

Nuclear science hits new frontiers

C Konrad Gelbke argues that nuclear science has a bright future thanks to the possibilities being opened in particular by the exploration of rare isotopes.

Nuclear science is undergoing a renaissance as it confronts new and previously unapproachable research opportunities. One such opportunity, the study of short-lived nuclei far from stability, is emerging as a major frontier in nuclear science. Rare-isotope research is tied to astrophysics and mesoscopic science, fields in which voracious demand for new data is generating worldwide interest in high-power, next-generation accelerators.

New facilities will probe the limits of nuclear stability and determine nuclear properties in uncharted regions of nuclei with unusual proton-to-neutron ratios. The new data will challenge descriptions of nuclei that are based on data limited to nuclei near the valley of nuclear stability. These improved models of nuclei – two-component, open mesoscopic systems – will increase our understanding of mesoscopic systems in fields such as chemistry, biology, nanoscience and quantum information. More directly, the models will greatly boost our understanding of the cosmos.

Today, our descriptions of stellar evolution, and especially of explosive events, such as X-ray bursts, core-collapse supernovae, gamma-ray bursts, thermonuclear (Type Ia) supernovae and novae, are limited by inadequate knowledge of important nuclear properties. We need new data for nuclei far from stability and better nuclear theories to develop accurate models of these astrophysical phenomena. Improved models, in turn, will help astrophysicists make better use of data from ground- and space-based observatories, understand the nuclear processes that produce the elements observed in the cosmos and learn about the environments in which they were formed.

We already have the first concrete evidence that nuclear structure, well established for nuclei near the line of stability, can change dramatically as we move away from the line of stability. The effective interactions far from stability



– pairing, proton–neutron, spin-orbit and tensor – are different, but largely unknown. We need quantitative experimental information to refine theoretical treatments that describe these exotic isotopes.

There are several particularly promising research directions. For example, nuclei with unusual density distributions have been discovered for the lighter elements, but little is known about the properties of heavier, very neutron-rich nuclei. These heavier nuclei may have multi-neutron halo distributions with unusual cluster or molecular structures, which otherwise only occur at the surface of neutron stars. Such nuclei provide a unique opportunity to study the nucleon–nucleon interaction in early pure neutron matter.

Intense beams of neutron-rich isotopes will be used to synthesize transactinide nuclei that are more neutron-rich than is possible with stable beams. These nuclei are predicted to be sufficiently strongly bound and long-lived for detailed chemical study.

Energetic nucleus–nucleus collision experiments with beams of very neutron-rich and very neutron-poor isotopes will explore the asymmetry energy term in the equation of state of neutron-rich nuclear matter. This term is important in understanding the properties of neutron stars.

Nuclei are self-sustaining finite droplets of a two-component – neutron and proton – Fermi-liquid. Selectively prepared nuclei will allow us to study, on a femtoscopic

scale, typical mesoscopic phenomena: self-organization and complexity arising from elementary interactions, symmetry and phase transformations, coexistence of quantum chaos and collective dynamics. The openness of loosely bound nuclei owing to strong coupling to the continuum allows us to probe general mesoscopic concepts, such as information processing and decoherence, which are key ideas in quantum computing.

The interplay of strong, electromagnetic and weak interactions determine detailed nuclear properties. Selecting nuclear systems that isolate or amplify the specific physics of interest will allow better tests of fundamental symmetries and fuel the search for new physics beyond the Standard Model.

Beyond advancing basic research questions, new accelerators should yield practical benefits for science and society. In fact, nuclear science has a long record of such applications. Technologies rooted in nuclear science – such as positron-emission tomography, the use of radioactive isotopes for treating or diagnosing disease, and more recently, the use of dedicated accelerators for treating cancer patients (see p17) – have transformed medicine. Sterilization of fresh produce or surgical instruments with ionizing radiation is growing in importance. Ultra-sensitive nuclear detection, such as Rutherford backscattering, proton-induced X- and gamma-ray emission and accelerator mass spectrometry, has provided diagnostic tools for archaeology and material science.

Next-generation rare-isotope research and this tradition of applied work promise new opportunities for cross-disciplinary collaboration on national and international security, biomedicine, materials research and nuclear energy. Nuclear science is well positioned to deliver new benefits to physics and society in the coming decades.

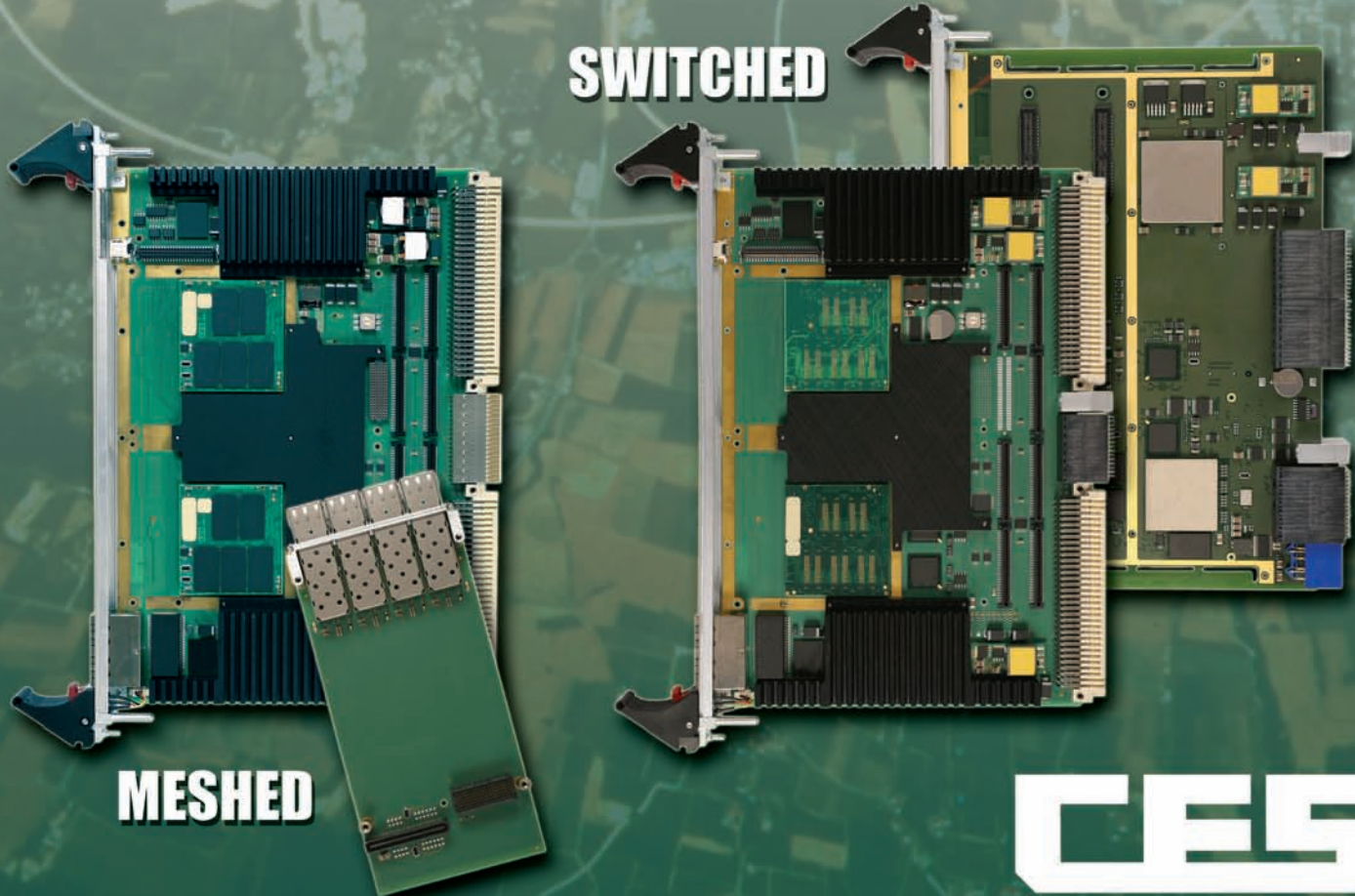
C Konrad Gelbke, director of the National Superconducting Cyclotron Laboratory and University Distinguished Professor of Physics at Michigan State University.

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