Aurel Bulgac

- Structure of ground and excited states and reactions and non-equilibrium dynamics of large numbers of strongly interacting fermion systems:

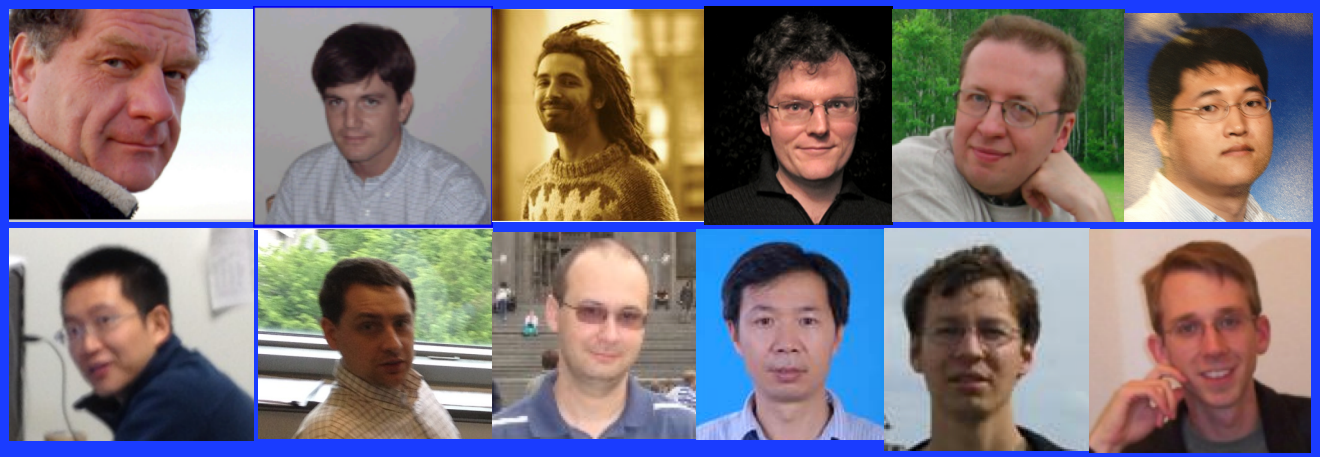
  Nuclei, Neutron Star Crust, Cold Atoms

- ***Density Functional Theory (DFT)*** – developed and implemented new extensions of DFT to superfluids and time-dependent phenomena: *SLDA and TDSLDA.* *Started with Y. Yu (PhD 2003)*

- ***Quantum Monte Carlo (QMC)*** – implemented and obtained a long series of new qualitative results for thermodynamic properties and transport processes. *Started with J.E. Drut (PhD 2008)*

- ***High Performance Computing (HPC)*** – developed and implemented new numerical and computational techniques for studying structure (DFT) and reactions (TDDFT) on DOE leadership class supercomputers (Franklin, JaguarPF, Hopper, Titan).
  Started with K.J. Roche and Y. Yu in 2006

- Main publications since 2010:
  1 Science, 4 Phys. Rev. Lett., 2 Phys. Rev. Rapid Comm. + 2 PLRs submitted



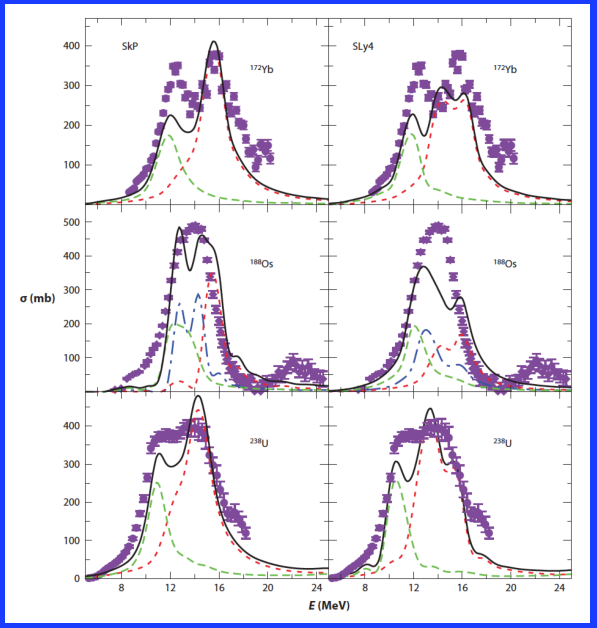
to model turbulent fermionic superfluids. Although the underlying quantum mechanical equations are straightforward, solving them required the use of one of the world's most powerful supercomputers, Jaguar at Oak Ridge National Laboratory in

Tennessee. In their simulations, Bulgac and his colleagues agitated a fermionic superfluid by shooting spherical projectiles through it or by stirring it with a laser beam. Turbulent superfluids are known to harbor tubes of quantized vorticity. As the figure shows, the simulation could track how two vortex tubes (marked a and b) joined to form a ring, which then opens in a manner reminiscent of the unzipping of a DNA molecule during transcription. Bulgac's model could help astronomers understand another agitated superfluid: the interior of a rapidly spinning neutron star. For more on quantum turbulence, see PHYSICS TODAY, April 2007, page 43. (A. Bulgac et al., *Science* **332**, 1288, 2011.) —CD

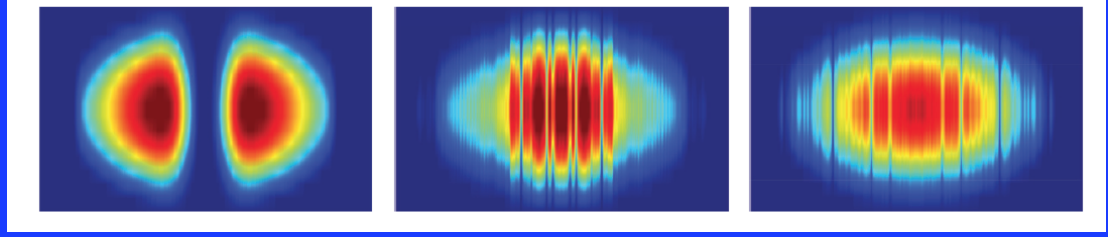
AB, K.J. Roche (staff PNNL and assoc. prof. UW), J.E. Drut (PhD 2008, now asst. prof. UNC), M.M. Forbes (junior fellow INT and asst. prof. WSU), Sukjin Yoo (PhD 2010, APCTP, S. Korea), P. Magierski (prof. Warsaw/UW), Y.-L. Luo (PhD 2013), G. Wlazlowski (asst. prof. Warsaw/UW), I. Stetcu (staff, LANL), Y. Yu(PhD 2003, prof. Wuhan), S. Moroz (UW), J.W. Holt (UW)

SLDA and TDSLDA

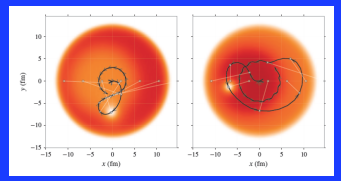
Quantum dynamics in real-time and full 3D with no restrictions



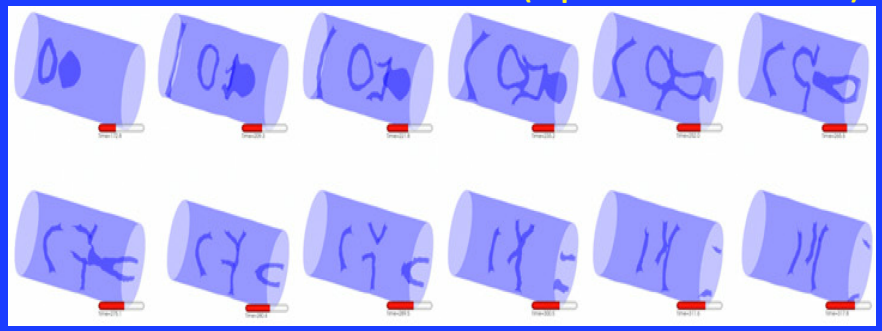
GDR in superfluid 3D deformed heavy nuclei



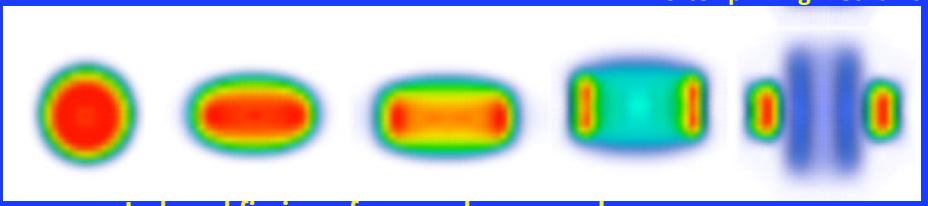
Collision of two superfluid clouds with ≈750 fermions and formation of quantum shock waves and domain walls (aspect ratio not to scale)



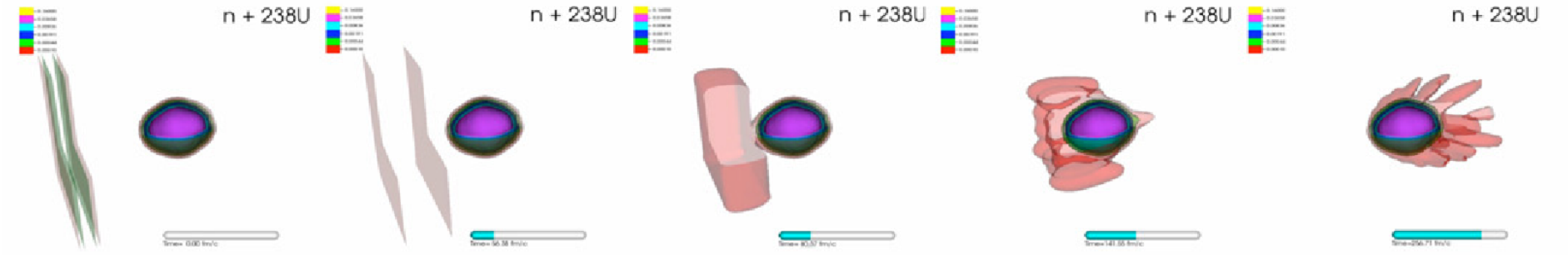
Vortex pinning mechanism



Crossing and reconnection of quantized vortices
This is how quantum turbulence sets in



Induced fission of a superheavy nucleus

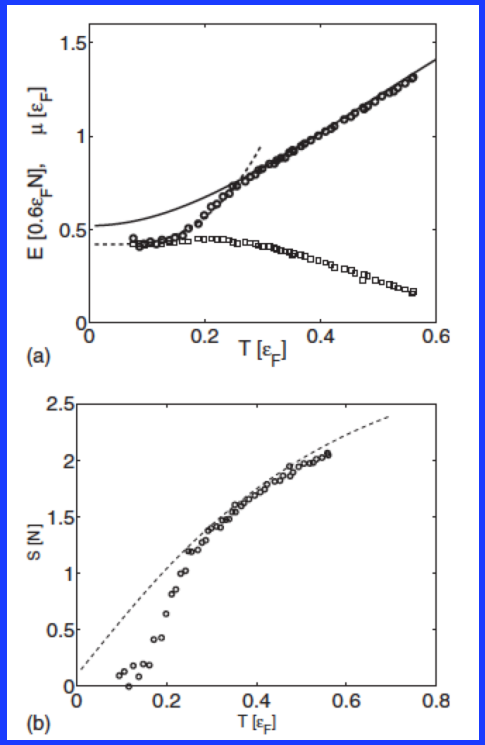


Neutron scattering (plane wave) off ^{238}U

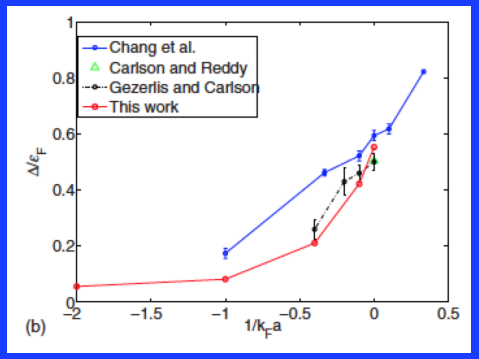
- 1 Science, 8 Phys. Rev. Lett., 3 Rapid Comm. + 2 PRL sub.
- PhD students: Y. Yu (2003) Henderson prize, prof. Wuhan, Chinese Acad. Scie.; S. Yoon (2009), postdoc APCTP, S. Korea; Y.-L. Luo (2013), Karrer prize, A&S Graduate Medal; Adam Richie-Halford, incoming, Department of Energy Computational Science Graduate Fellowship
- *Capable to describe in real time low energy nuclear reactions and induced nuclear fission without any restrictions (unique capability)*

Quantum Monte Carlo

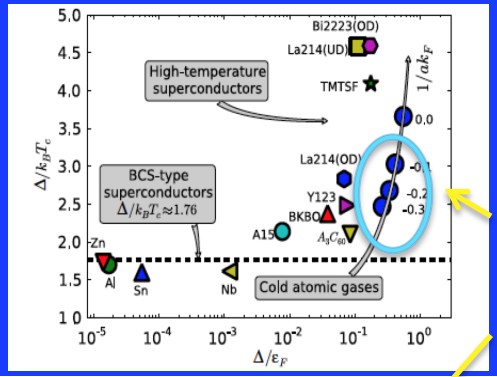
Structure, thermodynamics, transport coefficients



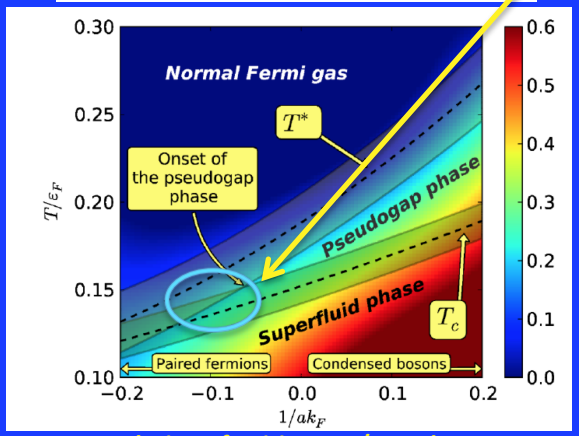
E(T), μ(T), S(T)



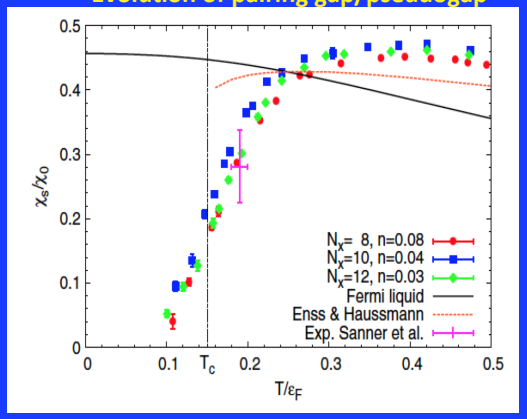
Δ at T=0



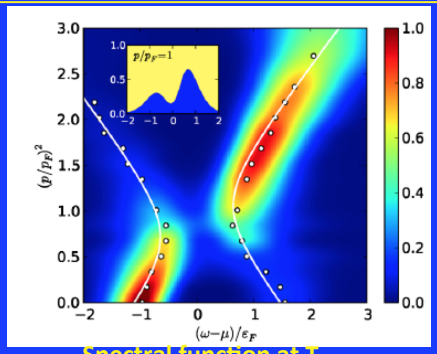
Dilute neutron matter in neutron star crust



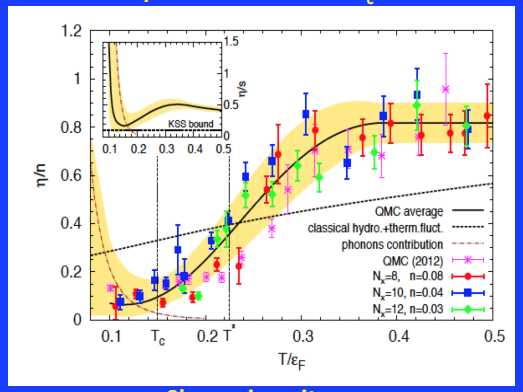
Evolution of pairing gap/pseudogap



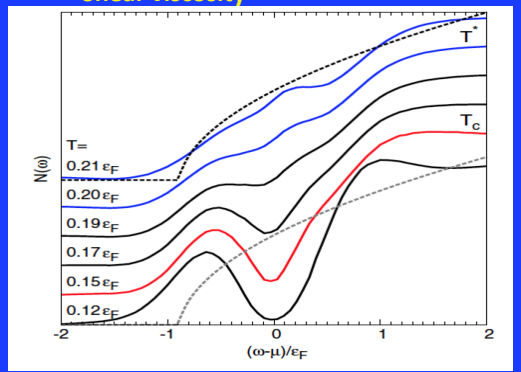
Spin susceptibility



Spectral function at T_c

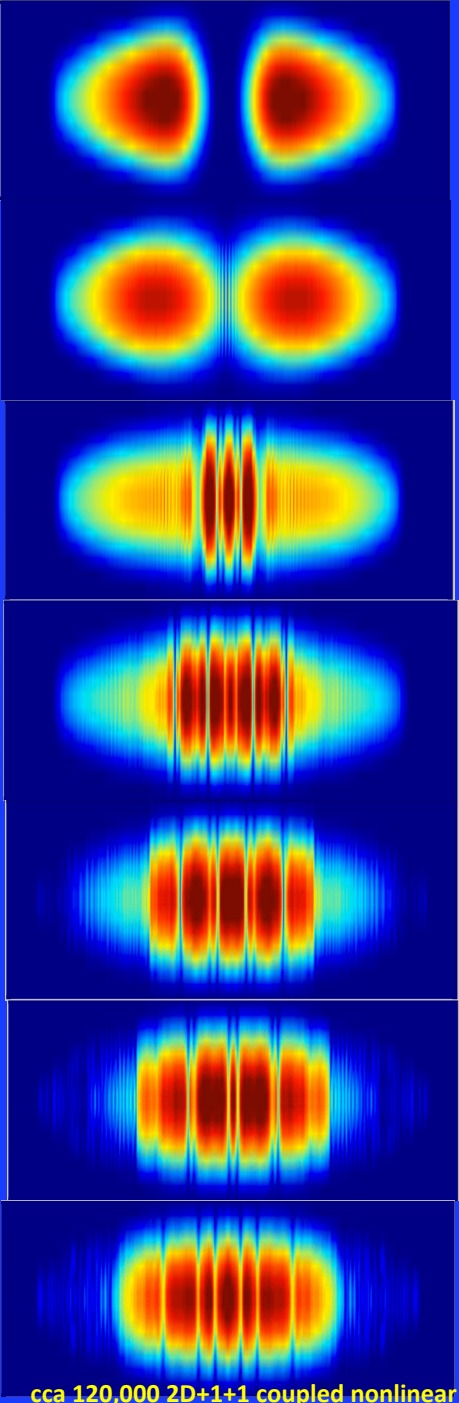


Shear viscosity



Density of states across T_c

- 10 Phys. Rev. Lett. (AB 5 PRLs) and 4 Rapid Comm.
- PhD students: ; J.E. Drut (2008, adv. Bulgac) Henderson prize, Kümmel prize, asst. prof and Melchor fellow, Univ. of NC; G. Wlazlowski (2010, adv. Magierski) asst. prof. Warsaw Univ. Tech.
- *Implemented/ongoing QMC on massively parallel computers for the calculation of the properties of neutron matter and of medium and heavy even-even nuclei with chiral perturbation theory nuclear forces (AB, J.W. Holt, S. Moroz, K.J. Roche. G. Wlazlowski)*



cca 120,000 2D+1+1 coupled nonlinear PDEs on UW Hyak

High Performance Computing

- Developed a very strong collaboration with a computer scientist K.J. Roche (ORNL, now PNNL/UW)
  10 publications + 2 submitted so far, among them:
  1 Science, 2 Phys. Rev. Lett. + 2 PRL submitted, 1 Rapid Comm.

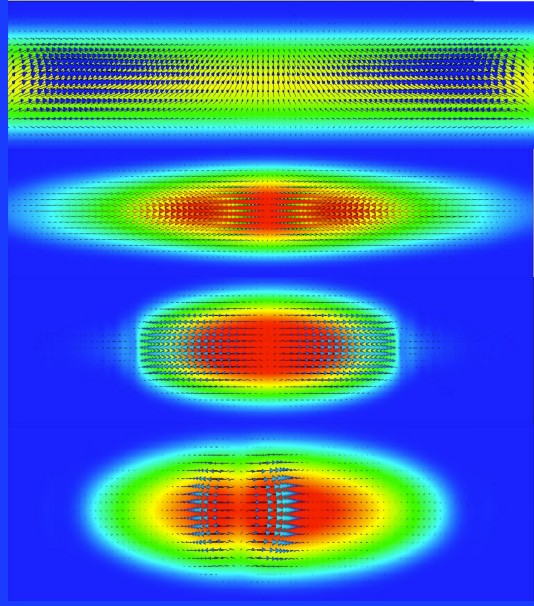
- Performed calculations on largest DOE computers for open: Franklin, JaguarPF, Hopper, Titan.
  More than 100M CPU hours used/allocated so far

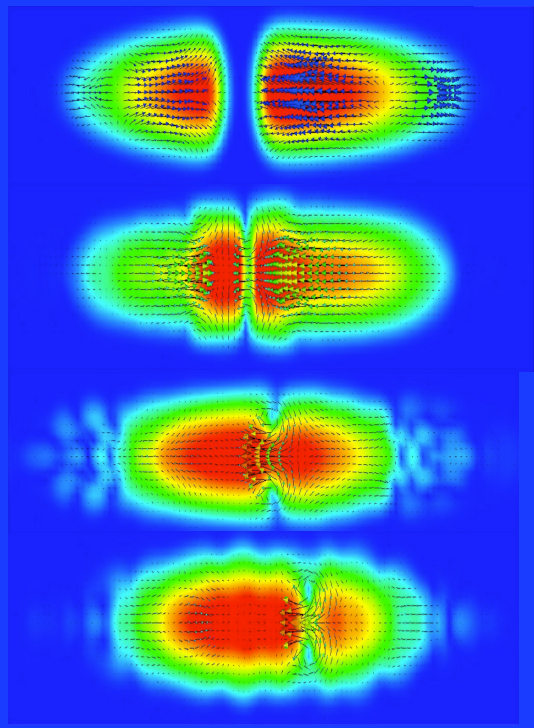
- Developed/implemented several new numerical/computational techniques for QMC and DFT/TDDFT calculations of large many strongly interacting fermions with realistic interactions

- *Actively using the new disruptive GPU (graphic processing unit) technology to significantly increase the speed of calculations*

- *Able to simulate nuclear volumes up to 80^3 fm^3 (which can contain up to cca 80,000 nucleons at normal nuclear density), up to times of the order of 10^{-19} sec. and simulate a number of nuclear reactions, solved extremely large systems $O(10^6)$ of timed-dependent 3D nonlinear coupled PDEs with no restrictions*

- *Currently studying: ^{238}U excitation with relativistic heavy ions, hope to describe induced nuclear fission and thus be able to settle a number of question concerning the dissipation mechanism in large amplitude collective motion*





Quantum engineering of quantum states: cca 55,000 3D+1 nonlinear PDEs on 256 GPUs on Titan