The National Ignition Facility (NIF): Bringing Star Power to Earth

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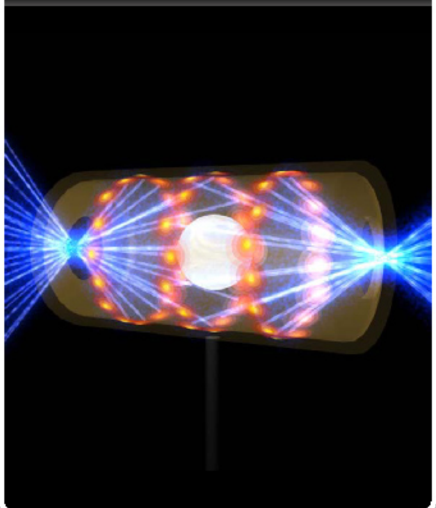
Lawrence Livermore National Laboratory


Could we build a
miniature sun on earth?
. . . to provide significant
carbon-free energy
for humankind.

Fusion energy is attractive, but needs to be timely

Safe



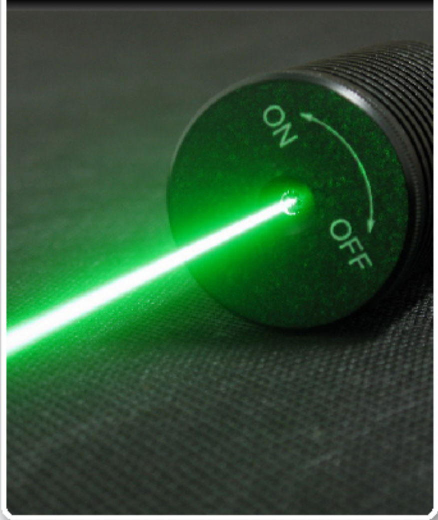
Sustainable

Energy security

Baseload

Carbon-free

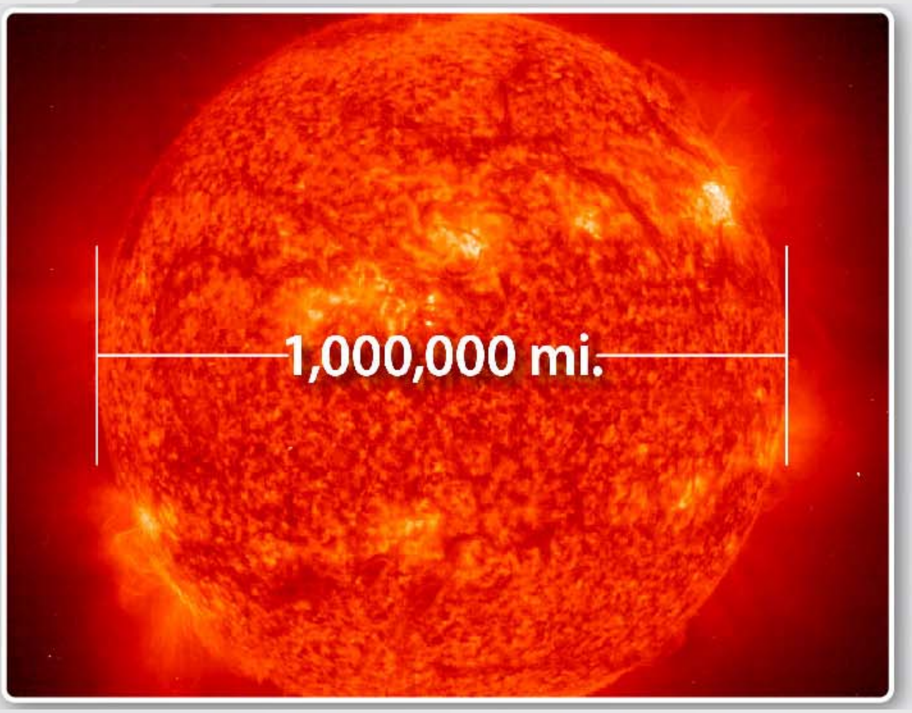
Industrially attractive

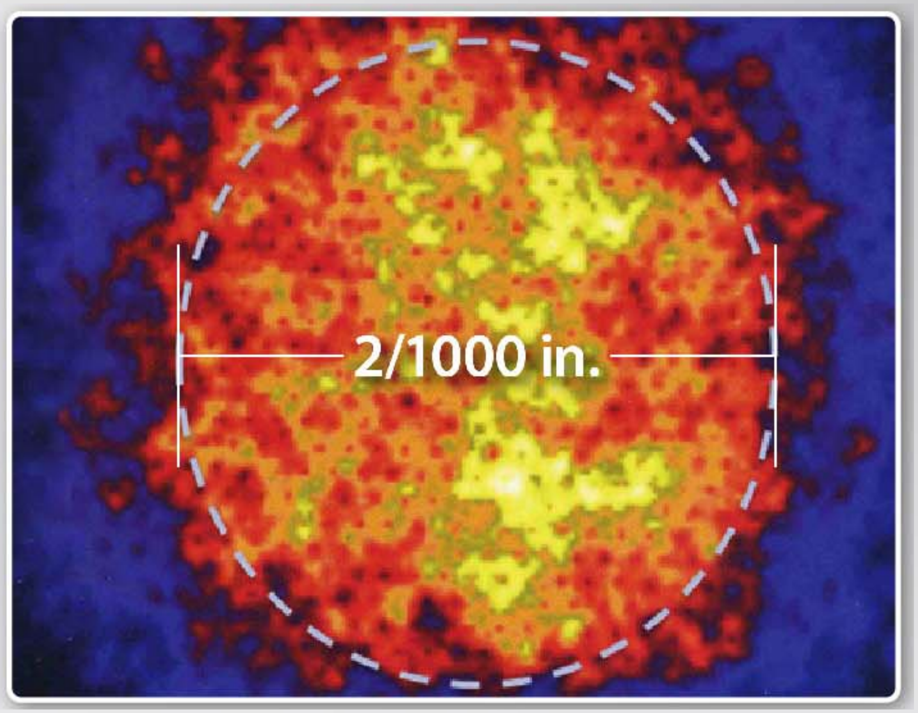


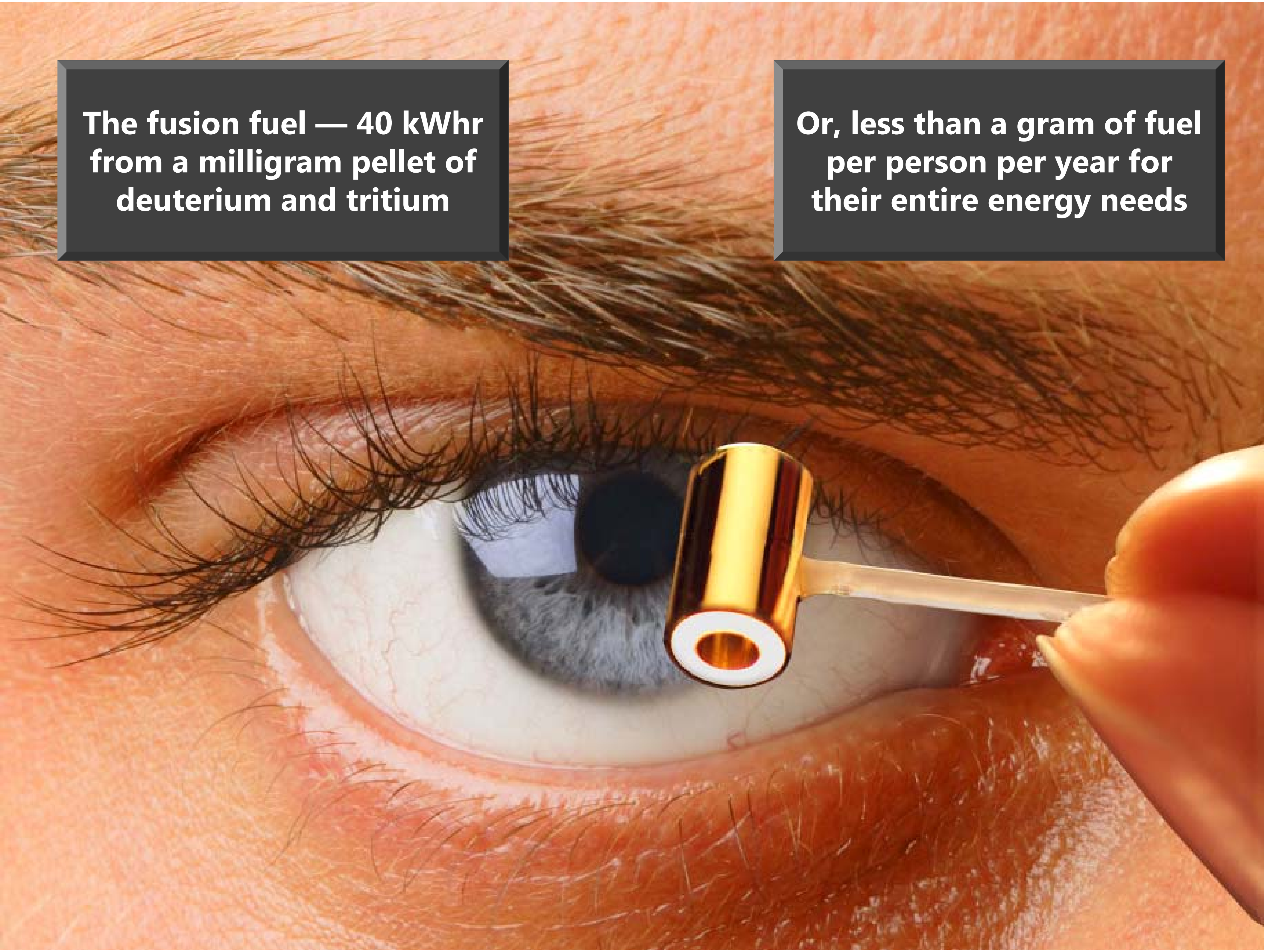
No geologic storage

Bringing star power to Earth

Use very high power lasers to create fusion – releasing city-scale energy output, safely and sustainably

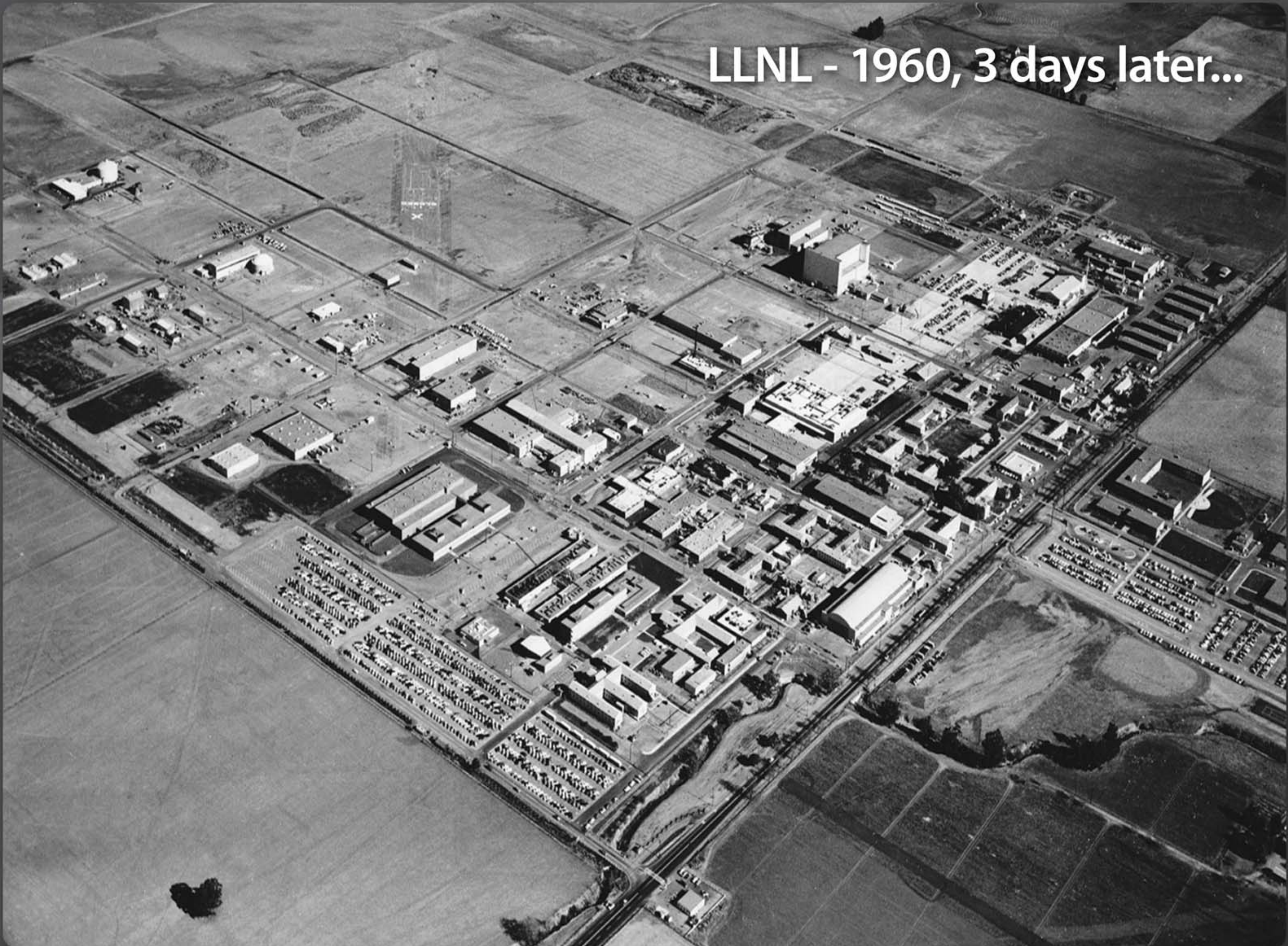




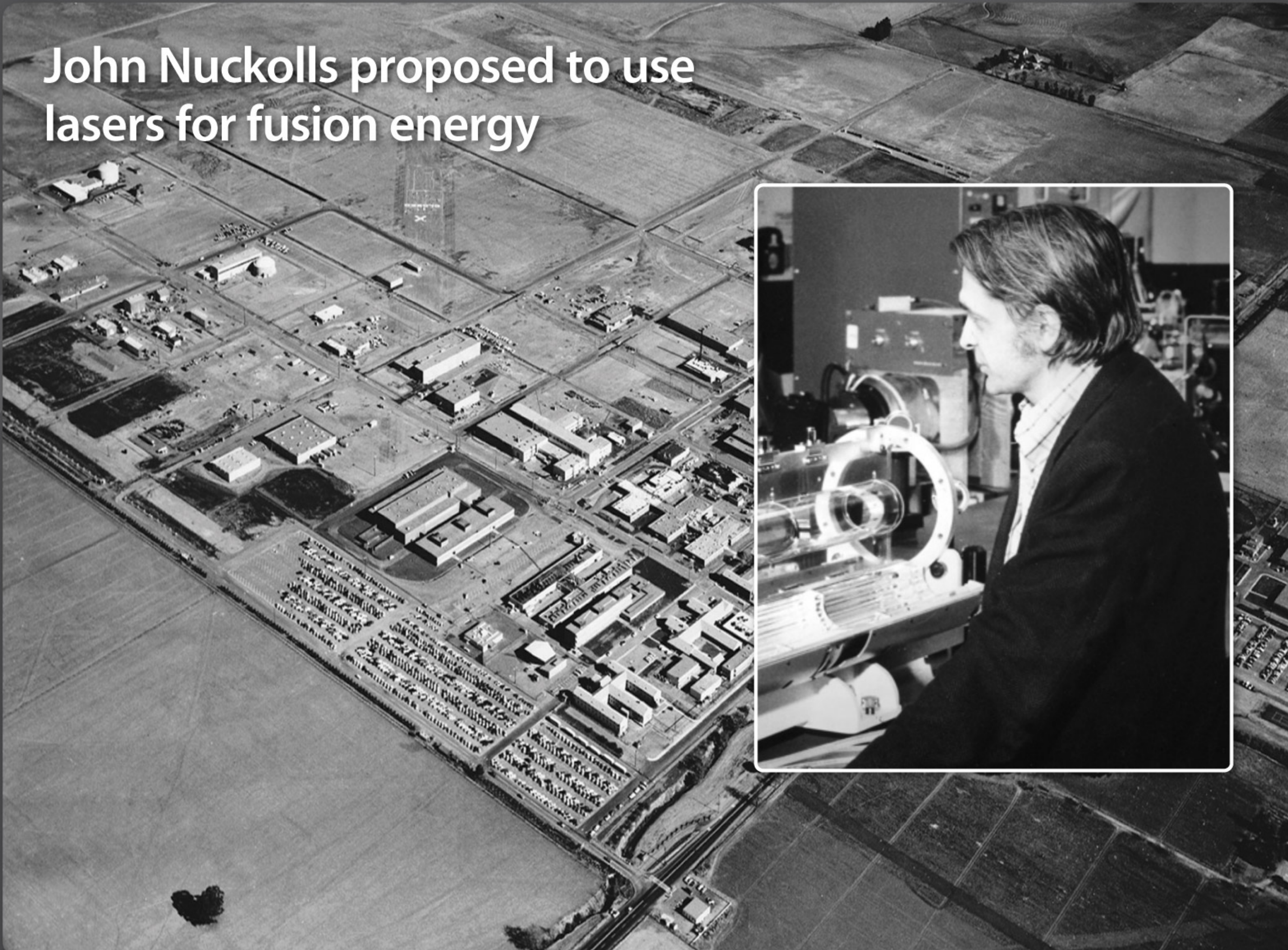

The fusion fuel — 40 kWhr from a milligram pellet of deuterium and tritium
Or, less than a gram of fuel per person per year for their entire energy needs

Malibu, California — 1960

Ted Maiman First laser demonstrated on May 16, 1960


LLNL - 1960, 3 days later...

John Nuckolls proposed to use lasers for fusion energy



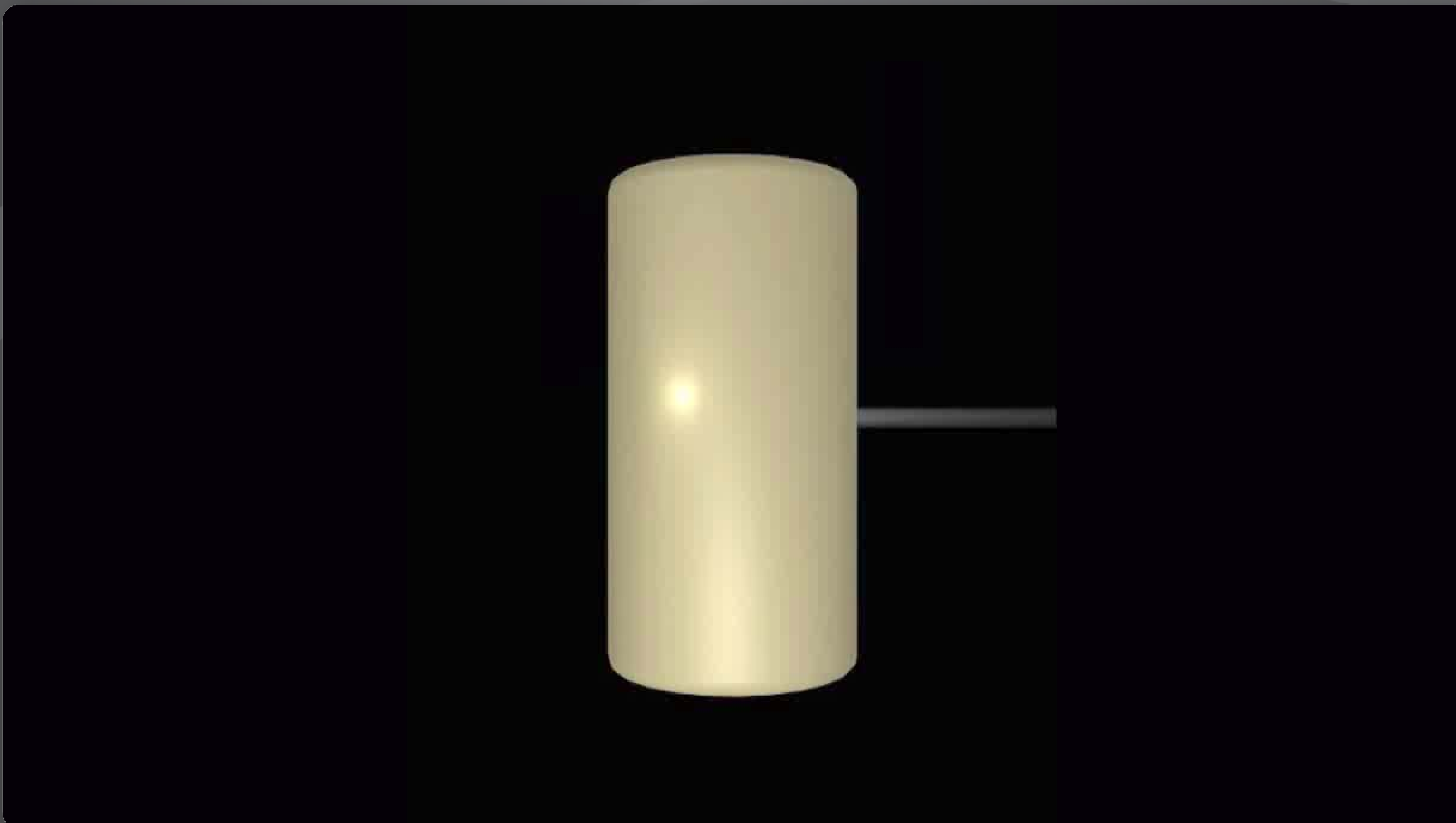
Recipe for fusion on earth

Ingredients

Hydrogen from water

Directions

1. Filter out D_2O, breed tritium
2. Place in 4 Million degree K oven
3. Ablate for a few billionths of a second and bring to fusion conditions
4. Convert mass to copious amounts of clean energy



The NIF facility is the culmination of many decades of US leadership and investment in this field

Janus, 1973

100J IR

Argus, 1976

1kJ IR

Shiva, 1977

10kJ IR

Nova, 1984

30kJ UV

NIF, 2009

1.8MJ UV

NIF can demonstrate full-scale performance for a 1000 MWe plant

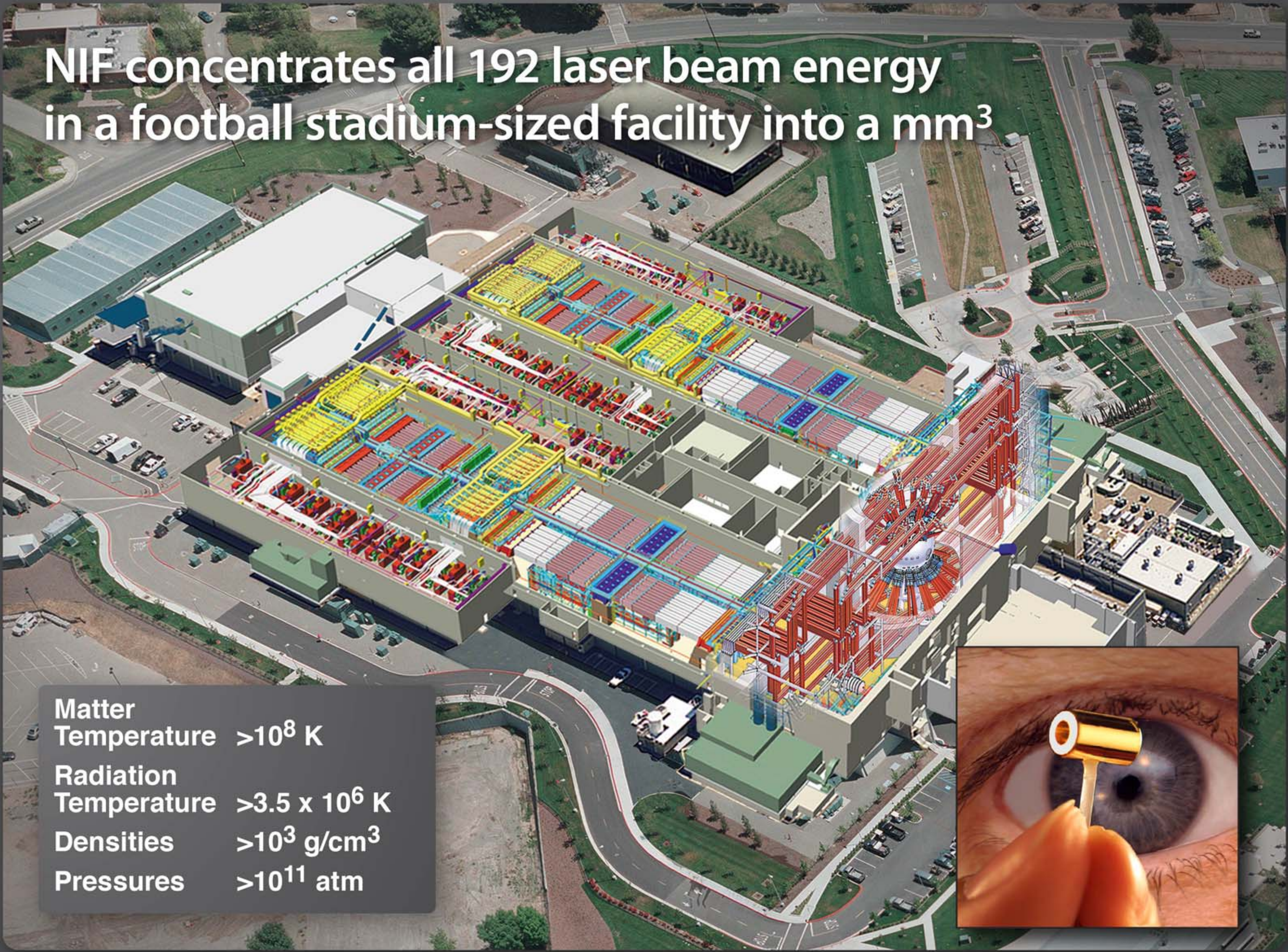
U.S Partners in NIF Enterprise

• Contracts

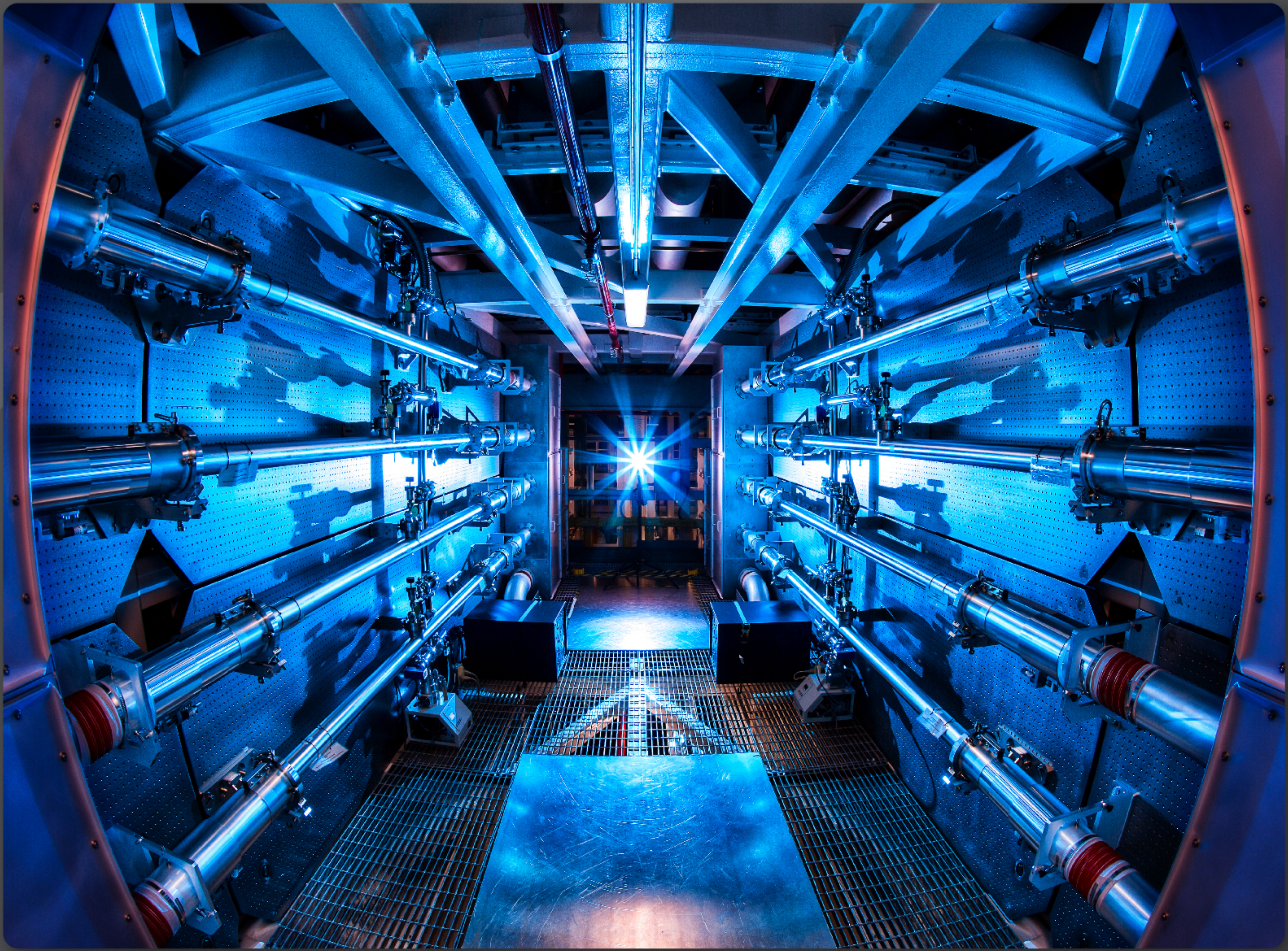
NIF is now operational and ignition campaigns are underway

NIF is the world's most energetic laser by 100x

NIF concentrates all 192 laser beam energy in a football stadium-sized facility into a mm³



Matter Temperature	$>10^8$ K
Radiation Temperature	$>3.5 \times 10^6$ K
Densities	$>10^3$ g/cm^3
Pressures	$>10^{11}$ atm

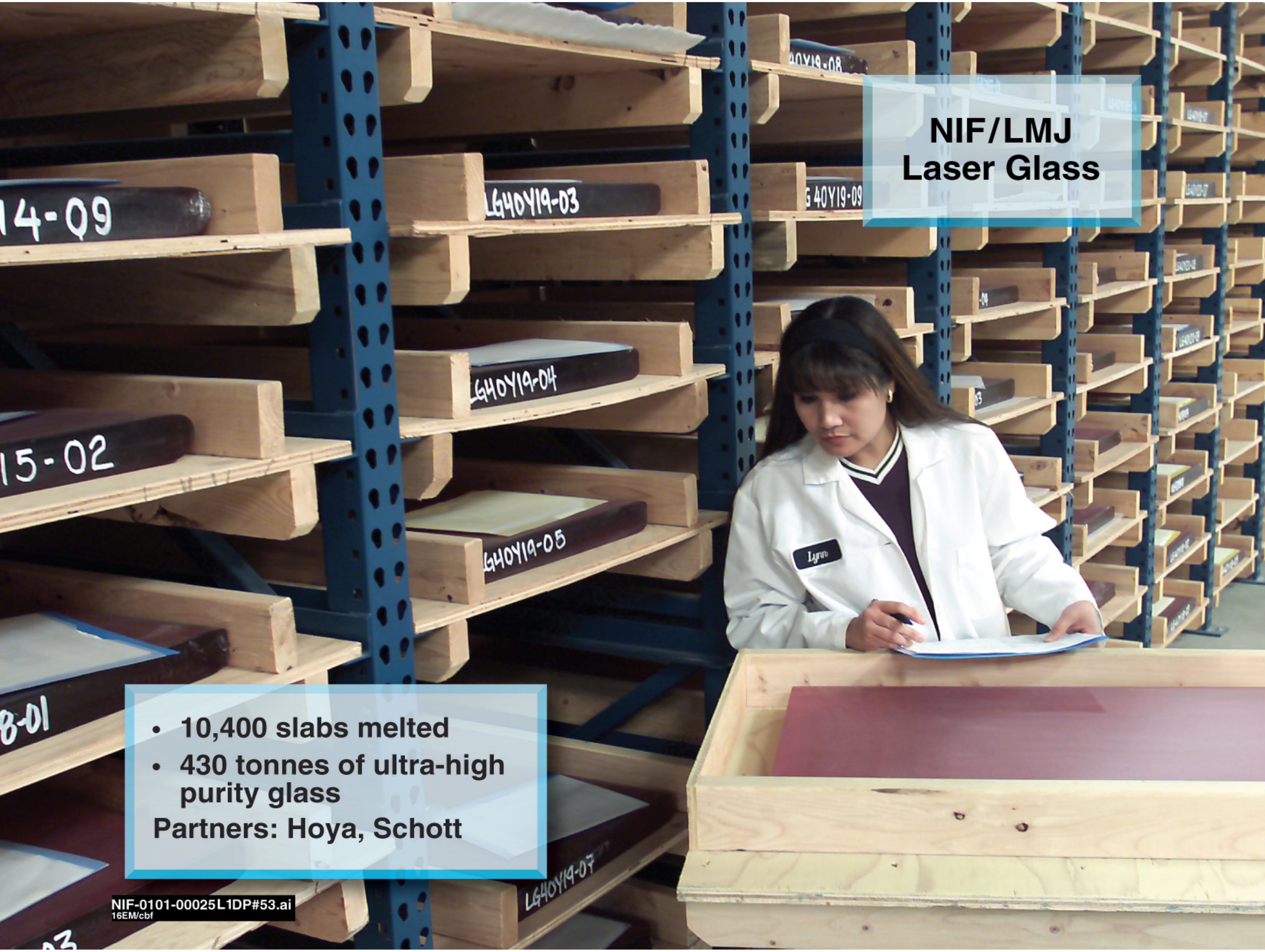


15EIM/mfm • 2012-041066s1

NIF/LMJ Laser Glass

- 10,400 slabs melted
- 430 tonnes of ultra-high purity glass

Partners: Hoya, Schott

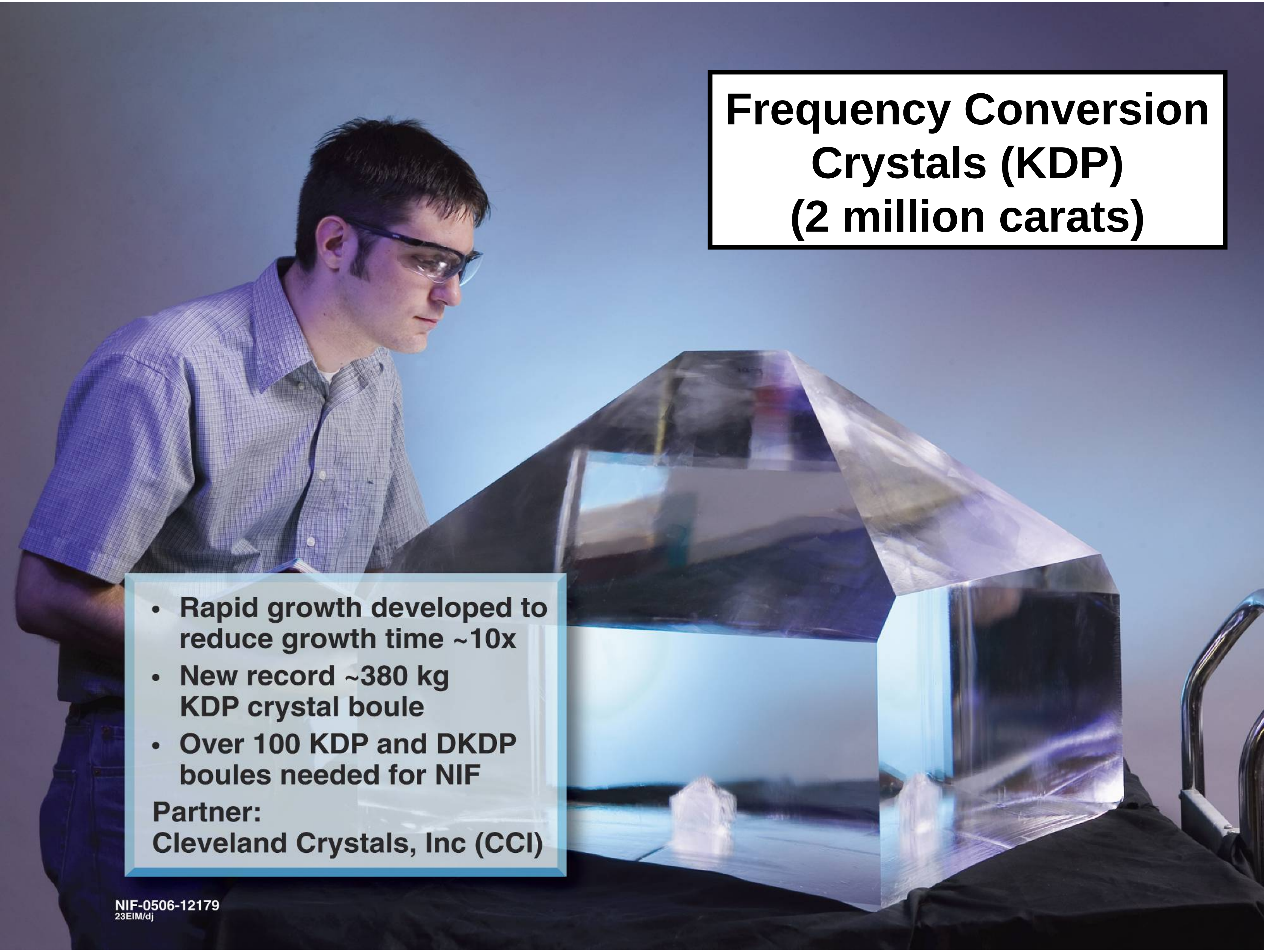


NIF-0101-00025L1DP#53.ai
16EM/cbf


LB2-HWAY 1-18
LB2-HWAY 2-18

03EIM/dj • NIF-0409-16233s1

Frequency Conversion Crystals (KDP) (2 million carats)

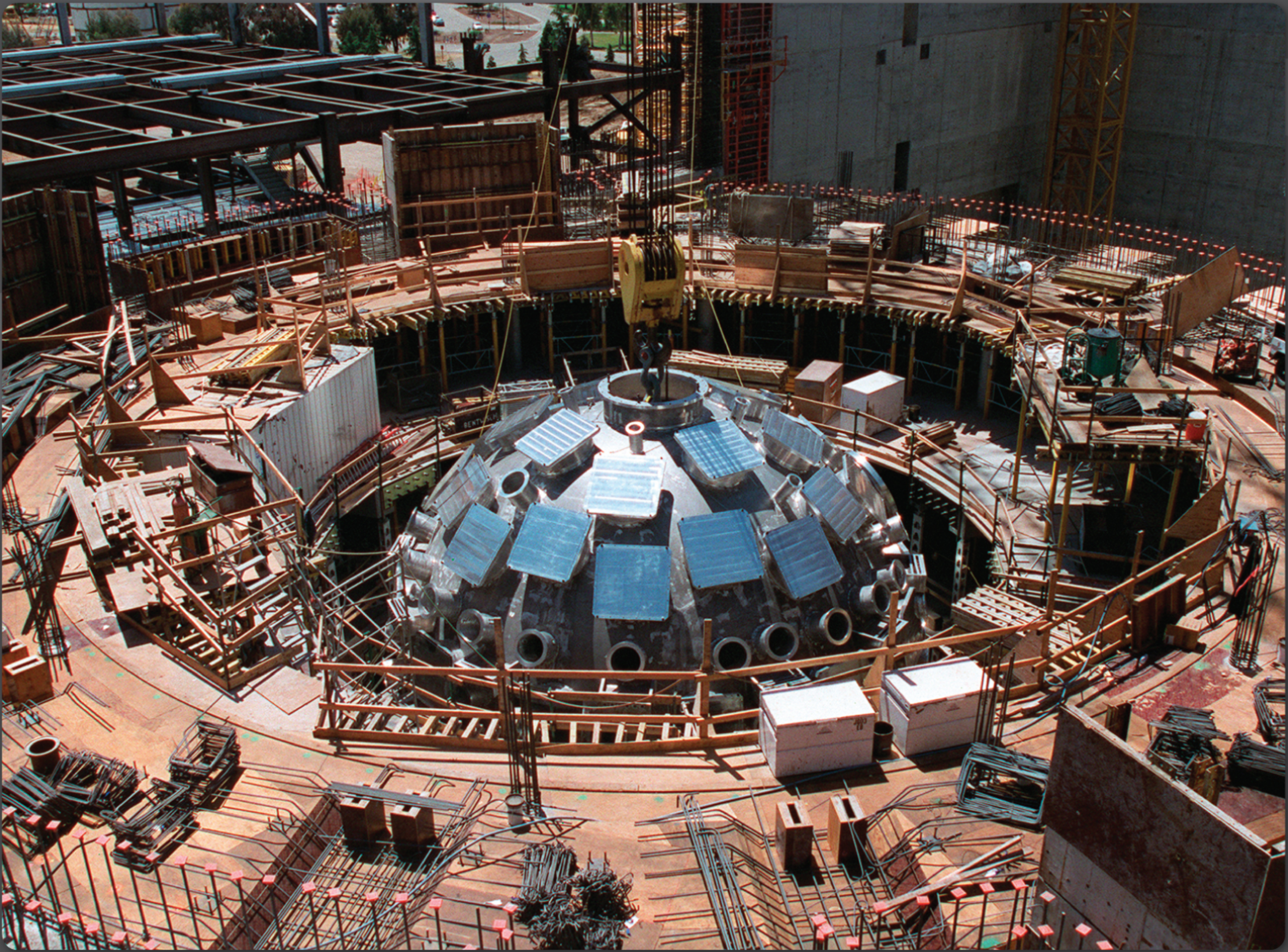


- Rapid growth developed to reduce growth time ~10x
- New record ~380 kg KDP crystal boule
- Over 100 KDP and DKDP boules needed for NIF

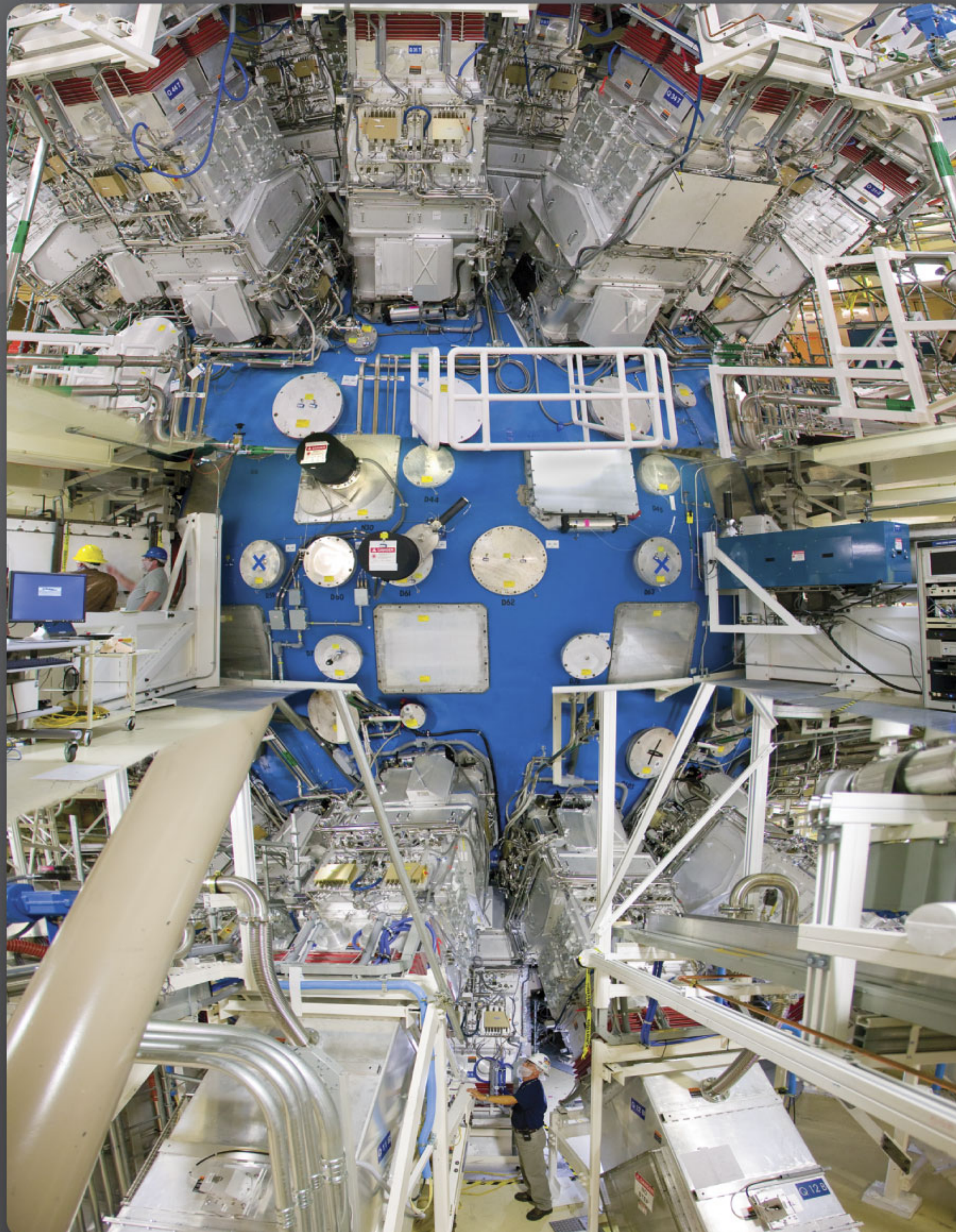
Partner:
Cleveland Crystals, Inc (CCI)

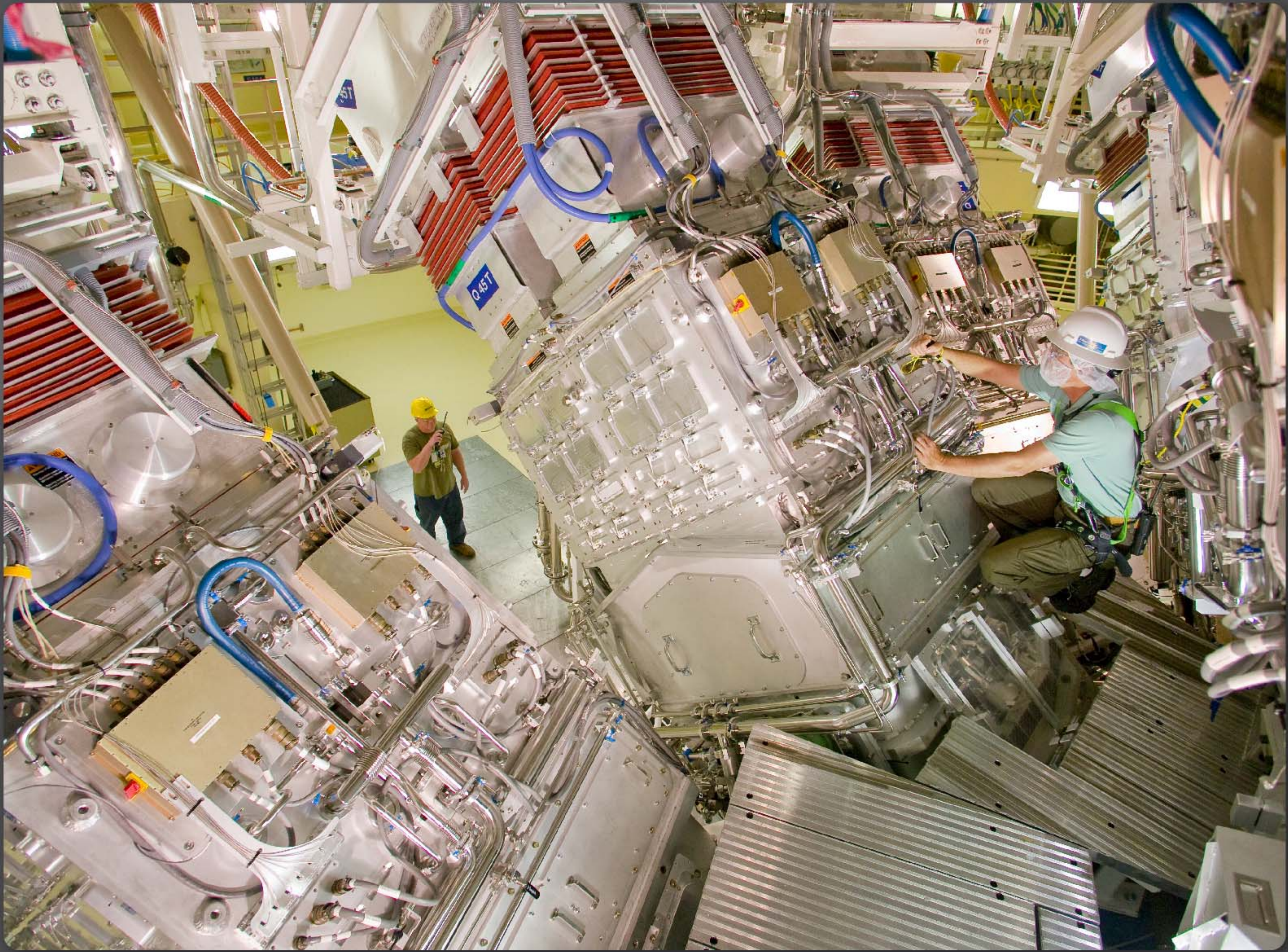
NIF-0506-12179
23EIM/dj

Target Chamber
June 1999



00ABC/abc • NIF-0609-16642



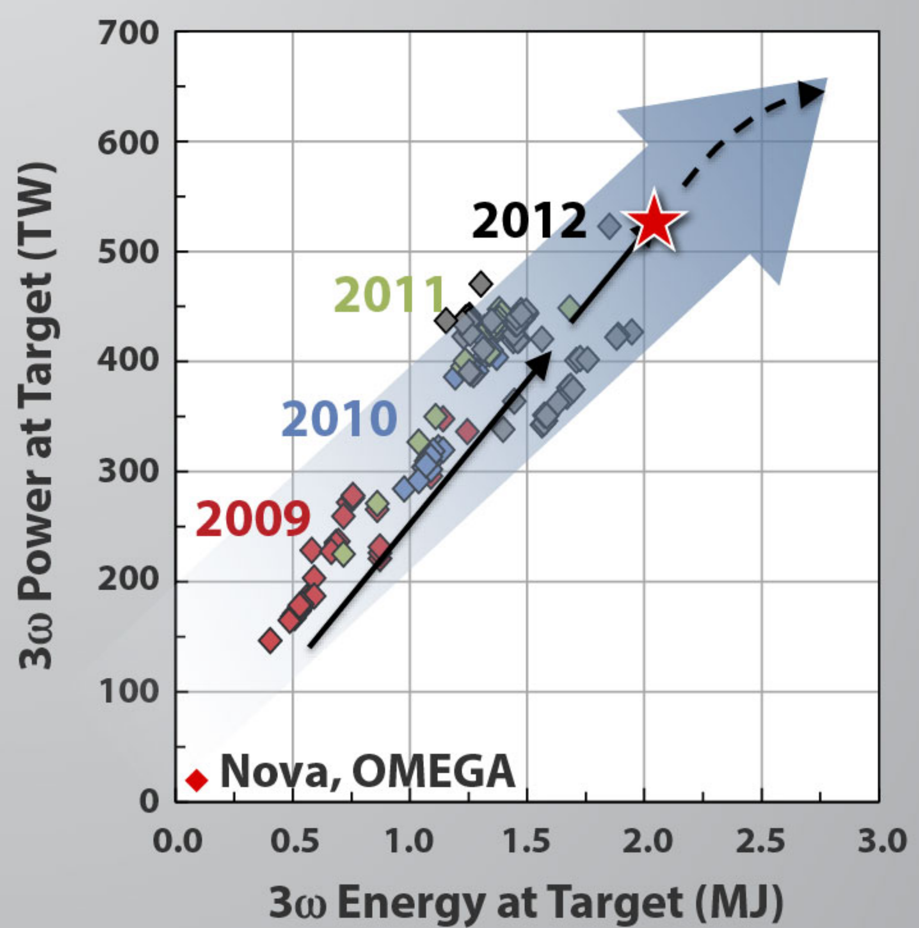


15EIM/tr • 2012-041103s1L2

NIF operational capabilities — laser energy/power

- NIF laser is steadily increasing the laser energy and power
- NIF Laser is operating 24/7 with exceptional reproducibility and reliability (99%)
- Currently supporting the NIC at 1.4 to 1.8 MJ
- We have achieved the 1.8 MJ milestone and a power of 522 TW in a NIC-relevant pulse format
- The NIF has intrinsic capability to continue on this growth path for several more years

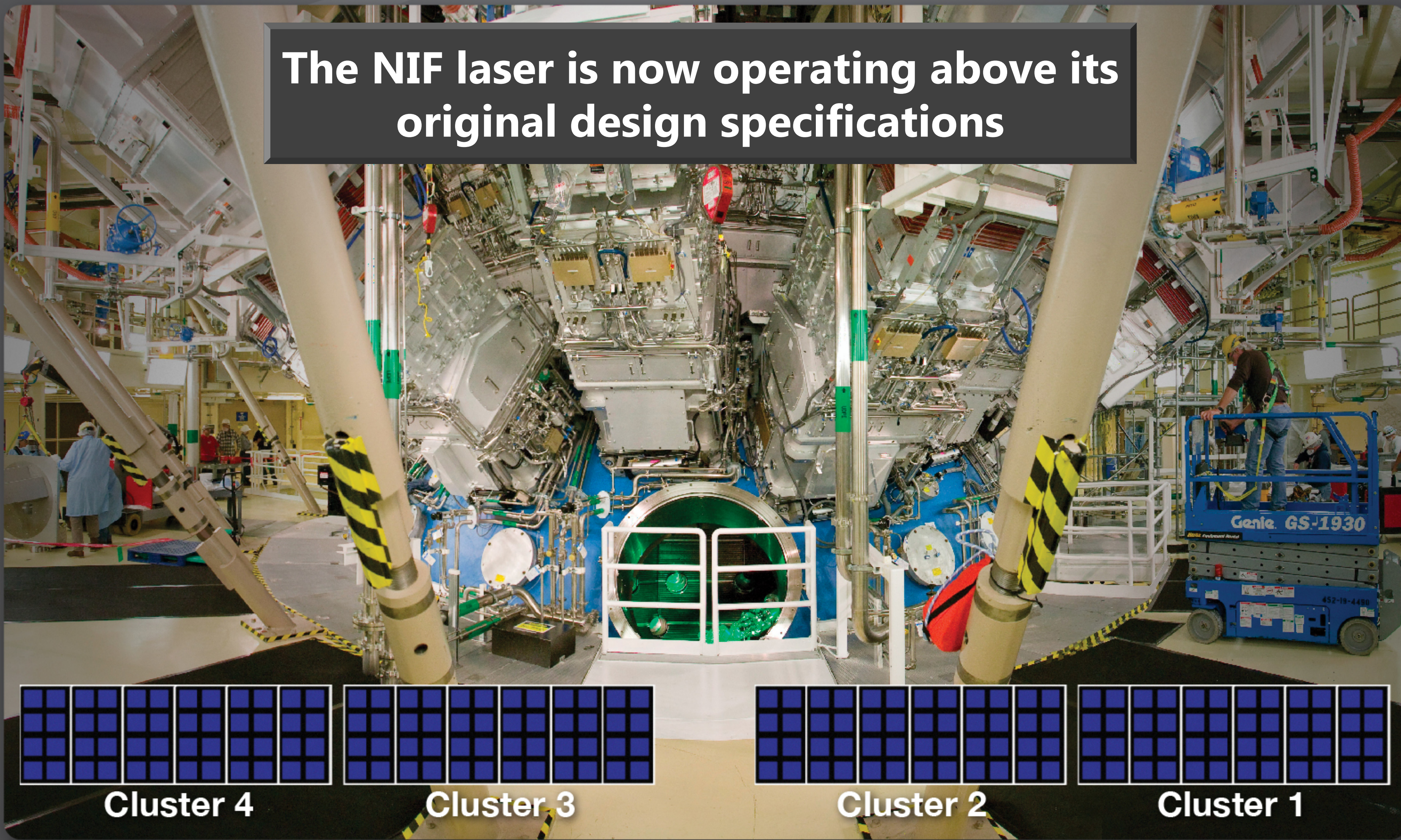
The laser energy and power available for experiments have been steadily increasing



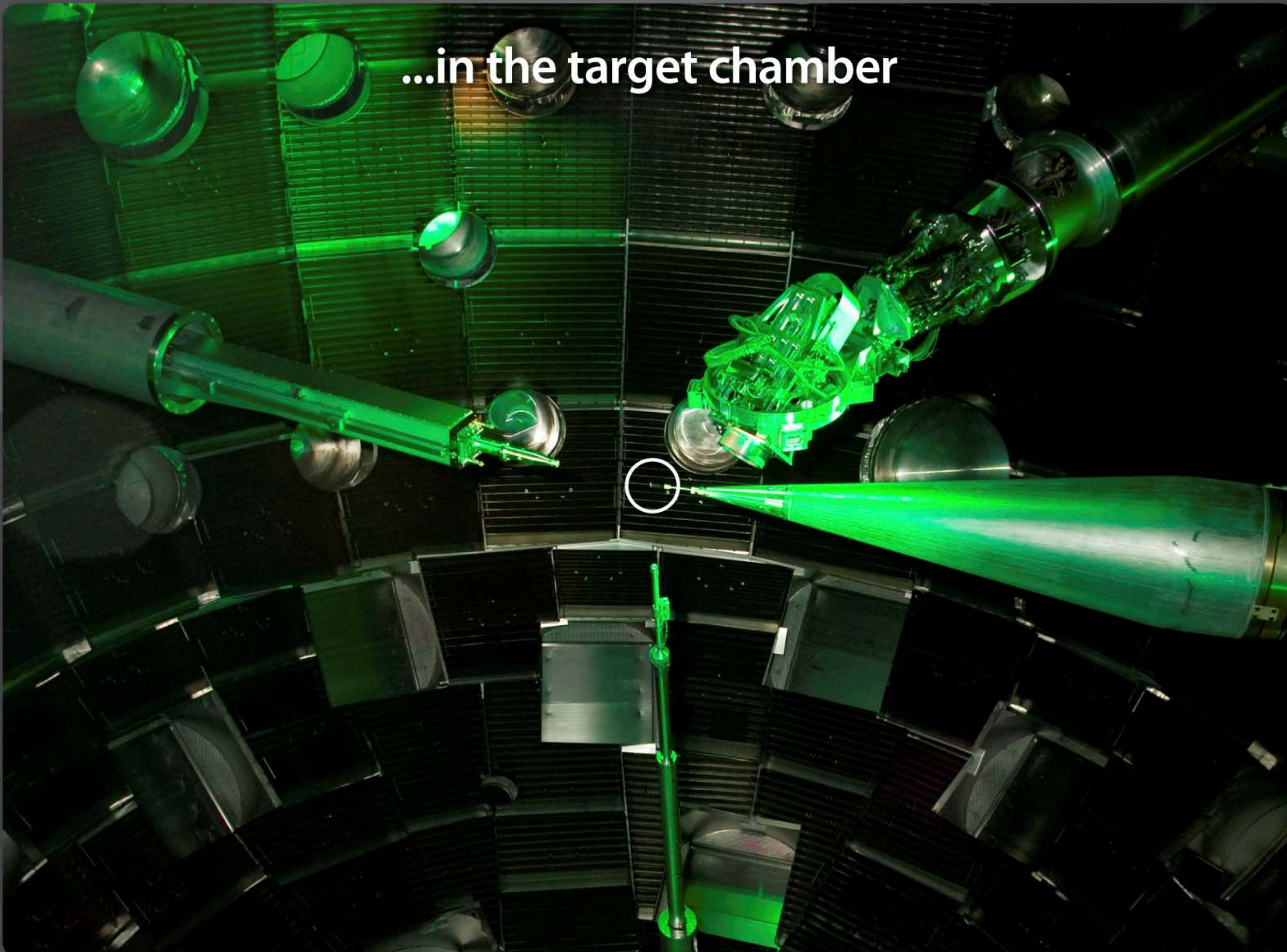
March 15, 2012
1.875 MJ
411 TW

July 5, 2012
1.855 MJ
523 TW

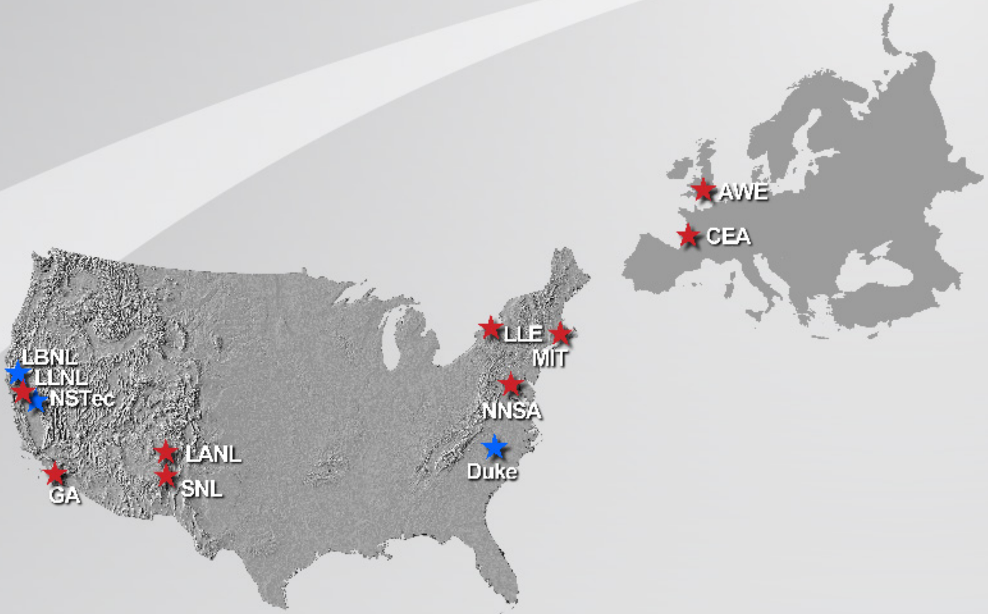
The NIF laser is now operating above its original design specifications



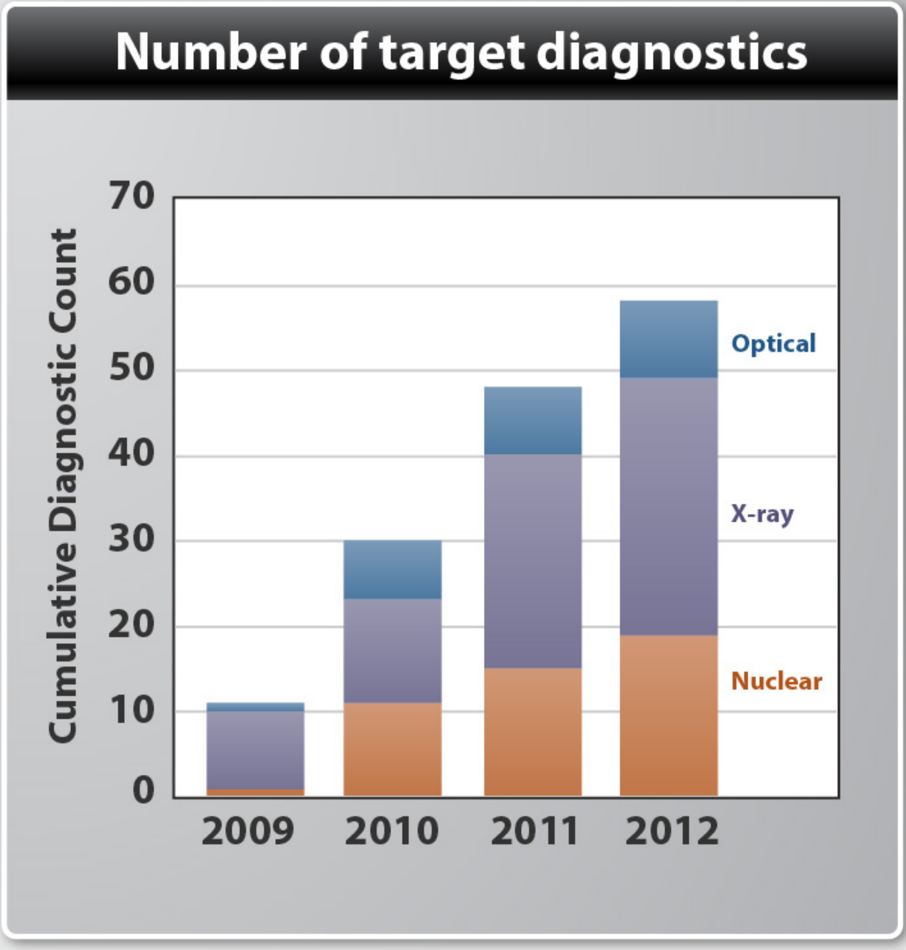
Inside the target chamber


...in the target chamber

50 target diagnostics enable cutting edge science on the NIF

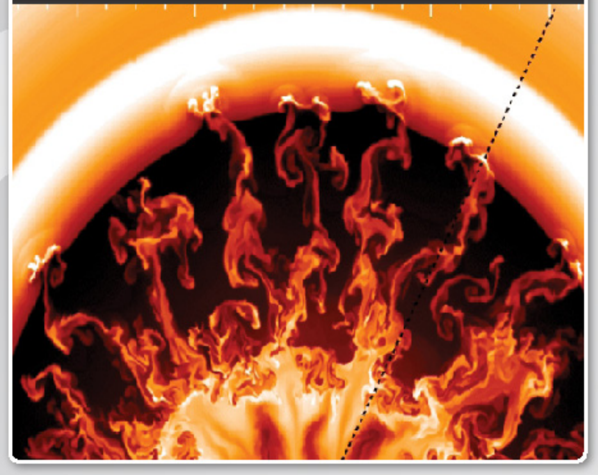


- LLNL
- LANL
- LLE
- NSTec
- U of M
- LBNL
- AWE
- MIT
- CEA
- Duke
- SNL
- GSI



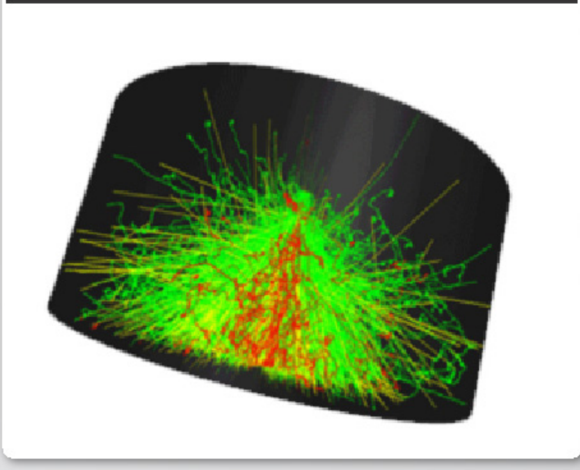
NIF and its evolving capabilities will address compelling scientific questions

How do supernovae explode?

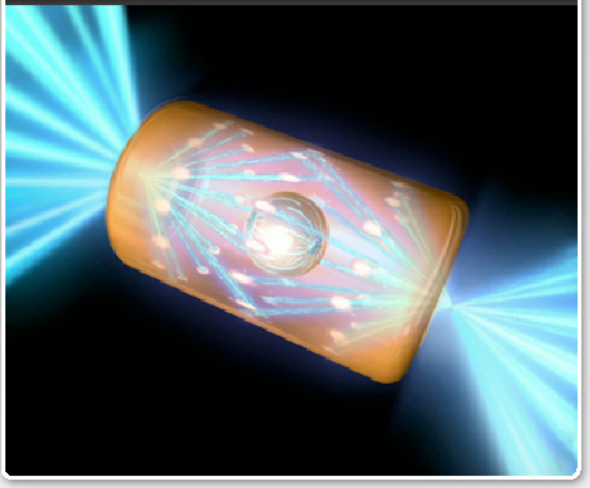


How do dust-filled nebulae (stellar nurseries) evolve?

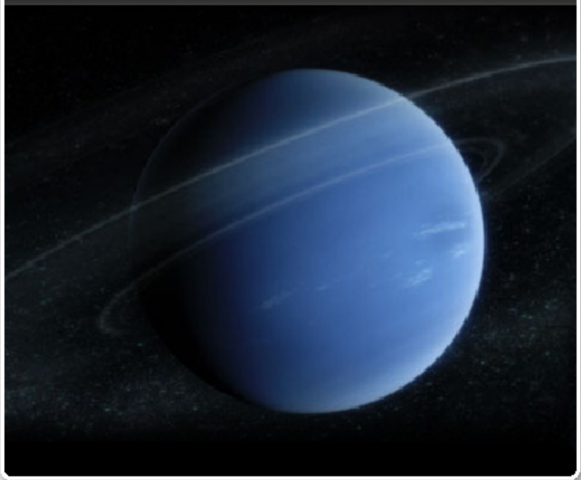
How do gamma-ray bursts occur?



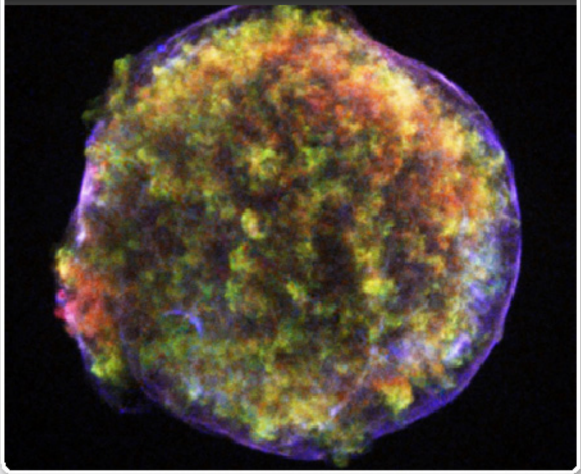
What are the characteristics of burning plasmas?



Do giant planets contain "oceans of diamonds"?



What is the source of the highest-energy cosmic rays?



National Ignition Campaign

NNSA
National Nuclear Security Administration

GENERAL ATOMICS

UR LLE

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

MIT

AWE

cea

NSTec

BERKELEY LAB

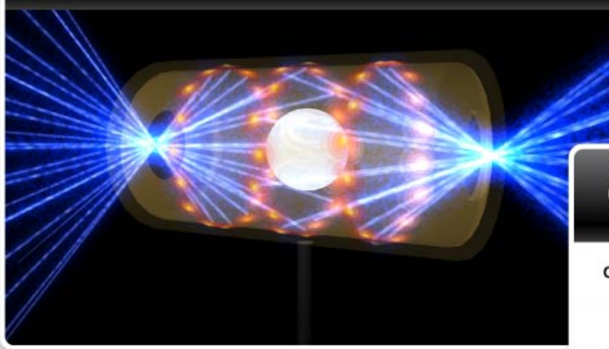
Duke UNIVERSITY

Four steps to ignition

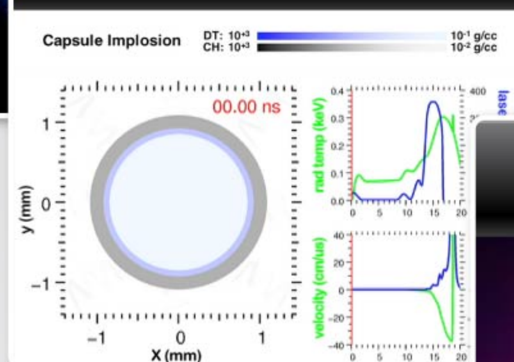
We are taking a systematic approach to learning and improving our engineering design to achieve ignition

Commission laser

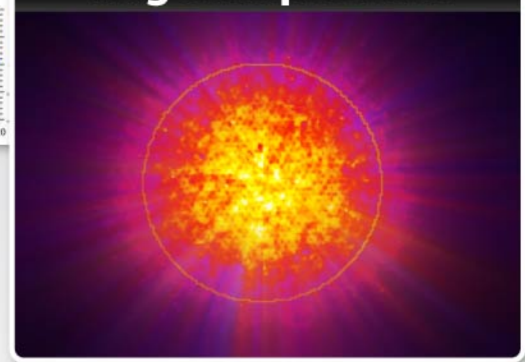
Commission hohlraum



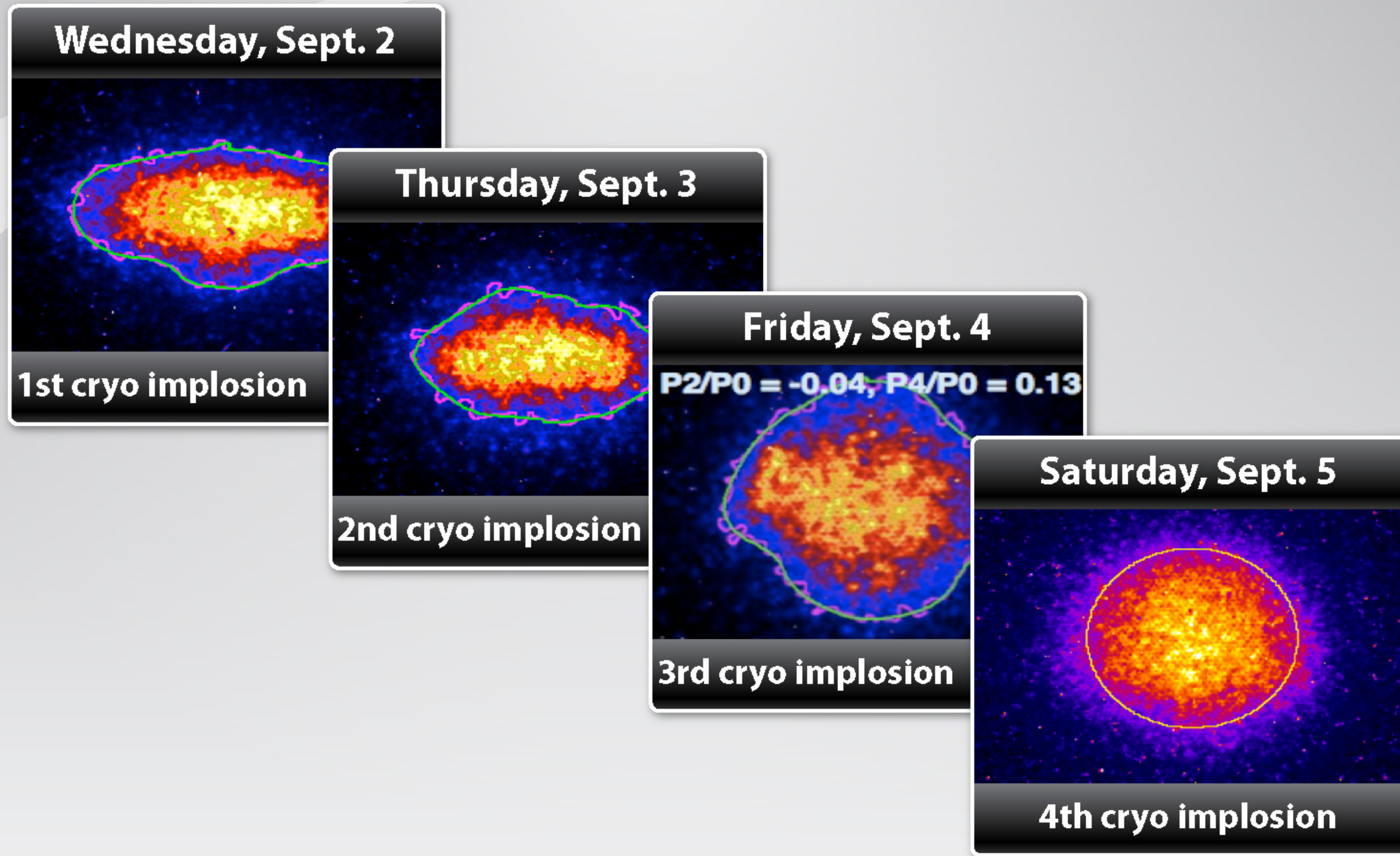
Commission capsule



Commission layered target implosions



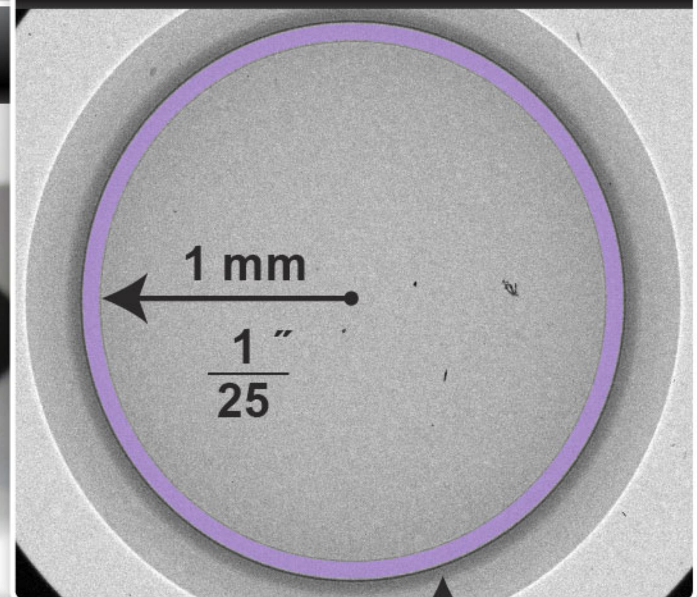
On September 2, 2009 NIF conducted first hohlraum experiments



On May 4, 2011 NIC conducted the first cryo-layered DT target experiment on NIF

Target ready to be cooled

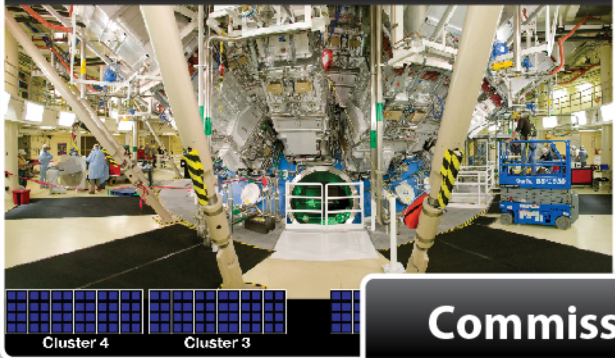
Frozen DT layer



"Cryo DT ice layer" at ~19 deg K

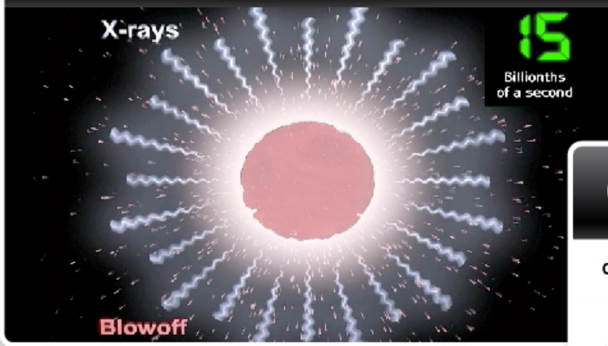
Highlights of progress towards ignition

Build a laser



1.855 MJ
523 TW
300:1 contrast

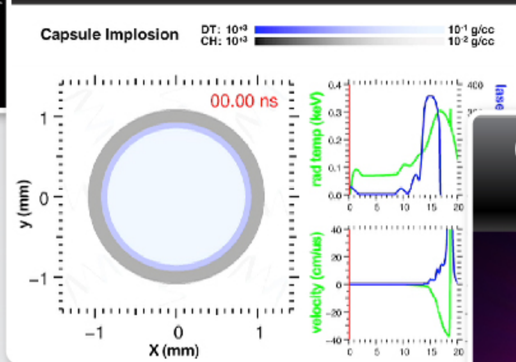
Commission hohlraum



330 eV
~85% absorbed energy

Convergence ratio ~35,
ρR ~1.3 gm/cm^2 (85% of requirement)
$V_{implosion}$ ~350 km/sec

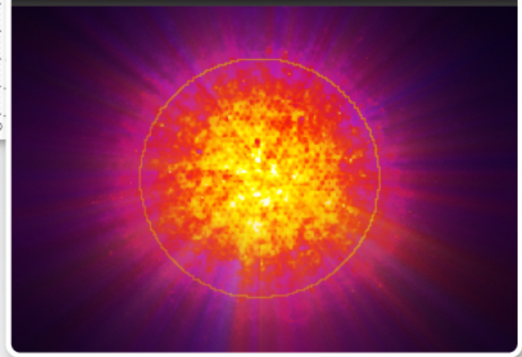
Commission capsule



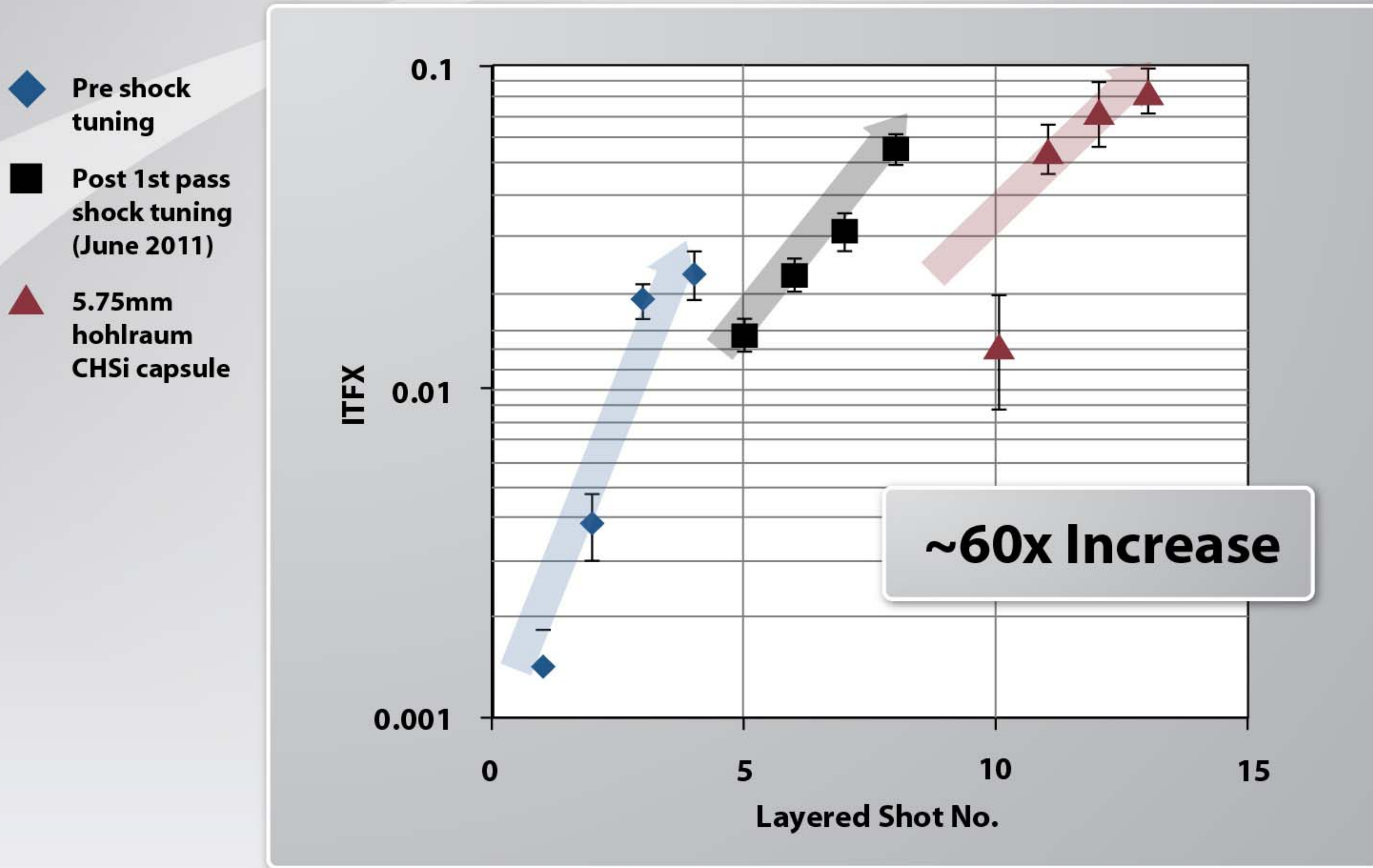
Pressure ~150 GBar

Y~9e14

Commission layered target implosions



We are now within a factor of 2 to 3 of the required fuel pressures (350 billion atmospheres!)

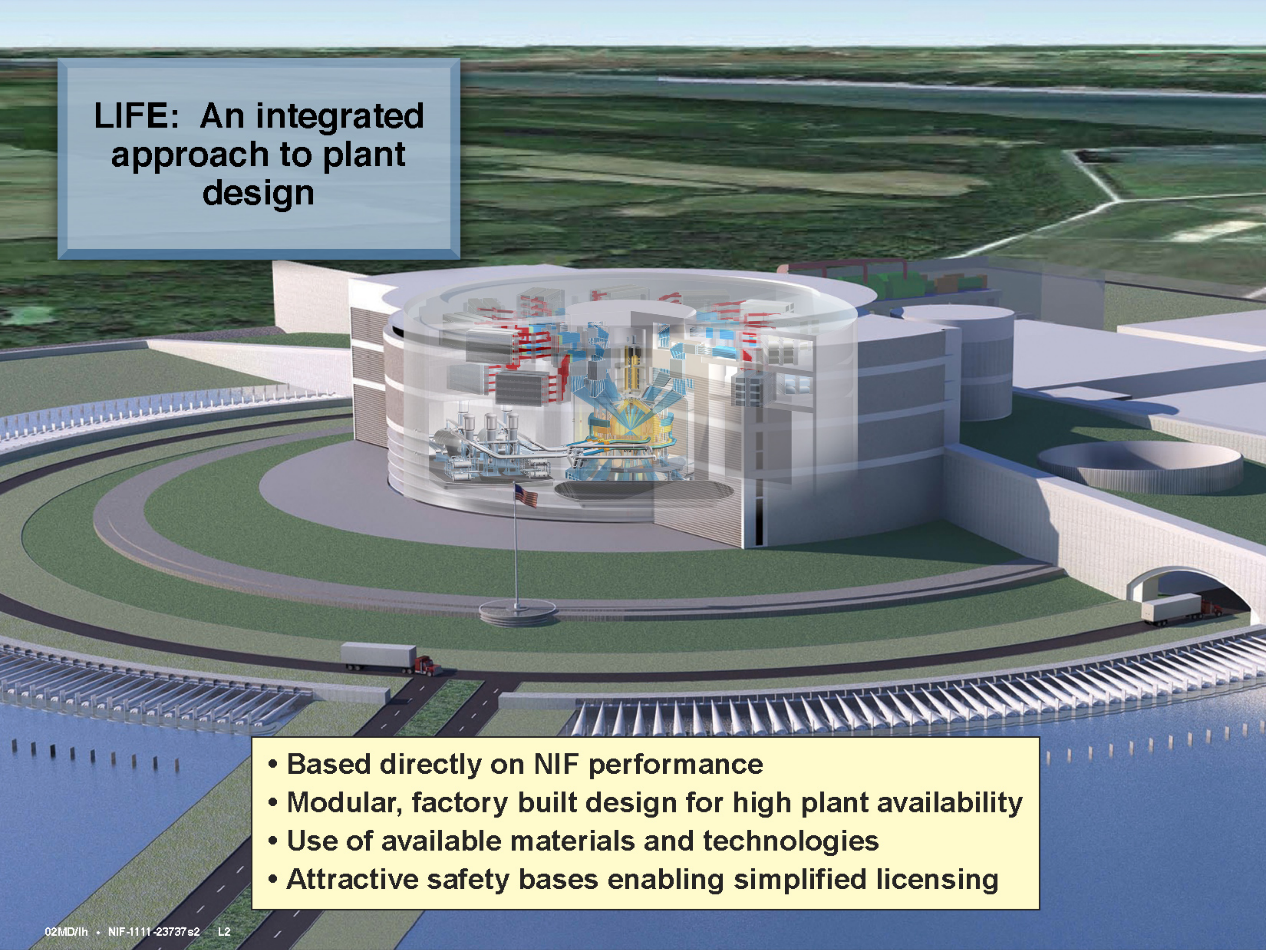


NIF can demonstrate full-scale performance for a power plant based on Laser Inertial Fusion Energy (LIFE)

LIFE: A sustainable, carbon-free source of safe baseload electricity

- Security of supply (reducing our reliance on foreign oil imports)
- No enrichment, no reprocessing, and no high-level radioactive waste
- Global commercial competitiveness from a U.S.-led solution
- Compatibility with existing grid infrastructure

LIFE: An integrated approach to plant design



- Based directly on NIF performance
- Modular, factory built design for high plant availability
- Use of available materials and technologies
- Attractive safety bases enabling simplified licensing

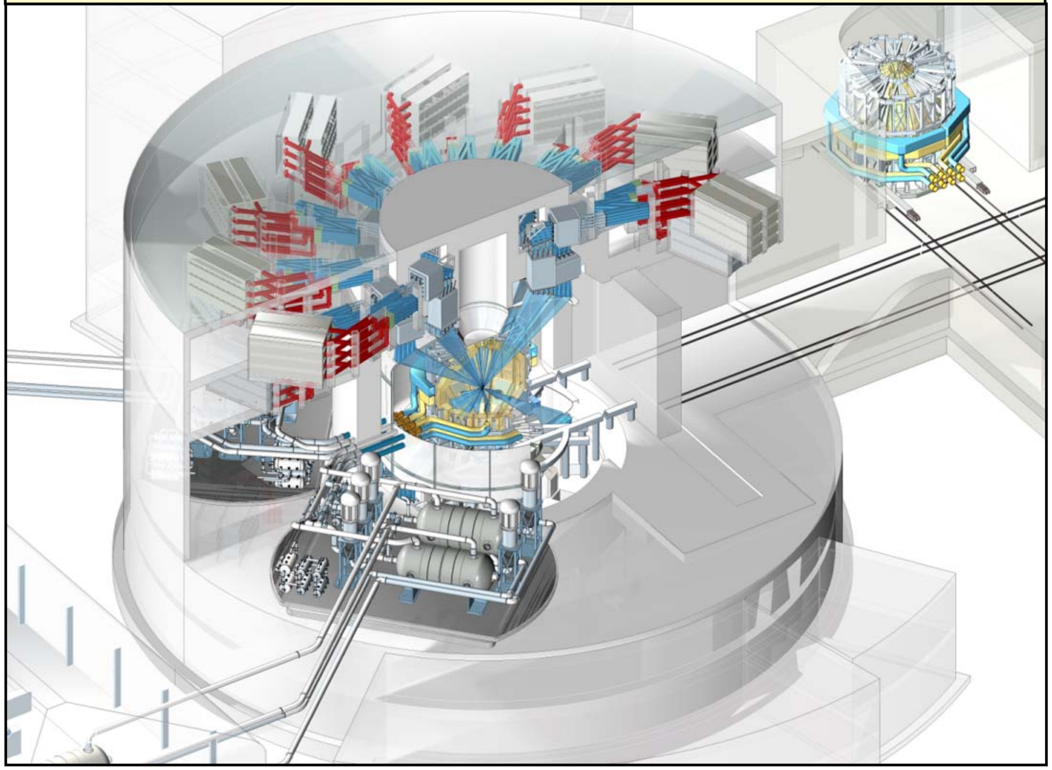
Consultation with the end-users is our starting point

- **Charles "Chip" Pardee (Chairman) —SVP and COO, Exelon Generation**
- **William Fehrman (Vice-Chair)—President and CEO, MidAmerica Energy Company**
- **David Christian—CEO, Dominion Generation; President, Virginia Power**
- **Brian Debs (Member in residence)—former SVP, Ontario Power Generation Corp.**
- **John Herron—President and CEO, Entergy Operations**
- **Steve Kuczynski—President and CEO, Southern Nuclear Operating Company**
- **Michael Sellman—CEO, Nuclear Management Company (Retired)**
- **Joseph Callan—Former Executive Director, U.S. Nuclear Regulatory Commission**

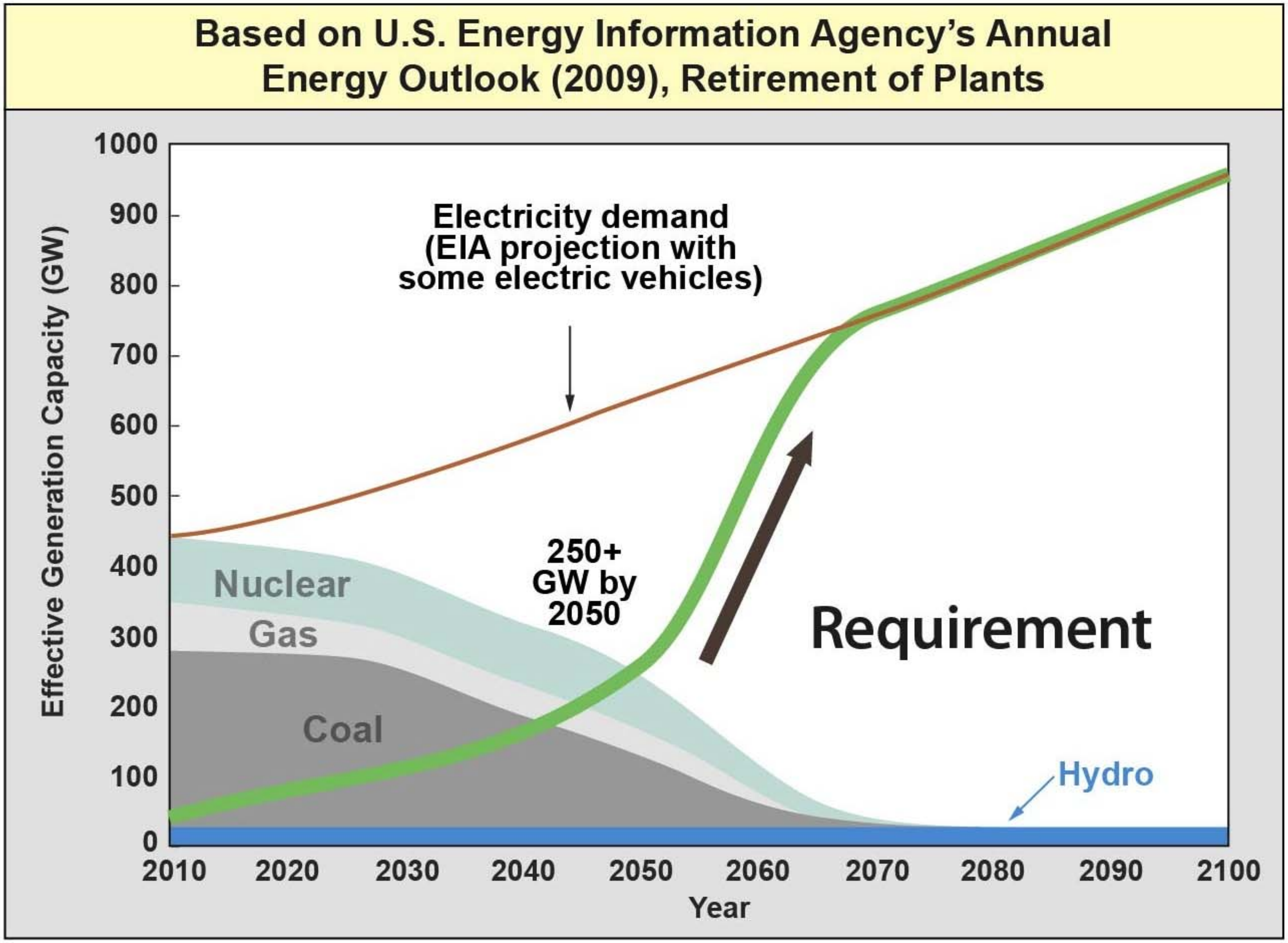
End-user requirements for operations & licensing

- Grid compatibility
- Plant availability
- Economically competitive
- Sustainable (e.g. water use)
- Conventional M&O regime
- Simple regulatory path
- Timely

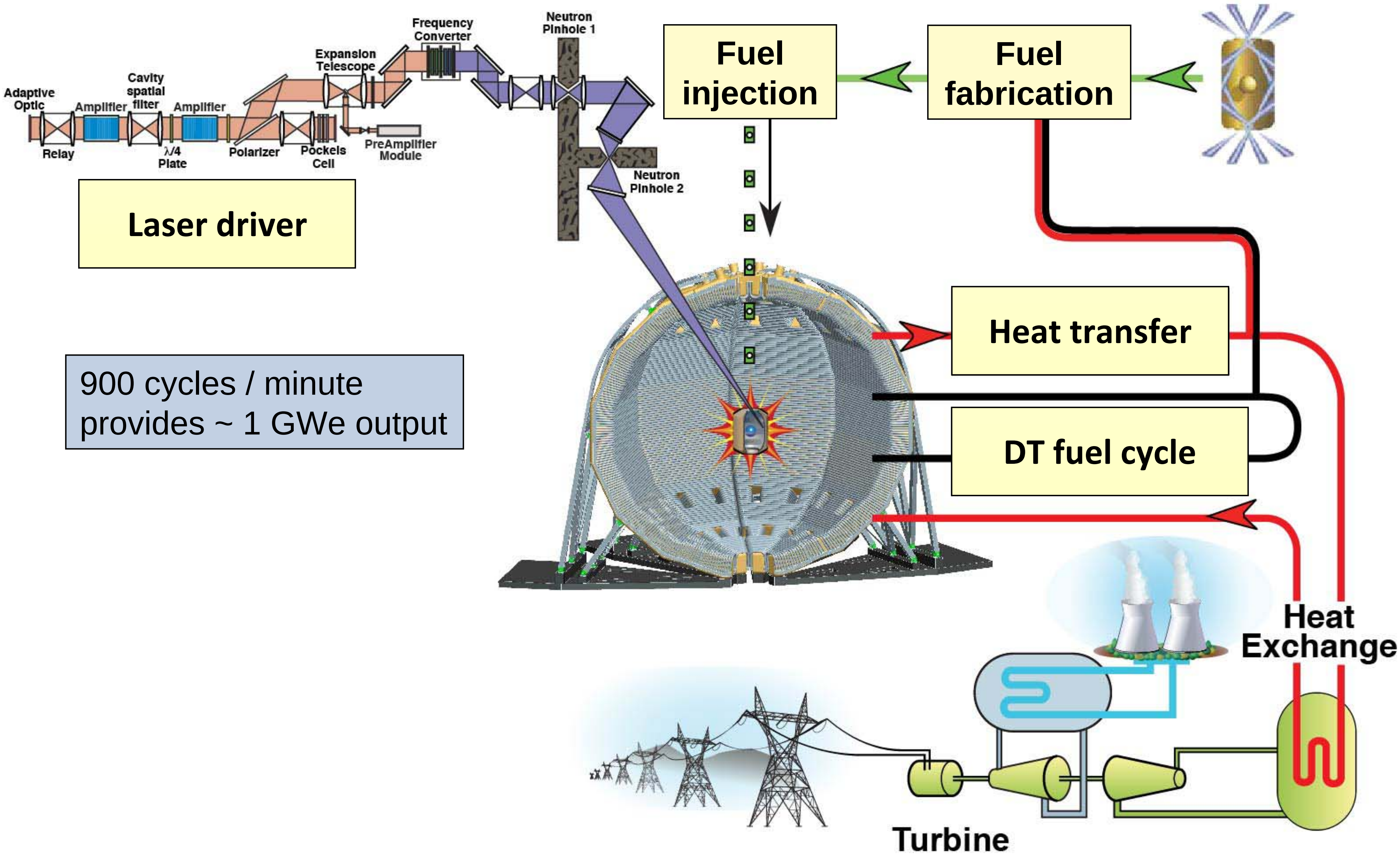
- Focus on pure fusion, utility-scale, power producing plant
- Use of commercial materials, technologies and delivery mechanisms



How we meet the energy challenge has profound implications for our economy and security

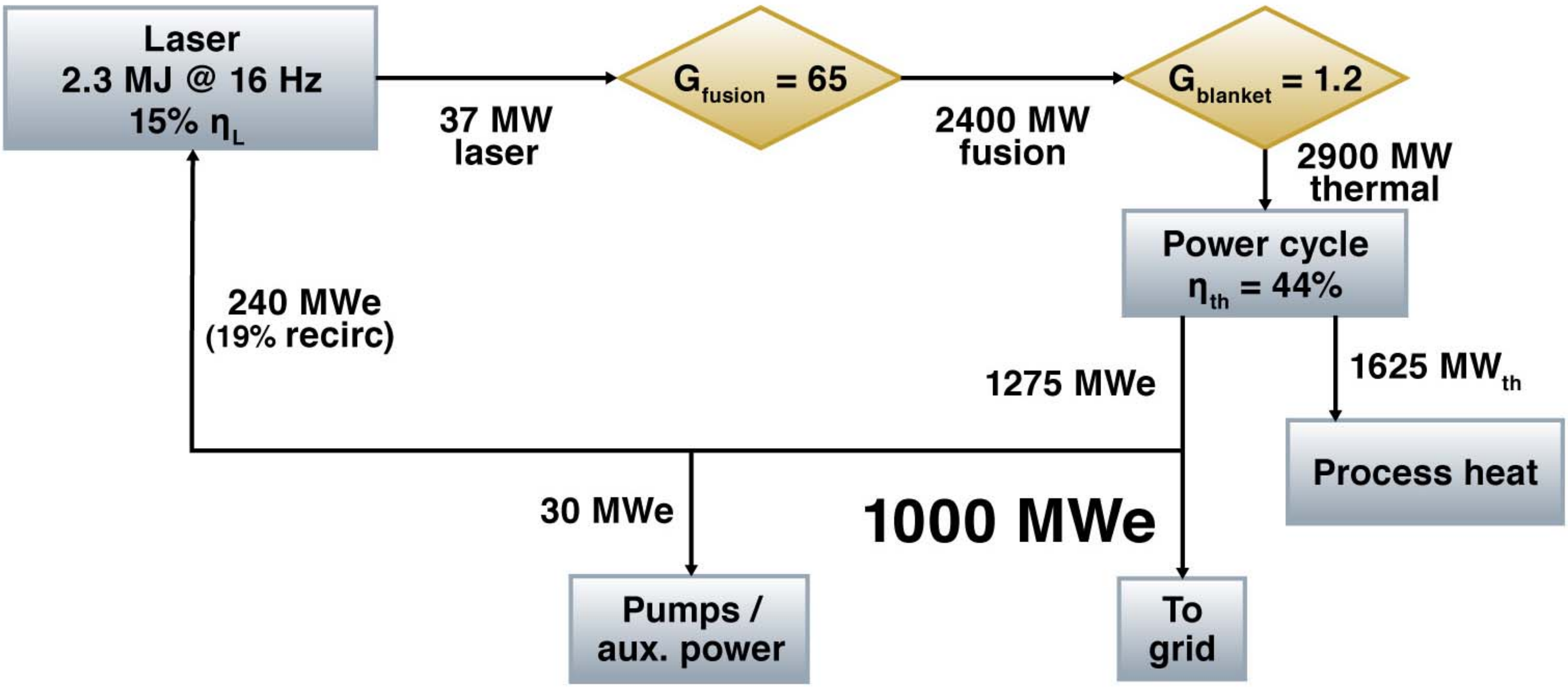


Principle of LIFE plant operation

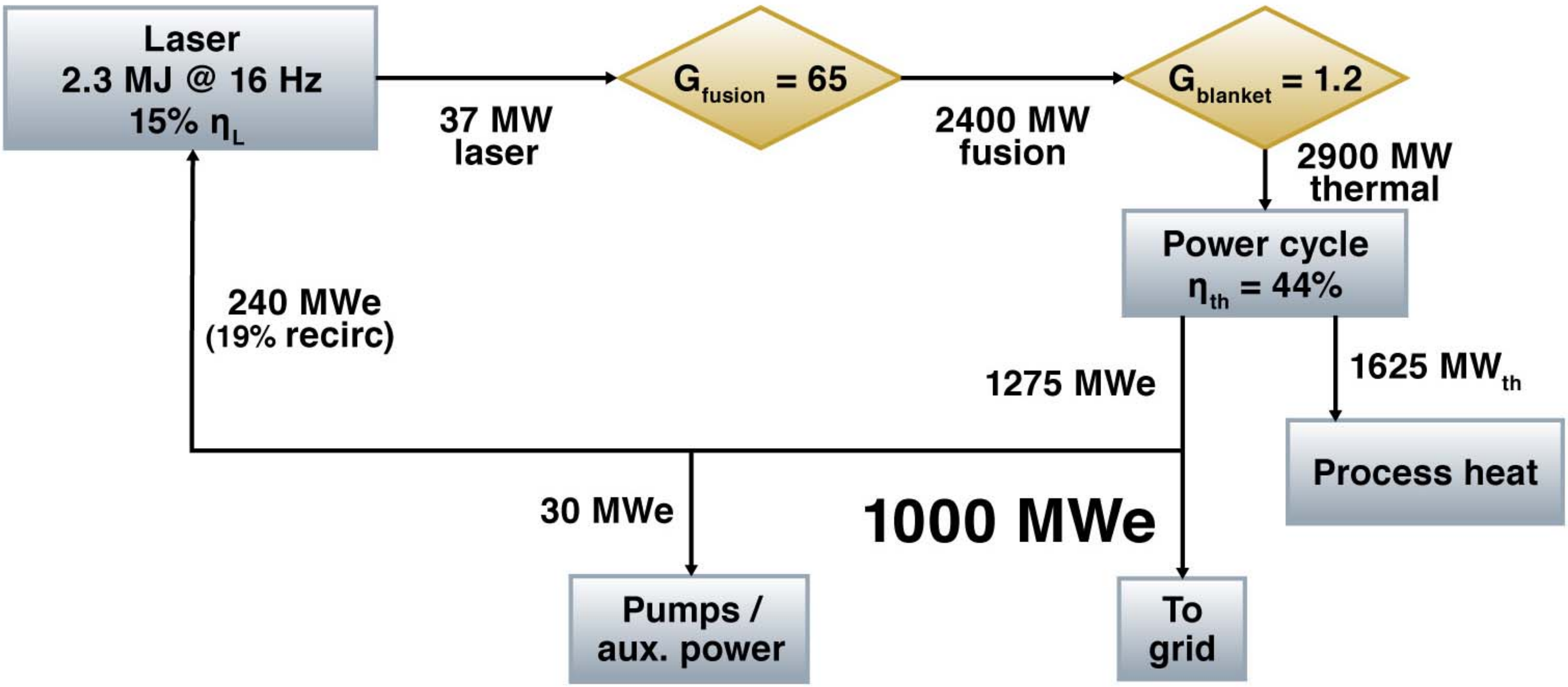


900 cycles / minute
provides ~ 1 GWe output

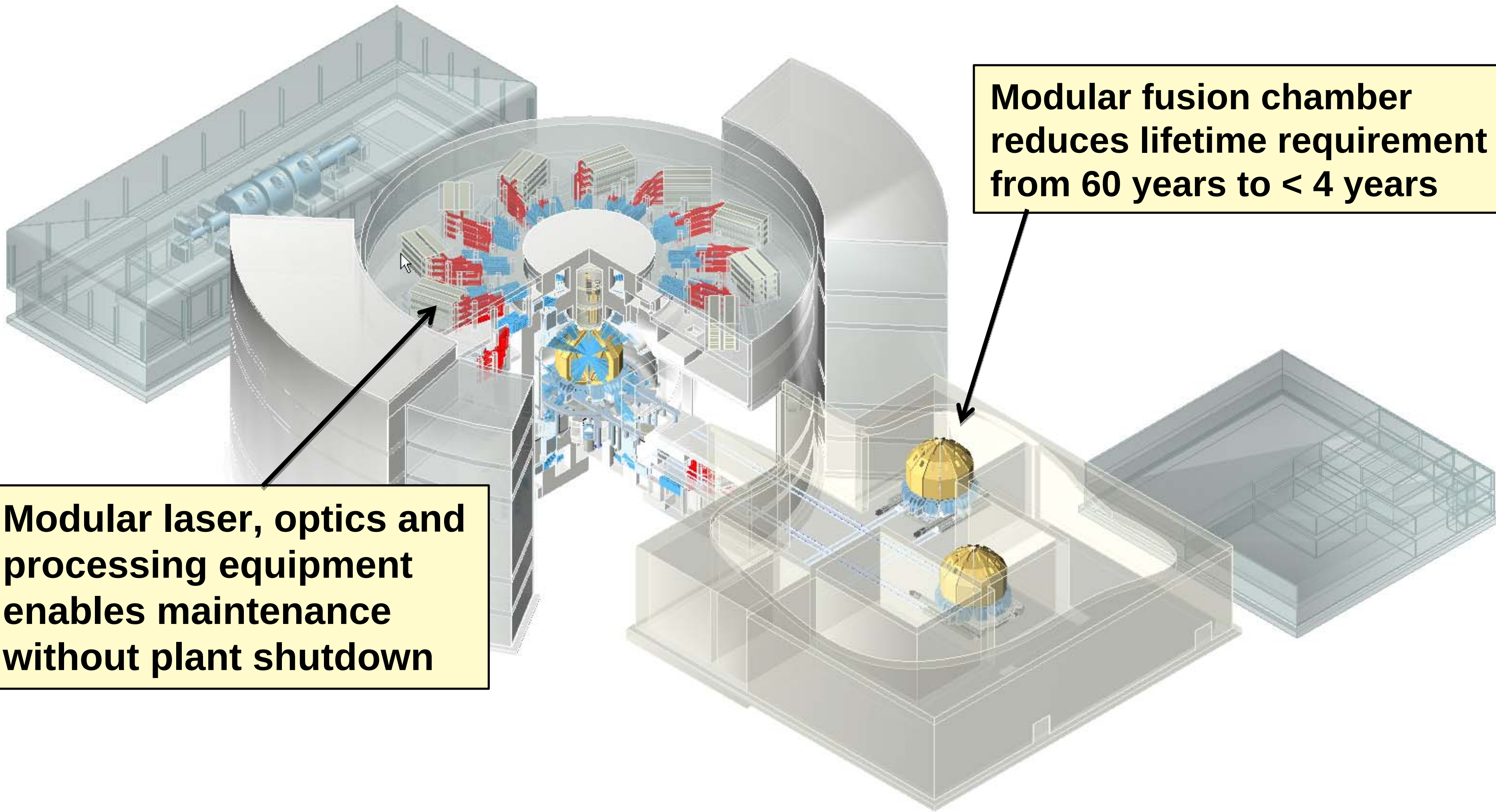
LIFE Power Balance (example)



LIFE Power Balance (example)



NIF performance, and LIFE's modular architecture is what enables commercialization in a relevant timeframe



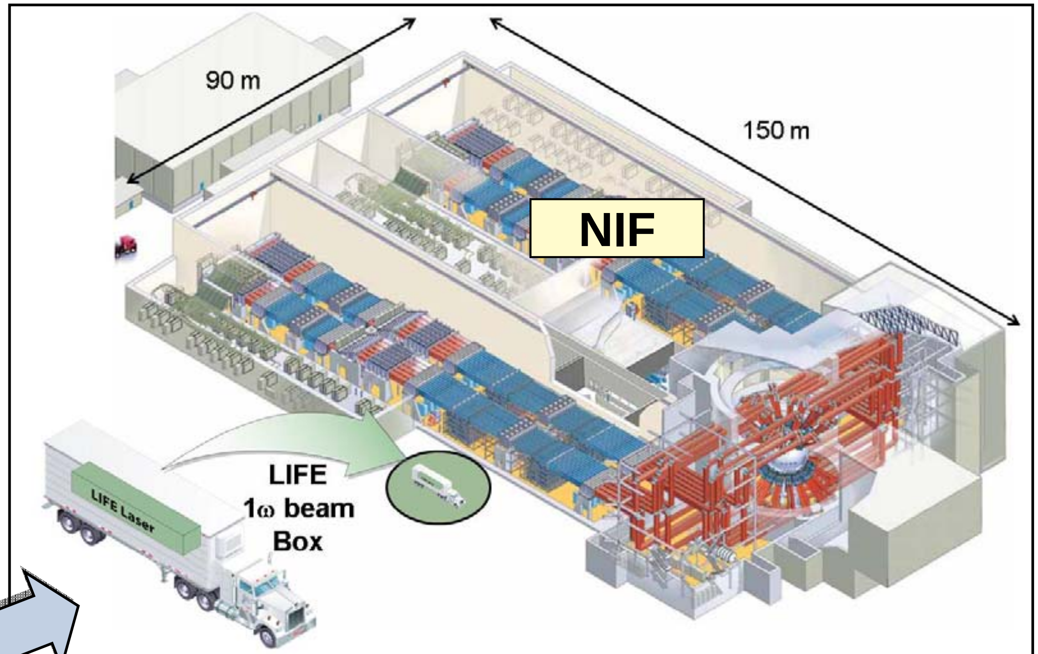
Modular fusion chamber reduces lifetime requirement from 60 years to < 4 years

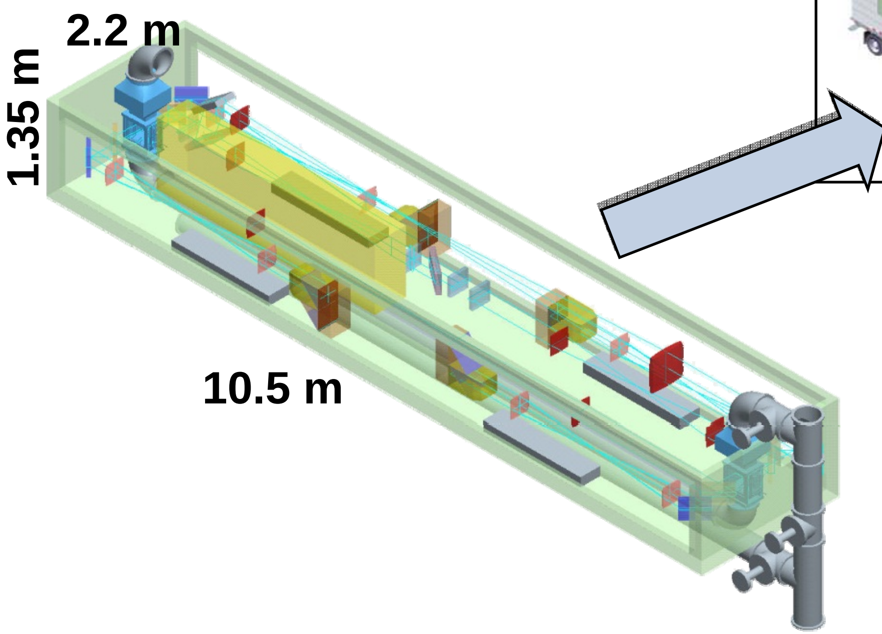
Modular laser, optics and processing equipment enables maintenance without plant shutdown

Fusion chamber can use conventional steel rather than wait for new radiation-resistant alloys to be developed

A LIFE beamline folds into a transportable box, enabling an efficient & cost-effective supply chain

Ability to “hot swap” beamlines during plant operations.

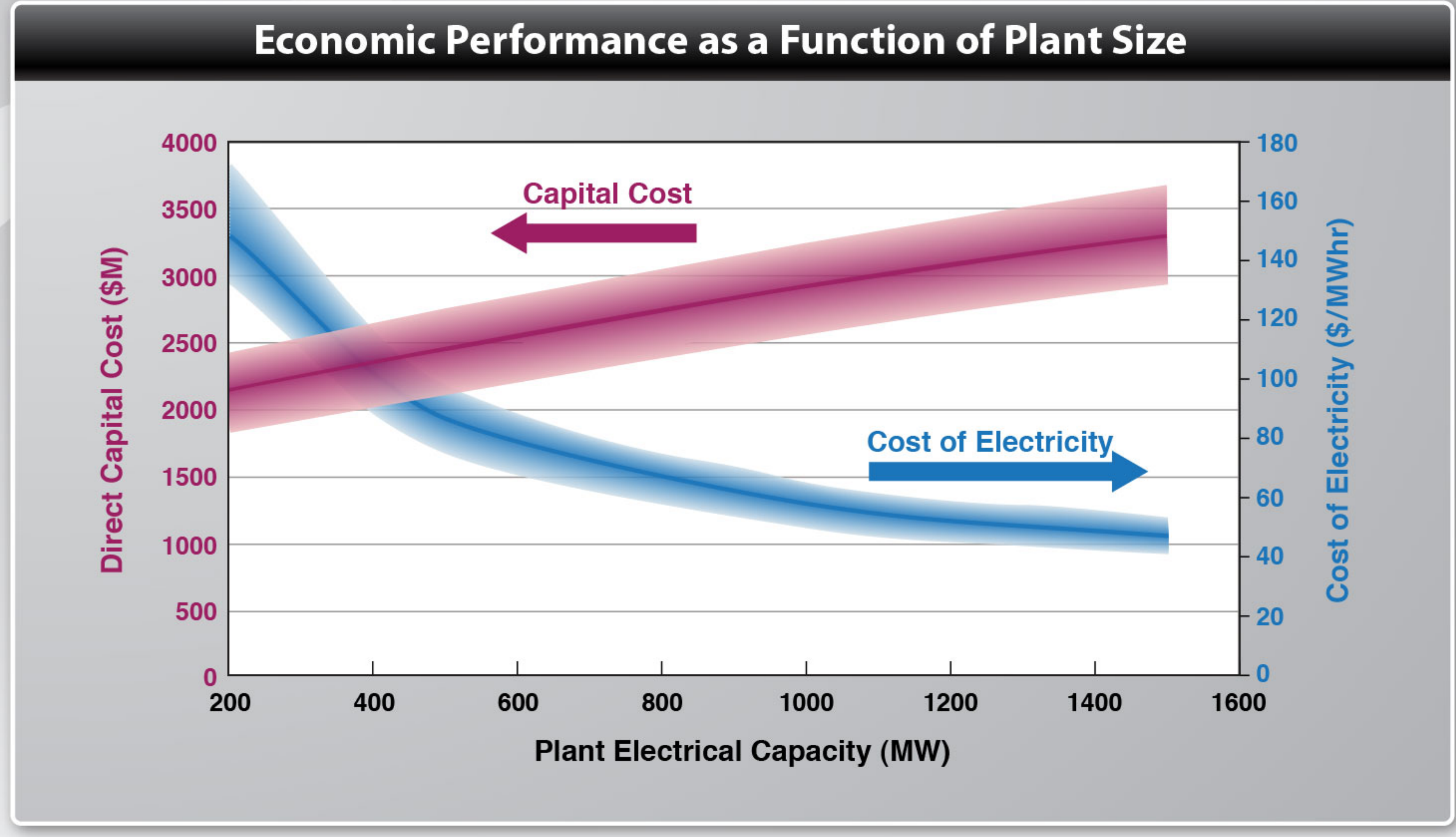




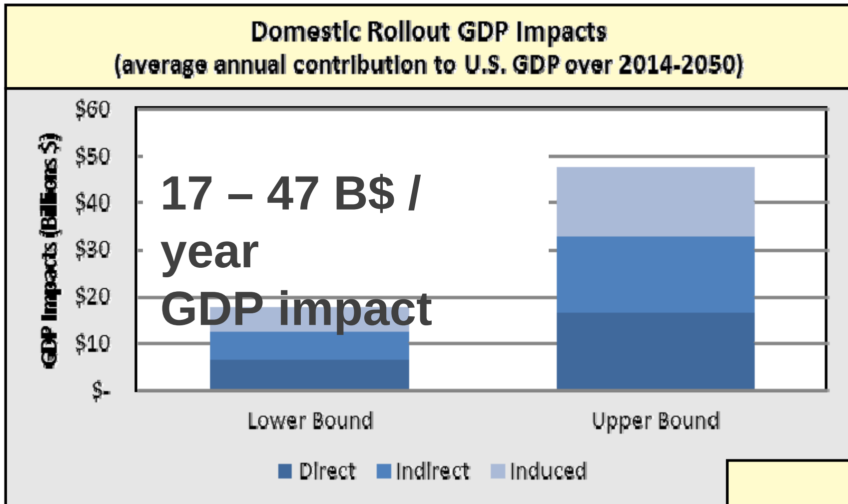
- **Offsite beamline factory**
- **Truck-shippable 1ω beamline**
- **Low-overhead installation**
  - **Kinematic placement**
  - **Few interfaces**

LIFE box in NIF laser bay

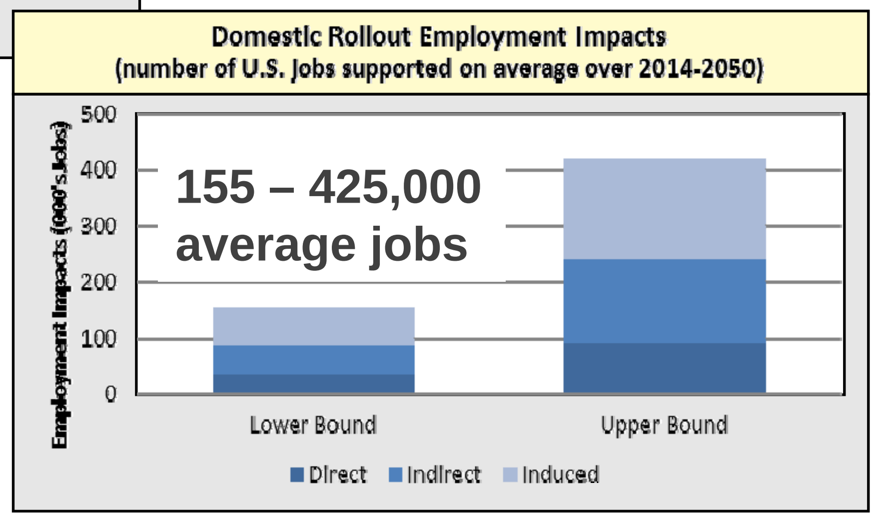
LIFE is economically viable over a range of plant sizes



Oxford Economics have calculated the potential impact of domestic rollout on GDP and new jobs



- 4 to 12 B$ annual federal and state tax revenue
- Substantial jobs impact in the high-tech sector



Similar industrial scale to:

- Aircraft manufacturing (230,000)
- Machine shops (246,000)
- Semiconductor manufacturing (182,000)

Low / High scenarios are for 10 or 5 year doubling times

We have been consulting with a range of environmental groups on the sustainability of LIFE

Compact land use

Minimal water use

Abundant, distributed fuel

CO_2 free

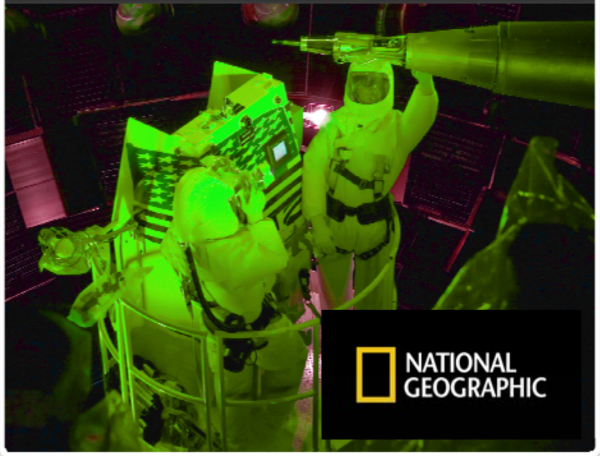
No toxic emissions

Efficient use of power

Recent TV / documentary coverage of NIF and LIFE

BBC with Steven Hawking

National Geographic

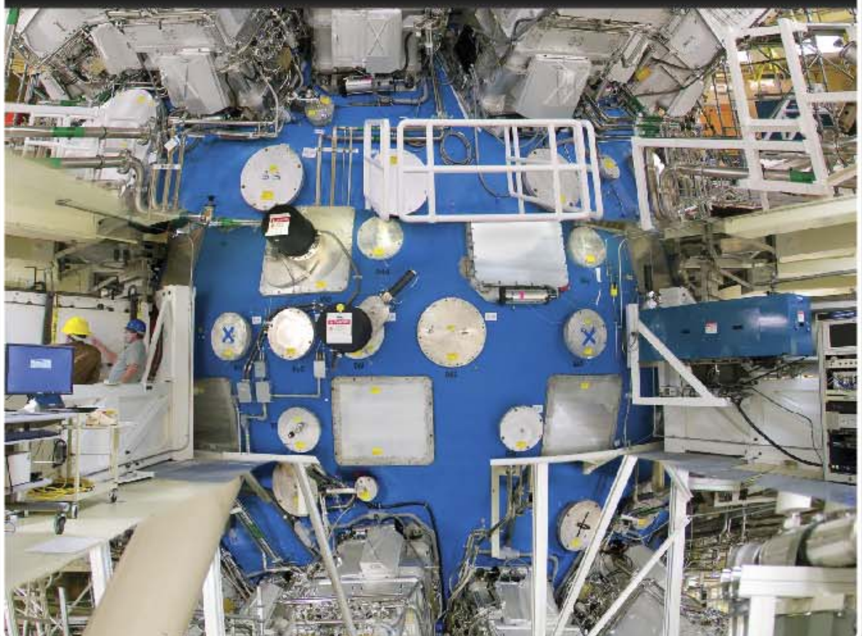


Horizon with Brian Cox

Discovery Channel's NOVA

International activity in this area

USA - NIF Laser



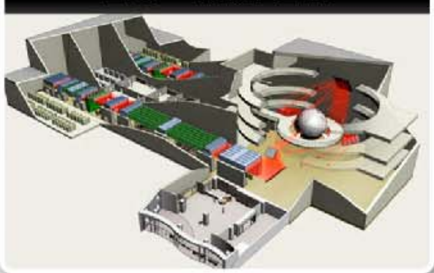
China - SG-III

France - LMJ

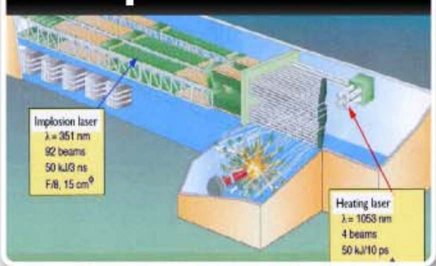
UK - ORION

Russia - ISKRA

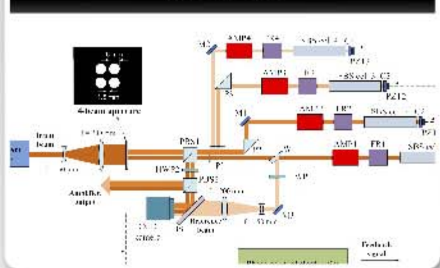
EU - HiPER



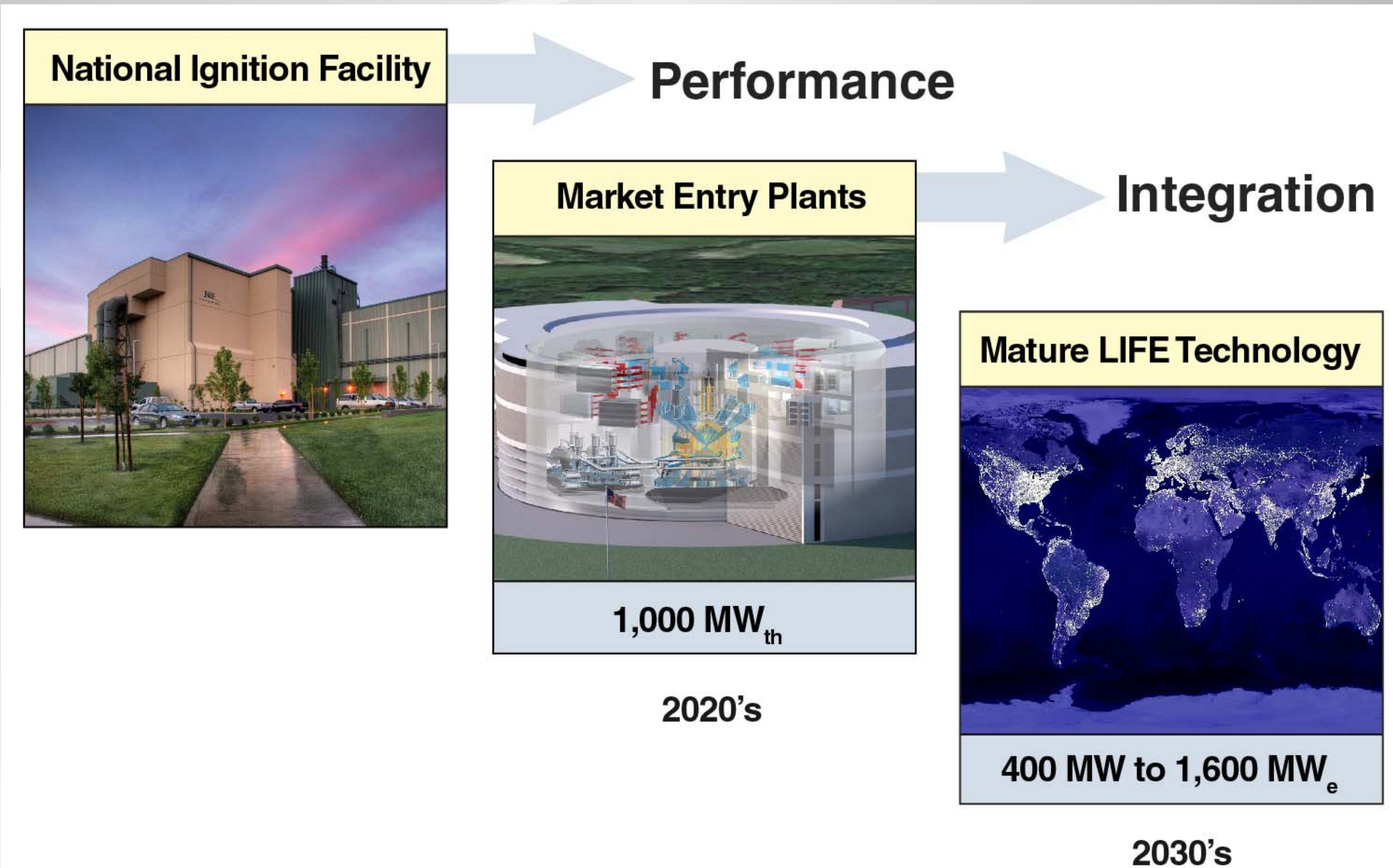
Japan - FIREX



Korea

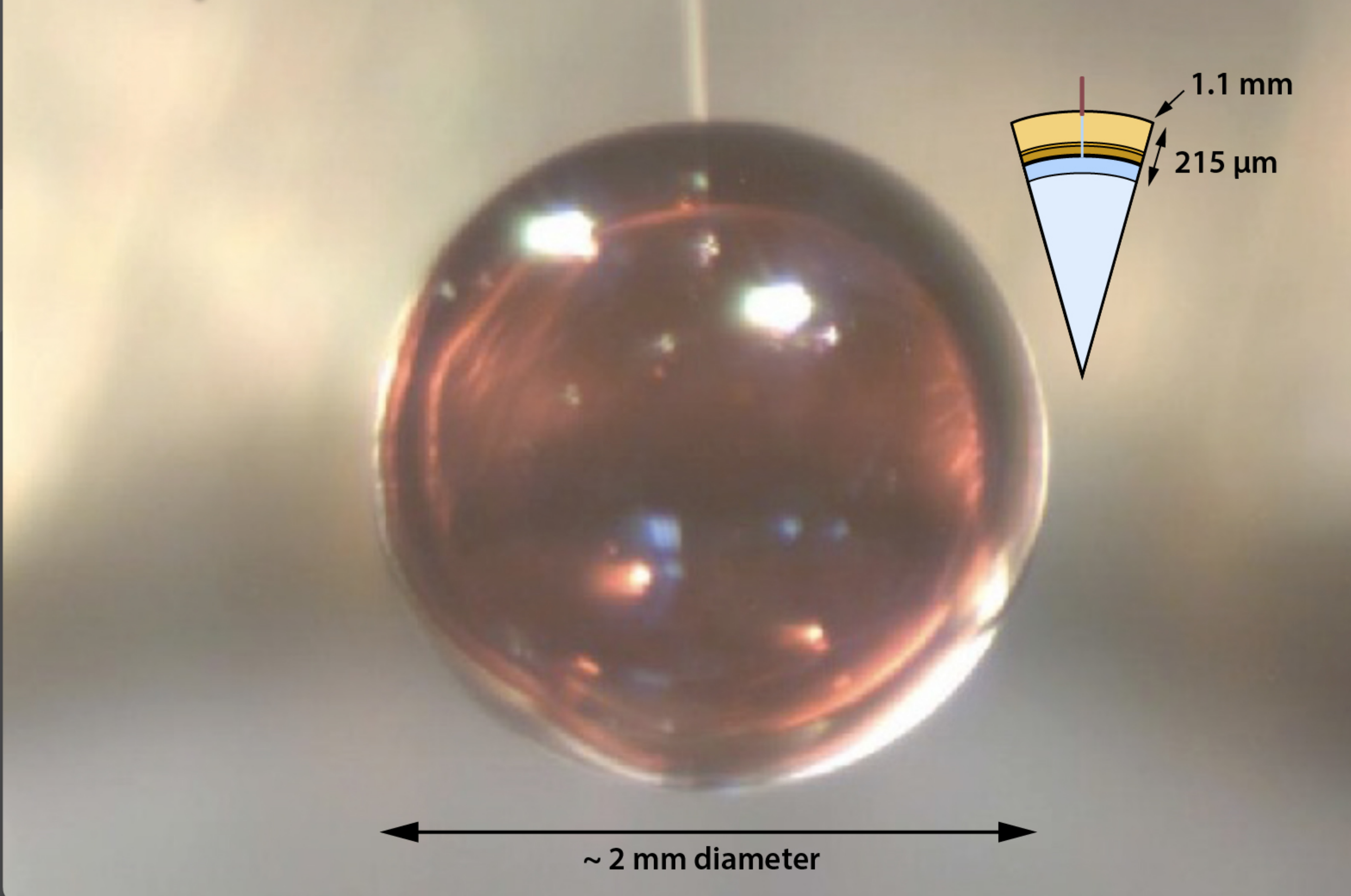


Fusion energy – soon enough to make a difference



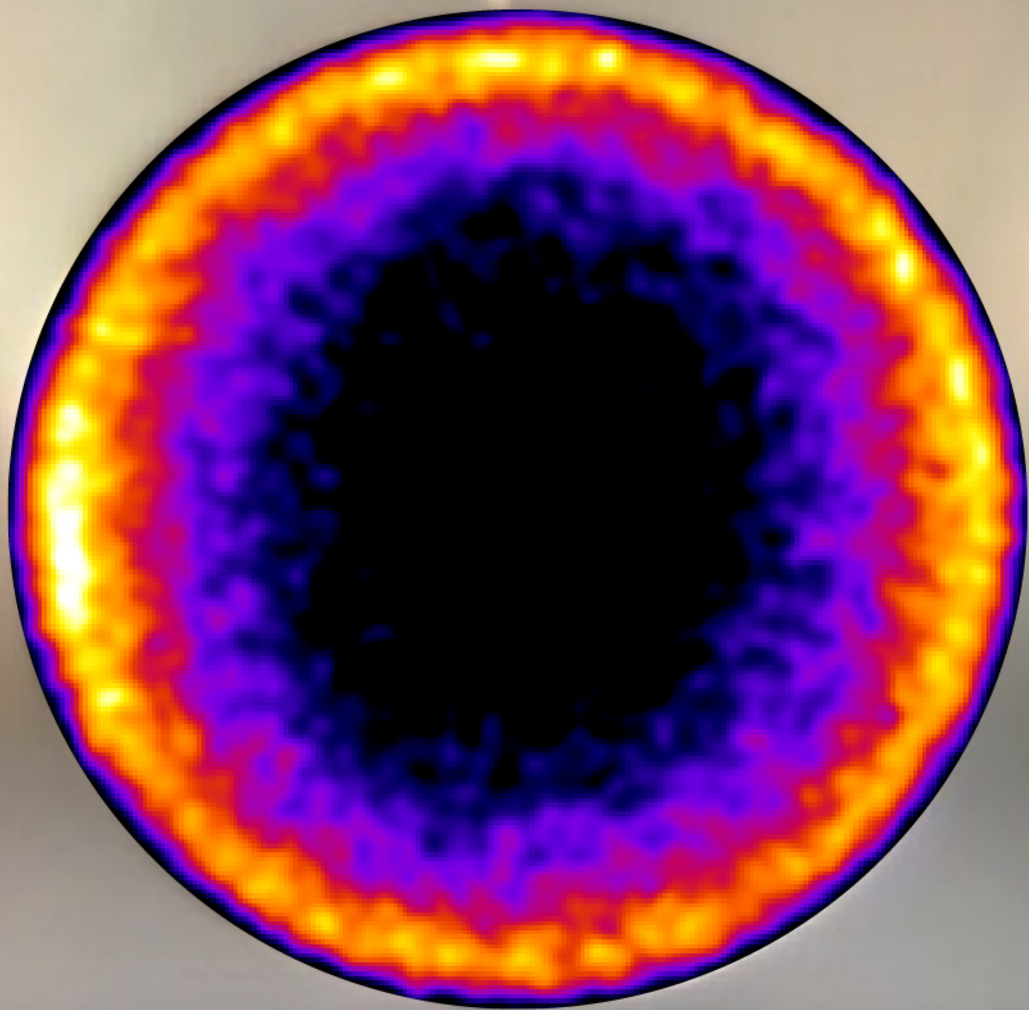
Achieving ignition on NIF can be a defining moment for the world's energy future

The capsule starts at 2mm diameter



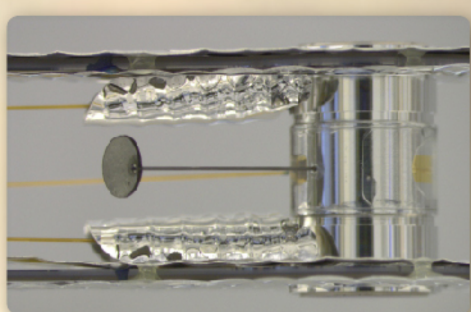
Re-emission sphere measures early time x-drive symmetry

Bang time – 19 ns

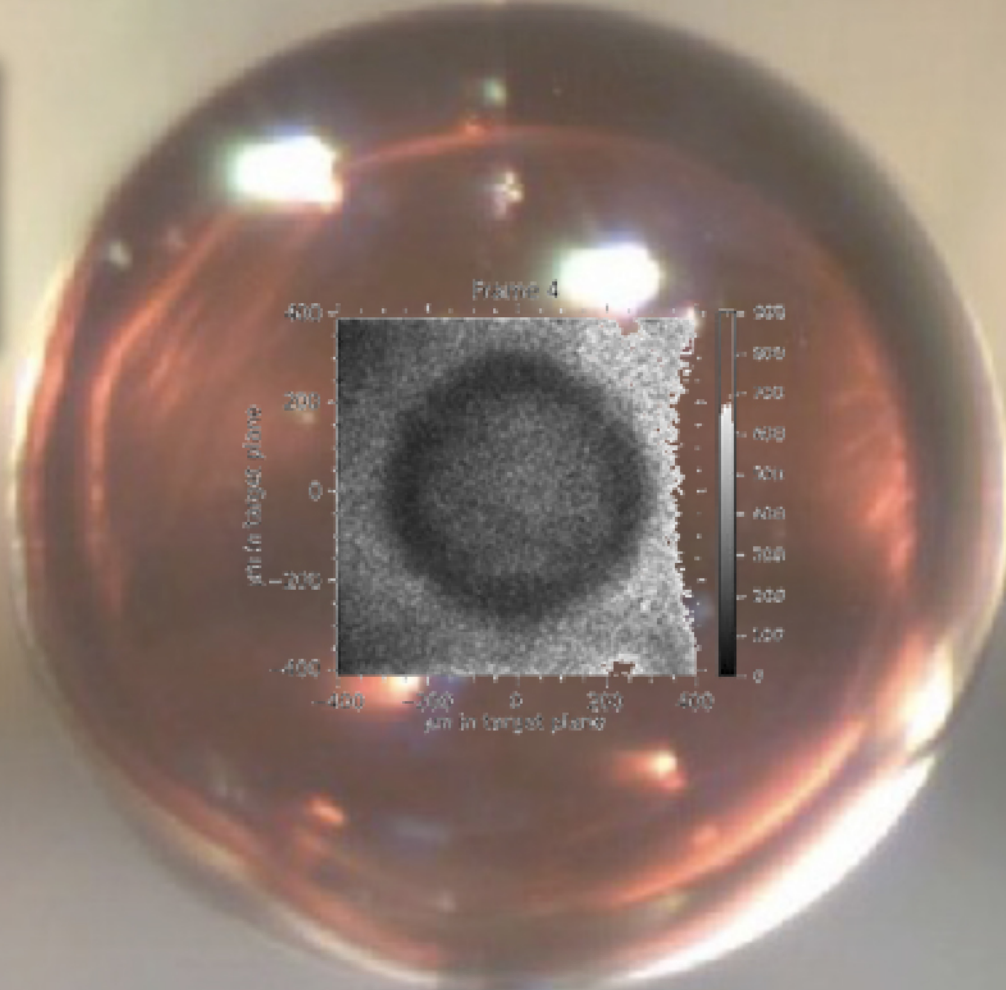


1 billionth of a second into the laser pulse

Radiography measures the shape of the capsule in-flight

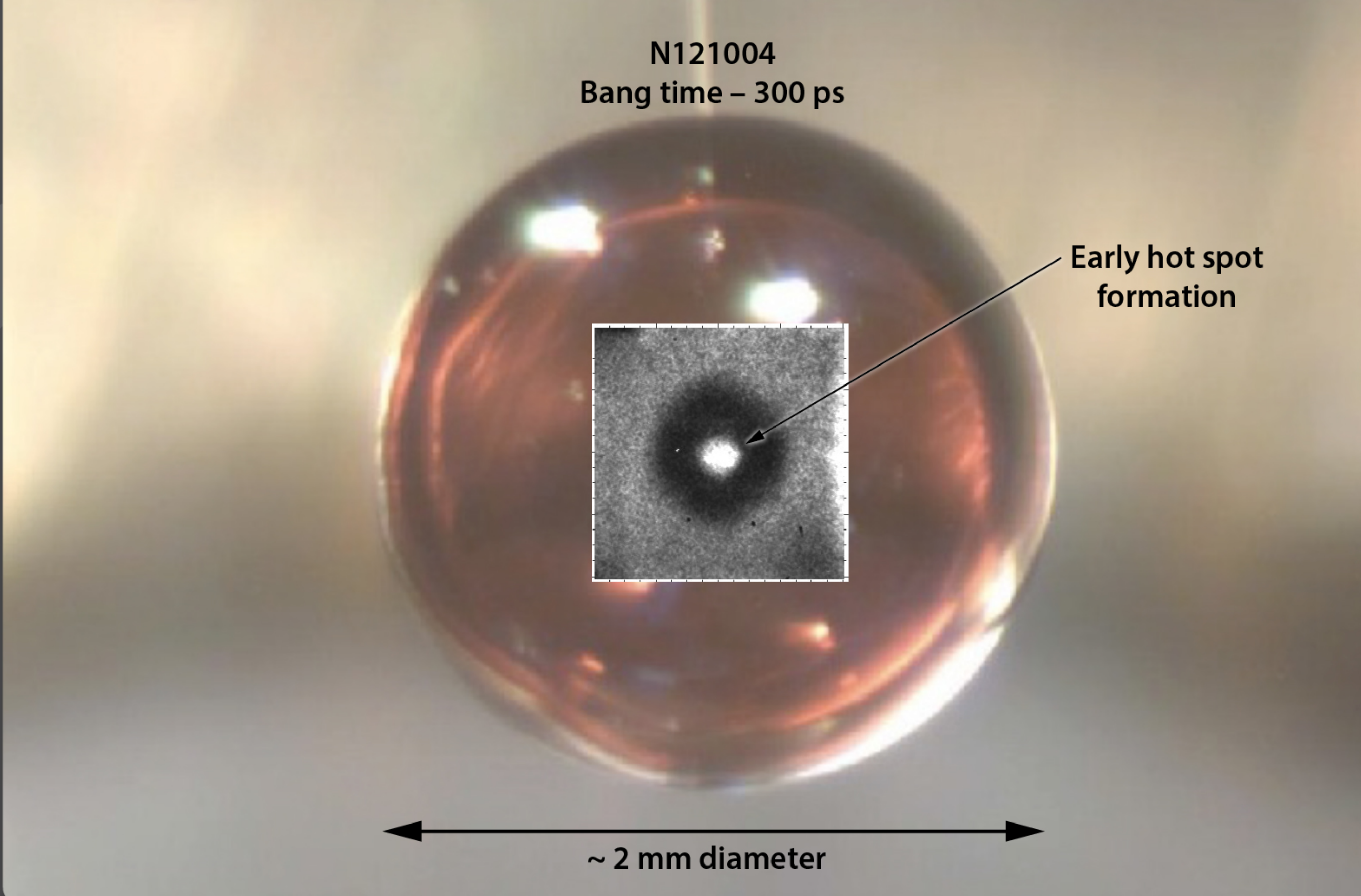


N121004
Bang time – 600 ps

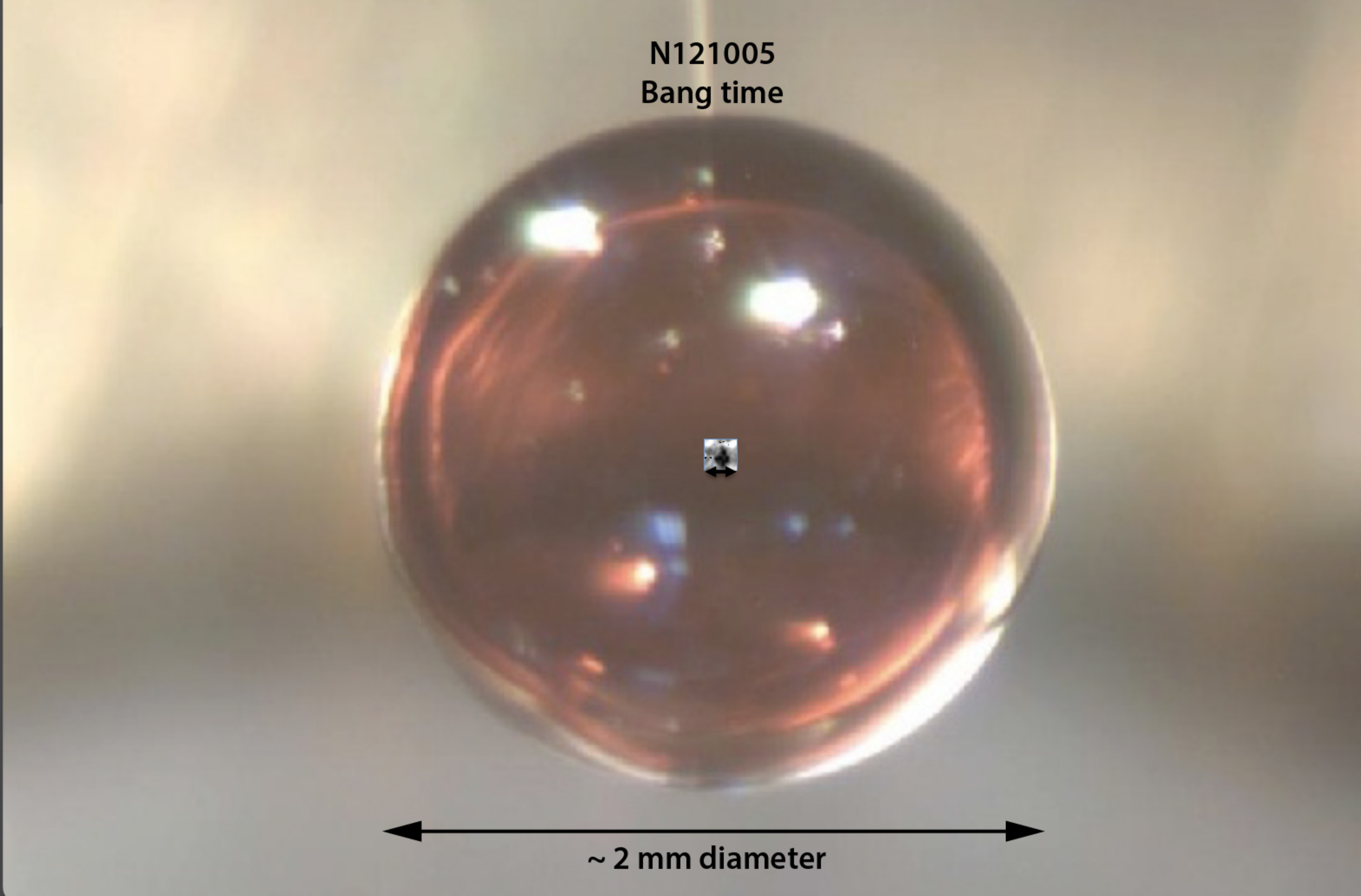


~ 2 mm diameter

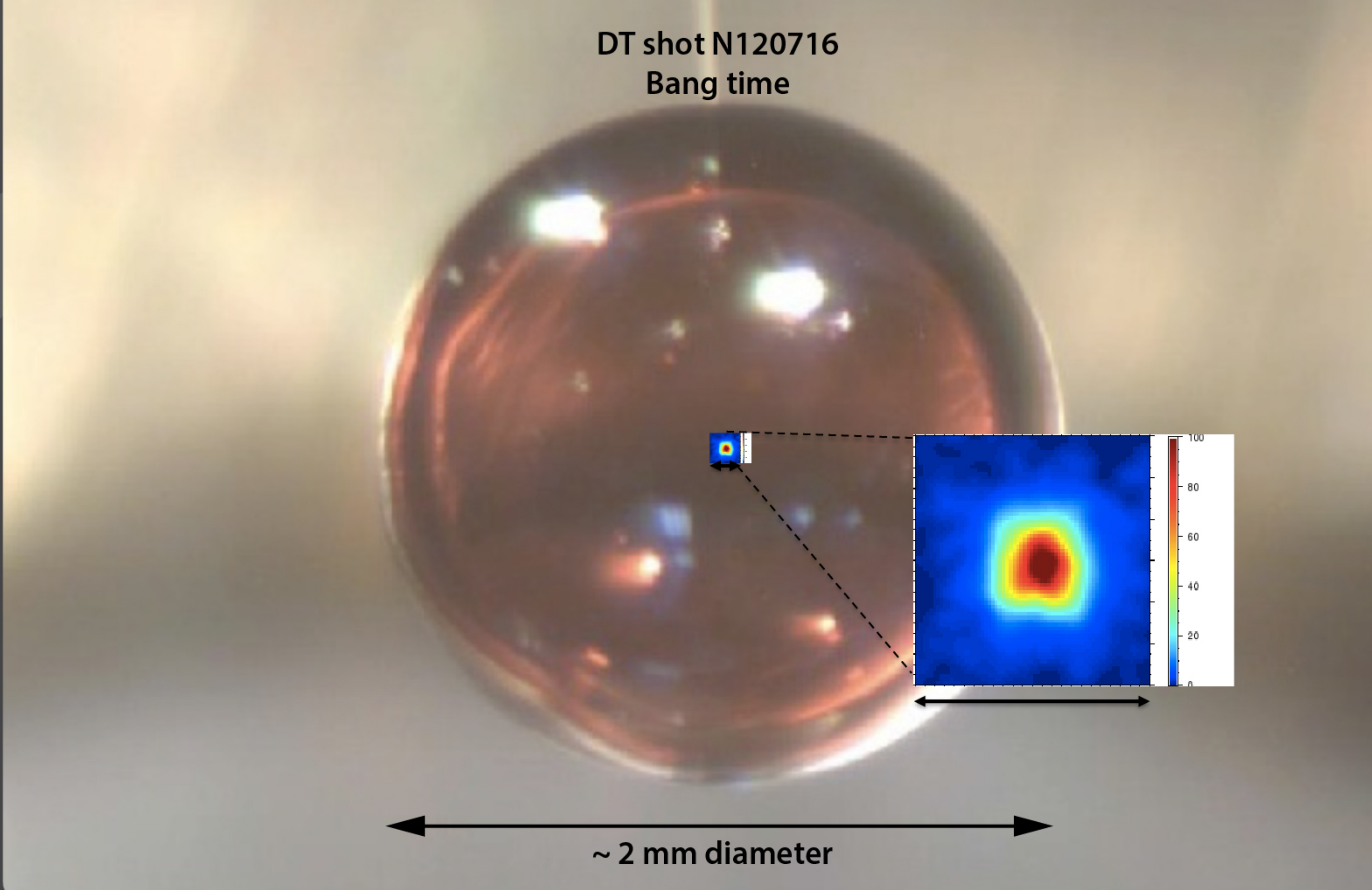
Radiography measures the shape of the capsule in-flight



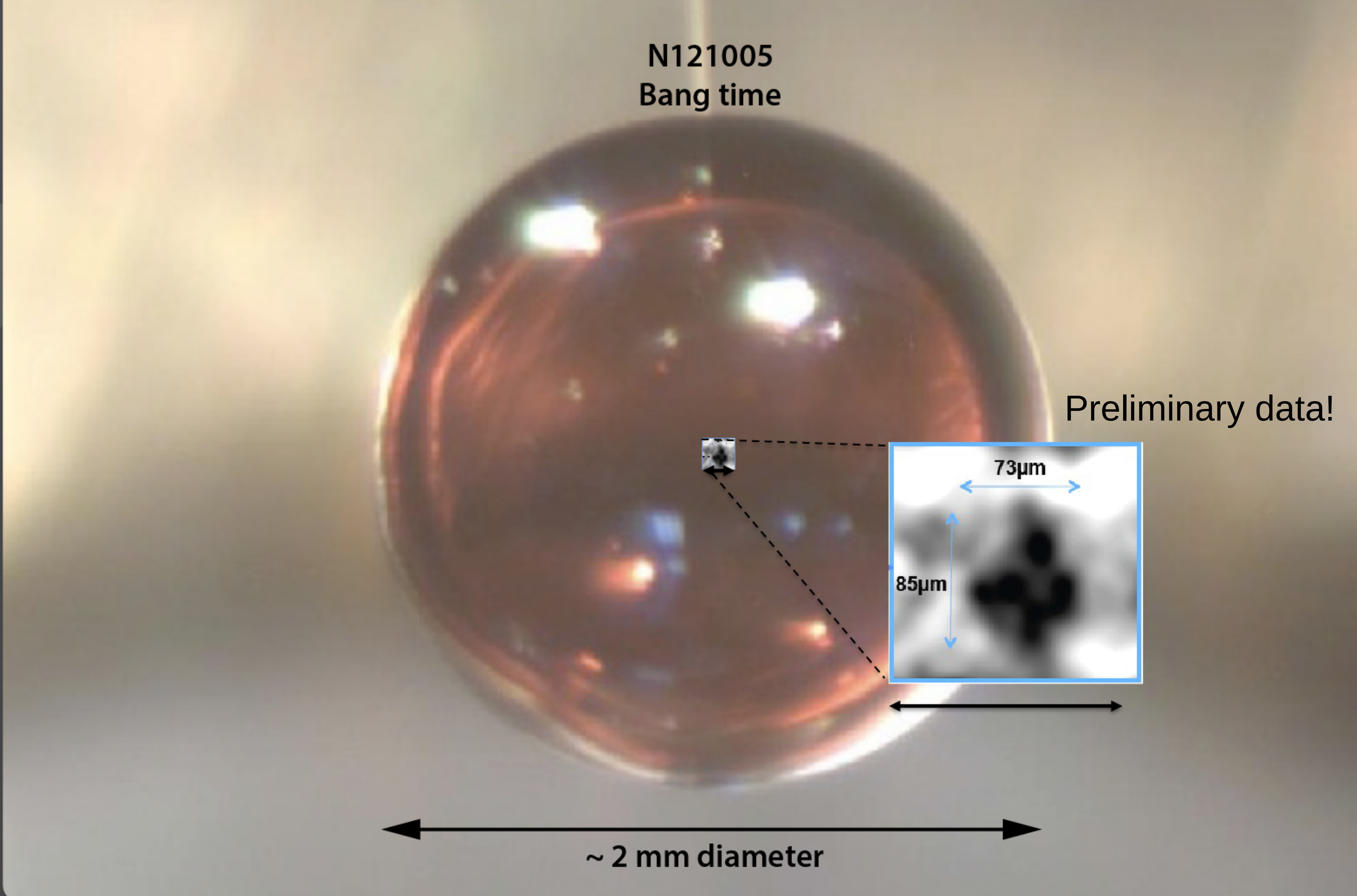
Compton radiography probes fuel shape at stagnation



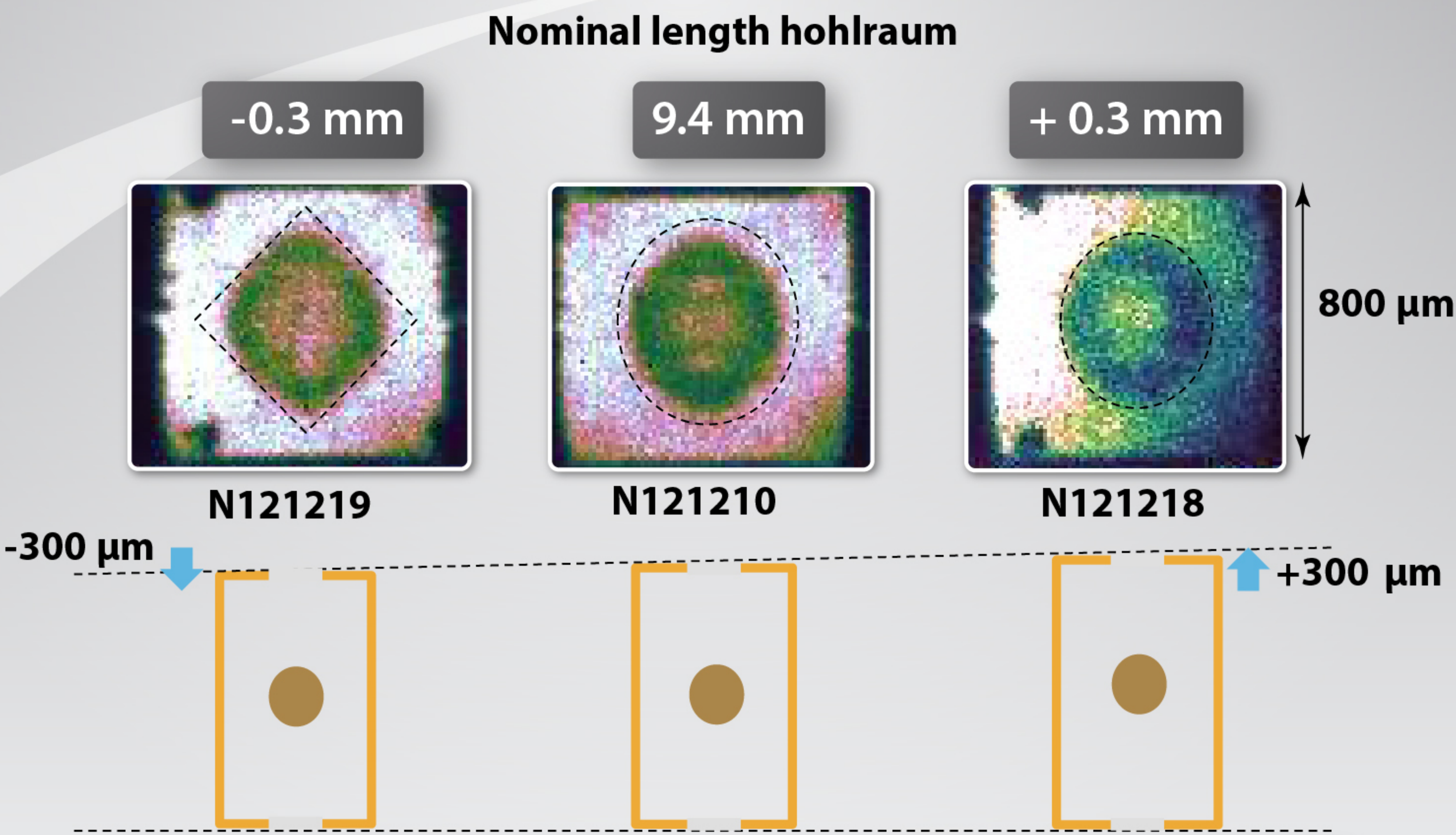
The hot spot looks quite round!



Compton radiography probes fuel shape at stagnation



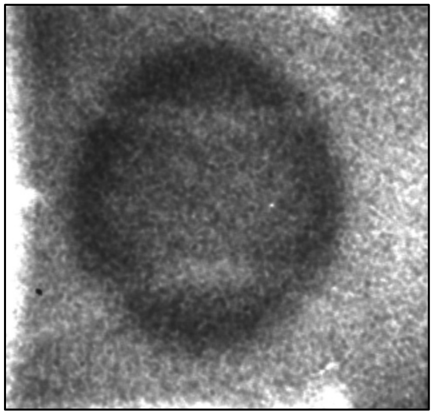
Experiments are working on the P4 (diamond) shape



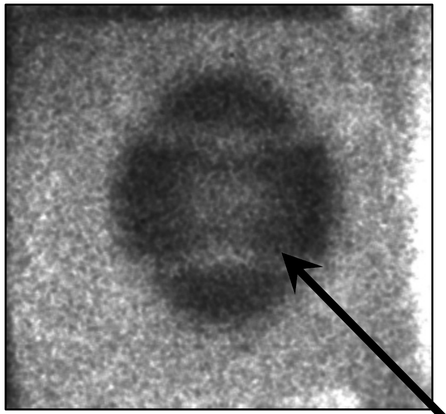
X-ray drive symmetry must be controlled to the ~1% level

Radiography reveals possible signature of ablation front instability growth from tent

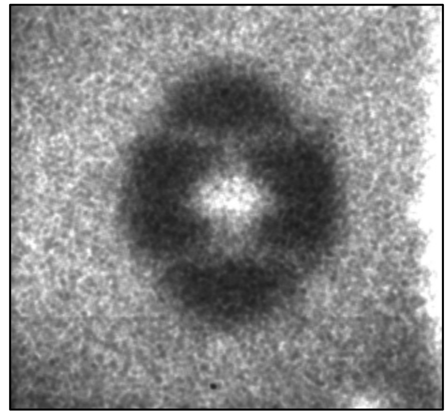
Bang time – 640ps	BT– 430ps	BT– 340ps



800 µm

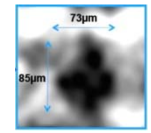


800 µm



800 µm

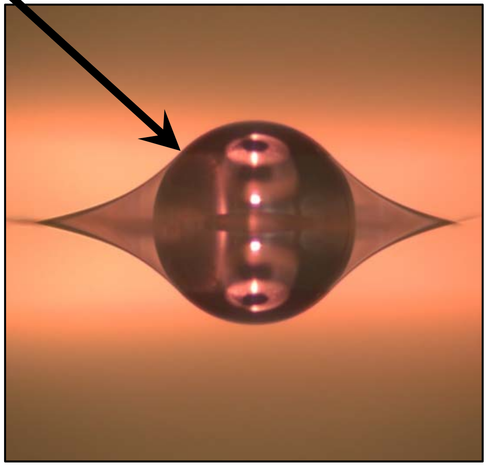
BT± 50ps



150 µm

Perturbation seeded by the tent?

- Perturbation is larger than predicted
- Motivates
  - — Thinner tent / alternate mounting
  - — Experiments to study



Tent
~40 nm