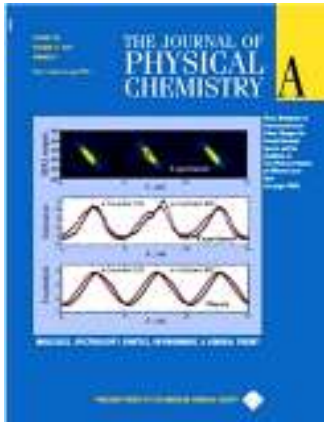
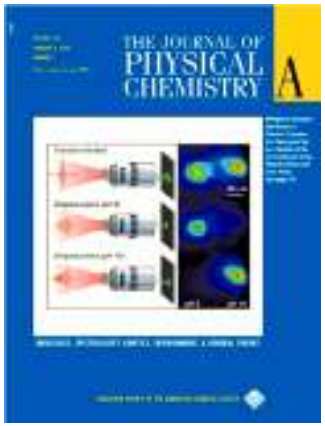
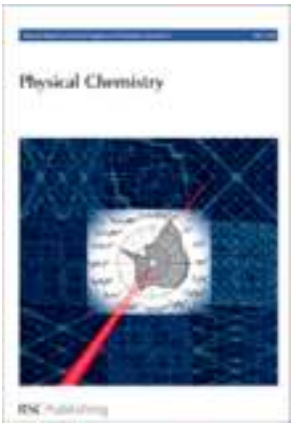
Controlling NLO processes, vibrational and electronic excitation, and strong field chemistry

Prof. Marcos Dantus

Prof. Vadim V. Lozovoy







Biophotonic
SOLUTIONS INC
ULTRAFAST PULSE SHAPING & COMPRESSION

NSF

Office of Basic Energy Sciences
Serving the Present, Shaping the Future

NATIONAL INSTITUTES OF HEALTH

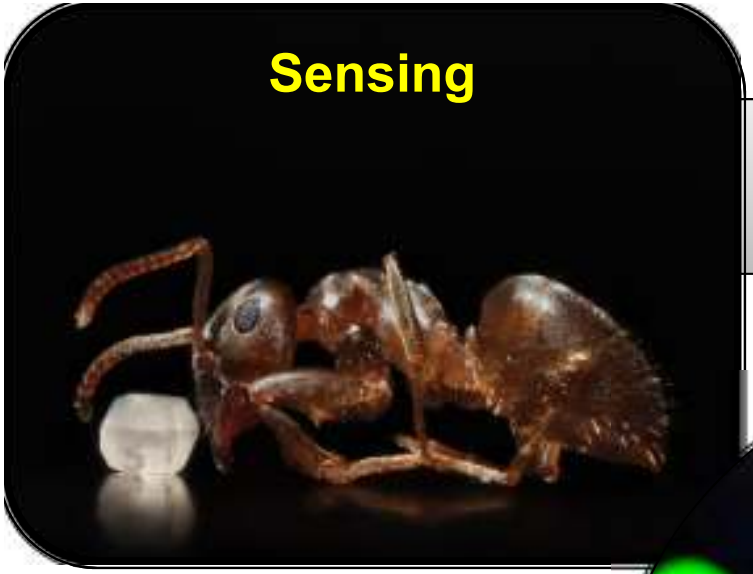
U.S. DEPARTMENT OF HOMELAND SECURITY

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

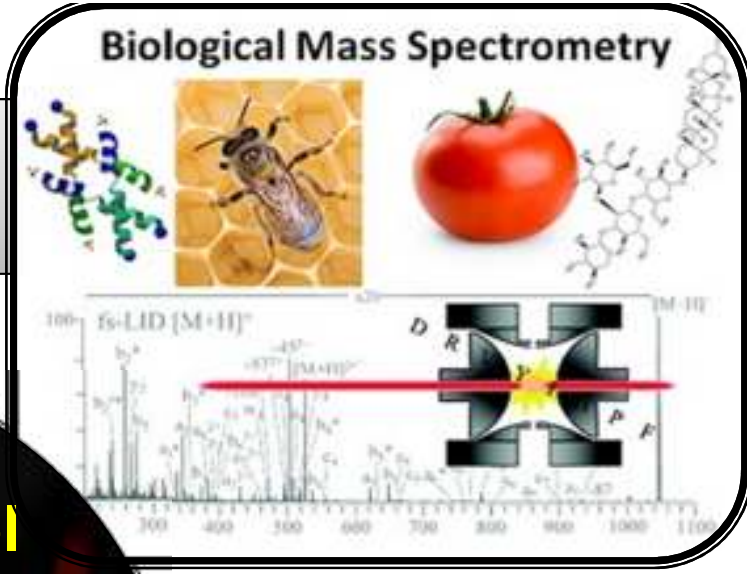
MICHIGAN
ECONOMIC DEVELOPMENT CORPORATION

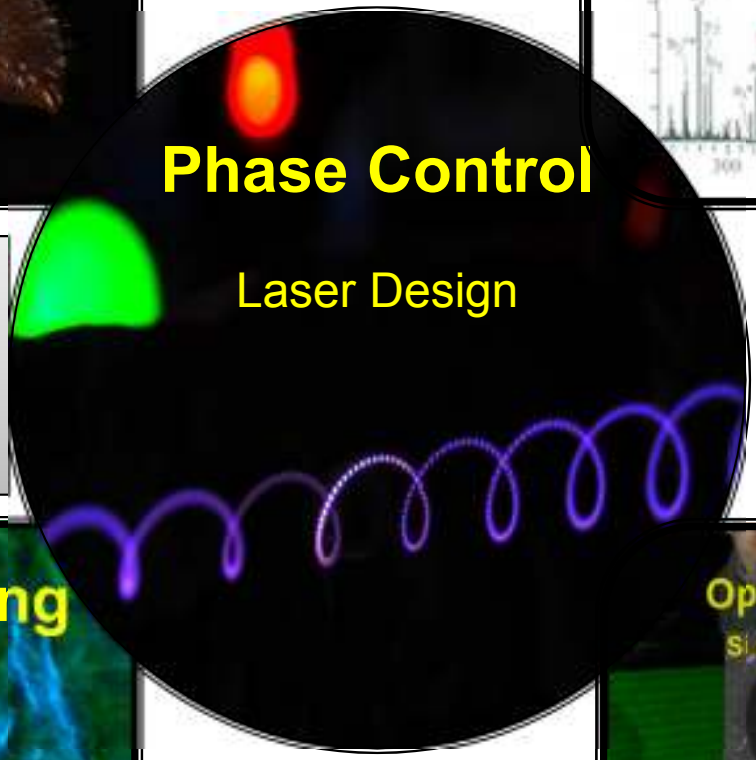
MICHIGAN STATE
UNIVERSITY

COI Disclosure: Dantus is the founder and president of Biophotonic Solutions Inc.

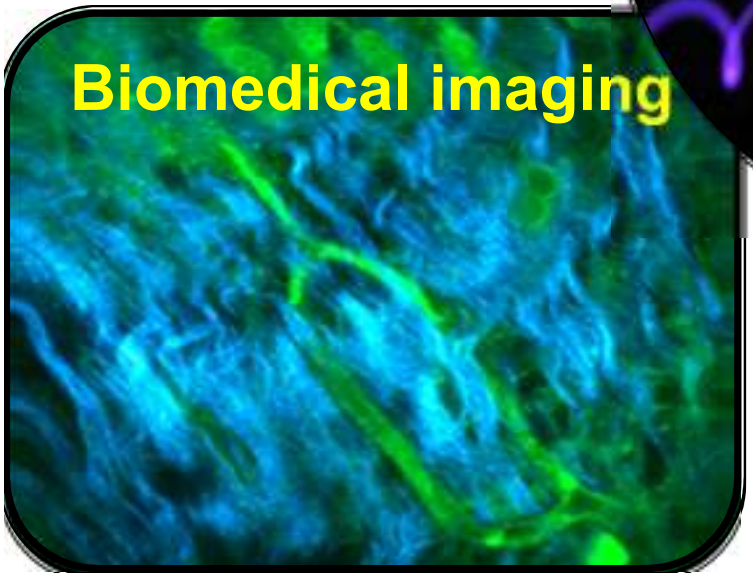


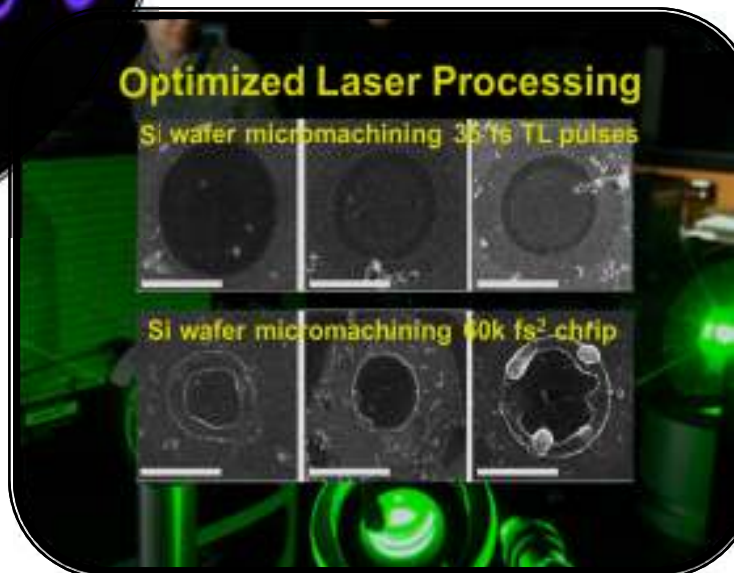
Dantus Group





Multidisciplinary
Collaborations with
Universities and Industry





Multiphoton Intrapulse Interference (MII)

General approach to control n-photon transitions and non-linear optical processes

Walowicz, Pastirk, Comstock, Shane, Xu, Coello, Lozovoy and Dantus

J. Phys. Chem. A **106**, 9369 (2002).

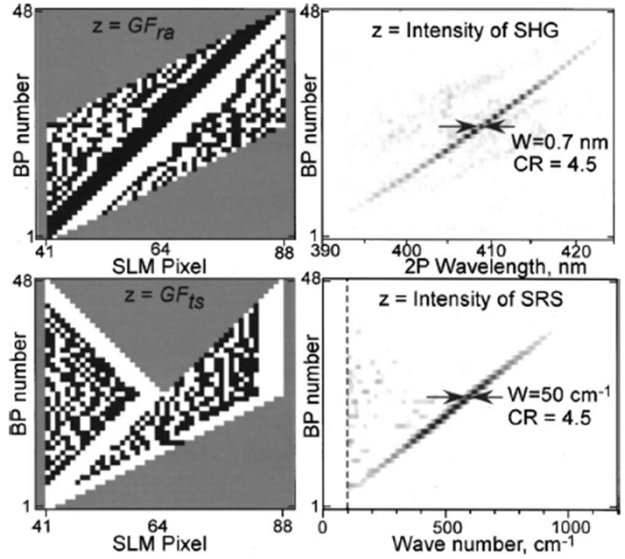
J. Chem. Phys. **118**, 3187 (2003). Two vs. three photon

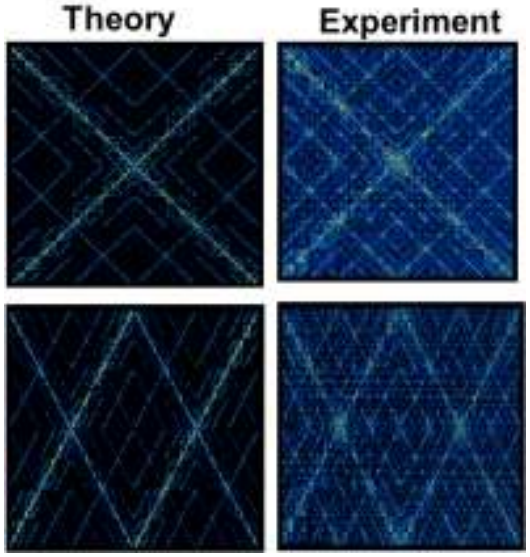
Optics Express **12**, 1061-1066 (2004). Binary phases

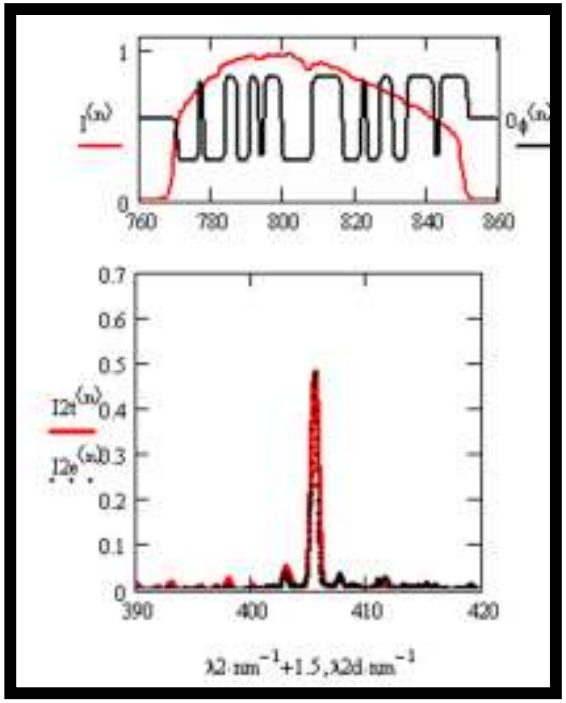
Optics Express **13**, 10882 (2005). Selective excitation

Physical Review A **74**, 041805(R) (2006). **pseudorandom Galois fields**

Applied Optics, **49**, (32), 6348-6353 (2010). Two-photon excitation spectroscopy







Binary Phase Modulation: Physical Review A **74**, 041805(R) (2006)

Pulse Characterization and Compression

Pastirk, Xu, Gunn, Dela Cruz, Zhu, Martin, Rezan, Fry, Mackay, Coello, Harris, Shane, Gunaratne, Borukhovich, Tseng, Weinacht, Nogueira, Cruz, Pestov, Lozovoy and Dantus

Optics Letters **29**, 775-777 (2004).First

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Opt. Express **14**, 8885-8889 (2006).**Remote**

Opt. Express **14**, 9537-9543 (2006).**Pre amp**

Opt. Express 14, 10939-10944 (2006).**Octave spanning**

Opt. Express 15, 16061 (2007) **Surface SHG**

Opt. Express, **15**, 1932-1938 (2007).**THG in air**

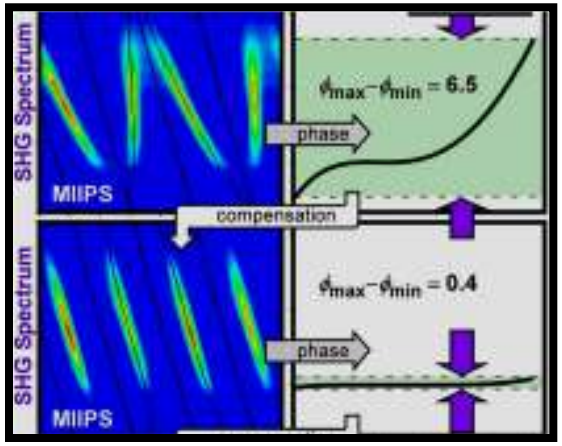
Laser Focus World **43**, 101-104, (2007)

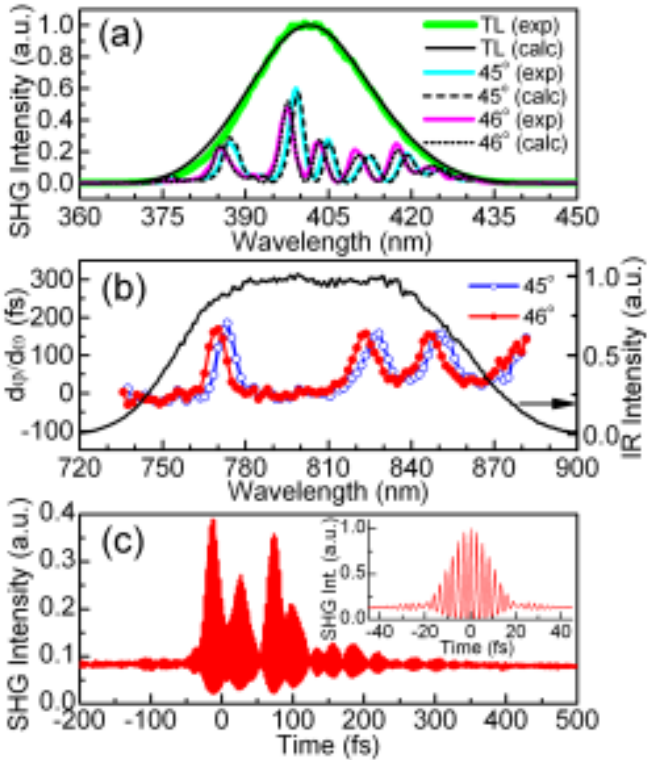
J. Opt. Soc. Am. B **25**, A140-A150 (2008) **Interference without interferometer**

Opt. Express **16**, 592-597 (2008).**MIIPS 2**

Opt. Express, **16**, Issue 14, pp. 10033-10038 (2008) **2GHZ Octave spanning**

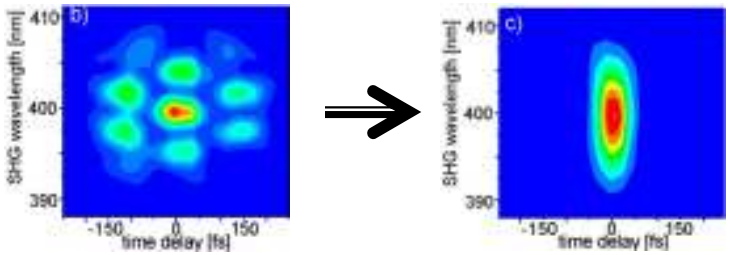
Opt. Letters **35**, 1422-1424 (2010).**MIIPS sonogram**





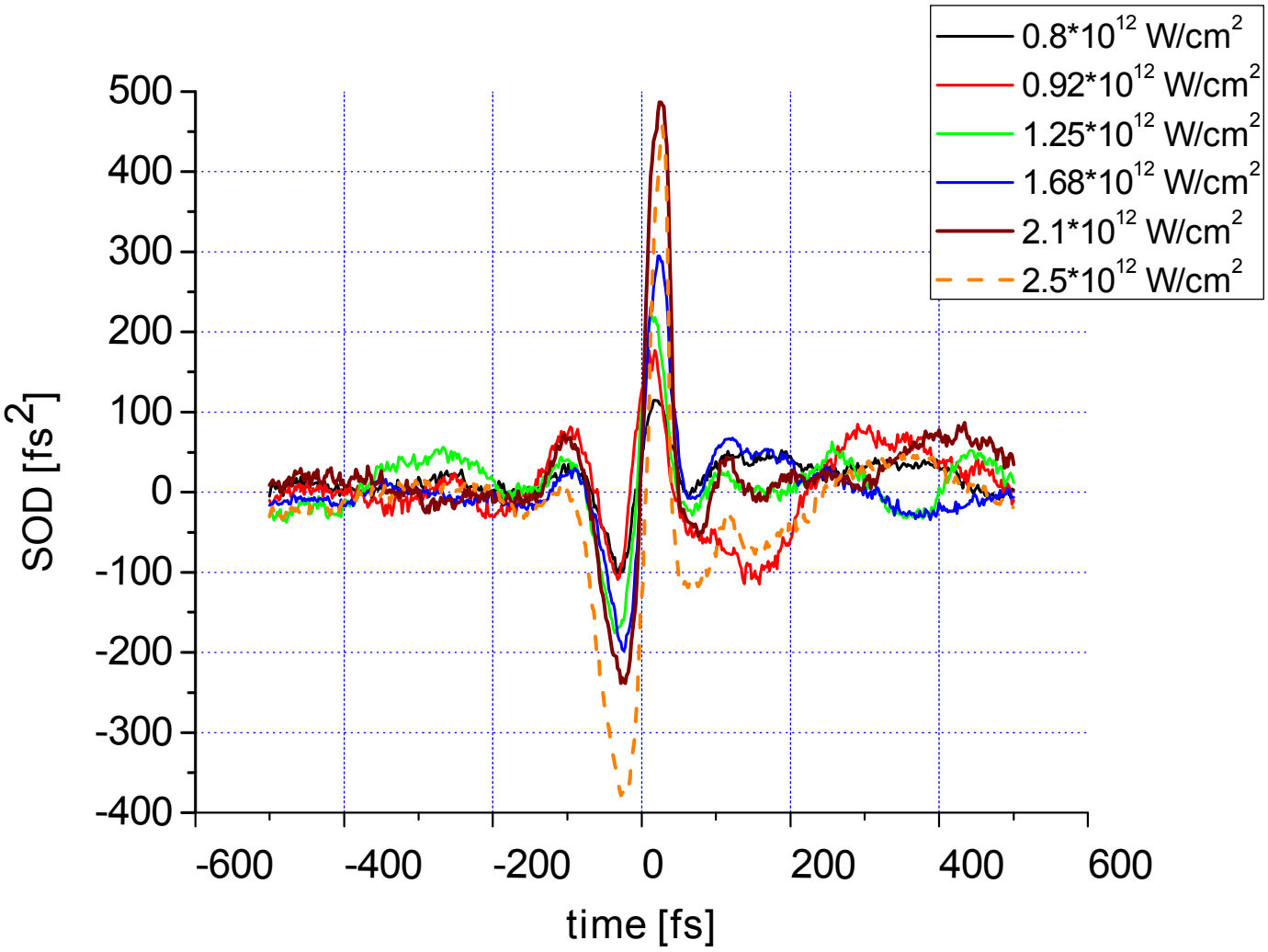
Preamp

Shaping

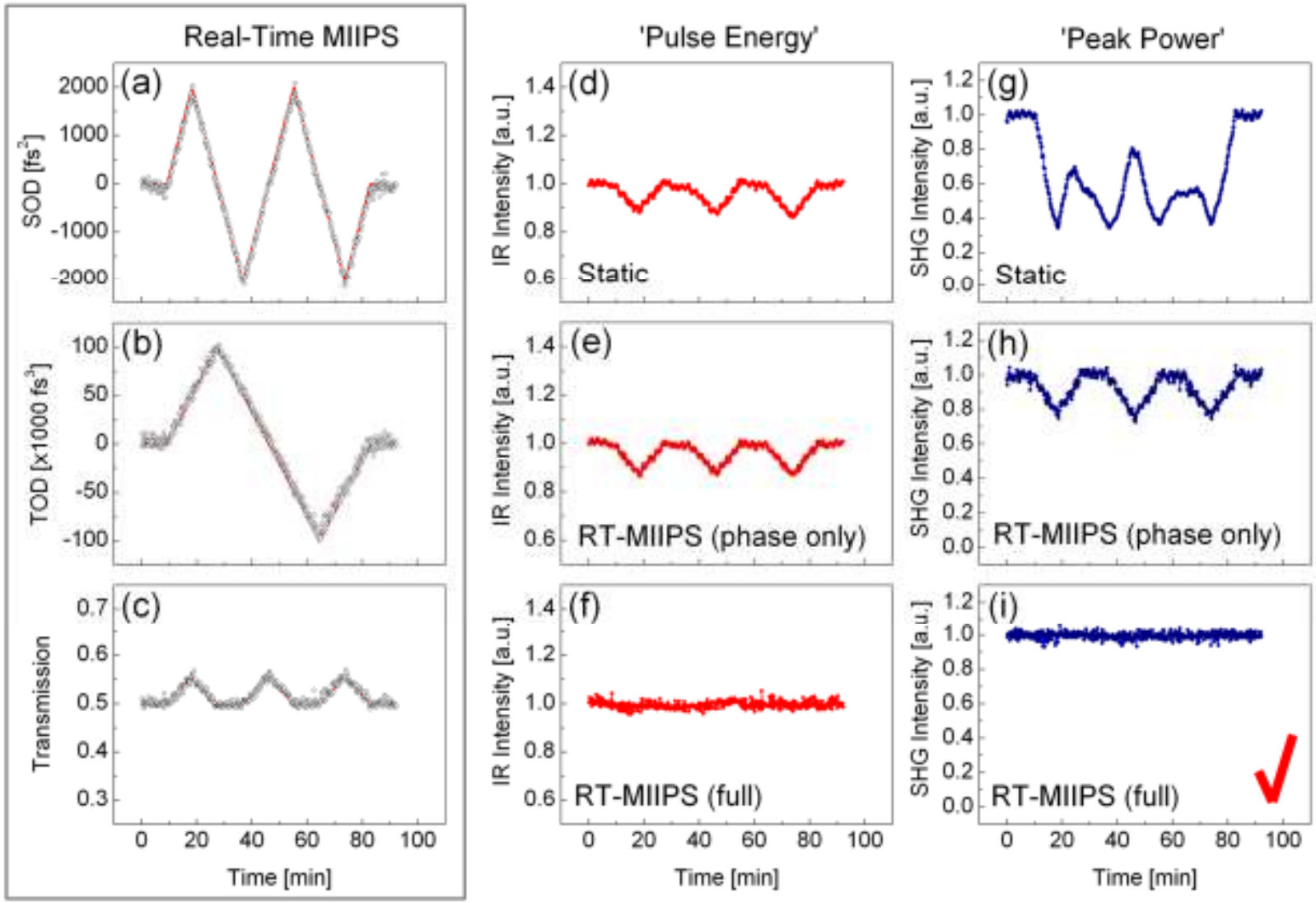


Transient SOD changes measured by single shot MIIPS

Results from1mm quartz



Experimental Results: Active SOD+TOD+Amplitude Compensation



Biophotonic SOLUTIONS INC

Pestov et al. Presented at UFO 2011

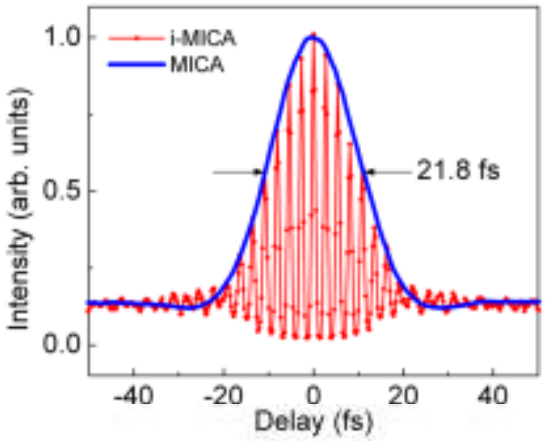
Pulse Shaping and Communications

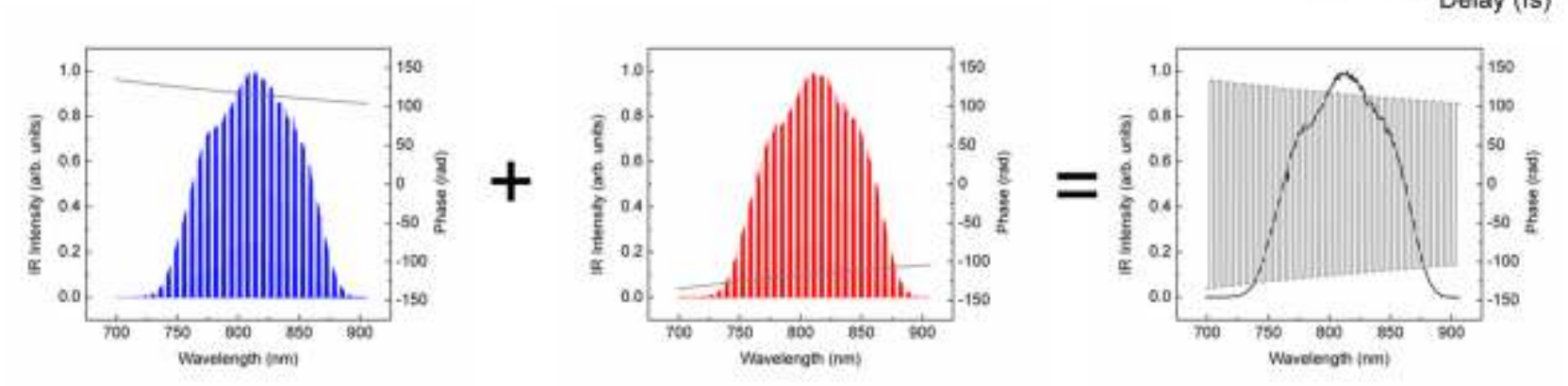
Pestov, Xu, Coello, Nogueira, Cruz, Lozovoy, and Dantus

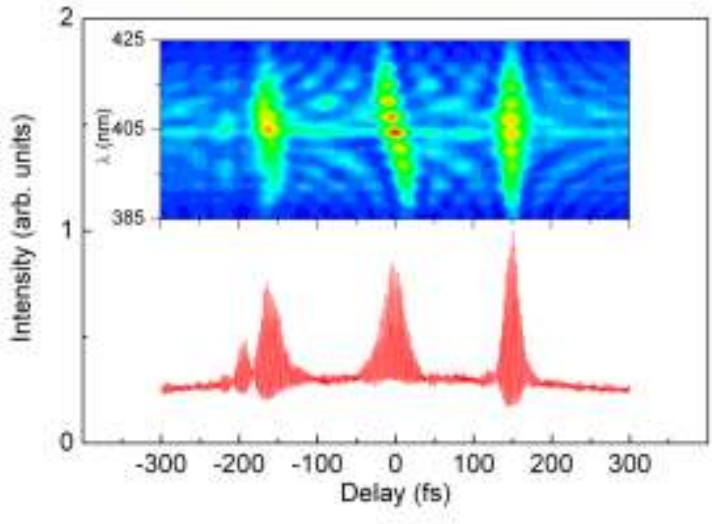
Optics Express, **17**, 14351 (2009) **Multi-comb Shaping**

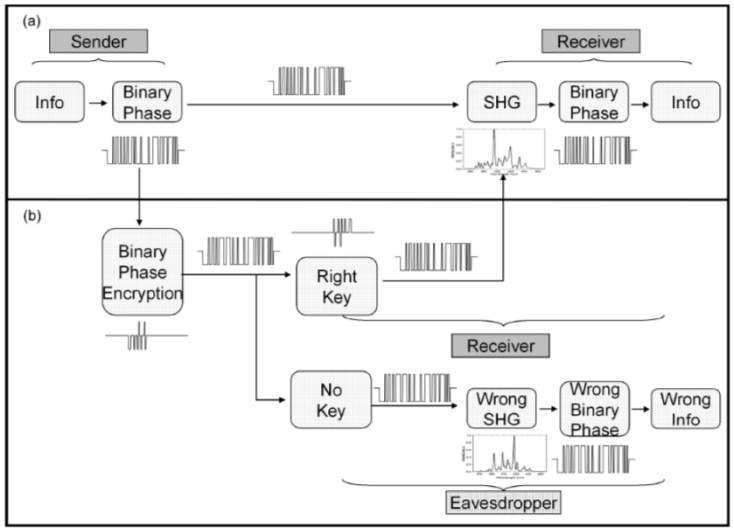
Optics and Photonics News **20**, 42-43 (2009).

Optics Express, 16, 15109 (2008) Asynchronous encrypted information transmission with sub-6 fs with 2.12 GHz repetition rate laser.









Metrology and GVD Measurements (sub-fs^2 accuracy)

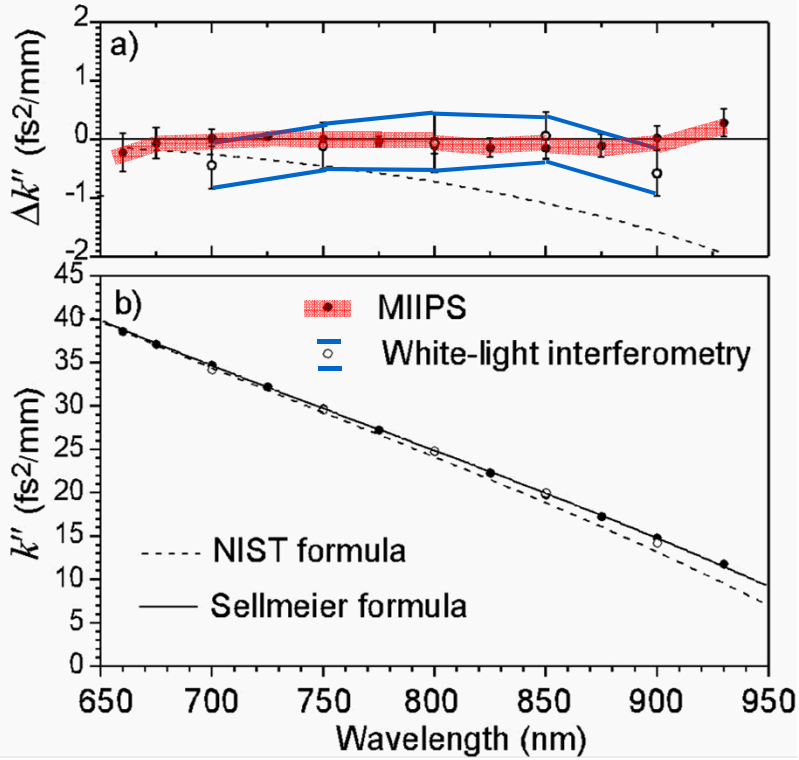
Coello, Xu, Miller, Wrzesinski, Gord, Roy, Devi, Pestov, Lozovoy and Dantus

Appl. Opt. 46, 8394 (2007) **Water and ocular GVD**

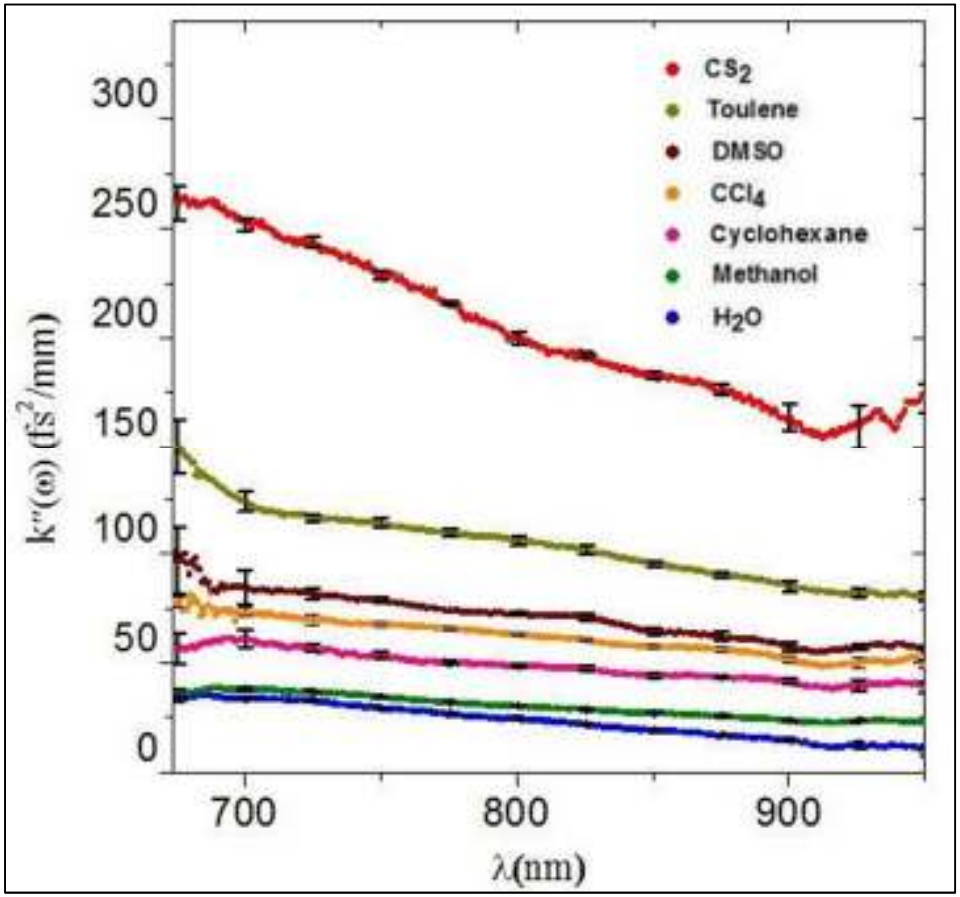
Optics Express **19**, 5163-5170 (2011) **GVD of atmospheric gases**

AIP Advances **1**, 032166 (2011) **GVD of solvents**

Dispersion of water



Dispersion of common solvents



Microscopy Imaging

Pastirk, Xu, Dela Cruz, Walowicz, Comstock, Schelhas, Andegecko, Weisel, Xi, Freudiger, Min, Holtom, Xie, Saytashev, Arkhipov, Winkler, Zuraski, Pestov, Lozovoy and Dantus

J. Phys. Chem. A **108**, 53 – 58 (2003)..

Optics Express 11, 1695-1701 (2003).

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Optics Express 12, 4144 (2004).

J. Photochem. Photobio. A **180**, 307 (2006).

Nanomed.Nanotec.Bio. Med. **2,** 177 (2006).

Opt. Commun. 281, 1841 (2008)

J. Biomed. Opt., 14, 014002 (2009)

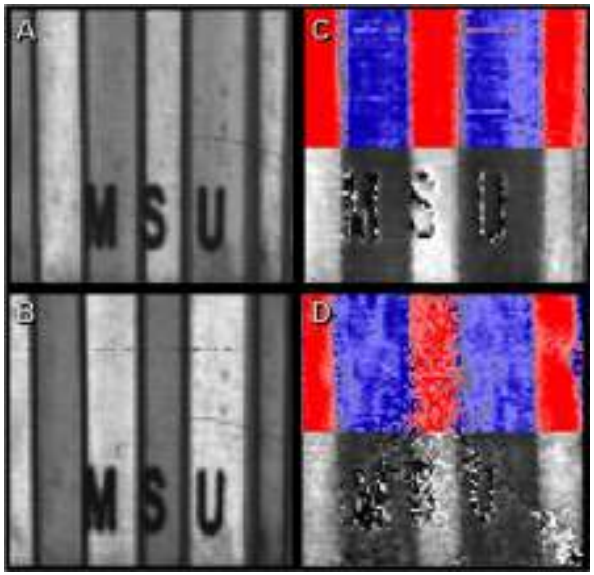
BioOptics World 2 23-24 (2009)

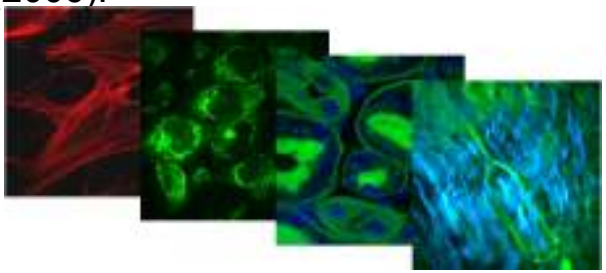
J. Opt. **12**, 084006 (2010).

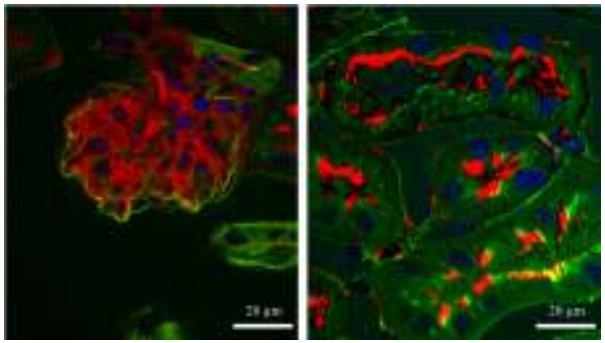
Nature Photonics, **5**, 103–109 (2011). **Video rate selective SRS**

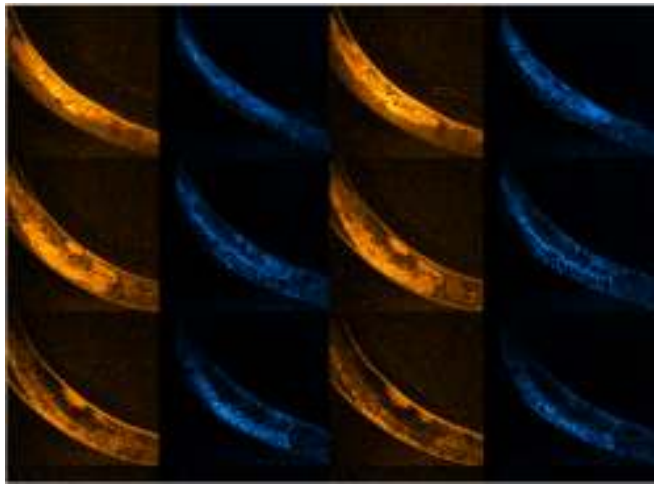
J. Photochem. Photobio B: **115**, 42 (2012). **Photodamage**

Quantum Control-Based
Functional Imaging Through Biological Tissue









Standoff Detection

Inspired by Dudovich Oron Silberberg Nature 418, 512 (2002)

Li, Harris, Xu, wrzesinski, Pastirk, Bremer, Butcher, Lozovoy and Dantus

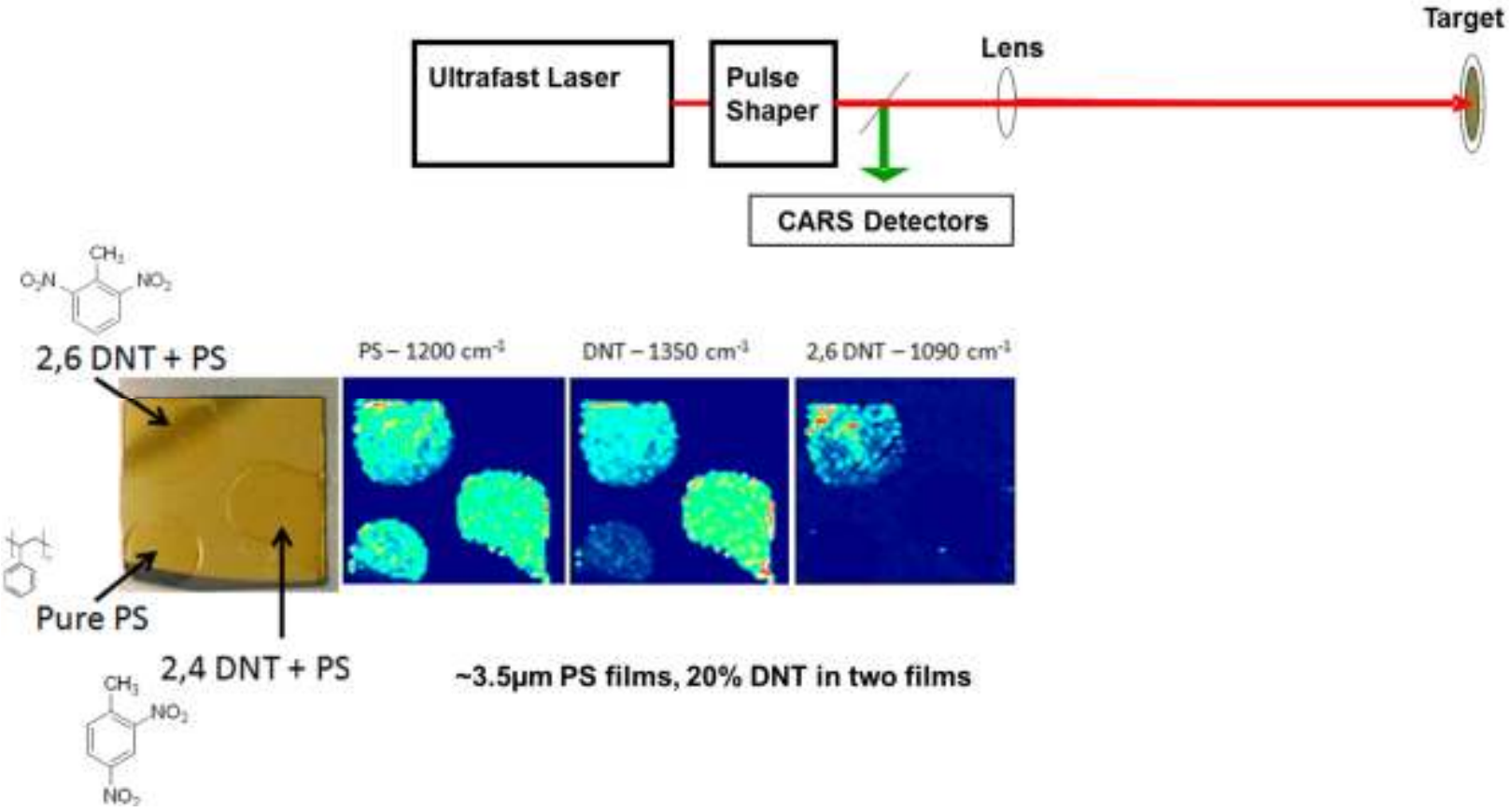
Opt. Express 16, 5499-5504 (2008)

Int. J. High Speed Electronics and Syst. **18**, 63 (2008).

Optics & Photonics News 19, 46 (2008)

Appl. Opt. **48**, B17 (2009)

Applied Physics Letters **99**, 101109 (2011).



Gas phase CARS

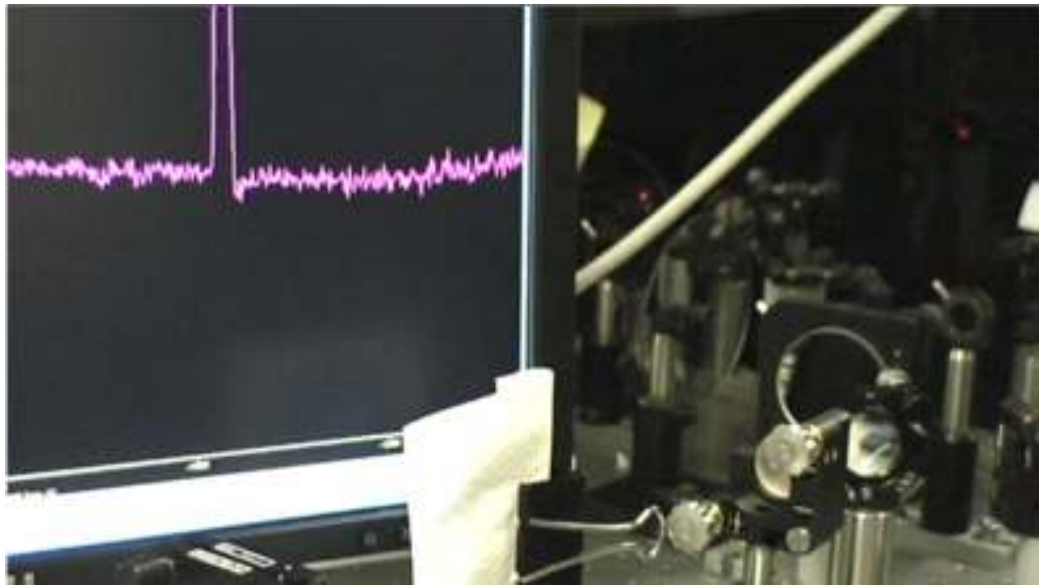
Roy, Wrzesinski, Pestov, Gunaratne, Gord, Xu, Yue, Bremer, Lozovoy and Dantus

Applied Physics Letters, L09-03549R1 (2009)

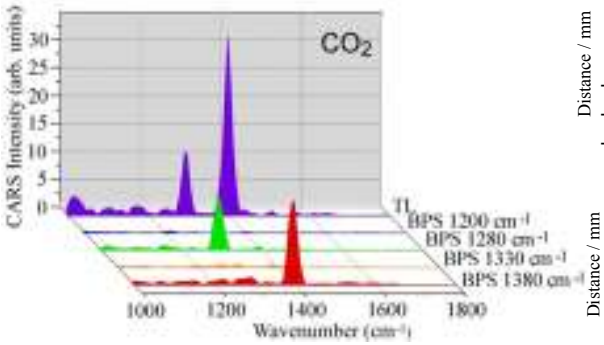
Optics and Photonics News **21**, 49 (2010).

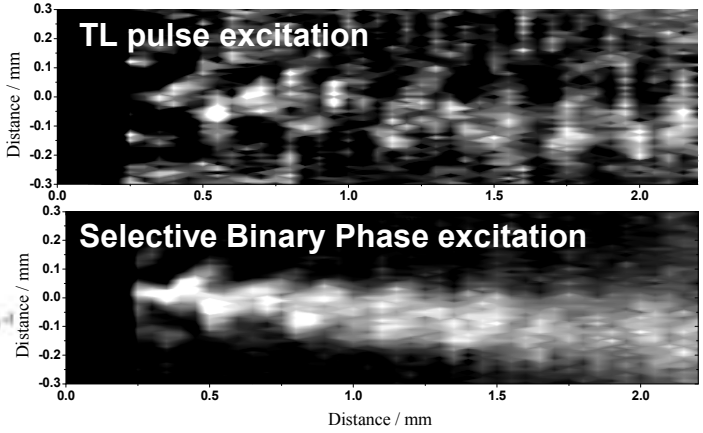
J. Raman Spec. **42**, 393-398 (2011)

J. Phys. Chem. A, (2012)

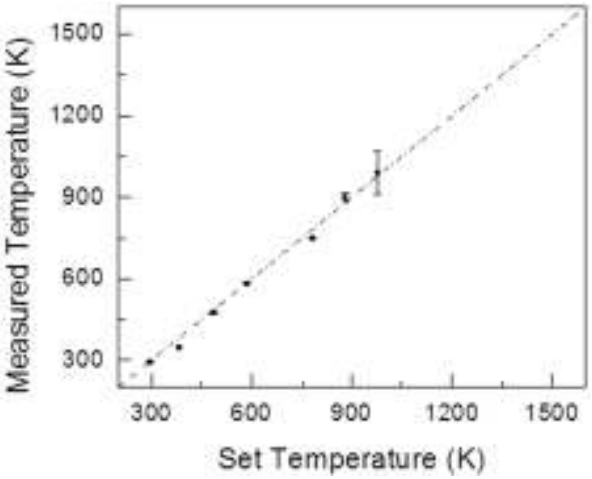


Selective Single Beam CARS





Single shot thermometry



Micromachining & LIBS

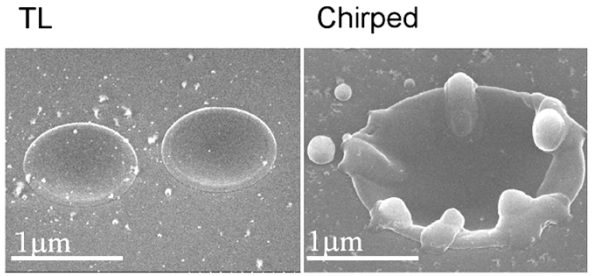
Gunaratne, Kangas, Singh, Gross, Zhu, Parker, Parker, Nie, Lozovoy and Dantus

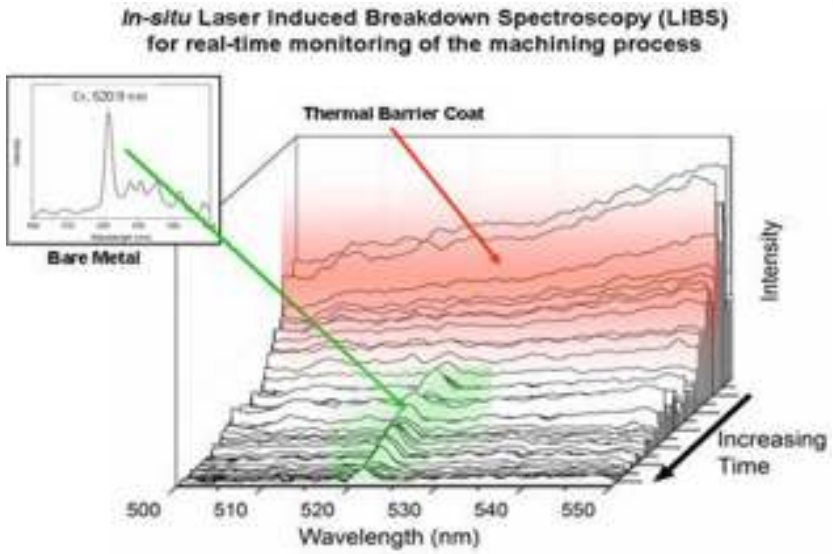
Chemical Physics Letters **423**, 197-201 (2006) Metals

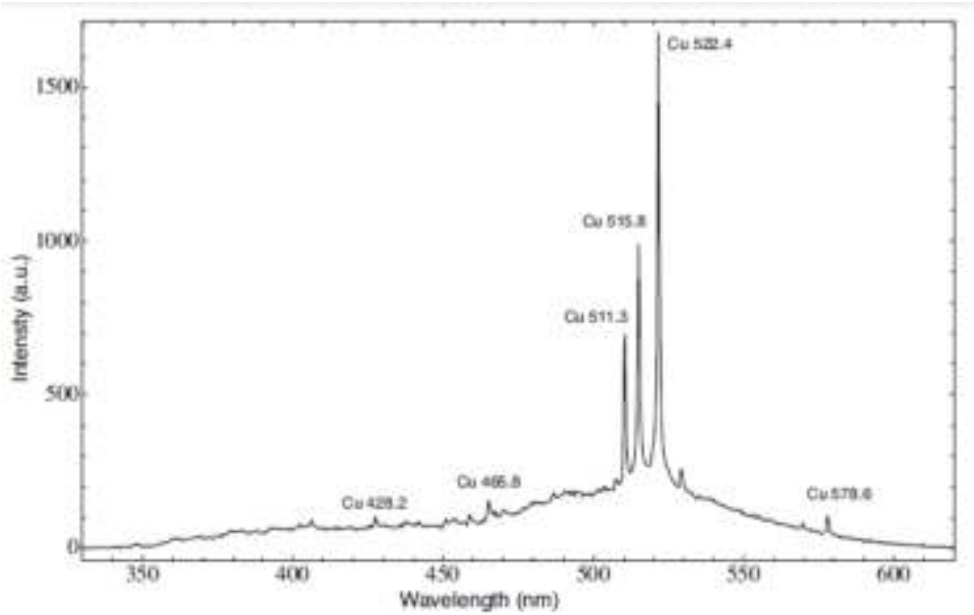
J. Appl. Phys. **106**, 123101 (2009) Silicon

Chem. Phys. Lett. (2012) LIBS using fiber oscillator

Single shot ablation of silicon







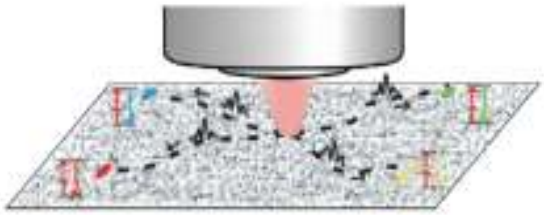
Plasmonics and nanoparticles

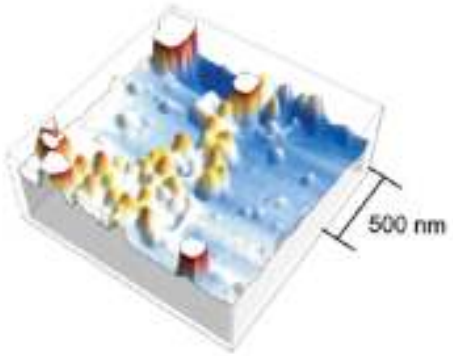
Gunn, Ewald, High, Lozovoy and Dantus

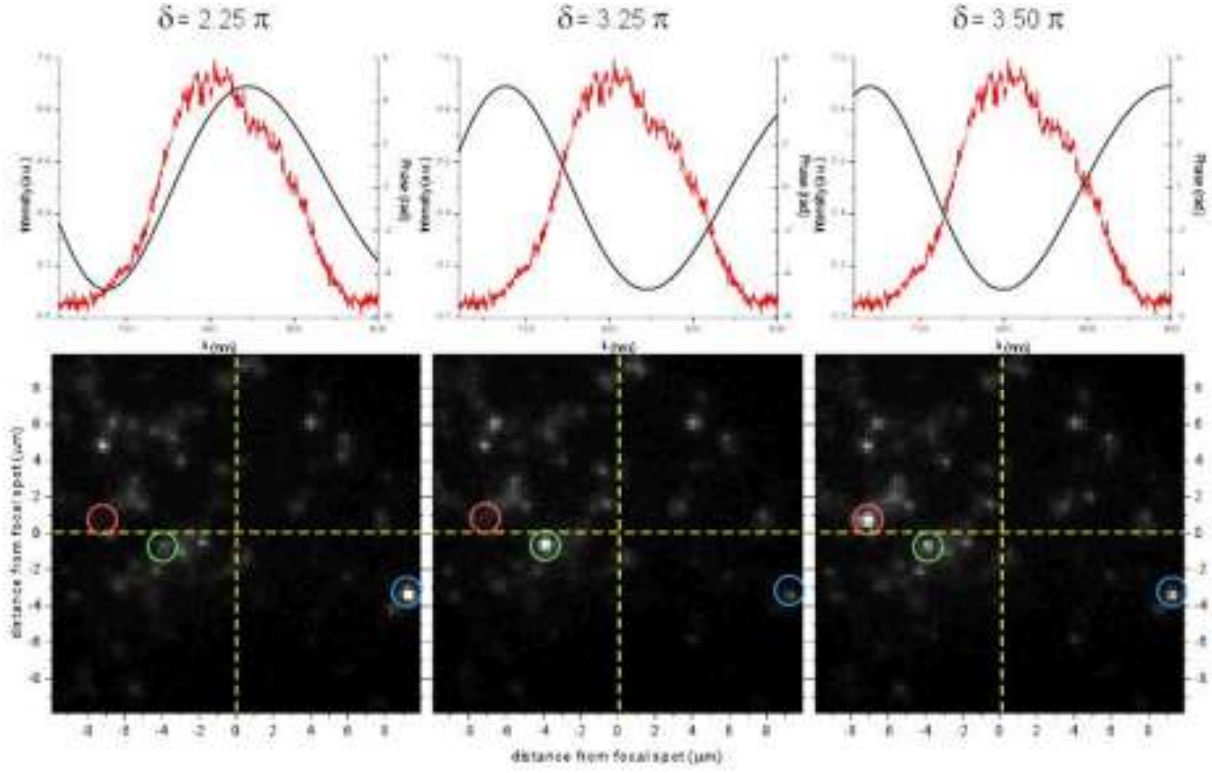
Nano Letters 6, 2804-2809 (2006).

J. Phys. Chem. C C **114**, (29), 12375 (2010).

Measurement and Control of Ultrashort Optical Pulse Propagation in Metal Nanoparticle-Covered Dielectric Surfaces; Up to distances >100x focal spot.







Two-photon induced luminescence, far from focal spot

Surface Plasmon Transmission through nanoparticle wires.

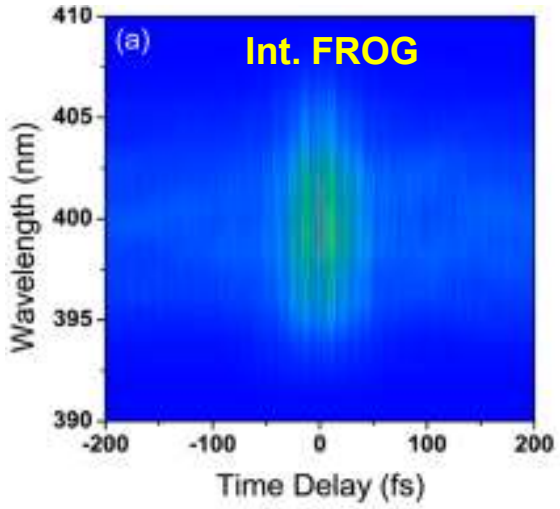
Solvation Dynamics

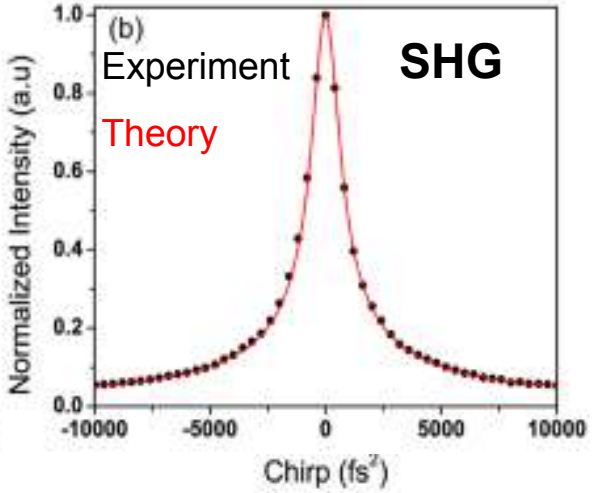
Konar, Shah, Lozovoy and Dantus

J. Phys. Chem. Letters **3,** 2458 (2012)

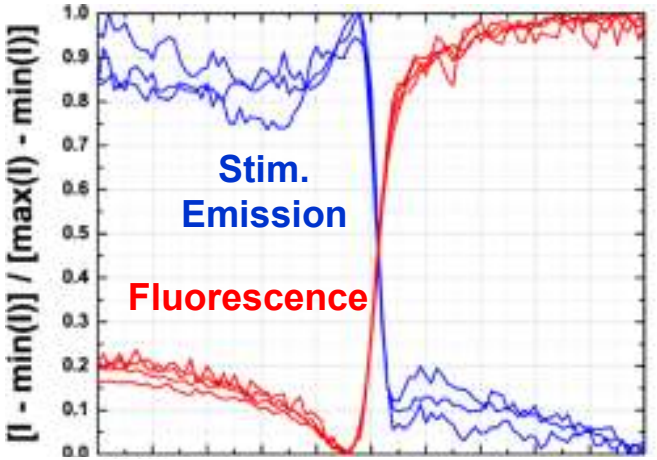
Revisiting the chirp effect observed by Bardeen and Shank,

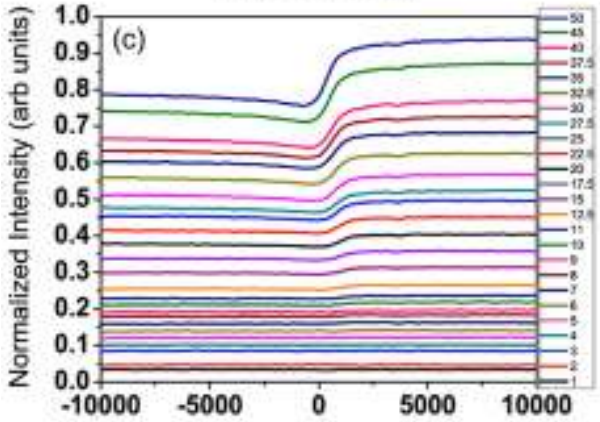
Later by Wilson's group



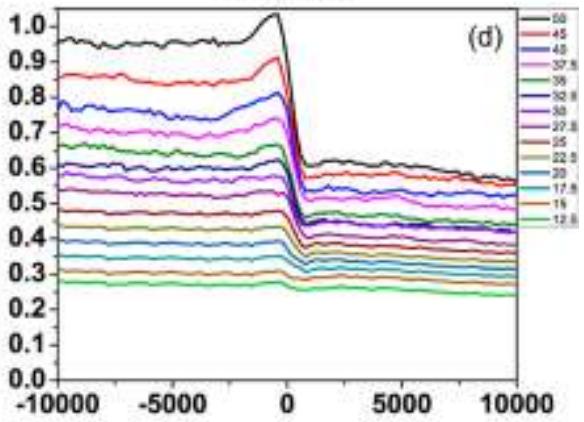


Intensity Invariant

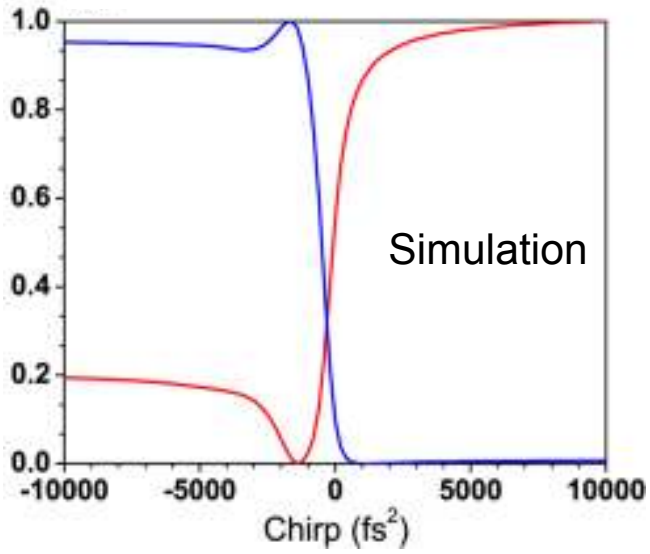




Fluorescence



Stim. Emission



Solvation Dynamics

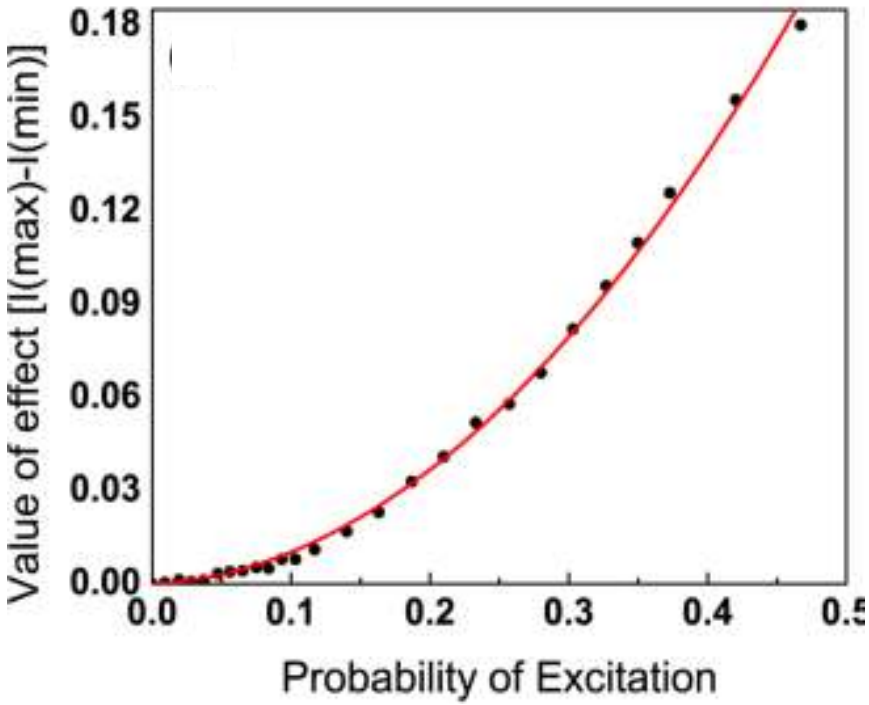
Konar, Shah, Lozovoy and Dantus

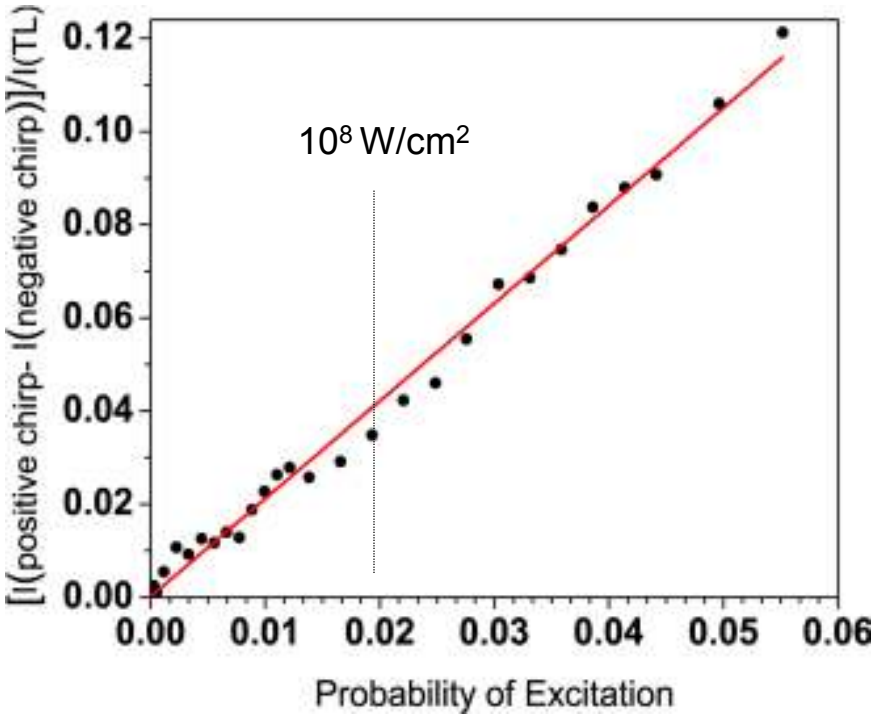
J. Phys. Chem. Letters **3,** 2458 (2012)

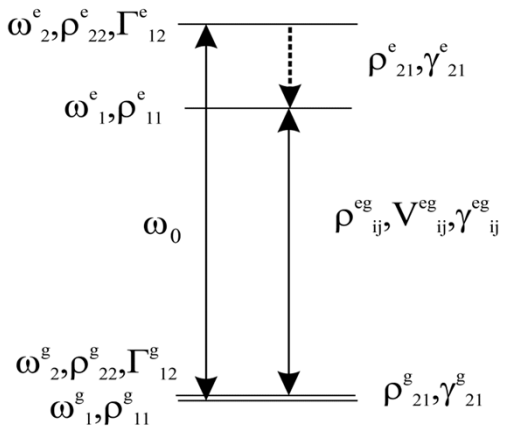
Normalized Effect = [Max (I_{FL}) – Min (I_{FL})] / (I_{FL} TL)

If found to be = x

Because I_{FL} ***TL=x*** then ***Effect = x^2***





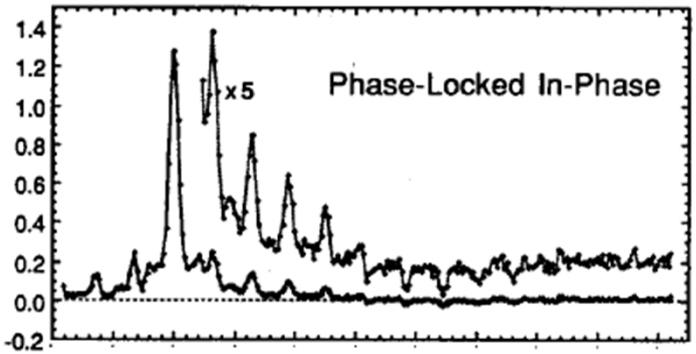


Excitation Range from 0.02% to 6%

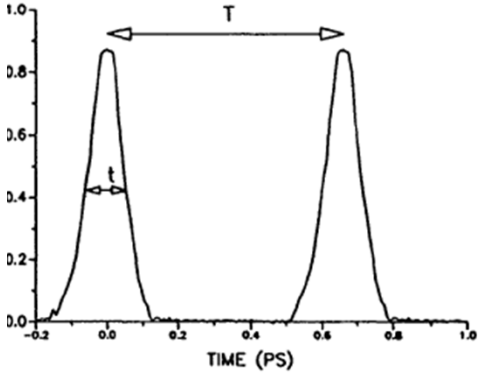
Quadratic Intensity Dependence

Measuring Interference Between Laser Pulses and Wave Packets Without Imposing

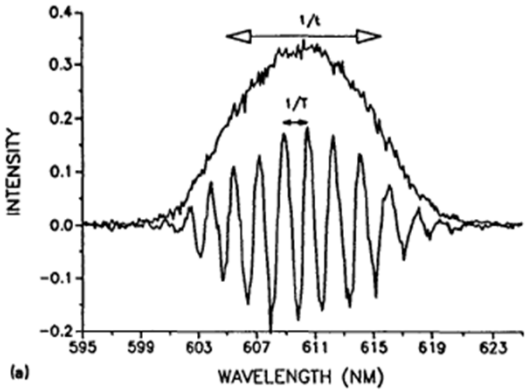
Scherer et al. JCP 93, 856 (1990), JCP 95, 1487 (1991)



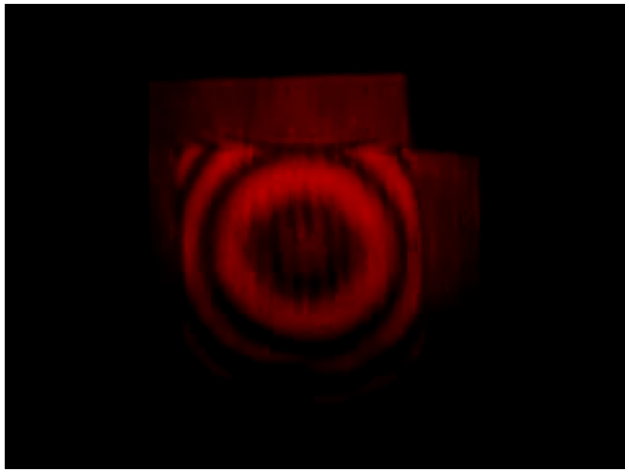
The two optical pulses interfere



The spectrum is modulated

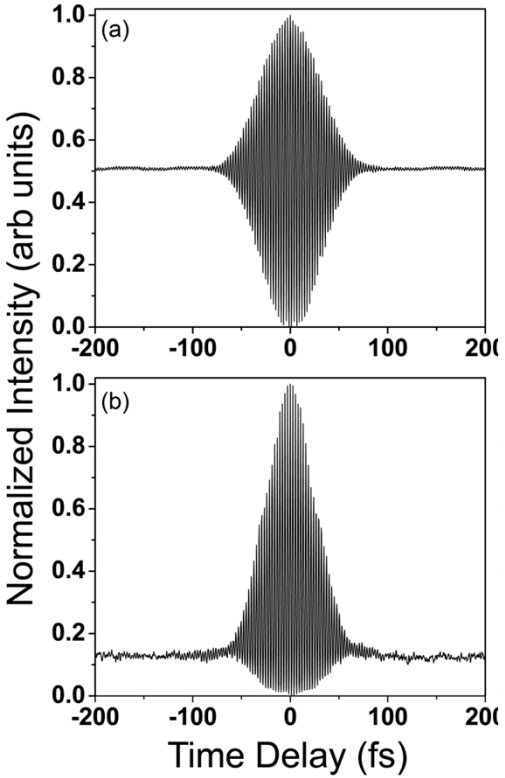


Michelson Interferometer



1st order autocorrelation

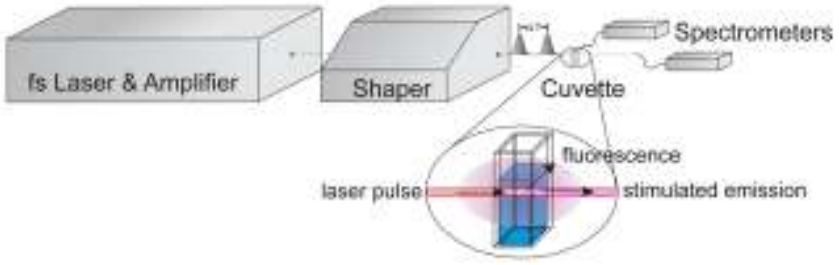
2nd order autocorrelation

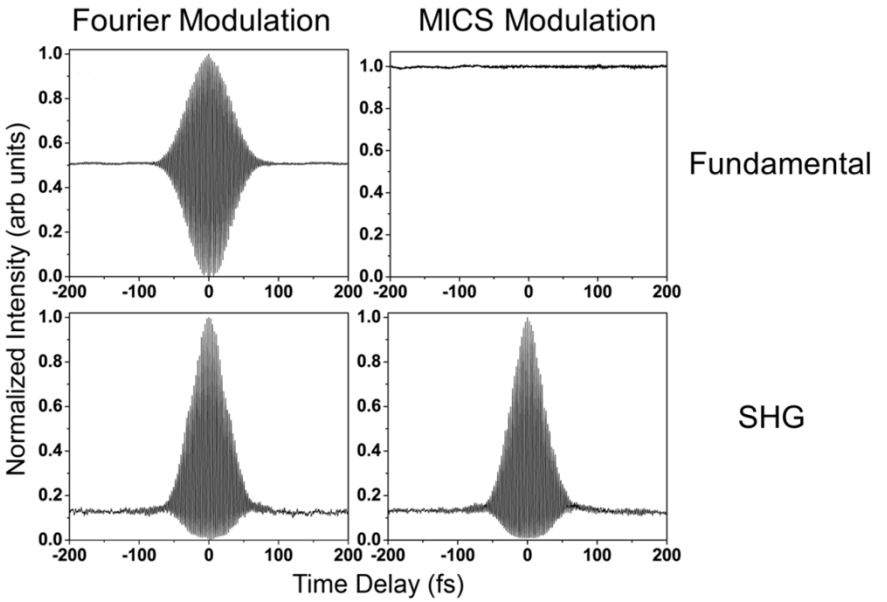


Solvation Dynamics

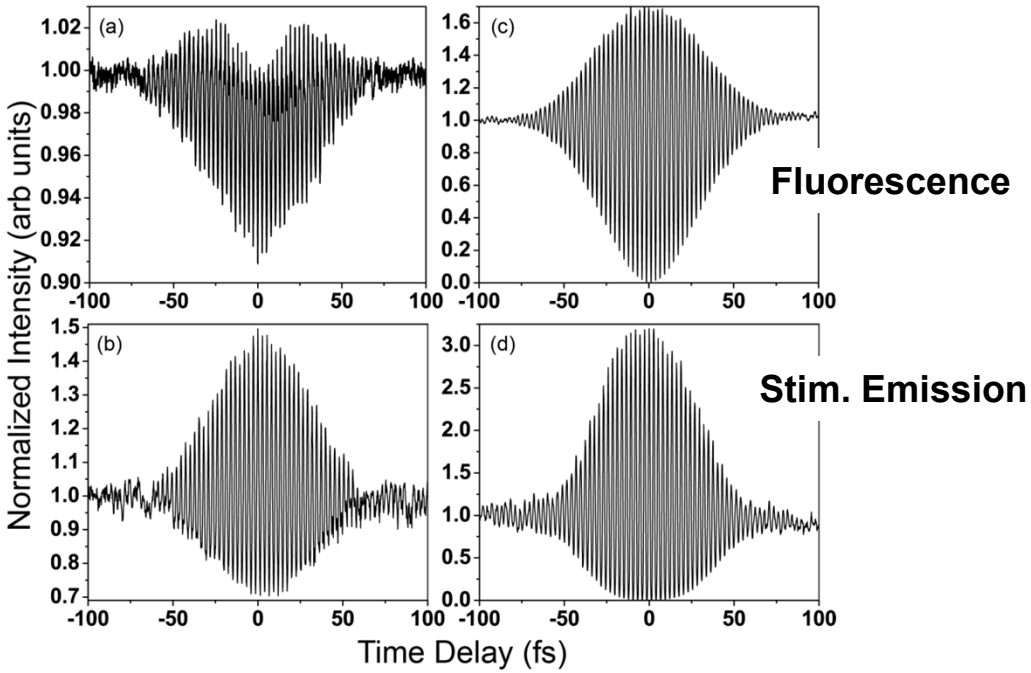
Konar, Shah, Lozovoy and Dantus

J. Phys. Chem. Letters **3**, 1329 (2012).

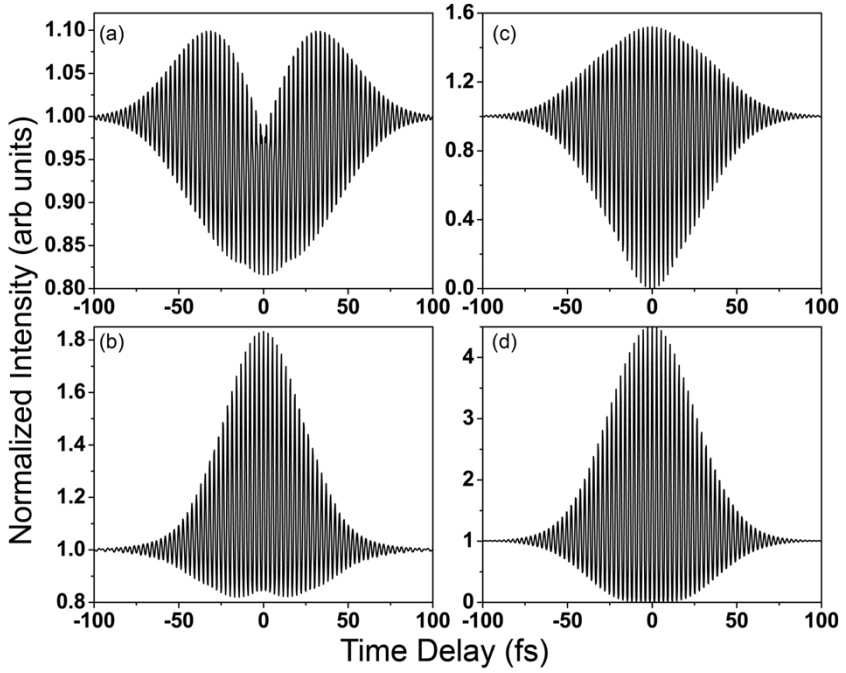




Non-interfering Interfering



Simulations



Fiber Laser Design

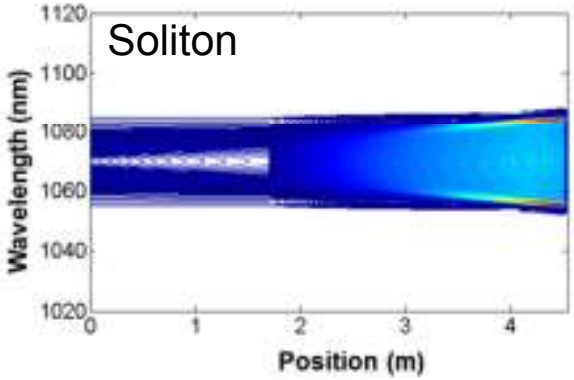
Nie, Pestov, Wise, Chong, Liu, Gale, Wabnitz, Renninger, Saytashev, Arkhipov, Lozovoy and Dantus

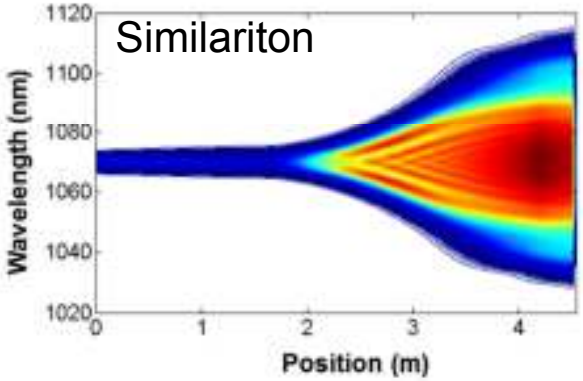
Optics Express **19**, 12074-12080 (2011) 42 fs, 10nJ Yb fiber laser

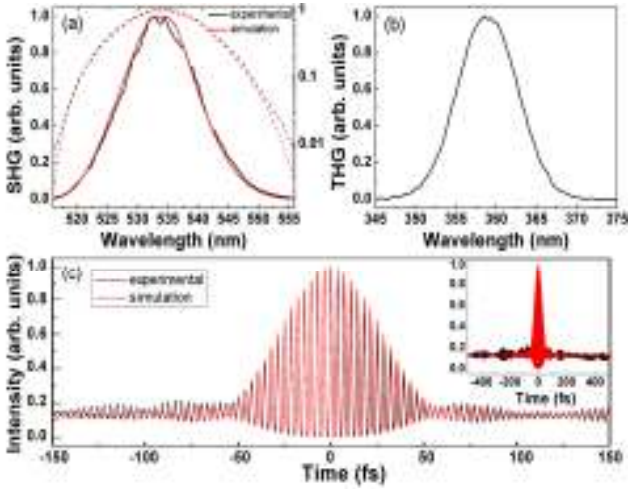
Optics and Photonics News **22**, 47 (2011) Self similar evolution

Optics Express **20**, 14213 (2012) Osc. with bandwidth greater than gain

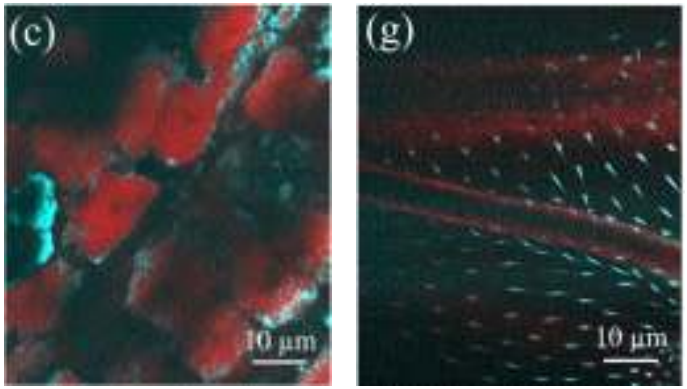
Biomed. Optics Express B, 1750 (2012) Imaging with sub-30fs Yb fiber







Sub-30fs Ytterbium oscillator



Compact <9fs fiber lasers

Strong Field

Pastirk, Kangas, Dela Cruz, Shane, Gunaratne, Zhu, Harris, Lozovoy and Dantus

J. Phys. Chem. A **109**, 2413-2416 (2005) binary phases for multidimensional analysis

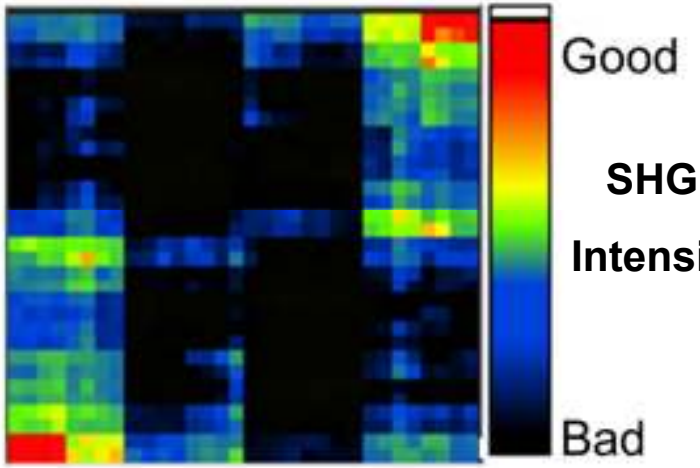
J. Phys. Chem. A **110**, 11388-11391 (2006) search space mapping

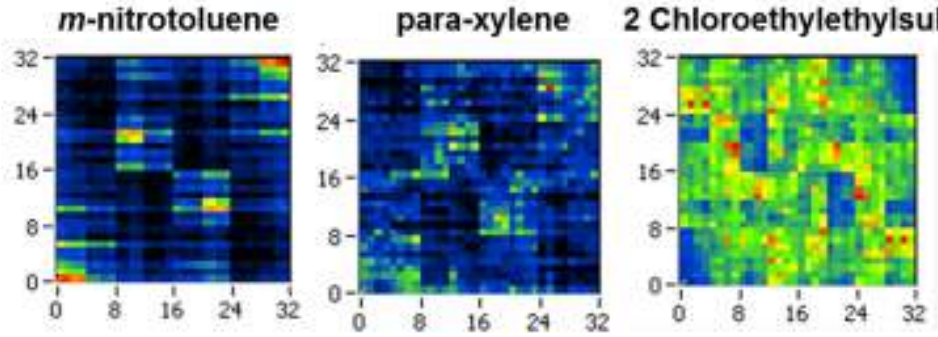
Journal of Modern Optics **53**, 2533 (2006) chemical recognition

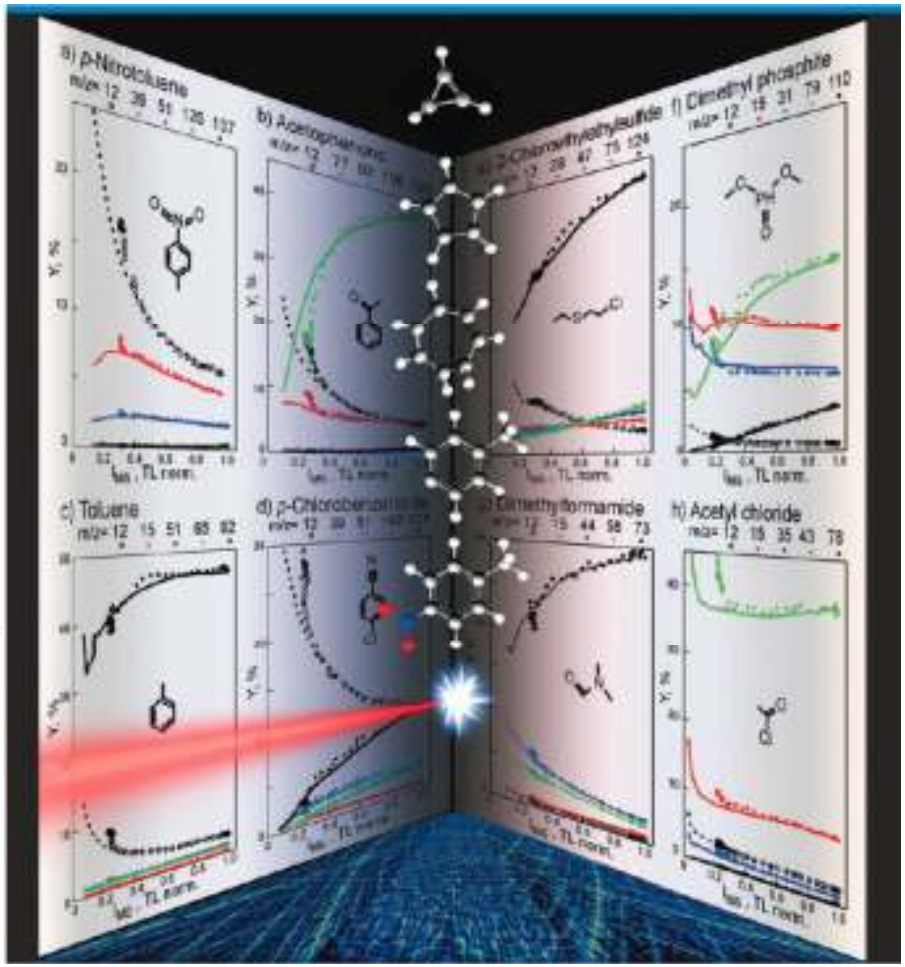
ChemPhysChem, **7**, 2471-2473 (2006) control using binary phases

J. Phys. Chem. A.112,3789 (2008) No evidence of interference

Binary Search Space Mapping







Mass Spectrometry Analysis and Imaging

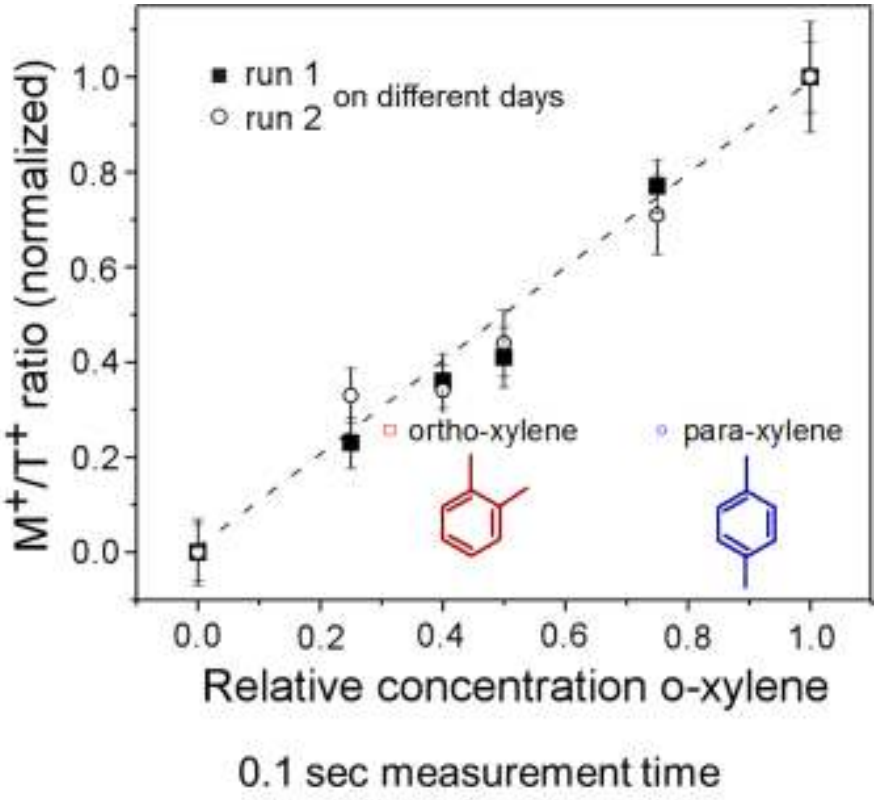
Dela Cruz, Pastirk, Coello, Jones, Gunaratne, Lozovoy and Dantus

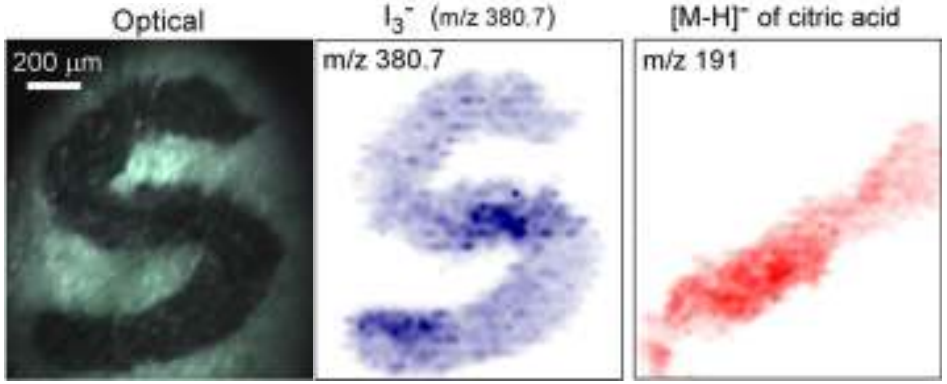
J. Phys. Chem. A **109**, 8447-8450 (2005) **quantitative isomer identification**

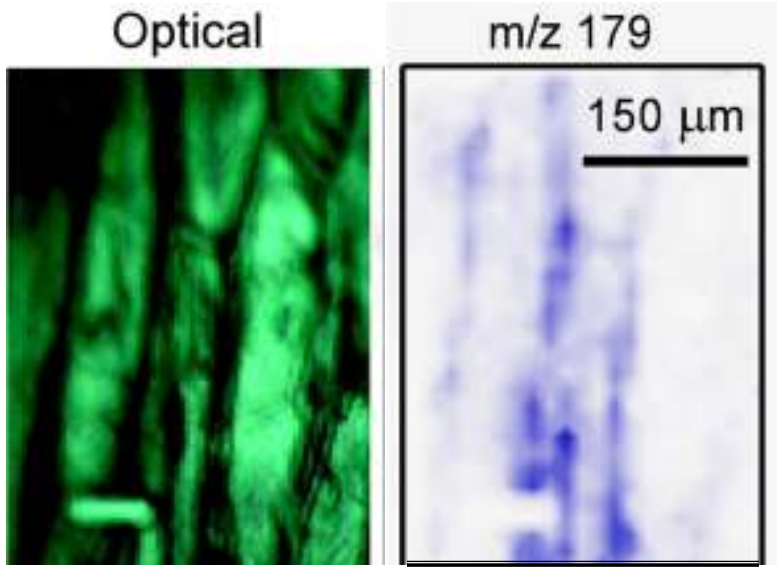
Journal of Mass Spectrometry 42 178 (2006) Isomer identification

Applied Optics, in press (2007). multidimensional

Anal. Chem. **82**, 2753 (2010) **Atmospheric pressure femtosecond laser imaging mass spectrometry**







Mass Spec. Proteomics and Metabolomics

Kalcic, Gunaratne, Jones, Reid, Winkler, Smith, Safran, Stemmer, Palumbo, Lozovoy and Dantus

J. Am. Chem. Soc. 131, 940 (2009) FS-LID

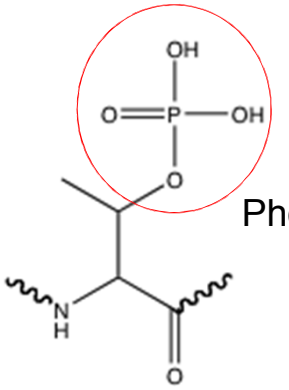
J. Phys. Chem. A, **114**, 10380 (2010).

Journal of the American Society for Mass Spectrometry **12**, 2031 (2010).

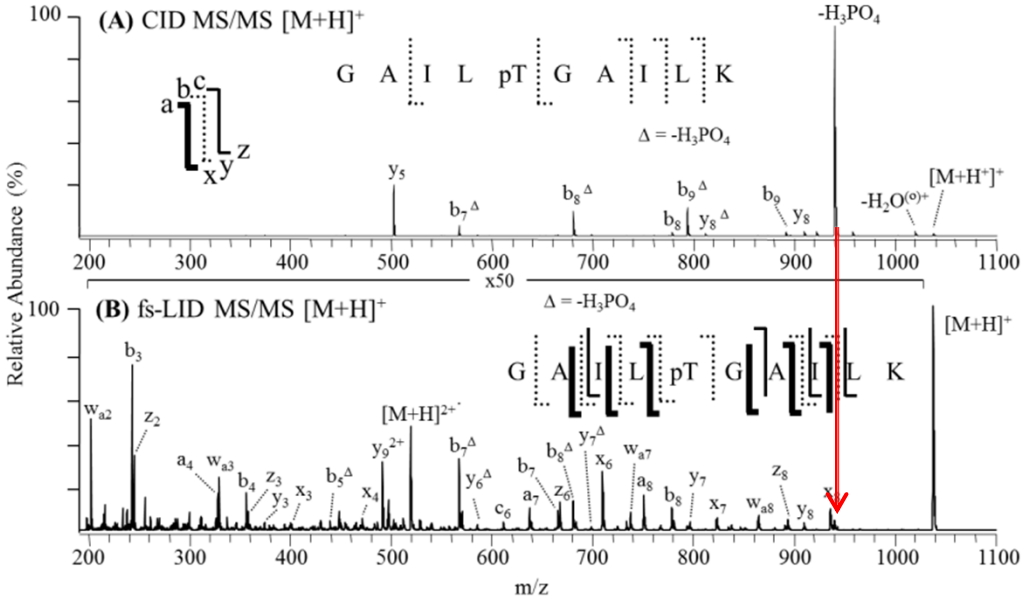
Mass Spectrometry Reviews **30**, 600 (2011) Phosphoproteomics

Journal of Physical Chemistry A **116**, 2764 (2012) The mechanism

Breaking strong chemical bonds while leaving weak ones intact



Phosphorylation



Post-translational modifications: a challenge for proteomics *Proteomics* 6,1525-6 (2004)

Tumor antigen p53: (*Science* Molecule of the year 1993), has >18 phosphorylation sites.

DNA winds around Histones, gene regulation and DNA repair depend on histone PTM's.

Coherent Control

Marvet, Gross, Backhaus, Schmidt, Pastirk, Brown, Grimberg, Gunaratne, Zhu, Shah, Goswami, Lozovoy and Dantus

Photoassociation

Chem. Phys. Letters **245**, 393 (1995) J. Chem. Phys.**106**, 8013 (1997) Chem. Phys. Letters **306**, 18 (1999)

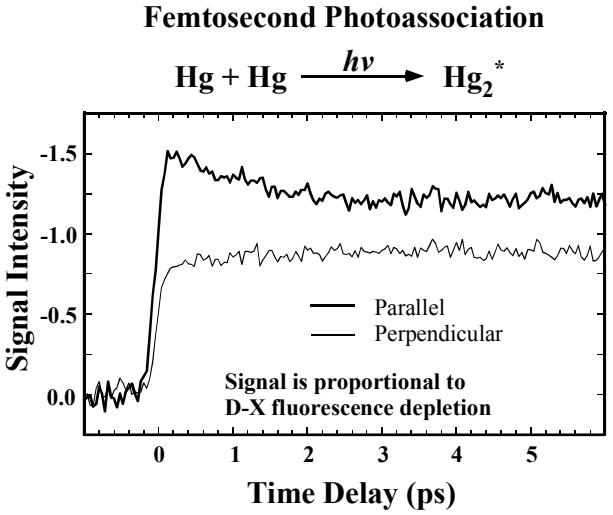
Chirp control of chemical reaction J. Chem. Phys. **108**, 4375-4378 (1998)

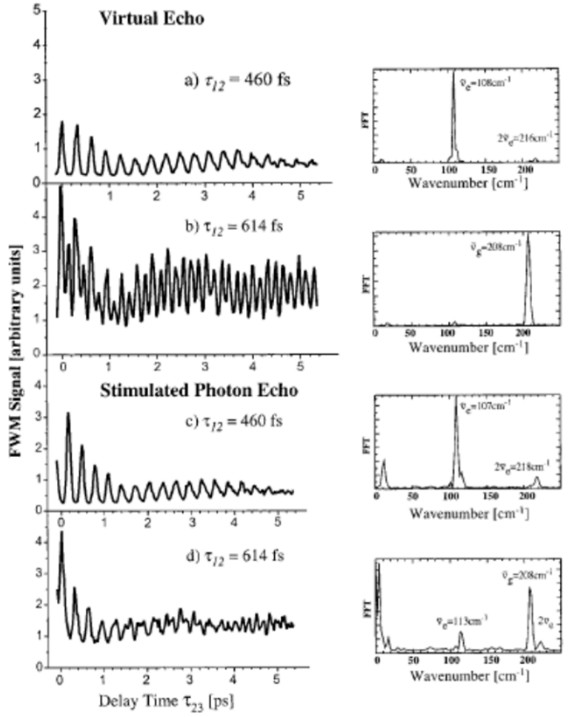
Four Wave Mixing (includes CARS) J. Chem. Phys. **111**, 3779 (1999) J. Phys. Chem. A **103**, 10226 (1999)

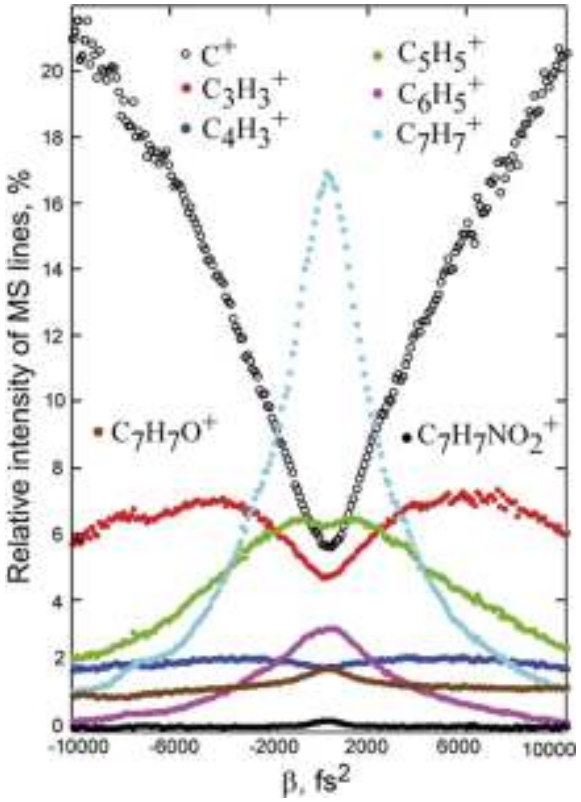
Temporal symmetry Chem. Phys.**338**, 259 (2007).

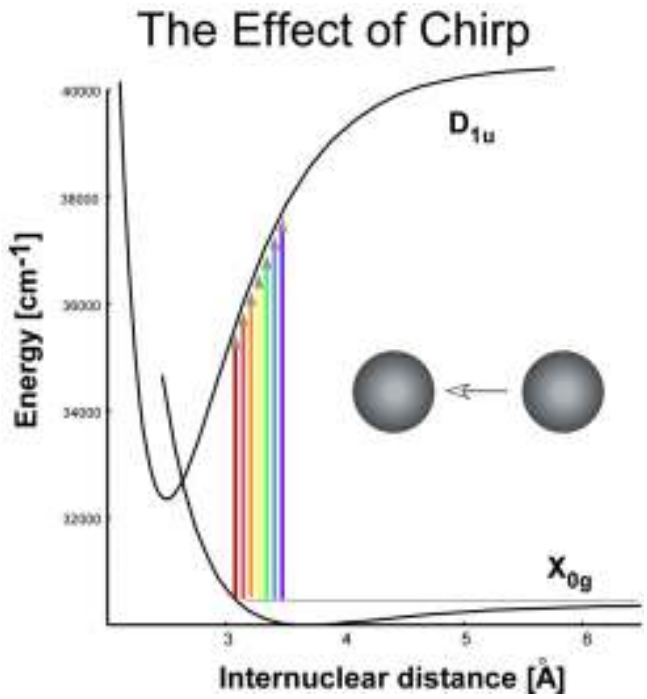
Comment (no toluene found from acetophenone) J. Phys. Chem. A 113, 5264 (2009)

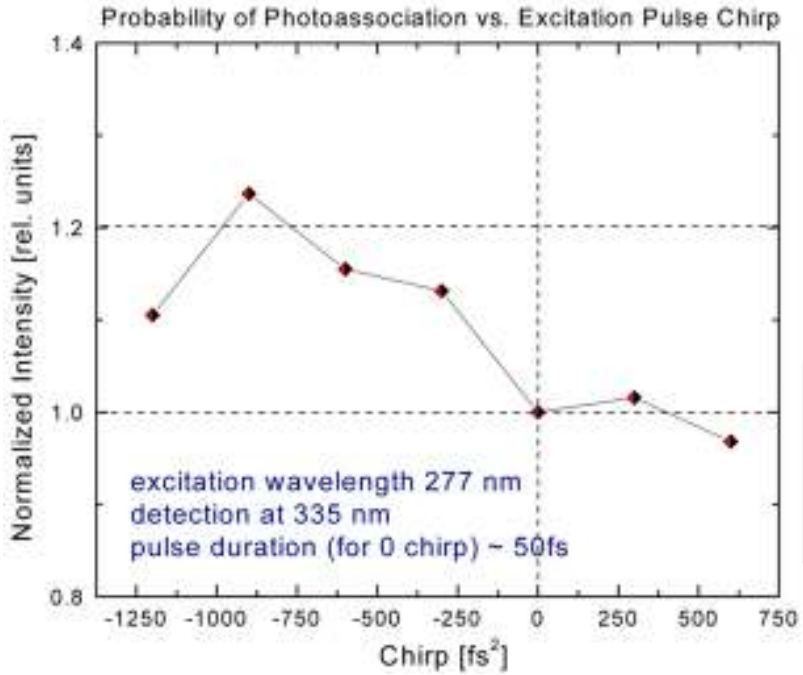
Dynamics observed in acetophenone J. Phys. Chem. A **115**, 1305 (2011)











Back of the Envelope Calculation

$$\frac{\Delta V}{\Delta R} = 10^4\, cm^{-1} / \text{Å}$$

The relative velocity of the mercury atoms

$$\bar{v} = -300 m/s = -3x10^{-3}\ \text{Å}/\ fs$$

The expected chirp in the absorption spectrum

$$\varphi = -30 cm^{-1} / fs$$

The calculated chirp required

$$\phi = -\frac{1}{30c} = -10^3\, fs^2$$

Unpublished data by I. Pastirk, presented

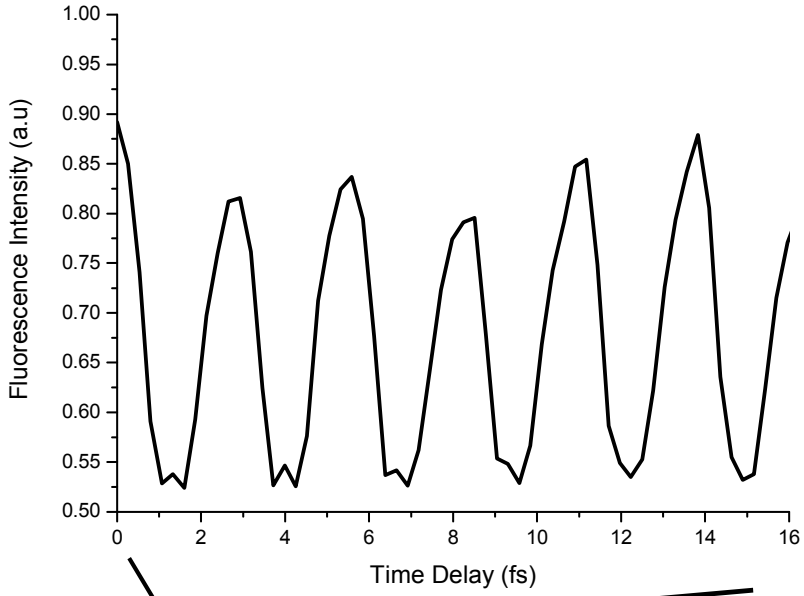
Cold Molecule 2001: Coherent Control and Cold Molecules

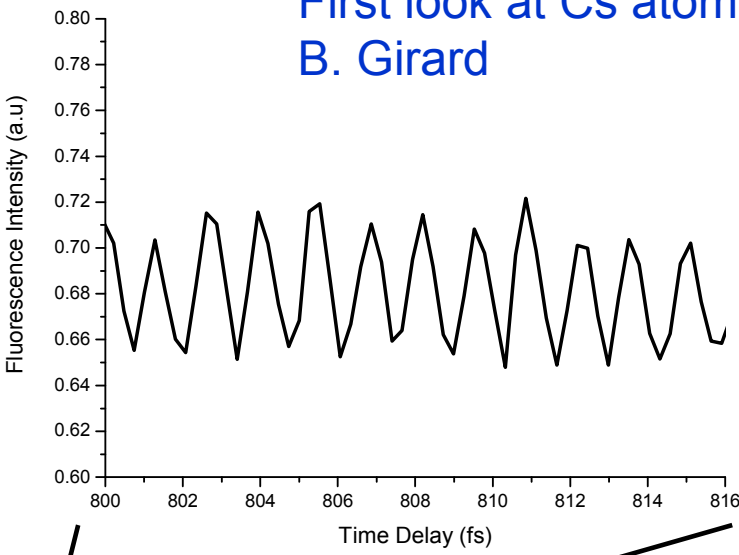
Gif-sur-Yvette, France,

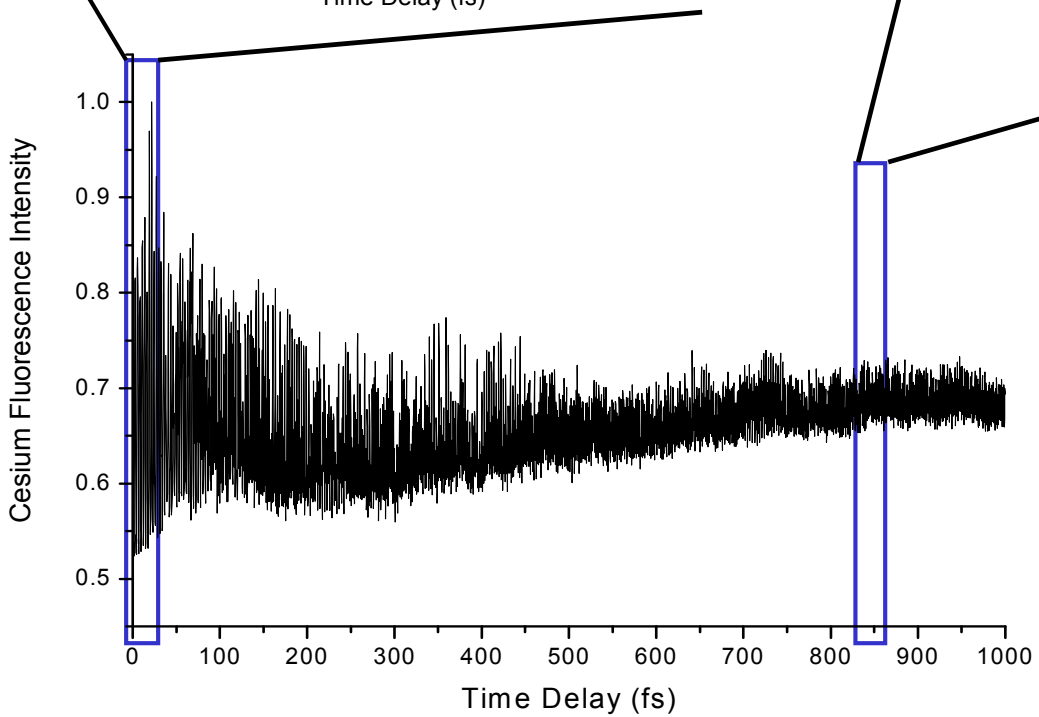
October 21-25, 2001

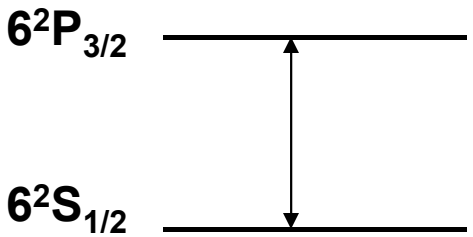
Looking for electronic coherence in strong fields

First look at Cs atoms
B. Girard



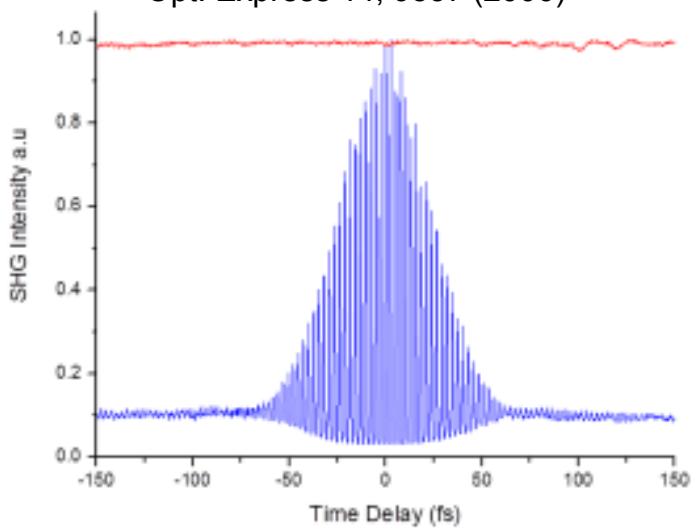


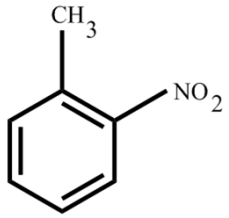




Looking for evidence of electronic coherence in o-NT photodissociation

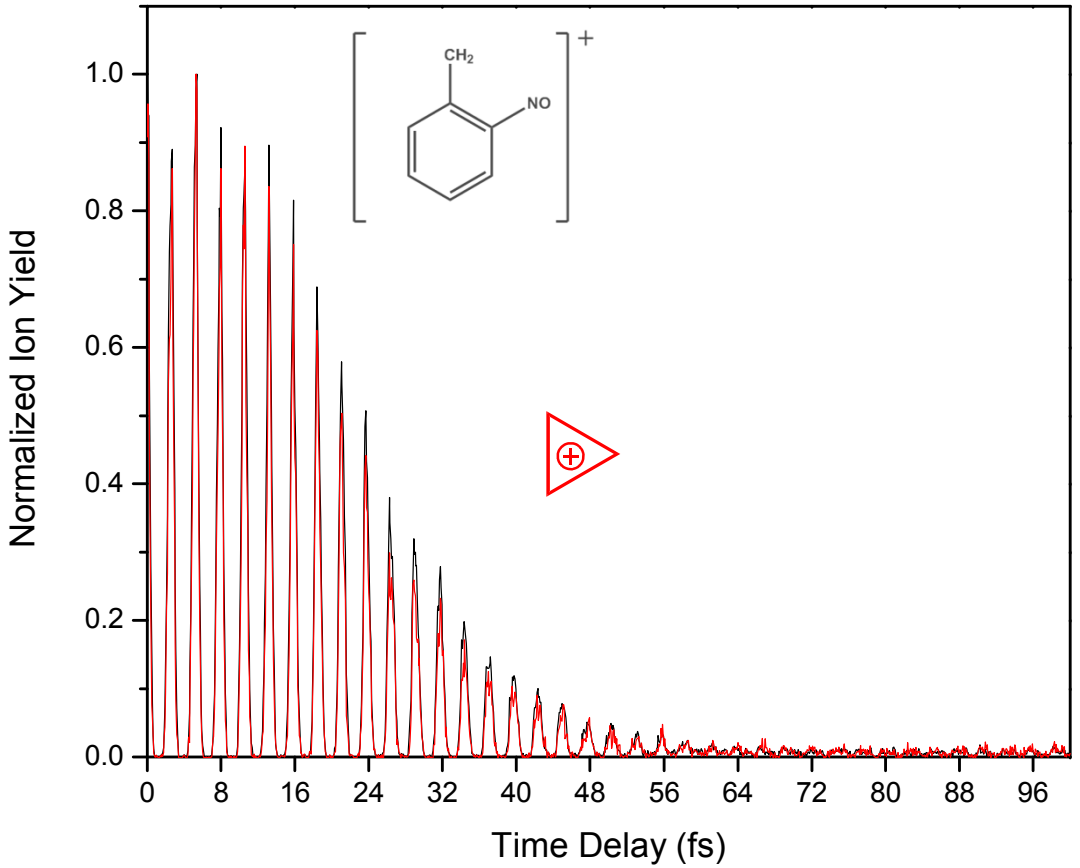
Opt. Express 14, 9537 (2006)



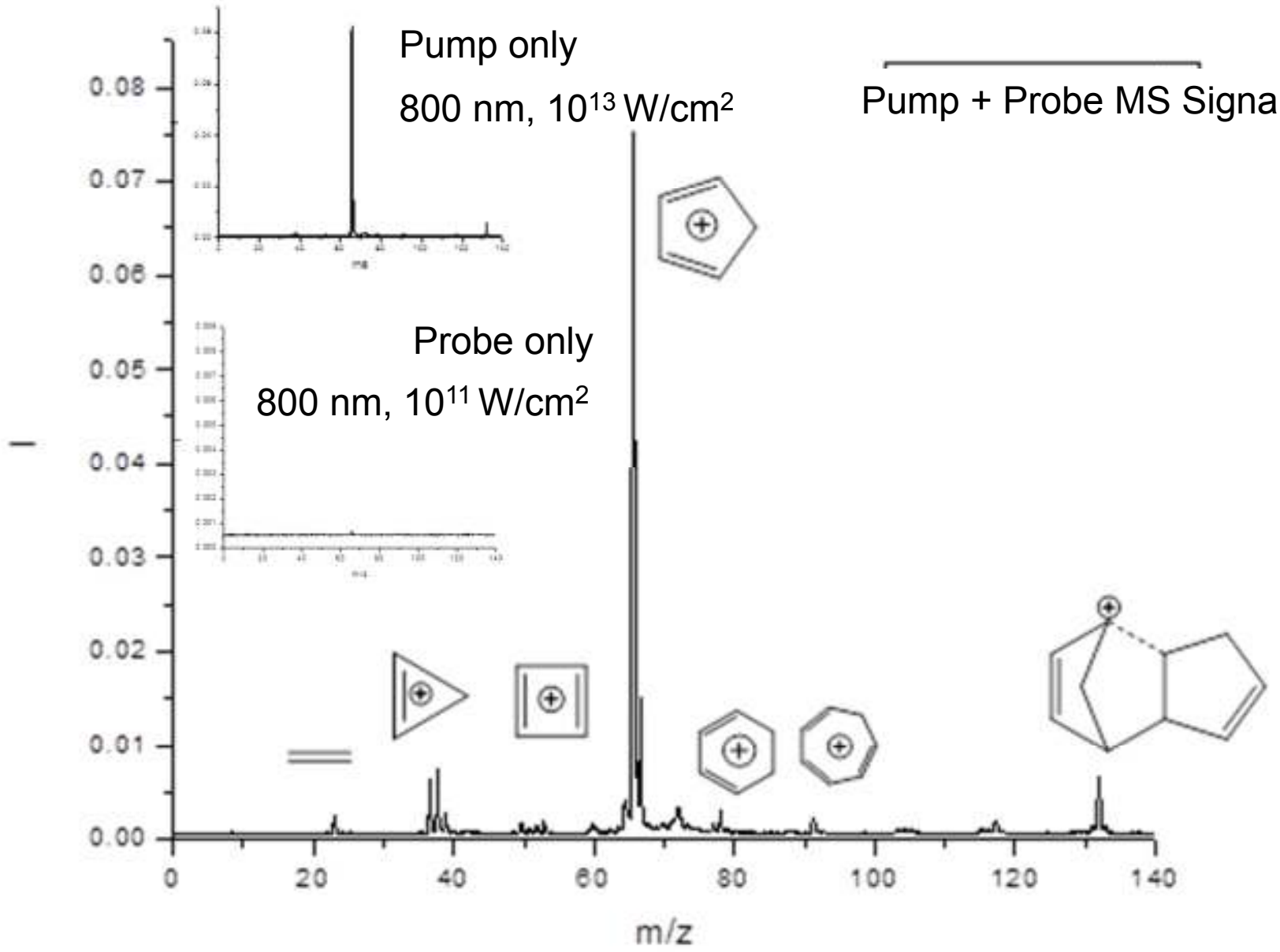


ortho-Nitrotoluene

Peak Intensity = 8×10^{13} W/cm^2

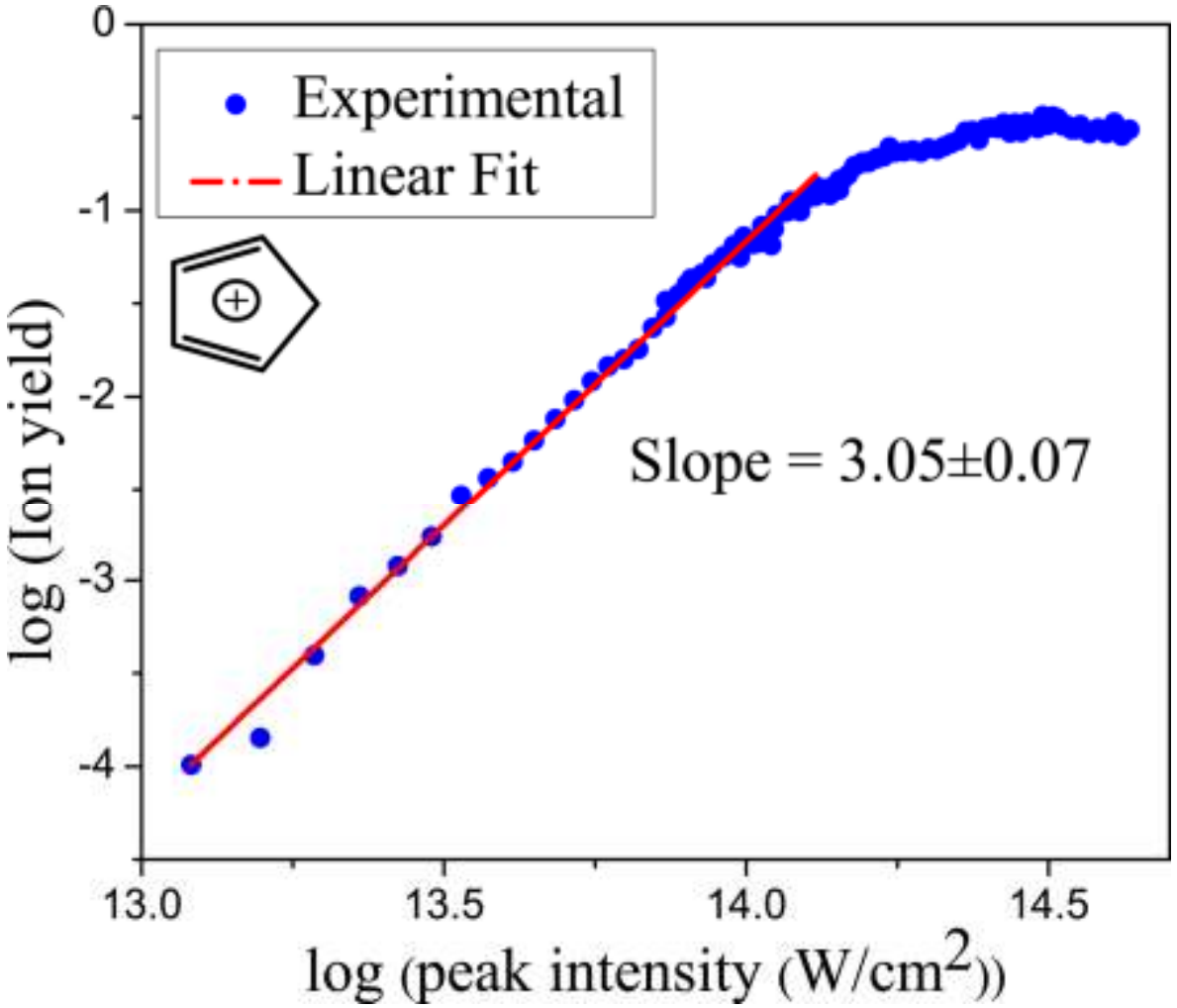


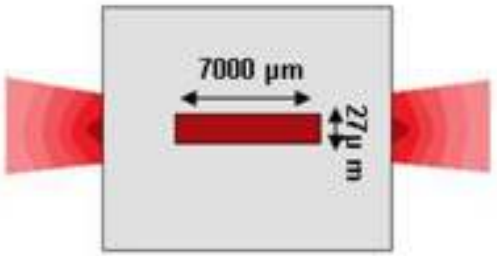
Dicyclopentadiene (DCDP)



Goswami, Shah, Konar, Lozovoy and Dantus to be submitted (2012)

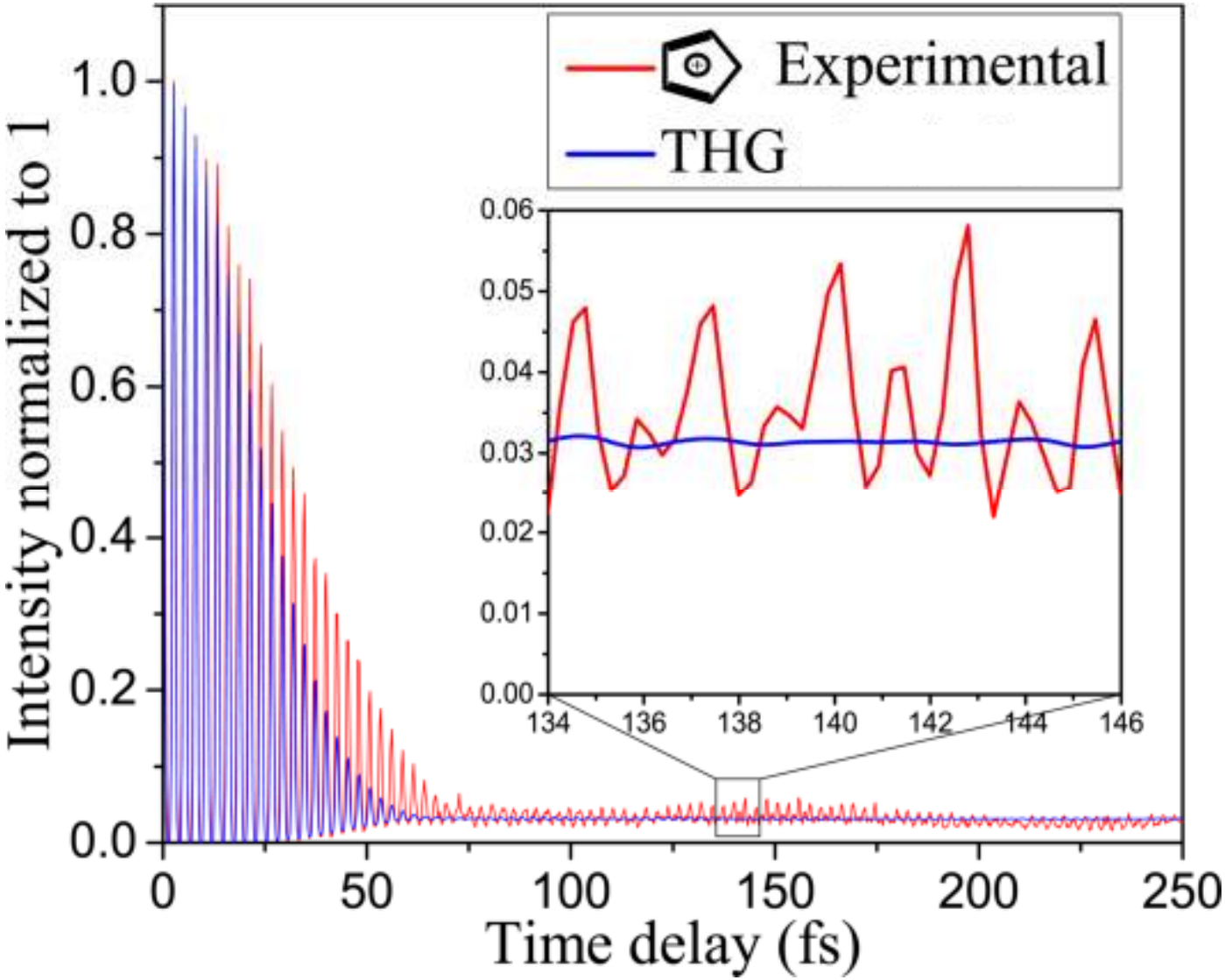
Power Dependence Fit for CPD^+





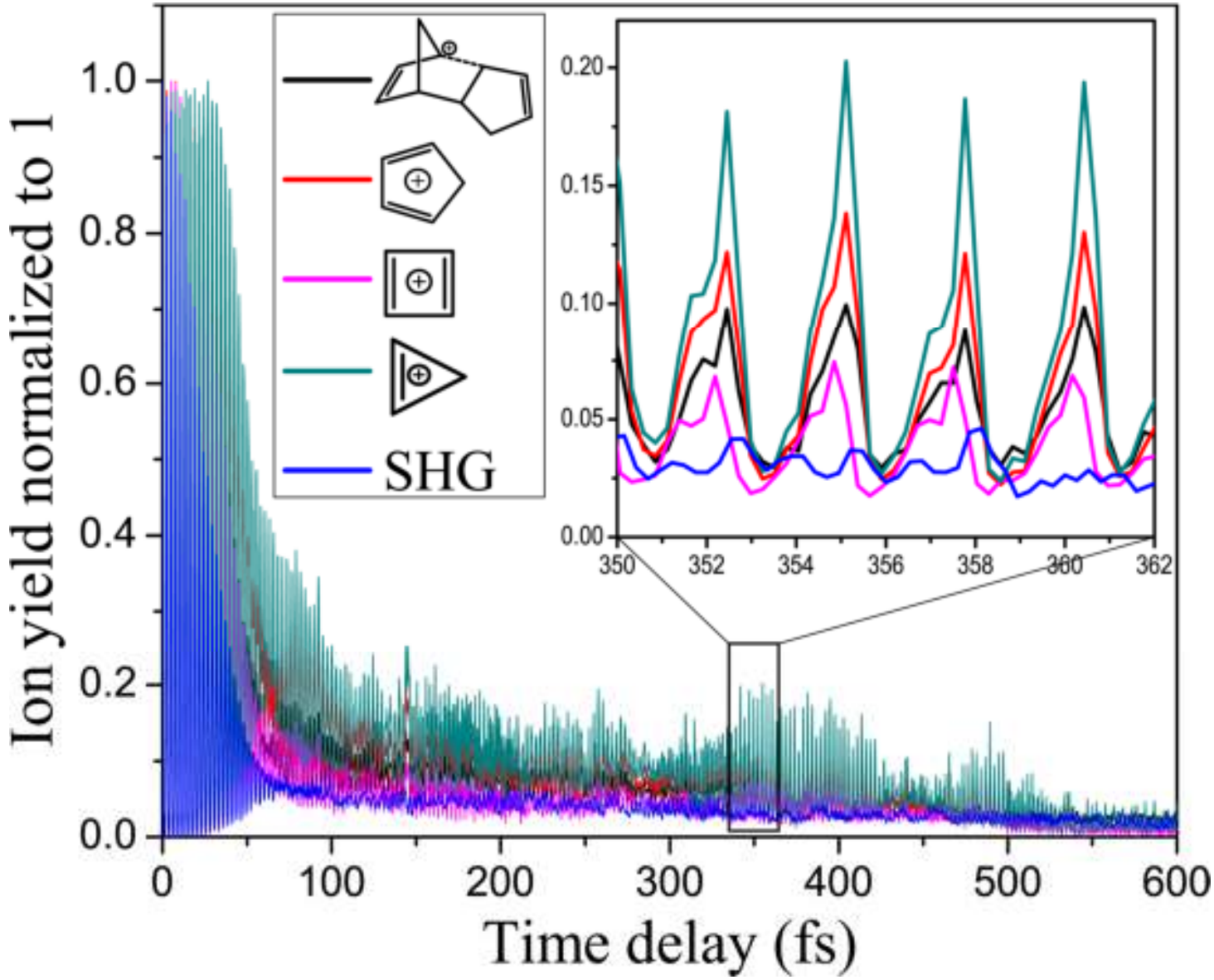
Goswami, Shah, Konar, Lozovoy and Dantus to be submitted (2012)

Comparison to Third Harmonic Generation Signal



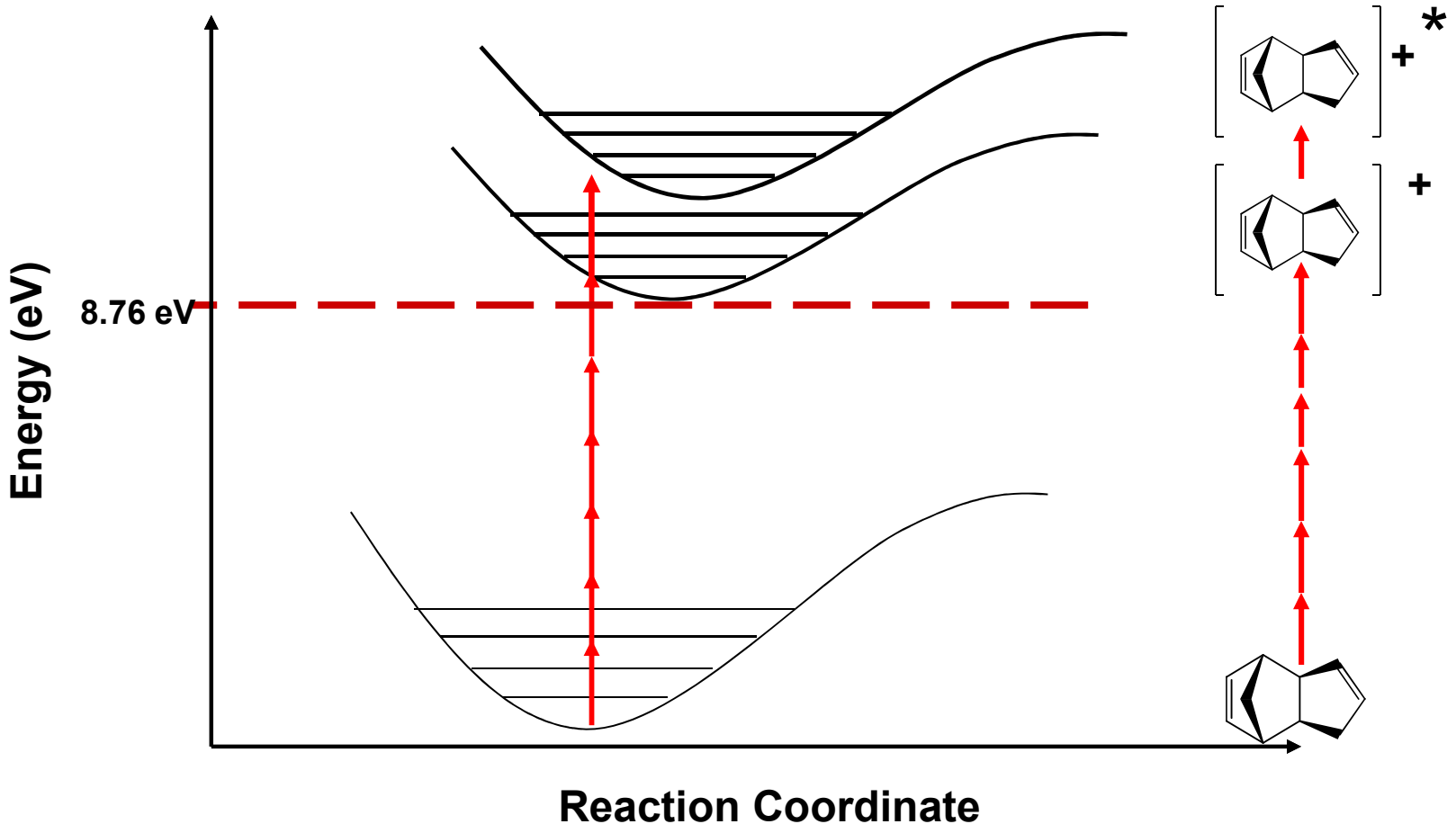
Goswami, Shah, Konar, Lozovoy and Dantus to be submitted (2012)

Long lived electronic coherence – DCPD fragments



Goswami, Shah, Konar, Lozovoy and Dantus to be submitted (2012)

Multiphoton Ionization of Di-Cyclopentadiene

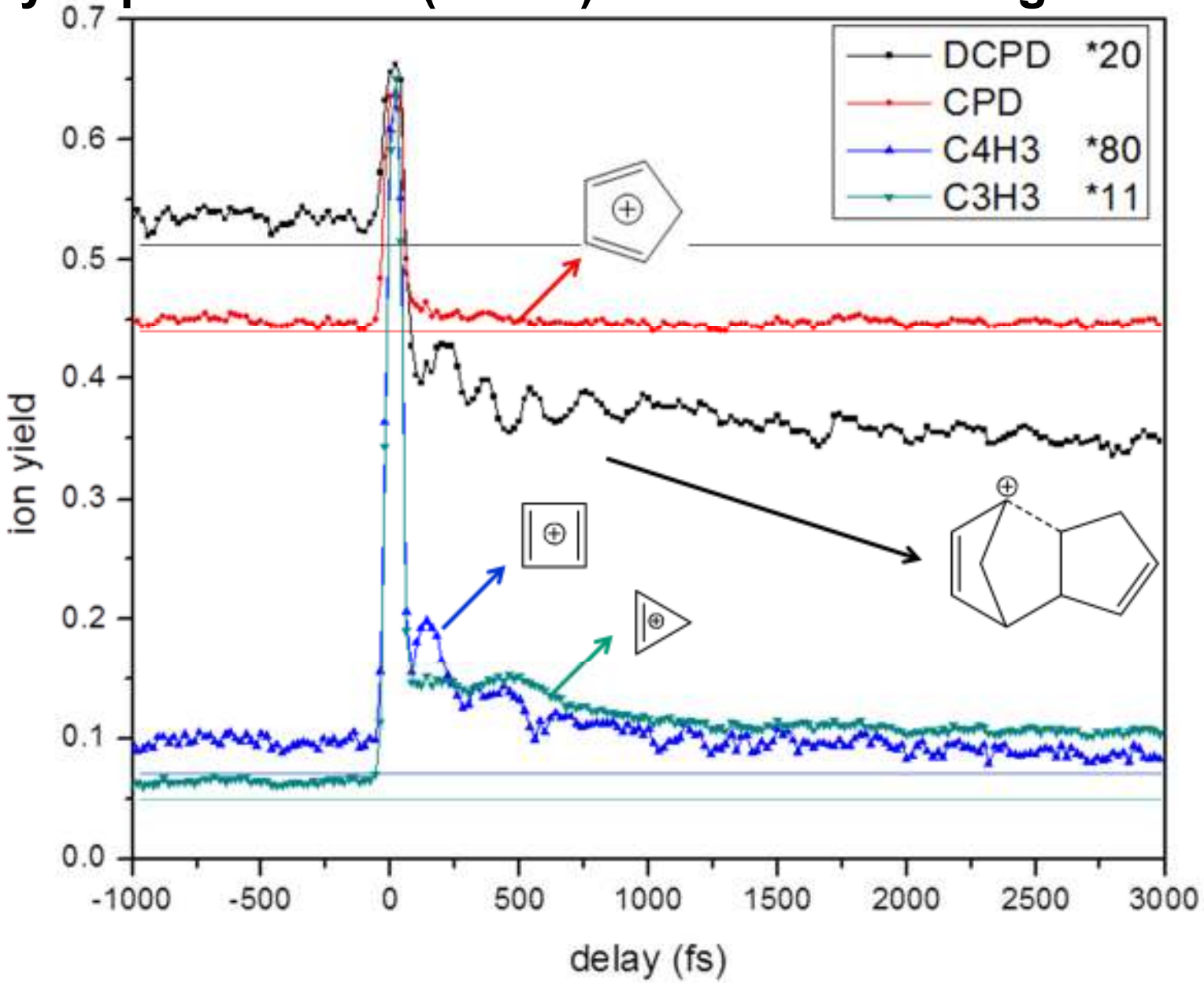


=1.5 eV, 800nm

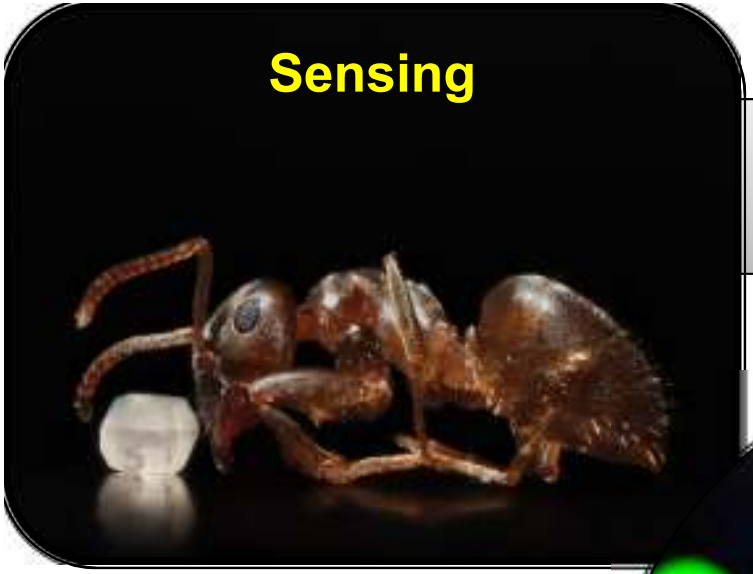
Electronic coherence occurs between the ground and first excited state ion states

Baker *et al.*, *Anal Chem, 42*, (1970)

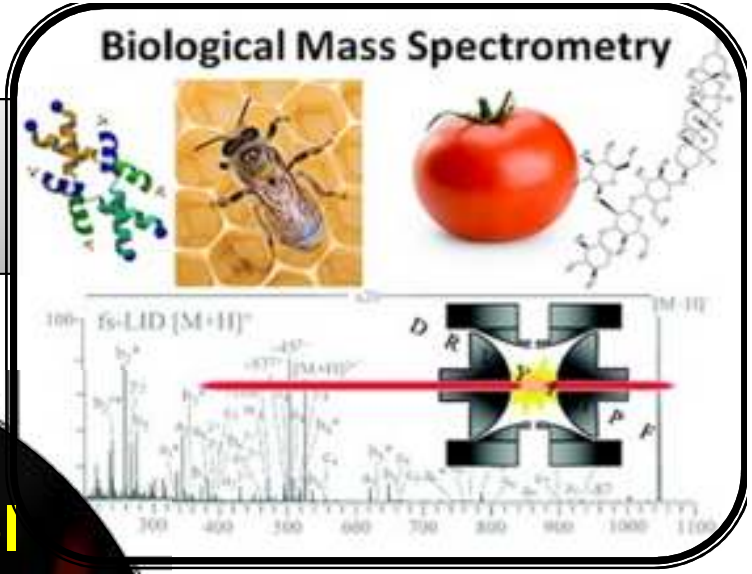
Dicyclopentadiene^{+} (DCDP) time-resolved fragmentation

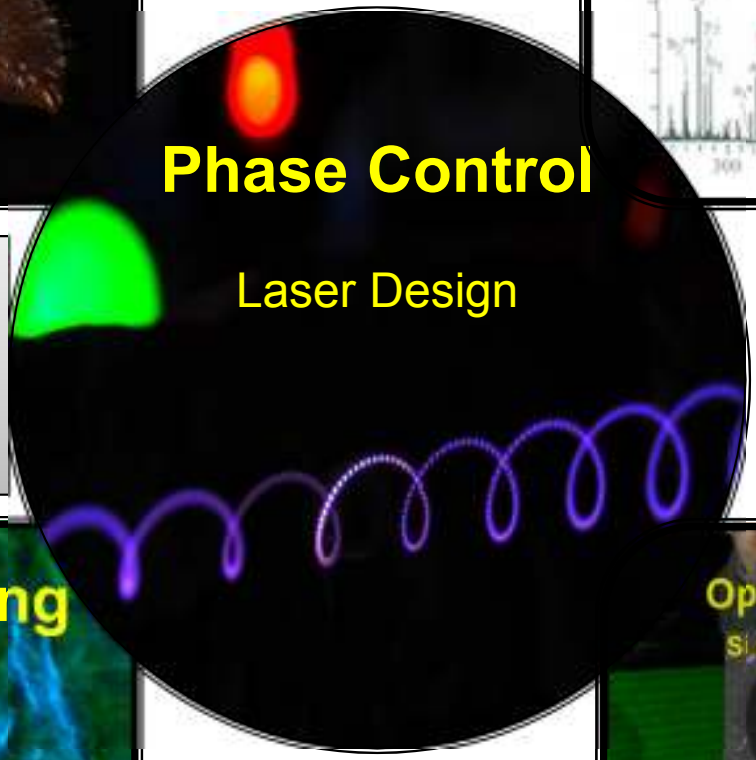


Goswami, Shah, Konar, Lozovoy and Dantus to be submitted (2012)

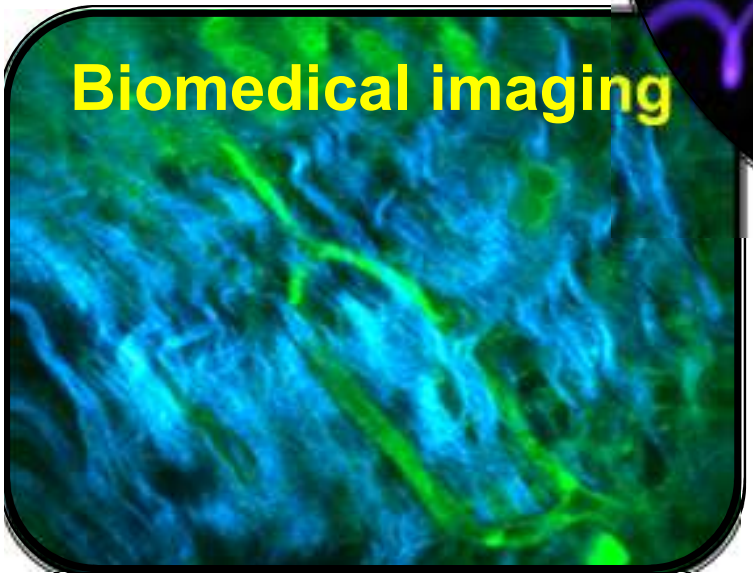


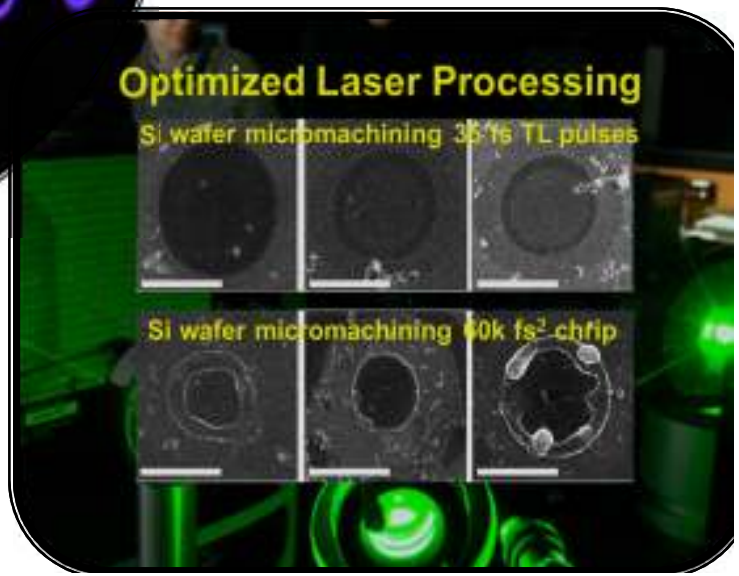
Dantus Group

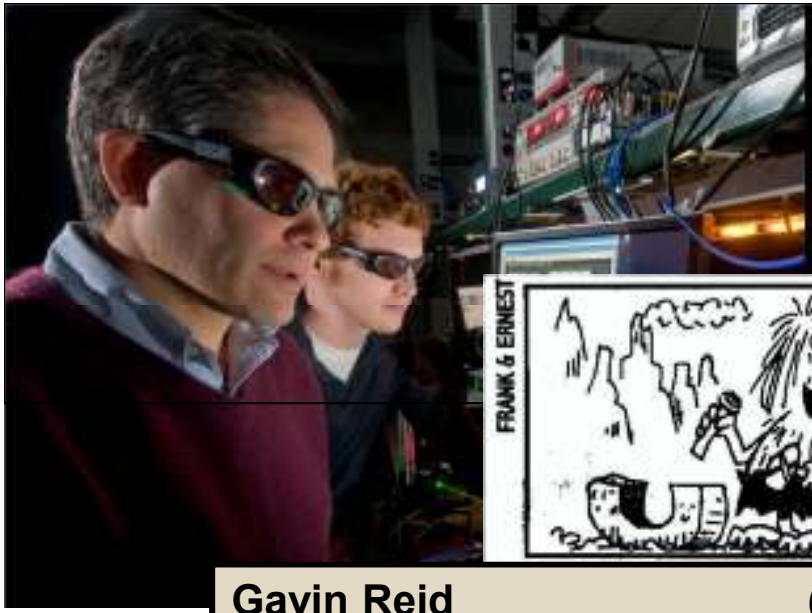




Multidisciplinary
Collaborations with
Universities and Industry

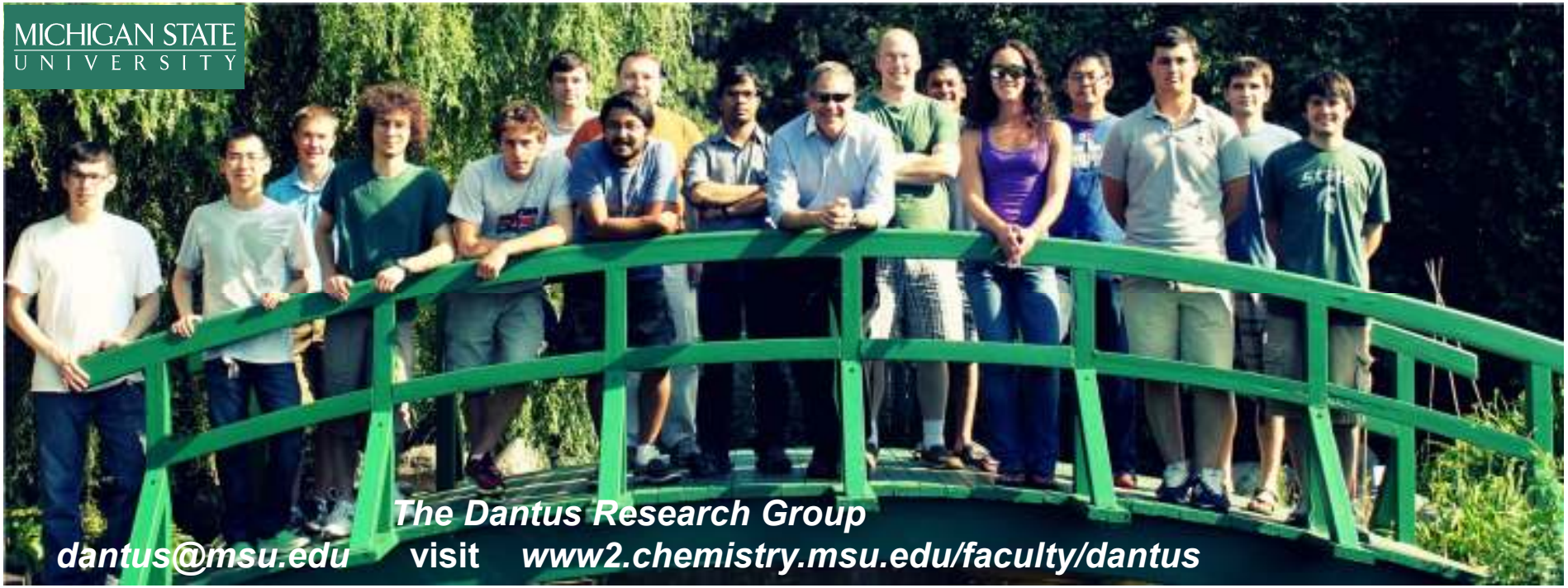


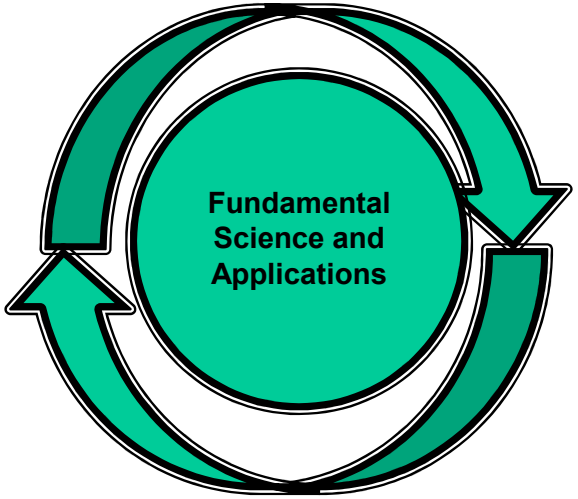




Gavin Reid	(MSU, Chemistry, Proteomics)
Daniel Jones	(MSU, Bio Chem, Metabolomics)
Shaul Mukamel	(UC Irvine, NLO pathway assignment)
George Abela MD	(MSU, Cardiology)
Chong-Yu Ruan	(MSU, ultrafast electron diffraction)
James Resau MD	(Van Andel Institute, cancer)
Stephen Boppart	(UIUC, femtosecond endoscopy)
Jim Gord	(Air Force Research Lab, CARS)
Sukesh Roy	(Spectral Engines LLC, CARS, Machining)
Flavio Cruz	(UNICAMP, Brazil, Novel laser sources)
Sunney Xie	(Harvard, CARS microscopy)
Rich Mathis	(Berkeley, low frequency in biomolecules)
Frank Wise	(Cornell, fiber laser design)
Thomas Weinacht	(SUNY Stony Brook, UV pulse shaping)
Maurice Jansen	(Free Univ. Amsterdam, PEPICO)
Shaul Mukamel	(UC Irvine, NLO Theory)

Phase control enables fundamental research and applications

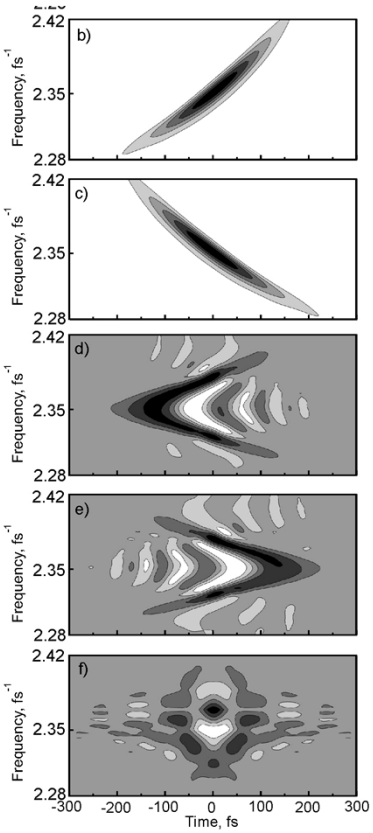


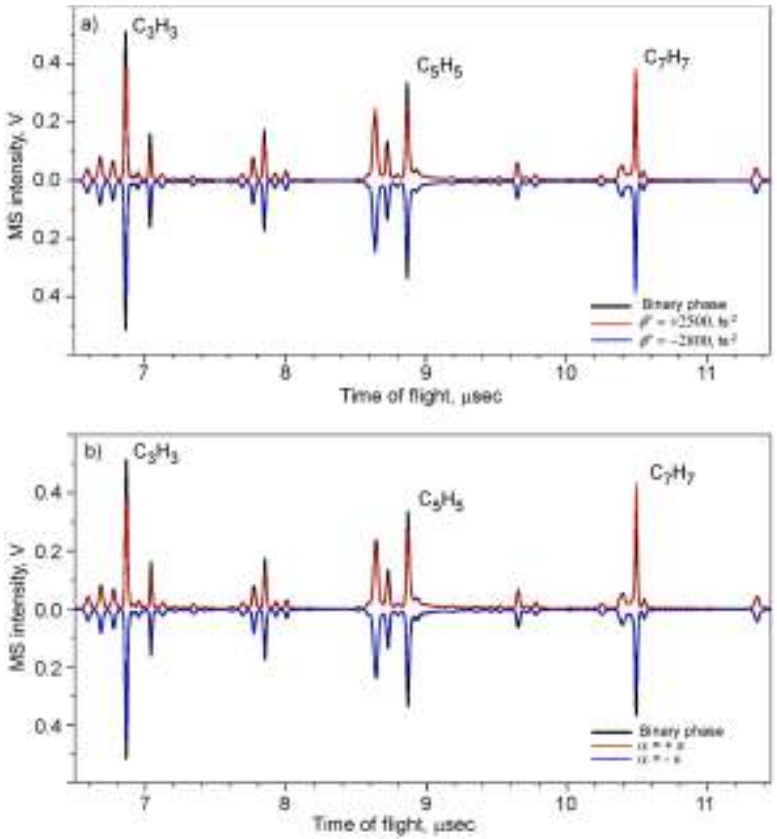


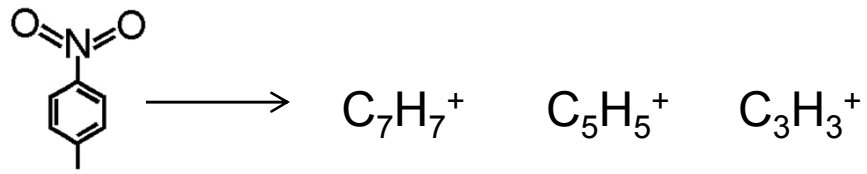
Backup Slides for Follow Up Discussion

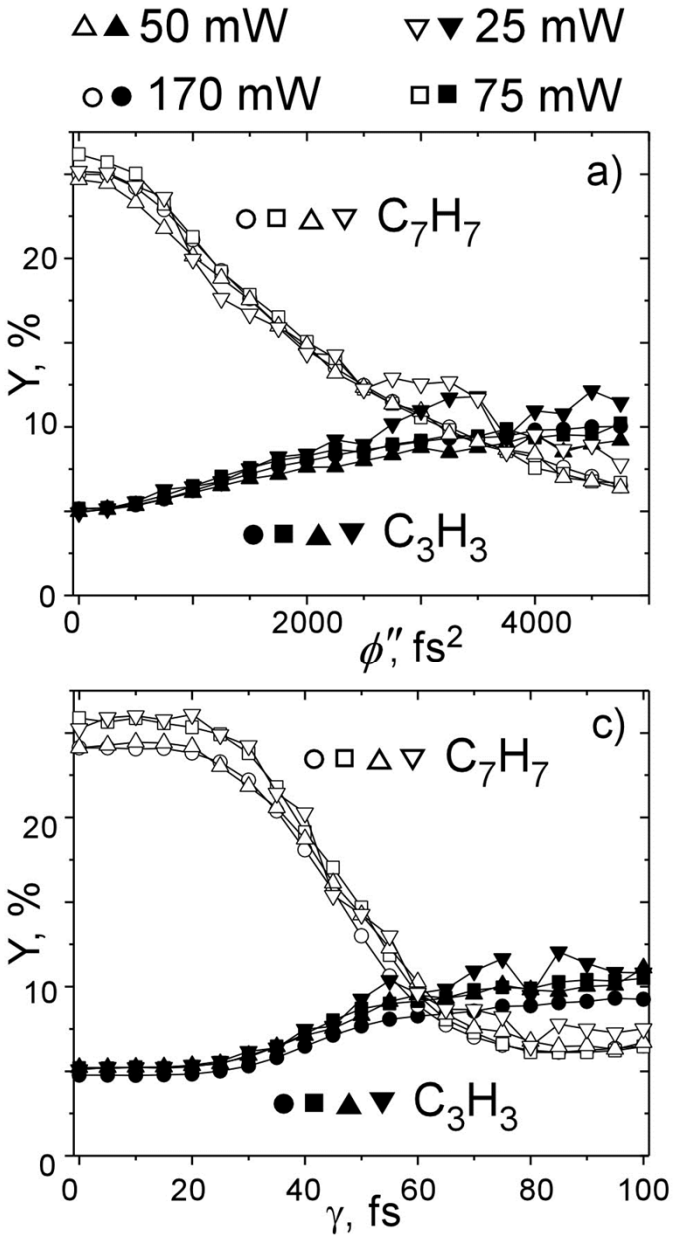
Is photofragmentation pattern phase dependent?

Comprehensive exploration on the role of phase coherence on the fragmentation of large molecules by intense shaped pulses



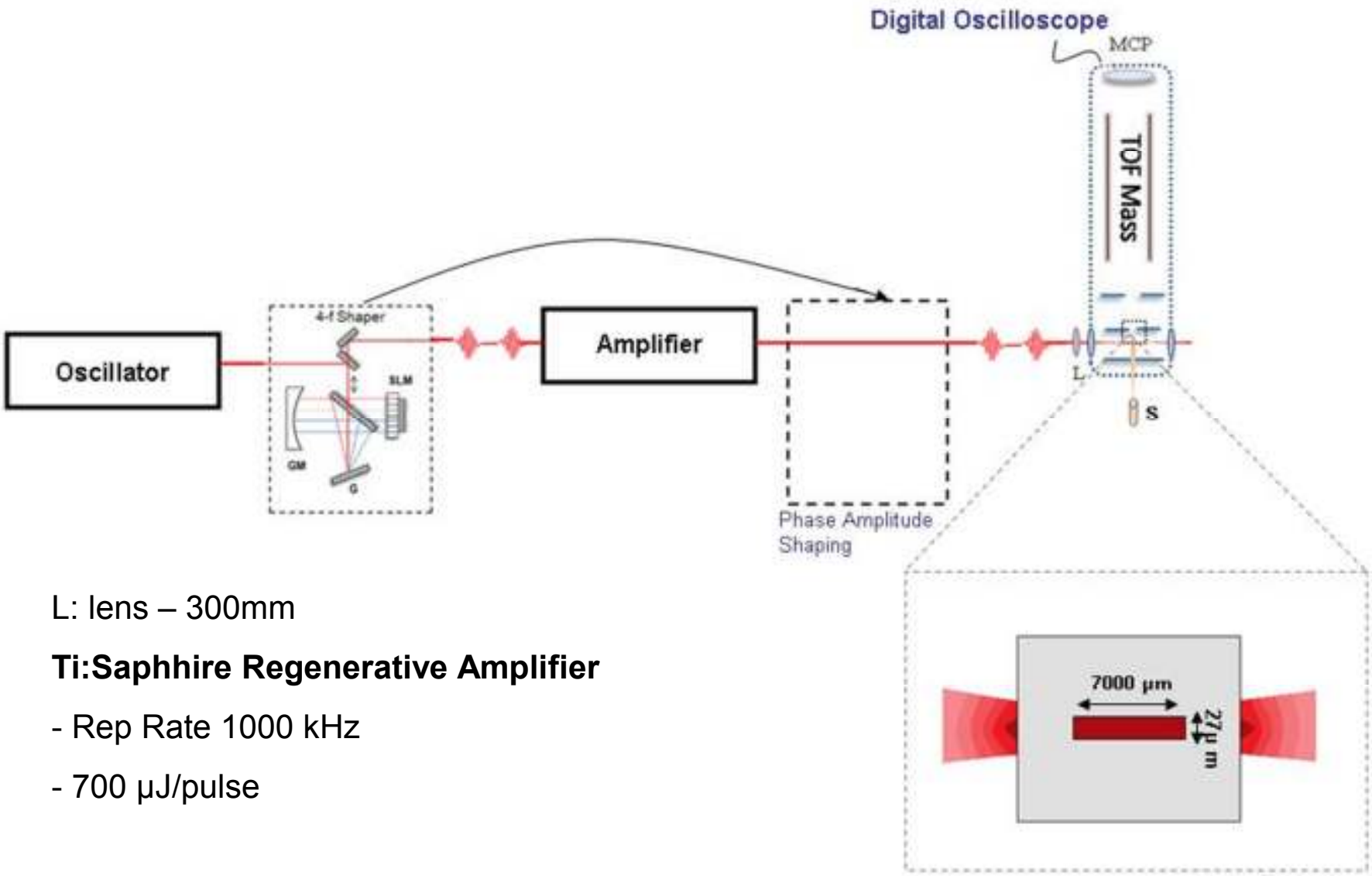






Zhu et al. J. Phys. Chem. A. 112, 3789 (2008)

Experimental Set-Up



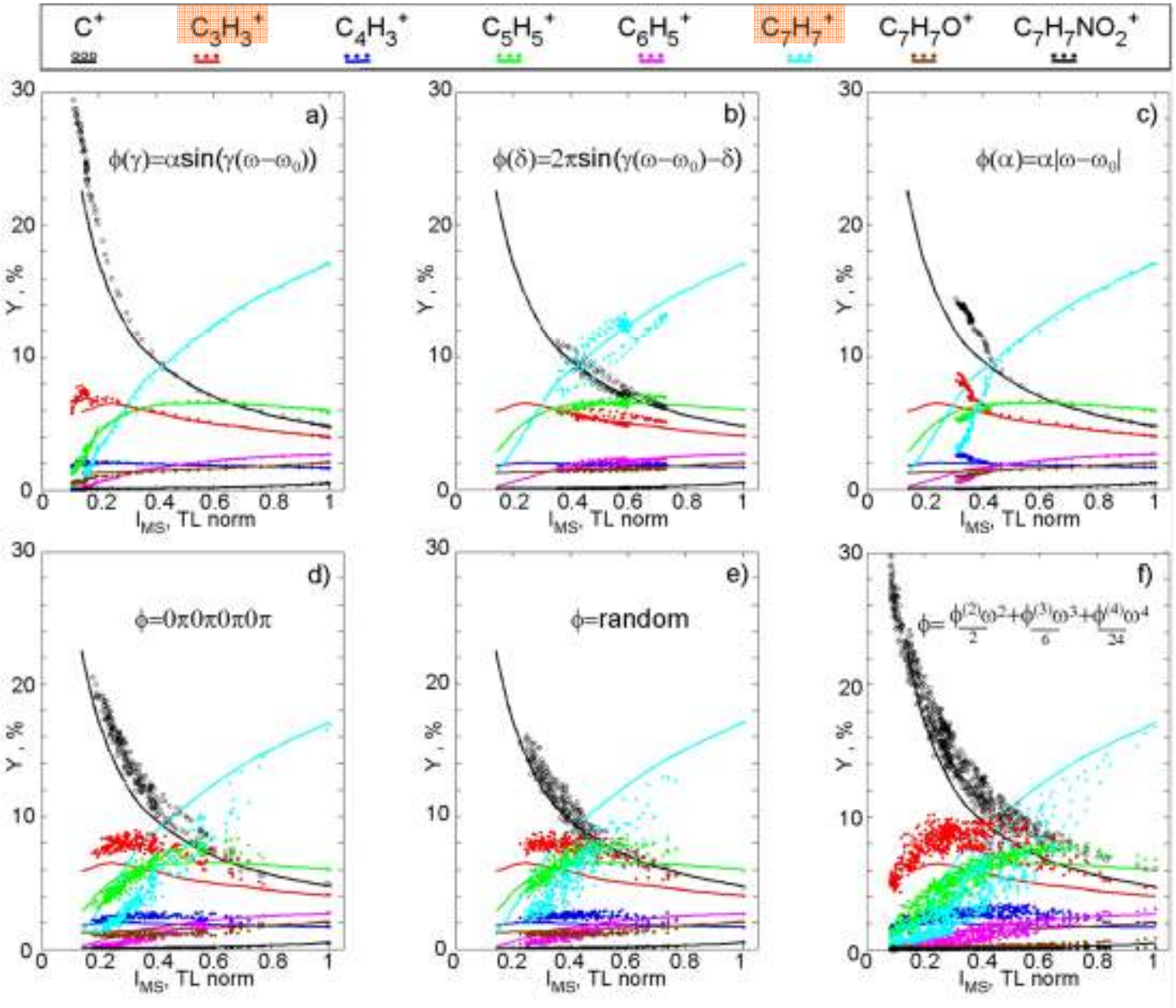
L: lens – 300mm

Ti:Saphhire Regenerative Amplifier

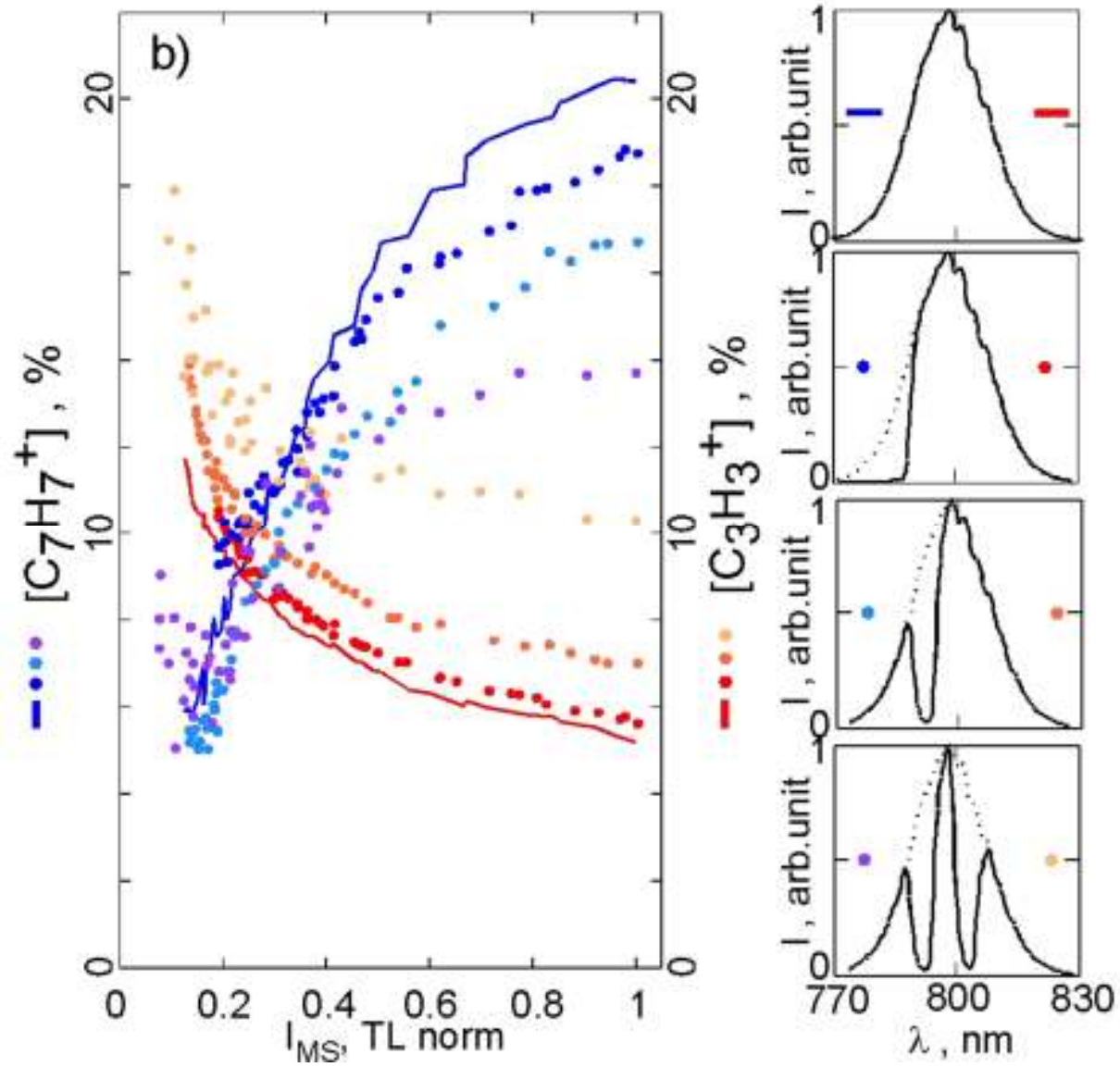
- Rep Rate 1000 kHz

- 700 µJ/pulse

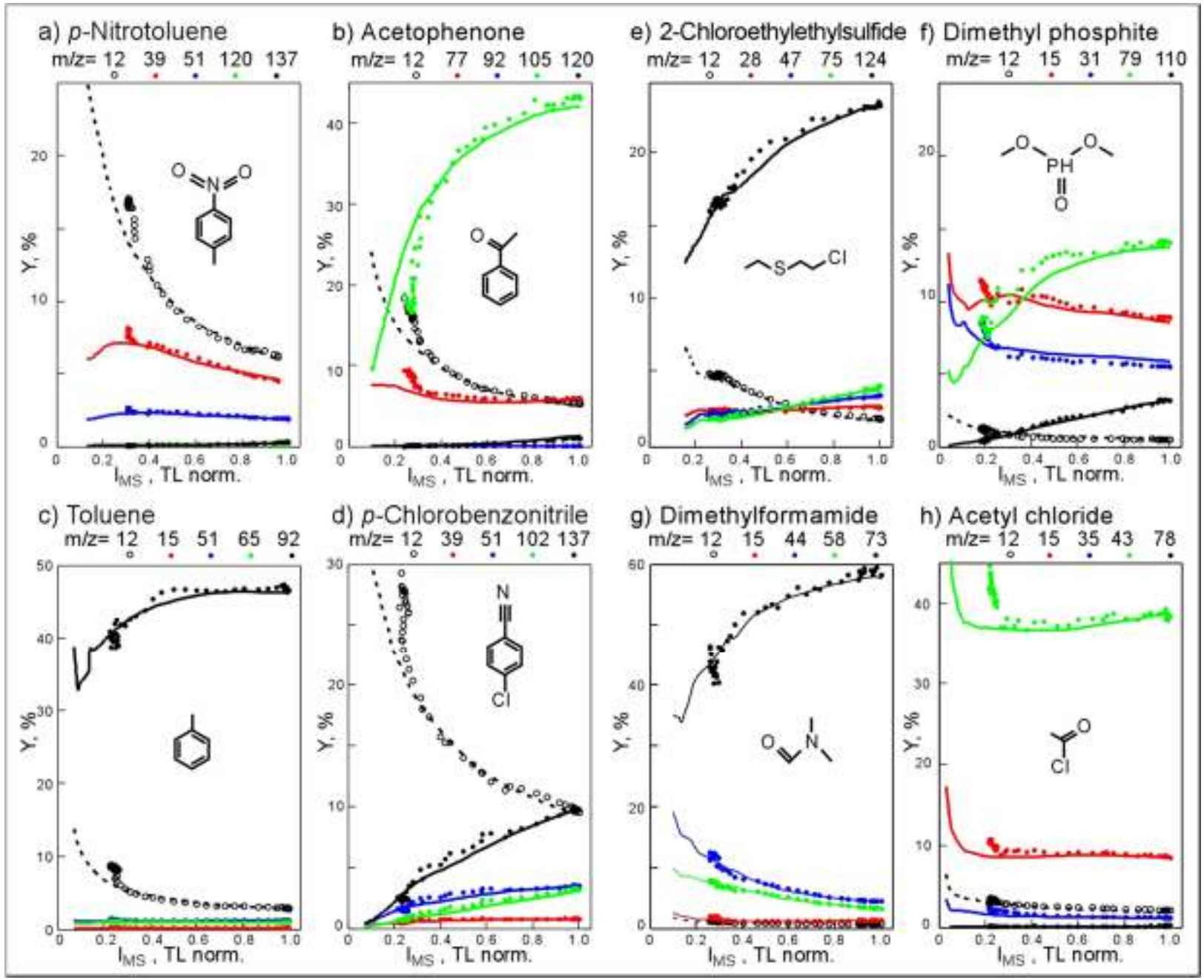
Is molecular response predictable?



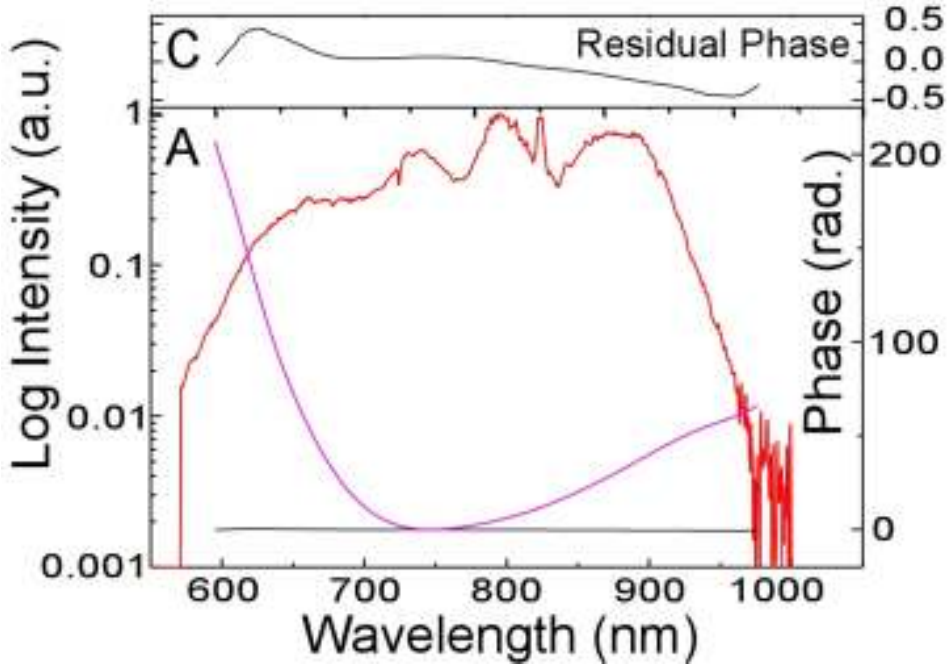
Effect of phase & amplitude shaping

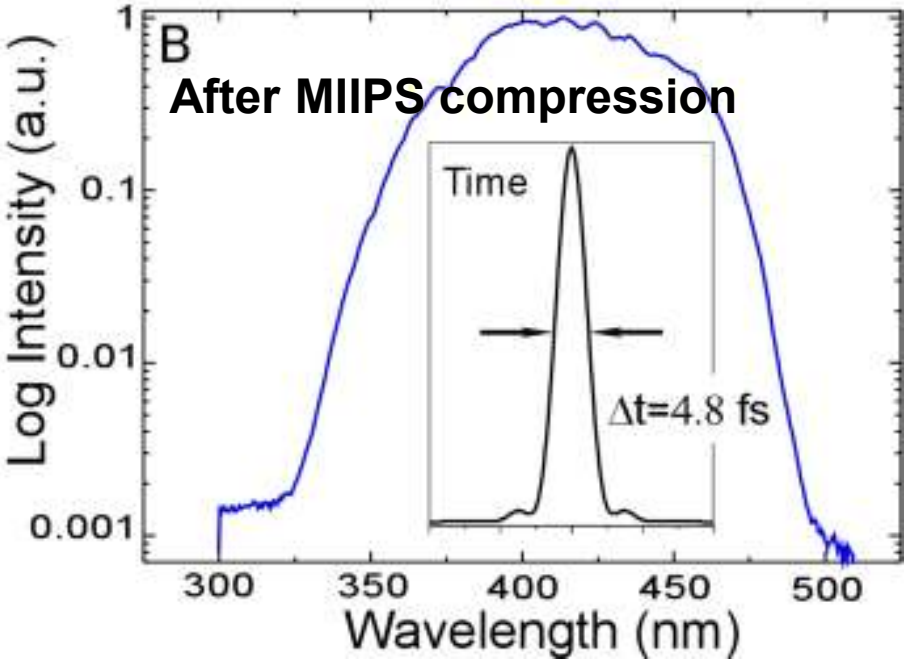


Generalizing to other molecules



Experimental Single-Beam CARS Setup





2010 Pulse Shaping Workshop

August 20-22, 2010
Michigan State University

Teaching scientists worldwide how to use sub-5fs pulses routinely

2011 Pulse Shaping Workshop @ MSU Aug 19-21. Keynote by Andrew Weiner