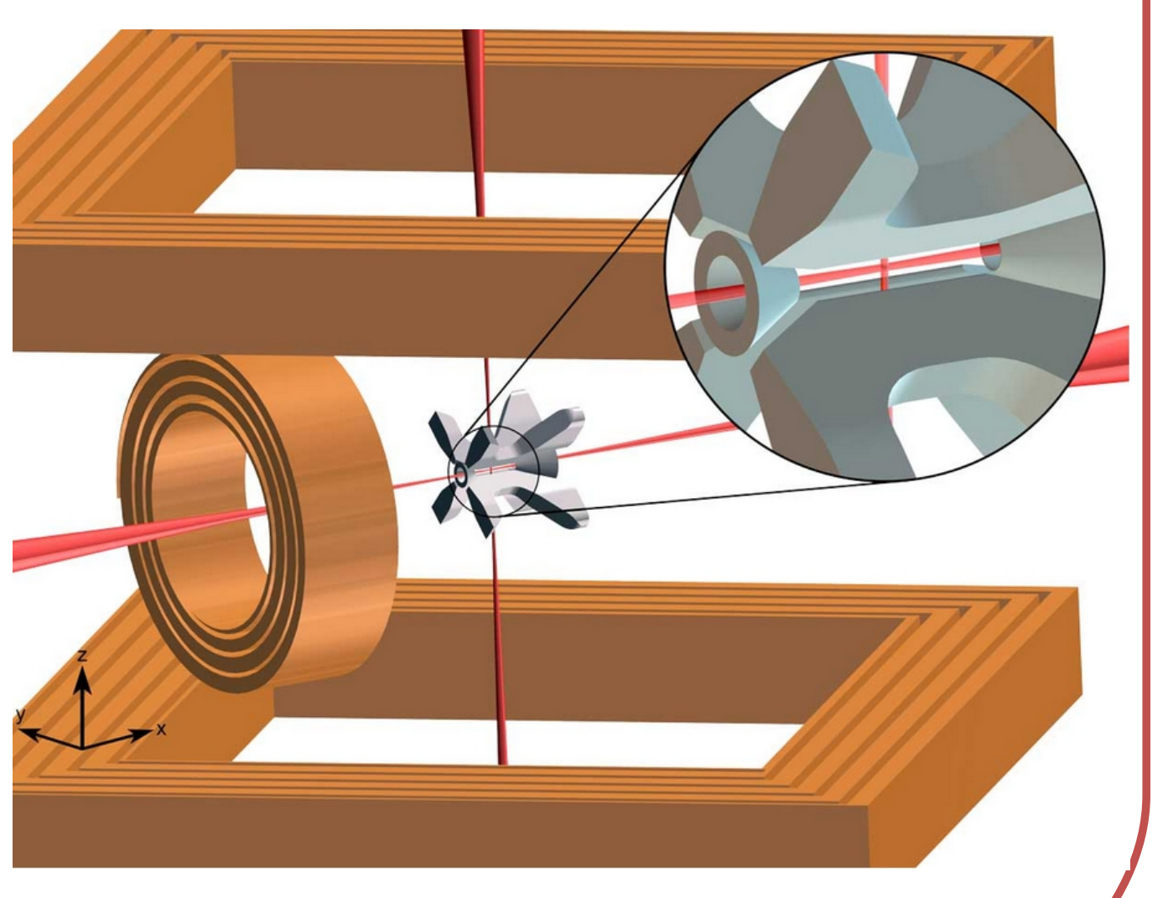
Controlling chemical reactions of a single particle

Carlo Sias*, Lothar Ratschbacher, Christoph Zipkes, and Michael Köhl
Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK

The hybrid system of trapped atoms and ions offers key advantages for studying chemical reactions at the most elementary level: ion traps have a large potential well depth in order to trap the reaction products, while the absence of a Coulomb-barrier allows the particles to collide at short internuclear distance. Here, we report on the experimental tuning of the exchange reaction rates of a single trapped ion with ultracold neutral atoms by exerting control over both their quantum states. We observe the influence of the hyperfine state on chemical reaction rates and branching ratios and monitor the kinematics of the reaction products.

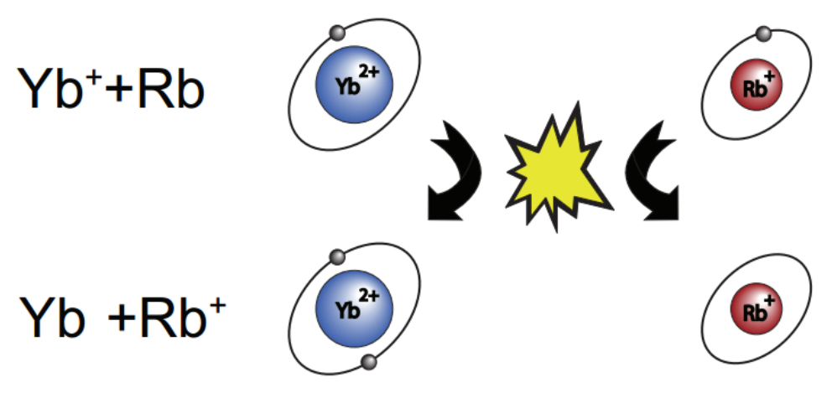
The hybrid atom-ion trap

In the same physical location, we trap $^{174}Yb^+$ single ions in a radio-frequency Paul trap and ^{87}Rb neutral atoms in a magnetic or in an optical dipolar trap.

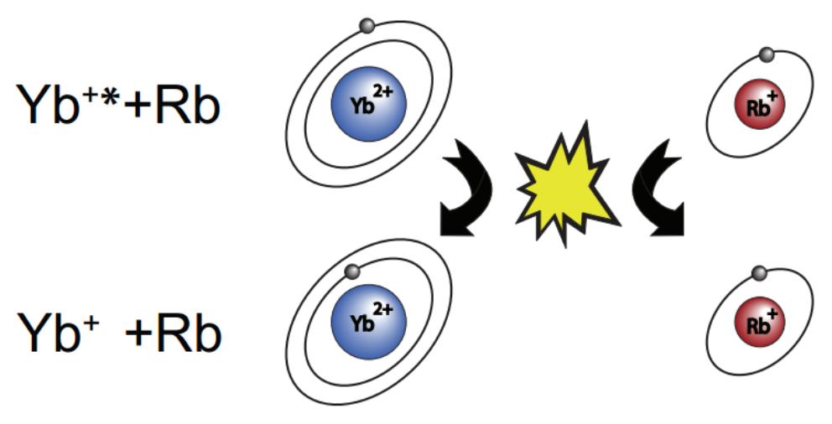


Physical processes

CHARGE EXCHANGE:



COLLISIONAL QUENCHING:



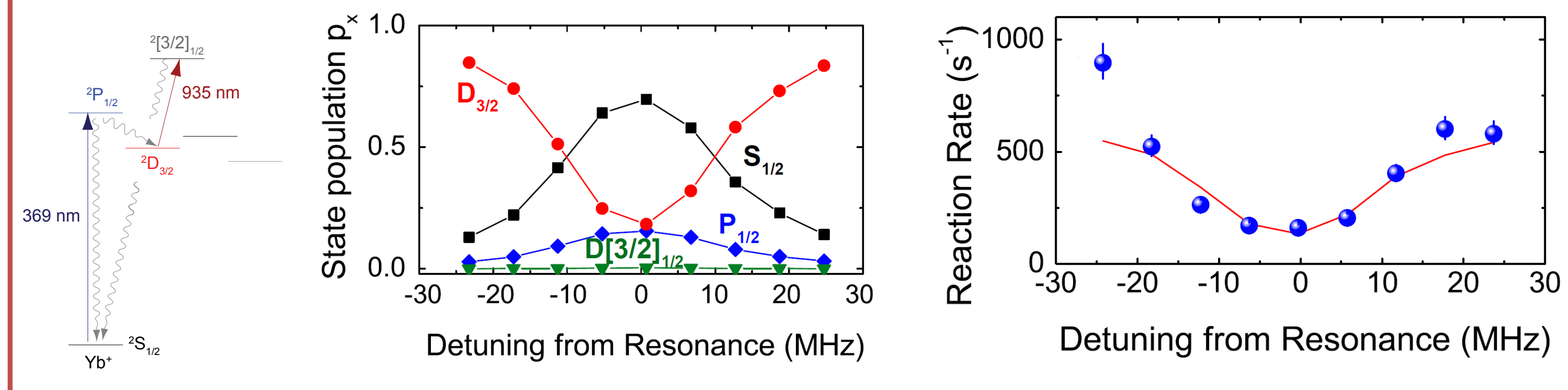
Tuning the reactions

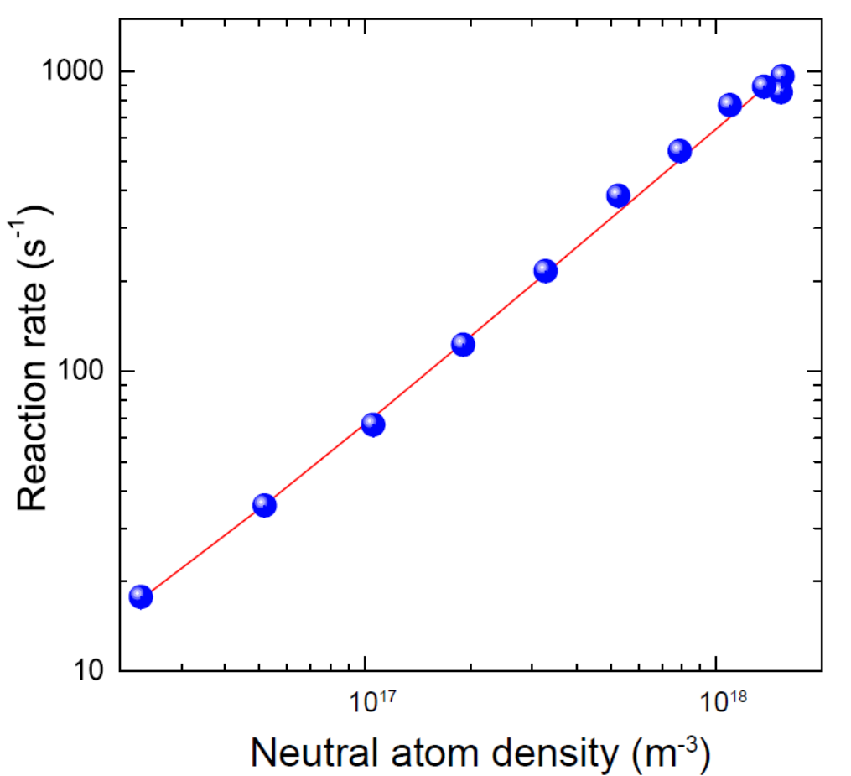
Changing the state of the ion and the atoms we are able to tune the inelastic collision rate by up to 5 orders of magnitude!

	$^2S_{1/2}$	$^2D_{3/2}$	$^2F_{7/2}$	$^2P_{1/2}$	$^2S_{1/2}$	$^2D_{3/2}$
ϵ	$10^{-5\pm0.3}$	1.0 ± 0.2	0.018 ± 0.004	0.1 ± 0.2	$(35\pm11)\epsilon_S^{\|2,2\rangle}$	1.0 ± 0.2
charged particle lost	65%	87%	84%		50%	
Rb^+ identified	35%	12%	15%		48%	
dark Yb^+ identified		< 1%			< 1%	
hot ion (unidentified)			1%		2%	
number of events	283	754	225		236	

Interactions in the presence of light

We tune the inelastic collision rate by varying the 935nm re-pumping light detuning

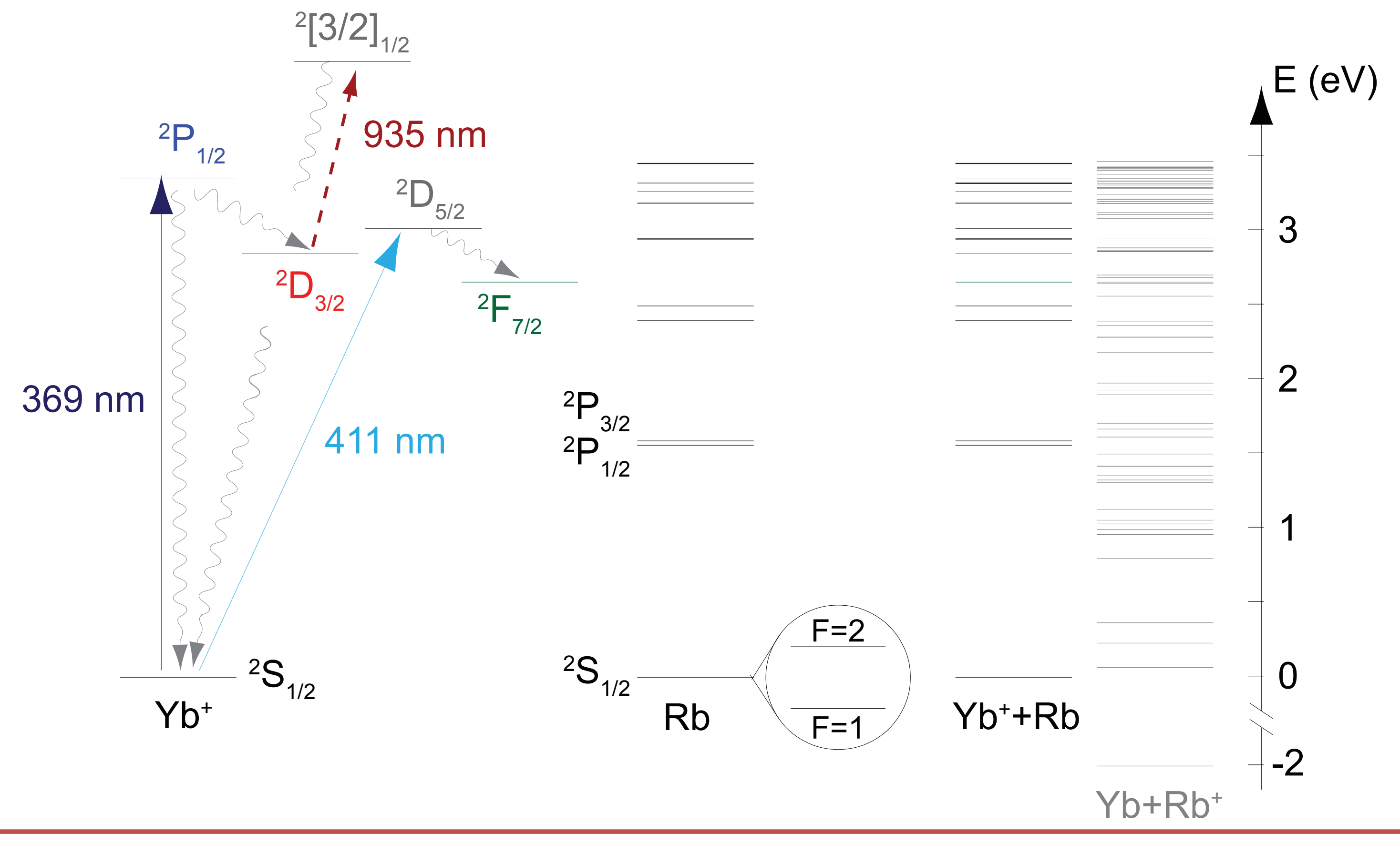




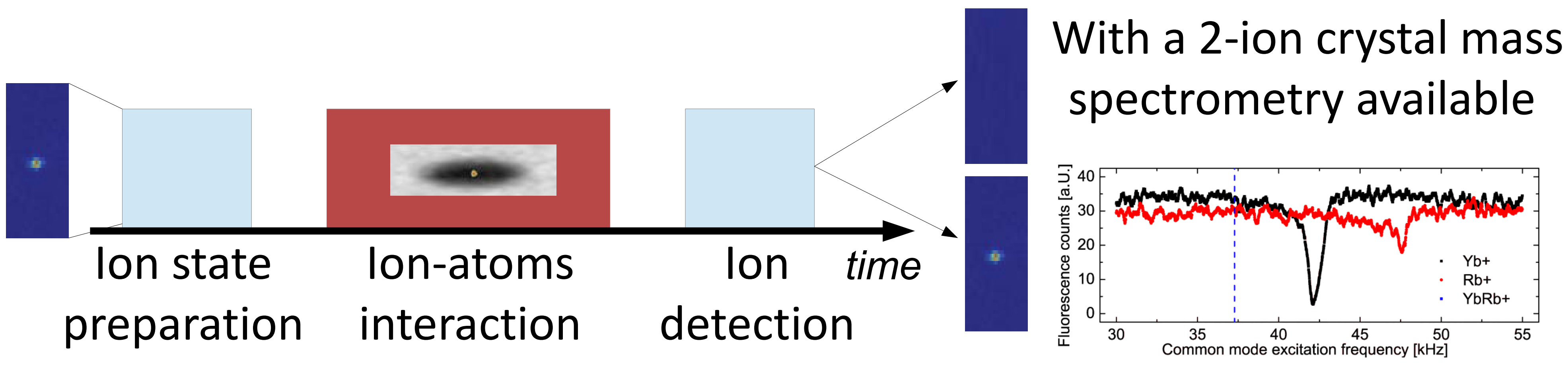
We verify the linearity of the reaction rate. The measured exponent is 0.98 ± 0.02

The level scheme

We prepare the Yb^+ ions in a number of excited states, while the neutral atoms are prepared in the hyperfine F=1 or F=2 state.



Time sequence



With a 2-ion crystal mass spectrometry available

The model

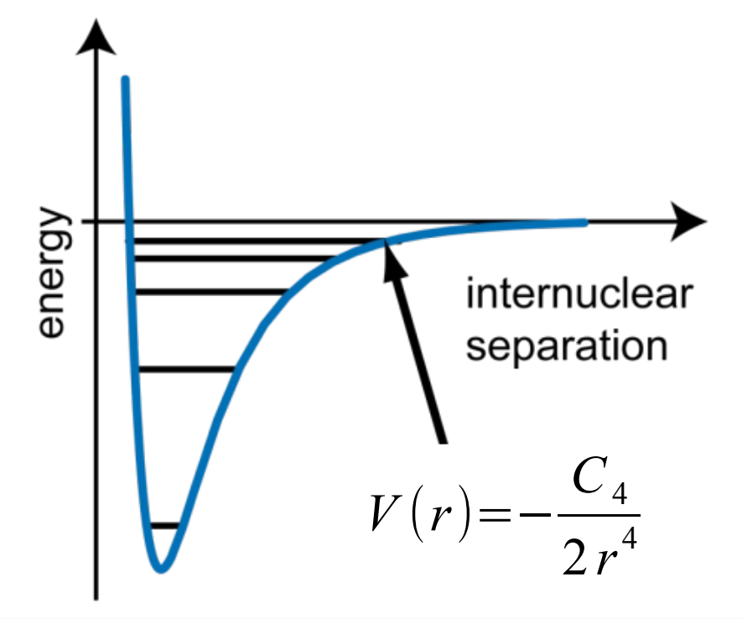
We model the inelastic collisions making use of three asssumptions:

- An inelastic process happens only in a Langevin-type collision
- The characteristic collision time is shorter than the radiative lifetime
- Inelastic collisions can only be exothermic

Inelastic Loss Rate: $\gamma_l = 2\pi\sqrt{C_4/\mu}\, n_a \sum_x p_x \epsilon_x$

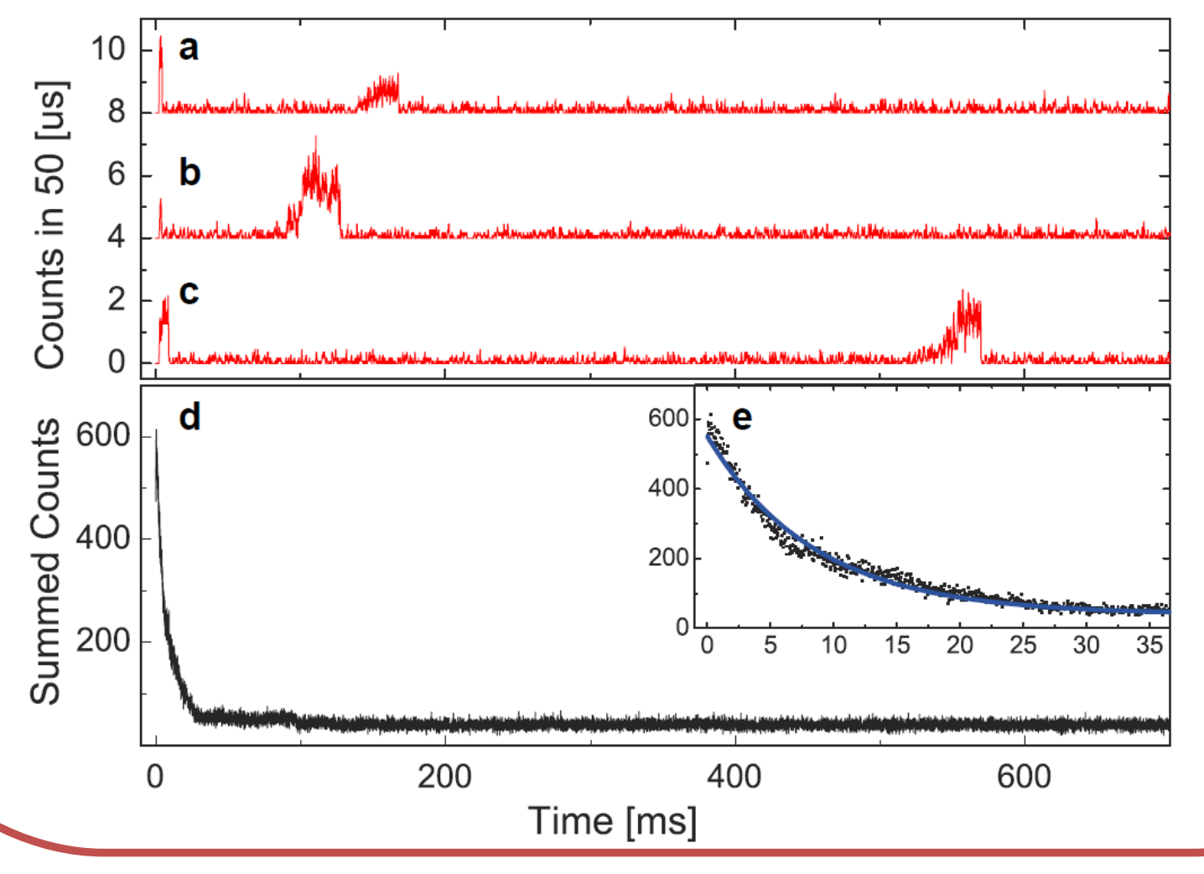
p_x occupation probability of state x

ϵ_x state dependent proportionality constant



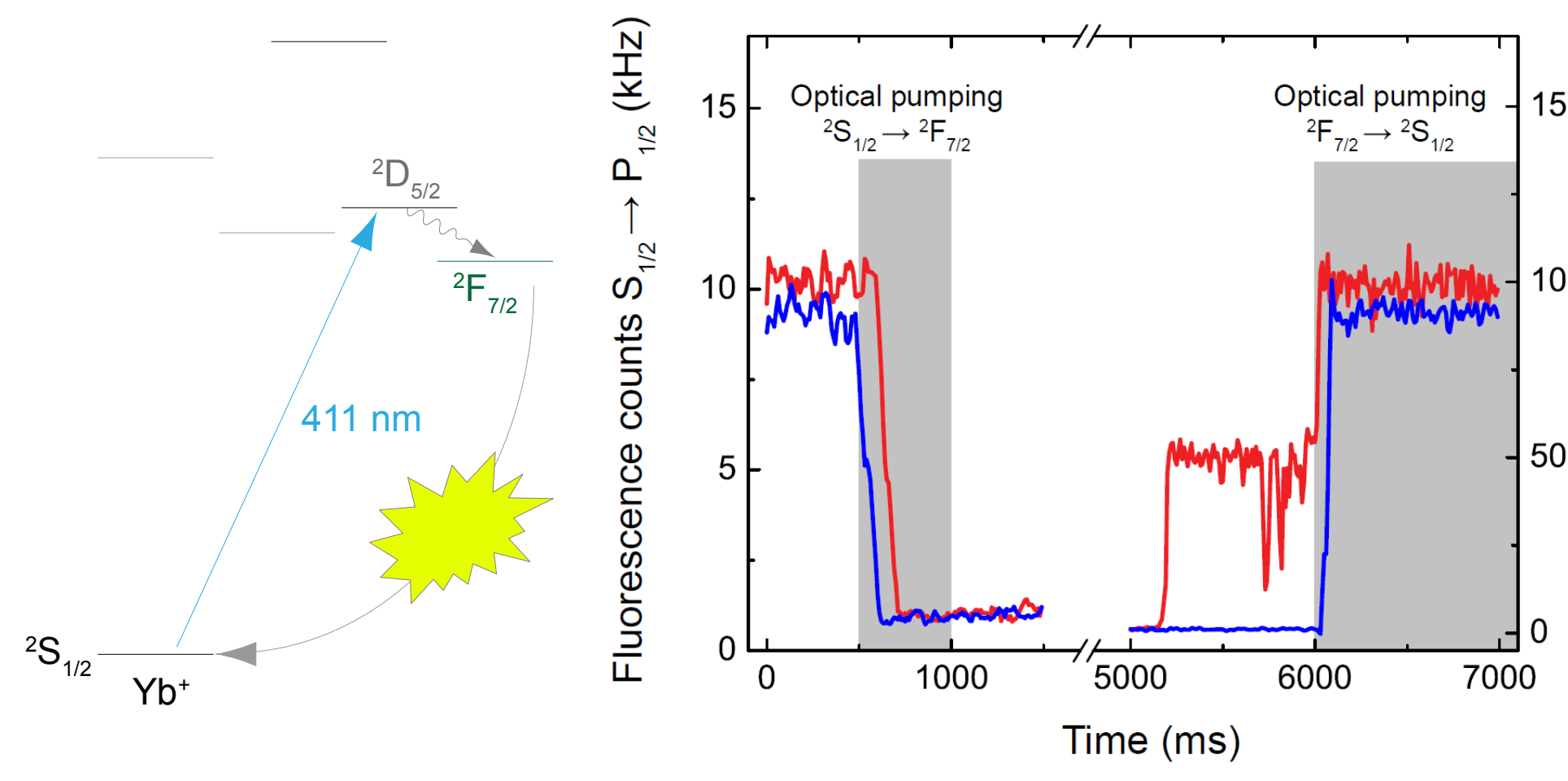
Collisions in real time

By using resonant light, we are able to observe the inelastic collisions as they happen in real time



Collisional Quenching

We directly observe quenching of the ion due to collisions with neutral atoms.



Lothar Ratschbacher, Christoph Zipkes, Carlo Sias, and Michael Köhl, Nature Physics DOI 10.1038/NPHYS2373, arXiv 1206:4507

Related works: Basel, UCLA, Ulm, Bangalore,...

*Permanent Address: CNR-Istituto Nazionale di Ottica, Sesto Fiorentino, Italy