<Journal club presentation>

Spatio-temporal characterization of mid-infrared laser pulses with spatially encoded spectral shearing interferometry

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Abstract

Abstract: We report on the spatially resolved full amplitude and phase characterization of mid-infrared high intensity laser pulses generated in a three stage OPA. We use a spatially-encoded arrangement (SEA-)SPIDER with spectral filters for ancilla generation for spatially resolved characterization. Using five interchangeable filter sets we are able to characterize pulses from 1 to 2 μm with one single device with minimal adjustments.

Spectral phase interferometry for direct electric – field reconstruction (SPIDER)

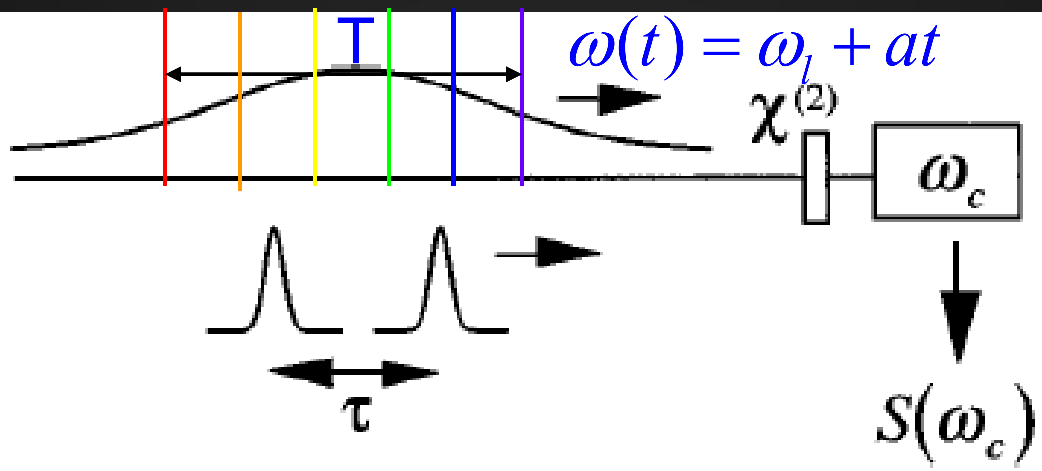


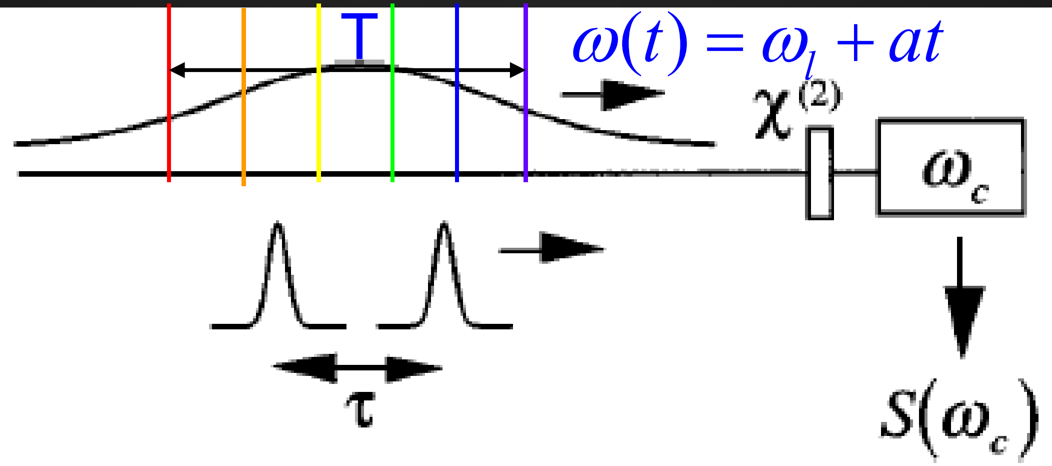
Fig. 1. The SPIDER apparatus. $\chi^{(2)}$ is a nonlinear material. The geometry is entirely collinear and, if a detector array is used at the output of the spectrometer (ω_c), has no moving components.

Iaconis and Walmsley. "Optics letters 23.10 (1998): 792-794.

$$\delta\omega = aT$$

$$\Omega = a\tau = (\delta\omega\tau / T)$$

Spectral phase interferometry for direct electric – field reconstruction (SPIDER)



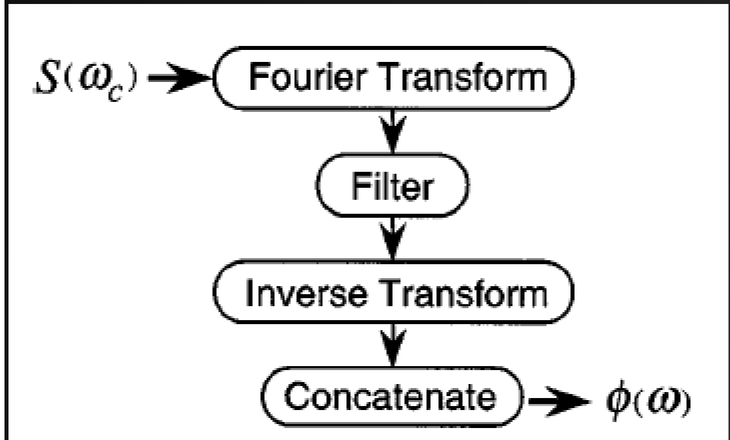
Interference between two SF fields , $E(\omega_c)$ and $E(\omega_c+\Omega)$

$$\delta\omega = aT$$

$$\Omega = a\tau = (\delta\omega\tau / T)$$

$$S(\omega_c) = |\tilde{E}(\omega_c)|^2 + |\tilde{E}(\omega_c + \Omega)|^2 + 2|\tilde{E}(\omega_c)\tilde{E}(\omega_c + \Omega)| \times \cos[\phi_\omega(\omega_c + \Omega) - \phi_\omega(\omega_c) + \omega_c\tau], \quad (1)$$

Spectral phase interferometry for direct electric – field reconstruction (SPIDER)



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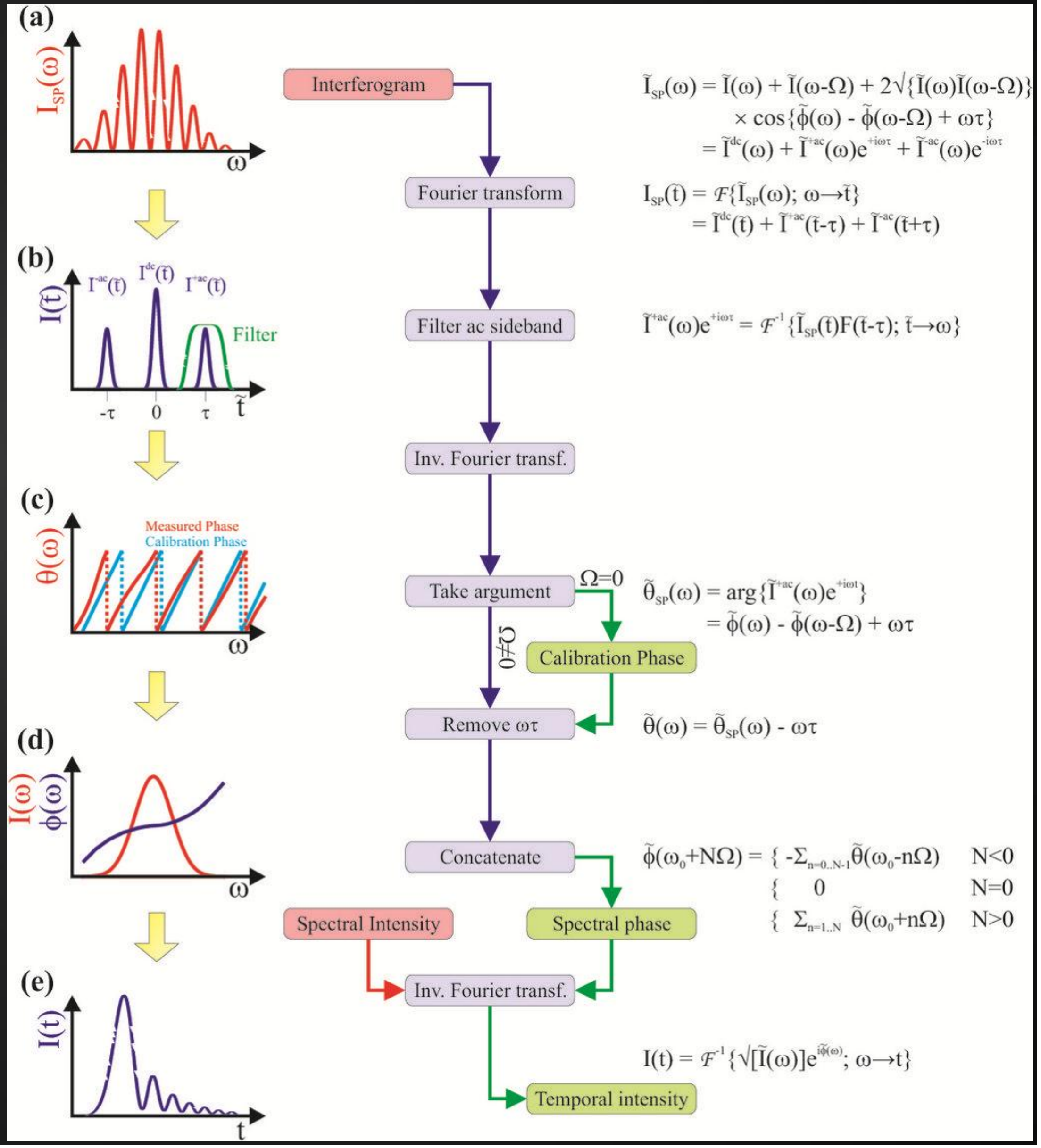


Wikipedia

Spatially encoded arrangement SPIDER

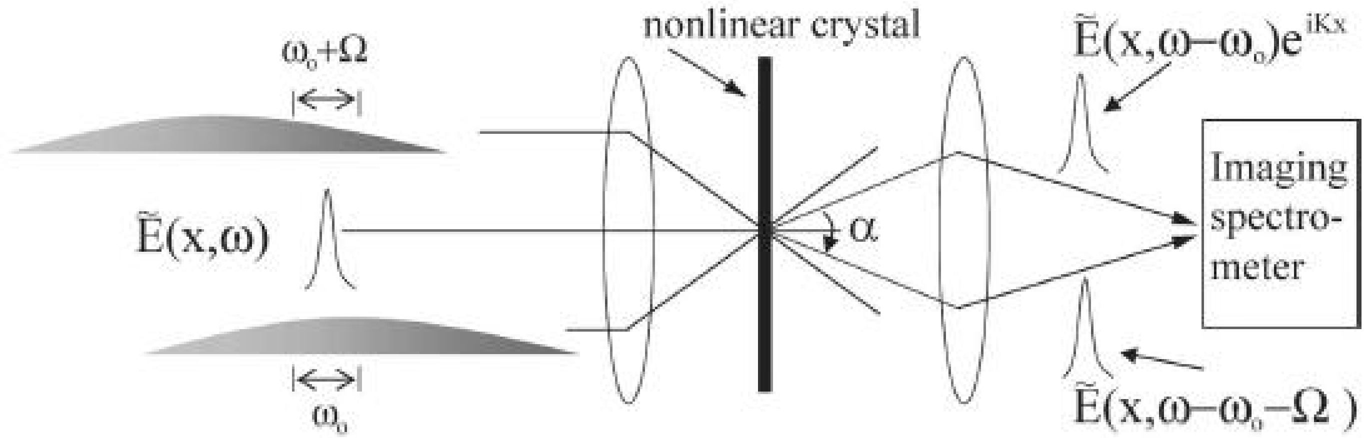
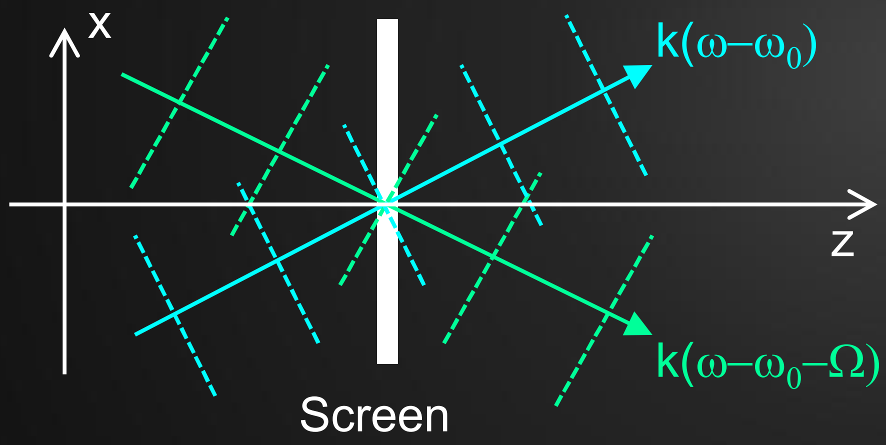


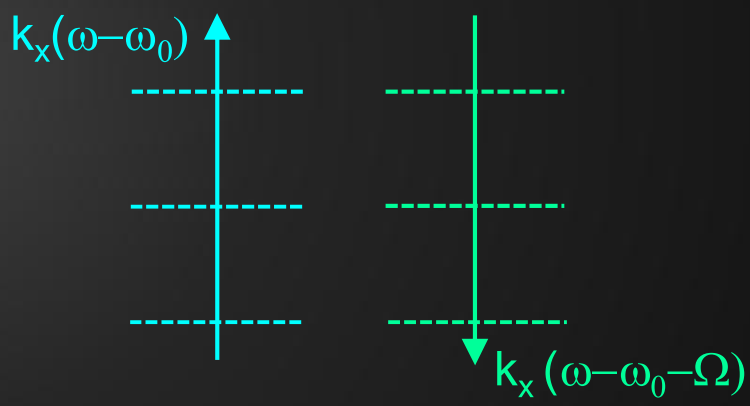
Fig. 1. Experimental setup for SEA-SPIDER. The unknown pulse, $\tilde{E}(x,\omega)$, and the two chirped ancillary pulses are focused into a nonlinear crystal. The unknown pulse upconverts with two different monochromatic frequencies, resulting in a relative spectral shear Ω between the upconverted replicas. The angle between the two ancillaries at the time of upconversion encodes a tilt between the two sheared pulses, resulting in spatial interference fringes when they are focused into an imaging spectrometer.

Kosik et al. Optics letters 30 (2005) 326-328.

Spatially encoded arrangement SPIDER

$$\tilde{S}(x,\omega) = |\tilde{E}(x,\omega-\omega_0)|^2 + |\tilde{E}(x,\omega-\omega_0-\Omega)|^2 + 2|\tilde{E}(x,\omega-\omega_0)|\,|\tilde{E}(x,\omega-\omega_0-\Omega)| \times \cos[\phi(x,\omega-\omega_0) - \phi(x,\omega-\omega_0-\Omega) + Kx], \quad (1)$$





$K = k_x(\omega-\omega_0) - k_x(\omega-\omega_0-\Omega)$

Kosik et al. Optics letters 30 (2005) 326-328.

Spatially encoded arrangement SPIDER

$$\begin{aligned}\tilde{S}(x,\omega) = {} & |\tilde{E}(x,\omega-\omega_0)|^2 + |\tilde{E}(x,\omega-\omega_0-\Omega)|^2 \\ & + 2|\tilde{E}(x,\omega-\omega_0)|\,|\tilde{E}(x,\omega-\omega_0-\Omega)| \\ & \times \cos[\phi(x,\omega-\omega_0) - \phi(x,\omega-\omega_0-\Omega) \\ & + Kx], \end{aligned} \tag{1}$$

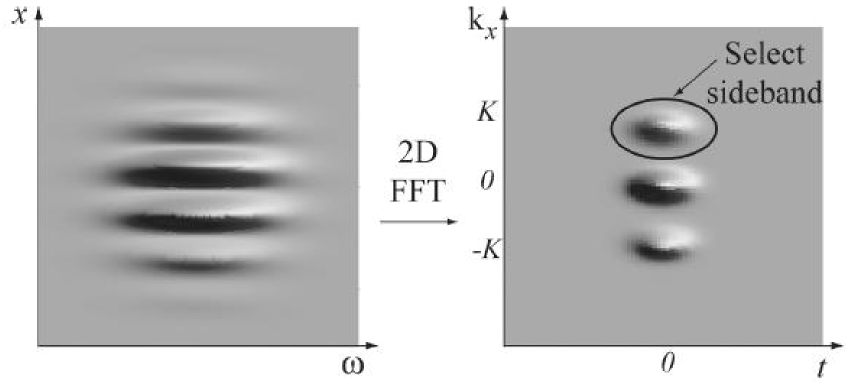


Fig. 2. First step in the SEA-SPIDER inversion algorithm. The 2-D interferogram, $\tilde{S}(x,\omega)$, is 2-D Fourier transformed, and one of the Fourier sidebands is selected for further analysis. This process separates the interference term from the rest of the signal. FFT, fast Fourier transform.

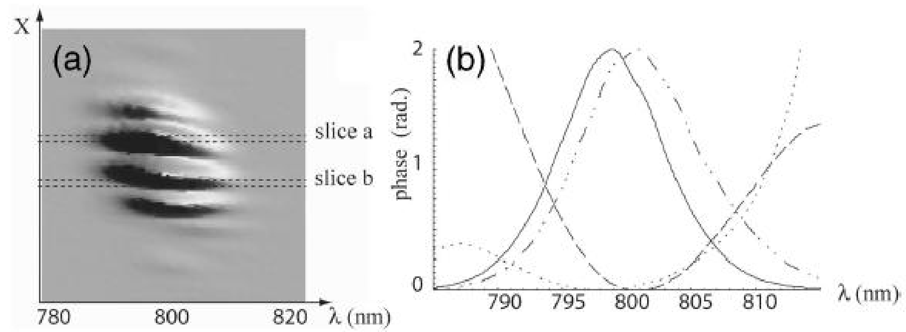


Fig. 3. (a) SEA-SPIDER interferogram of a spatially chirped pulse and (b) reconstructed fields for two different spatial slices. The spectral density and phase at spatial slice a are given by the solid and dotted curves, respectively, while those for spatial slice b are given by the dashed–dotted and dashed curves, respectively.

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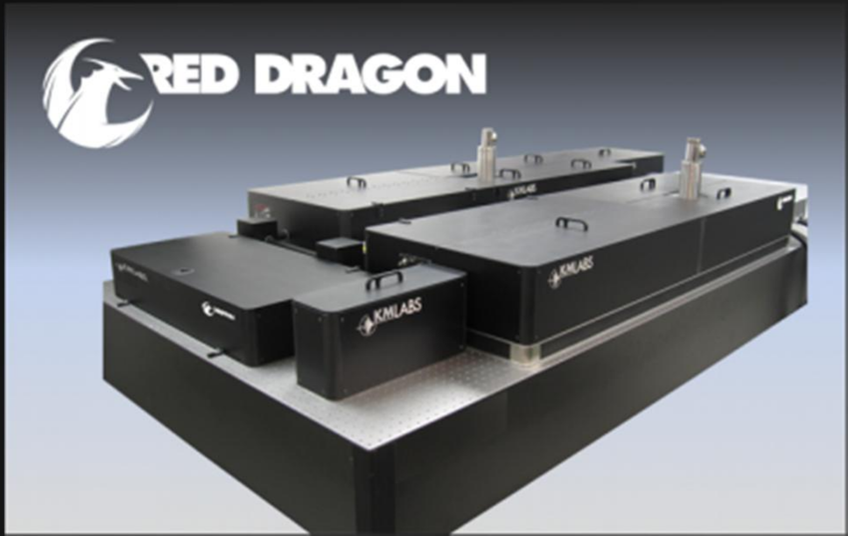
Spatially encoded arrangement SPIDER



RedDragon – KMLabs (USA)
Ti:Sa amp, 1 kHz, 20 mJ, 25 fs.
(in the paper, 8 mJ, 28 fs pulse input for pumping OPA)

HE-TOPAS
Signal: 1.1 – 1.55 μm
Idler: 1.7 – 2.2 μm
Maximum energy (sig+idl) ~ 1.8 mJ
Output duration (26 – 70 fs)

Spatially encoded arrangement SPIDER

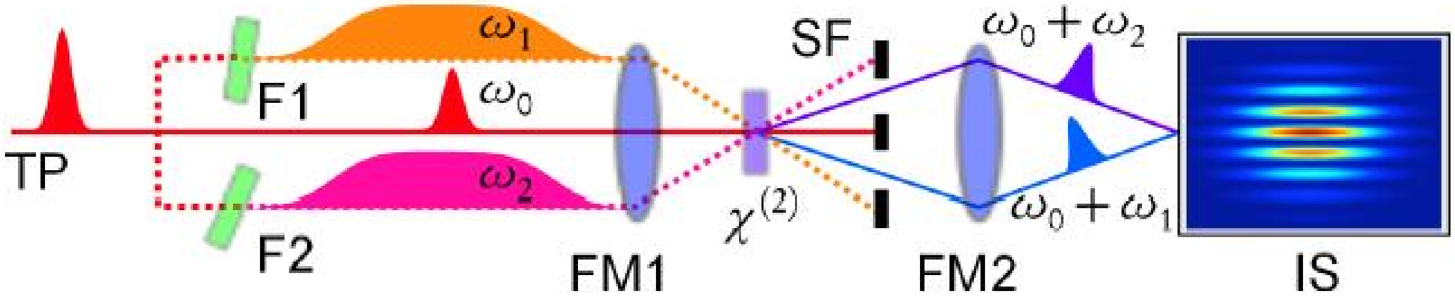


Fig. 1. Concept of the mid-IR SEA-F-SPIDER apparatus. Please refer to the text for a detailed explanation.

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$$\begin{aligned} S(y,\omega) = & |E(y,\omega)|^2 + |E(y,\omega-\Omega)|^2 + \\ & 2|E(y,\omega)||E(y,\omega-\Omega)| \times \\ & \cos[\phi(y,\omega) - \phi(y,\omega-\Omega) + \Delta k y], \end{aligned} \quad (1)$$

Spatially encoded arrangement SPIDER

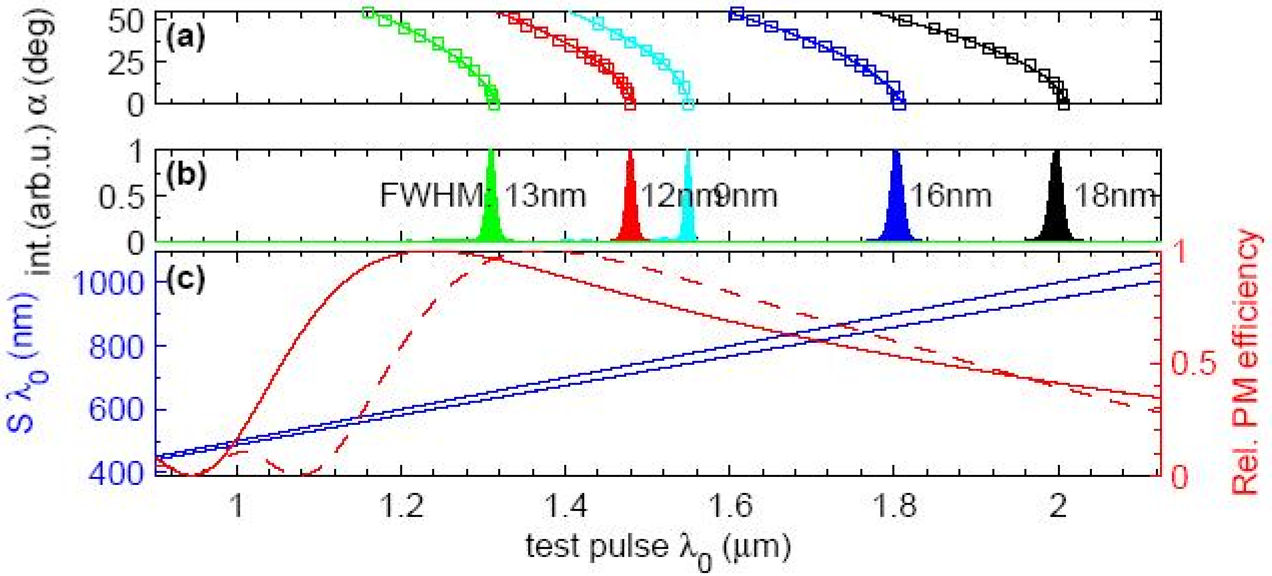

Fig. 2. Ancilla filters tuning range: (a) transmitted beam center wavelength as function of filter angle, (b) Transmission spectra for normal incidence. (c) SPIDER signal wavelength (range indicated by blue lines); phasematching efficiency (50 μm BBO red solid line, 100 μm BBO red dashed line). Details in text.

Spatially encoded arrangement SPIDER

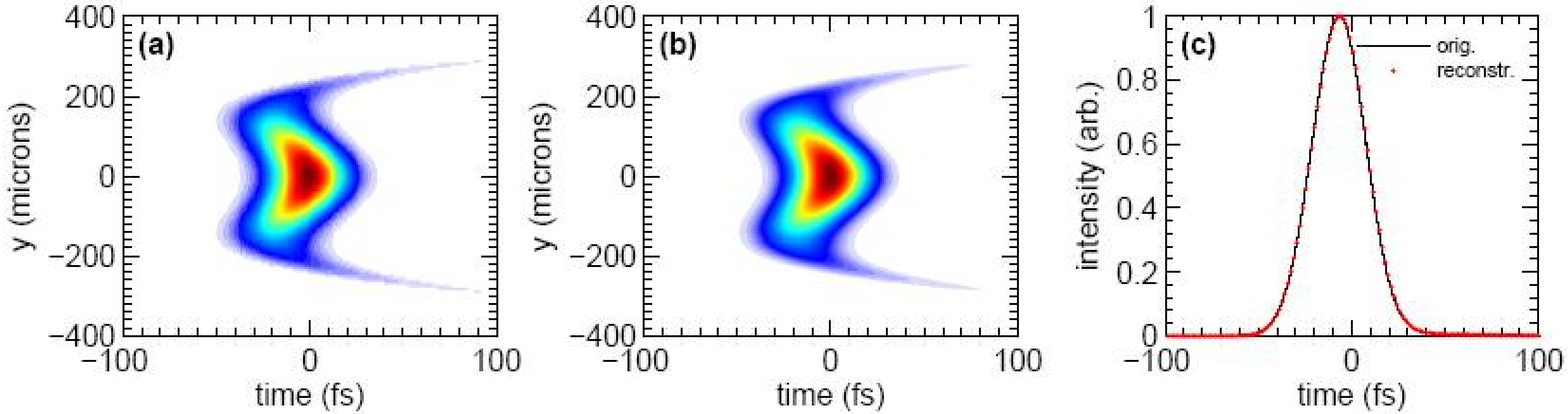

Fig. 3. Spatio-temporal reconstruction with SEA-SPIDER. (a) simulated spatio-temporal intensity $|E(y,t)|^2$, (b) SEA-F-SPIDER reconstruction, (c) 1D marginals. For details please refer to the text.

Spatially encoded arrangement SPIDER

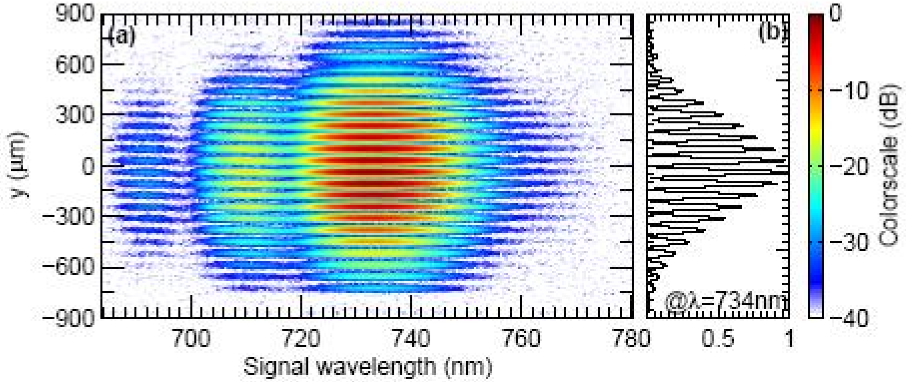

Fig. 4. SEA-F-SPIDER data trace for a 1450 nm test-pulse. 40 dB colour scale. 40 laser shots integration time

Spatially encoded arrangement SPIDER

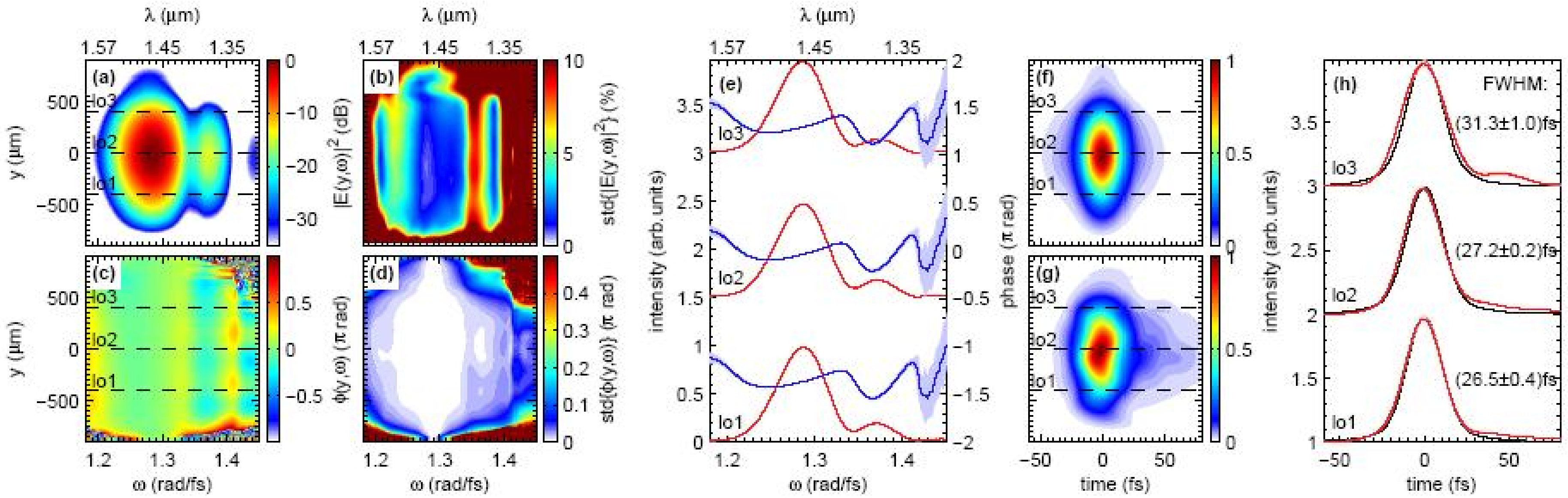

Fig. 5. Spatially resolved pulse reconstruction for a 1.4 μm pulse. (a) to (e) spectral domain, (f) to (h) temporal domain. (a) Mean of 25 spectra $|E(y,\omega)|^2$ (40 dB colour scale). (b) Relative standard deviation of $|E(y,\omega)|^2$ in percent. (c) Mean of spectral phase $\langle\varphi(y,\omega)\rangle$. (d) Standard deviation of phase $\sigma[\varphi(y,\omega)]$. (e) Lineouts of the spectral intensity and phase at the y_i positions indicated in (a) and (c) by the black dashed lines. The shaded area represents the $\pm 1\sigma$ interval. (f) Fourier-limited temporal intensity $|E(y,t)|^2$ (lin. colour scale). (g) Temporal intensity $|E(y,t)|^2$ (lin. colour scale, same y-axis as (a) to (d)). (h) $|E(y_i,t)|^2$ for the spatial positions y_i indicated by the dashed black horizontal lines in (a), (c), and (f)/(g). Black is the Fourier-limited pulse. The red curve is the actual pulse.

Spatially encoded arrangement SPIDER

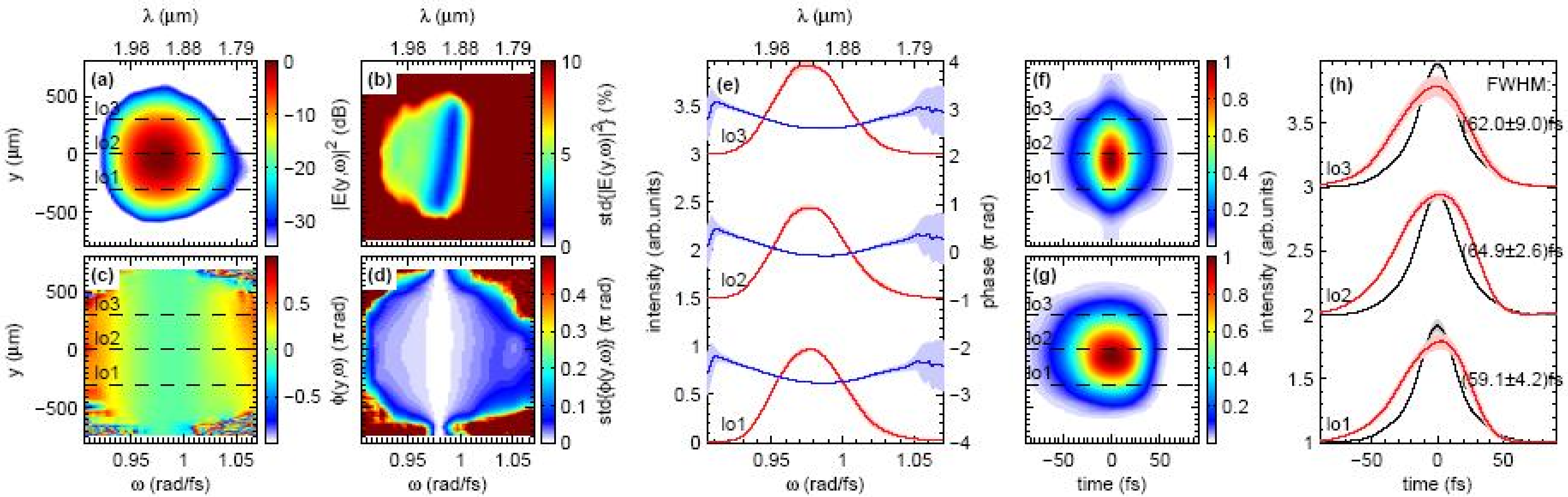

Fig. 6. Spatially resolved pulse reconstruction for a 1.9 μm pulse. For a description of the subplots see the caption of Fig. 5.

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4. Conclusion

In conclusion we have demonstrated the spatially resolved characterization of ultrashort mid-IR pulses for the first time. Our device can reconstruct the pulse field (spectrum and phase) from a data trace with all information contained in principle in a single shot data trace. It is flexible in terms of test pulse wavelength and allows the extraction of spatial information and at the same time the recording of statistics of the laser source fluctuations. We envisage such spatially revolved characterization to be vital for ultrashort and few-cycle mid-IR pulses and it will greatly aid in the compression and optimization of the source performance.

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