CROSSING PHYSICAL BOUNDARIES

The University of Science and Technology of China (USTC) has forged an excellent reputation for basic research in physical sciences. Now it is integrating those strengths to develop exciting cross-disciplinary innovations.

Computational geometry studies by USTC mathematicians have applications in 3D printing.

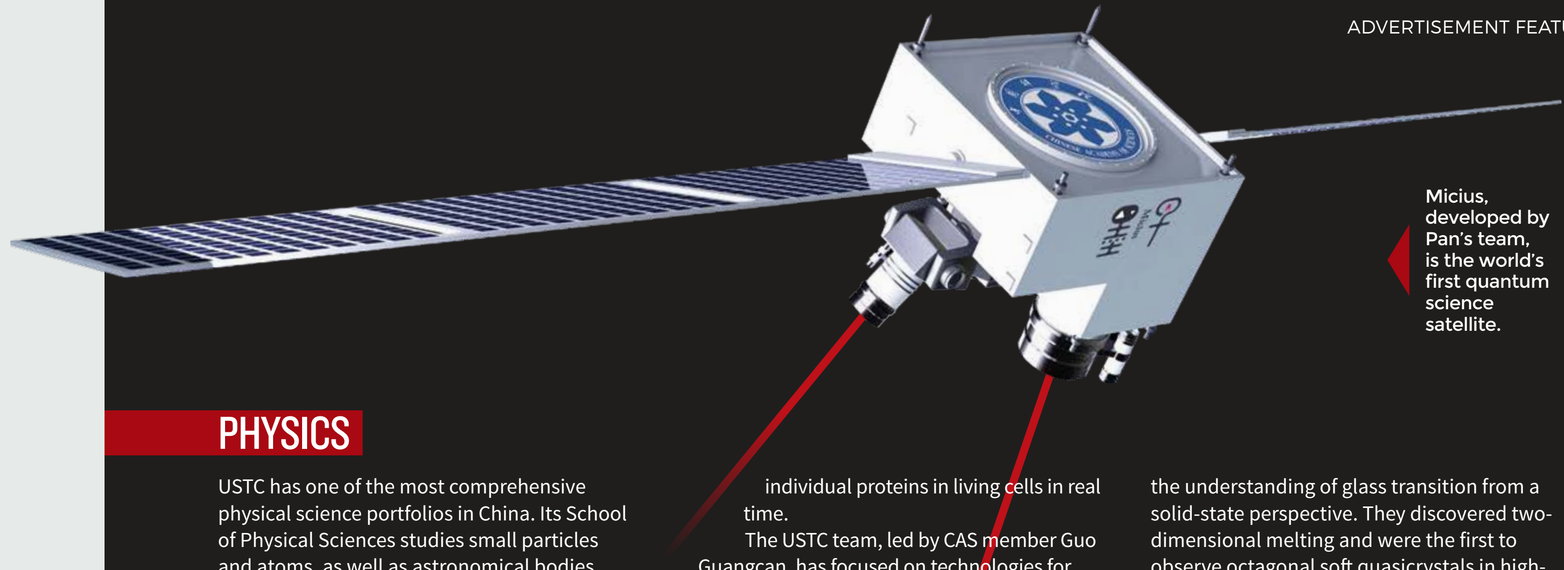
MATHEMATICS

Mathematics, as the foundation of many physical science subjects, is the bedrock of USTC's development. The university reorganized its maths department into the School of Mathematical Sciences (SMS) in 2011, which is now a leader in China's mathematical research and education.

The school's outstanding mathematicians are exploring new possibilities in algebra and algebraic geometry, differential geometry, graph theory, dynamic systems, mathematical physics, partial differential equations, and probability and statistics. Their research results have important implications to many physical science and engineering fields. Based on theories such as spline functions, geometric modelling and sparsity optimization, the computational geometry group has developed a series of novel algorithms and methods for cost-effective 3D printing, light-weight and interlocking structure designs, shape decomposition, and customized mechanical structure design. These works, published in top journals, have also led to patented technologies, making an impact in both the academic community and the fabrication industry.

Other breakthroughs by SMS mathematicians include: introducing Higgs de-Rham flow, a fundamental notion in arithmetic and algebraic geometry, which supports use of the Hodge theory; establishing the connection between dynamic systems and combinatorial number theory by finding relations among the set of common differences of arithmetic progressions in a 'big' subset of integers and higher-order, almost automorphic systems; proving the Bando-Siu conjecture in differential geometry; and deriving Gaussian curvature estimates for the convex level sets of p-harmonic functions.

Works by SMS scholars have led to around 150 papers published each year in journals listed in the Science Citation Index (SCI), including top journals of the field, such as *Annals of Mathematics* and *Inventiones Mathematicae*, and numerous national awards. Several USTC mathematicians have been invited to address the International Congress of Mathematicians (ICM). SMS also regularly hosts mathematicians from around the world, and organizes national and international conferences to promote global exchange. ■



Micius, developed by Pan's team, is the world's first quantum science satellite.

PHYSICS

USTC has one of the most comprehensive physical science portfolios in China. Its School of Physical Sciences studies small particles and atoms, as well as astronomical bodies and the universe, covering everything from theoretical physics to photonics engineering, and from microelectronics to biophysics.

Many of its programmes were established as USTC was founded, in 1958, by renowned scientists of the time, such as Yan Jici and Qian Sanqiang. Today, USTC has integrated its physical science strengths and established advanced research platforms, including Hefei National Laboratory for Physical Sciences at the Microscale (HFNL), the National Synchrotron Radiation Laboratory (NSRL), and key laboratories of the state, the Chinese Academy of Sciences(CAS) and the province. With these platforms, the school has achieved remarkable research results, particularly in quantum communication and computation, super-conductivity, and single-molecular physics.

A research group led by Pan Jianwei, a CAS member, seeks to apply basic theories in quantum mechanics into quantum communication, computation and precision measurement. Notably, Pan's research on the entanglement of photons has provided a possible solution to secure long-distance communication, promoting its real-world application. To achieve inter-continental quantum communication, Pan led the development and launch of Micius, the world's first quantum science satellite, a success in all planned experiments. By manipulating multi-photon entanglement, the core of quantum computation, Pan's group has also tested all the major quantum algorithms, and developed the first photon-quantum computer prototype which outperforms early-generation classical computers.

USTC work has improved computing power by considerably lengthening the state of quantum superposition, or the coherence time, of electron spin in a noisy environment. The team, led by CAS member, Du Jiangfeng, realised the prolonged quantum states through pioneering decoupling technology, which they also applied for quantum precision measurement. Using the diamond nitrogen-vacancy centre as a probe, in a world first, they obtained the paramagnetic resonance spectra of single protein molecules in room-temperature environment and disclosed the underling kinetic properties. This was hailed as an important milestone toward imaging individual proteins in living cells in real time.

The USTC team, led by CAS member Guo Guangcan, has focused on technologies for quantum cryptography, quantum chips and simulators. They simultaneously observed both the particle and wave natures of photons in experiments, challenging the complementarity principle proposed by Bohr. Their achievements also include developing China's first fibre quantum key system; entangling eight photons using ultra-bright photon sources; and creating the solid-state quantum memory with the world's best performance.

Particle and nuclear physics explores composition and interactions at the sub-atomic scale. The State Key Laboratory of Particle Detection and Electronics at USTC provides leading technologies in support of the development of the field. Its researchers have contributed to some major breakthroughs of the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) in the Brookhaven National Laboratory, including developing the time-of-flight spectrometer that increases the particle identification reach, discovering the anti-helium-4, the heaviest antimatter nucleus, and measuring antiproton interactions. Other projects include work on the Higgs boson particle discovery, and constructing the Beijing Spectrometer III detector.

In plasma physics, a 20-plus member USTC group has established the Keda Torus eXperiment (KTX), China's only reversed field pinch (RFP) device that magnetically confines plasma. Designed and built entirely in China, KTX has high Ohmic power, high beta ratio, and automatically maintains magnet-heat balance. The device facilitates cutting-edge fusion research and theoretical and experimental research on three-dimensional toroidal physics. Its size and function also make KTX an ideal platform for training researchers on nuclear fusion.

The USTC foray into soft matter and biophysics covers everything from non-crystal solids, quasi-crystal and crystallization to dynamics of bacterial behaviour and flagellar motors. This area uses physics to solve biological questions and is integral to USTC's interdisciplinary efforts.

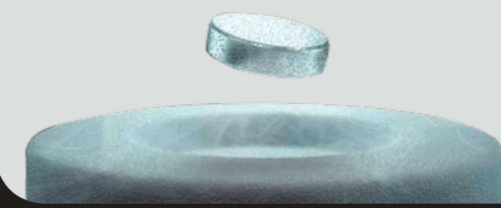
Using simulation and theoretical analysis, USTC researchers have studied the structure of non-crystal solids, or glass, allowing for the understanding of glass transition from a solid-state perspective. They discovered two-dimensional melting and were the first to observe octagonal soft quasicrystals in high-density systems of soft-core particles. Using novel biophysics tools, researchers have measured the switching dynamics of flagellar motors, which propel many bacteria. Their results are published in high-profile journals, such as *Physical Review Letters* and *Nature Physics*. ■

High-temperature superconductivity

Superconductors, able to transmit electricity with no energy loss, are sought-after materials in many fields, ranging from information technology to biomedicine. However, the low transition temperature has limited their applications. Breakthroughs by a joint team from USTC and the Institute of Physics (IOP) at CAS have raised the transition temperature considerably, shedding light on more efficient power transmission.

USTC researchers, led by CAS member Chen Xianhui, with their IOP colleagues, have identified a new family of high-temperature superconductors in iron-based materials, which are normally considered poor conductors. They achieved superconductivity at a transition temperature of 55K, raising the critical temperature well above 40K at ambient pressure for the first time. The team also synthesized a series of novel iron-based superconducting materials, including an air-stable iron selenide superconductor.

These achievements won Chen the first prize of the National Natural Science Award in 2013 and the 2015 Bernd T. Matthias Prize for Superconducting Materials.



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GEOSCIENCE

Earth and space sciences are a traditional strength at USTC. Original departments of applied geophysics, geochemistry and rare elements, established at the founding of the university, were integrated into the School of Earth and Space Sciences (SESS) in 2001. The school exploits the brilliance of USTC resources in physics, chemistry and other fields for further development.

Major research areas include space physics, solid geophysics, atmospheric science, geochemistry and environmental science. With advanced research platforms, including CAS key laboratories on the near Earth space environment and on crust-mantle materials and environment, a provincial key laboratory on polar environment and global change, and a wilderness science observation station, the school has made breakthrough results in basic research and applicable technologies. It stands out for research on subduction zones, deep-Earth, the space environment, the polar environment and atmospheric remote sensing. These works have supported developing advanced instruments, such as quantum laser radar and space payload.

As China grows into a research powerhouse, the exploration of deep sea, deep Earth and deep space is on the national strategic agenda. Seizing this priority, SESS is maintaining its leading position by enhancing its strengths, and initiating new programmes in emerging fields.

One such area is comparative planetology, which integrates almost all areas of geoscience. The exploration of planets also has important implications to the future of society. Committed to developing this frontier field, SESS is deeply involved in China's major space research projects, including the missions to explore Mars and the Moon. It has also undertaken the job of building carrying capacity for space shuttles and other exploration infrastructure. ■

ASTRONOMY

The USTC astronomy programme started in 1972 and has grown into a research institution and training base with global impact. In collaboration with the CAS Purple Mountain Observatory, China's cradle of modern astronomy, USTC established a school of astronomy and space science in 2016, cementing the integration of astronomical research and education.

Housing five CAS key laboratories, the USTC astronomy programme worked on the Wukong satellite, the dark matter explorer, and the Ali CMB Polarization Telescope (AliCPT), the first ground-based cosmic microwave background (CMB) project in the northern hemisphere. Its researchers are currently developing a 2.5m wide field survey telescope (WFST). Based on an advanced primary-focus system, the novel optical design will enable the telescope to precisely survey a wide swathe of sky at wide wave bands. The focal plane is equipped with a 0.9 gigapixel mosaic CCD camera, allowing the entire northern hemisphere to be surveyed every three nights.

When completed in 2021, the WFST will be the most advanced of its type in the northern hemisphere, gathering valuable observatory data to monitor astronomical events efficiently. ■

USTC took part in the development of Wukong satellite, China's first dark matter explorer.

USTC geo-scientists joined China's Antarctic and Arctic voyages for polar research.

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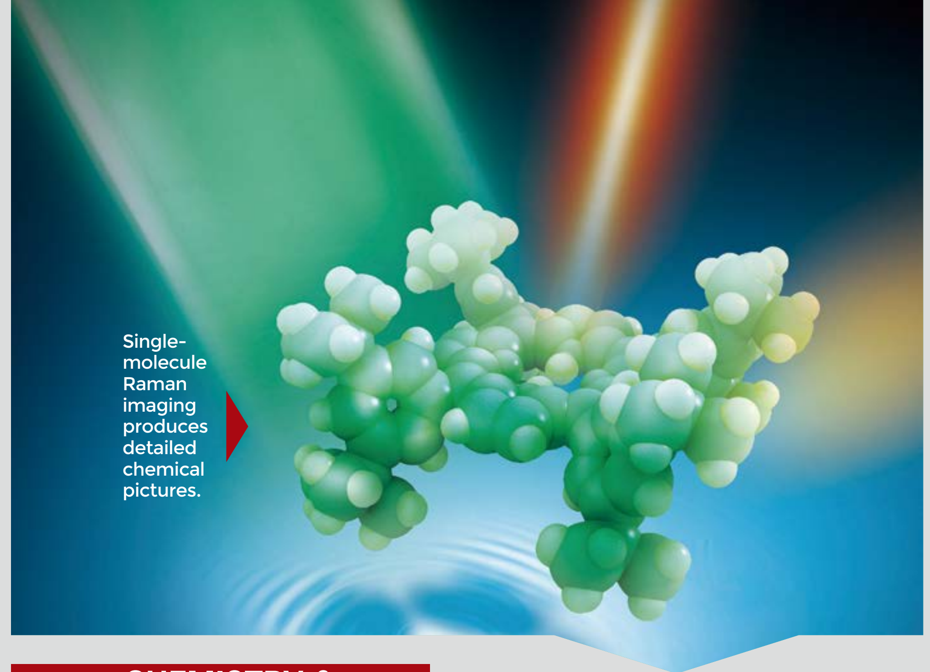

Single-molecule Raman imaging produces detailed chemical pictures.

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CHEMISTRY & MATERIAL SCIENCE

Chemistry and material sciences are central priorities at USTC. Cutting-edge science and interdisciplinary areas were set as focus from the very beginning.

One feature is the integration of chemistry and physics in the chemical physics department and polymer chemistry and physics department established in 1958. The former was set to meet the demands for talent at the interface between chemistry and physics; while the latter, China's first polymer science department, played a key role in the speedy growth of China's polymer industry of plastic, rubber and fibre.

Now, the USTC School of Chemistry and Materials Science houses three CAS key laboratories, on energy conversion materials, soft matter chemistry, and urban pollutant conversion, as well as two provincial key laboratories of biomass clean energy and functional materials, and two platforms for technology application. The school spearheads the development of single-molecular chemical physics, nanomaterials, as well as organic and soft matter functional materials, with a series of internationally recognized breakthroughs.

A team on single molecular optoelectronics, led by USTC professors, Hou Jianguo, a CAS member, and Dong Zhenchao, developed high spatial resolution optical characterization technology, incorporating a scanning probe technique. It enables single-molecule Raman imaging, producing detailed chemical images with spatial resolution below one nanometre. They also developed super-resolution electroluminescent imaging technology, which allows observing intermolecular dynamics, such as dipole-dipole coupling. Their research provides new tools for chemical imaging, opening up a new avenue for studying molecular interactions and energy transfer.

Inspired by biomaterials, the biomimetic material group, led by USTC professor Yu Shuhong, has developed fabrication techniques for making bulk artificial mother-of-pearl, very similar to the natural material, with enhanced strength. Biomimetic materials they fabricated also include super elastic and anti-fatigue carbon-based aerogel, and a resin-based porous material that mimics wood and is light-weight, resilient, fire-proof and corrosion resistant. With the team's mass production technologies, Yu hopes to soon use these biomimetic materials in bone transplantation and biomedicine, body shielding, as well as aerospace.

Aiming to control pollution using chemical tools, a team led by USTC professor, Yu Hanqing, focuses on novel techniques for wastewater treatment. Their quantitative in-situ infrared spectroscopy method can test for multiple pollutants by a high-throughput method for microbiome screening. It biologically treats wastewater based on extracellular electron transfer. They have also developed new catalyst materials for degradation of organic pollutants.

In the field of asymmetric homogeneous catalysis, USTC chemist, Gong Liuzhu, and his team have been studying organo- and metal combined asymmetric catalysis since it was first reported in 2001. Integrating cooperative and relay catalysis of organic molecules and metal complexes, they have achieved chemical reactions unattainable by using a single catalyst alone. ■

Hefei National Laboratory for Physical Sciences at the Microscale

The Hefei National Laboratory for Physical Sciences at the Microscale (HFNL) was established at USTC as a pillar in support of building Hefei into a national science centre. This interdisciplinary platform focuses on emerging fields of national strategic importance, such as information science, new energy and health, and leverages USTC's resources in nanotechnology, biotechnology, cognitive science and information technology to support basic and applied research.

With 10 research divisions, HFNL seeks to make original breakthroughs in optical and cold atom physics, single molecular and low-dimensional physics and chemistry, nanomaterials, catalysis and energy conversion, as well as molecular and cell biophysics, neural circuits and brain cognition, molecular medicine and computation science. Its innovative researchers have undertaken numerous national major research projects, ranging from quantum control and quantum information to nanotechnology and protein machines. World-leading results include achieving entanglement swapping with storage and retrieval of light, which clears the way for long-distance quantum communication, and developing novel, iron-based superconducting materials, promoting condensed matter physics research.

With an efficient, novel management system and world-class public technology platforms, equipped with advanced instruments, HFNL is poised to become a first-class centre for basic research, talent training and innovative technologies.

Advances in nanomaterials assist in carbon recycle

A USTC research team has established techniques for fabricating ultra-thin two-dimensional (2D) materials that may be used in novel energy materials to curb carbon emission.

Based on revealing the unique electronic state and the precise structural characterization of these materials, the team, led by CAS member, Xie Yi, constructed highly active and stable hybrid systems for 2D ultrathin materials. They also showed how the oxides on the pristine metal surface influence its electroreduction of CO_2, shedding light on 2D nanomaterials as promising catalysts for converting CO_2 into useful fuels. Their work, published in *Nature*, contributed to the development of sustainable carbon economy and was selected as one of the top 10 major scientific advances of the year in China.