Adiabatic Raman Photoassociation of a desired continuum waveform

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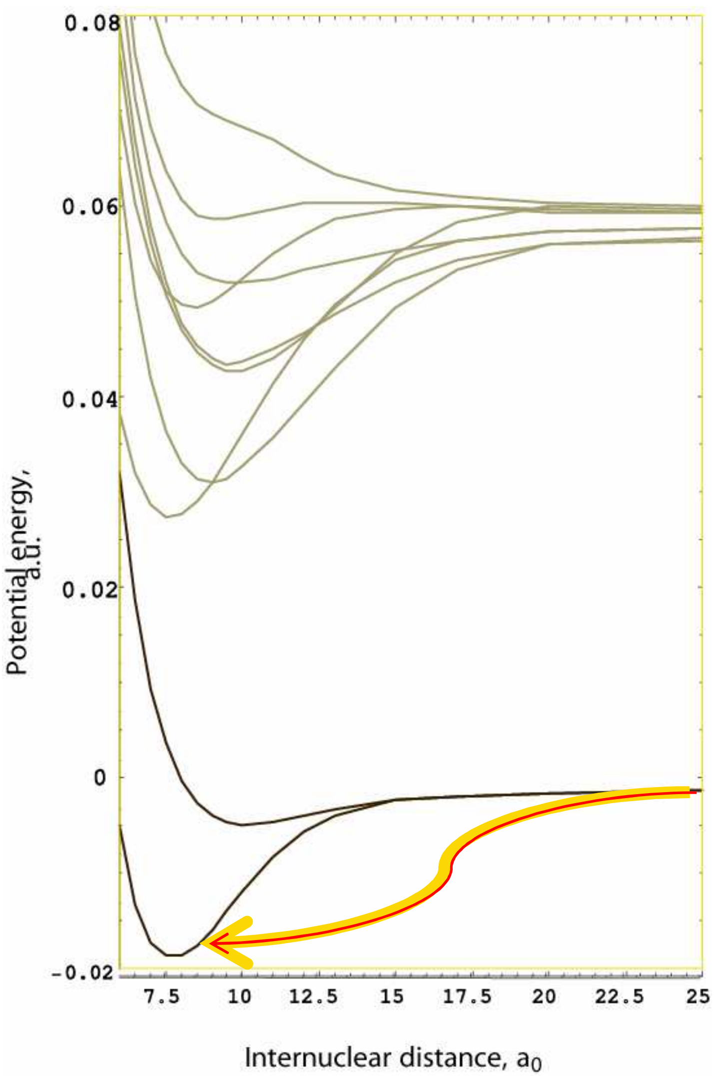
Outline

General picture:
coherent control to measure the input quantum state

- Adiabatic Raman Photoassociation
- Wavepacket measurement in PA with single input channel
- Superposition state measurement in multi-channel PA

Association of ultracold molecules



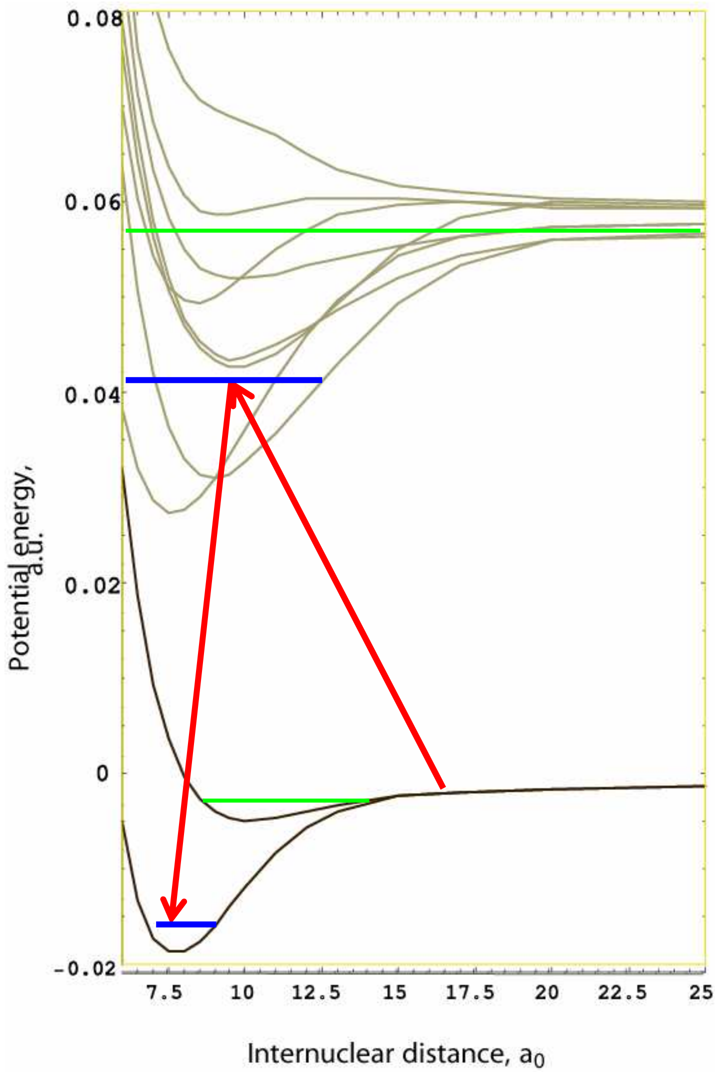
- cool dynamics
- cold molecules
- applications:

  few ↔ many particles, BEC, ….
  different chemistry
  quantum computation, …

Future:
complex dynamics in complex traps

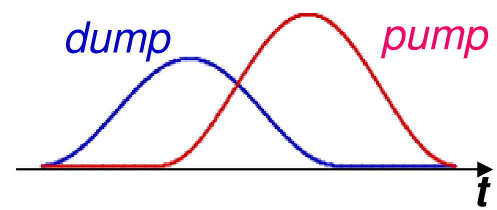
Creating "normal" molecules is difficult

(Adiabatic) Raman Photoassociation



Raman PA → PA spectroscopy
Band, Julienne, PRA **51** R4317 (1995).

STIRAP
Vitanov *et.al.*, Adv. At. Mol. Opt. Phys. **46** 55 (2001).



STIRAP-like PA
Vardi *et.al.*, JCP **107** 6166 (1997).

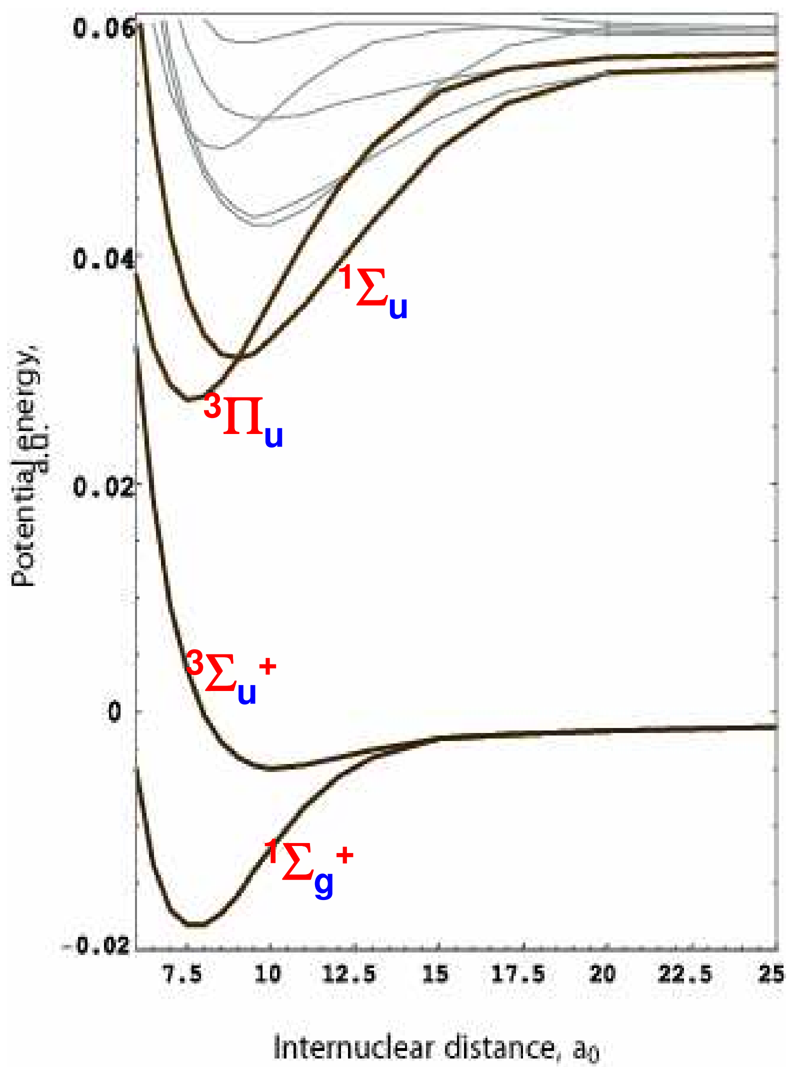
Is continuum-bound STIRAP possible?

Do the wave functions sufficiently overlap?

Can pulse shaping influence?

Next: STIRAP PA in an optical lattice - ?
With BEC - ?

Modeling of Rb_2, KRb



Potentials:

LS-coupled short-range $^1\Sigma_u$ and $^3\Pi_u$;
Short-range $^1\Sigma_g$ and $^3\Sigma_u$ smoothly joined with the long-range $-C_6/R^6$ such that the experimental scattering lengths are recovered.

Bound states:

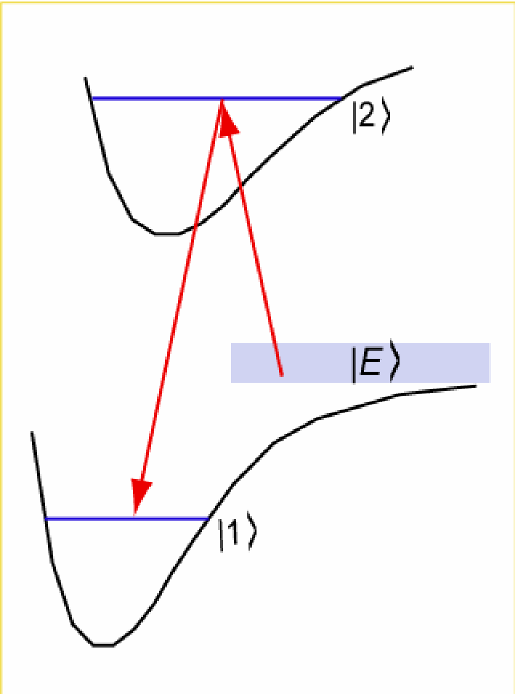
Finite-difference, A.&D. Abrashkevitch, Comp. Phys. Commun. **82** 193 (1994);

Bound-free FC factors:

Artificial Channel, M. Shapiro, JCP **56** 2582 (1972).

Rb_2 : u $\not\leftrightarrow$ u transition rule

Basics of the single-cannel PA



$$\psi = \sum b_i e^{-iE_i t} \left| i \right\rangle + \int dE \;\; b_E e^{-iEt} \left| E \right\rangle$$

RWA

Adiabatic elimination of the continuum

$$\dot{b}_1 = i\Omega_{bb}^{*} b_2$$

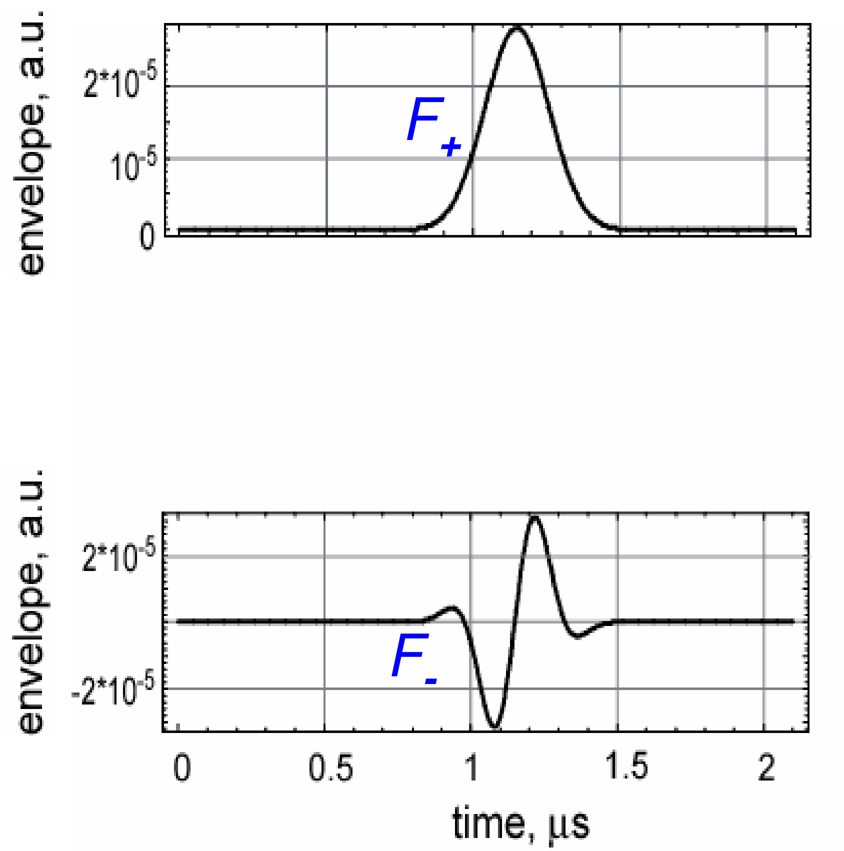
$$\dot{b}_2 = i\Omega_{bb} b_1 - \Gamma b_2 + i\Omega_E F_0(t)$$

Envelope of the initial continuum wave packet

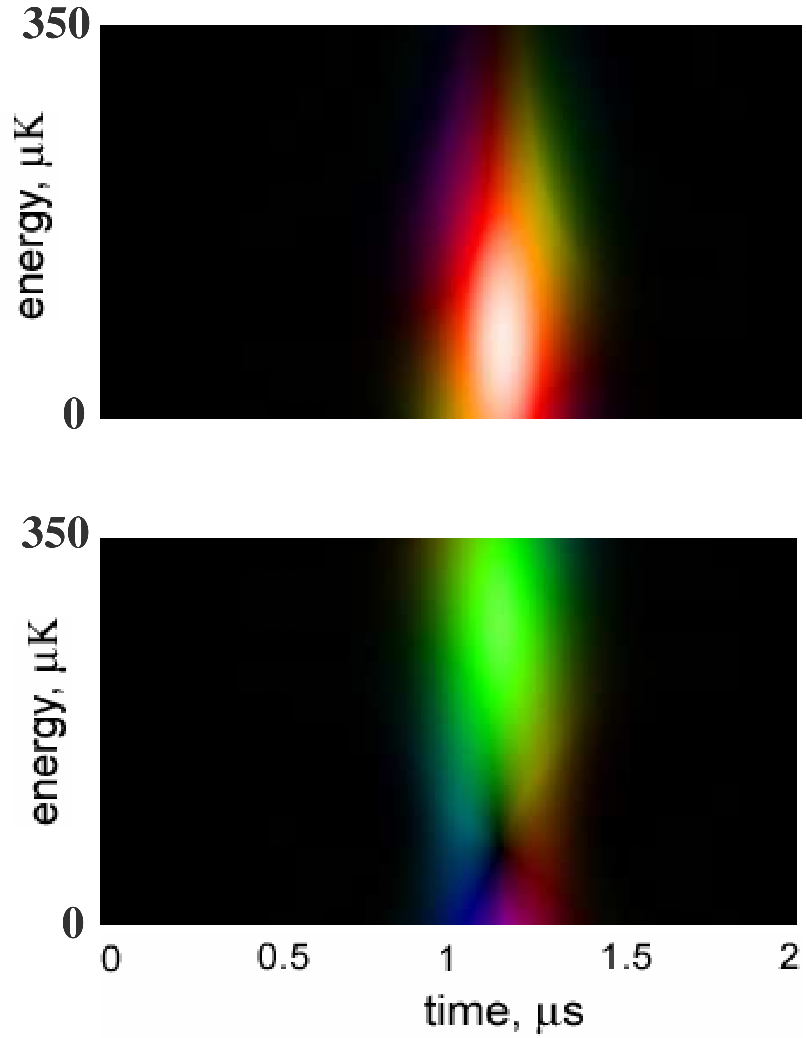
$$F_0(t) = \int b_{E,t=0} \, e^{i\Delta_E t} dE$$

Initial continuum wave packet

$$F_0(t) = \int b_{E,t=0}\, e^{i\Delta_E t}\, dE$$



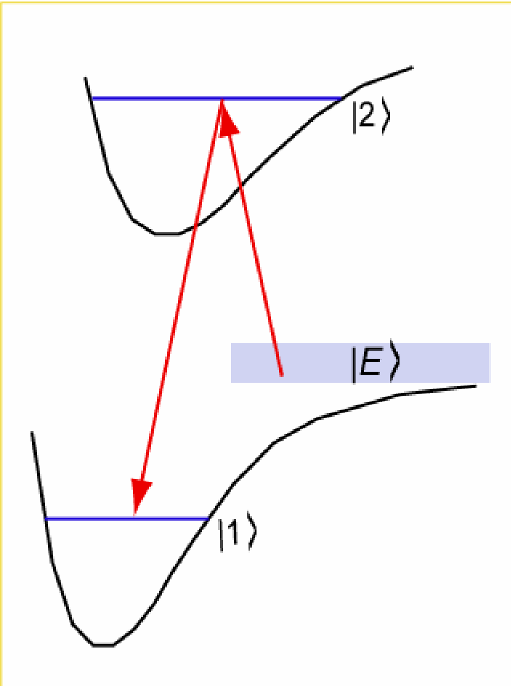
Time-energy Husimi function:



|0> vs. |1> as in PRL **91** 237901 (2003)

Thanks to Michael Spanner

Single-cannel PA



Adiabatic solution:

$$b_1(T) = \left\langle F^*_{PA} \middle| F_0 \right\rangle_t \equiv \int_{-\infty}^{T} F_{PA}(t)\ F_0(t)\ dt$$

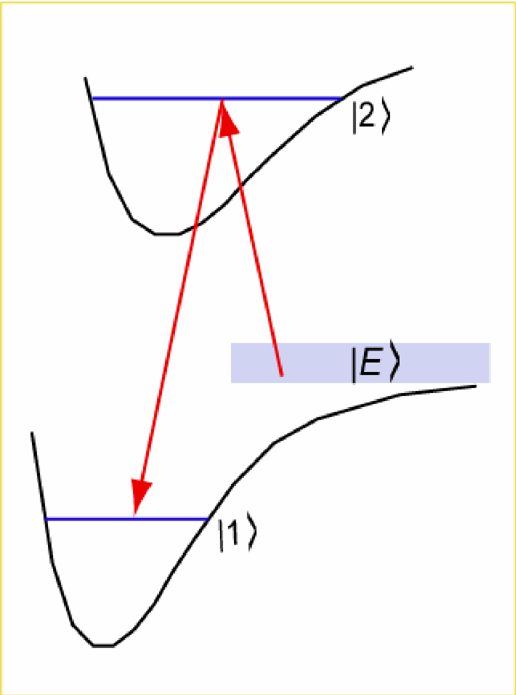
The shape of F_{PA} is controlled by the laser pulses

$$F_{PA}(t) = i\ \Omega_E(t)\ e^{i\int_t^{T_{PA}} \mathcal{E}_-(t')dt'} \cos\theta_{mix}$$

Pump Rabi frequency, with the phase, easy to control

Mixing of eigenstates

Photoassociation of "+" vs. "-" in $^{(85)}$Rb.



E ~ 100 μK

|1> : v = 4 of $^1\Sigma_g$

|2> : # 133 of $^3\Pi_u$-$^1\Sigma_u$

pulses: 0.75 μs FWHM, fit for a 100-μk ensemble

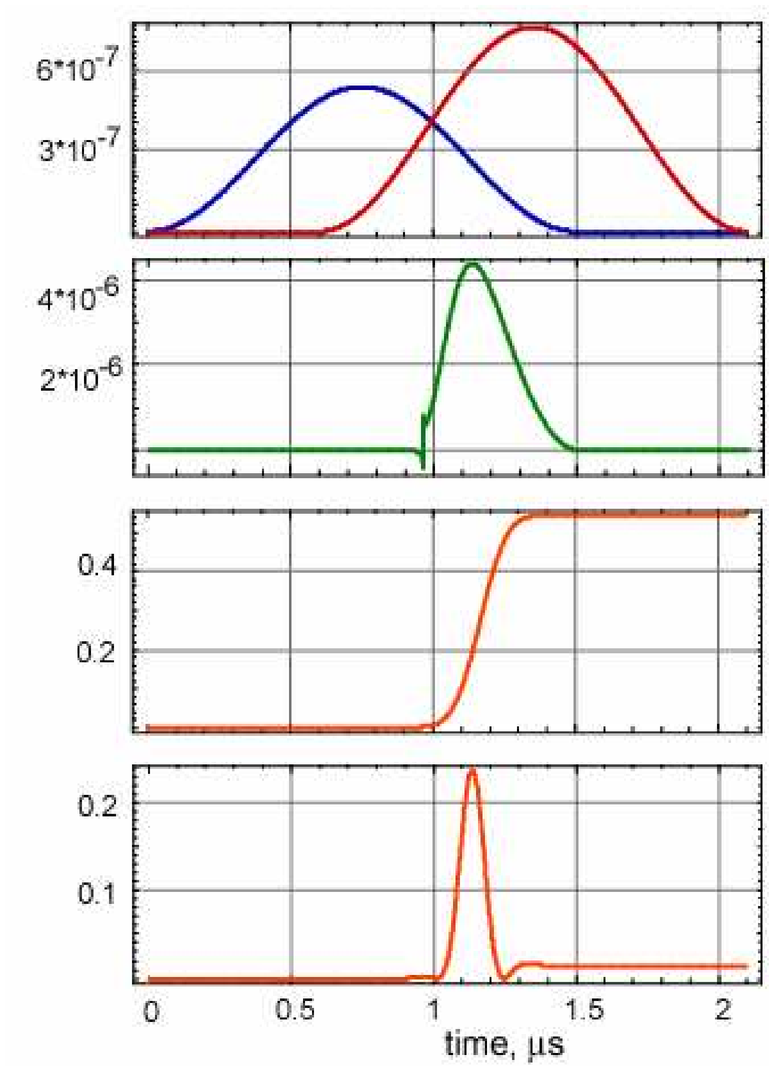
λ_{pump} = 1064 nm

I_{pump} = 10^4 W/cm^2

λ_{dump} = 733 nm

I_{dump} = 7*10^3 W/cm^2

Photoassociation of “+” vs. “-” in $^{(85)}$Rb.

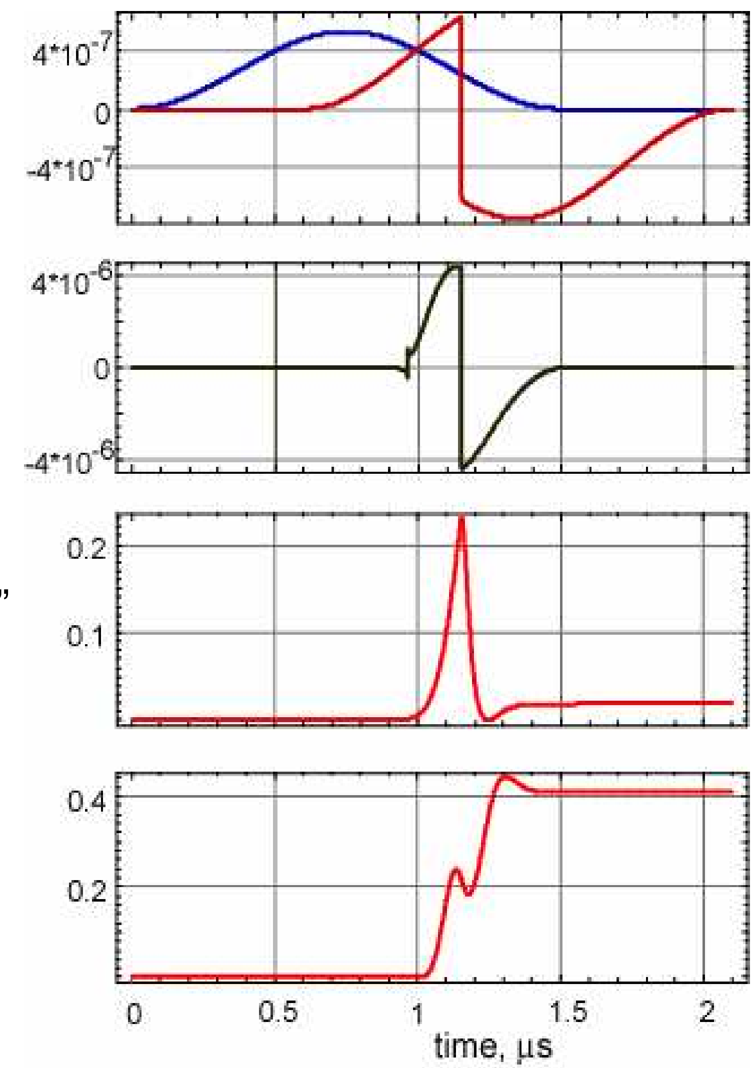


pump, dump envelopes (a.u.)

$Re(F_{PA}(t))$

$P_1(t)$ for the initial “+” wave packet

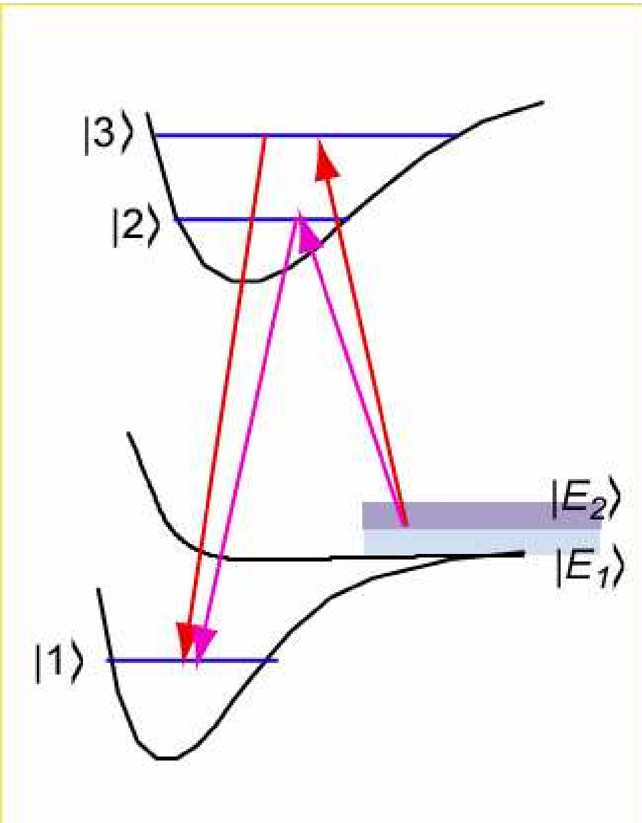
$P_1(t)$ for the initial “-” wave packet



$P_{1+} / P_{1-} > 40$

$P_{1-} / P_{1+} > 20$

Multi-cannel PA



The incoming wave function is a superposition evolving in several channels

average dump Rabi frequency

effective excitation amplitude

$$\dot{b}_1 = i\Omega_{bb} b_{exc}$$

$$\dot{b}_{exc} = i\Omega_{bb} b_1 + i\underline{\Omega}^*_{1b}\,\underline{\overline{\Omega}}_E\,\overline{F}_0(t)/\Omega_{bb} - \underline{\Omega}^*_{1b}\,\underline{\overline{\Gamma}}\,\overline{b}/\Omega_{bb}$$

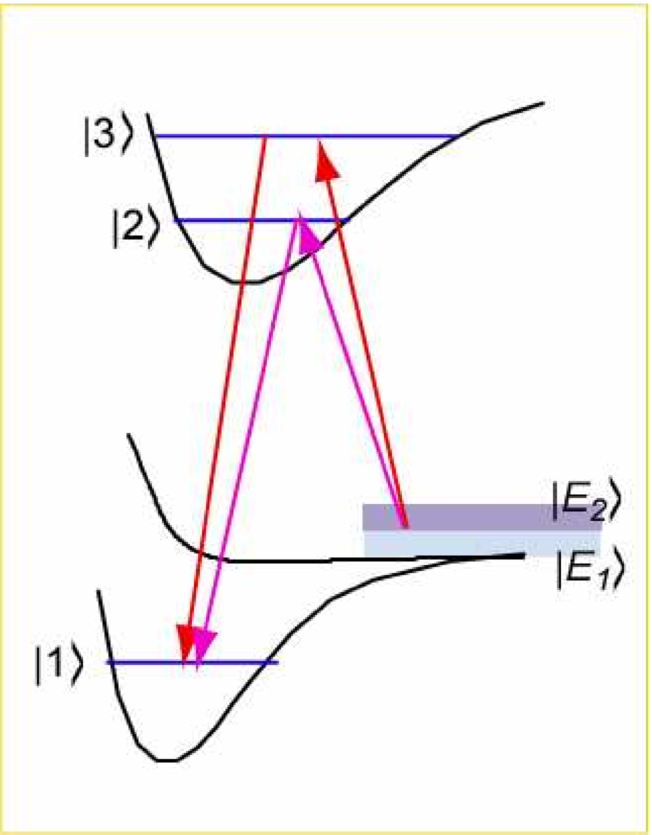
dump Rabi vector

pump matrix

multi-channel continuum wave packet

decay

Multi-cannel PA



$$\dot{b}_1 = i\Omega_{bb} b_{exc}$$

$$\dot{b}_{exc} = i\Omega_{bb} b_1 + i\underline{\Omega}^*_{1b}\overline{\underline{\Omega}}_E \overline{F}_0(t)/\Omega_{bb} - \underline{\Omega}^*_{1b}\overline{\underline{\Gamma}}\overline{b}/\Omega_{bb}$$

Projection of the pumped continuum $\overline{\underline{\Omega}}_E \overline{F}_0(t)$
onto the dump Rabi vector $\underline{\Omega}^*_{1b}$

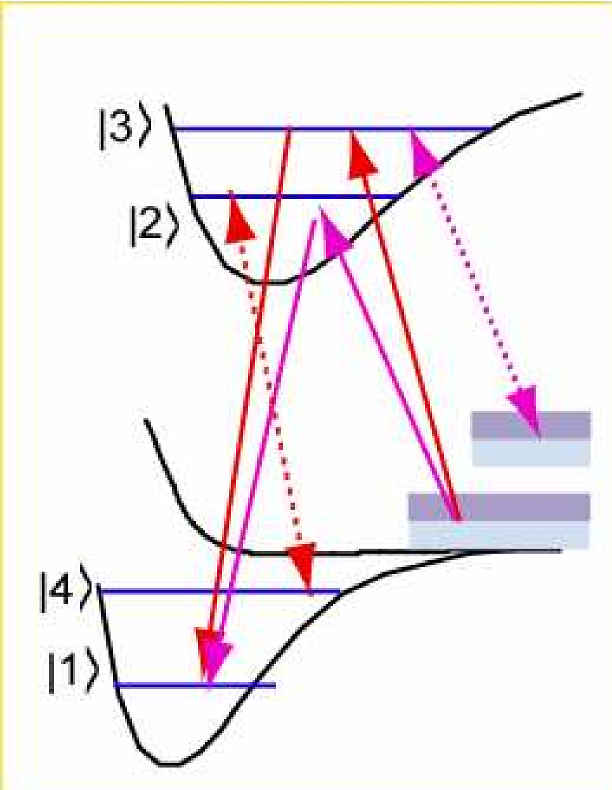
Difficulty in detection:

$\overline{\underline{\Omega}}_E$ transfers mutually orthogonal $\overline{F}_1, \overline{F}_2$
into non-orthogonal vectors

Optimization:

- tune $\overline{\underline{\Omega}}_E$ such that $\overline{\underline{\Omega}}_E \overline{F}_1 \perp \overline{\underline{\Omega}}_E \overline{F}_2$
- tune $\underline{\Omega}^*_{1b}$ such that $\overline{F}_1$ is photoassociated, and $\overline{F}_2$ is not

Multi-cannel PA in real life



$|1>$: $v = 13$ of $^1\Sigma_g$

$|2>$: # 107 of $^3\Pi$-$^1\Sigma$

$|3>$: # 141 of $^3\Pi$-$^1\Sigma$

$|4>$: $v = 54$ of $^1\Sigma_g$

two additional continua at E~1200K

pulses: the pumps come together,
the dumps come together

λ_{E2} = 1065.6 nm λ_{E3} = 778 nm

I_{E2} = $8*10^5$ W/cm^2 I_{E3} = 3.3*106 W/cm^2

$\pi/2$ phase between the two pump fields

Photoassociating a Gaussian wave packet: $\left|{}^1\Sigma^+\right\rangle + \left|{}^3\Sigma^+\right\rangle$ vs. $\left|{}^1\Sigma^+\right\rangle - \left|{}^3\Sigma^+\right\rangle$

I_{12} = $1.5*10^4$ W/cm^2
I_{13} = $2.6*10^4$ W/cm^2
ϕ_{13} = $-\pi/12$

$P_{1-} / P_{1+} = 30$

I_{12} = 0
I_{13} = $3*10^4$ W/cm^2
ϕ_{13} = $-\pi/12$

$P_{1+} / P_{1-} = 12$

SUMMARY

- adiabatic photoassociation:
  projection onto a pre-chosen wave packet

- multi-channel:
  projection onto a pre-chosen multi-channel superposition

- non-unitary pump matrix has to be tuned
  extra decay terms cause no harm

- coherent controlled adiabatic passage measures the input wave packet by projecting onto a state of our choice

THANKS

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Ioannis Thannopulos   *UBC*