Generation and characterization of few-cycle phase-controlled 1.7 μm pulses

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Motivation

- Strong-field physics: wavelength scaling of continuum electron kinetic energy and HHG cutoff

  Yakovlev *et al.* (2007); Agostini *et al.* (2004); Clatterbuck *et al.* (2003); Popmintchev *et al.* (2009)

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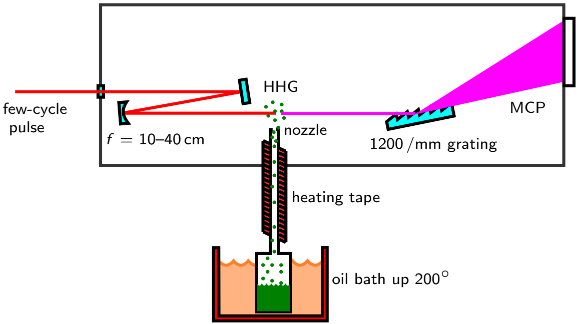
- HHG spectroscopy — return KE $> 60\,\mathrm{eV}$ in molecules with $I_\mathrm{p} \approx 10\,\mathrm{eV}$



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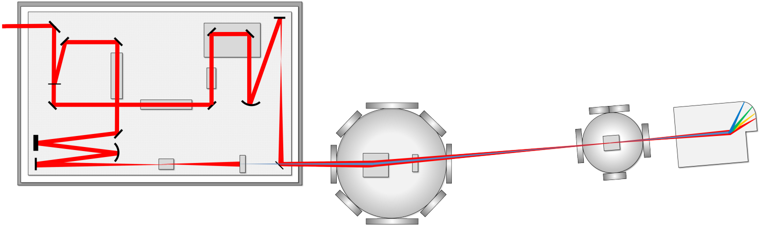
- HHG spectroscopy — return KE $> 60\,\mathrm{eV}$ in molecules with $I_\mathrm{p} \approx 10\,\mathrm{eV}$
- Transient absorption around around carbon, nitrogen, and oxygen edges



Survey of techniques

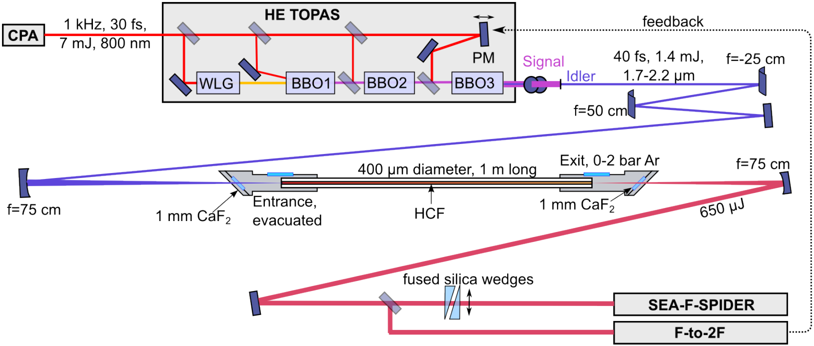
- Filamentation: simpler, spatio-temporal coupling $\leftrightarrow$ inefficiency, not yet below two optical cycles

  Hauri *et al.* (2007); Mücke *et al.* (2009); Driever *et al.* (2013)
- OPCPA: complex, but has achieved 9.0 fs 550 μJ, 1.6 μm

  Ishii *et al.* (2012)
- Hollow fibre compression: well established at 800 nm, phase compensation in fused silica, sub two cycles, up to 0.7 mJ at 1.75 μm

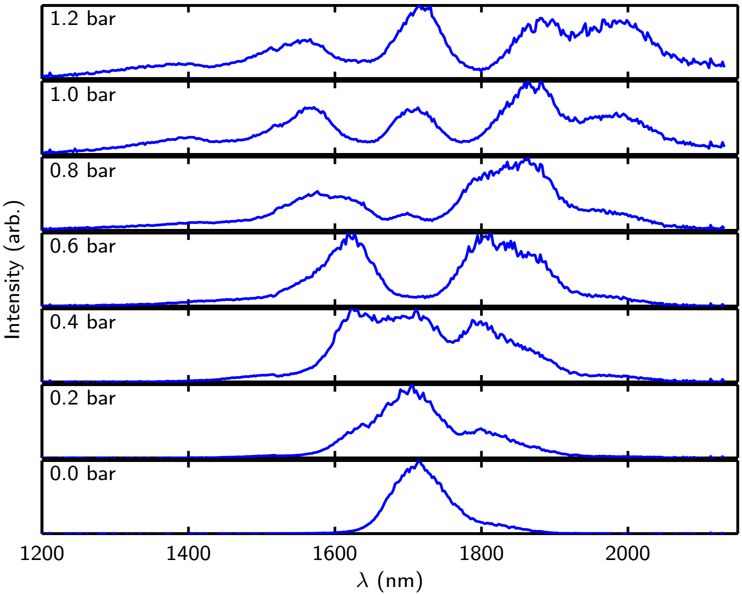
  Schmidt *et al.* (2010); Li *et al.* (2011)

Setup

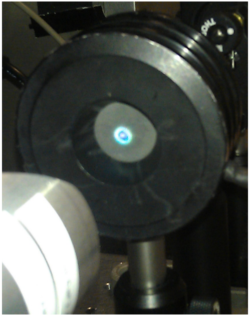


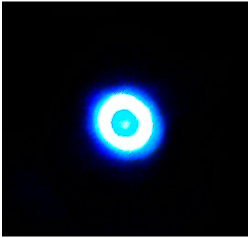
Transmission: 58%

Spectral broadening

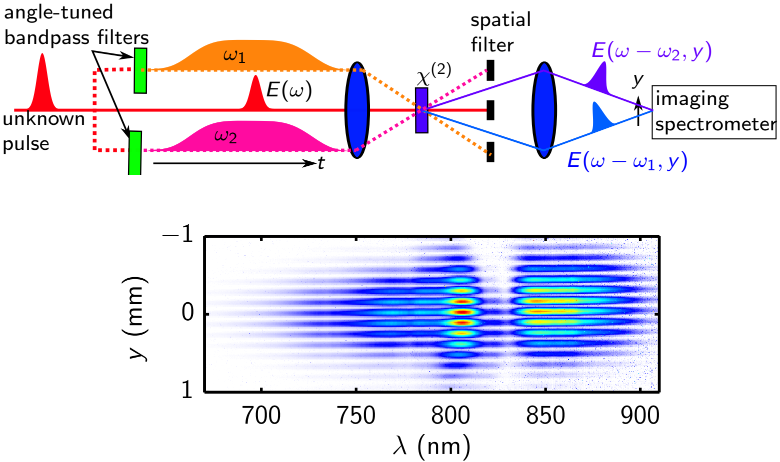


Visible appearance

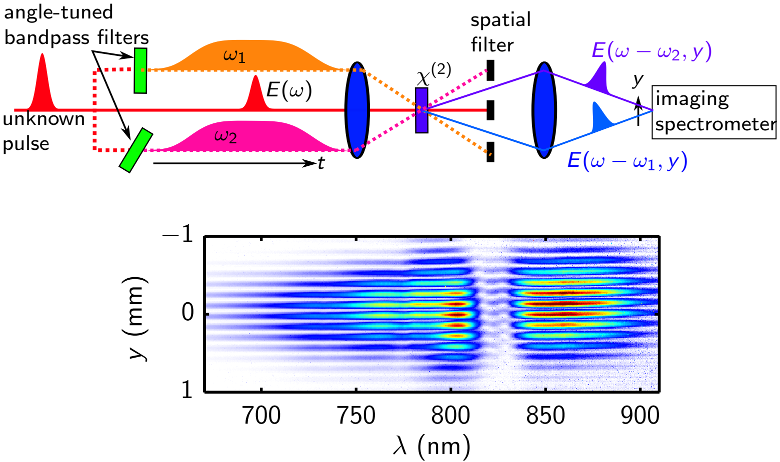




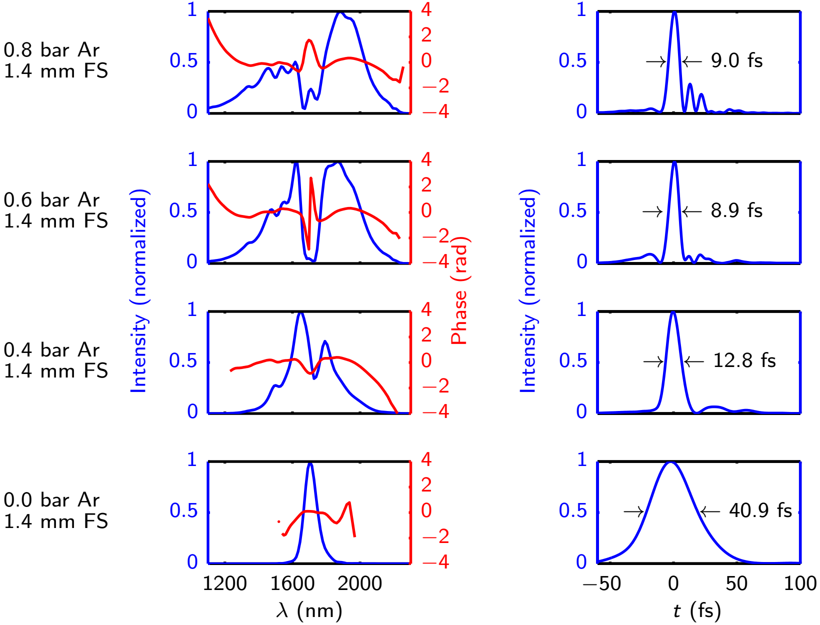
SEA-F-SPIDER concept



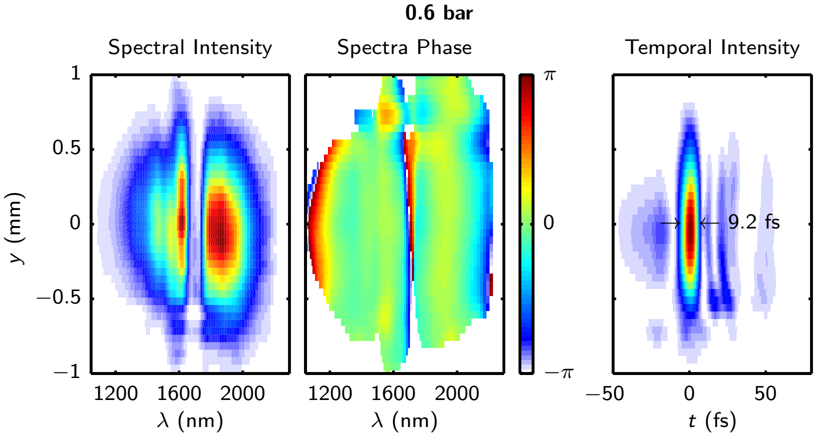
SEA-F-SPIDER concept



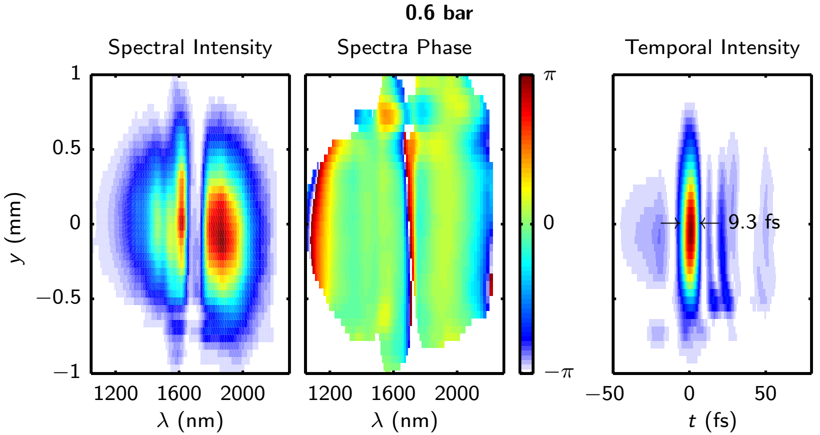
Pulse profiles at $y = 0$



Spatially resolved pulse profiles

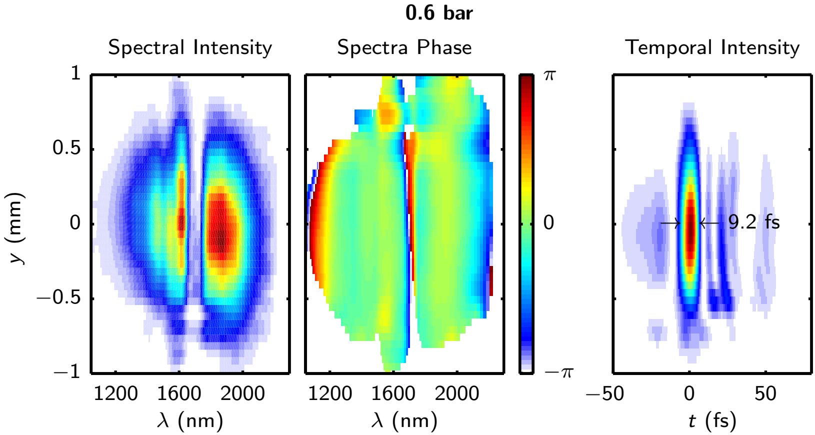


Stability



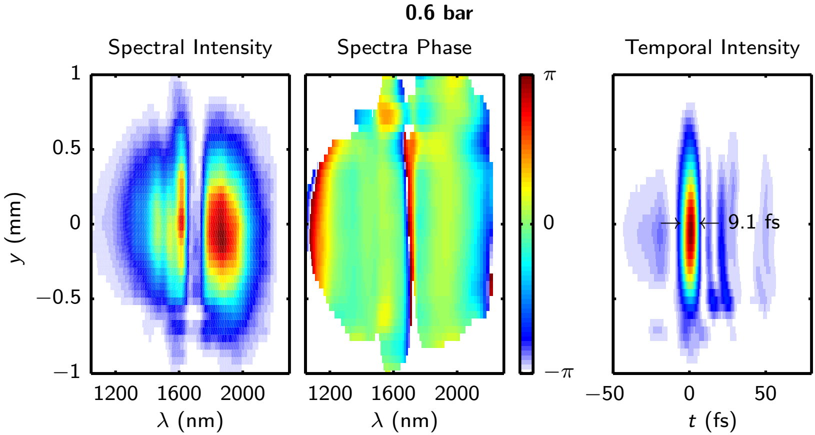
0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
π
0
−π
9.3 fs
−50
0
50
t (fs)

Stability



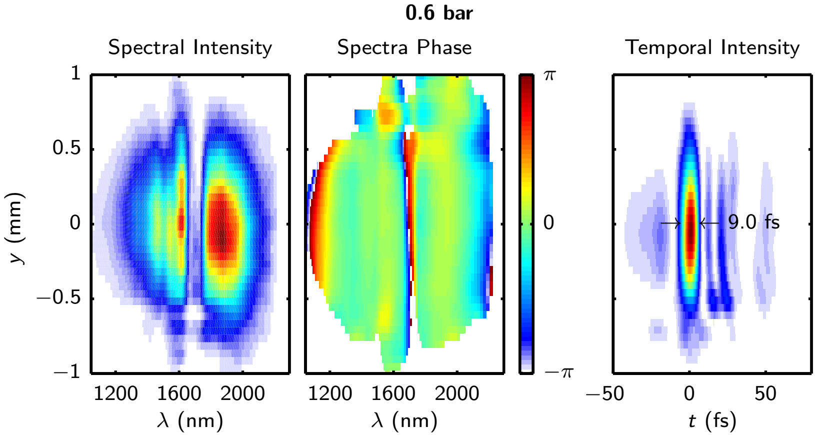
0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
1200
1600
2000
λ (nm)
π
0
−π
9.2 fs
−50
0
50
t (fs)

Stability

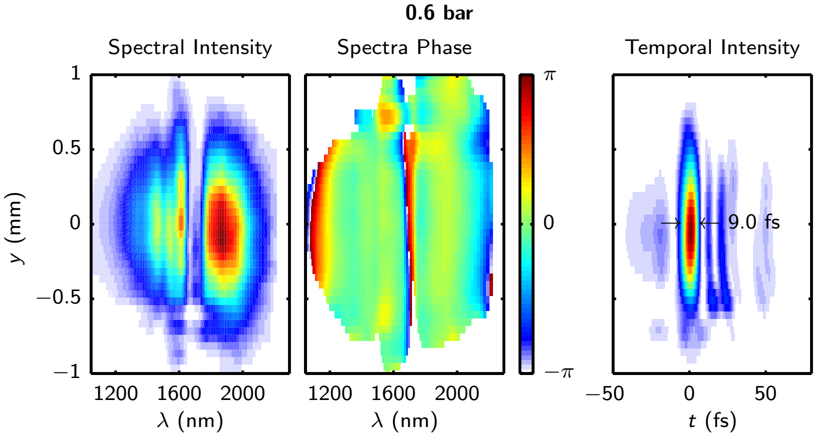


0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
π
0
−π
9.1 fs
−50
0
50
t (fs)

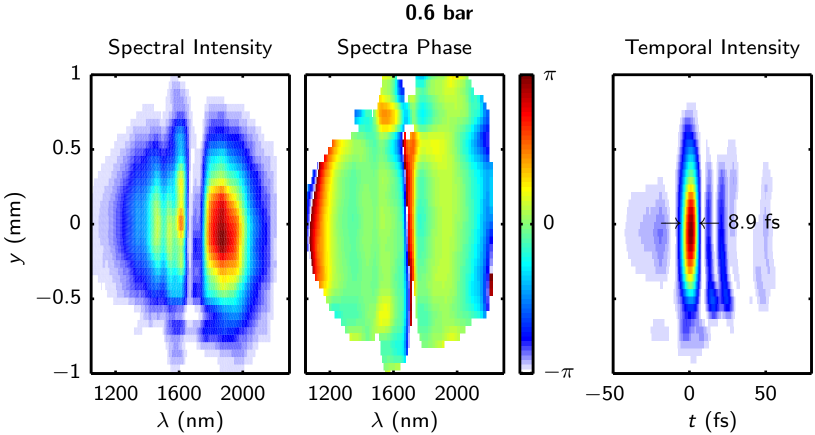
Stability


0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
π
0
−π
9.0 fs
−50
0
50
t (fs)

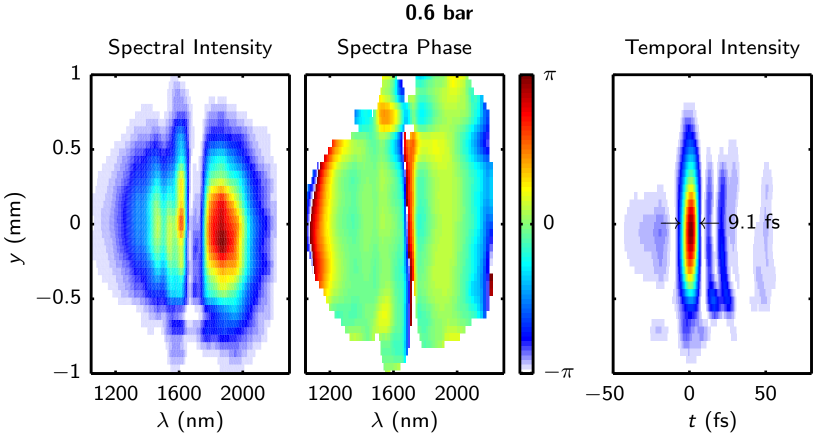
Stability


0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
1200
1600
2000
λ (nm)
π
0
−π
9.0 fs
−50
0
50
t (fs)

Stability

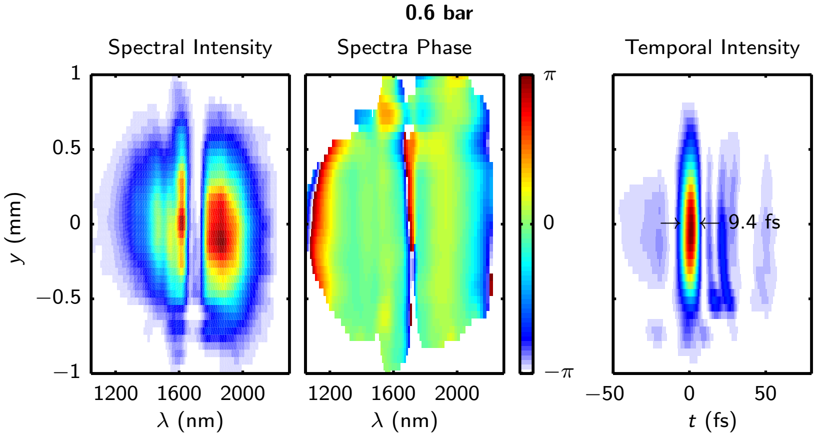

0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
1200
1600
2000
λ (nm)
π
0
−π
8.9 fs
−50
0
50
t (fs)

Stability



0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
1200
1600
2000
λ (nm)
π
0
−π
9.1 fs
−50
0
50
t (fs)

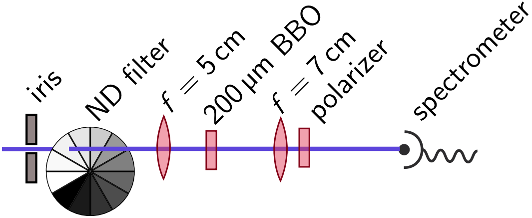
Stability

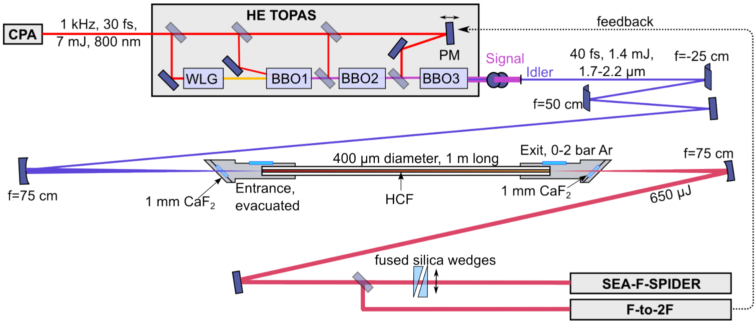


0.6 bar
Spectral Intensity
Spectra Phase
Temporal Intensity
1
0.5
0
−0.5
−1
y (mm)
1200
1600
2000
λ (nm)
1200
1600
2000
λ (nm)
π
0
−π
→ ← 9.4 fs
−50
0
50
t (fs)

CEP monitoring and control

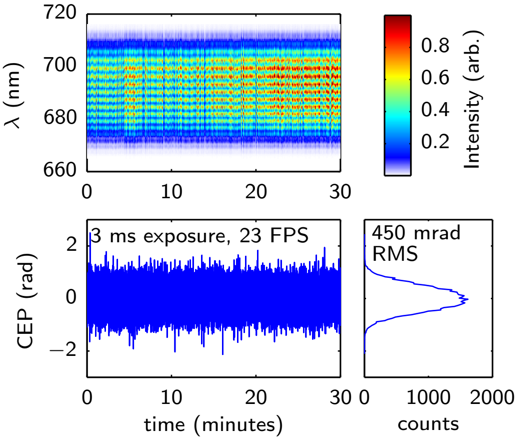
- f-to-$2f$ interferometer, piezo actuator in TOPAS third stage, "slow loop" feedback





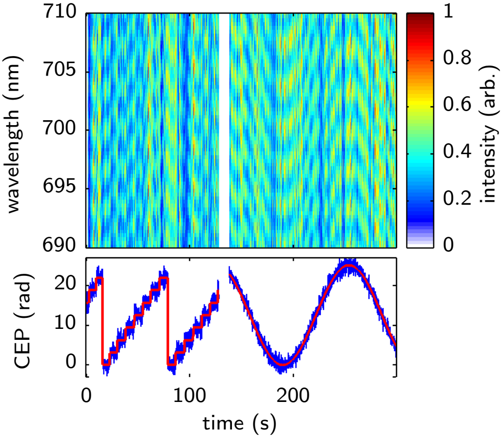
CEP monitoring and control

- f-to-$2f$ interferometer, piezo actuator in TOPAS third stage, "slow loop" feedback
- 880 mrad single-shot RMS over 30 minutes

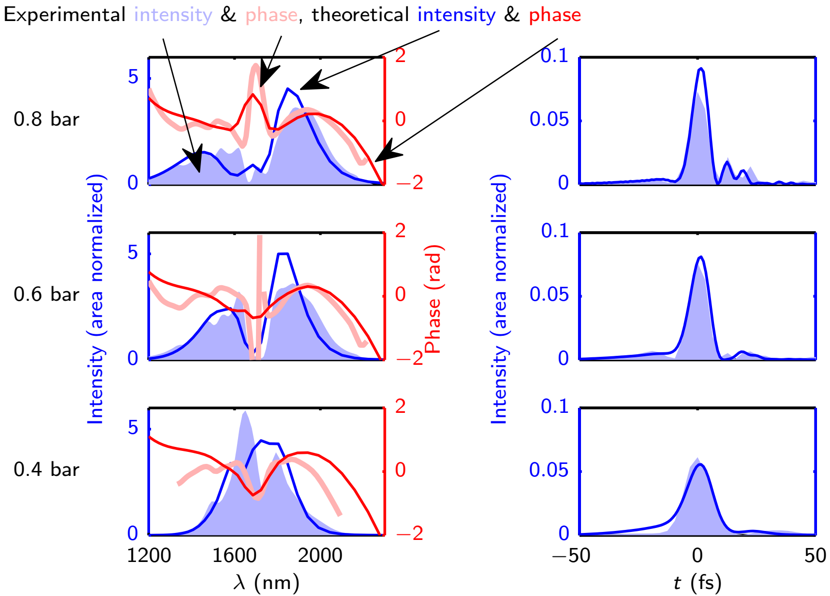


CEP monitoring and control

- f-to-$2f$ interferometer, piezo actuator in TOPAS third stage, “slow loop” feedback
- 880 mrad single-shot RMS over 30 minutes
- Arbitrary sequences

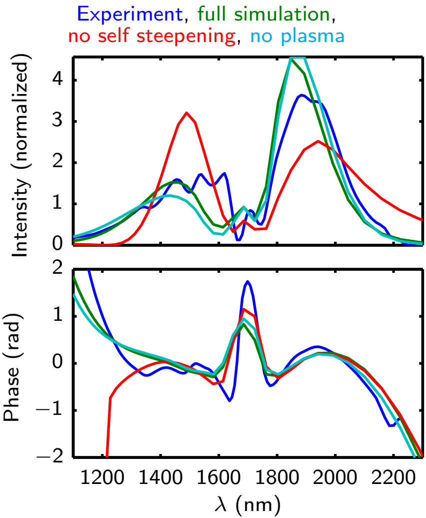


Comparison of model with experiment



Model implications

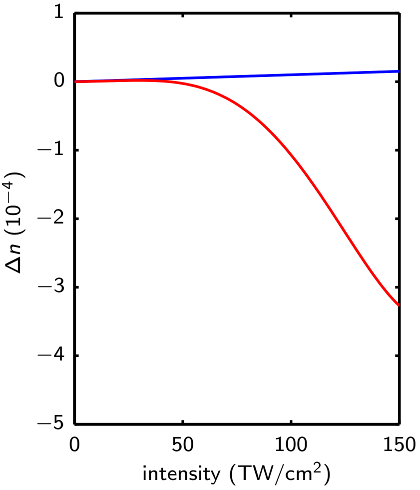
- Self-steepening crucial
  Schmidt *et al.* (2010); Béjot *et al.* (2010)
- Onset of plasma effects



Model implications

- Self-steepening crucial
  Schmidt *et al.* (2010); Béjot *et al.* (2010)
- Onset of plasma effects
- Kerr+Drude model sufficient — Kerr saturation not observed
  Loriot *et al.* (2009)

Linear, higher-order Kerr effect



Summary

- Spectral broadening of commercial OPA pulses in argon-filled hollow fibre
- 650 μJ, 9 fs (1.6 optical cycles), 1.7 μm pulses
- 880 mrad CEP shot-to-shot
- Consistent with Kerr+Drude model

Thanks to coauthors: Tobias Witting, Sébastien Weber, Paloma Matía-Hernando, Allan Johnson, Thomas Siegel, John Tisch and Jon Marangos

Thanks to workshop technicians: Andy Gregory and Peter Ruthven

Imperial College London

Model details

- Forward Maxwell equation, coupled HE1*m* spatial modes (cylindrical symmetry), frequency & mode dependent dispersion and loss

  Husakou *et al.* (2001); Couairon *et al.* (2011); Marcatili *et al.* (1964)

- Linear Kerr effect ($\Delta n = n_2 I$) with self-steepening, Drude plasma phase and loss (ADK rate)

  Lehmeier *et al.* (1985); Geissler *et al.* (1999)

- Launched HE11 mode with 80% efficiency, adjusted modal loss to match measured transmission of 55%.

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