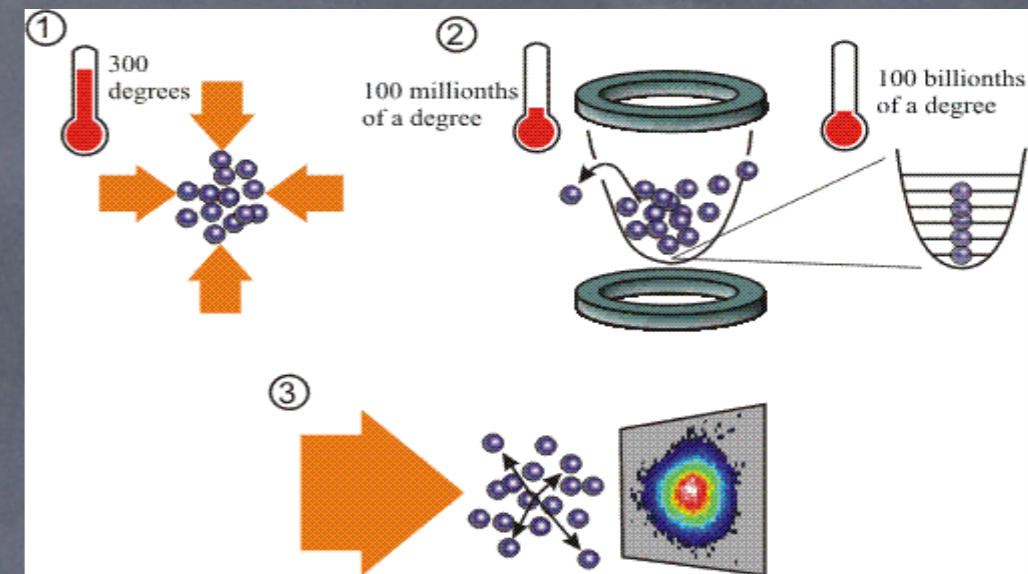


Atomic Gas Experiments

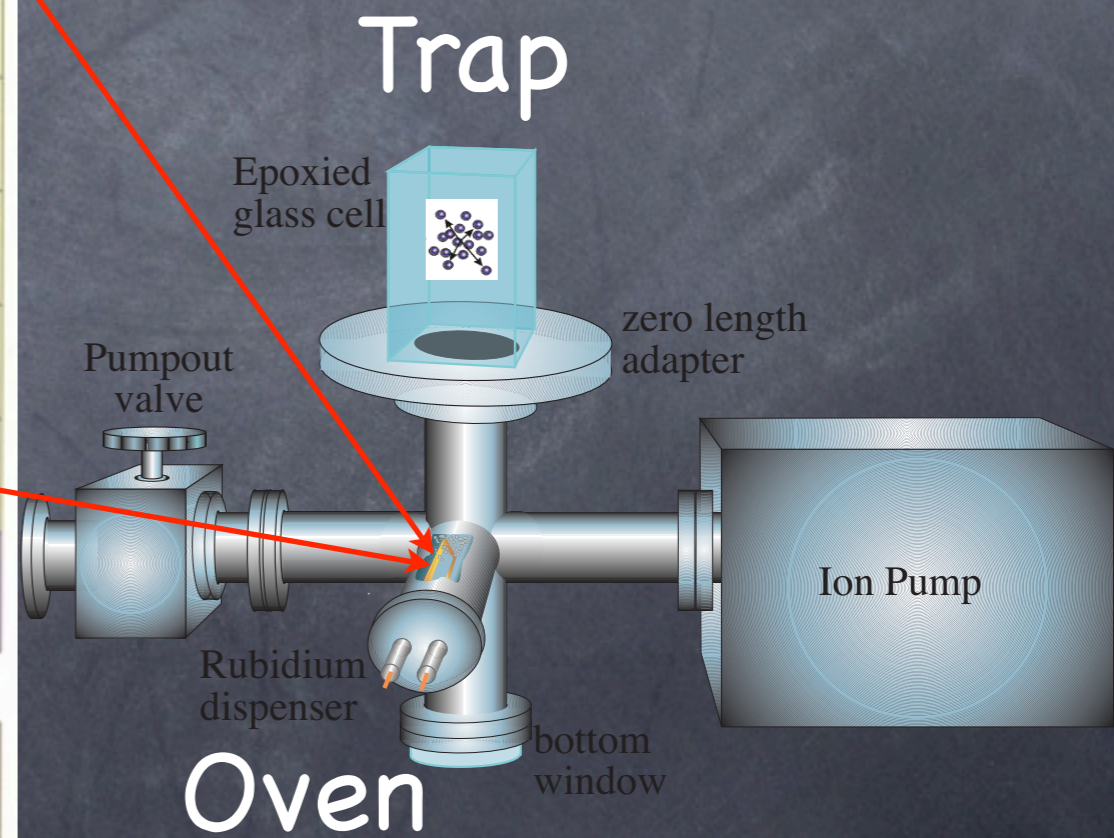


THE PERIODIC TABLE

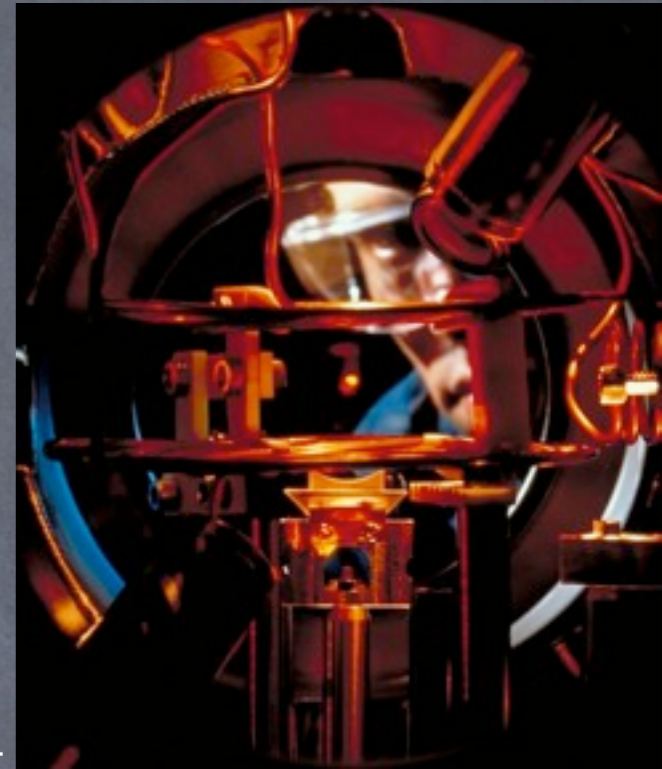
1																	18
H 1 1.008 Hydrogen																	He 2 4.00 Helium
Li 3 6.94 Lithium	Be 4 9.01 Beryllium											B 5 10.81 Boron	C 6 12.01 Carbon	N 7 14.01 Nitrogen	O 8 16.00 Oxygen	F 9 19.00 Fluorine	Ne 10 20.18 Neon
Na 11 22.99 Sodium	Mg 12 24.31 Magnesium	3	4	5	6	7	8	9	10	11	12	Al 13 26.98 Aluminum	Si 14 28.09 Silicon	P 15 30.97 Phosphorus	S 16 32.07 Sulfur	Cl 17 35.45 Chlorine	Ar 18 39.95 Argon
K 19 39.10 Potassium	Ca 20 40.08 Calcium	Sc 21 44.96 Scandium	Ti 22 47.88 Titanium	V 23 50.94 Vanadium	Cr 24 52.00 Chromium	Mn 25 54.94 Manganese	Fe 26 55.85 Iron	Co 27 58.93 Cobalt	Ni 28 58.69 Nickel	Cu 29 63.55 Copper	Zn 30 65.39 Zinc	Ga 31 69.72 Gallium	Ge 32 72.61 Germanium	As 33 74.92 Arsenic	Se 34 78.96 Selenium	Br 35 79.90 Bromine	Kr 36 83.80 Krypton
Rb 37 85.47 Rubidium	Sr 38 87.62 Strontium	Y 39 88.91 Yttrium	Zr 40 91.22 Zirconium	Nb 41 92.91 Niobium	Mo 42 95.94 Molybdenum	Tc 43 (97.9) Technetium	Ru 44 101.07 Ruthenium	Rh 45 102.91 Rhodium	Pd 46 106.42 Palladium	Ag 47 107.87 Silver	Cd 48 112.41 Cadmium	In 49 114.82 Indium	Sn 50 118.71 Tin	Sb 51 121.76 Antimony	Te 52 127.60 Tellurium	I 53 126.90 Iodine	Xe 54 131.29 Xenon
Cs 55 132.91 Cesium	Ba 56 137.33 Barium	La 57 138.91 Lanthanum	Hf 72 178.49 Hafnium	Ta 73 180.95 Tantalum	W 74 183.85 Tungsten	Re 75 186.21 Rhenium	Os 76 190.2 Osmium	Ir 77 192.22 Iridium	Pt 78 195.08 Platinum	Au 79 196.97 Gold	Hg 80 200.59 Mercury	Tl 81 204.38 Thallium	Pb 82 207.2 Lead	Bi 83 208.98 Bismuth	Po 84 (209) Polonium	At 85 (210) Astatine	Rn 86 (222) Radon
Fr 87 223.02 Francium	Ra 88 226.03 Radium	Ac 89 227.03 Actinium	Rf 104 (261) Rutherfordium	Db 105 (262) Dubnium	Sg 106 (263) Seaborgium	Bh 107 (262) Bohrium	Hs 108 (265) Hassium	Mt 109 (266) Meitnerium	Unamed Discovery 110 Nov. 1994	Unamed Discovery 111 Nov. 1994	Unamed Discovery 112 1996		Unamed Discovery 114 1999	Unamed Discovery 116 1999	Unamed Discovery (210)	Unamed Discovery (222)	Unamed Discovery 118 1999
ALKALI METALS	ALKALI EARTH METALS															HALOGENS	NOBLE GASES
LANTHANIDES		Ce 58 140.12 Cerium	Pr 59 140.91 Praseodymium	Nd 60 144.24 Neodymium	Pm 61 (145) Promethium	Sm 62 150.36 Samarium	Eu 63 152.97 Europium	Gd 64 157.25 Gadolinium	Tb 65 158.93 Terbium	Dy 66 162.50 Dysprosium	Ho 67 164.93 Holmium	Er 68 167.25 Erbium	Tm 69 168.93 Thulium	Yb 70 173.04 Ytterbium	Lu 71 174.97 Lutetium		
ACTINIDES		Th 90 232.04 Thorium	Pa 91 231.04 Protactinium	U 92 238.03 Uranium	Np 93 237.05 Neptunium	Pu 94 (240) Plutonium	Am 95 243.06 Americium	Cm 96 (247) Curium	Bk 97 (248) Berkelium	Cf 98 (251) Californium	Es 99 252.08 Einsteinium	Fm 100 257.10 Fermium	Md 101 (257) Mendelevium	No 102 259.10 Nobelium	Lr 103 262.11 Lawrencium		

Legend:
H — SYMBOL
 1 — ATOMIC NUMBER
 1.008 — ATOMIC WEIGHT
 Hydrogen — NAME
 () = ESTIMATES

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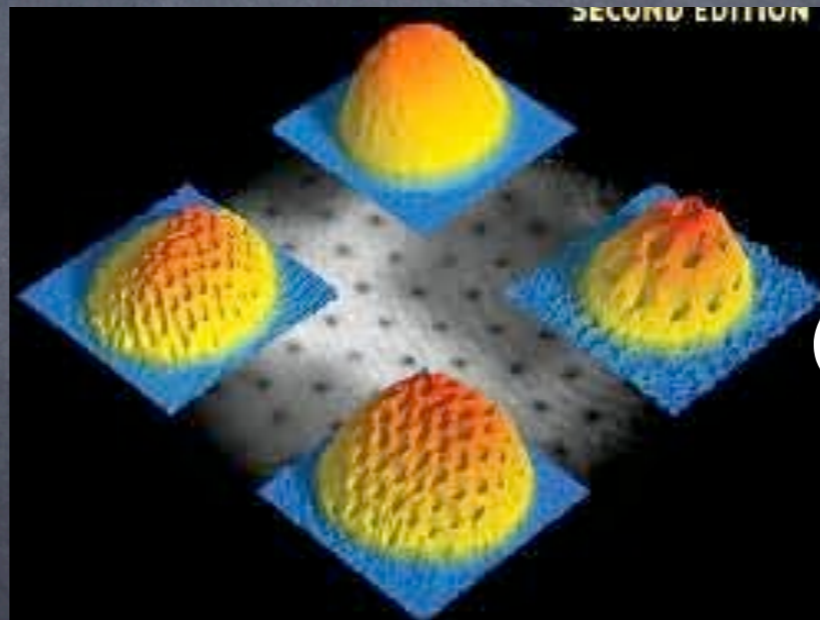
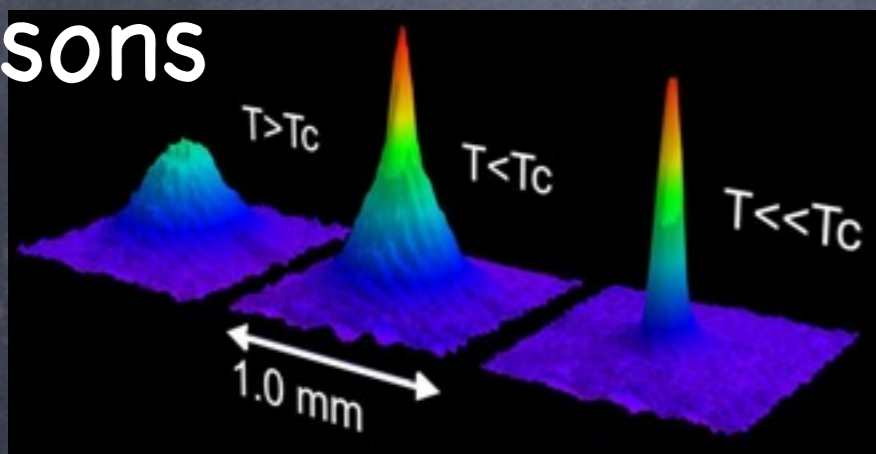


- Alkali atoms: H, Li, Na, K, ...
- $N \approx 10^8 - 10^9$
- Very dilute $n \approx 10^{13} - 10^{15} \text{ cm}^{-3}$ (air $n \approx 10^{19}$)
- Coldest place in the universe* $T \sim 0.45 \text{ nK}$
 $n \lambda_T^3 \sim 1$
 Guinness World Records 2008



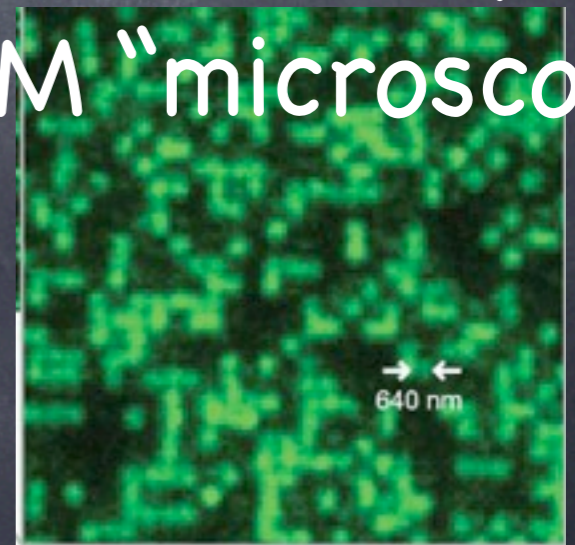
New Quantum Systems

Bosons

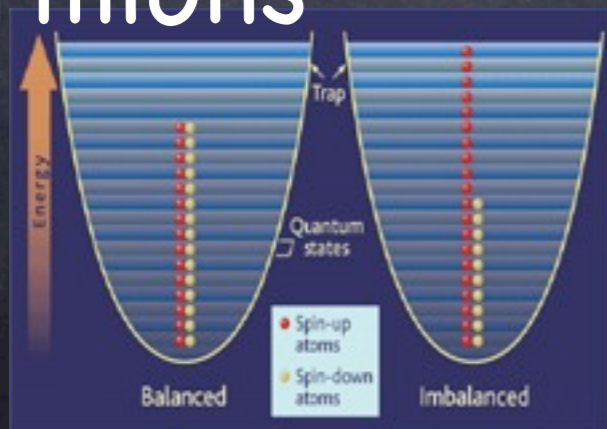


Microtraps

QM "microscope"



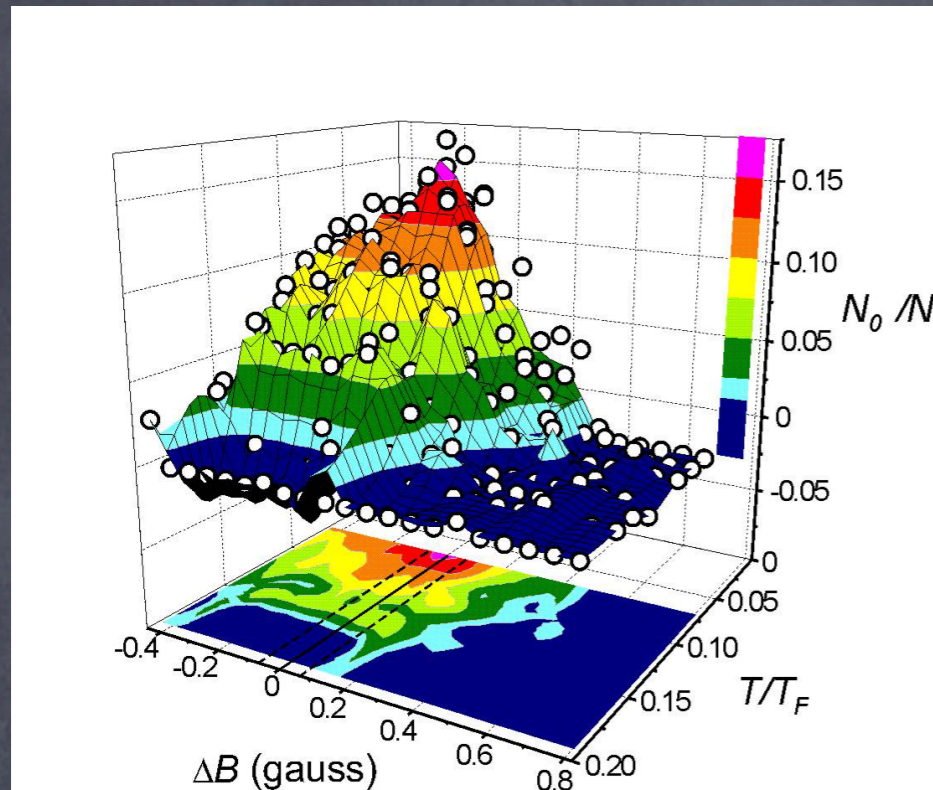
Fermions



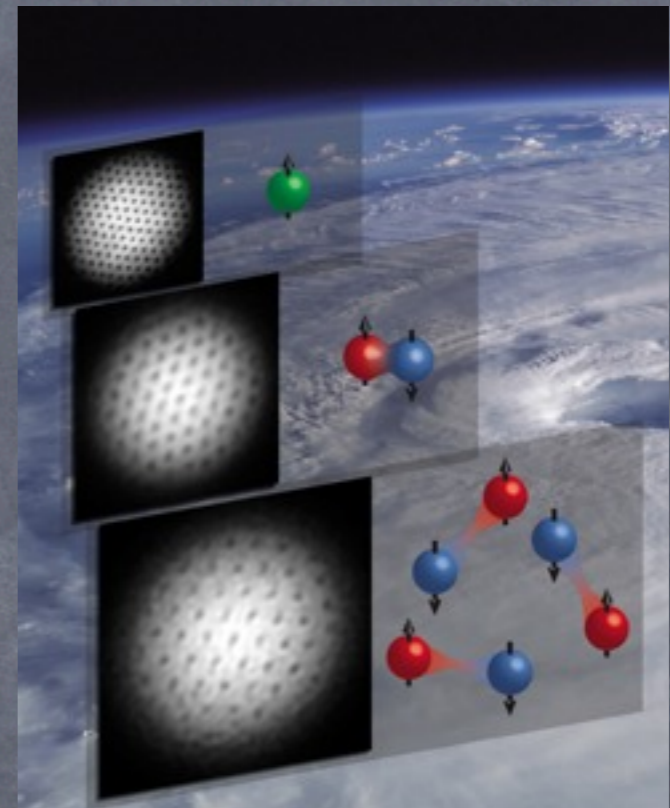
Macroscopic QM.

Greiner Lab, Harvard 2009

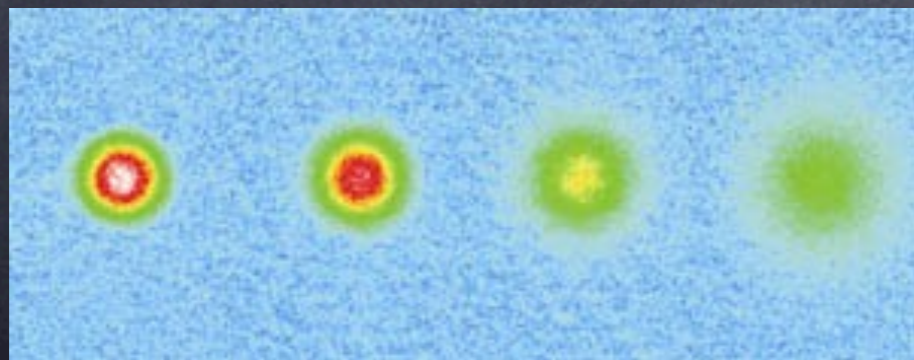
BEC-BCS cross-over



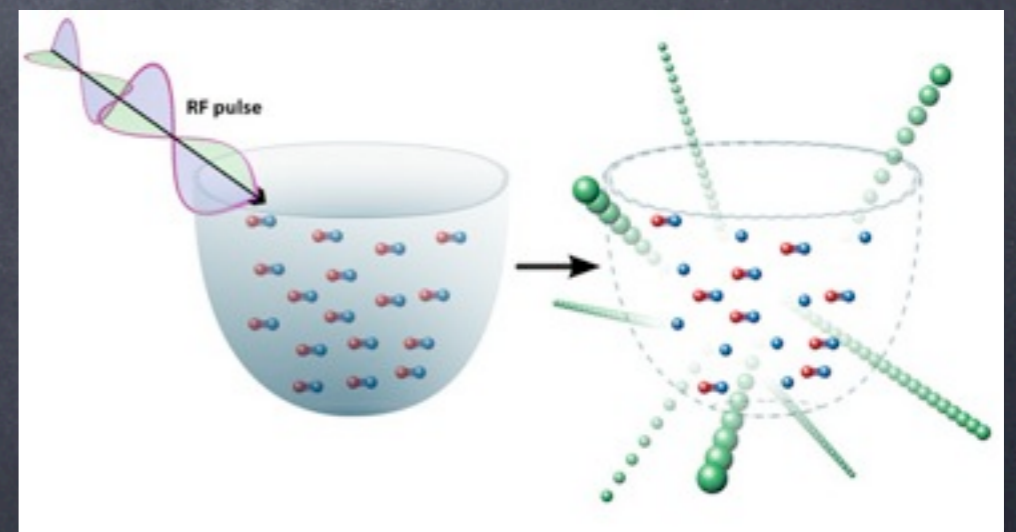
Rotation



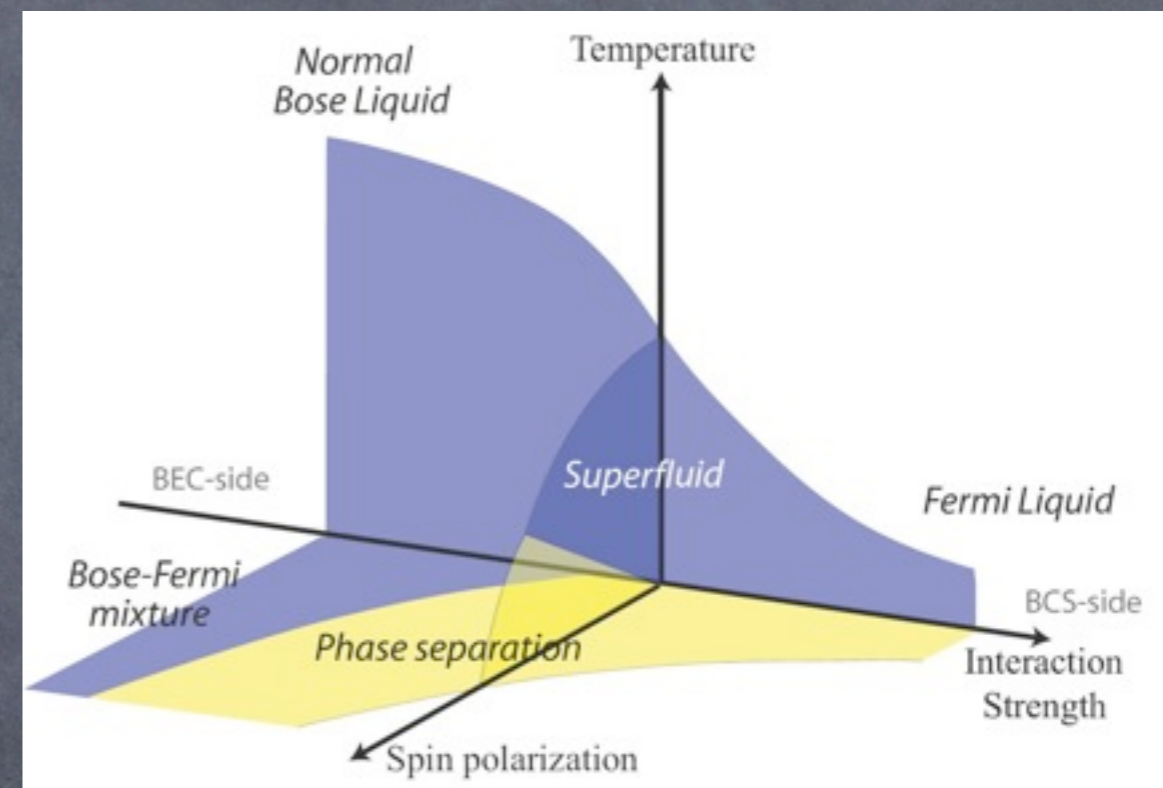
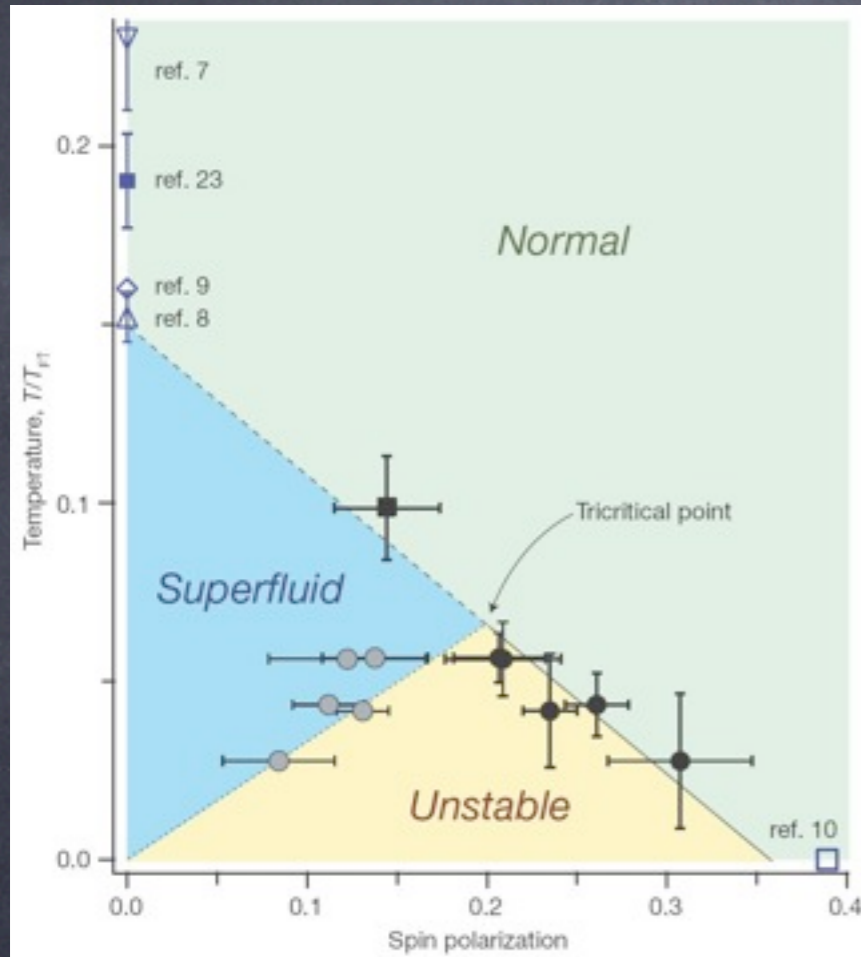
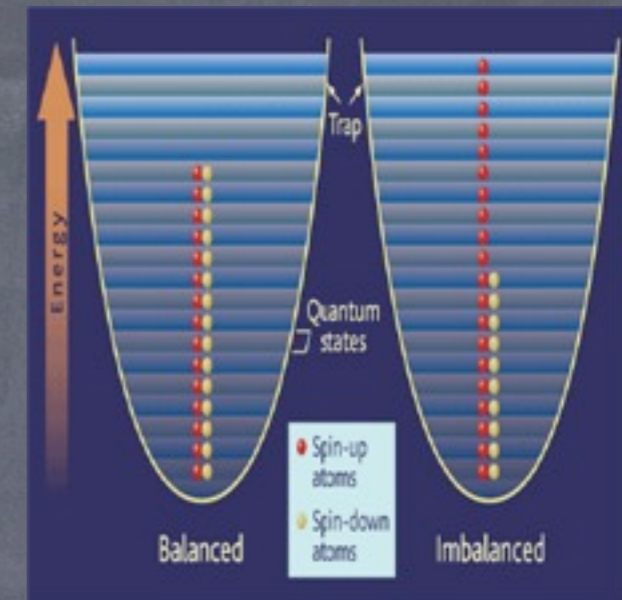
Expansion experiments



Bragg spectroscopy

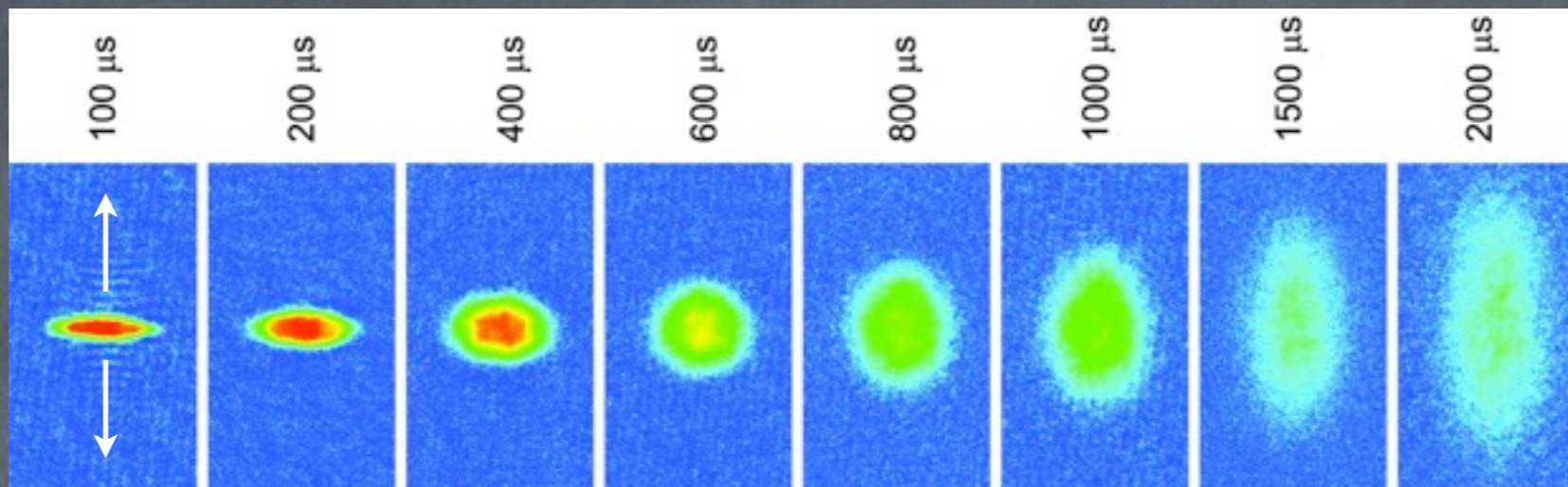


Polarization:
$$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} > 1$$



Hydrodynamic Expansion

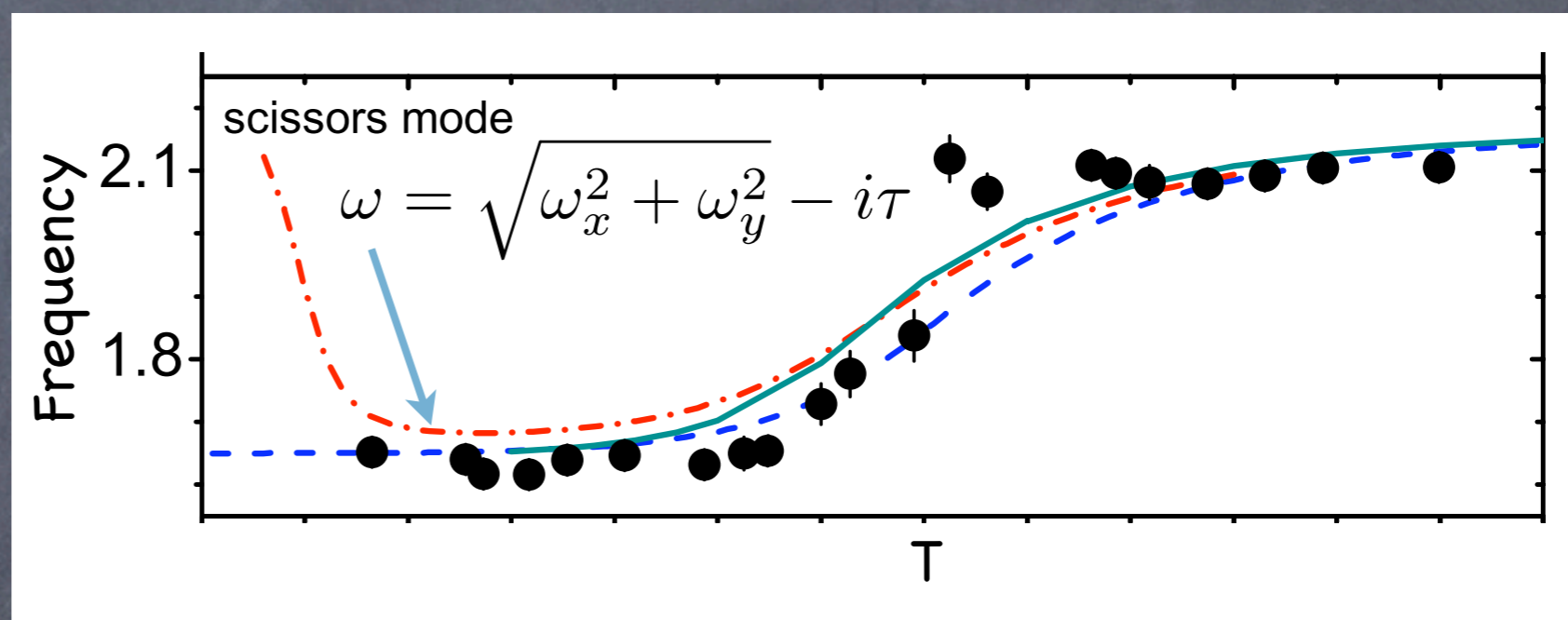
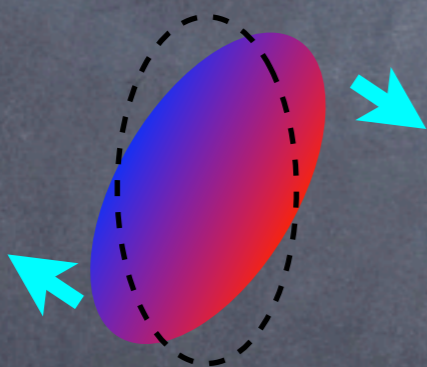
$$\rho \partial_t \mathbf{u} = -\nabla P$$



Thomas Lab, Duke 2004

Collective Modes

Scissors Mode



Grimm Lab, Innsbruck 2009

“Perfect” Fluid
10000 thinner than air

Ideal and Viscous Fluids

Hydrodynamics (Low energy eff. theory)

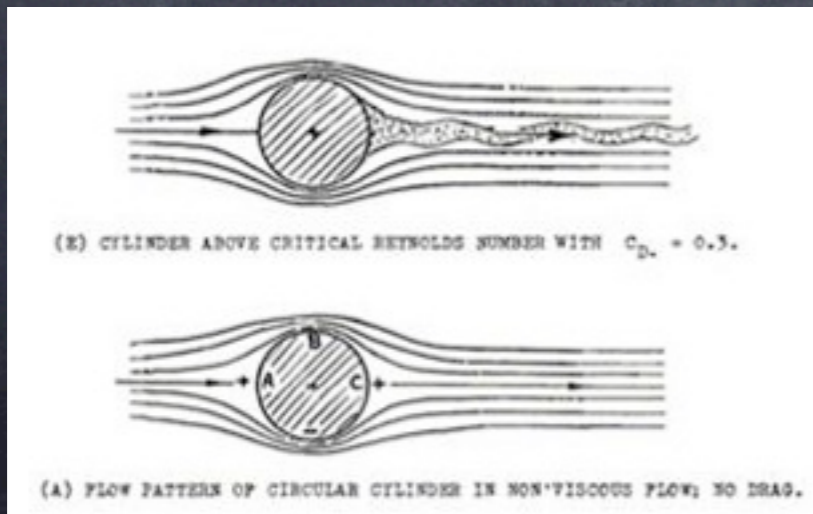
• Continuity: $\partial_t \rho + \nabla \cdot (\rho \mathbf{v}) = 0$

• Euler: $\partial_t (\rho v_i) + \partial_k \Pi_{ik} = 0$

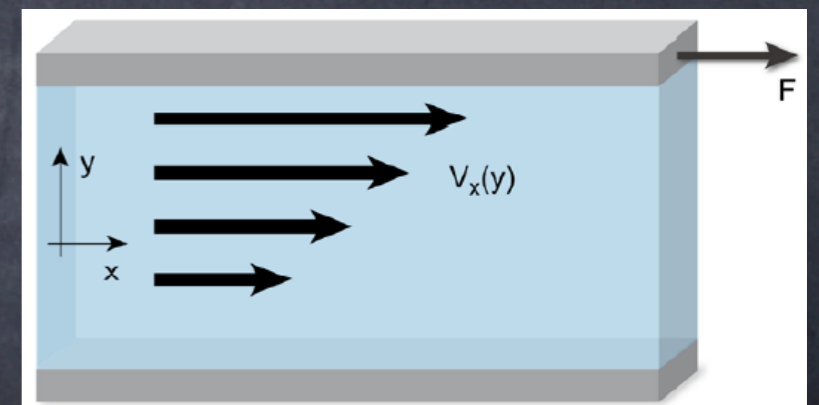
$$\Pi_{ik} = P \delta_{ik} + \rho v_i v_k - \eta \left(\partial_i v_j - \partial_j v_i - \frac{2}{3} \delta_{ij} \nabla \cdot \mathbf{v} \right) - \zeta \delta_{ij} (\nabla \cdot \mathbf{v})$$

Ideal Fluid
Dissipative

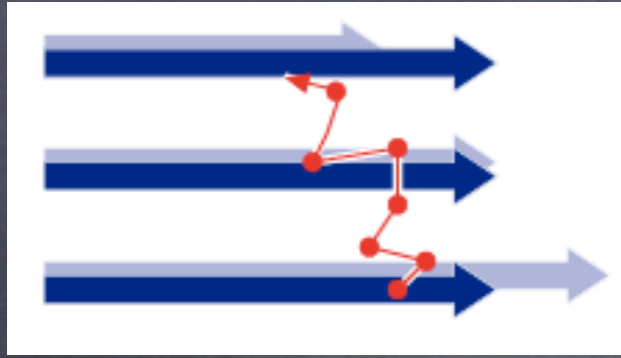
Shear Viscosity: "Friction"



$$\frac{F}{A} = \eta \partial_y v_x$$



Kinetic Picture

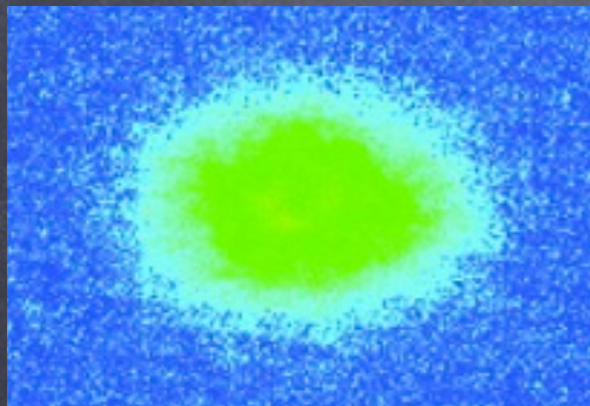


Low collision rate \rightarrow Large Viscosity

High collision rate \rightarrow Small Viscosity

Small Viscosity means strong interactions

Cold Gases



$T \approx 10^{-7} \text{K}$

Coldest place
on planet

$$\eta \sim 10^{-15} \text{Pa} \cdot \text{s}$$

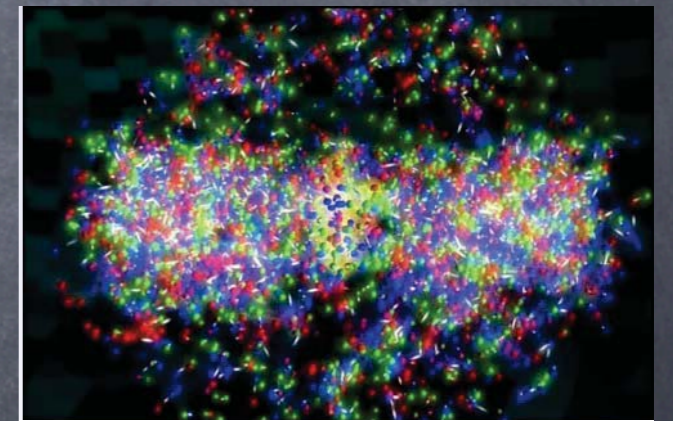
Liquid Helium



$T \approx 1 \text{K}$

$$\eta \sim 10^{-6} \text{Pa} \cdot \text{s}$$

Quark-Gluon Plasma



$T \approx 10^{12} \text{K}$

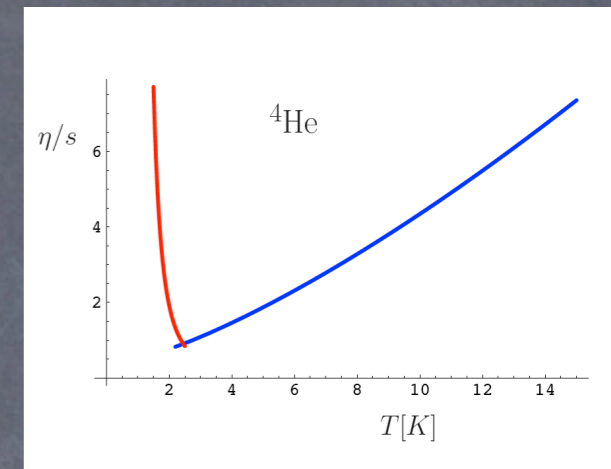
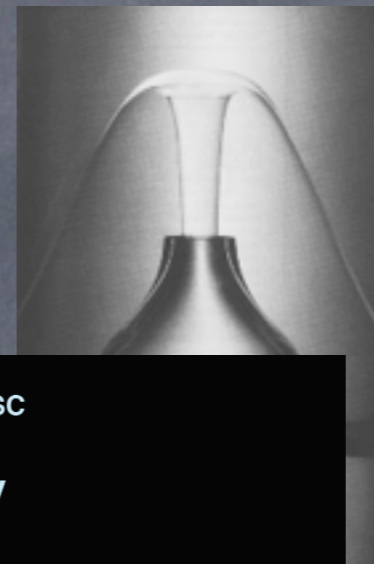
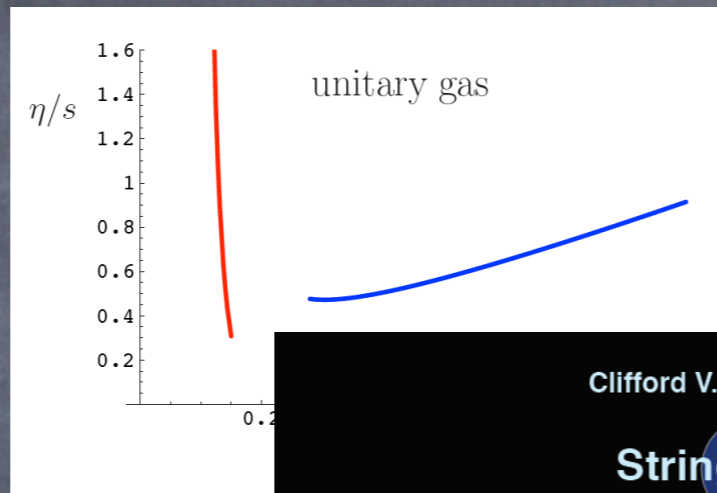
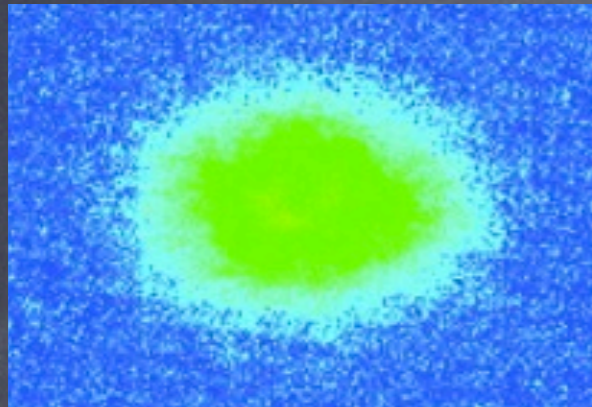
Hottest place
on planet

$$\eta \sim 10^{11} \text{Pa} \cdot \text{s}$$

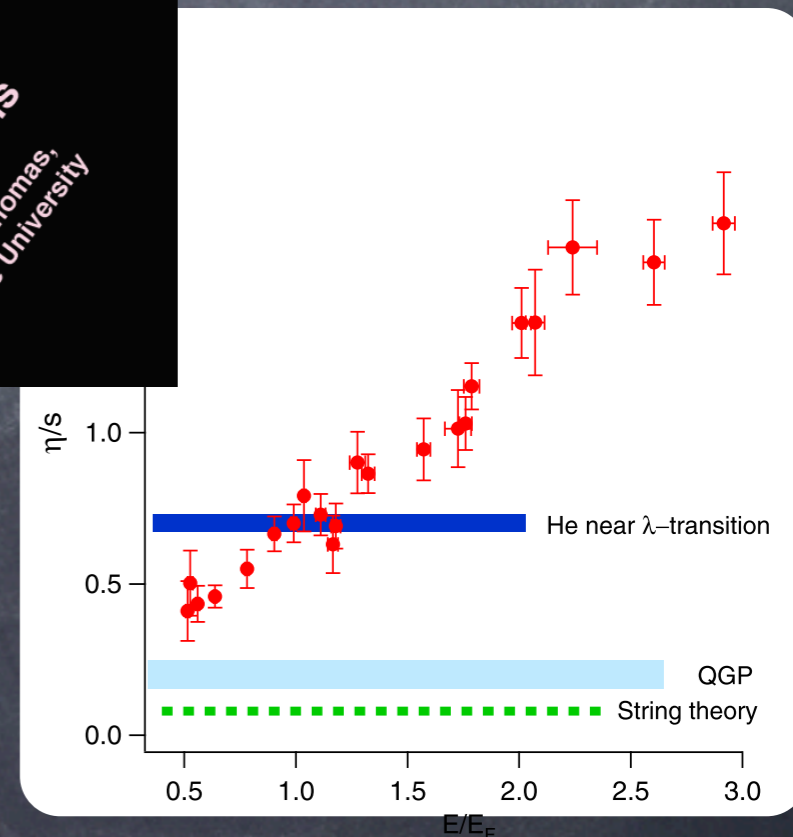
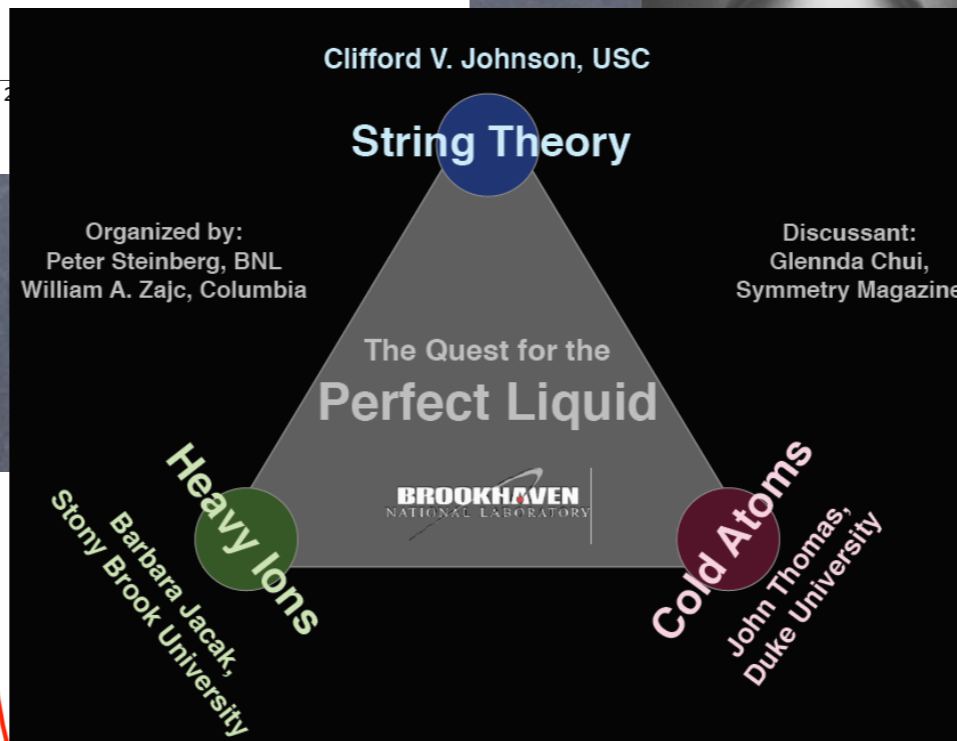
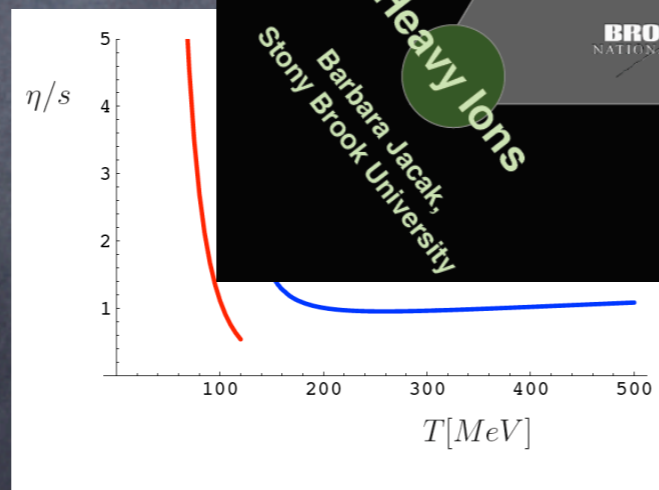
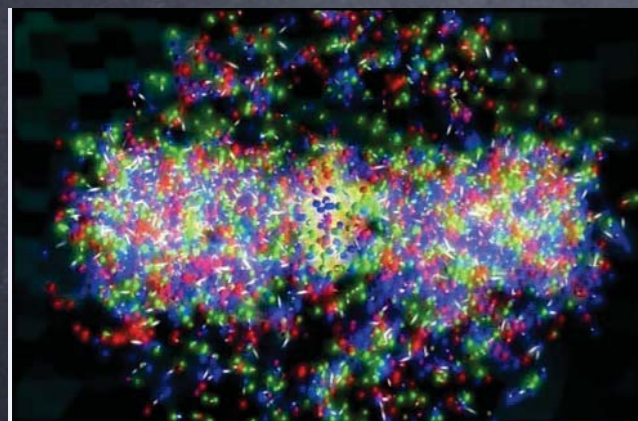
String-theory & AdS/CFT: $\frac{\eta}{s} \geq \frac{\hbar}{4\pi k_B}$

Cold Gases $T \approx 10^{-7}K$

Liquid Helium $T \approx 1K$

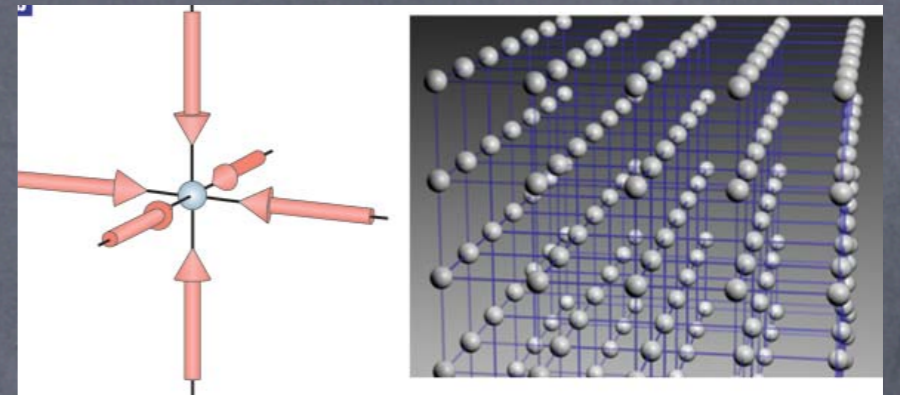


Quark-Gluon
Plasma $T \approx 10^{12}K$

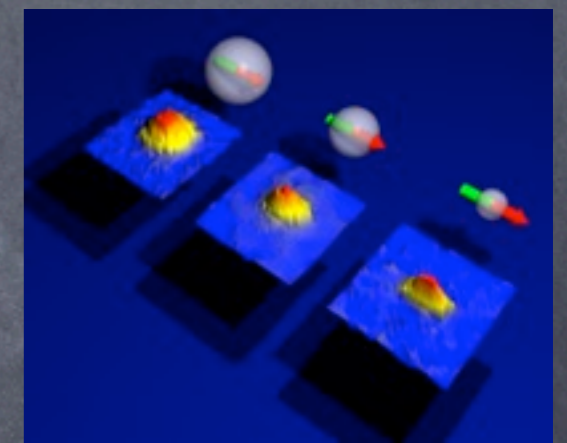


Perspectives

- Optical lattices. Spin physics, Hubbard model ...



- Dipolar molecules/atoms. New phases ..



- Polarized systems

- Bose-Fermi mixtures, multicomponent systems, ..

- Transport, non-equil.

