# Transverse Focusing Effects in the Zeeman Deceleration of Hydrogen Atoms

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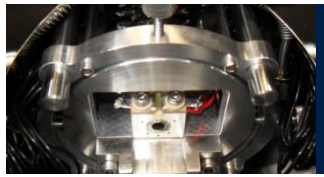
Lille, July 3, 2014



UNIVERSITY OF OXFORD


# Outline

(1) Motivation

(2) Basics of Zeeman Deceleration

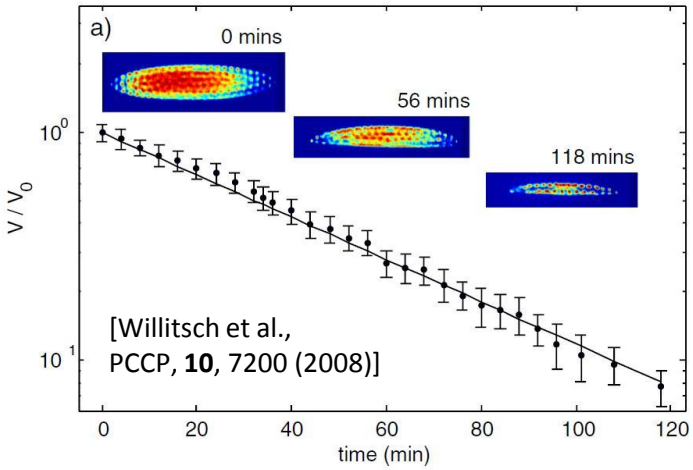
(3) Transverse Focusing of Hydrogen Atoms

(4) Zeeman Deceleration of Light Metastable Atoms

# (1) Chemistry at mK Temperatures

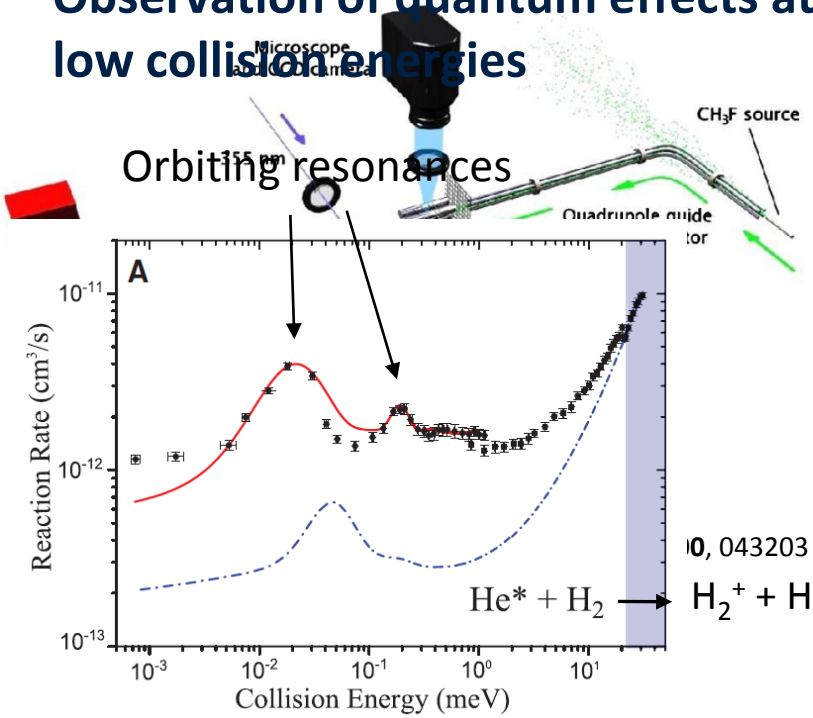
## Cold ion-molecule reactions

Rate constants from decrease in Coulomb-crystal volume




## Observation of quantum effects at low collision energies

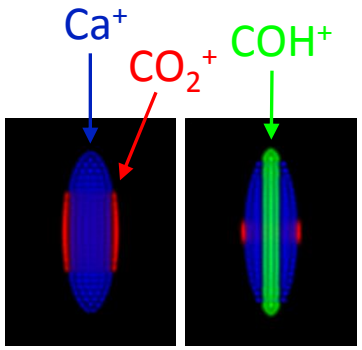
Orbiting resonances




**0**, 043203 (2008)]

Now: buffer gas cooling + ion trap [Henson et al., Science, **338**, 234-238 (2012)]

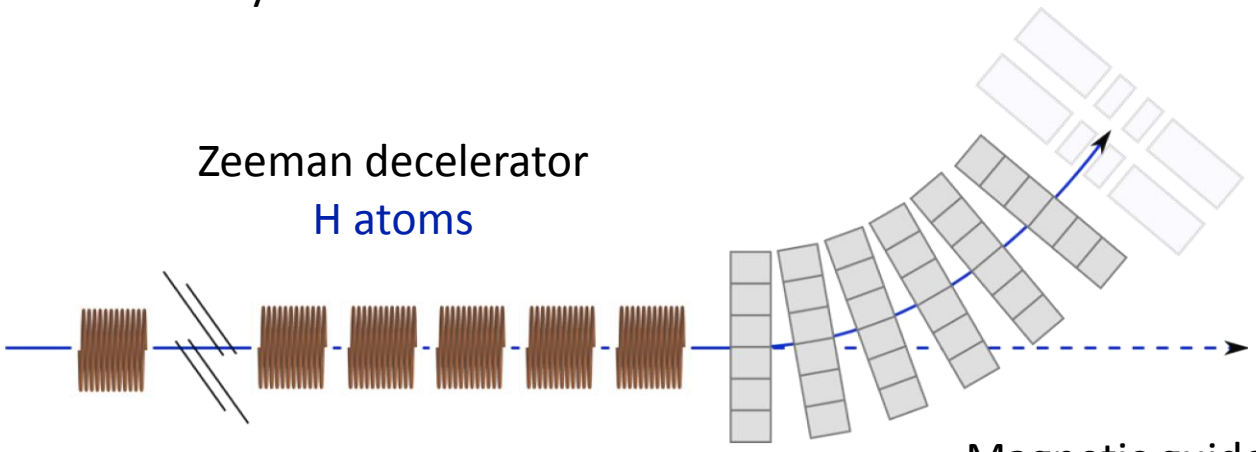
# (1) This Research Project




Paul trap
$Ca^+$ - $CO_2^+$
Coulomb crystal

## Benefits of a Zeeman decelerator:

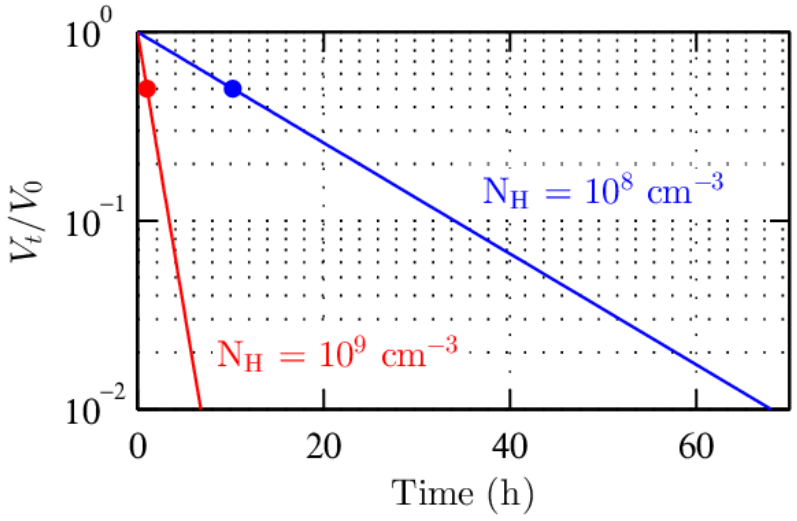
a) Deceleration of open-shell atoms/molecules
b) Internally and translationally cold beams (mK regime)
c) Tunable collision energies
d) Quantum-state selectivity



# (1) This Research Project

## Requirements:

- Good overall transmission through the decelerator
- Effective particle focusing into the ion trap




$$CO_2^+ + H \longrightarrow COH^+ + O$$

$k_{bi}$ = 4.7·10$^{-10}$ cm$^3$ s$^{-1}$ (15-300K *)

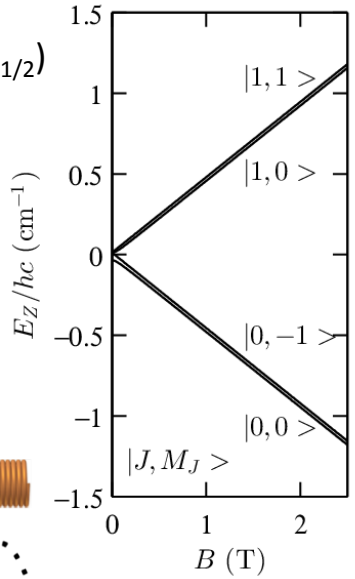
$f$ = 10 Hz **PULSED BEAM!**

$t_{pulse}$ = 40 µs

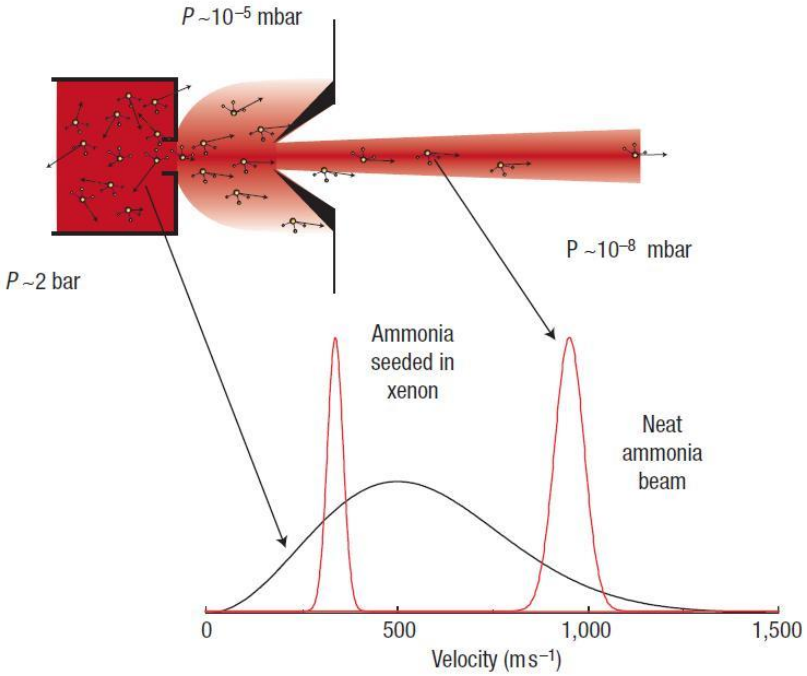
* [Borodi et al., Int. J. Mass. Spectrom., **280**, 218 (2009)]

# (2) Zeeman Deceleration

H (1s $^2S_{1/2}$)

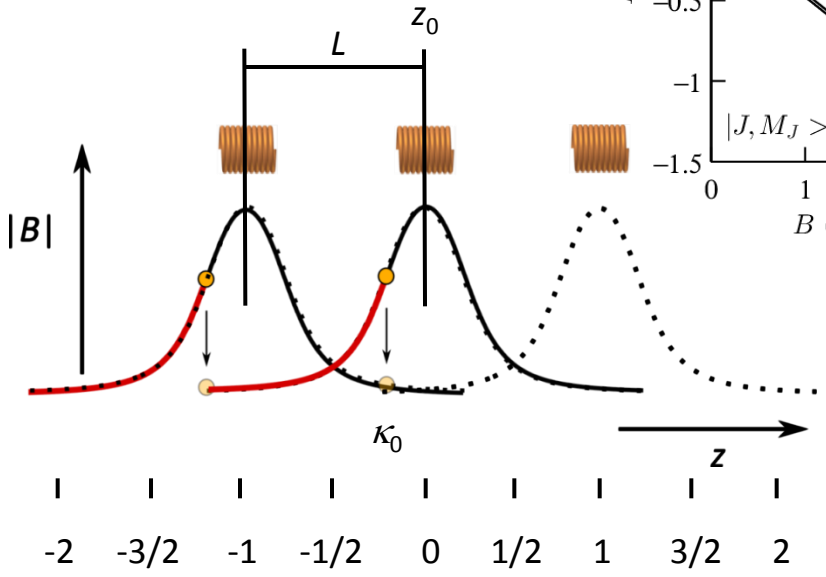



## Supersonic expansion:




[Van de Meerakker et al., Nature Phys., **4**, 595 (2008)]

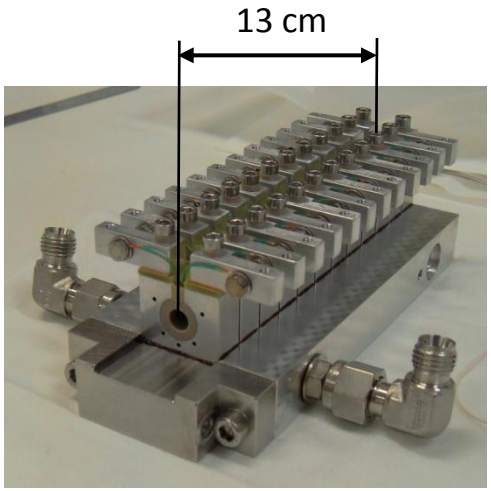
## Zeeman deceleration:




Reduced position $\kappa = (z\text{-}z_0)/L$

# (2) Experimental Setup

## Zeeman deceleration of H atoms




Pulsed valve assembly

$NH_3$ / Kr, 4 bar

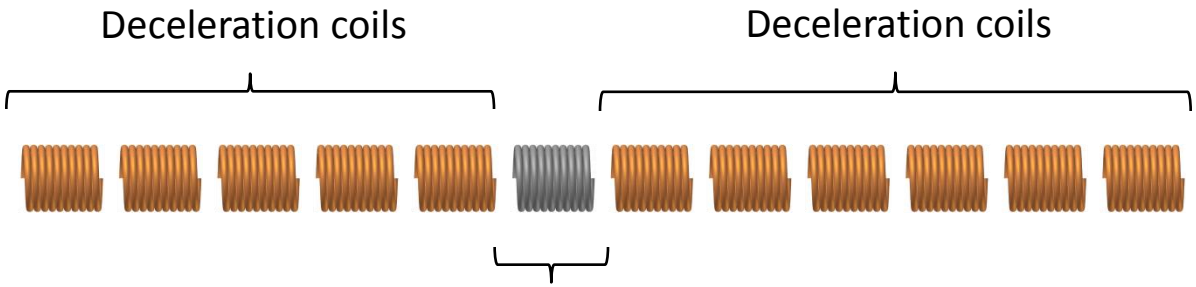
Zeeman decelerator

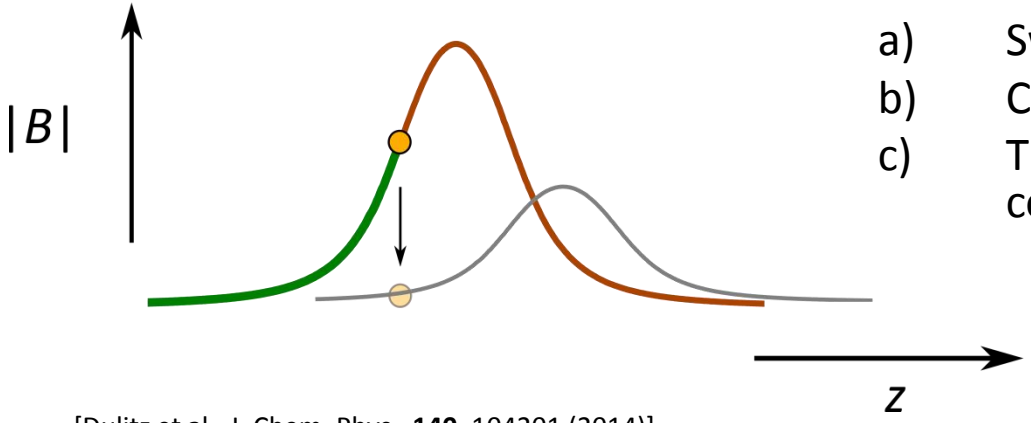
Time-of-flight mass spectrometer

ArF excimer laser, 193 nm

Pulsed dye laser, 243 nm, (2+1) REMPI via 2s $^2S_{1/2}$ state

# (3) Experiments on Transverse Focusing




[Dulitz et al., J. Chem. Phys., **140**, 104201 (2014)]

## Variables:

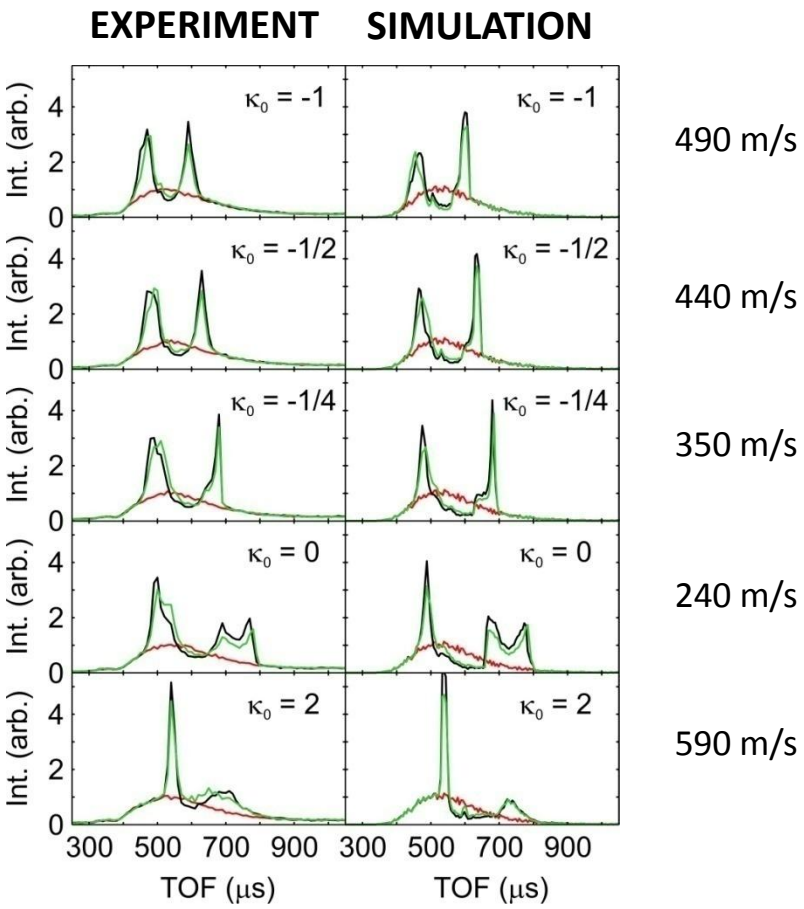
a) Switch-off position $\kappa_0$
b) Current to focusing coil: $I \leq \pm 100$ A
c) Timings (and position) of focusing coil

# (3) Experiments on Transverse Focusing

## a) Reduced position $\kappa_0$

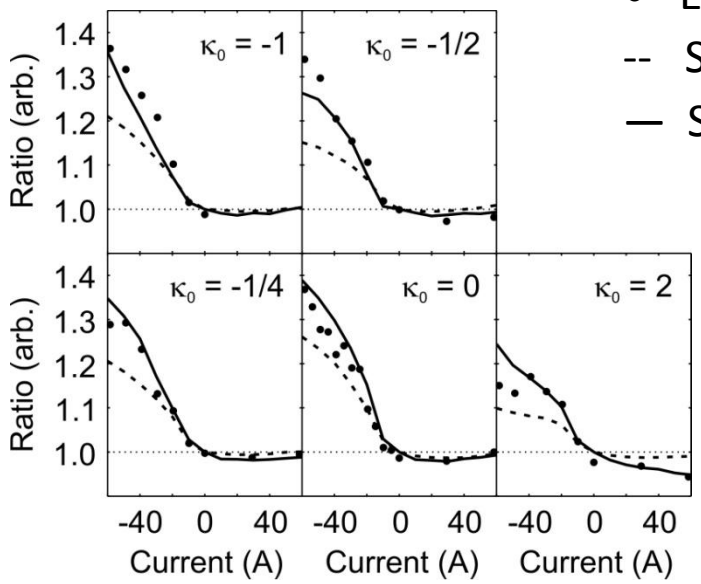
$I_{foc}$ = - 30 A
$I$ = 243 A
$v_0$ = 500 m/s

Reference data at $B = 0$ and without the focusing coil taken on a three-shot basis




# (3) Experiments on Transverse Focusing

## b) Current to focusing coil




- Experimental data
-- Simulation (all particles)
— Simulation (only particles inside laser focus)

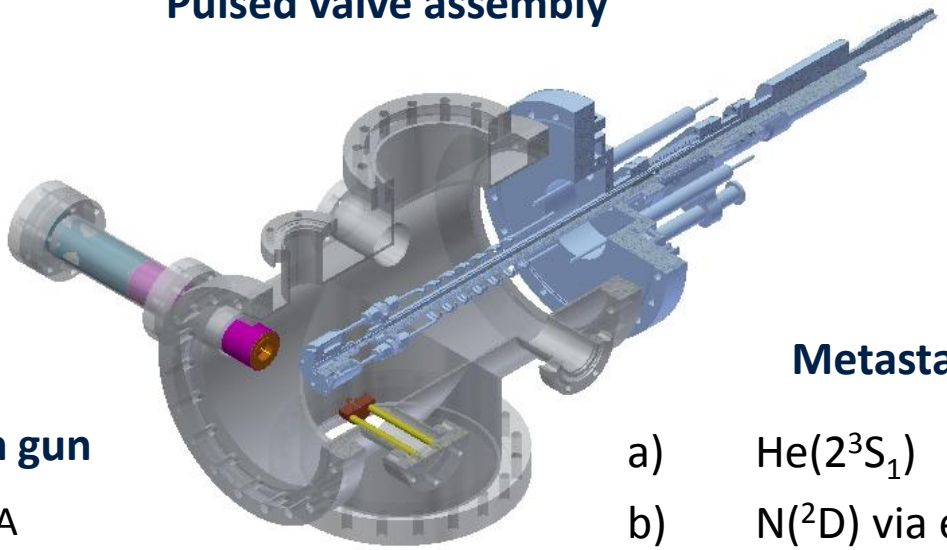
Same current direction:
No signal increase

Reverse current direction:
Formation of a temporally varying quadrupole field that increases transverse particle confinement

# (4) Zeeman Deceleration of Light Metastable Atoms

Design adapted from: PSP Vacuum Technology, ELS 100

## Pulsed valve assembly



## Pulsed electron gun

100 eV, 1-2 mA

## Metastable Species

a) $He(2^3S_1)$

b) $N(^2D)$ via electron impact dissociation of $N_2$

$$N_2 \xrightarrow{e^-} N(^4S) + N(^2D)$$

[Cosby, J. Chem. Phys., **98**, 9544 (1993)]

Thanks to James Bull (ex Vallance group, now at Durham University, Neville Baker and Howard Lambourne (PTCL workshops)

# (4) Zeeman Deceleration of He($2^3S_1$)

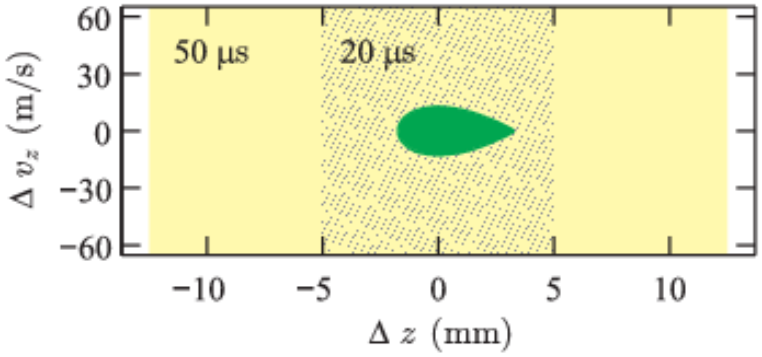
**Deceleration:**

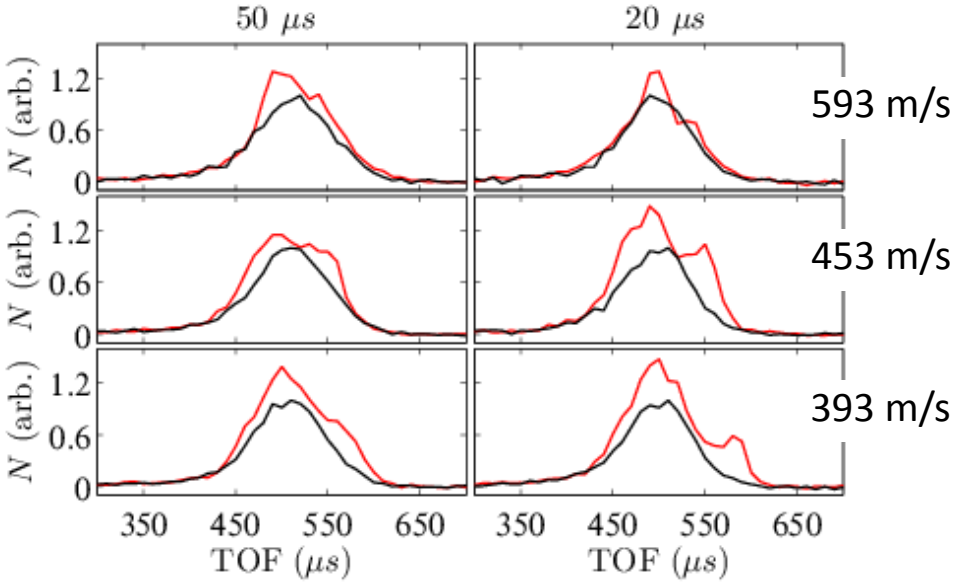
243 A, 12 coils, $v_0$= 505 m/s
1:3 mixture He in Ar, 6 bar, $T_v$ = -130°C

**Detection:**

(1+1) REMPI via $3^3P_J$ state,
389 nm

**Phase-space matching**



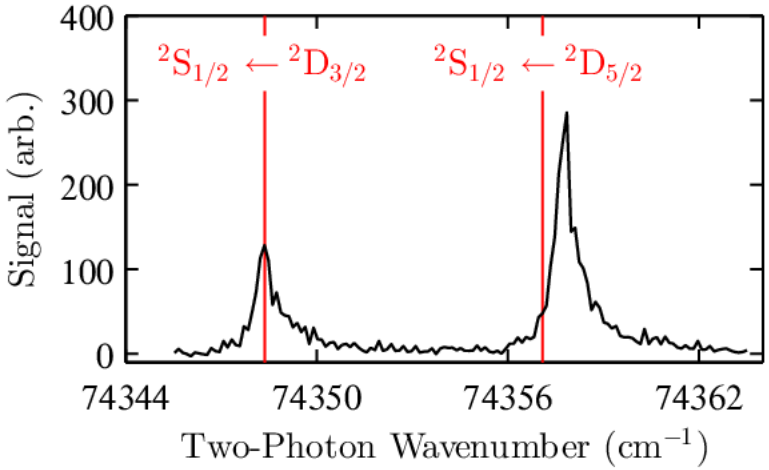



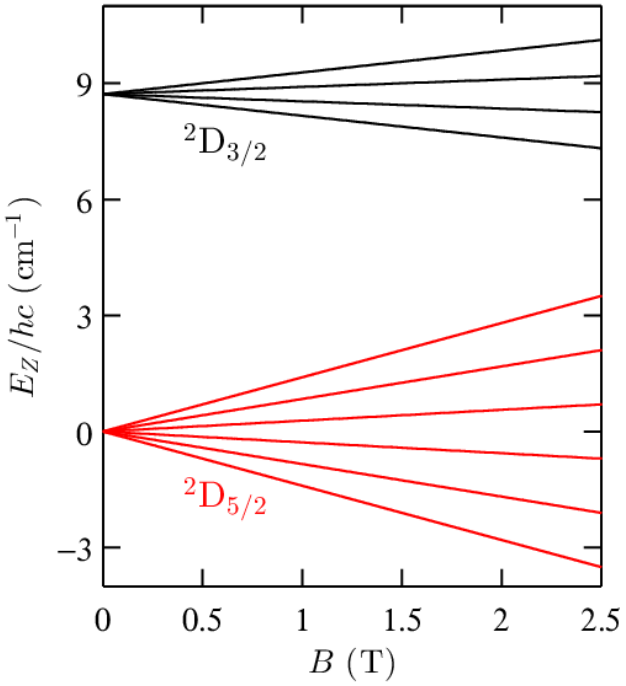

Lowest velocity achieved: 374 m/s
(-50 % in kinetic energy)

# (4) Towards Zeeman Deceleration of N($^2$D)

**Detection:**

(2+1) REMPI via 3p $^2S_{1/2}$ state, 269 nm

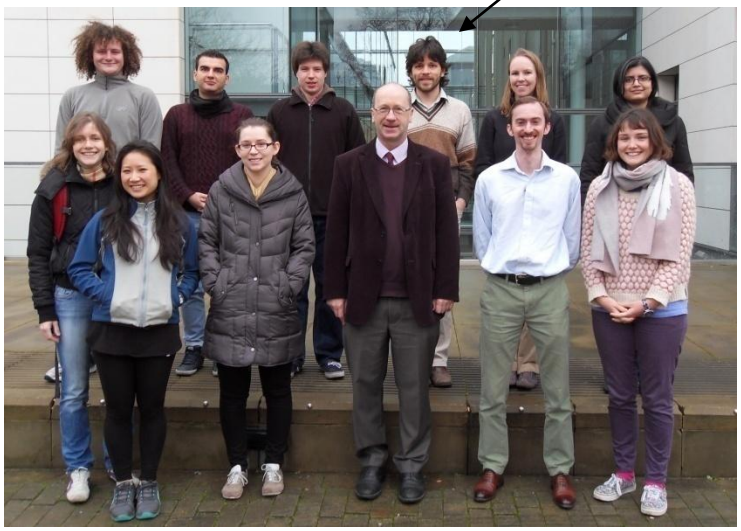



# Acknowledgements


## Tim Softley group

Atreju Tauschinsky



## Electronics & Mechanical workshops

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## Collaborators

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