“A scientific journey from wakefields to astrophysics and fusion: Symposium in honor of Toshi Tajima”
UC-Irvine, January 25, 2018

Corrupted by Toshi:

confessions of a former condensed-matter physicist

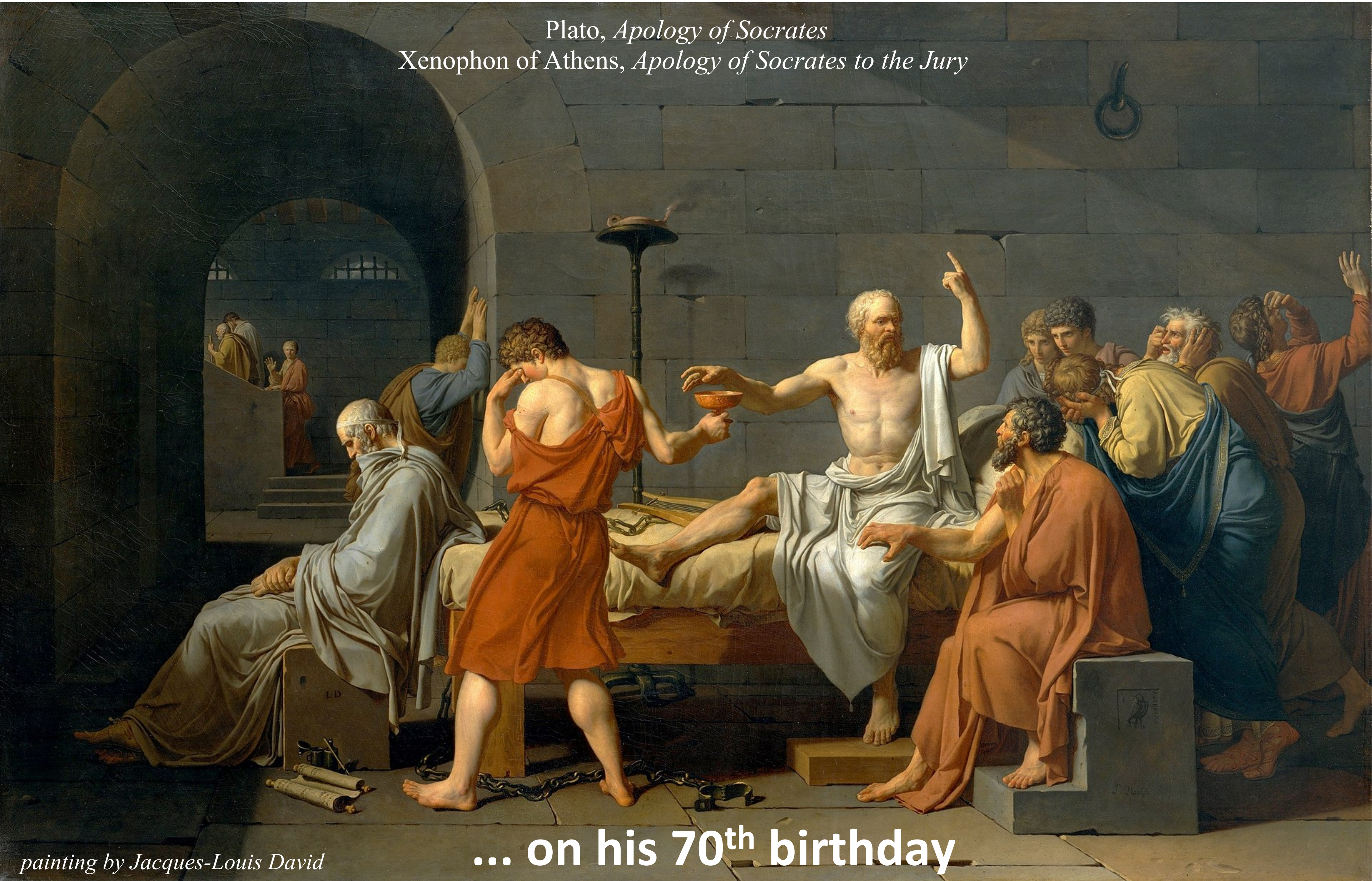
Mike Downer (U. Texas-Austin)

Tajima at UT-Austin:
early 1980s to ~2002

Downer at UT-Austin:
early 1985 to present

Seventeen years
(1985 – 2002)
as colleagues at
U. Texas-Austin

A jury of 500 Athenians tried and executed Socrates (470-399 BC) for “corrupting the youth” of Athens ...



Warnings from my condensed matter colleagues

**"Watch out for Tajima. He's got really crazy ideas.
They will never work. Stick to condensed matter physics."**

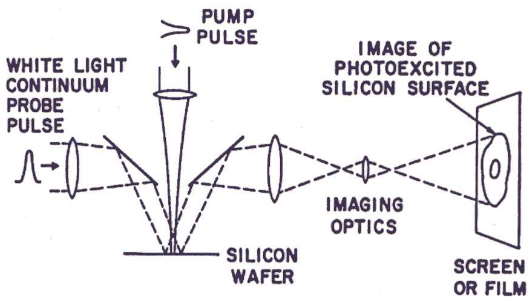
"Downer used to be a decent condensed matter physicist until Tajima corrupted him."

Next few slides: Selected highlights of my work from 5 to 1 BC*

***BC = Before Corruption**

Femtosecond Melting & Evaporation of Silicon: The Movie

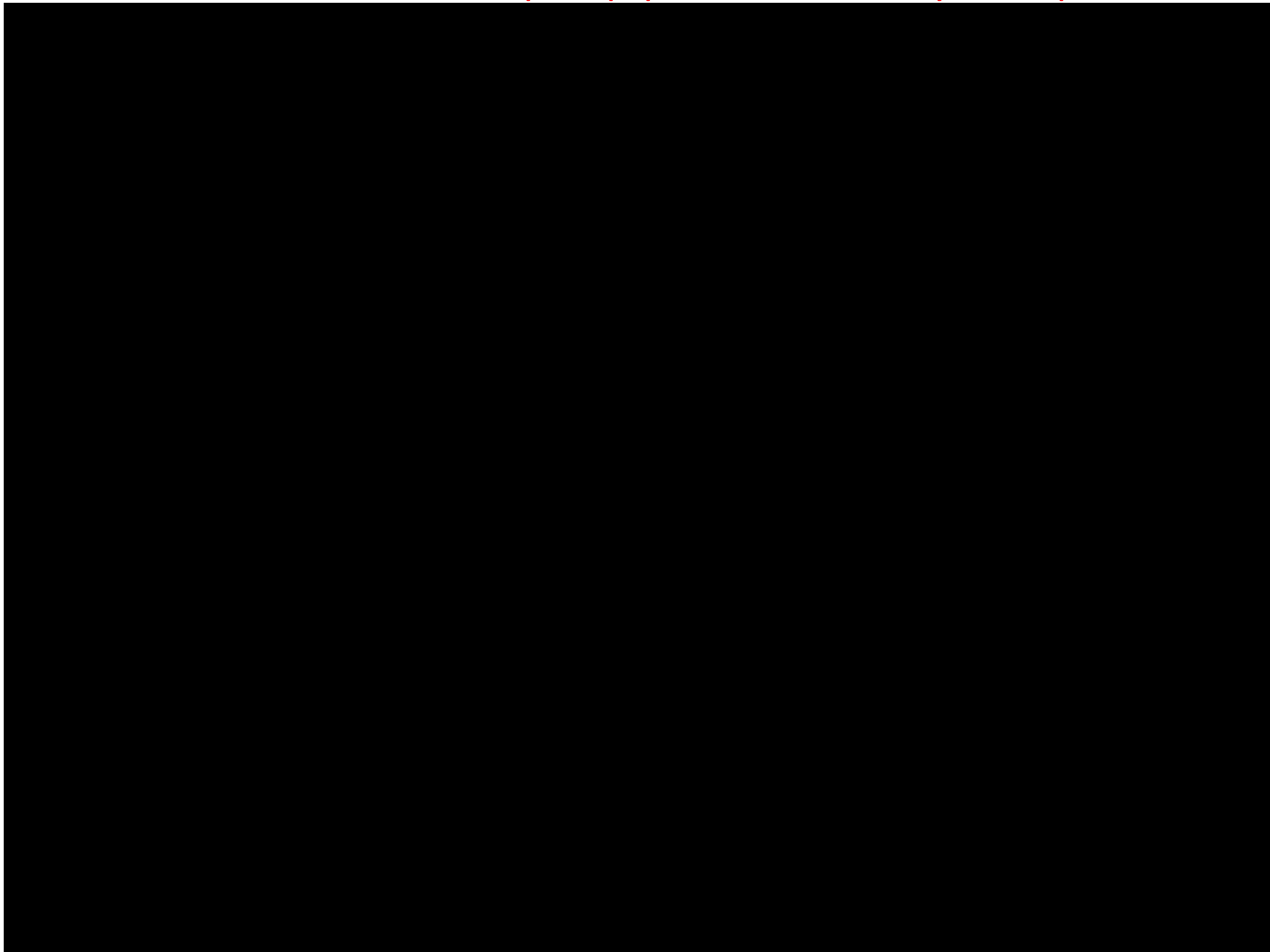
MD, J. Opt. Soc. Am. B **2**, 595 (1985)



MAJOR EVENTS:

- $\Delta t < 0$: semiconducting Si surface ($R = 0.3$)
- $-0.04 < \Delta t < 0.04$ ps: pump absorbed
- $\Delta t \cong 1$ ps: liquid metal Si surface ($R = 0.6$)
- $\Delta t \geq 10$ ps: absorption from ejecta ($R \cong 0$)

Red numbers denote pump-probe time delay Δt in ps



pump parameters:

$\lambda = 620$ nm
$w_0 = 75$ µm on target
$\tau = 80$ fs
energy = 0.1 mJ
$E_{max} = 0.5$ J/cm^2 on target
$I_{max} = 10^{13}$ W/cm^2 on target

Silicon melting threshold:

$E_{THRESHOLD} = 0.1$ J/cm^2

Nature **356**, 110 (1992)

NEWS AND VIEWS

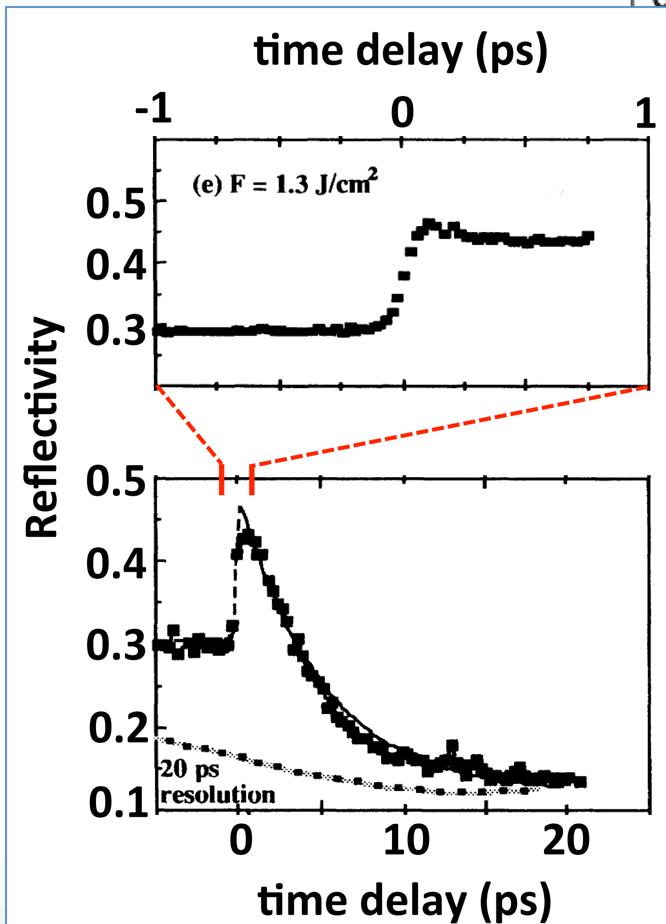
CONDENSED STATE

First light on fluid carbon

Nicolaas Bloembergen

RESEARCHERS at the University of Texas, Austin, may have caught the first, fleeting glimpse of fluid carbon. D. H. Reitze, H. Ahn and M. C. Downer describe in *Physical Review* (B45, 2677–2693; 1992) how both graphite and diamond can be melted momentarily by intense laser irradiation before expanding as a hot plasma.

The liquid phase of the element carbon is elusive, as it appears to exist in equilibrium only at temperatures of about 5,000 K and at pressures above several hundred atmospheres. The phase cannot be contained in any vessel, because all other materials melt or chemically react before the temperature required for the liquid state of carbon is reached. Clearly the structure of this state is of interest to those studying condensed matter physics, but because these conditions can be found in planetary interiors, it is also important for



surface layer to a depth equal to the optical absorption depth and permits the determination of the material's dielectric

Because the probe laser sees the elec-
on plasma, not the state of the carbon
ns, an indirect argument is needed to
ggest that a fluid state of carbon is
eated. Indeed, for pump pulses above
m, the phase transition initially is an
ectronic one, as it seems unlikely that

* U. Texas outstanding PhD dissertation prize (1991)
Currently Director, LIGO Laboratory

Ladies & gentlemen, we have detected gravitational waves. We did it!

I had diverse interests in condensed physics prior to my corruption...

M. C. Downer and C. V. Shank, "Ultrafast heating of silicon-on-sapphire by femtosecond optical pulses," *Phys. Rev. Lett*. **56**, 761 (1986).

X. Y. Wang, D. M. Riffe, Y. S. Lee and M. C. Downer, "Time-resolved electron temperature measurement in a highly excited gold target using femtosecond thermionic emission," *Phys. Rev. B* **50**, 8016 (1994).

J. I. Dadap, B. Doris, Q. Deng, M. C. Downer, J. K. Lowell and A. C. Diebold, "Randomly-oriented angstrom-scale microroughness at the Si(100)/SiO_2 interface probed by optical second-harmonic generation," *Appl. Phys. Lett*. **64**, 2139 (1994).

J. I. Dadap, X. F. Hu, M. Anderson, M. C. Downer, J. K. Lowell and O. A. Aktsipetrov, "Optical second-harmonic spectroscopy of a Si(001) metal-oxide-semiconductor structure," *Phys. Rev. B* **53**, R7607 (1996).

M. K. Grimes, A. R. Rundquist, Y. S. Lee and M. C. Downer "Experimental identification of vacuum heating at femtosecond-irradiated metal surfaces," *Phys. Rev. Lett*. **82**, 4010 (1999).

⋮

... and the name "Tajima" does not appear on any of them

Toshi's 1990 Letter to Eugene Colton is the earliest documentation of my corruption

DEPARTMENT OF PHYSICS

THE UNIVERSITY OF TEXAS AT AUSTIN

Austin, Texas 78712-1081 • (512) 471-1153

May 8, 1990

Dr. Eugene P. Colton
Science and Technology Division
Office of Superconducting Supercollider
Department of Energy
Washington, DC 20585

Dear Dr. Colton:

In a recent telephone conversation you expressed an interest in receiving a research proposal from me on the problem of laser acceleration of particles. Recently I have been developing collaborative research plans in this area with my colleague **Prof. Michael Downer, an experimentalist in the UT Physics department and an NSF Presidential Young Investigator whose research focuses on intense femtosecond laser pulses and their interaction with dense plasmas.** As you know, such laser sources and such interactions play a central role in a number of recent proposed particle acceleration schemes, including our own.

Toshi's 1990 Letter to Eugene Colton is the earliest documentation of my corruption

determining the feasibility of various proposed structures. Prof. Downer's group has performed extensive femtosecond time-resolved measurements of melting and ionization of solid targets using reflectivity, transmission, and photoemission techniques, measurements which we believe can be extended to prototypical waveguide structures. **In short, the current experimental program has developed capabilities which can be extended naturally into studies of particle acceleration mechanisms.**

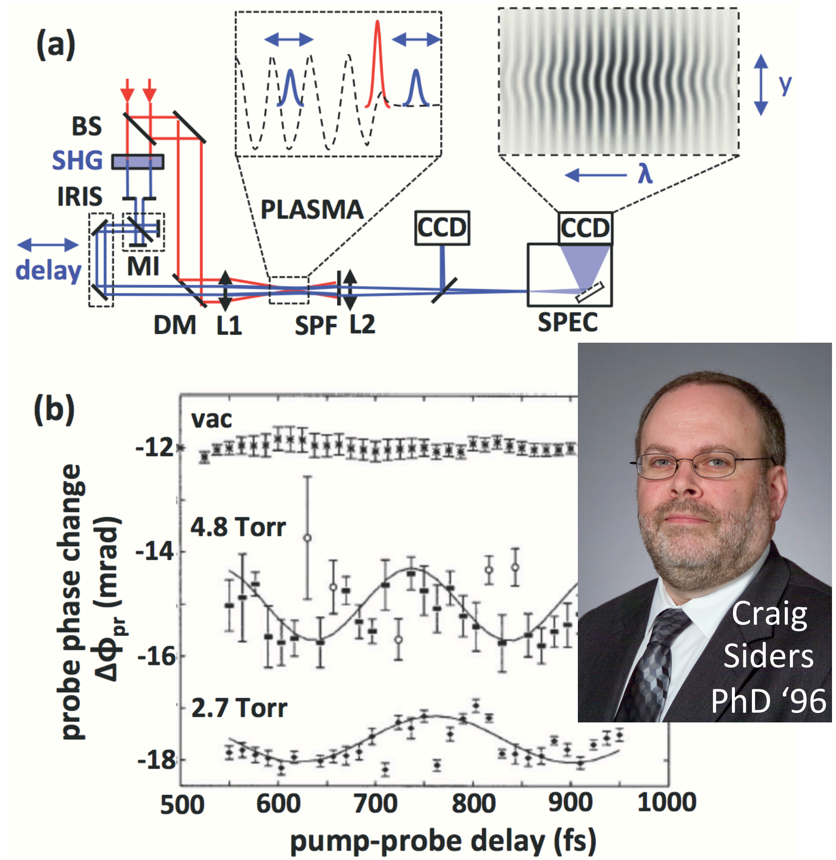
Our anticipated research falls into two general areas: 1) Experimental investigations of wakefield density modulations in atmospheric density plasmas. The general approach is to excite a laser-produced plasma with several intense femtosecond pulses applied at carefully controlled, periodic intervals corresponding to the period of longitudinal plasma oscillations. Periodic excitation serves to amplify the density oscillations, the source of the accelerating electric field, which will then be monitored by various optical diagnostics, including spectral shifting, light emission from the plasma, forward Raman scattering, and Thomson scattering. Initial experiments will be performed in a gas cell in which gas density can be accurately controlled. At a later stage the experiments can be performed on gas jets in a vacuum chamber, allowing observations of acceleration of electrons from within the plasma or injected from an external source. 2) Experimental investigations of the optical transmission and mode structure properties of prototype waveguide structures under intense femtosecond excitation. While several experiments have been performed on smooth metal surfaces, little is known about the transient optical properties of periodically loaded microstructures under intense femtosecond excitation. Prototype structures will be fabricated, and the transmission of femtosecond pulses

original signed by Toshiki Tajima

First results emerged 1 PhD student lifetime after DoE proposal submitted and funded

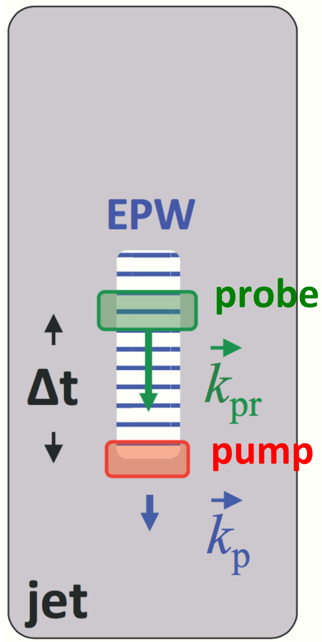
standard resonant wake

C. W. Siders, T. Tajima, M. C. Downer *et al.*, *Phys Rev. Lett*. **76**, 3570 (1996)

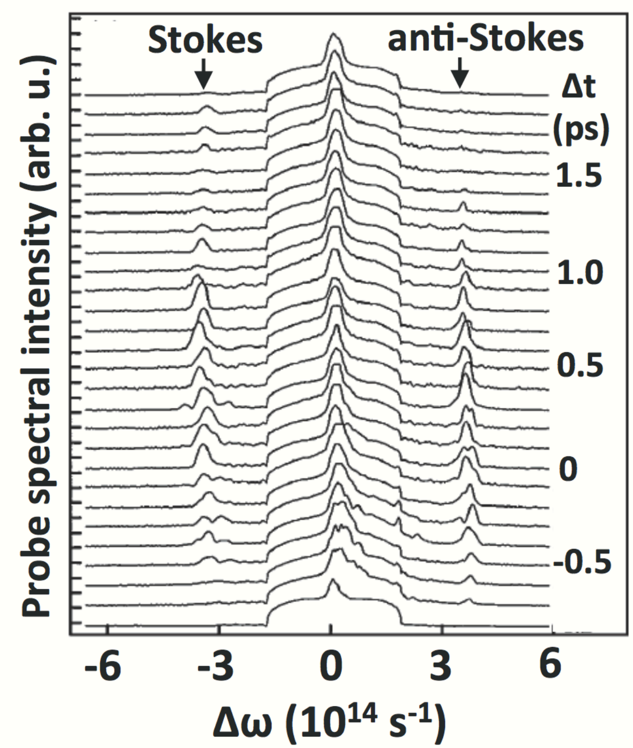


self-modulated wake

S. P. LeBlanc, T. Tajima, M. C. Downer, D. Umstadter, G. Mourou *et al., Phys. Rev. Lett*. **77**, 5381 (1996)



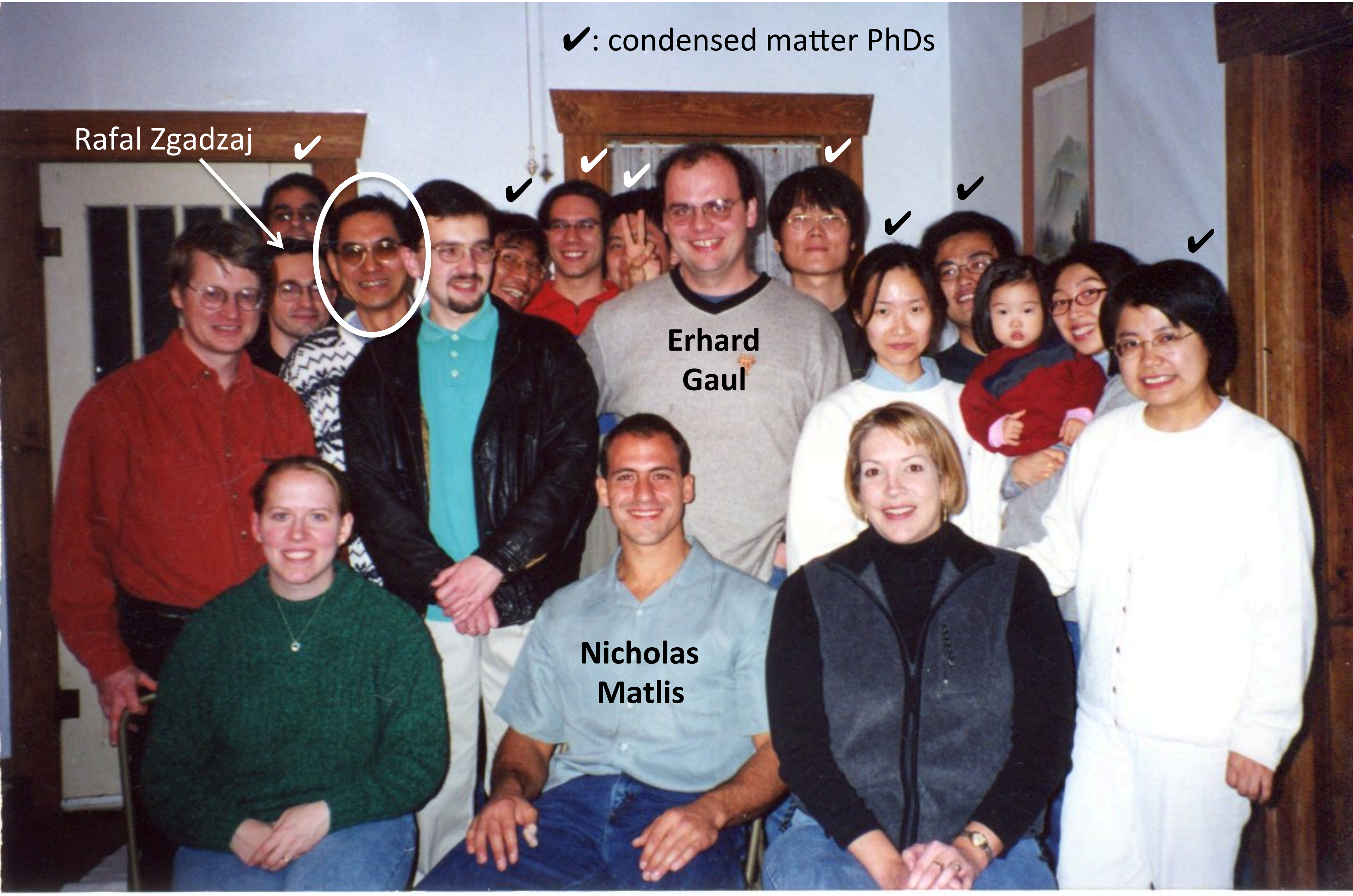
forward scattered probe spectra



Related work: J. R. Marques *et al., Phys. Rev. Lett.* **76**, 3566 (1996); **78**, 3463 (1997)

Related work: A. Ting *et al., Phys. Rev. Lett.***77**, 5377 (1996)

Toshi appeared regularly in Downer group photos of late 1990s



Toshi's influence on us continued long after he left U. Texas ca. 2002

nature physics | VOL 2 | NOVEMBER 2006 | www.nature.com/naturephysics

Snapshots of laser wakefields

N. H. MATLIS[1]*, S. REED[2], S. S. BULANOV[2], V. CHVYKOV[2], G. KALINTCHENKO[2], T. MATSUOKA[2], P. ROUSSEAU[2], V. YANOVSKY[2], A. MAKSIMCHUK[2], S. KALMYKOV[1], G. SHVETS[1] AND M. C. DOWNER[1]*

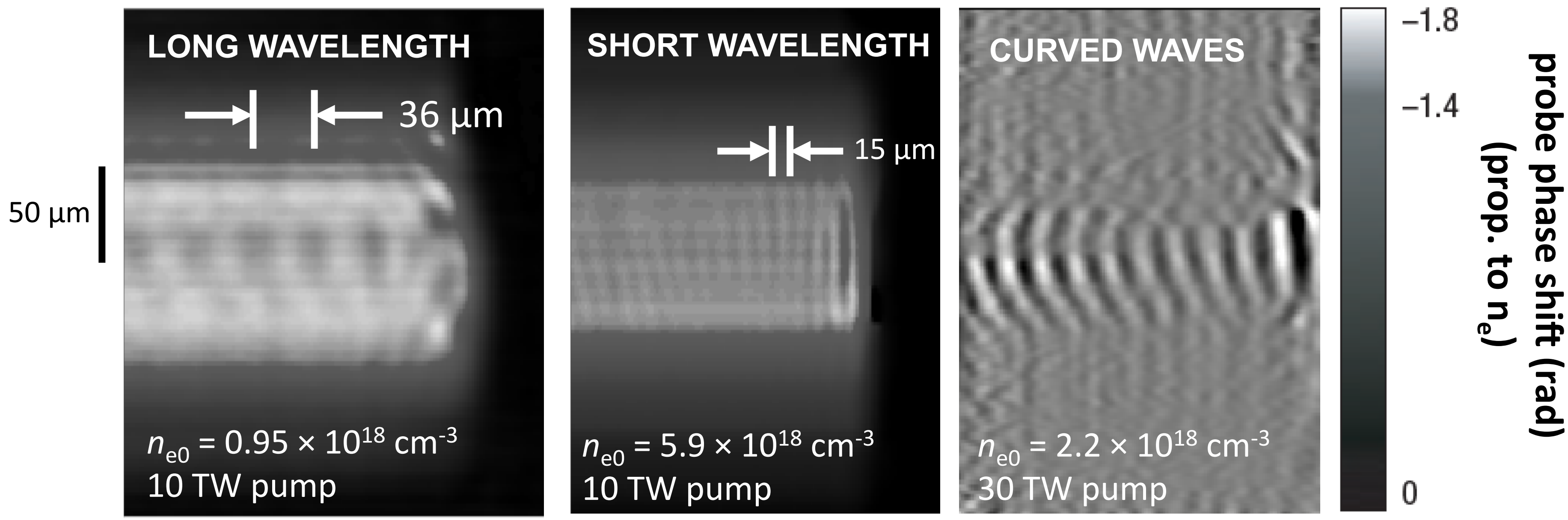
[1]FOCUS Center, Department of Physics, University of Texas at Austin, 1 University Station C1600, Austin, Texas 78712-1081, USA
[2]FOCUS Center and Center for Ultrafast Optical Science, University of Michigan, 2200 Bonisteel Blvd, Ann Arbor, Michigan 48109, USA

Nicholas Matlis
PhD '06

currently AXSIS project leader at DESY

Laser-plasma accelerators come in many shapes & sizes

See Cowley, *PRL* **119**, 044802 (2017) for recent application of this technique.



The ability to capture pictures of plasma waves helps us understand and improve laser-plasma accelerators

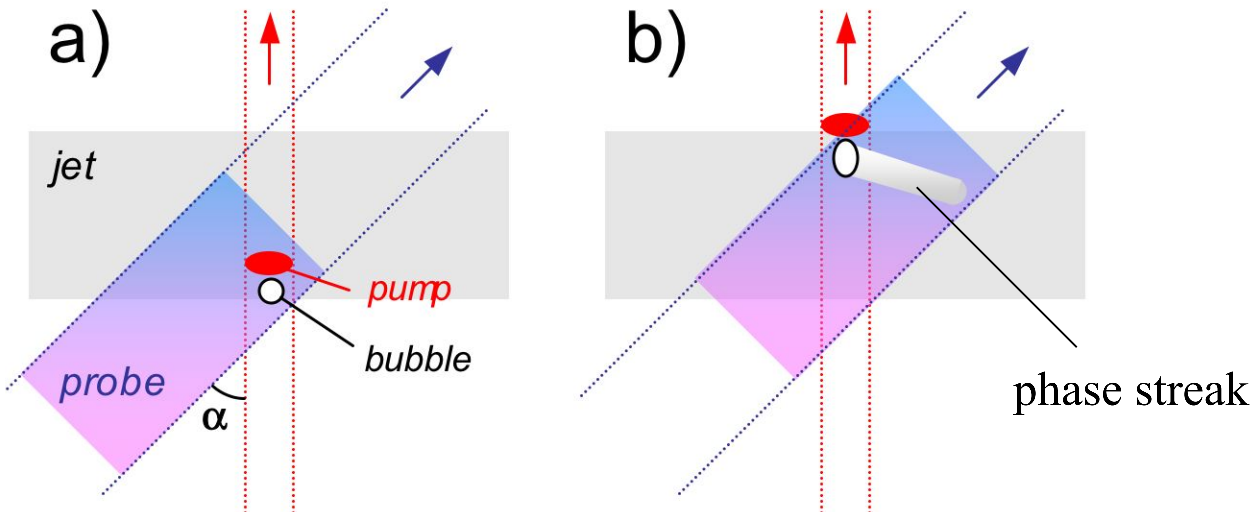
Frequency-Domain "Streak Camera" Records EVOLUTION of Plasma Bubble in ONE shot

Z. Li *et al.*, *Opt. Lett.* 35, 4087 (2010)
, *Nature Photonics* **5**, 68 (2011)
, Phys. Rev. Lett. (2014)

Zhengyan Li
PhD 2014

poster prize winner at AAC 2012 & 2014

currently Prof. Physics, Huazhong U. Sci. & Technol.



- Phase streak is a temporal sequence of the object's projections
- We can record several of them simultaneously to recover the object's evolving structure tomographically

Z. Li *et al.*, *Nature Commun.* **5**, 3085 (2014)

Forthcoming in *Rev. Mod. Phys.*: culmination of Toshi's 1990 vision

Diagnostics for plasma-based electron accelerators

M. C. Downer* and R. Zgadzaj

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Austin, TX 78712,
USA

A. Debus and U. Schramm

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M. C. Kaluza

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Friedrich-Schiller-University, 07743 Jena,
Germany
Helmholtz Institute Jena, 07743 Jena,
Germany

"Diagnostics in widespread use with conventional RF accelerators have, by and large, proven in-sufficient for characterizing plasma-based electron accelerators."

I. Introduction

II. Properties of plasma accelerator structures & beams

A. General properties of plasma lepton accelerators
B. Plasma accelerator configurations
C. Electron beams from strongly nonlinear LWFAs

III. Diagnostics of plasma-accelerated electron bunches

A. Radiation from plasma-accelerated electrons
B. Bunch charge and energy measurement
C. Transverse emittance measurement
D. Bunch length measurement

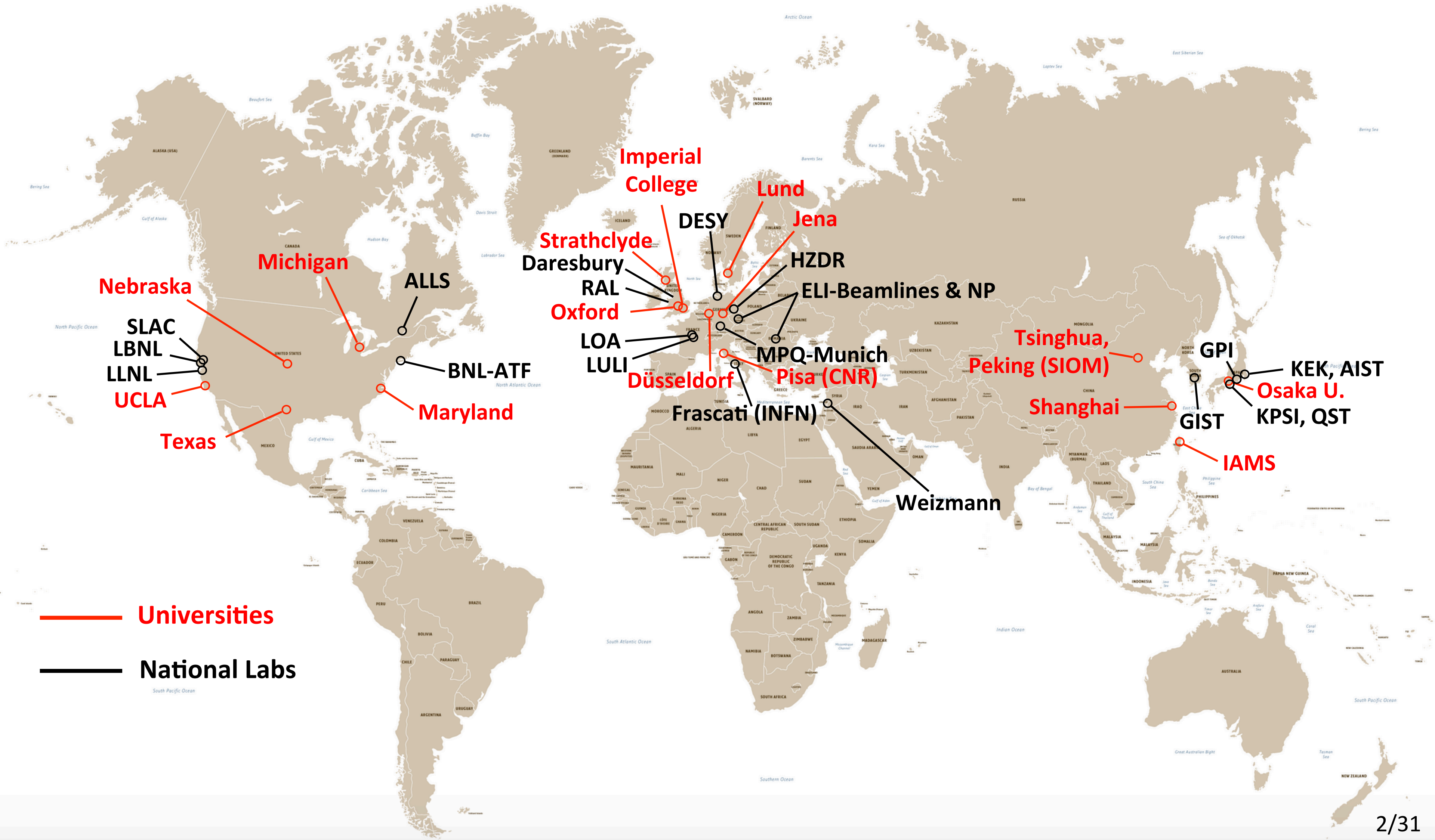
IV. Diagnostics of plasma accelerator structures

A. Light emission & scattering from plasma waves
B. Multi-shot sub-lp probes
C. "Snapshots" of wake structures
D. "Movies" of wake evolution
E. Scaling of wake probes with plasma density

V. Conclusion

LWFA* experimental projects: Toshi's worldwide legacy

** LWFA = Laser Wake-Field Accelerator*



Thanks for corrupting all of us, Toshi!