Applying Avatar Machine Learning to NIF Optics Inspection Analysis

Presentation to

The NASA CIDU Conference

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Lawrence Livermore National Laboratory • National Ignition Facility & Photon Science (LLNL-PRES-458291)

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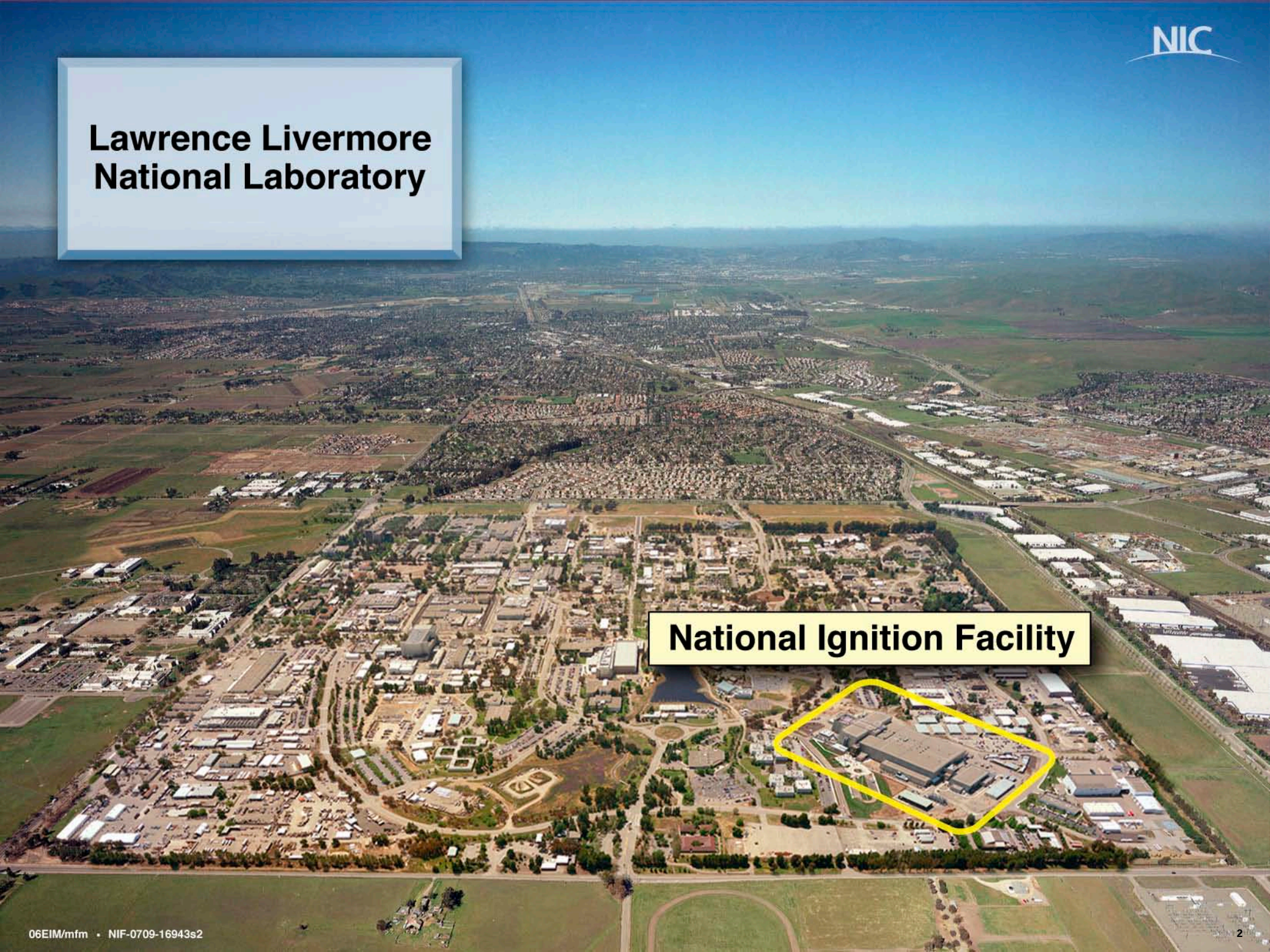
Lawrence Livermore
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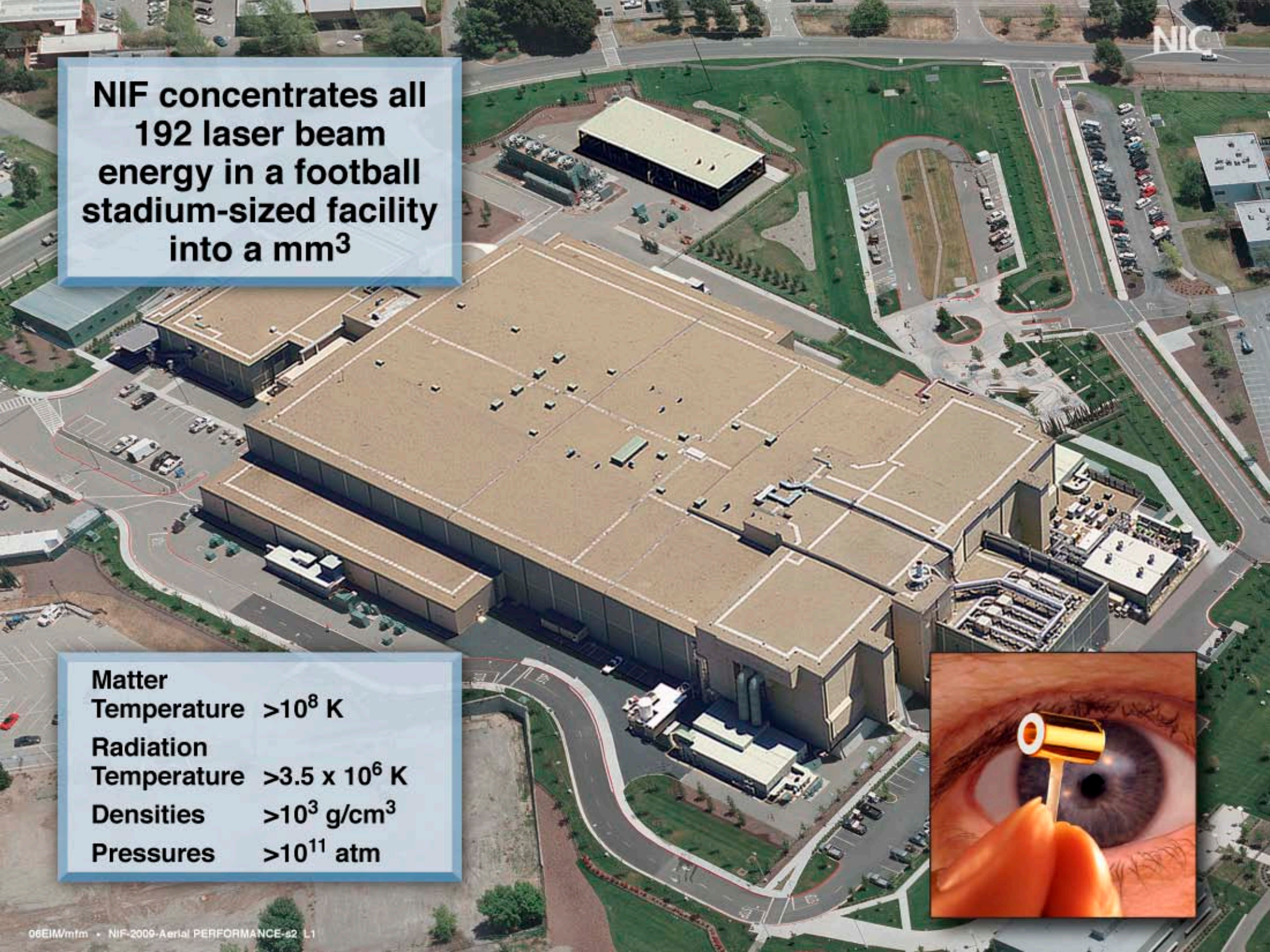
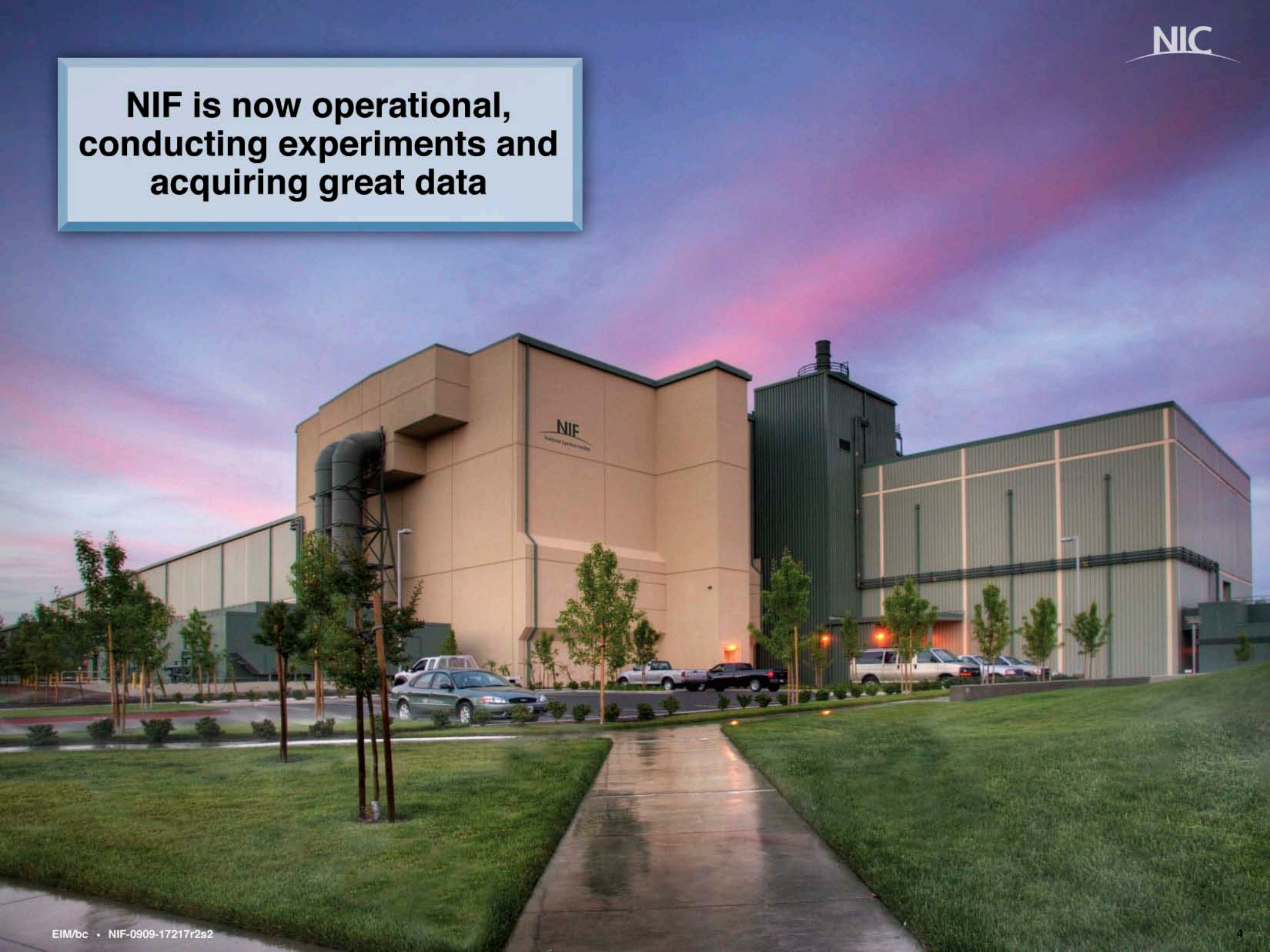

NIF concentrates all 192 laser beam energy in a football stadium-sized facility into a mm3
Matter Temperature >10^8 K
Radiation Temperature >3.5 x 10^6 K
Densities >10^3 g/cm^3
Pressures >10^11 atm
06EIM/mfm • NIF-2009-Aerial PERFORMANCE-s2 L1

NIF is now operational, conducting experiments and acquiring great data



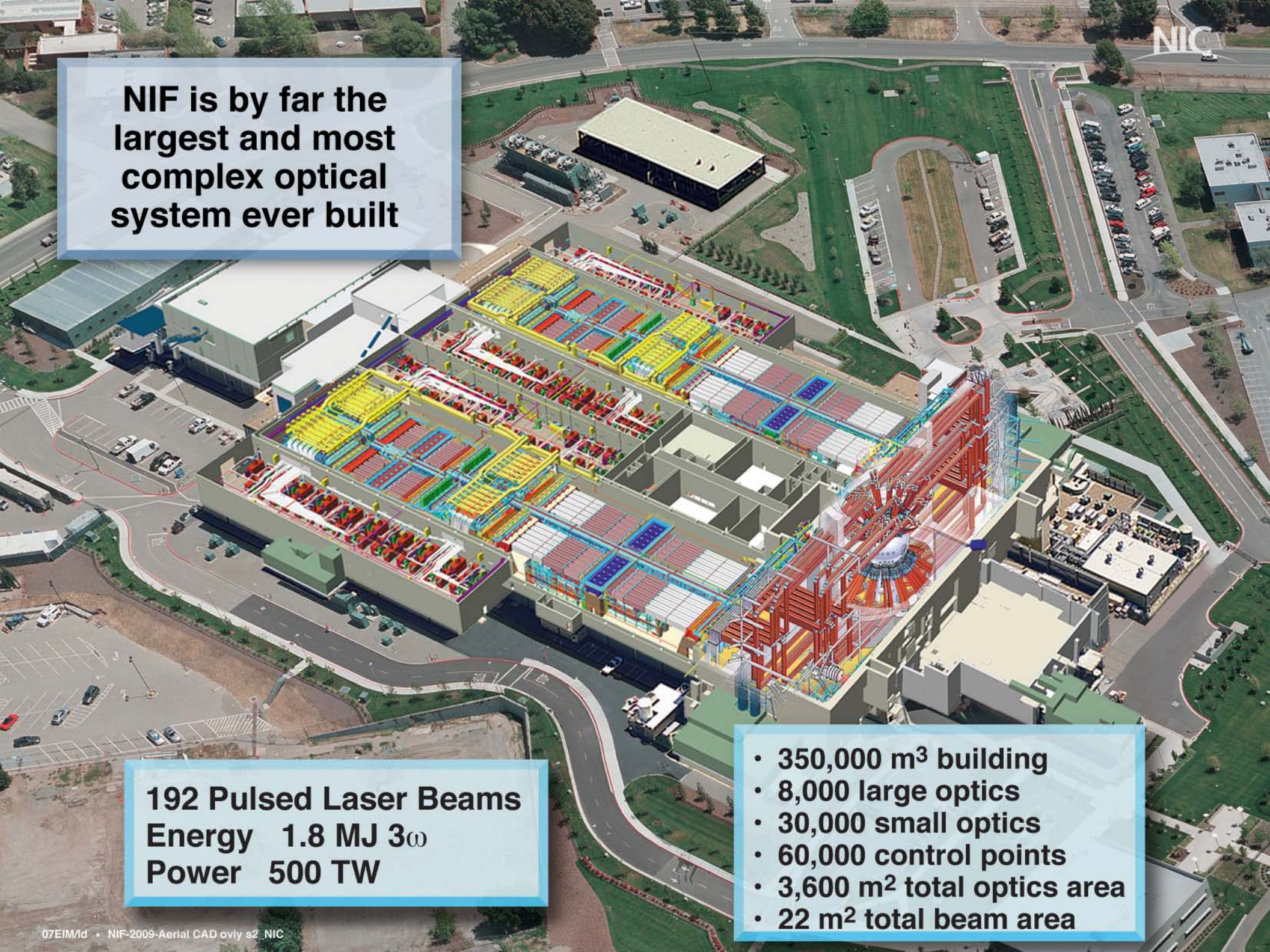
NIF Missions

Ensuring National Security and Global Stability

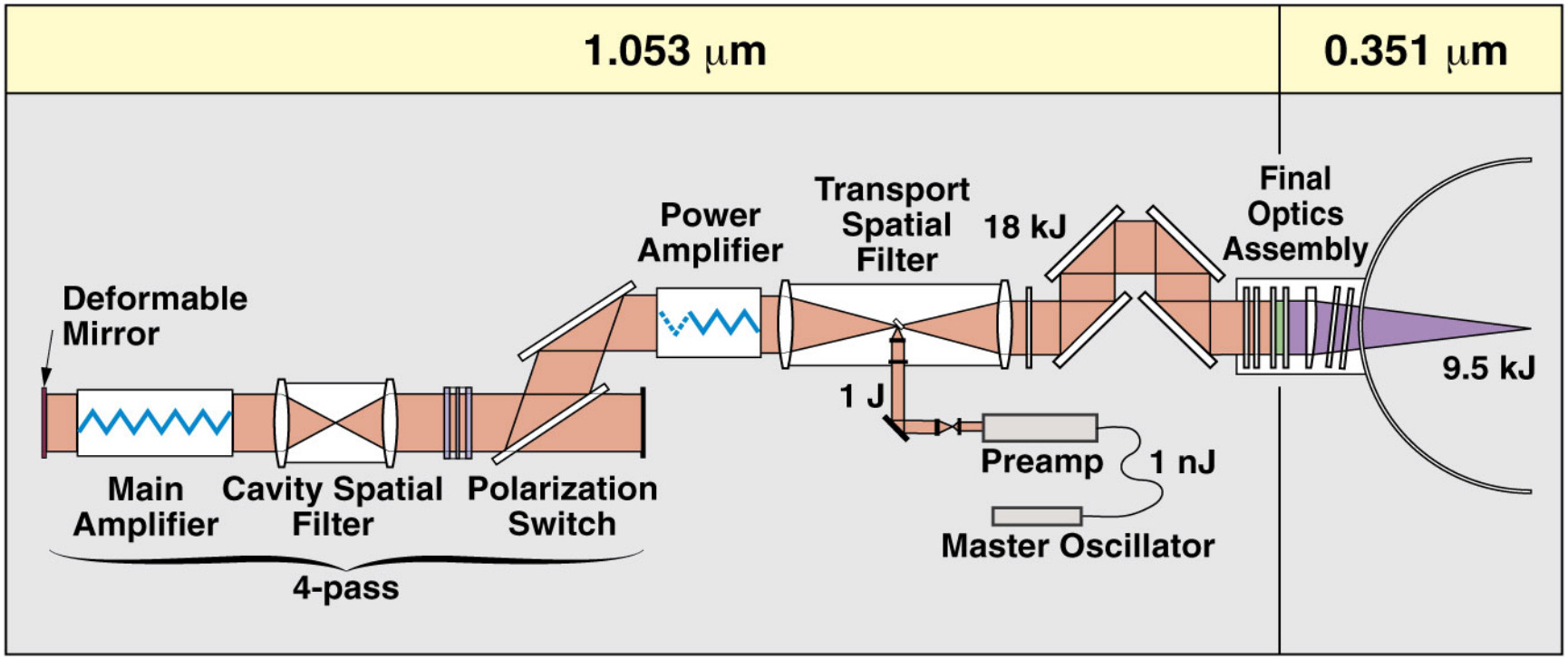
Advancing frontier science

Enabling clean energy

Building future generations of HED scientists


NIF is by far the largest and most complex optical system ever built
192 Pulsed Laser Beams
Energy 1.8 MJ 3ω
Power 500 TW
• 350,000 m³ building
• 8,000 large optics
• 30,000 small optics
• 60,000 control points
• 3,600 m² total optics area
• 22 m² total beam area
07EIM/ld • NIF-2009-Aerial CAD ovly s2_NIC

NIF has thousands of optics on the beamlines which must be inspected after every shot



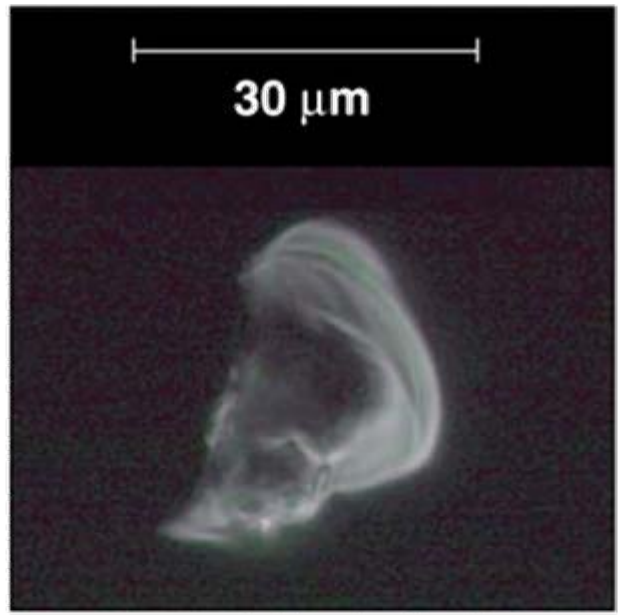
NIF laser is made possible by six "wonders": high volume laser glass production, large aperture polarization switch, high gain preamplifier, deformable mirror, rapid growth crystals, and integrated control system

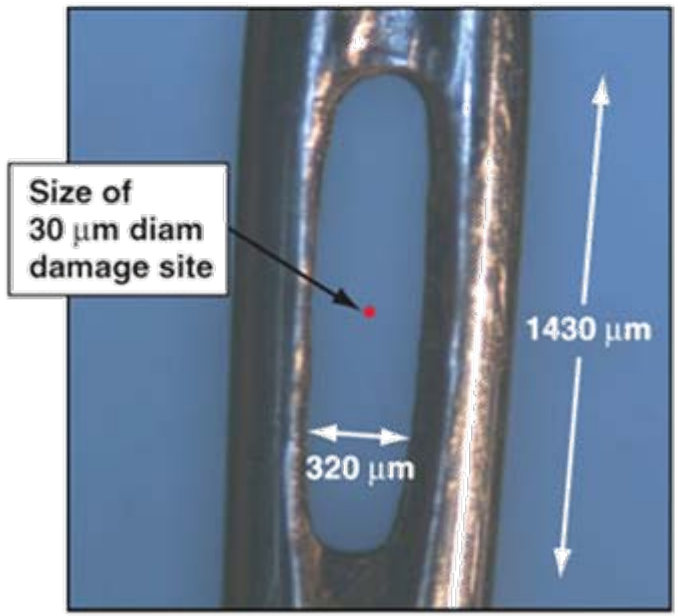

Laser Bay
00ABC/abc • NIF-0508-14729s2

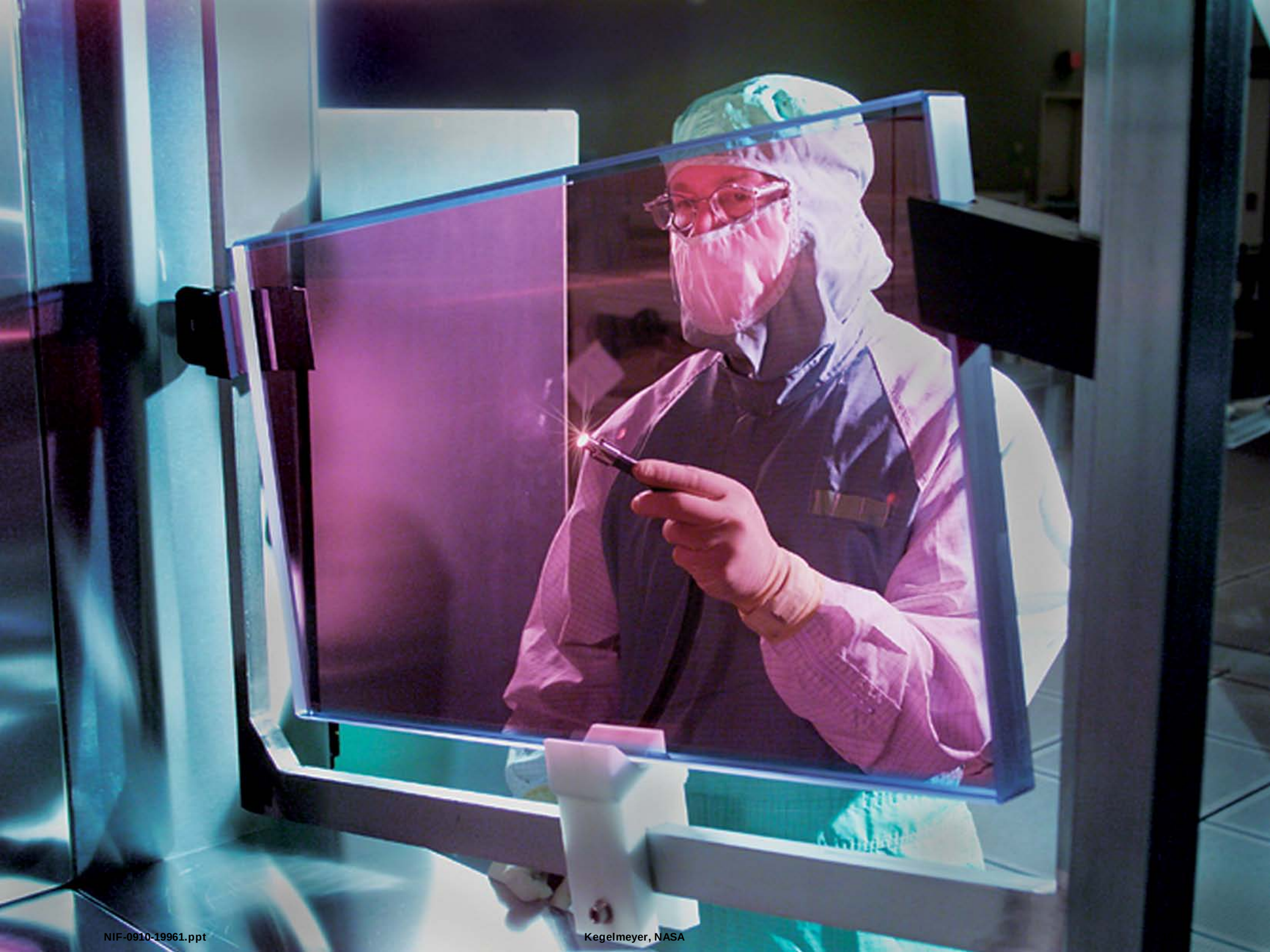
On high quality surfaces initiated damage sites are very small

- Damage sites are typically initiated with diameters of 20 to 50 μm

- Damage sites initiate at:
  - "Precursors"
    - Flaws in the surface
  - Contaminants on the surface







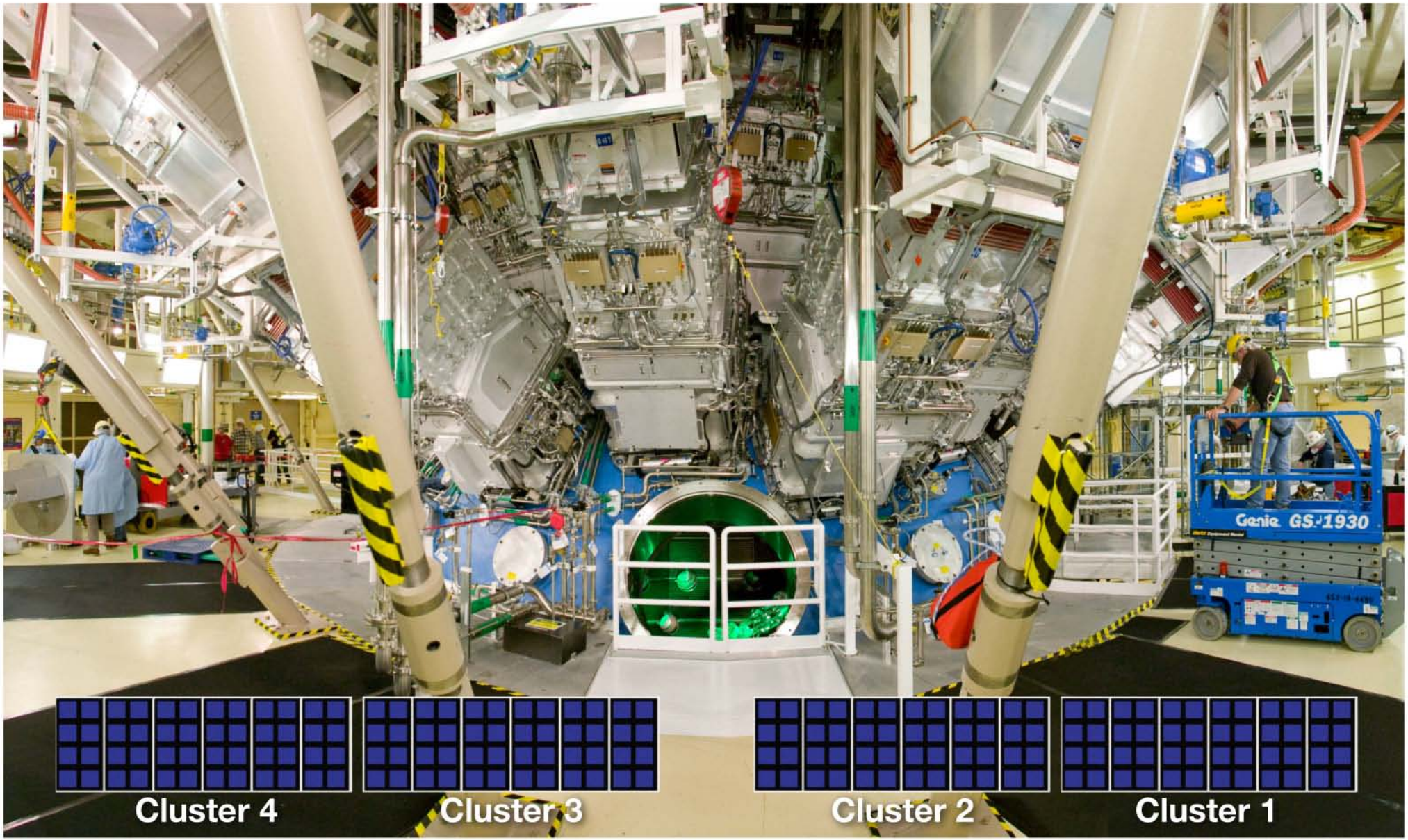
NIF-0910-19961.ppt

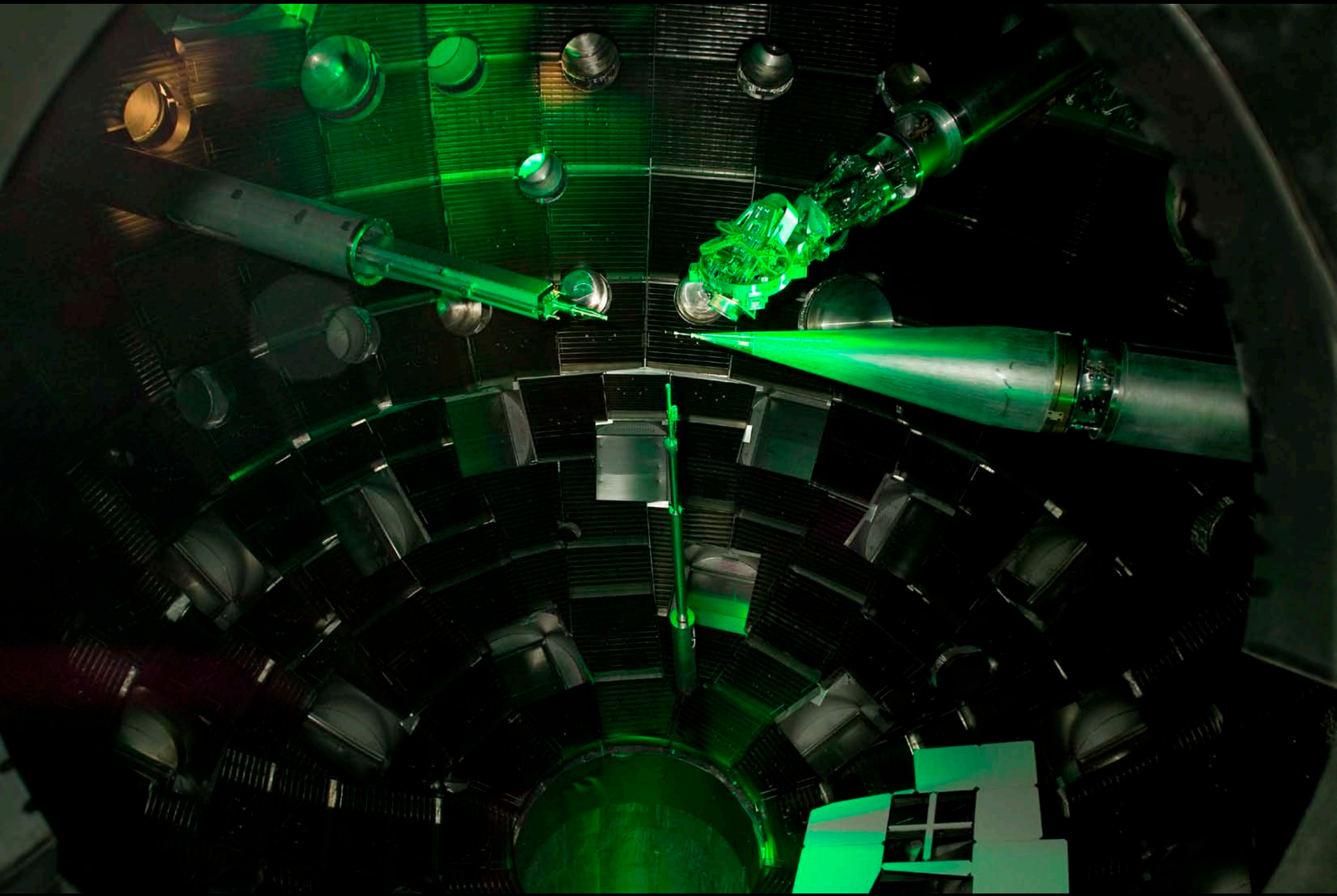
Kegelmeyer, NASA


NIF
Randy


Target
Chamber
June 1999

192 beams operational at 3ω — 1.2 MJ on target December, 2009

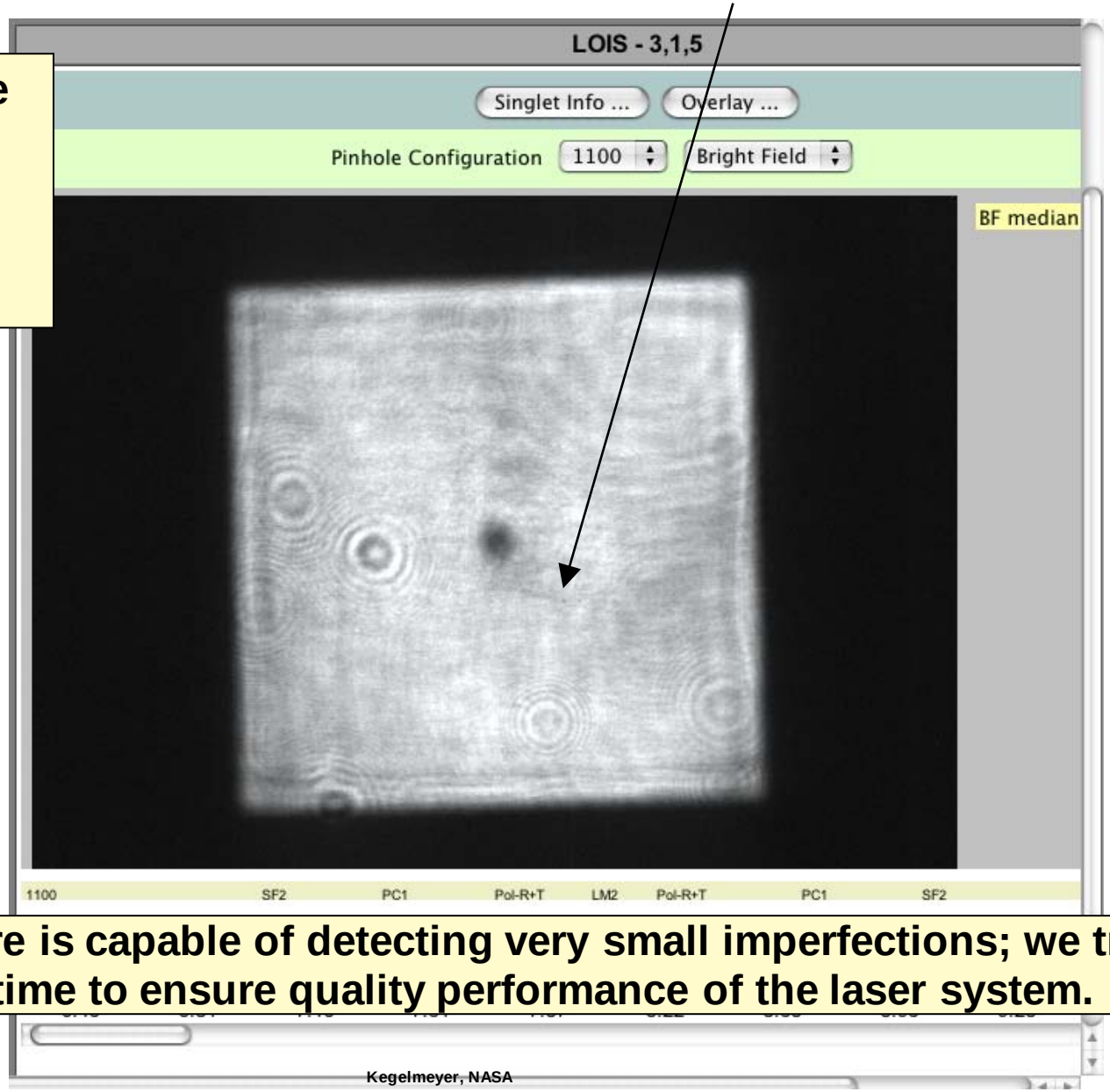




The LOIS inspection system for the Main Laser has mirrors, relay optics and intervening glass. Light scattering sites can still be detected

Real light scattering sight

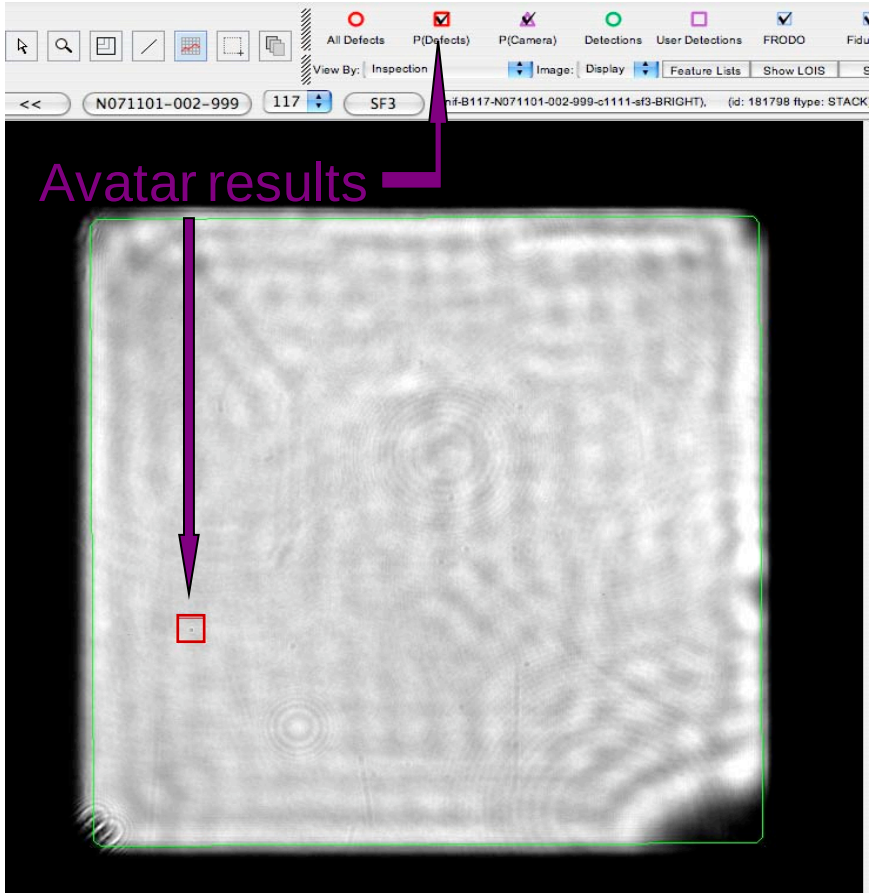
We must detect the site, identify the optic on which it resides and estimate its size

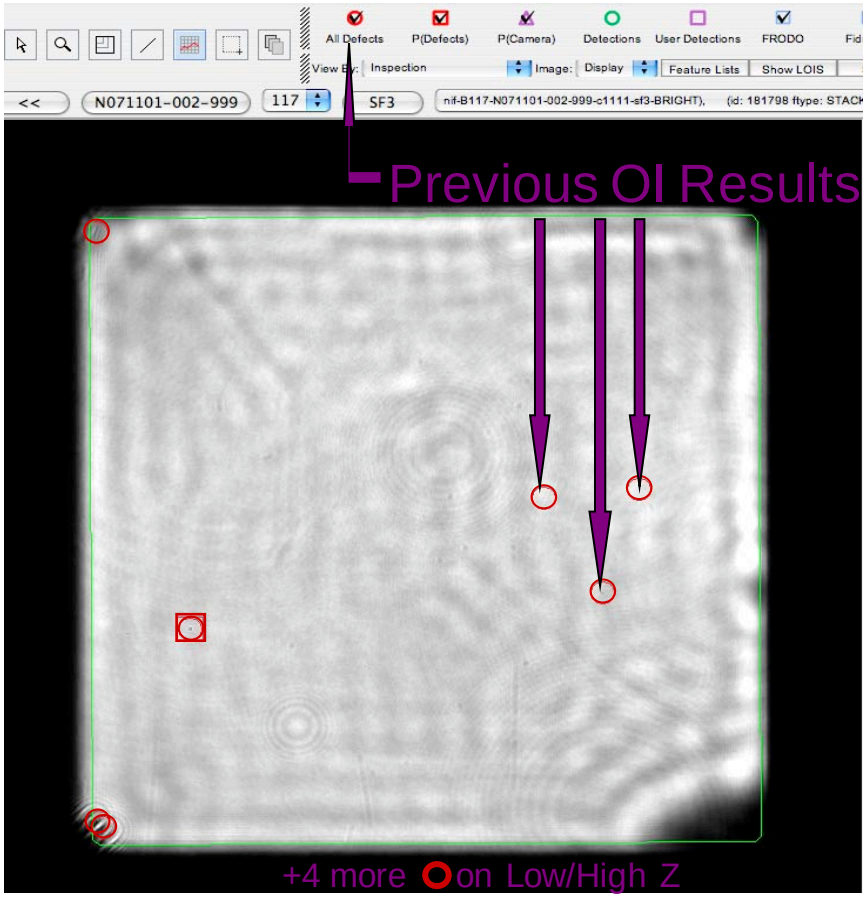


Analysis software is capable of detecting very small imperfections; we track these over time to ensure quality performance of the laser system.

Modern, real-world data is too cumbersome to handle with traditional mathematical & human analysis methods

- High-tech applications generate overloads of data that can be skewed, noisy
- For NIF, thousands of optics must be inspected and tracked





Initial machine learning results have been excellent (> 99% accuracy).
Previous false positives (50 for this bundle) are eliminated;
the 1 high probability defect is flagged

Overview of Pattern Recognition (i.e. supervised machine learning, statistical inference, data mining)

Input: expert-labeled "ground truth"

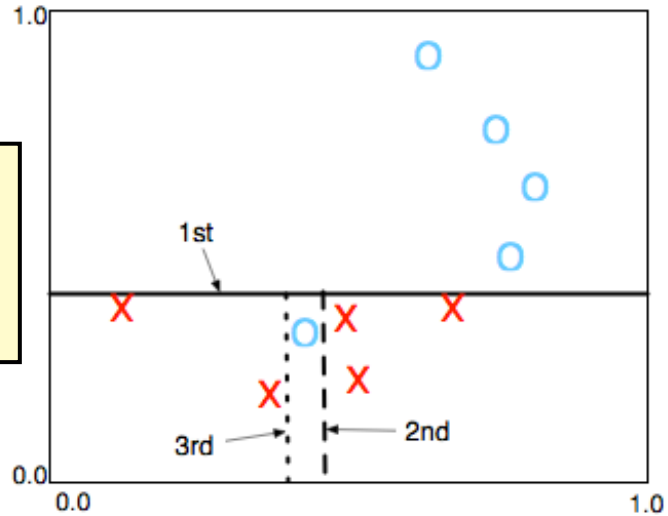
Sample	Attributes		Truth	
Data point 1	size1	optic-type1	brightness1…	"defect"
Data point 2	size2	optic-type2	brightness2…	"camera flaw"
Data point 3	size3	optic-type3	brightness3…	"debris"

Generate a classifier

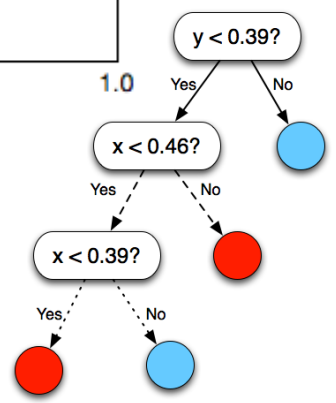
- Decision trees
- Neural networks
- Support Vector Machines

Output: Rules for labeling new, unlabeled data: A partitioning of attribute space with which to classify (predict the classification of) new data points

2-D Attribute space



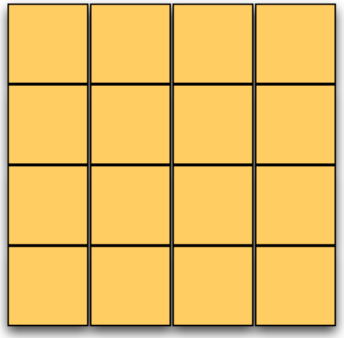
Decision tree



Current wisdom in machine learning: Use ensembles of classifiers for robust accuracy

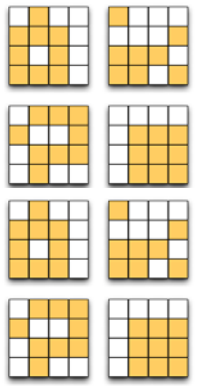
✗ The traditional "craftsman" model of Pattern Recognition

- Use 100% of training data to build a "sage"
- Painstakingly screen & select features
- Normalize attributes (essential but challenging)
- Prune the tree (black art)
- Use domain knowledge to tune parameters and weight attributes



✓ Use randomized 100% of training data to build an "expert". Repeat to build many experts and let them vote.

- Always improves accuracy
- Robust in face of noise (accepts data as it is)
- Concept scales to terabytes of data
- No need to tune parameters
- Specially handles skewed data

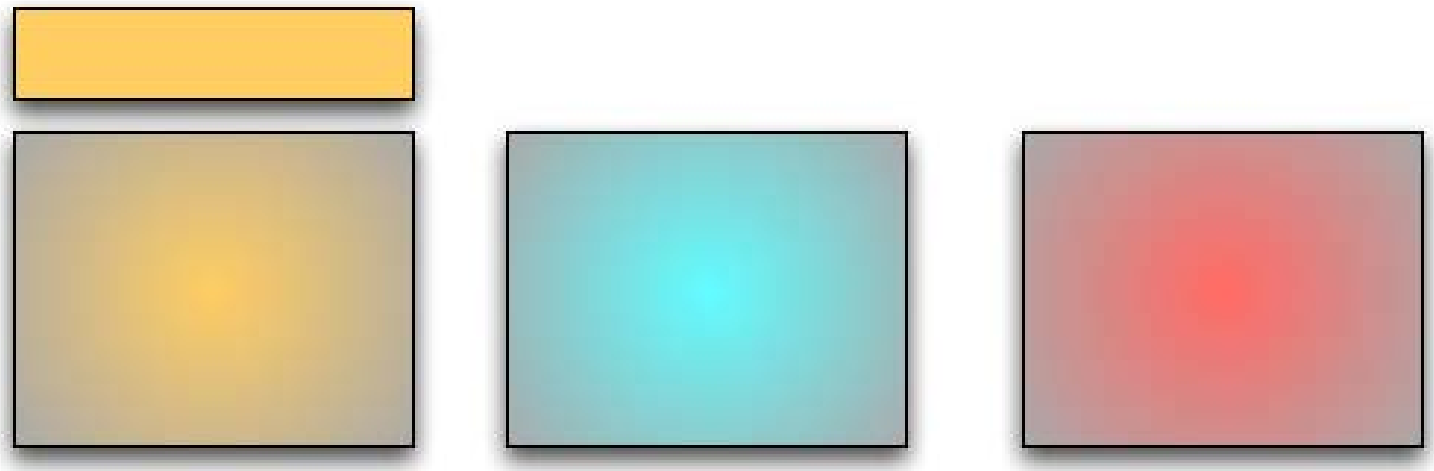


Avatar innovations

Repeated Bagging (sample with replacement) generates experts that have seen different training points and have "diversity"

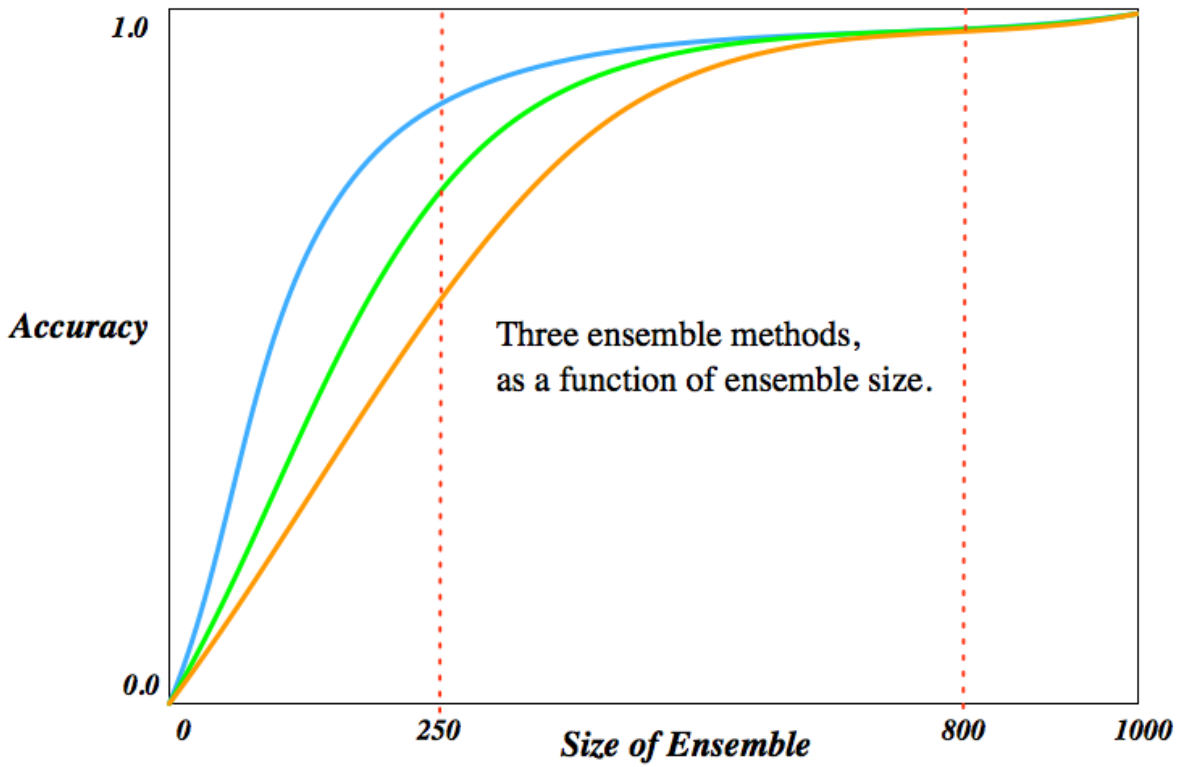
Why do ensembles work? One key is diversity

- Imagine 3 classes, each expert is only 10% accurate and when wrong, chooses randomly among the 3 classes
- After voting, the correct class has more votes than the others -- 100% accurate!



How many trees to grow?

- **Don't use fixed size ensembles. They can be deceptive!**



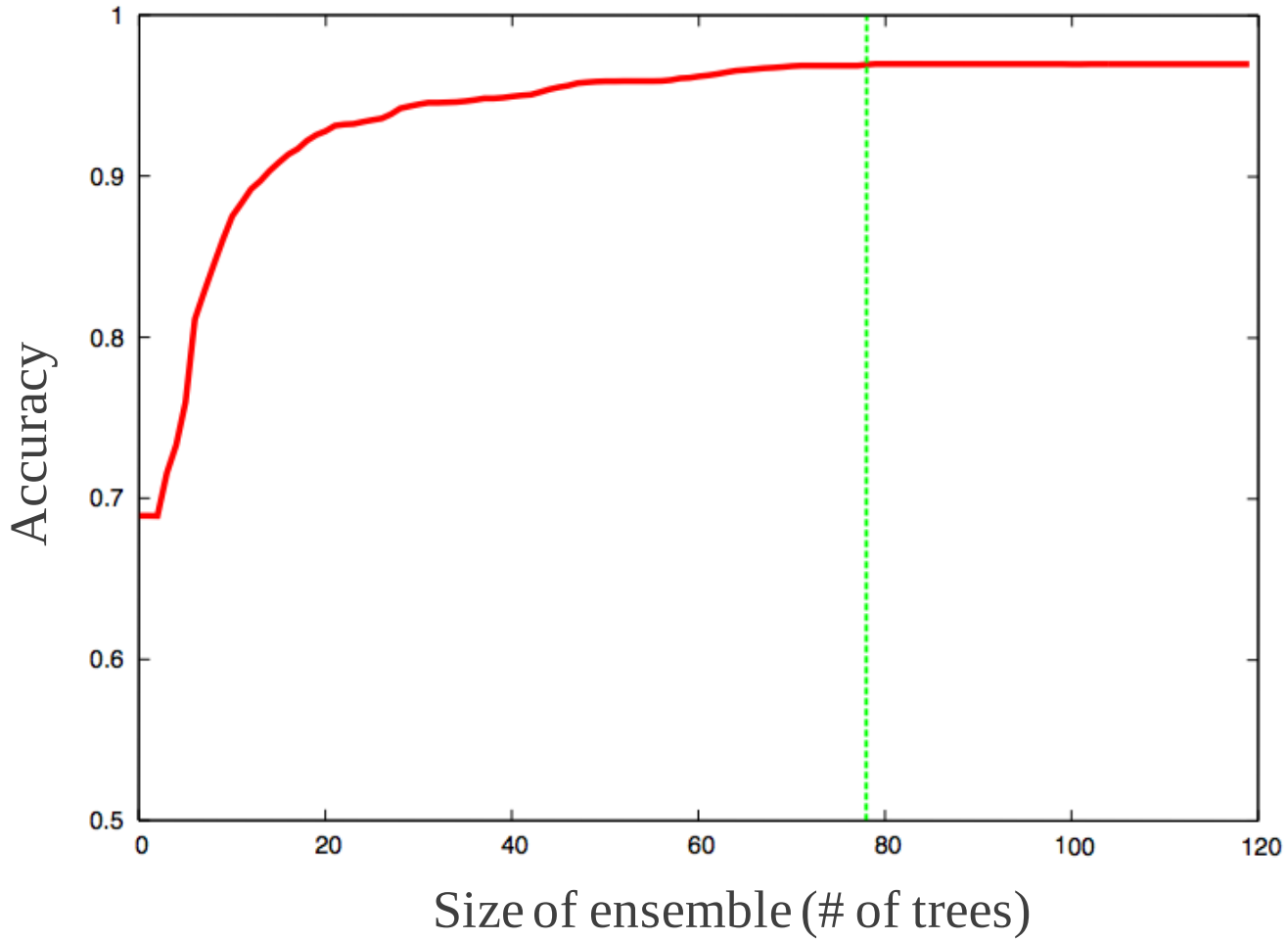
- **Instead, stop when accuracy levels off**
- **How to measure accuracy? Need method that is inexpensive and easy**

Out of Bag (OOB) accuracy is possible because every expert doesn't see some samples….

- In other words: every sample is unseen by some classifiers!

How many trees to grow?

Avatar innovation: Stop generating trees when accuracy flattens out



Other Avatar innovations handle skewed data

- Say you have 9000 labeled examples from mammograms of "benign" and you have 100 labeled examples for "cancer"
- Any classifier that always picked "benign" would be 98.9% accurate and you would have missed all of the most important data points!
- Avatar Tools has 2 functions which inherently deal with skewed data.
  - Hellinger distance metric instead of InfoGain for measuring impurity of the nodes (we use this)
  - SMOTE (Synthetic Minority Over-sampling Technique): a method which adds more examples of the scarce class by sampling from an estimate of the minority classes' distribution.

Steps for applying Avatar (from Sandia's ASC program, WP Kegelmeyer) machine learning to NIF shotcycle inspections

Training phase

Experts "Log Defects" to train data

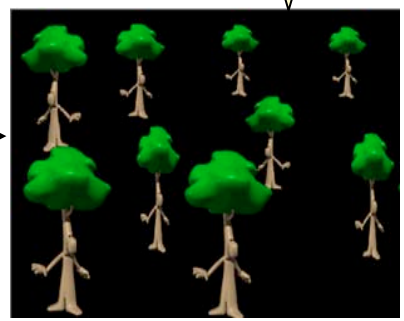
OI Analysis team collects all logged defects and "cleans" the data

Avatar uses cleaned data to grow an ensemble of decision trees

Test or prediction phase

Current Operations: Send images to OI to analyze new images and find defect candidates

Candidates are "fed" to decision trees



Trees vote for predicted class

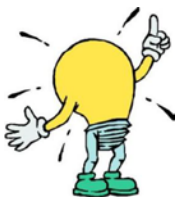
This has not changed. These candidates are presented as "All Defects" on GUI.

Probability for a class is the percentage of trees that voted for that class. These are presented as P(Defects) on GUI.

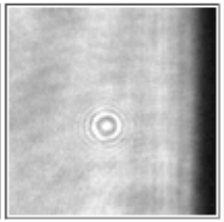
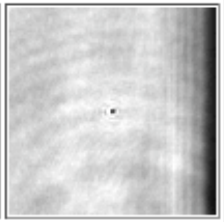
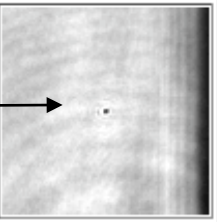
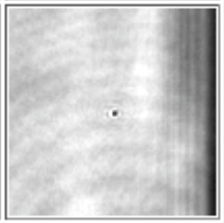
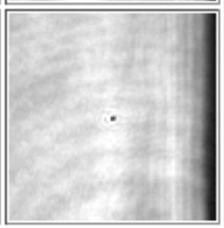
Training phase 1: We fed initial training data to the Avatar decision tree ensemble and used 10-fold cross validation to evaluate the results

- "Experts" labeled 354 defect candidates
- We trained Avatar on these and tested it.
- Initial results helped us identify "errors" in the training data. e.g. complications from
  - relay optics
  - white (phase) defects
  - "expert wars" (different definition and classification given by different experts for same defect candidate)

- We cleaned the training data so it could be resubmitted. We also realized….

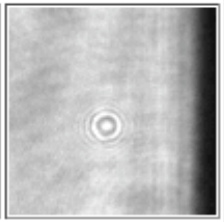
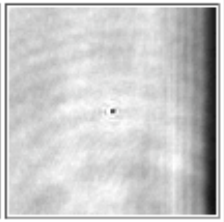
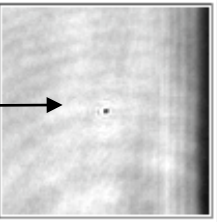
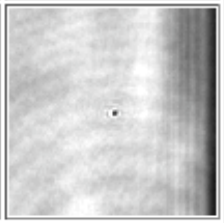
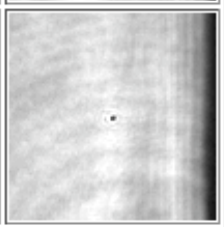


OI software tracks defects through history, so if a candidate defect was classified during any one inspection....

Shot Id	Image Id	Defect Name Id	Beamline	System	Defect Id	Comment Id	Classification	Thumbnail
N050719-001-999	44129	663592	314	SHOTCYCLE_SF3	697238			
N050729-001-999	44364	663592	314	SHOTCYCLE_SF3	698434			
N050801-001-999	45114	663592						
N050803-002-999	45235	663592	314	SHOTCYCLE_SF3	703542			
N050804-001-999	45320	663592	314	SHOTCYCLE_SF3	703906			

1. Label as “defect” once

... we could apply the same “expert truth” label to each instance in history to get nearly 6000 data points!

Shot Id	Image Id	Defect Name Id	Beamline	System	Defect Id	Comment Id	Classification	Thumbnail
N050719-001-999	44129	663592	314	SHOTCYCLE_SF3	697238		defect	
N050729-001-999	44364	663592	314	SHOTCYCLE_SF3	698434		defect	
N050801-001-999	45114	663592						
N050803-002-999	45235	663592	314	SHOTCYCLE_SF3	703542		defect	
N050804-001-999	45320	663592	314	SHOTCYCLE_SF3	703906		defect	

1. Label as “defect” once

2. Apply label to all

Accuracy was 98.39% with only 23 candidate sites "mis-categorized" in the "wrong" direction (expert "defect" called "not-a-defect")

Expert label

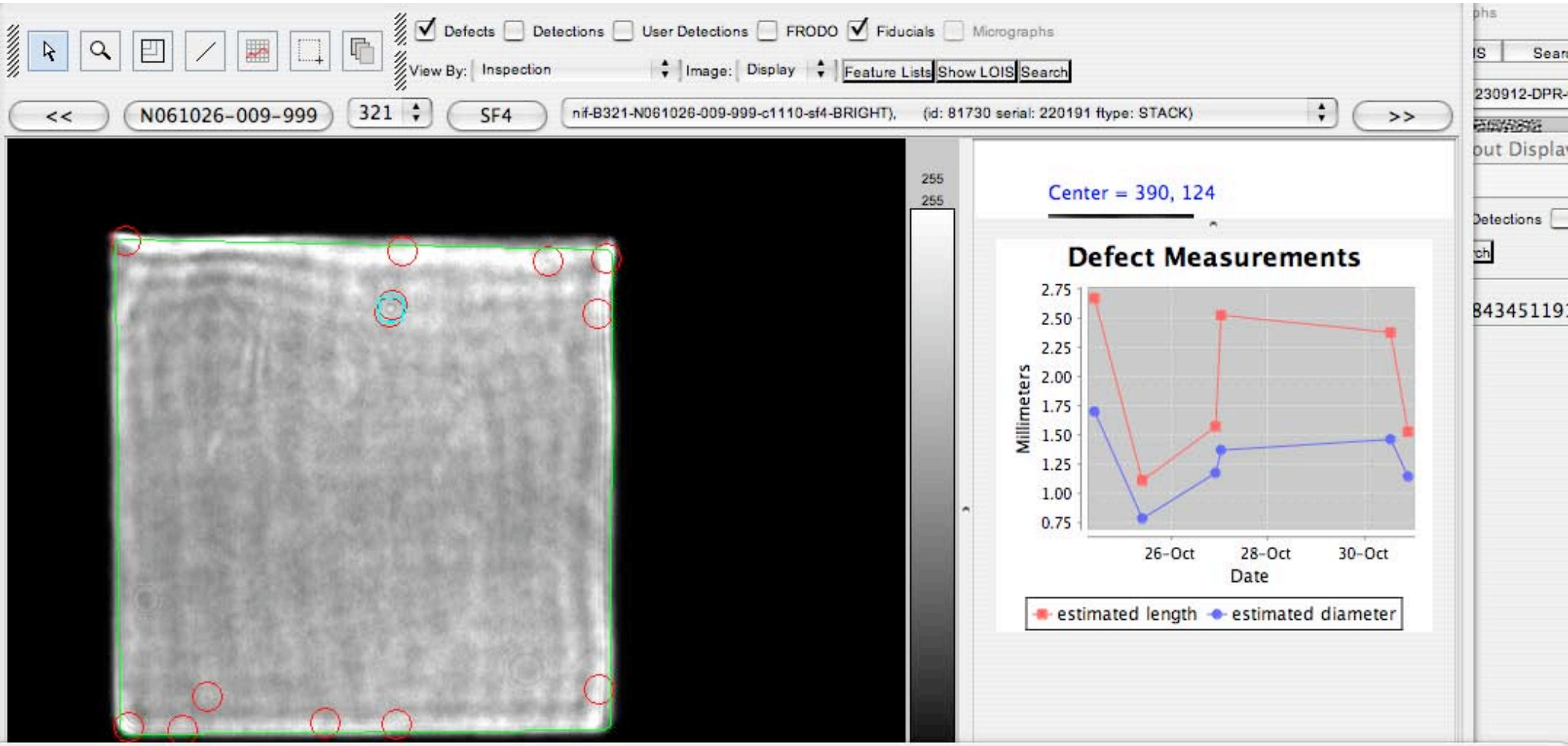
Avatar Prediction	White	Camera	Defect	Not_a_defect
White	227	0	14	0
Camera	3	976	6	6
Defect	23	10	1848	11
Not_a_defect	2	3	17	2803
	255	989	1885	2820

These "errors" helped us identify problems with the training process.

Training phase 2: identify and correct mislabeled "truth" in the training set

- Candidate sites may be mislabeled for a variety of reasons
- Don't always know what classes will be needed
- Some cases are trickier than others

- Examples follow...



Feature Lists

ransfer

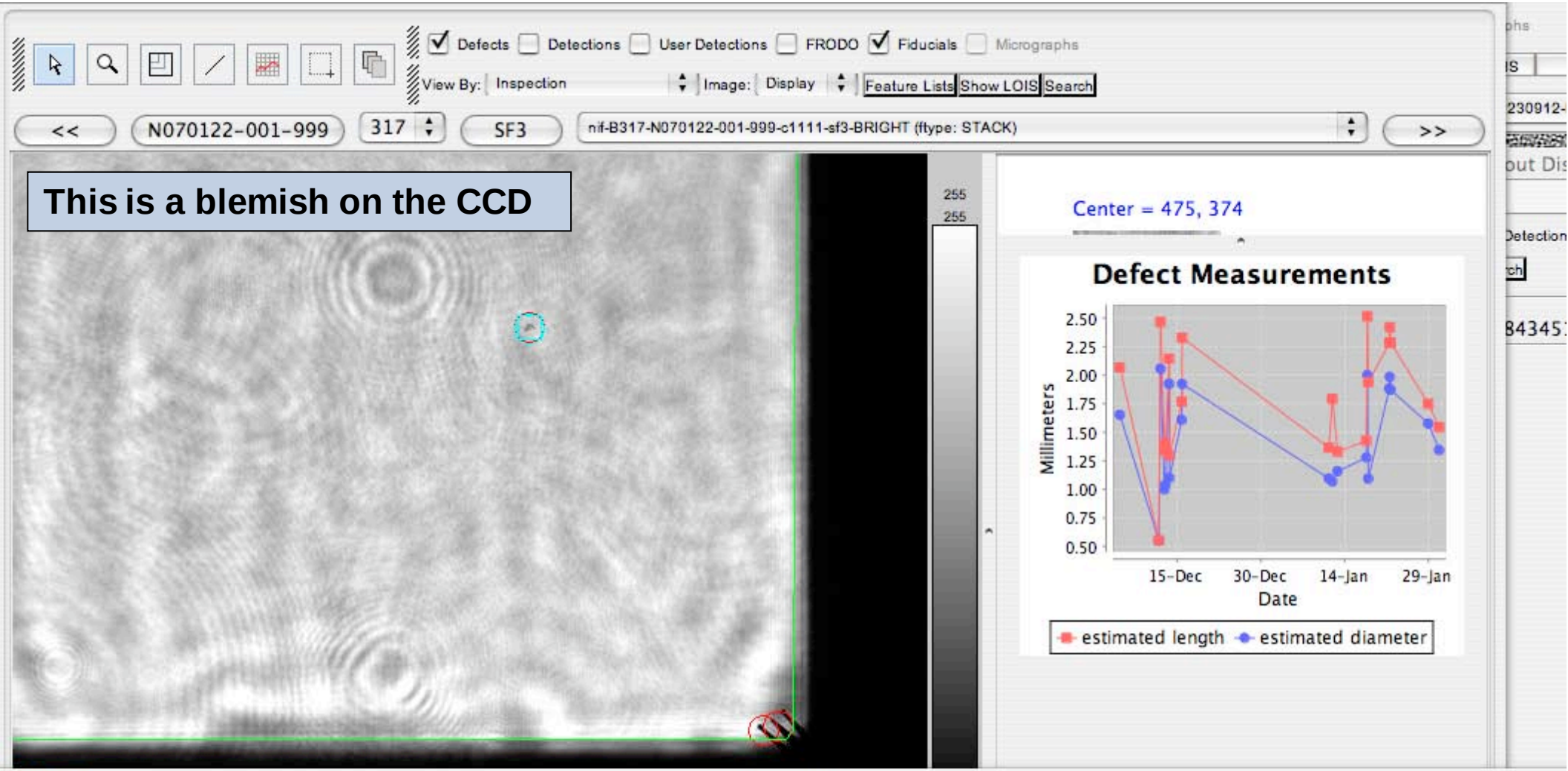
Detection List | Log | FRODO | Fiducials | Defect List

Save As... | Filter by Name | Filter by last 10 days

Expert Wars

# of rows: 2 # filtered: 1

Date	Name	X	Y	Est Dia	Est Length	Est Diam (pi	Class	Criterio	Comment	User	Shot ID	
Oct 30, 2...	694386	390	125	1.461	2.375	2.764	Not a d...	☑	Bump on ring of a different defocused defect...	salmon2	LOIS061030B	DEFECT
Oct 27, 2...	694386	391	122	1.369	2.524	2.764	Defect	☑	Tracking for growth	buckman3	N061026-009-999	DEFECT



Feature Lists

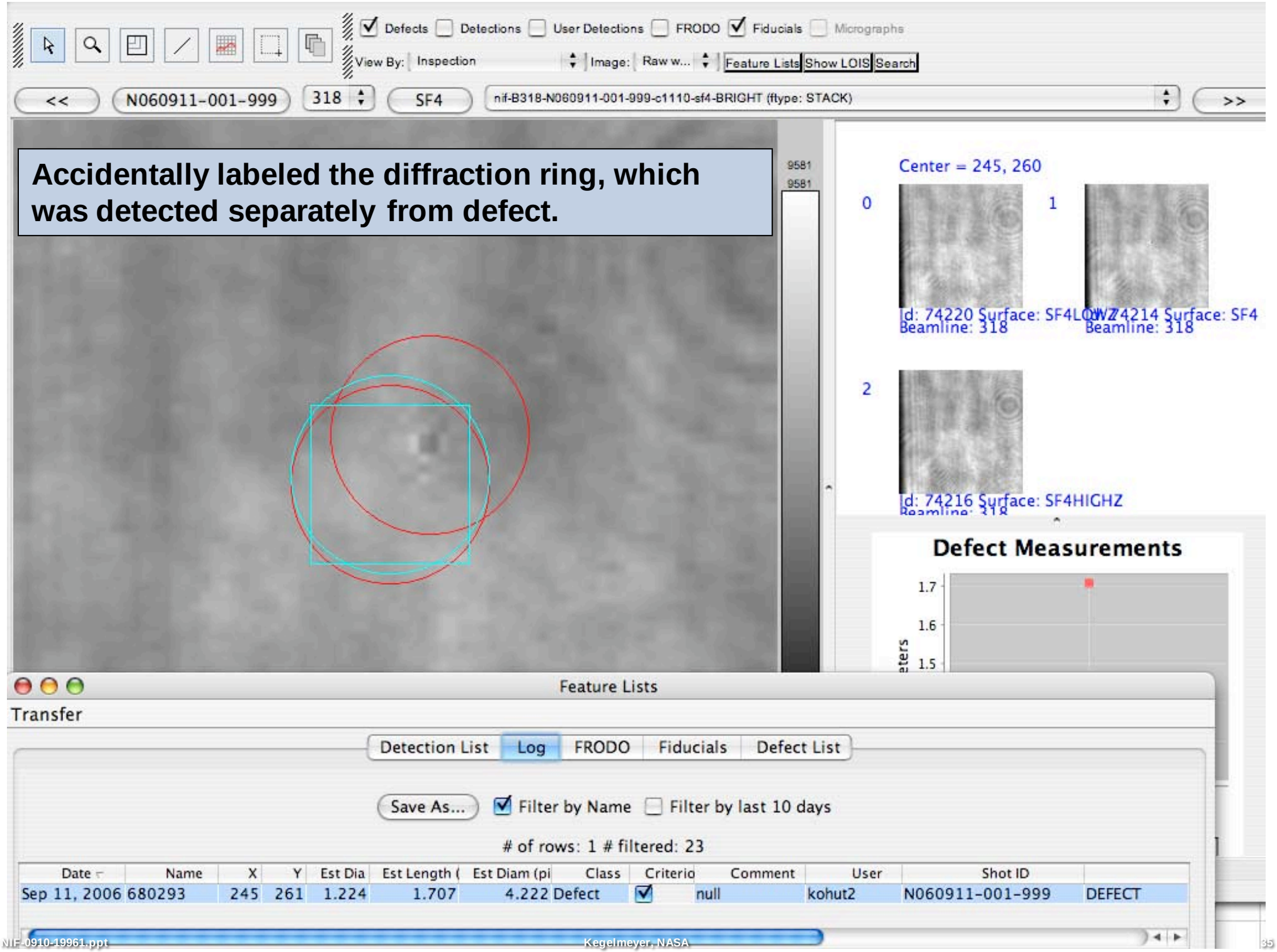
Transfer

Detection List | Log | FRODO | Fiducials | Defect List

Save As... | Filter by Name | Filter by last 10 days

# of rows: 1 # filtered: 12

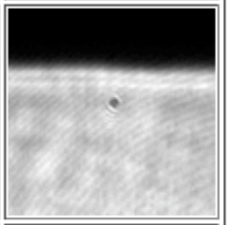
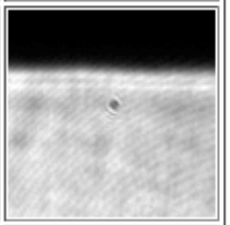
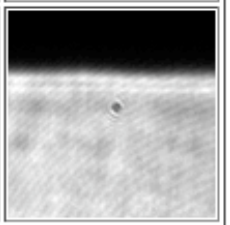
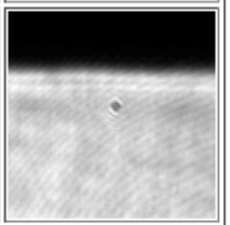
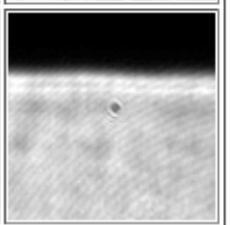
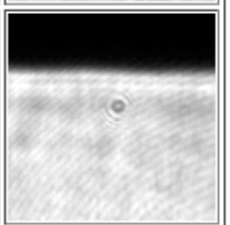
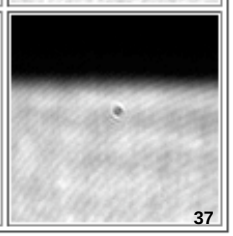
Date	Name	X	Y	Est Dia	Est Length	Est Diam (pi	Class	Criterio	Comment	User	Shot ID	
Jan 22, 2...	706128	475	373	1.983	2.418	5.171	Defect	☑	appears to be on image plane for bl315 also	buckman3	N070122-001-999	DEFECT


Defects
Detections
User Detections
FRODO
Fiducials
Micrographs
View By:
Inspection
Image:
Raw w...
Feature Lists
Show LOIS
Search
<<
N060911-001-999
318
SF4
nif-B318-N060911-001-999-c1110-sf4-BRIGHT (ftype: STACK)
>>
Accidentally labeled the diffraction ring, which was detected separately from defect.
9581
9581
Center = 245, 260
0
1
Id: 74220 Surface: SF4LOWZ
Beamline: 318
Id: 74214 Surface: SF4
Beamline: 318
2
Id: 74216 Surface: SF4HIGHZ
Defect Measurements
1.7
1.6
1.5
Feature Lists
Transfer
Detection List
Log
FRODO
Fiducials
Defect List
Save As...
Filter by Name
Filter by last 10 days
# of rows: 1 # filtered: 23
Date
Name
X
Y
Est Dia
Est Length (
Est Diam (pi
Class
Criterio
Comment
User
Shot ID
Sep 11, 2006
680293
245
261
1.224
1.707
4.222
Defect
null
kohut2
N060911-001-999
DEFECT

Training phase 3: determine what additional measurements can help distinguish different classes

- The decision trees won't predict well if they were not trained with salient features (measurements or other attributes)
- We provided as many measurements as we could think of, but....
- Using Avatar provides additional information we can use -- the historical average of Avatar probabilities for one site can be fed back as salient features (measurements or attributes) to the ensemble of trees to improve results further
- Examples follow....

OI found 8 times. Avatar mis-classified 1 time out of 8

N070329-005-999	113431	920395	416	SHOTCYCLE_SF4	2323755			
N070403-001-999	113723	920395	416	SHOTCYCLE_SF4	2343733	924	Defect	
N070403-006-999	114559	920395	416	SHOTCYCLE_SF4	2364812			
BU41LOIS070405	115571	920395	416	SHOTCYCLE_SF4	2380051			
N070423-003-999	121324	920395	416	SHOTCYCLE_SF4	2511628			
N070425-001-999	122400	920395	416	SHOTCYCLE_SF4	2528097			
N070711-005-999	144564	920395	416	SHOTCYCLE_SF4	3107521			

OI found 8 times. Avatar mis-classified 1 time out of 8, but average over all time gives correct classification.

N070329-005-999	113431	920395	416	SHOTCYCLE_SF4	2323755			
N070425-001-999	122400	920395	416	SHOTCYCLE_SF4	2528097			
N070711-005-999	144564	920395	416	SHOTCYCLE_SF4	3107521			

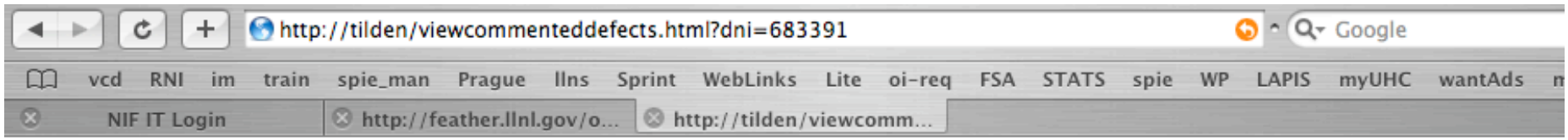
P(white)	P(camera)	P(defect)	P(NOT defect)
0.027	0.000	0.840	0.133
0.048	0.000	0.857	0.095
0.000	0.000	0.548	0.452
0.000	0.000	0.961	0.039
0.286	0.000	0.667	0.048
0.000	0.000	0.729	0.271
0.000	0.000	0.714	0.286
0.095	0.000	0.095	0.810
0.06	0.00	0.68	0.27

10-fold cross validation gives a stringent estimate of accuracy for the ensemble; also helps clean dataset

Avatar Prediction	Expert label: White	Camera	Defect	Not_a_defect
White	238	0	15	1
Camera	1	985	1	3
Defect	16	2	1867	3
Not_a_defect	0	2	2	2812
	255	989	1885	2819

Accuracy is > 99%

OI found this site only twice. AvatarTools called it "Not a defect" both times.



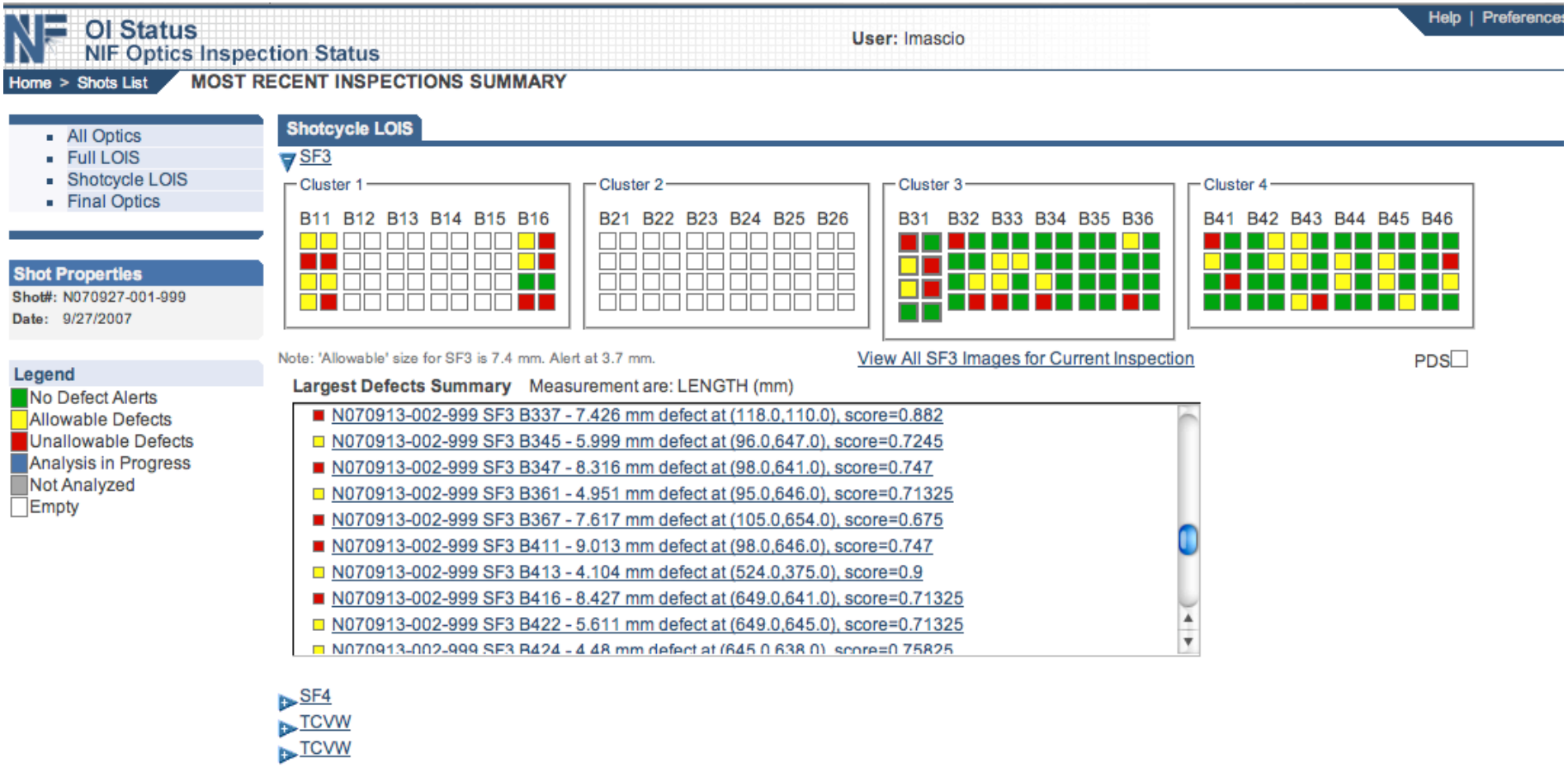
defect_name_id: 683391

Submit

(SD/Expert)

Shot Id	Image Id	Defect Name Id	Beamline	System	Defect Id	Comment Id	Classification	Thumbnail
LOISOQ060914	75549	683391	324	SHOTCYCLE_SF4	1898144			
LOISOQ060918	76284	683391	324	SHOTCYCLE_SF4	1901469	505	Defect	

With traditional image analysis, the Inspection Summary Chart had too many false alarms to follow-up in the time constraints



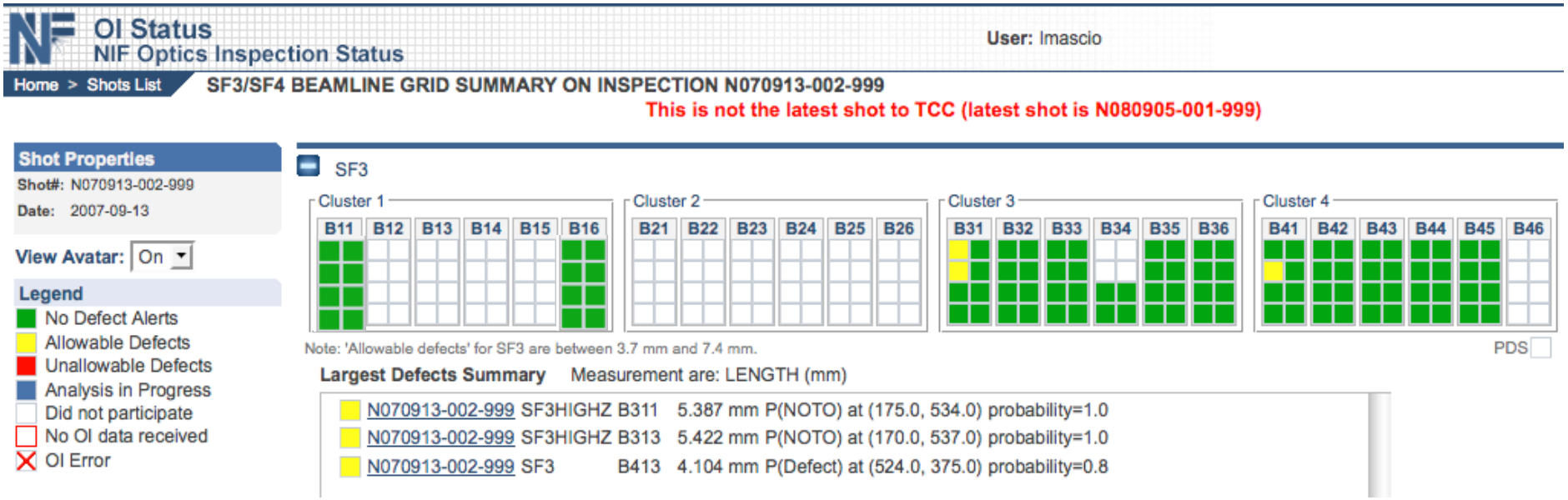
False alarms were adversely impacting the efficiency of operations

- SF lenses inspected every shot; 4 x 192 lenses = 768 optics
- Five (5) false alarms per image x 768 images = 3840 false alarms !
- $T_{inspection} = (T_{image} + T_{review}) \times N_{images(false)}$ … Time used to review false alarms
- $T_{inspection} = (7 \text{ sec} + 60 \text{ sec}^{1}) \times 768 = 14.3$ hours !

- Eliminating 99% of the false alarms using Avatar
- $N_{images(false)} = 3840$ false alarms x 0.01 = 38.4 false alarms
- $T_{inspection} = (7 \text{ sec} + 12 \text{ sec}^{2}) \times 38.4 = 12.2$ minutes

Avatar machine learning makes it possible to follow up on flagged sites

Using Avatar machine learning, the 192-beamline inspection summary is accurate and usable within time constraints



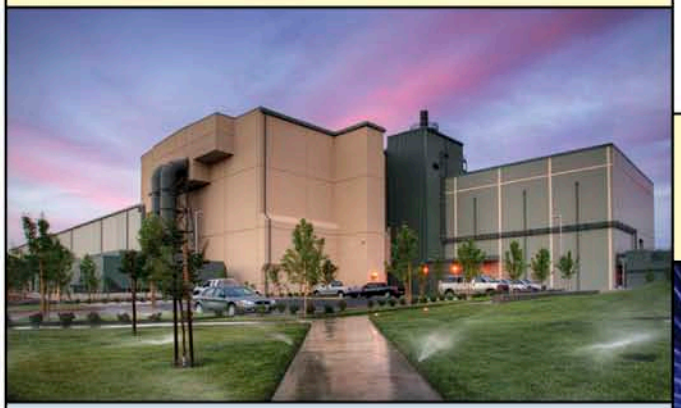
"It will be through the use of technologies such as machine learning, … that will help to address this information overload.
By using such technologies, a computer will soon be able to sift through the data and present
… the most important areas of concern."

Drawbaugh (U Pittsburgh Medical Center) in Wired Magazine (July 30, 2008)


NIF

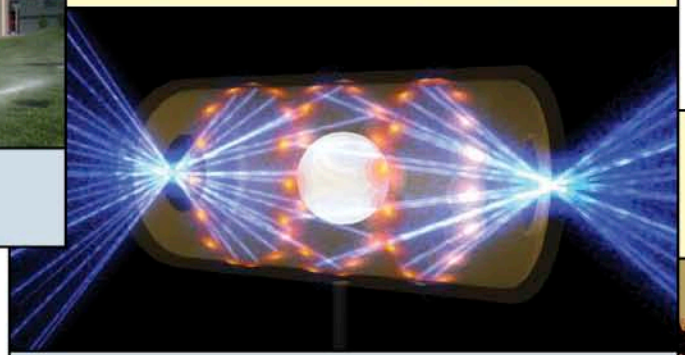
NIF Master Strategy

NIF Project



Operational

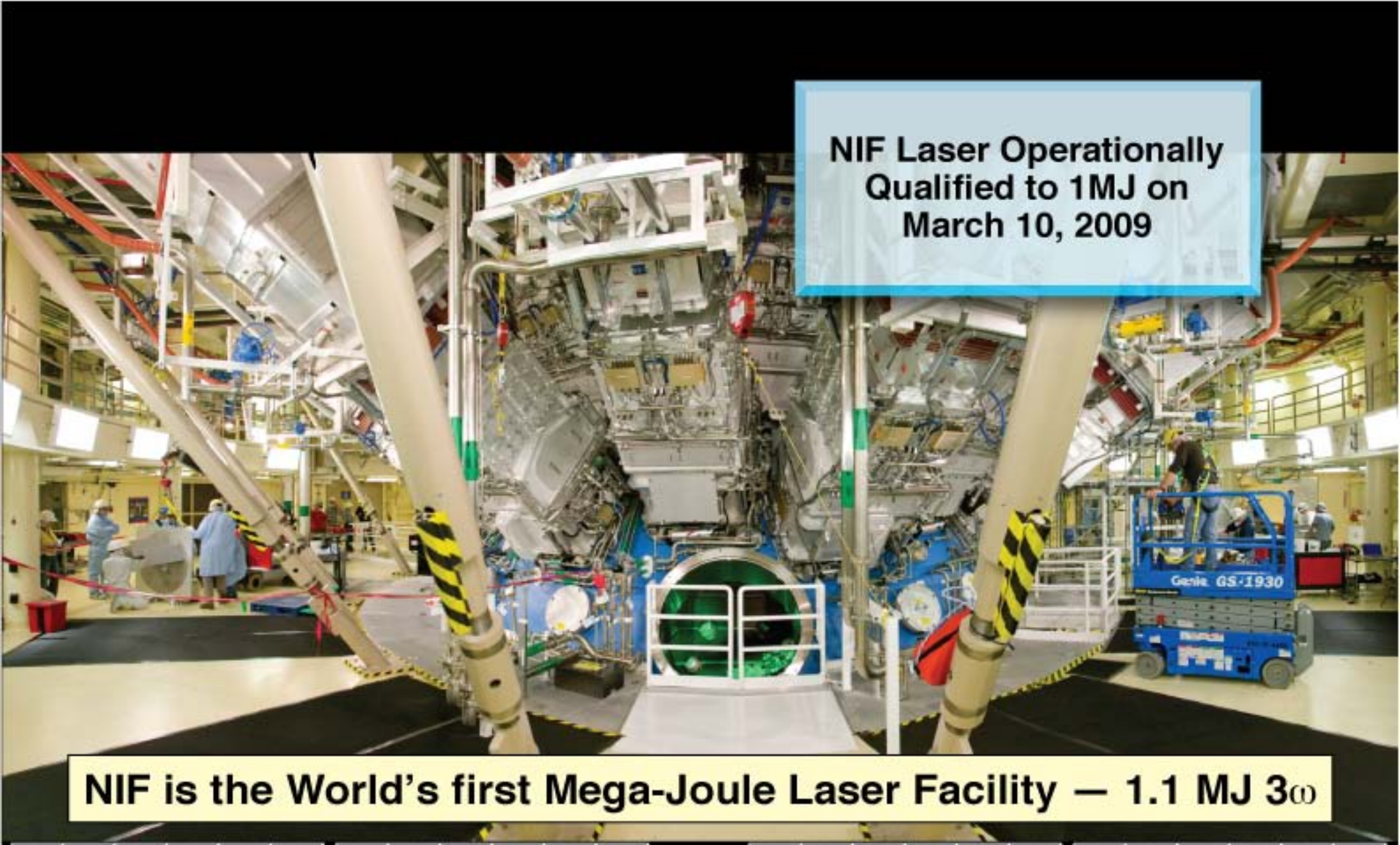
National Ignition Campaign



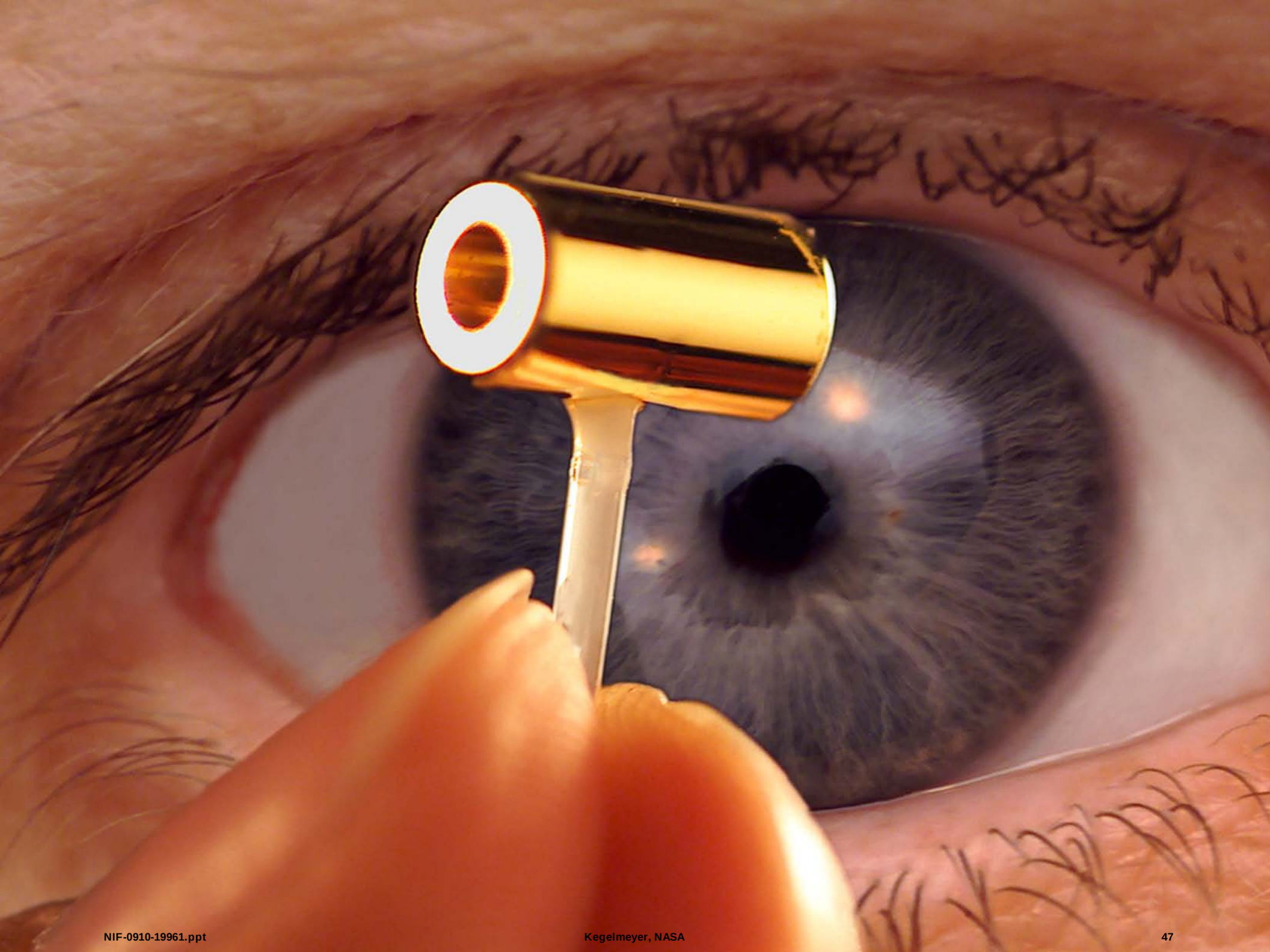
2006–2012

National User Facility

2009–2030

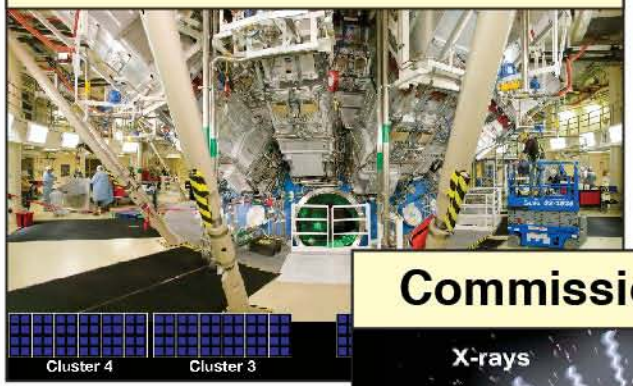


NIF-0109-15860r3
11MLS/cld

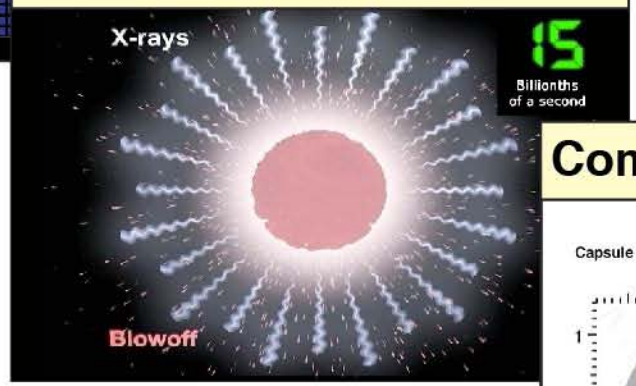


Four steps to ignition

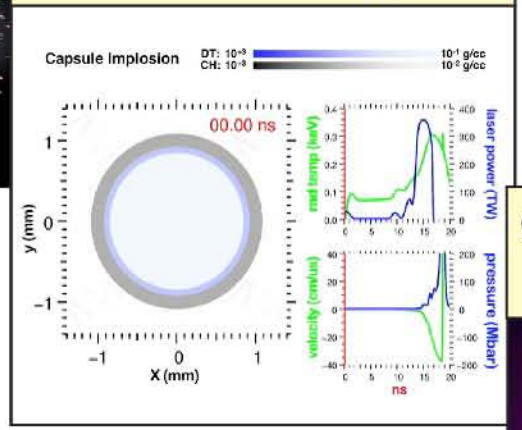
Commission laser



Commission hohlraum

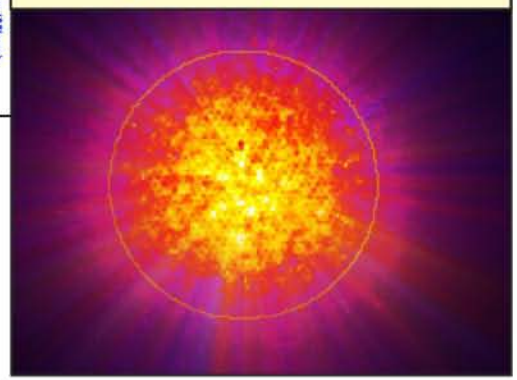


Commission capsule

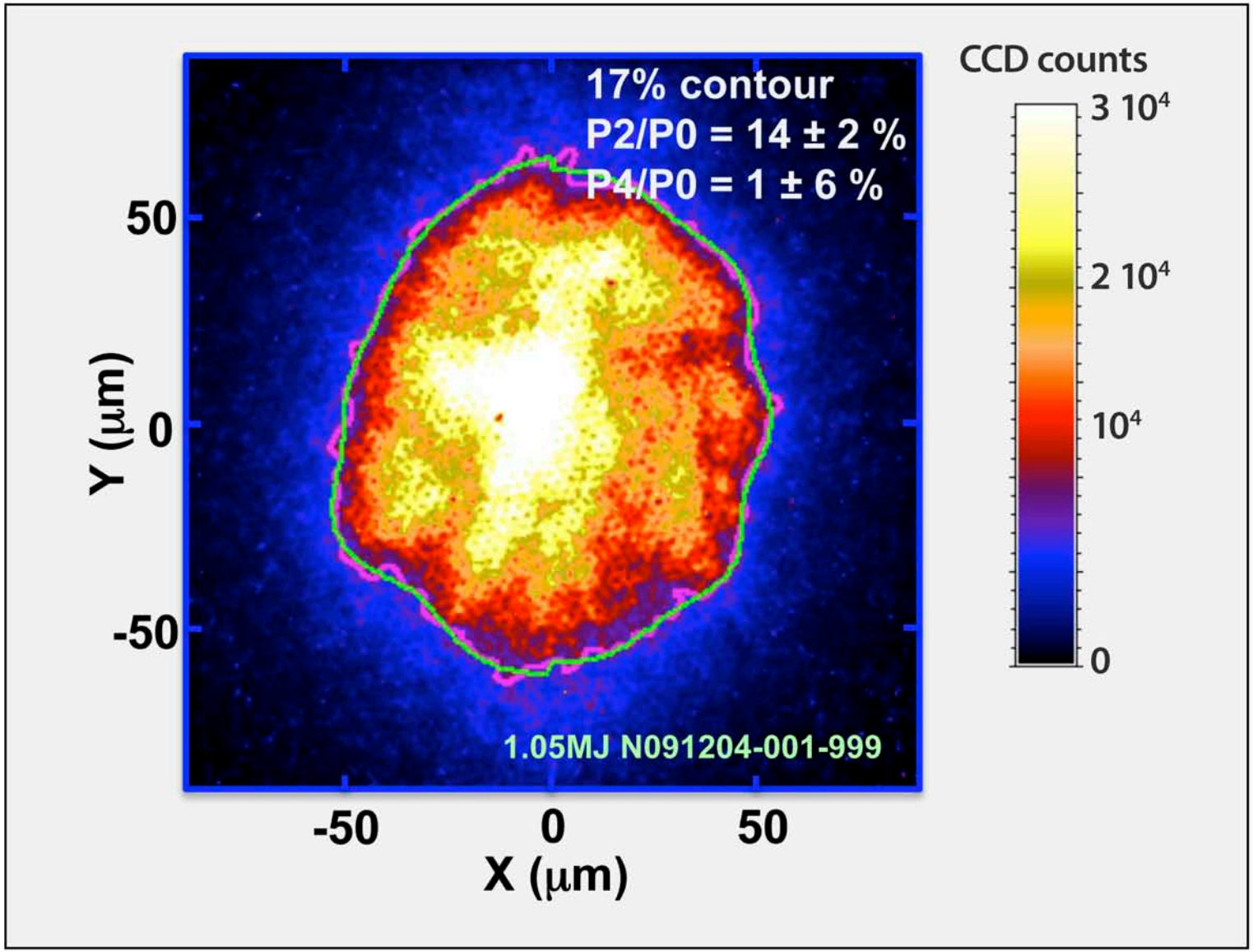


We are taking a systematic approach to learning and improving our enginering design to achieve ignition

Commission layered target implosions



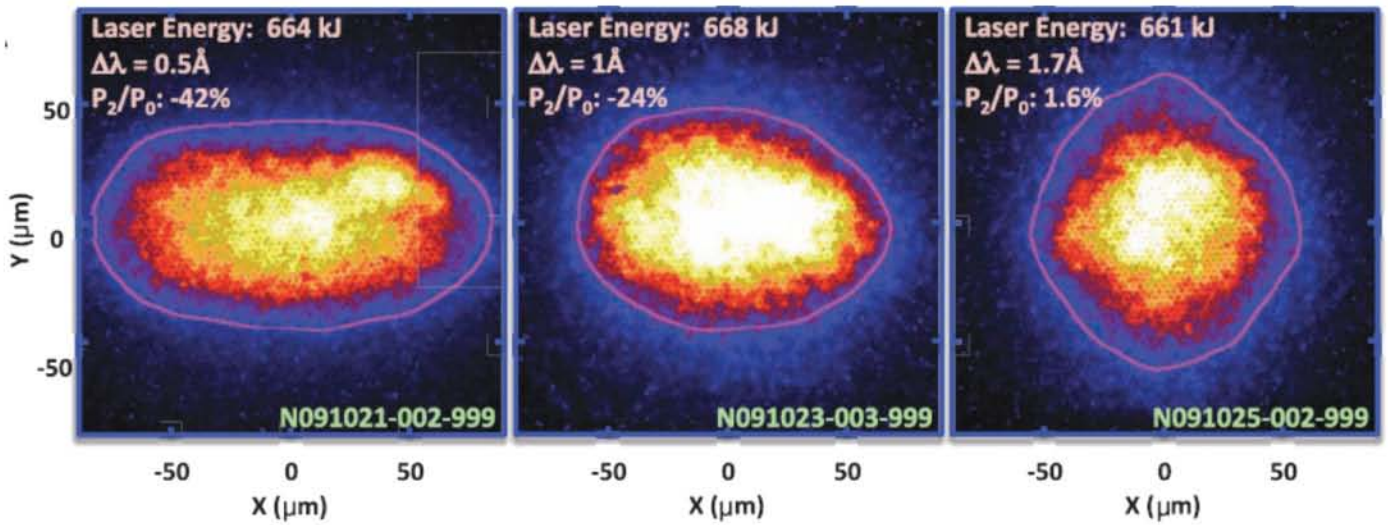
Capsule implosions in 1 MJ cryogenic gas-filled hohlraum have shown good symmetry at 284 eV



Recent publication in SCIENCE – March 5, 2010

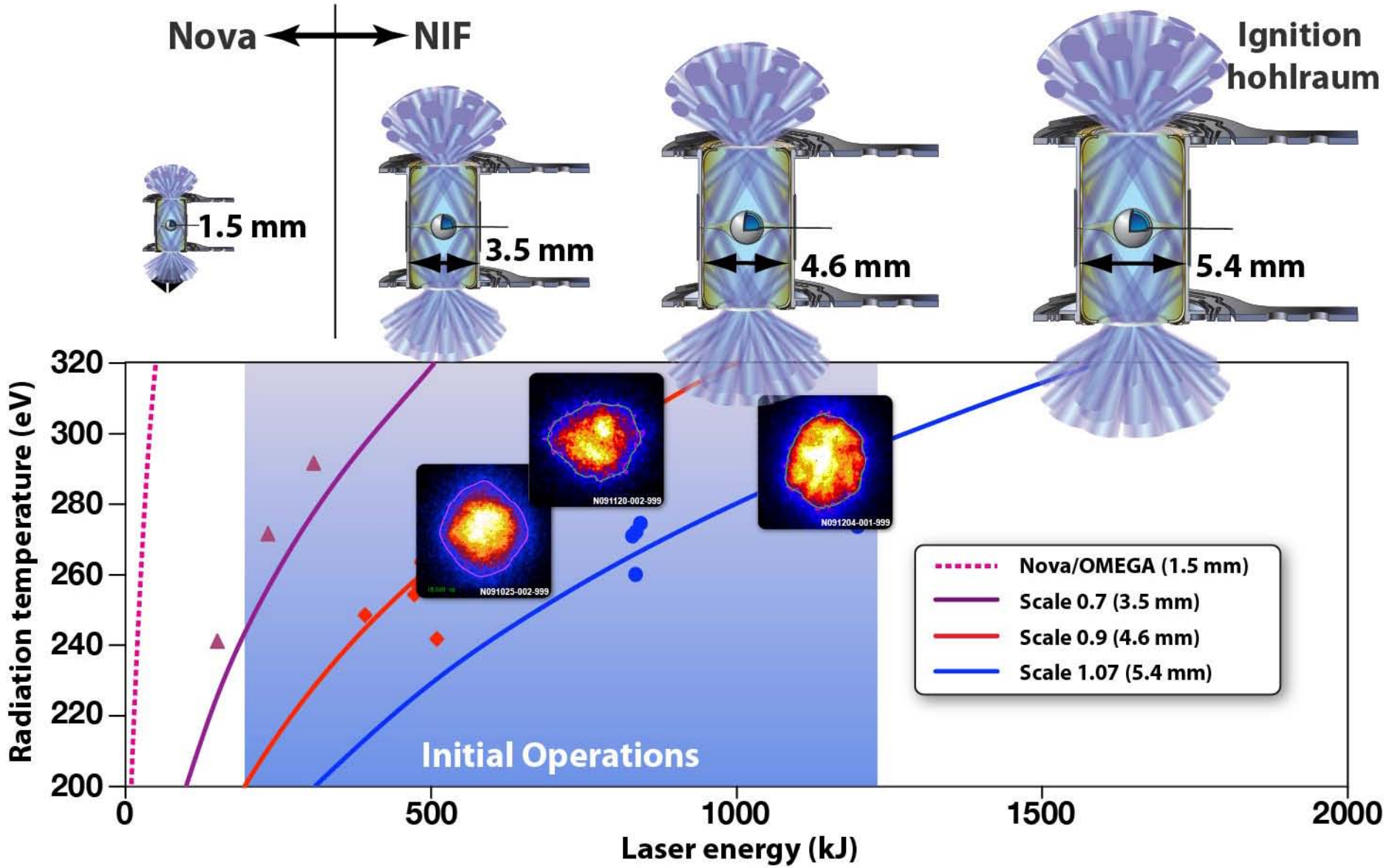
Symmetric Inertial Confinement Fusion Implosions at Ultra-High Laser Energies

S. H. Glenzer,[1*] B. J. MacGowan,[1] P. Michel,[1] N. B. Meezan,[1] L. J. Suter,[1] S. N. Dixit,[1] J. L. Kline,[2] G. A. Kyrala,[2] D. K. Bradley,[1] D. A. Callahan,[1] E. L. Dewald,[1] L. Divol,[1] E. Dzenitis,[1] M. J. Edwards,[1] A. V. Hamza,[1] C. A. Haynam,[1] D. E. Hinkel,[1] D. H. Kalantar,[1] J. D. Kilkenny,[3] O. L. Landen,[1] J. D. Lindl,[1] S. LePape,[1] J. D. Moody,[1] A. Nikroo,[3] T. Parham,[1] M. B. Schneider,[1] R. P. J. Town,[1] P. Wegner,[1] K. Widmann,[1] P. Whitman,[1] B. K. F. Young,[1] B. Van Wonterghem,[1] L. J. Atherton,[1] E. I. Moses[1]



Reports on NIC use of LPI in the Laser entrance holes of NIF hohlraums to achieve symmetrical implosions of cryogenic target capsules

We have demonstrated hohlraums that scale to ignition conditions



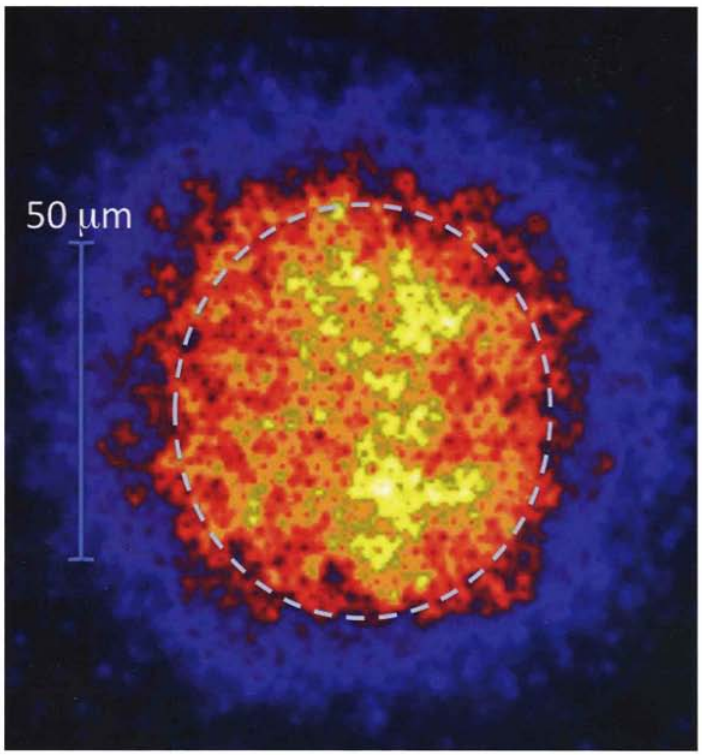
BULLETIN

OF THE AMERICAN PHYSICAL SOCIETY

51st Annual Meeting of the Division of Plasma Physics

November 2–6, 2009

Atlanta, Georgia



November 2009

Volume 54, No. 15

APS physics


"This laser technology has the potential to revolutionize our energy future. . . This type of innovation is why we are a world leader in science, technology, and clean energy, and I could not be prouder that this work is happening right here in California."
— Governor Schwarzenegger
NIF-0409-16228
23EM/bc