Micro-Kelvin Molecule Production

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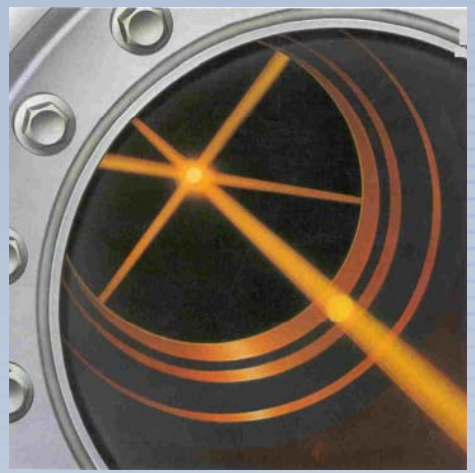

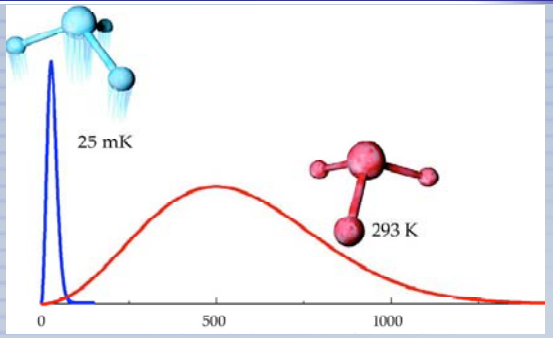

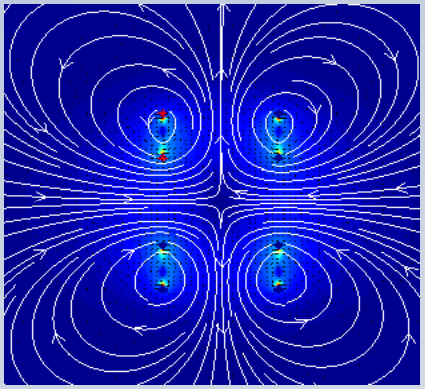

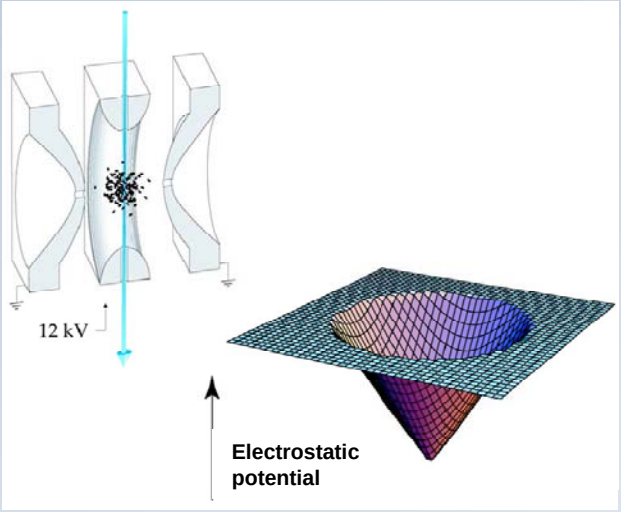

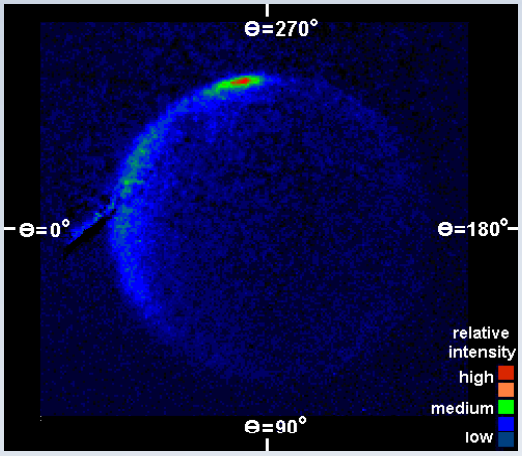

LDRD Day, 2008

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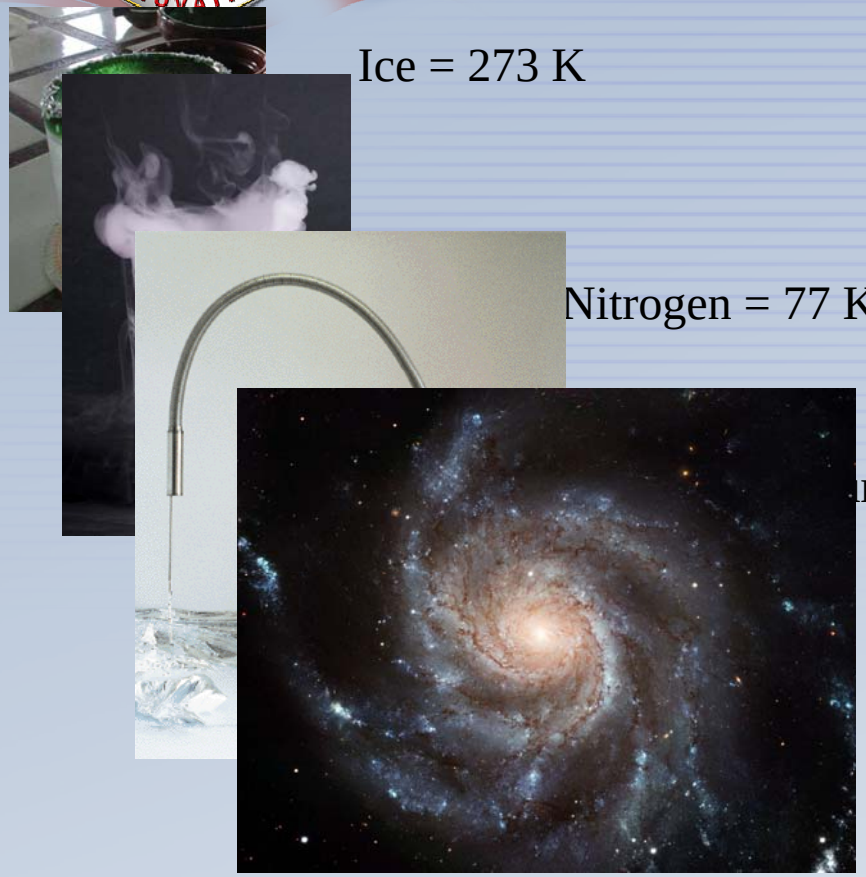
Cold molecules: How cold is cold?



Ice = 273 K

Nitrogen = 77 K

m = 4 K

Deep Space = 3 K

This LDRD aims to produce molecules at 0.000001 K.

In 1-D; Temperature = ½ x mass x velocity^2

Cold molecules: why?

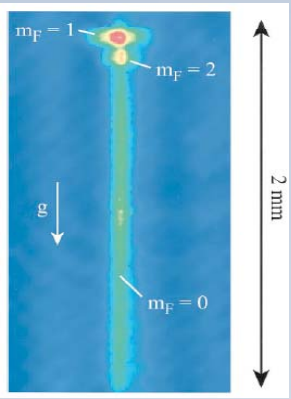
"The only way of discovering the limits of the possible is to venture a little way past them into the impossible." *Arthur C. Clarke*

Cold molecules, like cold atoms and ions, can be trapped, stored, and manipulated with external electric and magnetic fields.

Cold molecules can be initialized into user-selected quantum state, removing the randomness and averaging necessary in thermal chemical dynamics experiments.

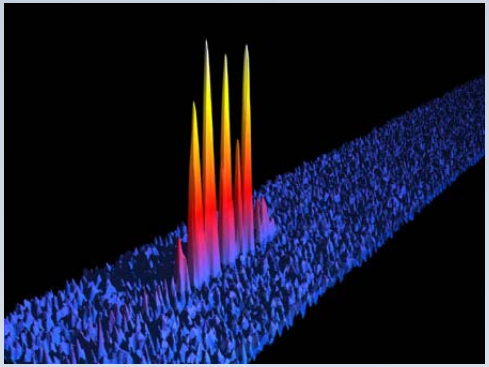
Cold molecules can be manipulated to form exotic states of matter.

Matter Laser

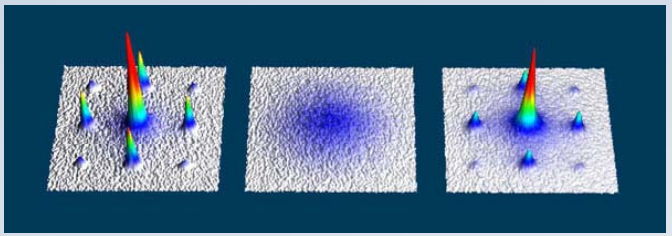


Max Planck Quantum Optics:(2001)

Matter-wave Solitons

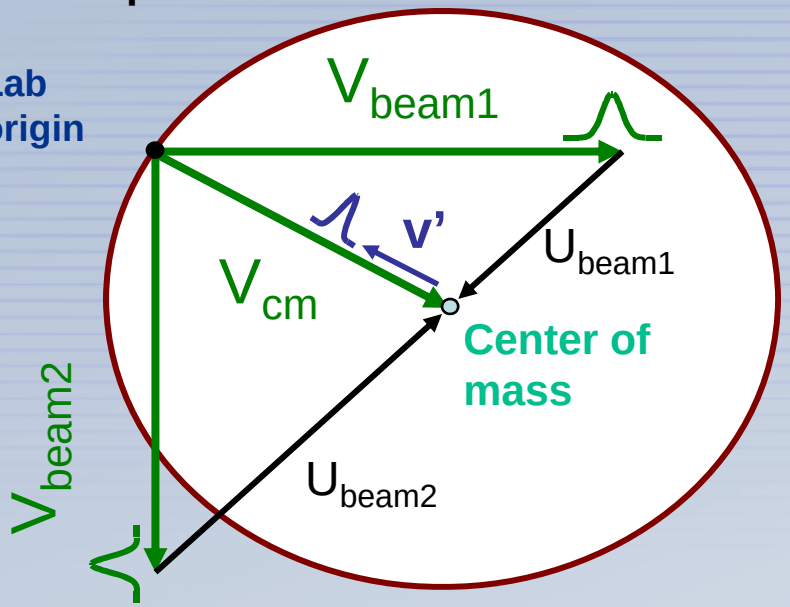


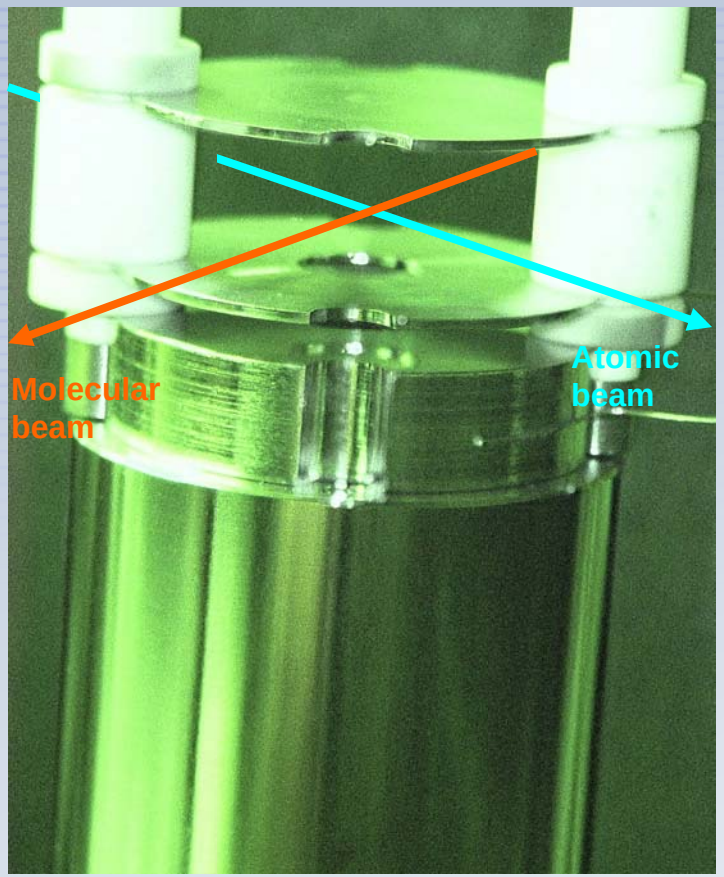
Mott - insulator phase transition



Cooling Molecules: Kinematic cooling

Collision between atomic and molecular beams produce cold molecules





Molecules backscattered from the center of mass have an energy given by:

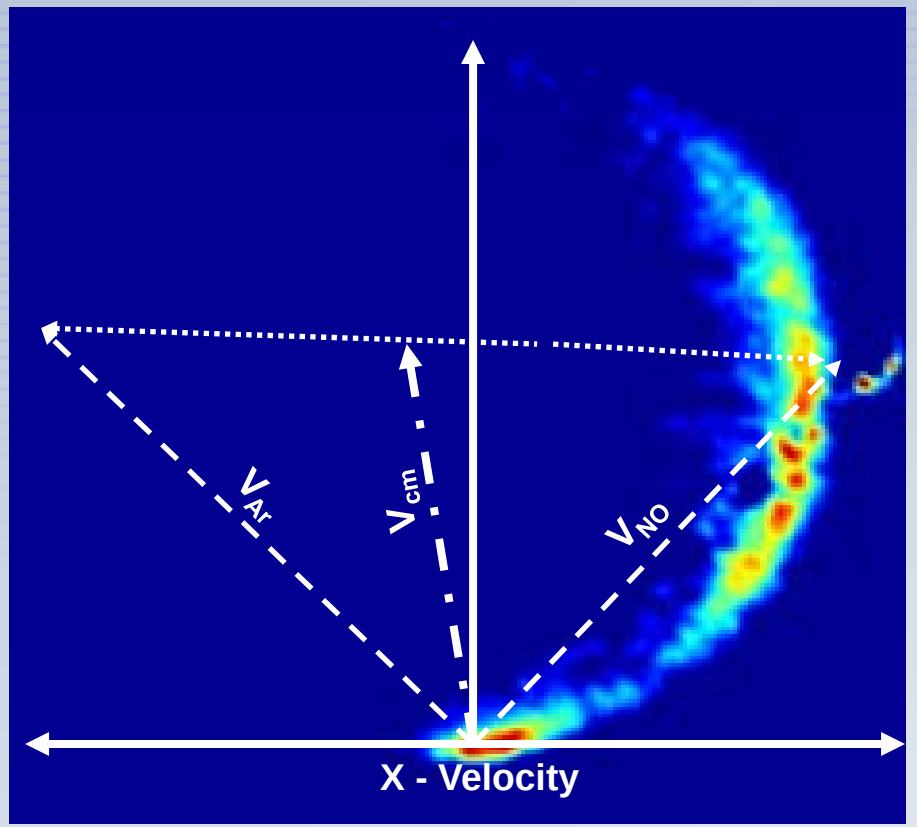
$$E_{res} = \left(1 - \frac{m_1}{m_2}\right) E_1$$

Kinematic cooling of molecules

Cold Molecules "pile-up" near the origin.

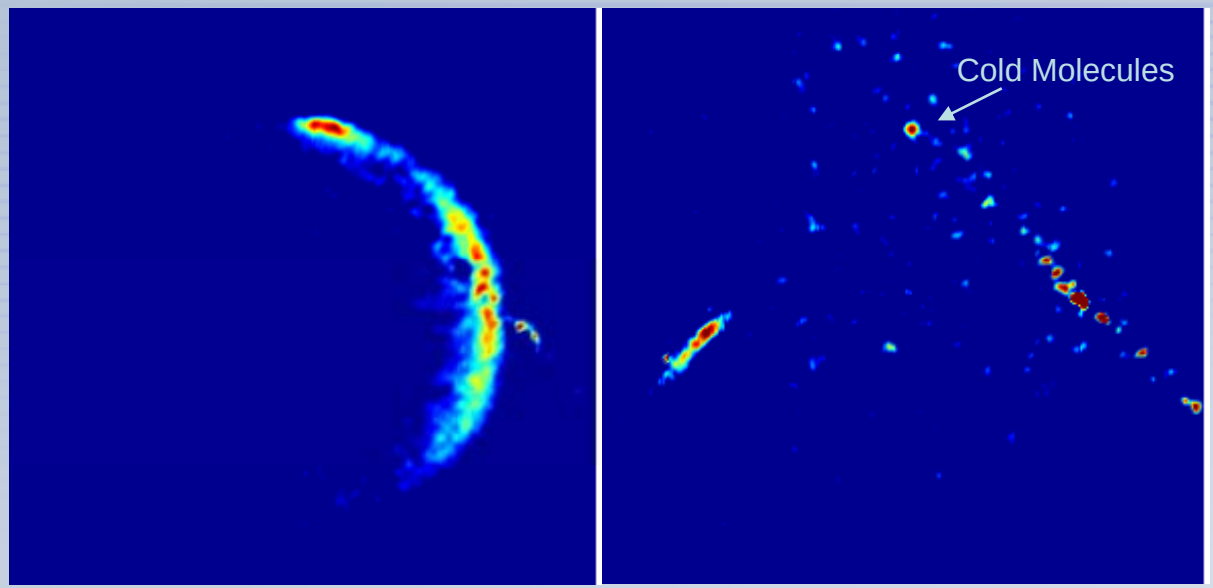
Molecules are ionized using state selective resonance enhanced multi-photon ionization (REMPI).

Velocity mapped ion imaging *(a technique pioneered at Sandia)* gives a direct picture of momentum space.



Cold molecule production

The cold molecules are stationary in the Lab.



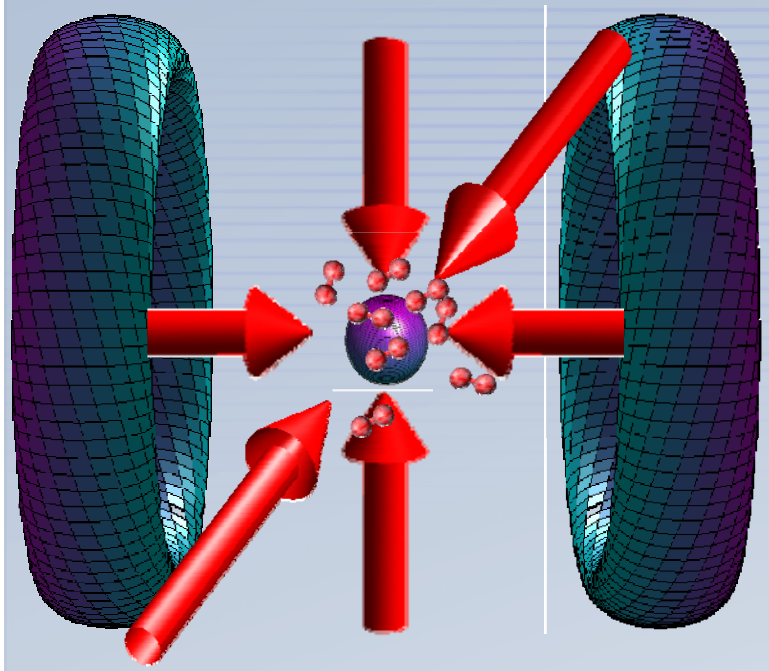
Peak of Molecular Beam Overlap

100 microseconds after molecular beams overlap

We can observe one packet of molecules for up to 150 μs

This amounts to kHz-resolution spectroscopy on a single quantum state.

Micro-Kelvin Cold Molecules



Hybrid between laser cooling of atoms and Kinematic cooling of molecules.

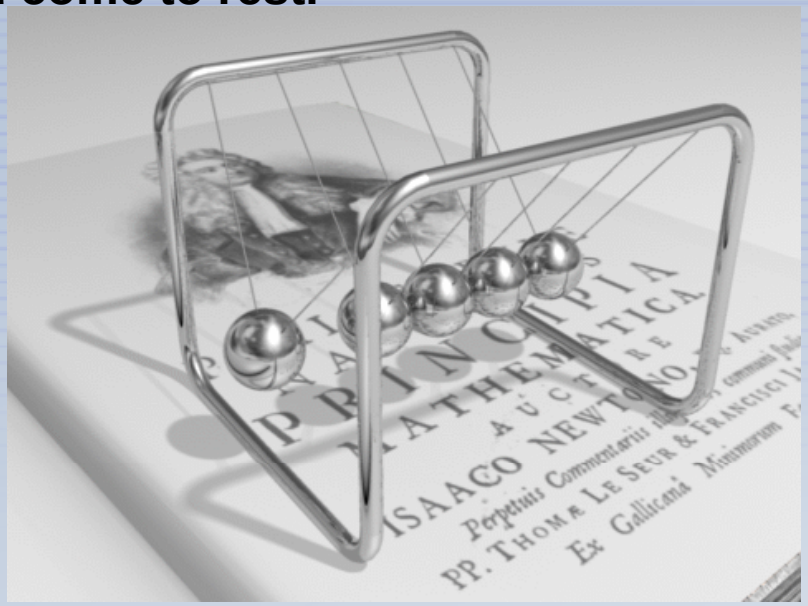
Instead of two beam hitting each other, we stop the atom beam using laser cooling.

The atomic beam is replaced by a stationary sample of atoms in a Magneto-Optical Trap.

If the atom and molecule have near equal masses, there is some probability the molecule will transfer nearly all its energy to the atom.

Kinematic or single collision cooling with a MOT

For equal masses it acts as a Newton's cradle; a hot molecule can displace a cold atom and come to rest.

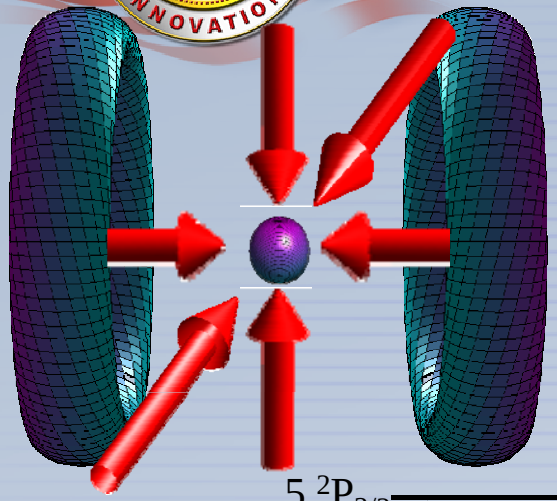


Fraction of stopped molecules is given by (J.J. Valentini):

$$f = \frac{2\,[E_f/E_i - \Delta^2/4]}{1 - \Delta^2/4}$$

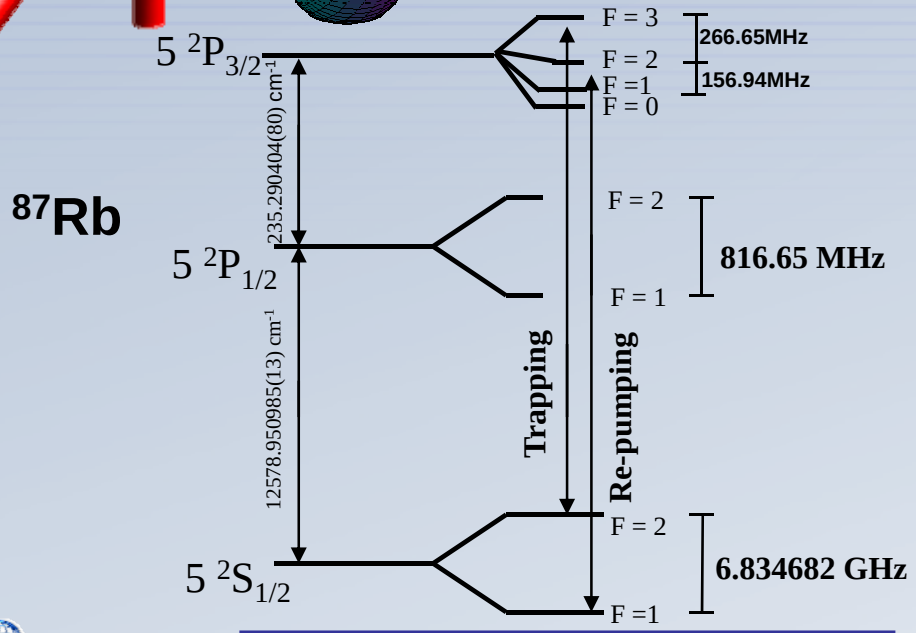
Roughly, for particles with 1% mass differences, 10% of the collisions will remove 90% of the energy

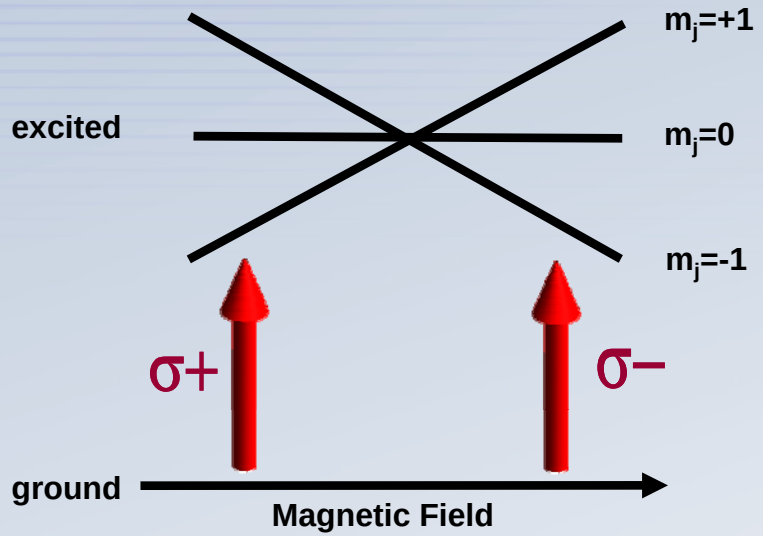
Magneto-Optical Trapping (MOT)



Magneto-optical trap - From Wikipedia,

A magneto-optical trap (abbreviated MOT) is a device that cools down non-charged atoms to temperatures near absolute zero and traps them at a certain place using magnetic fields and circularly polarized laser light.





Hint: ~ 30GHz/cm^{-1}

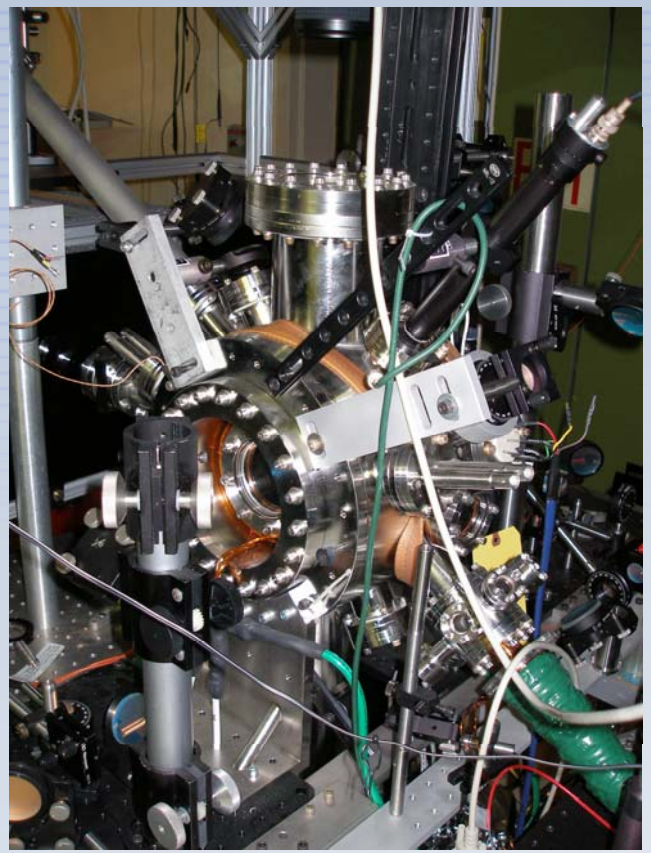
Micro-Kelvin Cold Molecules

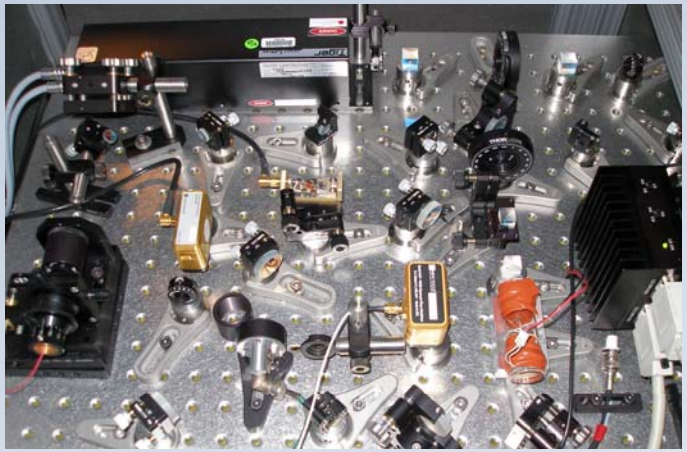
Built a dual- MOT apparatus.

Consists of a UHV chamber, pressure > 10^{-10} Torr (outer space ~10^{-7} torr)

CW laser system stabilized to 1 part in 10^8.

9 individual laser frequencies generated using AO and EO technologies.



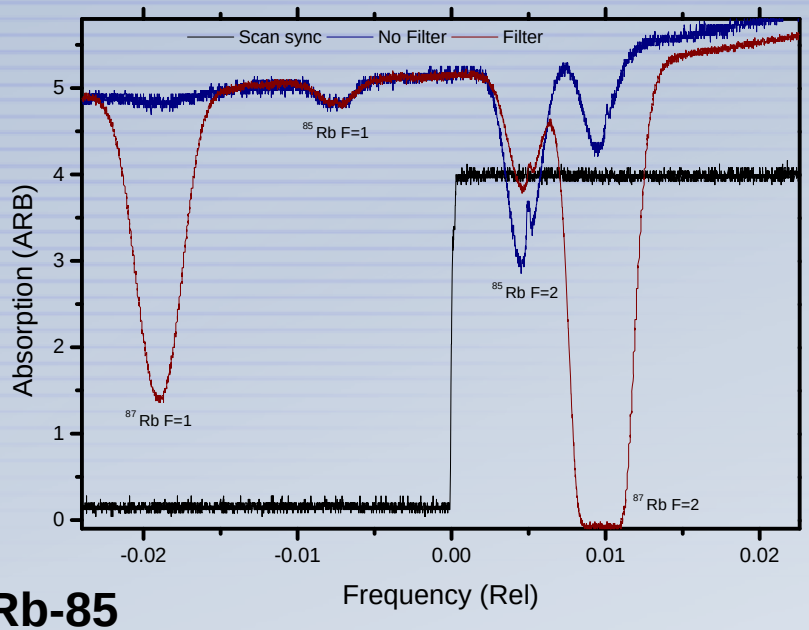


Micro-Kelvin Molecules: proof-of-principle

We are currently attempting the proof-of-principle experiment.

We have a dual Rb 87- 85 MOT and has an imaging system capable of individually detecting fluorescence from each isotope (separation is ~ 0.05cm^{-1})

Rb-87 is actively laser slowed from a thermal oven. Rb-85 is present in a thermal (300 K) background.



Theoretical models predict the number of Rb-85 cooled should be ~ 1/100 the number of Rb-87. Well within our predicted detection limit.

Once this technique is proven, we will attempt to stop DBr (mass 83) using Rb-85 which also removes nearly 98% of the initial energy in a single collision.

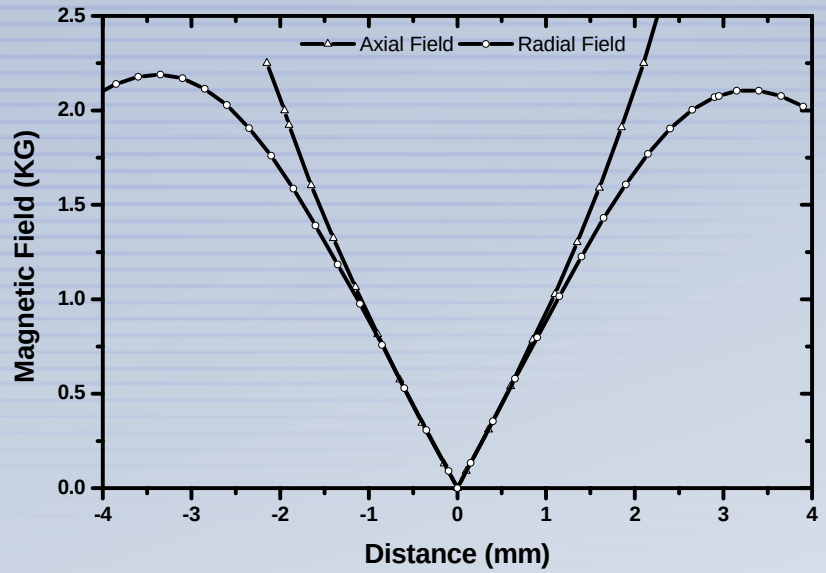
Micro-Kelvin Molecules: Trapping Molecules

We are designing and testing cold molecule traps on the original kinematic cooling apparatus.

Magnetic trap works for molecules with magnetic moments

Toy store permanent magnets (NdFeB) can produce nearly 1 T/cm field gradients

Nitric Oxide has trap depth of ~ 240 mK



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Micro-Kelvin Molecules: Trapping Molecules

Electro-static traps work for polar molecules

Requires switching 15 KV in 100 ns.

We have built and are currently testing an electrostatic trap for trapping ammonia.

By increasing the voltage to 25 KV, the trap is nearly 0.5 K deep for ammonia

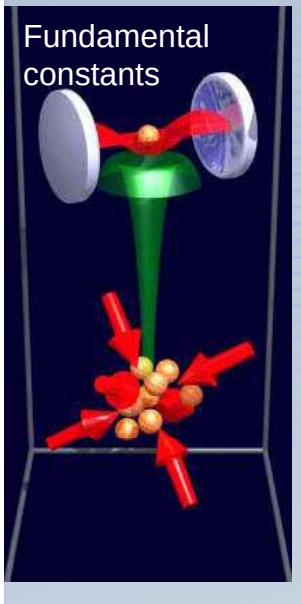
Micro-Kelvin Molecule Production

***Scientific Significance*: When successful we will have produces the coldest ground state molecular samples in the world.**

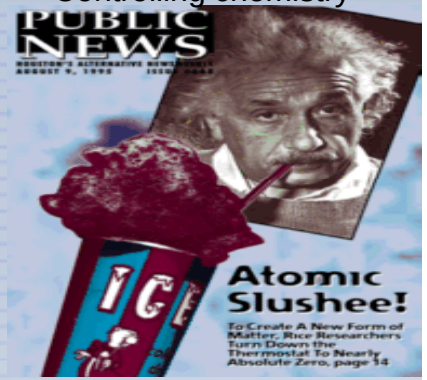
Cold molecules represent an enabling technology for the exploration of fundamental science, the creation of novel sensors, quantum simulators, solid state emulators, and directly tackle one of DOE/BES's grand challenges of being able to manipulate and control chemical dynamics and reactions.

This collisional cooling technique is the only "general" molecular cooling technique proposed to date.

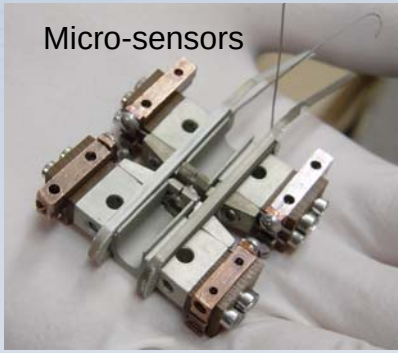
Fundamental constants



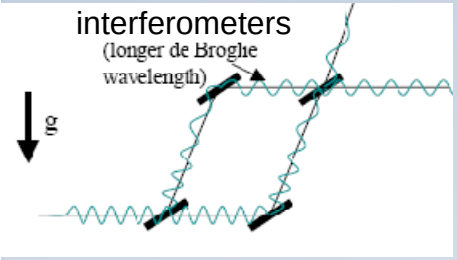
Controlling chemistry



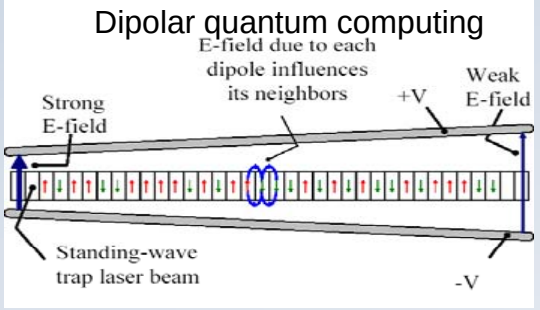
Micro-sensors



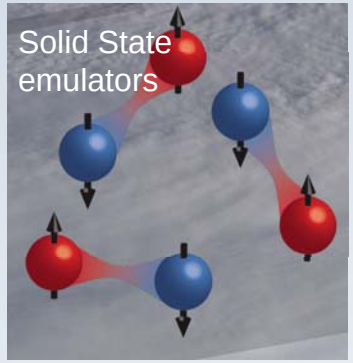
interferometers



Dipolar quantum computing



Solid State emulators



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LDRD

LDRD Day, 2008

MicroKelvin Molecules :Current and Future Milestones

2008 – Finish proof-of-principle experiment on cooling ^{85}Rb with ^{87}Rb

2009 – Integrate CO_2 laser into MOT apparatus and test trapping on both atoms and molecules.

2009 – Incorporate electrostatic trap into MOT apparatus for the trapping to DBr

2009 – Incorporate ion imaging into MOT apparatus for the detection of cold atoms and molecules by laser ionization

2009 – Investigate feasibility of other molecules of appropriate mass: DRb, FeNO, FeCO, LiBr, Si_3, NiCN, GaO, CF_4, CF_3O and CD_2Cl_2