Trapping SH/SD molecules by photostop

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1 Introduction

The production and application of cold and ultra-cold molecules (defined as < 1 K and < 1 mK, respectively) is a rapidly expanding area in molecular physics.

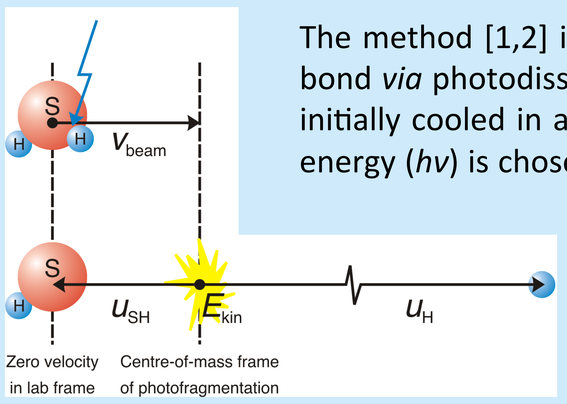
We are interested in:

- Control of long-range dipole-dipole interactions in a lattice of polar ultra-cold molecules, *e.g.* for quantum simulators of exotic condensed matter systems.
- Cold and ultra-cold chemistry, *e.g.* external field control over resonances.

A major challenge is to trap cold molecules at high density (> 10^{11} cm^{-3}) for sympathetic cooling with ultra-cold atoms to ultra-cold temperatures.

We present an accessible, impulsive method for the production of cold molecules at rest *via* the photodissociation of a precursor molecule in a molecular beam.

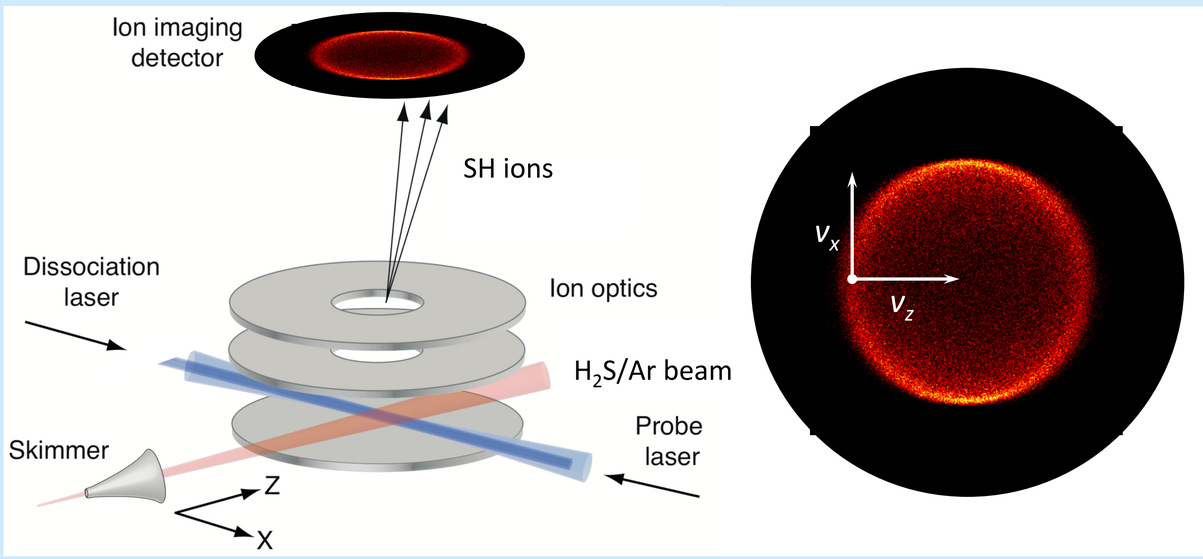
2 The Photostop Method



The method [1,2] is based on the controlled breaking of one bond *via* photodissociation of a precursor molecule (*e.g.* H_2S) initially cooled in a supersonic molecular beam. The photon energy ($h\nu$) is chosen such that the recoil velocity ($\boldsymbol{u}_{SH}$) of one of the fragments (SH) cancels the velocity of the molecular beam ($\boldsymbol{v}_{beam}$) such that this fragment is produced with zero velocity in the lab frame: $\boldsymbol{u}_{SH} = -\boldsymbol{v}_{beam}$.

3 Experiment

Schematic setup to photo-stop SH from H_2S.



Detection of SH($^2\Pi_{3/2}$) fragments via 2+1 REMPI and LIF in trapping experiments.

Velocity map ion imaging perpendicular to molecular and laser beams allows the direct measurement of molecular beam velocity and the (v_x, v_z) velocity components of the SH fragments.

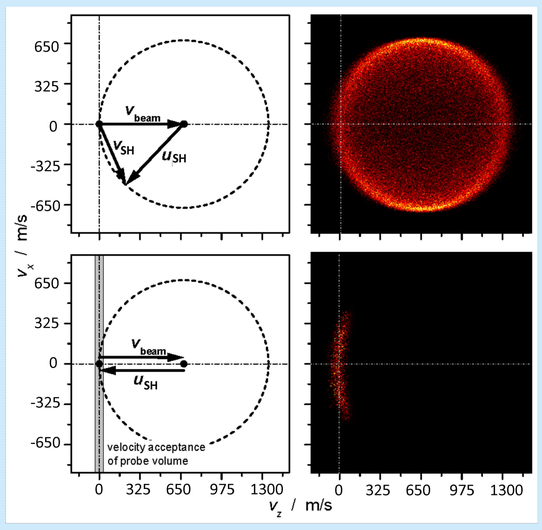
Ion image of SH($^2\Pi_{3/2}$) from H_2S dissociation at λ_{diss} = 193.3 nm.

Due to the unpolarised dissociation laser and the perpendicular transition [3] from the ground state to the dissociating state the peak of the distribution appears perpendicular to the molecular beam.

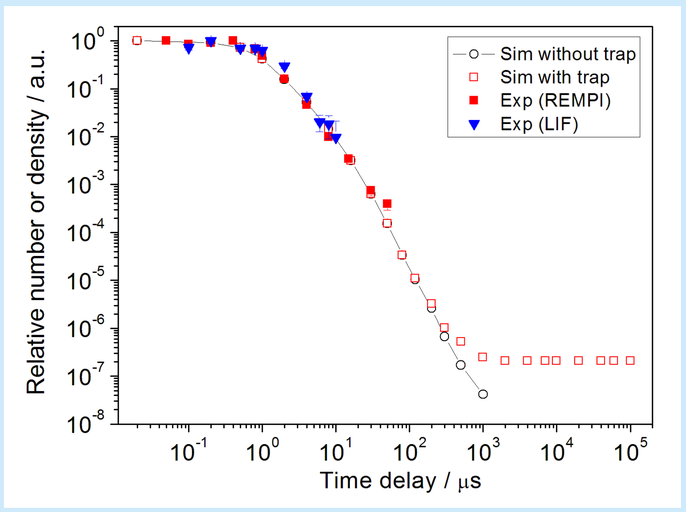
4 Photostop and trapping of SH

Photostop of SH from H_2S dissociation:

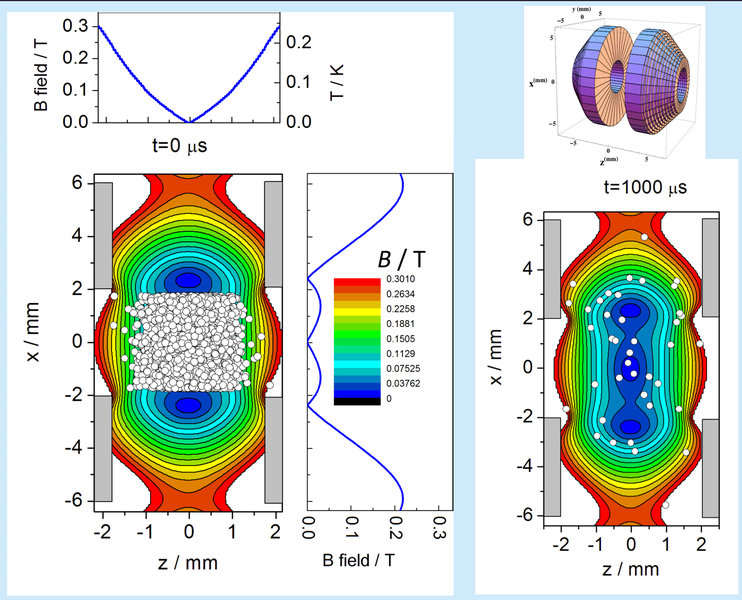
Molecular beam velocity adjusted to v_{beam} = 660 m/s by varying the precursor / carrier gas ratio to match the photostop wavelength of 193.3 nm .



Left: Newton diagrams showing relationship between centre-of-mass ($\boldsymbol{u}_{SH}$) recoil and lab velocities ($\boldsymbol{v}_{SH}$). Top right: Ion image at a delay of 50 ns between dissociation and probe laser pulses. Bottom right: After 15 µs delay is T_z ~ 6 K and probed density is $\rho_{SH} = 10^9 \sim 10^{10}$ cm^{-3}

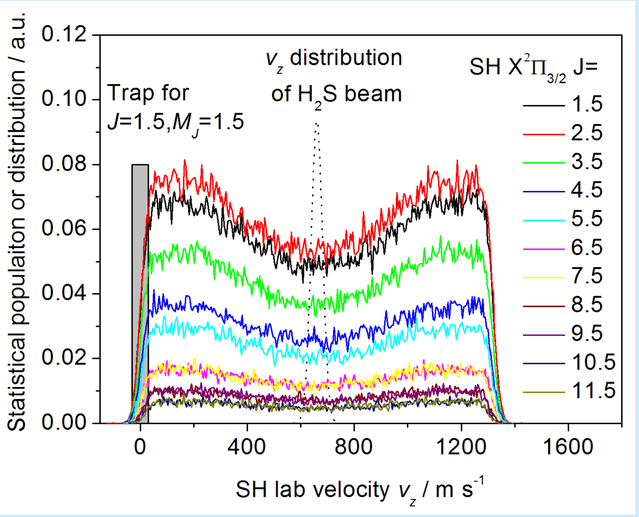


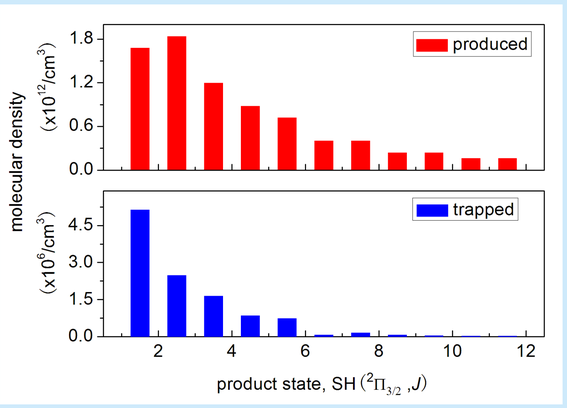
Relative number/density of SH ($X\,^2\Pi_{3/2}$, J = 3/2, M_J = 3/2) molecules in the probe volume as a function of time delay between the dissociation and probe lasers. Experimental data (solid symbols) show current detection limits for REMPI and LIF detection. Simulations (open symbols) suggest that trapping will not be observable until a delay of ~500 µs. Simulations do not yet include loss due to absorption of blackbody radiation, collisions with background gas or Majorana transitions.



Permanent magnet trap, anti-Helmholtz quadrupole configuration, ~200 mK deep for SH($X\,^2\Pi_{3/2}$, J = 3/2, M_J = 3/2). Spatial profiles of molecules in the trap for time delay of 0 µs (left) and 1 ms (right) after dissociation from Monte Carlo trajectory simulations.

5 State distributions & densities in trap



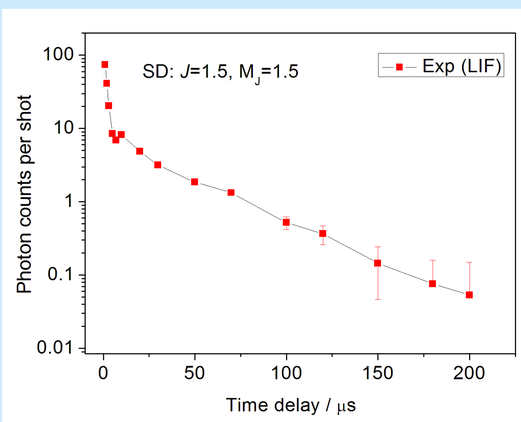


Measured density distribution of product states (assuming a H_2S density of 3.4 x 10^{13} cm^{-3}).

Velocity distribution in z-direction of photostopped molecules in various J states showing overlap with trap acceptance around 0 m s^{-1}.

From simulations expect to trap a density of 10^6 cm^{-3} SH in J = 3/2, M_J = 3/2 and a density of 5.0 x 10^6 cm^{-3} in states up to J = 5.5.

6 Photostop of SD



Left: Photon counts for LIF detection of SD ($X\,^2\Pi_{3/2}$, J = 3/2, M_J = 3/2) molecules in the probe volume as a function of time delay up to 200 µs between the dissociation and probe lasers.

Molecular beam speed adjusted to 770 m/s to match the dissociation wavelength of 213 nm for photostop of SD (from D_2S)

7 References / Acknowledgements

[1] A. Trottier, E. Wrede and D. Carty, *Mol. Phys.* **109**, 725 (2011).

[2] W. G. Doherty, M. T. Bell, T. P. Softley, A. Rowland, E. Wrede and D. Carty, *Phys. Chem. Chem. Phys.* **13**, 8441 (2011).

[3] L. J. Rogers, M. N. R. Ashfold, Y. Matsumi, M. Kawasaki, B. J. Whitaker, *J. Chem. Soc. Faraday Trans.*, **92**, 5182 (1996).

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