Nonlinear Optics (WiSe 2017/18)

Lecture 17: December 14, 2017

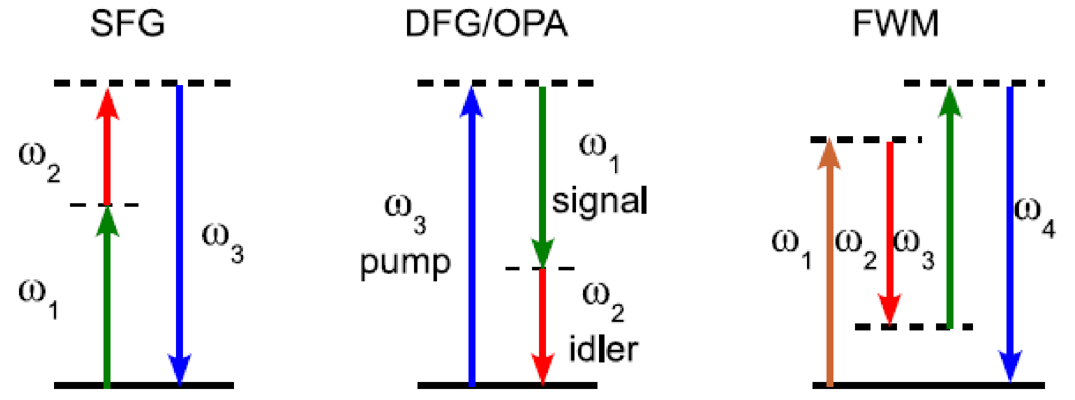
9.10.2 Generation of CEP-stable pulses from an OPA:

CEP-stable IR pulses from hybrid type-II OPCPA/filamentation system

OPCPA of a 2-µm seed pulse obtained by intrapulse DFG

Dual-chirped infrared optical parametric amplification (DC-OPA)

Parametric sub-cycle optical waveform synthesizers

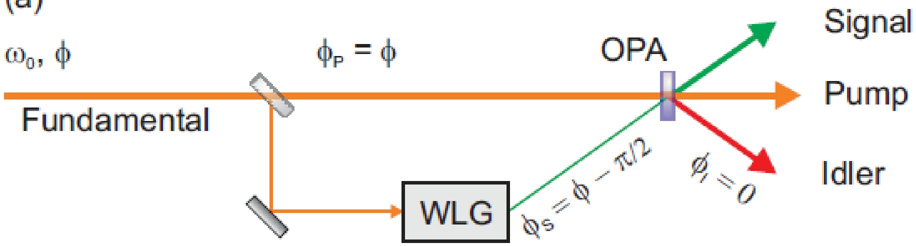


$\omega_3 = \omega_1 + \omega_2$
$\varphi_3 = \varphi_1 + \varphi_2 - \pi/2$

$\omega_2 = \omega_3 - \omega_1$
$\varphi_2 = \varphi_3 - \varphi_1 - \pi/2$

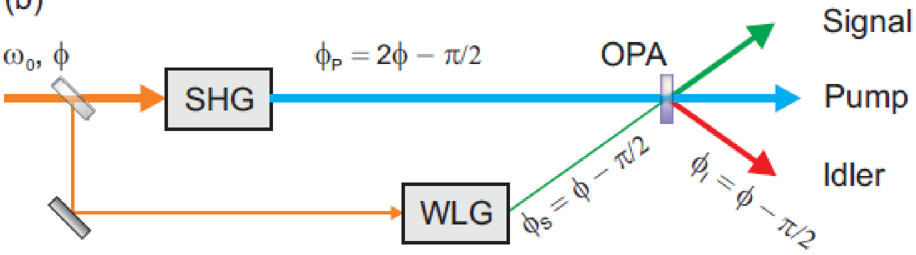
$\omega_4 = \omega_1 - \omega_2 + \omega_3$
$\varphi_4 = \varphi_1 - \varphi_2 + \varphi_3 - \pi/2$

(a)



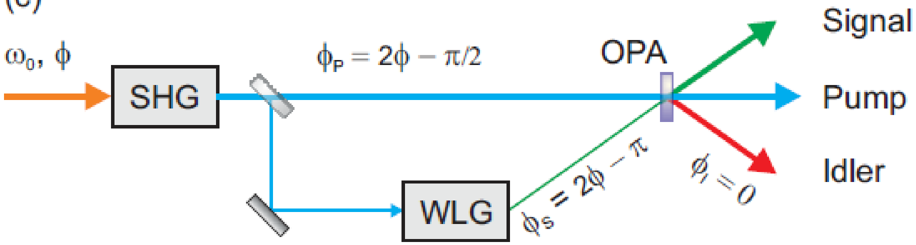
CEP-stable idler

(b)



’phase-repeating OPA’

(c)



CEP-stable idler

CEP-stable IR pulses from hybrid type-II OPCPA/ filamentation system

building blocks:

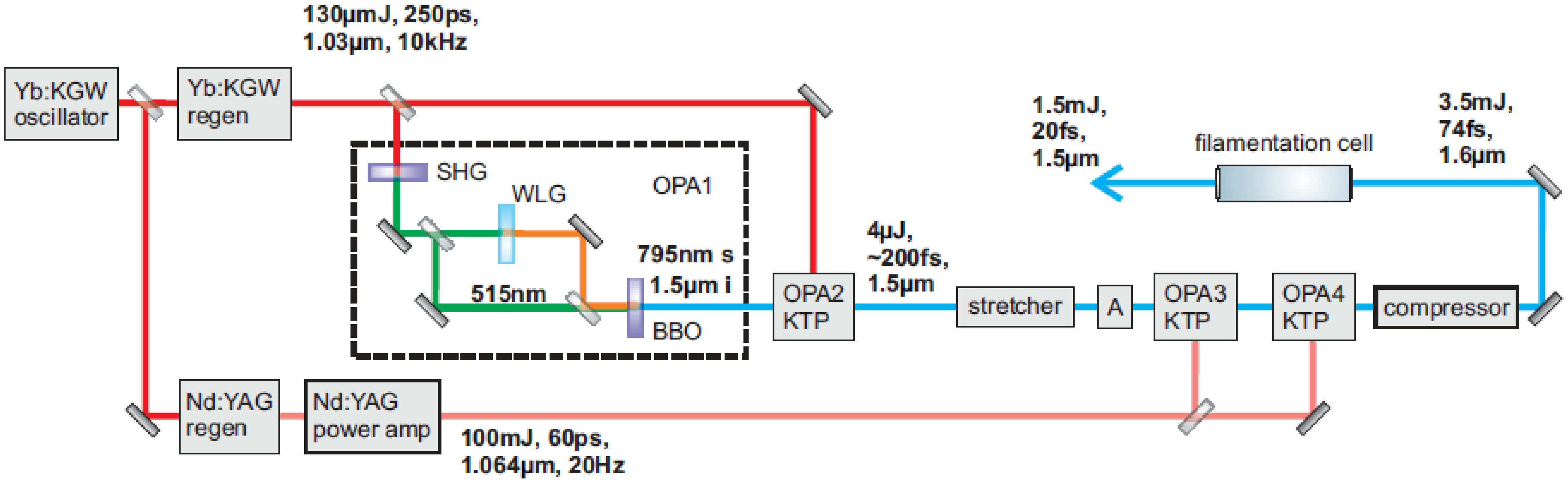
(i) self-CEP-stabilized 1.5-µm frontend:
CEP-stable collinear type-I BBO OPA + narrowband type-II KTP OPA
(ii) type-II KTP OPCPA based on picosecond Nd:YAG technology
(iii) pulse self-compression by filamentation in noble gases

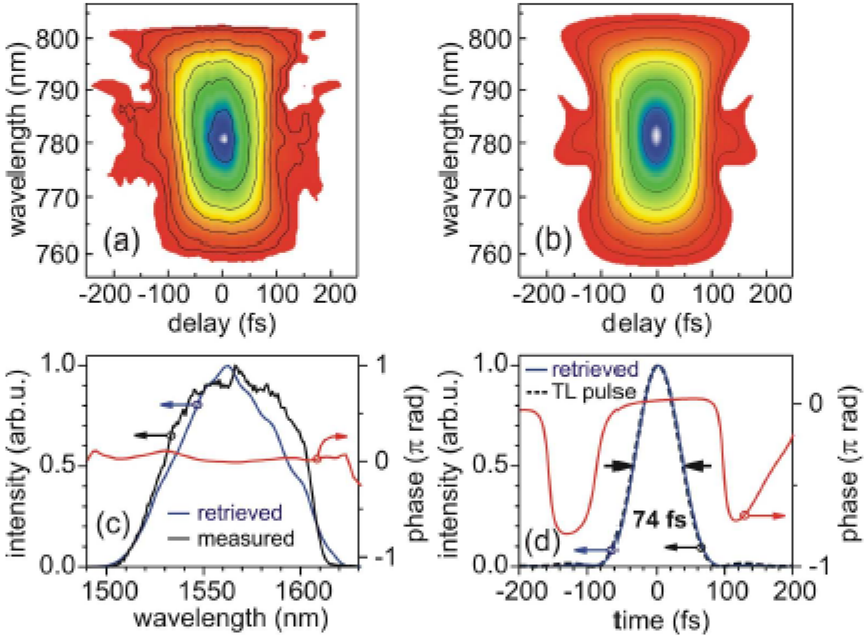
motivation for architecture:

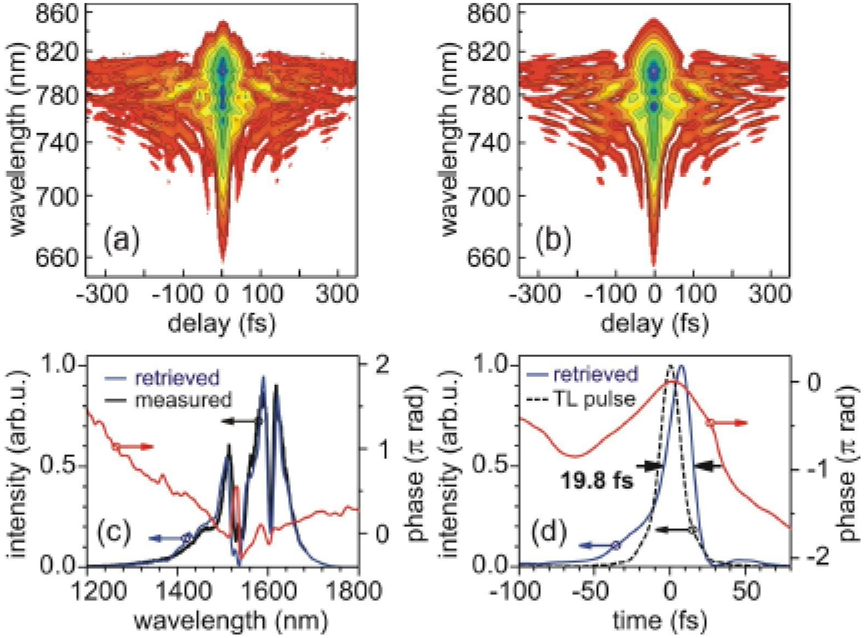
(a) near-degenerate type-I OPAs have worst possible quantum defect for signal
(b) even though group-velocity-matched OPAs deliver ultrabroad output spectra (>200 nm), quality of resulting compressed pulses most often remains poor due to intrinsically steep slopes of the parametrically amplified spectra
(c) more narrowband amplification has the advantage of optimizing the spectral brightness of the signal (suppression of parametric superfluorescence)
(d) when scaling the pulse energies of type-I OPAs to the mJ-level, cascaded FWM can cause unwanted losses due to parasitic self-diffraction.

O. D. Mücke *et al.*, Opt. Lett. **34**, 118-120 (2009)

O. D. Mücke *et al.*, Opt. Lett. **34**, 2498-2500 (2009)



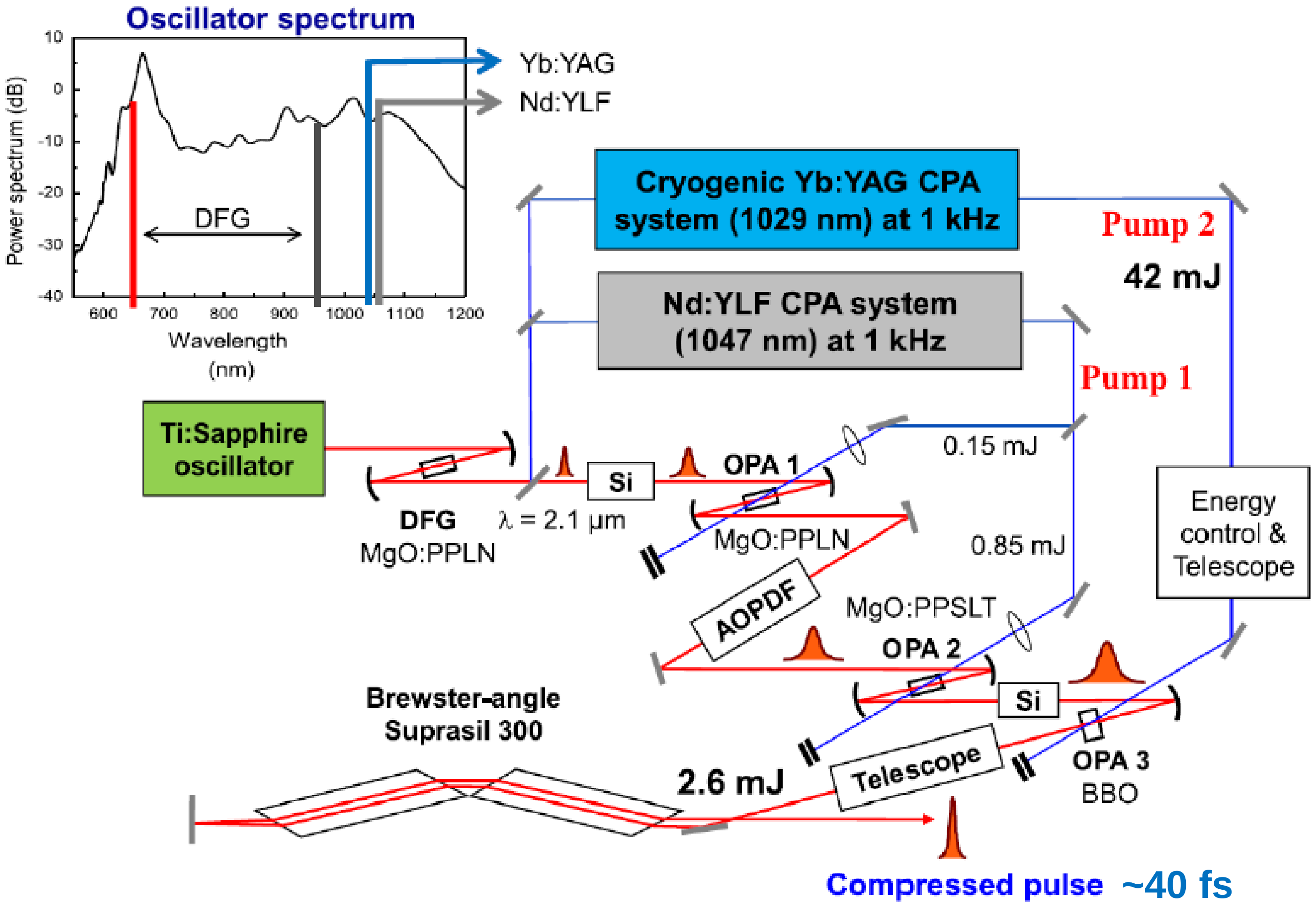




O. D. Mücke *et al.*, Opt. Lett. **34**, 118-120 (2009)

O. D. Mücke *et al.*, Opt. Lett. **34**, 2498-2500 (2009)

OPCPA of a 2-µm seed obtained by intrapulse DFG

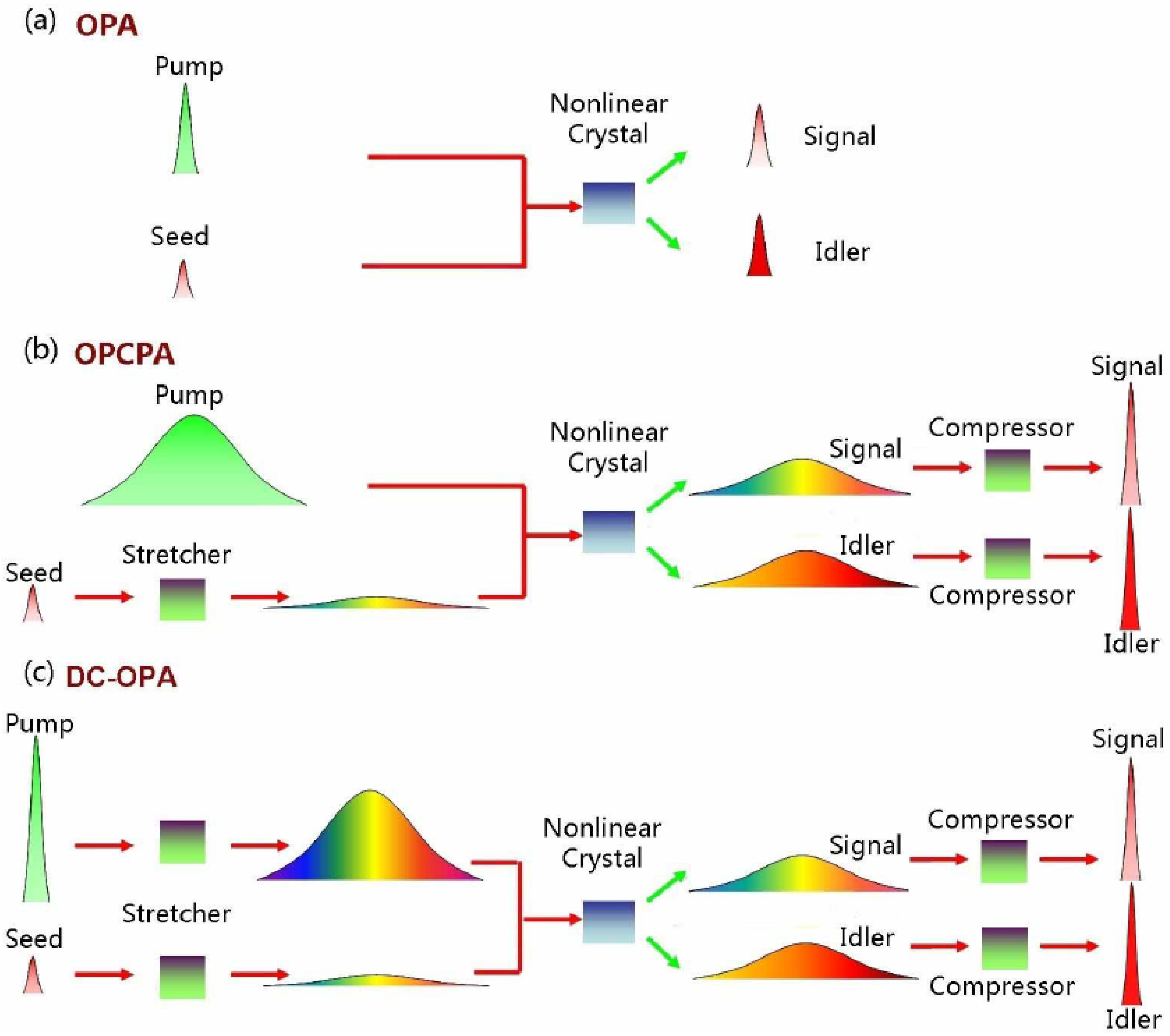


K.-H. Hong *et al.*, Opt. Lett. **39**, 3145 (2014)

K.-H. Hong *et al.*, Opt. Express **19**, 15538 (2011)

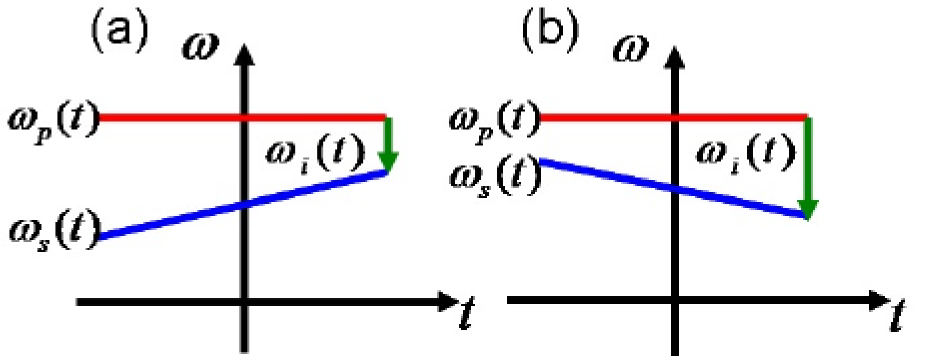
J. Moses *et al.*, Opt. Lett. **34**, 1639 (2009)

at MPQ: T. Fuji *et al.*, Opt. Lett. **31**, 1103 (2006); X. Gu *et al.*, Opt. Express **17**, 62 (2009);
Y. Deng *et al.*, Opt. Lett. **37**, 4973 (2012).

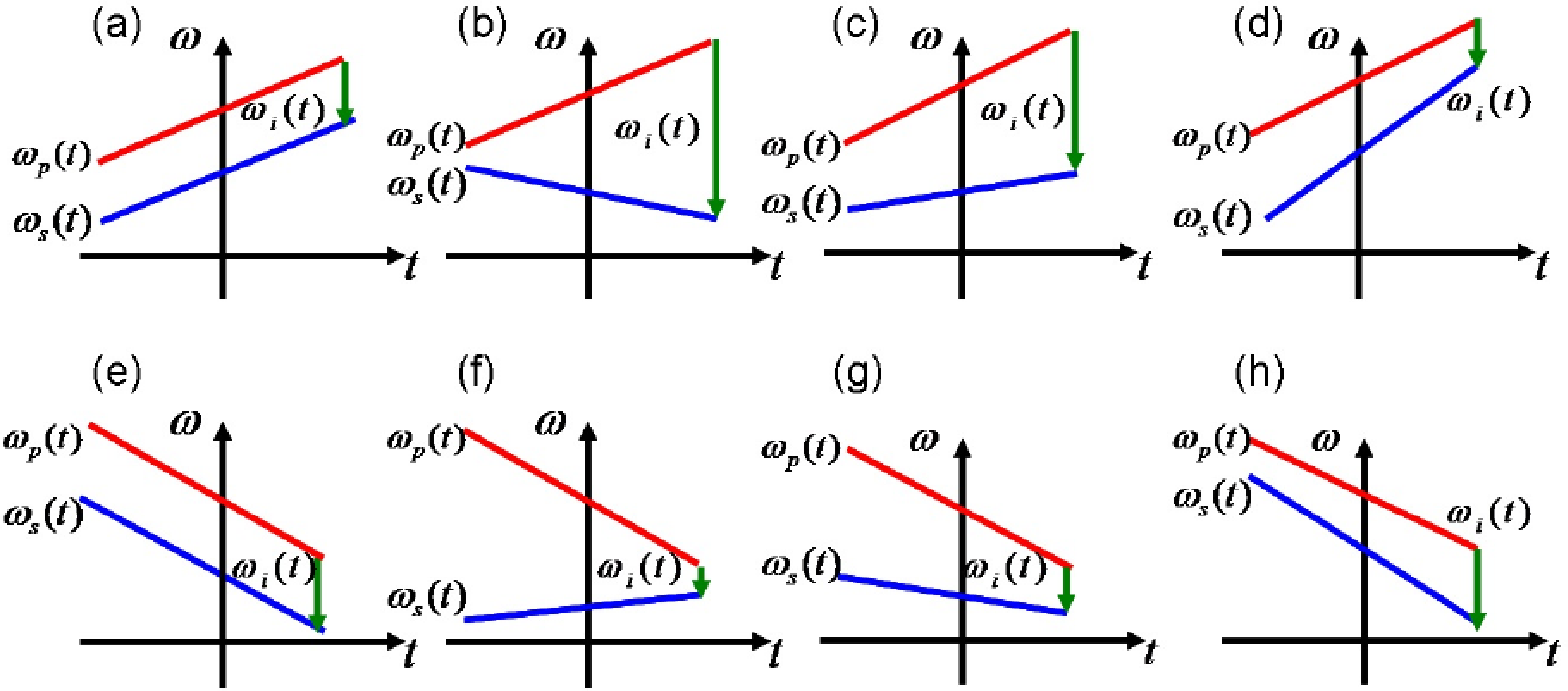

(a) OPA
Pump
Seed
Nonlinear Crystal
Signal
Idler
(b) OPCPA
Pump
Seed
Stretcher
Nonlinear Crystal
Signal
Idler
Compressor
Compressor
Signal
Idler
(c) DC-OPA
Pump
Seed
Stretcher
Nonlinear Crystal
Signal
Idler
Compressor
Compressor
Signal
Idler

Dual-chirped IR optical parametric amplification

OPCPA

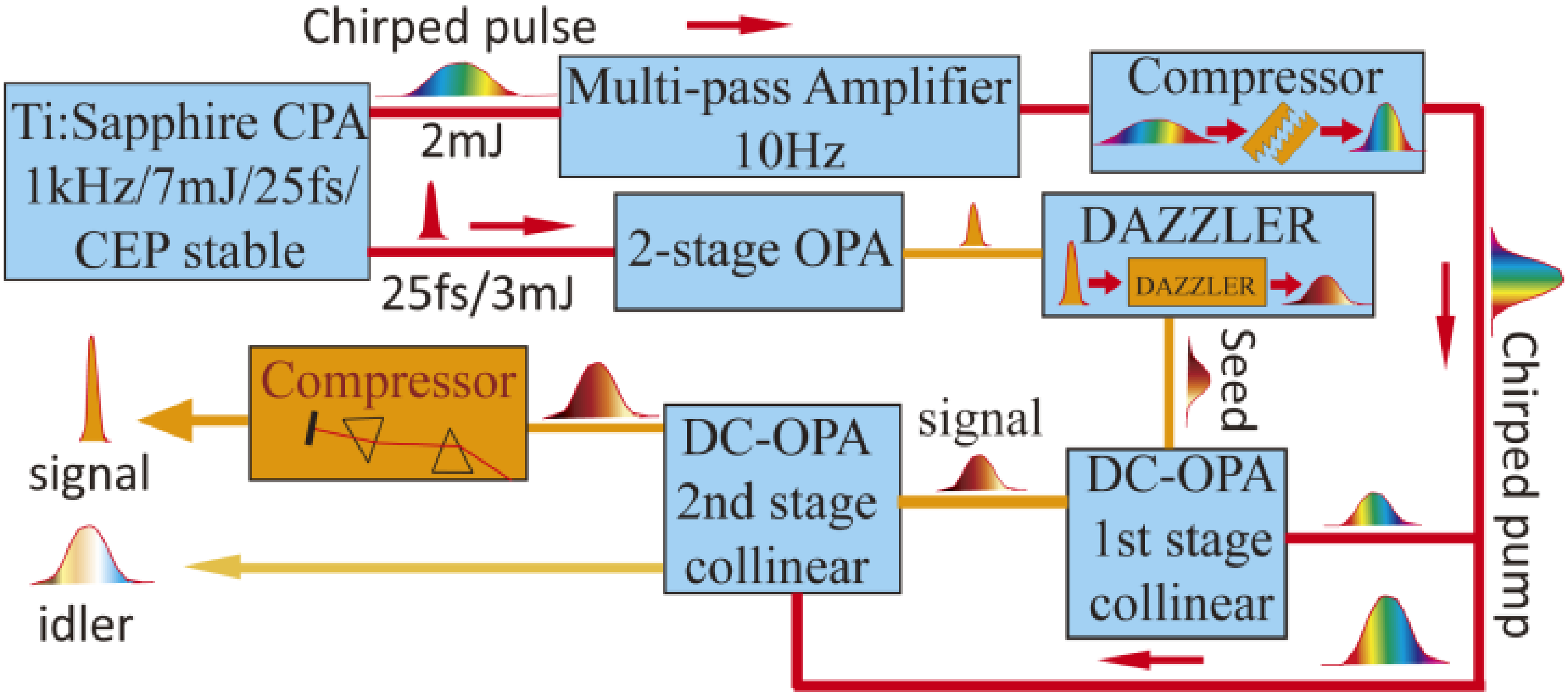


DC-OPA



Q. Zhang *et al.*, Opt. Express **19**, 7190-7212 (2011)

Dual-chirped IR optical parametric amplification



Y. Fu *et al.*, Opt. Lett. **21**, 5082-5085 (2015)

Y. Fu *et al.*, J. Opt. **17**, 124001 (2015)

Dual-chirped IR optical parametric amplification

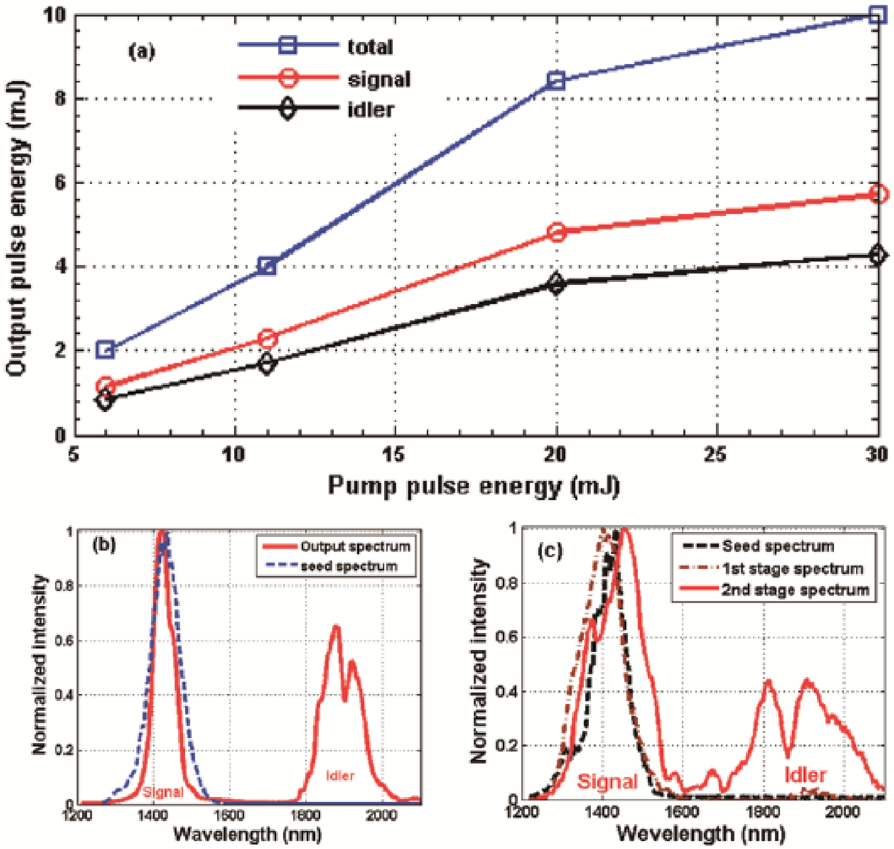


Figure 9.53: (a) Energy scalability experimentally confirmed by a single-stage DC-OPA. Blue solid-square, total output energy; red solid-circular, signal pulse energy; black solid-rhombic, idler pulse energy. (b) Typical seed (blue dashed) and output (red solid) spectra corresponding to panel (a). (c) Spectra for 80 mJ pumping in a two-stage DC-OPA. Black dashed curve, seed spectrum; brown dash-dotted curve, signal spectrum after first stage; red solid curve, spectrum after second stage. [32]

30%-40% total (=s+i) efficiency

pump at 100-mJ level

signal compressed to 27fs

self-CEP-stabilized idler

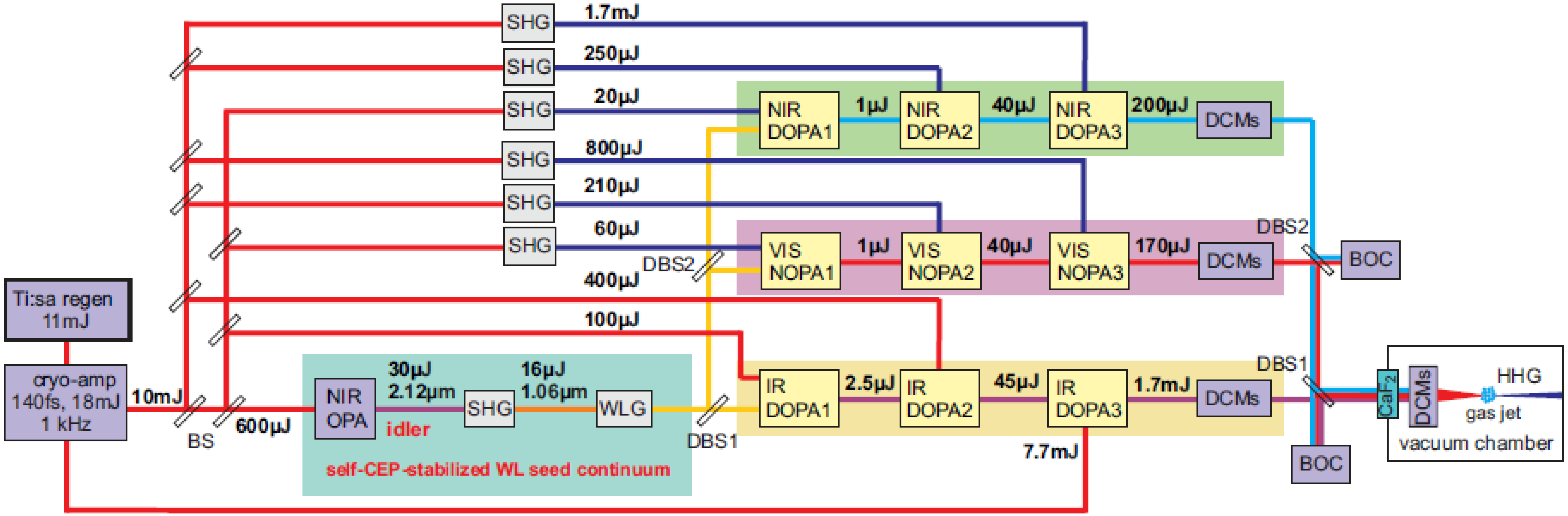
good prospects for scaling to hundred-mJ-level and even J-level

Y. Fu *et al.*, Opt. Lett. **21**, 5082-5085 (2015)

Y. Fu *et al.*, J. Opt. **17**, 124001 (2015)

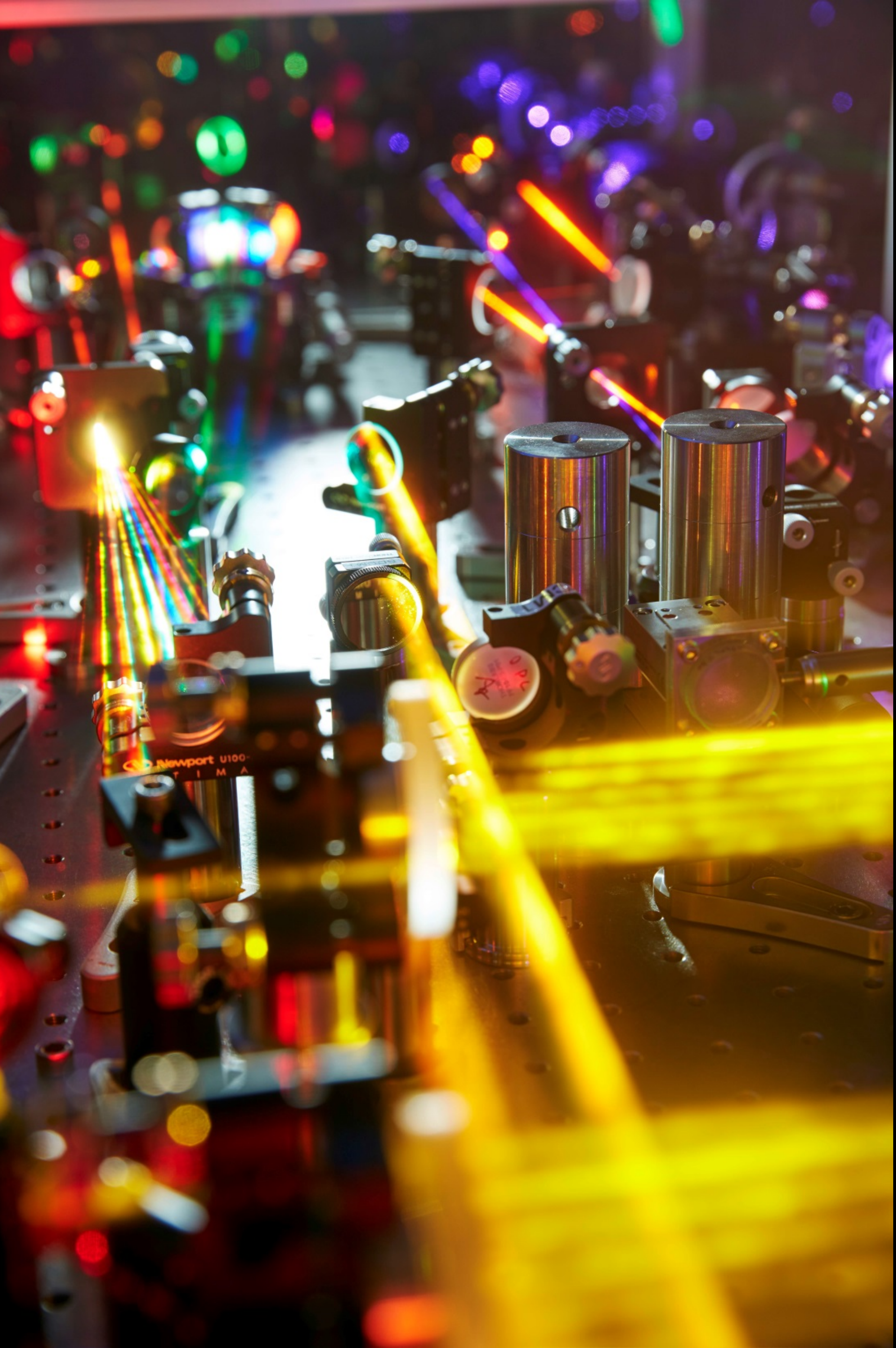
Parametric sub-cycle optical waveform synthesizers

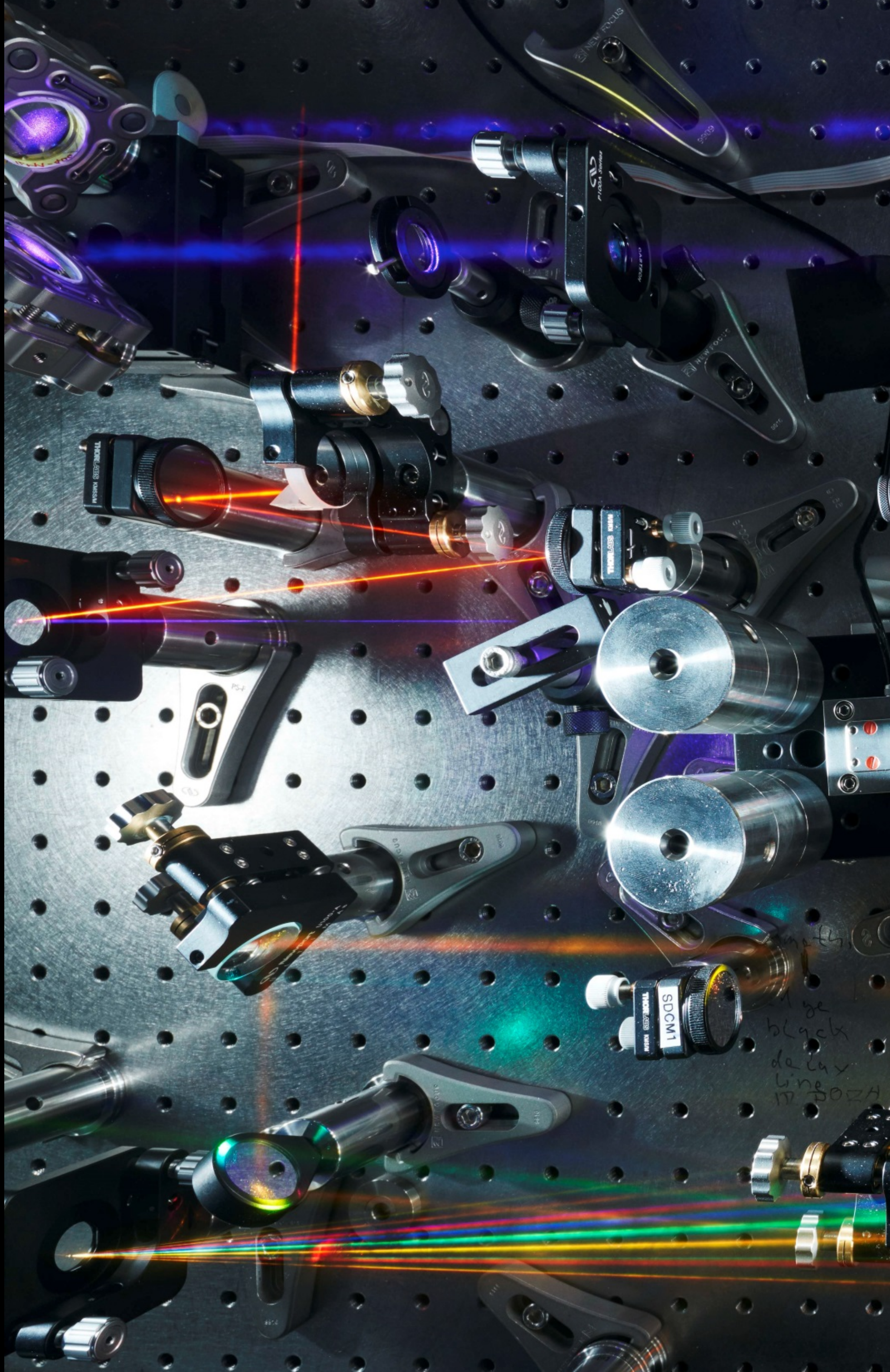
- ☐ >2-octave-wide waveform synthesis from OPAs at the multi-mJ level and at 1 kHz
- ☐ WLG seed split into 3 wavelength channels and amplified in 3 OPA stages each
- ☐ 3 channels are individually compressed and coherently recombined
- ☐ relative timing is tightly locked using balanced optical cross-correlators (BOCs)



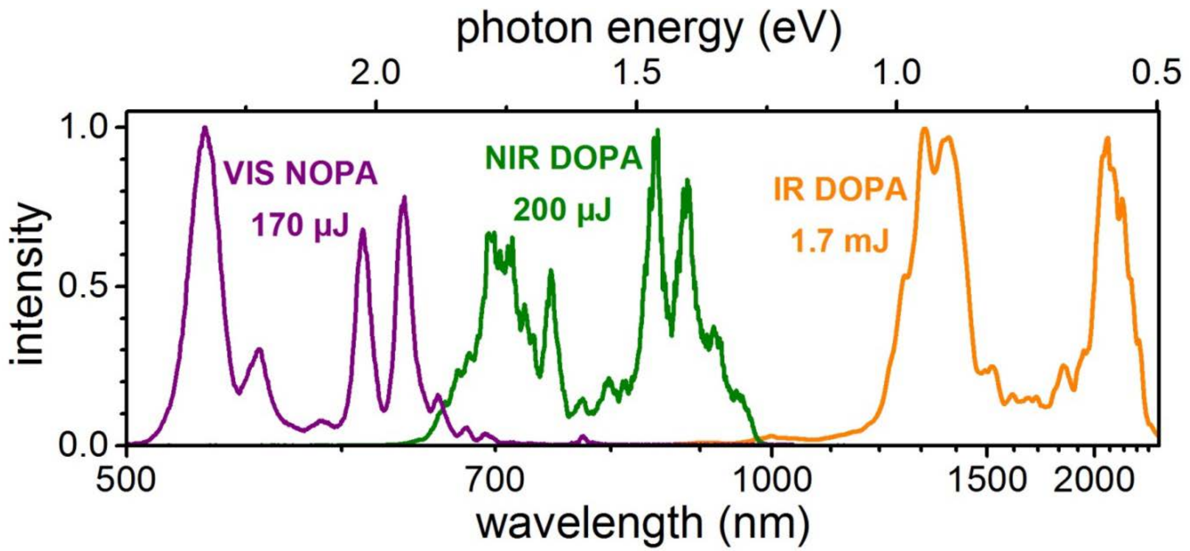
NOPA: noncollinear OPA; DOPA: degenerate OPA

O. D. Mücke *et al.*, IEEE J. Sel. Top. Quantum Electron. **21**, 8700712 (2015)
C. Manzoni *et al.*, Laser & Photonics Rev. **9**, 129-171 (2015)


Newport U100-
TIMA


SDCM1

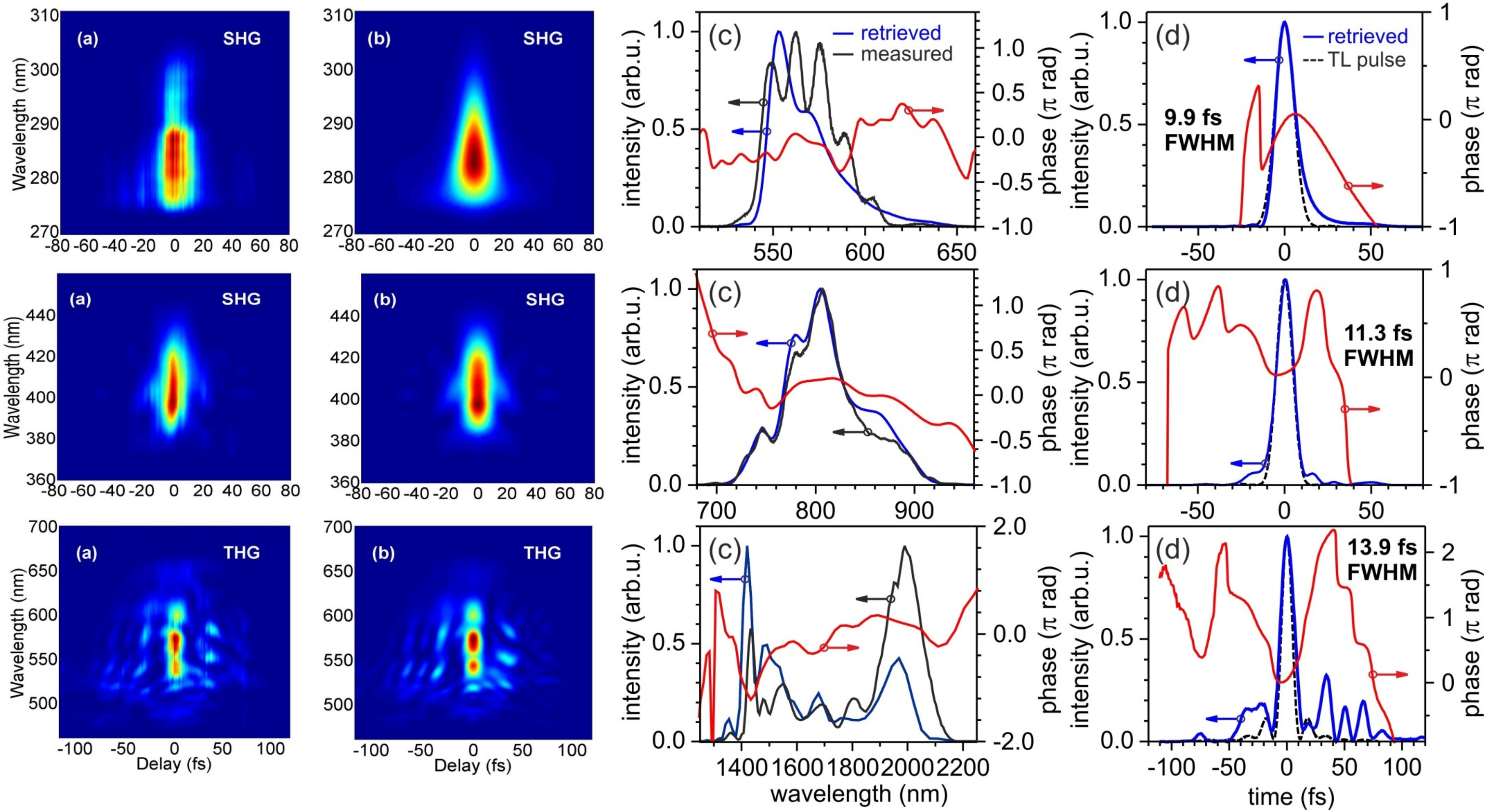
Parametric sub-cycle optical waveform synthesizers



VIS NOPA	NIR DOPA	IR DOPA
0.17 mJ signal	**0.20-0.25 mJ signal**	**1.7 mJ octave-spanning signal**
20% (0.8 mJ pump) pump-signal conversion efficiency	**12-15%** (1.7 mJ pump) pump-signal conversion efficiency	**22%** (7.7 mJ pump) pump-signal conversion efficiency
TL 5.6 fs	TL 5.2 fs	TL 5.2 fs
2.9 optical cycles @ λ_c=573nm	2.1 optical cycles @ λ_c=750nm	**1.1** optical cycle @ λ_c=1.4um

O. D. Mücke *et al.*, IEEE J. Sel. Top. Quantum Electron. **21**, 8700712 (2015)

Parametric sub-cycle optical waveform synthesizers

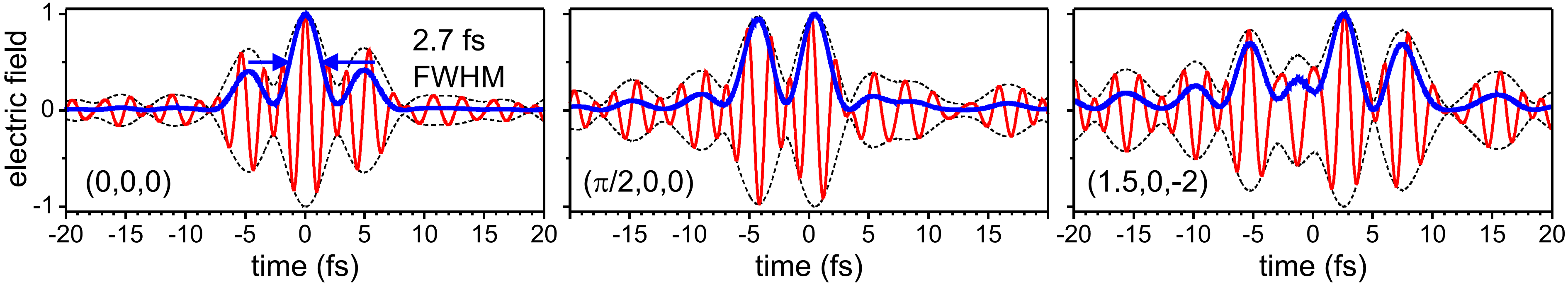


- recompressed all channels simultaneously close to TL at **synthesis point**
- flexible dispersion compensation scheme can be used at multi-mJ level

O. D. Mücke *et al.*, IEEE J. Sel. Top. Quantum Electron. **21**, 8700712 (2015)

Parametric sub-cycle optical waveform synthesizers

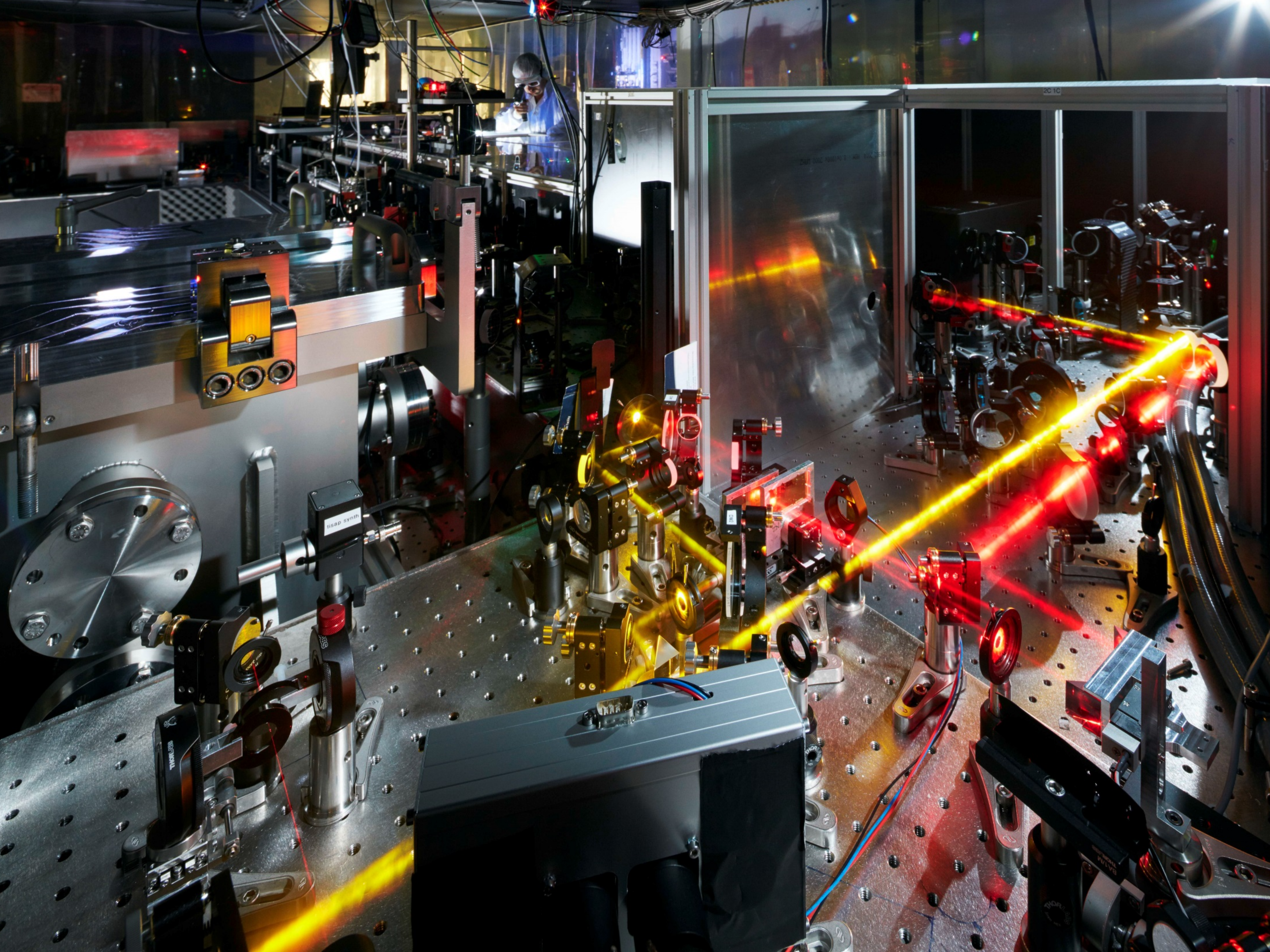
3 possible synthesized *E*(*t*), computed form the FROG-retrieved pulses (2^{nd} stage)



Ongoing: recompress more broadband spectra → TL 1.9 fs

complete locking of relative timing and phase

O. D. Mücke *et al.*, IEEE J. Sel. Top. Quantum Electron. **21**, 8700712 (2015)


tisap synth