Magnetic Trapping of Methyl Radicals

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Cold molecules

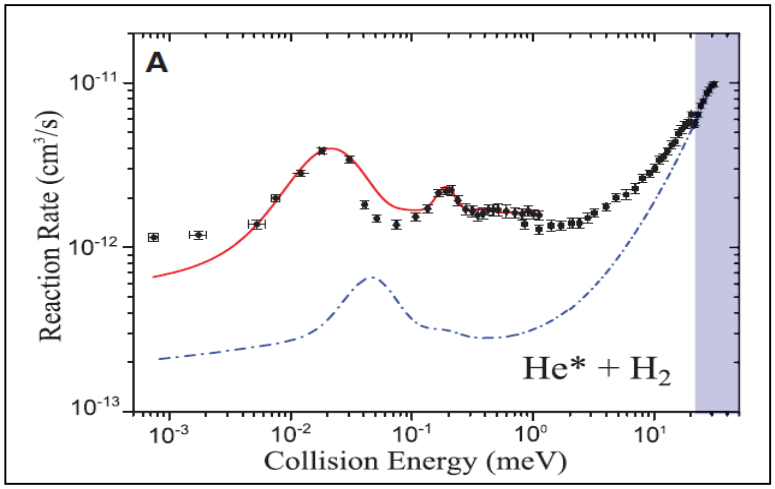
Velocity

$1/2\ mv^2 = 3/2k_BT$

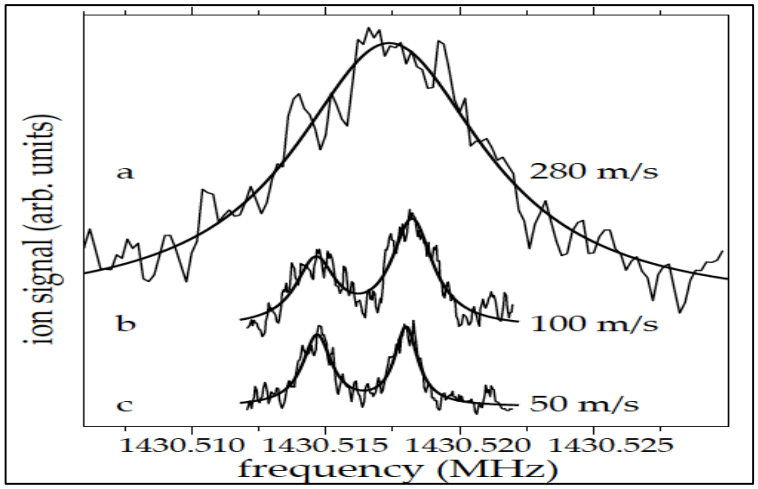
Thermal De Broglie wavelength

$$\Lambda = \sqrt{\frac{h^2}{2\pi m k_B T}}$$

T	Rb(v)	Rb(λ)	CH_4(v)	CH_4(λ)
300 K	170 m/s	0.1 A	400 m/s	0.2 A
1 K	10 m/s	1.89 A	23 m/s	4.3 A
0.1 mK	10 cm/s	18.9 nm	23 cm/s	43 nm
10 nK	1 mm/s	1890 nm	2.3 mm/s	4370 nm



Cold Chemistry

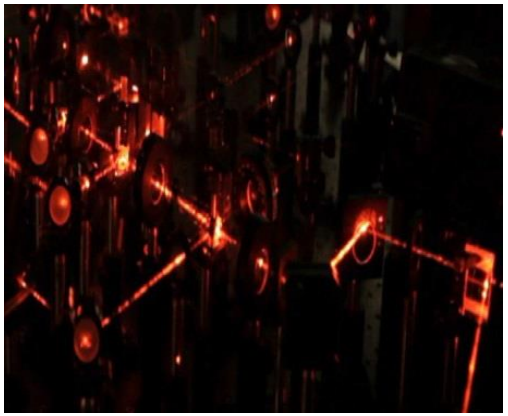


Precision Spectroscopy

How to reach this regime (Below 1 K)

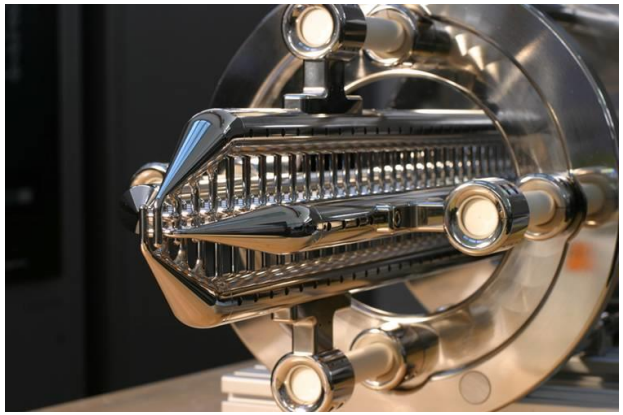
Laser Cooling

- Direct cooling of molecules
- **Very limited**



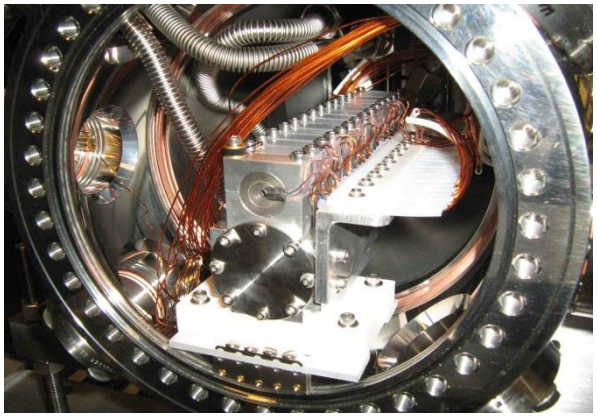
Stark Technique

- Electric dipole moment
- **No ground rotational state**
- **Many groups working**



Zeeman Technique

- Any free radical/molecules with magnetic moment
- **Any rotational including ground state**
- **Robust technique**
- **Only few groups working**



Trapped molecules so far

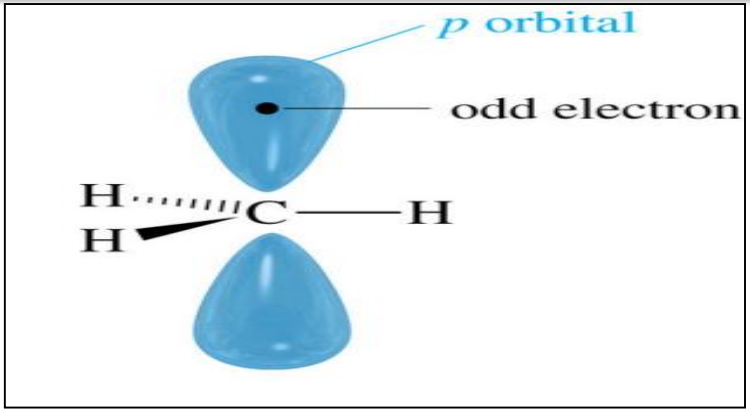
Diatomic molecules

- NH, OH – Stark Decelerator
- KRb,Li_2 – Laser Cooling
- CaF,CaH – Buffer gas cooling
- O_2 – Zeeman Decelerator

Polyatomic molecules

- NH_3 – Stark Decelerator
- CH_3F– Laser Cooling
- **CH_3 Radical: Our Work**
  Zeeman decelerator

First ever Magnetic Snaring of Methyl Radicals



- Most fundamental reactive hydrocarbon intermediate

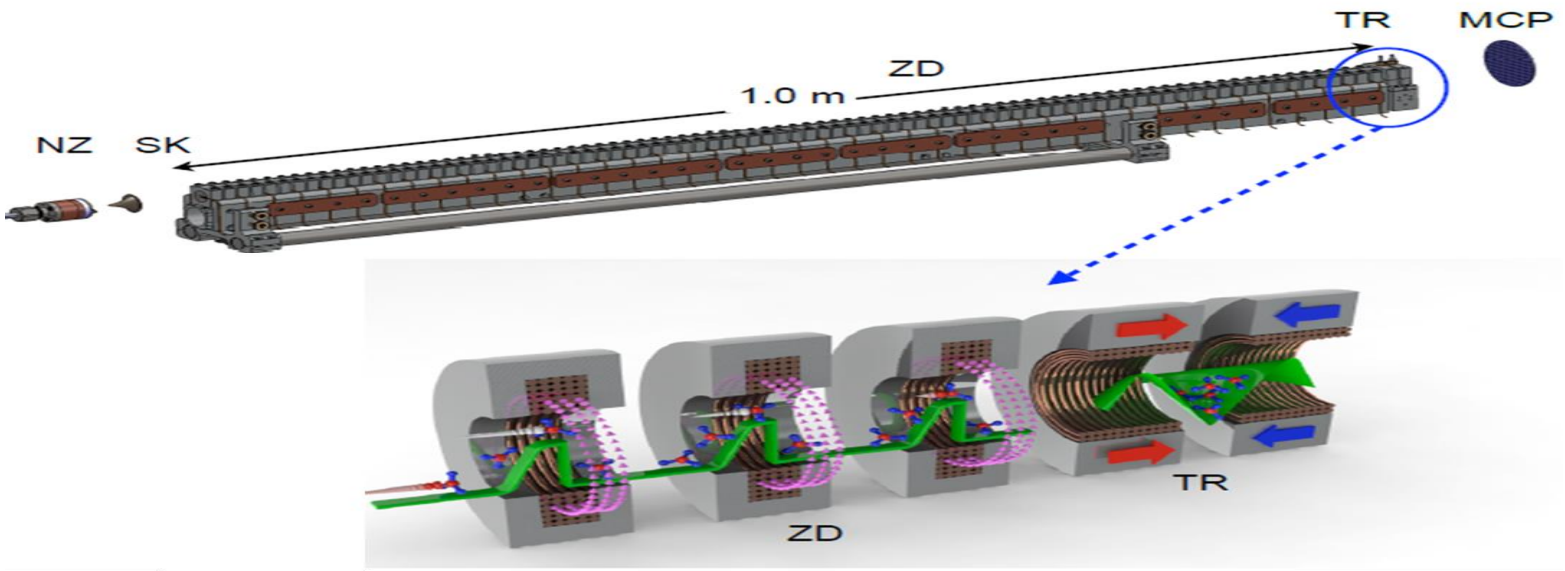
- No electric dipole
  Can be trapped for a long time without any excitation

- An ideal molecule to demonstrate sympathetic cooling.

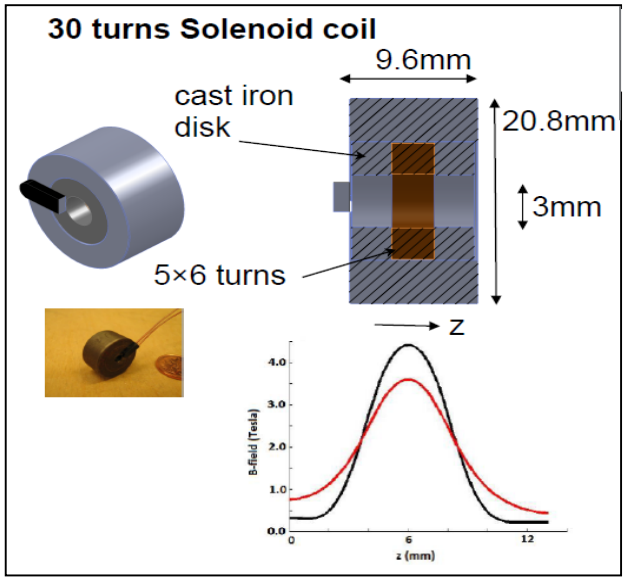
Tscherbul et al. Phys. Rev. Lett. 106, 073201 (2011)

Experimental Approach

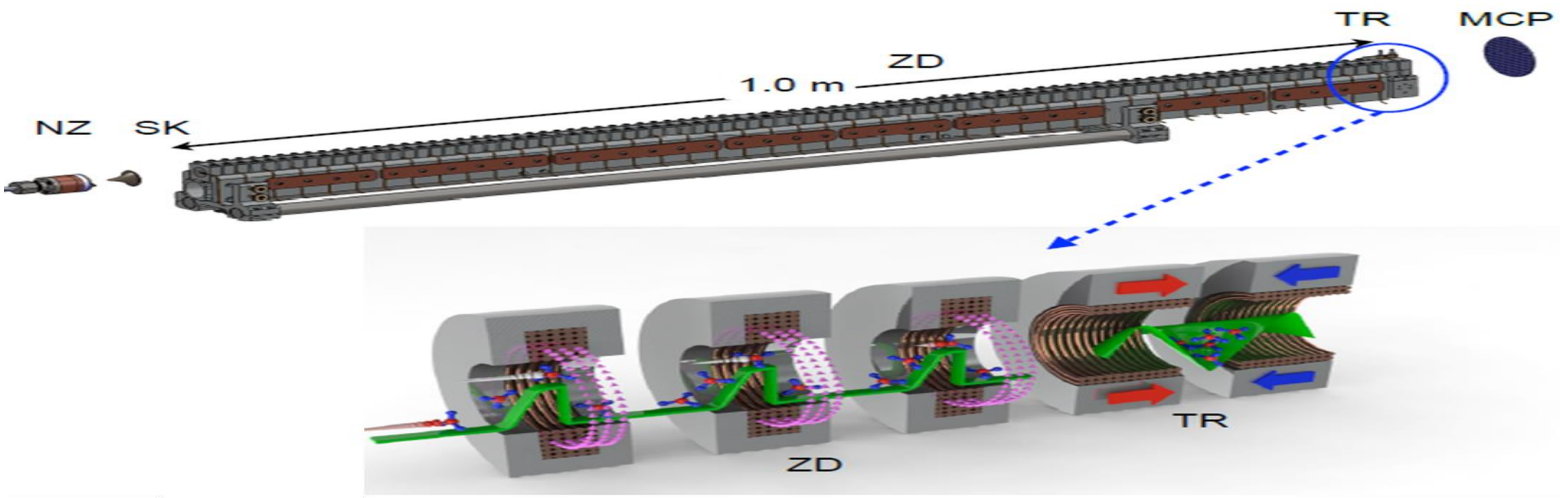
- CH_3 in the ground rotational and vibrational state was created by an electric discharge of a supersonic beam of CH_4 seeded in Kr.
- The translational energy of the supersonic CH_3 beam was removed by a 85-coils Zeeman decelerator.
- Decelerated and trapped radicals were detected by REMPI



Experimental Design of Solenoids



- Max Field: B=4.27 T at 600 Amp
- Max. energy removed at each coil: ΔE=2.87 K
- Fast switching of magnetic fields (turn off 600 A in 4 us - a technical challenge) .



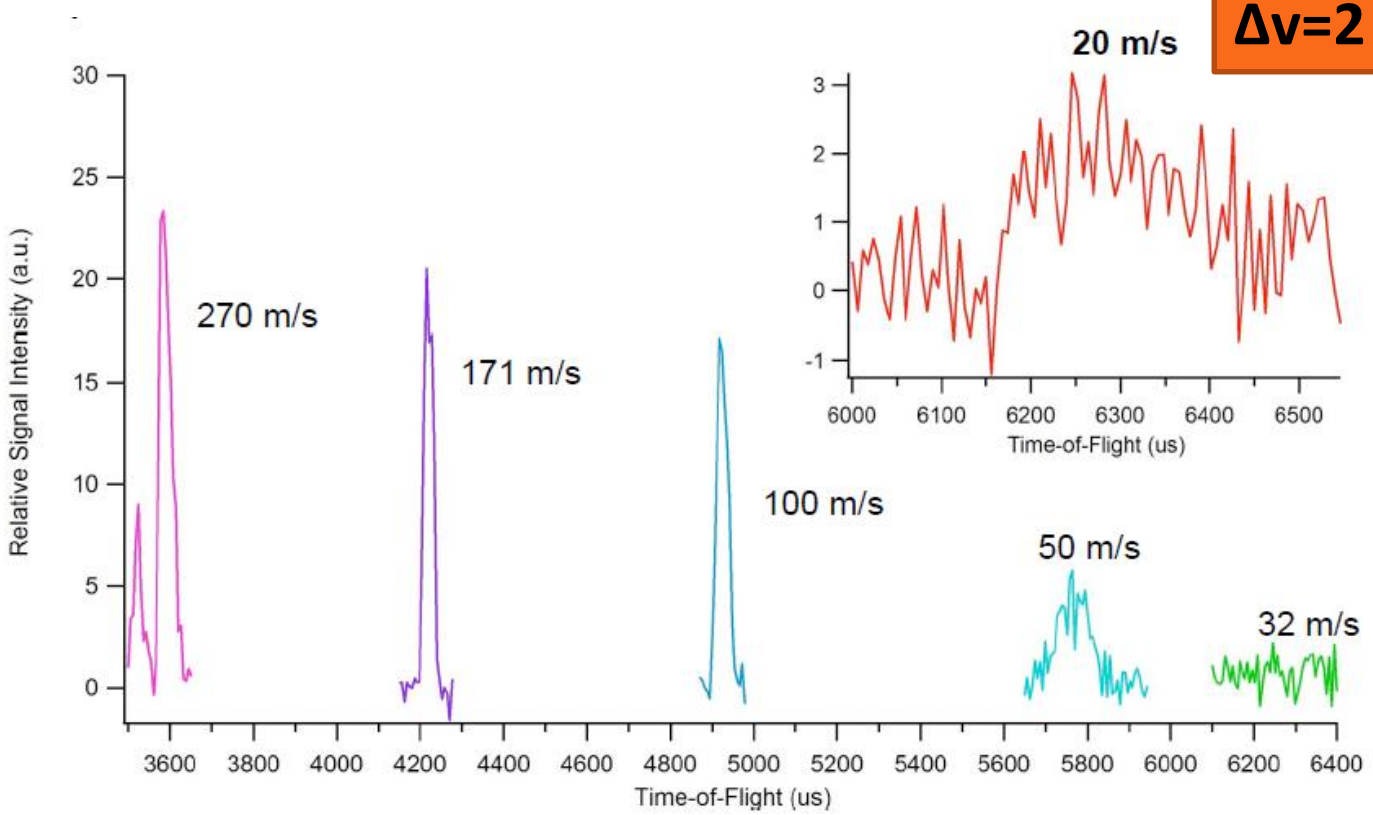
Extent of Deceleration

Input Velocity: 340 m/s
T=104 K

→

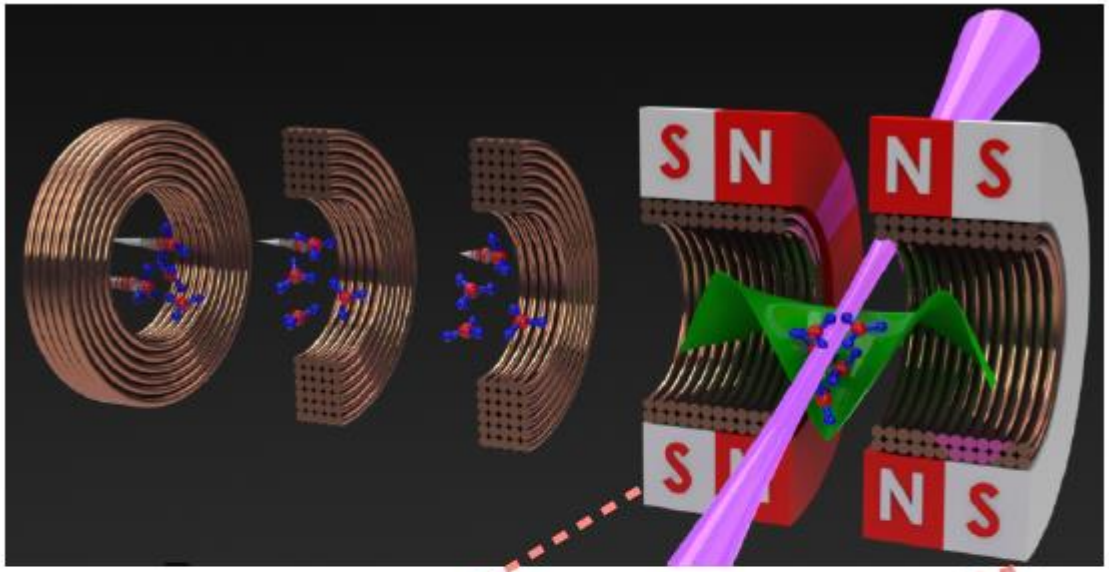
Output Velocity:20m/s
T=360 mK(Lab frame)

Δv=2 m/s , T=15 mK



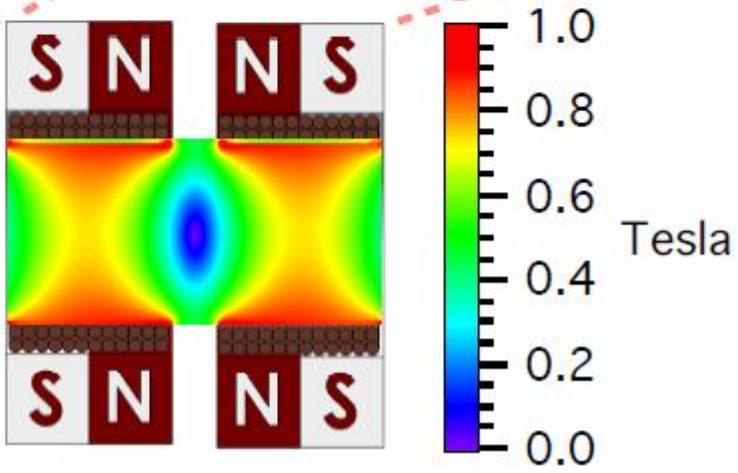
Well-collimated quantum pure slow radical beams

Trapping Decelerated Molecules



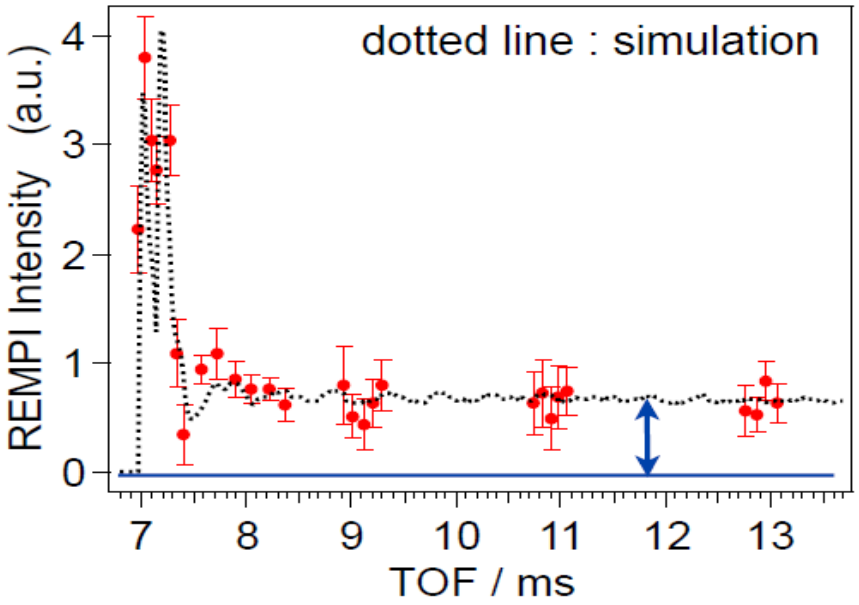
Potential depth
T_{long} = 500 mK
T_{tran} = 300 mK

500 mK ~ 25 m/s

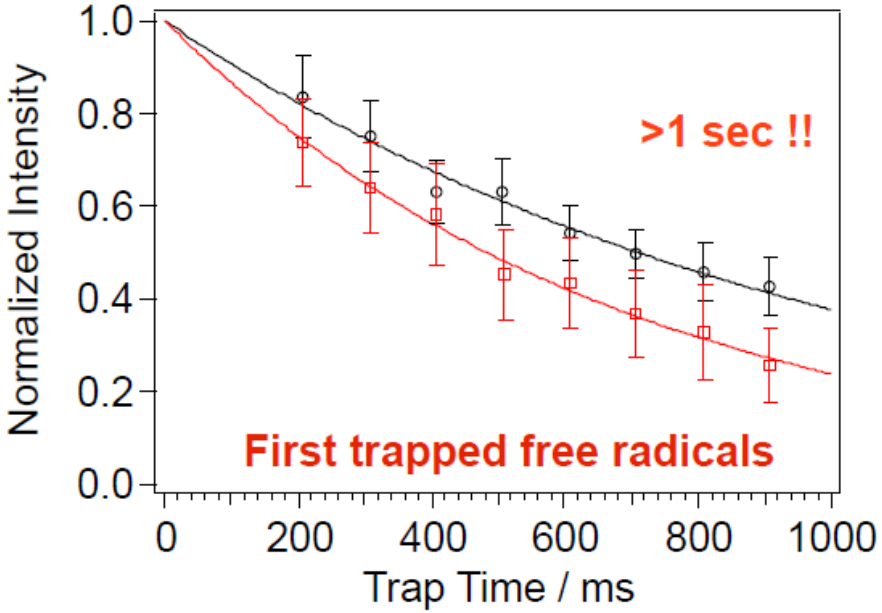


First signals of trapped CH_3

REMPI Signal



Trap Loss



The trap loss is caused by collisions with background gases.

$H_2 : N_2 = 2.3 : 1$

Exp = 3× Theory

$\sigma_{H_2} \sim 380\ \text{Å}^2$

anisotropy

Background pressure

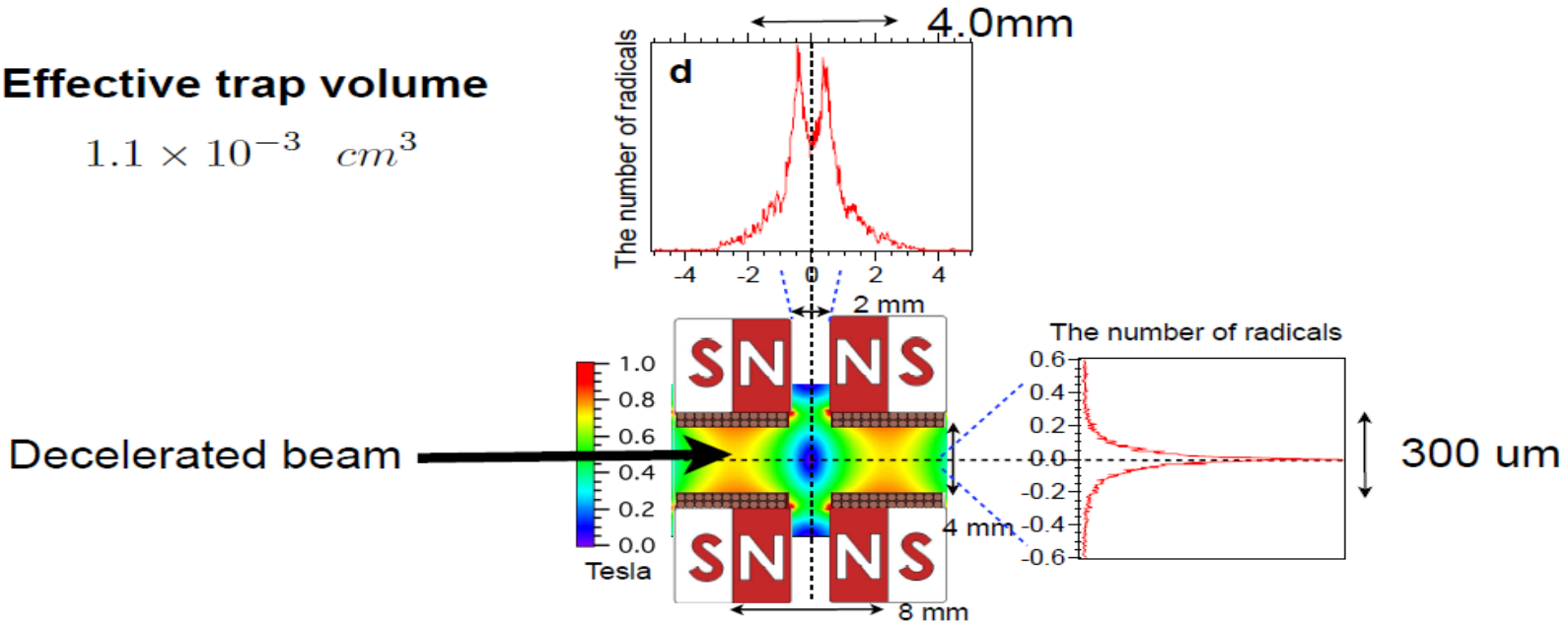
Red: 6.3×10^{-9} Torr
Black: 3.8×10^{-9} Torr

Density Estimate: Trapped Molecules

REMPI efficiency → **Number of trapped radicals~55000**

Effective trap volume

$1.1 \times 10^{-3} \quad cm^3$



Density =5 x 10^7 cm^{-3}

Mean temperature=100 mK

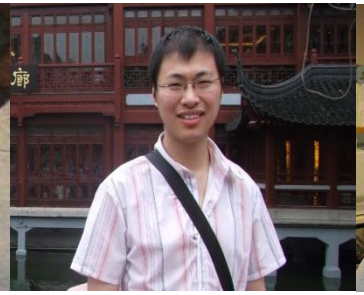
On going projects with trapped radicals

- Increase the density of trapped CH_3 radicals.
- Observation of cold (reactive) collisions with different gases.
- Infrared spectroscopy to resolve hyperfine transitions.
- Sympathetic cooling with ultra-cold Rb atoms (<100 uK)

Zeeman Technique: A robust method to produce various cold reactive molecules

Acknowledgements

Dr. Taka Momose



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Dr. David Carty (Durham, UK)

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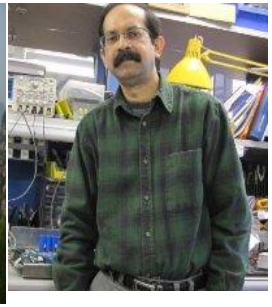

Sajjad Haider

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Fondation canadienne pour l'innovation

CRUCS

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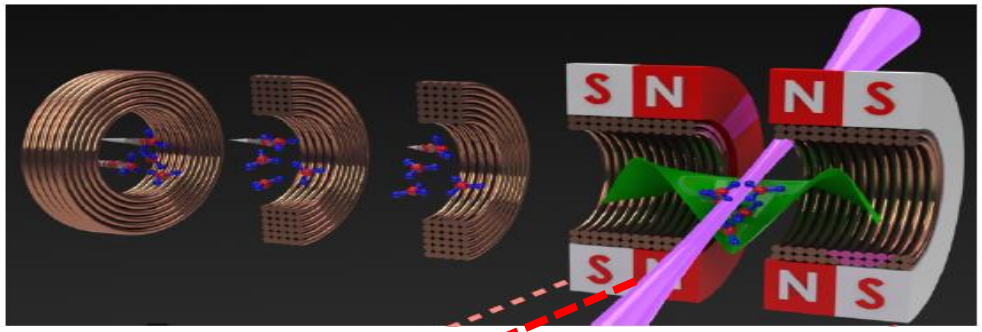
Trapping Decelerated Molecules



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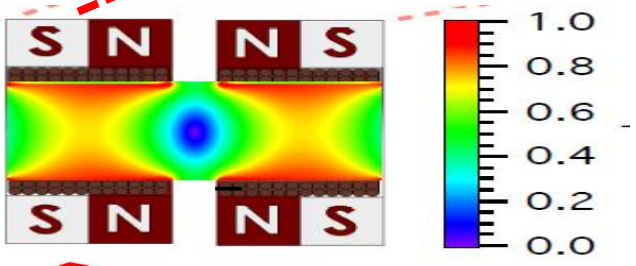
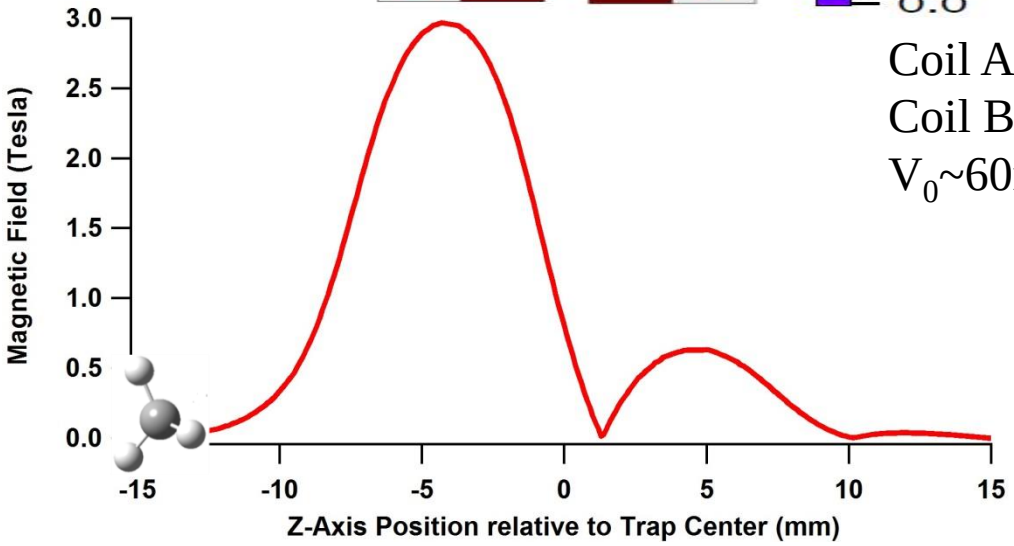
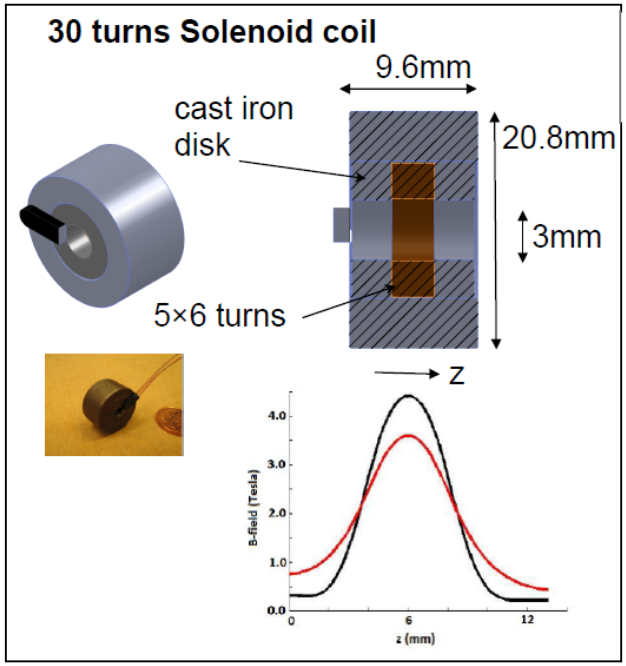




Coil A: 600A
Coil B: 0A
V_0~60m/s

Experimental Design of Solenoids



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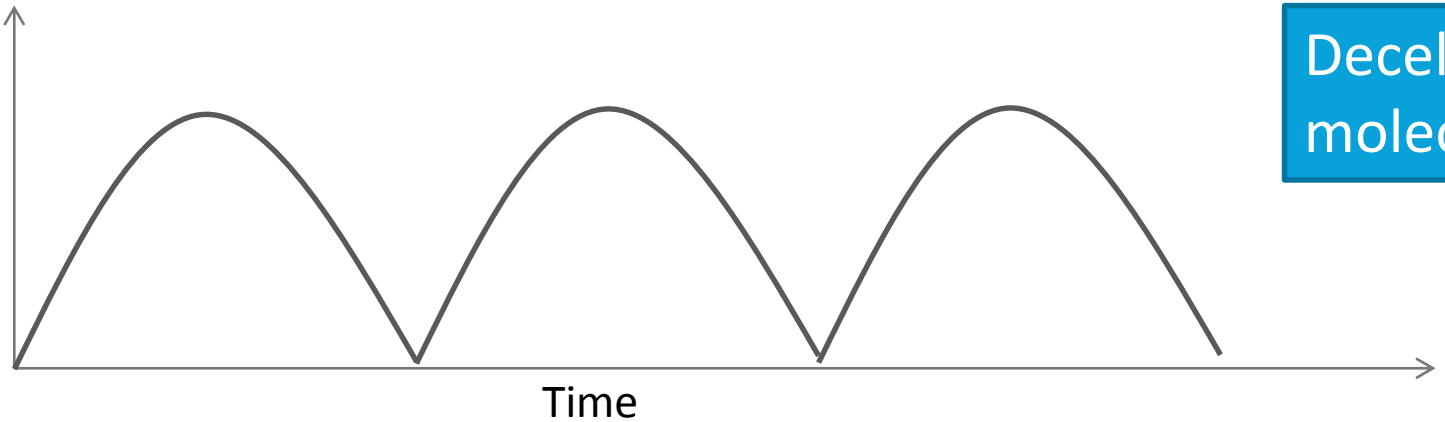
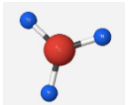
Decelerated molecule