



Materials Growth and Measurement Laboratory

**ANNUAL REPORT
2023**

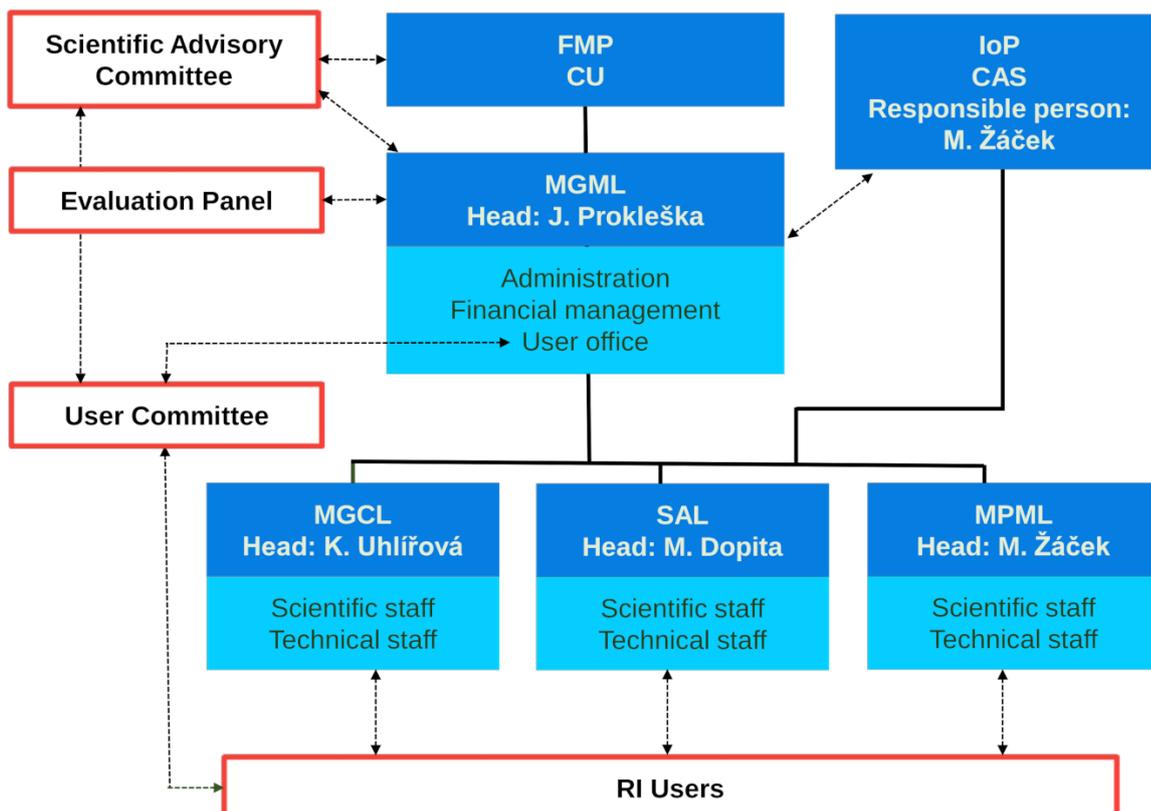
About MGML

MGML is a research infrastructure financed by the Ministry of Education, Youth and Sports within the program of Large Infrastructures for Research, Experimental Development and Innovation of CR (project No. LM2023065). It is an open access research infrastructure available to all users from Czech Republic and abroad.

The research infrastructure is hosted by the Faculty of Mathematics and Physics of Charles University with the Institute of Physics of the Czech Academy of Sciences, v. v. i. as the partner institution.

MGML provides a laboratory base for advanced material research. Within its two closely co-operating units, Material Growth and Characterization Laboratory (MGCL) and Material Properties Measurement Laboratory (MPML), MGML offers open access for external users to a vast experimental instrument suite as well as high-level expertise of its scientists. MGCL has state-of-the-art facilities for metal refinement, synthesis of new materials, and the preparation of high-quality single crystals with several different techniques. The unique combination of different crystal growth methods allows users a great deal of flexibility and optimization of the technology of producing entirely new materials. Modern X-ray diffraction and electron microscopy instruments allow detailed structural and phase characterization of samples. MPML offers the measurement of a wide portfolio of physical (magnetic, transport, thermal, acoustic and elastic) properties of materials through several complementary experimental methods. The extensive range of MGML instruments makes it possible to carry out the measurements in the temperature range from mK up to several hundred degrees Celsius, magnetic (up to 20 T) and electric (from -50V to + 50V) fields, hydrostatic and uniaxial pressures up to 15 GPa. Also important is the possibility of preparation, characterization and measurement of uranium materials, for which the institution has the appropriate license. Interconnection of this wide range of experimental techniques for the preparation, characterization and measurement of physical properties makes MGML a unique research infrastructure in the Czech Republic, fully comparable with the world's leading laboratories.

Organizational chart of MGML:



Our laboratories are located in three places in Prague:

The MGCL technology laboratories are located in the building of the Faculty of Mathematics and Physics – Ke Karlovu 5. You can also find the administration unit here.



The measurements of material properties are performed mostly in the cryo-pavilion of the Faculty of Mathematics and Physics in Troja, V Holešovičkách 2. The helium liquefier located in this building supplies all the cryogenic needs of the laboratory.

Some instruments for measurements of material properties and structural analysis are situated in the building of the Institute of Physics, Cukrovarnická 10.



MGML in 2023

The Large Research Infrastructure Materials Growth and Measurement Laboratory (LRI MGML) has successfully operated all experimental facilities throughout the year 2023, without any notable operational disruptions. This year, we have provided support for 60 user proposals in our open-access regime. These encompassed a wide range of studies, including 29 long-term research proposals, 9 standard proposals, and 10 proof of concept and 12 test proposals.

Cooperation with other European partner laboratories, especially within the framework of the ISABEL project (as introduced in previous reports), has been one of the keys to our international engagement. A notable highlight was the participation of David Hovancik, a Ph.D. student from the Faculty of Mathematics and Physics at Charles University (FMP CU), in the EMFL/ISABEL exchange program. During his time at National des Champs Magnétiques Intenses (LNCMI) facility in Grenoble, Hovancik gained invaluable experience in advanced spectroscopic techniques. His work focused on mastering Raman scattering and infrared spectroscopy performed at high magnetic fields – a critical area of research in contemporary material science.

One of the most fruitful scientific pursuits of our users has been the investigation of the superconductivity of UTe₂, a topic that stands at the forefront of condensed matter research. The discovery of superconductivity in this heavy-fermion paramagnet has gained widespread attention in the scientific community. This is particularly due to the reinforcement of superconducting properties near quantum phase transitions, which are induced by external factors such as magnetic fields and/or pressures. A comprehensive understanding of this relationship is essential not only for a deeper insight into UTe₂'s properties but also for advancing the broader knowledge of magnetically-mediated superconductivity. LRI users succeeded in growing excellent single crystals and subjected these crystals to extensive experimental investigations, utilizing the full spectrum of our laboratory's capabilities.

The successful growth of a series of high-quality single crystals of vdW transition metal trihalides, focused on V³⁺ systems and investigated for their magnetism, is another notable achievement within the user community. This work, benefitting from our participation in the HORIZON 2020 project ISABEL, illustrates the successful integration of Czech scientific expertise with large-scale European research infrastructure. The outcome of this part of the user community is related to the achievements of our scientific community members, particularly David Hovancik was honored with The Best Poster Award at the SCES23 conference held in Incheon, Korea. His poster titled "Terahertz Magnetic and Lattice Excitations in van der Waals Ferromagnet V₁₃" received widespread acclaim. Additionally, Hovancik's significant contributions to the field were further recognized through his paper "Robust intralayer antiferromagnetism and tricriticality in the van der Waals compound VBr₃", which was selected as an "Editors' Suggestion" in the journal Physical Review B.

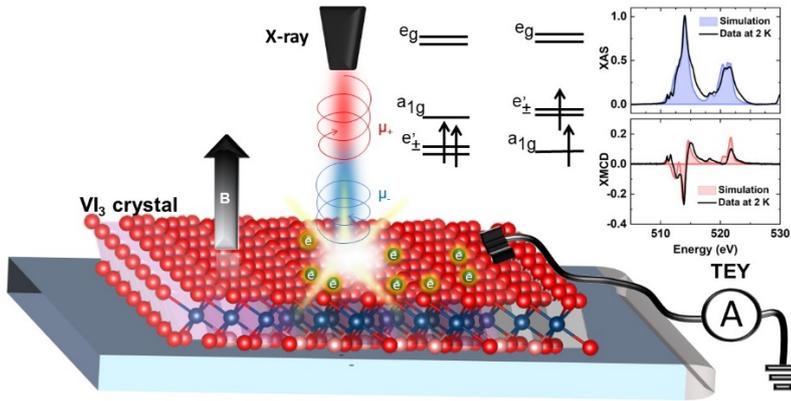
Scientific Highlights

Sizable orbital moment revealed in 2D magnets



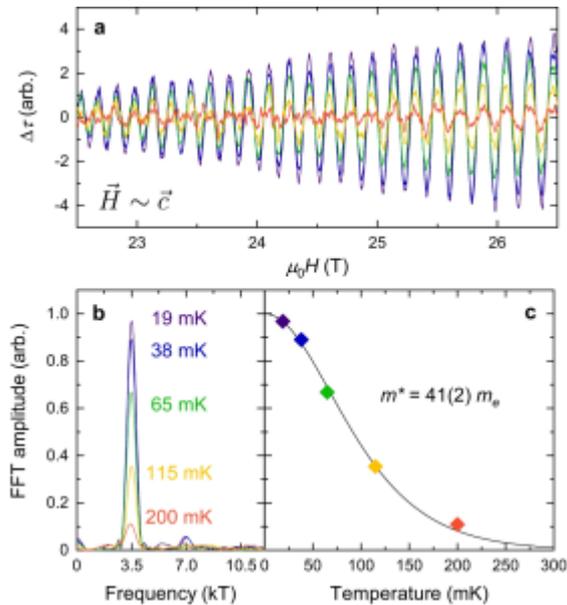
Van der Waals materials exhibiting two-dimensional magnetism are an ideal platform for the on-demand engineering of multifunctional devices suitable for spintronics, quantum computing, etc. Magnetocrystalline anisotropy is considered a key ingredient of the long-range magnetic order in two dimensions. The ferromagnetic semiconductor Vl_3 has recently attracted large attention due to its huge anisotropy. It was an open question whether such strong anisotropy originates from a non-zero orbital moment of Vanadium ion.

Our group focused on studying the orbital moment of Vanadium to solve this problem and explain the mechanism of connection of magnetic anisotropy with the electronic structure of Vl_3 . We used a unique capability of the X-ray magnetic circular dichroism (XMCD) technique to determine the magnetic orbital moment component of V ions. Our XMCD results unambiguously proved the existence of an exceptionally large magnetic orbital moment component of $0.6 \mu_B$ per V ion. In synergy with the density functional theory calculations, we proposed the V electronic ground state configuration and ascribed the origin of the strong magnetocrystalline anisotropy to the entanglement of the non-zero orbital and spin moment of V ion. Our ligand field multiplet simulations of XMCD spectra well match the scenario of two inequivalent V ion positions in Vl_3 structure present at low temperatures. The details of our study was recently published in the ACS Nano Letters journal.



Basic principle of the XMCD technique revealing the orbital momentum on Vanadium site

Outcome of large international cooperation published in Nature Communications

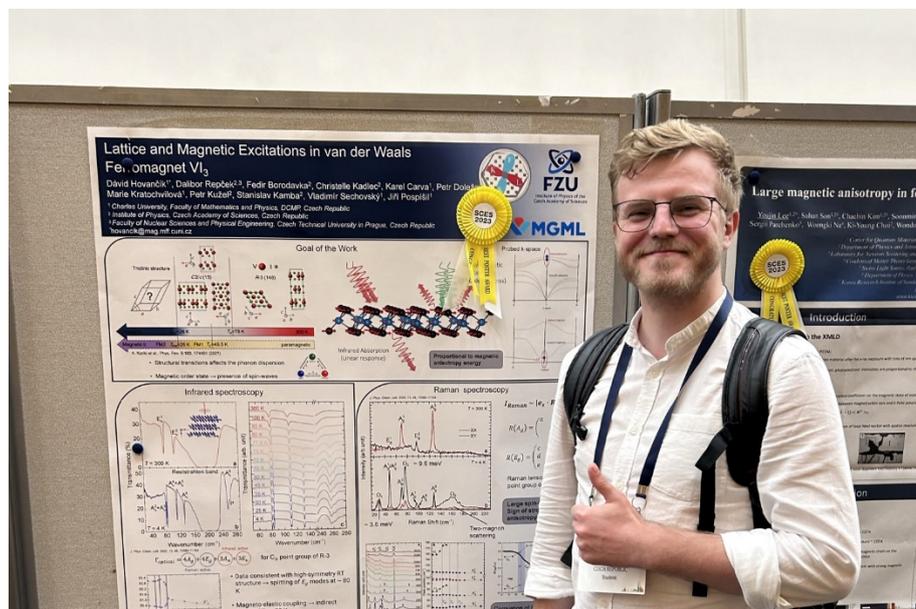


Dr. M. Vališka's team has successfully prepared high-quality single crystals of UTe₂ specifically tailored for quantum oscillation studies. Utilizing these samples, the Cambridge group, led by A. Eaton, conducted a series of experiments in high magnetic field facilities, followed by advanced modelling to assess the potential geometries of Fermi sheets in UTe₂.

In the paper, the authors explore the complex superconductivity of the heavy fermion paramagnet UTe₂, a material showing signs of spin-triplet superconductivity. Addressing uncertainties about its electronic structure, they conducted magnetic quantum oscillation measurements on high-quality UTe₂ crystals. Their findings reveal a quasi-2D Fermi surface, represented by two types of cylindrical Fermi sheets – electron and hole. These sheets display significant undulation but minimal corrugation, potentially facilitating near-nesting that could enhance magnetic fluctuations and the triplet pairing mechanism. Notably, their research finds no evidence of 3D Fermi surface sections in UTe₂. The published results provide strong constraints on the possible symmetry of the superconducting order parameter.

Student achievements in MGML

Student Clinches Best Poster Award for 2D Ferromagnetism



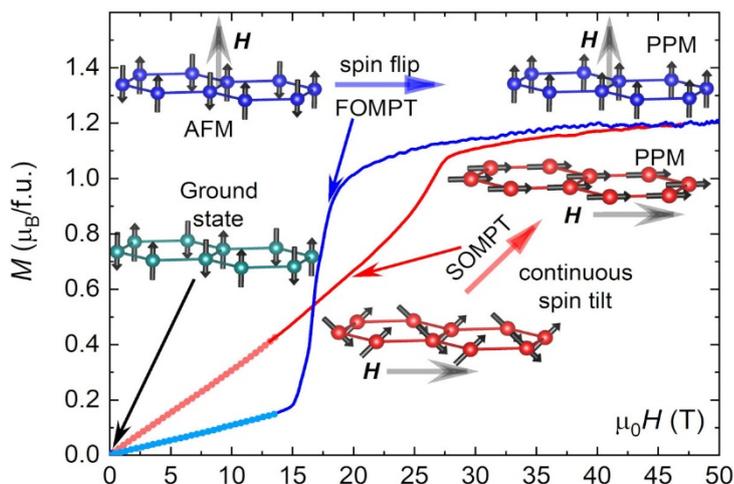
Dávid Hovančík

Dávid Hovančík a Ph.D. student at the Department of Condensed matter physics presented a poster at the international [SCES conference 2023](#) held in Seoul, South Korea summarizing his scientific results. Dávid was awarded the Best Poster prize in the category of two-dimensional materials for the most accomplished poster presentation entitled “Lattice and Magnetic Excitation in van der Waals Ferromagnet VI_3 ”. The presented study has resulted from a collaboration among the Department of Condensed Matter Physics, Physical Institute of Czech Academy of Science and MGML.

Dávid’s research area is the two-dimensional magnetism in van der Waals (vdW) materials. These systems have gained a lot of attention because of their 2D fundamental properties and notable potential applications in spintronics and data storage. The winning poster outlines temperature-dependent infrared and Raman spectroscopy studies of vanadium triiodide (VI_3), a member of the family of 2D vdW magnets hosting a rather complex ferromagnetic (FM) order. The study has settled the VI_3 lattice symmetry in different structural phases, which numerous papers were divided on. Most importantly, Raman scattering revealed a highly energetic FM resonance in a terahertz (THz) range in the FM phase. The observed THz FM resonance in VI_3 is a promising indicator of the application potential of 2D vdW FM in ultrafast THz spintronics even though it was previously considered an exclusive domain of antiferromagnets.¹

Ref: ¹ **D. Hovančík**, D. Repček, F. Borodavka, C. Kadlec, K. Carva, P. Doležal, M. Kratochvílová, P. Kužel, S. Kamba, V. Sechovský, and J. Pospíšil, *Terahertz Magnetic and Lattice Excitations in van der Waals Ferromagnet VI_3* , **J. Phys. Chem. Lett.** 13 (2022) 11095–11104. doi:[10.1021/acs.jpcclett.2c02944](https://doi.org/10.1021/acs.jpcclett.2c02944); David’s research is supported by Charles University Grand Agency (GAUK) project number 214523.

PRB Editors' suggestion for Student Paper on van der Waals magnetism



Dávid Hovančík a Ph.D. student at the Department of Condensed matter physics is the leading author of the paper [Robust intralayer antiferromagnetism and tricriticality in the van der Waals compound VBr₃](#) selected as Editors' choice in PRB. This study is the result of a large collaboration between experimentalists and theoreticians from the Department of Condensed Matter Physics, Department of Inorganic Chemistry, Physical Institute of the Czech Academy of Science, Hochfeld-Magnetlabor Dresden, and MGML.

In this paper, the authors demonstrate the strong anisotropy of uniaxial antiferromagnetism in the van der Waals trihalide VBr₃, with a tricritical point in the H-T phase diagram in an out-of-plane field. The robustness of the antiferromagnetic state manifested by a high critical metamagnetic field is explained by ab initio calculations that predict a zigzag antiferromagnetic order of V moments described within the J1-J2-J3 model. The observed saturated moment of 1.2 $\mu_B/f.u.$ indicates a significant vanadium orbital moment that is the main ingredient of the strong anisotropy.²

Collaboration with commercial partners

Our efforts have led to several contractual agreements, with a total turnover of almost 20 thousand EUR. This not only signifies the partial economic viability of our operations but also underscores our role as a bridge between academic research and industrial application, particularly in the rapidly evolving field of pharmaceuticals.

Ref: ² D. Hovančík, M. Kratochvílová, T. Haidamak, P. Doležal, K. Carva, A. Bendová, J. Prokleška, P. Proschek, M. Míšek, D.I. Gorbunov, J. Kotek, V. Sechovský, J. Pospíšil, *Robust intralayer antiferromagnetism and tricriticality in the van der Waals compound VBr₃*, **Physical Review B** 108 (2023) 104416.
doi: [10.1103/PhysRevB.108.104416](https://doi.org/10.1103/PhysRevB.108.104416)

Conferences

Annual colloquium of the Czech and Slovak Crystallographic association, Conference Structure 2023, Uherské Hradiště, Czech Republic. May 29. - June 2. 2023. The conference topics was dedicated to presentation of research groups focused to the structural studies and use of the X-ray scattering, electrons and neutrons. <https://xray.cz/xray/csca/kol2023/>

PCFES2023:

14th Prague Colloquium on f-Electron Systems, (<https://pcfes.kfkl.cz/archive/>), held in June 15-18, 2023 was attended by 52 (mostly foreign) participants. This event is traditionally focused on physics and chemistry of rare-earth and uranium-based materials.