Science enabled by Photon Sources: local research interests in Virginia

The role of photon sources in materials research: Past, Present, and Future

Ward Plummer
Louisiana State University

- Historical perspective.
- Political Landscape.
- Research and training at Tantulus.
- Examples of time domain materials studies.
- My present research interest in light sources.

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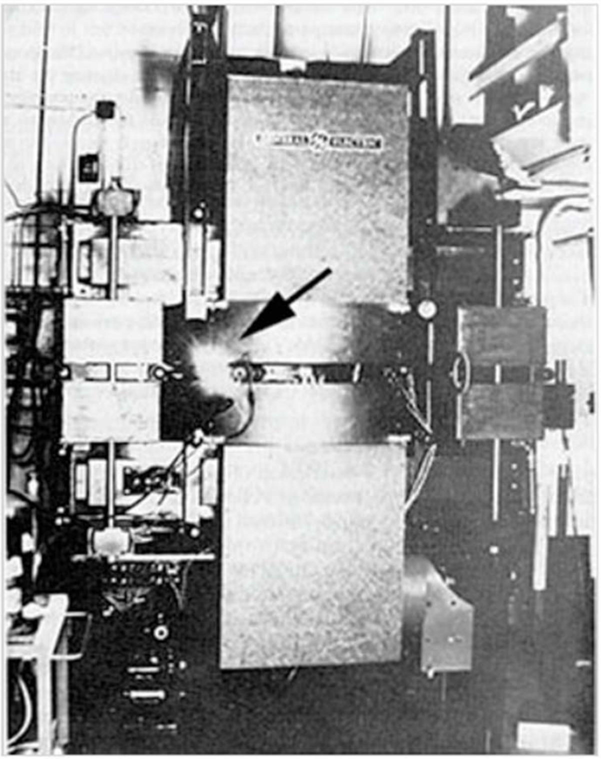
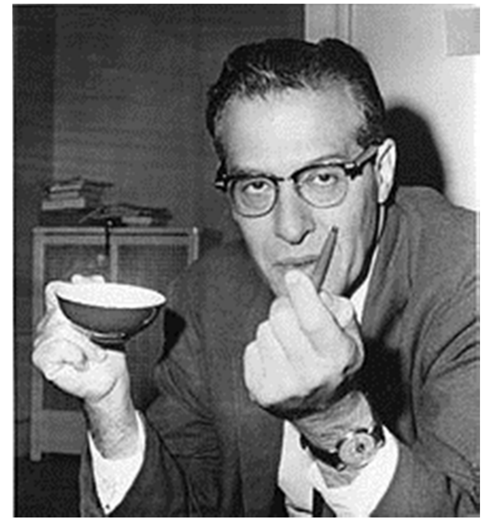
Historical Perspective:



General Electric synchrotron accelerator built in 1946, the origin of the discovery of synchrotron radiation. The arrow indicates the evidence of radiation.

F. R. Elder, A. M. Gurewitsch, R. V. Langmuir, H. C. Pollock, "Radiation from Electrons in a Synchrotron, *Physical Review,* ***71****, 829 (1947)*

"In 1945 Julian Schwinger provided an exact analytical treatment of the phenomenon, including the description of the spectrum."



Julian Schwinger:
1918—1994
Nobel Prize 1965
"His laboratory is his ballpoint pen."

The discovery of synchrotron radiation

Herbert C. Pollock
2147 Union Street, Schenectady, New York 12309

Am. J. Phys. **51**, 279 (1983)

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LSU TIGERS

Historical Perspective:

Ed Rowe, Physics Today, 34, 28 (1981)

--1956: Diron Tomboulian and Paul Hartman demonstrated use of Cornell synchrotron as source of ultraviolet radiation--

--1961: Bob Madden and Keith Codling measured spectra of noble gases with 180-MeV synchrotron at NBS--SURF--

--1966: Midwest Universities Research Association Laboratory (MURA) in Wisconsin began preparation to make 240-MeV synchrotron available for materials research --

--1972: Stanford and Harvard submitted proposals to NSF to use existing accelerators as sources of synchrotron radiation.--

--1976: NRC Panel An Assessment of the national Need for Facilities Dedicated to the production of Synchrotron Radiation," NAS

--Funding for ALS, NSLS, Tantulus, SSRL, Cornell

--1984:Eisenberger-Knotex Committee "Planning Study for Advanced National Synchrotron Radiation Facilities, DOE

--Funding for APS

Historical Perspective: Today and Tomorrow

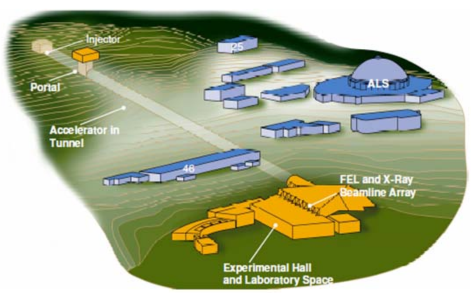
--NSLS II: 3 BeV, operational in 2015

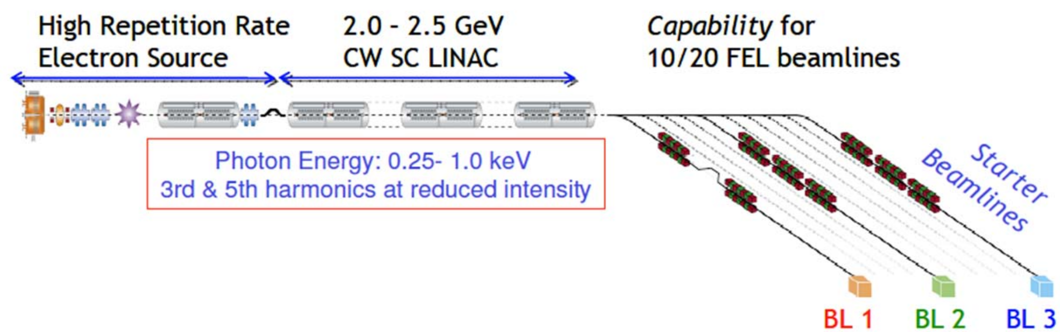
--Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory.

Pulse: Institute for Ultrafast Energy Science at Stanford

--An Upgrade of APS

--NGLS at LBL: Next generation light source, x-ray FEL completed > 2015





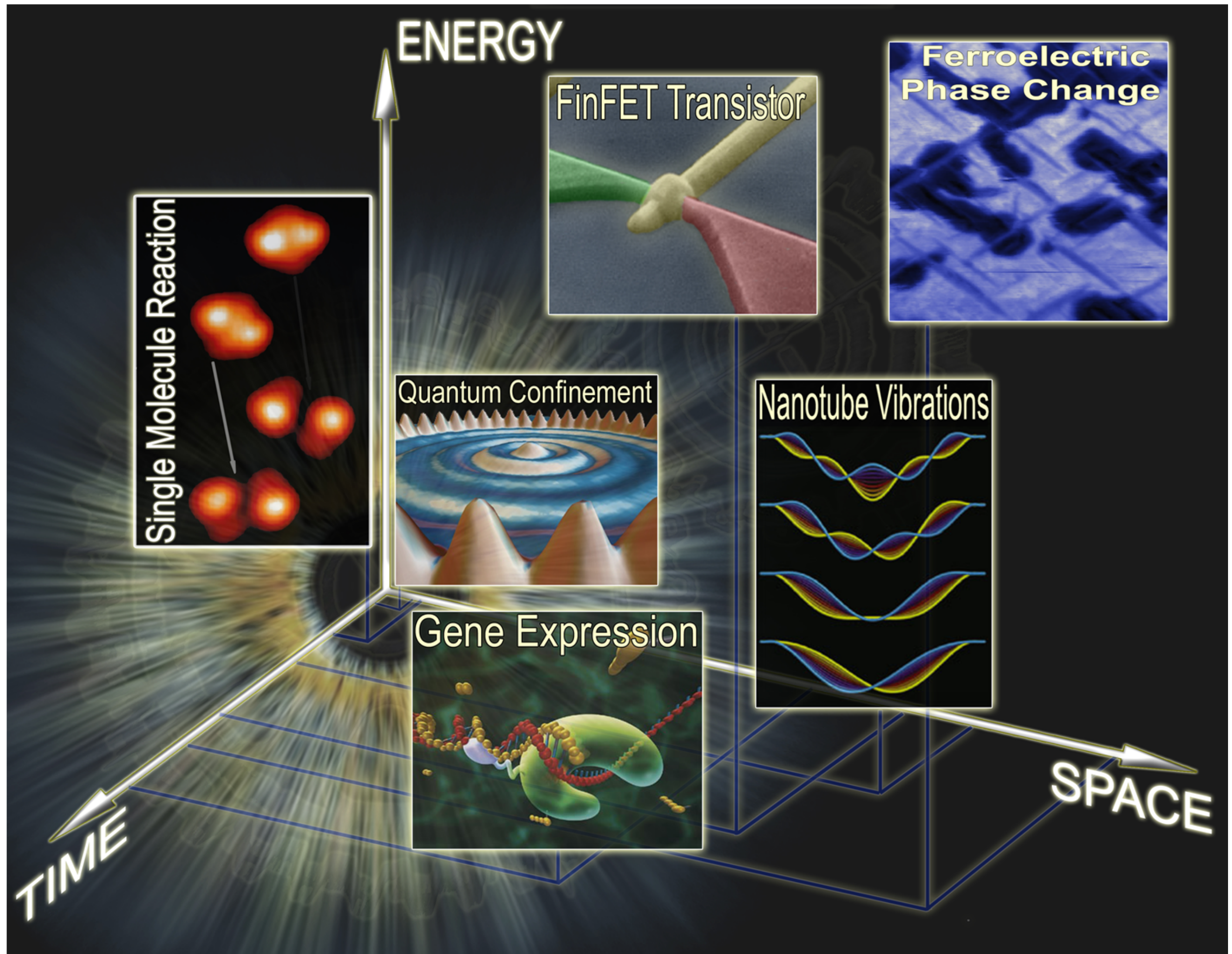
--A FEL at Jefferson Lab?

Political Landscape in USA: Funding, Directions, etc.

Controlling Matter and Energy: Five Challenges for Science and the Imagination

DOE-BESAC Report

Ch. 7: Implementation New experimental techniques to characterize materials on the proper time, energy and length scale.



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New DOE Basic Energy Science Initiative: Meeting May 14th & 15th Chicago

Mesoscopic Materials and Chemistry

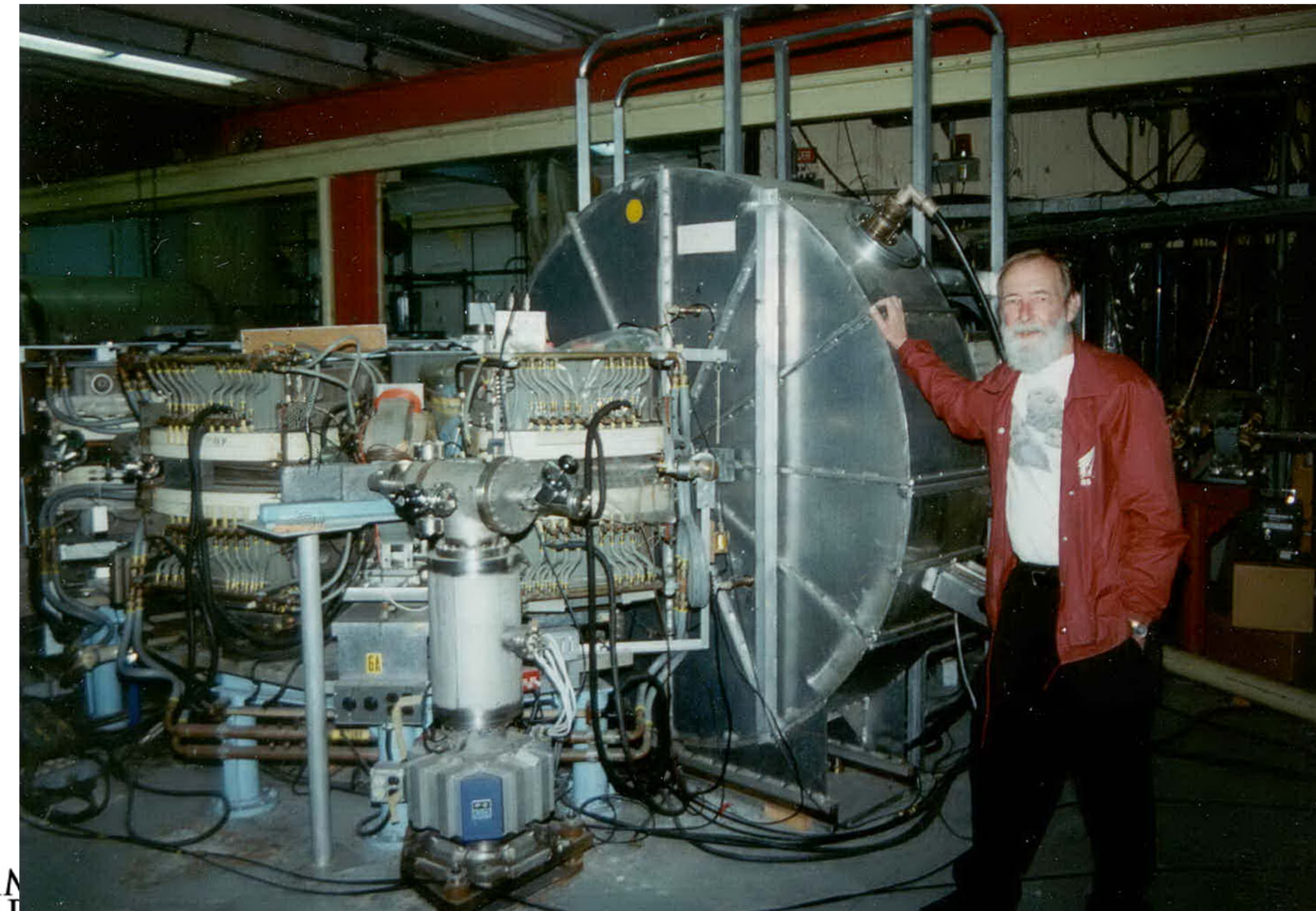
Basic Energy Sciences Advisory Committee

Charge from Brinkman: A central theme of these reports is the importance of atomic and molecular scale understanding of how nature works and how this relates to advancing the frontiers of science and innovation. I would now like BESAC to extend this work by addressing the research agenda for **mesoscale** science, the regime where classical, microscale science and nanoscale science meet. I see two parts to this new study:

1. Identify mesoscale science directions that are most promising for advancing the Department's energy mission.
2. Identify **how current and future BES facilities** can impact mesoscale science.

This study could prompt a national discussion of mesoscale science at the level heard during the initial formulation of the National Nanotechnology Initiative a decade ago.

Ed Rowe and the mighty Tantalus

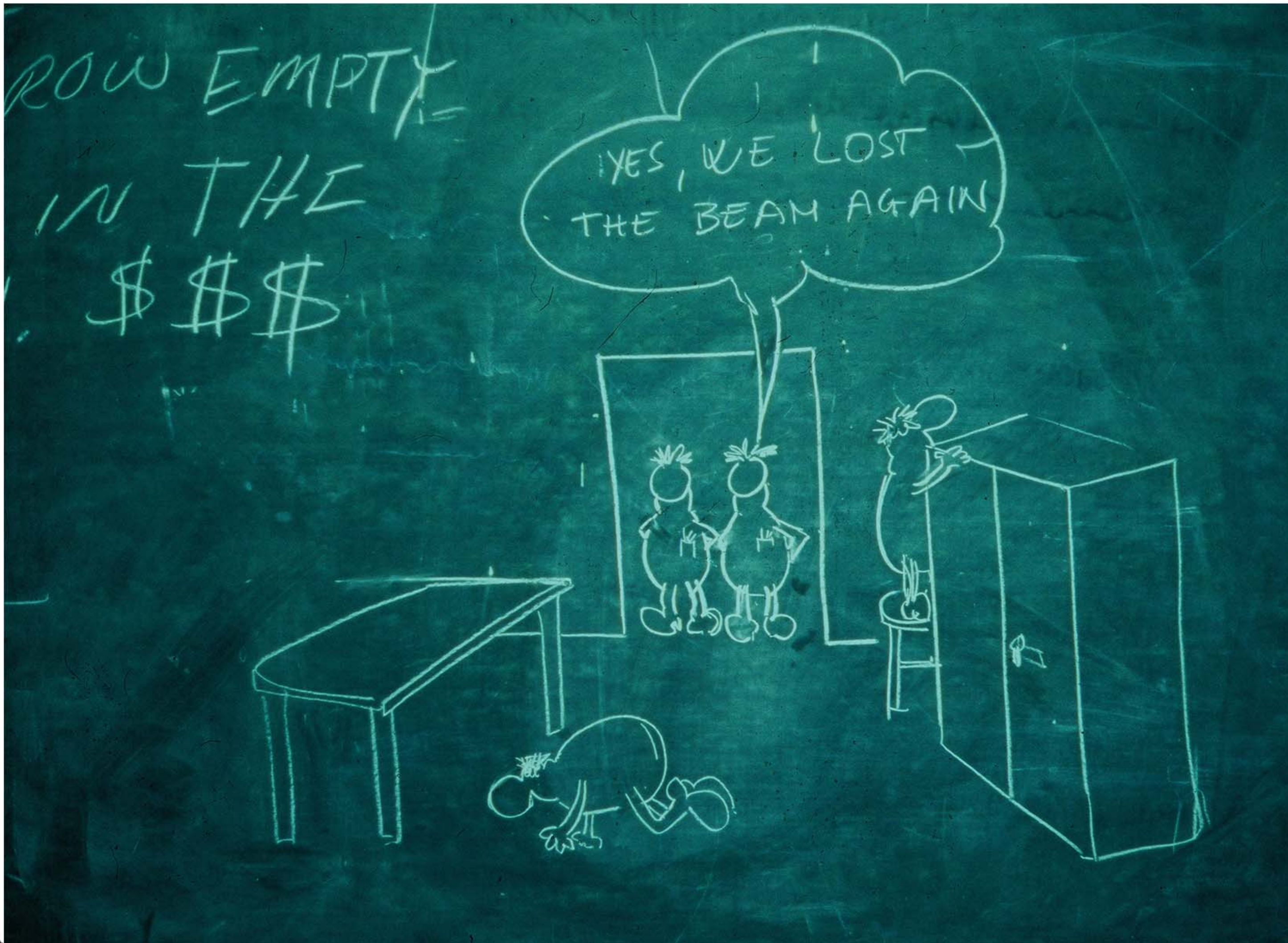


Tantalus

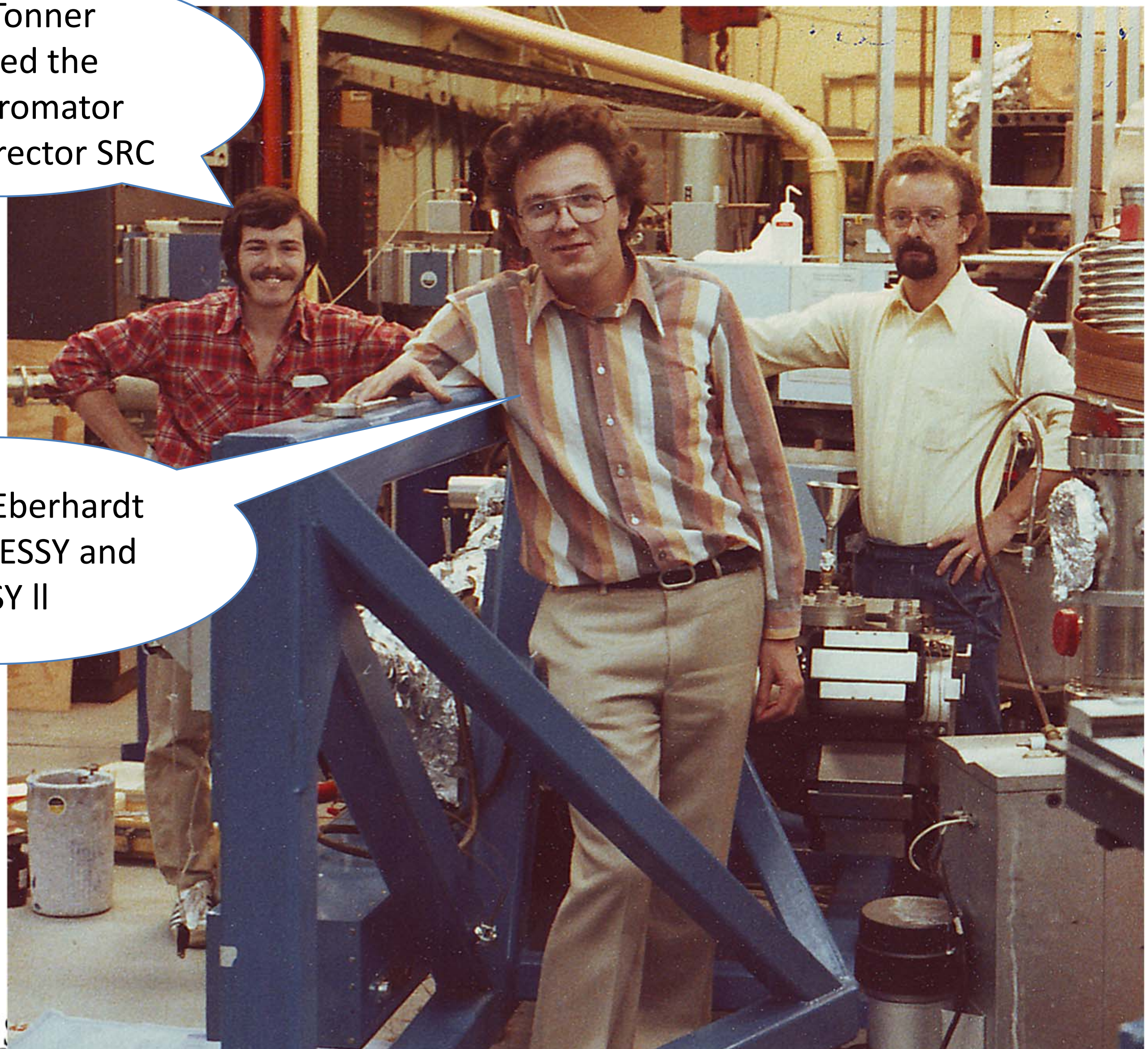
Two lost souls on the way to the control room.

Much more difficult in the winter.

Country Humor



The Tantalus Era: 1978-



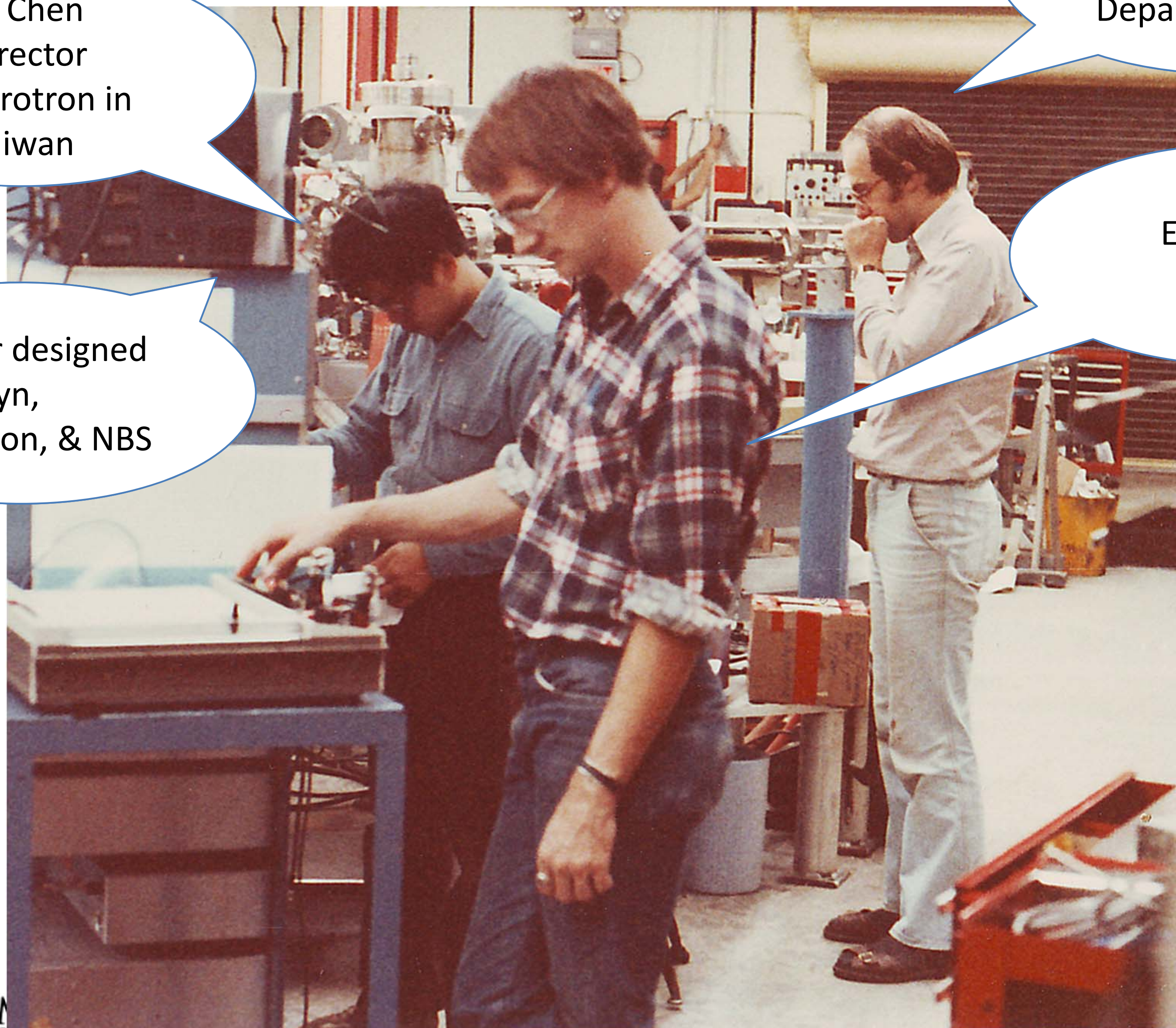
Brian Tonner
Designed the
monochromator
Science director SRC

Wolfgang Eberhardt
Director BESSY and
BESSY II

The People at Tantalu

CT Chen
Director
Synchrotron in
Taiwan

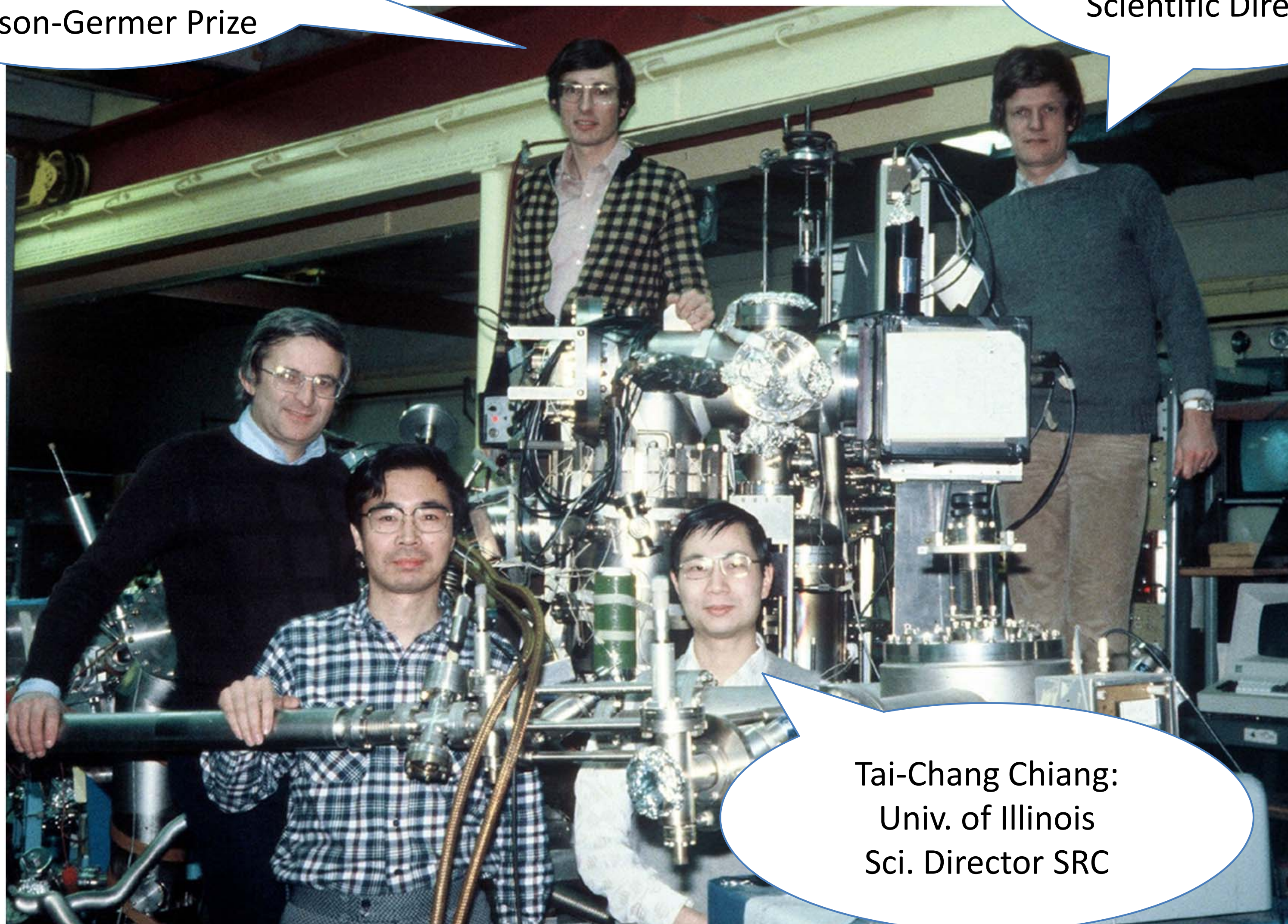
Torgny Gustafsson
Rutgers Univ.
Department head



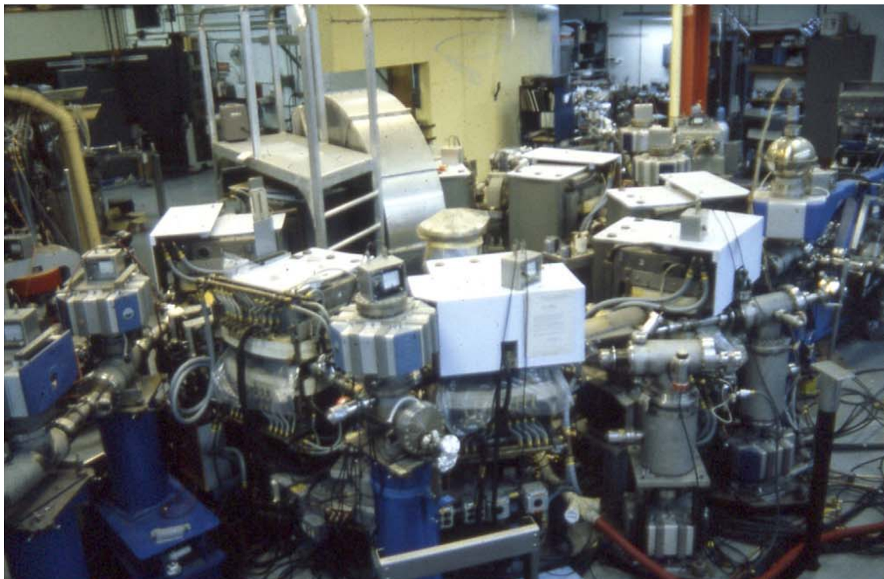
Analyzer designed
by C. Allyn,
Gustafsson, & NBS

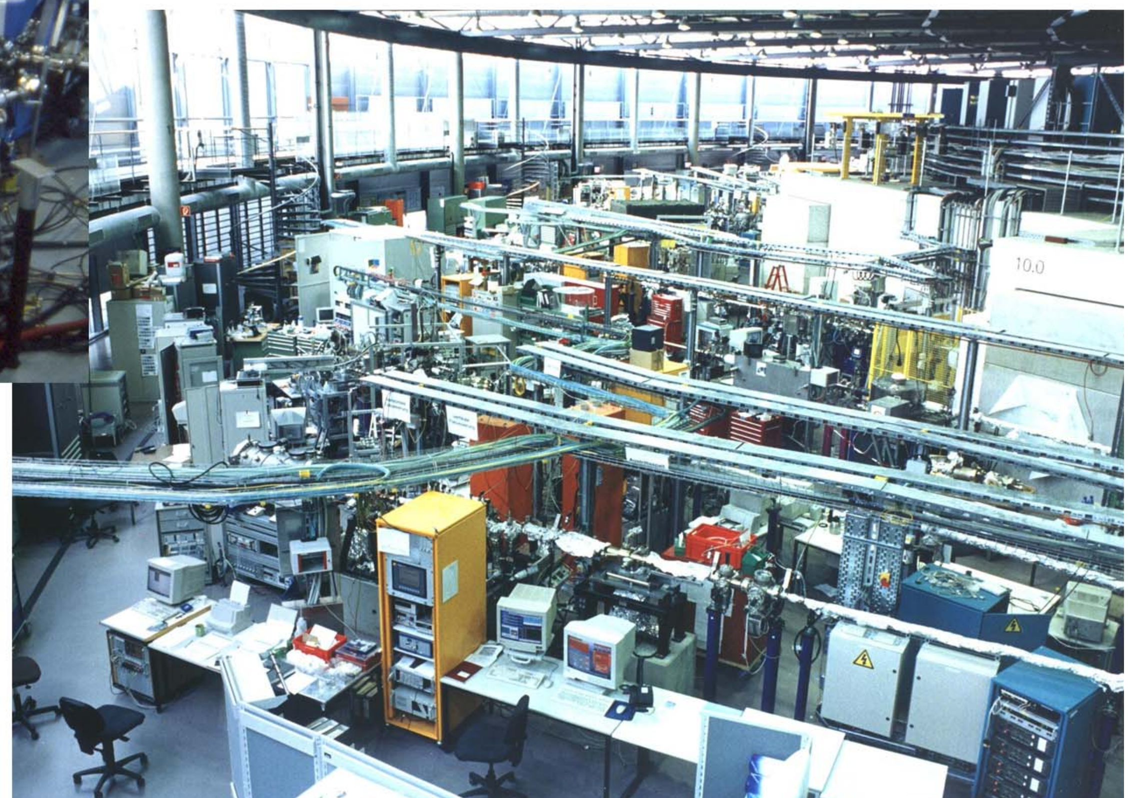
Eric Jensen
Brandeis

The People at Tantalus IBM Mafia



30 years of Progress???





Tantalus products
•Two members of NAS
• Ten Synchrotron Directors
• Three Davisson –Germer prizes
• Two Welch Awards
• One Buckley Prize

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LSU

What has changed?
Are the Changes good or bad?

The size of the team!

"The Effects on Photoemission of the Spatially Varying Photon Field at a Metal Surface," H. J. Levinson, E. W. Plummer, and P. J. Feibelman, *Phys. Rev. Lett.* **43**, 952 (1979).

"Direct Extraction of the Eliashberg Function for Electron-Phonon Coupling: A Case Study of Be(1010) ," Junren Shi, S.-J. Tang, Biao Wu, P. T. Sprunger, W. L. Yang, V. Brouet, X. J. Zhou, Z. Hussain, Z.-X. Shen, Zhenyu Zhang, and E. W. Plummer, *Phys. Rev. Lett.* **92**, 186401 (2004).

Is this really a good way to train experimental graduate students?

You have the opportunity in Virginia do light source based research in a different way! Forefront research coupled with training of the next generation.

Examples of materials exeriments
In the time domain,
Using light sources

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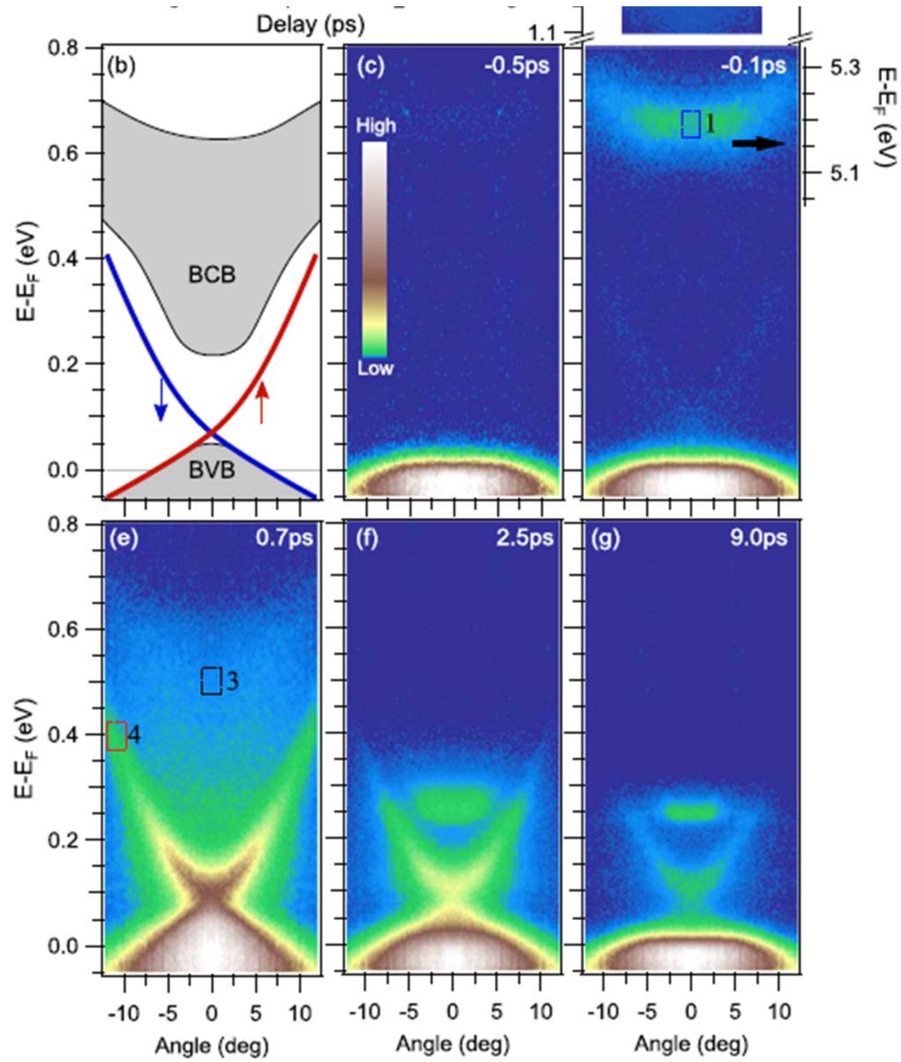
PRL **108,** 117403 (2012) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2012

Ultrafast Optical Excitation of a Persistent Surface-State Population in the Topological Insulator Bi_2Se_3

J. A. Sobota,[1,2,3] S. Yang,[1,2,3] J. G. Analytis,[1,2] Y. L. Chen,[1,2,3] I. R. Fisher,[1,2] P. S. Kirchmann,[1,4,*] and Z.-X. Shen[1,2,3,†]

Using femtosecond time- and angle-resolved photoemission spectroscopy, we investigated the nonequilibrium dynamics of the topological insulator Bi_2Se_3. Optical excitation leads to a metastable population at the bulk conduction band edge, which feeds a nonequilibrium population of the surface state persisting for >10 ps. This unusually long-lived population of a metallic Dirac surface state with spin texture may present a channel in which to drive transient spin-polarized currents.



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5/16/12

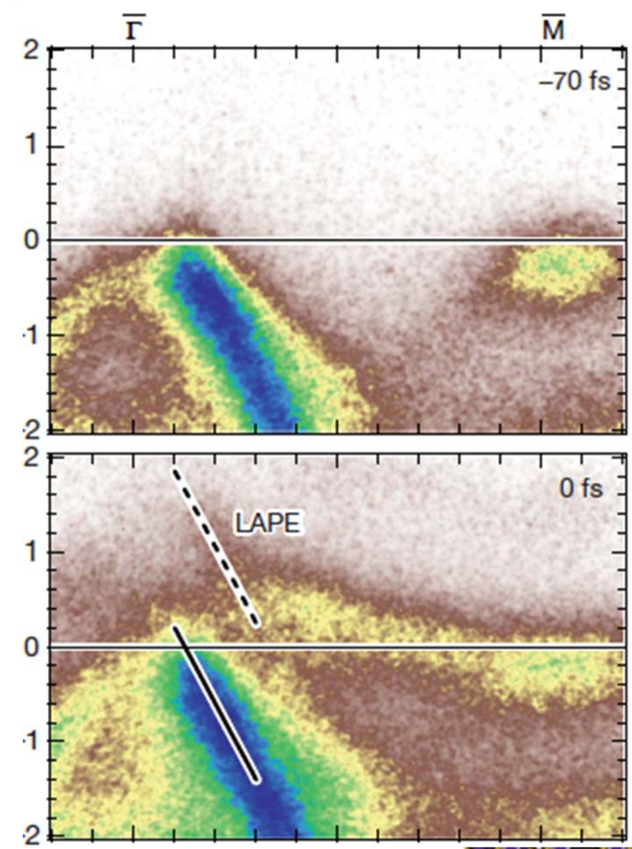
LETTER

doi:10.1038/nature09829

Collapse of long-range charge order tracked by time-resolved photoemission at high momenta

Timm Rohwer[1]*, Stefan Hellmann[1]*, Martin Wiesenmayer[1], Christian Sohrt[1], Ankatrin Stange[1], Bartosz Slomski[1], Adra Carr[2], Yanwei Liu[3,4], Luis Miaja Avila[5], Matthias Kalläne[1], Stefan Mathias[2,6], Lutz Kipp[1], Kai Rossnagel[1] & Michael Bauer[1]

Here, using femtosecond extreme-ultraviolet pulses delivered by a high-harmonic-generation source, we use time- and angle-resolved photoemission spectroscopy to measure the photoinduced vaporization of a charge-ordered state in the potential excitonic insulator 1T-TiSe2



By way of stroboscopic imaging of electronic band dispersions at large momentum, in the vicinity of the edge of the first Brillouin zone, we reveal that the collapse of atomic-scale periodic long-range order happens on a timescale as short as 20 femtoseconds. 43eV light

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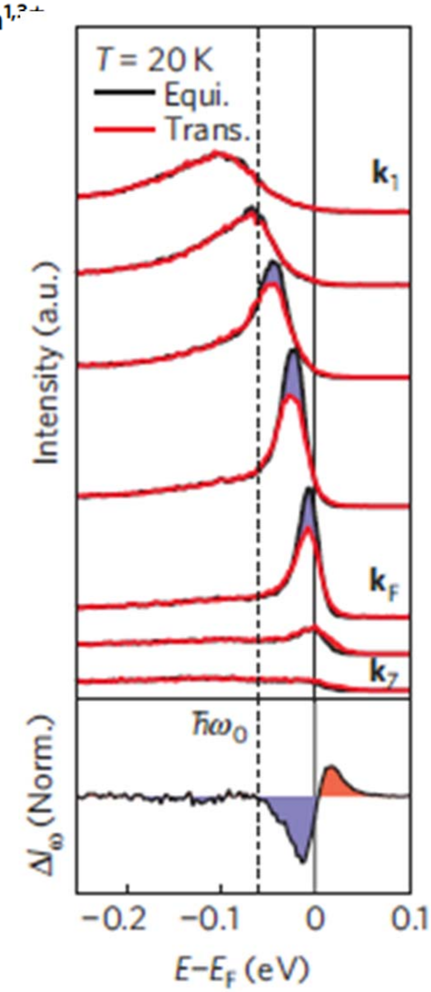
nature physics
ARTICLES
PUBLISHED ONLINE: 3 JULY 2011 | DOI: 10.1038/NPHYS2027

Nodal quasiparticle meltdown in ultrahigh-resolution pump–probe angle-resolved photoemission

J. Graf[1†], C. Jozwiak[1,2†], C. L. Smallwood[3], H. Eisaki[4], R. A. Kaindl[1], D-H. Lee[1,3] and A. Lanzara[1,3*]

Here we reveal an unexpected link between nodal quasiparticles and superconductivity using high-resolution time- and angle-resolved photoemission on optimally doped Bi2Sr2CaCu2O8C. We observe a suppression of the nodal quasiparticle spectral weight following pump laser excitation, and measure its recovery dynamics.----840 nm Laser



In summary, we propose that the observed temperature- and/or pump-driven suppression of QP spectral weight is due to an increase in superconducting Cooper pair phase fluctuations4042 corresponding to a loss in superfluid density.

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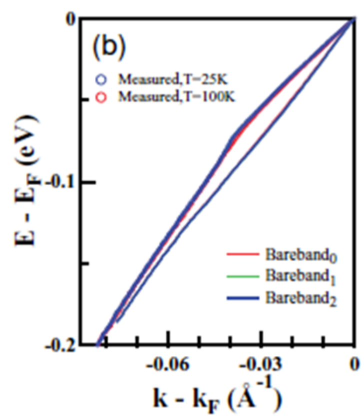
What is the most important advancement in light sources Needed for my immediate research??

High resolution RIXS.
Experimental determination of
The role of EPC in superconductors

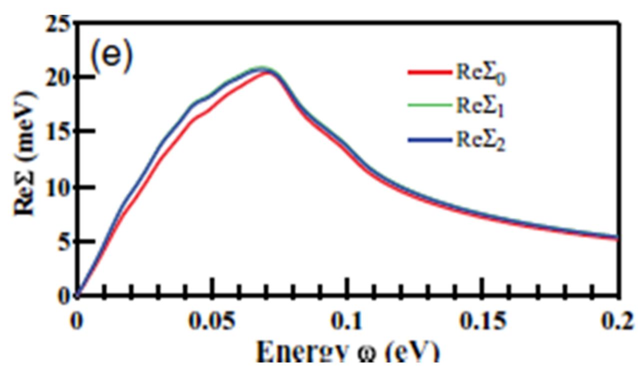
Signature of electron phonon coupling

One of the most important issues associated with physics of high-T_C superconductivity is the role of electron-phonon coupling (EPC) in the electron pairing for unconventional superconductors. At present the heated debates surrounding the role of EPC have been largely theoretical and ideological in nature. It is now possible to determine the role of each bosonic mode experimentally!!!

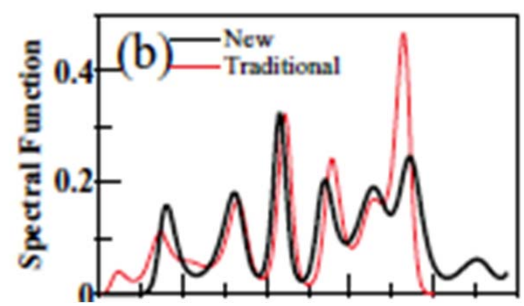
X. J. Zhou's group using laser based ARPES, **Quantitative determination of Eliashberg function and evidence of strong electron coupling with multiple phonon modes in heavily overdoped $(Bi,Pb)_2Sr_2CuO_{6+\delta}$** , Phys. Rev. **B83,** 184515 (2011)



Kink



Real part of self energy Σ



Eliashberg Function
α^2F

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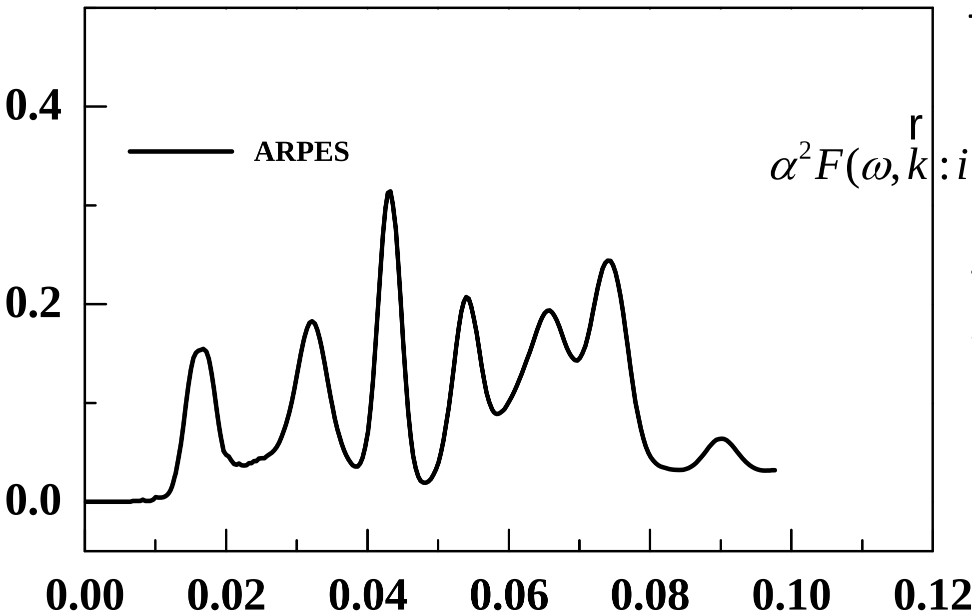
Role of each mode in superconductivity



The momentum resolved Eliashberg function is

$$\alpha^2 F(\omega, \vec{k} : i) = \int_{BZ} \frac{d\vec{k}'}{(2\pi)^2} \, |g(\vec{k}' - \vec{k} : i)|^2 \; \delta(\omega - \omega_{\vec{q}}) \delta(\varepsilon_{\vec{k}} - \varepsilon_{\vec{k}'} + \omega)$$

The challenge is to determine experimentally the origin of each one of the peaks i in the ELF. This can't be done with ARPES but it can be done by combining ARPES with measurements of the phonon mode dispersion and then determining the EPC matrix element $|g(k,k')|^2$ for each peak i.

We have done this using ARPES measurements for the electronic band dispersion and High resolution inelastic electron scattering to measure the phonons. In the future RIXS can be used to interrogate each mode.

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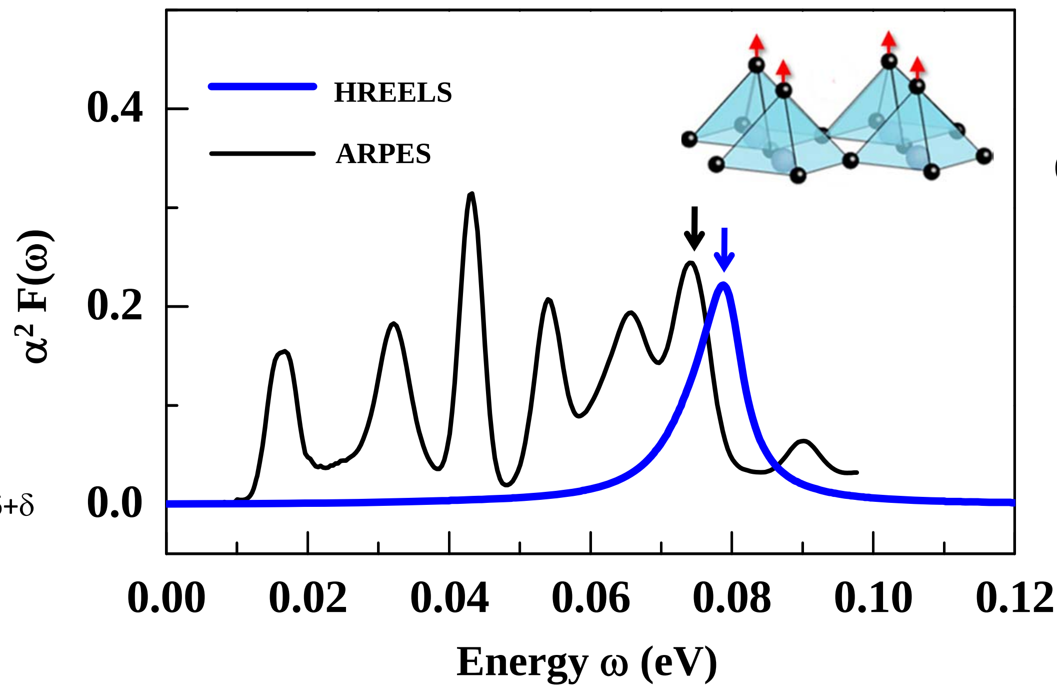
The Role of the Apical O A_{1g} phonon in superconductivity

Zhou's data
For ELF on
$(Bi,Pb)_2Sr_2Cu_{6+\delta}$
Bi2201



Our data for the A_{19} mode
$Bi_2Sr_2CaCuO_{6+\delta}$
Bi2212

Raman calculation indicates there is a small shift of the peak position (~ 7 meV) between Bi2212 and Bi2201. Kovaleva *et al.,* PRB 69, 054511 (2004)

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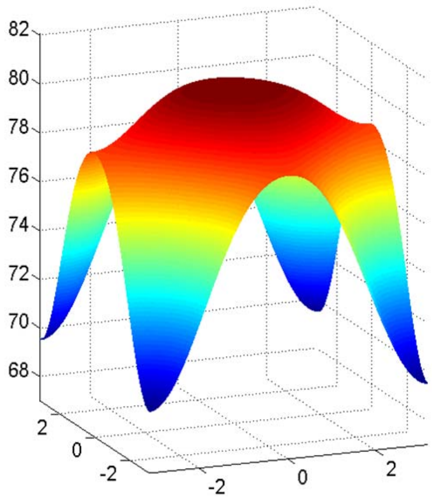
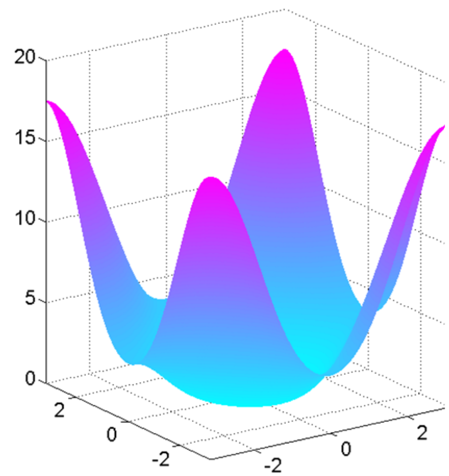
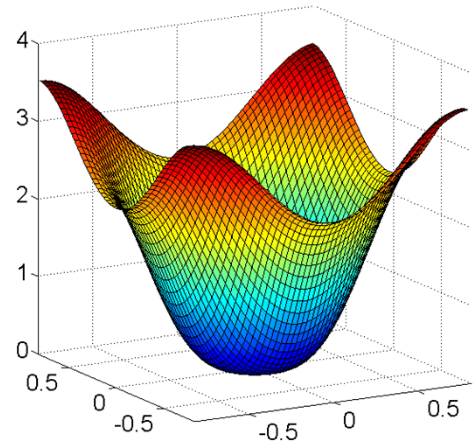
Apical O A_{1g} phonon in cuprates



Phonon Energy



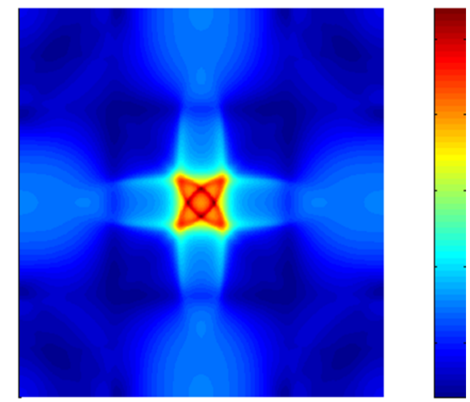
Phonon Width



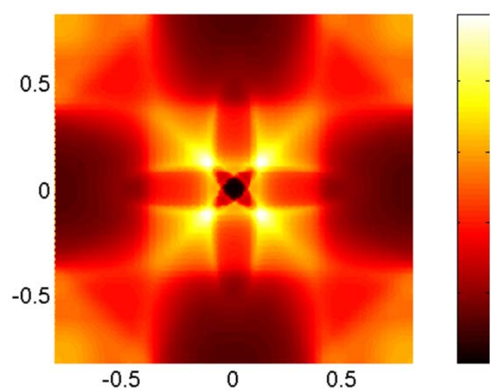
$|g(k,k':A_{1g})|^2$

r

$|g(q:A_{1g})|^2$

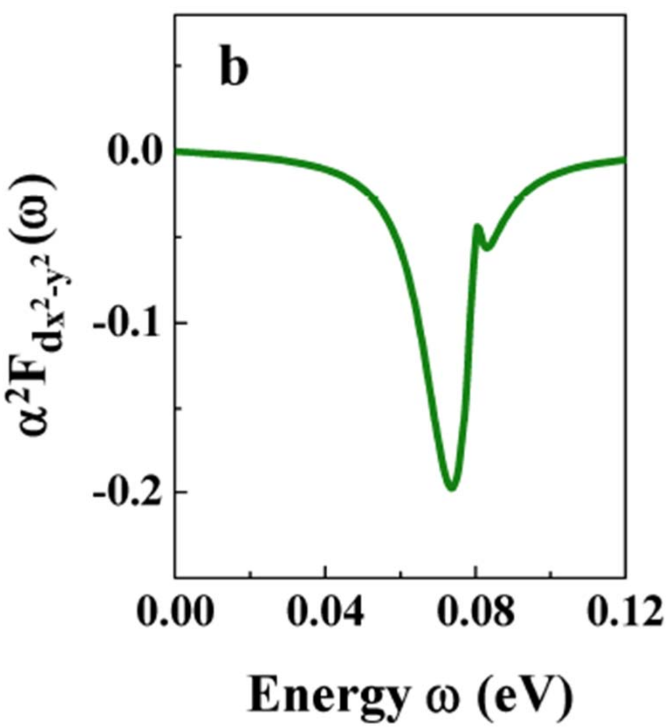


Real part Lindhard response function

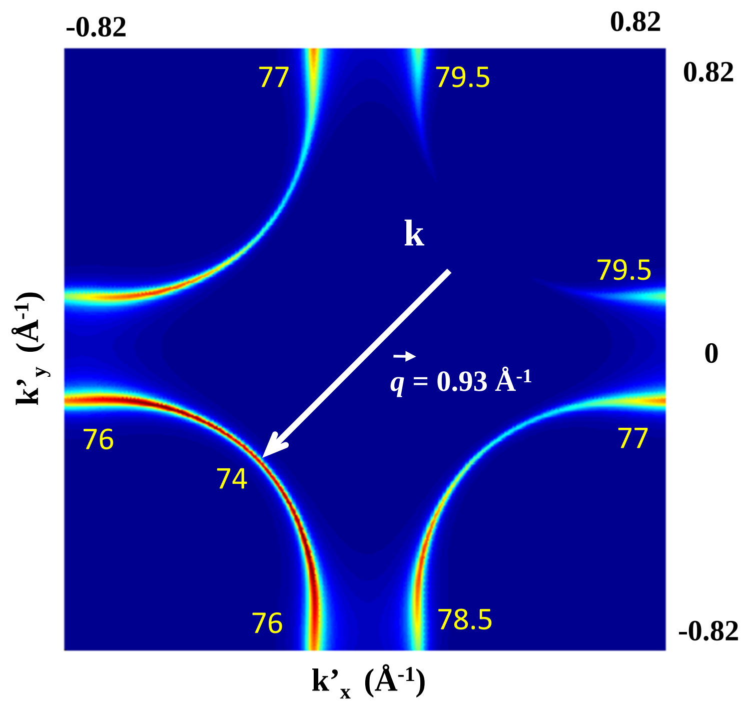


Imaginary part Lindhard function

Apical O A_{1g} phonon in cuprates



d-wave component of ELF is negative, so the A_{1g} O mode has nothing to do with d-wave pairing.



Knowing $g(q)^2$ and the phonon spectra properties we can determine where the transitions occur in k' space

Synchrotron based high resolution Inelastic X-ray scattering

PRL **107,** 136401 (2011) PHYSICAL REVIEW LETTERS week ending 23 SEPTEMBER 2011

Understanding the Complex Phase Diagram of Uranium: The Role of Electron-Phonon Coupling

nature physics ARTICLES

PUBLISHED ONLINE: 10 JULY 2011 | DOI:10.1038/NPHYS2041

Intense paramagnon excitations in a large family of high-temperature superconductors

D. Reznik, “Giant electron-phonon coupling anomaly in doped La_2CuO_4 and other cuprates,” *Adv. Cond. Mat. Phys.* ***2010****, 523549 (2010).*

J. Graf, M. d’Astuto, C. Jozwiak, D. R. Garcia, N. L. Saini,M. Krisch, K. Ikeuchi, A.Q.R. Baron, H. Eisaki, and A. Lanzara, “A. *Bond stretching phonon softening and kinks in the angle-resolved photoemission spectra of optimally doped* $Bi_2Sr_{1.6}La_{0.4}Cu_2O_{6+\delta}$ *superconductors,” Phys. Rev. Lett. 100, 2270002 (2008)*

D. R. Garcia, & A.Lanzara, “Through a lattice darkly: shedding light on electron-phonon coupling in the high T_c cuprates,” *Adv. Cond. Mat. Phys.* ***2010, 807412 (2010).***

Thank you!

Good Luck!

Disentangling the Electronic and Phononic Glue in a High-T_c Superconductor

Science ***335, 1600 (2012);***

S. Dal Conte,[1*] C. Giannetti,[2,3†] G. Coslovich,[4‡] F. Cilento,[4] D. Bossini,[3§] T. Abebaw,[4||] F. Banfi,[2,3] G. Ferrini,[2,3] H. Eisaki,[5] M. Greven,[6] A. Damascelli,[7,8] D. van der Marel,[9] F. Parmigiani[4,10]

We performed optical spectroscopy on $Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_{8+\delta}$ crystals with simultaneous time and frequency resolution; this technique allowed us to disentangle the electronic and phononic contributions by their different temporal evolution. The spectral distribution of the electronic excitations and the strength of their interaction with fermionic quasiparticles fully account for the high critical temperature of the superconducting phase transition. Laser 1.5 eV