Applications of filaments generated by high-power spaceborne lasers

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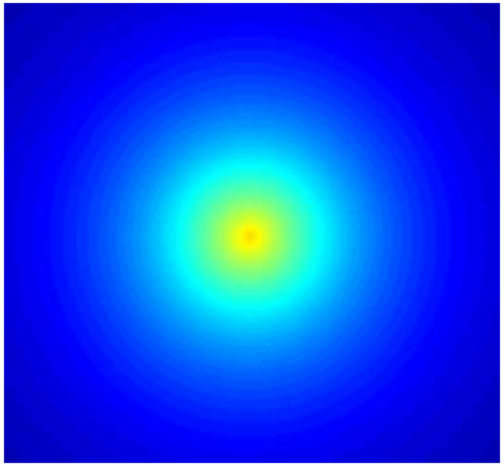
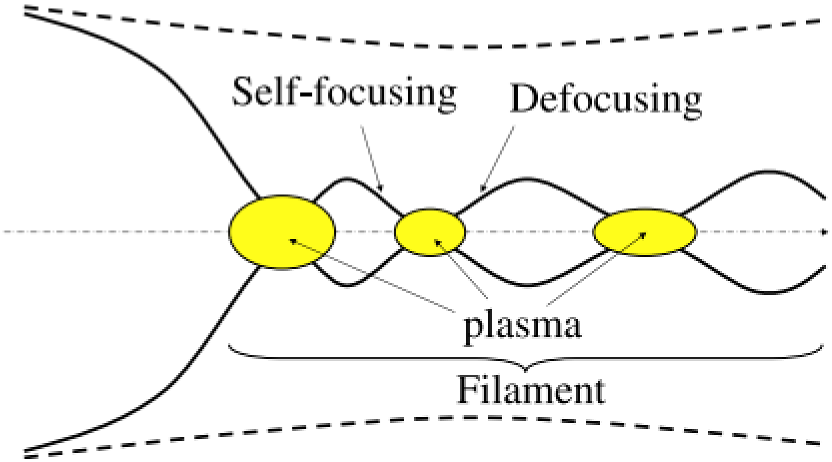
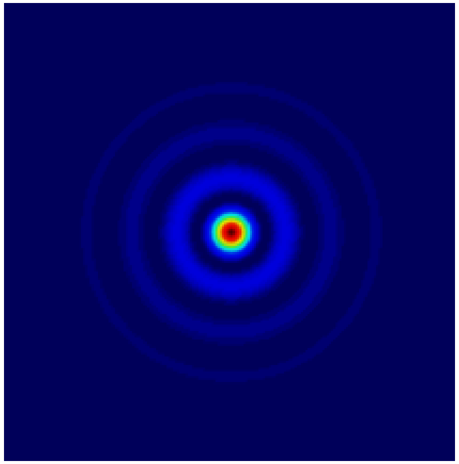
What is a filament?



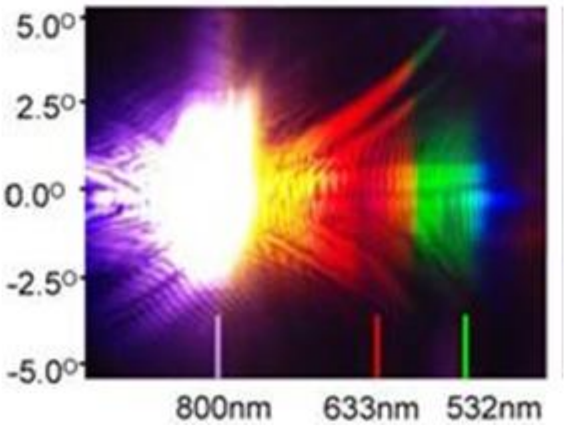




Filamentation is a nonlinear propagation regime: The beam does not spread due to a competition between self-focusing and plasma defocusing.

Length ~ 10's to 100's m **Diameter ~ 100 μm** **Intensity ~ 10^{14} W/cm^2**

Why it is interesting?

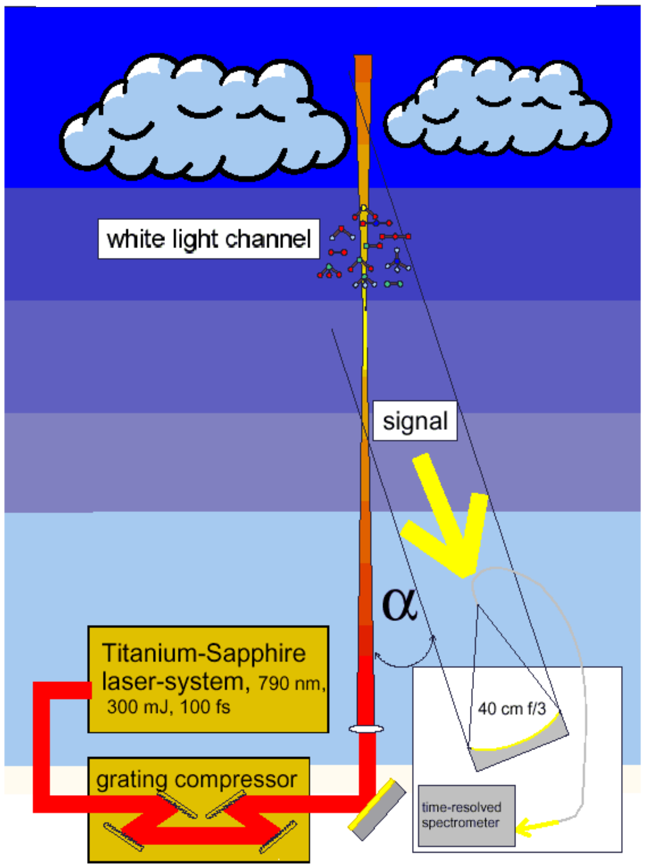


- It generates white light at km distances from the laser.
- Suitable for applications to detect pollutants in the atmosphere via (Light Detection And Ranging) **LIDAR** technique.

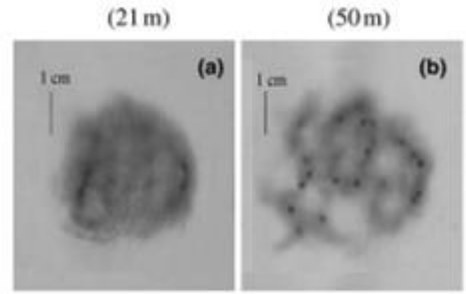
A. Braun et al. Opt. Lett . **20** (1995); P. Polynkin at al. Phys.Rev.Lett. **103**, 123902 (2009); A. Couairon and A. Mysyrowicz, Phys. Rep., **441**, 47 (2007)

Why filamentation from space?

Conceptual femtosecond LIDAR from the ground



High power beam multifilamentation



Drawbacks of Femtosecond LIDAR from ground

- Powerful beam will undergo multifilamentation
- The backscattered signal is weak
- Only local analysis of the atmosphere is possible

J. Kasparian et al. , Science **301**, 61 (2003); G. Mechain et al., Opt. Commun. **247,** 171 (2005);

Why filamentation from space?

Advantages of Femtosecond LIDAR from space:

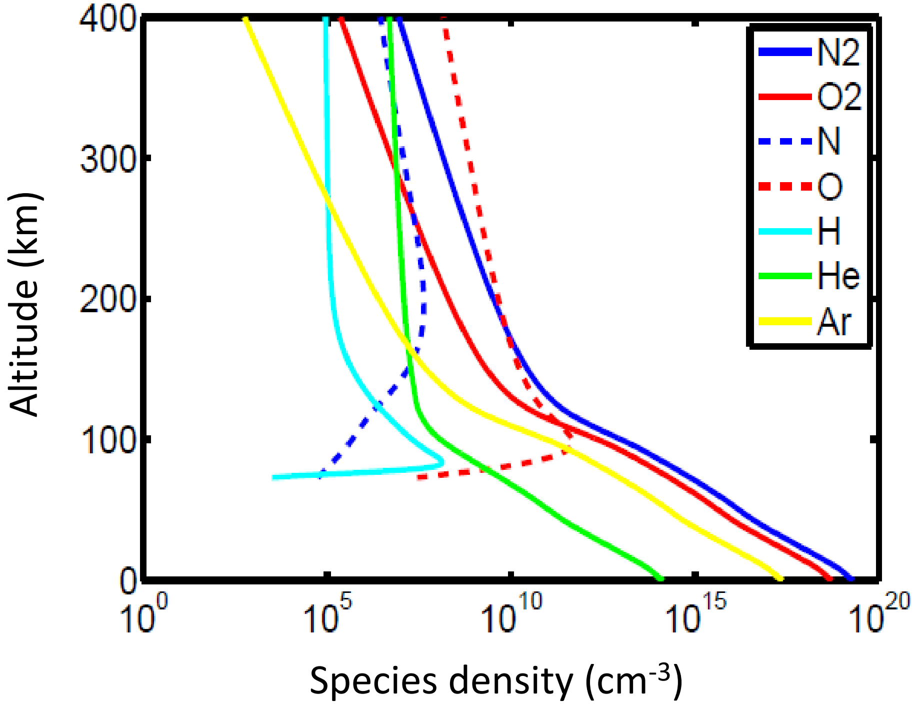
• Both the filament and the backscattered signal cross an underdense medium (less distortion and less loss)

• Global solution for atmospheric monitoring

Development of a model for laser propagation and filamentation through stratified atmosphere

Direct numerical simulations of unidirectional pulse propagation equation

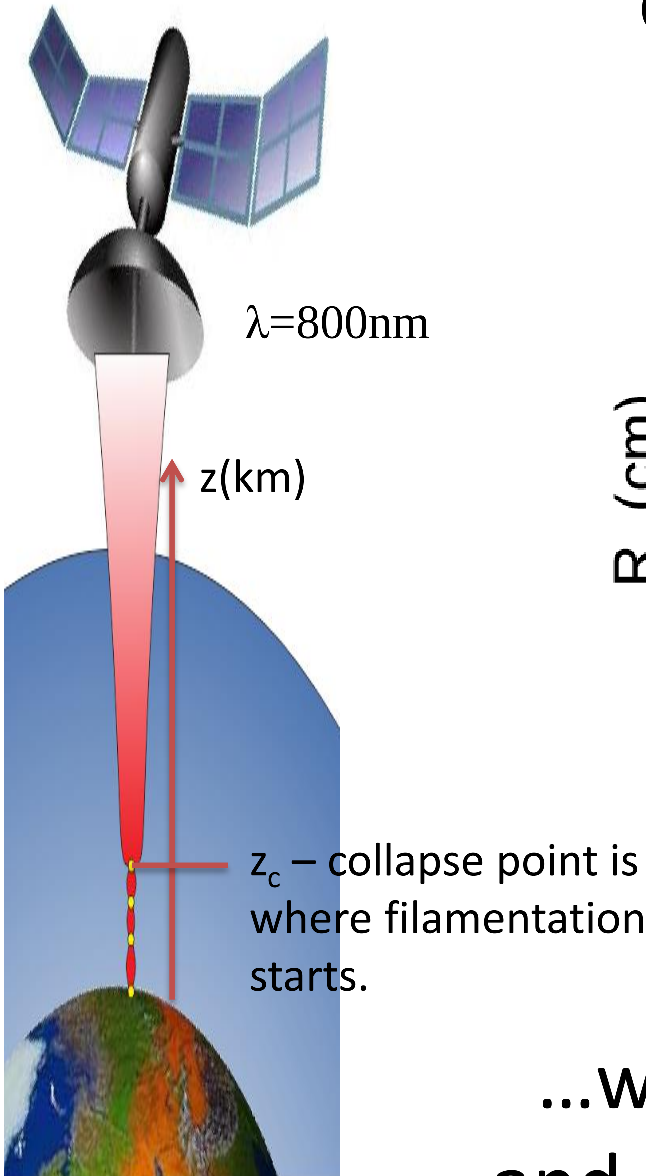
Physical effects:
Diffraction, optical Kerr effect, ionization, nonlinear absorption of energy, stratified atmosphere.

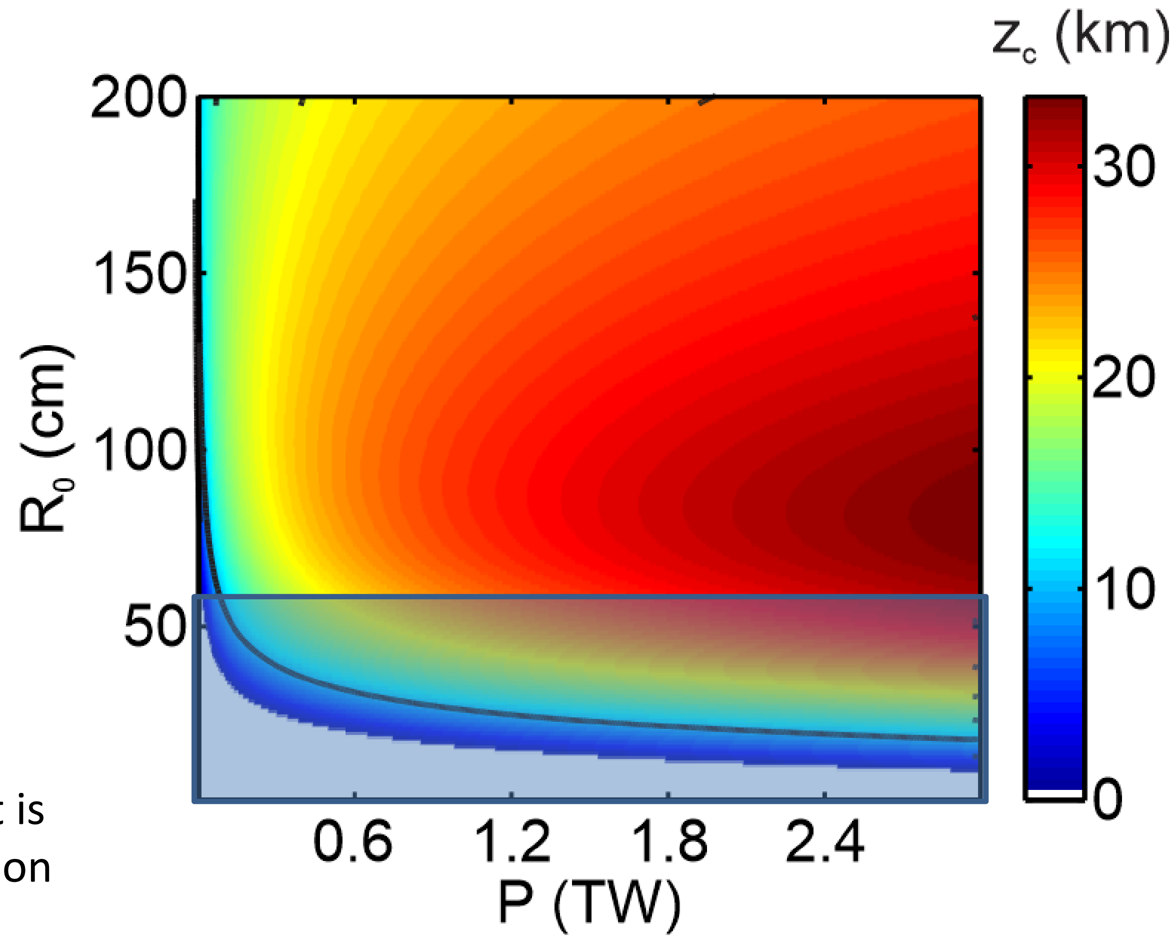


Density of different species retrieved using MSIS model.

CCMC: community Coordinated Modeling Center

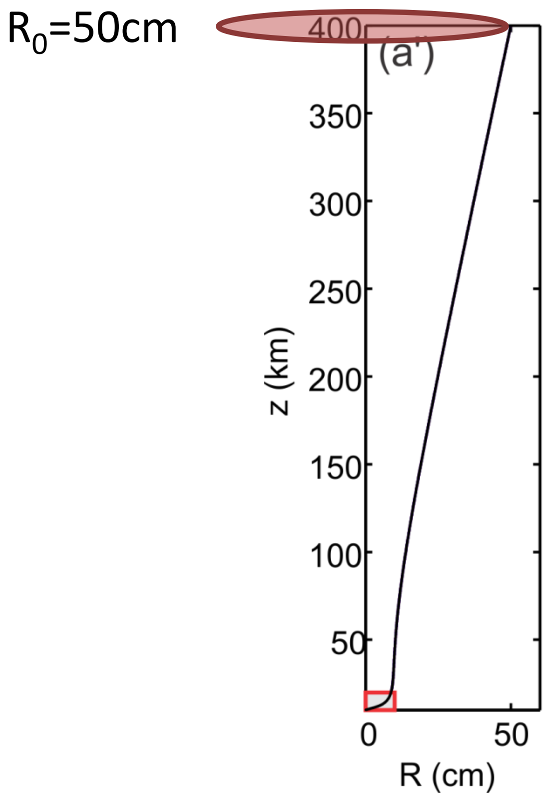
Filamentation from space (400 km) is possible at desired heights…





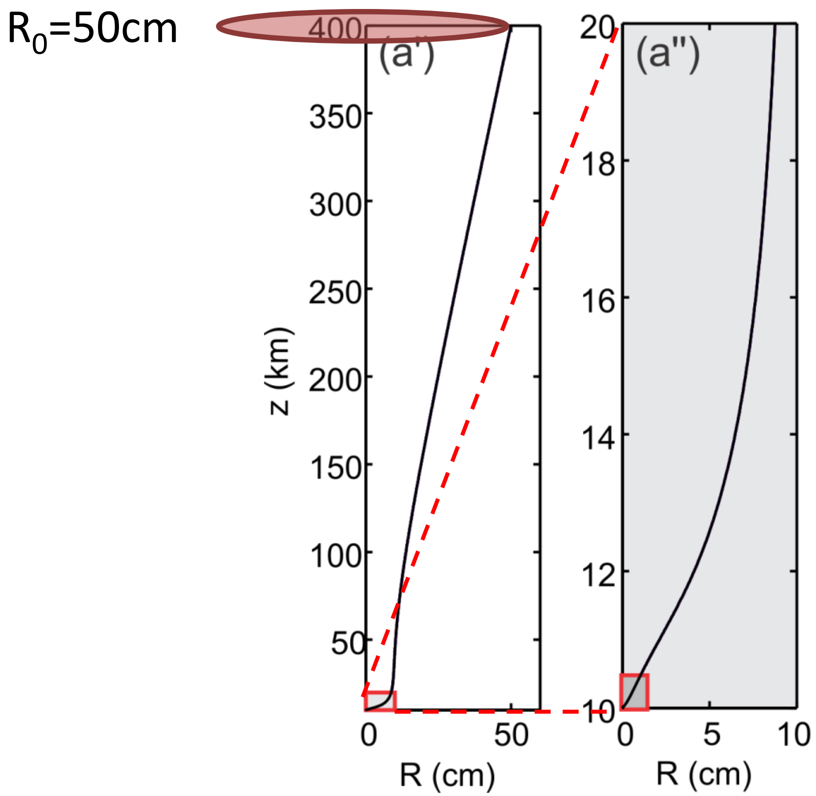
…with beam radius R_0 ~ 10 - 60 cm
and beam powers P ~ 100 GW - 5 TW

Simulations show beam compression, filamentation from space and high intensities



Initial beam radius R_0 = 50 cm; Initial beam power P = 143 GW.

Simulations show beam compression, filamentation from space and high intensities



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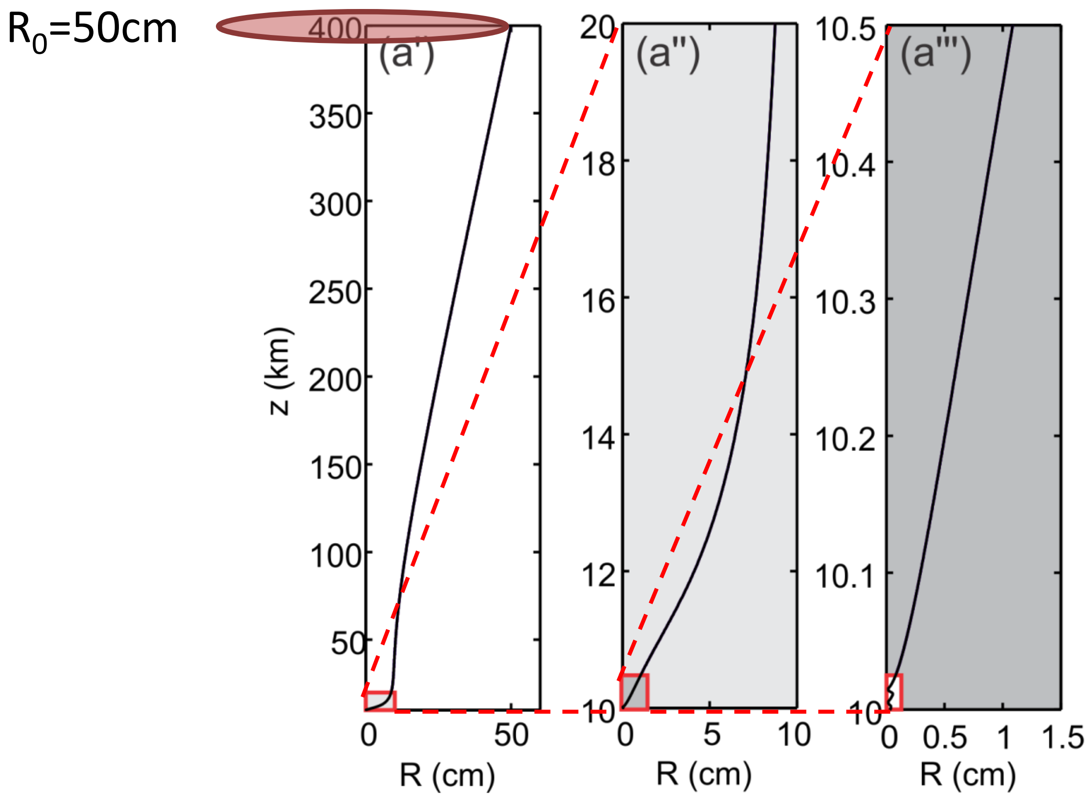

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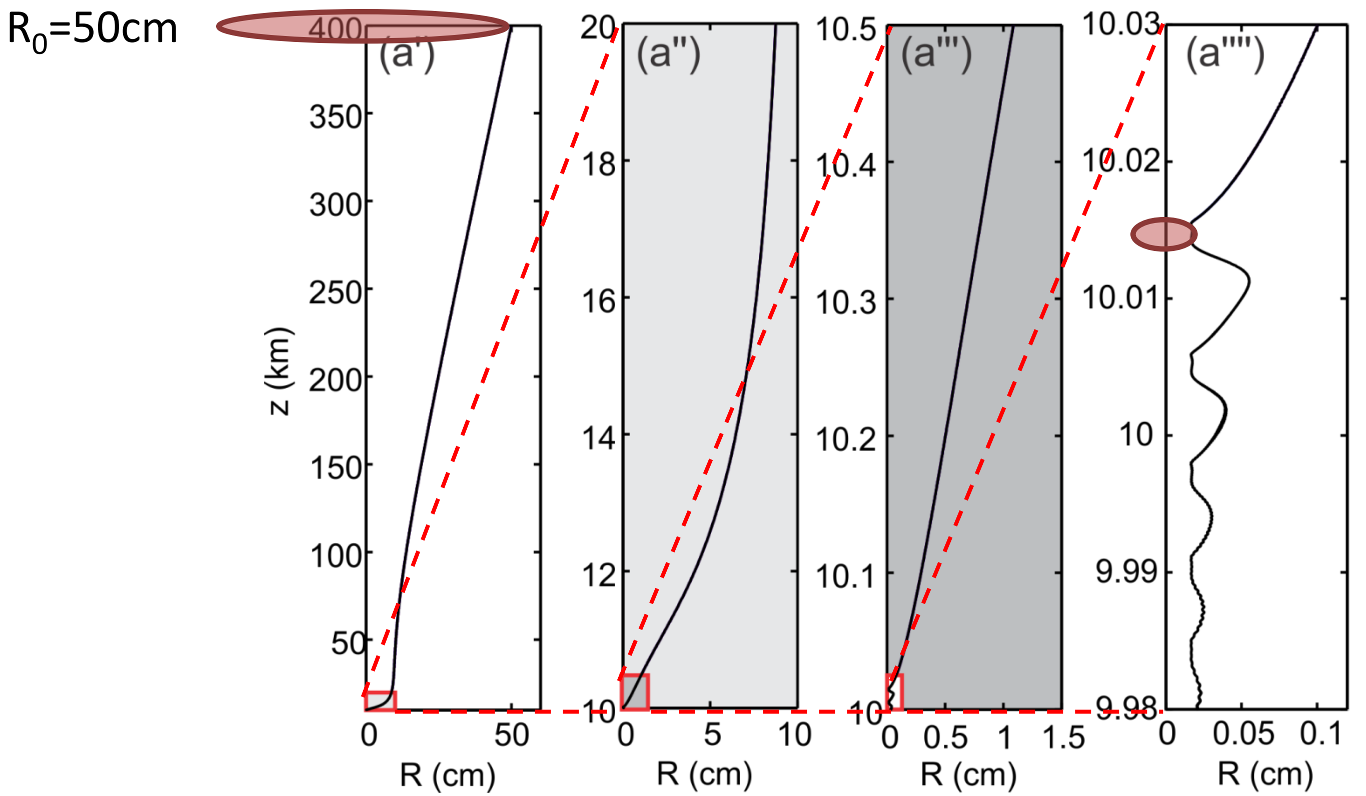
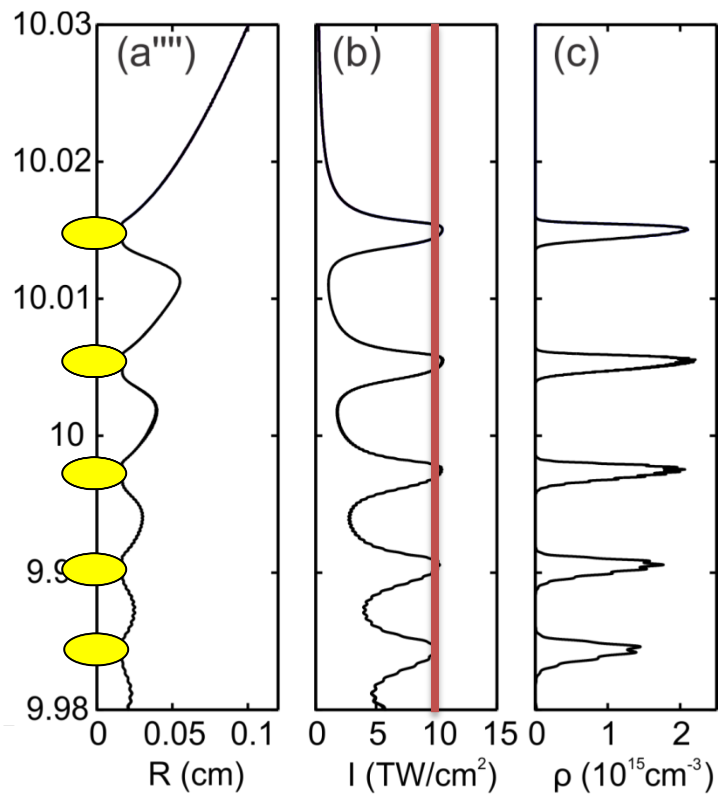


Initial beam radius R_0 = 50 cm; Initial beam power P = 143 GW.

Beam compresses 5000 times: from 50 cm to 100 µm radius!

Simulations show beam compression, filamentation from space and high intensities



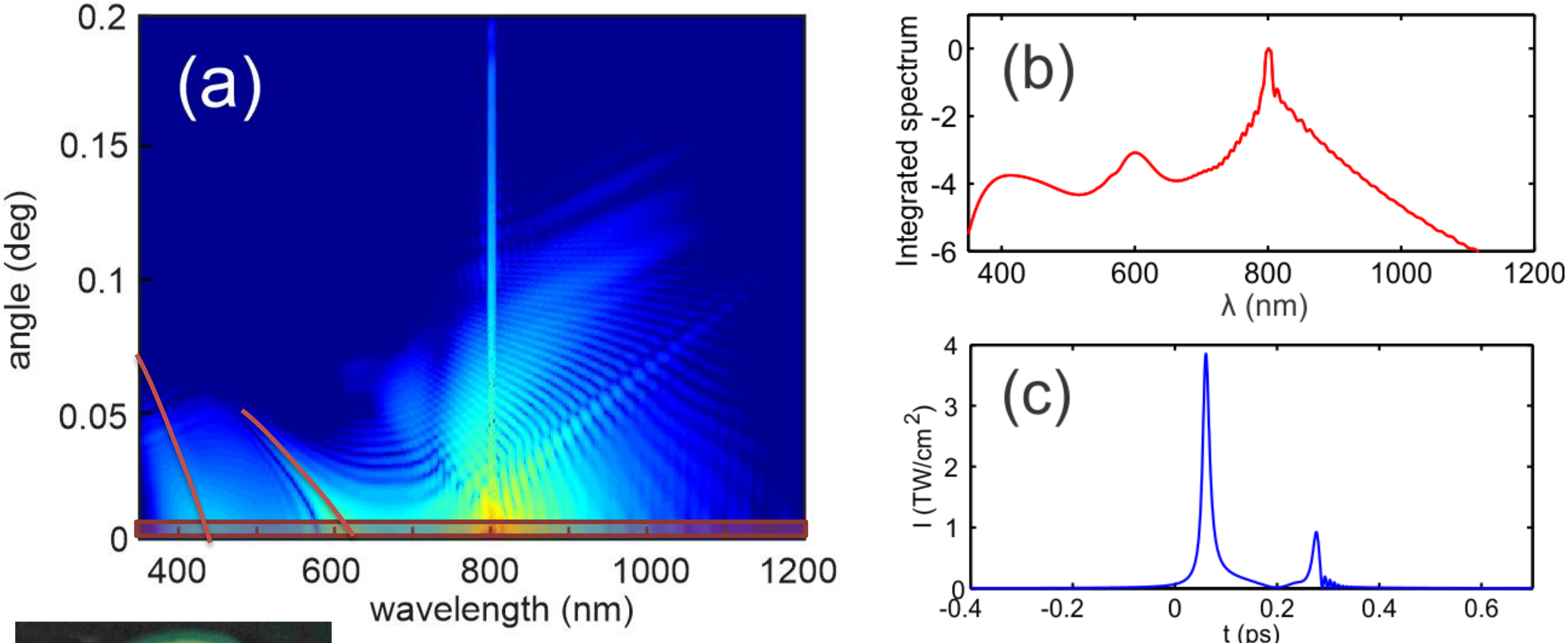
Initial beam radius R_0 = 50 cm; Initial beam power P = 143 GW.

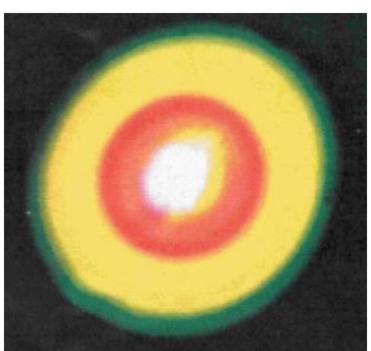
Beam compresses 5000 times: from 50 cm to 100 µm radius!

Reaches 10 TW/cm^2 over 30 m at 10 km above sea level.

Intensity and propagation distance large enough to generate a broadband supercontinuum.

Simulations show the generation of a broadband supercontinuum

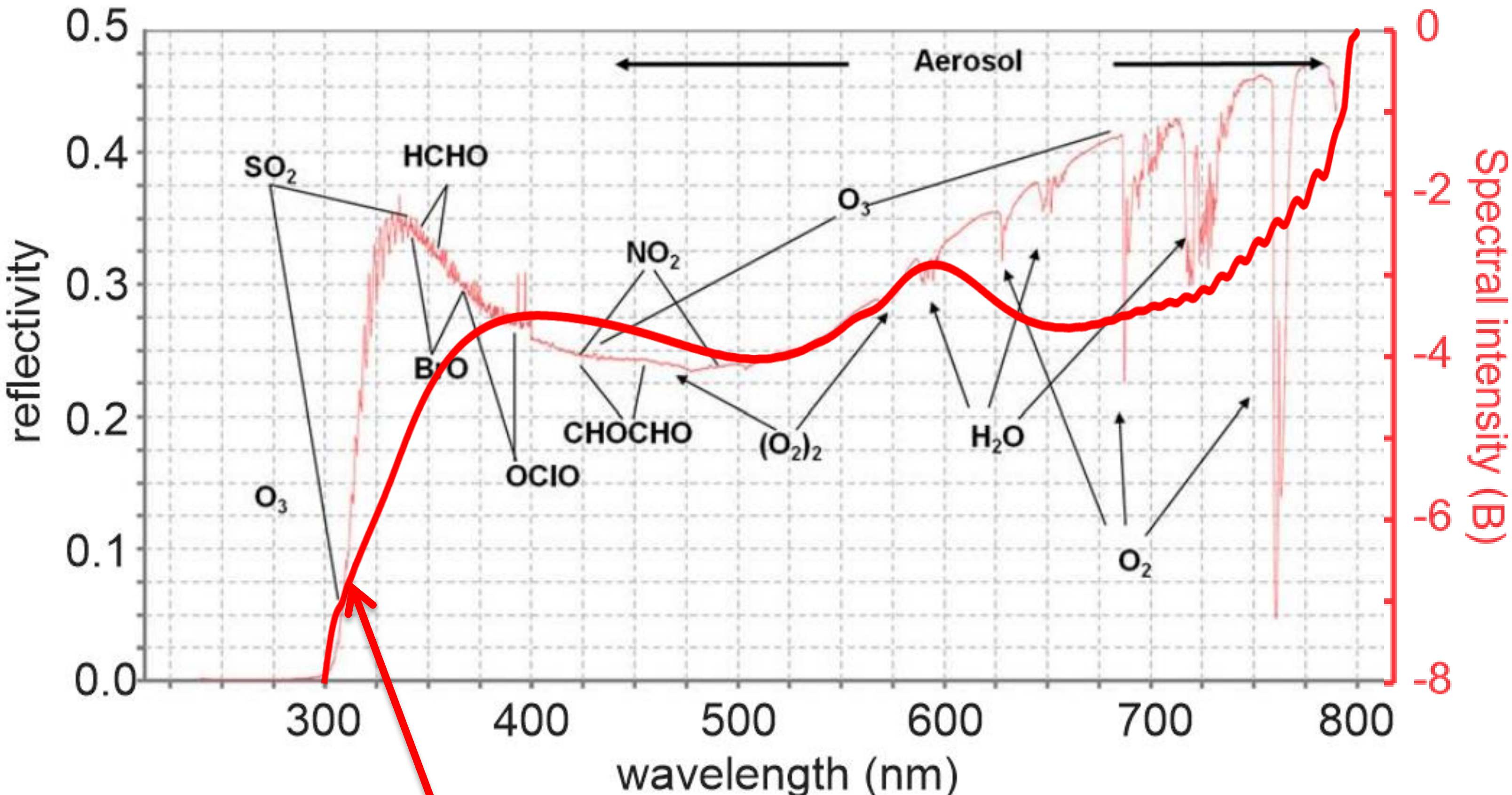




Initial beam radius R_0 = 50 cm;
Initial pulse duration FWHM = 500 fs; Energy = 76 mJ.

E. T. J. Nibbering et al., Opt. Lett. **21,** 62 (1996); M. Kolesik et al., Opt. Express, **13,** 10729 (2005).

LIDAR application: Supercontinuum covers spectral lines for monitoring atmospheric constituents, pollutants



Numerically calculated
filament spectrum

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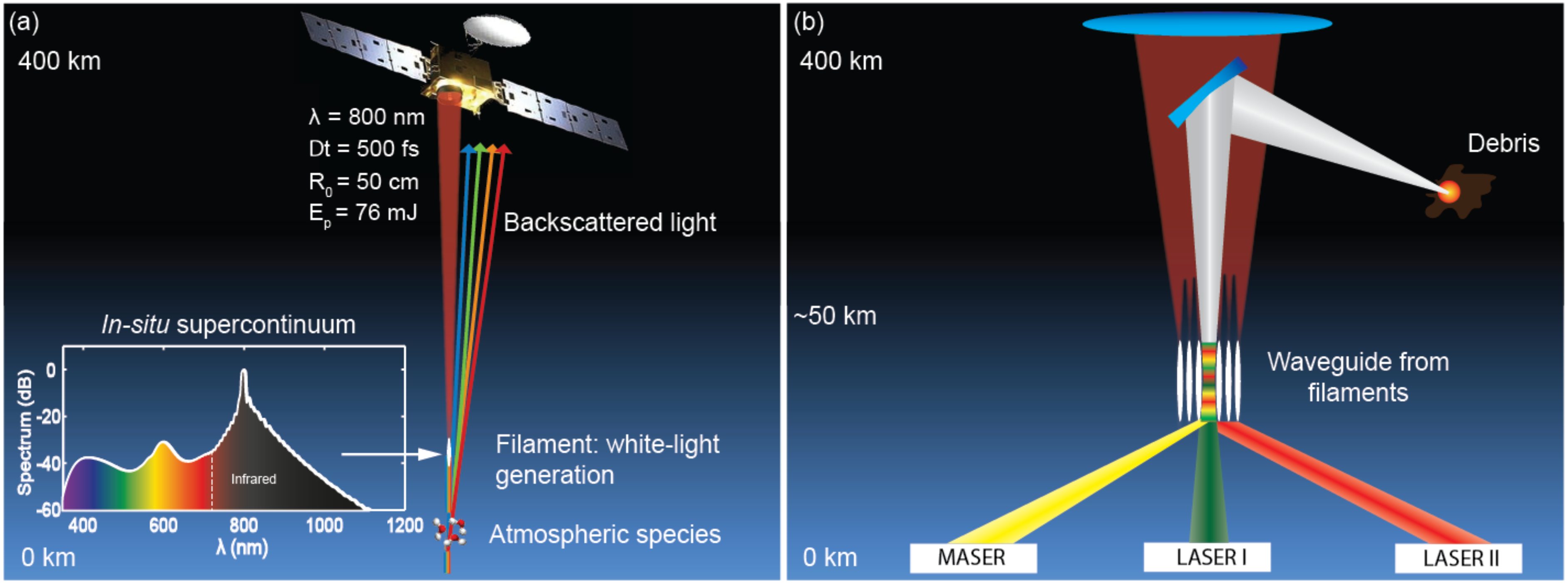
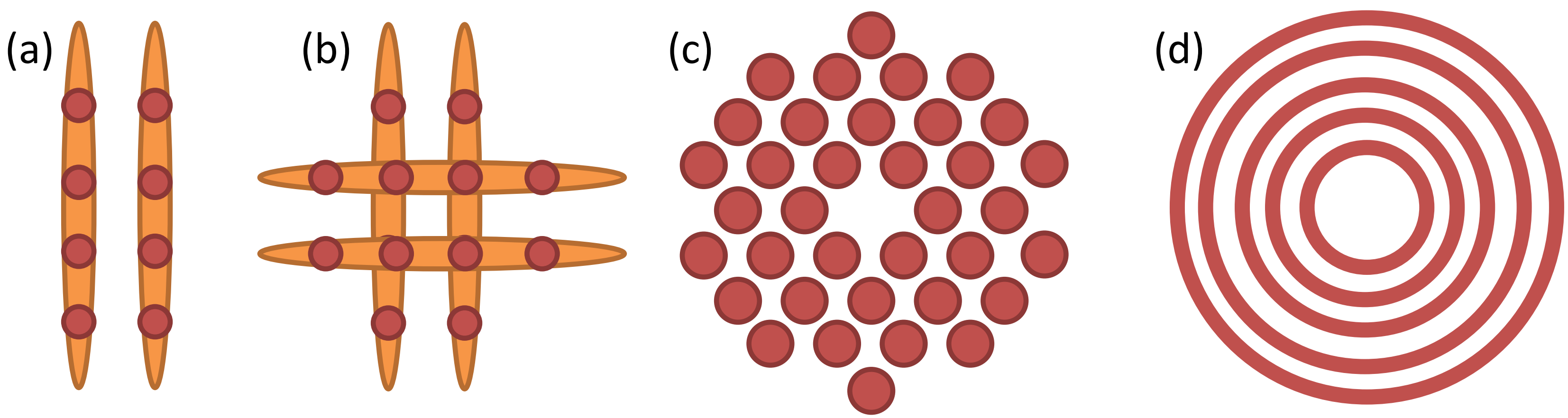
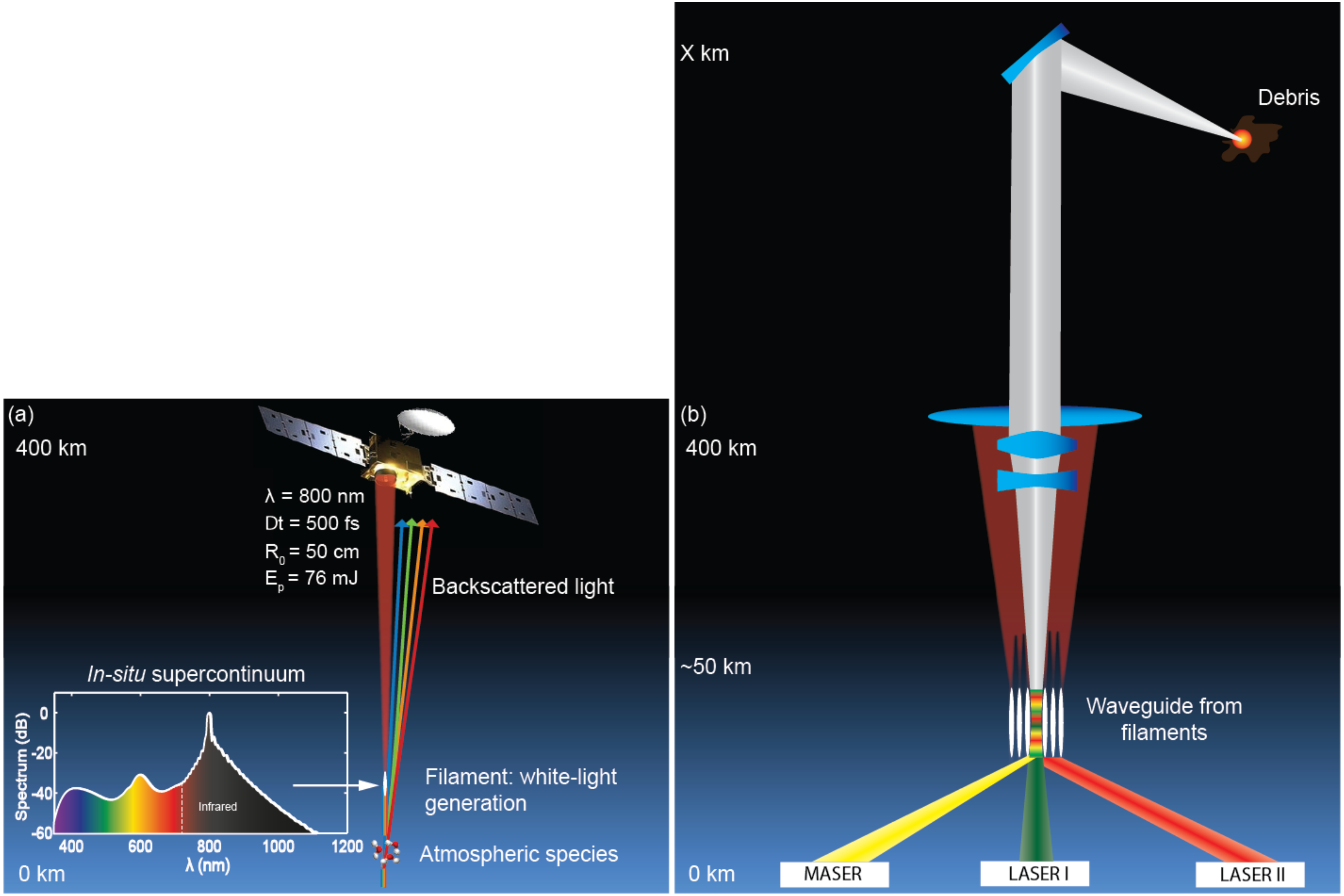
Plasma waveguide generation



Wave guiding of high power microwave or laser pulses emitted from the ground.

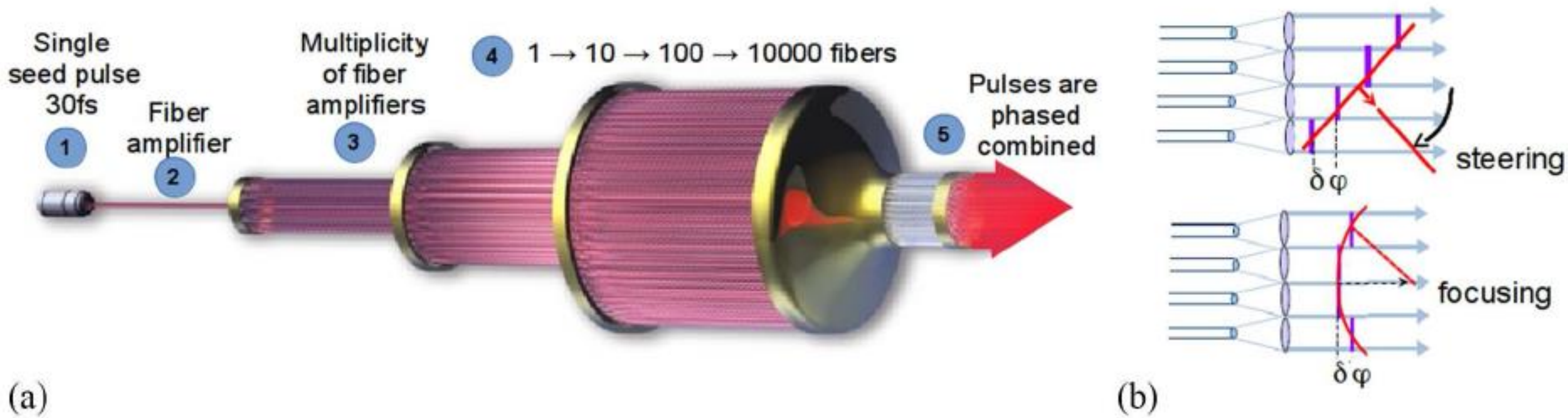


Plasma waveguide generation



Wave guiding of high power microwave or laser pulses emitted from the ground.

CAN laser benefits

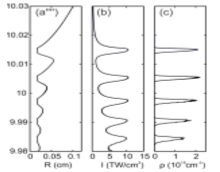


Efficiency **Complexity** **Scalability**	**High repetition rate** **High power** **Spatial phase control**

G. Mourou, et al., Nat. Photonics 7, 258 (2013)

Conclusions

1. Laser filamentation from space is possible.

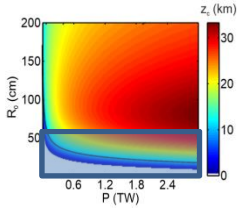


2. New numerical techniques were developed.

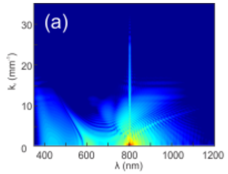
3. Conditions for filamentation from orbit:

   - beam radius R ~ 10 - 60 cm;

   - beam powers P ~ 100 GW - 5 TW.

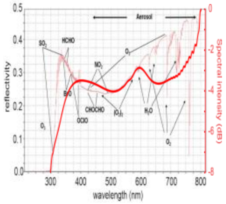


4. Supercontinuum generation from orbit demonstrated.

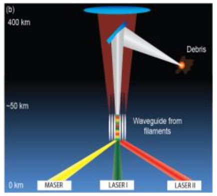


5. Applications:

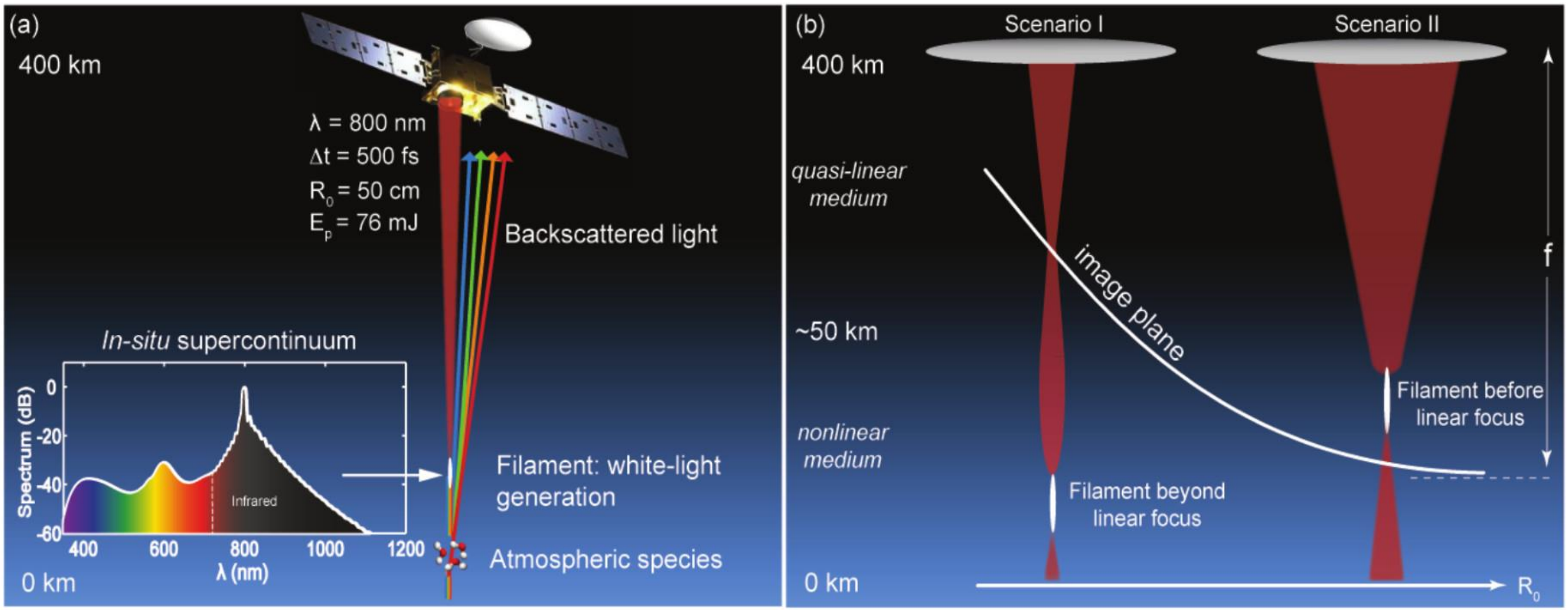
   - multispectral (fs-LIDAR) analysis of the atmosphere.



   - wave guiding of high power microwave or laser pulses emitted from the ground.



Filamentation dependence on focusing conditions



Two different scenarios for initiating a filament in atmosphere.

Ti:Sapphire laser

Commercially available TT-Mobile laser (Amplitude technologies co)
300 mJ, 40fs, 10Hz
Consumes 10kW; Dimensions 1.5x3x1.9m; Weight 1400 kg.