Space-based femtosecond laser filamentation

Project Summary

Objective

This project will study femtosecond laser filamentation from orbit, with a focus on the development of a model for the nonlinear propagation of intense femtosecond laser pulses. The goal is to gain insights on the impact of initial parameters on the filament formation.

Target university partner competences

theoretical physics, nonlinear optics, terawatt femtosecond laser systems, plasma physics

ACT provided competences

Space-based instrumentation, laser spectroscopy, theoretical physics.

Keywords

laser filamentation, femtosecond pulses, nonlinear propagation, optical Kerr effect, multiphoton ionization, plasma, white-light Lidar, wireless power transmission, self-phase modulation, nonlinear Schrödinger equation, group velocity dispersion.

1. Study objective

This Ariadna project will study femtosecond laser filamentation from orbital altitudes. In particular, a model of the downward vertical nonlinear propagation of intense femtosecond laser pulses launched from orbital altitude (~400 km) will be developed. The project's goal is to gain insights on the impact of initial parameters on the filament formation.

2. Background and study motivation

Laser filamentation, resulting from the nonlinear propagation of intense ultrashort laser pulses in the atmosphere, has become a promising tool in various fields such as the remote sensing of pollutants using Lidar (Light Detection and Ranging) technology, wireless power transmission, electric field mapping of thunderstorms, and propulsion [1-2].

In this technique, femtosecond laser pulses in the terawatt optical power range propagate in the atmosphere behaving as quasi-solitons thanks to a dynamic competition between the optical Kerr effect focusing the beam and the induced plasma effect defocusing the beam. This results in the formation of thin filaments where efficient nonlinear phenomena take place, including self-phase modulation leading to the generation of a coherent broadband continuum spanning from 300 nm to 14 μm [3].

This phenomenon could be of interest for Lidar systems. The white-light continuum generated from femtosecond filamentation can provide additional information about water vapour and temperature profiles, enabling the direct measurement of relative humidity, and can simultaneously acquire multispectral Lidar information using a single laser source. Ground-based white-light lidar has been demonstrated recently by firing TW laser pulses in the atmosphere and measuring the backscattered white-light using a telescope and a few detectors and spectrometers [4-6]. Furthermore, laser filamentation can also deliver strong optical intensities at kilometric distances in a self-focused optical beam and can guide microwave radiation along induced-plasma channels for wireless power transmission applications [7].

Applications of femtosecond filamentation can be envisaged in the areas of:

- White-light Lidar for the remote sensing of aerosols and greenhouse gases
- Wireless power transmission
- Electric field mapping of thunderstorms
- Lightning control
- Cloud seeding
- Propulsion

3. Proposed Methodology

The following methodology is proposed for this study, though universities are invited to propose different approaches with the accompanying arguments why these would better achieve the main goals.

i. Construct a model for long-distance femtosecond filamentation.
ii. Add the effect of air turbulence, density variations, and humidity on the long-distance propagation.
iii. Study the impact of initial laser parameters such as beam shape, laser wavelength, initial focusing, and initial chirp on the filament formation.
iv. Identify the impact of rarefied plasma and other upper atmospheric conditions on femtosecond filamentation.
v. Study the impact of orbital parameters such as altitude and orbital inclination.
vi. Assess the use of femtosecond filamentation for wireless power transmission applications.

4. ACT Contribution

The project will be conducted in close scientific collaboration with ESA researchers. In particular ESA researchers will provide technical expertise in space-based instrumentation for realistic simulation parameters. ESA researchers will also run the simulations in parallel to help identify the impact of laser parameters on the filament formation from orbital altitude. Finally ESA researchers will investigate wireless power applications of femtosecond filamentation.

5. Bibliography

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