

DAZSCOPE: a Shaper Assisted Pulse Optimization Technique

Nicolas Forget

FASTLITE, Bat 403, Ecole Polytechnique, 91128 Palaiseau, France

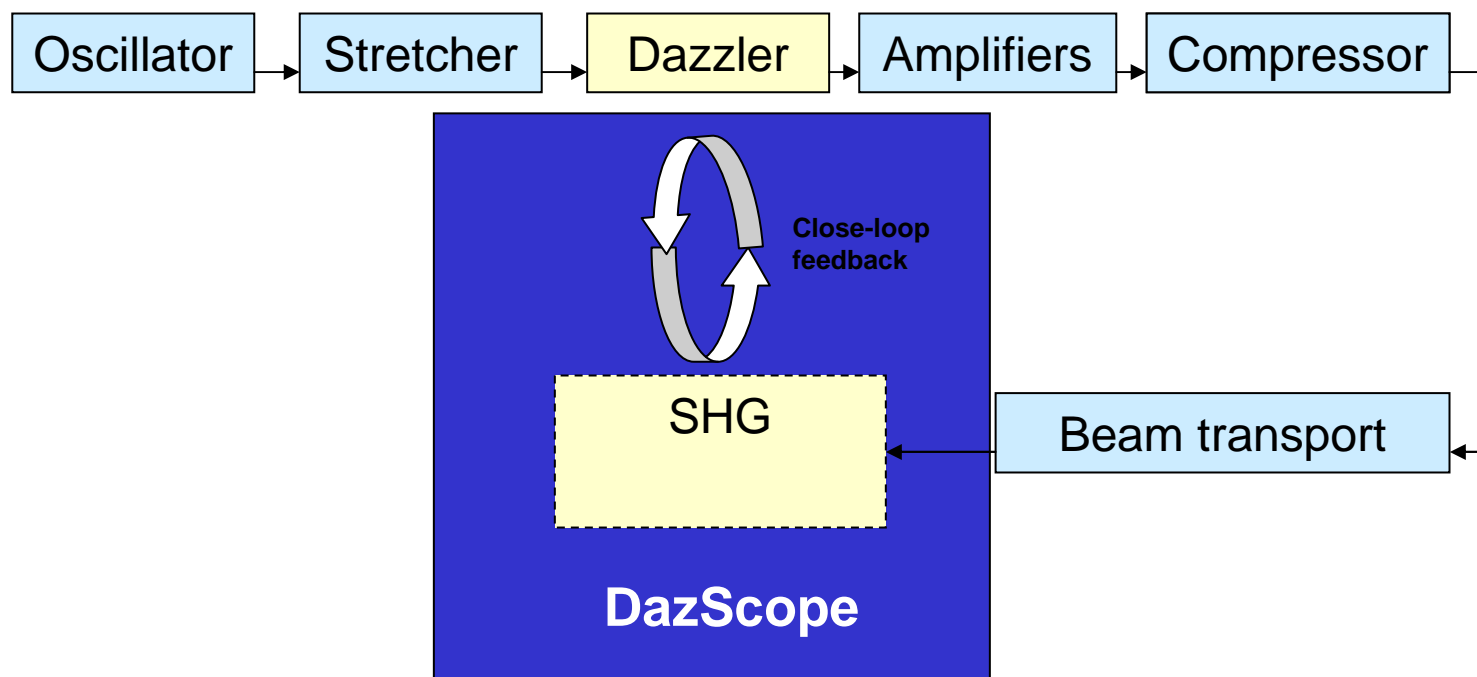
FASTLITE

ULTRAFAST SCIENTIFIC INSTRUMENTATION

Breakthroughs in Ultrafast Laser Technology

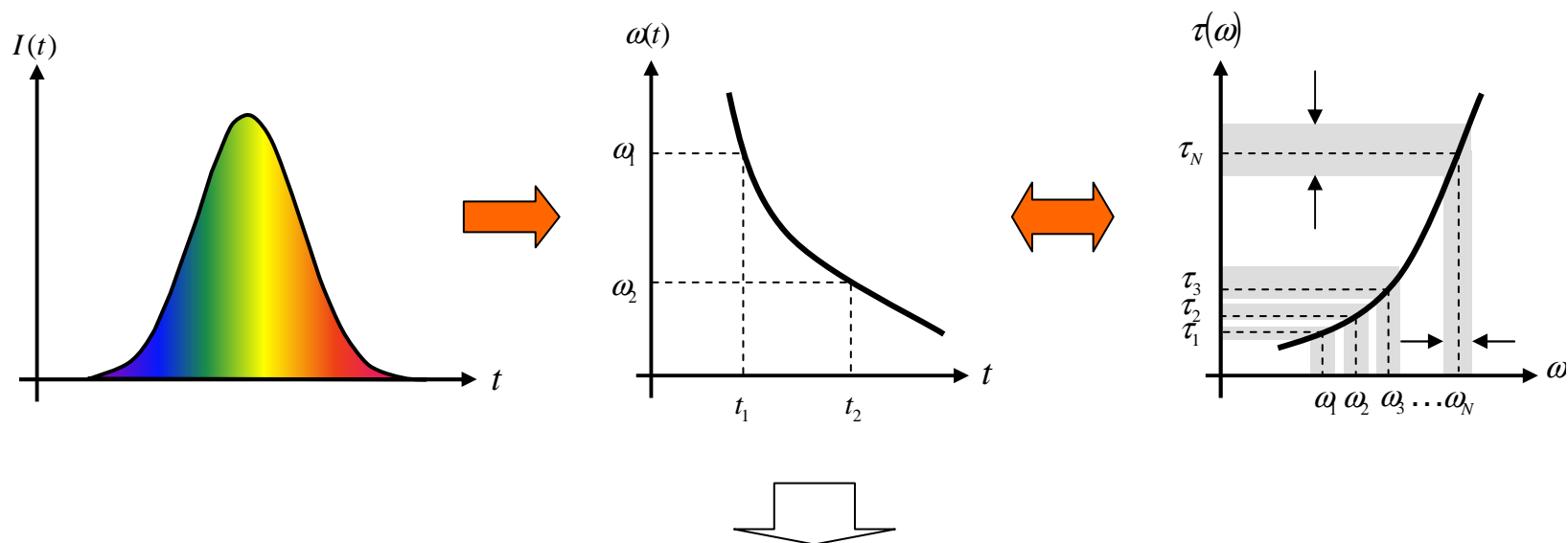
Optical implementaion

- **Dazzler located at the Front-end of the CPA laser**
- **DazScope located at the output of the compressed pulse**



SHG of a chirped pulse

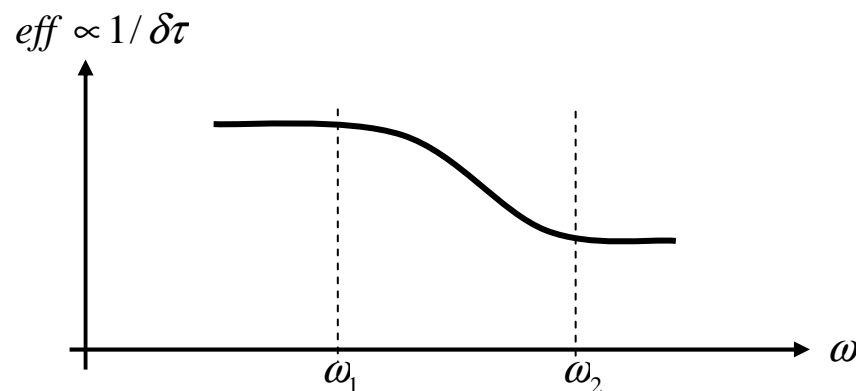
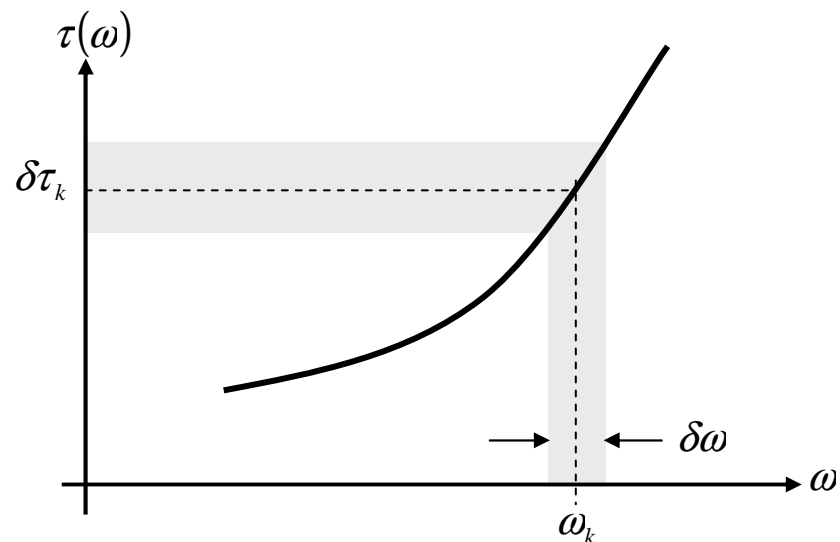
- Time-Spectrum description of a highly chirped pulse
 - ✓ pulse duration \gg TF pulse duration ($\sim 1/\Delta\omega$)
 - ✓ group delay as a function of frequency is monotonic ($\phi''(\omega) \neq 0$)



Pulse can be interpreted as a sequence of independent pulses of fixed spectral width but of unequal duration and intensity

SHG of a chirped pulse

- Second harmonic spectrum of a highly chirped pulse



$$\delta\tau_k \approx \sqrt{|\varphi''(\omega_k)|}$$

+

$$\eta_{SHG} \propto I(t)^2 \propto \left(\frac{E}{\Delta t}\right)^2$$



$$\eta_{SHG}(\omega_k) \propto \left(\frac{I(\omega_k)\delta\omega}{\delta\tau(\omega_k)}\right)^2$$



$$I_{SHG}(2\omega) \propto \frac{I^2(\omega)}{|\varphi''(\omega)|}$$

Rigorous: stationary phase approximation

Pulse measurement technique – recursive

1. Start from a roughly optimized pulse
2. Add a set of purely linear chirps to the pulse (min = 2)

$$\phi(\omega) = \varphi(\omega) + \varphi_2 \frac{(\omega - \omega_0)^2}{2}$$

3. Record for every chirp the SHG spectrum of the pulse

$$I_{SHG}(2\omega) \propto \frac{I(\omega)^2}{|\varphi''(\omega) + \varphi_2|}$$

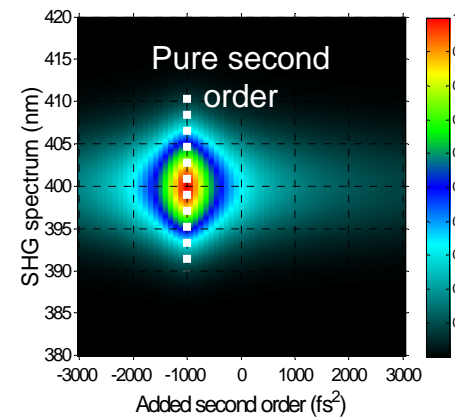
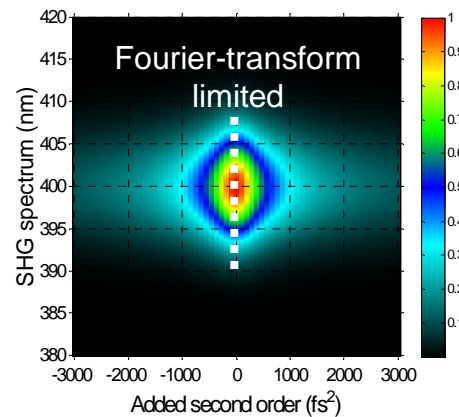
4. Use stationary phase formula to extract spectral phase:

$$\varphi''(\omega) = -\varphi_2^{optim}$$

Intuitive figures: simulations

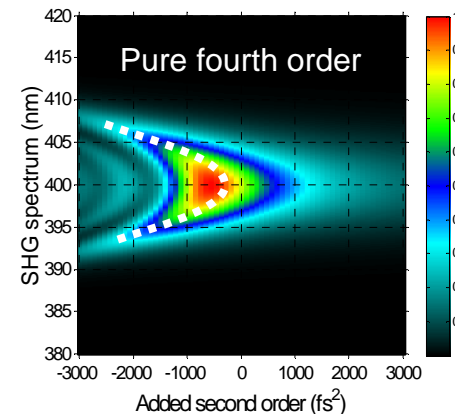
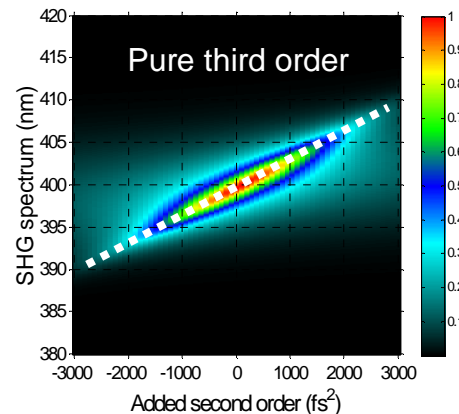
- Basically, the caustic (the loci) of maxima follows $\phi''(\omega)$

$$\phi''(\omega) = 0$$



$$\phi''(\omega) = cte$$

$$\phi''(\omega) = \phi^{(3)}(\omega)(\omega - \omega_0)$$

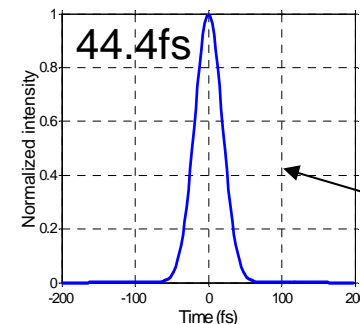
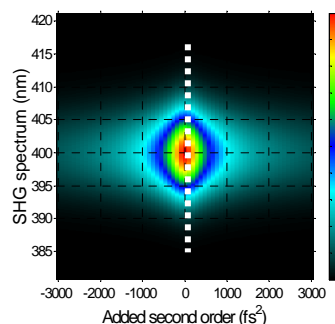
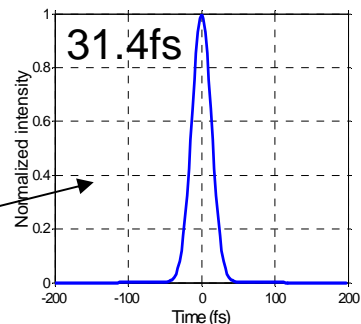


$$\phi''(\omega) = \phi^{(4)}(\omega) \frac{(\omega - \omega_0)^2}{2}$$

Effect of second order phase - simulations

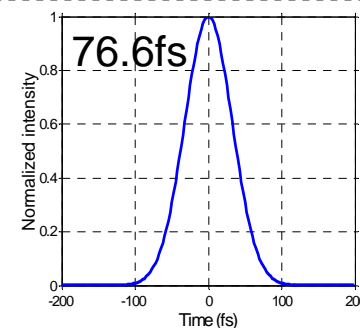
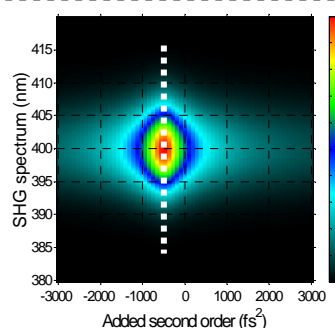
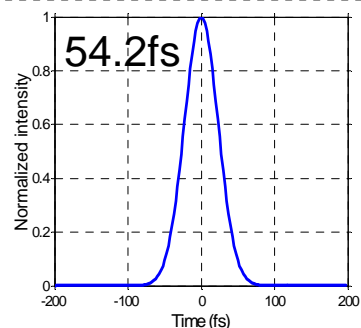
(Gaussian pulse of 30nm FWHM)

Time intensity

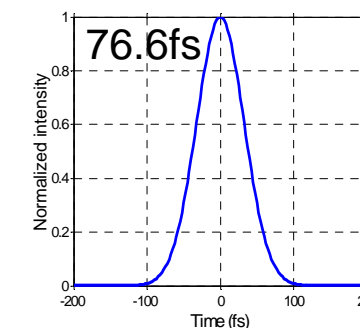
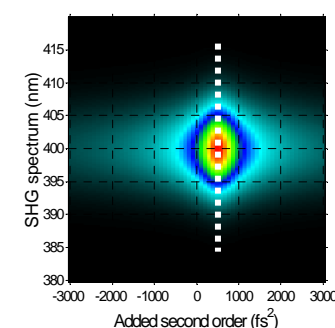
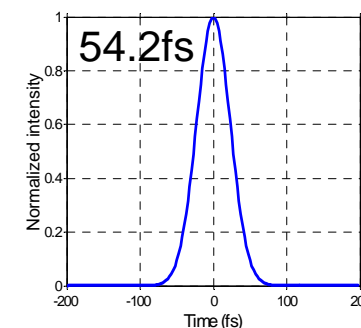


Autocorrelation

+500fs²



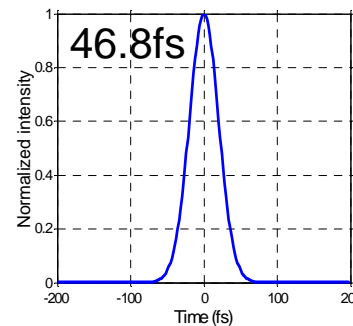
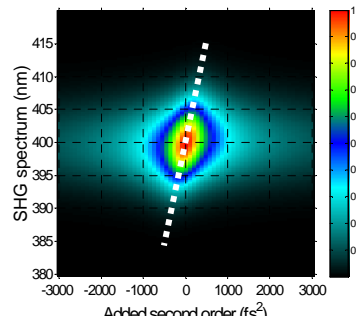
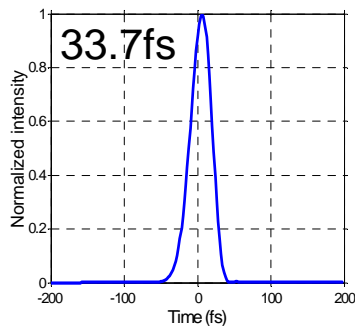
-500fs²



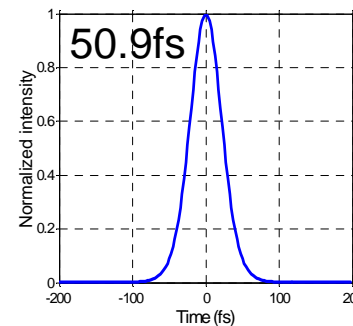
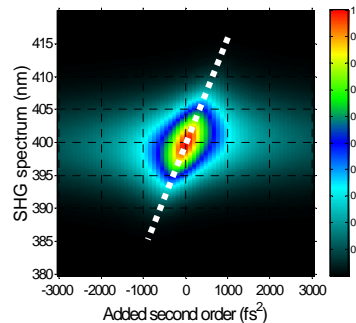
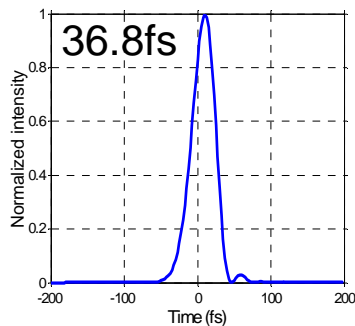
Effect of third order phase - simulations

(Gaussian pulse of 30nm FWHM)

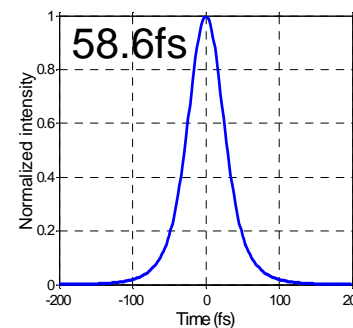
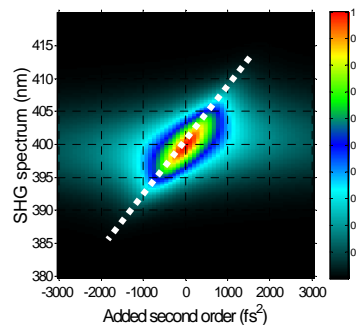
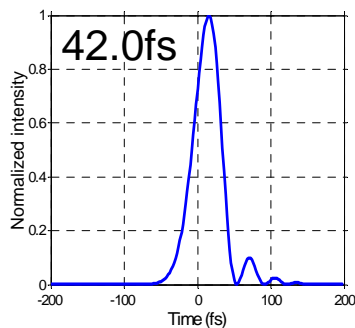
+5 000fs³



+10 000fs³



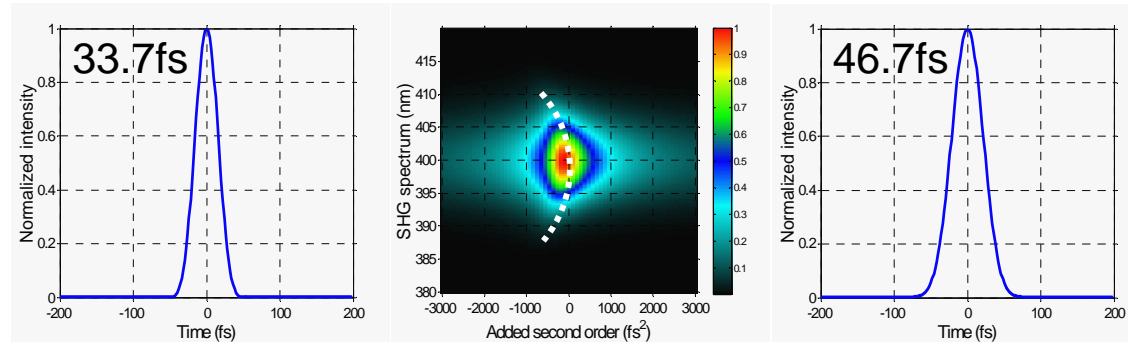
+20 000fs³



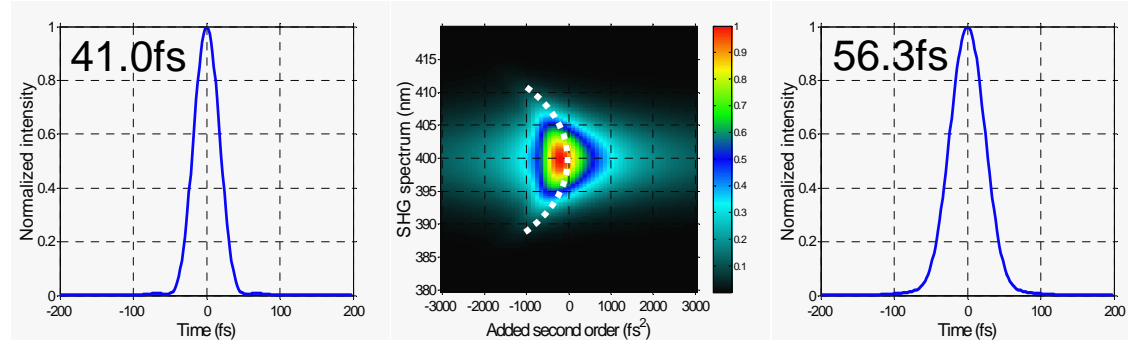
Effect of fourth order phase - - simulations

(Gaussian pulse of 30nm FWHM)

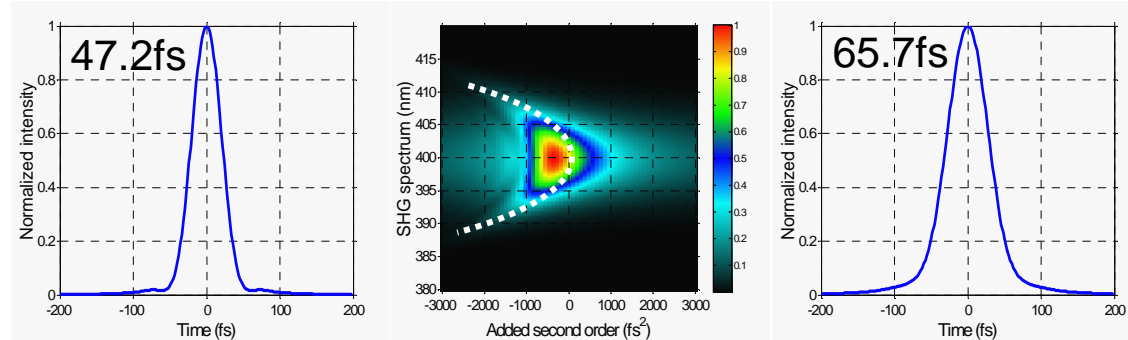
$+2.10^5 \text{ fs}^4$



$+4.10^5 \text{ fs}^4$



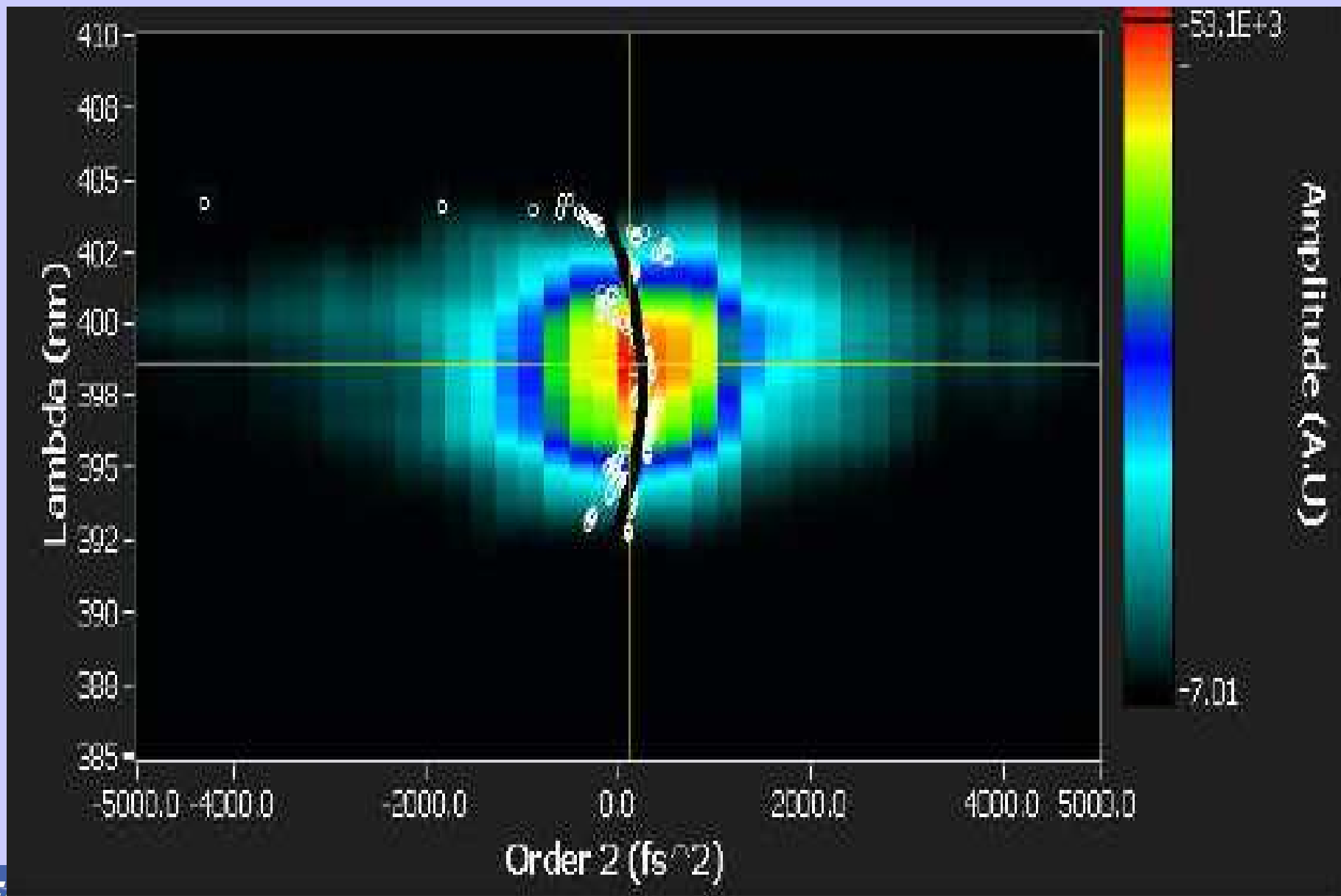
$+8.10^5 \text{ fs}^4$



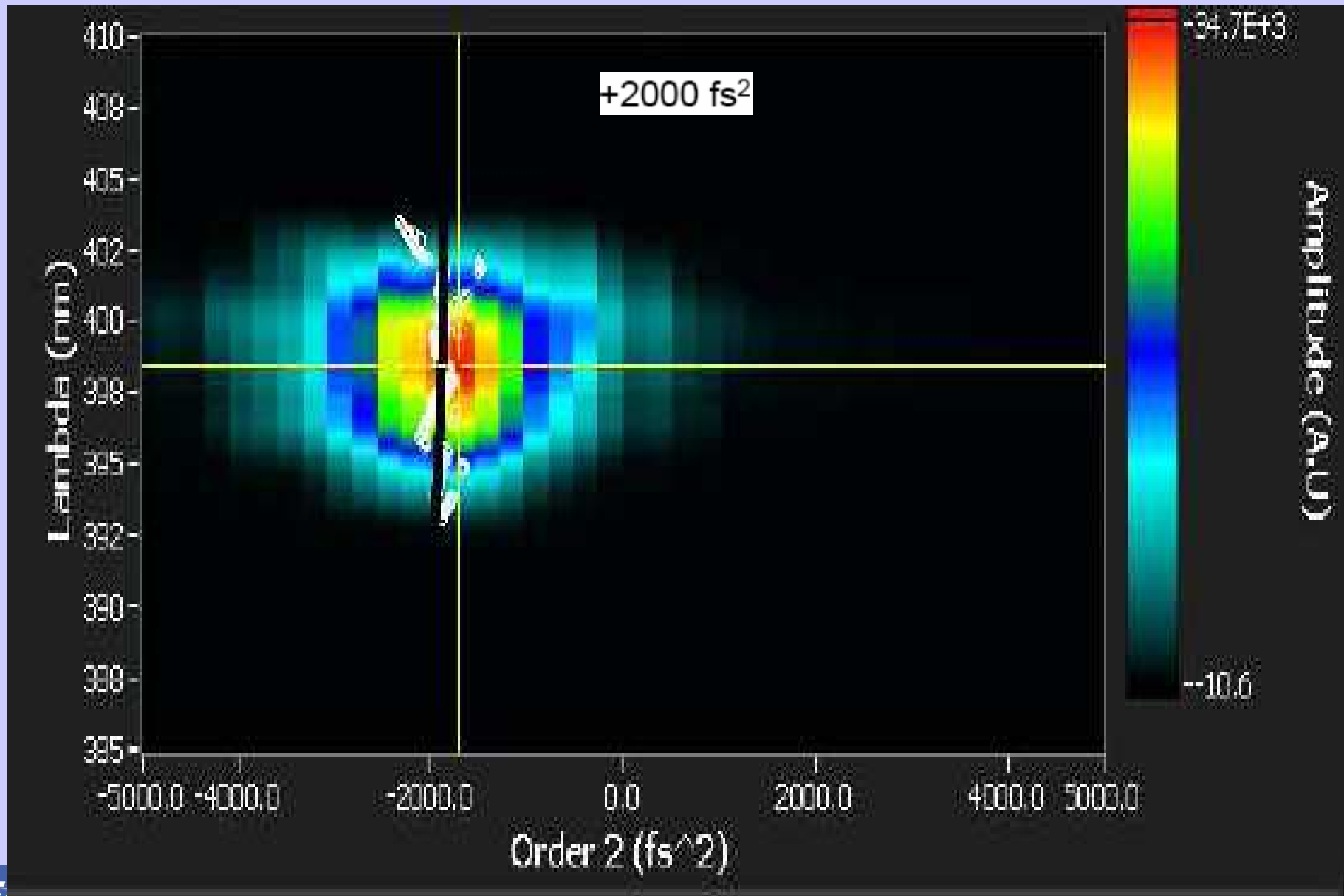
Dazscope Experimental data: 20Hz, TW class Ti:Sa CPA system

- Outline of the experimental data:
 - Data obtained on a 20Hz TW class Ti:Sa CPA system
 - Initial experimental conditions: a DazScope optimized pulse
 - Further experimental data:
 - Added known amount of second, third and fourth order phase using the quantitative Dazzler pulse shaper

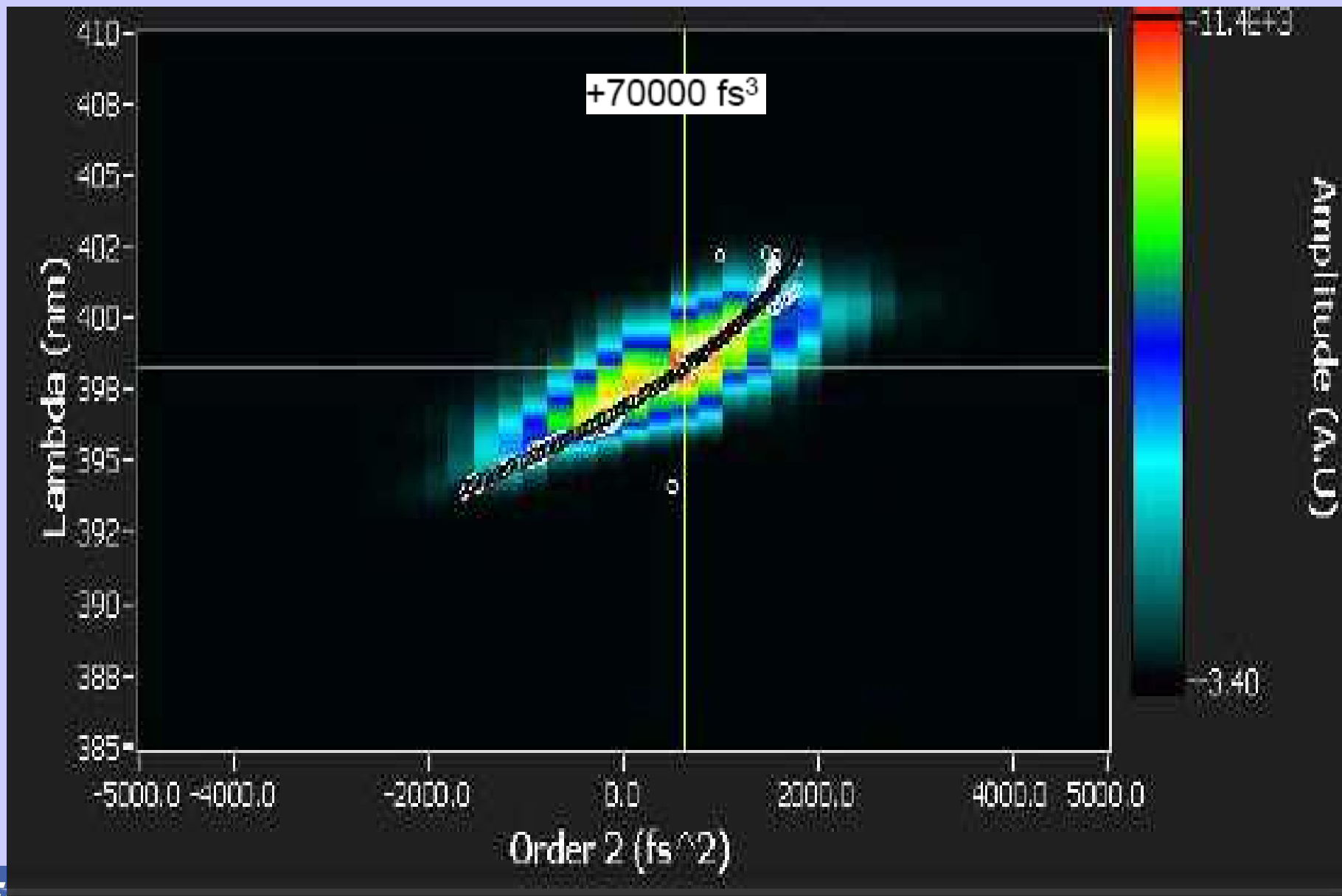
Dazzler Optimization result on a 20 Hz TW class Ti:Sa laser



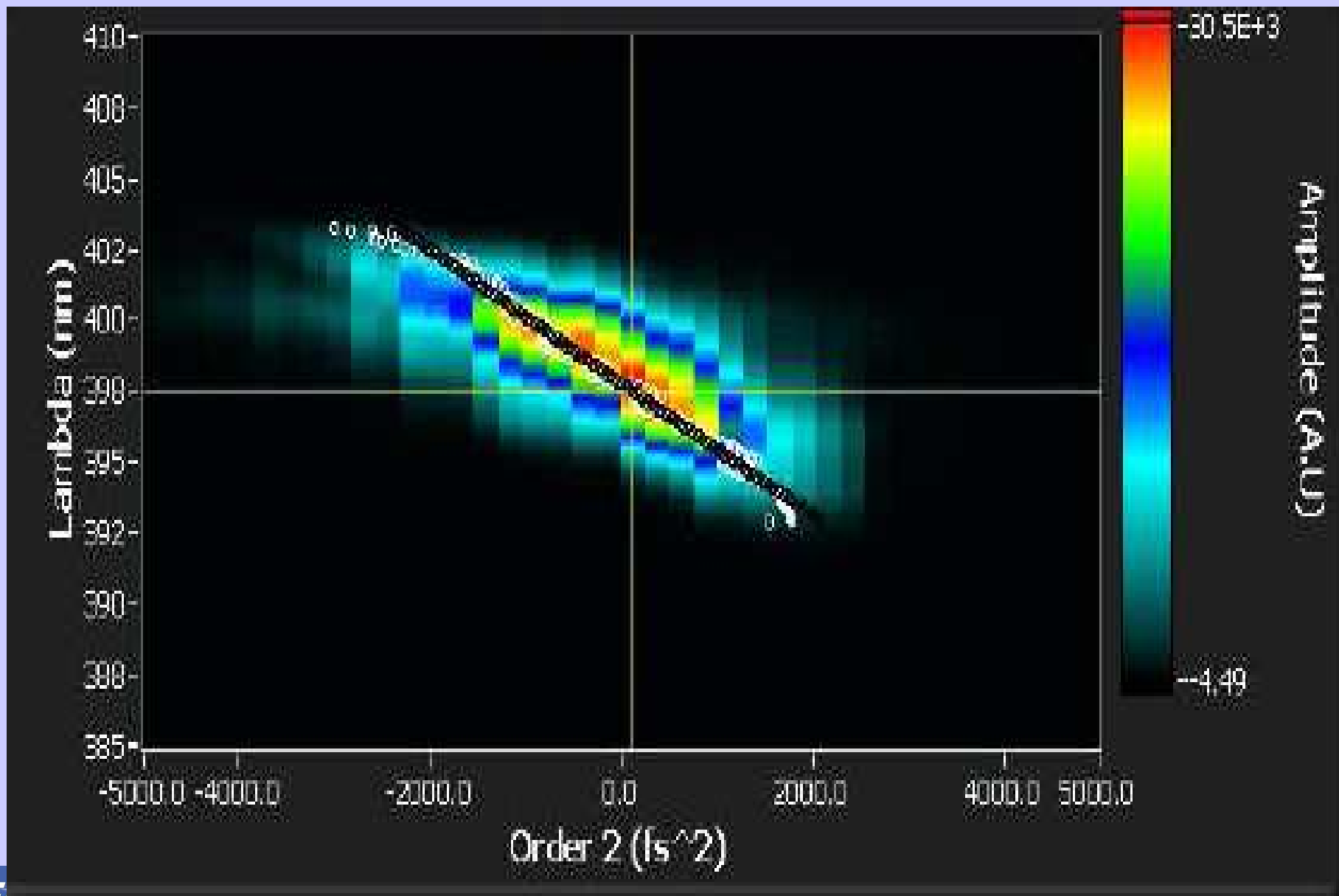
Second order value of -2000fsec square added to the optimized pulse



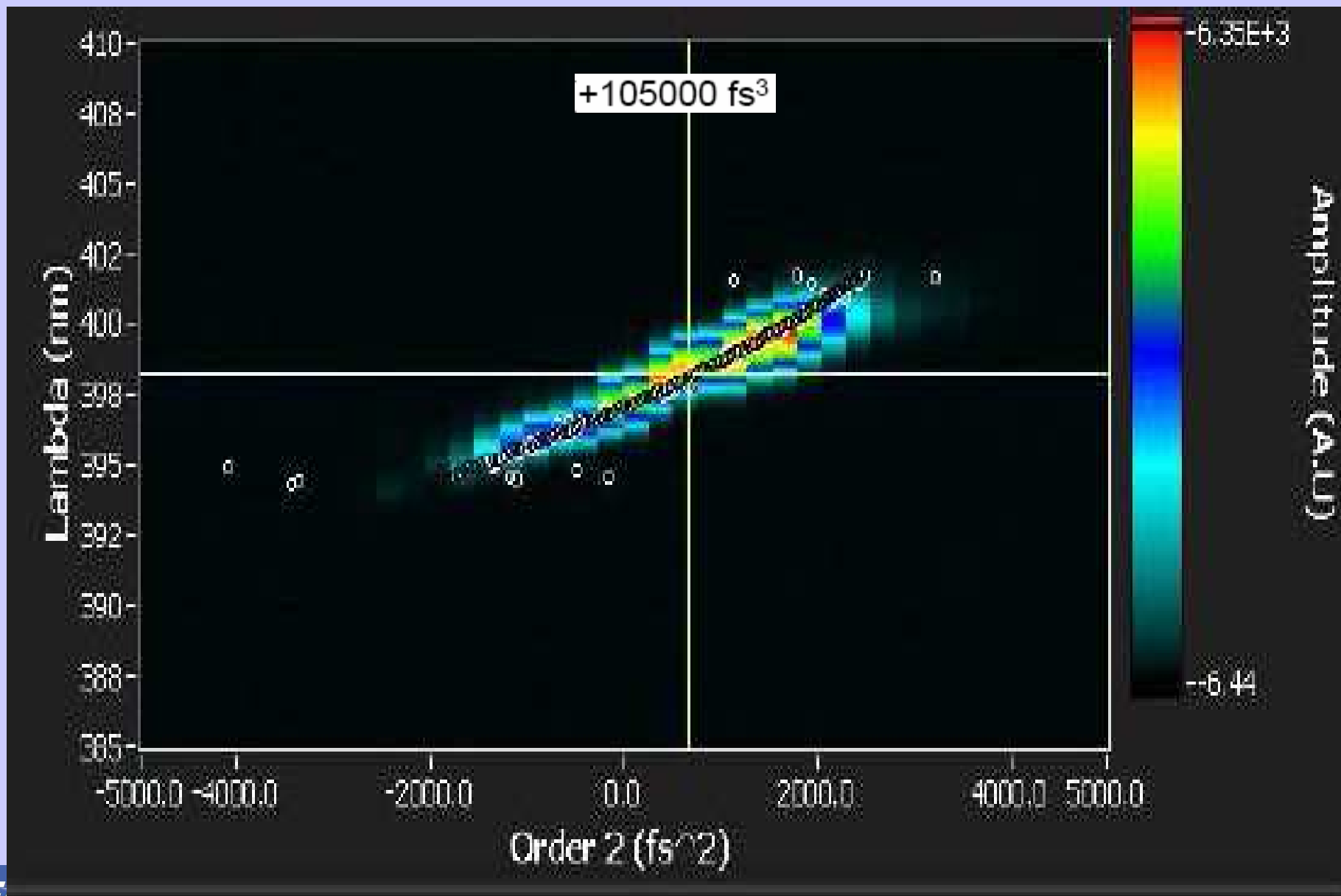
Third order value of 70000fsec cubic added to the optimized pulse



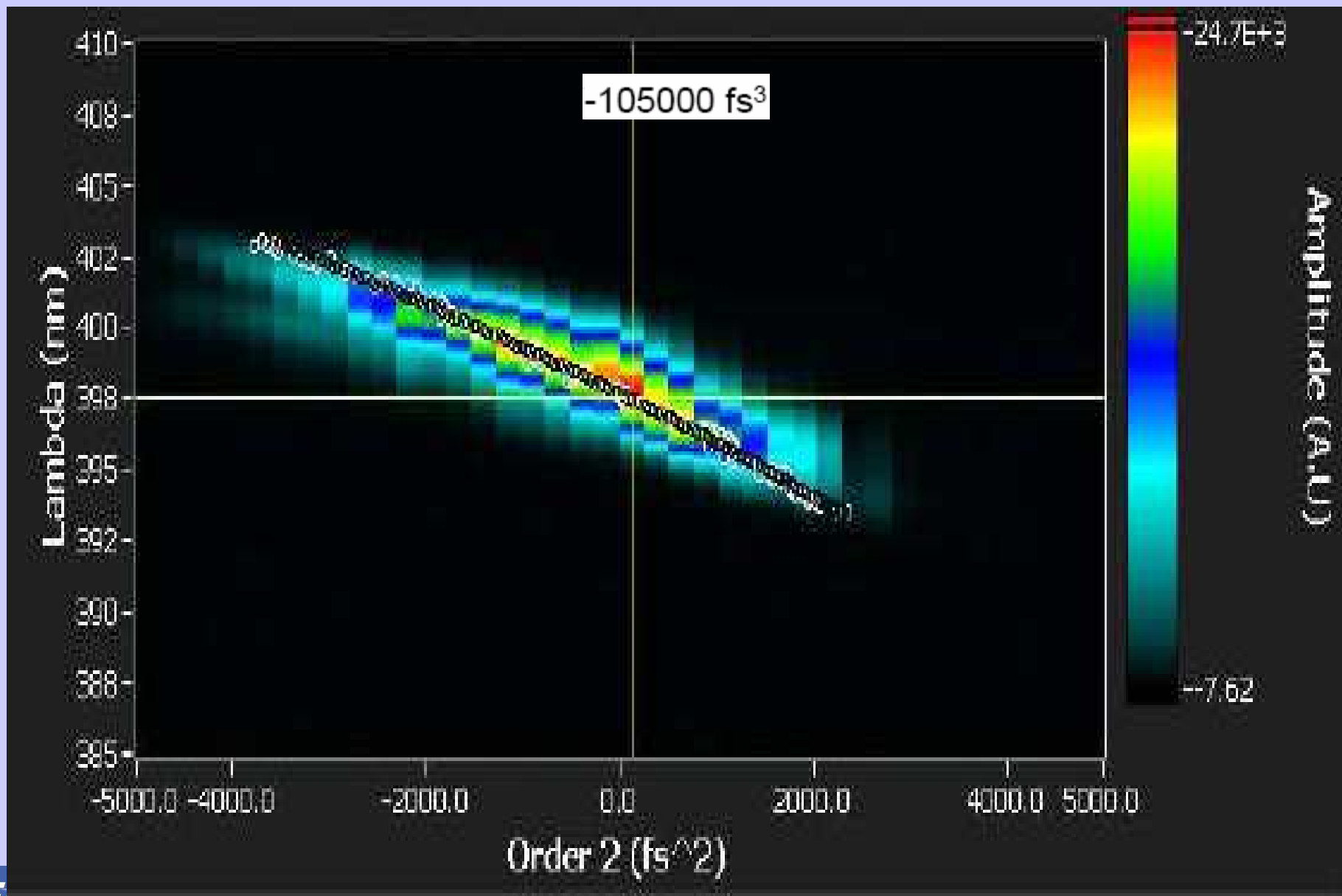
Third order value of -70000fsec cubic added to the optimized pulse



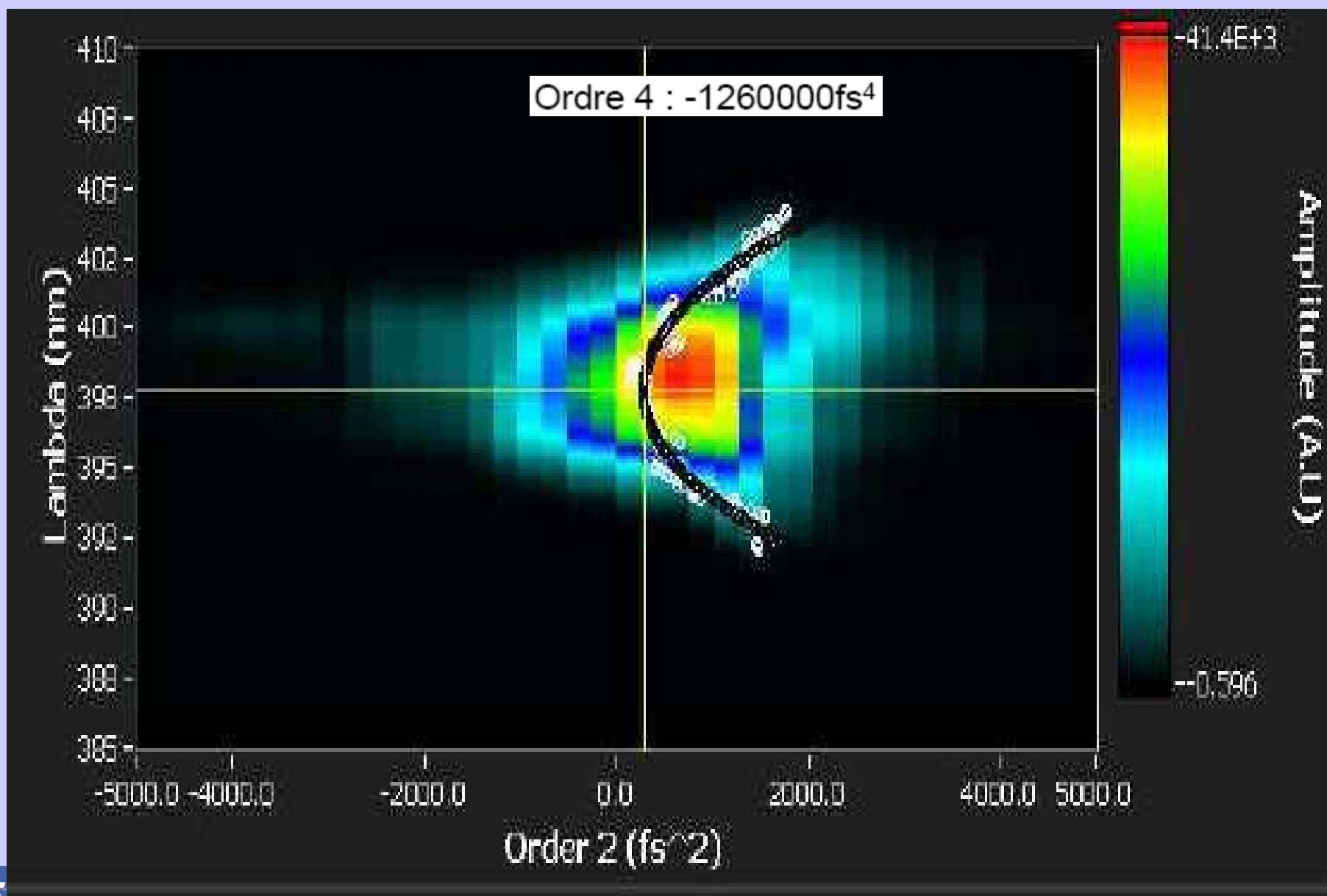
Third order value of 105000fsec cubic added to the optimized pulse



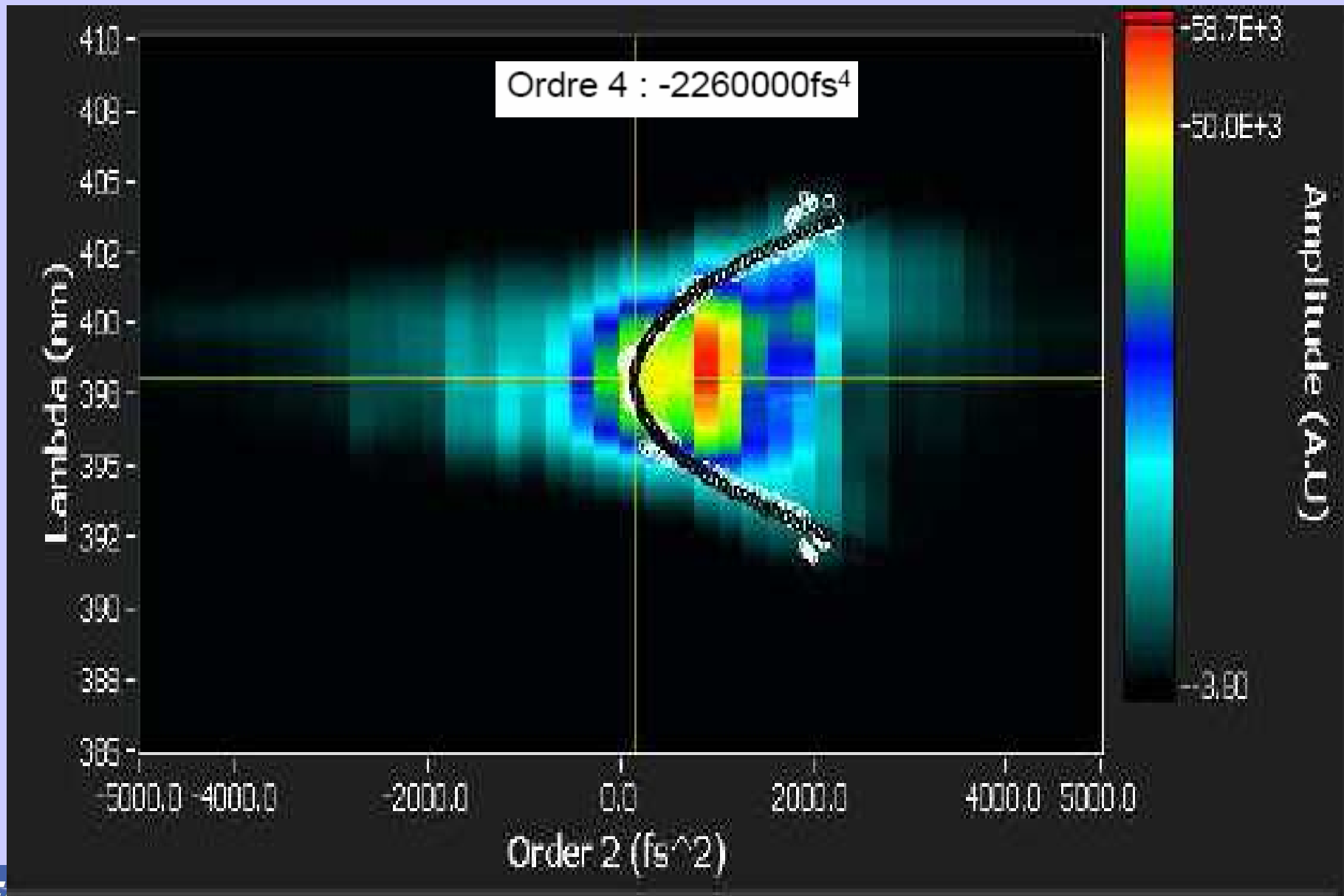
Third order value of -105000fs^3 cubic added to the optimized pulse



Fourth order value of -1260000fsec^4 added to the optimized pulse



Fourth order value of -2260000fs^4 added to the optimized pulse



Dazscope Experimental data: 30fsec class ,KHz, multimilliJoule output Ti:Sa CPA system

The Dazzler™ spectral amplitude settings were first tuned to compensate for the gain narrowing of the amplifier's cavity, providing a wide amplified spectrum (figure 7, left). The DazScope™ algorithm was then used to measure the spectral phase second, third and fourth orders. This measurement was fed back to the Dazzler™ in order to flatten the phase of the amplified pulse. The resulting autocorrelation trace FWHM was 42.7fs (figure 7, right), corresponding to a pulse duration of 27 to 30fs, depending on the exact temporal profile.

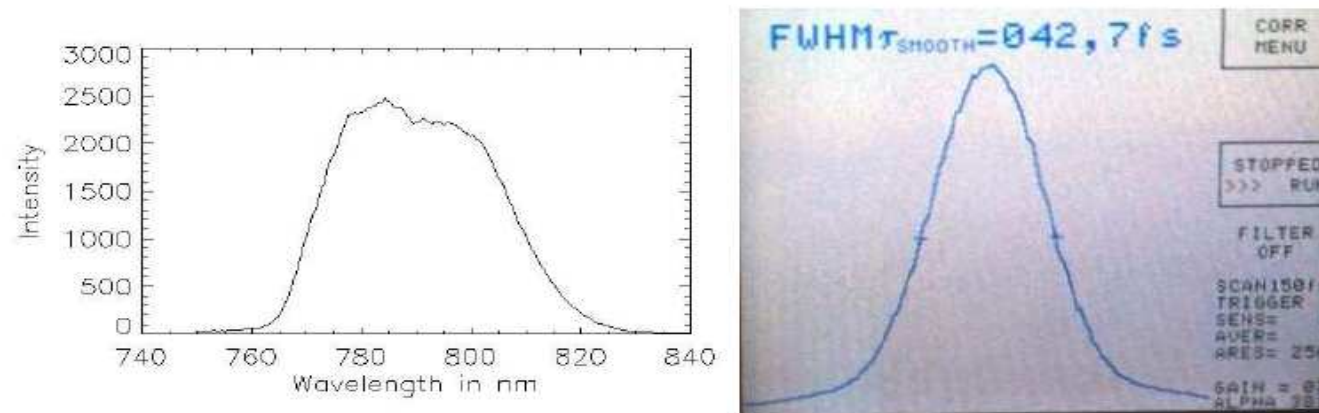


Figure 7: Left: Spectrum measured at the output of Spitfire Amplifier (FWHM= 37nm). Right: Autocorrelation trace obtained after Dazzler™/ DazScope™ optimization.

Dazscope Experimental demonstration: Data obtained on a 30fsec class ,KHz, multimilliJoule output Ti:Sa CPA system

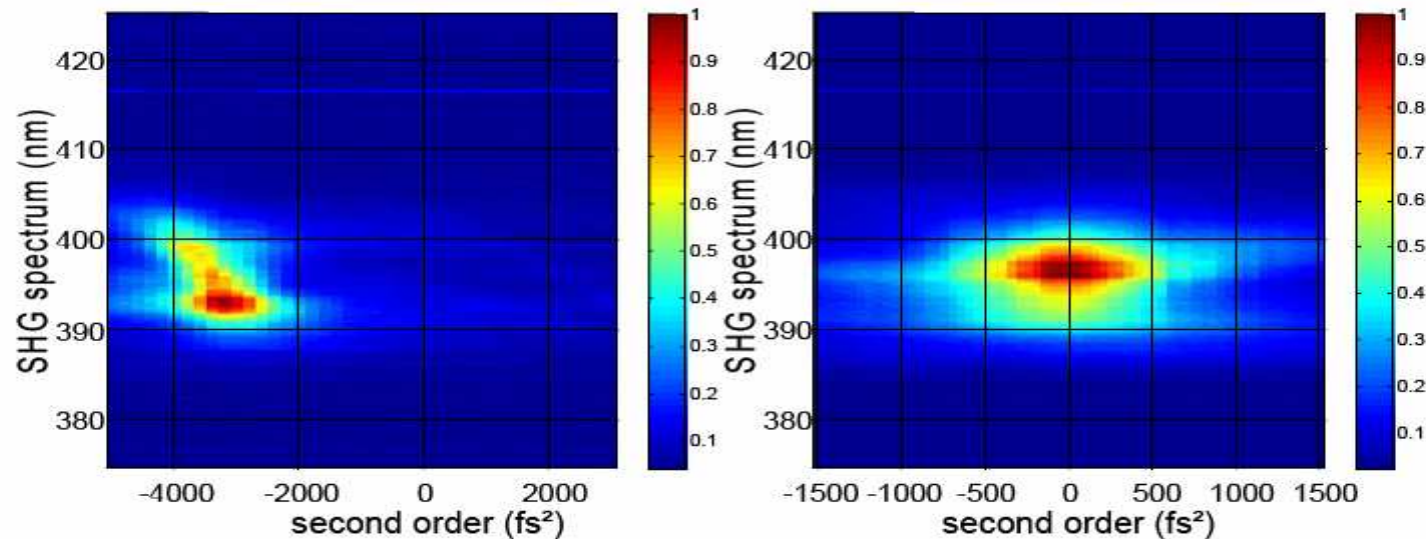


Figure 8: DazScope™ traces showing frequency doubled (SHG) spectrum as a function of the second order distortion pre-added in the Dazzler™ pulse shaper. Top: trace obtained after misalignment of the compressor (rotation by 10'). The measured pulse autocorrelation FWHM is 310 fs, strong second order ($\sim -3500\text{fs}^2$) and higher order distortions are visible. Bottom: trace obtained after DazScope™ optimization. The measured pulse autocorrelation FWHM is 43 fs. The measured spectral phase is essentially flat, as illustrated by the symmetry of the trace. The derived residual polynomial phase orders are: $\phi_2 = -21\text{fs}^2$, $\phi_3 = -1600\text{fs}^3$, and $\phi_4 = 90000\text{fs}^4$, all within the noise limit set by pulse stability.

Conclusions

- Very simple optical setup (almost optics less !)
- Intuitive interpretation of results
- High sensitivity
- Quantitative determination of polynomial phase expansion
- Demonstrated on 20Hz and kHz amplified laser systems, with pulse durations from 20 to 100fsec