Compression of Ultra-high Power Laser Pulses.

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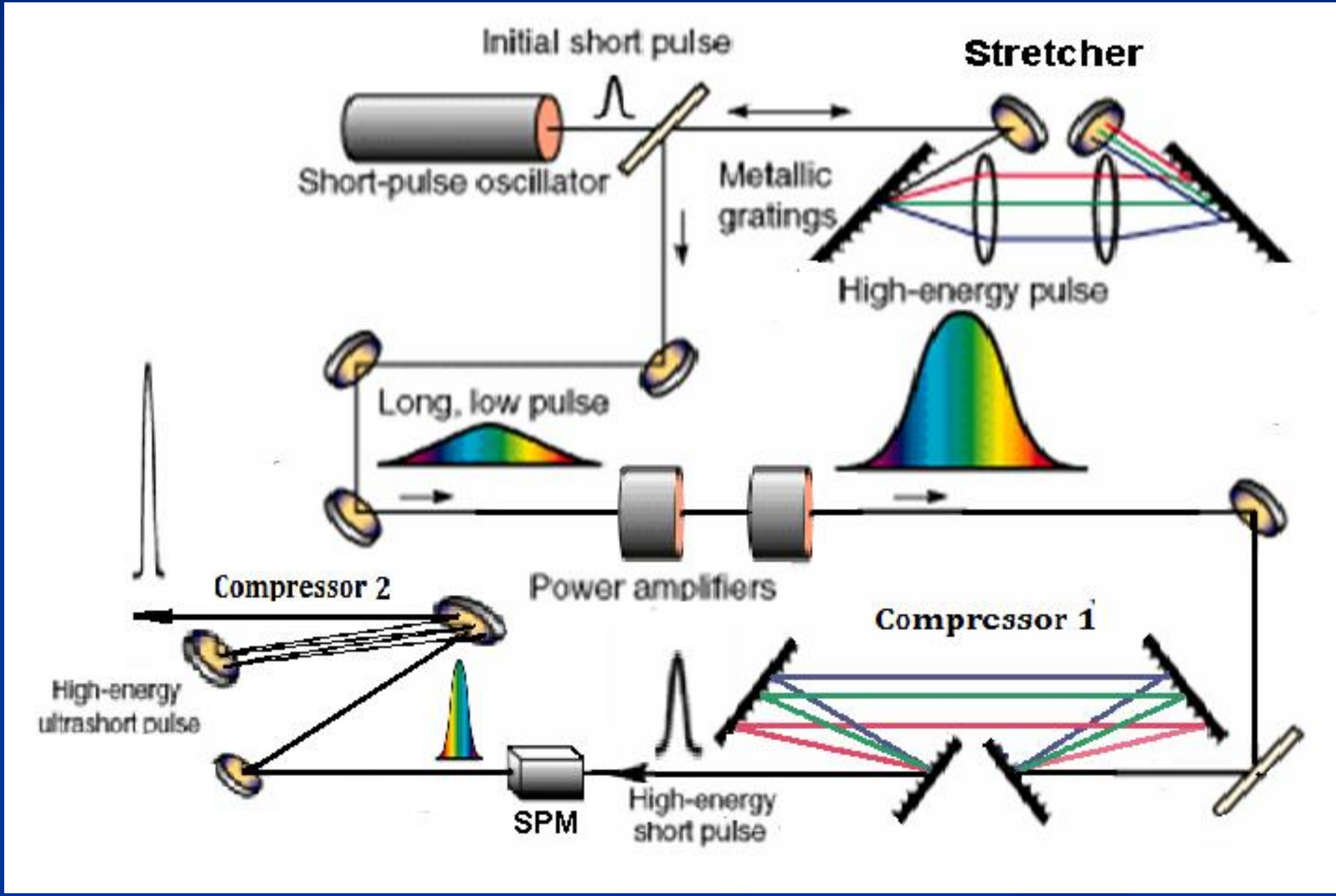
Outline

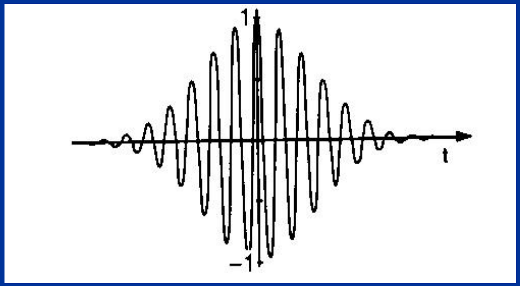
- CPA-SPM double compression (origins).
- Previous experiments and results.
- SPM of the Super Gaussian Beam
- Proof-of-principle experiment and results.
- Complications and their possible resolution.
- Conclusion.

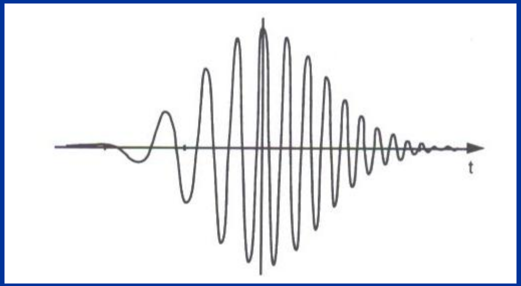
CPA+SPM – two stage compression.

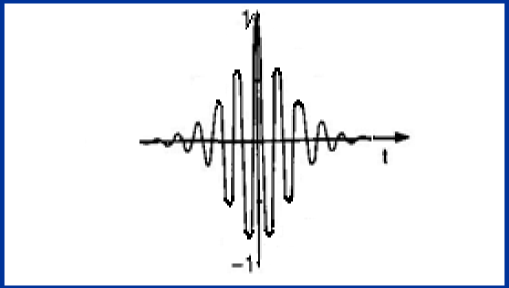


SPM – the method for coming to new transform limit

Fourier transform limited pulse	Linear chirped pulse	New transform limited pulse







$E = E_0 \exp(-t^2/2\tau_0^2)\exp(i\omega_0 t)$

$E = E_0 \exp(-t^2/2\,\tau_0^2)\exp(i(\omega_0 t - at^2))$

$E = E_0 \exp(-t^2/2\tau'^2_0)\exp(i\omega_0 t)$

$\tau'_0 = \tau_0 /(1 + 4\,\tau_0^4\, a^2)^{1/2}$

$$i\frac{\partial A}{\partial z} = D^2\frac{\partial^2 A}{\partial \tau^2} + iD^3\frac{\partial^3 A}{\partial \tau^3} - N|A|^2 A$$

$A(z,\tau)$ – slow varied amplitude, $\tau = (t - \beta_1 z)$, t and z – time and special coordinate of pulse distribution

$$D^2 = \frac{1}{2L_{D2}},\quad D^3 = \frac{1}{6L_{D3}},\quad N = \frac{1}{L_{nl}},\quad L_{D2} = \frac{T_0^2}{|\beta_2|},\quad L_{D3} = \frac{T_0^3}{|\beta_3|},\quad L_{nl} = \frac{c}{n_2\omega_0 I_0}$$

For intensity ~ 1 TW/cm² and fused silica for bulk material we have coefficients of the right hand terms of the equation - $D^2 = 0.04$, $D^3 = 0.004$, $N = 2$.

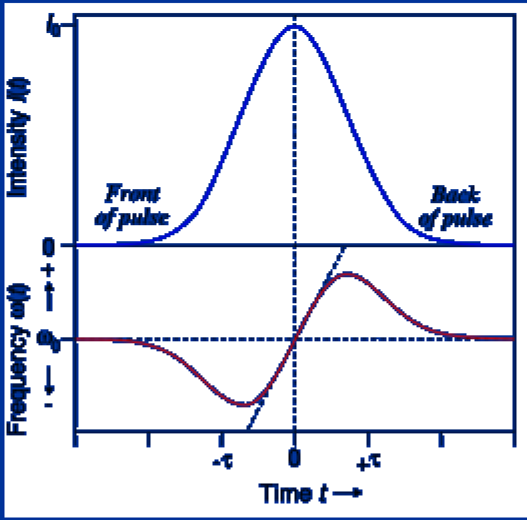
$$A(z,\tau) = A(0,\tau)\exp(i|A(0,\tau)|^2 z/L_{nl})$$

$$A(0,\tau) = \exp(-\tau^2/2T_0^2)$$

$$\varphi = \omega_0\tau - \exp(-\tau^2/T_0^2)z/L_{nl}$$

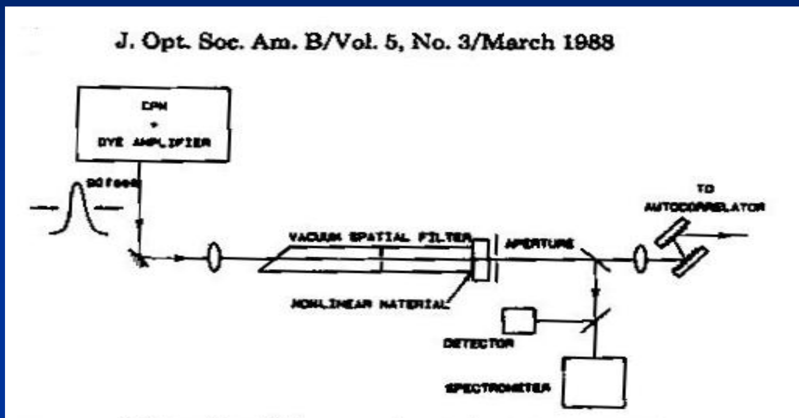
$$\frac{\partial\varphi}{\partial\tau} = \omega = \omega_0 - \tau\exp(-\tau^2/T_0^2)z/\,T_0^2 L_{nl}$$

$$\omega(t) = \omega_0 - \alpha\cdot t$$

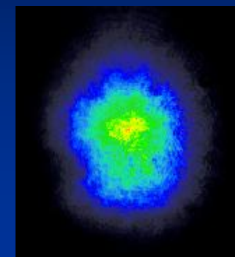


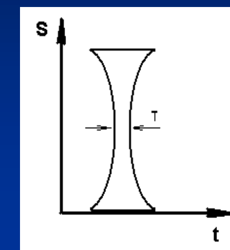
Previous experiments and results.

Near field spatial filtering of the Gaussian beam profile of the laser pulse.



Schematic of the experimental apparatus used for high-power compression.





Peak intensity ~ $0.5*10^{12}$ W/cm^2, energy of incident pulse – 0.5mJ, bulk of material – 1.2 cm plate of quartz. Pulse compression by factor of 5 (from 92 fs to 19 fs) with a few percent transmission efficiency

Far field spatial filtering of the Gaussian beam profile.

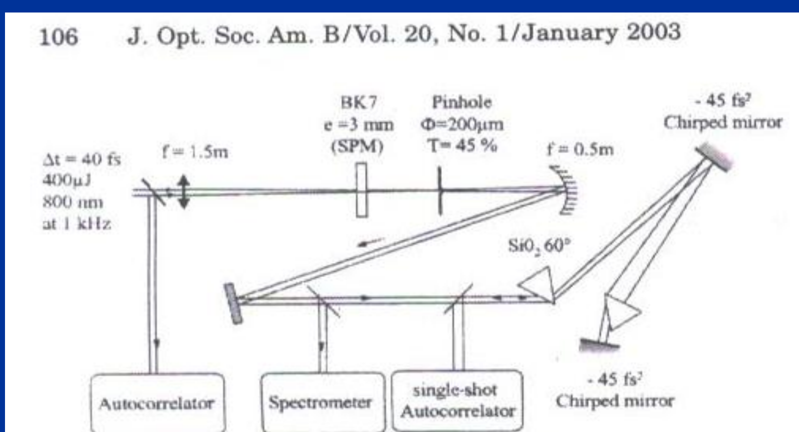


Fig. 1. Schematic of the experimental setup.

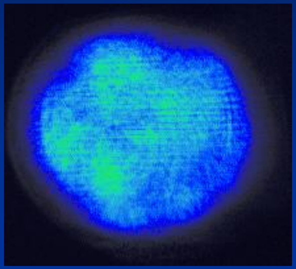
Peak intensity ~ $8*10^{12}$ W/cm^2, energy of incident pulse – 0.48mJ, bulk of material – 0.3 cm BK7. Pulse compression by factor of 3 (from 42 fs to 14 fs) with 45 % transmission efficiency

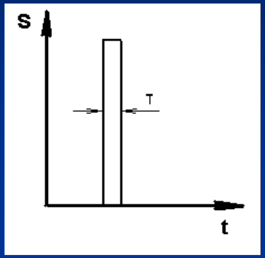
Limitations for both cases are the low compressed pulse energy and low transmission efficiency

These could be overcome by utilization of a beam with super Gaussian transverse energy distribution.

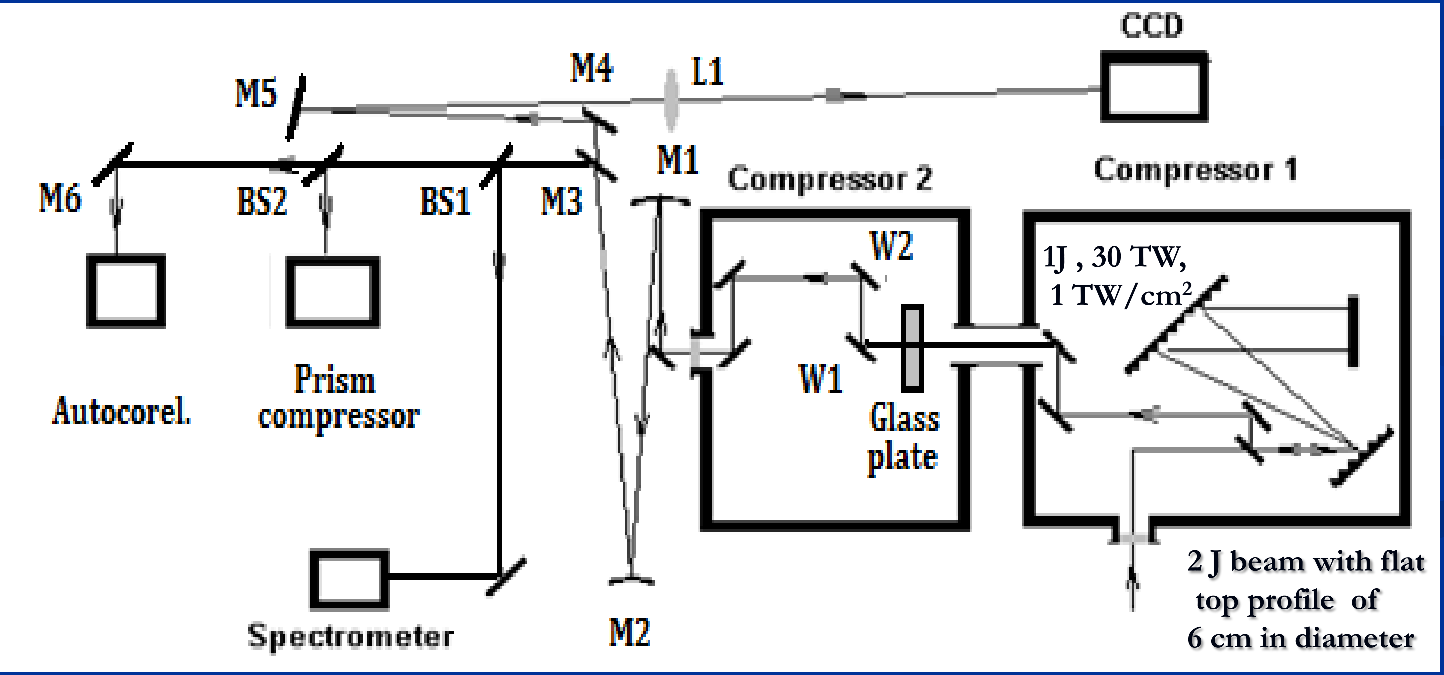
CPA+SPM of the beam with super-Gaussian transverse energy distribution.

Near field profile of the Hercules laser pulse (6J)



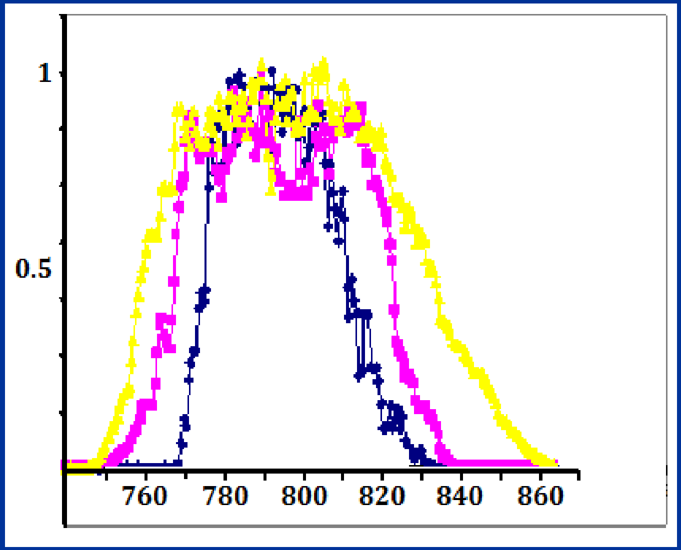


Layout of the CPA+SPM experiment



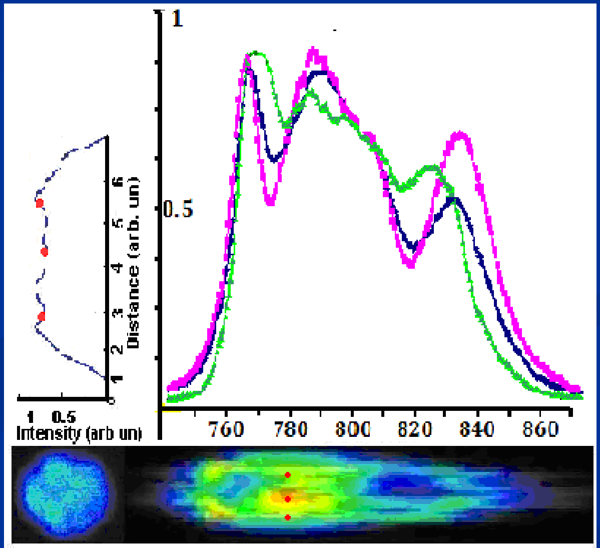
The spectral broadening using self-phase modulation.

Spatially integrated pulse spectrums.



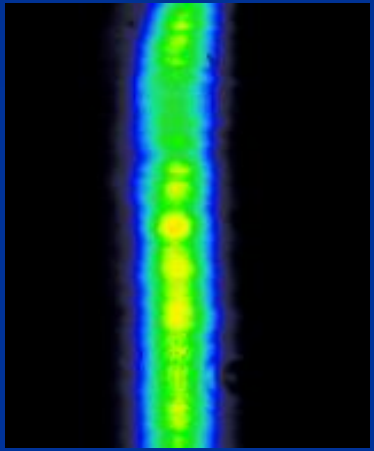
Blue curve (diamonds) represents the spectrum without the glass plate (no SPM), pink curve (squares) – with plate of the 0.8 cm thickness and yellow curve (triangles) – with glass plate of 2 cm thickness.

The spatially resolved spectrum.

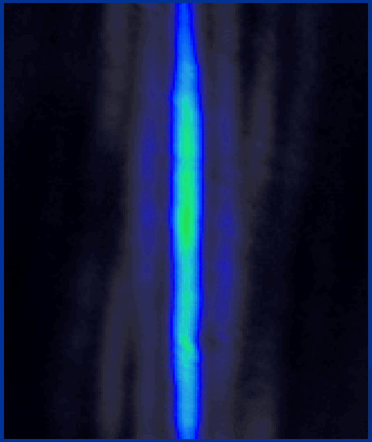


Bottom picture: on the left-output beam of the HERCULES laser, on the right - spectrally resolved beam passed through 2cm glass plate, above: on the left - spectrally integrated spatial energy distribution, on the right - lineout of the spectrum taken at the spatial points shown as red dots.

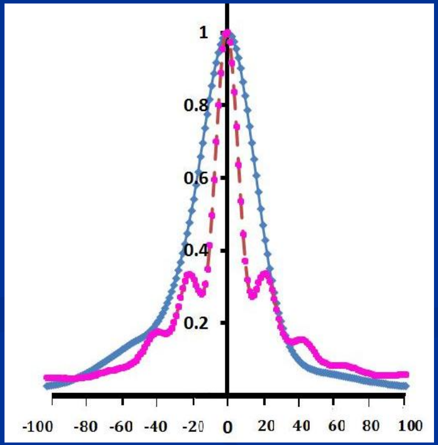
Results of the Autocorrelation Measurements of the SPM Pulses.



a



b



c

a – autocorrelation picture of the initial transform limited pulse (30 fs), b - compressed pulse after SPM, c – autocorrelation trace of the initial transform limited pulse (solid blue line) and compressed pulse after SPM (dashed pink line corresponded 14fs).

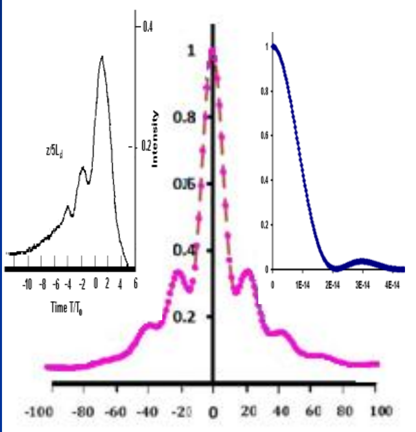
Complications and their resolution.

- Instability and Wings of autocorrelation trace.

  Prisms compressor with prisms from SF10.

$$i\frac{\partial A}{\partial z} = D_2\frac{\partial^2 A}{\partial \tau^2} + iD_3\frac{\partial^3 A}{\partial \tau^3} - N|A|^2 A \qquad D_3 = \frac{|\beta_3|}{T_0^3}$$

For intensity ~ 0.3 TW/cm^2 and equal dispersion properties we have coefficients of the right hand terms of the equation $D_2 = -1.8$, $D_3 = -1.1$, $N = 0.6$



Possible solution: replace prisms with chirped mirrors.

- White light generation.

In our experiments up to 30% of incident energy were exhausted into white light generation.

Possible solution: for SPM to use thinner plate of materials with low phase matching for parametrical harmonic generation.

In *E. Mével, O. Tcherbakoff, F. Salin, E. Constant; J. Opt. Soc. Am. B; 20 105 (2003)* **with 3mm BK7 white light generation was negligible.**

Conclusion.

- We suggest using super-Gaussian beam profile for CPA + SPM double compression method to avoid limitation of the incident energy and to increase transmission efficiency.

- We demonstrated more than doubling of the spectral pulse width via SPM, while maintaining a spatially uniform spectrum for 30TW- laser pulse with super-Gaussian beam profile.

- We demonstrated the possibility of pulse compression from 30 to 14 fs for 30TW- laser pulse.

- This scalable compression method if used with chirped mirrors will allow generation of ~10fs pulses at petawatt and exawatt power levels..