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EDITORIAL

Dear reader,

We are pleased to present the LIP Annual Report 2025, offering a snapshot of a dynamic year at the Laboratory of Ion Beam Physics. As in previous volumes, the report brings together concise contributions that reflect both the depth and breadth of our work, inviting readers to explore the many facets of ion beam physics and its applications.

This year has again been marked by strong performance and continued evolution of our accelerator facilities. Improvements to the 6 MV Tandem system, the reliable operation of the 1.8 MV Tandetron and the 0.5 MV Tandy as working horses for various Ion Beam Applications and ^{129}I , respectively, the growing role of MILEA for ^{10}Be and the actinides, as well as the continuous, high throughput operation of our three radiocarbon systems (LEA, LIP-, and Proto MICADAS) highlight our ongoing commitment to precision, stability, and innovation. At the same time, developments such as the MI-Q prototype and new analytical tools demonstrate how we continue to push technical boundaries.

The scientific contributions span an impressive range - from radiocarbon applications in archaeology, climate research, and even extraterrestrial materials, to studies of cosmogenic and anthropogenic nuclides and advances in materials science. Together, they illustrate how our instrumentation enables insights across disciplines and scales, connecting fundamental processes with real-world questions.

This report is, above all, the result of a collective effort. We warmly thank all members of the LIP - scientific, technical, and administrative staff - for their dedication and expertise. Our sincere gratitude also goes to our users, partners, and collaborators for their trust, enthusiasm, and continued support. It is through these shared efforts that LIP remains a vibrant and collaborative environment for world class research.

We hope you enjoy reading and find inspiration in the work presented here.

A handwritten signature in blue ink, appearing to read 'M. Christl', with a stylized, cursive script.

Marcus Christl (and the editorial team led by Urs Ramsperger and Lindita Abazi)

THE LIP ACCELERATOR FACILITIES



Finished LE-side of the Tandem accelerator setup.

Activities on the 6 MV Tandem system

Tandetron operation

Activities on the 0.5 MV Tandy system

Activities on the 0.3 MV MILEA System

Routine ^{10}Be measurements on MILEA

^{14}C on the 200 kV MICADAS and the 50 kV LEA

ACTIVITIES ON THE 6 MV TANDEM SYSTEM

Beam time and sample statistics

C. Vockenhuber, scientific and technical staff, Laboratory of Ion Beam Physics

In 2025 we took full advantage of the new era at the 6 MV Tandem accelerator that started last year with the completion of upgrade of the LE side. The new beam line layout, the MICADAS-type ion source and the full integration in the control software brings a boost in performance, reliability and comfort.

As seen in beam time statistics (Fig. 1) the total operation hours in 2025 were with 876 h higher than in the years before the upgrade. Most of the beamtime was dedicated to AMS, with measurements for ^{36}Cl with the Gas-filled Magnet (GFM) taking the largest share (86%); the remaining AMS beamtime was used for final measurements related to the redetermination of the half-life of ^{32}Si using both the GFM and the absorber setup. Under the category material sciences, we have done irradiations with high energy Cu beams in the framework of a ReMade@ARI TNA proposal.

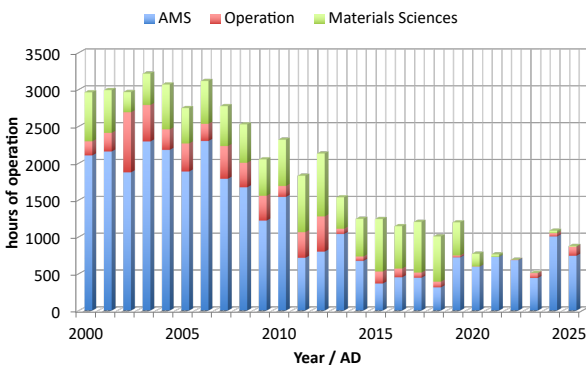


Fig. 1: Time statistics of the Tandem operation subdivided into AMS (blue), materials sciences (green), and service and maintenance activities (red).

A highlight of the 2025 running time was a longer beamtime of 25 consecutive days for uninterrupted ^{36}Cl measurements. During this beamtime a long series of ice core samples were measured. The upgraded system with the new

ion source and a well-behaving tandem accelerator allowed for a mostly unattended beamtime.

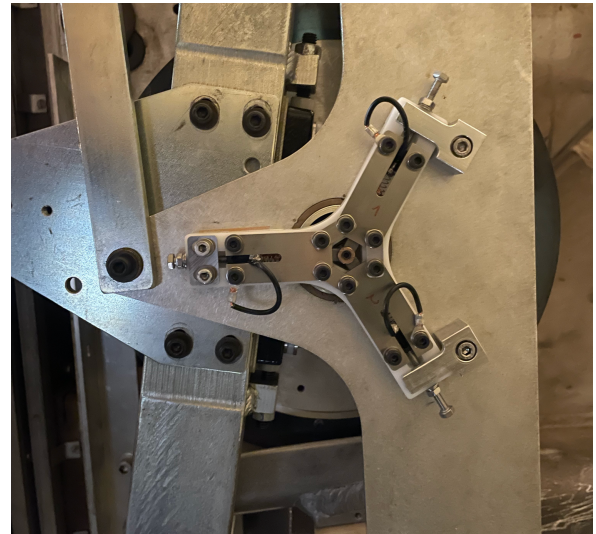


Fig. 2: Improved contact design at drive sheaves at the 6 MV Tandem accelerator.

However, in summer we had to open the Tandem accelerator for a longer, deep maintenance. It turned out that the bearings at the drive sheaves started to fail. Careful inspection revealed contact problems in the original design, which was improved with a more sophisticated design that prevents contact losses under harsh running conditions (Fig. 2). After the longer shutdown the restart was slow with problems to related discharges and forced us to reopen the tank once more. Although no obvious problem was found, after additional drying of the insulation gas the situation improved and allowed to resume with ^{36}Cl measurements before the end of the year.

TANDETRON OPERATION

Materials science at the 1.7 MV Tandetron

A. M. Müller, A. Crnjac, scientific and technical staff of Laboratory of Ion Beam Physics

Compared to the previous years, we saw a further increase in operating hours of the 1.7 MV Tandetron facility. In total about 100 operating days corresponding to about 1000 hours were completed, which corresponds to a new record since the installation of the accelerator in 2017.

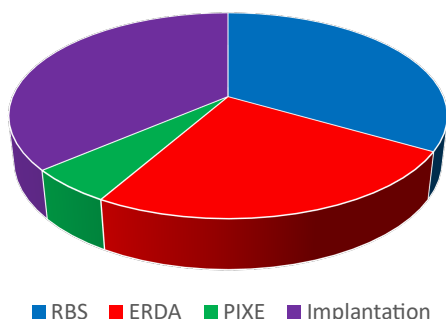


Fig. 1: Breakdown of the 1506 analyses sorted by applied technique.

In total 1506 analyses were conducted last year, including collaborative and pure service measurements performed for research and industry partners. The pie chart in Fig. 1 shows the distribution by means of the different IBA techniques. The major fraction was allocated to implantation and Rutherford Backscattering Spectrometry (RBS) runs, which made up 36% and 34% respectively of all experiments performed in 2025. Elastic Recoil Detection Analysis (ERDA) contributed 31% to all IBA analyses. The remaining measurements are mainly attributed to Elastic Recoil Detection Analysis (ERDA) with heavy ions (25%), while only a few Particle Induced X-Ray Emission (PIXE) measurements were conducted.

Apart from normal maintenance work, we did not have to carry out any major repairs, and the beam downtime could therefore be kept minimal. One exception was related to external electronic noise sources coupling into the RBS data acquisition chain. This issue significantly

reduced the resolving power of the spectrometer. Various measures were taken to optimize the electronic noise level. The installation of a high-performance shielding of the preamplifier electronics (Fig. 2) helped among other measures to reduce the electronic noise to an acceptable level.

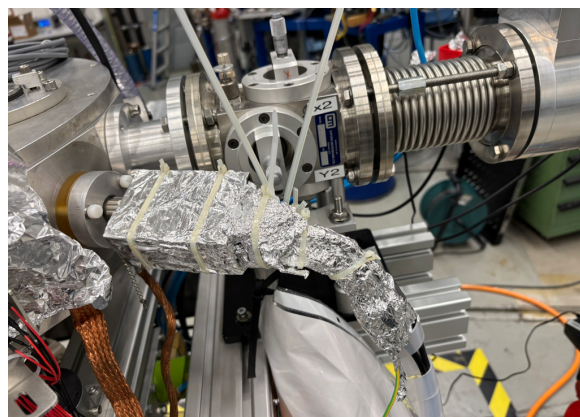


Fig. 2: High performance shielding of the RBS preamplifier minimizing the coupling of external electronic noise.

To increase occupational safety, new indicator lights visible from afar (Fig. 3) were installed, showing the operational status of the accelerator facility.



Fig. 3: Two lamps were installed late 2025 indicating the Tandetron operating status.

ACTIVITIES ON THE 0.5 MV TANDY SYSTEM

Beam time and sample statistics

C. Vockenhuber, N. Casacuberta, scientific and technical staff, Laboratory of Ion Beam Physics

2025 continued to be a very successful year for the multi-isotope system Tandy with many beamtimes for ^{129}I , which is currently the only radionuclide measured at Tandy. As seen in the sample statistics (Fig. 1) we reached an all-time high for the samples measured for ^{129}I , a total of 1868 unknown samples were measured at Tandy this year. Most of the samples were part of the TITANICA project that investigates the distribution of artificial nuclides in the Arctic and Subarctic Oceans. A small fraction was part of ongoing monitoring program in Germany. Tandy was operational for 2300 h, similar to the beam time hours in the previous years.

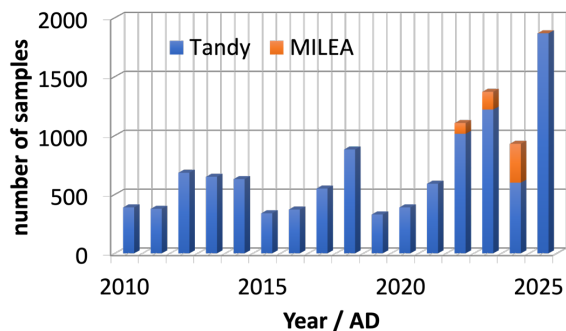


Fig. 1: Statistics of measured ^{129}I samples on Tandy (blue) and MILEA (orange).

Tandy proved to be a very reliable machine, only one source revisions were done in 2025, but one tank opening was necessary after problems with the Pelletron charging system which was caused by a short circuit at the inductor feedthrough (Fig. 2).

Another incident caused the repair of the turbo pump at the HE side directly after the tandem accelerator. The suppressor ring of a moveable Faraday cup fell into the running turbo pump, causing some damage to the rotor plates (Fig. 3). Luckily our excellent technical staff could successfully repair it and put it back into operation.

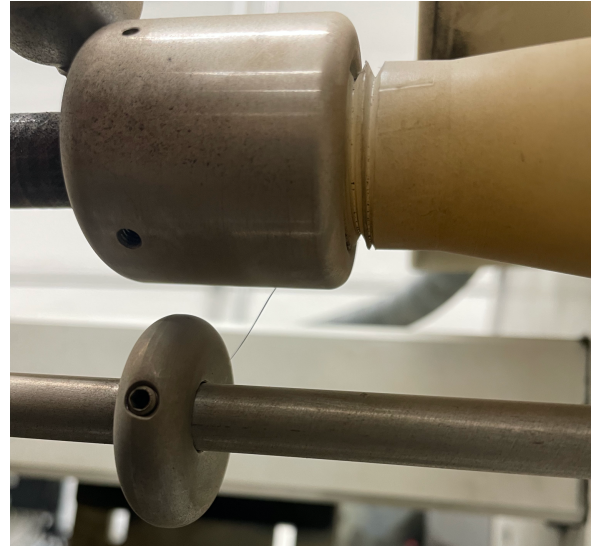


Fig. 2: A fine metal shaving from the pellets caused a short circuit at the inductor feedthrough.

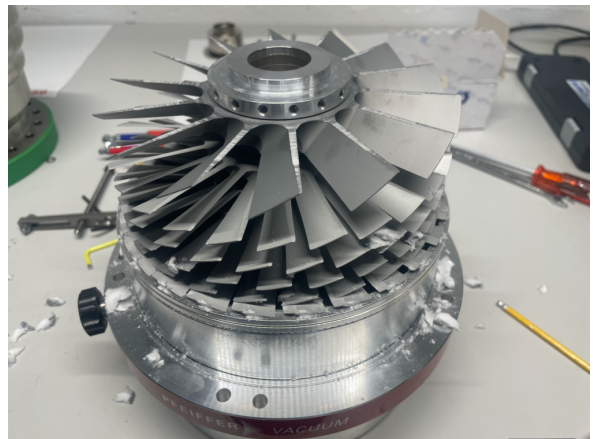


Fig. 3: Repair of the turbo pump after the suppressor ring fell into it.

Additionally, to the AMS analyses Tandy was used for measurements of a master thesis which investigates several detector designs and counting gases. The excellent scaling of the magnetic fields at Tandy facilitated these measurements of different beams and a wide range of energies.

ACTIVITIES ON THE 0.3 MV MILEA SYSTEM

Beam time and sample statistics

M. Christl, H. Perez-Tribouillier, P. Gautschi, C. Vockenhuber, Scientific and technical staff, Laboratory of Ion Beam Physics

In 2025, the MILEA system was in operation for more than 4'300 hours, which is slightly less than in 2024, which was mainly caused by downtime due to several broken stripper gas capillaries, and a damaged high voltage feedthrough cable, that had to be fixed. Nevertheless, with more than 2'800 user samples the number of AMS analyses on MILEA reached a new maximum in 2025.

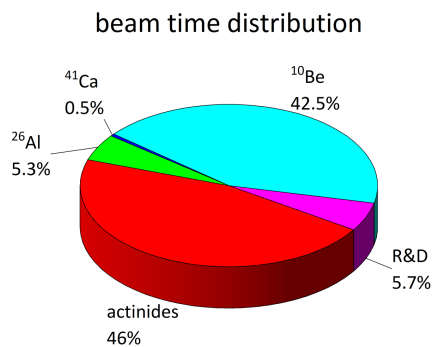


Fig. 1: Relative beam time distribution for the different operations on MILEA in 2025.

MILEA was used in almost equal parts for actinide (46% beam time, Fig. 1) and ^{10}Be measurements (43% beam time). For some of the ^{10}Be user samples also ^{26}Al was analysed which took ca. 5% of the beam time. In 2025, also radionuclides new for MILEA (^{41}Ca , ^{231}Pa) were explored. For this ca. 6% of the beam time was allocated (R&D, Fig. 1). The number of user samples increased in 2025 to more than 2'800. Also here sample numbers (Fig. 2) split about equally between ^{10}Be and the Actinides (^{236}U , Pu- and Am-isotopes, and ^{231}Pa), while the temporal trend for the actinides is still increasing (Fig. 3).

Actinide projects were covering mainly sea water samples (TITANICA project) but also other sample matrices such as sediments and external standard materials were analysed. The majority of ^{10}Be samples came from ice core projects to study past solar storms, while the remaining part

was analysed for projects using in-situ ^{10}Be (and ^{26}Al) for exposure dating and/or the determination of erosion rates.

In 2025 again, AMS samples came from various international universities and institutions. The diversity of all our in-house and external user projects is reflected in the various reports presented in this volume using actinides and cosmogenic radionuclides (^{10}Be , ^{26}Al). Meanwhile, MILEA has established as a working horse for actinide and cosmogenic nuclide measurements. Still, new nuclides such as ^{41}Ca and ^{231}Pa are being explored and student projects are carried out.

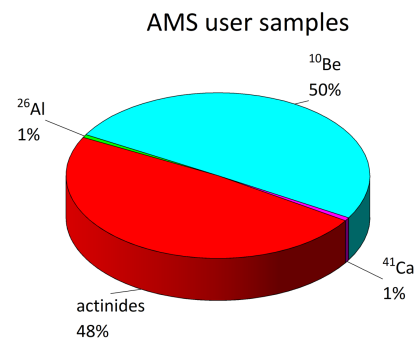


Fig. 2: Relative distribution of AMS samples (per nuclide) measured in 2025.

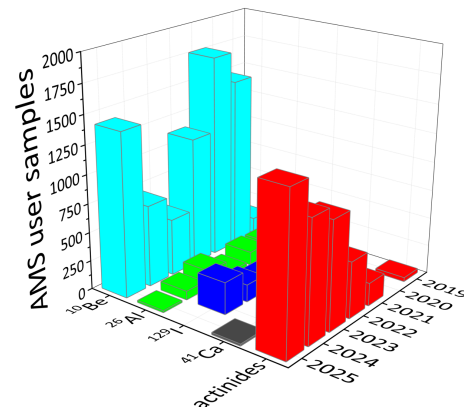


Fig. 3: AMS user samples (no standards, blanks) measured on MILEA, per isotope and year.

ROUTINE ^{10}Be MEASUREMENTS ON MILEA

Currents, sample types and efficiency

P. Gautschi, M. Christl, Scientific and technical staff, Laboratory of Ion Beam Physics

In 2025, more than 1'400 user samples were analysed for ^{10}Be on MILEA, doubling the throughput compared with the previous year. Over 90% of these measurements focused on meteoric ^{10}Be from ice cores and sediments (Fig. 1), carried out in collaborative projects with Lund University, Leibniz Institute for Baltic Sea Research Warnemünde (IOW), and the University of Zurich. Analyses of in-situ produced ^{10}Be were performed in collaboration with the ETH Zurich Geological Institute, UCLouvain, and the University of Bern.

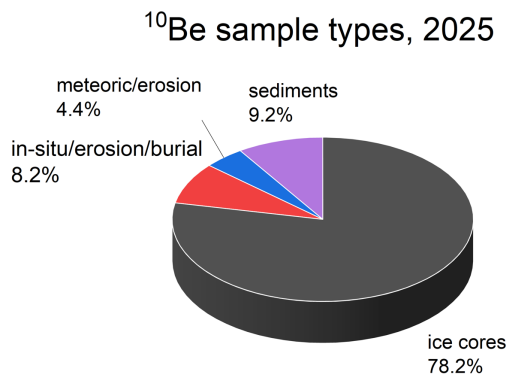


Fig. 1: Types of ^{10}Be samples analysed in 2025. Most analyses were of meteoric ^{10}Be , predominantly from ice-core samples.

The runtime distribution (Fig. 2) indicates that, for most MILEA targets, sufficient statistics are reached after ~30 minutes of measurement. Longer runtimes (up to 2.5 h) were reserved for samples with very low ^{10}Be concentrations or for targets exhibiting reduced ion-current production.

On average, user samples yielded a mean BeO^- current of ~3 μA , with values ranging from 0.1 to 9 μA . The current depends on several factors, including the amount of Be carrier added, chemical yield, and the purity of the sample material.

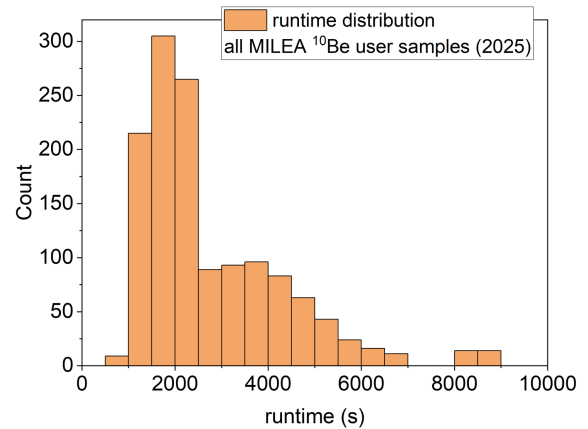


Fig. 2: Runtime distribution of all ^{10}Be samples measured on MILEA in 2025.

The total number of ^{10}Be atoms per sample in 2025 (as calculated from the AMS measurement) ranged from 2.8×10^4 to 1.6×10^{10} atoms (median: 4.1×10^6 atoms). The resulting maximum overall detection efficiency was 1.4‰ (Fig. 3).

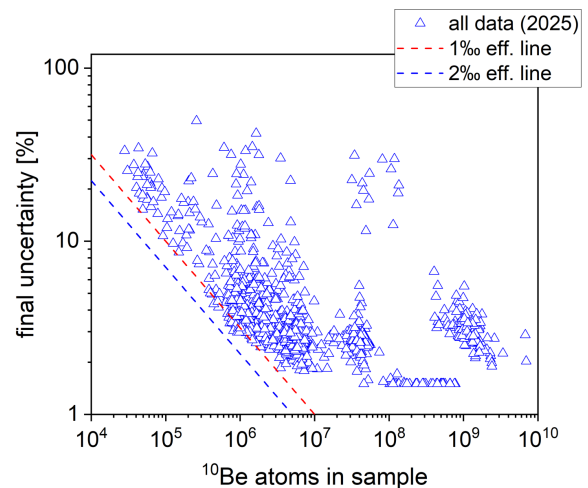


Fig. 3: Final uncertainties of all ^{10}Be data reported in 2025 vs. ^{10}Be (at) in the sample. The red (blue) dashed line indicates a (minimal) detection efficiency of 1‰ (2‰).

^{14}C ON THE 200 KV MICADAS AND THE 50 KV LEA

Performance and sample statistics

L. Wacker, N. Haghipour, U. Ramsperger, and scientific and technical staff of LIP

With nearly 13'000 analyses in 2025, we measured in total just 300 samples less than in 2024. While the number of gas samples decreased by more than 20% due to the reduced activities in the EAPS department (retirement of Prof. Timothy Eglinton in summer 2025), significantly more graphite samples were measured in 2025 (Fig. 1).

The number of samples measured for costumers and research partners stayed relatively constant whereas the high-precision tree-ring measurements for solar reconstructions and for the IntCal radiocarbon calibration curve increased significantly.

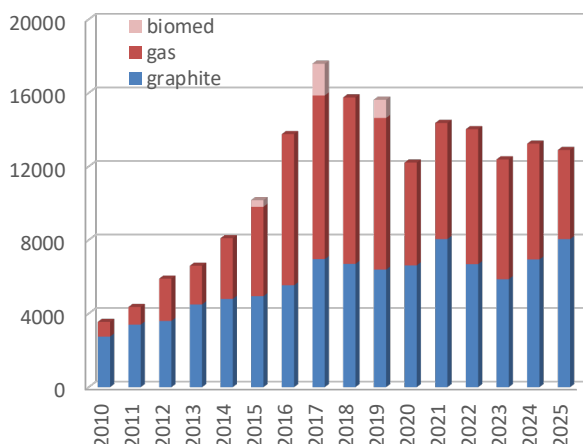


Fig. 1: The total number of measured radiocarbon samples in 2025 was comparable to 2024. The number of graphite over-compensates the significantly lower numbers of gas measurements.

About 1700 annual tree-ring samples were measured for solar reconstruction and/or the radiocarbon calibration curve. Most of those samples were measured to cover the first millenium AD in a joint project with the MPI Göttingen (Prof. Sami Solanki) for solar reconstructions [1].

The total number of counted ^{14}C atoms increased again by 20%, reaching a new record of more than 5 billion, namely due to the increase number of graphite measurements. Also impressive is the dead-time corrected ^{14}C measurement time of the MICADAS with 292 days (running on 344 days) and the LEA with 241 days (running on 325 days) respectively.

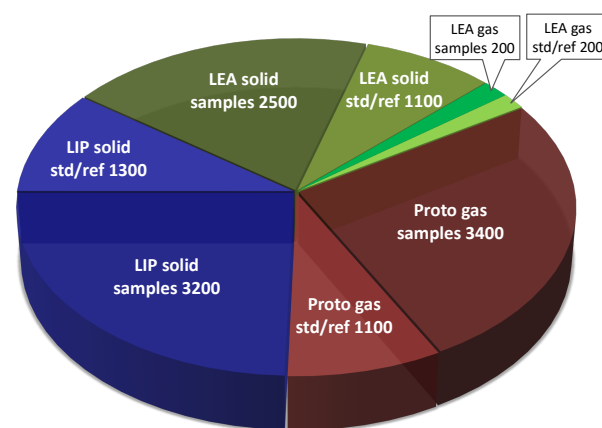


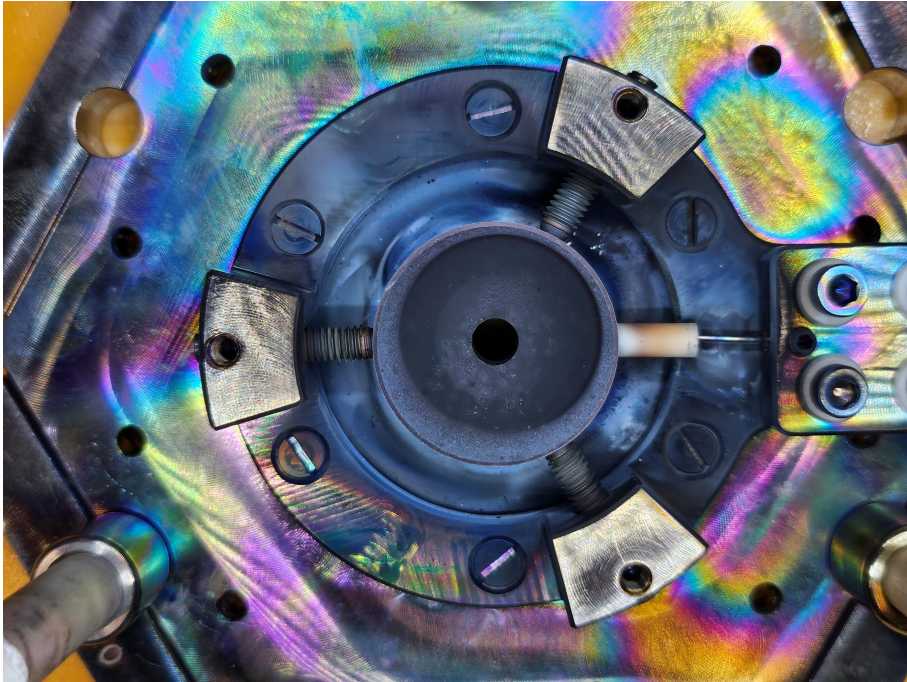
Fig. 2: Overview of all samples measured on the two MICADAS and the LEA system in 2025 at LIP. Graphite samples were measured on the LIP-MICADAS (blue) and the LEA (green). Most samples were measured as gas on the Proto-MICADAS (red).

The LEA system received a significant upgrade to its vacuum infrastructure: a new computer-controlled fore-vacuum system was installed, and one of the two fore-vacuum pumps was replaced with a 20-liter vacuum tank [2]. These improvements bring clear advantages: most notably, a reduction in the maintenance required for the fore-vacuum pumps and a more secure and reliable vacuum system overall.

[1] N. Brehm, Annual report 2025 40

[2] L. Wacker, Annual report 2021 18

INSTRUMENTAL AND ANALYTICAL DEVELOPMENTS



Improved ionizer platform of the MICADAS ion source after first use.

From BioMICADAS to MI-Q

Charge exchange of ^9Be at low energies

Feasibility and optimization of ^{41}Ca AMS at MILEA

A new dedicated air graphitization unit for ICOS

A new ionizer platform for the Cs-source

Engineering at LIP

FROM BIOMICADAS TO MI-Q

Next Generation AMS with classic DNA

L.T. Bezzina, C. Vockenhuber, Scientific and Technical Staff of LIP

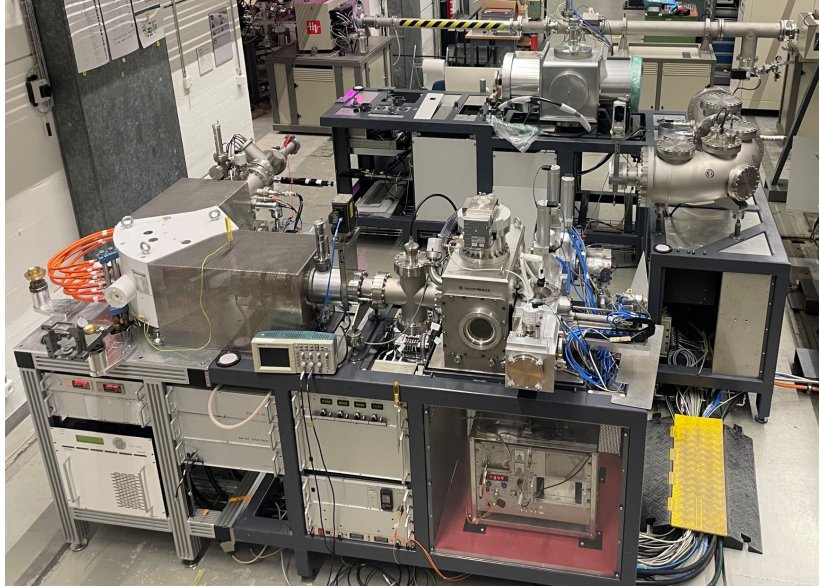


Fig. 1: MI-Q as set up at the end of 2025: the ion source, LE magnet and a beam profile monitor were all under vacuum and undergoing recommissioning.

In 2024, LIP welcomed back the BioMICADAS, the first MICADAS system built for another institution, from its extensive operations at Vitalea Science Inc. and DirectAMS in the USA. This MICADAS forms the backbone of the new system: MI-Q, which aims to integrate laser-based isobar suppression, enabling for the first time the measurement of ^{36}Cl and ^{26}Al with a compact AMS system.

Throughout 2025, significant effort has been focused on recommissioning the low energy end of the MICADAS, from the ion source through to a beam dump established after the low energy magnet. This had included moving the major beamline components into place, establishing vacuum, plumbing cooling water and compressed air, and thoroughly testing electrical connections, and control software. All members of the LIP technical team were involved in one stage or another, and their combined efforts meant that the first beam was measured on 20th May 2025.

In parallel, the conceptual and technical design of the suppression system was begun. A radiofrequency quadrupole (RFQ) forms the heart of this system, required for cooling the beam down to eV energies (from their initial tens of keV). Much of the scientific staff of LIP approached the design with excitement and many ideas to tackle the design challenges of differential pumping and high voltage delivery, as well as detailed shaping of the quadrupolar field. Advice from groups running similar systems (such as those from HZDR and University of Vienna), however, suggested simplicity as the best first approach. As such, the first mechanical and electrical designs are underway to deliver a working prototype of an RFQ in the first half of 2026.

Extra enthusiasm for the project was delivered along with the announcement of the successful funding of the “COOLER” proposal for the MI-Q led by Christof Vockenhuber in the October 2025 SNF funding round.

CHARGE EXCHANGE OF ^9Be AT LOW ENERGIES

Charge exchange cross sections of ^9Be ions in He below 200 keV

I. Himstedt, U. Ramsperger, P. Gautschi

Accelerator Mass Spectrometry (AMS) relies on efficient suppression of interfering species while maintaining high transmission of the nuclide of interest. Overall efficiency is strongly influenced by the charge-state yield in the stripper, because only one positive charge state can be selected and transported to the detector. Literature charge-state data [1] indicate an interesting low-energy regime where $^9\text{Be}^{2+}$ can exceed $^9\text{Be}^{1+}$ below ~ 90 keV stripping energy (a “crossover”), potentially enabling efficient 2+ operation at low energies (Fig. 1).

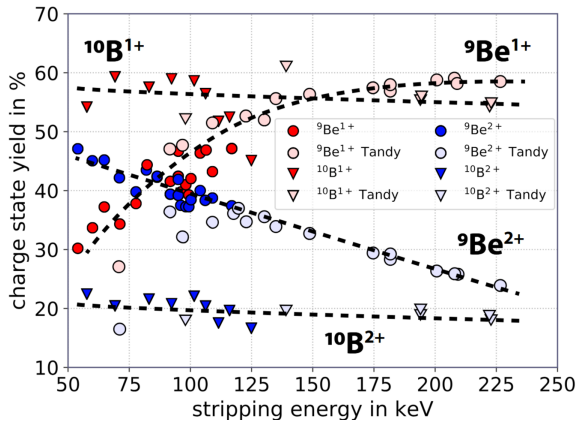


Fig. 1: Charge-state yields for ^9Be and ^{10}B as a function of stripping energy. At low energies, the $^9\text{Be}^{2+}$ share can exceed $^9\text{Be}^{1+}$, motivating improved understanding of charge-exchange processes in He.

To better understand and quantify the underlying processes, a compact model describing charge-state evolution as a function of stripper gas density was adapted [2]. Starting from coupled rate equations linking charge-state yields to charge-exchange cross-sections, the system was simplified to the dominant states (0, 1+, 2+) and solved analytically via a matrix-exponential approach. This provides a direct way to fit measured transmission (converted to charge-state shares) and extract the effective

cross sections governing electron loss and capture between neighboring charge states.

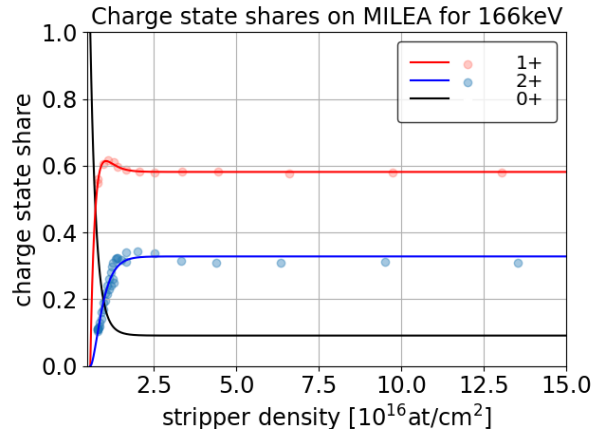


Fig. 2: Measured $^9\text{Be}^{1+}$ and $^9\text{Be}^{2+}$ shares versus stripper density on MILEA (symbols) with analytical model fit (lines), used to extract charge-exchange cross sections.

Experimentally, first measurements on the low-energy AMS system LEA showed insufficient quality of very low current measurements when injecting negative ^9Be ions. Therefore, measurements were repeated on MILEA, which allowed good current measurements, but did not allow reaching the low stripping energies accessible with the LEA system. Transmission curves for $^9\text{Be}^{1+}$ and $^9\text{Be}^{2+}$ were recorded at stripping energies of 166 keV and 236 keV and fitted with the analytical model (Fig. 2). The resulting charge-exchange cross sections ($\sigma_{0 \rightarrow 1}$, $\sigma_{1 \rightarrow 0}$, $\sigma_{1 \rightarrow 2}$, $\sigma_{2 \rightarrow 1}$) are internally consistent and compatible with simulation constraints. These results support the applicability of the model and establish an experimental baseline for extending the study towards the <100 keV regime where the crossover is expected to be most relevant.

[1] P. Gautschi, Doctoral Thesis ETH, (2024)

[2] H.D. Betz, Rev. Mod. Phys. 44 (1972)

FEASIBILITY AND OPTIMIZATION OF ^{41}Ca AMS AT MILEA

Performing charge state measurements and standard isotope analysis

L. Weinhhammer, P. Gautschi, C. Vockenhuber

The radionuclide ^{41}Ca is an important tracer in biomedical research. While ^{41}Ca AMS has been successfully established at several facilities at LIP, only preliminary studies have been performed at the 300 kV MILEA system so far. This project evaluated MILEA's suitability for ^{41}Ca measurements by determining the charge state distributions and analysing isotope ratios of various standard reference materials.

MILEA's ion optics were manually tuned to obtain maximal beam currents and stable transmission of ^{40}Ca , ^{41}Ca , and ^{39}K beams. Using the optimized settings, charge-state distributions of Ca^+ , Ca^{2+} , and Ca^{3+} were measured at stripper energies of 149 keV and 159 keV at terminal voltages of 240 kV and 265 kV, respectively. The results (Fig. 1) provide relevant insights into the stripping dynamics. The 2+ charge state showed the highest yield and was selected for all subsequent measurements.

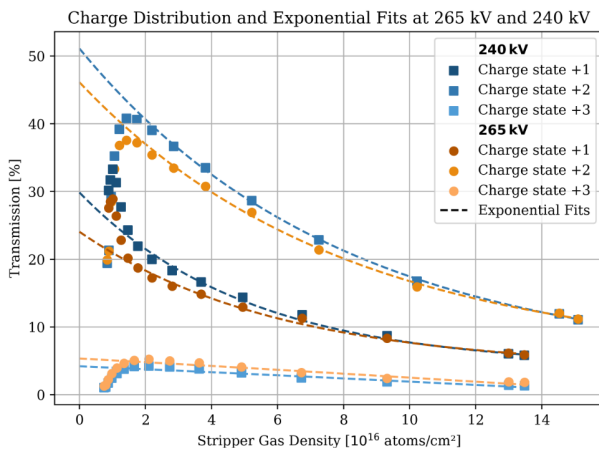


Fig. 1: Measured transmissions for different charged states of ^{40}Ca as a function of He areal gas density. Charge state yields are given by the extrapolation to zero stripper gas density.

Isotope ratio measurements were then performed using alternating detection of ^{41}M and ^{39}K . A K-correction procedure was implemented

to account for isobaric ^{41}K interference. The calibration factor β was found to be close to the expected value from the natural isotopic abundance (Fig. 2), where β quantifies the proportionality between the measured ^{39}K signal and the interfering ^{41}K . The performed data analysis closely follows established methodology [1] and has been validated against previously collected data. Although isobar separation is not possible at the low energies at MILEA, the K correction and additional selection criteria based on minimal current and transmission provides robust isotope ratio measurements despite varying ^{41}K contribution. However, within this project we had sample-preparation issues resulting in unstable beam currents and unreliable $^{41}\text{Ca}/^{40}\text{Ca}$ ratios.

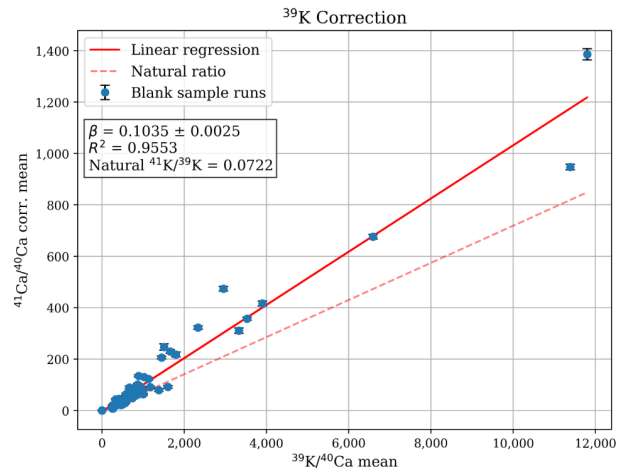


Fig. 2: K-correction: Linear regression onto the measured $^{39}\text{K}/^{40}\text{Ca}$ and $^{41}\text{K}/^{40}\text{Ca}$ ratios from the blank samples. The slope gives the constant beta.

The charge-state results and the K-correction confirm that ^{41}Ca AMS on MILEA is technically feasible and provide a basis for developing reliable ^{41}Ca capabilities on MILEA for future biomedical applications.

[1] C. Vockenhuber et al., NIM B 361 (2015) 273

A NEW DEDICATED AIR GRAPHITIZATION UNIT FOR ICOS

Intercomparison results

T. Knaack¹, J. Della-Coletta¹, P. Gautschi, S. Preunkert¹, L. Wacker, S. Hammer¹

At the Integrated Carbon Observation System Central Radiocarbon Laboratory (ICOS-CRL) atmospheric air samples from more than 19 stations of the European ICOS atmospheric network are processed for $^{14}\text{CO}_2$ analyses. A primary objective of these analyses is to assess the deviation of the atmospheric $^{14}\text{CO}_2$ at these rural continental stations compared to the marine background of $^{14}\text{CO}_2$, caused by the combustion of ^{14}C -free fossil fuels. Because even during wintertime, i.e. the heating period, gradients in $\Delta^{14}\text{CO}_2$ observed at ICOS stations are very small (on the order of 5 to 15‰), highest analytical precision is required also at the stage of sample preparation. Due to a recent increase in sample throughput of more than 2'000 $^{14}\text{CO}_2$ samples per year an extension to the existing ICOS-CRL sample preparation with a high level of automatization became necessary. Consequently, a new air loading interface and automated graphitization system (ALF-newAGE) was developed at the Laboratory of Ion Beam Physics (LIP) in Zürich (see Fig. 1) allowing for automated sample loading and graphitization of ICOS flask samples, consisting of air samples stored in 3 L glass cylinders.

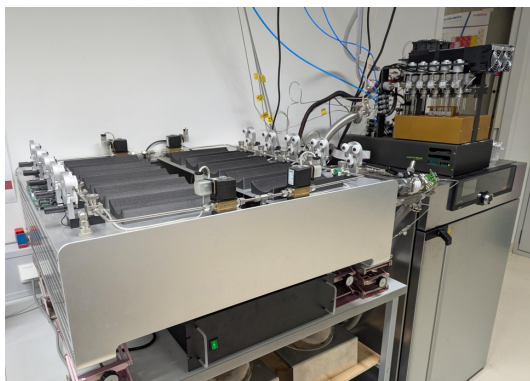


Fig. 1: Setup of the ALF-NewAGE System at the ICOS-CRL. In the left the ALF allowing the automated loading of ICOS-Flask samples. In the right the newAGE allowing the automated graphitization of the samples

In 2025 more than 130 Quality Control (QC) Samples were processed with the ALF-new AGE and measured in 7 different AMS measurement runs made at the LIP and at the Curt Engelhorn Centre for Archaeometry in Mannheim, enabling a first evaluation of the sample preparation performance of this new device. The QC samples consisted of either oxalic acid I (Ox I) with a defined $\Delta^{14}\text{CO}_2$ signature or air quality control samples prepared from cylinders of compressed ambient air for which the $\Delta^{14}\text{CO}_2$ signature was calibrated via the existing ICOS-CRL $^{14}\text{CO}_2$ measurement chain [1].

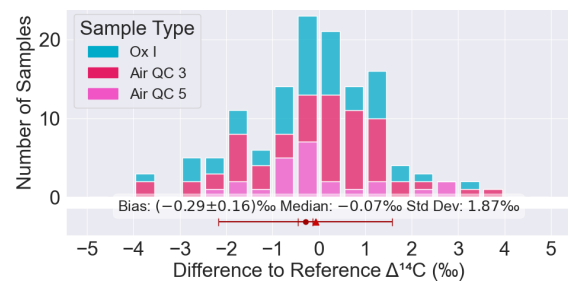


Fig. 2: QC measurements made with the ALF-newAGE system in 2025 revealed a mean bias of $(0.71 \pm 0.16) \text{‰}$ with a precision of 1.9 ‰.

The comparison between the measured QC-samples and their reference $\Delta^{14}\text{CO}_2$ signatures revealed a mean bias of $(0.71 \pm 0.16) \text{‰}$ over all QC samples. This bias could be at least partly contributed to a contaminated oxalic acid II standard, used for calibration, having a $(1.4 \pm 0.4) \text{‰}$ lower than expected $\Delta^{14}\text{CO}_2$ signature. Thus, reducing the expected bias to approx. $(-0.3 \pm 0.4) \text{‰}$ in future measurements. Currently this is verified using a new set of measurements calibrated using a new Ox II standard.

[1] J. Lux, PhD Thesis, Uni Heidelberg 2018

¹ICOS-CRL, Institute of Environmental Physics, Univ. of Heidelberg, Germany

A NEW IONIZER PLATFORM FOR THE Cs-SOURCE

Re-designing the ionizer platform for simplicity and modularity

V. Hernandez, U. Ramsperger, L. Wacker, A. Wagner

Recent advances in Cs-ion source technology have boosted efficiency, stability, and serviceability, setting a new standard for MICADAS, MILEA, and LEA accelerator mass spectrometers. A compact, modular Cs nozzle [1] improves vapor output while lowering reservoir temperatures without sacrificing ionization efficiency. In-house developed ionizers [2] now offer longer life and better operational stability.

As a further development of the existing Cs source, the ionizer platform has been prioritized. It is redesigned as a modular assembly and is integrated into the current Cs source. Straightforward installation and precise adjustment of the ionizer are ensured, while removal and reinstallation of the ionizer holder are enabled without necessitating subsequent realignment. Furthermore, the base plate of the ionizer platform is structurally simplified to enhance overall system robustness and maintainability.

Fig. 1 shows the complete Cs-AMS source with the newly implemented ionizer platform (1) highlighted in green (upper part). The lower part of the figure presents the ionizer platform disassembled into three components. (2) The base plate, which serves as the mechanical interface between the extractor and the target holder, also provides the mounting structure for the ionizer assembly, including the ionizer, ionizer holder, and Cs nozzle. (3) The ionizer holder secures the ionizer using three screws, which allow lateral adjustment for precise alignment with the ion beam trajectory. (4) The Cs nozzle is directly attached to the ionizer holder, through which the Cs vapor is distributed concentrically toward the ionizer and ionized on the hot ionizer surface (up to 1'200 °C).

This Cs source is installed in a MICADAS system at LIP. It has been operating continuously for more than six months and has processed over

2'000 graphite samples. The stability and reliability of the system have improved noticeably, along with a significant simplification of the monthly maintenance procedures.

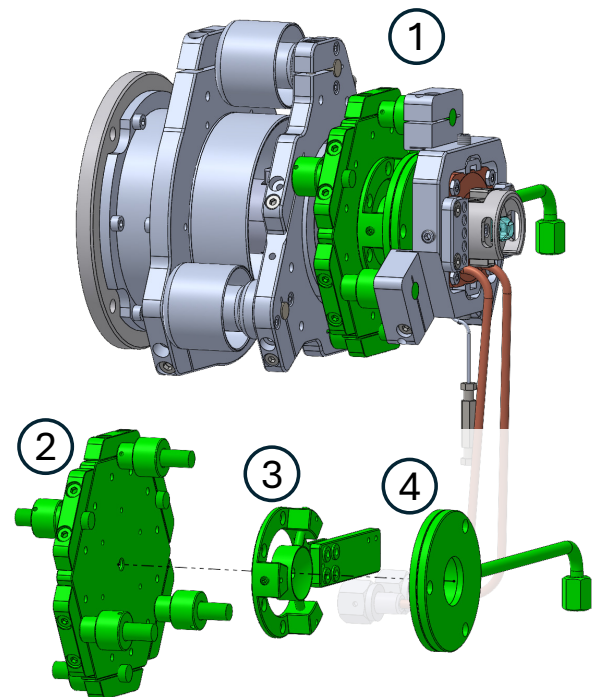


Fig. 1: (1) New ionizer platform integrated into the AMS Cs source. (2) Simplified base plate serving as the mechanical interface between the extractor and the target holder. (3) Ionizer holder with the ionizer, fixed and laterally adjustable by three screws. (4) Cs nozzle distributing Cs vapor concentrically toward the ionizer.

This work is completed as part of the practical final project for the Physics Laboratory Technician program.

[1] U. Ramsperger, Annual report 2024, 27

[2] U. Ramsperger, Annual report 2023, 16

ENGINEERING AT LIP

Comprehensible decision-making using Utility Analysis

T. Wulff, L. T. Bezzina, C. Vockenhuber

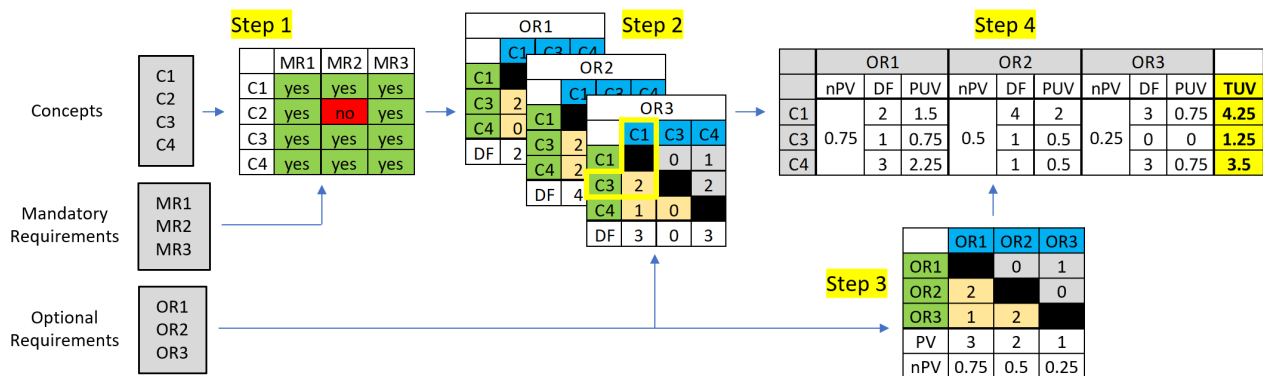


Fig. 1: Exemplary Utility Analysis as in use at LIP

It is a common – and desired – fact that not just one but a variety of ideas is developed to achieve a scientific goal. However, selecting the most promising concept to pursue can turn into a difficult ranking game. Discussions, especially in large groups, to evaluate the options' strengths and weaknesses can spin in circles and topics may shift according to the participants' priorities. The decision-making process may thus be driven by intuitive factors. To put a more transparent process in place, LIP established a stepwise technique that is depicted in an exemplary case in Fig. 1, where a set of *Mandatory* (MR1 – MR3) and *Optional Requirements* (OR1 – OR3) are applied to evaluate a set of *Concepts* (C1 – C4).

Step 1: In the first step, it is investigated if each concept meets all MRs, which is a simple “yes-or-no” decision. In Fig. 1, C2 for example does not meet all the requirements and is consequently eliminated from further evaluation.

Step 2: During the second step, the *Pairwise Comparison* (PC) technique is applied to calculate the remaining concepts' individual *Degree of Fulfillment* (DF) against each OR. For the fields marked in yellow, the question to ask to conduct the PC must be: “Does C1 fulfill OR3 better than C3?”. If the answer is yes, two points are given (as in this case). One point would be given if both

of the compared concepts equally meet the OR (as in C1 vs. C4) and zero points would be given if the answer to the question is no (as in C3 vs. C4). The DF then is the vertical sum of the achieved points, resulting for example in a DF of 3 for C1.

Step 3: The PC method is again applied in identical fashion in the third step to define the *Priority Value* (PV) of the ORs. The PV is then converted into the *Normalized Priority Value* (nPV) by dividing the achieved PV through the max. achievable number of points (OR1 scores 3 points and max. PV is 4, so its nPV is 0.75).

Step 4: In the fourth and final step, for every remaining concept and every single OR, the nPVs of step three are multiplied with the DFs of step two - providing the *Partial Utility Value* (PUV). Finally, the *Total Utility Value* (TUV) is defined as the horizontal sum of the PUVs – with concept C1 scoring strongest in this case with a TUV of 4.25.

The method neither automatically provides a correct answer nor does it prevent “lively” discussions. However, it provides a structure with clearly demarcated decision points, rendering discussions more efficient and facilitating their documentation. It was first applied in the (ongoing) development of LIP's Ion Cooler MI-Q where it proved to be an effective tool in structuring the decision-making process.

RADIOCARBON



Carnegiea gigantea in Tucson, Arizona

^{14}C preparation lab in 2025

Badger archaeology and Capricorn Barbecue

Dating of historical monuments (MORDAT)

The bearded vulture, an archaeologist

The rhythm of past agricultural decision-making

Two 17th-18th-century armchairs
Volcanic CO₂ degassing and ¹⁴C dating
Iron-manganese concretions in the Baltic Sea
Dating volcanic eruption of Thera
Radiocarbon anomalies in the 3rd millenium BP
Extending late glacial ¹⁴C-calibration
¹⁴C in the Western Mediterranean Sea
¹⁴C analysis of asteroid Ryugu at ETH Zurich
Organomineral interactions in marine sediments
OC transit times of three lakes in DR Congo
Sunspot cycles over the first millenium BCE
Annual dating for annual report
How old are Saguaro Cacti?
Canadian Arctic coastal bluffs: ORO-¹⁴C insights
Chemical weathering pathways in river systems
Landscape control in the Himalayas
Tracing erosion rates in sediments using ¹⁴C
Backfilling vs degrading organic soils
Radiocarbon inventories of Switzerland
The importance of process blanks in CSRA

^{14}C PREPARATION LAB IN 2025

Overview of applications and samples

I. Hajdas, A. Albrecht, N. Brehm, M. Christl, P. Gautschi, N. Haghipour, C. Motel Mikosch, G. Scacco, A. Studer, U. Ramsperger, L. Wasowicz, L. Wacker

The ETH ^{14}C laboratory continues to prepare and analyse samples for different applications (Fig. 1).

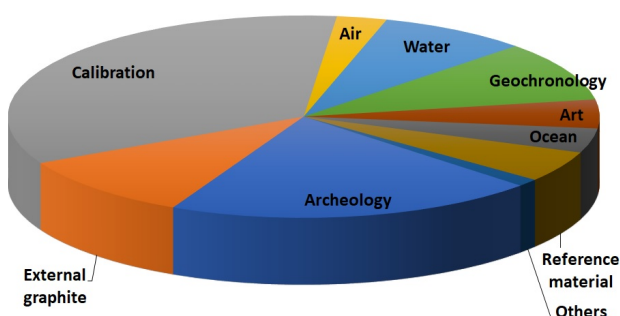


Fig. 1: ^{14}C analysis for various research disciplines, performed in 2025.

Archaeology and Geochronology remain important applications of ^{14}C dating, and the number of analyses has increased over the past 2 years (Fig. 2), although samples measured for calibration predominate.

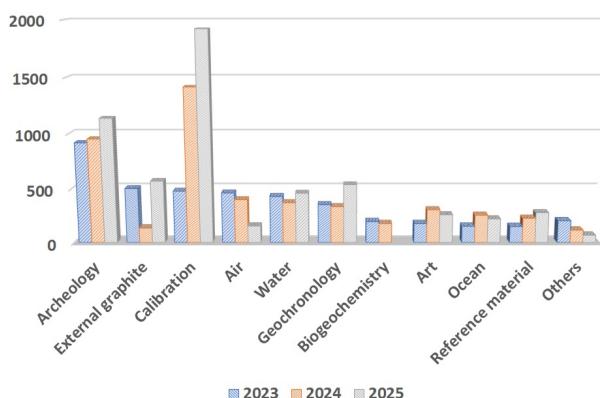


Fig. 2: Comparison between a number of ^{14}C analyses performed for significant applications in 2023, 2024, and 2025.

Notable projects from various applications are presented in this issue; others are published or ongoing studies. Table 1 shows examples of published collaboration projects in the fields of Archaeology and Geochronology. Our application categories are quite general; therefore, for example, archaeology also includes investigations into the historic period, and Geochronology includes climate research.

Application	Publication	Samples type
Archeology	[1-3]	Charcoal
	[4-5]	Mortar
	[6-7]	Bones
Geochronology	[8-11]	Macrofossils, Wood, Organic mat. Charcoal

Tab.1: Studies supported by our ^{14}C analysis.

- [1] C. Cervera et al., Journal of African Arch., 23 (2025) 178
- [2] C. Pruvost et al., PLoS One, 20 (2025) e0329824
- [3] A. Izdebski et al., PNAS, 122 (2025) e2409056122
- [4] P. Povinec et al., Radiocarbon, 67 (2025) 135
- [5] M. Caroselli et al., Radiocarbon, (submitted)
- [6] S. Greaney et al., Antiquity, 99 (2025) 665
- [7] P. Arnold et al., Current Biology, 35 (2025) 5363
- [8] R. Dobrowolski et al., The Holocene, 35 (2025) 479
- [9] M. Ortler et al., Sedimentary Geology, 482 (2025) 106881
- [10] D. Tamas et al., Scientific Reports, 15 (2025) 23379
- [11] V. Rime et al., Sedimentology, 72 (2025) 475

BADGER ARCHAEOLOGY AND CAPRICORN BARBECUE

The Stali rock shelter (Muotathal, CH)

U. Leuzinger¹, W. Imhof², P. Beeler³, W.H. Schoch⁴, N. Reynaud Savioz⁵, I. Hajdas



Fig. 1: The archaeological excavation in August 2025. Photo: W. Imhof

The Stali rock shelter is located at 960 m a.s.l. in the Hürital valley in the Canton of Schwyz CH (Fig. 1). A living surface measuring 23×5 m survived thanks to the protection of the overhanging rock. Several springs flow past the site. At some stage it was discovered by a badger, who dug up bones and charcoal without official permission. Archaeological research took place in 2007, 2019 and 2025 on behalf of the State Archive of Schwyz. Anthracological investigations showed that *Abies alba* and *Fagus sylvatica* were used as firewood. Radiocarbon analyses on charcoal and animal bones yielded dates from the Late Neolithic to the Late Iron Age (cal., 2 sigma): ETH-32480: 2925 ± 80 BP, 1380–910 BC; ETH-32481: 4050 ± 55 BP, 2760–2460 BC; ETH-34463: 2265 ± 50 BP, 410–200 BC; ETH-34472: 2510 ± 55 BP, 800–480 BC; ETH-34475: 3590 ± 55 BP, 2060–1770 BC; ETH-35073: 2550 ± 50 BP, 820–510 BC; ETH-97890: 2172 ± 25 BP, 358–280 BC; ETH-153830: 2205 ± 19 BP, 364–197 BC.



Fig. 2: Upper third molar of an adult ibex from the Stali Rock Shelter. Photo: N. Reynaud Savioz

The 2025 excavation – a 1×1 m test trench – uncovered a hearth from the 3rd or 2nd century BC at a depth of 50 cm. A number of animal bones were found in the same layer. The worn chewing surface on a molar (M³) of an ibex showed that this was an adult animal that had been hunted and brought to the rock shelter during the Late Iron Age. Archaeological remains from this period are not very often found in the Alpine area.

The Stali rock shelter is strategically well positioned in the Hürital valley, which leads to the Chinzig Pass towards the Schächental valley and the main Alpine ridge. It is a key site for understanding how humans in Muotathal used their environment during the prehistoric period.

¹Amt für Archäologie Thurgau, Frauenfeld

²Muotathal

³Rickenbach b. Schwyz

⁴Laboratory for Ancient Wood, Langnau am Albis

⁵Laboratoire d'archéozoologie, Sion

DATING OF HISTORICAL MONUMENTS (MORDAT)

A new research project on ^{14}C dating of historical mortars at LIP

P. Tomanová^{1,a}, I. Hajdas

Determining the precise age of architectural monuments and construction relics remains a major problem in archaeology and construction history. Standard archaeological or stylistic dating methods can determine ages only in broad chronological intervals. Radiocarbon dating of lime mortars has the potential to significantly contribute to the precise dating of architecture. Although this method has been known since the 1960s, numerous obstacles remain to its routine use as a dating method [1,2].



Fig. 1: St. John Monastery in Müstair – an UNESCO site in Switzerland, is one of the sites included in the MORDAT project.

MORDAT, a new European project, addresses some of the major problems preventing the wider use of ^{14}C mortar dating in architectural research (Fig. 1). The project aims to (1) compare and improve various methods of sample treatment to increase the purity of the extracted carbon and to obtain more accurate ^{14}C data, (2) date four medieval sites in Switzerland and the Czech Republic, (3) support the interdisciplinary cooperation of archaeologists and geochronologists, and to (4) investigate the social impact of scientific dating.

During 2025, samples were collected and characterized using optical and electron

microscopy, and the first samples were pretreated and dated at LIP (Fig. 2) following the procedure developed by Hajdas et al. [3].

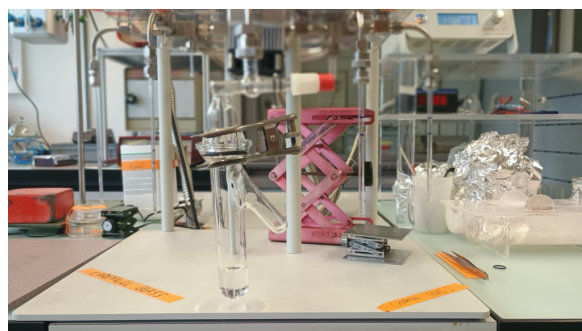


Fig. 2: A tube with a mortar sample and phosphoric acid placed in the decomposition line – part of the mortar treatment procedure used at LIP.

Moreover, dissemination activities were organized, including a conference session on “problematic” radiocarbon data at the 31st Annual Meeting of the European Association of Archaeologists (EAA 2025) in September. Further, in November, a workshop “Radiocarbon dating in Archaeology of the Early Middle Ages” took place in Brno, Czech Republic. This workshop was followed by visits to collaborating institutions in Prague, including the Czech Radiocarbon Laboratory.

Papers presented at both events will be published in a special part of a regular issue of the Radiocarbon Journal.

- [1] J. Labeyrie, G. Delibrias, *Nature* 201 (1964) 742
- [2] R. Hayen et al., *Radiocarbon* 59 (2017) 1859
- [3] I. Hajdas et al., *Radiocarbon* 62 (2020) 591

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THE BEARDED VULTURE, AN ARCHAEOLOGIST

Their nests reveal centuries of ecosystems and human history

A. B. Marín-Arroyo¹, A. Margalida^{2,3}, S. Couto⁴, L. Agudo Pérez¹, S. O. Pinedo⁵, J. M. Gil-Sánchez⁶, I. Hajdas

The bearded vulture, listed as Near Threatened by IUCN, is known for eating bones. Due to its diet, it plays an essential role in nature: it recycles carrion, preventing the spread of pathogens that can affect both livestock and human health. In Prehistory, this vulture alternated with humans in the occupation of karstic caves and rock shelters [1].



Fig. 1: An adult bearded vulture with a sheep extremity before carrying it to the nest. ©A. Margalida

To protect its chicks from the cold, the bearded vulture gathers natural materials, such as wool and branches, and builds nests in sheltered areas where the microclimate remains stable year-round.

Over time, these nests have become true “time capsules.” Our team analysed several historical nests of the species in southern Spain, where it has been extinct for over 70-100 years. The material was collected layer by layer using archaeological methods to preserve the temporal sequence of the recovered remains.

Among bones, eggshells, branches, and faeces, we uncovered surprising objects that add an archaeological dimension to these nests: a complete medieval sandal made from esparto grass, was ¹⁴C dated to 674±22 BP (ETH-138982), alongside a fragment of sheep leather with red

lines drawn dated at 651±22 BP (ETH-138981) and a basketry fragment dated at 151±22 BP (ETH-138980) [2].



Fig. 2: A collection of handcrafted and dated materials found in ancient Bearded Vulture nests. ©L. Agudo Pérez

These finds provide valuable insight into the bearded vulture’s diet since the Middle Ages and help reconstruct historical ecosystems, species abundances, and environmental changes. They also reveal aspects of traditional human-made technologies and everyday practices that have remained remarkably consistent for centuries and are scarce in archaeological contexts. More research will yield new insights into this species “archaeological” behaviour.

[1] Marín-Arroyo et al., J. Arch.Sci. 36 (2009), 284

[2] Margalida et al., Ecol. 106 (2025), e70191

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³Pyrenean Institute of Ecology (CSIC), Jaca, Spain

⁴MEMOLab, Universidad de Granada, Granada, Spain

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⁶Universidad de Granada, Granada, Spain

THE RHYTHM OF PAST AGRICULTURAL DECISION-MAKING

Direct dating of archaeological cereal grains reveals past crop dynamics

F. Antolín^{1,2}, G. Salvador-Baiges^{1,3}, H. Martínez-Grau², I. Hajdas

Prehistoric farmers in the Mediterranean region cultivated a wide range of cereals, including hulled and naked barley, naked wheat, and the glume wheats emmer, einkorn, and *Timopheevii* wheat. These crops were not grown at the same scale across regions or through time. Local and regional dynamics likely reflect differences in climatic niches, culinary traditions, and economic choices, as glume wheats are more labour-intensive. Investigating agricultural decision-making in small-scale societies, therefore, offers valuable insights into broader socio-political transformations and resilience strategies. Such processes can only be traced with high chronological precision, as changes in crop use may be short-lived and linked to climatic variability or human mobility; broad chronocultural frameworks often obscure these finer dynamics.

The AgriChange project [1] addresses this issue by examining Neolithic agricultural developments (5'800–2'300 BCE) in the transition zone between the north-western Mediterranean and Switzerland. Several hundred radiocarbon dates have been obtained from charred cereal remains. In north-eastern Spain alone, around 100 dates indicate the presence of domesticated plants from at least 5'600 BCE and an overall continuity of farming practices (Fig. 1). Crop-specific dynamics were analysed using summed probability distributions (SPDs) calculated with the R package *rcarbon* [2].

The results reveal alternating phases of higher and lower crop diversity. An initial phase up to c. 5'300 BCE is characterised by a wide range of cultivated cereals. This is followed by a period of reduced diversity, with a focus on naked wheat and barley until c. 4'700 BCE, after which glume wheats reappear for approximately 200 years. These shifts have not been well explored to date.

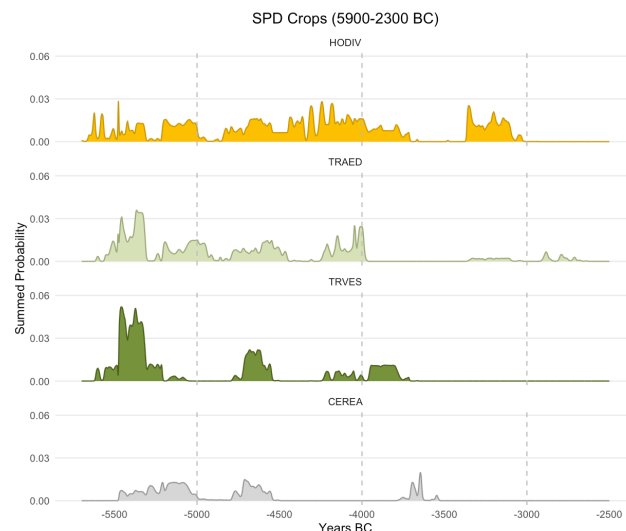


Fig. 1: Summed probability distributions (SPD) of barley (HODIV), naked wheat (TRAED), glume wheat (TRVES) and unidentified cereal remains (CEREA) from the NE of the Iberian Peninsula.

While barley remains well attested until around 3'500 BCE, a phase dominated by naked wheat is observed between c. 4'300 and 4'000 BCE, followed by another phase in which glume wheats prevail (c. 4'000–3'700 BCE). This shift around 4'000 BCE has also been documented in other areas of the north-western Mediterranean [3], suggesting a broader regional process. It may reflect previously unrecognised socio-political dynamics, possibly linked to the westward expansion of glume wheats from the Balkan region.

- [1] F. Antolín et al., *PAGES* 26 (2018) 26
- [2] E. Crema & A. Beavan, *Radiocarbon* (2021) 63, 23
- [3] F. Antolín et al. *The Holocene* (2024) 34, 239

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²IPAS, University of Basel

³Universitat Autònoma de Barcelona, Spain

TWO 17th-18th-CENTURY ARMCHAIRS

¹⁴C dating and the examination of historic seating furniture

L. Schaad¹, K. Wyss², I. Hajdas

Upholstery presents a particular conservation challenge due to its complex layering and the wide variety of materials used. Because it is usually concealed beneath decorative textiles, it is often difficult to access. Furthermore, research on upholstery has remained limited largely because it has historically received little attention within the field of conservation and restoration. Attention tends to focus primarily on the furniture frame or the covering textiles, while the upholstery itself is seldom been examined in detail.



Fig. 1: Armchair 1 (left) and Armchair 2 (right) in 2025 before restoration, Historisches Museum Blumenstein Solothurn.

As part of the Master's thesis, a pair of armchairs from the Historisches Museum Blumenstein in Solothurn served as a case study (see Fig. 1). Visual examination allowed an initial assessment of the upholstery and revealed several features characteristic of 18th century upholstery techniques. Additional analytical methods, including light microscopic fiber identification and X-radiography, provided further insight into the structure and materials used (see Fig. 2). To refine the dating of the upholstery and validate the initial hypothesis, a sample of the filling material from the back upholstery of Armchair 1 was taken. The sampling location was selected to

allow material to be taken without opening the upholstery or damage the cover fabric. Radiocarbon analysis of the sample confirmed the historical authenticity that it constitutes an exceptionally rare example of original upholstery dating from the late 17th to early 18th century.

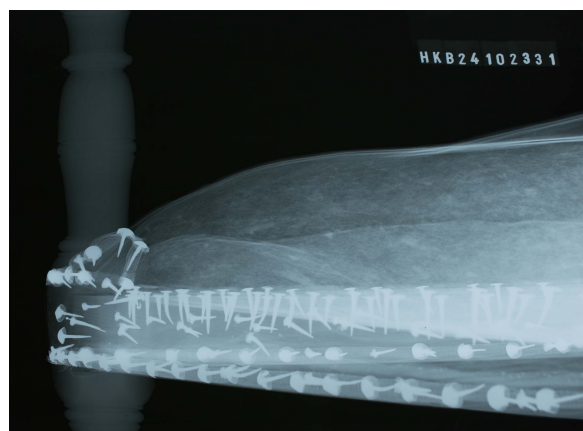


Fig. 2: X-ray image of the seat upholstery in cross-section of armchair 1.

Because the long-standing tradition of reupholstering seating furniture often resulted in extensive alterations, many examples preserved in museum collections no longer feature their original upholstery. As a result, they offer only limited information on historical upholstery techniques and authentic construction forms. The rarity of preserved original upholstery, underscores the importance of establishing a precise chronological context so that such structures can serve as valuable comparative references for future research.

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VOLCANIC CO₂ DEGASSING AND ¹⁴C DATING

The effect of ‘old’ carbon on the age of organic material at Laacher See

S. Albers¹, L. Claeys^{1,2}, I. Hajdas, M. De Batist¹

Lake sediments provide a continuous record for reconstructing past climate and natural events. In recent (Quaternary) sediments, radiocarbon dating of organic material is a fundamental technique, but building reliable chronologies can be challenging since the method depends on material type, depositional conditions, and potential ¹⁴C contamination. Volcanic CO₂, for example, is depleted in ¹⁴C and can dilute atmospheric ¹⁴C where it is released. This project investigates how volcanic CO₂ emissions containing this ‘old’ carbon affect the ¹⁴C age of different types of organic carbon at Laacher See, a volcanic crater lake in the Eifel region of western Germany. Formed after an eruption ~13 ka BP, the crater hosts several CO₂-degassing vents, including underwater bubble seeps (“wet mofettes”) and onshore soil-gas emissions (“dry mofettes”).

Several sources of organic material in the lake and its catchment were sampled for ¹⁴C analysis (Fig. 1): low-growing plants (dandelions and marsh sedge), beech tree leaves and outer tree rings, soil, macrophytes (whorled water-milfoil), and particulate organic matter (POM) filtered from the water column of the lake. To investigate the spatial variability in ¹⁴C signature, samples were collected both near and far from known underwater and soil degassing spots. Additionally, dandelions were sampled regularly (every ~50 m) along a transect extending from the lake shore, where CO₂ degassing occurs, to beyond the crater rim. Ultimately, these samples, representing mostly ‘living’ organic material, were compared with organic bulk sediment samples taken from a >4 m long sediment core from the lake.

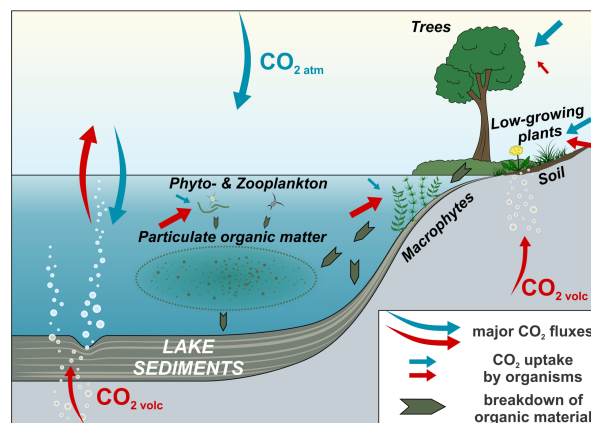


Fig. 1: Simplified overview of CO₂ fluxes and CO₂ uptake by different organic sources in the lake and catchment of Laacher See.

Our results show that all dated samples exceed their true or expected ages, with variable radiocarbon ages of up to 9'000 a BP for living plant material. Plants growing near mofettes show a strong ¹⁴C depletion that decreases with distance. In addition, there is a stronger influence of volcanic CO₂ in the lake water than in the surrounding catchment, likely due to a reduced mixing with atmospheric CO₂ in the water. This heavily affects the radiocarbon ages of bulk organic material found in the lake sediments and shows that radiocarbon dating does not provide reliable results to establish a chronology for the sedimentary infill of Laacher See. Therefore, other age-dating techniques should be considered to establish an age-depth model with reliable, non-¹⁴C dependent ages.

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IRON-MANGANESE CONCRETIONS IN THE BALTIC SEA

Deciphering the ^{14}C signature on the birth certificates of concretions

M. Liira^{1,2}, A. Lepland^{1,2,3}, D. Koll⁴, S. Suuroja¹, W.-L. Hong⁵, M. Christl, L. Wacker, A. Studer

Seafloor iron–manganese (oxy)hydroxide precipitates (Fe–Mn concretions) occur in a variety of marine areas experiencing low sedimentation. In the shallow Baltic Sea, they form where bottom currents hinder sediment build-up (Fig. 1). Baltic Fe–Mn concretions grow faster than deep-sea nodules and thus show distinct mineralogical, chemical, and isotopic fluctuations and trends. They are especially abundant in the Gulf of Finland (Fig. 2), where they develop on exposed Late Pleistocene glaciolacustrine clays, glacial till, or crystalline bedrock [1,2].

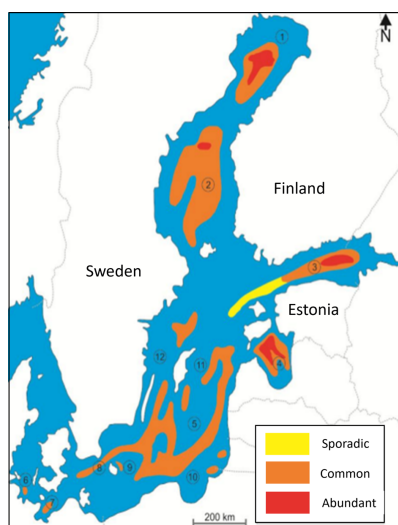


Fig. 1: Distribution of authigenic Fe–Mn precipitates on the seafloor of the Baltic Sea. Modified after [1,2].

Redox-controlled precipitation produces spherical, disc-like, or crustal bodies with alternating Fe- and Mn-rich layers around a nucleus (Fig. 3). These concretions archive changing bottom-water and porewater conditions since the Last Glacial Maximum, but their absolute dating remains challenging because growth is discontinuous and may involve reworking of older material. Radiocarbon measurements of associated or incorporated

organic matter may allow to age constrain growth histories of Baltic Sea Fe–Mn concretions and provide clues for assessing their formation controls. Preliminary data on three selected Fe–Mn concretions indicate that they roughly grew between 12 and 3 ka cal BP.



Fig. 2: ROV observations of the Fe–Mn concretions field in the Gulf of Finland.



Fig. 3: Cross-sectional view revealing the layered internal structure of Fe–Mn concretions.

- [1] G. Glasby et al., Geological Society 119 (1997) 213
- [2] J. Wasiljeff, MSc Thesis. Univ. of Helsinki (2015)

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DATING VOLCANIC ERUPTION OF THERA

Resolving dating controversy over the Bronze Age eruption of Thera

L. Wacker, C. L. Pearson¹, M. Friedrich^{2,a}, B. Kromer³, N. Brehm

The Bronze Age eruption of Thera (Santorini) showered the lands and cultures of the Aegean, Levant, Anatolia and Egypt in ash, and rafted pumice across the Mediterranean Sea. These deposits form a temporal marker horizon, capable of synchronizing the timelines of these interconnected regions. The longstanding pursuit of an exact eruption date has been blocked by a contradiction in evidence between archaeological dating, placing the event between 1'560-1'520 BCE and radiocarbon and tree-ring and ice-core evidence, which placed the event to about 1'620-1'580 BCE.

Here, we re-dated a previously dated olive tree sample (Fig. 1) buried in the tephra from the Thera eruption [1].



Fig. 1: 36 sub-samples were taken from the sample shown in the figure.

Previously only 4 samples were dated. In this study, 36 samples with a weight of 10 to 30 mg wood were taken from the olive piece (only a small fraction of the piece shown in Fig. 1). As tree-ring boundaries were very difficult to identify, and annual growth is not guaranteed in olive trees, our best estimate was that c.78 yr were represented in the sample, based on growth band counts. This was very close to the original counting, using x-ray CT [1] and implies that we sampled with a resolution of c.2-4 yr. The cellulose of the sample was extracted with the BABAB treatment and measured on the MICADAS for high precision.

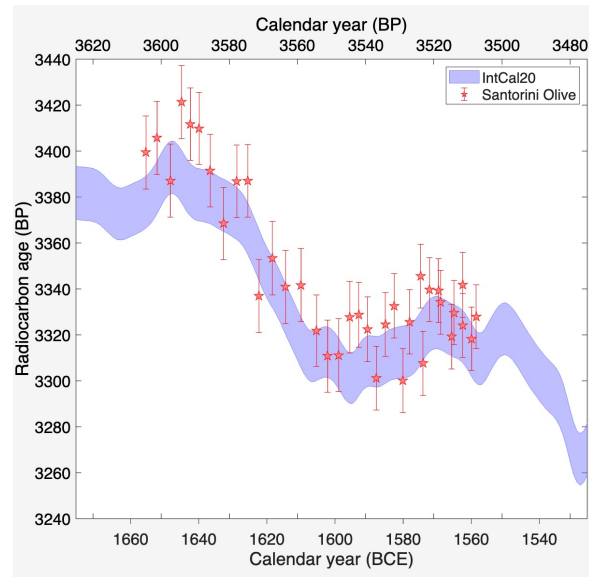


Fig. 2: Most likely placement of the 36 samples matched on the IntCal20 calibration curve that is based on annually resolved and replicated raw data from European trees.

The results of the measurement were spaced according to our ring counting and best-fit to the IntCal calibration curve allowing for a regional offset of +15 yr. The shape of the Thera samples fits well on the curve, indicating that our ring counting was reasonably accurate. Applying a ring count uncertainty of $\pm 25\%$, the Thera eruption happened between 1'580 and 1'540 BCE, considerably younger than the original low-resolution dating on the lower resolution calibration curve IntCal04 [1]. The new result brings the radiocarbon dating in agreement with archaeological evidence.

[1] W.L. Friedrich et al., *Sci.*, 312 (2006) 548

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RADIOCARBON ANOMALIES IN THE 3rd MILLENNIUM BP

Replicated tree-ring measurements detect smaller Miyake-type events

D. Frank¹, Lukas Wacker, Nicolas Brehm, and data contributors

Rapid increases in cosmogenic isotopes in annually dated paleoarchives point to rarer perturbations in the Heliosphere over the past millennia [1, 2]. Identifying additional ¹⁴C spikes – so-called Miyake Events – and/or to replicate or refute published event candidates have become a research priority. Yet, there are still large gaps, both in magnitude and understanding, between more frequent and lower energy events in space-age measurements and larger rare events inferred from Holocene paleoarchives.

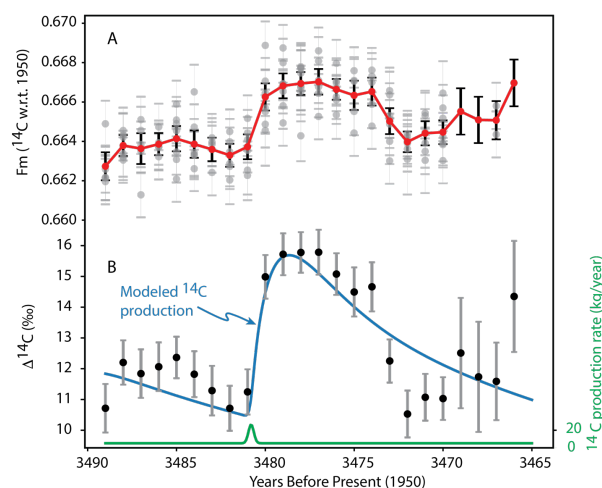


Fig. 1: **A)** Replicated measurements from 3'489 to 3'470 BP (grey points together with 1 sigma uncertainty) to obtain a higher precision mean (red, with 1 sigma uncertainty in black). **B)** Modelled ¹⁴C production using a 22-box carbon cycle model [4] captures the general shape of the replicated data and is consistent with ¹⁴C production from solar energetic particle event(s). Note the last 4 years have replication and greater uncertainties more typical for the Holocene.

Here, to address this gap, we generate annually-resolved data from previously prepared wood cellulose. We focus our high-precision measurements on four shorter (10-21 year) intervals between 3-4k BP where initial ¹⁴C data suggest the presence of a radiocarbon

production anomaly and/or episodes of higher than usual errors in the tree-ring radiocarbon measurement continuum. An illustrative example for 3'489-3'470 BP is shown in Fig. 1 where previously measured ETH data in collaboration with UK and US (Arizona) colleagues suggested a possible increase in radiocarbon between ~3'482 and 3'478 BP [3].

Our study adds evidence to delineate two likely, and one possible, Miyake-type events at 3'762 BP (likely), 3'481 BP (very likely) & 3'060 BP (possible). Initial carbon cycle modelling (Fig. 1B) following Brehm et al. [4] for the 3'481 BP period points to an additional rapid (< 1 year) production of 8.0 kg of ¹⁴C which is about a 2-fold increase above typical ¹⁴C production rates. Initial modelling for the three candidate periods overall suggests ¹⁴C production anomalies 3-5x smaller than the 774/775 AD event [1] and 20-80% smaller than the 5'410 BP event [2].

The identification and delineation of such "smaller" Miyake-type events helps fill a critical gap between more frequent low energy events observed during the space age and the large events (with correspondingly larger signals) so far identified in paleorecords. Our results are poised to increase known Miyake-type events by 50%, and suggest such ¹⁴C extremes could occur a couple times per millennium. Related back-of-the-envelope calculations suggest approximately 20x more data could be required for each year to address critical questions such as the amplitude of solar-cycle variations over the past millennia.

- [1] F. Miyake et al. Nature 486 (2012) 240
- [2] F. Miyake et al. GRL 48 (2021) 093419
- [3] C. Pearson et al. PNAS 117 (2020) 8410
- [4] N. Brehm et al. Nat. Comm. 13 (2022) 1196

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EXTENDING LATE GLACIAL ^{14}C -CALIBRATION

Towards a Late Glacial tree ring chronology of N-Italy

M. Friedrich^{1,a}, B. Kromer², S. Talamo³, K. Ando, L. Wacker

Tree-ring chronologies provide the most precise annually resolved calendar of the past. Currently, the longest continuous tree-ring chronology of German oak and pine trees extends back to 12'325 cal BP [1, 2]. Recent advances in multi-proxy dendrochronology, integrating AMS ^{14}C dating and stable isotope analysis ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$) allowed the precise anchoring of the floating Swiss-/ German pine chronology of the Late Glacial, thereby extending the absolutely dated tree-ring record to 14'139 cal BP [2] into the Bølling Interstadial (GI-1e), the first major climatic warming phase following the LGM, when trees re-colonized Central Europe. At present, the oldest trees are from Dättlau (Winterthur) forming the oldest section of the existing tree-ring chronology. Future efforts to further extend the tree-ring record is now focused on identifying subfossil trees in S-/SE-Europe, where tree populations may have persisted during the coldest phases of the Last Glacial period.

We work on new subfossil trees that we recovered in the last years in northern Italian gravel pits and bogs [3,4]: (i) 32 logs from Avigliana, Dora Riparia River near Torino, pre-dated to 14'400 – 14'100 BP [4,5] and (ii) 38 subfossil trees from Carmagnola, Po River, Torino, ^{14}C -pre-dated to 14'900-14'150 BP [4]. (iii) In addition, 203 subfossil trees from a bog at Palughetto in the Venetian Pre-Alps, all from Bølling-Allerød, with the oldest tree starting growth around 14'800 BP [3]. Accordingly, the first Italian trees start growing at ca. 15'000 BP, indicating earlier reforestation compared to Central-Europe.

In the new SNF-project 'SiGnaL' by ETH and WSL Birmensdorf, we work towards a continuous tree-ring chronology from N-Italy and linking it to existing chronologies from Switzerland, Germany and France. We perform annual ^{14}C analyses, that give valuable information about the global

carbon cycle and past solar activity in the Late Glacial, and may approve a recently postulated Solar Proton Event around 12.3 ka BP [6]. In addition, new stable isotope and advanced quantitative wood anatomy analysis will allow us to investigate growth performance and physiology of trees during periods of extreme climatic fluctuation in the Late Glacial. We expect to provide a comprehensive basis to understand Late Glacial climate dynamics and the extension of the tree-ring-based radiocarbon calibration curve back to ca.15'000 BP, which will provide a precise time scale to synchronize other ^{14}C -dated records, including sediments and other paleoclimate proxy records.

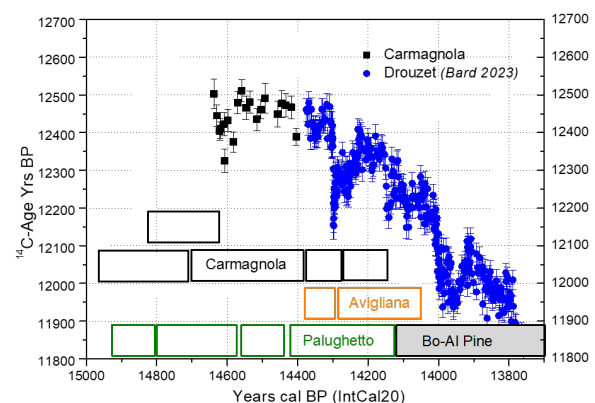


Fig. 1: Coverage of Italian tree-ring records placed by ^{14}C comp. to French trees (blue) and the continuous European tree-ring record (grey bar).

- [1] M. Friedrich et al., Radiocarbon 46 (2004)
- [2] F. Reinig et al., Tree Ring Res. 81 (2025)
- [3] M. Friedrich et al., Alp. & Med.Q. 37 (2024)
- [4] K. F. Kaiser et al., QSR 36 (2012)
- [5] F. Adolphi et al., QSR 170 (2017)
- [6] E. Bard et al., Ph.Tr. A MPhysSci 27 (2023)

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^{14}C IN THE WESTERN MEDITERRANEAN SEA

Tracing of intermediate to deep water mass pathways

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The decadal turnover time of the Western Mediterranean Sea (WMS) allows it to respond quickly to climate forcing. This rapid response makes it an ideal setting for studying short-term ocean circulation processes affected by climate change [1]. Circulation in the WMS is changing, prompting the use of transient tracers like radiocarbon (^{14}C) to understand these shifts [1]. This study investigates the distribution of $\Delta^{14}\text{C}$ (ranging from -26‰ to 30‰) in seawater samples collected during the TAIPro Expedition in May 2022. This dataset provides an assessment of ^{14}C fluctuations and their relationship to circulation dynamics [2].

The identification of water masses for samples using Temperature, Salinity and Oxygen allowed for the calculation of the mean $\Delta^{14}\text{C}$ of each water mass. The investigated water masses primarily consisted of the Western Mediterranean Deep Water (WMDW) and the Western Intermediate Water (WIW), both formed in the Gulf of Lion, and the Levantine Intermediate Water (LIW), stemming from the Eastern Mediterranean Sea.

Radiocarbon confirmed the reported circulation path of WMDW. As visible in Fig. 1 (Light blue lines), WMDW travels first to the Algero-Provençal Basin (APB) before reaching the Tyrrhenian Basin (TB) and the Ligurian Basin (LB) in accordance with [3]. The most positive mean radiocarbon can be found in the APB, while the TB and LB show similar mean values, which therefore suggests a clear flow path of WMDW in a relatively slow manner.

Visible in Fig. 2, identifying patterns in intermediate waters proved to be much more complex due to the high deviations found within a basin and low differences between them. [3] reports LIW (Solid lines, Fig. 2) being dominantly found in the WMS, which in terms of $\Delta^{14}\text{C}$ would be visible in significantly more negative

concentration in the APB and the LB. Adversely, our measurements indicate that WIW (Dashed lines, Fig. 2) rather than LIW is found in the APB.

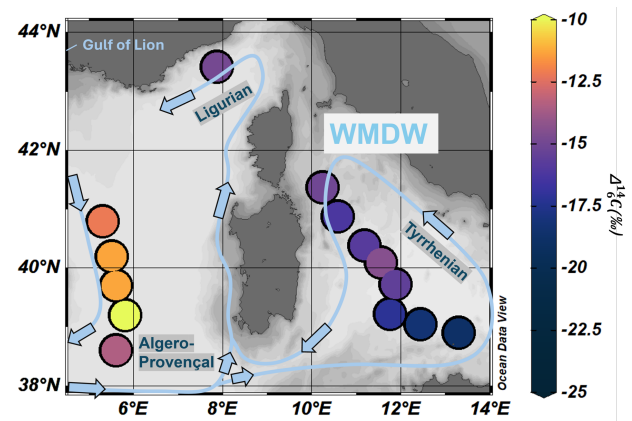


Fig. 1: Isosurface distribution of mean $\Delta^{14}\text{C}$ for Deep Water WMDW from the TAIPro Exp., 2022.

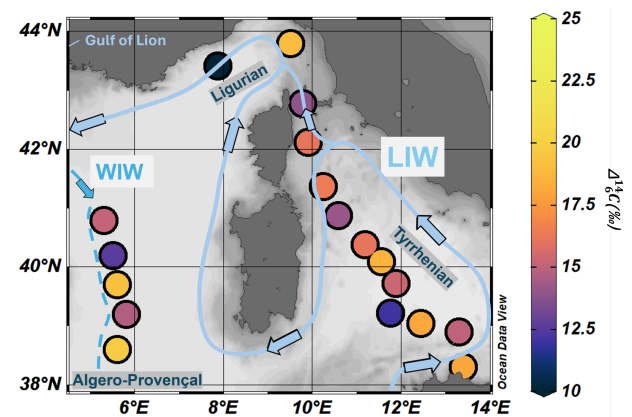


Fig. 2: Isosurface distribution of mean $\Delta^{14}\text{C}$ for Intermediate Waters WIW and LIW from the TAIPro Expedition, 2022.

- [1] M. Leimbacher et al., J. Mar. Sci. Eng. (2024)
- [2] T. Tanhua et al., Earth Syst. Sci. Data (2013)
- [3] N. Pinardi et al., Elsevier (2023)

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^{14}C ANALYSIS OF ASTEROID RYUGU AT ETH ZURICH

Successful measurement of an extraterrestrial sample returned to Earth

T. M. Blattmann^{1,2}, N. Haghipour², M. Bolandini², L. Bröder², T.I. Eglinton², Y. Takano³

Geochemical investigations using radiocarbon (^{14}C) on Earth have provided countless insights into the global carbon cycle. As a cosmogenic nuclide, ^{14}C is produced wherever cosmic rays interact with parent nuclei also beyond Earth, such as on the moon as has been previously investigated [1].

The research target, Ryugu, is a carbonaceous asteroid enriched in light elements such as carbon and nitrogen [2] that was returned with the Hayabusa2 space mission launched by the Japan Aerospace Exploration Agency (JAXA). The Hayabusa2-Initial Analysis team reported the carbon and nitrogen dynamics and the isotopic characteristics of soluble organic matter (SOM) both from surface and potential sub-surface samples [3]. Therefore, incorporating radiocarbon (^{14}C) to elucidate the astrochemical dynamics represents a significant complementary scientific opportunity for understanding surface reaction processes.

In this investigation, online ramped oxidation-accelerator mass spectrometry (ORO-AMS) [4] was used to resolve the ^{14}C isotope composition of carbon-bearing materials across multiple thermal windows in the carbonaceous asteroid Ryugu (Fig. 1). In preparation for measurements on this precious extraterrestrial sample, we tested our method using Murchison meteorite C2 reference material (Fig. 2). Previous thermogravimetric investigation of asteroid Ryugu revealed distinct carbon-bearing phases releasing CO_2 at different temperatures reflecting characteristic thermal reactivities for a range of organic components, carbonates and graphite [5]. This pattern is largely reflected in the Ryugu sample. Across a temperature range from 150-950 °C under the presence of O_2 , we collected CO_2 that evolved from the pristine asteroid using a zeolite double-trap interface and measured ^{14}C isotope composition of CO_2 .

The results of this investigation were presented at the Hayabusa 2025 Symposium hosted by JAXA and will be published in a future article. This study presents the first ^{14}C analysis ever conducted on a sample from an asteroid.

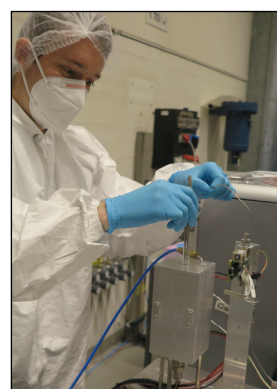


Fig. 1: Inserting asteroid Ryugu sample into the ETH Zurich ORO-AMS system.

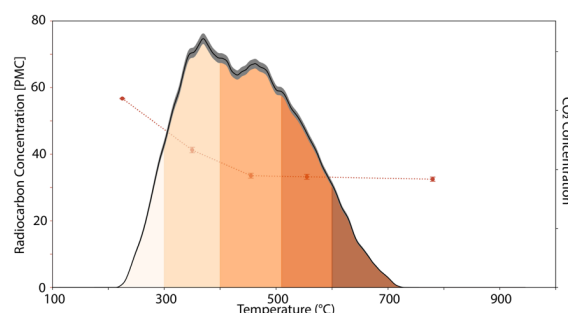


Fig. 2: Thermal degradation pattern and ^{14}C results of the Murchison meteorite reference material as part of the rehearsal study.

- [1] J. A. T. Jull et al., Radiocarbon 42 (2000) 151
- [2] H. Naraoka et al., Sci. 9033 (2023) 379
- [3] Y. Takano et al., Nat. Comm. 15 (2024) 5708
- [4] M. Bolandini et al., Radiocarb. 67 (2025) 471
- [5] T. Yokoyama et al., Sci. 379 (2022) 6634

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ORGANOMINERAL INTERACTIONS IN MARINE SEDIMENTS

Ramped oxidation characterization of organic-rich Miocene shales

E.S.C. Anttila¹, M. Bolandini¹, N. Haghipour

Understanding the mechanisms that drive the preservation and burial of organic carbon is crucial to our ability to model the global carbon cycle. Most organic carbon burial occurs in marginal marine depositional settings [1], and yet the drivers of organic carbon preservation in geologically ancient marginal marine sediments are largely unconstrained.

As part of a larger campaign seeking to understand the role of mineral protection in the long-term preservation of organic carbon in ancient marine sediments, we utilized a ramped oxidation protocol on the ORO instrument at LIP [2] to characterize the bond strength diversity [3] of organic carbon in bulk marine sediment samples.

To explore the role of sedimentation rate in determining the preservation mechanism of organic carbon in marginal marine sediments, a selection of organic-rich shales spanning the full range of modeled sedimentation rates observed within well-characterized sections of the Miocene Monterey Formation [4] were powdered, decarbonated, and combusted over a 5 °C/min. temperature ramped temperature gradient in an oxygen-replete environment.

The resultant thermograms (Fig. 1) indicate that most organic carbon in the Monterey Formation is closely associated with a mineral matrix. However, the relative proportion of higher-temperature CO₂ exsolution, likely sourced from non-mineral-associated organic material, increases with sedimentation rate, suggesting that sedimentation rate variability plays a role in determining the specific preservation mechanism of organic carbon in marginal marine sediments. These data are being combined with a suite of other mineralogical and geochemical observations to develop a model for organic carbon preservation and burial across the diverse

sedimentological conditions present in marginal marine settings.

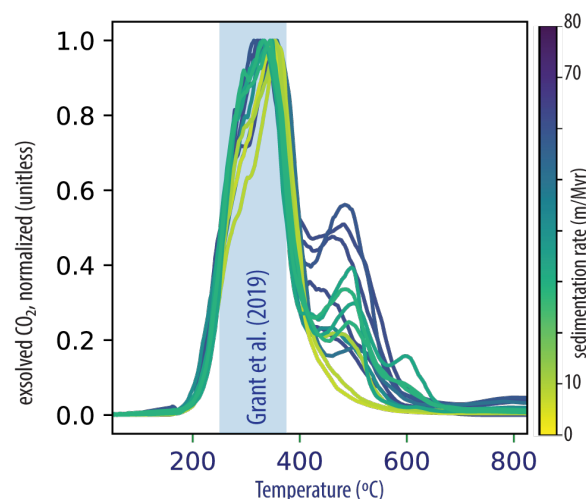


Fig. 1: Thermograms (depicting CO₂ exsolved via oxidation vs. temperature) of bulk sediment samples of the Monterey Formation from El Capitan Beach, CA, normalized by maximum CO₂ value, and shaded by modeled sedimentation rate [4]. The primary CO₂ peak for all samples is consistent with that observed for mineral-bound organics in tropical soils (temperature range indicated by blue bar [5]). The proportion of higher-temperature CO₂ exsolution in a given sample (likely derived from non-mineral-bound organic material) increases with sedimentation rate.

- [1] J. Hedges and R. Keil, Mar. Chem. 49.2-3 (1995) 81
- [2] Bolandini et al., Radiocarbon (2025), 1-16
- [3] Hemingway et al., Nature, 570(7760) (2019) 228
- [4] Anttila et al., EPSL 620 (2023) 118343
- [5] Grant et al., Biogeochem. 144.3 (2019) 291

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OC TRANSIT TIMES OF THREE LAKES IN DR CONGO

Combining fallout radionuclide and radiocarbon measurements

M. Engelhardt¹, N. Etzensperger¹, A. de Clippele², A. Ludjwera³, N. Haghipour¹, J. Six², T.W. Drake², K. van Oost⁴, J. Hemingway¹

The Congo rainforest has one of the highest net primary production rates globally, amounting to approximately $3.5 \text{ kg C m}^{-2} \text{ year}^{-1}$ [1], primarily providing a major sink of atmospheric carbon. Partially, the fixed OC is stored in the aboveground biomass, and partially it is distributed to the soil via litterfall and roots. Lateral fluxes such as erosion further displace the soil organic carbon into rivers and lakes. The time-scale on which this process occurs and how it is influenced by changes in the landscape (e.g. slash-and-burn agriculture), remains widely understudied, though. However, this is of crucial importance when budgeting carbon sources and sinks with wider implications for the global climate. It is therefore important to gain a deeper understanding on OC transit times in lake catchments of the Congo Basin and how it's impacted by on-going and future rainforest contraction.

To provide such information, we aim to determine OC transit times in lake catchments from three lakes in the Kasai Basin, Democratic Republic of Congo, which constitutes the southwest portion of the Congo Basin (Fig. 1).

Fallout radionuclide (FRN) (^{210}Pb , ^{137}Cs) data was used as a proxy for the depositional age of the uppermost 25 cm of sediment at approximately 1-cm resolution (measured at "Commissariat à l'énergie atomique et aux énergies alternatives", Gif-sur-Yvette, France). Sedimentation rates were calculated with the *serac* package based on the ages derived from the ^{210}Pb and ^{137}Cs data [2].

Radiocarbon dating was used to determine the age of the deposited bulk OC to inform on potential pre-aging effects and source contributions. Similarly to the FRN measurements, radiocarbon was measured at approximately 1-cm intervals on the uppermost 25 cm of each core.

We aim to apply different models to calculate the turnover times and back out the possible contributors such as soil OC or autochthonous OC using the radiocarbon bomb-spike as a tracer.

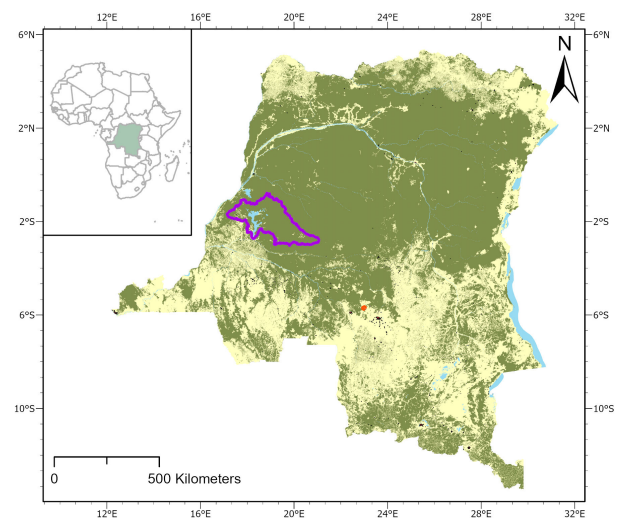


Fig. 1: Map showing the outlines of the lake catchments in purple and orange.

However, further work is needed on data handling and interpretation since current models cannot explain the observed patterns shown by the data. A potential source of complication might reside in the lakes' locations in the Southern Hemisphere, where the bomb-spike and ^{137}Cs signals are less pronounced and understudied [3].

- [1] Xiufang, Z. et al., Ecological Indicators 158 (2024)
- [2] R. Bruel & P. Sabatier, J. Env. Rad. 225 (2020)
- [3] Dicen et al., ESSD (2025)

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⁴Earth and Life Institute, UCLouvain, Belgium

SUNSPOT CYCLES OVER THE FIRST MILLENIUM BCE

Sunspot number reconstruction based on annual ^{14}C measurements

I. Usoskin¹, T. Chatzistergos², S. K. Solanki², N. Krivova², G. Kovaltsov³, N. Brehm, M. Christl, L. Wacker

The Sun exhibits magnetic activity, which arises due to the dynamo action in its interior. Solar magnetic activity has many manifestations, with sunspots at the surface of the Sun being among the most prominent ones. The number of sunspots rises and falls in what is known as the solar cycle, which typically lasts around 11 years but can range from about 8 to 14 years. Visual observations of sunspots exist since the early 1600s and thus they constitute the longest available direct metric of solar activity. Sunspot counts show that on top of the ~ 11 -year solar cycle, the Sun also goes through much longer periods of unusually low activity (like the *Maunder Minimum* in the mid-1600s) or unusually high activity (like in the late 1900s). However, the direct sunspot counts include only these two periods of unusual activity.

Insights about solar activity on longer timescales can be derived from cosmogenic isotopes, e.g. ^{14}C . Cosmogenic isotopes are created in Earth's atmosphere through interactions with cosmic rays. The number of produced isotopes changes depending on how active the Sun is and how strong Earth's magnetic field is. If the Sun is more active, it shields Earth from cosmic rays better, so fewer isotopes get produced. The produced ^{14}C gets stored in trees. By measuring the concentration of ^{14}C , and using independent data about Earth's magnetic field, we can estimate past solar activity going back thousands of years. For a long time, measurements of concentrations of cosmogenic isotopes were of low resolution (decadal values), so individual ~ 11 -year solar cycles could not be resolved in solar activity reconstructions. That changed recently when measurements of ^{14}C with annual resolution became possible.

In this study [1], we used new high-precision ^{14}C data [2] covering the period 1'000–2 BCE to reconstruct sunspot numbers, which resolve

individual sunspot cycles (Fig. 1). The process follows the following 4 steps: Invert the carbon-cycle model to obtain the production rate of ^{14}C ; Account for geomagnetic-field changes; Compute the open solar magnetic flux; Convert this flux into sunspot numbers.

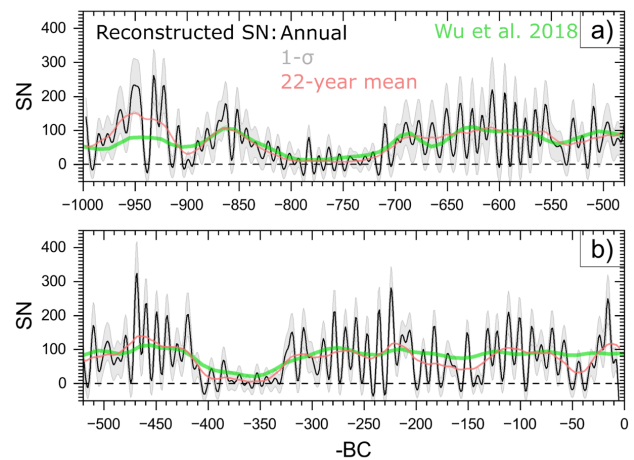


Fig. 1: Reconstructed sunspot numbers (SN) over 1'000–2 BCE.

Over this interval, we identified 93 solar cycles that were previously unresolved, with an average duration of 10.5 years. Over this period, we find two grand minima (807–721 BCE and 403–335 BCE). The long-term variations of our reconstructed sunspot number align closely with previous decadal reconstructions [3] (green in Fig. 1), except for the period around 1'000–920 BCE. Having more annual ^{14}C data would be invaluable for extending annual sunspot-number reconstructions further into the past.

- [1] Usoskin et al., A&A, 698 (2025) A182
- [2] Brehm et al., Nat. Comm., 16 (2025) 406
- [3] Wu et al., A&A, 615 (2018) A93

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ANNUAL DATING FOR ANNUAL REPORT

Using annual calibration curves for high precision dating

N. Brehm^{1,a}, C. L. Pearson¹, M. Christl, L. Wacker

Radiocarbon dating is a cornerstone method for determining the age of organic material, relying on measurements of radiocarbon content calibrated against a reference curve. The accuracy and precision of this method are fundamentally tied to the structure, resolution, and reliability of the calibration curve. Recent advancements have significantly refined portions of the curve through high-resolution measurements of radiocarbon concentrations in individual tree rings. These improvements have revealed previously unresolved fine-scale features, including signatures of the 11-year solar cycle and short-lived solar energetic proton events.

Several studies have demonstrated that the radiocarbon signal produced by individual solar proton events can be used to achieve annual-level dating precision [1, 2]. In contrast, the periodic signal of the 11-year solar cycle alone has not yet been sufficient to independently constrain calendar years. This limitation has largely been due to the insufficient resolution and continuity of earlier calibration datasets.



Fig. 1: Absolutely dated Bristlecone pine sample used for annual dissection.

Here, we demonstrate the potential for highly resolved calibrated dates for a short absolutely dated Bristlecone pine tree-ring sequence (Fig 1). Specifically, we used newly available annual tree-ring data to create an annual radiocarbon curve covering the first millennium BCE [3] to wiggle-match a short Bristlecone pine sequence of known age (Fig. 2). The resulting posterior probability distribution exhibits three extremely narrow peaks separated by approximately 11

years, with the highest peak corresponding to the correct calendar position.

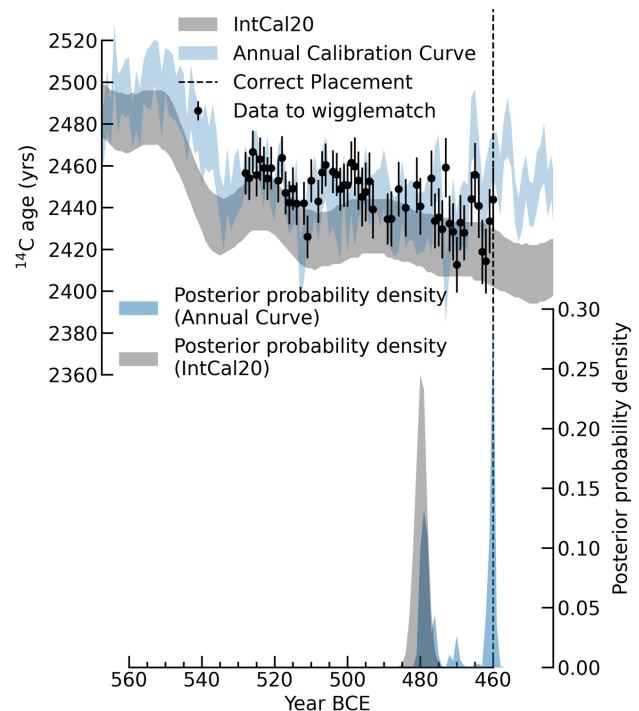


Fig. 2: Bayesian radiocarbon wiggle match of a Bristlecone pine tree ring sequence using an annual calibration curve.

These results highlight the power of annual-resolution calibration data to exploit small solar variations, such as the 11-year solar cycle and its perspective use for annual dating.

- [1] B. Phillipsen et al., *Nature*, 601 (2025) 392
- [2] A. Maczkowski et al., *Nature Comm.* 15 (2024) 462
- [3] N. Brehm et al., *Nature Comm.* 16 (2025) 406

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HOW OLD ARE SAGUARO CACTI?

Dating the growth rate of Saguaros

U. Ramsperger, D. Frank¹, C. L. Pearson¹, P. Brewer¹, M. Bolandini², L. Wacker, and students

In the landscapes surrounding Tucson, Arizona, a Saguaro cactus (*Carnegiea gigantea*) of unknown age was selected for scientific investigation. In Saguaro cacti, spines are only formed at the growing stem or arm tip(s). We systematically sampled spines at various heights along the cactus, reflecting its growth history. The preparation of these spine samples for Accelerator Mass Spectrometry (AMS) radiocarbon measurements, as well as the subsequent AMS analysis, were conducted as part of the student project “ETH Studienwoche 2025”. While the present report focuses on the age determination of the Saguaro cactus, an overview of the student project is available in a separate report [1].



Fig. 1: Photograph of the Saguaro cactus, located in Tucson, Arizona, from which spine samples were collected every 20 whorls. The specific spines used for analysis are marked with blue tags.

The spines were washed with 1 M HCl before they were converted to graphite and measured for ¹⁴C with a MICADAS. Radiocarbon concentrations obtained for the spines from

19 cm (oldest) up to 299 cm (youngest) nicely follow the atmospheric radiocarbon bomb spike.

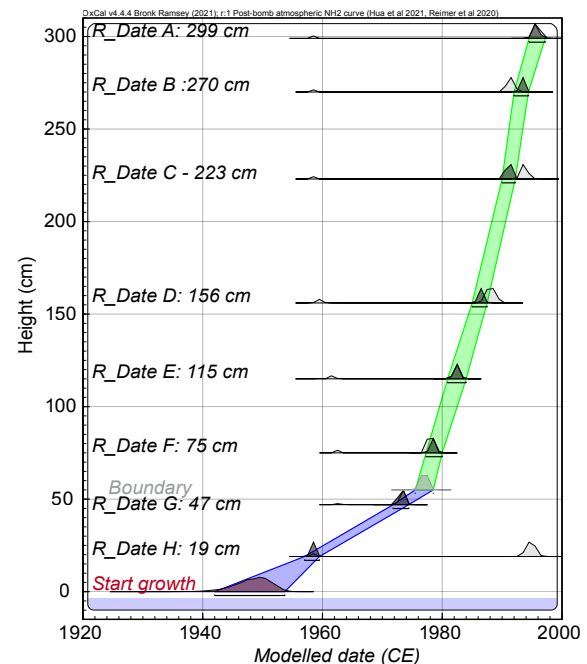


Fig. 2: The dated spines were calibrated with OxCal 4.4 using a p-sequence(1) model with a boundary at 55 cm. The growth rate before 1980 CE was about 2 cm/year and then rose to more than 10 cm/year.

An OxCal age model (p-sequence) was used to determine the growth rate. A relatively slow growth rate of about 2 cm/year was obtained until the cactus reached a height of about 55 cm in the late 1970s. The cactus then grew more than 5 times as fast, averaging more than 10 cm/year. The estimated start of growth of this specific Saguaro was in the late 1940s or about 80 years ago.

[1] Annual report 2025, 90

[2] <https://c14.arch.ox.ac.uk/oxcal.html>

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CANADIAN ARCTIC COASTAL BLUFFS: ORO- ^{14}C INSIGHTS

Persistent radiocarbon age offset despite similar thermal structure

M. Bolandini¹, J. D. Hemingway¹, N. Haghipour¹, F. Van Crimpen², J. E. Vonk³, T. I. Eglinton¹, L. Bröder¹

Arctic warming is accelerating coastal erosion across ice-rich permafrost terrains, mobilising previously frozen organic matter (OM) into nearshore environments [1]. Ice-rich bluff coasts are characterised by rapid retreat—commonly several metres per year and locally exceeding 10 m yr^{-1} —and the formation of offshore deposition zones at shallow water depths, where eroded material accumulates following coastal transport and hydrodynamic redistribution [2].

In contrast to recently thawed debris in terrestrial settings, these nearshore sediments are additionally influenced by marine processes, including hydrodynamic sorting and potential inputs of marine-derived OM. Whether sediments accumulating in these offshore deposition zones retain the OM signature of the parental bluff material or instead represent dynamically mixed carbon pools remains unresolved.

To address this, we applied Online Ramped Oxidation coupled to Accelerator Mass Spectrometry (ORO-AMS) to characterise thermally resolved radiocarbon signatures of parental material (PM) and deposition-zone (DZ) sediments. Samples were analysed following [3] using a linear temperature ramp from $150\text{--}600\text{ }^{\circ}\text{C}$, with radiocarbon (F^{14}C) measured across discrete thermal windows and CO_2 evolution (“thermograms”) normalised for comparison.

Fig. 1 shows a representative PM–DZ pair. Their thermograms (PM: solid green; DZ: black dotted) nearly overlap, indicating similar thermal stability, yet their radiocarbon signatures diverge strongly. Across the main oxidation window ($\sim 400\text{--}550\text{ }^{\circ}\text{C}$), PM (green upward triangles) exhibits depleted F^{14}C values ($\sim 0.05\text{--}0.15$), whereas DZ sediments (black downward triangles) are substantially younger ($\sim 0.45\text{--}0.60$),

a pattern consistent across additional pairs (data not shown).

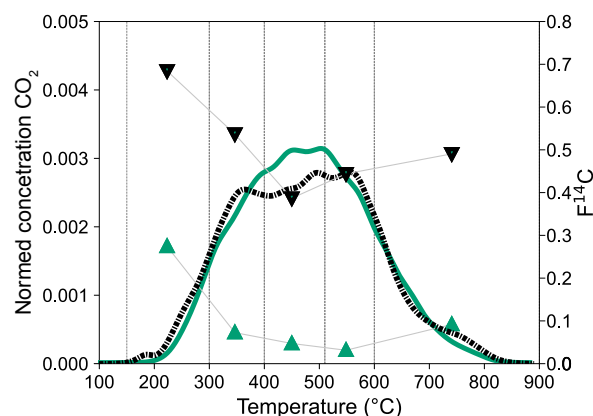


Fig. 1: Parental material (PM; solid green line, green upward triangles for F^{14}C) and deposition-zone sediments (DZ; black dotted line, black downward triangles for F^{14}C). Bluff of ice-rich coastal type with thermograms and thermally resolved F^{14}C measurements.

This persistent age offset despite comparable thermal structure indicates that bluff material is not simply accumulated but reworked within the deposition zone. Hydrodynamic sorting, selective loss of terrigenous OM, and incorporation of marine-derived carbon likely drive this decoupling between energetic structure and radiocarbon age, highlighting shallow coastal deposition as a dynamic processing environment for permafrost carbon.

[1] J.E. Vonk et al., GRL (2012) 39

[2] F. Van Crimpen et al., GRL (2024) 51.16

[3] M. Bolandini et al., Radiocarb. 67 (2025) 471

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CHEMICAL WEATHERING PATHWAYS IN RIVER SYSTEMS

Sensitivity of riverine DI^{14}C and DI^{13}C

S. Pradhan^{1,2}, N. Haghipour¹, I.S. Sen², J. D. Hemingway¹

Drainages in active mountain belts export dissolved inorganic carbon (DIC) generated during rock weathering, where the CO_2 involved in the weathering reaction can be derived from the atmosphere, soil organic carbon (SOC) respiration or from petrogenic sources (carbonate weathering or metamorphic decarbonation) [1]. Paired $\delta^{13}\text{C}_{\text{DIC}}$ and $F^{14}\text{C}_{\text{DIC}}$ measurements in DIC are a promising tool to unmix DIC sources in aquatic environments, if the source signature is well-constrained and riverine DIC isotopic signature is not subsequently modified.

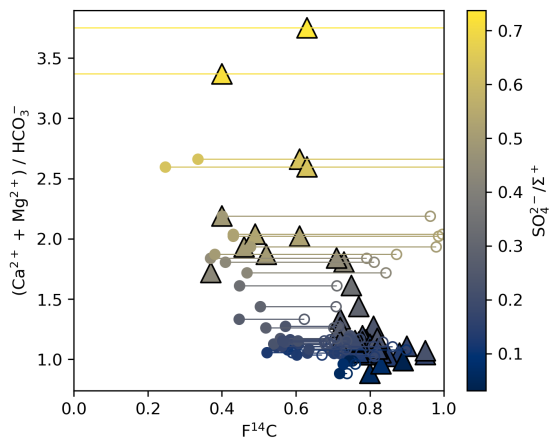


Fig. 1: $F^{14}\text{C}$ vs $\text{Ca}^{2+} + \text{Mg}^{2+} / \text{HCO}_3^-$ values in Upper Ganges color-coded with respect to SO_4^{2-} / E^+ , where E^+ indicates the sum of base cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+). Higher SO_4^{2-} / E^+ indicates greater contribution of pyrite oxidation to river chemistry. Open and closed circles indicate modelled closed system and open system $F^{14}\text{C}_{\text{DIC}}$ values, constrained using inversion of river chemistry.

While the effects of in-stream processing on riverine DIC isotopes have received considerable attention, uncertainties in the isotopic composition of weathering-derived DIC at the source across different weathering pathways

remain a critical limitation. To address this, we make new major ion, $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$ measurements of DIC from the headwaters of the Ganga River in the Himalaya. We model predicted $F^{14}\text{C}_{\text{DIC}}$ values in closed and open-system scenarios using an inversion of the major ion chemistry. For instance, pyrite-oxidation driven carbonate weathering can result in radiocarbon-dead DIC production in rivers ($F^{14}\text{C}_{\text{DIC}} = 0$) (closed system). Alternatively, pyrite oxidation-driven carbonate weathering can result in degassing of CO_2 with the release of base cations being charge-balanced by dissolved SO_4^{2-} (open system) [2]. We find that measured $F^{14}\text{C}_{\text{DIC}}$ in Himalayan rivers can be described as mixing between closed and open system scenarios of pyrite oxidation-derived carbonate weathering, with no further contributions of atmospheric or soil-derived CO_2 required (Fig. 1). This is unlikely since silicate and carbonate weathering by carbonic acid (H_2CO_3) would involve atmospheric or soil-derived CO_2 ($F^{14}\text{C} \sim 1$). Nevertheless, our results demonstrate that DIC unmixing is highly sensitive to assumptions about weathering pathways and emphasize the need to explicitly account for petrogenic carbon inputs in tectonically active mountain belts.

[1] J.F. Dean et al., Nature 642 (2025), 105

[2] M.A. Torres et al., Nature 507 (2014), 346

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LANDSCAPE CONTROL IN THE HIMALAYAS

Pyrite oxidation and silicate weathering

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Erosive landscapes in active mountain belts such as the Himalayas stimulate the chemical weathering of pyrite, a trace mineral commonly hosted in metasedimentary and magmatic rocks. Riverine SO_4^{2-} concentrations are used to quantify pyrite oxidation and associated carbonate weathering, after accounting for evaporite weathering and atmospheric inputs [1]. The relative contributions of pyrite and evaporite sources are typically distinguished using sulfate isotopes ($\delta^{18}\text{O}_{\text{SO}_4}$ and $\delta^{34}\text{S}_{\text{SO}_4}$), assuming that they have not been modified by microbial sulfate reduction (MSR) by anaerobic bacteria [2, 3].

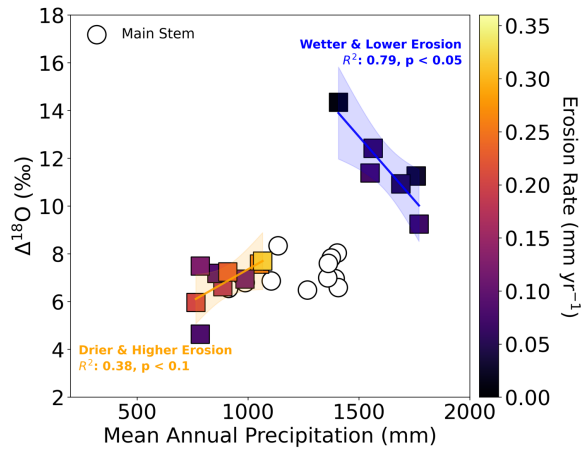


Fig. 1: Catchment-averaged Mean Annual Precipitation (MAP) vs. $\Delta^{18}\text{O}$ in the Upper Ganges, color-coded by ^{10}Be -derived erosion rates, showing the differential behavior of wetter, lower-erosion catchments and drier, higher-erosion catchments.

Previous studies have attributed elevated $\Delta^{18}\text{O}$ ($\Delta^{18}\text{O} = (\delta^{18}\text{O}_{\text{SO}_4} - \delta^{18}\text{O}_{\text{H}_2\text{O}})$) in Himalayan catchments variably to evaporite weathering and MSR since the mechanisms governing the interplay between pyrite oxidation and MSR in terrestrial environments remain unresolved. To address this, we integrate $\delta^{18}\text{O}_{\text{SO}_4}$ and $\delta^{34}\text{S}_{\text{SO}_4}$

measurements in the headwaters of the Ganga in the Himalayas with ^{10}Be -derived erosion rates, to understand the role of landscape properties in controlling MSR. Our results indicate that MSR overprinting of pyrite oxidation's isotopic signal is ubiquitous in the Ganga headwaters and particularly prominent in low-erosion catchments with relatively lower MAP, which maximizes fluid residence times (Fig. 1). Dissolved SO_4^{2-} quantitatively sourced from pyrite oxidation, displays a wide range of sulfate isotopic values, which we attribute to secondary MSR in soils and aquifers. Therefore, landscape-mediated MSR is as important as lithological variability in determining the isotopic composition of terrestrially derived dissolved SO_4^{2-} .

- [1] P.C. Kemeny et al., *Geochim. Cosmochim. Acta*, 294 (2021), 43
- [2] J.D. Hemingway et al., *Proc. Natl. Acad. Sci. U.S.A.*, 117 (2020), 7650
- [3] A.V. Turchyn et al., *Earth Planet. Sci. Lett.*, 374 (2013), 36

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TRACING EROSION RATES IN SEDIMENTS USING ^{14}C

Footprints of the iron age in the Three-Lakes Region

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The Three-Lakes Region (Swiss Plateau) was shaped by Lateglacial to early Holocene deglaciation and related sedimentary processes. Under humid Holocene conditions, the Three-Lakes Region lowland developed extensive peatlands and several small lakes that are in the meantime sedimented. Multi-proxy geochemical approaches are widely used to determine sediment provenance, assess weathering intensity and detect human impact. Around 4'000 yr ago and later, particularly during the Iron Age, Central Europe underwent major settlement expansion and agricultural intensification. Deforestation, cultivation and settlement altered soil formation and local geomorphology, leaving persistent environmental signals. Of particular interest is the Early Iron Age (Hallstatt period (800 - 450 yr BCE)), as the Three-Lakes Region represents a key area in terms of burial patterns, agriculture and communication for the northern Alpine area, yet its archaeological potential is insufficiently explored. In the Three Lakes Region, the Early Iron Age is characterised by numerous richly furnished burial mounds, while only a few traces of settlements have been identified (Fig. 1).

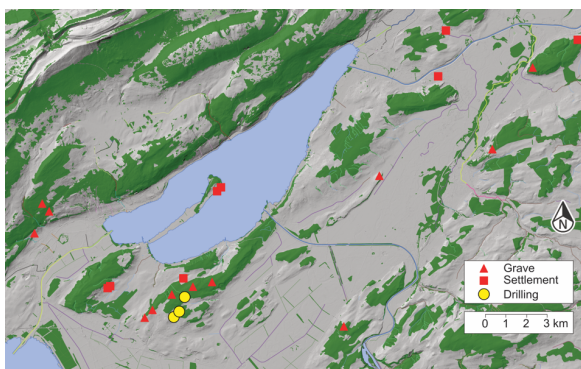


Fig. 1: Graves and settlements in the Three Lakes Region that were assigned to the Iron Age [1].

Three sediment cores were drilled in a small plain near large grave mounds that are assigned to the Hallstatt period [1]. Samples include former peatland/lake and colluvial profiles integrating natural and human-induced signals.

The results of radiocarbon dating enabled the calculation of sedimentation rates at these sites over time. A clear natural signal at the transition from the Pleistocene (end of the last glacial-cold phase) to the Holocene (warm period) is clearly discernible. The abrupt climate changes gave rise to strongly increased geodynamics and surface processes. An additional peak due to high erosion rates and subsequent sedimentation occurs at the beginning of the Hallstatt period (Fig. 2), and, thus, reflects a clear anthropogenic signal [1]. In a next step, the influence of the Iron Age on biogeochemistry will be determined based on the obtained age constraints.

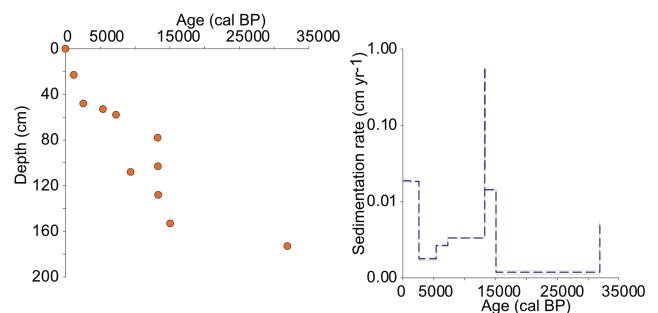


Fig. 2: Age-depth (^{14}C data) trend for one of the drilling sites and derived sedimentation rates of a former lake as a function of time.

[1] T.L. Geitlinger et al., Collection AFEAF 171 (2022) 127

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BACKFILLING VS DEGRADING ORGANIC SOILS

Susceptibility of organic matter to decay

M. Egli¹, C. McMackin¹, I. Hajdas

Over the past 100 to 150 years, soils in the Three-Lakes Region in Switzerland have undergone severe subsidence due to the oxidation of peat and organic matter of strongly organic soils [1]. Due to soil fertility loss, measures have been taken for several decades, such as backfilling (Fig. 1). A main question is if backfilling of soils reduces the decomposition of the buried organic soil or whether decomposition continues unabated. Therefore, we investigated the form and quantity in which organic matter occurs and how stable this organic matter is in the original soil and in the backfilled material. Three sites in the Three-Lakes Region were selected. At all sites, backfilled soils could be directly compared with adjacent soils in their original state.



Fig. 1: Profile of an optimally prepared backfilling overlaying an organic soil beneath.

A physical fractionation into particle size classes of $<63\ \mu\text{m}$ and $>63\ \mu\text{m}$ was carried out, together with radiocarbon dating. In addition, CO_2 measurements (soil respiration) were done at all sites in summer and winter, and both CO_2 fluxes and the age of the respired carbon ($^{14}\text{CO}_2$) were determined. The backfilling contained less organic carbon than the original soils. The undisturbed soils were more hydrophobic and contained markedly less altered and had, thus, less mature organic matter than the backfilled soils. Soil organic matter of the backfilled soils

was more transformed (“more mature”) and clearly less hydrophobic. Soil backfilling not only alters the amount of organic matter in the soil, but also fundamentally changes its chemical composition and degradability. The age of organic matter in the $>63\ \mu\text{m}$ (coarse) fraction was slightly (not significantly) higher than in the fine fraction (Fig. 2). In the artificial soils, a larger proportion of organic carbon was present in the fine fraction ($<63\ \mu\text{m}$). This organic carbon is better protected against decomposition due to stronger binding to the mineral matrix. The ages of CO_2 emissions from the backfilled sites were distinctly younger ($\Delta^{14}\text{C}$: $-86\ \text{‰}$) than those from the undisturbed soils ($\Delta^{14}\text{C}$: $-152\ \text{‰}$). Organic matter in the undisturbed soils is much less protected, due to the respiration of very old carbon. Soil backfilling, thus, can have positive effects for ecological aspects—provided that suitable material is used and that minimum standards for subsequent land management are respected.

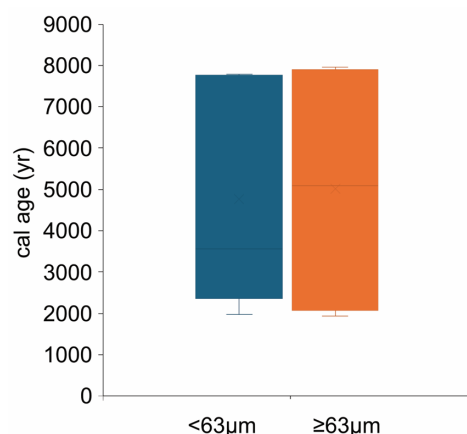


Fig. 2: Distribution of calibrated radiocarbon ages in the soil fractions $\leq 63\ \mu\text{m}$ and $>63\ \mu\text{m}$.

[1] M. Rösli and M. Egli, Swiss Journal of Geosciences 117 (2024) 9

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RADIOCARBON INVENTORIES OF SWITZERLAND

Presenting the world's first national ^{14}C database

A. S. Brunmayr^{1,2}, D. Geissbühler^{3,4}, T. Laemmel³, T. M. Y. Rhyner^{1,5}, B. V. A. Mittelbach^{1,6}, M. E. White^{1,7}, M. Moreno Duborgel^{1,8}, L. I. Minich^{1,8}, S. Paradis⁹, N. Haghipour¹, L. Wacker, S. Szidat³, F. Hagedorn⁸, T. I. Eglinton¹, H. D. Graven²

The Radiocarbon Inventories of Switzerland database (RICH) is the first comprehensive national ^{14}C database. Unlike the typical field-specific databases or fragmented repositories for environmental ^{14}C data, RICH provides a unified framework for metadata and data management to integrate ^{14}C data across all major carbon reservoirs and fluxes in Switzerland's diverse climates and landscapes: from the atmosphere (CO_2 , CH_4) and terrestrial carbon (leaves, wood, roots, soils and soil respiration) to aquatic systems (groundwater, rivers, lakes, sediments), as well as anthropogenic sources (industrial CO_2 emissions, ^{14}C from nuclear power plants).

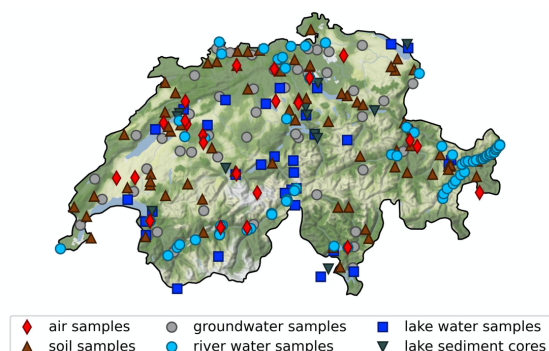


Fig. 1: RICH covers all Swiss ecoregions.

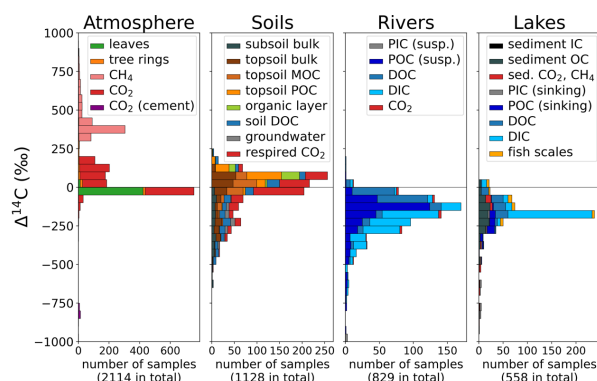


Fig. 2: RICH contains more than 4'000 ^{14}C concentration and flux measurements from all major carbon reservoirs in Switzerland.

The RICH database already comprises a vast dataset of more than 4'000 ^{14}C measurements alongside extensive data on stable isotopes, major element concentrations, and other key parameters. The data of RICH can be queried and downloaded through the map interface at rich.ethz.ch or through dedicated Python and R packages.

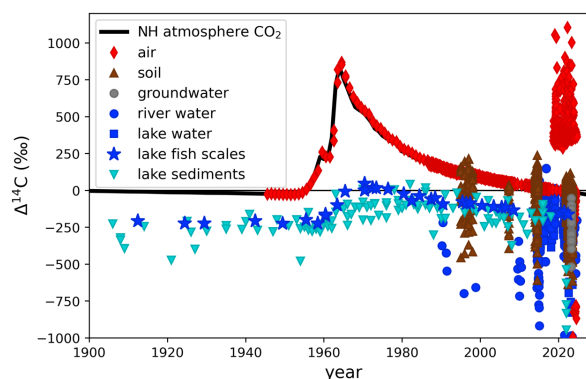


Fig. 3: Most samples are from the past 10 years, but archival samples capture the bomb- ^{14}C peak.

By providing a comprehensive, unified, and accessible national database with RICH, we aim to promote multidisciplinary applications of ^{14}C in environmental sciences and facilitate research on cross-ecosystem interactions and air–land–water connections in the terrestrial carbon cycle.

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⁶Geological and Planetary Sciences, Caltech, USA

⁷Earth, Ocean and Atmospheric Sciences, Univ. of British Columbia, Canada

⁸Forest Soils and Biogeochemistry, WSL

⁹Environmental Systems Sciences, ETH Zurich

THE IMPORTANCE OF PROCESS BLANKS IN CSRA

Time and cost-effective method optimization

L. Rumpf^{1,2}, N. Haghipour, L. Hendriks¹

Within the development of compound-specific radiocarbon analysis (CSRA) for natural organic dyes and pigments, targeted carbon masses fall below the 50 µg ranges hence requiring an uncompromising approach to exogenous carbon contamination control. The latter (C_{Ex}) is caused by multiple sources introduced at different stages of workflow and covers the sum of the sample matrix (C_{Matrix}), the chemical extraction ($C_{Chemistry}$), the chromatographic separation (C_{Chrom}) and combustion and ^{14}C analysis (C_{EA-AMS}) [1].

The quantification of this overall extraneous carbon contamination may be evaluated by monitoring of processing blanks (direct approach) or through constant contamination modelling using standards of known complementary ^{14}C content (indirect approach). Here, special attention was given to the characterization of process blanks as displayed in Fig. 1. The systematic evaluation of contamination sources, ranging from packaging material used for online EA-AMS analysis, chromatographic parameters (column, acid phase modifier) and chemical extraction regarding different substrates proved essential to minimize C_{Ex} [2]. By refining these parameters, we substantially lowered the extraneous carbon contribution to an average of 3 ± 1 µg C, in agreement with the values obtained in a pilot study [1]. The dominant exogenous carbon contribution arises from the chromatographic step, whereas extraction procedures contribute minimally. This work underlines the necessity of detailed blank characterization for achieving accurate and reproducible ^{14}C results in emerging CSRA applications to heritage materials. By systematically monitoring processing blanks during method development, substantial time and resources can be saved. This approach enables rapid identification of contamination sources. As a result, method optimization can be

guided more effectively, minimizing both analytical time and AMS-related costs. Only when process blanks reach a minimal threshold is it worth carrying the indirect approach.

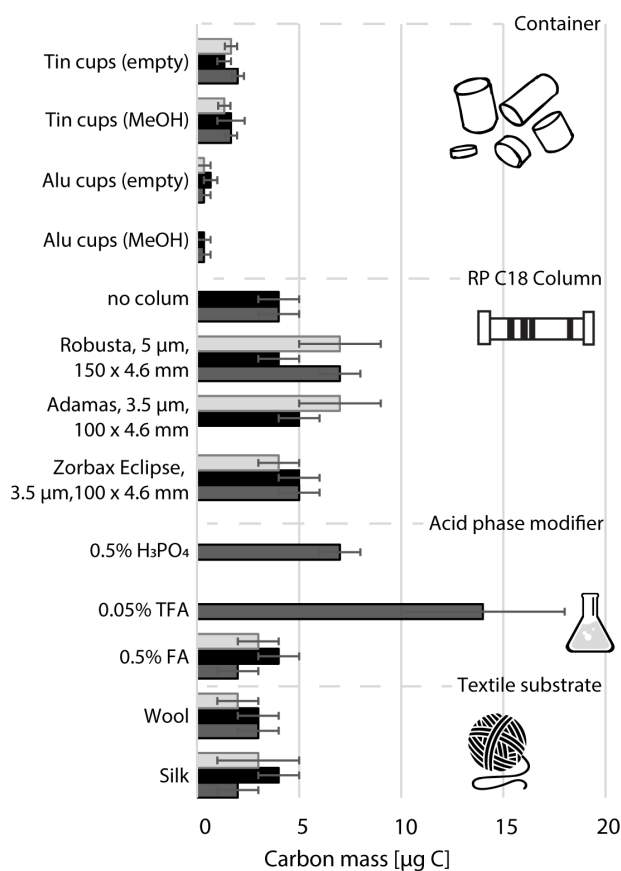


Fig. 1: Measured exogenous carbon introduced at different stages of the CSRA workflow. Adapted from Rumpf et al. *Chimia* (2025), licensed under CC BY 4.0. [2]

[1] L. Hendriks et al., *Chimia* 77 (2023) 792

[2] L. Rumpf et al., *Chimia* 79 (2025) 784

¹HEIA, HESSO, Fribourg

²DCBP, Univ. Bern

COSMOGENIC NUCLIDES



Landslide deposits in Buthan.

Solar storms over the Holocene period

Filling the solar storm gap

Mid-Pleistocene transition and foreland incision

Early Holocene failure of the Sierre landslide

Long term erosion rates in the Congo Basin

Long-term peat thickness from ^{26}Al and ^{10}Be

SOLAR STORMS OVER THE HOLOCENE PERIOD

Towards a complete assessment of larger solar storms

B. Bacho¹, E. Ditlefsen¹, A. Hansson¹, A. Nilsson¹, P. Gautschi, C. Vockenhuber, M. Christl, L. Wacker, J. Beer², R. Muscheler¹

In addition to the indirect effects of solar and geomagnetic shielding on the flux of galactic cosmic rays reaching Earth, there are occasional, albeit rare, solar energetic particle (SEP) events that can leave detectable anomalies in tree-ring ^{14}C and ice core ^{10}Be and ^{36}Cl records. Currently, we lack annual ^{14}C and high-resolution ^{10}Be and ^{36}Cl data over the complete Holocene period, so we cannot conclude that all major solar storms during this time have been detected. However, a complete understanding of these potentially devastating events is crucial for assessing their recurrence rates and the connected risks for modern society.

In the ERC project *PastSolarStorms* we aim to generate high-resolution ^{10}Be and ^{36}Cl records using samples from the East Greenland Ice Core Project (EGRIP). In connection to this project we already collected more than 10'000 ^{10}Be and ^{36}Cl samples [e.g. 1] over the Holocene period to achieve a higher temporal resolution compared to already existing ice core data. Since sample preparation and measurement are extremely time consuming, we will begin with time intervals of interest for possible SEP events inferred from low-resolution data from other ice cores, such as GRIP, or ^{14}C data from tree rings.

Fig. 1 shows an example with normalized ^{10}Be and ^{36}Cl data from the GRIP ice core. The data shows a doubling in ^{10}Be concentration over 2 years (marked by red-shaded area) hinting at an exceptional event, while no counterpart is visible in the ^{36}Cl record. Higher-resolution ^{10}Be and ^{36}Cl measurements from the EGRIP ice core should reveal if the GRIP ^{10}Be peak is due to a SEP event, in which case the absence of a ^{36}Cl peak could be explained by the lower temporal resolution, or if it is connected to a volcanic eruption, that have been shown to occasionally cause enhanced ^{10}Be deposition in Greenland [2].

Furthermore, we aim to disentangle the solar cycle, as well as geomagnetic and climate influences on the radionuclide data, and detect all major solar storms during the Holocene period by following a multi-radionuclide approach and by developing a Bayesian model that takes into account all known effects on radionuclide data in ice cores.

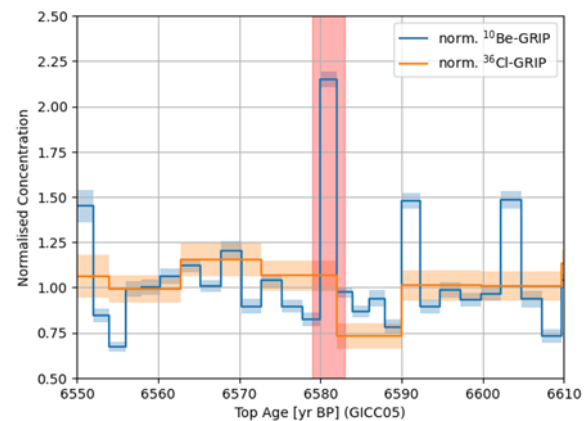


Fig. 1: ^{10}Be and ^{36}Cl from the GRIP ice core in about 2 year and 8 year resolution normalised to their average concentration (excluding the peak). The blue and orange shaded areas mark the measurement uncertainties. The ages are shown in years before present (i.e. before 1950) based on the GICC05 age scale [3].

- [1] Paleari et al., *Clim. Past* 19 (2023) 2409
- [2] Zheng et al., *GRL* in press
- [3] Vinther et al., *JGR* 111 (2006) D06102

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FILLING THE SOLAR STORM GAP

Medium-sized solar storms over the past millennia

E. Ditlefsen¹, B. Bacho¹, A. Hansson¹, A. Nilsson¹, P. Gautschi, C. Vockenhuber, M. Christl, L. Wacker, R. Muscheler¹

The present record of solar storms is based on either direct observation (largely from neutron monitoring stations), or cosmogenic radionuclides, such as ¹⁴C from tree rings, or ¹⁰Be and ³⁶Cl in ice cores. The former only covers recent events while the latter is biased toward bigger events. This leaves intermediate solar storms largely unexplored.

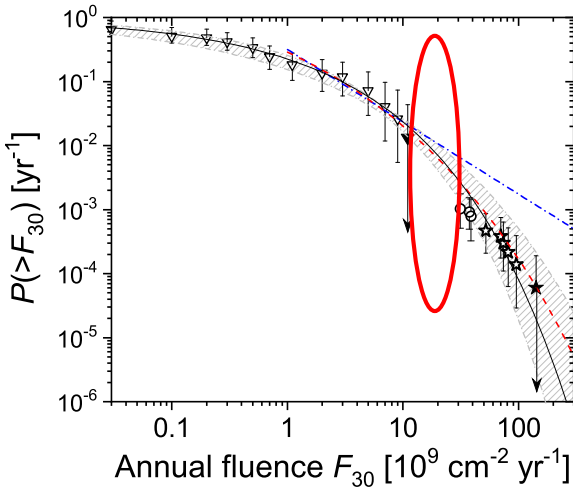


Fig. 1: Occurrence probability density function for solar particle events for a given annual fluence (modified from [1] and references therein). The red circle indicates the presently completely unexplored range of solar storms exceeding observed fluences but having significantly smaller fluences than paleoevents.

Both deposition and atmospheric transport of radionuclides in ice cores exhibit seasonality [2]. When sampling ice at near yearly resolution, this seasonality may appear as noise. To limit the influence of seasonality, we plan to use the annual markers identified in the EGRIP ice core in the process of making the GICC21 ice core chronology [3]. These are based on several seasonally varying aerosol records.

A further concern is the 11-year solar cycle. Solar storms are easier to detect near solar minima, when radionuclide production is highest. We plan to use Bayesian methods to model the 11-year cycle, to better resolve solar storms.

Lastly, ³⁶Cl has usually been measured at lower temporal resolution than ¹⁰Be, due to lower abundance and the difficulty of separating it from ³⁶S. Recent AMS improvements and using larger sample sizes should allow for annual ³⁶Cl measurements as well. Not only will this make searching for solar storms easier, as ³⁶Cl production is more sensitive to the energies of solar energetic particles, it will also make it easier to investigate the energy spectrum of the solar energetic particle event through comparison with ¹⁰Be data.

We plan to investigate the last 3'000 years, bridging the gap between the already existing EGRIP samples and the present. Initially, we have gotten access to ice samples from the EGRIP ice core covering the years AD 990 to 1300. This covers periods of both high and low solar activity as well as the known solar storm in AD 993 and multiple proposed solar storms based on high-resolution and high-precision ¹⁴C data [e.g. 4].

- [1] Cliver et al., Liv. Rev. Sol. Phys. 19:2 (2022)
- [2] Zheng et al., EPSL 541 (2020) 116273
- [3] Sinnl et al., Clim. Past 18 (2022) 1125
- [4] Brehm et al., NGE0 14 (2021) 10

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MID-PLEISTOCENE TRANSITION AND FORELAND INCISION

Deckenschotter gravels show faster incision between 1 Ma and 500 ka

C. Dieleman¹, M. Christl, C. Vockenhuber, P. Gautschi, F. Schlunegger¹, N. Akçar¹

Glaciations can reshape landscapes, but it is often difficult to determine when and how fast rivers and valleys deepened as climate oscillated through glacial–interglacial cycles. In this study, we use the Swiss northern Alpine Foreland as a natural archive to reconstruct landscape evolution during the Early to Middle Pleistocene, with a focus on how relief (the height difference between valleys and surrounding terrain) developed through time [1].

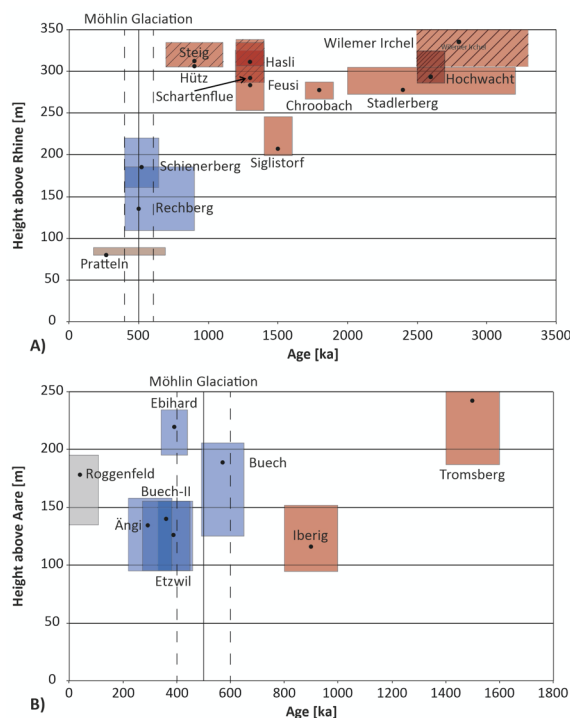


Fig. 1: Chronology of the Early and Middle Pleistocene gravel deposits in the Swiss northern Alpine Foreland plotted against their height above the Rhine (A) and the Aare rivers (B). The Deckenschotter deposits are indicated in reddish brown. Deposits related to the MEG are shown in blue, the one to the HT in light brown, and the one from the Roggenfeld site in gray [1].

We examined glaciofluvial gravel deposits at seven sites in the Mandach and Lake Constance

regions. Clast petrography shows that gravels in the Mandach area were supplied by multiple Alpine glacier systems (Aare, Reuss, Linth, and Rhaetian), whereas the Schienerberg sediments (Lake Constance region) were transported mainly by the Rhaetian glacier. To establish an absolute time framework, we applied cosmogenic $^{26}\text{Al}/^{10}\text{Be}$ isochron-burial dating to these deposits [1].

The burial chronology (Fig. 1) indicates Middle Pleistocene deposition, consistent with gravels formed around the Möhlin glaciation (ca. 500 ka). Because these deposits sit at different elevations above today's rivers, they also record changes in incision over time. The ages imply that bedrock incision accelerated from ca. 100 m/Myr before 1 Ma to ca. 200 m/Myr between 1 Ma and ca. 500 ka and then slowed again to ca. 100 m/Myr afterwards. The timing suggests that this relief increase was likely linked to the Mid-Pleistocene Transition, when glacial cycles shifted to longer, more intense rhythms—leaving a measurable imprint on foreland erosion and river base level.

Overall, this study provides a process-based timeline for foreland relief growth and shows that the shift to longer, more intense glacial–interglacial cycles around about 1 Ma left a measurable imprint on erosion and river incision. By combining sediment provenance with isochron-burial dating with $^{26}\text{Al}/^{10}\text{Be}$, we also provide a transferable workflow for extracting quantitative incision histories from glaciofluvial gravel archives elsewhere.

[1] C. Dieleman et al., *Geomorph.* 492 (2026) 110060

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EARLY HOLOCENE FAILURE OF THE SIERRE LANDSLIDE

Timing, triggers, and runout from cosmogenic ^{36}Cl dating and modelling

A. Rubin¹, N. Akçar¹, S. Ivy-Ochs², M. Binaghi¹, J. Aaron², C. Vockenhuber, C. Schlüchter¹

Large rock avalanches in Alpine valleys can have long-lasting impacts on landscape evolution and pose major hazards to settlements and infrastructure. The Sierre landslide in the Rhône Valley (Valais) is among the largest Alpine landslides, extending ca. 12 km and forming a prominent “tuma” landscape, yet its age and triggering context remain poorly constrained [1].

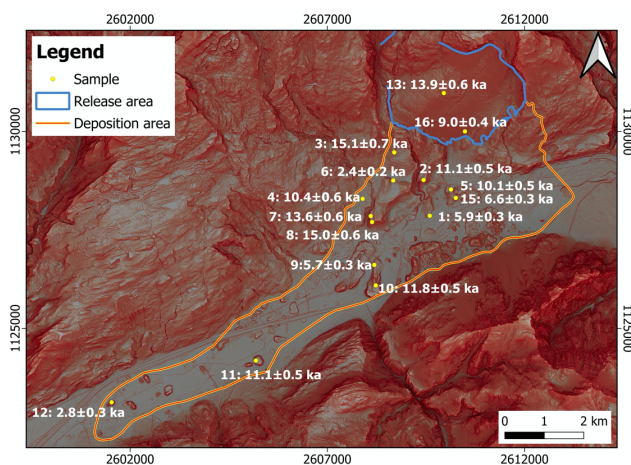


Fig. 1: Red Relief Image Map (RRIM) of the Sierre landslide showing sample locations and erosion-corrected ^{36}Cl exposure ages (10 mm/ka erosion). Errors show external uncertainties [1].

In this study, we combined detailed geomorphological mapping with cosmogenic in-situ ^{36}Cl surface-exposure dating and dynamic runout modelling to determine when, how, and why the Sierre rock avalanche occurred. Fifteen samples (13 boulders on the deposit and 2 from the detachment surface) were collected for ^{36}Cl analysis, and the pre-failure topography was reconstructed to enable physically based simulations using DAN3D [1].

The cosmogenic ^{36}Cl chronology indicates that the Sierre landslide occurred at 10.7 ± 1.5 ka, i.e., during the transition from the Younger Dryas to the Early Holocene [1]. The failure of the Sierre landslide mobilized ca. 1.4 km^3 of rock, which

bulked up to ca. 1.7 km^3 during runout. Our dynamic modelling reproduces the long runout and indicates rapid motion (up to about 138 m/s) and short travel times (order minutes, about 10 minutes), with best fits requiring very low basal friction in valley-floor sediments (Coulomb friction coefficient ca. 0.0125–0.02) [1].

The timing of the collapse (10.7 ± 1.5 ka), together with field observations and model results, points to a slope failure that occurred in a largely glacier-free valley, rather than being directly triggered by glacier interaction. Earlier ideas emphasized the presence and role of a glacier, but our results instead suggest that the failure was mainly controlled by the pre-failure slope geometry and the mechanical behavior of the rock and debris. The runout simulations further indicate that the moving mass likely travelled over soft valley-floor sediments with very low friction, allowing it to spread unusually far. More generally, our study highlights that valley-floor conditions can be as important as the initial slope failure in controlling how far a large rock avalanche travels—because runout depends strongly on the substrate the mass moves over, not only on the source slope.

Overall, our study revises the interpretation of the Sierre event by providing a robust age and a process-based explanation for one of the Alps’ largest rock avalanches. These results improve our understanding of how large Alpine slopes can fail after glacier retreat and offer useful insights for assessing landslide hazards in narrow Alpine valleys that are highly urbanized and popular tourist destinations.

[1] A. Rubin et al., Swiss Jour. Geosci. 119 (2026)

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LONG TERM EROSION RATES IN THE CONGO BASIN

River bank sediment dating with in situ ^{10}Be

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Soil erosion is an important process that can modulate atmospheric CO_2 levels. It acts as a carbon source when the remobilization of soil organic carbon (OC) results in extensive degradation during lateral transport. Meanwhile, the subsequent burial and preservation of soil OC in floodplains plays the role of a carbon sink.



Fig. 1: Field sampling of bank sediments in the Kasai River Basin.

In this work, we attempt to elucidate the mechanistic controls on the fate of eroded soil OC and quantify associated fluxes across gradients of climate, vegetation cover, and weathering intensity in the Kasai River Basin (DR Congo). Erosion rates – constrained by *in situ* produced cosmogenic ^{10}Be in river bank sediments (Fig. 1) – provide “natural” background denudation rates of the catchment. Due to the long integration timescale ($\sim 10^2$ to 10^5 yr), ^{10}Be -derived denudation rates can be used as a baseline to quantify anthropogenically accelerated erosion with river load gauging and satellite derived estimates (~ 10 to 10^2 yr). Spatial variations of erosion rates within the basin may also provide useful information on sedimentation dynamics (e.g., sediment storage in floodplains). In addition, clay mineralogy of river suspended sediments are constrained by

quantitative XRD analyses, providing insights into mineral-organic carbon interactions and the effect of stabilization during lateral transfer.

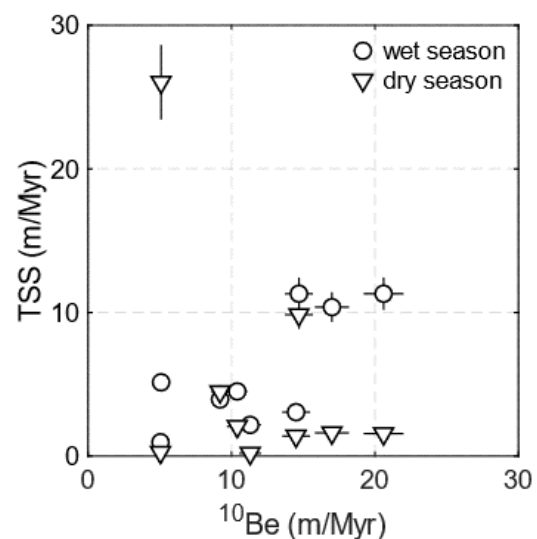


Fig. 2: Erosion rates constrained by ^{10}Be and estimated by total suspended sediment (TSS).

Preliminary data show that the long-term erosion rates constrained by ^{10}Be are higher than the short-term erosion rates estimated by discharge and total suspended sediments (TSS) measurements in the field. This result is contrary to previous global observation that anthropogenically induced erosion has significantly increased global sediment yield [1] and warrants further investigation.

- [1] J. P. M. Syvitski et al., Nat. Rev. Earth. Environ. 3 (2022) 179

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LONG-TERM PEAT THICKNESS FROM ^{26}Al AND ^{10}Be

Inverse-modelling of cosmogenic nuclides in the Belgian Ardennes

A. Moore¹, V. Vanacker^{1,2}, P. Gautschi, M. Christl

The ability to detect former peat cover thickness would assist in studying the impacts of land use and climate change on peatland dynamics. The accumulation of cosmogenic nuclides in a sample is sensitive to the amount of overlying mass shielding the sample from cosmic radiation. Consequently, when two nuclides are measured, and the exposure timescale is long enough for differential radioactive decay to be significant, the surface age or denudation rate and the overburden thickness may be determined simultaneously. We tested this approach using ^{26}Al and ^{10}Be in the Hautes Fagnes, an upland peatland in the Belgian Ardennes with a long history of human disturbance. The study site is located on a hillslope incised into a low-relief paleo-surface, where the landscape is believed to be down-wasting at an extremely slow rate [1].



Fig. 1: Photograph of the study hillslope in the Hautes Fagnes, Belgian Ardennes.

We collected quartz-bearing saprolite samples by coring through the peat blanket and measured ^{10}Be and ^{26}Al concentrations. All $^{26}\text{Al}/^{10}\text{Be}$ ratios plot below the steady-state denudation line on a two-isotope plot. We interpreted this as evidence of the existence of thicker peat in the past and inverse-modelled the concentrations to constrain denudation rates and long-term average peat thicknesses.

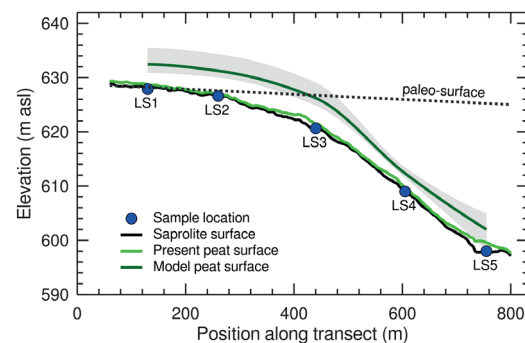


Fig. 2: Study hillslope cross section with 10× vertical exaggeration, showing the sample positions. The black, solid line shows the elevation of the top of the saprolite surveyed with ground penetrating radar. The light green line shows the elevation of the modern peat surface. The cosmogenic nuclide model-based estimate of peat thickness is shown by the dark green line and the 90% CI by the grey band.

Modelled denudation rates are consistent with independent geomorphic data. Similarly, modelled overburden thicknesses fit theoretical constraints for a low-gradient peatland in a temperate climate, but exceed the modern peat thicknesses. This discrepancy likely arises from the negative effects of land use on peat mass balance at the study site since the Middle Ages, as well as from peat subsidence following drainage and afforestation in the early 20th century. These results indicate that cosmogenic nuclides provide a promising tool for studying long-term peat thicknesses in landscapes with slow process rates.

- [1] A. Demoulin et al., *Landscapes and Landforms of Belgium and Luxembourg*, Springer (2018) 63

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ANTHROPOGENIC RADIONUCLIDES



View of the Fukushima Daiichi Nuclear Power Plant from the research vessel Shinsei Maru (September 2025).

Actinide measurement at MILEA

Protactinium-231 measurements at MILEA

Tracking European nuclear reprocessing signal

Historical ^{233}U and ^{236}U signals in the Baltic Sea

Anthropogenic uranium in the Black Sea

Sources of the East Greenland current

Atlantic water pathways in the Arctic Ocean

^{129}I time series across Fram strait

Water mass provenance in Baffin Bay

Long-term Fukushima impacts

Fate of Anthropogenic CO_2 in the Sargasso Sea

ACTINIDE MEASUREMENT AT MILEA

Samples measured for U, Pu, Am and Pa during 2025

H. Pérez-Tribouillier, P. Gautschi, C. Vockenhuber, M.Christl

One of the primary measurement activities of the Multi-Isotope Low-Energy AMS facility at ETH Zurich is the analysis of actinides in a wide range of environmental samples. During 2025, a total of 1'367 actinide samples were measured (Fig. 1).

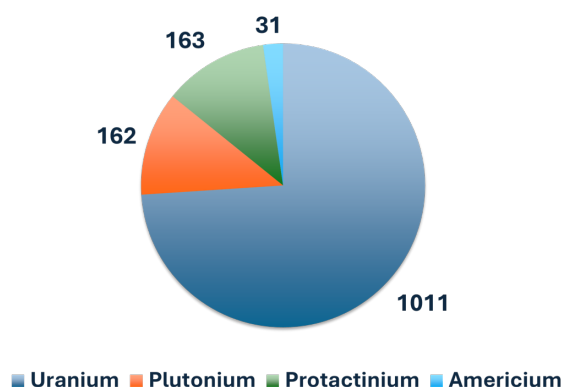


Fig. 1: Total amount of actinide samples measured with MILEA during 2025.

Uranium isotopes constituted the main analytical focus, with 1'011 samples analysed (Fig. 2). Of these, 739 seawater samples were measured for ^{236}U concentrations, the majority originating from the Arctic and North Atlantic Oceans. These measurements were carried out in support of the TITANICA project of the Department of Environmental Systems Science at ETH Zurich.

The second most significant uranium-related activity involved the determination of ultra-low levels of $^{236}\text{U}/^{238}\text{U}$ and $^{233}\text{U}/^{238}\text{U}$ ratios in marine sediment samples from the Baltic and Black Seas, conducted in support of activities at the Centro Nacional de Aceleradores (Seville, Spain). Additional samples were also measured in this configuration to track the influence of nuclear fuel reprocessing activities and global fallout in the North Sea. Due to the extremely low levels of ^{233}U in this type of samples the measuring times need to be significantly extended, with some samples requiring several days before achieving appropriate counting statistics.

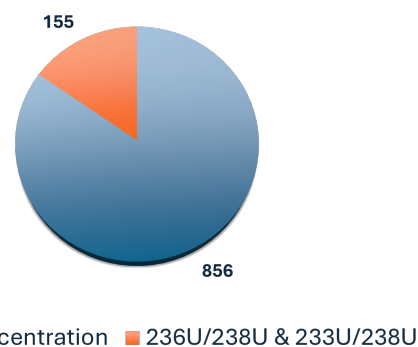


Fig. 2: Type of uranium measurements performed with MILEA during 2025.

A notable increase in analytical activity was observed for Pa in 2025, with 163 samples measured during the year. These analyses supported a PhD project at Helmholtz-Zentrum Dresden-Rossendorf and included both method development and the analysis of various environmental sample types.

Comparable numbers of samples were analysed for plutonium isotopes (^{239}Pu and ^{240}Pu), primarily from seawater collected in the vicinity of the Fukushima Daiichi Nuclear Power Plant, as well as from the North Sea.

Finally, a smaller number of samples were measured for the determination of ^{241}Am . These consisted mainly of seawater samples from the North Sea and river water samples collected to monitor potential releases of this isotope from nuclear power plants in Switzerland.

A detailed description of the projects associated with these samples is provided in the Anthropogenic Radionuclides section of this annual report.

PROTACTINIUM-231 MEASUREMENTS AT MILEA

Finding the best binder material

J. Wolf¹, M. Christl, S. Fichter¹, P. Gautschi, H. Perez Tribouillier, S. Winkler¹, A. Wallner¹

The first measurements of ^{231}Pa at the MILEA AMS system used Nb as a binder material [1]. Here, we present the results of investigations into alternative binder materials. In earlier ^{231}Pa measurements with ETH's Tandy AMS system, Al was used as a binder [3], while measurements at ANU used Nb [4]. Both these AMS systems utilized a MC-SNICS ion source. For detecting other actinides at MILEA, optimal performance was achieved with samples containing 3 mg Fe and 6–9 mg Nb [2].

In order to test which binder yields the highest efficiency for $^{231}\text{PaO}^-$ -output from the MILEA ion source, we produced standards containing ^{233}U and ^{231}Pa following the protocol described in [1]. Fe_2O_3 matrix was mixed with different binder materials of varying amounts: Ag, Al, Nb, and Cu.

Each target was sputtered for 25–35 minutes. For each cathode, the count rate was still increasing at the end of sputtering, so the total efficiency may still be higher than observed here. Nevertheless, by comparing sputtered mass with detected counts, we can determine the efficiency during the first 30 min. of beam time.

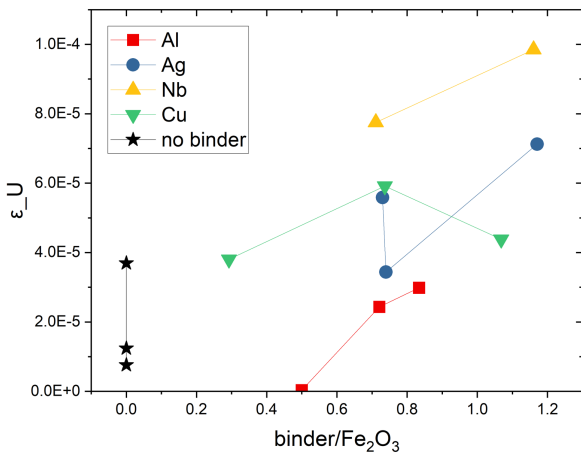


Fig. 1: Efficiency of ^{233}U for cathodes containing different ratios of binder to the Fe_2O_3 matrix.

As shown in Fig. 1, the highest efficiencies for ^{233}U were achieved in cathodes containing Nb, confirming the observations in [2]. Both Nb/ Fe_2O_3 ratios of 0.7 and 1.2 reached efficiencies higher than any cathode using other binders.

A distinctly different behavior was observed for ^{231}Pa . Firstly, the efficiency of ^{231}Pa was up to one order of magnitude lower than that of ^{233}U . The efficiency in cathodes containing Nb was not significantly higher than those containing other binder material (see Fig. 2). While there is one outlier among the cathodes containing only Fe_2O_3 , the highest efficiencies were achieved in cathodes without any binder. Based on these observations, omitting any binder from ^{231}Pa samples shows to the highest measurement efficiencies.

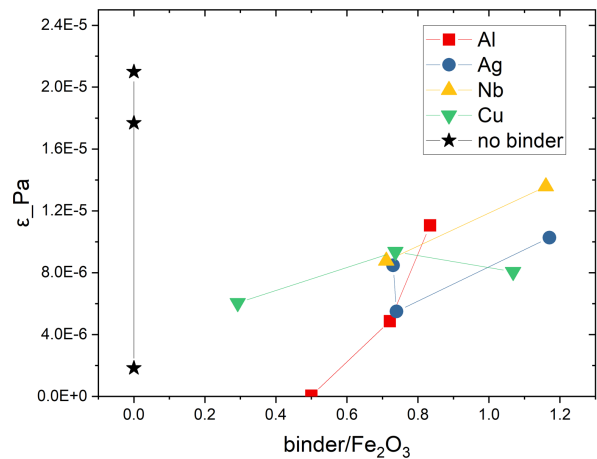


Fig. 2: Efficiency of ^{231}Pa for cathodes containing different ratios of binder to the Fe_2O_3 matrix.

[1] J. Wolf et al., NIM B 567 (2025) 165824

[2] M. Christl et al. NIM B 532 (2023) 61

[3] M. Christl et al., NIM B 268 (2010) 1159

[4] P. Medley et al., NIM B 438 (2019) 66

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TRACKING EUROPEAN NUCLEAR REPROCESSING SIGNAL

Seawater actinide and ^{129}I concentrations in the North Atlantic

H. Pérez-Tribouillier, M. Christl, C. Vockenhuber, M. Castrillejo¹, J. Corcho-Alvarado², S. Röllin², N. Casacuberta³

European nuclear fuel reprocessing plants, notably Sellafield and La Hague, represent an important and continuous source of anthropogenic radionuclides to the subpolar North Atlantic and adjacent Arctic shelf seas. Characterizing the distribution and accumulation of these elements is crucial not only for radioecological assessments, but also for the use of ^{129}I and actinides as tracers of Arctic Ocean circulation and transport pathways [1].

Here, we report ^{129}I (Fig. 1, top), $^{236}\text{U}/^{238}\text{U}$ (Fig. 1, bottom), and $^{233}\text{U}/^{236}\text{U}$ (not shown) atom ratios in surface seawater samples collected during two research cruises: aboard the RV Pelagica in the North Sea (May 2018), and aboard the RV Skagerak along the Norwegian coast and at the Barents Sea opening (September 2024). Samples from the RV Skagerak were processed in collaboration with Spiez Laboratory to achieve lower ^{233}U procedural blanks and to determine ^{238}U concentrations by sector field inductively coupled plasma mass spectrometry (SF-ICP-MS). Finally, ^{129}I concentrations were measured using the Tandy system, while actinides were measured with the MILEA system.

Both surface ^{129}I concentrations and $^{236}\text{U}/^{238}\text{U}$ ratios exhibit a pronounced spatial gradient across the study area (Fig. 1). Elevated values are observed in the southern North Sea and along the Dutch and Belgian coasts, followed by a progressive decrease northward along the Norwegian coast and into the Nordic Seas. The lowest values occur at the northernmost stations, including the Barents Sea opening.

The spatial patterns of ^{129}I and $^{236}\text{U}/^{238}\text{U}$ confirm the superposition of reprocessing-derived inputs and global fallout, underscoring the need for constraining transport pathways and to refine estimates of anthropogenic radionuclide inputs to the Arctic Ocean [2].

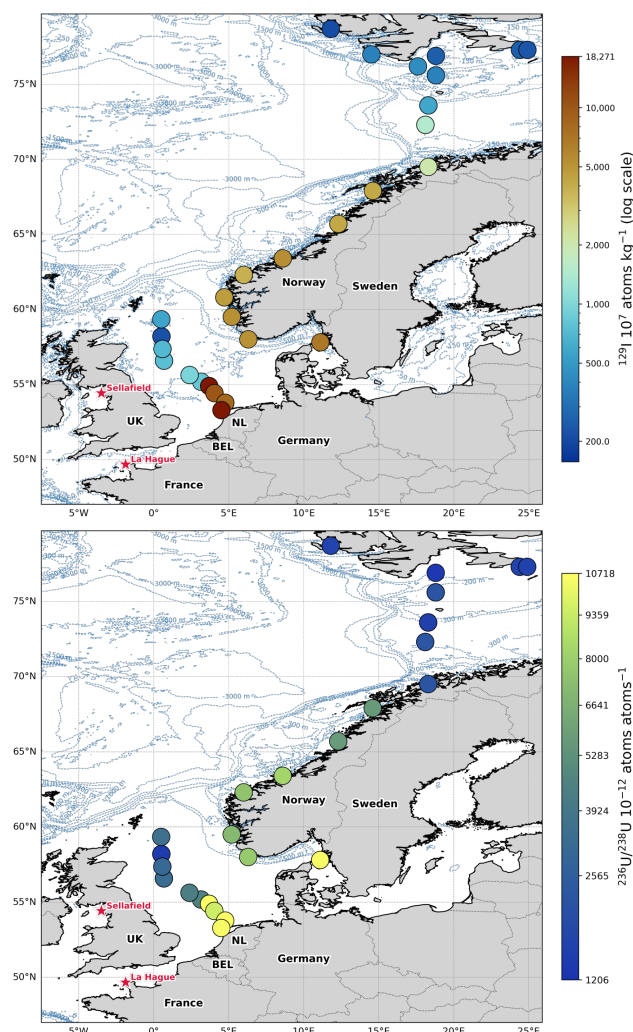


Fig. 1: Surface ^{129}I concentrations and $^{236}\text{U}/^{238}\text{U}$ in the North (2018) and Barents Seas (2025).

- [1] N. Casacuberta et al., Annu. Rev. Mar. Sci. 15 (2023) 203
- [2] M. Christl et al., JGR Oceans 120 (2015) 7282

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HISTORICAL ^{233}U AND ^{236}U SIGNALS IN THE BALTIC SEA

Tracing anthropogenic uranium in Baltic Sea sediments

M. López-Lora¹, E. Chamizo¹, G. Olszewski², H. Perez-Tribouillier, M. Christl, A. López-Fuentes¹, M. Eriksson³

The Baltic Sea has been historically exposed to multiple local and regional actinides sources: i) atmospheric debris from the Chernobyl accident (1986), ii) radioactive discharges from nuclear facilities in the North Sea and the Baltic Sea region, and iii) possible leakages from dumping sites [1]. These sources coexist with the baseline contribution from atmospheric nuclear weapon testing (1945-1980) or global fallout (GF).

This study investigates the anthropogenic isotopes ^{236}U ($T_{1/2} = 23.4 \text{ My}$) and ^{233}U ($T_{1/2} = 0.16 \text{ My}$) in a set of sediment cores collected from multiple stations across the Baltic Sea (Fig. 1), expanding beyond earlier studies [2]. A total of 39 sediment samples have been analyzed at the 300 kV MILEA ETH AMS facility. The objective is to distinguish the different sources of ^{236}U using the novel $^{233}\text{U}/^{236}\text{U}$ atom ratio fingerprint [3]. This approach relies on the fact that ^{233}U originates predominantly from GF, whereas commercial nuclear power reactors and reprocessing facilities produce negligible amounts of ^{233}U , in contrast to ^{236}U .

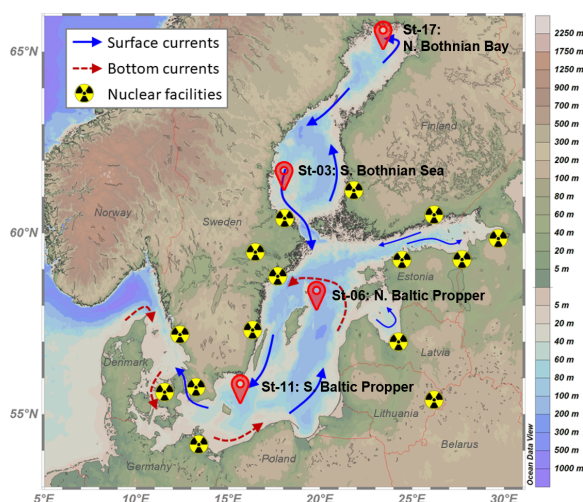


Fig. 1: Sampling locations of the studied sediment cores. Sampling was performed by the Swedish Geological Survey (SGU) in 2020.

Measured $^{236}\text{U}/^{238}\text{U}$ atom ratios range from 1.3×10^{-11} to 3.8×10^{-8} , evidence of the anthropogenic origin of the ^{236}U . The $^{233}\text{U}/^{236}\text{U}$ atom ratios across all analyzed samples range from 0.57×10^{-2} to 3.9×10^{-2} . The $^{233}\text{U}/^{236}\text{U}$ depth profiles show a consistent pattern among the sediment cores, with the highest values occurring in the deepest layers (Fig. 2). These elevated ratios reflect the influence of early thermonuclear tests, whereas the lower values observed in surface sediments indicate enhanced ^{236}U contributions from reactor and reprocessing activities in recent decades.

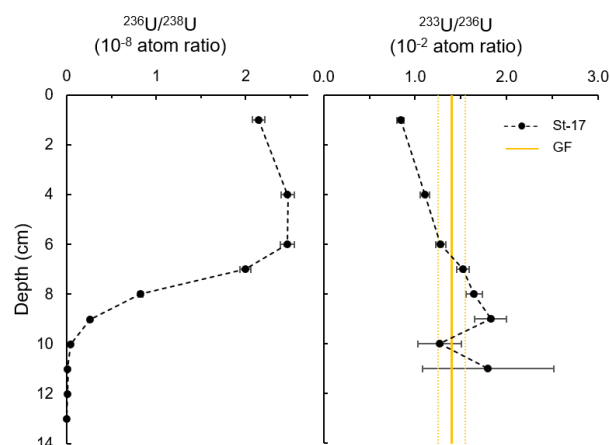


Fig. 2: $^{236}\text{U}/^{238}\text{U}$ and $^{233}\text{U}/^{236}\text{U}$ atom ratios measured at station St-17 (Fig. 1). For comparison reasons, the expected $^{233}\text{U}/^{236}\text{U}$ atom ratio from GF is also shown [3].

- [1] HELCOM (2018) Baltic Sea Environment Proceedings No. 151
- [2] M. Lin et al., Environ. Sci. Technol. 55 (2021) 8918
- [3] K. Hain et al., Nat. Commun. 11 (2020) 1275

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ANTHROPOGENIC URANIUM IN THE BLACK SEA

^{233}U and ^{236}U in a sediment core from the northwestern Black Sea

A.J. López-Fuentes^{1,2}, E. Chamizo¹, M. López-Lora^{1,3}, H. Pérez-Tribouillier, M. Christl, M. Ilie⁴ and T. Sava⁵

The Black Sea is the largest anoxic basin in the world. Between 80-200 m depth a stable halocline separates the oxygenated zone from a permanent anoxic environment. Under oxygen depleted conditions, soluble U(VI) is reduced to poorly soluble U(IV), which is then incorporated into the sediments [1]. In this work, a 10 cm long sediment core collected in 2019 at 684 m depth in the anoxic northwestern Black Sea (43°45'5.98"N, 30°34'6.00"E, labeled as 6MC1) was analyzed for its $^{236}\text{U}/^{238}\text{U}$ and $^{233}\text{U}/^{238}\text{U}$ atomic ratios (ARs) at the 300 kV MILEA ETH AMS facility.

Seven samples corresponding to the sediment interval 0.75 to 4.25 cm depth were chemically processed at the Centro Nacional de Aceleradores (CNA, Spain). Aliquots ≤ 5 g were leached using concentrated HNO_3 , HCl and H_2O_2 . Actinides were concentrated with $\text{Fe}(\text{OH})_3$, and U subsequently purified using UTEVA® resins. No spike or Fe carrier was added to prevent contamination.

The obtained $^{236}\text{U}/^{238}\text{U}$ and $^{233}\text{U}/^{238}\text{U}$ ARs range from 3.5×10^{-12} to 2160×10^{-12} and from 0.21×10^{-12} to 40×10^{-12} , respectively (Fig. 1). $^{238}\text{U}^{3+}$ presented currents from 10 to 25 nA. Overall, the samples are highly enriched in U, as indicated by gamma-spectrometry analysis (Fig. 1). ^{233}U count rates were close to the instrumental blank levels below 2.25 cm depth (Fig. 1).

Both $^{236}\text{U}/^{238}\text{U}$ and $^{233}\text{U}/^{238}\text{U}$ AR results for the studied sediment core show a maximum value in the first available sample followed by a sharp decrease, eventually reaching the baseline with values of about 10^{-12} and 10^{-13} . The corresponding $^{233}\text{U}/^{236}\text{U}$ AR shows an increasing trend, ranging from 1.92×10^{-2} to 6×10^{-2} . At 0.75 cm depth, the measured ratio $(1.92 \pm 0.20) \times 10^{-2}$ is consistent with the estimated average for global fallout in the Northern Hemisphere, $(1.40 \pm 0.15) \times 10^{-2}$ [2].

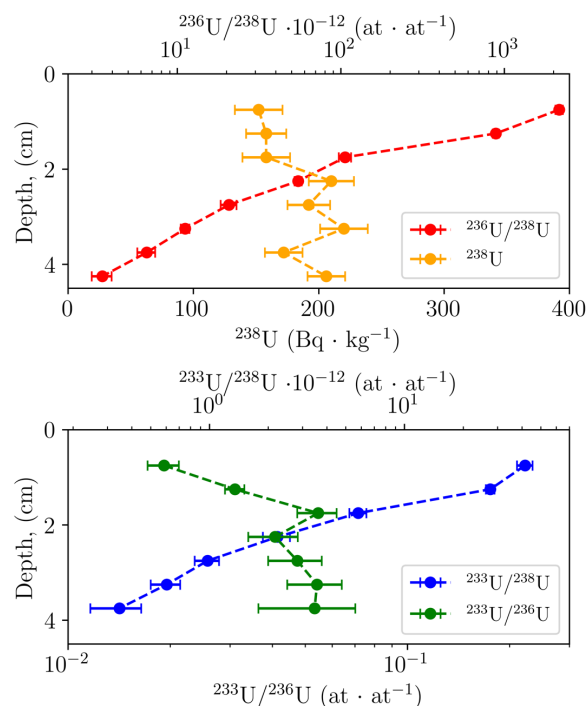


Fig. 1: Obtained $^{233}\text{U}/^{238}\text{U}$, $^{236}\text{U}/^{238}\text{U}$ and $^{236}\text{U}/^{238}\text{U}$ ARs and ^{238}U for the 6MC1 sediment core.

To the best of our knowledge, these are the first ^{233}U and ^{236}U results for a sedimentary reservoir from the Black Sea. The authors are grateful to Horia Hulubei National Institute and GeoEcoMar in Romania for providing the samples used in this study.

- [1] R. F. Anderson et al., GCA 53(9) (1989) 2215
- [2] K. Hain et al., Nat. Commun. 11 (2020) 1275

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⁴Horia Hulubei National Institute, Bucharest, Romania

⁵Univ. of Bern

SOURCES OF THE EAST GREENLAND CURRENT

A voyage to the North of Greenland onboard R/V Polarstern

N. Casacuberta^{1,a}, A.-M. Wefing², W. J. Von-Appen³, T. Kanzow³

The East Greenland Current (EGC) is one of the major oceanic currents outflowing the Arctic Ocean, through the western side of the Fram Strait. It transports Polar Surface Waters and sea ice from the Arctic Ocean, and thus it is a major conduit of cold and freshwater at the surface, but also warm and saline waters at the subsurface (i.e., Arctic Atlantic Waters). With the Arctic Ocean undergoing unprecedented changes, the East Greenland Current composition is also changing and this will ultimately impact the circulation in the Atlantic Ocean [1].

With the aim to understand the origin and sources of the East Greenland Current, this summer we embarked in an expedition onboard R/V Polarstern (Fig. 1). The voyage started on the 3rd of September in Longyerbyen (Svalbard) and ended on the 24th of October in Bremerhaven (Germany).



Fig. 1: Anne-Marie Wefing and N ria Casacuberta at the arrival port in Bremerhaven and standing in front of the German R/V Polarstern.

Our group was representing the transient tracers team, which collected samples for radionuclide tracers at different stations along the multiple hydrographic sections. We collected about 250 samples for the analysis of ¹²⁹I and ²³⁶U transient

tracers (Fig. 2) to understand the sources and composition of Polar Surface Waters as well as the intermediate Arctic Atlantic Waters in this particular location.

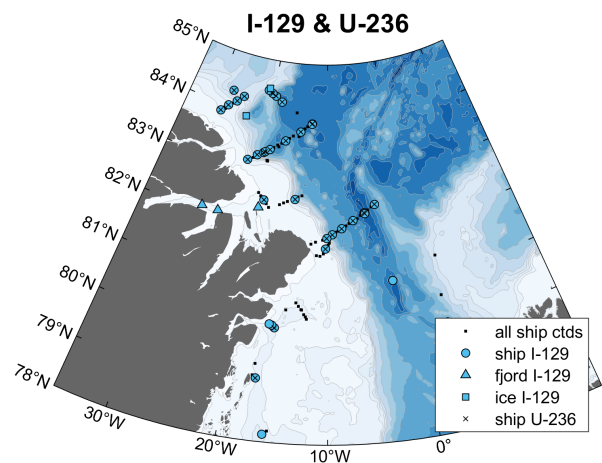


Fig. 2: Map showing all the stations sampled during the EGC expedition. Blue dots represent the stations where samples were collected for the analysis of ¹²⁹I and ²³⁶U radionuclides.

By coupling these two radionuclides with other gas transient tracers (i.e., CFC, SF₆, ¹⁴C and ³⁹Ar) we will constrain circulation timescales and mixing of waters [2], and contribute to the general understanding of the sources and changes of the East Greenland Current.

[1] Polyakov et al., Sci.Adv. 11 (2025) eadq7580

[2] Casacuberta & Smith, ARMS 15 (2023) 203

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ATLANTIC WATER PATHWAYS IN THE ARCTIC OCEAN

Surface concentrations of the transient radionuclide tracer ^{129}I

M. Scheiwiller¹, H. Pérez-Tribouillier, C. Vockenhuber, W. Geibert², N. Casacuberta¹

The Arctic Ocean is experiencing unprecedented changes primarily driven by anthropogenic climate change [1, 2]. The resulting increase in ocean temperatures and sea ice melting are compounded by Atlantification—the progressive intrusion of increasingly warm Atlantic Water (AW) [3, 4]. This warmer AW, situated at mid-depths, is exerting a rising thermal and dynamical influence on the surface layer and, consequently, on overall circulation dynamics. The degree to which this process contributes to the observed changes is currently unknown. Therefore, studying the physical transport and thermodynamic influence of this Atlantic Water is crucial to enhancing our understanding of these complex processes and to anticipating the long-term consequences of a rapidly changing Arctic marine system.

This study presents ^{129}I data collected in the central Arctic Ocean during the 2024 PS144 / ArcWatch-2 expedition aboard the German research vessel *Polarstern* (Fig. 1). We utilize the spatial distribution of these ^{129}I concentrations to explicitly delineate Atlantic Water pathways into the Arctic Basin. Crucially, the concurrent analysis of the dual-tracer pair with ^{236}U (not shown here), will subsequently enable the robust quantification of lateral transport timescales within these key oceanographic currents [5].

The primary source of ^{129}I introduced into the Arctic Ocean is effluent from two European Nuclear Reprocessing Plants, releasing the radionuclide into coastal waters, which ultimately reach the Barents and Kara Seas. From there, the Atlantic-derived surface current advects the signal along the continental slope of the Eurasian Basin and is subsequently transported back toward the Fram Strait via the Transpolar Drift. This transport pathway is indicated by the gradual decrease of ^{129}I concentrations along this entire route (Fig. 1).

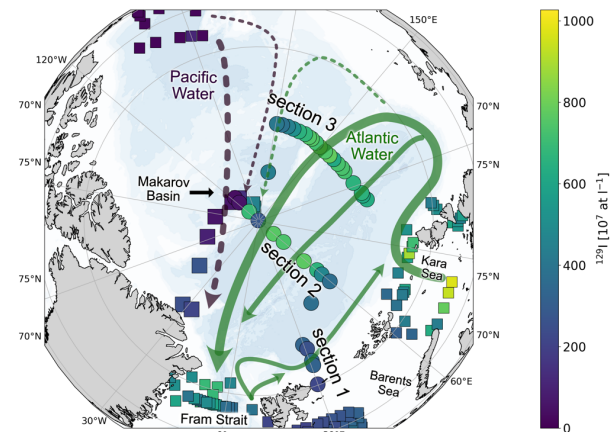


Fig. 1: Isosurface map of ^{129}I concentrations in the Arctic Ocean (top 15 m). Circles are from the Polarstern expedition PS144 in 2024 and squares from past expeditions.

In addition to Atlantic Water, the Arctic Ocean surface layer also contains Pacific-origin waters that enter through the Bering Strait. As these waters are essentially tracer-free, the front separating them from the Atlantic Water is strikingly highlighted in Fig. 1, specifically by the very low ^{129}I concentrations observed in the Makarov Basin. Further analysis (Section 3) details the progressive mixing and advection of these Atlantic and Pacific Water masses as they converge toward the Mendeleev Ridge.

- [1] M. Previdi et al., *Env. Res. Let.* 16 (2021) 093003
- [2] Q. Shu et al., *Sci. Adv.* 377 (2022) 109838
- [3] I. V. Polyakov et al., *Science* 226 (2023) 105607
- [4] J.E. Box et al., *Env. Res. Let.* 14 (2019) 045010
- [5] N. Casacuberta, J.N. Smith, *Annual Review of marine Sciences* 15 (2023) 203

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¹²⁹I TIME SERIES ACROSS FRAM STRAIT

Temporal changes between 2020 and 2024

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Fram Strait is the major gateway connecting the Arctic to the Atlantic Ocean, featuring a two-way exchange of waters. In the eastern part, warm and saline Atlantic Waters are transported northward with the West Spitsbergen Current (WSC), while in the western part, the East Greenland Current (EGC) transport Arctic Waters south (Fig. 1).

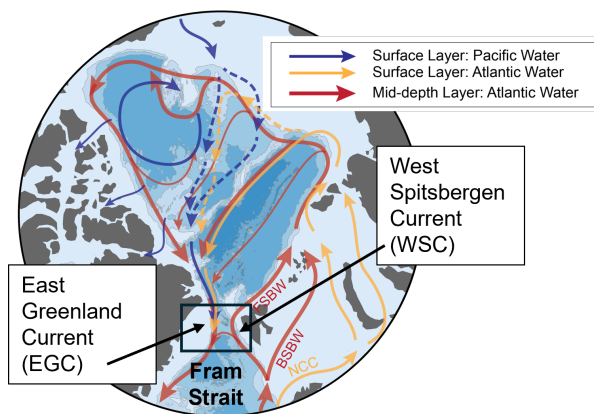


Fig. 1: Circulation in the Arctic Ocean, highlighting Fram Strait.

Since 2020, measurements of the anthropogenic radionuclide ¹²⁹I in seawater samples from Fram Strait have been conducted at the Laboratory for Ion Beam Physics, building a time series of annual ¹²⁹I concentrations. Sampling has been focused on the EGC, where ¹²⁹I can be used as a tracer to distinguish different water masses, in particular Atlantic- and Pacific-origin waters [1].

Generally, higher ¹²⁹I concentrations in the EGC indicate Atlantic-sourced waters, which are labelled by the releases from European nuclear fuel reprocessing plants. Between 2020 and 2024, the distribution of ¹²⁹I across the EGC was similar, but differences were observed between sampling years, especially in the upper 100 m (Fig. 2). Here, concentrations were overall higher in 2021 compared to the other years, while in the upper 50 m concentrations were lowest in 2023.

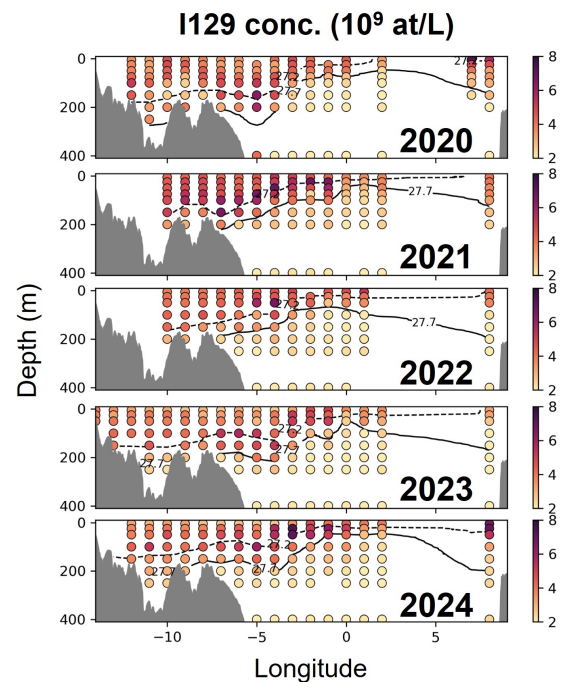


Fig. 2: Section plots of ¹²⁹I concentrations across Fram Strait between 2020 and 2024.

The combination of ¹²⁹I and salinity was used to quantify fractions of Pacific Water exiting Fram Strait, pointing to an increase in Pacific Water present in the EGC in Fram Strait in 2023 and 2024, compared to earlier years.

In summer 2025, seawater samples have been collected again for the analysis of ¹²⁹I, repeating previous stations and depths to extend the time series. Furthermore, samples have been collected during the Polarstern expedition PS150, which took place in Sep/Oct 2025 and focused on a study area north of Fram Strait to investigate the sources of the EGC [2].

- [1] Wefing et al., Front. Mar. Sci., 9 (2022) 16
- [2] N. Casacuberta, Annual report 2025, 65

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WATER MASS PROVENANCE IN BAFFIN BAY

Using artificial radionuclides to trace water mass formation

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The Baffin (Fig. 1) is confined between Greenland and Canada and serves as a key conduit between the Arctic Ocean and the Northern Atlantic through Davis Strait. It provides the northern connection to the Canadian Arctic Archipelago (CAA) via Nares Strait and Lancaster Sound and links southward into the Labrador Sea, thereby acting as an important gateway for Arctic-Atlantic water exchange.

Under ongoing climate change, both the Arctic Ocean and the CAA are undergoing profound transformations. The outflow of Arctic water through the passages of the CAA has the potential to modify water mass formation in the North Atlantic and ultimately the Atlantic Meridional Overturning Circulation [2].

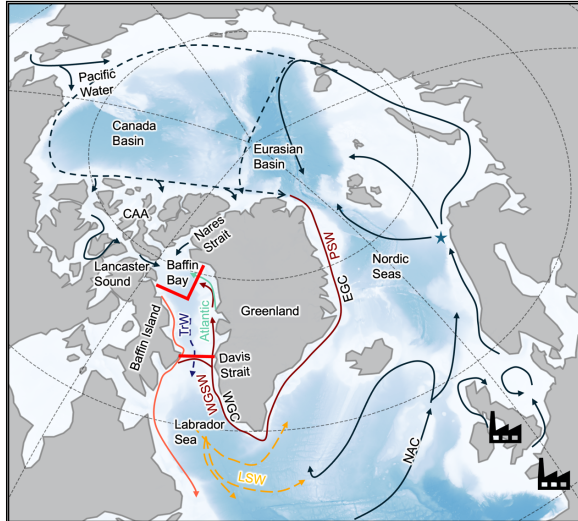


Fig. 1: Study area and overview of the most important currents in the North Atlantic and Arctic Ocean.

Artificial radionuclides ^{129}I and ^{236}U , originating from European nuclear reprocessing plants, were measured in seawater from northern Baffin Bay in October 2024, aiming to better understand the water mass formation in northern Baffin Bay.

The highest ^{129}I concentrations were measured at the surface along the Greenland shelf (WGSW), while the highest ^{236}U (Fig. 2) was measured at intermediate depth at central Baffin Bay in the Transition Waters (TrW).

The tracer concentrations revealed that the surface of eastern Baffin Bay was dominated by WGSW, while the center and western bay was dominated by Arctic outflow, propagating to Davis Strait (Fig. 2A). At intermediate depth the formation of TrW was found to be more complex (Fig. 2B) and revealed a cyclonic circulation at the center of the bay. The circulation mixes fresh and ^{236}U -rich water outflowing Lancaster Sound with warm and saline Atlantic Water inflowing via Davis Strait. It further showed contributions of WGSW which cascaded during winter along the Greenland shelf.

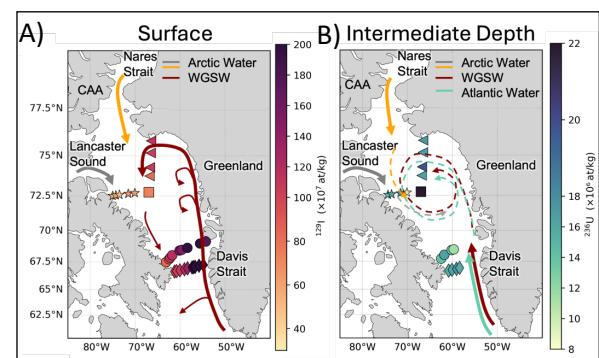


Fig. 2: Isosurfaceplots of ^{129}I and ^{236}U with the main circulations at surface and intermediate depth.

- [1] J. Huang et al., Prog. Oceanogr. 229 (2024) 103322
- [2] Yang et al., Nat. Commun. 7, (2016) 10525

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LONG-TERM FUKUSHIMA IMPACTS

2011-2025 time-series of Fukushima derived radionuclides

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On 11 March 2011, the Tōhoku earthquake and tsunami triggered a severe accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP), resulting in the release of large quantities of radionuclides. A coordinated international monitoring programme, initiated shortly after the accident, has generated multi-year time series of radionuclides in seawater, beaches, groundwaters, and rivers of the western North Pacific (Fig. 1). The dataset covers the period from April 2011 to September 2025 [1, 2].

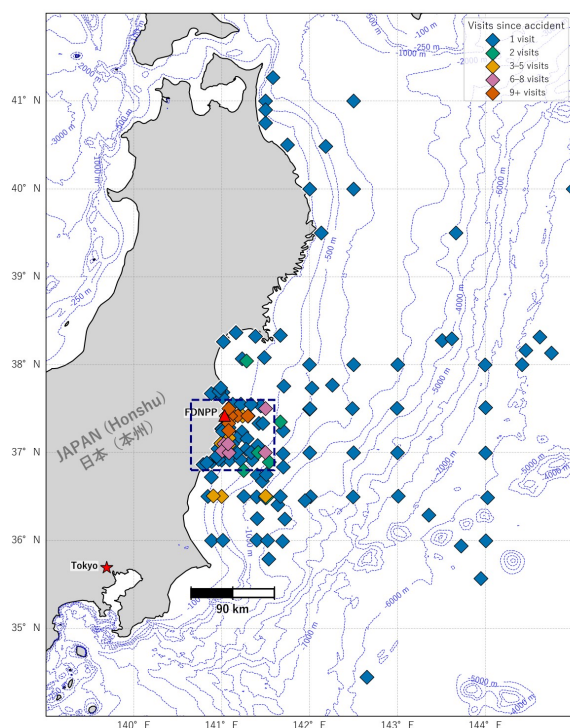


Fig. 1: Radionuclide sampling (2011-2025)

^{137}Cs and ^{129}I data from 2011 to 2016 showed the greatest variability in radionuclide activities (Fig 2). By 2016, activities were approximately one order of magnitude lower than in 2011. After 2016, ^{137}Cs declined toward pre-accident levels, whereas ^{129}I remained elevated. In contrast, ^{137}Cs and ^{129}I levels in beach porewaters near the FDNPP (not shown) exhibit no significant

temporal decrease, indicating that beaches act as long-term radionuclide reservoirs.

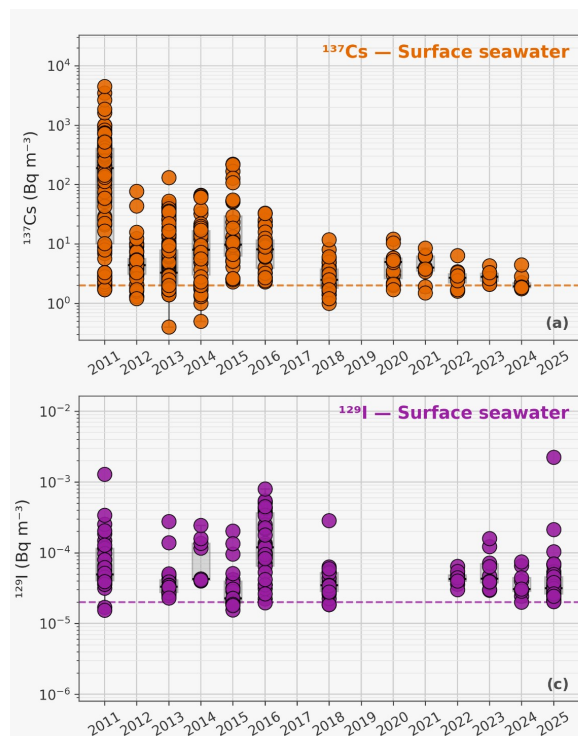


Fig. 2: ^{137}Cs and ^{129}I in seawater around FDNPP. Dashed horizontal lines: pre-accident levels.

The temporal variability of ^{129}I and ^{137}Cs concentrations observed in this study reflects signals from different FDNPP sources, with treated wastewater becoming increasingly dominant in recent years. Variability is influenced by decontamination activities, rainfall, flooding, wind direction, and subsequent tsunami events. These results form part of a broader ongoing investigation, results will be published soon.

- [1] Buesseler et al., Proc. Natl. Acad. Sci. (2012)
- [2] Kenyon et al., Environ. Sci. Technol. (2020)

¹Woods Hole Oceanographic Institution, USA

²AORI, Univ. of Tokyo, Japan

³Inst. Nat. & Env. Tech. Kanazawa University, Japan

FATE OF ANTHROPOGENIC CO₂ IN THE SARGASSO SEA

¹⁴C as a tracer in the marine carbon pool

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Between 1960 and 2012, the ocean carbon sink has taken up $25 \pm 2\%$ of anthropogenic CO₂ emissions [1], through atmospheric exchange with dissolved inorganic carbon (DIC). However, in the surface ocean, DIC is also utilized by primary producers, generating particulate organic carbon (POC). This POC is either remineralized by zooplankton/microbes, sinks rapidly (days to weeks), or persists as suspended particles (months to years) until eventually being sequestered in the deep. Dissolved OC (DOC) represents the oldest OC pool (years to millennia), as evidenced by radiocarbon (¹⁴C) measurements [2].

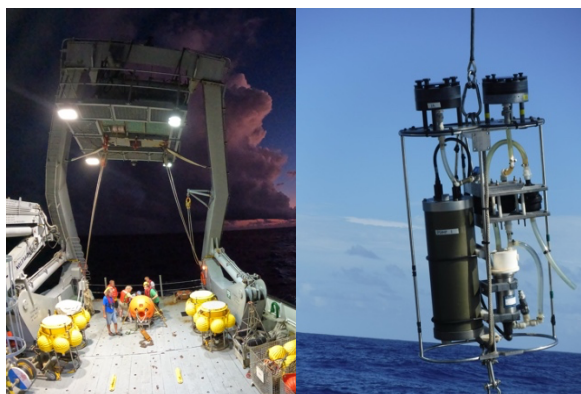


Fig. 1: Sediment trap cruise on the R/V Atlantic Explorer (left) (Raphaëla Joseph, 2022) and In-situ pumping of suspended particles (right) (JC Weber, 2023).

The release of ¹⁴C-enriched carbon from mid-20th century nuclear bomb tests, known as the "bomb spike," enables the tracing of these short-term marine carbon cycle processes. The mixing-induced bomb-spike decay curve is, however, also influenced by fossil fuel emissions (¹⁴C-dead and ¹³C-depleted carbon), steepening its return toward pre-bomb levels. While this decay trend is well-documented for DIC globally, its relationship with OC pools remains unclear.

We aim to apply different models to calculate the turnover times and back out the possible contributors such as soil OC or autochthonous OC using the radiocarbon bomb-spike as a tracer.

To investigate this, we analyze long-term radiocarbon records from the Sargasso Sea, combining measurements from surface waters, suspended particles, sinking particles, and dissolved organic carbon. Surface ocean radiocarbon is reconstructed from coral CaCO₃, while organic matter is collected using sediment traps and in-situ filtration systems (Fig. 1).

Our results reveal distinct radiocarbon signatures across marine carbon pools. Surface-derived organic matter reflects recent carbon fixation, whereas deeper suspended and sinking particles show evidence for older, more refractory carbon that has been transported laterally or recycled within the ocean interior. Despite these differences, sinking particles largely track surface carbon Suess effect and bomb-spike signals, indicating that vertical export remains a key pathway for transferring anthropogenic carbon to the deep sea.

- [1] N. Gruber et al., Nature Reviews Earth & Environment (2023) 4(2) 119
- [2] E.R.M. Druffel et al. GRL (2016) 43(10), 5279

¹Earth and Planetary Sciences, ETH Zurich

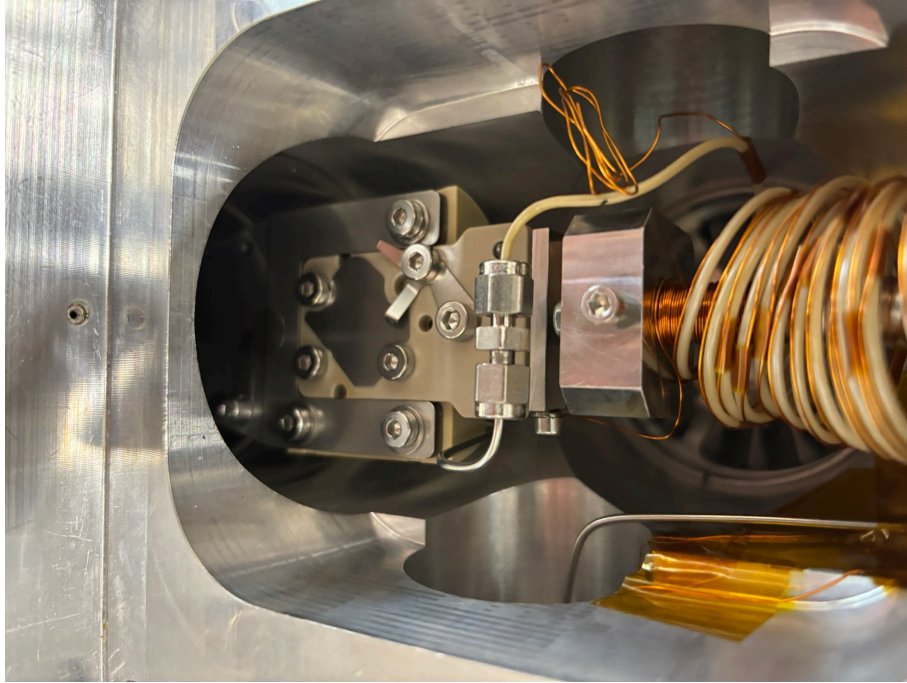
²Ecosystems Center, MBL, USA

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MATERIALS SCIENCES



Electrolysis cell for testing hydrogen in-operando uptake in materials, mounted and installed in the sample-transfer lock of the ERDA station.

Increasing battery lifespan using thin films
Establishing advanced ion implantation system
Development of a windowless gas detector
Windowless transmission-style gas detector
Transition metal fluoride cathodes in batteries
In-operando material science using ERDA
Future micro PIXE capabilities at LIP
Elemental profiling of silicon nitride membranes
Silicon implantation in diamond
Oxynitrides for solar hydrogen production
Microstructure & mechanics from processing
Ion microbeam studies of n-LGAD detector
Impact of stratospheric aerosol injection on O₃
Resonant oxygen quantification in Röntgen film
Recycling of silicon PV modules

INCREASING BATTERY LIFESPAN USING THIN FILMS

Optimizing protective coatings for cathode surface stability

L. Lapeyre¹, A. M. Müller

Ni-rich cathodes (NMC) enable high-energy lithium-ion batteries but suffer from rapid degradation due to unstable cathode–electrolyte interfaces [1]. Ultrathin protective coatings deposited by atomic layer deposition (ALD) offer a promising route to stabilize the cathode surface while preserving lithium-ion transport. Lithium niobium oxide (LiNbO_x) thin films are promising candidates to suppress degradation at cathode surface, although it requires deposition process optimization [2]. The goal is to understand how chemical composition and thickness of these coatings influence cathode stability and battery lifetime. The LiNbO_x /NMC stack is shown in Fig. 1.

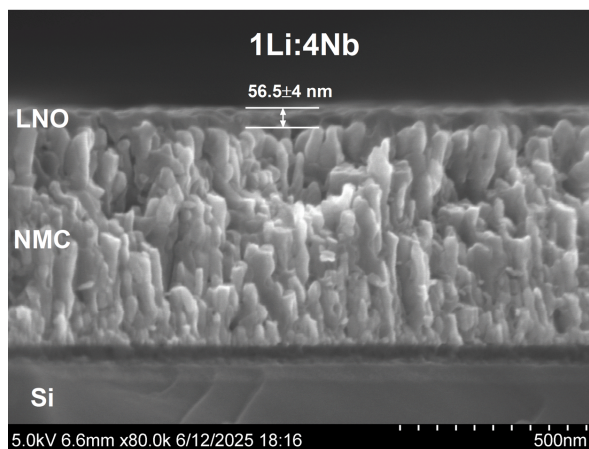


Fig. 1: Cross-sectional SEM image of LiNbO_x film deposited on NMC811.

The cycling performance of uncoated and LiNbO_x -coated NMC811 cathodes is compared in Fig. 2 for different Li:Nb ratios. While uncoated cathodes show rapid capacity fading, LiNbO_x coatings significantly improve capacity retention. The optimized 1Li:4Nb composition achieves the best stability, with ~90% capacity retention after 100 cycles at 4.3 V. In contrast, the lithium-rich 1Li:1Nb coating shows inferior retention due to chemical inhomogeneity and lower film density.

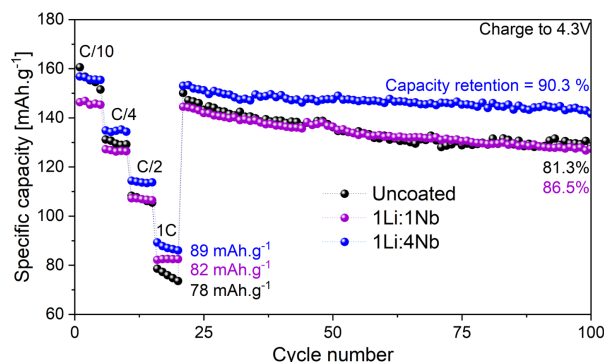


Fig. 2: Cycling performance of uncoated and LiNbO_x -coated NMC cathodes with different Li:Nb composition.

These results demonstrate that the chemical composition, determined via RBS-ERDA, of ultrathin LiNbO_x films critically governs interfacial stability. An optimized Li:Nb ratio enables denser, chemically uniform coatings that effectively suppress parasitic surface reactions. This work highlights the importance of precise thin-film engineering at the atomic scale for extending lithium-ion battery lifetime. The methodology developed here directly supports the design of next-generation protective coatings for high-energy cathodes.

- [1] Li et al., *Electrochem. Energy Reviews*, 3 (2019) 43
- [2] Lapeyre et al., *J. Phys. Chem. C*, 129 (2025) 16409

¹Empa, Switzerland

ESTABLISHING ADVANCED ION IMPLANTATION SYSTEM

Start of the ETHZ-RBI bilateral project on deterministic ion implantation

Z. Siketić¹, A. M. Müller, A. Crnjac, F. Boussahoul¹, M. Matijević¹

A joint research project has recently been established between the ion beam laboratories at ETH Zurich and the Ruđer Bošković Institute (RBI) in Zagreb, Croatia. This initiative is co-funded by the SNF and the Croatian Science Foundation. The objective of the project is to develop a technique for deterministic implantation of keV-energy ions using RBI's ion implanter, which will be equipped with an advanced transmission gas particle detector currently under development at LIP. The first collaborative visit took place in Nov. 2025, when members of RBI visited ETH Zurich. During this visit, two main topics were addressed: the design of a gas detector compatible with the implanter end station, and new ion-optics simulations aimed at optimizing low-energy ion transmission.

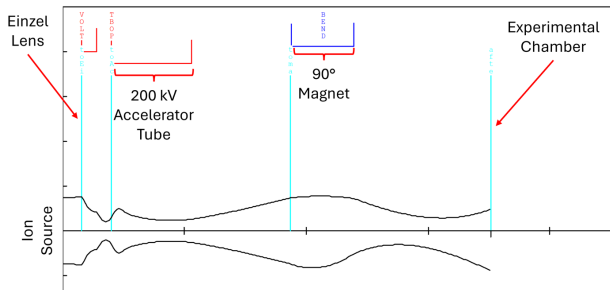


Fig. 1: Ion optics simulation of RBI's current ion implanter setup.

Fig. 1 shows the simulated ion beam optics on RBI's current ion implanter setup. The simulation was performed with the PSI Graphic Transport Framework code [1]. The simulation shows that, although the beam is divergent at the target chamber, the short distance between the magnet exit and the end station (approximately 1.1 m) allows the beam size to be adjusted using a set of slits, without significant degradation of the ion beam current. However, single-ion implantation requires advanced ion-beam manipulation, including beam focusing on the micrometer scale and beam steering. The

integration of these additional components necessitates a comprehensive re-optimization of the beam optics. Consequently, new simulations must be carried out to determine the optimal positioning and settings of all beamline elements using GICOSY [2], which was selected because it allows for the explicit, user-defined modelling of magnetic and electric fringe fields, a capability that is not supported by the Transport PSI code.

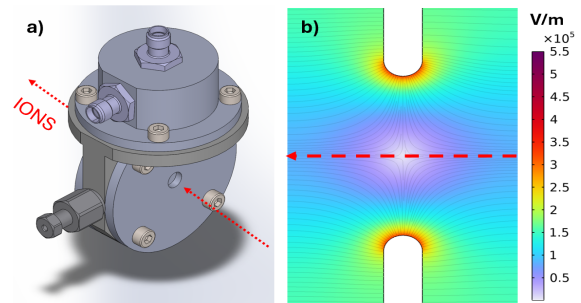


Fig. 2: a) Proposed design of the gas particle detector for ion implantation. b) COMSOL simulation of the electric field inside the detector.

Fig. 2 shows the new design of the transmission gas particle detector, which is central to achieving deterministic ion implantation. The design is subject to strict requirements, as the final device must: be compact to fit inside the vacuum chamber, allow for ion transmission without significant energy loss, and have high detection efficiency to enable single ion implantations. The proposed design satisfies all three requirements and is now progressing into the realization phase of development. During the first half of 2026, members of ETH Zurich will visit RBI to support the installation of the detector.

- [1] PSI Graphic Transport Framework by U. Rohrer
- [2] GICOSY by M. Berz et al.

¹Laboratory for Ion Beam Interactions, Ruđer Bošković Institute, Zagreb, Croatia

DEVELOPMENT OF A WINDOWLESS GAS DETECTOR

Maximizing detection efficiency for minimal energy losses

S. Marty, A. Crnjac, A. M. Müller

Gas ionization chambers are widely used in particle physics experiments. However, the detector analysed in this semester project follows a special objective: traversing ions should lose minimal amounts of energy while still being detected with maximal efficiency. Thus, the detector design shown in Fig. 1 features a movable wire, allowing for the electric field in the detection region to be changed. In addition, the detector relies on a windowless entrance to further reduce the total energy loss. Due to the ensuing gas outflow, the internal gas pressure is limited to below 11 mbar. As for the gas, isobutane C_4H_{10} is used due to its low ionization energy. A photograph of the assembled detector is shown in Fig. 2.

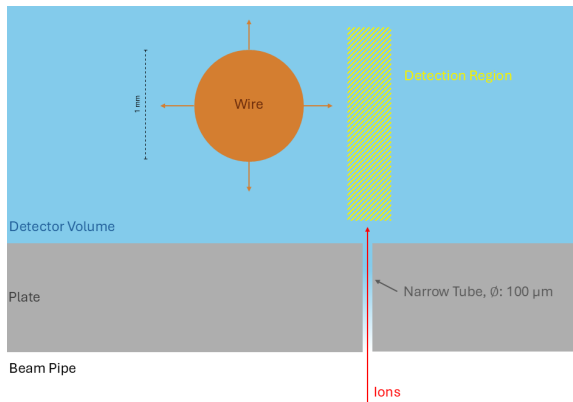


Fig. 1: A schematic of the detection region in the windowless gas ionization detector.

A small energy loss inherently leads to a low number of primary ionizations. Consequently, operation in ionization mode is insufficient, and the detector must be operated in proportional mode where primary electrons are accelerated enough to induce secondary ionizations. The signal on the wire anode is thus amplified enough to allow for detection. The detection efficiency was measured by counting ions simultaneously in the gas volume and in the back-positioned solid-state detector (reference detector).



Fig. 2: A photo of the gas ionization counter showing the anode wire holder and the stainless-steel plate.

When only ions within a coincidence window (timing gate during which the counts were considered as real) of around $30 \mu s$ are counted, efficiencies of around 90% were observed for the most difficult detection case - protons. Disregarding this coincidence time, efficiencies up to 99% were measured. This could indicate that some of the recorded signals in the gas detector are false positives. The voltage applied on the anode wire during these measurements was around 430 V. Since similar efficiencies were measured for different detector geometries, we conclude that the position of the wire is secondary as long as the electric field in the detection region is sufficiently strong. For the pressure, a lower limit of 3 mbar was found, but for pressures from 5 to 8 mbar the results are inconclusive. Lastly, the coincidence time is also bound from below at around $25 \mu s$. This detection principle, where signal gain is achieved through charge multiplication in the gas, has proved very promising, and newer versions of the transmission gas detector have been developed.

WINDOWLESS TRANSMISSION-STYLE GAS DETECTOR

Progress towards deterministic focused ion beam implantation

A. Crnjac, J. Abendroth¹, T. Wulff, S. Marty, C. Vockenhuber, A. M. Müller

Here we report on the progress of developing a novel transmission-style gas ionisation detector that is intended for irradiation of samples with focused ion beam. Previously, a thin SiN (20 nm) entrance window was used as a vacuum-gas barrier (see [1]). Now we have devised a novel windowless detector where ions are injected into the gas volume through a thin (100 μm diameter) opening which holds the gas pressure due to capillary effect. Details of the charge collection principle are shown in Fig. 1.

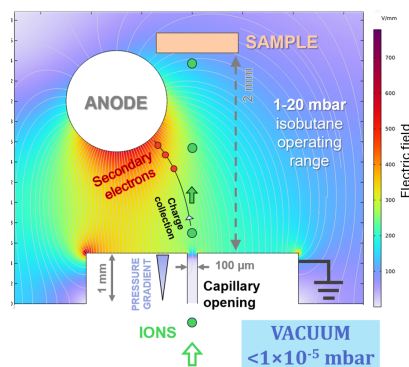


Fig. 1: Charge collection process during ion detection in the novel gas detector.

This new design was first tested as a part of student semester project (S. Marty, results from this work can be seen in a separate report). Detector was tested with several ion species and energies with very promising results in terms of detection efficiency. For example, 2 MeV protons were detected with 99% confidence in the proportional charge collection regime. Further tests were performed with ^{15}N ions. The ion beam was produced from isotopically enriched K- C^{15}N powder. As ^{14}N is a common contaminant in synthetic diamond production, its presence represents a limiting factor in deterministic implantation and NV fabrication studies. Using ^{15}N over ^{14}N is therefore beneficial, as background contamination can be excluded in the analysis. Focused 1.44 MeV ^{15}N was scanned

across detector opening and detected with near 100% efficiency across all scanning positions. Beam focus performance can be seen on transmission map through a micromachined grid with 6 μm bar size (see Fig. 2.-left). We estimated <1 μm beam spot size, limited by ion optics and not interactions in the gas volume (under 5 mbar pressure). This clearly demonstrates that the minimal interaction mechanism in the gas enables preservation of spatial precision in the windowless geometry, which is a significant improvement over our last design.

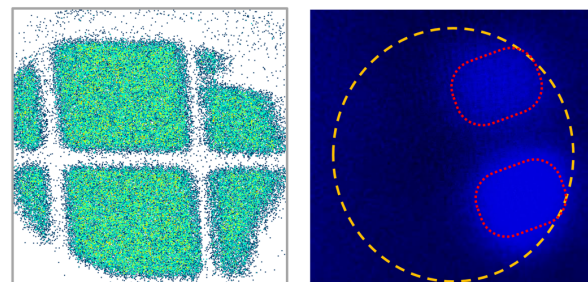


Fig. 2: Implantation of ^{15}N . Left: scan across calibration grid. Right: photoluminescence coming from ion implanted ^{15}N centres in diamond. Scan area covers 100 μm in both cases.

Currently, ion implantation studies with ^{15}N are being conducted (one example with two regions of different fluence can be seen in in Fig. 2. right: photoluminescence map performed after the implantation in the ETHZ “Spin physics group”), including systematic spot irradiation with fluences down to 1 ion/ μm^2 . We expect that these results will support novel understanding of NV formation. The detector was also used to study SiV formation in collaboration with “Hybrid Quantum Systems group ETHZ” (see report [2]).

[1] Crnjac et al., *Eur. Phys. Jour. Plus* (2025)

[2] C. Adambukulam, Annual Reports 2025, 80

¹Spin physics group, D-PHYS, ETH Zurich

TRANSITION METAL FLUORIDE CATHODES IN BATTERIES

High energy cathodes in thin-film solid-state batteries

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Lithium-ion batteries are reaching intrinsic limits in energy density, prompting exploration of conversion-type cathodes with theoretical energy densities up to 4 times higher than for common intercalation cathodes. Transition-metal fluorides (TMFs) are promising candidates due to their high voltage and capacities. However, their mainstream implementation remains limited by poor reversibility, kinetic losses, and interfacial instability. These works establish a thin-film solid-state platform enabling systematic, additive-free evaluation of TMF cathodes and reveal key structure–property relationships governing their electrochemical operation.

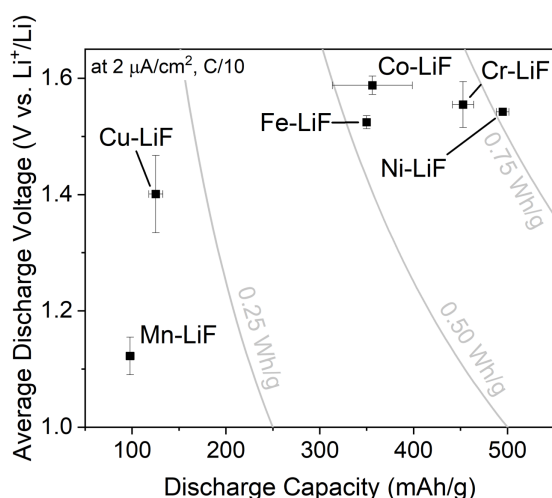


Fig. 1: Voltage vs. Capacity of the lithiated TMF conversion cathodes of Cr, Mn, Fe, Co, Ni, and Cu.

A LiPON-based solid-state thin-film architecture was developed and demonstrated with FeF₂, achieving stable long-term cycling and after 2000 cycles a capacity increase approaching its theoretical limit [1]. This framework enabled direct comparison of six TMF chemistries (Cr, Mn, Fe, Co, Ni, and Cu), evidencing substantial performance differences (Figs. 1 and 2) [2]. Of

the tested single-metal cathodes, Cr-based TMFs consistently delivered the highest capacities and rate capability (Fig. 2). Combined experimental and first-principles analysis identified the dominant conversion pathways occurring during cycling [3].

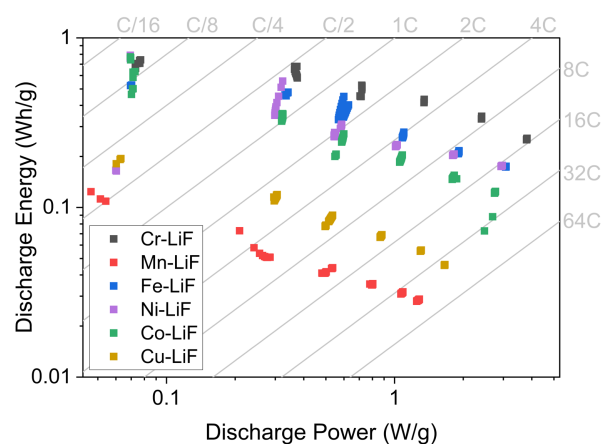


Fig. 2: Ragone plot of the lithiated TMF conversion cathodes of Cr, Mn, Fe, Co, Ni, and Cu.

Overall, these works provide the first systematic thin-film benchmarking of TMF conversion cathodes, expands viable material candidates beyond state-of-the-art FeF₂, and delivers a dataset and mechanistic framework to guide rational design of next-generation high-energy solid-state batteries.

- [1] J. Casella et al., ACS Nano 2024 18 (5), 4352
- [2] J. Casella et al., ACS Applied Energy Materials 2025 8 (20), 15101
- [3] J. Casella et al., ChemRxiv. 2025

¹Thin Films & Photovoltaics, Empa

²Electron Microscopy, Empa

³Materials, University of Oxford, UK

⁴Ion Beam Physics, ETH Zürich

⁵Electronics, ITET, ETH Zürich

IN-OPERANDO MATERIAL SCIENCE USING ERDA

New device to monitor hydrogen diffusion in real-time

T. Wulff, A. M. Müller, C. Menegus¹, C. Cancellieri¹

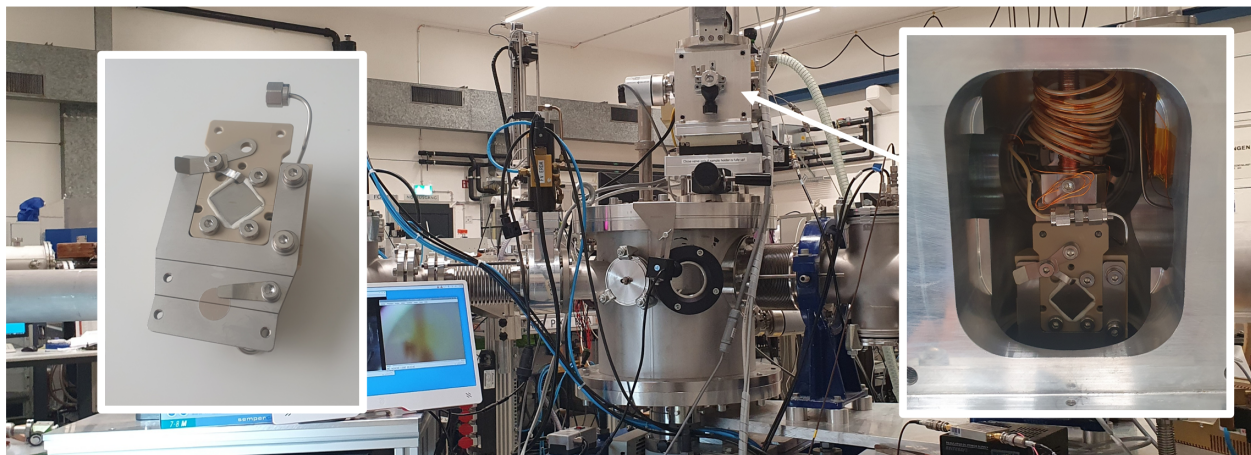


Fig. 1: ERDA measurement chamber flanked by an image of the electrolysis cell (left) and the cell being installed in ERDA's sample transfer lock (right). The sample is the metal square glued to the cell.

In the context of a growing hydrogen economy, hydrogen storage and transport have become urgent issues, fueling a demand to investigate its interaction with container materials. To observe the permeation of hydrogen through steel in-operando, LIP and Empa developed an electrolysis cell that can be used inside LIP's Elastic Recoil Detection Analysis (ERDA) facility.

With the sample acting as the cathode, electrochemical charging enables the introduction of hydrogen into the sample by generating atomic hydrogen on its surface. Adjusting the applied current, the amount of hydrogen produced can be controlled. A fraction of the atomic hydrogen recombines to form molecular hydrogen gas, while the remainder is absorbed into the sample. The absorbed hydrogen diffuses through the sample and is detected on the opposite side, providing in-operando information about the hydrogen diffusion profile within the material.

Two major constraints drove the cell's design. First, the electrolysis creates gaseous hydrogen and oxygen. However, a pressure build-up inside the cell would be dangerous for ERDA as well as

it would have an influence on the permeation rate. To keep its internal pressure stable, the cell is connected to the outside atmosphere. Inside ERDA's vacuum chamber this connection leads to a nominal overpressure of one bar inside the cell which has a strong implication on the second constraint: The ion beam's angle of incidence on the sample surface is 18° . Structures extending above the surface of the sample to hold it down mechanically can easily interfere with the beam. For this reason, in the first version of the cell, the sample was glued to the cell and the bonding was extensively tested. Although the bonding technique and the cell proved to reliably withstand pressures of up to six bars, chemical compatibility issues led to the design of a second version of the cell. In the new design, the sample is mechanically fixed and the usage of glue is no longer necessary. Work on this design has been finished as of the time this article is written. However, with manufacturing and assembly being planned for January 2026, no proof of concept can yet be presented.

¹Empa, Dübendorf

FUTURE MICRO PIXE CAPABILITIES AT LIP

Proof-of-principle experiment with a borrowed X-ray detector

A. Crnjac, C. Vockenhuber, A. M. Müller, M. Stükelberger¹

LIP is planning to implement a micro-PIXE experiment at the micro beam end-station of the 1.7 MV Tandetron facility, which is intended to be used in the frame of In-Group Project (IGP) as a part of the D-Phys practica. A proof-of-principle test was carried out using an SDD detector temporarily borrowed from Deutsches Elektronen-Synchrotron (DESY) research centre (by kind offer from Dr. M. Stükelberger). Even with a non-optimised detector geometry (Fig. 1)—where the detector was positioned outside the vacuum chamber, resulting in a very small solid angle—element-specific X-ray maps were successfully acquired.

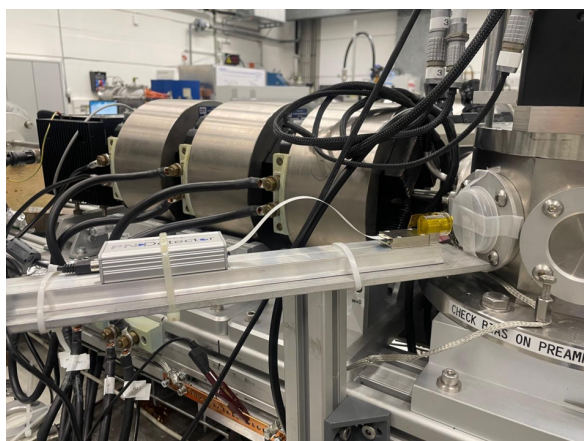


Fig. 1: X-Ray detector temporarily mounted at the micro-beam end-station.

If an appropriate detector is bought, solid angle would be increased by more than two orders of magnitude, which would enable fast and efficient map collection. Several historical Swiss stamps with postmarks from the Bern Museum were analysed to identify pigment compositions used in 19th-century. In Fig. 2 we show one example from this preparatory experiment. A portion of the stamp was exposed to the scanning 2 MeV protons ion beam, while also observed under the optical microscope. One can quickly identify from

which features on the stamp the emission is stemming.

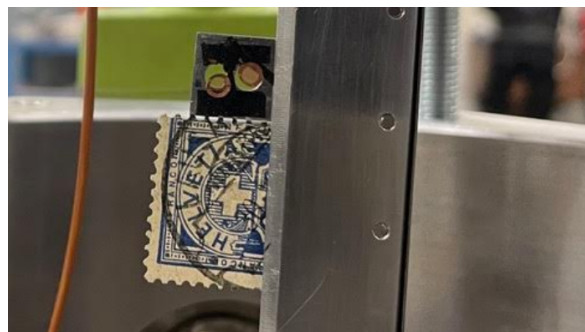


Fig. 2: Postmark mounted on the sample holder.

As an example, we extracted an intensity map of all X-ray events (Fig. 3). These measurements demonstrated the feasibility of micro-PIXE pigment analysis on objects of cultural heritage (e.g. paintings, manuscripts, stamps, etc.) where X-ray based localized elemental information can help in origination, dating and restoration of such objects. If this IGP is established, current research activities at LIP will be widened to include a wider range of similar analyses for identification of pigment mixtures, historical manufacturing techniques and degradation processes.

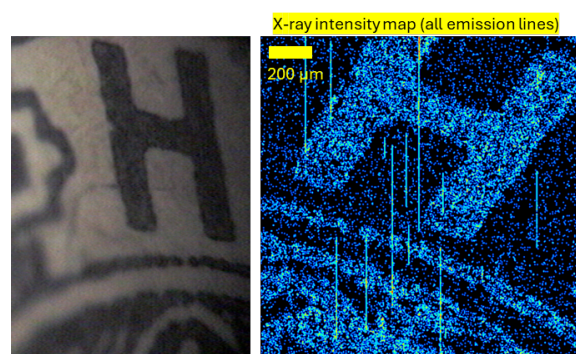


Fig. 3: X-Ray intensity map of the postmark excerpt on the left side

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ELEMENTAL PROFILING OF SILICON NITRIDE MEMBRANES

Effect of stoichiometry and H on the quality factor of SiN membranes

G. Benga¹, A. Eichler¹, A. M. Müller¹, A. Armanious¹

Silicon nitride (SiN) thin membranes are widely regarded as ideal candidates for quantum applications due to their exceptionally high mechanical quality factors, primarily enabled by large intrinsic tensile stresses through a mechanism known as dissipation dilution. While this effect significantly reduces energy losses, further improvements in the intrinsic quality factor—i.e., losses directly related to the material itself—remain essential for advancing quantum technologies.

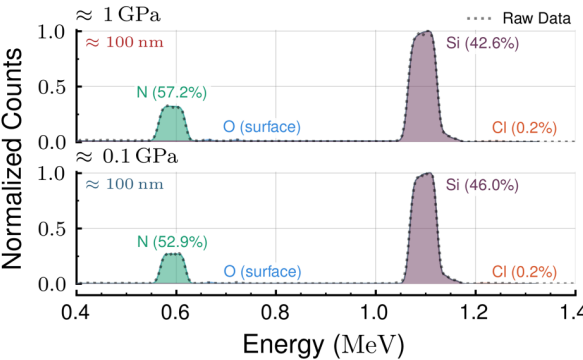


Fig. 1: RBS data of high (top) and low (bottom) stress 100 nm Silicon Nitride thin film.

Material properties such as stoichiometry [1] and hydrogen [2] incorporation are believed to play a key role in determining the intrinsic dissipation mechanisms of SiN membranes. To investigate these effects, Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA) were employed to obtain detailed elemental profiles of membranes with different stress levels. The measurements revealed substantial differences between low-stress and high-stress membranes. High-stress membranes (≈ 1 GPa) were found to be primarily composed of stoichiometric silicon nitride (Si_3N_4), whereas low-stress membranes (≈ 0.1 GPa) exhibited a reduced Si:N ratio of approximately 0.87:1 (Fig. 1). Interestingly, despite their superior mechanical performance,

the high-stress membranes contained nearly five times higher hydrogen concentration compared to their low-stress counterparts (Fig. 2), with hydrogen evenly distributed across the membrane. In addition, trace amounts of chlorine were detected in both types of membranes, along with the presence of oxide layers on the membrane surfaces.

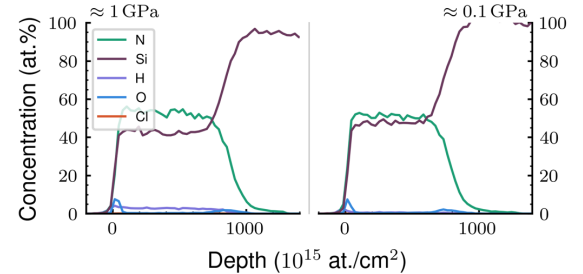


Fig. 2: ERDA data of high (left) and low (right) stress 100 nm Silicon Nitride thin film.

These findings represent one of the first detailed elemental composition profiles of SiN membranes, providing valuable insight into the correlation between material composition and mechanical quality factor. Ongoing work focuses on deliberately manipulating the composition — verified through ion beam analysis — and assessing the impact on quality factors, with the goal of engineering resonators that reliably operate in the quantum regime.

	Si:N	H:N
Low Stress	≈ 0.87	≈ 0.01
High Stress	≈ 0.75	≈ 0.05

Tab. 1: Summary of elemental composition

- [1] Villanueva, L. G. & Schmid, S. Phys. Rev. Lett. 113 (2014) 227201
- [2] Mittal, S. et al. Phys. Rev. Appl. 21 (2024) 054044

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SILICON IMPLANTATION IN DIAMOND

Spin-based colour centres for quantum bulk acoustic wave devices

C. Adambukulam¹, A. Crnjac, A. M. Müller

Spin-based atomistic point defects – also known as colour centres – in wideband semiconductors such as diamond have become promising platforms for the development of quantum memories [1], particularly in the context of long-distance quantum networking [2]. This follows from the long spin coherence times [1] and optical access provided in the spin sub-levels of these defects. However, coupling colour centres to other physical implementations of quantum bits (qubits) – notably those more amenable to the construction of a quantum computer (e.g. superconducting circuits) – has remained undemonstrated and is technically challenging. This project aims to couple the spin of an individual colour centre to single bulk phonons and thereby provide an intermediary to couple the spin to wide variety of different solid-state qubits. A particular focus would be to interface the colour centre via phonons to a superconducting circuit, for which an acoustic interface has been previously demonstrated [3].

Owing to its large elastic dipole and excellent coherence properties, the silicon vacancy (SiV) in diamond is the natural candidate for engineering spin-phonon coupling. To do so requires its incorporation into an acoustic resonator – for which we use a high-overtone bulk acoustic wave resonator (HBAR). Due to the nature of the HBAR, spin-phonon interactions occur within the bulk of the diamond from which the HBAR is constructed and that hosts the SiVs. In our case, strongest interactions occur at 1.5 μm from the surface of the substrate. To that end, we implant the substrate with ^{28}Si at an energy of 5 MeV, as determined by a simulation using the Transport of Ions in Matter (TRIM) package of Stopping Ranges of Ions in Matter (SRIM) software suite. At such large energies, the process of ion implantation produces significant damage. While a portion of that damage may be repaired via a

high temperature anneal, the overall process can produce spurious defects.

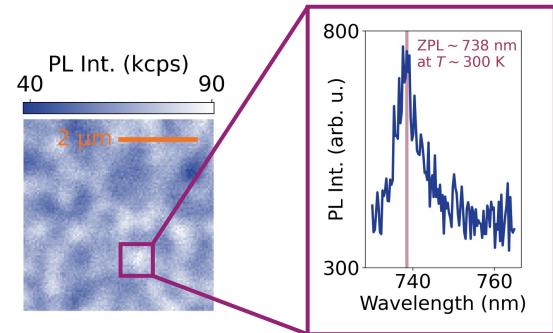


Fig. 1: (left): Fluorescence image of SiVs in diamond. (right): Fluorescence spectrum of selected SiV.

At 5 MeV, an insufficient ^{28}Si fluence can suppress the creation of SiVs and instead produce nitrogen vacancy (NV) centres. These form due to the residual nitrogen within the substrate, as nitrogen is a common and somewhat unavoidable contaminant during diamond growth. To determine the appropriate ^{28}Si fluence, we performed implantation with a focused ion beam (spot size $\sim 50 \mu\text{m}$) to create multiple zones of differing fluence from which an optimum was determined. The effect of implantation damage on the quality of the HBAR is also a concern. While preliminary experiments show little difference between implanted and un-implanted HBARs, we are exploring the use of written, focused ion beam (spot size $\sim 2 \mu\text{m}$) implantation and single ion counting to implant the minimal necessary amount of ions within the confines of the HBAR and in doing so, limit the induced damage for potentially better devices.

- [1] Sukachev et al., Phys. Rev. Lett. 119 (2017)
- [2] Bersin et al., Phys. Rev. Appl. 21 (2024)
- [3] Bild et al., Science 380 (2023) 274

¹Hybrid Quantum Systems Group, D-PHYS, ETH Zurich

OXYNITRIDES FOR SOLAR HYDROGEN PRODUCTION

Advanced PLD fabrication techniques for thin film photoanodes

K.J. Stephens^{1,2}, D. Pergolesi¹, A. M. Müller, T. Lippert^{1,2}

Production of hydrogen in a sustainable way is very important as it is a high-volume product used in many vital areas of our society. Some of its most common applications are in ammonia production for fertilizers, crude oil refining, and fuel cells for vehicles [1]. Currently, the majority of hydrogen is obtained from hydrocarbon feedstocks, and as we shift away from this direction there will be a need for alternative, carbon-neutral production methods. Water electrolysis provides an avenue for this need with many options of implementation. One of which is a photocatalytic system that utilizes the energy of sunlight to drive water electrolysis, or “water splitting”, to generate hydrogen.

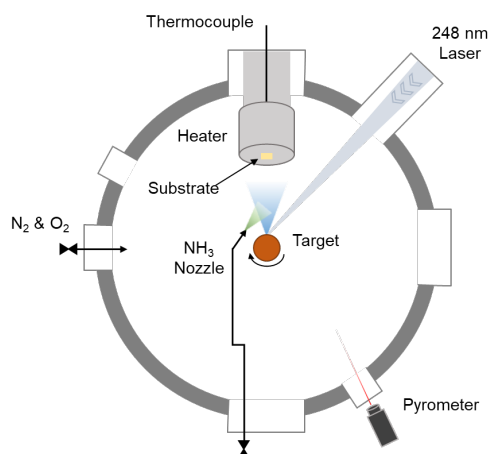


Fig. 1: Top-down view of a PRCLA setup.

In the development of photocatalysts, our group mainly uses materials in the form of epitaxial “thin films” with thickness in the nanometer regime. Our lab employs the pulsed laser deposition (PLD) method [2] to fabricate complete photoanodes on MgO single crystal substrates with a 50 nm TiN conducting layer and a 100 nm LaTiO_xN_y photoactive layer; cocatalysts such as NiO_x are also employed as overlayers. Nitrogen is notoriously difficult to incorporate into the oxynitride films, so pulsed reactive cross-beam laser ablation (PRCLA, [3]) with ammonia

gas is being developed to improve this deficiency which is important for band gap optimization. An example of this setup is seen in Fig. 1.

The elemental composition of the grown films must be determined after PRCLA in order to establish the technique, a solution that Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA) measurements with LIP provides. Figure 2 shows an example of RBS/ERDA on a LaTiO_xN_y photoanode system where its N/O ratio was determined.

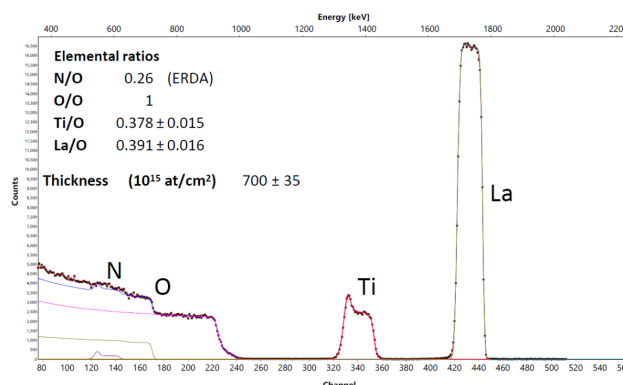


Fig. 2: RBS/ERDA results of a $\text{LaTiO}_x\text{N}_y/\text{TiN}$ photoanode fabricated with PRCLA.

The nitrogen content achieved here surpasses all previous attempts for this technique, allowing us to approach proper perovskite stoichiometries of ABO_2N . This will improve performance and enable more meaningful fundamental studies in the future.

- [1] T. Capurso et al., *Energy Convers. Manag.*, 251 (2022) 114898
- [2] N.A. Shepelin et al., *Chem. Soc. Rev.* 52 (2023) 2294
- [3] P.R. Willmott, *Appl. Phys. A* 69 (1999) S437

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MICROSTRUCTURE & MECHANICS FROM PROCESSING

Micromechanical insights into 3D printed and sintered NiTiNb alloys

N. Abando¹, R.A. Gallivan¹, N. Toncich¹, A. M. Müller², R. Spolenak

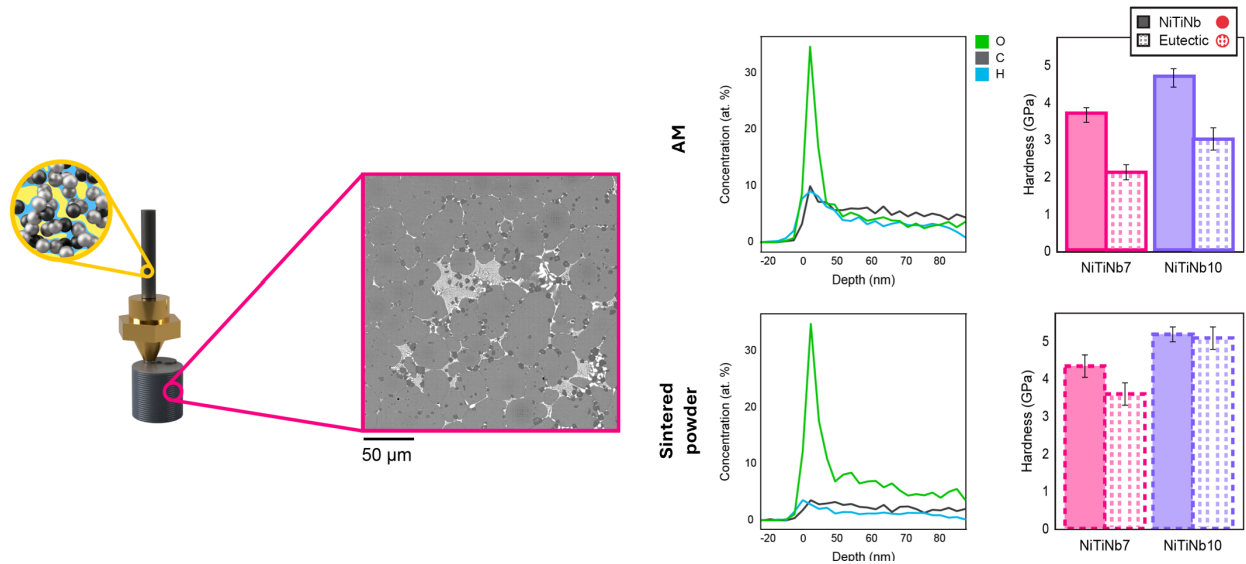


Fig. 1: Schematic of metal filament-based printing, showing the microstructure of one of the studied alloys after sintering. Despite the increased carbon and hydrogen in additive manufacturing (AM) shown with Hi ToF-ERDA measurements, hardness data presents a strong correlation with local Nb concentration.

The combination of active materials with complex geometries enabled by additive manufacturing (AM) allows access to unprecedented mechanical responses. Among available techniques, filament-based materials extrusion (f-MEX) offers exceptional design freedom for metals, though final properties are often limited by poor sintering behavior. While current filament formulations focus on polymeric additives, the role of metallic additives remains underexplored.

In this work [1], Nb powder is added to NiTi filaments to promote liquid-phase sintering and significantly reduce densification time. This alloying approach produces eutectic pools and a complex microstructure containing Nb- and Ti-rich precipitates. Although binder-derived light elements such as carbon are known to influence mechanical properties, no direct correlation is observed here. To accurately quantify binder contributions, Hi ToF-ERDA measurements were performed at LIP.

The mechanical behavior is dominated by local composition and solid-solution hardening effects from Nb. However, pronounced Nb concentration gradients and Nb-free regions are observed in both printed and powder samples due to residual B19' regions in as-received powders, leads to spatially distinct alloy features. Optimized short sintering times inhibit full diffusion equilibrium, preserving remnants of the original powder state, as observed with X-Ray diffraction. Overall, this study highlights sintering-optimized strategies for extrusion-based metal AM and provides micromechanical insight into the spatial complexity of NiTiNb, supporting the design and optimization of functional properties in additively manufactured shape memory alloys. Manufacturing and assembly is planned for early 2026.

[1] N. Abando et al., Adv. Eng. Mat. (2025)

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ION MICROBEAM STUDIES OF N-LGAD DETECTOR

Ion beam-induced donor removal and Global Gain Quenching (GGQ)

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Recently, a new Si-based technological solution for the detection of shallow-penetrating radiation (1 μm of depth) has been proposed by IMB-CNM. A detector based on an n-type substrate using low-gain avalanche technology (named nLGAD) has been demonstrated to successfully detect shallow-penetrating photons down to 250 nm with high gain (20–40), with new fabrication runs aiming to push its sensitivity down to soft X-rays, ideally in single-photon mode.

For the purpose of extending its application, experiments with heavy ions have been performed at the Laboratory of Ion Beam Physics at ETH Zürich. Using a 1.7 MV Tandetron HVEE electrostatic accelerator, 1'285 MeV gallium ions were used to probe the detector response with the aim of estimating gain capabilities and radiation hardness. This energy was chosen intentionally, as the ions deposit their energy directly in the so-called gain layer, consisting of moderately doped silicon with phosphorus atoms. Localized irradiation of a small area of $250 \times 280 \mu\text{m}^2$ was selected with two different ion fluences, and the charge collection efficiency maps are shown in Fig. 1.

The results show that nLGAD has a pronounced vulnerability to heavy-ion exposure, as gain loss is observed at fluences as low as 4×10^9 ions/cm². Within the irradiated regions, the gain layer becomes effectively inactive due to an effect called donor removal. This effect is microscopically under investigation by techniques such as DLTS and TSC, which indicate that the inactivation of gain most probably occurs via VP defect creation, by which phosphorus atoms become electrically inactive.

Beyond the locally irradiated zones, a global reduction of charge collection efficiency was observed across the detector in pristine regions. This unexpected long-range effect indicates a

global modification of the internal electric field triggered by permanent localized damage in the multiplication layer.

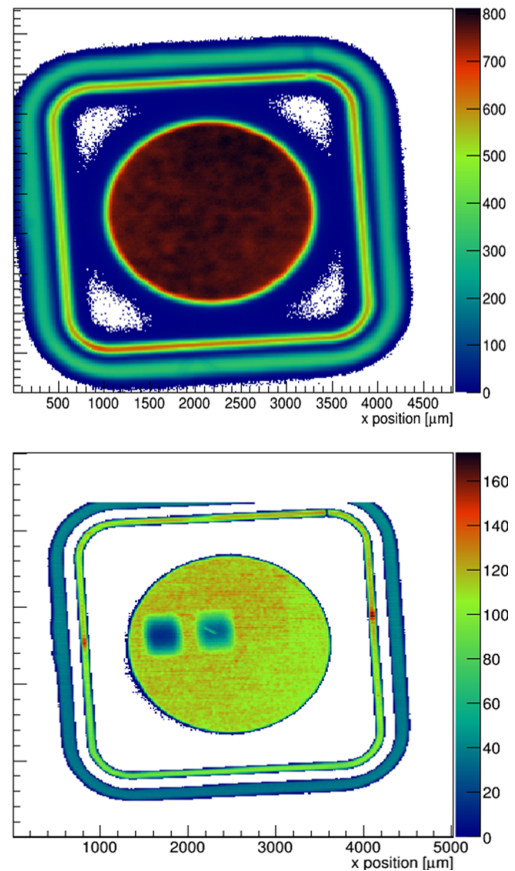


Fig. 1: 2D generated charge plot of the nLGAD sample: before (top), after irradiation (bottom).

This phenomenon is referred to as *Global Gain Quenching (GGQ)* and is reported in our work for the first time. This work has high impact on the fundamental understanding of the donor removal mechanism relevant for the so-called compensated LGAD design and deep-junction (DJ-LGAD) for HL-LHC.

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IMPACT OF STRATOSPHERIC AEROSOL INJECTION ON O₃

HNO₃ and HCl heterogenic chemistry with CaCO₃ aerosol particles

C. Paolucci¹, S. Vattioni², A. M. Müller, C. Vockenhuber, M. Ammann¹

Insufficient action in climate change mitigation is driving research on solar radiation modification via stratospheric aerosol injection (SAI), i.e., the injection of aerosols or their precursors into the stratosphere to increase Earth's albedo, inducing global cooling. Recent studies suggest injection of solid particles such as calcite (CaCO₃) and alumina (Al₂O₃) [1]. Expanding available surface for heterogeneous chemistry in the stratosphere could increase ozone (O₃) depletion by moving passive reservoir species (HCl, ClONO₂) to their active, O₃ depleting form (ClO). Furthermore, basic mineral particles such as CaCO₃ could provide a sink for the reservoir species. Removal of HCl would be beneficial to the O₃ layer while removal of HNO₃ would likely be detrimental. However, the heterogeneous mechanisms and kinetics of the important reactions are poorly constrained by lab experiments [2].

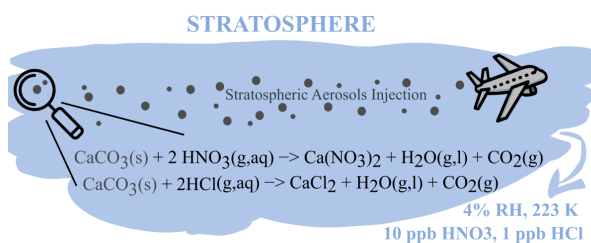


Fig. 1: Schematic of relevant heterogeneous reactions on CaCO₃ in regards to stratospheric O₃ cycle.

The objective of this study is to investigate heterogeneous reactions of stratospheric gases such as HNO₃ and HCl with CaCO₃ and Al₂O₃ and follow up earlier studies by Vattioni [3]. Several research gaps such as uptake studies at stratospheric temperatures (from -60°C to -30°C) and under long-term exposure, the role of RH in reactivity and hydrates formation, or the combined exposure to acidic gases are being investigated. Surface characterization is performed using Heavy Ion Elastic Recoil Detection Analysis (HI-ERDA) after long-term

exposure of samples and with in-situ Ambient Pressure X-Ray Photoelectron Spectroscopy (AP-XPS). CaCO₃ crystals were exposed to HNO₃ under near-stratospheric conditions for 15 days. After exposure, surface reaction and diffusion in the bulk was characterized with ERDA. First experiments show increased uptake uptake with increased Relative Humidity (RH) (Fig. 2).

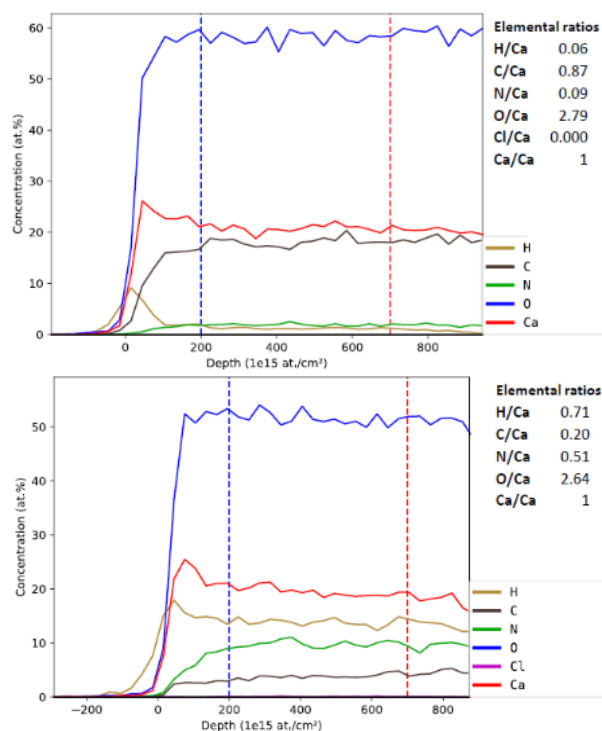


Fig. 2: Elemental depth profile of CaCO₃ reacted with HNO₃ under RH of 1.7% (above) and 10.7% (below).

- [1] D. W. Keith et al., PNAS, 2016
- [2] S. Vattioni et al., Commun. Earth Environ., 2025
- [3] S. Vattioni, PhD Thesis, ETH 2024

¹Atmospheric Chemistry, PSI, Villigen

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RESONANT OXYGEN QUANTIFICATION IN RÖNTGEN FILM

Quantitative and highly accurate characterization of Ho₂O₃ with RBS

S. Rameshbabu^{1,2}, A. M. Müller, C. Vockenhuber, D. Bleiner^{1,2,3}

Holmium oxide (Ho₂O₃) is a rare-earth oxide enabling application as “Röntgen material” for X-ray laser on a chip. The Ho₂O₃ thin film grown by pulsed laser deposition was quantitatively examined using Rutherford Backscattering Spectrometry (RBS) [1]. To accurately determine the oxygen content, the measurement was carried out under a resonance-enhanced condition, which increases the energy sensitivity for light elements. Because both the Ho₂O₃ layer and the substrate are highly dielectric, a thin gold overlayer was applied to ensure sufficient surface conductivity and suppress charging effects. The beam energy was accordingly increased to account for energy losses within the Au layer and to access the resonance region. RBS measurements were run at 3.06 MeV He²⁺ ion beam incident at 7°, while backscattered ions were detected at a scattering angle of 167.5°. The measured spectrum and the corresponding SIMNRA fit are shown in Fig. 1.

grown with 18’000 laser pulses. Notably, the oxygen edge in the film was increased in the resonance condition paving the way for precise quantification. The Au capping layer was determined to have an areal density corresponding to a thickness of 31 ± 1.6 nm (185 ± 9 × 10¹⁵ at cm⁻²). The Ho₂O₃ layer displayed an areal density equivalent to a thickness of 218 ± 11 nm (1464 ± 73 × 10¹⁵ at cm⁻²). Importantly, the film maintained stoichiometric integrity, with Ho and O concentrations measured at 39.5 ± 1.6 at% and 60.5 ± 0.6 at%, respectively. The quantified data was provided in Tab. 1.

	Ho	O	Thickness (nm)
Thin film (at %)	40 ± 1.6	60 ± 0.6	218 ± 11

Tab. 1: Elemental quantification obtained from RBS analysis.

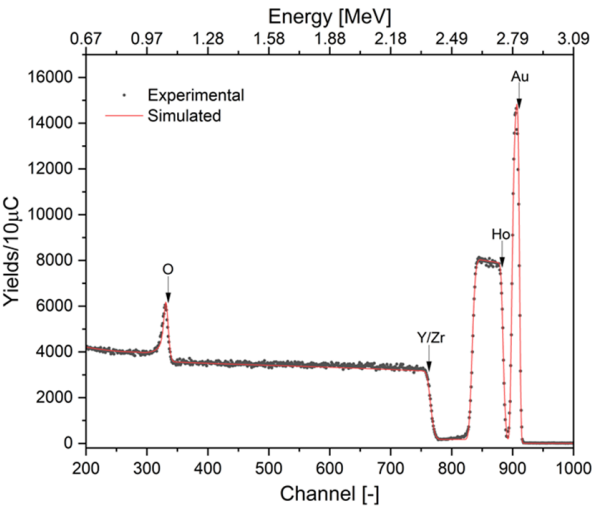


Fig. 1: RBS data of the LSCO thin film was collected under the ¹⁶O resonance condition.

The substrate was utilized as an internal standard for calibrating the detector’s solid angle. Fig. 1 presents the RBS spectrum of the Ho₂O₃ thin film

[1] R. Sharath, et al., Optical Materials (2025) 117557

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RECYCLING OF SILICON PV MODULES

Implantation of Cu impurities in monocrystalline Si solar cells

A. M. Müller, C. Vockenhuber, M. Stückelberger¹, T. Kaiser¹

In the frame of the Remade@ARI [1] proposal, implantation experiments in monocrystalline Si solar cell were performed, investigate possible and efficient recycling schemes for PV modules. Studies demonstrated a decrease in efficiency for recycled modules, which was attributed partially to impurities. Different spatially patterned fluences were implanted into a Si crystal as a basis for manufacturing PV modules to investigate and characterize the degradation dependent on the distribution and number of impurities.

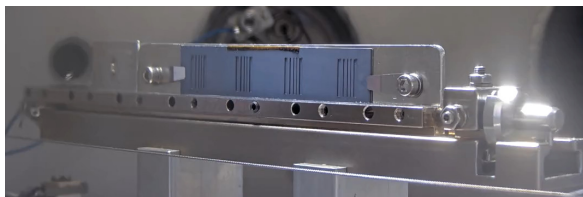


Fig. 1: Stripe of a high purity Si wafer mounted on the sample holder with a patterned Si mask. The holder is introduced into the implantation chamber at the 6 MV Tandem accelerator facility.

Implantation runs were performed in April 2025 at the 6 MV Tandem accelerator with Cu at 44 MeV and fluences ranging from 10^{14} - 10^{15} at/cm². Several sets of Si crystals equipped with patterned masks were transferred into the implantation chamber after the 15° ESA (Fig. 1). An elaborate preparation of these experiments was performed, since both the irradiation area and the energy of the Cu beam needed to be maximized. Magnetic steerers installed in front of 15° ESA and controlled by two triangular function generators were used to sweep and homogenize the irradiation area. Numerous test runs were conducted in advance to find the optimal parameters regarding efficiency, energy and irradiation homogeneity (Fig. 2). Due to the limited energy dispersion of the ESA the implantation area needed to be restricted to $6 \times 10 \text{ mm}^2$ for Cu in the 7+ charge state. Otherwise,

neighboring charge states would also pass the apertures in front of the chamber. Easy to use sample holders were built to hold the Si stripes with minimal mechanical stress (Fig. 3).

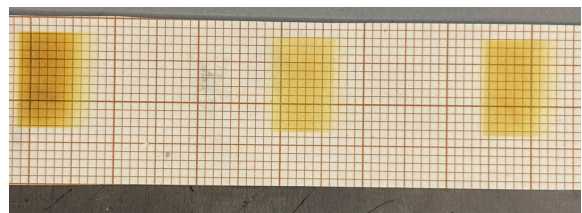


Fig. 2: Graph paper was used to visualize the improvement of homogeneity of the irradiation.

The irradiated Si stripes will be processed further towards operatable PV modules. After the processing it is planned to investigate the elemental distribution, electrical performance and the crystallographic defects by X-ray (XRF, XBIC & XRD) and ion beam (PIXE & IBIC) techniques.



Fig. 3: Mounting of the Si stripes and masks.

- [1] Remade@ARI co-funded by the EU Horizon Europe programme, UKRI & SERI (www.remade-projet.eu)
- [2] Xin L., et al. Sci. Technol. Adv. Mater. 20(1) (2019) 813

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EDUCATION AND OUTREACH



Organization committee of the ECAART 15 conference

ECAART 15 conference in Zurich

Lab tours at LIP

ETH Studienwoche 2025

The LIP snow day

ECAART 15 CONFERENCE IN ZURICH

Welcoming the international accelerator community at ETH Zurich

A. M. Müller, scientific and technical staff of Laboratory of Ion Beam Physics



Fig. 1: Conference photo in front of HPH building.

In 2025, LIP had the great honor to host the 15th European Conference on Accelerators in Applied Research and Technology (ECAART 15) from September 8th to 12th, 30 years after gathering the conference for the first time. The venue was located on the campus Höggerberg, ETH Zurich. Approximately 100 participants from 24 countries were attending the conference (Fig. 1). A broad variety of accelerator-related topics were covered and presented during this week: latest developments in accelerator technologies, fundamentals and simulations, IBMM, IBA, AMS as well as applications in nuclear physics, quantum technology, life sciences and cultural heritage.

In the tradition of the ECAART conference, no parallel oral sessions were organized, so that the participants had the chance to follow the entire scientific program. Two poster sessions were held in a nice atmosphere with food and drinks to facilitate coming together, enabling fruitful scientific discussions and to promote personal academic collaboration (Fig. 2). Student awards were granted for the best oral and poster presentation.



Fig. 2: Lively scientific discussions at one of the two poster sessions.

The program was completed by a broad variety of social activities. Several visits were offered to the participants. At the ice-breaker, aperitif tours through the labs of LIP were offered (Fig. 3). The participants had also the opportunity to visit the production site of the Ionplus company and to attend guided tours through the monastery of Einsiedeln and the laboratories of PSI as the crowning finale of the 15th ECAART conference.



Fig. 3: The participants had the chance to visit the LIP facilities during the conference ice breaker to initiate scientific discussions.

LAB TOURS AT LIP

A closer look at our accelerator facilities

U. Ramsperger, scientific and technical staff of Laboratory of Ion Beam Physics

Each year, the Laboratory of Ion Beam Physics (LIP) is pleased to welcome visitors interested in learning about our research facilities. In 2025 we hosted over 25 classes and groups, in total around 300 visitors. Our lab features a range of AMS (Accelerator Mass Spectrometry) systems with different accelerators, housed in over 500 m² of space. These instruments support a variety of research projects and reflect the experience our team has developed in accelerator technology over the years.



Fig. 1: Dr. A. Müller presents the 6 MV Tandem accelerator (visible in the background).

In last year's annual report, we highlighted our lab tour program and the opportunities it offers [1]. In this year's report, we turn our focus to the heart of our research infrastructure. Our accelerator park comprises eight state-of-the-art machines, each tailored for specific applications:

Radiocarbon Measurements:

- **LEA** (operational at LIP since 2022, prototype): An AMS system with a 50 kV tandem accelerator designed for both solid and gas targets.

- **LIP-MICADAS** (since 2016): An AMS system with a 200 kV tandem accelerator dedicated to solid targets.
- **Proto-MICADAS** (since 2004, prototype): An AMS system with a 200 kV tandem accelerator now exclusively used for gas targets.

Multi-Isotope AMS:

- **MILEA** (since 2017): A 300 kV tandem accelerator enabling multi-isotope analysis of ¹⁰Be, ¹⁴C, ²⁶Al, ⁴¹Ca, ¹²⁹I, and actinides.
- **Tandy** (since 1998, prototype): Our 600 kV tandem accelerator for multi-isotope AMS for ¹⁰Be, ¹⁴C, ²⁶Al, ⁴¹Ca, ¹²⁹I, and actinides.

Specialized Accelerators:

- **Tandem** (since 1963): A historic 6 MV accelerator, adapted for AMS in 1979, still in use for ³²Si and ³⁶Cl measurements.
- **Tandetron** (since 2017): A 1.7 MV system for Ion Beam Analysis (IBA), Rutherford Backscattering Spectrometry (RBS), Elastic Recoil Detection Analysis (ERDA), and microbeam applications.
- **MiQ-MICADAS** (since 2025): A 200 kV accelerator currently being converted for innovative Laser based isobar separation experiments.

Our lab tours offer a unique opportunity to see these remarkable machines in action, learn about their scientific applications, and engage with the researchers who operate them.

[1] U. Ramsperger, Annual report 2024, 94

ETH STUDIENWOCHE 2025

Bomb peak embedded in a Carnegiea Gigantea

U. Ramsperger, M. Bolandini, D. Frank¹, C. L. Pearson¹, A. S. Studer, L. Wacker, M. Christl

Following our annual tradition, we welcomed five students from academic secondary schools across different regions of Switzerland. This year's primary objective was to estimate the age and growth rates of a cactus from a series of cactus spines. The spines were collected from a cactus in Tucson, Arizona, labelled, and sent by post to ETH.

Carnegiea gigantea, commonly known as the Saguaro cactus, is native to the region surrounding Tucson. Saguaro is well-known for its remarkable size and longevity, reaching heights of up to 20 meters and lifespans exceeding 200 years (Fig. 1).



Fig. 1: *Carnegiea gigantea* in Tucson, Arizona from which the spines were sampled. All samples are taken from the main stem. The oldest measured spine, located 19 cm above ground level, dated to 1958; therefore, the plant is older than 73 years.

The students' task was to prepare the samples for measurement on one of our AMS systems. Sample preparation and reduction to pure graphite take approximately two days, while the AMS measurements require about 24 hours. Afterward, the students analysed the results, which are presented in the form of a poster on the final day of the course (Fig. 2).



Fig. 2: The five students presenting their poster prior to the final-day poster session with fellow students.

The growth pattern of the Saguaro reflects its age and developmental history. The spines on the main stem are arranged chronologically, with the oldest spines located at the base of the trunk and progressively younger spines toward the apex. This vertical gradient in spine age serves as a useful indicator of both cactus growth rates and atmospheric radiocarbon production over time. The complete results are reported elsewhere [1].

[1] U. Ramsperger, Annual report 2025, 42

¹LTRR, Univ. of Arizona, Tucson, USA

THE LIP SNOW DAY

Enjoying a beautiful winter day together

C. Vockenhuber, all staff, Laboratory of Ion Beam Physics



Fig. 1: Group picture of LIP snow day.

After several years we revived a LIP tradition in 2025. The first time after the pandemic we organized a common winter activity on March 4th, a beautiful late-winter day with lots of blue sky, crisp temperatures in the morning and pleasant ones in the afternoon. Perfect for a common end at a local hut (Fig. 1).

We went to Engelberg in central Switzerland which can be easily reached by public transportation and by car. It also offers different winter activities from hiking in the snow up to 3000 m, cross country skiing and world-class skiing and snowboarding (Fig. 2).



Fig. 2: LIP members skiing down the steep slopes from the Titlis glacier.

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Using annual calibration curves for highly resolved dating

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Millennia of Solar Cycles and Extreme Solar Events from Tree-Ring ¹⁴C Records

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USA, Fairbanks, 17.09.2025, NASA Sun-Climate Symposium

N. Brehm, M. Christl, R. Muscheler, A. Bayliss, E. Casanova, T. Knowles, K. Nicolussi, C. Pearson, P. Fonti, R. Hanterimov, L. Wacker

Millennia of solar cycles and extreme solar events from tree-ring ¹⁴C records

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M. Caroselli, Ch. Lumia, S. Luppichini, I. Hajdas, R. Kruć-Fijałkowska
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N. Casacuberta
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N. Casacuberta, M. Christl, C. Vockenhuber, W. Aeschbach, M. Oberthaler
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Spain, Manlleu, 14.03.2025, Inaugural talk in a Museum to present a new exhibition about women in science

C.-Y. Chen, S. Willett, M. Christl
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P. De Cesare, M. Egli, D. Tikhomirov, M. Christl, G. Imbrogno, F. Scarciglia
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Germany, Bonn, 05.11.2025, CORSO General Assembly

C. Gerling, M. Depaermentier, C. Alder, I. Hajdas, M. Kempf, J. Gretzinger, Z. Hofmanová, J. Krause, P. A. Schwarz
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I. Hajdas
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I. Hajdas, M. Isler, S. Benguerel, U. Leuzinger, R. Schweichel, R. Turck
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Users Laboratories and ¹⁴C dating objects of cultural heritage
Poland, Krakow, 07.02.2025, 25th Radiocarbon Conference

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Reading the ¹⁴C lab report: how reliable is the result?
Serbia, Belgrade, 09.03.2025, 31st EAA Annual Meeting

I. Hajdas
Introduction to Radiocarbon Dating Concepts and Practical Guide
Austria, Vienna, 28.04.2025, EGU 2025

I. Hajdas, J. Braakhekke, G. Monegato, F. Gianotti, M. Christl, S. Ivy-Ochs
Different ¹⁴C ages for different fractions of peat
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I. Hajdas
Radiocarbon Dating in Medieval archaeology
Czech Republic, Prague, 27.11.2025, Institute of Archaeology of the Academy of Sciences of the Czech Republic, Prague

I. Hajdas
Radiocarbon dating – a tool for studies of past and present climate and environment
Poland, Warszawa, 28.10.2025, Institute of Geography and Spatial Organization Polish Academy of Sciences

I. Hajdas

Radiocarbon based chronologies of past and present climatic records—an overview

Poland, Lublin, 13.09.2025, Polish Congress of Geography

I. Hajdas

Radiocarbon dating of bones -- potential and limitations

Switzerland, Frauenfeld, 15.01.2025, Uncovering Migration and Population Development in the Late Antiquity: Achievements and Limitations in Archaeology

I. Hajdas

Possibilities and limitations of Radiocarbon Dating in Medieval archaeology

Czech Republic, Brno, 26.11.2025, Workshop "Radiocarbon dating in Early Medieval Archaeology"

I. Hajdas

¹⁴C Dating of Manuscripts, the Method, and Applications with a Focus on the Graz Collection

Germany, Hamburg, 25.03.2025, Workshop on Manuscript Cultures in the Caucasus

D. R. Hardy, M. Worek, M. Schwikowski, I. Hajdas, L. Wasowicz, U. Ramsperger, K. Burdzy

Kilimanjaro mummified animals and their ¹⁴C ages

Poland, Krakow, 07.02.2025, 25th Radiocarbon Conference

L. Hendriks, L. Robbiola, E. Desplanques, N. Haghypour, C. Reynaud, C. Portmann, L. Bertrand

¹⁴C analysis of mineralised textiles from the Creney-le-Paradis site

France, Rouen, 01.04.2025, GMPCA XXVe colloque

E. Hieronimus, D. Dale, F. Meienburg, A. Junkermann, I. Arnedo, Y. Ark, D. Wachs, J.-E. Tremblay,

M. Oberhaler, N. Casacuberta, W. Aeschbach

Studying age distributions of water masses in Baffin Bay, Canada, using Argon Trap Trace Analysis Czech Republic, Prague, 09.07.2025, Goldschmidt 2025

S. Jerome, R. Andreassen, D. Arnold, O. Cankur, L. Chambon, M. Christl, J. A. Corcho Alvarado, B. Engin, A. Gudelis, K. Hain, V. Hansen, S. Happel, M.-R. Ioan, J. Irrgeher, B. Lalère, A. Lehnert, D. Malinkovskiy, M. Mazánová, J. Krneta Nikolić, J. Noireaux, M. Oelze, H. Perez-Tribouillier, D. Pröfrock, J. Qiao, Russell, S. Röllin, S. Salminen-Paatero, C. Schöpke, L. Skipperud, S. Virtanen, C. Walther, S. Winkler, T. Zuliani

Outputs from EURAMET Project 21GRD09 - MetroPOEM

Italy, Florence, 16.02.2025, 12th International Conference on Isotopes

S. Jess, L.M. Schoenbohm, N. Akçar, J. Rimando, J. Paredes, C. Rivadavia, A. Peace, M. Christl

Unraveling the Rodados Patagónicos: Cosmogenic nuclide dating of uplifted post-rift sediments across the Patagonian passive margin

USA, New Orleans, 16.12.2025, AGU25

L. P.H. Jeurgens, A. M. Müller, T. Wulff, S. Gramatte, C. Menegus, I. Utke, P. Schmutz, V. Turlo,

C. Cancellieri

Chemical Interaction of Hydrogen with Functional Oxides by Combining Ion-Beam Analytical and Spectroscopic Techniques

Switzerland, Zurich, 10.09.2025, ECAART 15

M. Joyce, C. Boxall, M. Christl, P. Collins-Price, P. Gaca, P. Gautschi, F. Livens, A. Madina, K.T. Semple, P. Warwick, R. Wilbraham
Plutonium-240 abundance in refractory fallout in england and the Chernobyl nuclear explosion hypothesis
USA, Kailua-Kona, 25.03.2025, MARC XIII

N. Kappelt, E. Wolff, M. Christl, C. Vockenhuber, R. Muscheler
Dating old ice with the $^{36}\text{Cl}/^{10}\text{Be}$ ratio
Austria, Vienna, 28.04.2025, EGU 2025

N. Khamaiko, O. Komar, I. Hajdas, M. Wołoszyn
AMS Dating for Medieval Kyiv: A New Approach
Serbia, Belgrade, 09.03.2025, 31st EAA Annual Meeting

P. Kittel, N. Haghipour, I. Hajdas, M. Krąpiec, M. Słowiński, D. Łuców, E. Gauthier, M. Rządziejewicz, D. Okupny, Y. Kublitskiv, A. Mazurkevich
The chronology of 13 m long organic deposits core from Serteya Mire (Western Russia) – geoarchive of palaeoenv. changes & human-environ. relationships on East European Plain
Poland, Krakow, 30.06.2025, 25th Radiocarbon Conference

T. Knaack, P. Gautschi, J. Della-Coletta, R. Friedrich, S. Preunkert, L. Wacker, S. Hammer
Increasing ICOS CRL's $^{14}\text{CO}_2$ Sample Processing Capacity: First Results from the Fully Automated Graphitization System Developed within CORSO
Germany, Bonn, 05.11.2025, CORSO General Assembly

L. Leist, K. Azetsu-Scott, C. Lee, M. Castrillejo, M. Ringuette, H. Pérez-Tribouillier, C. Vockenhuber, N. Casacuberta
Tracing Water Masses in Baffin Bay and Labrador Sea: Finding the ^{236}U source of Baffin Bay Transition Water
Spain, Barcelona, 14.05.2025, ASOF 2025

L. Leist, K. Azetsu-Scott, C. Lee, M. Castrillejo, M. Ringuette, H. Pérez-Tribouillier, C. Vockenhuber, N. Casacuberta
Tracing Water Masses in Baffin Bay and Labrador Sea: Finding the ^{236}U source of Baffin Bay Transition Water
Switzerland, Zurich, 25.04.2025, IBP Congress

D. Mair, J. von Allmen, P. Ruffiner, M. Binaghi, C. Schmidt, S. Garipova, N. Akçar, M. Christl, F. Schlunegger
Linking highly variable Detrital ^{10}Be Erosion Rates to heterogeneous Topography in Small and Alpine Catchments
Austria, Vienna, 29.04.2025, EGU 2025

S. Marty, A. Crnjac, A. M. Müller
Optimization of the operating principle of a gas ionization detector for ion implantation
Switzerland, Zurich, 12.09.2025, ECAART 15

D. Michalska, M. Caroselli, Ch. D'Erme, N. Haghipour, I. Hajdas, R. Kruć-Fijałkowska
 ^{14}C dating of mortars-Integrating improvements in chracterization and pretreatment
Poland, Krakow, 30.06.2025, 25th Radiocarbon Conference

F. Moliterno, R. Buompane, S. Cantoni, A. Crnjac, M. De Stefano Fumo, A. Del Vecchio, L. Gialanella, M.L. Mitsou, A. Müller, M. De Cesare

Ion Beam techniques for Space TPS material characterizations

Switzerland, Zurich, 12.09.2025, ECAART 15

A. Moore, Y. Li, M. Henrion, M. Christl, P. Gautschi, F. Jonard, S. Lambot, K. Van Oost, S. Opfergelt, V. Vanacker

Using paired cosmogenic ^{26}Al and ^{10}Be to study landscape transience in the Belgian Ardennes

Austria, Vienna, 27.04.2025, EGU 2025

R. Paque, A. Moore, J. Dixon, Y. Montes, M. Christl, V. Vanacker

Orographic and convective precipitation control meteoric ^{10}Be wet depositional fluxes at low latitude

Austria, Vienna, 27.04.2025, EGU 2025

A. Payne, L. Raimondi, A. M. Wefing, C. Vockenhuber, H. Perez-Tribouillier, B. Williams, S. Zimmermann, N. Casacuberta

Nuclear Waste Reveals 20 Years of Circulation Changes and Anthropogenic Carbon Storage in the Canada Basin

Spain, Barcelona, 12.05.2025, Arctic Subarctic Ocean Fluxes Meeting 2025

U. Ramsperger, L. Wacker, L. Meyer, V. Hernandez, A. Wagner, J. Thut

Improvements in AMS Cs-Sources

Poland, Krakow, 01.07.2025, 25th Radiocarbon Conference

U. Ramsperger, L. Wacker, L. Meyer, V. Hernandez, A. Wagner, J. Thut

Improvements in AMS Cs-Sources

Switzerland, Zurich, 10.09.2025, ECAART 15

A.-M. Wefing, H. Pérez-Tribouillier, C. Vockenhuber, P. A. Dodd, M. Christl, J. P. Gwynn, N. Casacuberta

Circulation and Mixing Timescales in the Fram Strait Using Transient Tracers ^{129}I and ^{236}U

Spain, Barcelona, 12.05.2025, Arctic Subarctic Ocean Fluxes Meeting 2025

C. Schmidt, D. Mair, F. Schlunegger, B. McARDell, M. Christl, N. Haghipour, N. Akçar

From Overland Flow to Landslides: Deciphering Sediment Flux and Erosion Histories with Cosmogenic ^{10}Be , ^{26}Al , and ^{14}C

Austria, Vienna, 29.04.2025, EGU 2025

C. Spack, C. Portmann, N. Haghipour, A. Serrano, M.R. van Bommel

How old is red? Compound Specific Radiocarbon (^{14}C) Dating of anthraquinone-based colourants in historical textiles

Switzerland, Beatenberg, 01.03.2025, CH analysis

H.-A. Synal

Accelerator Mass Spectrometry and recent developments in AMS technology

Italy

Lecce, 05.05.2025, Advanced accelerator mass spectrometry fundamentals and application School CEDAD-Department of Mathematics and Physics

H.-A. Synal

As time goes by ...is there a Half-life of AMS Instrumentation?

Austria, Vienna, 24.10.2025, Symposium in honour of Robin Golser

P. Tomanová, Z. Robak

WHEN TWO PEOPLE DO THE SAME THING, IT'S NOT THE SAME THING: Same churches, same ^{14}C data, different absolute ages.

Poland, Kraków, 29.06. - 04.07.2025, 25th Radiocarbon Conference

P. Tomanová

Traditional perspectives on early medieval strongholds versus new radiocarbon data. Case study of the Budeč Stronghold

Serbia, Belgrade, 03. - 06.09.2025, 31st EAA Annual Meeting

P. Tomanová, N. Košťová

Několik radiouhlíkových dat z budečské akropole a jejich příspěvek k poznání vývoje hradiště. // Several radiocarbon dates from the Budeč acropolis and their contribution to our understanding of the development of the fortified settlement.

Czech Republic, Brno, 25. - 26.11.2025, Radiocarbon dating in early medieval archaeology

G. Vance, E. Erlanger, R. Clementucci, Y. Wang, N. Haghipour, M. Christl, P. Gautschi, V. Picotti, S. D. Willett

Catchment-averaged denudation rates derived from cosmogenic ^{10}Be in the Northern Apennines (Italy) and implications for landscape dynamics

Austria, Vienna, 02.05.2025, EGU 2025

C. Vockenhuber, H.-A. Synal, M. Schlomberg, T. Wulff, U. Ramsberger, L. Wacker, M. Christl

Upgraded LE side of the 6 MV Tandem Accelerator

Germany, Cologne, 10.03.2025, DPG Spring Meeting 2025

C. Vockenhuber, M. Christl, U. Ramsberger, M. Schlomberg, H.-A. Synal, L. Wacker

Improved ^{36}Cl and ^{32}Si AMS Measurements at the 6 MV Tandem accelerator at ETH Zurich

Switzerland, Zurich, 10.09.2025, ECAART 15

C. Vockenhuber

From Stars to Earth - what we can learn from long-lived radionuclides

Austria, Vienna, 30.09.2025, Univ. Wien

L. Wacker, C. L. Pearson, D. Frank, M. Friedrich, B. Kromer, S. Talamo, N. Brehm, K. Sbonias, W. L. Friedrich

RE-DATING THE THERA ERUPTION

Poland, Krakow, 01.07.2025, 25th Radiocarbon Conference

K. Nicolussi, L. Wacker, G. Kaufmann, P. Pernter, N. Brehm, T. Pichler, A. Putzer, E. Vallazza

REFINEMENT OF THE ^{14}C -BASED AGE DETERMINATION OF THE ALPINE GLACIER MUMMY ÖTZI

Poland, Krakow, 02.07.2025, 25th Radiocarbon Conference

A.-M. Wefing, M. Scheiwiller, N. Casacuberta, P. Giertzuch, M. Granskog, C. Stedmon, P. A. Dodd,
C. Vockenhuber, L. de Steur

I-129 as a tracer to distinguish Pacific and Atlantic Water in Fram Strait

Spain, Barcelona, 12.05.2025, ASOF 2025

J. Wolf, M. Christl, S. Fichter, H. Perez Tribouillier, S. Winkler, and A. Wallner

Detecting Environmental ^{231}Pa Using Accelerator Mass Spectrometry

Germany, Cologne, 14.03.2025, DPG Spring Meeting 2025

M. Wołoszyn, P. Jarosz, N. Pantić, I. Hajdas

Absolute Dating of Early Magyar Cemeteries: Przemyśl (Poland) and Batajnica-Velika humka (Serbia)

Serbia, Belgrade, 09.03.2025, 31st EAA Annual Meeting

T. Wulff, A. M. Müller, C. Menegus, C. Cancellieri

In-Operando Material Science using ERDA

Switzerland, Zurich, 10.09.2025, ECAART 15

SEMINAR

'CURRENT TOPICS IN ACCELERATOR MASS SPECTROMETRY AND RELATED APPLICATIONS'

Spring semester

19.02.2025

Samuel Hammer (Univ. Heidelberg), $^{14}\text{CO}_2$ as a Tool for Monitoring Carbon Cycle Changes

26.02.2025

Adrien Delvoye (Univ. of Geneva, Towards an archaeology of ancient domestic settlements in the megalithic region of Senegal and The Gambia (1st-2nd mill. CE): Preliminary results of the SNSF Project HOME.

05.03.2025

Andrej Maczkowski (Univ. of Berne), 8ka-2.6ka BP dendroarchaeology in the southwestern Balkans: state-of-the-art, and prospects of calendar-year dating

12.03.2025

Lucia Winkler (Univ. of Jena), Using a ^{14}C tracer approach to measure CO_2 fixation rates in groundwater

19.03.2025

Esther Thomasius (ETHZ), New compact air sampler: Graphitize CO_2 from waste incineration plant emissions for radiocarbon analysis

19.03.2025

Simona Staub (ETHZ), Multi-proxy tree-ring dating around the Older Dryas

26.03.2025

Anne Sofie Sondergaard (ETHZ), A North Greenland-wide in-situ cosmogenic ^{14}C ice sheet chronology

02.04.2025

Kerstin Treydte (WSL), Oxygen isotopes in tree rings as atmospheric moisture proxies

09.04.2025

Silvan Wigger (ETHZ), Boron-10 suppression in low energy Beryllium-10 AMS

16.04.2025

Dominik Koll (Dresden Univ. of Technology), Interstellar Radionuclide Deposition on Earth: When, Where and How Much?

30.04.2025

David Frank (Univ. of Arizona), Perspectives on a Couple of Interdisciplinary Applications of Dendrochronology

07.05.2025

Aaron Lehnert (Univ. of Hannover), Blue light, what does it do? – Updates on resonant ionisation mass spectrometry

14.05.2025

Claudia Cancellieri (EMPA), Characterization of thin oxides and their interfaces with ion beam techniques

21.05.2025

Marcel Scheiwiller (ETHZ), Changes of circulation timescales and mixing in the Fram Strait from 2016 to 2021

28.05.2025

Gabrielle Vance (ETHZ), Uplift, erosion, and advection within the orogenic wedge of the Northern Apennines (Italy)

Fall semester

17.09.2025

Andreo Crnjac (ETHZ), No Window, No Problem: Low-Pressure Gas Detector and Ion Implantation

24.09.2025

Ira Himstedt (ETHZ), Feasibility and Optimization of ^{41}Ca AMS at the Low-Energy AMS System MILEA

24.09.2025

Lisa Weilhammer (ETHZ), Charge exchange cross sections of Be-9 ions in Helium below 200keV

24.09.2025

Samuel Marty (ETHZ), Optimization of a gas ionization detector for ion implantation

01.10.2025

Chantal Schmidt (Uni Bern), Quantifying erosion in a pre-Alpine catchment at high resolution with concentrations of cosmogenic ^{10}Be , ^{26}Al , and ^{14}C

08.10.2025

Filipa Naughton (IPM Lisbon), Chronology problems within extreme climatic events

15.10.2025

Michael Stükelberger (DESY Hamburg), Connecting ion beams with X-ray microscopy for semiconductor research

22.10.2025

Jian Wang (Uni Groningen), Single-Year Radiocarbon Analysis: Automation, Solar Activity Insights, and Chronological Anchoring

29.10.2025

Jordan Hemingway (ETHZ), Constraining the drivers of carbon dynamics in the Kasai Basin, Democratic Republic of Congo

05.11.2025

Johann Meerschgaut (IMEC Leuven), Ion beam analysis and semi-conductors at imec: a semi-industrial context

12.11.2025

Tancrede Leger (UNIL), Insights into the last deglaciation of the Greenland Ice Sheet from new Terrestrial Cosmogenic Nuclide data and model reconstructions

19.11.2025

Johannes Lachner (HZDR), Isobar suppression with an ion cooler for a 1MV tandem accelerator

26.11.2025

Anne Marie Wefing (Norwegian Polar Institute), Anthropogenic radionuclides tracing changes in Atlantic Water circulation in the central Arctic Ocean

03.12.2025

Edouard Bard (Collège de France), Sea level and paleoclimate changes over the last glacial cycle

17.12.2025

Janis Wolf (HZDR), Establishing a Procedure for the measurement of Pa-231 at the MILEA AMS System

THESES (INTERNAL)

Term paper/Bachelor

Annalena Marie Burkhardt

Distribution of radionuclide transient tracer ^{129}I in the Fram Strait in Spring 2022

ETH Zurich

Ira Himstedt

Measurements of charge exchange cross sections of ^9Be ions in Helium below 200keV

ETH Zurich

Lisa Weinhhammer

Feasibility and Optimization of ^{41}Ca AMS at the Low-Energy AMS System MILEA

ETH Zurich

Diploma/Master theses

Simona Staub

Multi-proxy tree-ring approach to improve the dating around the Older Dryas

ETH Zurich (Switzerland)

Doctoral theses

Benedict Mittelbach

Tracing Carbon Sources and Turnover Times Using Sedimentary Radiocarbon Signatures in Swiss Lakes

ETH Zurich

Kai Nakajima

Advancing particle-selective ^{14}C analysis for studies on paleo-environmental dynamics

ETH Zurich

Annabel Payne

Expanding the Ocean's Toolkit: Anthropogenic Radionuclides as Tracers of Circulation, Freshwater Sources, and Carbon Uptake in a Changing Arctic

ETH Zurich

Timo Rhyner

The Nature of Riverine Radiocarbon in Switzerland

ETH Zurich

Gabrielle Vance

Tectonics, Drainage Reorganization, and Riverine Biodiversity in the Northern Apennines (Italy)

ETH Zurich

Stephan Wartenweiler

Reconciling geomorphological and biogeochemical perspectives on hillslope soil and soil carbon dynamics

ETH Zurich

Apprentice theses

Virginia Hernandez
Neudesign von Ionisatorplattform für Cs-Ionen-Sputterquelle
ETH Zurich

THESES (EXTERNAL)

Doctoral theses

Dylan Geissbühler
Monitoring of Sources, Sinks, and Transport of Atmospheric CO₂ over Switzerland using Radiocarbon
University of Bern

Madison Hoffman
The radiological impact of historical nuclear testing on the marine environment of the Montebello Islands, Western Australia
Edith Cowan University (AUS)

Niklas Kappelt
Dating Ice Cores with the ³⁶Cl/¹⁰Be Ratio
Lund University (Sweden)

Julia Loftfield
Recordings of cosmogenic beryllium in marine sediments during the Laschamps geomagnetic dipole low: implications for synchronization of paleo archives and geomagnetic field reconstructions
University of Bremen (Germany)

COLLABORATIONS

Australia

Edith Cowan University, School of Science, Perth

Monash University, School of Earth, Atmosphere and Environment, Melbourne

The Australian National University, Research School of Physics, Canberra

University of Tasmania, School of Geography, Hobart

Austria

AlpS - Zentrum für Naturgefahren- und Riskomanagement GmbH, Geology and Mass Movements, Innsbruck

Austrian Academy of Sciences, Institute for Oriental and European Archaeology, Vienna

Geological Survey of Austria, Sediment Geology, Vienna

International Atomic Energy Agency, Vienna

University of Innsbruck, Institute of Geography, Geology and Botany, Innsbruck

University of Salzburg, Geography and Geology, Salzburg

University of Vienna, VERA, Faculty of Physics, Vienna

Vienna University of Technology, Institute for Geology, Vienna

Belgium

Royal Institute for Cultural Heritage, Brussels

Université catholique de Louvain, Earth and Life Institute, Louvain-la-Neuve

Bermuda

Bermuda Institute of Ocean Sciences, Bermuda

Canada

Bedford Institute of Oceanography, Bedford Institute of Oceanography, Halifax

Chalk River Laboratories, Dosimetry Services, Chalk River

Université du Québec à Rimouski, Quebec

China

China Institute for Radiation Protection, Dosimetry Services, Taiyuan City

Chinese Academy of Sciences, Xi'an AMS Centre, Xi'an

Croatia

Ruder Boskovic Institute, Laboratory for Ion Beam Interactions, Zagreb

Czech Republic

Czech Technical University, Nuclear Chemistry, Prague

Denmark

Risø DTU, Risø National Laboratory for Sustainable Energy, Roskilde

University of Copenhagen, Globe Institute, Copenhagen

University Southern Denmark, Department of Physics, Chemistry and Pharmacy, Odense

Estonia

University of Tartu, Tartu

Finnland

University of Jyväskylä, Accelerator Laboratory, Physics Department, Jyväskylä

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Aix-Marseille University, Collège de France, Aix-en-Provence

Sorbone, Department of Earth Sciences, Paris

Université de Savoie, Laboratoire EDYTEM, Le Bourget du Lac

Germany

Alfred Wegener Institute of Polar and Marine Research, Marine Geology, Bremerhaven

Berlin-Brandenburgische Akademie der Wissenschaften, Berlin

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DESY, X-Ray Nanoscience and X-Ray Optics, Hamburg

Fraunhofer-Institut für Molekularbiologie und Angewandte Oekologie, IME, Schmallenberg

GFZ German Research Centre for Geosciences, Earth Surface Geochemistry, Department of Earth Sciences, Potsdam

Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Institute of Ion Beam Physics and Particle Physics, Dresden

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IFM-GEOMAR, Palaeo-Oceanography, Kiel

Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal, Karlsruhe

Leibniz Institute for the History and Culture of Eastern Europe (GWZO), Leipzig

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Potsdam-Institut für Klimafolgenforschung, Complexity Science, Potsdam

Reiss-Engelhorn-Museen, Curt-Engelhorn-Zentrum Archäometrie gGmbH, Mannheim

RWTH Aachen, Engineering Geology, Aachen

University of Applied Sciences, TH Köln, Technology Arts Sciences, Cologne

University of Cologne, Institute of Geology and Mineralogy, Cologne

University of Hannover, Institute for Radiation Protection and Radioecology, Hannover

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University of Mainz, Geowissenschaften, Mainz

University of Tübingen, Department of Geoscience, Early Prehistory and Quaternary Ecology, Archaeozoologie, Tübingen

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Trinity College Dublin, Physical Geography, Dublin

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Geological Survey of the Provincia Autonoma di Trento, Landslide Monitoring, Trento

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Japan

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Liechtenstein

Oerlikon Surface Solutions AG, Balzers

Monaco

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University of Waikato, Radiocarbon Dating Laboratory, Waikato

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Norwegian Geological Survey, Trondheim

Norwegian Polar Institute, Tromsø

Norwegian Radiation Protection Authority, Tromsø

Norwegian University of Science and Technology, Physical Geography, Trondheim

Rogaland Fylkeskommune, Stavanger

The Arctic University of Norway, Tromsø

The Bjerkness Centre for Climate Res., Bergen

The University Museum of Bergen, Bergen

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University of Seville, Physics Department and National Center for Accelerators, Seville

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Geneva Fine Art Analysis Sarl, Lancy, Geneva

Haute école d'ingénierie et d'architecture de Fribourg, Fribourg

Kanton Graubünden, Archäologischer Dienst, Chur

Kanton St. Gallen, Kantonsarchäologie, St. Gallen

Kanton Turgau, Kantonsarchäologie, Frauenfeld

Kanton Zug, Kantonsarchäologie, Zug

Kanton Zürich, Kantonsarchäologie, Dübendorf

Labor für quartäre Hölzer, Langnau am Albis

Labor Spiez, Radiochemie / Anorganische Analytik, Spiez

Laboratoire Romand de Dendrochronologie, Cudrefin

Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Wettingen

Office et Musée d'Archéologie Neuchatel, Neuchatel

Paul Scherrer Institut (PSI), Magnet Section, Radioanalytik, Materials Group, Mesoscopic Systems, Labor für Radio- und Umweltchemie, Villigen

Physikalisch-Meteorologisches Observatorium Davos, PMOD, Davos

Rockwaterconsulting, Boll

Stadt Zürich, Amt für Städtebau, Zurich

Stiftung Pro Kloster St.-Johann, UNESCO Welterbe, Münstair

SUPSI, Dipartimento ambiente costruzioni e design (DACD), Lugano

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Landscape Dynamics, Dendroecology, Soil Sciences, Birmensdorf

Swiss Gemmological Institute – SSEF, Basel

Swiss Institute for Art Research SIK ISEA, Zurich

University of Basel, IPAS, IPNA, DUW, Departement Altertumswissenschaften, Basel

University of Bern, Institute of Geology, Climate and Environmental Physics, Oeschger Center for Climate Research, LARA, Bern

University of Freiburg, Faculty of Environmentat and Natural Resources, Freiburg

University of Geneva, Department of Anthropology and Ecology, Geneva

University of Lausanne, Department of Geology, Lausanne

University of Zurich, Abteilung Ur- und Frühgeschichte, Institute of Geography, Institut für Evolutionäre Medizin, Zurich

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National Taiwan University, Department of Geosciences, Taipei

The Netherlands

Twente University, Nanotechnology, Twente

Türkiye

Dokuz Eylül University, Department of Geological Engineering, Izmir

Istanbul Technical University, Faculty of Mines, Istanbul

Tunceli Üniversitesi, Geology Department, Tunceli

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Brithish Arctic Survey, Cambridge

Cambridge University, Department of Earth Sciences, Geography, Cambridge

Durham University, Department of Geography, Durham

Queen Mary University of London, School of Geography, London

University of Aberdeen, School of Geosciences, Aberdeen

University of Bristol, School of Chemistry, Bristol

University of Lancaster, Nuclear Engineering, Lancaster

University of Leicester, School of Geography, Leicester

USA

Center for New Mexico Archaeology, Santa Fe

Florida State University Earth, Ocean & Atmospheric Science, Florida

NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu

University of Arizona, Arizona

University of Utah, Geology and Geophysics, Salt Lake City

Woods Hole Oceanographic Institution, Center for Marine and Environmental Radioactivity, National Ocean Sciences Accelerator Mass Spectrometry, Woods Hole

VISITORS AT THE LABORATORY

Francesco Moliterno

Department of Mathematics and Physics, University of Campania “Luigi Vanvitelli”, Caserta, Italy

28.01.2025 - 30.05.2025

David Frank

University of Arizona, Tucson, USA

01.02.2025 - 30.06.2025

Ralph Spolenak

ETH Zurich, Zürich, Switzerland

25.02.2025

Stephane Sanfilippo

PSI, Villingen, Switzerland

06.03.2025

Antonio López Fuentes

University of Seville, Seville, Spain

17.03.2025 - 28.03.2025

Mercedes Lopez Lora

University of Seville, Seville, Spain

17.03.2025 - 19.03.2025

Adrien Delvoye

University of Geneva , Geneva, Switzerland

26.03.2025

Michael Stückelberger

DESY, Hamburg Germany

15.04.2025 - 17.04.2025

Claudia Canellieri

Interface Reactivity of Nanostructured Materials, EMPA Dübendorf, Dübendorf, Switzerland

07.05.2025

Sandra Baur

PSI, Villingen, Switzerland

09.05.2025

Danuta Michalska

Adam Mickiewicz University, Poznań, Poland

21.05.2025 - 23.05.2025

Janis Wolf

HZDR , Dresden, Germany

16.06.2025 - 25.06.2025

Yao Gu

Nanjing University, Nanjing, China

25.06.2025

Huei-Ting Lin

National Taiwan University, Taiwan, Taiwan

03.07.2025

Dania Achermann

University of St. Gallen, St. Gallen, Switzerland

15.08.2025

Lukas Martin

NAGRA Wettingen, Switzerland

21.08.2025

Miriam Kiiczka

University of Bern, Bern, Switzerland

21.08.2025

Urs Mäder

Rockwater Consulting, Vechingen, Switzerland

21.08.2025

Sandra Baur

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21.08.2025

Liana Lüthard

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25.08.2025

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16.09.2025

Jan Zalasiewicz

University of Leicester, Leicester, UK

06.10.2025

Filipa Naughton

IPMA, Lisbon, Portugal

08.10.2025 - 09.10.2025

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DESY, Hamburg, Germany

14.10.2025 - 16.10.2025

Miriam Mindova
Czech Technical University, Prague, Czech Republic
16.10.2025

Janis Wolf
HZDR , Dresden, Germany
03.11.2025 - 14.11.2025

Maksymilian Jędrzejewski
Silesian University of Technology, Gliwice, Poland
03.11.2025 - 15.11.2025

Buhar Bacho
Lund University Lund, Sweden
05.11.2025 - 07.11.2025

Esben Ditlefsen
Lund University, Lund, Sweden
05.11.2025 - 07.11.2025

Anton Hansson
Lund University, Lund, Sweden
05.11.2025 - 07.11.2025

Simon Wyss
Forensisches Institut Zürich, Zürich, Switzerland
05.11.2025 - 05.11.2025

Meershaut Johan
Ion Beam Analysis, IMEC, Leuven, Belgium
05.11.2025 - 07.11.2025

Raimund Muscheler (and guests)
Lund University, Lund, Sweden
06.11.2025 - 07.11.2025

Sato Akitsugu
Swiss Gemmological Institute – SSEF, Basel, Switzerland
07.11.2025

Johannes Lachner
HZDR , Dresden, Germany
18.11.2025 - 20.11.2025

Matijevic Matija
Laboratory for Ion Beam Interactions Ruder Boskovic Institute, Zagreb, Croatia
24.11.2025 - 28.11.2025

Edouard Bard
College de France / CEREGE, Aix en Provence, France
02.12.2025 - 03.12.2025