB DECOS-2 detector observed Forbush decreases on March 22, April 1–4, and April 16. Corresponding satellite data (GOES) showed increased geomagnetic and particle activity (magnetometry, planetary Kp-index, electron and proton fluxes). On April 1, clear skies and high electron flux enabled visual observation of auroral activity over Lindenberg. Despite proton events on February 26, April 1, and May 14, none resulted in significant ozone depletion, unlike the notable event observed on Mother's Day 2024 (12 May) during the Brussels campaign.

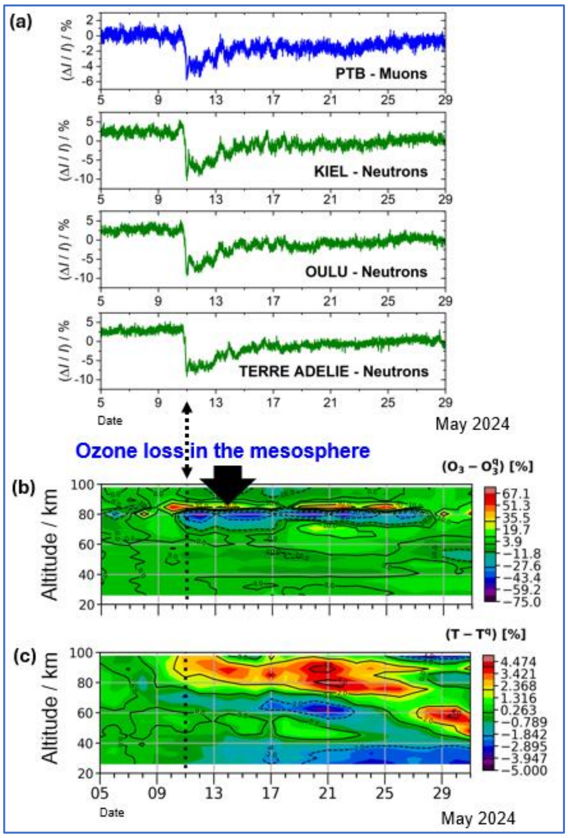


Muon fluxes measured by PTB's DECOS2 (black) on the ground, showing anticorrelation with ground pressure (red) and Forbush decreases during three SPE events.

Stunning aurora borealis triggered by the April 1st SPE, over the Falkenberg measurement Field (part of DWD Meteorological Observatory Lindenberg). Night of April 1–2, 2025.

Geomagnetic Storms, Secondary Cosmic Radiation (SCR) and Ozone Depletion

In early May 2024, the Sun underwent an intense period of activity, culminating on May 11 with a powerful X5.8-class solar flare that triggered one of the most powerful solar particle events in decades. This eruption released a stream of high-energy protons, reaching energies up to approximately 1.6 GeV (A. Papaioannou et al., 2025, https://doi.org/10.48550/arXiv.2505.09180), resulting in Ground Level Enhancement 74 (GLE74)—a rare event in which solar particles penetrate Earth's atmosphere and are detected by ground-based neutron monitors (Pierrard et al., 2024, https://doi.org/10.3390/universe10100391.



***(a)**: Ground-based measurements of Forbush decrease with muon and neutron monitors. **(b)**: Relative difference between mean quiet-condition ozone profiles (O_3^q) and daily AURA/MLS ozone profiles (O_3) from May 5–30; **(c)**: Same for temperature profiles (Winant et al., 2025, https://doi.org/10.5194/angeo-2024-29)*

The associated coronal mass ejections (CMEs) merged and struck Earth, driving a severe geomagnetic storm that reached G5 intensity (K_p = 9) and caused a Dst index drop to nearly –412 nT, marking the strongest geomagnetic disturbance since 2003 (Pierrard et al., 2025a, https://doi.org/10.3390/atmos16030299. This event was captured using ground-based observations of secondary cosmic rays, particularly neutrons and muons (neutron monitors and BIOSPHERE muon detectors), which serve as key signatures of solar energetic particles (SEPs) reaching Earth (Pierrard et al., 2025b, https://doi.org/10.3934/geosci.2025007, see figure above.

While the storm disrupted communications and navigation systems and sparked auroras at far more equatorial latitudes than usual in both the Northern and Southern hemispheres, its most scientifically significant atmospheric effect was a marked, albeit short-lived, depletion of ozone in the mesosphere and lower thermosphere. Investigations by the members of the BIOSPHERE consortium indicated mesospheric ozone depletion for 18 days reaching a maximum of 60% (Winant et al., 2025, https://doi.org/10.5194/angeo-2024-29).

Atmospheric Chemistry: Electron Impact Induced Fragmentation of Halogenic Molecules

How can cosmic radiation showers influence the ozone column density in the Earth's atmosphere? A main mediator could be the abundant low energetic secondary electrons which are produced by the primary high energetic particles. Within the present project fundamental data on the interaction of these electrons with relevant atmospheric gases of both natural and anthropogenic origin are collected. Of particular interest are trace gases which are involved in catalytic ozone loss cycles like the nitrogen oxides or the chlorofluorocarbons (CFCs). The data accumulated can be used for atmospheric chemistry simulations and for future predictions of the amount of halogens and other radicals in the Earth's atmosphere. Recently, measurements of absolute cross sections for ionization of the greenhouse gases CF_4, CHF_3 (https://doi.org/10.1063/5.0219527, https://doi.org/10.1039/d5cp00746a) and the ozone damaging molecules $CHClF_2$, $CClF_3$, CCl_2F_2 and CH_2Cl_2 were carried out at electron energies up to 1 keV.

The measurement setup is shown in Fig. 1. It includes an electron beam crossing a gas target. The ions produced in the interaction region are extracted by means of an electric field and detected.

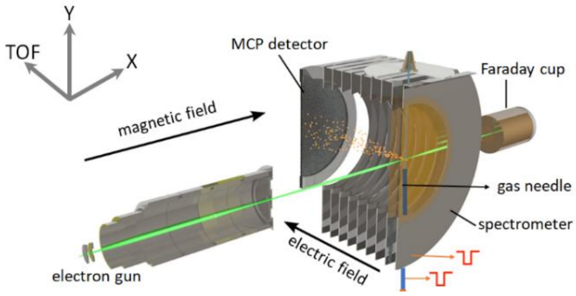


***Fig. 1**: Schematics of the experimental setup with electron beam (green), gas delivery needle (blue), ion spectrometer and ion detector.*

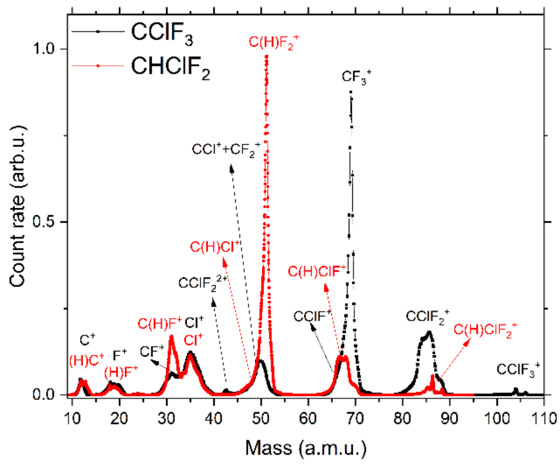


***Fig. 2**: The ion mass spectra for electron impact ionization of $CClF_3$ (black) and $CHClF_2$ (red).*

In Fig. 2 the measured mass spectra for $CClF_3$ and $CHClF_2$ are superimposed. The dominant fragmentation channels for both molecules are the CF_3^+ and CHF_2^+ ions, respectively, which implies that in both cases it is most likely that neutral chlorine is emitted. This radical is responsible for the breaking the oxygen-ozone cycle, and, thereby, destroying the ozone layer in the stratosphere.

From the individual line intensities the partial ionization cross sections and the total single ionization cross section can be extracted. In Fig. 3 we show the results for $CClF_3$ as function of the impact energy. It is important to mention that there are no data available in the literature for comparison with our partial cross sections.

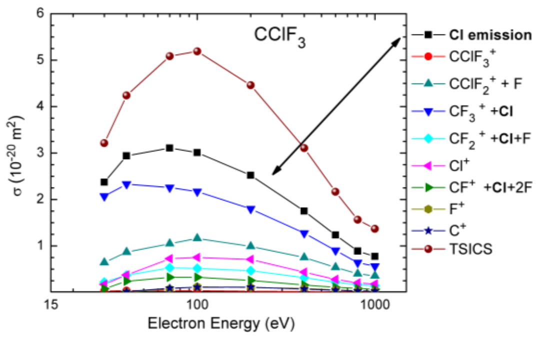


***Fig. 3**: The partial single ionization cross section and the total single ionization cross section (brown symbols) as function of impact energy for $CClF_3$. The sum of all chlorine producing channels is shown as black curve.*

The data collected in our lab-based measurements and also from our literature research were included in an open access data repository on Zenodo (https://zenodo.org/records/15398189). In this way it is generally available, e.g., for future modelling and simulation of the cosmic ray induced atmospheric chemistry.

Finally, in order to directly observe the effects of ionized CFCs on ozone, experimental simulations of electron induced dynamics in gas mixtures resembling the atmospheric composition were performed. Therefore, at TUBITAK (Gebze/Turkey) a plasma chamber was filled with the gases nitrogen, oxygen and 6 % of ozone at a total pressure of up to 2 mbar. By starting a glow discharge in the chamber an electron gas was produced which was characterized in density and temperature by a commercial Langmuir probe. The gas composition was monitored with a mass spectrometer provided by MPG. The discharge resulted in a significant reduction of ozone by a factor of three likely due to direct collisions with electrons. On the other hand a much stronger effect was observed by addition of a few percent of $CHClF_2$ resulting in ozone depletion by more than two orders of magnitude. This can be assigned presumably to the radical production by electron induced dissociation of $CHClF_2$. These first data from TUBITAK demonstrate that atmospheric electron induced chemistry can be simulated by lab-based studies. Presently the apparatus is upgraded by an optical spectrometer to get additional information, e.g., on short lived radicals.

Simulation of SCR Propagation and DNA Damage

A simulation study has been performed to explore the relationship between SCR propagation and vertical atmospheric profiles using extensive numerical and analysis tools. The investigation focused on how variations in temperature and density at different atmospheric layers influence the ground-level muon flux. Utilizing Monte Carlo N-Particle (MCNP) simulations with radiosonde-based input data, the study quantified the sensitivity of muon flux to atmospheric changes over time and altitude. Key insights include:

At lower altitudes, a negative correlation between muon flux and air pressure is observed, since the increasing weight of the overlying air enhances decay losses, see Fig. 4.

A positive correlation appears in the stratosphere where meson production and decay are more temperature sensitive.

These patterns are observed consistently across diverse geographical regions, confirming the reliability of the findings.

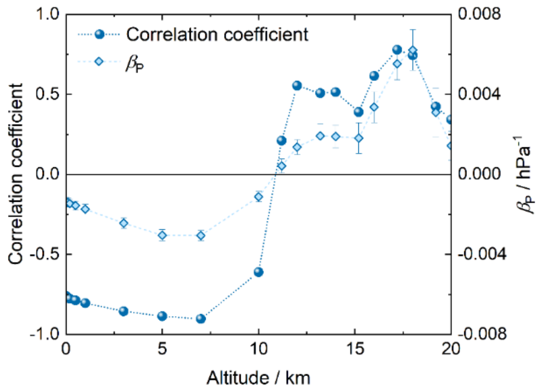


Fig. 4: *Pearson correlation coefficient between atmospheric pressure and muon flux rate, and barometric coefficient, as a function of altitude*.

The vertical profiles of muon flux simulated using MCNP are in good agreement with those obtained using AtRIS (Atmospheric Radiation Interaction Simulator; Banjac *et al*., 2019, https://doi.org/10.1029/2018JA026042; Winant et al., 2023, https://doi.org/10.3390/universe9120502), with minor quantitative differences (up to 7%) attributed to the differing assumptions between the two simulation approaches, see Fig. 5.

This modeling not only enhances understanding of SCR behavior in response to atmospheric dynamics but could also provide useful information for the calibration procedures for cosmic radiation detectors used in environmental and metrological applications.

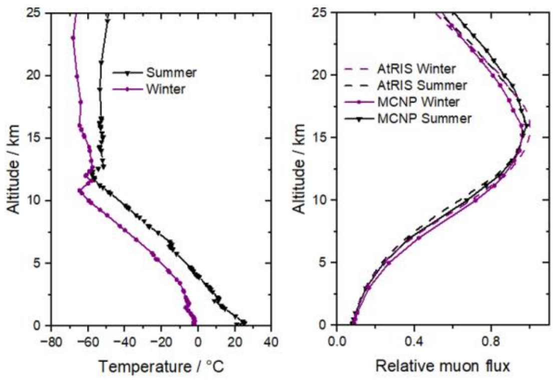


Fig. 5: *Seasonal (summer and winter) variations in atmospheric temperature and the corresponding normalized muon flux with altitude simulated using MCNP and AtRIS models*.

A simulation-based study was also conducted to investigate DNA damage patterns under mixed-field cosmic radiation conditions, specifically focusing on the effects of protons and electrons present at ground level. Using the PHITS Monte Carlo code (v3.34) with its track-structure mode, the study modeled interactions at the DNA scale (see Fig. 6), incorporating realistic energy spectra for cosmic-ray particles generated via the EXPACS interface (based on the PARMA 4.0 model) for Athens, Greece. Before applying environmental spectra, the simulation model was benchmarked using monoenergetic beams of protons and electrons across various energies. DNA strand break yields obtained from the model showed good agreement with experimental data and other simulation tools, such as PARTRAC and Geant4-DNA.

Following validation, ground-level energy spectra for protons and electrons were used to estimate the resulting DNA damages. The simulation considered both separate and combined exposures, applying effective dose rates as calculated by EXPACS. The project examined parameters such as single- and double-strand breaks (SSBs and DSBs) and explored how different types of radiation contribute to early biological endpoints.

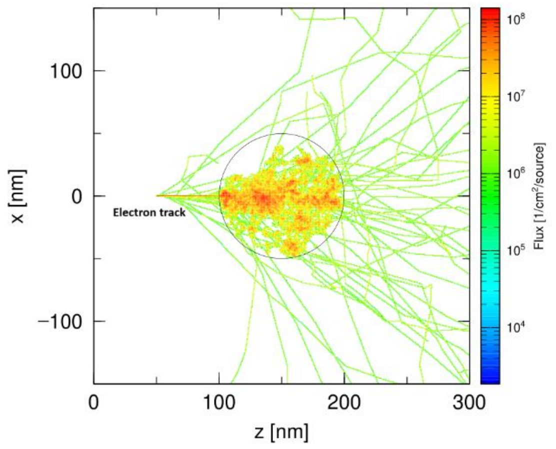


Fig. 6: *Track structure simulation of electron induced energy deposition in a DNA scale water target using PHITS.*

Events in 2025

Conference/ Workshop	Date/Location	Reason for attending
COSPAR 2025 Scientific Symposium	November 3-7, 2025/ Nicosia, Cyprus	Presentation: Superstorm event of 10-11 May 2024 — Exceptional solar effects on electron and proton radiation belts, ionosphere and atmospheric ozone
ECUVM2025	September 9-11, 2025/Vienna, Austria	Presentation of the project results with a focus on the BIOSPHERE measurement campaigns
ERRS 2025 Meeting	September 2-4, 2025/ Brussels, Belgium	Presentation of the project results with a focus on the radiobiology research
RAD 2025	June 2025/ Herceg Novi, Montenegro	Poster presentation about SCR variations on the ground and at flight altitudes
150th Anniversary of the Metre Convention and the BIPM	Virtual, BIPM Anniversary site: https://thebipm150.org/posters-online/	Overview of the BIOSPHERE projects with selected highlights
ConRad 2025 (26th Nuclear Medical Defence Conference)	May 2025/ Munich, Germany	Presentation on the achievements of BIOSPHERE/ Radiobiology experiments
NOG2025 Meeting	April 2025, Helsinki, Finland	Presentation of the project results with a focus on the BIOSPHERE measurement campaigns
EGU 2025	April 2025/ Vienna, Austria	Presentation of evolution of the South Atlantic Anomaly during solar events, min and max activity
Annual International Astrophysics Conference (AIAC)	April 2025/ Compostela, Spain	Presentation of Biosphere solar wind events
EURADOS Annual Meeting 2025, WG 3 meeting	February 2025/ Bucharest, Romania	Update on the BIOSPHERE project and measurement campaigns with a focus on charged component of secondary cosmic radiation
EURADOS Annual Meeting 2025, WG11 meeting	February 2025/ Bucharest, Romania	Update on the BIOSPHERE project and measurement campaigns
PHITS Workshop and Intermediate Course at Japan Atomic Energy Agency in Tokai	February 2025/ Tokai, Japan	Presentation on the use of PHITS in BIOSPHERE measurement campaigns.

Past Events

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Our publications

1) **Synergistic Effects of UVB and Ionizing Radiation on Human Non-Malignant Cells: Implications for Ozone Depletion and Secondary Cosmic Radiation Exposure**, Gkikoudi A, Manda G, Beinke C, Giesen U, Al-Qaaod A, Dragnea E-M, Dobre M, Neagoe IV, Sangsuwan T, Haghdoost S, Vasilopoulos SN, Triantopoulou S, Georgakopoulou A, Tremi I, Koutsoudaki PN, Havaki S,

Gorgoulis VG, Kokkoris M, Krasniqi F, Terzoudi GI, Georgakilas AG. Biomolecules 2025, 15(4), 536. https://doi.org/10.3390/biom15040536

2) **Solar wind electron core-halo correlations and temperature anisotropy**, Shaaban, S. M., Kennis, S., Lazar, M., Pierrard, V., and Poedts, S. (2025). Journal of Geophysical Research: Space Physics, 130, e2025JA033838. https://doi.org/10.1029/2025JA033838
3) **The DNA Damage Response as an Auxiliary Indicator of Senescence in Cancer: A User-Friendly Toolkit of Markers and Detection Methods**. Stella Logotheti, Spyridon N. Vasilopoulos, Ioanna Tremi, Angeliki Gkikoudi, Michalis Fragkos, Athanasia Pavlopoulou, Sophia Havaki, and Alexandros G. Georgakilas (2025). In: Gorgoulis, V.G., Cavinato, M., Evangelou, K. (eds) Oncogene-Induced Senescence. Methods in Molecular Biology, vol 2906. Humana, New York, NY. https://doi.org/10.1007/978-1-0716-4426-3_6
4) **BIOSPHERE measurement campaign from January 2024 to March 2024 and in May 2024: Effects of the solar events on the radiation belts, UV radiation and ozone in the atmosphere**. Viviane Pierrard, David Bolsée, Alexandre Winant, Amer Al-Qaaod, Faton Krasniqi, Maximilien Péters de Bonhome, Edith Botek, Lionel Van Laeken, Danislav Sapundjiev, Roeland Van Malderen, Alexander Mangold, Iva Ambrozova, Marek Sommer, Jakub Slegl, Styliani A Geronikolou, Alexandros G Georgakilas, Alexander Dorn, Benjamin Rapp, Jaroslav Solc, Lukas Marek, Cristina Oancea, Lionel Doppler, Ronald Langer, Sarah Walsh, Marco Sabia, Marco Vuolo, Alex Papayannis, Carlos Granja. AIMS Geosciences, 2025, 11(1): 117-154. https://doi.org/10.3934/geosci.2025007
5) **Absolute electron impact ionization cross-sections for CF4: Three dimensional recoil-ion imaging combined with the relative flow technique**, W. Wolff, M. Dogan, H. Luna, L. H. Coutinho, D. Mootheril, Woonyong Baek, T. Pfeifer, A. Dorn, Rev. Sci. Instrum. 1 September 2024; 95 (9): 095103. https://doi.org/10.1063/5.0219527
6) **Electron impact single and double ionization and dissociation: revisiting CF4 and CHF3 with an improved experimental method**. M. Dogan, W. Wolff, D. M. Mootheril, T. Pfeifer, A. Dorn, Phys. Chem. Chem. Phys. 27, 10057 (2025), DOI: 10.1039/d5cp00746a (https://pubs.rsc.org/en/content/articlelanding/2025/cp/d5cp00746a)
7) **High-resolution mapping of secondary cosmic rays with miniaturised stacked pixel telescope**. Granjaa, C., Chanalc, H., Zachd, V., Chvátild, D., Oanceaa, C., Poklopb, D., ... & Jakůbeka, J. (2025). Acta Polytechnica, 65(1), 16-24. https://doi.org/10.14311/AP.2025.65.0016
8) **Effects of the Geomagnetic Superstorms of 10–11 May 2024 and 7–11 October 2024 on the Ionosphere and Plasmasphere**. Pierrard, V., Verhulst, T. G., Chevalier, J. M., Bergeot, N., & Winant, A. (2025), Atmosphere 2025, 16(3), 299; https://doi.org/10.3390/atmos16030299.
9) **Elastic and inelastic electron scattering cross sections of trichlorofluoromethane**, Dinger, M., Park, Y. and Baek, W. Y., Phys. Rev. A 111, 022809 (2025)

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11) **Computer-Aided Identification and Design of Ligands for Multi-Targeting Inhibition of a Molecular Acute Myeloid Leukemia Network**. Asfa SS, Arshinchi Bonab R, Önder O, Uça Apaydın M, Döşeme H, Küçük C, Georgakilas AG, Stadler BM, Logotheti S, Kale S, Pavlopoulou A. Cancers (Basel). 2024 Oct 25;16(21):3607. doi: 10.3390/cancers16213607. PMID: 39518047; PMCID: PMC11544916.
12) **RadPhysBio: A Radiobiological Database for the Prediction of Cell Survival upon Exposure to Ionizing Radiation**. V. Zanni, D. Papakonstantinou, S.A. Kalospyros, D. Karaoulanis, G.M. Biz, A. Adamopoulos, A. Pavlopoulou, A.G. Georgakilas, Physica Medica, Volume 127, Supplement 1, 2024, 104568, ISSN 1120-1797, https://doi.org/10.1016/j.ejmp.2024.104568.
13) **Induction of complex DNA damage after proton therapy beam irradiation to plasmid DNA and human prostate cancer cells**. Souli, M. P., Nikitaki, Z., Spyratou, E., Efstathopoulos, E. P., Sihver, L., & Georgakilas, A. G. (2024). PP. 7.2 Physica Medica, 127, 104613.
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15) **Development and evaluation of a proton irradiation experimental setup for use in human cells**. Zonitsas, S., Gkikoudi, A., Vasilopoulos, S. N., Georgakopoulou, A., Chasapoglou, S., Diakaki, M. & Georgakilas, A. G. (2024). P. Physica Medica, 127, 104707.
16) **Flash radiation therapy: a review on the ultra-high dose rate paradigm of radiotherapy**. Koutsostathis, A., Rangos, V., Adamopoulou, A., Koumenis, C., & Georgakilas, A. G. (2024). P. 1.19 Physica Medica, 127, 104641.
17) **The Mother's Day solar storm of 11 May 2024 and its effect on Earth's radiation belts**. Viviane Pierrard, Alexandre Winant, Edith Botek, and Maximilien Péters de Bonhome, Universe, 10, 10, 391, 10 October 2024, https://doi.org/10.3390/universe10100391 (data DOI: 10.5281/zenodo.13626553)
18) **Statistics and models of the electron plasma density from the Van Allen Probes**. Ripoll, J.-F., S. Thaller, D. Hartley, D. Malaspina, W. Kurth, G. S. Cunningham, V. Pierrard, J. Wygant, Journal of Geophys. Res.: Space Physics, 129, e2024JA032528. https://doi.org/10.1029/2024JA032528.
19) **Radial Evolution of Non-Maxwellian Electron Populations Derived from Quasi-Thermal Noise Spectroscopy: Parker Solar Probe Observations**, December 2024. Zheng X., Mihailo M. Martinović, Kaijun Liu, Viviane Pierrard, Mingzhe Liu, Kun Cheng, https://doi.org/10.3847/1538-4357/ad236d.

20) **High-resolution mapping of secondary cosmic rays by miniaturized stacked pixel telescope**. Carlos Granja, Herve Chanalb et al., journal of the Czech TU Prague, Acta Polytechnica.
21) **Dual Targeting of DNA Damage Response Proteins Implicated in Cancer Radioresistance**. Vasilopoulos, S.N.; Güner, H.; Uça Apaydın, M.; Pavlopoulou, A.; Georgakilas, A.G. Genes 2023, 14, 2227. https://doi.org/10.3390/genes14122227
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25) **Geomagnetic Storm Effects on the LEO Proton Flux during Solar Energetic Particle Events**, Kirolosse M. Girgis, Tohru Hada, Akimasa Yoshikawa, Shuichi Matsukiyo, Viviane Pierrard, Susan W. Samwel, Space weather, 21, 12, e2023SW003664, doi: 10.1029/2023SW003664, 2023. (https://doi.org/10.1029/2023SW003664)
26) **The Role of Plasmasphere in the Formation of Electron Heat Fluxes**, Khazanov G. V., Pierrard V., Ma Q., Botek E., Journal of Geophys. Res.: Space Physics, Vol.128, Issue 11, November 2023, e2023JA032013 (https://doi.org/10.1029/2023JA032013)
27) **The atmospheric influence on cosmic ray induced ionization and absorbed dose rates**, Alexandre Winant, Viviane Pierrard, Edith Botek, Konstantin Herbst, Universe, 9, 502, 1-17, 2023. https://doi.org/10.3390/universe9120500
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For the time being, the project BIOSPHERE has established the following collaborations by a Letter of Agreement (in the order of signature date): Collaborators by signed letters of agreement:

1. Bundeswehr Institute of Radiobiology, Germany,
2. UK Health Security Agency (Radiation Effects Department), United Kingdom,
3. University of Naples Federico II (Radiation Biophysics Laboratory), Italy,
4. Biomedical Research Foundation of the Academy of Athens, Greece.