MILLER INSTITUTE NEWSLETTER

Winter 2007

Miller Fellow Focus: Greg Engel

Second year Miller Fellow Greg Engel is a physical chemist collaborating with Professor Graham Fleming in the Department of Chemistry.

Life on earth is effectively solar powered. At the very bottom of the food chain, bacteria, algae and higher plants use photosynthesis to harness energy from the sun. As these organisms thrive, grow, and store energy, they provide the food sources for all other life. The process of photosynthesis itself is ancient and extremely complex. Having evolved for over 2.7 billion years, the photosynthetic apparatus demonstrates an unparalleled level of evolutionary finesse with nearly perfect quantum efficiency, and at the molecular level, the workhorse of the photosynthetic light harvesting apparatus is the chlorophyll molecule. Chlorophyll pigments are the dominant chromophore in nearly every photosynthetic system and carry out such varied tasks as light harvesting, energy transfer, charge separation, and even electron transport.

From a chemical perspective, that a single chromophore can perform such a myriad of tasks indicates a truly remarkable system. The field of chemistry hinges on understanding chemical properties, manipulating chemical reactivity, and designing molecules for particular tasks. In general, the chemist tries to tailor the molecule to the job; in photosynthesis nature has taken an entirely different approach by using the same molecule over and over again (some light harvesting complexes have hundreds of chlorophyll molecules) but placing it in slightly different environments to perform a staggering array of different functions. Greg's research focuses on understanding the fundamental design principles governing the behavior of these light harvesting photosynthetic complexes: How does the structure of the protein complex surrounding the chlorophyll molecules control the behavior of the complex? How should we think about the transfer of energy through these complexes? How do chlorophyll molecules work together cooperatively to control the flow of energy? Do motions of the protein complex play an active role in determining the dynamics of the system? At the heart of all these scientific questions is a common theme: electronic coupling.

The protein complexes into which the chlorophyll molecules are embedded hold the chlorophyll molecules very close to one another forming very strict geometric relationships between them. Because of the close proximity to one another, the electronic states of the monomer chlorophylls mix or couple, creating emergent electronic properties and structure. This electronic coupling is determined by the protein environment, the orientations of the chlorophylls, and the distances between them. In this way, the mixed electronic excited states or excitons form, and it is these electronic states and the interactions among them that give rise to the extraordinary array of functions observed from photosynthetic complexes.

To observe, characterize and measure these excitons and the energy transfer among them, we require extremely fast time resolution and multiple interactions with the system. The timescale of energy transfer in photosynthetic systems ranges over more than nine orders of magnitude

from femtoseconds to microseconds. Though photosynthesis has been studied for centuries, recent advances in ultrafast laser technology producing laser pulses as short as ten femtoseconds (one femtosecond is equal to one millionth of a billionth of a second) now permit direct observation of the energy transfer phenomena within the complexes.

In many ways, the study of such ultrafast phenomena seems to be a dramatic change for Greg. Having completed his doctoral work in

continued on page 2

INSIDE THIS EDITION

Miller Fellow Focus 1
Miller Professor Awards 3
Next Steps.....3
Publications.....3
Visiting Professor Awards....4
Birth Announcements.....4
Obituaries.....4
Awards & Honors..... 5
Correction.....5
Members In The News.....6

physical chemistry at Harvard University with Professor James Anderson designing laser spectrometers to dissect mechanisms of water transport affecting global climate change, Greg Engel has moved from in situ airborne studies requiring extreme sensitivity with characteristic timescales from seconds to centuries, to laboratory studies more than a trillion times faster. However, Greg has found more similarities than differences between the two fields; both hinge of detailed understanding of statistical mechanics, quantum structure, and careful dissection of hypotheses into observables accessible through laser spectroscopy.

In conjunction with Graham Fleming's group, Greg uses Two Dimensional Ultrafast Electronic Spectroscopy to observe energy transfer within the photosynthetic complexes.

Using multiple ultrafast pulses to create a photon echo signal, a beam that is emitted from the sample in a unique direction and excitation from three other laser pulses, this technique permits direct observations of energy and coupling with femtosecond time resolution. Effectively, the data produce a mapping of excitonic structure that is directly analogous to two dimensional nuclear magnetic resonance (NMR) data used to determine molecular structure.

Recently, using this 2D electronic spectroscopy, Greg and his coworkers discovered a long-lived electronic coherence beating signal that suggests coherence transfer must play an important role in the dynamics of the Fenna-Matthews-Olson light harvesting complex. Such coherence transfer, a purely quantum mechanical effect, means that superposition states excited by a fast absorption event evolve into other super position states within the system and that the excitation moves through the system spatially with wavelike character.

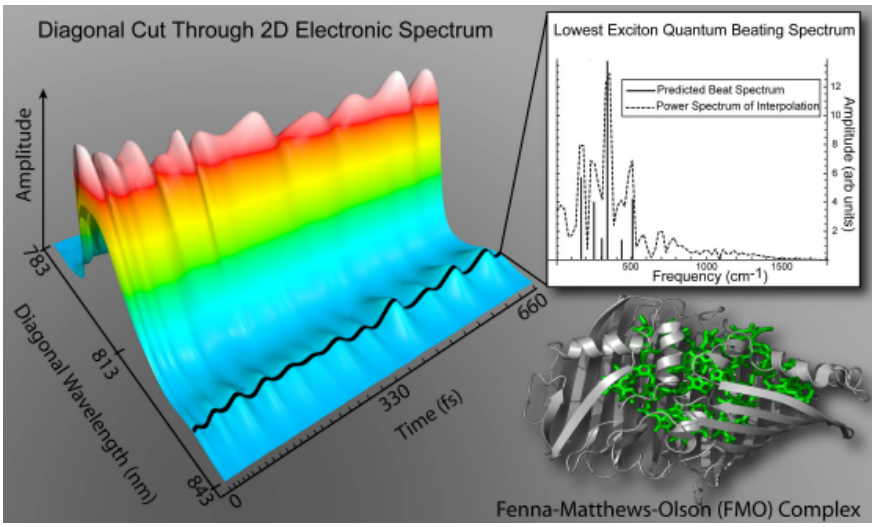


Figure 2

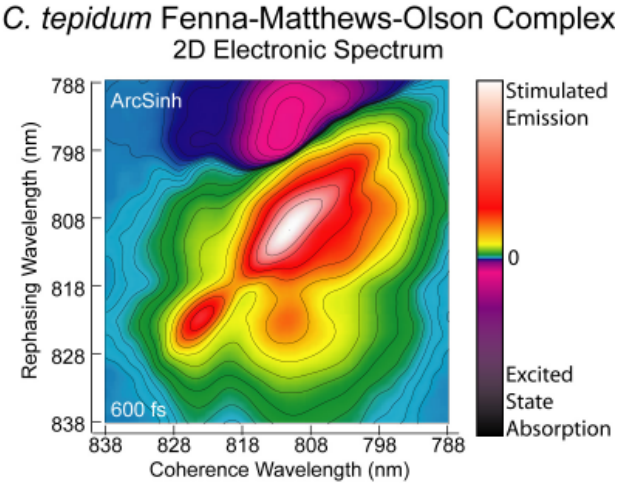


Figure 1

In the two dimensional spectrum of FMO shown above (Figure 1), the excitons appear on the main diagonal, while the cross-peaks indicate coupling. In a simplified interpretation, the ordinate axis can be considered the excitation wavelength while the abscissa shows the emission from 600 fs later. Within this interpretation, the main diagonal represents absorption and emission from the same state, while a cross peak indicates absorption in one state and emission from another. An immense amount of information about correlation functions, homogenous and inhomogeneous broadening and the system-bath dynamics is included in these spectra. Most recently, we have analyzed the dynamics of the lowest energy exciton feature (lower left peak on the main diagonal, well resovled from the other 6 excitons).

Oscillations of the lowest exciton peak in the data as a function of time are shown in the data to the left (Figure 2). The power spectrum of this beating signal is shown in the inset panel along with the expected pattern due to excitonic coherence. The agreement between experiment and theory (confirmed with peak shape oscillations, not shown) and the stark disagreement with the expected dynamics of a purely vibrational wavepacket, indicate that this quantum beating must arise from electronic coherence. This quantum beating signal implies that wavelike energy motion, rather than stepwise hopping from one state to another, helps govern the movement of the energy through the complex. This phenomenon may also help to explain the extraordinary efficiency with which the complex operates by allowing the excitation to

continued on page 3

Miller Professorship Awards

The Miller Institute is happy to announce the awards for Miller Research Professorship terms in Academic Year 2007-2008. Recipients are released from teaching and administrative duties, allowing them to pursue their research, following promising leads as they develop.

Steven Brenner	Plant & Microbial Biology
John Clarke	Physics
Mark Haiman	Mathematics
Jenny Harrison	Mathematics
Ellen Robey	Molecular & Cell Biology

Next Steps

Munira Khalil (Miller Fellow 2003-06) will be continuing at Lawrence Berkeley Labs through the end of the spring semester, and then taking a position as Assistant Professor in Chemsitry at the University of Washington. The Miller Institute congratulates Munira on her future endeavors.

Publications

The following Miller Institute members have recently published works resulting from research during their Miller Institute terms. For more information about these publications, please visit the Miller Institute's website at: http://millerinstitute.berkeley.edu/publications.htm

Munira Khalil
Miller Fellow 2003-06

❖

Yong-Baek Kim
Visiting Miller Professor
Fall 2006

❖

Rory Waterman
Miller Fellow 2004-06

Miller Fellow Focus, continued from page 2

reversibly sample many exciton states simultaneously, effectively sampling a larger swath of the quantum dynamical phase space.

Greg is currently working on developing new spectroscopic polarization schemes to separate the different third order nonlinear response pathways in an effort to isolate the signal due to electronic couplings from other aspects of the nonlinear response. These methods leverage an absolute phasing scheme Greg invented that allows accurate phasing without the use of pump-probe spectroscopy.

When not working in dimly lit laser labs (stray photons pollute the data), Greg can be found outside soaking up some sun learning to cross-country ski or firing on the rifle range where he competes in target matches. Over the years, Greg has set 25 national records, has earned six grand slams, and has placed as high as third in the nation in NRA Rifle Metallic Silhouette competition.

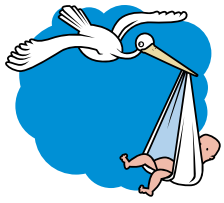
Visiting Miller Professorship Awards

The Miller Institute is pleased to announce the Visiting Miller Professorships granted during this year's competition cycle. The purpose of the Visiting Professorship program is to bring promising or eminent scientists to the Berkeley campus for collaborative research interactions. The recipients will be on campus for terms during academic year 2007-08.

Emilio Artacho *Cambridge University, England*	Chemistry, sponsored by Martin Head-Gordon
Vincent Bouchiat *CNRS Grenoble, France*	Physics, sponsored by John Clarke
Bruce Driver *University of California, San Diego*	Mathematics, sponsored by Peter Teichner
Eitan Reuveny *Weizmann Institute of Science, Israel*	Molecular & Cell Biology / Helen Wills Neuroscience Institute, sponsored by Ehud Isacoff
Salil Vadhan *Harvard University*	Electrical Engineering & Computer Science, sponsored by Luca Trevisan
Jaqueline Van Gorkom *Columbia University*	Astronomy, sponsored by Leo Blitz
Jean-Pierre Vilotte *Institute de Physique du Globe*	Earth & Planetary Science, sponsored by Barbara Romanowicz
Jack Wisdom *Massachusetts Institute of Technology*	Astronomy / Earth & Planetary Science, sponsored by Eugene Chiang and Michael Manga

Birth Announcements

Congratulations to **Yi Cui** (Miller Fellow 2003-05) and his wife Meng Sui on the birth of their son, Andy. Andy was born on January 21, 2006.



Congratulations to **Josh Eisner** (Miller Fellow 2005-08) and his wife Kelly on the birth of their daughter, Annabelle. Annabelle was born on January 3, 2007.

Congratulations to **Birgit Schwickert** (Miller Fellow 1999-2002) and her husband Marcus on the birth of their son Max. Max was born on December 3, 2006.

Obituaries

Chester O'Konski (Miller Professor 1960-61) passed away on August 2, 2006 at the age of 85. O'Konski, a UC Berkeley professor emeritus of chemistry, was one of the first chemists to study nucleic acids and proteins using physical chemistry methods.

Awards & Honors

The American Association for the Advancement of Science (AAAS) Council has elected 449 members as Fellows of AAAS. These individuals will be recognized for their contributions to science and technology at the Fellows Forum to be held on 17 February 2007 during the AAAS Annual Meeting in San Francisco. Former Miller Institute members named this year include:

- **Steven G. Louie** (Miller Professor 1986-87, Fall 1995)
- **Alan S. Perelson** (Visiting Miller Professor, Spring 2004)
- **Lars Stixrude** (Visiting Miller Professor, Spring 2005)
- **William B. Tolman** (Visiting Miller Professor, Spring 1997)

Adrian Bejan (Miller Fellow 1976-78) was awarded the 2006 Luikov Medal of the International Heat Transfer Conference.

Dmitri Budker (Miller Professor 2002-03) was elected a fellow of the American Physical Society.

Shmuel Einav (Miller Professor 1991) was elected Fellow of the International Academy of Medical and Biological Engineering, and Fellow of the Biomedical Engineering Society.

Alex Filippenko (Miller Fellow 1984-86, Miller Professor Spring 1996, 2005) was named U.S. Professor of the Year by the Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education.

George Leitmann (Miller Professor 1966 - 67) received the Werner Heisenberg Medal of the Alexander von Humboldt Foundation on the occasion of his 80th birthday. The Universitaet der Bundeswehr Muenchen established a yearly Leitmann Lecture and Prof. Leitmann presented the inaugural lecture in June 2006. Leitmann was named the Nyquist Lecturer at the 2006 International Mechanical Engineering Congress and Exposition.

David Milstein (Visiting Miller Professor Spring 2006) was the recipient of the American Chemical Society Award in Organometallic Chemistry for 2007.

Grigori Perelman (Miller Fellow 1993-95) was awarded the Fields Medal by the International Mathematics Union for solving the Poincaré conjecture. He subsequently refused the award. The Fields Medal is the highest honor in the field of mathematics.

Jasper D. Rine (Miller Professor Fall 2003) has been appointed the Director of the Center for Computational Biology (also known as the Computational Biology Initiative) by UC Berkeley Executive Vice Chancellor and Provost George Breslauer.

Yayu Wang (Miller Fellow 2004-07) has been awarded this year's William L. McMillan Prize in condensed matter physics.

The Miller Institute is happy to share news of awards and honors received by past members. Please notify us with details of awards you or other past members receive so that we can include them in our list. Additional news on members is listed on our website at http://millerinstitute.berkeley.edu/awards

Correction

In the Fall 2006 Newsletter, we incorrectly identified new Miller Advisory Board member **Michael Klein** as being a professor at Penn State. Professor Klein is actually the Hepburn Professor of Physical Science at **University of Pennsylvania**. The Institute apologizes for this error.

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Miller Members In The News

The research of **Donald Backer** (Miller Professor Spring 2007) on gravitational waves was featured in ScienceMatters@Berkeley. For the full article, please visit:
http://sciencematters.berkeley.edu/archives/volume3/issue24/story2.php

The research of **Jillian Banfield** (Miller Professor 2006-07) on newly-discovered nanoorganisms was featured in a press release on UC Berkeley's News website. To read more, please visit:
http://www.berkeley.edu/news/media/releases/2006/12/21_microbes.shtml

The constructal theory of **Adrian Bejan** (Miller Fellow 1976-78) is featured in an article co-authored with Prof. James Marden in the July-August issue of American Scientist. According to constructal theory, the generation of flow configuration is a physics phenomenon governed by principle: survival and evolution mean that, in time, existing flow configurations are replaced by easier flowing configurations. Animal mass, river basins and atmospheric currents flow based on the same principle.

The San Francisco Chronicle featured an article about how physics classes taught by **Richard Muller** (Miller Professor 1990) and broadcast on the web are being watched by self-starting students all over the globe. To read the full article, please visit:
http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/11/06/BAGCVM6PHC1.DTL&sn=001&sc=1000

George Oster (Miller Executive Committee member and Miller Professor 1983-83 and 2003) and his research on protein engines was featured in ScienceMatters@Berkeley. To read more, see:
http://sciencematters.berkeley.edu/archives/volume3/issue21/story1.php

The research of **Andy Suarez** (Miller Fellow 2001-03) and **Sheila Patek** (Miller Fellow 2001-04) on trap-jaw ants and mantis shrimp was featured in several news articles, including the front page of the San Francisco Chronicle. Andy and Sheila's collaboration began during their terms as Miller Fellows, and they began discussing it during one of the Miller Institute's Tuesday lunches. More information:
http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/08/22/MNGRNKMQTT1.DTL&sn=001&sc=1000
http://www.berkeley.edu/news/media/releases/2006/08/21_ant.shtml

The Miller Institute is "dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems."