



Gordon Research Conference on photosynthesis: photosynthetic plasticity from the environment to synthetic systems

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Abstract

Here, we provide a summary of the 2017 Gordon Research Conference on Photosynthesis: “Photosynthetic plasticity: from the environment to synthetic systems”. This conference was held at the Grand Summit Resort Hotel at Sunday River, Newry, Maine, USA, from July 16 to 21, 2017. We have also included here a brief description of the Gordon Research Seminar (for students and post-docs) held during 2 days preceding this conference. Following the conclusion of the conference’s scientific program, four young scientists (Han Bao, Vivek Tiwari, Setsuko Wakao, and Usha Lingappa) were recognized for their research presentations, each of whom received a book as a gift from one of us (Govindjee). Having chaired the 2015 Gordon Research Conference on Photosynthesis in 2015, Fabrice Rappaport, who lost his fight against cancer in January 2016, was remembered for his profound impact on the field of photosynthesis research.

Keywords Han Bao · Vivek Tiwari · Setsuko Wakao · Usha Lingappa · Arthur Grossman · Petra Fromme · Robert Burnap · Fabrice Rappaport

This manuscript was edited by **William W. Adams III** and accepted for publication in *Photosynthesis Research* by **Barbara Demmig-Adams** with the comment, “this exciting conference combined vantage points ranging from biophysics and biochemistry of molecules to the performance of organisms in their natural environment, and included specific elements to highlight the work of junior researchers.”

Dedicated to Fabrice Rappaport (1967–2016).

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Introduction

The 2017 Gordon Research Conference (GRC) on Photosynthesis was held at the Grand Summit Resort Hotel at Sunday River, Newry, Maine from July 16 to 21, 2017. An abbreviated history of all photosynthesis conferences since 1969 can be found at <https://www.grc.org/photosynthesis-conference/default.aspx>. The conference was chaired by Arthur R. Grossman with able assistance from the Vice Chair Petra Fromme (Fig. 1 top left and top right), who will serve as the Chair of the 2019 GRC on Photosynthesis. Robert Burnap

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Fig. 1 Top left Arthur Grossman (Chair) and Petra Fromme (Vice Chair) at a coffee break. Top right Eva Nowack, Kevin Redding, Arthur Grossman, Benjamin Engel, and Petra Fromme during the evening mixer. Bottom left Attendees of the GRC from the Fromme Group: Cesar Luna-Chavez, Shatabdi Roy-Chowdhury, Petra Fromme, Jesse Coe (sitting), Raimund Fromme, Erin Discianno, Alex

Jones, and Zachary Dobson. Bottom right Francis André Wollman, Michi Suga, Jian-Ren Shen, and Robert Burnap (2019 GRC Vice Chair). Source: Bottom left A staff member of the Grand Summit Resort Hotel at Sunday River; all others from the archives of Govindjee

(Oklahoma State University, Fig. 1 bottom right) was elected to be Vice Chair of the 2019 GRC on Photosynthesis.

The 2017 conference's title, "Photosynthetic plasticity: from the environment to synthetic systems", reflected the importance of bridging several disciplines to access the most intricate of nature's design, and to efficiently utilize it for practical application. Prior to the conference, a Gordon Research Seminar (GRS), entitled "Decoding the Dynamic Nature of Photosynthesis: Sensing, Regulation, and Remodeling", was held for students and post-docs. The conference hosted almost 170 attendees from Australia, Belgium, Canada, China, Croatia, Czech Republic, France, Germany, Hungary, India, Israel, Japan, Netherlands, New Zealand, Russia, Singapore, South Africa, Sweden, Switzerland, United Kingdom, and the United States of America.

Figure 2 is a photograph of most of the conference attendees on the conference grounds.

Speaker topics and presentations

Among the conference participants, many presented their most recent discoveries. The speakers' expertise reflected a high degree of diversity in the community and the GRC was the perfect venue to inspire collaboration among them.

There were nine discussion sessions, each of which was introduced and led by a designated discussion leader (photographs of the nine discussion leaders are shown in Fig. 3). The session topics spanned a broad range of disciplines in photosynthesis research, and also offered a significant amount of overlap, encouraging collaboration and camaraderie during the conference. We present below a summary of the nine sessions.

Session 1, Metals, Redox and Photosynthetic Control, was led by Michel Goldschmidt-Clermont with three talks: "A Day in the Life of *Chlamydomonas*" (by Sabeeha Merchant), "Molecular Players of Sustained Energy Dissipation"

(by Alizée Malnoë), and “New Regulators of Photosynthetic Electron Flow” (by Giovanni Finazzi).

Session 2, The Translational Potential of Photosynthesis, was led by David Savage with five talks: “Beyond Structure and Function: The Carboxysome and the OCP as Units of Evolution and Engineering in Cyanobacteria” (by Cheryl Kerfeld), “Understanding the Structural Factors Dictating Charge Transfer in Synthetic and Biohybrid Architectures for Artificial Photosynthesis” (by Karen Mulfort), “Mechanical Regulation of Photosynthesis” (by Jeffery Cameron), “Computer Assisted Modeling of Photosynthetic Electron Transport in Cyanobacteria” (by Imre Vass), and “Transcriptional Activation of the Chloroplast Unfolded Protein Response Requires the Protein Kinase MARS1” (by Silvia Ramundo).

Session 3, Light Harvesting Complexes and Membrane Organization, was led by Roberta Croce with four talks: “Structural Insights into Light Harvesting and Its Regulation in Plants” (by Zhenfeng Liu), “Acclimation of Photosynthetic Light-Harvesting in Nature” (by Jun Minagawa), “Native Molecular Architecture of the Chloroplast” (by Benjamin Engel), and “STN7 Kinase at the Crossroad Between Short-Term and Long-Term Acclimation: Potential Renewal of State Transitions After Completing the Long-Term Acclimation to High Light Conditions” (by Maria Borisova-Mubarakshina).

Session 4, Carbon Metabolism and Alternative Electron Flow, was led by Rebekka Wachter with six talks: “Photosynthesis and Metabolic Partitioning in Salt Water Algae” (by Matthew Posewitz), “Evolution of Photosynthetic Electron Transfer Components in Secondary Alga *Euglena gracilis*” (by Pierre Cardol), “Dynamic Remodeling and Regulation of the CO₂-Fixing Micro-Compartment in *Chlamydomonas reinhardtii*” (by Moritz Meyer), “CAM Biodesign: Improving Water-Use Efficiency and Drought Tolerance in Plants” (by John Cushman), “Exploring the Diversity of Rubisco Activation Proteins” (by Oliver Mueller-Cajar), and “Photosynthetic Flexibility During the Elimination of Major Sinks for Electrons” (by Shai Saroussi).

Session 5, The Evolution of Photosynthetic Function, was led by Christopher Howe with three talks: “Of Stolen Plastids and the Evolution of Streptophyte Plastid-Nucleus Communication” (by Jan de Vries), “*Paulinella chromatophora* – Converting a Cyanobacterial Endosymbiont into a Full-Fledged Photosynthetic Organelle” (by Eva Nowack), and “The Dynamic Interplay Between Photoprotection and Photoinhibition in Photosynthetic Organisms” (by Vasco Giovagnetti).

Session 6, Photosynthesis in the Environment, was led by Barbara Demmig-Adams with five talks: “Iron Limited Photosynthesis and Carbon Metabolism over Diel Cycles in *Phaeodactylum tricornutum*” (by Sarah Smith), “Shedding Light on *Synechococcus*: How Photosynthetic Adaptations Give Rise to Biogeographical Patterns in the Ocean” (by Katherine Mackey), “Functional and Genomic Diversity in

Phototrophic Microbial Communities” (by Devaki Bhaya), “Photosynthetic Upregulation Relies on Increased Capacity for Foliar Sugar Export” (by William Adams), and “Photosynthetic Control by Cytochrome b₆f Complex in C₄ Model Plant *Setaria viridis*” (by Maria Ermakova).

Session 7, The Control of Photosynthetic Processes, was led by David Kramer with three talks: “Contributions of Functional Studies to the Understanding of Structural Features in Photosynthesis” (by Francis-André Wollman), “Interplay Between Oxygen Photoreduction Pathways and the Regulation of Photosynthetic Electron Transport” (by Giles Peltier), and “Light and Carbon Metabolism-Dependent Regulation of Photoprotection” (by Dimitris Petroustos).

Session 8, Reaction Centers: Structure, Function and Dynamics, was led by Nathan Nelson with six talks: “X-ray Crystallography and X-ray Spectroscopy of the Water Oxidation Reaction in Photosystem II” (by Junko Yano), “Structure Function Studies of the Cyanobacterial Photosystem I Complex” (by Yuval Mazor), “Mechanism of Photosynthetic Water-Splitting from a Structural Point of View” (by Jian-Ren Shen), “The High Resolution Structure of the *Helicobacterium modesticaldum* - A Different Reaction Centre” (by Raimund Fromme), “X-ray Structure of the Type-I Reaction Center from *Helicobacterium modesticaldum* at 3.2 Å Resolution” (by Genji Kurisu), and “Manganese and the Evolution of Photosystem II” (by Usha Lingappa).

Session 9, Developing and Implementing New Approaches, was led by Robert Blankenship and included two talks: “What Can We Learn from Single-Molecule Imaging and Trapping? From Super-Resolution Microscopy to Multivariate Photodynamics of Individual Pigment-Proteins in Solution” (by William Moerner), and “Dynamics of Photosynthetic Light Harvesting: From Conformational Changes to Excitation Energy Transfer” (by Gabriela Schlau-Cohen).

Research highlights

The talks were at the cutting edge of science and sparked great interest and “hot” discussions. They included reports about chloroplast-mitochondria physical and metabolic interactions in diatoms (Giovanni Finazzi), the discovery of a COP signalosome involved in retrograde signaling (Jun Minagawa), recent advances in cryo-electron tomography and microscopy (Ben Engel), new insights into the regulation of NPQ proteins in different CO₂ conditions (Dimitris Petroustos), talks about the time-resolved studies of the oxygen-evolving complex of Photosystem II (Junko Yano and Jian-Ren Shen), and the structural elucidations of the homodimeric reaction center from heliobacteria (Raimund Fromme and Hirozo Oh-Oka). See Fig. 4 for photographs.

The GRC also included two discussion sessions that were spontaneously organized by the participants: they



Photosynthesis
Gordon Research Conference
July 16-21, 2017
Grand Summit Hotel at Sunday River, Newry, ME
Chair: Arthur Grossman
Vice Chair: Petra Fromme

◀ **Fig. 2** A group photograph of most of the participants at the Gordon Research Conference on Photosynthesis held, on July 16–21, 2017, at the Grand Summit Resort Hotel at Sunday River, Newry, ME, USA. Chair: Arthur Grossman; Vice Chair: Petra Fromme. Row 1 (left to right): Matthew Posewitz, Jun Minagawa, Raimund Fromme, Vasco Giovagnetti, Govindjee, Arthur Grossman, Petra Fromme, Rebekka Wachter, Nathan Nelson, W. E. Moerner, Sabeeha Merchant, Devaki Bhaya, Sarah Smith, Katherine Mackey, Christopher Gee, Alizée Malnoë. Row 2 (left to right): Jeffrey Cameron, Eva Nowack, Jan de Vries, Junko Yano, Vivekanand Tiwari, Shivani Upadhyaya, Christopher Gisriel, Usha Lingappa, Barbara Demmig-Adams, William Adams, Imre Vass, Zhenfeng Liu, Jian-Ren Shen, Giovanni Finazzi, Robert Blankenship, Michel Goldschmidt-Clermont, Cesar Luna-Chavez, Benjamin Engel, David Kramer, Christopher Howe, Shai Saroussi, Hila Toporik, Lital Davidi, Orly Levitan, Maya Antoshvili Zilberman, Jenny Zhang. Row 3 (left to right): David Savage, Rhys Wyber, Manoj Mandal, Harvey Jian-Min Hou, Johannes Messinger, Gaozhong Shen, Casper de Lichtenberg, Pattarasiri Rangsitphoti, Vasily Kurashov, Haniyeh Koochak, Ipsita Ghosh, Stenbjörn Styring, Julian Eaton-Rye, Atsuko Kanazawa, Emanuel Sanz-Luque, Maria Agustina Dominguez Martin, Divya Matta, Marcia Ortega Ramos, Han Bao, Juliana Artier, Isha Kalra, Gregory Cook, Beverley Green, Daniel Canniffe, Meng Li, Vivek Tiwari, Ming-Yang Ho, Benjamin Wolf. Row 4 (left to right): Andrei Herdean, Hrvoje Fulgosi, Himadri Pakrasi, Terry Bricker, Roberta Croce, Nicoletta Liguori, Chihiro Azai, Shigeru Itoh, Yuki Egami, Hirozo Oh-Oka, Shaun Bailey, William Lambert, Fedor Kuzminov, Karen Mulfort, Lisa Utschig, Richard Debus, Karen Zinzus, Anne Sawyer, Maithili Krishnan, Emanuela Crisafi, Fikret Mamedov, Sara Sohail, Maria Dost, Sujith Puthiyaveetil, Iskander Ibrahim, David Vinyard, Ru Zhang, Oliver Mueller-Cajar, Cecilia Blikstad, Setsuko Wakao, Long Vo Pham, M. Aguila Ruiz-Sola, Nikki Magdaong. Row 5 (left to right): Charles Dismukes, Michal Gwizdzala, Pierre Cardol, Maria Ermakova, Shatabdi Roy-Chowdhury, Ashley Compton, Maria Borisova-Mubarakshina, Ronald Pace, Benjamin Endelman, Jingcheng Huang, Alex Jones, Petr Ilik, Mautusi Mitra, Anjali Pandit, Charush-eela Ramanan, Michi Suga, Wojciech Nawrocki, Rachael Morgan-Kiss, Avihai Danon, Nathan Ennist, Dagmar Lyska, Marcel Fuciman, Yoshihiro Sato, Joseph Weissman, Zev Cariani, Gourab Banerjee, Philipp Simon, Holger Dau, Shira Bar-Zvi, Robert Niederman. Row 6 (left to right): Matthias Schonborn, Felix Buchert, Moritz Meyer, Kevin Redding, Gilbert Kanyanja, Jonathan Morris, Vinzenz Bayro-Kaiser, Yuval Milrad, Pini Marco, Iftach Yacoby, Gilles Peltier, James Allen, Robert Burnap, Tom Avenson, Ben Lucker, Neil Miller, Cynthia Amstutz, Gadiel Saper. Source: Gordon Research Conference; reproduced with permission

were focused on the mechanism of water oxidation in photosynthesis and the regulation of cyclic electron flow. The discussion session on the mechanism of water splitting was led by James Barber. Participants discussed how recent results obtained by different methods ranging from structural biology (time-resolved femtosecond crystallography), various spectroscopic approaches (e.g., FTIR, EPR, X-ray spectroscopy, ultrafast optical spectroscopy), and deuterium exchange experiments, can be combined with theoretical studies to unravel the mechanism of water-splitting. Consensus was reached that the field has made large breakthroughs in the recent years, but the goal of resolving the mechanism of water-splitting at the atomic and electronic level has not yet been reached and this effort

will require further development of experimental methods and theory. No group alone can achieve this objective and highly collaborative efforts between research groups of different disciplines will be the most promising way to reach the goal.

The other spontaneous discussion concerned the “nuts and bolts” of *cyclic electron flow* (CEF) in photosynthesis. This unique session, led by Arthur Grossman, and including major researchers studying photosynthetic electron flow, focused on presenting various aspects of CEF activity and methods to measure that activity, while providing an open stage for all scientists interested in expressing their ideas and opinions on the subject. One major goal of this session was to reach a consensus on the definition of CEF and to discuss how CEF should be measured. Although the group could not come up with an agreed-upon definition of CEF, a very general description was accepted: the reduction of Photosystem I by electrons that did not originate from water splitting (i.e., in the presence of DCMU, a Photosystem II inhibitor). A major discrepancy occurred within the group when considering the bioenergetics of CEF: one ‘camp’ accepted the above-mentioned description of CEF, while the other held the view that electron transfer around Photosystem I should only be considered CEF if a ΔpH across the thylakoid membrane is generated and ATP is synthesized. This second view requires the coupling of electron flow around Photosystem I to cyclic photophosphorylation.

By the end of the session, participants decided to write a collaborative review article on this topic, with contributions from all the scientists in the field. This review will provide detailed guidelines on the methods currently used for measuring CEF and improve consensus in the field.

Poster presentations

One hundred thirteen (113) posters covered a wide span of important aspects of photosynthesis research across seven generalized topics (see below) similar to the topics of the talks, but split into two sessions, A and B. Poster presenters enthusiastically conveyed their experimental results and conclusions to both the novice participants and the expert scientists.

An outstanding event that further focused on the poster presenter’s research were two 30-minute “flash-talk” sessions (one for each session, A and B) within the oral part of the conference. This approach followed the example set at the 2015 GRC on Photosynthesis (Govindjee et al. 2016). Presenters formed a long line (Fig. 5, top left), and each received only 1 min and 1 slide in which to quickly convey the most pertinent and exciting aspect of their research—a difficult task for any scientist. In preparation, presenters were allowed a “dry-run” before the sessions to ensure



Fig. 3 Top left Michel Goldschmidt-Clermont (Discussion Leader) and Gilles Peltier. Top center Cheryl Kerfeld, David Savage (Session Leader), and Karen Mulfort. Top right Roberta Croce (Discussion Leader) and Silvia Ramundo. Middle left Rebekka Wachter (Discussion Leader). Middle center Christopher Howe (Discussion Leader). Middle right Barbara Demmig-Adams (Discussion Leader) and William Adams. Bottom left Wojciech Nawrocki, Roberta Croce, and

David Kramer (Discussion Leader, showing the use of his new instrument to measure photosynthesis in nature). Bottom center Nathan Nelson (Discussion Leader), Usha Lingappa, and Junko Yano. Bottom right Robert Blankenship (Discussion Leader). Source: Middle left Rebekka Wachter, Middle center Christopher Howe; all others from the archives of Govindjee

perfect timing and give the participants a trial attempt. This approach was highly successful, and the flash-talks were a stimulating platform for poster presenters to individually highlight their discoveries to the larger body of the conference attendees. The flash talk session was open to all poster presenters and the chance to advertise their poster was taken on by both young and experienced scientists. The following people presented their poster in a flash talk in session A, which covered the topics *Control of Photosynthetic Function & Metals and Redox*, *The Translational Potential of Photosynthesis*, and *Light Harvesting Complexes*

and Membrane Organization: Cynthia Armstutz, Felix Buchert, Maria Dominguez-Martin, Maria Dost, Govindjee, Atsuko Kanazawa, Gilbert Kayanja, Haniyeh Koochak, Maithilli Krishnan, Johannes Messinger, Neil Miller, Yuval Milrad, Yonathan Morris, Wojciech Nawrowski, Emanuel Sanz-Luque, Anne Sawyer, Vivekanand Tiwari, Shivani Upadhyaya, Setsuko Wakao, Vinzenz Bayro-Kaiser, Fikret Marmedov, Gadiel Saper, Han Bao, Emunuela Crisafi, Michal Gwizdala, Fedor Kuzminov, Orly Levitan, Nicoletta Liguori, Mautusi Mitra, Charusheela Ramanan, and Hila Toporik. The Flash talk session B was focused on the



Fig. 4 Top left Junko Yano, Top right Jian-Ren Shen, Bottom Raimund Fromme, Hirozo Oh-Oka, and Shigeru Itoh. Source: Bottom Chihiro Azai; all others from the archives of Govindjee

topics of *Carbon Metabolism and Alternate Electron Flow*, *Photosynthesis in the Environment*, *Reaction Centers: Structure, Function, and Dynamics*, and *Developing and Implementing New Approaches*. The following participants presented a flash talk on their poster in session B: Juliana Artier, Zack Dobson, Shigeru Itoh, William Lambert, Robert Niederman, Pattarasiri Rangrikhitphoti, Benjamin Wolf, Rhys Wyber, Karen Zinzius, Maya Antoshvili Zilberman,

Chihiro Azai, Gourab Banerjee, Jesse Coe, Casper de Lichtenberg, Richard Debus, Charles (Chuck) Dismukes, Nathan Ennist, Ipsita Ghosh, Christopher Gisriel, Manoj Mandal, Pini Marco, Divya Matta, Marcia Ortega Ramos, Ronald Pace, Shatabdi Roy-Chowdhury, Stenboern Styring, Jenny Zhang, Jingcheng Huang, Anjali Pandit, Matthias Schonborn, Gaozhong Shen, and Philipp Simon.



Fig. 5 Top left Gilbert Kayanja, Atsuko Kanazawa, Govindjee, Maria Dost, Maria Agustina Dominguez Martin, Felix Buchert, and Cynthia Amstutz waiting in line to give their one-minute flash talks on their posters. Top center Vinzenz Bayro-Haiser and Cesar Luna-Chavez. Top right Karen Mulfort, Lisa Utschig, Katherine Mackey, and Shaun Bailey. Middle left Hirozo Oh-Oka, Barbara Demmig-Adams, William Adams, Harvey Jian-Min Hou, and Anne Sawyer. Middle center Maria Dost, Haniyeh Koochak, Shira Bar-Zvi, Maya Antoshvili, and

Meng Li. Middle right Giovanni Finazzi and Jun Minagawa (in the bus coming to the GRC from the Boston airport). Bottom left Devaki Bhaya, Sabeeha Merchant, Francis André Wollman, Arthur Grossman, and Michel Goldschmidt-Clermont. Bottom center Usha Lingappa, Zev Cariani, Isha Kalra, Govindjee, Gregory Cook, and Maya Antoshvili. Bottom right Benjamin Endelman, Cynthia Amstutz, Alizée Malnoë, and Christopher Gee. Source: Bottom right Benjamin Endelman; all others from the archives of Govindjee

Gordon research seminar

During the 2 days prior to the GRC, the Gordon Research Seminar (GRS) on Photosynthesis, titled “Decoding the Dynamic Nature of Photosynthesis: Sensing, Regulation, and Remodeling”, was chaired by Shai Saroussi (Carnegie Institution for Science) and Silvia Ramundo (University of California, San Francisco). See their photographs in Fig. 6 (top left, top center, and bottom). About 50 graduate students and post-docs participated in this seminar with posters and oral presentations, sharing their latest research findings while discussing ideas and future directions in the field of photosynthesis. The 2017 GRS program focused on regulatory mechanisms that allow photosynthetic flexibility but it also highlighted the interactions between photosynthesis,

cellular metabolism, and the potential to tailor photosynthesis to man-made systems.

The opening keynote lecture was given by Roberta Croce (Vrije Universiteit, Amsterdam); she discussed the photosynthetic properties of a genetically-engineered tobacco plant lacking a specific carotene but still able to quench excess energy using astaxanthin. Then, Hila Toporik from Arizona State University led the session, “Photosynthesis and the Environment”. In this context, Han Bao, a post-doc with Cheryl Kerfeld at Michigan State University, presented structural studies on the orange carotenoid proteins (OCPs) involved in cyanobacterial photoprotection (Bao et al. 2017b). Nicoletta Liguori, a post-doc with Roberta Croce at Vrije Universiteit, Amsterdam, explained the mechanism of quenching within the



Fig. 6 Co-Chairs (Shai Saroussi and Silvia Ramundo) of the Gordon Research Seminar (GRS) are shown with others while attending the GRC. Top Left Arthur Grossman and Shai Saroussi (GRS Co-Chair). Top Center Nicoletta Liguori, Govindjee, and Silvia Ramundo (GRS Co-Chair). Top right Usha Lingappa, Chris Gisriel (2019 GRS

Chair), and Vivekanand Tiwari. Bottom From left to right, Michel Goldschmidt-Clermont, Dimitris Petroustos, Silvia Ramundo, David Kramer, and Shai Saroussi at the “CAMP” hotel restaurant. Source: Top center Shai Saroussi; all others from the archives of Govindjee

light harvesting complex using *in silico* analyses. Cynthia Amstutz, a graduate student with Krishna Niyogi at the University of California, Berkeley, discussed a genetic screen that led to the discovery of OTK1, a previously unknown player in the regulation of photoprotection in *Arabidopsis thaliana*. Next, Ming-Yang Ho, a post-doc with Don Bryant at Penn State University, presented a novel mechanism that some cyanobacteria employ to capture and absorb far-red light (Ho et al. 2016), and Christopher Gisriel, a graduate student with Kevin Redding at Arizona State University, presented the first high-resolution crystal structure of the homodimeric reaction center from *Heliobacterium modesticaldum* (Gisriel et al. 2017). During the second day of the GRS, Shai Saroussi introduced the first session on the integration of photosynthesis with cellular metabolism and alternative pathways for electron flow. Karen Zinziuz, a graduate student with Michael Hippler at the Universität Münster, presented her recent findings on the regulation of a unique calcium-dependent thioredoxin, known as calredoxin (Hochmal et al. 2016), that is involved in

stress acclimation of *Chlamydomonas reinhardtii*. Felix Buchert, a post-doc with Francis-André Wollman at the Institute de Biologie Physico-Chimique, Paris, discussed the possible regulatory effects of reactive oxygen species on the function of the chloroplast ATP synthase by modifying the reducing state of specific cysteine residues on the ATP synthase gamma subunit (Buchert et al. 2017). Continuing on redox regulation, Vivekanand Tiwari, a post-doc with Avihai Danon at the Weizmann Institute of Science, discussed the function of the di-sulphide state of the cysteine groups on the enzymatic activity of the chloroplast alternative oxidase, PTOX, in *Arabidopsis thaliana*. Shivani Upadhyaya, a post-doc with Basuthkar Rao at the Tata Institute of Fundamental Research, Mumbai, presented data on cross-talk between photosynthesis and the target of rapamycin (TOR) signaling pathway while *Chlamydomonas reinhardtii* cells starve for nitrogen. In the final talk for this session, Juliana Artier, a graduate student with Robert Burnap at Oklahoma State University, discussed the structure and function of the CO₂ uptake protein, CupA, and its involvement in the cyanobacterial

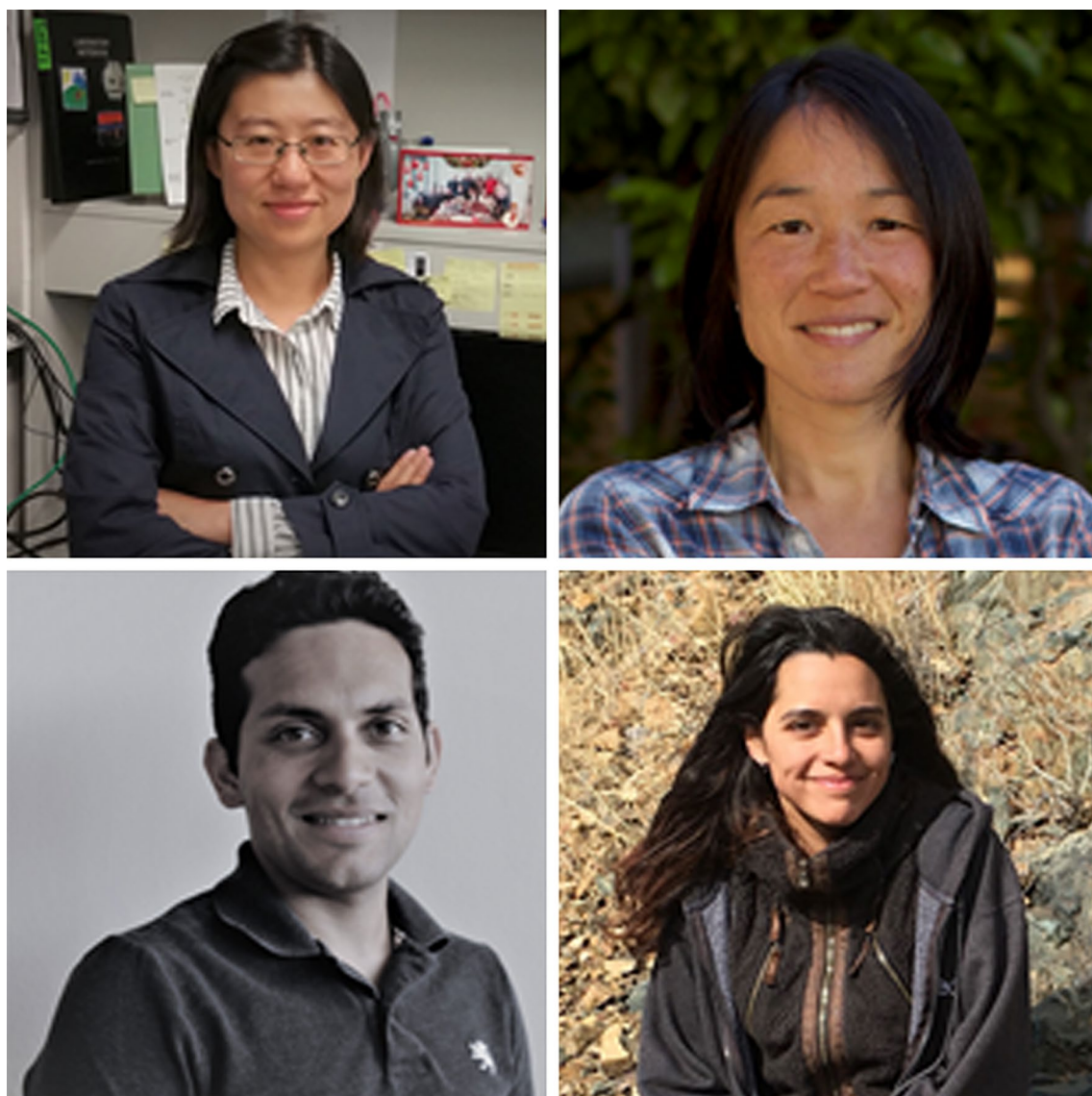


Fig. 7 The three poster winners of the GRC: Top left Han Bao, Top right Setsuko Wakao, and Bottom left Vivek Tiwari. Bottom right shows Usha Lingappa, the awardee for the best talk by a young investigator. Source: Photos provided by each of the awardees

carbon-concentrating mechanism. The concluding session of the 2017 GRS was led by Marcia Ortega-Ramos, a graduate student with John Golbeck at Penn State University, who focused on potential approaches to harness Photosystem II (PSII) for the production of sustainable and renewable energy. In this context, Vinzenz Bayro-Kaiser, a post-doc with Nathan Nelson at Tel-Aviv University, Israel, discussed the role of hydrogen (H_2) as a source of clean energy and presented PSII temperature-sensitive mutants in *Chlamydomonas reinhardtii* that alternate between oxygenic photosynthesis and anoxic H_2 production (Bayro-Kaiser and Nelson 2016). Jenny Zhang, a graduate student with Erwin Reisner at the University of

Cambridge, demonstrated the electrogenic activity of PSII using a *Synechocystis* biofilm coupled to an electrode.

Recognition of research by young scientists

Among the many excellent poster presentations throughout the GRC, three poster-presenting scientists were awarded the opportunity to deliver a 10-min “Short Talk” about their research toward the closing of the conference. These were: Han Bao, Vivek Tiwari, and Setsuko Wakao (Fig. 7, top left, top right, and bottom left). There was also an award for the “best talk by a young scientist”, given to Usha Lingappa (Fig. 7, bottom right). These four awardees

received a collective recognition of their research during the closing section of the GRC and a book from the Springer series (details below). The focus of the research and university affiliations of these awardees are:

- Han Bao (of Michigan State University, East Lansing, MI, USA) was recognized for her work on the “functional characterization of a new family of orange carotenoid proteins”.
- Vivek Tiwari (of the University of Michigan, Ann Arbor, MI, USA) was recognized for his work on “two dimensional fluorescence detected electronic spectroscopy for spatially resolved and sub-ensemble measurements”.
- Setsuko Wakao (of the University of California at Berkeley, Berkeley, CA, USA) was recognized for her work on the “dissection of reactive oxygen species-specific response during high light shift by comparative transcriptome analysis”.
- Usha Lingappa (of CalTech, Pasadena, CA, USA) was recognized for her work on “manganese and the evolution of Photosystem II”.

We present below a summary of each of these outstanding awardees:

Han Bao received her Ph.D. in Chemistry at the Chinese Academy of Sciences in Beijing in 2009. There, she studied the properties of the redox-active tyrosine, Y_Z , and primary quinone acceptor, Q_A , in PSII by using EPR spectroscopy and other biophysical approaches. She joined Robert Burnap’s lab in Oklahoma State University in 2012 to study proposed proton and substrate water pathways of the Mn_4CaO_5 cluster of PSII. The focus of her research was on the hydrophobic amino acid Val185 in the D1 subunit, which is located in close vicinity to the oxo bridge atom, O5, of the metal cluster and faces the broad channel, which allows the exchange of the substrates and products as they pass the Mn_4CaO_5 cluster. Previously, she had won a poster award for her work on “Mutations disturbing water cluster alter the kinetics of the final steps of water oxidation” (Bao and Burnap 2015) at the 2014 Gordon Research Conference on Photosynthesis (Rappaport et al. 2015). In March 2016, she joined Cheryl Kerfeld’s research group in the MSU-DOE Plant Research Laboratory at Michigan State University. Her current project is to study the OCP-mediated non-photochemical quenching mechanism of cyanobacteria (Bao et al. 2017a). She and her colleagues have found a new family of OCPs; she showed that the OCP homologs from *Fremyella diplosiphon*, a chromatically acclimating cyanobacterium, exhibit very different properties from the canonical OCP.

The title of Han’s poster and talk was “Functional Characterization of a new family of Orange Carotenoid Proteins”

(Bao et al. 2017b). In recognition of her achievements, Govindjee presented Han with a copy of the 2016 book “Cytochrome Complexes: Evolution, Structures, Energy Transduction, and Signaling”, edited by William A. Cramer and Toivo Kallas, in the Series: Advances in Photosynthesis and Respiration, Vol. 41, Springer (Series editors: Tom Sharkey and Govindjee).

Vivek Tiwari graduated from the Indian Institute of Technology, Kanpur (India), in 2009 with a Bachelor’s and a Master’s degree in Chemistry. He completed his Ph.D. in Chemical Physics in 2014 at the University of Colorado, Boulder, under Prof. David Jonas. The title of his thesis was: *Non-adiabatic Mechanism for Photosynthetic Energy Transfer and All-optical Determination of Concentration Using Femtosecond Lasers* (Tiwari 2014). For this work, he had developed a theoretical and experimental framework to measure the pump–probe signal in terms of absolute photon number changes, and thereby determined the concentration of the transient species in solution all-optically and without any calibrant. His interest in photosynthesis arose from another project from his dissertation where Vivek showed that anti-correlated intramolecular pigment vibrations can drive the early stages of excitation energy transfer in photosynthesis in a strongly non-adiabatic regime (Tiwari et al. 2013), which is starkly different from the adiabatic energy transfer framework laid down by Theodor Förster in the 1940s (for a review, see Wu and Brand 1994), and adopted ever since, in most cases, in describing excitation energy transfer in photosynthesis. Continuing his interest in exploring the energy transfer mechanisms involved in natural photosynthetic systems, Vivek joined the group of Prof. Jennifer Ogilvie at the University of Michigan, Ann Arbor in 2015 as a postdoctoral fellow. He is currently developing a fluorescence-based two-dimensional spectroscopic technique for spatially resolved and sub-ensemble spectroscopic measurements, with the goal of resolving the spatial variation of energy transfer timescales in sub-ensembles of photosynthetic antennas across domains in cells or membrane fragments.

The title of Vivek’s poster and talk was *Two-dimensional Fluorescence Detected Electronic Spectroscopy for Spatially Resolved and Sub-ensemble Measurements*. In recognition of his work, Govindjee presented Vivek a copy of the 2014 book “The Structural Basis of Biological Energy Generation”, edited by Martin F. Hohmann-Marriott, in the Series: Advances in Photosynthesis and Respiration, Vol. 39, Springer (Series editors: Tom Sharkey and Govindjee).

Setsuko Wakao received her Ph.D. from Michigan State University working under Christoph Benning on characterizing the roles of glucose-6-phosphate dehydrogenases in supplying NADPH for oil accumulation in seeds of *Arabidopsis*. Developing seeds have limited photosynthesis to supply ATP and NADPH and it has been a long-standing question in the

field of plant lipid biosynthesis what alternative source supplies reducing equivalents. Having learned the importance of redox regulation in metabolism and signaling, she went on to do her postdoctoral work with Krishna Niyogi at the University of California, Berkeley on singlet oxygen signaling in *Chlamydomonas reinhardtii*. Her poster presented the group's work on large-scale whole genome sequencing of *Chlamydomonas* mutants defective in photosynthesis (Dent 2005; Dent et al. 2015), identifying the genetic lesions in hundreds of mutants; her work included discussion of many genes with no annotations, potentially opening paths to understanding many of their functions. In parallel, she presented a comparative transcriptomic analysis between datasets describing responses to (a) low-to-high light transition, (b) hydrogen peroxide, (c) singlet oxygen, and (d) dark-to-light transition to tease apart light- and reactive oxygen species-dependent signaling events and narrowing down on the regulatory genes during excess light. By combining these two large-scale sequencing projects, Niyogi's research group has the goal of accelerating functional genomics of photosynthetic genes in *Chlamydomonas* and of serving as a resource for the photosynthesis community.

The title of Setsuko's poster and talk was "Dissection of reactive oxygen species-specific response during high light shift by comparative transcriptome analysis". In recognition of her achievements, Govindjee presented her with a copy of the 2014 book "Non-Photochemical Quenching and Energy Dissipation in Plants, Algae and Cyanobacteria", edited by Barbara Demmig-Adams, Gyoza Garab, William Adams III, and Govindjee, in the Series: Advances in Photosynthesis and Respiration, Vol. 40, Springer (Series editors: Tom Sharkey and Govindjee).

Usha Lingappa, a Ph.D. student in Woody Fischer's group at Caltech, is studying the relationship between photosynthesis and manganese in both modern and ancient environments. Her talk at the 2017 GRC was about investigating the evolutionary origin of the water-oxidizing complex of Photosystem II; its title was: "Manganese and the Evolution of Photosystem II". This work involved investigating the history of manganese preserved in the sedimentary rock record and the capacity for manganese oxidation by modern Cyanobacteria, revealing potentially important implications for the role of Photosystem II in biogeochemical manganese cycling (Johnson et al. 2013). Usha received her Bachelor's degree in Astrobiology from Hampshire College in 2012. Prior to starting her graduate studies, she worked at Prosetta Biosciences studying the biochemistry of the rabies virus, and at NASA Ames Research Center studying oxidative stress responses in algae.

For her achievements, Govindjee presented Usha with a copy of the 2016 book "Canopy Photosynthesis: From Basics to Applications", edited by Kouki Hikosaka, Ülo Niinemets, and P.R. Niels Anten, in the Series: Advances

in Photosynthesis and Respiration Series, Vol. 42, Springer (Series editors: Tom Sharkey and Govindjee).

Concluding remarks

The 2017 GRC and GRS provided both fledgling and veteran researchers with an opportunity to pass on their knowledge of, and gain insights into, the most recent discoveries in the field of photosynthesis research. Furthermore, the friendly atmosphere provided a platform for the forming and strengthening of relationships among researchers. (See Supplementary Material for figures S1-S4, cited below.) For photographs depicting the general ambiance of the GRC between poster and speaker sessions, see Figs. S1 and S2. Group activities were held including archery, kayaking, soccer (Fig. S3), and a large group dinner at a mountain-top restaurant (Fig. S4). In addition to the cultural diversity of the attendees, the ages of the attendees varied widely. Fig. S1 shows one of the oldest conference attendees (top left) and one of the youngest conference attendees (top right). Summaries and perspectives of previous Photosynthesis GRC's can be found in Govindjee et al. (2007), Govindjee et al. (2011), and Rappaport et al. (2015).

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