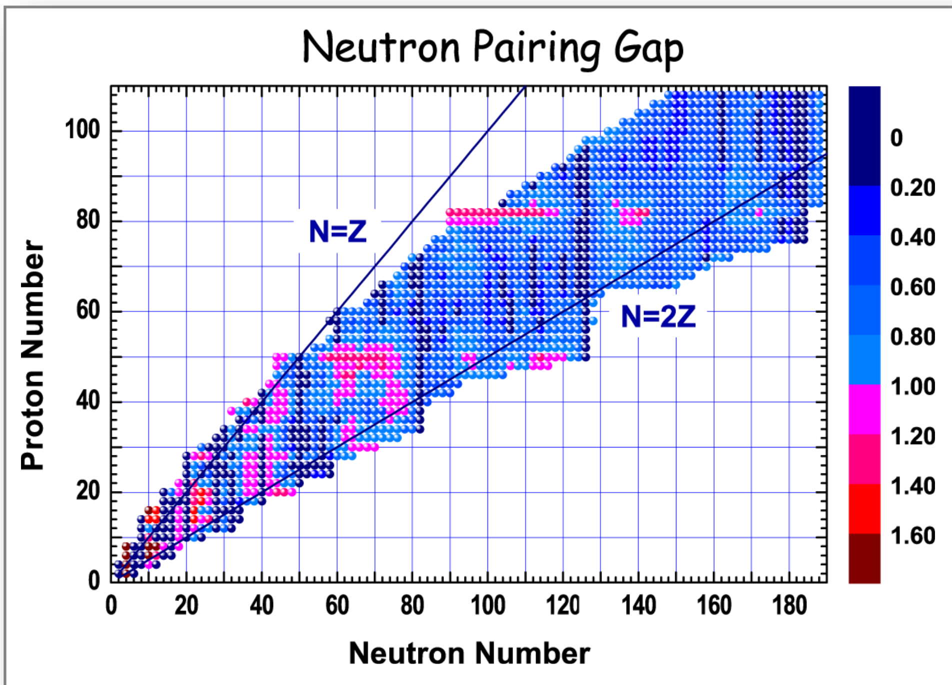
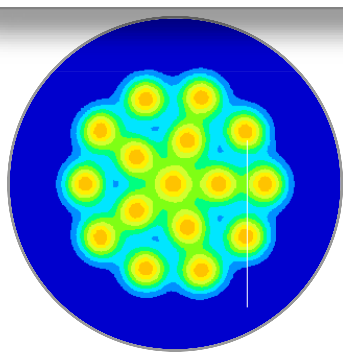
Nucleus as a Finite Many-Body System: Exploring the Intersections

The atomic nucleus is a complex, finite many-fermion system of particles interacting via a complicated force. As such, it shows many similarities to other mesoscopic systems, such as molecules, clusters, grains, quantum dots, and Bose Einstein Condensates. Solving the quantum many-body problem requires extensive use of modern parallel computing systems. Understanding the nuclear many-body problem significantly impacts our knowledge of nuclear structure, which in turn directly influences our knowledge of element production in the Universe. Thus, a three-way synergy exists among many-body problem, astrophysics, and computational science.

The common theme in many-body physics is the phenomenon of superconductivity: any weak attractive interaction can give rise to coherent many-body states. The nucleus is not an exception: at low excitatiion energies most nuclei are superconductors, as are metals and possibly the quark-gluon plasma. Since they are made of protons and neutrons, nuclei can exist in neutron, proton, and proton-neutron pairing phases. One of the scientific goals of the planned Radioactive Isotope Accelerator (RIA) is to probe different pairing phases of nucleonic matter, especially the neutron pairing in weakly-bound neutron-rich exotic nuclei, and the anisotropic proton-neutron Cooper pairs in proton-rich radioactive species. The figure below shows the results of the microscopic calculations of the neutron pair gap (in MeV) in even-even nuclei. The modern computers, such as the ORNL's Eagle machine, allow theorists to calculate in one day ground-state properties (masses, radii, shapes, pairing gaps) of several thousand nuclei. By iteratively comparing results of many such calculations with experiment, one is aiming at developing a realistic nuclear model, which will enable us to make reliable predictions for unknown, astrophysically important nuclei. Such large-scale computing is essential to theory underlying RIA.



Eagle is the IBM RS/6000 SP supercomputer at ORNL. It performs 1 trillion arithmetic operations per second.



Historically, many concepts and tools of nuclear structure **theory were brought to nuclear physics** from other fields. **Today, thanks to the wide arsenal of methods,** many ideas from **nuclear** physics have been applied to studies of other complex **systems**. The figure shows results of calculations, using nuclear **physics** technology for electrons trapped in a two-dimensional **quantum** dot. The electrons tend to localize into Wigner crystal patterns when strong magnetic fields act in the third dimension.