



George R. Harrison Spectroscopy Laboratory Massachusetts Institute of Technology

Michael S. Feld (1940-2010)



Michael S. Feld, Professor of Physics and Director of the George R. Harrison Spectroscopy Laboratory, died Saturday April 10, 2010 after an eight-year struggle with multiple myeloma.

He is survived by his wife Alison Hearn, his daughter Alexandra Feld, and his two sons Jonathan and David Feld.

Feld became director of the Spectroscopy Laboratory in 1976. For over thirty years his leadership shaped the mission of the laboratory and took it in new directions, most recently, medical applications of spectroscopy. In his early career he made fundamental contributions to the development of laser science. For the past twenty years he has pioneered applying physics to biomedical problems. His doctoral students and post-doctoral research associates have become leaders in physics and biomedical science.

He first came to MIT in 1958 as an undergraduate. He went on to do his PhD at MIT under the supervision of Prof. Ali Javan, and in 1968 he became a member of the MIT faculty. During his 52 years at MIT he was an active contributor to the MIT community; he was particularly proud of his work helping to develop a welcoming ambience for minority students, staff, and faculty.

Go to <http://web.mit.edu/newsoffice/2010/obit-feld.html> for a more complete obituary. There will be a memorial service at MIT later this spring. ✨

Gary Forrest Award for 3 Ph.D. Theses

Adam Steeves, Kathy Stone, and Gautum Nair are the three winners of the Gary Forrest Award in 2009 for excellence in spectroscopy doctoral thesis research.

Adam Steeves, a student of Prof. Field, wrote on "Electronic Signatures of Large Amplitude Motions." **Kathy Stone**, who studied with Prof. Nelson, composed her thesis on "Coherent multi-exciton dynamics in semiconductor nanostructures via two-dimensional Fourier transform optical spectroscopy." A student of Prof. Bawendi, **Gautum Nair's** thesis is titled "Many-Body Processes in the Photophysics of Colloidal Semiconductor Nanocrystals."



Gary Forrest

Forrest, continues on Page 2

Wolfgang Ketterle to Present 2010 Lord Lecture

by Gabriel Holbrow

On April 27, Dr. Wolfgang Ketterle, the John D. MacArthur Professor of Physics at MIT, will deliver the 19th annual Richard C. Lord Lecture, "Quantum magnetism of ultracold atoms."

Born and educated in Germany, Ketterle came to MIT in 1990 and since then has pioneered exploration into the properties of ultracold gases and new forms of matter at ultracold temperatures, a new subfield of atomic physics made possible in part by his achievements. Building on technological advances in atom trapping and laser cooling



which he and his collaborators developed, Ketterle was among the first to observe Bose-Einstein condensate, in 1995, and the first to realize an atomic laser, in 1997. These achievements were recognized by the Nobel Prize in Physics for 2001, awarded to Ketterle jointly with Eric A. Cornell and Carl E. Wieman.

Ketterle has been the recipient of numerous awards both before and after his Nobel Prize, including MIT's James R. Killian, Jr. Faculty Achievement Award for 2004-2005, and most recently a 2009 Humboldt research award. He is an elected fellow of the American Physical Society, the Optical Society of America, the Academy of Arts and Sciences, and the Institute of Physics (IOP).

Although today he is a leader in the physics of cold atoms, Ketterle switched into the field relatively late, after successful periods both as a theoretical physicist in condensed matter theory, as an experimentalist in molecular spectroscopy and as an applied physicist in combustion diagnostics.

Born in Heidelberg, Germany in 1957, he spent his childhood in the neighboring village of Eppelheim and in 1976 entered the University of Heidelberg. Two years later, he transferred to the Technical University of Munich, completing a diploma thesis (equivalent to a master's) in 1982 on spin relaxation in disordered materials under Professor Wolfgang Götze.

Ketterle, continues on Page 2

Looking to gain experience with experimental physics, he began a Ph.D. project at the Max Planck Institute for Quantum Optics in Garching under Professor Herbert Walther and Dr. Hartmut Figger. "I was attracted to experimental physics because of the potential to apply experimental techniques to the real world," he says. For his project, he eventually focused on basic spectroscopy of small molecules, in particular triatomic hydrogen (H_3) and helium hydride (HeH), and was the first to observe the discrete spectra of HeH , thereby formally confirming the existence of the molecule. "It was exciting to determine the basic properties of a new molecule," he says, "like the old days when molecular spectroscopy was established."

After receiving the Ph.D. in physics from the University of Munich in 1986 for his work in molecular spectroscopy and three postdoctoral years in the same area, Ketterle felt himself pulled toward other areas of

physics. He considered pursuing academic research in more fundamental physics or in applied physics more directly related to the needs of society, or even leaving academia for a job in industry.

In the end, he decided to join Professor Jürgen Wolfrum's group at the University of Heidelberg, using laser spectroscopy to study combustion processes. "This work fascinated me," say Ketterle, "and it gave me a special form of satisfaction when I applied my knowledge of fundamental physics to real world problems." He found that applied science came with its own challenges, however. One of his projects in collaboration with Volkswagen was conducted at an engine test stand in an auto plant where he and his collaborators encountered "soot on the windows of the transparent engine and optics dripping with oil coming from a diesel engine," Ketterle recalls.

Despite switching to a very different field of research, Ketterle found he could apply much of what he learned from his previous experience and quickly gained confidence in the new field. "Changing fields was a crucial experience for me," he says. "I realized that general skills are much more important than specific knowledge." He credits the self-confidence he gained with providing the impetus for another bold change, to another research field and another country.

At the age of 32, Ketterle switched fields once more, leaving stable employment in Germany for a post-doc position in the United States, working on cold atom sources with Professor David Pritchard at MIT. Missing "the quest for pure knowledge" and looking to move into fundamental physics, he identified cold atoms as the most promising area where he could use his knowledge of optics and spectroscopy. "At the time," Ketterle recalls, "my assessment

was that the field of laser cooling and trapping had reached its peak, but there was still enough to be done. I didn't anticipate that the best was still to come," including a Nobel Prize!

With Professor Pritchard at MIT, Ketterle initially worked on improving trapping and cooling techniques toward the goal of studying cold collisions. Existing laser cooling and evaporative cooling methods could not produce high enough densities at low enough temperatures, so Ketterle and his collaborators developed new techniques, including an magneto-optical atom trap called the "dark" SPOT (spontaneous force optical trap) and rf-induced evaporative cooling. The success of these advances encouraged the group to focus on another problem that required high densities at low temperatures: the observation of Bose-Einstein Condensation.

First predicted by Satyendra Nath Bose and Albert Einstein in 1925 but still unachieved in the early 1990's, the Bose-Einstein condensate (BEC) is a state of matter in which atoms at nanokelvin temperatures are locked together in the lowest quantum state of the system. Because the atoms share the same quantum state, the condensate exhibits quantum mechanical effects at the macroscopic scale, providing a connection between the microscopic world described by quantum mechanics and the familiar macroscopic world described by classical physics.

The race to BEC was head-to-head between the MIT group and a team lead by Cornell and Wieman at the University of Colorado, Boulder. In June 1995, the Boulder group made the first observations of BEC with a gas of rubidium atoms. Less than four months later in September, Ketterle's group realized BEC in sodium.

Ketterle, continues on Page 7

THE SPECTROGRAPH

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GEORGE R. HARRISON SPECTROSCOPY LABORATORY

Director: Michael S. Feld

Associate Directors:
Robert W. Field
Ramachandra R. Dasari

The Spectroscopy Laboratory houses two laser research resource facilities. The MIT Laser Research Facility provides shared facilities for core researchers to carry out basic laser research in the physical sciences. The MIT Laser Biomedical Research Center (LBRC), a National Institutes of Health Biomedical Research Technology Center, is a resource center for laser biomedical studies. The LBRC supports core and collaborative research in technological research and development. In addition, it provides advanced laser instrumentation, along with technical and scientific support, free of charge to university, industrial, and medical researchers for publishable research projects. Call or write for further information or to receive our mailings.

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Forrest (continued from Page 1)

The award was established by Gary Forrest, who earned his Ph.D. in the Spectroscopy Laboratory under Prof. Richard Lord, to "continue the philosophy of independent thinking by students that characterized Prof. Lord." Forrest ran Sensor Physics, a laser test equipment business, for a successful 15 years, and is now using his MIT opto-mechanical experience to design and build small pieces of furniture incorporating photographs printed on very thin mulberry paper.



Hot Results

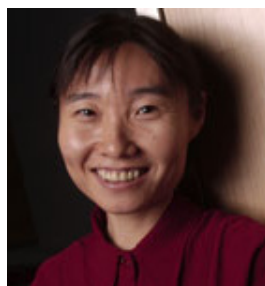
A selection of exciting recent findings from the Spectroscopy Laboratory



Kimberley Hamad-Schifferli, the Esther and Harold E. Edgerton Assistant Professor of Mechanical Engineering and Biological Engineering, and her research group have developed a selective drug release system using two different shapes of gold nanorods that melt at different wavelengths of infrared light. The system, published in *ACS Nano's* first issue in 2009, has been widely reported in publications from ComputerWorld to the New York Times and the Times of India. Different wavelengths of infrared light cause two nanorod shapes, called "nanobones" and "nanocapsules," to dissolve and release their drug contents. The system shows great potential for fighting cancer, AIDS, and other diseases treated by combinations of multiple drugs. The research also produced a successful Ph.D. thesis for **Andy Wijaya**, the lead author of the paper and a June 2009 doctoral graduate.

A. Wijaya, S.B. Schaffer, I.G. Pallares, K. Hamad-Schifferli, "Selective release of multiple DNA oligonucleotides from gold nanorods," *ACS Nano* **3**(1) 80-86 (2009).

Mildred Dresselhaus and **Jing Kong**, the ITT Career Development Associate Professor of Electrical Engineering, collaborated on studies of graphene. Large area single layer and bilayer graphene samples prepared by chemical vapor deposition (CVD) were characterized by their Raman spectra to show that the inter-layer stacking arrangement was highly sensitive to the parameters used in the synthesis process.



A. Reina, S. Thiele, X.T. Jia, S. Bhaviripudi, M.S. Dresselhaus, J.A. Schaefer, J. Kong, "Growth of Large-Area Single- and Bi-Layer Graphene by Controlled Precipitation on Polycrystalline Ni Surfaces," *Nano Research* **2**(6) 509-516 (2009).

X. Ling, L.M. Xie, Y. Fang, H. Xu, J. Kong, M.S. Dresselhaus, J. Zhang, Z.F. Lui, "Can graphene be used as a substrate for Raman enhancement?" *Nano Letters* **10**(2) 553-561 (2010).



Dresselhaus also reports on progress made with carbon nanotubes working in collaboration with Jing Kong. The resonance windows for the specific $(2n+m)$ families of individual (n,m) carbon nanotubes were studied in detail by Raman spectroscopy, showing a linear increase in the resonance window width with chiral angle, with the smallest window width occurring for zigzag single wall carbon nanotubes (SWNTs) ($\theta = 0^\circ$) and the largest window width for armchair

SWNTs ($\theta = 30^\circ$). The resonance windows were twice as large for metallic tubes as for semiconducting tubes of the same chiral angle and diameter. Electrochemical studies have shown the various Raman features to be sensitive to variation of the Fermi level. Likewise, doping double wall carbon nanotubes with halogens like bromine or iodine was shown to vary the intensity, frequency, and lineshape of each feature in the Raman spectra differently for the inner and outer tubes. It was further shown that the intensity, frequency, and lineshape of the various features of the same inner tube (for example the (6,5) carbon nanotube) of a double wall nanotube can be varied significantly by changing the (n,m) of its outer tube partner.

G.M. do Nascimento, T. Hou, Y.A. Kim, H. Muramatsu, T. Hayashi, M. Endo, N. Akuzawa, M.S. Dresselhaus, "Comparison of the Resonance Raman Behavior of Double-Walled Carbon Nanotubes Doped with Bromine or Iodine Vapors," *Journal of Physical Chemistry C* **113**(10) 3934-3938 (2009).

F. Villalpando-Paez, H. Muramatsu, Y.A. Kim, H. Farhat, M.M. Endo, M. Terrones, M. S. Dresselhaus, "Wall-to-wall stress induced in (6,5) semiconducting nanotubes by encapsulation in metallic outer tubes of different diameters: A resonant Raman study of individual C-60-derived double wall carbon nanotubes," *Nanoscale* **2**(3) 406-411 (2010).

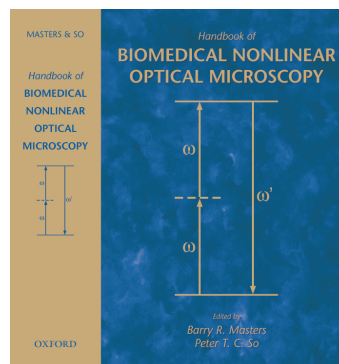
Y.P. Hsieh, M. Hofmann, E.B. Barros, A. Souza Filho, H. Farhat, Y.F. Chen, M.S. Dresselhaus, J. Kong, and C.T. Liang, "Resonant window from isolated semiconducting and metallic single-walled carbon nanotube within families on a SiO_2/Si substrate," *Applied Physics Letters*, in press (2010). ✨

Masters Named AAAS Fellow

Barry R. Masters, Visiting Scientist in Biological Engineering, has been elected a Fellow of the American Association for the Advancement of Science (AAAS). Also a fellow of SPIE and the Optical Society of America, Masters's research interests include the development of in vivo microscopy of the human eye and skin, biomedical imaging and spectroscopy, and the fractal analysis of branching vascular patterns. He is the



author of over 80 research papers and nine books, including most recently the *Handbook of Biomedical Nonlinear Optical Microscopy*, published by Oxford University Press in 2008. The handbook was edited by Masters and fellow Spectroscopy Lab professor **Peter So**. ✨



RESEARCH REPORTS

Three students from the Spectroscopy Laboratory won prizes at the lab's poster session held on January 15, 2010 during Independent Activities Period (IAP). **Lisa Marshall**, of Prof. Bawendi's group, won for most science; **Seungeun Oh** of Prof. Feld's group for most spectroscopy; and **Yan Zhou** of Prof. Field's group for most originality. This issue of the *Spectrograph* presents abstracts from Lisa Marshall and Yan Zhou's winning research, along with abstracts of **Josh Lessing** (Tokmakoff group) and **Daniel Turner** (Nelson group) whose posters won honorable mention. Seungeun Oh's research was featured in the Fall 2009 issue.

Extracting Spectral Dynamics from Single Chromophores in Solution

Lisa Marshall

We demonstrate a novel interferometric technique for extracting time dependent single chromophore spectral dynamics from intensity correlations in the interference pattern of an ensemble fluorescence spectrum. By replacing the beam splitter in a standard Fluorescence Correlation Spectroscopy (FCS) experiment with a Michelson interferometer (Fig. 1), we are able to analyze

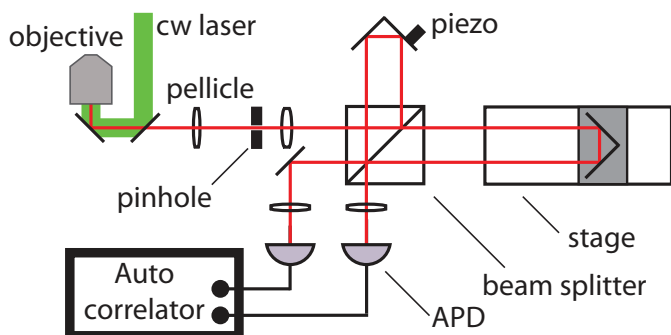


Figure 1 As seen in Photon Correlation Fourier Spectroscopy (PCFS), we cross-correlate the outputs of a scanning Michelson interferometer to convert fast frequency fluctuations into measurable intensity fluctuations.

intensity correlations as a function of interferometer position to extract the distribution of energy separations between photons over a series of temporal separations (i.e. spectral correlations). Spectral correlations of single chromophores are statistically separated from the ensemble using intensity fluctuations caused by diffusion. (Fig. 2) We applied our technique to solutions of colloidal quantum dots and explored the spectrum of single particles on timescales not feasible with conventional fluorescence measurements.

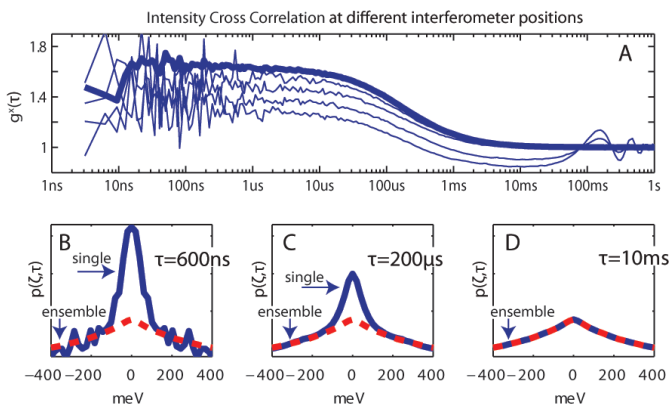


Figure 2 a) For each position of the interferometer, we measure a cross correlation while dithering one mirror. b)-d) The diffusion weighted spectral correlation for three representative temporal spacings. As the temporal spacing increases, the single particle component decreases and, eventually, only ensemble information remains.

Talking Directly to Rydberg Atoms

Yan Zhou

Chirped Pulse Fourier Transform Millimeter-Wave Spectroscopy (CPmmW) was recently developed by Brooks Pate and coworkers [1] and applied for rotational spectroscopy of ground state molecules. The technique allows one to obtain instantaneously a high-resolution mm-wave spectrum over a range as wide as 10 GHz, and averaging can be done in the time domain. This approach has been applied to pure electronic Rydberg-Rydberg transitions in calcium atoms. Whereas Rydberg states are generally detected by ionization, in this work they are detected by the field they radiate upon excitation. (Figs. 1 and 2) The possibility of stabilizing Rydberg molecules with shaped mm-wave pulses is discussed.

[1] Gordon G. Brown, Brian C. Dian, Kevin O. Douglass, Scott M. Geyer, Steven T. Shipman, and Brooks H. Pate, Rev. Sci. Inst. **79**, 053103 (2008).

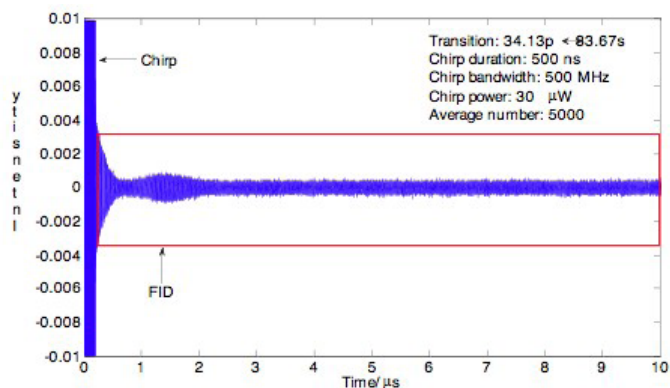


Figure 1 The sample-polarizing 76.910-76.950 GHz Chirp and the resultant Free Induction Decay (FID) from the Ca atom 34.13p ↔ 33.67s transition.

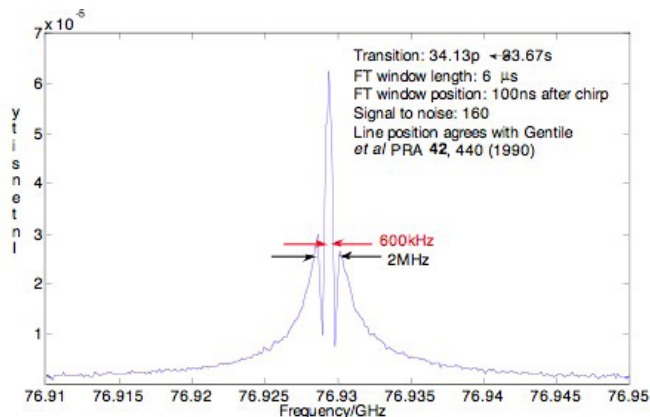


Figure 2 Typical Rydberg-Rydberg CPmmW spectrum.

Coherent Measurements of High-Order Electronic Correlations in GaAs Quantum Wells

Daniel Turner

Strong, long-range Coulomb interactions can lead to correlated motions of multiple charged particles, which can induce important many-body effects in semiconductors. The exciton states formed from correlated electron-hole pairs have been studied extensively, but basic properties of multiple-exciton correlations—such as coherence times, population lifetimes, binding energies, and how many particles may be correlated—are largely unknown because they are not spectroscopically accessible from the ground state. Here we present direct observations of high-order coherences in GaAs quantum wells, achieved through two-dimensional (2D) multiple-quantum spectroscopy methods in which up to seven successive light fields were used to generate and characterize multiple-exciton coherences. The measurements were made possible through the combination of a spatial beam shaper and a spatiotemporal pulse shaper (Fig. 1). The results reveal triexciton coherences whose existence was not obvious since the third exciton spin is unpaired. The results also produced values for the coherence times and binding energies of the triexciton coherences (Fig. 2 left). We also determined that there are no significant four-exciton correlations (Fig. 2 right). The limits as well as the properties of many-body correlations in this system were revealed.

K.W. Stone, K. Gundogdu, D.B. Turner, X. Li, S.T. Cundiff, and K.A. Nelson, *Science* **324**, 1169 (2009).

D.B. Turner, and K.A. Nelson, submitted (2010).

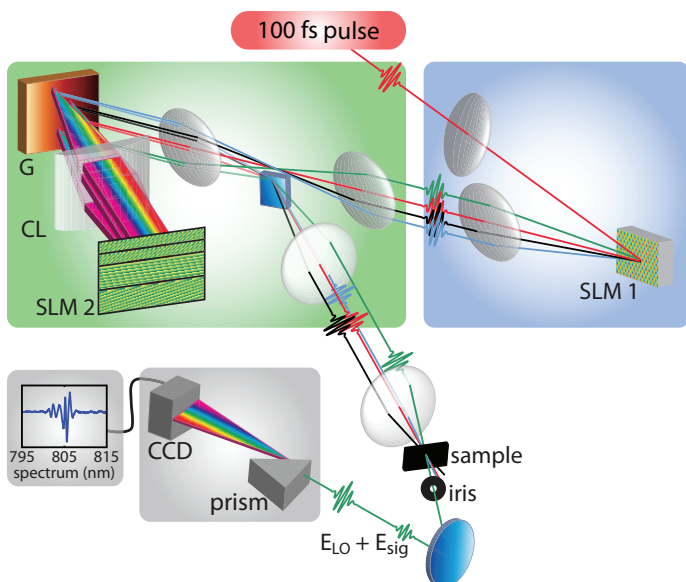


Fig. 1. Fully coherent multidimensional spectrometer. (blue box) The single incident beam is converted to a user-defined geometry using a spatial light modulator (SLM 1) in the beam shaper. (green box) The relative time delays and phases of pulses in all the beams are controlled using SLM 2 in the spatiotemporal pulse shaper. (grey box) The pulses are focused to the sample, and the signal and local oscillator (LO) fields are superposed and directed to a CCD spectrometer.

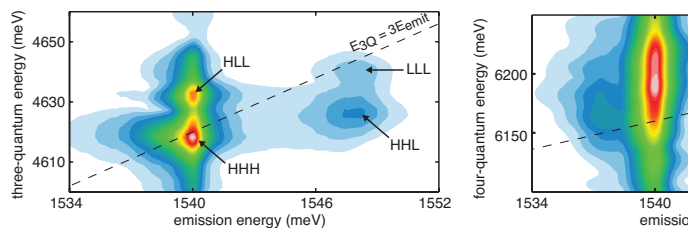
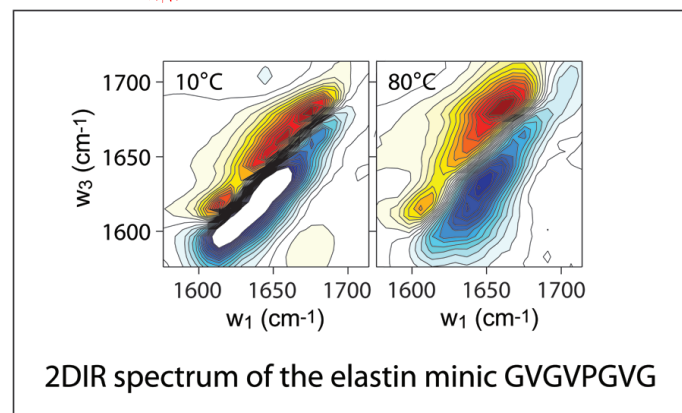


Fig. 2. (left) Fifth-order three-quantum 2D FTOPT. Four main peaks appear, one for each triexciton state. Coherent oscillations in the signal field were Fourier transformed to yield the three-quantum energies. (right) Seventh-order four-quantum 2D FTOPT. The main features are due to scattering between free carriers and excitons; there is a distinct absence of quadexciton peaks.

2-D IR Vibrational Spectroscopy of Elastin-Like Peptides

Josh Lessing

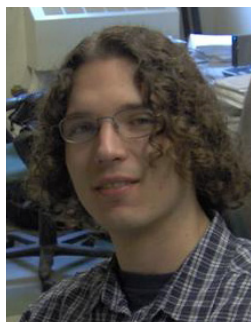
Elastin protein is responsible for the elasticity of organs including the skin, lungs, and arterial tissues. This remarkable biomaterial is 10x stronger than steel, 3x stronger than Kevlar and has a half life of 70 years during which time it can perform one billion extension compression cycles (Urry 2002). To date the structure of elastin and the origin of its elasticity is unknown. To investigate this we have performed temperature dependent FTIR and 2D IR experiments on the amide I peptide backbone vibration of bovine neck elastin and isotope edited synthetic elastin mimics. Through the use of isotope labeling it has been possible to get amino acid specific information on the peptide backbone with picosecond resolution. This time resolved and site specific approach will provide information on the proteins structure and dynamics and thereby elucidate the mechanism for its elasticity.



2DIR spectrum of the elastin minic GVGPGVG

Spec Lab Graduates

More than a ten lab members earned Ph.D. degrees from MIT in the past year. The Laboratory is proud of their work here, and wishes them success in their future work.



Sean Roberts

Sean Roberts competed his Ph.D. in Chemistry in December 2009 under Prof. Tokmakoff. His thesis was titled “Hydrogen Bond Rearrangements and the Motion of Charge Defects in Water Viewed

using Multidimensional Ultrafast Infrared Spectroscopy.” The new Dr. Roberts is currently a postdoc at the USC, working to further our understanding of charge transport in organic solar cells.

Adam Steeves, student of Prof. Field, earned a Ph.D. in Chemistry in May 2009. His thesis “Electronic Signatures of Large Amplitude Motions” won a Gary Forrest Award. He is currently working on a postdoc in computational biophysics at UCSF under the direction of former Spectroscopy Lab graduate student Matt Jacobson.



Adam Steeves

Qiong Yang studied under Prof. van Oudenaarden, earning her Ph.D. in Physics in September 2009. Her thesis was titled “Dynamics of stochastic gene expression



Qiong Yang

and signal transduction in single cells.” She is now a postdoc in James Ferrell’s lab at Stanford, focusing on circuit design principles underlying robust mitotic

oscillation in early embryonic development.

Kathy Stone completed her Ph.D. in Chemistry in May 2009 under Prof. Nelson. She won a Gary Forrest Award for her thesis “Coherent multi-exciton dyna-

ics in semiconductor nanostructures via two-dimensional Fourier transform optical spectroscopy.” At present, she holds a joint postdoc research position at MIT with Profs. Vladimir Bulovic (RLE) and Keith Nelson (Chemistry), investigating nonlinear optical properties of J-aggregates and how single and multi-exciton dynamics play a role in the physics of strong coupling of J-aggregate excitons to cavity-confined photons.



Kathy Stone

Other new doctors include:

Andy Wijaya (Prof. Hamad-Schifferli), Ph.D. in Chemical Engineering 2009 “Selective Heating of Multiple Nanoparticles as a New Strategy for Controlled Release Applications”

Sunho Park (Prof. Hamad-Schifferli), Ph.D. in Mechanical Engineering 2009, “Characterization of nanoparticle-DNA conjugate and control of DNA conformation on particle surface”

Marie-Eve Aubin-Tam (Prof. Hamad-Schifferli), Ph.D. in Biological Engineering 2009, “Structure and Activity of Protein-Nanoparticle Conjugates: Towards a Strategy for Optimizing the Interface”

Gautham Nair (Prof. Bawendi), Ph.D. in Chemistry 2009 “Many-Body Processes in the Photophysics of Colloidal Semiconductor Nanocrystals” Gary Forrest Award

Seungeun Oh (Prof. Feld), Ph.D. in Physics 2010 “Quantitative phase microscopy for the study of electromotility in living cells”

Zoya Volynskaya (Prof. Feld), Ph.D. in Electrical Engineering and Computer Science 2010 “Multimodal spectroscopy: real-time diagnosis of breast cancer during core needle biopsy”

Joshua Alper (Prof. Hamad-Schifferli), Ph.D. in Mechanical Engineering 2010, “Physical and Practical Limits of a Biomolecular Control System Using Nanoparticles and Electromagnetic Field Irradiation” ✨

Faculty Profile:

Andrei Tokmakoff

by Ziad Ganim

Andrei Tokmakoff started his research group in the Chemistry Department at MIT in 1998 with the broad goal of using multidimensional vibrational spectroscopy to study the structure and dynamics of liquids, solutions, proteins, and peptides. Andrei only seems to be interested in those systems that are murky, messy, and without a doubt, disordered.

Tokmakoff, a Sacramento-born Californian, completed a B.S. (1989) in chemistry from California State University at Sacramento,



and an M.S. (1991) and a Ph.D. (1995) in chemistry from Stanford University. As a graduate student under the direction of Michael Fayer, Tokmakoff participated in several groundbreaking experiments. He used Stanford’s Free Electron Laser to help perform the first vibrational photon echo experiments in the liquid and glass phases. Tokmakoff also built the first mid-IR tabletop source with suitable power for performing nonlinear, transient grating experiments. Through the combination of tabletop and facility-based sources, Tokmakoff enjoyed a prolific graduate career with 19 publications, including 11 as the first author. (Anonymous rumors state that he did in fact publish every piece of data he acquired, aside from the discovery of an elaborate 37-wave mixing process that precluded his need for sleep.)

A series of classic experiments by Tokmakoff quantified temperature-dependent vibrational relaxation rates using echo experiments to remove the influence of the slower vibrational frequency modulations induced by the static distribution of solvent microenvironments. With such work, Tokmakoff realized that the congested vibrational absorption spectra that often arise in the condensed phase could encode system-bath interactions on a variety of timescales and may be systematically disentangled using multipulse spectroscopies.

Tokmakoff, continues on Page 9

Spec Lab Babies!

The spectroscopy community keeps growing. The Spectrograph is pleased to announce some of the babies born to current and former lab members in the past year. Congratulations to the new fathers and mothers!



Zakir Owen Baxamusa was born on November 18, 2009. Sal Baxamusa, postdoc in the Hamad-Schifferli group and proud father, says Zakir's middle name is in honor of Owen Chamberlain, the late Nobel laureate

physicist and friend to the family. Zakir Owen is the 7th baby born in the Hamad-Schifferli group!

Josh Baraban, graduate student in Prof. Field's lab, welcomed his daughter **Ayelet Ruth Baraban** into the world on May 4, 2009. Ayelet, pictured reading Bob Field's book, seems to have impeccable taste in literature.



Sage Akayla Bechtel was born on December 15, 2009. Her parents Hans and Kate Bechtel are both former postdocs of the Spectroscopy Lab; Hans worked with Prof. Field and Kate with Prof. Feld. Hans is now at the Lawrence Berkeley National Laboratory, and Kate works for Triple Ring Technologies. Quite a pedigree for Sage!



Chris Fang-Yen's son **Anders** was born on December 16, 2009, just one day apart from Sage Bechtel. Chris was also a graduate student in the Feld group, and is now a physics postdoc at Harvard.



Former Feld group graduate student and current Weill Cornell postdoc Abigail Haka's son **Leo** already turned two on February 21, 2010, but the Spectrograph couldn't resist including his photo. ✨

Green Appointed Hottel Professor

William H. Green was named the Hoyt C. Hottel Professor of Chemical Engineering in December 2009. In his appointment, the Department of Chemical Engineering recognized the contribution of his research on accurate predictive kinetic models to the development of new energy technologies. Green is the editor-in-chief of the International Journal of Chemical Kinetics, and is a member of MIT Energy Initiative's task force. ✨



Ketterle (continued from Page 2)

Since achieving BEC in 1995, Ketterle has remained a leader in the study of ultracold forms of matter. In 1997, Ketterle announced the first realization a coherent beam of matter, called the "atom laser" by analogy to the coherent light waves of the optical laser. His interference experiment between two BECs, analogous to optical interferometry, provided the first direct confirmation that the matter in the BECs formed coherent waves. In 1998, his group observed Feshbach resonances, and in 2005, superfluidity of ultracold fermions. His group has also developed new tools to study and manipulate cold atoms, including the cloverleaf magnetic trap, the rf output coupler, new dispersive imaging techniques, and the use of Bragg scattering for spectroscopy of condensates.

Ketterle's successes in the lab brought

him attention and recognition. In 1993 he joined the physics faculty of MIT and in 1998 was appointed the John D. MacArthur Professor of Physics. In 2001 Ketterle was awarded the Nobel Prize in Physics jointly with Cornell and Wieman, the two researchers at Boulder, "for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates." Since 2006, Ketterle has been the director of the MIT-Harvard Center for Ultracold Atoms.

Ketterle continues work on laser cooling and trapping, atom optics, and atom interferometry, as well as investigations of BEC and Fermi degeneracy, with major focus on novel aspects of ultracold matter including superfluidity, coherence, and correlations in many-body systems.

Throughout his life, Ketterle has maintained a love of long-distance running and cycling. In his thirties he ran several marathons in under three hours, including his personal best of 2:50, and he continues to run regularly. Last summer saw Ketterle in Iceland for a long-distance bicycle tour. In a life filled with many successes as well as many bold changes, it would not be surprising to see Ketterle re-make himself again, this time as a champion bicyclist.

Now in its nineteenth year, the Lord lecture commemorates the achievements of Richard C. Lord, a pioneer in infrared and biochemical spectroscopy and director of the Spectroscopy Laboratory for 30 years. Each year's lecturer is selected by a committee of chemists, physicists and engineers at MIT who are active in various fields of spectroscopy. ✨

Researchers from Around the Globe

With students, researchers, and faculty from across the spectrum of the world's countries and with alumni working around the globe, the G.R. Harrison Spectroscopy Laboratory is truly an international place. Like our lab, MIT itself is increasing a global institution. According to the MIT International Student Office, in the current 2009-2010 school year 27.8% of all MIT students, and 38.6% of graduate students, are international, not even counting students from other countries who may have US citizenship or permanent residency.

This spring, the *Spectrograph* invited members of the lab to show off their diverse geographic backgrounds by telling us a little about themselves—in English and in their own languages. This issue features 13 current students and post-docs so we can learn about them in their own words.

Niyom Lue

Place: Chinese, born and raised in Thailand, lived in the US for 20 years.
Staff Researcher in Field Group.

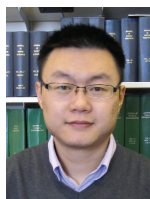


สวัสดี

Read as
“Sawadee,”
means “Hello”

Zhichuan Xu 徐 誌川

Place: Lanzhou, China.
Postdoctoral Researcher in Hamad-Schifferli Group.



The most enjoyable thing for me in the lab is making nanoparticles, while at home I enjoy cooking. The enjoyments are similar: delicious food is usually seasoned by flavorings, while the size and shape of nanoparticles can be controlled by additives (surfactants). Making nanoparticles is just like cooking. There is so much fun in both.

对于我来讲，实验室里最有趣的事情就是制备纳米颗粒，而工作之余最有趣的事情就是练习厨艺。这两件事情在某种角度看非常相似。例如，食物的口味需要调味料来添加，而纳米颗粒的尺寸和形状可以通过添加剂（表面活性剂）来控制。制备纳米颗粒就象烹饪，都是非常有趣的事情。

Helena de Puig Guixé

Place: Catalonia, Spain.
Visiting Student in Hamad-Schifferli Group.



Here in MIT, I am helping in a research program. We are trying to conjugate DNA with gold nanoparticles. I came to MIT, because I like research, and I'm trying to gain experience to study a PhD in the future.

Català (Catalan): Aquí al MIT, estic ajudant en una investigació. Intentem lligar ADN a nanopartícules d'or. He vingut al MIT, ja que m'encanta l'investigació, i estic intentant agafar experiència per, més endavant, fer un doctorat.

Español (Spanish): Aquí en el MIT, estoy ayudando en una investigación. Intentamos unir ADN a nanopartículas de oro. He venido al MIT porque me encanta la investigación, y intento coger experiencia para, más adelante, hacer un doctorado.

Yan Zhou

周 岩

Place: China.
Graduate Student in Field Group.



I like this Chinese ancient aphorism which was said by Confucius more than 2000 years before. It guides my research and my life all the time.

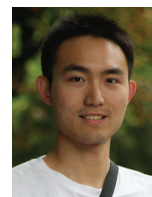
子曰：“学而时习之，不亦乐乎？有朋自远方来，不亦乐乎？知，而不愠，不亦君子乎？”

The Master said, “To learn and at due times to review what one has learned, isn't that a pleasure? To have friends come to you from afar, isn't that delightful? To feel no discontent when others do not know you, isn't that what is expected of a gentleman?”

Chunte (Sam) Peng

彭 峻德

Place: Taiwan
Graduate Student in Tokmakoff Group
I'm a huge fan of basketball!



我熱愛籃球！

Kirill Kuyanov-Prozument

Кирилл Куянов-Прозумент

Place: Latvia
Postdoctoral Associate in Field Group

*I'm an ordinary man
Who desires nothing more
Than just an ordinary chance
To live exactly as he likes*

And do precisely what he wants

(“My Fair Lady,” George Cukor 1964)

Скромн, обаятелен, легко входит в доверие. Характер - нордический. Не женат.



Raoul Correa

Place: born in India, raised in New Zealand, studied in California, and now researching in Cambridge.
Graduate Student in Bawendi Group.

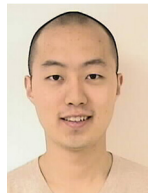


Raoul Correa すこし日本語を
わかることができます, and
is constantly on the lookout for the
best carne asada burrito this side of the
border. Unfortunately, the data suggests
that the Northeast is the wrong place to
look for such (delicious) things, but he
hasn't given up hope. Yet!

YongKeun (Paul) Park

박용근

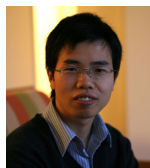
Place: Seoul, Korea.
Graduate Student in
Feld Group.
Paul is Jolly!



쾌활!

Dan Fu 傅丹

Place: China.
Postdoctoral Associate in Feld Group.
I enjoy nature.



我热爱大自然

Timothy Hillman

Place: Perth, Australia.
Postdoctoral Associate in Feld Group.
I'm from Perth,
Western Australia, the
furthest world city from
MIT. Culturally, the
gap is much smaller,
but as a student of
American society, the
subtle differences are fascinating to
observe close up.



Chae-Ryon Kong

공재련

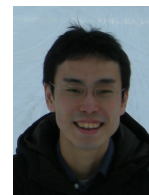
Place: South Korea.
Graduate Student in
Feld Group.
“Nomad.” Went to
school in Norway,
South Korea, Greece
and the U.S.
“떠돌이”. 학교를 노르웨이, 한
국, 그리스, 미국으로 옮겨다
녔음.



Toyohiko Yamauchi

山内豊彦

Place: Japan
Visiting Scientist in Feld
Group
I came from Hamamatsu
Photonics in Hama-
matsu city. As “hama” means beach and
“matsu” means pine trees, Hamamatsu
city is a very comfortable place to live
in.



浜松市の浜松ホトニクスから来
ました. 海の浜と松の木を意味
する浜松市は, とても住みやす
いところです.



Tokmakoff (continued from Page 6)

After graduate school, Tokmakoff spent a year as a postdoctoral researcher with Alfred Laubau at the Technical University of Munich, and continued with a second year in the lab of Graham Fleming at the University of Chicago. In this work, he sought to answer a challenge laid down by theoreticians to bring multidimensional Fourier transform techniques, which revolutionized NMR spectroscopy, into the optical regime. These experiments aimed at revealing picosecond dynamics of how liquids rearrange using their broad low-frequency spectra (read: undistinguishable blobs) with 2D Raman experiments. He showed how to think about ultrafast vibrational experiments in the time and frequency domains, and redefined pain with nonlinear Raman experiments that are formally equivalent to looking for albino polar bears among regular polar bears hiding in the arctic. (To this date, this experiment has only worked on three systems—the exceptionally Raman active CS₂, benzene, and formamide.)

Upon his arrival at MIT, Tokmakoff sought to continue his trend using the newest optical technologies to drive new spectroscopies. His best-cited work is as

an advisor on IR echo experiments that quantify hydrogen bond beating and subsequent restructuring of liquid water. He is also known for his painstakingly systematic approach to understanding 2D IR spectra, which answered questions such as how to obtain the best resolution features, how to quantify correlated line broadening dynamics, and how to extract molecular potentials of coupled oscillators from 2D peak positions.

Tokmakoff is on a continuing quest to demonstrate that ultrafast time resolution is a powerful approach to the study of biological systems and can complement the ultrahigh structural resolution used in standard approaches. The use of ultrafast time resolution has often been met by the defiant question: who cares about what happens faster than a millisecond? Nonetheless, Tokmakoff believes that many fundamental biomolecular motions can be best revealed using the fastest possible time-resolution.

Tokmakoff's picture of chemical reactions is reflected in the way he envisions ultrafast experiments; he would challenge the claim that we are producing “molecular movies” that track ensembles of molecules, eerily marching in lockstep over activation barriers. He argues that in the disordered,

condensed phase we use ultrafast lasers to produce snapshot pictures with a superb shutter speed—pictures that begin to blur less than a picosecond after the flash goes off.

As he has transitioned from junior faculty to a tenured, full professor, Tokmakoff continues to push for the study of increasingly complicated systems. Whether he is investigating how disordered proteins can recognize and bind one another, studying the interplay of water expulsion and elasticity in hydrophobic polymers, or analyzing the mechanisms of charge transfer in liquids, facing murky complexity only heightens his curiosity.

The advising style of Andrei Tokmakoff emphasizes fundamental science through a true physical chemistry approach of building instruments and making measurements. He has advised four postdocs and three graduate students to faculty positions, with many more also aspiring. Tokmakoff's students are jazzed (big time) to have him as a personable advisor with an unshakable temperament and soft spot for Biergartens and Augustiner Bräu. Tokmakoff is a part of a strong, loving family with his wife, Karen, and their children, Lena and Alex. 

clear writings by the Greek philosophers on the subject, and some possible observations recorded in myths and folklore. But the scientific observation of the spectra of astronomical bodies clearly took a giant step forward when Isaac Newton used his prism to break up light from the sun into its constituent colors, and to re-assemble them into white light. Newton himself does not appear to have used his prism to study starlight, nor do any of those who repeated his experiments. At any rate, if they did so, they don't seem to have recorded it.

This isn't altogether surprising—starlight is much dimmer than sunlight. What is surprising is that no one seems to have addressed the issue for the century between Newton's Optics and the beginning of the 19th century. It would have been relatively simple to look at a star through a telescope with prism near the eyepiece, however, and observe the color separation. Nevertheless, no one seems to have done this until Joseph Fraunhofer did so in 1814. Fraunhofer had already repeated William Wollaston's 1802 experiment of observing the solar spectrum and noting the dark absorption bands. But Fraunhofer carried his work on the solar spectrum past qualitative observation to quantitative measurement. He constructed a diffraction grating by winding wire on a

frame, and used the known spacing to determine the wavelengths he was observing. After he did this with the solar spectrum, observing, measuring, and naming the Fraunhofer lines, he did the same with stellar spectra. He noted similarities between the solar spectrum and that of Betelgeuse, and differences with that of Sirius. It's not surprising that he concentrated on the brightest stars at first—they would be by far the easiest ones to observe. He would undoubtedly have moved on to other stars, had he not died of tuberculosis at the young age of 39 in 1826.

Perhaps it was Fraunhofer's amazing early use of a grating to calibrate wavelength that is responsible for his work being recorded and transmitted. Wollaston's observation of the dark bands resulted from his using a prism with greater resolving power than had been used before. Fraunhofer's contribution was the measurement of wavelengths. After his death, others carried on the work on the solar spectrum, refining his measurements. But his work on stellar spectra lay pretty much ignored for about forty years.

Why? One wonders. Certainly there was no shortage of stars to study, and there were many discoveries yet to make in the study of stellar spectra. I thought that the answer

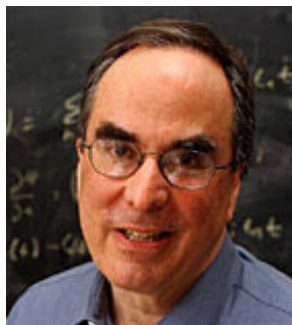
might be the lack of a good recording medium. But Fraunhofer did his work entirely by eye. Photography—especially technical photography for scientific measurement—was in its infancy, so the first solar spectra were drawn by hand. Edmond Becquerel photographed the solar spectrum in 1842, and J.W. Draper repeated this the next year. But stellar spectra, of course, are significantly dimmer. In the 1860s such pioneers as G.B. Donati and Angelo Secchi drew their stellar spectra by hand, as Fraunhofer had. So the lack of recording media does not explain the lacuna in stellar spectroscopy.

Nevertheless, the 1860s saw a sudden blossoming of interest in Stellar Spectra, with independent and early simultaneous work by Donati and Secchi in Italy, by Royal Astronomer George Biddell Airy at Greenwich, by Lewis Rutherfurd in New York, and by William Huggins and William Allen Miller in London. It soon became clear that there were certain characteristic sets of absorption lines, and that stars tended to fall into a few definite types.

The next step beyond this is to record not only the wavelengths of these lines, but also their relative widths and strengths. Even with photography as a tool, these parameters were not so easy to establish. What was needed was something that could

Honors for Field and His Students

Robert W. Field, the Haslam and Dewey Professor of Chemistry, won the 2009 Arthur L. Schawlow Prize in Laser Science from the American Physical Society (APS). The award cited Field's "pioneering development and application of multiple resonance laser spectroscopy and effective Hamiltonian models that reveal fundamental mechanisms of chemical bond breaking, electronic rearrangement, intramolecular vibrational redistribution, and unimolecular isomerization."



Field was also honored with a special issue of the Journal of Physical Chemistry A. The Robert W. Field Festschrift special issue, published November 19, 2009 (Vol. 113, no. 47), contained over 40 original research articles by his colleagues including previous students and postdocs.

Two of Field's students also won major awards in 2009. Ph.D. candidate **Barratt Park** was awarded the K. Narahari Rao Prize for his talk "Design and chemical application of chirped-pulse millimeter-wave spectroscopy" which he delivered at the International Symposium on Molecular Spectroscopy at Ohio State University in June 2009. **Annelise R. Beck**, 2009 B.A. in Chemistry, received the Senior Academic Award from the Association of MIT Alumnae (AMITA) for "the highest level of academic excellence," the Chemistry Department's Alpha Chi Sigma Award for "distinguished scholastic achievement, originality, and breadth of interest in chemistry," as well as a National Science Foundation graduate fellowship at Berkeley. ✨

Dresselhaus and Bawendi Honored by ACS

Continuing from an award-filled 2009, Institute Professor **Mildred Dresselhaus** received the American Chemical Society's Award for Encouraging Women into Careers in the Chemical Sciences on March 23, 2010 at the ACS National Meeting in San Francisco. Her award is sponsored by the Camille and Henry Dreyfus Foundation.

Also awarded at the ACS National Meeting on March 23, 2010 was **Moungi Bawendi**, the Lester Wolfe Professor of Chemistry. He received the 2010 ACS Award in Colloid and Surface Chemistry. His award is sponsored by Proctor and Gamble. ✨



measure the strength of the signal and record it. There had been efforts to build photometers dating back to John Herschel in the 1830s. But these depended upon human eyes to compare the intensity of a light to some reference standard. Some sort of objective device, not dependent upon human judgment, was needed.

The breakthrough for this came in 1873 when Willoughby Smith discovered photoconductivity in selenium. Alexander Graham Bell used this effect to create his photophone in 1880, an invention that he considered the greatest he ever made, surpassing the telephone. It used a beam of light to transmit telephone conversations across distances without any wires between the sender and the receiver. A year later the selenium cell was used to produce what was essentially a fax machine, capable of sending pictures over telephone lines.

With the selenium photoconductor and the selenium photocell one could measure the relative strength of a signal automatically and objectively. But it still couldn't be recorded except perhaps in the most delicate ways—using a whisker, perhaps, to make a track in a carbon film on smoked glass. In order to do something useful, such as using a motor-driven pen to make a permanent record, would require the signal to be amplified. And there was, as yet, no way to do this. Until signals could be amplified, selenium cells (and the other photocells being discovered) had to remain limited devices, mainly of scientific value and novelty items.

The lack of a good amplifier for electrical circuits made itself felt in other areas as well. Consider the motion picture. Edison had invented the Kinetoscope in 1891. Most sources will tell you that the first sound movie didn't appear until 1927, when *The Jazz Singer* was released. A few will admit that there were less well-known experiments prior to his, but it is true that sound films effectively date from *The Jazz Singer*'s release. But the sound in this film came from what were, in essence, phonograph records—why did this take so long to develop? Edison is responsible for both the phonograph and the motion picture. Is it likely that he wouldn't connect the two? We know, in fact, that he did. There is a famous piece of film showing a man playing a violin into an oversized phonograph

bell while two men dance. Clearly there was a sound recording to go with that film footage. The recording has been found recently, and synchronized with the film.² The recording was made in 1894 or 1895 by William Dickson, and there were, in fact, many record-accompanied films after that date. Edison and Dickson had invented the Kinetophone to exploit the marriage of sound and film,³ so why do people count the relatively late *Jazz Singer* as the first sound film?

Why? One wonders. Certainly there was no shortage of stars to study, and there were many discoveries yet to make in the study of stellar spectra.

The answer is that the effective audience for such a sound film was limited by the range of the phonograph providing the sound. At first, the sound was generated by a needle vibrating in a groove, amplified by the effect of the metal bell attached to the diaphragm. Such a mechanical amplifier could not provide much range, limiting the prospective audience to a small roomful of people. The missing item needed to make sound movies practical for a real audience was a reliable electrical amplifier.

The needed element was the thermionic valve, colloquially known as the vacuum tube, invented in 1916-1918 and almost immediately used in radios, boosting the rectified signal from a tiny output requiring earphones to a healthy output that could drive a large speaker. Radio could go from a single-listener device to a device that could play to an entire room. Broadcasting went from a hobby to an industry. More powerful amplifiers allowed sound from a recording to fill an auditorium and made sound movies a commercial reality.

In the early 1930s vacuum tubes allowed electronics to boost the feeble output of photocells to power motors as well, and to give the oomph needed to trip relays. A burst of engineering creativity provided Electric Eyes that opened doors and moved things for those crippled by polio.⁴

The Century of Progress International Exposition was set to open in 1933 in Chicago, celebrating the city's centennial. The previous World's Fair held in Chicago had

been forty years earlier in 1893. Someone realized that it would be a coup if they could somehow tie the new Fair to that older one in a technological way—the theme of the exhibition was, after all, “A Century of Progress.” Noting that the star Arcturus was 37 light-years away, someone saw that the light just arriving at Earth would have left shortly after the time of the previous exhibition. It was decided to turn the lights on for the Fair for the first time using the light from Arcturus. With the new vacuum tube amplifiers the signal from a photocell placed in a concentrator at the end of a telescope could be amplified enough to trip a set of relays. So in 1933, light from Arcturus started a Rube Goldbergian chain of events that led to the powering of the lights at the Chicago World's Fair.⁵ And in the late 1920s the F.L. Moseley Company sold chart recorders that used amplified signals from photodetectors to take spectra.⁶

Scientific spectroscopy had advanced from a labor-intensive art to a laboratory tool.

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Sound Movies, the World's Fair, and Stellar Spectroscopy

Stephen R. Wilk swilk@comcast.net



The History of Ideas shows peculiar gaps where progress is not made for long periods of time. Often, when you ex-

amine these gaps, you find out why those gaps are there—some critical piece of equipment was missing, perhaps, or some philosophical jump was needed. Then again, sometimes it's not at all clear why no progress was made. The case of Stellar Spectroscopy has both sorts of gaps. Along the way, we'll also have a look at the gap between the movies and sound movies, and the interesting opening of the World's Fair in Chicago in 1933. It will all come together, I assure you.

In a very rough way, of course, stellar spectroscopy has an ancient history—the observation that different stars are different colors goes back to antiquity, with very

Wilk, continues on Page 10

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