Experimental study about the optimized evaporative cooling for BEC

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The 5th Laser Cooling Workshop in Awajisima (Jan. 07, 2003)

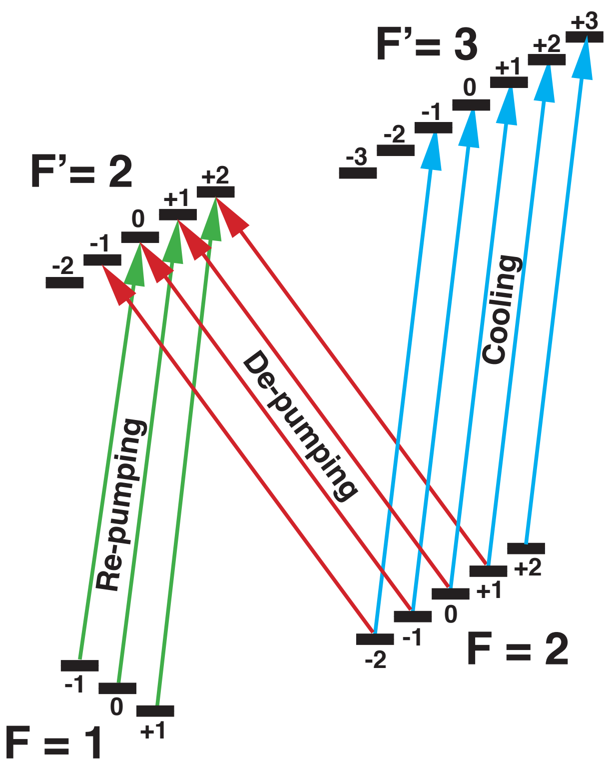
Motivation

Evaporative cooling is the key technique to achieve Bose-Einstein condensation (BEC). According to the calculation based on the quantum kinetic theory of a Bose gas*), large three-body loss at the final step before reaching BEC degrades the efficiency of evaporative cooling and commonly used exponential RF function is not always the best route to get the maximum number of condensed atoms. I'm trying to apply this theory on ^{87}Rb atoms to optimize the evaporation process in BEC experiment.

***) Makoto Yamashita et al., to be published in Phys. Rev. A.**

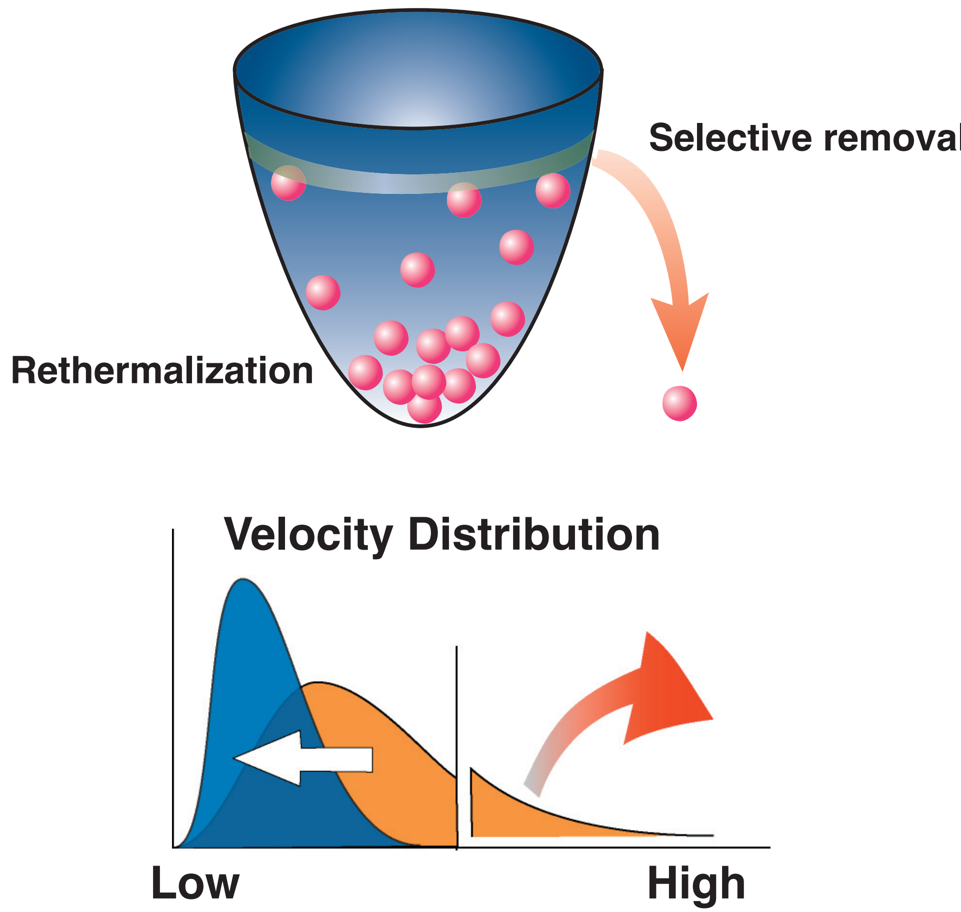
Main cooling schemes for BEC

Laser Cooling



^{87}Rb Energy level

Evaporative Cooling



Quantum kinetic theory of Dr. Yamashita

Trapped atoms are removed from the potential by not only evaporation but also undesirable collisions. The change rates (i.e., loss rates) of the total number of atoms and the total internal energy are calculated respectively as the sum of the contributions of all processes such that,

$$\frac{d\tilde{N}}{dt} = -\int \dot{n}_{\rm ev}(\mathbf{r})\ d\mathbf{r} - \sum_{s=1}^{3} G_s \int K_s(\mathbf{r})[\tilde{n}(\mathbf{r})]^s\ d\mathbf{r} + \left(\frac{\partial \tilde{N}}{\partial \epsilon_t}\right)_{T,\mu} \dot{\epsilon}_t,$$

$$\frac{d\tilde{E}}{dt} = -\int \dot{e}_{\rm ev}(\mathbf{r})\ d\mathbf{r} - \sum_{s=1}^{3} G_s \int K_s(\mathbf{r})\tilde{e}(\mathbf{r})[\tilde{n}(\mathbf{r})]^{s-1}\ d\mathbf{r} + \left(\frac{\partial \tilde{E}}{\partial \epsilon_t}\right)_{T,\mu} \dot{\epsilon}_t.$$

The rates $\dot{n}_{\rm ev}$ and $\dot{e}_{\rm ev}$ denote the evaporation rates of density functions derived from a general collision integral of a Bose gas system. The parameters G_1, G_2, and G_3 are the decay rate constants of trapped atoms due to the background gas collisions, dipolar relaxation, and three-body recombination, respectively. K_s represents the correlation function which describes the s-th order coherence of trapped atoms, and we assume the expressions of K_s for an ideal Bose gas system. The terms proportional to the change rate of truncation energy, $\dot{\epsilon}_t = d\epsilon_t/dt$, give the contribution of extra atoms "spilled over" when ϵ_t changes continuously in the forced evaporative cooling.

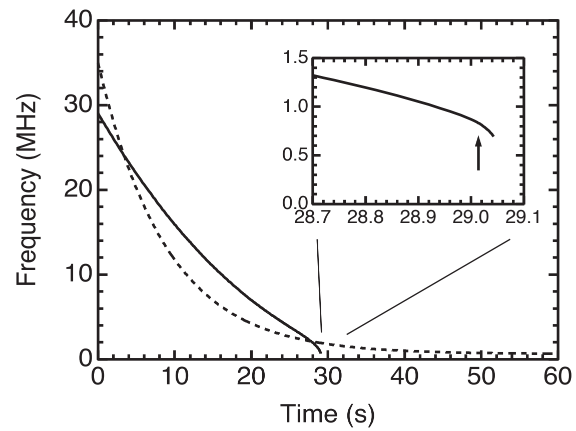


FIG. 1: Sweeps of rf-field frequency in the optimized case (solid) and in the exponential case (dashed). The inset shows the last part of the optimized sweep using an expanded scale. The arrow in the inset indicates the point at which the BEC transition occurs.

Makoto Yamashita et al., to be published in Phys. Rev. A

Double MOT

Push beam :

5ms resonant pulse,

15Hz repetition,

Intensity < 10mW/cm^2

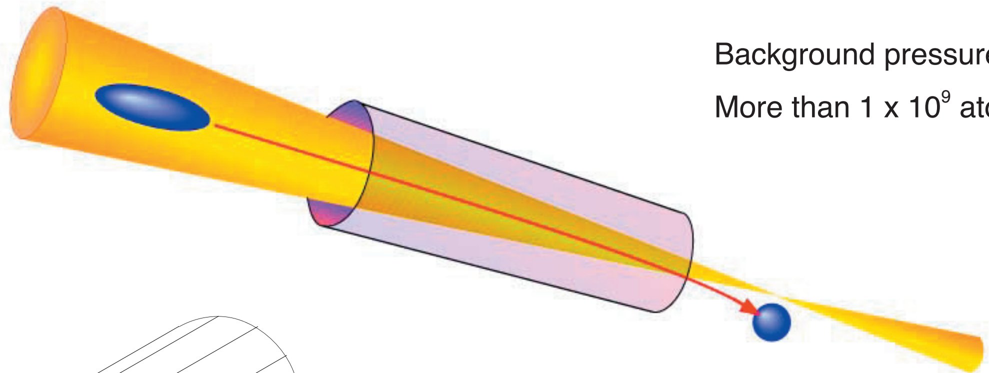
Connection tube :

Diameter 10mm,

Length 343mm,

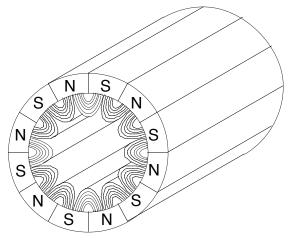
inclined 30° from horizontal

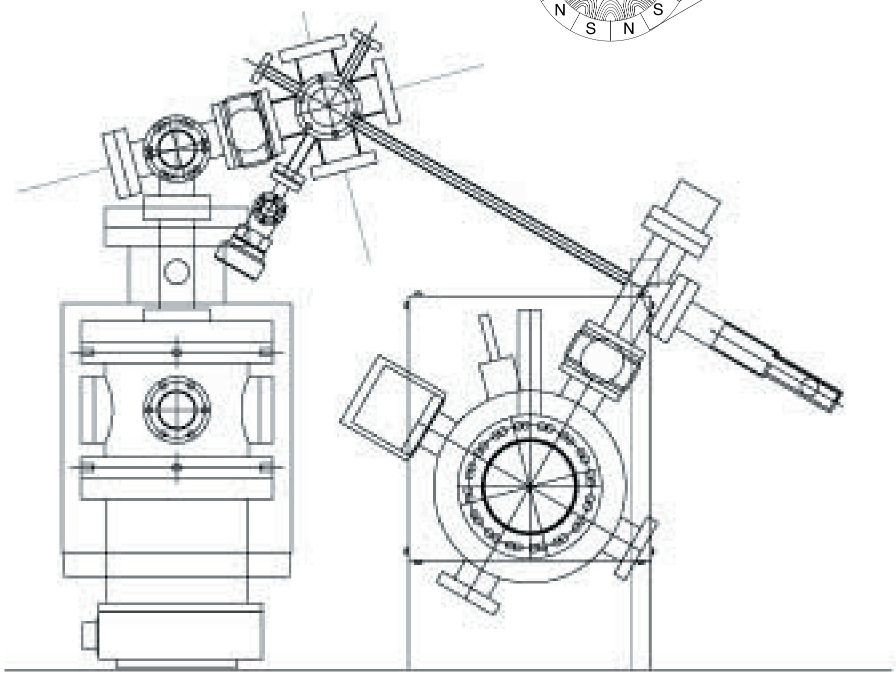
hexapole magnetic guide

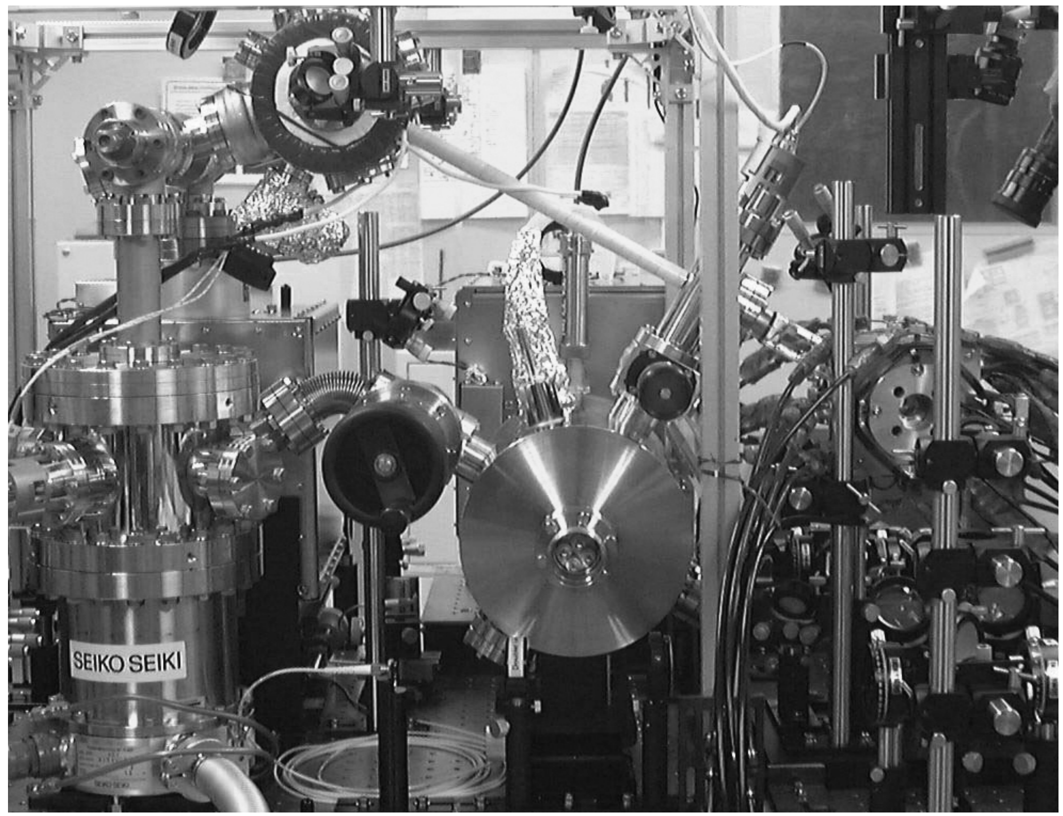


Background pressure = 2.4±0.4 x 10^{-11} torr

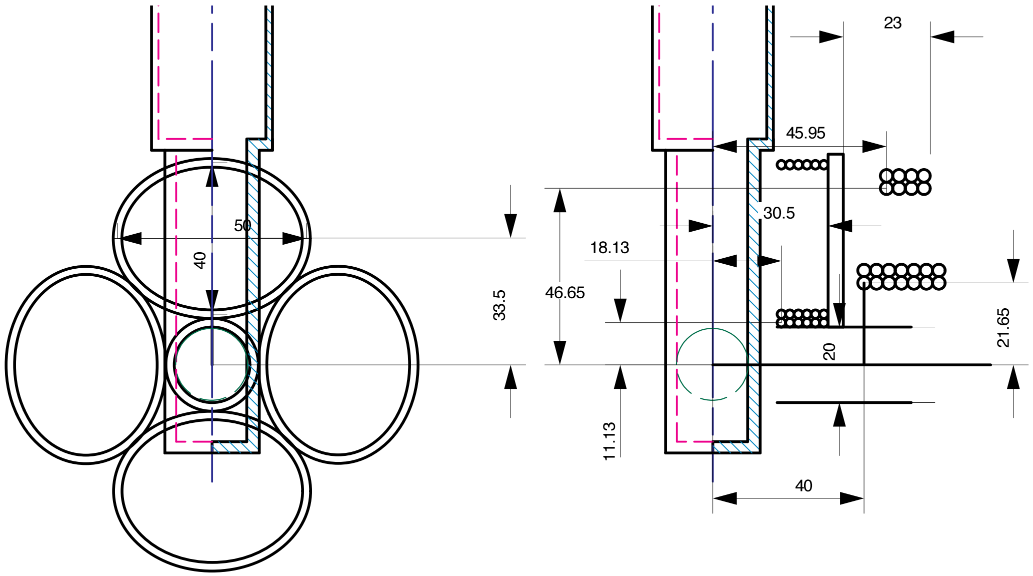
More than 1 x 10^9 atoms are trapped in the 2nd MOT in 30s







Cloverleaf trap coil



Coil tube :

curb & clover = ϕ 2mm

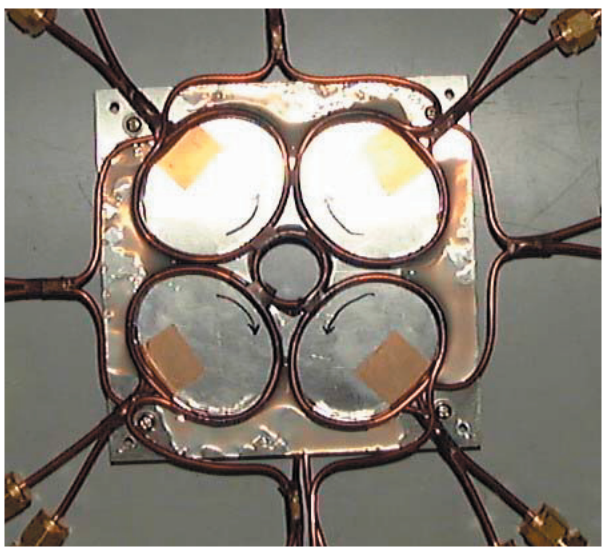
bias & MOT = ϕ 3mm

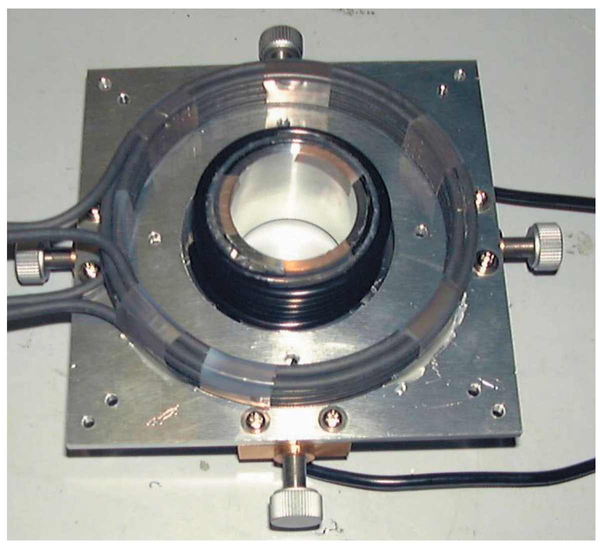
Max current : 230A

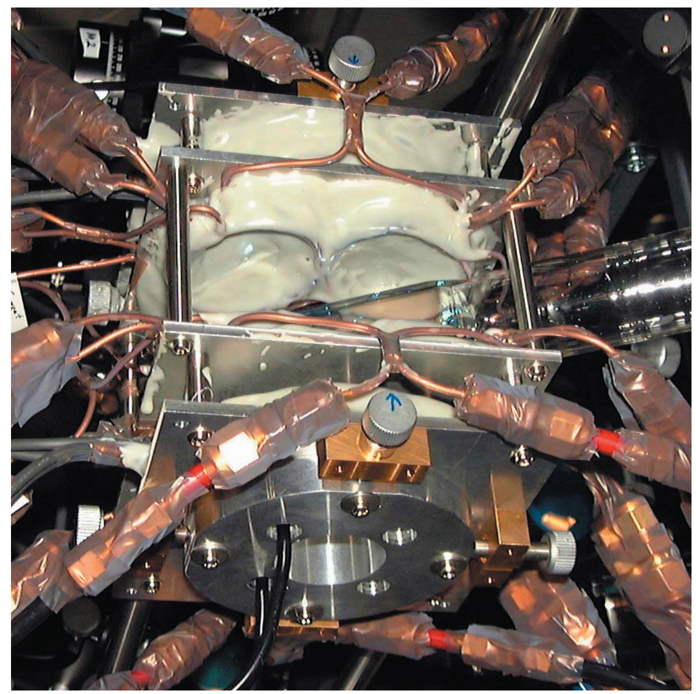
MT Coil Parameters :

$\omega_z = 2\pi \times 18.8$ Hz (axial)

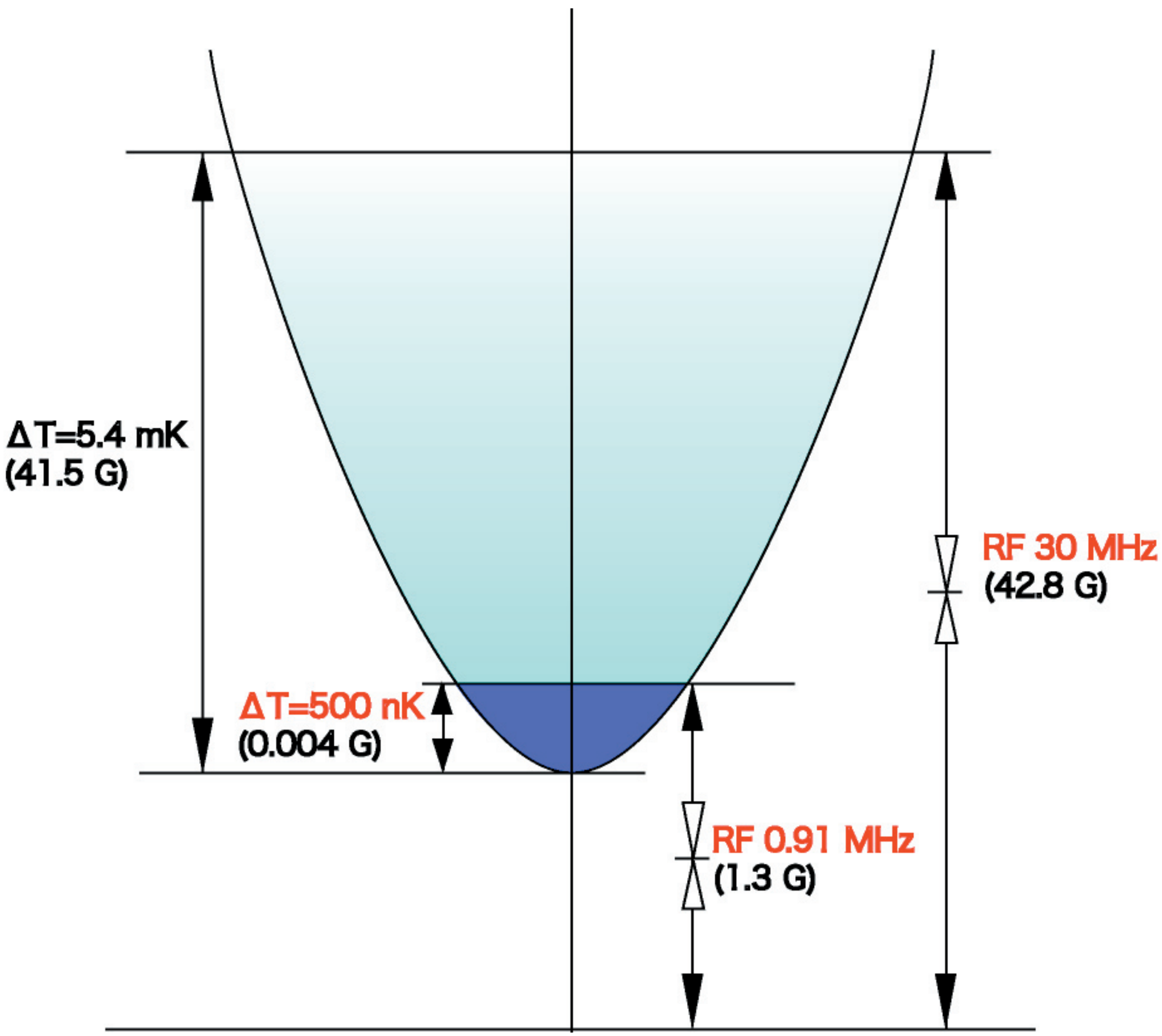
$\omega_\rho = 2\pi \times 182$ Hz (radial)

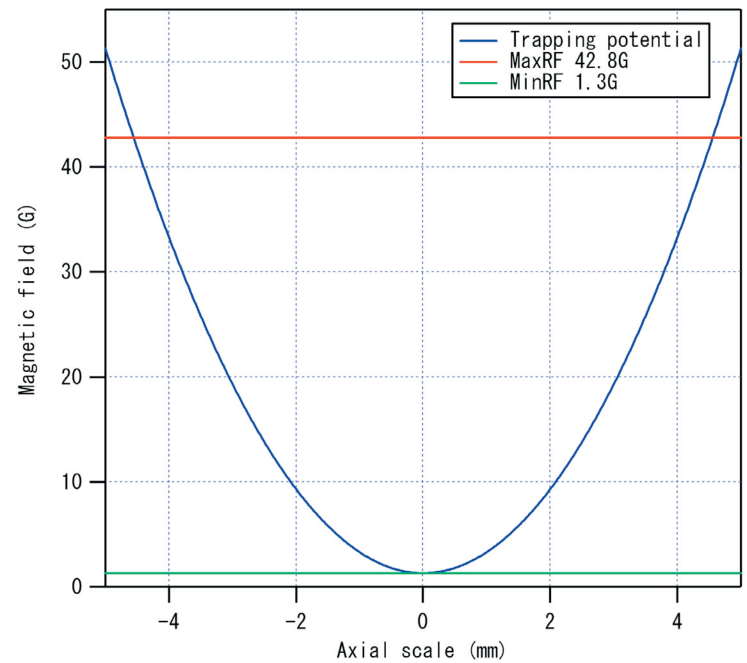


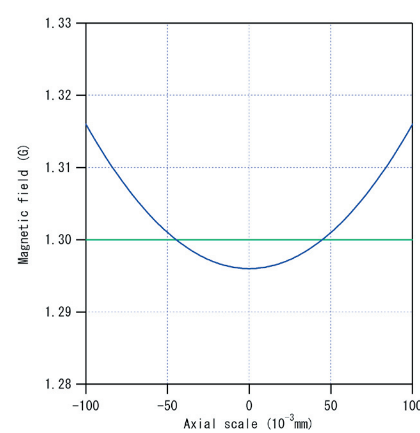


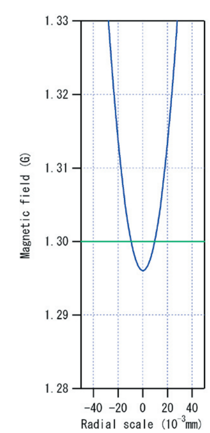


Magnetic field of Cloverleaf trap









Condensation and stabilization

2002.07.10

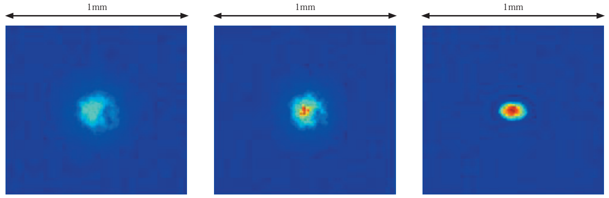
BEC in NTT*

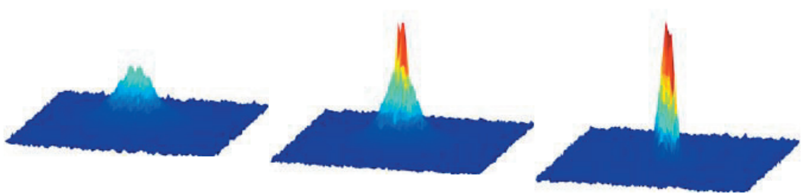
Japanese telecommunication company has made it.

As of July 8, 2002, BEC has been achieved in ^{87}Rb $|F=2\ m_F+2>$. At first about 5×10^8 atoms are collected in the 2nd MOT in 30 seconds. After polarization gradient cooling, the atoms are loaded into a cloverleaf magnetic trap. The trap is adiabatically compressed over about 4s to an axial trap frequency of 18.8 Hz and radial trap frequencies of 182 Hz. Evaporative cooling is performed with a quasi-exponential RF ramp from 30 MHz to around 1.00 MHz in 44s, and end up with a condensate of $(2.0\pm0.3) \times 10^5$ atoms.

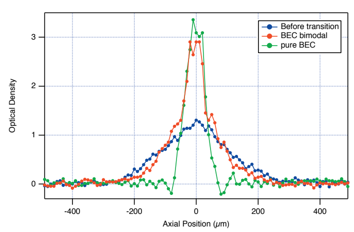
Atom Species : ^{87}Rb $|F=2, m_F=+2>$
Pre-cooling : Double MOT (Back ground pressure : $(2.4\pm0.4) \times 10^{-11}$ torr)
MT type : Cloverleaf (IP trap), ($\omega_z=2\pi \times 18.8$ Hz, $\omega_\rho=2\pi \times 182$ Hz)
Number of condensed atoms = $(2.0\pm0.3) \times 10^5$

RF = 1.02MHz (43.7s evaporation) | RF = 1.01MHz (43.8s evaporation) | RF = 0.99 MHz (44.0s evaporation)





Time of flight images are taken after 16ms along gravitational axis.



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Thank you for helpful discussion with:
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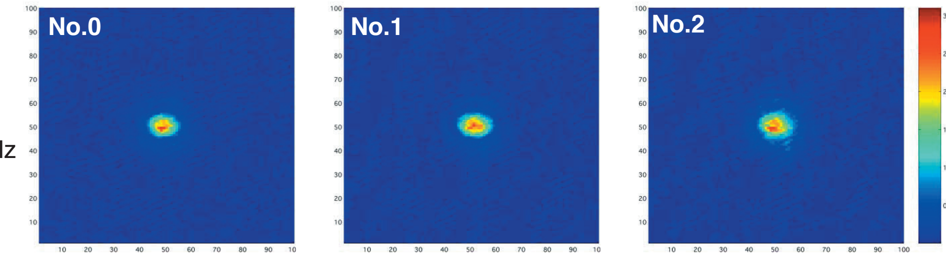
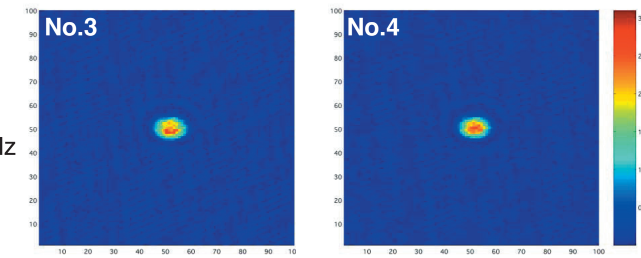
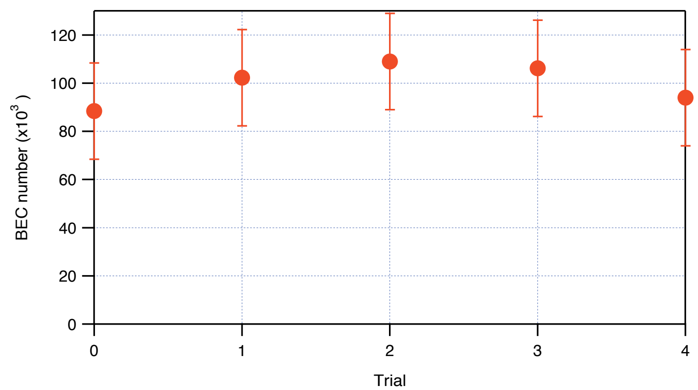
* NTT : NIPPON TELEGRAPH AND TELEPHONE CORPORATION

T_{final} = 41.2ºC
RF_{final} = 1.30MHz



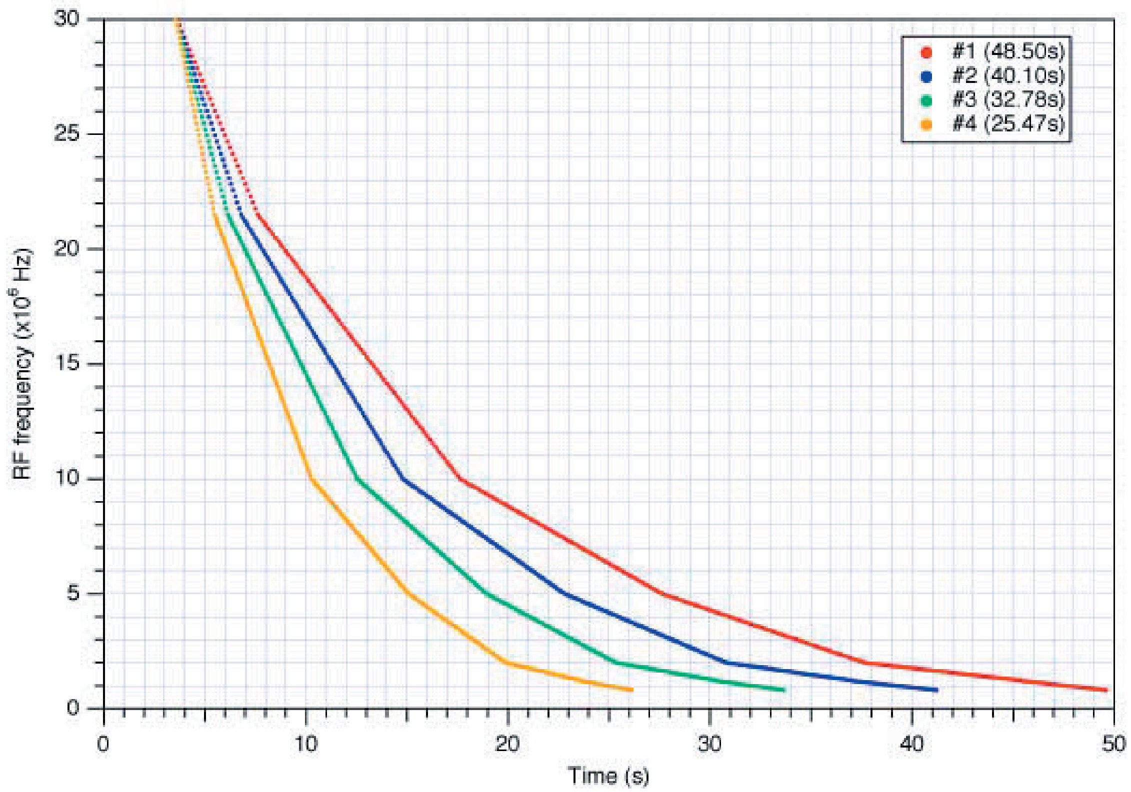
T_{final} = 40.5ºC
RF_{final} = 1.25MHz



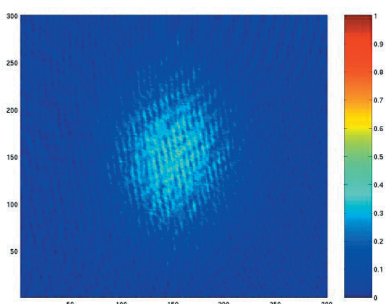


If the initial condition is the same, about 1×10^5 atoms are condensed at each trial.

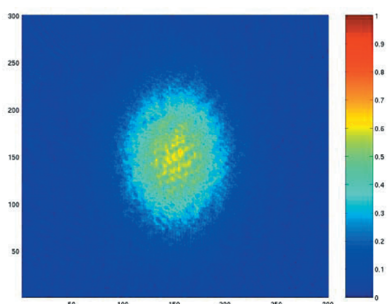
From 30MHz to 2MHz RF sweep



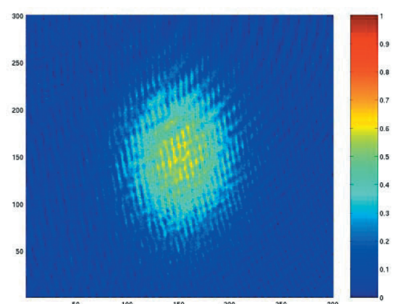
#4 : Fastest



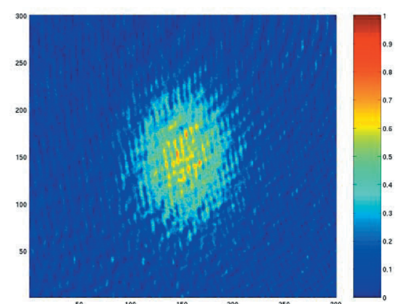
#3 : Faster



#2 : Slower



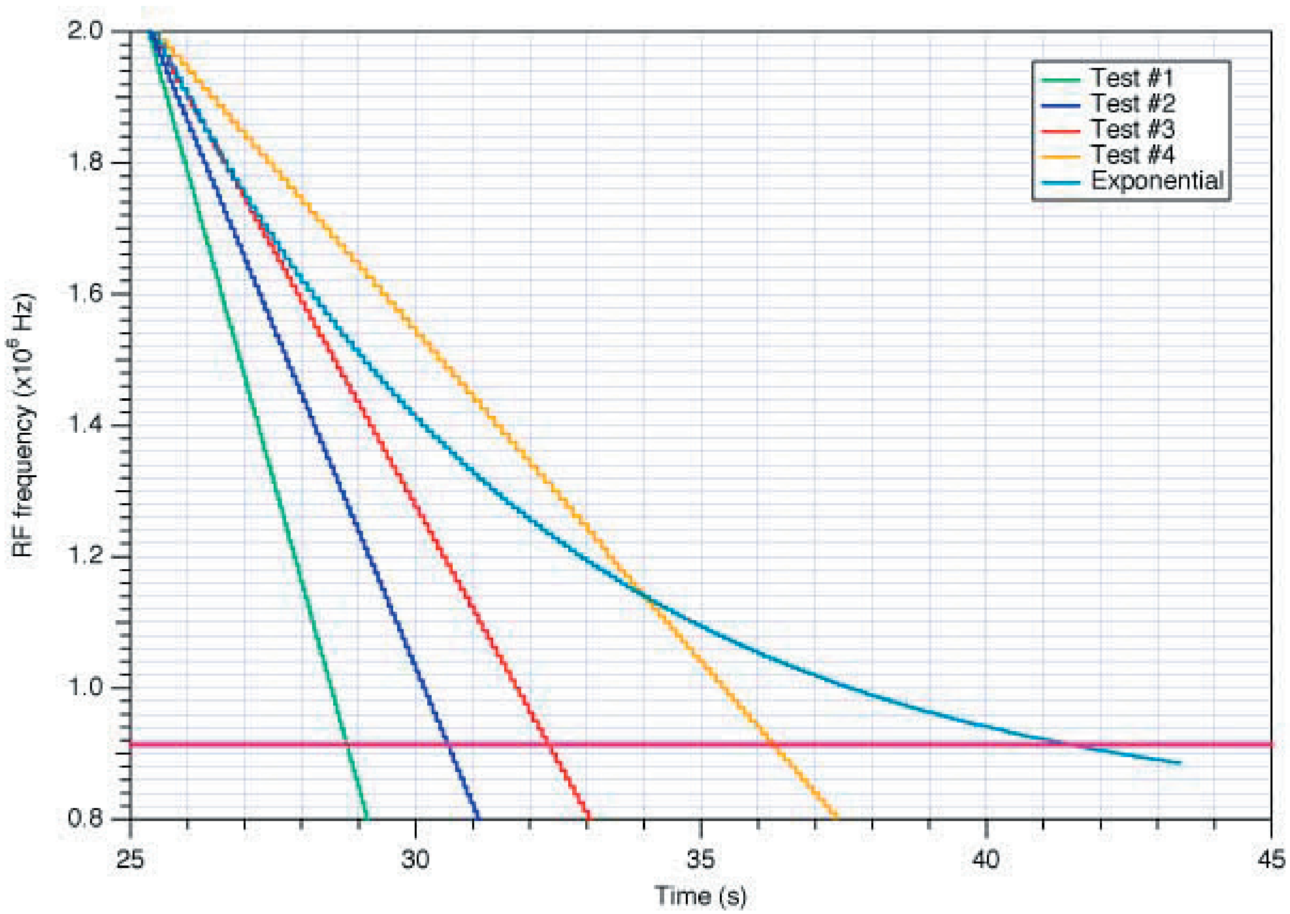
#1 : Slowest



Evaporative cooling is not so sensitive to the RF sweep function until 2MHz.

TOF 9ms (3mm x 3mm)

Last 1MHz before reaching BEC



In progress

Conclusion

Up to last 1MHz before reaching BEC, evaporative cooling is not so sensitive to the RF function. This is consistent with the calculation based on the quantum kinetic theory of a Bose gas.

At the final 1 MHz evaporation, three-body recombination loss is calculated to be not so small and now experimental understanding is in progress.