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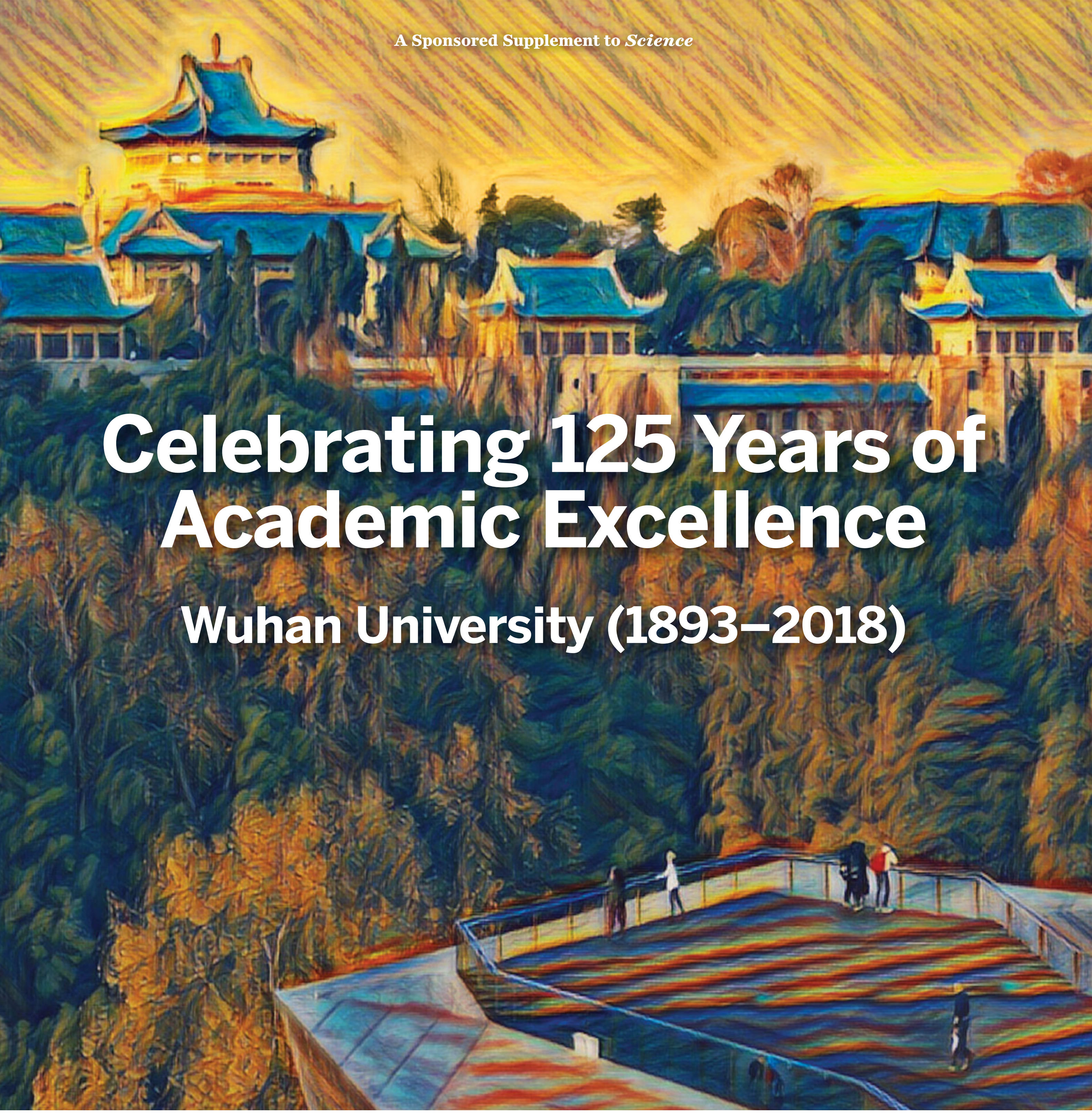

Celebrating 125 Years of Academic Excellence

Wuhan University (1893–2018)

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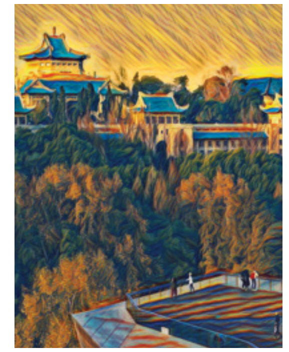

The cover is taken from a collection of computer-generated pictures called "AI Artist," designed by Zhao Wangyu and Yao Jiaxin, Master's students at Wuhan University. The original photo was taken by Peng Min, a professor at the school.

This work uses the most advanced artificial intelligence technology and deep-learning algorithms to integrate the artistic elements of world-famous paintings into the beautiful scenery of the Luojia campus, interpreting the unique charm of Wuhan University through the combination of technology and art. This work also shows the deep love of Wuhan University students for their alma mater and their sincere wishes for her 125th birthday, while perfectly conveying the university's motto—"Self-improvement, Perseverance, Truth-seeking and Innovation."

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This booklet was produced by the *Science*/AAAS Custom Publishing Office and sponsored by Wuhan University.

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Part 3: Research in the natural sciences

Part 4: State Key Laboratories at Wuhan University

Part 5: Engineering research at the GRC

Beautiful campus, beautiful minds: Wuhan University celebrates 125 years of education and research

To commemorate Wuhan University's quasiquicentennial, this booklet surveys the best schools and brightest minds on campus.

Nestled against rolling hills and greenery, with fragrant flowers blooming year-round and shimmering silver carp swimming in nearby East Lake, Wuhan University is considered by many to have one of the most beautiful campuses in China. For decades, it has been ranked as one of the country's top 10 universities. It is also designated as a Chinese Ministry of Education Class A Double First-Class University, as part of China's strategy to transform a group of its elite universities and university departments into world-class universities and first-class disciplines by the end of 2050.

The origins of Wuhan University stem from the late Qing Dynasty, when Zhang Zhidong, then governor of Hubei and Hunan Provinces, founded the Ziqiang Institute in 1893. Although the institute has changed its names several times over the years, finally settling on Wuhan National University in 1928, its motto of "Self-Improvement, Perseverance, Truth-Seeking, and Innovation" has remained the same.

To commemorate Wuhan University's quasiquicentennial, this booklet surveys the best schools and brightest minds on campus. Part 1 explores its top humanities and social science schools, namely, the Institute of International Law, the Research Institute of Environmental Law, the Center of Bamboo and Silk Manuscripts of Wuhan University, and the Center for Studies of Information Resources. Part 2 highlights the research laboratories of Bao-Liang Song, a preeminent biochemist and cell biologist and current dean of the College of Life Sciences, and Zhengyou Liu, an engineer renowned for his work on phononic crystals and acoustic metamaterials.

The natural sciences are the focus of Part 3. The topics touched upon range from nanomaterials and devices to extreme environments (ultra-high and ultra-low temperatures and high irradiation). Research in these fields has led to numerous applications, such as alternative energy resources, bioinspired materials, and geophysical and biomedical sensors.

The university receives significant state funding, as indicated by its inclusion in Project 985 and Project 211. It also houses numerous State Key Laboratories that receive financial support from China's central government. Part 4 looks at four of these labs: the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing; the State Key Laboratory of Water Resources and Hydropower Engineering Science; the State Key Laboratory of Virology; and the State Key Laboratory of Hybrid Rice. Several other State Key Laboratories collaborate with Wuhan University's Global Navigation Satellite System Research Center, which is described in Part 5.

Wuhan University's worldly aspirations are reflected not only in its trailblazing research but also in its unique architecture. In designing its early buildings, American architect F. H. Kales, educated at the Massachusetts Institute of Technology, blended Western styles with traditional Chinese elements, which are most evident in the blue-tiled roofs and their overhanging eaves. The university's idyllic surroundings and campus lend themselves to academic contemplation, as exemplified by this booklet's cover, which uses artificial intelligence to incorporate elements of famous paintings into a photograph taken by a professor at the university.

We wish Wuhan University the best as it celebrates this momentous anniversary and continues to break new ground with cutting-edge research and to inspire a new generation of students.

Jackie Oberst, Ph.D.
***Science*/AAAS Custom Publishing Office**

In the President's words: Welcoming a future of compassionate innovation

The diversity of thought and endeavor present at Wuhan is evident in the university's prodigious achievements over the decades.

Before you begin reading this supplement, as the President, I would like to pay homage to you on behalf of Wuhan University, a Chinese higher-education institute with a 125-year history of schooling, supported by an exceptional team of 7,600 staff members responsible for educating our 56,000 students.

Since its origin as the Ziqiang Institute in 1893, around the time of the late Qing Dynasty, Wuhan University has been pondering the future of China. The primary focus at that time was on learning from the advanced scientific technologies of the West. This thinking has continued, despite the earth-shaking changes that have marked China's recent history. Wuhan University is now revisiting this task with an even broader view and a more open mind.

The diversity of thought and endeavor present at Wuhan is evident in the university's prodigious achievements during the last few decades. For example, the man-made satellite Luojia-1A, researched and developed under Wuhan University's leadership, is currently orbiting the earth, monitoring the entire planet via nighttime-light remote sensing. In addition, Sienho Yee, a law professor at the university, has put forward the idea of an international law of co-progressiveness, and published many rigorous analyses on important international legal issues, some of which have been cited by judges and governments in proceedings before the International Court of Justice, the International Tribunal for the Law of the Sea, and the Law of the Sea arbitration tribunals. Moreover, Lei Jun, an outstanding alumnus of Wuhan University, founded Xiaomi Corporation, which has just become the fourth-largest Internet-focused technology company in the world; Jun is collaborating with the university on efforts to develop artificial intelligence systems.

As China becomes an increasingly active player in the international arena, Wuhan University is also broadening its horizons by endeavoring to join with other countries in solving global issues through rigorous scientific approaches, supported by its uniquely Chinese philosophical perspective.

Wuhan University is honored to publish this supplement with *Science* magazine. However, the primary aim of this booklet is by no means to simply highlight the university's achievements. Rather, its purpose is more of an invitation—with 125 years of experience in education, we hope to attract more future-oriented scholars and increase the visibility and reputation of our university through this broad platform. We aim to encourage the building of deep bonds of cooperation between Wuhan University and other institutions around the globe, bringing the university more squarely onto the world stage. Our current mission is to move forward with a focus on scientific innovation, while remaining compassionate and looking to the needs of society and our fellow humans.

Thank you!

Xiankang Dou
President, Wuhan University

PHOTO: WUHAN UNIVERSITY

Overview of Wuhan University

Continuous self-improvement

Distilled in Wuhan University's motto, "Self-Improvement, Perseverance, Truth-Seeking, and Innovation," is over 100 years of humanist achievement. Consistently ranked among the top universities in China, Wuhan University (WHU) is devoted to excellence in teaching, learning, and research. We have steadfastly nurtured and developed talented individuals who have become recognized in many subjects.

WHU is considered one of the most beautiful universities in China, seamlessly combining Eastern and Western architectural styles. Its cultural atmosphere blends with Wuhan's gorgeous natural scenery, making it an ideal place for students to study, think, innovate, and fulfill their dreams. WHU is historic yet dynamic; founded in 1893 as the Ziqiang Institute, it strives to be a world-class university while retaining its Chinese characteristics. The university currently enrolls over 54,000 degree candidates and features five national key labs, and five primary and 17 subordinate national key disciplines. The May 2017 Essential Science Indicators (ESI) ranking puts 16 of its disciplines in the world's top one percentile.

However, the university's ambitions are even loftier. A team of WHU scientists recently launched the Luojia-1A satellite, and others are working diligently to support national construction projects and social advancement initiatives. Their spirit of cooperation is manifested in high-tech industry platforms and more than 70 high-tech enterprises. The university's remarkable achievements have earned it an outstanding international reputation. In 1999, the world-renowned journal *Science* listed WHU as one of China's most prominent higher education institutions.

Nurturing the human spirit

In its quest to develop a world-class university with Chinese characteristics, WHU aims not only to promote talent, academic excellence, and entrepreneurship, but also to nurture the human spirit. It instills in students a strong sense of moral purpose, social responsibility, and an international outlook, so they can face the challenges of tomorrow in an ethical and sustainable manner. Its teachers share a profound commitment to providing an education that empowers students to develop critical thinking and enhance their ability to adapt to a changing world. WHU cultivates an environment that stimulates students' curiosity and helps them become leaders in their fields. For example, the university launched the Luojia Innovation Angel Fund, which supports undergraduate student innovation, entrepreneurship, and the commercialization of promising projects. Through such efforts, WHU devotes tremendous resources toward the betterment of humanity.

A flourishing campus culture

Life at WHU is dynamic, with unlimited possibilities for enhancing the student experience. In addition to providing an excellent education, the university boasts a rich tradition of cultural, athletic, and social activities. Students have opportunities to participate in several clubs to forge leadership skills, meet friends, and improve their physical stamina. WHU has created an atmosphere humming with diversified campus culture. The campus is home to 134 student unions and associations, including the University Art Troupe, the Wenhua Theatre Group, and the Green Boat Association of Environmental Protection, among many others. Furthermore, the university hosts a range of activities to provide students an unforgettable college experience, such as the Luojia Golden Autumn Art Festival, the International Cultural Festival, and the International Universities Rowing Regatta, to name a few. All in all, WHU is a place to learn, explore, and thrive, offering students an enriching environment full of opportunities for self-development.

PHOTO: WUHAN UNIVERSITY

Contributing to a better world

WHU is committed to achieving excellence in research and ensuring that research outcomes create tangible, long-term contributions to society. It does so by providing a vibrant and supportive environment, freedom to exercise creativity and innovation, and numerous initiatives aimed at attracting and nurturing talents.

WHU's research activities greatly contribute to the betterment of society. The university cooperates closely with local and national industries to foster social development and offer competitive solutions to practical problems. For example, the university has taken part in scientific research to advance state key projects, such as the Manned Space Project, the Three Gorges Project, the South-to-North Water Diversion Project, the West-East Electricity Transmission Project, and the Qinghai–Tibet Railway Project. Its researchers are continually making discoveries in areas as diverse as polar scientific exploration and the prevention and control of disease epidemics. WHU has yielded tangible social and economic benefits in the fields of ecology and the environment, hybrid rice, space physics, satellite positioning and navigation, new energy and materials, and many others.

The university has expanded its cooperation with local government, commercial enterprises, and institutions both at home and abroad in a variety of fields, such as electronic information, computer science, bioindustry, and geoinformatics. Its joint research institutes and industrial parks are taking WHU's research to new frontiers by commercializing the results of these collaborations.

Working together in global partnerships

WHU promotes international understanding through teaching and partnerships with peers around the world, to advance the frontiers of knowledge, engage in cross-disciplinary research, and find solutions to issues that impact all of humanity. The university has established long-term partnerships and links with 233 world-renowned universities and research institutions from 32 countries and regions. Its close and long-standing affiliations with French universities and institutes has earned it the designation of "Model of Sino-French Cooperation"—just one example of its consistent commitment to enriching students' experience as global citizens capable of adapting to a fast-changing world.

To improve its competitiveness, the university has launched international courses in partnership with universities in Europe, the Americas, and Asia in such areas as physics, chemistry, medicine, remote sensing, environmental science, law, and management. The campus is now home to over 3,500 international students from 128 countries studying in 35 schools and departments.

A shared path toward excellence: The Duke Kunshan University

The Duke Kunshan University (DKU) is a partnership between WHU, Duke University, and Kunshan Municipality. It aims to become a world-class university with competitive academics geared to both Chinese and international students. In 2014, DKU welcomed its inaugural class to programs in medical physics, global health, and management. That same year, DKU established the WHU–Duke Research Institute. This scientific research platform attracts faculty and students from WHU, Duke, DKU, and other universities worldwide to collaborate on scientific projects of common interest through, for example, DKU's Global Health Research Center.

Our partners in science and innovation

Wuhan University has established joint research platforms to strengthen cooperation with foreign universities and research institutes. These include collaborations between the following organizations: China's Ministry of Science and Technology and Thailand's Sirindhorn International Research Center for Geoinformatics; the Joint Research Center for Geospatial Information Science and the Netherlands' Delft University of Technology; the Nano-optical Joint Laboratory and Rice University; WHU's Institute for Advanced Studies and the Berkeley Global Science Institute at the University of California, Berkeley (UC Berkeley); the Joint Innovation Center and UC Berkeley; and the WHU–Aberdeen Joint Research Institute (WHU and the University of Aberdeen).

Toward a legacy

WHU trains people to build a better world and to care for it. People stand at the heart of this endeavor. Since its establishment, the university has cultivated more than 300,000 professionals in various occupations, among whom 100 are members of the Chinese Academy of Sciences (CAS) and the Chinese Academy of Engineering (CAE). Of its current faculty team, 11 academicians are in CAS, seven are in the CAE, 62 are Changjiang Scholars, 56 are Distinguished Young Scholars of the National Natural Science Foundation, and 15 are nationally recognized as "best teachers." They form the heart of the university and its efforts to educate people toward building a better tomorrow.

PART 1: Top schools at Wuhan University—humanities and social sciences

The Institute of International Law

Zhu Lei*

Founded in 1980, Wuhan University's Institute of International Law (IIL) is China's first collegiate institute focused on research and education in this area. It is widely regarded as the nation's leading authority in international law. The institute deploys research, teaching, and consulting activities and applies its excellent scholarship to government policy and real-world legal practice. In 2000, the Chinese Ministry of Education designated the IIL as a National Key Research Center for the Humanities and Social Sciences.

The research and teaching of international law at Wuhan University have a long history. Over the decades, the university has employed many preeminent scholars, judges, and arbitrators. Notable figures include Gengsheng Zhou (the founding father of public international law in China), Ru'ao Mei (a judge for the International Military Tribunal for the Far East), Shijie Wang (an arbitrator for the Permanent Court of Arbitration at The Hague, Netherlands), Haopei Li (a judge for the Appeals Chamber at the International Criminal Tribunal for the former Yugoslavia), Tieya Wang (also a judge for the International Criminal Tribunal for the former Yugoslavia), and Lihai Zhao (a judge for the International Tribunal for the Law of the Sea). The IIL is committed to interdisciplinary scholarship in international law. Its investigations cover a breadth of topics, including laws concerning the United Nations, the European Union, global cyberspace, and international air and space. Currently, its research comprises four thematic clusters: national security and the international rule of law, sustainable development, the new global economic order, and transnational business and global governance.

The institute strives to provide a forum and platform for the critical and constructive inquiry of international law. It routinely organizes conferences, seminars, symposiums, and workshops to foster intellectual exchange and dialogue (Figure 1). Journals published by the institute include the *Chinese Journal of International Law*, *Wuhan University International Law Review*, and *Chinese Yearbook of Private International Law and Comparative Law* (Figure 2). In 2014, the IIL began to publish annual reports on China's practice of international law. Since 2000, it has undertaken more than 140 funded-research projects at the national and provincial level and published more than a thousand articles and a hundred academic books. Some of these references have been quoted by many international tribunals and Chinese national courts.

The institute works closely with governments throughout China and advises on drafting legislation, international negotiation, and implementation of treaties to promote sound and efficient governance and uphold the rule of law. The Ministry of Foreign Affairs, the Ministry of Commerce, and the Supreme People's Court appoint many institute staff members to serve as legal counsels, policy advisors, and consultants. In 2015, the IIL was selected as one of China's high-level think tanks.

The institute is keen to promote global collaboration and exchange. It is widely connected with leading scholars, research institutions, and organizations worldwide and has established long-term partnerships with academic institutes and think tanks in the United States, United Kingdom, Germany, France, South Korea, and other countries. Its staff members participate in the work of global organizations such as the International Committee of the Red Cross, the United Nations Commission on International Trade Law, the Hague Conference on Private International Law, and the International Institute for the Unification of Private Law.

The IIL has been praised as "the cradle of talents in international law in China" for its remarkable achievements in training academics and practitioners. For example, its moot court teams have performed skillfully in worldwide competitions in recent years, ranking in the top 32 of the Willem C. Vis International Commercial Arbitration Moot in 2011 and the top 16 of the Philip C. Jessup International Law Moot Court Competition in 2014.

FIGURE 1. Global Forum on Private International Law and China Society of Private International Law Annual Conference 2017. The forum's theme was "Cooperation for Common Progress: The Evolving Role of Private International Law."

FIGURE 2. The publications of the Institute of International Law.

PHOTOS: WUHAN UNIVERSITY

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Many graduates of the institute have achieved successful careers and made outstanding contributions to society. Its distinguished alumni include Karim Massimov (the former prime minister of Kazakhstan), E'xiang Wan (the deputy chairman of the Standing Committee of China's National People's Congress), and Kaiyuan Tao (the vice president of China's Supreme People's Court).

The institute, with its stable financial support, provides its researchers and students with a superb infrastructure of world-class research facilities, including offices, seminar rooms, conference facilities, and a library. Its main library offers a rich collection of books as well as electronic research tools, including WestlawNext, HeinOnline, and Lexis Advance.

The Research Institute of Environmental Law

Hu Bin*

The former National Environmental Protection Agency and Wuhan University cofounded the Research Institute of Environmental Law (RIEL) in 1981. It is the oldest and most respected environmental law institution in China and the Asia-Pacific region. The Chinese Ministry of Education appointed RIEL a National Key Research Center for the Humanities and Social Sciences in 1999 and designated its environmental law program a National Key Program in 2001 and 2007. RIEL serves as a think tank for development of Chinese environmental law as well as global environmental negotiation for China's parliamentary and environment-related ministries. The secretariat of the Chinese Society of Environment and Resource Law is based at the institute. The International Union for the Conservation of Nature (IUCN) Academy of Environmental Law appointed RIEL as the world's first advanced training center for the teaching and research of environmental law. The institute is also the research center for environment-related legal theory for China's Supreme People's Court.

The first director of RIEL was Depei Han, a pioneer and founder of environmental law in China. Tianbao Qin is the current director. RIEL employs 12 full-time researchers, including seven professors, four associate professors, and one assistant professor, in addition to more than 30 part-time and adjunct professors.

RIEL initiated China's first Master's degree program for environmental law in the early 1980s and a doctoral program in the 1990s. Currently, the institute enrolls about 20 Master's students and 10 Ph.D. students each year. Aiming to cultivate more senior environmental law specialists with global vision and core competitiveness for China, RIEL has recruited top talent from overseas and created a distinctive teaching and training approach, which it combines with advanced, internationally accepted training methods and teaching resources, such as its environmental law clinic supported by the United Nations Environment Programme. Some outstanding alumni include Zhenhua Xie, China's Special Representative for Climate Change and former Minister of the State Environmental Protection Administration, and Fang Liu, the secretary general of the International Civil Aviation Organization.

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RIEL aspires to play the role of primary think tank for advancing the environmental rule of law in China. Adhering to this principle, it provides legislative support, policy advice, decision-making consultancy, and other practical resources to policy makers and governments. RIEL is committed to building an advanced environmental legal system that promotes fair and efficient environmental enforcement and deepens the reform of environmental justice and rights, thereby amplifying the potency of the environmental rule of law.

RIEL has headed or participated in drafting almost all the major environmental bills in China to date, including the Environmental Protection Law, the Air Pollution Prevention and Control Law, and the Soil Pollution Prevention and Control Law. Many RIEL scholars serve as legal advisers and consultants to legislatures, central and local governments, and judicial organs. The institute also pays close attention

FIGURE 1. International Conference on Compliance and Enforcement of Environmental Law.

FIGURE 2. The launch ceremony for RIEL's journals.

PHOTOS: WUHAN UNIVERSITY

to global trends, offering advice on China's environmental diplomacy, negotiation, and international compliance. For example, in 2014 and 2016, Qin Tianbao served as the principal legal expert of the Chinese delegation for the 12th and 13th Conferences of the Parties to the Convention on Biological Diversity.

RIEL is a significant force in the globalization of China's environmental law. All of its members studied overseas, and many are internationally renowned. Tianbao currently serves as a member of the governing board of the IUCN Academy of Environmental Law, and Ben Boer formerly served as the deputy chair of the IUCN World Commission on Environmental Law. In 2017, RIEL launched China's first English-language doctoral program in environmental law, which enrolls eight to 10 overseas students each year.

RIEL has been intimately involved with the IUCN Environmental Law Programme, hosting the IUCN Academy of Environmental Law Annual Colloquium in Wuhan in 2009 and conducting the IUCN Academy of Environmental Law's Training the Teachers Program in Wuhan in 2011. In 2015, RIEL hosted the Protected Areas Law Teachers and Trainers Workshop in Wuhan, together with the IUCN World Commission on Environmental Law and the IUCN Environmental Law Centre.

RIEL has demonstrated its commitment to promoting dialogue in environmental law by establishing world-class academic platforms such as the Luojia Forum on Environmental Law, the Luojia Lecture Series on Environmental Law, and the RIEL Alumni Salon (Figure 1). RIEL publishes three academic journals on environmental law: the *Chinese Journal of Environmental Law* and *Climate Law* are both in English, and the *Wuhan University Environmental Law Review* is in Chinese (Figure 2). The institute also hosts a specialized library and information center offering a comprehensive set of research materials concerning environmental law in China. Additionally, the institute has created and now maintains the China Environmental Law website (http://en.riel.whu.edu.cn).

The Center of Bamboo and Silk Manuscripts of Wuhan University

Li Tianhong*

At the beginning of the 20th century, vast troves of bamboo, silk, and wooden manuscripts were unearthed in China, one after another. The dates from which they originated range from the Warring States period (475 BC–221 BC), up to the Qin (221 BC–206 BC), Han (206 BC–AD 220), Wei (AD 220–AD 265), and Jin (AD 265– AD 420) Dynasties. Their content mainly includes bureaucratic and private documents and historical, philosophical, and cultural texts. These excavated manuscripts, handwritten around 2,000 years ago, have substantially filled lacunae in the received record, and have continuously stimulated new developments in the study of pre-Qin and early Chinese imperial history. The immense value of these manuscripts as artifacts and texts makes them an invaluable part of humanity's cultural heritage. Because of the tremendous historical significance of these documents and texts, particularly those published from the 1990s up to the present, scholars from the fields of paleography, ancient history, philology, philosophy, and the history of ideas and technology gravitate toward them. Thus, the interdisciplinary and highly international field of "bamboo and silk studies" was born.

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The Center of Bamboo and Silk Manuscripts (CBSM) was established in early 2005. The center's core strengths lie in the restoration of excavated Chinese manuscripts from the Warring States period and Qin and Han Dynasties, and the study of the significant historical and cultural data they carry. Its main areas of expertise are paleography, primarily of the Warring States scripts; the restoration and study of the Warring States, Qin, and Han excavated manuscripts; the manuscript-based investigation of Warring States, Qin, and Han history (including historical paleography and linguistics; the history of law, institutions, and ideas; and manuscript-culture studies); and the preservation of manuscript data and images through digitization and the establishment of a database.

FIGURE 1. Li Tianhong and Peng Hao preparing bamboo manuscripts for conventional and infrared photography.

PHOTO: WUHAN UNIVERSITY

CBSM's approach is unique in its organic integration of traditional methods for manuscript study and restoration, the use of interdisciplinary and cutting-edge technological research methods (including digitization and infrared imaging), and its strong commitment to national and global cooperation. This distinctive approach has garnered substantial influence and support for the center among colleagues both in China and abroad.

CBSM edits and publishes two academic journals: *Jian Bo* (Shanghai Chinese Classics Publishing House Co., Ltd.) and *Bamboo and Silk* (Brill). Both journals are double-blind peer reviewed and publish state-of-the-art investigations from scholars all over the world, reflecting the latest trends and status of bamboo and silk studies. The center's book publications, such as *Excavated Warring States Bamboo*

FIGURE 2. The *Corpus of Qin Documents Written on Bamboo and Wood* (Wuhan University Press, 2014).

FIGURE 3. Scholars participating in the Second Overseas Academic Week of Wuhan University, held in 2014 at the International Forum for the Study of Chinese Excavated Texts, at the University of Chicago in Illinois.

PHOTOS: WUHAN UNIVERSITY

Strip Manuscripts from the Chu Region: Fourteen Collections and *Corpus of Qin Documents Written on Bamboo and Wood* (Figure 2), have been referred to by colleagues as "milestones in the restoration and research of Chu and Qin bamboo strip manuscripts." CBSM's website, *Wuhan University Bamboo and Silk Web*, features the latest academic news, research articles, and notes, and hosts a lively discussion on its forum. Additionally, it hosts the *Chinese Bamboo and Silk Manuscript Character Form and Word Usage Example Database*. This database is freely accessible to all through the center's website and enables rapid and thorough searching for the forms of a character or word usage. CBSM also boasts a library and a laboratory for deciphering bamboo and silk manuscripts. It engages in scholarly cooperation with institutions worldwide, such as the University of Chicago and many others. For example, it established the International Symposium on Chinese Bamboo and Silk Studies conference series, which convenes in locales around the world and has already become an influential platform for global academic exchange and communication (Figure 3).

CBSM is composed of seven full-time teachers and around 20 affiliated part-time research fellows from Wuhan University's schools of history, literature, and philosophy. Bamboo and wooden strip manuscript expert Chen Wei is director of the center, and paleography expert Li Tianhong is vice-director (Figure 1).

CBSM educates Master's and Ph.D. students and accepts international students for advanced graduate study.

The Center for Studies of Information Resources

Zhao Yiming*

The Center for Studies of Information Resources of Wuhan University (CSIR), one of the Ministry of Education's National Key Research Centers for Humanities and Social Sciences, was founded in 2000. As China's sole national research center in the discipline of library and information science (LIS), CSIR is the driving force for its growth there. The history of LIS at Wuhan University began with the founding of the Boone Library School in 1929. The last century has witnessed the impressive growth of Wuhan University's LIS discipline, which in 2017 was ranked first in the nation by China's Ministry of Education and fourth in the world by Shanghai Ranking's Global Ranking of Academic Subjects.

CSIR is dedicated to research into the organization, management, development, and use of information resources, particularly digital information, in light of the rapid growth and popularization of information and web technologies since 2000. CSIR researchers have probed extensively into the theories, tools, methods, technologies, and policies dealing with the management of information resources. They have also completed numerous research projects, including "The Planning, Management, and Utilization of Digital Information Resources" (funded by the Chinese Ministry of Education), "The Deep Development and Management Mechanism of Digital Information Resources Based on the Life-Cycle Theory" [funded by the National Natural Science Foundation of China (NSFC)], and "The Strategies of the Value-Added Exploitation of Information Resources in China's Public Sectors" (funded by the National Social Science Foundation of China).

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FIGURE 1. CSIR leading scientist Feicheng Ma giving his keynote speech, "Achieving the Sequence and Governance of Information through Users' Self-Discipline on the Internet," at the New Media Forum at the Third World Internet Conference, held at Wuzhen, Zhejiang province, China, in 2016.

PHOTO: WUHAN UNIVERSITY

In honor of his contributions to the field of digital information resources, Feicheng Ma, the leading scientist at CSIR, was invited to give a keynote speech entitled "Achieving the Sequence and Governance of Information through Users' Self-Discipline on the Internet" at the New Media Forum at the Third World Internet Conference, held at Wuzhen,Zhejiang province, China, in 2016 (Figure 1).

CSIR has recently refocused its research to embrace the era of big data, receiving funding from the NSFC for a collaborative project with the University of Wisconsin and the University of Pittsburgh called "Research on Knowledge Organization and Service Innovation in the Context of Big Data." CSIR is now gearing up to explore the applications of big data in a variety of domains, such as finance, health care, and culture.

In the financial domain, CSIR researchers have constructed a financial knowledge graph by extracting stock exchange data from stock markets, public information released by 47 million companies, and other online economic consensus data. This knowledge graph supports a variety of objectives, such as risk regulation and the identification of actual controllers.

In the health care domain, CSIR scientists have built the "Knowledge Base for Hypertension" as well as the supporting "Big Data Management and Analysis Platform," both of which are mainly used to integrate and analyze real-time physical data of patients as well as static-case data generated by simulations. The platform can perform real-time stream processing and frequent-pattern mining of health-related data to assist in disease analysis and patient services.

In the culture domain, the researchers have created an ontological model for deep semantic annotation and a knowledge representation framework for mural images of the Thousand-Buddha Grottoes in the Dunhuang Caves. CSIR collaborated on this project with the Center for Digital Humanities at Wuhan University, which explores the application of information technologies for knowledge production, dissemination, and teaching in the arts and humanities.

Inspired by the success of these projects, Wuhan University founded the Big Data Institute in 2018, to encourage innovation in the humanities and social sciences, incubate new disciplinary growth points, and facilitate large-scale interdisciplinary studies between the arts and sciences. The institute has invited domestic and foreign experts and scholars to present over 20 lectures on the concepts, methods, and skill sets required for big-data analysis, targeting faculty and students in the humanities and social sciences who need training in these investigational techniques.

To promote scientific communication, CSIR launched an open-access, peer-reviewed international journal, *Data and Information Management* (ISSN: 2543-9251) as well as two peer-reviewed Chinese periodicals, *Document, Information & Knowledge* (ISSN: 1003-2797) and the *Journal of Information Resources Management* (ISSN: 2095-2171). CSIR researchers have served as associate editors and members of the editorial boards for several international journals, such as the *Journal of Information Science* and *Government Information Quarterly*.

CSIR values openness and collaboration, forging close cooperative relationships with Chinese research institutions such as Beijing University, Nanjing University, the National Library of China, and the Chinese Institute of Science and Technology. Global collaborations with prominent institutions such as the University of Wisconsin, the University of Pittsburgh, the University of Copenhagen, and the Free University of Amsterdam have become increasingly frequent. More than 50 international guests are invited to visit CSIR every year. CSIR has also been an active member of many global organizations, such as the iSchools, the International Federation of Library Associations and Institutions (IFLA), and the American Library Association (ALA). In 2017, CSIR jointly hosted the iConference in Wuhan in collaboration with the iSchool at Wuhan University and Sungkyunkwan University in South Korea.

CSIR Director Gang Li is leading the center's scientists in exploring critical areas, including the integration of information resources into smart urban construction and the theory and application of information science for economic and social development.

PART 2: Research at the cutting edge

The research group of Bao-Liang Song

Jie Luo*

Bao-Liang Song received his bachelor's degree from the Department of Biological Science and Technology at Nanjing University in 1997, and his doctorate from the Institute of Biochemistry and Cell Biology at the Chinese Academy of Sciences (CAS) in 2002. He then pursued his postdoctoral training in the laboratory of Michael Brown and Joseph Goldstein (1985 Nobel laureates in Physiology or Medicine) at the University of Texas Southwestern Medical Center in Dallas between 2002 and 2005, where he studied the mechanisms underlying sterol-regulated degradation of 3-hydroxy-3-methylglutaryl-CoA reductase (HMGCR), the rate-limiting enzyme in cholesterol biosynthesis. In 2005, Song returned to the Institute of Biochemistry and Cell Biology at CAS and was appointed principal investigator. He was made associate director of the State Key Laboratory of Molecular Biology in 2012, and assistant director of the Institute of Biochemistry and Cell Biology in 2013, before relocating to Wuhan University in 2014.

Song is currently dean of the College of Life Sciences and director of the Hubei Key Laboratory of Cell Homeostasis. He is a Cheung Kong Scholar and the recipient of numerous awards, such as the 2012 Tan Kah Kee Award for Young Scientists, the 2013 Arthur Kornberg Memorial Award, the 2014 C. C. Tan (Jia-Zhen Tan) Life Science Innovation Award, and the 2015 Promega Innovation Award. Song serves as an associate editor of the *Journal of Molecular Cell Biology* and an editorial board member of the *Journal of Biological Chemistry*.

Song's research group consists of two associate professors, four staff members, three postdoctoral fellows, and 31 graduate students. The group combines biochemical, cellular, and genetic approaches to elucidate cholesterol metabolism under both physiological and pathological conditions in mice and humans. So far, the Song group has published more than 50 scientific articles in prestigious journals, including *Science*, *Cell*, *Nature Medicine*, *Nature Cell Biology*, *Cell Metabolism*, and *Molecular Cell*. Their work published in *Cell* (*1*) was ranked as one of China's Top Ten Life Sciences Advances in 2015 by the China Association for Science and Technology.

Bao-Liang Song

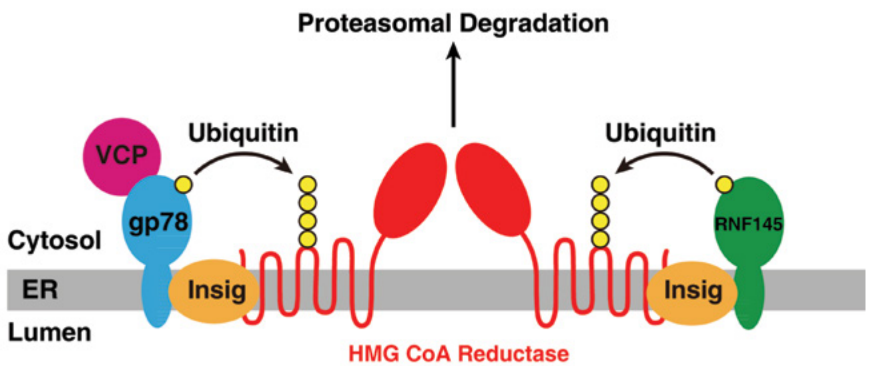

FIGURE 1. Sterol-regulated ubiquitination and degradation of HMGCR. This figure is modified from (*6*). VCP, valosin-containing protein; ER, endoplasmic reticulum.

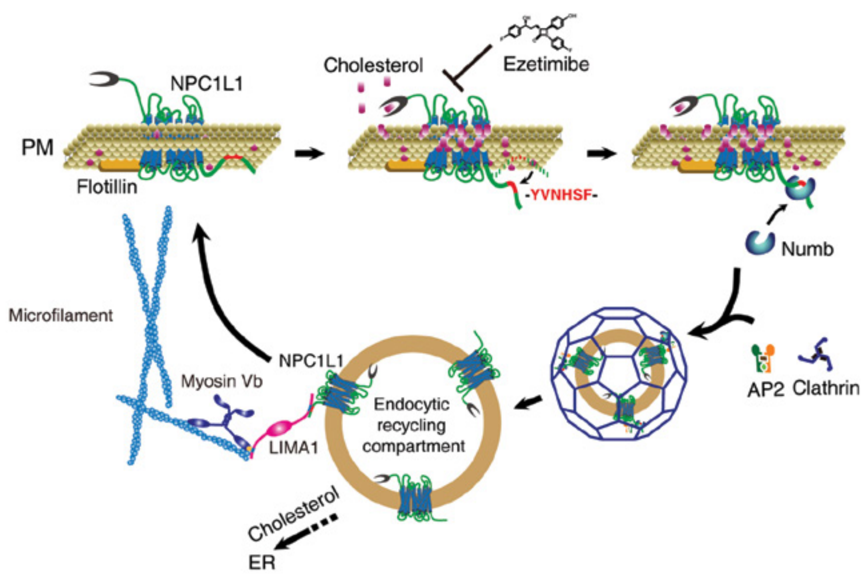

FIGURE 2. The molecular pathway of NPC1L1-mediated intestinal cholesterol absorption. Image reprinted with permission from (*17*). © 2017 Elsevier: *Molecular Cell*. PM, plasma membrane; ER, endoplasmic reticulum.

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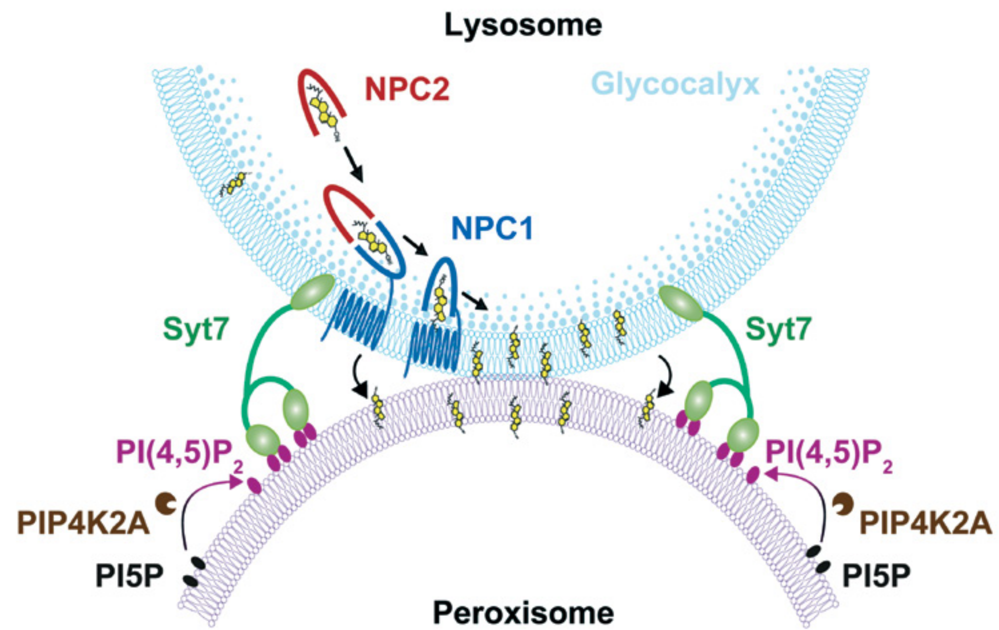

FIGURE 3. Intracellular cholesterol transport is mediated by lysosome-peroxisome membrane contacts. Image reprinted with permission from (*1*). © 2015 Elsevier: *Cell*.

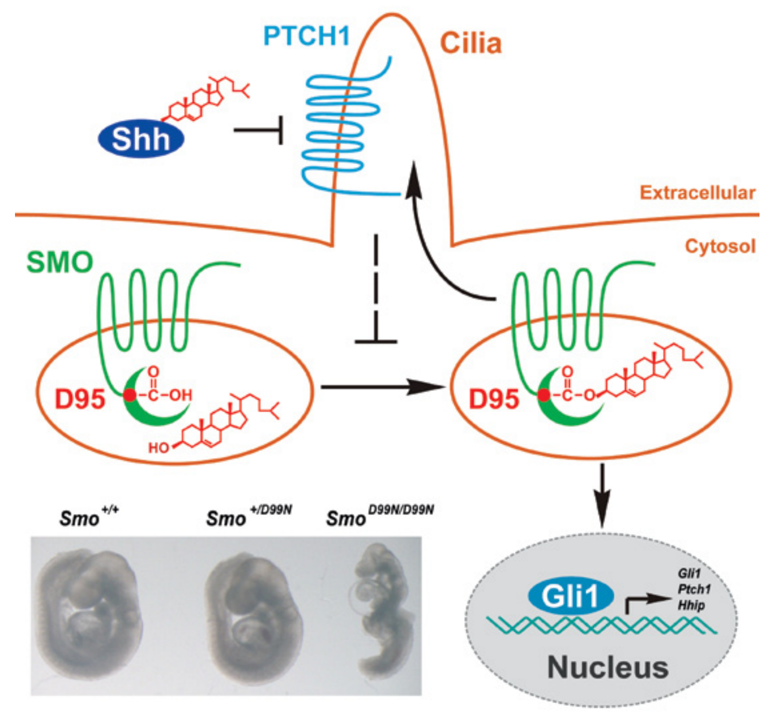

FIGURE 4. SMO is covalently modified by cholesterol at the D95 residue. Image reprinted with permission from (*17*). © 2017 Elsevier: *Molecular Cell*.

The major contributions made by Song's research team are summarized as follows:

1. Uncovering the regulatory mechanisms of cholesterol biosynthesis.

Cholesterol is an essential component of eukaryotic membranes and the precursor to oxysterols, bile acids, steroid hormones, and vitamin D. It can be synthesized de novo or obtained from the diet. HMGCR is a critical biosynthetic enzyme whose stability is tightly regulated through multivalent feedback regulatory mechanisms. High concentrations of cholesterol decrease transcription of the *HMGCR* gene by inhibiting the sterol regulatory element-binding protein (SREBP) pathway. Song's group has found that lanosterol, 24,25-dihydrolanosterol, geranylgeraniol, and various forms of vitamin E promote ubiquitination and degradation of the HMGCR protein (*2–4*). They have also demonstrated that sterol-induced HMGCR degradation is mediated by the ubiquitin ligase gp78 and its cofactor Ufd1 (*5, 6*) and also by ring finger protein 145 in specific cell types (*7*) (Figure 1). They further discovered that ablation of gp78 in the liver or application of a small compound called betulin blunts the SREBP pathway and decreases lipid biosynthesis, thereby improving hyperlipidemia and insulin resistance (*8, 9*).

2. Elucidating the molecular pathway of dietary cholesterol absorption.

The Niemann-Pick C1-like 1 (NPC1L1) protein is a critical player in dietary and biliary cholesterol absorption in the small intestine and liver. However, the mechanisms of NPC1L1-mediated cholesterol uptake have long remained elusive. Song's work has revealed that NPC1L1 and flotillins form cholesterol-rich microdomains in the plasma membrane (PM) (*10*). When the cellular cholesterol level is high, cholesterol binds to the extracellular domain of NPC1L1, releasing its cytoplasmic tail to recruit the clathrin adaptor Numb and initiating clathrin-mediated endocytosis (*11*). The endocytic vesicles travel along the microfilaments to the endocytic-recycling compartment (ERC). When the cellular cholesterol level is low, the small guanosine triphosphatase Cdc42 is activated and binds to NPC1L1, promoting Myosin Vb recruitment and actin polymerization near NPC1L1-containing vesicles, which enables the

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NPC1L1-flotillin complex to translocate from the ERC to the PM (*12, 13*). The cholesterol absorption inhibitor ezetimibe blocks cholesterol uptake by impairing NPC1L1 endocytosis (*14*). Most recently, Song's group identified a rare frameshift variant in the *LIMA1* gene from a Chinese family of Kazakh ethnicity with inherited low levels of low-density lipoprotein cholesterol (LDL-C) and reduced cholesterol absorption (*15*). LIMA1 bridges NPC1L1 to Myosin Vb and transports NPC1L1 to the PM. Loss-of-function mutations in *LIMA1* reduce intestinal cholesterol absorption and lower plasma LDL-C levels in mice and humans. The molecular pathway of NPC1L1-mediated cholesterol uptake is depicted in Figure 2 (previous page).

3. Characterizing intracellular cholesterol trafficking via lysosome–peroxisome membrane contacts.

Most mammalian cells take up cholesterol from LDL through receptor-mediated endocytosis. After reaching lysosomes, LDL-derived cholesterol continues to transit to downstream organelles, including the endoplasmic reticulum (ER), for specific structural and functional needs. However, the itineraries and detailed molecular mechanisms by which cholesterol moves from lysosome to downstream organelles are poorly understood. Song's group has demonstrated that cholesterol can be conveyed through membrane contact sites formed between lysosomal protein synaptotagmin VII (Syt7) and peroxisomal lipid phosphatidylinositol 4,5-bisphosphate [($PI(4,5)P_2$)] (*1*). Depletion of Syt7 or peroxisomal $PI(4,5)P_2$ reduces lysosome–peroxisome contact sites and induces massive cholesterol accumulation in the lysosome. Intriguingly, in human patients and a mouse model of peroxisomal disorders, cholesterol accumulates well in advance of manifestation of the neurological phenotypes, suggesting that intracellular cholesterol accumulation might cause peroxisomal disorders. Song's team recently showed that phosphatidylinositol 5-phosphate 4-kinase type-2 α upregulates peroxisomal $PI(4,5)P_2$ levels and facilitates intracellular cholesterol transport (*16*). Collectively, their work suggests that peroxisome plays an essential role in intracellular cholesterol transport (Figure 3, previous page).

4. Identifying a new cholesterol-modified Smoothened protein.

Hedgehog (Hh) was believed to be the only cholesterol-modified morphogen that plays a pivotal role in development and tumorigenesis. A major unsolved question was how Hh signaling regulates the activity of its downstream effector Smoothened (SMO). By using a synthesized cholesterol probe and "click chemistry" reactions, Song's group showed that SMO is covalently modified by cholesterol at the Asp95 (D95) residue through an ester bond (*17*). This modification is inhibited by Patched-1 but enhanced by Hh. The cholesterylation of SMO is critical for Hh signal transduction, assuring proper embryonic development (Figure 4, previous page). Their work suggests that targeting SMO cholesterylation may provide a therapeutic approach for treating Hh pathway-related cancers.

Ultimately, the long-term goal of Song's group is to reveal the cellular and molecular processes of cholesterol metabolism and develop novel strategies to treat cholesterol-related diseases.

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Phononic Crystals and Acoustic Metamaterials Research

Chunyin Qiu and Manzhu Ke*

Zhengyou Liu leads the Phononic Crystals and Acoustic Metamaterials Research Group in the School of Physics and Technology. The group comprises three faculty members (Chunyin Qiu, Manzhu Ke, and Zhengyou Liu) and more than 15 postgraduate students, and is housed in a laboratory of approximately $300\ m^2$. The laboratory is equipped with a series of world-class acoustics instruments, including a Brüel & Kjær Pulse multichannel-analysis system, a Panametrics ultrasonic-scanning system, a vibrometer vibration-measurement system, and a sound-radiation–force measurement system. Liu's group has made remarkable contributions to the field of phononic crystals (PCs) and acoustic metamaterials. His work has generated considerable attention worldwide and been published in prestigious peer-reviewed journals, such as *Science*, *Nature*, *Nature Physics*, and *Physical Review Letters*. Liu received the Brillouin Medal from the International Phononics Society in 2015 and the National Natural Science Second Place Award from the Chinese government in 2010.

1. Acoustic metamaterials

For classical waves such as light or sound, diffraction sets a natural limit on how finely the details of an object's image can be recorded. In recent years, the concept of metamaterials has opened many fascinating avenues in optics and acoustics research. In 2000, Liu and his collaborators from the Hong Kong University of Science and Technology (*1*) first proposed locally resonant PCs, which exhibit spectral gaps at extremely low frequencies (i.e., two orders of magnitude smaller than the Bragg frequency associated to the lattice constant).

Following their pioneering work on acoustic metamaterials, Liu's group proposed acoustic metamaterials with doubly negative effective parameters (*2*) and zero indices (*3*) (Figure 1). The metamaterial depicted in Figure 1 simultaneously possesses a negative effective bulk modulus (EBM) and an effective mass density (EMD). It is a zinc-blende structure consisting of one face-centered cubic array of bubble-contained water spheres (BWSs) and another relatively shifted face-centered cubic array of rubber-coated gold spheres (RGSs) in an epoxy matrix. The negative bulk modulus and mass density are simultaneously derived from the coexisting monopolar resonances (from the embedded BWSs) and dipolar resonances (from the embedded RGSs). The band structure calculated with the multiple-scattering-theory method (Figure 1B) revealed that a new passband with a normalized frequency extending from 0.373 to 0.414 emerges in the overlap region of the negative EBM and EMD, which is a typical negative-refraction band with a shape of negative group velocity. Figures 1C and 1D depict a metamaterial with simultaneous zero indices for both the longitudinal and transverse waves. The effective mass density ρ_{eff}, reciprocal of shear modulus $1/\mu_{eff}$, and $1/(\mu_{eff} + \kappa_{eff})$ pass through zero simultaneously and linearly (Figure 1C), and the effective refraction index for both the P wave and S wave also passes through zero; however, the group velocity remains finite. When scattering objects such as cylinders are present in the metamaterial slabs, as depicted in Figure 1D, elastic waves can transmit through the metamaterial slabs almost perfectly, exhibiting the well-known

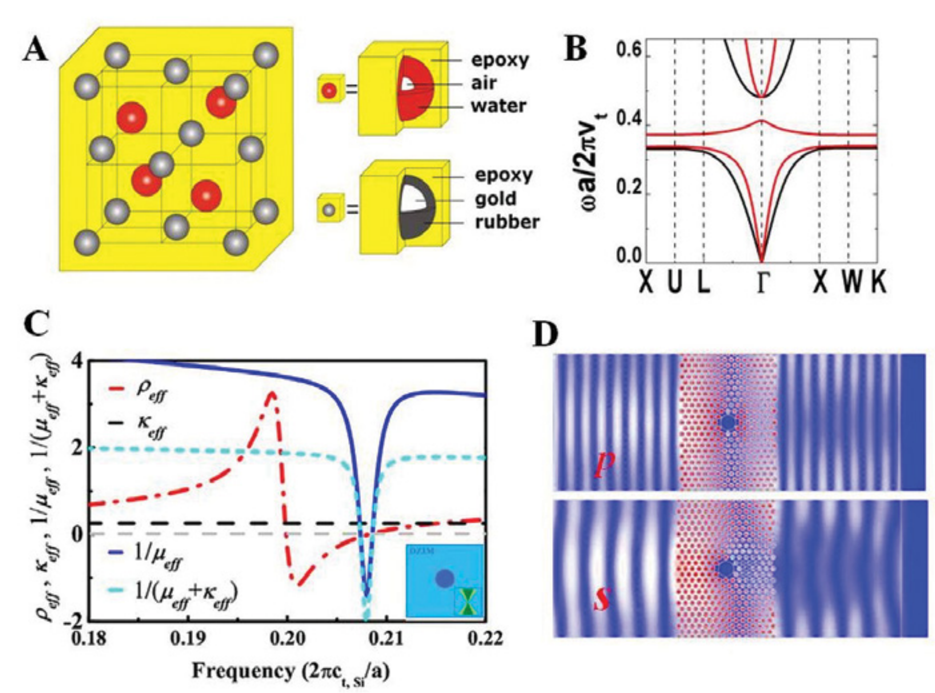

FIGURE 1. Acoustic metamaterials with double-negative effective parameters and a zero index. (A) A unit cell of the zinc-blende structure made by combining an array of bubble-contained water spheres (BWSs) with an array of rubber-coated gold spheres (RGSs) in an epoxy matrix (left), and the insides of two structural units (right); **(B)** A band structure for a zinc-blende structure consisting of both BWSs and RGSs in epoxy; **(C)** The effective mass density ρ_{eff}, bulk modulus κ_{eff}, reciprocal of shear modulus $1/\mu_{eff}$, and $1/(\mu_{eff} + \kappa_{eff})$ as a function of frequency, with the inset showing a unit cell consisting of the elastic double zero-index metamaterial and an embedded cylinder; **(D)** the displacement-field distributions for a two-dimensional PC system with embedded steel cylinders for achieving transmission-preserving plane-wave characteristics with incident P and S waves (*2, 3*).

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cloaking effect of zero-index metamaterials. Interestingly, despite the occurrence of elastic-wave scattering, there is, counterintuitively, no mode conversion between the longitudinal and transverse waves during this process, in contrast to what is observed in conventional elastic media.

Through rigorous derivation, Liu's group has also shown that the dynamic, effective mass density of an inhomogeneous mixture, when used in the prediction of wave velocities in the long-wavelength limit, can differ from the static version, which is the volume average of the component mass densities (*4*). However, the Berryman density, which was first derived more than two decades ago, gives a closer correspondence between the acoustic and electromagnetic metamaterials by allowing for negative-mass densities at frequencies around resonance.

2. Extraordinary acoustic transmission

In 1998, Ebbesen and colleagues found that an optically opaque metal film perforated with a periodic array of subwavelength-sized holes was abnormally transparent for certain resonant frequencies or angles of incidence. This finding represented an extraordinary optical transmission that garnered considerable attention from researchers. More recently, Liu's group demonstrated that for acoustic waves, such striking effects occur when sounds interact with planar structures.

In 2007, Liu's group first explored the extraordinary acoustic transmission (EAT) induced by sound interacting with planar structures (Figure 2). They demonstrated that a remarkable transmission peak with an amplitude of almost 90% appeared in the band-gap frequency range when acoustic waves penetrated through a structure comprising a steel plate and a PC, whereas negligible transmission was detected when the acoustic waves penetrated through a lone steel plate or PC slab (*5*). The group deduced that this EAT derives from the resonant coupling of the incident waves with the surface states at the interface of the PC slab and the plate (Figure 2B). They could also generate the EAT through structure-induced resonant excitation with a structure consisting of periodic rectangular gratings on both sides of a uniform brass plate (*6*). This observation suggested that the EAT could occur in the subwavelength region (Figure 2C) that arises from the resonant excitation of the nonleaky Lamb modes intrinsic to uniform solid plates (Figure 2D). This EAT is a close analog to the transmission enhancement associated with the surface-plasmon excitation in its optical counterpart. Liu's group also designed acoustic metasurfaces of subwavelength thickness to anomalously deflect transmitted airborne sound, which breaks conventional reflection and refraction laws (*7*).

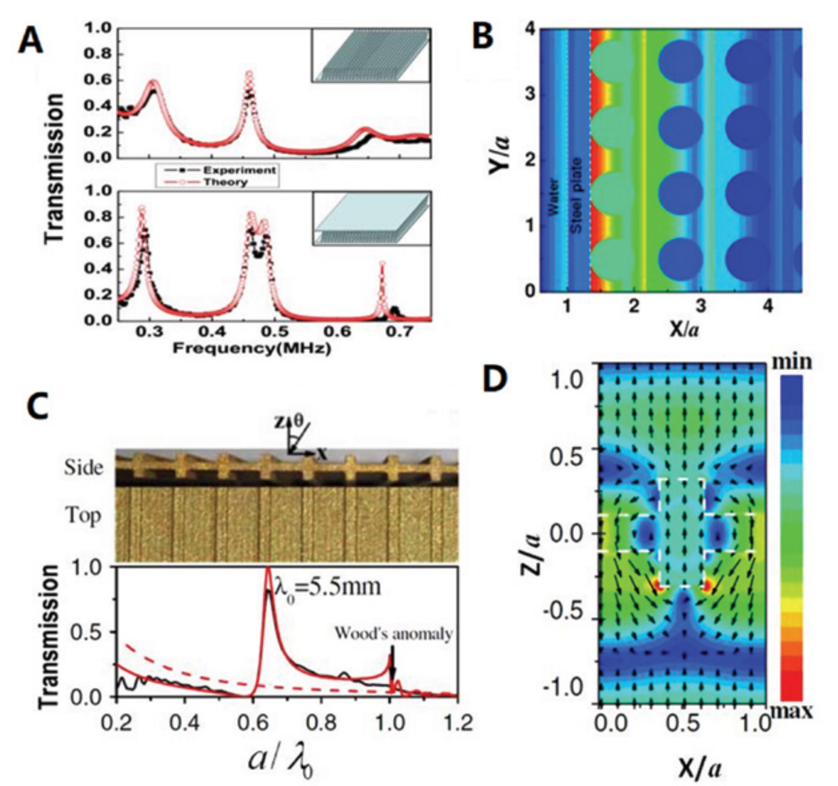

FIGURE 2. Extraordinary acoustic transmission (EAT) induced by sound interacting with planar structures. (A) The transmission spectra of acoustic waves through combined structures, with the inset showing a PC slab accompanied by a steel plate on the bottom surface (top) and a PC slab sandwiched by two steel plates (bottom); **(B)** The displacement-field distribution throughout the sample of (A), subject to an incident plane wave at the resonant frequency; **(C)** A structure consisting of periodic rectangular gratings on both sides of a uniform brass plate (top), and the transmissions (experimental: dark solid line; numerical: red solid line) at the normal incidence plotted as a function of the normalized frequency, shown with the transmission obtained using a uniform plate (red dashed line); **(D)** The displacement-field distribution for the sample shown in (C), excited by a normal incident-plane wave at the resonant frequency (*5, 6*).

3. Valley transport of sound

The discovery of novel internal quantum degrees of freedom for electrons is of considerable interest to the field of condensed-matter physics. Recently, the discrete-valley degree of freedom has attracted tremendous attention since it is potentially a new carrier of information and thus useful in modern electronic devices. Liu's group introduced the concept of "valleytronics" to PCs for scalar sound (*8*), which lacks intrinsic degrees of freedom like the charge and spin in electrons, and is, therefore, inert to external electric and magnetic fields. The group revealed the vortex nature of acoustic valley states (Figure 3) and established valley selection rules for such states. Furthermore, the group proposed a mimicked spin Hall effect for sound, in which split beams carry different vortex chirality. In contrast with electronic systems, where the population and detection of purely polarized valley states often resort to additional external fields, acoustic valley states can be directly excited by sound stimuli and detected from the field distributions inside and outside the crystals, thereby benefiting from the macroscopic nature of PCs. Liu's group confirmed the robustness of valley pseudospins by experimentally probing the quantized phase-winding number of the acoustic valley vortex states (*9*). In addition to providing a new degree of freedom with which to control sound, the findings also raised the possibility of innovative applications for the acoustic valley vortex states, such as for designing acoustic micromotors.

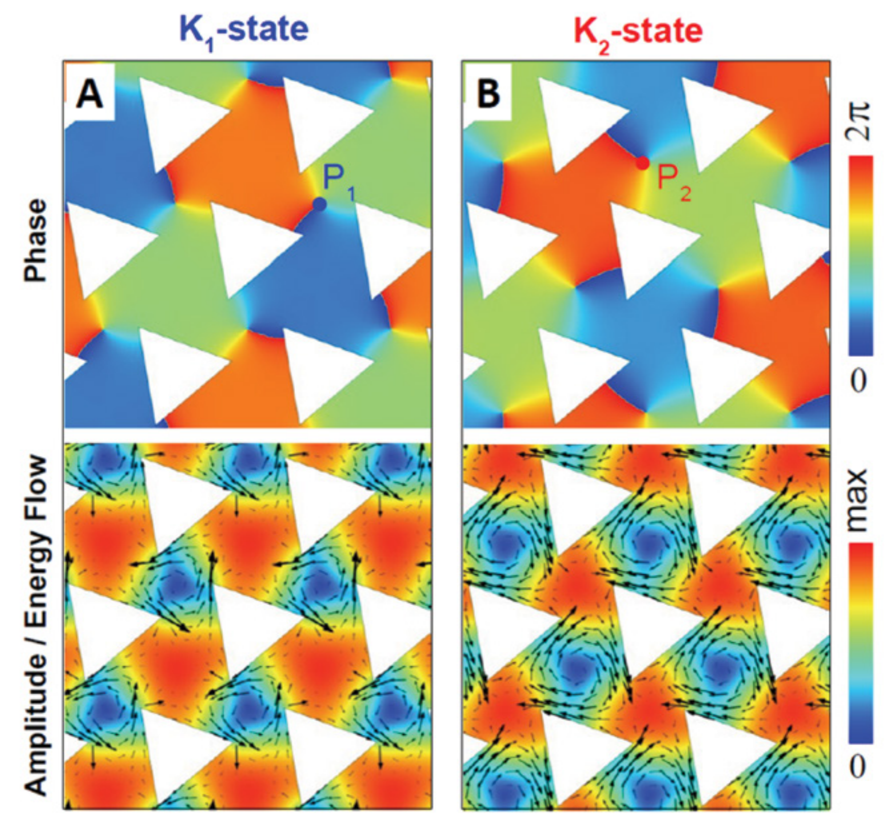

FIGURE 3. Vortex nature of the acoustic valley states. Here K_1 and K_2 label the lowest two valley states located at the K point of the hexagonal Brillouin zone (*8*).

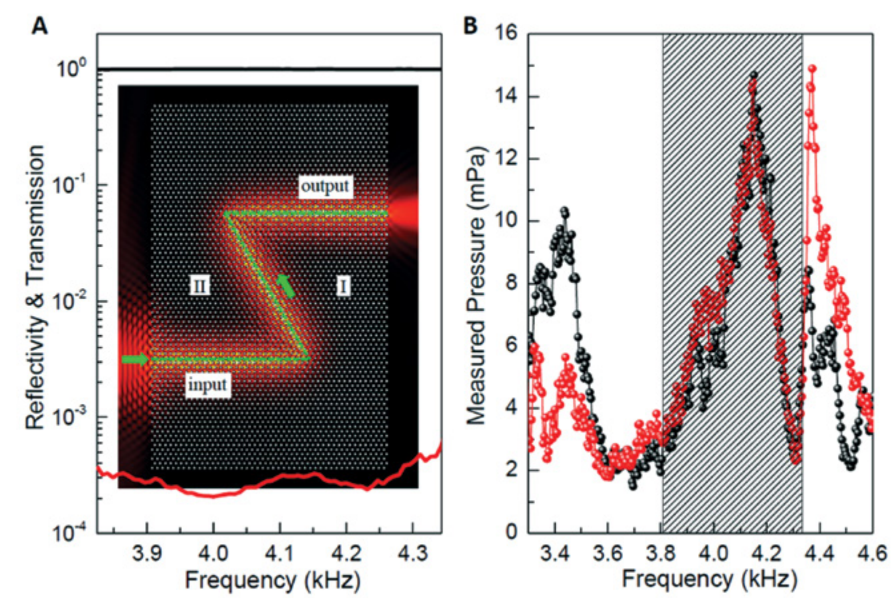

FIGURE 4. Reflection immunity of the valley-projected edge modes from sharp corners. (A) Power transmission (black line) and reflection (red line) spectra calculated for the two sharp turns in a zigzag path; (B) Transmitted pressure measured for the zigzag path (red circles), compared to that of a straight channel sample (black circles). The good agreement in the bulk gap (shadow region) shows a small influence of the bending corners on the interface transport (*10*).

Liu's group also discovered the existence of two kinds of topologically distinct acoustic valley Hall phases (*10*), in which the phase transition can be achieved by simply rotating triangular scatterers. They reported a topological valley transport of sound in an interface that separates different acoustic valley-Hall insulators and experimentally demonstrated many exotic transport properties, such as valley-selective excitations and antireflection in bent corners (Figure 4). Interestingly, the rotating-scatterer mechanism enabled easily tunable operation bandwidth and a reconfigurable shape for the interface. These characteristics, along with intriguing valley-transport properties that are absent in conventional waveguides, could be valuable for designing exceptional acoustic devices.

Liu's group also proposed a unique bilayer design for PCs (*11*) to attain and enrich the topological phase diagram. Based on the new degree of freedom introduced by the additional layer, they predicted that by integrating the different topological transport phenomena together in a compact device, the valley-projected edge modes could be used to mediate versatile controllability for applications such as intra-/interlayer communications. They also studied the valley physics in non-Hermitian acoustic systems (*12*) and were able to adjust the bulk or edge states to be either attenuating or amplifying, depending on the gain and loss factor of the system. These findings may pave the way for exploring intensity-controllable valley transport in various classical but non-Hermitian systems.

4. Weyl physics in acoustics

Recently, Weyl semimetals, which feature doubly degenerate crossing points in three-dimensional momentum space, have become a hot topic in the field of topological matter. Weyl points are monopoles of Berry flux with topological charges characterized by quantized Chern numbers. In addition to the tantalizing bulk properties that

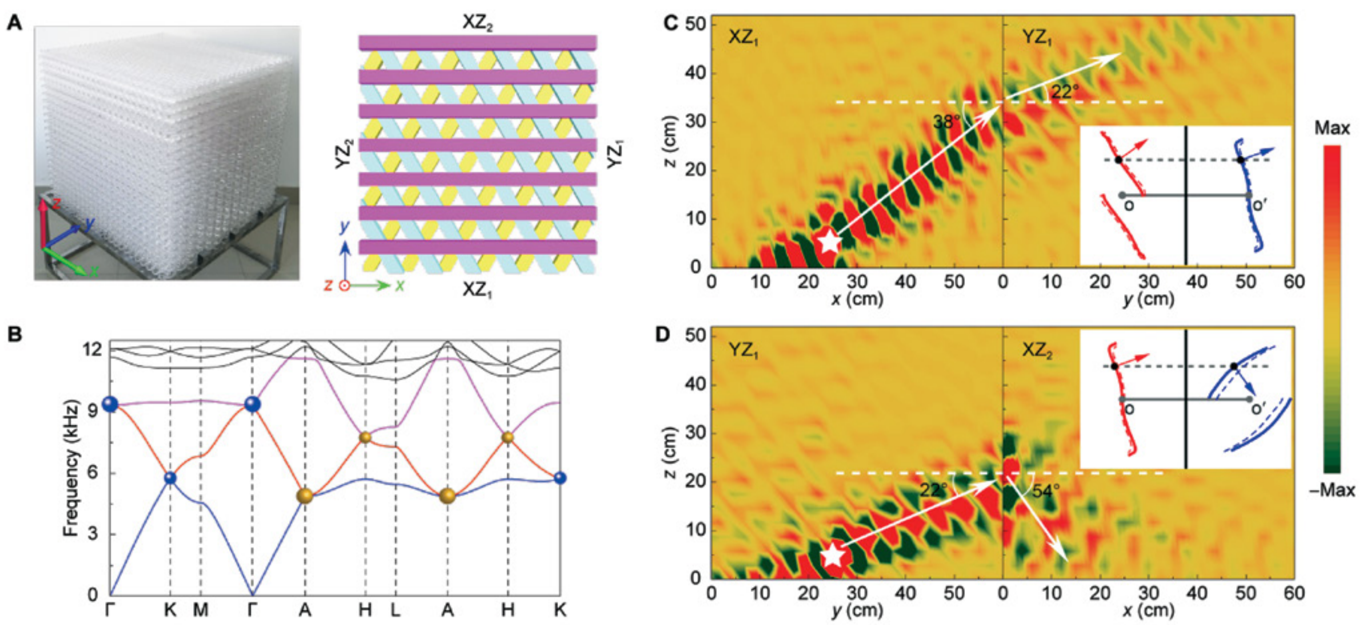

FIGURE 5. A woodpile Weyl PC and the topological negative refraction of surface acoustic waves. (A) An image of the experimental sample (left) and the fine structures of the four side surfaces XZ_1, YZ_1, XZ_2, and YZ_2 (right); (B) Bulk band dispersions simulated along high-symmetry directions. The color spheres label Weyl points with different topological charges; (C, D) Positive and negative refraction responses to the two one-dimensional edges of the YZ_1 surface shared with the XZ_1 and XZ_2 surfaces. Insets: Schematics of echo-free interfacial phenomena, illustrated according to the equifrequency-contour analysis. In both cases, the experimentally measured beam propagations exhibit negligible interfacial reflections (*14*).

manifest the chiral anomaly, the nontrivial band topology endows Weyl semimetals with appealing surface states hosted by sample boundaries. Remarkably, the surface-band dispersion at Fermi energy can form open arcs connecting projected Weyl points of opposite topological charge. Liu's group extended Weyl physics to acoustics (*13*) and presented the first experimental observation of acoustic Weyl points in a three-dimensional chiral PC. Using airborne-sound experiments, they demonstrated topologically protected, one-way propagations of surface arc states and their immunity to defects.

Liu's group made another breakthrough using the open nature of surface arcs in Weyl PCs. They reported an intriguing negative refraction of topologically nontrivial surface waves (Figure 5) (*14*). This novel phenomenon is markedly counterintuitive in two respects: The refraction beam deflects into an anomalous direction, and the unwanted reflection is completely forbidden. The former is attained by meticulously designing the surface terminations of the Weyl PC, and the latter inherently originates from topological Weyl physics. Interestingly, such interfacial phenomena can even exist in a single Weyl PC, where interfaces consist of one-dimensional edges shared by two adjacent facets. The proposed scheme can be directly extended to realize a wide variety of exceptional interfacial-sound responses, such as focusing and imaging without any reflection. Similar phenomena should also be observable in other Weyl systems, such as photonics and electronics, thus offering unprecedented possibilities for controlling waves. This work not only advances the current understanding of interfacial acoustics, but also enriches Weyl physics in condensed-matter systems, such as Fermi arc engineering, and establishes a new paradigm of exotic phenomena arising from band topology.

5. Future direction

In the years ahead, Liu's group will continue to focus on various fascinating forms of topological PCs, including topological (phononic) insulators and semimetals as well as the design of acoustic fields using artificial structures for particle manipulation.

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PART 3: Research in the natural sciences

The Natural Sciences Division

Yuxian Zhu[1*], Guojia Fang[2], Xiang Zhou[3], Xianzheng Zhang[3], Jie Zhao[4], Huijiang Zhao[5], Dihua Wang[6], and Yi Deng[1]

The Natural Sciences Division comprises six colleges or institutes: the Institute for Advanced Studies (IAS), the School of Physics and Technology (SPT), the College of Chemistry and Molecular Sciences (CCMS), the College of Life Sciences (CLS), the School of Mathematics and Statistics (SMS), and the School of Resource and Environmental Sciences (SRES). A brief summary of this critical sector of Wuhan University follows.

I. The Institute for Advanced Studies

IAS was established in 2014 to enhance the natural sciences at Wuhan University. It has recruited high-energy and particle physicists, biologists, chemists, materials, and informatics scientists in five research centers with the aim of promoting interdisciplinary studies targeting critical scientific issues likely to have a profound near-term impact (Figure 1).

1. The Omics Center (TOC). Biology is a multifaceted discipline with methodologies that draw on chemistry, physics, computation, mathematics, and even engineering. IAS founded the TOC to create resources for studying genomics, transcriptomics, translatomics, proteomics, and metabolomics of both animals and plants, primarily in nonmodel organisms. The TOC is actively recruiting chemists to discover novel natural and synthetic small molecules for translational studies in biomedicine and agriculture.

2. The Nano-Catalysis Center (NCC). The NCC, directed by Aiwen Lei, aims to solve fundamental problems in chemistry, physics, materials, and energy research (Figure 2). The NCC team actively encourages interdisciplinary collaborations to facilitate innovation. Lei conceived a program whereby graduate students and postdoctoral fellows train for the required technical skills by rotating through different subgroups within the NCC as well as international laboratories. The team has worked diligently on photocatalysis, electrocatalysis, and activation of small molecules, such as CH_4, H_2O, CO_2, and N_2. Notably, they have achieved hydrogen evolution by an external, oxidant-free, oxidative cross-coupling reaction.

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[3]The College of Chemistry and Molecular Sciences
[4]The College of Life Sciences
[5]The School of Mathematics and Statistics
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FIGURE 1. The new IAS building, which is near the main gate of Wuhan University and can house more than 60 laboratories. Credit: Yuxian Zhu

FIGURE 2. Aiwen Lei, Nano-Catalysis Center (NCC) director, discusses oxidative cross-coupling reactions with his students. Credit: Yuxian Zhu

3. The Quantum Materials Center (QMC). The QMC concentrates on condensed matter physics and material science. The goal of the center is to investigate physical mechanisms of exotic properties in quantum systems for the design and development of novel quantum materials with superior electric, optical, acoustical, and thermal properties that can be applied in energy and electronic devices. Specific areas of focus include light–matter interactions, correlated electronic systems, nanomaterials and nanodevices, topological phases and related phenomena, quantum behaviors of low-dimensional systems, thin films, and heterostructures. The QMC also serves as a facilitative platform to provide chemists, biologists, and material scientists with various experimental and theoretical approaches for investigating subjects such as soft matter, organic material, and biomaterials.

4. The Center for Precision Synthesis (CPS). The CPS is building a competitive research team comprising outstanding scholars and young talents from China and overseas. The team is poised to achieve groundbreaking innovations at the frontiers of synthetic chemistry. The research program focuses on the development of conceptually new catalytic methods that allow for more efficient and cost-effective "green" synthesis of pharmaceuticals, agrochemicals, energy, and functional materials.

5. The Wuhan Photon Source (WHPS). The WHPS is set to open its doors in the early 2020s. It will be led by its current and founding dean, **Yuxian Zhu,** and will be one of the key interdisciplinary platforms at IAS and Wuhan University. Zhu, a fellow of the Chinese Academy of Sciences (CAS), is internationally renowned for his contributions to basic cotton research, especially in genomics and genetics (Figure 3). The WHPS aims to be the first world-class, medium-energy synchrotron radiation source in China that uses fourth-generation technologies for achieving high brightness, high resolution, high coherence, and low emittance (Figure 4). The WHPS is particularly keen to promote scientific and technological innovation, education reform, and industrial upgrades in the central and western regions of China.

FIGURE 3. A cotton "flower" bouquet that Yuxian Zhu, founding director of the Wuhan Photon Source (WHPS), keeps in his office. An ex-student sent it to him for his 60th birthday party a few years ago. Though cotton is not a flower, its Chinese translation, *mianhua*, sounds like the Chinese words *baihehua* (for lily) and *meiguihua* (for rose). Credit: Yuxian Zhu

FIGURE 4. Yuxian Zhu reporting on the progress of the Wuhan Photon Source (WHPS). Credit: Yuxian Zhu

FIGURE 5. Dean Hongxing Xu (left) and Deputy Dean Jiangbo Wang (right), discussing the future development of the School of Physics and Technology (SPT). Credit: Guojia Fang

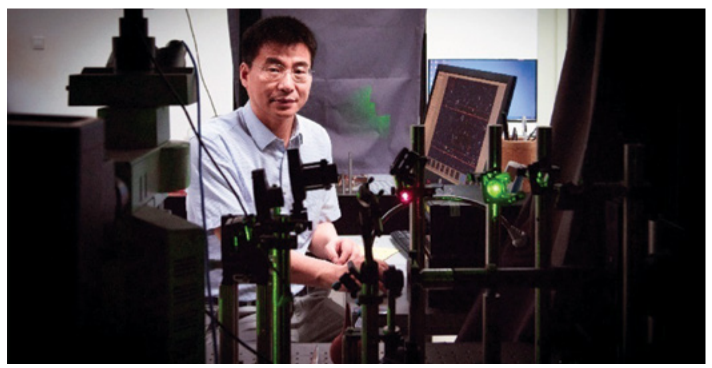

FIGURE 6. Hongxing Xu doing experiments on a Raman microscope, exploiting the electromagnetic enhancement in plasmonic nanogaps. Credit: Guojia Fang

II. The School of Physics and Technology

Physics at Wuhan University traces back to 1893, when the discipline of *gezhi*, or natural sciences, was founded at the Ziqiang Institute. Currently, physics at Wuhan University is ranked in the top 1% among similar institutional departments in the world by the Essential Science Indicators (ESI) international ranking system. The School of Physics and Technology (SPT) consists of the Department of Physics, the Department of Materials Physics, the Department of Microelectronics, and a national experimental teaching demonstration center. The SPT focuses on six major areas: theoretical physics, condensed matter physics, optics, radio physics, particle physics, and nuclear physics. Minor working groups also conduct research in acoustics, atomic and molecular physics, computational physics, semiconductor physics, and nanoscience and nanotechnology. The SPT houses the Hubei Province Key Laboratory of Nuclear Solid Physics and the Ministry of Education (MOE) Key Laboratory of Artificial Microstructures. Among the current 150 faculty members, one is a member of the CAS, four are MOE Changjiang Scholars, four are National Natural Science Foundation Distinguished Young Scholars, and 11 are young 1,000 Talents Scholars supported by the national 1,000 Youth Talents Program. The SPT publishes about 200 papers per year in international journals, a number that substantially increases each year.

The SPT has established cooperative relationships with research institutes in more than 40 countries and holds several international conferences and workshops annually. Moreover, over 50 faculty members and students are invited to present at international conferences each year.

Hongxing Xu, the dean of the SPT, has published more than 190 papers (Figure 5). He has over 13,000 cumulative citations and an h-index of 56 in the Web of Science. Xu was associate editor of the journals *Nanoscale* and *Optics Express*. He has given more 70 invited presentations at international conferences and organized more than 20 international conferences and workshops. Xu was elected to CAS in 2017.

He has made his most notable contributions in the following two areas of nanoscience:

1. Single-molecule surface-enhanced Raman spectroscopy (SERS) and the plasmonic nanogap effect: Xu has demonstrated both experimentally and theoretically that in a metal nanoparticle dimer, the surface plasmons of each of two nanoparticles can couple across the

FIGURE 7. The College of Chemistry and Molecular Sciences building. Credit: Xiang Zhou

nanogap between them, confining the electromagnetic field into a tiny volume and resulting in an enormous enhancement of electromagnetism (Figure 6). One representative publication from this work has been cited more than 1,700 times (*1*) and another, which was honored by the journal *Physical Review E* as a milestone paper, was cited more than 1,200 times (*2*).

2. Surface-plasmon propagation in metal nanowires and networks: Xu has pioneered this critical area of plasmonics, performing the most systematic studies to date. He discovered the highly tuneable beating of surface plasmon modes, which is the basis for manipulating light propagation in nanowaveguides and nanocircuits. He also discovered the chiral propagation of surface plasmons in metal nanowires and the strong spin–orbit interaction of light in plasmonic nanostructures and nanocircuits. These studies have enabled the miniaturization and high-density integration of optical devices at the nanoscale, and form the basis for nanophotonic circuit development.

III. An Overview of the College of Chemistry and Molecular Sciences

The College of Chemistry and Molecular Sciences (CCMS) is one of the first chemistry institutions in China, dating back to a chemistry school founded by Governor Zhidong Zhang in 1893. When National Wuhan University was formed in 1928, the chemistry school became the Department of Chemistry in the Science and Engineering College, with Professor Xinggong Wang as its first departmental chair. Then in August 2000, Wuhan University, the Wuhan University of Hydraulic and Electrical Engineering, the Wuhan Technical University of Surveying and Mapping, and Hubei Medical University amalgamated to form what is now Wuhan University. The college was reorganized and renamed CCMS in January 2001 (Figure 7).

The department has trained and advanced numerous chemistry professionals and eminent entrepreneurs. At least 15 academicians at CAS and the Chinese Academy of Engineering have either graduated from or taught at CCMS. The college is home to a state key discipline in analytical chemistry, and provincial key disciplines in physical chemistry, organic chemistry, and polymer chemistry.

Since 2013, chemistry at Wuhan University has been ranked in the top 0.1% by ESI, and in 2017 was selected by the MOE as a key discipline in the national "Plan for the Construction of World-Class Universities and First-Class Disciplines."

FIGURE 8. Chuansin Cha, renowned electrochemist and CCMS academician. Credit: Xiang Zhou

Chuansin Cha is a fellow of CAS and an outstanding figure among the earlier generation of electrochemists in China (Figure 8). His research interests include the adsorption of surfactants on electrode surfaces, electrochemical catalysis, semiconductor electrochemistry, bioelectrochemistry, fuel cells, and chemical power sources. Cha's monograph *Introduction to the Kinetics of Electrode Processes* is one of the most influential academic works and postgraduate teaching materials in the field of electrochemistry in China.

Renxi Zhuo is a fellow of CAS. He has concentrated his research on biomedical and biodegradable polymers that can be used in biomedical applications for the controlled release of drugs and gene delivery (Figure 9). Zhuo has published more than 600 journal articles and received many honors recognizing his research achievements, including the National Natural Science Award, the National Science Congress Award, and the MOE's Natural Science Award.

Lina Zhang is a fellow of CAS and associate editor for *ACS Sustainable Chemistry & Engineering* (Figure 10). *Chemistry World* has named her "China's green chemistry vanguard." She has devoted her career to studying the green conversion of natural polymers, pioneering new technologies for dissolving intransigent macromolecules, such as cellulose, chitin, and polyaniline, in urea-based alkaline aqueous solutions with cooling, and has proposed new dissolution mechanisms for low temperatures. In 2011, she was the first Chinese scientist to receive the Anselme Payen Award from the American Chemical Society. Zhang has published 16 books and nearly 600 papers in international journals; her work has been cited over 18,000 times.

FIGURE 9. Renxi Zhuo, CCMS academician, is a preeminent expert in biomedical and biodegradable polymers. Credit: Xiang Zhou

FIGURE 10. Lina Zhang, China's foremost authority on green chemistry, the design of chemical products and processes that reduce or eliminate pollution. Credit: Xiang Zhou

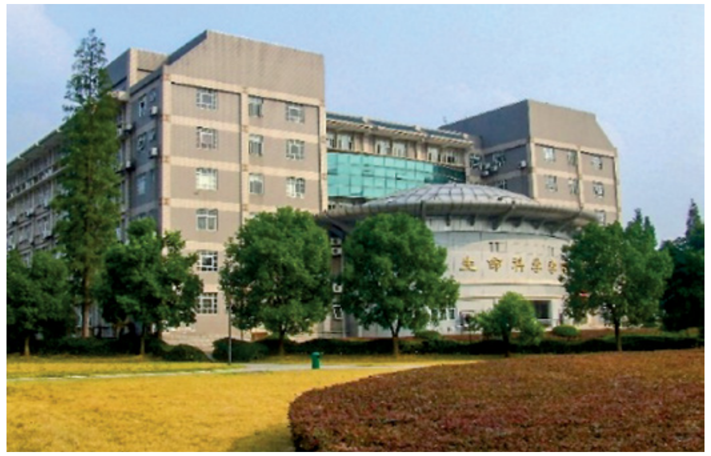

FIGURE 11. The College of Life Sciences (CLS) building, which is located at the center of the natural science complex of Wuhan University, and hosts more than 80 laboratories working on almost all aspects of biology. Credit: Jie Zhao

FIGURE 12. The famous Liangzi Lake shoreline. CLS has a National Field Station there that is at the forefront of restoring the health of lake ecosystems. Credit: Jie Zhao

IV. The College of Life Sciences

The College of Life Sciences (CLS) at Wuhan University is one of China's earliest higher education institutions dedicated to biological science. Its history dates back to 1893, when it was called the School of "*Gezhi*" ("the study of natural phenomena") (Figure 11). The current CLS consists of 109 faculty with diverse research interests, studying organisms ranging from viruses, bacteria, and yeast to plants, animals, and humans, and addressing questions spanning from molecules to cells, and from organisms to ecosystems. Among the CLS's faculty members, three are members of the Chinese National Academy of Sciences, nine are MOE Yangtze River Scholars, and 10 are Chinese National Science Foundation Distinguished Young Scholars. Several faculty members serve on editorial boards and national grant advisory boards.

The CLS currently houses the State Key Laboratories for Virology and Hybrid Rice. Its National Field Station for the Freshwater Ecosystem at Liangzi Lake is at the forefront of restoring aquatic vegetation in degraded lakes in China, and has made remarkable progress in improving the health of lake ecosystems (Figure 12). The CLS comprises seven academic departments in biochemistry, cell biology, ecology, genetics, microbiology, plant science, and virology. It also manages the China Center for Type Culture Collection, and operates a well-equipped instrument core facility, an animal facility, and a greenhouse.

FIGURE 13. Huijiang Zhao, dean of the School of Mathematics and Statistics, in a discussion with young scholars Shuyang Dai, Shangkun Weng, Zhijian Yang, Wanke Yin, and Jin Zhou. Credit: Huijiang Zhao

Over the past five years, CLS research groups have published around 900 research articles in Science Citation Index journals, with more than 60 in leading scientific journals, such as *Science*, *Cell*, *Immunity*, *Cell Host & Microbe*, *Molecular Cell*, *Developmental Cell*, and *Proceedings of the National Academy of Sciences of the United States of America*.

The CLS undergraduate program enrolls approximately 150 students per year and teaches a curriculum emphasizing both fundamental knowledge and experimental technologies. The CLS undergraduate teaching facility serves as a National Biology Experimental Teaching and Demonstration Center. The CLS graduate program currently enrolls around 900 M.S. and Ph.D. students. The CLS website (www.bio.whu.edu.cn) provides more in-depth information about the college, including highlights of each faculty member and their laboratory.

V. The School of Mathematics and Statistics

Wuhan University's School of Mathematics and Statistics (SMS) originated from the "*Suanxue*" (mathematics) school of Ziqiang College, which was established in 1893. The faculty's research interests represent almost all core areas of modern mathematics, with a particular focus on partial differential equations, complex analysis and complex geometry, probability theory, and stochastic analysis as well as applied and computational mathematics (Figure 13).

The partial differential equations research group at the SMS is investigating several questions at the vanguard of this field: the theory of microlocal analysis in partial differential equations, spectral analysis of degenerate elliptic operators, the well-posedness theory of the Prandtl equation in Sobolev and Gevrey spaces, the boundary layer and incompressible Navier–Stokes–Fourier limit of the Boltzmann equation in bounded domains, global well-posedness of complex kinetic equations in the perturbative framework, the De Giorgi conjecture, and the classification of finite Morse index solutions to the Allen–Cahn equation.

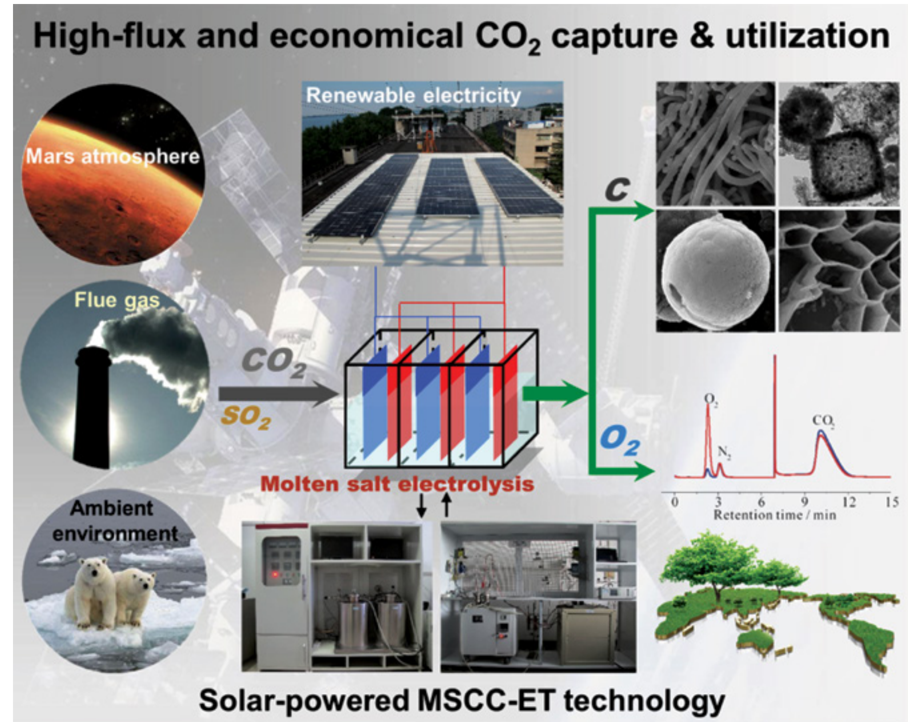

FIGURE 14. A research team led by Dihua Wang in the School of Resource and Environmental Sciences is developing a novel approach to effectively convert CO_2 into value-added carbonaceous materials and oxygen gas (O_2) through the so-called "molten salt CO_2 capture and electrochemical transformation" (MSCC-ET) process. The process, driven by renewable electricity, can capture and utilize CO_2 in a high-flux, economically and environmentally friendly way, making it a promising technology for large-scale carbon sequestration and utilization. Credit: Dihua Wang

The complex variables and complex geometry group is primarily interested in the geometric aspects of several complex variables. They have made breakthroughs in proper holomorphic mappings between bounded symmetric domains, equivalence and complex Plateau problems on codimension-two real submanifolds embedded in complex spaces, deformation problems in complex manifolds, and the Ohsawa–Takegoshi extension theorem for pseudoconvex domains as well as embedding theorems on Cauchy–Riemann (CR) manifolds.

The probability theory and stochastic analysis team focuses on singular stochastic differential equations, stochastic analysis of nonlocal operators, large deviations in Markov processes, and statistics.

The applied and computational mathematics group mainly studies multiscale modeling, simulation and analysis in materials science, ill-posed mathematical problems and their analysis and computation, problems in computational fluid mechanics and their applications, numerical solutions of partial differential equations, finite element methods, intelligent computation, and biological computation. The group has made significant progress in modeling, the algorithms and analysis of materials problems, regularization theory, calculations of ill-posed problems, and computational biology.

VI. The School of Resource and Environmental Sciences

The School of Resource and Environmental Sciences (SRES) is an intellectually vibrant, research-intensive school that focuses on geography and environmental science and engineering. The school comprises the Department of Geoinformation Science and Cartography (DGSC), the Department of Environmental Science and Engineering (DESE), and the Department of Geography and Land Resource Management (DGLRM). SRES offers seven bachelor's, seven Master's, and eight doctoral degree programs, and presently enrolls approximately 1,200 undergraduate students and 700 graduate students, including Ph.D. students. The school enjoys tremendous faculty strength with 119 full-time members. According to the *QS World University Rankings* for 2018, Wuhan's geography and environmental science disciplines ranked 150th and 251st in the world, respectively.

The geography department houses several vital research and teaching platforms: the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing; the MOE Key Laboratory of Geographic Information Systems; and the MOE International United Laboratory of Geo-Information Science (GIS). DGSC and DGLRM research is strong in GIS principles and applications, cartography and geovisualization, spatial analysis and data mining, land use and land-cover change, economic geography and regional planning, and complex geographical computation and aquatic ecosystems. Recently, the department began advancing cutting-edge research areas such as coupled human–nature system analysis, health geography, and smart cities. It is recognized worldwide for its competitive teaching and research in geospatial technology.

DESE is a central training center for talents in environmental science and engineering in China. Its signature research areas include the behavior and effects of chemical pollutants, ecotoxicology and environmental biology, environmental pollution control and restoration, environmental materials and resource efficiency, construction of a sky–earth combined platform for environmental observation and big-data processing, regional environment and risk management, mine safety, and environmental engineering. DESE has been nationally and internationally recognized for its work in the environmental field (Figure 14).

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Medical Research at Wuhan University

Wen Ye*

FIGURE 1. Wuhan University Medical School Campus.

Medicine at Wuhan University: From evolution to revolution

Medicine at Wuhan University originated with the founding of the Hubei Provincial Medical College in 1943 in Ensi, a mountainous area in western Hubei Province. The founders chose a site just dozens of miles away from one of the fiercest battlefields in the War of Resistance against Japan (the Second Sino-Japanese War, 1937–1945) to avoid Japanese airstrikes while they provided medical service to Chinese soldiers from nearby battlefields. Through tremendous effort and dedication, the founders fostered new generations of medical students, thereby saving lives both during and after the war.

After the war, the college moved to a new campus in Wuhan, settling next to the scenic East Lake. It became part of the newly integrated Wuhan University in 2000 and was renamed the Wuhan University School of Medicine (WUSM) (Figure 1). After decades of expansion, the college has become one of the leading medical schools in China. WUSM now contains more than a dozen specialized schools, institutes, and affiliated teaching hospitals, and provides comprehensive research and training programs in broad areas of medicine. WUSM employs more than 1,500 faculty members, many of whom are well-recognized scientists and physicians carrying out innovative research in medicine, pharmaceuticals, and public health. WUSM currently enrolls over 3,000 medical, pharmaceutical, public health, and nursing students, over 2,600 graduate students, and over 600 international students.

As one of the flagship universities in China, Wuhan University aims to establish a world-class medical program to meet the country's increasing challenges to human health. Toward this goal, the university has recently founded the multidisciplinary and elite Medical Research Institute (MRI) in the hopes that it will become a significant force in revolutionizing medicine at Wuhan University and in China.

The MRI: A mission to CURE

Wuhan University founded the MRI in April 2014 in the newly built Double-Lake Research Tower on the medical school campus. "Our mission is to build a world-class medical research center to carry out collaborative, multidisciplinary, and disease-oriented research to improve disease treatment and human health. We have all we need to make a difference right now," says Hong-Bing Shu, founding director of the MRI. Shu also serves as a vice president of Wuhan University and is an elected member of the Chinese Academy of Sciences (CAS).

The core goals of the MRI are to "**CURE**": **C**ollaborate across multiple disciplines, **U**ncover disease mechanisms, **R**esearch thoroughly, and **E**mpower scientists. The MRI strongly encourages its scientists to collaborate with internal colleagues, clinicians in the affiliated teaching hospitals, and scientists and clinicians worldwide. The MRI organizes many seminar series to encourage science communications and foster collaboration. It also provides internal funding and administrative support to facilitate collaborative activities. Research activities conducted at the MRI accelerate the understanding of the molecular basis of human diseases and translate discovery into effective prevention and treatment. The MRI has created an environment in which scientists can take high risks, dare to test bold ideas, and fully use their talents to make fundamental discoveries.

In the four years since its establishment, the MRI has successfully recruited 17 new principal investigators (PIs) in addition to the nine founding PIs who were selected from other institutes within the university. The diverse research interests of these PIs range from infection and immunity, cancer, genome editing, and stem cell/regenerative medicine to neurodegenerative diseases and metabolic disorders. The MRI continues to rapidly expand, actively recruiting outstanding young scientists from all over the world who are dedicated to dissecting the molecular and cellular mechanisms of human diseases and forging new paths to next-generation diagnoses, disease prevention, and therapeutics. "At this point, we are actively recruiting creative young PIs in all fields of biomedicine. The most important criterion is whether the candidates have an outstanding track record and great potential for a successful scientific career," says Shu, who envisions that the MRI will employ over 100 PIs by 2025. The university plans to build a second adjacent biomedical research tower to meet the demands for growth.

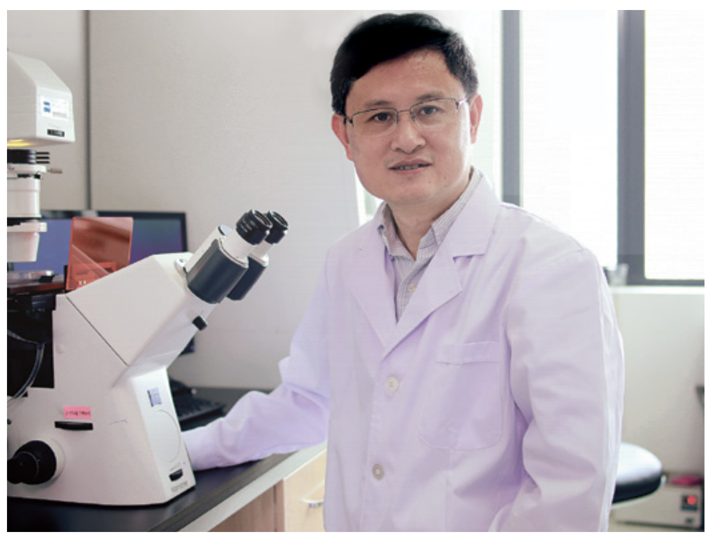

FIGURE 2. Hong-Bing Shu, director of the MRI, is committed to building a world-class medical research center.

PHOTOS: WUHAN UNIVERSITY

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FIGURE 3. The Shu group has identified key components of the innate antiviral response.

PHOTO: WUHAN UNIVERSITY

Innate immunity: The beautiful pathway

Shu is a well-recognized scholar in the field of innate antiviral immunity and inflammation (Figure 2). "It has been a long pathway for me to be here to push the MRI forward," he says. Shu was born in a small mountain village in Chongqing, China. His mother died of a fever at age 32 because she lacked medicine, an event that has driven him to pursue first-class biomedical research. Shu received his B.S. in biology at Lanzhou University and his M.S. in cell biology at CAS and Peking Union Medical College in China. He received his Ph.D. in cell and developmental biology from Emory University in Atlanta and performed his postdoctoral training at Tularik (now Amgen) in South San Francisco, California, with David Goeddel, a legendary molecular biologist and biotechnologist. Shu continued his scientific career first as an assistant professor and then associate professor at the integrated Department of Immunology at National Jewish Medical and Research Center (now National Jewish Health), University of Colorado Health Sciences Center in Denver. With a strong desire to contribute to research and education in China, he started to work as a Cheung Kong Scholar professor at Peking University in late 1999. In 2005, he was recruited by Wuhan University to serve as dean of the College of Life Sciences. In 2014, he started a new venture as the MRI's founding director.

For many years, Shu has been dedicated to understanding how signaling pathways are activated and regulated in infectious, inflammatory, and immunological diseases. In the 1990s, one of the hottest topics in the biomedical sciences was deciphering how tumor necrosis factor (TNF), a proinflammatory cytokine, induces apoptosis (an active cell-death process) and inflammation. While a postdoc in the Goeddel lab, Shu carried out elegant biochemical experiments to demonstrate how upon TNF stimulation, downstream signaling components are sequentially recruited to the TNF receptors, now a classical model for TNF receptor–mediated signaling. While an independent investigator at the National Jewish Medical and Research Center, he identified a novel TNF family member called TALL-1 (TNF- and APOL-related leukocyte-expressed ligand 1) (*1*). After his group published this discovery, several other groups reported on the same molecule, calling it Blys/BAFF/THANK. The U.S. Food and Drug Administration (FDA) has approved a TALL-1/Blys/BAFF-targeting antibody, developed by Human Genome Sciences and trademarked as Benlysta (belimumab), for treating lupus and related autoimmune diseases.

Since returning to China, Shu's group has been investigating how the human body clears invading viruses. The innate immune response is the first line of host defense against pathogen invasion. After host cellular receptors detect viral nucleic acids, host cells initiate a series of signaling cascades or pathways that ultimately induce the expression of downstream antiviral genes, such as type I interferons and inflammatory cytokines. These proteins inhibit viral replication and clear viral infected cells, leading to an innate antiviral immune response. In 2005, the Shu group at Peking University identified a protein called VISA (virus-induced signaling adaptor), which acts as a relay station in the transmission of a signal that elicits an innate immune response to RNA viruses (*2*). The identification of VISA (also called MAVS, IPS-1, and Cardif) was a landmark for understanding the molecular mechanisms of innate immune response to RNA viruses, and in 2005 was selected as a breakthrough in cell signaling by *Science*. The *Molecular Cell* paper reporting the discovery of VISA has been cited more than 1,000 times by follow-up studies.

After joining Wuhan University, the Shu group continued to make breakthroughs in innate immunity. In 2008, they used expression screening to identify a novel protein called MITA (mediator of IRF3 activation) and demonstrated its critical role as a signaling component in the innate immune response (*3*). In addition to mediating the innate immune response to RNA viruses in certain cell types, MITA is an essential adaptor protein required for the innate immune responses induced by cytosolic DNA from viruses, bacteria, or damaged and leaky cells. It has now been well established that MITA [also identified by Glenn Barber's group at the University of Miami and named STING (stimulator of IFN genes)] is the critical adaptor protein in innate immune signaling pathways triggered by DNA pathogens or DNA from damaged cells. The *Immunity* paper reporting the discovery of MITA has been cited around 500 times. Because MITA/STING is also vital for the immune response to damaged DNA in cancer cells, several large pharmaceutical companies are developing MITA/STING activators as cancer immunotherapy drugs.

After identifying VISA and MITA, the Shu group went on to discover essential mechanisms for how the innate immune response to viruses is efficiently mounted upon viral infection and arrested before immune damage occurs (Figure 3). Their results have been extensively published in prestigious journals in the field, such as *Immunity*, *Nature Immunology*, *Cell Host &*

FIGURE 4. Guoliang Qing (second row, third from left) and Hudan Liu (front row, third from right), who work on cancer metabolism and leukemia, respectively, were the MRI's first recruits.

PHOTO: WUHAN UNIVERSITY

Microbe, the *Journal of Experimental Medicine*, and *Proceedings of the National Academy of Sciences of the United States of America*. Over his 30-year scientific career, Shu has published 147 papers in peer-reviewed journals, which have been cited more than 10,000 times. He has won numerous scientific awards, including two Chinese National Natural Science Awards. Because of these remarkable contributions, Shu was elected a member of CAS in 2011 and of the Academy of Sciences for the Developing World (TWAS) in 2012.

Beyond his accomplishments as researcher and administrator, Shu's primary mission is to be a qualified mentor for young students and scholars. "I attempt to take the responsibility to guide the trainees toward a successful scientific career, which is extremely important for a huge developing country like China," he says. Among the trainees from his group, more than 20 have become faculty members in prominent universities or institutes in China. In 2015, he was a recipient of the *Nature* Award for Mentoring in Science from the *Nature* Publishing Group, which he considers the most meaningful award he has ever received.

Bo Zhong, one of Shu's most successful Ph.D. students, recalls, "I was a college student majoring in English who then became interested in biological sciences. It was extremely lucky that Dr. Shu took me into his lab for graduate study even though I did not have much background in biology." Zhong identified MITA and published two first-author papers in *Immunity* during his graduate studies. After his postdoctoral training in Chen Dong's lab at the University of Texas MD Anderson Cancer Center in Houston, Zhong received China's 1,000 Talents Distinguished Young Scholar Program Award and joined the MRI as a PI in 2014. Diverting from his early studies, Zhong is now working on posttranslational modifications that regulate innate and adaptive immune responses, as well as tumor metastasis.

The MRI continues to build its strength in the areas of innate immunity and virus–host interactions. In addition to recruiting Shu and Zhong, it recently recruited Ke Lan to head the State Key Laboratory of Virology (SKLV). Lan also serves as an associate director of the MRI and has a critical role in recruiting new PIs for the SKLV and MRI. Before joining Wuhan University, Lan was already well known for his work on the Kaposi's sarcoma virus's evasion of the host immune response and its ability to cause tumors. Bishi Fu, a productive scholar from Harvard Medical School, specializes in the virus–host interactome network and innate evasion strategies of both DNA and RNA viruses, and in 2018 became the most recent addition to the MRI's innate immunity team.

Cancer biology: Exploring its many facets

Myc, a well-known oncogene, is a potent transcriptional factor involved in multiple cellular processes, such as cell cycle and metabolism. Dysregulation of Myc is a frequent driver of tumorigenesis, making it an attractive therapeutic target. With an innovative perspective gleaned from a childhood solid-tumor model, Guoliang Qing was one of the first PIs recruited to the MRI in 2015 (Figure 4). He uncovered a previously unsuspected mechanism by which Polo-like kinase 1 (PLK1) regulates Myc (*4*). The Qing group is also interested in how tumor cells develop a variety of metabolic strategies to maintain exacerbated growth and survival, and has demonstrated that Myc acts through multiple mechanisms to stimulate glucose and glutamine uptake in tumor cells. More recently, his group has reported a novel role for Myc in enhancing essential amino acid (EAA) uptake from the extracellular milieu through activation of an EAA transporter. The elevated EAAs in turn stimulate Myc translation, leading to Myc-dependent transcriptional amplification. These findings reveal a feed-forward regulatory circuit that underlies EAA metabolism, Myc deregulation, and tumorigenesis. Qing's contributions to cancer metabolism research are well recognized, as evidenced by his National Outstanding Young Scholarship Award.

Cancers are complicated diseases with many facets. New fundamental discoveries, such as their underlying cellular and molecular pathways, the structures and functions of biomolecules, and the epigenetic regulation of cancer progression, can align pieces of the cancer puzzle. To this end, Qing helped to recruit five talented young investigators to the newly established Cancer Biology Center in the MRI. Two of them are recipients of China's prestigious 1,000 Young Talents Scholarship. Haojian Zhang, previously trained at the Dana-Farber Cancer Institute of Harvard Medical School, was recruited to the MRI to focus on the role of cancer stem cells in the pathogenesis of myeloid leukemia. Qiang Chen, a talented young scientist recruited from the University of Michigan, works on glycosylation and tumorigenesis. Other faculty members include Hudan Liu, Youjun Li, and Cheguo Cai, who have strong interests in the pathogenesis of pediatric acute leukemia, hepatic cancers, and breast cancers, respectively. The MRI is a catalyst for multidisciplinary collaboration and creative thinking in the study of basic cancer biology and clinical oncology. Scientists at the MRI work with each other and with physicians at the neighboring university-affiliated Zhongnan and Renmin Hospitals.

The CRISPR hope: From Boston to Wuhan

CRISPR (clustered regularly interspaced short palindromic repeats) is a simple but remarkably potent genome-editing technology that allows for precise and directed changes to genomic

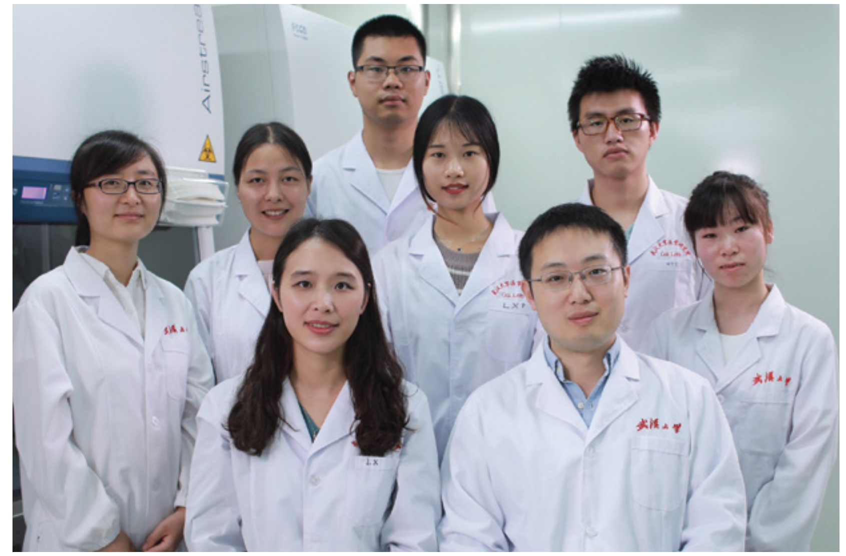

FIGURE 5. Hao Yin and Ying Zhang (front row, right and left) have brought the hope of new, CRISPR-mediated therapies from Boston, Massachusetts to Wuhan.

PHOTO: WUHAN UNIVERSITY

DNA. This revolutionary technology has transformed many areas of research in biomedicine and has raised hopes for new treatments for a wide range of inheritable genetic disorders, such as cystic fibrosis, Duchenne muscular dystrophy, and sickle cell disease. However, many hurdles remain on the path to adapting CRISPR for therapeutic applications. Hao Yin and Ying Zhang, who have recently joined the MRI, aim to solve pressing challenges in using CRISPR for in vivo and ex vivo therapies, respectively.

Before joining the MRI, Yin was a research scientist at the Massachusetts Institute of Technology (MIT) and then at Vertex Pharmaceuticals in Boston, Massachusetts. Yin and his collaborators demonstrated that CRISPR could correct genetic mutations in vivo to reverse the lethal phenotype of an inherited disease (*5*). This proof of concept provided the first direct evidence that CRISPR can potentially be used to improve human health. Confident that CRISPR could edit genomes of somatic cells, he worked with his collaborators to apply CRISPR to generating a mouse cancer model, thereby establishing a remarkable new avenue for the study of cancer genomics (*6*).

When applying CRISPR to therapeutics, one of the most significant obstacles is the difficulty of delivering the massive CRISPR machinery into target cells at the appropriate time. Yin and his colleagues have made tremendous progress in solving this challenge, as evidenced by two of their recent studies (*7, 8*). In these studies, they applied cutting-edge in vivo messenger RNA (mRNA) delivery technology to efficiently deliver Cas9 protein into the liver, where it efficiently corrected a defective gene (*7*). They also engineered an enhanced single-guide RNA (e-sgRNA) through structure-guided chemical modifications (*8*). A single dose of e-sgRNA and Cas9 can efficiently edit a disease-prone gene in vivo (*8*). The technologies they developed may lead to a wide range of applications, such as depleting mutated proteins, lowering cholesterol levels, or eliminating hepatitis virus infections.

While Yin's group focuses on the delivery of CRISPR into tissues in vivo, Ying Zhang works on adapting CRISPR for ex vivo therapies (Figure 5). Zhang aims to correct genetic mutations in hematopoietic stem cells (HSCs) with the goal of treating such blood-related diseases as primary immune deficiencies and storage and metabolic disorders. The use of allogeneic HSC transplantation to treat genetic blood disorders has become the standard of care, but is limited by the availability of matched donors and the potential for graft-versus-host diseases. CRISPR-mediated genome editing using autologous HSCs can avoid these limitations and thus brings new hope for those suffering from these devastating diseases. Before joining MRI, Zhang was an early founding scientist and a group leader at CRISPR Therapeutics in the Boston area, where she led a preclinical program to develop autologous HSC therapy for treating severe combined immunodeficiencies (SCIDs). Zhang plans to continue translational research in China, where patients desperately need effective new medicines that can be developed through cutting-edge research and innovations.

Outstanding people and infrastructure afford an advantageous scientific environment. Yin and Zhang have found the administrative team at the MRI to be highly efficient and friendly, making the institute run smoothly. Fortuitously, about half of their faculty colleagues are from the Boston area, and the other half from top labs in the United States and Europe. Yin and Zhang have decided to set up side-by-side labs at the MRI. They have found the recruited graduate students and postdoctoral fellows to be genuinely dedicated and enthusiastic about learning. "It is really exciting to work with students," says Zhang. "We will continue our exploration in genome editing and bring hope to patients in China and the rest of the world."

The MRI has also been advancing in other critical areas of biomedical research. Wei Jiang, one of the first PIs recruited, works on epigenetic regulation of stem-cell differentiation. The MRI recently recruited Wei Song from Harvard Medical School, who uses divergent animal models, including *Drosophila* and mouse, to study human metabolic diseases. Yanxun Yu and Yan Zhou employ *Caenorhabditis elegans* and mouse models to investigate neuronal sensing of environmental changes and neuronal development, respectively. Youngnam Jin, a Korean native who trained in the United States, recently joined the MRI to investigate disease mechanisms using Zebrafish models. Rui Xiao, who recently completed his postdoctoral training with Xiang-Dong Fu at the University of California, San Diego (UCSD), will continue his studies of RNA biology. Kai Jiang, a cell biologist recruited from the Netherlands, investigates microtubule assembly and dynamics. The MRI will continue recruiting more outstanding young PIs from all over the world to strengthen and complement its current research programs.

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The Institute of Technological Sciences

Sheng Liu*, Chengliang Sun*, and Qian Peng*

The Institute of Technological Sciences (ITS) was founded by Wuhan University (WHU) in 2017 and is independent of but directly affiliated with the university. Professor Sheng Liu, the dean of the School of Power and Mechanical Engineering, is the executive director. The institute focuses on pervasive problems that are hindering technological progress, as outlined by the documents *Chinese National Science and Technology Major Projects*, the *Special Project for the Internet of Things,* and the *Guideline for the Promotion of the Development of the National Integrated Circuit Industry.* These challenges are: (1) multiphysics, multiscale modeling and simulation, and large-scale scientific computing; (2) the experimental verification of models and simulations in varying temporal and spatial scales; and (3) sensors for onboard diagnostics in high-end smart equipment that require the development of new functional materials.

The mission of the ITS

The scientific research at the ITS is cross-disciplinary and based on the engineering disciplines of WHU. The institute's mission is to contribute to academics and industry in China by developing innovative and disruptive technologies and intellectual property, attracting a new pool of talent to introduce new ideas and techniques to the ITS engineering community, and helping companies to be technologically competitive (Figures 1 and 2). The institute's major areas of focus are advanced manufacturing, alternative energy sources, advanced materials, and aerospace engineering (Figure 3).

The ITS offers a unique scientific research platform that appeals to world-class scholars, researchers, and young talents who do not fit the profile of a traditional engineering major, yet are outstanding in their academic fields. The institute has attracted a group of experts, most of whom have doctoral degrees from internationally renowned universities such as Stanford and Tsinghua. Some are members of the Chinese Academy of Engineering, some are professors from the Ministry of Education's Changjiang Scholars program, and others are from the National Outstanding Young Scientists, 1,000 Talents, and 1,000 Young Talents programs. One expert is a National Natural Science Foundation of China (NFSC)/White House Presidential Faculty Fellow.

The ITS has a flexible policy for recruiting talent, educating undergraduate students, and developing its disciplines to cultivate graduate students with cross-disciplinary capabilities. One way the institute is establishing the university's reputation in engineering is through its "development zone" for emerging disciplines, which is advancing the frontiers of technology and engineering in critical scientific areas. The ITS has also established the "School of Hong Yi," a special class comprising students with the highest entrance examination scores in significant engineering fields, such as advanced manufacturing.

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FIGURE 1. The 2018 International Interdisciplinary Forum.

FIGURE 2. The 2018 Institute of Technological Sciences (ITS) Summer Camp

PHOTOS: WUHAN UNIVERSITY

The development goals of the ITS

The ITS is continually improving its staffing, facilities, and reputation. Among its development goals for 2021 are to recruit 30–60 outstanding principal investigators; to achieve breakthroughs in fundamental research and applied sciences; to win national and international awards for the invention of new technologies; and to launch well-equipped research facilities and a scientific computing platform.

Discipline orientation

The ITS's principal research areas are described below, followed by their subspecialties. Each research area is cross-disciplinary and integrates some combination of chemistry, physics, mechanics, electronic information, automation, computer technology, and materials science.

1. Advanced manufacturing:

- **Electronic manufacturing**–the production of semiconductor-based electronics, flexible electronics, and femtosecond laser-based micro–nano devices, including microelectromechanical systems (MEMS), packaging materials, and processes;
- **Intelligent manufacturing**–the integrated design, production, and testing of smart equipment for the "Internet of Things";
- **Robotics**–especially the development of novel sensors and other critical technologies for service and industry;
- **3D printing**–especially the generation of high-precision printing equipment and new printable materials.

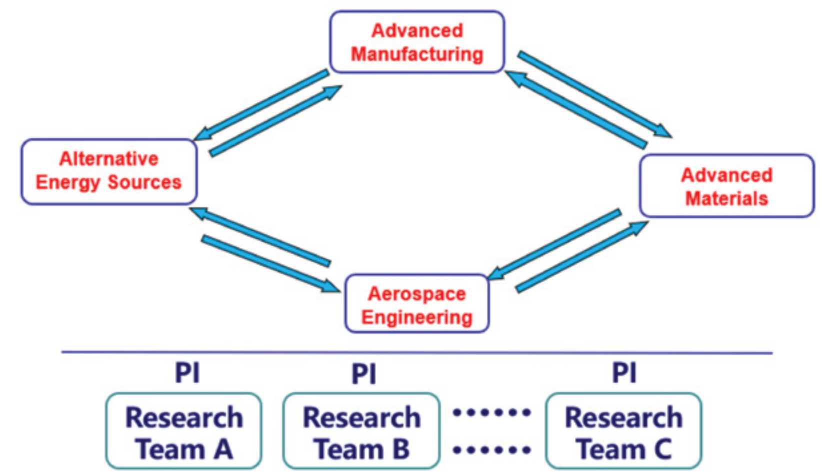

FIGURE 3. The main research areas targeted by the ITS. PI, principal investigator.

2. Alternative energy sources:

- **Shale gas**–especially the creation of a systematic shale gas geological policy system for China to provide independent shale gas–mining equipment and technologies for Chinese geological systems;
- **Renewable energies and advanced energy storage**–including the exploitation of ocean and environmental energy and the development of new technologies for high-density and low-cost energy storage and supercapacitors;
- **Power electronics**–the development of technologies ranging from bulk crystals to packaging systems, to reduce new-energy costs and improve the quality and efficiency of power conversion, especially in ultrahigh-voltage-based smart grids and electric vehicles.

3. Advanced materials:

- **Bioinspired materials**–the study of the optimum bionic design to create new multifunctional smart materials and systems;
- **Intelligent composite materials**–an applied-research area focusing on high-strength structural composite materials and smart composite materials and systems;
- **Nanomaterials**–their development, synthesis, and application, with real-time monitoring of low-dimensional materials and single-crystal thin films.

4. Aerospace engineering:

- **Laser-strengthened materials and laser processing**–the development of technologies for laser material surface-strengthening and femtosecond laser-based aerospace machining, such as turbine-blade cooling-hole processing;
- **Sensing in extreme environments**–the improvement of aero-engines through the measurement of pressure, temperature, vibration, and gas concentration using modalities such as surface-acoustic waves, piezoelectricity, ruggedized transducers, and lasers;
- **Reliability assessment in extreme environments**–the evaluation of materials under extreme conditions, such as ultra-high and -low temperatures and high irradiation, by physical-property testing, numerical modeling, and evaluating reliability virtually.

The School of Power and Mechanical Engineering

Intelligent ultrasound inspection technology and its application to industrial nondestructive testing

Xiaohong Li* and Jun Zhang*

The ultrasonic inspection of industrial components with complicated geometries and heterogeneous materials has been a significant challenge to the nondestructive testing (NDT) and monitoring of the health of major equipment. To address this gap, the School of Power and Mechanical Engineering has developed an innovative ultrasonic-testing system with intelligent procedure design, data acquisition, and analysis modules to maintain the security of new-generation industrial equipment.

The school established application-oriented acoustic models as the theoretical basis for a method to analyze the propagation

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FIGURE 1. Ultrasonic inspection equipment for control rod. Credit: Xiaohong Li, Jun Zhang

FIGURE 2. Ultrasonic inspection equipment for reactor pressure vessel. Credit: Xiaohong Li, Jun Zhang

behavior of ultrasonic waves and how they interact with defects. The scientists developed a process-planning module based on probability-of-detection theory that optimizes the inspection parameters as sections are changed, and commands a real-time adjustment of inspection strategy during the scanning process. They developed more than 80 types of automated-scanning devices with flexible-fixture tools to fit various industrial components. They also established a data-analysis module based on ultrasonic image reconstruction and intelligent recognition algorithms for automatic evaluations.

The system has been widely used in industry for a variety of applications, such as the inspection of the Taishan nuclear power plant, the first commercially operated plant that uses third-generation nuclear technology. Some of its complex components, such as the sealing weld of the control rod drive mechanism and the turbine of the hydropower plant unit, both of which were considered unsuitable for ultrasonic testing, have been efficiently and reliably inspected using the system (Figures 1 and 2).

Enhanced shale gas recovery using supercritical carbon dioxide

Xiaohong Li* and Yong Kang*

Shale gas is an unconventional gas that is found trapped within shale formations. It is estimated that China has the world's largest shale gas reserves, with technically recoverable reserves of 21.8 trillion m^3. Nonetheless, a significant gap between shale gas production and the growing demand for natural gas is becoming increasingly evident. Therefore, it is crucial to improve the production of shale gas.

In China, achieving high yields of shale gas through commercial enterprises has been hindered by the inaccessibility of the country's deep underground reservoirs, and the low permeability and porosity of shale. Highly advanced technologies in horizontal well drilling and hydraulic fracturing (fracking) technology have enabled the exploitation of shale gas; however, achieving satisfactory gas output has remained highly problematic. One limitation is the wide distribution of shale gas in water-scarce regions, such as Sichuan Province and the Ordos Basin, which hinders large-scale industrial shale gas recovery. Yet in areas where water is available, aqueous fracturing also leads to problems, potentially damaging the shale reservoir because of the high clay content of the soil, which can limit well production and slow the rate of production.

To address these challenges, Xiaohong Li, an academician of the Chinese Academy of Engineering (CAE) from Wuhan University, proposed a novel method to enhance shale gas recovery by using supercritical carbon dioxide (SC-CO_2) as a nonaqueous fracturing fluid (Figure 1). SC-CO_2 is a supercritical state of CO_2, where its temperature exceeds 304.1 K and its pressure exceeds 7.38 MPa. SC-CO_2 has some unique and interesting properties, such as low viscosity and high permeability.

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Li and his team proposed a method for identifying geological "sweet spots" of shale gas and established theoretical models of SC-CO_2 fracturing and CO_2-CH_4 adsorption–desorption and replacement. In particular, they developed process technology and experimental equipment for SC-CO_2 nonaqueous fracturing, which achieved a series of outstanding results.

Based on their theories and experimental results, in June 2017 the first SC-CO_2 fracturing experiment with continental shale gas was successfully conducted in the Yan-2011 shale gas well in Shaanxi Province, China. The success of this project showed that SC-CO_2 fracturing technology can effectively form a complex fracture network and increase stimulated reservoir volume, as compared to the results of conventional hydraulic fracturing. After SC-CO_2 fracturing, a continuous test of flowback indicated that the CO_2-retention rate was 39.5%. As compared to conventional hydraulic fracturing, the shale gas production rate using SC-CO_2 fracturing was increased 1.5 times. The test results show that SC-CO_2 fracturing for shale reservoirs is an efficient method for enhancing gas recovery, reducing water consumption, and achieving geological sequestration of CO_2. As of June 2018, SC-CO_2 fracturing has been applied in three other shale gas wells. Efficient shale gas reservoir reconstruction and CO_2-geological storage were also achieved in these wells, confirming that the theories and technologies developed by Li and his group have led to a breakthrough in improving continental shale gas recovery, CO_2 utilization and geological storage, and water conservation. This method of shale gas recovery is not only superior in its efficiency and environmental sustainability, but also paves the way for other unconventional methods of natural gas exploitation.

Nine universities and research institutes have contributed to the project: Wuhan University; Chongqing University; the China University of Petroleum (Beijing and East China); Southwest Petroleum University; Shaanxi Yanchang Petroleum (Group) Corp. Ltd.; the Sinopec Geophysical Research Institute; the Sinopec Jianghan Oilfield; and the Chinese Academy of Science's Institute of Rock and Soil Mechanics. This project is financially supported by the National Key Basic Research Program of China (No. 2014CB239200).

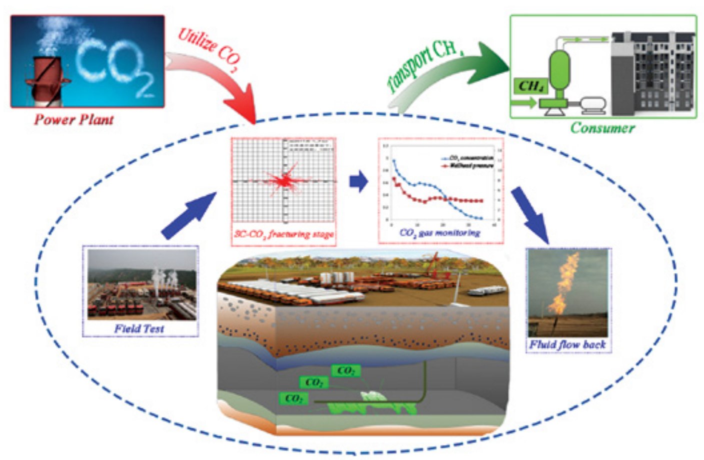

FIGURE 1. Schematic diagram of supercritical carbon dioxide (SC-CO_2) fracturing in shale gas exploitation. Credit:Xiaohong Li, Yong Kang

The School of Electrical Engineering

Electrical engineering research

Xiaoming Zha*, Jian Xu, Meng Huang*, Zhanhui Yang

The origins of Wuhan University's School of Electrical Engineering (SEE) can be traced to 1934, when National Wuhan University launched a department of electrical engineering, which was conformed to other schools due to a national department arrangement in 1953. In 1959, the Wuhan Institute of Hydraulic and Electric Engineering also established a department of electrical engineering that was later renamed the "Third Department" in 1964 and the "Department of Electrical Engineering" in 1977. In 2000, the department was named the "School of Electrical Engineering at Wuhan University," which constituted a reestablishment of Wuhan University's electrical engineering department, upon the amalgamation of the former Wuhan University, the Wuhan University of Hydraulic and Electrical Engineering, the Wuhan Technical University of Surveying and Mapping, and Hubei Medical University. It is one of the key schools funded by the former Ministry of Power and is part of the 211 Project and the 985 Project.

FIGURE 1. Testing of an artificial lightning strike on transmission lines.

The SEE practices advanced educational methods and rigorous teaching, and is considered the cradle of senior-talent training for China's electric-power industry. It attaches great importance to the improvement of teaching quality, as evidenced by the caliber of its educators and their spirit of innovation as well as the strong theoretical training and achievements of its students. By December 2018, the school had graduated more than 30,000 students with bachelor's, Master's, or doctoral degrees. Most graduates take on technical, leadership, or business roles in the power industry or become academic leaders in universities and research institutes. Many graduates are considered pioneers in Chinese academic science: Xiaoxiang Zhang is also known as the "Father of Chinese Computers"; Ouyang Yu is the chief designer of the Qinshan nuclear power plant, the first nuclear power plant designed by Chinese engineers; Daguang Yu is a pioneer of detonation-control and telemetry systems for China's nuclear weapons; and Yuan Pan is the primary inventor of nuclear-fusion electromagnetic engineering and large-scale pulsed-power technology.

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FIGURE 2. The Key Laboratory of High-Voltage Engineering and Insulation Technology.

One of the SEE's principal interests is lightning protection and grounding technology, with ongoing research on lightning phenomena and the laws governing the flow of ground current in the earth. Significant figures in this area are Guangrun Xie and Cixuan Chen, who enjoy their reputation as the "Fathers of Lightning Protection and Grounding Technology." The lightning group works on the physical characteristics of lightning as well as the protection of power systems and large buildings. Their studies include observations of natural lightning, detecting lightning in transmission lines, conducting rocket-triggered lightning tests and simulation tests to determine lightning-strike characteristics in transmission lines (Figure 1), and the numerical simulations for pilots when encountering a lightning strike. They have also developed advanced methods to study complex soil-resistivity measurement and modeling, direct-current distributions in wide-area land transmission systems, and the design of grounding for composite soils.

The SEE has solved a number of pressing lightning-related engineering issues. These include the lightning-protection design of a 1,000 kV AC and ±800 kV DC ultrahigh-voltage transmission line and high-speed railway station, lightning protection for the Three Gorges Project, and the mitigation of the influence of transmission lines and of DC-grounding poles on the parallel oil and gas pipelines in the corridor. Consequently, the SEE occupies a leading international position in lightning protection and grounding technology.

The SEE is home to the Key Laboratory of High Voltage Engineering and Insulation Technology (Figure 2), the Research Center for Lightning Protection and Grounding-Technology Engineering (affiliated with the Ministry of Education), and the Wuhan Center of Lightning-Protection-Equipment Quality Testing and Supervision. The school also operates a continuously adjustable, outdoor substation of 0–220 kV for experimentation; a high-voltage, experimental facility (the largest among Asian universities); and a high-voltage, large-capacity, circuit-breaker test bench. In addition, it also hosts a training center for its real-time, power-system digital simulator, as well as a smart-grid research center that it operates with industrial cooperation. These facilities provide a strong foundation for high-level teaching, academic research, and talent cultivation at the undergraduate, graduate, doctoral, and postdoctoral levels.

China's recent reforms in energy technology and policy shifts toward low carbon have encouraged innovative technologies such as artificial intelligence, electric vehicles, demand response, and renewable energy. The School of Electrical Engineering will continue to be guided by China's strategic needs for renewable energies, and will continue to conduct leading-edge research on the areas of overvoltage protection, power systems, and power electronics.

PART 4: State Key Laboratories at Wuhan University

The State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing

Mi Wang[1], Yongjun Zhang[2], Yanfei Zhong[1], Xin Huang[2], Xiangyun Hu[2], Nengcheng Chen[1], Bisheng Yang[1], Jingbin Liu[1], Huanfeng Shen[3], Zeming Wang[4], Liqiong Chen[1*], Jinglin He[5], and Steve McClure[1]

Founded in 1989, the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS) of Wuhan University is the first institution of its kind in China. LIESMARS focuses on the integration of fundamental and applied research, with the aim of creating effective mechanisms and systems for scientific and technological innovations that will result in concrete achievements. The laboratory is world renowned for its training of highly skilled talent and its scientific research in surveying, mapping, and remote sensing.

LIESMARS is affiliated with a cluster of Wuhan University research and educational institutions that specialize in surveying, mapping, and remote sensing, thus constituting one of the world's largest and best-integrated educational programs in these fields. In addition to LIESMARS, the complex consists of the School of Geodesy and Geomatics, the School of Remote Sensing and Information Engineering, the School of Resource and Environmental Sciences, the Global Navigation Satellite System (GNSS) Research Center, and the Chinese Antarctic Center of Surveying and Mapping.

In 2012, Wuhan University won the Geospatial World Leadership Award in the Geospatial World Forum, in recognition of its distinguished contributions to the Fundamental Research and Capacity Development in the field (Figure 1). In 2017 and 2018, Wuhan University's remote sensing discipline was ranked first in Shanghai Ranking's Global Ranking of Academic Subjects (Figure 2).

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FIGURE 1. Wuhan University won the Geospatial World Leadership Award in Fundamental Research and Capacity Development in Geospatial Sciences in the 2012 Geospatial World Forum. Credit: Lite Shi

1. General overview of LIESMARS

1.1. Research fields

LIESMARS' major research fields include aerial and space photography, remote-sensing (RS) information processing, geospatial information systems (GIS) and services, 3S (GIS-RS-GNSS) integration and network communication, navigation and location-based services, cartography, and polar geomatics. These research fields are organically integrated based on the theories and methods of earth-observation systems, remote sensing data, spatial information, geoscientific knowledge, and network services. Areas of specialization include high-precision orbit and attitude determination, multiplatform, multisensor Earth-observation systems, high-precision automated photogrammetry and remote-sensing data processing, automated extraction and intelligent interpretation of remote-sensing information, and integration and intelligent services for geographic information and navigation location information. The research provides fundamental support and applications that contribute to social and economic development and the advancement of related disciplines.

1.2. International academic participation

LIESMARS researchers serve the geospatial community in many capacities. More than 20 have served in international academic organizations or on the editorial board of well-known international journals. Li Deren was awarded an honorary doctoral degree by ETH Zurich, was the former chairman of Commissions III and VI of the International Society for Photogrammetry and Remote Sensing (ISPRS), and was named an Honorary Member of ISPRS, a distinction given to a maximum of 10 living scientists. Furthermore, he was also the first president of the Asia Geographic Information System (GIS) Association. Other notable contributors are Gong Jianya, who chaired ISPRS Commission VI; Liu Yaolin, associate chair of the International Cartographic Association (ICA); Du Qingyun, who chairs the theoretical commission of the ICA; Liu Jingnan, who serves on the board of the International GNSS Service; and Li Jiancheng, who serves on two committees of the International Association of Geodesy (IAG).

FIGURE 2. Li Deren attending the 22nd International Society for Photogrammetry and Remote Sensing (ISPRS) Congress, where he was awarded the title of "Honorary Member," the highest honor given by ISPRS, and awarded to only 10 living scientists (Melbourne, Australia, 2012). Credit: Lite Shi

FIGURE 3. On June 2, 2018, the Luojia-1A scientific experimental satellite designed by LIESMARS was successfully launched from the Jiuquan Satellite Launch Center in China. Credit: Lite Shi

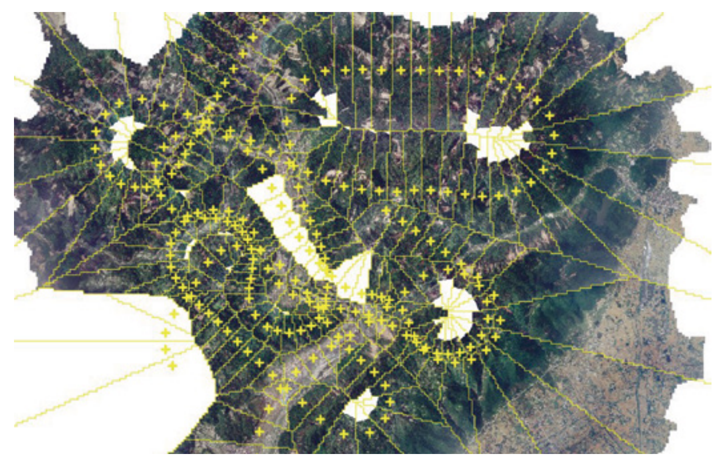

FIGURE 4. The digital photogrammetry grid-processing system DPGrid was widely used for emergency responses and played an important role in emergency monitoring after the Wenchuan earthquake. Credit: Yongjun Zhang

1.3. Education

LIESMARS and its related schools enroll both doctoral and Master's students. Graduate students from LIESMARS have gone on to become part of the elite backbone of many of the world's leading universities and research institutions, receiving praise and welcome along the way.

LIESMARS has launched joint training projects with more than 30 well-known universities in the United States, Germany, Britain, France, Canada, the Netherlands, Australia, Singapore, and Finland, among other countries, and has seen its enrollment of international students increase each year.

Every year, LIESMARS holds the International Geoinformatics Doctoral Forum and Summer School. Since 2011, Wuhan University, the Moscow State University of Geodesy and Cartography, the Siberian State University of Geosystems and Technologies, and Tongji University have taken turns holding the annual "3S" Student Summer Seminar.

1.4. Research facility

LIESMARS has built an array of facilities for training and scientific research. They are running a satellite ground station at Wuhan University as well as two testing sites (Figure 3), the laser optics testing ground, and the simultaneous localization and mapping (SLAM) indoor calibration site.

The laboratory has also built an atmosphere–land–water quantitative remote-sensing ground-verification platform, with advanced research equipment that includes multiple hyperspectral measuring systems for visible/near-infrared/infrared light, thermal infrared cameras, 16/24 channel video spectral systems, digital aerial cameras, ground-based light detection and ranging (Lidar), unmanned aerial vehicle (UAV) laser point-cloud measuring systems, photogrammetry workstations, an automatic corner reflector, a radiation calibrator, and microwave radiometers.

2. Scientific research

2.1. Aerial and space photogrammetry

Measurement-error processing is not only a basic theoretical problem in the surveying and mapping field, but is also a challenging technical problem that has restricted the productivity of surveying and mapping projects. To tackle this problem, Li Deren has proposed a theory for the discriminability of accidental error, systematic error, and gross error, and a method for detecting systematic error and gross error. The error differentiability theory he proposed was lauded as "a solution to a 100-year-old problem of surveying." It is referred to as the "Li Deren method" in international photogrammetry circles.

Zhang Zuxun and his team first proposed and investigated the concept of a "full digital automation mapping system," creating VirtuoZo, an intellectual property of China. The team also advanced a novel digital photogrammetrc grid processing system (DPGrid), which was China's first set of technologies for fully automatic processing of remotely sensed aerospace images with completely independent intellectual property rights (Figure 4). DPGrid made a crucial breakthrough by transitioning from human–machine interaction to automatic processing, which improves production efficiency by at least 10-fold. Major national engineering projects, such as geographical conditions

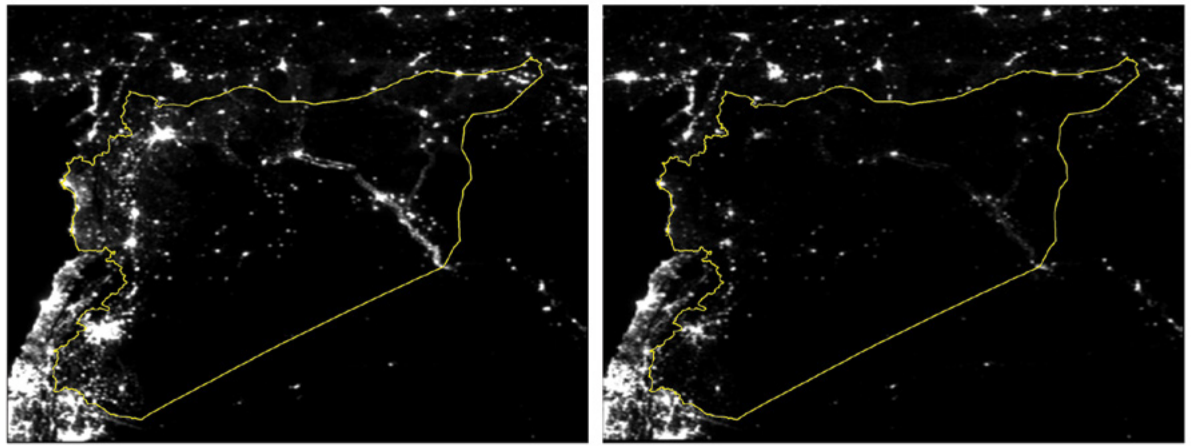

FIGURE 5. Li Deren and Li Xi closely monitored the situation of cities in Syria before (left) and after (right) the Syrian War, with nighttime-light images collected by remote-sensing technologies, as cited in a report by the 7,418th meeting of the United Nations Security Council. Credit: Xi Li

monitoring and emergency response systems, have applied these innovations widely (Figure 5). The Environmental Systems Research Institute's ArcGIS system has integrated the core technology of DPGrid, boosting its popularity and use around the world.

LEISMARS has also developed a satellite ground-processing system that eliminates systematic and gross errors in remote-sensing images, and improves the direct-positioning accuracy of Chinese resource satellite remote-sensing images from 300 m to 5 m. They demonstrated a scheme for parameter and error processing in the Ziyuan-3 (ZY-3) satellite system and designed and constructed the first high-precision satellite remote-sensing geometric calibration field in China.

2.2. Remote-sensing information processing

As more and more high-spatial/spectral/temporal-resolution remote-sensing images are acquired, automating their interpretation and geological application has become challenging. LIESMARS has proposed to solve the problem by analyzing remote-sensing big data using intelligent processing theory and methods, and also by developing the technologies for aquatic, atmospheric, and terrestrial environments.

To improve the interpretation of high-spatial-resolution (HSR) imagery, the laboratory proposed a "pixel-object-scene" HSR image-understanding framework. LIESMARS not only built a "feature-representation, precise-classification, mixed-pixel analysis" processing framework to extract land-cover/land-use information through hyperspectral remote-sensing information processing for agricultural and environmental applications, but also established a method for information extraction from permanent scatterers interferometric synthetic-aperture radar (InSAR) data, which has millimeter-level deformation monitoring accuracy. The researchers use deep learning and intelligent remote-sensing approaches geared toward analyzing big data to mine multisource images. For remote-sensing applications, they developed atmospheric Mie-scattering Lidar, Raman Lidar, and dual-wavelength polarization Lidar, and successfully developed techniques to monitor the lakes and wetlands of the Yangtze River Basin.

LIESMARS combined interactive computer vision with machine learning to create an "easy-feature" software system for remote-sensing images. It significantly improves the efficiency of GIS data collection and land-cover change detection and is now in use in many companies and government agencies in China. LIESMARS' research has received awards from Earth Resources Data Analysis System (ERDAS) as well as the Boeing Award for Best Scientific Paper in Image Analysis and Interpretation from the American Society of Photogrammetry and Remote Sensing (ASPRS), and the Theoretical Innovation Award from the Society of Photographic Instrumentation Engineers (SPIE). The remote sensing group also won first place in the Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society Data Fusion Contest in 2014 and 2018. The principal investigator of the group working on remote-sensing image processing, Zhang Liangpei, was on Elsevier's 2015 list of "Most Cited Chinese Researchers." The work of Chen Xiaoling made it onto Google Scholar's list of classic papers in 2016 as one of the 10 most-cited articles that were published 10 years prior in the field of remote sensing. Major engineering projects have put LIESMARS' remote-sensing groups' theoretical achievements into practice, including its hyperspectral remote-sensing data-processing system, global land-cover mapping, and the Euro-Chinese Dragon Project Earth-observation system.

2.3. Geographical information systems and services

LIESMARS proposed the first concept and data model for object-oriented GIS and established the first object-oriented GIS software, GeoStar. The researchers proposed a theory and method of spatial information sharing and interoperability, on which was based the multisource spatial-information sharing platform GeoSurf, and the web-based, integrated, 3D spatial-information sharing platform GeoGlobe. Now this theory and method have become the software infrastructure for the geographic information public-service platform MapWorld (天地图), China's first official open web mapping service.

The GIS group at LIESMARS has also contributed to the theoretical framework and technological system for the collection of Earth spatial information. They proposed a series of theories and web-service standards for gathering geographic information on China, including those for object-oriented geographic-data models, task-oriented and focused web services for geographic information, generalized spatial grids, spatial data mining, measurable real images, and virtual reality.

LIESMARS is also a world pioneer in the development of city-level 3D cadastral systems. These systems supported the development of digital and smart cities in Shenzhen, Hangzhou, and other municipalities, which exemplify the laboratory's global leadership in this area (Figure 6). Additionally, LIESMARS scientists proposed a multilevel statistical framework and indicators for geographical conditions, and developed theories, techniques, and tools, such as software packages, for their

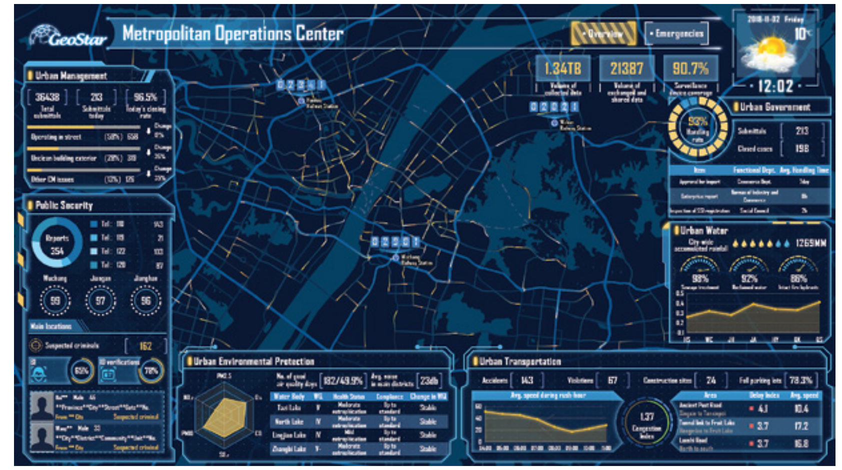

FIGURE 6. GeoSmarter: This smart-city operational platform integrates static and dynamic information that supports real-time spatiotemporal decision-making. Credit: Guoliang Wang

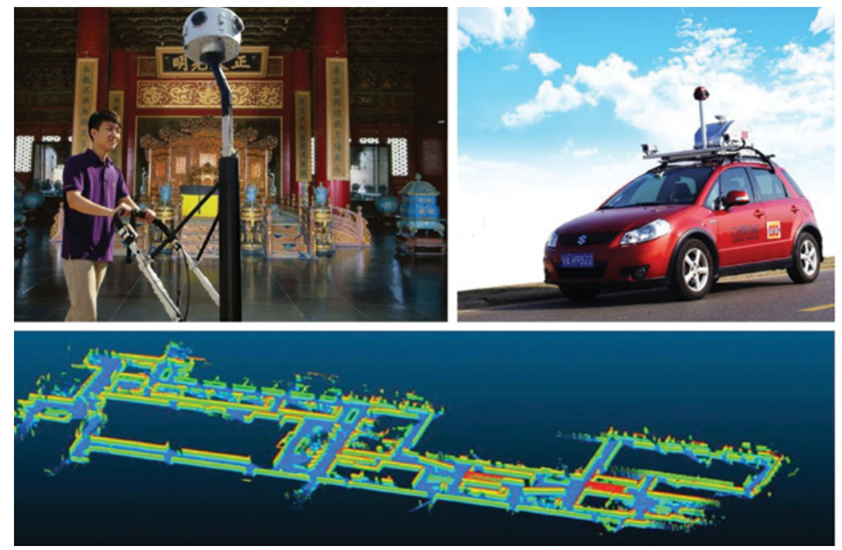

FIGURE 7. LIESMARS developed a 3S mobile-mapping system for panoramic and indoor maps that is widely used in power lines, corridor mapping, and health monitoring of infrastructures such as highways and bridges. Credit: Bisheng Yang

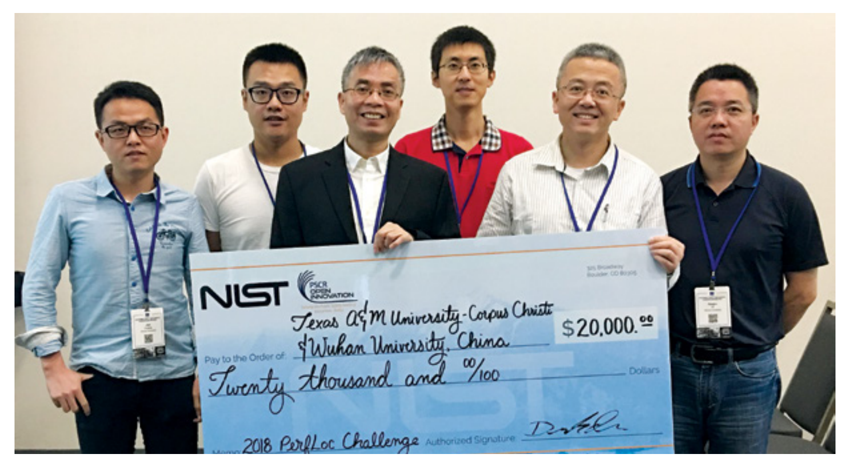

FIGURE 8. In May 2018, LIESMARS won the PerfLoc Competition organized by the U.S. National Institute of Standards and Technology (NIST). Credit: Guangyi Guo

analytics. These tools were applied in nationwide surveys for geographical conditions, enabling measurements and statistics for many types of previously unknown geographical features.

LIESMARS has implemented the standard "Geographic Information–Content Components and Encoding Rules for Imagery and Gridded Data," issued by the International Organization for Standardization (ISO) in 2016.

In 2018, LIESMARS developed real-time GIS theory and implemented a spaceborne-airborne-ground integrated sensor web, which enabled the development of instantaneous geospatial information service.

2.4. 3S Integration and network communication

By the end of the last century, three geomatics technologies had emerged worldwide: remote sensing (RS), geographic information systems (GIS), and global navigation satellite systems (GNSS). However, their development as separate technologies limited their use. LIESMARS was the first to propose a theory and methodology for "3S" integration, a technology that made possible the geolocation of remote-sensing imagery, which in turn made rapid emergency surveying and remote-region mapping a reality (Figure 7). The researchers combined GNSS receivers and inertial navigation sensors with aerospace and terrestrial transmitters and solved key technical issues, such as multisensor synchronization and precise calibration. These advances not only significantly reduced the field survey workload and overcame the difficulties of mapping in hazardous or inaccessible regions, but also paved the way for an integrated space–air–ground emergency response system that reduces the time required for emergency surveying and data processing by 20–30 fold.

Using this theory of 3S integration, LIESMARS developed mobile- and aerial-mapping systems that incorporated "high-precision, high-reliability, and high-usability" automatic-positioning and orientation-computing software and hardware. The first-generation Chinese 3S-integration equipment opened a new era of multisensing integration and combined space–air–ground technologies with modern geomatics. These advances elevated the key technologies of Chinese emergency surveying and space-time information services to an internationally competitive level.

2.5. Navigation and location-based services

In recent years, LIESMARS has carried out research on the next generation of navigation and positioning technologies for various environments, ranging from indoor to outdoor, and from Earth to deep space.

LIESMARS developed indoor/outdoor seamless-positioning technologies, including a newly designed radiofrequency (RF)-signal base station and data-fusion algorithms for multisource integrated positioning. This system can be adapted to a variety of mobility scenarios and can achieve an accuracy of greater than 1 m across in indoor and outdoor spaces. In May 2018, the navigation team won the PerfLoc

Competition (Figure 8, on previous page) organized by the U.S. National Institute of Standards and Technology (NIST). The navigation team also won the Indoor Localization Competition for the smartphone-based positioning and foot-mounted inertial measurement unit (IMU)-based positioning tracks at the Indoor Positioning and Indoor Navigation (IPIN) conference in September 2018.

LIESMARS developed the scientific experimental satellite Luojia- 1A, which was successfully launched in June 2018. With its support, LIESMARS successfully carried out the first experiment in low Earth orbit (LEO) to be based on GNSS signal augmentation, which is considered pioneering work in establishing the feasibility of LEO-based navigation systems.

The laboratory has been continuously conducting planetary geodesy research and has built an observatory station for planetary spacecraft tracking. The station has been used to successfully track the Chang'E-3 lander, the Chang'E-4 relay satellite, and Mars spacecraft, including the Mars Express (MEX), Mars Reconnaissance Orbiter (MRO), and Odyssey. LIESMARS also developed the first software platform in China for determining the precise orbit of planetary spacecraft and solving dynamical parameters. It was used to process Chang'E orbiters, MEX, and Rosetta tracking data, and achieved accuracy comparable to that of U.S. National Aeronautics and Space Administration (NASA) software. A research team including scientists in LIESMARS also generated China's first high-accuracy lunar gravity field by coupling tracking data from the Chang'E-1 mission, which revealed a partial melt zone inside the lower lunar mantle.

2.6. Cartography

LIESMARS proposed a map algebra theory, established techniques for automated map generalization and scale transformation, and developed the first cartographic database system in China. Its commercial map-generalization software, DoMap, improved the efficiency of map production (number of map products in unit time) in national mapping agencies in China by up to fivefold. In the era of new technologies, the laboratory further developed a fast and smart mapping system, WebAtlas, in response to the changing demands of the worldwide web and new media. The system played an important role in national projects such as the Second National Land Survey, Geographical Conditions Monitoring, and Digital Cities. Furthermore, it took the lead in establishing a new generation of map-production modes for decision-making. For example, it created the first map specifications for island and reef mapping and boosted fully digital map-production technologies for the mapping and surveying industry in China. Last but not least, it carried out mapping projects that have served national economic development, scientific discovery, and resource surveys; the "Shenzhen City Atlas" is one example that was awarded an international medal for excellent cartographic work, China's first (Figure 9).

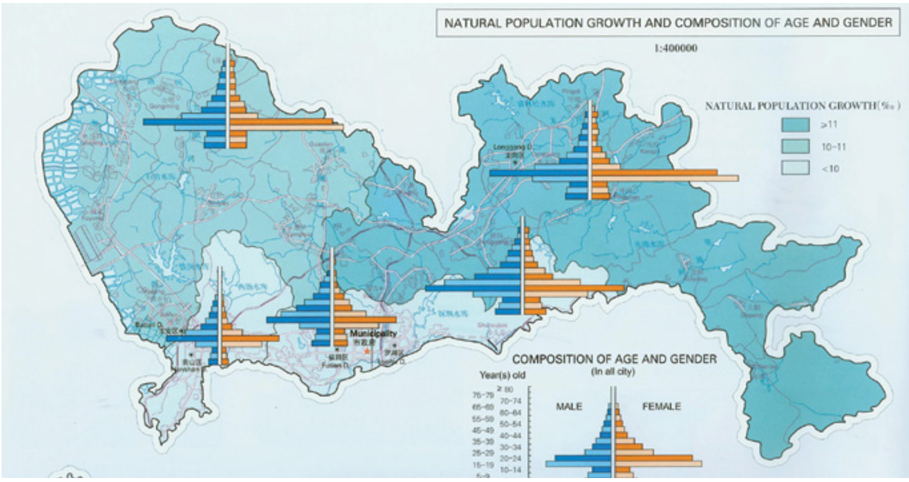

FIGURE 9. The "Shenzhen City Atlas," produced by LIESMARS, which received China's first international medal for excellent cartographic work. Credit: Zongyi He

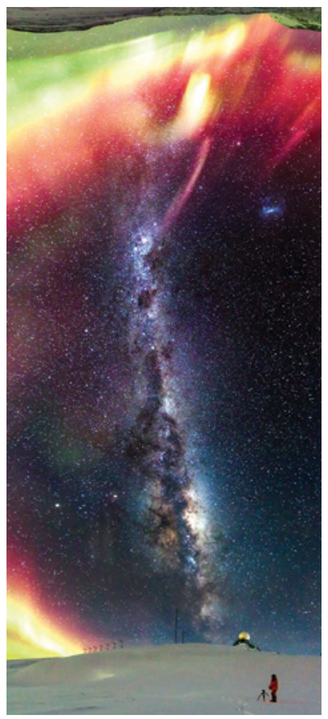

FIGURE 10. A panorama of the Antarctic night sky from Zhongshan Station, shot by geodesist Hang Li of Wuhan University, won the 2018 #ScientistAtWork photo contest organized by *Nature* magazine and was published in the April 26, 2018 edition of *Nature* (Volume 556, Issue 7702). Credit: Hang Li

2.7. Polar geomatics expedition and research

Since 1984, Wuhan University has participated in 34 Chinese Antarctic expeditions and 15 Chinese Arctic expeditions (Figure 10). Its polar research group established GNSS tracking stations, tidal stations, geodetic reference networks, satellite observation networks, gravity reference networks, and a GIS in both the Antarctic and Arctic. They also gave 359 Antarctic sites Mandarin names that filled gaps in the Antarctica toponymy. The group compiled an original atlas of the Arctic and Antarctic that reflects the polar environment and presents it cartographically, representing the cumulative results of Chinese polar geomatics expeditions. These achievements have enhanced China's influence on international polar geomatics research.

3. Future plans

LIESMARS aims to fill a significant national demand and expand China's international academic frontier in the field of information engineering in the areas of surveying, mapping, and remote sensing. The laboratory aims to advance globalization of earth observation, indoor and outdoor navigation, and dynamic geographic information systems. LIESMARS strives to make breakthroughs in geospatial computation and artificial intelligence by promoting the transformation of basic research into real-world applications through scientific and technological innovation.

The State Key Laboratory of Water Resources and Hydropower Engineering Science

Pan Liu, Liangsheng Shi, Junqiang Xia, Wei Zhou, YIfeng Chen, Zijun Cao, Zhongdong Qian, Weijia Yang, Jun Xia, Shenglian Guo, Wenbo Lu, Lihua Xiong, Gaohui Wang, and Chunxiu Ren*

The Chinese Ministry of Science and Technology approved the establishment of Wuhan University's State Key Laboratory of Water Resources and Hydropower Engineering Science (WRHES) in 2003. Its mission is to establish a world-class innovation platform for scientific research and engineering applications in the fields of water resources and hydropower engineering. WRHES currently employs 58 tenured researchers, 24 contract researchers, four technicians, and three administrative staff. Both tenure-track and contract positions are open for application all year long.

WRHES occupies six buildings on the Wuhan University campus with a total area of 13,000 m², and owns two off-campus research facilities equipped with instruments and experimental systems for various types of complex and comprehensive investigations. The laboratory has become one of the superior facilities of its kind in China and abroad.

WRHES consists of five research institutes, each run by a director who oversees the scientific groups and programs.

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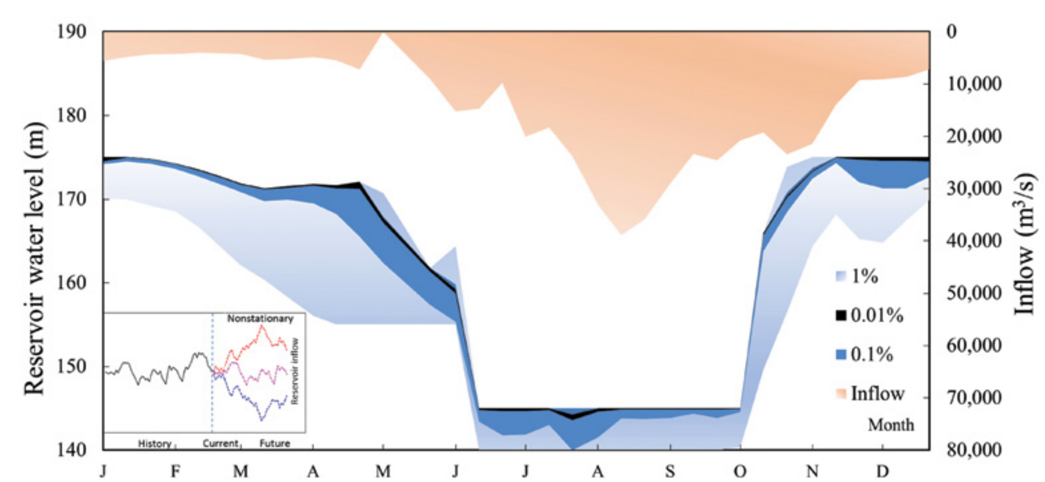

FIGURE 1. Flexible intervals for adaptive operation of reservoirs. Credit: Pan Liu

I. The Institute of Hydrology and Water Resources (IHWR).

The IHWR centers its research on the spatiotemporal distribution of water resources in China and their integrated management under conditions of changing environments. The institute's research comprises the following three research topics:

1. Runoff-generation mechanisms at the catchment scale

Predicting runoff generation is of fundamental importance for flood forecasting, hydrological modeling, and water resource management. IHWR scientists have proposed a new nonlinear theory for runoff generation called the "time-variant gain model" (TVGM). It integrates the impacts of antecedent soil moisture, precipitation intensity, land cover, soil properties, and topographical characteristics on runoff generation at the catchment scale. TVGM is widely considered one of the most advanced theories for interpreting the nonlinear behavior of catchment runoff generation. Its application in a variety of settings has demonstrated it to be an effective, practical tool for accurately forecasting floods and assessing the impacts of climate- and land-coverage change on catchment water yields. TVGM has been used to assess future water resource availability from essential river basins in China, such as the Yangtze River, Yellow River, and Pearl River basins, as cited by the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report.

2. Hydraulic engineering design under nonstationary conditions

Traditional hydrological designs for water-resource planning assume that the probability distribution of hydrological extremes such as flood and drought is stationary (i.e., remains unchanged over time). However, climate change and human activities have precipitated a nonstationary hydrological time series that is complicating the design of hydraulic infrastructures. IHWR's research team has discovered a mechanism for adjusting hydrological time series for nonstationary behavior, and proposed novel methods for deriving the frequency distributions of low flow, annual mean flow, and extreme flood events under nonstationary conditions. These findings provide scientific support for strategies to ensure the safety of large dams in China under changing environmental conditions; these strategies have been adopted by the Office of State Flood Control and Drought Relief Headquarters.

3. The adaptive operation of multireservoir systems

China is home to more than half of the world's large dams. These immense reservoirs play a key role in green-energy production, provide economic benefits, and lower the risk of water hazards for populations and cities downstream. However, the adaptive operation of multireservoir systems under the changing environment is a tremendous challenge, as shown in Figure 1. Scientists at IHWR have developed new rules for operating multireservoir systems under future conditions, based on implicit and explicit stochastic optimization. To address the uncertainty of short-term hydrological forecasts, they developed ensemble predictions of streamflow coupled with reservoir operations. They then used a data-assimilation approach to obtain adaptive reservoir-operating rules, and tracked the most effective rules under changing environmental conditions. Hydrologists have successfully applied these operating rules to the upstream Yangtze River's multireservoir system (Figure 2), resulting in remarkable economic, social, and ecological benefits.

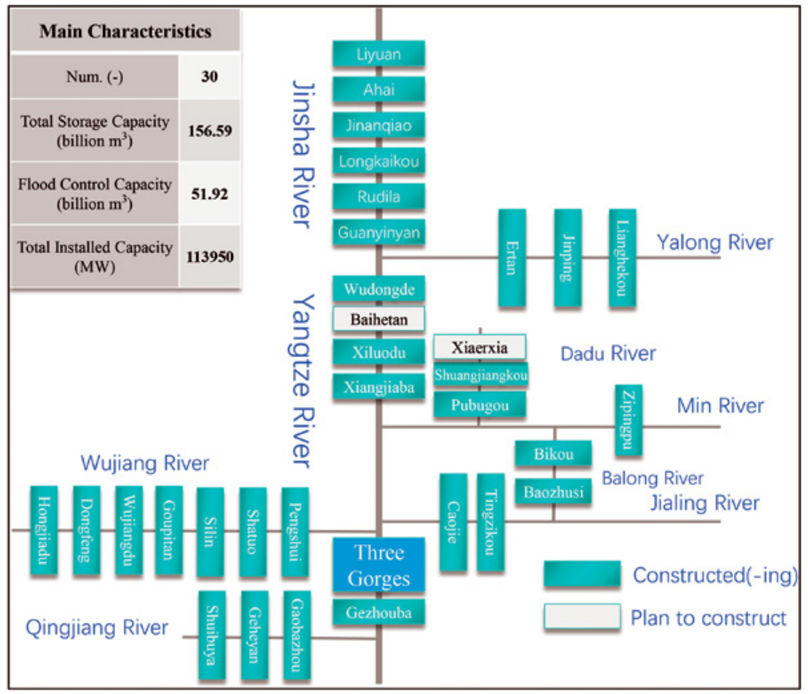

FIGURE 2. Multireservoir systems in the upstream Yangtze River. Credit: Pan Liu

II. The Institute of Agricultural Water Resource Utilization (IAWRU)

IAWRU focuses on establishing and propagating sustainable agricultural-management measures through the development of cutting-edge technologies, education and training, and agricultural-advisory services. The institute identifies the most pressing management needs in agriculture, the environment, and food security, and finds innovative solutions. Of particular interest are the improvement of saline–alkaline soil in Northern China, water-saving and environment-friendly rice-paddy production, agricultural environmental remediation, ecological restoration, and agricultural artificial intelligence. Through these efforts, the institute has substantially and positively impacted agricultural management practices. For example, Zhi Mao, a member of the Chinese Academy of Engineering, proposed the novel irrigation technique of alternating wet and dry conditions in paddy fields, which is now being widely applied to irrigation management in China and Southeast Asia. Another integrated wetland system developed by IAWRU has reduced nitrogen discharge by 25.4% and phosphorus discharge by 13.2%, conserved 13.8% of irrigation water, and increased rice yield by 5.7% in southern China, using a combination of paddy fields, drainage ditches, and small reservoirs.

In Northern China, the sustainability of irrigated agriculture is threatened by water scarcity and severe soil salinization, making efficient use of agricultural water an issue of extreme importance. The institute has proposed various strategies for the combined use of surface and groundwater to reduce soil salinity and maintain the productivity of saline soil using minimum irrigation, which have been implemented by the Hetao Irrigation District of Inner Mongolia, one of the three largest water districts in China.

The IAWRU is also developing big-data technologies to mine ground and remote-sensing data for information on crop water and nutrient status. The institute is not only introducing farmers to the benefits of digital agriculture, but is also collaborating with them to deploy novel technologies for crop sensing, crop diagnostics, irrigation, and fertilization (Figure 3).

FIGURE 3. Graduate student Lijun Wang working on precision management of wheat.

PHOTO: WUHAN UNIVERSITY

III. The Institute of River and Lake Engineering (IRLE)

Scientists at IRLE study river dynamics, especially the transport of flow and sediment in alluvial rivers, fluvial processes, and the theory and techniques for controlling the impact of human activities on rivers and lakes. The institute participates in many pivotal projects and provides technical consulting services for the regulation and management of rivers and lakes in China.

FIGURE 4. Changes in bank erosion along the Jingjiang Reach of the Middle Yangtze River after the Three Gorges Project began operation. UJR, Upper Jinjiang Reach; LJR, Lower Jinjiang Reach. Credit: Junqiang Xia

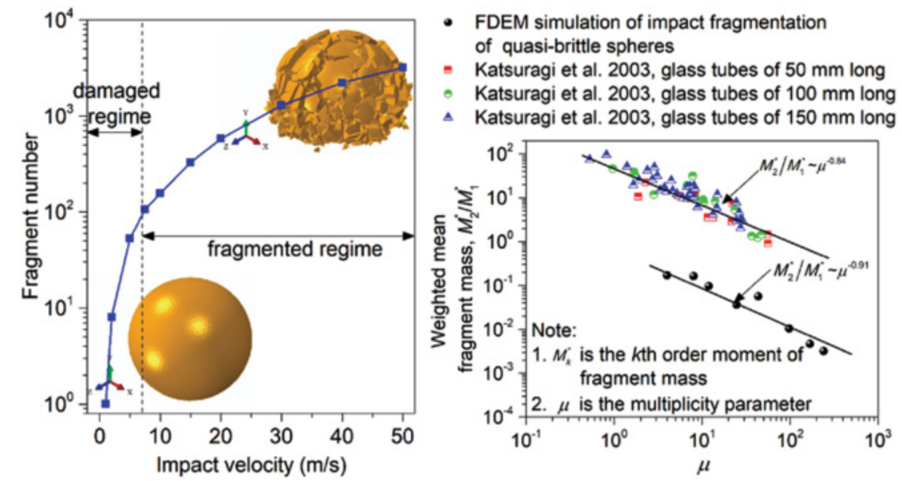

FIGURE 5. Verification of the statistical distribution of fragment characteristics for quasi-brittle spheres subjected to impact tests, showing fractal behavior and multiplicity of fragment mass. FDEM, finite–discrete element method. Credit: Wei Zhou

After the Three Gorges Project (TGP) began, the Middle Yangtze River started experiencing a remarkable level of channel degradation and severe bank erosion, presenting a serious risk to channel stability, flood-control management, and navigation safety, especially in the Jingjiang Reach. Consequently, the institute began to study fluvial processes under the new flow and sediment regime, and to develop bank-erosion modeling techniques for the Jingjiang Reach.

IRLE's measurements indicated a slight change to the Jingjiang Reach's reach-scale bankfull width, with channel adjustments occurring mainly at bankfull-depth level because of the construction of a large-scale bank revetment. In local regions lacking this type of bank-protection engineering, the banks continued to severely erode, with the reach-scale bankfull channel dimensions generally responding to the five-year average of fluvial erosion intensity during flood seasons. IRLE scientists concluded that the observed changes in Jingjiang Reach's channel geometry are the direct consequence of recent human activities such as the TGP operation (Figure 4).

IRLE's scientific team also elucidated the mechanisms for erosion of the composite riverbanks along the Jingjiang Reach using field investigations and laboratory experiments. They proposed multiscale coupled morphodynamic models for bed evolution and bank erosion, including modules for groundwater flow and bank erosion and for sediment transport at section-scale and one- and two-dimensional scales. They applied the models to a simulation of multiscale fluvial processes in the Jingjiang Reach using a detailed process of model calibration and verification, and confirmed that they can accurately represent flow and sediment transport processes and predict sites of severe bank erosion.

Researchers in the field of river dynamics have begun to apply these models to comprehensive regulation of the "Golden Waterway" (Yangtze River), including bankline planning, levee-protection engineering, and early warnings for bank erosion; they are now yielding considerable economic and social benefits.

IV. The Institute of Hydraulic Structure (IHS)

IHS scientists are engaged in a range of research relating to the construction of hydraulic structures. This research includes construction hydraulics for river closure and diversion; composite element algorithms for rock and hydraulic engineering; life-cycle performance evaluation for high dams; generalized multifield coupling approaches; flow-stress coupled permeability for fractured rock masses; water conservancy and hydropower engineering for seepage control; control of damage caused by blasting and excavation in high-rock slopes; theory and technology for the support of weak and soft rock masses surrounding deep tunnels; and performance prediction of tunnel-boring machines for mechanically breaking rock masses.

To explain the behavior of rockfill materials at both macro- and microscopic levels, IHS researchers have developed a stochastic granule discontinuous deformation (SGDD) model and a combined finite and discrete element method (FDEM). Using this method, they showed that after particle breakage, fragment sizes are distributed in a fractal structure (Figure 5). They also established a full-life-cycle deformation-control system for high-rockfill dams that integrates design, construction, and operation, effectively solving the "scale-effect" problem for rockfill materials and overcoming limitations in conventional methods of deformation control.

Institute scientists have also proposed a universal model to describe the relationship between viscous and inertial permeability for geologic media of varying scales and proposed a series of micro-macro constitutive models for water retention and permeability in fractured geologic media. They proposed a full-phase diagram for multiphase flow in rough fractures (Figure 6), discovered a pattern of multiphase flow in rock fractures, and detected a fundamental link between flow-pattern transitions and energy conversion. They also devised a formula describing uniform parabolic variational inequality for transient and saturated-unsaturated flow problems with infiltration-evaporation-seepage boundaries, and a multiobjective inverse-modeling technique for transient or unsaturated flow at site-scale using time-series measurements of the piezometric head and discharge.

The IHS has developed a robust, efficient framework for assessing the reliability and managing the risks inherent in slope stability, a challenging task in geotechnical engineering because of the highly nonlinear behavior of slopes, the complexity of uncertainty sources of slope stability and their propagation, and the unpredictability of 3D failure modes (Figure 7). They developed a probabilistic framework for geotechnical uncertainty quantification as well as simulation-based methods for slope-system reliability analysis and strategies for risk assessment and control that consider realistic 3D failure modes. Together, these methodologies and tools constitute an integral and novel framework for uncertainty quantification, reliability assessment, and risk management in the field of slope engineering. Moreover, they provide the tools to explore important aspects of slope system reliability and risk, such as the need for a rational treatment of 3D spatial variability in the practice of slope design.

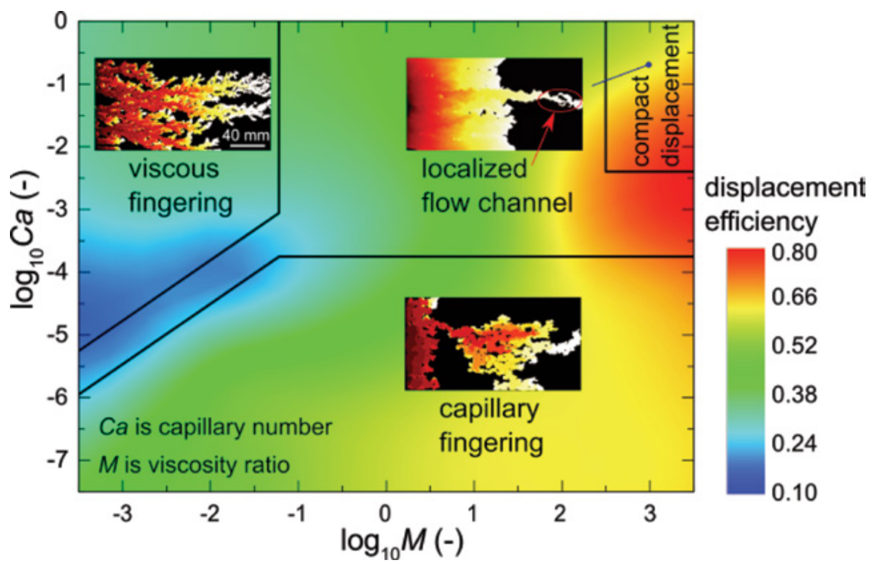

FIGURE 6. Multiphase flow in rough fractures, showing flow regimes of viscous fingering, capillary fingering, compact displacement, and crossover zones, all of which are related to displacement efficiency. Credit: Yifeng Chen

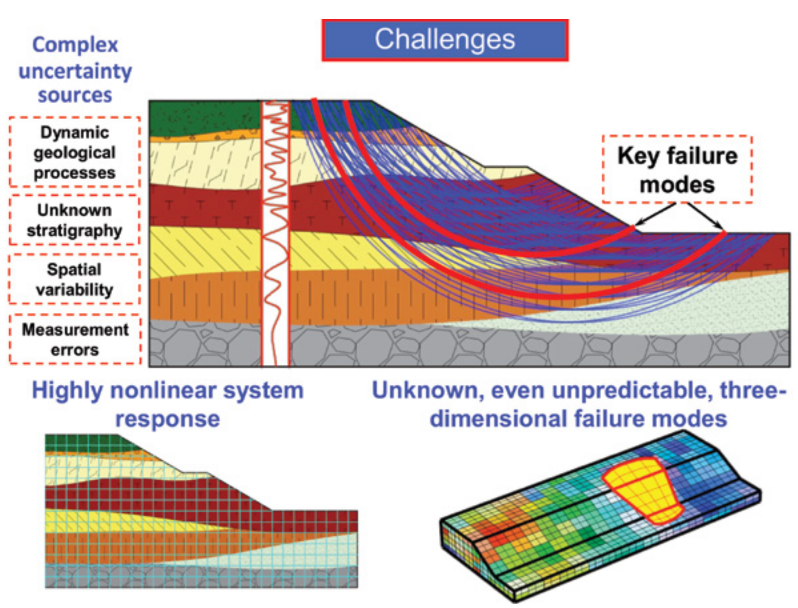

FIGURE 7. Challenges in reliability assessment and risk management of slope stability. Credit: Dianqing Li

V. The Institute of Hydropower Station Operation and Management (IHSOM)

IHSOM comprises the hydropower plant (HPP) and the hydraulic machinery and systems research teams (HMS). The HPP research team investigates the transient processes and control of hydropower plants (Figure 8) as well as design theory for hydropower plant waterway systems; they also study applied-fluid transients and their interactions with power systems. IHSOM's array of experimental pumped-storage plants constitutes the world's first platform for studying their transient processes through high-risk experiments. The team has amassed considerable data solving crucial technical problems that threaten the safe and stable operations of hydropower plants: For instance, they have proposed a theory of hydraulic-mechanical-electrical coupling transient processes, a design theory for surge tanks and tailrace tunnels that integrates free-surface-pressurized flows and sloping ceilings, and an improved theory of applied-fluid transients.

Currently, the HPP research team is studying the dynamic characteristics of hydropower units for future smart grids with highly or fully renewable energy sources. They are investigating oscillation mechanisms, variable speed pumped-storage technology, transient processes of seawater pumped-storage plants, and the operation and control of hybrid power systems that combine hydropower with renewable energy sources.

The HMS research team is also investigating ways to make the operations of hydraulic machinery and systems more efficient, safe, and stable. During the past decade, they have concentrated on hydraulic machinery and systems along the Yellow River, especially their unsteady multiphase flow, along with mechanisms of sediment erosion and strategies for erosion control. The team also is investigating coupling mechanisms for sediment and cavitation erosion as well as a bionic design for pump impellers inspired by desert creatures such as the cold-hardy lizard *Phrynocephalus erythrurus* (Figure 9).

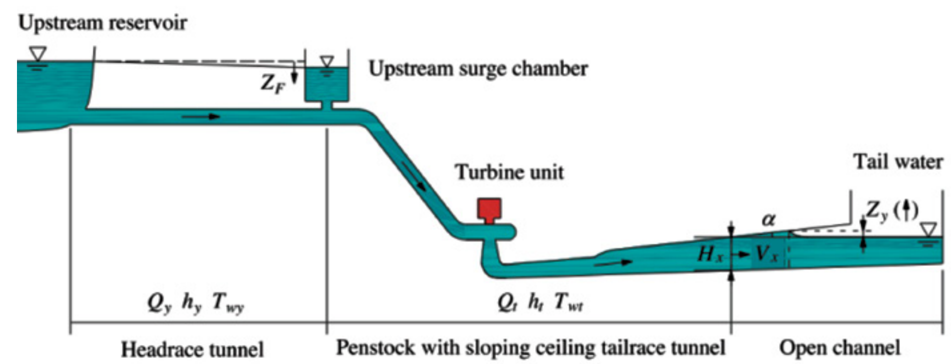

FIGURE 8. Mathematical modeling of transient processes of a hydropower plant with complex waterway systems. Credit: Jiangdong Yang

FIGURE 9. The unique scale morphology on the back of *Phrynocephalus erythrurus* (left) and a bionic antierosion impeller with mimicked structures on the inlet and outlet of the blades (right). Credit: Zhongdong Qian

PHOTO: WUHAN UNIVERSITY

FIGURE 10. Jun Xia and his team are honored with China's National Natural Science Award in 2017 (second prize).

Groundbreaking hydrology discoveries made by WRHES scientists

Jun Xia and Shenglian Guo have led their teams in innovative research that has yielded clear benefits to both society and the environment. Xia clarified the time-variant runoff generation mechanism and developed a new nonlinear model that has been applied both domestically and globally in river-flow forecasting, flood control, and water resource management; he won the 2017 National Natural Science Award in China for this contribution (Figure 10). Guo has established strategies for floodwater use optimization in hydropower generation at the Three Gorges Reservoir (TGR), the largest multipurpose hydrodevelopment project in the world.

1. Runoff generation and transformation in basins: A novel nonlinear mechanism

Hydrology constitutes a critical branch of Earth science devoted to the study of water cycles. The nonlinear mechanism of runoff generation and transformation at the basin scale is a crucial and challenging issue for both hydrological science and its impact on water management practices.

In his discussion of the highly nonlinear behavior of slopes, Xia made a groundbreaking scientific discovery. He showed that nonlinear slope behavior is controlled by three key factors in a nonlinear combination: rainfall intensity, soil wetness, and land-cover types (Figure 11). He then developed a new TVGM to quantify runoff generation and advanced a new paradigm of hydrologic systems in large basins. His theories address the contradictions and conflicts in the scientific operation of flood control and water environment protection in high-density water projects and river systems in developing countries. His nonlinear theory and TVGM model were tested using datasets from more than 60 river basins in different representative climatic regions across the world, resulting in an increase of up to 63% in the accuracy of runoff predictions, with an average accuracy of 45%, as compared to linear models.

This new approach has significantly improved the understanding of water/land/environment/human/ecosystem interactions, potential impacts of climate change on water planning and management processes, and the scientific management of river basins. For his outstanding research on hydrology and its applications, Xia won the 2014 International Hydrology Prize Volker Medal from IAHS/UNESCO/WMO. His Volker Prize citation reads, "It is an honor to award the first Volker medal to Professor [Jun Xia], for outstanding contributions to the science of hydrology and application of his research and hydrological expertise to the benefit of society" (iahs.info/About-IAHS/Competition--Events/International-Hydrology-Prize/International-Hydrology-Prize-Winners/XiaJun).

2. Floodwater use at the Three Gorges Reservoir

The TGR is the most massive and economically critical reservoir built along China's longest river, the Yangtze (Figure 12). Management objectives for the TGR include flood control, power generation, and improved navigation. With a flood storage capacity of 2.215×10^{11} m^3 per year, the TGR plays a vital role in flood control for the Yangtze River. Guo and his colleagues Lihua Xiong, Pan Liu, and others, have developed floodwater utilization strategies to increase the economic benefits provided by the TGR without compromising its original flood-prevention standards.

Guo's team proposed varied seasonal flood-limited water levels (FLWL) to improve flood control. They used the copula function to model the joint distribution of seasonal floods, which clarified the relationship between the frequencies of seasonal flood quantiles and those of the annual maximum, and established a constraint by which the total flood risk of the seasonal FLWL is required to be less than that of the original FLWL. From these parameters, they developed a simulation-based optimization model to maximize multiple benefits, such as flood control, hydropower generation, and navigation.

The dynamic FLWL was tested in the operation of the TGR in real time. Given accepted risk constraints for flood-control operations, the team was able to estimate a dynamic control boundary for reservoir FLWL using a Monte Carlo simulation.

The team then optimized the TGR's refill operation. By advancing the start of the refill period to the beginning of the postflood season, they could estimate seasonal design flows during the new refill period. They proposed a multiobjective refill operation model by simultaneously combining flood control and conservation. Finally, they developed optimal TGR refill operating rule curves using the simulation-optimization-test framework.

These innovations have now been applied to the practical operation of the TGR. Data indicates that the FLWL can be safely increased from 145.0 m to 156.0 m, and the start of the refill period can be advanced from October 1 to September 10. Implementing these changes has increased hydropower generation by 23.7 billion kWh over the last three years, which is equivalent to saving about 2.9 million metric tons of coal fuel. TGR's scene of refilling to the normal pool water level in 2016 is depicted in Figure 13.

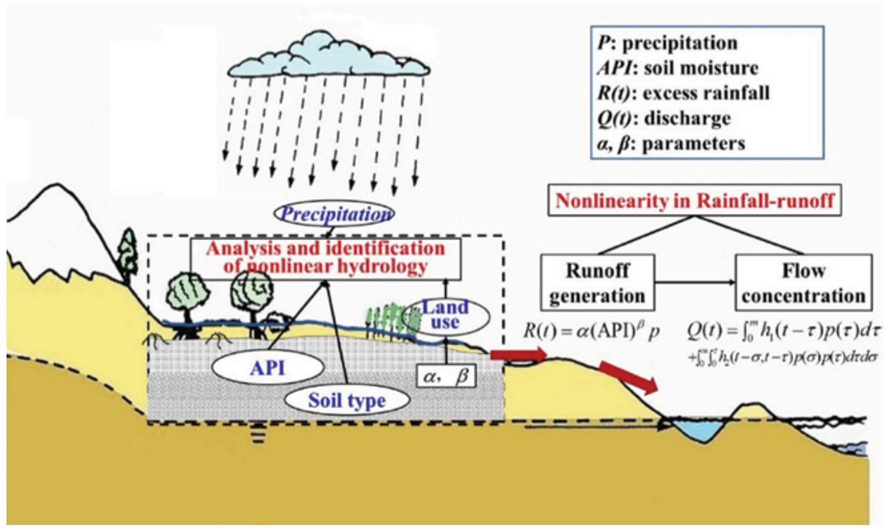

FIGURE 11. A graphical depiction of the time-variant gain runoff generation mechanism. Credit: Jun Xia

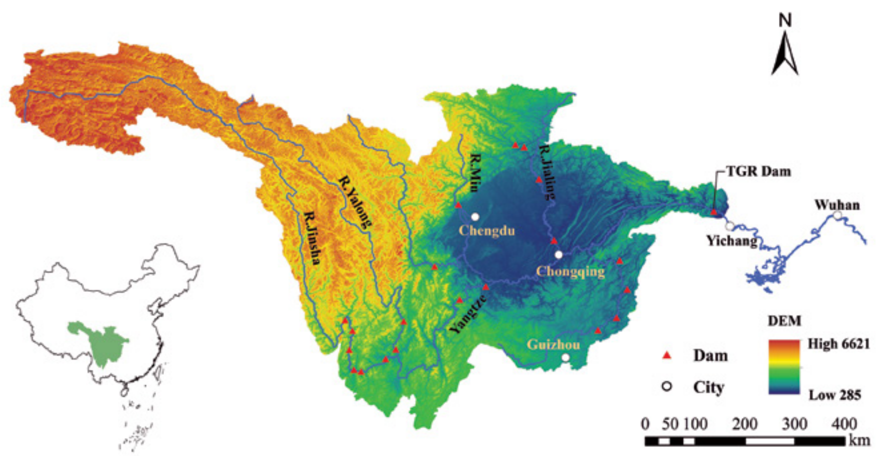

FIGURE 12. Location of the Three Gorges Dam. Credit: Pan Liu

FIGURE 13. The TGR refilled to the normal pool water level in 2016. Credit: Pan Liu

The State Key Laboratory of Virology

Ke Lan*, Fang Liu, Mingzhou Chen, Ying Zhu, Jiangguo Wu, Yu Chen, Mingming Hu, Daiwen Pang, Xiangdong Fu, Yu Zhou, Yan Zhang, and Ying Zhu

I. The history of virology research at Wuhan University

Virology has a long history at Wuhan University. Gao Shangyin, a principal founder of modern virology in China, opened the university's first virology laboratory in 1948. Gao went on to establish a Ministry of Education–approved institute and department of virology in 1978. Virology later became a national key discipline, with the first group of doctoral programs launching in 1981 and virology becoming a key subject in the 211 Project in 1997. In 1998, the institute became one of the first distinguished-professor stations in the Changjiang Scholars Program. That year also saw approval of the virology department's doctoral program as a first-level discipline and its designation as a national training base for science talents in biology. In 2003, the Ministry of Education approved the creation of a key laboratory of virology at Wuhan University, and in November 2004, the Ministry of Science and Technology approved its official launch as the State Key Laboratory of Virology (SKLV), which took place in March 2005.

FIGURE 1. Shangyin Gao (1909–1989), opened Wuhan University's first virology laboratory in 1948 and created the Department of Virology in 1978.

Shangyin Gao: Founder of virology at Wuhan University

Shangyin Gao (1909–1989) was born in Jiashan in Zhejiang Province (Figure 1). He was a world-renowned virologist and member of the Chinese Academy of Sciences (CAS). Gao graduated from Soochow University in 1930, and obtained his Ph.D. from Yale University in 1935. Upon returning to China, he began a long and illustrious career at Wuhan University, where he served as dean of the Department of Biology and Virology and vice president of the university. He was also one of the most esteemed figures in Chinese virology, serving as vice president of the Wuhan Branch of the CAS, director of the Central South Institute of Microbiology, and vice president of the Chinese Society for Microbiology. Gao headed the biological subject-evaluation group for the State Council Degree Committee, was vice chairman of the Political Consultative Conference of Hubei Province, and was vice chairman of the Hubei Association of Science and Technology and the Hubei Association of Foreign Relations. During his scientific career, Gao made many outstanding contributions to virology. He was the first in the world to culture the influenza virus from embryonic allantoic fluid (*1*), and a monolayer culture method he created for insect cells was hailed internationally as a breakthrough in insect virus research (*2*). His research won him the China National Science Conference Award in 1978, and the Second Prize of the National Natural Science Award in 1991. Among his other accomplishments, Gao was a pioneer in microbiology and virology education in China.

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II. Overview of the State Key Laboratory of Virology (SKLV)

SKLV was established in 2004 under the administration of the Ministry of Science and Technology and the sponsorship of Wuhan University and the CAS Wuhan Institute of Virology. Ke Lan is director of the laboratory (Figure 2), and Zihe Rao is director of the academic committee (Figure 3). SKLV currently employs 58 principal investigators, including two members of the CAS, eight Distinguished Young Scholars of the National Natural Science Foundation of China (NSFC), three distinguished professors from the Cheung Kong Scholars Program, and three NSFC innovation teams. In recent years, SKLV has trained more than 1,000 graduate students and postdoctoral fellows. SKLV conducts basic and applied research in virology to solve critical scientific problems and makes landmark discoveries to advance national interests and human health. Its ultimate goal is to find new ways to prevent and treat viral infectious diseases. The laboratory has four areas of emphasis: viral genetics and molecular epidemiology, virus–host interactions, immunity and pathogenesis, and the prevention and control of viral diseases. Since its establishment, SKLV has become an internationally recognized virology research center with a sustained capacity for innovation, a training base for world-class virology researchers, and a crucial component of the national science and technology system.

III. Representative achievements of SKLV

Since its inception, SKLV has made a series of outstanding achievements in diverse fields of virology. Particularly in the past five years, SKLV scientists have published more than 1,200 papers in top-tier academic journals such as *Nature*, *Science*, *Cell*, *Immunity*, *Lancet*, *Nature Immunity*, *Cell Host & Microbe*, *PLOS Pathogens*, *Molecular Cell*, *Proceedings of the National Academy of Sciences of the United States of America*, and the *Journal of Virology*. They have edited and coedited 26 academic publications and obtained 129 nationally authorized patents. Some of the laboratory's key scientific achievements are summarized below.

FIGURE 2. Ke Lan, director of the State Key Laboratory of Virology.

Achievement I: The molecular mechanisms of persistent infection and pathogenesis for medically significant viruses.

1. The underlying molecular mechanism of hepatitis virus replication and the host immune response.

SKLV scientists discovered that the host major vault protein (MVP) interacts with the adaptor protein MyD88 to suppress hepatitis C virus (HCV) RNA replication and protein synthesis. The mechanism

FIGURE 3. Zihe Rao, director of the State Key Laboratory of Virology academic committee.

for suppression involves an increase in type I interferon (IFN) messenger RNA (mRNA) expression and protein secretion, which is mediated by the translocation of the interferon regulatory factor IRF7 and NF-kB from the cytosol to the nucleus (*3*). The scientists reported that the hepatitis B surface antigens HBsAg and HBeAg block the molecular interaction between the MVP and MyD88, which suppresses MVP-induced NF-kB and IFN signaling (*4*) (Figure 4). They also discovered that the host Golgi protein GP73, which plays a novel role in regulating host cellular immunity, facilitates HCV infection (*5*). Also, the microRNA miR-21 is upregulated during HCV infection and negatively regulates IFN-α signaling through MyD88 and IRAK1 (interleukin-1 receptor-associated kinase-1), suggesting that miR-21 could represent a therapeutic target for antiviral intervention (*6*).

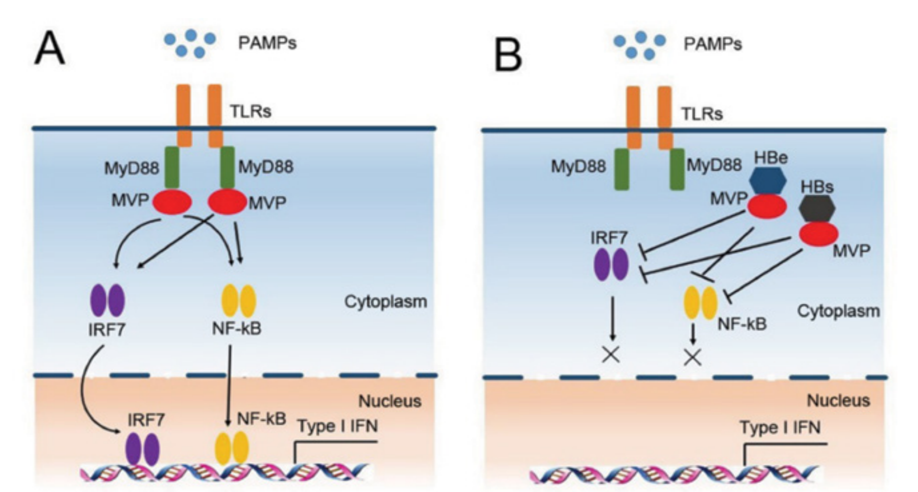

FIGURE 4. A working model for the mechanism by which the hepatitis B virus proteins HBsAg and HBeAg "hijack" the host innate immune response. Image reprinted with permission from (*4*). © 2015 Elsevier: *Journal of Hepatology*. *See text for more detail.*

2. Deciphering a novel mechanism for KSHV latency control and its related pathogenesis.

Kaposi's sarcoma-associated herpesvirus (KSHV) was first identified in Kaposi's sarcoma (KS) biopsies in 1994, and has since proven to be the etiological agent of several human cancers, including KS, primary effusion lymphoma, and multicentric Castleman's disease. Lan Ke's group demonstrated that two viral proteins, namely LANA (latency-associated nuclear antigen) and RTA (replication and transcription activator), regulate each other, and proposed a LANA–RTA feedback mechanism for viral latency control (*7–12*). They discovered that KSHV "hijacks" Notch and BMP-Smad1-Id signaling to promote tumorigenesis (*13–15*), which suggests that these signaling pathways could be promising therapeutic targets for KS. The group's mapping of the epigenetic landscape of the KSHV genome in classic KS tissues provided new insights into KSHV pathogenesis (*16*). Their further studies revealed that male hormones could activate the protein tyrosine kinase ephrin type-A receptor 2 (EphA2) to facilitate KSHV infection, which helps explain the gender disparity seen in KS patients (*17*) (Figure 5).

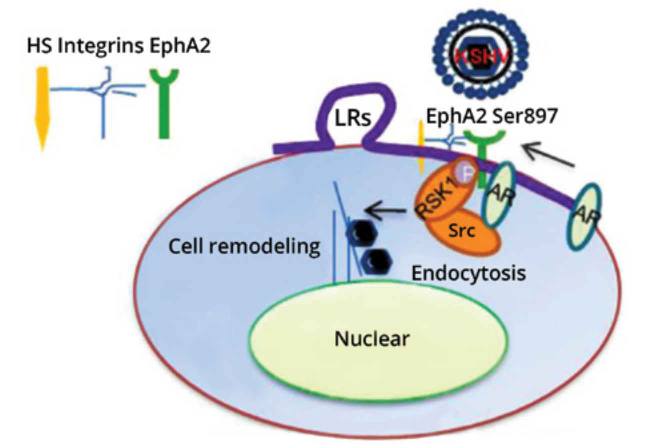

FIGURE 5. The working model of androgen receptor–mediated phosphorylation of ephrin type-A receptor 2 (EphA2) during Kaposi's sarcoma-associated herpesvirus (KSHV) entry (*17*).

Achievement II: Revealing the molecular mechanisms underlying the acute infection and pathogenesis of medically significant viruses.

1. Elucidating the mechanism by which the human parainfluenza virus HPIV3 controls host-defense systems to facilitate viral replication, assembly, and budding.

SKLV scientists discovered that human parainfluenza virus type 3 (HPIV3) matrix protein could trigger mitophagy by bridging the interaction between autophagosomes and mitochondria through the autophagosome-localized light chain 3 and mitochondria-localized Tu translation elongation factor (*18*). This mechanism enables viruses to evade the host immune system and exit host cells. They also reported that the interaction between viral nucleoprotein and phosphoprotein forms special structures called "inclusion bodies" (IBs) that are the sites of viral RNA synthesis (*19*). Further investigation revealed that the formation of IBs is dynamic, with small IBs fusing together to form large IBs, a process regulated by acetylated α-tubulin (*20*). Production and accumulation of viral RNAs within the cytoplasm induce the formation of stress granules (SGs) that sequester viral RNAs and inhibit translations of viral proteins. To combat this component of the host defense system, the IBs of HPIV3 sequester newly synthesized viral RNA, which suppresses the formation of SGs (*21*). The HPIV3 matrix protein not only triggers host mitophagy but also mediates internal viral protein assembly through its interaction with nucleoprotein (*22*). The viruses also use the membrane structure of autophagosomes to accelerate the process of viral budding, and an HPIV3 phosphoprotein blocks autophagosome–lysosome fusion; both events further increase virus production (*23*).

2. Coronaviruses: From molecular mechanism to antiviral drug development.

Coronaviruses (CoVs) are etiological agents of respiratory, gastrointestinal, hepatic, and central nervous system diseases in humans, livestock, and wild animals. During the severe acute respiratory syndrome (SARS) outbreak of 2003, SKLV scientists obtained a SARS-CoV isolate (designated SARS-WHU) from a local patient (*24*). From this sample,

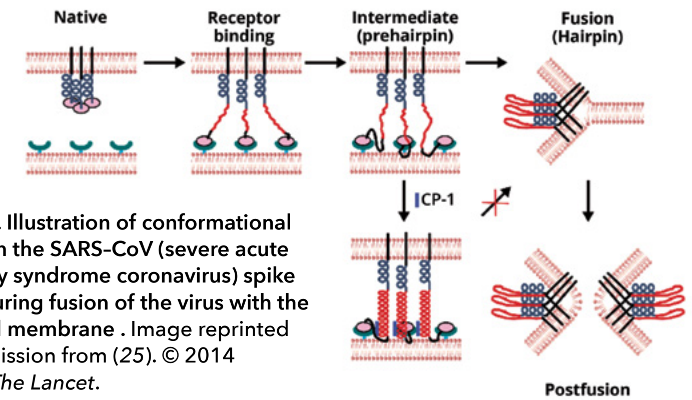

FIGURE 6. Illustration of conformational changes in the SARS-CoV (severe acute respiratory syndrome coronavirus) spike protein during fusion of the virus with the target-cell membrane . Image reprinted with permission from (*25*). © 2014 Elsevier: *The Lancet*.

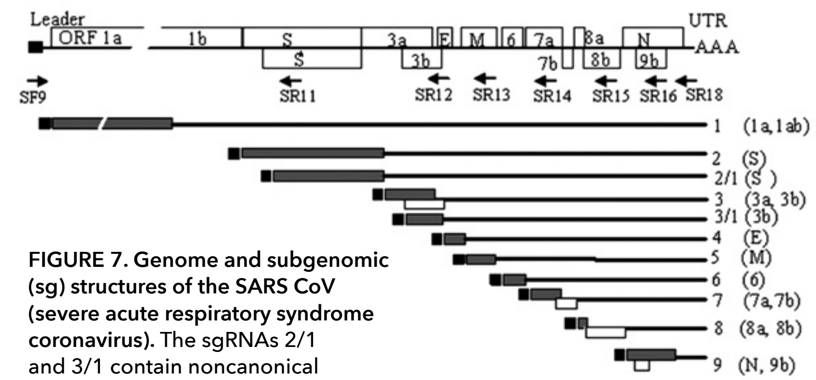

FIGURE 7. Genome and subgenomic (sg) structures of the SARS CoV (severe acute respiratory syndrome coronavirus). The sgRNAs 2/1 and 3/1 contain noncanonical transcription regulatory signals (*26*).

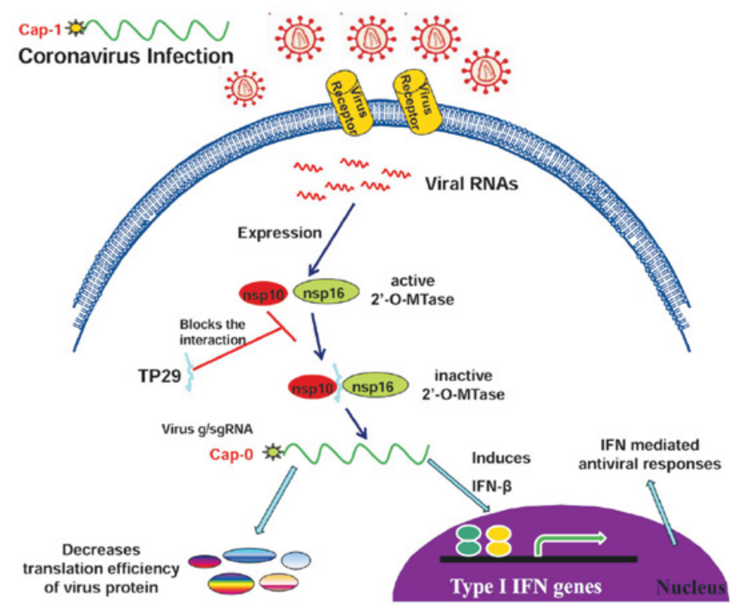

FIGURE 8. Coronaviral replication is inhibited by the TP29 peptide, which prevents the formation of the nsp10/nsp16 complex, thereby decreasing the translation efficiency of viral RNAs, promoting the recognition of viral RNAs by cellular innate RNA sensors, and leading to enhanced immune responses (*32*). *See text for more detail.*

they discovered that the mechanism by which the virus fuses to target cell membranes involves an interaction between two regions within the SARS-CoV spike protein. The scientists built on this finding by identifying specific inhibitors of that fusion event (*25*) (Figure 6). They also identified 10 subgenomic RNAs (sgRNAs), including two novel sgRNAs, which have core sequences derived from the host's transcription regulatory sequences, reinforcing the model of discontinuous transcription at minus-strand synthesis (*26*) (Figure 7). The team then determined that a CoV nonstructural protein, nsp14, is a novel N7-methyltransferase (N7-MTase) (*27, 28*) and that the nsp10-nsp16 complex functions as a 2′-O-methyltransferase (2′-O-MTase) that specifically synthesizes viral RNA encoding the cap-0 and cap-1 structures (*29*). Further studies from the group elucidated the mechanisms of CoV RNA methylation and generated an optimized peptide derived from the conserved interaction domain of nsp10. In vitro, the peptide showed broad-spectrum activity against 2′-O-MTase, and in vivo, it inhibited replication of multiple types of CoVs (*30–32*) (Figure 8).

Achievement III: Antiviral immune signal transduction and its regulatory mechanisms.

The innate immune system forms the first line of defense against pathogens. It functions by initial recognition of conserved microbial structures called "pathogen-associated molecular patterns" (PAMPs) and eventual induction of downstream effector genes, including type I IFNs and proinflammatory cytokines. These cytokines are crucial for the maturation and activation of antigen-presenting cells, such as dendritic cells. However, the mechanisms by which the host senses virus-derived PAMPs and the viral infection triggers immune and inflammatory responses remain enigmatic. In recent years, Shu Hong-Bing's team has achieved a series of breakthroughs addressing these questions in the field of innate antiviral immunity.

1. Identification of critical proteins for virus-triggered innate antiviral immune signaling.

Hong-Bing's group identified several proteins, including MITA, LSM14A, and ZCCHC3, which could activate the IFN-β promoter in reporter assays and are of vital significance in innate antiviral immunity. Further investigation indicated that MITA acts as a critical adaptor that mediates viral DNA-induced innate antiviral immune signaling (*33*). LSM14A acts as a novel sensor for viral DNA and RNA (*34*), while ZCCHC3 acts as a coreceptor for the cytosolic viral RNA receptor RIG-I/MDA5 and the viral DNA sensor cGAS for efficient sensing of viral nucleotides (*35, 36*).

Revealing a series of regulatory mechanisms for the adaptor MITA

Hong-Bing's team went on to elucidate a series of regulatory mechanisms crucial for switching MITA on or off during viral infection (Figure 9). First, they found that RNF5 catalyzes K48-linked polyubiquitination and promotes degradation of MITA to avoid an excessive immune response triggered by viral infection (*37*), whereas RNF26 competes with RNF5 for the same residue (K150) of MITA (*38*). Second, they determined that the ER-associated protein ZDHHC1 mediates dimerization of MITA to facilitate a MITA-mediated antiviral immune response (*39*). Third, they found that iRhom2 is required for translocation of MITA from the endoplasmic reticulum (ER) to the Golgi and mediates the stability of MITA during trafficking (*40*).

Uncovering the molecular mechanisms of sumoylation- and phosphorylation-mediated regulation of innate antiviral immunity

Guo De-Yin's and Hong-Bing's groups uncovered a series of regulatory mechanisms by which posttranslational modifications mediate innate antiviral immunity. They discovered that TRIM38 acts as an E3-SUMO ligase that catalyzes sumoylation of the RNA sensor RIG-I/MDA5, the DNA sensor cGAS, and the adaptor MITA, thereby regulating their activities and stability (*41, 42*). De-Yin's group also discovered that the tumor suppressor PTEN dephosphorylates IRF3 at Ser97, leading to its translation from the cytosol to the nucleus and its activation (*43*).

2. Mechanisms by which RNA viruses induce inflammatory responses.

Excessive inflammatory responses caused by acute viral infections, such as by enterovirus 71 [(EV71), the agent of hand, foot, and mouth disease] and the Zika virus (ZIKV), cause harmful damage to host tissues. Decoding the molecular mechanisms of viral replication, as well as virus-inducing acute and excessive inflammatory responses, will advance the development of antiviral agents and therapies. Jian-Guo Wu's group at SKLV focuses on the molecular mechanisms of viral-induced inflammatory responses. They found that the EV71 3D protein could stimulate NLRP3 inflammasome activation, procaspase-1 cleavage, and IL-1β release through direct binding to NLRP3. ZIKV induces inflammatory responses by facilitating ZIKV NS5 protein-mediated NLRP3 inflammasome complex assembly and IL-1β activation (*44, 45*).

Other groups led by Yuanyang Hu and Xi Zhou study the replication mechanism of insect viruses such as Wuhan nodavirus (WhNV), the first reported nodavirus isolated from insects in China. The groups found that WhNV B2 inhibits Dicer-mediated double-stranded RNA (dsRNA) cleavage and the incorporation of small interfering RNA (siRNA) into the RNA-induced silencing complex, and that sgRNA3 is synthesized through an internal-initiation mechanism from its transcriptional start site (*46, 47*). Moreover, WhNV B2 could also suppress the RNA interference (RNAi) pathway by directly interacting with the PAZ and RNase III domains of Dicer-2 and blocking the activity of Dicer-2 (*48*).

Achievement IV: New technologies for virus tracking and visual detection.

Quantum dots (QDs) are fluorescent semiconductor nanocrystals with the characteristics of strong fluorescence, high photostability, multicolor fluorescence tunability, and a long fluorescence lifetime, as compared to conventional fluorescent proteins and organic dyes. Dai-wen Pang's group at SKLV is using QDs as "biolabels." They combine QDs with fluorescent proteins and organic dyes to develop efficient strategies for virus labeling. They have also proposed a new 3D radial-symmetry (RS)-based algorithm for fast and high-accuracy localization of QD-labeled viruses.

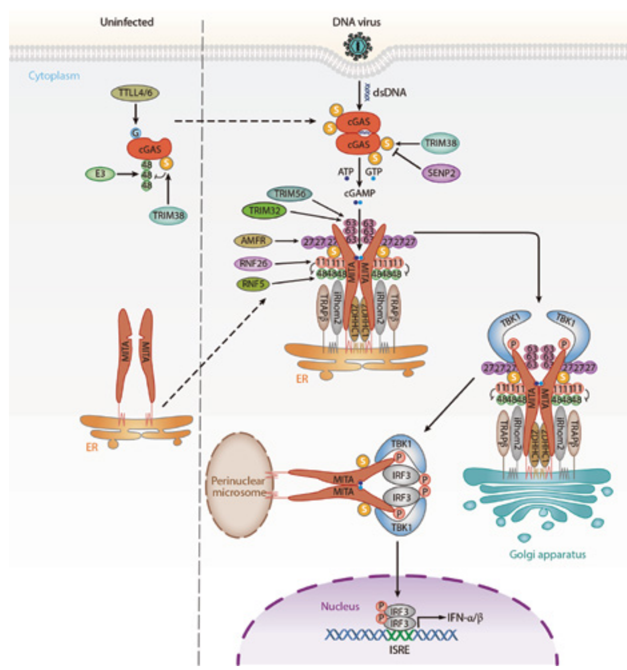

FIGURE 9. Molecular mechanism and regulation of innate antiviral immunity. Image reprinted with permission from (*37*). © 2018 Copyright Clearance Center, Inc.: *Annual Review of Cell and Developmental Biology. See text for more detail.*

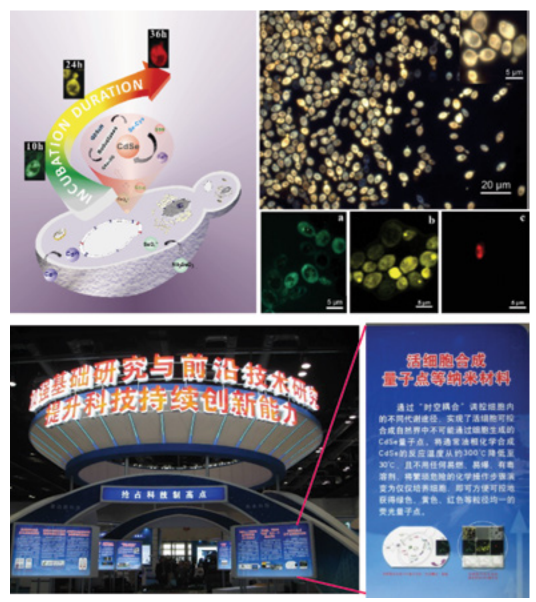

FIGURE 10. (A) Live-cell synthesis of nanomaterials, such as quantum dots in living yeast cells (*50*). (B) Picture for Exhibition of the National Major Science and Technology Achievements of China during the period of the 11th Five-Year Plan.

1. A method for synthesizing QDs in living cells.

Pang's group proposed a spatiotemporal coupling strategy for producing QDs (*50–53*) and expanded the mode of synthesis from live cells to cell-free quasibiosystems (*54, 55*). QD use has become

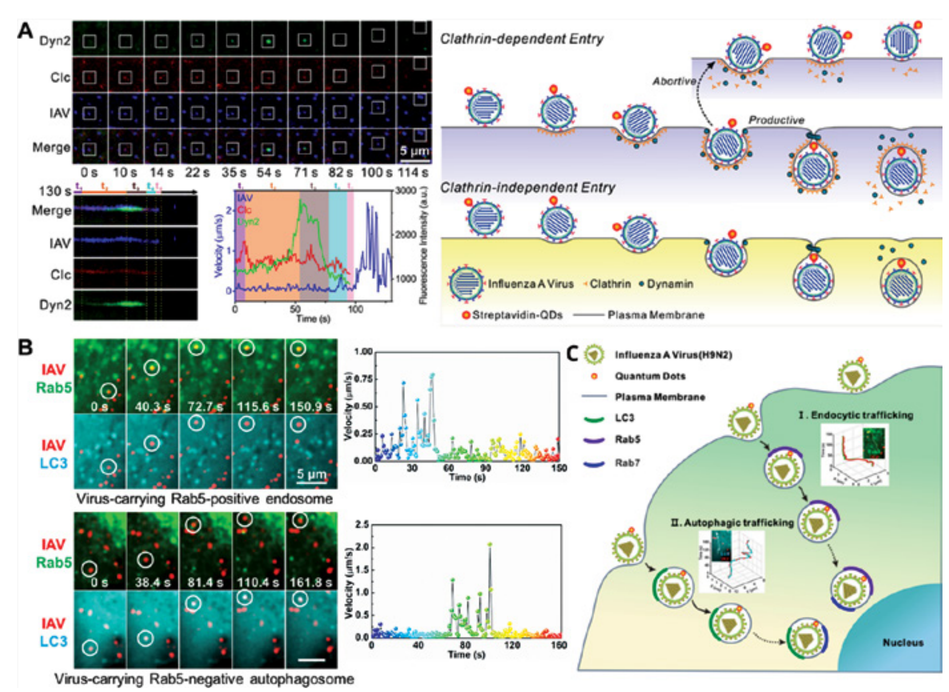

FIGURE 11. (A) The avian influenza virus (IAV) enters host cells through one of two distinct dynamin-dependent endocytic routes (*71*). (B) After entry into host cells, the IAV is internalized by endocytic vesicles and (C) is trafficked toward the cell nucleus by either the endocytic or autophagic trafficking pathways (*68, 72*).

increasingly widespread because of breakthroughs in the large-scale production of high-quality QDs: There are now more than 1,000 QD users worldwide. During the last decade, Pang's group developed methods for synthesizing QDs in the second near-infrared window that are free of toxic heavy metals and soluble in aqueous solution (*54–57*). Their achievement was selected for showcasing at the exhibition of the National Major Science and Technology Achievements of China during the period of the 11th Five-Year Plan (2006–2010) (Figure 10).

2. Dynamic tracking of single viruses in real time.

Pang's group created eight efficient techniques for the labeling of critical viral components from different structural hierarchies, such as viral nucleic acids, nucleocapsids, and viral envelopes. They leveraged innate self-assembly processes by which host cells propagate viruses, and coupled to these processes related methods such as the self-exchange of biotin-derived phospholipids in the membrane, reverse-genetics techniques, HaloTag catalysis, and affinity intercalation. These methods can be used to readily realize monocolor or multicolor labeling of key viral components (*58–63*).

In further studies, the group developed fluorescent QD-labeled viruses that meet the rigorous requirements for 3D fast imaging. They successfully employed these viruses to establish a rapid 3D, real-time, single-virus tracking method along with a 3D radial-symmetry-based algorithm for quick, high-accuracy (ca. 5 nm) localization of the labeled viruses (*63–69*).

3. Elaborating the invasion mechanism of the influenza A virus.

Pang's group has used QD-based, real-time, single-virus tracking to systematically study phenomena such as the invasive behaviors of avian influenza virus H9N2 in single host cells and interactions between the virus and host-cell proteins or organelles. The single-virus tracking technique can unravel virus behavior spanning the point of viral entry, intracellular trafficking, and transmembrane-mediated transport out of the cell. The team discovered that the invasion of Madine-Darby canine kidney (MDCK) cells by the avian influenza virus (IAV) involves a previously unknown five-stage viral-transport process (*70*). Their experiments revealed that the recruitment of clathrin and dynamin during clathrin-dependent entry of the virus is asynchronous, based on the sequential progression of protein recruitment and viral motility (*71*) (Figure 11A). They also discovered two distinct vesicular-trafficking routes that transport the IAV virus after it is internalized into the MDCK cells by endocytosis (*68, 72*) (Figure 11B).

Pang's group went on to find that the retrograde motor proteins myosin VI (myoVI) and dynein, which mediate the switching of vesicles from microfilaments (MF) to microtubules (MT), is also responsible for the seamless transfer of viruses from MFs to MTs during infection. Such a "driver switchover" mechanism answers a longstanding enigma of viral infection (*73*) (Figure 12A) and facilitates a better understanding of endocytosis. The group also gained new insights into the influence of microtubule geometry on viral infection (*74*) (Figure 12B). They found that the "intersection configuration" of microtubules could interfere with the transport behaviors of viruses in live cells. This geometry produced five new microtubule-dependent transport behaviors, including long-duration pauses and directional changes. Most of the viruses move along straight microtubules rapidly and unidirectionally, from the cell periphery to the microtubule organizing center (MTOC) near the bottom of the cell, such that the viruses are confined to a grid of microtubules near the top of the cell and at the MTOC near the bottom of the cell.

In further studies, the group established a temporally controllable capsid-specific HaloTag labeling strategy based on reverse genetics, which enables continuous visualization of the entire process of virus infection and replication. When combined with single-virus tracking, this strategy provides a versatile tool for capturing a global view of the dynamic viral lifecycle (*75*).

Achievement V: Genetic and epigenetic regulation of gene expression.

Xiang-Dong Fu's group focuses on two specific subfields of RNA biology: pre-mRNA processing and its coupling to transcription, and microRNA biogenesis and function.

1. Position-dependent regulation of alternative splicing by RNA binding proteins.

Fu's group discovered that PTB (a known splicing repressor) and U2AF (a well-established splicing activator) have opposing functions:

PTB binding near the alternative exon causes exon skipping, and its actions near distal constitutive splice sites also result in exon skipping (*76*). In comparison, U2AF shows the opposite functional consequences in those distinct locations (*77*). Fu's group discovered that SR-family splicing regulators exert either synergistic or antagonizing effects, depending on their pre-mRNA substrate, on the control of position-sensitive regulation of alternative splicing (*78*).

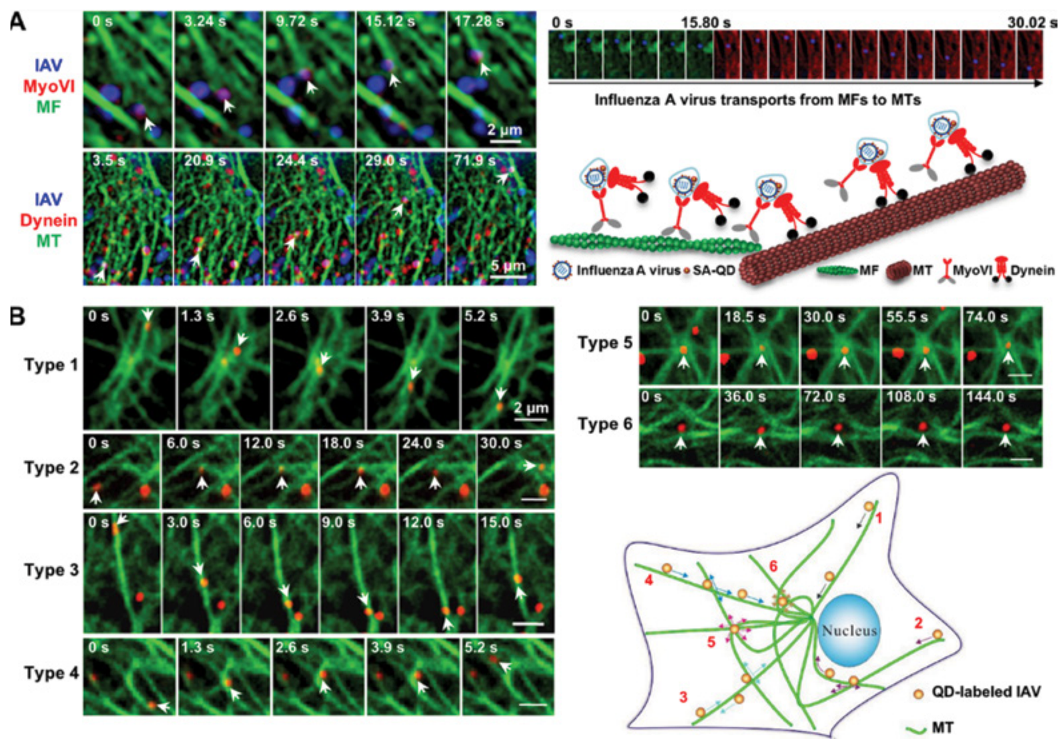

FIGURE 12. (A) To reach the cell nucleus, an avian influenza virus (IAV) translocates through the cytosol along microfilament and microtubule "railways" and is transferred from one track to another by the motor-mediated "driver switchover" mechanism (*73*). (B) In the microtubule-mediated, long-range transport process, an IAV has six choices of motion types when it encounters a microtubule intersection (*74*).

2. RNA-binding proteins at the interface of transcription and RNA processing.

Fu's team focuses on typical SR protein family members, which they found are directly involved in transcriptional control at gene promoters. The mechanism for this regulation involves the critical CDK-kinase complex pTEFb, which switches through a serine/arginine (SR) protein-dependent process, from the inhibitory 7SK complex to nascent RNA located near gene promoters (*79*). The group extended the analysis to all the major members of the SR and hnRNP family of RNA-binding proteins and showed that many of them could modulate transcription (*80*). More recently, the group has applied these concepts to understanding the function of SRSF2 in disease (*81, 82*).

3. Regulation of microRNA biogenesis by RNA-binding proteins and lncRNA.

Fu's group also found that the long noncoding RNA (lncRNA) Neat1, which is involved in the organization of nuclear paraspeckles, interacts with both specific RNA-binding proteins and the Microprocessor complex (*83, 84*). These findings reveal a new mechanism for lncRNA-regulated microRNA processing and provide critical insights into RNA-mediated phase separation and its functional impact. In a separate study, they discovered that the nuclear matrix protein SAF-A/hnRNP U plays a related role in regulating the formation of the Cajal body as a mechanism to modulate alternative splicing (*85*).

4. Novel microRNA activities in cancer and cell differentiation.

Another area of focus for Fu's group is microRNA-mediated mRNA decay. The team discovered that excessive target RNA, such as HBx present in HBV-infected cells, can induce the targeting of specific microRNAs for degradation. They reported that specific microRNAs also could function in the mitochondria, especially in the enhancement of mitochondrial translation critical for muscle differentiation (*86*). In another line of research, they serendipitously discovered that depletion of the splicing repressor PTB induces transdifferentiation of diverse cell types into neurons (*87*). They seized upon this unexpected finding to uncover a novel RNA program that drives neuronal induction, in which PTB antagonizes a neuronal-specific microRNA. These findings have paved the way to an understanding of the processes underlying the generation of new neurons, which may lead to applications in regenerative medicine.

IV. A perspective on the future

After decades of maturation, SKLV has emerged as an internationally recognized virology research center with a proven capacity for sustained innovation. To continue strengthening its research programs, and with the support of Wuhan University, the Wuhan Institute of Virology, and CAS, SKLV plans to recruit 20–30 full-time principal investigators in virology and related fields in the coming years.

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The State Key Laboratory of Hybrid Rice

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I. Introduction

Established in October 2011, Wuhan University's State Key Laboratory of Hybrid Rice (SKLHR) ranked in the top 10% of state key laboratories in 2016 for research excellence and is increasingly recognized as one of the premier state-sponsored key laboratories. SKLHR's core facilities consist of a 6,000-m^2 laboratory building, a purpose-built 2,300-m^2, environment-controlled greenhouse, a 47-acre rice field station in Wuhan, and a rice winter-breeding field station in Hainan. Each year, 242 graduate students join SKLHR for academic training and career development. Since 2011, SKLHR has successfully trained 167 Master's and 162 doctoral students.

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The faculty of SKLHR is dedicated to laboratory and fieldwork, teaching and mentoring, and to translating their academic findings into premier crop-breeding programs that profoundly contribute to agricultural efficiency, food security, and environmental protection. Some notable achievements include discovering the functional genes for male sterility in Honglian (HL)-hybrid rice and the fertility-restorer genes *Rf5* and *Rf6*, and elucidating the molecular mechanisms underlying cytoplasmic male sterility (CMS) and fertility recovery in HL-hybrid rice. SKLHR's standard breeding programs for HL-hybrid rice have led to its widespread planting in China and Vietnam, the Philippines, Malaysia, and sub-Saharan Africa. Another of SKLHR's achievements is the cloning of brown planthopper (BHP)-resistance genes from wild rice; the genes have been successfully bred into several elite rice cultivars to develop new varieties that offer effective and long-lasting planthopper control.

SKLHR chiefly focuses on the following six research areas:

1. The molecular mechanisms of rice heterosis

SKLHR scientists have established new theories and methods to effectively control plant fertility and facilitate the breeding of improved crops. They have cloned and functionally characterized several quantitative trait loci (QTL) and genes that contribute to heterosis. A priority for SKLHR is gaining a better understanding of the genetic basis of heterosis and the mechanisms for the strong dominance of *indica* and *japonica* subspecies and their interspecific hybrids.

2. Mechanisms for the development and fertility of rice

SKLHR researchers are also studying the genes involved in fertility and their regulatory roles in triple-crossed rice and two-line hybrid rice as well as the molecular basis of rice development, pollination and fertilization, seed development, plant development, and high yield. They hope to establish novel methods for controlling rice fertility, exploiting heterosis for breeding of new rice varieties, and generating superior male-sterile and restorer lines of rice.

3. Hybrid-rice germ plasm innovation and gene discovery

To obtain superior hybrid-rice germ plasm for future sustainable agricultural and environmental protection, and to secure the protection of seed production by intellectual property (e.g., patents, trademarks, and copyrights), SKLHR scientists are using hybrid-rice germ plasm resources to clone and characterize genes that confer superior traits. The laboratory is striving to generate hybrid-rice germ plasm for plants with enhanced photosynthetic efficiency, disease and insect resistance, and abiotic stress resistance.

4. The "super hybrid rice" breeding program

SKLHR is focusing on several areas of plant breeding for their superior hybrid-rice program, including the use of heterosis among subspecies, innovative breeding techniques, and methods such as polymerization, intervariety hybridization, intersubspecies hybridization, hybridization of distantly related subspecies, molecular marker–assisted selection, spaceflight breeding, and somatic cell clones.

5. Hybrid-rice breeding and seed science

SKLHR is also conducting basic and applied research to elucidate the physiological and biochemical mechanisms of hybrid-rice biology, and working on automated planting with sowing machines and germ plasm–related propagation and identification.

6. The physiology and ecology of super high-yield hybrid rice

SKLHR scientists are also keen to develop new approaches and techniques for improving the efficiency of plants' light-energy harvesting, cultivation physiology and ecology, and anti-inversion cultivation physiology.

II. Representative achievements of SKLHR scientists

Achievement I: Honglian-hybrid rice—research and applications

Although hybrid rice is typically regarded as one of the most prominent examples of successful heterosis in crop plants, little is known about the underlying mechanisms of rice heterosis. Hybrid rice is typically classified as either a two-line or three-line type, based on the characteristics of the male-sterile lines. Three-line hybrid rice can be further categorized into three subtypes: wild abortive (WA), Honglian (HL), and Baotai (BT) types. This classification is based on the genetic and cytological characteristics of CMS, which has been extensively used for hybrid seed production (*1*).

FIGURE 1. SKLHR scientists investigate the performance of Honglian (HL)-hybrid rice in the field. Credit: Shaoqing Li

1. Honglian hybrid rice's profound contribution to world food security

HL-hybrid rice, developed by Wuhan University in the 1970s, differs from the WA and BT types in that it possesses the useful traits of gametophytic sterility and fertility restoration (Rf). After endeavoring for nearly three decades, SKLHR scientists finally overcame the many challenges hindering industrialization of HL-hybrid rice, including the large-scale production of pure male-sterile lines and the stable and potent restoration of fertility to the hybrids. In the early 2000s, the scientists developed a few elite HL-hybrid rice varieties, such as Honglianyou 6, Yueyou 938, and Luoyou 8, which have been widely popularized in the mid-Yangtze River region of China (Figure 1). HL-hybrid rice integrates many excellent traits, including high grain yield, good rice quality, wide adaptability, high nitrogen (N) utilization, and high-temperature endurance during the flowering period, all of which have ensured its outstanding production and popularity in the market.

Importantly, HL-hybrid rice performs better in Southeast Asian countries than any other type of hybrid rice, offering almost double the grain yield compared with local rice varieties. Today, HL-hybrid rice is widely planted in the Philippines, Vietnam, Indonesia, Malaysia, Bengal, Myanmar, and Pakistan. Over 500,000 acres of HL-hybrid rice are cultivated in the Philippines each year (*2*), representing about three-quarters of the total area of cultivated hybrid rice. In 2013, the HL-hybrid rice Luoyou 8 was awarded the national "Food Security Gold Award" in Vietnam, reflecting HL-hybrid rice's impressive contribution to world food security.

2. Elucidating the genetic mechanism of CMS in HL-hybrid rice

Breeding of CMS and fertility restorer lines forms the basis for the development of hybrid rice. To exploit this breeding by molecular techniques, SKLHR scientists cloned *orfH79*, the gene responsible for CMS in HL-hybrid rice. *orfH79* is an aberrant chimeric mitochondrial gene that encodes a 79-residue amino-acid peptide located downstream of *H-atp6*; the two genes are cotranscribed to form an atp6-orfH79 dicistron (*3*). The ORFH79 peptide interacts with P61, a subunit of the electron transport complex III, causing a decline in

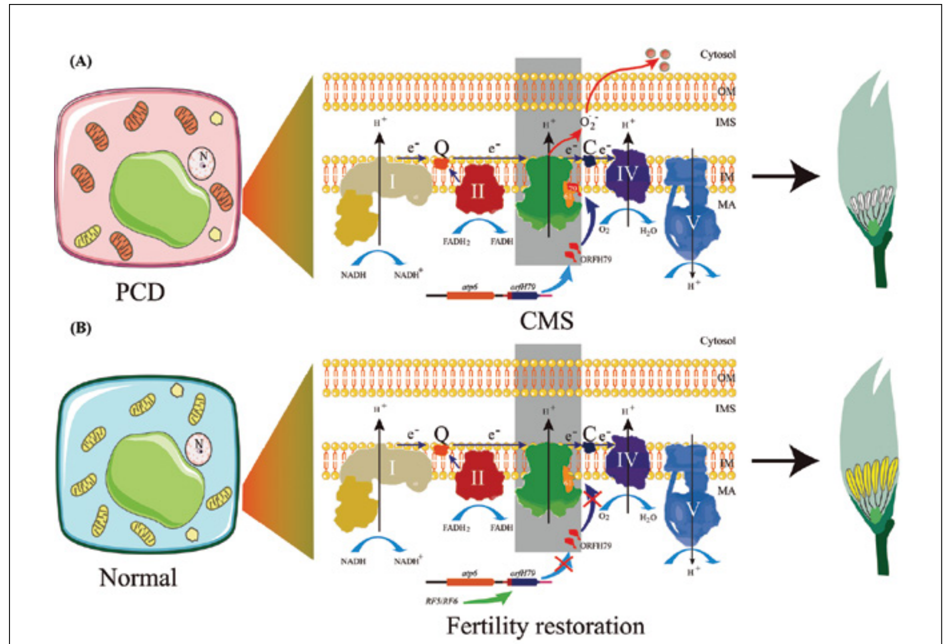

FIGURE 2. Schematic diagram of the mechanisms of (A) Honglian CMS and (B) restoration of male fertility in Honglian hybrid rice. *See text for details.* CMS, cytoplasmic male sterility; PCD, programmed cell death; NADH, nicotinamide adenine dinucleotide; FADH, flavin adenine dinucleotide; IMS, intermembrane space; OM, outer membrane; MA, matrix space; N, nucleus. Credit: Shaoqing Li

mitochondrial function and ultimately pollen sterility through an atypical programmed cell-death process (Figure 2A) (*4*). SKLHR scientists used *orfH79* as a molecular marker to screen wild rice and landrace resources, and found 32 lines carrying the CMS cytoplasm. Using the wild rice accessions, they developed four new CMS lines similar to the HL hybrid.

3. Deciphering the molecular mechanism of fertility restoration in HL-hybrid rice

The complete male sterility of CMS lines makes them a convenient and efficient system for hybrid seed production (*1*). Studies have shown that the rice nuclear genome contains a class of *Rf* genes that eliminate the fertility impairments conferred by CMS genes. In the Honglian system, one pair of *Rf* genes can completely rescue fertility of the spikelet. However, stably maintaining the fertility of F1 hybrids in environments with frequently fluctuating temperatures is challenging, thus hampering the production and popularization of HL-hybrid rice. To address this problem, SKLHR researchers testcrossed thousands of Rf lines with the HL-CMS lines and discovered two *Rf* genes, *Rf5* and *Rf6*, in restorer line 9311 (*5*). These genes effectively help the plant withstand unfriendly climes, thereby accelerating the breeding and popularization of HL-hybrid rice (*5*).

Further investigation by map-based cloning revealed that *Rf5* is located on chromosome 10, and encodes a 791 amino-acid residue pentatricopeptide (PPR)-repeat protein that is expressed in all tissues throughout plant development. SKLHR scientists discovered that RF5 could interact with the glycine-rich protein GRP162 (also designated RFC2) to form the 400 kDa–500 kDa restoration-of-fertility complex (RFC). RFC cleaves the CMS-associated transcripts *atp6-orfH79* and *orfH79(s)*, thereby blocking the formation of the toxic ORFH79 peptide (Figure 2B). They also found that GRP162 forms a homodimer that directly binds to the CMS-associated transcripts *atp6-orfH79* and *orfH79(s)* at different loci. These data suggested that GRP162 is a candidate for engineering as an artificial *Rf* gene. Further molecular analysis showed that the restoration mechanism of Mt-GRP162 entails suppression of the cytotoxic ORFH79 peptide at a posttranscriptional level rather than cleavage of *atp6-orfH79* (*6*).

Seeking further insights into the mechanism of restoration of fertility, SKLHR researchers identified RFC3, a third subunit of RFC. RFC3 is a DUF1620-containing and WD40-like repeat protein that interacts with RF5 and GRP162 in vitro and in vivo. Using RNA interference (RNAi) lines, they showed that RFC is disrupted upon downregulation of RFC3 expression, suggesting that RFC3 functions as an indispensable scaffold protein for the assembly of the RFC complex (*7*). The scientists also identified two other subunits, one responsible for the sublocalization of the RFC complex and the other encoding an endonuclease that directly cleaves CMS-associated transcripts.

In other work, SKLHR scientists discovered that *Rf6* encodes a novel PPR-family protein with a characteristic duplication of PPR motifs 3–5. Similar to RF5, RF6 localizes to the mitochondria where it physically associates with hexokinase 6 (OsHXK6) and promotes the processing of the CMS-associated transcript *atp6-orfH79* at nucleotide 1238. This mechanism ensures normal pollen development and leads to restoration of fertility. The researchers also showed that the duplicated motif 3 of RF6 is essential for the RF6-OsHXK6 interaction, aberrant transcript processing, and restoration of fertility. A decrease in the levels of OsHXK6 triggers an accumulation of the *atp6-orfH79* transcript, resulting in male sterility, and suggesting that OsHXK6 is required for the restoration of *Rf6* in HL-CMS fertility (*8*).

In sum, this project has provided novel insights into the various mechanisms by which *Rf5* and *Rf6* regulate mitochondrial RNA metabolism in HL-hybrid rice.

Achievement II: Exploring host resistance for sustainable control of the brown planthopper in rice

Rice is one of the world's primary staple food crops. Its yield, however, is threatened by the brown planthopper (BPH), *Nilaparvata lugens* (Stål), one of the most destructive rice crop pests (Figure 3A). BPH infestation can cause a costly reduction in rice yield, thus posing a severe threat to world rice production (*9*). Cultivating BPH-resistant rice varieties is an economical, practical, and environmentally sustainable strategy to control this pest, which has prompted SKLHR researchers to explore the use of BPH-resistance genes and their use in sustainable-control strategies for rice imperiled by BPH.

1. Exploring BPH-resistance genes in rice germ plasm

Some wild rice species and traditional rice varieties are naturally highly resistant to BPH. SKLHR scientists have taken advantage of these traits by hybridizing and backcrossing BPH-resistance genes into the germ plasm of modern rice varieties, using molecular markers to map their chromosomal locations. They identified the genes *Bph6*, *Bph7*, and *Bph9* in the landraces (Figure 3B), and

Bph12, *Bph14*, and *Bph15* in the wild-rice species (*10–16*).

2. Isolation and functional characterization of BPH-resistance genes

SKLHR researchers identified the first BPH-resistance gene, *Bph14*, using a map-based cloning strategy (*17*). *Bph14* encodes a protein with a coiled-coil, nucleotide-binding site, and leucine-rich repeat (CC-NB-LRR) motif. The BPH14 protein functions as a receptor that perceives signals delivered by BPH during feeding. It forms a homocomplex that interacts with the transcription factors WRKY46 and WRKY72 to activate the salicylic acid signaling pathway and expression of defense genes (*18*). The scientists also showed that the *Bph9* gene on chromosome 12L encodes a rare type of CC-NB-LRR protein that contains two nucleotide-binding site (NB) domains (*19*). Eight of the BPH-resistance genes previously mapped to chromosome 12L are alleles of *Bph9*, suggesting that its allelic diversity is a vital mechanism for combating the naturally occurring variation of insect virulence (*19*). *Bph15* falls within the genomic region that contains a gene encoding the plasma membrane-localized lectin receptor kinase (LecRK). LecRK interacts with OsADF to activate expression of the defense genes that confer resistance to BPH (*20*). SKLHR scientists also discovered *Bph6*, a gene that encodes an uncharacterized protein that localizes to exocysts and interacts with OsExo70E1 to promote exocytosis for cell-wall maintenance and reinforcement (*21*). Collectively, these results constitute the crucial discovery that the proteins encoded by BPH-resistance genes function as immune receptors in plants.

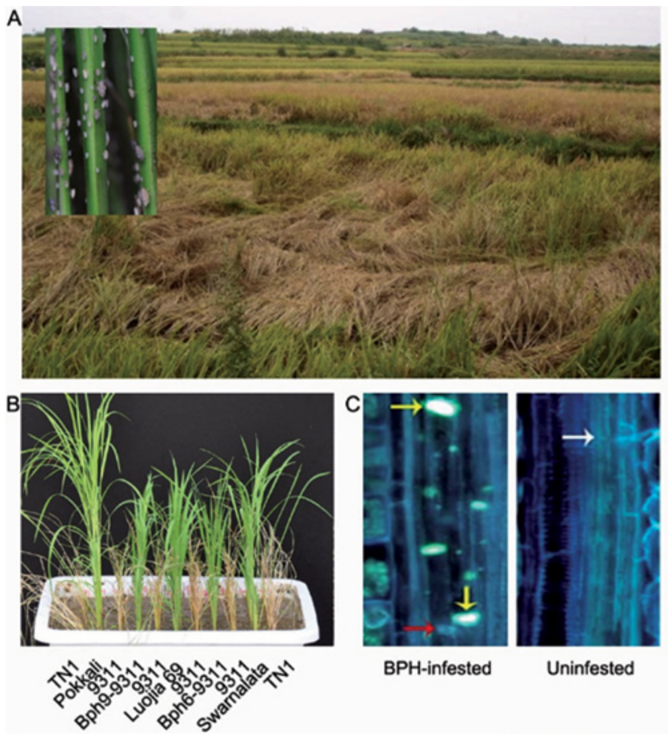

FIGURE 3. SKLHR scientists are working on solutions to fight the brown planthopper (BPH), which threatens rice production. (A) BPH insects on rice plants (upper left) and a rice crop heavily damaged by BPH. (B) A comparison of the performance of rice lines carrying different resistance genes under BPH attack. (C) BPH-induced callose deposition on the sieve plates of rice, a crucial mechanism of resistance. Credit: Guangcun He

3. Molecular mechanism of rice resistance to BPH

Brown planthopper (BPH) insects secrete saliva into rice tissues during the feeding process (*22, 23*). The saliva contains cues recognized by BPH-resistance proteins, which coordinate the jasmonic acid, salicylic acid, and cytokinin signaling pathways (*17–21*). SKLHR researchers demonstrated that BPH feeding on rice elicit the reprogramming of the plant's transcription and activation of its defense mechanisms (*24–27*). One such defense is the induction of callose deposition on sieve plates, which occludes the sieve tubes and directly inhibits feeding (Figure 3C) (*28*). They also discovered that proteins and metabolites implicated in chemical defenses against insect herbivores are elevated in resistant rice plants (*21, 29, 30*).

4. Application of BPH-resistance genes in rice breeding

The BPH-resistance genes identified by SKLHR scientists display broad-spectrum resistance to BPH and whitebacked planthopper (WBPH) without sacrificing yield, making them popular in rice-breeding programs (*16, 21*). The SKLHR's release of rice varieties carrying *Bph14* and *Bph15* has laid the foundation for the sustainable control of BPH with reduced use of chemical pesticides.

Achievement III: The molecular mechanism of fertilization and early embryogenesis in angiosperms

Fertilization and early embryogenesis are essential processes in plant sexual reproduction, and are the critical developmental stages for studying crop fertility during crop breeding, especially for crossing different subspecies, species, or cultivars. SKLHR scientists established a series of novel approaches to investigate the molecular mechanisms underlying these processes, including a highly efficient method for gamete isolation, and in vitro fertilization and in vitro embryogenesis systems for cellular and molecular biological studies, based on small numbers of gametes (Figure 4). They have also established a complete database of species-specific gene expression patterns in eggs, sperm, zygotes, and early embryos. These tools have allowed them to investigate critical areas of sexual plant reproduction, such as gamete development and its impact on early embryogenesis, the maternal to zygotic transition, the contribution of parent-of-origin genes to early embryogenesis, cell-fate determination during early embryogenesis, and cell-cell communication in plant sexual reproduction.

Recently, SKLHR scientists cloned the first maturation factor in egg cells. Studies indicated that cell–cell communication between gametes plays a critical role in gamete maturation, and that the late-stage processes of egg-cell maturation are dispensable for fertilization, but required for the initiation of embryogenesis. They showed that during the process of maturation, the egg cell produces molecular machinery required for embryogenesis and requires de novo transcription for the initiation of embryogenesis after fertilization. Moreover, in dicot zygotes, the process of genome activation follows a timecourse with unique characteristics. In another avenue of research, the scientists developed a model system using embryonic suspensors to study the molecular mechanisms underlying cell-fate determination. They discovered that autonomous cell-fate specification occurs at the two-celled proembryo stage immediately following zygote division. The basal-cell lineage continues to have the potential for embryogenesis but is suppressed by the apical-cell lineage. They also identified a molecular switch that controls programmed cell death of the suspensor during embryogenesis and elucidated its molecular mechanism. These results have enhanced the understanding of the mechanisms underlying fertilization and embryogenesis, and introduced new concepts of plant sexual reproduction, especially relating to crop improvement.

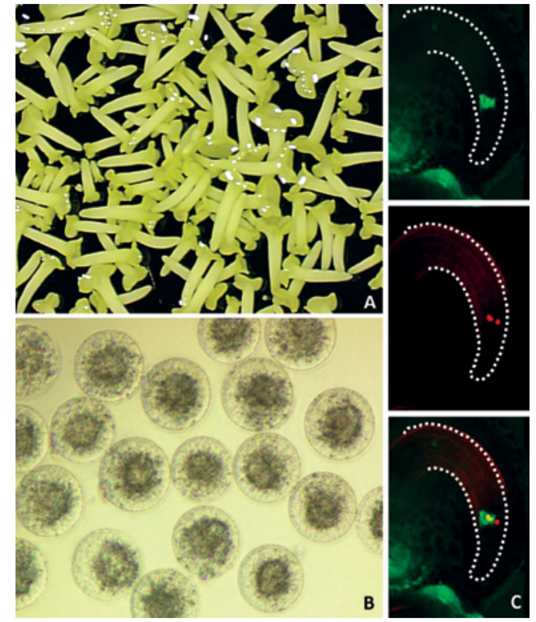

FIGURE 4. Research on plant gamete development and fertilization. (A) A population of embryos derived from microspores. (B) Isolated egg cells from maize. (C) The fusion of sperm nucleus (red) with central cell nucleus (green) in *Arabidopsis* embryo sac (dotted line). Credit: Meng-Xiang Sun

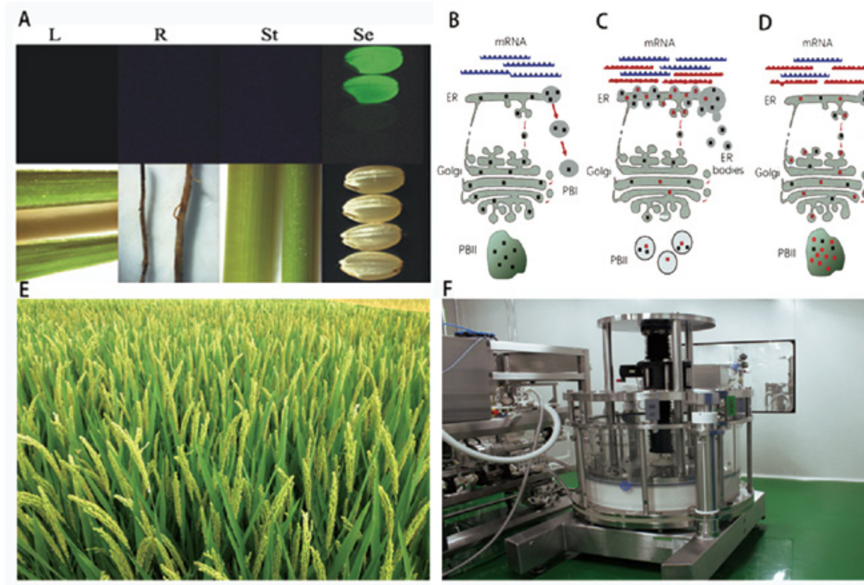

FIGURE 5. Rice endosperm as a bioreactor to produce recombinant human proteins. (A) The structure of the rice endosperm-specific *Gt13a* promoter (L=leaf, R=root, St=stem, and Se=endosperm). (B) Normal protein trafficking in the endomembrane system. (C) Overexpressing recombinant proteins cause endoplasmic reticulum (ER) stress, which elicits ER-associated degradation (ERAD) of proteins. (D) Alleviation of ER stress improves protein trafficking and expression of recombinant proteins by reducing endogenous storage protein expression. Red bars indicate recombinant protein. (E) and (F) Rice field trial for raw-material production and pilot-scale manufacturing, respectively. mRNA, messenger RNA; PBII, protein body type II. Credit: Daichang Yang

Achievement IV: From rice to blood—a significant milestone for recombinant human protein production

Human serum albumin (HSA) is the most abundant protein in blood, constituting 40%–50% of plasma proteins and maintaining plasma oncotic pressure and fluid balance in the body. Since World War II, HSA has been used widely as a blood volumizer to treat patients with blood loss after major surgeries, malfunctions of the liver including cirrhotic ascites, and other types of hypoalbuminemia (*33*). Since the only source of HSA is human plasma donations, the supply is severely limited by the increasing demand from developing countries and possible risk of viral contamination.

Since 1981, scientists have used recombinant DNA technology to produce recombinant HSA (rHSA) in organisms such as bacteria, yeast, animals, and plants (*34–38*). However, the cost-effective production of sufficient nonimmunogenic rHSA for the large dosing of human treatments has been challenging, and no clinical trials have been attempted.

Currently, three major obstacles remain. First and most importantly, since HSA is often used in extremely high dosages, recombinant rHSA needs to be of exceptionally high purity to be safe for human use, and a highly sensitive assay is required to ensure it is free of trace amounts of residual host-cell protein. Second, expression levels of rHSA must be sufficient to justify the cost of purification. Third, rHSA must be produced in large enough quantities to satisfy the massive shortage of supply while remaining affordable.

To overcome these hurdles, SKLHR researchers have used rice endosperm as a bioreactor to produce clinical-grade rHSA. They achieved a high yield of 9.6 g rHSA/kg of brown rice in a single batch at pilot scale by combining several different strategies: the use of an endosperm-specific promoter to drive HSA expression (Figure 5A), the specific targeting of rHSA to storage vacuoles, endoplasmic reticulum (ER)-stress alleviation to improve target-protein trafficking (Figure 5B–5D), and the use of codons optimized for rice. They further achieved a purity of >99.99% OsrHSA (rHSA from *Oryza sativa*) with just three steps of chromatography, and established a sensitive, accurate, and process-based assay to measure trace residual host-cell proteins with a detection limit as low as 1.25 ng/mL (*39*). The SKLRH could at least meet the global demand for OsrHSA through a good manufacturing practice (GMP)-compliant process with easy scalability and cost-effectiveness capable of producing at pilot scale a single batch of OsrHSA weighing 5 kg in only 36 h (Figures 5D and 5E).

OsrHSA was confirmed to be identical to plasma-derived human serum albumin (pHSA) in terms of amino-acid sequence, circular dichroism spectrum (Figure 6A), crystal structure (Figure 6B), location of 17 disulfide bonds (Figure 6C), and drug-binding sites (Figure 6E) (*40*). A comprehensive panel of preclinical studies in Sprague–Dawley rats and cynomolgus monkeys confirmed that OsrHSA and pHSA are identical in all measurable pharmacological, toxicological, and pharmacokinetic properties (Figure 6F), and that OsrHSA and pHSA are equivalently efficacious in the in vivo treatment of ascites in rats with liver cirrhosis and ischemic shock in rabbits (Figure 6G). The immunogenicity potentials of OsrHSA also proved similar to those produced in animals, and the immunogenicity and anti-drug antibody (ADA) residual host-cell proteins in OsrHSA were low in rats and unlikely to elicit allergic responses in humans. Armed with these solid preclinical results, in 2017 the SKLHR sought and won approval by the China Center for Drug Evaluation (CDE) for a first-in-human clinical trial testing the safety and efficacy of OsrHSA.

SKLHR's rice endosperm expression platform boasts many superior features: high expression, facile scalability, reliability, ease of processing, cost-effectiveness, absence of prions, and environment friendliness. The system can produce high yields of human proteins falling within a molecular mass of 14 kDa–125 kDa and an isoelectric point of 4.5–11.0. As noted by one of the project scientists, Daichang Yang, "Hopefully in the future, with a little help from rice, we can drastically decrease the prohibitive cost of biological pharmaceuticals and satisfy the demands [for them] independent of plasma donations."

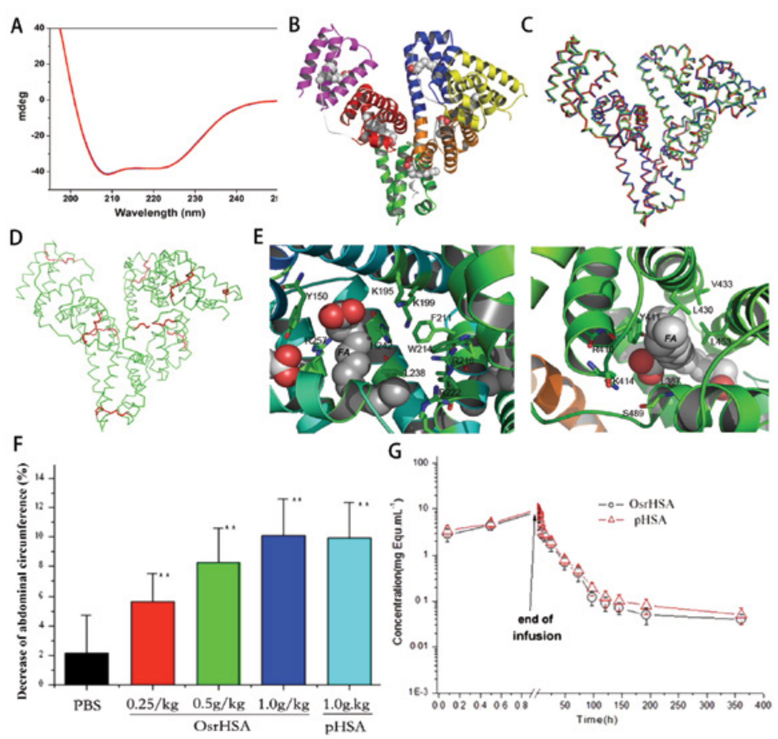

FIGURE 6. Chemical and physical characteristics, efficacy, and pharmacokinetic properties of OsrHSA (recombinant human serum albumin from *Oryza sativa*). (A) Circular dichroism spectra of OsrHSA (red) and pHSA (plasma-derived human serum albumin, blue). **(B)** Overall crystal structure of OsrHSA. **(C)** Superposition of molecule of OsrHSA (green) and HSA from program database files with codes 2I2Z (blue, rmsd=0.67 Å) and 1BJ5 (red, rmsd= 0.69 Å). **(D)** Disulfide profile of OsrHSA showing location of disulfide bonds. **(E)** OsrHSA drug-binding sites I and II. Myristic acid moieties binding near drug sites are represented as spheres. **(F)** The efficacy of OsrHSA is equivalent to that of pHSA in the treatment of ascites in rats with liver cirrhosis (*40*). **(G)** The pharmacokinetic properties of OsrHSA in monkeys. rmsd, root-mean-square deviation; PBS, phosphate buffered saline.

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PART 5: Engineering research at the GRC

The GNSS Research Center at Wuhan University

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Founded in January 1998, the Global Navigation Satellite System (GNSS) Research Center (GRC) at Wuhan University is China's Ministry of Science and Technology's (MOST's) national center for engineering research. It comprises six research units: the Institutes of Space & Time Datum, BeiDou Navigation, Location-Based Services (LBS), Intelligent Multisensor Navigation, Internet-of-Things (IoT), and the International GNSS Service (IGS) Analysis Center at Wuhan University.

The GRC is not only a crucial platform for research and innovation in satellite navigation in China, but is also one of three major data and analysis centers within the IGS. MOST has designated the GRC a pilot unit for navigation and location service technology nationwide, making it one of China's largest institutions for GNSS positioning and navigation research and applications, and for related graduate education. Wuhan University's well-established satellite navigation–relevant curriculums, personnel training, and international collaboration have made the GRC a premier institution in the exploration of new technologies and methodologies for satellite navigation and positioning technologies, as well as for training high-profile engineering professionals.

Research platforms and facilities

The GRC is an influential scientific research facility that hosts many prestigious national and international research labs and centers. These include the National Engineering Research Center for Global Satellite Positioning Systems; the Ministry of Education Key Laboratory for Satellite Navigation and Positioning; the National Administration of Surveying, Mapping, and Geoinformation; the Shanghai Key Laboratory of Navigation and Location-Based Services (LBS); the Ministry of Education Joint Research Center for the BeiDou Navigation Satellite System; and the Ministry of Education Joint Research Center of the Crustal Movement Observation Network of China.

The GRC is also home to organizations within the IGS: namely, the IGS's Analysis Center, Data Center, Multi-GNSS Experiment (MGEX) Analysis Center, and Ionosphere Analysis Center. The GRC also manages two organizations within the International GNSS Monitoring and Assessment System (iGMAS): the GMAS Data Center and iGMAS Analysis Center. It has built many research facilities, including the IGS Reference Station, Galileo Reference Station, BeiDou Global Observation Experimental Network, and BeiDou Ground-Based Augmentation Network.

GRC's main research areas include the acquisition and maintenance of high-precision time and space data; theory, methods, and software for GNSS positioning and navigation, and an augmentation system for application in precise positioning; navigation chips and terminals (i.e., integrated navigation); navigation and LBS; indoor positioning and indoor/outdoor seamless navigation; and precise timing based on GNSS and time synchronization.

Graduate education

The GRC is deeply committed to building world-class graduate education in the GNSS field. Recruiting both doctoral and Master's degree candidates, the center emphasizes each student's ability to innovate and acquire practical abilities as well as an international perspective, which will make them leaders in their careers. GRC students achieve fundamental knowledge, professional breadth, high standards of quality and creativity, and a keen specialization in positioning and navigation to meet the national demand for highly skilled personnel in this area.

International academic communications

The IGS has recognized the GRC as an analysis center since 2012, a fifth data center since 2014, and the Ionospheric Center since 2016. Many GRC researchers have served in international academic organizations, GNSS research communities, and on the editorial boards of well-known international journals. These illustrious figures include Liu Jingnan, a board member of the International GNSS Service; Jiang Weiping, a member of the International Association of Geodesy in the Next-Generation Gravity Mission Group; Zhao Qile, a member of the IGS Governing Board and the Multi-GNSS Group; Geng Jianghui, an associate member of the IGS and the IAG SG442 Multi-GNSS group, and a member of the University NAVSTAR (Navigation Satellite Time and Ranging) Consortium (UNAVCO); Li Min, a director of the WHU Analysis Center of the IGS and member of the IGS SG 4.3.x Real-Time GNSS Group; Liu Hui, the chairman of the Radio Technical Commission for Maritime Services (RTCM) Special Committee (SC) 104 Network Working Group, and a member of the editorial board of the journal *GPS Solutions*; and Niu Xiaoji, a key staff member of the International Society for Photogrammetry and Remote Sensing (ISPRS) Working Groups 1 and 7.

Scientific research and awards

The GRC's main research interests include satellite navigation–augmentation systems and precision positioning; indoor and outdoor seamless navigation technology; integrated navigation technology and applications; high-precision low-power navigation chips; navigation-terminal design and applications; IoT communication technology; cloud computing applications; advanced vehicle-navigation systems and LBS; radar systems and information-processing technologies; intelligent-control technologies; and power-management chips.

GRC scientists have made many internationally and nationally recognized achievements in satellite navigation and related fields. For instance, they have pioneered a wide-area differential global positioning satellite (GPS) system for China and proposed an innovative distributed wide-area differential technology. They have developed the first Chinese satellite navigation precision data-processing software, PANDA (Position And Navigation Data Analyst), which has become the core data processing software for scientific projects such as the Crustal Movement Observation Network of China, and has been applied to research projects in the United States, the Netherlands, the United Kingdom, Australia, and other countries. GRC researchers have developed a relative mechanical

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model for satellite clusters and proposed a state-parameter estimation method to perform relative-orbit determinations that achieve an accuracy of 1 mm~2 mm. Furthermore, the GRC's theory of fast and precise orbit determination for spacecraft has improved satellite orbit accuracy from 5 m~10 m to 2 cm~3 cm, providing critical support for the operation of satellite systems such as the BeiDou Navigation Satellite System (BDS), Ocean No. 2, and Resources No. 3.

The GRC is also a pioneer in building China's regional GPS and Beidou navigation ground-based augmentation systems, which provide cm-level real-time location services. GRC scientists built the BDS high-precision observation experiment network and the Beidou Data Center and Data Analysis Center. They also solved critical problems in the GNSS fiducial station network by establishing a new system for the base-station network and implementing a new engineering solution. In addition, they have helped modernize Chinese surveying benchmarks by developing a new coordinate reference framework.

The GRC has conducted 15 projects funded by the 863 Program, four projects funded by the 973 Program, and 41 projects funded by the National Natural Science Foundation of China (NSFC), and is now taking on four projects as part of the National Key Research and Development Program. The GRC has also taken part in a national major scientific and technological infrastructure construction project and a European Union FP6 project, as well as other international cooperation projects. It is managing over 30 research projects funded by provincial or ministerial bodies, including the Science and Industry Commission of National Defense, the Ministry of Science and Technology, the Ministry of Education, and the Hubei Provincial Government, as well as over 300 other engineering projects and programs.

The GRC has twice won the National Science and Technology Progress Prize (second class), and seven times won the Science and Technology Progress Award at the provincial and ministerial level (first class). It has won more than 10 other prizes, including the Outstanding Contribution Prize awarded by the General Armament Department of the Chinese People's Liberation Army, the Army's Science and Technology Progress Award (second class), as well as Science and Technology Progress Awards at the provincial and ministerial level. The GRC also has been designated as the BDS's only civilian data center for its contribution to the BDS-2 system.

Cooperation and industrialization

The GRC has collaborated closely with universities, research institutes, and high-tech companies in more than 20 countries and regions. These include the GFZ German Research Centre for Geosciences, Nottingham University, the Royal Melbourne Institute of Technology, Newcastle University, the University of Calgary, the State Geospatial Information Center of China, the China Aviation Industry Corporation, and the China Aerospace Science and Technology Corporation. To promote the industrialization of navigation products and expand its market, the GRC also provides technical support for various companies, such as the Alibaba Group, Tencent, and Baidu. These collaborations have encouraged academic research and promoted new applications for advanced navigation technologies.


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