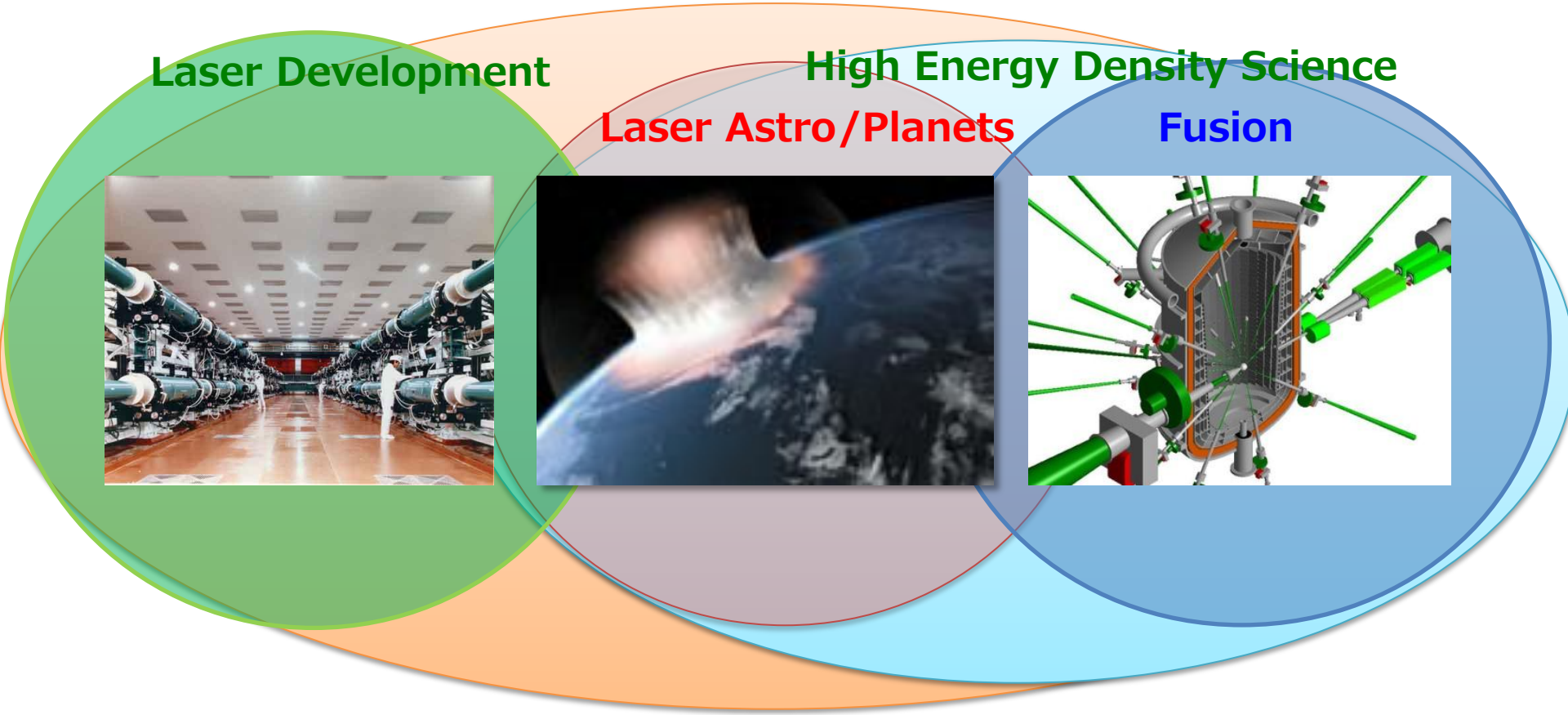
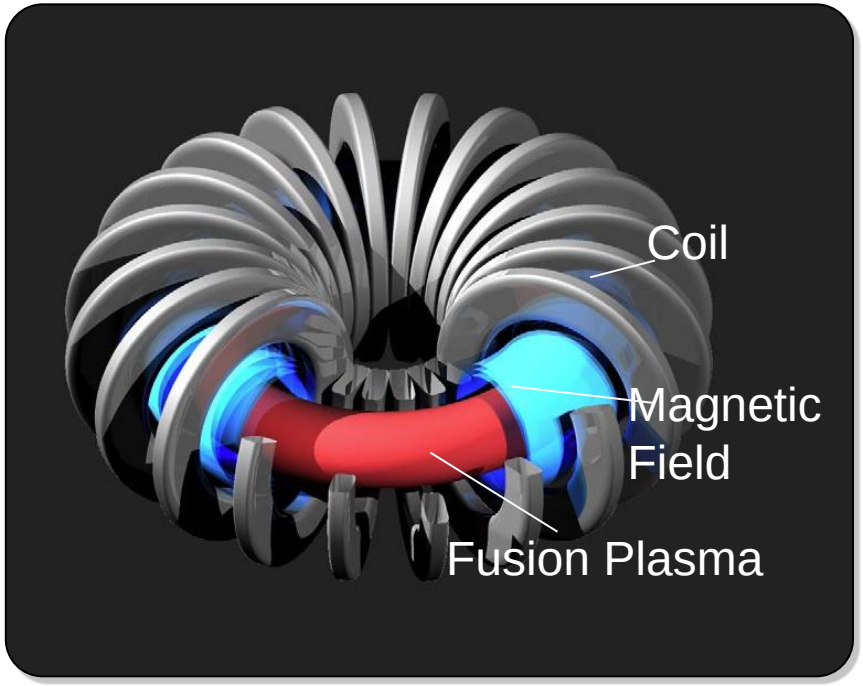
Fast Ignition Realization Experiment and Prospect to Inertial Fusion Energy in Japan



Hiroshi AZECHI
Director, Institute of Laser Engineering, Osaka University
Fusion Energy Conference of IAEA 2014.10.14
St. Petersburg, Russia

Magnetic and Laser Fusion

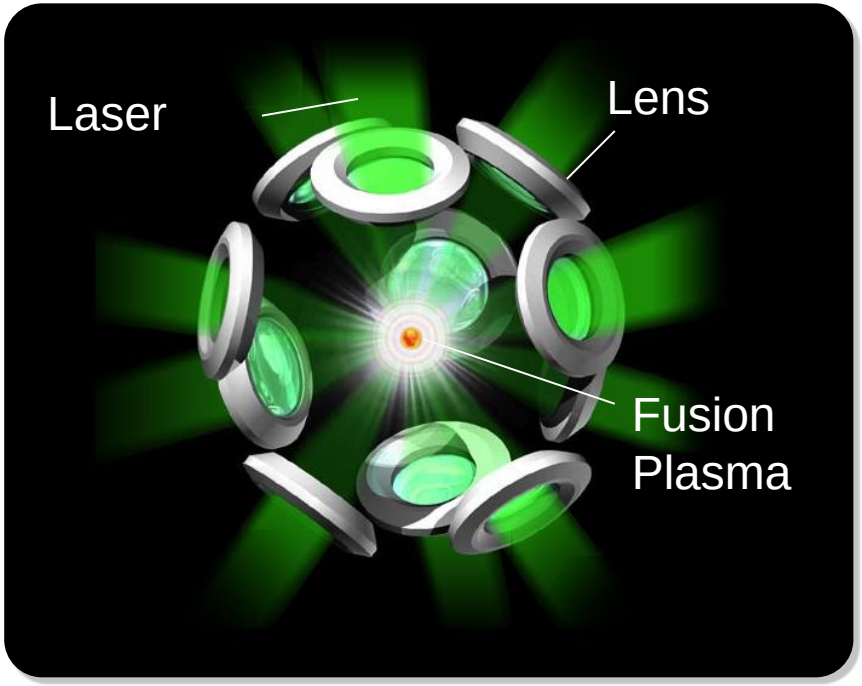
Magnetic Fusion



One Billionth of Solid Density (10^{-9})
Fuel Diameter: 10 m
Steady State Reactor→ Base-load

ITER Organization
Japan Atomic Energy Agency
National Institute for Fusion Science

Laser Fusion



Thousand Times Solid Density (10^{3})
Fuel Diameter: mm→ Compact
Pulse Reactor→ Peak-load

Lawrence Livermore National Laboratory
French Atomic Energy Commission
Osaka University

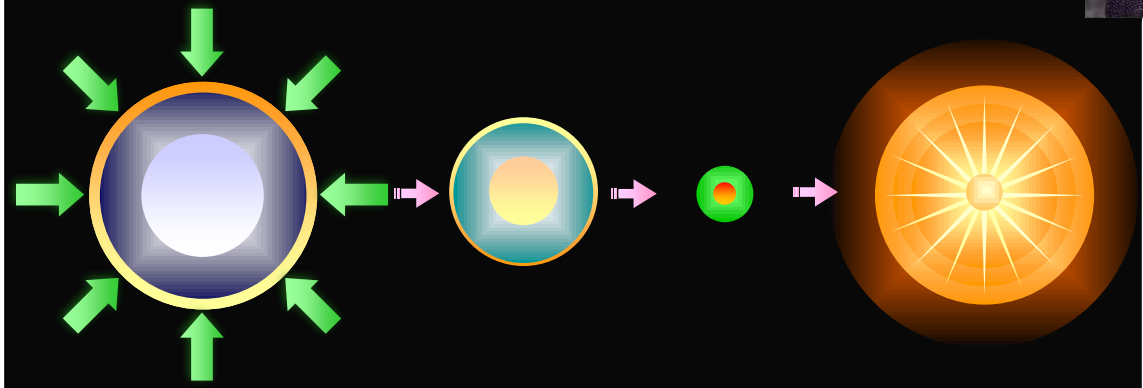
Central and Fast Ignition Schemes

OSAKA UNIVERSITY

Institute of Laser Engineering

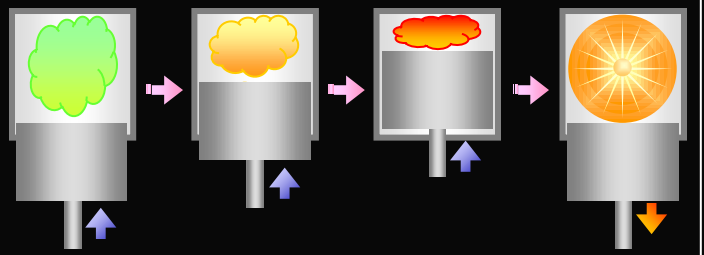
Central Ignition proposed by J. Nuckolls in 19

Compression Ignition Burn

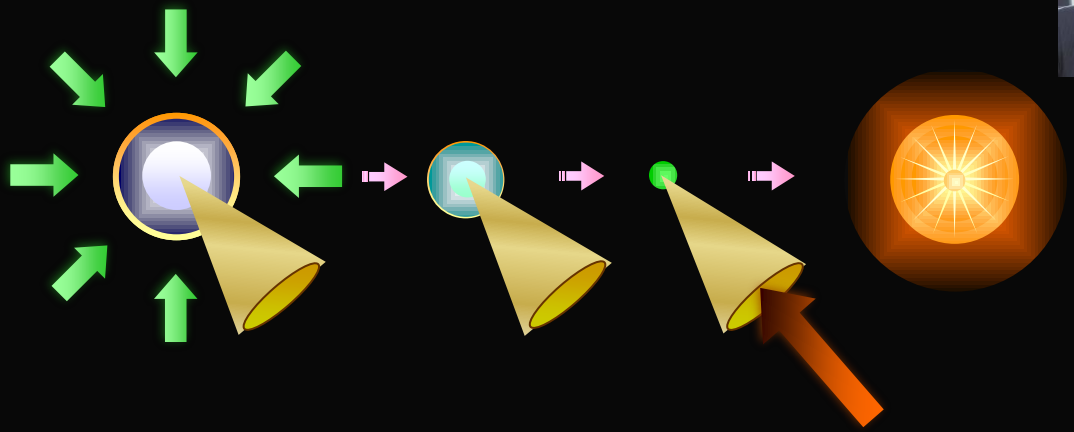


Diesel Engine

Compression Ignition Burn

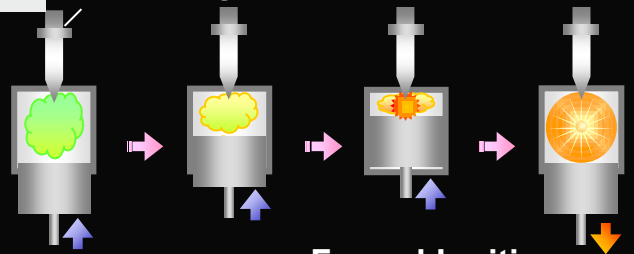


Fast Ignition proposed by T. Yamanaka in 198



Gasoline Engine

Spark Plug



Forced Ignition
→Compactness

Compact fusion will accelerate inertial fusion energy development.

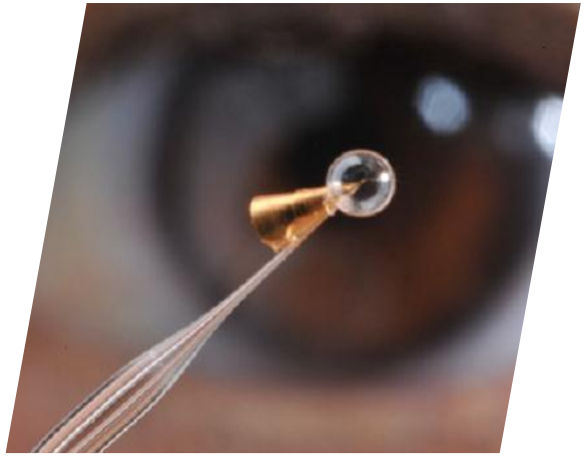
Fast Ignition Realization EXperiment

Nano-sec Implosion Laser
GEKKO-XII

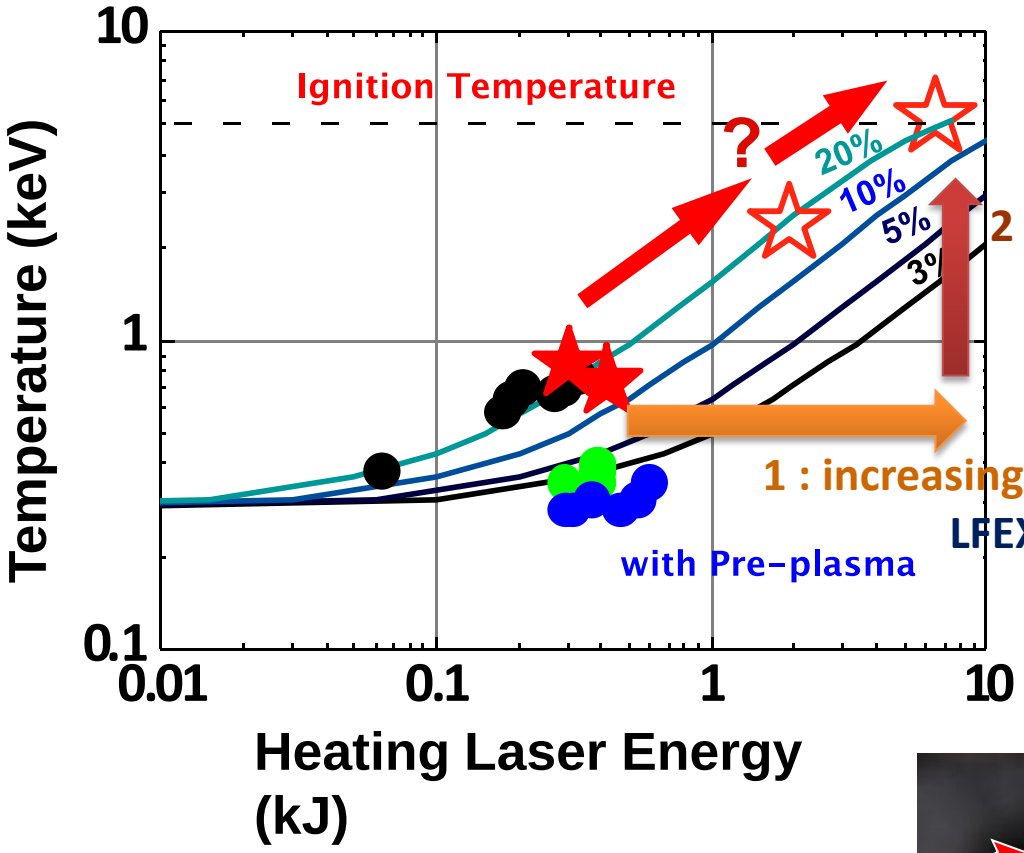
Pico-sec Heating Laser
LFEX: World largest pico-sec laser

So far, 1-keV is demonstrated.

FIREX-I Heating to 5 keV
FIREX-II Ignition and burn



Approach to ignition temperature

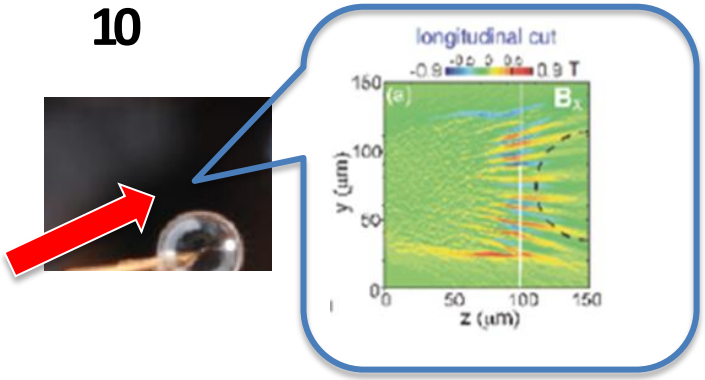


2 : increasing heating efficiency

Fast Electron Guiding by B Field

1 : increasing laser energy

LFEX: 1 beam to 4 beams



Fiscal Year		
2013		Heating Basics
2014	4-Beam operation	Heating Scaling
201x		5-keV Heating
201x	Check-and-Review of FIREX-I	

1 : increasing laser energy

2 : increasing heating efficiency

1: increasing laser energy

Giant Lasers developed in the past 40 years

LFEX 2009

2014
4 beams
10 kJ /10ps

2013
3 beams
2011
2 beams
2009
1 beam

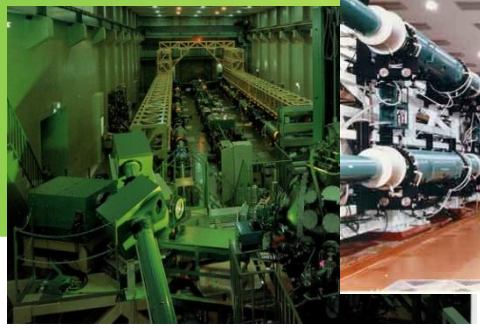
Peta Watt 1996

10 kJ 10 ps

GEKKO-XII
1983

0.5 kJ 0.5 ps

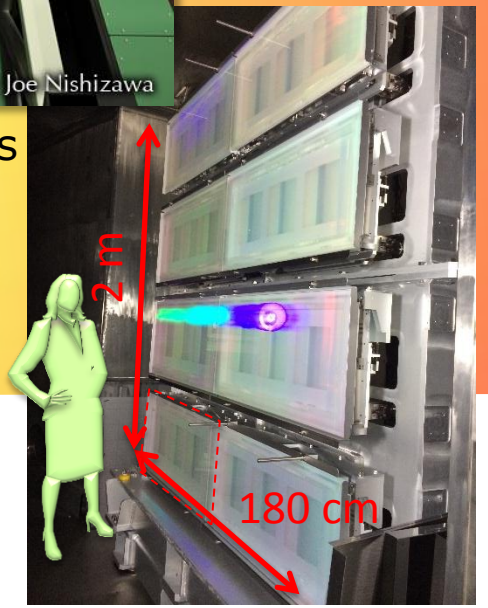
GEKKO-MII 1979
GEKKO-IV 1977
GEKKO-II 1973



2 kJ 1ns

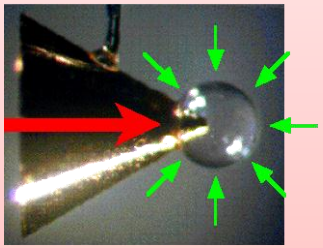
10 kJ 1ns

Precision gratings ensure high energy output.

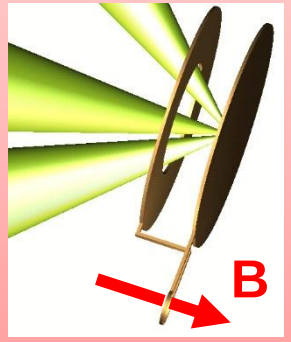


2 : increasing heating efficiency

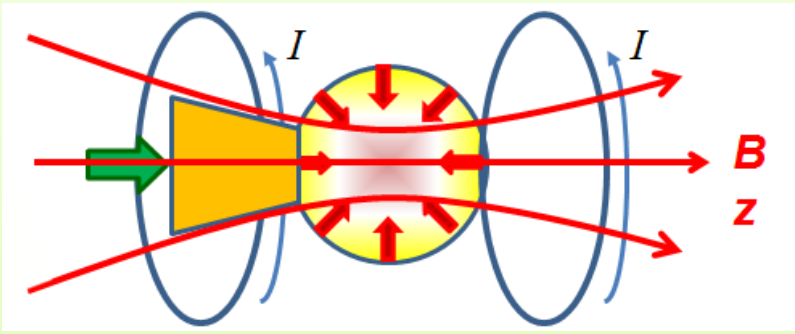
Fast Ignition Target
Nature 2001, 2002



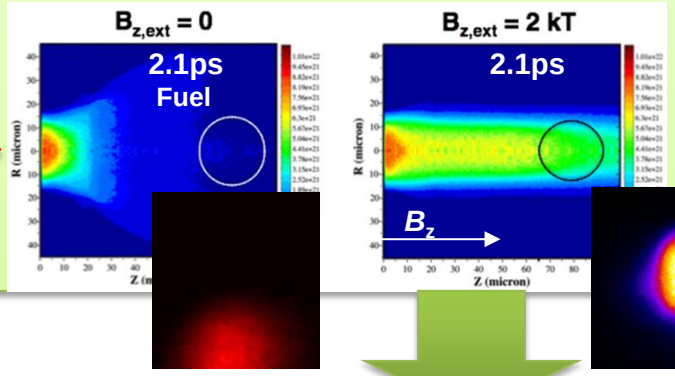
High B Field
Sci. Report 2013

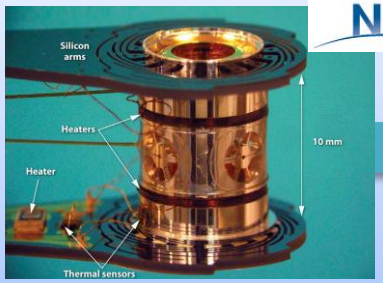


Fast Electron Guiding by B Field
⇒Efficient heating



Heating Laser





Fuel Gain > 2 (2014)

Fujioka, Thu Morning

Worldwide collaboration
on new concepts

Strategy towards Fusion Power Generation

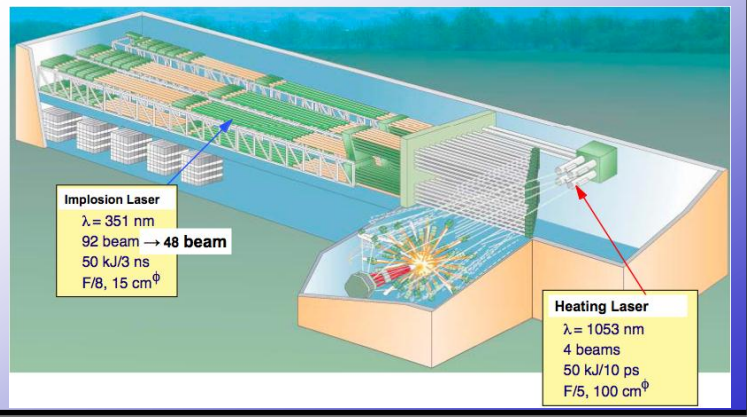
OSAKA UNIVERSITY

Institute of Laser Engineering

～2015

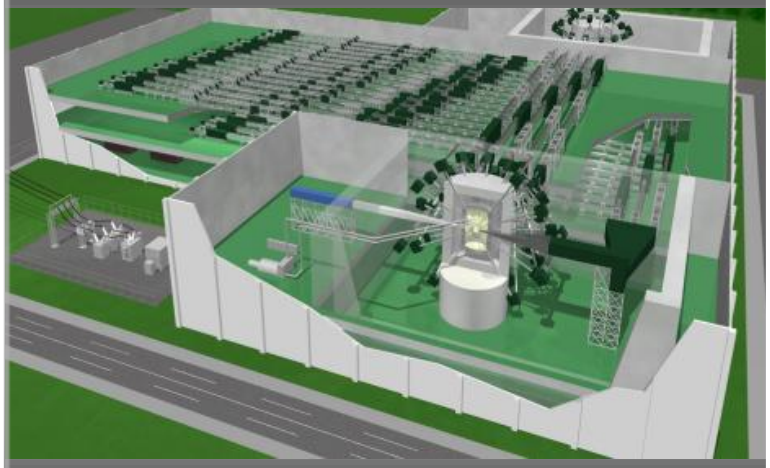
FIREX-I: Ignition Temp

～2025



FIREX-II: Ignition&Burn

～2035



LIFT: Power Generation

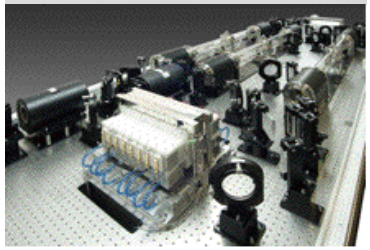
Atomic Energy Commission of Japan reported (Oct. 2005): "Based on its (FIREX-I) achievement, decide whether it should be advanced to the second-phase program aiming at the realization of ignition and burning"

***Laboratory Inertial Fusion Test**

Two innovations for high repetition laser

From Flush Lamps to Diodes

Flash Lamps
Broad spectra
→Inefficiency

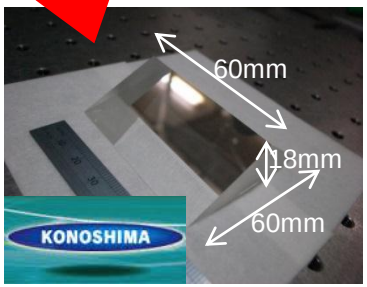


Laser Diodes
Emission lines≈ absorption lines

100 times efficiency

From Glasses to Ceramics

Laser Glasses
- **Large optics**
- **Low thermal conductivity**

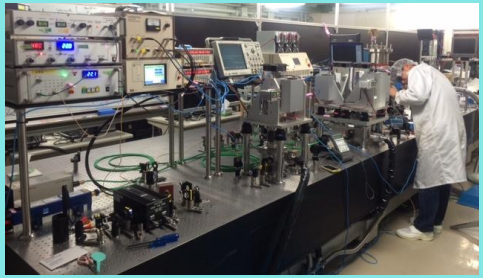


Yb: YAG Cooled Ceramic Crystal
- **Large optics**
- **High thermal conductivity**

1000 times thermal conductivity

GEMBU Laser 1J, 100Hz

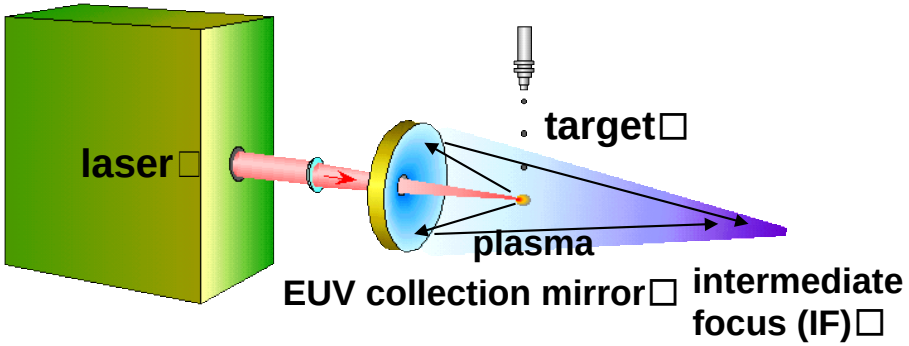
Cooled Ceramic Crystal Laser developed in ILE becomes Global Standard.



Outflow

- DiPOLE (UK Rutherford Lab.) 10J, 10Hz
- Lucia (France LULI) >10J, 10Hz
- ELI Beamlines (Czech) L2: 100J, 10Hz

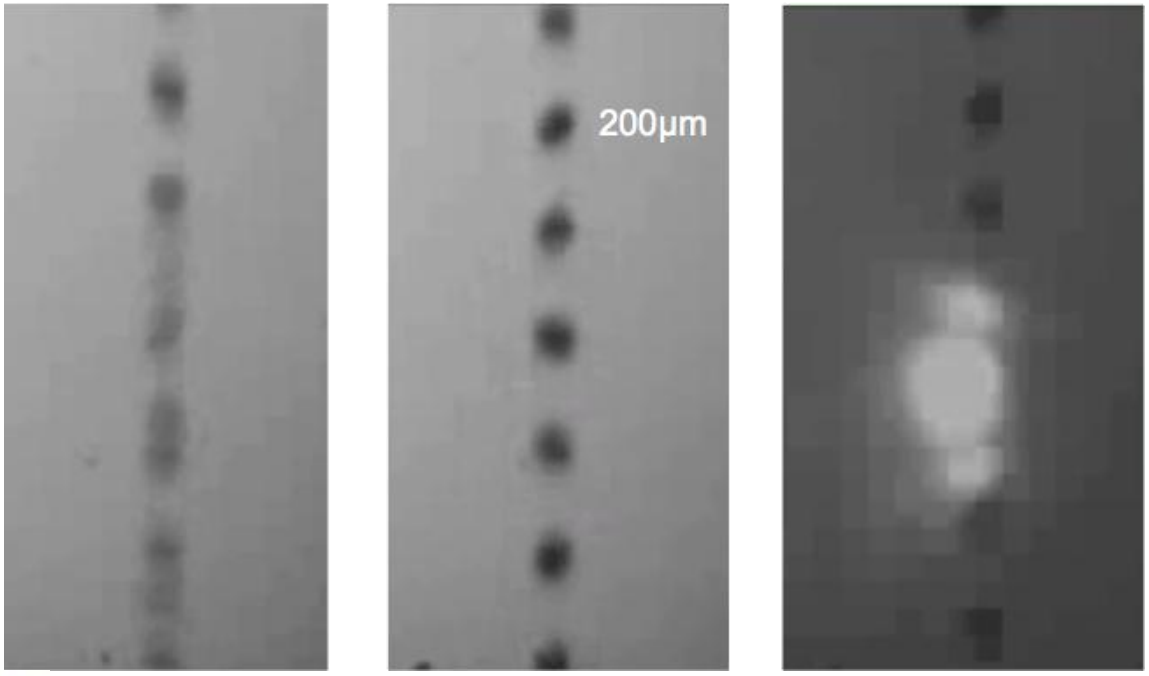
EUV project has already demonstrated Target Injection and Beam Pointing



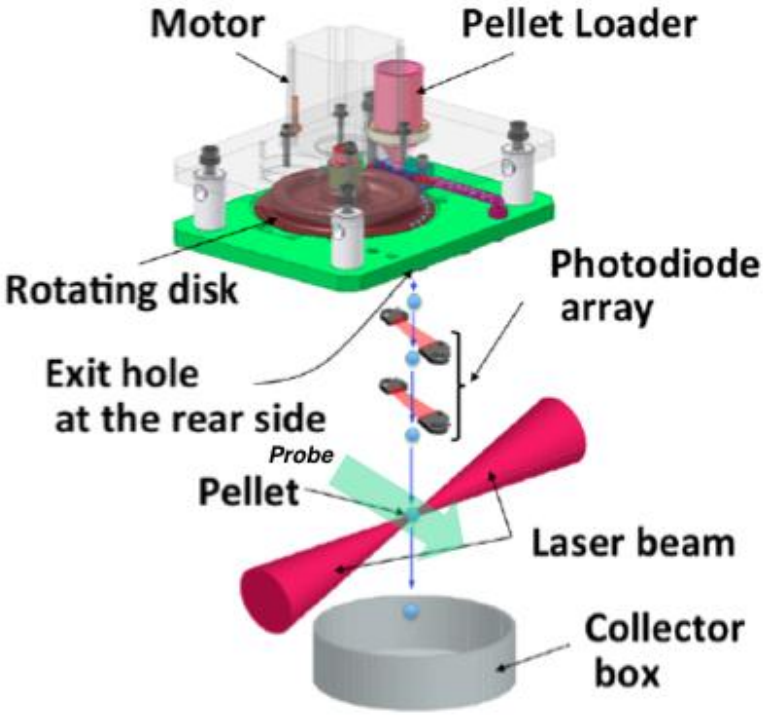
Unsynchronized Backlight

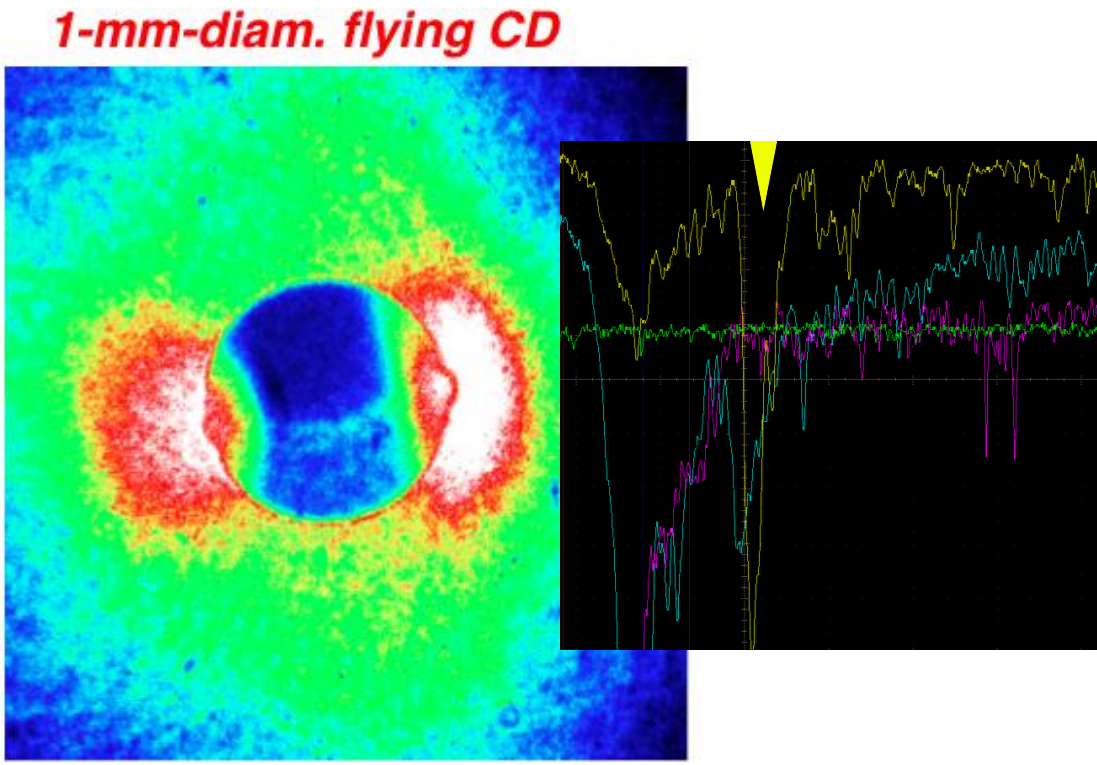
Synchronized

Laser never miss the target



First Fusion Target Injection





SUBJECT AREAS:
LASER-PRODUCED PLASMAS
EXPERIMENTAL NUCLEAR PHYSICS
DIODE LASERS
ULTRAFAST LASERS

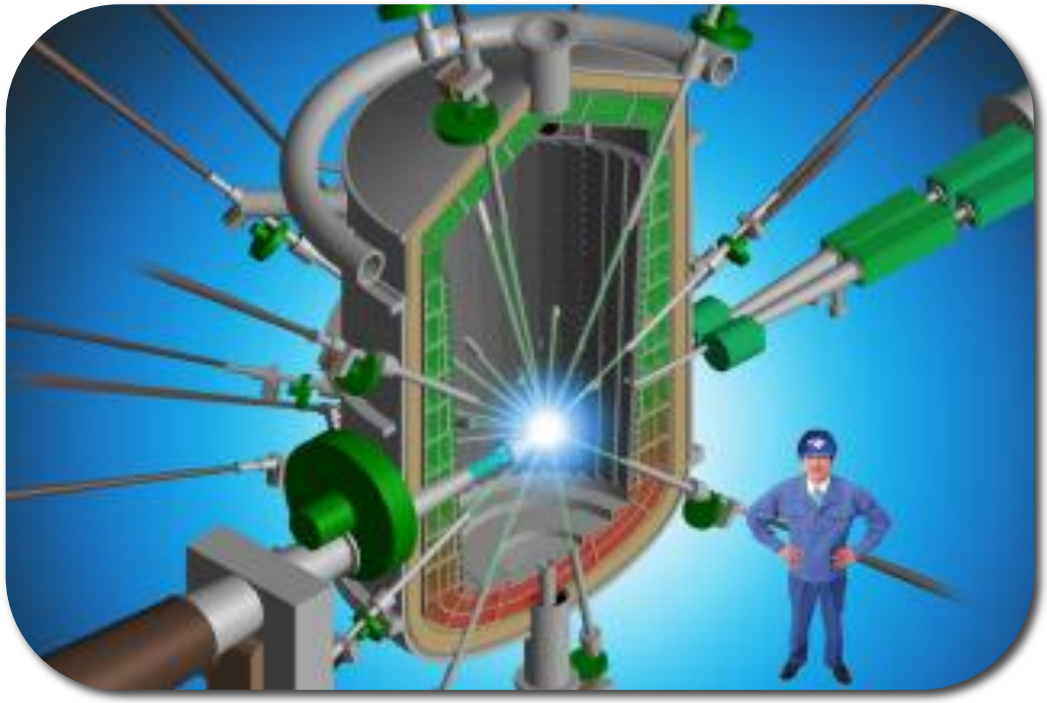
of 1-Hz-injected flying pellets and neutron generation

Osamu Komeda[1], Yasuhiko Nishimura[2], Yoshitaka Mori[1], Ryohei Hanayama[1], Katsuhiro Ishii[1], Suisei Nakayama[1], Yoneyoshi Kitagawa[1], Takashi Sekine[3], Nakahiro Sato[3], Takashi Kurita[3], Toshiyuki Kawashima[3], Hirofumi Kan[3], Naoki Nakamura[4], Takuya Kondo[4], Manabu Fujine[4], Hirozumi Azuma[5], Tomoyoshi Motohiro[5], Tatsumi Hioki[5], Mitsutaka Kakeno[5], Atsushi Sunahara[6],

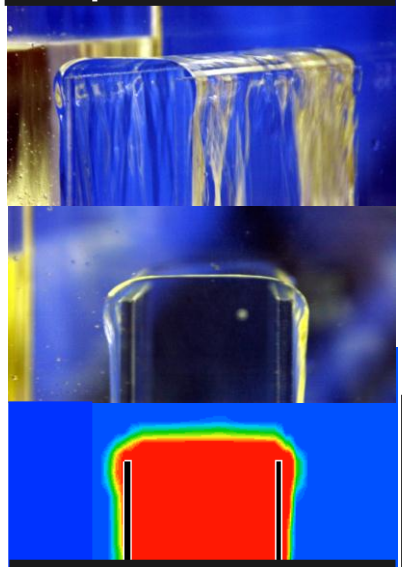
Komeda, Sci. Rep. 2013
4 posters on Thursday

Cascaded Liquid Wall

Laser fusion chamber has
- **Cascaded liquid wall**
- **Beam port protection**

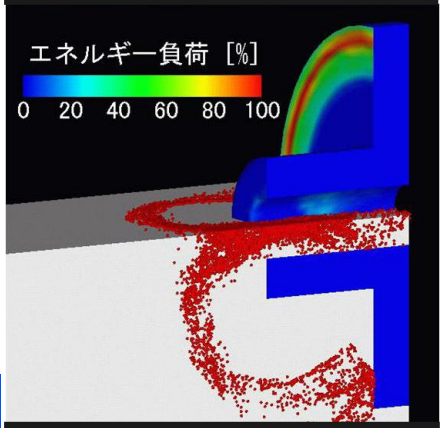


Liquid Wall Stability at equal Weber #



Kyoto U.

Port Protection

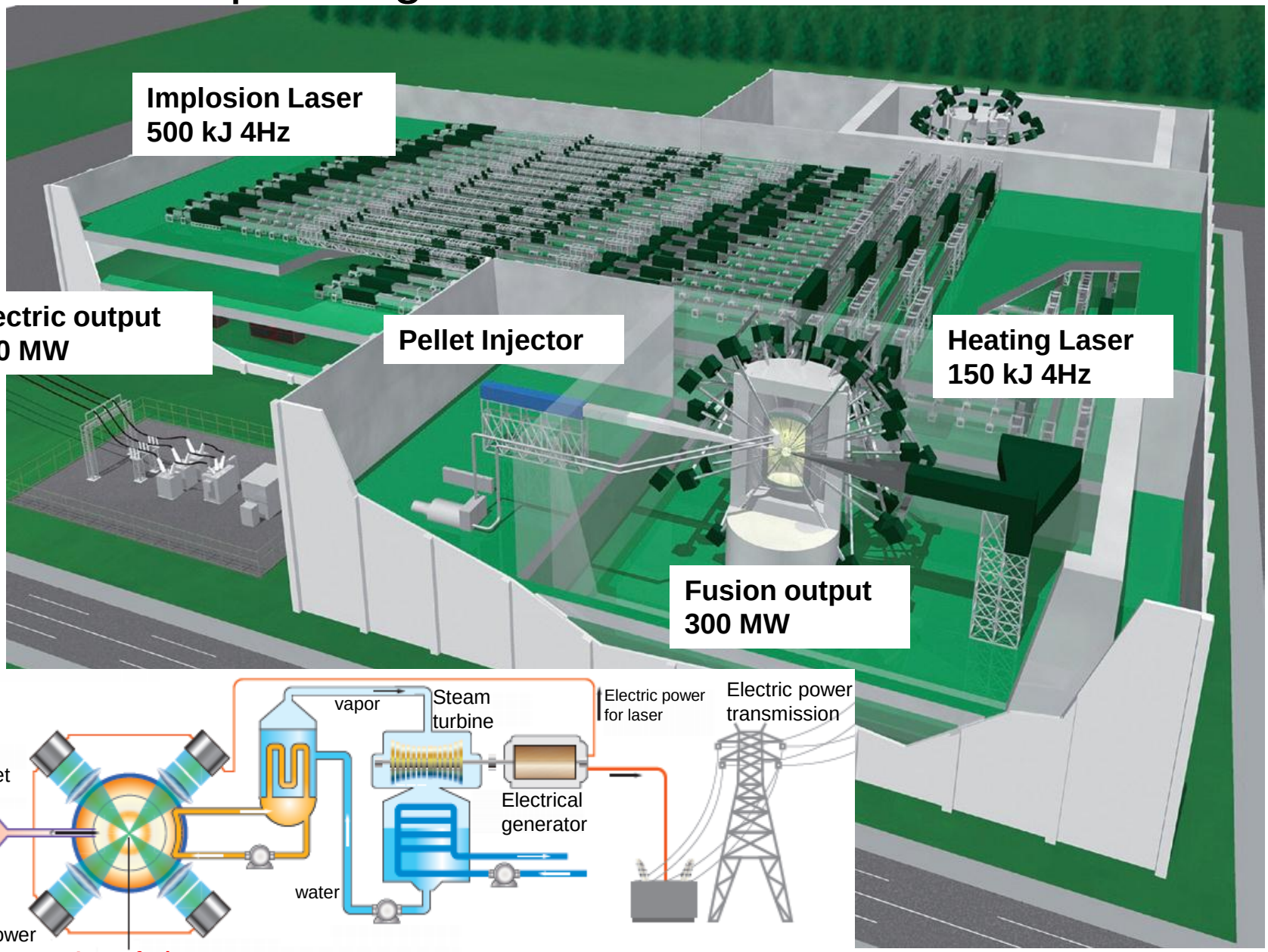


Kyushu U. and Kyoto U.

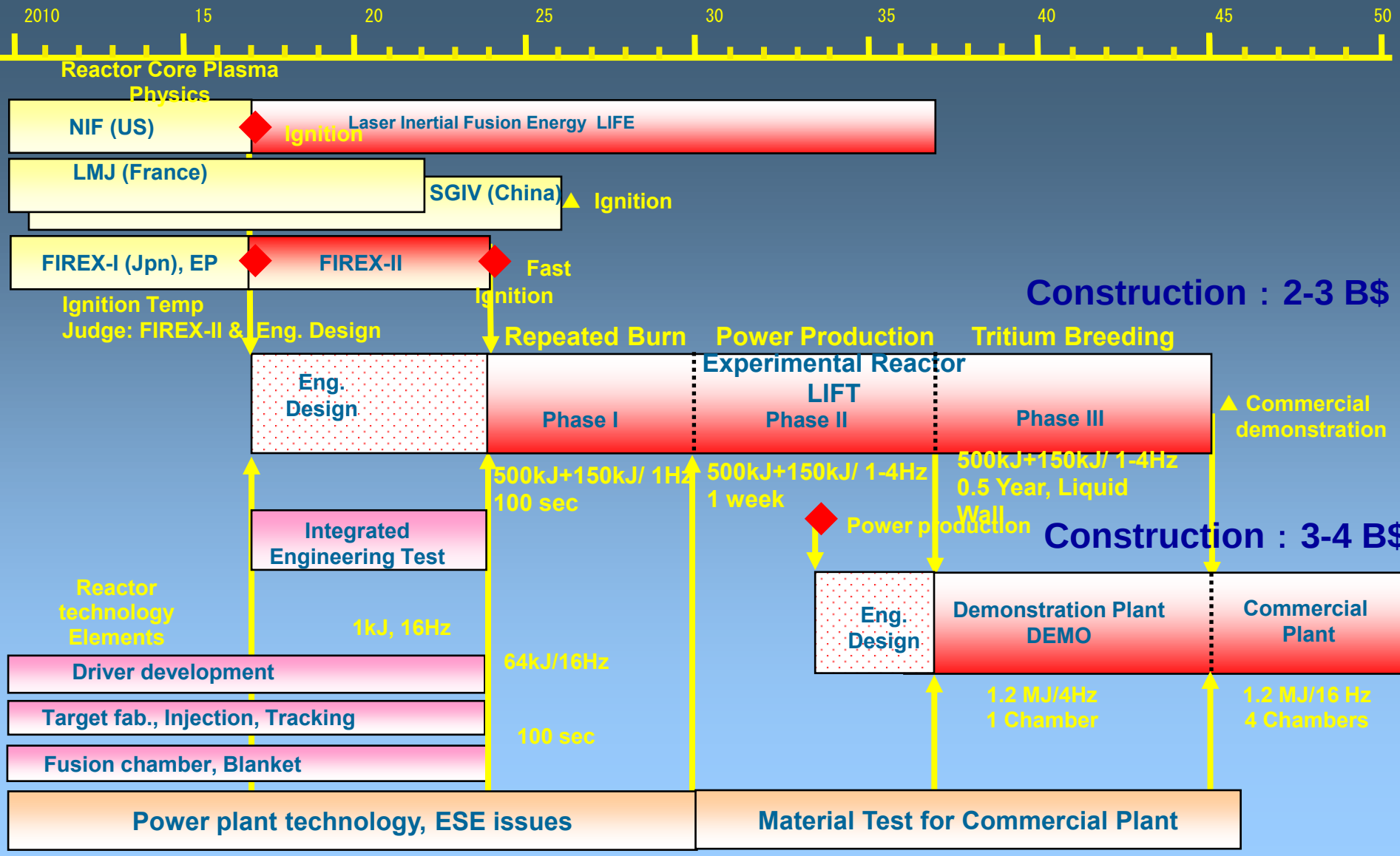
Beam port can be protected with 1-T magnetic field.

Demo of reactor core plasma is critical

Experimental Test Facility, LIFT for power generation



Experimental reactor (i-)LIFT integrates all physics and engineering activities.



(i-)LIFT is Laser based Fast Track. Revised in 2014

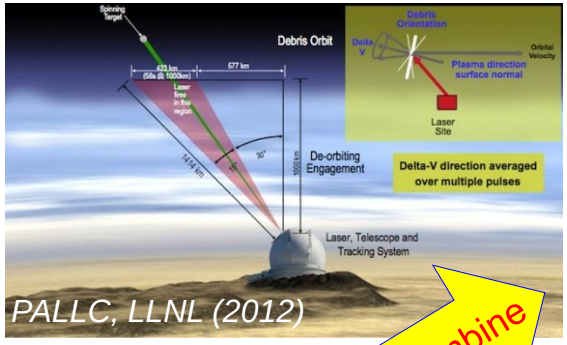
Strategy to Practical Use (Plan)

OSAKA UNIVERSITY

Institute of Laser Engineering

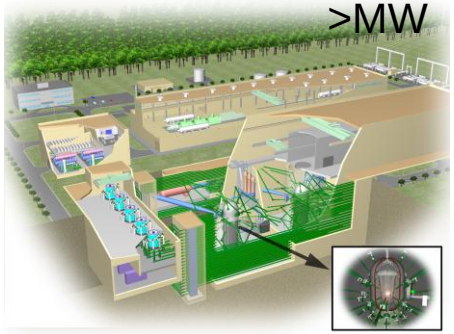
【Guidelines】
- 国産技術の活用と光技術の進展
- 確実な目標設定とスケーラビリティ
- 新産業基盤技術の創成
- 既存産業におけるイノベーション

Space debris elimination

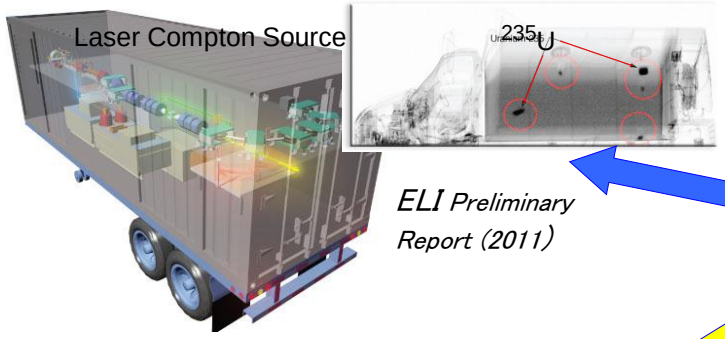


PALLC, LLNL (2012)

Fusion Laser



Non-destructive test by trailer-top γ source

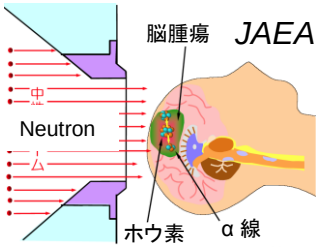


ELI Preliminary Report (2011)

Goal
1 kJ
Module

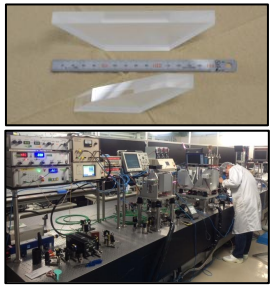
Beam combine

Boron Neutron Cancer Therapy



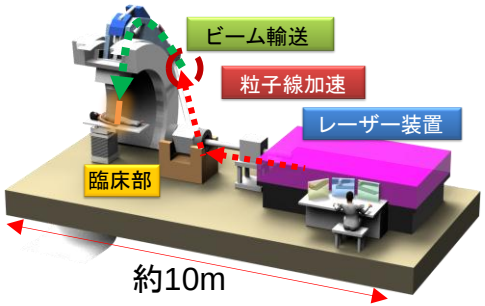
Power LD
Large Ceramic
Cooling

High Pulse Energy
System Design


GENBU
Yb:YAG Ceramic
1J, 100Hz


HALNA 20
20J, 10Hz

Beam Cancer Therapy



NIKKEI Newspaper JAEA (2011)

Optical technology evolution

- Optical material
- Polishing
- Multi layer coating

Industrial Innovation


CFRP manufacturing


Solar Battery・FPD (PolySi, Cutting


医療
器具
加工

OSAKA UNIVERSITY

Institute of Laser Engineering

Alliance with

International
Industrial
Academic

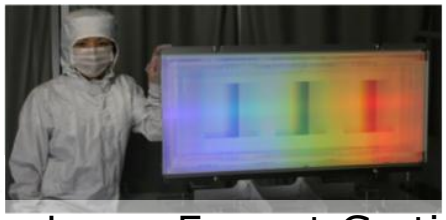
Communities

World Centers for High Power Lasers

Photon Industries in Japan

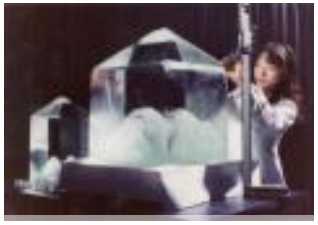
Laser Technologies created in GEKKO Series

Random Phase Plates
Kato, PRL1984

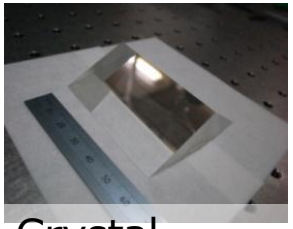


Large Format Grating

Laser Glasses
Yamanaka, Izumitani



Nonlinear Cristal
Sasaki, APL1995



Ceramic Crystal
Yoshida, J. Am. Ceram. Soc.1995
Ueda, Appl. Phys. Lett. 2001

Contribution to Growth of Industries

TOSOH
Shin-Etsu
USHIO
SOC 昭和オプトロニクス株式会社
神島化学工業 株式会社 Konoshima Chemical Co.,Ltd.
MITSUBISHI
Canon
HOYA
GIGAPHOTON
HAMAMATSU PHOTON IS OUR BUSINESS
OKAMOTO optics

World-class photon industries and engineers are created.

Industry's Engagement into Laser Fusion

TOYOTA's President Emeritus,
Sho-ichiro Toyoda, visited ILE, Osaka

TOYOTA is not a company just to make automobiles. TOYOTA has responsibility to generate energy.

TOYOTA's existing technology

Latest Looming Machine has
Wept injection: >10 Hz, 80 m/s
pointing accuracy: better than mm

HAMAMATSU and TOYOTA demonstrated compact laser fusion system "TERU"

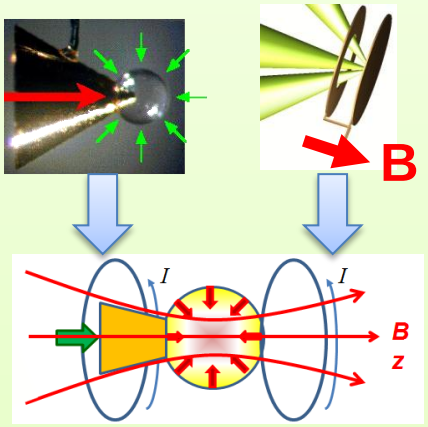
Diode pumped laser
100 J, >10 Hz

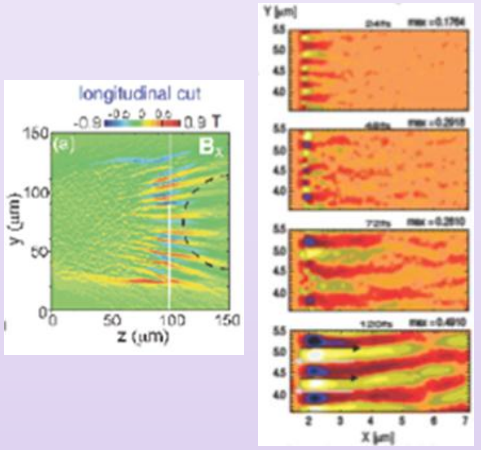
Contributions to basic science

OSAKA UNIVERSITY

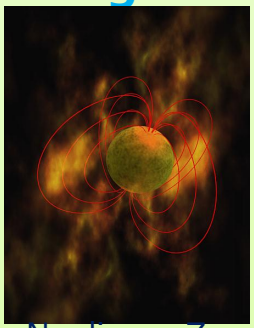
Institute of Laser Engineering

	Hydrodynamics	High Field	Plasma Phys.
Fusion	**Implosion**	**Efficient Heating**	**Electron Stream**
Science	**Meteorite Collision**	**Magnetic Field**	**Collisionless Shock**

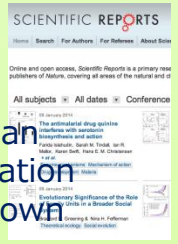




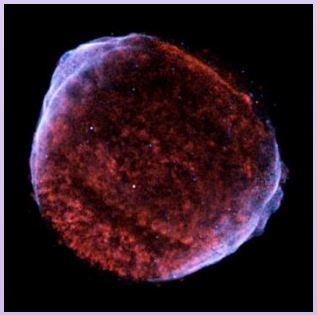
Nature Geosci. 2014

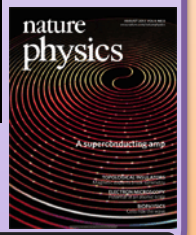


- Nonlinear Zeeman
- Landau Quantization
- Vacuum Breakdown



Sci. Report 2013



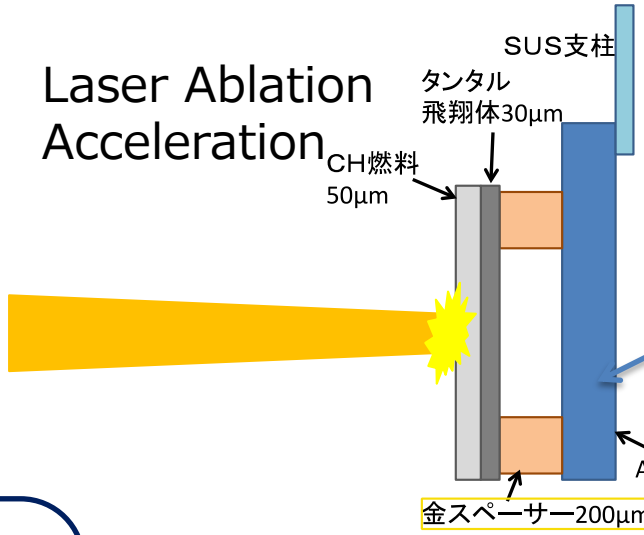


Nature Physics 2012

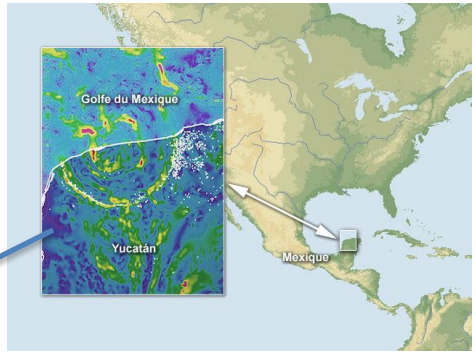
Meteorite Collision

Ohno, 2014

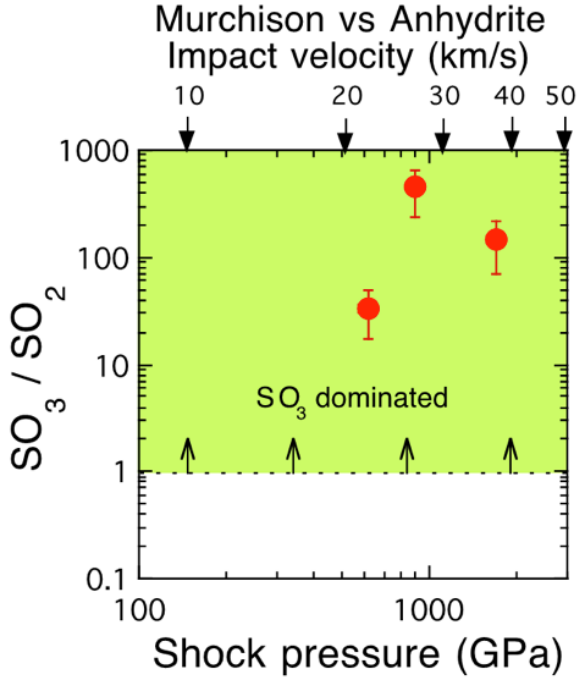
Laser Ablation Acceleration



Chicxulub crater at Yucatan



Sulphate-rich vapor



global acid rain, destroying the ecosystem

Dynasours Extinction

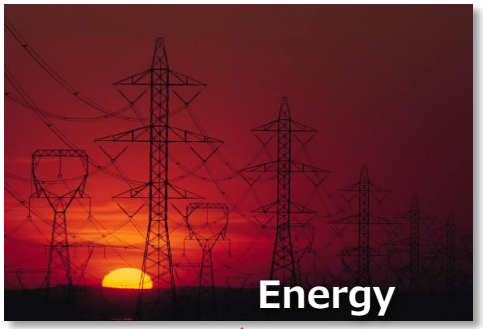
A huge quantity of sulphur trioxide made sulfuric acid ocean.

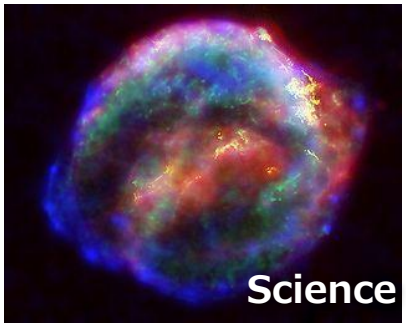
Our mission

OSAKA UNIVERSITY

Institute of Laser Engineering

Near Future





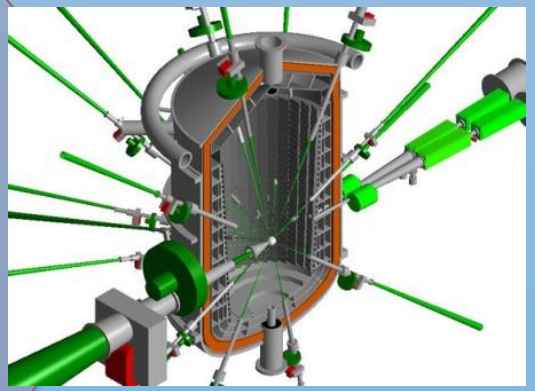
Present

Laser Development

High Energy Density Science

Laser Astro/Planets

Fusion



Summary

- **Fast ignition scheme is steadily on going as FIREX I project.**
  We will achieve 5-keV temperature within a few years,
  with the increase of heating efficiency
  by magnetic field guiding of electron beam and
  the full performance operation in LFEX.

- **Toward future power plant, we are developing high rep. rate laser technologies including ceramic lasers invented by ILE.**

- **Our activities toward fusion energy are also contributing to enlarge photonics industry, basic science research with intense lasers, and the education of people for all of these related society.**