Numerical model for femtosecond pulse propagation in hollow core fibers

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Abstract. A numerical model used to obtain pulsed field configuration along and across a hollow core dielectric waveguide filled with an ionizing gas and operated as a device for high harmonics generation is presented. The model was developed for an arbitrary gas density profile and arbitrary fiber diameter variation. The results of the calculation were tested against experimental measurements and excellent agreement was obtained for the fluorescence emission along the waveguide.

The free space propagation

$$\nabla^2 E_1(r,z,t) - \frac{1}{c^2}\frac{\partial^2 E_1(r,z,t)}{\partial t^2} = \frac{\omega^2}{c^2}(1-\eta_{eff}^2)E_1(r,z,t)$$

$$\eta_{eff}(n_a,n_e,r,z,t) = \eta_0(n_a)+\eta_2(n_0)I(r,z,t) - \frac{\omega_p^2(n_e,r,z,t)}{2\omega^2}$$

After going to moving frame z', paraxial approx. and FT:

$$\nabla_\perp^2 \tilde{E}_1(r,z',\omega) - \frac{2i\omega}{c}\frac{\partial \tilde{E}_1(r,z',\omega)}{\partial z'} = \tilde{G}(r,z',\omega)$$

The guided propagation

Linear step

$$\nabla_\perp^2\tilde{E}_1(r,z',\omega) - \frac{2i\omega}{c}\frac{\partial\tilde{E}_1(r,z',\omega)}{\partial z'} = 0$$

$$\tilde{E}_1(r,z',\omega) = \sum_j b_j(z',\omega) J_0(\mu_j r/a)\exp\left(i\int_0^{z'}\gamma_j(z)dz\right)$$

$$b_j = \int_0^a r J_0\left(\mu_j \frac{r}{a}\right) E_1(r)dr$$

$$b_j(z'+\Delta z') = b_j(z')\cdot\exp(\kappa_j\Delta z' - \alpha_j \Delta z')$$

$$\tilde{E}_1(r,z'+\Delta z',\omega) = \sum_j b_j(z'+\Delta z',\omega)J_0(\mu_j r/a)$$

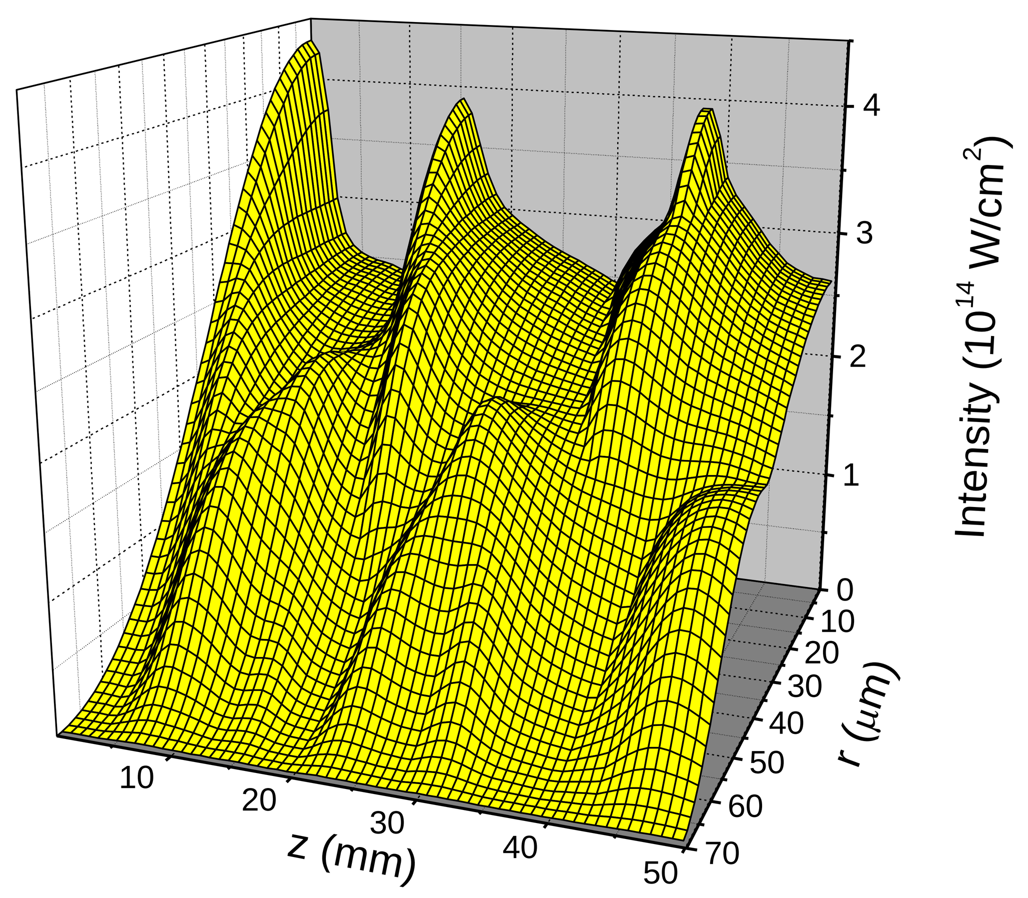
Non-linear step

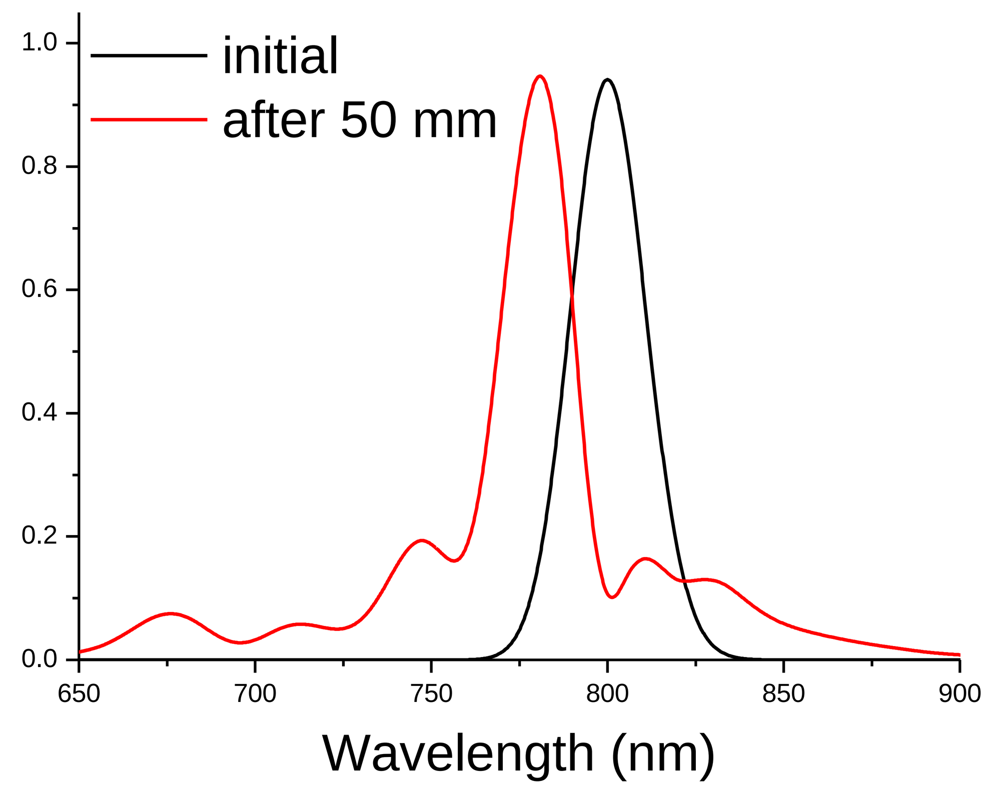
$$-\frac{2i\omega}{c}\frac{\partial \tilde{E}_1(r,z',\omega)}{\partial z'} = \tilde{G}(r,z',\omega)$$

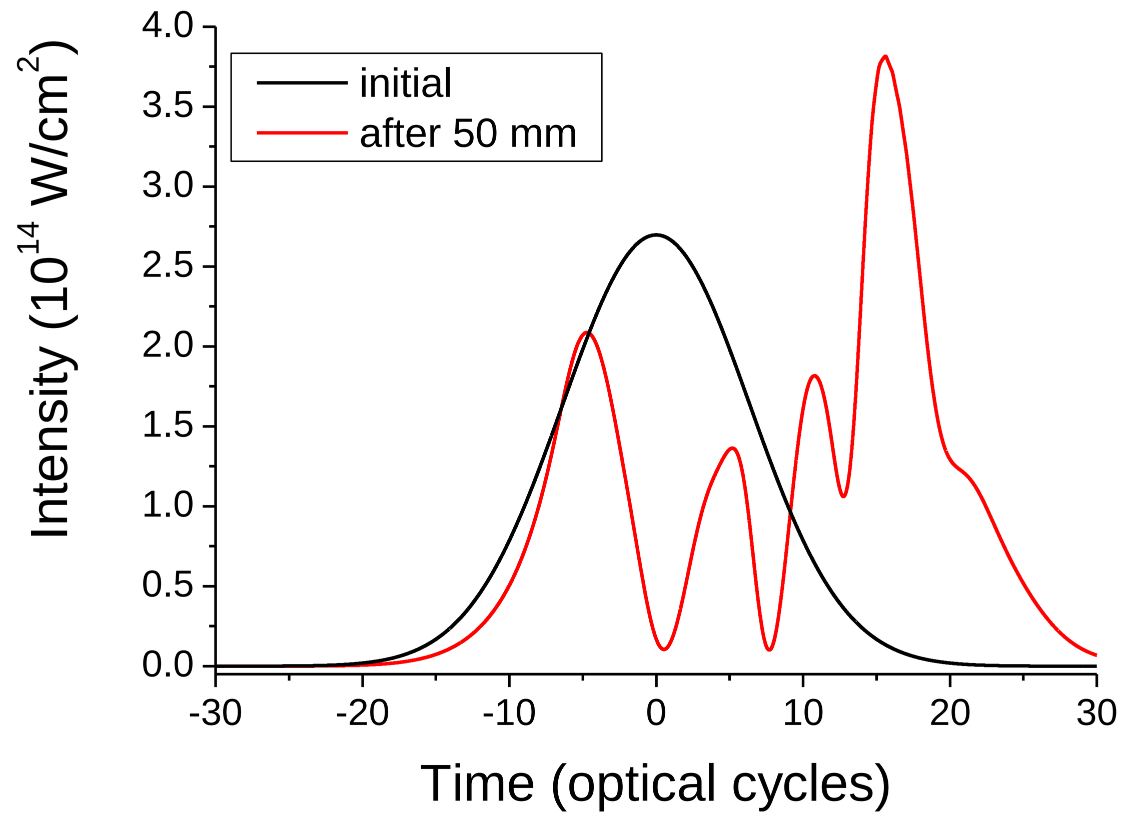
$$\tilde{G}(r,z',\omega) = \hat{F}\left\{\frac{\omega_p^2}{c^2}E_1(r,z',t') - 2\frac{\omega_0^2}{c^2}[\delta_1+\eta_2 I(r,z',t')]E_1(r,z',t')\right\}$$

$E_1(r,z',\omega) \rightarrow E_1(r,z',t) \rightarrow G(r,z',t) \rightarrow G(r,z',\omega) \rightarrow E_1(r,z',\omega) \rightarrow$ *converged?* $\rightarrow$ *OUT*

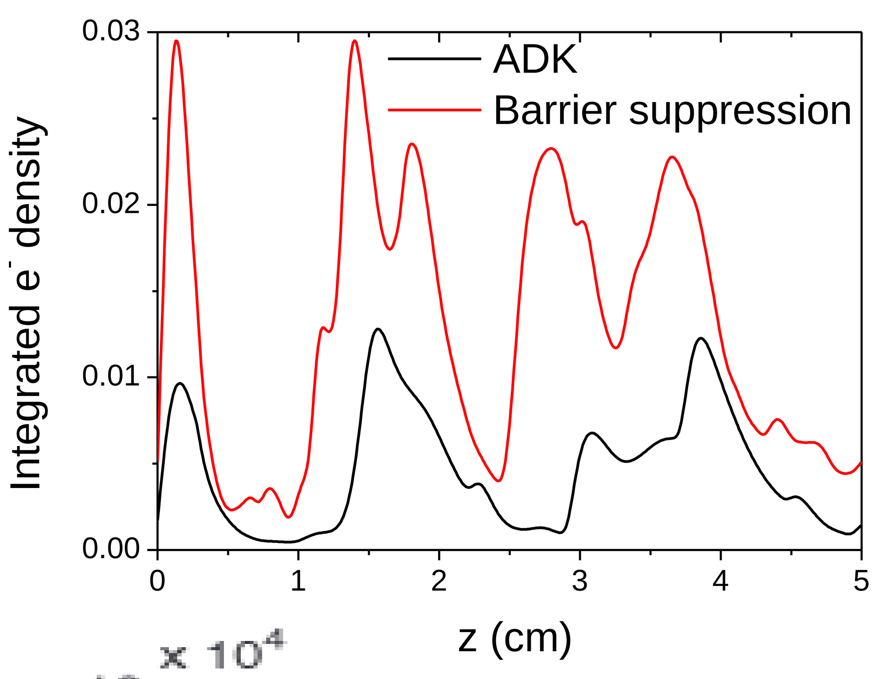
no

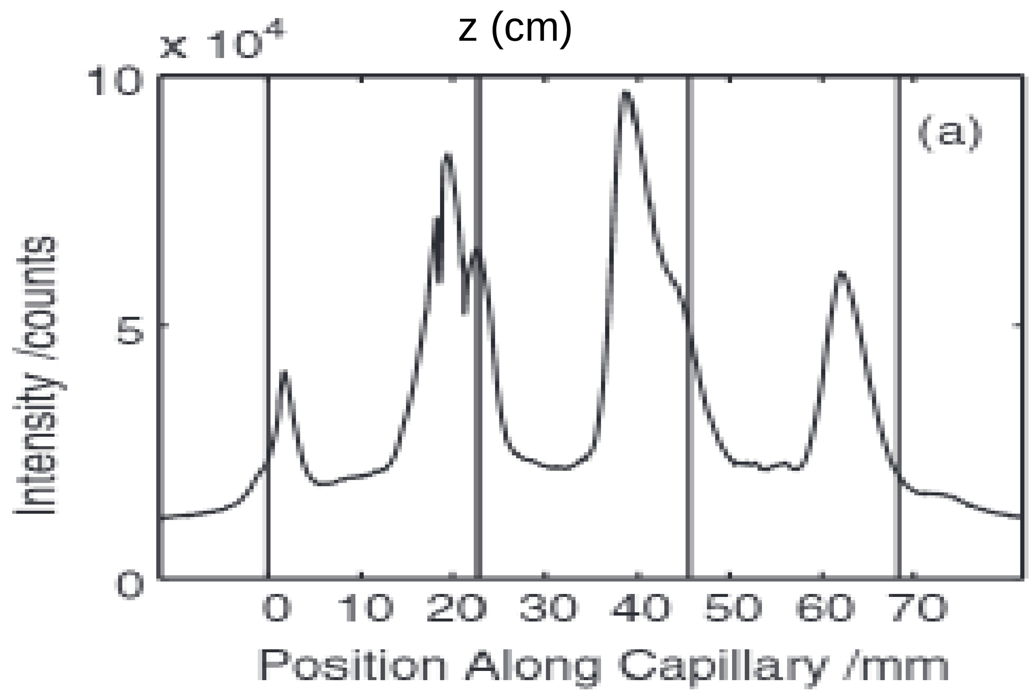




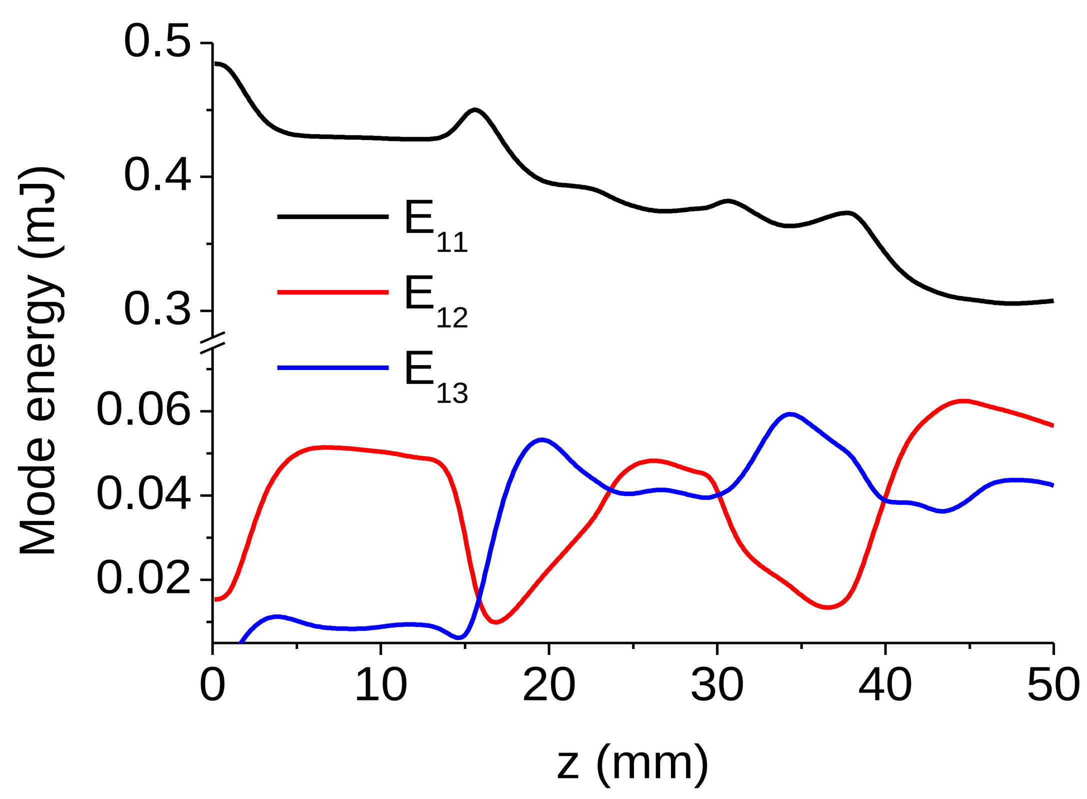


On-axis field in frequency and time

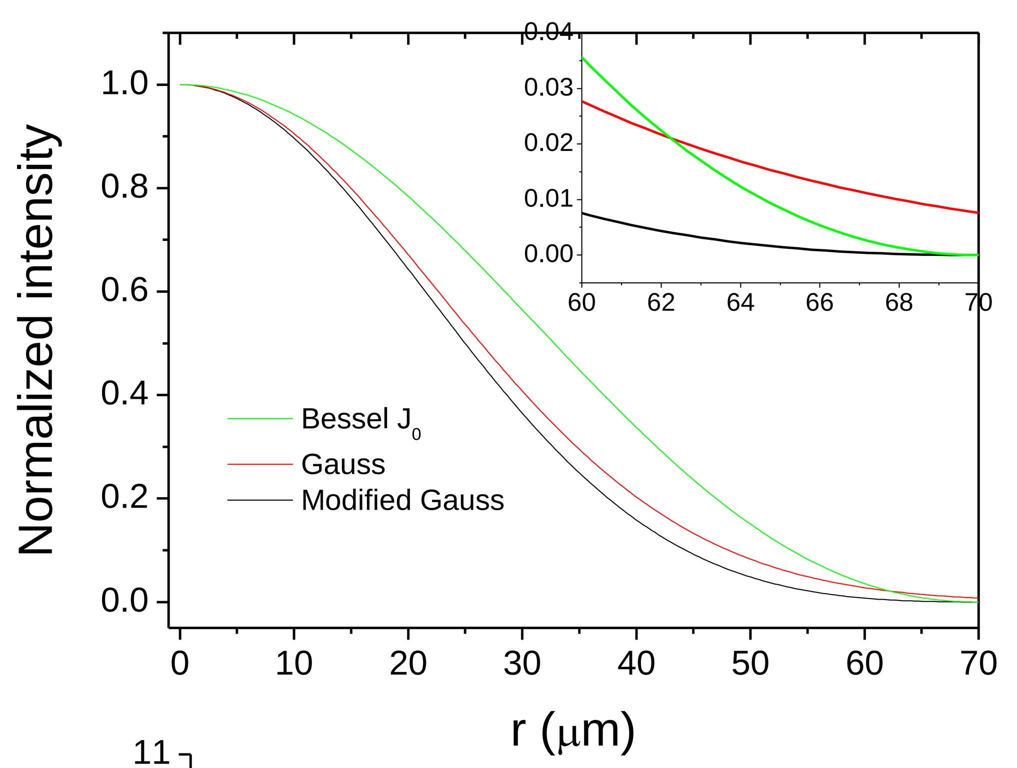


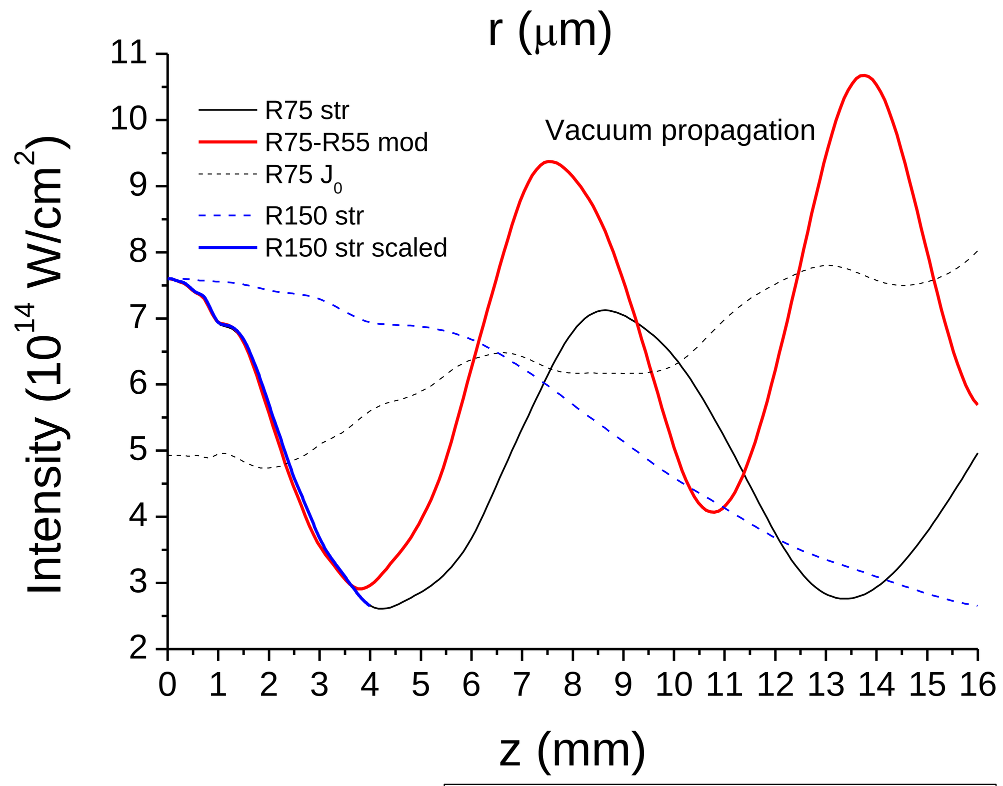


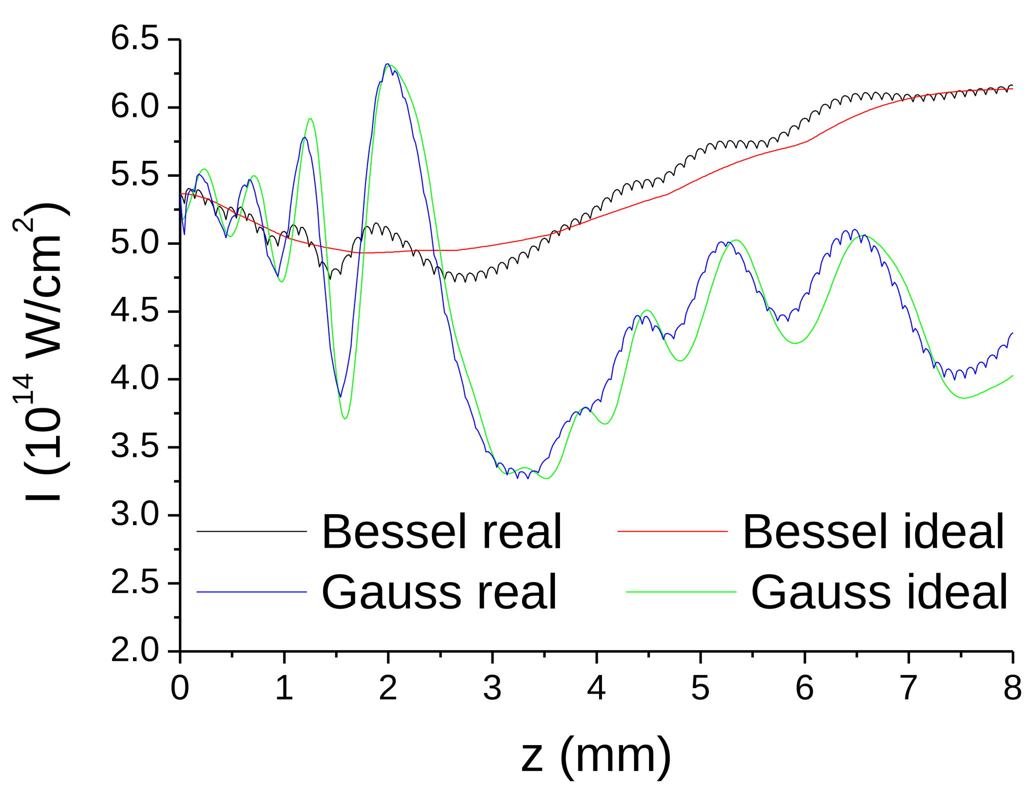
Measured emission of Ar species along propagation
C.A. Froud et al., J. Opt. A **11** 054011 (2009)



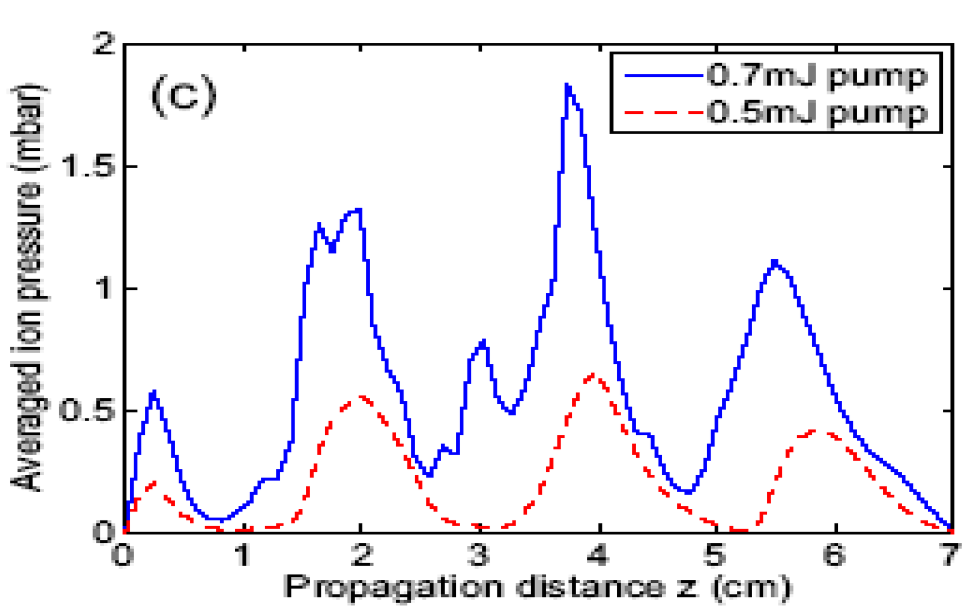
Mode energies evolution







On axis intensity for two initial profiles (Gauss and Bessel) and for ideally straight fiber and real (from fabrication) fiber



Nonlinear Schrodinger equation:
R.T Chapman et al, Opt. Express **18** 13279 (2010)

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