Bose-Einstein Condensation Lesson

- This is the last lecture from PHYS1010 at CU Boulder and covers Bose-Einstein Condensation, as researched by Professor Carl Wieman. Multiple applets are used, including Temperature, Optical Molasses, Laser Cooling, and Evaporative Cooling, and there are two concept questions.
- The lesson covers the physics (known as of 2003) of Bose-Einstein Condensation, its uses, and what is to be researched in the future.

Bose-Einstein condensation, Quantum weirdness at the lowest temperature in the universe

JILA BEC Effort: Eric Cornell, Carl Wieman **1990 –**
Anderson, Ensher, Jin, Hall, Matthews, Myatt, Monroe, Claussen, Roberts, Cornish, Haljan, Donley, Thompson, Papp, Zirbel, Lewandowski, Harber, Coddington, Engels, McGuirk, Hodby,...

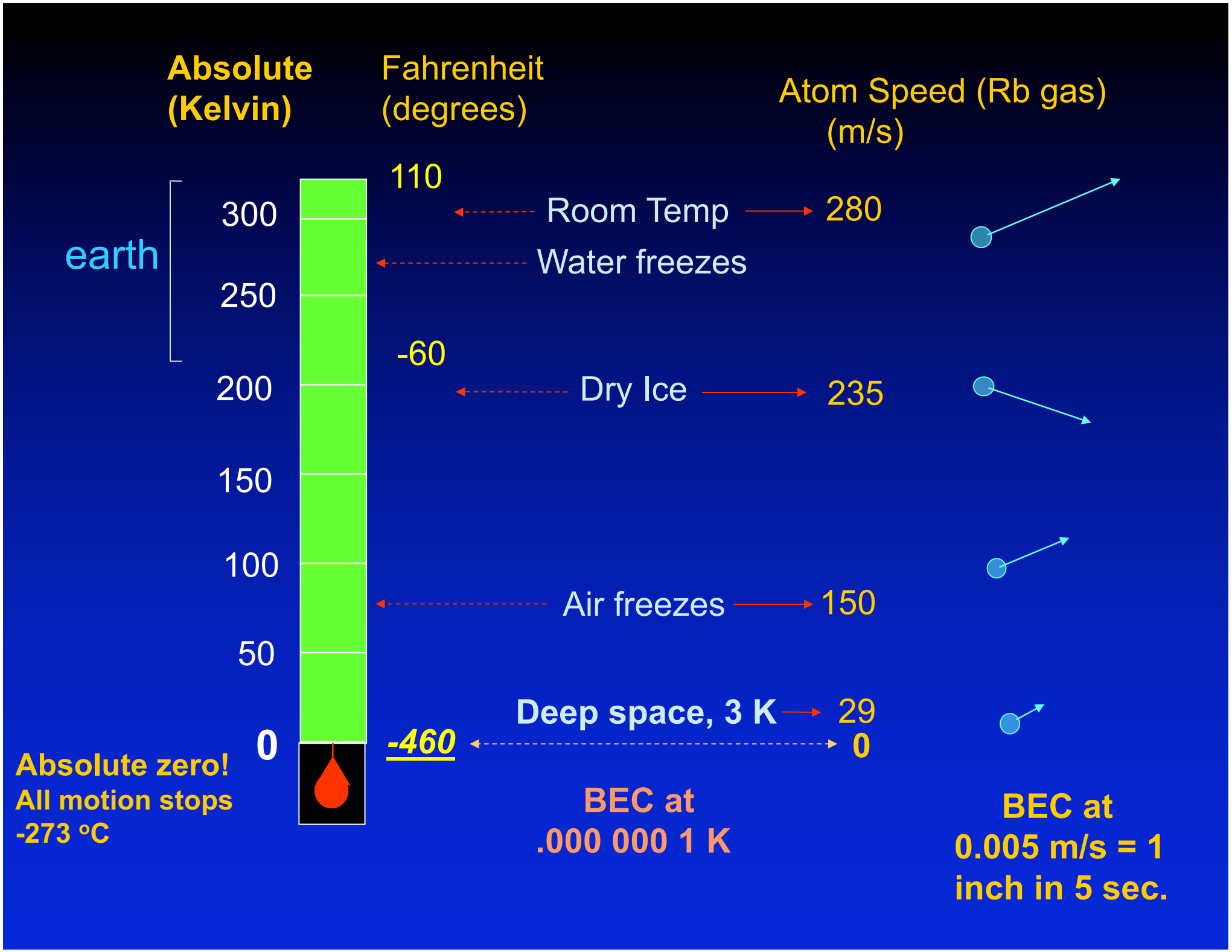
$$ (NSF, ONR, NIST)

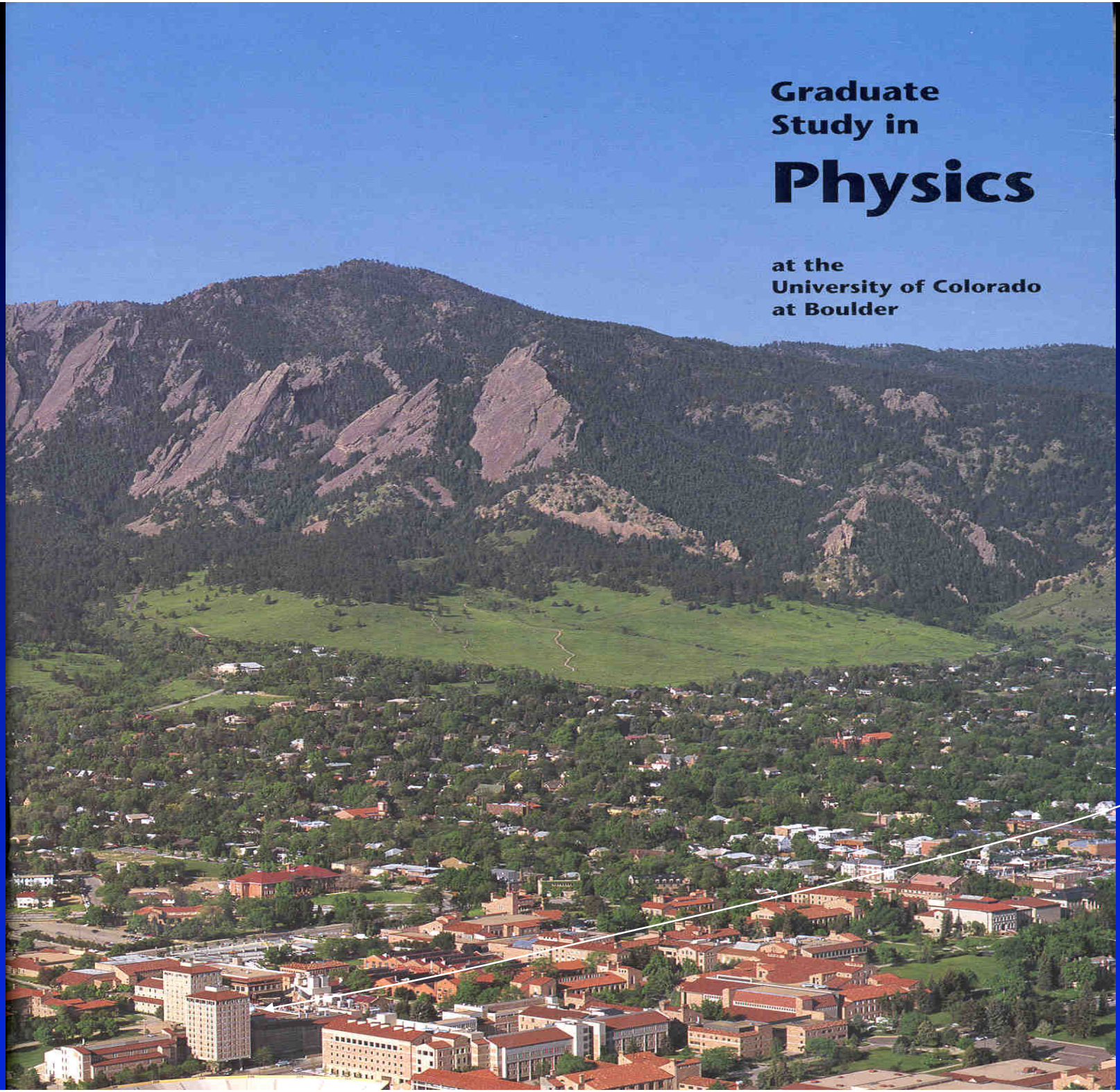
Part I. (1924-95) Making Bose-Einstein Condensation in a gas
BEC – a new form of matter predicted by Einstein in 1924 and first created in 1995 by our group.

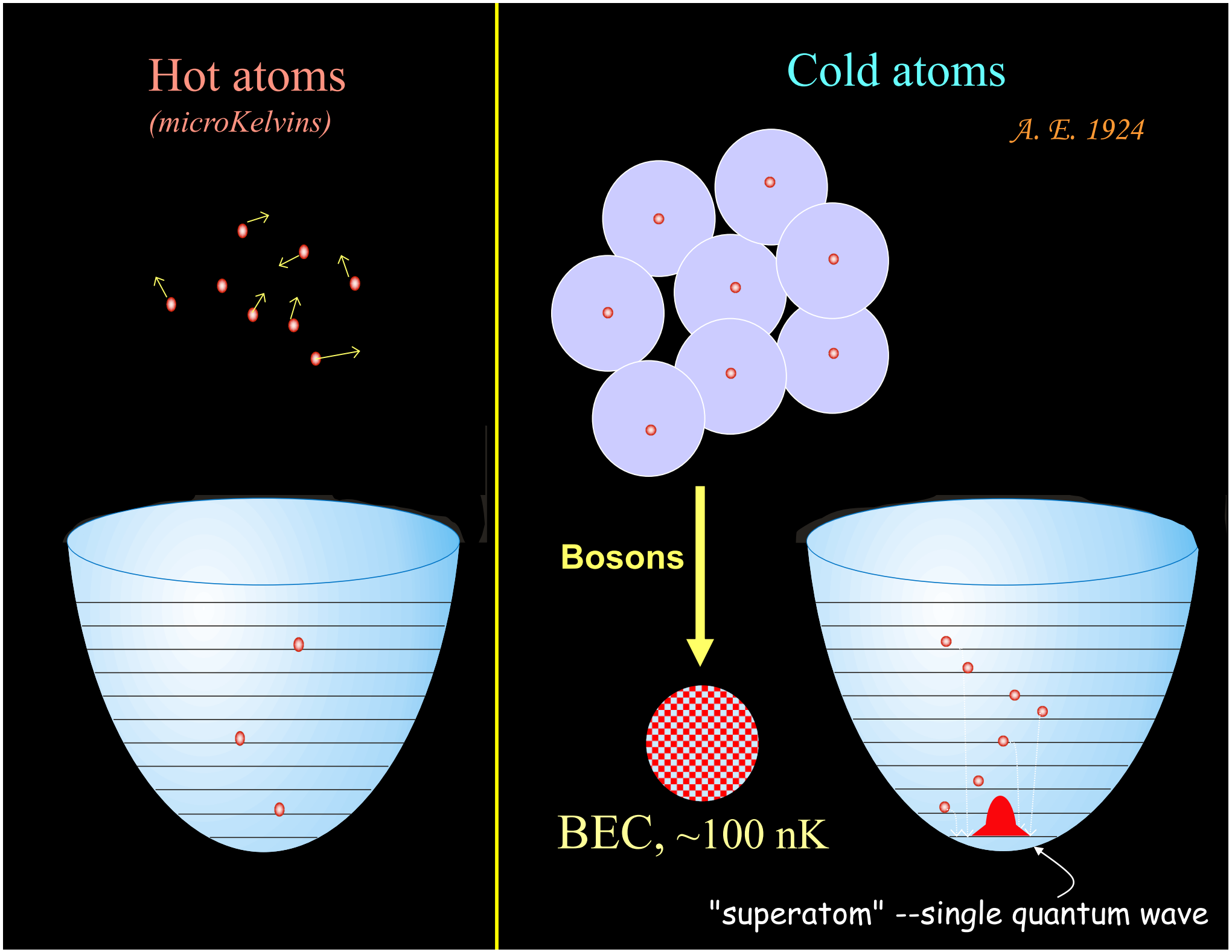
Part II. A bit of recent research with BEC

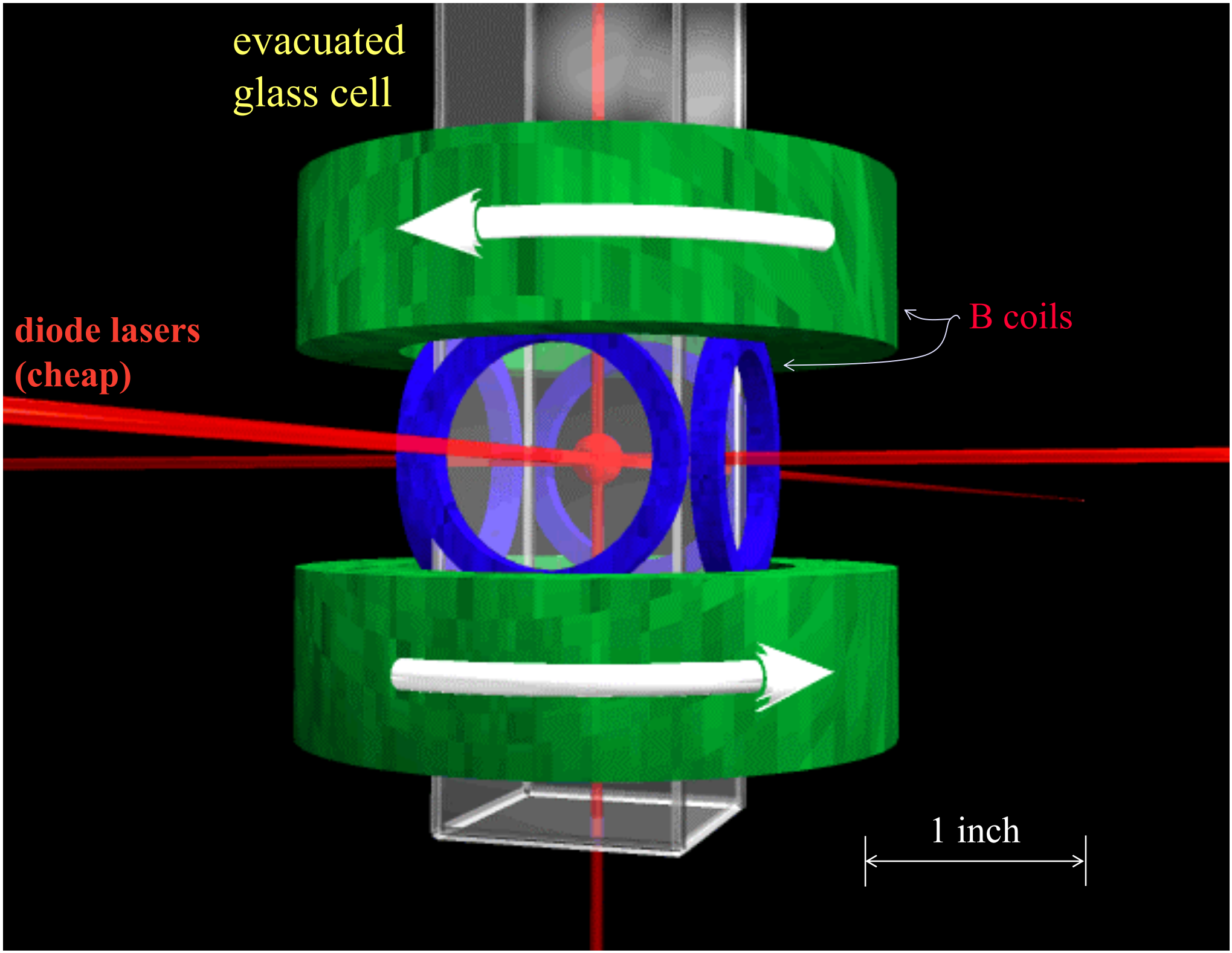
Proceed to the temperature applet on PhET's website.

The coldest place in the universe can be found
a. at the south pole of the earth.
b. at a temperature of absolute zero.
c. on Pluto.
d. in space between the galaxies
e. at both b and d.

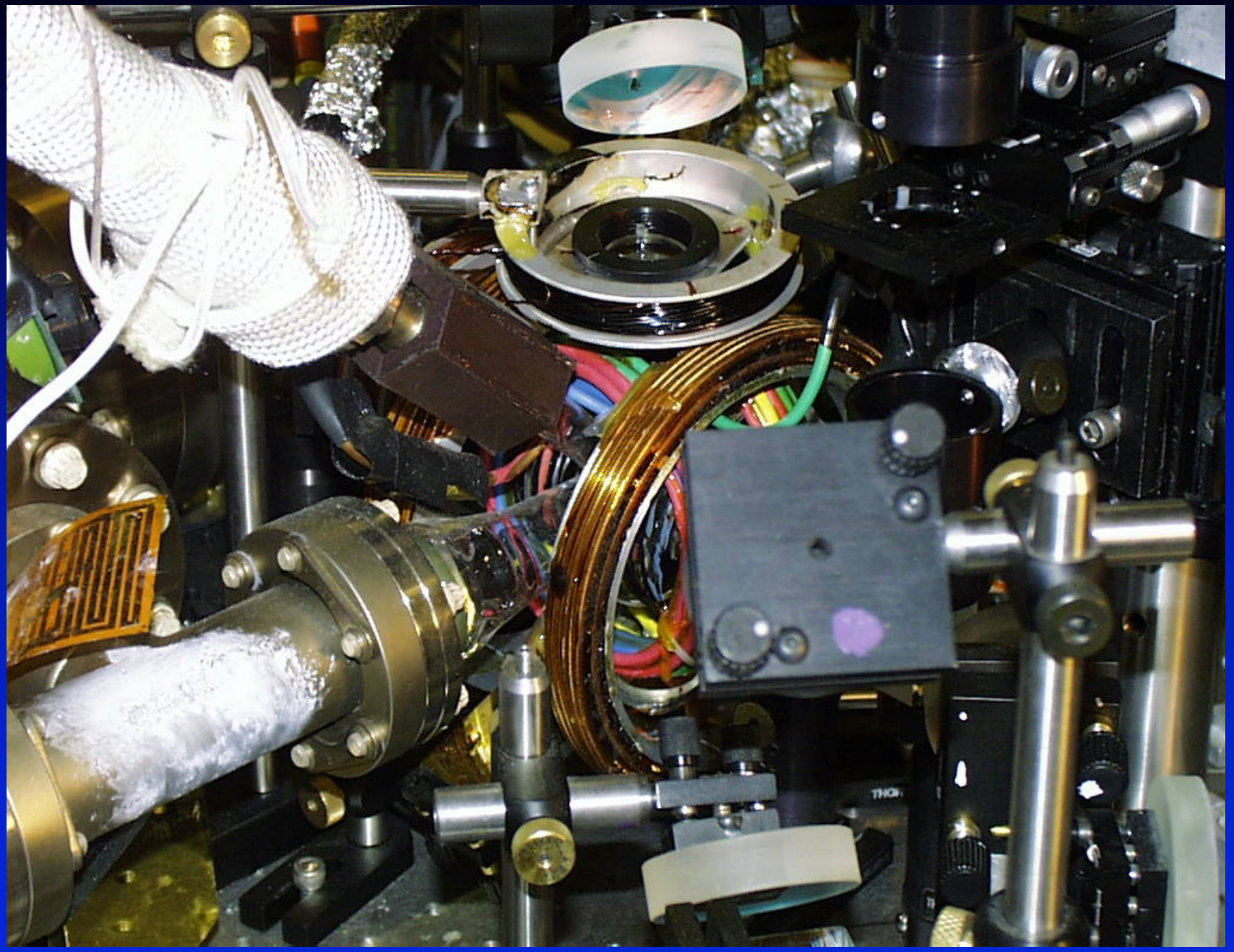

Absolute (Kelvin)
Fahrenheit (degrees)
Atom Speed (Rb gas) (m/s)
earth
300
250
200
150
100
50
0
110
Room Temp
280
Water freezes
-60
Dry Ice
235
Air freezes
150
Deep space, 3 K
29
-460
0
Absolute zero!
All motion stops
-273 °C
BEC at
.000 000 1 K
BEC at
0.005 m/s = 1
inch in 5 sec.


Graduate
Study in
Physics
at the
University of Colorado
at Boulder
CSIU


Hot atoms
(microKelvins)
Cold atoms
A. E. 1924
Bosons
BEC, ~100 nK
"superatom" --single quantum wave


evacuated
glass cell
diode lasers
(cheap)
B coils
1 inch

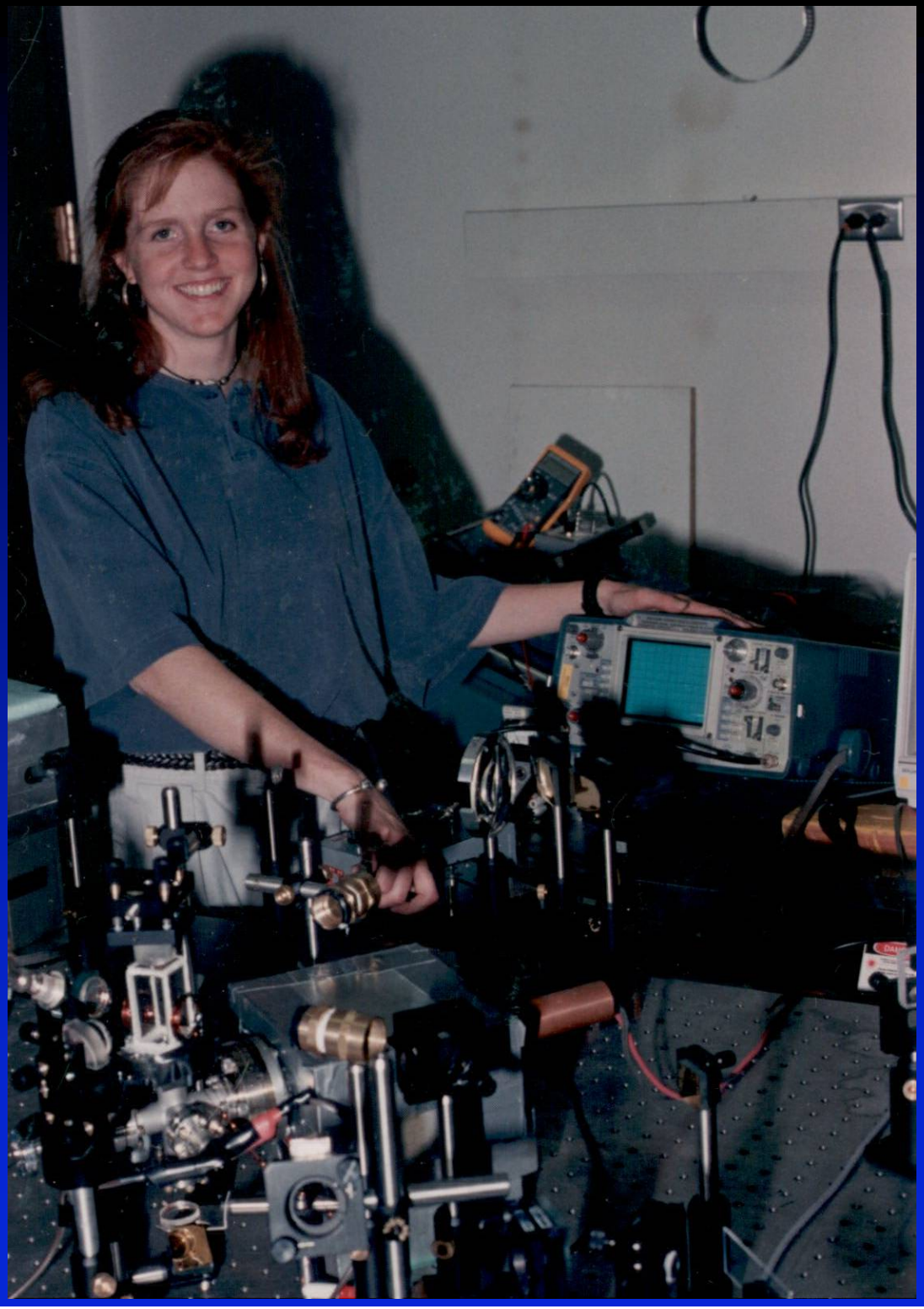
JILA BEC #2 *(#1 at Smithsonian)*



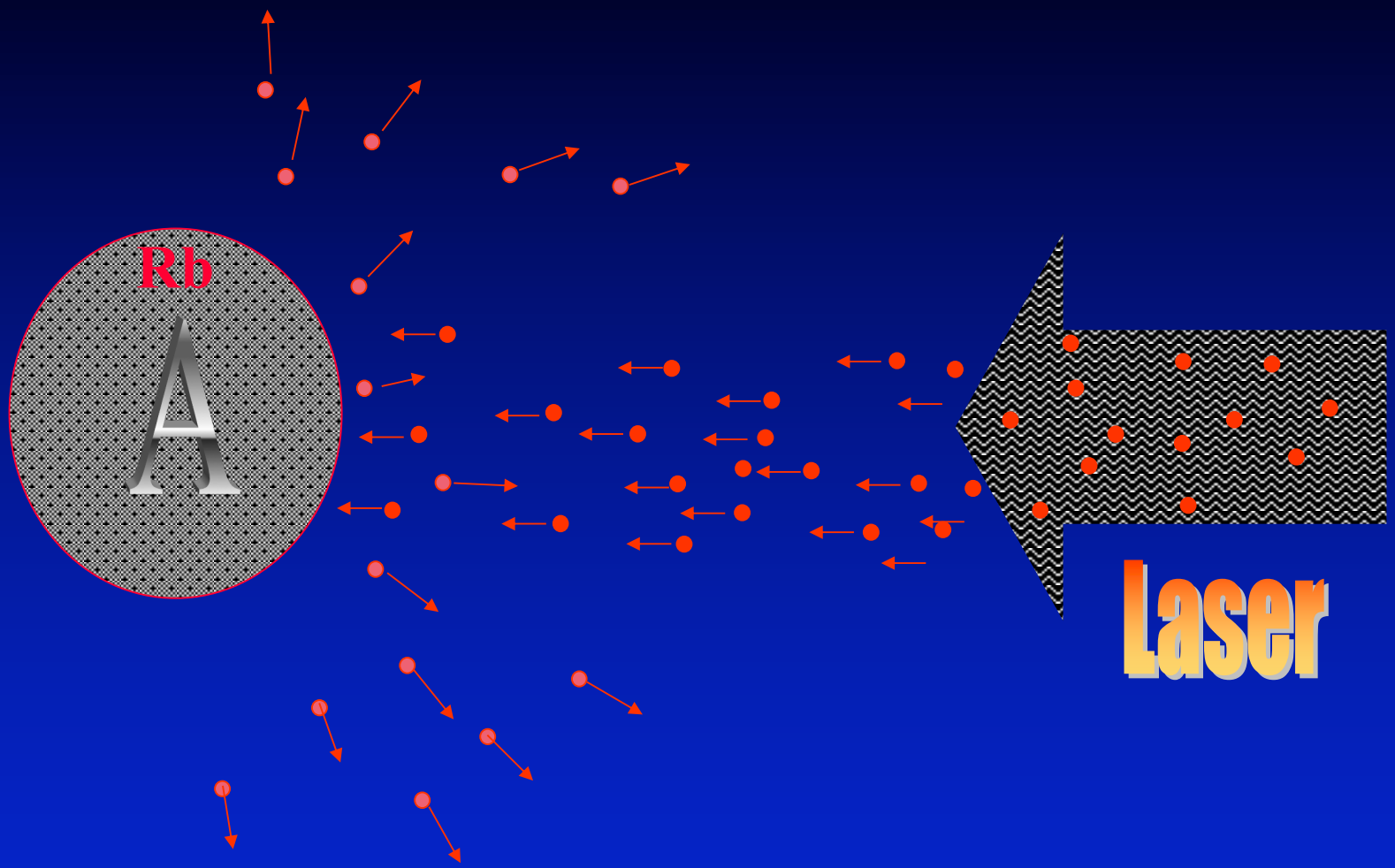
2 in.

Grad students Neil Claussen, Sarah Thompson, postdoctorate Liz Donley working on BEC experiment.

Undergrad Gwenn Flowers with her laser trap system.



Cooling down atoms – step 1



Pushing atoms with light

Gas atoms can absorb and radiate light

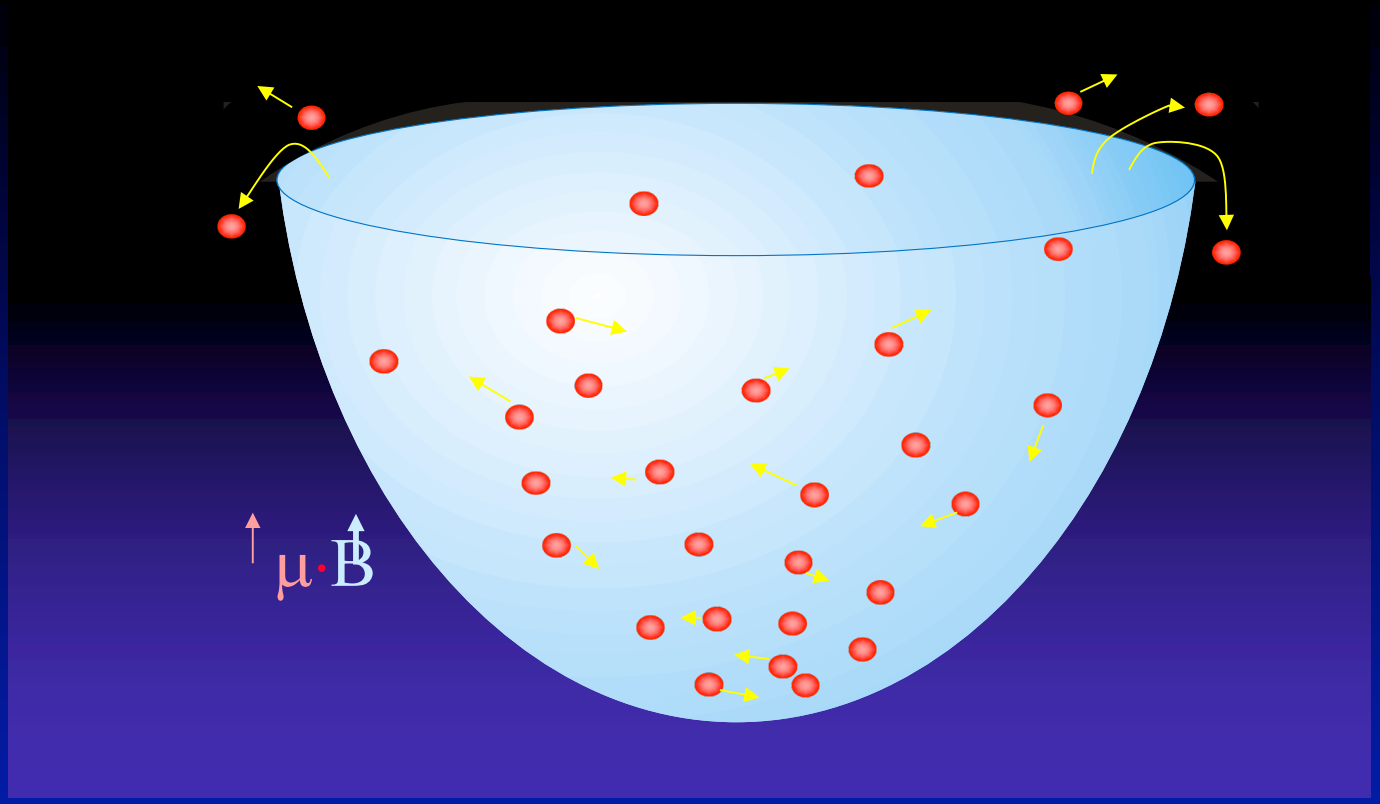
a. of any color that shines on them.

b. at any lower frequency than the light hitting them.

c. only at particular precise frequencies or colors.

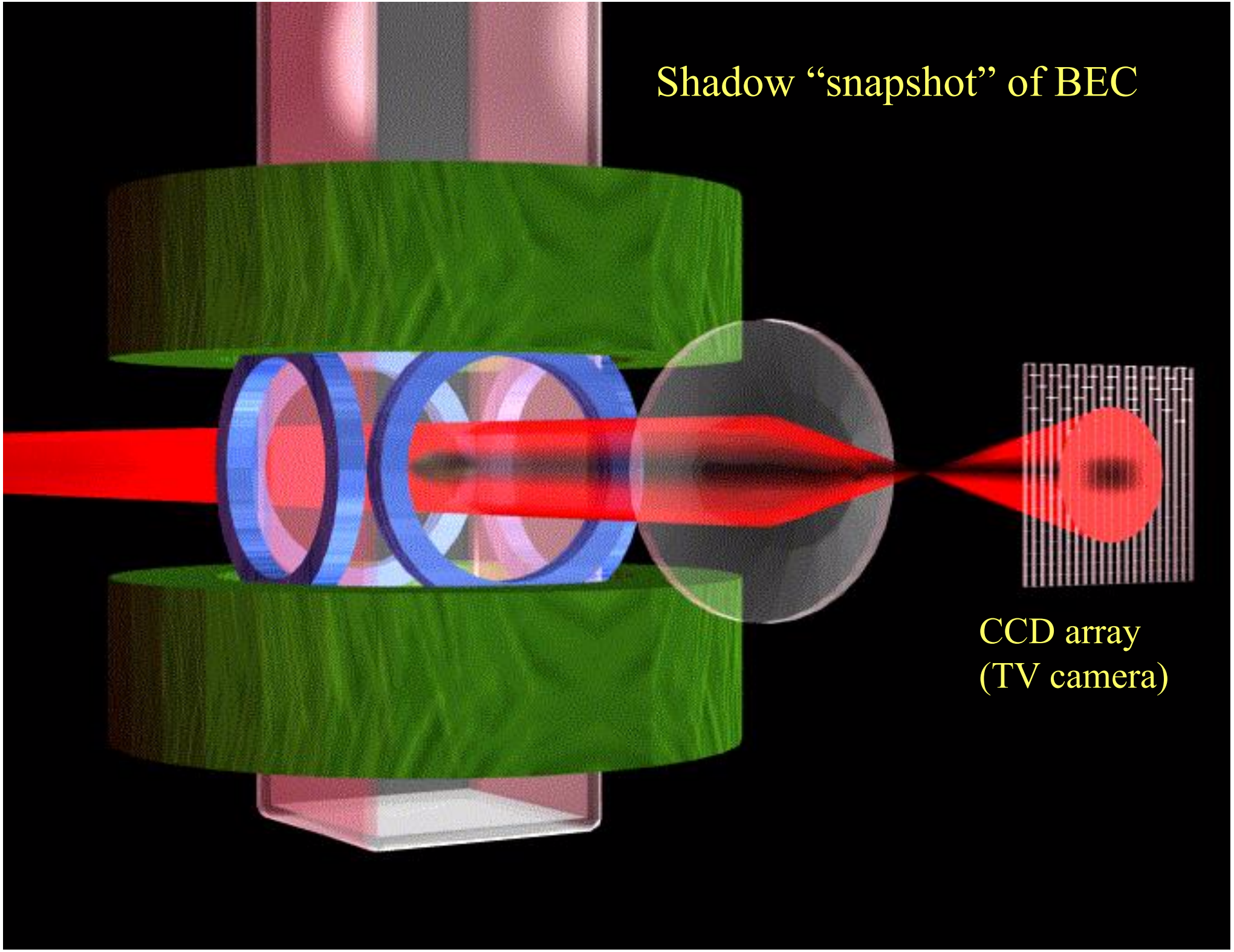
d. in the visible part of the electromagnetic spectrum.

Go to the laser cooling applet



If the atoms in the bowl were extremely cold, they would
a. sink down to form a tiny blob at the bottom.
b. spread out to fill entire bowl.
c. spill out over the top.

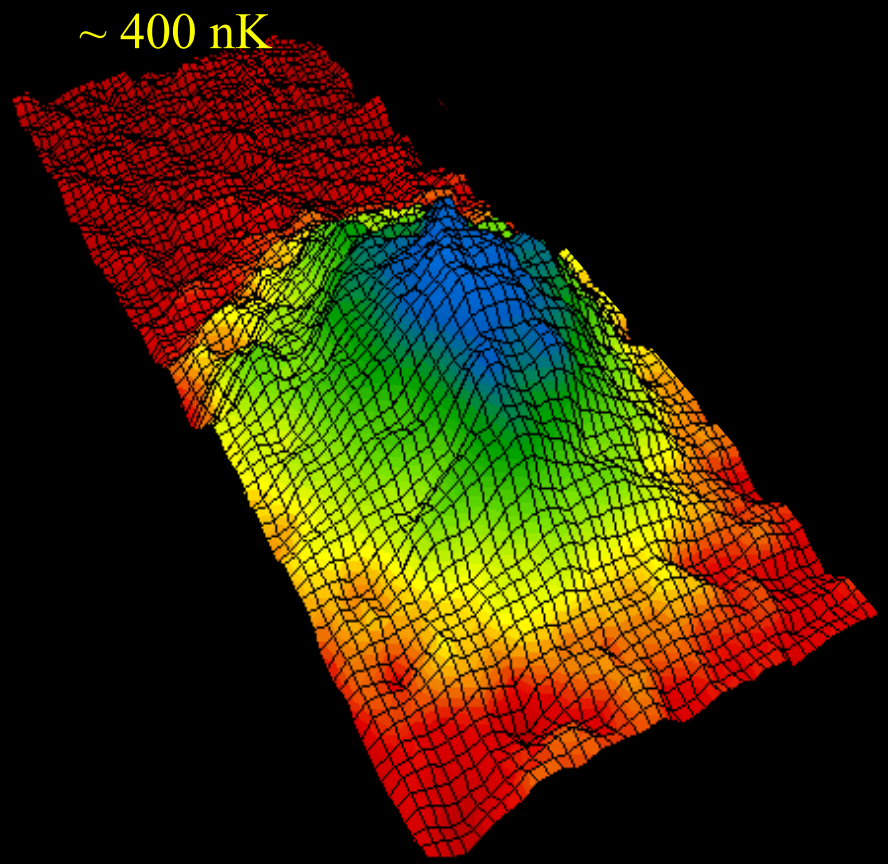
Optical molasses applet
Magnetic trapping applet
Evaporative cooling applet

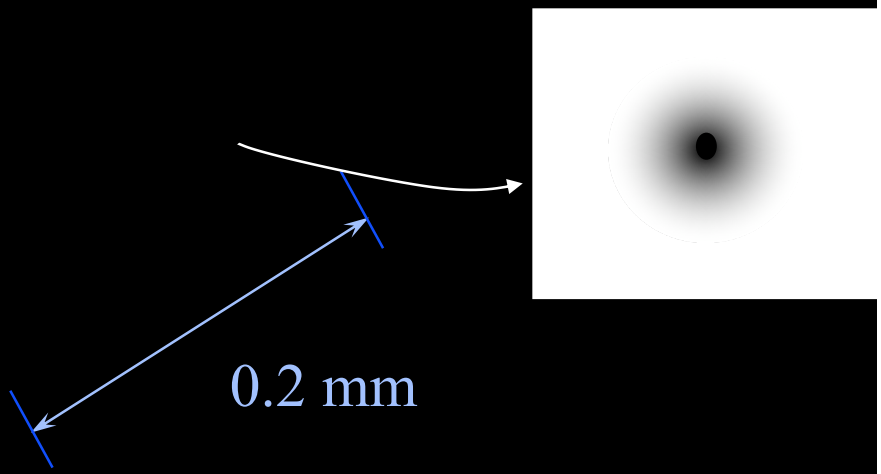

Shadow “snapshot” of BEC
CCD array
(TV camera)

BEC! *JILA – 1995*

"nK" = billionths of a degree above absolute zero.

Like a drop of water forming.

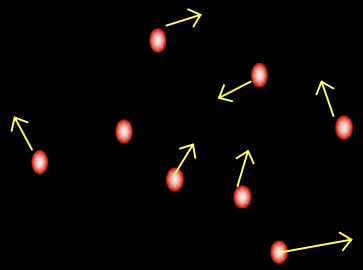


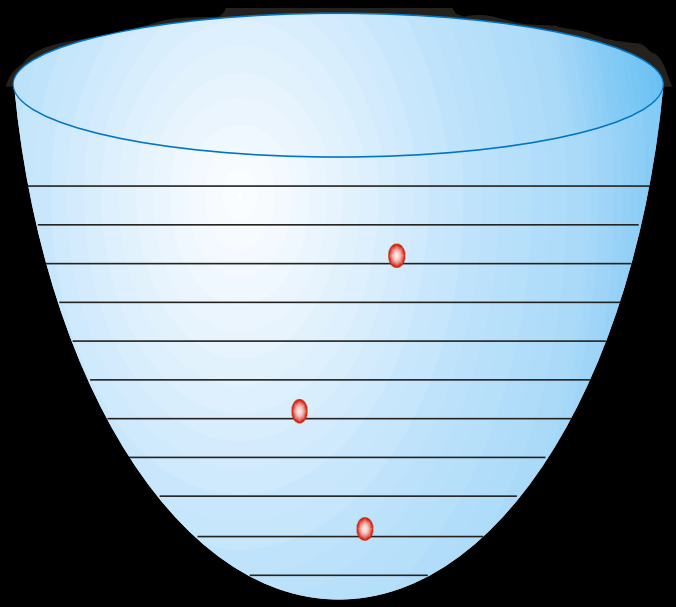


False color images of cloud

Hot atoms

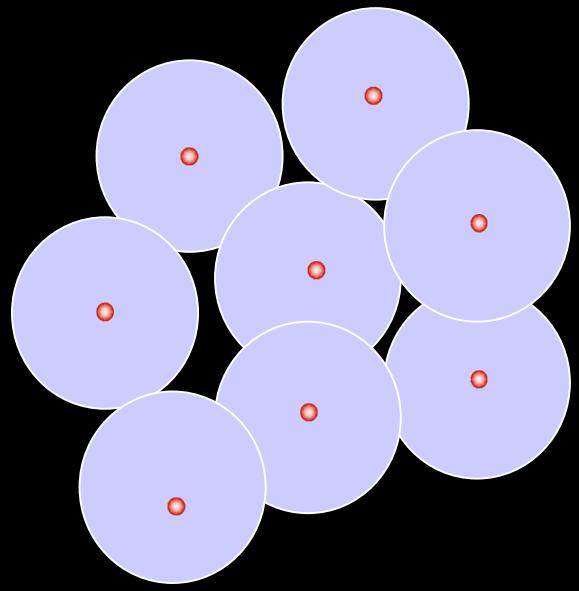
(microKelvins)



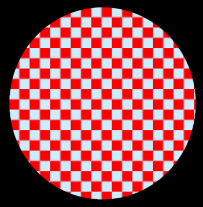


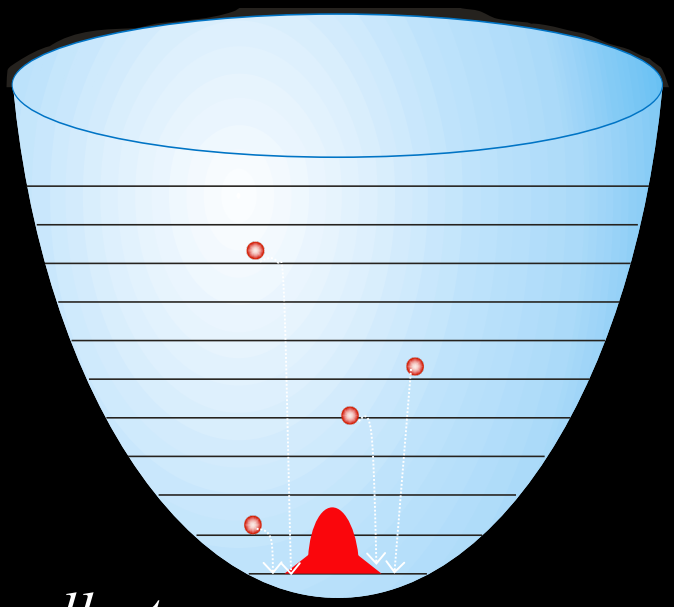
Cold atoms

A. E. 1924



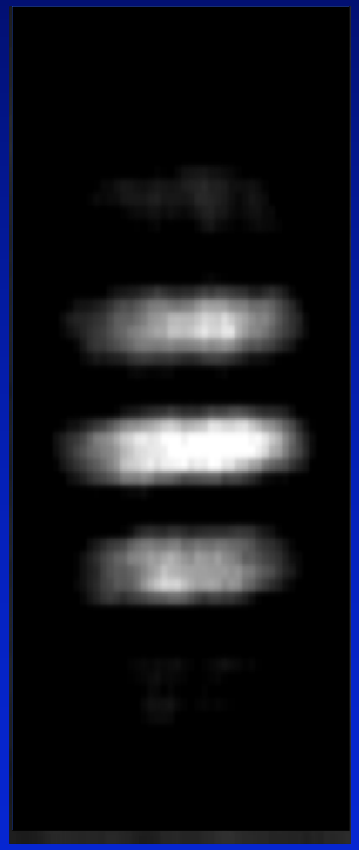
Bosons





Lowest level, smallest width – set by uncertainty principle

Quantum physics on "human" sized scale
Control and Observe



About the width of a human hair

Fringes formed with two overlapping condensates- waves interfering.

(NIST Gaithersburg atom cooling group
- courtesy S. Rolston)

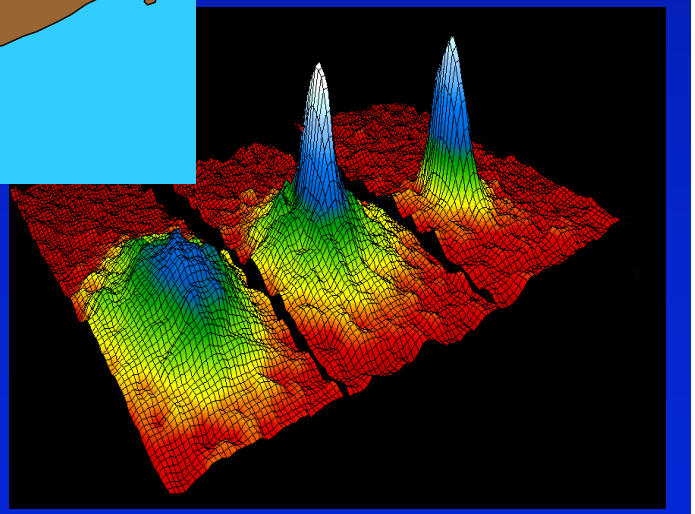
Where is BEC now (post June '95)?

New regime of physics –
directly observe and manipulate quantum wave function

~ 40+ working experiments, many atoms (^{87}Rb, Na, Li, H, ^{85}Rb, He*,K, Cs)
countless theorists – atomic, condensed matter, nuclear } *~1000 scientists*

~2500 papers, ~1 every 1.5 days

Scientists have measured and predicted all sorts of properties, and now there are new properties to study, new ways to make and manipulate, potential applications.



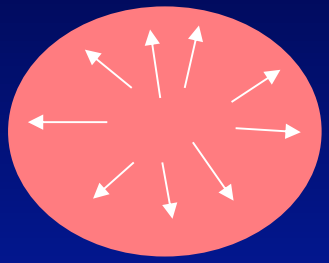
Stockholm Sweden, Dec. 10, 2001


ROSLAGE
NOBEL PRIZE
CENTENNIAL
1901–2001

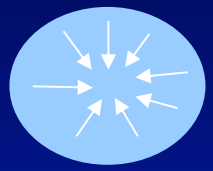
Latest exciting stuff – bosenova explosions, weird new kind of molecules…

Controlling self-interactions with ^{85}Rubidium BEC

Roberts, Claussen, Donley, Thompson, Carl Wieman



repulsive (^{87}RB, Na), $a > 0$



attractive (Li, ^{85}Rb), $a < 0$
(unstable if N large, $N_{max} \propto 1/a$)

In ^{85}Rb, the experimental knob can adjust atoms from large repulsive to nothing to large attractive!

3 billionths of a degree!

Magnetic field
(like knob to control gravity)

Plunging into the unknown – interaction attractive

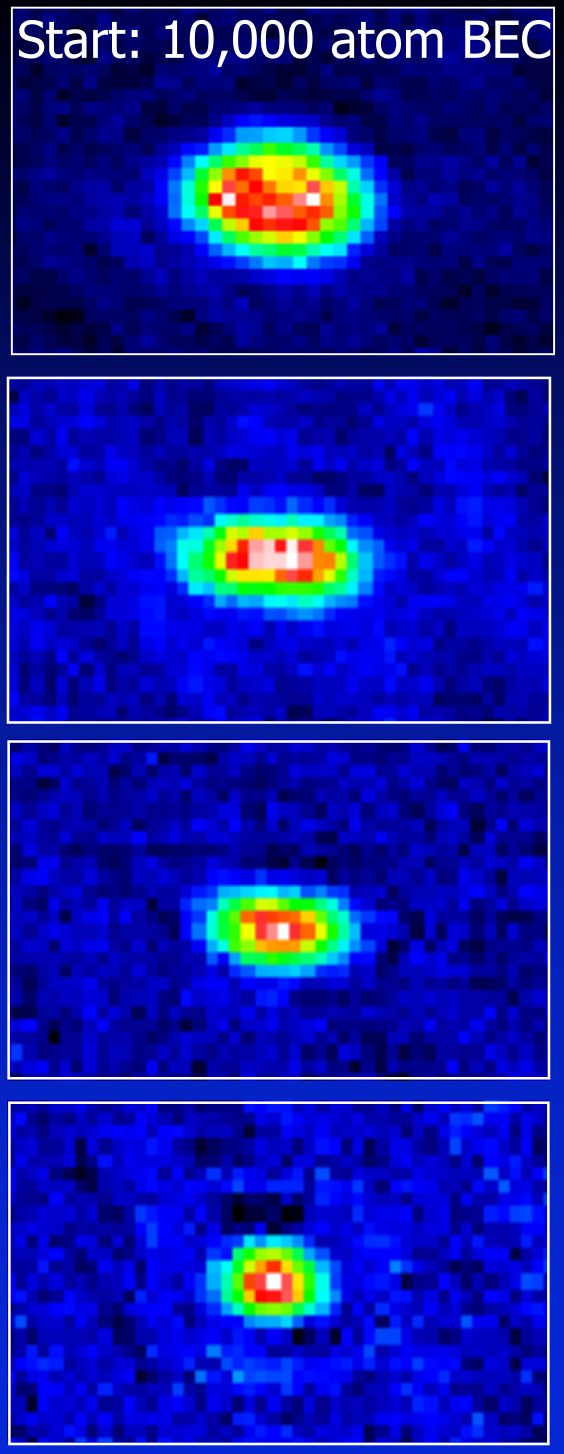
Lots of theory, varies wildly, little data

1. Make BEC magnetic field where repulsive

2. Switch to attractive.

What happens?

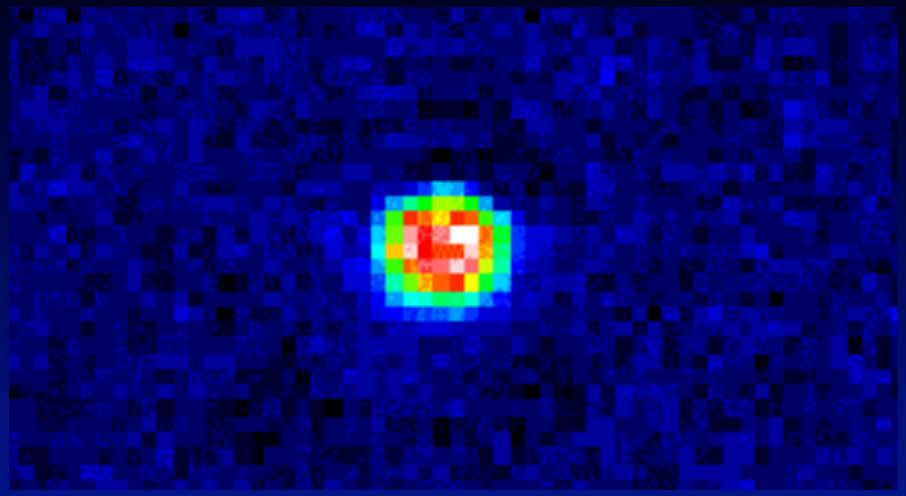
(how do quantum wavefunctions die?)



Collapse

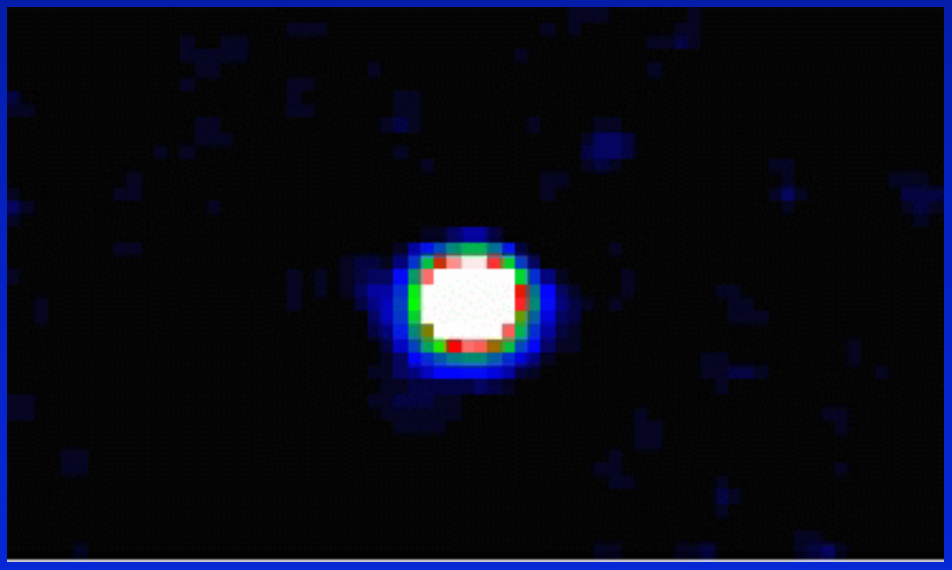
time

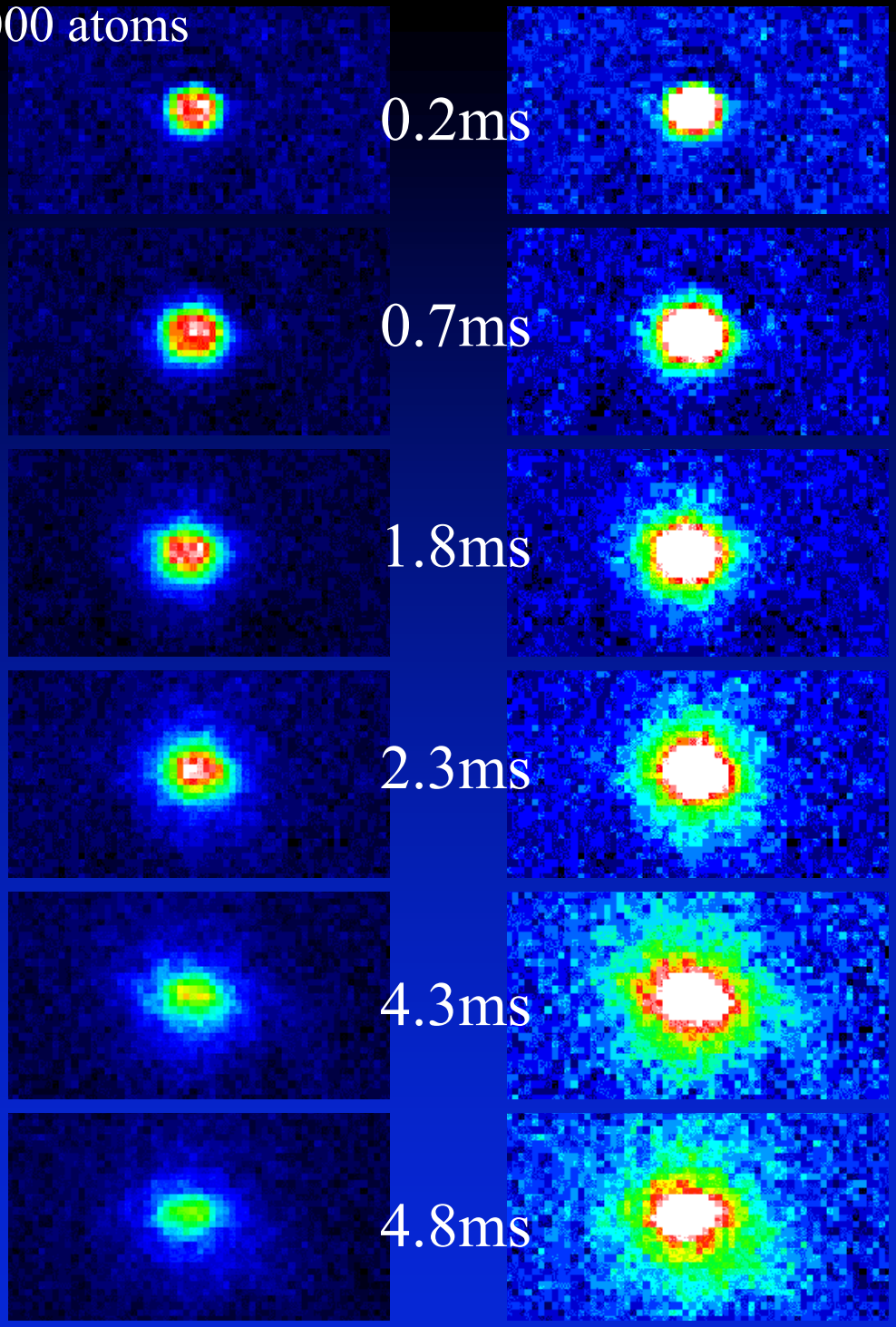
then…



x 3

Explosion !!





Much like in a supernova:

- collapse
- explosion… (x 10^{-73})
- cold remnant

"Bosenova"

What are the physics behind the explosion???
Why burst energy and how much?
Why is there a cold remnant afterwards?

1500 atom burst
T ~ 200 nK

What is next ?

(What is it good for?)

I. Measure and understand properties

a. New area of quantum world to explore – many surprises,
Bosenova & weird giant molecules converted from BEC

b. Physics relevant to behavior of smaller wires and computer chips.

II. Uses (??)…in about 5-20 years *("laser-like atoms")*

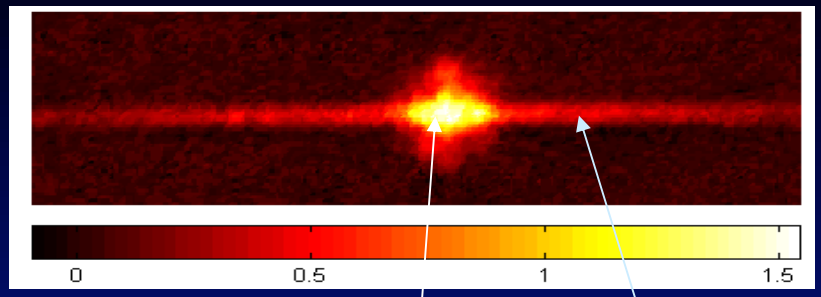
a. Ultrasensitive detectors (time, gravity, rotation)
see changes in phase of quantum wave

b. Place very many atoms exactly where want them
subnanofabrication (tiny stuff)

The applets shown and many more can be found at
www.colorado.edu/physics/2000/
For the BEC section, visit http://www.colorado.edu/physics/2000/bec/index.html

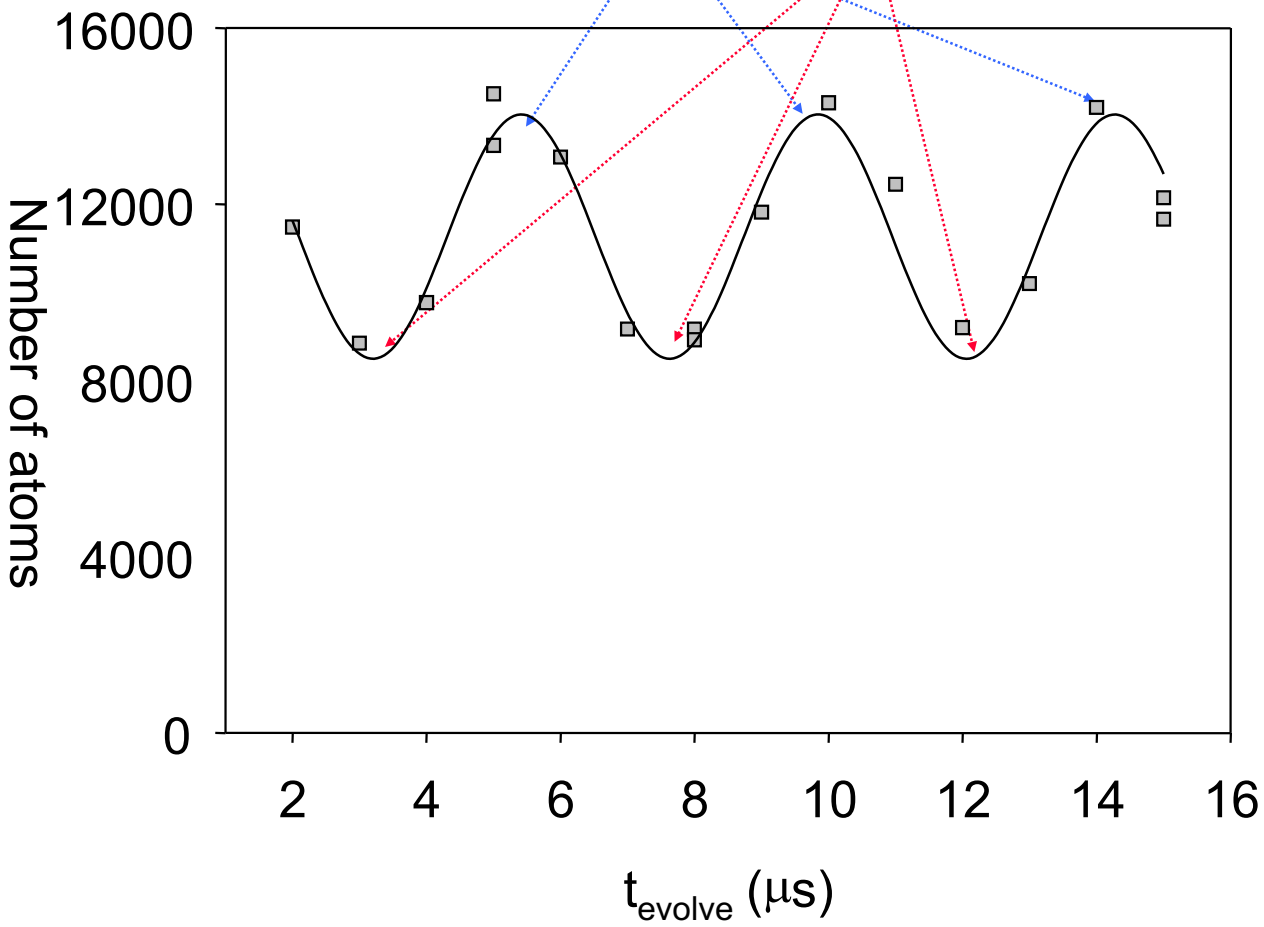
The very latest from 2003

Sudden magnetic "shock" creates BEC in atom-molecule quantum superposition!



remnant + burst

oscillates between atom and molecule BEC



Only atoms visible, oscillation frequency implies going to molecules and then back to atoms.

Very strange molecule! Currently studying formation and behavior