Science at the Jupiter Laser Facility

Pravesh Patel

September 6, 2009

LLNL-PRES-417830

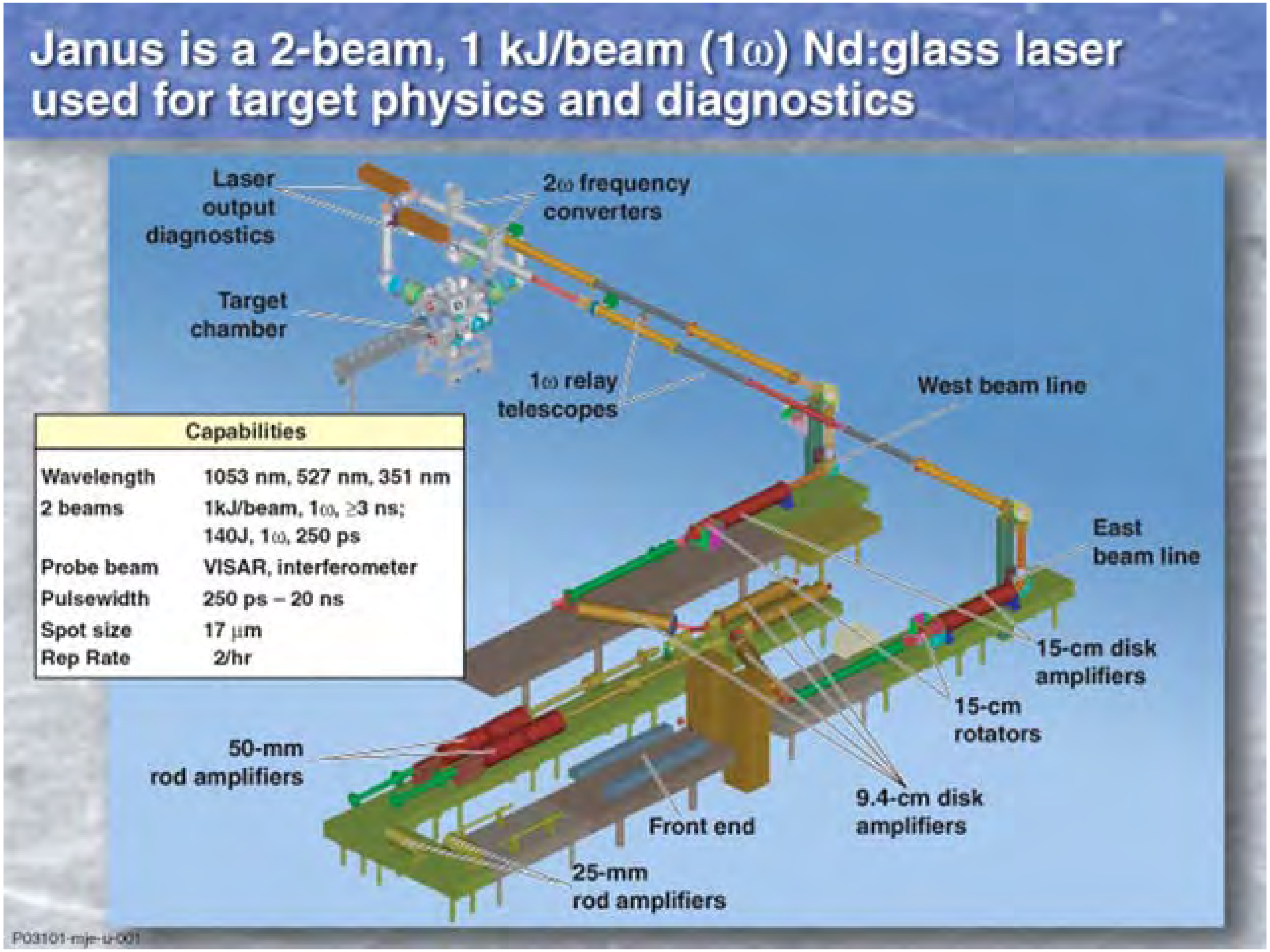
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

JLF is a premier research facility for HED Science

- Relativistic Laser Absorption
- Warm Dense Matter
- Material Strength
- Fast Ignition
- EOS
- Opacity
- X-ray Lasers
- Proton Acceleration
- Relativistic Pair Plasmas
- Laser Wakefield Acceleration

- Thermal Broadband Backlighting
- Compton Radiography
- K-alpha Radiography
- Proton Radiography
- X-ray Diffraction
- X-ray Interferometry
- X-ray Thomson Scattering
- NIF Diagnostic Development

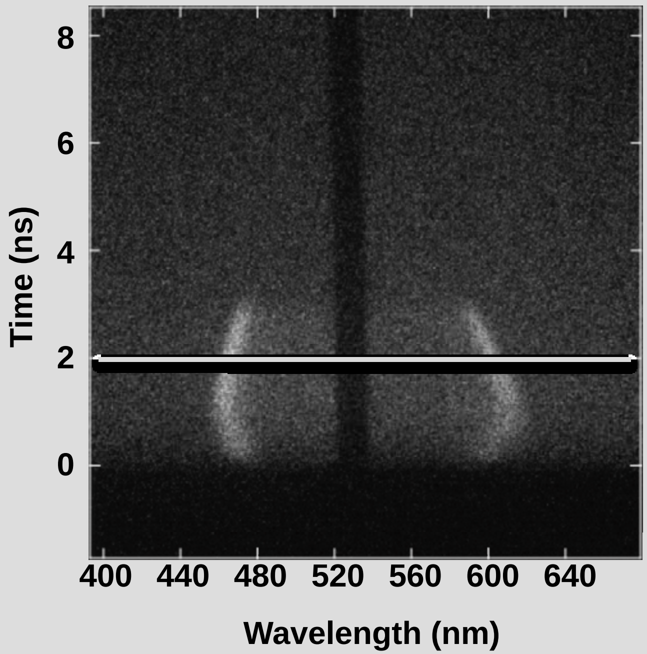
Janus has enabled three decades of research in ICF, plasma physics, EOS, material properties, LPI, more…



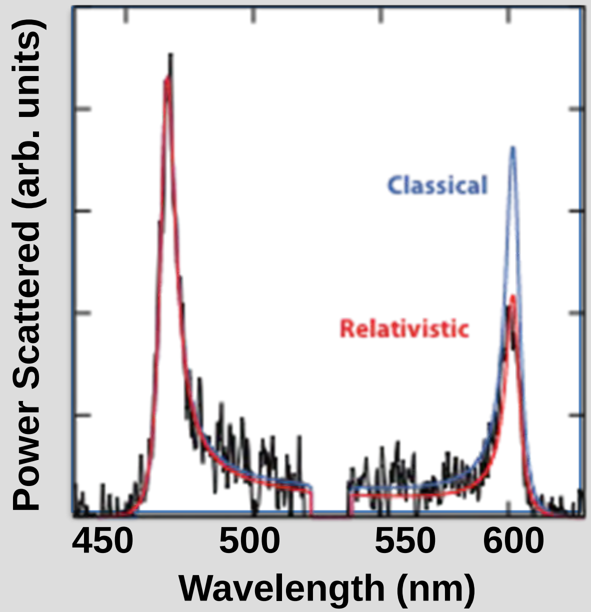
The first measurements of relativistic effects in collective Thomson scattering were demonstrated on Janus

J. S Ross, G. Tynan (UCSD)
D. H. Froula, J. Palastro (LLNL)

Thomson scattering from electron-plasma waves in a T_e~200 eV, N_e~10^{19} cm^{-3}, gas-jet plasma



Thomson-scattering form factor including relativistic effects shows excellent agreement with measurement

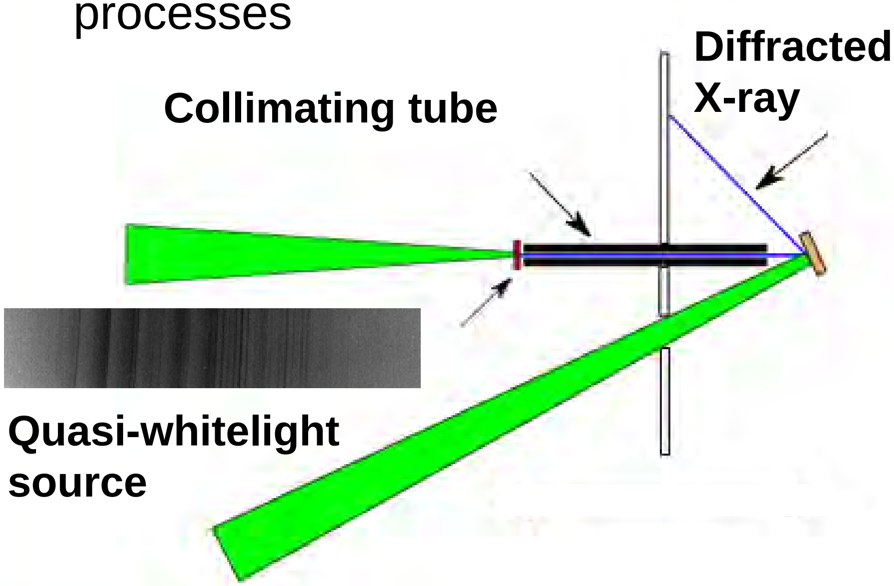


In preparation for Phys. Rev. Lett.

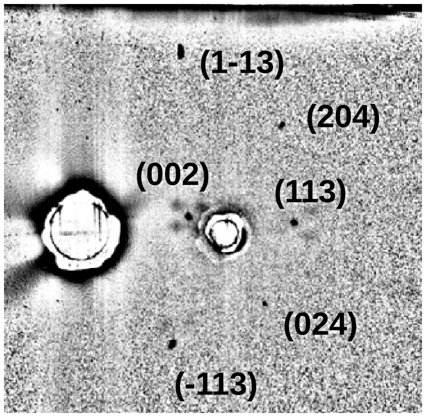
Dynamic Whitelight Laue is a new diagnostic technique spearheaded by the University of Oxford

J. Wark (University of Oxford)
N. Park (AWE)
J. Hawreliak, B. Remington (LLNL)

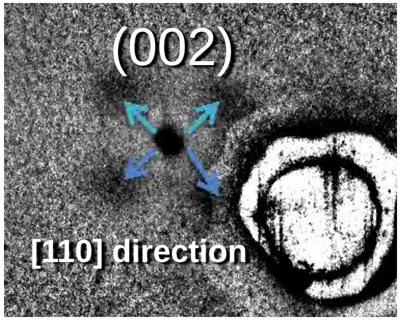
- Mixed element foil is used to generate a broadband source
- X-rays diffracted from single crystal samples provide nsec resolution to investigate dynamic material processes



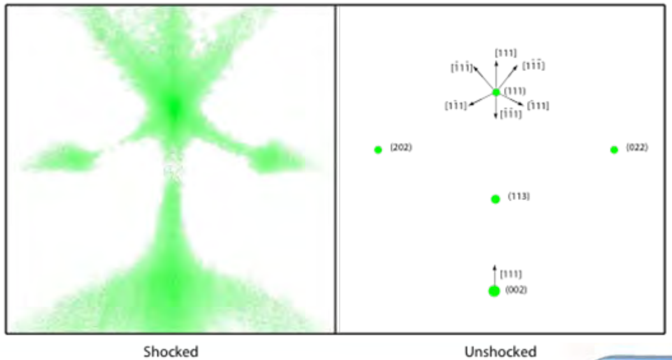
Dynamic Broadband experiments



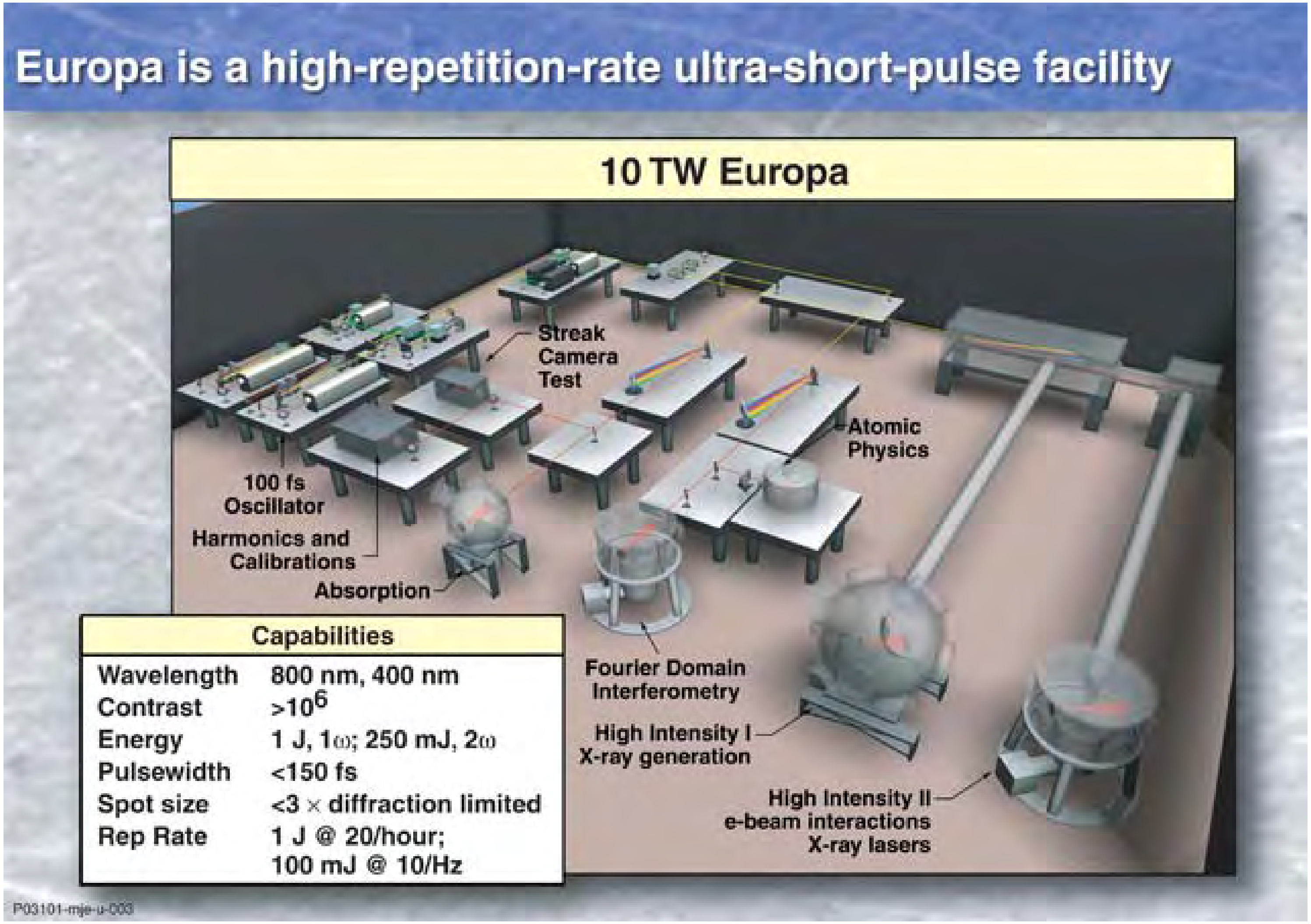
Experimental Data
Janus May 2009



Simulated Diffraction from MD

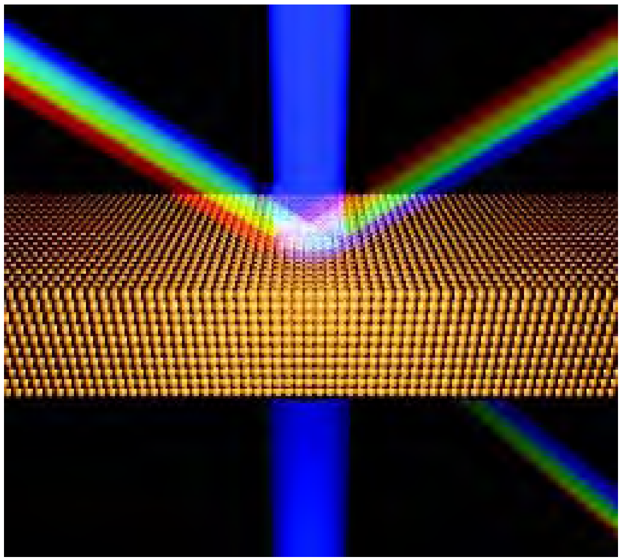


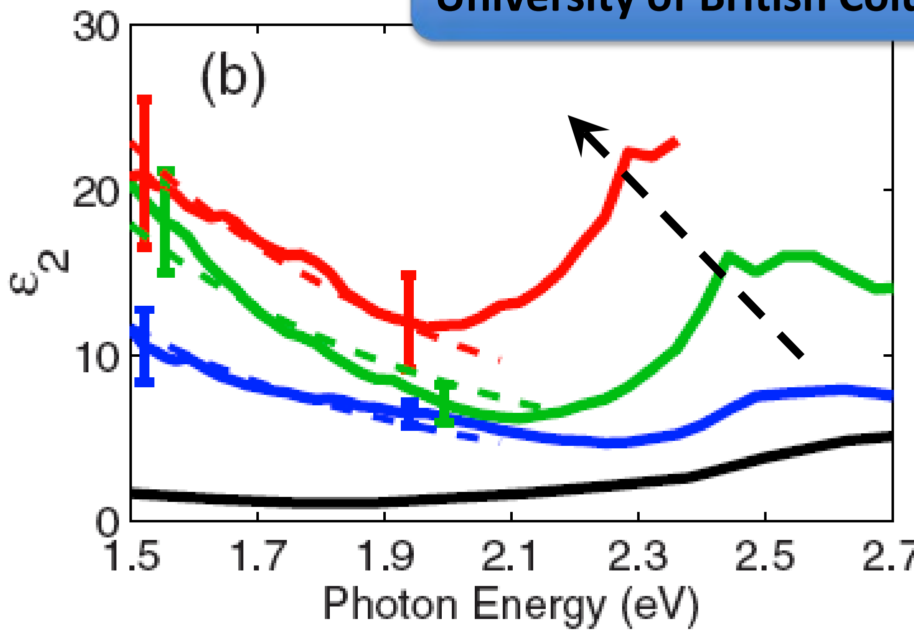
Europa was built as a high rep-rate, ultrashort-pulse laser with multiple chambers for simultaneous experiments



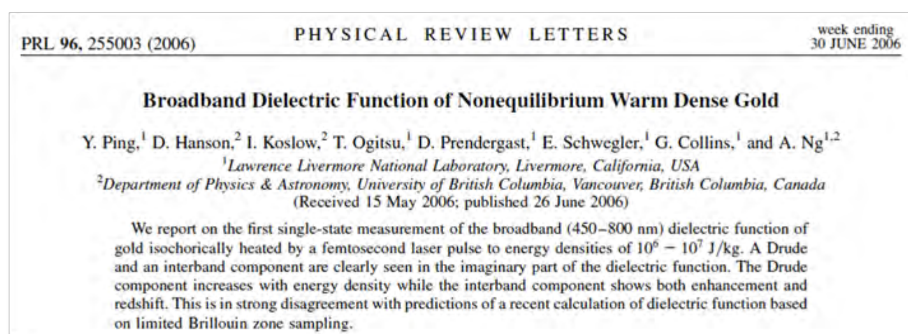
Pump-probe experiments on USP measured the dielectric function of warm dense gold

Y. Ping (LLNL)
University of British Columbia





- Warm dense matter is created by isochoric laser heating of free-standing nano-foils. The ultrafast excitation leads to a non-equilibrium state with Te>> Ti.
- A super-continuum probe is employed to measure the evolution of both intraband and interband transitions.



PRL 96, 255003 (2006) PHYSICAL REVIEW LETTERS week ending 30 JUNE 2006

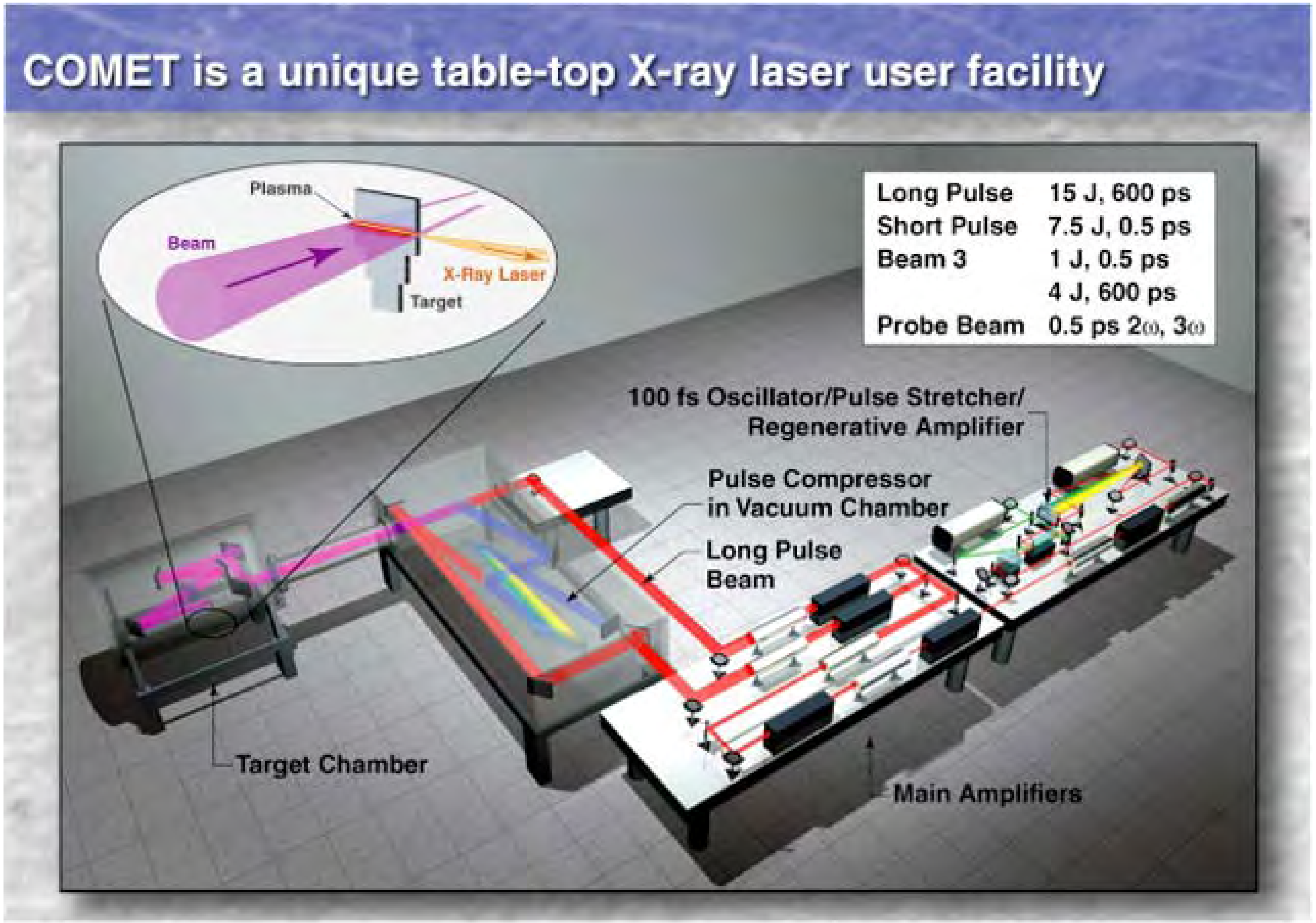
Broadband Dielectric Function of Nonequilibrium Warm Dense Gold

Y. Ping,[1] D. Hanson,[2] I. Koslow,[2] T. Ogitsu,[1] D. Prendergast,[1] E. Schwegler,[1] G. Collins,[1] and A. Ng[1,2]
[1]*Lawrence Livermore National Laboratory, Livermore, California, USA*
[2]*Department of Physics & Astronomy, University of British Columbia, Vancouver, British Columbia, Canada*

(Received 15 May 2006; published 26 June 2006)

We report on the first single-state measurement of the broadband (450–800 nm) dielectric function of gold isochorically heated by a femtosecond laser pulse to energy densities of $10^6 - 10^7$ J/kg. A Drude and an interband component are clearly seen in the imaginary part of the dielectric function. The Drude component increases with energy density while the interband component shows both enhancement and redshift. This is in strong disagreement with predictions of a recent calculation of dielectric function based on limited Brillouin zone sampling.

COMET was the first LLNL laser combining long-pulse and short-pulse beams



X-ray lasers provide unique, ultrabright sources for dynamic probing of materials and dense plasmas

J. Dunn et al. (LLNL)
J. Rocca (Colorado State University)
S. Shlyaptsev (UC Davis)

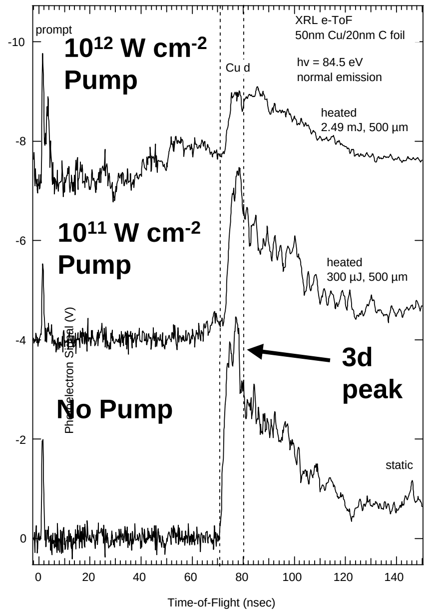
APPLIED PHYSICS LETTERS VOLUME 85, NUMBER 25 20 DECEMBER 2004

X-ray laser-induced photoelectron spectroscopy for single-state measurements

A. J. Nelson, J. Dunn, T. van Buuren, and J. Hunter
Lawrence Livermore National Laboratory, Livermore, California 94551

(Received 21 July 2004; accepted 25 October 2004)

We demonstrate single-shot x-ray laser-induced time-of-flight photoelectron spectroscopy on metal and semiconductor surfaces with picosecond time resolution. Our compact multipulse terawatt tabletop x-ray laser source provides the necessary high photon flux ($>10^{12}$/pulse), monochromaticity, picosecond pulse duration, and coherence for probing ultrafast changes in the chemical and electronic structure of these materials. Static valence band and shallow core-level photoemission spectra are presented for ambient temperature polycrystalline Cu foils and Ge(100). Surface contamination was removed by UV ozone cleaning prior to analysis. The ultrafast nature of this technique lends itself to true single-state measurements of shocked and heated materials. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1841473]



Photoemission spectroscopy of laser-heated Cu foils tracks the depopulation of 3d electronic states during heating

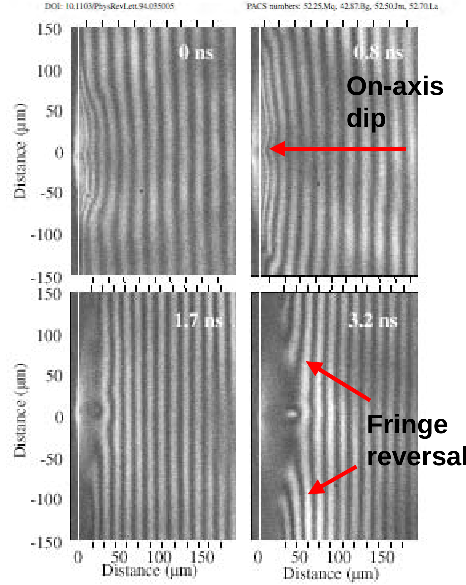
PRL 94, 035005 (2005) PHYSICAL REVIEW LETTERS

Observation of a Multiply Ionized Plasma with Index of Refraction Gr

J. Filevich,* J. J. Rocca, and M. C. Marconi
NSF ERC for Extreme Ultraviolet Science and Technology and Department of Electrical and Co
Colorado State University, Fort Collins, Colorado 80523, USA
S. J. Moon, J. Nilsen, J. H. Scofield, J. Dunn, R. F. Smith, R. Keenan, and J. R. H
Lawrence Livermore National Laboratory, Livermore, California 94550, USA
V. N. Shlyaptsev
Department of Applied Science, University of California Davis-Livermore, Livermore, California 94451, USA
(Received 5 July 2004; published 27 January 2005)

We present clear experimental evidence showing that the contribution of bound electrons can dominate the index of refraction of laser-created plasmas at soft x-ray wavelengths. We report anomalous fringe shifts in soft x-ray laser interferograms of Al laser-created plasmas. The comparison of measured and simulated interferograms shows that this results from the dominant contribution of low charge ions to the index of refraction. This usually neglected bound electron contribution can affect the propagation of soft x-ray radiation in plasmas and the interferometric diagnostics of plasmas for many elements.

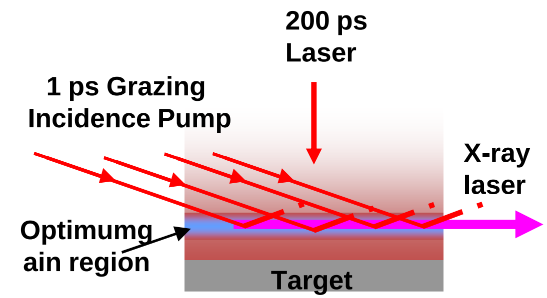
DOI: 10.1103/PhysRevLett.94.035005 PACS numbers: 52.25.Mq, 42.87.Bg, 52.50.Jm, 52.70.La

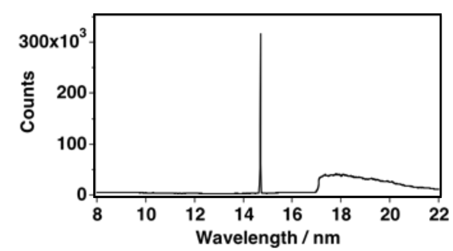


X-ray laser interferometry at 14.7 nm of laser-produced Al plasma revealed new high density plasma phenomena

We have demonstrated a 10 Hz Ni-like Mo x-ray laser operating at 18.9 nm with 150 mJ total pump energy by employing a novel pumping scheme. The grazing-incidence scheme is described, where a picosecond pulse is incident at a grazing angle to a Mo plasma column produced by a slab target irradiated by a 200 ps laser pulse. This scheme uses refraction of the short pulse at a predetermined electron density to increase absorption to pump a specific gain region. The higher coupling efficiency inherent to this scheme allows a reduction in the pump energy where 70 mJ long pulse energy and 80 mJ short pulse energy are sufficient to produce lasing at a 10 Hz repetition rate. Under these conditions and by optimizing the delay between the pulses, we achieve strong amplification and close to saturation for 4 mm long targets.

DOI: 10.1103/PhysRevLett.94.103901 PACS numbers: 42.55.Vc, 32.30.Rj, 42.60.By, 52.50.Jm

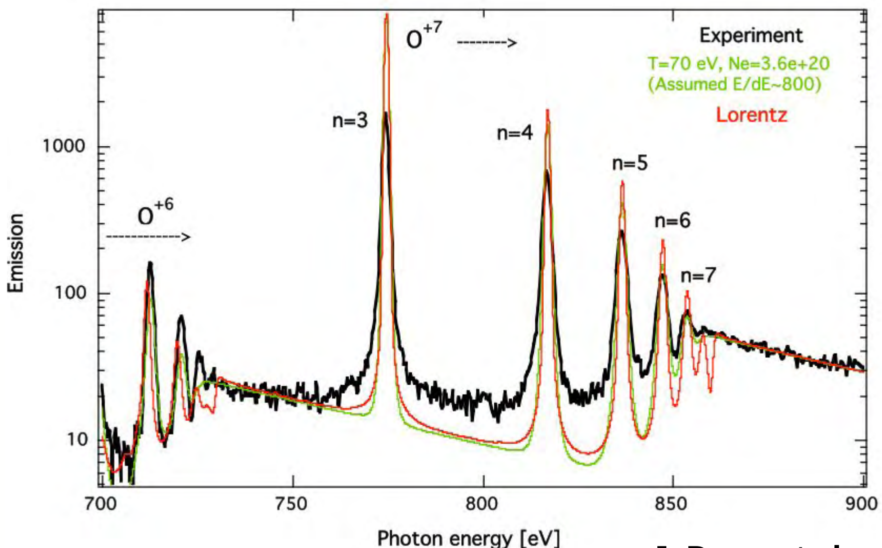




A new concept for high rep-rate (10 Hz), high efficiency X-ray laser was demonstrated on the JLF "tabletop" lasers at 18.9 nm

Recently, an experimental platform for line emission opacity measurements has been developed on COMET

High *n* lineshape measurements to test LLNL OPAL code



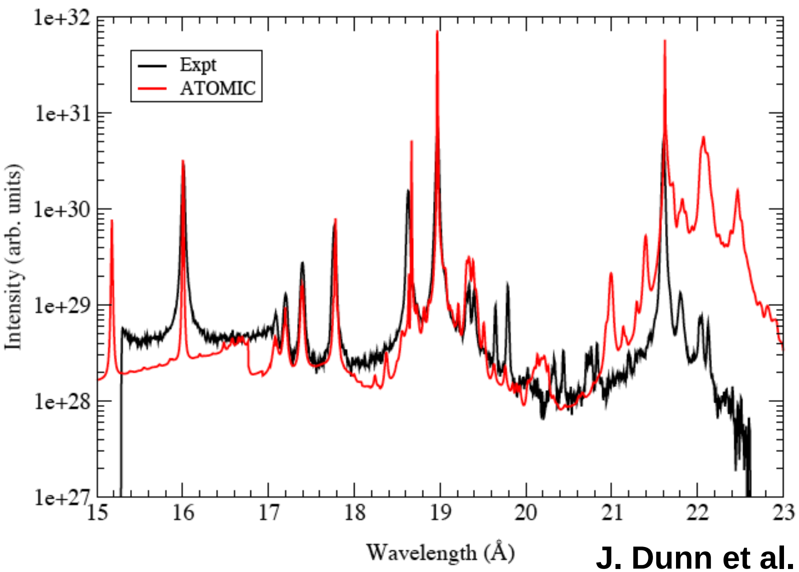
J. Dunn et al.

Laser and Target Parameters:
λ: 527 nm
t: 150 ps (FWHM) Gauss.
E: 4.0 J
Focus ~20 μm (FWHM) Gauss.
I = 5×10^{15} W cm^{-2}.
Target material: 3 μm foil Mylar ($C_{10}H_8O_4$) ρ 1.4 gm cm^{-3}

*OPAL Voigt with a cut-off from second-order line shape theory

*C.A. Iglesias, B. Wilson, LLNL OPAL calculations (2008)

Satellite struture measurements to test LANL ATOMIC code



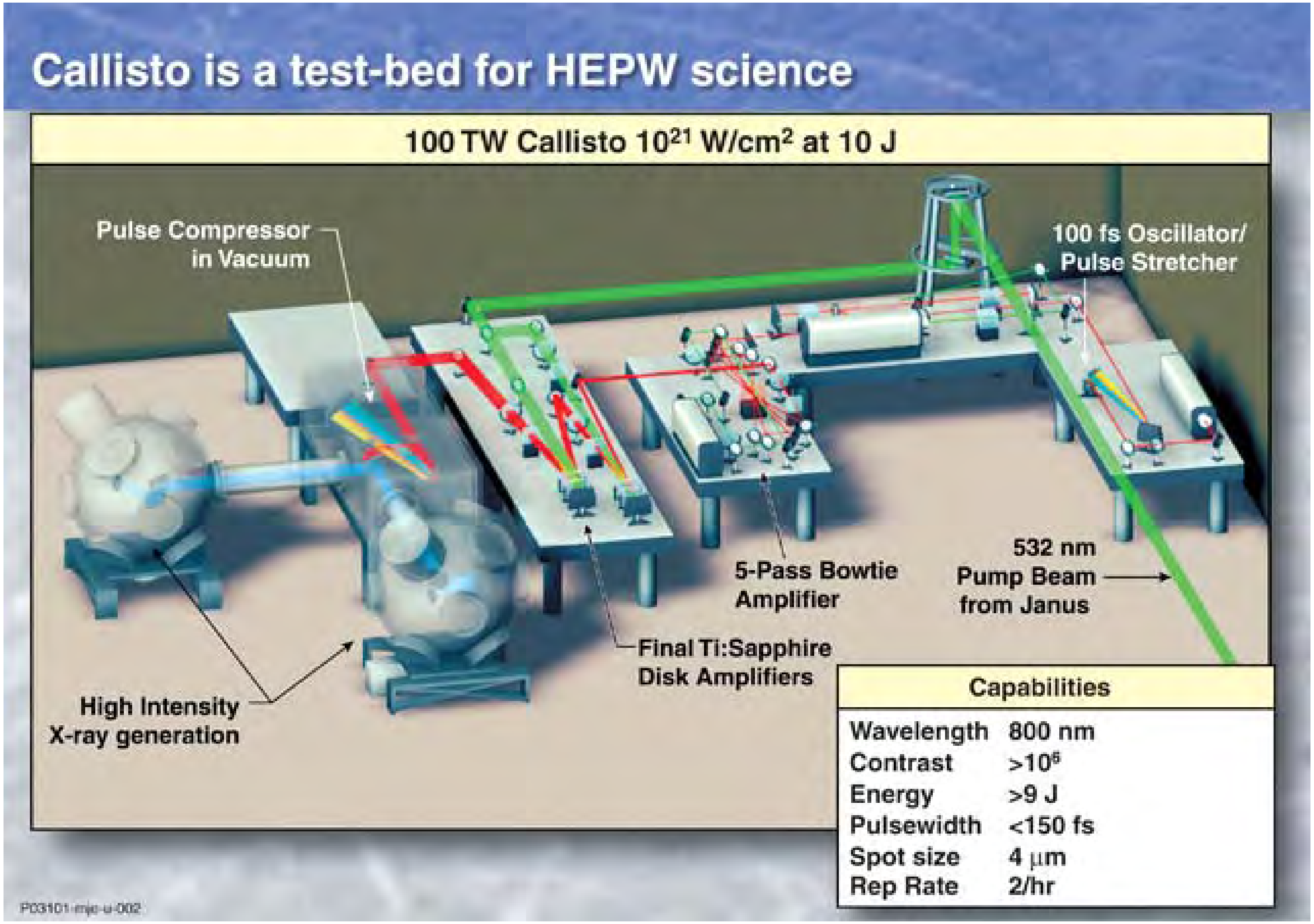
J. Dunn et al.

'Mixed' Two temperature spectra:
-99% hot, less dense (T_e = 150 eV, N_e = 3.6 x 10^{20} cm^{-3})
-1% colder, denser (T_e = 60 eV, Ne = 5 x 10^{22} cm^{-3})

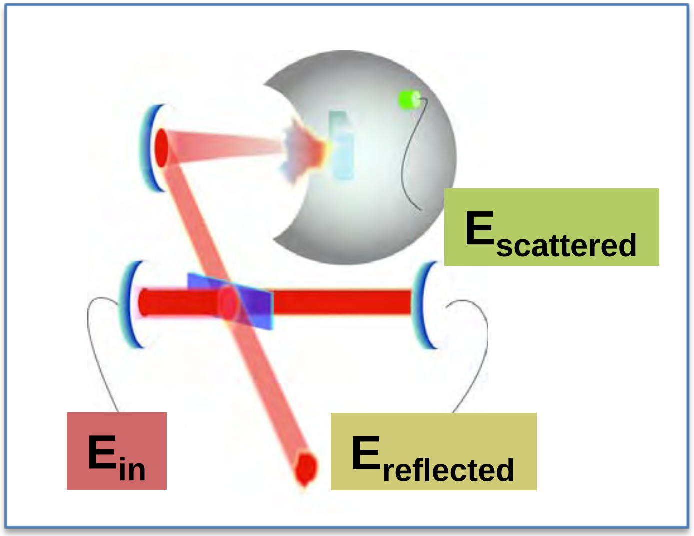
J. Colgan, J. Abdallah, Jr., C. J. Fontes, D. P. Kilcrease, J. Dunn, and R. W. Lee in preparation for HEDP (2009)

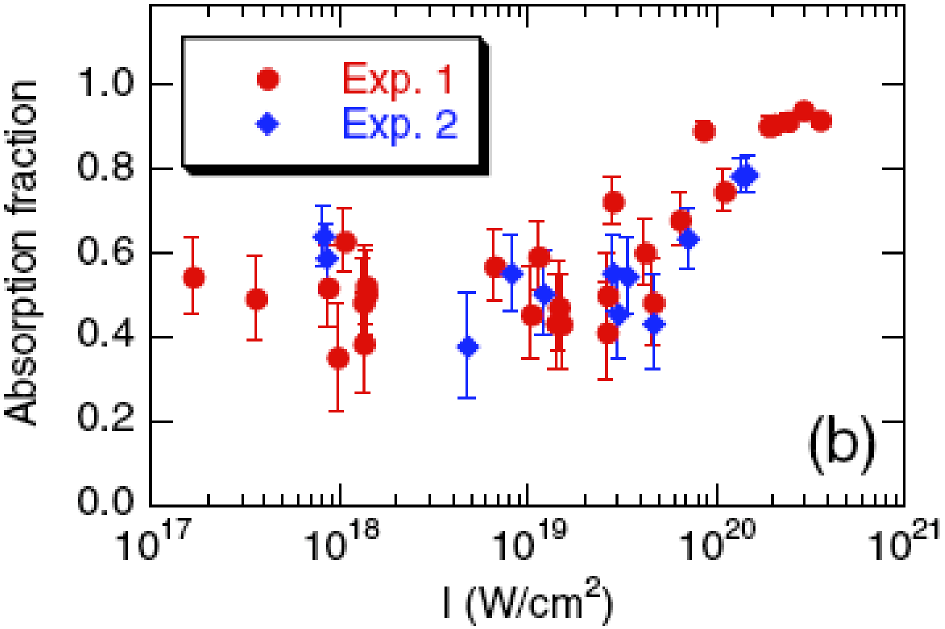
**J. Colgan, J. Abdallah, Jr., C. J. Fontes, D. P. Kilcrease, LANL ATOMIC code calculations (2009)

Callisto is an ultrahigh intensity laser used to study relativistic laser-plasma interaction physics



Callisto has been used to study laser absorption at ultra-relativistic laser intensities



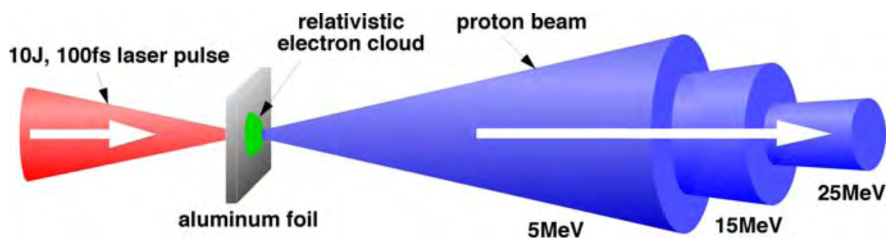


- Absorption reaches 80-90% for 45p at intensities above 10^{20} W/cm^2.
- Both preplasma and hole boring effects contribute to the enhanced absorption in the ultra-relativistic regime.
- 2D PIC simulations show that of ~90% absorbed energy, ~60% goes to hot electrons, and the rest to ion acceleration, field generation and hydro motion.

Ping et al. Phys. Rev. Lett. 100, 085004 (2008)

Generation of intense proton beams was studied, and applications developed in isochoric heating/radiography

Ultraintense proton beam generation on the Callisto laser



VOLUME 88, NUMBER 21 PHYSICAL REVIEW LETTERS 27 MAY 2002

Enhancement of Proton Acceleration by Hot-Electron Recirculation in Thin Foils Irradiated by Ultraintense Laser Pulses

A. J. Mackinnon,[1] Y. Sentoku,[2] P. K. Patel,[1] D. W. Price,[1] S. Hatchett,[1] M. H. Key,[1] C. Andersen,[3] R. Snavely,[3] and R. R. Freeman[3]

VOLUME 91, NUMBER 12 PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2003

Isochoric Heating of Solid-Density Matter with an Ultrafast Proton Beam

P. K. Patel,[1] A. J. Mackinnon,[1] M. H. Key,[1] T. E. Cowan,[2] M. E. Foord,[1] M. Allen,[1] D. F. Price,[1] H. Ruhl,[2] P. T. Springer,[1] and R. Stephens[3]

VOLUME 92, NUMBER 5 PHYSICAL REVIEW LETTERS week ending 6 FEBRUARY 2004

Multi-MeV Proton Source Investigations in Ultraintense Laser-Foil Interactions

M. Borghesi,[1] A. J. Mackinnon,[2] D. H. Campbell,[3] D. G. Hicks,[2] S. Kar,[1] P. K. Patel,[2] D. Price,[2] L. Romagnani,[1] A. Schiavi,[4] and O. Willi[5]

PRL 93, 265004 (2004) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2004

Direct Experimental Evidence of Back-Surface Ion Acceleration from Laser-Irradiated Gold Foils

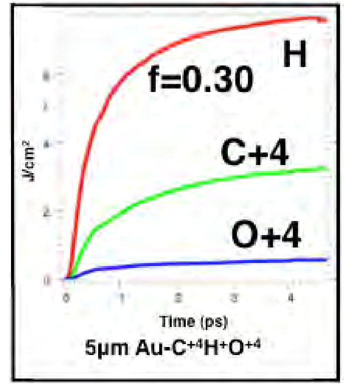
Matthew Allen,[1,2,*] Pravesh K. Patel,[2] Andrew Mackinnon,[2] Dwight Price,[2] Scott Wilks,[2] and Edward Morse[1]

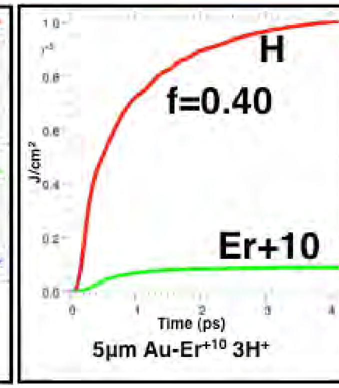
[1]*Department of Nuclear Engineering, University of California, Berkeley, California 94720, USA*

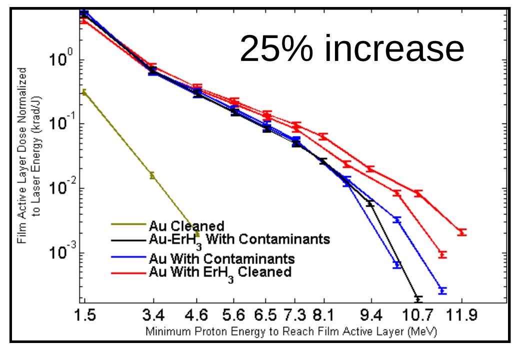
[2]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*

(Received 17 February 2004; published 29 December 2004)

Effects of heavy ions on proton acceleration







Enhanced proton production from hydride-coated foils
M.E. Foord et al. J. Appl. Phys. 103, 056106 (2008)

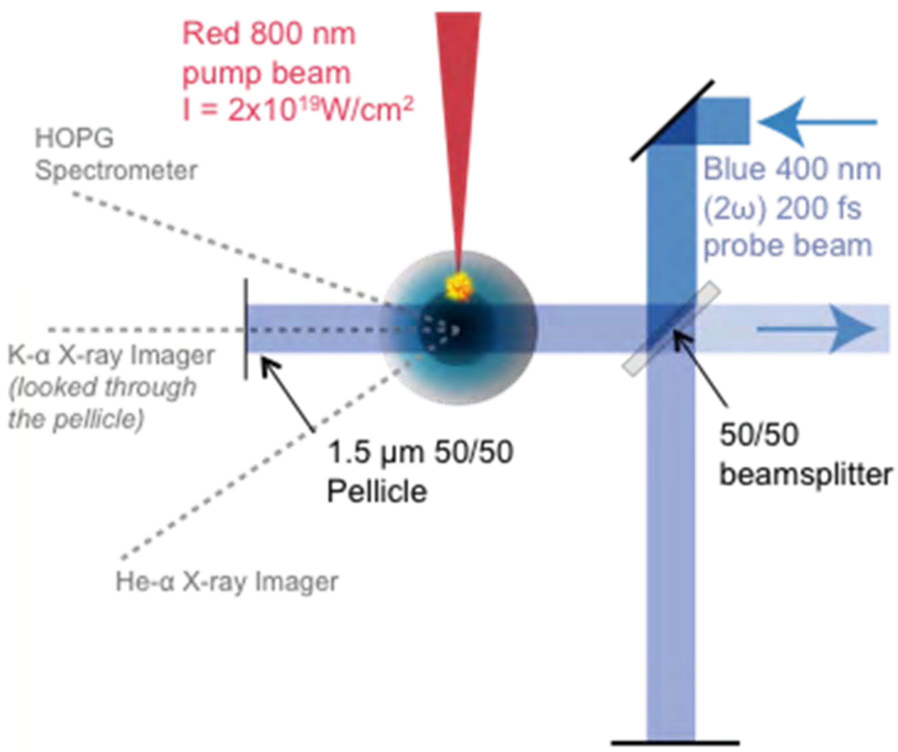
Observations of Proton Beam Enhancement Due to Erbium Hydride on Gold Foil Targets
D.T. Offermann et al. Phys. Plasmas, in print (2009)

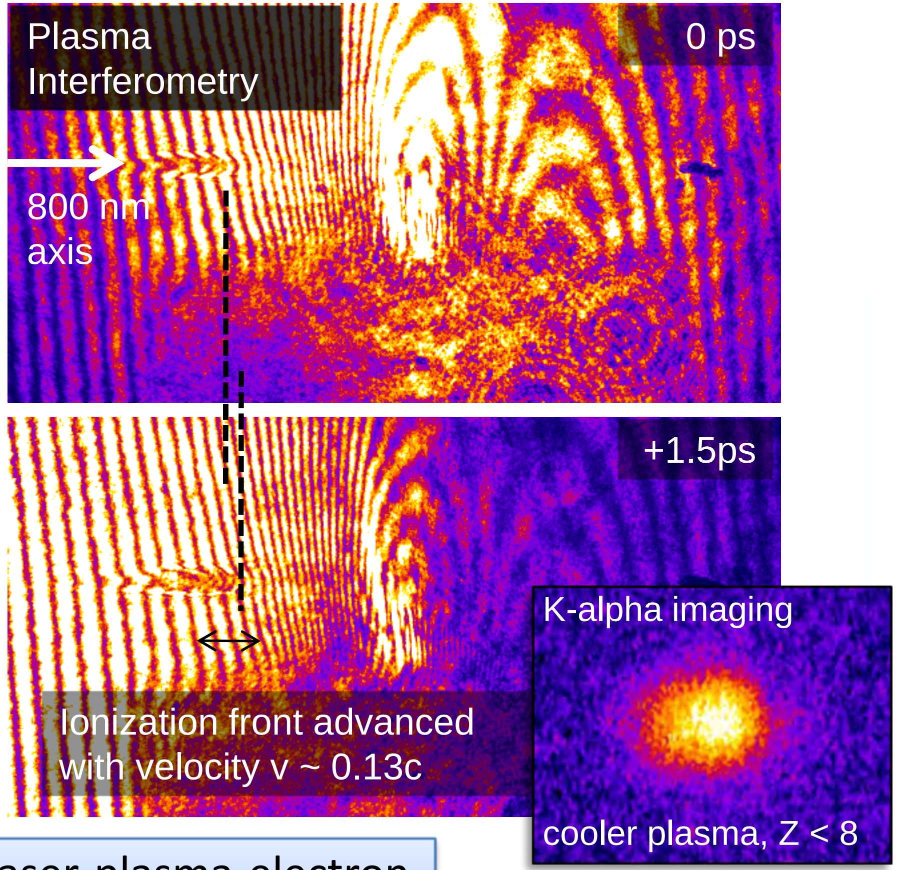
Ultrafast optical probing and x-ray imaging is being used to study high intensity laser channeling

Innovative Geometry for Simultaneous X-ray Imaging and Interferometry

UCLA

N. Kugland, C. Neimann (UCLA)
S. Glenzer (LLNL)





These experiments are studying high intensity laser-plasma-electron coupling physics and energy balance

Physical and Life SCIENCES

An LLNL/UCSD/UCLA collaboration is combining Callisto and Janus lasers to study Laser Wakefield Acceleration

These experiments are part of a strong university/LLNL collaboration

Lawrence Livermore National Laboratory

D. H. Froula, J. E. Ralph, F. Albert, T. Doeppner J. P. Palastro, P. Michel, L. Divol, S. H. Glenzer

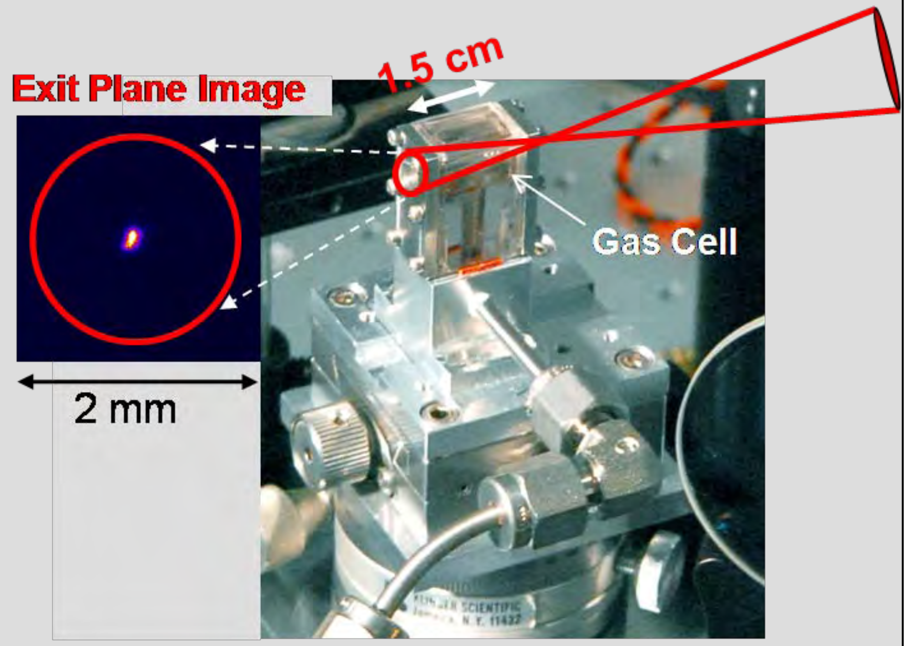
University of California at San Diego

B. B. Pollock, J. S. Ross, G. Tynan

University of California at Los Angeles

C. E. Clayton, S. Martins, A. Pak, K. A. Marsh, W. B. Mori, C. Joshi

A gas cell was used with laser powers up to 300 TW; highest power LWFA experiments to date

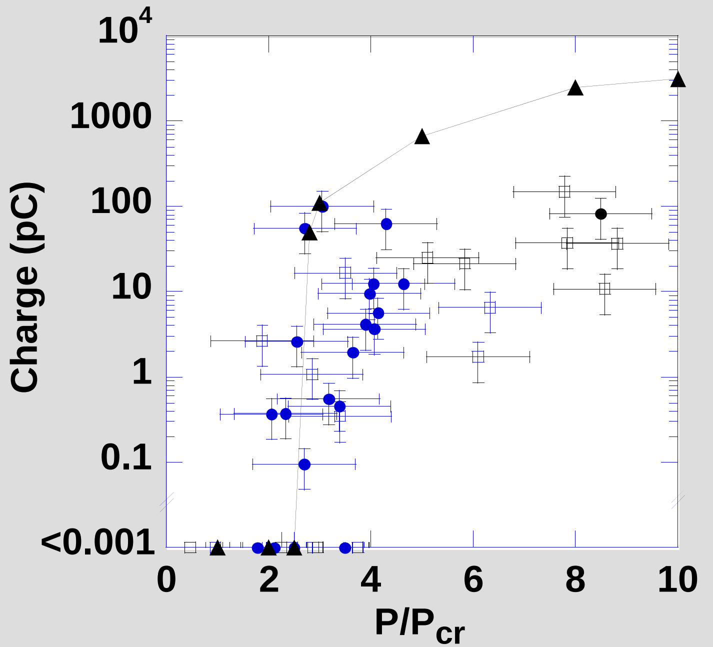


A 170 TW, 60 fs laser pulse was self-guided through a gas tube and measured to have <20 μm radius after propagating 1.5 cm

J. Ralph, Invited Talk at the upcoming DPP, Atlanta (2009)

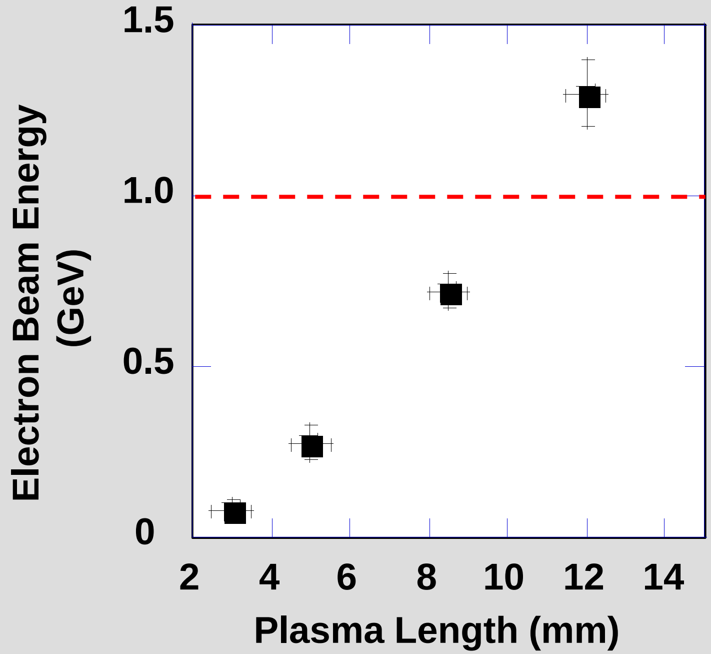
Self-guiding a 200 TW short pulse laser beam has accelerated electrons beyond 1 GeV

The self-injection threshold for LWFA was measured using 200TW/60fs



Froula et al., In Review Phys. Rev. Lett. (2009)

The acceleration length was scaled by increasing the plasma length

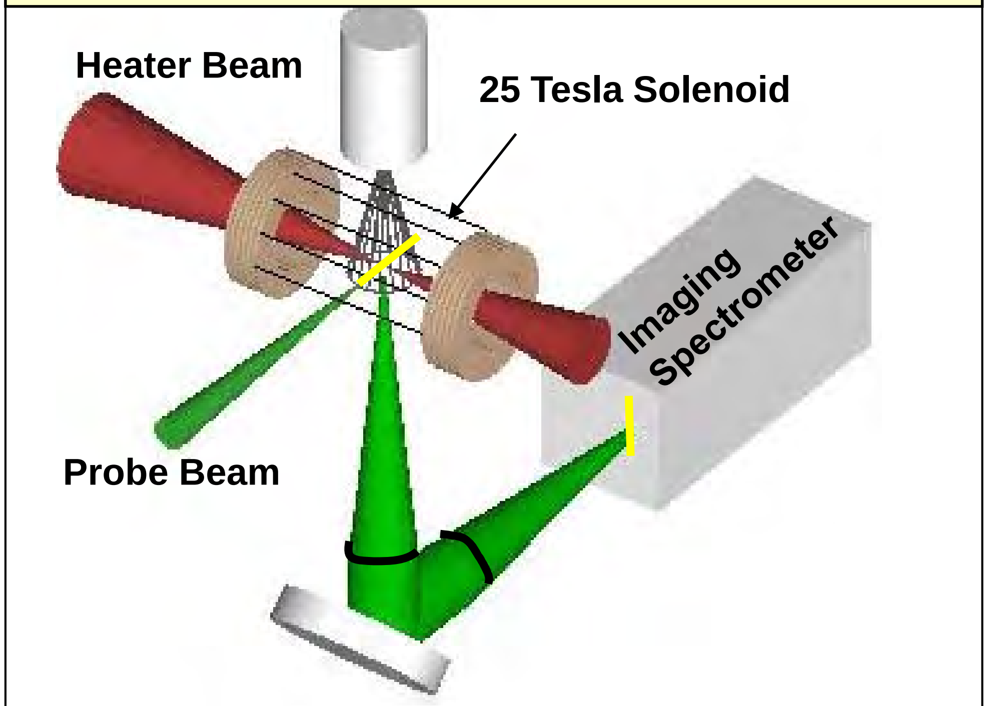


A novel injection method* was instrumental in accelerating >1.5 pC of charge over 1 GeV

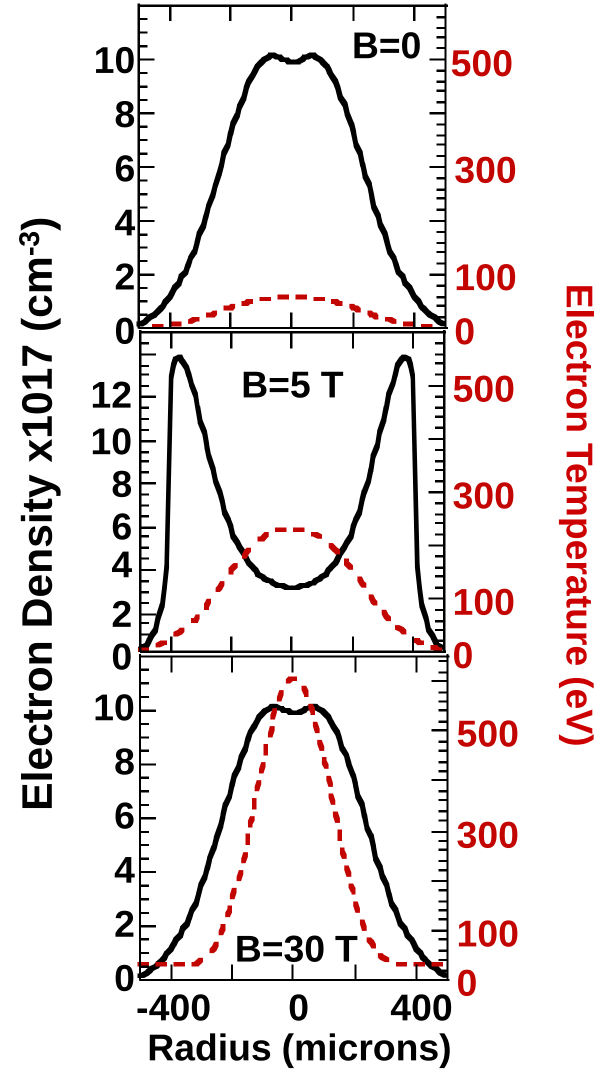
*Ionization induced trapping, A. Pak et.al. In Review Phys. Rev. Lett. (2009)

Using Janus a magnetically-controlled plasma channel is being developed to guide the 200TW Callisto beam 5 cm

The depth of the channel can be matched for ideal guiding using the magnetic field

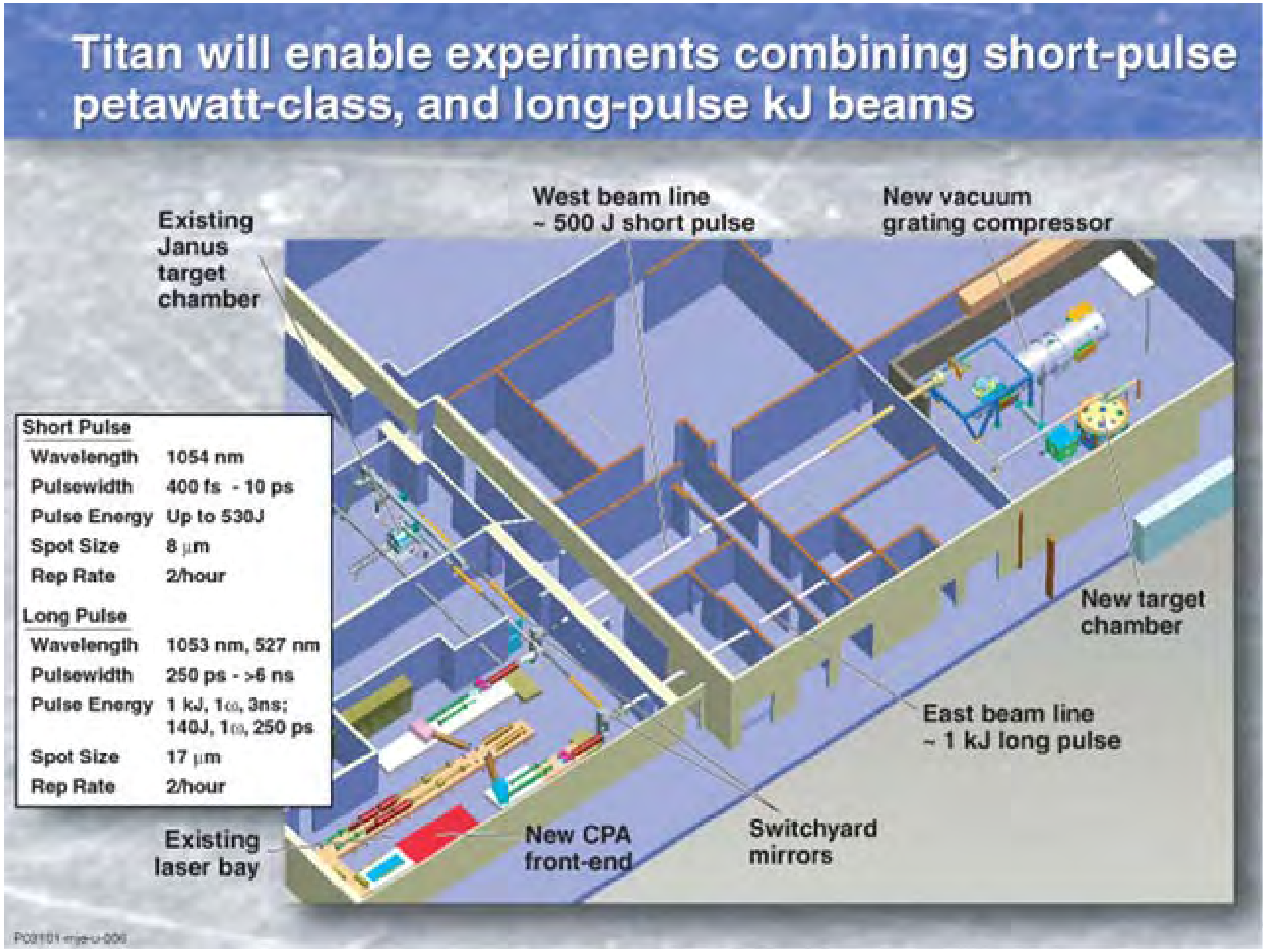


Introducing a magnetic field localizes the heat flux allowing channels to be produced at densities less than 10^{18} cm^{-3}



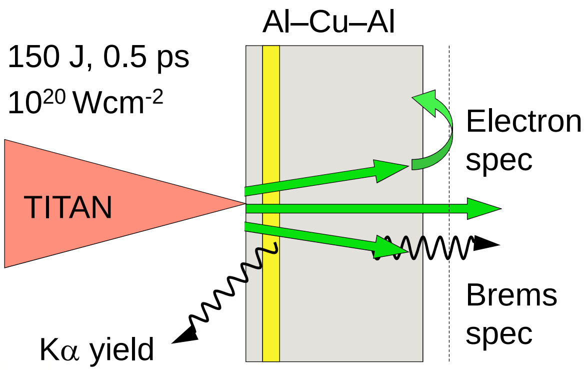
Froula et al. PRL 98, 135001 (2007)

Titan combines a 350 J Petawatt-class short-pulse beam with a 1 kJ long-pulse

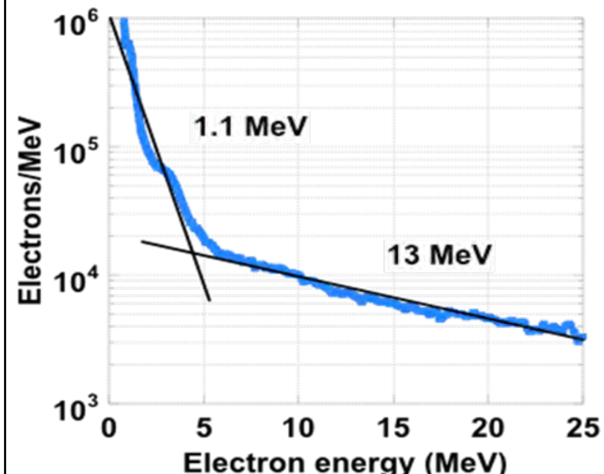


TITAN has enabled accurate measurements of high intensity laser to fast electron coupling for Fast Ignition

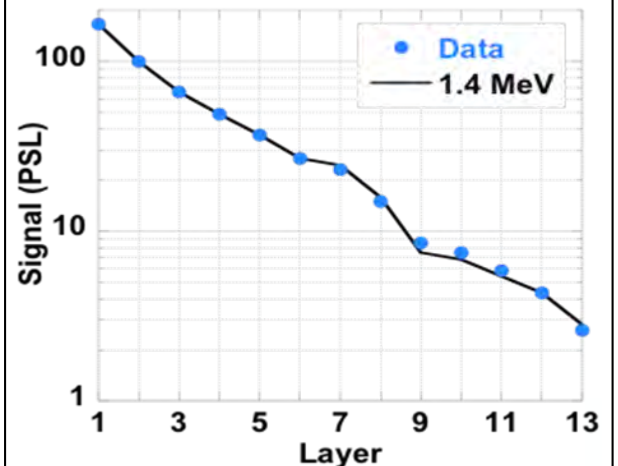
TITAN experiment



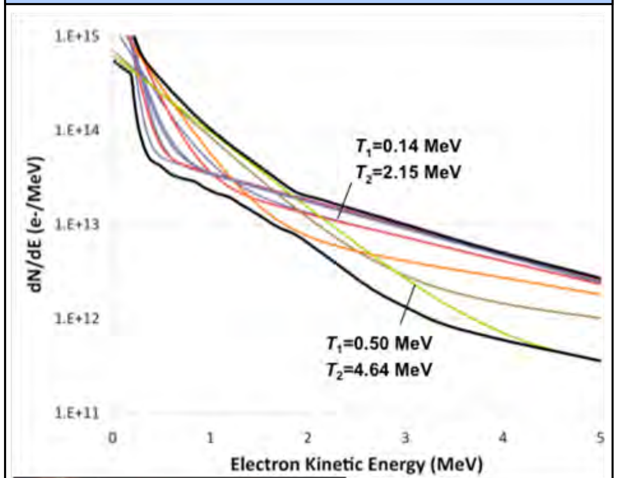
Vacuum electron spectrum



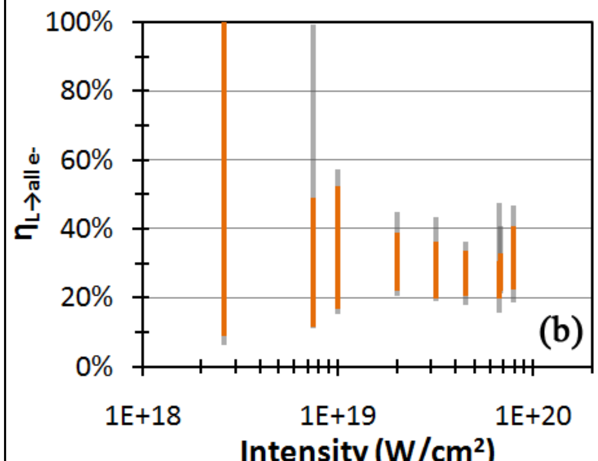
1-Temp fit to brems data



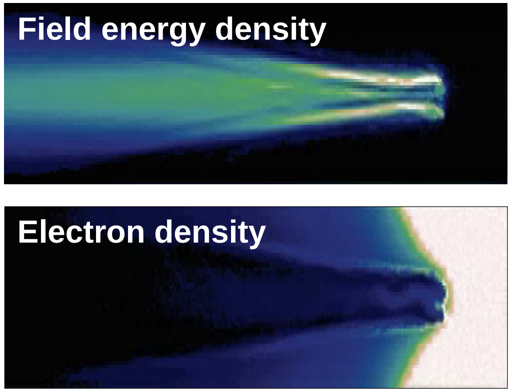
2-Temp allowable distributions



Conversion efficiency



Full-scale PIC modeling

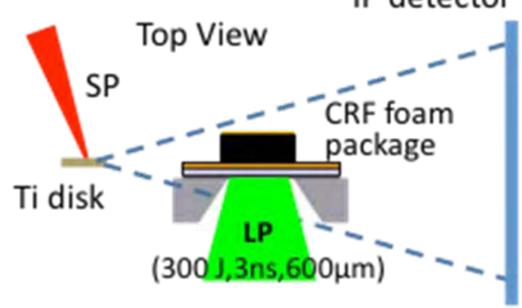


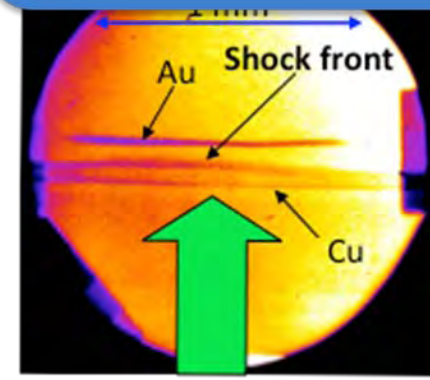
C.D. Chen, *Phys. Plasmas* (2009)

Experiments were recently performed by a UCSD group to study fast electron transport in WDM

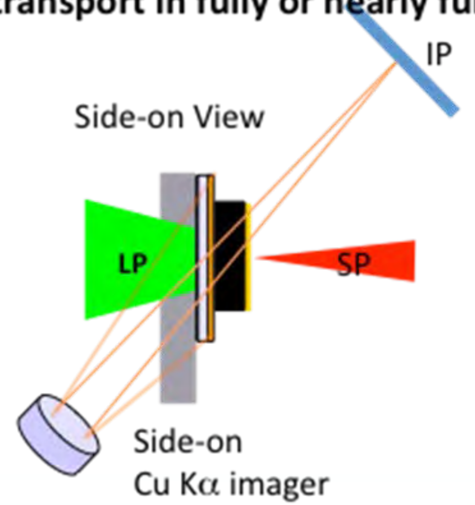
M.S. Wei, F. Beg et al. (UCSD)
K. Akli, R. Stephens (GA)
A. MacPhee, S. LePape,
D. Hey et al. (LLNL)

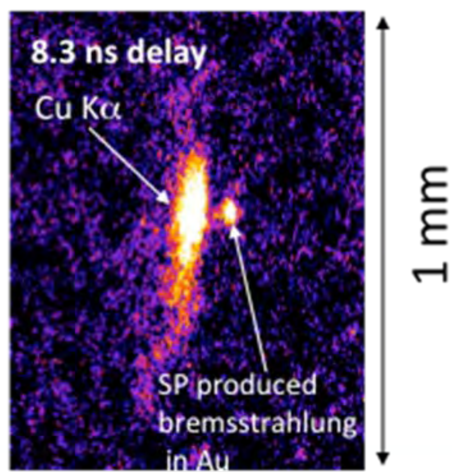
Ti X-ray radiography provides information on the shock Propagation and compression of CRF foam

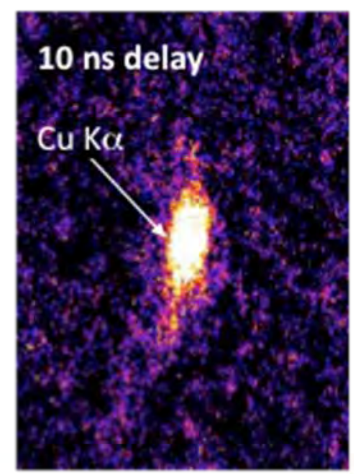




A large Kα emission spot (≈ 200 μm) is observed only for transport in fully or nearly fully shocked dense CRF foam plasmas

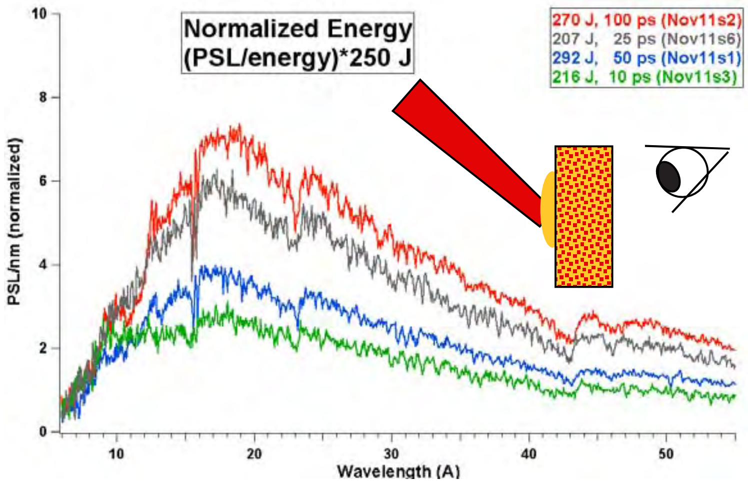






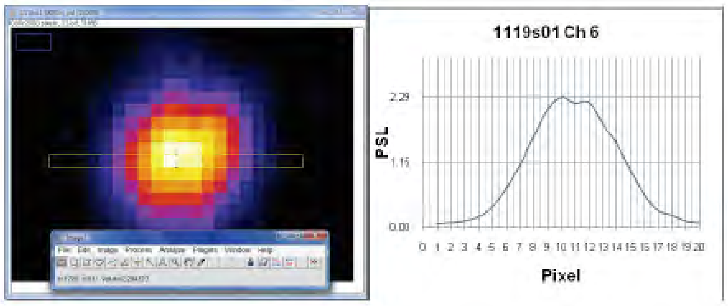
TITAN is used for development of short-duration broadband x-ray sources for opacity measurements

Measured soft x-ray spectra from back of ~3µm thick Cu



- Broad-band spectra:
  - optically thick
  - high radiation field in target
  - back side is cold if pulse length $\leq$ 5 ps

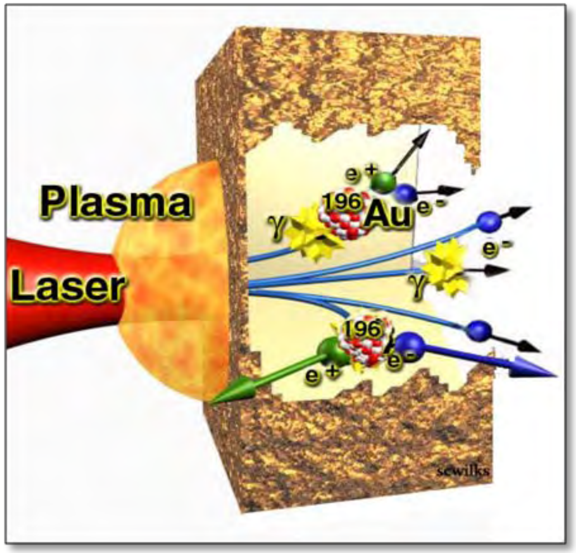
Measure spot size on back of target with soft x-ray imager

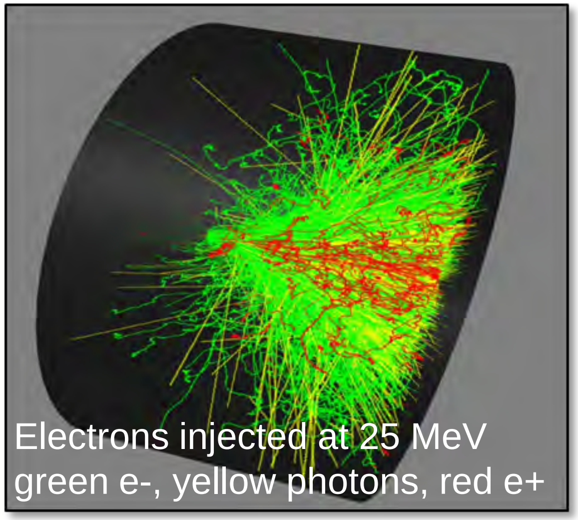


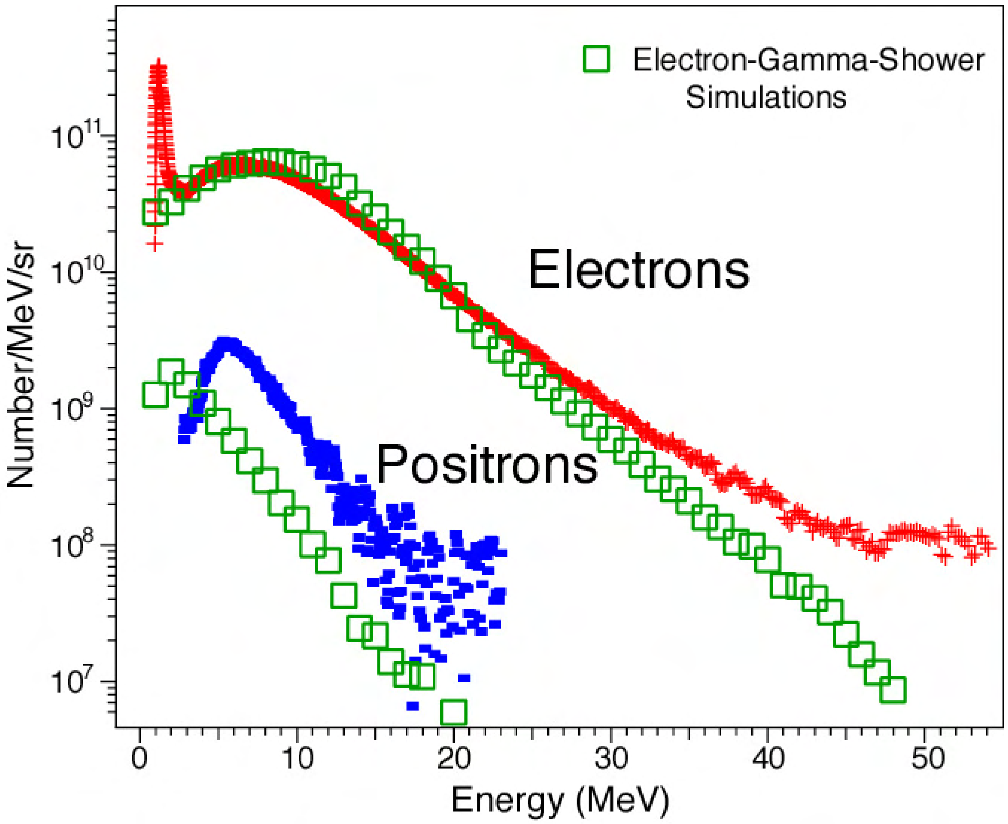
- Images at 3 energy bands
  - < 800 eV
  - 400 – 800 eV
  - > 6000 eV
- Heated spot size varies, ~ 50µm

M. Schneider et al.

The highest density of positrons in the laboratory were generated on TITAN experiments





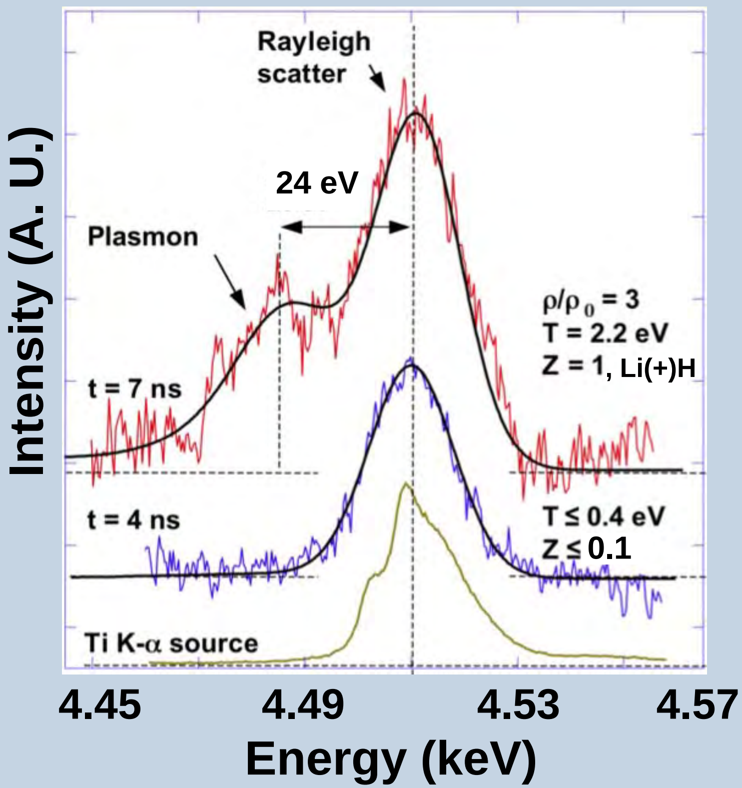


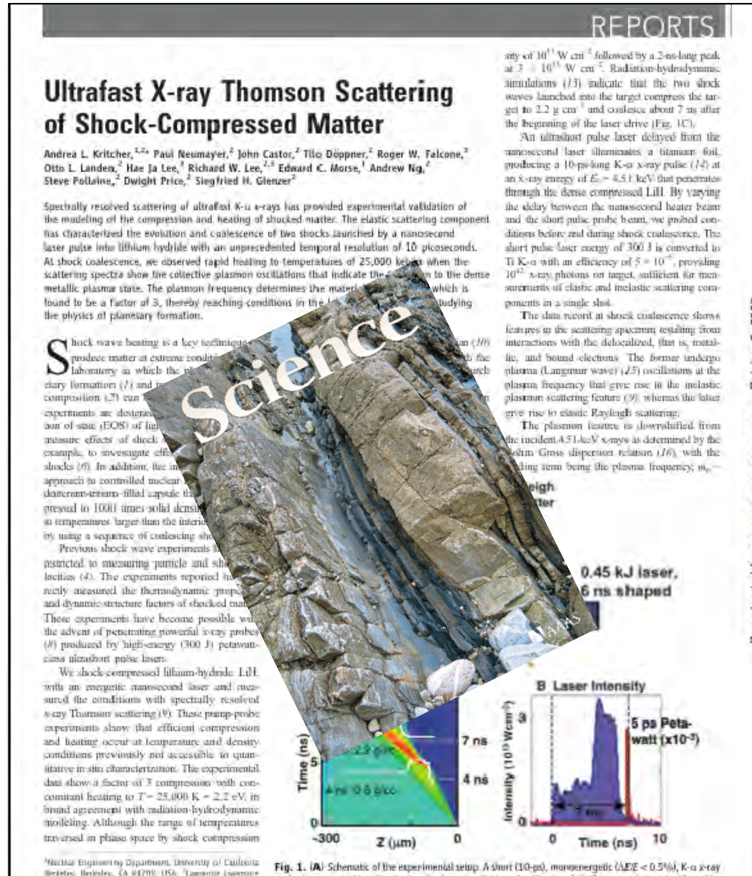
Super hot electrons (~9 MeV temperature)
$1x10^6$ e+ observed, implies 10^{16} e+/cm^3 inside target
Positron/Electron ratio $>10^{-2}$ (about 10^{-4} from NOVA)

H. Chen, S.C. Wilks et al. PRL (2009)

TITAN short-pulse was used for the first ultrafast x-ray Thomson scattering measurements of shocked matter

TITAN measurements




REPORTS

Ultrafast X-ray Thomson Scattering of Shock-Compressed Matter

Andrea L. Kritcher,[1,2]* Paul Neumayer,[2] John Castor,[2] Tilo Döppner,[2] Roger W. Falcone,[3] Otto L. Landen,[2] Hae Ja Lee,[3] Richard W. Lee,[2,3] Edward C. Morse,[1] Andrew Ng,[2] Steve Pollaine,[2] Dwight Price,[2] Siegfried H. Glenzer[2]

Spectrally resolved scattering of ultrafast K-α x-rays has provided experimental validation of the modeling of the compression and heating of shocked matter. The elastic scattering component has characterized the evolution and coalescence of two shocks launched by a nanosecond laser pulse into lithium hydride with an unprecedented temporal resolution of 10 picoseconds. At shock coalescence, we observed rapid heating to temperatures of 25,000 kel... when the scattering spectra show the collective plasmon oscillations that indicate the ... to the dense metallic plasma state. The plasmon frequency determines the materi... which is found to be a factor of 3, thereby reaching conditions in the ... studying the physics of planetary formation.

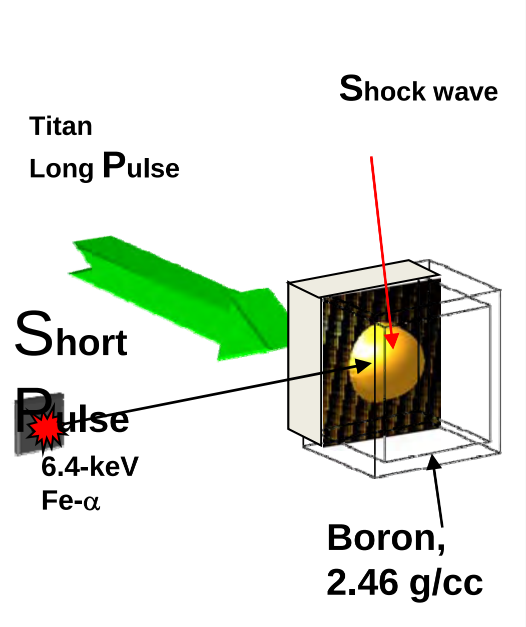
A. Kritcher et. al. Science (2008)

Scattering at 4 ns shows small inelastic signal indicating low Temp & Z*

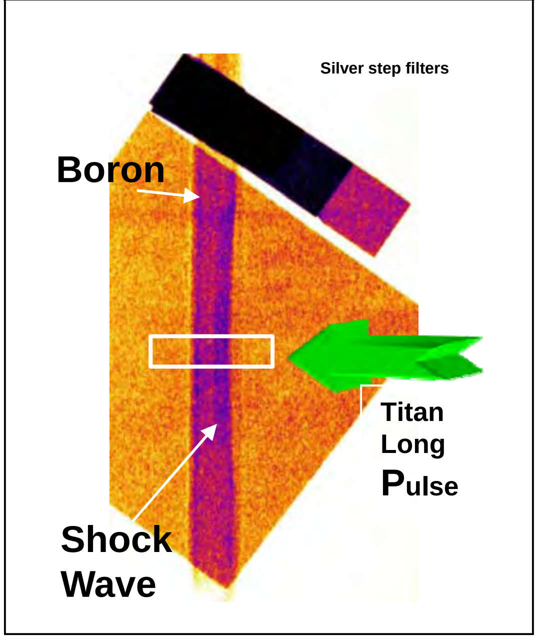
Observation of plasmon at 7ns indicates transition from an insulator to a dense metallic state

Further experiments have characterized the plasma collisionality in shocked Boron

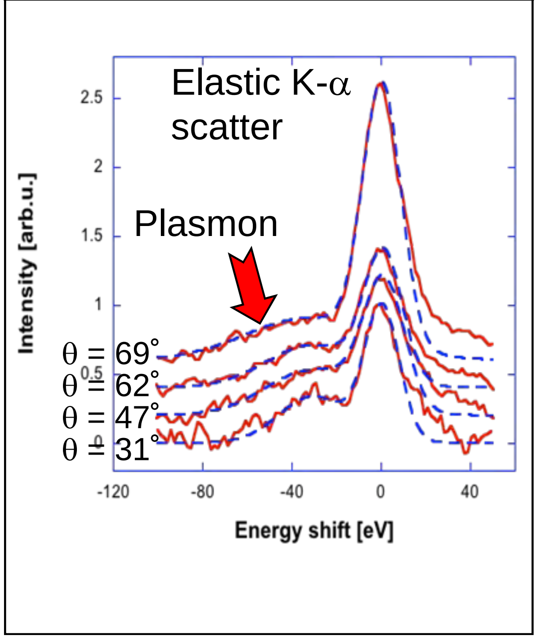
Radiography on shocked B has established the target platform



Radiography at t = 3.8 ns delay with a smoothed green laser, 13 TW/cm²



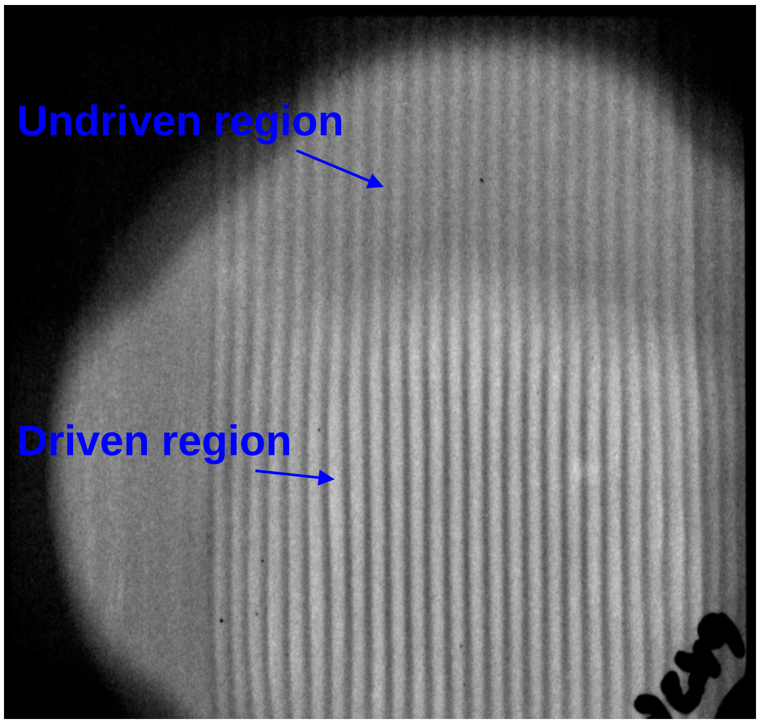
K-α ray scattering spectra provides accurate measurements of n_e, ν_{ei}



- 1st order Born approximation
- Electron density from X-ray Thomson scattering agrees with radiography
- S. LePape et al., Invited Talk at the upcoming APS DPP meeting (2009)

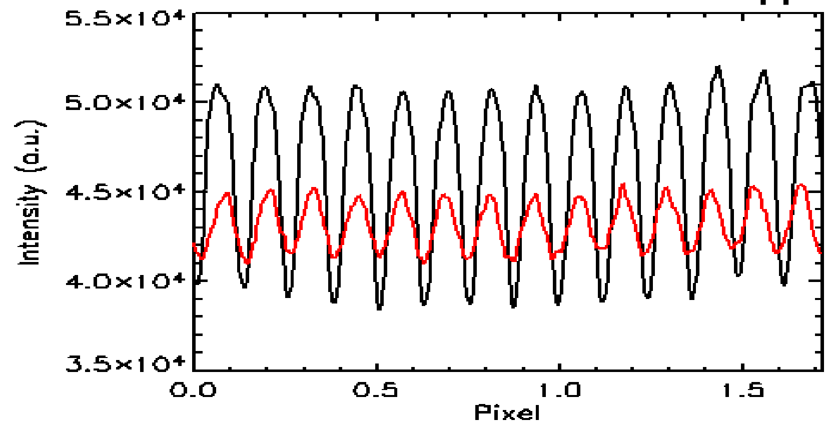
40kev K-alpha radiography with 10um resolution has been used to measure RM/RT instability growth rates

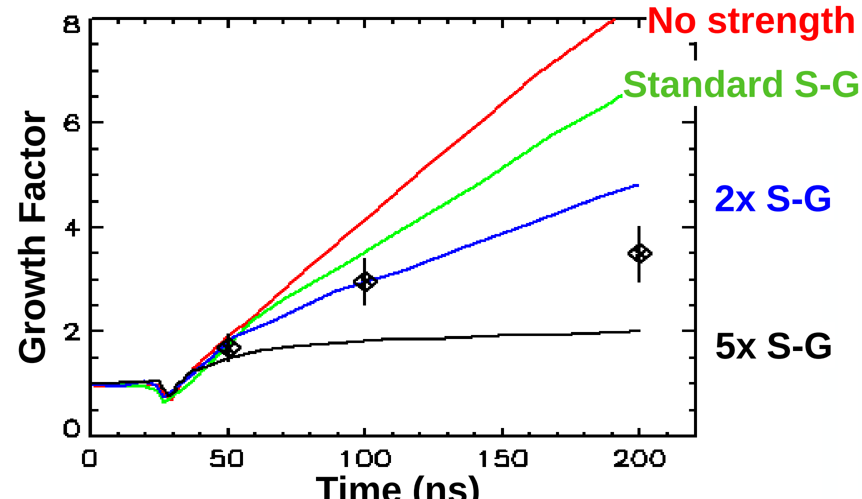
Laser E=128 J, 1.5 ns, 1mm x 1mm phase plate; Backlighter, Sm 40 keV, 100x100x10 μm, delay 200 ns



(H. Park, Plasticiy, 2007)

Lineouts of drive and undriven ripple



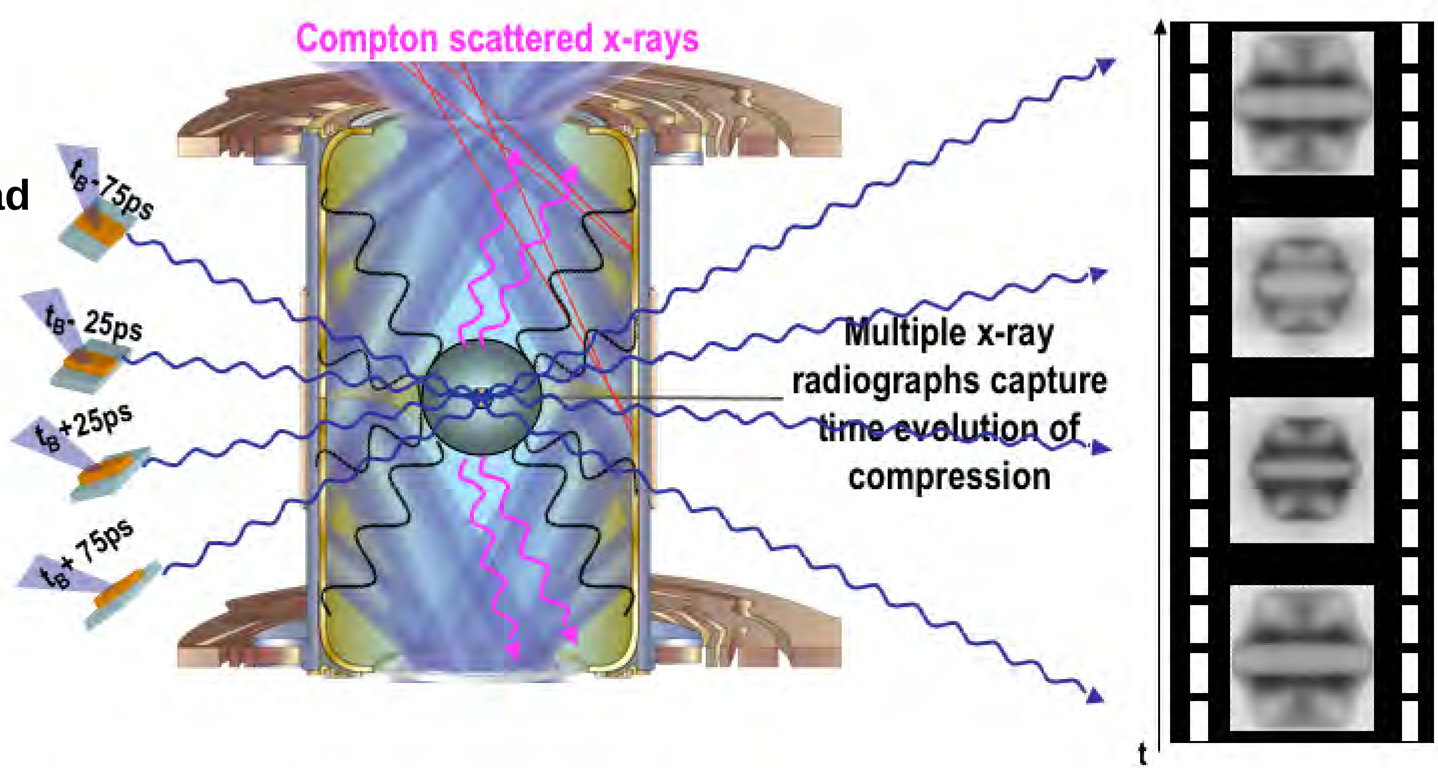


We find that the measured growth factors are smaller than simulations using the nominal Steinberg-Guinan strength model

JLF is playing an important role in the development of NIF diagnostics for NIC and HED Science Campaigns

Multi-pulse Compton radiography, using NIF ARC, is being developed to measure ρR and asymmetry of the compressed core in NIF implosions

NIF ARC Quad beamlines

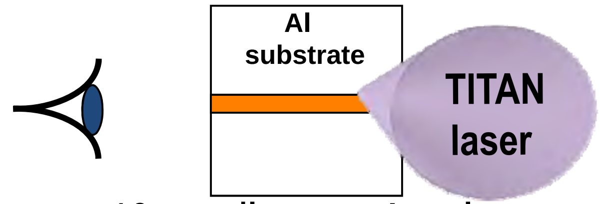


R. Tommasini

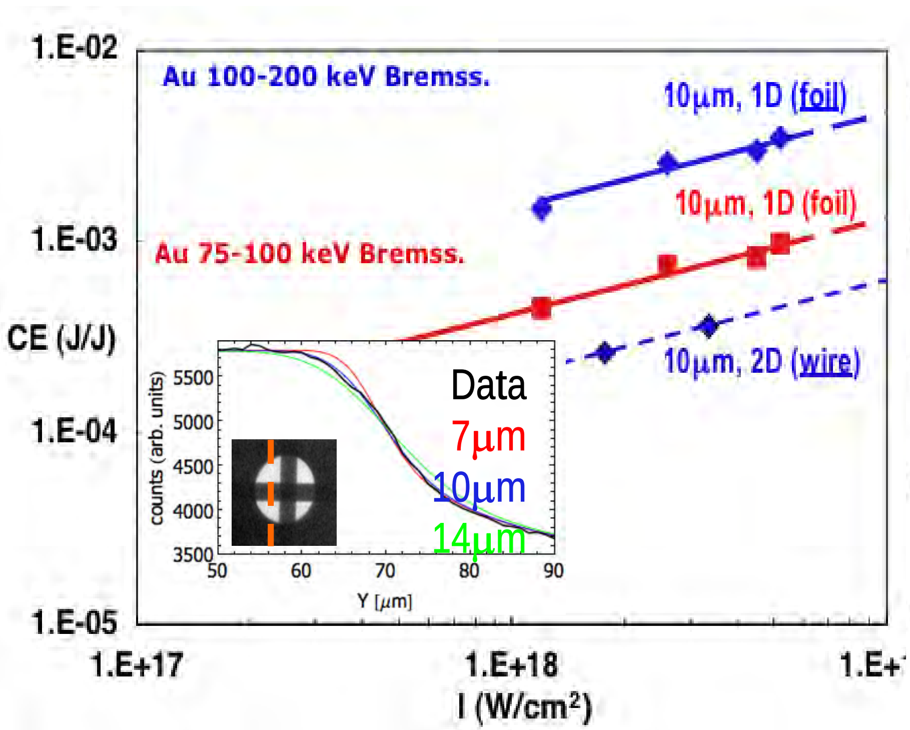
TITAN experiments were used to optimise source size and conversion efficiency into 100-200keV x-rays

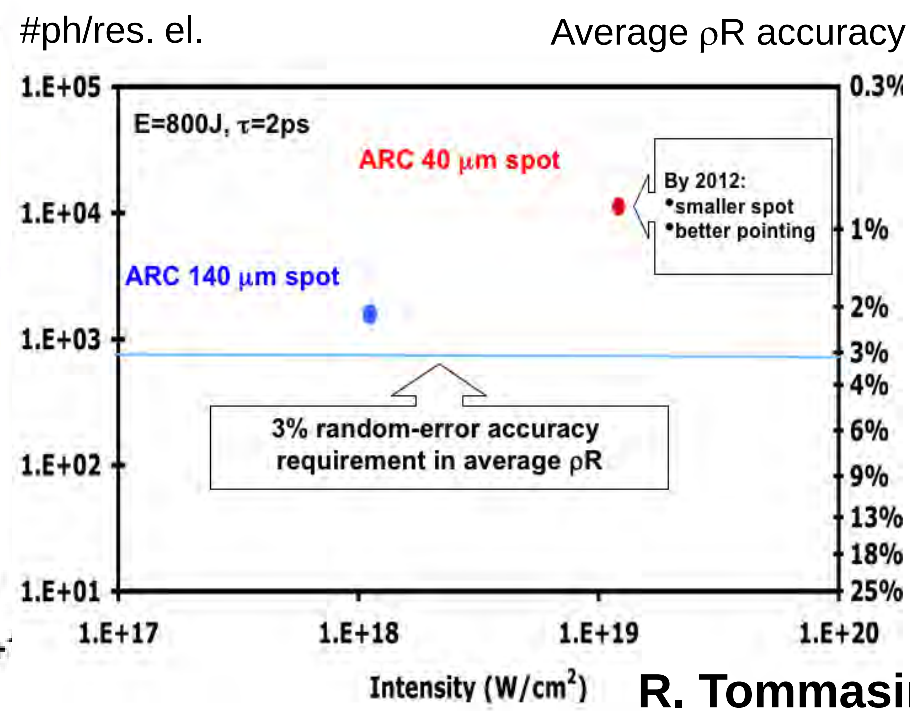
Titan parameters:

- **Spot size ~ 50 m FWHM (15 m)**
- **Energy ~ 150J; Intensity: variable by changing pulse duration**
- **Incidence angle matching ARC: 35 deg**



10 µm-diameter Au wire





R. Tommasini

TITAN results are scaled to NIF ARC laser parameters

JLF is a premier research facility for HED Science

- Relativistic Laser Absorption
- Warm Dense Matter
- Material Strength
- Fast Ignition
- EOS
- Opacity
- X-ray Lasers
- Proton Acceleration
- Relativistic Pair Plasmas
- Laser Wakefield Acceleration

- Thermal Broadband Backlighting
- Compton Radiography
- K-alpha Radiography
- Proton Radiography
- X-ray Diffraction
- X-ray Interferometry
- X-ray Thomson Scattering
- NIF Diagnostic Development