

NONEQUILIBRIUM PHENOMENA IN SUPERFLUID SYSTEMS: ATOMIC NUCLEI, LIQUID HELIUM, ULTRACOLD GASES, AND NEUTRON STARS



12 May 2025 — 16 May 2025

SUPPORTING INSTITUTIONS AND PROJECTS





Theory Alliance facility for rare isotope beams



# <u>Key words:</u>

- Superfluid systems (mostly: Fermi systems)
- Nonequilibrium conditions

# <u>Fermi superfluids</u>

- More demanding to describe using microscopic approaches.
- More difficult to study in labs (eg. Ultracold gases: bosonic vs fermionic).
- Richer physics (as compared to BEC).



# **Structure of the program**

# **Monday**

#### Nonequilibrium conditions in small superfluid systems (atomic nuclei).

- Role of superfluidity (pairing correlations) in nuclear fission dynamics.
- Role of symmetry restoration in the description of pairing in finite systems.
- Time scale of equilibration. Do we have a reliable theoretical model (eg. TDDFT) to describe the time scale of thermalization of superfluid systems?



 Fission dynamics of
 <sup>240</sup>Pu

 A. Bulgac, et al., Phys. Rev. Lett. 116, 122504 (2016)



Collisions: <sup>96</sup> Zr + <sup>96</sup> Zr

P. Magierski, et al., Phys. Rev. Lett. 119, 042501 (2017)

## **Tuesday**

#### Vortex dynamics in Fermi superfluid: dissipative, inertial effects.

- Quantized states in the vortex core and their role in dissipative dynamics.
- Do we see signatures of *lordanskii force* in experiments?
- How good is TDDFT in the description of dissipative dynamics?
- Where the semiclassical description (*Kopnin etal.*) breaks down as the pairing gap-to-Fermi energy ratio increases?
- Impact of spin imbalance on vortex dynamics: enhanced dissipation?



#### <u>Wednesday</u>

#### Neutron stars, glitches, supersolids, stability of superflows in inhomogeneous systems.

- The relations between observational data and superfluidity
- Simulations of vortex pinning-depinning mechanism, dissipative effects.
- Superflows and their stability, superfluid fraction in inhomogeneous systems.
- Dipolar supersolids and relations to neutron star glitches.



## <u>Thursday</u>

#### Dynamics of many-vortex systems. Turbulence. Neutron star glitches.

- Bosonic vs Fermionic turbulence: is there any difference in the decay pattern?
- Time scale of equilibration: is it properly described within TDDFT?
- The role of quantized (Andreev) states in the core in the turbulence decay, dynamics of reconnections, etc.



Numerical simulation of compressible turbulence in a unitary Fermi gas on a 100<sup>3</sup> cubic lattice.

(see Antonopoulou, Haskell & Espinoza, Reports on Progress in Physics 85, 126901 (2022) for a review)

G. Wlazłowski et al. PNAS Nexus 3, p. 160 (2024)

## **Friday**

#### Dynamics of BEC. Unconventional superfluids.

- Vortex dynamics in BEC
- Solitonic dynamics at BCS-BEC crossover
- Impurity dynamics in BEC
- Pairing dynamics in unconventional superfluids.



# **Discussion sessions**

#### <u>Goal:</u>

- Discuss problems related to the talks.
- Discuss topics of common interest. Everyone is welcome to suggest a topic.

#### Preliminary list subjects to discuss:

- Probing various aspects of NS superfluidity in the lab.
- Cosmological and laboratory quantum condensate systems.
- Recent 3He results on the Kelvin wave cascade in the context of quantum turbulence.
- Time crystals and their dynamics.
- Using superfluid 3He as a dark matter detector.
- Testing the theory of first order phase transitions in superfluid 3He and how this may be relevant to early Universe physics.
- Iordanskii force how to detect it?
- The role of core states in vortex dynamics and turbulence decay.

#### Invited speakers:

Aurel Bulgac (University of Washington)\* Luis Robledo (Autonomous University of Madrid) Dario Vretenar (University of Zagreb) Alessio Recati (INO-CNR Pitaevskii BEC Center) Michael Forbes (Washington State University) Marco Antonelli (CNRS) Samuli Autti (Aalto University) Vladimir Eltsov (Aalto University) Mathieu Gibert (Univ. Grenoble Alpes) Vanessa Graber (University of London) Martin Zwierlein (Massachusetts Institute of Technology) Giulia del Pace (University of Florence) Pierbiagio Pieri (University of Bologna) Elena Poli (University of Innsbruck) Nir Navon (Yale University)

CONDAZIONE RUNO KESSLER

Nonequilibrium phenomena in superfluid systems: atomic nuclei, liquid helium, ultracold gases, and neutron stars 99 12-16 MAY, 2025

ECT\* Villa Tambosi, Villazzano

WORKSHOP



Organizers: Brynmor Haskell Piotr Magierski Giacomo Roati Gabriel Wlazłowski The workshop aims to discuss and exchange results and ideas concerning the description of superfluid systems in nonequilibrium conditions. In particular, we would like to focus on fermionic superfluidity, treating bosonic superfluids as auxiliary systems. Thanks to advances in experimental techniques in the field of ultracold gases, we can now explore the BCS-BEC crossover and investigate nonequilibrium phenomena both in the BEC and BCS limits, pinning down differences. These phenomena involve the dynamics of vortices, dissipative flows, dynamics of solitonic excitations, stability of persistent currents or droplet collisions. We may also study the influence of inhomogeneous systems and/or supersolid phases on the behavior of the superflow or the vortex dynamics. On the other hand, superfluid dynamics is crucial for our understanding of other fermionic systems, such as atomic nuclei and neutron stars.

#### ECT\* Director: Prof. Ubirajara van Kolck

Abstract:

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