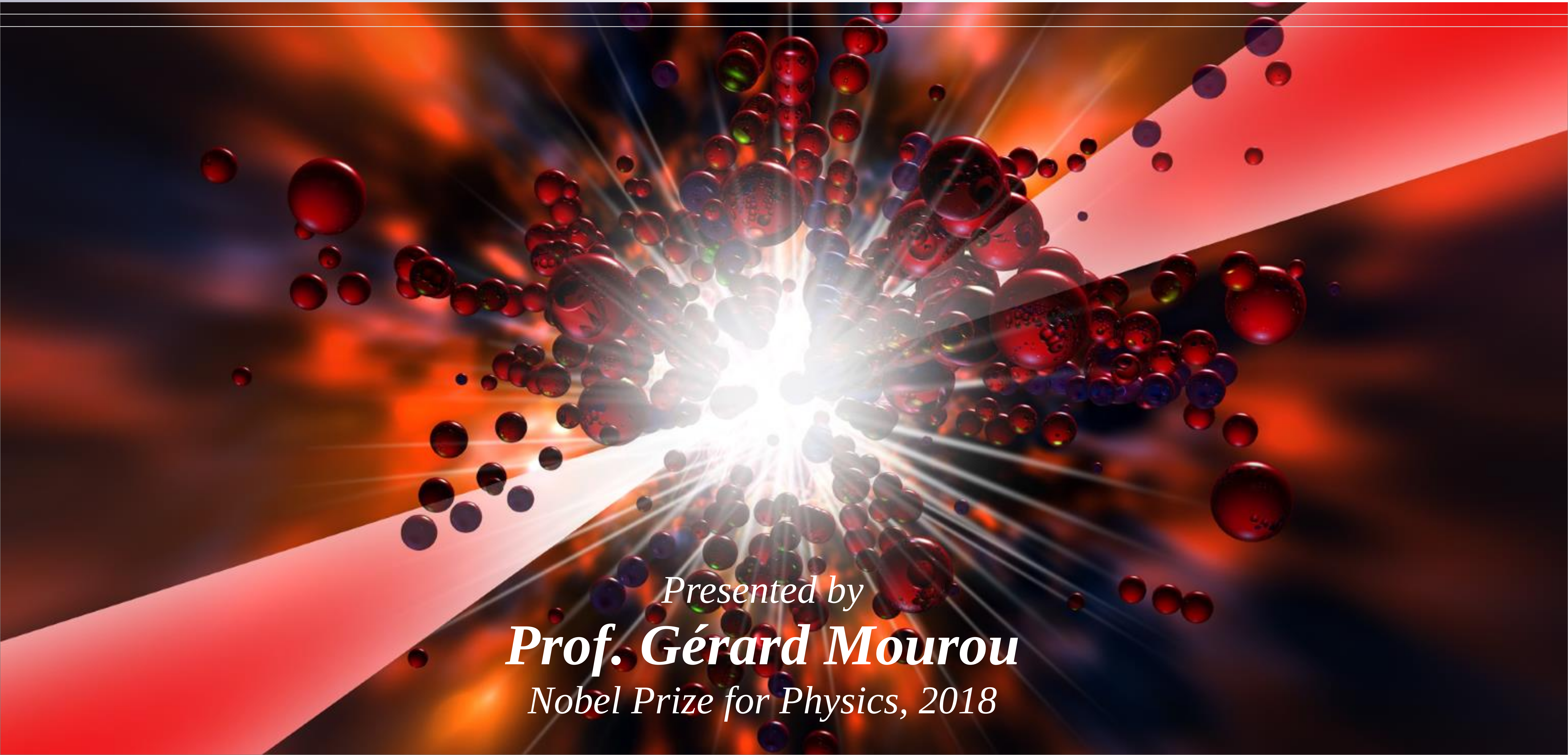
# *A PASSION FOR EXTREME LIGHT : CLEO MUNICH*

*For the Greatest Benefit of Human Kind*



*Presented by*

***Prof. Gérard Mourou***

*Nobel Prize for Physics, 2018*

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*Nobel Prize for Physics, 2018*

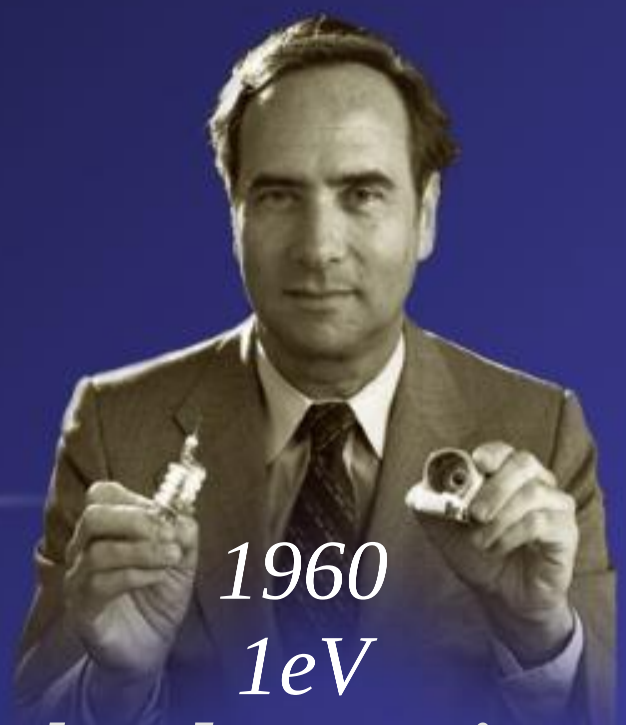
***Theodore Maiman***
*(July 11, 1927 – May 5, 2007)*

# *A PASSION FOR EXTREME LIGHT*

*For the greatest benefit to human kind (Alfred Nobel)*

*Slowing down atoms*

*2018*



*1960*

*1eV*

***Theodore Maiman***

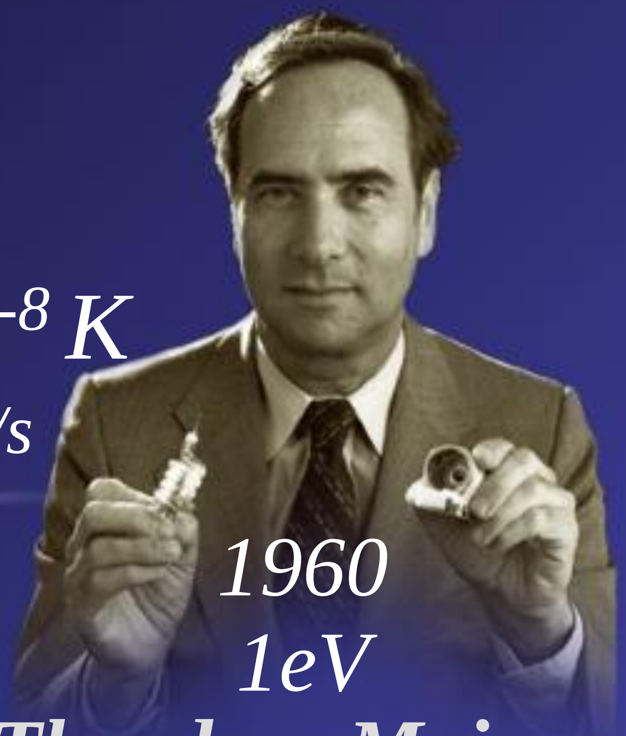
*(July 11, 1927 – May 5, 2007)*

## Quantum Optics

μeV – peV  Temp. = $10^{-8}$ K

K  Slowing down atoms to cm/s

2018



1960

1eV

**Theodore Maiman**

(July 11, 1927 – May 5, 2007)

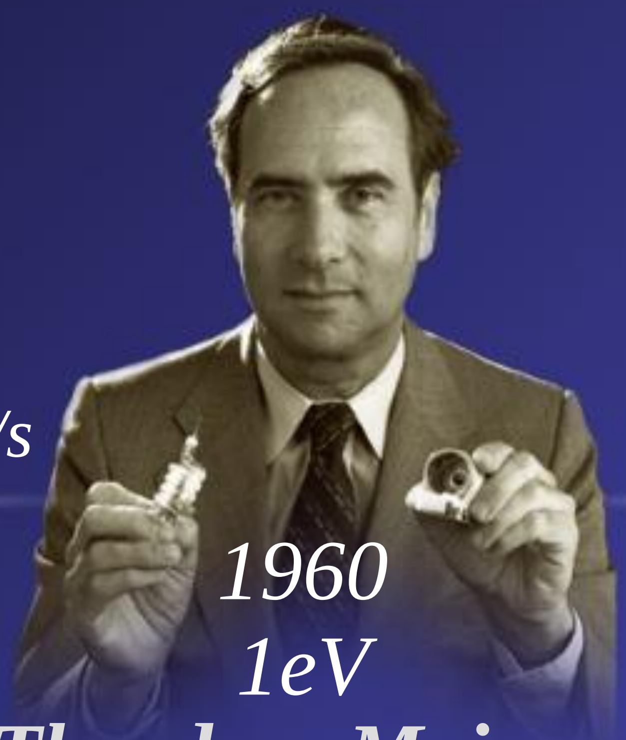
## Atomic Molecular Optics

* cold atoms
* metrology
* atom optics
* condensed-matter physics
* quantum information science
* chemistry

**Quantum Optics**
*μeV - neV*

*Slowing down atoms to cm/s*

*2018*



*1960*
*1eV*
***Theodore Maiman***
*(July 11, 1927 – May 5, 2007)*

*Accelerating particles to C*

*2018*

***Atomic Molecular Optics***

- ***cold atoms***
- ***metrology***
- ***atom optics***
- ***condensed-matter physics***
- ***quantum information science***
- ***chemistry***

**Quantum Optics**

*µeV – peV Temp =10 $^{-8}$ K*

*Slowing down atoms to cm/s*

*2018*

*1960*

*1eV*

***Theodore Maiman***

*(July 11, 1927 – May 5, 2007)*

**Relativistic Optics**

*GeV - TeV*

*Accelerating particles to C*

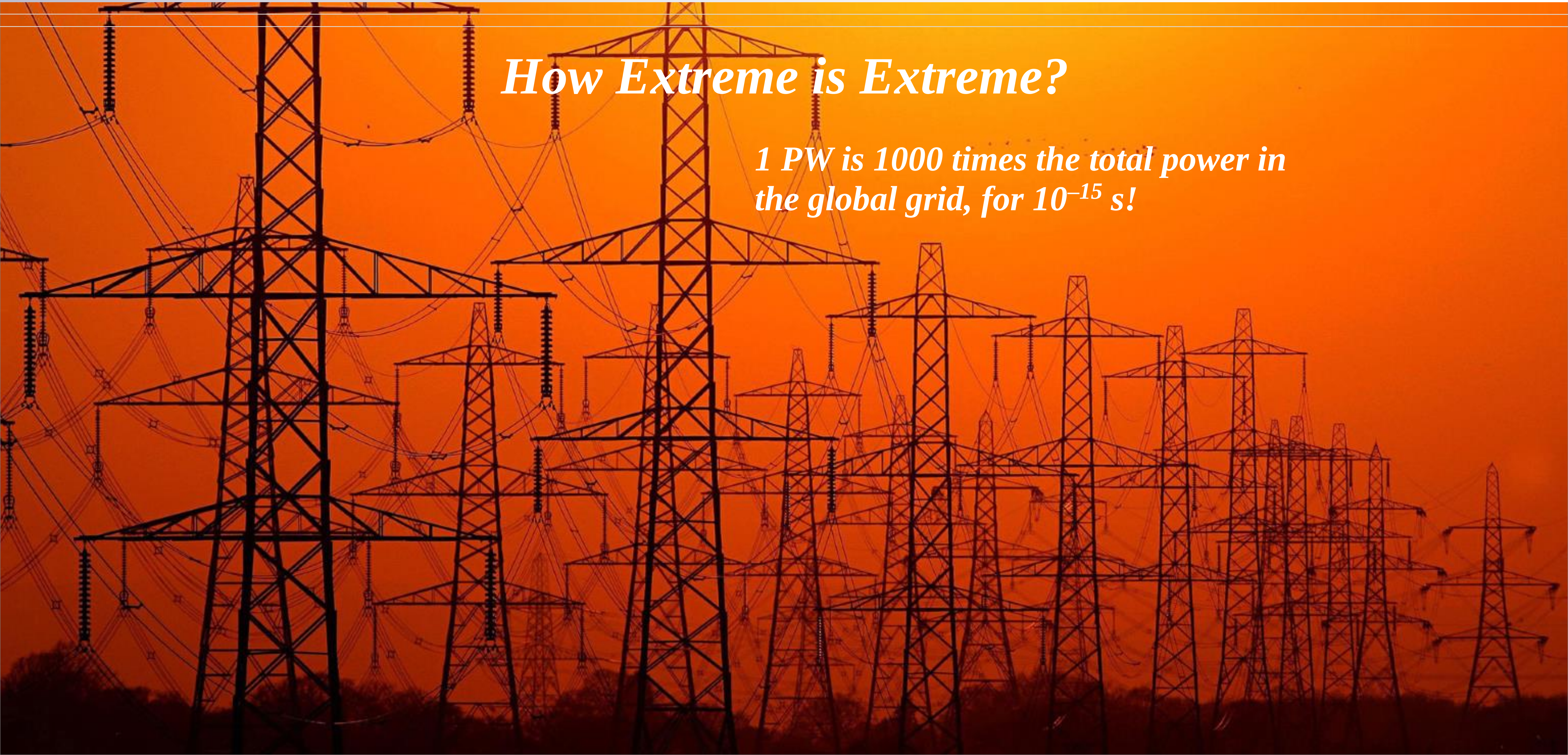
*2018*

***Atomic Molecular Optics***

* cold atoms
* metrology
* atom optics
* condensed-matter physics
* quantum information science
* chemistry

***Relativistic and Ultra-relativistic Optics***

* accelerator physics
* nuclear physics
* cosmology
* NL QED
* general relativity
* extradimension physics



# _How Extreme is Extreme?_

**_1 PW is 1000 times the total power in the global grid, for $10^{-15}$ s!_**

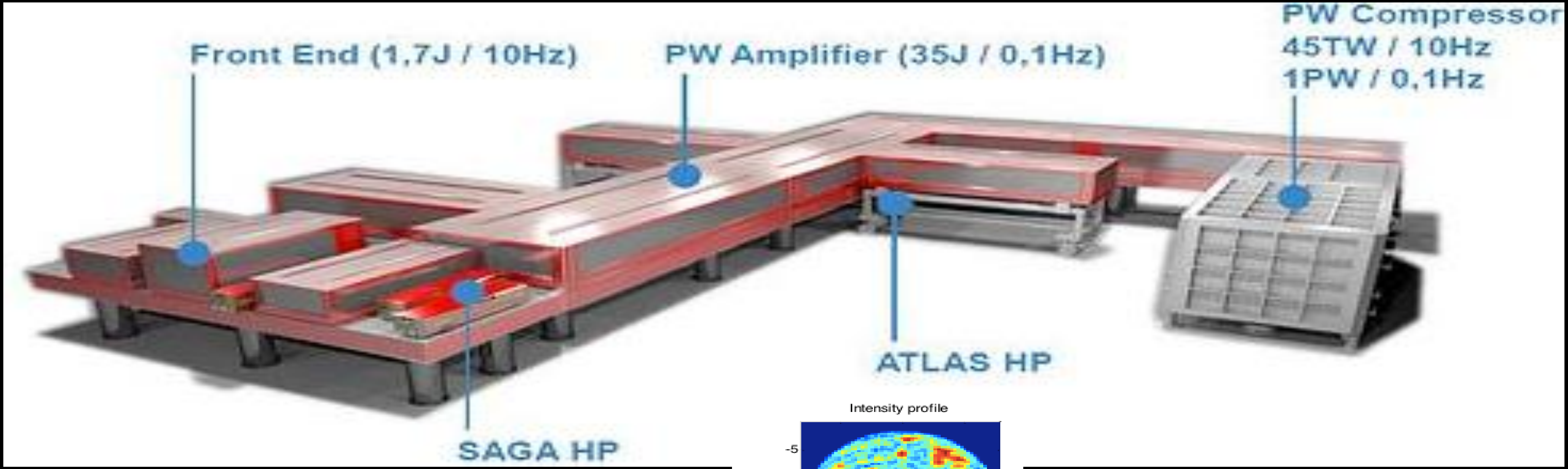
# How Much Pressure Does a PW Laser Exert?

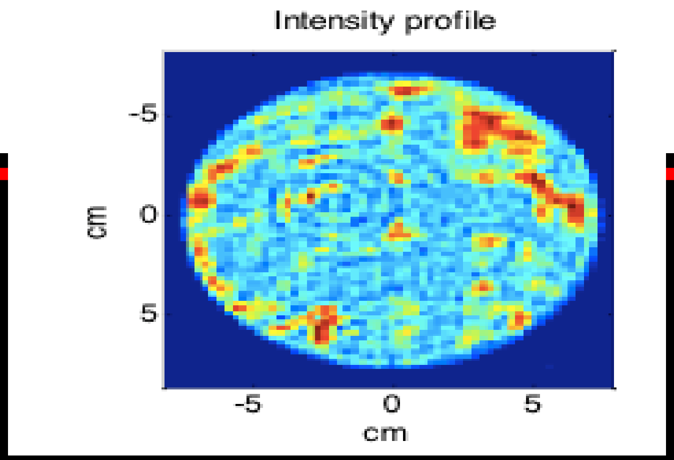
1 PW/1μm spot size corresponds to $10^{23}$ w/cm$^2$

That is the equivalent of the pressure of 10 million Eiffel Towers on the tip of your finger!!

Seriously extreme!

# *Petawatt Laser Provides*
# *A 10-1000J Uniform wave front in*
# ***Phase and Amplitude***

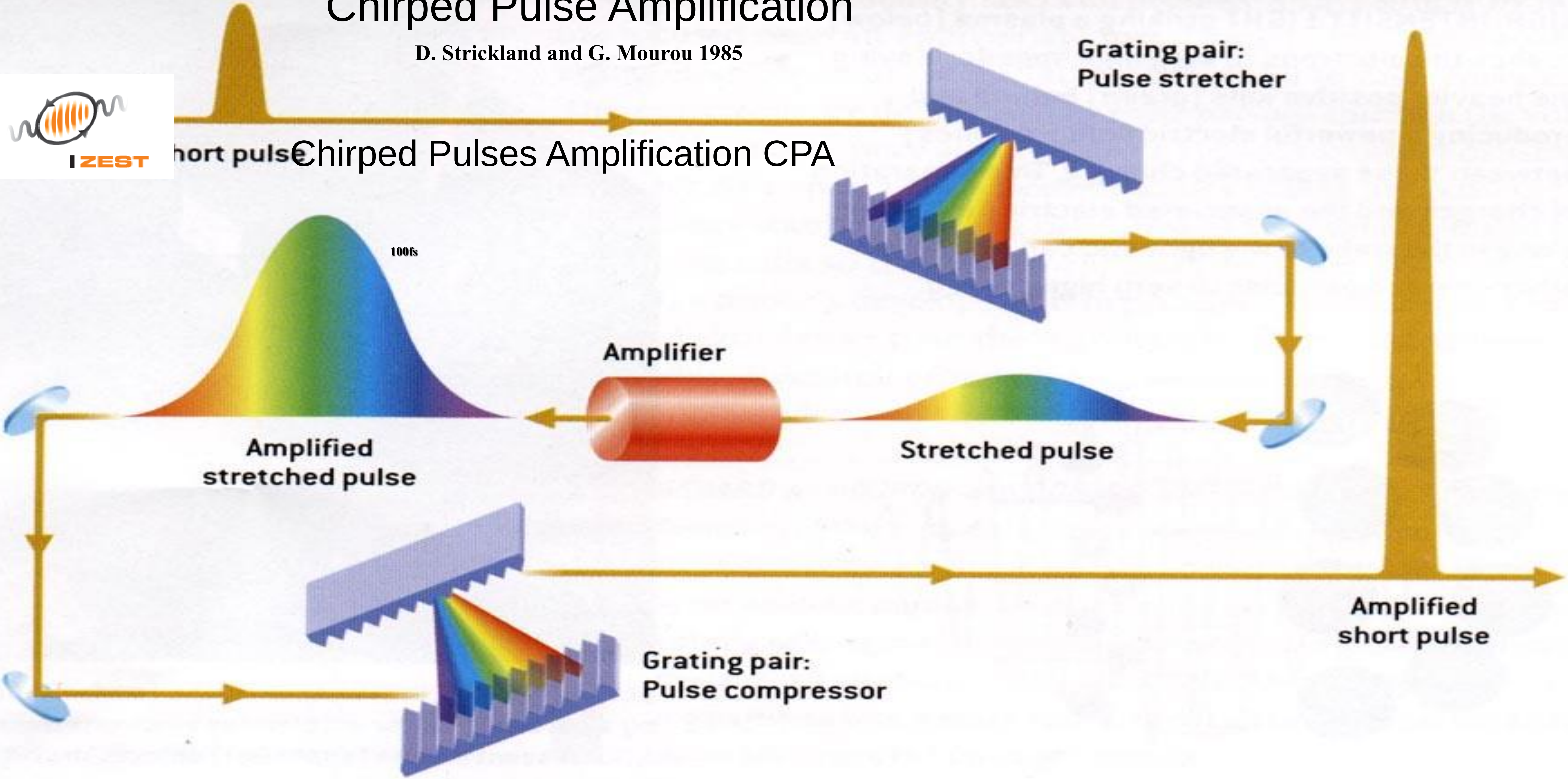


# Chirped Pulse Amplification

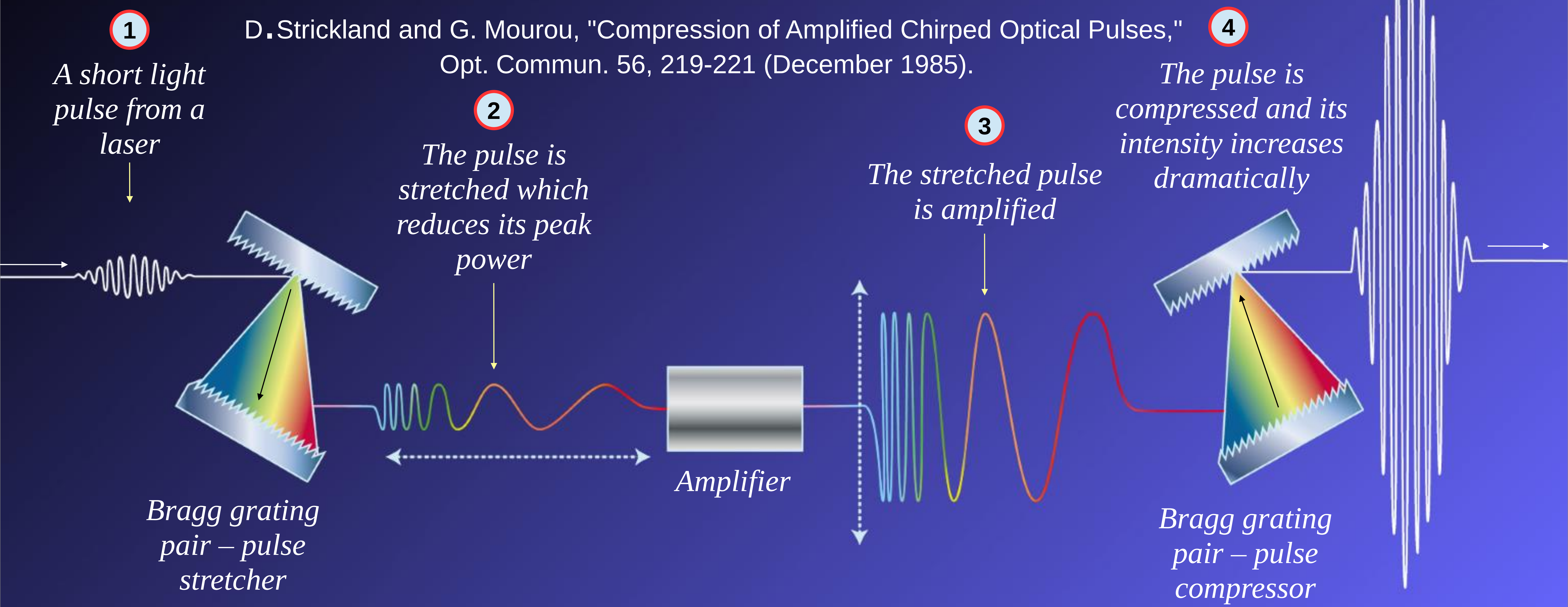
D. Strickland and G. Mourou 1985

## Chirped Pulses Amplification CPA



# *Chirped Pulse Amplification (CPA)*

D. Strickland and G. Mourou, "Compression of Amplified Chirped Optical Pulses," Opt. Commun. 56, 219-221 (December 1985).



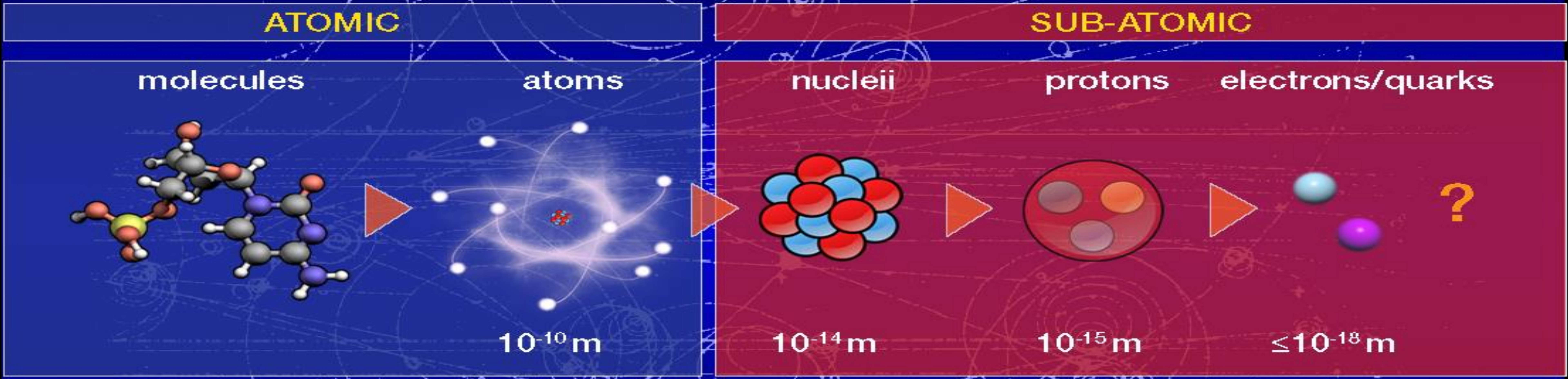
Extreme light Laser is capable to produce,

1. the largest peak power,
2. the largest temperature,
3. the largest pressure,
4. largest acceleration,
5. the largest field.

It is a universal source of High Energy Particles and Radiations

# Laser Exploration : From Atomic to Sub-Atomic

eV → TeV



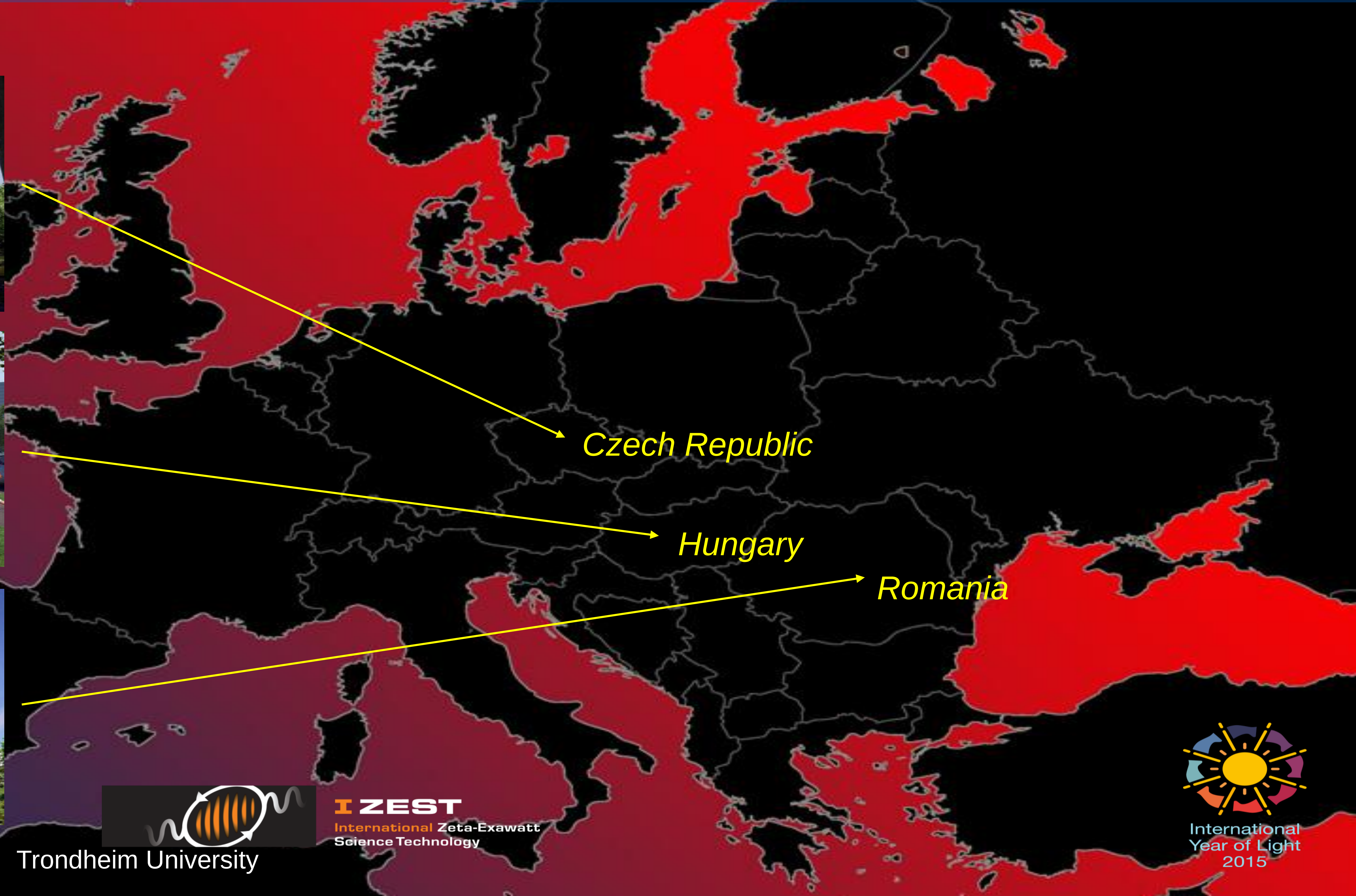

Nobel NSF

# Extreme Light Infrastructure - ELI

## The Largest Civilian Laser Infrastructure

**Initiated and Coordinated(PP) by, G. Mourou (EP)**

**ELI (Delivery Consortium) W. Sandners**

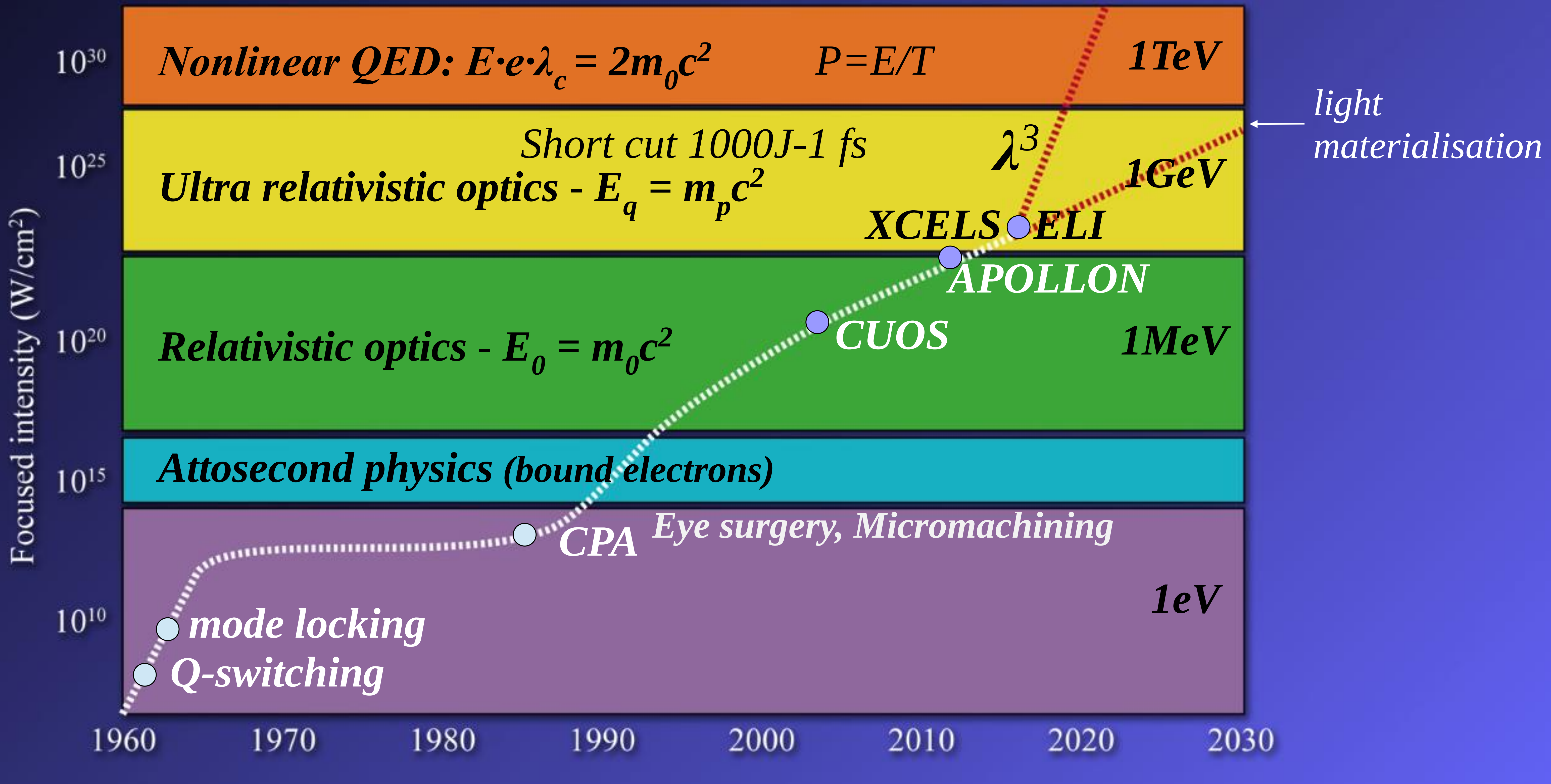



Trondheim University

IZEST International Zeta-Exawatt Science Technology

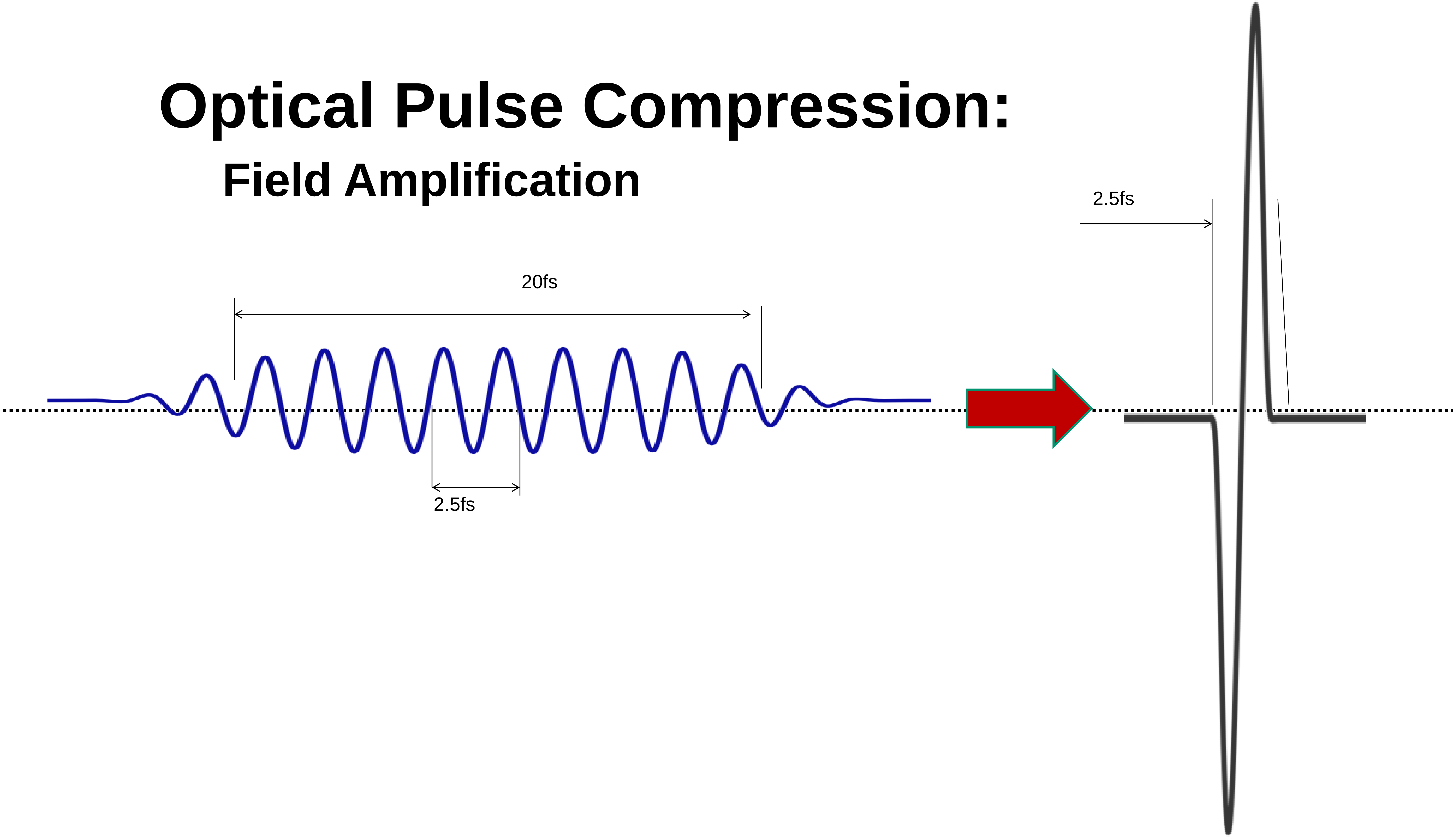
International Year of Light 2015

## Extreme light roadmap and ultra high intensity shortcut

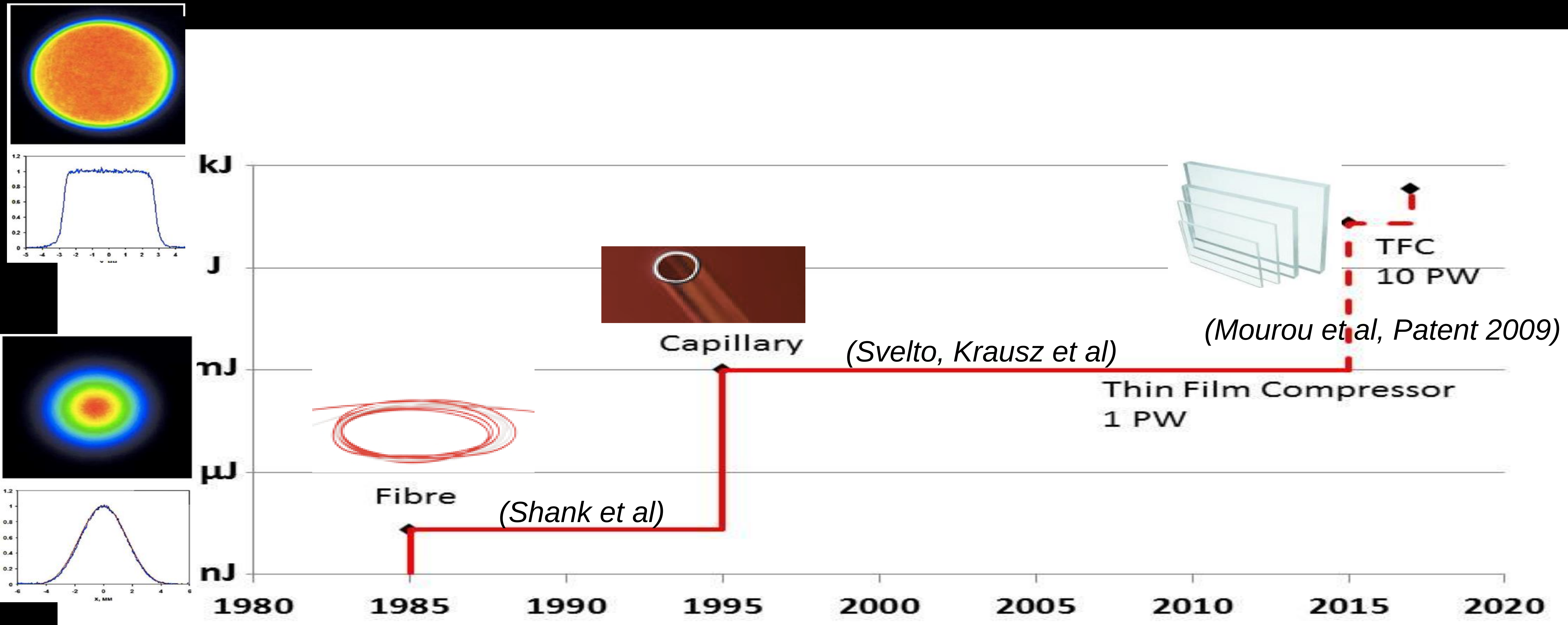


# Optical Pulse Compression:

## Field Amplification



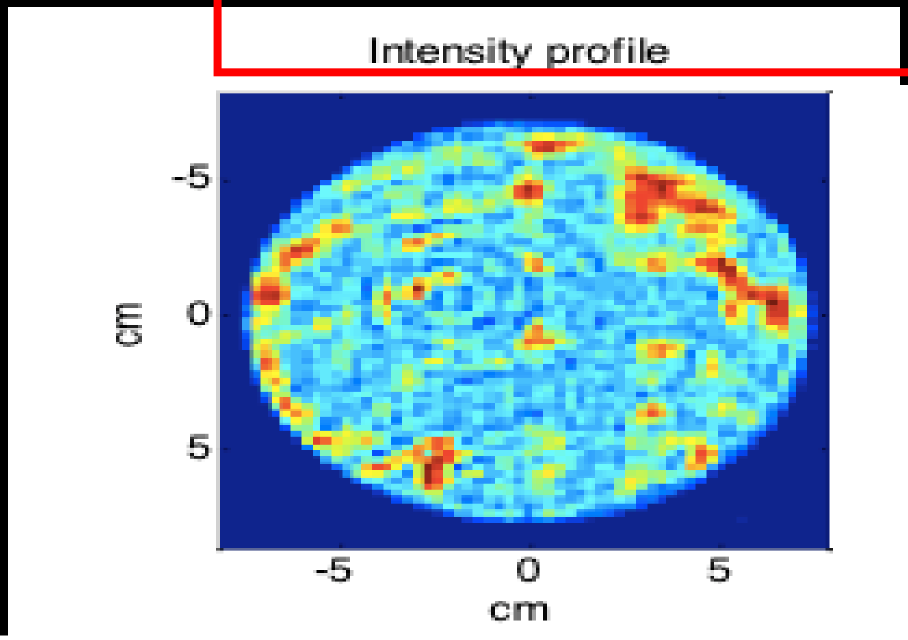
# Single Cycle Pulse Compression Pulse: History

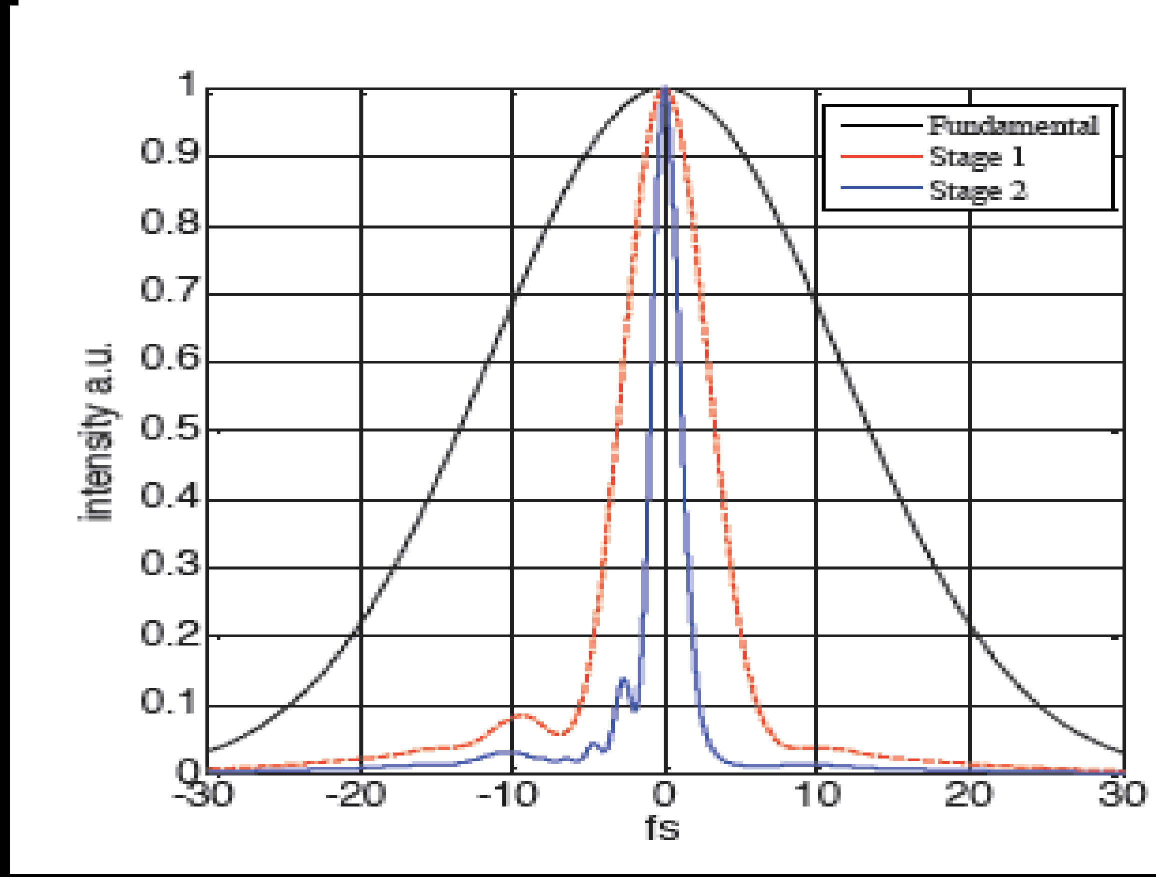


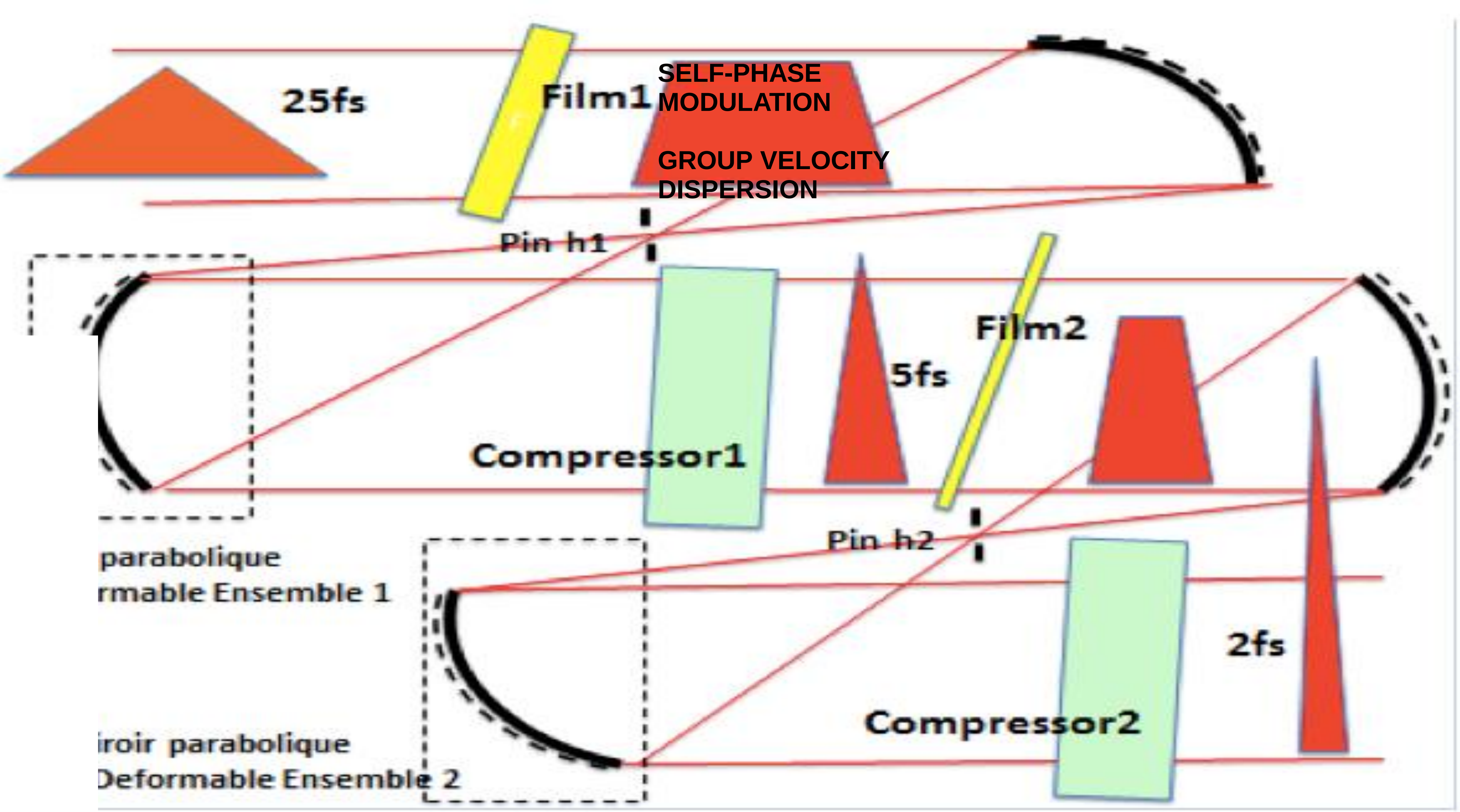

Gérard Mourou, Gilles Cheriaux, Christophe Radier,Device for generating a short duration laser pulse US 20110299152 A1

# Thin Film Compressor to Single Cycle (TFC)

Mourou, G. Cheriaux, C. Radier Patent 2009




A.A. Voronin, A.M. Zheltikov, T. Ditmire, B. Rus and G. Korn Optics. Com. 2011

G. Mourou, S. Mironov, E. Khazanov and A. Sergeev, Single cycle Physics , Eur. Phys. J. Special Topics, 223, 1181(2014)

# Thin Film Pulse Compression

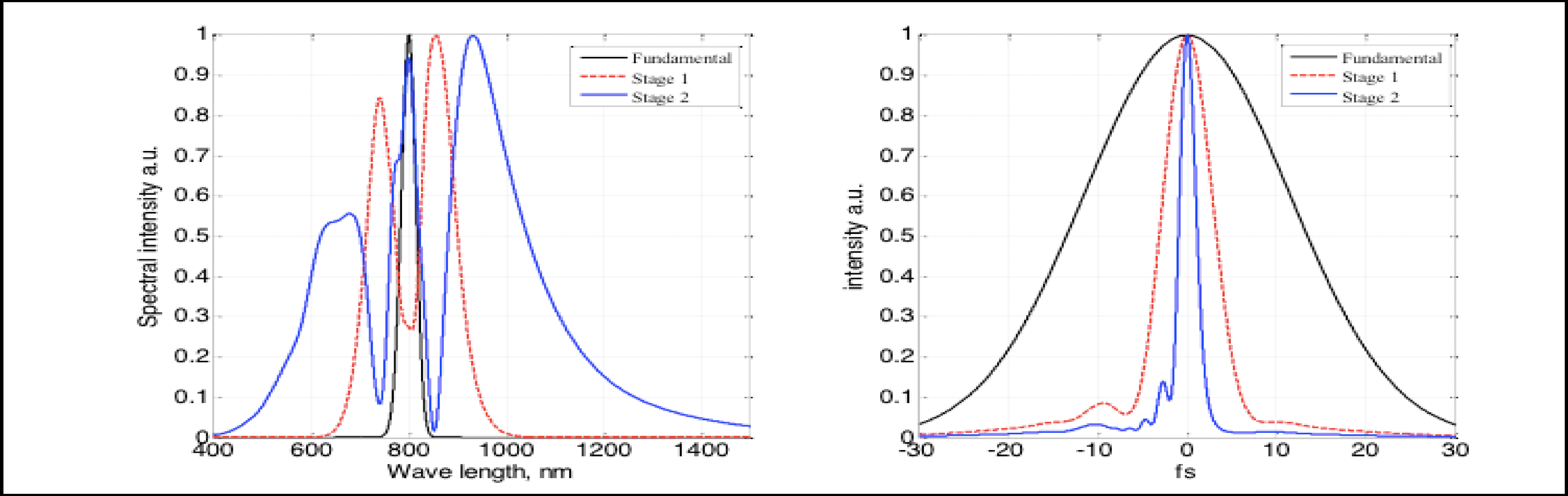
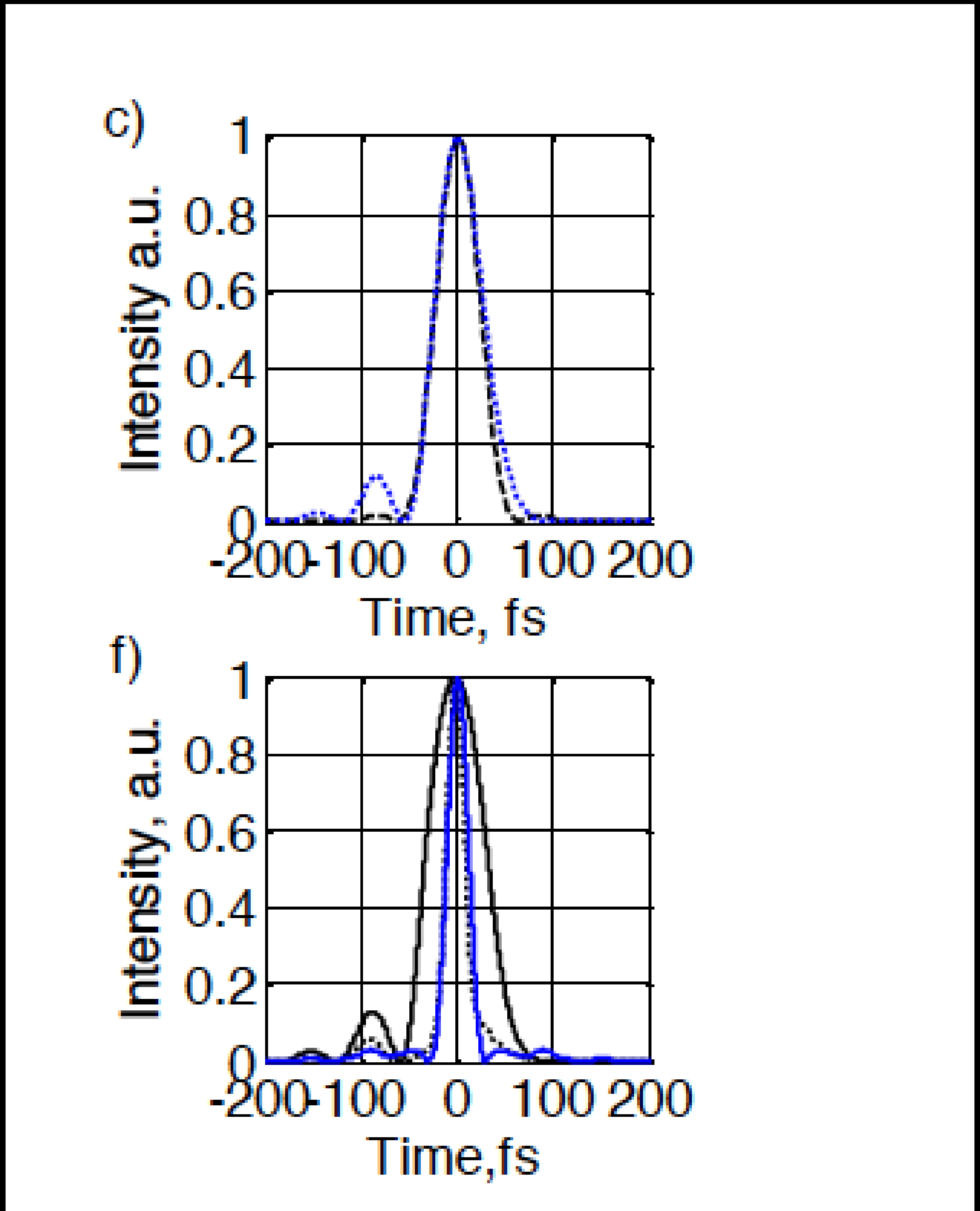



Fig. 4 shows the successive spectra and pulse durations corresponding to the laser out put, after the first stage and second stage. After the first stage the pulse 6.4fs, after the second stage the pulse is shrunk to 2.1fs

# Pulse Compression on PEARL

Pulse Duration In
75 fs



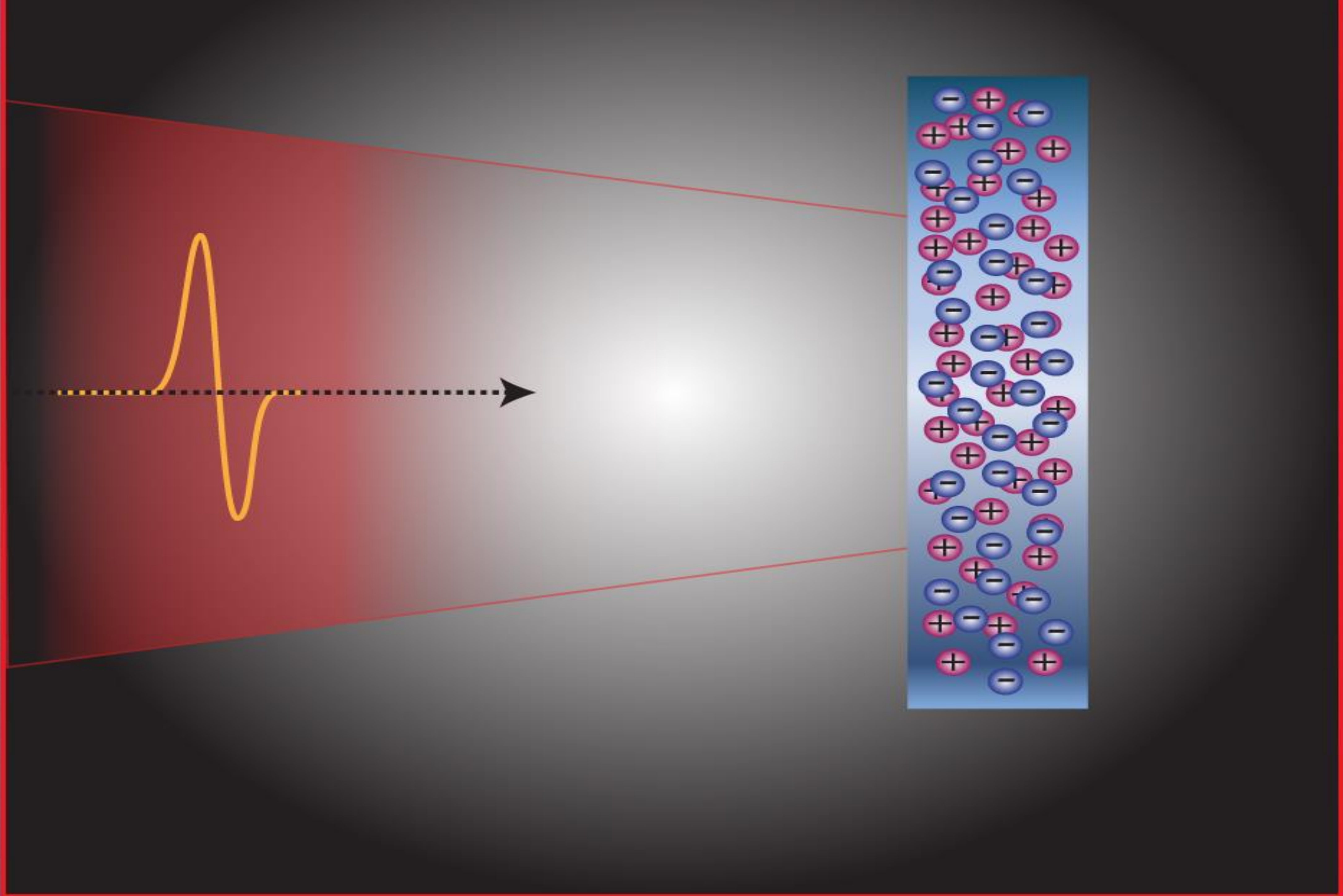

Pulse Duration out
15 fs
Compression 5

# Relativistic Compression
# Scalable Isolated Attosecond Pulses

N. M. Naumova, J. A. Nees, I. V. Sokolov, B. Hou, and G. A. Mourou,

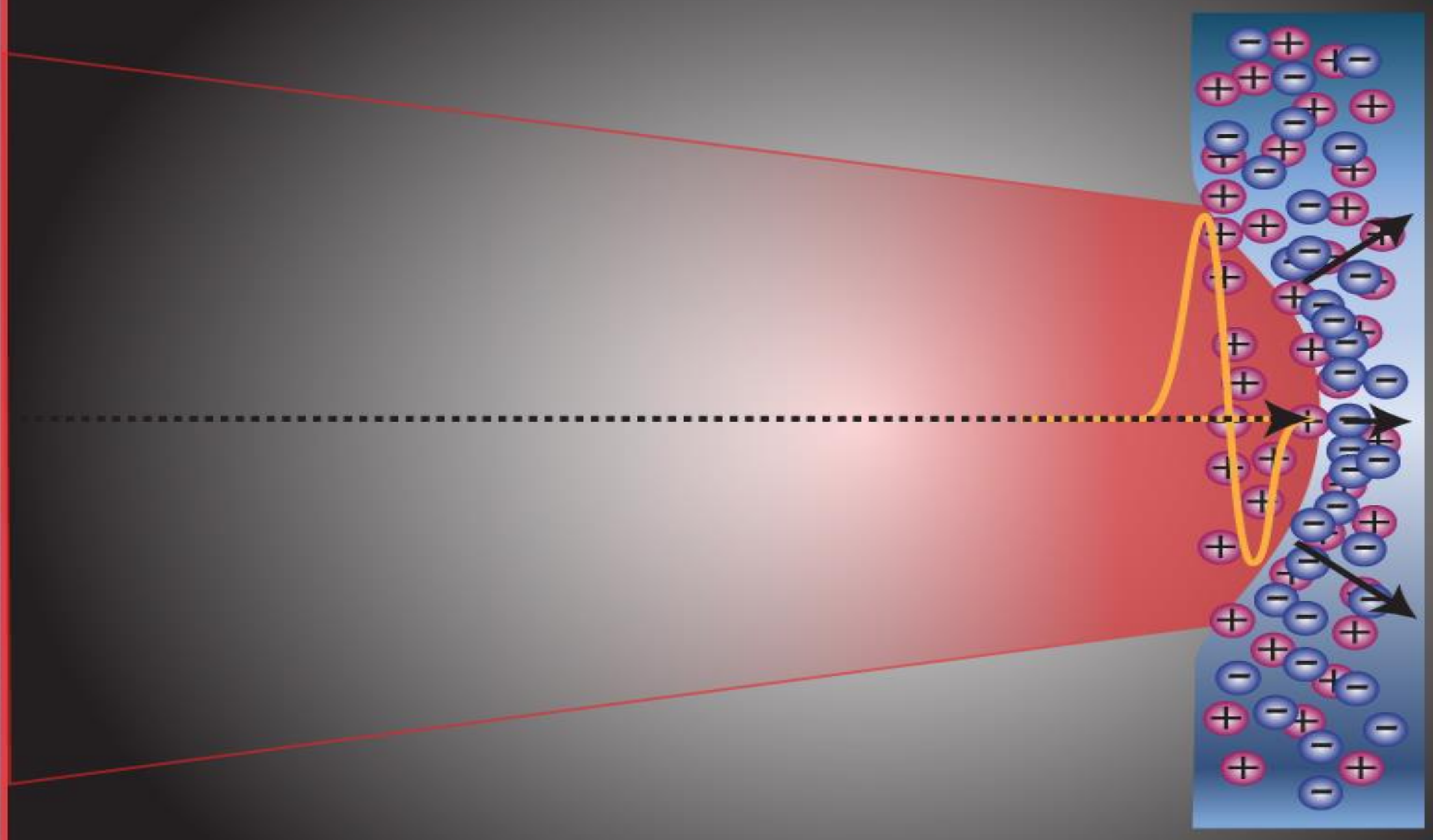
Relativistic generation
of Isolated attosecond Pulses in a $\lambda^3$ Focal Volume, Phys. Rev. Lett. 92, 063902-1 (2004).

# Relativistic Compression



Georgia tech

# Relativistic Compression



Georgia tech

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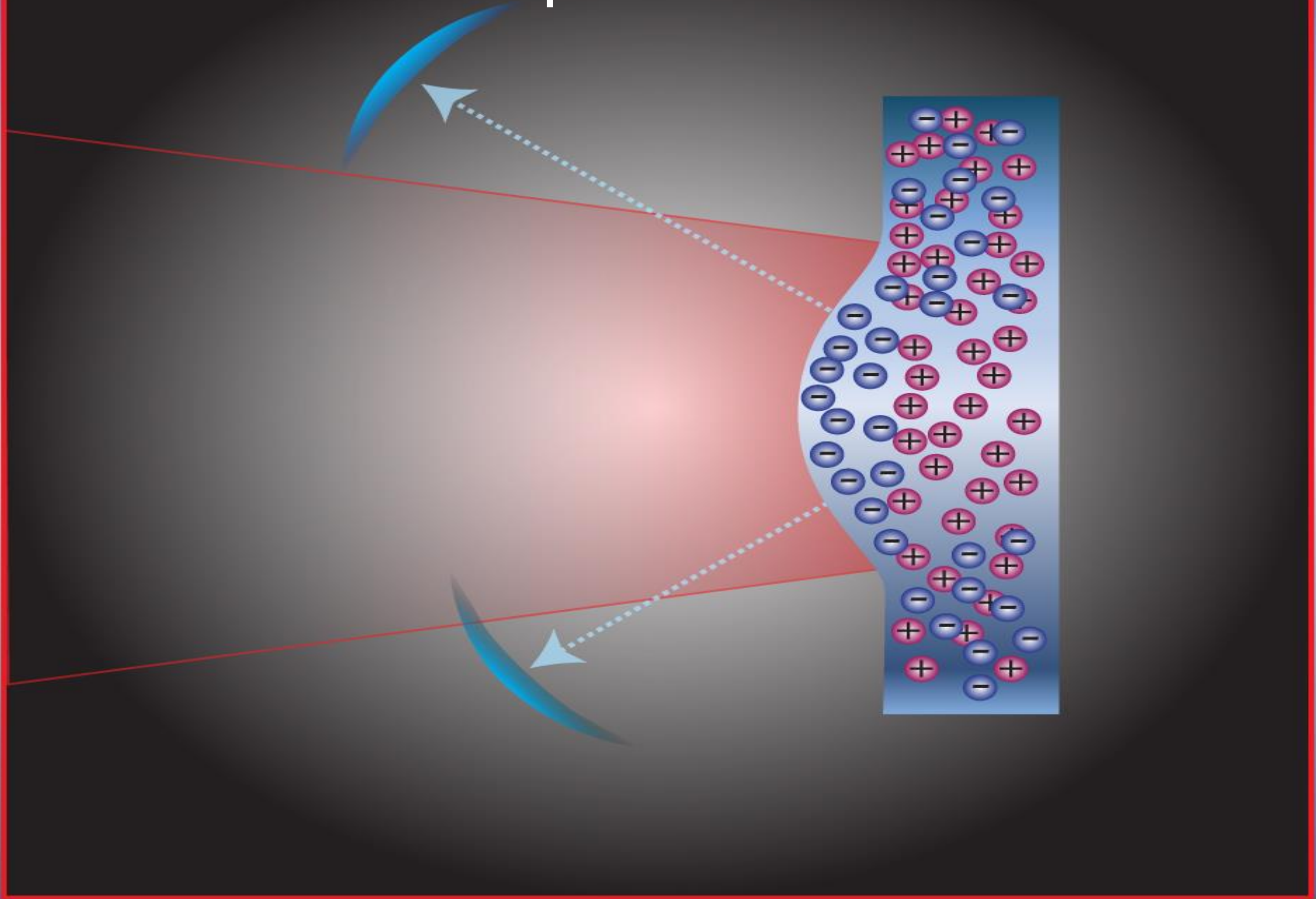

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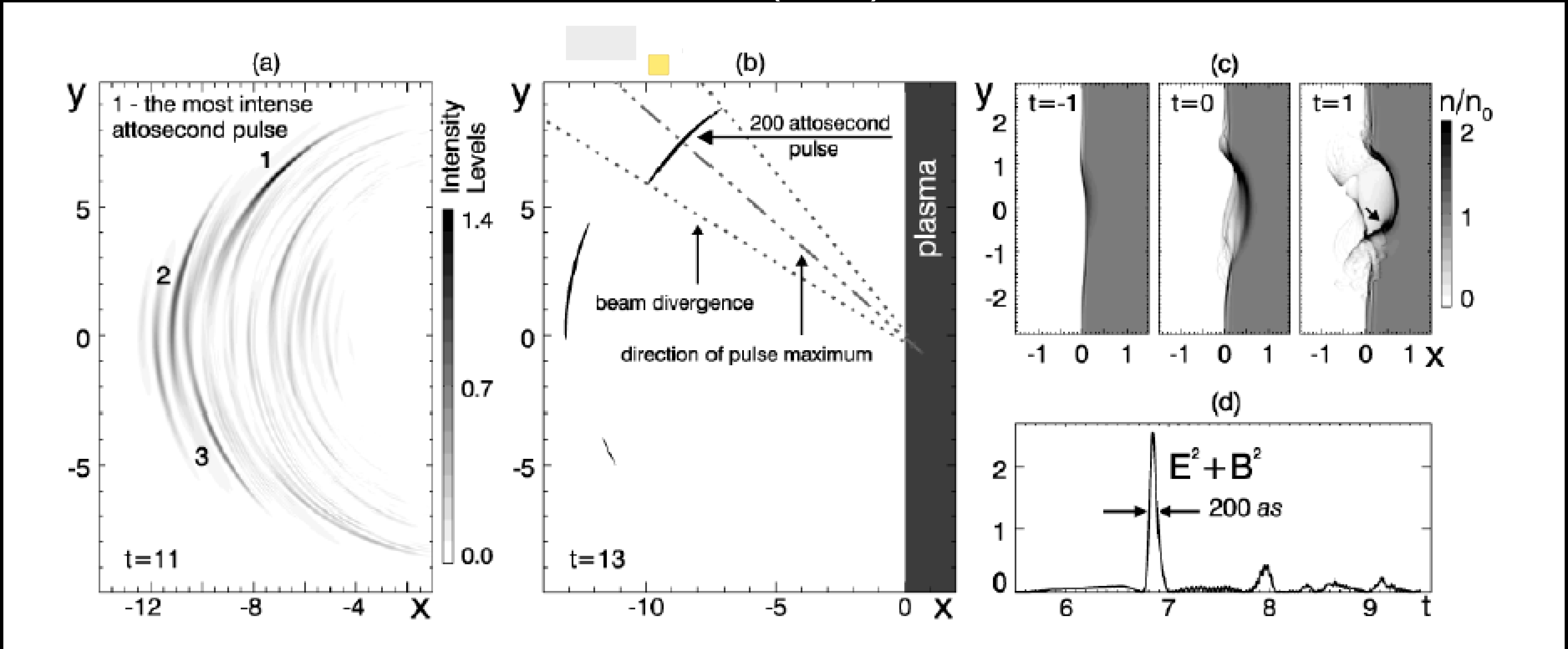
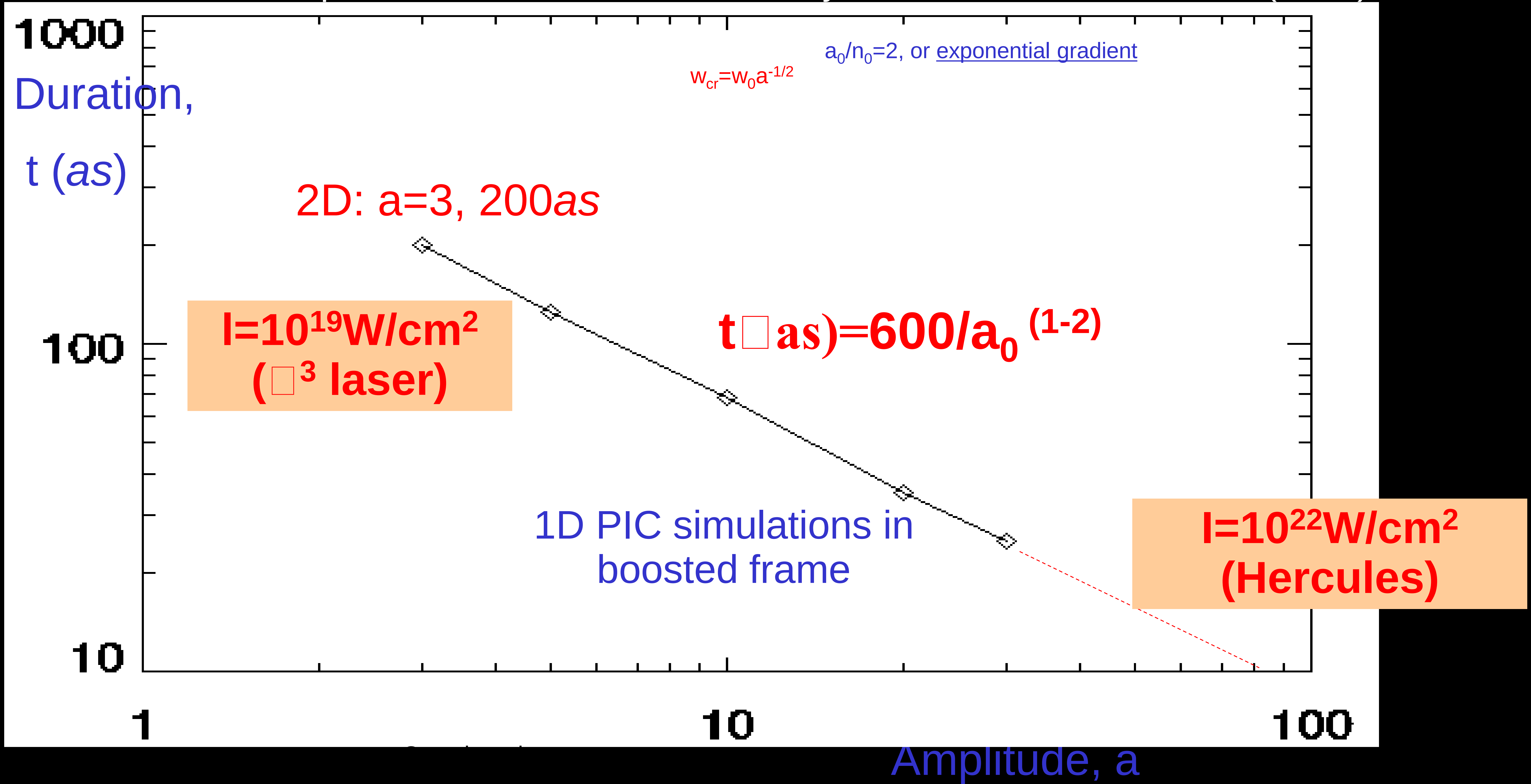
# Relativistic Compression

N. M. Naumova, J. A. Nees, I. V. Sokolov, B. Hou, and G. A. Mourou, Relativistic generation of isolated attosecond pulses in a $\lambda^3$ focal volume, Phys. Rev. Lett. 92, 063902-1 (2004).

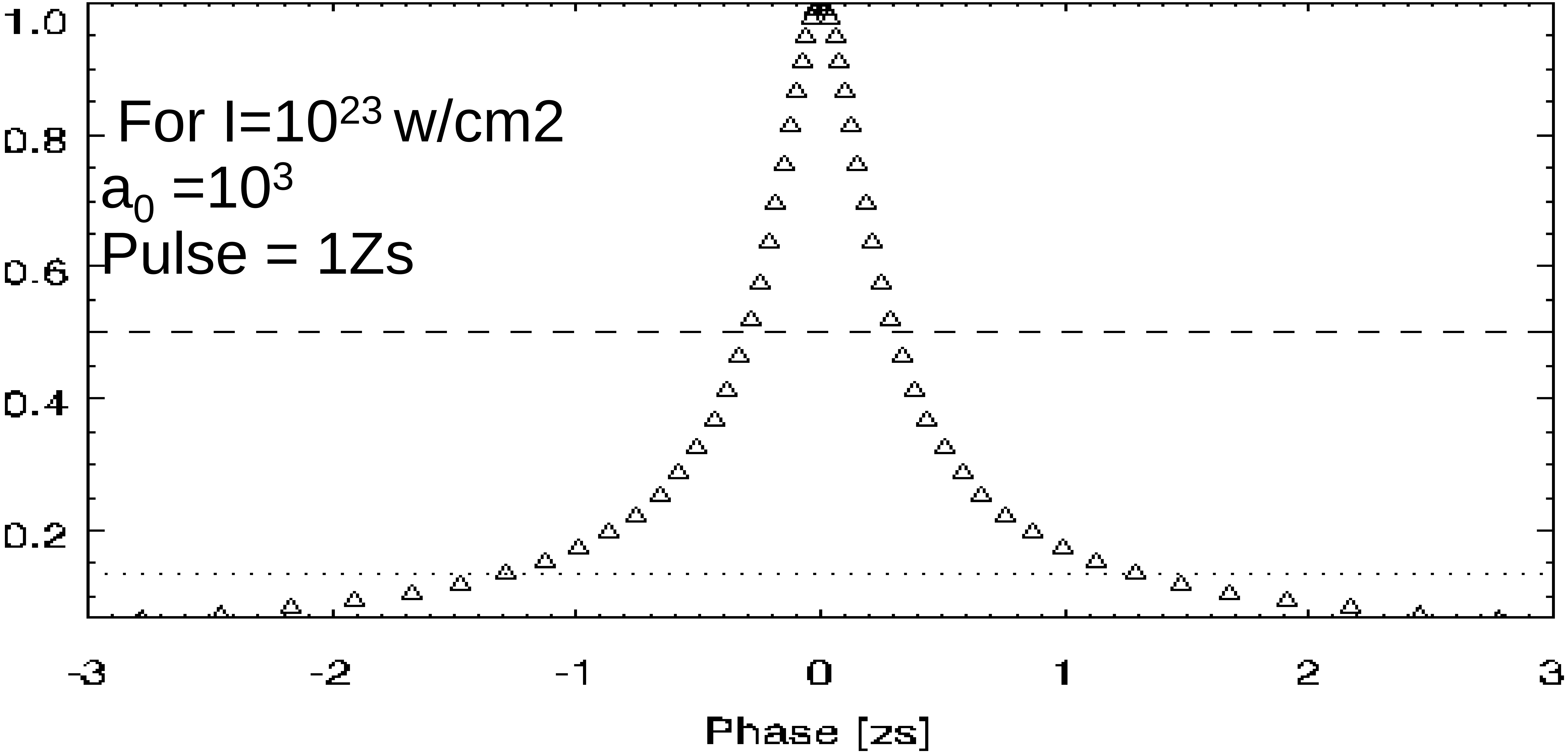


# Scalable Isolated Attosecond Pulses

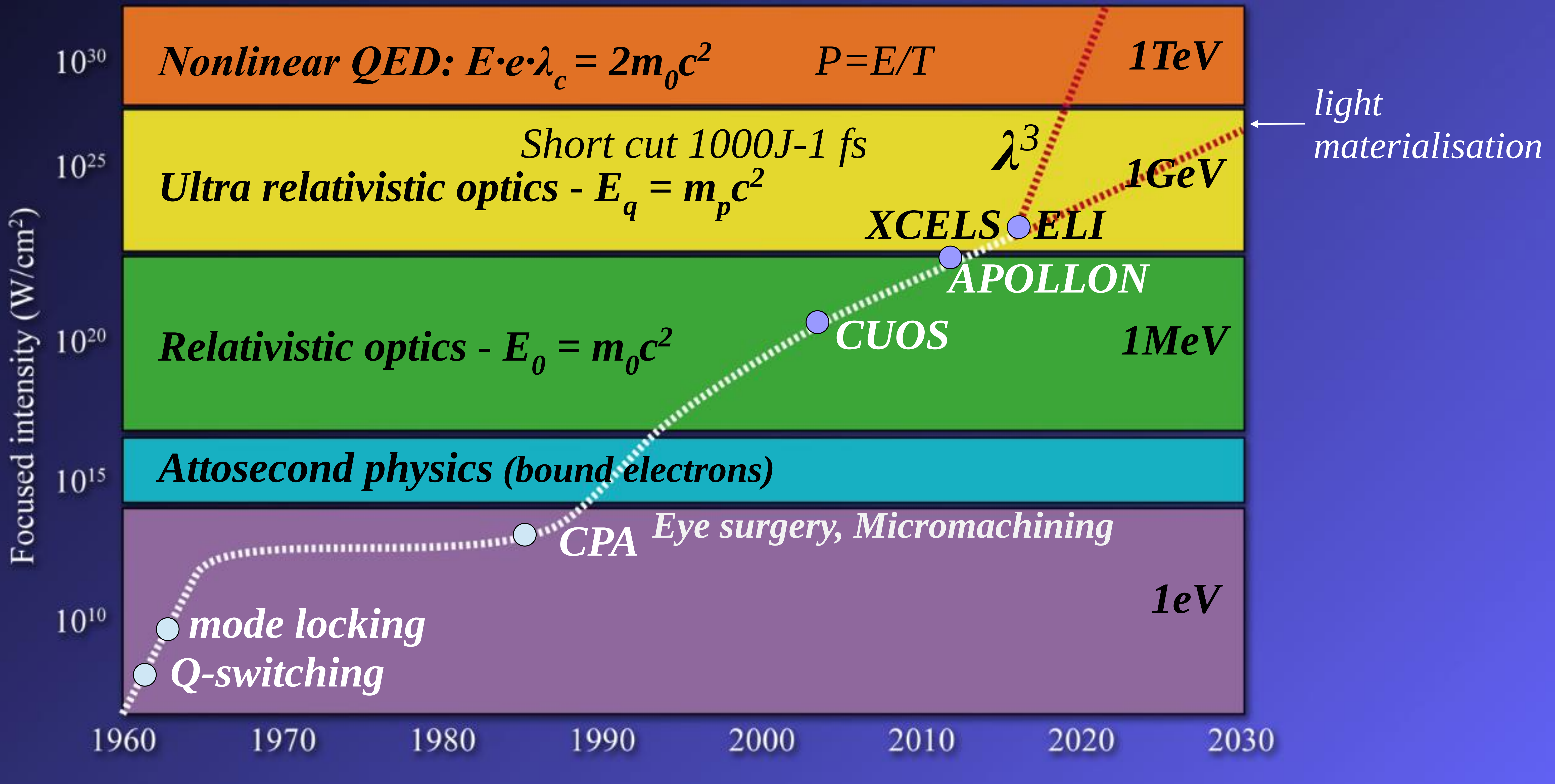
N. M. Naumova, J. A. Nees, I. V. Sokolov, B. Hou, and G. A. Mourou, Relativistic generation of isolated attosecond pulses in a $\lambda^3$ focal volume, Phys. Rev. Lett. 92, 063902-1 (2004).



Zeptosecond pulses, (N. Naumova, I. Sokolov, G. Mourou)
(Preliminary Result)



# Extreme light roadmap and ultra high intensity shortcut



# *A PASSION FOR EXTREME LIGHT*

*For the greatest benefit to human kind (Alfred Nobel)*

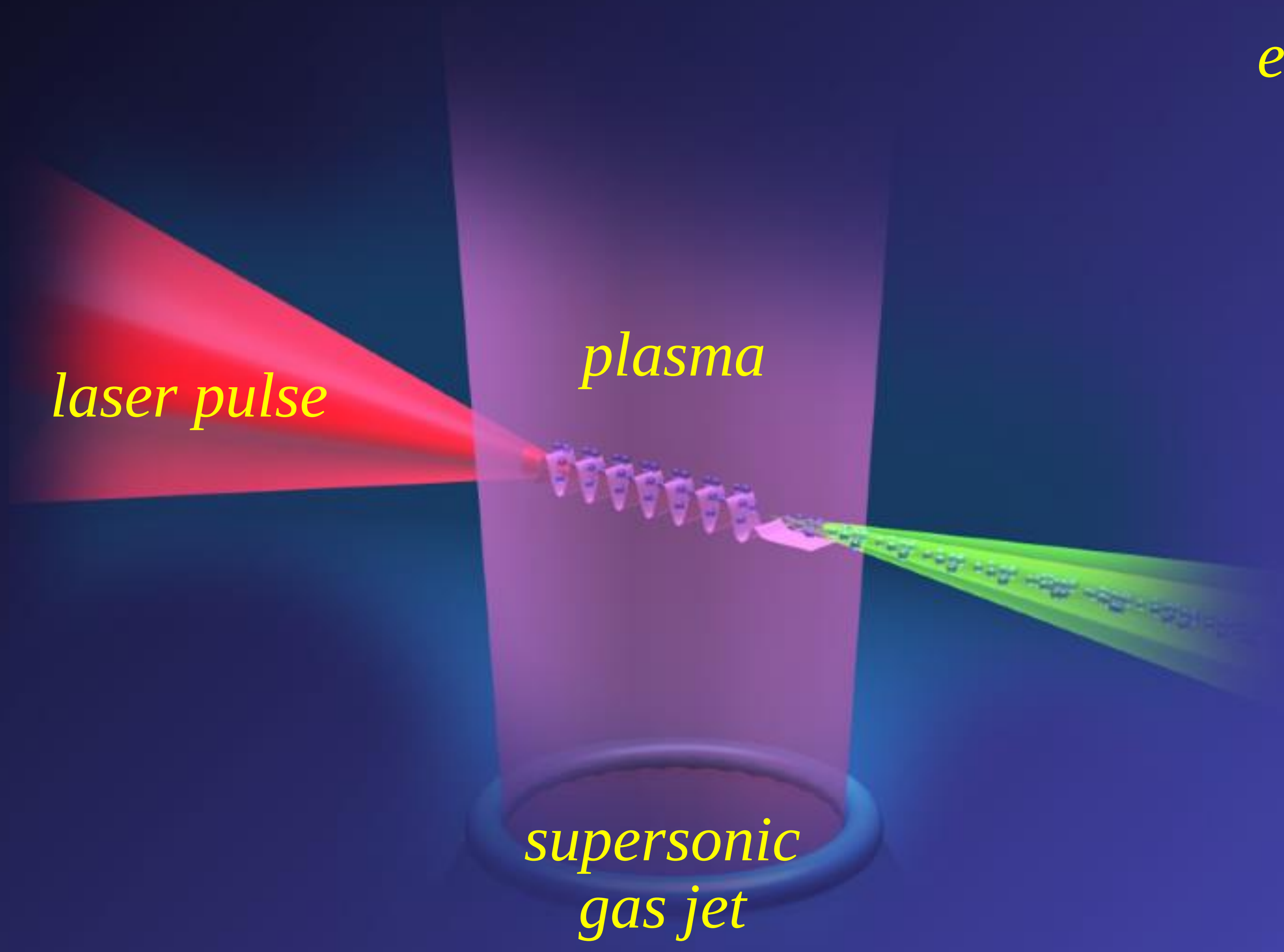
## *Giant wakefield acceleration in gas and solid*

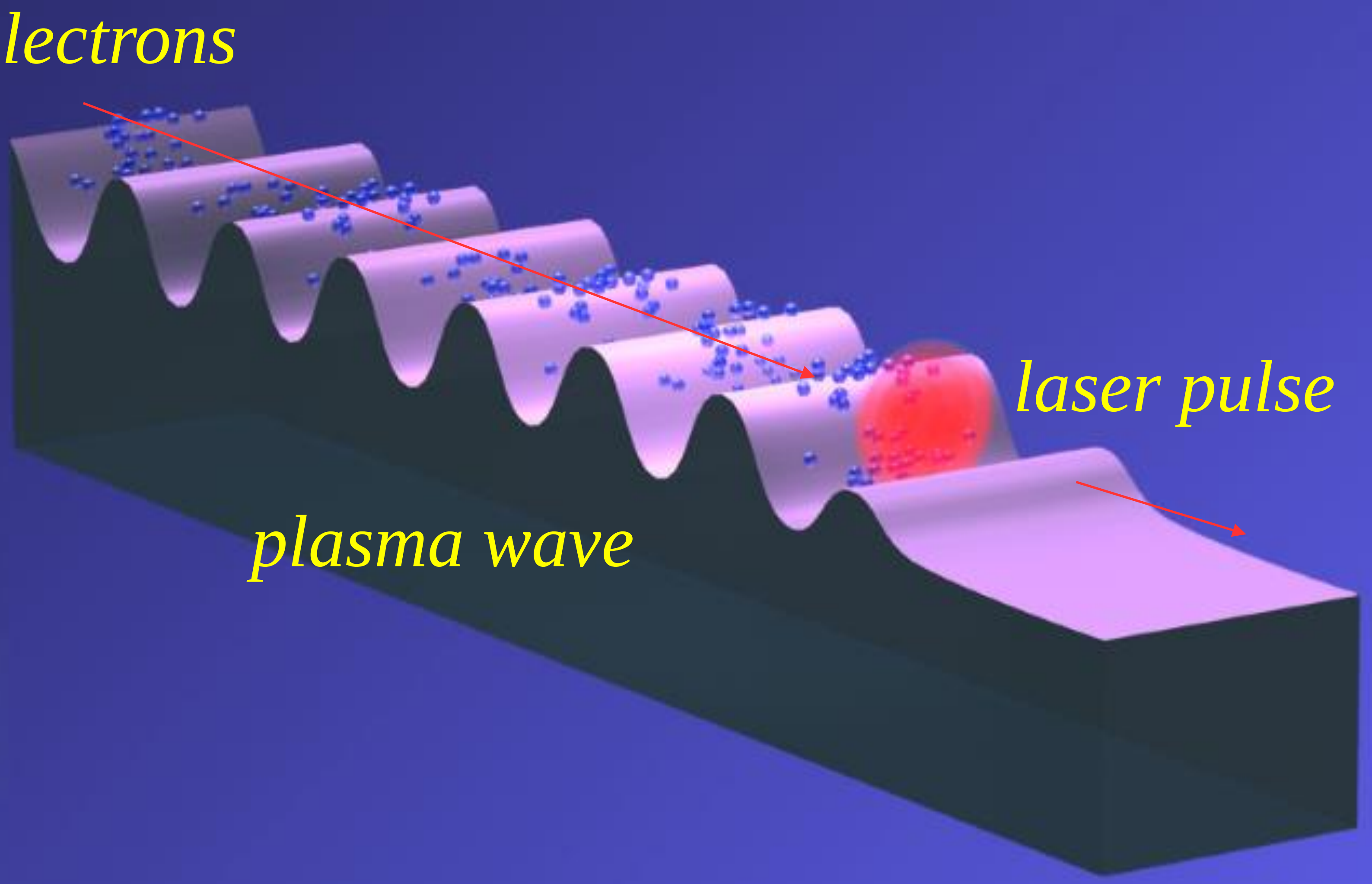
*Tajima et Dawson (1979)*

***A surfer riding down the face of a wave is accelerated by energy of the wave***

## ***Giant wakefield acceleration***

*Tajima et Dawson (1979)*



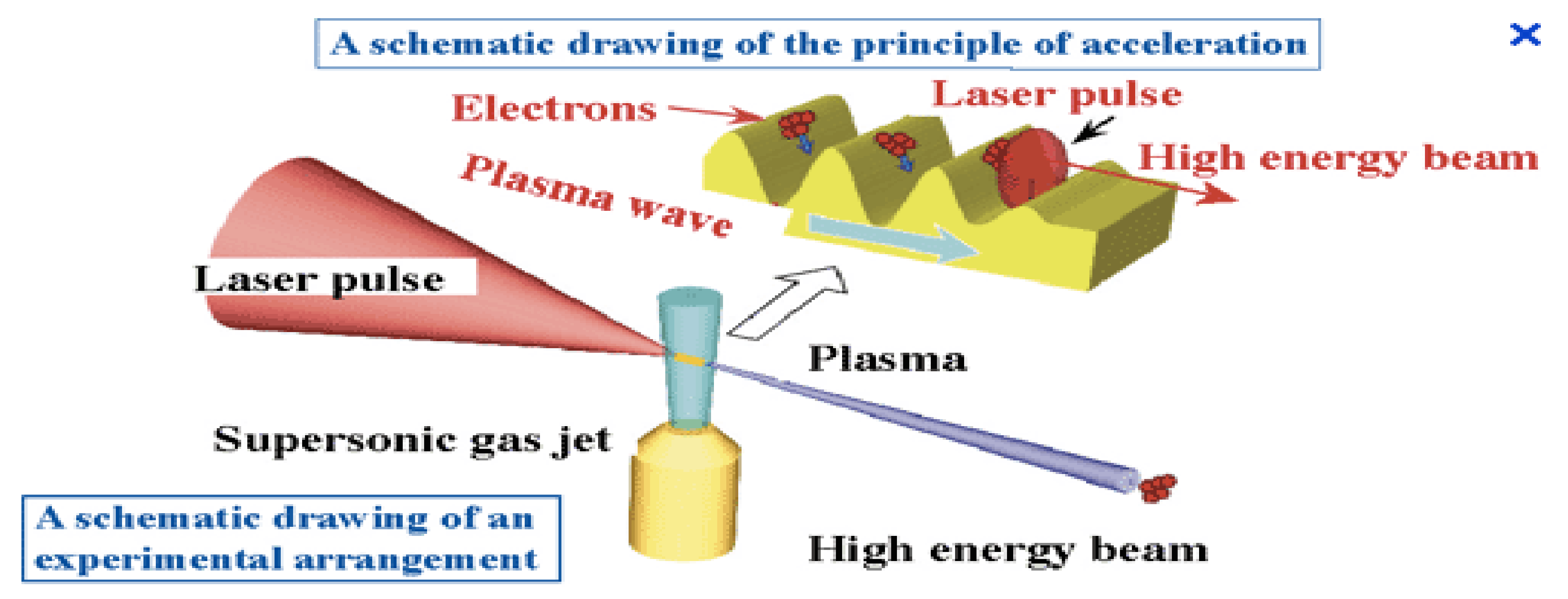

***High Energy beam***
***GeV/cm***

# Synchrotron SOLEIL 3GeV

S

# Giant Wake Field Acceleration in Gas and Solid

**Femtosecond Visible Light Driver in Gas** ***Tajima et Dawson 1979***




Plasma Acceleration Energy Gain

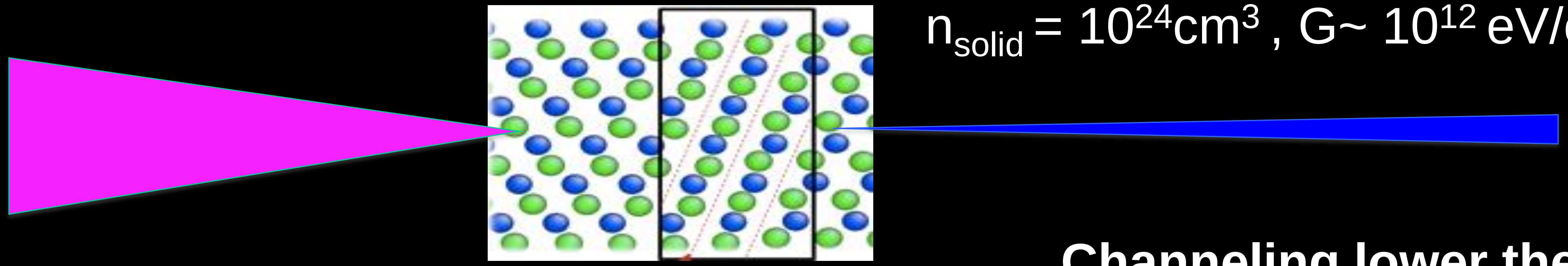
$G \alpha n^{1/2}$ eV/cm

1eV light $n_c \sim 10^{21} cm^{-3}$

$n_{gas} = 10^{18} cm^{-3}$ , $G \sim 10^{9}$, GeV/cm

**Atto-zepto, X-ray Driver, Solid,** ***Tajima et Cavenago 1987***

$n_{solid} = 10^{24} cm^{3}$ , $G \sim 10^{12}$ eV/cm, TeVcm

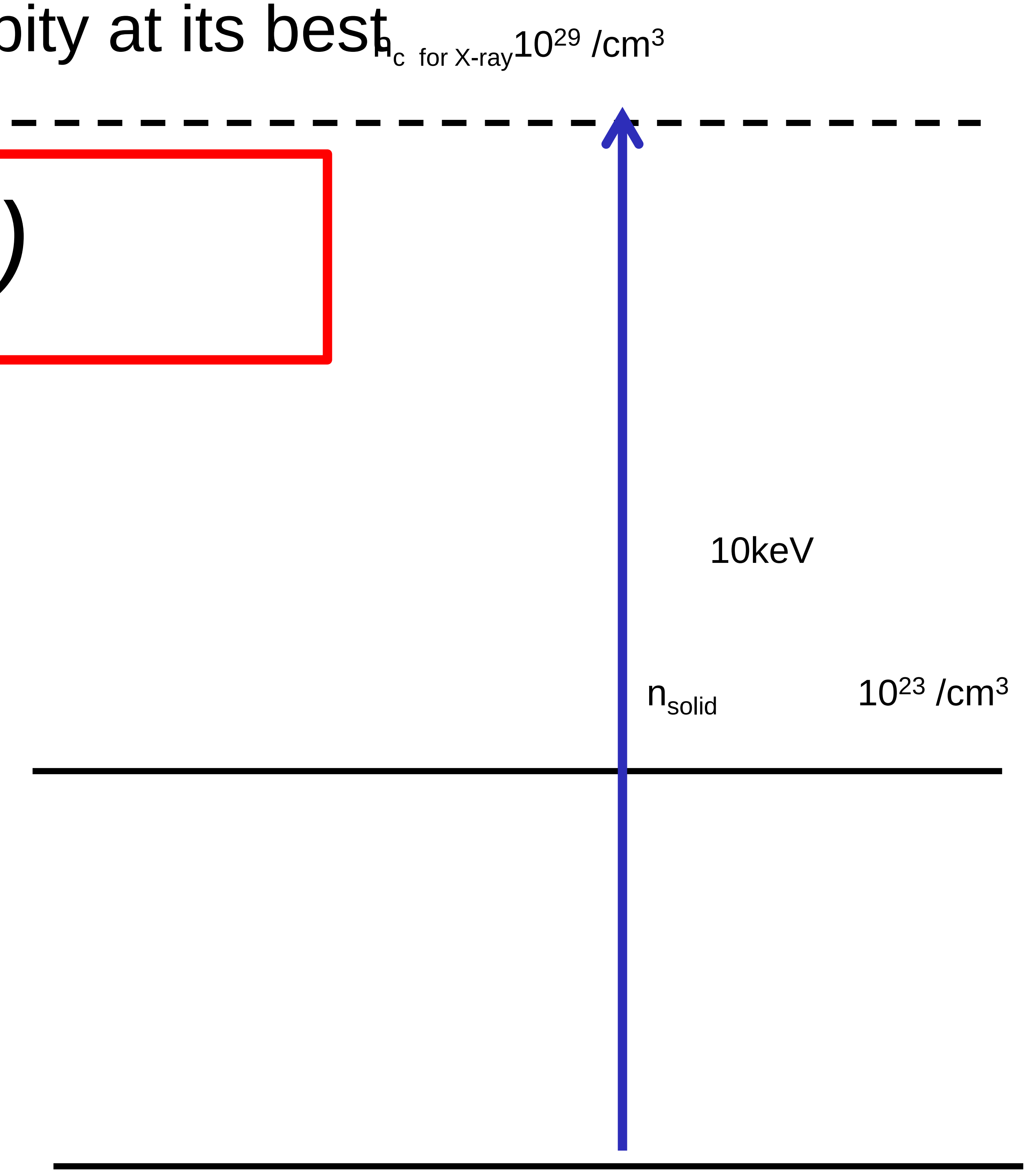


Drive pulse X-Ray, 600zs
+ as electron pulse

**Channeling lower the emittance**
**Valid for electron, muons, heavy ions**

# Laser-Wake-Field Acceleration
# Gas/Light vs Solid/ X-Ray

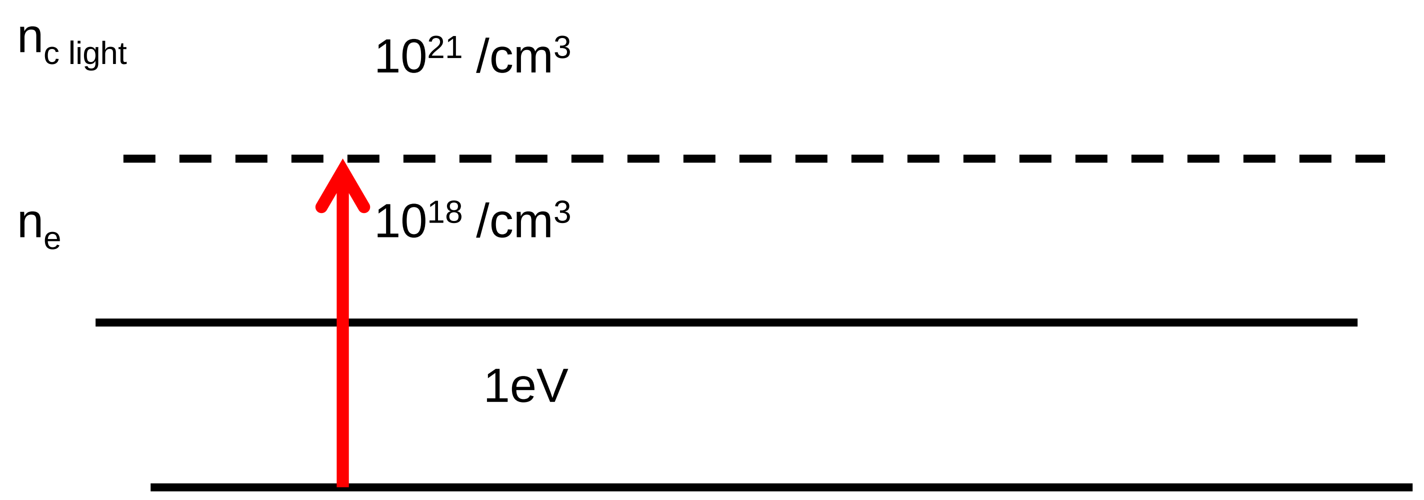
Serendipity at its best



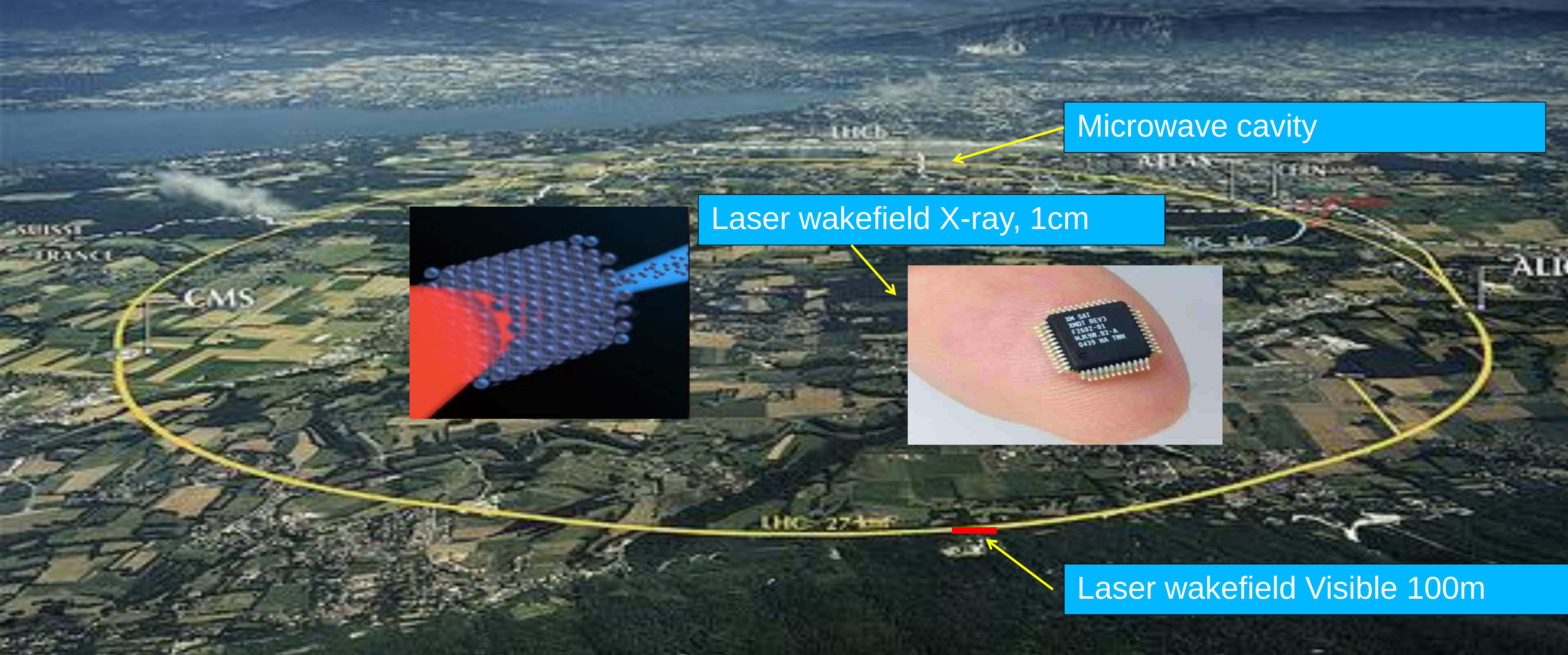

**Energy Gain** $E=a_0^2 m_o c^2 (n_c/n_e)$

In the visible $n_c = 10^{21}$/cm$^3$ Low gaz density

In the X-ray, $n_c = 10^{29}$/cm$^3$ Solid density



# *Outlook for*
# *Laser-Particle acceleration TeV*

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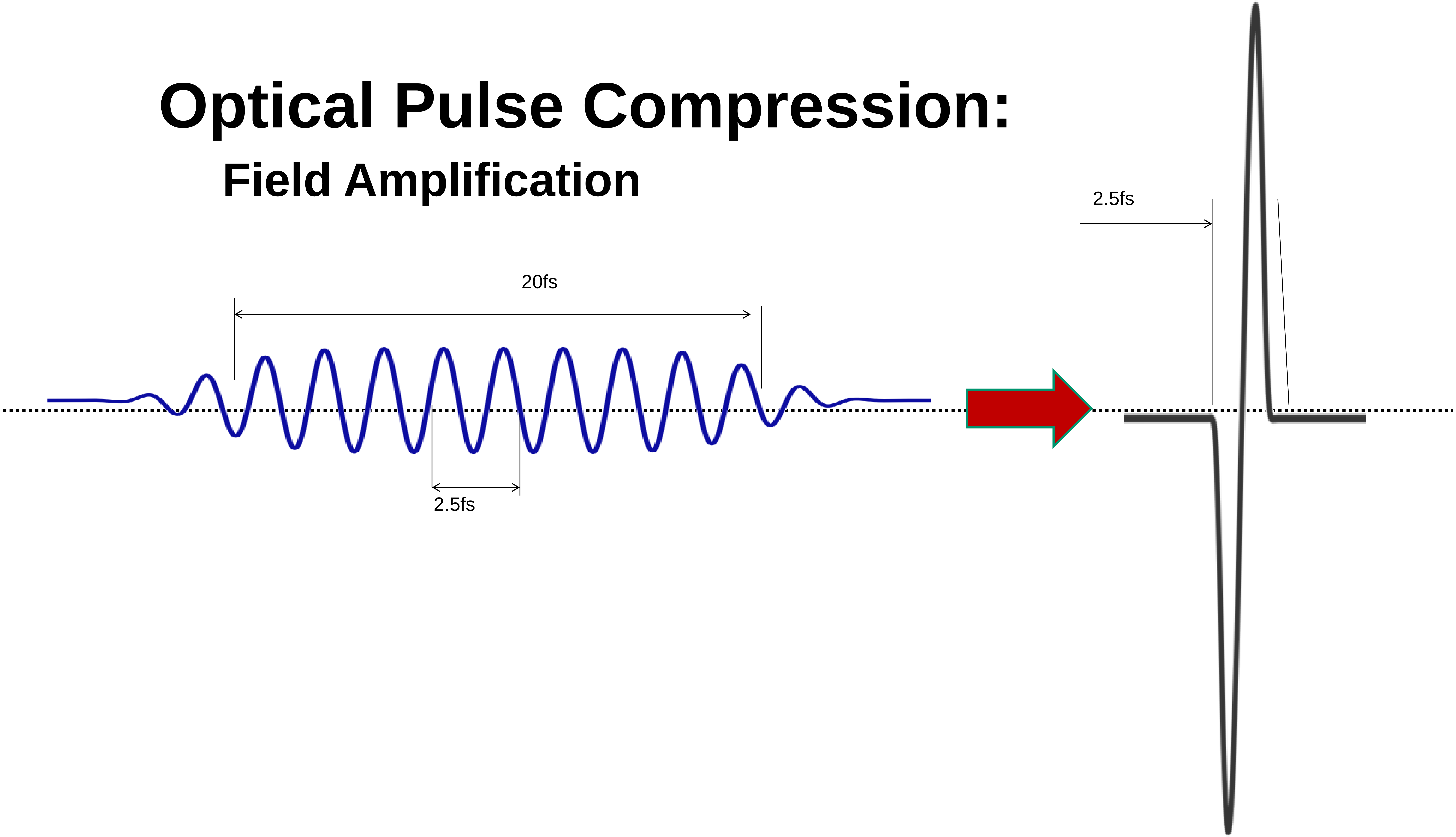
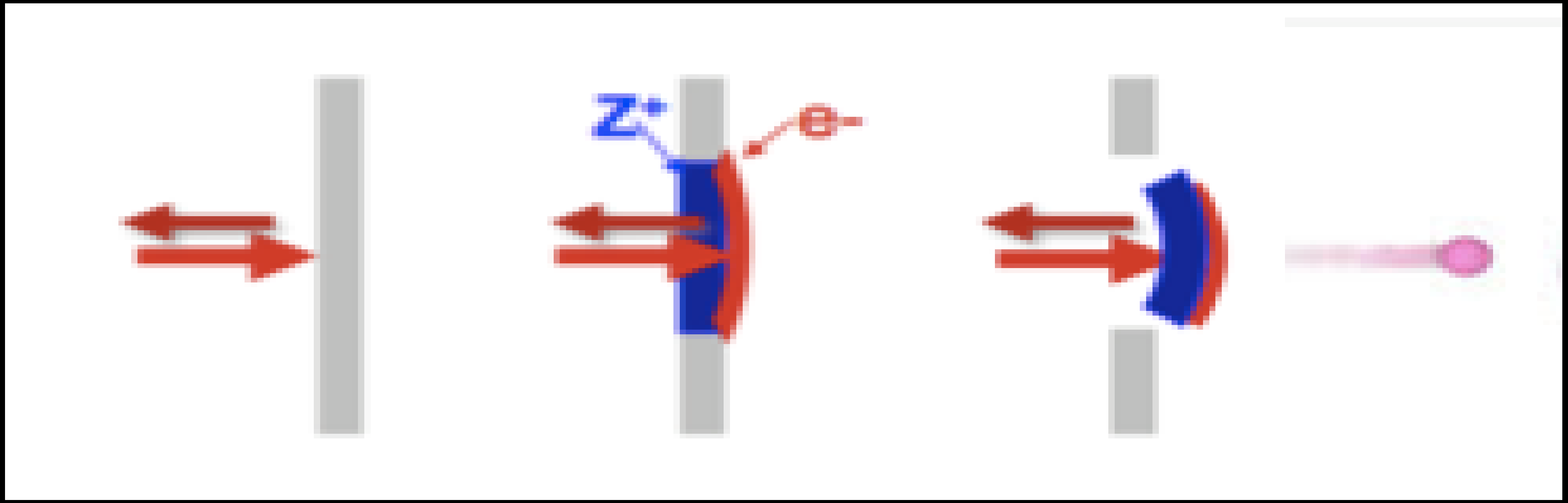
# Optical Pulse Compression:

## Field Amplification

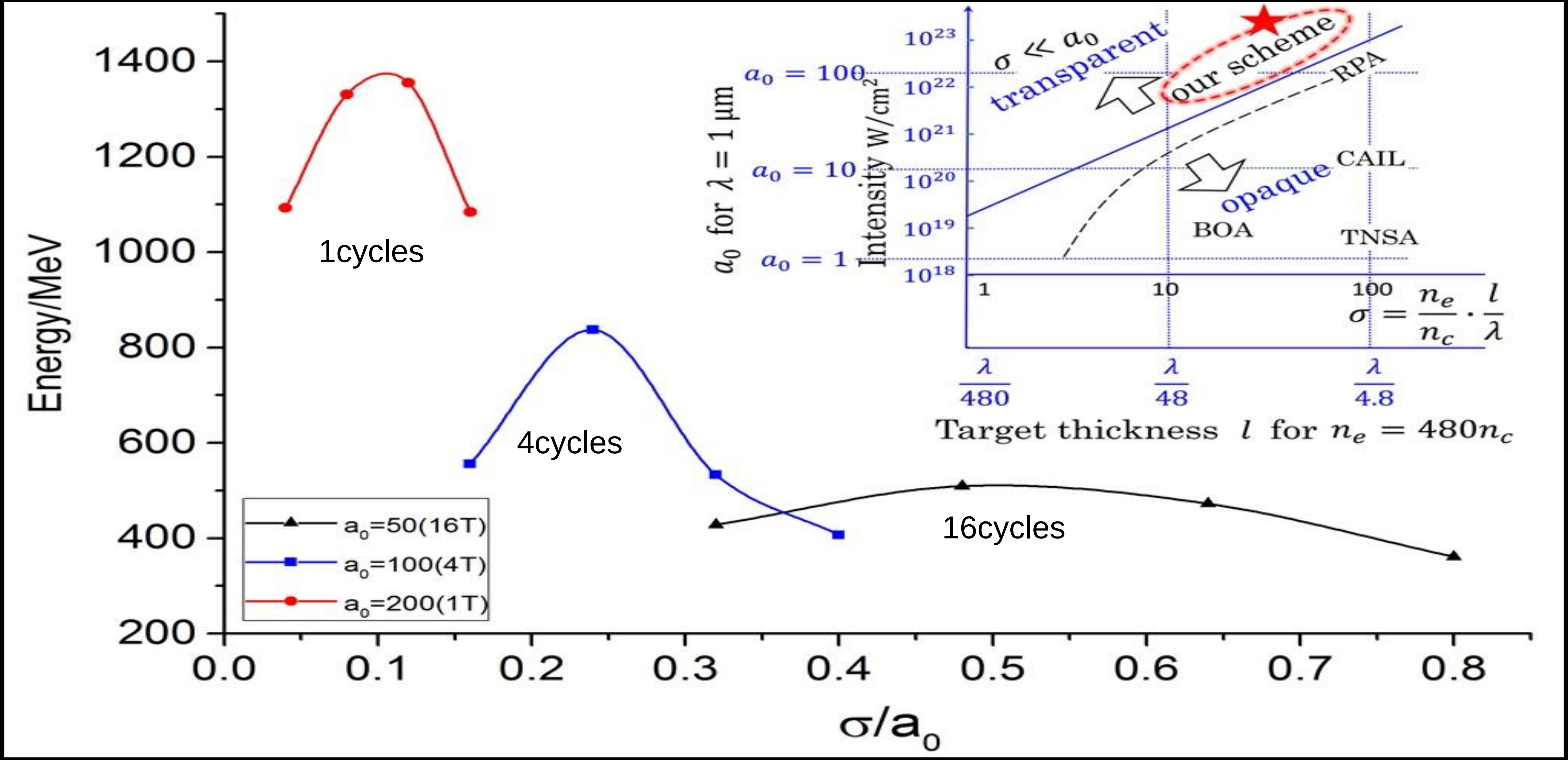


# *Low Hanging Fruit: High Energy Proton Generation*

GeV Proton Generation



# Applications of Single Cycle to Proton Generation vs $a_0$

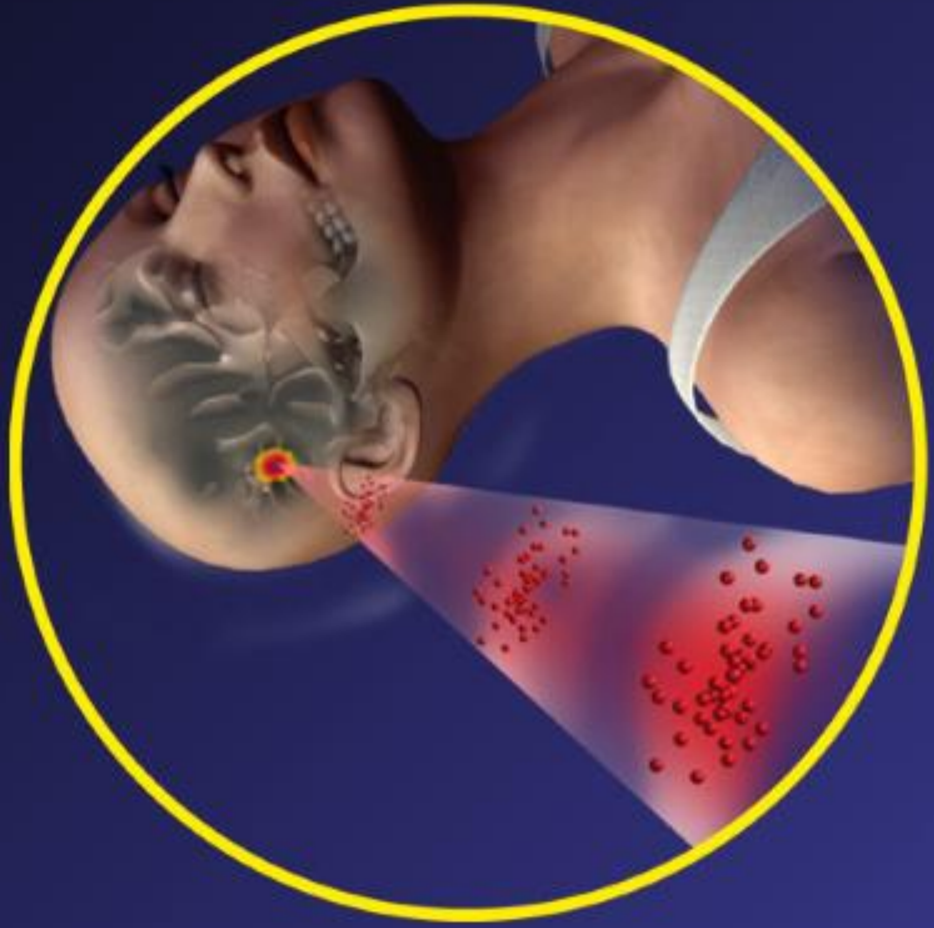


**RELATIVISTIC PROTON ACCELERATOR**
**for**
**TRANSMUTATION**

**Projet MYRRHA**

# *CPA in Nuclear Medicine*

**Proton therapy**



Extreme light technology will be tens of times more compact, more precise and less expensive

**Nuclear therapy**

Radionuclides are used to implant radioactive pellets directly into a tumour

**Nuclear diagnostics**

When a scanner needs a radioisotope, extreme laser acceleration in the clinic would make this fast and safer

# *CPA Mitigating Nuclear waste*

# *A PASSION FOR EXTREME LIGHT*

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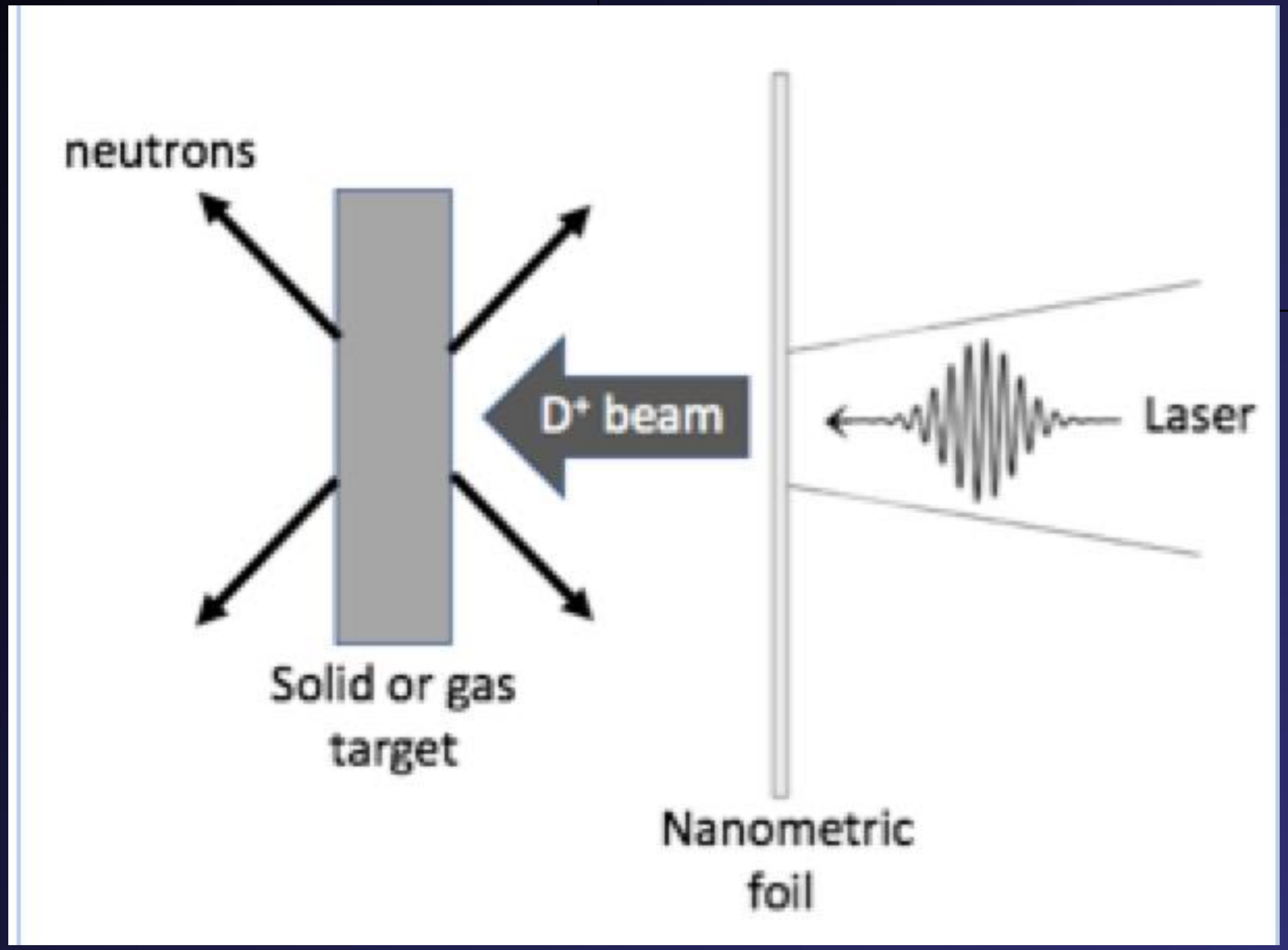
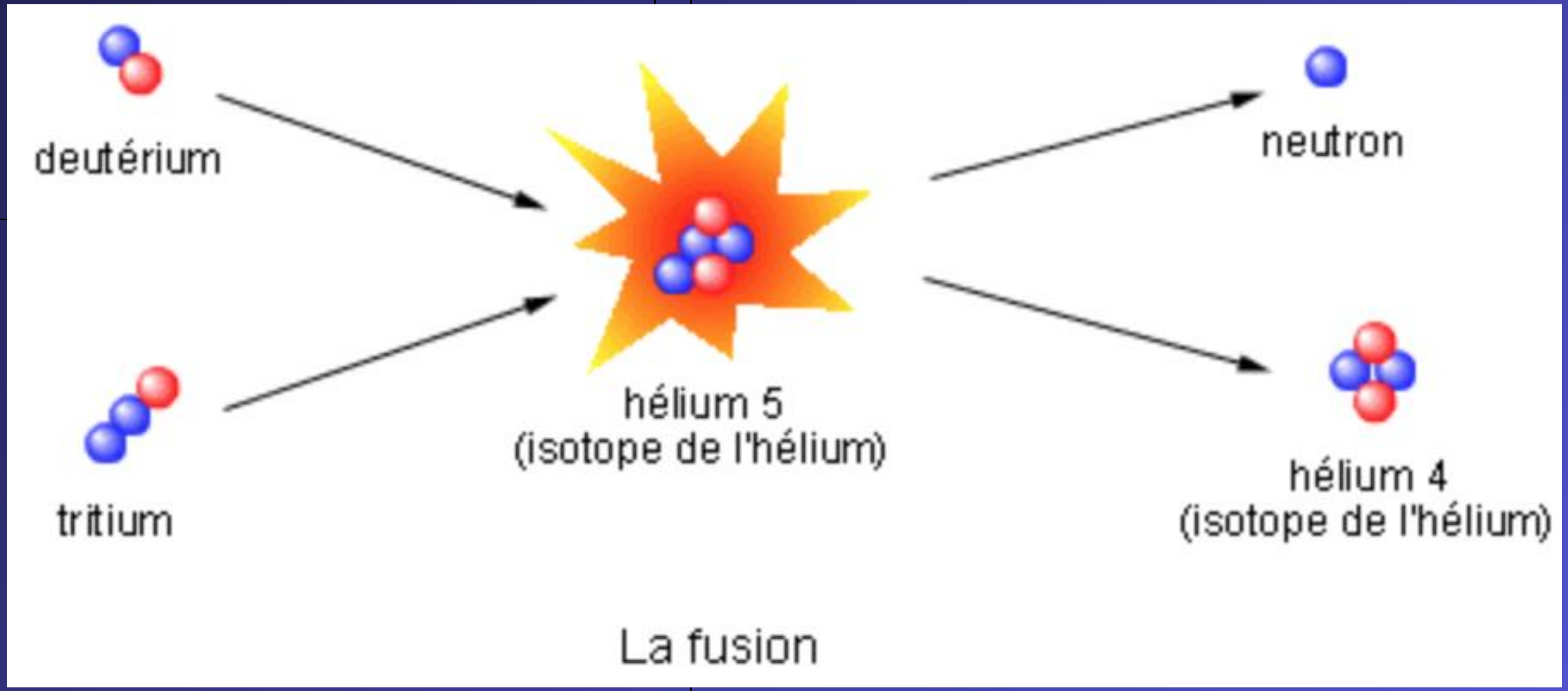
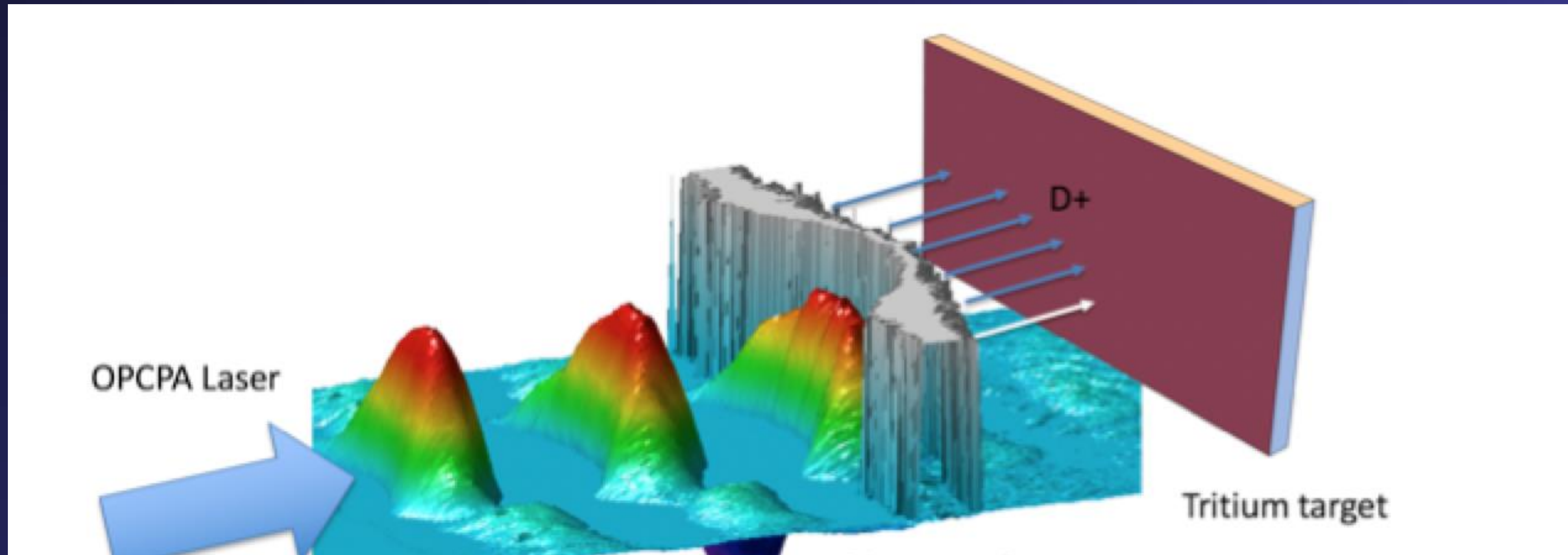
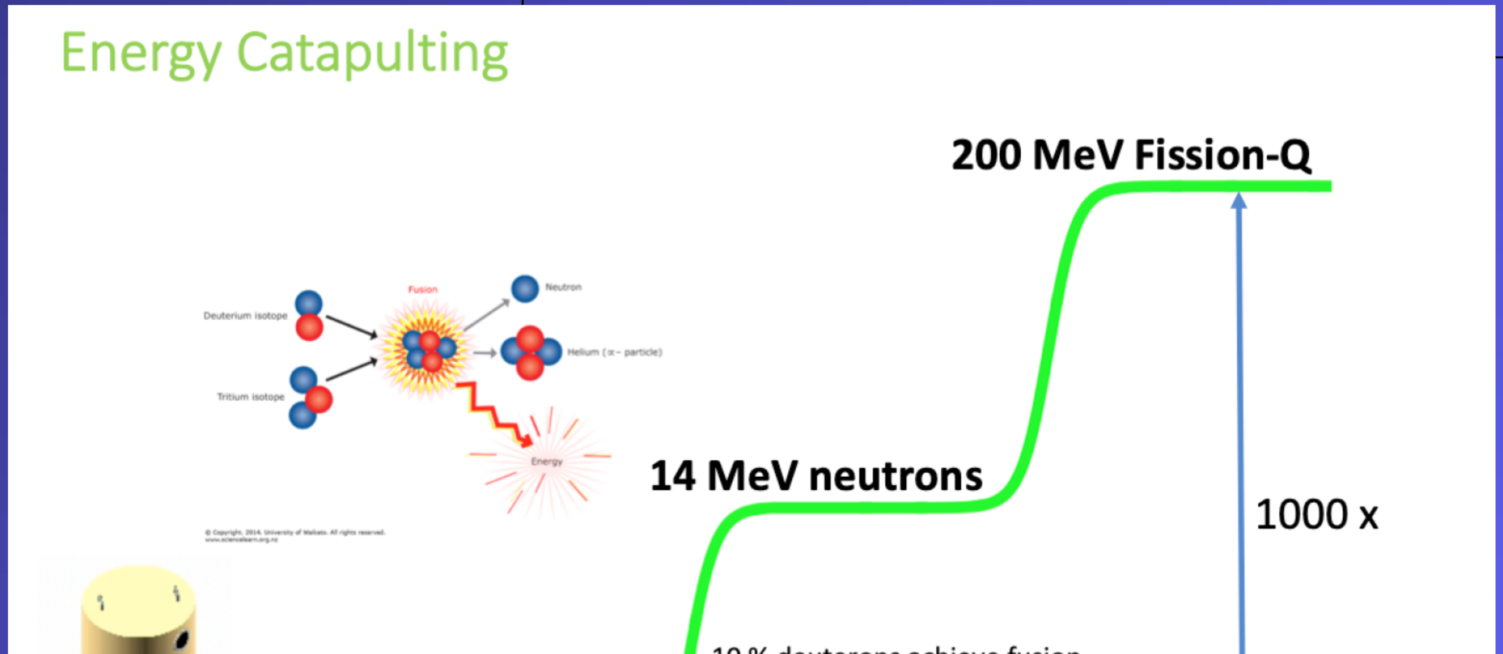
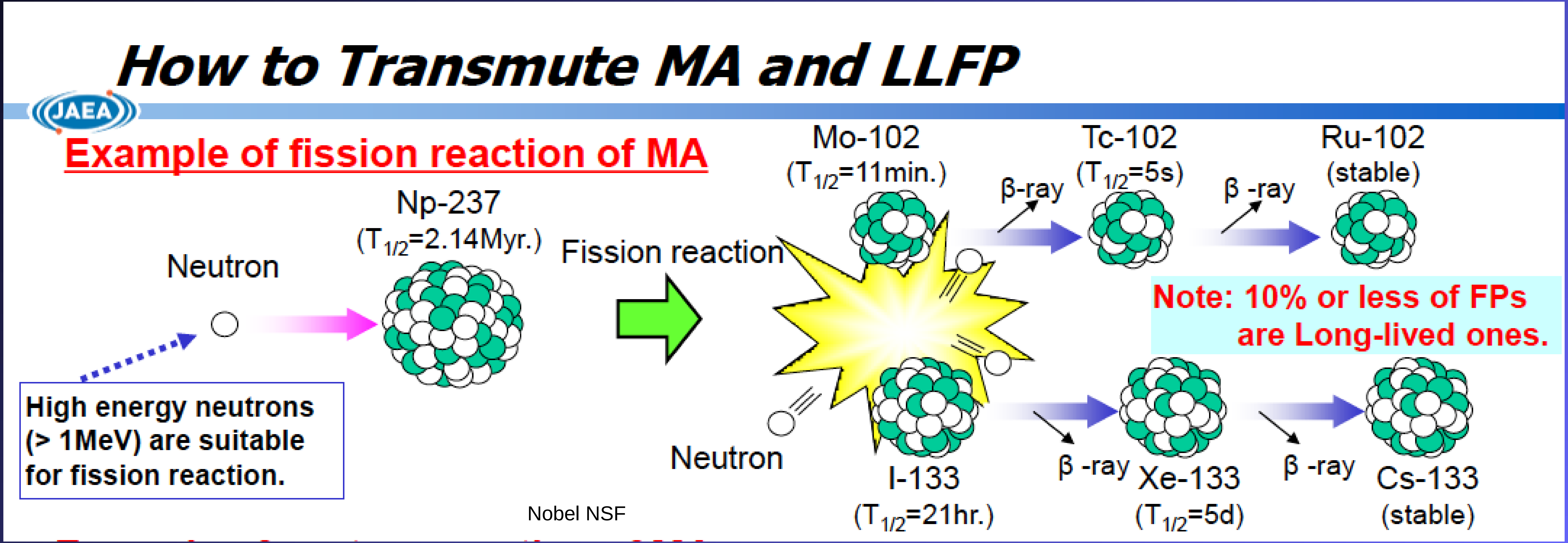


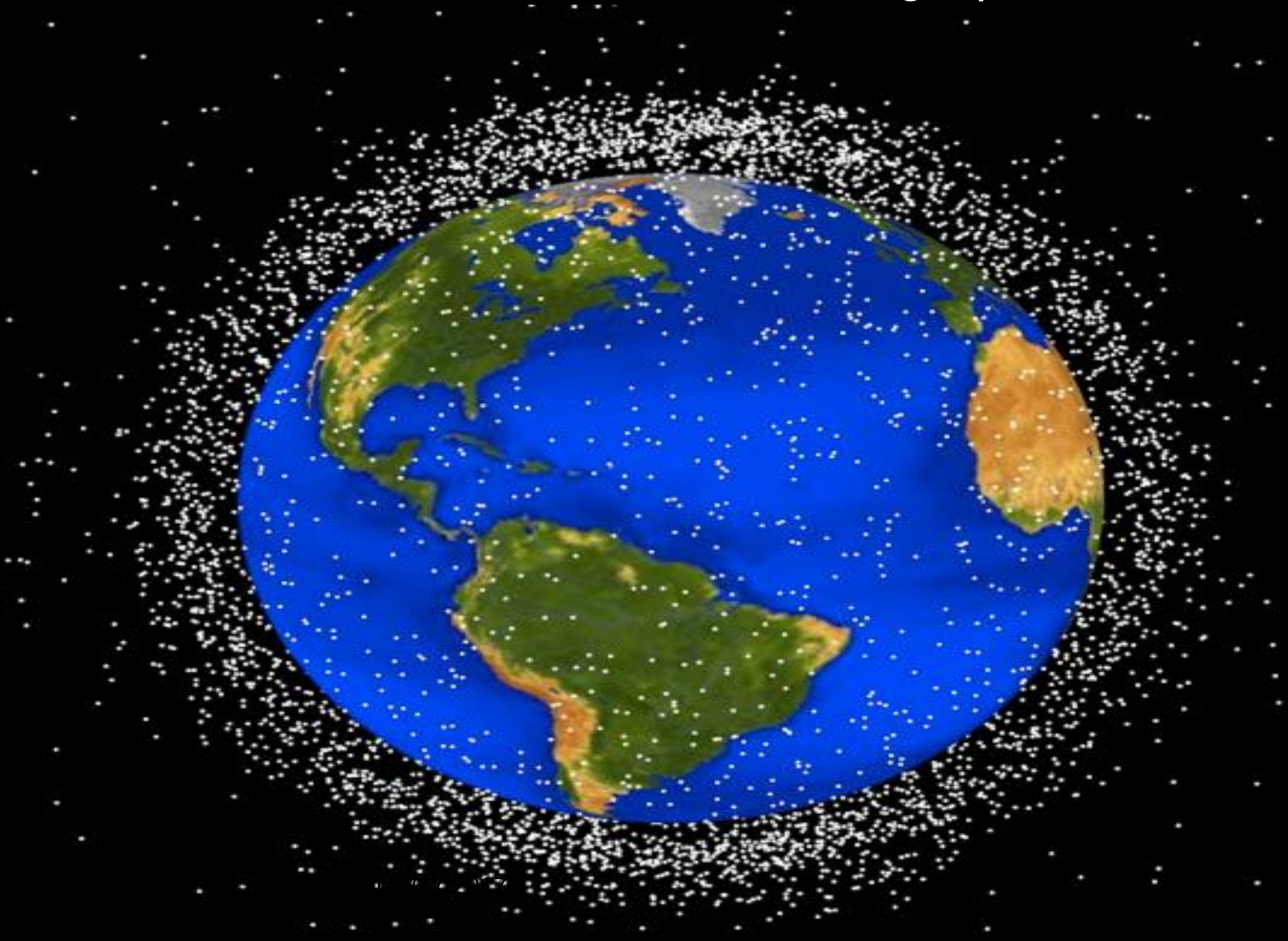



# NUCLEAR TRANSMUTATION CONCEPT



# *Space Debris*

*Millions of orbital debris are cluttering  space*



# SPACE DEBRIS - A state of emergency!

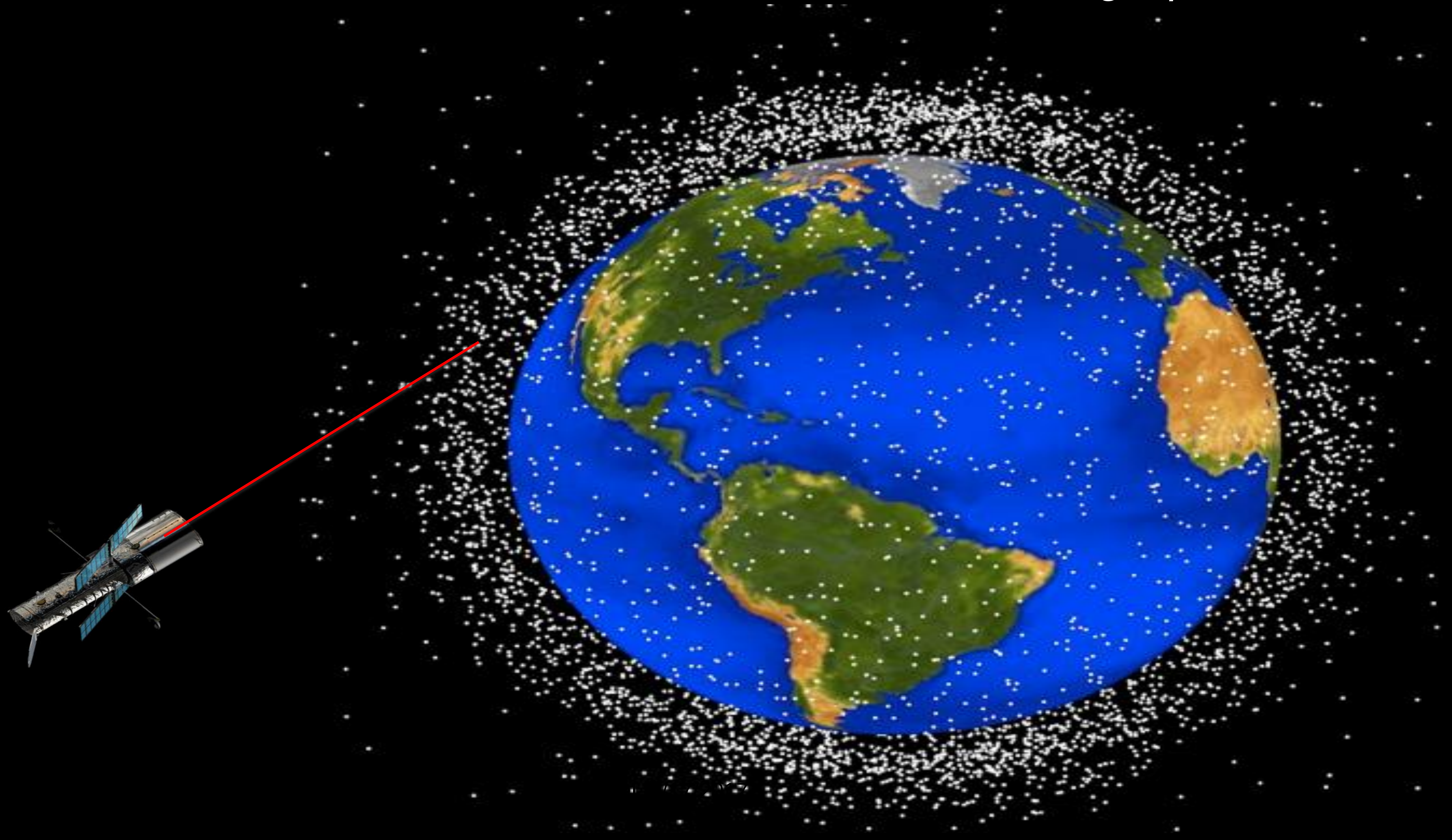
4x 7,000 tons = **28,000 tons!!!**

## How much is that?

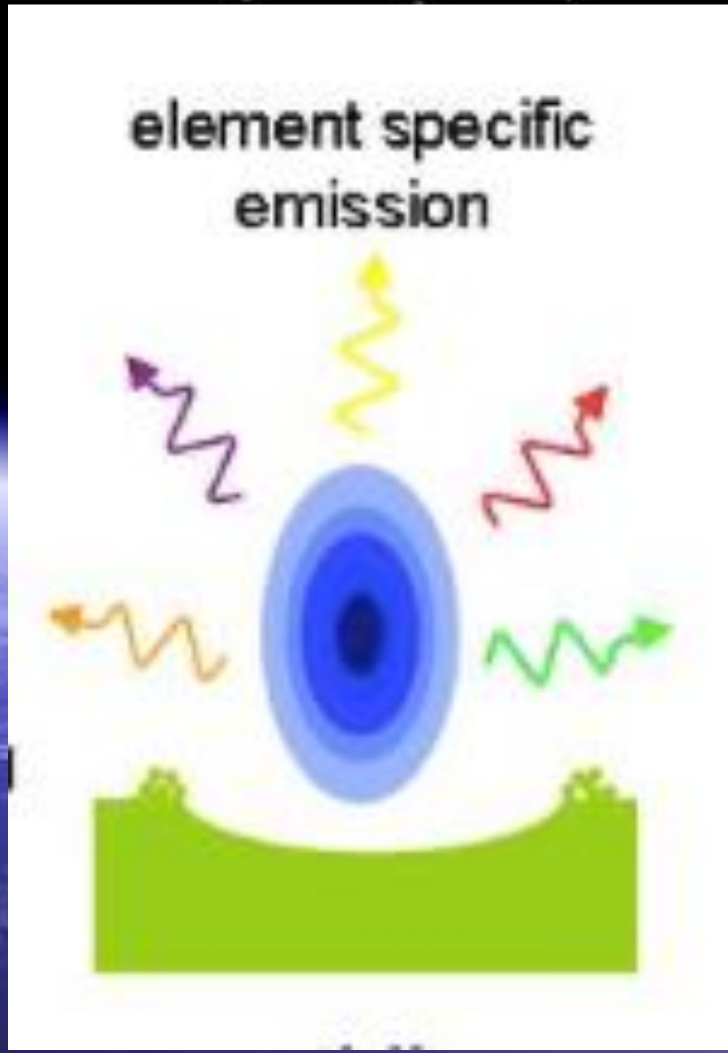
***We have put the equivalent of over 4 Eiffel Towers into space!***

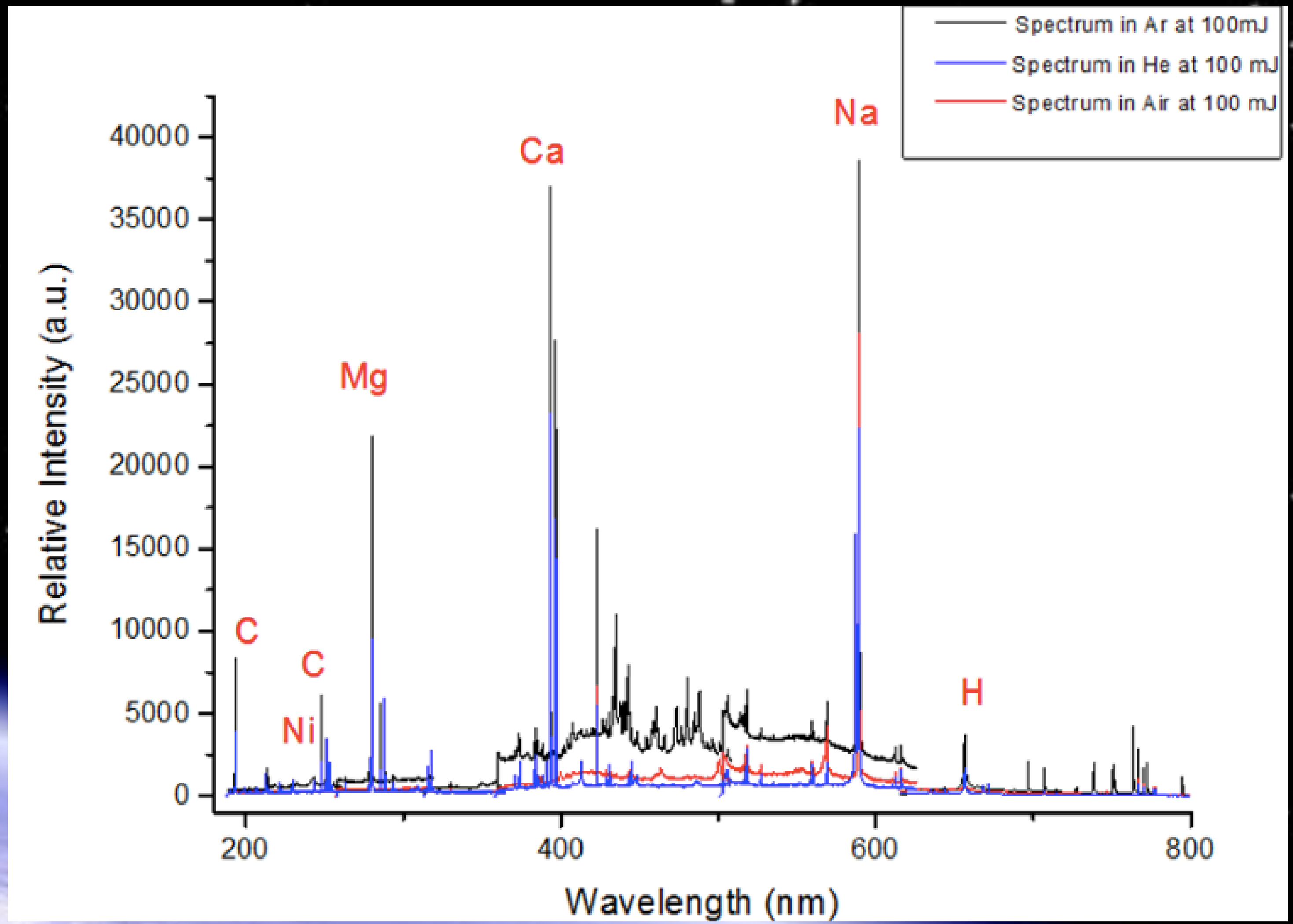
# Space Debris

*Millions of orbital debris are cluttering space*



# Debris identification: Laser Induced Breakdown Spectroscopy




ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

***In conclusion, extreme light is capable of generating the largest fields, largest accelerations, the largest temperatures and the largest pressures***

***It carries the best hopes and opportunities for the future of science and society***

# The best is yet to come!

gettyimages
JONATHAN NACKSTRAND
1071247972

## *A PASSION FOR EXTREME LIGHT*

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# Low Hanging Fruits