Towards Coherent Control of Single Cold Molecular Ions

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Summer School on Basics on Quantum Control
Cargese, Corsica, France
August 20, 2008

Why experimenting with cold molecular ions ?

- **Cold collisions/reactions**

  Astrophysics (interstellar clouds: ~10 K)
  State specific processes (< 10 K)
  Ultracold Chemistry (< mK)

- **High resolution spectroscopy**

  State specific experiments
  Long interrogation times

- **Quantum control/optics**

  Single molecule manipulations
  Coherent control
  Quantum information

Outline

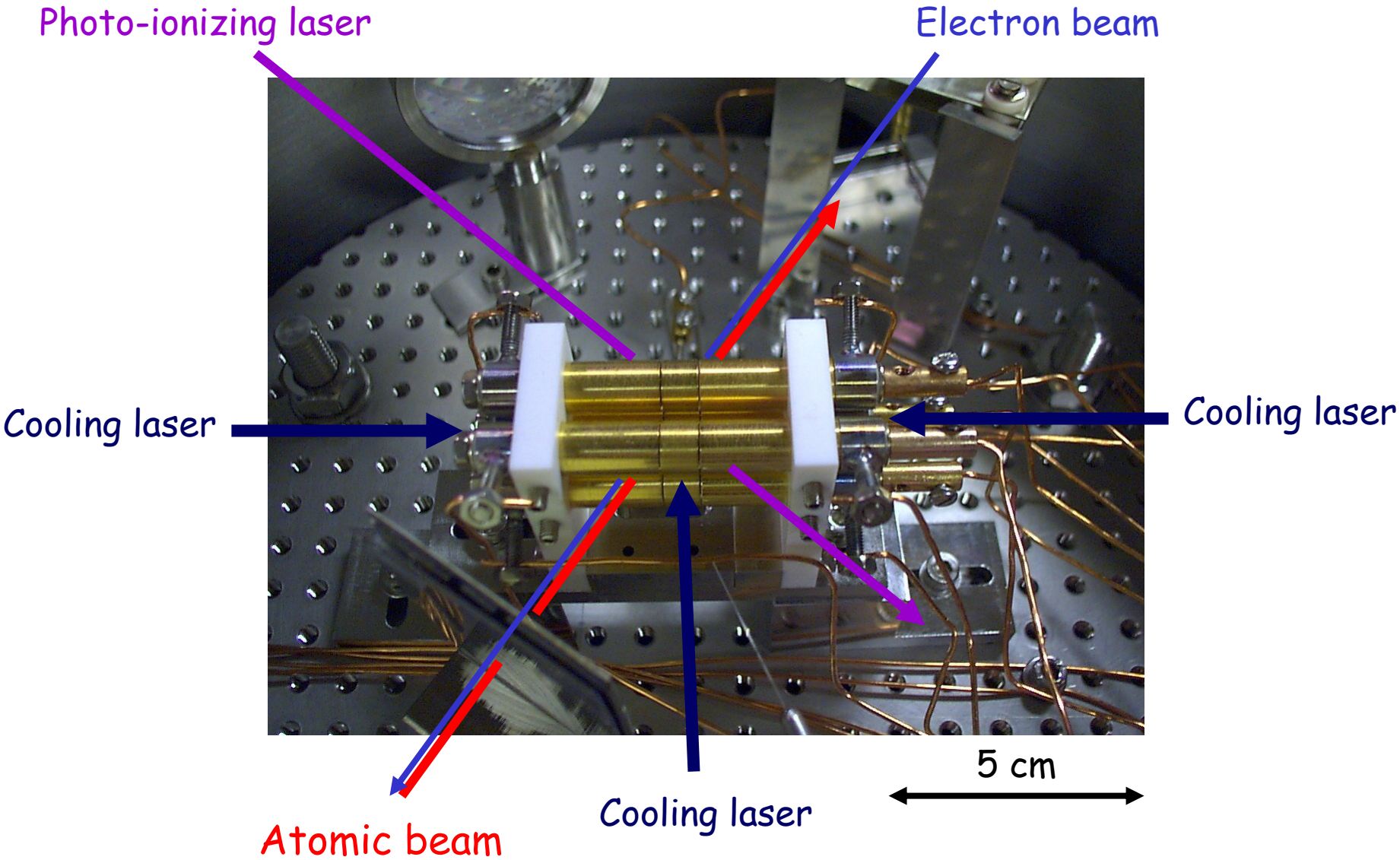
I) Brief intro. to ion trapping and cooling

II) Experiments with trans. cold single mol. ions

III) How to produce internally cold mol. ions ?

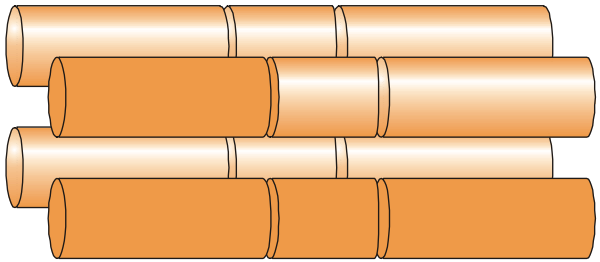
IV) Coherent manipulation of single mol. ions

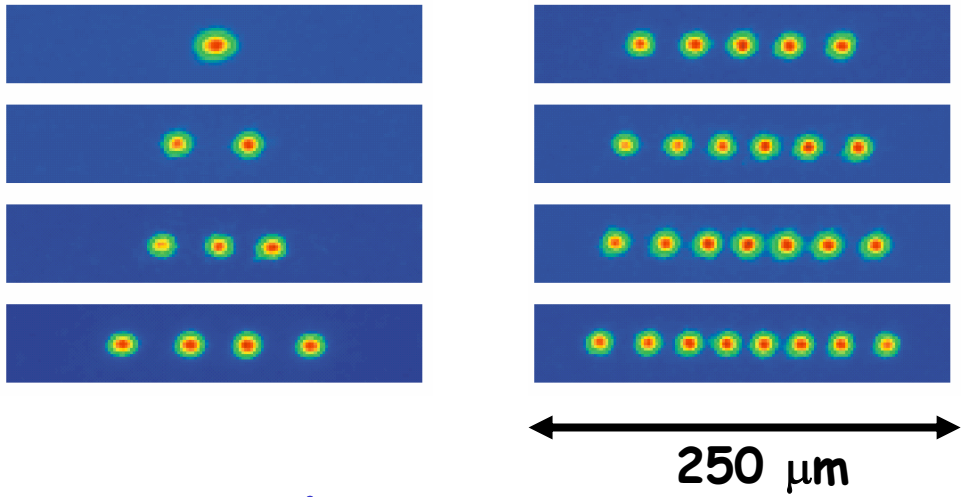
I) Brief intro. to ion trapping and cooling



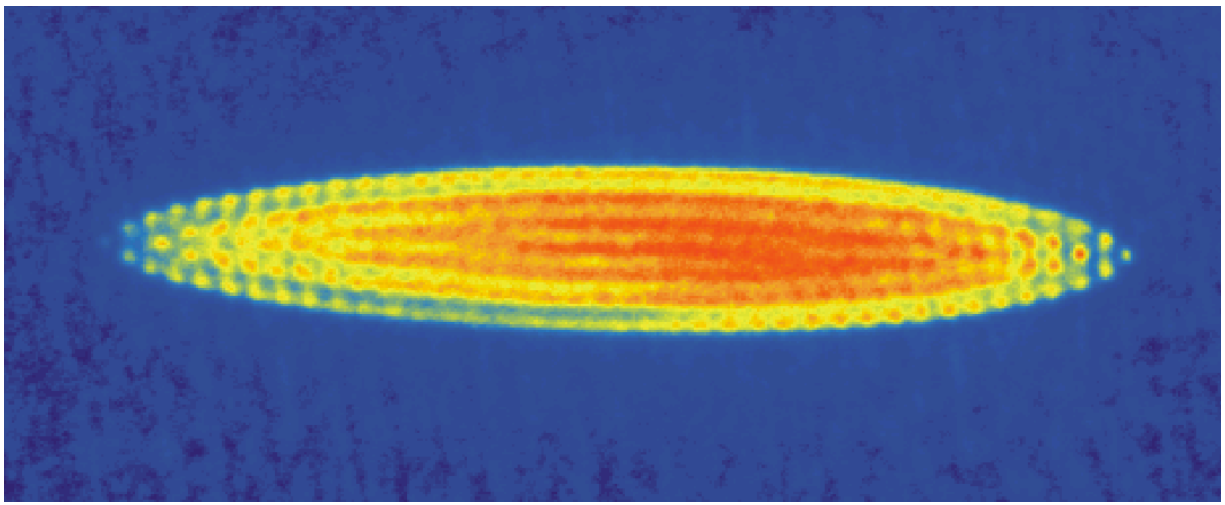
Single species ion Coulomb crystals

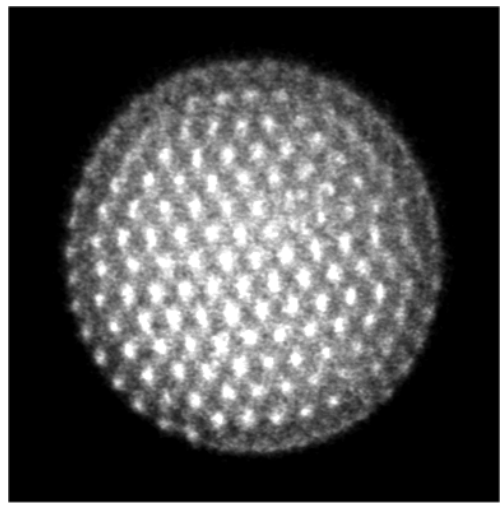
Strings of ions





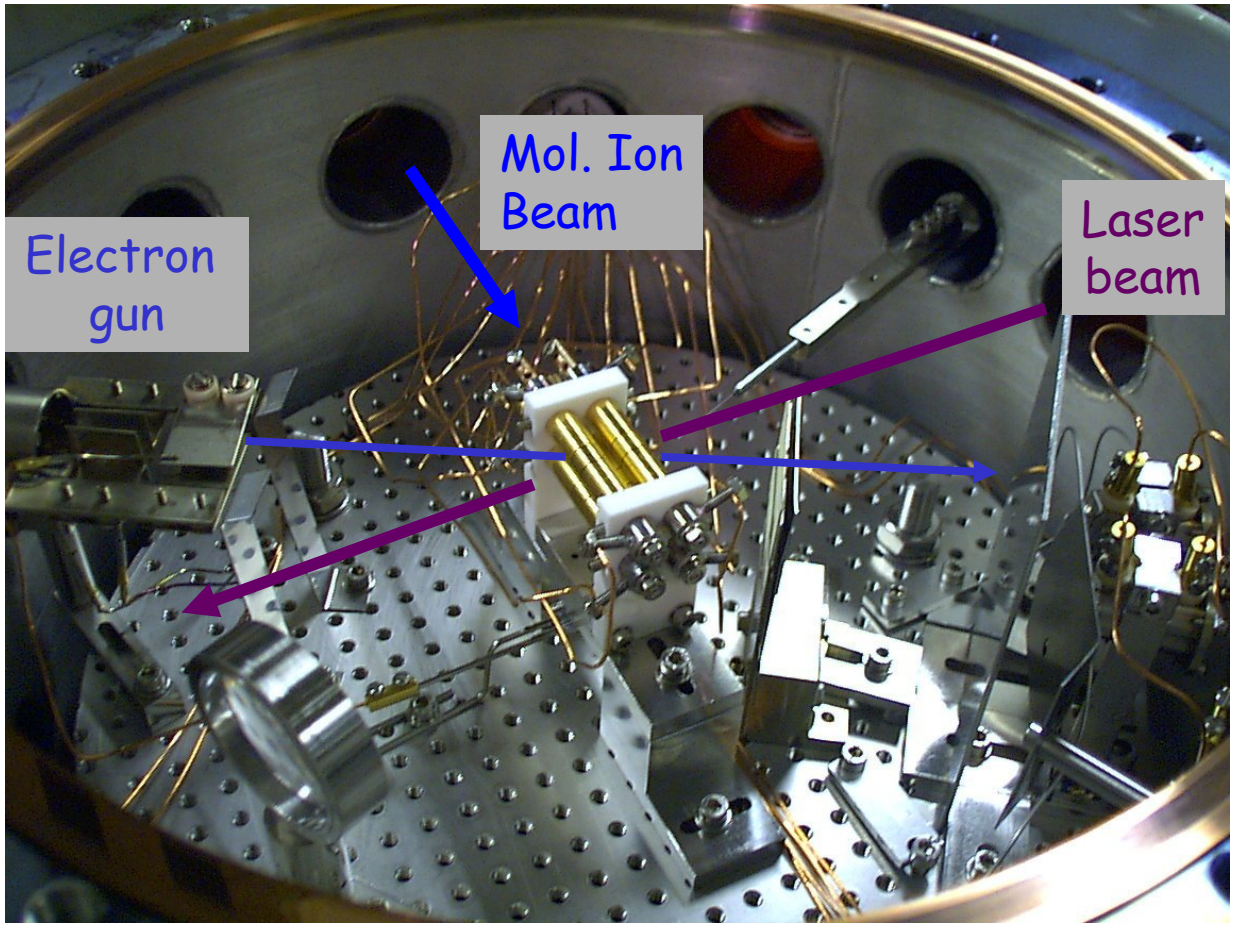
Larger crystals





Phys. Rev. Lett. **96**, 103001 (2006)

Creation of Coulomb c.'s including molecular ions



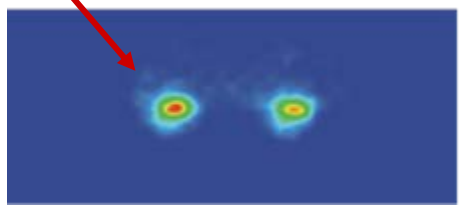
Gas inlet through leak-valve

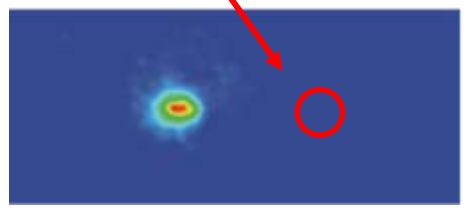
1) Reactions with trapped atomic ions
2) Electron impact ionization of neutral molecules
3) Photoionization of neutral molecules
4) Injecting molecular ions

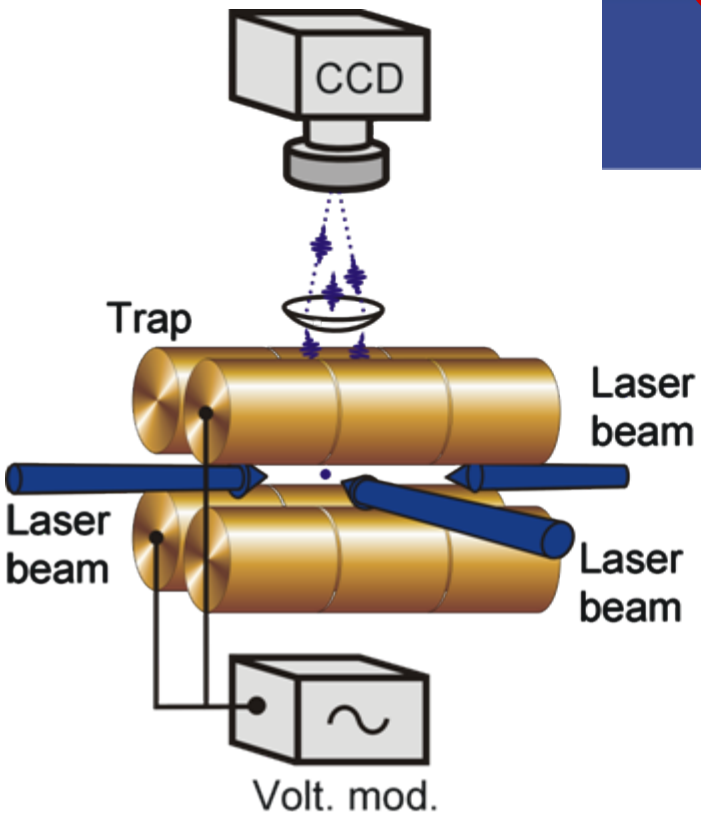
II) Experiments with single trans. cold mol. ions

Reactions with trapped atomic ions

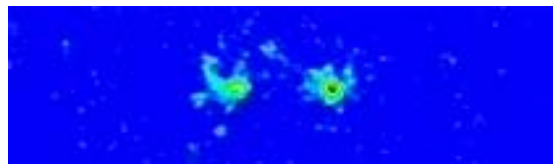
$^{26}Mg^+ + HD \longrightarrow {}^{26}MgH^+ (^{26}MgD^+) + D(H)$?



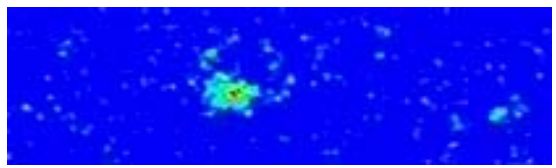




The two $^{26}Mg^+$ ions:



One $^{26}Mg^+$ and one $^{26}MgH^+$:

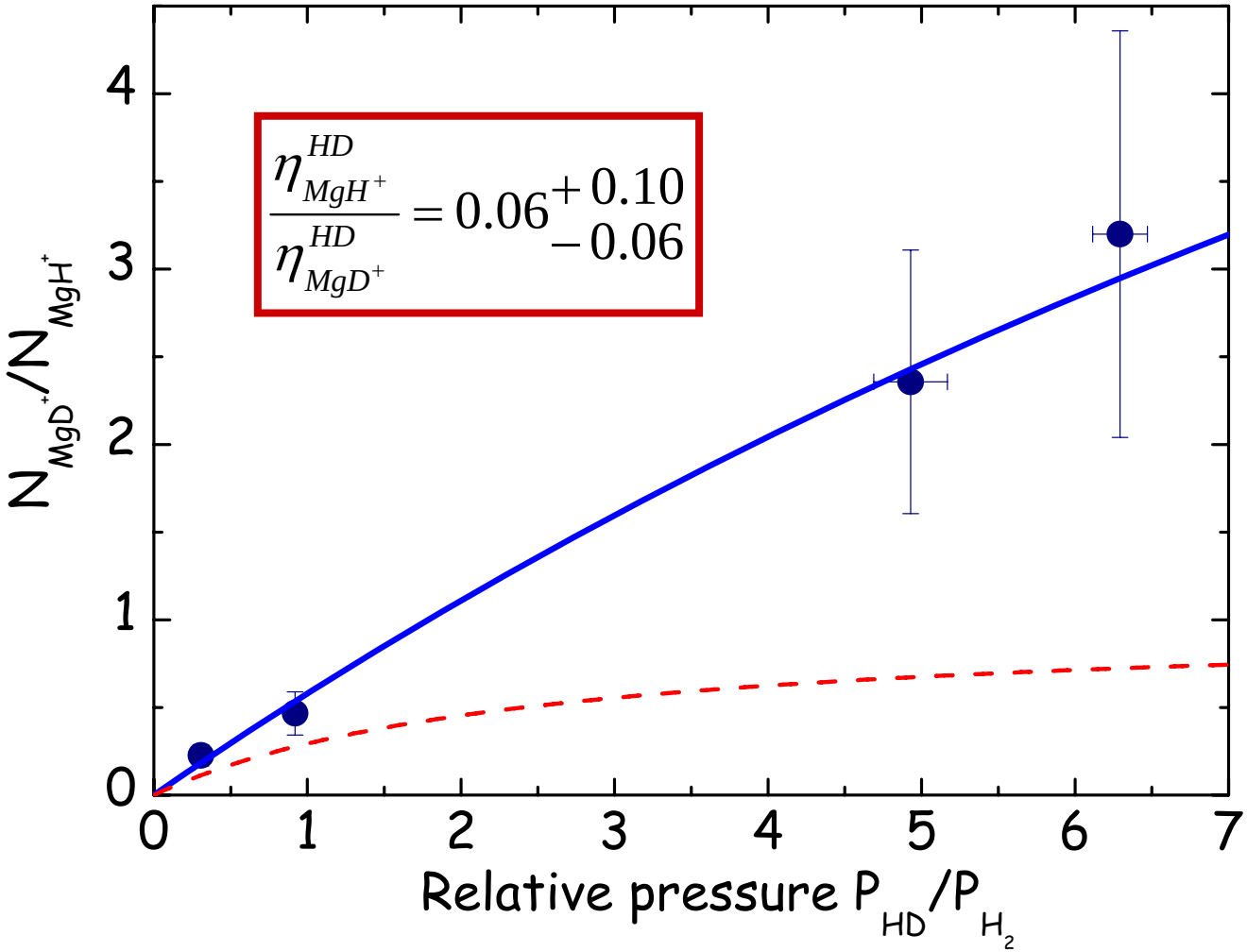


Mass resolution: $\Delta m/m \sim 10^{-2}$.

Phase sens. Meas. : $\Delta m/m \sim 10^{-4}$

Phys. Rev. Lett. **93**, 243201 (2004)

Isotope effect in $^{26}Mg^{+}(3p)$+HD, H_2 reactions



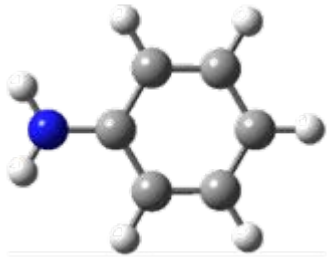
Numbers of reactions: ~300 !

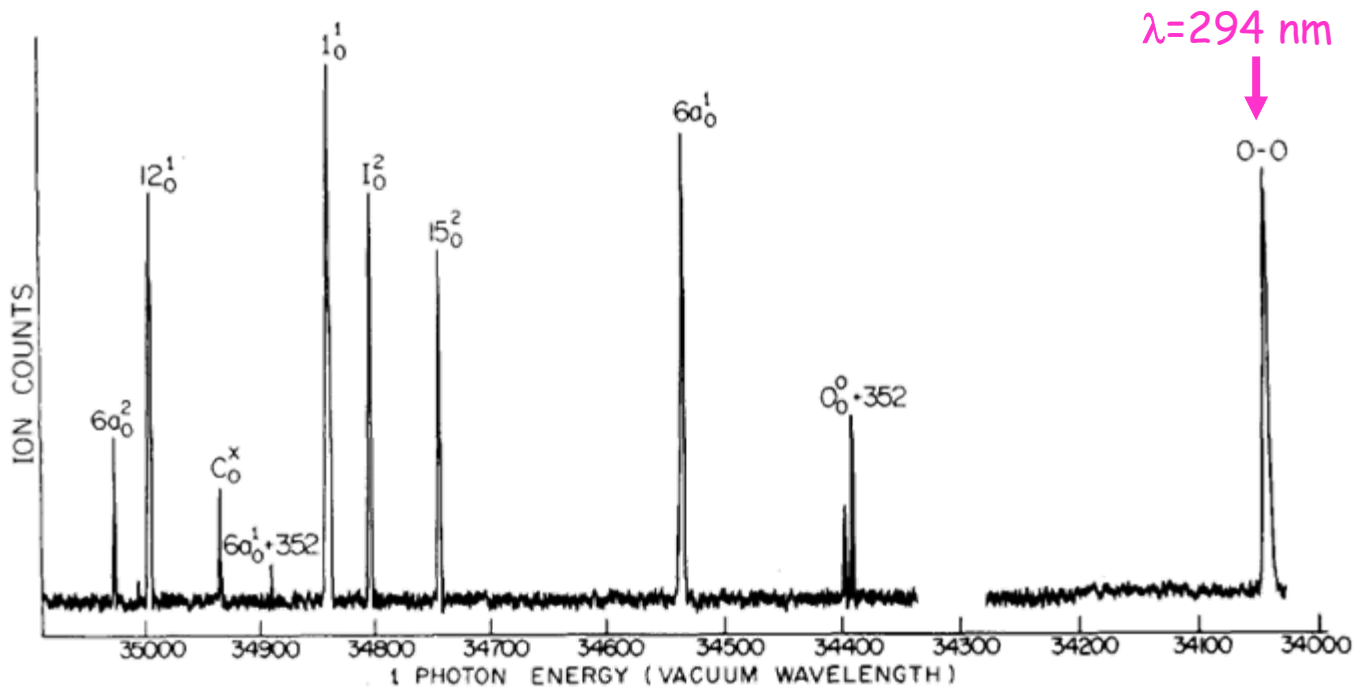
Phys. Rev. Lett. **100**, 243003 (2008)

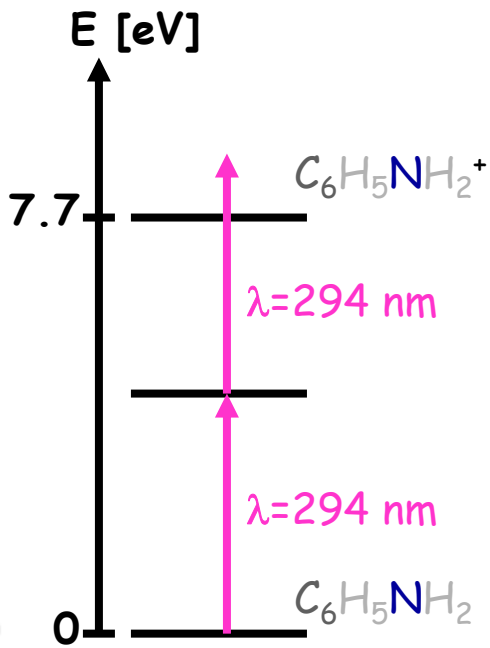
Experiments with single complex molecular ions

1+1 REMPI of the Aniline molecule

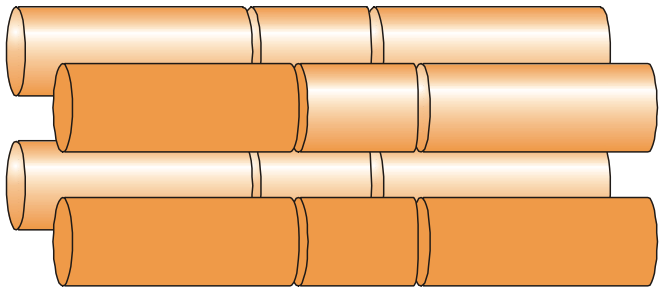
$C_6H_5NH_2$:

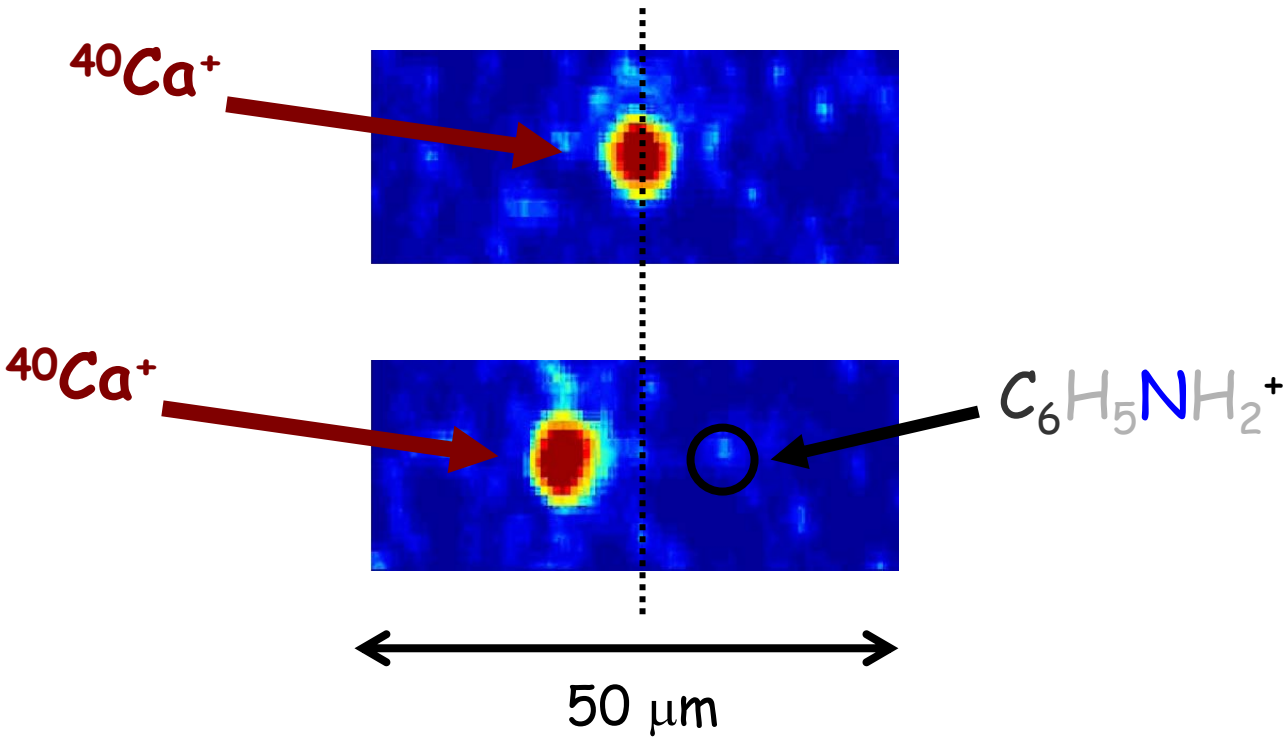




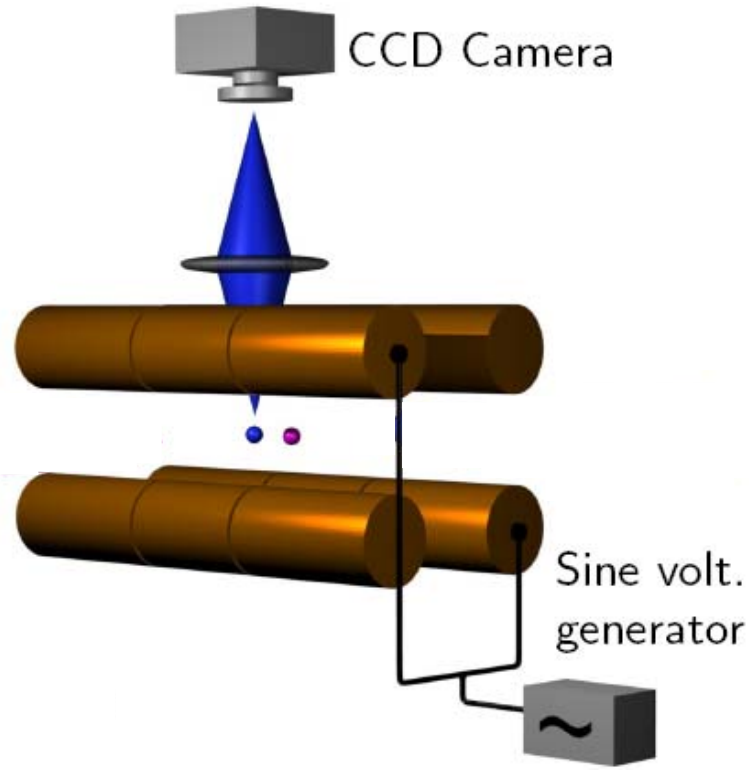


Observation of the production of a single Aniline ion

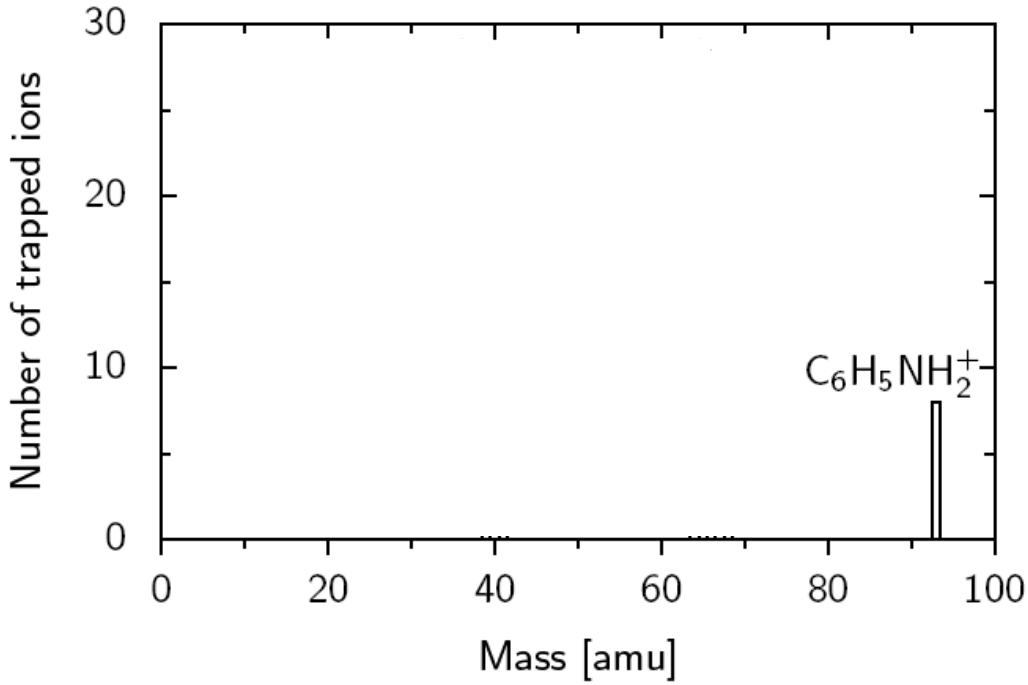




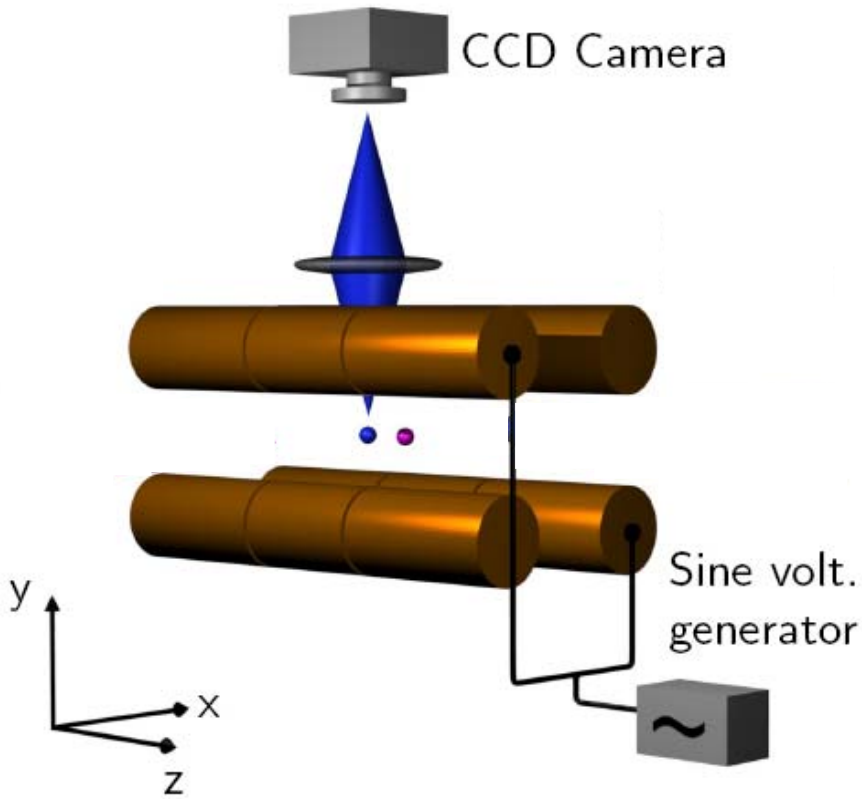
1+1 REMPI experiments with single Aniline molecules

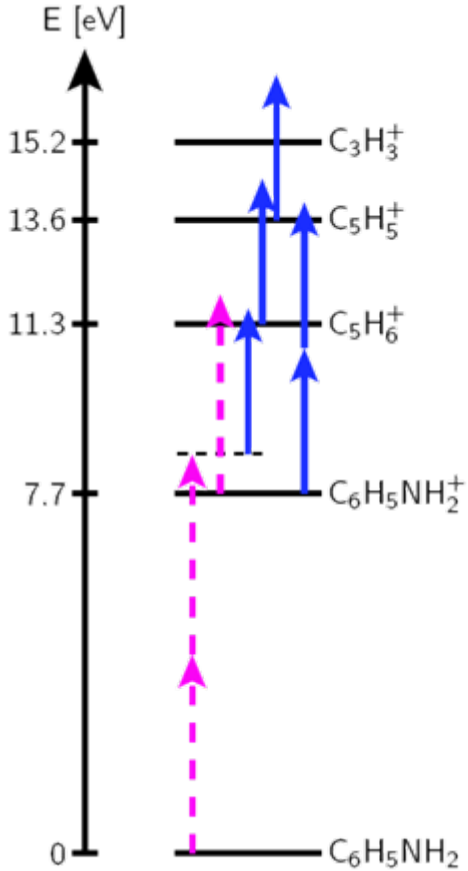


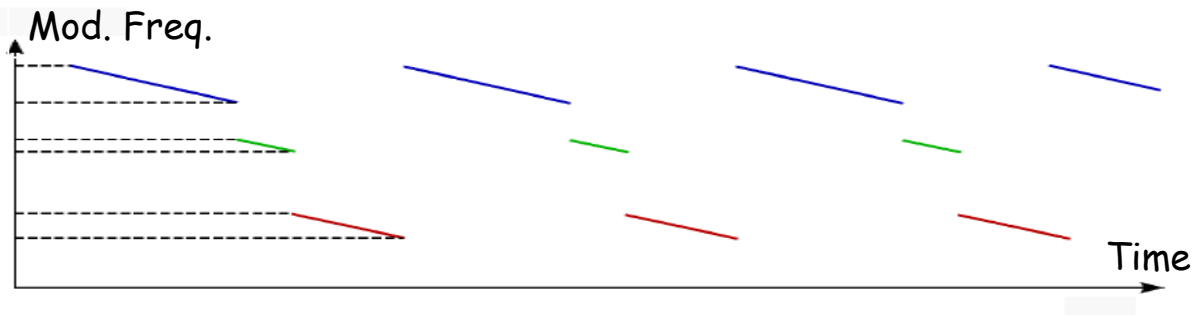
Mass spectrum



Explanation of observed molecular ions

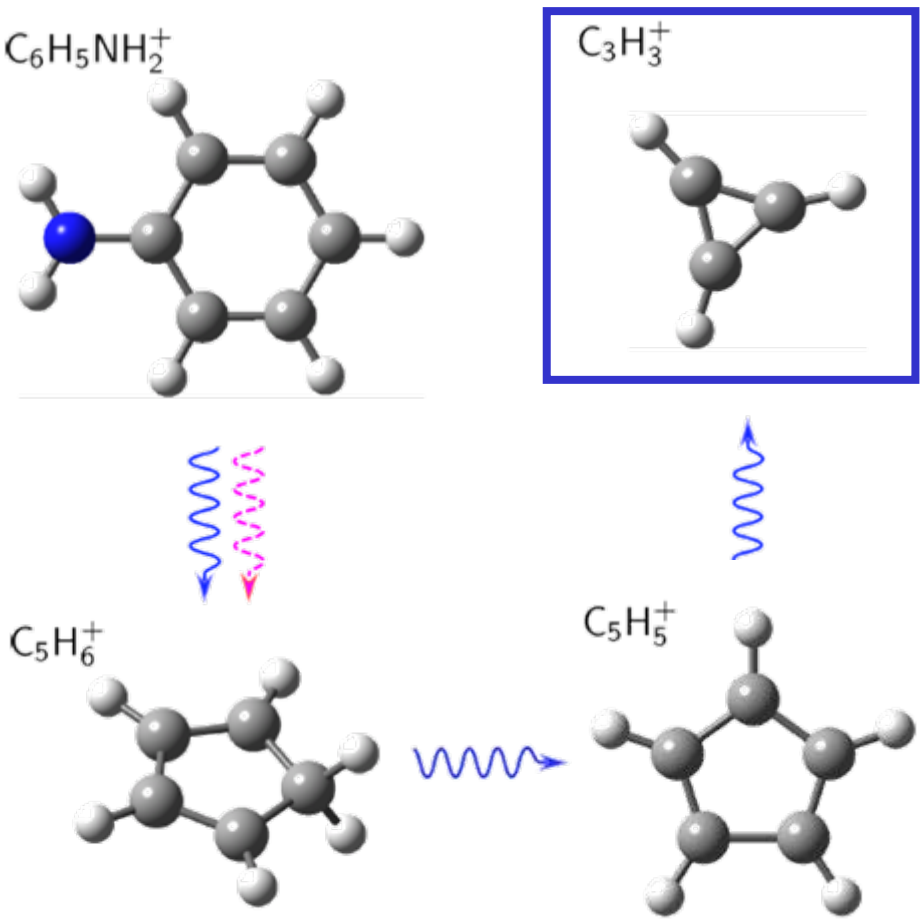


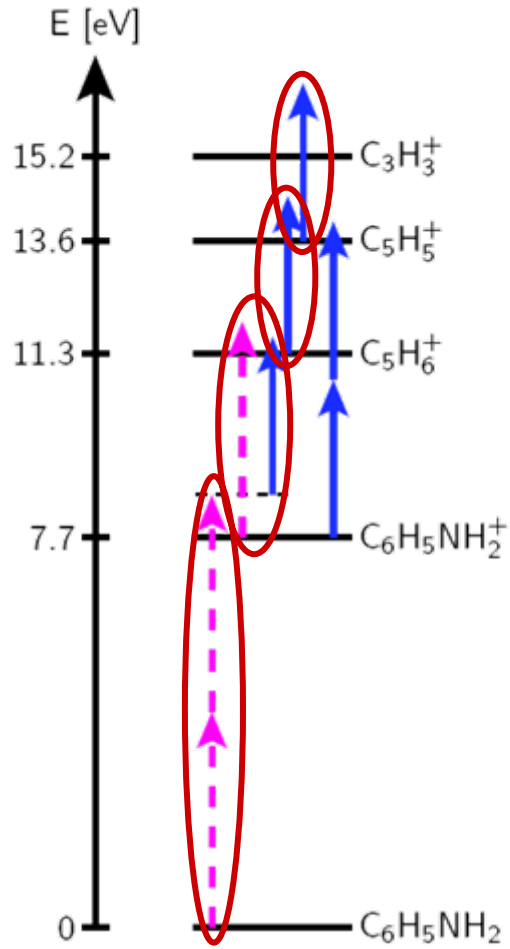




Observation of consecutive photofragmentation:

" Stable product"

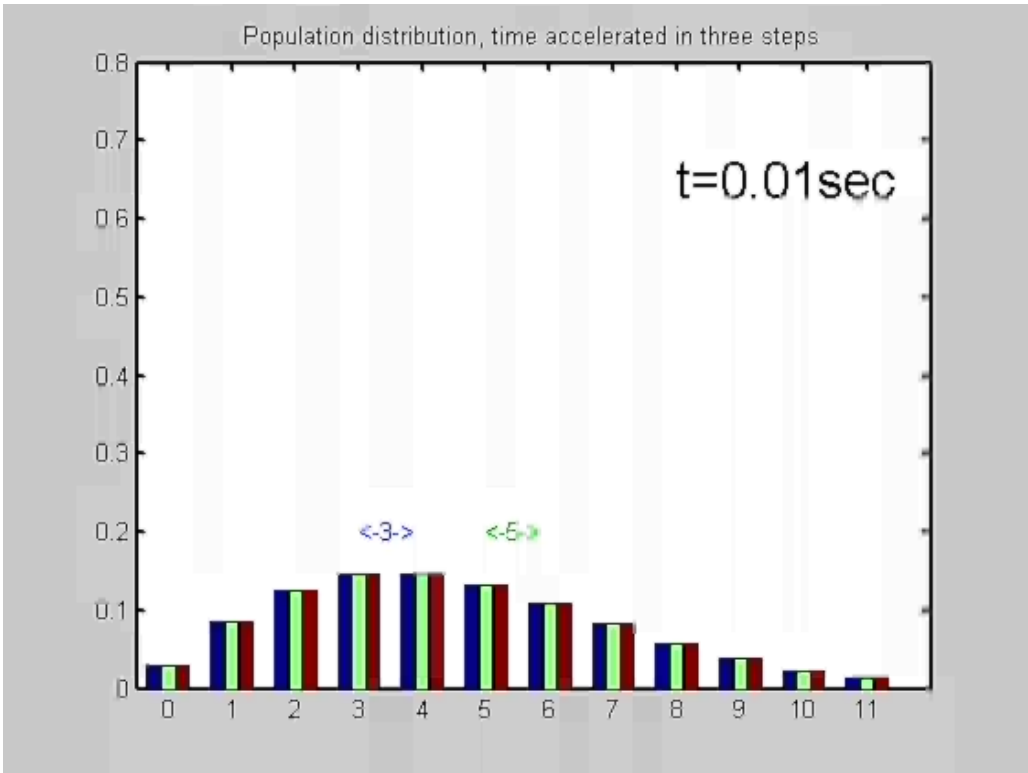


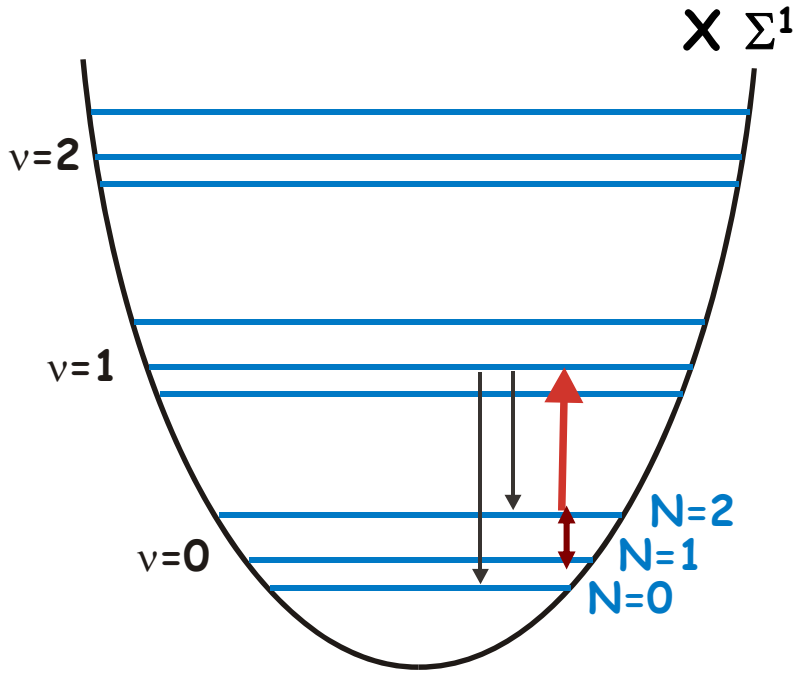


Rev. A 77, 030702(R) (2008)

III) How to produce internally cold mol. ions ?

MgH^+





J. Phys. B: At. Mol. Opt. Phys. **37**, 4571 (2004)

Two laser field cooling: Phys. Rev. Lett. **89**, 173003 (2002)

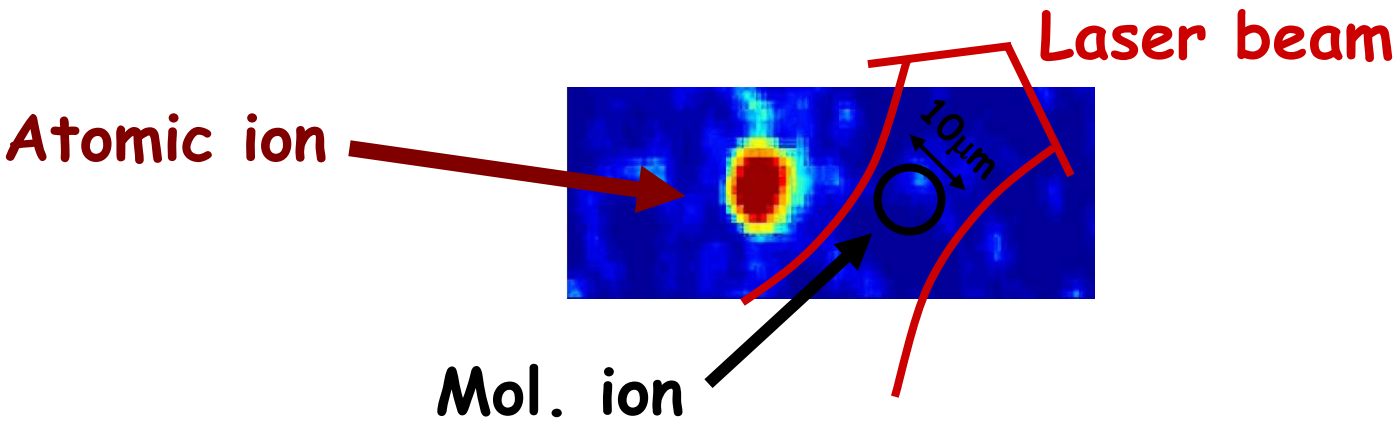
Ground potentials other than $^1\Sigma$: Phys. Rev. *A* **70**, 053412 (2004)

IV) Coherent manipulation of a single molecular ion

Advantages:

- Well-known target (Mass measurement)
- Spatial well-localized target ($|\Delta \mathbf{r}| \sim 1\ \mu m$)

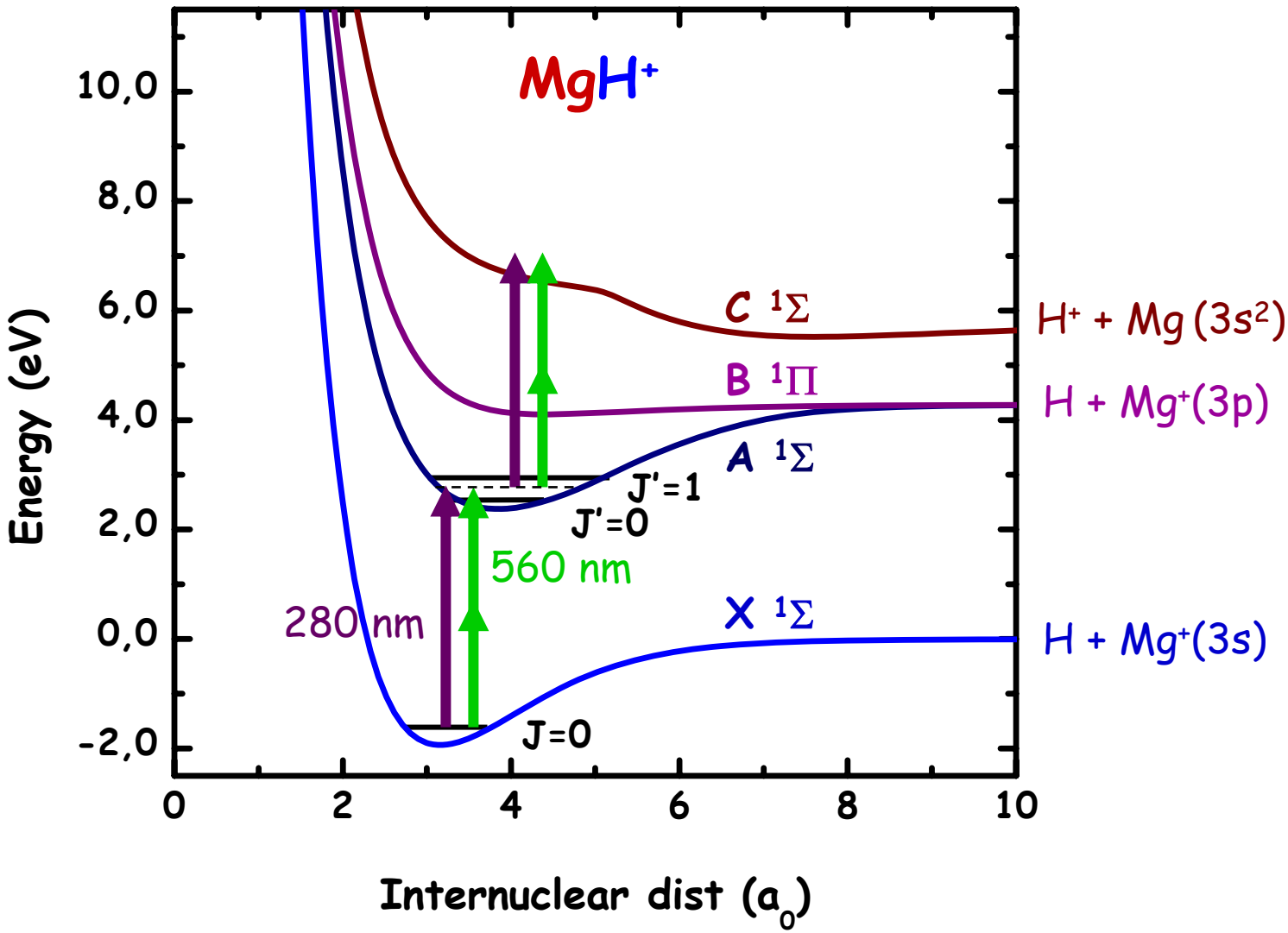
  => No volume averging effects
  (Well-defined phases and intensities at the target)



- No ensemble averaging (Internal state prep.)

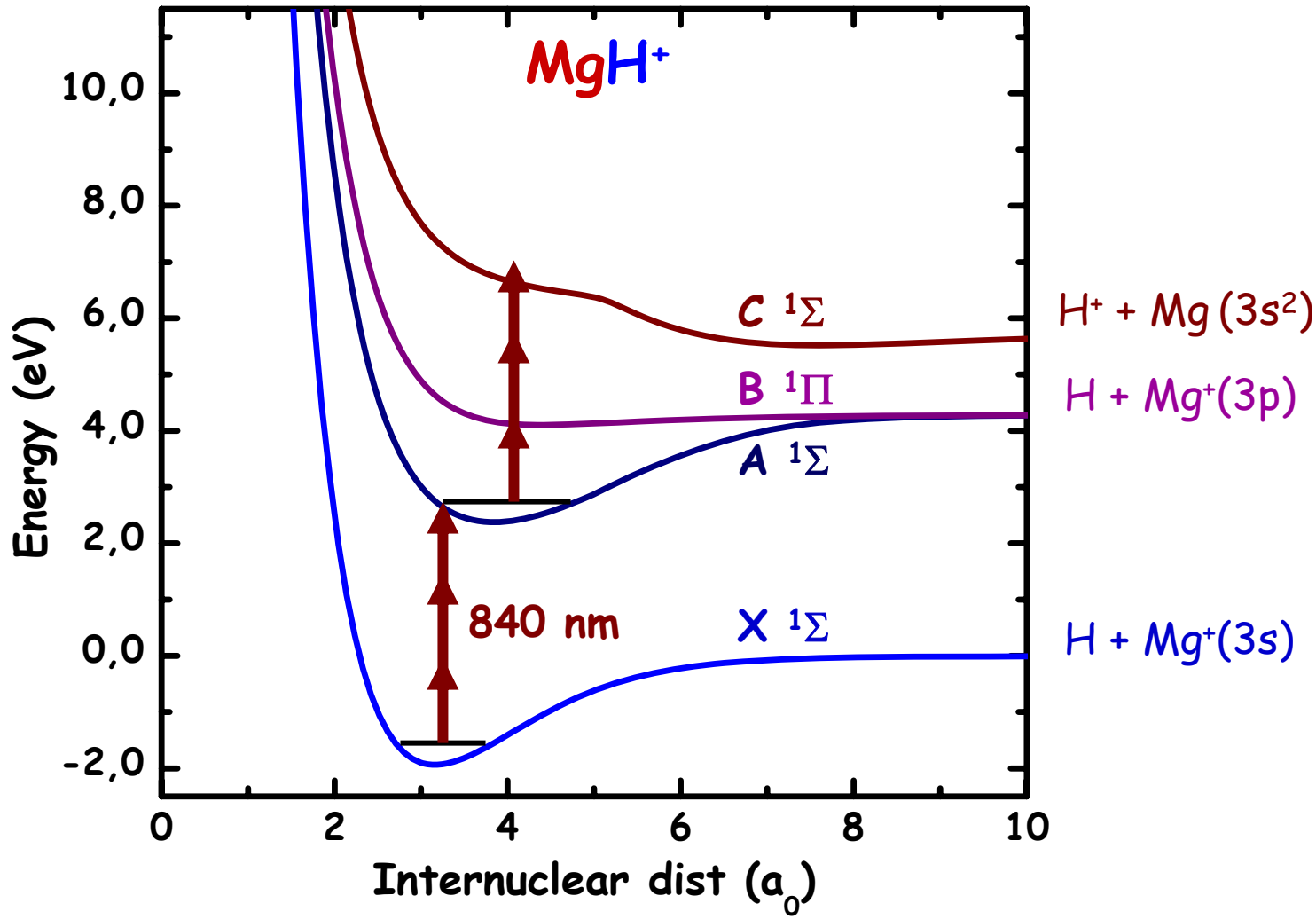
First goal: ns laser path-way interference

Interference paths in photodissociation of MgH^+



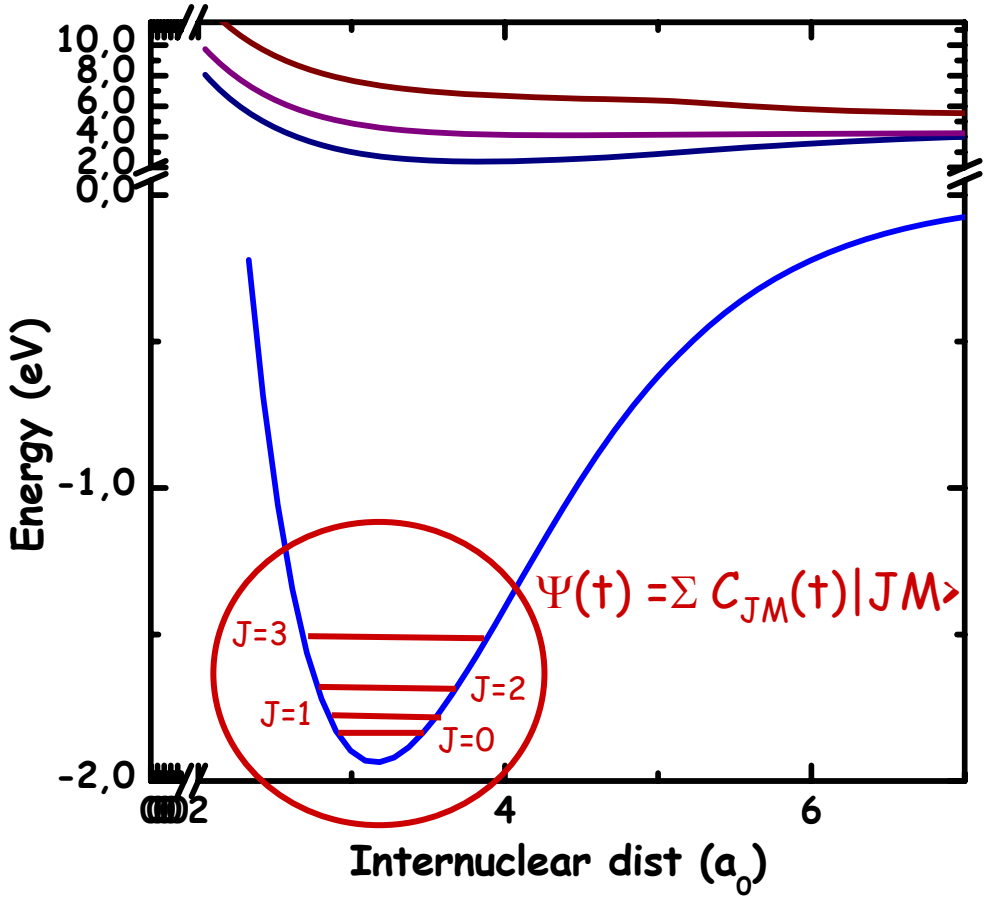
Study fs laser wave packet dynamics

Ex. I: Control of diss. through two-pulse interference



Ex. II: Study long-term coherent rotational dynamics

Short pulse alignment + free evolution



Timescales available: ~fs -> ~s

Collaboration with Henrik Stapelfeldt, Dept. of Chem., Aarhus University, within FASTQUAST

PhD position open !

People involved mol. ion exp.

Ion Trap Group:

Jens Lykke Sørensen
Anders Mortensen
Peter Staanum

Klaus Højbjerre

Kristian Mølhave
Niels Nissen
Anders Bertelsen

Visitors:

David Offenburg
Roland Wester
Stefan Willitsch

Fs-laserlab:

Henrik Stapelfeldt
Christer Z. Bisgaard

Theory (cooling):

Lars B.Madsen
Ivan S.Vogelius

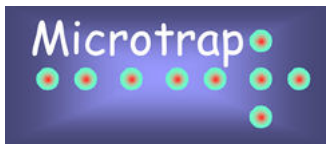
Theory (diss. dyn.):

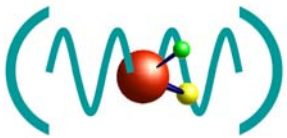
Solvejg Jørgensen
Ronnie Kosloff

Theory (coh.cont.):

Moshe Shapiro

Funding





Lundbeck

Carlsberg