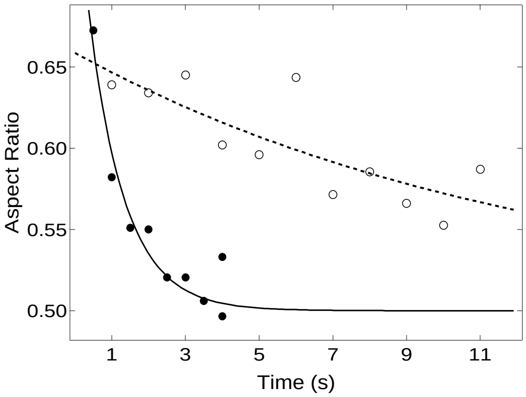
Progress in year 1994

1. An analytical model for evaporative cooling

We have developed an analytical model for evaporative cooling [1]. By simulating evaporation as a sequence of discrete steps, we could predict the time dependence of all important parameters such as temperature, density, elastic collision rate. By incorporating trap loss due to background gas collisions into our model we derived the threshold conditions for "run-away" evaporation. This is characterized by an increase in the rate at which the cloud rethermalizes and ensures efficient evaporative cooling.

2. Elastic collision cross section for ultracold sodium atoms

Since evaporative cooling is driven by elastic collisions, it is important to determine collisional properties of ultracold atoms. By perturbing the thermal equilibrium and observing the rethermalization we could directly observe elastic collisions between magnetically trapped sodium atoms in the F=1 hyperfine state [2]. Our measurement narrowed down the range of theoretical predictions and showed that sodium has very favorable collisional properties for evaporative cooling and Bose condensation.



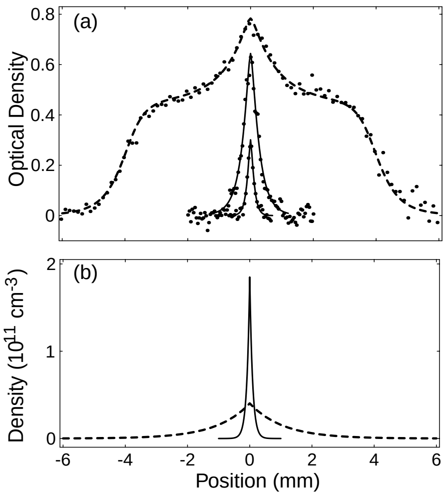
Thermal relaxation of an atom cloud after one-dimensional heating. The figure shows the time variation of the aspect ratio of the cloud for two different initial densities (solid circles: $5\ 10^{10}$ cm^{-3}, open circles: $4\ 10^{9}$cm^{-3}). The lines represent simple exponential fits with time constants of 1.0 s and 13 s, respectively.

3. Evaporative cooling with laser cooled atoms

In 1994, we accomplished the first demonstration of evaporative cooling for an atom other than hydrogen (simultaneously with the JILA group) [3, 4]. Using the Dark SPOT trap, we were able to achieve the initial conditions for evaporative cooling. Evaporative cooling requires the selective removal of those atoms which have more energy than those remaining trapped, resulting in a net cooling of the trapped sample. Evaporating atoms are usually selected by lowering the depth of the trap [5] which has the potential disadvantage of weakening the trapping potential. The recently demonstrated optical evaporation [6] requires very high optical densities. In our experiments, we have realized a novel evaporation technique, rf-induced evaporation, which was originally suggested in

Ref. [7]. Atoms above some energy are removed from the trap by inducing an rf transition to an untrapped state.

The advantages of this method are threefold: First, the trap does not have to be weakened to continue the evaporative cooling process, second, the rate of evaporation and the potential energy of atoms which escape are controlled by the frequency of the applied radiation, and third, the space from which particles escape from the trap is not limited to the (spatially restricted) saddle point in the trapping potential.



Optical density (a) and density (b) before and after evaporative cooling. (a): The initial cloud was cooled by adiabatic compression at constant rf frequency (middle trace) and further cooled by decreasing the rf frequency. The lines are fits to the observed profiles. The “bumpy” structure of the initial profile is a result of Zeeman shifts of the transitions used for probing the atoms. (b): Density before and after evaporation as obtained from the fits to the optical density profiles (temperatures are 200 μK and 17 μK, respectively).

4. Runaway evaporation in alkali atoms

Evaporative cooling is driven by elastic collisions. As the cooling progresses, an increase in density is crucial to avoid a slow-down of the cooling process. A high initial density and a long trapping time are required to enter the regime of increasing collision rate. Accelerated or “runaway” evaporation for alkali atoms was first demonstrated by our group when we observed a doubling of the collision rate during evaporative cooling [2].

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