# Metrology for Earth biosphere: cosmic rays, ultraviolet radiation and fragility of ozone shield

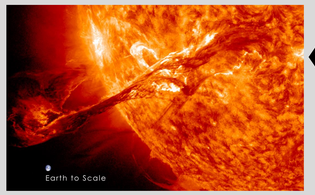
F. S. Krasniqi,[1] B. Rapp,[2] D. Bolsée,[3] A. Dorn,[4] A. G. Georgakilas,[5] and V. Pierrard[3]

[1]*Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany*
[2]*Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel (LNE-LNHB), F-91129, Palaiseau, France*
[3]*Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Av. Circulaire 3, 1180 Uccle, Belgium*
[4]*Max Planck Institute for Nuclear Physics (MPG), Saupfercheckweg 1, 69117 Heidelberg, Germany*
[5]*National Technical University of Athens (NTUA), Zografou 15780, Athens, Greece*

## ❶ Need

Streams of energetic particles from the Sun such as solar particle events can lead to ozone layer depletion

Less ozone leads to more harmful solar UV radiation for biological systems on Earth




*Coronal mass ejection (Source: NASA)*

**Challenges & knowledge gaps:**

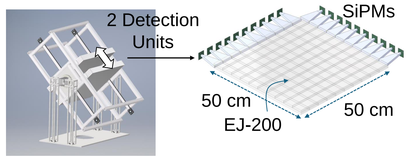
- A need for refined methodologies to better link ground-based measurements with cosmic events and atmospheric parameters and processes
- Limited data on the role of cosmic ray-induced electrons in ozone depletion
- Incomplete understanding of the combined effects of cosmic rays and UV radiation on biological systems (e.g., DNA damage and repair, cell death and stress responses)

**The BIOSPHERE project (https://euramet-biosphere.eu/) is designed to address existing scientific gaps**

## ❷ Objectives and methodology

- **Develop a method to measure cosmic ray-induced atmospheric ionization from ground-based measurements**

  *This includes measurements of secondary cosmic ray (SCR) fluxes with mobile detectors on the ground and the development of Monte Carlo simulation models*



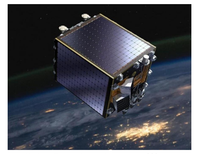

*Muon detector DECOS2*

- **Determine how cosmic ray flux influences ozone concentration**

  *This includes side-by-side traceable measurements of the terrestrial solar UV spectrum, total ozone column, SCR flux rates and, measurements of energetic particle fluxes and ozone concentration from satellites (GOES, PROBA-V/EPT, AURA/MLS)*



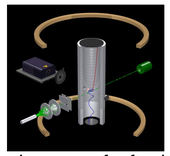
*UV instruments*



*PROBA-V satellite*

- **Determine the interaction cross-sections between cosmic ray-induced electrons and atmospheric gases**

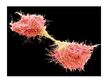
  *This includes measurement of ionization, dissociation and elastic scattering cross section for number of molecules relevant to ozone chemistry (e.g., CFCs, $N_2$0, $C_2H_6O$, etc.)*



*Reaction microscope for fundamental data*

- **Explore the effects of combined SCR and UV radiation fields on human skin and blood cells**

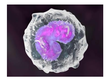
  *This includes the irradiation of human primary cells (fibroblasts, keratinocytes, monocytes, and lymphocytes) with protons, gamma rays, and UV radiation under a simulated ozone depletion scenario*



*Hs27 human fibroblasts*



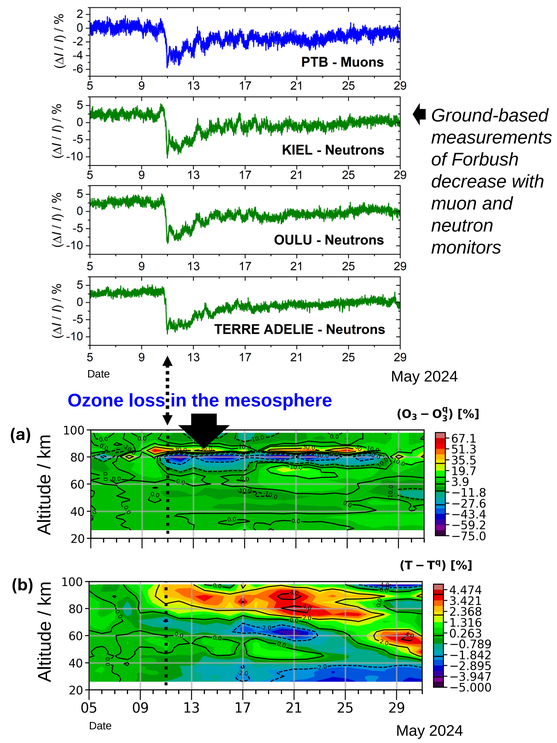
*HaCaT human keratinocytes*



*CRL9855 human monocytes*

## ❸ Results

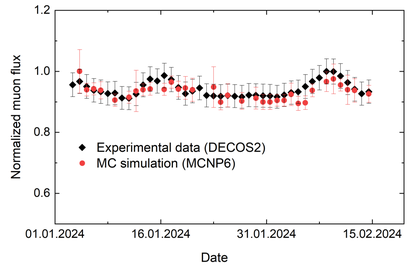
**The effect of May 11th 2024 *Mother's day* solar storm in the ozone layer**




***(a)**: Relative difference between mean quiet-condition ozone profiles ($O_3^q$) and daily AURA/MLS ozone profiles ($O_3$) from May 5–30. **(b)**: Same for temperature profiles (Winant et al., 2025, https://doi.org/10.5194/angeo-2024-29)*

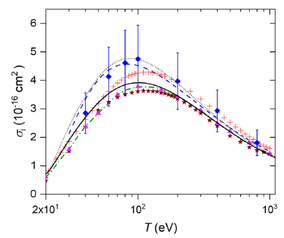
*Ground-based measurements of Forbush decrease with muon and neutron monitors*

**Monte Carlo models linking atmospheric ionization to ground-based cosmic ray measurements**




*Normalized muon flux on the ground during the 2nd BIOSPHERE campaign (Brussels) vs. MCNP6 model calculations*

**Fundamental data on the interaction of low-energy cosmic ray-induced electrons with relevant atmospheric gases**

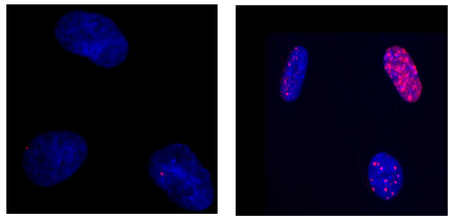



**$N_2O$ is an emerging ozone-depleting substance** that forms reactive $NO_x$, catalytically breaking down stratospheric ozone

*Total ionization cross sections of $N_2O$ (Dinger et al., 2023, https://doi.org/10.1140/epjd/s10053-024-00880-0)*

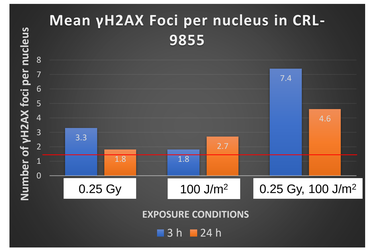
**Simulation of ozone layer depletion: Effects of combined cosmic and UV radiation fields on biological systems**

Co-exposure of cells to protons and UVB radiation exhibits synergistic effects, potentially altering biological responses and leading to unforeseen health impacts in humans



0.5 Gy, 24 h | 0.5 Gy, 100 J/m², 24 h

*Human normal fibroblasts cells exposed to protons (left) and co-exposed to 100 J/m² UVB and 0.5 Gy protons (right), all 24 h post-irradiation (nucleus: blue color, DNA damages-double strand breaks: red color foci)*




*Human monocytes irradiated with protons followed by UVB radiation. A phosphorylated form of the histone protein H2AX is used to mark DNA double-strand breaks (DSBs)*

## ❹ Conclusions and Outlook

- Solar storms impact atmospheric ozone levels. In May 2024, mesospheric ozone depletion is observed during 18 days and reaches a maximum of 60% (Winant *et al.*, 2025, https://doi.org/10.5194/angeo-2024-29).
- Monte Carlo models (AtRIS Geant4, MCNP6) were developed to quantify cosmic ray and solar energetic particle effects on the atmosphere (see also Winant *et al.*, 2023, https://doi.org/10.3390/universe9120502).
- Key molecular data (more than 15 species) relevant to ozone chemistry, including emerging ozone-depleting substances, have been measured, alongside fragmentation cross-sections of several CFCs. A comprehensive database will be created.
- Combined radiation exposure leads to greater and more persistent DNA damage, reducing cell viability. Identified gene targets will guide therapeutic strategies to mitigate these effects.

**OUTLOOK: High-latitude measurements of muon, neutron, and UVB spectra, along with total ozone column data, need to be explored for assessing solar storm impacts on the stratosphere. Additionally, the synergistic effects of neutrons and UVB in biological systems must be systematically integrated and further investigated to assess their broader implications.**

## Acknowledgement

The project 21GRD02 BIOSPHERE has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

***For more details, visit 21GRD02 BIOSPHERE website:***

**https://euramet-biosphere.eu/**