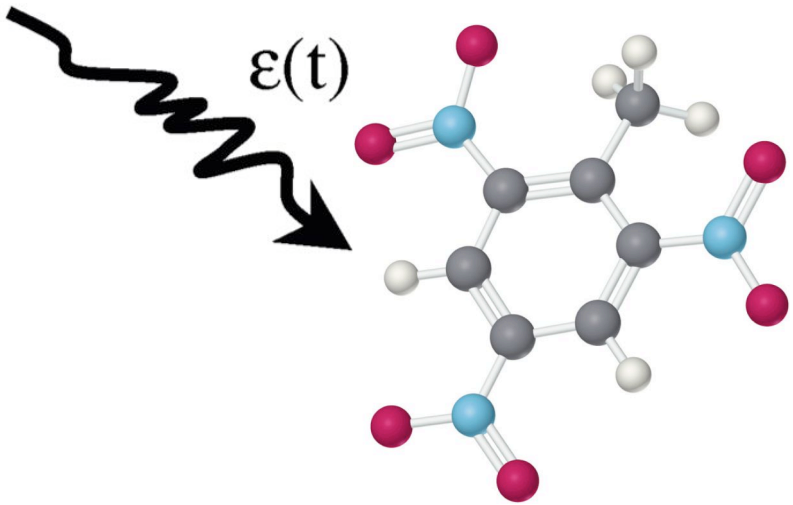
Effects on Safety Eyewear by Shaped Ultra-Short Laser Pulses



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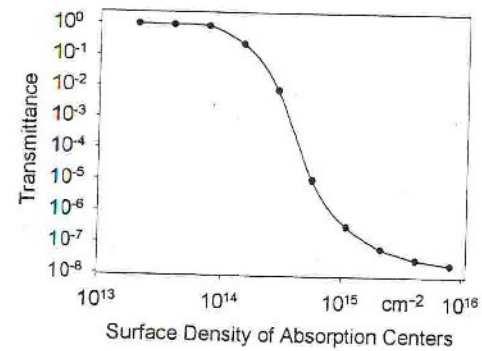
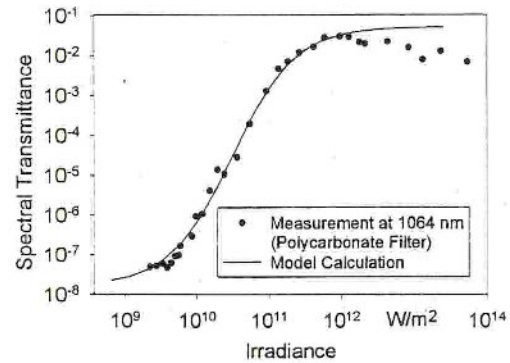
Outline

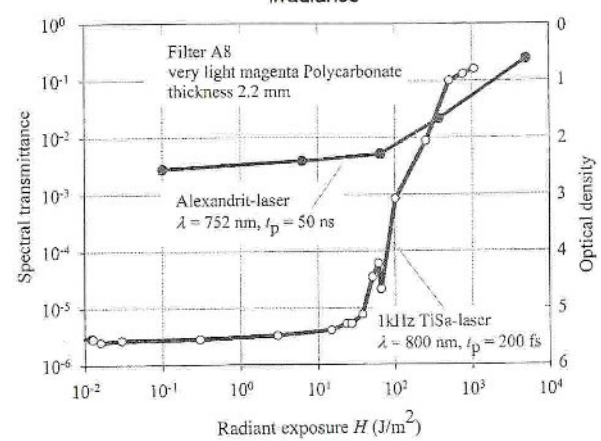
- History and background
- Why should we care?
- Pulse shaping technology
  - Laser sources
  - AOM versus SLM
- Closed loop optimization
- Studied eyewear
- Results

History and background

- Previous studies of induced transmittance
  - Shirmacher et al. Physikalisch-Technische Bundesanstalt, Braunschweig
    - 15 ns pulses:
      - Showed induced transmission at irradiances > 10^{11} W/cm^2
      - OD drops five orders of magnitude for irradiance increase from 10^{11} to 10^{12} W/cm^2
    - 250 fs pulses:
      - Showed induced transmission at irradiances > 4 x 10^9 W/cm^2
      - OD drops six orders of magnitude for irradiance increase from 4 x 10^9 to 4 x 10^{11} W/cm^2
    - The non-linear induced transmission could be explained by saturated single photon absorption

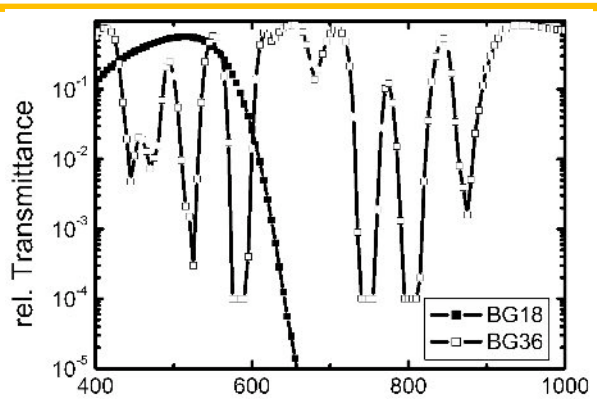


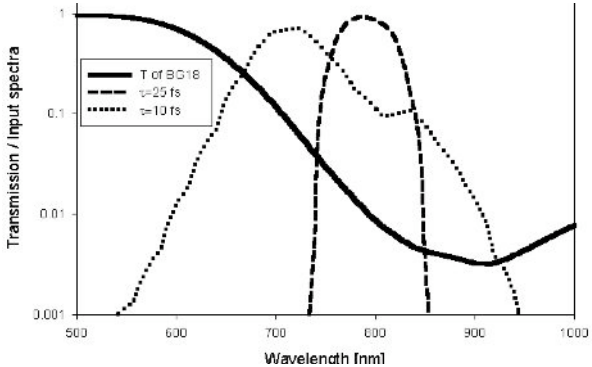


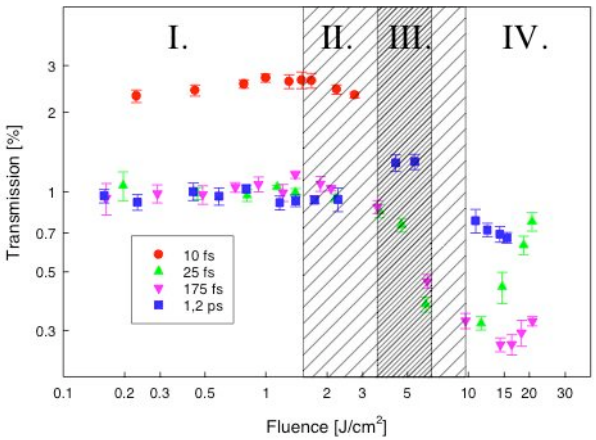


History and background - 2

- Spielmann et al. TU-Wien, Austria
  - Compared ps to fs pulses in plastic and glass absorptive and dielectric reflective eyewear
    - Found for pulses < 1 ps the transmission does not increase with fluence up to the damage threshold
    - The 1.2 ps pulse produced a small amount of induced transmission above 3 J/cm^2





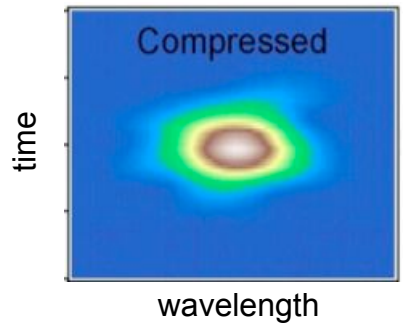


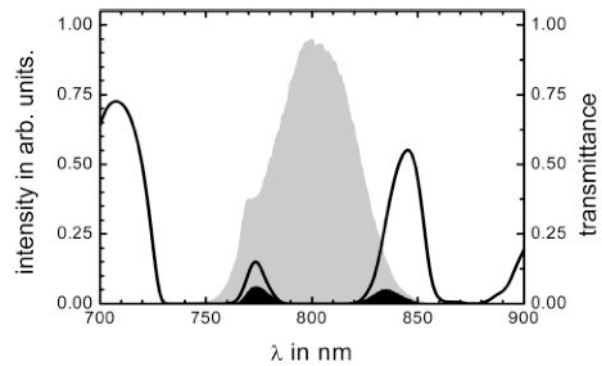
Why should we care?

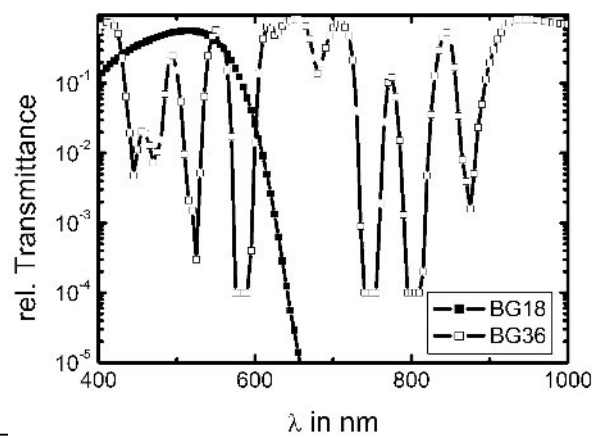
- Previous lasers usually "transform limited"
  - Pulse length and wavelength bandwidth related by a Fourier transform:

$$p = \Delta\tau^{\mathrm{I}}_{1/2}\Delta\nu^{\mathrm{I}}_{1/2}$$

- Broad bandwidth of ultrashort pulses presents some problems
  - Spielmann et al. studied some of these phenomena
    - Gray area is laser bandwidth for 30 fs pulse
    - Black line is BG36 transmission spectrum
    - Black area is transmitted laser
    - BG36 blocks all of 800 nm 100 fs pulse
    - BG18 blocks all of the 30 fs pulse
- Luminous transmission of BG18 is quite low compared to BG36…



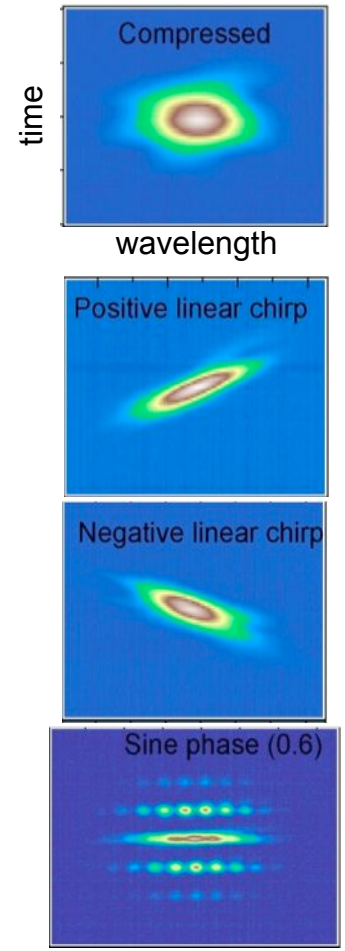




Why do this study?

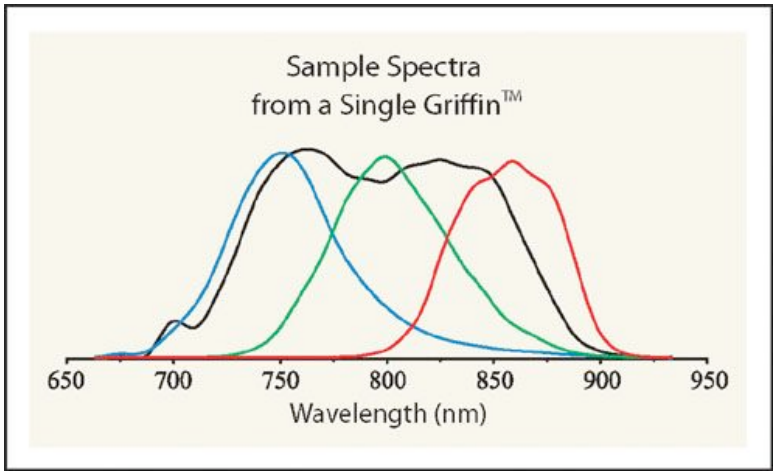
- Recent advances in ultrafast pulse manipulation
  - Allow shaping the spectral phase
    - Chirping - stretches pulse and changes frequency with time
    - Rapid impulses - multiple very fast pulses within a long (few ps) envelope
    - Arbitrary pulse shapes

- The questions we asked were:
  - How does standard laser eyewear respond to such arbitrary pulses?
  - Can a pulse shape be devised that dramatically increases a given filter's transmission?



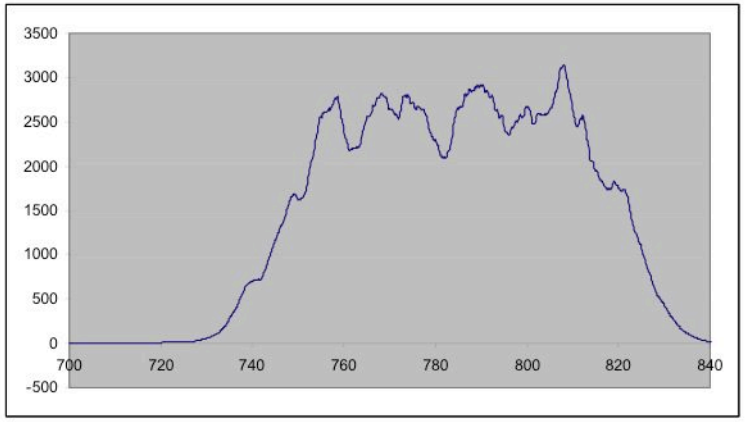
Pulse shaping technology

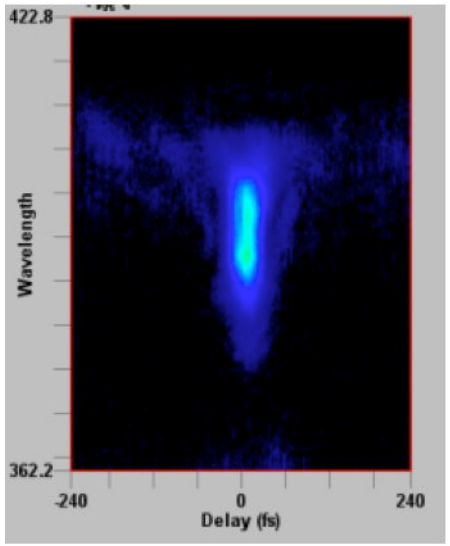
Laser sources



Laser amplifiers

Amplifier output spectrum 1kHz, 12W
FWHM: ~75 nm

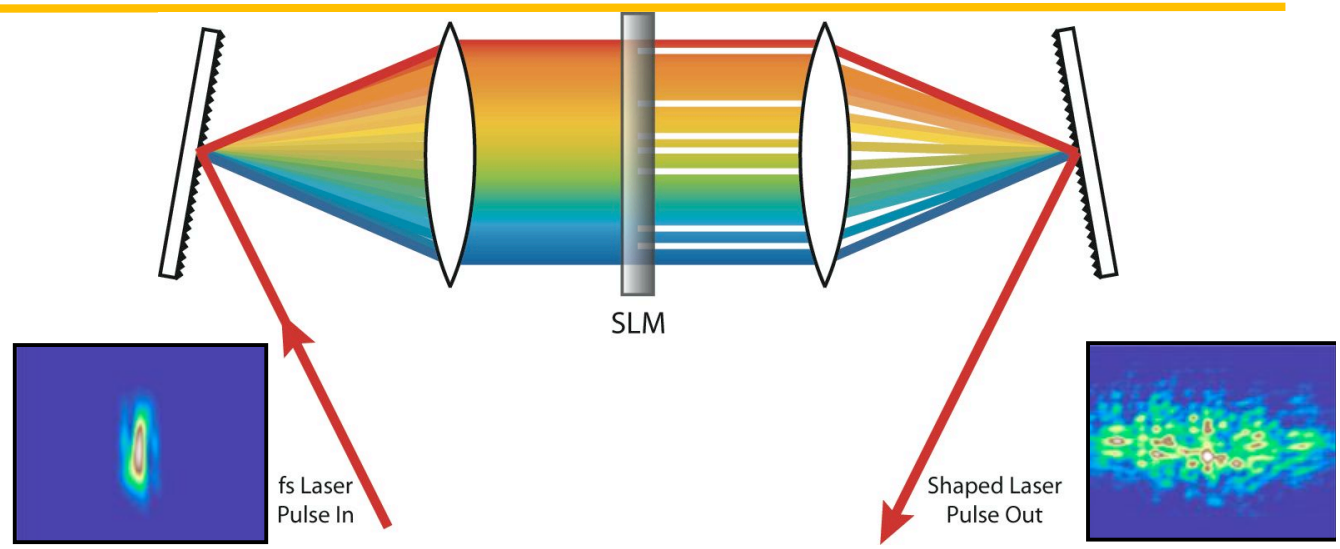




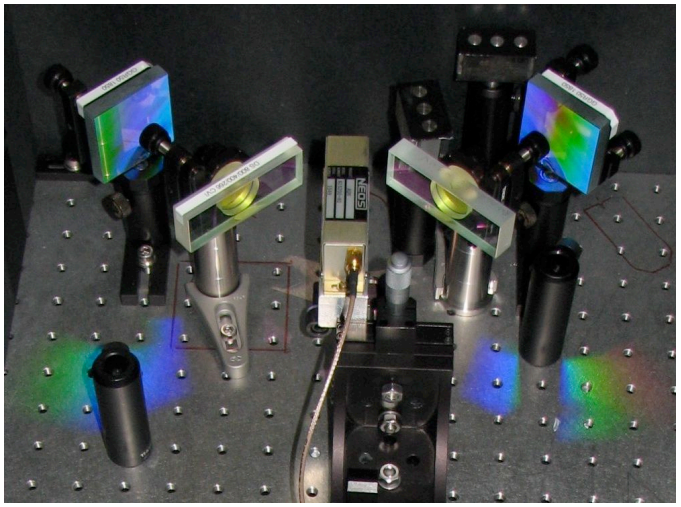
Pulse width
25 fs
Energy
12 mJ
Rep rate
1 kHz

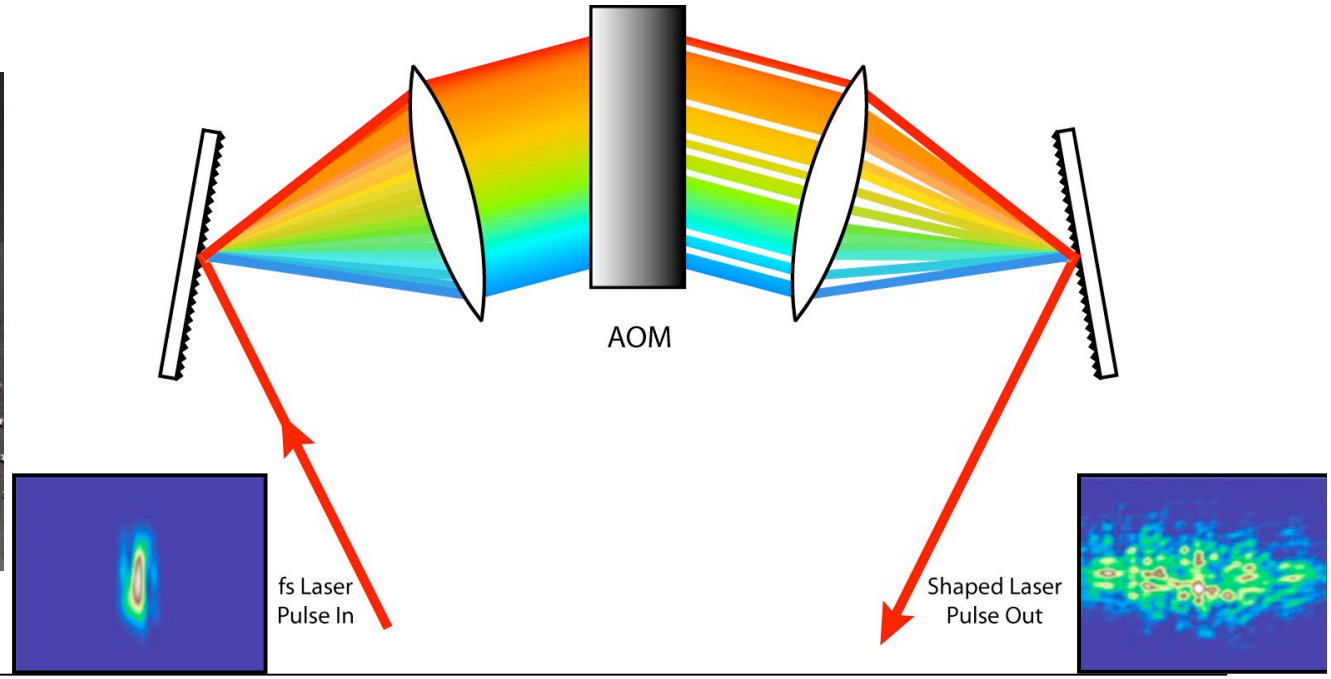
Pulse shaping technology

SLM based



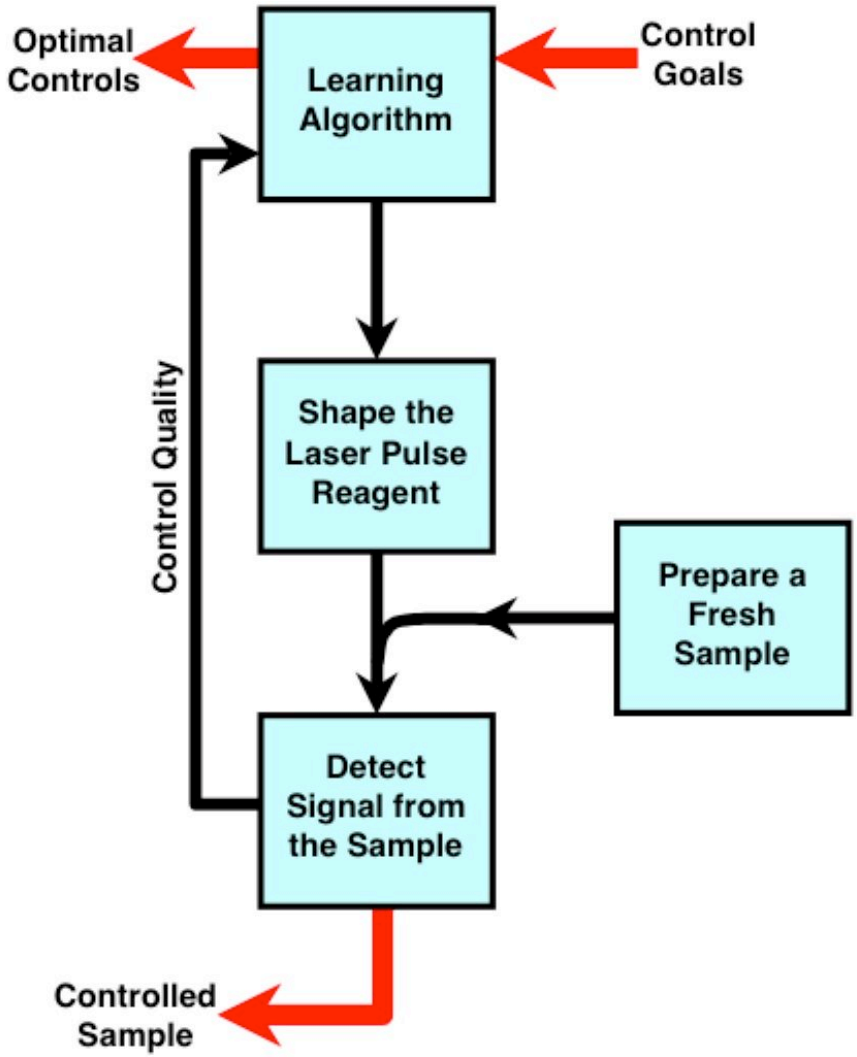
AOM based





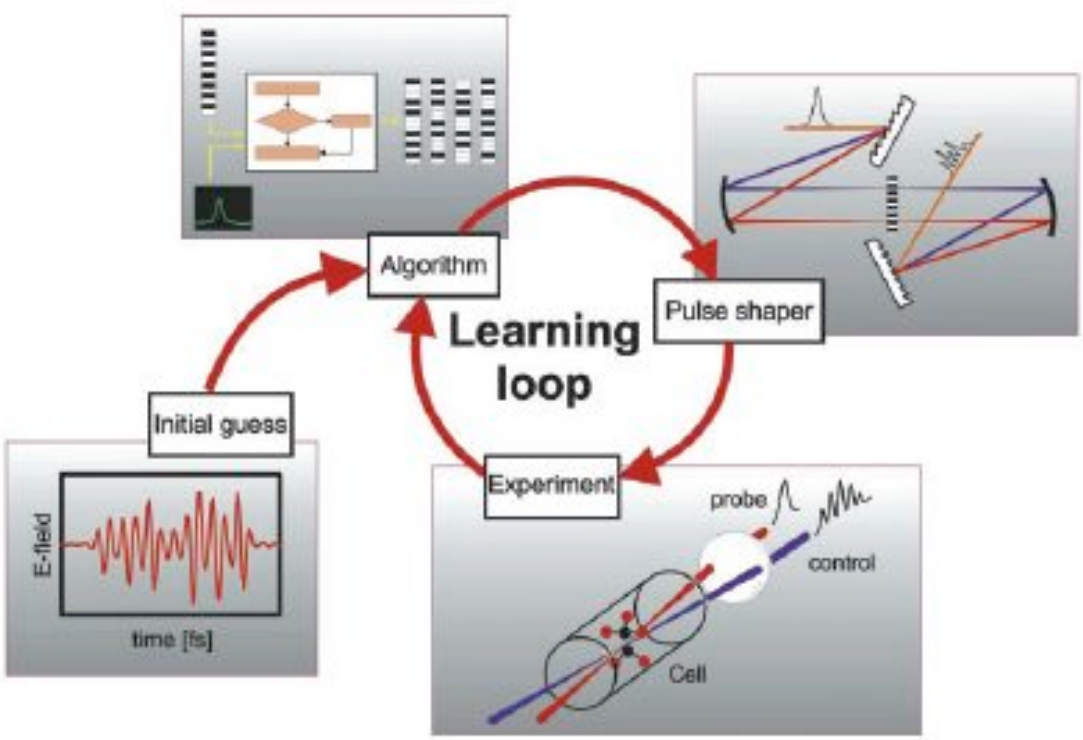
Closed loop optimization

- Closed loop adaptive machine using tailored laser pulses as photonic reagents
  - A shaped ultrashort laser pulse excites the sample
  - A suitable detection scheme measures the effect of the particular pulse on the sample (the fitness function)
  - The signal is fed back to the learning algorithm
  - The learning algorithm proposes a new excitation pulse shape
  - The process repeats to maximize the fitness function
  - Adaptive learning is fast and efficient
    - Minutes to hours
  - Process designed in 1992
  - First demonstrations in 1997
  - 70 labs worldwide have capability and are applying to a wide variety of problems

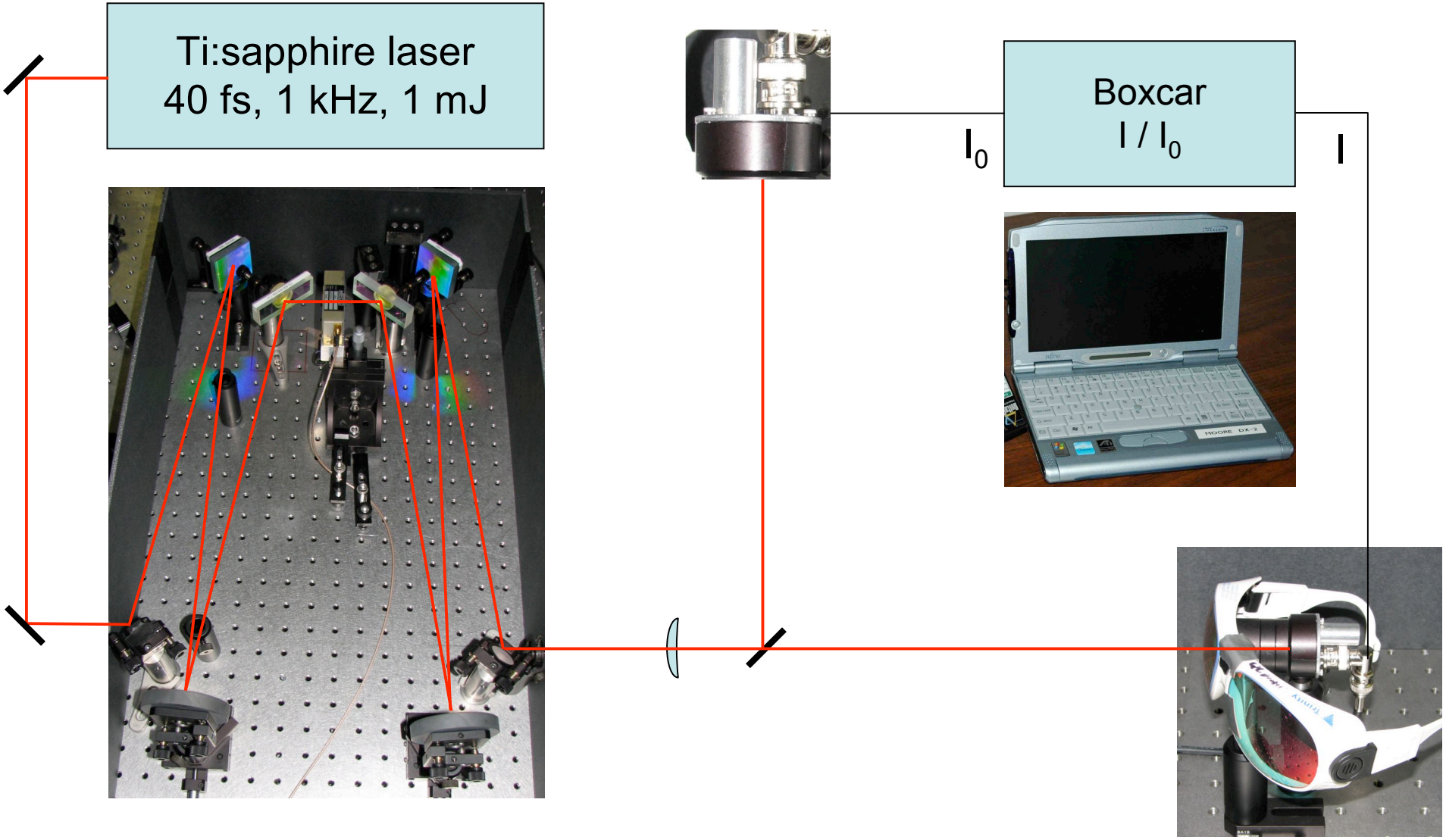


Optimization in practice

- Guess an initial pulse shape
- Measure the shape
- Connect pulse shaper to learning algorithm
- Provide a measure of success (fitness) via “the experiment”
- Search to find optimal pulse shape for objective
  - Adaptive learning (Genetic, simulated annealing, differential evolution
  - Local searches (downhill simplex, conjugate gradient)



Experiment schematic



Studied eyewear

Reflective dielectric

- Trinity
- Model 1128
  - > 6 OD @ 700-825

- Trinity
- Model 1117
  - > 7 OD @ 800-1600

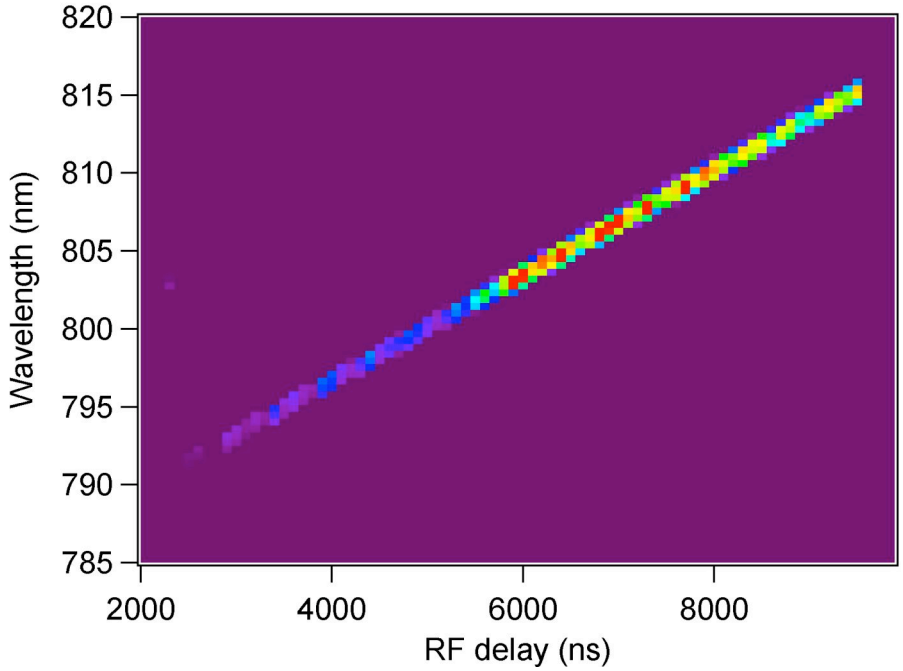
Absorptive plastic

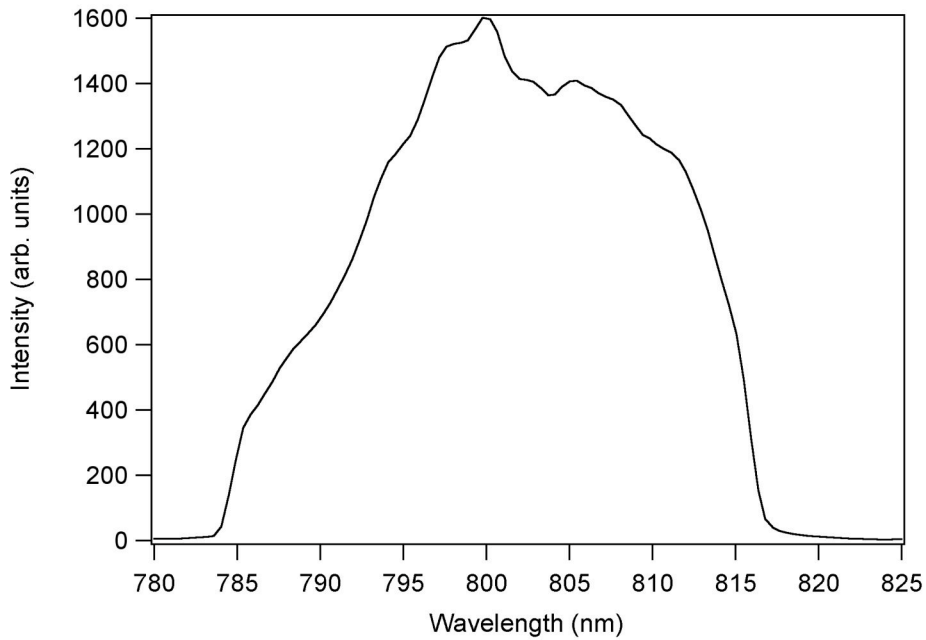
- Lasergard
- Argon/Nd:YAG
  - > 5 OD @ 800 nm

- UVEX
- ALEX
  - > 6 OD @ 766-800

Calibration

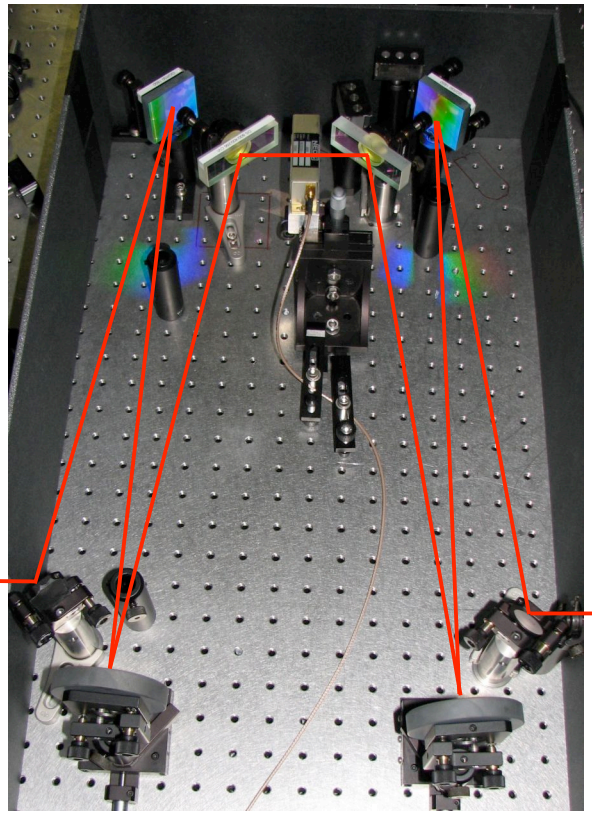
- Calibration of pulse shaper
  - Calibrate RF pulse delay versus wavelength passed through AOM
  - Relates AOM pixel to affected wavelength in laser pulse





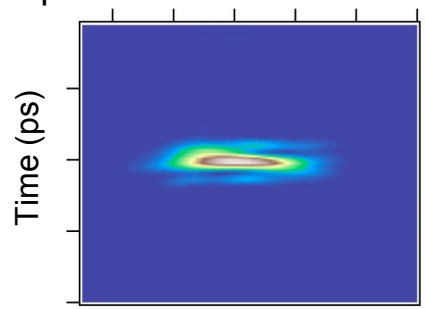
Measuring the pulse shape

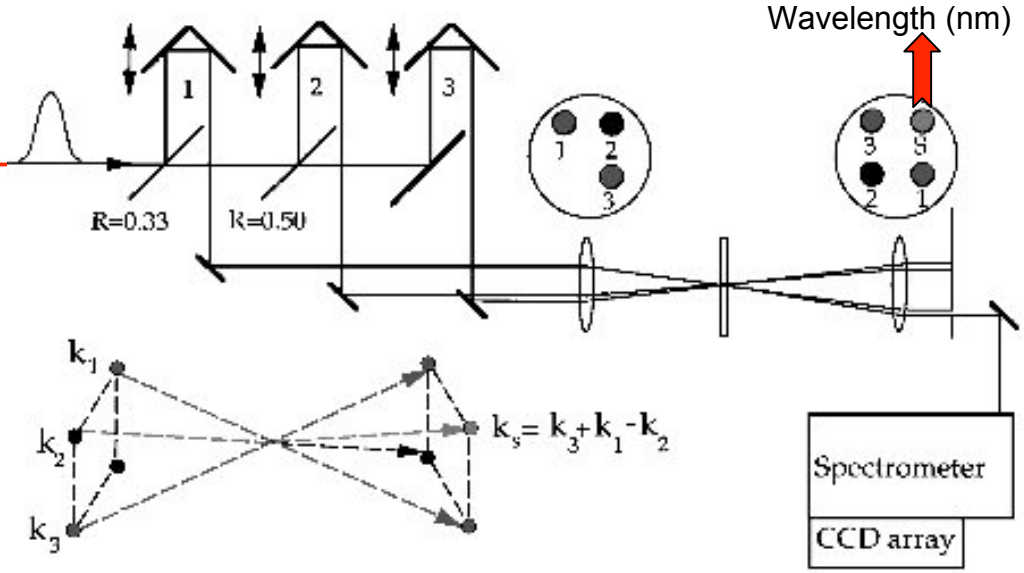
Ti:sapphire laser
40 fs, 1 kHz, 1 mJ



Transient-grating frequency resolved optical gating
TG-FROG

- Split pulse into three beams
- Generate transient grating in fused silica (X3)
- Probe temporally and spectrally resolved transient grating
  - Four wave mixing diffracted output





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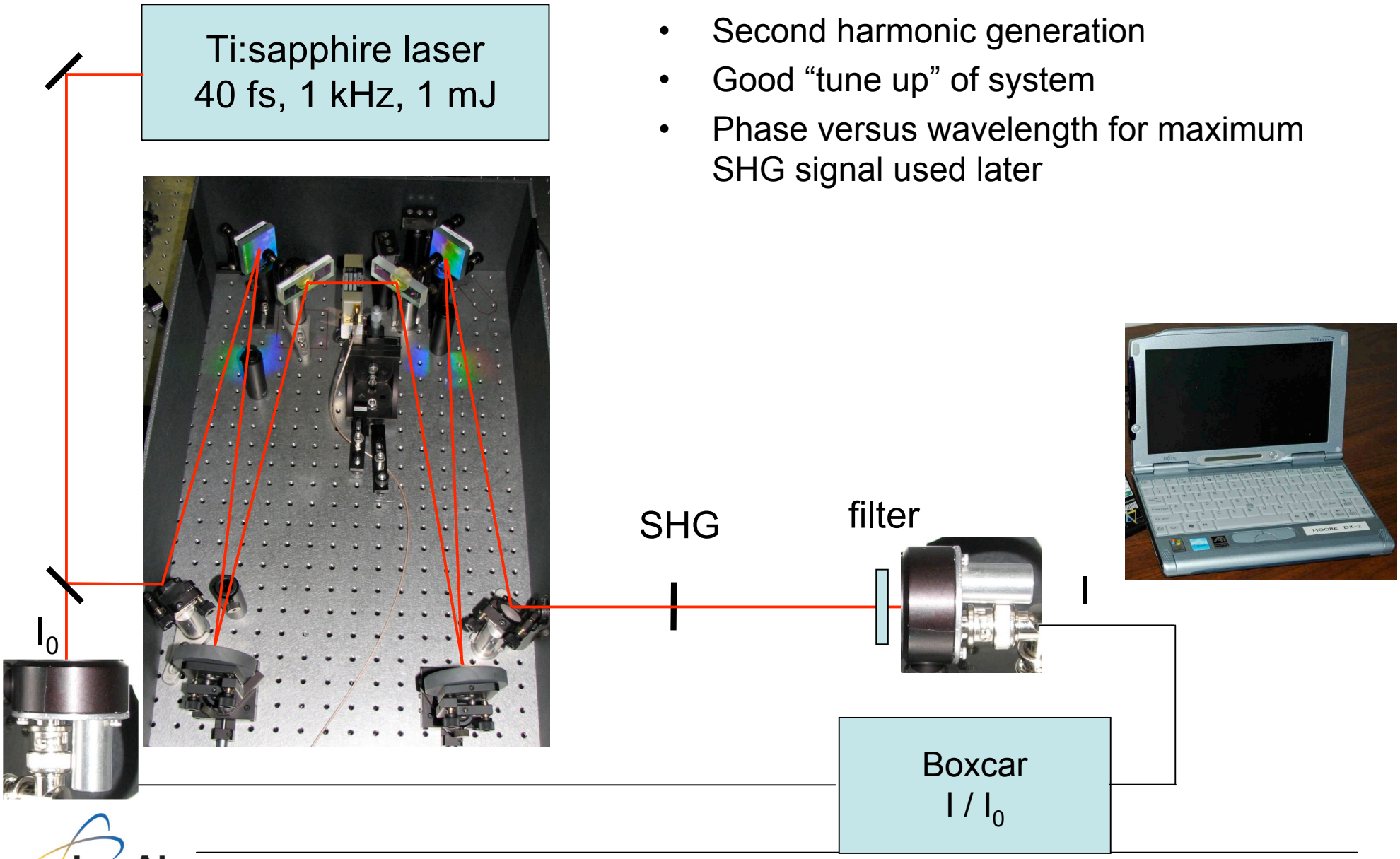
EST. 1943

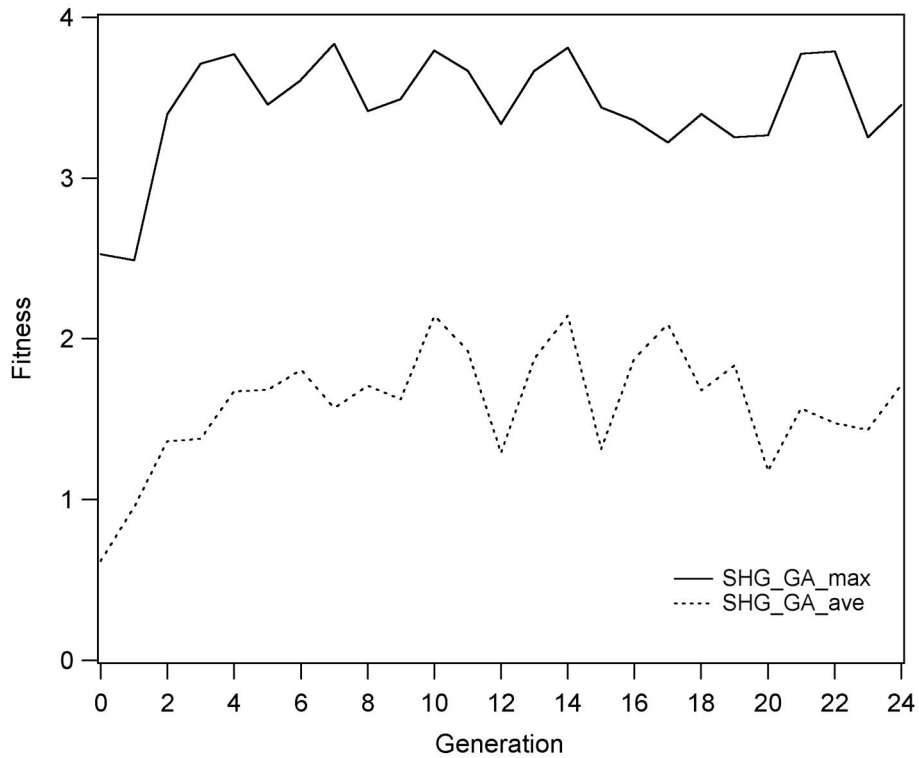
Perform test on a known

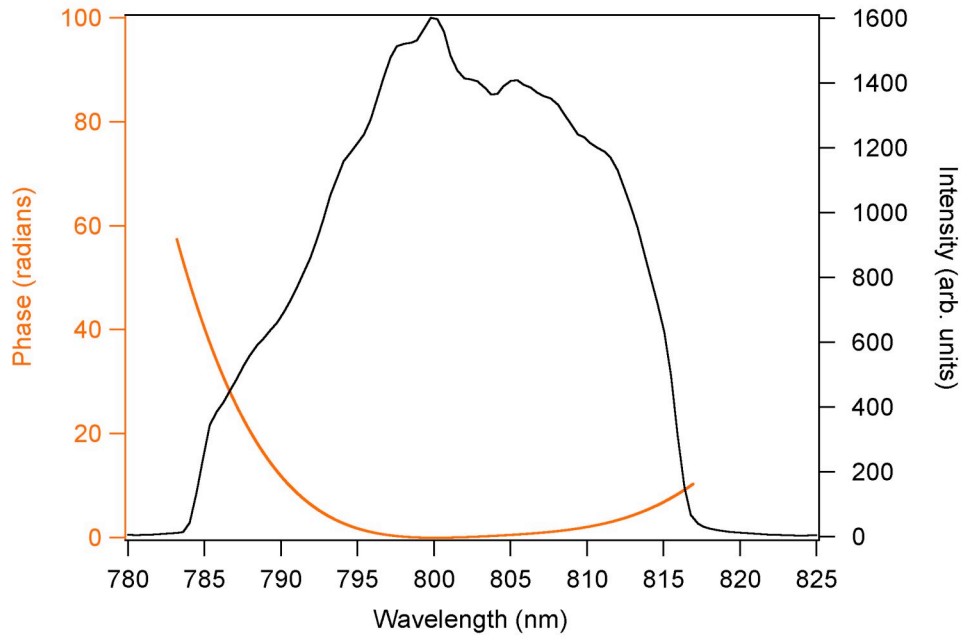


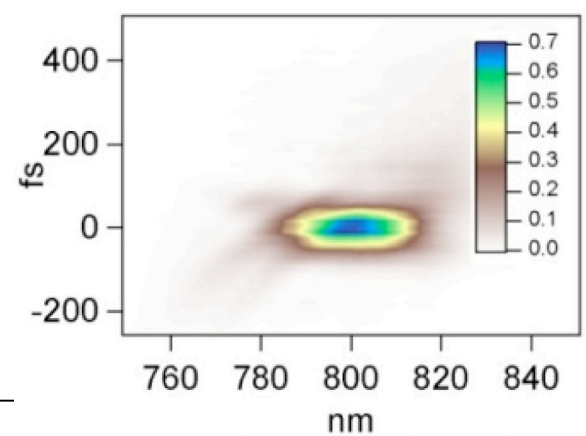
- Second harmonic generation
- Good “tune up” of system
- Phase versus wavelength for maximum SHG signal used later

SHG results

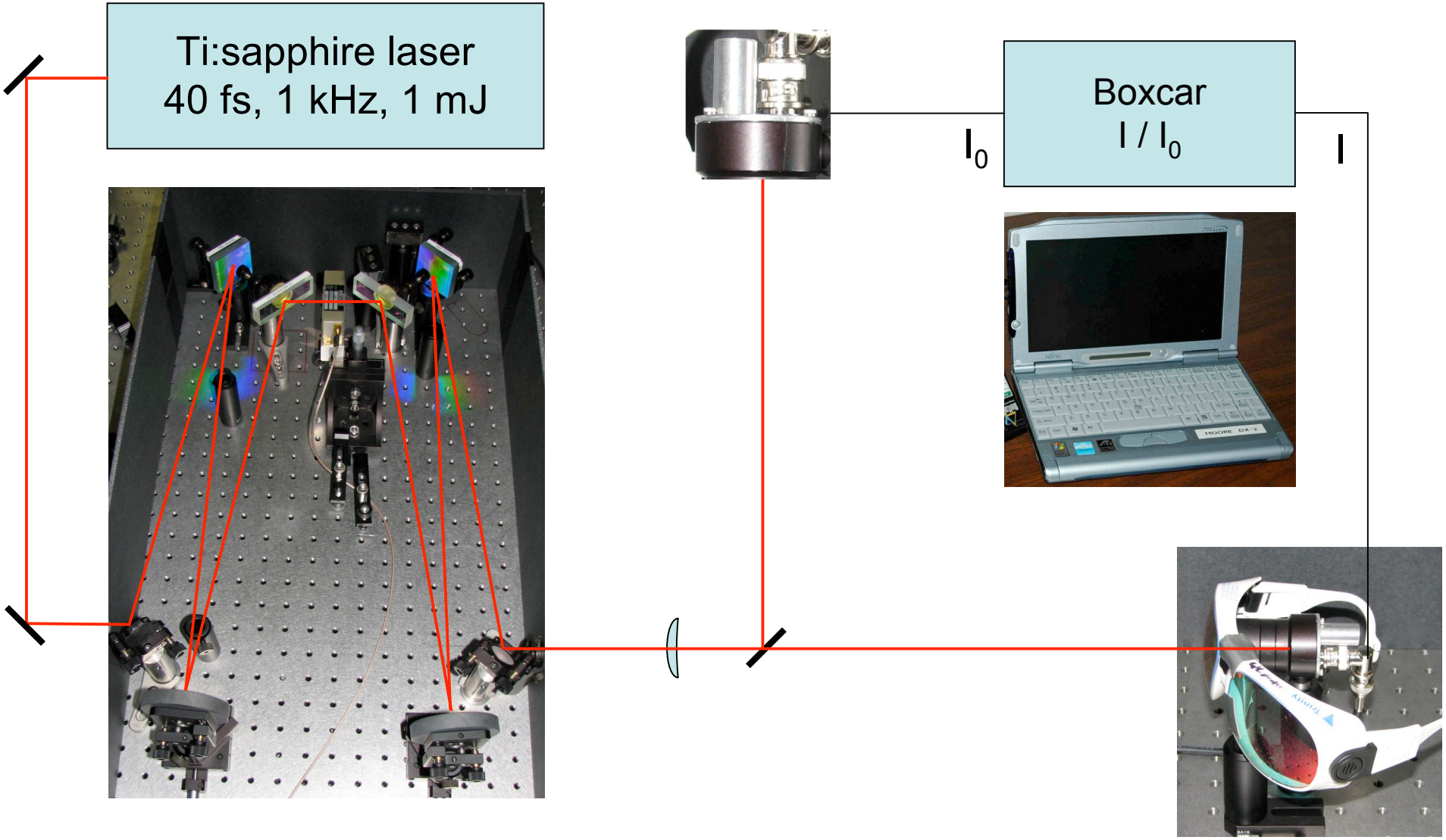
- Started from “hand maximized” SHG signal
- Phase versus wavelength for maximum SHG signal used later





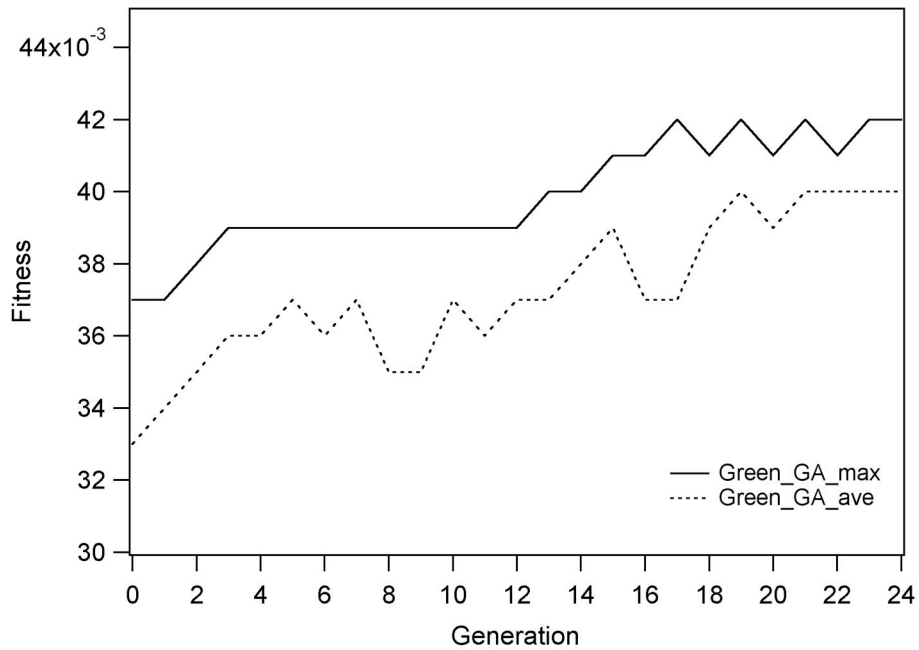


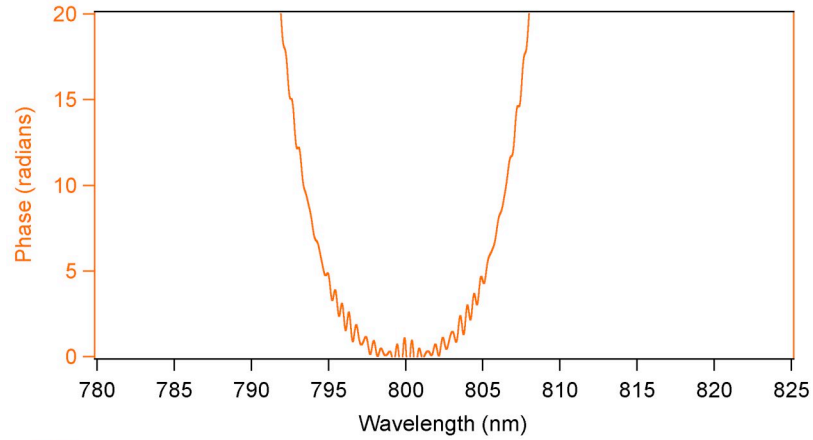
Experiment schematic



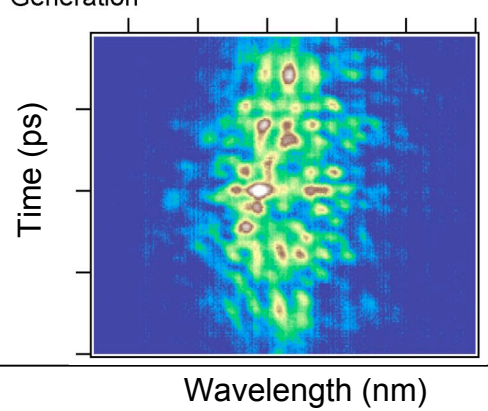
Green Glasses - Genetic Algorithm

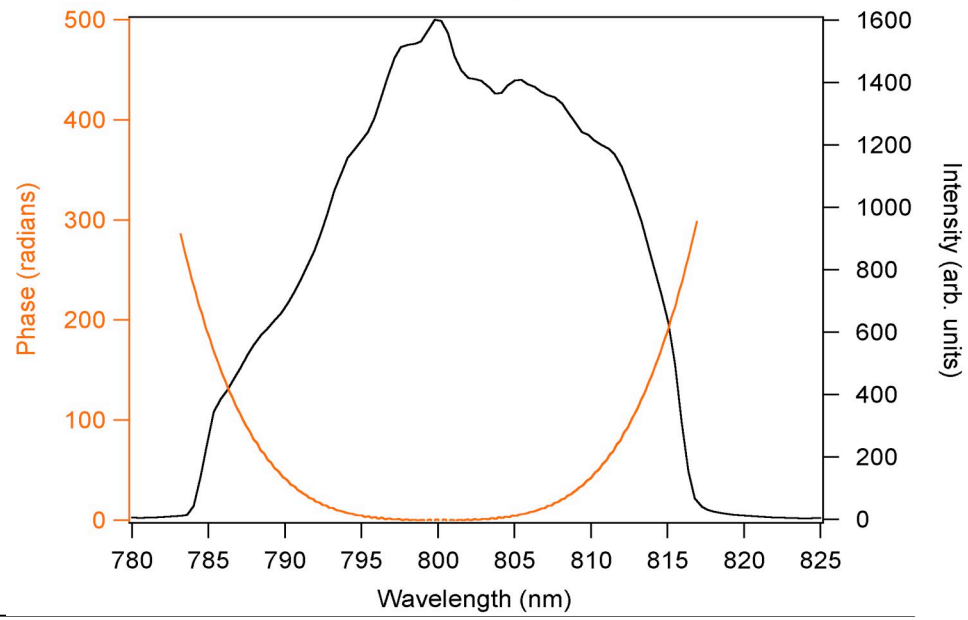
- Lasergard Argon/Nd:YAG
- Phase versus wavelength for maximum SHG signal subtracted from optimal phase after GA





FROG of
Best shape

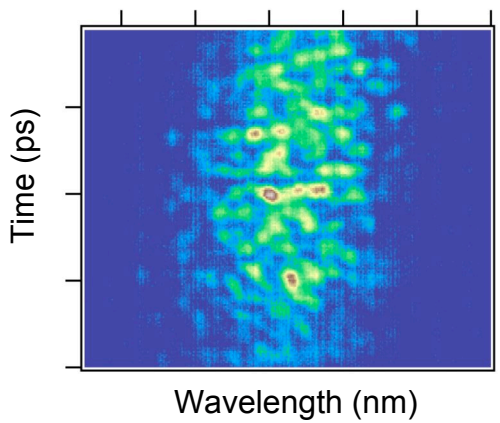


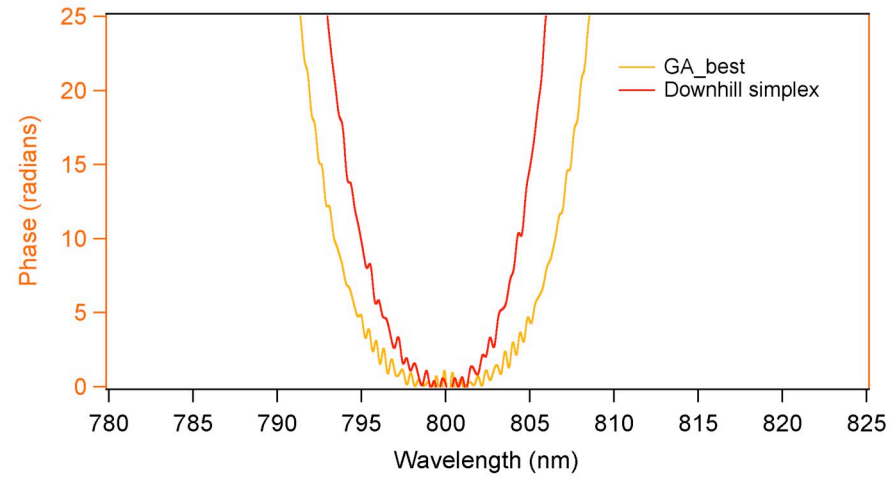


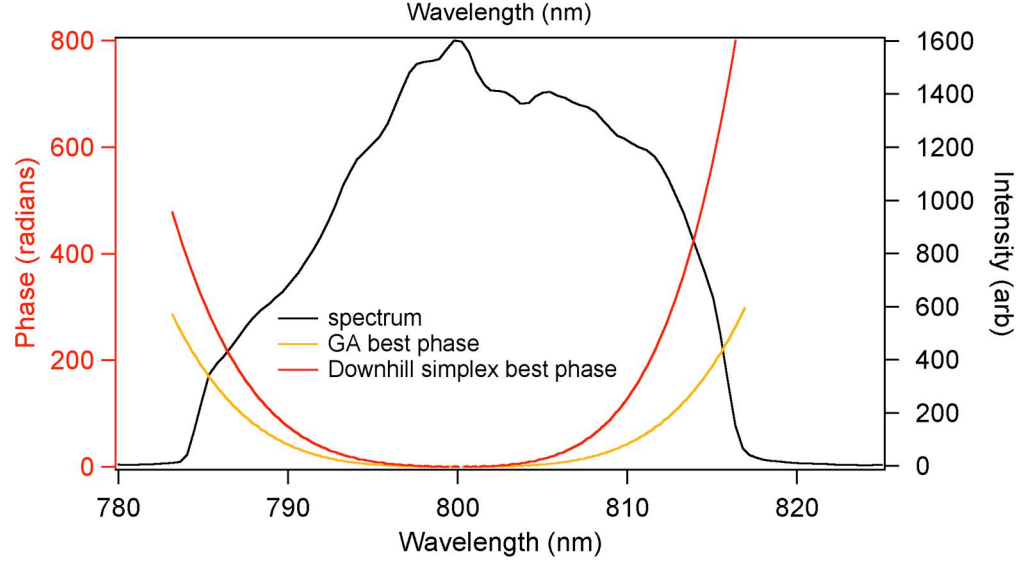
Green Glasses - Downhill Simplex

- Optimized using Downhill Simplex local search
- Phase versus wavelength for maximum SHG signal subtracted from optimal phase after Downhill Simplex
- Achieved Fitness 0.45 at end
  = 2 x starting fitness

FROG of
Best shape







Preliminary results

Reflective dielectric

- No increase
- Signal / noise too low?

- 50 % transmission increase
- Same at
  - 0.15 mJ/cm2
  - 0.45 mJ/cm2

Absorptive plastic

- 100% transmission increase at 0.45 mJ/cm^2
- 65% transmission increase at 0.15 mJ/cm^2

- No increase
- Signal / noise too low?

Next steps

- For these tested laser safety glasses:
- The greatest increase in transmission that could be achieved was x 2
  - for the investigated intensities / fluences
  - Not a safety concern…
- However, the investigated intensities were only ~ 1% of the damage threshold
- Need to repeat this study at 10 to 100 times higher intensities
  - The required rebuilding of the pulse shaper is underway
  - Stay tuned for the conclusion about whether there are safety concerns…