HCI-22nd

惠州·中国·2026

22nd International Conference on the Physics of Highly Charged Ions

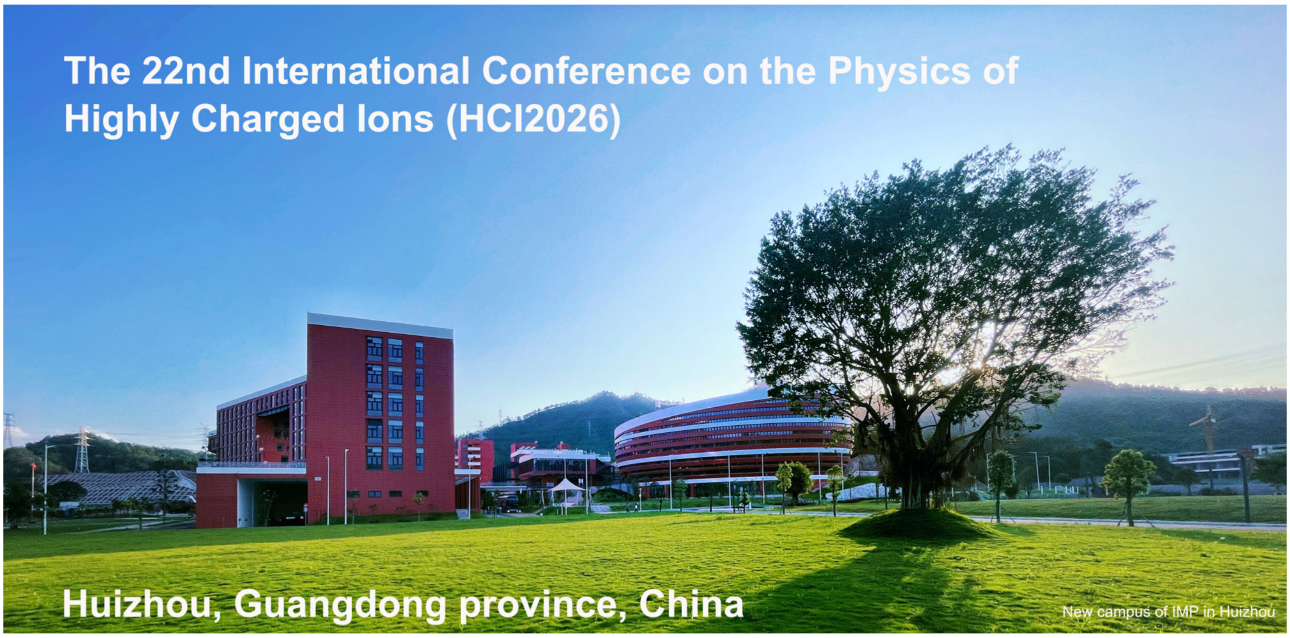
HCI2026

Conference Handbook

September 07-11, 2026,
Huizhou, Guangdong, China

Contents

1. About the conference



The 22nd International Conference on the Physics of Highly Charged Ions (HCI2026) will be held from September 7 to 11, 2026, in Huizhou, China. As a prominent event in the international HCI conference series, HCI2026 will offer a global forum for researchers to share and discuss the latest breakthroughs in the field of highly charged ions. Since its inception in 1982, the biennial HCI conference series has continuously evolved, attracting scientists from diverse disciplines around the world.

In recent years, the field of highly charged ions has seen remarkable progress, driven by substantial experimental innovations and significant theoretical developments. HCI2026 aims to bring together experimentalists and theorists to explore a broad spectrum of topics, including:

- Fundamental Aspects, Structure, and Spectroscopy
- Collisions with Electrons, Ions, Atoms, and Molecules
- Interaction with Clusters, Surfaces, and Solids
- Interactions with Photons and Plasmas
- Strong Field and Ultrafast Processes
- Production, Experimental Developments, and Applications

The conference will feature a single-session format, ensuring that every participant has the opportunity to engage in all discussions. Additionally, ample space will be provided for poster presentations, allowing researchers to present their findings.

Highly charged ions represent a cornerstone of modern atomic and plasma physics research, with broad implications across multiple scientific disciplines. Their unique properties make them an ideal testbed for advanced quantum electrodynamics (QED) calculations. They also hold promise for applications such as next generation atomic clocks, searches for variations in fundamental constants, and exploration of physics beyond the Standard Model. Moreover, HCIs are ubiquitous in high-temperature plasmas, ranging from stellar objects and black hole accretion disks to laboratory fusion devices and semiconductor processing plasmas. The diagnosis of such extreme environments demands a deep understanding of the structural, collisional, and radiative properties of HCIs—knowledge that is often still insufficient.

A central theme of HCI physics is the generation of fundamental atomic data—spanning both structural and collisional properties—underscoring the interplay between theory and experiment. Theoretical domain includes many-body effects in QED calculations and the accurate modeling of energy transfer in strongly radiating plasmas dominated by HCIs. Experimental advancements rely on advanced facilities and innovative instrumentation for HCI production—Such as accelerators, electron-cyclotron resonance sources, electron-beam-ion-sources/traps, and free-electron lasers—as well as the development of methods to probe HCI behavior in complex environments like clusters and surfaces.

We eagerly anticipate welcoming colleagues from around the world to HCI 2026. Together, we will engage in stimulating discussions, share new insights, and advance the understanding of highly charged ions in this rapidly evolving field.

Host:

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China.

Co-organizers:

National Key Laboratory of Computational Physics, Institute of Applied Physics and Computational Mathematics, Beiing, China.

State Key Laboratory of Heavy Ion Science and Technology, Institute of Modern Physics, Chinese Academy of Sciences.

Southern Center for Nuclear-science Theory (SCNT), Institute of Modern Physics, Chinese Academy of Sciences.

Contact Information

HCI2026@impcas.ac.cn

HCI2026 Conference webpage

https://indico.impcas.ac.cn/e/HCI2026

2. Conference Venue and Social Activities

The Conference Hall (Tanyue Hall) locates on the hotel's 2nd floor.

Hotel Address:
Near No.213 County Road (Binhai Tourist Resort, Nianping Peninsula Shuangyuewan, Huidong, Guangdong, China, which is close to the HIAF site.

地址：广东省惠州市，惠东港口镇东山海地段，惠州双月湾檀悦都喜天丽度假酒

店 Hotel Service Counter Telephone: +86 752 888 9999

Social activities/social program

- Reception:

A welcome reception will be held in the evening of Sunday, 6 September.

- HIAF tour/visit:

A guided tour of High Intensity heavy ion Accelerator Facility (HIAF) will be organized.

- Excursion:

An excursion to Turtle Island will be arranged.

- Conference dinner:

A conference dinner will be arranged in the evening of Thursday, 10 September 2026.

3. Committee

International Advisory Board

Toshiyuki Azuma (Japan)	Peter Beiersdorfer (USA)	Manolis Benis (Greece)
Julian Berengut (Australia)	Amine Cassimi (France)	James Colgan (USA)
José Crespo Lopez-Urrutia (Germany)	Ronnie Hoekstra (the Netherlands)	Joanna Hoszowska (Switzerland)
Clara Illescas (Spain)	Xinwen Ma (China)	Nobuyuki Nakamura (Japan)
Sebastian Otranto (Argentina)	Marek Pajek (Poland)	Roberto Rivarola (Argentina)
Nina Rohringer (Germany)	Marianna Safronova (USA)	José Paulo Santos (Portugal)
Reinhold Schuch (Sweden)	Emma Sokell (Ireland)	Thomas Stöhlker (Germany)
Hajime Tanuma (Japan)	Károly Tőkési (Hungary)	Martino Trassinelli (France)
Lokesh Tribedi (India)	Richard Wilhelm (Austria)	Ke Yao (China)
Henning Zettergren (Sweden)		

Local Organizer Committee (LOC)

- **Chair**: Xinwen Ma (IMPCAS)
- **Co-chairs**: Xiangjun Chen (USTC), Jianguo Wang (IAPCM)
- **Secretaries**: Shaofeng Zhang (IMPCAS), Weiqiang Wen (IMPCAS)
- **LOC Members**:

Lin Chen (LZU),	Xiaobin Ding (NWNU),	Hua Guan (APM),
Zhimin Hu (SCU),	Guiyun Liang (NAOC)	Lijun Mao (IMPCAS),
Jieru Ren (XJTU),	Xueguang Ren (XJTU),	Caojie Shao (IMPCAS),
Maogen Su (NWNU),	Liangting Sun (IMPCAS),	Baoren Wei (FDU),
Yong Wu(IAPCM),	Shenyue Xu (IMPCAS),	Xinliang Yan (IMP)
Jie Yang (IMPCAS),	Ke Yao (FDU),	Jianmin Yuan (JLU),
Weimin Zhou (LFRC),	Linfan Zhu (USTC),	Xiaolong Zhu (IMPCAS)

4. Scientific program

7th September (Monday)	
Chair: **Xinwen Ma,** *Institute of Modern Physics, CAS, Lanzhou, China*	
09:00-09:10	Opening Address: **Meng Wang,** *Institute of Modern Physics, CAS, Lanzhou, China*
09:10-09:40	**LR:** An Overview of Research Activities at IMP and Opportunities at HIAF **Meng Wang,** *Institute of Modern Physics, CAS, Lanzhou, China*
09:40-10:25	**RR:** Sensing old and, possibly, new physics with highly charged ions **José R. Crespo López-Urrutia,** *Max-Planck Institute for Nuclear Physics, Germany*
10:25-11:05	**Conference Photo and Coffee Break**
Chair: **Marek Pajek,** *Jan Kochanowski University, Poland*	
11:05-11:35	**PR:** Progress towards a trapped-ion nuclear clock **Atsushi Yamaguchi,** *RIKEN Center for Advanced Photonics, Wako, Japan*
11:35-11:55	**ST:** Periodic table for ultra-accurate highly charged ion clocks **Chunhai Lyu,** *Max Planck Institute for Nuclear Physics, Heidelberg, Germany*
11:55-14:00	**Lunch**
Chair: **Yuri Ralchenko,** *University of Maryland, Goddard Space Flight Center, USA*	
14:00-14:30	**PR:** Highly Charged Tungsten Ion Observation: Enabling Insights into Tungsten Transport Study in Magnetically Confined Fusion Plasma **Ling Zhang,** *Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China*
14:30-14:50	**ST:** Recent activities of the Japanese EBITs: optical and EUV spectroscopy and instrument development **Naoki Kimura,** *National Institute for Fusion Science, Gifu, Japan*
14:50-15:10	**ST:** Charge-exchange emissions in astrophysical and laboratory simulated plasmas **Guiyun Liang,** *National Astronomical Observatories, CAS, Beijing China*
15:10-15:30	**ST:** Atomic processes in dense plasma **Jieru Ren,** *School of Science, Xi'an Jiaotong University, Xi'an, China*
15:30-16:00	**Coffee break**

Chair: **Ke Yao,** *Fudan University, Shanghai, China*	
16:00-16:30	**PR:** Spin-statistics breaking in swift collisions of He-like metastable ions with atoms **Stefanos Nanos,** *Institut des Nanosciences de Paris, Sorbonne Université, CNRS,France*
16:30-16:50	**ST:** Cross Section Measurements and State-Selective Electron Capture in Ne^{7+}–H_2/He Collisions **Yijiao Wu,** *Institute of Modern Physics, Fudan University, Shanghai, China*
16:50-17:10	**ST:** Observation of highly excited fragment atomic ions from diatomic molecules in collisions with highly charged ions in EUV emission spectra **Hajime Tanuma,** *Tokyo Metropolitan University, Tokyo, Japan*
17:10-17:30	**ST:** X-ray emission following charge exchange between Al^{13+} and He **Guocheng Wei,** *Institute of Modern Physics, CAS, Lanzhou, China*
17:30-17:50	**ST:** Classical and Quasi Classical Modeling of Ion–Atom Collision Cross Sections for Fusion Research **Károly Tőkési,** *HUN-REN Institute for Nuclear Research, Debrecen, Hungary*
18:00-19:00	**Dinner**

8th September (Tuesday)	
Chair: **Ronnie Hoekstra,** *University of Groningen, The Netherlands*	
09:00-09:45	**RR:** From clusters of galaxies to tiny nuclei: the robust utility of EBIT spectroscopy **Yuri Ralchenko,** *University of Maryland, Goddard Space Flight Center, USA*
09:45-10:15	**PR:** Recent Progress on Sympathetic Cooling of Ni Highly Charged Ions for Optical Clock Development **Shaolong Chen,** *Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan, China*
10:15-10:35	**ST:** Application of Dielectronic Recombination in Strong-Field Physics and Kilonova Spectroscopy **Chunyu Zhang,** *Institute of Modern Physics, CAS, Lanzhou, China*
10:35-11:05	**Coffee Break**
Chair: **José R. Crespo López-Urrutia,** *MPIK, Germany*	

11:05-11:35	**PR:** A nuclear clock based on Th-229 **Shiqian Ding,** *Department of Physics, Tsinghua University, Beijing, China*
11:35-11:55	**ST:** Nuclear Clock Meets Highly Charged Ions **Wu Wang,** *Institute of Theoretical Physics, CAS, Beijing, China*
11:55-14:00	**Lunch**
	Chair: **Károly Tőkési,** *HUN-REN Institute for Nuclear Research, Hungary*
14:00-14:30	**PR:** Looking behind the surface to disentangle electron emission mechanisms in HCI-solid interactions **Victoria Vojtech,** *TU Wien, Institute of Applied Physics, Vienna, Austria*
14:30-14:50	**ST:** Detecting surface magnetism with highly charged ions **Martino Trassinelli,** *Institut des NanoSciences de Paris, CNRS, Sorbonne Universit´e, Paris, France*
14:50-15:10	**ST:** Highly charged ion-induced surface modifications studied by low-angle X-ray techniques **Grzegorz Wesolowski,** *Institute of Physics, Jan Kochanowski University,*
15:10-15:30	**ST:** Electron emission induced by slow Sn^{1-5+} ions on metal surfaces **Luc Assink,** *Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands*
15:30-16:00	**Coffee break**
16:00-18:00	**Poster Session-A**
18:00-19:00	**Dinner**

	9th September (Wednesday)
	Chair: **Thomas Stöhlker,** HI-Jena & GSI, Germany
09:00-09:45	**RR:** Surprises in Electron Capture by low-energy Sn ions: Hop-skip-and-jump versus long-jump double electron capture from H_2 **Ronnie Hoekstra,** *University of Groningen, The Netherlands*
09:45-10:15	**PR:** Highly Charged Ions as Emerging Probes of Nuclear Structure **Endre Takacs,** *Department of Physics and Astronomy, Clemson University, USA*

10:15-10:35	**ST:** Study of electron temperature anisotropy in high temperature plasmas via x-ray/EUV polarization spectroscopy **Tomoko Kawate,** *National Institutes for Quantum Science and Technology, Naka, Japan*
10:35-11:05	**Coffee Break**
	Chair: **Martino Trassinelli,** *CNRS & Sorbonne Universit ́e, Paris, France*
11:05-11:35	**PR:** Damaging intermolecular relaxation processes of hydrated biomolecules after heavy-ion irradiation **Shenyue Xu,** *Institute of Modern Physics, CAS, Lanzhou, China*
11:35-11:55	**ST:** Measuring ion-induced biomolecular fragmentation using a Velocity Map Imaging spectrometer **Antonin Bourgeteau,** *Centre de Recherche sur les Ions, CIMAP, CEA-CNRS-ENSICAEN-UNICAEN, Normandie Université, Caen, France*
11:55-14:00	**Lunch**
	Chair: **Hajime Tanuma,** *Tokyo Metropolitan University, Tokyo, Japan*
14:00-14:30	**PR:** Fully differential ion–atom collision experiments in storage rings: past, present and future **Daniel Fischer,** *Missouri University of Science and Technology, Rolla, USA*
14:30-14:50	**ST:** Absolute cross sections for excitation of helium-like uranium in relativistic collisions **Alexandre Gumberidze,** *GSI, Darmstadt, Germany*
14:50-15:10	**ST:** Angular and spin-polarization properties of Auger electrons emitted from nonradiative decay of highly charged ions **Zhongwen Wu,** *Northwest Normal University, Lanzhou, China*
15:10-15:30	**ST:** State-resolved target-excitation and electron-loss cross sections in ion collisions with high charge states of Ne and Ar **Nicholas Antonio,** *Curtin University, Perth, Australia*
15:30-16:00	**Coffee break**
16:00-18:00	**Poster Session-B**
18:00-19:00	**Dinner**

	Chair: **Reinhold Schuch,** *Stockholm University, Stockholm, Sweden*
19:00-20:00	**Public Lecture:** *Time Frontier: Extending Human Cognizance of the Dynamic Universe* **Di Li,** *Tsinghua University & National Astronomical Observatories, Beijing, China*

10th September (Thursday)

	Chair: **Richard Wilhelm,** *TU Wien, Institute of Applied Physics, Vienna, Austria*
09:00-09:45	**RR:** QED Tests via Resonant Coherent Excitation in Thin Crystals and Muonic Atoms **Toshiyuki Azuma,** *AMO Physics Lab RIKEN, WPI-QUP, KEK, Japan*
09:45-10:15	**PR:** Quantum Electrodynamics in Strong Electromagnetic Fields: Substate Resolved $K\alpha$ Transition Energies in Heliumlike Uranium **Günter Weber,** *Helmholtz Institute Jena & GSI, Darmstadt, Germany*
10:15-10:35	**ST:** From laboratory EBITs to space observatories: precision atomic data for X-ray plasma diagnostics **Chintan Shah,** *Nasa Goddard Space Flight Center*
10:35-11:05	**Coffee Break**
	Chair: **Shenyue Xu,** *Institute of Modern Physics, CAS, Lanzhou, China*
11:05-11:35	**PR:** Ultrafast Highly Charged Ion Dynamics **Moto Togawa,** *Institute of Space and Astronautical Science, JAXA, Japan*
11:35-11:55	**ST:** Imaging the variation of electron density of the covalent bond in photolysis reaction of CH_3I **Enliang Wang,** *Hefei National Research Center for Physical Sciences at the Microscale and Department of Modern Physics, USTC, Hefei, China.*
11:55-14:00	**Lunch**
13:00-18:00	**HIAF Tour (13:00-17:00)** **&** **Social activity**
19:00-21:00	**Conference Dinner**

11th September (Friday)	
Chair: **Shaofeng Zhang,** *Institute of Modern Physics, CAS, Lanzhou, China*	
09:00-09:30	**PR:** Generalized independent-atom-model approach for net ionization of molecules by multiply-charged heavy-ion impact **Tom Kirchner,** *Department of Physics and Astronomy, York University,*
09:30-09:50	**ST:** High precision experimental benchmarks for helium double-to-single ionization by fast highly charged ions **Tianyu Zheng,** *Institute of Modern Physics, CAS, Lanzhou, China*
09:50-10:10	**ST:** Co-Moving Heavy-Ion Beam Collisions in the ESR near the Coulomb Barrier **Sergey Litvinov,** *GSI, Darmstadt, Germany*
10:10-10:30	**ST:** Ionization by dense electron beams versus ionization by beams of highly charged ions **Alexander Voitkiv,** *Institute for Theoretical Physics I, Heinrich-Heine-University Düsseldorf, Germany*
10:30-11:05	**Coffee Break**
Chair: **Toshiyuki Azuma,** *AMO Physics Lab RIKEN, WPI-QUP, KEK, Japan*	
11:05-11:35	**PR:** Precision experiments at the intersection of Atomic, Nuclear and Astrophysics **Yury Litvinov,** *GSI, Darmstadt, Germany & Universitat zu Koln, Germany*
11:35-11:55	**ST:** Mass and decay lifetime measurements of highly-charged Ions at the HIAF-SRing facility **Xinliang Yan,** *Institute of Modern Physics, CAS, Lanzhou, China*
11:55-14:00	**Closing and Lunch**

REVIEW REPORTS

RR-1

Sensing old and, possibly, new physics with highly charged ions

José R. Crespo López-Urrutia[1,*]

[1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Our current theoretical description of the physical world is very successful in its predictive power, yet it leaves essential phenomena unexplained, including the nature of dark matter and dark energy and the observed matter–antimatter asymmetry. Searches for physics beyond the Standard Model therefore remain a major goal of fundamental physics. Precision experiments in atomic systems can provide sensitive probes of hypothetical new particles and fifth forces. Historically, increasingly precise studies of the discrete spectrum of hydrogen, including its fine and hyperfine structure, the Lamb shift, and proton-radius effects, have played a central role in testing and developing fundamental theory. Highly charged ions (HCI), particularly hydrogenlike systems, extend such tests into the strong-field regime, where relativistic, quantum-electrodynamic (QED) and nuclear-size effects are greatly enhanced. Few-electron ions provide similarly clean testing grounds for QED and *ab initio* treatments of electron correlation, and remarkable agreement between experiment and theory has been achieved (see, e. g., Refs. [1–3]). HCI are also promising systems for searches for physics beyond the Standard Model [4]. At the precision frontier, however, uncertainties associated with nuclear structure limit further progress. Nuclear charge radii, hyperfine anomalies such as the Bohr–Weisskopf effect, and nuclear polarization obscure the atomic-structure contributions of interest. Even the exceptional precision now available in isotope-shift measurements and King-plot analyses does not in general eliminate these nuclear-structure limitations [5–9].

Rather than merely constituting an obstacle, this situation offers an opportunity. The novel tools of frequency metrology can be used to investigate open problems in nuclear physics while simultaneously improving atomic-structure theory for increasingly complex electronic systems. The well-known advantages of systematic studies along HCI isoelectronic sequences are particularly valuable in this context. Their potential for resolving such "old-physics" questions must be fully exploited if searches for "new physics" are to become robust. Precision measurements of many-electron HCIs, isotope shifts, including those involving radioactive nuclei, and nuclear moments coupled to electronic structure can progressively disentangle the relevant atomic and nuclear contributions and may ultimately reveal signatures of physics beyond the Standard Model.

References

[1] J. Morgner, *et al.*, Nature **622**, 53 (2023)
[2] J. Morgner, *et al.*, Science **388**, 945 (2025)
[3] M. Togawa, *et al.*, Phys. Rev. A **110**, L030802 (2024)
[4] M. G. Kozlov, *et al.*, Rev. Mod. Phys. **90**, 045005 (2018)
[5] A. Wilzewski, *et al.*, Phys. Rev. Lett. **134**, 233002 (2025)
[6] C. Cheung, *et al.*, Phys. Rev. Lett. **135**, 093002 (2025)
[7] N. H. Rehbehn, *et al.*, Phys. Rev. A **112**, L061101 (2025)
[8] N. H. Rehbehn, *et al.*, Phys. Rev. Lett. **131**, 161803(2023)
[9] S. A. King, *et al.*, Nature **611**, 43 (2022)

* Email: crespojr@mpi-hd.mpg.de

RR-2

From clusters of galaxies to tiny nuclei: the robust utility of EBIT spectroscopy

Yuri Ralchenko[1,*]

Department of Astronomy, University of Maryland, College Park, MD 20742
X-Ray Astrophysics Laboratory, NASA/GSFC, Greenbelt, MD 20771
CRESST II, NASA/GSFC, Greenbelt, MD 20771
[1]Former address: National Institute of Standards and Technology, Gaithersburg, MD 20899

Over the past four decades, electron beam ion traps (EBITs) have become among the most versatile and widely used sources of highly charged ions (HCIs). They have enabled studies of HCI interactions with solids, provided some of the most stringent tests of quantum electrodynamics (QED) in atomic structure and spectroscopy, supplied critical atomic data for astrophysics and fusion plasma diagnostics, and supported searches for physics beyond the Standard Model, among many other applications.

Since the mid-1990s, the EBIT facility at the National Institute of Standards and Technology (NIST) has been at the forefront of HCI research, producing landmark results in the spectroscopy and physics of medium- and high-*Z* ions from a wide range of elements. Although the NIST EBIT program was recently terminated, the research effort will continue following the relocation of the EBIT to NASA's Goddard Space Flight Center (GSFC).

In this talk, I will highlight the program's major achievements over the past several years. Topics will include the determination of charge radii of heavy nuclei [1]; measurements of electron-impact ionization cross sections in He-like Fe [2], which are important for modeling the spectroscopic signatures of shock waves generated during galaxy-cluster collisions; tests of relativistic atomic structure and bound-state QED in Co-like ions [3]; and investigations of the role of metastable states in ladder-type ionization processes in highly charged ions.

<u>References</u>
[1] A. Hosier et al, J. Phys. B **57**, 195001 (2024).
[2] Y. Yang et al, A&A, **700**, A263 (2025).
[3] R. Silwal et al, Phys. Rev. A, **111**, 042821 (2025).

* Email: yralchen@umd.edu

RR-3

Surprises in Electron Capture by low-energy Sn ions: Hop-skip-and-jump versus long-jump double electron capture from H_2

Ronnie Hoekstra

[1]University of Groningen, Groningen, the Netherlands
[2] Advanced Research Centre for Nanolithography, Amsterdam, the Netherlands

The forefront of photolithography is defined by Extreme UltraViolet (EUV) photolithography at 13.5 nm is. Because loosely speaking, the shorter the wavelength the smaller and faster the features that one can pattern. A hot plasma of tin ions is used to generate the 13.5-nm light in so-called Laser-Produced tin Plasma (LPP) sources. The figure shows the operational schematics of such a source. A 50-kHz stream of liquid tin droplets is irradiated twice with infrared laser light. A first prepulse reshapes the droplet into a larger pizza-shaped disk. The prepulse is followed by a high-power main pulse to convert the liquid into a plasma of, of approximately 500,000 K. Line radiation by highly charged tin ions in the plasma is the actual source of the 13.5 nm EUV light.

Artistic atomic physicist's impression of the ion world inside an EUV photolithography machine.

In this talk we follow the "life" of tin ions from their creation inside the EUV generating plasma all the way to their mitigation in the H_2 buffer gas surrounding the plasma or their running into plasma facing materials. To start out I will briefly address why Sn ions in charge states of 10+ - 15+ all radiate at 13.5 nm and why so efficiently, and why does one not observe ions escaping from the plasma in charge states higher than roughly 8+?

After this scene setting part, I will focus on their interactions inside the buffer gas surrounding the laser-produced plasma. Since the charge transfer reaction from Sn^{2+} to Sn^{+} is forbidden (endothermic), why is the final charge state of the ions in the H_2 buffer gas not 2+, but 1+? And even more puzzling, why does a highly endothermic (energy forbidden) reaction as two-electron capture by Sn^{3+} occur at low energies? In particular, the answer to the latter question let to new insights in the physics of ion-molecule interactions [1]. The synchronous-sequential electron-capture explanation of the large two-electron capture cross sections at low collision energies (< 5 keV) requires an expansion of the internuclear distance of the transient H_2^{+} during the collision. This process that we coined the "Hop-Skip-Jump" mechanism implies that kinetic energy release KER) to the protons is much less than the Coulomb explosion value of almost 20 eV. To proof that the hop-skip-jump mechanism is indeed underlying the large two-electron capture cross sections we have measured KER values in Sn^{3+} - H_2 collisions. By measuring the KERs in other low-energy collision systems, we seek to verify the universal nature of the hop-skip-jump mechanism.

References

[1 L. Oltra *et al*, Phys. Rev. Lett. **134**, 093002, (2025)

RR-4

QED Tests via Resonant Coherent Excitation in Thin Crystals and Muonic Atoms

Toshiyuki Azuma[1*]

[1] WPI-QUP, International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles, High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan.

The experimental study of bound-state QED using highly charged ions (HCIs) has a long history and has been pursued by many groups. The standard approach relies on storing HCIs in ion storage rings or ion traps. Our group, however, has developed and pursued two distinctive approaches.

One is **resonant coherent excitation using a single thin silicon crystal**. By utilizing the periodic electric field of a crystal, we can excite HCIs of relativistic velocities in the x-ray energy regime for the transition. We have applied this technique to precision tests of bound-state QED of Li-like uranium ions provided at GSI. This project has been ongoing for more than a decade, during which we have overcome a variety of experimental challenges step by step [1]. We prepared a uranium ion beam with a narrow energy spread by introducing electron cooling at the ESR and determined its absolute energy with high precision by monitoring the voltage applied to the electron-cooler electrode. Recently, we have reached the stage where the absolute transition energy can be compared with theoretical predictions at a precision better than a few tenths of an eV. At this level of the absolute energy comparison, however, a new issue has emerged concerning the characterization of the thin crystal itself.

Our second approach uses **muonic atoms**. During the formation and cascade processes of muonic atoms, the bound electrons can be completely stripped off, leaving a simple two-body system consisting of a muon and a nucleus for muonic Ne or muonic Ar. The electric field experienced by the muon is comparable in strength to that experienced by a 1s electron in uranium [2]. Following successful proof-of-principle experiments on x-ray detection using a superconducting transition-edge sensor (TES) calorimeter for muonic Ne [3], we have recently completed measurements on muonic Ar. In the course of these studies, we also succeeded in observing highly charged exotic atoms consisting of a muon, electrons, and a nucleus [4], and, furthermore, the electron-refilling process of highly charged muonic atoms embedded in metallic solids [5]. The initial stage of muon capture into atoms is also understood in the light of the concept of *orbital collapse* [6].

In this talk, I will present the latest status of these two complementary approaches and discuss their respective advantages and limitations for precision tests of bound-state QED.

References

[1] Y. Nakano, TA et al., Phys. Rev. **A87**, 060501R(2013)
[2] N. Paul, TA et al., Phys. Rev. Lett. **126**, 1730018 (2021)
[3] T. Okumura, TA et al., Phys. Rev. Lett. **130**, 173001 (2023)
[4] T. Okumura, TA et al., Phys. Rev. Lett. **134**, 243001 (2025) *Editors' Suggestion*.
[5] T. Okumura, TA et al., Phys. Rev. Lett. **127**, 053001 (2021)
[6] X. M. Tong, TA et al., Phys. Rev. Lett. **107**, 012804 (2023) *Editors' Suggestion*.

* Email: toshiyuki.azuma@kek.jp

PUBLIC LECTURE

Time Frontier: Extend Human's Cognizance of the Dynamic Universe

Di Li[1,*]

[1]Department of Astronomy, Tsinghua University, Beijing 100084, China

Modern physics and astronomy both originated from Galileo. Since Galileo's pioneering use of telescopes, optical observations have been dominating astronomy. Hertz invented the first antenna and demonstrated the wave-particle duality of light. These developments give rise to radio astronomy and giant dishes.

The 20th century saw the advent of a scientific and technical wonder that is Arecibo. Since its inception in November of 1963 as a direct result of the cold war, the Arecibo telescope perched on the apex of human antenna for more than half a century, generating a series of landmark discoveries, including the double neutron star that won the Nobel prize in 1993.

First proposed in 1990s, the Five-hundred-meter Aperture Spherical radio Telescope (FAST) started full operation in early 2020. Since then it has become a leading observatory in radio astronomy, facilitating 12 Nature/Science (main journal) publications in its first 5 years.

Most of the major discoveries so far from FAST came from its 19-beam system, which was built by the same group who has built the Parkes 13-beam system. Parkes became famous when it broadcasted the first Apollo landing. As a major upgrade to Parkes telescope, its multi-beam system transformed single-dish radio astronomy, delivering the largest haul of new pulsars, definitive HI galaxy catalogues, and the standard HI maps of the Southern sky. These landmark surveys had to be conducted separately, due to the conflicting observation requirements. We invented the high-cadence CAL technique, in which the calibration signal is injected at the sampling rate and facilitate, for the first time, truly commensal pulsar and spectral-line surveys. Implemented on FAST with drift-scan mode, the Commensal Radio Astronomy FAST Survey (CRAFTS) has multiplied the survey efficiency of FAST an discovered more than 260 pulsars as well as 10 Fast Radio Bursts (FRBs) and released over 5,000 square degrees of calibrated HI images. I will report a few science highlights from CRAFTS, in the context of surveying the dynamic radio sky.

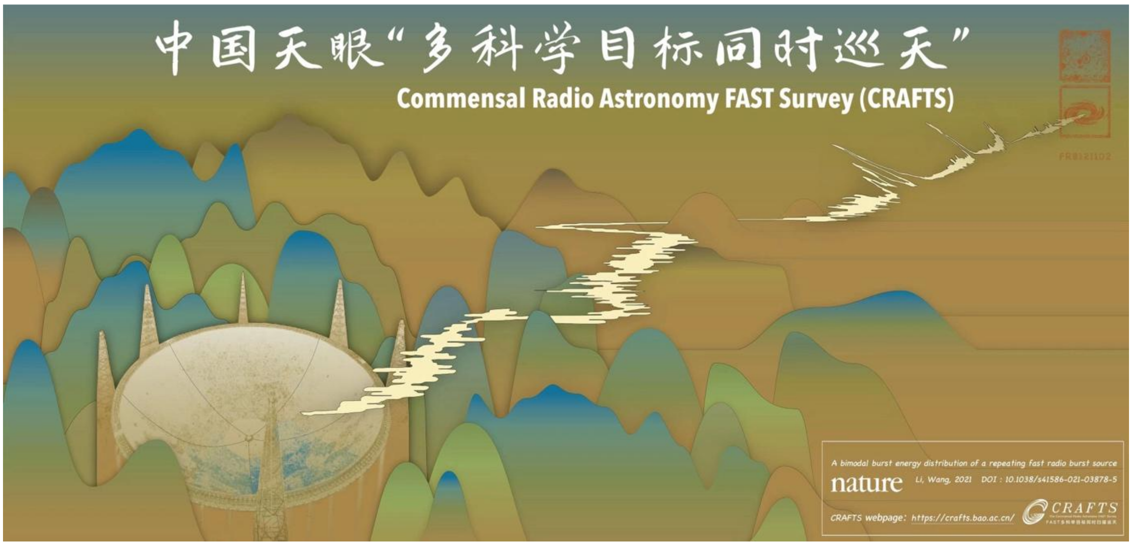


Fig. 1 Artist's impression of CRAFTS's detection FRBs.

* Email:dili@tsinghua.edu.cn

The experience of setting up high-cadence surveys also lead to a few recent discoveries, including the first radio pulsar from a Central Compact Object (CCO) with the MeerKAT array and the first long-period-transient (LPT) residing in a supernova remnant with the DART array. These recent discoveries from radio telescopes world-wide are filling in the missing puzzles of a richer and more complete picture of compact objects, which started by Landau’s suggestion of a ‘giant nucleus’, elucidated by Baade & Zwicki’s invention of the terms of supernova as well as neutron stars, make prominent by Bell’s discovery of pulsars that won the Nobel prize in 1974.

CRAFTS' high cadence sampling of the radio sky also give rise to the concept of the "time frontier". I coined this term to represent the quantum foundation of the Universe that is to be revealed by exploring extreme transients. Hypothetical considerations will be given to possible lines of investigations.

PROGRESS REPORTS

PR-1

Progress towards a trapped-ion nuclear clock

Atsushi Yamaguchi[1,*]

[1]RIKEN Center for Advanced Photonics, Wako, Saitama, Japan

The first excited nuclear state of thorium-229 (^{229}Th), known as the isomer, has attracted significant interest due to its remarkably low energy, which has been determined to be approximately 8.4 eV [1-3]. This specific nuclear transition between the ground and isomeric states of ^{229}Th provides an unprecedented platform for direct laser spectroscopy of an atomic nucleus. A primary application is a nuclear clock based on this nuclear transition frequency [4]. Because this nuclear transition frequency is exceptionally resilient against external environmental disturbances, a ^{229}Th-based nuclear clock is anticipated to surpass the performance of existing atomic clocks [5]. Furthermore, various proposals suggest employing this nuclear clock as a highly sensitive detector to search for novel physical phenomena, including dark matter and temporal variations in fundamental constants.

We are currently developing a trapped-ion nuclear clock. An ion trap serves as a suitable framework for achieving ultra-high accuracy, as it allows ^{229}Th ions to be isolated within an ultra-high vacuum environment. Our experimental setup is specifically engineered to confine triply charged thorium ions ($^{229}Th^{3+}$). Triply charged thorium ions feature closed cyclic electronic transitions, wherein an electron excited by a laser spontaneously relaxes back to its initial state. These cyclic transitions are an essential prerequisite for implementing laser cooling, laser-induced fluorescence detection, and electronic state preparation, all of which are critical operations for running a trapped-ion nuclear clock.

For our $^{229}Th^{3+}$ ion source, we utilize uranium-233 (^{233}U), which undergoes α-decay into ^{229}Th. The recoil ^{229}Th ions are subsequently thermalized and cooled using helium buffer gas. During this buffer-gas cooling phase, charge-exchange collisions simultaneously manipulate the charge state of the thorium ions to the 3+ state. The ^{229}Th ions are then gathered via a radio-frequency carpet acting as an ion collector [6] and confined within a linear Paul trap. A distinct benefit of utilizing a ^{233}U source is that it yields ^{229}Th ions not only in their nuclear ground state but also in the isomeric state, with a branching ratio of roughly 2%. Leveraging this, we have developed a nuclear-state-selective laser spectroscopy method that permits the isolated detection of isomer ions. This spectroscopy technique allows us to identify and analyze the detailed characteristics of trapped, triply charged ^{229}Th isomers [7]. As a next step towards a nuclear clock, we are currently working on cooling of the trapped $^{229}Th^{3+}$ ions.

References
[1] J. Tiedau *et al.*, Phys. Rev. Lett. **132** 182501 (2024).
[2] R. Elwell *et al.*, Phys. Rev. Lett. **133** 013201 (2024).
[3] C. Zhang *et al.*, Nature **633** 63 (2024).
[4] E. Peik and Chr. Tamm, Europhys. Lett. **61** 181 (2003).
[5] C. J. Campbell *et al.*, Phys. Rev. Lett. **108** 120802 (2012).
[6] M. Wada *et al.*, Nucl. Instrum. Methods Phys. Res. B **204** 570 (2003).
[7] A. Yamaguchi *et al.*, Nature **629** 62 (2024).

* Email: atsushi.yamaguchi.fv@riken.jp

PR-2

Highly Charged Tungsten Ion Observation: Enabling Insights into Tungsten Transport Study in Magnetically Confined Fusion Plasma

Ling Zhang[1,*] , Yunxin Cheng[1], Runjia Bao[1,2] ,Shigeru Morita[3], Darío Mitnik[4]

[1]Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
[2]University of Science and Technology of China, Hefei 230026, China
[3]National Institute for Fusion Science, Toki 509-5292, Japan
[4]Instituto de Astronomía y Física del Espacio, Buenos Aires 1428, Argentina

With tungsten being widely adopted as plasma-facing material in magnetically confined fusion devices, highly charged tungsten ions are prevalent in high-temperature plasmas. Consequently, the investigation and effective control of tungsten impurity transport have emerged as critical issues for achieving steady-state operation of fusion devices.

Recently, significant progress has been made on this topic at the EAST tokamak with a full-tungsten divertor. A high-performance spectroscopic diagnostic platform for tungsten impurities has been established [1], enabling the observation of the fast temporal behaviour of W^{4+}-W^{46+} ions and the spatiotemporal evolution of W^{24+}-W^{46+} ions [2]. The observation and quantitative diagnosis of highly charged tungsten ion distributions, combined with numerical simulations, have been successfully applied to the study of tungsten impurity transport [3-5]. Based on these achievements, effective control strategies for tungsten impurities have been developed.

This work provides important insights into the understanding of tungsten impurity behaviour in fusion plasmas and contributes to the development of impurity control techniques for future fusion reactors, making it highly relevant to the theme of this conference on Applications of the field of highly charged ions.

References
[1] YX Cheng, L Zhang et al., 2025 JINST 20 C04016
[2] WM Zhang, L Zhang et al., Phys. Scr. 99 (2024) 105609
[3] WM Zhang, L Zhang et al., Nucl. Fusion 64 (2024) 086004
[4] WM Zhang, L Zhang et al., Nucl. Fusion 65 (2025) 052003
[5] YX Cheng, L Zhang et al., Nucl. Fusion 65 (2025) 062003

* Email: zhangling@ipp.ac.cn

PR-3

Spin-statistics breaking in swift collisions of He-like metastable ions with atoms

S. Nanos[1, 2, 3, *], I. Madesis[2, 3], A. Laoutaris[2, 3], T.J.M. Zouros[2], E.P. Benis[4], J.W. Gao[5, 6, 7], A. Dubois[7]

1. Institut des Nanosciences de Paris, Sorbonne Université, CNRS, 75005 Paris, France
2. Department of Physics, University of Crete, GR-70013 Heraklion, Greece
3. Tandem Accelerator Laboratory, INPP, NCSR "Demokritos", GR-15310 Agia Paraskevi, Greece
4. Department of Physics, University of Ioannina, GR-45110 Ioannina, Greece
5. Institute of Applied Physics and Computational Mathematics, 100088 Beijing, China
6. Laser Fusion Research Center, China Academy of Engineering Physics, 621900 Mianyang, China
7. Sorbonne Université, CNRS, Laboratoire de Chimie Physique-Matière et Rayonnement, F-75005 Paris, France

*nanos.stefanos@insp.jussieu.fr

The process of single electron capture in fast ion–atom collisions provides a sensitive probe for studying correlated many-electron dynamics in highly excited atomic systems. Recent combined experimental and theoretical studies in collisions of He-like pre-excited carbon projectiles in the 1s2s ^{3}S state[1] with He gas targets, showed that the population of the final 1s2s2p configuration, resulting in the 1s2s2p ^{4}P and $^2P_\pm$ states, cannot be explained solely by spin statistics or by the frozen-core approximations, thereby resolving a long-standing puzzle in the field[2]. The studies further indicated the presence of a "Pauli shielding" mechanism, in which exchange-driven electron correlations selectively suppress specific capture channels, resulting in strongly non-statistical final state populations. These findings provide new insight into the quantum dynamics governing multi-open-shell ion-atom collisions and highlight the limitations of simplified population models.

Building on these results, an ongoing systematic isoelectronic investigation extends the study to low-Z He-like ions, aiming to explore how electron-correlation effects evolve along the sequence[3]. In this talk, previous findings and ongoing studies will be discussed, together with prospects for future investigations.

References

1. T. J. M. Zouros, A. Laoutaris, S. Nanos and E.P. Benis, J. Phys. B **58** (2025) 055201.
2. I. Madesis, A. Laoutaris, T. J. M. Zouros, E. P. Benis, J.W. Gao, A. Dubois, Phys. Rev. Lett. **124** (2020) 113401.
3. S. Nanos, PhD thesis, Dept. of Physics, School of Sciences, University of Ioannina (2023) 10.12681/eadd/55038.

PR-4

Recent Progress on Sympathetic Cooling of Ni Highly Charged Ions for Optical Clock Development

Shaolong Chen[1], Guosheng Zhang[1], Hao Li[1], Jun Xiao[2], Yao Huang[1], Kelin Gao[1*], **Hua Guan**[1,*]

[1]Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, Wuhan 430071, China

[2]Fudan University, Shanghai 200433, China

Highly charged ions (HCIs) are promising candidates for next-generation optical clocks. Compared with neutral atoms or singly charged ions, HCIs feature compact electron clouds and reduced sensitivity to external perturbations, making them promising platforms for realizing optical clocks with uncertainties at the 10^{-19} level or even lower. In addition, HCIs exhibit enhanced sensitivity to variations in the fine-structure constant , enabling stringent tests of its possible temporal variation and searches for new physics beyond the Standard Model [1–3].

In recent years, our group has selected Ni^{12+} [4] as a candidate system for HCI optical clocks and has carried out a series of key technological developments toward its realization. In collaboration with Fudan University, we developed a Shanghai-Wuhan electron beam ion trap (SW-EBIT) and successfully produced Ni^{12+} ions. With fluorescence spectroscopy in the SW-EBIT, the wavelength measurement accuracy was improved to the sub-picometer level [5,6]. We further designed and constructed an ion deceleration and trapping system, enabling the preparation of pure, low-energy Ni HCIs [7]. Using Be^{+} ions as coolant ions, we experimentally achieved sympathetic cooling and the formation of Coulomb crystals composed of Ni HCIs and Be^{+} ions [8].

References

[1] J. C. Berengut, et al, Phys. Rev. Lett. 105 **(2010)** 120801
[2] A. Derevianko, et al, Phys. Rev. Lett. 109 **(2012)** 180801
[3] M. G. Kozlov, et al, Rev. Mod. Phys. 90 **(2018)** 045005
[4] Y. M. Yu and B. K. Sahoo, Phys. Rev. A 97 **(2018)** 041403(R)
[5] S. Y. Liang, et al, Rev. Sci. Intrum. 90 **(2019)** 093301
[6] S. L. Chen, et al, Phys. Rev. Research, 6 **(2023)** 013030
[7] Z. Q. Zhou, et al, AIP Adv. 12 **(2022)** 035220
[8] S. L. Chen, et al, Phys. Rev. A, 112 **(2025)** 063115

*** Email:** klgao@apm.ac.cn, guanhua@apm.ac.cn

PR-5

A nuclear clock based on Th-229

Shiqian Ding[1,2*]

[1] Department of Physics, Tsinghua University, Beijing 100084, China
[2] Beijing Academy of Quantum Information Sciences, Beijing 100193, China

The Th-229 nucleus has an isomeric transition near 8.4 eV, which is the only known nuclear transition directly accessible to laser excitation and is a promising reference for a nuclear optical clock. In this talk, I will present our recent progress on continuous-wave laser spectroscopy and clock operation of the Th-229 nuclear transition.

We have developed a continuous-wave 148 nm vacuum-ultraviolet laser based on resonance-enhanced four-wave mixing in cadmium vapor. The source provides tunable, narrow-linewidth VUV radiation near the nuclear resonance with high output power. Using this laser together with home-grown Th-229-doped CaF2 crystals, we perform fluorescence and absorption spectroscopy, resolve nuclear transitions in the solid-state environment, and close the feedback loop by stabilizing the laser to a selected nuclear transition. Our results establish continuous-wave optical interrogation and clock operation of the Th-229 nuclear transition, providing a platform for compact solid-state nuclear clocks and future precision tests of fundamental physics.

References

[1] Q. Xiao, G. Penyazkov, R. Yu, B. Huang, J. Li, J. Shi, Y. Yu, Y. Mo, S. Ding, "Generation of continuous-wave vacuum ultraviolet laser light for Th-229 isomer precision spectroscopy", Phys. Rev. Appl. 25, 024034 (2026)

[2] Q. Xiao, G. Penyazkov, X. Li, B. Huang, W. Bu, J. Shi, H. Shi, T. Liao, G. Yan, H. Tian, Y. Li, J. Li, B. Lu, L. You, Y. Lin, Y. Mo, S. Ding, "Continuous-wave narrow-linewidth vacuum ultraviolet laser source", Nature 650, 852 (2026)

[3] B. Huang, G. Yan, Q. Xiao, W. Bu, Z. Zhang, C. Zhao, C. Yan, Z. Chen, P. Zhang, G. Penyazkov, Z. Zhan, L. Yan, Y. Wang, L. Li, S. Li, X. Qian, X. Liu, Q. He, T. Sun, H. Tian, B. Lu, N. Ma, J. Li, Y. Wu, Q. Gong, Y. Li, H. Shi, X. Li, L. Ma, S. Zhu, Y. Mo, J. Lin, L. You, Y. Lin, X. Zhang, Y. Hang, L. Su, and S. Ding, "A nuclear clock based on ^{229}Th". arXiv:2606.08870v1 (2026)

* Email: dingshq@mail.tsinghua.edu.cn

PR-6

Looking behind the surface to disentangle electron emission mechanisms in HCI-solid interactions

Victoria Vojtech[1,*], Christoph Lemell[2], Anna Niggas[1], Matthias Werl[1], Filip Vuković[1], Fernando Aguilar-Galindo[3,4], Friedrich Aumayr[1], Richard A.Wilhelm[1]

[1]TU Wien, Institute of Applied Physics, Vienna, Austria
[2]TU Wien, Institute for Theoretical Physics, Vienna, Austria
[3]Universidad Autónoma de Madrid, Department of Chemistry, Madrid, Spain
[4]Universidad Autónoma de Madrid, Institute for Advanced Research in Chemical Sciences, Madrid, Spain

The impact of a slow highly charged ion (HCI) on a surface is typically accompanied by the emission of numerous low-energy electrons (~100 per ion) [1]. Detection of these electrons provides an experimental way to study the electron dynamics responsible for neutralization and subsequent deexcitation of the ion. In fact, measurements of ion-induced electron yields have largely shaped the current understanding of HCI-surface interactions [2]. For conventional bulk targets, however, the observable electron yield is not a direct fingerprint of the ion neutralization and deexcitation processes, but is obscured by secondary processes in the bulk.

Here, we separate the total electron yield into its contributions from electrons originating in the primary HCI–surface interaction and from those generated by secondary processes in the bulk. We achieve this by using freestanding single-layer graphene (SLG) as a model system for the topmost surface layer of highly oriented pyrolytic graphite (HOPG). Because of its single-atom thickness, electron–electron scattering is strongly suppressed, and the emitted electrons originate mostly from the primary interaction between ion and surface. In addition, freestanding SLG facilitates experimental access to the electron yields emitted in backward *and* forward directions as well as to the transmitted ion and the number of electrons it has captured during the interaction. By performing coincidence spectroscopy of ion and electrons on SLG and comparing with electron yields from bulk HOPG, we estimate the relative contributions of surface and bulk processes to the total low-energy electron yield [3].

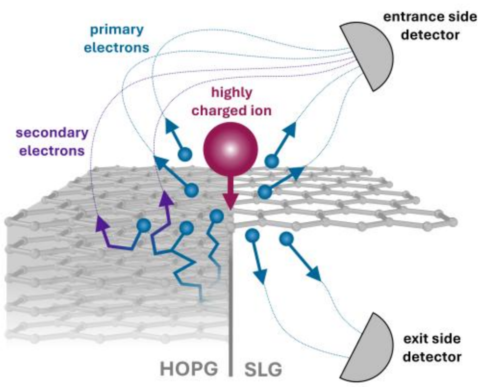


Figure 1. The contribution of primary electrons to the HCI-induced electron yield can be isolated experimentally by reducing the target thickness from HOPG (left) to a single layer of graphene (right).

References

[1] Schwestka J et al. *J. Phys. Chem. Lett.* **17** 4805-4811 (2019)

[2] Burgdörfer J et al. *Phys. Rev. A* **44** 5674-5685 (1991), Burgdörfer J et al. *Nucl. Instrum. Meth. Phys. Res. B* **98** 415-419 (1995)

[3] Vojtech V et al. *submitted*

* Email: vojtech@iap.tuwien.ac.at

PR-7

Highly Charged Ions as Emerging Probes of Nuclear Structure

E. Takacs[1,2*], H. Staiger[1], C.A. Faiyaz[1], A. Hosier[1], R. Silwal[1,3], S.A. Blundell[4], Dipti[1,2], A.A. Kwiatkowski[5], G. Gwinner[6], A. Lapierre[7], N. Kimura[8], H.A. Sakaue[8], R.F. Garcia Ruiz[9], W. Nazarewicz[7], P.-G. Reinhard[10], C. Suzuki[8], Yu. Ralchenko[2,11], I. Murakami[8], D. Kato[8], I. Angeli[12], J.D. Gillaspy[2,13], N. Nakamura[14]

[1] Department of Physics and Astronomy, Clemson University, Clemson, SC 29634, USA
[2] National Institute of Standards and Technology, Gaithersburg, MD 20899, USA
[3] Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608, USA
[4] Univ. Grenoble Alpes, CEA, CNRS, Grenoble INP, IRIG, SyMMES, 38000 Grenoble, France
[5] TRIUMF, Vancouver, BC V6T 2A3, Canada
[6] Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB R3T 2N2, Canada
[7] Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824, USA
[8] National Institute for Fusion Science, Toki, Gifu 509-5292, Japan
[9] Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[10] Institut für Theoretische Physik II, Friedrich-Alexander-Universität, 91058 Erlangen, Germany
[11] Department of Astronomy, University of Maryland, College Park, MD 20742, USA
[12] Department of Experimental Physics, University of Debrecen, Debrecen 4026, Hungary
[13] Department of Physics, Colorado State University, Fort Collins, CO 80521, USA
[14] Institute for Laser Science, The University of Electro-Communications, Tokyo 182-8585, Japan

Precise knowledge of nuclear charge radii is essential not only for nuclear structure studies, but is also increasingly recognized as a key uncertainty in precision tests of fundamental physics [1]. In heavy atomic systems, uncertainties associated with the nuclear charge distribution can limit the interpretation of beyond-the-Standard-Model searches, including isotope-shift searches for new physics and searches for possible variation of the fine-structure constant.

In Na-like and Mg-like heavy ions, electronic wavefunctions contract toward the nucleus, enhancing nuclear-size sensitivity while retaining sufficiently simple atomic structure for precision theory. Our collaboration has established precision extreme-ultraviolet spectroscopy of these ions as a quantitative method for nuclear charge-radius studies. This approach is complementary to traditional techniques such as optical isotope-shift measurements, muonic-atom spectroscopy, and elastic electron scattering, while offering unique advantages for heavy and radioactive nuclei.

Using this method, we have performed recent measurements in the deformed rare-earth region, where the extracted charge radii reveal pronounced isotonic odd–even staggering and challenge current nuclear density-functional calculations [2]. Because this experimental approach requires only a small number of trapped ions and can be implemented at existing electron beam ion trap facilities, it is particularly promising for future studies of short-lived radioactive isotopes.

References

[1] M. S. Safronova *et al.*, “Search for new physics with atoms and molecules,” *Rev. Mod. Phys.* **90**, 025008 (2018).

[2] E. Takacs *et al.*, “Puzzling Isotonic Odd-Even Staggering of Charge Radii in Deformed Rare Earth Nuclei,” *Nature Communications* (2026), accepted for publication.

*E-mail: etakacs@clemson.edu

PR-8

Damaging intermolecular relaxation processes of hydrated biomolecules after heavy-ion irradiation

Shenyue Xu[1,2,*], Hang Yuan[1,2], Yue Gao[1,2], Shaofei Gu[1,2], Bo Yang[1,2], Mei Wang[1,2], Dalong Guo[1,2], Xiaolong Zhu[1,2], Dongmei Zhao[1,2], Shaofeng Zhang[1,2] and Xinwen Ma[1,2]

1State Key Laboratory of Heavy Ion Science and Technology, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[2]School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

Heavy-ion-irradiation can cause severe damage to cell and DNA. Acting on cancer cells, heavy ion therapy servers as an efficient radiotherapy technique due to the ability of carrying a large amount of energy and accurate delivering these energies to the tumor area by controlling the depth of the so-called Bragg Peak, and the high biological effectiveness of killing cancer cells. Despite its importance in both fundamental research and clinical applications, the mechanistic details of the heavy ion irradiation are unclear. Employing the reaction microscope built up in the Heavy Ion Research Facility in Lanzhou, we investigated the relaxation mechanisms of the hydrated pyrimidine clusters after heavy-ion irradiation [1].

The measurements were performed with the 25-MeV/u bare Fe^{26+} beam and the 112.5-keV/u C^{5+} beam. The carbon beam has been successfully applied in radiotherapy. It was found that inner-valence ionization of the clusters can initiate ICD and trigger proton transfer between water molecules, producing destructive low-energy electrons, HO· radicals, and hydrated protons. The efficiency of ICD was found to increase dramatically with the number of water molecules, making ICD the dominant decay mechanism after inner-valence ionization. Such processes can significantly contribute to the high biological effectiveness of heavy-ion irradiation.

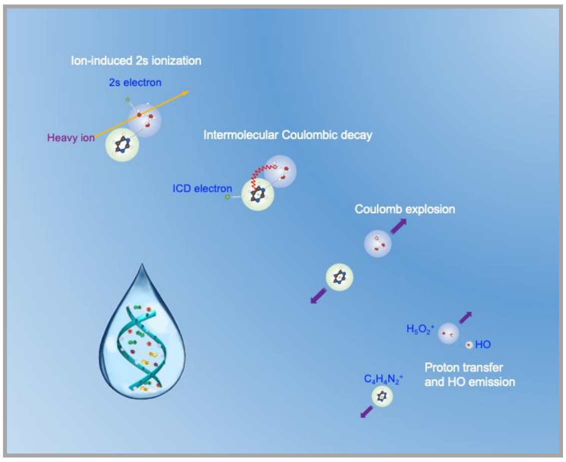


Figure 1. Schematic description of the observed relaxation mechanisms.

References
[1] Y. Gao *et al*, Phys. Rev. X. **133**, 193002 (2025)

* Email: s.xu@impcas.ac.cn

PR-9

Fully differential ion–atom collision experiments in storage rings: past, present and future

D. Fischer[1*], R. Hubele[2], F. Herrmann[2], W. Zhang[2], M. A. K. A. Siddiki[2], M. Schulz[1,2], A. Dorn[2], M. Grieser[2], F. Grussie[2], H. Kreckel[2], O. Novotný[2], R. Moshammer[2], T. Pfeifer[2], C. D. Schröter[2], G. Kastirke[3] M. Schöffler[3]

[1] Missouri University of Science and Technology, Rolla, MO 65401, USA
[2] Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany
[3] University Frankfurt, Institute for Nuclear Physics, 60438 Frankfurt am Main, Germany

Reaction microscopes (ReMi/COLTRIMS) provide kinematically complete information on atomic collision processes by measuring three-dimensional momenta of electrons and recoil ions in coincidence. In ion storage rings, they combine this capability with intense, well-defined projectile beams. This contribution reviews past and present storage-ring reaction-microscope experiments and discusses new opportunities with an in-ring COLTRIMS spectrometer at CRYRING.

Early experiments at the Test Storage Ring (TSR) of the Max Planck Institute for Nuclear Physics demonstrated the feasibility of operating reaction microscopes inside a storage ring. A magneto-optical trap combined with a reaction microscope provided a cold, state-selective lithium target [1]. Fully differential ionization measurements with stored highly charged ions revealed pronounced sensitivity of the electron emission pattern to the electronic structure and initial-state preparation.

More recently, an in-ring reaction microscope has been implemented at the Cryogenic Storage Ring (CSR) in Heidelberg [2]. Its cryogenic environment provides exceptionally cold stored ion beams with reduced translational and internal excitation, enabling state-selective, high-resolution collision studies under technically demanding conditions. Neutralized projectiles are also detected in coincidence after electron transfer. Recent measurements of He–Ar^+ electron transfer reveal contributions from metastable projectile states, whose evolution with storage time allows their lifetimes to be extracted directly.

A new generation of storage-ring reaction-microscope experiments is now being prepared at CRYRING at GSI/FAIR [3]. A COLTRIMS spectrometer with a supersonic gas-jet target has been designed and constructed within the SPARC Reaction Microscope collaboration. Combined with highly charged ion beams at GSI, it will enable momentum-resolved multi-coincidence studies of charge transfer, ionization, and fragmentation. Of particular interest are correlated few- and many-electron dynamics driven by the strong, ultrashort electromagnetic fields generated in heavy-ion collisions.

The developments from TSR through CSR to CRYRING illustrate the evolution of storage-ring COLTRIMS from fully differential ionization measurements toward versatile multi-particle imaging experiments with increasingly complex and highly charged projectiles.

References

[1] D. Fischer *et al.*, Phys. Rev. Lett. **109**, 113202 (2012).

[2] M. Schulz *et al.*, Phys. Rev. A **110**, 022818 (2024).

[3] M. Lestinsky *et al.*, Eur. Phys. J. Spec. Top. **225**, 797–882 (2016).

*E-mail: fischerda@mst.edu

PR-10

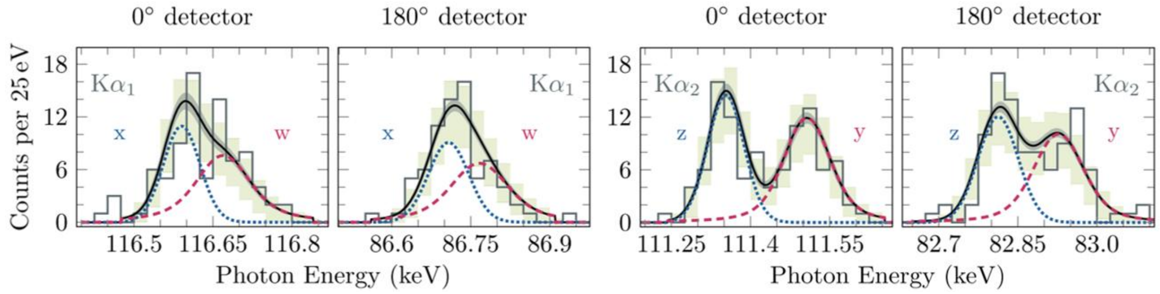
Quantum Electrodynamics in Strong Electromagnetic Fields: Substate Resolved Kα Transition Energies in Heliumlike Uranium

G. Weber[1, 2], Ph. Pfäfflein[1, 2, 3,] S. Allgeier[4], Z. Andelkovic[2], S. Bernitt[1, 2], A. I. Bondarev[1, 2], A. Fleischmann[4], O. Forstner[1, 2, 3], M. Friedrich[4], J. Glorius[2], A. Gumberidze[2], Ch. Hahn[1,2], F. Herfurth[2], D. Hengstler[4], M. O. Herdrich[1, 2, 3], P.-M. Hillenbrand[2, 5], A. Kalinin[2], F. M. Kröger[1, 2, 3], P. Kuntz[4], M. Lestinsky[2], E. B. Menz[1, 2, 3], T. Over[1, 3], N. Petridis[2], S. Ringleb[1, 3], D. A. Schnauß-Müller[1, 2, 3], U. Spillmann[2], S. Trotsenko[2], J. Walch[1, 2, 3], A. Warczak[8], B. Zhu[1, 2, 3], Ch. Enss[4], and Th. Stöhlker[1, 2, 3]

1 Helmholtz Institute Jena, Germany
2 GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
3 IOQ , Friedrich Schiller University Jena, Germany
4 KIP, Heidelberg University, Germany
5 I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany
6 Laboratoire Kastler Brossel, Sorbonne Universite, Paris, France
7 School of Physics and Astronomy, The University of Edinburgh, UK
8 Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland

Precision spectroscopy of radiative transitions in few-electron, high-Z systems is an indispensable tool for the study of relativistic effects and bound-state quantum electrodynamics (QED) in the presence of strong electromagnetic fields [1]. However, in the past spectroscopy of heavy ions in the hard x-ray regime was limited by the intrinsic resolution of semiconductor detectors (a few 100 eV FWHM at 100 keV photon energy). While crystal spectrometers can overcome this limitation, their applicability is usually limited to a narrow window of photon energies, combined with a high sensitivity to uncertainties in the geometry of the experimental setup [2].

To achieve a high spectral resolution over a broad range of x-ray energies, novel microcalorimeter detectors were developed within the SPARC collaboration, in particular the maXs detector design [3]. These are based on the metallic magnetic calorimeter (MMC) technology, where at operation temperatures below 30 mK the temperature increase of an small-volume absorber upon absorption of an incident x-ray is measured via the change in the magnetisation of a paramagnetic sensor. Nowadays, MMC detectors combine an excellent energy resolution (a few tens of eV FWHM at 100 keV) comparable to hard x-ray crystal spectrometers with the broad bandwidth acceptance of semiconductor detectors (from 0.1 to above 100 keV).



Spectral region of the n = 2 → n = 1 transitions in U^{90+}, observed by MMC detectors at 0° and 180° with respect to the ion beam axis. The achieved resolution enabled for the first time to unambiguously determine the energies of all four transitions (x, y, w, and z, respectively) [5].

In this contribution, we report on a recent study performed at CRYRING@ESR, where two maXs-type detectors were employed to record the x-ray transitions in helium like uranium (U^{90+}) [4]. A spectral resolution of <90 eV FWHM over a wide energy range from a few keV to above 100 keV was achieved. This enabled for the first time to disentangle all four components of the Ka radiation of U^{90+}, resulting in an accurate determination of their transition energies [5]. As a cross-check, we also obtained an accurate value of the U^{90+} groundstate ionization energy. Moreover, radiative transitions from the N and M shell to the L shell were also studied. details of the experimental setup as well as its scientific output will be presented, together with an overview on current developments.

References
[1] P. Indelicato, *Journal of Physics* B **52**, 232001 (2019).
[2] T. Gassner et al., *New Journal of Physics* **20**, 073033 (2018)
[3] D. Hengstler et al., *Physica Scripta* **2015**, 014054 (2015)
[4] P. Pfäfflein et al., *Physica Scripta* **97**, 114005 (2022).
[5] P. Pfäfflein et al., *Physical Review Letters* **134**, 153001 (2025).

PR-11

Ultrafast Highly Charged Ion Dynamics

M. Togawa[1*], T.M. Baumann[2], M. Meyer[2], C. Shah [3], Y. Amano[4],
J.R. Crespo López-Urrutia[3], H. Yamaguchi[1]

[1] Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 252-5210, Japan
[2] European XFEL, Schenefeld, 22869, Germany
[3] Max-Planck-Institut für Kernphysik, 69117,Germany
4 National Institute for Fusion Science, National Institutes of Natural Sciences, 509-5292, Japan

Highly charged ions (HCIs) allow for stringent tests of relativistic effects, quantum electrodynamics, and nuclear structure. Monochromatic X-rays are particularly well suited for probing their core-electron dynamics, yet most previous studies have been limited to states accessible through single-photon excitation. In this presentation, I will discuss how X-ray free-electron lasers (XFELs) and fourth-generation synchrotron sources, combined with electron-beam ion traps (EBITs), enable new approaches for investigating the atomic structure and ultrafast dynamics of HCIs.

First, I will present experiments in which HCIs confined in an EBIT are irradiated with ultraintense XFEL pulses, allowing controlled studies of multiply excited states. These measurements reveal novel nonlinear two-photon ionization pathways beyond the well-known resonance-enhanced X-ray multiphoton ionization (REXMI) mechanism. In particular, the interplay of relativistic and electron-correlation effects leads to near-cancellation of energy shifts for specific states, creating quasi-degenerate resonant conditions that strongly enhance nonlinear ionization processes.

Second, I will describe an all–X-ray pump–probe scheme realized using the two-color operation mode of the European XFEL. Pairs of femtosecond X-ray pulses were used to directly record the exponential decay of femtosecond atomic lifetimes in HCIs in the time domain. Unlike conventional linewidth-based approaches, which become challenging in this regime, this technique enables precision lifetime measurements with unprecedented sensitivity to atomic-structure effects.

Finally, I will present recent results obtained at the NanoTerasu fourth-generation synchrotron, where full angular distributions of resonantly scattered X-rays were measured while controlling the incident linear polarization. By exploiting the Hanle effect in this configuration, precise lifetime measurements in the previously inaccessible picosecond regime may become possible.

These precision laboratory studies provide critical benchmarks for state-of-the-art atomic theory and valuable reference data for current and future X-ray astronomy missions.

References

[1] Kühn S *et al.*, 2022 *Phys. Rev. Lett.* **129, 245001**

[2] Fukuzawa H *et al.* 2013 *Phys. Rev. Lett.* **110** 173005

[3] Roerig A *et al.* 2023 *Nat. Com.* **14** 5738

[4] Togawa M *et al.*, 2025 *Phys. Rev. Lett.* **135, 223003**

[5] Togawa M *et al.*, 2024 *Phys. Rev. Lett.* **133, 163202**

*E-mail: moto.togawa@jaxa.jp

PR-12

Generalized independent-atom-model approach for net ionization of molecules by multiply-charged heavy-ion impact

Tom Kirchner[1*], Hans Jürgen Lüdde[2], Marko Horbatsch[1]

[1] Department of Physics and Astronomy, York University, Toronto, Ontario, Canada M3J 1P3
[2] Center for Scientific Computing, Goethe-Universität, D-60438 Frankfurt, Germany

There has been considerable recent interest in collisions involving complex molecules, a major motivation being their relevance across a wide spectrum of areas ranging from astrochemistry to ion-beam cancer therapy. We demonstrated in previous work that the independent-atom-model pixel-counting method (PCM) is successful in describing net ionization in proton–molecule collisions and also for moderately-charged ion impact at relatively high (nonrelativistic) impact energies [1]. The method was introduced to amend the additivity rule (AR) in which ion–atom cross sections are simply added together, by taking into account geometric overlaps of atomic cross-sectional areas. PCM cross sections are smaller than or, in the case of negligible overlap, equal to AR cross sections and in many instances in better agreement with experimental data. For highly-charged projectiles we have found that the PCM appears to overcorrect AR predictions.

The work presented in this talk will focus on an extension of the PCM to incorporate the possibility of multiple scattering along the projectile trajectory [2]. The extension is based on estimated mean free paths for sequential ion–atom collisions within the target molecule. We find that the new model agrees well with the original PCM for proton and moderately-charged ion impact but provides cross sections that are in between PCM and AR results for highly-charged projectiles. If the target molecule has a large atomic number density for a given species as is the case for, e.g., the carbon atoms in anthracene ($C_{14}H_{10}$), the multiple-scattering effect can become very substantial. These predictions, to be detailed at the conference, call for experimental verification.

References

[1] H. J. Lüdde, M. Horbatsch, and T. Kirchner in *Reviews of Light and Heavy Particle Collisions with Atoms and Molecules*, edited by Dž. Belkić (World Scientific, Singapore) Chap. 6, pp 153–177 (2026) and arXiv:2509.07822

[2] H. J. Lüdde, M. Horbatsch, and T. Kirchner *Phys. Rev. A* **112** 052820 (2025)

*E-mail: tomk@yorku.ca

PR-13

Precision experiments at the intersection of Atomic, Nuclear and Astrophysics

Yury A Litvinov*

GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany
Institut für Kernphysik, Universität zu Köln, 50937 Köln, Germany

Radioactive decays of atomic nuclei are conventionally studied in neutral atoms. But this is a poor proxy for the conditions inside stars, where atoms are stripped of most or all of their electrons. In such highly charged ions (HCI), the interplay between the nuclear and atomic degrees of freedom can dramatically alter decay properties. Familiar decay channels can be blocked, while new ones, forbidden for neutral atoms, can open up. These effects make HCI decay studies relevant simultaneously to nuclear structure, atomic physics, and stellar nucleosynthesis [1].

To observe such processes experimentally, a radioactive species must be produced and held in a well-defined, high atomic charge state for a time comparable to or longer than its decay half-life. This is achievable today in a heavy-ion storage ring operated under ultra-high vacuum [2]. Coupled to the FRS fragment separator, the Experimental Storage Ring (ESR) at GSI, Darmstadt, has hosted the vast majority of such experiments to date. The methodology relies decisively on versatile beam manipulations, such as accumulation of weakly produced secondary beams and stochastic and/or electron cooling, together with sophisticated instrumentation. At the heart of these experiments lies the non-destructive Schottky diagnostics. In recent years, its performance was boosted, enabling half-life measurements in the millisecond range [3].

This contribution concentrates on two representative cases. The first is the bound-state β-decay of fully ionized $^{205}Tl^{81+}$, in which the emitted electron is created directly in the empty K-shell of the daughter ^{205}Pb ion — a decay channel that does not exist for neutral atoms. We stored $^{205}Tl^{81+}$ ions for up to 10 hours and obtained the first measurement of this decay. This removed the dominant nuclear-physics uncertainty in the ^{205}Pb–^{205}Tl cosmo-chronometer, with direct consequences for dating the isolation of the Sun's parent molecular cloud [4]. Furthermore, our result constrained the possible application of Tl-bearing mineral lorandite as a long-term Solar pp-neutrino detector [5].

The second case is the nuclear two-photon (2γ) decay, a rare second-order process observable in bare ions when competing first-order channels (single-photon emission, internal conversion, pair creation) are kinematically or selection-rule suppressed. We report the measured 2γ decay of bare ^{72}Ge [6], together with the ongoing analysis of ^{98}Zr and ^{98}Mo.

We close with an outlook on future perspectives at existing and upcoming facilities, including FAIR in Germany and HIAF in China.

References
[1] Yu.A. Litvinov and F. Bosch, Rep. Prog. Phys. **74**, 016301 (2011).
[2] M. Steck and Yu.A. Litvinov, Prog. Part. Nucl. Phys. **115**, 103811 (2020).
[3] M. Sanjari, *et al.*, Rev. Sci. Instrum. **91**, 083303 (2020).
[4] G. Leckenby, *et al.*, Nature **635**, 321 (2024).
[5] R.S. Sidhu, *et al.*, Phys. Rev. Lett. **133**, 232701 (2024).
[6] D. Freire-Fernández, *et al.*, Phys. Rev. Lett. **133**, 022502 (2024).

* Email: y.litvinov@gsi.de

Abstract index for Selected Talks (page at the Abstract Book)

Abstract index for Poster-A on Tuesday (page at the Abstract Book)

Abstract index for Poster-B on Wednesday (page at the Abstract Book)

Industrial Sponsors

兰州泰基离子技术有限公司
Lanzhou Taiji Ion Technology Co., Ltd.

兰州离子仪器有限公司
Lanzhou Ion Instrument Co., Ltd.

埃地沃兹贸易（上海）有限公司
Edwards Technologies Trading (Shanghai) Co., Ltd.

中船鹏力（南京）超低温技术有限公司
CSSC Pride (Nanjing) Cryogenic Technology Co., Ltd.

MDPI

北京中凯威科技发展有限责任公司
Beijing Zhongkaiwei Technology Development Co., Ltd.

北方夜视科技（南京）研究院有限公司
North Night Vision Science & Technology(Nanjing) Research Institute Co.,Ltd .

沈阳慧宇真空技术有限公司
Shenyang Huiyu Vacuum Technology Co., Ltd.

星朗浩宇光电科技（上海）有限公司
Xinglang Haoyu Optoelectronic Technology (Shanghai) Co., Ltd.

卓凌精密设备（合肥）有限公司
Zhuoling Precision Equipment (Hefei) Co., Ltd.

北京鑫东鑫科技有限公司
Beijing Xindongxin Technology Co., Ltd.

天津盈科卓控科技有限公司
Tianjin Yingke Zhuokong Technology Co., Ltd.

安捷伦科技（中国）有限公司
Agilent Technologies (China) Co., Ltd.

RoentDek，Germany

About LANITH
兰州泰基简介

兰州泰基离子技术有限公司成立于2002年4月，是国科离子医疗科技有限公司旗下的高新技术企业。

Founded in April 2002, Lanzhou Ion Therapy Co., Ltd. (LANITH) is a high-tech subsidiary of Cas Ion Medical Technology Co., Ltd.

人才团队 Talent Pool

现有员工近500人，其中博士约30人、硕士约100人、本科以上人员占比＞80%。

LANITH has almost 500 employees on the payroll. Among them, employees with bachelor's degree or higher account for more than 80%, including 30 PhDs and 100 master's degree holders.

资质证照 Qualifications and Certifications

ISO9001、13485质量管理体系，III 类医疗器械生产和经营许可证、I 类射线装置辐射安全许可证等。

ISO 9001 Quality Management System Certificate; ISO 13485 Medical Device Quality Management System; Production License and Business License of Class III Medical Devices; Safety License of Class I Radiation Devices.

生产能力 Production Capacity

年产离子治疗系统＞3台，科研装备＞300台套。

Ion therapy systems > 3 per year, Units for R&D purpose > 300 per year

Program

Date / Time	6 Sept Sun	7 Sept Mon	8 Sept Tue	9 Sept Wed	10 Sept Thu	11 Sept Fri
		Chair: Xinwen Ma	**Chair: Ronnie Hoekstra**	**Chair: Thomas Stöhlker**	**Chair: Richard Wilhelm**	**Chair: Shaofeng Zhang**
9:00-9:45		**Opening** **Meng Wang** **José R. Crespo López-Urrutia** **Conf. Photo**	**Yuri Ralchenko**	**Ronnie Hoekstra**	**Toshiyuki Azuma**	**Tom Kirchner** Tianyu Zheng Sergey Litvinov
9:45-10:15			**Shaolong Chen**	**Endre Takacs**	**Günter Weber**	
10:15-10:35			Chunyu Zhang	Tomoko KAWATE	Chintan SHAH	Alexander Voitkiv
10:35-11:05		**Coffee Break**				
		Chair: Marek Pajek	**Chair: José R. Crespo López-Urrutia**	**Chair: Martino Trassinelli**	**Chair: Shenyue Xu**	**Chair: Toshiyuki Azuma**
11:05-11:35		**Atsushi Yamaguchi**	**Shiqian Ding**	**Shenyue Xu**	**Moto Togawa**	**Yury Litvinov**
11:35-11:55		Chunhai Lyu	Wu Wang	Antonin Bourgeteau	Enliang Wang	Xinliang Yan
11:55-14:00		Lunch				**Closing**
		Chair: Yuri Ralchenko	**Chair: Károly Tőkési**	**Chair: Hajime Tanuma**		
14:00-14:30	Registration, 14:00-22:00	**Ling Zhang**	**Victoria Vojtech**	**Daniel Fischer**	**HiAF tour 13:00-17:00**	Adjourn --------------- Transport to IMP new campus for follow-up related meetings*.
14:30-14:50		Naoki Kimura	Martino Trassinelli	Alexandre Gumberidze		
14:50-15:10		Guiyun Liang	Grzegorz Wesolowski	Zhongwen Wu		
15:10-15:30		Jieru Ren	Luc Assink	Nicholas Antonio		
15:30-16:00		**Coffee Break**				
		Chair: Ke Yao				
16:00-16:30		**Stefanos Nanos**	Poster Session-A	Poster Session-B		
16:30-16:50		Yijiao Wu				
16:50-17:10		Hajime Tanuma				
17:10-17:30		Guocheng Wei			**Social activity**	
17:30-18:00		Károly Tőkési				
18:00-19:00	Reception	Dinner				
				Chair: Reinhold Schuch		
19:00-20:00 **19:00-21:00**				**Public Lecture** **Di Li**	**Conference Dinner**	

*For those taking part in the scheduled FIPI - SPARC 2026 meeting