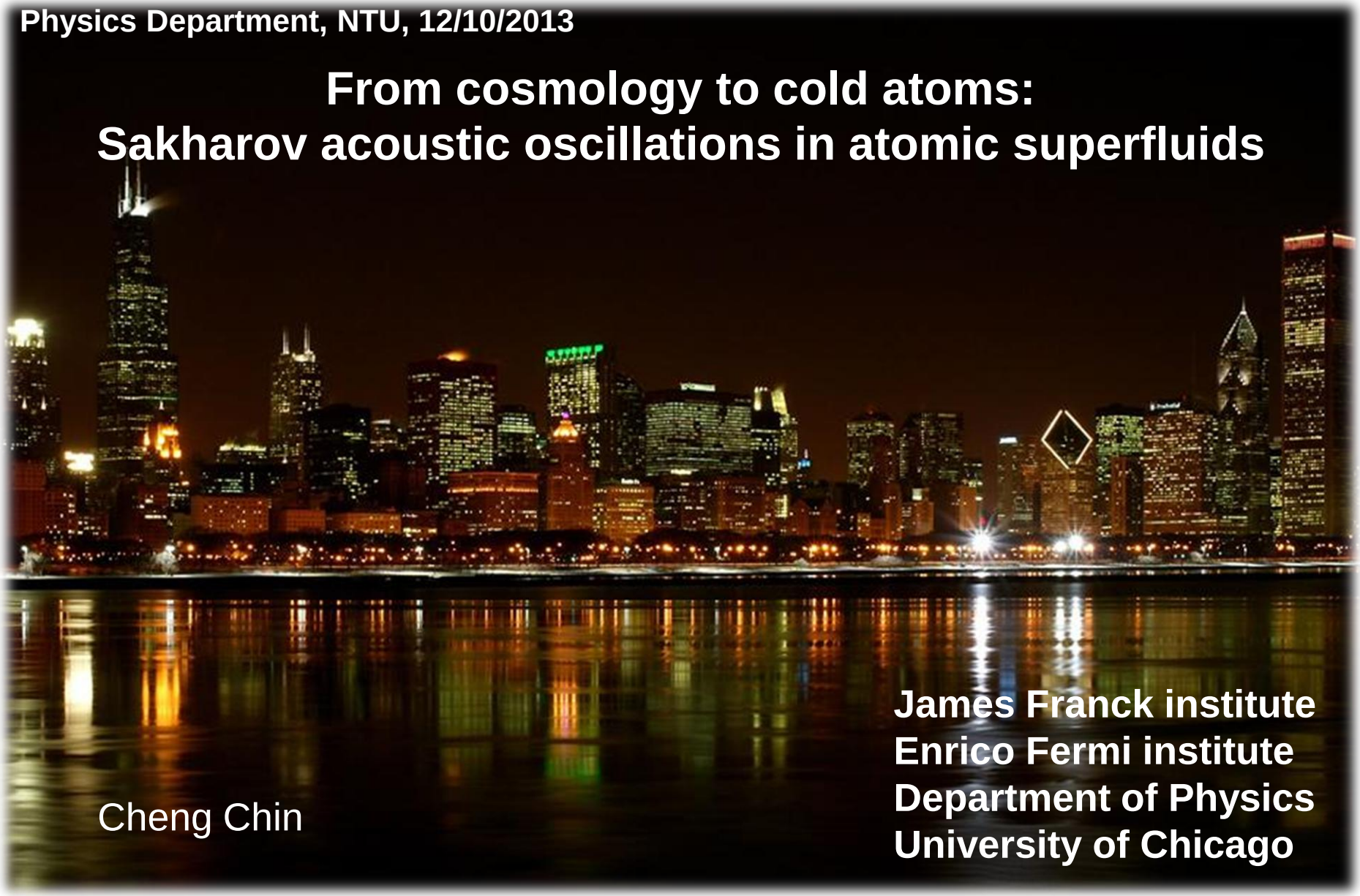
Physics Department, NTU, 12/10/2013

From cosmology to cold atoms: Sakharov acoustic oscillations in atomic superfluids

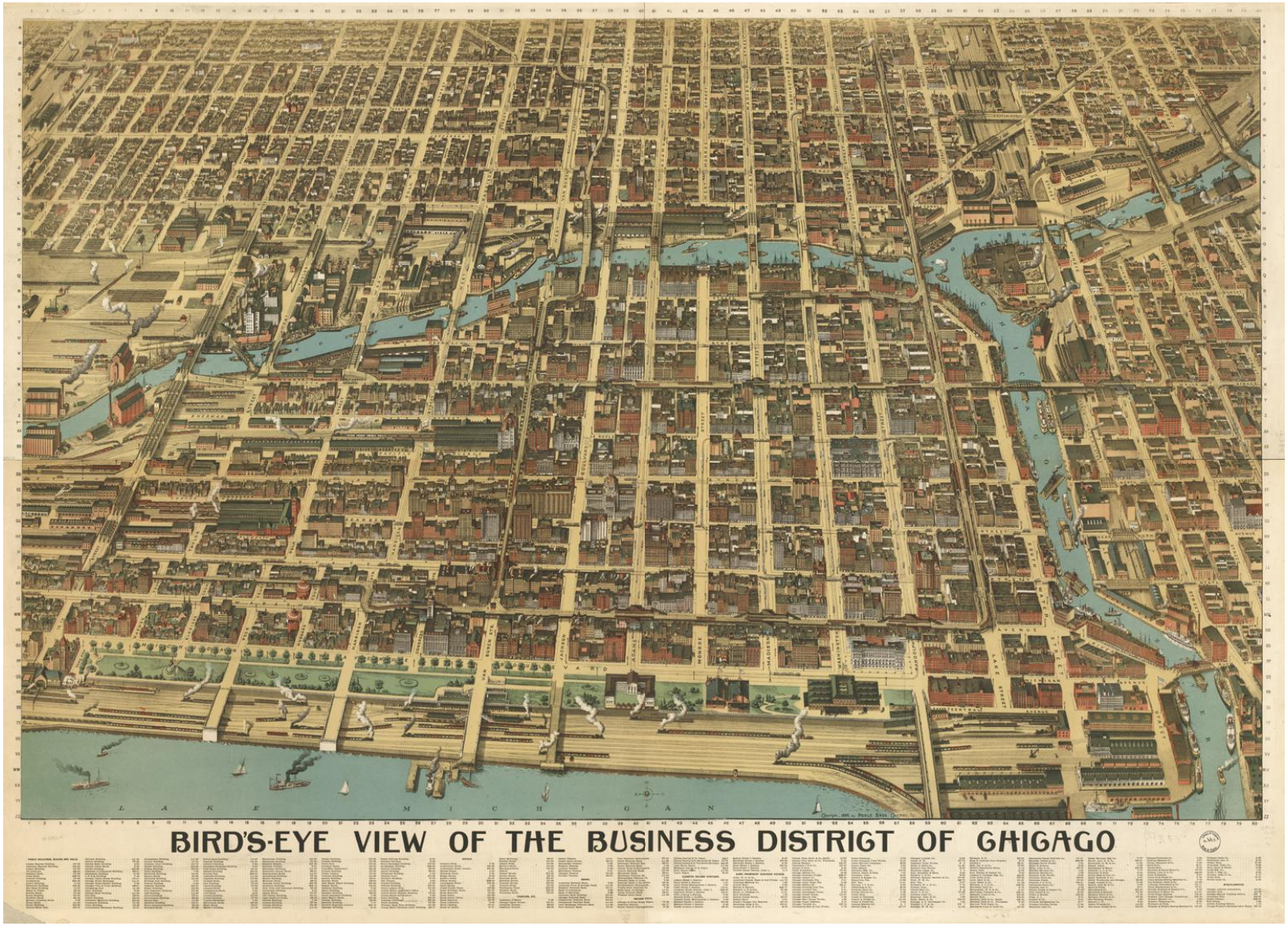


Cheng Chin

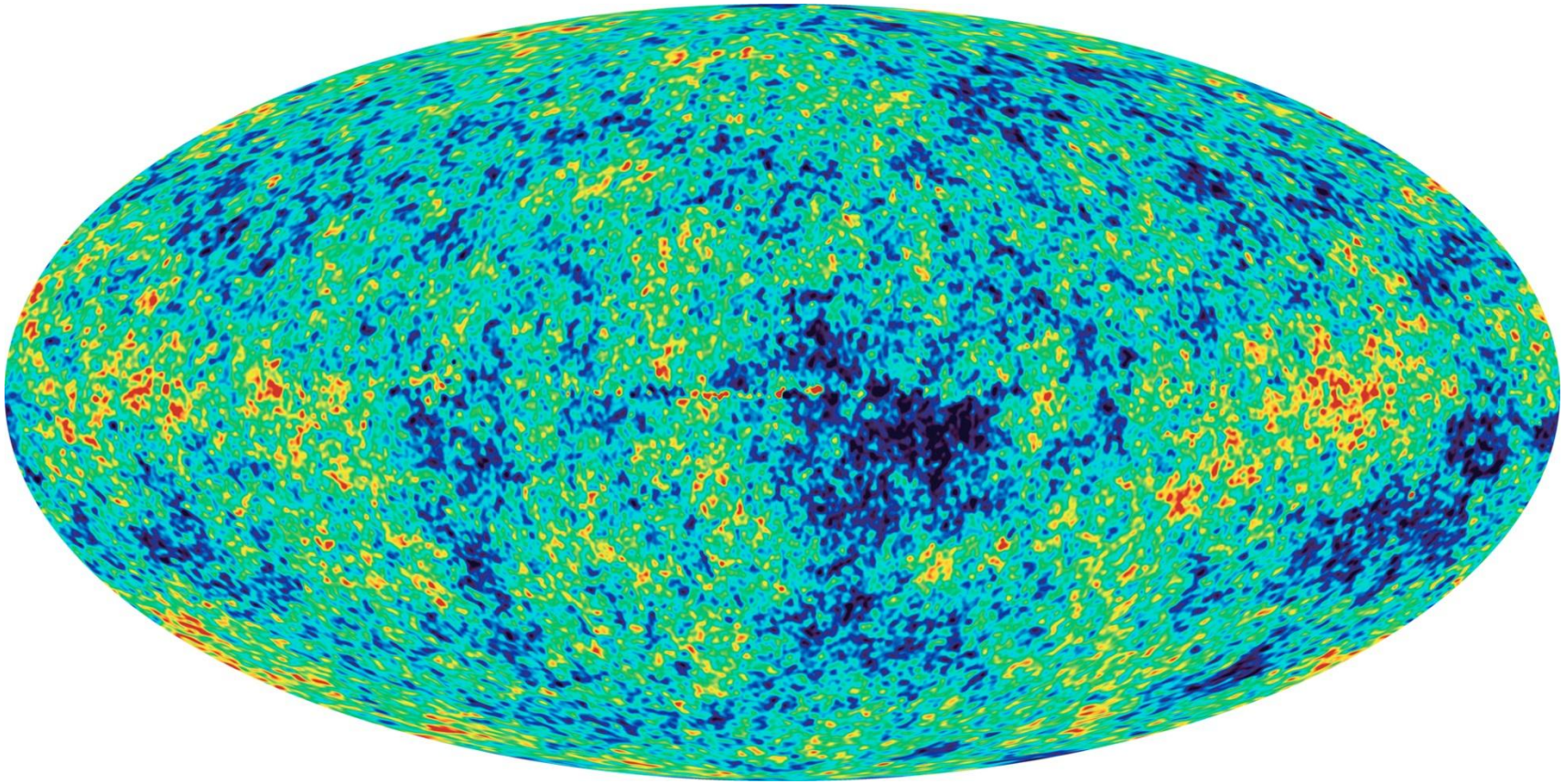
James Franck institute
Enrico Fermi institute
Department of Physics
University of Chicago

Funding: NSF, the David & Lucile Packard Foundation, DARPA, AFOSR Air Force Office of Scientific Research, MRSEC

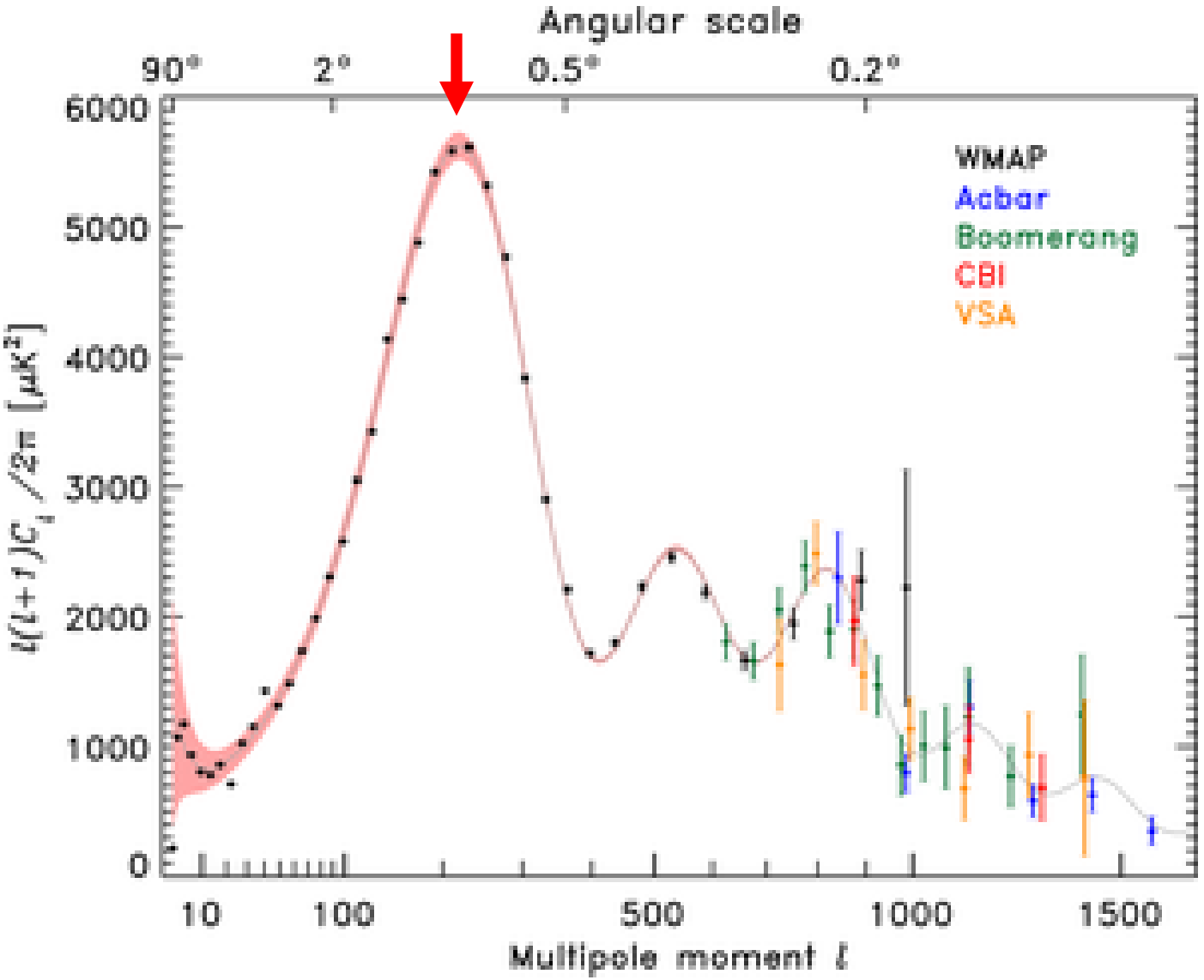
Chicago in 1898



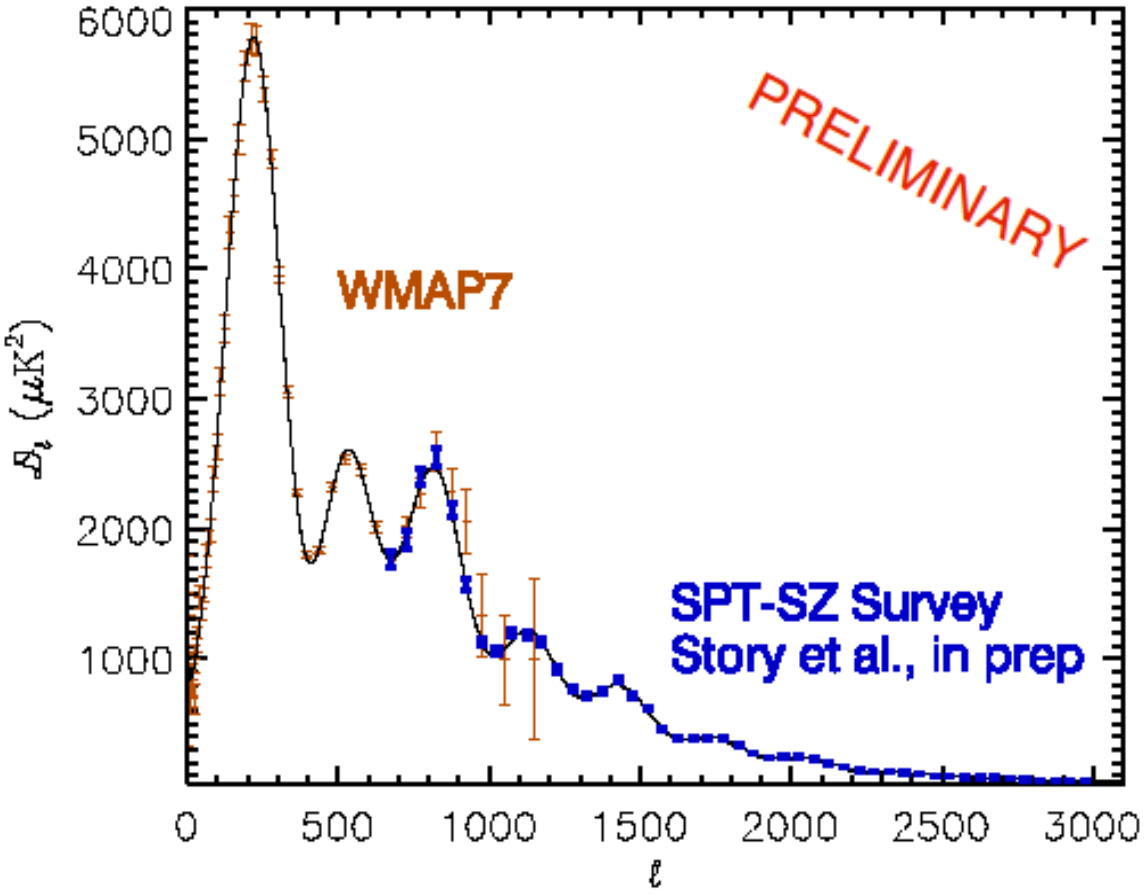
Cosmic microwave background (CMB) radiation



CMB angular power spectrum



South Pole Telescope Survey (University of Chicago)



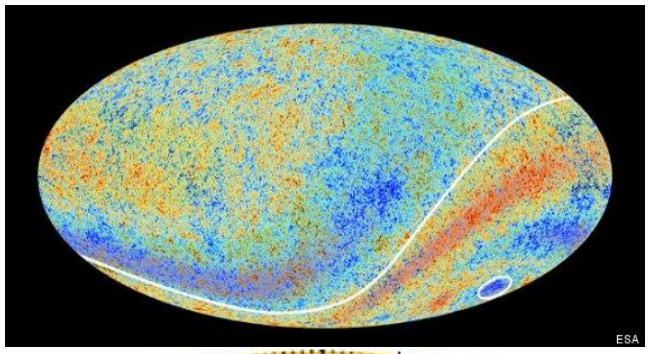
Courtesy of Kyle Story (John Carlstrom group)

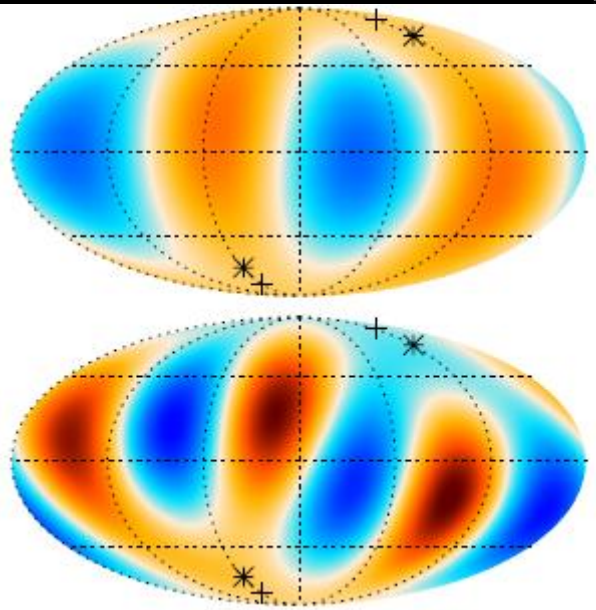
Sakharov acoustic oscillations (1965)

Size = velocity $\times$ time

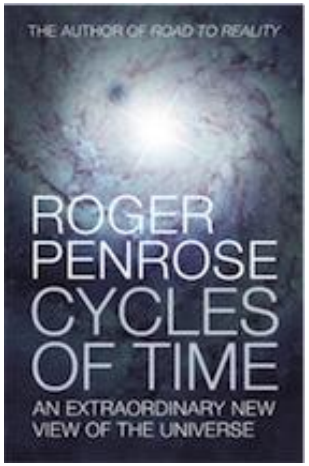
(Andrei Sakharov)

CMB anomalies and physics before Big Bang (?)



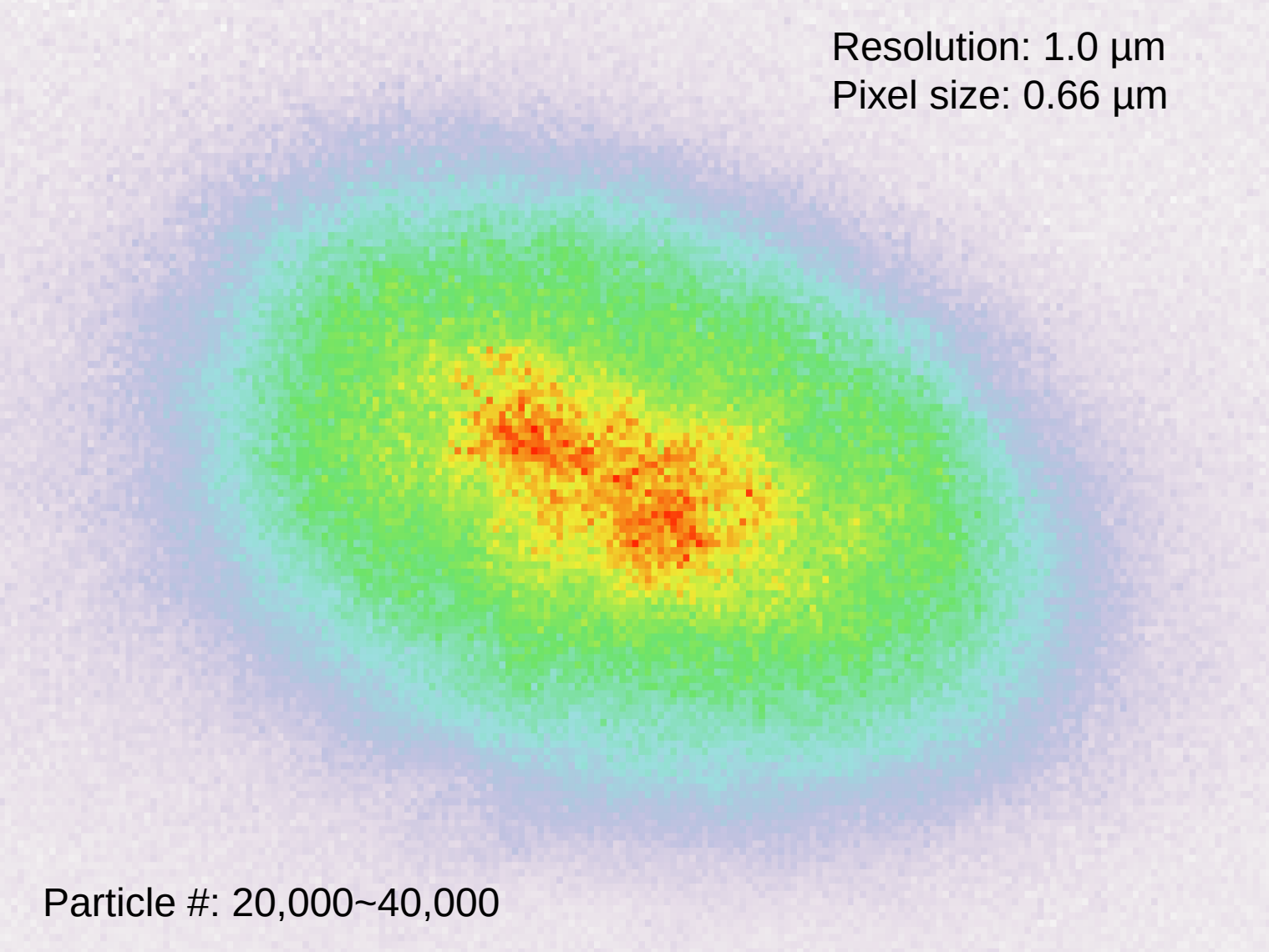


axis of evil, cold spot
cyclic universe (Penrose)



arXive: 1303.5062-90 ***Planck*** **2013 results. XXIII. Isotropy and statistics of the CMB**

Bose-Einstein condensate of atomic cesium



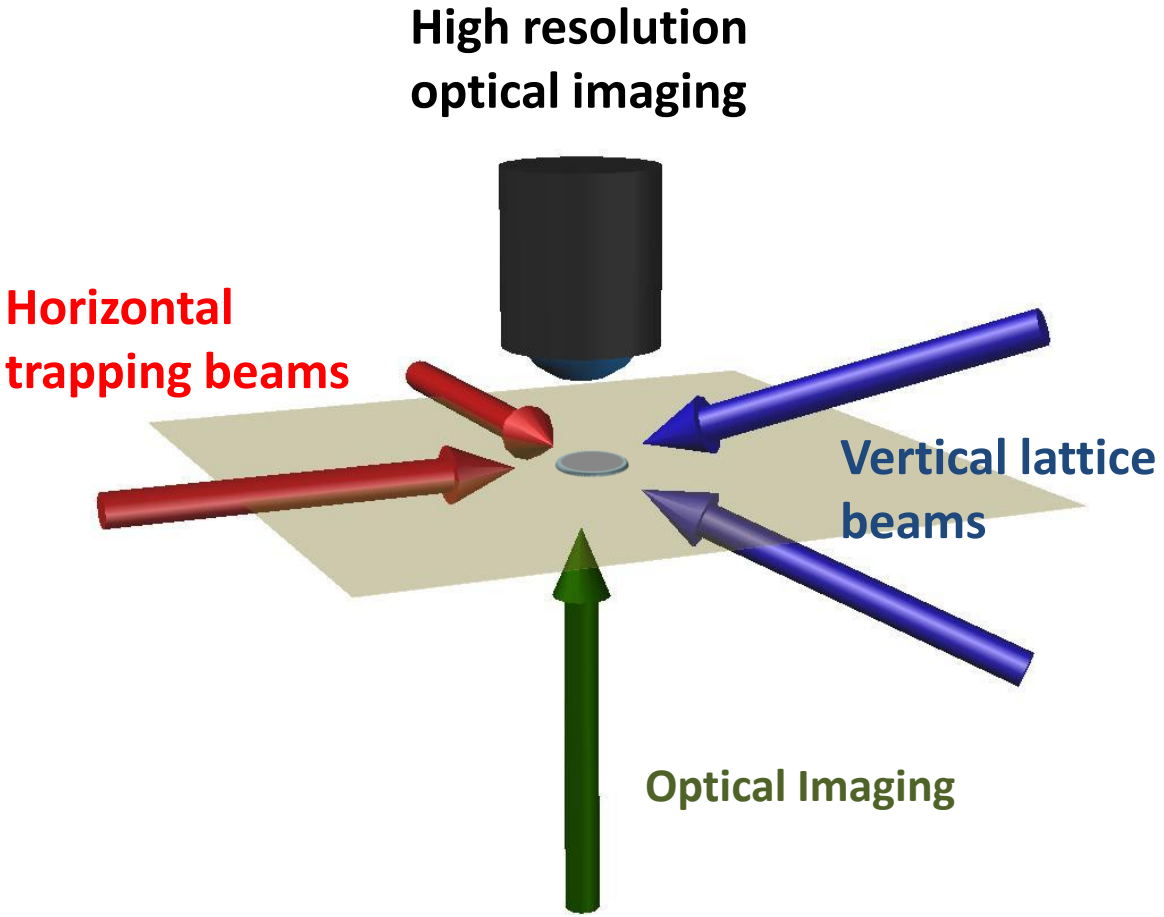
Synopsis

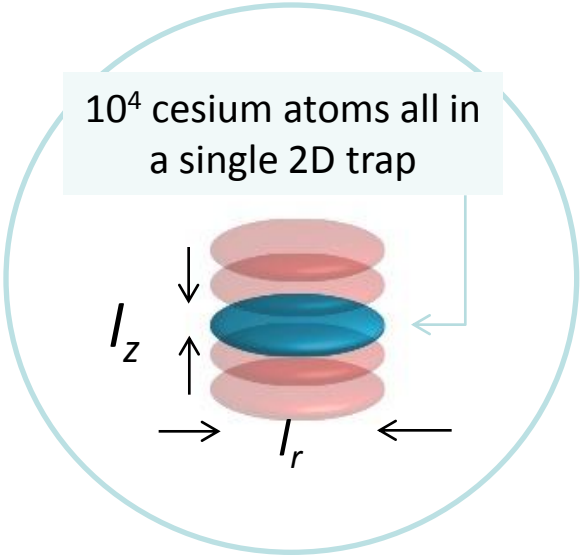
New experimental tools and observables

- Density, correlations and fluctuations
- Inspiration from cmb radiation anisotropy
- Sakharov acoustic oscillations

Future projects: Black hole and gauge-gravity duality

In situ probing a monolayer of 2D quantum gases

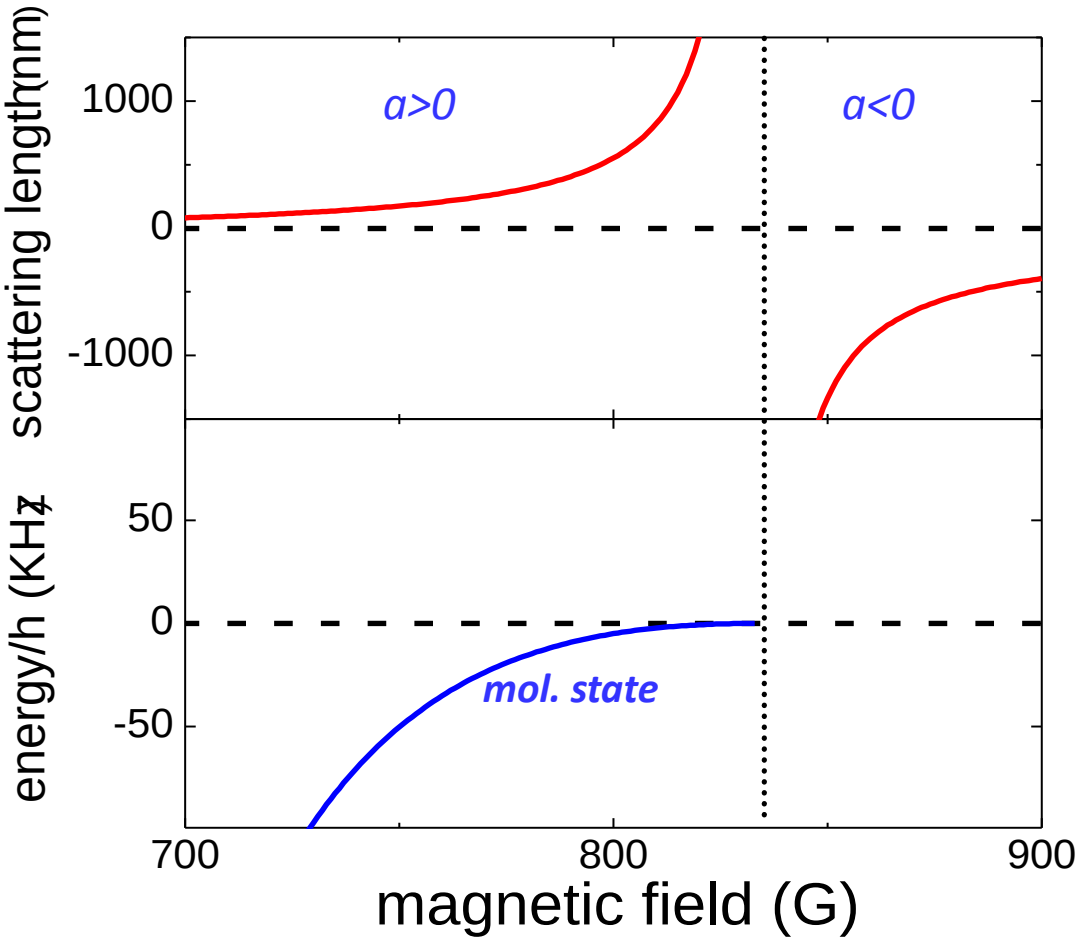




Oscillator length l_z: 200nm
Radial size: 50 μm

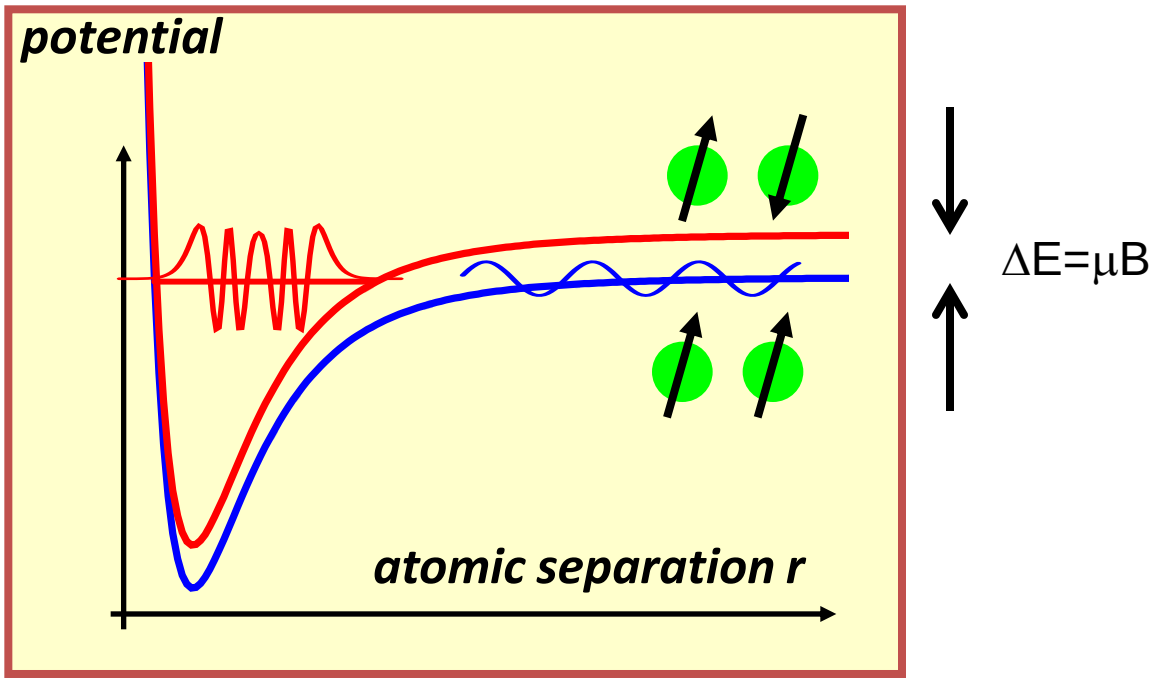
Quantum gas experiments in Taiwan: Ming-Shien Chang and Yuju Lin

Feshbach resonance: control atomic interaction



C. Chin, R. Grimm, P. Julienne and E. Tiesinga, Rev. Mod. Phys., ***82*** *1225 (2012)*

Feshbach resonances in cold atom collisions



Transition matrix

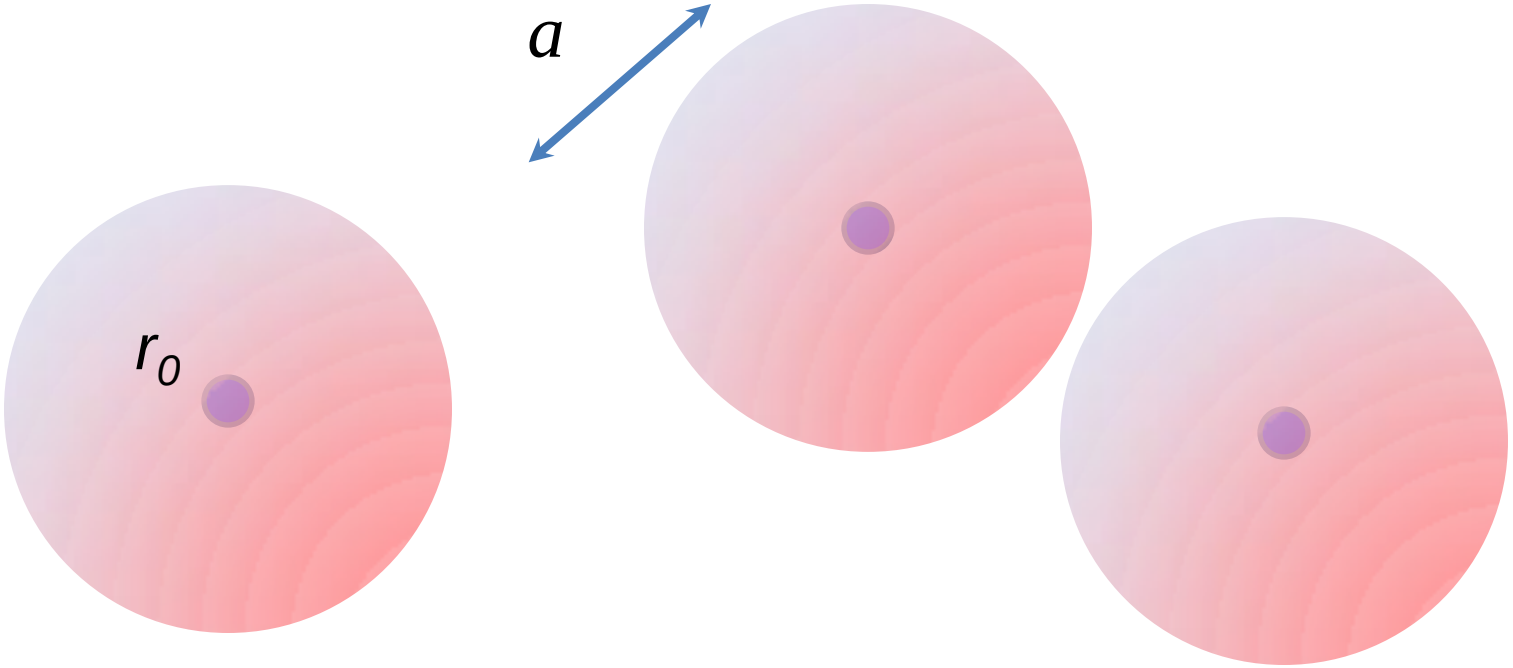
$$T_{fi} = T_{fi}^{0} + \frac{\left\langle \chi_f^- \middle| V \middle| \phi \right\rangle \left\langle \phi \middle| V \middle| \chi_i^+ \right\rangle}{E - E_\phi + i\,\Gamma/2}$$

→

Scattering length:

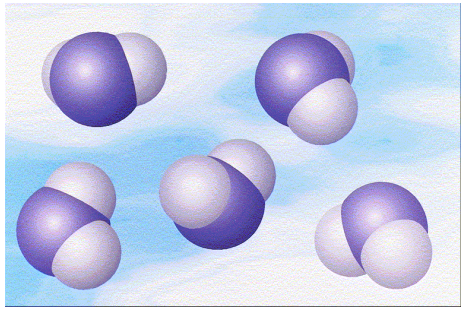
$$a = a_{bg}\left(1 - \frac{\Delta B}{B - B_0}\right)$$

Low energy scattering



Cross section: $\sigma=8\pi a^2$

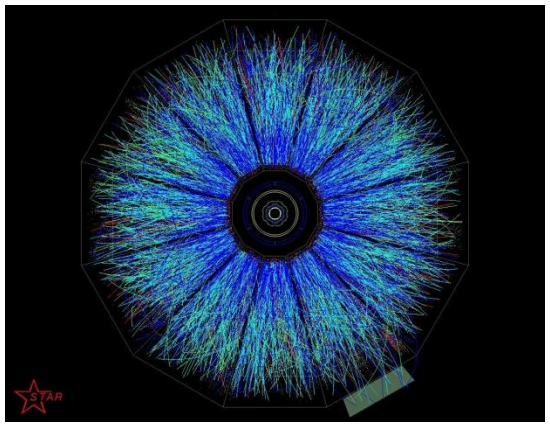
Quantum Simulation based on



Ultracold atoms and molecules

Systems being simulated:
condensed matter,
nuclear physics,
HEP,
cosmology…

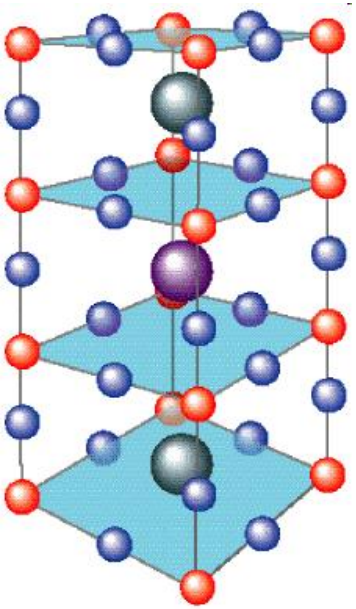
Nuclear physics



Efimov trimer states

Theory: *(1970)*
Experiment: *(2006)*

Condensed matter

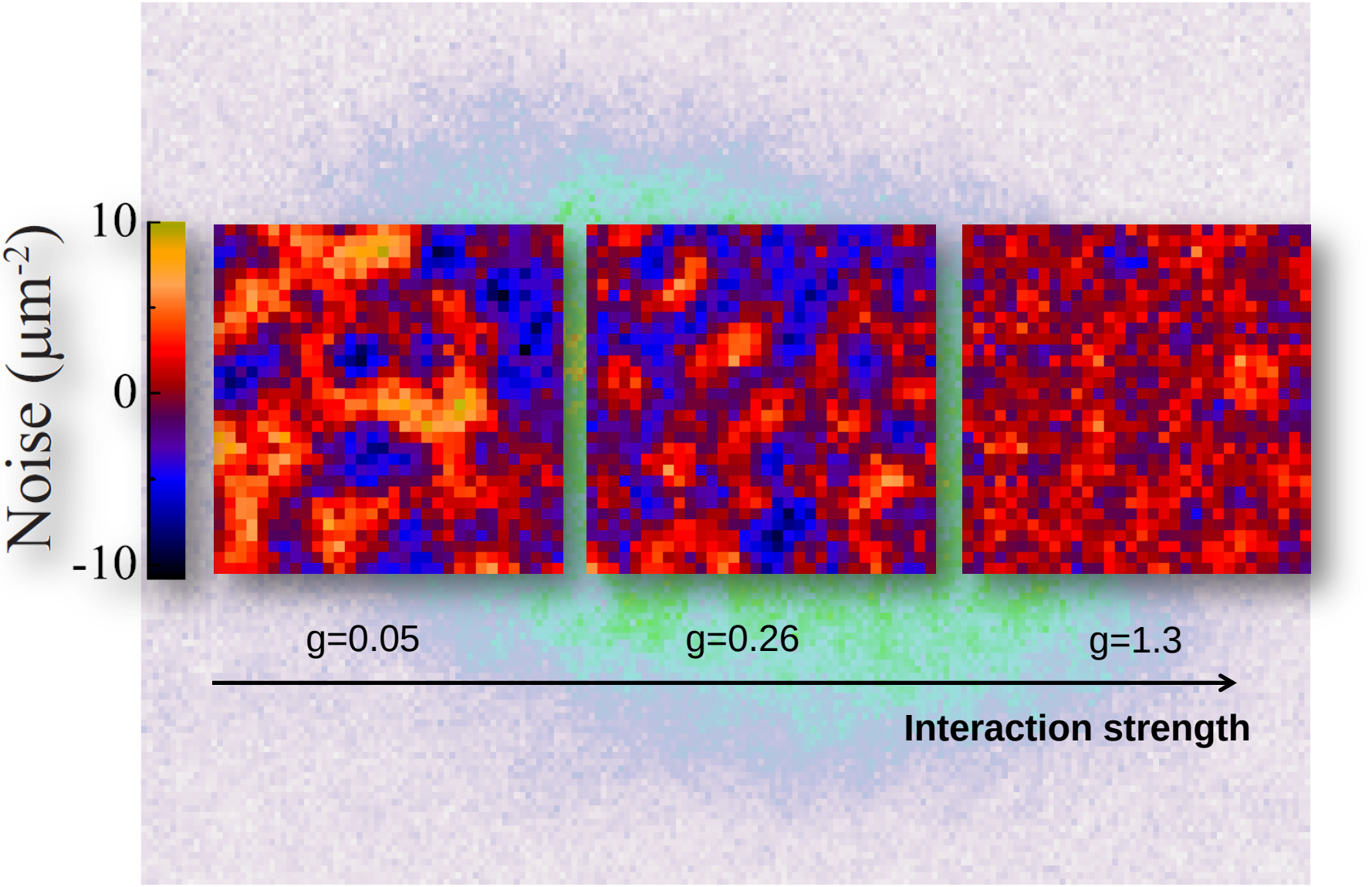


Superconductivity

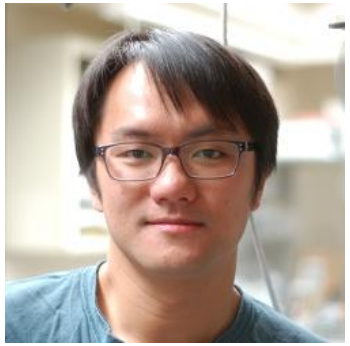
BCS = BEC??
Eagles (1969) Leggett (70)

Experiment: *(2004)*

Can we see the same anisotropic oscillations?

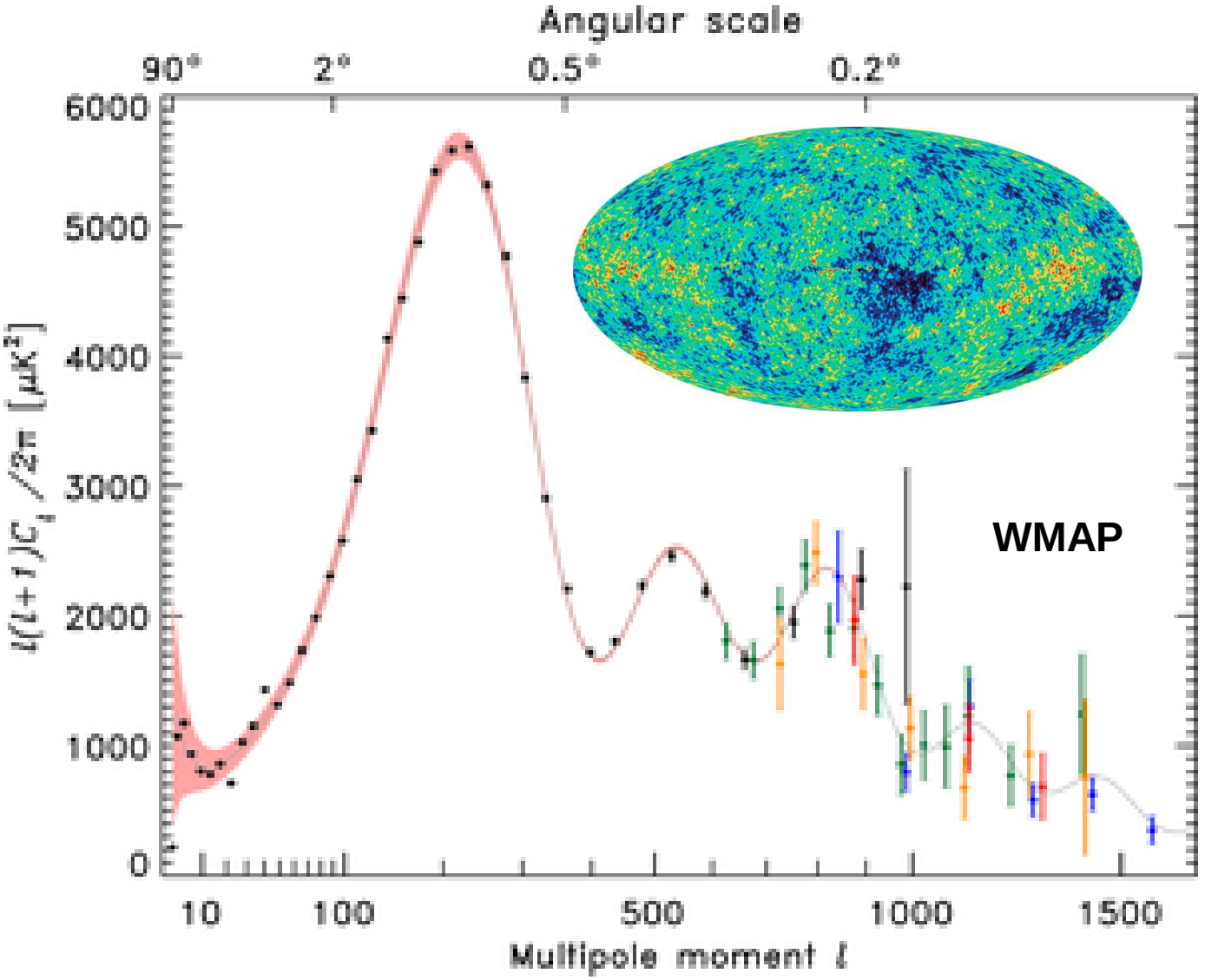


Sakharov acoustic oscillations in CMB

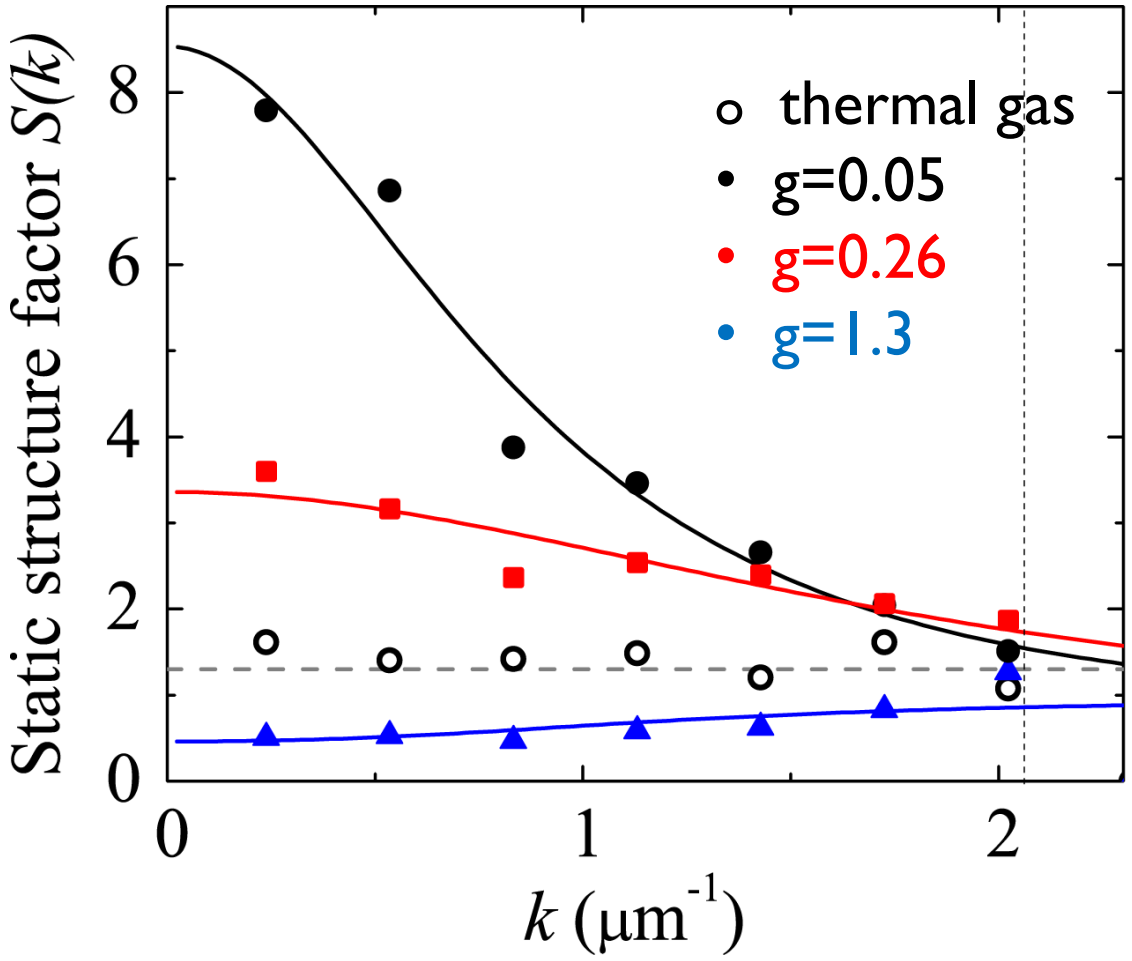


Dr. Chen-lung Hung
(postdoc at CalTech)

Prof. Chao-Lin Kuo
(Physics, Stanford
and south pole)

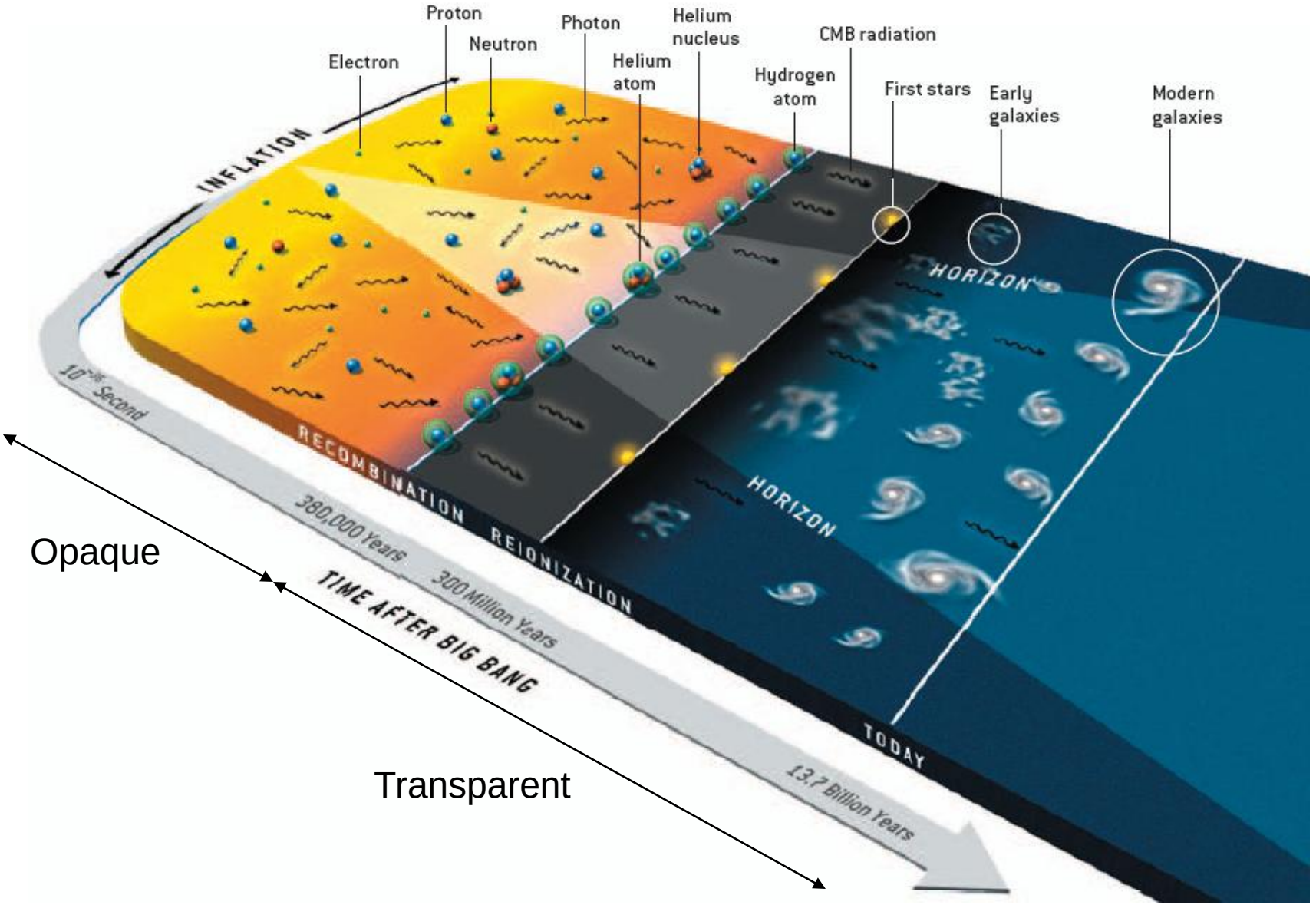


Power spectrum of fluctuations *S(k)*



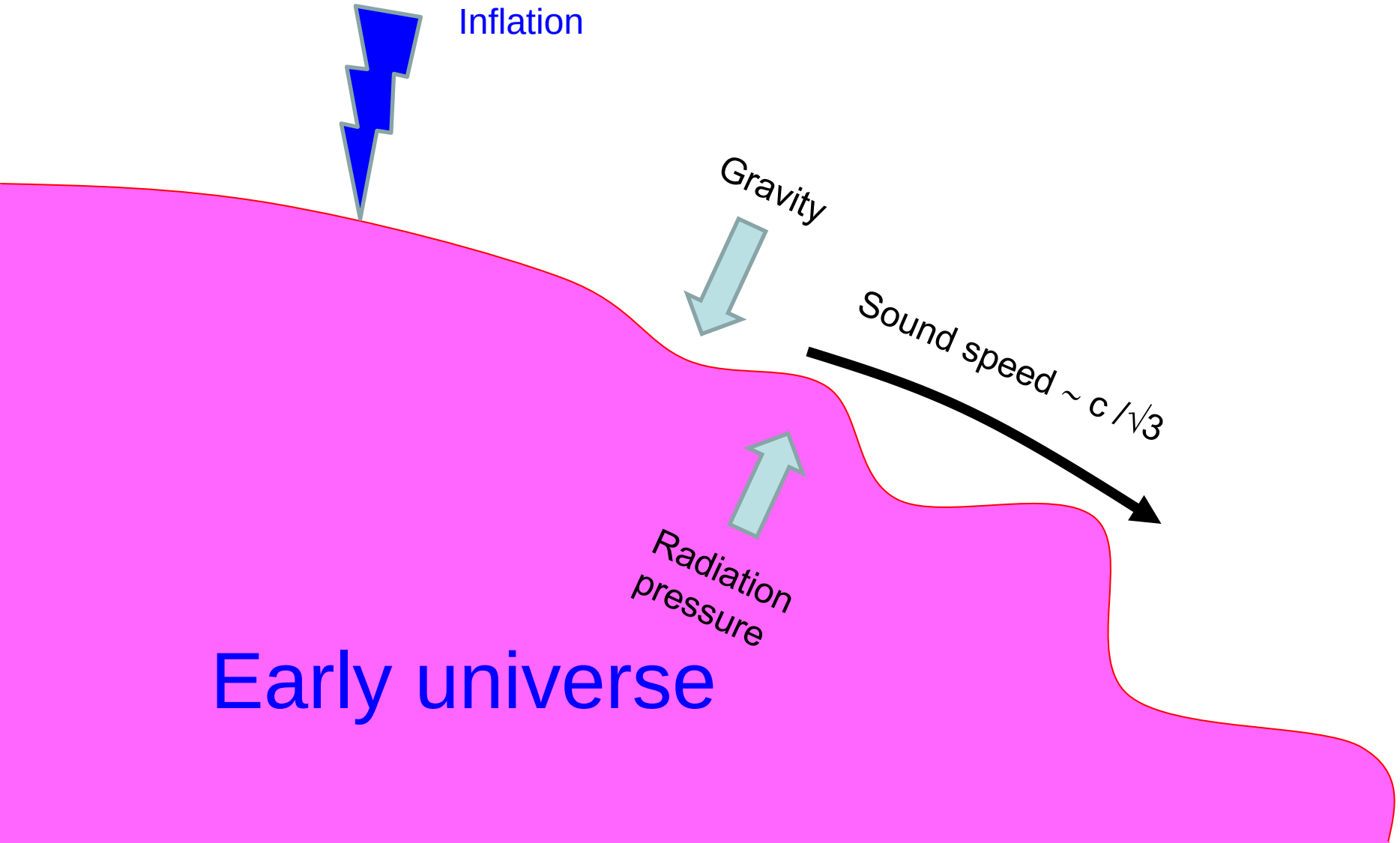
Hung et al., New Journal of Physics (2011)

Evolution of the universe

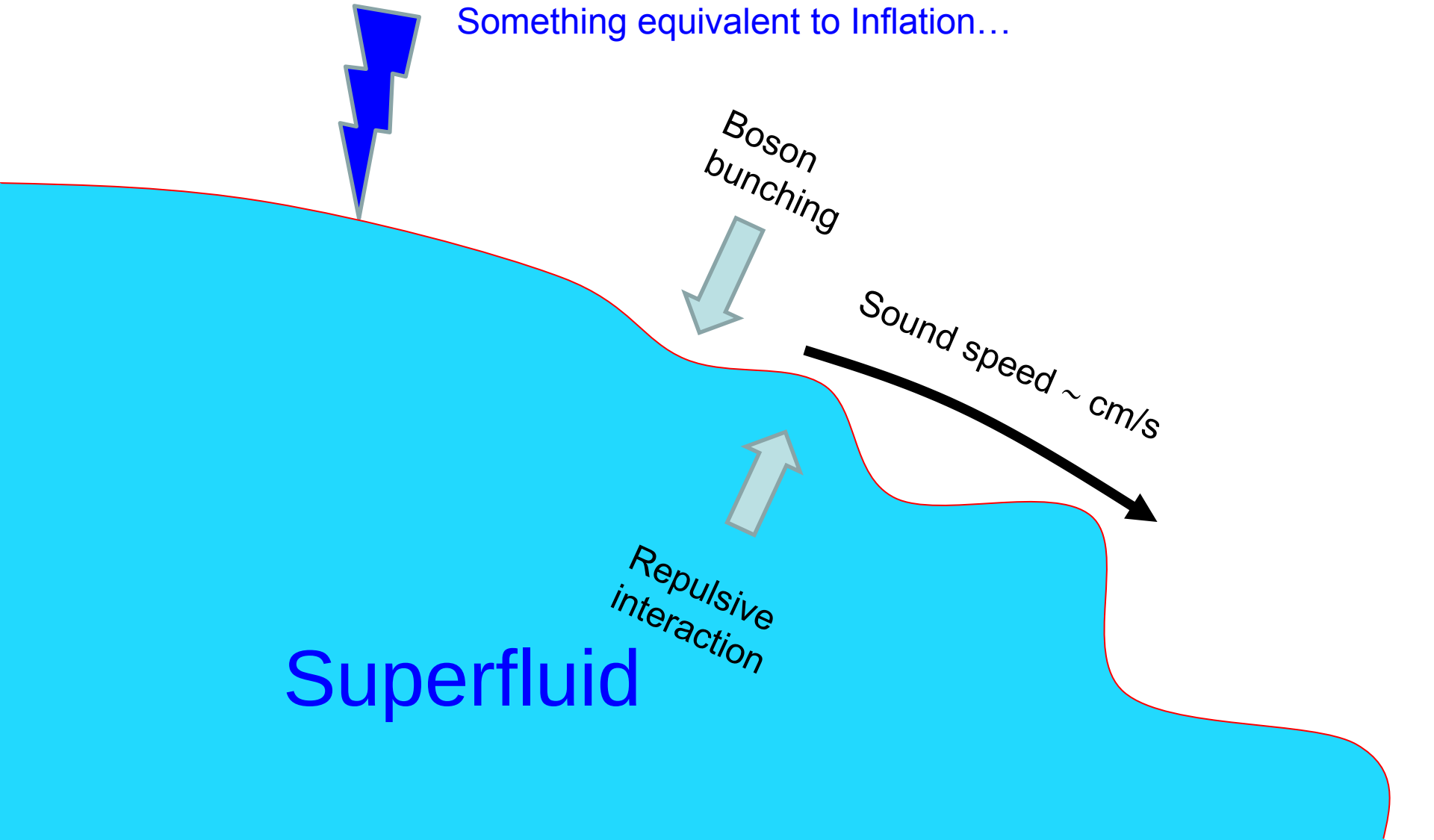


Hu & White, Sci. Am., 290 44 (2004)

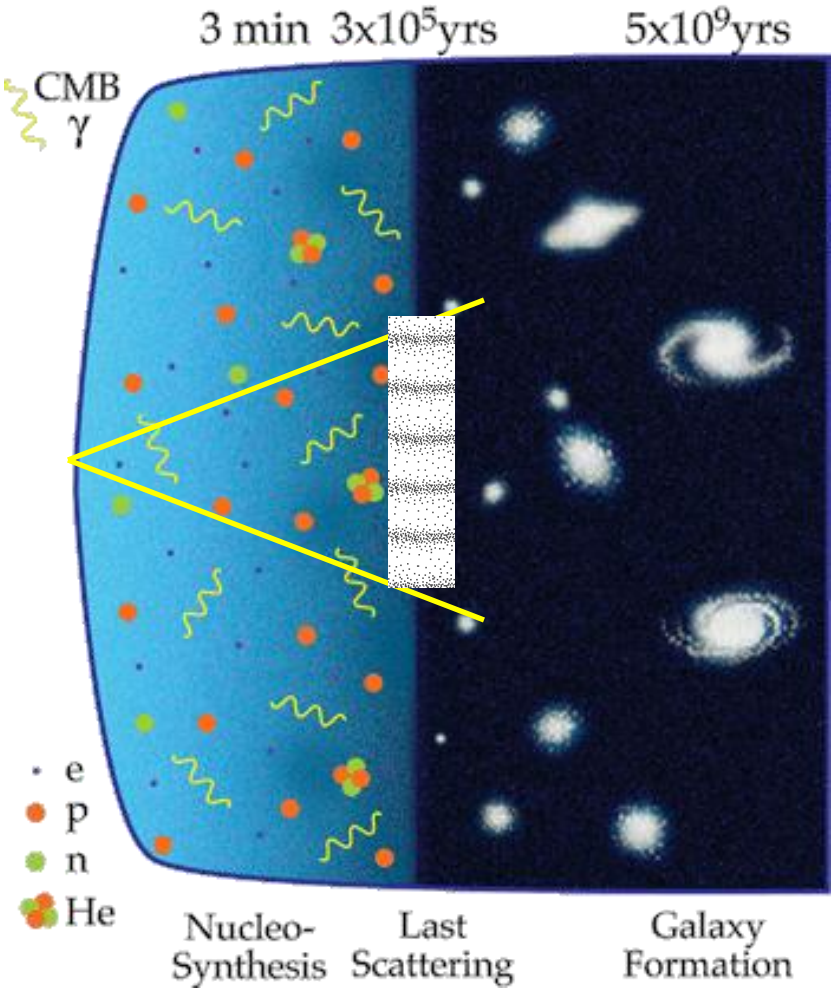
Sakharov acoustic oscillations in early universe



Sakharov acoustic oscillations in atomic superfluids

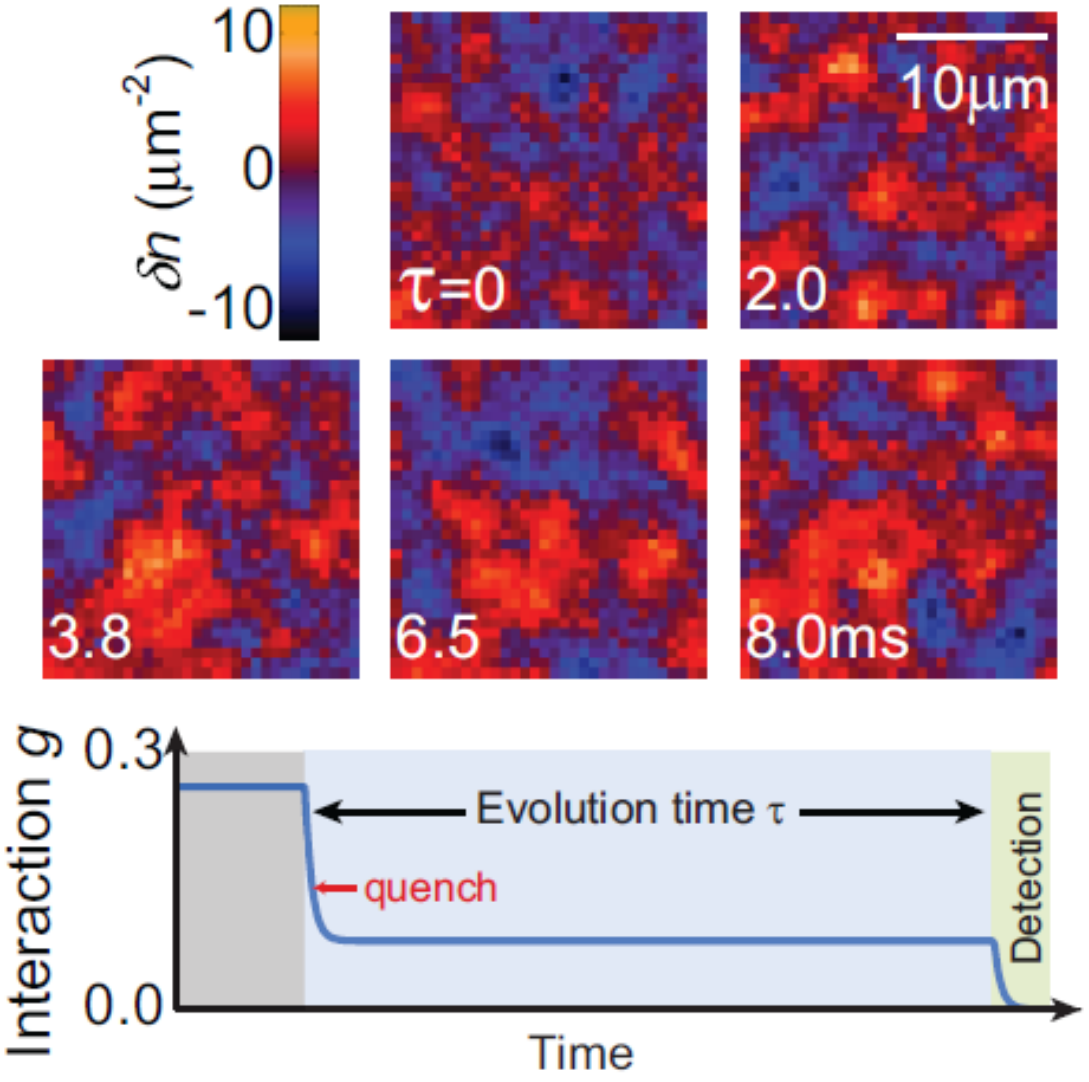


Origin of the oscillations in the cmb angular spectrum

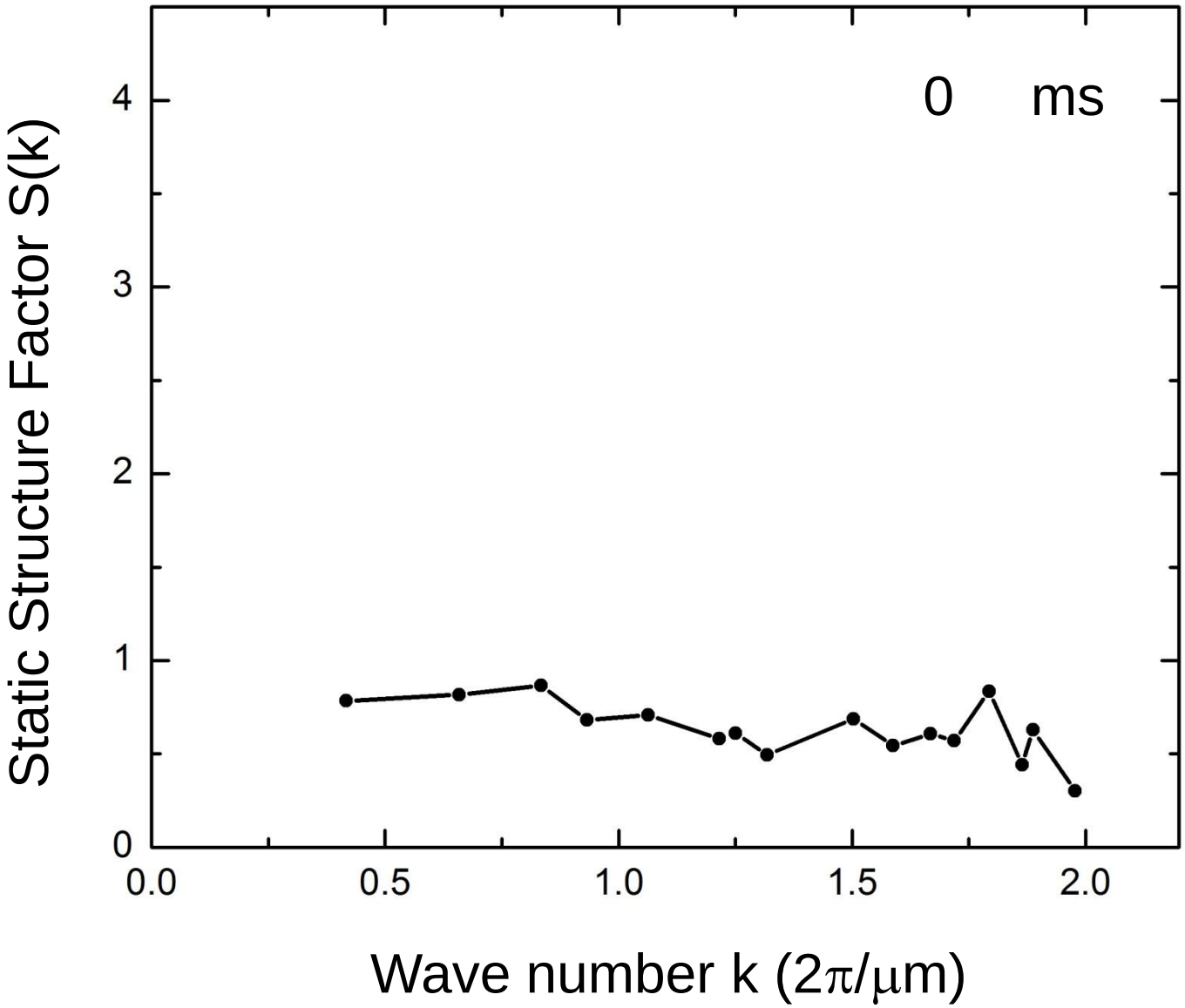


W. Hu, CMB tutorials, http://background.uchicago.edu/

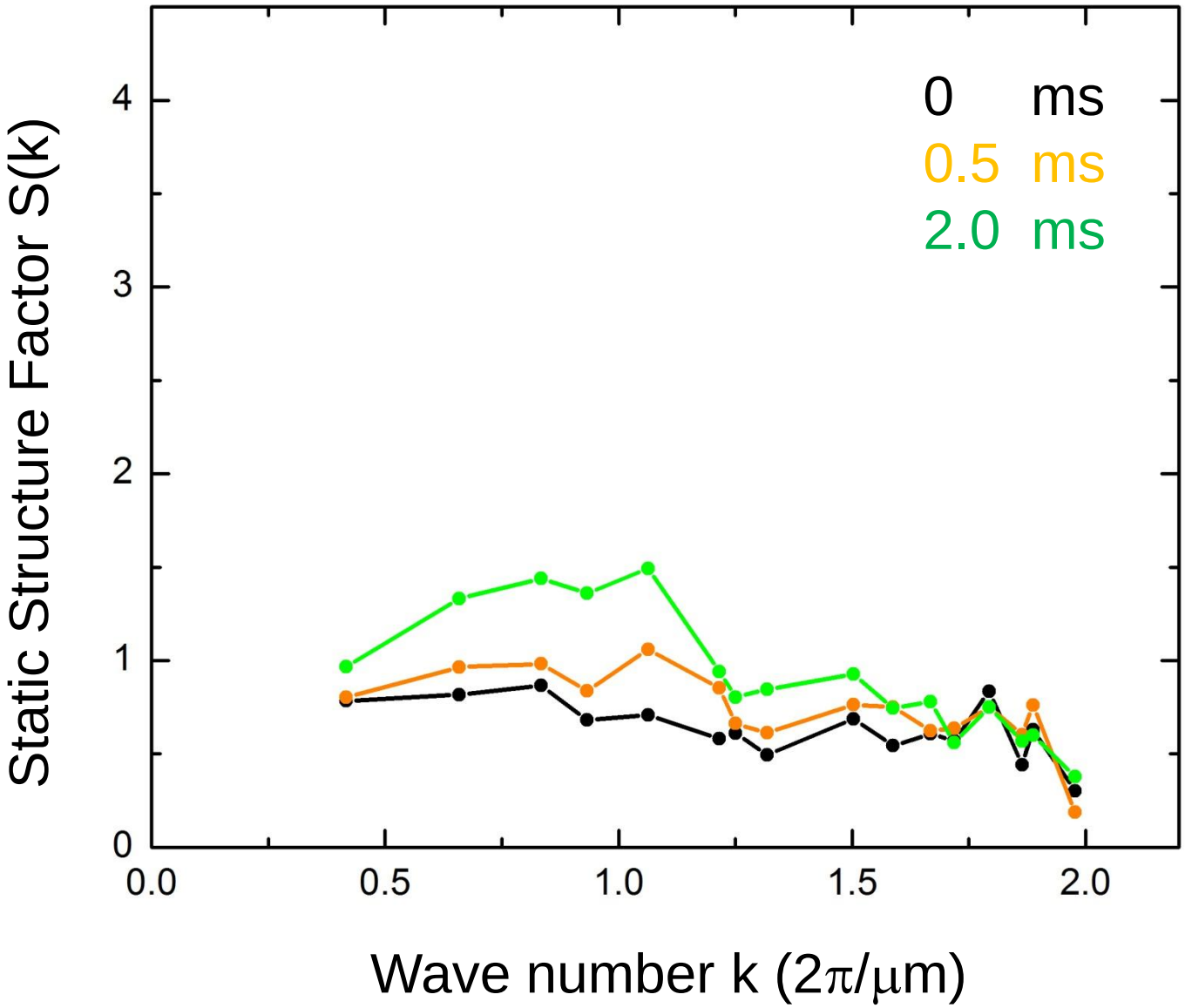
Quantum Quench (from g=0.26 to 0.05)



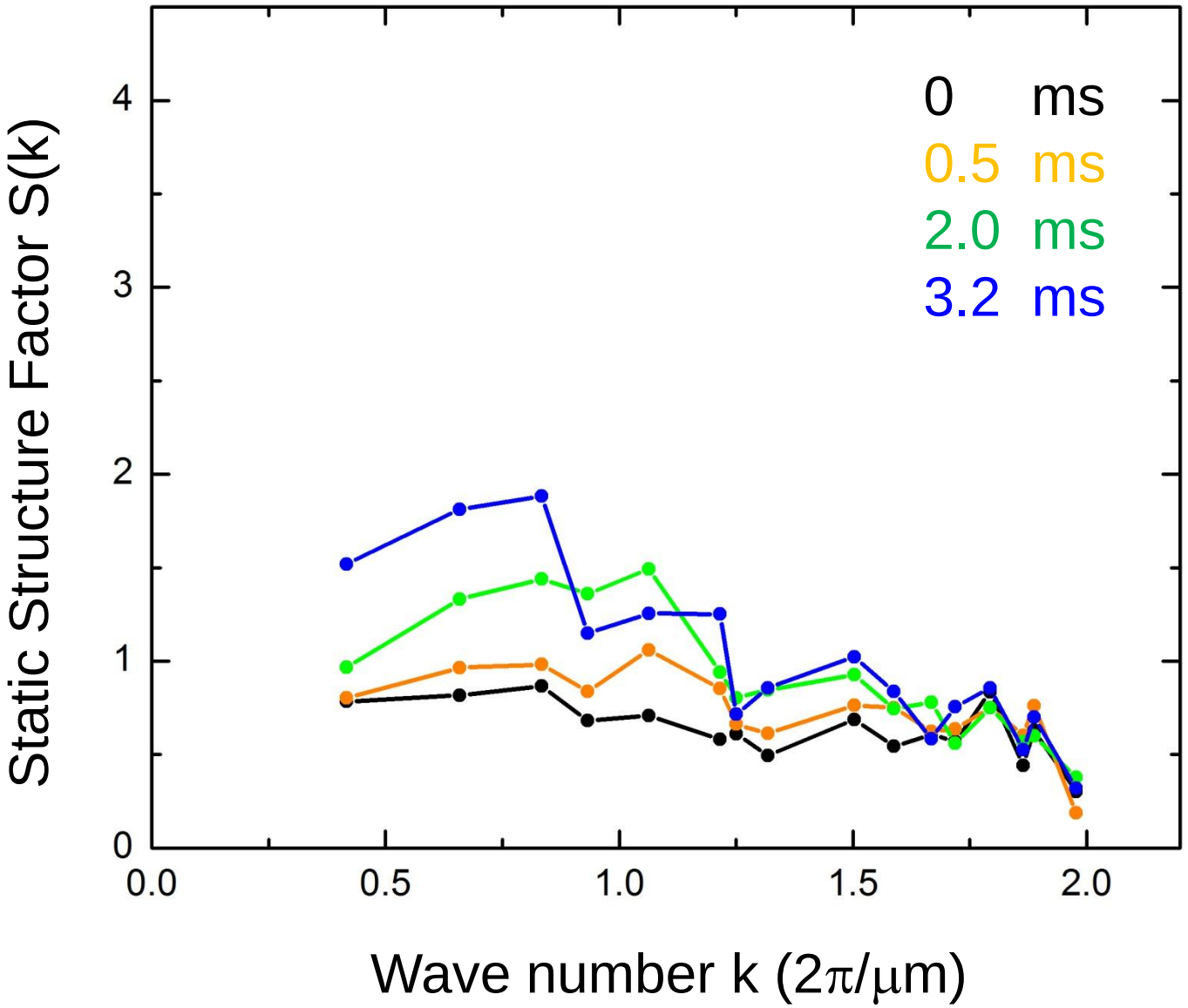
Evolution of density-density correlations



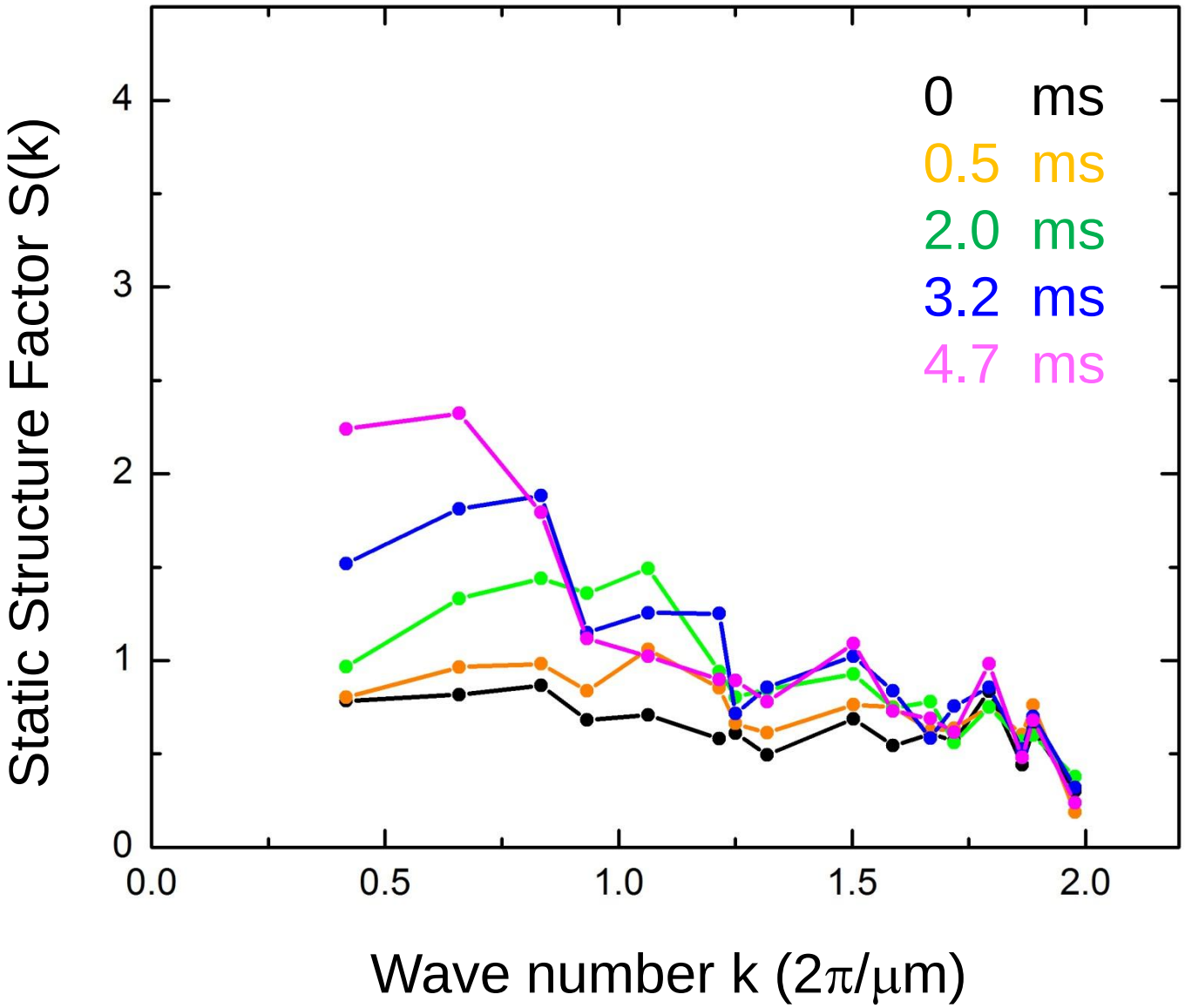
Evolution of density-density correlations



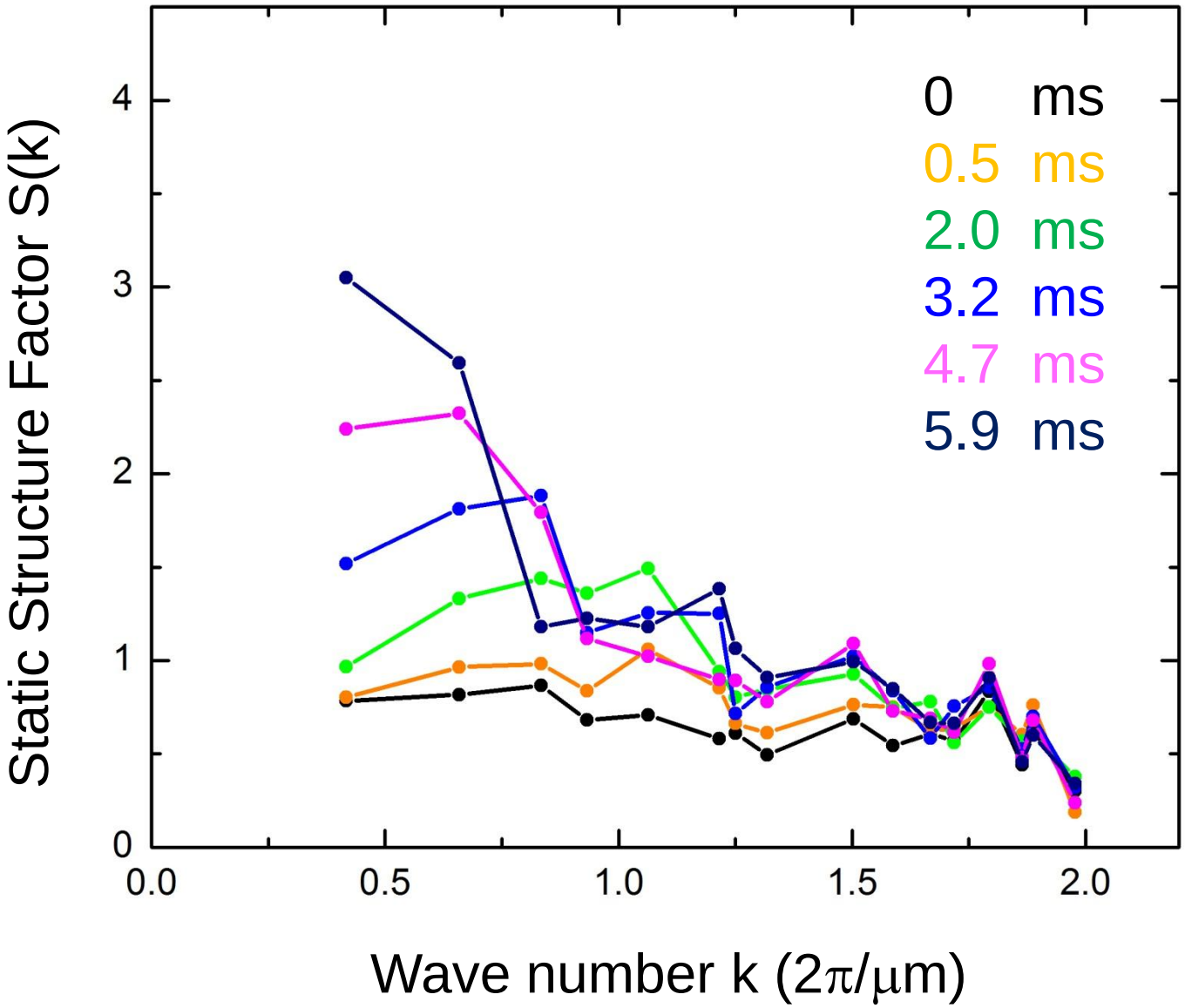
Evolution of density-density correlations



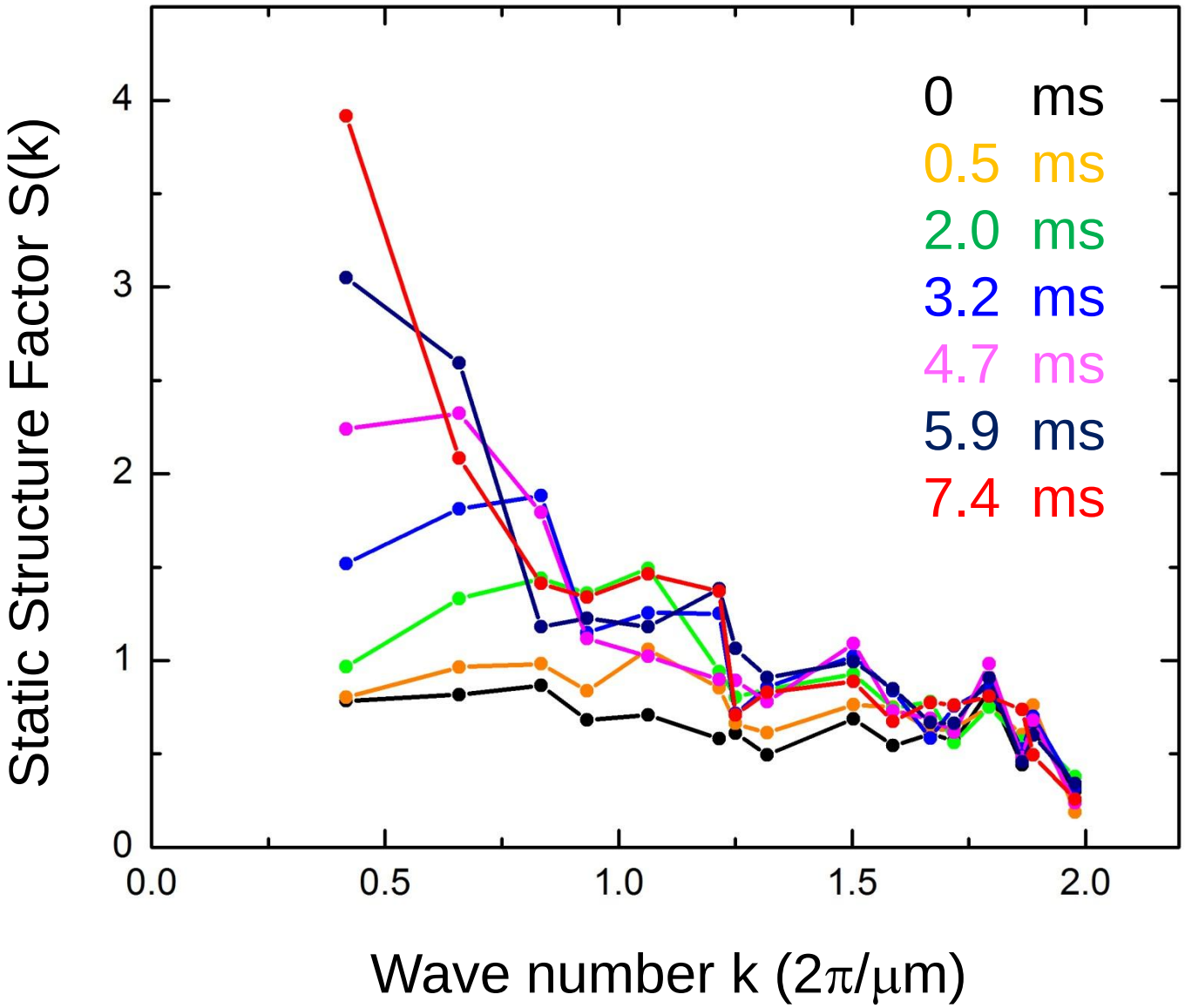
Evolution of density-density correlations



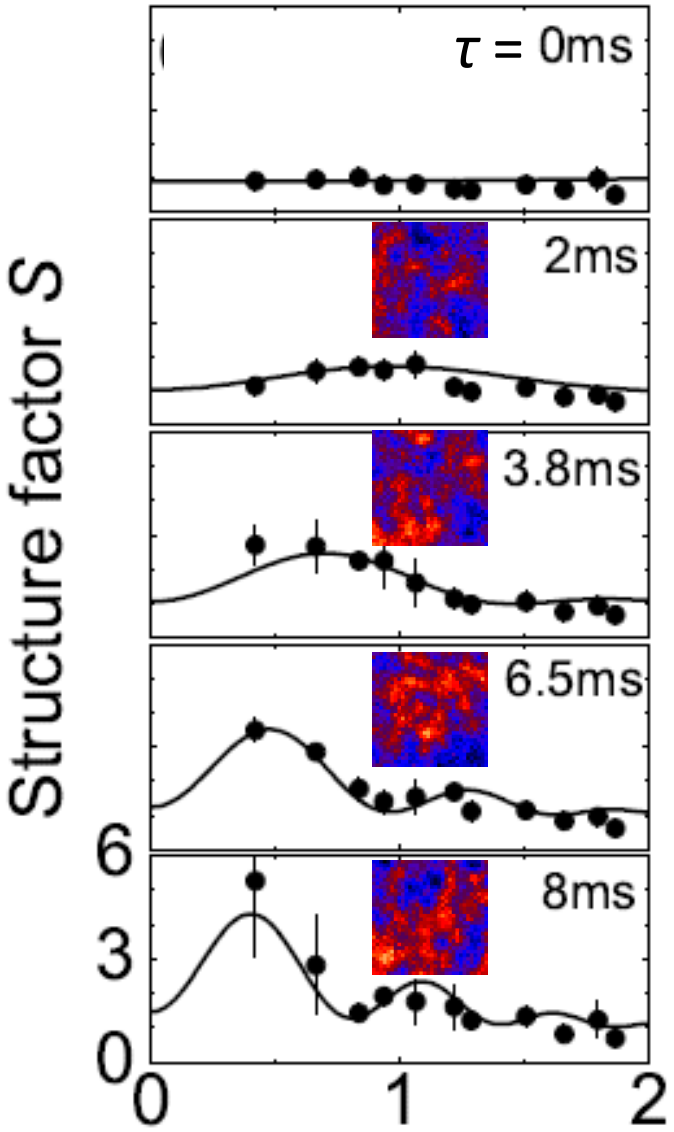
Evolution of density-density correlations

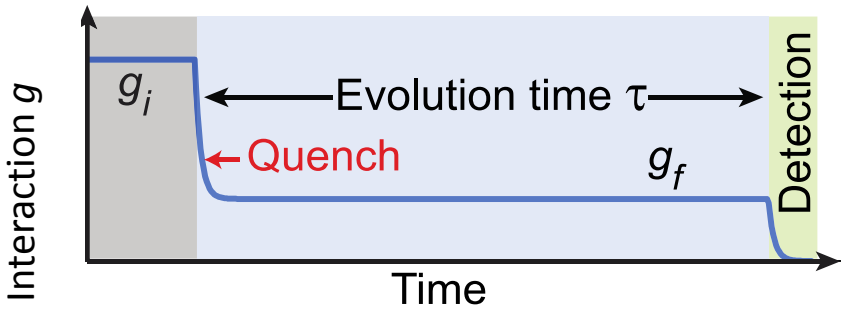


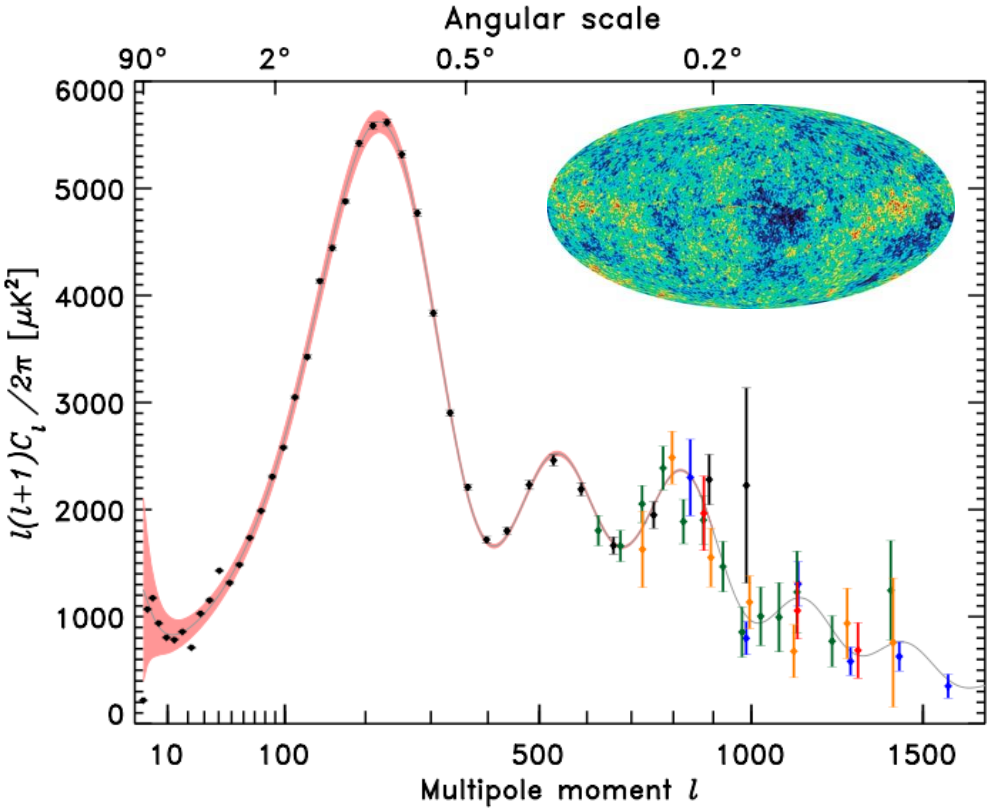
Evolution of density-density correlations



Sakharov acoustic oscillations in space coordinate



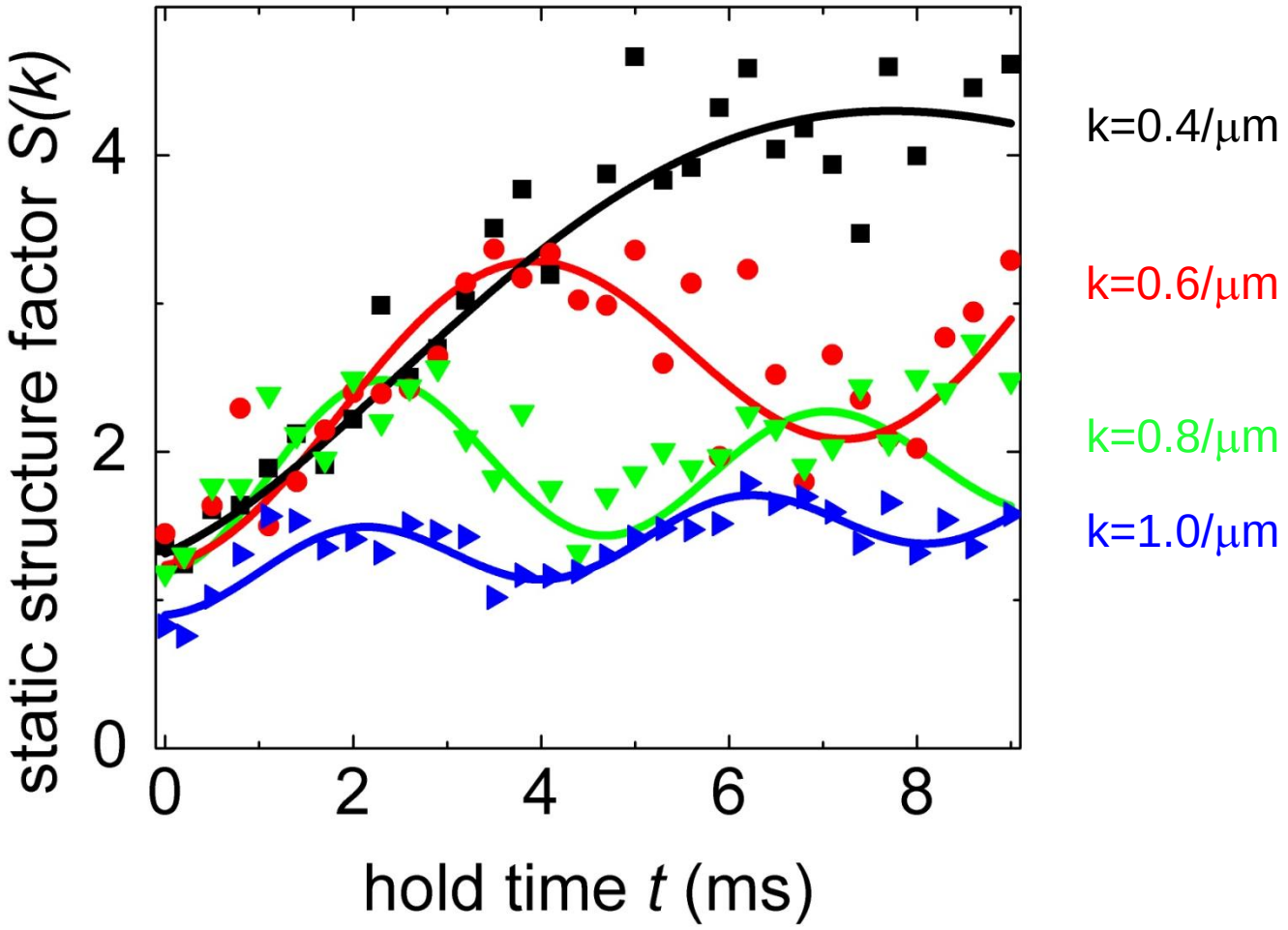


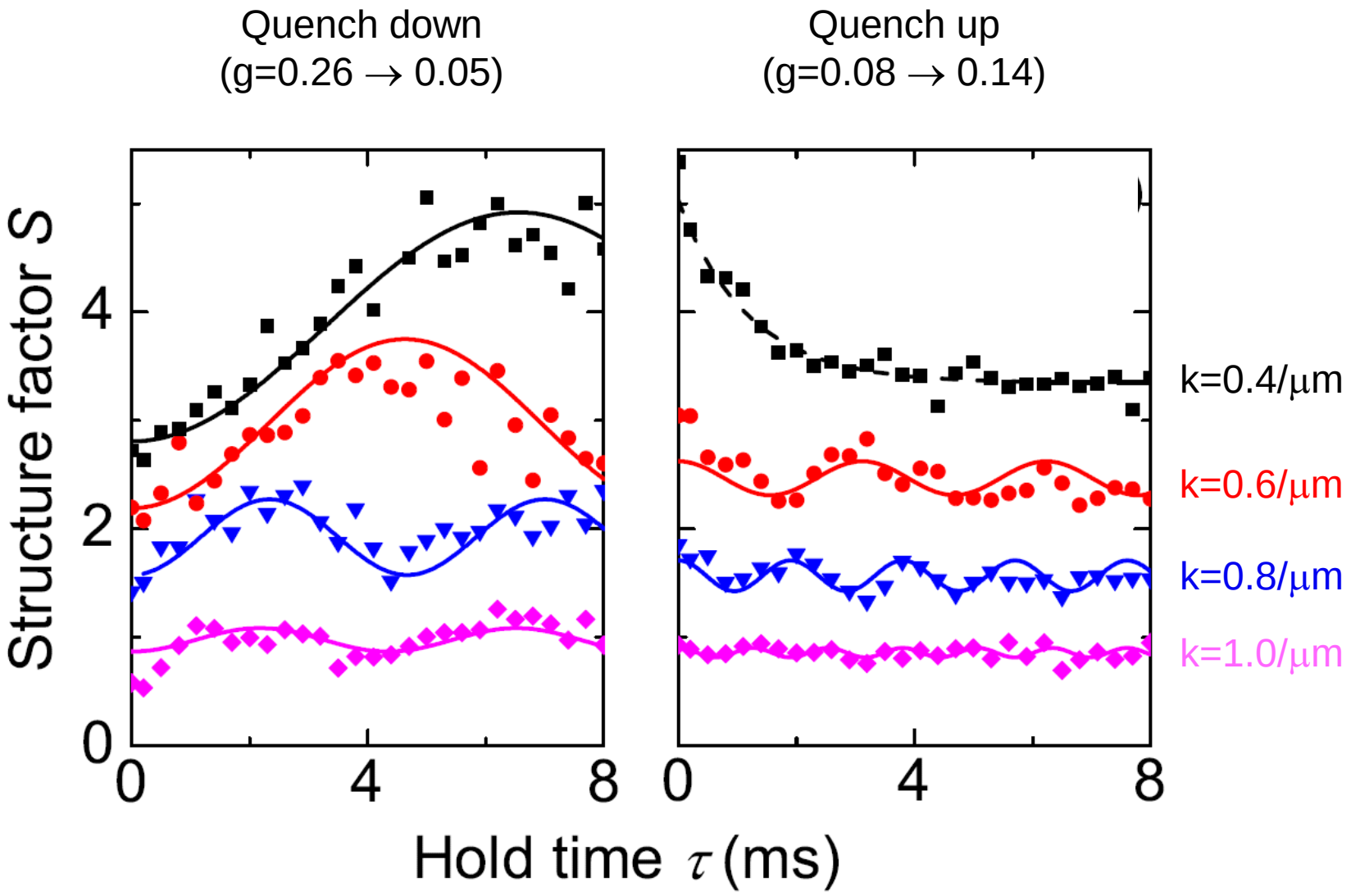


Hung, Gurarie and Chin, Science 341 1213 (2013)

WMAP

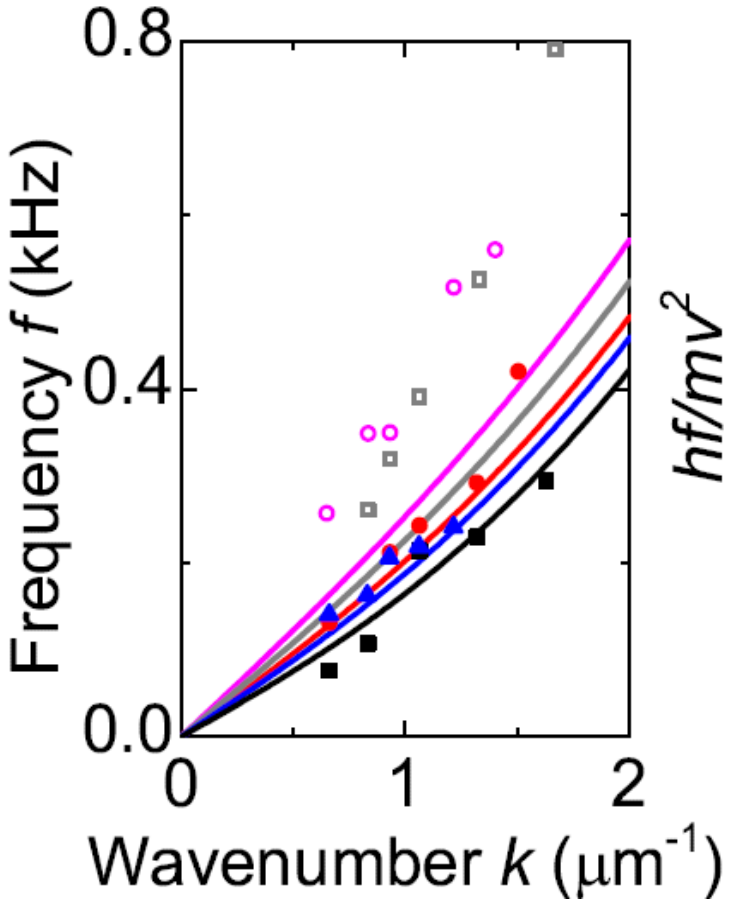
Sakharov oscillations in time domain

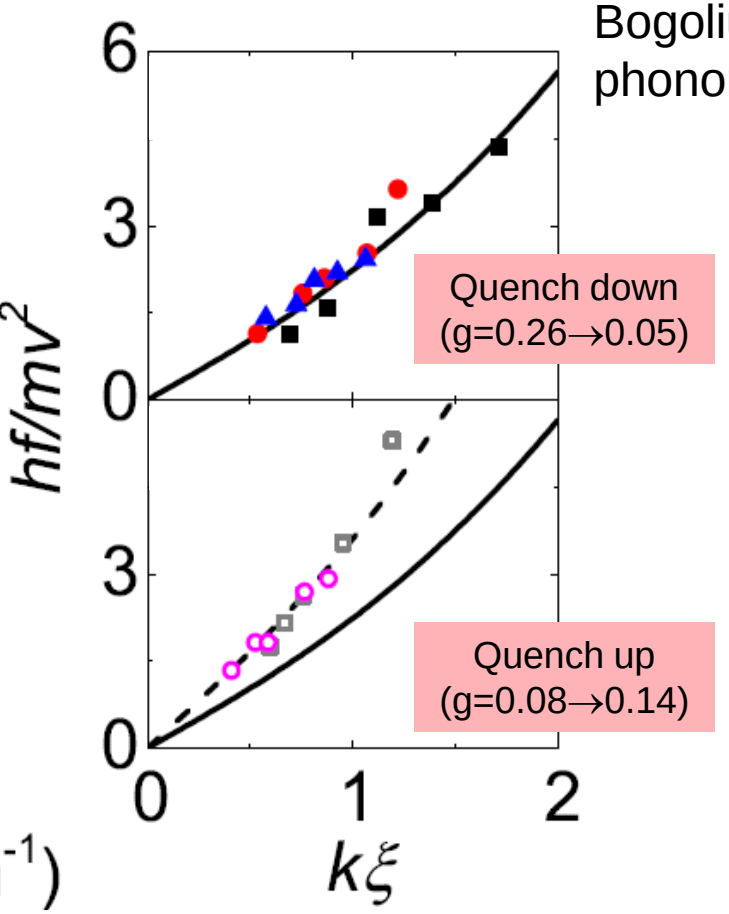




**each curve is offset by 0.5 for clarity*

Time and length scales of Sakharov oscillations





Bogoliubov phonons

Quench down (g=0.26→0.05)

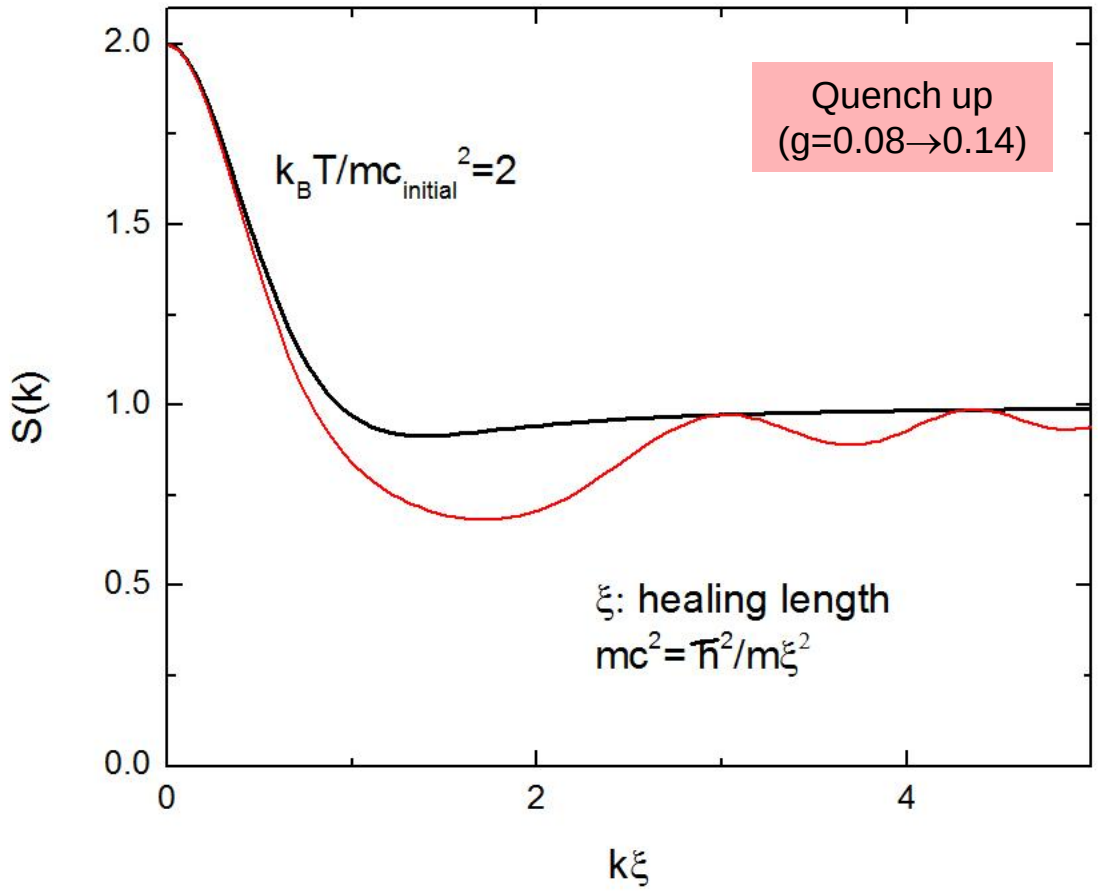
Quench up (g=0.08→0.14)

ξ: healing length
v: sound speed

Theoretical model (Bogoliubov approximation)

$$S(k)=\frac{\hbar^2 k^2}{2m\epsilon_0(k)}\coth\frac{\epsilon_0(k)}{2kT}\left[1-\frac{\epsilon(k)^2-\epsilon_0(k)^2}{\epsilon(k)^2}\sin^2\epsilon(k)t\right]$$

Equilibrum contribution Interference of acoustic waves



Landau and Liftshitz, Statistical Physics Vol. 9 P. 386

Conclusion

Quenched superfluids and Sakharov oscillations

- Inference of acoustic waves
- Correlations in time and spatial scales
- Questions: Damping of Sakharov oscillations?

Related projects

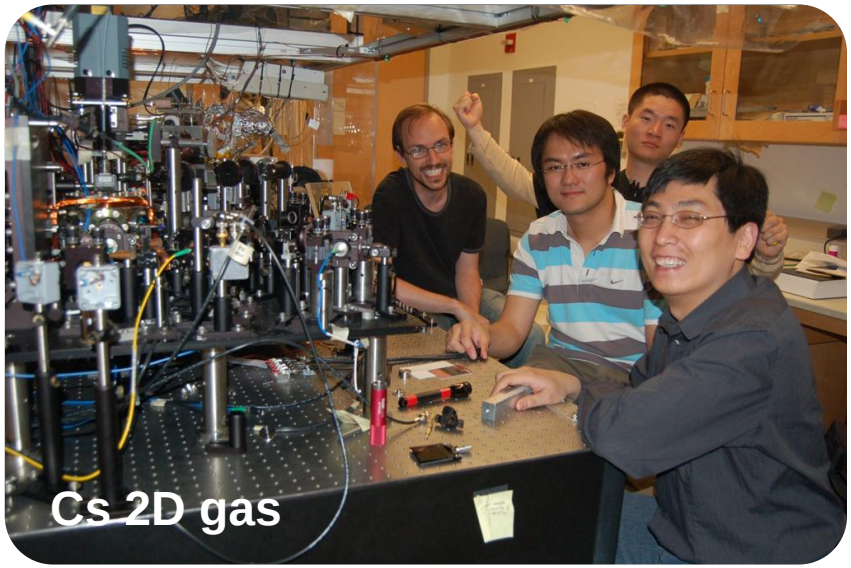
Quantum analog of gravitational physics

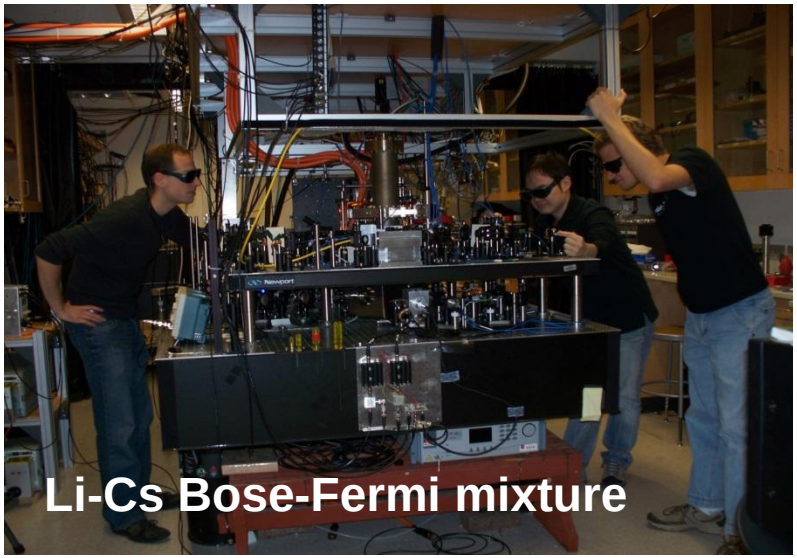
- Sonic black hole and Hawking radiation and Unruh effect
- Quantum criticality and AdS-CFT correspondance

Discrete scaling symmetry

- Discrete scaling symmetry in Efimov three-body bound states
- Universality in far from equilibrium quantum dynamics

Experiments





Former member (left to right):

Prof. Nathan Gemelke (Penn state)

Dr. Chen-Lung Hung(Caltech)

Dr. Xibo Zhang (JILA)

Current group members:

Dr. Shih-Kuang Tung

Harry L.C. Ha

Dr. Colin V. Parker

Jacob Johansen

Dr. Eric Hazlett

Logan Clark