

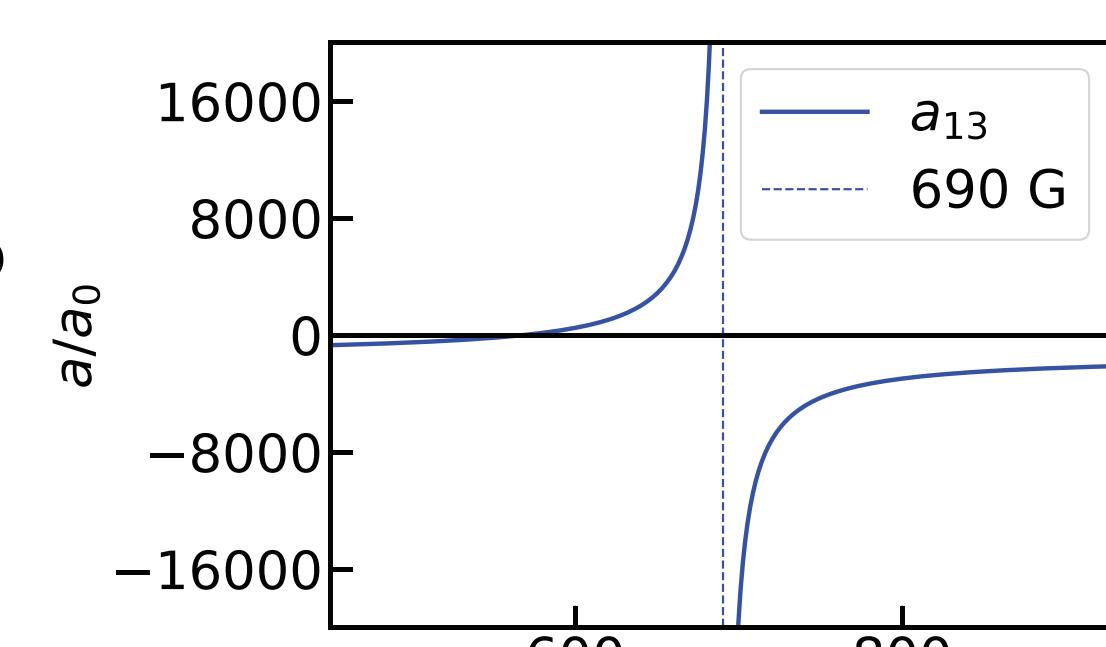
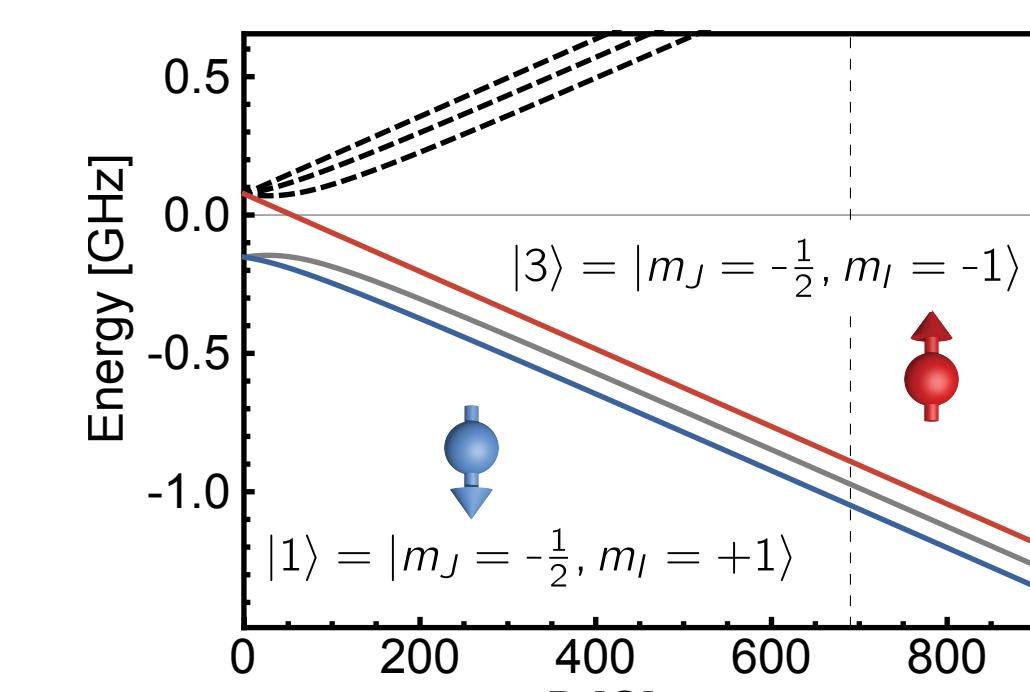
Eric Wolf, Huan Q. Bui, Parth B. Patel, Zhenjie Yan, Biswaroop Mukherjee, Carsten Robens, Richard Fletcher, Martin Zwierlein

MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics,  
Massachusetts Institute of Technology, Cambridge, MA 02139

## Unitary Fermi Gas in a Box Potential

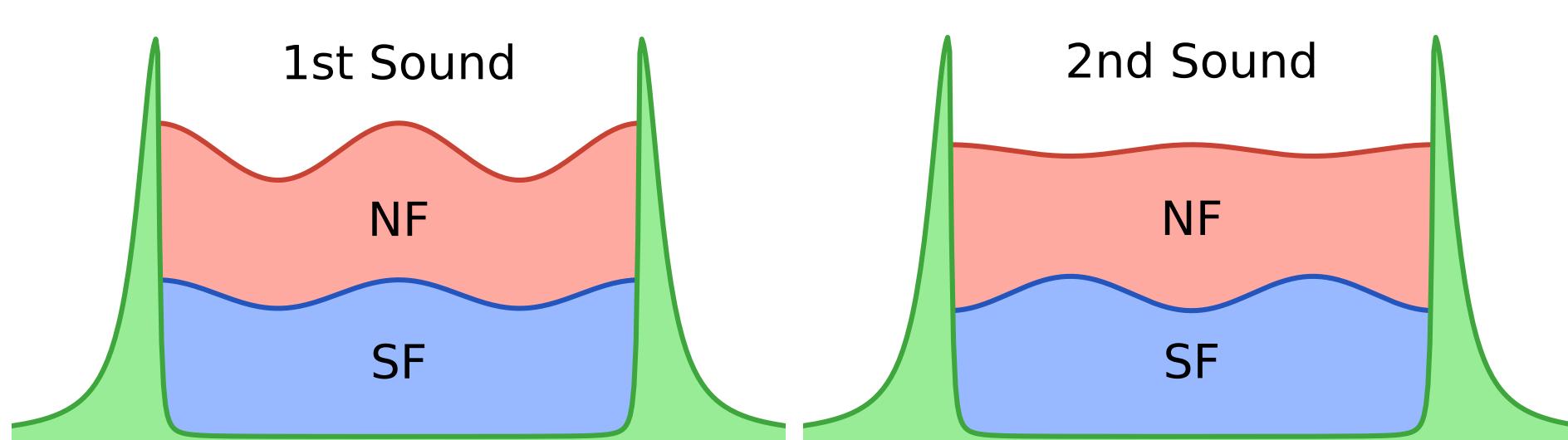
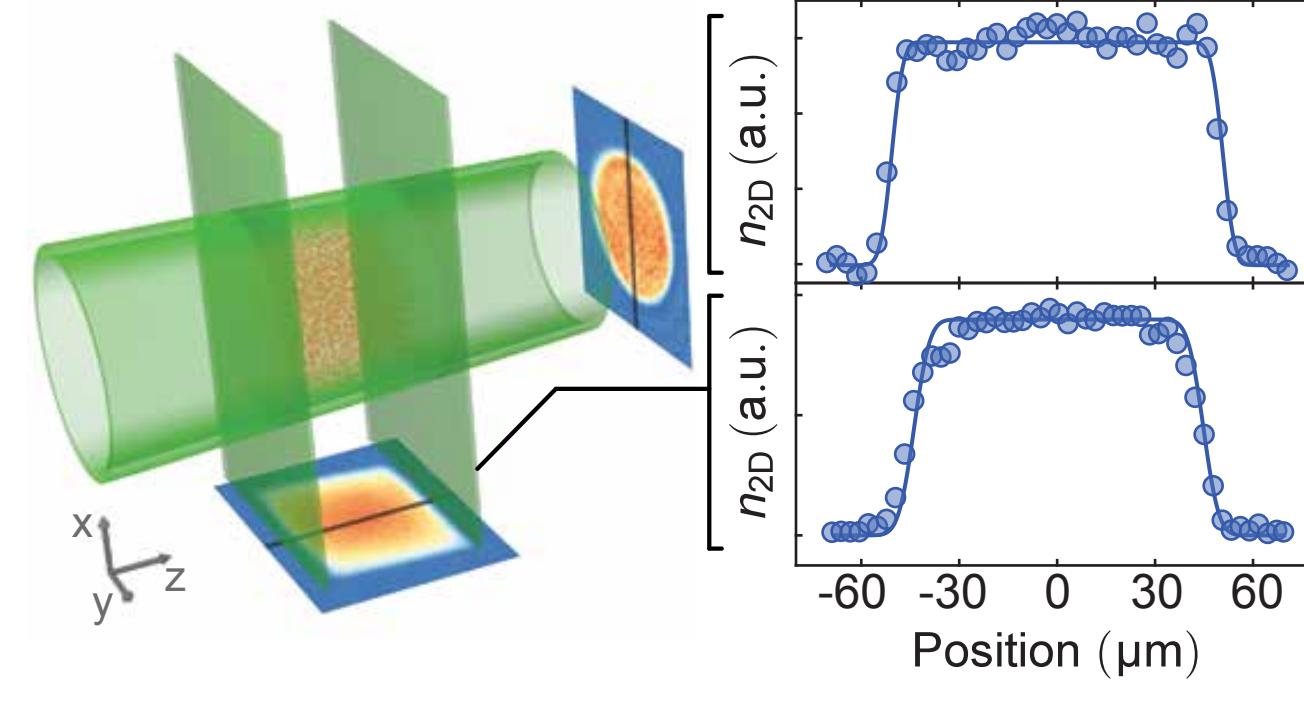
### Unitary Fermi Gas

- Relevant to systems ranging from neutron stars to high- $T_c$  superconductors
- Unitary Fermi gas is scale-invariant
- Realize unitarity with  $|1\rangle - |3\rangle$  Feshbach resonance in  ${}^6\text{Li}$
- Evaporatively cool spin mixture to below  $T_F$



### Box Potential [1]

- Hollow blue-detuned beams realize (quasi) flat potential
- Reduces influence of trap averaging & targets smaller range of densities
- Momentum imaging possible via residual axial harmonic trap

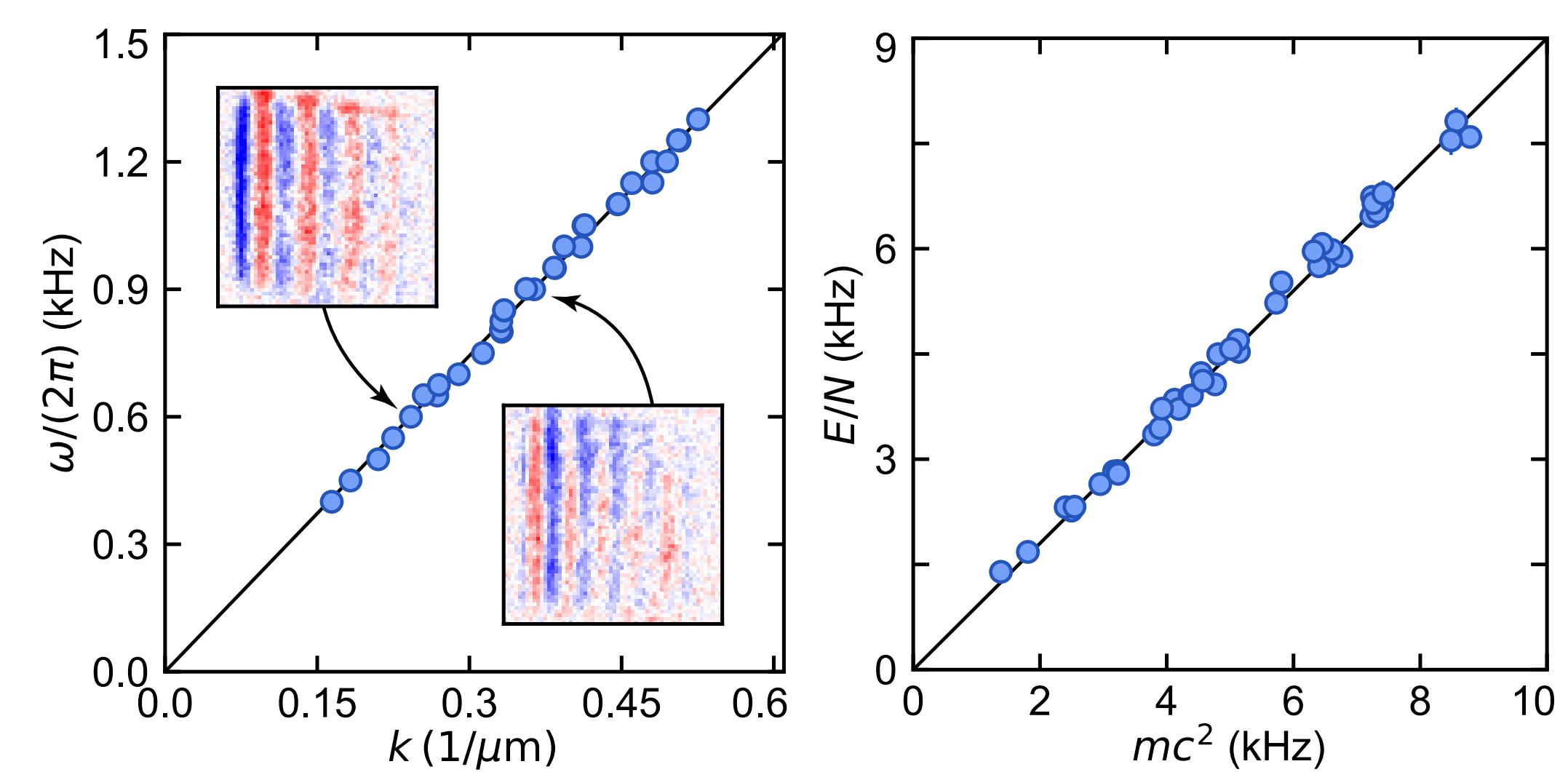
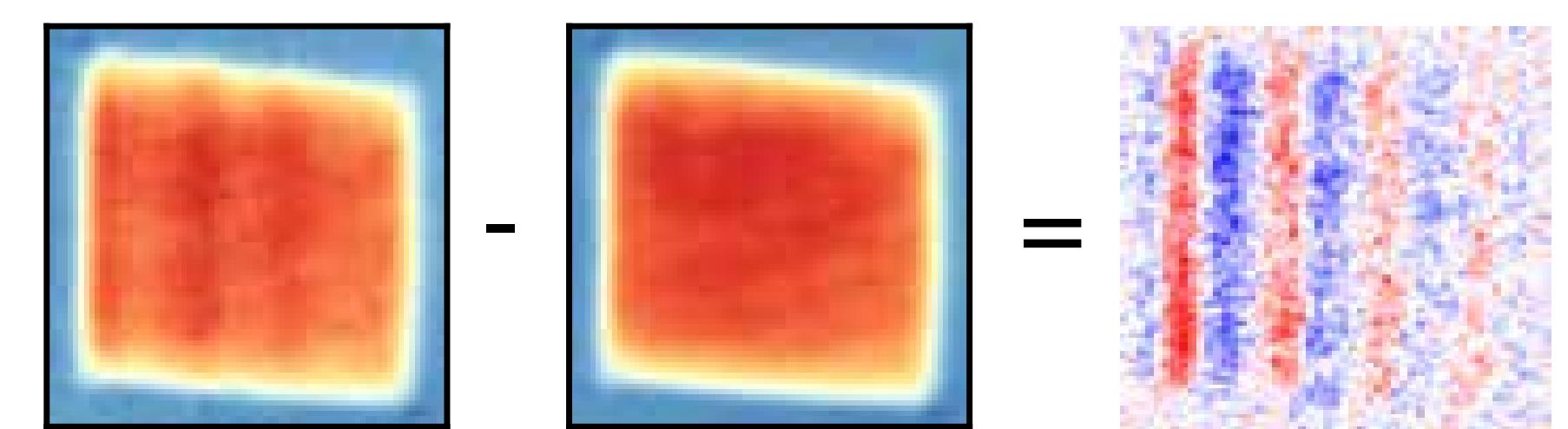


### First Sound

- Density oscillations: in-phase oscillation of normal and superfluid phase
- Excite by shaking box walls
- Image density waves in-situ – extract wavevector  $k$  for a given  $\omega$  to get  $c$
- Speed of sound in scale-invariant system given by system energy

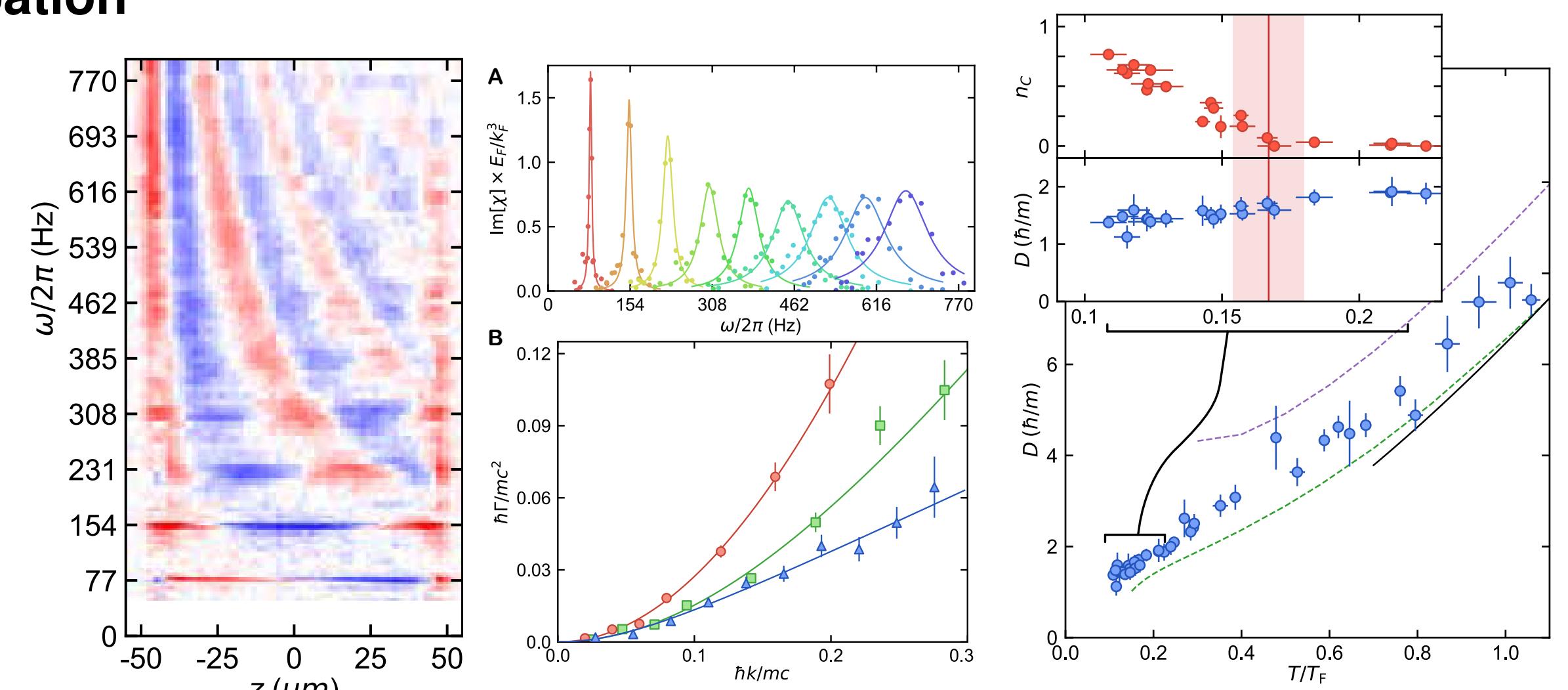
$$mc^2 = \frac{10E}{9N}$$

Sound injection



### Resonant Modes and Dissipation

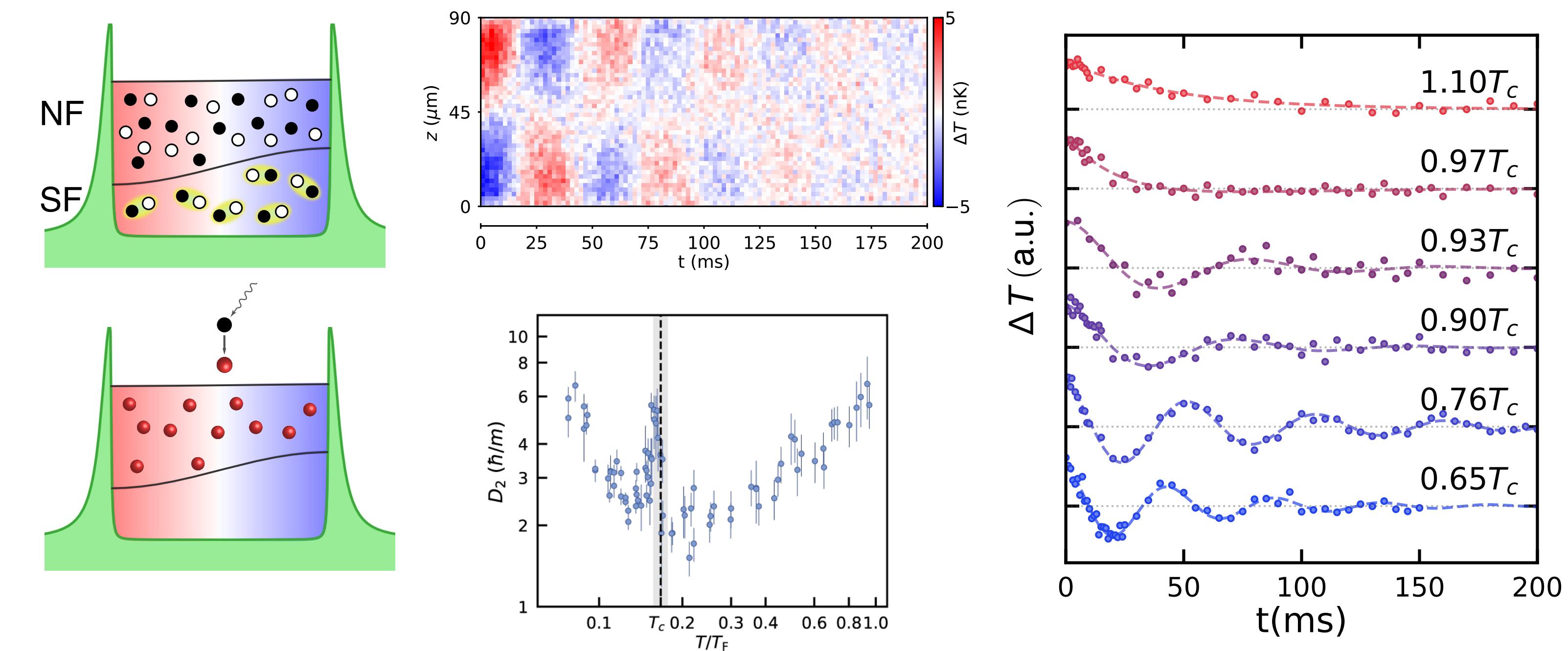
- Sound speed constrained by scale invariance, but dissipation is not
- Hydrodynamics predicts damping rate  $\Gamma \propto k^2$ , with proportionality constant  $D_s$ , the sound diffusivity
- $D_s$  depends on shear viscosity and thermal conductivity
- Measure damping vs.  $k$  using width of resonant box modes – extract  $D_s$



## Temperature Response – Second Sound [3]

### Second Sound

- Temperature oscillations: out-of-phase oscillations of normal and superfluid phase
- Excite oscillations by imprinting high-frequency sound waves to locally heat the gas
- Measure temperature locally using RF spectroscopy
- Second sound arises at temperatures below the superfluid transition temperature
- Damping rate of second sound gives thermal conductivity

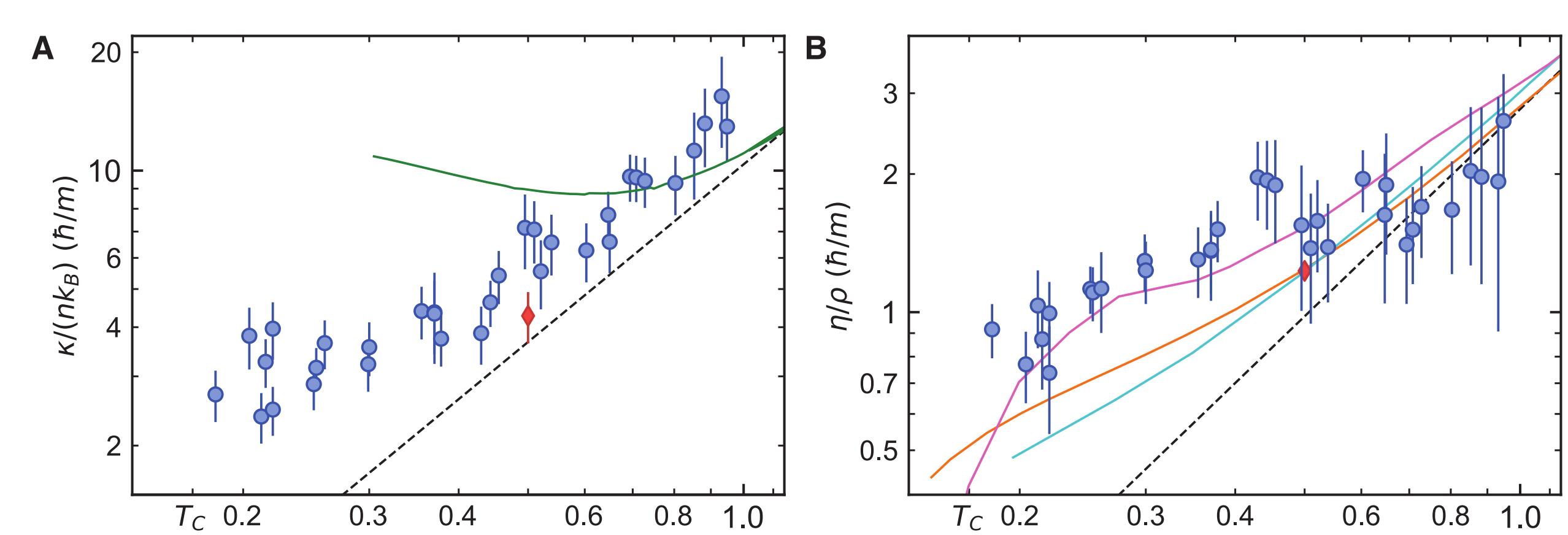


Z. Yan et al., arXiv:2212.13752 (2022)

## Hydrodynamics – Transport Properties

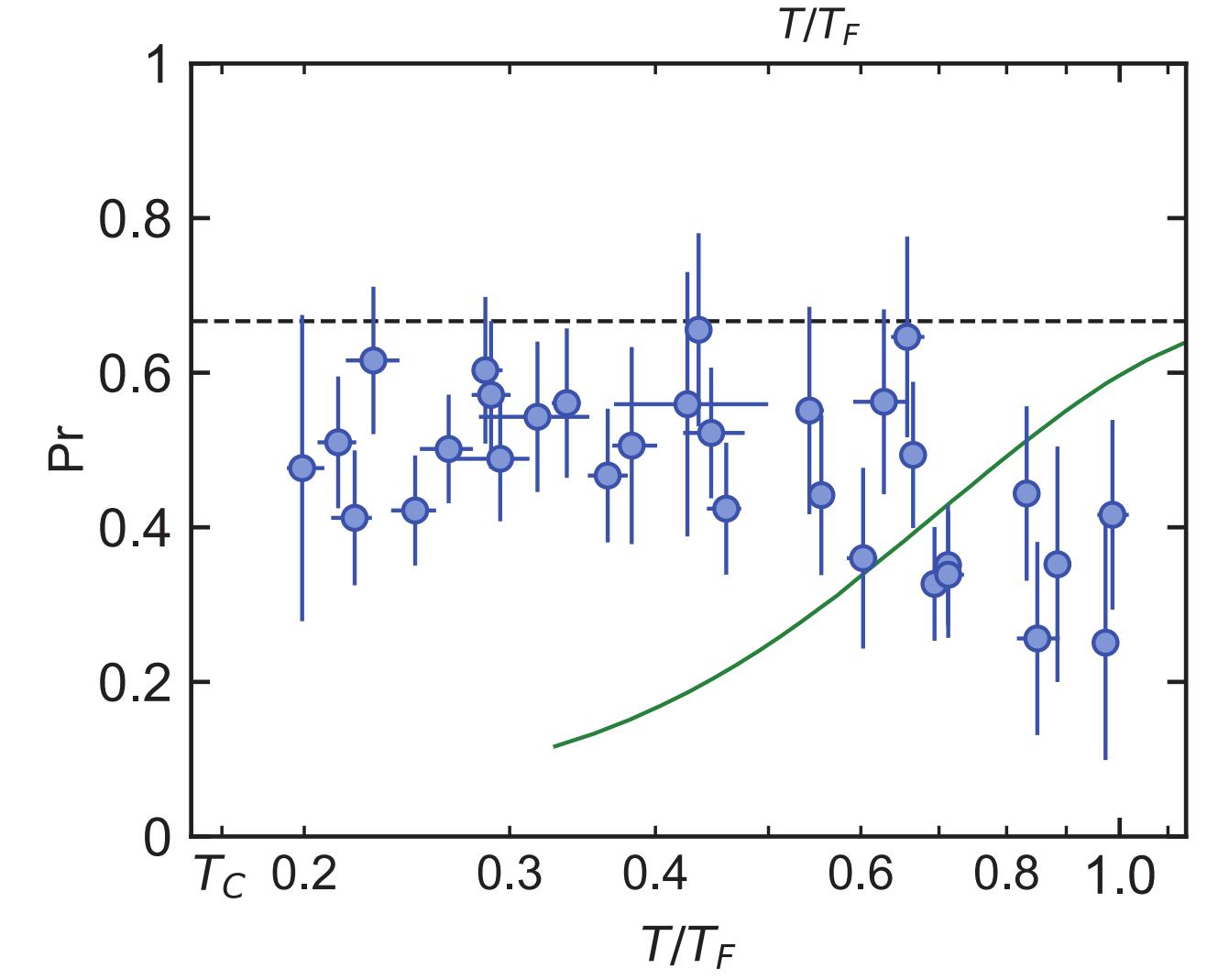
### Hydrodynamic Quantities

- Hydrodynamic quantities above  $T_c$ : shear viscosity  $\eta$  and thermal conductivity  $\kappa$
- Bulk viscosity vanishes for scale-invariant systems; below  $T_c$ , superfluidity density is conserved
- First sound dissipation given by  $\kappa$  and  $\eta$ ; second sound dissipation by  $\kappa$  and  $c_P$
- Together with equation of state [4], first and second sound give  $\eta$  and  $\kappa$  above  $T_c$



### Results

- Viscosity agrees with prior results and theory
- Thermal conductivity differs strongly from theory predictions near  $T_c$
- Prandtl number  $\frac{c_P \eta}{\kappa}$ , ratio of momentum to thermal diffusivity, remains close to typical  $2/3$  value for gases



Red diamond [5], green line [6], pink line [7], cyan line [8], orange line [9]

## References

- [1] B. Mukherjee et al., PRL 2017
- [2] P.B. Patel et al., Science 2020
- [3] Z. Yan et al., arXiv:2212.13752 2022
- [4] M.J.H. Ku et al., Science 2012
- [5] L. Baird et al., PRL 2019
- [6] B. Frank et al., Phys Rev Research 2020
- [7] J. A. Joseph et al., PRL 2015
- [8] M. Bluhm et al., PRL 2017
- [9] T. Enss et al., Annals of Physics 2011



## Funding

AFOSR-MURI, National Science Foundation, Office of Naval Research, Vannevar Bush Faculty Fellowship