

Trapping of cold molecules

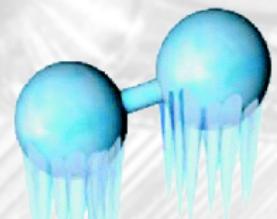
Optimizing the Stark decelerator beamline using evolutionary strategies



Jochen Küpper

*Fritz-Haber-Institut der MPG
Berlin*

20. June 2006



Cold Molecules



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Cold Molecules

Germany – Ecuador 3:0
Poland – Costa-Rica 2:1

1. Germany 9 points
2. Ecuador 6 points
3. Poland 3 points
4. Costa Rica 0 points

Applications of cold molecules

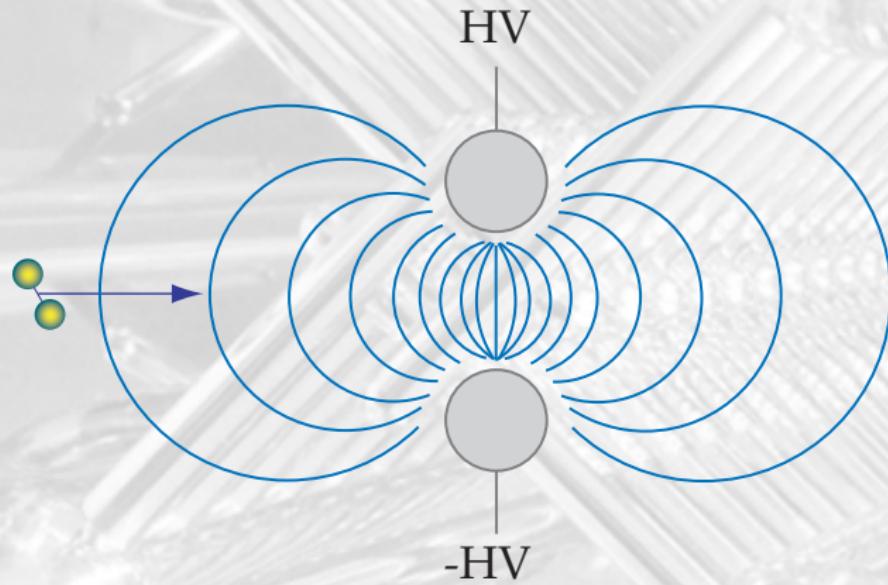
- Getting complete control over both the internal and external degrees of freedom of molecules:
 - Beams of molecules in a single (or a small subset of) quantum states
 - Spatially oriented molecules
 - Beams/packets of molecules with a computer controlled velocity distribution
- Slow molecular beams for metrology; sensitive symmetry tests:
 - Weak interactions in chiral molecules
 - Time-reversal violating electric dipole moment of the electron (EDM)
 - Time variation of fundamental constants (i. e. da/dt)
- Novel molecular beam collision, reaction, and interferometry experiments:
 - Conformational interchange and dynamics (*folding*)
 - Collisions at variable, well-defined energies
 - Scattering resonances
 - Quantum-controlled chemistry
- Ultra-low temperature phenomena:
 - Anisotropic dipole-dipole interaction:
 - repulsive
 - attractive
 - Molecular BEC

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Stark effect

Interaction of molecular charge distribution with external electric field:



$$U_{pot} = W_{Stark}$$

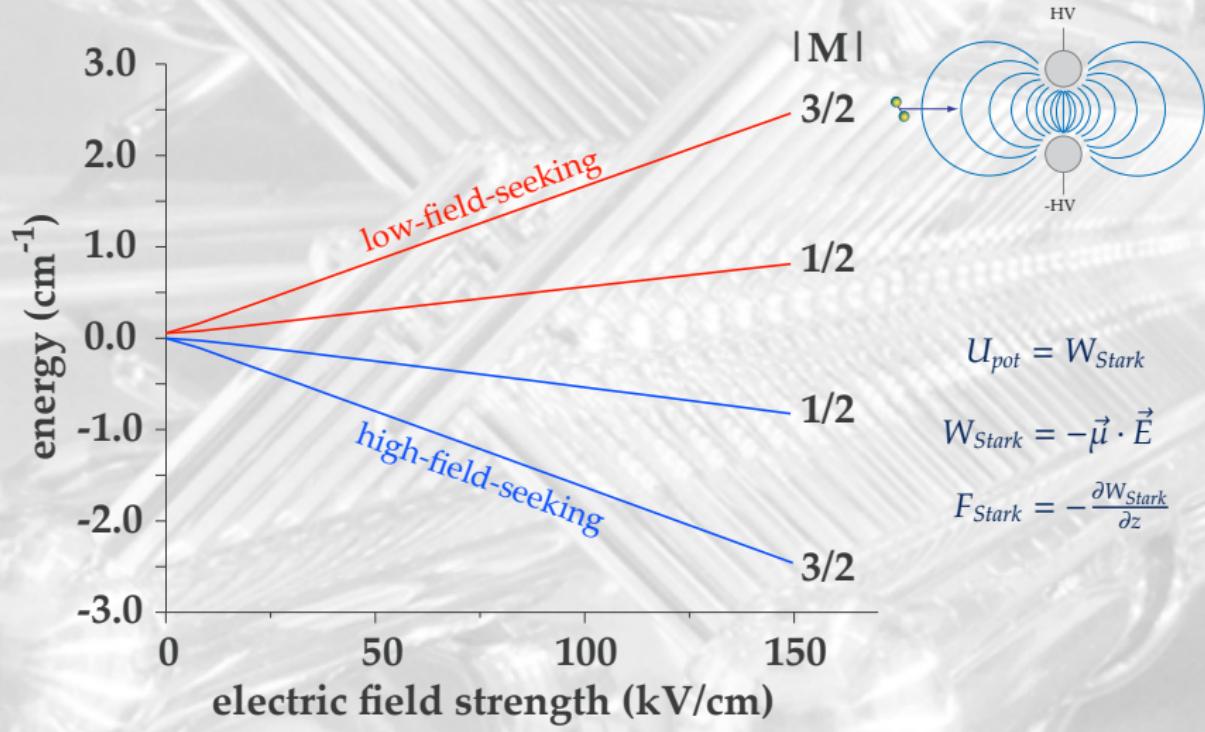
$$W_{Stark} = -\vec{\mu} \cdot \vec{E}$$

$$F_{Stark} = -\frac{\partial W_{Stark}}{\partial z}$$

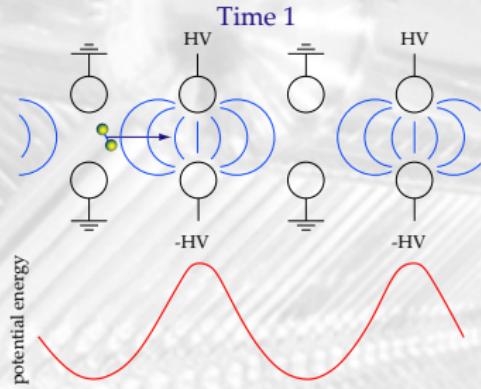
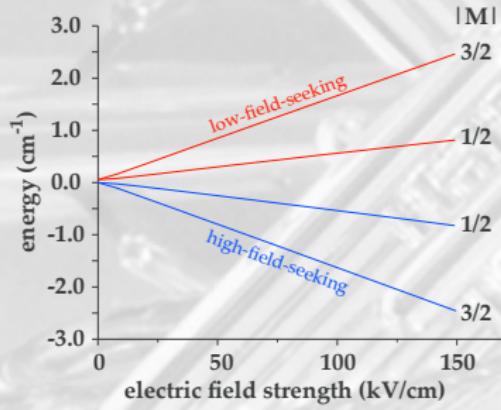
Stark effect of OH

$X^2\Pi_{3/2}, v = 0, J = 3/2$

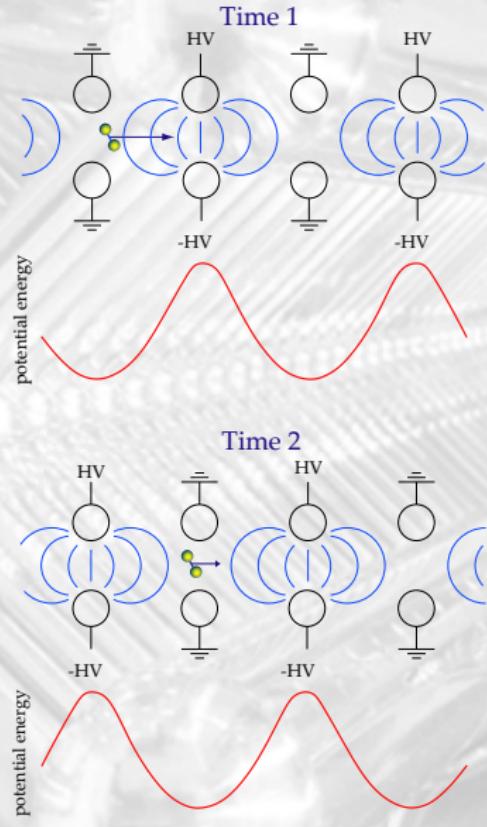
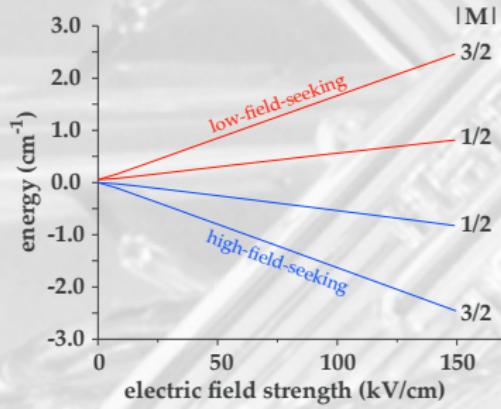
Interaction of molecular charge distribution with external electric field:



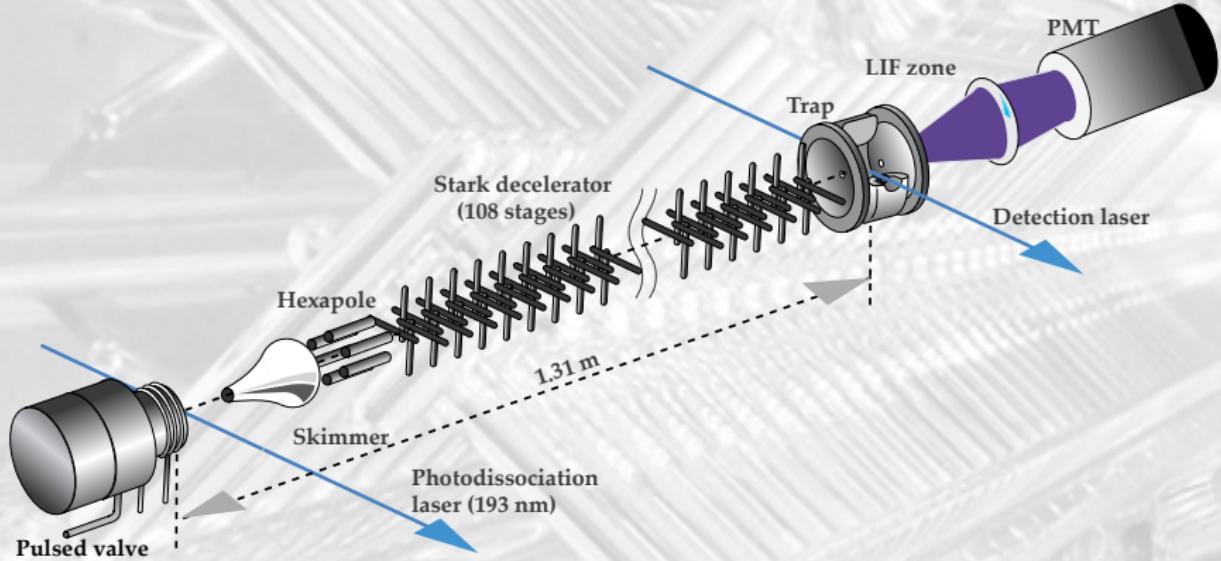
Deceleration principle



Deceleration principle



Experimental setup



Experimental setup

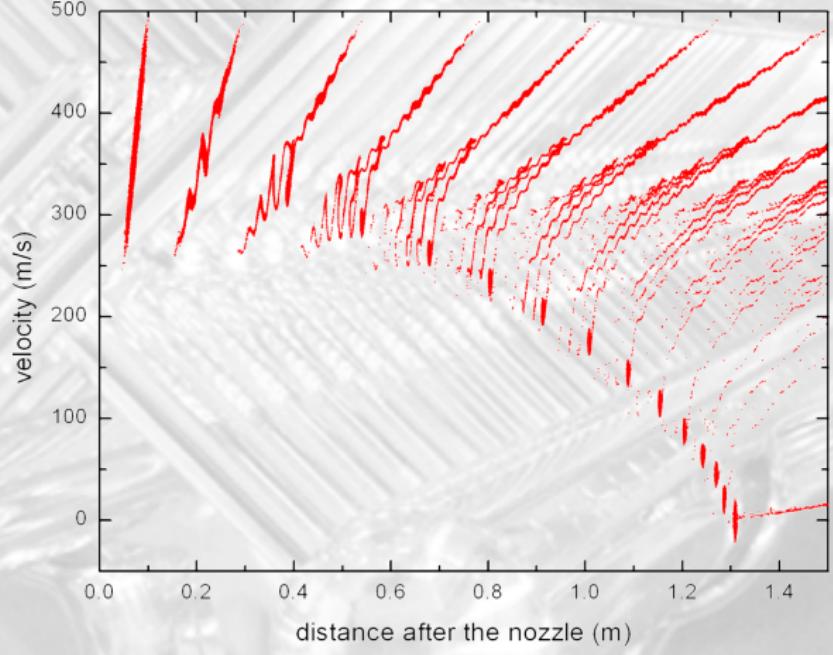
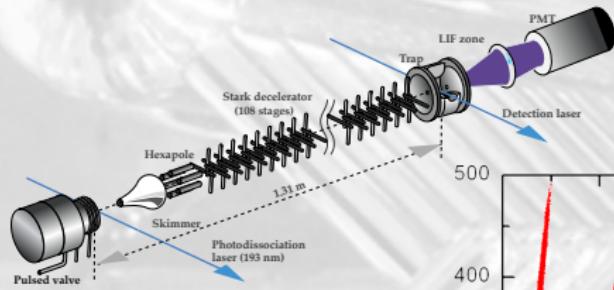


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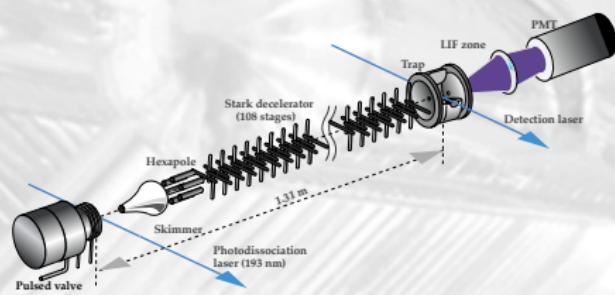
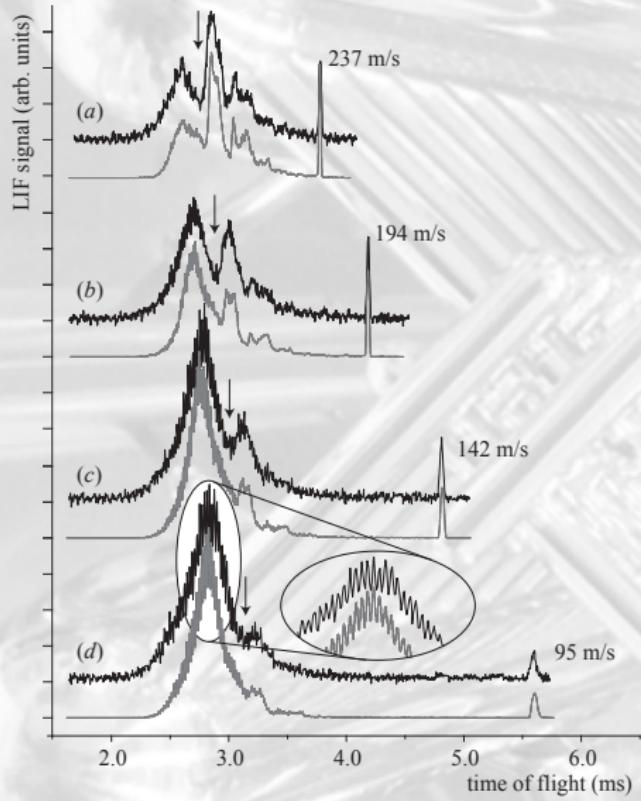


Experimental setup

Phase-space evolution

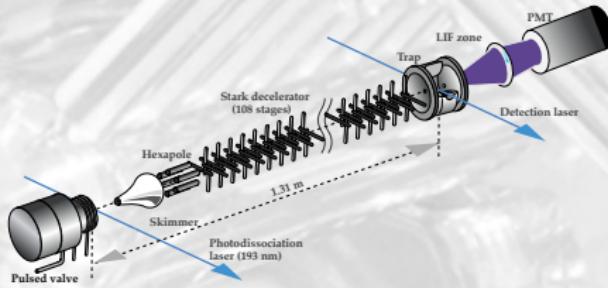
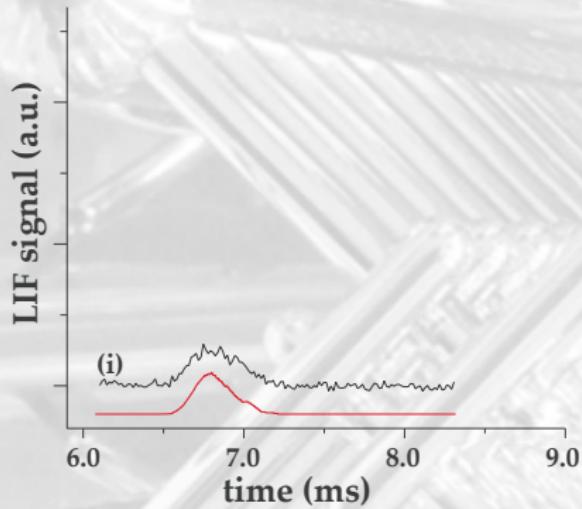


Stark deceleration



- OH radicals in a *single quantum state* are trapped in the traveling potential well of the decelerator
- translational temperatures ~ 100 mK
- molecules can be decelerated to any computer-controlled velocity
- 10^6 OH radicals per packet
- density of 10^7 – 10^8 cm $^{-1}$

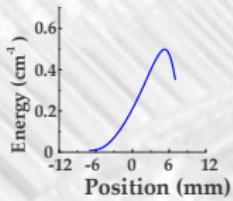
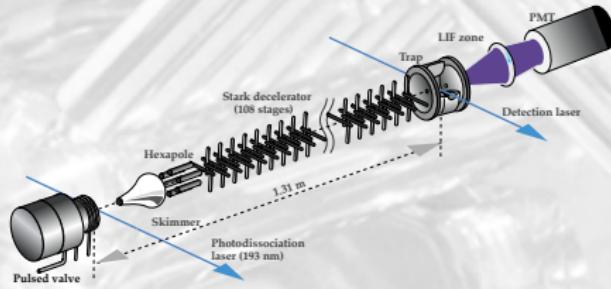
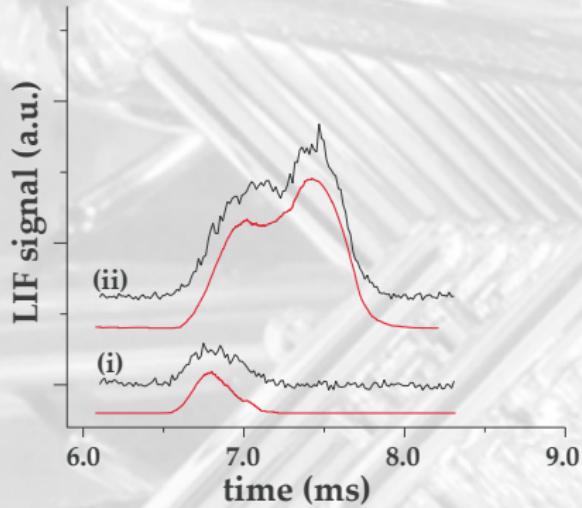
Trap loading and trapping

Meerakker et al, *Phys. Rev. Lett.* **94**, 023004 (2005)

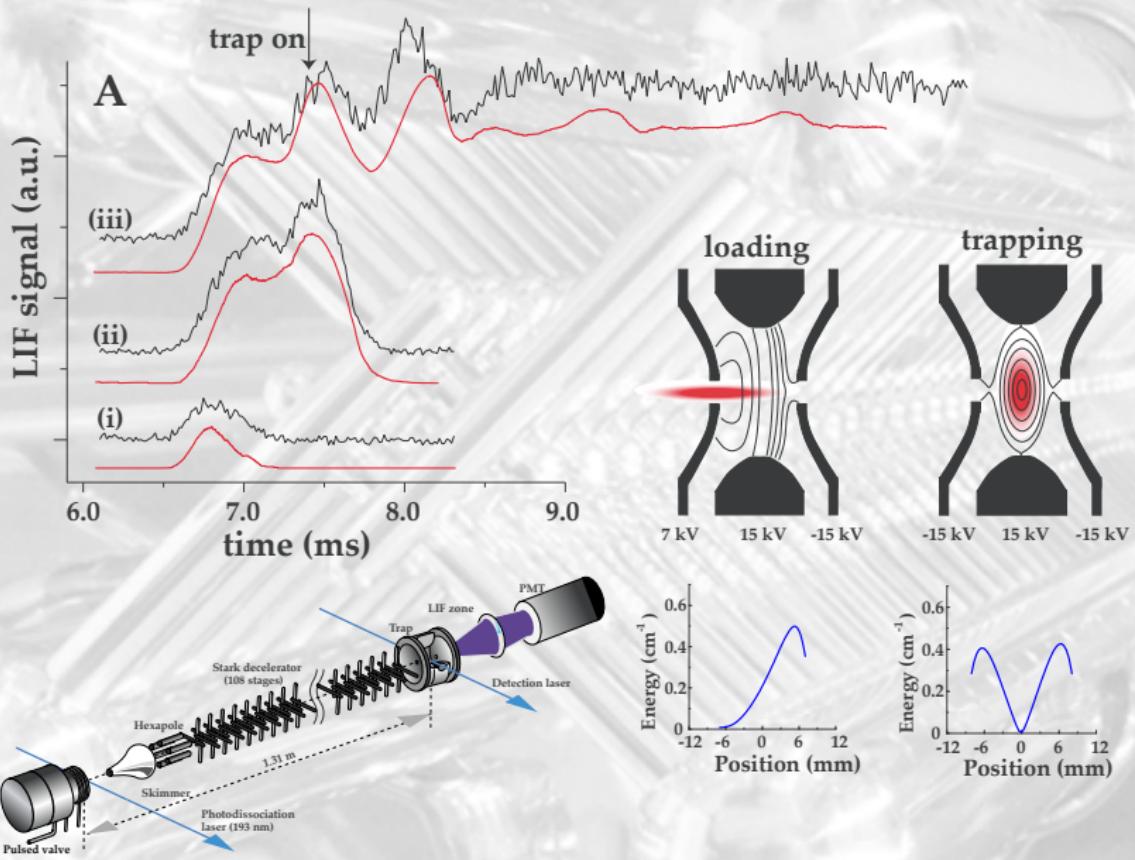
Columbus, OH — 20. June 2006

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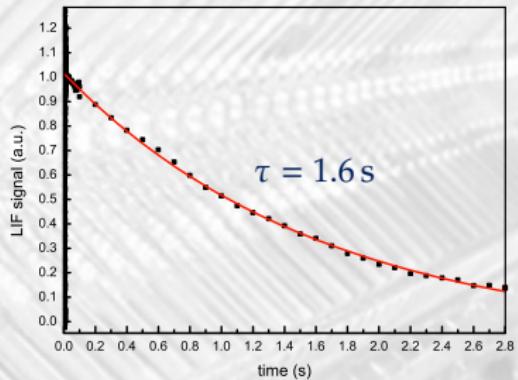
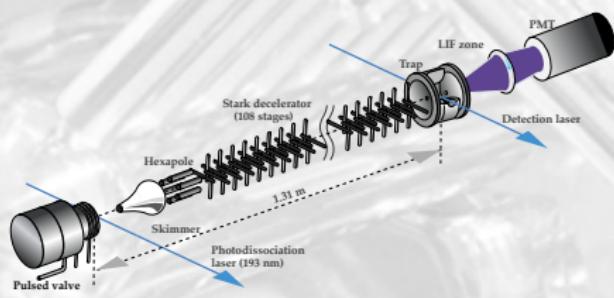
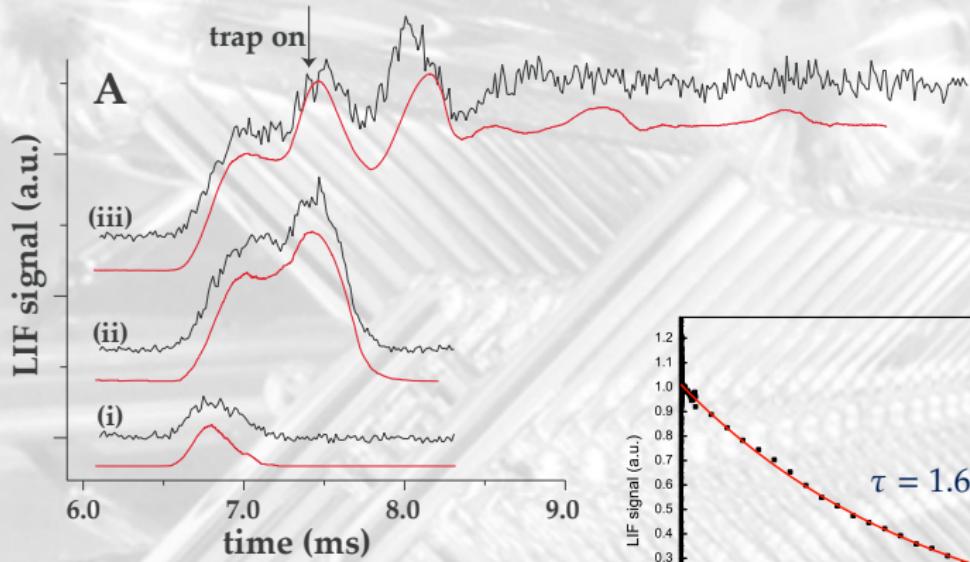
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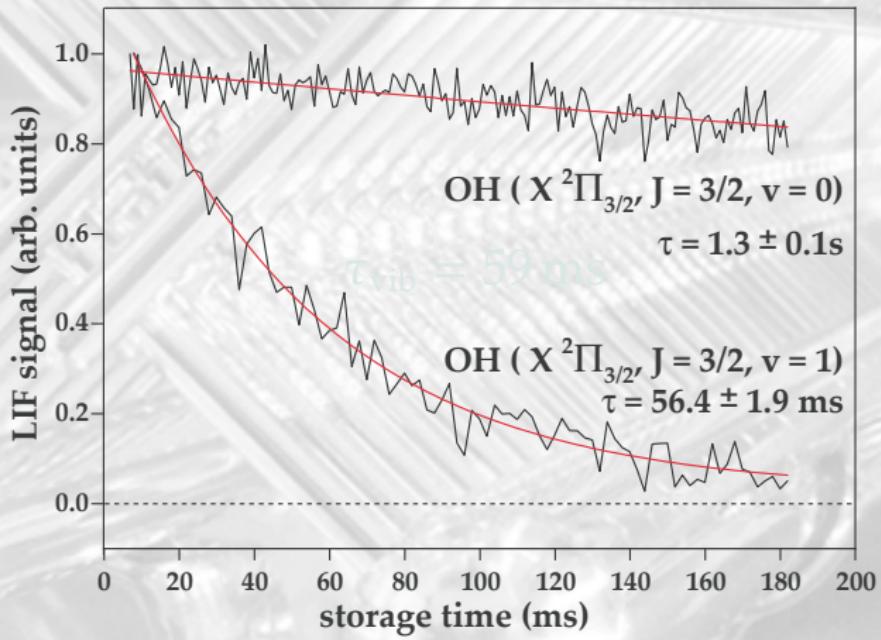
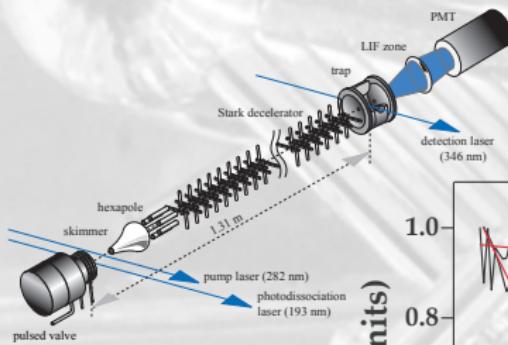


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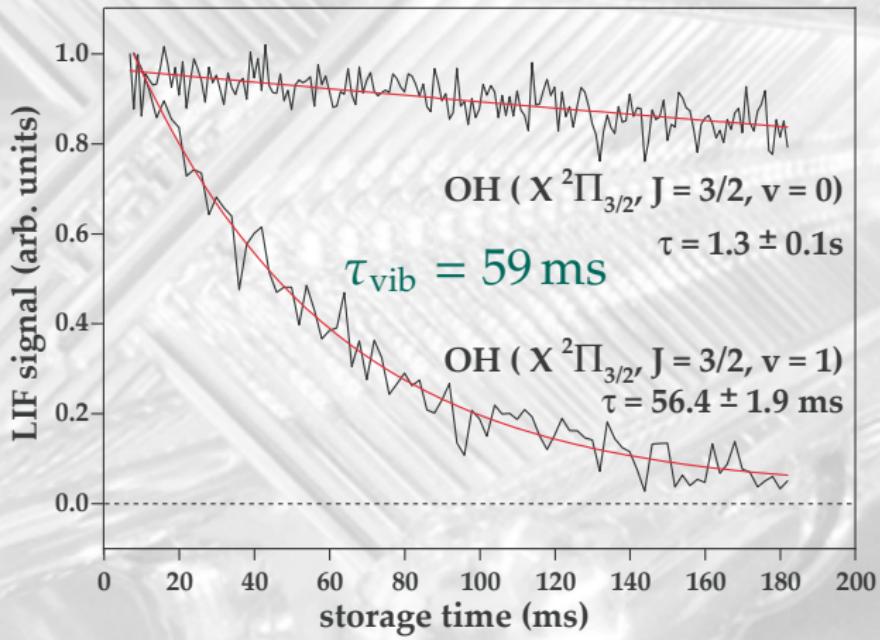
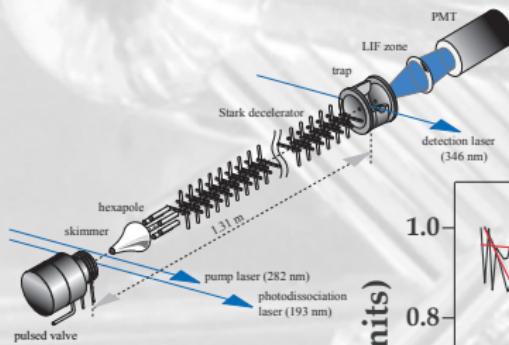
Direct lifetime measurements

The vibrational lifetime of OH $X^2\Pi_{3/2}, v = 1, J = 3/2$



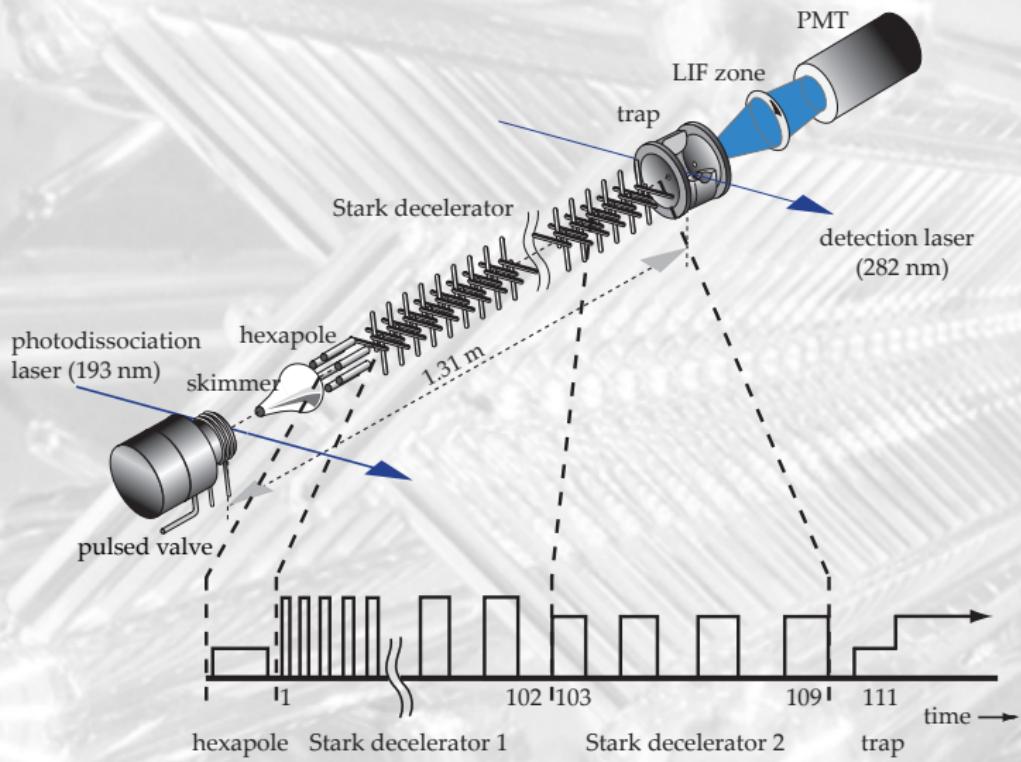
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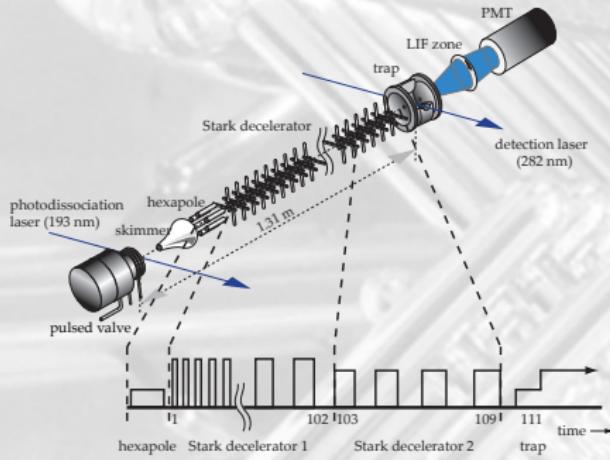
Optimization parameter



Gilijamse et al, arXiv physics/0603108, accepted by Phys. Rev. A 73 (2006)

Parameter encoding

Parameter reduction



full parameter vector:

$$\boldsymbol{t} = (t_1, p_{1,0}, \dots, t_{102}, p_{102,0}, \dots, (\mathbb{R}^+)^{106})^\top$$

- Encode deceleration in polynomial:
Decelerator 1 ($i = 1\text{--}102$):

$$t_i = t_{i,0} + \sum_{j=0}^{o_1} p_{j+1} \cdot (i - 1)^j$$

- Decelerator 2 ($i = 103\text{--}106$):

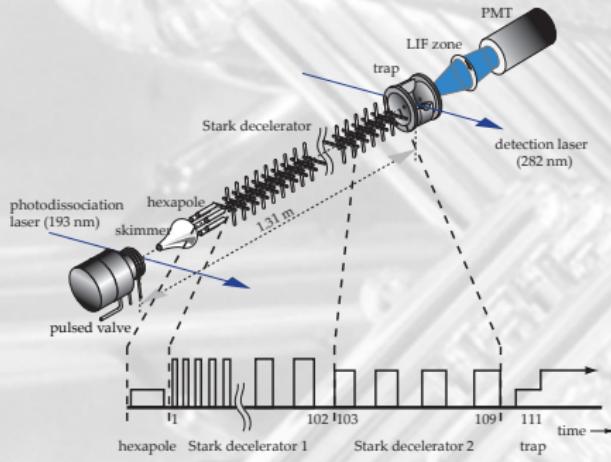
$$t_i = t_{i,0} + \sum_{j=0}^{o_2} p_{j+o_1+2} \cdot (i - 103)^j$$

- Directly use Δt 's for last timings
($i = 107\text{--}111$):

$$\Delta t_i = t_i - t_{i-1} = p_{i+o_1+2} - 103$$

Parameter encoding

Parameter reduction



Full parameter vector

$$\vec{P} = (p_1, p_2, \dots, p_{o_1+o_2+7})^T \in (\mathbb{R}_+)^{1+o_2+7}$$

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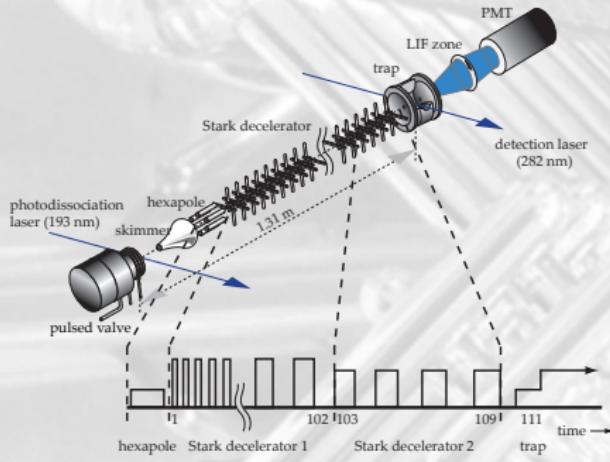
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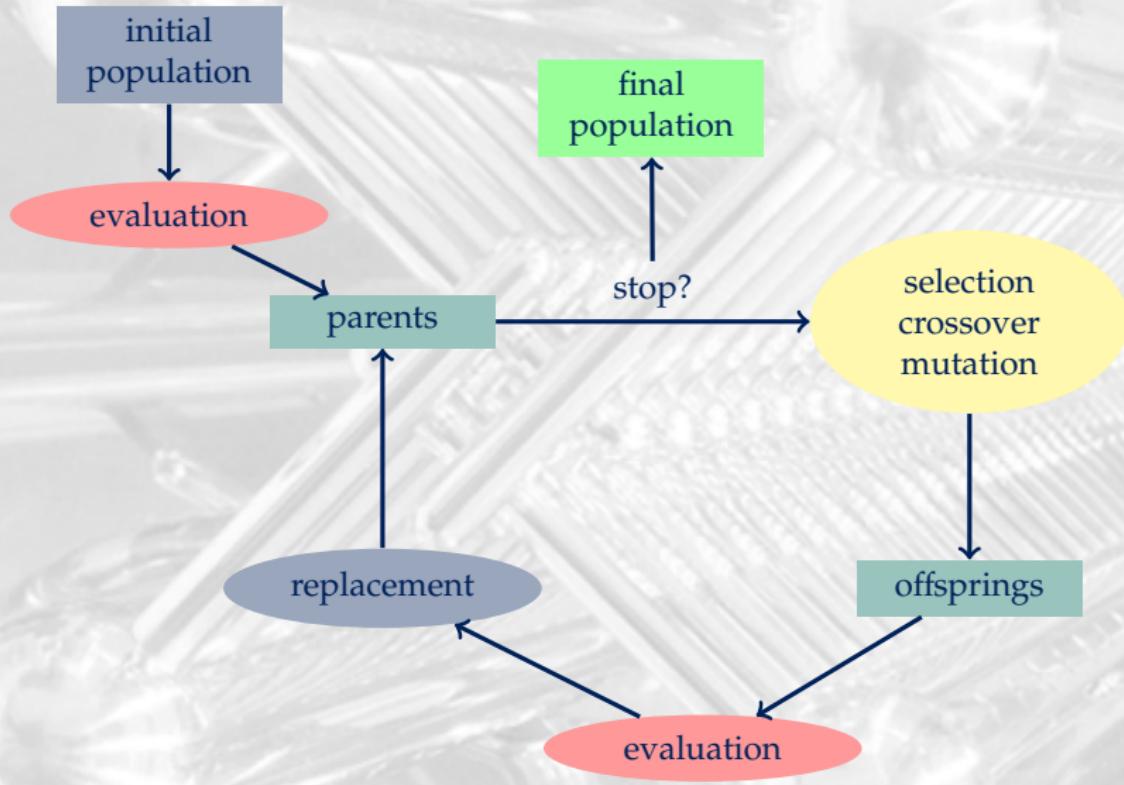
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Evolutionary Algorithms



Implementation of experimental feedback-control system

- Completely computer-controlled experiment:
 - Homebuilt burst-units to control high-voltage switches
 - 4 channels per unit, 10 ns resolution, FPGA-based 6U-cPCI cards
 - User-friendly homebuilt control and data-acquisition software KouDA
 - C++, Qt, VxWorks, Linux → <http://kouda.cold-molecules.info>
- Evolutionary computation framework:
 - *Evolving Objects* → <http://eodev.sourceforge.net>
- *eoEsSdevo* algorithm: Evolutionary Strategy with
 - individual mutation matrices for all parameters
 - optimization of mutation widths as meta-parameters
 - no correlation of parameters utilized

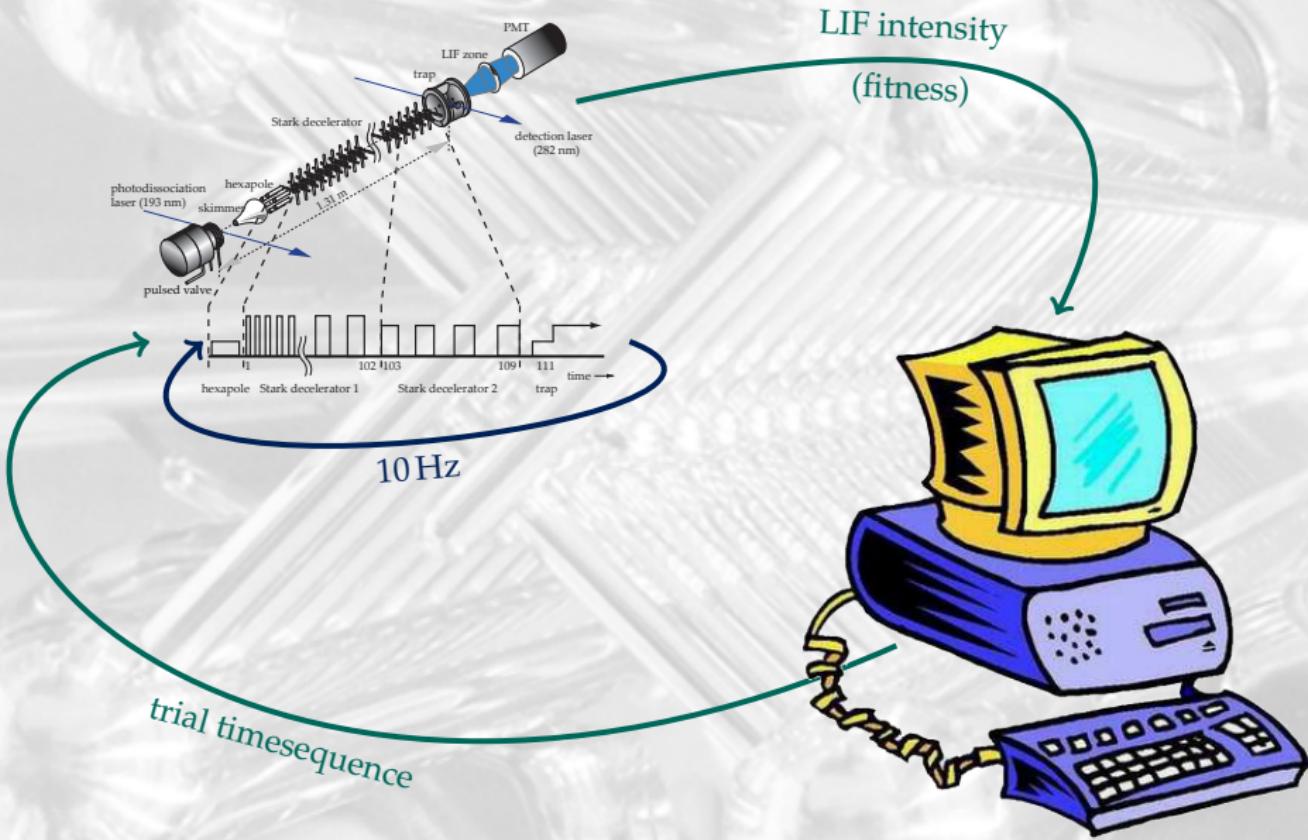
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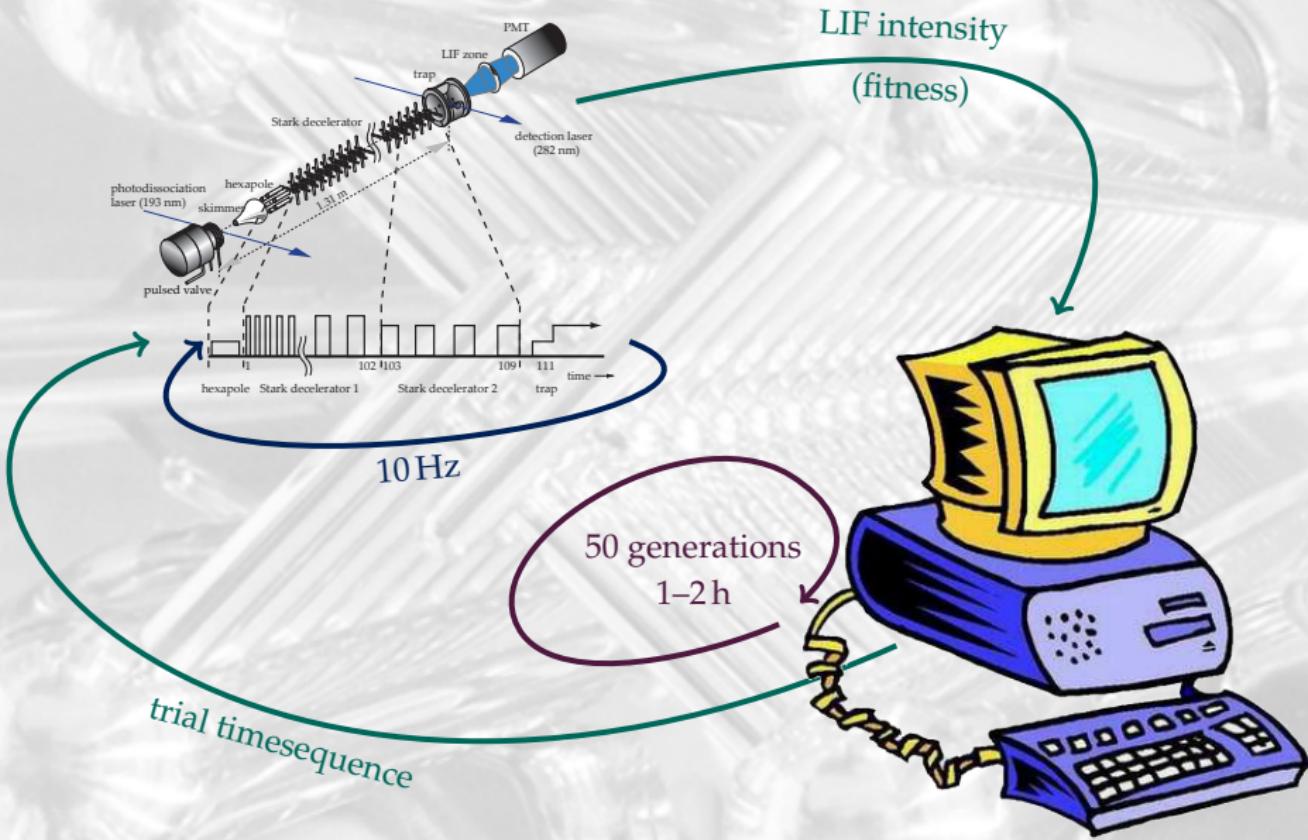
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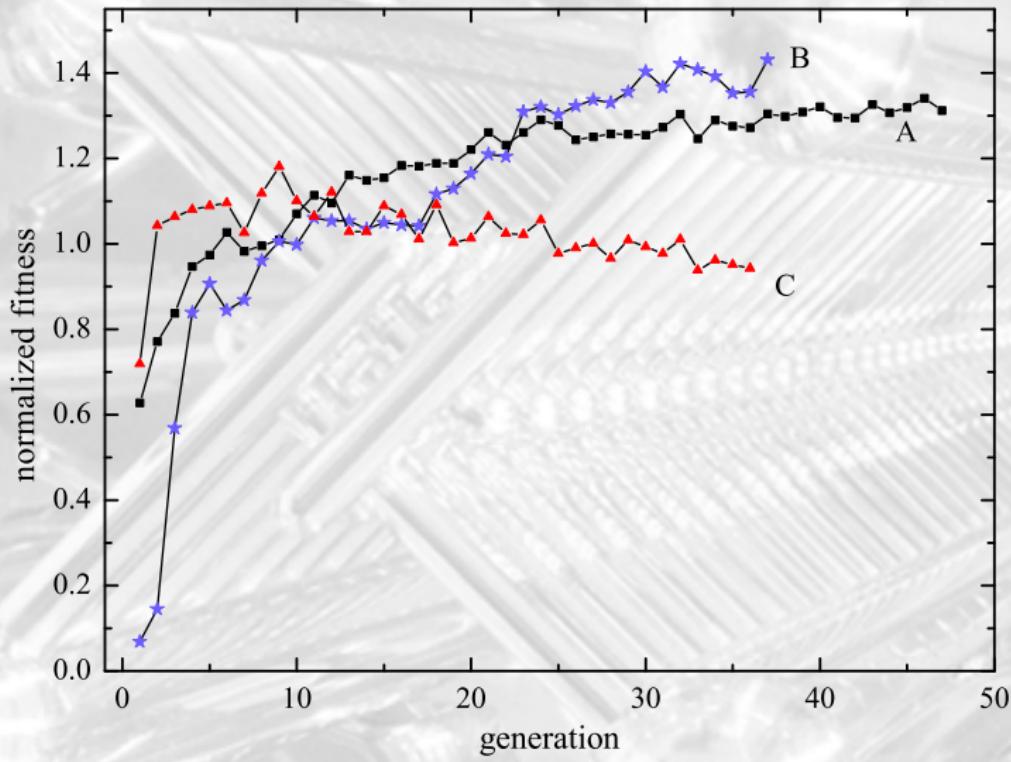
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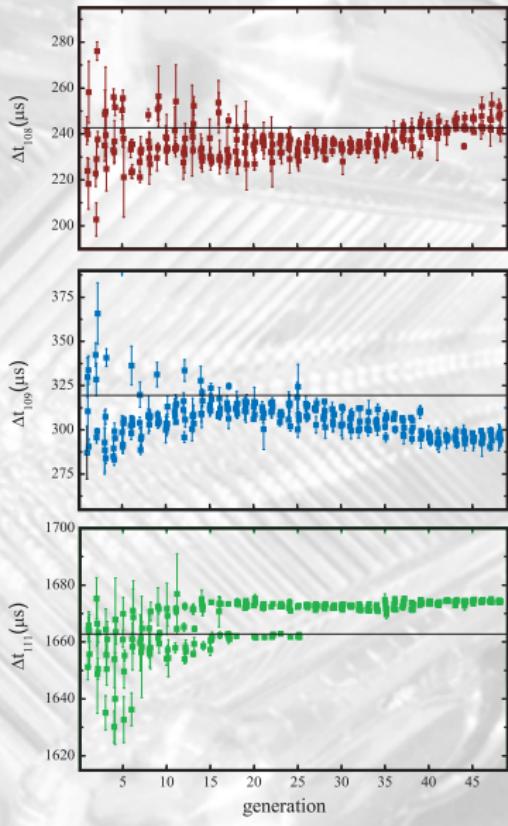
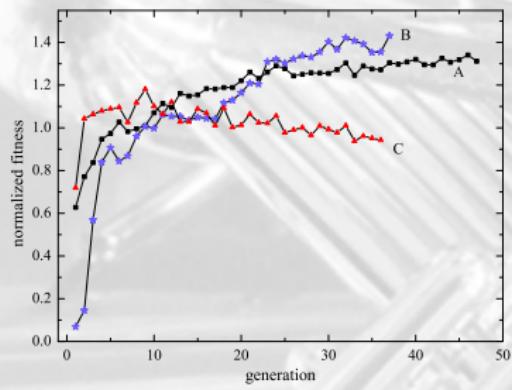
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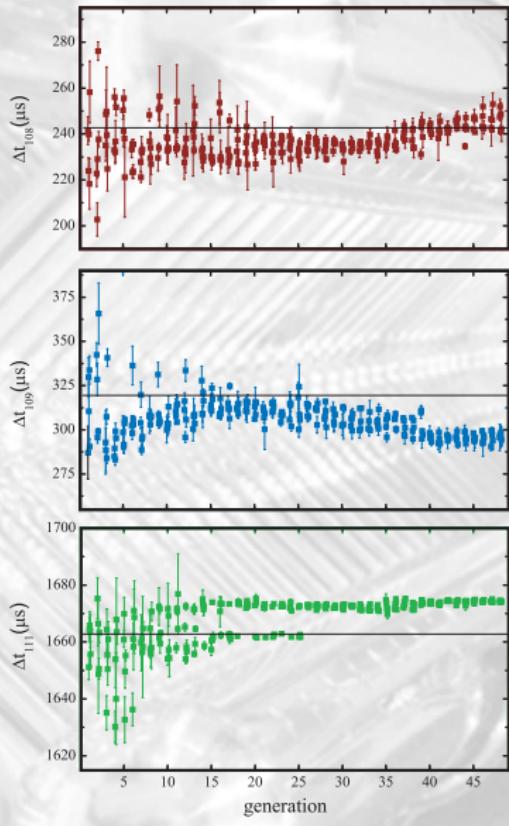
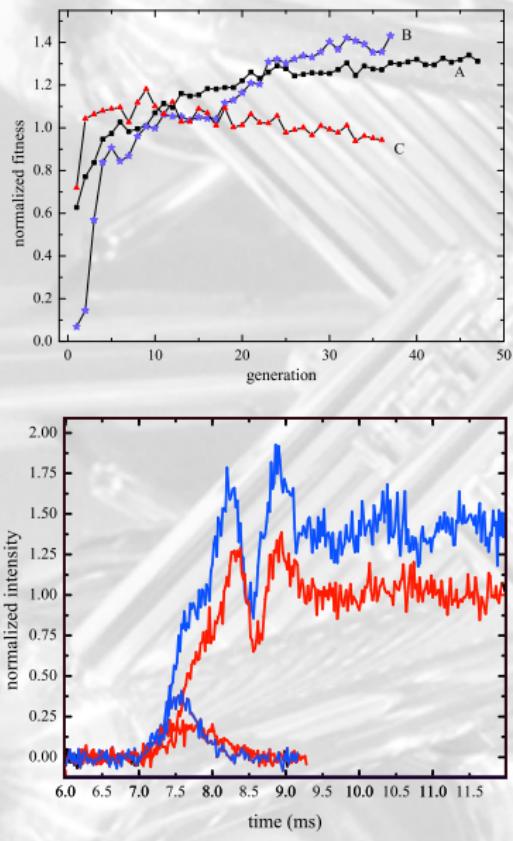
Optimization results



Optimization results



Optimization results



Gilijamse et al, arXiv physics/0603108, accepted by Phys. Rev. A 73 (2006)

Conclusions

- Time-varying electric fields can be used to decelerate and trap neutral polar molecules
- OH radicals have been trapped at a density of 10^7 – 10^8 cm^{-3} and a temperature of 50–500 mK
- The switching times of the Stark decelerator beamline have been optimized using evolutionary strategies
- The number of trapped OH radicals has been increased by 40 %
- Jochumse et al. arXiv:physics/0603108, accepted by *Phys. Rev. A*, 73 (2006)
- Advanced optimization objectives
 - Minimize footprint of trapped packet
 - Optimize number of trapped molecules and temperature simultaneously
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