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Laser Plasma as a Source of Intense, Single Attosecond Pulses via High-Order Harmonic Generation

Advanced Laser Light Source

Université d'avant-garde

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- S. Chan, S. D. Kahn, Z. Chang (Kansas State U.)

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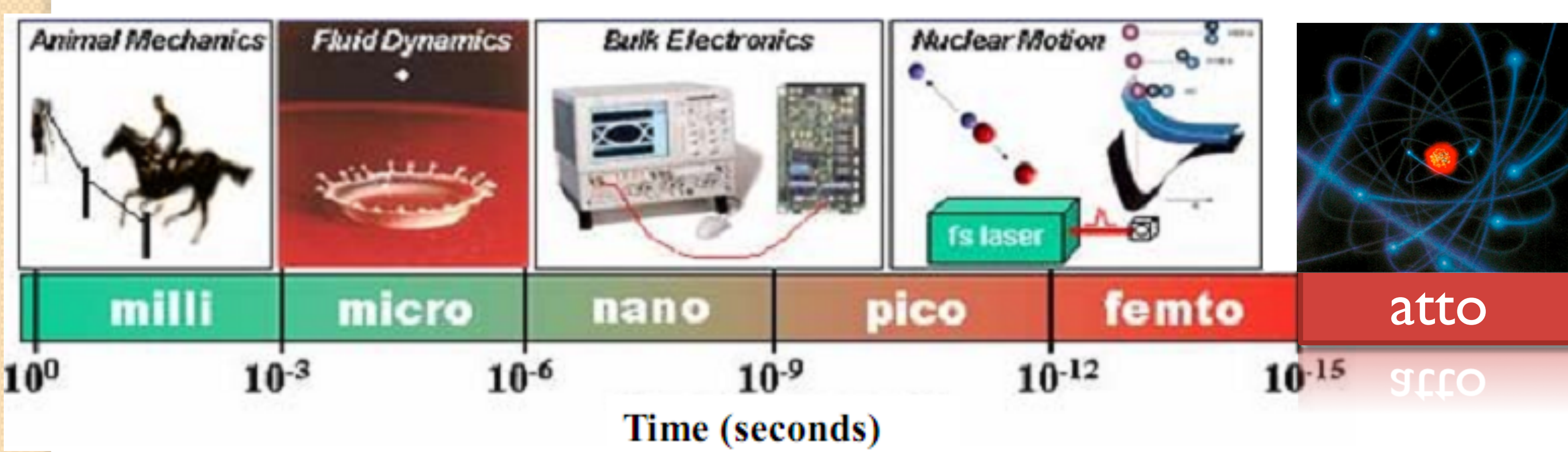
Shorter & Shorter

Attosecond phenomena: electron motion



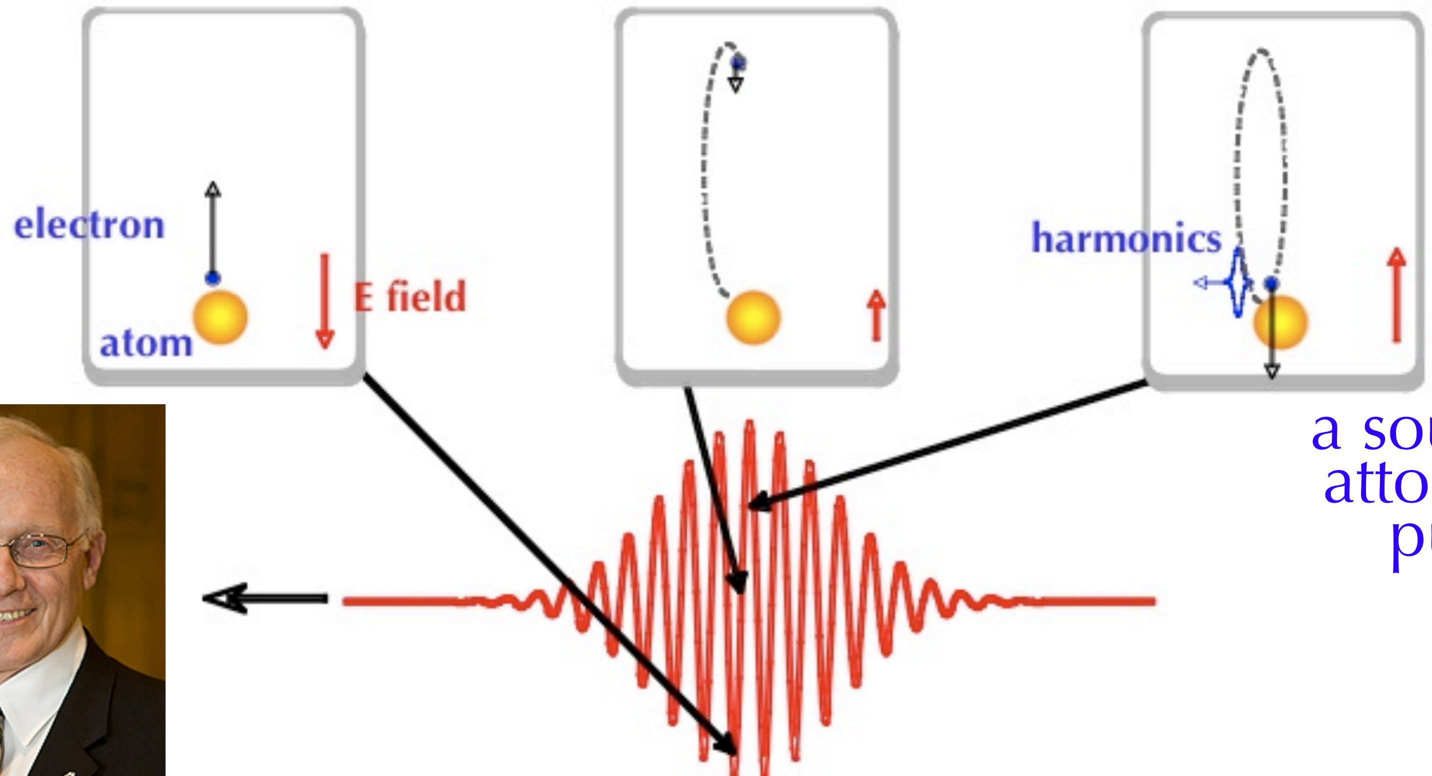
Period of the first Bohr orbit : 150 attoseconds

Three-Step Model of High-Order Harmonic Generation

1. High E field of laser ionizes atom

2. Electron starts to oscillate in laser field

3. Electron recollides with atom, and emits harmonics



a source for attosecond pulses

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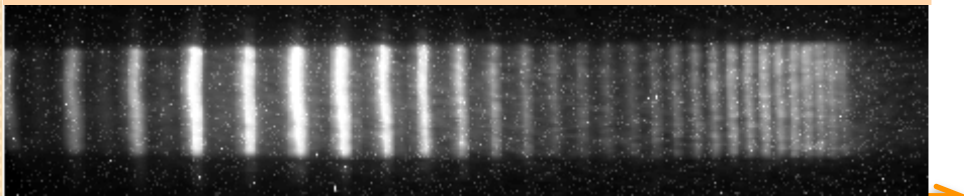
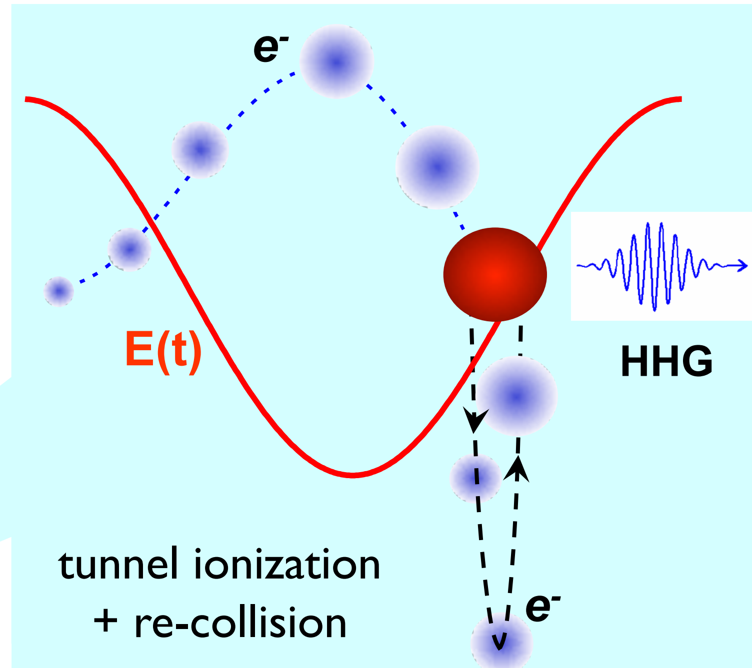
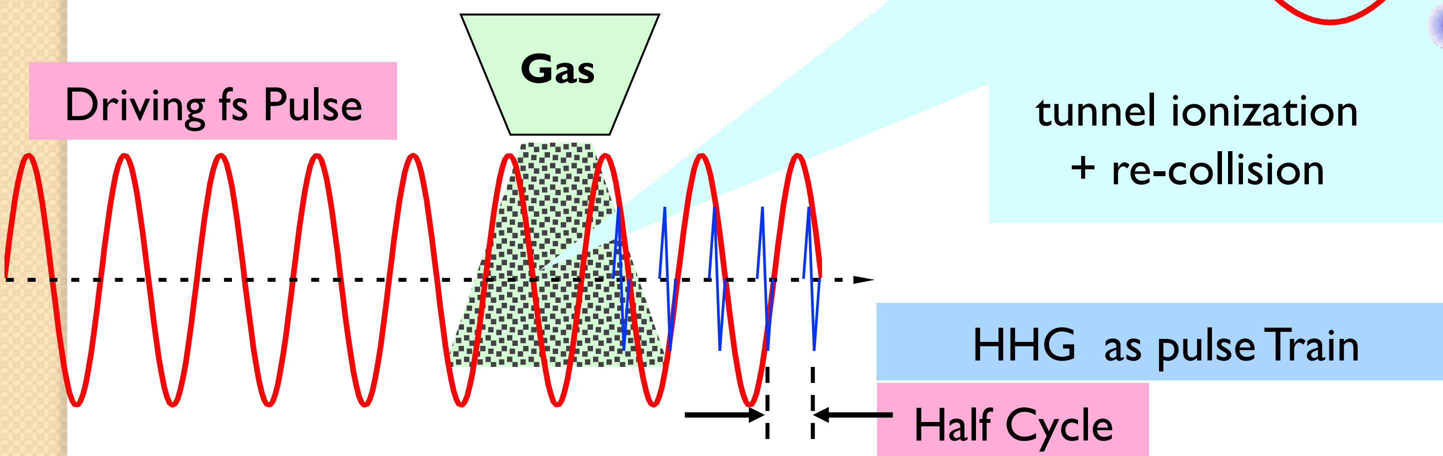
Attosecond pulse train by HHG

Experimental Observation

HHG Spectrum: Discrete Spectral Lines







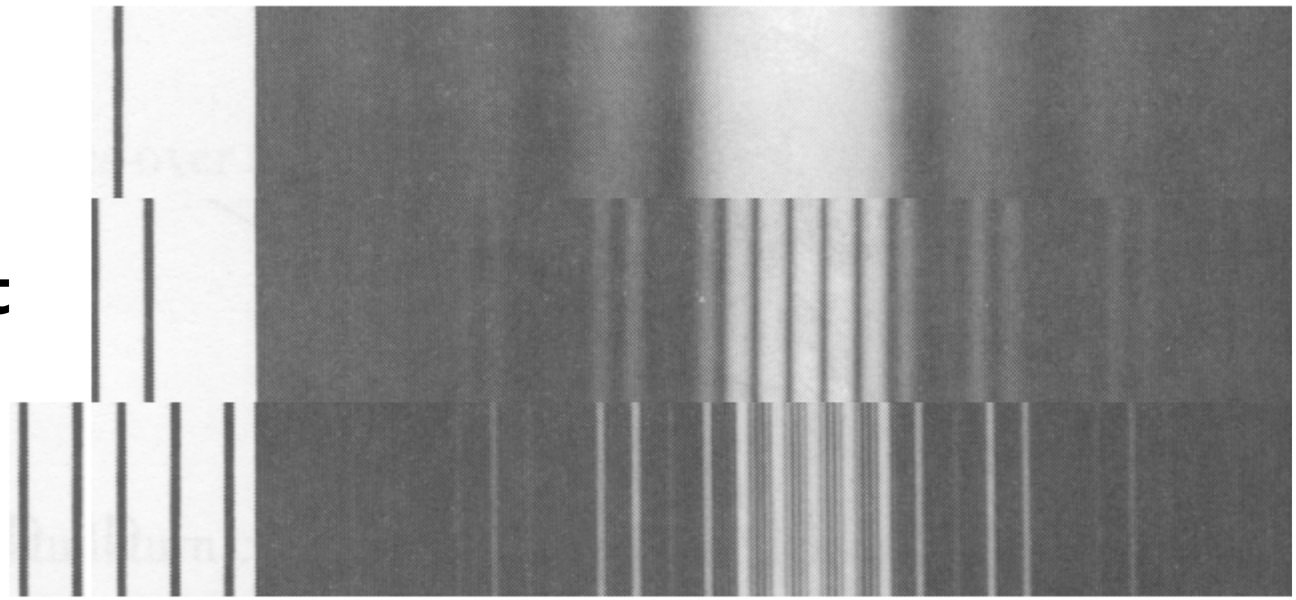
Discrete harmonic orders in the plateau

Spatial analogy of pulse train interference

Single slit

Double slit

Multi slit



Diffraction patterns (spatial frequency)

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The Goal

- Intense, Single Attosecond Pulses
  - Single Attosecond Pulse
    - (= Broad Bandwidth; ~ 20 eV)
  - High Intensity (> 1 μ J)
    - (= High Efficiency)

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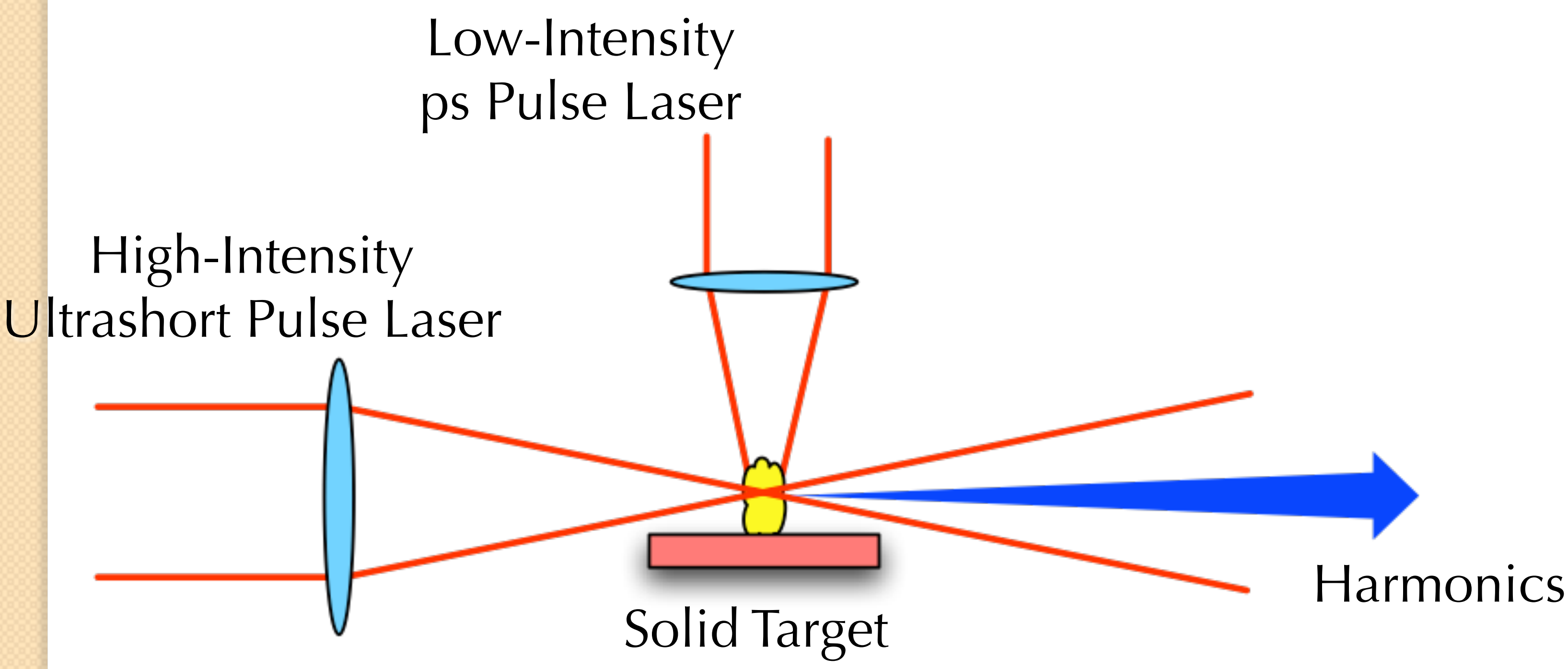
Plasma Harmonics

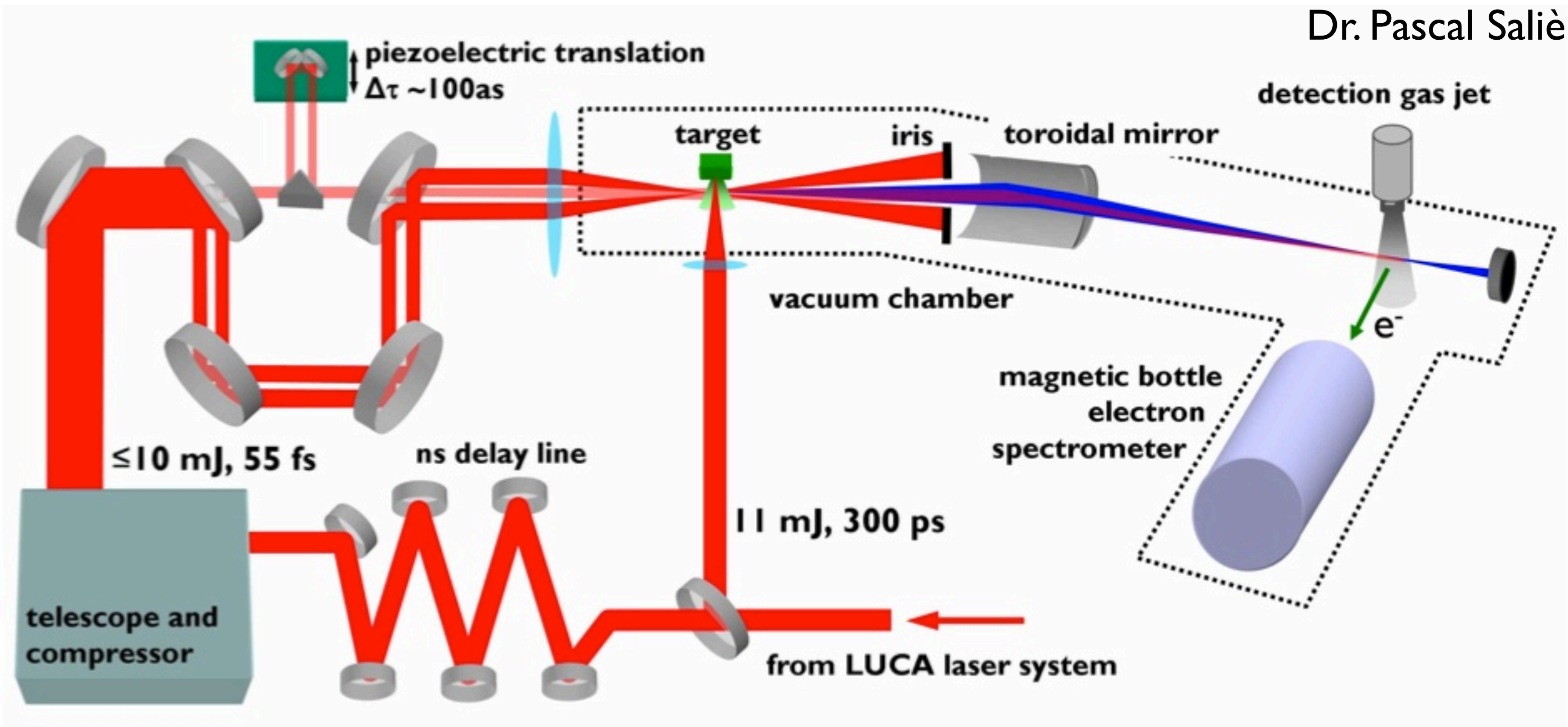
An Alternative to High Intensity Harmonic Generation



Reconstruction of attosecond beating by the interference of two photons transitions (RABITT)

Modified CEA RABITT SET UP

Dr. Pascal Salières



Elouga Bom et al., Opt. Exp. 19, 3677 (2011)

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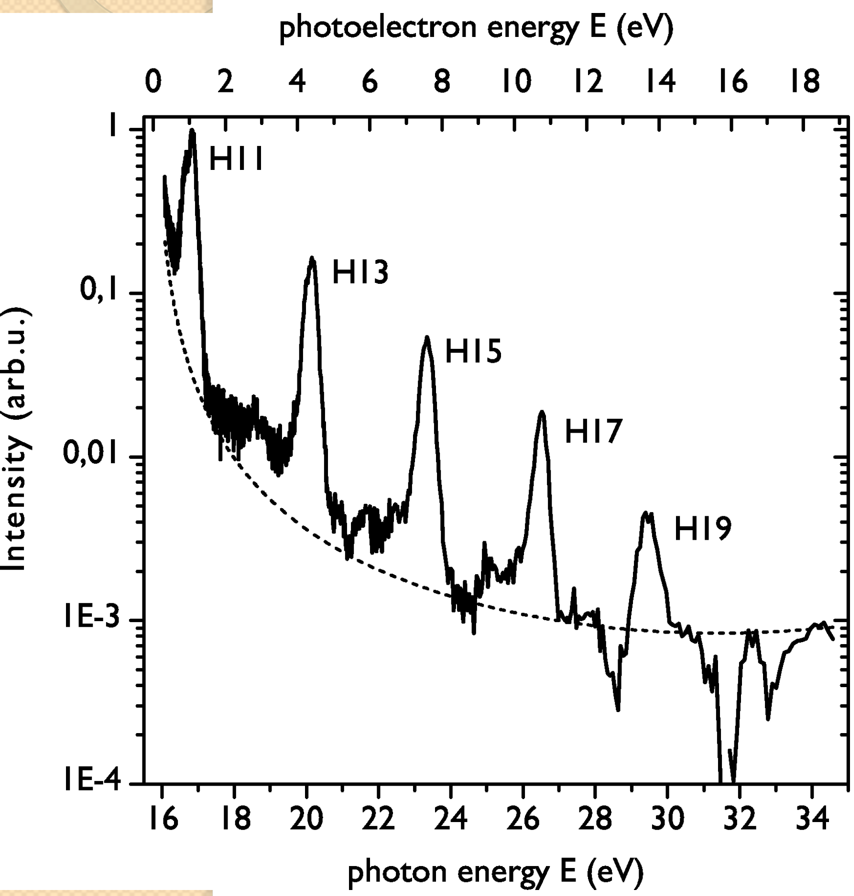
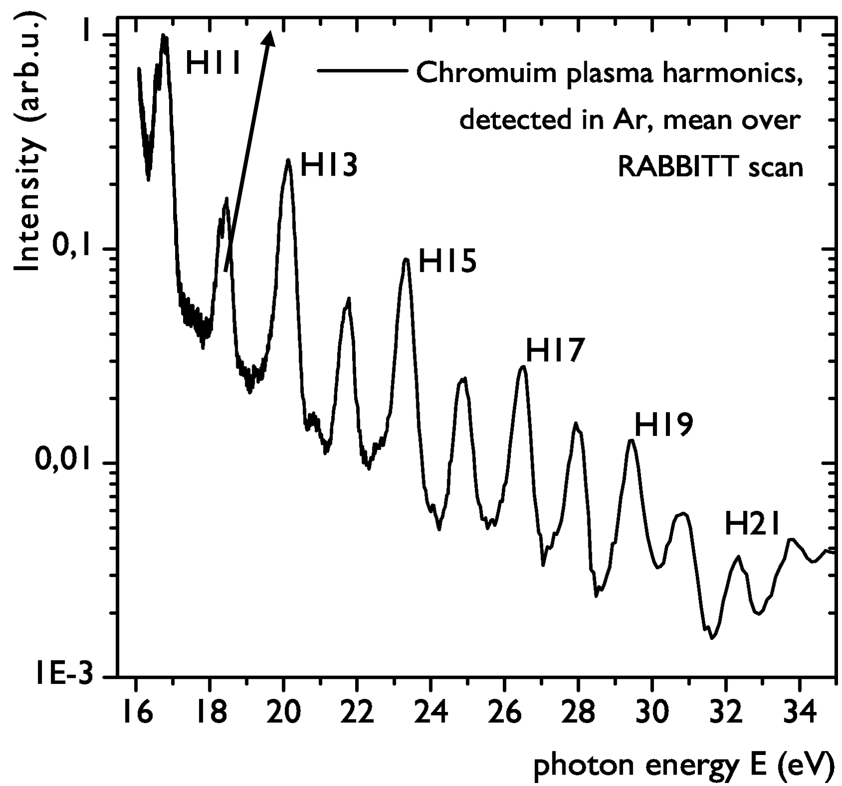
RABITT method for electric field reconstruction

- Case of chromium plasma



Sidebands from two photons two Colors transitions in the detection gas.



Elouga Bom et al., Opt. Exp. 19, 3677 (2011)

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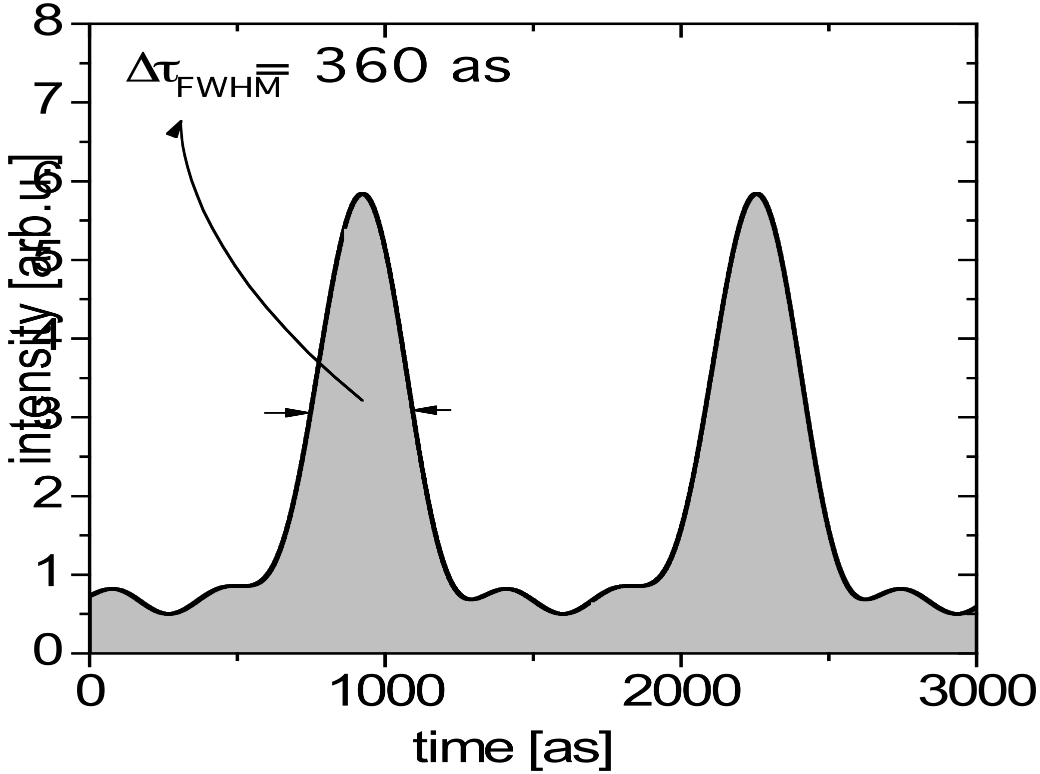
Plasma harmonics are also Attosecond pulses

Reconstructed electric field of chromium harmonic spectrum



360 as measured using low laser pump intensity ($4\times10^{14}\,Wcm^{-2}$)

Dr. Pascal Salières

Elouga Bom et al., Opt. Exp. 19, 3677 (2011)

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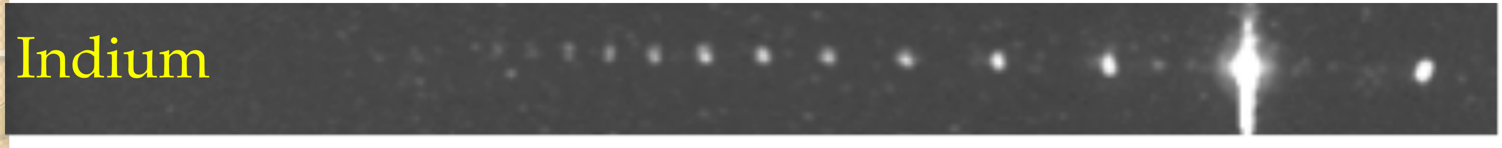
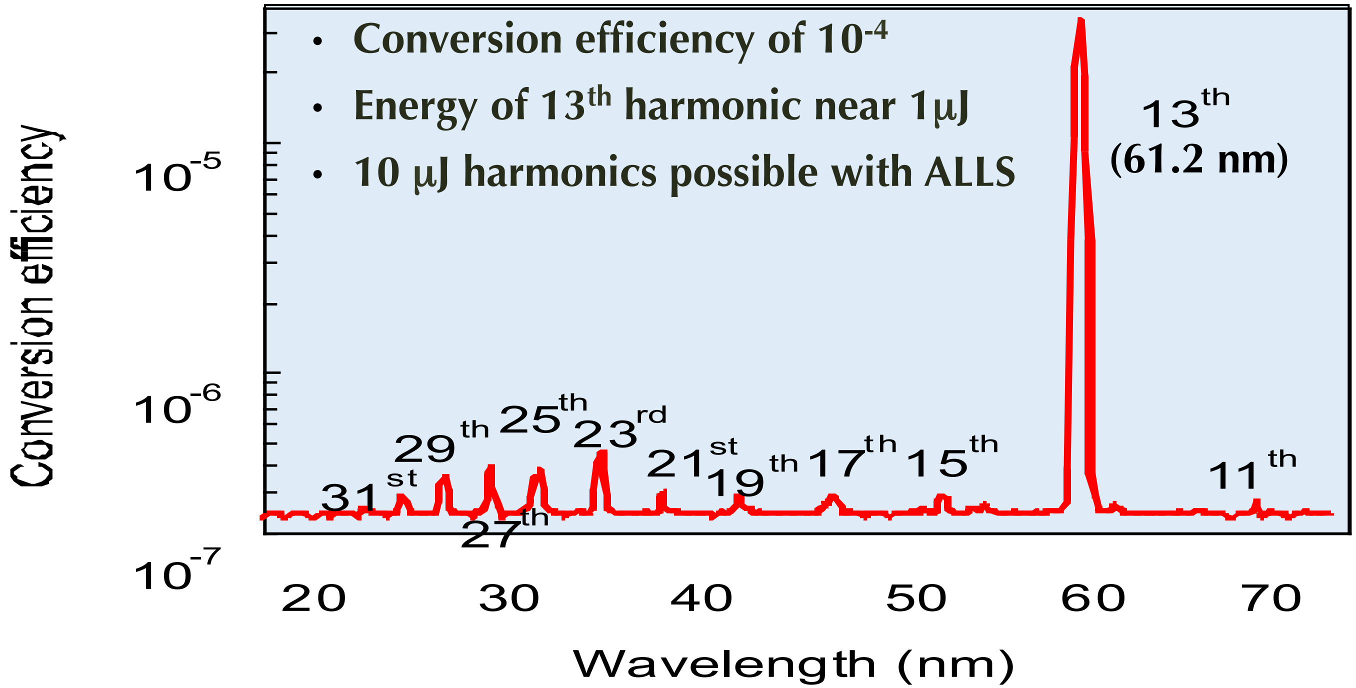
Intense Quasi-monochromatic Harmonics from Indium Ablation





Intense but Narrow-band

Opt. Lett. **31**, 1699-1701 (2006).

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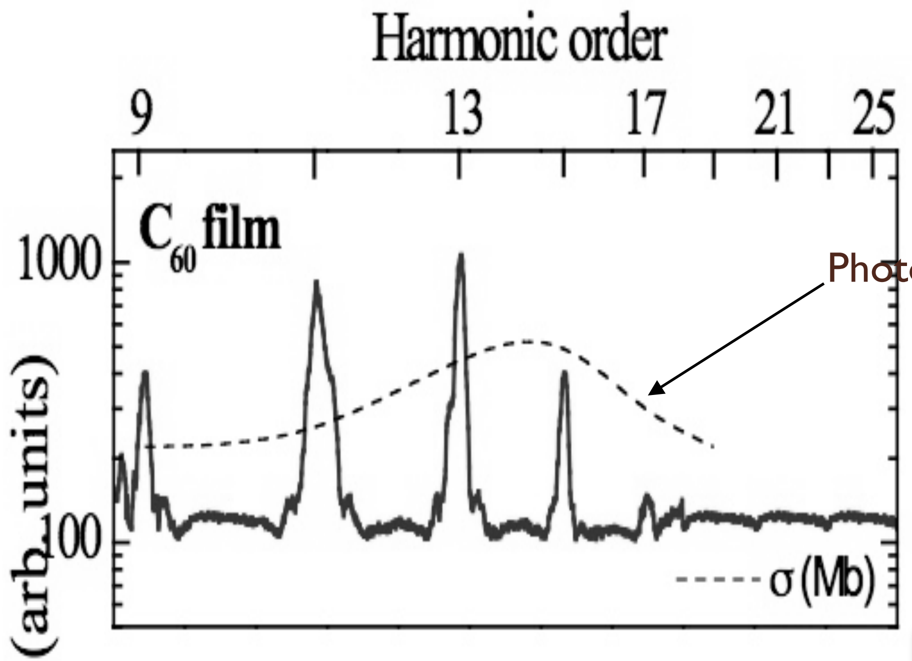
C_{60} Harmonics

Prepulse: 5×10^{9} W cm^{-2}
Main pulse: 1×10^{14} W cm^{-2}



13th harmonic from C_{60} is several times stronger than that from Indium … efficiency > 10^{-4}

… but the harmonic intensity rapidly decreases, due to target degradation

- Phys. Rev. Lett. **102**, 013903 (2009).
- Phys. Rev. A **80**, 043808 (2009).

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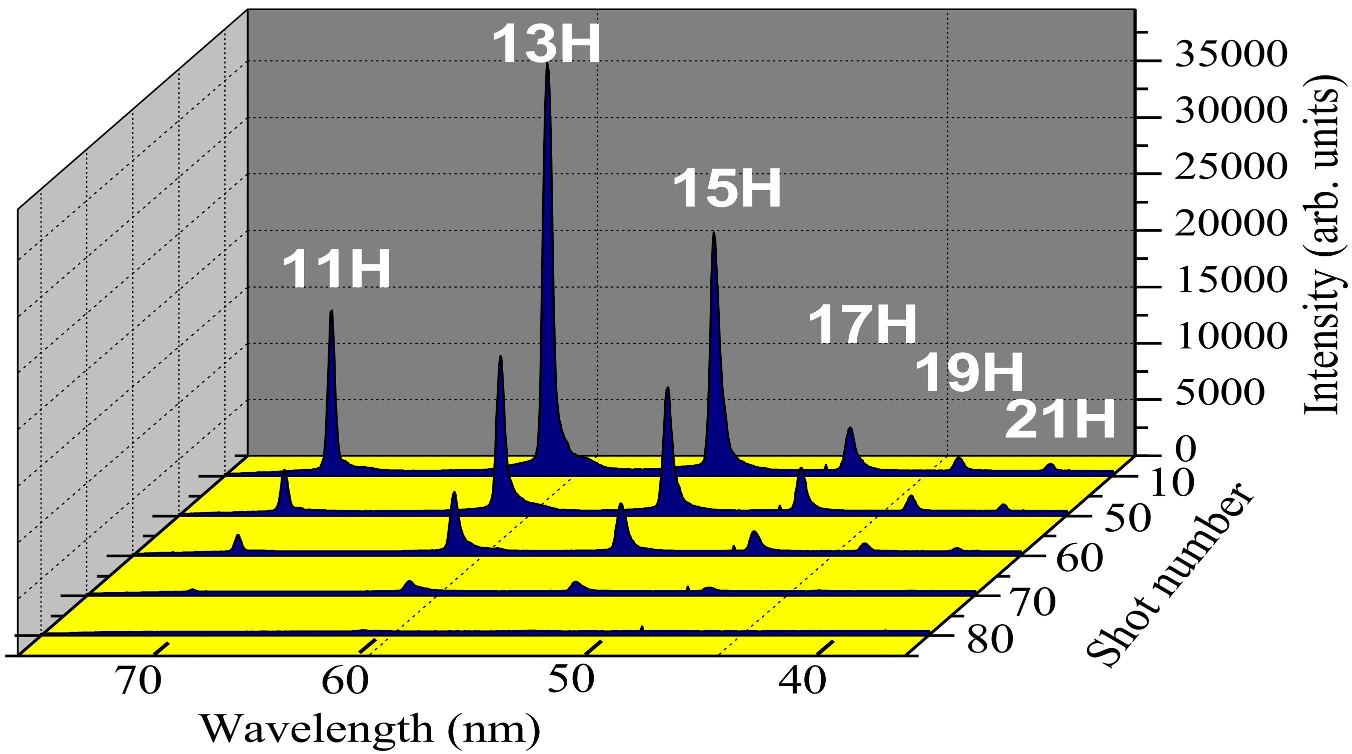
The problem of using nanoparticles is the instability of the signal



By creating plasma at the same position on the target, the harmonic signal decreases fast and disappears after 6 s

Intense and Broad-band but Unstable

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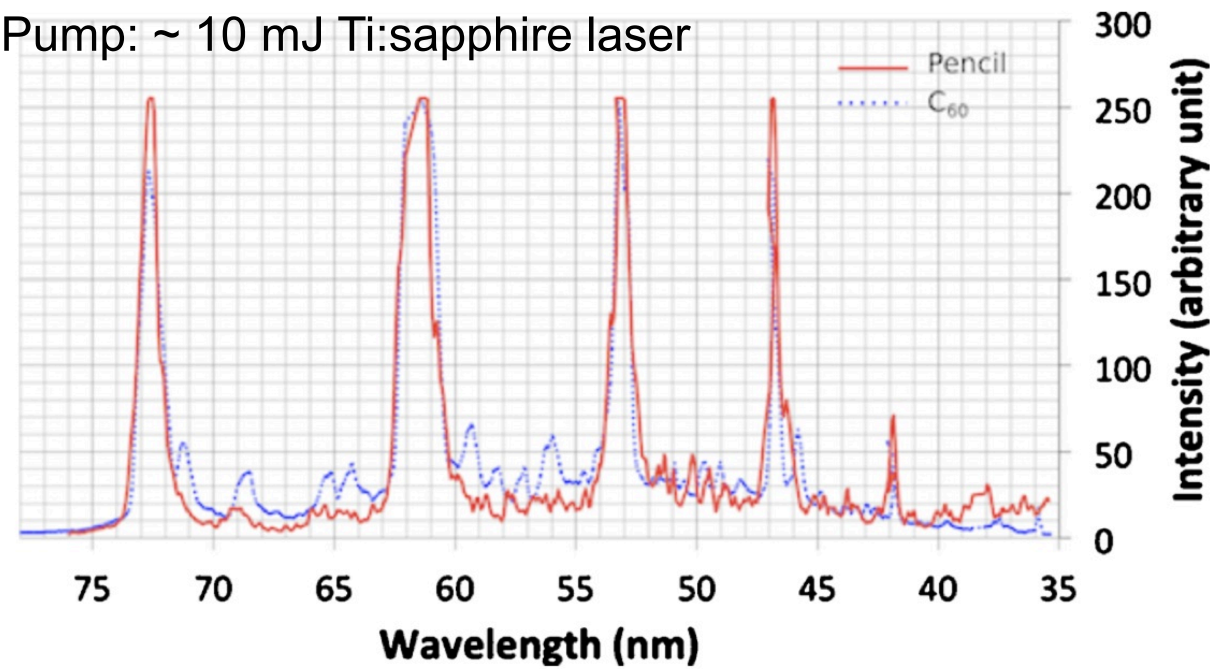
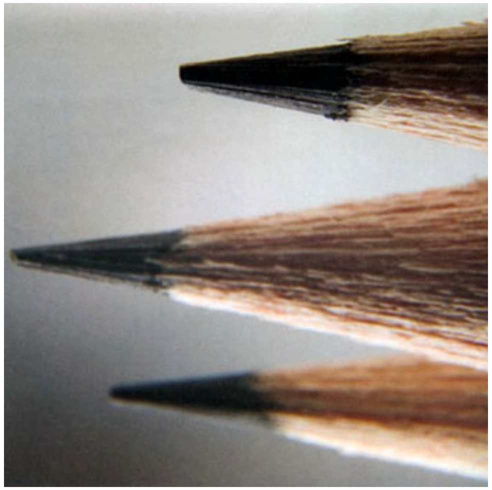
Intense Harmonics from Pencil Lead

Pump: ~ 10 mJ Ti:sapphire laser





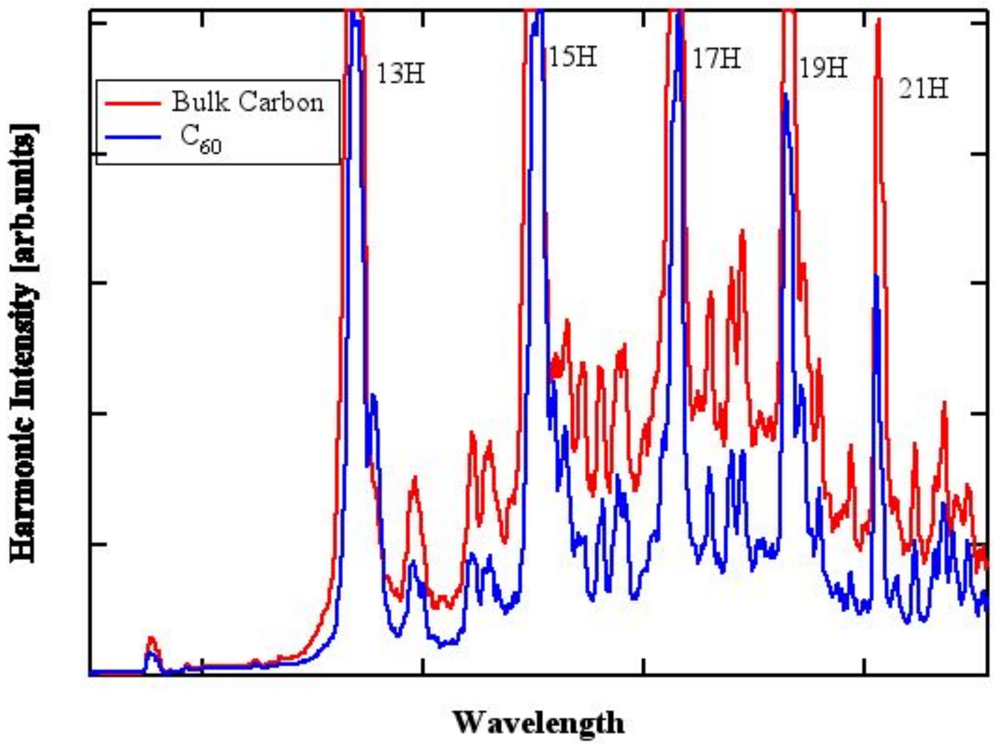
Composition (XPS)

	Al	C	O	Si
Point A	6.0 %	30.6 %	47.0 %	16.4 %
Point B	1.6 %	69.2 %	23.8 %	5.4 %

Pertot et al., Appl. Phys. Lett. **98**, 101104 (2011).

Bulk Carbon Targets as a Source for Intense Harmonics

Pump: ~ 10 mJ Ti:sapphire laser



Elouga Bom et al., Opt. Exp. **19**, 3077-3085 (2011).

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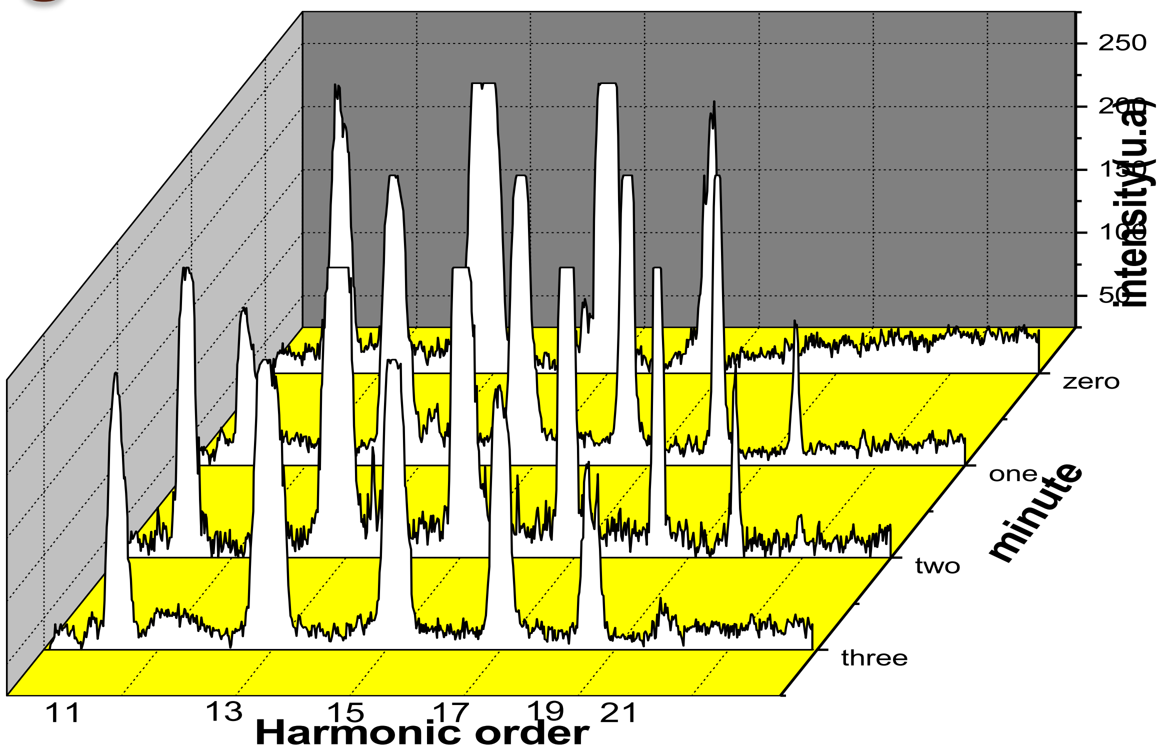
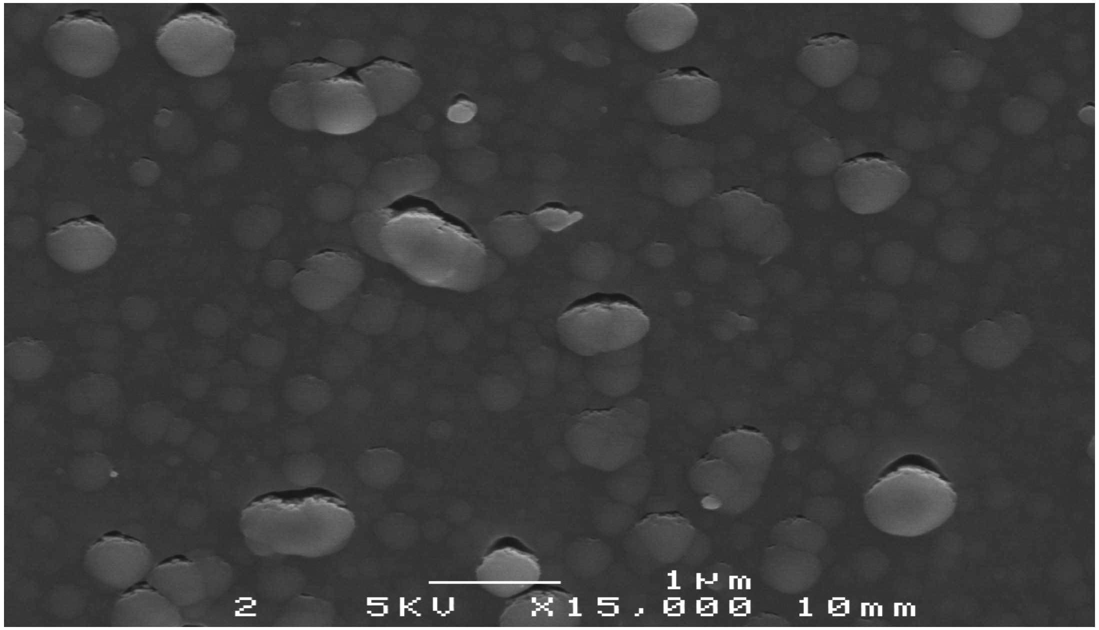
Signal stability using carbon solid targets



Harmonic signal from solid targets remains constant for at least 5 minutes.

Intense, Broad-band and Stable

Why are carbon harmonics so intense?



- SEM image of carbon bulk plasma deposition on silicon substrate shows that plasma created from bulk carbon targets contains a large number of nanoparticles.

- Therefore, it seems that for HHG in bulk carbon the fs laser interacts with nanoparticles, rather than ions as for most of solid targets.

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Elouga Bom et al., Opt. Exp. **19**, 3077-3085 (2011).

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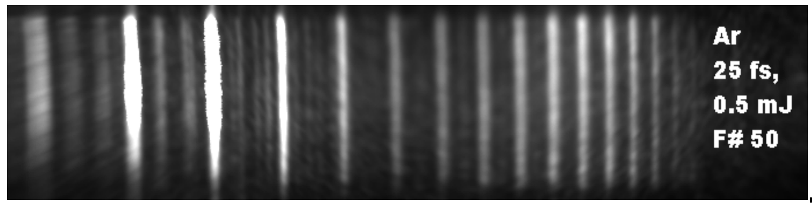
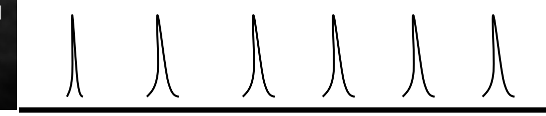
Shorter fs-pulse to get a single atto-pulse

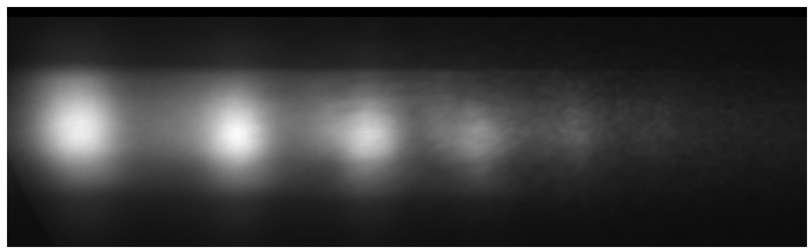
fs-pulses → Harmonic generation → Atto-pulses

With ~25 fs pulses





With ~10 fs pulses



With ~5 fs pulses

??

Super continuum at near cutoff

Traditional method : generation of single atto-second pulses

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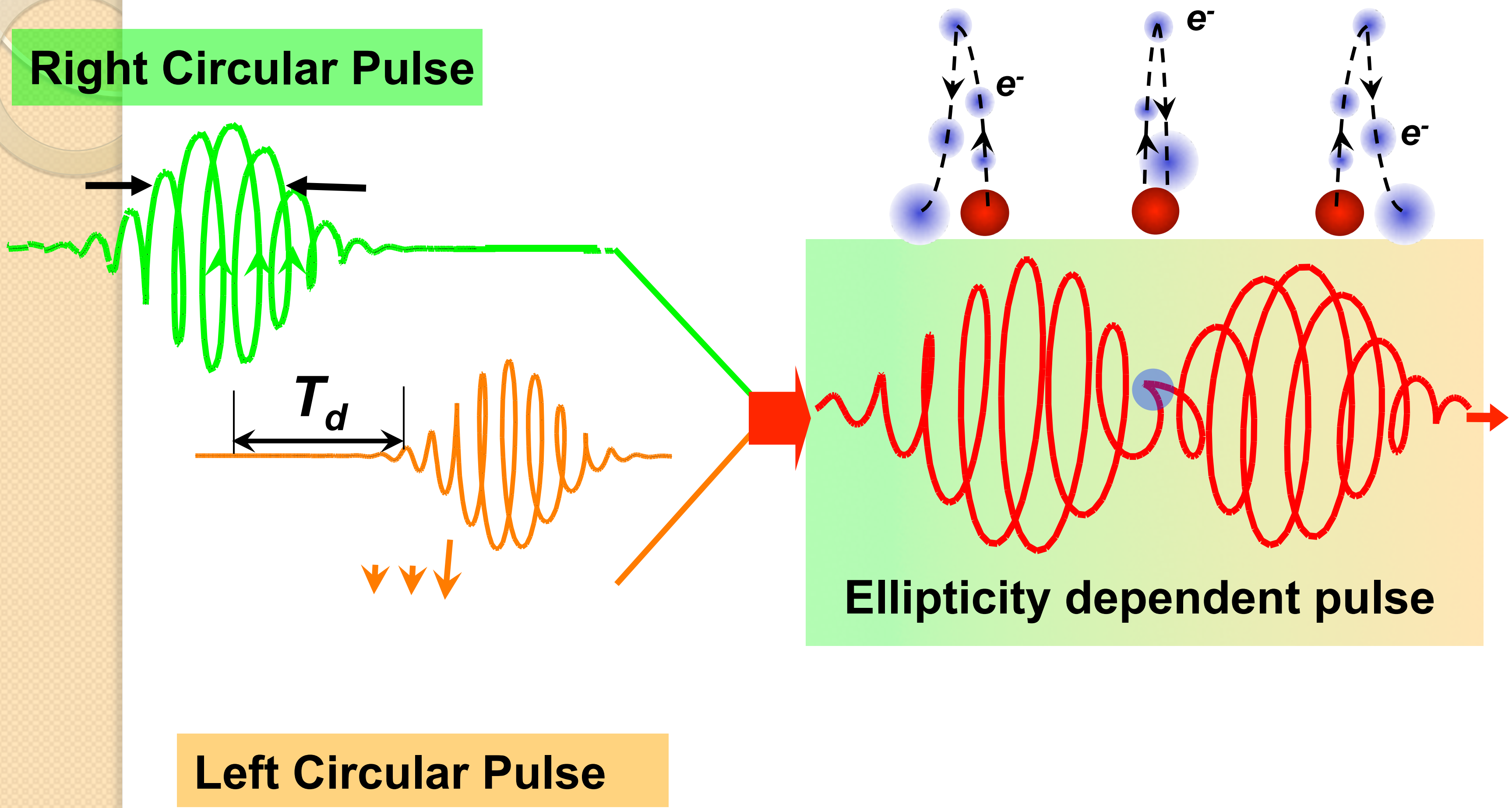
Polarization gating for a single atto-pulse



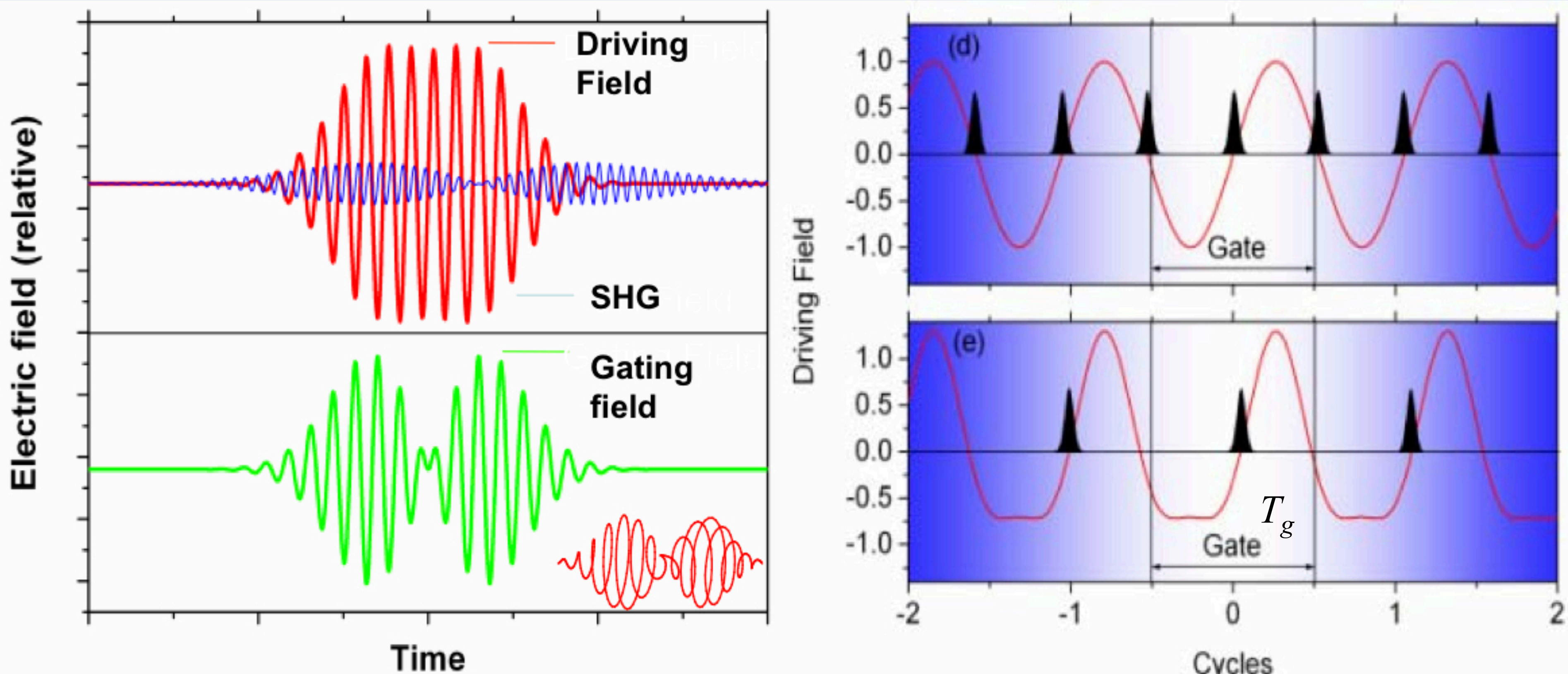
P. B. Corkum, N. H. Burnett, and M. Y. Ivanov, Opt. Lett. **19**, 1870 (1994)
V. T. Platonenko and V. V. Strelkov J. Opt. Soc. Am. B **16**, 435 (1999)

Double Optical Gating

Dr. Zenghu Chang

University of Central Florida

K-STATE



$$T_g = 0.3\frac{\tau_p^2}{T_d}$$

T_g: Gating width; τ_p: pulse duration

T_d: delay for polarization gating

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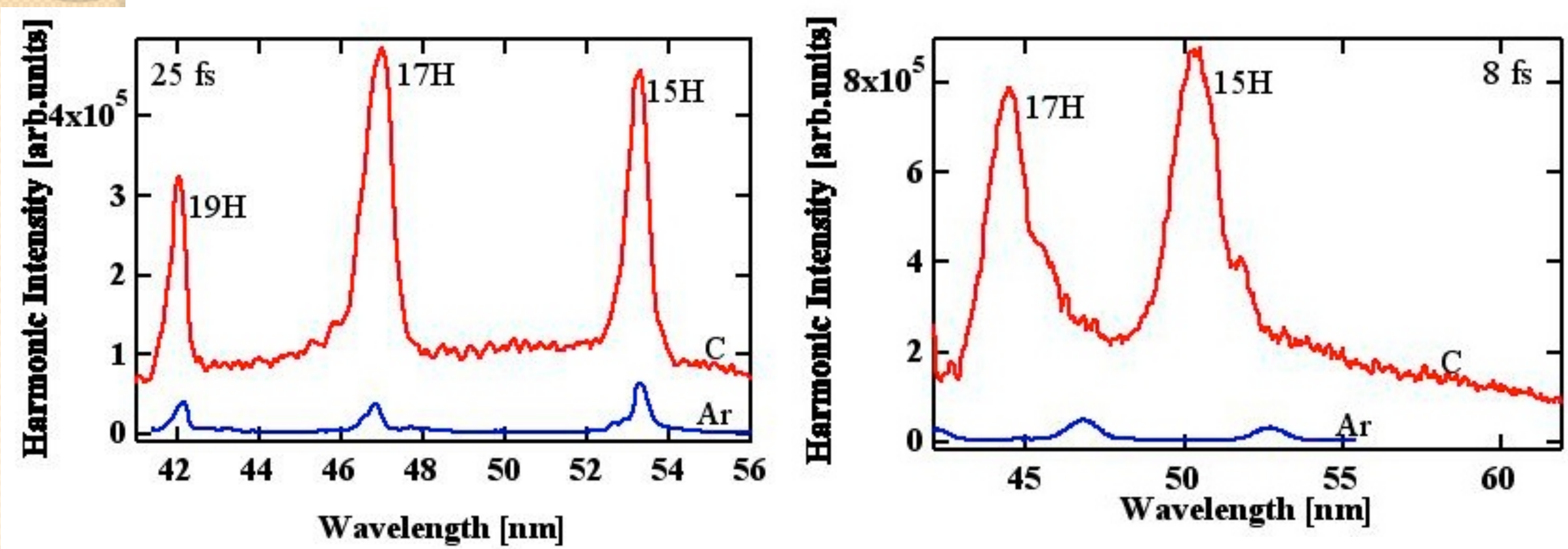
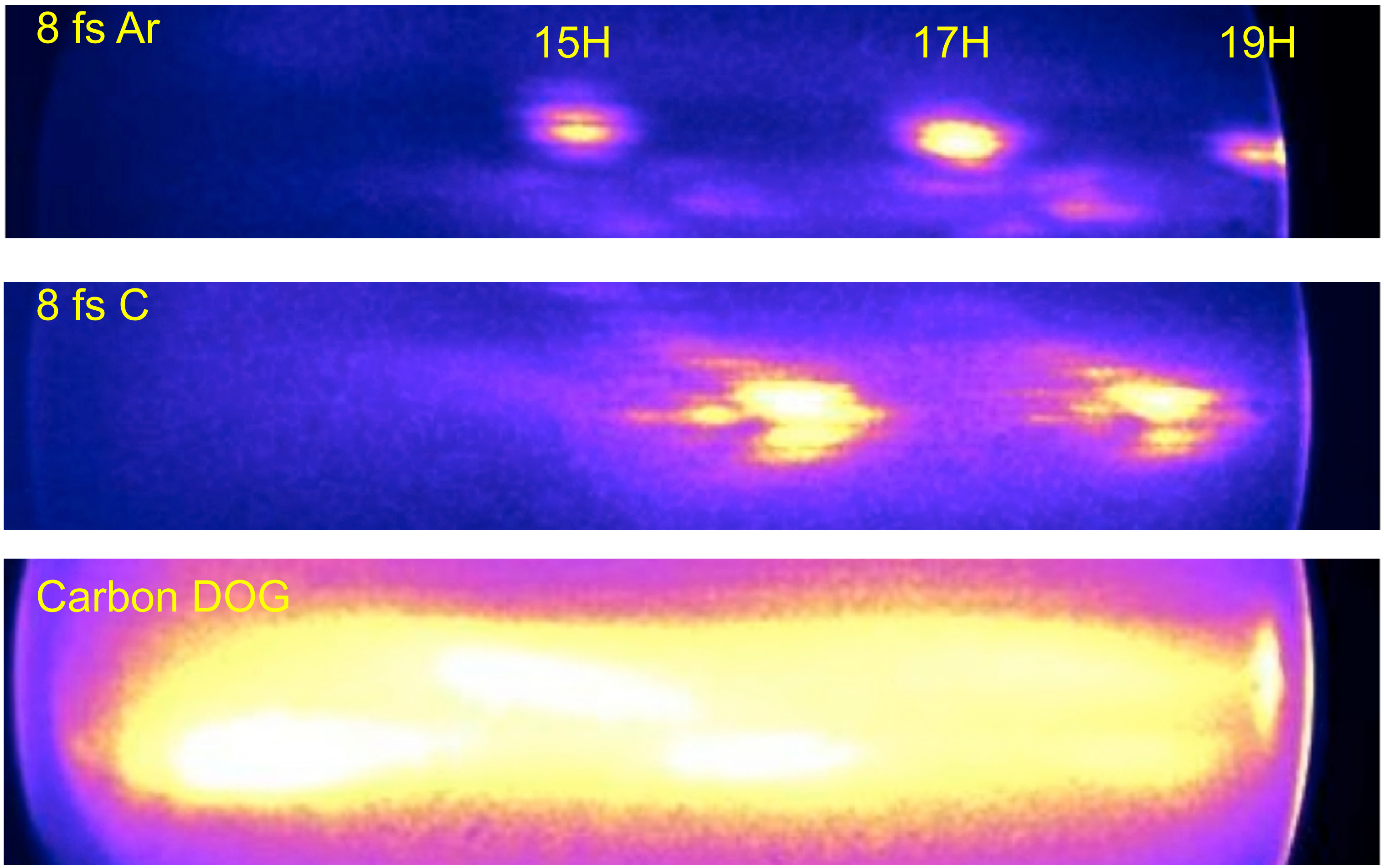
Step 1: Comparing Harmonics from Carbon Plasma and Argon Gas Cell

Pump: ~ 1.4 mJ (25 fs) & 0.7 mJ (8 fs) Ti:sapphire laser



Ar: 0.262 nJ; C: 2.49 nJ

Step 2: Generating Continuum Harmonics from Carbon Plasma



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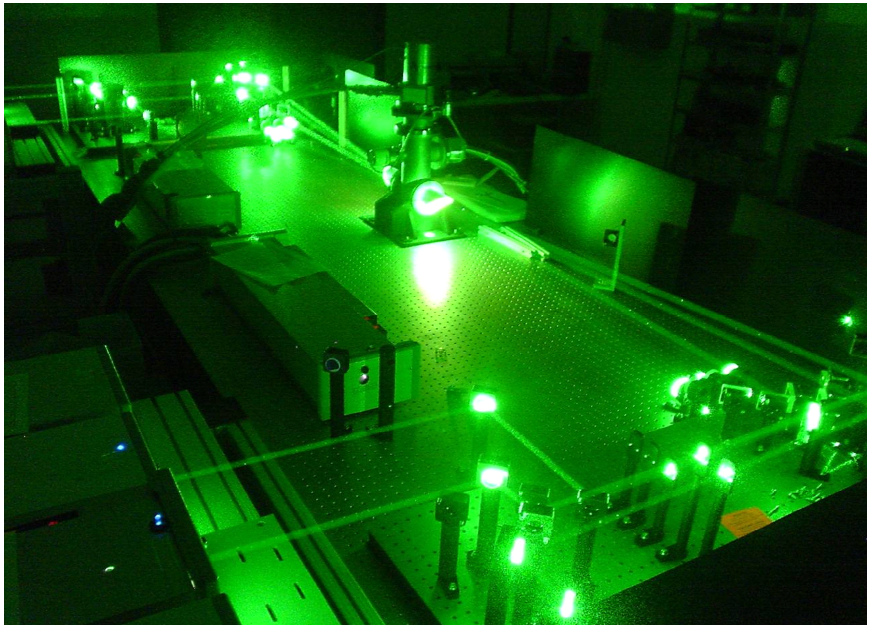
Thank You



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