Arkadii Yastremskii, Valery Losev

Evolution of laser radiation spectrum in XeF(C-A) amplifier of THL-100 laser system

Institute of High Current Electronics SB RAS 2/3

Academichesky Ave., 634055, Tomsk, Russia
ayastremskii@yandex.ru

INTRODUCTION

Currently, the area of physics associated with the generation of high-powerful femtosecond laser beams is of great interest [1]. Solid-state laser systems based on amplification of frequency-modulated laser radiation have been created. It was received laser radiation with a peak power of 10 PW and more.

To obtain maximum radiation power, as a rule, such systems operate in gain saturation modes. The saturation effect leads to a narrowing of the emission spectrum. As a result, the duration of compressed frequency-modulated laser radiation inevitably increases. This leads to a decrease in the output power of the laser radiation.

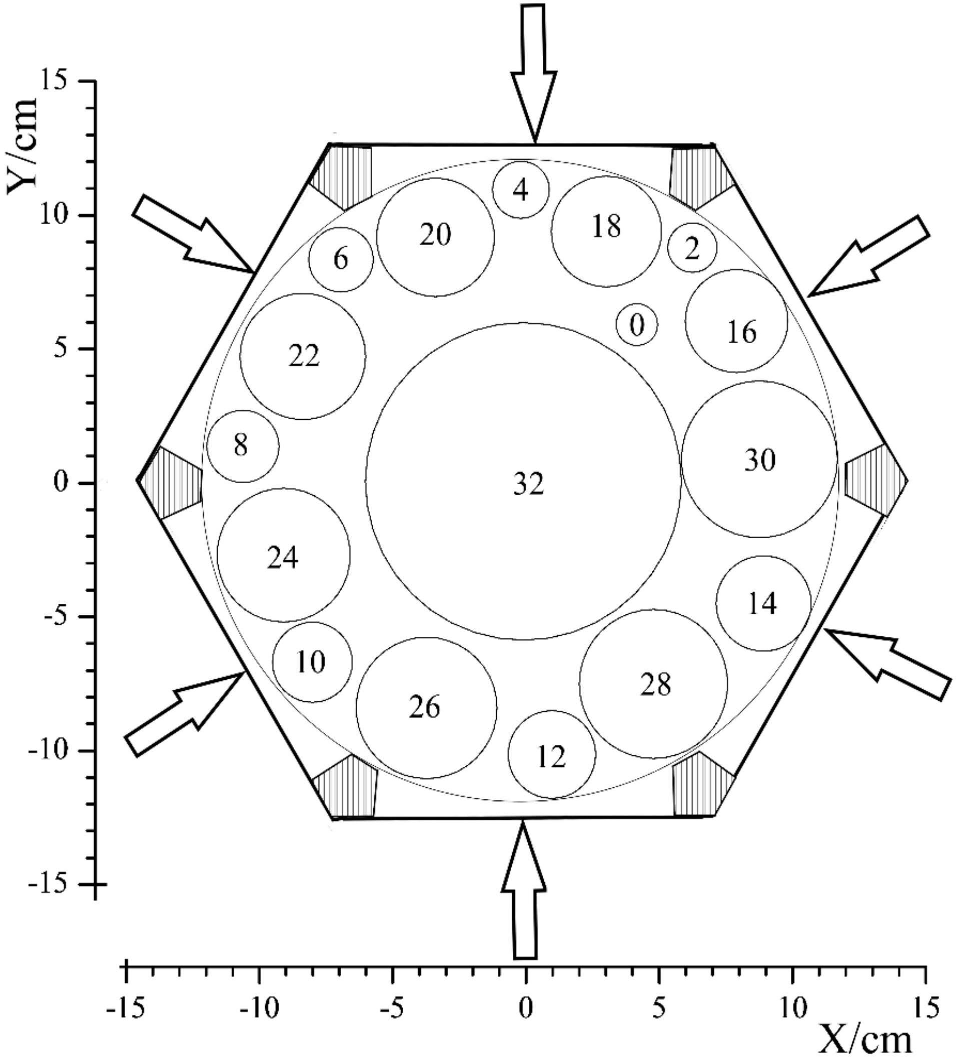
The main goal of this work is the experimental and numerical study of the influence the gain saturation effect on the evolution of spectral characteristics the laser radiation in XeF (C-A) amplifier of the THL-100 laser system.

EXPERIMENTAL SETUP AND MEASUREMENT TECHNIQUES

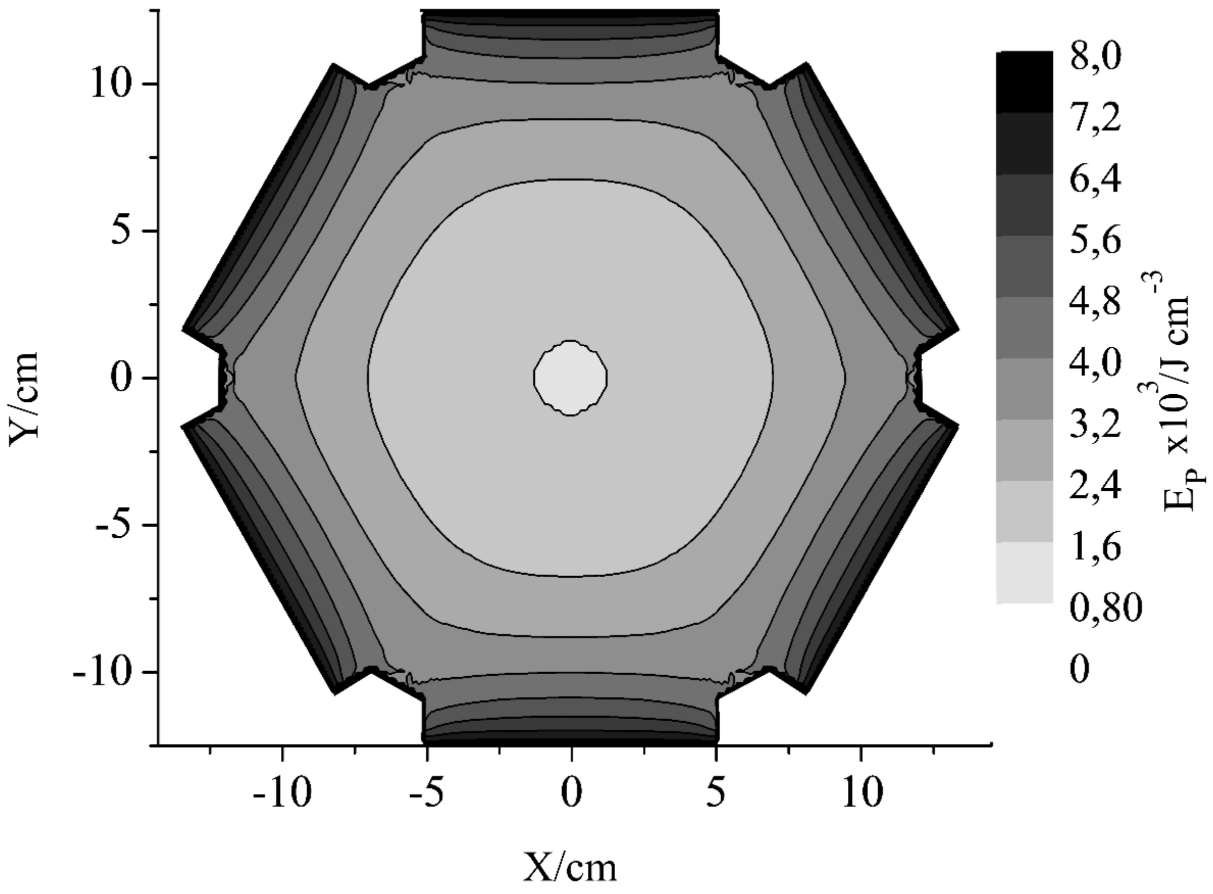
The THL-100 laser system includes Ti: the Start-100 sapphire femtosecond start complex, developed by Avesta-Project, and the XeF(C-A) photo dissociation amplifier, designed and built in institute of High Current Electronics SB RAS. The master oscillator of the start complex formed spectrally limited pulses at a central wavelength of 950 nm with a duration of 60 fs, which were stretched to a duration of ~ 100 ps FWHM and amplified in Ti: Sa amplifiers to an energy of 57 mJ. The conversion of the radiation of the first harmonic to the second was carried out in a KDP crystal 2 mm thick.

The second harmonic radiation had a Gaussian distribution with a diameter of 3.5 mm (over the decay of intensity in e^2), a pulse duration of 250 ps, and an energy of up to 5 mJ. After this, the beam expanded in a mirror telescope with an increase in M = 5 and was amplified in a multi-pass optical system XeF (C-A) amplifier, consisting of 32 mirrors. To exclude diffraction on the XeF (C-A) mirrors of the amplifier, the radiation passed a toothed diaphragm with an inner diameter of 11 mm and a ratio of tooth height to pitch h / d = 7. As the gain increased at 31 passes, the beam expanded to a diameter of 60 mm. In the last two passes, its diameter increased to 120 mm due to the fact that the penultimate mirror was convex.

The gas mixture of the XeF (C-A) amplifier consisted of a buffer gas of nitrogen and XeF_2 vapor in the ratio N_2: XeF_2 = 380: 0.2 (Torr). The active medium (XeF (C_0) molecules) was created upon photo dissociation of XeF_2 VUV molecules by pump radiation, with wavelength of λ = 172 nm. Laser energy was recorded by Gentec and OPHIR meters. Spectral measurements were carried out using an Ocean Optics HR4000 spectrometer.



Amplifier block of mirrors diagram. The numbers of the mirrors correspond to the number of beam transits across the amplifier prior to passing to the mirror. The output unit of the amplifier has the same set of mirrors with odd numbers. Arrows indicate the direction of VUV pump radiation. Dashed domains are opaque for pump radiation.



Distribution of specific absorbed pump energy E_P in the transverse cross section of the amplifier. The total pump energy is E_P= 270 J [Quantum Electronics 46(11) 982–988 (2016)]

EQUATIONS AND ALGORITHMS

Wigner function

The energy density distribution of the incoming laser pulse in the t - w (time - frequency) phase space was presented in the form of a Wigner distribution. For Gaussian beams, the Wigner function is written as:

$$W(t,w) = \rho_0^2 \frac{\tau_0}{\sqrt{\pi}} \exp\left\{-at^2 - \frac{(w-\beta t-w_0)^2}{a}\right\};$$

$$V_0^2(z) = 1 + \left(\frac{\boldsymbol{z}}{\boldsymbol{L_D}}\right)^{\boldsymbol{2}}; \quad a = \frac{1}{\boldsymbol{V_0^2(z)\tau_0^2}}; \quad \beta = \frac{\left(\frac{\boldsymbol{z}}{\boldsymbol{L_D}}\right)^{\boldsymbol{2}}}{\boldsymbol{V_0^2(z)K_2 z}}; \qquad L_Д = \tau_0^2/|k_2|;$$

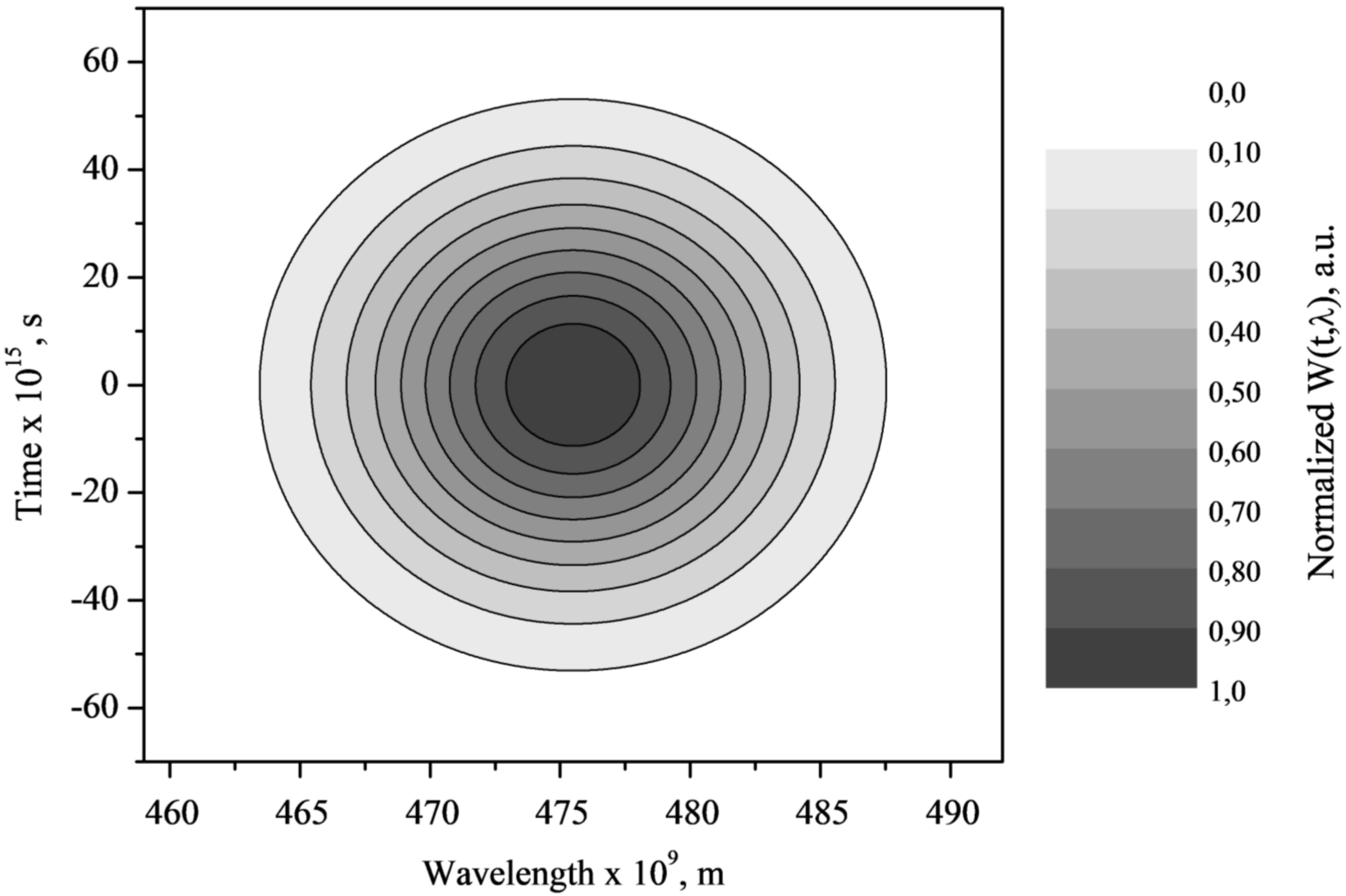
t is the time in the moving coordinate system associated with the laser beam, z is the distance passed by the laser beam in the dispersing medium, τ_0 is the duration (FWHM) of the spectrally limited pulse. k_2 characterizes the dispersion of group velocity in a first approximation, L_D is dispersive length, ρ_0 is the amplitude of the electric field, w_0 is the central frequency. For clarity, on the figures the frequency are displayed in form of wavelength.

Integrating the Wigner function over *w* and over *t*, we obtain the intensity $I(t)$ and the spectral density of radiation energy S(*w*).

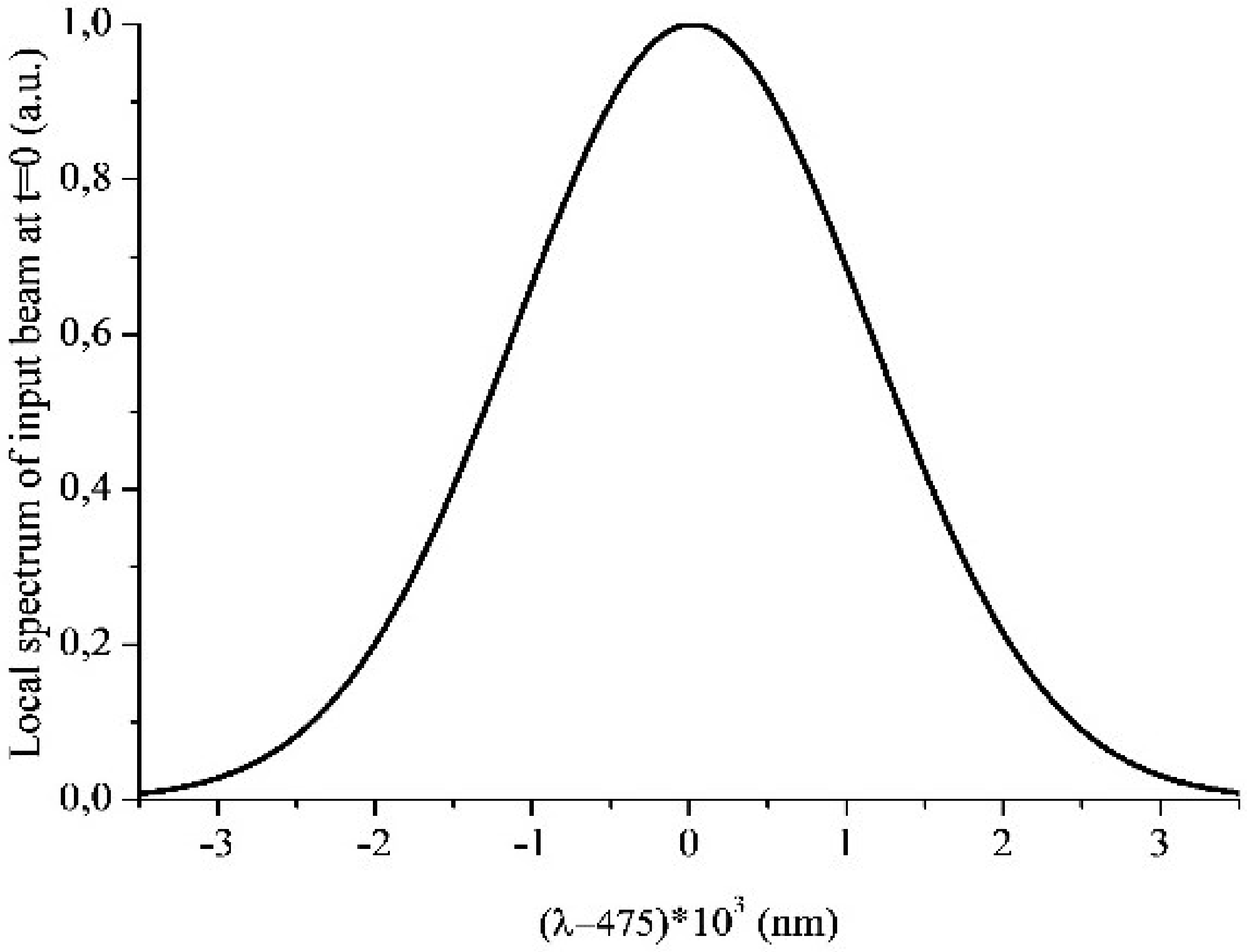
$$I(t) = \int_{-\infty}^{\infty} W(t,w)dw = \rho_0^2 \frac{\tau_0}{\tau_z}\, exp\{-at^2\};$$

$$S(w) = \int_{-\infty}^{\infty} W(t,w)dt = \rho_0^2\, \tau_0 \sqrt{\frac{a}{a^2+\beta^2}} . \times \exp\{(w-w_0)^2 \left(-\frac{a}{(a^2+\beta^2)}\right);$$

τ_z - Is the pulse duration of the frequency-modulated laser beam at a distance z in a dispersing medium.

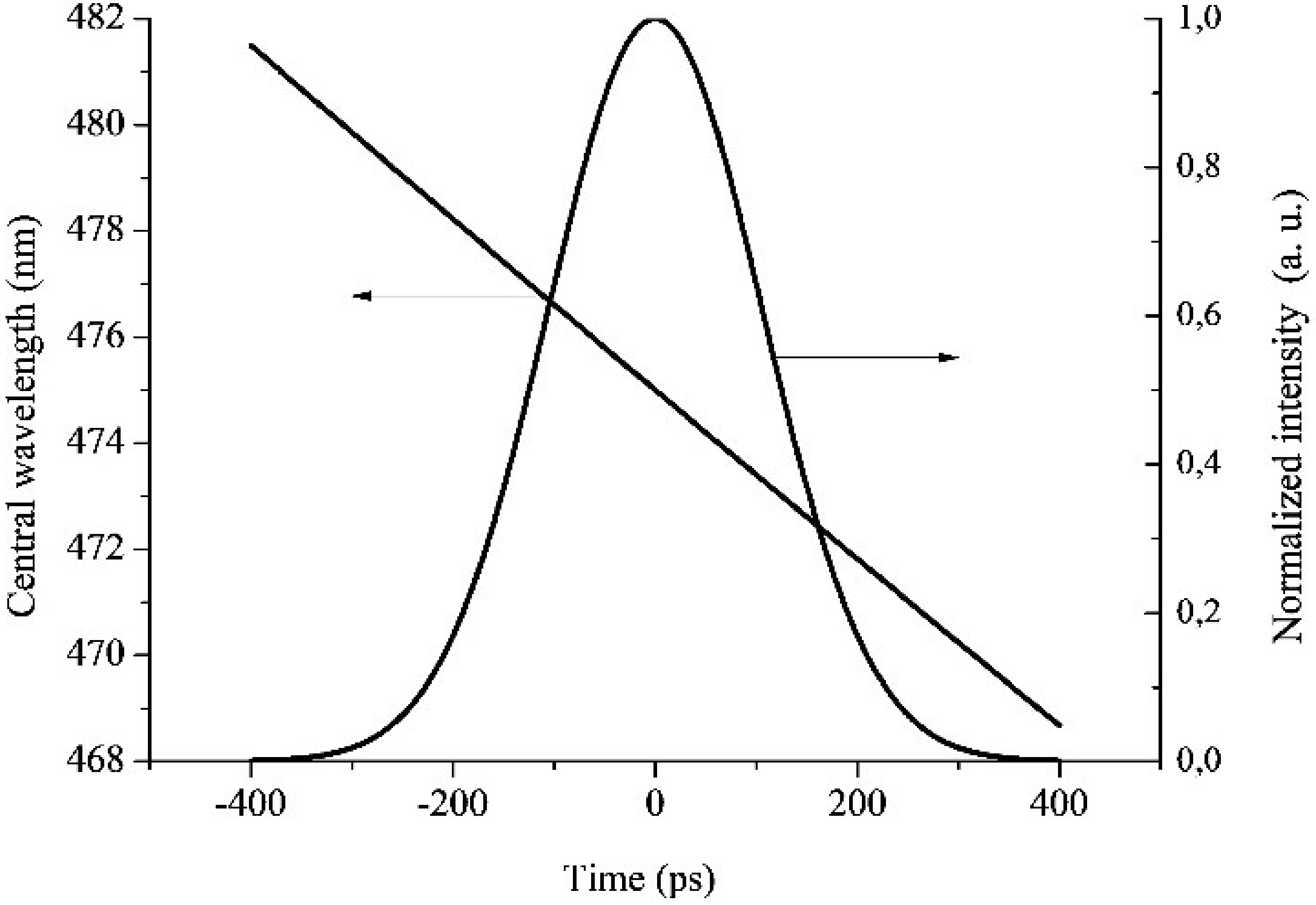


Normalized Wigner function of a spectrally limited laser beam. FWHM τ_0 = 60 fs, λ_0= 475 nm



Normalized local spectrum $S(\lambda)$ in the center of the laser beam (t =0), obtained at $\tau_0 = 60$ fs in the case of the chirped pulse duration FWHM $\Delta t = 250$ ps. The width $S(\lambda)$ FWHM is $\approx 3\ 10^{-3}$ nm. In this wavelength range, the relative change in the induced radiation cross section at the XeF (C – A) transition does not exceed 10^{-3} % and it can be neglected. The frequency $w_{max}(t)$ at which $I_w(t, w)$ reaches its maximum value is proportional to the time and coefficient β.

$$w_{max}(t) = \beta t + w_0$$



Normalized intensity of input chirped radiation and central wavelength of local spectrum as a functions of time

Photon flux

$$F(t) = I(t)/hw_{max}(t) = \frac{W_0}{hw_{max}(t)} exp\left\{-\frac{1}{\tau_z^2}t^2\right\}; \qquad W_0 = \rho_0^2\ \frac{\tau_0}{\tau_z}$$

$$F_{in}(\alpha, r, t) = F(t) \cdot \exp\left(-2\frac{r^2}{R_0^2}\right)$$

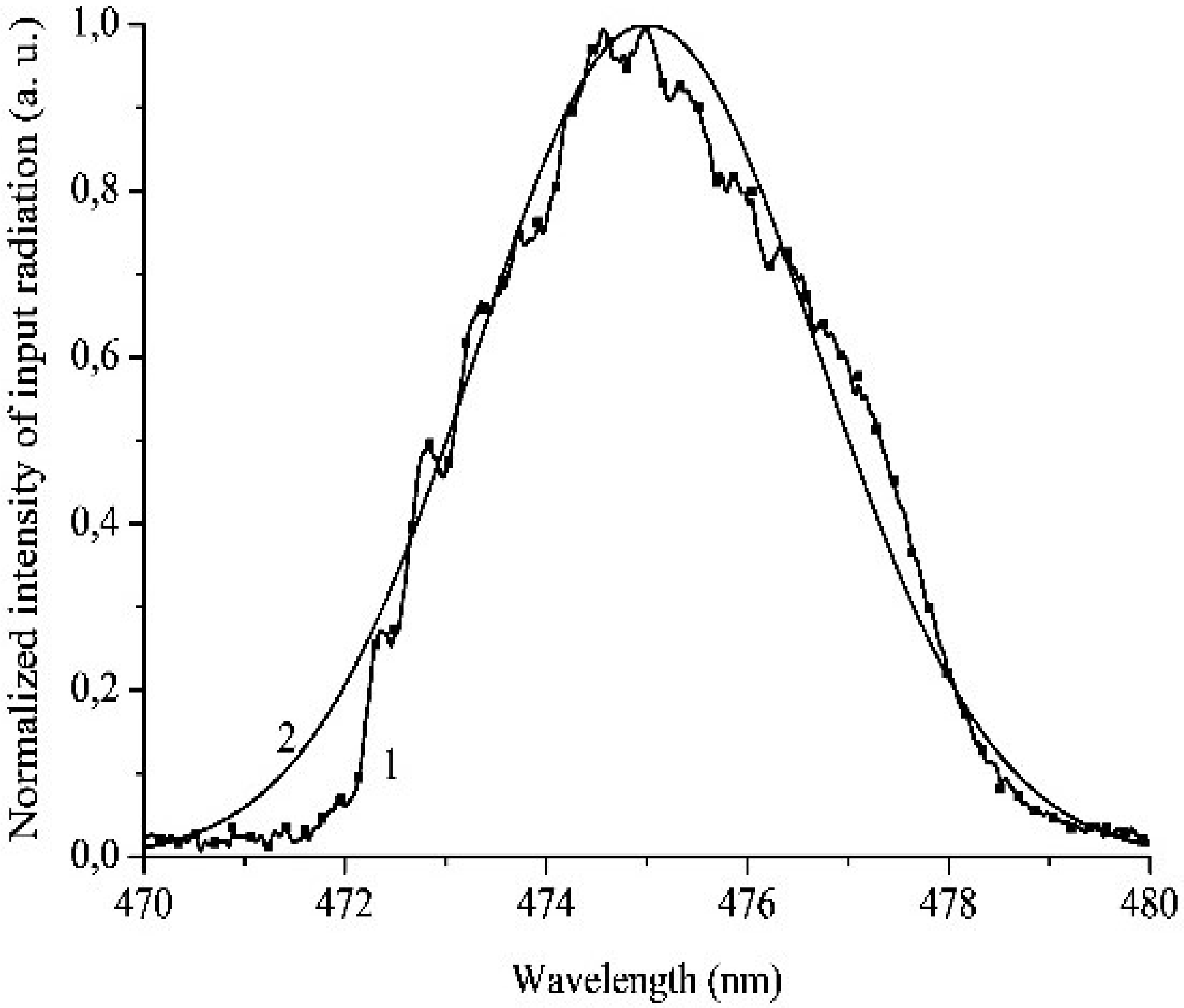
R_0 – radius of input pulse by the level $1/e^2$, ρ_0^2 – was determined from the normalization of F_{in} to number of photons of the input radiation with an energy E_{in}.

The spatial-temporal distribution of the laser photon flux density $F(\alpha,r,z_l,t_l)$ and the density of XeF (C) - $n_C(\alpha,r,z_l,t_l)$ were found from the solutions of the system of equations, written in moving coordinate system associated with the amplifier:

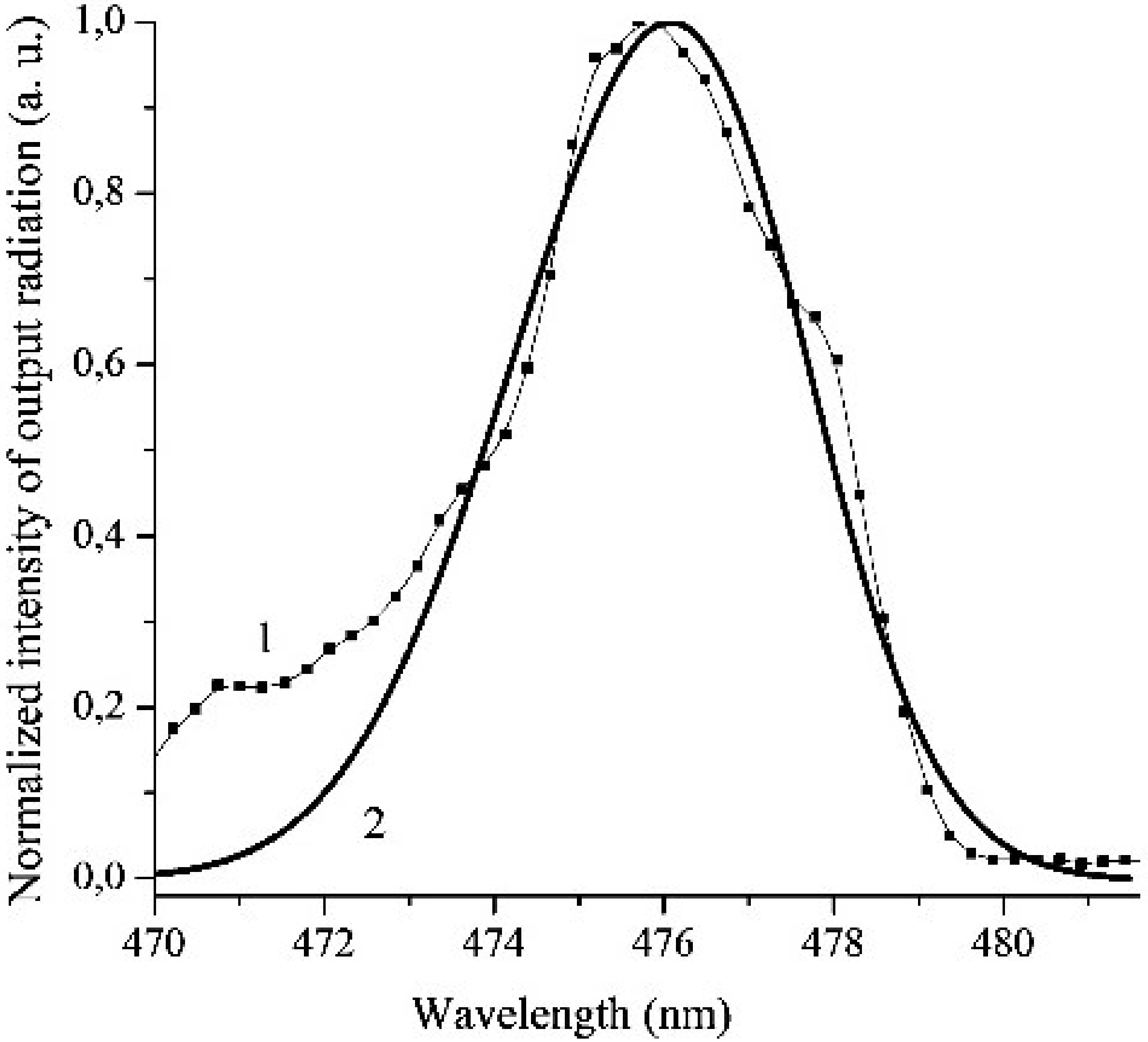
$$\left[\frac{\partial}{\partial z_l} + K_R + \frac{1}{c}\frac{\partial}{\partial t_l} - n_{\mathrm{C}}(a, r, z_l, t_l) \cdot \sigma_{CA}(\lambda)\right] \times\ F(a, r, z_l, t_l,) = 0;$$

$$\left[\frac{\partial}{\partial \eta} + \sigma_{CA}(\lambda) \cdot\ F(a, r, z, \eta)\right] \cdot n_{\mathrm{C}}(a, r, z, \eta) = 0$$

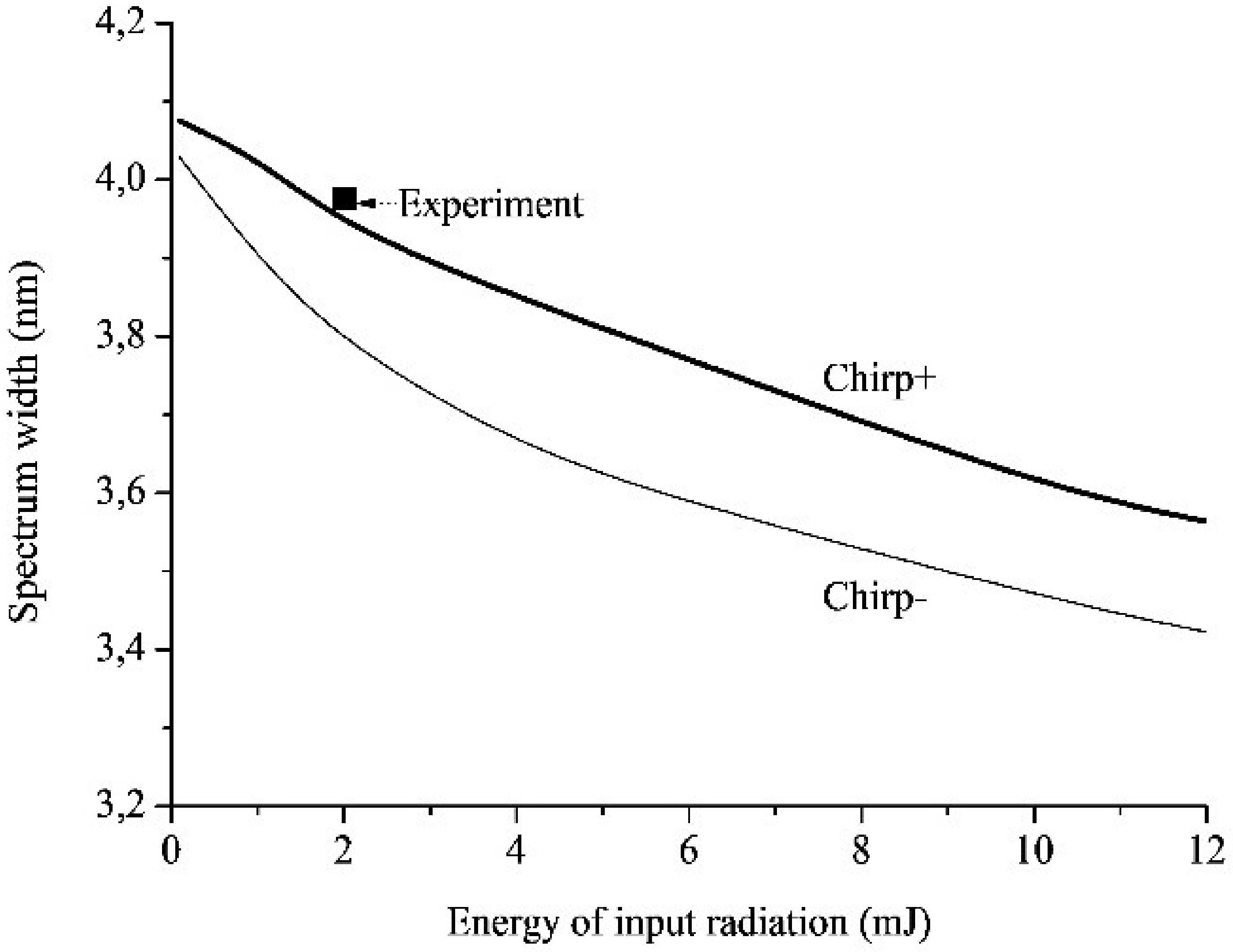
Here: K_R is the attenuation coefficient of the photon flux density of laser radiation due to beam expansion; σ_{CA} (λ) is the cross section of the induced radiation, depending on the wavelength.



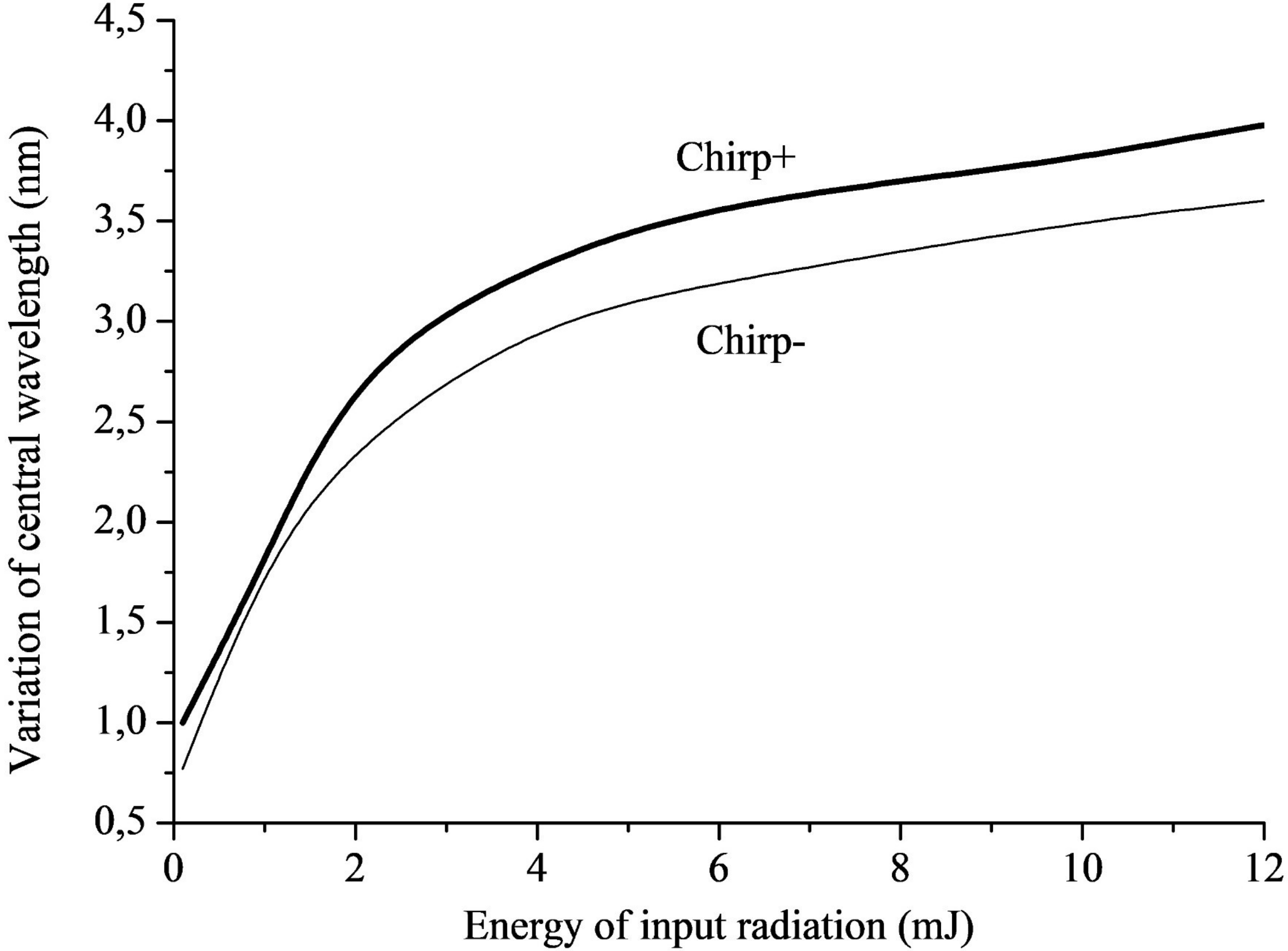
Spectra of radiation on the input window of amplifier. 1 – Experimental data, 2 – calculation result



Spectra of radiation on the output window of amplifier.
1 – Experimental data, 2 – calculation result. E_{in}= 0.1 mJ



Calculated output radiation spectrum width (FWHM)
as a function of input energy



Central wavelength of output radiation as a function of input radiation energy

CONCLUSION

Based on the Wigner time-frequency distribution for the energy density of electromagnetic radiation, a numerical model is constructed for calculating the evolution of the spectra upon amplification of chirped radiation in the XeF (C-A) amplifier of the THL-100 laser system. The model demonstrate the good agreement between the calculated and experimental radiation spectra at the input and output of the amplifier. The poster presents the numerical study results of the influence of input energy on the output radiation spectra evolution of the amplifier XeF (C-A) for the mode of positive and negative chirps.