Space-based Femtosecond Laser Filamentation

Executive Summary

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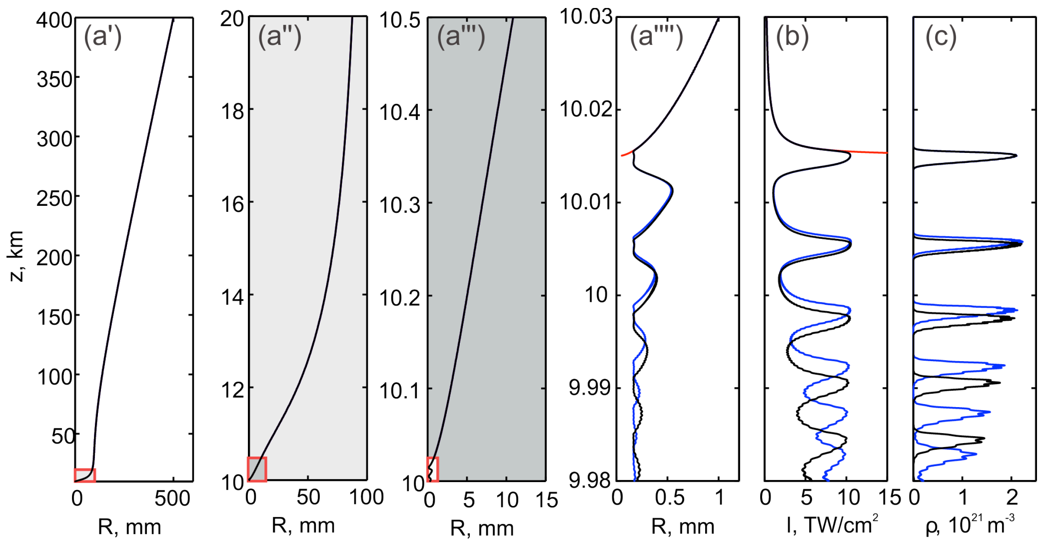
Picture:



Motivation:

This study aimed at developing the numerical framework to investigate whether the remote generation of laser filaments from orbital altitude was theoretically feasible and in this case to gain insights on the required initial laser parameters to remotely generate a filament.

Methodology:

In this work the state-of-the-art theory on self-focusing, filamentation and collapse has been extended to long-distance propagation of ultrashort laser pulses in a stratified atmosphere. The model consists of a unidirectional propagation equation with a medium's response model and includes diffraction laws, optical Kerr effect, plasma defocusing, multispecies ionisation and multiphoton absorption. Propagation in the stratified atmosphere was taken into account via an air density profile depending on the molecule type and altitude profile. Supercontinuum generation was studied by adding the temporal dimension to the simulations, accounting for group velocity dispersion in air and the resulting spectral broadening.

Results:

- Remote laser filamentation generation in the atmosphere from orbital altitude is possible for a large range of peak pulse powers (100 GW-5 TW) and beam radii (10-60 cm), targeting altitudes ranging from 5-45 km from the ground..
- Scaling laws for the collapse point, i.e. where filamentation is starting, were obtained based on direct numerical simulations of nonlinear unidirectional pulse propagation equations.

- Laser filamentation can lead to the remote generation of a supercontinuum in the atmosphere extending e.g. from 300 nm to 1.1 μm, collocated with pulse splitting and beam collapse at a typical altitude of 7.3 km.
- These findings provide a solid theoretical basis for an application study, e.g. for multispectral backscatter and differential absorption lidar space systems, as well as for a detailed system-level study of a spacecraft payload based on laser filamentation, starting from the tested ground system and taking into account recent developments in ultra-short pulsed lasers to conceive a space system.
- Wireless power transfer and directed energy applications based on self-focusing were not investigated in this study.

Publications:

The results of this Ariadna study are in the process of being published in dedicated journal papers:

- I. Dicaire*, V. Jukna*, C. Milian, C. Praz, A. Couairon, and L. Summerer, “*Laser filaments for space research*”.
- V. Jukna, C. Praz, I. Dicaire, C. Milian, A. Couairon, L. Summerer, "*A theoretical model for laser filamentation from orbit".*

Highlights:

The work has not only demonstrated for the first time that via an extension of state-of-the-art models, the remote generation of laser filamentation was possible from orbital altitudes; it also showed that the general parameters (e.g. power level, mass, size) of such a space system would be within the reach of current technological capabilities, thus opening the field for a range of novel applications. It would e.g. lead to a better retrieval of cloud and aerosol size distributions or a simultaneous retrieval of various trace gas profiles using a single laser source, with the added benefit of robust propagation through adverse atmospheric conditions.