Piecewise Adiabatic Passage

Evgeny Shapiro

Department of Chemistry, The University of British Columbia

CQIQC-III
Toronto, August 2009

Work in progress

In collaboration with

Moshe Shapiro

Valery Milner

Sergey Zhdanovich

John Hepburn

Cian Menzel-Jones

Ioannis Thanopulos

Petr Kral

Avi Pe'er

Jun Ye

Two limits of quantum control

Perturbative control with shaped broadband pulses

flexible, intuitive
reaches many goals

fast

often too sensitive
to pulse parameters,
or transferred population
is small

Adiabatic passage

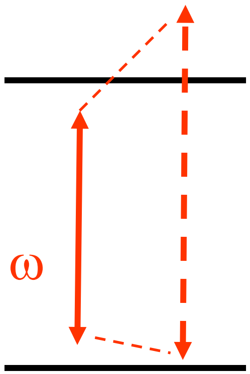
not flexible, reaches few goals

inherently slow

complete population transfer,
robust with respect to particular
pulse parameters

Looking for a method that is fast, flexible, but robust; and intuitively simple.

The simplest adiabatic passage.

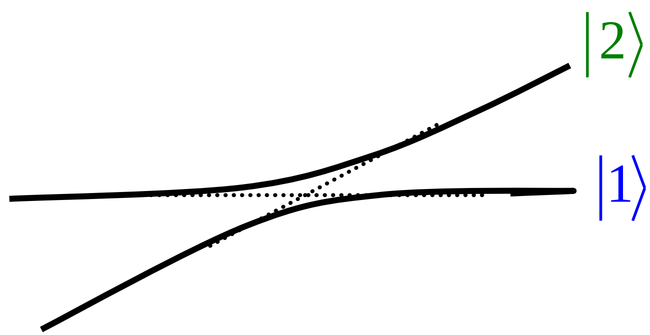


$$\hat{H} = \hat{H}_0 + \varepsilon \hat{\mu} \cos \omega t$$

$$\hat{H}_{eff} = \begin{pmatrix} 0 & \Omega / 2 \\ \Omega^* / 2 & \Delta \end{pmatrix} \qquad \Delta = E_2 - (E_1 + \omega)$$

Start in $|1\rangle$, slowly chirp ω,

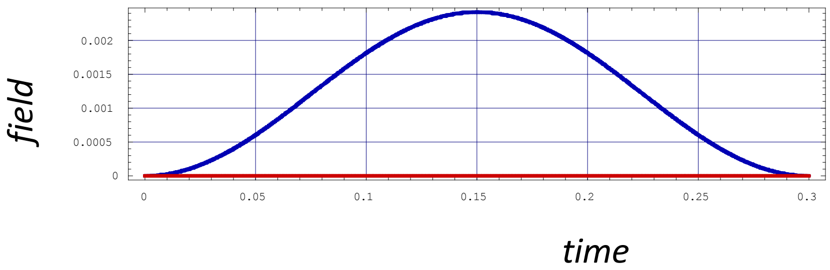
end up in $|2\rangle$

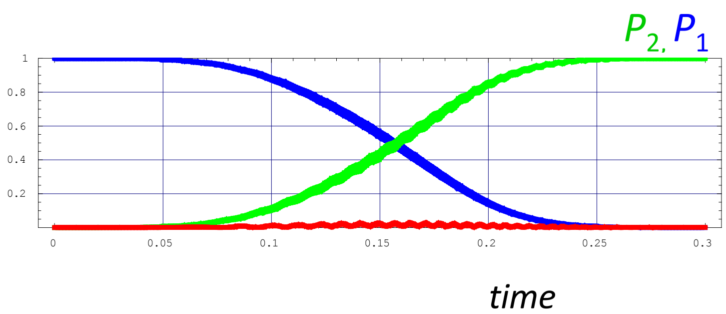


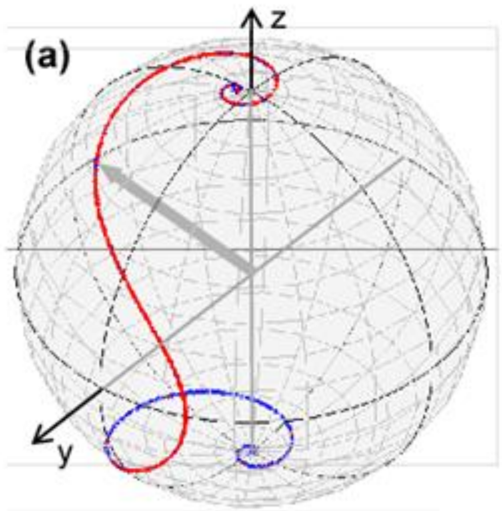
Adiabaticity:

$$\dot{\theta} << \sqrt{\Omega^2 + \Delta^2} \qquad \text{where} \qquad \tan 2\theta = \Omega / \Delta$$

2-state AP in Na



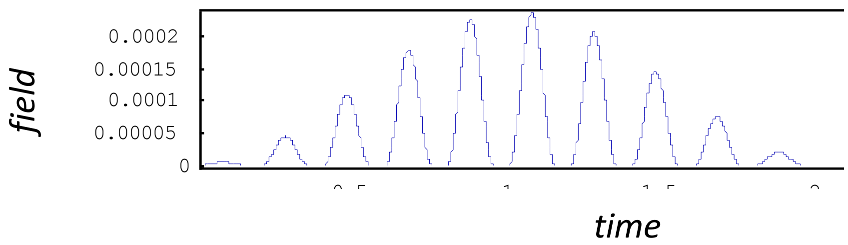


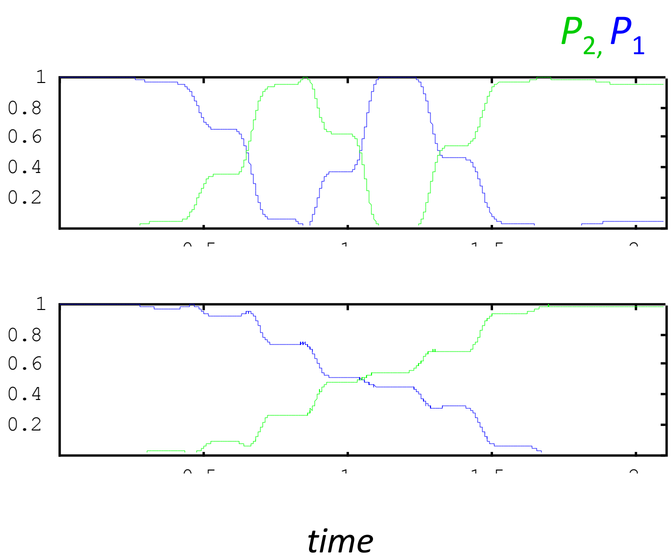


Bloch vector evolution in the resonance frame: spiral

Piecewise 2-state AP in Na

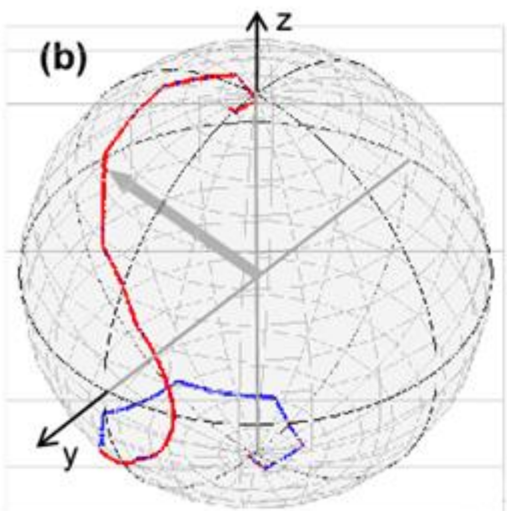
$$\phi_n = \alpha(n-n_0)^2/2$$





$\alpha = 0$

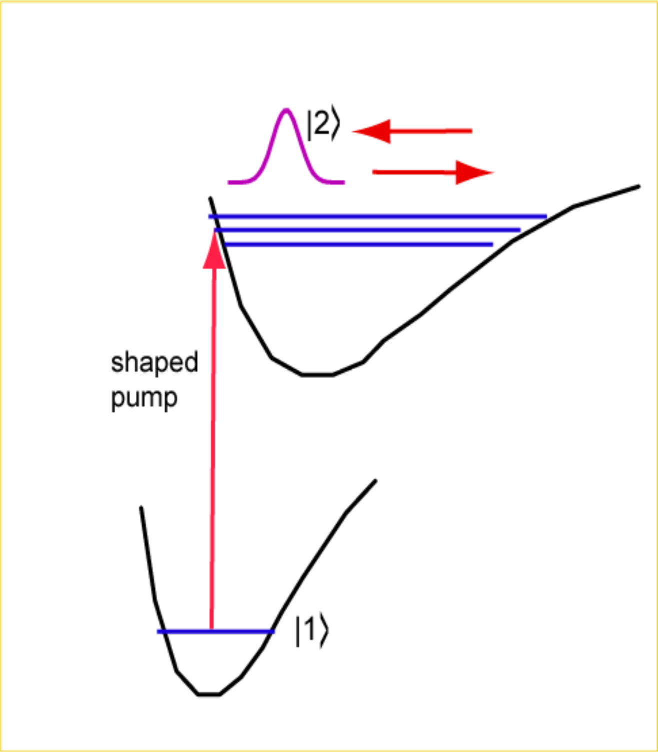
$\alpha = \pi/4$



Bloch vector evolution: piecewise spiral

PRL ***100,*** *103004 (2008)*

Transfer into a molecular wave packet.

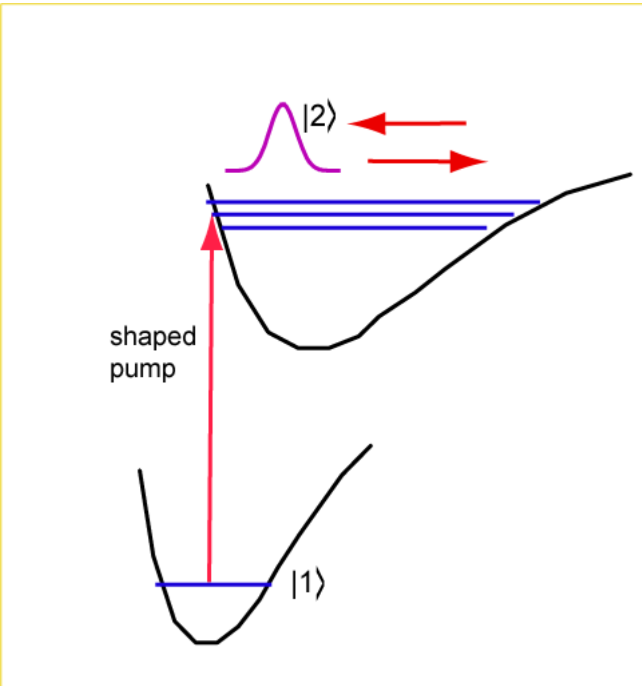


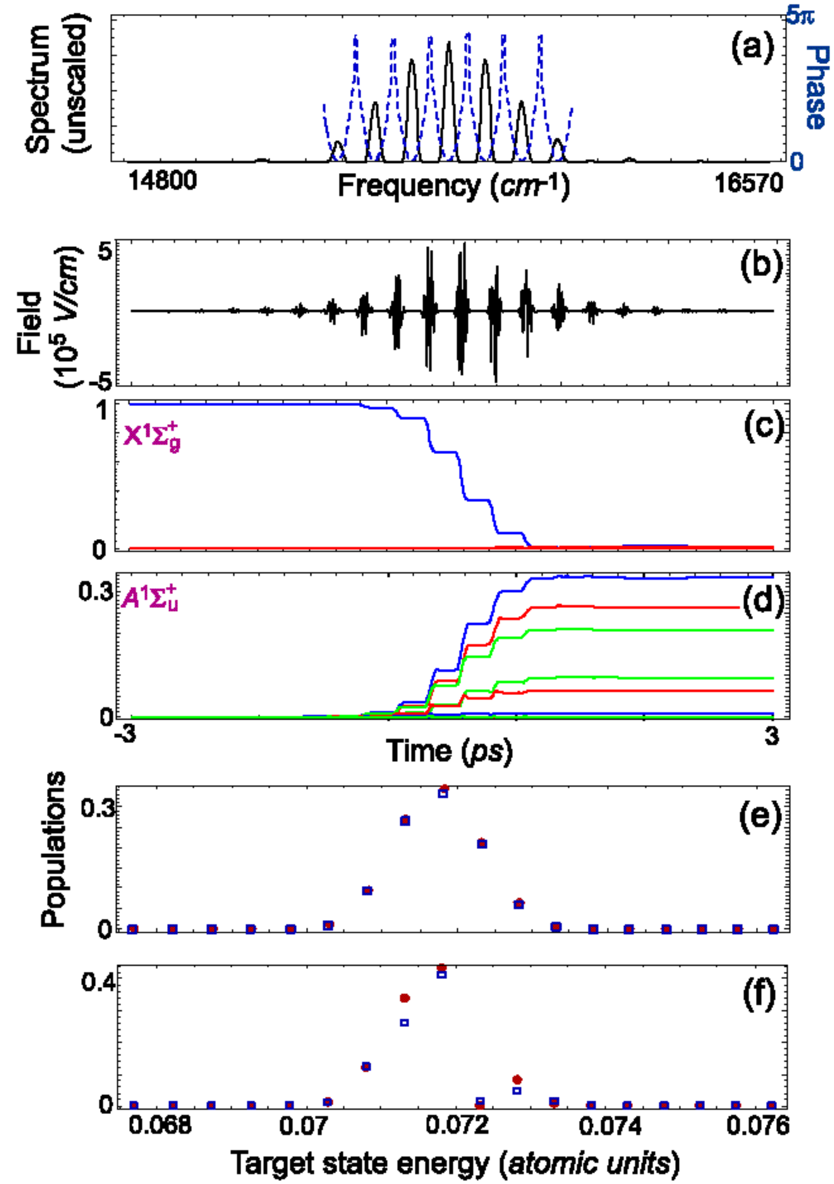
Shaped femtosecond pulses separated by the vibrational period of the wave packet;

Quadratic phase variation ensures robust and complete population transfer;

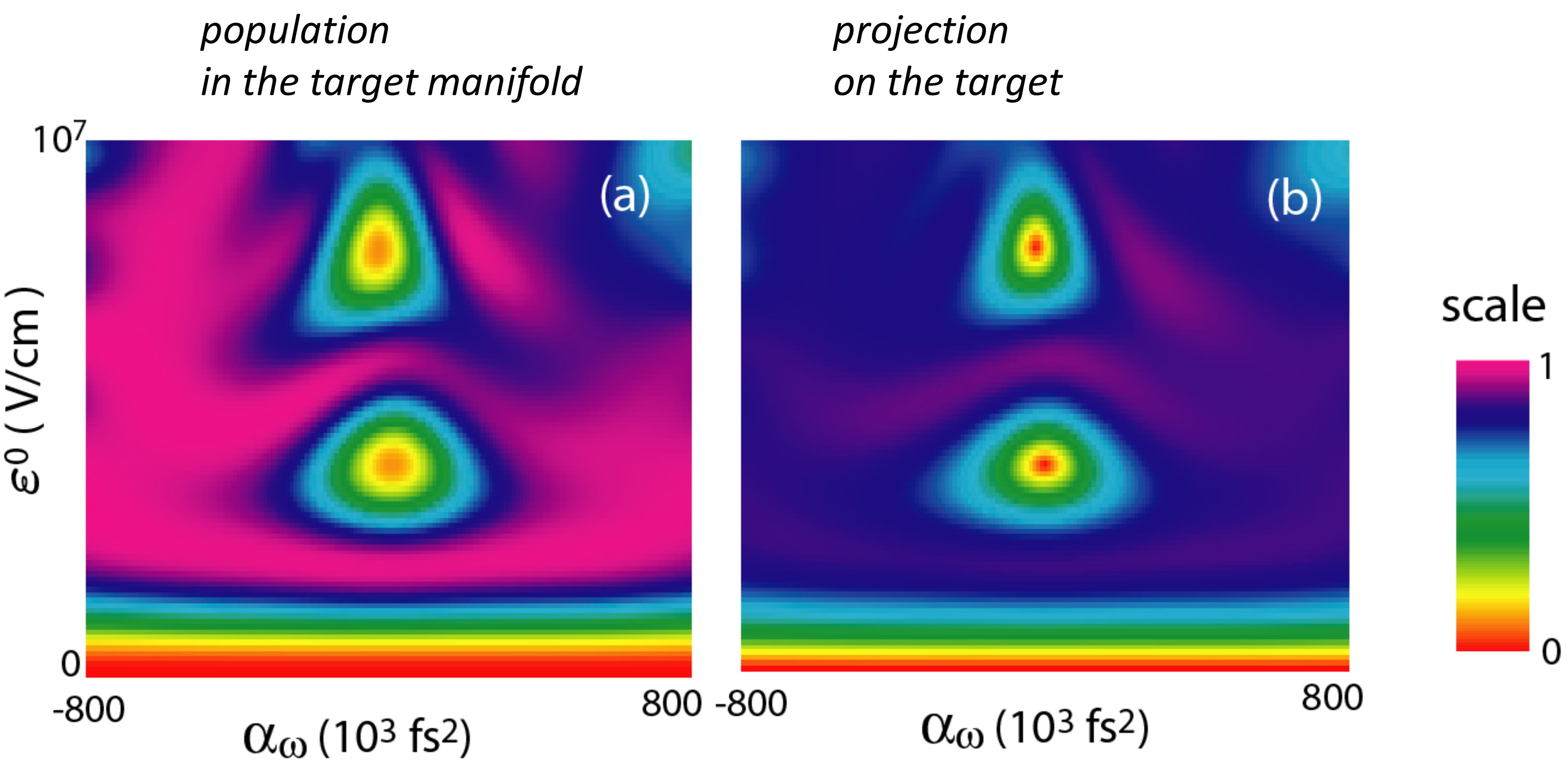
Pulse shaping controls the state amplitudes in the wave packet.

Transfer into a molecular wave packet. Na_2.



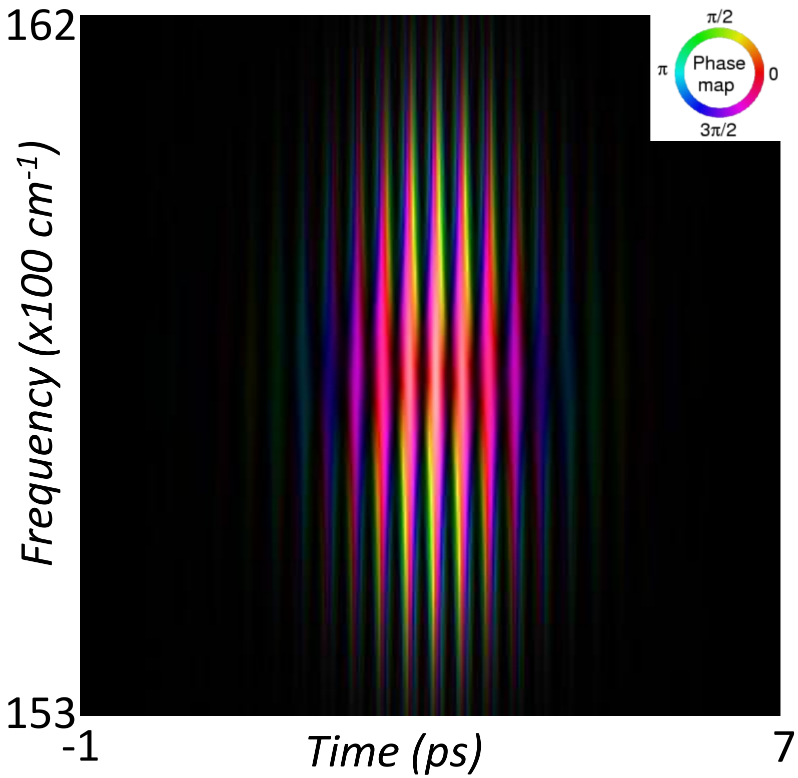


Transfer into a molecular wave packet.

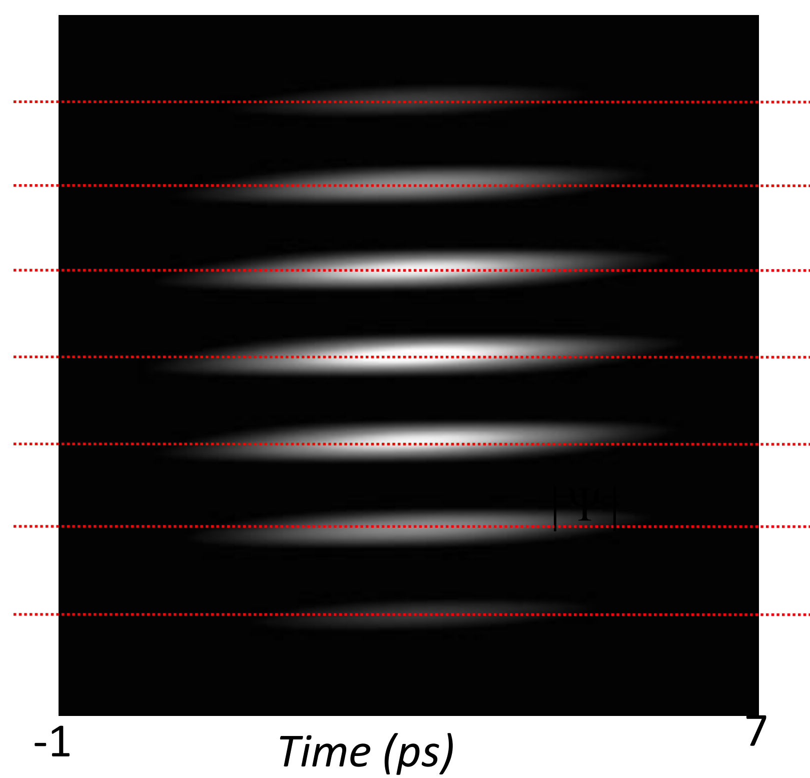


PAP or CCAP?

Husimi – 50 fs probe pulses



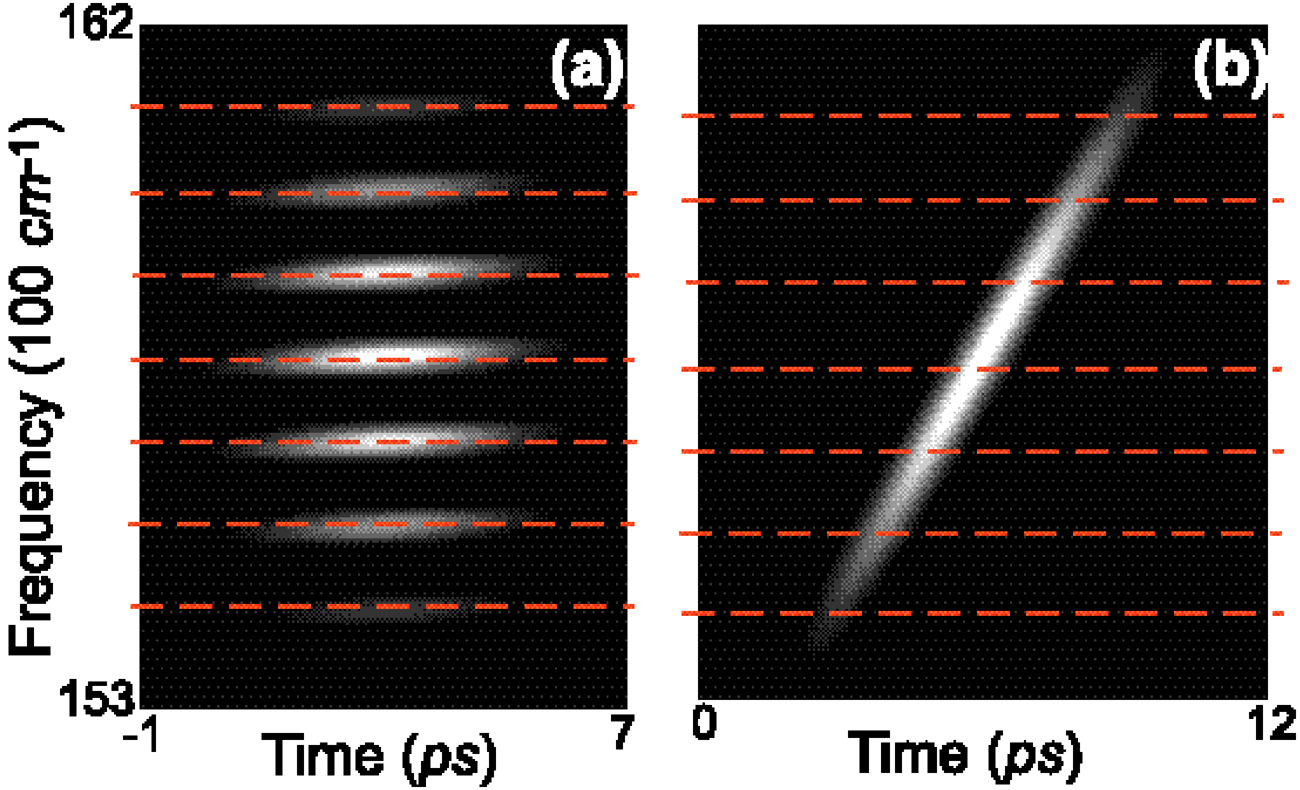
Husimi – 1000 fs probe pulses



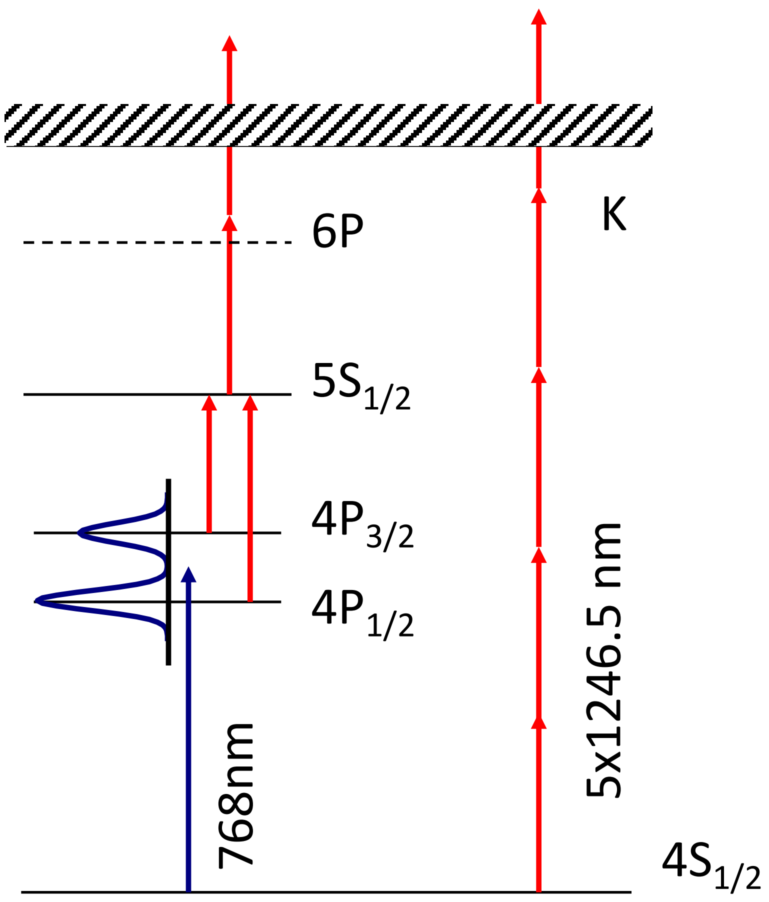
Frequency-domain consideration is more general and intuitive, but skips the short-term dynamics:

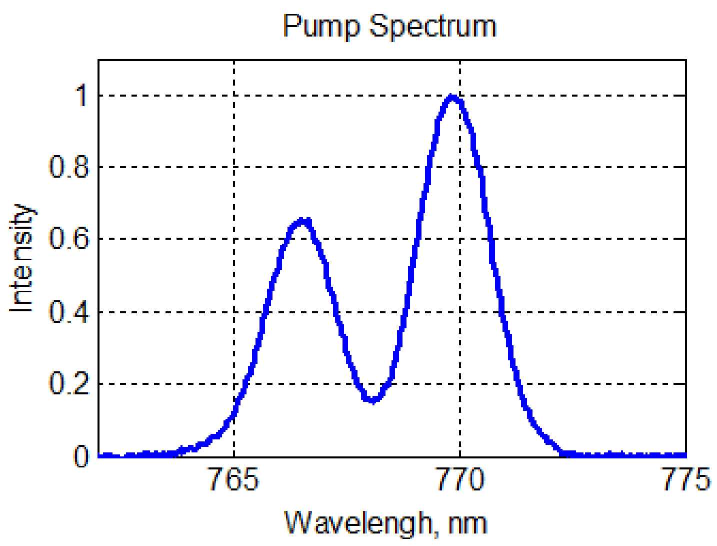
The transfer is only coarse-grained adiabatic.

Vs. "Molecular π-pulse".

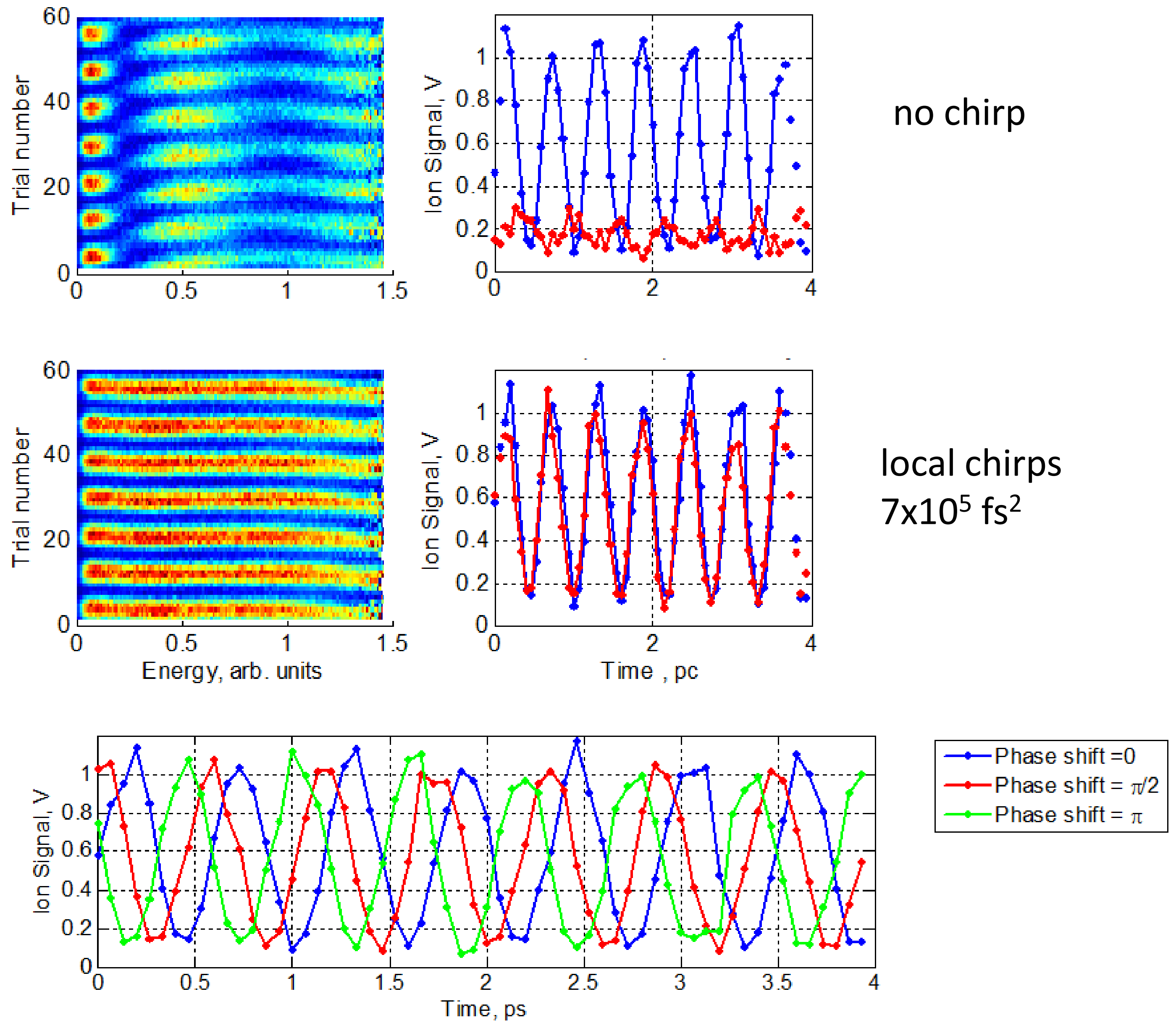


Experiment: $4S_{1/2} \rightarrow 4P_{1/2}$-$4P_{3/2}$ in K .

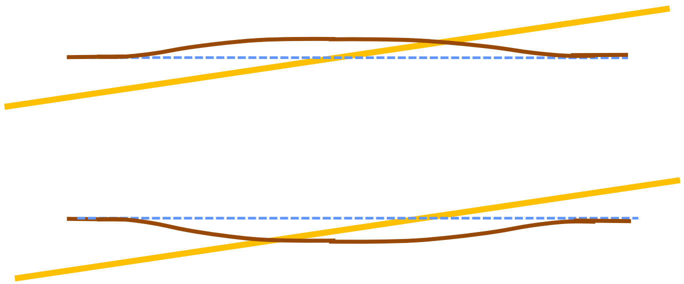




Experiment: $4S_{1/2} \rightarrow 4P_{1/2}$-$4P_{3/2}$ in K .



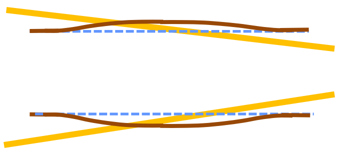
The Dreadful Stark shifts.



Tricks and rules of thumb
for better transfer.

minor numerical optimization

or



opposite-sign chirps

and

nice wave packets come out nicer

etc etc

SUMMARY.

PAP

Flexible,
reaches many goals

Complete population transfer,
robust with restrictions

As fast as several femtosecond
pulses. No ultimate speedup.

Outlook

Extension of simple AP schemes
to complex systems

Using interferences in the broadband spectrum. *Spectroscopy*, Ramsey clocks, with robust complete population transfer

Decoherence control?
Using the silent periods
between the pulses

NB: beat the Stark shifts

and build a frequency comb with ps repetition rate

REFERENCES on PAP-CCAP

With 2 effective states, RAP-like

S. Zhdanovich, M. Shapiro, J. Hepburn, V. Milner, in preparation – *exp, wave packet*

E. A. Shapiro, V. Milner, M. Shapiro*, PRA **79,** 023422 (2009)* – *theory, wave packet*

S. Zhdanovich, E.A. Shapiro, J. Hepburn, M. Shapiro, V. Milner, *PRL **100** 103004 (2008)*

-- *theory and exp., 2 states.*

With 3 effective states, STIRAP-like, theory.

PAP: time domain perspective, applications.

E.A. Shapiro, A. Pe'er, J. Ye, M. Shapiro , *PRL* **101** , 023601 (2008).

E.A. Shapiro, V. Milner, C. Menzel-Jones, and Moshe Shapiro , *PRL* **99** , 033002 (2007).

A. Pe'er, E.A. Shapiro, M.C. Stowe, Moshe Shapiro, and J. Ye , *PRL* **98** , 113004 (2007).

CCAP: frequency domain perspective, applications.

E. A. Shapiro, M. Shapiro, in *"Cold Molecules", Krems,* Stwalley, Friedrich*, eds, (2009)*.

X. Li, G.A. Parker, P. Brumer, I. Thanopulos M. Shapiro, *J. Chem. Phys. **128**, 184113 (2008)*

I. Thanopulos and M. Shapiro, *J. Phys. B: At. Mol. Opt. Phys., **41** 074010 (2008)*

P. Kral, I. Thanopulos, M. Shapiro, *RMP 79, 53 (2007), and references therein*