Photoassociation of Ultracold Atoms with Chirped Pulses*

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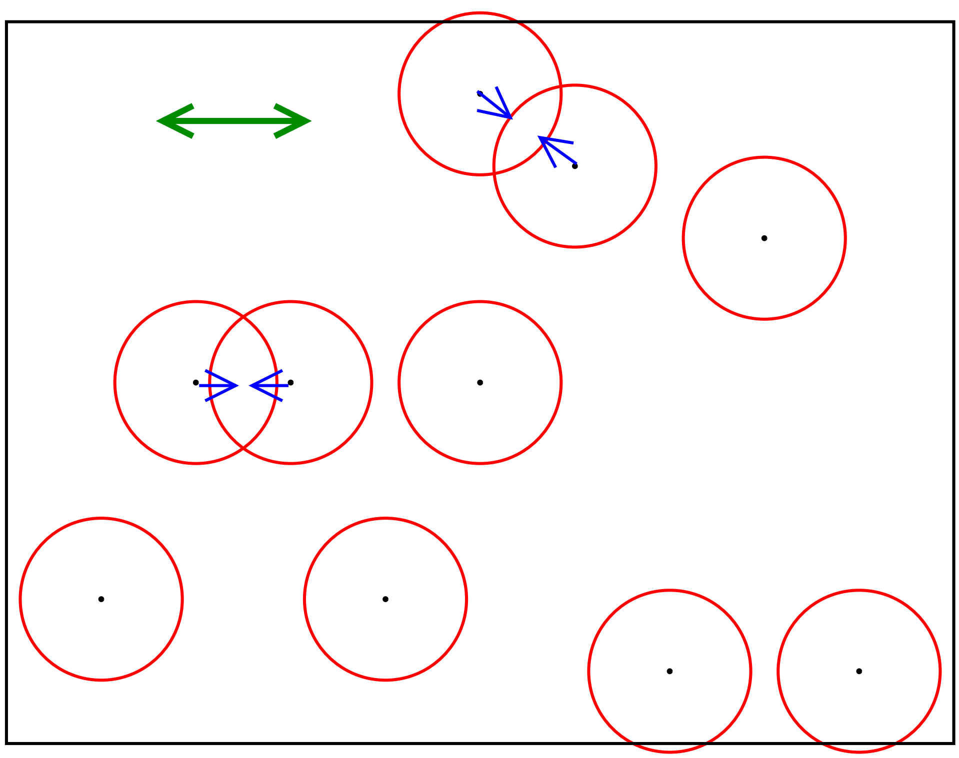
Motivation

- Ultracold gases generally dilute $\rightarrow$ low collision rates
- Higher collision rates would increase signals in Photoassociation experiments
- Increased collision rates may lead to more efficient molecule production
- Collision rates can be increased dramatically with lasers tuned slightly red of atomic asymptote, at moderate intensity

Ultracold Collisions, Photoassociation, and Molecule Formation

- Photoassociation requires atoms close together ($R \sim 10\ a_0$)
- Typical internuclear distances in ultracold gas $R \gtrsim 10,000\ a_0$
- Limit for photoassociation $R \sim 1,000\ a_0$
- Process to bring atom pairs from $R = 1,000\ a_0 \rightarrow 10\ a_0$ would greatly improve production and studies of ultracold molecules



Reasons for Chirping

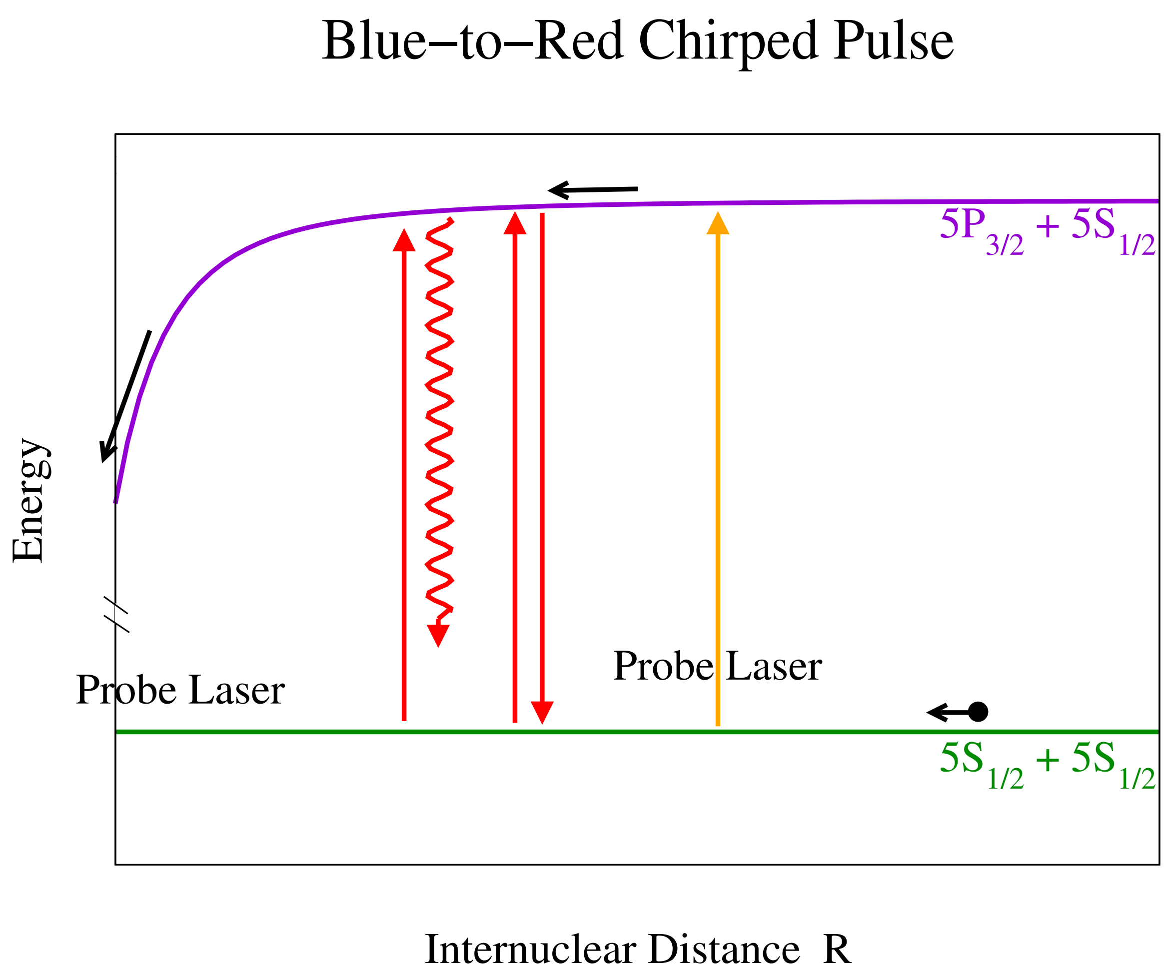
- CW lasers only excite molecules at one internuclear distance
- Chirped lasers at moderate intensities can excite molecules over large range of R
- 1 GHz chirp can excite molecules anywhere from $R = 500\ a_0 \to 2000\ a_0$
- Each chirp produces a pulse of collisions
- Many molecule formation schemes involve pulsed lasers $\to$ atoms need to be close together only when the pulses arrive
- What kinds of chirped pulses will work best?

Diode Lasers for Chirping

- Diode lasers allow for very fast modulation (bandwidth $\simeq 10$ GHz)
- External cavity diode lasers ideal for chirps of depth < 1 GHz (narrow linewidth, but limited by mode hops)
- Chirp depth can be be extended with intracavity EOM (Mossberg, et. al.)
- Slew rates $>$ 10 GHz / μs possible (probably much larger)
- Low cost

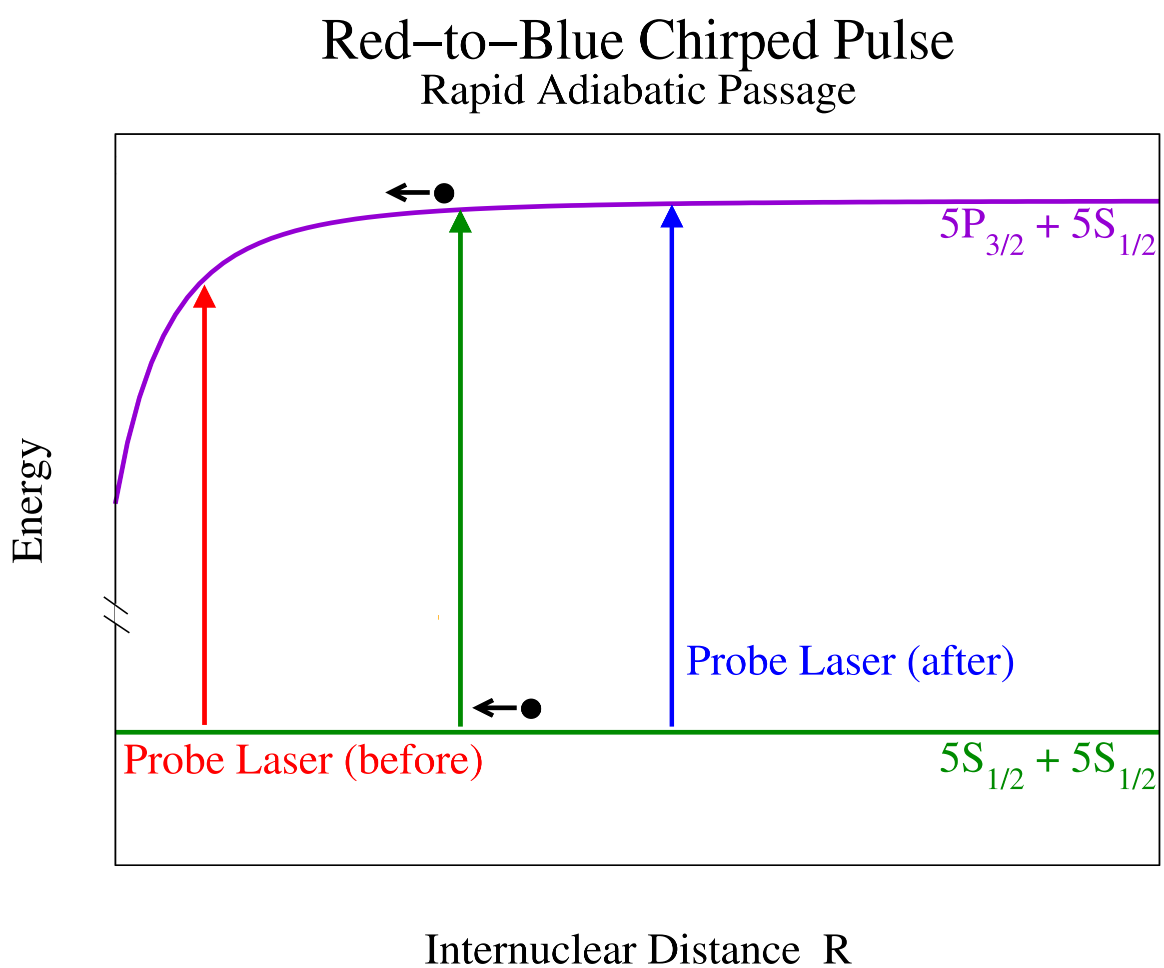
Blue-to-Red Chirp

- Molecule excited initially at very large R
- Spontaneous decay leaves molecule in (flat) ground state
- As chirp proceeds, molecule is re-excited
- Stimulated emission causes cycling between ground and excited states while molecule is close to resonance with laser



Red-to-Blue Chirp

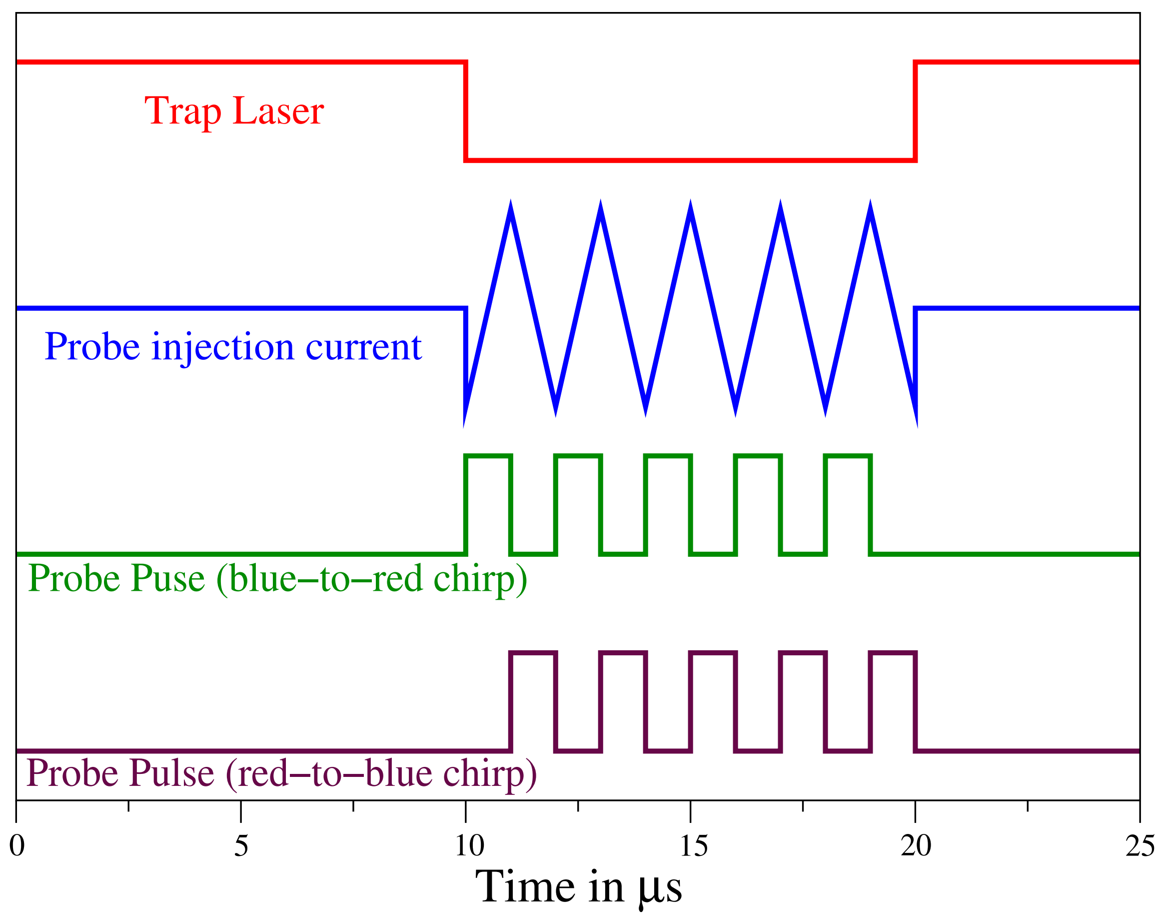
- Atoms initially at internuclear distance R
- Laser frequency sweeps through resonance from red $\rightarrow$ blue
- Atoms promoted to excited state with near-unit efficiency (no stimulated emission problems)
- After spontaneous decay, chirp is repeated



Experiment

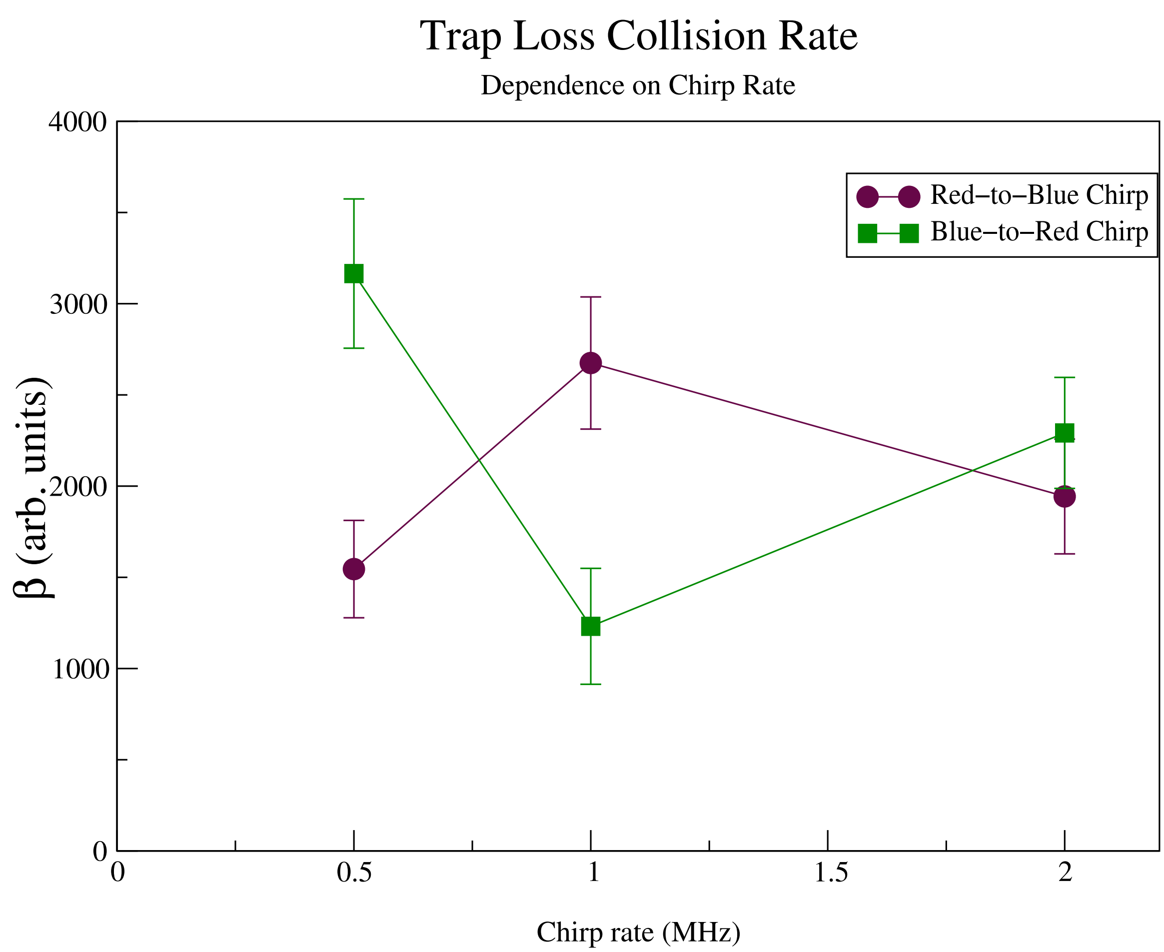
- Monitor trap-loss rate from Rb MOT, chop trap laser 50
- During trap-off time, chirped pulses are applied
- Varied pulse duration and chirp rate

Chirped Pulse Timing



(Preliminary) Data

- Collisional trap-loss rate due to chirping laser



Prospects for Coherent Control

- More complicated pulse shapes and chirp shapes possible
- In general this will require:
  - Aribrary waveform generator
  - Linearized chirp response (adaptive pulse shaping or fast servo)
  - High bandwidth AOM or EOM for pulse intensity control
- Coherent control of ultracold collisions may be possible
  - Collisional channels with different phases interfere
  - Possible focusing of collisional wavepacket at a particular R
- Feedback may be used to optimize chirped pulses for a particular application (i. e., population of a particular molecular state, high-J collisions, etc) without detailed knowledge of potentials involved

Conclusion

- Demonstrate Chirped, Pulsed Photoassociation of Rb_2 using Diode Lasers

- Measure dependence on direction of pulse, chirp rate

- Two mechanisms proposed to describe chirp rate dependence

- Possible use for Coherent Control

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