Societal Applications of Extreme Light Sources

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IAP RAS, Nizhny Novgorod, Russia

Cremlin Innovation Workshop, 9-10 October 2017, Copenhagen, Denmark

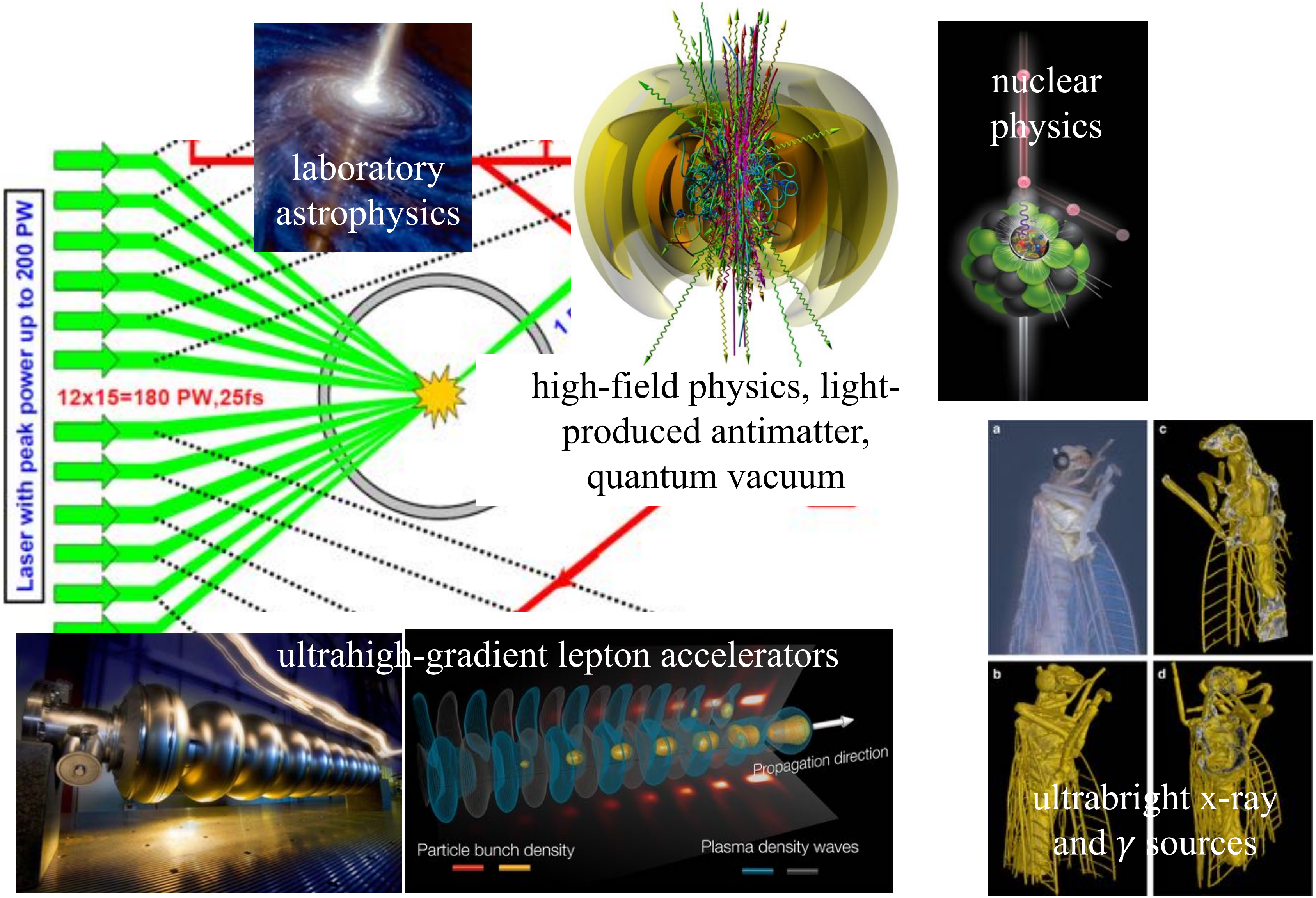
Extreme Light Physics

Extreme light physics is rather young but fast developing area of science and the innovation activity in this field is at the very initial stage now.

The first 2 multi-PW laser systems have been constructed in the past 2 years around the world. These are 4PW system in Korea and about 5 PW system in China. Several 10 PW systems are under construction now in EU.

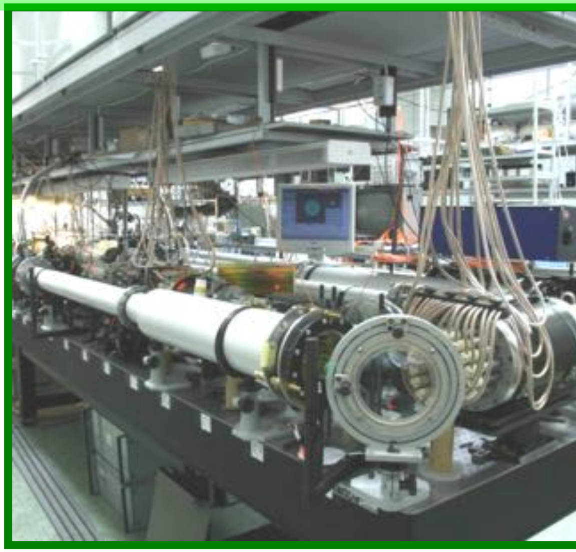
However, there are several national and international programs and research platforms focused on applications and innovative technologies.

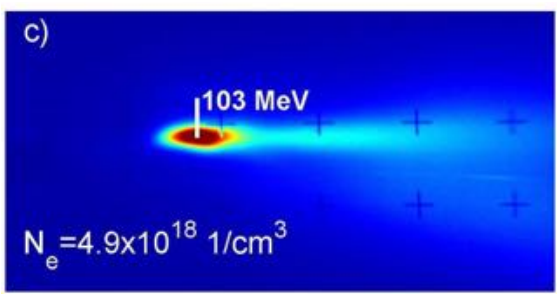
New Science and Technology with XCELS



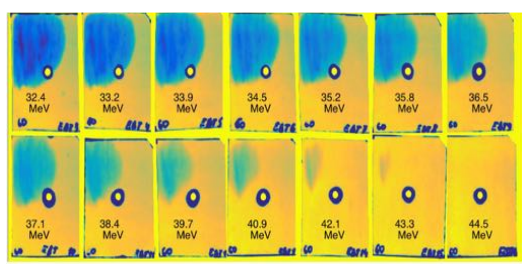
Besides the basic research XCELS is also focused on developing innovative technologies, related to particle and radiation sources, nuclear physics, medicine and others.

PEARL & XCELS at IAP RAS





Electron acceleration experiments
A.A. Soloviev et al., NIMA 653, 35 (2011).

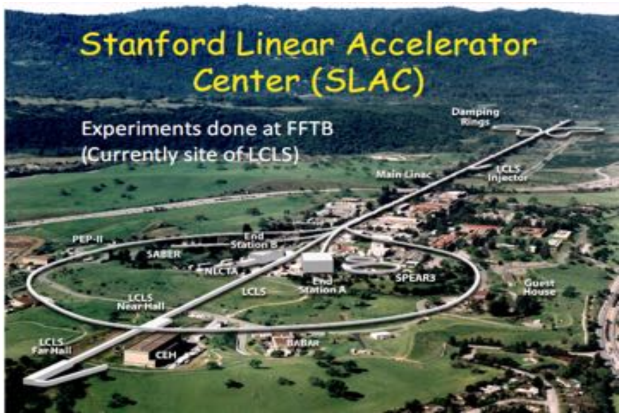


Proton acceleration experiments
A.A. Soloviev et al., Sci. Rep. 7, 12144 (2017).

Sub-PW laser system PEARL, which is a prototype of XCELS, was constructed in 2007. The system is used to study laser-plasma electron acceleration. The second generation of PEARL laser system commissioned in 2013 was used to study proton acceleration.

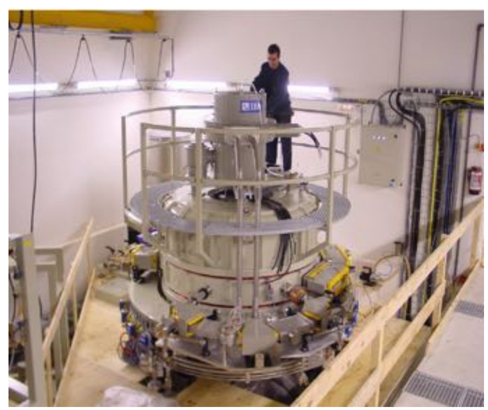
Electron Accelerators

If we speak about extreme light applications with innovation potential and social impact we should mention particle accelerators.



Science (high-energy physics, nuclear physics, radiation sources, etc.)

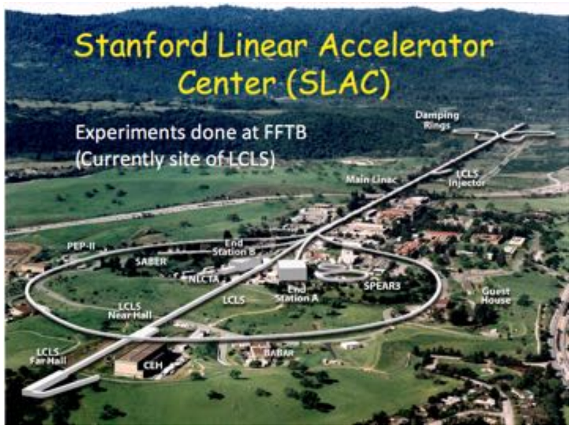
Medicine (particle therapy, diagnostics, etc.)

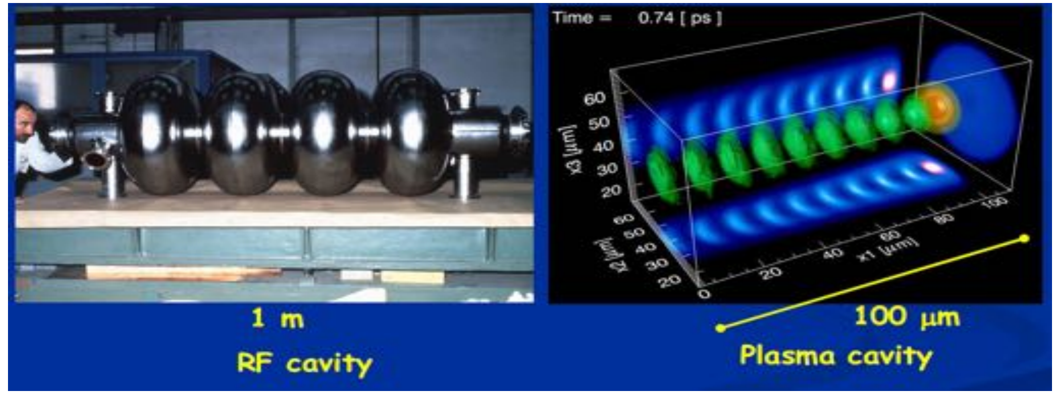


Industry (material processing and diagnostics, etc.)

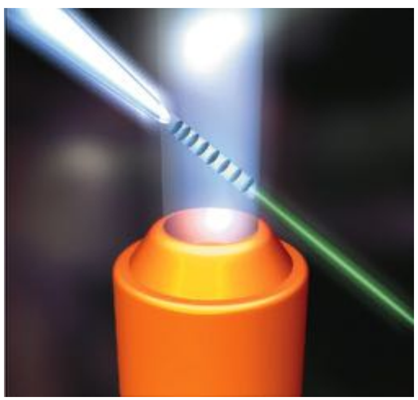
Security (non-invasive inspection, screening technologies, etc.)

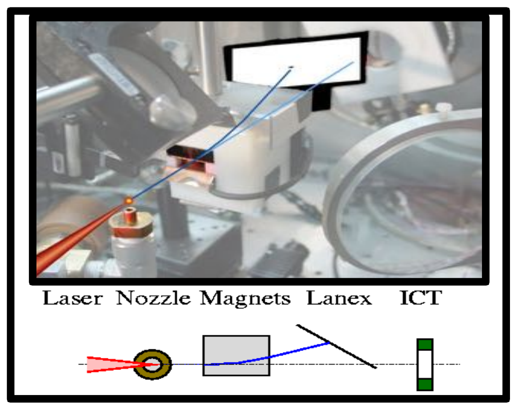
Laser-Plasma Electron Accelerators

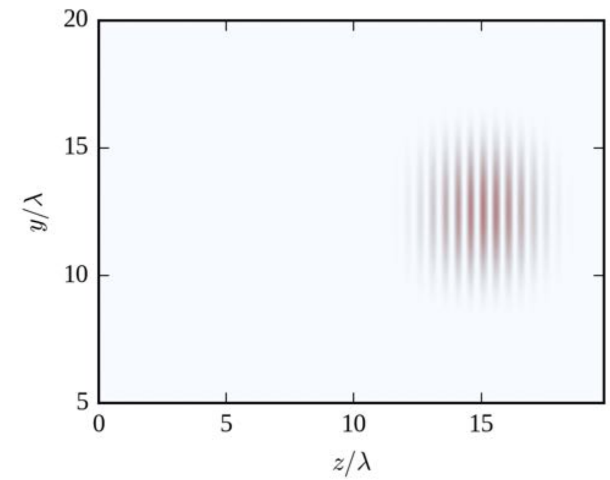




V. Malka, Dream Beam 2007



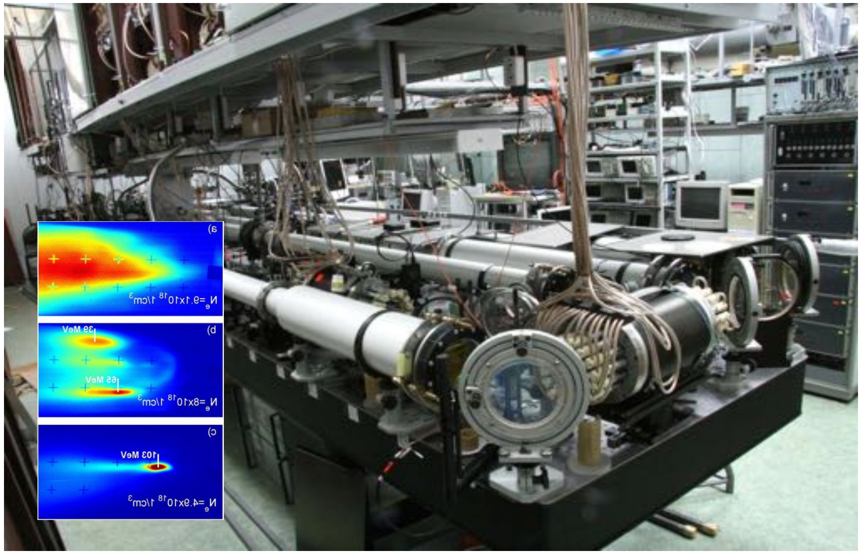




V. Malka, Dream Beam 2007

High-energy electron accelerators are very large and costly machines. This limits their wide use in various areas of human activity. At the same time, the laser fields and the plasma fields, generated by laser pulses, are several orders of magnitude stronger than the accelerating fields in conventional accelerators. The plasma accelerating structure can be several orders of magnitude shorter than the conventional metallic accelerating structure.

Laser-Plasma Electron Accelerators



A.A. Soloviev et al., NIMA 653, 35 (2011).

Last result: Electron energy > 8 GeV, EAAC Conference (Elba, Italy 2017)

4.2 GeV at 300 TW

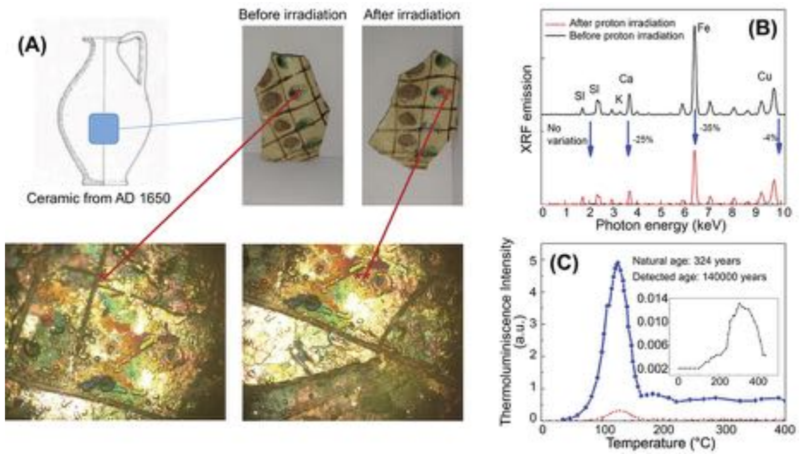
W. Leemans et al., PRL 113, 245002 (2014).

Now the quasi-monoenergetic bunches of electrons accelerated in laser plasma can be routinely produced in laboratory. Laser-plasma acceleration of electrons has been studied in our institute. In LBNL experiments, the energy of electrons has reached 8 GeV

Proton and Ion Accelerators

Medical application (proton therapy)

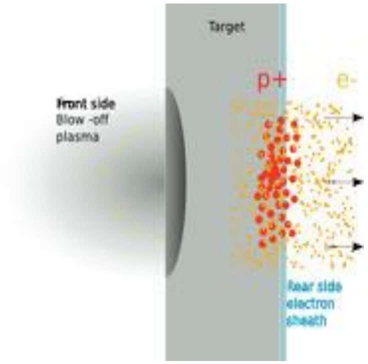
Industrial application (ion implantation)



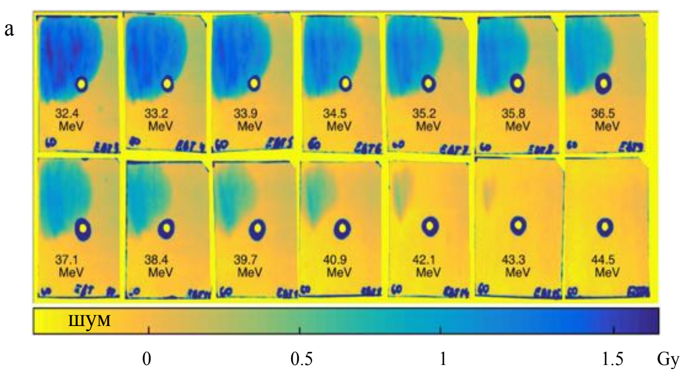
Innovative laser-based acceleration for diagnostic and conservations of objects of interest for Cultural Heritage. M. Barberio, Sci. Rep. 2017

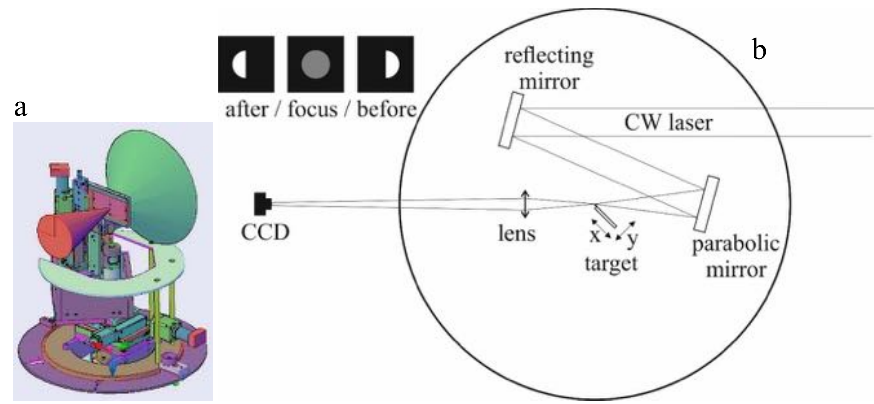
Laser-Accelerated Protons

The laser-matter interaction can be also used for efficient generation of high-energy protons and ions in very small volume.



Hegelich B. M. et al.. 160 MeV laser-accelerated protons from CH2 nano-targets for proton cancer therapy. arXiv 1310.8650 (2013).





Experimental stand for study of the impact of 25 MeV laser-accelerated protons on biological objects. It is demonstrated the doses up to 10 Gy to the object can be transferred in a single shot. The technique of irradiating the cell culture HeLa Kyoto and measuring the fraction of survived cells is developed.

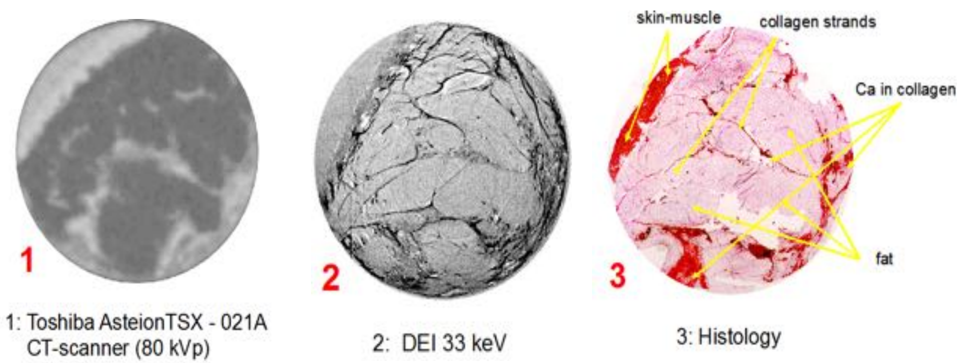
K.F. Burdonov et al., Quantum Electron., **46** 283 (2016.)

Radiation Sources

The radiation sources have probably even stronger social impact. For example, the bright x-ray and gamma ray sources can be used for phase contrast imaging in medicine and nanotechnology with much better resolution than with traditional computer tomography. However, they also have large size and high cost since their basic part is high-energy electron accelerator.

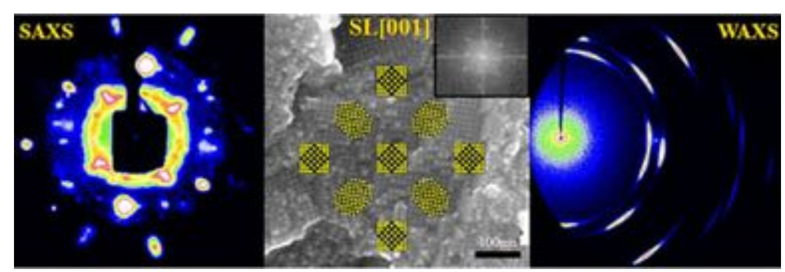
XFEL

The Diamond synchrotron facility



Keyriläinen et al. European Journal of Radiology 53, 226-237 (2005)

Medicine

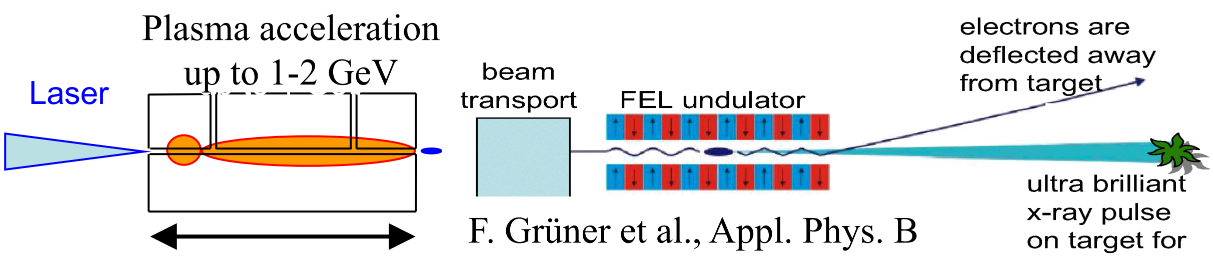


Nanotechnology

Radiation Sources (x-ray, γ-ray)

As a relativistic laser-plasma interaction is accompanied by the intense flows of high-energy particles and radiation and can be used to reduce the size of radiation sources.

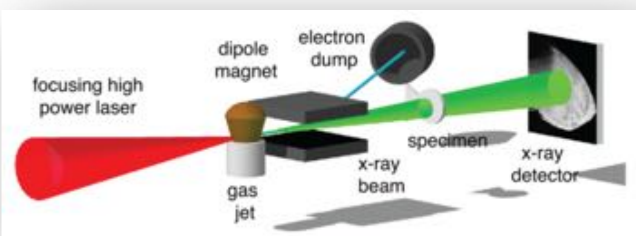
Magnetic scheme: laser-plasma XFEL

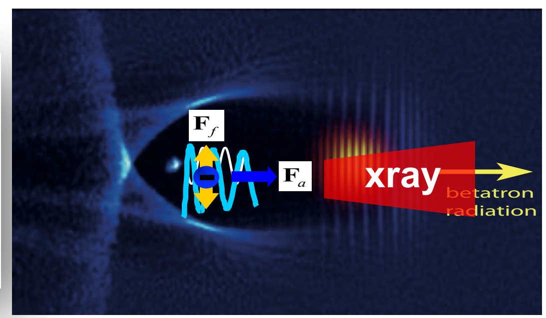


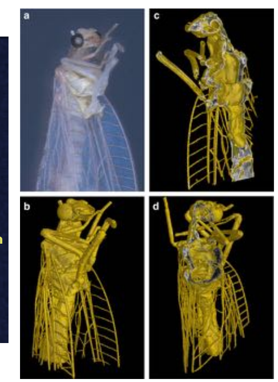
F. Grüner et al., Appl. Phys. B 86, 431 (2007).

Ultra-compact XFEL

Plasma scheme: betatron radiation source

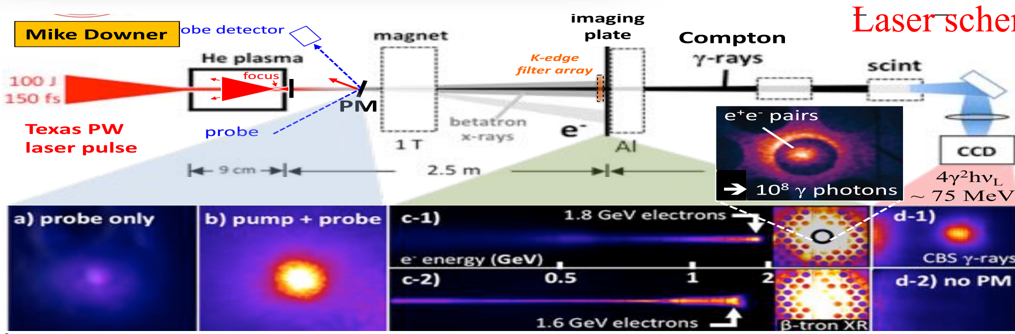






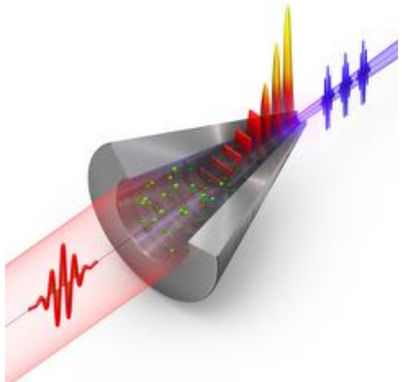
S. Corde et al., Rev. Mod. Phys. 85, 1 (2013).

Laser scheme: Compton source



Hai-En Tsai et al., Phys. Plasmas 22, 023106 (2015).

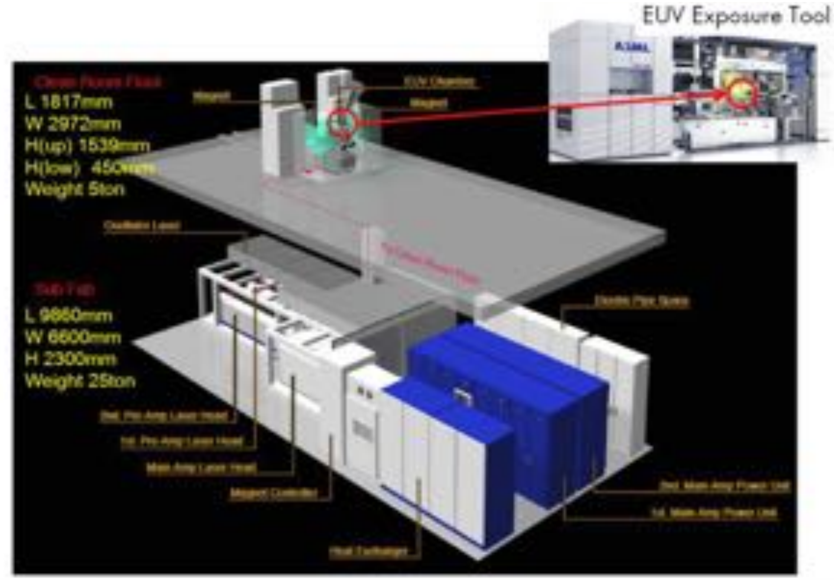
High Harmonic Generation (XUV-EUV)



In-Yong Park et al., Nature Photonics 5, 677 (2011).

Table-top HHG source with a megahertz fibre laser: (25-40 eV) radiation; at 30 eV an average power of 143 μW ($3 \cdot 10^{13}$ photons/s).

R. Klas et al., Optica 3, 1167 (2016).

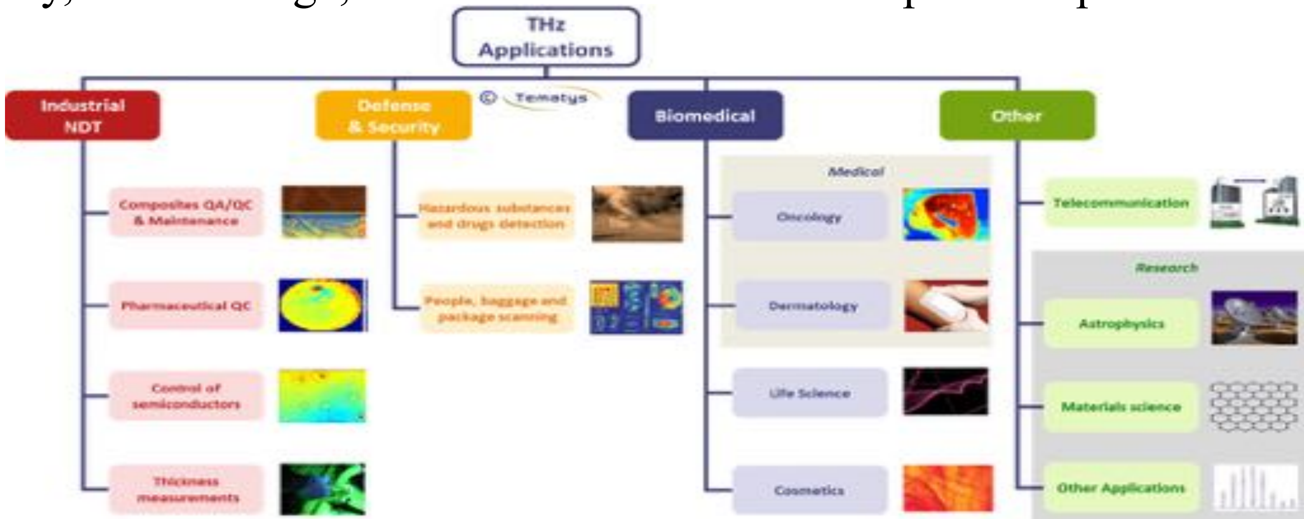


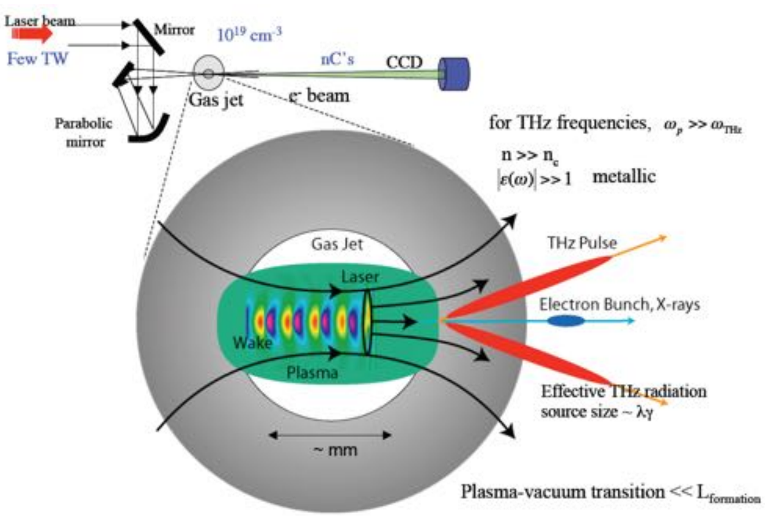
Laser-plasma EUV source for lithography

The laser-based radiation sources in EUV range are probably the most prepared for innovation and commercialization.
Laser-atom interaction is also a highly nonlinear process which can be accompanied by HHG. This can be used for EUV sources. The source based on such innovative technology are attracted much attention and have bright prospects.

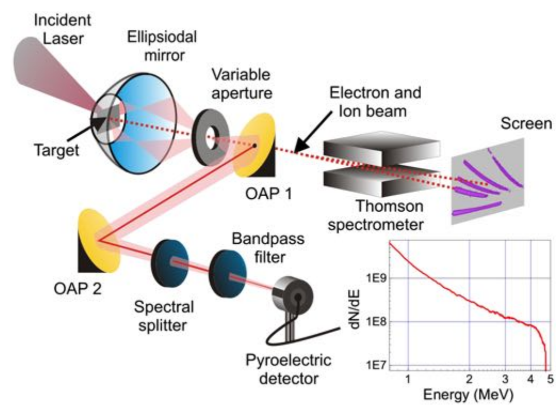
Radiation Sources (THz Radiation)

Laser plasma as a highly nonlinear media can also efficiently emit in low-frequency range, and particularly, in THz range, where there is a lack of compact and powerful sources





W. P. Leemans et al., Phys. Plasmas 11, 2899 (2004).

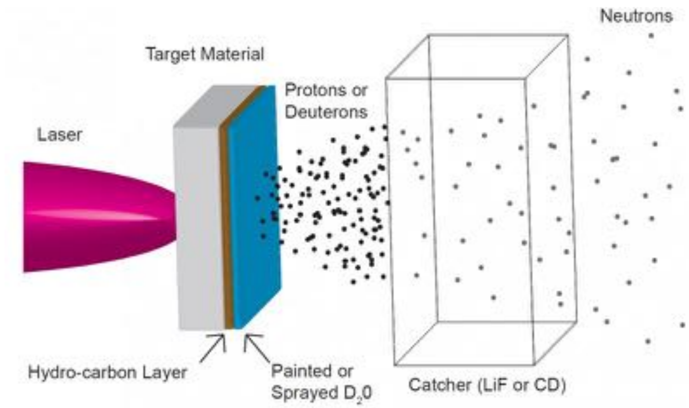


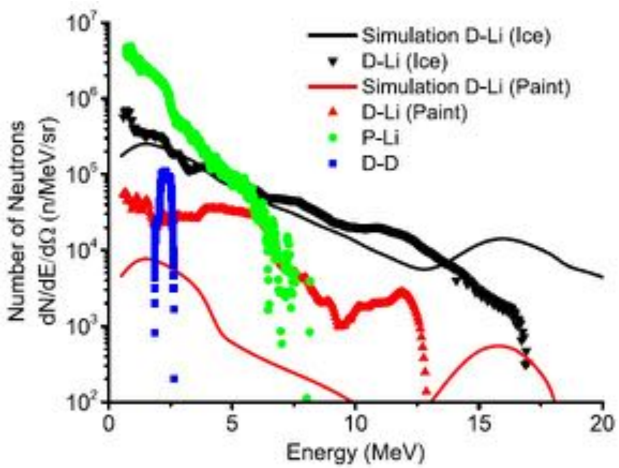
PRL 111, 074802 (2013) PHYSICAL REVIEW LETTERS week ending 16 AUGUST 2013

Observation of Gigawatt-Class THz Pulses from a Compact Laser-Driven Particle Accelerator

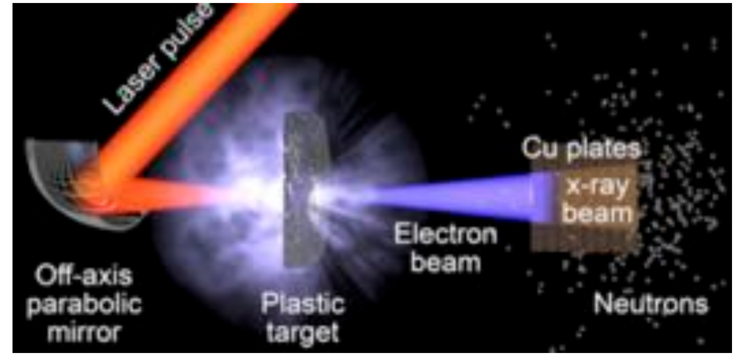
A. Gopal,[1,2,*] S. Herzer,[1,2] A. Schmidt,[1] P. Singh,[1,†] A. Reinhard,[1] W. Ziegler,[1] D. Brömmel,[3] A. Karmakar,[3,‡] P. Gibbon,[3] U. Dillner,[4] T. May,[4] H-G. Meyer,[4] and G. G. Paulus[1,2]

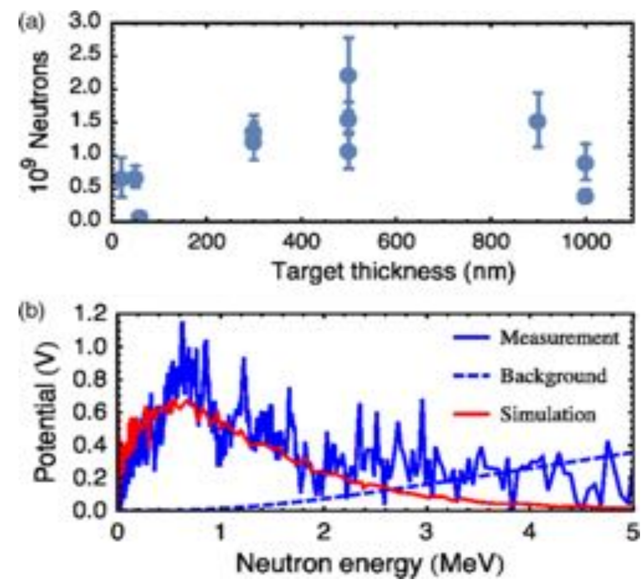
Neutron Sources





B. Hou et al., Phys. Plasmas 4, 040702 (2011).





I. Pomerantz et al., Phys. Rev. Lett 113, 184801 (2014).

The world-highest neutron number in single shot, ~4 x 10^{11} (ILE, Osaka).

M. Kando, ANAR Workshop (CERN, 2017).

Neutron Source Applications

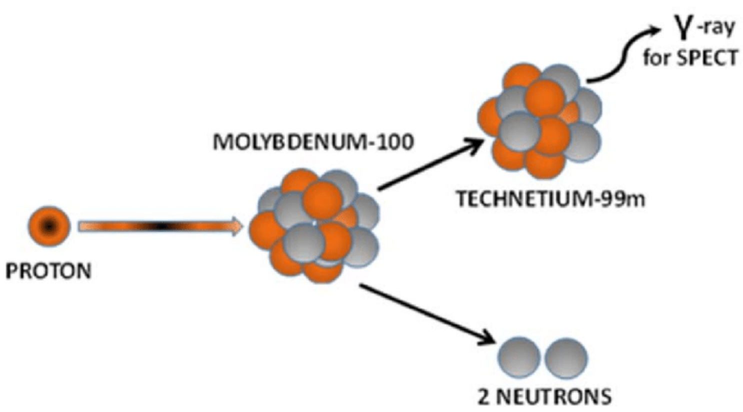
A number of an infrastructures had been built in 1960s-70s. These structures will soon exceed their life-time of about sixty years. There is a strong need for non-destructive inspection of infrastructures which are mainly formed of concrete. High energy neutrons penetrate thick concrete and can be used to detect, for example, water in concrete nondestructively.

Y. Sekic et al., Proceedings of IPAC2016.

Laser-based neutron sources can produce higher neutron flux than the radio isotope sources and, thus, can provide more accurate analysis for very large concrete objects.

Laser-Based Nuclear Pharmacology

Laser-based proton sources can also facilitate isotope production. Isotope plays now an indispensable role in medicine, for example, for single-photon emission computer tomography (Tc-99m), for positron-emission tomography (for example, the carbon isotope C-11). It should be noted that the leading world suppliers of technetium-99m, the most widely used isotope in nuclear medicine (up to 80% of all diagnostic procedures) are two reactors in Canada and the Netherlands, which are planned for closing in the coming years.. To initiate nuclear reactions, it is necessary to obtain the maximum number of protons/deuterons with the energy exceeding the threshold (for example, above 8 MeV for the Mo-100(p,2n) and Tc-99m reaction).



V.Yu. Bychenkov et al., Phys.-Uspekhi 58, 71 (2015).

Exotic Applications

СЕМИНАР ОТДЕЛЕНИЯ НЕЛИНЕЙНОЙ ДИНАМИКИ И ОПТИКИ

Пятница 6 октября 2017 г. 11-00   (Friday, 06.10.2017, 11:00)
к.5663   (Зал семинаров ИПФ)

Toshikazu Ebisuzaki
(RIKEN, Japan)

Space Debris deorbit by High Intensity Laser

Innovations with Extreme Light

There are several national and international programs and research platforms focused on applications and innovative technologies.

Supported by EU Horizon 2020

EuPRAXIA

Europe

Ultimately, EuPRAXIA will: use the world-wide leading high power lasers from European industry, drive laser innovation in the connected companies, provide for the first time usable electron beam quality from a plasma accelerator, and serve pilot users from science, engineering, medicine and industry.

LAPLACIAN

Laser Acceleration Platform as a Coordinated Innovative Anchor

Japan

LAPLACIAN: Laser Acceleration Platform as a Coordinated Innovative Anchor

革新的研究開発推進プログラム ImPACT Impulsing Paradigm Change through Disruptive Technologies Program

***ImPACT* - UPL (Ubiquitous Power Laser)**

Ubiquitous Power Laser for achieving a safe, secure and longevity society

US

Bring revolutionary compact accelerator technology developed in the labs over decades to the point where we can put it to work solving Big Problems that impact peoples lives.

Russia

РНФ Russian Science Foundation

RSCF Project “Laser-plasma isotope sources”, Lebedev Institute, V.Yu. Bychenkov

Summary

- Despite the fact that Extreme Light Science is very young it has a large innovative potential and important societal applications.
- Laser-based methods are able to strongly reduce the cost and size of the bright particle and radiation sources and dramatically enhance their spread in science, medicine and industry.
- New laser technologies providing higher laser efficiency, repetition rate and better stability are needed. There are fast developing technologies like fiber lasers (ICAN technology), disk lasers and others, which can open hopeful path toward needed parameters range.
- It is generally believed that laser-based sources could revolutionize future science and technology in a similar way to the great changes in science and industry from near-visible light lasers in the 20th century.