Influence of Laser Pulse Duration on Filamentation Process in LiF

A.V. Kuznetsov, V.P. Dresvyanskiy

Irkutsk branch of Institute of laser physics SB RAS

a.v.kuznetsov@bk.ru

Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.

Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.

Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.
- Electrons in conduction band reduce effective refractive index of material.

Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.
- Electrons in conduction band reduce effective refractive index of material.
- Intensity growth is limited by order of magnitude $\approx 10^{13\text{-}14}$ W/cm^2.

Femtosecond laser filamentation

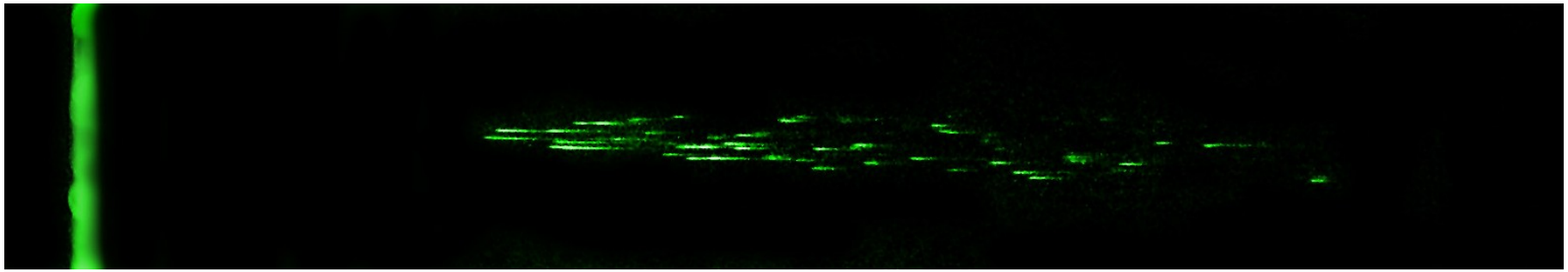
- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.
- Electrons in conduction band reduce effective refractive index of material.
- Intensity growth is limited by order of magnitude $\approx 10^{13\text{-}14}$ W/cm^2.
- The balance of self-focusing, diffraction and plasma defocusing leads to formation of light and plasma filaments.

Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.
- Electrons in conduction band reduce effective refractive index of material.
- Intensity growth is limited by order of magnitude $\approx 10^{13\text{-}14}$ W/cm^2.
- The balance of self-focusing, diffraction and plasma defocusing leads to formation of light and plasma filaments.
- In LiF crystals e-h pairs and excitons can transform to stable defects, including fluorescent F_2 and F_3^+ color centers [L. Courrol et al. Optics express, **12**, (2004), E.F. Martynovich et al., Quantum Electronics **43**, (2013)].

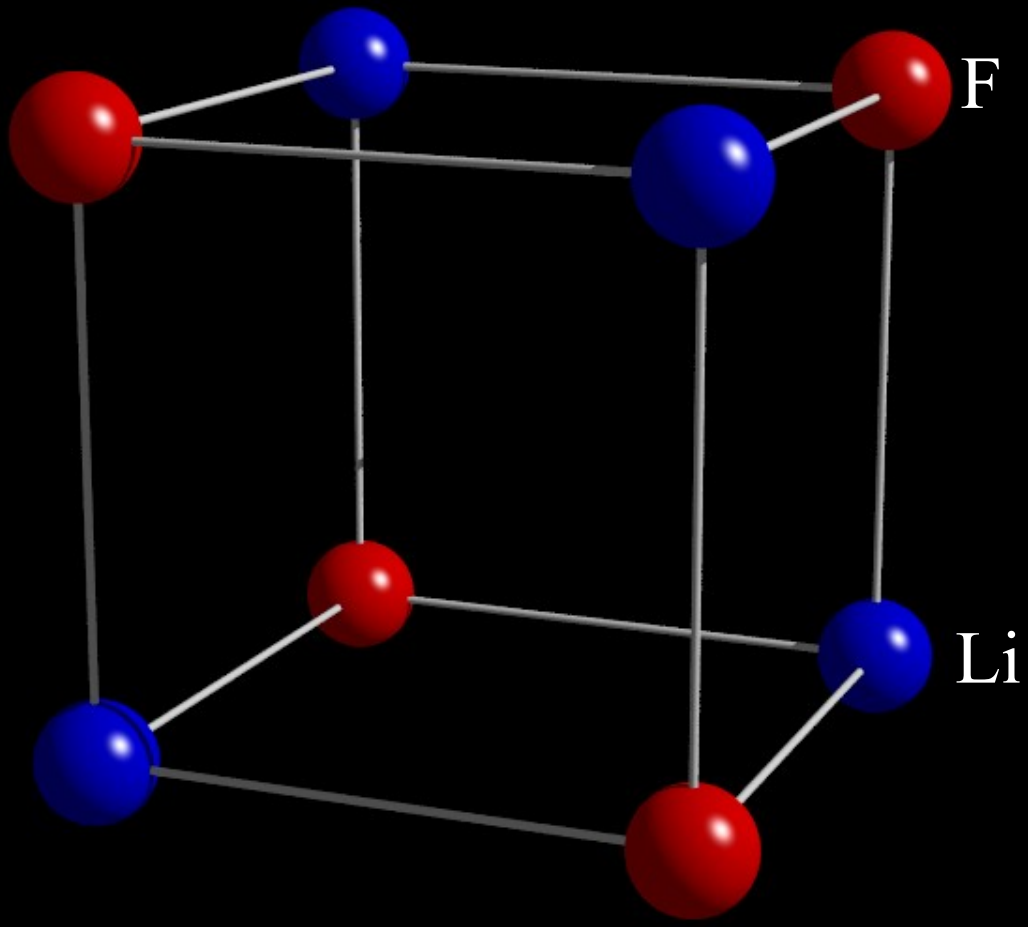
Femtosecond laser filamentation

- Self-focusing leads to lateral compression of laser pulses.
- Increase of intensity results in nonlinear photoionization.
- Electrons in conduction band reduce effective refractive index of material.
- Intensity growth is limited by order of magnitude $\approx 10^{13\text{-}14}$ W/cm^2.
- The balance of self-focusing, diffraction and plasma defocusing leads to formation of light and plasma filaments.
- In LiF crystals e-h pairs and excitons can transform to stable defects, including fluorescent F_2 and F_3^+ color centers [L. Courrol et al. Optics express, **12**, (2004), E.F. Martynovich et al., Quantum Electronics **43**, (2013)].

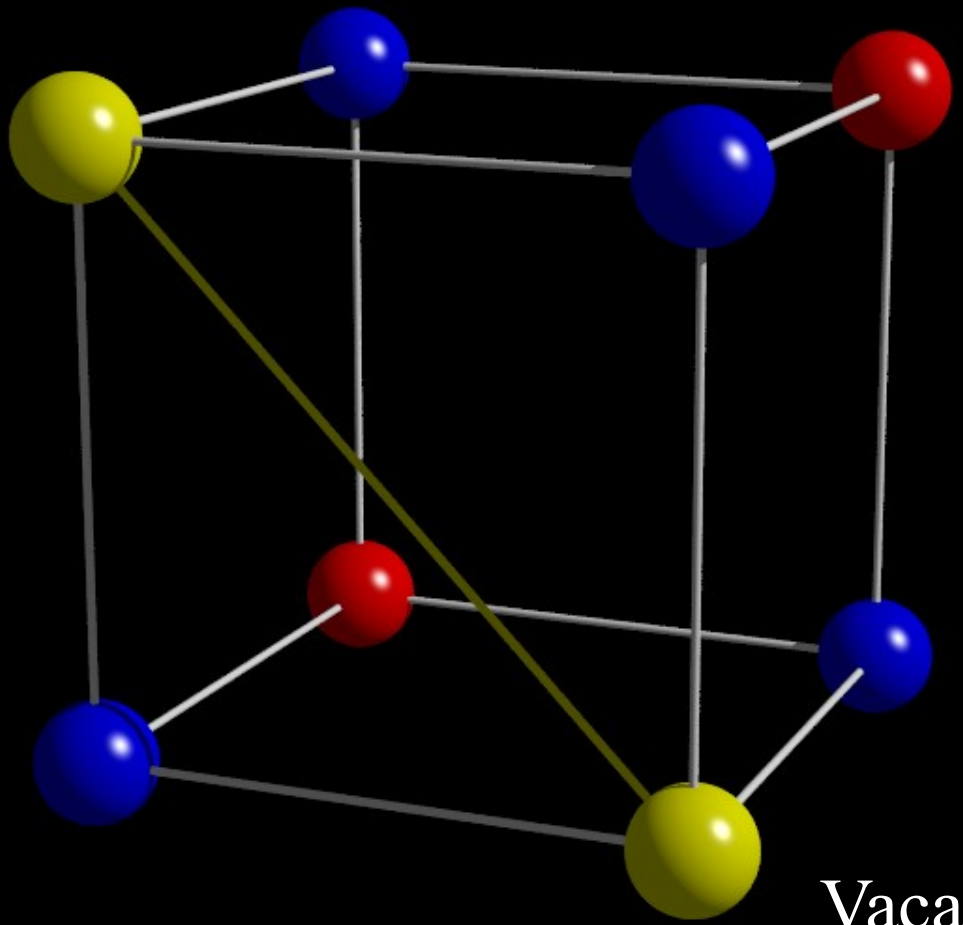


Traces of filamentation of Ti-Sapphire laser pulse in LiF: 30 fs, 850 nm, 0.5 mJ

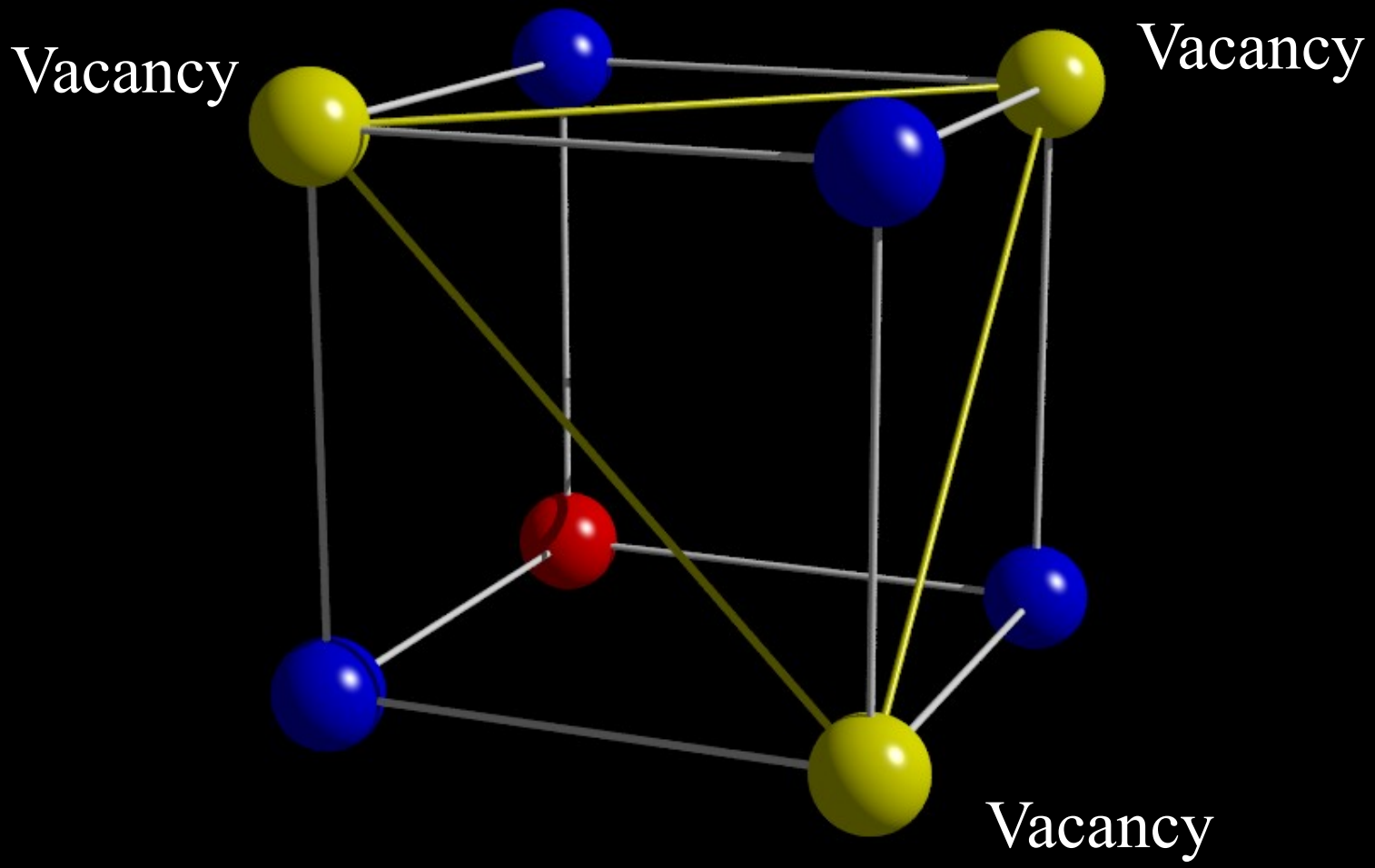
LiF crystal lattice cell



F_2 color center



F_3^+ color center



Spectral bands of color centers in LiF

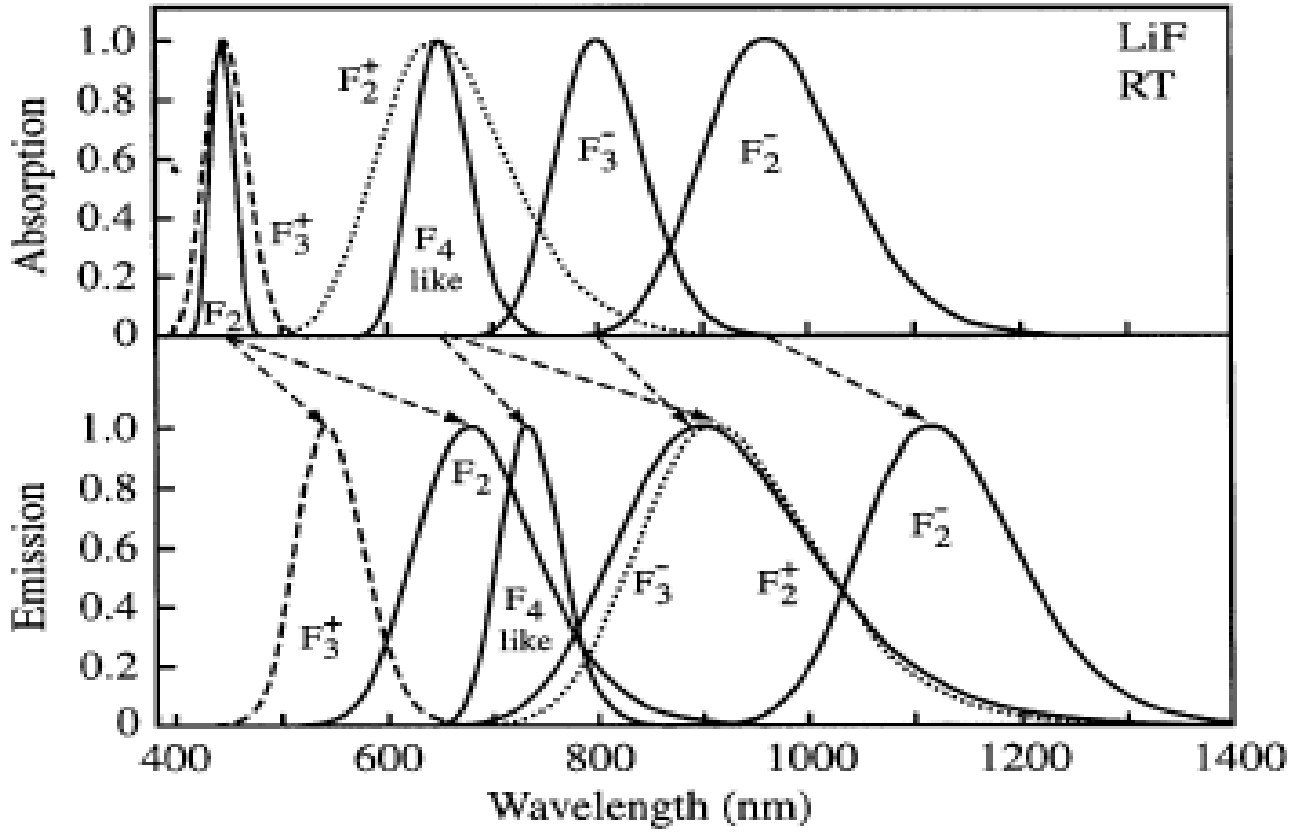


Fig. 3. Schematic absorption and emission bands, in a colored LiF crystal, belonging to CCs which are known to posses also photoluminescence.

G. Baldacchini, 2002.

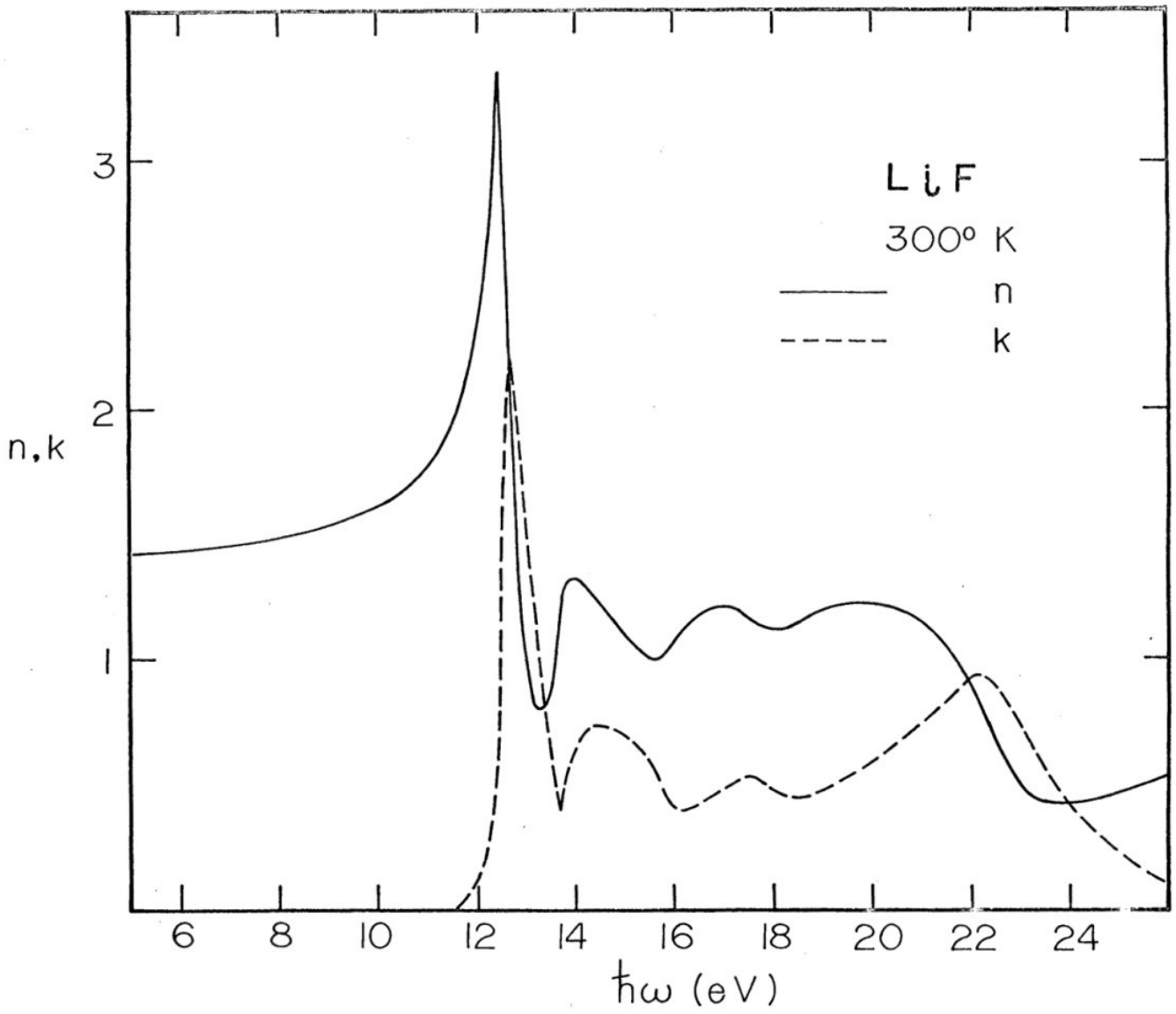
Goal of this work

The goal of our investigation is to study theoretically the dependence of ionization efficiency of LiF on duration of laser pulses.

Motivation

Prediction of possibility of experimental determination of the contribution of avalanche ionization to overall nonlinear photoionization process.

Energy of 13-14 eV is necessary for one e-h pair creation



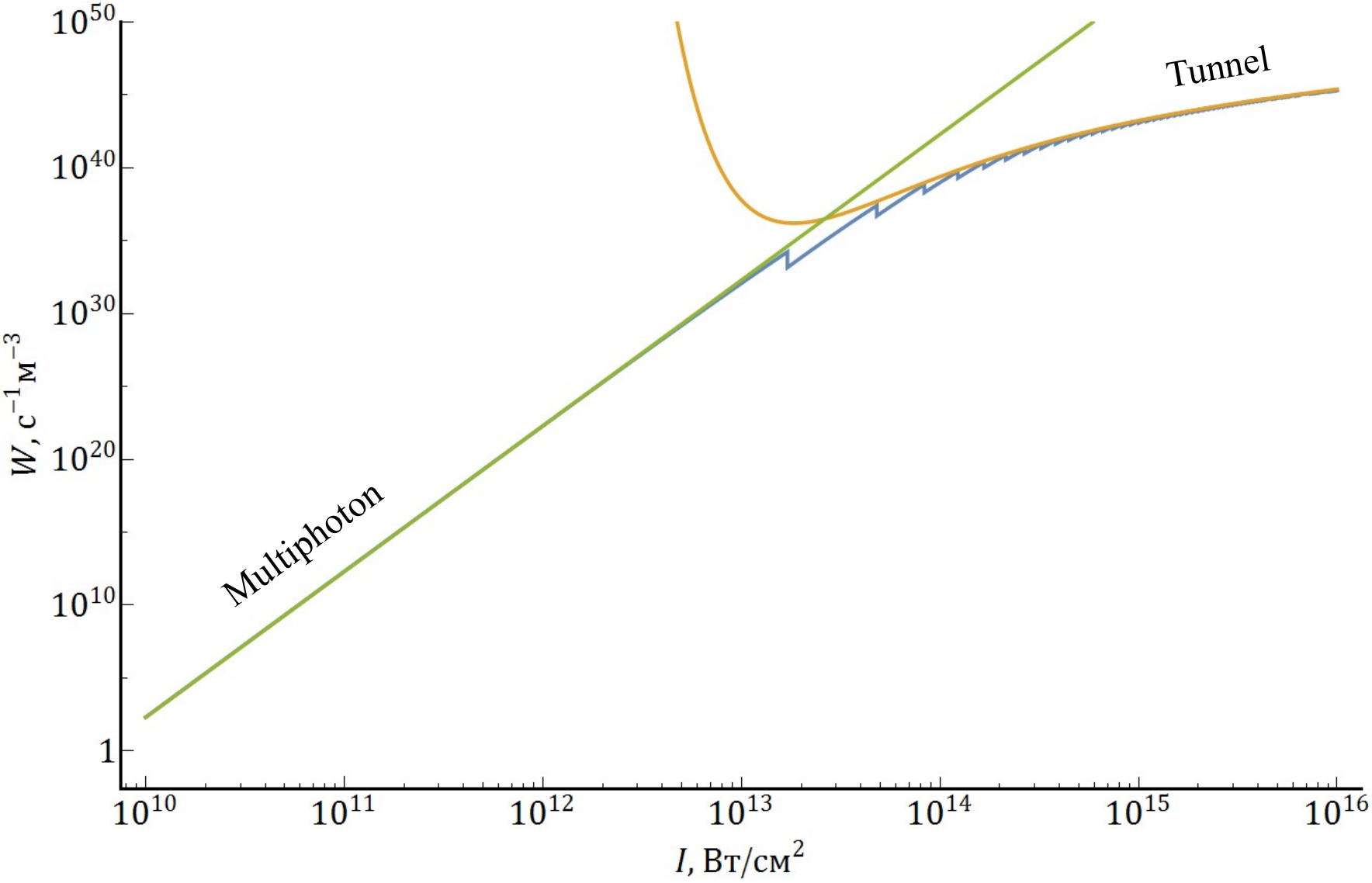
D.M. Roessler, W.C. Walker, J. Opt. Soc. Am. – 1967. – V. 57. – P. 835-836

Mechanisms of nonlinear photoionizanion

Multiphoton-tunnel ionization: nonlinear in intensity / linear in time.

Avalanche ionization: linear in intensity / nonlinear in time.

Multiphoton-tunnel ionization rate in LiF (λ=800 nm)



Avalanche ionization

Electrons in conduction band are accelerated by electric field of laser pulse. They «knock out» new electrons from valence band.

$$\frac{\partial \rho}{\partial t} = \frac{|A|^2 e^2}{2U\omega_0^2 m_e \tau_c}\rho$$

Evolution of plasma density ρ

$$\frac{\partial \rho}{\partial t} = \left(W\left(|A|\right) + \frac{|A|^2 e^2}{2U\omega_0^2 m_e \tau_c}\rho \right)\left(1 - \frac{\rho}{\rho_{\max}}\right) - \beta\rho$$

Multuphoton-tunnel ionization

Avalanche ionization

Saturation

Recombination

Model of pulse propagation

Filamentation model is based on nonlinear Schrödinger equation that is derived from Maxwell equations with introduction of some approximations. Initial pulse profile is Gaussian.

$$\frac{\partial A_j}{\partial z} = \left(-i\frac{c}{2\omega_0 n_0}\Delta_\perp + i\frac{1}{2}k_2\frac{\partial^2}{\partial \tilde{t}^2} - i\frac{\omega_0}{c}\left[n_2\left|A_j\right|^2 - \frac{2\pi e^2 N_e}{n_0\omega_0^2 m_e}\right] - \frac{2\pi e^2 N_e}{c n_0 \omega_0^2 m_e \tau_c} - \frac{4\pi}{c n_0}\frac{U}{\left|A_j\right|^2}W\left(\left|A_j\right|\right)\right) A_j$$

Diffraction

Dispersion of group velocity

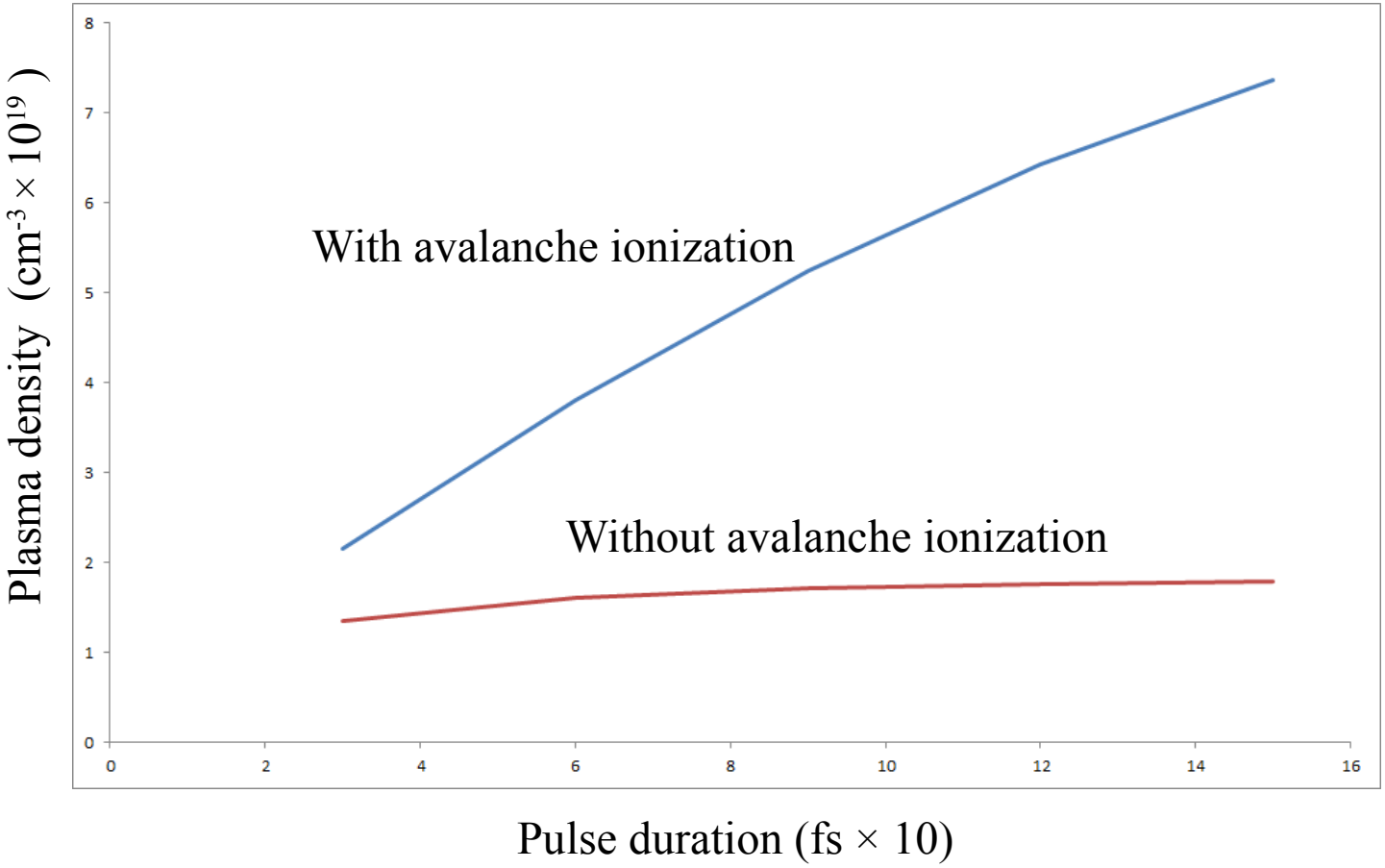
Self-focusing

Plasma defocusing

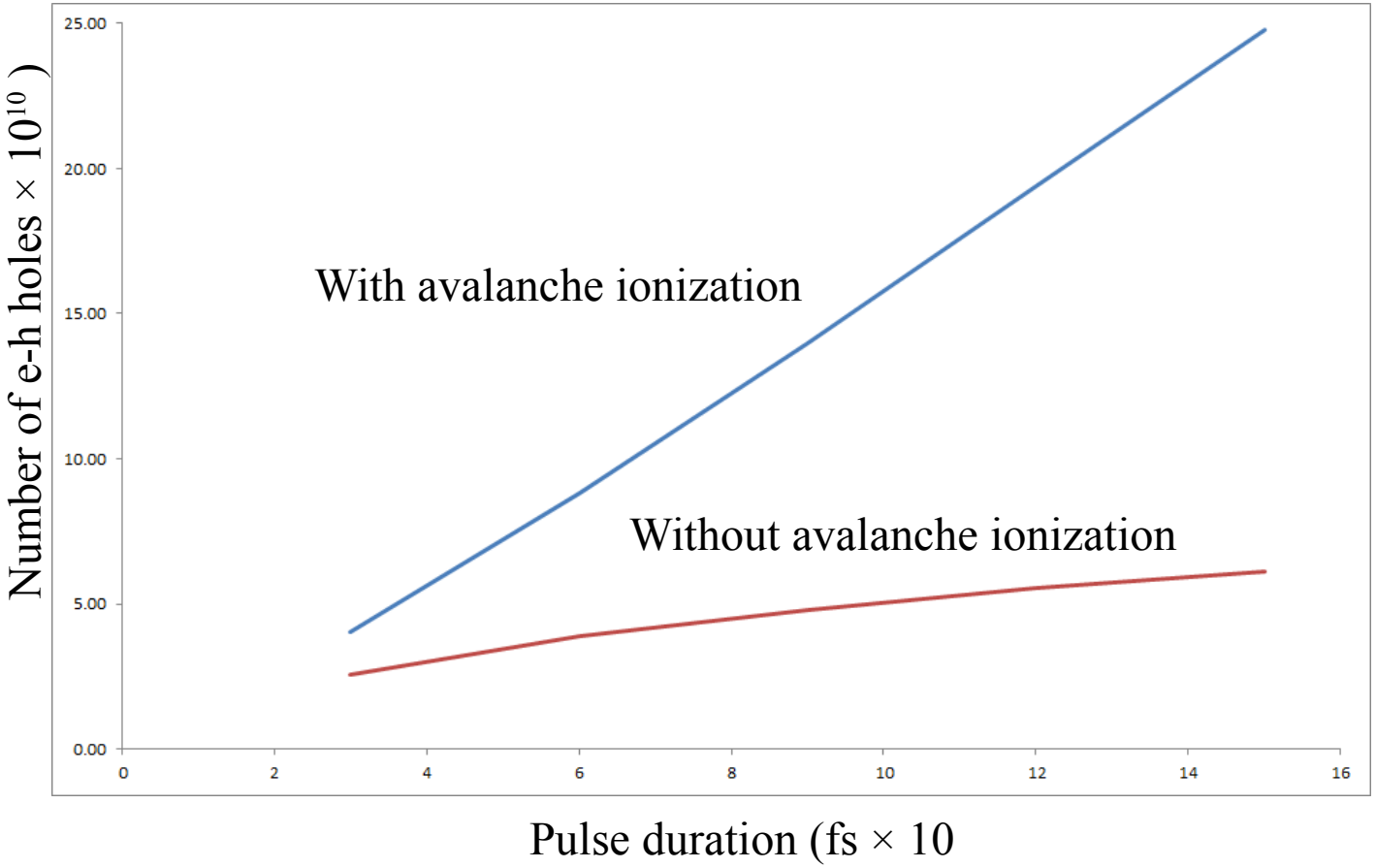
Plasma absorption

Multiphoton-tunnel ionization

Dependence of the maximum plasma density on pulse duration



Dependence of total plasma amount on pulse duration



Conclusion

Simulations predict that account of avalanche ionization qualitatively influences the form of e-h pairs number dependence on pulse duration. This fact can be used for experimental determination of the contribution of avalanche ionization to overall nonlinear photoionization process.