Quantum Degenerate Gases of Ytterbium Atoms

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Group Members

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Professor T. Yabuzaki

multiply charged quantized vortex

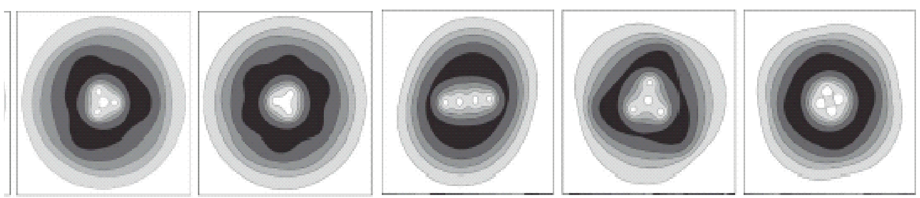
Collaboration with prof. M. Kumakura (Fukui), Mr. H. Yasuda (Kyoto), Dr. Isoshima (Kyoto)

“^{87}Rb BEC in *F* = 2, m_F = 2 state”

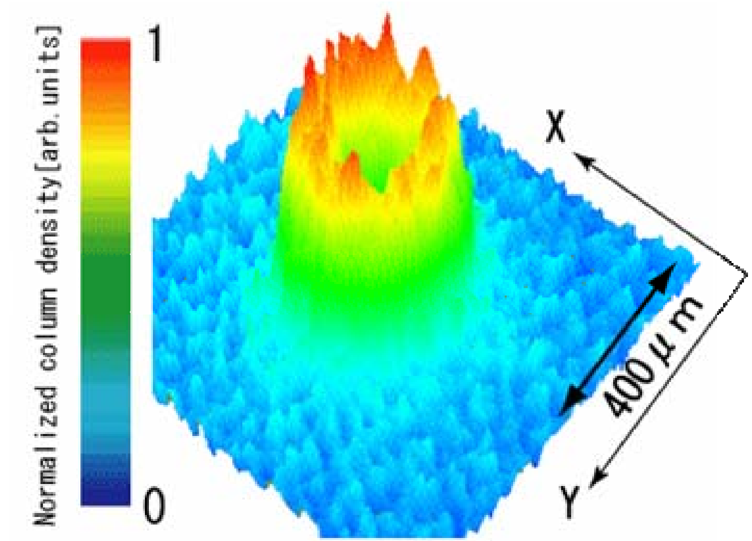
magnetic field reversal :

0.4 G ⟶ - 0.4G (3ms)

Quadruply Charged Quantized Vortex



Y.Kawaguchi and T.Ohmi, Phys.Rev.A 70, 043610(2004)



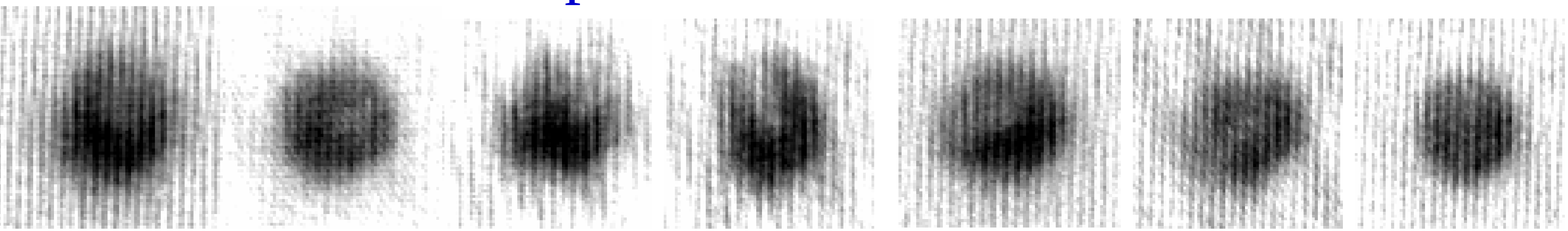
axial image (TOF = 25 ms)

[M. Kumakura et al, PRA**73**, 063605 (2006)]

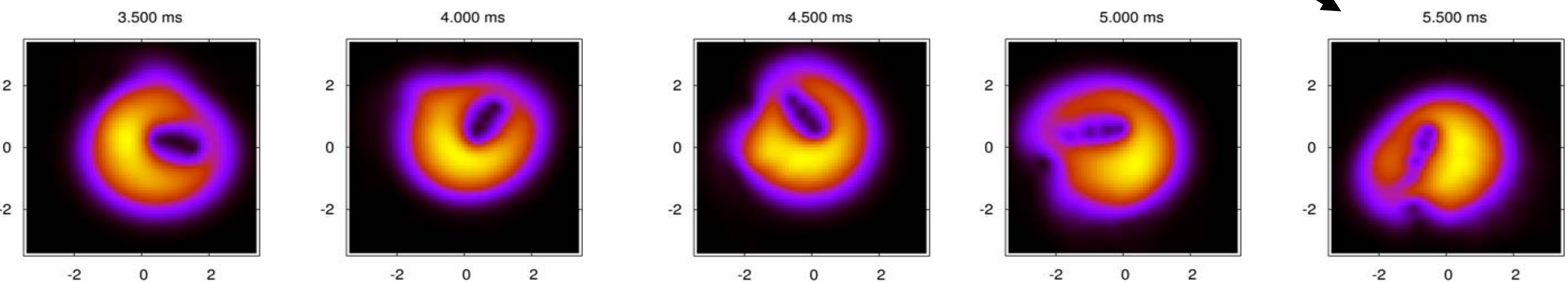
multiply charged quantized vortex

vortex deformation

Experimental results



3.0 ms 4.0 ms 4.3 ms 4.5 ms 5.5 ms 6.5 ms 7.5 ms

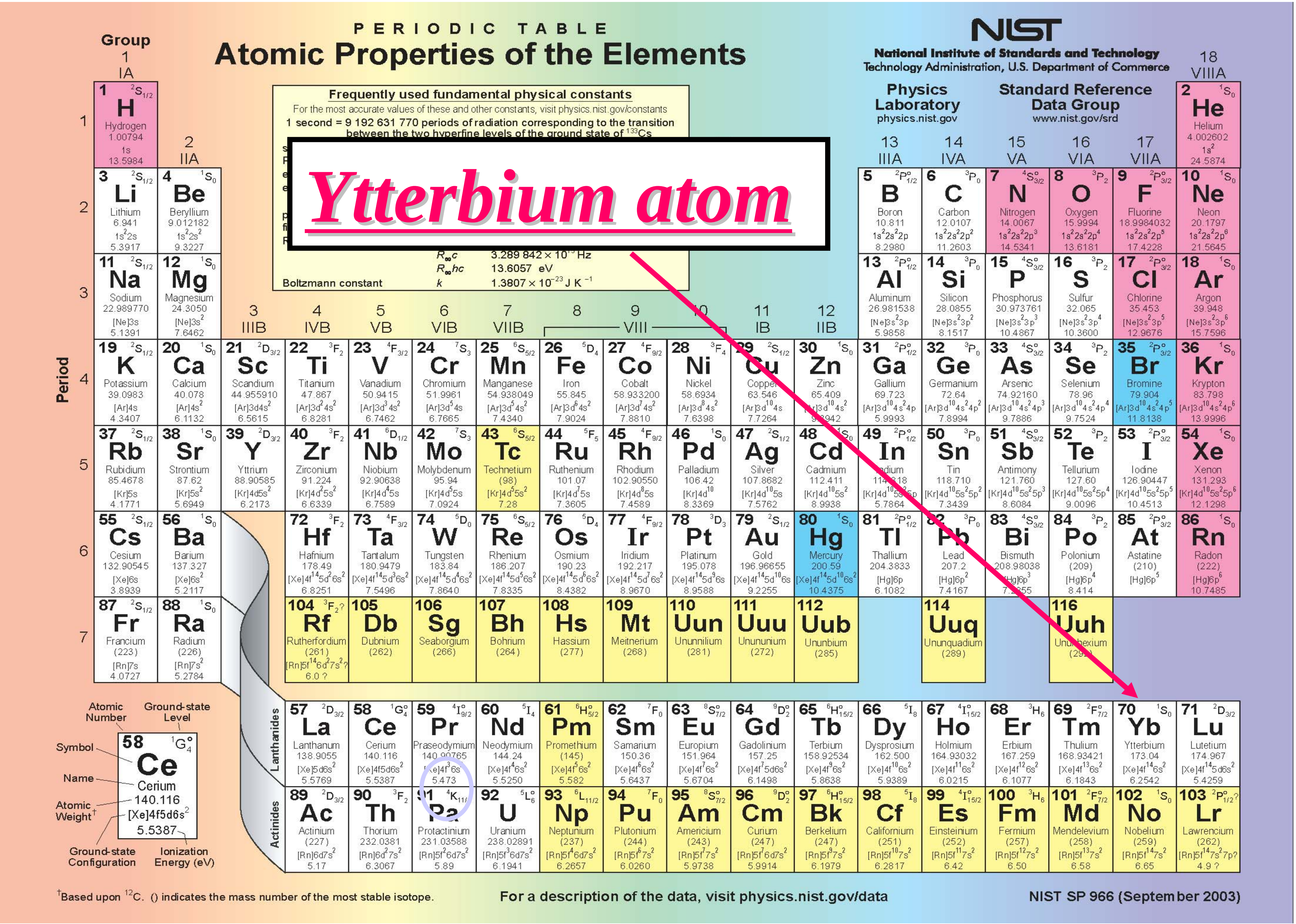


3D calculation [T.Isoshima]

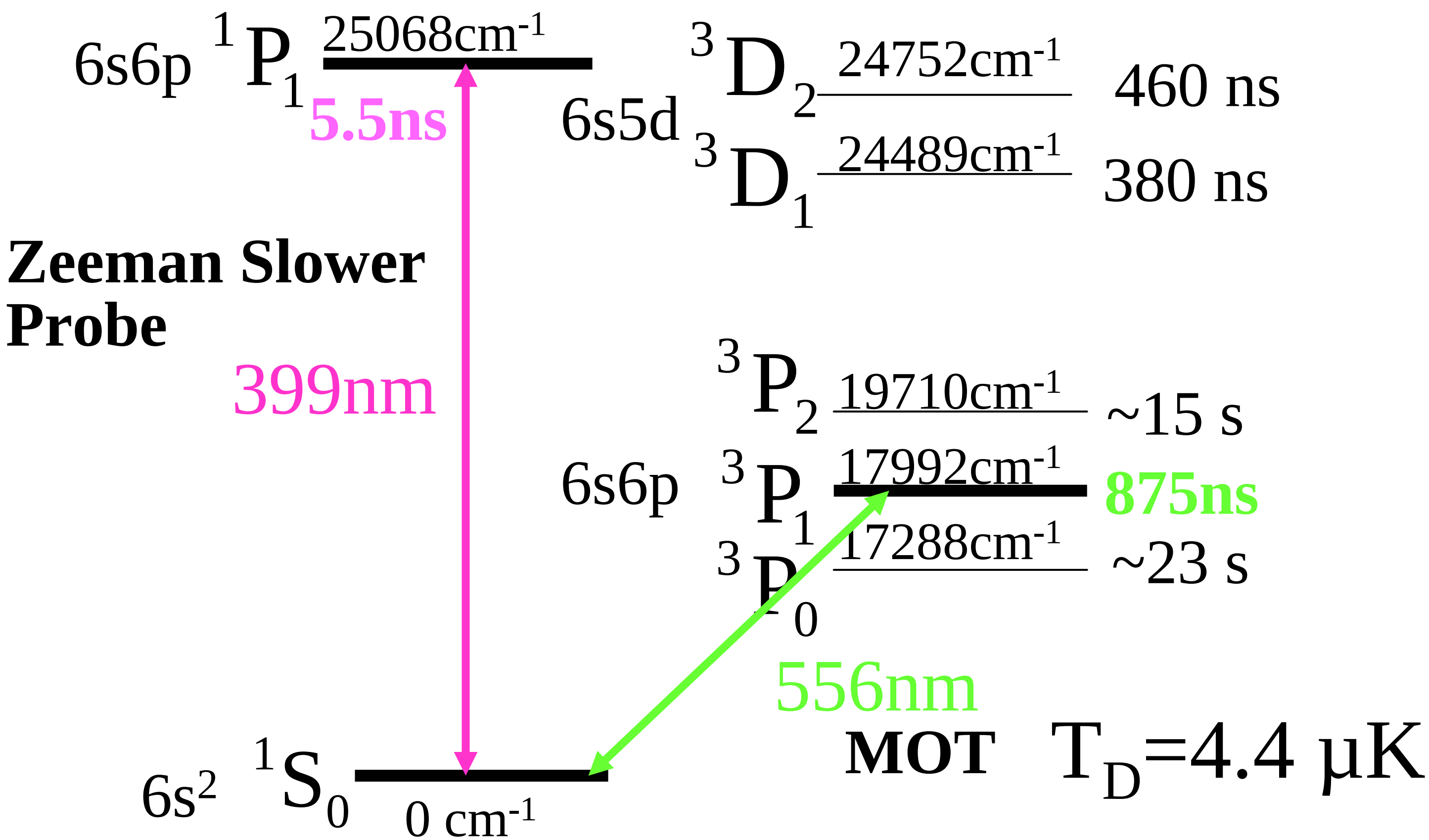
Atomic BEC and Fermi Degeneracy

1995	^{87}Rb, ^{23}Na, ^{7}Li
1998	^{1}H
1999	^{40}K
2000	^{85}Rb
2001	^{41}K $^{4}He^{*}$ ^{6}Li
2003	^{133}Cs ^{174}Yb
2005	^{52}Cr

Ytterbium atom



Energy Levels of Yb Atom



Two-Electron Atom: (Xe) $4f^{14}$ $6s^2$

Unique Property of Yb Atom

A Variety of Isotopes

Boson: ^{168}Yb (0.13%), ^{170}Yb (3.05%), ^{172}Yb (21.9%),
(even mass number) ^{174}Yb (31.8%), ^{176}Yb (12.7%)

Fermion: ^{171}Yb (14.3%, I=1/2), ^{173}Yb (16.2%, I=5/2)
(odd mass number)

Various Quantum Degenerate Gases

BEC: ^{168}Yb, ^{170}Yb, ^{172}Yb, ^{174}Yb, ^{176}Yb

Fermi Degeneracy: ^{171}Yb, ^{173}Yb

Various Mixtures of BEC and FD

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Various Mixtures of BEC and FD

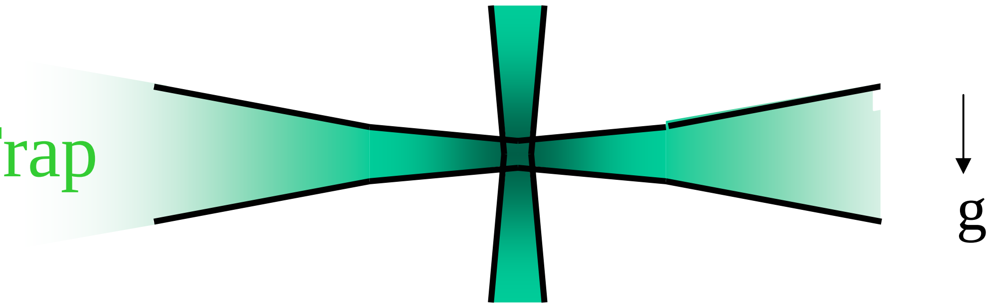
Stability analysis of n-component BEC [D. Roberts and M. Ueda, PRA**73** 053611 (2006)]

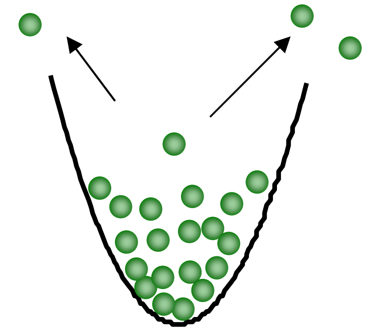
Formation of Quantum Degenerate Gas

^{174}Yb (31.8%) Boson, I=0	^{170}Yb (3.05%) Boson, I=0
^{176}Yb (12.7%) Boson, I=0	^{173}Yb (16.2%) Fermion, I=5/2

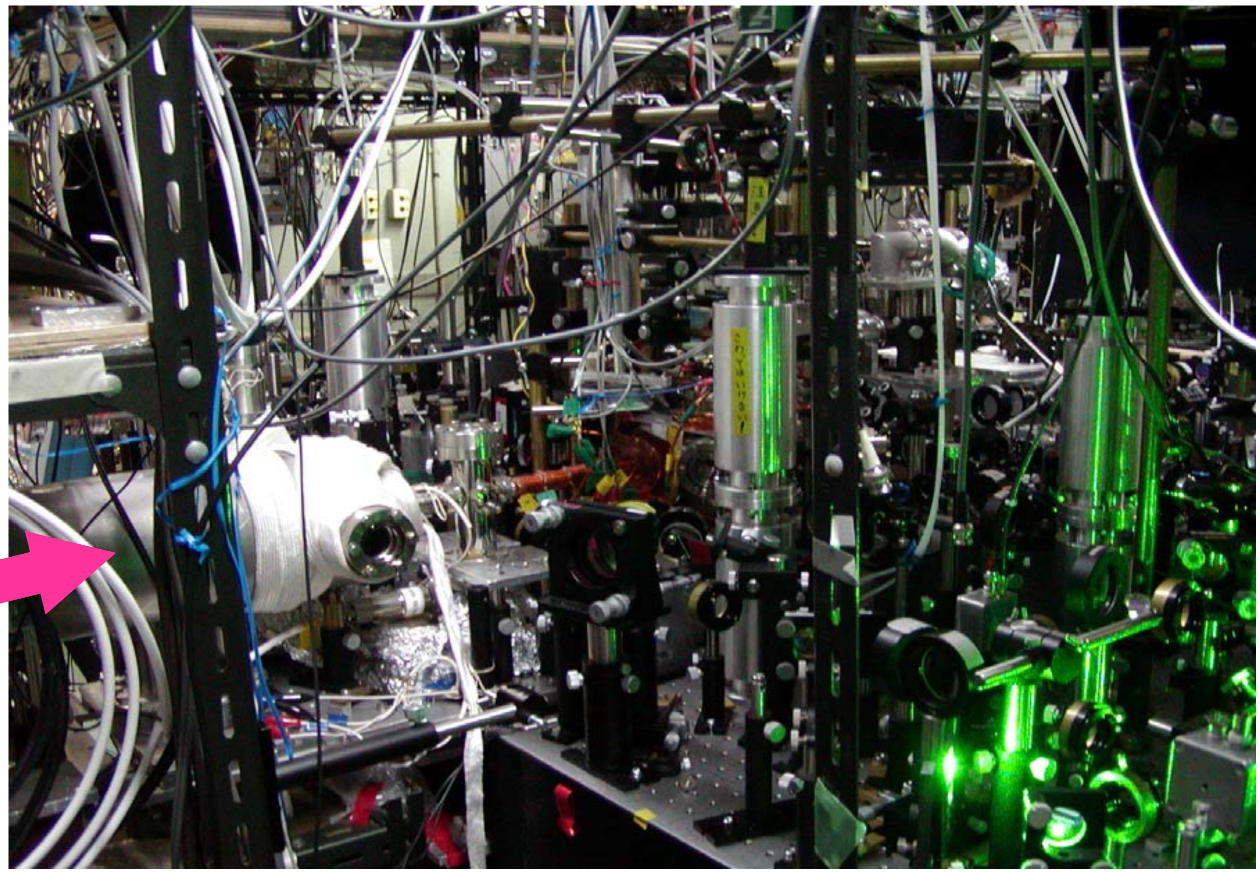
Experimental Setup

Optical Trap





Atomic Beam



Optical Trapping Beams (532 nm)

Formation of Quantum Degenerate Gas

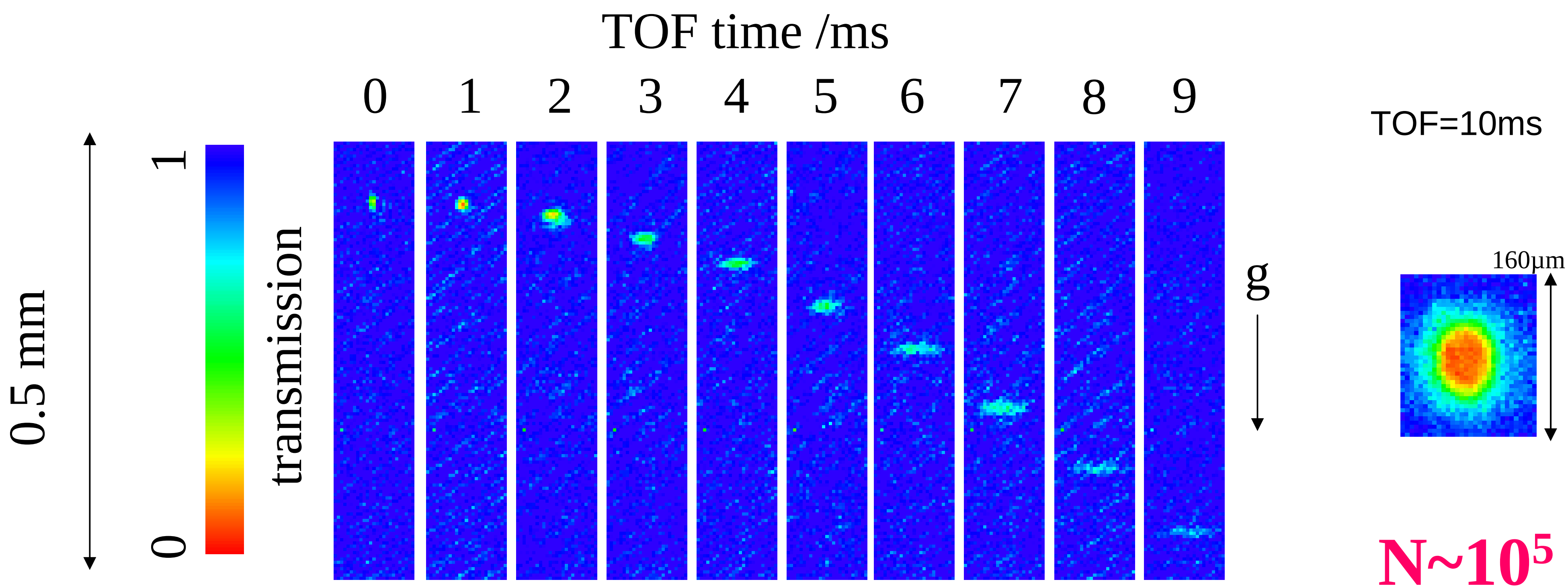
^{174}Yb (31.8%) Boson, I=0	^{170}Yb (3.05%) Boson, I=0
^{176}Yb (12.7%) Boson, I=0	^{173}Yb (16.2%) Fermion, I=5/2

^{174}Yb BEC

^{174}Yb (31.8%)

BEC N~10^4

[Y. Takasu et al, PRL 91 040404(2003)]

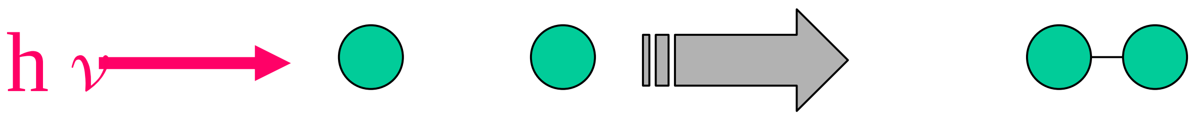


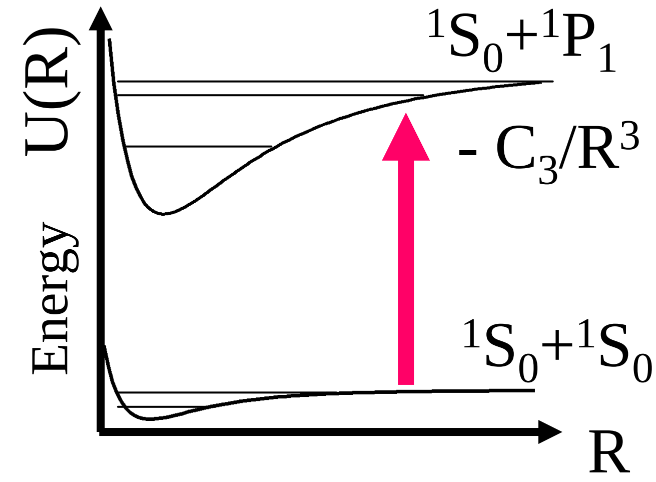
N~10^5

Quick Formation of BEC: t ~ 15 seconds

^{174}Yb: determination of scattering length

Photo-Association Spectroscopy

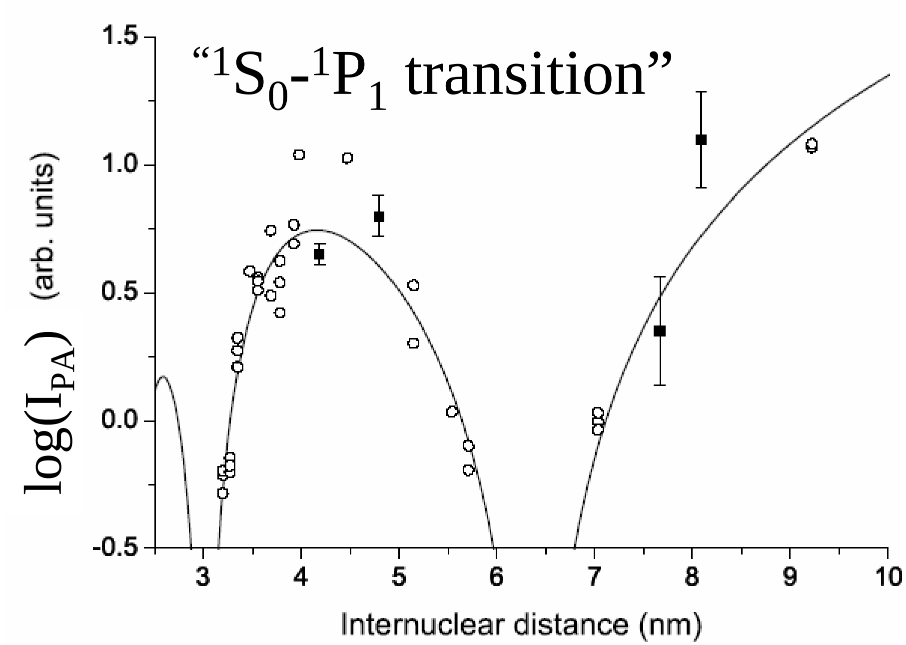




$$I_{PA}(\Delta) \propto \frac{\left|\Psi_g(R)\right|^2}{\sqrt{\Delta}} \qquad \frac{C_3}{R^3} = \hbar\Delta$$

Scattering wavefunction

Julienne, *J. Res. NIST*. **101**, 487 (1996).



→ *a=5.5 nm ± 0.2 nm*

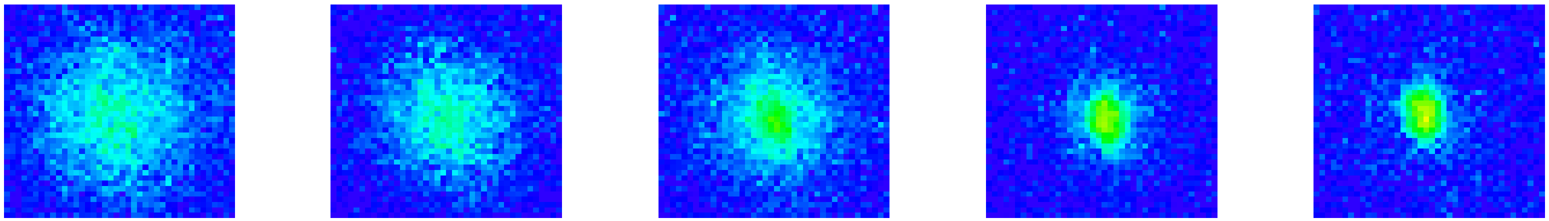
Formation of Quantum Degenerate Gas

^{174}Yb (31.8%) Boson, I=0	^{170}Yb (3.05%) Boson, I=0
^{176}Yb (12.7%) Boson, I=0	^{173}Yb (16.2%) Fermion, I=5/2

^{170}Yb BEC

^{170}Yb (3.05%)

high ← Potential depth → low



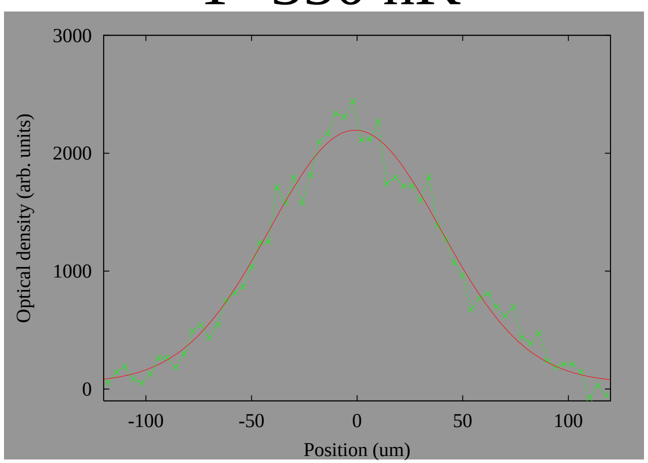
TOF=10ms

thermal

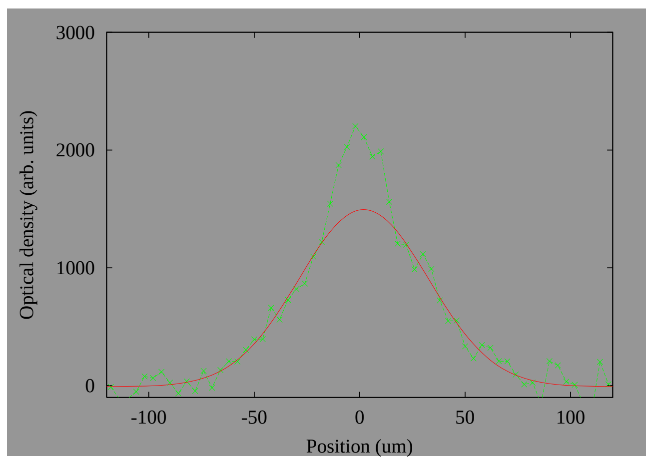
bimodal

BEC

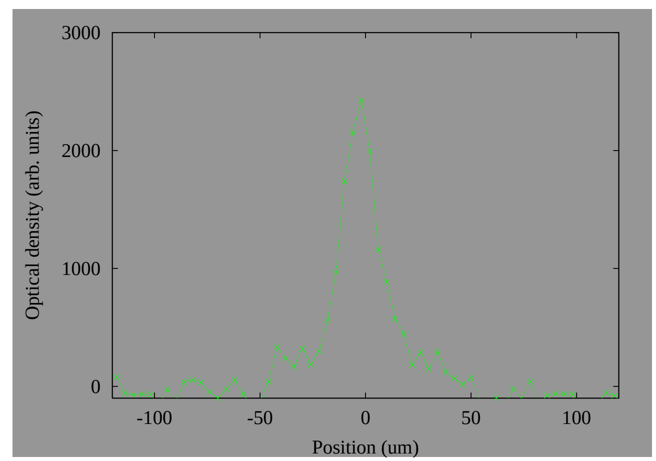
T=350 nK



T=200 nK



N~1×10^4

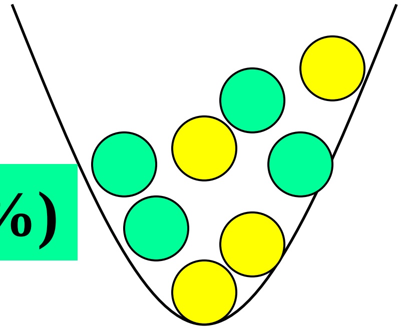


By mass scaling law we can know the scattering lengths of all the isotopes

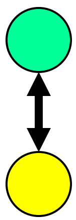
Formation of Quantum Degenerate Gas

^{174}Yb (31.8%) Boson, I=0	^{170}Yb (3.05%) Boson, I=0
^{176}Yb (12.7%) **Boson, I=0**	^{173}Yb (16.2%) Fermion, I=5/2

^{176}Yb BEC:sympathetic cooling with boson ^{174}Yb

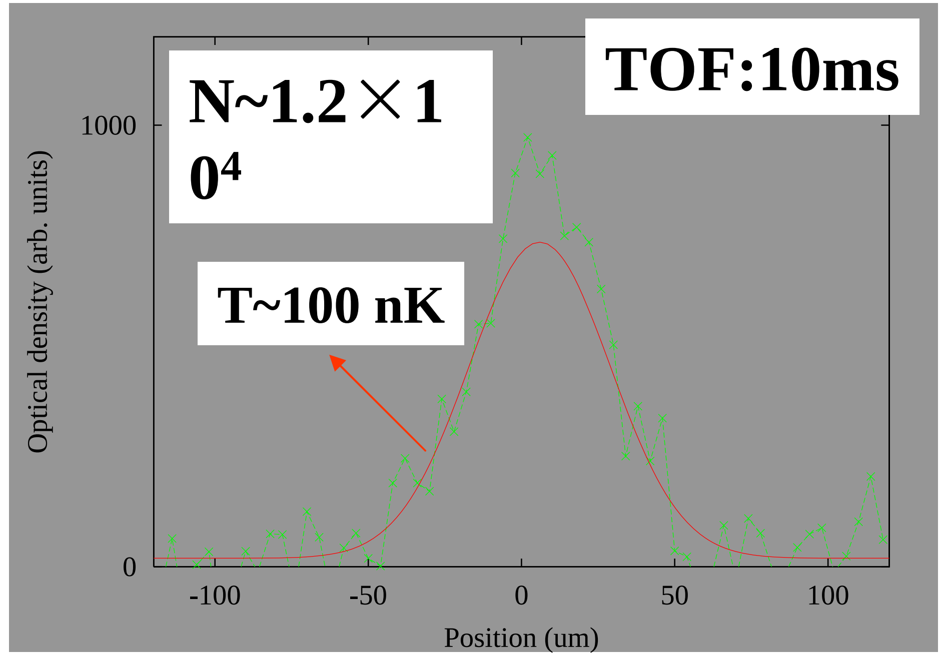


^{176}Yb (12.7%)

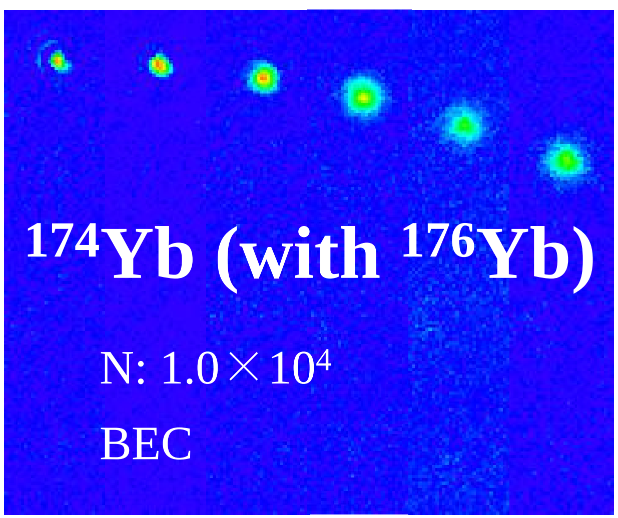


^{176}Yb : small collision rate

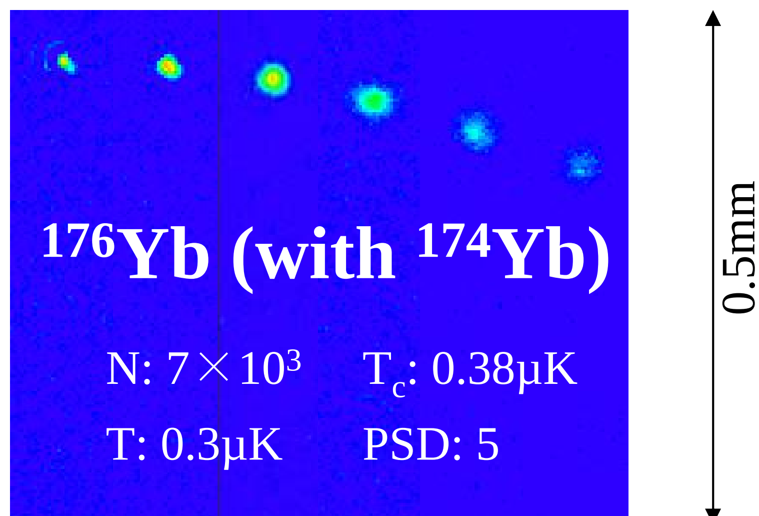
^{174}Yb : large collision rate



TOF (ms) 0 1 2 3 4 5



0 1 2 3 4 5



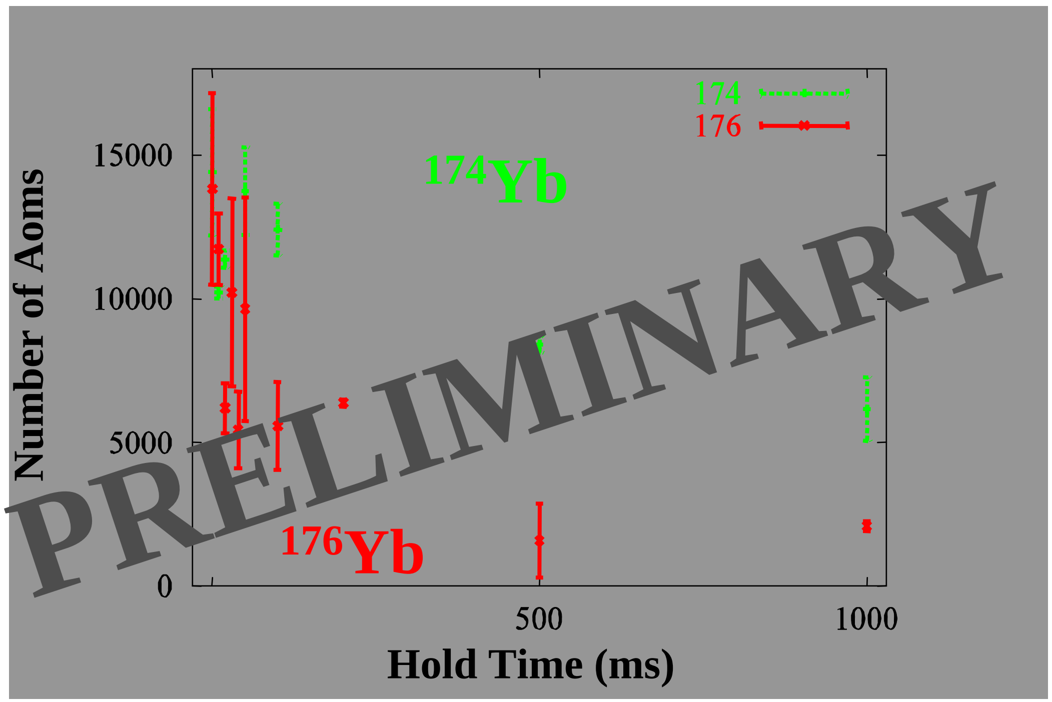
^{176}Yb BEC:sympathetic cooling with boson ^{174}Yb

"Further evaporative cooling did not increase the condensate fraction"

Possibility

$a_{176} < 0$: attractive interaction $N_C \approx 0.6 \times \frac{a_{osc}}{|a_{176}|}$

~ 600 if $a_{176} = -1$ nm



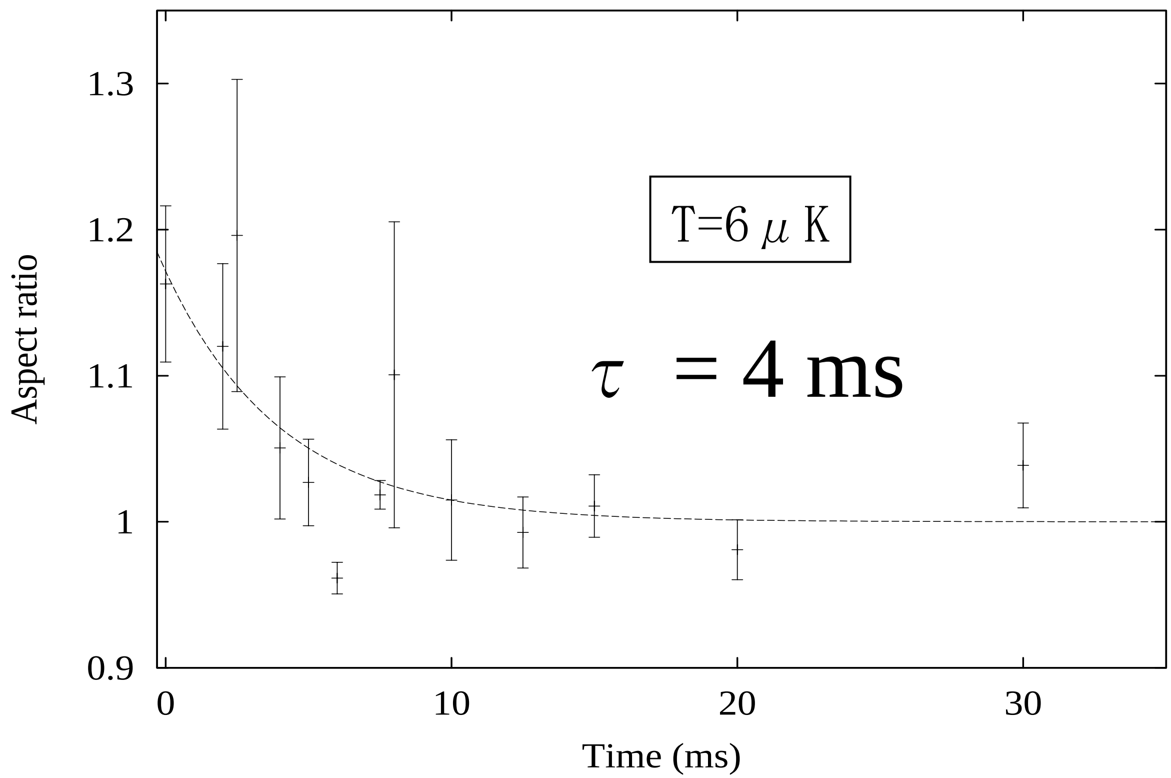
Formation of Quantum Degenerate Gas

^{174}Yb (31.8%) Boson, I=0	^{170}Yb (3.05%) Boson, I=0
^{176}Yb (12.7%) Boson, I=0	**^{173}Yb (16.2%)** **Fermion, I=5/2**

^{173}Yb Fermi Degeneracy

^{173}Yb (16.2%, I=5/2)

m_F=-5/2, -3/2, -1/2, +1/2, +3/2, +5/2



Anisotropy in Temperature by Parametric Heating

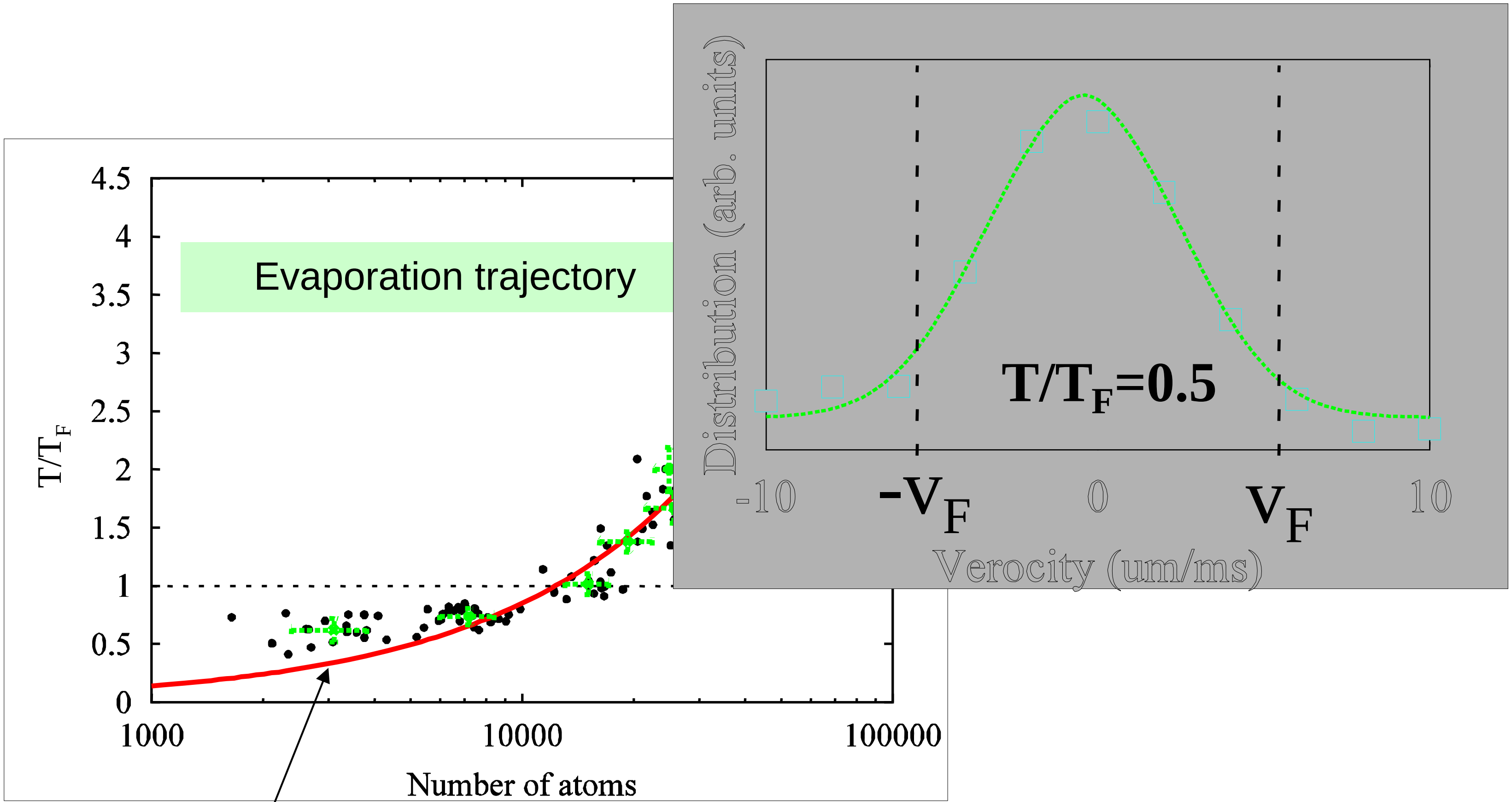
Observe Re-thermalization

$$|a| \approx 6 \text{ nm} \pm 2 \text{ nm}$$

^{173}Yb Fermi Degeneracy

^{173}Yb (16.2%, I=5/2)

m_F=-5/2, -3/2, -1/2, +1/2, +3/2, +5/2



onset of Fermi degeneracy

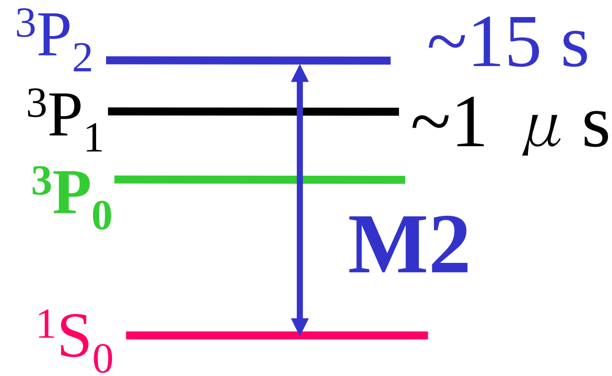
$T/T_F \sim 0.5$

Atomic BEC and Fermi Degeneracy

1995	^{87}Rb ^{23}Na ^{7}Li
1998	^{1}H
1999	^{40}K
2000	^{85}Rb
2001	^{41}K $^{4}He^{*}$ ^{6}Li
2003	^{133}Cs ^{174}Yb
2005	^{52}Cr
2006	^{170}Yb ^{176}Yb ^{173}Yb $^{3}He^{*}$

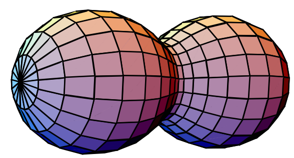
Future Possibilities

Ultra-Narrow Optical Transition



$^1S_0$-$^3P_2$ (507 nm: linewidth ~ 10 mHz)

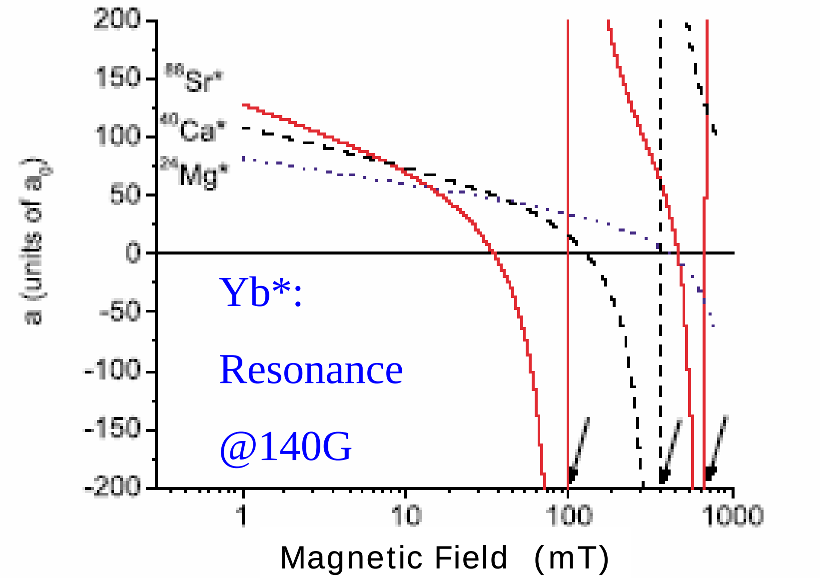
Creating BEC in the $^3P_2$ state



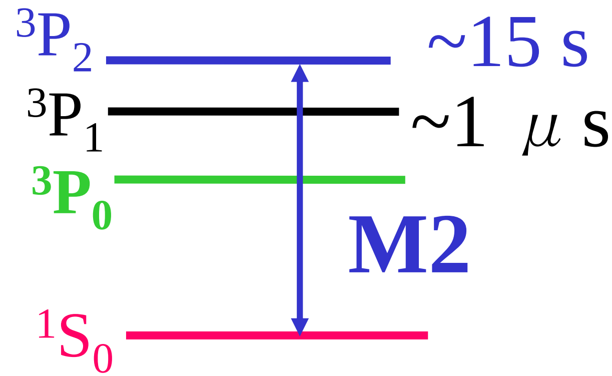
— dipolar BEC: $\mu(^3P_2)=3\mu_B$

— Tuning the scattering length

[A. Derevianko *et al.*,PRL **90**, 063002(2003)]



Ultra-Narrow Optical Transition

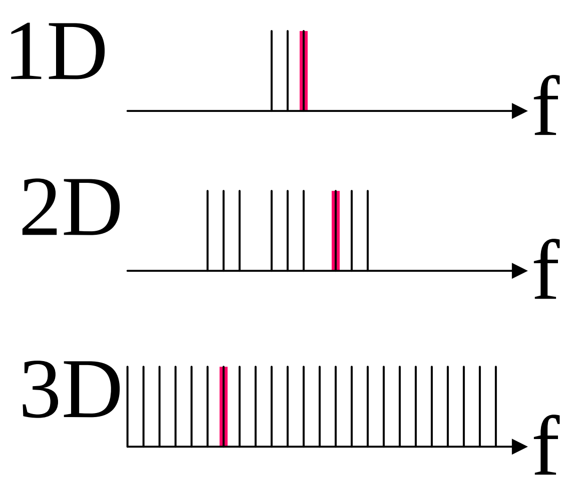


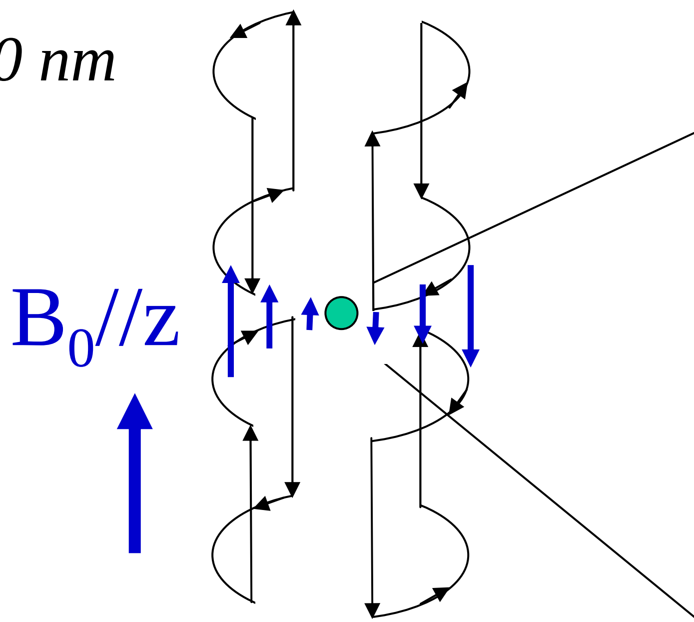
$^1S_0$-$^3P_2$ (507 nm: linewidth ~ 10 mHz)

Optical Magnetic Resonance Imaging

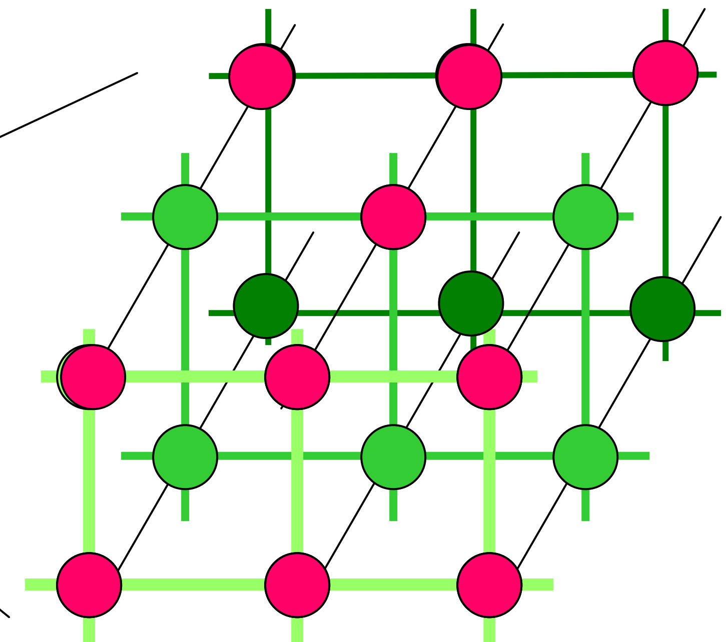
$\partial B_z / \partial x = 10G/cm, \delta\nu = 1kHz$

→ δx=250 nm





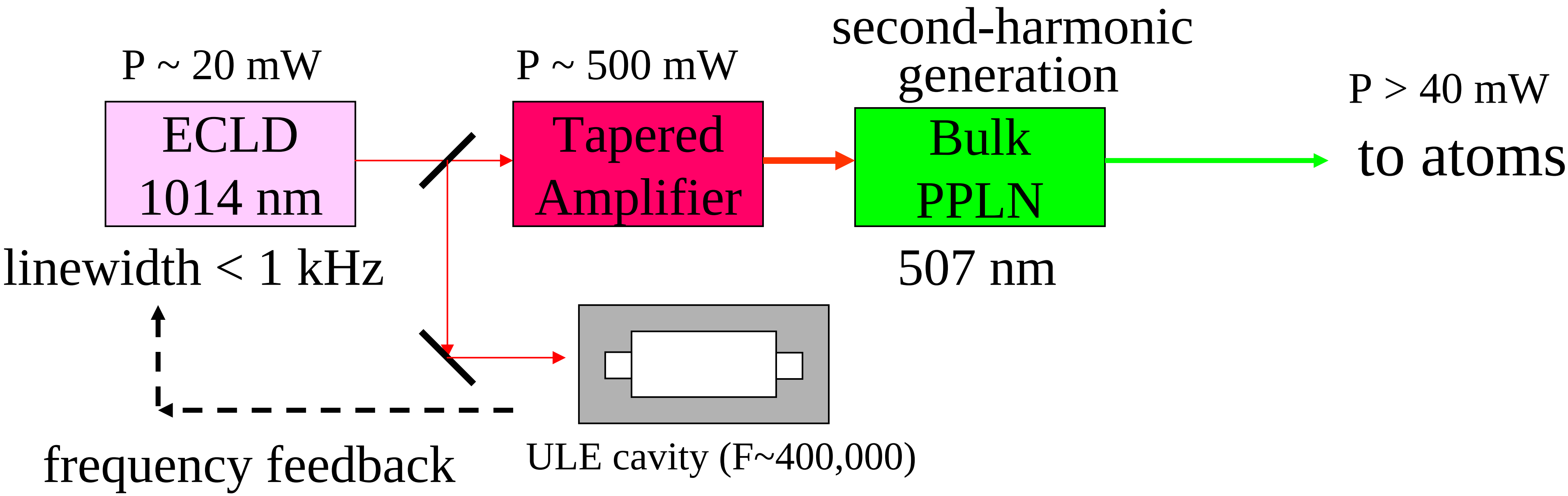
"Optical Lattice"



Use of Ultra-narrow Optical Transition

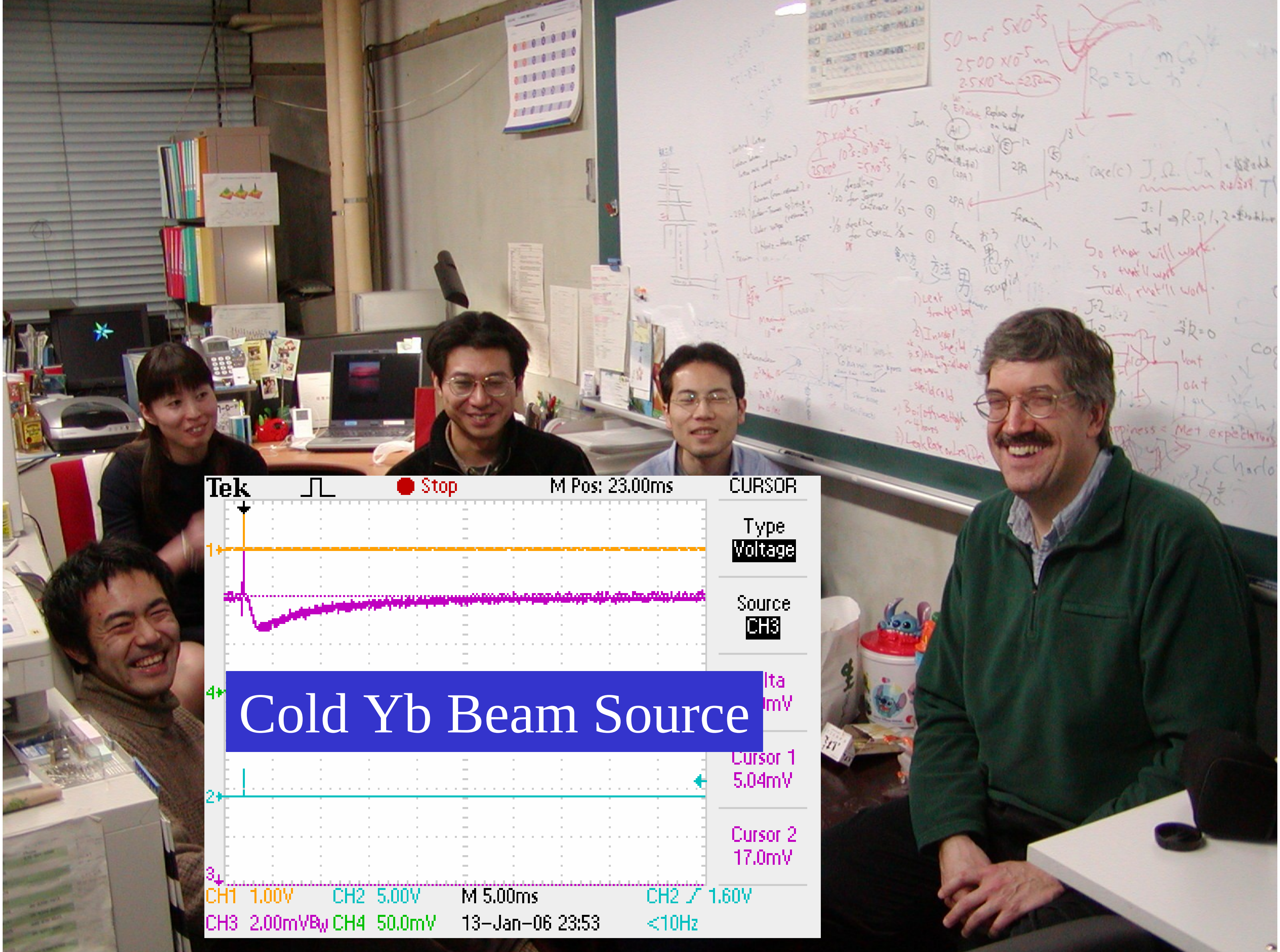
development of stable light source:

$^1S_0$-$^3P_2$ (507 nm: linewidth << 1 kHz)



under construction

Cold Yb Beam Source



Thank you very much for attention.