Cornucopia: CAS Research Dominant in Top 10 S&T News

By SONG Jianlan (Staff Reporter)

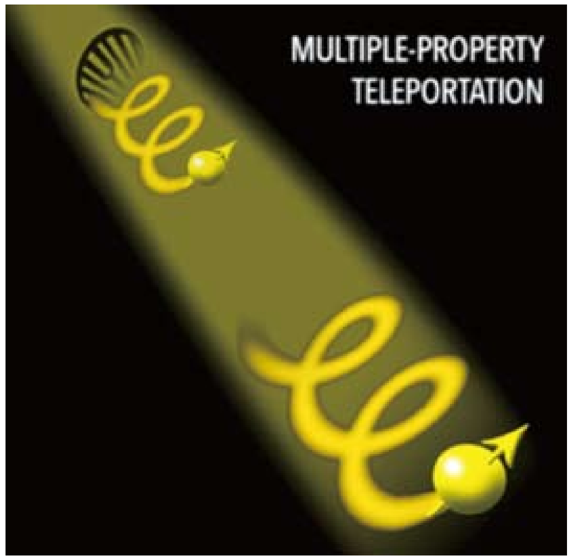
CAS scientists and their work frequently hit headlines in 2015, the final year of the period of the 12th National Five-Year Plan of China (2011–2015). Among the Top 10 Science Advances of 2015 released on February 26 by the Chinese Ministry of Science and Technology, seven resulted from research led or participated in by CAS scientists, including the first six ones and the last.

Approaching the end of every year since 2005, prominent scientists in China vote for the top 10 science advances of China from a large pool of nominees. To decide on the finalists of the year 2015, a large jury, consisting of Members of CAS and the Chinese Academy of Engineering, chief scientists of projects under the National Basic Research Program (dubbed "973 Program") and directors of State Key Laboratories needed to make their choice out of as many as 256 candidates. As expected by many, winner of the First Prize from the 2015 National S&T Awards for Natural Sciences, the breakthrough in quantum teleportation made by a team led by CAS Member Prof. PAN Jianwei at the University of Science and Technology of China (USTC) topped the winner list of this highly competitive event.

Quantum Teleportation of Multiple Degrees of Freedom of a Single Photon

PAN's team has frequently entered the spotlight since their early pursuit of quantum teleportation, a formidable issue on the frontier of quantum mechanics that promises great opportunities in encrypted data communications over ten years ago. According to quantum mechanics, two entangled photons always strictly maintain synchronized in terms of their quantum states — in other words, from either of the photon pair, one can read the quantum state of another, as they share the same state anytime. Taking advantage of this mysterious spooky "empathy" between the pair of photons, scientists can "send" a quantum state from one to the other without sending the carrier photon itself. Moreover, inherent physical law of the quantum world makes it theoretically impossible to intercept the information being sent/shared by the photon pair, because any effort of such purpose can change the quantum state in communication according to quantum mechanics and hence reveals itself. Based on this basic property of quantum entanglement, encrypted data communication can be achieved at a very high level of security via teleportation.

Due to the great potential in encrypted communication, teleportation has become a hotly pursued topic in the physical circle since 1997, when the first successful experimental demonstration of quantum teleportation of single degree of freedom was reported. Quantum teleportation has since been achieved in different physical systems, but all successful efforts had been limited to transmitting only one single degree of freedom of the quantum state. Considering a quantum state naturally involves multiple physical properties — for example, a basic particle as simple as a single photon naturally has a quantum sate defined by wavelength, momentum, spin and orbital angular momentum — quantum teleportation has to break through and deal with the composite quantum state, unless its application in communications would be greatly restricted. Therefore quantum teleportation of multiple degrees of freedom has been seen as necessity for the development of expandable quantum computation and quantum communication network, and attracted intensive attention from researchers all over the world.



A team led by Prof. PAN Jianwei at USTC, a university under the umbrella of CAS, reported successful quantum teleportation of multiple degrees of freedom of a single photon in *Nature* in 2015, the final year of the Period of the 12^{th} National Five-Year Plan (2011–2015). This feat tops the winner list of the annual top 10 science advances elected by prominent scientists of China. (Image by PAN's group.)

In cooperation with Prof. LU Chaoyang and other colleagues, Prof. PAN's group at the National Laboratory for Physical Sciences at Microscale and the Department of Modern Physics of USTC creatively developed a number of novel strategies to manipulate the quantum entanglement of systems involving multiple particles and multiple degrees of freedom, and finally arrived at a solution for quantum teleportation of the composite quantum states of a single photon encoded in both spin and orbital angular momentum.

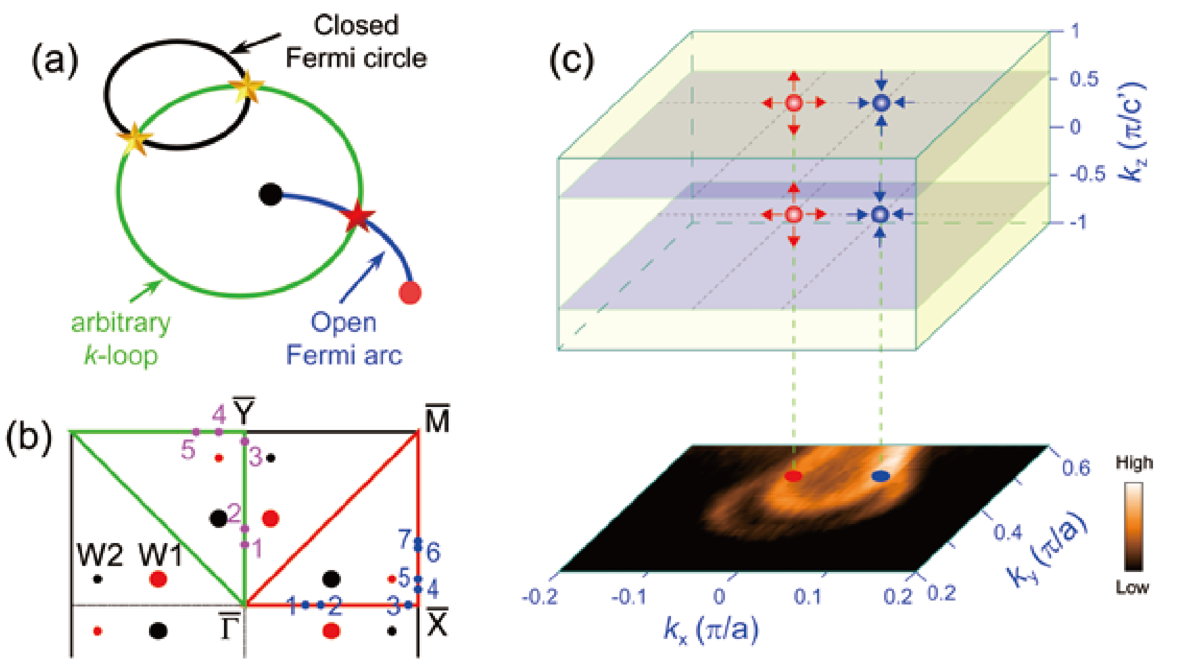
The team used photon pairs entangled in both degrees of freedom (or hyper-entangled) as the quantum channel for teleportation, and developed a method to project and discriminate hyper-entangled Bell states by exploiting probabilistic quantum non-demolition measurement, which can be extended to more degrees of freedom. They then verified the teleportation for both spin–orbit product states and hybrid entangled states, and achieved a teleportation fidelity ranging from 0.57 to 0.68, above the classical limit.

The team reported their discovery in *Nature* on February 26, 2015 (*Nature*, 518, 516–519; doi: 10.1038/nature14246). To highlight this encouraging achievement, *Nature* invited Prof. Wolfgang Tittel, leading expert in photonics to author a commentary in the same issue of the journal. "... Wang[1] and colleagues' demonstration is an important step in understanding, and showcasing, one of the most profound and puzzling predictions of quantum physics. It may serve as a powerful building block for future quantum networks, which generally require teleportation units for the transmission of quantum data, " Tittel commented. This feat stood out from others and was chosen by the Institute of Physics of UK (IOPUK) as the No. 1 of the greatest 10 physical breakthroughs of 2015 in the world.

Theoretical Prediction and Experimental Verification of Weyl Semimetal TaAs

Another achievement achieved by CAS physicists also won the honor to be ranked into the greatest 10 physical breakthroughs of 2015 by IOPUK — the theoretical prediction and experimental identification of Weyl semimetal TaAs, contributed by a joint team led by Profs. FANG Zhong and CHEN Genfu at the CAS Institute of Physics (IOPCAS).

As proposed by German scientist H. Weyl in 1929, the massless solution of the Dirac equation represents a pair of chiral particles, later named as Weyl fermions. However, Weyl fermion as a fundamental particle remains evasive in the following more than eight decades, during



Three groups at the Institute of Physics, CAS predicted and experimentally verified the existence of Weyl fermions in the form of semimetals, a type of exotic condensed matter. (Image by IOPCAS)

[1] First author of the *Nature* paper by PAN's team published on February 26, 2015.

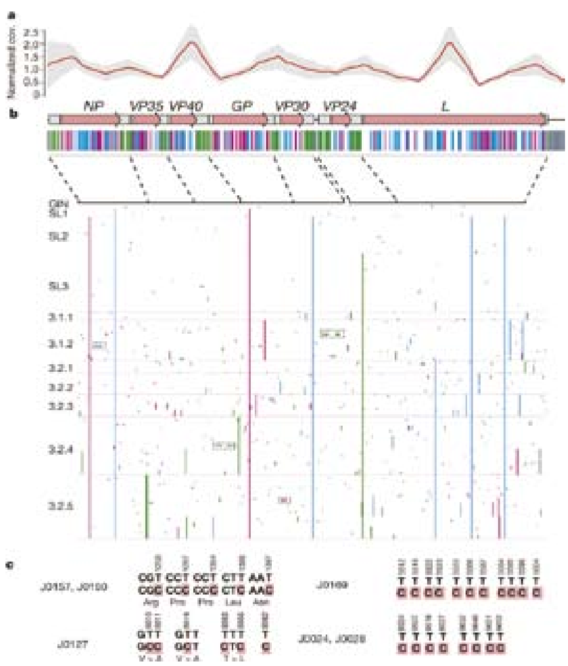
which efforts to verify its existence failed time and time again. Neutrinos, once considered a candidate for Weyl fermions was found to actually possess mass and failed to meet the description given by Weyl. Thankfully, recent developments in topological insulator, particularly topological semimetals have inspired new strategies for the search of Weyl fermions, indicating they could be hosted in Weyl semimetal (WSM), a type of exotic condensed matter.

Drawing on the latest developments in this field, Profs. WENG Hongming, DAI Xi, and FANG Zhong at IOPCAS and their collaborators further predicted via theoretical calculation that the TaAs family, a type of non-magnetic and non-centrosymmetric transition-metal monoarsenide could be a case of WSMs [*Physical Review X*, (5, 011029)]. A group led by their IOPCAS colleague, Prof. CHEN Genfu followed up and successfully grew crystals of this compound. His group also observed negative magnetoresistance in this material, agreeing with the prediction by Weyl [*Physical Review X*, (5, 031023)]. Finally another IOPCAS group, the one involving Profs. DING Hong and QIAN Tian, worked in cooperation with collaborators and observed the 3D electron energy spectrum and Fermi arc [*Physical Review X*, (5, 031013); *Nature Physics*, (11(9): 724–727); and *Physical Review Letters*, (115, 217–601)]. Working hand in hand, the three groups at IOPCAS eventually jointly identified the "phantom particle" that has stayed obscure for over 80 years. On the other hand, a group at Princeton University led by Prof. Z. Hasan and another at Tsinghua University of China led by Prof. CHEN Yulin and their collaborators obtained similar results in their work [*Nature Physics*, (11(9): 728–732)]. Raising many new issues for physicists, their discovery might meanwhile shed new light on the development of revolutionary technologies like electronic devices of low energy consumption.

Evolutionary Dynamics and Genetic Diversity of Ebola Virus

The Ebola epidemic, which broke out early 2014 in western Africa, claimed a death toll of over 11,000 so far. Previous research showed that the virus might have been evolving at a rate twice the mean rate of the previous outbreaks, evoking panic in epidemic prevention institutions and also the worries that the quick mutation rate might help produce strains of even more vicious nature, and might pose challenges to existing virus detection techniques based on PCR.

In cooperation with Prof. CAO Wuchun from the State Key Laboratory of Pathogen and Biosecurity and Prof. HE Fuchu at the State Key Laboratory of Proteomics, CAS Member Prof. George F. GAO at the Institute of Microbiology, CAS (IMCAS) sequenced the large number of specimens collected during their field work in Sierra Leone from September to November 2014, and obtained the data of the full-length genome sequences of 175 strains. Analysis of the data revealed that the Ebola virus causing that round of outbreak had evolved to be more phylogenetically and genetically



Genomic variations of the 2014 Ebola virus.

diverse since July 2014, with multiple novel lineages emerging. The substitution rate for the virus, however, was estimated to be 1.23×10^{-3} substitutions per site per year, approximately equal to that observed between previous outbreaks. Published in *Nature* on August 6, 2015 [*Nature*, 524(7563): 93–96], their results timely defused the prevailing worries and provided valuable reference for later design of primers for quick virus detection on the spot; on the other hand they inspired the R&D of Ebola vaccines and therapy research. To highlight the importance of their contribution, the journal *Nature* invited experts in the field to author a commentary. On publication, the achievement was widely covered by media at home and abroad, and the paper was soon cited by lots of top journals, including *Nature*, *Cell*, and *New England Journal of Medicine*.

(For details please refer to previous report in page 83 of the Issue 2, 2015 of *BCAS*.)

Measurement of Interaction between Antiprotons

Interaction between the nucleons plays a crucial role in the atomic nucleus. However very little about the nuclear force between antinucleons is known directly to scientists so far. In cooperation with Prof. TANG Aihong at the Brookhaven National Laboratory (BNL) of USA, a team led by Prof. MA Yugang at the Shanghai Institute of Applied Physics, CAS performed a study of the antiproton pair correlations among data collected by the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) of BNL. At the RHIC, gold ions are collided with a centre-of-mass energy of 200GeV per nucleon pair and produce large number of antiprotons, which makes it feasible to study details of the antiproton–antiproton interaction. By applying a technique similar to Hanbury Brown and Twiss intensity interferometry, the joint team demonstrated that the force between two antiprotons is attractive. In addition, they reported two key parameters that characterize the corresponding strong interaction: the scattering length and the effective range of the interaction. Their measurement of parameters is consistent within errors with the corresponding values for proton–proton interactions. Their results, which provided direct verification of the interaction between two antiprotons, one of the simplest systems of antinucleons, are believed to have laid a foundation for further understanding of the structure of more-complex antinuclei and their properties.

Their results were published in *Nature* on November 19, 2015 [*Nature*, 527(7578): 345–348].

Identification of an Ultraluminous Quasar with a Twelve-Billion-Solar-Mass Black Hole at Centre

Quasars from the early stage of the formation of our cosmos with high red-shift has been attractive to astronomers, as these bright celestial bodies carry important information about the structure of the early cosmos. So far astronomers have identified over 300,000 such quasars, among which only around 40 have redshifts bigger than 6 (meaning they are over 12.7 billion light years away). Using data from observations by a 2.4-meter optic telescope at the Yunnan Astronomical Observatory, CAS, and those from follow-up observations by four large optic and infrared telescopes overseas, a team led by Prof. WU Xuebing at Peking University and their cooperators successfully identified an extremely bright quasar named SDSS J010013.02+280225.8, a celestial body 430 trillion times brighter than the Sun with a twelve-billion-solar-mass black hole at the center. With a redshift of 6.30, the quasar is identified to be about 12.8 billion light years away from the Earth. This marked the brightest quasar known by humans from early cosmos with a black hole of the biggest mass at its center. It is also the first quasar with a redshift bigger than 6.0 identified by a 2-meter optic telescope.

Published in *Nature* on February 26, 2015 [*Nature*, 518(7540): 512–515], this discovery demonstrated that black holes as big as twelve billion solar mass could had taken shape as early as when the cosmos was only 900 million years old, posing challenges to current theories for the formation and growth of black holes, as well as those for the evolution of black holes and galaxies.

Earliest Modern Humans in East Asia

The origin of human beings has been hotly disputed with theories polarized. So far the dominant theory supports that modern humans originated from Africa about 190,000 years ago, and migrated to Eurasia about 60,000 years ago. Over the past decade, Chinese scholars made important progress in this area and determined that early modern humans emerged in southern China at least 100,000 years ago. The exact time at which modern humans appeared in East Asia remained unknown to scientists, however. Filling this gap, Profs. LIU Wu and WU Xiujie from the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), CAS, and their British cooperator María Martinón-Torres announced the discovery of 47 human teeth between 80,000 and 120,000 years old from the newly excavated Fuyan Cave in Daoxian, southern China in a paper published October 15 online in *Nature* [526(7575): 696–699], and provided the earliest evidence of unequivocally modern humans outside Africa. This discovery indicated that *Homo sapiens* might have trekked into Asia far earlier than previously known and much earlier than into Europe, providing important evidence for the study of migration routes of modern humans.

(For more please refer to previous report in page 251 of Issue 4, 2015 of *BCAS*.)

Single-protein Spin Resonance Spectroscopy under Ambient Conditions

Magnetic resonance is an essential measure to investigate the structure and dynamics of biomolecules. Measuring the magnetic resonance spectrum of single biomolecules, however, has remained challenging, as traditional measuring technologies could only deal with a system beyond millimeter dimension with over 10 billion molecules. A team led by Prof. DU Jiangfeng at the Hefei National Laboratory for Physical Sciences at the Microscale and the Department of Modern Physics, USTC successfully detected the electron spin resonance signal from a single spin-labeled protein (with a diameter of only 5 nanometer) under ambient conditions for the first time in the world, with aid from the state-of-the-art quantum manipulation technology, and reported their work in *Science* [347(6226): 1135–1138] on March 6, 2015. As anticipated, this technology might greatly help the science community understand mechanisms underlying physical science and life sciences at the single-molecule level, hence might find applications in many areas, including physics, chemistry and life sciences.