High Magnetic Field Laboratory

Steady High Magnetic Field Facility (SHMFF, Hefei)

2024 Annual Report

High Magnetic Field Laboratory, CAS

2025.03

CONTENTS

Overview

High Magnetic Field Facilities (HMFF) Project was approved on January 25th, 2007, which was jointly applied by Chinese Academy of Sciences and Ministry of Education. The HMFF Project includes two parts: Steady High Magnetic Field Facility (SHMFF), constructed by Hefei Institutes of Physical Science, CAS; Pulsed High Magnetic Field Facility (PHMFF), constructed by Huazhong University of Science and Technology.

SHMFF started its construction on May 19th, 2008. Partial magnets of SHMFF have been open to users since October 28th, 2010. SHMFF passed national acceptance and was fully put into operation on September 27th, 2017.

SHMFF consists of a world-record 45.22T hybrid magnet, five water-cooled magnets (42.02T/Φ32, 25T/Φ50, 20T/Φ200, 27.5T/Φ32 and 35T/Φ50), four superconducting magnets (10T/Φ100/Φ100, 20T/SMA, 20T/NMR and 9.4T/MRI) and series of experimental systems (transport, magnetic, magneto-optical, extremely low temperature, ultrahigh pressure, STM-AFM-MFM combo, etc.).

SHMFF gives priority to original fundamental research, applied research with important application prospects and high-tech development to improve technical innovation in China, encourages users to undertake national and ministerial major research projects, and welcomes industrial users. Users have been playing a leading role in its operation and opening, which are conductive to feature scientific objectives, prioritize key research fields, and promote important scientific outcomes.

By the end of 2024, SHMFF has provided exceeding 660,000 hours of operation time and executed more than 3800 approved user projects. Users from 205 organizations across the world have carried out research here, and have made series of important research achievements in materials, chemistry, biology science and other disciplines. The users have published over 2700 peer-reviewed journal articles, including dozens in Nature, Science, Cell and other top journals.

In 2024, SHMFF completed the operation task, and provided 53472 hours of operation time. 293 users' projects from 73 organizations carried out research projects and published 272 articles in peer-reviewed journals.

SHMFF focuses on three missions:

1. Advance magnet-related technology, stimulate invention and creation in high magnetic fields.

2. Perform the frontier research of physics, chemistry, biology and material under high magnetic fields.

3. Promote economic development such as pharmaceuticals, medical treatment etc.

Research progress and results

Research highlights

In 2024, SHMFF achieved a number of significant results in multiple fields, including quantum control, exploration of superconducting mechanisms, applications of high-temperature superconducting materials, low-power-consumption quantum materials/metals/catalytic/magnetically induced superelastic material**s**, and biomedicine. The representative results are as follows:

- **Observation of Fractional Quantum Hall Effect in High-Mobility Two-Dimensional Semiconductors**

Achieving fractional quantum Hall states in high-mobility two-dimensional intrinsic semiconductors is particularly challenging by electrical transport, mainly due to the difficulty in obtaining ohmic contacts with low carrier concentrations. A team, led by Prof. Han Zhen from Shanxi University, fabricated n-type semiconductor field-effect transistors of MoS_2, which exhibit Ohmic contact and high mobility across the entire temperature range at low carrier concentrations. Using a low-noise, low-temperature transport experiment system under WM1 of SHMFF, they observed the quantum limit at filling factor = 1 and fractional quantized transverse conductance plateaus at filling factors of ⅖ and ⅘. This study provides a potential solution for nanoelectronic devices with low-temperature, high-mobility electronic transistors based on two-dimensional semiconductors. The results were published in ***Nature Electronics*****.**

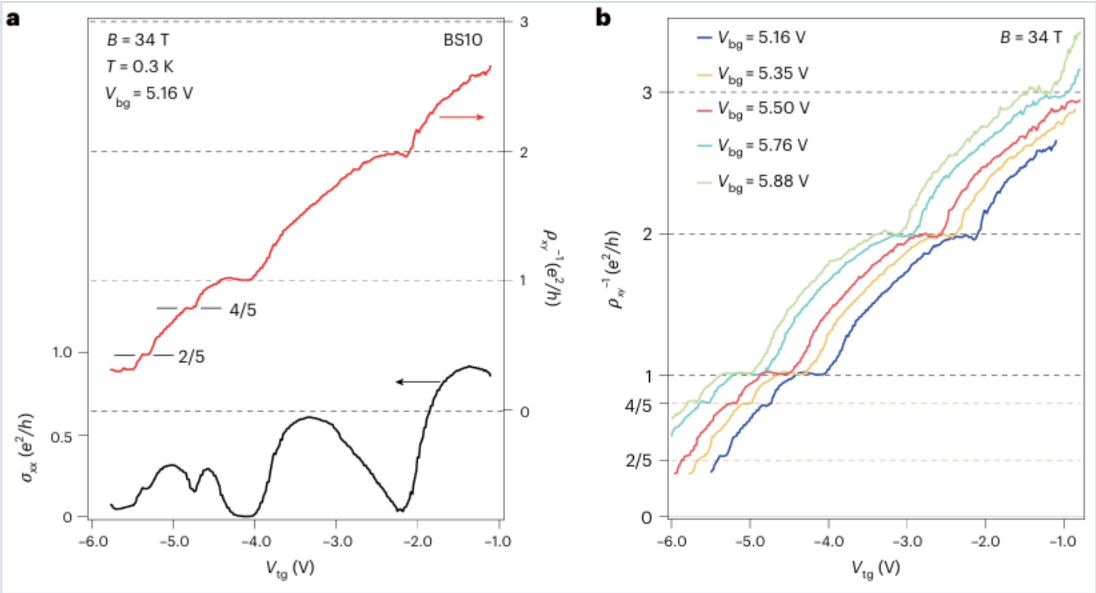

Fig.1. Fractional quantum Hall effect in the lowest Landau level of bilayer MoS_2

- **Supporting the Research and Development of Intrinsic Ferromagnetic Polarized Metals**

It is extremely challenging to simultaneously achieve ferromagnetism, electrical polarization, metallic conductivity, and their mutual coupling within a single system. A team led by Prof. Yu Pu from Tsinghua University created $Ca_3Co_3O_8$ thin films through atomic-scale manipulation. Ultrafast nonlinear optical measurements of SHMFF confirmed the existence of electrical polarization, which is strongly coupled with ferromagnetism and metallic properties. High-field transport measurements of SHMFF revealed an anomalously stable topological Hall effect under magnetic fields ranging from 0 to 30T. This study provides a promising material platform for exploring new spintronic devices. The results were published in ***Nature Materials*****.**

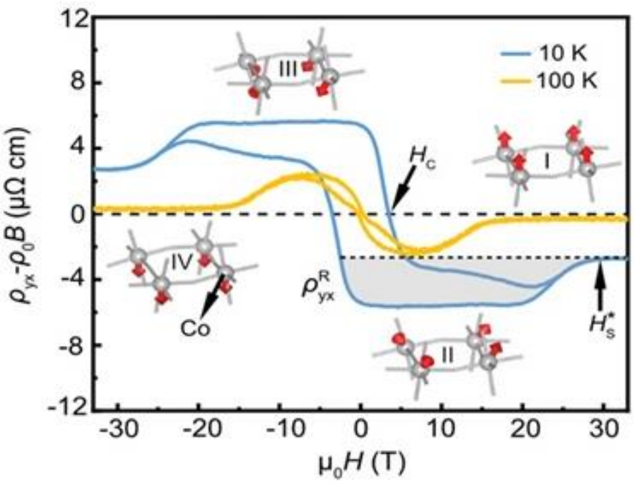

Fig.2. Anomalously stable topological Hall resistance under steady-state strong magnetic fields

- **Revealing Quantum Griffiths Singularities in Nickel-Based Superconductors**

Nickel-based superconductors are one of the key material families among unconventional superconductors. A research team led by Prof. Nie Jiacai from Beijing Normal University conducted a scaling analysis on the superconductor-metal phase transition driven by a magnetic field in $Nd_{0.8}Sr_{0.2}NiO_2$ thin films. They discovered that the effective dynamic critical exponent diverges near the zero-temperature critical point B_c^*, showing isotropic quantum Griffiths singularities(QGS). Under 36T magnetic field generated by the WM1 of SHMFF, experimental evidence indicates that the isotropic QGS arises from the interplay of superconducting fluctuations and Kondo scattering. The study helps to reveal the unconventional superconducting mechanism in nickel-based superconductors. The results were published in ***Physical Review Letters*** and selected as an Editors' Suggestion.

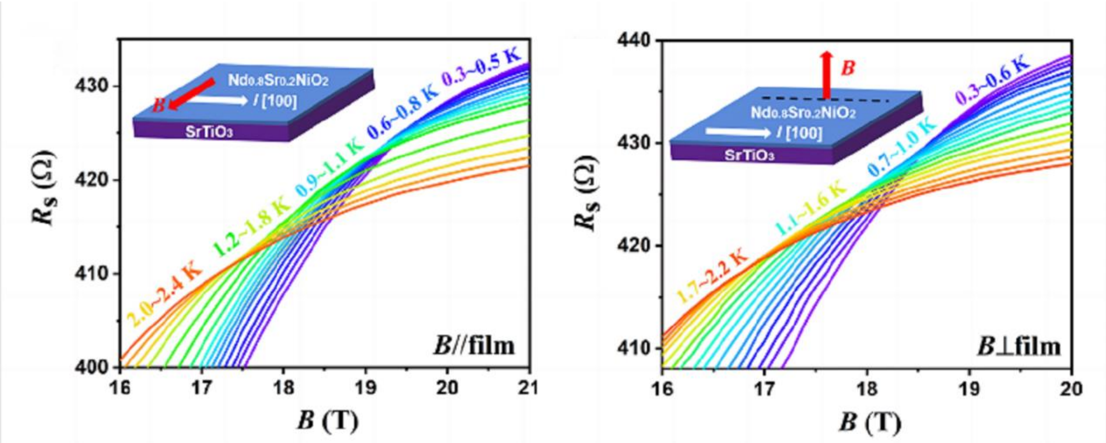

Fig.3. Isothermal Rs(B) curves of the low-temperature region under in-plane and perpendicular magnetic fields. The inset shows the experimental configuration of the magnetic field and current directions.

- **Elucidates the Stereoselective Catalytic Mechanism of Photoenzymes**

Enzymes are recognized as exceptional catalysts for achieving high stereoselectivities, but their ability to control the reactivity and stereoinduction of free radicals lags behind that of chemical catalysts. Prof. Huang Xiaoqiang and Liang Yong from Nanjing University, along with Prof. Tian Changlin from CHMFL developed a dual-catalyst system consisting of a ThDP-dependent light-driven enzyme and an organophotoredox catalyst to achieve an unnatural enantioselective radical transformation. Mechanistic investigations were conducted to explore the proposed dual photoredox and biocatalytic mechanism. In particular, two crucial intermediates (Int.B and Int.C) were confirmed by low-temperature electron paramagnetic resonance (EPR) and room-temperature spin trapping EPR spectroscopy of SHMFF, respectively. Mechanistic studies reveal that this previously elusive dual-enzyme catalysis/photocatalysis directs radicals with the unique ThDP cofactor and evolvable active site. This work not only expands the repertoire of biocatalysis, but also provides a unique strategy for controlling radicals with enzymes, complementing existing chemical tools. The study was published in ***Nature***.

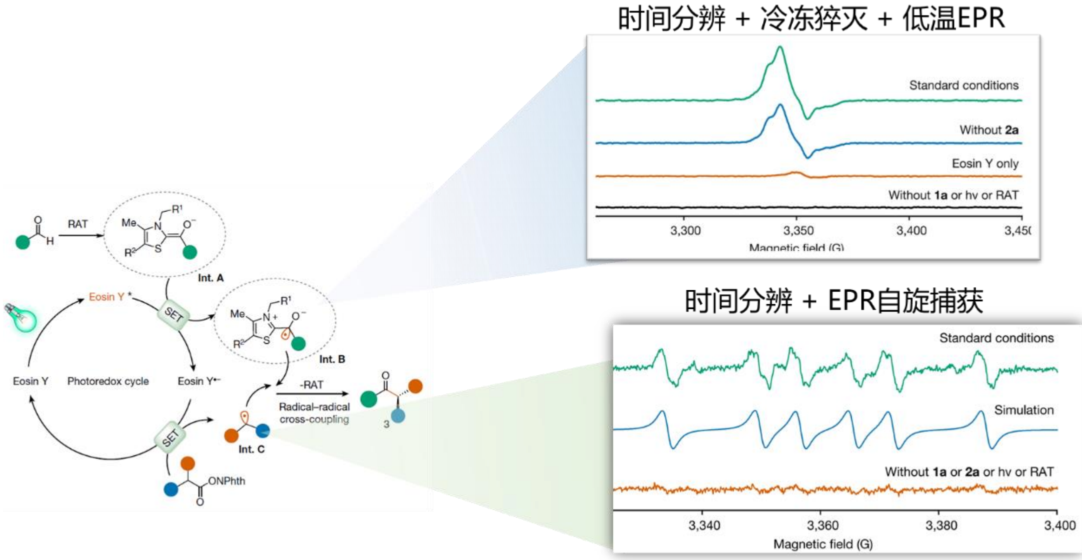

Fig.4. Mechanism speculation and mechanism exploration based on the ESR

- **Unveiling the Mechanism of Molecular Chaperone Hsp90**

Heat Shock Protein 90 (Hsp90), often referred to as the "signaling hub" within cells, is a critical molecular target in anticancer research. However, structural information about its protein-substrate complexes has remained scarce. A team led by Prof. Huang Chengdong from the University of Science and Technology of China, has for the first time resolved the structure of the complex formed by Hsp90 and intrinsically disordered protein substrates under 20T/850MHz NMR spectrometer of SHMFF. Their work proposes a dynamic molecular working mechanism for the chaperone Hsp90, deepening the understanding of its dynamic interactions and providing novel insights for designing anticancer drugs targeting this chaperone. The findings were published in ***Nature Structural & Molecular Biology*** and ***Nature Communications***.

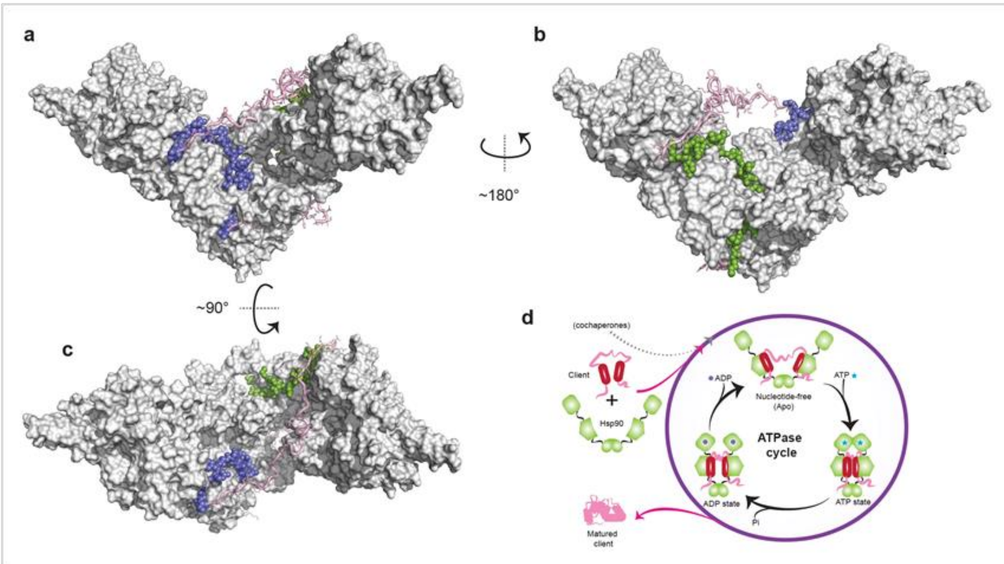

Fig.5. The structure of Hsp90 in complex with an intrinsically disordered protein and its dynamic interaction mechanism

Publications & Awards

The project "Triggering Mechanisms of T Cell Immunity" was awarded the Second Prize of the 2023 National Natural Science Award. (Led by Xu Chenqi's team at the Center for Excellence in Molecular Cell Science, CAS)

Zhang Jinglei from CHMFL was awarded the 7th Sir Martin Wood China Prize.

The project "R&D and Application of Key Technologies for High Reliable Operation of Large-scale Helium Refrigeration System" was awarded the Third Prize of the 2023 Anhui Science and Technology Progress Award. (Led by Li Junjie's team from CHMFL and Su Yulei's team from Anhui Wanrui Cold Electric Technology Co., Ltd.)

Number of Publications and patents related to SHMFF in 2024

SCI/EI	Number of awards received at/above the provincial or ministerial level	Authorized patents	Pending patents	Software copyrights	Nature Index Journal publications
265	3	22	43	1	88

Operation

In 2024, SHMFF served users from 73 universities and institutes, covering 293 projects. Planned running time is 51504 hrs, and actual running time is 53472 hrs.

	HW/WM	SM3+NMR	SM4+MRI
Planned time(hrs)	2070	8208	2500
Actual time(hrs)	2086	8209	2566

	Planned time（hrs）	**Actual time(hrs)**
SM1	2930	3020
SM2	6552	7056
PPMS	6600	6768
Cryostat	880	896
MPMS	7440	7776
ESR	1200	1334
Raman	900	917
FTIR	790	800
XRD	1120	1156
Extreme Low Temperature Transport System	2100	2380
Ultra-pressure Physical Measurement System	1070	1077
STM-MFM-AFM Combo	6144	6432
Condensed Nuclear Magnetic Resonance	1000	1000

Scientific & technical personnel and talent training

CHMFL has a total of 209 employees including 60 professors, 64 associate professors, and 85 other staff. CHMFL also has 33 postdocs and 340 graduate students.

Total number of facility staff	Classified by positions			Classified by professional titles			Students			In-house post-doctor
	Operation & maintenance staff	Researchers	Others	People with senior professional title	People with medium professional title	Others	graduated Ph.D	Graduates master	Post-graduate in progress	
209	120	83	6	124	74	11	30	44	340	33

Cooperation and exchange

International cooperation and exchanges were carried out in 2024. Scholars and experts were invited to visit SHMFF and gave academic presentations. The numbers of forums in recent five years are as follows:

Year	2024	2023	2022	2021	2020	2019
No. of presentations	24	24	12	9	7	17

From July 7th to 12th, the 13th International Conference on Research in High Magnetic Field (RHMF 2024) was held at Radboud University in Nijmegen, the Netherlands. A team of six researchers from CHMFL attended the conference. The team delivered a keynote report, showcasing China's latest achievements in high magnetic field research to the global scientific community, and participated in poster sessions, engaging in in-depth academic discussions with researchers worldwide. The team also visited HFML-FELIX after the conference.

During the event, Sheng Zhigao from the team participated in "2024 Annual Meeting of the Global High Magnetic Field Forum". He introduced the overall construction of SHMFF and its recent groundbreaking scientific achievements.

This exchange not only demonstrated China's research capabilities in steady-state high magnetic field studies but also laid a solid foundation for Sino-Dutch collaboration in this field. As international exchanges and cooperation continue to deepen, SHMFF will maintain its pivotal role in advancing high magnetic field technologies, making significant contributions to the global development of magnetic field science.

Fig. Team members engage at the RHMF 2024

Chronicle of events

- Jan.14 — "Workshop on High-Temperature Superconducting Materials and Applications" was held.
- Jan.20 — "Workshop on High-Field Magnetic Resonance Imaging SM4 - Advanced Scientific User Services" was held.
- Jan.21 — "Workshop on Superconducting Magnet SM3 and Supporting NMR Systems" was held.
- Apr. 19 — Zhang Jinglei from CHMFL was awarded the 7th Sir Martin Wood China Prize.
- May 25 — The meeting of the SHMFF User Committee was held.
- Sep. 12 — The maintenance and transformation project of " Low-Temperature In-Situ Atomic Imaging Platform in 35T Water-Cooled Magnet and superconducting magnet" successfully passed the acceptance test.

- Sep. 22 — Water-Cooled Magnet of SHMFF generated 42.02T steady-state magnetic field, setting a new world record of the same type of magnet.
- Oct. 24-27 — The 2st Conference of “Magnetic Biology and magnetic Medicine” was held.
- Jan. 4, 2025 — The meeting of the SHMFF Science & Technology Committee was held.