Maxwell-Fluid code for simulating the terahertz generation in high-intensity laser-plasma interaction

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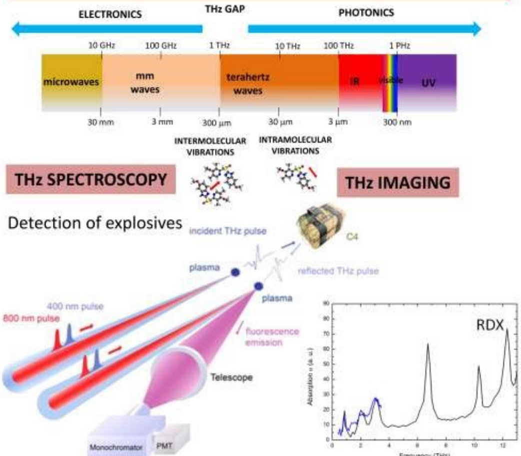
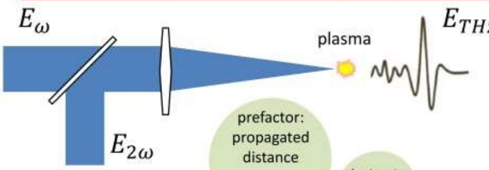
Terahertz (THz) radiation has many promising applications, in particular for the remote detection of drugs or explosives, and the medical imaging of tumours. Intense and broadband THz sources are needed for these applications. However, most of the existing techniques to supply THz radiation (conventional antennas, photoconductive switches, quantum cascade lasers and optical rectification in crystals) appear limited by damage thresholds or by their spectral narrowness. In this context, for more than ten years, an alternative technique, consisting in mixing several colours of intense femtosecond laser pulses inside a plasma spot that serves as a frequency down-converter in gases allows us to generate, even remotely through laser filaments, broadband THz signals.

THz TECHNOLOGY



THz BY PHOTO-IONIZATION: THE LOCAL CURRENT (LC) MODEL



radiated field

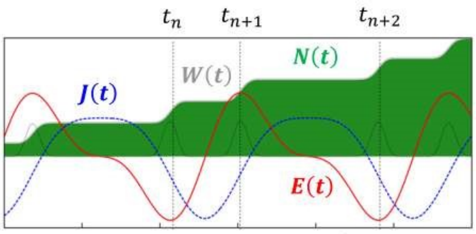
prefactor: propagated distance + plasma effects

derivative of electron current

$$\widetilde{E}(t) = g(Z, \widetilde{\omega}_p)\, \widetilde{\partial_t J(t)}$$

$$\partial_t N_e(t) = W[E(t)](N_a - N_e(t))$$

$$(\partial_t + \nu_c) J(t) = \frac{e^2}{m_e} N_e(t) E(t)$$

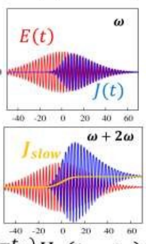


$$N_e(t) = \sum_n \delta N_e^n\, H_n(t - t_n)$$

$$J(t) = J_{fast}(t) + J_{slow}(t)$$

$$J_{fast}(t) = -e\, N_e(t)\, v_f(t)$$

$$J_{slow}(t) = e \sum_n \delta N_e^n\, v_f(t_n) e^{-\nu_c (t - t_n)} H_n(t - t_n)$$



$\rightarrow E_{THz}$

$$v_f(t) = \frac{q}{m} e^{-\nu_c t} \int_{-\infty}^{t} E(t') e^{\nu_c t'} dt'$$

NUMERICAL APPROACHES

MAXWELL EQUATIONS

$$\partial_t \boldsymbol{B} + \boldsymbol{\nabla} \times \boldsymbol{E} = \boldsymbol{0}$$

$$\partial_t \boldsymbol{E} - c^2 \boldsymbol{\nabla} \times \boldsymbol{B} = -\frac{1}{\varepsilon_0} \boldsymbol{J}$$

FLUID CODES

COLD-PLASMA FLUID EQUATIONS

$$\partial_t N_e + \boldsymbol{\nabla} \cdot (\boldsymbol{v}\, N_e) = \sum_{j=0}^{Z} j\, \partial_t N_j$$

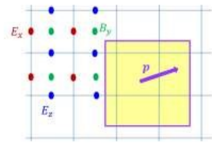
$$(\partial_t + \nu_c)(\gamma \boldsymbol{J}) + \boldsymbol{\nabla} \cdot (\boldsymbol{v} \otimes \gamma \boldsymbol{J}) = \frac{e^2}{m_e} N_e \boldsymbol{E} - \frac{e}{m_e} \boldsymbol{J} \times \boldsymbol{B}$$

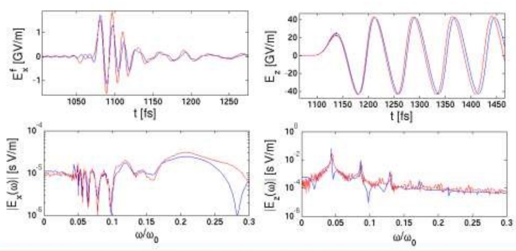
PIC CODES

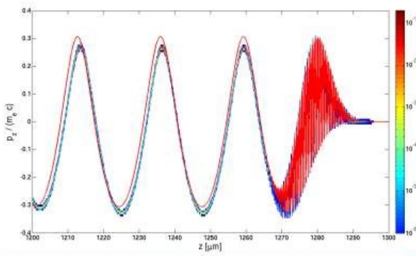
MACROPARTICLES

$$\partial_t \boldsymbol{p} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$$

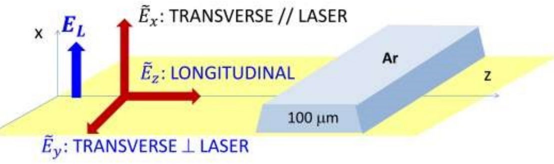
$$\partial_t \boldsymbol{r} = \boldsymbol{v} \qquad \boldsymbol{p} = m\gamma \boldsymbol{v}$$







COMPETITION: PHOTOIONIZATION vs. WAKEFIELD EFFECTS



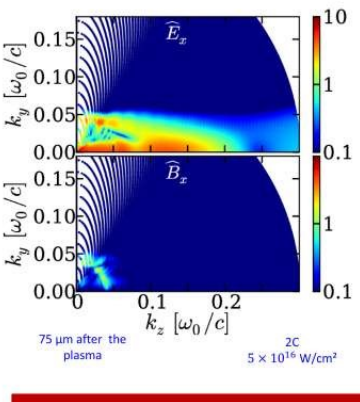
PHOTOIONIZATION → $\tilde{E}_x$

- ✓ dominant mechanism
- ✓ on-axis transmission
- ✓ 2C > 1C (if not saturated)

WAKEFIELD EFFECTS

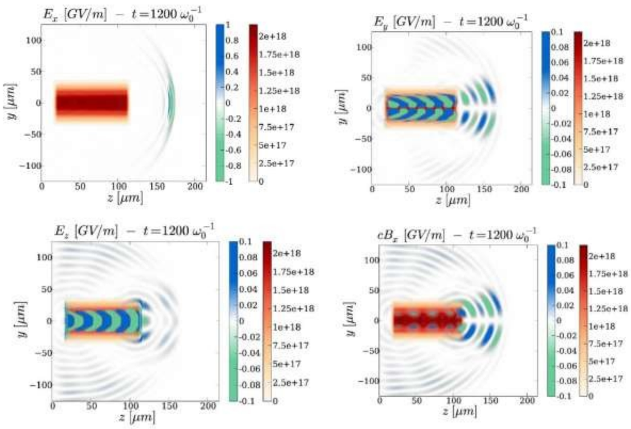
$\tilde{E}_z$
- ✓ vanishes
- ✓ 2C=1C

$\tilde{E}_y$
- ✓ off-axis transmission
- ✓ 2C=1C



75 µm after the plasma

2C
5×10^{16} W/cm²



REFERENCES

- P. González de Alaiza Martínez, X. Davoine, A. Debayle, L. Gremillet, and L. Bergé, "Terahertz emission by two-color laser pulses at near-relativistic intensities: Competition between photoionization and wakefield effets", submitted to Scientific Reports.
- V.A. Andreeva, O.G. Kosareva, N.A. Panov, D.E. Shipilo, P.M. Solyankin, M.N. Esaulkov, P. González de Alaiza Martínez, A.P. Shkurinov, V.A. Makarov, L. Bergé, and. S.L. Chin, "Ultrabroad terahertz spectrum generation from air-based filament plasma", submitted to Phys. Rev. Lett.
- P. González de Alaiza Martínez, I. Babushkin, L. Bergé, S. Skupin, E. Cabrera-Granado, C. Köhler, U. Morgner, A. Husakou, and J. Herrmann, "Boosting terahertz generation in laser-field ionized gases using a sawtooth wave shape", Phys. Rev. Lett. 114 (issue 18), 183901, 8 May 2015
- A. Debayle, P. González de Alaiza Martínez, L. Gremillet, and L. Bergé, "Nonmonotonic increase in laser-driven THz emissions through multiple ionization events", Phys. Rev. A Rapid Communication 91 (issue 4), 041801(R), 10 April 2015

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