Chinese Science Bulletin

Nuclear Physics

December 2012 Vol.57 No.36: 4805–4806
doi: 10.1007/s11434-012-5557-5

A new era of nuclear astrophysics research in China

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Nuclear astrophysics is a rapidly-growing interdisciplinary branch of physics involving a close collaboration among researchers in nuclear physics, astrophysics, and observational astronomy. The origin and fate of matter in our Universe are the primary questions in the nuclear astrophysics research [1,2], which, to large extent, have not been understood. In particular, the question of how heavy elements in the Universe (those heavier than iron) were created is one of the major unsolved puzzles in physics [3]. The above-mentioned fields are connected together because many important signatures of the microscopic nuclear processes of element production can directly be observed in cosmic phenomena. For example, the light curves of supernova and X-ray burst explosions contain information on the energy release from nuclear reactions [4]. Freshly-synthesized elements through various nuclear processes in stars can be detected through atomic absorption and emission lines, or, in some radioactive species, through characteristic gamma radiation. Thus, our desire of understanding the cosmos on the femto-scale while interpreting astrophysical observations on the tera-scale [5] creates a momentum which has propelled the field of nuclear astrophysics to the research forefront. Moreover, since most of the astrophysical processes of nucleosynthesis take place along the lines of extremely unstable nuclei in the nuclear chart, our knowledge on the basic nuclear properties has to be extended to those exotic nuclei, which is by itself a frontier of nuclear physics.

For the following reasons, now it seems to be a golden time for this research that crosses over several disciplines. The large collection of observational data from both ground- and space-based telescopes offers a wealth of information which needs to be interpreted by detailed theoretical modeling of complex hydrodynamic and nuclear processes. Rapidly-expanding computational capabilities and novel numerical techniques allow more realistic treatments of evolutionary processes in stars. Advances in experimental nuclear physics enable us to probe and simulate the behavior of nuclei under extreme conditions to understand the nuclear processes behind the cosmic phenomena. These exotic nuclear processes that play crucial roles in astronomical observations are defined in a wide range, including, for example, low energy charged particle reactions in the stellar interiors, thermo-nuclear reactions of extremely short-lived nuclei in stellar explosions, neutrino-nucleus interactions in the early supernova shock, and nuclear fusion processes induced by the extreme densities in neutron stars.

The fast economic growth recent years in China has stimulated steadily-increasing investments for the nation's basic science research. There have been several new National Major Scientific Projects that are closely related to the nuclear astrophysics research. The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, or the Guoshoujing Telescope), located at the Xinglong Observing Station of the National Astronomical Observatories of Chinese Academy of Sciences (CAS), is a telescope that possesses the highest spectrum acquiring rate in the world. It is designed with 4000 optical fibers in the optical path, covering a large region of the sky simultaneously. This unique system is now being used to conduct a survey of 10 million stars in our galaxy, as well as millions of distant galaxies. Another related facility is the development of the Shanghai Synchrotron Radiation Facility (SSRF) [6,7]. SSRF is a third-generation of synchrotron radiation light source, and up to now, is the biggest scientific platform for science research and technology development in China. More than hundreds of scientists and engineers from universities, institutes and industries in domestic and overseas can use SSRF for research each day. With the planed laser-gamma sources based on this facility, many important nuclear astrophysics reactions can be studied in the near future. Furthermore, China now has the world's fastest supercomputers for scientific computation. In 2010, the supercomputer Tianhe-1A at the National Supercomputing Center (NSCC)

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in Tianjin city, which can perform 2.57 quadrillion computing operations per second, topped the 36th edition of the world top 500 supercomputers list.

Because of the extreme nature of stellar conditions, an understanding of the nuclear processes in stars poses an enormous challenge to both nuclear theorists and experimentalists. It is important to note that most of the nuclei involved in the research are not ordinary ones that we are familiar with. They are exotic nuclei lying either on the neutron-rich side or on the proton-rich side of the nuclear chart, for which we know little about their properties. Most traditional methods for nuclear experiments that have been carried out on the Earth cannot work directly and the usual theoretical treatments for the stable nuclei cannot be simply extrapolated to exotic mass regions. However, with many new techniques and facilities, advances in experimental nuclear astrophysics make it possible to investigate many stellar processes in laboratory. These include the innovative methods to measure masses for very short-lived nuclei and to perform the extremely slow reactions in the interiors of stars, as well as the new facilities to produce the states in radioactive nuclei that exist in the extreme environments of stellar explosions. China now has two world-class facilities of this kind, the Lanzhou Cooler Storage Ring (CSR) and the Beijing HI-13 Tandem accelerator which will be upgraded to Rare Ion-Beam Facility in Beijing (BRIF) in 2014. While the Lanzhou CSR has begun to produce exciting results in the mass measurement [8–11], the Beijing HI-13 Tandem Laboratory has also performed an important experiment for determination of the $^{13}C(\alpha,n)^{16}O$ reaction rate [12].

The collaboration from different disciplines is obviously the key to the success for the nuclear astrophysics research. Scientists in the USA, for example, built a frontier center JINA (Joint Institute for Nuclear Astrophysics) at the University of Notre Dame, which serves as an intellectual center with the goal to enable swift communication and stimulating collaborations across field boundaries. In China, communication and collaboration among different disciplines in nuclear physics and astrophysics need to be enhanced. It is now a common understanding for Chinese scientists that a work-together is urgently needed in order to promote the nuclear astrophysics research in China. Establishment of organizations, similar to JINA in the USA, seems to be helpful. As an initial attempt, a joint workshop was held on May 17–20, 2012 in Shanghai. About thirty scientists from Chinese universities including, among others, Beijing University, Tsinghua University, Shanghai Jiao Tong University, and Beihang University, and from research institutes such as the China Institute of Atomic Energy, Institute of Modern Physics of CAS, Shanghai Institute of Applied Physics of CAS, National Astronomical Observatories of CAS, and Shanghai Astronomical Observatory of CAS. The aim of this first workshop was to establish an initial network for people working in different fields, but having the common interest in nuclear astrophysics. A China-born American scientist, Professor Yongzhong Qian from the University of Minnesota, USA, was invited to give a key-note speak on the current research in nuclear astrophysics. During the three-day meeting, the scientists discussed on the possibilities for further collaborations both in China and internationally. With increasing supports from the Chinese Science Foundation such as MOST and NSFC, the commitment of the national large-scale scientific projects, and a strong desire of collaborations among Chinese scientists, one may anticipate that a new era of nuclear astrophysics research will soon come in China.

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