Filamentation of ultrashort laser pulses

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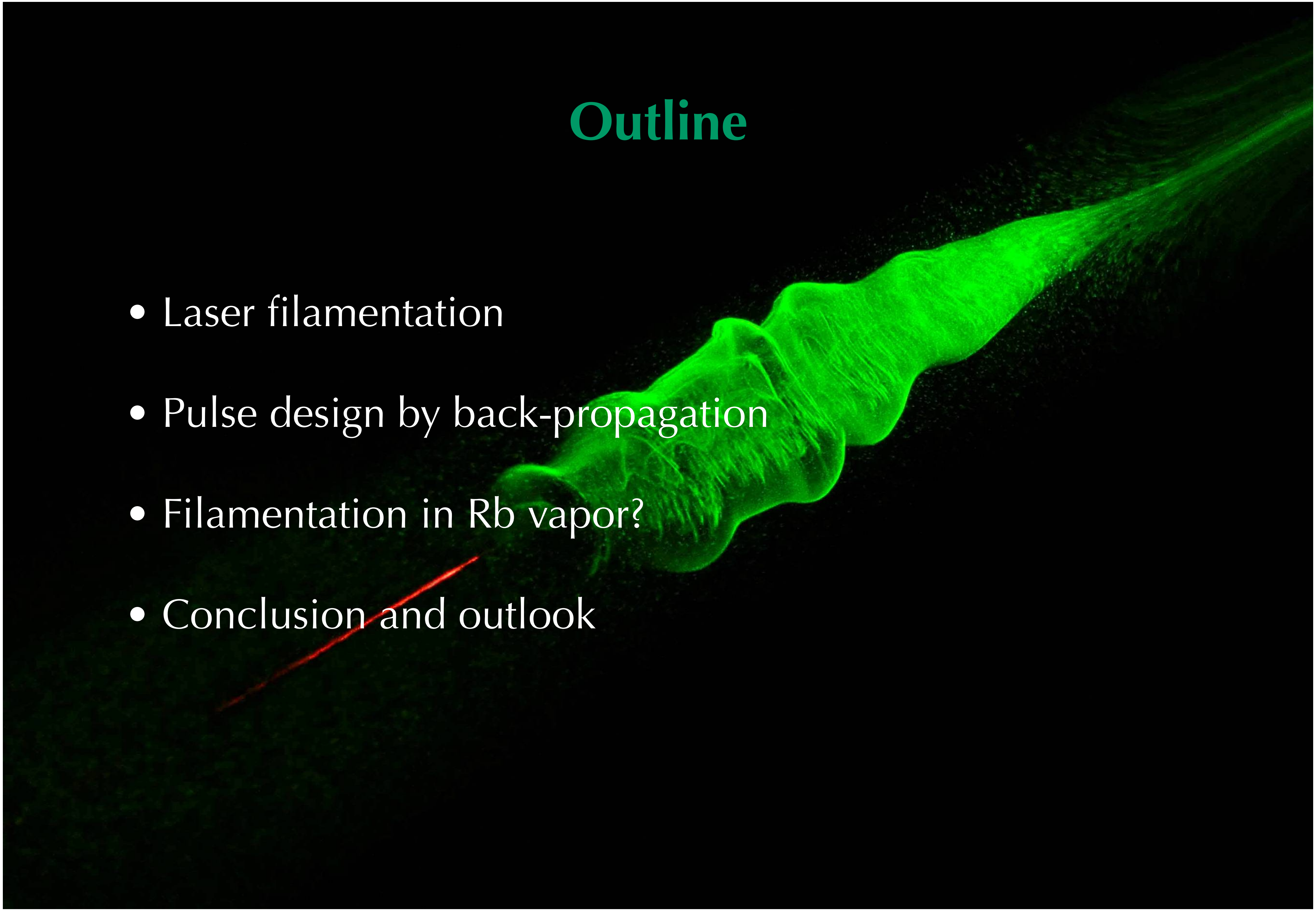
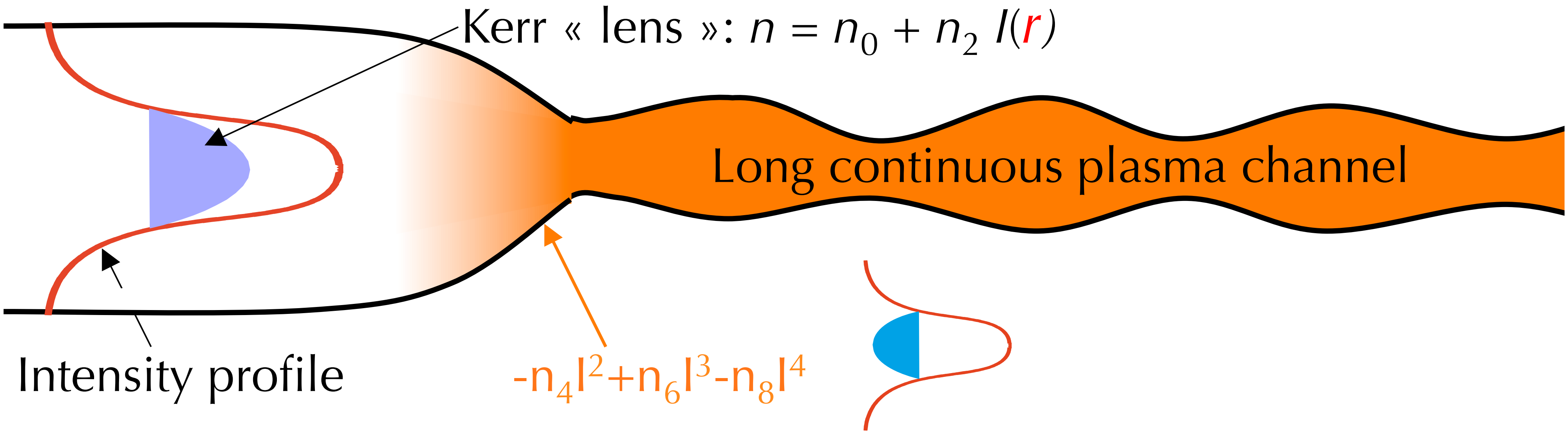
Outline



- Laser filamentation
- Pulse design by back-propagation
- Filamentation in Rb vapor?
- Conclusion and outlook

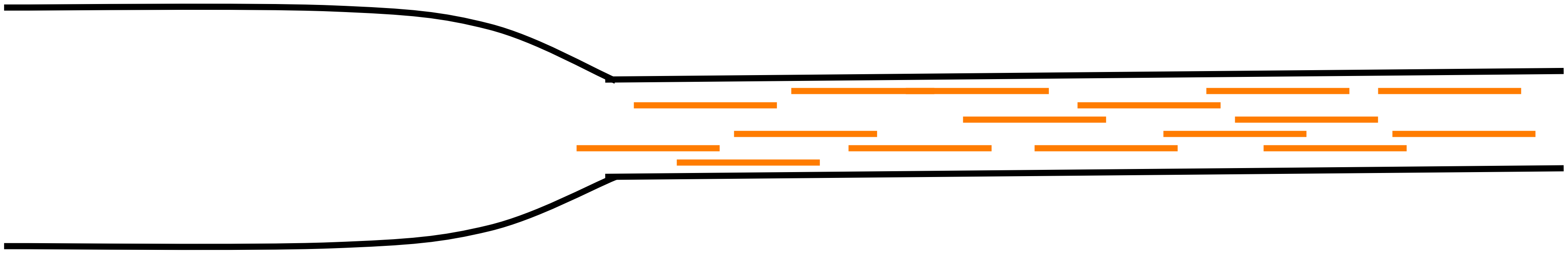
Self-guided propagation of ultrashort pulses



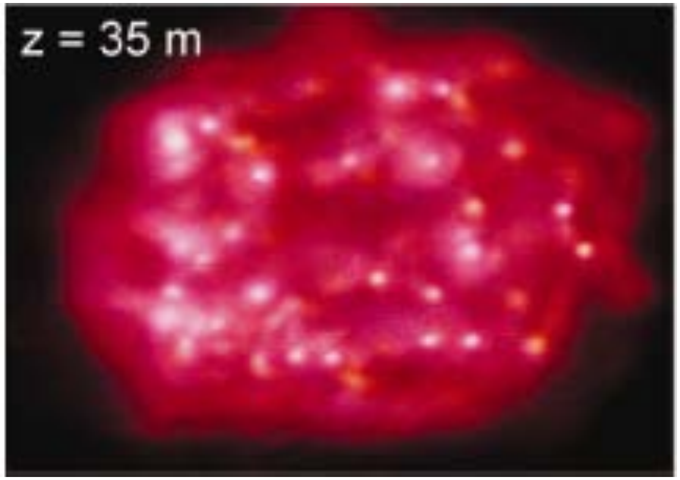
Filament: $\Phi = 100$ µm, $L > 100$ m, $I = 10^{14}$ W/cm^2, $\rho = 10^{15}$ cm^{-3}

Mechanism: PRL **104**, 103903 (2010); *Review*: RPP **70**, 1633 (2007)

High power: multiple filamentation

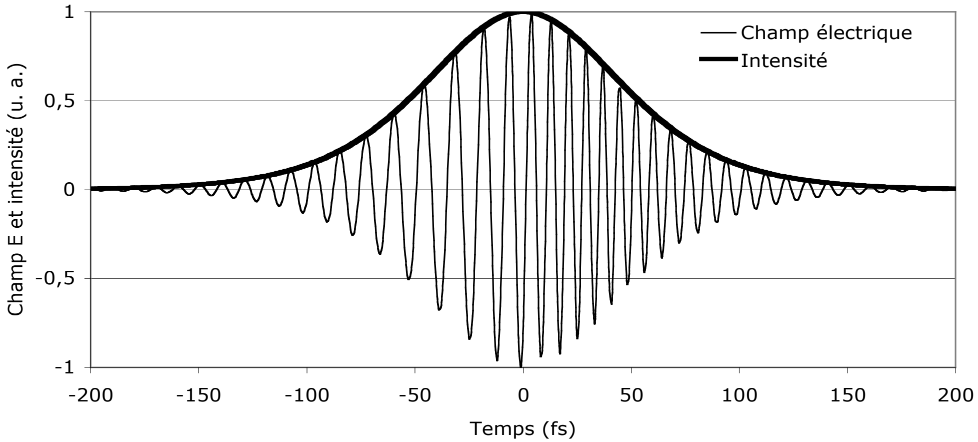


Each filament retains « normal » filaments properties.
Φ = 100 µm, *L* > 100 m, *I* = 10^{14} W/cm^2,
ρ = 10^{15} cm^{-3}

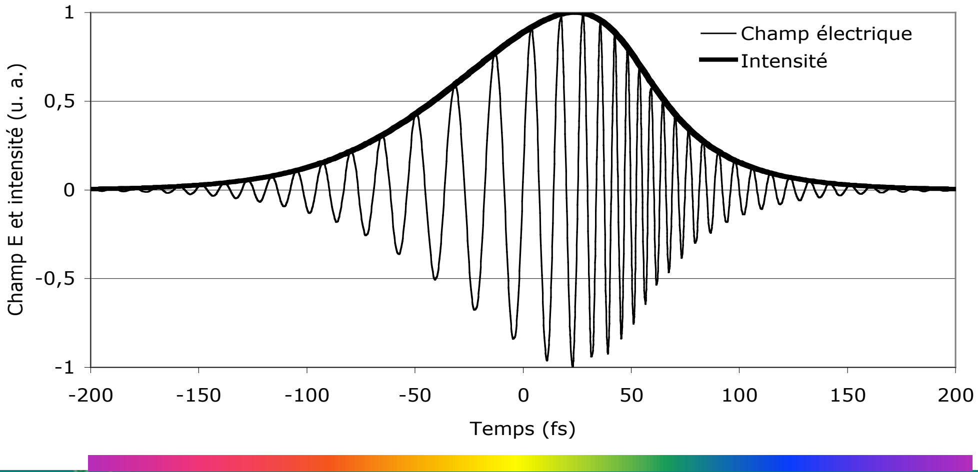


Mechanism: PRL **104**, 103903 (2010); *Review*: RPP **70**, 1633 (2007)

Self-phase modulation



Kerr : $n = n_0 + n_2 I(x,t)$



$$\omega(t) = \frac{d\Phi(t)}{dt}$$

$$= \omega_0 - \frac{n_2 \omega_0}{c} z \frac{dI(t)}{dt}$$

White-light generation

Ultrashort laser filaments

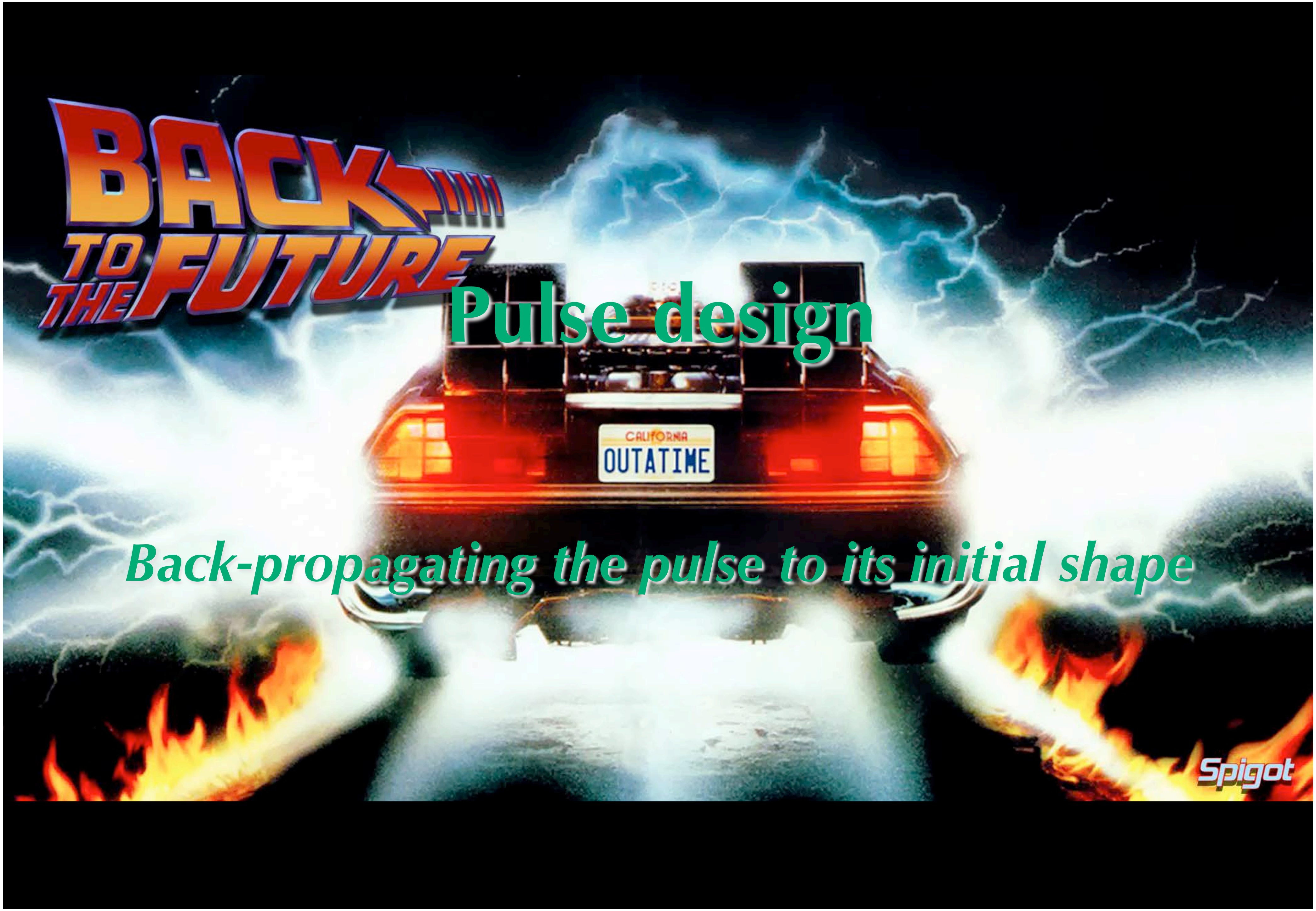
- Non-linear propagation in air : self-guiding
- Long distance propagation
- Propagation in perturbed atmosphere: « cloud-safe » laser
  - Turbulent atmosphere
  - Fog, rain, Reduced pressure
- Continuous plasma channel
  - ϕ = 100 µm
  - Weakly ionised, Conducting: 1 MΩ/m, 10-100 filaments in beam
- Continuous plasma channel
  - Efficient multiphoton photochemistry in plasma: condensation

Promizing candidates for **atmospheric applications**

Reviews : Science **301**, 61 (2003) ; Opt. Express **16**, 466 (2008)

Pulse design

Back-propagating the pulse to its initial shape

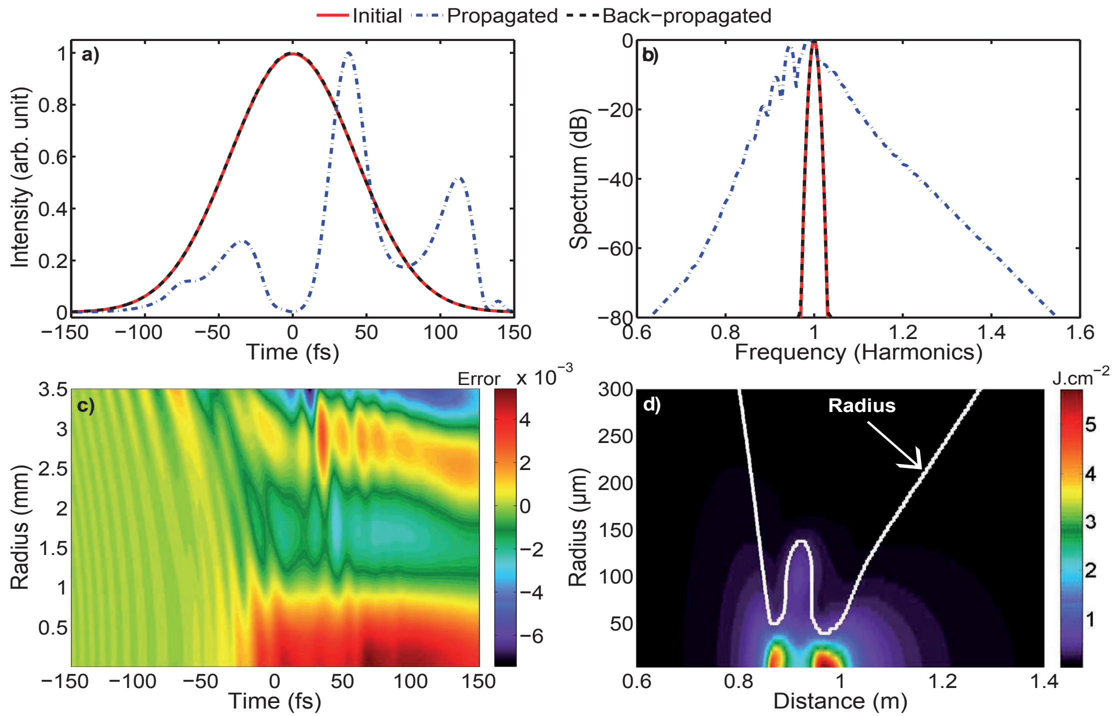


Back-propagation and pulse design

- Filaments deliver high intensity beyond diffraction limit
- Selective remote sensing: pulse shaping
- Filament : attractor (intensity clamping, beam diameter…)
- Beam scrambling
- Design input pulse for delivering specific shape remotely?

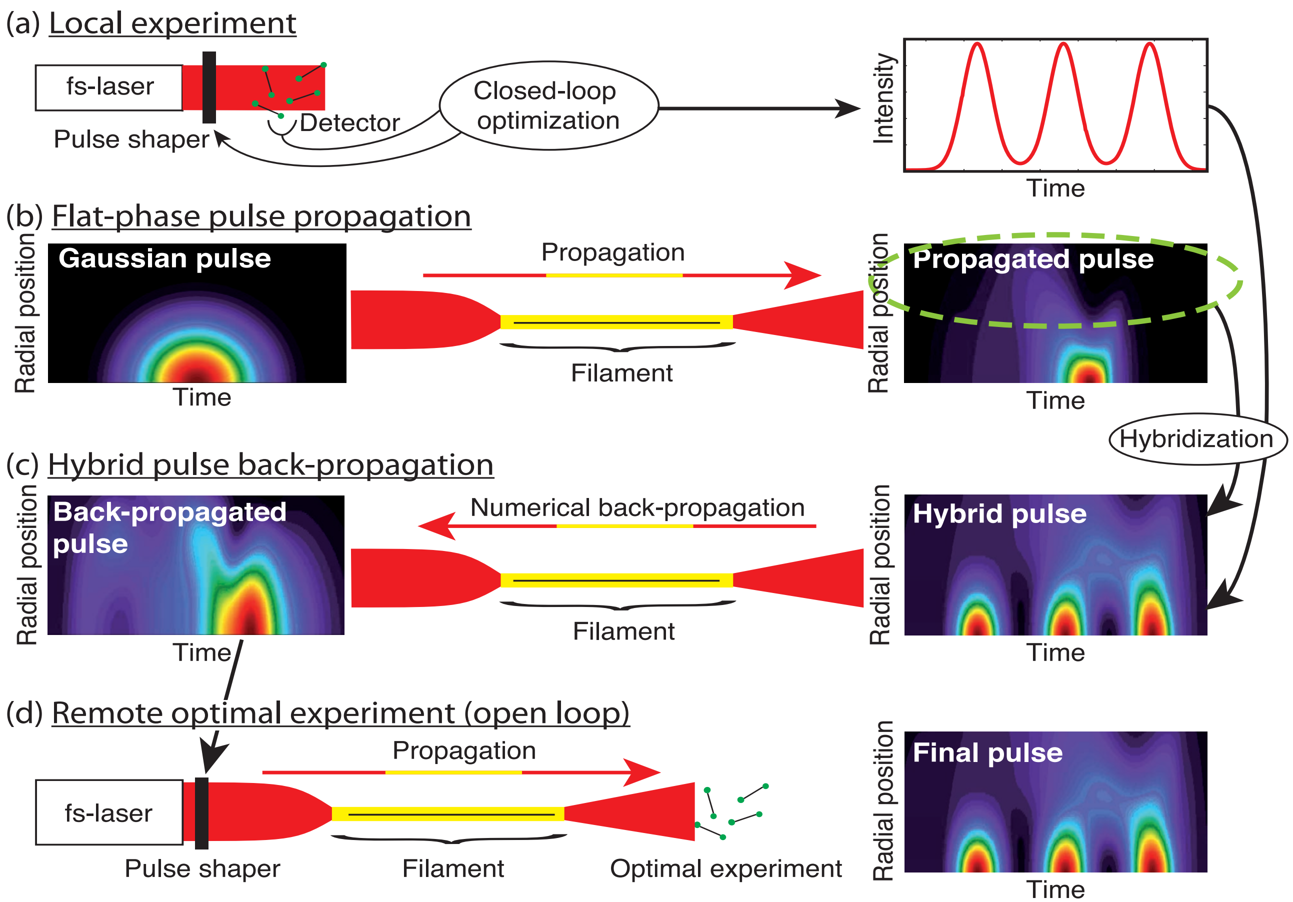
Inversibility of equations: *z* -> -*z*

$$\mathrm{i}\partial_z\varepsilon + \Delta_\perp\varepsilon + f(|\varepsilon|^2)\varepsilon = 0 \rightarrow \mathrm{i}\partial_z\varepsilon^* + \Delta_\perp\varepsilon^* + f(|\varepsilon|^2)\varepsilon^* = 0$$



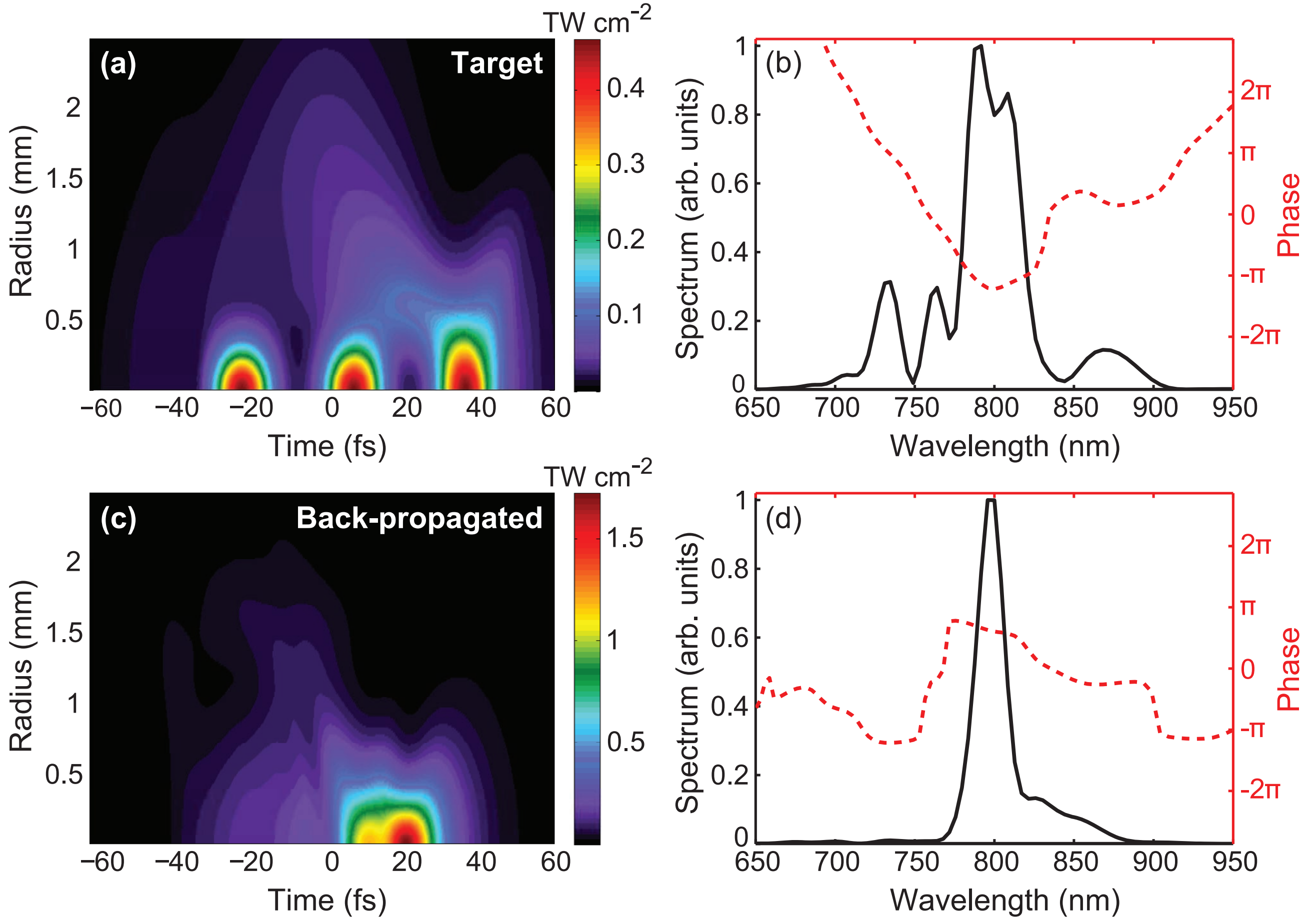
N. Berti *et al.*, *Optics Express* **22**, 21061 (2014)

« Intelligent design » of pulses



N. Berti *et al.*, *PRA* **91**, 063833 (2015)

« Intelligent design » of triple pulse



N. Berti *et al.*, *PRA* **91**, 063833 (2015)

Conclusion: Back-propagation & pulse design

- Filaments can be numerically back-propagated
- Pulse design for delivering high-intensity with predefined pulse
- Filamentation & desired shape: needs hybridization


Filamentation in Rb vapor
A new regime

Filamentation in Rb

	Air	Rb
Ionization potential	Oxygen : 13.6 eV 9 photons	4.2 eV 3 photons
Losses	Ionization (weak)	Ionization (strong) + D2 line : 852 nm
Dispersion	Weak	Strong (Kramers-Kronig)
Non-linearity	Constant	Dispersive (non-linear KK)

Propagation equation: NLSE

Diffraction Dispersion Plasma Losses Ionization

$$\partial_z \varepsilon = \frac{i}{2k_0}\Delta_\perp \varepsilon - i\frac{k''}{2}\partial_t^2 \varepsilon - i\frac{k_0}{2n_0^2\rho_c}\rho\varepsilon - \frac{\sigma}{2}\rho\varepsilon - \frac{\beta^{(K)}}{2}|\varepsilon|^{2K-2}\varepsilon$$

$$+i\frac{k_0}{n_0}\left(n_2|\varepsilon|^2 + n_4|\varepsilon|^4 + n_6|\varepsilon|^6 + n_8|\varepsilon|^8\right)\varepsilon$$

Kerr HOKE

Conclusion: Filamentation in Rb

- Same formalism
- More ionization, more losses
- Dispersion of the non-linearity

Conclusion and outlook

- Filamentation offers rich physics
- Homogeneously high intensities
- Simulate… and compare with experiments

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